UC Berkeley
UC Berkeley Previously Published Works

Title

Measurement of the top-quark mass in tt̄ + 1-jet events collected with the ATLAS detector in pp collisions at s = 8 TeV

Permalink

Journal

ISSN

Authors

Aad, G
Abbott, B
Abbott, DC
et al.

Publication Date

DOI

Peer reviewed

Measurement of the top-quark mass in $t\bar{t}+1$-jet events collected with the ATLAS detector in pp collisions at $\sqrt{s}=8$ TeV

The ATLAS collaboration

E-mail: atlas.publications@cern.ch

ABSTRACT: A determination of the top-quark mass is presented using 20.2 fb^{-1} of 8 TeV proton-proton collision data produced by the Large Hadron Collider and collected by the ATLAS experiment. The normalised differential cross section of top-quark pair production in association with an energetic jet is measured in the lepton+jets final state and unfolded to parton and particle levels. The unfolded distribution at parton level can be described using next-to-leading-order QCD predictions in terms of either the top-quark pole mass or the running mass as defined in the (modified) minimal subtraction scheme. A comparison between the experimental distribution and the theoretical prediction allows the top-quark mass to be extracted in the two schemes. The value obtained for the pole-mass scheme is:

$$m_t^{\text{pole}} = 171.1 \pm 0.4 \text{ (stat)} \pm 0.9 \text{ (syst)} \, ^{+0.7}_{-0.3} \text{ (theo) GeV}.$$

The extracted value in the running-mass scheme is:

$$m_t(m_t) = 162.9 \pm 0.5 \text{ (stat)} \pm 1.0 \text{ (syst)} \, ^{+2.1}_{-1.2} \text{ (theo) GeV}.$$

The results for the top-quark mass using the two schemes are consistent, when translated from one scheme to the other.

Contents

1 Introduction

The mass of the top quark, the heaviest known elementary particle, is a key parameter of the Standard Model (SM) of particle physics and must be determined experimentally. In the SM, the gauge structure of the interaction of the top quark with other particles establishes a relation between the top-quark, Higgs-boson and W-boson masses. A precise determination of these three parameters forms an important check of the internal consistency of the SM [1–5]. Precise measurements of the top-quark mass are also required in order to accurately predict the evolution of the Higgs quartic coupling at high scales, which affects the shape of the Higgs potential and is associated in the SM with the stability of the quantum vacuum [6, 7]. In this article the top-quark mass is inferred from the shape of a differential cross-section distribution.

Any quantitative statement about the value of a quark mass requires a precise reference to the *mass scheme* in which the mass is defined. The mass scheme which is used most often in top-quark mass measurements is the pole-mass scheme [8–14], where the renormalised top-quark mass (the pole mass, m_t^{pole}) coincides with the pole of the top-quark propagator. Several groups have extracted the running[1] top-quark mass in the modified

---

[1]The scale $\mu = m_t$ is used to express the value of top-quark running mass, $m_t(m_t)$.

minimal subtraction scheme ($\overline{\text{MS}}$) from the total top-quark pair ($t\bar{t}$) production cross section [15, 16] or the differential cross section [17]. The two mass schemes can be related precisely, with up to four-loop accuracy [18].

Direct top-quark mass measurements at hadron colliders, based on the reconstruction of the top-quark decay products and using Monte Carlo (MC) event generators in the fit to extract the mass, are frequently interpreted as the pole mass. Recent works estimate that such an interpretation is affected by a 0.5–1 GeV [19–24] uncertainty due to non-perturbative effects from below the MC lower scale at which perturbative quark and gluon radiation is terminated in the parton shower. With direct top-quark mass measurements reaching sub-percent precision [20] it becomes important to evaluate uncertainties associated with the interpretation of the measured mass at the same level of accuracy.

It is therefore of paramount importance to extract the top-quark mass by comparing data with predictions computed in a well-defined mass scheme. In this case the ambiguity related to the top-quark mass interpretation is avoided, allowing a precise evaluation of the uncertainty associated with the mass scheme chosen. In such measurements the Monte Carlo event generator is only used to correct distributions obtained from measured data for effects originating from the detector and the modelling of non-perturbative physics. The uncertainty associated to such effects can be estimated comparing Monte Carlo simulations produced with different sets of parameters, without specific assumptions on the top-quark mass interpretation. The theory uncertainty can then be estimated using the conventional techniques (scale variations and error sets of the parton distribution functions). Such mass measurements also yield greater flexibility in choosing the mass scheme [8, 9].

In this article, results are presented in both the pole-mass and $\overline{\text{MS}}$ schemes. The measurement reported in this study follows the approach developed in refs. [17, 25, 26], which takes advantage of the sensitivity to the top-quark mass of the differential cross section of $t\bar{t}$ production in association with at least one energetic jet. The presence of the additional jet enhances the sensitivity to the top-quark mass in comparison with similar observables defined for the $t\bar{t}$ system only [25]. In particular, the observable used to extract the top-quark mass, $\mathcal{R}$, is defined as the normalised differential $t\bar{t} + 1$-jet cross section:

$$\mathcal{R}(m_t^{\text{pole}}, \rho_{\text{s}}) = \frac{1}{\sigma_{t\bar{t}+1\text{-jet}}} \cdot \frac{\mathrm{d}\sigma_{t\bar{t}+1\text{-jet}}}{\mathrm{d}\rho_{\text{s}}},$$

where

$$\rho_{\text{s}} = \frac{2m_0}{m_{t\bar{t}+1\text{-jet}}},$$

with m_0 representing a constant fixed to 170 GeV and $m_{t\bar{t}+1\text{-jet}}$ being the invariant mass of the $t\bar{t} + 1$-jet system.[2]

The normalised differential cross sections are presented at the so-called *particle level* in which data are only unfolded for detector effects and at the *parton level* where $\mathcal{R}$ can be directly compared with available fixed-order calculations [17, 25]. The *particle-level* distribution is provided to allow comparisons with possible future calculations. A measurement of the top-quark pole mass [11] with this method using 4.6 fb^{-1} of 7 TeV pp

---

[2]The definition $\rho_{\text{s}} = 2m_0/\sqrt{s_{t\bar{t}+1\text{-jet}}}$ is also used in the literature [17, 25], with $\sqrt{s_{t\bar{t}+1\text{-jet}}} = m_{t\bar{t}+1\text{-jet}}$

collisions collected by ATLAS yielded an uncertainty of 2.3 GeV (1.3%) in the top-quark pole mass. In the current analysis the top-quark mass is determined using a sample of 8 TeV pp collisions collected in 2012. The large statistics of the 8 TeV dataset make it possible to achieve a high precision in the measurement of the $\mathcal{R}$ distribution, in particular in the region where it is most sensitive to the top-quark mass, ultimately allowing the top-quark mass to be extracted with high accuracy.

2   ATLAS experiment

The ATLAS experiment [27] at the Large Hadron Collider (LHC) is a multipurpose particle detector with a forward-backward symmetric cylindrical geometry and almost 4π coverage in solid angle.[3]

Its core consists of an inner tracking detector surrounded by a thin superconducting solenoid, which provides a 2 T axial magnetic field. The inner tracking detector covers the pseudorapidity range $|\eta| < 2.5$. It is equipped with silicon pixel, silicon microstrip, and transition radiation tracking detectors.

The inner detector is surrounded by the calorimeters and a muon spectrometer. Lead/liquid-argon (LAr) sampling calorimeters provide electromagnetic (EM) energy measurements with high granularity. An iron/scintillator-tile hadronic calorimeter covers the central pseudorapidity range ($|\eta| < 1.7$). The endcap and forward regions are instrumented with LAr calorimeters for EM and hadronic energy measurements up to $|\eta| = 4.9$.

The muon spectrometer consists of precision tracking chambers and fast detectors for triggering in a magnetic field with bending power in the range from 2.0 to 6.5 T m generated by three large air-core toroidal superconducting magnets with eight coils each.

A three-level trigger system is used to select events [28]. The first-level trigger is implemented in hardware and uses a subset of the detector information to reduce the accepted rate to at most 75 kHz. This is followed by two software-based trigger levels that together reduce the accepted event rate to 400 Hz on average.

3   Data sample

Collision events are selected with a combination of single-electron and single-muon triggers. Electrons (muons) are required to have transverse energy (transverse momentum, p_{T}) above a certain threshold. During the 2012 run the thresholds were set to 36 GeV for muons and 60 GeV for electrons, and reduced to 24 GeV for isolated muons and electrons.

The analysed data set is limited to periods with stable beam conditions when all detector subsystems were operational. The analysed sample corresponds to an integrated luminosity of 20.2 ± 0.6 fb^{-1} [29].

---

[3] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upwards. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z-axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$. Angular distance is measured in units of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$.

4 Monte Carlo simulation

The nominal $t\bar{t}$ sample that is used to unfold the data was generated using the POWHEG-hvq package [30–33], which is based on next-to-leading-order (NLO) QCD matrix elements. The CT10 [34] set of parton distribution functions (PDF) was used. The h_{damp} parameter [35] controls the scale of the damping of the real radiation in POWHEG and thus effectively regulates the high-transverse-momentum radiation of the matrix element (ME) calculation. It was set to the top-quark mass unless indicated otherwise. The sample is normalised to the most precise $t\bar{t}$ cross-section prediction for pp collisions at $\sqrt{s} = 8$ TeV, corresponding to $\sigma_{t\bar{t}} = 253^{+13}_{-15}$ pb for a top-quark mass $m_t = 172.5$ GeV, calculated at NNLO+NNLL [36–41] with the top++2.0 [42, 43] program using the MSTW2008 [44, 45], CT10 [34, 46] and NNPDF2.3 [47] PDF sets. The parton shower (PS), hadronisation, and the underlying event were simulated with PYTHIA 6.427 [48] using the CTEQ6L1 PDF [49] set and a set of tuned parameters called the Perugia 2011 [50] tune.

Several $t\bar{t}$ event samples with different choices of the value of the Monte Carlo top-quark mass, but otherwise the same settings as the nominal sample, are used to validate the analysis. Alternative samples are used to evaluate uncertainties in modelling the $t\bar{t}$ signal. These include samples produced with MC@NLO 4.01 [51] interfaced with HERWIG 6.520 [52] and JIMMY 4.31 [53] and samples generated with POWHEG + HERWIG, with the ATLAS AUET2 tune [54] and JIMMY [53] for multiple parton interactions. Some POWHEG samples were generated with $h_{\mathrm{damp}} = \infty$ and reweighted to $h_{\mathrm{damp}} = m_t$, following the strategy presented in ref. [13]. Two samples with variations of the renormalisation and factorisation scales, the value of the h_{damp} factor and the choice of parton-shower tune are used to estimate the uncertainty in modelling of initial- and final-state radiation [55].

Electroweak single-top-quark production was simulated with POWHEG matched with PYTHIA 6.425, with the CTEQ6L1 PDF set and the Perugia 2011C [50] tune. The cross sections are normalised to NNLO+NNLL calculations for t-channel [56], Wt [57], and s-channel production [58].

Leptonic decays of vector bosons produced in association with several high-p_{T} jets, referred to as W+jets and Z+jets events, with up to five additional final-state partons in the leading-order (LO) matrix elements, were produced with the ALPGEN generator [59] interfaced with HERWIG for parton fragmentation using the MLM matching scheme [60]. Samples corresponding to the production of a W boson in association with heavy-flavour quarks (b- and c-quarks) were generated separately, at leading order and including effects from the value of the mass of the heavy quarks. Overlap between heavy-flavour quarks that originate from matrix-element production and those that originate from the parton shower was removed. The W+jets samples are normalised to the inclusive W-boson NNLO cross section [61, 62].

Diboson events were generated with HERWIG with the CTEQ6L1 PDF. The multijet background is estimated using a data-driven matrix method described in ref. [63].

At the LHC, multiple, simultaneous pp interactions occur in each bunch crossing. The average number of additional pp interactions was 21 during the 2012 run. These pile-up collisions were simulated using PYTHIA 8.1 [64] with the MSTW2008 leading-order PDF

set [44] and the A2M tune [65]. The number of simulated pile-up events superimposed on each hard-scatter event was reweighted to match the distribution of the number of interactions per bunch crossing in data.

The response of the detector and trigger was simulated [66] using a detailed model implemented in GEANT4 [67]. For some samples used to evaluate systematic uncertainties, the detailed description of the calorimeter response was parameterised using the ATLFAST-II simulation [66]. For all the non-$t\bar{t}$ samples the top-quark mass was set to $m_t = 172.5$ GeV. Simulated events are reconstructed with the same software as the data.

5 Lepton and jet reconstruction

Electron candidates are reconstructed from clusters of energy deposits in the electromagnetic calorimeter, matched with a reconstructed inner-detector track [68]. Electrons are required to fulfill the tight identification requirement of ref. [68]. The calorimeter cluster is required to have transverse energy $E_T > 25$ GeV and pseudorapidity $|\eta| < 2.47$. Clusters in the transition region between the barrel and endcaps with $1.37 < |\eta| < 1.52$ are excluded. Non-prompt electrons are suppressed by cuts on the sum of transverse energy deposited in a cone of size $\Delta R = 0.2$ around the calorimeter cells associated with the electron and on the sum of track p_T in a cone of size $\Delta R = 0.3$. The longitudinal impact parameter (z_0) of the electron track relative to the selected event primary vertex[4] is required to be smaller than 2 mm [69].

Muon candidate reconstruction is based on track segments in the muon spectrometer combined with inner-detector tracks [70]. The combined track must satisfy $p_T > 25$ GeV and $|\eta| < 2.5$. Muon candidates have to be separated from any jet by $\Delta R > 0.4$ and the sum of the transverse momenta of tracks within a cone of size $\Delta R = 10$ GeV$/p_T^\mu$ around the muon candidate is required to be less than 5% of the muon transverse momentum, p_T^μ. The muon longitudinal impact parameter (z_0) relative to the primary vertex is required to be smaller than 2 mm.

Jet reconstruction starts from topological clusters [71] of energy deposits in the calorimeters. A local calibration scheme [72] corrects for the non-compensating response of the calorimeter, dead material and out-of-cluster leakage. Jets are reconstructed from these topological clusters using the anti-k_t algorithm [73, 74] with a radius parameter of $R = 0.4$. Jets are calibrated to the level of stable-particle jets using Monte Carlo simulation and the response is verified in situ [75]. Jet reconstruction is implemented in the FASTJET package [76]. Jets are accepted if $p_T > 25$ GeV and $|\eta| < 2.5$ after the calibration. To reduce the contribution from pile-up, jets with $p_T < 50$ GeV and $|\eta| < 2.4$ must have a jet-vertex-fraction (p_T-weighted fraction of tracks associated with the jet that point to the primary vertex) greater than 0.5 [77]. The closest jet within $\Delta R = 0.2$ of selected electrons is discarded to avoid double-counting of the electron candidate as a jet.

---

[4]A primary vertex candidate is defined as a vertex with at least two associated tracks, consistent with the beam collision region. The vertex candidate with the largest sum of squared transverse momenta of its associated tracks is taken as the primary vertex.

Jets with *b*-hadrons (*b*-jets) are tagged with the MV1 algorithm, based on multivariate techniques exploiting impact parameter and secondary vertex information [78]. The efficiency to tag *b*-jets in $t\bar{t}$ events is 70%, with a light-parton jet rejection factor of 130 and a *c*-jet rejection factor of 5. The simulated *b*-tagging efficiency is corrected to match the efficiency measured in data.

The missing transverse momentum (and its magnitude E_T^{miss}) is reconstructed from the vector sum of the transverse momenta of the reconstructed calibrated leptons, jets and the transverse energy deposited in the calorimeter cells not associated with these objects [79].

6 Event selection and reconstruction

Events are selected (preselection) if they pass several quality cuts and requirements to select final states with one reconstructed electron or muon and five or more jets [80, 81]. A reconstructed primary vertex with at least five associated tracks is required. Exactly one high-quality, isolated lepton with $p_T > 25$ GeV must be present. It must match the lepton that triggered the event within $\Delta R < 0.15$. At least five jets are required, exactly two of which must be *b*-jets. The magnitude of the missing transverse momentum E_T^{miss} and the *W*-boson transverse mass[5] must both be greater than 30 GeV. After these requirements the data sample contains 12419 events in the electron channel and 15495 events in the muon channel. Of these events $\sim 93\%$ are expected to be $t\bar{t}$ events.

The reconstruction of the $t\bar{t} + 1$-jet system follows that of ref. [11]. Candidates for the hadronically decaying *W* boson are formed by pairing all jets not tagged as *b*-jets and selecting pairs i, j that satisfy:

- $0.9 < m_W/m_{ij} < 1.25$

- $\min\left(p_T^i,\ p_T^j\right) \cdot \Delta R_{ij} < 90$ GeV

where p_T^i is the transverse momentum of the jet i, m_{ij} is the invariant mass of the jet pair, ΔR_{ij} their angular distance and m_W is the value of the *W*-boson mass reported by the Particle Data Group [5]. The application of these two requirements reduces the multijet and combinatorial backgrounds.

The neutrino momentum is reconstructed, up to a twofold ambiguity, by identifying the E_T^{miss} with its transverse momentum and using the *W*-boson mass constraint to infer its longitudinal momentum [11]. Only events where at least one neutrino candidate exists are considered. If there are two solutions, each of the neutrino candidates is added to the charged lepton, leading to two *W*-boson candidates.

Pairs of hadronic and semileptonic top-quark candidates are formed by combining all the hadronic and leptonic *W*-boson candidates with the two *b*-tagged jets. Among all possible combinations the one selected is that which minimises the absolute difference

---

[5]The transverse mass of the *W* boson is determined as $m_T^W = \sqrt{2p_{T,\ell} \cdot E_T^{miss}[1 - \cos(\phi_\ell - \phi_{E_T^{miss}})]}$, where ℓ is the selected lepton and E_T^{miss} is the missing transverse momentum.

Channel	e+jets	μ+jets
$t\bar{t}$	5530 ± 470	7080 ± 600
Single top	191 ± 15	226 ± 18
W+jets	100 ± 33	121 ± 37
Z+jets	24 ± 8	13 ± 4
Multijet	21 ± 11	< 11
Prediction	5870 ± 540	7440 ± 660
Data	6379	7824

Table 1. Summary of the event yield after the final selection. The observed event yield is compared with the prediction of the Monte Carlo simulation for top-quark pair production and the most important SM background processes. The estimate of the uncertainty in the normalisation of the expected signal and backgrounds yields includes the theoretical uncertainty in the cross section, as well as experimental systematic uncertainties as discussed in section 8. The contribution from diboson production is negligible.

between the masses of the reconstructed hadronic top ($m_{t_{\text{had}}}$) and the semileptonic top ($m_{t_{\text{lept}}}$) candidates, divided by their sum:

$$\frac{\left|m_{t_{\text{lept}}} - m_{t_{\text{had}}}\right|}{m_{t_{\text{lept}}} + m_{t_{\text{had}}}}$$

The $t\bar{t}$ candidates must satisfy $m_{t_{\text{lept}}}/m_{t_{\text{had}}} > 0.9$.

The four-momenta of the jets which are identified with the hadronic decay of the W boson are corrected by the factor $\frac{m_W}{m_{ij}}$. Among the jets not used in either top-quark candidate, the leading jet in p_{T} is taken as the jet produced in association with the top quarks, before their decay. Only events where this extra jet has a transverse momentum larger than 50 GeV are considered. Due to this requirement the selected $t\bar{t}$+1-jet events are reconstructed with a topology similar to the one used in the theoretical NLO calculation, where a similar p_{T} cut is applied [25].

In table 1 the event yield after the final selection cuts is presented. The contribution from diboson production is negligible and is hence not reported. The efficiency of the signal selection, relative to the events that passed the preselection cuts, is $\sim 51\%$. The purity of the sample is 94.3% for the electron channel and 95.2% for the muon channel. The yield predicted by the Monte Carlo simulation is lower than the observed yield in both channels, but is compatible within the MC normalisation uncertainty.

The $t\bar{t} + 1$-jet system is reconstructed adding the four-vectors corresponding to the b-jets, the selected W-boson candidates and the additional jet. The inclusive quantity ρ_{s} defined in section 1 is insensitive to ambiguities in the combinatorics and is not affected by an incorrect pairing of b-jets with W-boson candidates. The observed ρ_{s} detector-level distribution is presented in figure 1.

