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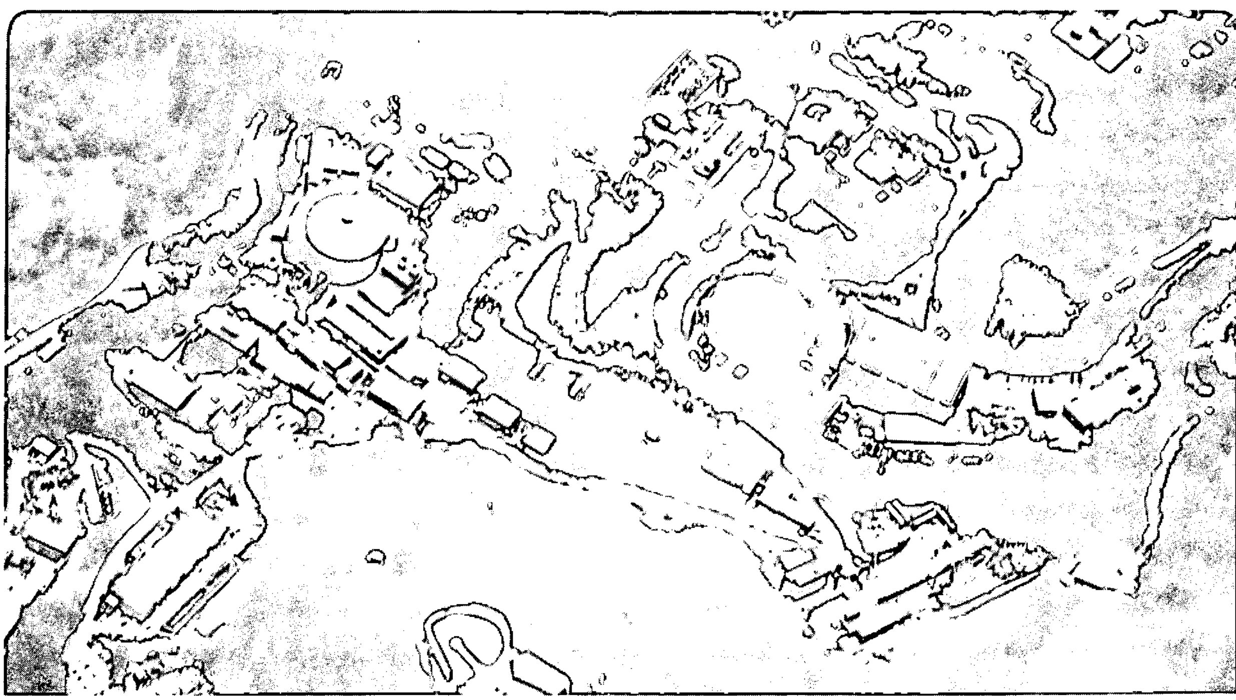
January 1993



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Intermediate Mass Higgs Detection with SDC * †

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Abstract

I review the work done by the SDC collaboration in simulation of Higgs detection at the SSC. I concentrate on the decays of the Higgs to two photons and to 4 charged leptons. In the former case, I discuss the signal to background ratio for events with and without an additional charged lepton.

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Santa Cruz, Dec 1992

Intermediate Mass Higgs at SSC with SDC

Ian Hinchliffe

Mass range

80 GeV $< M_H \lesssim$ 160 GeV

Two processes studied in detail

— $H \to ZZ^* \to 4\ell$ *i.e.* $4e$ or 4μ or $2e2\mu$

— $H \to \gamma\gamma$ (with and without and additional lepton)

Reminder of Rates and Branching ratios (fig)

References: SDC-90-00151 (letter of Intent of SDC collaboration), SDC-90-00099 (IH, R.M Barnett and K. Einsweiler), SDC-90-000113, (M. Mangano), SDC-92-201 (Technical Design Report), I H and K.J. Einsweiler (in preparation),

