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Dielectron Yields in p+d and p+p Collisions at 4.9 GeV

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Abstract

The dielectron yield in p+d and p+p collisions at a beam kinetic energy of 4.9 GeV has been measured using the Dilepton Spectrometer (DLS) at the Bevalac. The measured ratio of the yield in p+d to that in p+p collisions, 1.92±0.06, implies a small contribution from p+n bremsstrahlung in contrary to recent model calculations, and points to a hadron-like origin of the dielectron source. The expected contributions of hadronic decays to the dielectron yield are small compared to the p+p data.

Dileptons, when produced inside hot and dense nuclear matter formed in nucleus-nucleus collisions, are probes of the nuclear equation of state and of pion dynamics in the nuclear medium.[1,2,3,4] The Dilepton Spectrometer (DLS) collaboration has measured dielectron production at the Lawrence Berkeley Laboratory Bevalac for p+Be and Ca+Ca collisions with beam kinetic energies (E_k) ranging from 1.0 GeV to 4.9 GeV.[5,6,7,8] The existence of dielectron signals in these collisions has been firmly established. However, mechanisms for the dielectron production at these beam energies are still unclear. In this context we have recently made a high statistics measurement of the dielectron production in p+d and p+p collisions at $E_k = 4.9$ GeV with the number of measured pairs on the order of 10^4.

Our liquid-hydrogen/deuterium program was motivated by several calculations of dielectron production within a similar framework. In those calculations,[9,10,11] mechanisms of p+n bremsstrahlung and Dalitz decay of Δ are included to fit our previous p+Be and Ca+Ca measurements. Furthermore the bremsstrahlung of p+p scattering is considered to be too small, by an order of magnitude, to contribute to the overall dielectron yield. Those calculations indicated that p+n bremsstrahlung is a dominant source for dielectrons, and increasingly so with the beam energy; therefore, a ratio, as large as 10 at $E_k = 4.9$ GeV, for the dielectron yield in p+d and p+p collisions may be expected. Thus, a measurement of dielectron yield in these collisions provides a stringent constraint on the relative strength of p+n bremsstrahlung and Dalitz decay of Δ.

The DLS consists of two identical magnetic spectrometer arms, each with two hodoscope counter arrays, two Čerenkov counter arrays and three drift chambers. Details of the DLS have been described elsewhere.[12] For the recent measurements, the scattering chamber has been replaced by a liquid hydrogen/deuterium target. The target-full to target-empty ratio was measured to be about 10 for p+p collisions and about 20 for p+d collisions. In addition, p+p elastic collisions at $E_k = 1.0$ GeV have been measured for calibration of the spectrometer.

Figure 1 shows the yield of opposite-sign (OS) and background (BK) electron pairs as a function of pair mass for p+d and p+p collisions. The background pairs were constructed by randomly selecting an electron and a positron each from the sample of combinatorial same-sign (SS) pairs for each charge-field configuration. And the number of the background pairs was normalized to the square root of the product of number of electron-electron and positron-positron pairs. The SS spectrum is the same as the background in OS pairs only if the electrons and positrons in the combinatorial background have the same yield and kinematics. We observed an excess of electrons up to 30%, mostly in the forward angle, presumably due to Compton scattering of photons in the target. However, the difference between this new background subtraction and the simple SS subtraction described in previous papers is less than 15% for low mass region, and negligible for mass greater than 0.3 GeV/c^2.

Figure 2 shows the true (OS-BK) dielectron yield, without acceptance correction, in μb/(GeV/c^2) as a function of pair mass, to which an overall efficiency correction of 43% for p+d and 48% for p+p has been applied, respectively. The dielectron yields of p+d and p+p collisions are very similar in shape for dielectron mass range of 0.20-1.0 GeV/c^2, transverse momentum range of 0.0-1.0 GeV/c and rapidity range of 0.5-1.9, suggestive of common production mechanisms. Both spectra exhibit a clear resonance structure over the continuum due to dielectron decays of ρ-ω mesons, and an increase below 0.15 GeV/c^2 due to Dalitz decay of π^0's.

The ratio of the dielectron yield in p+d to that in p+p collisions, integrated for mass greater than 0.2 GeV/c^2, was found to be 1.92$\pm$0.06 with the errors being statistical only. No significant dependence of this ratio on dielectron mass, transverse momentum and rapidity has been observed. By fitting the spectra for masses greater than 0.4 GeV/c^2 with a gaussian superimposed on an exponential function, the ratio for the ρ-ω component was extracted to be 1.5$\pm$0.5.