7 Data unfolding

This analysis follows the approach of ref. [11] in which the measured $\mathcal{R}$ distribution is unfolded for detector, hadronisation and top-quark decay effects to the parton level where
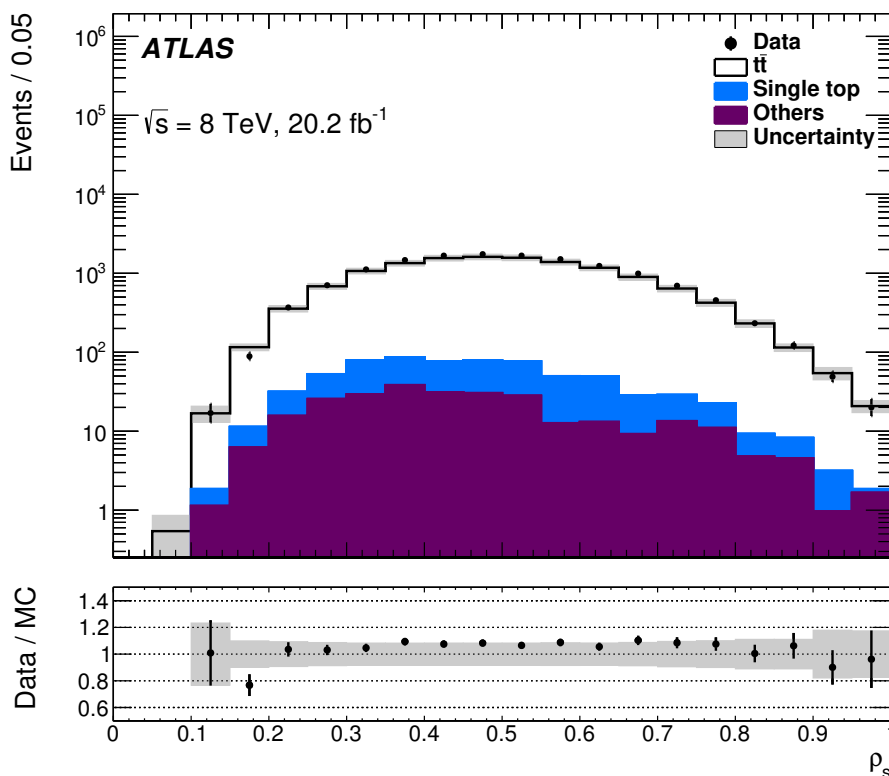
Figure 1. Distributions of the ρ_s variable in the $t\bar{t} + 1$-jet system after the final selection. Data are compared with the SM expectation as obtained with Monte Carlo calculation which includes a full simulation of the ATLAS detector. Statistical uncertainties in the observed event counts are indicated with error bars. The band estimates the uncertainty on the expected yields. It includes the uncertainty on the luminosity, effects from the cross-section normalisation computed as $8.5\%\sigma_{t\bar{t}} \oplus 7.8\%\sigma_{\text{single-}t} \oplus 33\%\sigma_{\text{V+jets}} \oplus 50\%\sigma_{\text{multijet}}$ and detector plus $t\bar{t}$ modelling uncertainties, as described in section 8. Sub-leading background contributions have been merged into the "Others" category to improve their visibility and reduce statistical fluctuations in the plot. The bin of the highest ρ_s interval includes events reconstructed with $\rho_s > 1$.

top quarks are on-shell. The distribution obtained at this level is then compared with theoretical predictions at fixed order, allowing the determination of the top-quark mass in a well-defined theoretical framework. In addition, in this paper, the $\mathcal{R}$ distribution is also presented at particle level, where data are unfolded for detector effects only. This will allow direct comparisons with possible future theoretical calculations which include top-quark decay and hadronisation effects.

The parton level is defined using on-shell top quarks and including initial- and final-state radiation from quarks and gluons before the top-quark decay. Jets are reconstructed by clustering u-, d-, c-, s-, b-quarks and gluons, via the anti-k_t jet algorithm with $R = 0.4$. The $t\bar{t} + 1$-jet fixed-order calculation at NLO is defined for a jet with p_T larger than 50 GeV and with absolute pseudorapidity smaller than 2.5, ensuring the observable is infrared-safe for calculation purposes. The same definition is also applied to MC reconstructed events.

The particle level is constructed from the collection of stable particles[6] from full matrix-element plus parton-shower generators, including top-quark decay and final-state radiation effects. Particles produced from interactions with the detector components or from pile-up of additional pp collisions are not considered at this level. The leptons' four-momenta are defined by clustering photons and the leptons with the anti-k_t jet algorithm, using a jet-radius parameter of $R = 0.1$. No isolation condition is imposed. In order to choose prompt leptons from W/Z-boson decay, the parent of the lepton is required not to be a hadron. Leptons from τ decay are considered as valid final-state particles. The neutrino from the W/Z decay is treated as a detectable particle and is selected for consideration in the same way as electrons or muons, i.e. the parent is required not to be a hadron. Jets are defined by clustering all the stable particles which have not been used in the definitions of electrons, muons and neutrinos with the anti-k_t algorithm. The value of the jet-radius parameter is chosen to be $R = 0.4$. A jet is tagged as a b-jet if any rescaled b-hadron[7] is included in the jet. Events where the leptons overlap with the selected jets are discarded. The fiducial volume at particle level is defined by applying the detector-level selection algorithm to the aforementioned particles as for data, the only difference being that the neutrino four-momentum is known. This choice minimises the magnitude of the correction to the data.

The unfolding procedure is detailed in the following. First, the detector-level distribution of ρ_s in figure 1 is re-binned as in figure 2 to maximise the sensitivity of the observable to the top-quark mass while keeping enough statistics in each bin. This is achieved by choosing a fine binning in the region $\rho_s \gtrsim 0.6$, where the observable is most sensitive to the top-quark mass [25]. Second, the predicted background contribution is subtracted and the distribution is normalised to unity. Finally, the distribution is unfolded with a procedure known as iterative Bayesian unfolding [82].

For the parton level the unfolding procedure takes the following form:

$$\mathcal{R}^{t\bar{t}+1\text{-jet}}(\rho_s) = \left[\mathcal{M}^{-1} \otimes \mathcal{R}^{\text{det}}(\rho_s) \right] \cdot f(\rho_s) \cdot f^{\text{ph.sp.}}\left(\rho_s, \mathcal{R}^{t\bar{t}+1\,\text{jet}}_{\text{ACC}} \right).$$

The unfolded distribution is denoted by $\mathcal{R}^{t\bar{t}+1\text{-jet}}(\rho_s)$ and the detector-level distribution by $\mathcal{R}^{\text{det}}(\rho_s)$. Migrations between the parton level and the detector level are described by the unfolding matrix $\mathcal{M}$. The matrix is built from the nominal ATLAS MC $t\bar{t}$ sample, using events which pass both the parton-level and detector-level selection cuts. The matrix is inverted and regularised with the Bayesian unfolding method of ref. [82]. The bin-by-bin correction factor f accounts for the acceptance and for the difference between the $t\bar{t} + g$ system in the nominal ATLAS MC sample (the first emission level of ref. [11]) and the $t\bar{t} + 1$-jet system at parton level. It has a residual dependence on the value of the mass used in the MC generator for the correction, near the threshold production of $t\bar{t} + 1$-jet events. This is due to the available phase space in this region, which depends on the top-quark mass. This effect is taken into account by a second factor $f^{\text{ph.sp.}}$, which is parameterised in

---

[6]A particle is considered stable if its lifetime is greater than 3×10^{-11} s.

[7]Intermediate b-hadrons with $p_T > 5$ GeV in the MC decay chain history are clustered in the stable-particle jets with their energies set to zero.

each bin as a function of the unfolded observable before acceptance correction, $\mathcal{R}_{\mathrm{ACC}}^{t\bar{t}+1\,\mathrm{jet}}$[8], removing any explicit dependence on the value of the top-quark mass. The $f^{\mathrm{ph.sp.}}$ factor is very close to one and only affects those bins close to the $t\bar{t}+1$-jet production threshold region ($\rho_s > 0.775$). The unfolding to particle level is performed using the same tools, but is simpler in two ways: f is a pure acceptance correction in this case and the phase-space correction $f^{\mathrm{ph.sp.}}$ is equal to one as the same event topologies are considered at detector and particle level.

The unfolded, normalised differential cross section at particle level is presented in figure 2, where it is compared with the prediction of the POWHEG + PYTHIA 6 generator with the top-quark mass parameter set to 172.5 GeV. The distributions obtained from the electron and muon channels separately, unfolded following the nominal procedure, are also presented in the same figure to show their compatibility with the combined result.

In figure 3 the same measurement is presented after unfolding to parton level. The result is compared with the prediction for $t\bar{t}+1$-jet production of refs. [25, 83]. The fixed-order calculation at NLO accuracy in QCD is interfaced to the parton shower and is labelled as "NLO+PS" in the following. The prediction is shown for two values of the top-quark pole mass, to demonstrate the sensitivity of the observable to the top-quark mass.

8 Extraction of the top-quark mass

The top-quark pole mass is extracted from the parton-level result with an NLO+PS calculation of $t\bar{t}+1$-jet production [25, 83]. The fit finds the optimal value of m_t^{pole} by minimising the following expression with the least-squares method:

$$\chi^2 = \sum_{i,j} \left[\mathcal{R}_{\mathrm{data}}^{t\bar{t}+1\text{-jet}} - \mathcal{R}_{\mathrm{NLO+PS}}^{t\bar{t}+1\text{-jet}}(m_t^{\mathrm{pole}})\right]_i \left[V^{-1}\right]_{ij} \left[\mathcal{R}_{\mathrm{data}}^{t\bar{t}+1\text{-jet}} - \mathcal{R}_{\mathrm{NLO+PS}}^{t\bar{t}+1\text{-jet}}(m_t^{\mathrm{pole}})\right]_j,$$

where indices $i,j \in \{1,2,\ldots,8\}$ refer to the bin number of the unfolded observable. co-variance matrix, of which diagonal terms are the experimental statistical uncertainties in the measured observable, bin-by-bin. Per-bin uncertainties are assumed to be Gaussian. Correlations between bins are taken into account via off-diagonal entries in V. The term $\mathcal{R}_{\mathrm{data}}^{t\bar{t}+1\text{-jet}}$ represents the measured differential cross section. In each bin i a continuous parameterisation $[\mathcal{R}_{\mathrm{NLO+PS}}^{t\bar{t}+1\text{-jet}}(m_t^{\mathrm{pole}})]_i$ is obtained by interpolating with a second-order polynomial between different $\mathcal{R}_{\mathrm{NLO+PS}}^{t\bar{t}+1\text{-jet}}$ predictions computed at fixed m_t^{pole} values.

Experimental systematic uncertainties are assigned to account for imperfections in the modelling of the detector response and signal and background simulations. Monte Carlo simulations with varied response or simulation parameters are used to compute a set of $\mathcal{R}$ distributions at detector level. These distributions are then unfolded using the nominal procedure described in the previous section to particle or parton levels. Systematic uncertainties in the unfolded distribution are evaluated by taking into account the difference of the variation bin-by-bin where the unfolded alternative MC samples are compared to their generator-level distribution. Uncertainties in the top-quark mass are evaluated instead

---

[8]The observable is defined at parton level, but only for those events which pass detector-level selection.
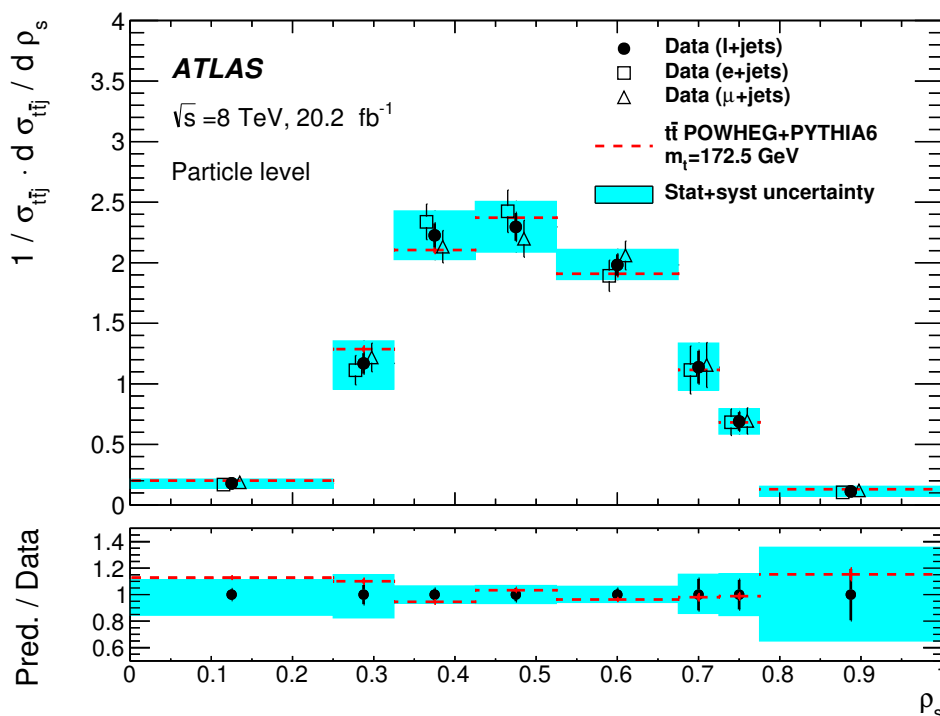
Figure 2. The normalised differential cross section for $pp \rightarrow t\bar{t} + 1$-jet production in pp collisions at $\sqrt{s} = 8$ TeV, as a function of ρ_s. The results in the electron and muon channels, and the combination of the two, are shown with different marker styles. The data are unfolded to the particle level and are compared with the prediction from the nominal MC generator, POWHEG + PYTHIA 6, with the top-quark mass parameter set to 172.5 GeV.

by comparing the values of the top-quark mass extracted from the unfolded distributions covering the systematic variations, and their numerical values are reported in table 2. A detailed description of the systematic uncertainties evaluated is given in the following.

Uncertainties in the modelling of the jet energy response are taken into account by varying the jet energy scale (*JES*) within its uncertainty for a number of uncorrelated components [84–86]. A separate uncertainty is assigned to the b-quark jet energy scale (*bJES*), which is uncorrelated with the *JES*. Systematic effects that affect the jet energy resolution (*JER*) and jet reconstruction efficiency are taken into account by smearing the jet energy and by randomly removing a fraction of the jets, respectively. Uncertainties originating from b-jet tagging/mistagging efficiency are also considered (*b-tagging efficiency and mistag*). Scale factors are applied to correct for the difference between efficiencies measured in data and in simulated events [68, 70]. The uncertainties in these correction factors are propagated to the measurement (*Lepton*). The modelling of $E_{\mathrm{T}}^{\mathrm{miss}}$ is affected by uncertainties in the jet energy and lepton momentum scales, as well as the response for the soft-term and pile-up modelling [79].

Modelling uncertainties cover a possible bias of the measurement due to imperfections in the description of signal and background processes in Monte Carlo generators. Several alternative models are used for $t\bar{t}$ production as introduced in section 4. Monte Carlo sim-
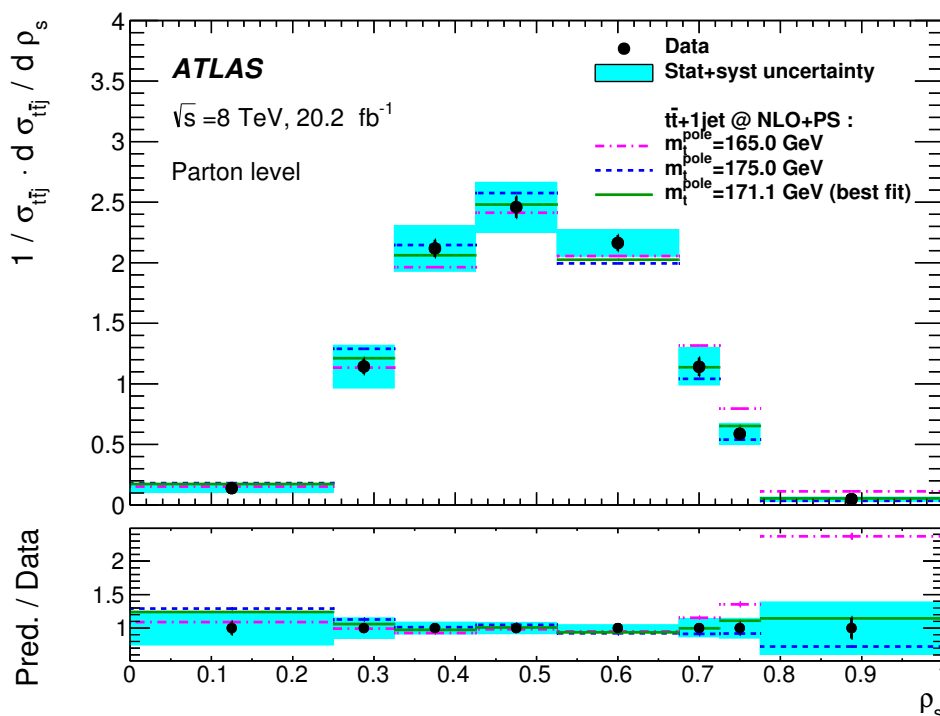
Figure 3. The normalised differential cross section for $pp \to t\bar{t} + 1$-jet production in pp collisions at $\sqrt{s} = 8$ TeV, as a function of ρ_s. The data are unfolded to the parton level as described in the text. The predictions of the NLO+PS calculation of refs. [25, 83] are shown for a top-quark pole mass of 165 GeV, 175 GeV and 171.1 GeV. Statistical errors are represented by error bars, while the shaded area represents the bin-by-bin sum in quadrature of the statistical and systematics uncertainties, as described in section 8. Bin-by-bin correlations are not shown in the plot.

ulations produced with a different matrix-element generator (PowHEG and aMC@NLO) are compared to evaluate the uncertainties in the calculation of the matrix elements (*Signal MC generator*). Uncertainties in $t\bar{t}$ modelling coming from the parton shower and hadronisation model (*Shower and hadronisation*) are evaluated by comparing PYTHIA 6 with HERWIG, both interfaced with PowHEG. Uncertainties due to the choice of proton PDF (*Proton PDF*) are evaluated following the prescriptions of ref. [87]. Uncertainties coming from the choice of parameter values that control initial- and final-state radiation (*ISR/FSR*), the colour reconnection (*Colour reconnection*) and underlying-event modelling (*Underlying event*) are estimated following the scheme of ref. [88]. The uncertainty in the modelling of background processes is evaluated by varying the normalisation and shape of several sources (*Background*). The normalisation is varied within the cross-section uncertainty for single-top ($\pm 7.8\%$) and V+jets ($\pm 33\%$) backgrounds, while the data-driven multijet contribution is scaled by $\pm 50\%$ [63]. Background shape uncertainties and luminosity uncertainty are found to be negligible.

The uncertainty due to the limited size of the Monte Carlo sample used to unfold the data (*MC statistics*) is evaluated by repeating the unfolding procedure 5000 times, varying the unfolding matrix within its uncertainties.

Finally, additional systematic uncertainties are assigned to the top-quark mass extraction procedure. The top-quark mass value is obtained by fitting the $\mathcal{R}(m_t)$ prediction to the data unfolded at parton level. One uncertainty is assigned to the fit procedure (*Fit parameterisation*) to account for a possible bias from the continuous parameterisation of the theoretical prediction and for non-closure effects. Another uncertainty is assigned to the phase-space correction factor $f^{\text{ph.sp.}}$ (*Unfolding modelling*). It is evaluated as half the difference between top-quark mass results obtained with and without the phase-space correction.

The theoretical uncertainty in the mass consists of two contributions. The uncertainty due to the truncation of the perturbative series is evaluated with the conventional procedure of varying the factorisation (μ_{F}) and renormalisation (μ_{R}) scales by factors of 2 and then 1/2 from the nominal scale $\mu_{\text{F}} = \mu_{\text{R}} = m_t$ (*Scale variations*). The scale uncertainty is taken as the mass shift for the alternative scale choices and is typically asymmetric. A positive (negative) shift of the extracted top-quark mass is found when decreasing (increasing) the renormalisation scale. Additional tests were performed in order to gain confidence in the values presented in table 2. The scale variation has a larger impact in the $\overline{\text{MS}}$ mass scheme, as already observed in ref. [17]. A redundancy exists between the theoretical uncertainty obtained from the scale variations and the one considered by the initial/final radiation, which is not subtracted. The uncertainty due to PDFs and the parametric uncertainty in the strong coupling constant, α_{s}, is evaluated by generating the prediction for three consistent choices of PDF set and α_{s}: CT10nlo with $\alpha_{\text{s}}(m_Z) = 0.118$ (nominal), MSTW2008nlo90cl with $\alpha_{\text{s}}(m_Z) = 0.120$ and NNPDF23 with $\alpha_{\text{s}}(m_Z) = 0.119$. The uncertainty is taken as half the envelope of the mass values extracted from the three choices mentioned above (*Theory PDF$\oplus\alpha_{\text{s}}$*). The total theory uncertainty is obtained by adding the scale and PDF uncertainties in quadrature. The parton shower barely affects the theoretical prediction [11] and its associated uncertainty is negligible.

9 Results

The fit to the parton-level differential cross section yields a top-quark pole mass of

$$m_t^{\text{pole}} = 171.1 \pm 0.4 \text{ (stat)} \pm 0.9 \text{ (syst)} {}^{+0.7}_{-0.3} \text{ (theo) GeV.} \tag{9.1}$$

The procedure for the extraction of the $\overline{\text{MS}}$ mass with the calculation from ref. [17] is completely analogous to the pole-mass fit described above. The result for the running mass in the $\overline{\text{MS}}$ scheme is:

$$m_t(m_t) = 162.9 \pm 0.5(\text{stat}) \pm 1.0(\text{syst}) {}^{+2.1}_{-1.2} \text{ (theo) GeV.}$$

The statistical uncertainty in the mass is evaluated by repeating the unfolding and fit procedure on pseudo-data samples, where the number of events in each bin is varied within the statistical uncertainty. The experimental systematic uncertainty is evaluated as described in section 8 and corresponds to those values quoted in table 2.