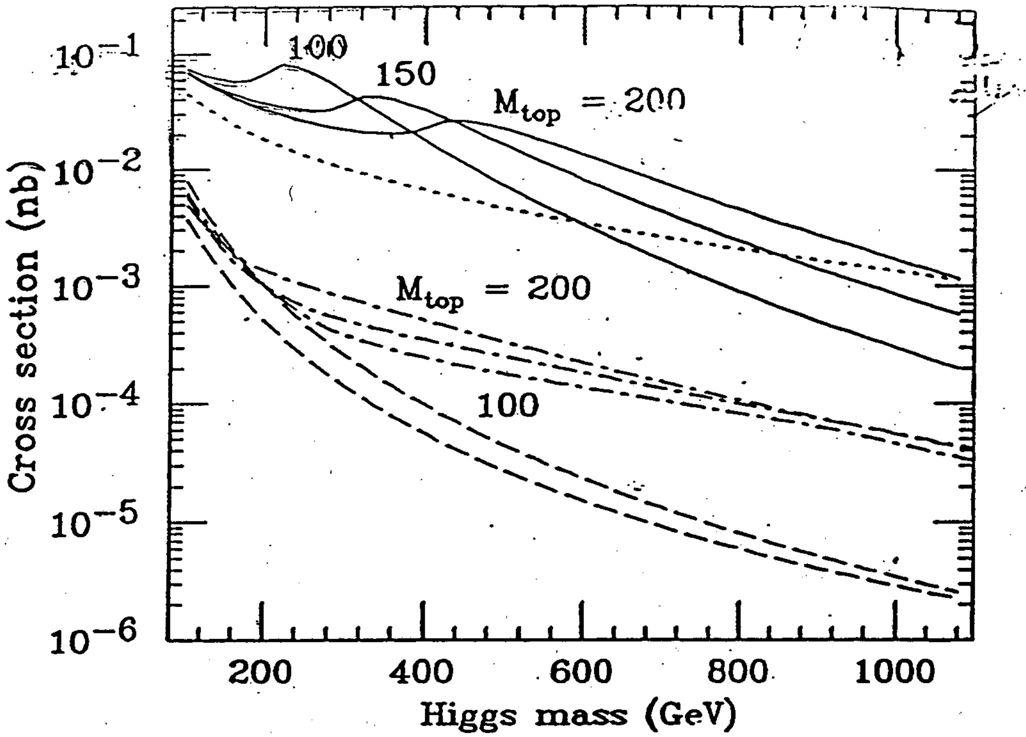
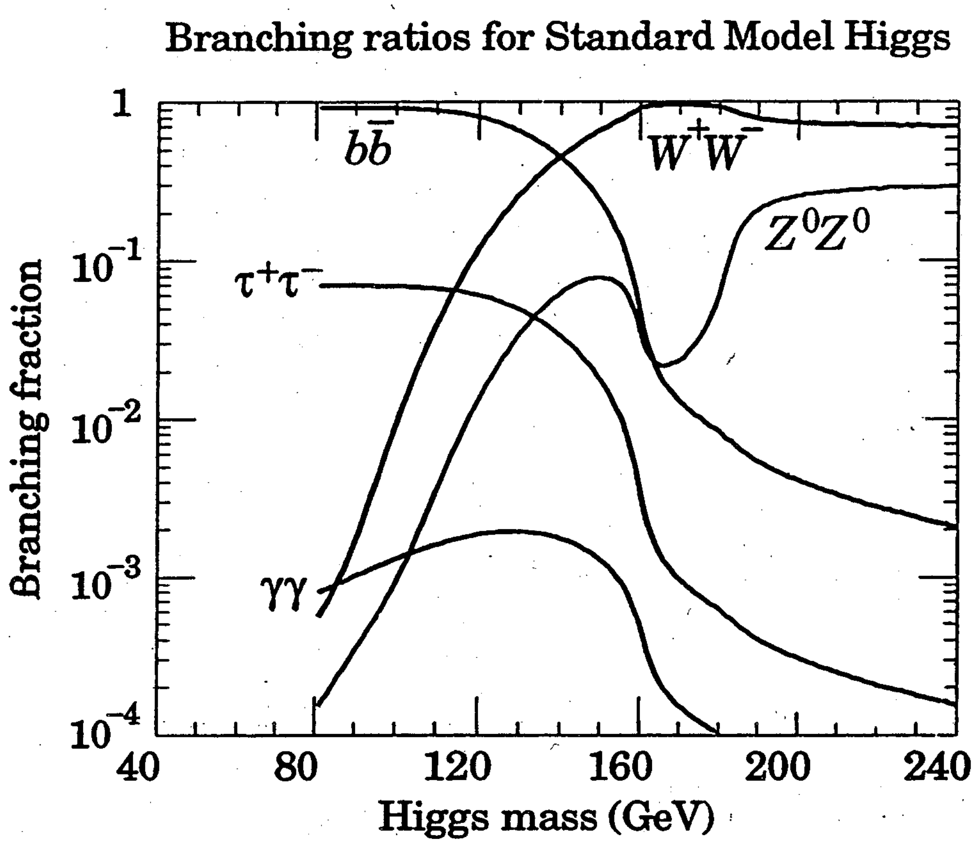


FIG. 3-3. The cross section for the production of a Higgs boson in pp collisions at $\sqrt{s} = 40$ TeV as a function of the Higgs boson mass for several different production mechanisms: gg fusion (solid), WW/ZZ fusion (dotted), $t\bar{t} + H$ production (dot-dashed), $W + H$ production (upper dashed), and $Z + H$ production (lower dashed). When the cross section depends on the t-quark mass, several curves have been included for different values of $M_{\rm top}$.



Assumes $t\bar{t}$ closed

Relevant SDC resolutions

– tracking/Muons (fig)

– EM calorimeter

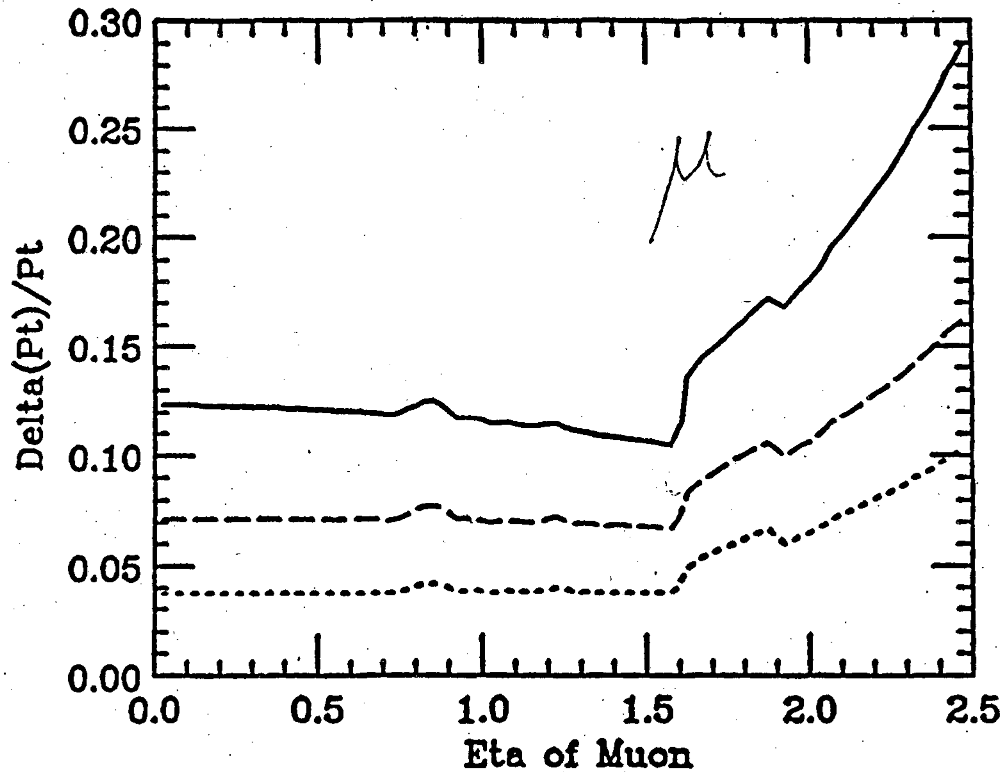
$$\frac{\sigma(E)}{E} = \frac{.14}{\sqrt{E_t}} \bigoplus 0.01 \text{ for } |\eta| < 1.4$$