The systematic error on the ratio was estimated to be less than 20% over the mass range. Our systematic uncertainties for the ratio mainly come from two sources. One is from the fact that the p+p and p+d data were taken at different beam intensities. The other is from the variation in the detection efficiency during the one-month period of data acquisition. We estimated that the beam calibration and any rate dependence of trigger efficiency contributed less than 15% to the systematic errors, and the variation in overall detection efficiency including drift chambers, Čerenkov and hodoscope counters was less than 15%. The systematic error on the absolute yield was estimated to be less than 40%.

Our observed ratio of the dielectron yield in p+d to that in p+p collisions is much smaller than the value of about 10 given by present model calculations assuming the dominance of p+n bremsstrahlung in these collisions. The soft-photon approximation (SPA) used in references[9,10,11] for bremsstrahlung, which has been applied to describe real photon production in collisions at several hundred MeV,[13] has often been called into question.[14] Haglin et al.[15] have performed a one-boson exchange model (OBE) calculation including all Feynman diagrams, in comparison with SPA and external-line emission model (i.e., initial and final state bremsstrahlung only). They have shown that the OBE gave a higher dielectron yield than did the SPA, with the prediction of the external-line emission model falling in between. Thus this type of more detailed calculation only increases the bremsstrahlung yield, contrary to experimental indications. However, these calculations are performed for particles on mass shell. The off-shell behavior of intermediate particles,[16] the forward peaking of the p+n elastic cross section,[17] and bremsstrahlung from multiparticle final states in both p+n and p+p collisions may significantly alter the results obtained when calculating the dielectron yields from p+d and p+p collisions.

The similarity of the mass spectra and the measured dielectron ratio of about 2 for p+d and p+p collisions point to a hadron-like origin of the dielectron production for these collisions. To estimate dielectrons from hadronic decays, we have included the Dalitz decays of η, ω and Δ, and 2-body decays of ρ and ω in a GEANT Monte Carlo simulation. For the Dalitz decays of η and ω we have followed the descriptions by Dalitz[18] and by Kroll and Wada.[19] For the Dalitz decay of Δ we have used the prescription by Wolf et al.[11] with a Breit-Wigner form factor. The differential cross sections of mesons were assumed to be gaussian in laboratory rapidity (y) and exponential in transverse mass (m_t), $\frac{d^3\sigma}{dyd^2m_t} \propto \exp\left(-\frac{(y-y_{cm})^2}{2\sigma_y^2}\right)*\exp\left(-m_t/T_y\right)$, with $m_t = \sqrt{m^2+p_t^2}$. The slope parameter, T_y, was assumed to be $T_0/cosh(y-y_{cm})$, where T_0 is the slope parameter at the center-of-mass rapidity (y_{cm}).[20] The Δ spectrum has a similar transverse mass distribution as mesons, but the rapidity distribution was assumed to be the same as protons, an exponential decrease from beam (target) rapidity with symmetry around the c.m. rapidity.[21] T_0 and σ_y were assumed to be 0.12 GeV and 0.7, respectively. Within reasonable variations in T_0 (± 0.02 GeV) and σ_y (± 0.2) the dielectron yield changes by less than 30%.

Figure 3 shows the most probable total hadronic decay contributions as they would be detected in the DLS in comparison with the observed true electron pairs from p+p collisions at $E_k = 4.9$ GeV. Also shown are the components from the Dalitz decay of η and 2-body decay of ω (hatched areas). The dominant hadronic decay component is the Dalitz decay of η , for which the production cross section was estimated to be 0.3 mb from a calculation by A. DePaoli et al.[22] An upper limit (90% c.l.) for an η cross section of 0.5 mb was measured by K. Jaeger et al.[23] in the 2-γ decay channel for p+p collisions at the incident momentum of 12.4 GeV/c. This sets an upper limit on the Dalitz contribution of η at our energy of about twice the probable one shown in figure 3. The production cross sections, $\sigma_\Delta = 5$ mb and $\sigma_{\rho,\omega} = 0.15$ mb, were estimated from a measurement by Alexander et al.[24] Even with the upper limit on the η cross section the observed dielectron yield in p+p collisions cannot be accounted for by hadronic decays alone. The Dalitz decays of other hadrons (e.g.. ρ, η', φ) or other resonances (e.g.. N^*) can in principle contribute to the low mass region. However, either the production cross sections and/or the decay branching ratios are too small compared to that of the η. ω or Δ to alter our conclusions. These results are consistent with early observations of unexpectedly large lepton production at higher energies.[25,26,27,28]

In conclusion, we have measured dielectron yields in p+d and p+p collisions at $E_k = 4.9$ GeV. The ratio of the dielectron yield in these collisions was found to be 1.92±0.06 without significant mass. transverse momentum or rapidity dependence. These results, indicative of a hadron-like origin of dielectron production, are in strong disagreement with models of p+n bremsstrahlung being the dominant dielectron source at that beam energy. Furthermore, our estimate of dielectron contribution from hadronic decays of η, ρ, ω and Δ can reproduce neither the total dielectron yield nor the shape of dielectron mass spectra.