Several tests were performed to verify the consistency and robustness of the result.

The measured value of the top-quark mass is stable with respect to variations of the p_{T} cut on the additional jet and the choice of binning of the ρ_{s} variable. The analysis

Mass scheme	m_t^{pole} [GeV]	$m_t(m_t)$ [GeV]
Value	**171.1**	**162.9**
Statistical uncertainty	**0.4**	**0.5**
Simulation uncertainties		
Shower and hadronisation	0.4	0.3
Colour reconnection	0.4	0.4
Underlying event	0.3	0.2
Signal Monte Carlo generator	0.2	0.2
Proton PDF	0.2	0.2
Initial- and final-state radiation	0.2	0.2
Monte Carlo statistics	0.2	0.2
Background	<0.1	<0.1
Detector response uncertainties		
Jet energy scale (including b-jets)	0.4	0.4
Jet energy resolution	0.2	0.2
Missing transverse momentum	0.1	0.1
b-tagging efficiency and mistag	0.1	0.1
Jet reconstruction efficiency	<0.1	<0.1
Lepton	<0.1	<0.1
Method uncertainties		
Unfolding modelling	0.2	0.2
Fit parameterisation	0.2	0.2
Total experimental systematic	**0.9**	**1.0**
Scale variations	$(+0.6, -0.2)$	$(+2.1, -1.2)$
Theory PDF$\oplus\alpha_{\mathrm{s}}$	0.2	0.4
Total theory uncertainty	**$(+0.7, -0.3)$**	**$(+2.1, -1.2)$**
Total uncertainty	**$(+1.2, -1.1)$**	**$(+2.3, -1.6)$**

Table 2. Summary table of the uncertainties in the measurement of the pole mass, m_t^{pole}, and the running $\overline{\mathrm{MS}}$ mass, $m_t(m_t)$.

is repeated using six bins, eight bins and ten bins. The central values of m_t^{pole} obtained with these different binning configurations agree within 0.3 GeV with the default setup. A higher number of bins increases the sensitivity and leads to a slightly reduced uncertainty of the measurement. However, the use of ten bins is affected by fluctuations in the unfolding procedure and the χ^2, originating from the limited statistics of the available simulations. The result obtained with eight bins is very stable in all aspects of the analysis and therefore this choice is finally adopted. The fits are also repeated excluding different bins in the χ^2 sum, with an agreement of the results obtained within 0.1 GeV.

Correlations between the extracted top-quark mass and the assumed value of m_W used in event selection are negligible.
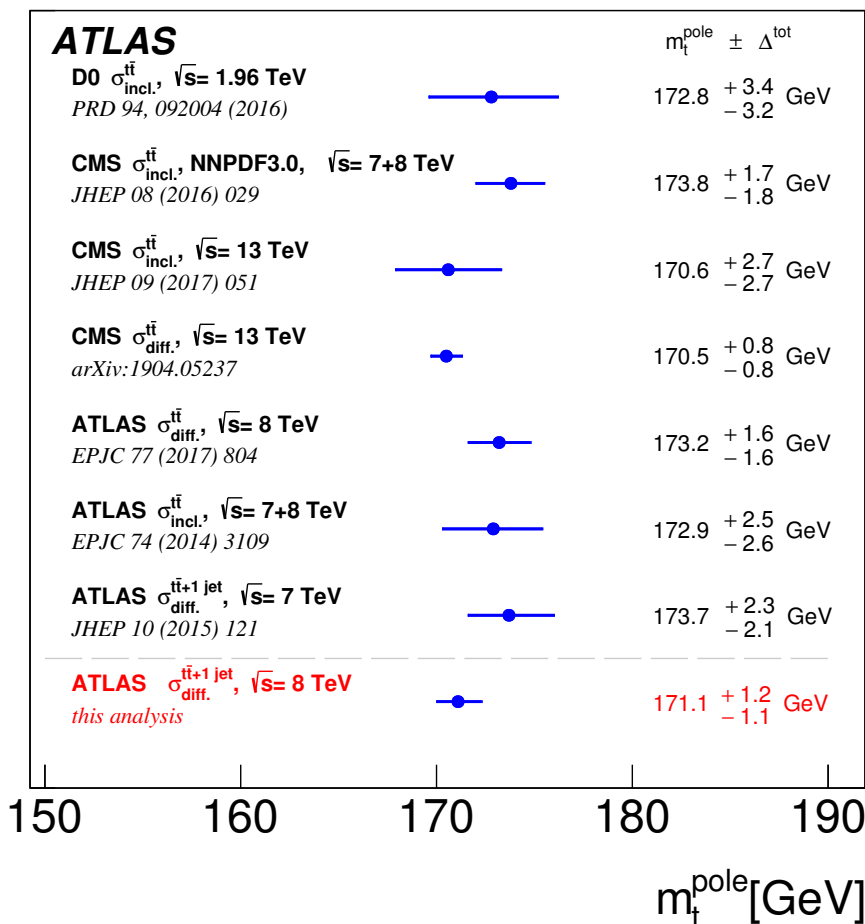
Figure 4. Summary of top-quark pole mass measurements at the Tevatron and the LHC.

The masses extracted from the electron channel and the muon channel separately are compatible. Effects associated to the top-quark finite width, off-shell effects and non-resonant contributions are small and covered by the $t\bar{t}$ MC modelling uncertainties. In addition, the measured top-quark mass is independent of the assumed top-quark mass in the MC simulation that is used to unfold the data. The fit is repeated for MC samples using different top-quark masses between 165 GeV and 180 GeV. For all samples the unfolding is based on MC simulation with a top mass of 172.5 GeV. The difference between simulated top-quark mass and the fit result is found to be compatible with zero over the entire range of top-quark masses tested.

The unfolding procedure is validated using pseudo-data samples which were generated by varying the bin contents of the observable at detector level according to their statistical errors. Pull distributions are produced using these samples. In addition, stress tests are performed to demonstrate that the unfolding procedure is independent of the input distribution. All these tests demonstrate that the analysis procedure is unbiased and correctly estimates the statistical uncertainties.

The assigned theoretical uncertainty to the measured top-quark pole mass is cross-checked in two alternative ways, following the approach applied to the measurement based

on the data set at 7 TeV centre-of-mass energy [11]:

- The value of the top-quark mass is evaluated based on an LO calculation and compared to the default, which is based on an NLO calculation. The difference is found to be 0.3 GeV and is covered by the assigned uncertainties due to the scale choice.

- An expansion of $\mathcal{R}$ in powers of α_S is performed and the theoretical uncertainty is re-evaluated performing scale variations on the new expression for $\mathcal{R}$. In this way, potential cancellations are avoided which may occur when expanding the numerator and the denominator or $\mathcal{R}$ separately as a function of α_S and can lead to a too optimistic uncertainty. Only the case of m_t^{pole} is considered in this test and the result obtained (+0.4, -0.2) is found to be compatible with that expressed in table 2,

All the above considerations and cross-checks suggest that the error assigned to unknown higher orders gives a reliable estimation of its value.

The scale variation has a larger impact in the $\overline{\text{MS}}$ mass scheme, as already observed in ref. [17].

The top-quark pole mass result obtained from data unfolded to parton level and reported in eq. (9.1) is compatible with previous measurements of the pole mass [8–14], as is shown in figure 4. Compared with the result obtained by ATLAS with the same method at 7 TeV [11] the statistical and systematic uncertainties of the new result are reduced by more than a factor of two.

The $\overline{\text{MS}}$ mass result is translated to the pole-mass scheme using the NLO QCD relationship [18] between the top-quark masses in the two schemes.[9] When converting $m_t(m_t)$ to m_t^{pole} the obtained value is $m_t^{\text{pole}} \approx 170.9$ GeV, which is in good agreement with the direct extraction of the pole mass. The measurements of m_t^{pole} and $m_t(m_t)$ are therefore fully compatible.

10   Conclusions

In this paper, the normalised differential cross section, $\mathcal{R}$, of top-quark pair production in association with an energetic jet is presented as a function of the inverse of the invariant mass of the $t\bar{t} + 1$-jet system $\rho_s = 2m_0/m_{t\bar{t}+1\text{-jet}}$. The measurement is performed using pp collision data at a centre-of-mass energy of 8 TeV collected by the ATLAS experiment at the LHC in 2012. The data sample corresponds to an integrated luminosity of 20.2 fb^{-1}. The distribution of $\mathcal{R}$ observed in the semileptonic final state is unfolded to the parton and particle levels. The result from data unfolded to parton level is compared with the NLO

---

[9]The QCD relation between the two schemes is known to four loops, but here the series is truncated at two loops to match the precision of the $t\bar{t} + 1$-jet cross section that was used to extract the mass in both schemes. The relationship between the two masses then takes the simple form:

$$m_t^{\text{pole}} = m_t(m_t) \left(1 + \frac{4}{3} \frac{\alpha_s\,(\mu = m_t)}{\pi}\right) + \mathcal{O}(\alpha_s^2).$$

The pole mass result quoted in the text is obtained for $\alpha_s(163 \text{ GeV}) \sim 0.116$.

QCD predictions in two different renormalisation schemes. The top-quark running mass in the $\overline{\text{MS}}$ scheme yields the following value:

$$m_t(m_t) = 162.9 \pm 0.5 \text{ (stat)} \pm 1.0 \text{ (syst)} \, ^{+2.1}_{-1.2} \text{ (theo)} \text{ GeV}.$$

The top-quark mass extracted in the pole-mass scheme yields

$$m_t^{\text{pole}} = 171.1 \pm 0.4 \text{ (stat)} \pm 0.9 \text{ (syst)} \, ^{+0.7}_{-0.3} \text{ (theo) GeV}$$

with a total uncertainty of $\Delta m_t^{\text{pole}} = \, ^{+1.2}_{-1.1}$ GeV.

The result for $m_t(m_t)$ suffers from a larger theoretical uncertainty as compared with the pole mass. This is due to a larger dependence on the renormalisation and factorisation scales of the $\overline{\text{MS}}$ scheme in the most sensitive region close to the $t\bar{t} + 1$-jet threshold.

Acknowledgments

References

[1] J. Haller et al., *Update of the global electroweak fit and constraints on two-Higgs-doublet models*, *Eur. Phys. J.* **C 78** (2018) 675 [arXiv:1803.01853] [ɪɴSPIRE].

[2] GFITTER GROUP collaboration, *The global electroweak fit at NNLO and prospects for the LHC and ILC*, *Eur. Phys. J.* **C 74** (2014) 3046 [arXiv:1407.3792] [ɪɴSPIRE].

[3] J. de Blas et al., *Electroweak precision observables and Higgs-boson signal strengths in the standard model and beyond: present and future*, *JHEP* **12** (2016) 135 [arXiv:1608.01509] [ɪɴSPIRE].

[4] S. Alekhin, J. Blümlein, S. Moch and R. Placakyte, *Parton distribution functions, α_s and heavy-quark masses for LHC Run II*, *Phys. Rev.* **D 96** (2017) 014011 [arXiv:1701.05838] [ɪɴSPIRE].

[5] PARTICLE DATA GROUP collaboration, *Review of particle physics*, *Phys. Rev.* **D 98** (2018) 030001 [ɪɴSPIRE].

[6] G. Degrassi et al., *Higgs mass and vacuum stability in the standard model at NNLO*, *JHEP* **08** (2012) 098 [arXiv:1205.6497] [ɪɴSPIRE].

[7] S. Alekhin, A. Djouadi and S. Moch, *The top quark and Higgs boson masses and the stability of the electroweak vacuum*, *Phys. Lett.* **B 716** (2012) 214 [arXiv:1207.0980] [ɪɴSPIRE].

[8] ATLAS collaboration, *Measurement of the $t\bar{t}$ production cross-section using $e\mu$ events with b-tagged jets in pp collisions at $\sqrt{s} = 7$ and 8 TeV with the ATLAS detector*, *Eur. Phys. J.* **C 74** (2014) 3109 [arXiv:1406.5375] [ɪɴSPIRE].

[9] CMS collaboration, *Measurement of the t-tbar production cross section in the e-μ channel in proton-proton collisions at $\sqrt{s} = 7$ and 8 TeV*, *JHEP* **08** (2016) 029 [arXiv:1603.02303] [ɪɴSPIRE].

[10] CMS collaboration, *Measurement of the $t\bar{t}$ production cross section using events with one lepton and at least one jet in pp collisions at $\sqrt{s} = 13$ TeV*, *JHEP* **09** (2017) 051 [arXiv:1701.06228] [ɪɴSPIRE].

[11] ATLAS collaboration, *Determination of the top-quark pole mass using $t\bar{t}$ + 1-jet events collected with the ATLAS experiment in 7 TeV pp collisions*, *JHEP* **10** (2015) 121 [arXiv:1507.01769] [ɪɴSPIRE].

[12] D0 collaboration, *Measurement of the inclusive $t\bar{t}$ production cross section in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV and determination of the top quark pole mass*, *Phys. Rev.* **D 94** (2016) 092004 [arXiv:1605.06168] [ɪɴSPIRE].

[13] ATLAS collaboration, *Measurement of lepton differential distributions and the top quark mass in $t\bar{t}$ production in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector*, *Eur. Phys. J.* **C 77** (2017) 804 [arXiv:1709.09407] [ɪɴSPIRE].

[14] CMS collaboration, *Measurement of $t\bar{t}$ normalised multi-differential cross sections in pp collisions at $\sqrt{s} = 13$ TeV and simultaneous determination of the strong coupling strength, top quark pole mass and parton distribution functions*, submitted to *Eur. Phys. J.* (2019), arXiv:1904.05237 [ɪɴSPIRE].

[15] U. Langenfeld, S. Moch and P. Uwer, *Measuring the running top-quark mass*, *Phys. Rev.* **D 80** (2009) 054009 [arXiv:0906.5273] [ɪɴSPIRE].

[16] CMS collaboration, *Measurement of the $t\bar{t}$ production cross section, the top quark mass and the strong coupling constant using dilepton events in pp collisions at $\sqrt{s} = 13$ TeV*, *Eur. Phys. J.* **C 79** (2019) 368 [arXiv:1812.10505] [INSPIRE].

[17] J. Fuster, A. Irles, D. Melini, P. Uwer and M. Vos, *Extracting the top-quark running mass using $t\bar{t}$ + 1-jet events produced at the Large Hadron Collider*, *Eur. Phys. J.* **C 77** (2017) 794 [arXiv:1704.00540] [INSPIRE].

[18] P. Marquard, A.V. Smirnov, V.A. Smirnov and M. Steinhauser, *Quark mass relations to four-loop order in perturbative QCD*, *Phys. Rev. Lett.* **114** (2015) 142002 [arXiv:1502.01030] [INSPIRE].

[19] M. Butenschoen et al., *Top quark mass calibration for Monte Carlo event generators*, *Phys. Rev. Lett.* **117** (2016) 232001 [arXiv:1608.01318] [INSPIRE].

[20] ATLAS, CDF, CMS, D0 collaboration, *First combination of Tevatron and LHC measurements of the top-quark mass*, arXiv:1403.4427 [INSPIRE].

[21] S. Moch et al., *High precision fundamental constants at the TeV scale*, arXiv:1405.4781 [INSPIRE].

[22] A. Juste et al., *Determination of the top quark mass circa 2013: methods, subtleties, perspectives*, *Eur. Phys. J.* **C 74** (2014) 3119 [arXiv:1310.0799] [INSPIRE].

[23] P. Nason, *The top mass in hadronic collisions*, arXiv:1712.02796 [INSPIRE].

[24] A.H. Hoang, *The top mass: interpretation and theoretical uncertainties*, in the proceedings of the 7th *International Workshop on Top Quark Physics (TOP2014)*, September 28-October 3, Cannes, France (2014), arXiv:1412.3649 [INSPIRE].

[25] S. Alioli et al., *A new observable to measure the top-quark mass at hadron colliders*, *Eur. Phys. J.* **C 73** (2013) 2438 [arXiv:1303.6415] [INSPIRE].

[26] G. Bevilacqua et al., *Top quark mass studies with $t\bar{t}j$ at the LHC*, *JHEP* **03** (2018) 169 [arXiv:1710.07515] [INSPIRE].

[27] ATLAS collaboration, *The ATLAS experiment at the CERN Large Hadron Collider*, 2008 *JINST* **3** S08003 [INSPIRE].

[28] ATLAS collaboration, *Performance of the ATLAS trigger system in 2010*, *Eur. Phys. J.* **C 72** (2012) 1849 [arXiv:1110.1530] [INSPIRE].

[29] ATLAS collaboration, *Luminosity determination in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector at the LHC*, *Eur. Phys. J.* **C 76** (2016) 653 [arXiv:1608.03953] [INSPIRE].

[30] S. Alioli, P. Nason, C. Oleari and E. Re, *A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX*, *JHEP* **06** (2010) 043 [arXiv:1002.2581] [INSPIRE].

[31] S. Frixione, P. Nason and C. Oleari, *Matching NLO QCD computations with Parton Shower simulations: the POWHEG method*, *JHEP* **11** (2007) 070 [arXiv:0709.2092] [INSPIRE].

[32] P. Nason, *A new method for combining NLO QCD with shower Monte Carlo algorithms*, *JHEP* **11** (2004) 040 [hep-ph/0409146] [INSPIRE].

[33] S. Frixione, P. Nason and G. Ridolfi, *A positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction*, *JHEP* **09** (2007) 126 [arXiv:0707.3088] [INSPIRE].

[34] H.-L. Lai et al., *New parton distributions for collider physics*, *Phys. Rev.* **D 82** (2010) 074024 [arXiv:1007.2241] [INSPIRE].

[35] S. Alioli, P. Nason, C. Oleari and E. Re, *NLO Higgs boson production via gluon fusion matched with shower in POWHEG*, *JHEP* **04** (2009) 002 [arXiv:0812.0578] [INSPIRE].

[36] M. Czakon, P. Fiedler and A. Mitov, *Total top-quark pair-production cross section at hadron colliders through $\mathcal{O}(\alpha_S^4)$*, *Phys. Rev. Lett.* **110** (2013) 252004 [arXiv:1303.2564].

[37] M. Czakon and A. Mitov, *NNLO corrections to top pair production at hadron colliders: the quark-gluon reaction*, *JHEP* **01** (2013) 080 [arXiv:1210.6832] [INSPIRE].

[38] M. Czakon and A. Mitov, *NNLO corrections to top-pair production at hadron colliders: the all-fermionic scattering channels*, *JHEP* **12** (2012) 054 [arXiv:1207.0236] [INSPIRE].

[39] M. Beneke, P. Falgari, S. Klein and C. Schwinn, *Hadronic top-quark pair production with NNLL threshold resummation*, *Nucl. Phys.* **B 855** (2012) 695 [arXiv:1109.1536] [INSPIRE].

[40] P. Bärnreuther, M. Czakon and A. Mitov, *Percent level precision physics at the Tevatron: first genuine NNLO QCD corrections to $q\bar{q} \to t\bar{t} + X$*, *Phys. Rev. Lett.* **109** (2012) 132001 [arXiv:1204.5201] [INSPIRE].

[41] M. Cacciari et al., *Top-pair production at hadron colliders with next-to-next-to-leading logarithmic soft-gluon resummation*, *Phys. Lett.* **B 710** (2012) 612 [arXiv:1111.5869] [INSPIRE].

[42] M. Aliev et al., *HATHOR: HAdronic Top and Heavy quarks crOss section calculatoR*, *Comput. Phys. Commun.* **182** (2011) 1034 [arXiv:1007.1327] [INSPIRE].

[43] M. Czakon and A. Mitov, *Top++: a program for the calculation of the top-pair cross-section at hadron colliders*, *Comput. Phys. Commun.* **185** (2014) 2930 [arXiv:1112.5675] [INSPIRE].

[44] A.D. Martin, W.J. Stirling, R.S. Thorne and G. Watt, *Parton distributions for the LHC*, *Eur. Phys. J.* **C 63** (2009) 189 [arXiv:0901.0002] [INSPIRE].

[45] A.D. Martin, W.J. Stirling, R.S. Thorne and G. Watt, *Uncertainties on α_s in global PDF analyses and implications for predicted hadronic cross sections*, *Eur. Phys. J.* **C 64** (2009) 653 [arXiv:0905.3531] [INSPIRE].

[46] J. Gao et al., *CT10 next-to-next-to-leading order global analysis of QCD*, *Phys. Rev.* **D 89** (2014) 033009 [arXiv:1302.6246] [INSPIRE].

[47] R.D. Ball et al., *Parton distributions with LHC data*, *Nucl. Phys.* **B 867** (2013) 244 [arXiv:1207.1303] [INSPIRE].

[48] T. Sjöstrand, S. Mrenna and P.Z. Skands, *PYTHIA 6.4 physics and manual*, *JHEP* **05** (2006) 026 [hep-ph/0603175] [INSPIRE].

[49] P.M. Nadolsky et al., *Implications of CTEQ PDF analysis for collider observables*, *Phys. Rev.* **D 78** (2008) 013004 [INSPIRE].