$$\frac{\sigma(E)}{E} = \frac{.17}{\sqrt{E}} \bigoplus 0.01 \text{ for } 1.4 < |\eta| < 2.5$$

Note $\bigoplus$ implies addition in quadrature

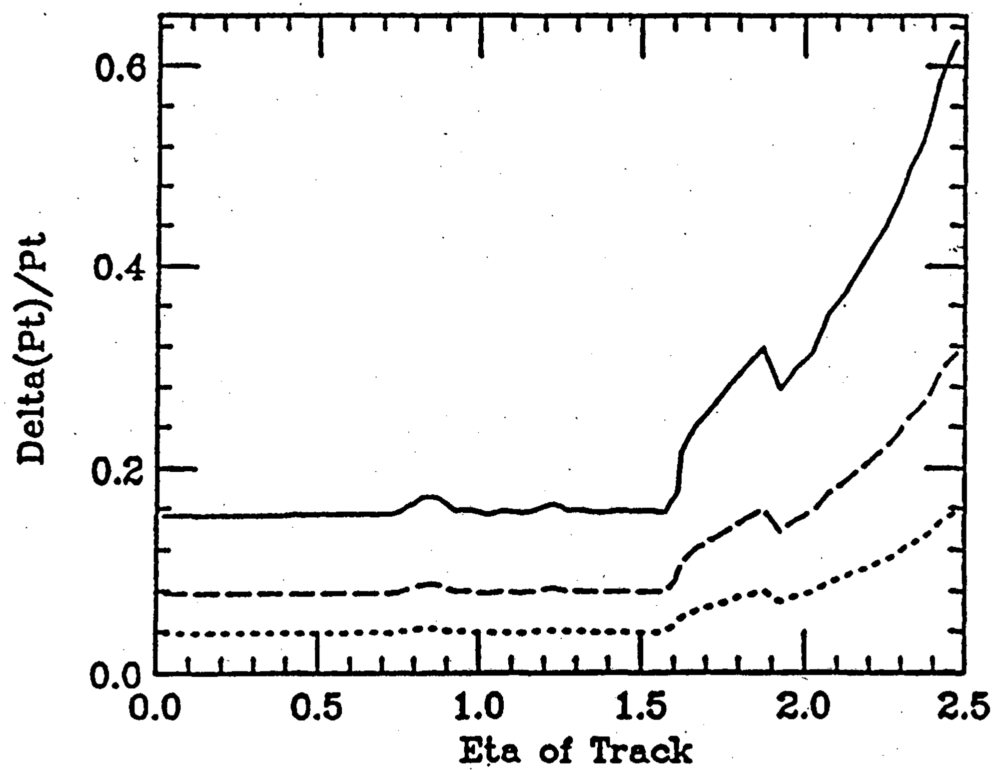
Simulations use detail GEANT studies where appropriate, *e.g.* secondaries making hits in the tracker

Parametrized resolution versus η :



Curves are for constant p_t of 100, 250, 1000 GeV.

Parametrized resolution versus η :



Isolation on leptons

Need a topological cut to get rid of backgrounds from leptons that arise from decays of bottom and charm.

Select a candidate lepton from a sample of ZZ^* and $t\bar{t}$ events.

Distribution of E_t in a cone $\Delta R = 0.3$ around lepton. (fig)

Require that excess $E_t < 5$ GeV. (table)

94% efficient for leptons from signal and $t \to be\nu$

Less than 0.05% efficient for leptons of $p_t > 20$ GeV from b decay.

Distribution of excess E_t in a cone of $R = 0.3$ around the leptons for the $H \to ZZ^*$ signal and the $t\bar{t}$ background.