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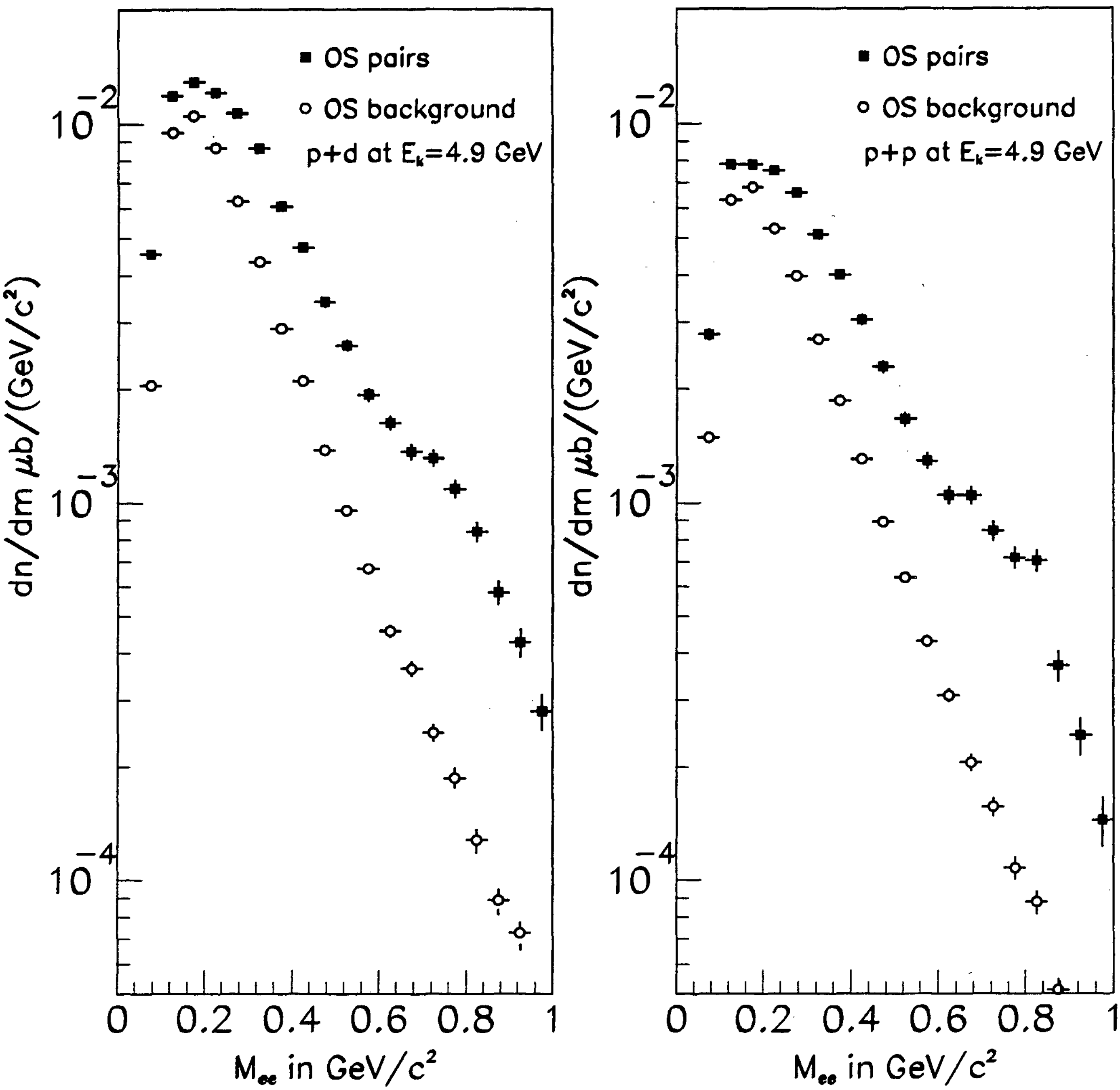
Figure Captions

Fig. 1 The opposite-sign (OS) and background (BK) dielectron mass distribution from p+d and p+p collisions at $E_k = 4.9$ GeV. The error bars are statistical only.