[50] P.Z. Skands, *Tuning Monte Carlo generators: the Perugia tunes*, *Phys. Rev.* **D 82** (2010) 074018 [arXiv:1005.3457] [INSPIRE].

[51] S. Frixione and B.R. Webber, *Matching NLO QCD computations and parton shower simulations*, *JHEP* **06** (2002) 029 [hep-ph/0204244] [INSPIRE].

[52] G. Corcella et al., *HERWIG 6: an event generator for hadron emission reactions with interfering gluons (including supersymmetric processes)*, *JHEP* **01** (2001) 010 [hep-ph/0011363] [INSPIRE].

[53] J.M. Butterworth, J.R. Forshaw and M.H. Seymour, *Multiparton interactions in photoproduction at HERA*, *Z. Phys.* **C 72** (1996) 637 [hep-ph/9601371] [INSPIRE].

[54] ATLAS collaboration, *New ATLAS event generator tunes to 2010 data*, ATL-PHYS-PUB-2011-008 (2011).

[55] ATLAS collaboration, *A study of the sensitivity to the PYTHIA8 parton shower parameters of $t\bar{t}$ production measurements in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS experiment at the LHC*, ATL-PHYS-PUB-2015-007 (2015).

[56] N. Kidonakis, *Next-to-next-to-leading-order collinear and soft gluon corrections for t-channel single top quark production*, *Phys. Rev.* **D 83** (2011) 091503 [arXiv:1103.2792] [INSPIRE].

[57] N. Kidonakis, *Two-loop soft anomalous dimensions for single top quark associated production with a W^- or H^-*, *Phys. Rev.* **D 82** (2010) 054018 [arXiv:1005.4451] [INSPIRE].

[58] N. Kidonakis, *NNLL resummation for s-channel single top quark production*, *Phys. Rev.* **D 81** (2010) 054028 [arXiv:1001.5034] [INSPIRE].

[59] M.L. Mangano, M. Moretti, F. Piccinini, R. Pittau and A.D. Polosa, *ALPGEN, a generator for hard multiparton processes in hadronic collisions*, *JHEP* **07** (2003) 001 [hep-ph/0206293] [INSPIRE].

[60] M.L. Mangano, M. Moretti and R. Pittau, *Multijet matrix elements and shower evolution in hadronic collisions: $Wb\bar{b} + n$ jets as a case study*, *Nucl. Phys.* **B 632** (2002) 343 [hep-ph/0108069] [INSPIRE].

[61] R. Hamberg, W.L. van Neerven and T. Matsuura, *A complete calculation of the order α_s^2 correction to the Drell-Yan K factor*, *Nucl. Phys.* **B 359** (1991) 343 [*Erratum ibid.* **B 644** (2002) 403] [INSPIRE].

[62] R. Gavin, Y. Li, F. Petriello and S. Quackenbush, *W physics at the LHC with FEWZ 2.1*, *Comput. Phys. Commun.* **184** (2013) 208 [arXiv:1201.5896] [INSPIRE].

[63] ATLAS collaboration, *Estimation of non-prompt and fake lepton backgrounds in final states with top quarks produced in proton-proton collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector*, ATLAS-CONF-2014-058 (2014).

[64] T. Sjöstrand, S. Mrenna and P.Z. Skands, *A brief introduction to PYTHIA 8.1*, *Comput. Phys. Commun.* **178** (2008) 852 [arXiv:0710.3820] [INSPIRE].

[65] ATLAS collaboration, *Summary of ATLAS PYTHIA 8 tunes*, ATL-PHYS-PUB-2012-003 (2012).

[66] ATLAS collaboration, *The ATLAS simulation infrastructure*, *Eur. Phys. J.* **C 70** (2010) 823 [arXiv:1005.4568] [INSPIRE].

[67] GEANT4 collaboration, *GEANT4 — A simulation toolkit*, *Nucl. Instrum. Meth.* **A 506** (2003) 250 [INSPIRE].

[68] ATLAS collaboration, *Electron efficiency measurements with the ATLAS detector using 2012 LHC proton-proton collision data*, *Eur. Phys. J.* **C 77** (2017) 195 [arXiv:1612.01456] [INSPIRE].

[69] ATLAS collaboration, *Reconstruction of primary vertices at the ATLAS experiment in Run 1 proton-proton collisions at the LHC*, *Eur. Phys. J.* **C 77** (2017) 332 [arXiv:1611.10235] [INSPIRE].

[70] ATLAS collaboration, *Measurement of the muon reconstruction performance of the ATLAS detector using 2011 and 2012 LHC proton-proton collision data*, *Eur. Phys. J.* **C 74** (2014) 3130 [arXiv:1407.3935] [INSPIRE].

[71] ATLAS collaboration, *Topological cell clustering in the ATLAS calorimeters and its performance in LHC Run 1*, *Eur. Phys. J.* **C 77** (2017) 490 [arXiv:1603.02934] [INSPIRE].

[72] ATLAS LIQUID ARGON ENDCAP collaboration, *Evaluation of the local hadronic calibration with combined beam-test data for the endcap and forward calorimeters of ATLAS in the pseudorapidity region $2.5 < |eta| < 4.0$*, *Nucl. Instrum. Meth.* **A 693** (2012) 74 [INSPIRE].

[73] M. Cacciari, G.P. Salam and G. Soyez, *The anti-k_t jet clustering algorithm*, *JHEP* **04** (2008) 063 [arXiv:0802.1189] [INSPIRE].

[74] M. Cacciari and G.P. Salam, *Dispelling the N^3 myth for the k_t jet-finder*, *Phys. Lett.* **B 641** (2006) 57 [hep-ph/0512210] [INSPIRE].

[75] ATLAS collaboration, *A measurement of the calorimeter response to single hadrons and determination of the jet energy scale uncertainty using LHC Run-1 pp-collision data with the ATLAS detector*, *Eur. Phys. J.* **C 77** (2017) 26 [arXiv:1607.08842] [INSPIRE].

[76] M. Cacciari, G.P. Salam and G. Soyez, *FastJet user manual*, *Eur. Phys. J.* **C 72** (2012) 1896 [arXiv:1111.6097] [INSPIRE].

[77] ATLAS collaboration, *Performance of pile-up mitigation techniques for jets in pp collisions at $\sqrt{s} = 8\,TeV$ using the ATLAS detector*, *Eur. Phys. J.* **C 76** (2016) 581 [arXiv:1510.03823] [INSPIRE].

[78] ATLAS collaboration, *Performance of b-jet identification in the ATLAS experiment*, 2016 *JINST* **11** P04008 [arXiv:1512.01094] [INSPIRE].

[79] ATLAS collaboration, *Performance of algorithms that reconstruct missing transverse momentum in $\sqrt{s} = 8\,TeV$ proton-proton collisions in the ATLAS detector*, *Eur. Phys. J.* **C 77** (2017) 241 [arXiv:1609.09324] [INSPIRE].

[80] ATLAS collaboration, *Measurements of top-quark pair differential cross-sections in the lepton+jets channel in pp collisions at $\sqrt{s} = 8\,TeV$ using the ATLAS detector*, *Eur. Phys. J.* **C 76** (2016) 538 [arXiv:1511.04716] [INSPIRE].

[81] ATLAS collaboration, *Measurement of the W boson polarisation in $t\bar{t}$ events from pp collisions at $\sqrt{s} = 8\,TeV$ in the lepton + jets channel with ATLAS*, *Eur. Phys. J.* **C 77** (2017) 264 [*Erratum ibid.* **C 79** (2019) 19] [arXiv:1612.02577] [INSPIRE].

[82] G. D'Agostini, *A multidimensional unfolding method based on Bayes' theorem*, *Nucl. Instrum. Meth.* **A 362** (1995) 487 [INSPIRE].

[83] S. Alioli, S.-O. Moch and P. Uwer, *Hadronic top-quark pair-production with one jet and parton showering*, *JHEP* **01** (2012) 137 [arXiv:1110.5251] [INSPIRE].

[84] ATLAS collaboration, *Determination of the jet energy scale and resolution at ATLAS using Z/γ-jet events in data at $\sqrt{s} = 8\,TeV$*, ATLAS-CONF-2015-057 (2015).

[85] ATLAS collaboration, *Monte Carlo calibration and combination of in-situ measurements of jet energy scale, jet energy resolution and jet mass in ATLAS*, ATLAS-CONF-2015-037 (2015).

[86] ATLAS collaboration, *Data-driven determination of the energy scale and resolution of jets reconstructed in the ATLAS calorimeters using dijet and multijet events at $\sqrt{s} = 8\,TeV$*, ATLAS-CONF-2015-017 (2015).

[87] M. Botje et al., *The PDF4LHC working group interim recommendations*, arXiv:1101.0538 [INSPIRE].

[88] ATLAS collaboration, *Comparison of Monte Carlo generator predictions from Powheg and Sherpa to ATLAS measurements of top pair production at 7 TeV*, ATL-PHYS-PUB-2015-011 (2015).

[89] ATLAS collaboration, *ATLAS computing acknowledgements*, ATL-GEN-PUB-2016-002 (2016).

The ATLAS collaboration

G. Aad[101], B. Abbott[128], D.C. Abbott[102], O. Abdinov[13,*], A. Abed Abud[70a,70b], K. Abeling[53],
D.K. Abhayasinghe[93], S.H. Abidi[167], O.S. AbouZeid[40], N.L. Abraham[156], H. Abramowicz[161],
H. Abreu[160], Y. Abulaiti[6], B.S. Acharya[66a,66b,p], B. Achkar[53], S. Adachi[163], L. Adam[99],
C. Adam Bourdarios[132], L. Adamczyk[83a], L. Adamek[167], J. Adelman[121], M. Adersberger[114],
A. Adiguzel[12c,al], S. Adorni[54], T. Adye[144], A.A. Affolder[146], Y. Afik[160], C. Agapopoulou[132],
M.N. Agaras[38], A. Aggarwal[119], C. Agheorghiesei[27c], J.A. Aguilar-Saavedra[140f,140a,ak],
F. Ahmadov[79], W.S. Ahmed[103], X. Ai[15a], G. Aielli[73a,73b], S. Akatsuka[85], T.P.A. Åkesson[96],
E. Akilli[54], A.V. Akimov[110], K. Al Khoury[132], G.L. Alberghi[23b,23a], J. Albert[176],
M.J. Alconada Verzini[161], S. Alderweireldt[36], M. Aleksa[36], I.N. Aleksandrov[79], C. Alexa[27b],
D. Alexandre[19], T. Alexopoulos[10], A. Alfonsi[120], M. Alhroob[128], B. Ali[142], G. Alimonti[68a],
J. Alison[37], S.P. Alkire[148], C. Allaire[132], B.M.M. Allbrooke[156], B.W. Allen[131], P.P. Allport[21],
A. Aloisio[69a,69b], A. Alonso[40], F. Alonso[88], C. Alpigiani[148], A.A. Alshehri[57], M. Alvarez Estevez[98],
D. Álvarez Piqueras[174], M.G. Alviggi[69a,69b], Y. Amaral Coutinho[80b], A. Ambler[103], L. Ambroz[135],
C. Amelung[26], D. Amidei[105], S.P. Amor Dos Santos[140a], S. Amoroso[46], C.S. Amrouche[54],
F. An[78], C. Anastopoulos[149], N. Andari[145], T. Andeen[11], C.F. Anders[61b], J.K. Anders[20],
A. Andreazza[68a,68b], V. Andrei[61a], C.R. Anelli[176], S. Angelidakis[38], A. Angerami[39],
A.V. Anisenkov[122b,122a], A. Annovi[71a], C. Antel[61a], M.T. Anthony[149], M. Antonelli[51],
D.J.A. Antrim[171], F. Anulli[72a], M. Aoki[81], J.A. Aparisi Pozo[174], L. Aperio Bella[36],
G. Arabidze[106], J.P. Araque[140a], V. Araujo Ferraz[80b], R. Araujo Pereira[80b], C. Arcangeletti[51],
A.T.H. Arce[49], F.A. Arduh[88], J-F. Arguin[109], S. Argyropoulos[77], J.-H. Arling[46],
A.J. Armbruster[36], L.J. Armitage[92], A. Armstrong[171], O. Arnaez[167], H. Arnold[120],
A. Artamonov[111,*], G. Artoni[135], S. Artz[99], S. Asai[163], N. Asbah[59], E.M. Asimakopoulou[172],
L. Asquith[156], K. Assamagan[29], R. Astalos[28a], R.J. Atkin[33a], M. Atkinson[173], N.B. Atlay[151],
H. Atmani[132], K. Augsten[142], G. Avolio[36], R. Avramidou[60a], M.K. Ayoub[15a], A.M. Azoulay[168b],
G. Azuelos[109,bb], M.J. Baca[21], H. Bachacou[145], K. Bachas[67a,67b], M. Backes[135],
F. Backman[45a,45b], P. Bagnaia[72a,72b], M. Bahmani[84], H. Bahrasemani[152], A.J. Bailey[174],
V.R. Bailey[173], J.T. Baines[144], M. Bajic[40], C. Bakalis[10], O.K. Baker[183], P.J. Bakker[120],
D. Bakshi Gupta[8], S. Balaji[157], E.M. Baldin[122b,122a], P. Balek[180], F. Balli[145], W.K. Balunas[135],
J. Balz[99], E. Banas[84], A. Bandyopadhyay[24], Sw. Banerjee[181,j], A.A.E. Bannoura[182], L. Barak[161],
W.M. Barbe[38], E.L. Barberio[104], D. Barberis[55b,55a], M. Barbero[101], T. Barillari[115],
M-S. Barisits[36], J. Barkeloo[131], T. Barklow[153], R. Barnea[160], S.L. Barnes[60c], B.M. Barnett[144],
R.M. Barnett[18], Z. Barnovska-Blenessy[60a], A. Baroncelli[60a], G. Barone[29], A.J. Barr[135],
L. Barranco Navarro[174], F. Barreiro[98], J. Barreiro Guimarães da Costa[15a], S. Barsov[138],
R. Bartoldus[153], G. Bartolini[101], A.E. Barton[89], P. Bartos[28a], A. Basalaev[46], A. Bassalat[132,au],
R.L. Bates[57], S.J. Batista[167], S. Batlamous[35e], J.R. Batley[32], B. Batool[151], M. Battaglia[146],
M. Bauce[72a,72b], F. Bauer[145], K.T. Bauer[171], H.S. Bawa[31,n], J.B. Beacham[49], T. Beau[136],
P.H. Beauchemin[170], F. Becherer[52], P. Bechtle[24], H.C. Beck[53], H.P. Beck[20,t], K. Becker[52],
M. Becker[99], C. Becot[46], A. Beddall[12d], A.J. Beddall[12a], V.A. Bednyakov[79], M. Bedognetti[120],
C.P. Bee[155], T.A. Beermann[76], M. Begalli[80b], M. Begel[29], A. Behera[155], J.K. Behr[46],
F. Beisiegel[24], A.S. Bell[94], G. Bella[161], L. Bellagamba[23b], A. Bellerive[34], P. Bellos[9],
K. Beloborodov[122b,122a], K. Belotskiy[112], N.L. Belyaev[112], D. Benchekroun[35a], N. Benekos[10],
Y. Benhammou[161], D.P. Benjamin[6], M. Benoit[54], J.R. Bensinger[26], S. Bentvelsen[120],
L. Beresford[135], M. Beretta[51], D. Berge[46], E. Bergeaas Kuutmann[172], N. Berger[5],
B. Bergmann[142], L.J. Bergsten[26], J. Beringer[18], S. Berlendis[7], N.R. Bernard[102], G. Bernardi[136],
C. Bernius[153], T. Berry[93], P. Berta[99], C. Bertella[15a], I.A. Bertram[89], G.J. Besjes[40],
O. Bessidskaia Bylund[182], N. Besson[145], A. Bethani[100], S. Bethke[115], A. Betti[24], A.J. Bevan[92],

J. Beyer[115], R. Bi[139], R.M. Bianchi[139], O. Biebel[114], D. Biedermann[19], R. Bielski[36],
K. Bierwagen[99], N.V. Biesuz[71a,71b], M. Biglietti[74a], T.R.V. Billoud[109], M. Bindi[53], A. Bingul[12d],
C. Bini[72a,72b], S. Biondi[23b,23a], M. Birman[180], T. Bisanz[53], J.P. Biswal[161], A. Bitadze[100],
C. Bittrich[48], K. Bjørke[134], K.M. Black[25], T. Blazek[28a], I. Bloch[46], C. Blocker[26], A. Blue[57],
U. Blumenschein[92], G.J. Bobbink[120], V.S. Bobrovnikov[122b,122a], S.S. Bocchetta[96], A. Bocci[49],
D. Boerner[46], D. Bogavac[14], A.G. Bogdanchikov[122b,122a], C. Bohm[45a], V. Boisvert[93],
P. Bokan[53,172], T. Bold[83a], A.S. Boldyrev[113], A.E. Bolz[61b], M. Bomben[136], M. Bona[92],
J.S. Bonilla[131], M. Boonekamp[145], H.M. Borecka-Bielska[90], A. Borisov[123], G. Borissov[89],
J. Bortfeldt[36], D. Bortoletto[135], V. Bortolotto[73a,73b], D. Boscherini[23b], M. Bosman[14],
J.D. Bossio Sola[103], K. Bouaouda[35a], J. Boudreau[139], E.V. Bouhova-Thacker[89], D. Boumediene[38],
S.K. Boutle[57], A. Boveia[126], J. Boyd[36], D. Boye[33b,av], I.R. Boyko[79], A.J. Bozson[93], J. Bracinik[21],
N. Brahimi[101], G. Brandt[182], O. Brandt[61a], F. Braren[46], B. Brau[102], J.E. Brau[131],
W.D. Breaden Madden[57], K. Brendlinger[46], L. Brenner[46], R. Brenner[172], S. Bressler[180],
B. Brickwedde[99], D.L. Briglin[21], D. Britton[57], D. Britzger[115], I. Brock[24], R. Brock[106],
G. Brooijmans[39], W.K. Brooks[147b], E. Brost[121], J.H Broughton[21], P.A. Bruckman de Renstrom[84],
D. Bruncko[28b], A. Bruni[23b], G. Bruni[23b], L.S. Bruni[120], S. Bruno[73a,73b], B.H. Brunt[32],
M. Bruschi[23b], N. Bruscino[139], P. Bryant[37], L. Bryngemark[96], T. Buanes[17], Q. Buat[36],
P. Buchholz[151], A.G. Buckley[57], I.A. Budagov[79], M.K. Bugge[134], F. Bührer[52], O. Bulekov[112],
T.J. Burch[121], S. Burdin[90], C.D. Burgard[120], A.M. Burger[129], B. Burghgrave[8], J.T.P. Burr[46],
J.C. Burzynski[102], V. Büscher[99], E. Buschmann[53], P.J. Bussey[57], J.M. Butler[25], C.M. Buttar[57],
J.M. Butterworth[94], P. Butti[36], W. Buttinger[36], A. Buzatu[158], A.R. Buzykaev[122b,122a],
G. Cabras[23b,23a], S. Cabrera Urbán[174], D. Caforio[56], H. Cai[173], V.M.M. Cairo[153], O. Cakir[4a],
N. Calace[36], P. Calafiura[18], A. Calandri[101], G. Calderini[136], P. Calfayan[65], G. Callea[57],
L.P. Caloba[80b], S. Calvente Lopez[98], D. Calvet[38], S. Calvet[38], T.P. Calvet[155], M. Calvetti[71a,71b],
R. Camacho Toro[136], S. Camarda[36], D. Camarero Munoz[98], P. Camarri[73a,73b], D. Cameron[134],
R. Caminal Armadans[102], C. Camincher[36], S. Campana[36], M. Campanelli[94], A. Camplani[40],
A. Campoverde[151], V. Canale[69a,69b], A. Canesse[103], M. Cano Bret[60c], J. Cantero[129], T. Cao[161],
Y. Cao[173], M.D.M. Capeans Garrido[36], M. Capua[41b,41a], R. Cardarelli[73a], F. Cardillo[149],
I. Carli[143], T. Carli[36], G. Carlino[69a], B.T. Carlson[139], L. Carminati[68a,68b], R.M.D. Carney[45a,45b],
S. Caron[119], E. Carquin[147b], S. Carrá[46], J.W.S. Carter[167], M.P. Casado[14,f], A.F. Casha[167],
D.W. Casper[171], R. Castelijn[120], F.L. Castillo[174], V. Castillo Gimenez[174], N.F. Castro[140a,140e],
A. Catinaccio[36], J.R. Catmore[134], A. Cattai[36], J. Caudron[24], V. Cavaliere[29], E. Cavallaro[14],
D. Cavalli[68a], M. Cavalli-Sforza[14], V. Cavasinni[71a,71b], E. Celebi[12b], F. Ceradini[74a,74b],
L. Cerda Alberich[174], K. Cerny[130], A.S. Cerqueira[80a], A. Cerri[156], L. Cerrito[73a,73b], F. Cerutti[18],
A. Cervelli[23b,23a], S.A. Cetin[12b], D. Chakraborty[121], S.K. Chan[59], W.S. Chan[120], W.Y. Chan[90],
J.D. Chapman[32], B. Chargeishvili[159b], D.G. Charlton[21], T.P. Charman[92], C.C. Chau[34], S. Che[126],
A. Chegwidden[106], S. Chekanov[6], S.V. Chekulaev[168a], G.A. Chelkov[79,ba], M.A. Chelstowska[36],
B. Chen[78], C. Chen[60a], C.H. Chen[78], H. Chen[29], J. Chen[60a], J. Chen[39], S. Chen[137], S.J. Chen[15c],
X. Chen[15b,az], Y. Chen[82], Y-H. Chen[46], H.C. Cheng[63a], H.J. Cheng[15a,15d], A. Cheplakov[79],
E. Cheremushkina[123], R. Cherkaoui El Moursli[35e], E. Cheu[7], K. Cheung[64], T.J.A. Chevalérias[145],
L. Chevalier[145], V. Chiarella[51], G. Chiarelli[71a], G. Chiodini[67a], A.S. Chisholm[36,21], A. Chitan[27b],
I. Chiu[163], Y.H. Chiu[176], M.V. Chizhov[79], K. Choi[65], A.R. Chomont[72a,72b], S. Chouridou[162],
Y.S. Chow[120], M.C. Chu[63a], J. Chudoba[141], A.J. Chuinard[103], J.J. Chwastowski[84], L. Chytka[130],
K.M. Ciesla[84], D. Cinca[47], V. Cindro[91], I.A. Cioară[27b], A. Ciocio[18], F. Cirotto[69a,69b],
Z.H. Citron[180,l], M. Citterio[68a], D.A. Ciubotaru[27b], B.M. Ciungu[167], A. Clark[54], M.R. Clark[39],
P.J. Clark[50], C. Clement[45a,45b], Y. Coadou[101], M. Cobal[66a,66c], A. Coccaro[55b], J. Cochran[78],
H. Cohen[161], A.E.C. Coimbra[36], L. Colasurdo[119], B. Cole[39], A.P. Colijn[120], J. Collot[58],
P. Conde Muiño[140a,g], E. Coniavitis[52], S.H. Connell[33b], I.A. Connelly[57], S. Constantinescu[27b],