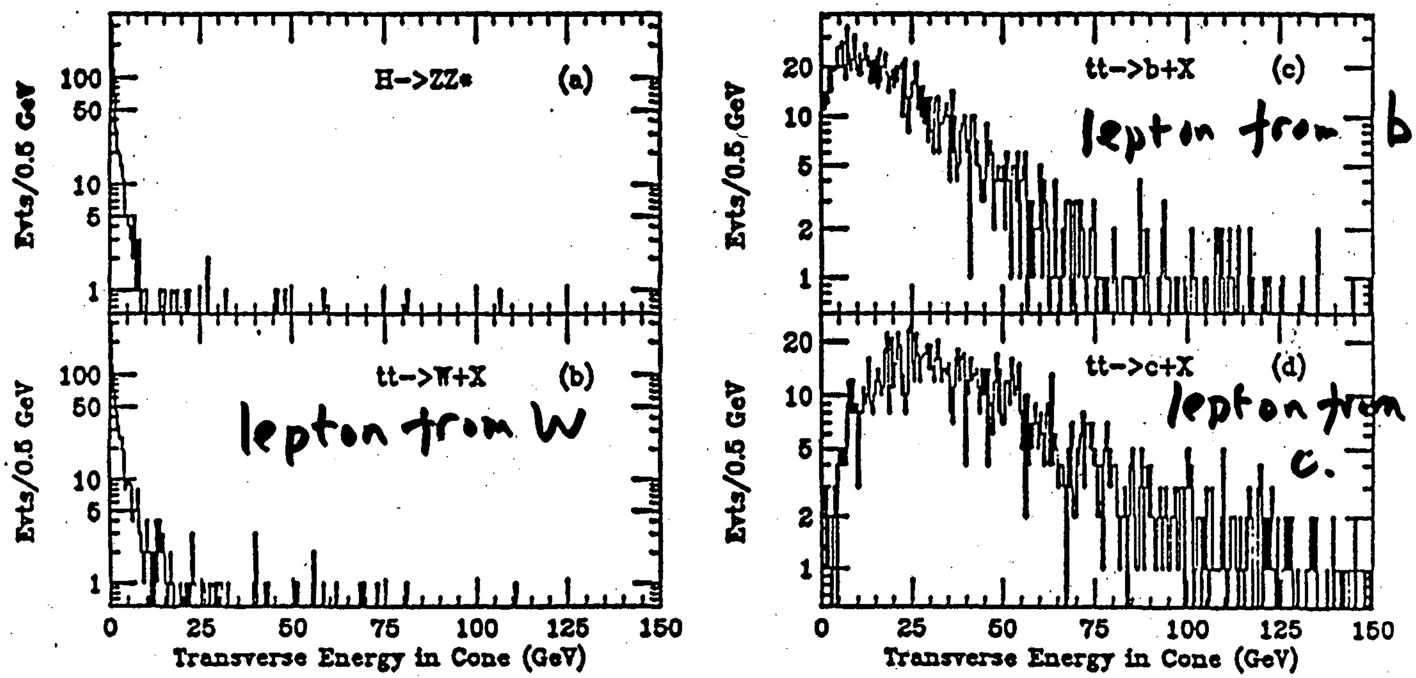


Table 3-6

A summary of the observed efficiencies for detecting electrons with different parents arising from two different processes as a function of the electron p_t and the radius of the surrounding cone. Electrons are accepted if there is less than 5 GeV of excess transverse energy in this cone. The "Z parent" column refers to electrons arising from $H \rightarrow ZZ^*$ with $M_{\mathrm{Higgs}} = 140$ GeV. The other columns are for $t\bar{t}$ events with $M_{\mathrm{top}} = 150$ GeV. Some entries are 68% confidence limits based on no observed events.

p_t range	Radius	Z parent	W parent	b parent	c, d, u parent
$10 < p_t < 20$	0.2	0.98 ± 0.005	0.96 ± 0.01	0.27 ± 0.01	0.034 ± 0.004
	0.3	0.95 ± 0.007	0.88 ± 0.01	0.11 ± 0.008	0.010 ± 0.002
	0.4	0.90 ± 0.01	0.79 ± 0.01	0.046 ± 0.005	0.005 ± 0.002
$20 < p_t < 30$	0.2	0.98 ± 0.003	0.94 ± 0.01	0.13 ± 0.01	0.015 ± 0.004
	0.3	0.96 ± 0.01	0.88 ± 0.01	0.045 ± 0.007	0.004 ± 0.002
	0.4	0.89 ± 0.01	0.79 ± 0.01	0.015 ± 0.004	0.001 ± 0.001
$30 < p_t < 50$	0.2	0.98 ± 0.003	0.94 ± 0.01	0.047 ± 0.008	0.013 ± 0.004
	0.3	0.93 ± 0.005	0.89 ± 0.01	0.012 ± 0.004	0.006 ± 0.003
	0.4	0.87 ± 0.01	0.79 ± 0.01	0.005 ± 0.003	0.002 ± 0.002
$50 < p_t < 150$	0.2	0.96 ± 0.004	0.95 ± 0.005	0.006 ± 0.003	0.001 ± 0.001
	0.3	0.89 ± 0.01	0.87 ± 0.01	0.002 ± 0.002	< 0.001
	0.4	0.81 ± 0.01	0.77 ± 0.01	< 0.002	< 0.001

Acceptance of Leptons

Detect 4 leptons

Issues are leptons with smallest p_t and largest η

Figure shows faction of events with 2 (4) leptons having $p_t \geq p_0$.

2 (4) lepton figure is relevant for trigger (analysis) Curves for Higgs mass M=120 (solid), 140 (dotted) and 160 (dashed), and η coverage to 1.5, 2.0, 2.5, and 3.0 (biggest rapidity coverage has largest acceptance)

SDC requires 2 leptons above $p_t = 20$ GeV (for trigger) and all 4 leptons above $p_t = 10$ GeV and $|\eta| < 2.5$ for analysis.