Fig. 2 The true (OS-BK) dielectron yield in μb/(GeV/c^2) from p+d and p+p collisions. An overall efficiency of 43% for p+d and 48% for p+p has been applied, respectively.

Fig. 3 The dielectron yield from p+p collisions in comparison with the total probable contribution (solid histogram) in the DLS acceptance from decays of η, ρ, ω and Δ. The production cross sections were estimated to be $\sigma_\eta = 0.30$ mb, $\sigma_\Delta = 5$ mb and $\sigma_{\rho,\omega} = 0.15$ mb. The hatched areas indicate the individual contributions from the Dalitz decay of η and dielectron decay of ω, respectively. The statistical errors in the simulation are comparable to those in the data.



OS pairs
OS background
p+d at E_k=4.9 GeV
dn/dm μb/(GeV/c²)
M_{ee} in GeV/c²
OS pairs
OS background
p+p at E_k=4.9 GeV
dn/dm μb/(GeV/c²)
M_{ee} in GeV/c²

Figure 1

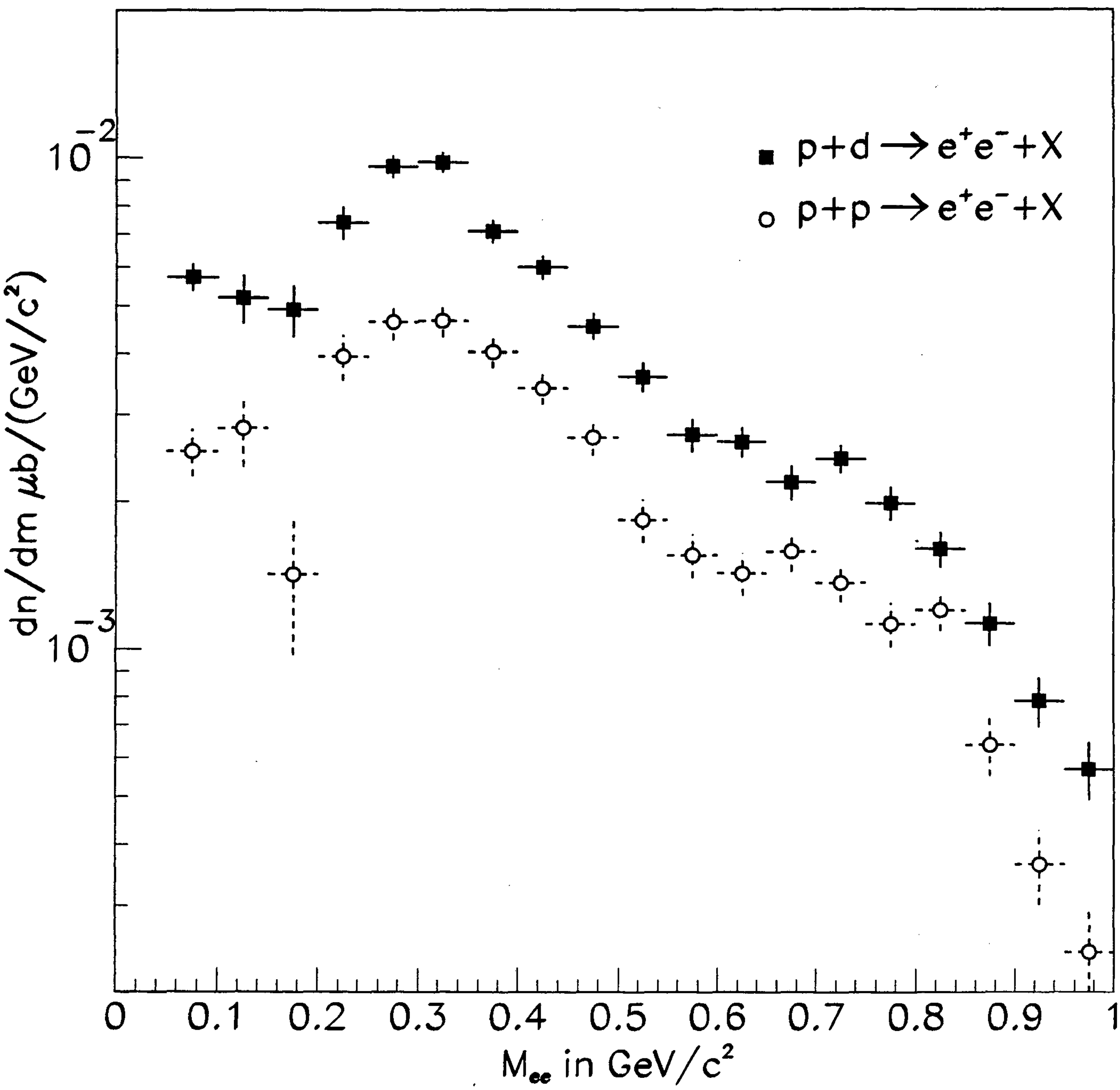
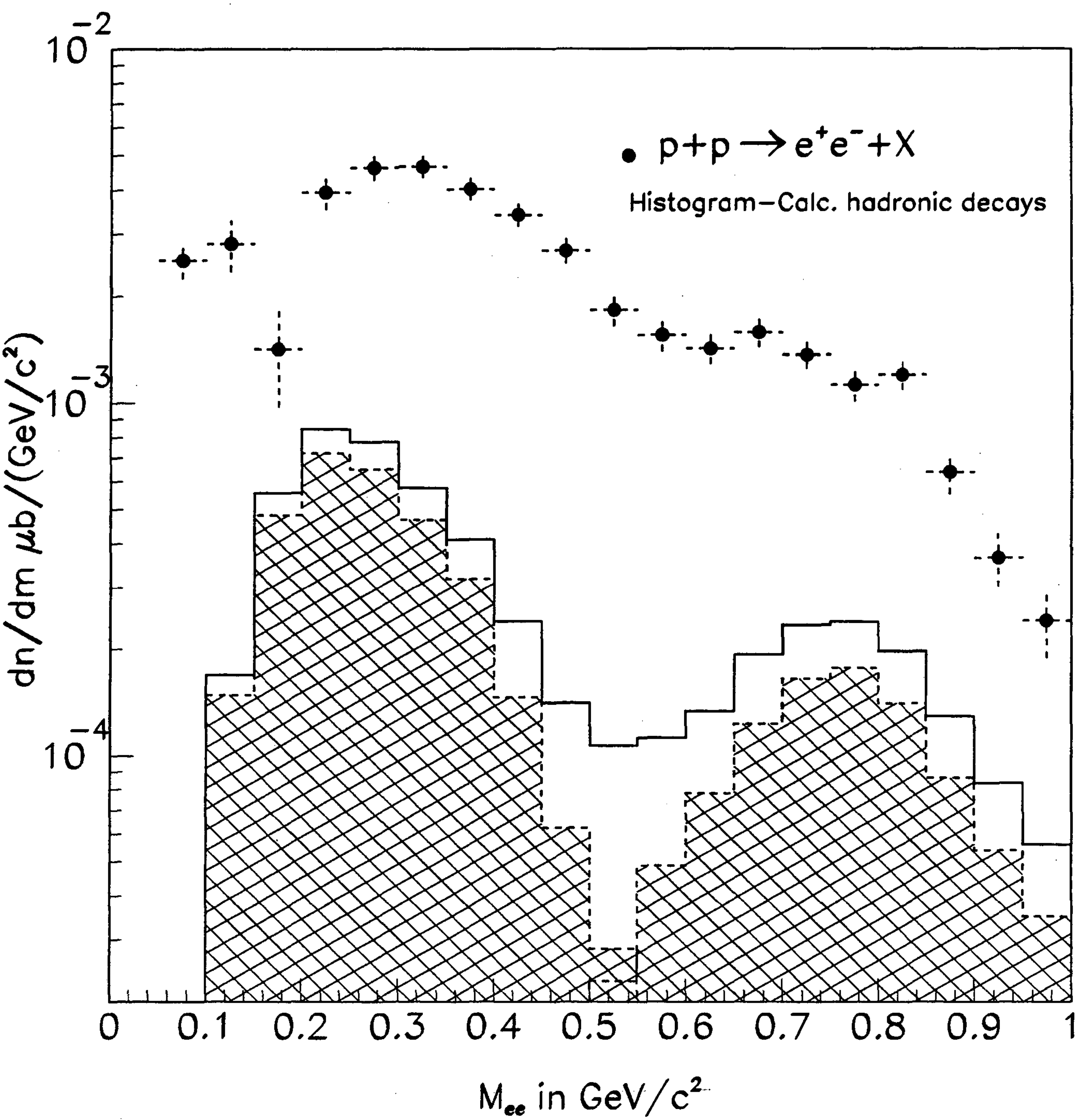

p+d → e⁺e⁻+X
p+p → e⁺e⁻+X
dn/dm μb/(GeV/c²)
10⁻²
10⁻³
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Mee in GeV/c²

Figure 2



10^{-2}
10^{-3}
10^{-4}
dn/dm μb/(GeV/c²)
p+p → e⁺e⁻+X
Histogram–Calc. hadronic decays
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
M_{ee} in GeV/c²

Figure 3

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