F. Conventi[69a,bc], A.M. Cooper-Sarkar[135], F. Cormier[175], K.J.R. Cormier[167], L.D. Corpe[94],
M. Corradi[72a,72b], E.E. Corrigan[96], F. Corriveau[103,ag], A. Cortes-Gonzalez[36], M.J. Costa[174],
F. Costanza[5], D. Costanzo[149], G. Cowan[93], J.W. Cowley[32], J. Crane[100], K. Cranmer[124],
S.J. Crawley[57], R.A. Creager[137], S. Crépé-Renaudin[58], F. Crescioli[136], M. Cristinziani[24],
V. Croft[120], G. Crosetti[41b,41a], A. Cueto[5], T. Cuhadar Donszelmann[149], A.R. Cukierman[153],
S. Czekierda[84], P. Czodrowski[36], M.J. Da Cunha Sargedas De Sousa[60b],
J.V. Da Fonseca Pinto[80b], C. Da Via[100], W. Dabrowski[83a], T. Dado[28a], S. Dahbi[35e], T. Dai[105],
C. Dallapiccola[102], M. Dam[40], G. D'amen[23b,23a], V. D'Amico[74a,74b], J. Damp[99], J.R. Dandoy[137],
M.F. Daneri[30], N.P. Dang[181,j], N.S. Dann[100], M. Danninger[175], V. Dao[36], G. Darbo[55b],
O. Dartsi[5], A. Dattagupta[131], T. Daubney[46], S. D'Auria[68a,68b], W. Davey[24], C. David[46],
T. Davidek[143], D.R. Davis[49], I. Dawson[149], K. De[8], R. De Asmundis[69a], M. De Beurs[120],
S. De Castro[23b,23a], S. De Cecco[72a,72b], N. De Groot[119], P. de Jong[120], H. De la Torre[106],
A. De Maria[15c], D. De Pedis[72a], A. De Salvo[72a], U. De Sanctis[73a,73b], M. De Santis[73a,73b],
A. De Santo[156], K. De Vasconcelos Corga[101], J.B. De Vivie De Regie[132], C. Debenedetti[146],
D.V. Dedovich[79], A.M. Deiana[42], M. Del Gaudio[41b,41a], J. Del Peso[98], Y. Delabat Diaz[46],
D. Delgove[132], F. Deliot[145,s], C.M. Delitzsch[7], M. Della Pietra[69a,69b], D. Della Volpe[54],
A. Dell'Acqua[36], L. Dell'Asta[73a,73b], M. Delmastro[5], C. Delporte[132], P.A. Delsart[58],
D.A. DeMarco[167], S. Demers[183], M. Demichev[79], G. Demontigny[109], S.P. Denisov[123],
D. Denysiuk[120], L. D'Eramo[136], D. Derendarz[84], J.E. Derkaoui[35d], F. Derue[136], P. Dervan[90],
K. Desch[24], C. Deterre[46], K. Dette[167], C. Deutsch[24], M.R. Devesa[30], P.O. Deviveiros[36],
A. Dewhurst[144], S. Dhaliwal[26], F.A. Di Bello[54], A. Di Ciaccio[73a,73b], L. Di Ciaccio[5],
W.K. Di Clemente[137], C. Di Donato[69a,69b], A. Di Girolamo[36], G. Di Gregorio[71a,71b],
B. Di Micco[74a,74b], R. Di Nardo[102], K.F. Di Petrillo[59], R. Di Sipio[167], D. Di Valentino[34],
C. Diaconu[101], F.A. Dias[40], T. Dias Do Vale[140a], M.A. Diaz[147a], J. Dickinson[18], E.B. Diehl[105],
J. Dietrich[19], S. Díez Cornell[46], A. Dimitrievska[18], W. Ding[15b], J. Dingfelder[24], F. Dittus[36],
F. Djama[101], T. Djobava[159b], J.I. Djuvsland[17], M.A.B. Do Vale[80c], M. Dobre[27b], D. Dodsworth[26],
C. Doglioni[96], J. Dolejsi[143], Z. Dolezal[143], M. Donadelli[80d], J. Donini[38], A. D'onofrio[92],
M. D'Onofrio[90], J. Dopke[144], A. Doria[69a], M.T. Dova[88], A.T. Doyle[57], E. Drechsler[152],
E. Dreyer[152], T. Dreyer[53], A.S. Drobac[170], Y. Duan[60b], F. Dubinin[110], M. Dubovsky[28a],
A. Dubreuil[54], E. Duchovni[180], G. Duckeck[114], A. Ducourthial[136], O.A. Ducu[109], D. Duda[115],
A. Dudarev[36], A.C. Dudder[99], E.M. Duffield[18], L. Duflot[132], M. Dührssen[36], C. Dülsen[182],
M. Dumancic[180], A.E. Dumitriu[27b], A.K. Duncan[57], M. Dunford[61a], A. Duperrin[101],
H. Duran Yildiz[4a], M. Düren[56], A. Durglishvili[159b], D. Duschinger[48], B. Dutta[46], D. Duvnjak[1],
G.I. Dyckes[137], M. Dyndal[36], S. Dysch[100], B.S. Dziedzic[84], K.M. Ecker[115], R.C. Edgar[105],
T. Eifert[36], G. Eigen[17], K. Einsweiler[18], T. Ekelof[172], M. El Kacimi[35c], R. El Kosseifi[101],
V. Ellajosyula[172], M. Ellert[172], F. Ellinghaus[182], A.A. Elliot[92], N. Ellis[36], J. Elmsheuser[29],
M. Elsing[36], D. Emeliyanov[144], A. Emerman[39], Y. Enari[163], J.S. Ennis[178], M.B. Epland[49],
J. Erdmann[47], A. Ereditato[20], M. Errenst[36], M. Escalier[132], C. Escobar[174], O. Estrada Pastor[174],
E. Etzion[161], H. Evans[65], A. Ezhilov[138], F. Fabbri[57], L. Fabbri[23b,23a], V. Fabiani[119], G. Facini[94],
R.M. Faisca Rodrigues Pereira[140a], R.M. Fakhrutdinov[123], S. Falciano[72a], P.J. Falke[5], S. Falke[5],
J. Faltova[143], Y. Fang[15a], Y. Fang[15a], G. Fanourakis[44], M. Fanti[68a,68b], A. Farbin[8], A. Farilla[74a],
E.M. Farina[70a,70b], T. Farooque[106], S. Farrell[18], S.M. Farrington[178], P. Farthouat[36], F. Fassi[35e],
P. Fassnacht[36], D. Fassouliotis[9], M. Faucci Giannelli[50], W.J. Fawcett[32], L. Fayard[132],
O.L. Fedin[138,q], W. Fedorko[175], M. Feickert[42], S. Feigl[134], L. Feligioni[101], A. Fell[149], C. Feng[60b],
E.J. Feng[36], M. Feng[49], M.J. Fenton[57], A.B. Fenyuk[123], J. Ferrando[46], A. Ferrante[173],
A. Ferrari[172], P. Ferrari[120], R. Ferrari[70a], D.E. Ferreira de Lima[61b], A. Ferrer[174], D. Ferrere[54],
C. Ferretti[105], F. Fiedler[99], A. Filipčič[91], F. Filthaut[119], K.D. Finelli[25], M.C.N. Fiolhais[140a,140c,a],
L. Fiorini[174], F. Fischer[114], W.C. Fisher[106], I. Fleck[151], P. Fleischmann[105], R.R.M. Fletcher[137],

T. Flick[182], B.M. Flierl[114], L. Flores[137], L.R. Flores Castillo[63a], F.M. Follega[75a,75b], N. Fomin[17],
J.H. Foo[167], G.T. Forcolin[75a,75b], A. Formica[145], F.A. Förster[14], A.C. Forti[100], A.G. Foster[21],
M.G. Foti[135], D. Fournier[132], H. Fox[89], P. Francavilla[71a,71b], S. Francescato[72a,72b],
M. Franchini[23b,23a], S. Franchino[61a], D. Francis[36], L. Franconi[20], M. Franklin[59], A.N. Fray[92],
B. Freund[109], W.S. Freund[80b], E.M. Freundlich[47], D.C. Frizzell[128], D. Froidevaux[36], J.A. Frost[135],
C. Fukunaga[164], E. Fullana Torregrosa[174], E. Fumagalli[55b,55a], T. Fusayasu[116], J. Fuster[174],
A. Gabrielli[23b,23a], A. Gabrielli[18], G.P. Gach[83a], S. Gadatsch[54], P. Gadow[115], G. Gagliardi[55b,55a],
L.G. Gagnon[109], C. Galea[27b], B. Galhardo[140a], G.E. Gallardo[135], E.J. Gallas[135], B.J. Gallop[144],
P. Gallus[142], G. Galster[40], R. Gamboa Goni[92], K.K. Gan[126], S. Ganguly[180], J. Gao[60a], Y. Gao[90],
Y.S. Gao[31,n], C. García[174], J.E. García Navarro[174], J.A. García Pascual[15a], C. Garcia-Argos[52],
M. Garcia-Sciveres[18], R.W. Gardner[37], N. Garelli[153], S. Gargiulo[52], V. Garonne[134],
A. Gaudiello[55b,55a], G. Gaudio[70a], I.L. Gavrilenko[110], A. Gavriljuk[111], C. Gay[175], G. Gaycken[24],
E.N. Gazis[10], A.A. Geanta[27b], C.N.P. Gee[144], J. Geisen[53], M. Geisen[99], M.P. Geisler[61a],
C. Gemme[55b], M.H. Genest[58], C. Geng[105], S. Gentile[72a,72b], S. George[93], T. Geralis[44],
L.O. Gerlach[53], P. Gessinger-Befurt[99], G. Gessner[47], S. Ghasemi[151], M. Ghasemi Bostanabad[176],
A. Ghosh[77], B. Giacobbe[23b], S. Giagu[72a,72b], N. Giangiacomi[23b,23a], P. Giannetti[71a],
A. Giannini[69a,69b], S.M. Gibson[93], M. Gignac[146], D. Gillberg[34], G. Gilles[182], D.M. Gingrich[3,bb],
M.P. Giordani[66a,66c], F.M. Giorgi[23b], P.F. Giraud[145], G. Giugliarelli[66a,66c], D. Giugni[68a],
F. Giuli[73a,73b], S. Gkaitatzis[162], I. Gkialas[9,i], E.L. Gkougkousis[14], P. Gkountoumis[10],
L.K. Gladilin[113], C. Glasman[98], J. Glatzer[14], P.C.F. Glaysher[46], A. Glazov[46],
M. Goblirsch-Kolb[26], S. Goldfarb[104], T. Golling[54], D. Golubkov[123], A. Gomes[140a,140b],
R. Goncalves Gama[53], R. Gonçalo[140a,140b], G. Gonella[52], L. Gonella[21], A. Gongadze[79],
F. Gonnella[21], J.L. Gonski[59], S. González de la Hoz[174], S. Gonzalez-Sevilla[54],
G.R. Gonzalvo Rodriguez[174], L. Goossens[36], P.A. Gorbounov[111], H.A. Gordon[29], B. Gorini[36],
E. Gorini[67a,67b], A. Gorišek[91], A.T. Goshaw[49], M.I. Gostkin[79], C.A. Gottardo[24], M. Gouighri[35b],
D. Goujdami[35c], A.G. Goussiou[148], N. Govender[33b,b], C. Goy[5], E. Gozani[160],
I. Grabowska-Bold[83a], E.C. Graham[90], J. Gramling[171], E. Gramstad[134], S. Grancagnolo[19],
M. Grandi[156], V. Gratchev[138], P.M. Gravila[27f], F.G. Gravili[67a,67b], C. Gray[57], H.M. Gray[18],
C. Grefe[24], K. Gregersen[96], I.M. Gregor[46], P. Grenier[153], K. Grevtsov[46], N.A. Grieser[128],
J. Griffiths[8], A.A. Grillo[146], K. Grimm[31,m], S. Grinstein[14,z], J.-F. Grivaz[132], S. Groh[99],
E. Gross[180], J. Grosse-Knetter[53], Z.J. Grout[94], C. Grud[105], A. Grummer[118], L. Guan[105],
W. Guan[181], J. Guenther[36], A. Guerguichon[132], F. Guescini[115], D. Guest[171], R. Gugel[52],
T. Guillemin[5], S. Guindon[36], U. Gul[57], J. Guo[60c], W. Guo[105], Y. Guo[60a,u], Z. Guo[101],
R. Gupta[46], S. Gurbuz[12c], G. Gustavino[128], P. Gutierrez[128], C. Gutschow[94], C. Guyot[145],
M.P. Guzik[83a], C. Gwenlan[135], C.B. Gwilliam[90], A. Haas[124], C. Haber[18], H.K. Hadavand[8],
N. Haddad[35e], A. Hadef[60a], S. Hageböck[36], M. Hagihara[169], M. Haleem[177], J. Haley[129],
G. Halladjian[106], G.D. Hallewell[101], K. Hamacher[182], P. Hamal[130], K. Hamano[176],
H. Hamdaoui[35e], G.N. Hamity[149], K. Han[60a,ao], L. Han[60a], S. Han[15a,15d], K. Hanagaki[81,x],
M. Hance[146], D.M. Handl[114], B. Haney[137], R. Hankache[136], E. Hansen[96], J.B. Hansen[40],
J.D. Hansen[40], M.C. Hansen[24], P.H. Hansen[40], E.C. Hanson[100], K. Hara[169], A.S. Hard[181],
T. Harenberg[182], S. Harkusha[107], P.F. Harrison[178], N.M. Hartmann[114], Y. Hasegawa[150],
A. Hasib[50], S. Hassani[145], S. Haug[20], R. Hauser[106], L.B. Havener[39], M. Havranek[142],
C.M. Hawkes[21], R.J. Hawkings[36], D. Hayden[106], C. Hayes[155], R.L. Hayes[175], C.P. Hays[135],
J.M. Hays[92], H.S. Hayward[90], S.J. Haywood[144], F. He[60a], M.P. Heath[50], V. Hedberg[96],
L. Heelan[8], S. Heer[24], K.K. Heidegger[52], W.D. Heidorn[78], J. Heilman[34], S. Heim[46], T. Heim[18],
B. Heinemann[46,aw], J.J. Heinrich[131], L. Heinrich[36], C. Heinz[56], J. Hejbal[141], L. Helary[61b],
A. Held[175], S. Hellesund[134], C.M. Helling[146], S. Hellman[45a,45b], C. Helsens[36],
R.C.W. Henderson[89], Y. Heng[181], S. Henkelmann[175], A.M. Henriques Correia[36], G.H. Herbert[19],

H. Herde[26], V. Herget[177], Y. Hernández Jiménez[33c], H. Herr[99], M.G. Herrmann[114],
T. Herrmann[48], G. Herten[52], R. Hertenberger[114], L. Hervas[36], T.C. Herwig[137], G.G. Hesketh[94],
N.P. Hessey[168a], A. Higashida[163], S. Higashino[81], E. Higón-Rodriguez[174], K. Hildebrand[37],
E. Hill[176], J.C. Hill[32], K.K. Hill[29], K.H. Hiller[46], S.J. Hillier[21], M. Hils[48], I. Hinchliffe[18],
F. Hinterkeuser[24], M. Hirose[133], S. Hirose[52], D. Hirschbuehl[182], B. Hiti[91], O. Hladik[141],
D.R. Hlaluku[33c], X. Hoad[50], J. Hobbs[155], N. Hod[180], M.C. Hodgkinson[149], A. Hoecker[36],
F. Hoenig[114], D. Hohn[52], D. Hohov[132], T.R. Holmes[37], M. Holzbock[114], L.B.A.H Hommels[32],
S. Honda[169], T. Honda[81], T.M. Hong[139], A. Hönle[115], B.H. Hooberman[173], W.H. Hopkins[6],
Y. Horii[117], P. Horn[48], L.A. Horyn[37], J-Y. Hostachy[58], A. Hostiuc[148], S. Hou[158],
A. Hoummada[35a], J. Howarth[100], J. Hoya[88], M. Hrabovsky[130], J. Hrdinka[76], I. Hristova[19],
J. Hrivnac[132], A. Hrynevich[108], T. Hryn'ova[5], P.J. Hsu[64], S.-C. Hsu[148], Q. Hu[29], S. Hu[60c],
Y. Huang[15a], Z. Hubacek[142], F. Hubaut[101], M. Huebner[24], F. Huegging[24], T.B. Huffman[135],
M. Huhtinen[36], R.F.H. Hunter[34], P. Huo[155], A.M. Hupe[34], N. Huseynov[79,ai], J. Huston[106],
J. Huth[59], R. Hyneman[105], S. Hyrych[28a], G. Iacobucci[54], G. Iakovidis[29], I. Ibragimov[151],
L. Iconomidou-Fayard[132], Z. Idrissi[35e], P. Iengo[36], R. Ignazzi[40], O. Igonkina[120,ac,*], R. Iguchi[163],
T. Iizawa[54], Y. Ikegami[81], M. Ikeno[81], D. Iliadis[162], N. Ilic[119], F. Iltzsche[48], G. Introzzi[70a,70b],
M. Iodice[74a], K. Iordanidou[168a], V. Ippolito[72a,72b], A. Irles Quiles[an], M.F. Isacson[172],
M. Ishino[163], M. Ishitsuka[165], W. Islam[129], C. Issever[135], S. Istin[160], F. Ito[169],
J.M. Iturbe Ponce[63a], R. Iuppa[75a,75b], A. Ivina[180], H. Iwasaki[81], J.M. Izen[43], V. Izzo[69a],
P. Jacka[141], P. Jackson[1], R.M. Jacobs[24], B.P. Jaeger[152], V. Jain[2], G. Jäkel[182], K.B. Jakobi[99],
K. Jakobs[52], S. Jakobsen[76], T. Jakoubek[141], J. Jamieson[57], K.W. Janas[83a], R. Jansky[54],
J. Janssen[24], M. Janus[53], P.A. Janus[83a], G. Jarlskog[96], N. Javadov[79,ai], T. Javůrek[36],
M. Javurkova[52], F. Jeanneau[145], L. Jeanty[131], J. Jejelava[159a,aj], A. Jelinskas[178], P. Jenni[52,c],
J. Jeong[46], N. Jeong[46], S. Jézéquel[5], H. Ji[181], J. Jia[155], H. Jiang[78], Y. Jiang[60a], Z. Jiang[153,r],
S. Jiggins[52], F.A. Jimenez Morales[38], J. Jimenez Pena[174], S. Jin[15c], A. Jinaru[27b], O. Jinnouchi[165],
H. Jivan[33c], P. Johansson[149], K.A. Johns[7], C.A. Johnson[65], K. Jon-And[45a,45b], R.W.L. Jones[89],
S.D. Jones[156], S. Jones[7], T.J. Jones[90], J. Jongmanns[61a], P.M. Jorge[140a], J. Jovicevic[36], X. Ju[18],
J.J. Junggeburth[115], A. Juste Rozas[14,z], A. Kaczmarska[84], M. Kado[72a,72b], H. Kagan[126],
M. Kagan[153], C. Kahra[99], T. Kaji[179], E. Kajomovitz[160], C.W. Kalderon[96], A. Kaluza[99],
A. Kamenshchikov[123], L. Kanjir[91], Y. Kano[163], V.A. Kantserov[112], J. Kanzaki[81], L.S. Kaplan[181],
D. Kar[33c], M.J. Kareem[168b], E. Karentzos[10], S.N. Karpov[79], Z.M. Karpova[79], V. Kartvelishvili[89],
A.N. Karyukhin[123], L. Kashif[181], R.D. Kass[126], A. Kastanas[45a,45b], Y. Kataoka[163], C. Kato[60d,60c],
J. Katzy[46], K. Kawade[82], K. Kawagoe[87], T. Kawaguchi[117], T. Kawamoto[163], G. Kawamura[53],
E.F. Kay[176], V.F. Kazanin[122b,122a], R. Keeler[176], R. Kehoe[42], J.S. Keller[34], E. Kellermann[96],
D. Kelsey[156], J.J. Kempster[21], J. Kendrick[21], O. Kepka[141], S. Kersten[182], B.P. Kerševan[91],
S. Ketabchi Haghighat[167], M. Khader[173], F. Khalil-Zada[13], M. Khandoga[145], A. Khanov[129],
A.G. Kharlamov[122b,122a], T. Kharlamova[122b,122a], E.E. Khoda[175], A. Khodinov[166], T.J. Khoo[54],
E. Khramov[79], J. Khubua[159b], S. Kido[82], M. Kiehn[54], C.R. Kilby[93], Y.K. Kim[37],
N. Kimura[66a,66c], O.M. Kind[19], B.T. King[90,*], D. Kirchmeier[48], J. Kirk[144], A.E. Kiryunin[115],
T. Kishimoto[163], D.P. Kisliuk[167], V. Kitali[46], O. Kivernyk[5], E. Kladiva[28b,*],
T. Klapdor-Kleingrothaus[52], M. Klassen[61a], M.H. Klein[105], M. Klein[90], U. Klein[90],
K. Kleinknecht[99], P. Klimek[121], A. Klimentov[29], T. Klingl[24], T. Klioutchnikova[36],
F.F. Klitzner[114], P. Kluit[120], S. Kluth[115], E. Kneringer[76], E.B.F.G. Knoops[101], A. Knue[52],
D. Kobayashi[87], T. Kobayashi[163], M. Kobel[48], M. Kocian[153], P. Kodys[143], P.T. Koenig[24],
T. Koffas[34], N.M. Köhler[115], T. Koi[153], M. Kolb[61b], I. Koletsou[5], T. Komarek[130], T. Kondo[81],
N. Kondrashova[60c], K. Köneke[52], A.C. König[119], T. Kono[125], R. Konoplich[124,ar],
V. Konstantinides[94], N. Konstantinidis[94], B. Konya[96], R. Kopeliansky[65], S. Koperny[83a],
K. Korcyl[84], K. Kordas[162], G. Koren[161], A. Korn[94], I. Korolkov[14], E.V. Korolkova[149],