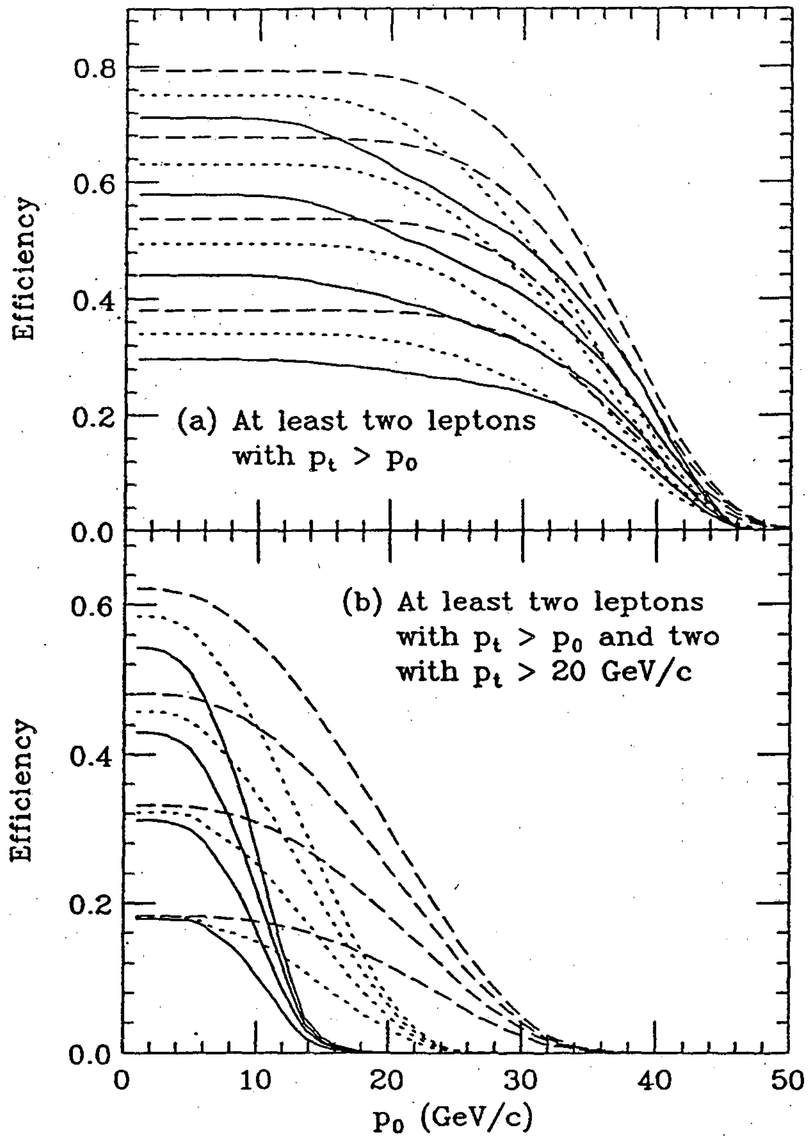


FIG. 3-15. Families of acceptance curves for $H \to ZZ^*$, for $M_{\text{Higgs}} = 120$ GeV (solid), 140 GeV (dotted), and 160 GeV (dashed). (a) The fraction of events with at least two leptons with $p_t > p_0$ as a function of p_0. Both leptons have $|\eta| < 1.5$ (lower curve), 2.0 (lower middle curve), 2.5 (upper middle curve), or 3.0 (upper curve). (b) The fraction of events containing two leptons with $p_t > 20$ GeV/c and $|\eta| < 2.5$ plus two others with $p_t > p_0$ and $|\eta| < 1.5$ (lower curve), 2.0 (lower middle curve), 2.5 (upper middle curve), or 3.0 (upper curve).

Backgrounds to 4ℓ modes

- Background from ZZ (or ZZ^*) – independent of detector.

- Background from real leptons from quark decays $Z + t\bar{t}$, $Z + b\bar{b}$ and $t\bar{t}$).

- Background from fake leptons – detector dependent.

Require that one pair of leptons reconstructs to $M_Z \pm 5$ GeV.

Background from $Z + b\bar{b}$, $t\bar{t}$ *etc.* must be controlled by requiring isolated leptons. Probably OK at even 10^{34} luminosity.

Mass resolution

For mass of 140 GeV, 4μ resolution is 0.8 GeV.

Calorimeter resolution is 1.9 GeV in $4e$ channel.

Tracking resolution of $4e$ is worse than 4μ due to material in tracker.

GEANT simulation –

(figure on Next page)

Use calorimeter alone to measure electron energies in this analysis

Resulting signal and background.

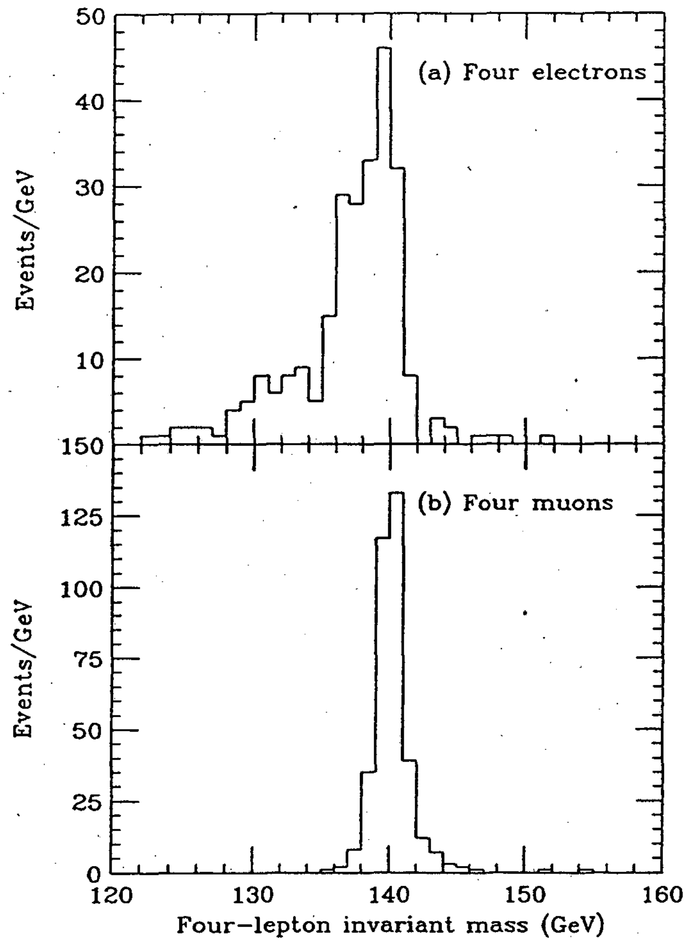


FIG. 3-17. The invariant mass reconstructed by the SDC tracking system for ZZ^* decaying to four leptons for a Higgs mass of 140 GeV. The plots contain events which have been passed through a detailed simulation of the tracking system, and contain the effects of material in the tracking volume, which severely degrades the performance for electrons due to the induced bremsstrahlung. (a) the mass distribution for the $4e$ final state. (b) the mass distribution for the 4μ final state.

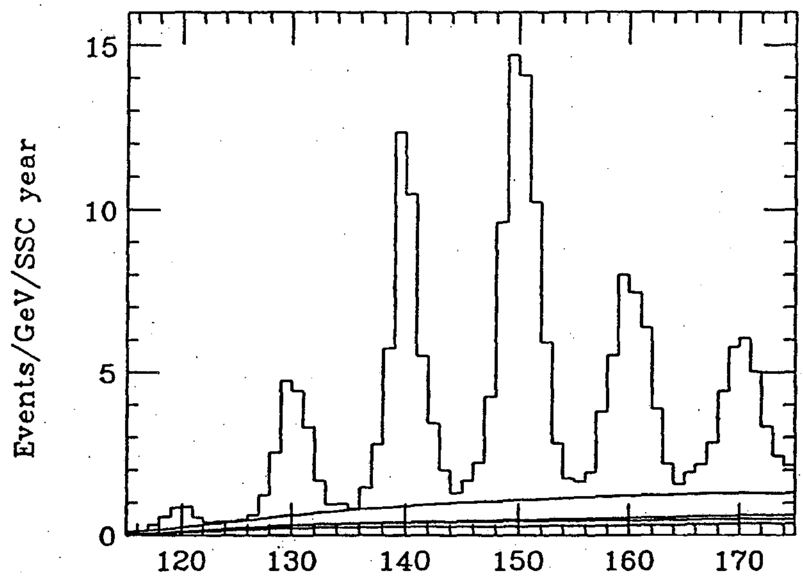


FIG. 3-18. The reconstructed Higgs mass for ZZ^* decaying to $4e$, 4μ, and $2e2\mu$ with $M_{\text{Higgs}} =$ 120, 130, 140, 150, 160, and 170 GeV, including the expected backgrounds. The backgrounds curves are cumulative, and are (from lowest to highest): $q\bar{q} \to ZZ^*$, multiplied by 1.65 to account for $gg \to ZZ^*$, $Z + b\bar{b}$, $Z + t\bar{t}$, and $t\bar{t}$. The invariant mass has been calculated using calorimeter measurements for the electrons.

Comments

- Becomes less useful at M_H falls because
  - Branching ratio is smaller
  - $< p_t >$ of leptons falls – loss of efficiency

- Signal/Background ratio improves dramatically at $m_H > 2M_Z$ since there are then two Z mass constraints.

Photon Pair Final state

o Background from $q\bar{q}$ (or gg) $\rightarrow \gamma\gamma$

– Need good resolution $\Delta E/E \lesssim 1\%$

– Need vertex to 5 mm

o Background from $jet-jet$, $jet-\gamma$

– $\sim 10^4$ rejection per jet needed

– Difficult to simulate; may be OK (LEP/CDF data)

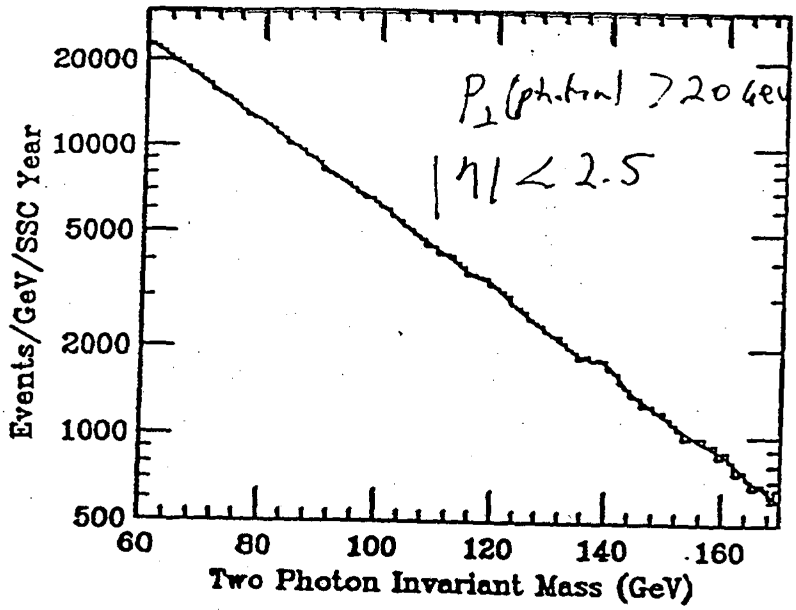
Plot shows signals at 80, 100,120,140,160 GeV. (plot)

Angular resolution assumed to be 1 mr.