N. Korotkova[113], O. Kortner[115], S. Kortner[115], T. Kosek[143], V.V. Kostyukhin[24], A. Kotwal[49],
A. Koulouris[10], A. Kourkoumeli-Charalampidi[70a,70b], C. Kourkoumelis[9], E. Kourlitis[149],
V. Kouskoura[29], A.B. Kowalewska[84], R. Kowalewski[176], C. Kozakai[163], W. Kozanecki[145],
A.S. Kozhin[123], V.A. Kramarenko[113], G. Kramberger[91], D. Krasnopevtsev[60a], M.W. Krasny[136],
A. Krasznahorkay[36], D. Krauss[115], J.A. Kremer[83a], J. Kretzschmar[90], P. Krieger[167], F. Krieter[114],
A. Krishnan[61b], K. Krizka[18], K. Kroeninger[47], H. Kroha[115], J. Kroll[141], J. Kroll[137], J. Krstic[16],
U. Kruchonak[79], H. Krüger[24], N. Krumnack[78], M.C. Kruse[49], J.A. Krzysiak[84], T. Kubota[104],
S. Kuday[4b], J.T. Kuechler[46], S. Kuehn[36], A. Kugel[61a], T. Kuhl[46], V. Kukhtin[79], R. Kukla[101],
Y. Kulchitsky[107,am], S. Kuleshov[147b], Y.P. Kulinich[173], M. Kuna[58], T. Kunigo[85], A. Kupco[141],
T. Kupfer[47], O. Kuprash[52], H. Kurashige[82], L.L. Kurchaninov[168a], Y.A. Kurochkin[107],
A. Kurova[112], M.G. Kurth[15a,15d], E.S. Kuwertz[36], M. Kuze[165], A.K. Kvam[148], J. Kvita[130],
T. Kwan[103], A. La Rosa[115], L. La Rotonda[41b,41a], F. La Ruffa[41b,41a], C. Lacasta[174],
F. Lacava[72a,72b], D.P.J. Lack[100], H. Lacker[19], D. Lacour[136], E. Ladygin[79], R. Lafaye[5],
B. Laforge[136], T. Lagouri[33c], S. Lai[53], S. Lammers[65], W. Lampl[7], C. Lampoudis[162], E. Lançon[29],
U. Landgraf[52], M.P.J. Landon[92], M.C. Lanfermann[54], V.S. Lang[46], J.C. Lange[53],
R.J. Langenberg[36], A.J. Lankford[171], F. Lanni[29], K. Lantzsch[24], A. Lanza[70a], A. Lapertosa[55b,55a],
S. Laplace[136], J.F. Laporte[145], T. Lari[68a], F. Lasagni Manghi[23b,23a], M. Lassnig[36], T.S. Lau[63a],
A. Laudrain[132], A. Laurier[34], M. Lavorgna[69a,69b], M. Lazzaroni[68a,68b], B. Le[104], E. Le Guirriec[101],
M. LeBlanc[7], T. LeCompte[6], F. Ledroit-Guillon[58], C.A. Lee[29], G.R. Lee[17], L. Lee[59], S.C. Lee[158],
S.J. Lee[34], B. Lefebvre[168a], M. Lefebvre[176], F. Legger[114], C. Leggett[18], K. Lehmann[152],
N. Lehmann[182], G. Lehmann Miotto[36], W.A. Leight[46], A. Leisos[162,y], M.A.L. Leite[80d],
C.E. Leitgeb[114], R. Leitner[143], D. Lellouch[180,*], K.J.C. Leney[42], T. Lenz[24], B. Lenzi[36], R. Leone[7],
S. Leone[71a], C. Leonidopoulos[50], A. Leopold[136], G. Lerner[156], C. Leroy[109], R. Les[167],
C.G. Lester[32], M. Levchenko[138], J. Levêque[5], D. Levin[105], L.J. Levinson[180], D.J. Lewis[21],
B. Li[15b], B. Li[105], C-Q. Li[60a], F. Li[60c], H. Li[60a], H. Li[60b], J. Li[60c], K. Li[153], L. Li[60c], M. Li[15a],
Q. Li[15a,15d], Q.Y. Li[60a], S. Li[60d,60c], X. Li[46], Y. Li[46], Z. Li[60b], Z. Liang[15a], B. Liberti[73a],
A. Liblong[167], K. Lie[63c], S. Liem[120], C.Y. Lin[32], K. Lin[106], T.H. Lin[99], R.A. Linck[65],
J.H. Lindon[21], A.L. Lionti[54], E. Lipeles[137], A. Lipniacka[17], M. Lisovyi[61b], T.M. Liss[173,ay],
A. Lister[175], A.M. Litke[146], J.D. Little[8], B. Liu[78,af], B.L Liu[6], H.B. Liu[29], H. Liu[105], J.B. Liu[60a],
J.K.K. Liu[135], K. Liu[136], M. Liu[60a], P. Liu[18], Y. Liu[15a,15d], Y.L. Liu[105], Y.W. Liu[60a],
M. Livan[70a,70b], A. Lleres[58], J. Llorente Merino[15a], S.L. Lloyd[92], C.Y. Lo[63b], F. Lo Sterzo[42],
E.M. Lobodzinska[46], P. Loch[7], S. Loffredo[73a,73b], T. Lohse[19], K. Lohwasser[149], M. Lokajicek[141],
J.D. Long[173], R.E. Long[89], L. Longo[36], K.A. Looper[126], J.A. Lopez[147b], I. Lopez Paz[100],
A. Lopez Solis[149], J. Lorenz[114], N. Lorenzo Martinez[5], M. Losada[22], P.J. Lösel[114], A. Lösle[52],
X. Lou[46], X. Lou[15a], A. Lounis[132], J. Love[6], P.A. Love[89], J.J. Lozano Bahilo[174], M. Lu[60a],
Y.J. Lu[64], H.J. Lubatti[148], C. Luci[72a,72b], A. Lucotte[58], C. Luedtke[52], F. Luehring[65], I. Luise[136],
L. Luminari[72a], B. Lund-Jensen[154], M.S. Lutz[102], D. Lynn[29], R. Lysak[141], E. Lytken[96], F. Lyu[15a],
V. Lyubushkin[79], T. Lyubushkina[79], H. Ma[29], L.L. Ma[60b], Y. Ma[60b], G. Maccarrone[51],
A. Macchiolo[115], C.M. Macdonald[149], J. Machado Miguens[137], D. Madaffari[174], R. Madar[38],
W.F. Mader[48], N. Madysa[48], J. Maeda[82], K. Maekawa[163], S. Maeland[17], T. Maeno[29],
M. Maerker[48], A.S. Maevskiy[113], V. Magerl[52], N. Magini[78], D.J. Mahon[39], C. Maidantchik[80b],
T. Maier[114], A. Maio[140a,140b,140d], K. Maj[84], O. Majersky[28a], S. Majewski[131], Y. Makida[81],
N. Makovec[132], B. Malaescu[136], Pa. Malecki[84], V.P. Maleev[138], F. Malek[58], U. Mallik[77],
D. Malon[6], C. Malone[32], S. Maltezos[10], S. Malyukov[79], J. Mamuzic[174], G. Mancini[51], I. Mandić[91],
L. Manhaes de Andrade Filho[80a], I.M. Maniatis[162], J. Manjarres Ramos[48], K.H. Mankinen[96],
A. Mann[114], A. Manousos[76], B. Mansoulie[145], I. Manthos[162], S. Manzoni[120], A. Marantis[162],
G. Marceca[30], L. Marchese[135], G. Marchiori[136], M. Marcisovsky[141], C. Marcon[96],
C.A. Marin Tobon[36], M. Marjanovic[38], Z. Marshall[18], M.U.F Martensson[172], S. Marti-Garcia[174],

C.B. Martin[126], T.A. Martin[178], V.J. Martin[50], B. Martin dit Latour[17], L. Martinelli[74a,74b], M. Martinez[14,z], V.I. Martinez Outschoorn[102], S. Martin-Haugh[144], V.S. Martoiu[27b], A.C. Martyniuk[94], A. Marzin[36], S.R. Maschek[115], L. Masetti[99], T. Mashimo[163], R. Mashinistov[110], J. Masik[100], A.L. Maslennikov[122b,122a], L.H. Mason[104], L. Massa[73a,73b], P. Massarotti[69a,69b], P. Mastrandrea[71a,71b], A. Mastroberardino[41b,41a], T. Masubuchi[163], A. Matic[114], P. Mättig[24], J. Maurer[27b], B. Maček[91], D.A. Maximov[122b,122a], R. Mazini[158], I. Maznas[162], S.M. Mazza[146], S.P. Mc Kee[105], T.G. McCarthy[115], L.I. McClymont[94], W.P. McCormack[18], E.F. McDonald[104], J.A. Mcfayden[36], M.A. McKay[42], K.D. McLean[176], S.J. McMahon[144], P.C. McNamara[104], C.J. McNicol[178], R.A. McPherson[176,ag], J.E. Mdhluli[33c], Z.A. Meadows[102], S. Meehan[148], T. Megy[52], S. Mehlhase[114], A. Mehta[90], T. Meideck[58], B. Meirose[43], D. Melini[174], B.R. Mellado Garcia[33c], J.D. Mellenthin[53], M. Melo[28a], F. Meloni[46], A. Melzer[24], S.B. Menary[100], E.D. Mendes Gouveia[140a,140e], L. Meng[36], X.T. Meng[105], S. Menke[115], E. Meoni[41b,41a], S. Mergelmeyer[19], S.A.M. Merkt[139], C. Merlassino[20], P. Mermod[54], L. Merola[69a,69b], C. Meroni[68a], O. Meshkov[113,110], J.K.R. Meshreki[151], A. Messina[72a,72b], J. Metcalfe[6], A.S. Mete[171], C. Meyer[65], J. Meyer[160], J-P. Meyer[145], H. Meyer Zu Theenhausen[61a], F. Miano[156], R.P. Middleton[144], L. Mijović[50], G. Mikenberg[180], M. Mikestikova[141], M. Mikuž[91], H. Mildner[149], M. Milesi[104], A. Milic[167], D.A. Millar[92], D.W. Miller[37], A. Milov[180], D.A. Milstead[45a,45b], R.A. Mina[153,r], A.A. Minaenko[123], M. Miñano Moya[174], I.A. Minashvili[159b], A.I. Mincer[124], B. Mindur[83a], M. Mineev[79], Y. Minegishi[163], Y. Ming[181], L.M. Mir[14], A. Mirto[67a,67b], K.P. Mistry[137], T. Mitani[179], J. Mitrevski[114], V.A. Mitsou[174], M. Mittal[60c], A. Miucci[20], P.S. Miyagawa[149], A. Mizukami[81], J.U. Mjörnmark[96], T. Mkrtchyan[184], M. Mlynarikova[143], T. Moa[45a,45b], K. Mochizuki[109], P. Mogg[52], S. Mohapatra[39], R. Moles-Valls[24], M.C. Mondragon[106], K. Mönig[46], J. Monk[40], E. Monnier[101], A. Montalbano[152], J. Montejo Berlingen[36], M. Montella[94], F. Monticelli[88], S. Monzani[68a], N. Morange[132], D. Moreno[22], M. Moreno Llácer[36], C. Moreno Martinez[14], P. Morettini[55b], M. Morgenstern[120], S. Morgenstern[48], D. Mori[152], M. Morii[59], M. Morinaga[179], V. Morisbak[134], A.K. Morley[36], G. Mornacchi[36], A.P. Morris[94], L. Morvaj[155], P. Moschovakos[36], B. Moser[120], M. Mosidze[159b], T. Moskalets[145], H.J. Moss[149], J. Moss[31,o], K. Motohashi[165], E. Mountricha[36], E.J.W. Moyse[102], S. Muanza[101], J. Mueller[139], R.S.P. Mueller[114], D. Muenstermann[89], G.A. Mullier[96], J.L. Munoz Martinez[14], F.J. Munoz Sanchez[100], P. Murin[28b], W.J. Murray[178,144], A. Murrone[68a,68b], M. Muškinja[18], C. Mwewa[33a], A.G. Myagkov[123,as], J. Myers[131], M. Myska[142], B.P. Nachman[18], O. Nackenhorst[47], A.Nag Nag[48], K. Nagai[135], K. Nagano[81], Y. Nagasaka[62], M. Nagel[52], E. Nagy[101], A.M. Nairz[36], Y. Nakahama[117], K. Nakamura[81], T. Nakamura[163], I. Nakano[127], H. Nanjo[133], F. Napolitano[61a], R.F. Naranjo Garcia[46], R. Narayan[42], D.I. Narrias Villar[61a], I. Naryshkin[138], T. Naumann[46], G. Navarro[22], H.A. Neal[105,*], P.Y. Nechaeva[110], F. Nechansky[46], T.J. Neep[21], A. Negri[70a,70b], M. Negrini[23b], C. Nellist[53], M.E. Nelson[135], S. Nemecek[141], P. Nemethy[124], M. Nessi[36,e], M.S. Neubauer[173], M. Neumann[182], P.R. Newman[21], T.Y. Ng[63c], Y.S. Ng[19], Y.W.Y. Ng[171], H.D.N. Nguyen[101], T. Nguyen Manh[109], E. Nibigira[38], R.B. Nickerson[135], R. Nicolaidou[145], D.S. Nielsen[40], J. Nielsen[146], N. Nikiforou[11], V. Nikolaenko[123,as], I. Nikolic-Audit[136], K. Nikolopoulos[21], P. Nilsson[29], H.R. Nindhito[54], Y. Ninomiya[81], A. Nisati[72a], N. Nishu[60c], R. Nisius[115], I. Nitsche[47], T. Nitta[179], T. Nobe[163], Y. Noguchi[85], I. Nomidis[136], M.A. Nomura[29], M. Nordberg[36], N. Norjoharuddeen[135], T. Novak[91], O. Novgorodova[48], R. Novotny[142], L. Nozka[130], K. Ntekas[171], E. Nurse[94], F.G. Oakham[34,bb], H. Oberlack[115], J. Ocariz[136], A. Ochi[82], I. Ochoa[39], J.P. Ochoa-Ricoux[147a], K. O'Connor[26], S. Oda[87], S. Odaka[81], S. Oerdek[53], A. Ogrodnik[83a], A. Oh[100], S.H. Oh[49], C.C. Ohm[154], H. Oide[55b,55a], M.L. Ojeda[167], H. Okawa[169], Y. Okazaki[85], Y. Okumura[163], T. Okuyama[81], A. Olariu[27b], L.F. Oleiro Seabra[140a], S.A. Olivares Pino[147a], D. Oliveira Damazio[29], J.L. Oliver[1], M.J.R. Olsson[171], A. Olszewski[84], J. Olszowska[84], D.C. O'Neil[152], A. Onofre[140a,140e], K. Onogi[117],