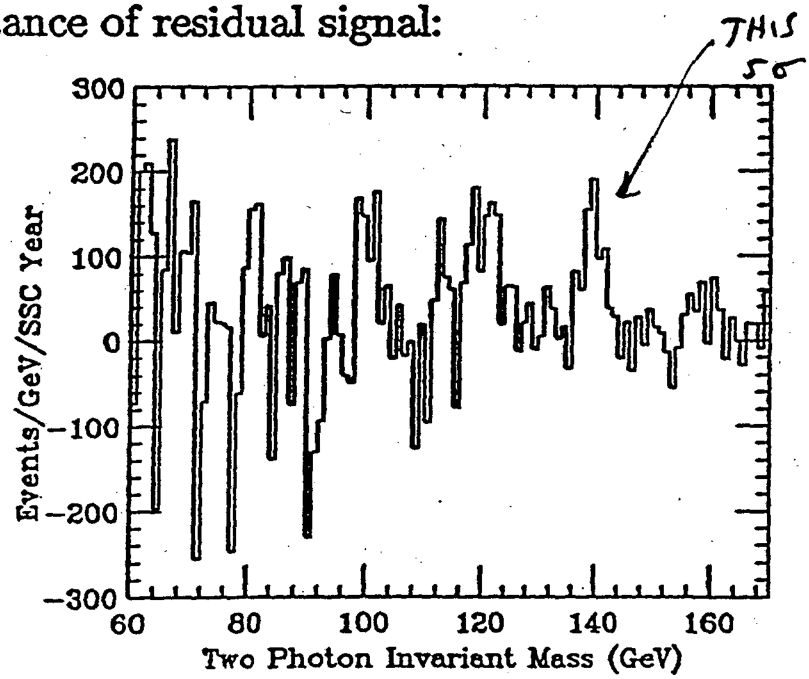
Fit to smooth background and subtract (plot)

Peak is 5σ at 140 GeV

Additional lepton reduces background



Subtract expected two photon background to study significance of residual signal:



Signal for $M = 140$ GeV has significance of 5σ, ignoring systematic errors arising from background subtraction. There are several hundred events in the peak.

$$H(\rightarrow \gamma\gamma) + W(\rightarrow \ell\nu))$$

From $q\bar{q} \rightarrow WH$ and $gg \rightarrow t\bar{t}H$ (fig)

Background less severe.

Lepton provides vertex so that angular resolution is straightforward

Backgrounds to $\gamma\gamma\ell$

Photons can be produced directly or radiated in decay of W,Z or t.

$W+\gamma, \quad W \rightarrow e\nu\gamma$

$W+\gamma+\gamma$

$Z+\gamma, \quad Z \rightarrow e\nu\gamma$

$t+\bar{t}+\gamma+\gamma, \quad t \rightarrow e+X$

$t+\bar{t}+\gamma, \quad t\bar{t} \rightarrow e+\gamma+X$

$t+\bar{t}, \quad t\bar{t} \rightarrow e+\gamma+\gamma+X$

$b+\bar{b}+\gamma+\gamma, \quad b \rightarrow e+X$

Cuts needed to reduce the backgrounds.

$M_{\ell\gamma} > 40 GeV$ reduces $W \rightarrow \ell\nu\gamma$

Leptons and photons isolated

Tracking inefficiency

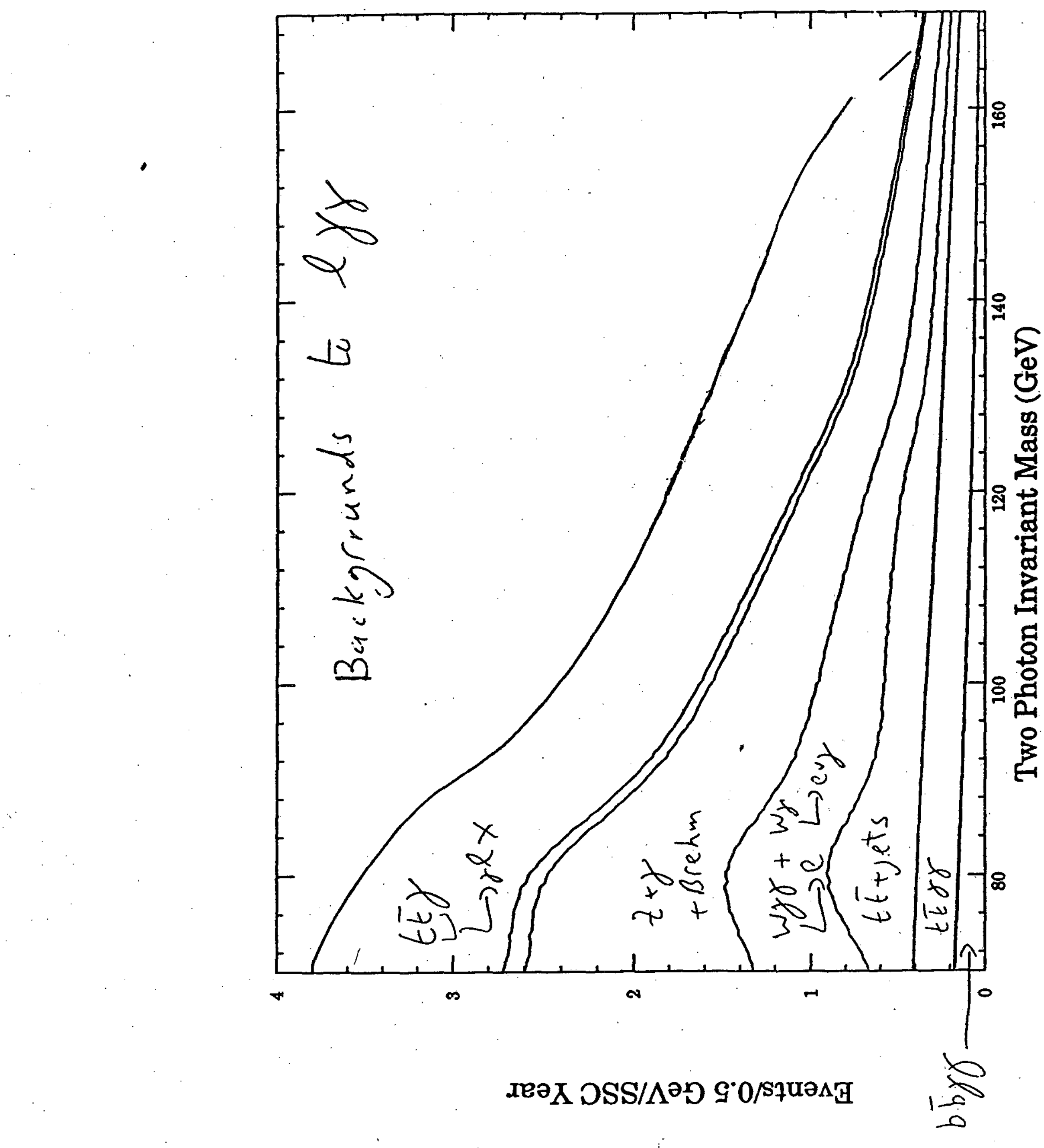
e looks like γ. Main problem is $Z \rightarrow e\bar{e}$ looking like $e\gamma$. Estimate 0.1% probability. Small rate and peak is at M_Z.