P.U.E. Onyisi[11], H. Oppen[134], M.J. Oreglia[37], G.E. Orellana[88], D. Orestano[74a,74b], N. Orlando[14],
R.S. Orr[167], V. O'Shea[57], R. Ospanov[60a], G. Otero y Garzon[30], H. Otono[87], M. Ouchrif[35d],
J. Ouellette[29], F. Ould-Saada[134], A. Ouraou[145], Q. Ouyang[15a], M. Owen[57], R.E. Owen[21],
V.E. Ozcan[12c], N. Ozturk[8], J. Pacalt[130], H.A. Pacey[32], K. Pachal[49], A. Pacheco Pages[14],
C. Padilla Aranda[14], S. Pagan Griso[18], M. Paganini[183], G. Palacino[65], S. Palazzo[50], S. Palestini[36],
M. Palka[83b], D. Pallin[38], I. Panagoulias[10], C.E. Pandini[36], J.G. Panduro Vazquez[93], P. Pani[46],
G. Panizzo[66a,66c], L. Paolozzi[54], C. Papadatos[109], K. Papageorgiou[9,i], A. Paramonov[6],
D. Paredes Hernandez[63b], S.R. Paredes Saenz[135], B. Parida[166], T.H. Park[167], A.J. Parker[89],
M.A. Parker[32], F. Parodi[55b,55a], E.W.P. Parrish[121], J.A. Parsons[39], U. Parzefall[52],
L. Pascual Dominguez[136], V.R. Pascuzzi[167], J.M.P. Pasner[146], E. Pasqualucci[72a], S. Passaggio[55b],
F. Pastore[93], P. Pasuwan[45a,45b], S. Pataraia[99], J.R. Pater[100], A. Pathak[181], T. Pauly[36],
B. Pearson[115], M. Pedersen[134], L. Pedraza Diaz[119], R. Pedro[140a], T. Peiffer[53],
S.V. Peleganchuk[122b,122a], O. Penc[141], H. Peng[60a], B.S. Peralva[80a], M.M. Perego[132],
A.P. Pereira Peixoto[140a], D.V. Perepelitsa[29], F. Peri[19], L. Perini[68a,68b], H. Pernegger[36],
S. Perrella[69a,69b], K. Peters[46], R.F.Y. Peters[100], B.A. Petersen[36], T.C. Petersen[40], E. Petit[101],
A. Petridis[1], C. Petridou[162], P. Petroff[132], M. Petrov[135], F. Petrucci[74a,74b], M. Pettee[183],
N.E. Pettersson[102], K. Petukhova[143], A. Peyaud[145], R. Pezoa[147b], L. Pezzotti[70a,70b], T. Pham[104],
F.H. Phillips[106], P.W. Phillips[144], M.W. Phipps[173], G. Piacquadio[155], E. Pianori[18], A. Picazio[102],
R.H. Pickles[100], R. Piegaia[30], D. Pietreanu[27b], J.E. Pilcher[37], A.D. Pilkington[100],
M. Pinamonti[73a,73b], J.L. Pinfold[3], M. Pitt[180], L. Pizzimento[73a,73b], M.-A. Pleier[29], V. Pleskot[143],
E. Plotnikova[79], D. Pluth[78], P. Podberezko[122b,122a], R. Poettgen[96], R. Poggi[54], L. Poggioli[132],
I. Pogrebnyak[106], D. Pohl[24], I. Pokharel[53], G. Polesello[70a], A. Poley[18], A. Policicchio[72a,72b],
R. Polifka[143], A. Polini[23b], C.S. Pollard[46], V. Polychronakos[29], D. Ponomarenko[112],
L. Pontecorvo[36], S. Popa[27a], G.A. Popeneciu[27d], D.M. Portillo Quintero[58], S. Pospisil[142],
K. Potamianos[46], I.N. Potrap[79], C.J. Potter[32], H. Potti[11], T. Poulsen[96], J. Poveda[36],
T.D. Powell[149], G. Pownall[46], M.E. Pozo Astigarraga[36], P. Pralavorio[101], S. Prell[78], D. Price[100],
M. Primavera[67a], S. Prince[103], M.L. Proffitt[148], N. Proklova[112], K. Prokofiev[63c], F. Prokoshin[79],
S. Protopopescu[29], J. Proudfoot[6], M. Przybycien[83a], D. Pudzha[138], A. Puri[173], P. Puzo[132],
J. Qian[105], Y. Qin[100], A. Quadt[53], M. Queitsch-Maitland[46], A. Qureshi[1], P. Rados[104],
F. Ragusa[68a,68b], G. Rahal[97], J.A. Raine[54], S. Rajagopalan[29], A. Ramirez Morales[92],
K. Ran[15a,15d], T. Rashid[132], S. Raspopov[5], M.G. Ratti[68a,68b], D.M. Rauch[46], F. Rauscher[114],
S. Rave[99], B. Ravina[149], I. Ravinovich[180], J.H. Rawling[100], M. Raymond[36], A.L. Read[134],
N.P. Readioff[58], M. Reale[67a,67b], D.M. Rebuzzi[70a,70b], A. Redelbach[177], G. Redlinger[29],
K. Reeves[43], L. Rehnisch[19], J. Reichert[137], D. Reikher[161], A. Reiss[99], A. Rej[151], C. Rembser[36],
M. Renda[27b], M. Rescigno[72a], S. Resconi[68a], E.D. Resseguie[137], S. Rettie[175], E. Reynolds[21],
O.L. Rezanova[122b,122a], P. Reznicek[143], E. Ricci[75a,75b], R. Richter[115], S. Richter[46],
E. Richter-Was[83b], O. Ricken[24], M. Ridel[136], P. Rieck[115], C.J. Riegel[182], O. Rifki[46],
M. Rijssenbeek[155], A. Rimoldi[70a,70b], M. Rimoldi[46], L. Rinaldi[23b], G. Ripellino[154], B. Ristić[89],
E. Ritsch[36], I. Riu[14], J.C. Rivera Vergara[176], F. Rizatdinova[129], E. Rizvi[92], C. Rizzi[36],
R.T. Roberts[100], S.H. Robertson[103,ag], M. Robin[46], D. Robinson[32], J.E.M. Robinson[46],
C.M. Robles Gajardo[147b], A. Robson[57], E. Rocco[99], C. Roda[71a,71b], S. Rodriguez Bosca[174],
A. Rodriguez Perez[14], D. Rodriguez Rodriguez[174], A.M. Rodríguez Vera[168b], S. Roe[36],
O. Røhne[134], R. Röhrig[115], C.P.A. Roland[65], J. Roloff[59], A. Romaniouk[112], M. Romano[23b,23a],
N. Rompotis[90], M. Ronzani[124], L. Roos[136], S. Rosati[72a], K. Rosbach[52], G. Rosin[102],
B.J. Rosser[137], E. Rossi[46], E. Rossi[74a,74b], E. Rossi[69a,69b], L.P. Rossi[55b], L. Rossini[68a,68b],
R. Rosten[14], M. Rotaru[27b], J. Rothberg[148], D. Rousseau[132], G. Rovelli[70a,70b], D. Roy[33c],
A. Rozanov[101], Y. Rozen[160], X. Ruan[33c], F. Rubbo[153], F. Rühr[52], A. Ruiz-Martinez[174],
A. Rummler[36], Z. Rurikova[52], N.A. Rusakovich[79], H.L. Russell[103], L. Rustige[38,47],

J.P. Rutherfoord[7], E.M. Rüttinger[46,k], M. Rybar[39], G. Rybkin[132], A. Ryzhov[123], G.F. Rzehorz[53],
P. Sabatini[53], G. Sabato[120], S. Sacerdoti[132], H.F-W. Sadrozinski[146], R. Sadykov[79],
F. Safai Tehrani[72a], B. Safarzadeh Samani[156], P. Saha[121], S. Saha[103], M. Sahinsoy[61a], A. Sahu[182],
M. Saimpert[46], M. Saito[163], T. Saito[163], H. Sakamoto[163], A. Sakharov[124,ar], D. Salamani[54],
G. Salamanna[74a,74b], J.E. Salazar Loyola[147b], P.H. Sales De Bruin[172], D. Salihagic[115,*],
A. Salnikov[153], J. Salt[174], D. Salvatore[41b,41a], F. Salvatore[156], A. Salvucci[63a,63b,63c],
A. Salzburger[36], J. Samarati[36], D. Sammel[52], D. Sampsonidis[162], D. Sampsonidou[162],
J. Sánchez[174], A. Sanchez Pineda[66a,66c], H. Sandaker[134], C.O. Sander[46], I.G. Sanderswood[89],
M. Sandhoff[182], C. Sandoval[22], D.P.C. Sankey[144], M. Sannino[55b,55a], Y. Sano[117], A. Sansoni[51],
C. Santoni[38], H. Santos[140a,140b], S.N. Santpur[18], A. Santra[174], A. Sapronov[79],
J.G. Saraiva[140a,140d], O. Sasaki[81], K. Sato[169], E. Sauvan[5], P. Savard[167,bb], N. Savic[115],
R. Sawada[163], C. Sawyer[144], L. Sawyer[95,ap], C. Sbarra[23b], A. Sbrizzi[23a], T. Scanlon[94],
J. Schaarschmidt[148], P. Schacht[115], B.M. Schachtner[114], D. Schaefer[37], L. Schaefer[137],
J. Schaeffer[99], S. Schaepe[36], U. Schäfer[99], A.C. Schaffer[132], D. Schaile[114], R.D. Schamberger[155],
N. Scharmberg[100], V.A. Schegelsky[138], D. Scheirich[143], F. Schenck[19], M. Schernau[171],
C. Schiavi[55b,55a], S. Schier[146], L.K. Schildgen[24], Z.M. Schillaci[26], E.J. Schioppa[36],
M. Schioppa[41b,41a], K.E. Schleicher[52], S. Schlenker[36], K.R. Schmidt-Sommerfeld[115],
K. Schmieden[36], C. Schmitt[99], S. Schmitt[46], S. Schmitz[99], J.C. Schmoeckel[46], U. Schnoor[52],
L. Schoeffel[145], A. Schoening[61b], P.G. Scholer[52], E. Schopf[135], M. Schott[99],
J.F.P. Schouwenberg[119], J. Schovancova[36], S. Schramm[54], F. Schroeder[182], A. Schulte[99],
H-C. Schultz-Coulon[61a], M. Schumacher[52], B.A. Schumm[146], Ph. Schune[145], A. Schwartzman[153],
T.A. Schwarz[105], Ph. Schwemling[145], R. Schwienhorst[106], A. Sciandra[146], G. Sciolla[26],
M. Scodeggio[46], M. Scornajenghi[41b,41a], F. Scuri[71a], F. Scutti[104], L.M. Scyboz[115],
C.D. Sebastiani[72a,72b], P. Seema[19], S.C. Seidel[118], A. Seiden[146], T. Seiss[37], J.M. Seixas[80b],
G. Sekhniaidze[69a], K. Sekhon[105], S.J. Sekula[42], N. Semprini-Cesari[23b,23a], S. Sen[49], S. Senkin[38],
C. Serfon[76], L. Serin[132], L. Serkin[66a,66b], M. Sessa[60a], H. Severini[128], T. Šfiligoj[91], F. Sforza[170],
A. Sfyrla[54], E. Shabalina[53], J.D. Shahinian[146], N.W. Shaikh[45a,45b], D. Shaked Renous[180],
L.Y. Shan[15a], R. Shang[173], J.T. Shank[25], M. Shapiro[18], A. Sharma[135], A.S. Sharma[1],
P.B. Shatalov[111], K. Shaw[156], S.M. Shaw[100], A. Shcherbakova[138], Y. Shen[128], N. Sherafati[34],
A.D. Sherman[25], P. Sherwood[94], L. Shi[158,ax], S. Shimizu[81], C.O. Shimmin[183], Y. Shimogama[179],
M. Shimojima[116], I.P.J. Shipsey[135], S. Shirabe[87], M. Shiyakova[79,ad], J. Shlomi[180], A. Shmeleva[110],
M.J. Shochet[37], J. Shojaii[104], D.R. Shope[128], S. Shrestha[126], E. Shulga[180], P. Sicho[141],
A.M. Sickles[173], P.E. Sidebo[154], E. Sideras Haddad[33c], O. Sidiropoulou[36], A. Sidoti[23b,23a],
F. Siegert[48], Dj. Sijacki[16], M.Jr. Silva[181], M.V. Silva Oliveira[80a], S.B. Silverstein[45a], S. Simion[132],
E. Simioni[99], R. Simoniello[99], S. Simsek[12b], P. Sinervo[167], N.B. Sinev[131], M. Sioli[23b,23a],
I. Siral[105], S.Yu. Sivoklokov[113], J. Sjölin[45a,45b], E. Skorda[96], P. Skubic[128], M. Slawinska[84],
K. Sliwa[170], R. Slovak[143], V. Smakhtin[180], B.H. Smart[144], J. Smiesko[28a], N. Smirnov[112],
S.Yu. Smirnov[112], Y. Smirnov[112], L.N. Smirnova[113,v], O. Smirnova[96], J.W. Smith[53],
M. Smizanska[89], K. Smolek[142], A. Smykiewicz[84], A.A. Snesarev[110], H.L. Snoek[120],
I.M. Snyder[131], S. Snyder[29], R. Sobie[176,ag], A.M. Soffa[171], A. Soffer[161], A. Søgaard[50], F. Sohns[53],
C.A. Solans Sanchez[36], E.Yu. Soldatov[112], U. Soldevila[174], A.A. Solodkov[123], A. Soloshenko[79],
O.V. Solovyanov[123], V. Solovyev[138], P. Sommer[149], H. Son[170], W. Song[144], W.Y. Song[168b],
A. Sopczak[142], F. Sopkova[28b], C.L. Sotiropoulou[71a,71b], S. Sottocornola[70a,70b], R. Soualah[66a,66c,h],
A.M. Soukharev[122b,122a], D. South[46], S. Spagnolo[67a,67b], M. Spalla[115], M. Spangenberg[178],
F. Spanò[93], D. Sperlich[52], T.M. Spieker[61a], R. Spighi[23b], G. Spigo[36], M. Spina[156], D.P. Spiteri[57],
M. Spousta[143], A. Stabile[68a,68b], B.L. Stamas[121], R. Stamen[61a], M. Stamenkovic[120],
E. Stanecka[84], R.W. Stanek[6], B. Stanislaus[135], M.M. Stanitzki[46], M. Stankaityte[135], B. Stapf[120],
E.A. Starchenko[123], G.H. Stark[146], J. Stark[58], S.H. Stark[40], P. Staroba[141], P. Starovoitov[61a],

S. Stärz[103], R. Staszewski[84], G. Stavropoulos[44], M. Stegler[46], P. Steinberg[29], A.L. Steinhebel[131],
B. Stelzer[152], H.J. Stelzer[139], O. Stelzer-Chilton[168a], H. Stenzel[56], T.J. Stevenson[156],
G.A. Stewart[36], M.C. Stockton[36], G. Stoicea[27b], M. Stolarski[140a], P. Stolte[53], S. Stonjek[115],
A. Straessner[48], J. Strandberg[154], S. Strandberg[45a,45b], M. Strauss[128], P. Strizenec[28b],
R. Ströhmer[177], D.M. Strom[131], R. Stroynowski[42], A. Strubig[50], S.A. Stucci[29], B. Stugu[17],
J. Stupak[128], N.A. Styles[46], D. Su[153], S. Suchek[61a], V.V. Sulin[110], M.J. Sullivan[90],
D.M.S. Sultan[54], S. Sultansoy[4c], T. Sumida[85], S. Sun[105], X. Sun[3], K. Suruliz[156], C.J.E. Suster[157],
M.R. Sutton[156], S. Suzuki[81], M. Svatos[141], M. Swiatlowski[37], S.P. Swift[2], T. Swirski[177],
A. Sydorenko[99], I. Sykora[28a], M. Sykora[143], T. Sykora[143], D. Ta[99], K. Tackmann[46,aa],
J. Taenzer[161], A. Taffard[171], R. Tafirout[168a], H. Takai[29], R. Takashima[86], K. Takeda[82],
T. Takeshita[150], E.P. Takeva[50], Y. Takubo[81], M. Talby[101], A.A. Talyshev[122b,122a], N.M. Tamir[161],
J. Tanaka[163], M. Tanaka[165], R. Tanaka[132], S. Tapia Araya[173], S. Tapprogge[99],
A. Tarek Abouelfadl Mohamed[136], S. Tarem[160], G. Tarna[27b,d], G.F. Tartarelli[68a], P. Tas[143],
M. Tasevsky[141], T. Tashiro[85], E. Tassi[41b,41a], A. Tavares Delgado[140a,140b], Y. Tayalati[35e],
A.J. Taylor[50], G.N. Taylor[104], W. Taylor[168b], A.S. Tee[89], R. Teixeira De Lima[153],
P. Teixeira-Dias[93], H. Ten Kate[36], J.J. Teoh[120], S. Terada[81], K. Terashi[163], J. Terron[98],
S. Terzo[14], M. Testa[51], R.J. Teuscher[167,ag], S.J. Thais[183], T. Theveneaux-Pelzer[46], F. Thiele[40],
D.W. Thomas[93], J.O. Thomas[42], J.P. Thomas[21], A.S. Thompson[57], P.D. Thompson[21],
L.A. Thomsen[183], E. Thomson[137], Y. Tian[39], R.E. Ticse Torres[53], V.O. Tikhomirov[110,at],
Yu.A. Tikhonov[122b,122a], S. Timoshenko[112], P. Tipton[183], S. Tisserant[101], K. Todome[23b,23a],
S. Todorova-Nova[5], S. Todt[48], J. Tojo[87], S. Tokár[28a], K. Tokushuku[81], E. Tolley[126],
K.G. Tomiwa[33c], M. Tomoto[117], L. Tompkins[153,r], B. Tong[59], P. Tornambe[102], E. Torrence[131],
H. Torres[48], E. Torró Pastor[148], C. Tosciri[135], J. Toth[101,ae], D.R. Tovey[149], A. Traeet[17],
C.J. Treado[124], T. Trefzger[177], F. Tresoldi[156], A. Tricoli[29], I.M. Trigger[168a], S. Trincaz-Duvoid[136],
W. Trischuk[167], B. Trocmé[58], A. Trofymov[145], C. Troncon[68a], M. Trovatelli[176], F. Trovato[156],
L. Truong[33b], M. Trzebinski[84], A. Trzupek[84], F. Tsai[46], J.C-L. Tseng[135], P.V. Tsiareshka[107,am],
A. Tsirigotis[162], N. Tsirintanis[9], V. Tsiskaridze[155], E.G. Tskhadadze[159a], M. Tsopoulou[162],
I.I. Tsukerman[111], V. Tsulaia[18], S. Tsuno[81], D. Tsybychev[155], Y. Tu[63b], A. Tudorache[27b],
V. Tudorache[27b], T.T. Tulbure[27a], A.N. Tuna[59], S. Turchikhin[79], D. Turgeman[180],
I. Turk Cakir[4b,w], R.J. Turner[21], R.T. Turra[68a], P.M. Tuts[39], S. Tzamarias[162], E. Tzovara[99],
G. Ucchielli[47], K. Uchida[163], I. Ueda[81], M. Ughetto[45a,45b], F. Ukegawa[169], G. Unal[36],
A. Undrus[29], G. Unel[171], F.C. Ungaro[104], Y. Unno[81], K. Uno[163], J. Urban[28b], P. Urquijo[104],
G. Usai[8], J. Usui[81], P. Uwer[ab], Z. Uysal[12d], L. Vacavant[101], V. Vacek[142], B. Vachon[103],
K.O.H. Vadla[134], A. Vaidya[94], C. Valderanis[114], E. Valdes Santurio[45a,45b], M. Valente[54],
S. Valentinetti[23b,23a], A. Valero[174], L. Valéry[46], R.A. Vallance[21], A. Vallier[36], J.A. Valls Ferrer[174],
T.R. Van Daalen[14], P. Van Gemmeren[6], I. Van Vulpen[120], M. Vanadia[73a,73b], W. Vandelli[36],
A. Vaniachine[166], D. Vannicola[72a,72b], R. Vari[72a], E.W. Varnes[7], C. Varni[55b,55a], T. Varol[42],
D. Varouchas[132], K.E. Varvell[157], M.E. Vasile[27b], G.A. Vasquez[176], J.G. Vasquez[183], F. Vazeille[38],
D. Vazquez Furelos[14], T. Vazquez Schroeder[36], J. Veatch[53], V. Vecchio[74a,74b], M.J. Veen[120],
L.M. Veloce[167], F. Veloso[140a,140c], S. Veneziano[72a], A. Ventura[67a,67b], N. Venturi[36],
A. Verbytskyi[115], V. Vercesi[70a], M. Verducci[74a,74b], C.M. Vergel Infante[78], C. Vergis[24],
W. Verkerke[120], A.T. Vermeulen[120], J.C. Vermeulen[120], M.C. Vetterli[152,bb], N. Viaux Maira[147b],
M. Vicente Barreto Pinto[54], T. Vickey[149], O.E. Vickey Boeriu[149], G.H.A. Viehhauser[135],
L. Vigani[135], M. Villa[23b,23a], M. Villaplana Perez[68a,68b], E. Vilucchi[51], M.G. Vincter[34],
V.B. Vinogradov[79], A. Vishwakarma[46], C. Vittori[23b,23a], I. Vivarelli[156], M. Vogel[182], P. Vokac[142],
S.E. von Buddenbrock[33c], E. Von Toerne[24], V. Vorobel[143], K. Vorobev[112], M. Vos[174],
J.H. Vossebeld[90], M. Vozak[100], N. Vranjes[16], M. Vranjes Milosavljevic[16], V. Vrba[142],
M. Vreeswijk[120], R. Vuillermet[36], I. Vukotic[37], P. Wagner[24], W. Wagner[182], J. Wagner-Kuhr[114],

H. Wahlberg[88], K. Wakamiya[82], V.M. Walbrecht[115], J. Walder[89], R. Walker[114], S.D. Walker[93],
W. Walkowiak[151], V. Wallangen[45a,45b], A.M. Wang[59], C. Wang[60b], F. Wang[181], H. Wang[18],
H. Wang[3], J. Wang[157], J. Wang[61b], P. Wang[42], Q. Wang[128], R.-J. Wang[99], R. Wang[60a],
R. Wang[6], S.M. Wang[158], W.T. Wang[60a], W. Wang[15c,ah], W.X. Wang[60a,ah], Y. Wang[60a,aq],
Z. Wang[60c], C. Wanotayaroj[46], A. Warburton[103], C.P. Ward[32], D.R. Wardrope[94], N. Warrack[57],
A. Washbrook[50], A.T. Watson[21], M.F. Watson[21], G. Watts[148], B.M. Waugh[94], A.F. Webb[11],
S. Webb[99], C. Weber[183], M.S. Weber[20], S.A. Weber[34], S.M. Weber[61a], A.R. Weidberg[135],
J. Weingarten[47], M. Weirich[99], C. Weiser[52], P.S. Wells[36], T. Wenaus[29], T. Wengler[36], S. Wenig[36],
N. Wermes[24], M.D. Werner[78], P. Werner[36], M. Wessels[61a], T.D. Weston[20], K. Whalen[131],
N.L. Whallon[148], A.M. Wharton[89], A.S. White[105], A. White[8], M.J. White[1], D. Whiteson[171],
B.W. Whitmore[89], F.J. Wickens[144], W. Wiedenmann[181], M. Wielers[144], N. Wieseotte[99],
C. Wiglesworth[40], L.A.M. Wiik-Fuchs[52], F. Wilk[100], H.G. Wilkens[36], L.J. Wilkins[93],
H.H. Williams[137], S. Williams[32], C. Willis[106], S. Willocq[102], J.A. Wilson[21], I. Wingerter-Seez[5],
E. Winkels[156], F. Winklmeier[131], O.J. Winston[156], B.T. Winter[52], M. Wittgen[153], M. Wobisch[95],
A. Wolf[99], T.M.H. Wolf[120], R. Wolff[101], R.W. Wölker[135], J. Wollrath[52], M.W. Wolter[84],
H. Wolters[140a,140c], V.W.S. Wong[175], N.L. Woods[146], S.D. Worm[21], B.K. Wosiek[84],
K.W. Woźniak[84], K. Wraight[57], S.L. Wu[181], X. Wu[54], Y. Wu[60a], T.R. Wyatt[100], B.M. Wynne[50],
S. Xella[40], Z. Xi[105], L. Xia[178], D. Xu[15a], H. Xu[60a,d], L. Xu[29], T. Xu[145], W. Xu[105], Z. Xu[60b],
Z. Xu[153], B. Yabsley[157], S. Yacoob[33a], K. Yajima[133], D.P. Yallup[94], D. Yamaguchi[165],
Y. Yamaguchi[165], A. Yamamoto[81], T. Yamanaka[163], F. Yamane[82], M. Yamatani[163],
T. Yamazaki[163], Y. Yamazaki[82], Z. Yan[25], H.J. Yang[60c,60d], H.T. Yang[18], S. Yang[77],
X. Yang[60b,58], Y. Yang[163], W-M. Yao[18], Y.C. Yap[46], Y. Yasu[81], E. Yatsenko[60c,60d], J. Ye[42],
S. Ye[29], I. Yeletskikh[79], M.R. Yexley[89], E. Yigitbasi[25], K. Yorita[179], K. Yoshihara[137],
C.J.S. Young[36], C. Young[153], J. Yu[78], R. Yuan[60b], X. Yue[61a], S.P.Y. Yuen[24], B. Zabinski[84],
G. Zacharis[10], E. Zaffaroni[54], J. Zahreddine[136], A.M. Zaitsev[123,as], T. Zakareishvili[159b],
N. Zakharchuk[34], S. Zambito[59], D. Zanzi[36], D.R. Zaripovas[57], S.V. Zeißner[47], C. Zeitnitz[182],
G. Zemaityte[135], J.C. Zeng[173], O. Zenin[123], T. Ženiš[28a], D. Zerwas[132], M. Zgubič[135],
D.F. Zhang[15b], F. Zhang[181], G. Zhang[60a], G. Zhang[15b], H. Zhang[15c], J. Zhang[6], L. Zhang[15c],
L. Zhang[60a], M. Zhang[173], R. Zhang[60a], R. Zhang[24], X. Zhang[60b], Y. Zhang[15a,15d], Z. Zhang[63a],
Z. Zhang[132], P. Zhao[49], Y. Zhao[60b], Z. Zhao[60a], A. Zhemchugov[79], Z. Zheng[105], D. Zhong[173],
B. Zhou[105], C. Zhou[181], M.S. Zhou[15a,15d], M. Zhou[155], N. Zhou[60c], Y. Zhou[7], C.G. Zhu[60b],
H.L. Zhu[60a], H. Zhu[15a], J. Zhu[105], Y. Zhu[60a], X. Zhuang[15a], K. Zhukov[110], V. Zhulanov[122b,122a],
D. Zieminska[65], N.I. Zimine[79], S. Zimmermann[52], Z. Zinonos[115], M. Ziolkowski[151], L. Živković[16],
G. Zobernig[181], A. Zoccoli[23b,23a], K. Zoch[53], T.G. Zorbas[149], R. Zou[37], L. Zwalinski[36]

1   *Department of Physics, University of Adelaide, Adelaide, Australia*
2   *Physics Department, SUNY Albany, Albany NY, U.S.A.*
3   *Department of Physics, University of Alberta, Edmonton AB, Canada*
4   *Department of Physics*[(a)]*, Ankara University, Ankara; Istanbul Aydin University*[(b)]*, Istanbul; Division of Physics*[(c)]*, TOBB University of Economics and Technology, Ankara, Turkey*
5   *LAPP, Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy, France*
6   *High Energy Physics Division, Argonne National Laboratory, Argonne IL, U.S.A.*
7   *Department of Physics, University of Arizona, Tucson AZ, U.S.A.*
8   *Department of Physics, University of Texas at Arlington, Arlington TX, U.S.A.*
9   *Physics Department, National and Kapodistrian University of Athens, Athens, Greece*
10   *Physics Department, National Technical University of Athens, Zografou, Greece*
11   *Department of Physics, University of Texas at Austin, Austin TX, U.S.A.*
12   *Bahcesehir University*[(a)]*, Faculty of Engineering and Natural Sciences, Istanbul; Istanbul Bilgi University*[(b)]*, Faculty of Engineering and Natural Sciences, Istanbul; Department of Physics*[(c)]*,

Bogazici University, Istanbul; Department of Physics Engineering[d], Gaziantep University, Gaziantep, Turkey

13. Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan

14. Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona, Spain

15. Institute of High Energy Physics[a], Chinese Academy of Sciences, Beijing; Physics Department[b], Tsinghua University, Beijing; Department of Physics[c], Nanjing University, Nanjing; University of Chinese Academy of Science (UCAS)[d], Beijing, China

16. Institute of Physics, University of Belgrade, Belgrade, Serbia

17. Department for Physics and Technology, University of Bergen, Bergen, Norway

18. Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley CA, U.S.A.

19. Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany

20. Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland

21. School of Physics and Astronomy, University of Birmingham, Birmingham, U.K.

22. Facultad de Ciencias y Centro de Investigaciónes, Universidad Antonio Nariño, Bogota, Colombia

23. INFN Bologna and Università di Bologna[a], Dipartimento di Fisica; INFN Sezione di Bologna[b], Italy

24. Physikalisches Institut, Universität Bonn, Bonn, Germany

25. Department of Physics, Boston University, Boston MA, U.S.A.

26. Department of Physics, Brandeis University, Waltham MA, U.S.A.

27. Transilvania University of Brasov[a], Brasov; Horia Hulubei National Institute of Physics and Nuclear Engineering[b], Bucharest; Department of Physics[c], Alexandru Ioan Cuza University of Iasi, Iasi; National Institute for Research and Development of Isotopic and Molecular Technologies[d], Physics Department, Cluj-Napoca; University Politehnica Bucharest[e], Bucharest; West University in Timisoara[f], Timisoara, Romania

28. Faculty of Mathematics[a], Physics and Informatics, Comenius University, Bratislava; Department of Subnuclear Physics[b], Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic

29. Physics Department, Brookhaven National Laboratory, Upton NY, U.S.A.

30. Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina

31. California State University, CA, U.S.A.

32. Cavendish Laboratory, University of Cambridge, Cambridge, U.K.

33. Department of Physics[a], University of Cape Town, Cape Town; Department of Mechanical Engineering Science[b], University of Johannesburg, Johannesburg; School of Physics[c], University of the Witwatersrand, Johannesburg, South Africa

34. Department of Physics, Carleton University, Ottawa ON, Canada

35. Faculté des Sciences Ain Chock[a], Réseau Universitaire de Physique des Hautes Energies — Université Hassan II, Casablanca; Faculté des Sciences[b], Université Ibn-Tofail, Kénitra; Faculté des Sciences Semlalia[c], Université Cadi Ayyad, LPHEA-Marrakech; Faculté des Sciences[d], Université Mohamed Premier and LPTPM, Oujda; Faculté des sciences[e], Université Mohammed V, Rabat, Morocco

36. CERN, Geneva, Switzerland

37. Enrico Fermi Institute, University of Chicago, Chicago IL, U.S.A.

38. LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand, France

39. Nevis Laboratory, Columbia University, Irvington NY, U.S.A.

40. Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark

41. Dipartimento di Fisica[a], Università della Calabria, Rende; INFN Gruppo Collegato di Cosenza[b], Laboratori Nazionali di Frascati, Italy

42. Physics Department, Southern Methodist University, Dallas TX, U.S.A.

43. Physics Department, University of Texas at Dallas, Richardson TX, U.S.A.

44 National Centre for Scientific Research "Demokritos", Agia Paraskevi, Greece

45 Department of Physics[(a)], Stockholm University; Oskar Klein Centre[(b)], Stockholm, Sweden

46 Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen, Germany

47 Lehrstuhl für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany

48 Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany

49 Department of Physics, Duke University, Durham NC, U.S.A.

50 SUPA — School of Physics and Astronomy, University of Edinburgh, Edinburgh, U.K.

51 INFN e Laboratori Nazionali di Frascati, Frascati, Italy

52 Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

53 II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany

54 Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland

55 Dipartimento di Fisica[(a)], Università di Genova, Genova; INFN Sezione di Genova[(b)], Italy

56 II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany

57 SUPA — School of Physics and Astronomy, University of Glasgow, Glasgow, U.K.

58 LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble, France

59 Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA, U.S.A.

60 Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics[(a)], University of Science and Technology of China, Hefei; Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE)[(b)], Shandong University, Qingdao; School of Physics and Astronomy[(c)], Shanghai Jiao Tong University, KLPPAC-MoE, SKLPPC, Shanghai; Tsung-Dao Lee Institute[(d)], Shanghai, China

61 Kirchhoff-Institut für Physik[(a)], Ruprecht-Karls-Universität Heidelberg, Heidelberg; Physikalisches Institut[(b)], Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany

62 Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan

63 Department of Physics[(a)], Chinese University of Hong Kong, Shatin, N.T., Hong Kong; Department of Physics[(b)], University of Hong Kong, Hong Kong; Department of Physics and Institute for Advanced Study[(c)], Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China

64 Department of Physics, National Tsing Hua University, Hsinchu, Taiwan

65 Department of Physics, Indiana University, Bloomington IN, U.S.A.

66 INFN Gruppo Collegato di Udine[(a)], Sezione di Trieste, Udine; ICTP[(b)], Trieste; Dipartimento Politecnico di Ingegneria e Architettura[(c)], Università di Udine, Udine, Italy

67 INFN Sezione di Lecce[(a)]; Dipartimento di Matematica e Fisica[(b)], Università del Salento, Lecce, Italy

68 INFN Sezione di Milano[(a)]; Dipartimento di Fisica[(b)], Università di Milano, Milano, Italy

69 INFN Sezione di Napoli[(a)]; Dipartimento di Fisica[(b)], Università di Napoli, Napoli, Italy

70 INFN Sezione di Pavia[(a)]; Dipartimento di Fisica[(b)], Università di Pavia, Pavia, Italy

71 INFN Sezione di Pisa[(a)]; Dipartimento di Fisica E. Fermi[(b)], Università di Pisa, Pisa, Italy

72 INFN Sezione di Roma[(a)]; Dipartimento di Fisica[(b)], Sapienza Università di Roma, Roma, Italy

73 INFN Sezione di Roma Tor Vergata[(a)]; Dipartimento di Fisica[(b)], Università di Roma Tor Vergata, Roma, Italy

74 INFN Sezione di Roma Tre[(a)]; Dipartimento di Matematica e Fisica[(b)], Università Roma Tre, Roma, Italy

75 INFN-TIFPA[(a)]; Università degli Studi di Trento[(b)], Trento, Italy

76 Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria

77 University of Iowa, Iowa City IA, U.S.A.

78 Department of Physics and Astronomy, Iowa State University, Ames IA, U.S.A.

79 Joint Institute for Nuclear Research, Dubna, Russia

80 Departamento de Engenharia Elétrica[(a)], Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora; Universidade Federal do Rio De Janeiro COPPE/EE/IF[(b)], Rio de Janeiro; Universidade Federal de São João del Rei (UFSJ)[(c)], São João del Rei; Instituto de Física[(d)], Universidade de São Paulo, São Paulo, Brazil

81   *KEK, High Energy Accelerator Research Organization, Tsukuba, Japan*

82   *Graduate School of Science, Kobe University, Kobe, Japan*

83   *AGH University of Science and Technology[a], Faculty of Physics and Applied Computer Science, Krakow; Marian Smoluchowski Institute of Physics[b], Jagiellonian University, Krakow, Poland*

84   *Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland*

85   *Faculty of Science, Kyoto University, Kyoto, Japan*

86   *Kyoto University of Education, Kyoto, Japan*

87   *Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka , Japan*

88   *Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina*

89   *Physics Department, Lancaster University, Lancaster, U.K.*

90   *Oliver Lodge Laboratory, University of Liverpool, Liverpool, U.K.*

91   *Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia*

92   *School of Physics and Astronomy, Queen Mary University of London, London, U.K.*

93   *Department of Physics, Royal Holloway University of London, Egham, U.K.*

94   *Department of Physics and Astronomy, University College London, London, U.K.*

95   *Louisiana Tech University, Ruston LA, U.S.A.*

96   *Fysiska institutionen, Lunds universitet, Lund, Sweden*

97   *Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France*

98   *Departamento de Física Teorica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid, Spain*

99   *Institut für Physik, Universität Mainz, Mainz, Germany*

100 *School of Physics and Astronomy, University of Manchester, Manchester, U.K.*

101 *CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France*

102 *Department of Physics, University of Massachusetts, Amherst MA, U.S.A.*

103 *Department of Physics, McGill University, Montreal QC, Canada*

104 *School of Physics, University of Melbourne, Victoria, Australia*

105 *Department of Physics, University of Michigan, Ann Arbor MI, U.S.A.*

106 *Department of Physics and Astronomy, Michigan State University, East Lansing MI, U.S.A.*

107 *B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus*

108 *Research Institute for Nuclear Problems of Byelorussian State University, Minsk, Belarus*

109 *Group of Particle Physics, University of Montreal, Montreal QC, Canada*

110 *P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia*

111 *Institute for Theoretical and Experimental Physics of the National Research Centre Kurchatov Institute, Moscow, Russia*

112 *National Research Nuclear University MEPhI, Moscow, Russia*

113 *D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia*

114 *Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany*

115 *Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany*

116 *Nagasaki Institute of Applied Science, Nagasaki, Japan*

117 *Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan*

118 *Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, U.S.A.*

119 *Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands*

120 *Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands*

121 *Department of Physics, Northern Illinois University, DeKalb IL, U.S.A.*

122 *Budker Institute of Nuclear Physics and NSU[a], SB RAS, Novosibirsk; Novosibirsk State University Novosibirsk[b], Russia*

123 *Institute for High Energy Physics of the National Research Centre Kurchatov Institute, Protvino, Russia*

124 *Department of Physics, New York University, New York NY, U.S.A.*

125 *Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo, Japan*

126 *Ohio State University, Columbus OH, U.S.A.*

127 *Faculty of Science, Okayama University, Okayama, Japan*

128 *Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, U.S.A.*

129 *Department of Physics, Oklahoma State University, Stillwater OK, U.S.A.*

130 *Palacký University, RCPTM, Joint Laboratory of Optics, Olomouc, Czech Republic*

131 *Center for High Energy Physics, University of Oregon, Eugene OR, U.S.A.*

132 *LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France*

133 *Graduate School of Science, Osaka University, Osaka, Japan*

134 *Department of Physics, University of Oslo, Oslo, Norway*

135 *Department of Physics, Oxford University, Oxford, U.K.*

136 *LPNHE, Sorbonne Université, Université de Paris, CNRS/IN2P3, Paris, France*

137 *Department of Physics, University of Pennsylvania, Philadelphia PA, U.S.A.*

138 *Konstantinov Nuclear Physics Institute of National Research Centre "Kurchatov Institute", PNPI, St. Petersburg, Russia*

139 *Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, U.S.A.*

140 *Laboratório de Instrumentação e Física Experimental de Partículas — LIP[a], Lisbon; Departamento de Física[b], Faculdade de Ciências, Universidade de Lisboa, Lisbon; Departamento de Física[c], Universidade de Coimbra, Coimbra; Centro de Física Nuclear da Universidade de Lisboa[d], Lisbon; Departamento de Física[e], Universidade do Minho, Braga; Universidad de Granada[f], Granada (Spain); Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia[g], Universidade Nova de Lisboa, Caparica; Av. Rovisco Pais[h], 1 1049-001 Lisbon, Portugal, Portugal*

141 *Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic*

142 *Czech Technical University in Prague, Prague, Czech Republic*

143 *Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic*

144 *Particle Physics Department, Rutherford Appleton Laboratory, Didcot, U.K.*

145 *IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*

146 *Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, U.S.A.*

147 *Departamento de Física[a], Pontificia Universidad Católica de Chile, Santiago; Departamento de Física[b], Universidad Técnica Federico Santa María, Valparaíso, Chile*

148 *Department of Physics, University of Washington, Seattle WA, U.S.A.*

149 *Department of Physics and Astronomy, University of Sheffield, Sheffield, U.K.*

150 *Department of Physics, Shinshu University, Nagano, Japan*

151 *Department Physik, Universität Siegen, Siegen, Germany*

152 *Department of Physics, Simon Fraser University, Burnaby BC, Canada*

153 *SLAC National Accelerator Laboratory, Stanford CA, U.S.A.*

154 *Physics Department, Royal Institute of Technology, Stockholm, Sweden*

155 *Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY, U.S.A.*

156 *Department of Physics and Astronomy, University of Sussex, Brighton, U.K.*

157 *School of Physics, University of Sydney, Sydney, Australia*

158 *Institute of Physics, Academia Sinica, Taipei, Taiwan*

159 *E. Andronikashvili Institute of Physics[a], Iv. Javakhishvili Tbilisi State University, Tbilisi; High Energy Physics Institute[b], Tbilisi State University, Tbilisi, Georgia*

160 *Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel*

161 *Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel*

162 *Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*

163 *International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan*

164 *Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan*

165 *Department of Physics, Tokyo Institute of Technology, Tokyo, Japan*

166 *Tomsk State University, Tomsk, Russia*

167 *Department of Physics, University of Toronto, Toronto ON, Canada*

168 *TRIUMF$^{(a)}$, Vancouver BC; Department of Physics and Astronomy$^{(b)}$, York University, Toronto ON, Canada*

169 *Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan*

170 *Department of Physics and Astronomy, Tufts University, Medford MA, U.S.A.*

171 *Department of Physics and Astronomy, University of California Irvine, Irvine CA, U.S.A.*

172 *Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*

173 *Department of Physics, University of Illinois, Urbana IL, U.S.A.*

174 *Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia — CSIC, Valencia, Spain*

175 *Department of Physics, University of British Columbia, Vancouver BC, Canada*

176 *Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada*

177 *Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany*

178 *Department of Physics, University of Warwick, Coventry, U.K.*

179 *Waseda University, Tokyo, Japan*

180 *Department of Particle Physics, Weizmann Institute of Science, Rehovot, Israel*

181 *Department of Physics, University of Wisconsin, Madison WI, U.S.A.*

182 *Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany*

183 *Department of Physics, Yale University, New Haven CT, U.S.A.*

184 *Yerevan Physics Institute, Yerevan, Armenia*

a *Also at Borough of Manhattan Community College, City University of New York, New York NY, U.S.A.*

b *Also at Centre for High Performance Computing, CSIR Campus, Rosebank, Cape Town, South Africa*

c *Also at CERN, Geneva, Switzerland*

d *Also at CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France*

e *Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland*

f *Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona, Spain*

g *Also at Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal*

h *Also at Department of Applied Physics and Astronomy, University of Sharjah, Sharjah, United Arab Emirates*

i *Also at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece*

j *Also at Department of Physics and Astronomy, University of Louisville, Louisville, KY, U.S.A.*

k *Also at Department of Physics and Astronomy, University of Sheffield, Sheffield, U.K.*

l *Also at Department of Physics, Ben Gurion University of the Negev, Beer Sheva, Israel*

m *Also at Department of Physics, California State University, East Bay, U.S.A.*

n *Also at Department of Physics, California State University, Fresno, U.S.A.*

o *Also at Department of Physics, California State University, Sacramento, U.S.A.*

p *Also at Department of Physics, King's College London, London, U.K.*

q *Also at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia*

^r Also at Department of Physics, Stanford University, Stanford CA, U.S.A.

^s Also at Department of Physics, University of Adelaide, Adelaide, Australia

^t Also at Department of Physics, University of Fribourg, Fribourg, Switzerland

^u Also at Department of Physics, University of Michigan, Ann Arbor MI, U.S.A.

^v Also at Faculty of Physics, M.V. Lomonosov Moscow State University, Moscow, Russia

^w Also at Giresun University, Faculty of Engineering, Giresun, Turkey

^x Also at Graduate School of Science, Osaka University, Osaka, Japan

^y Also at Hellenic Open University, Patras, Greece

^z Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain

^{aa} Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany

^{ab} Associated at Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany

^{ac} Also at Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands

^{ad} Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria

^{ae} Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary

^{af} Also at Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

^{ag} Also at Institute of Particle Physics (IPP), Vancouver, Canada

^{ah} Also at Institute of Physics, Academia Sinica, Taipei, Taiwan

^{ai} Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan

^{aj} Also at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia

^{ak} Also at Instituto de Fisica Teorica, IFT-UAM/CSIC, Madrid, Spain

^{al} Also at Istanbul University, Dept. of Physics, Istanbul, Turkey

^{am} Also at Joint Institute for Nuclear Research, Dubna, Russia

^{an} Associated at LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France

^{ao} Also at LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France

^{ap} Also at Louisiana Tech University, Ruston LA, U.S.A.

^{aq} Also at LPNHE, Sorbonne Université, Université de Paris, CNRS/IN2P3, Paris, France

^{ar} Also at Manhattan College, New York NY, U.S.A.

^{as} Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia

^{at} Also at National Research Nuclear University MEPhI, Moscow, Russia

^{au} Also at Physics Department, An-Najah National University, Nablus, Palestine

^{av} Also at Physics Dept, University of South Africa, Pretoria, South Africa

^{aw} Also at Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

^{ax} Also at School of Physics, Sun Yat-sen University, Guangzhou, China

^{ay} Also at The City College of New York, New York NY, U.S.A.

^{az} Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing, China

^{ba} Also at Tomsk State University, Tomsk, and Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia

^{bb} Also at TRIUMF, Vancouver BC, Canada

^{bc} Also at Universita di Napoli Parthenope, Napoli, Italy

[*] Deceased