External Bremsstrahlung

CDF says that external and internal bremsstrahlung for Z and W decays are roughly equal. Scale to the 13% radiation length of SDC, external is 5 times internal. Lepton remaining after bremsstrahlung must go undetected, *i.e.* have $p_t < 1$ GeV or $|\eta| > 2.5$. Hence external brem. is 1.3 times internal brem. for Z decay (1.1 for W)

Jet/gamma fakes

Must consider all of the above backgrounds where a γ is replaced by a jet and the jet then fakes a γ.
$W \rightarrow jets$ will produce a peak around 80 GeV. Detector simulation+PYTHIA implies sigma of 6 GeV
Assume a jet/gamma rejection factor of 10^{-3} these background are negligible compared to real photons


Backgrounds to ℓγγ
Two Photon Invariant Mass (GeV)
Events/0.5 GeV/SSC Year
0
1
2
3
4
80
100
120
140
160

Signal

Require photons and lepton to satisfy $p_t > 20$ GeV and $|\eta| < 2.5$

Leptons and photons isolated (<10 GeV in $\Delta R = 0.3$), 93% (73%) efficient for $W + H$ ($t\bar{t} + H$) events

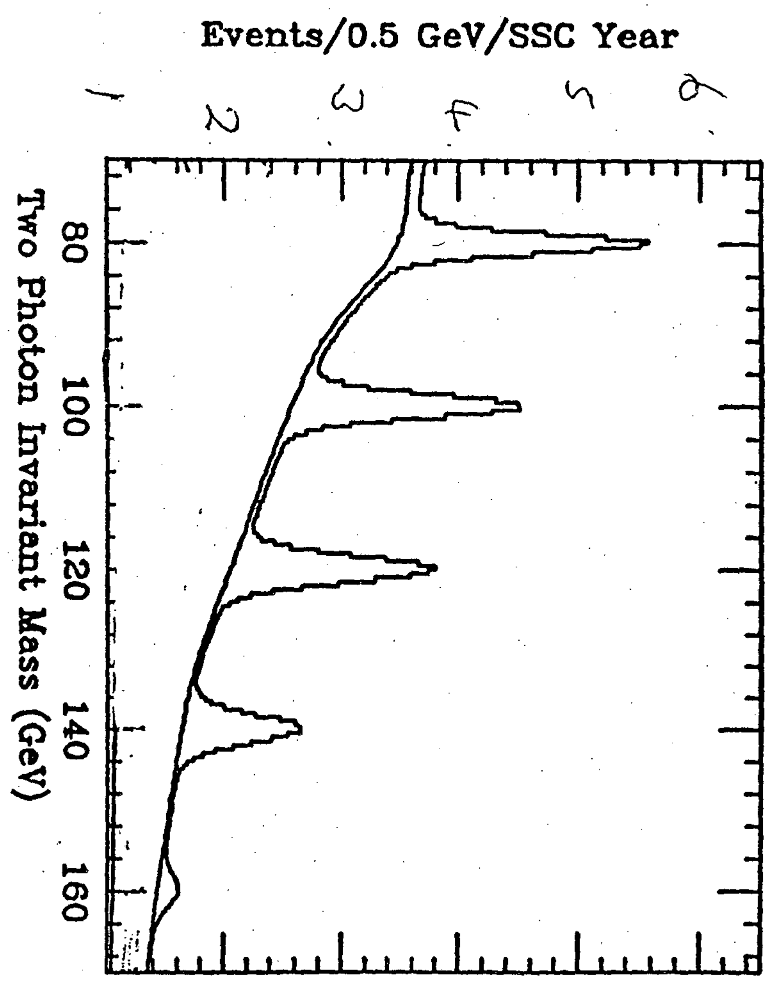
$M_{\ell\gamma} > 40$ GeV for both photons, 15% (25%) loss for $W + H$ $t\bar{t} + H$ events.

Signal/Background shown on figure

Note plot is for $M_{top} = 150 GeV$.

M_{top} between 100 and 200 gives same rate to ±15%

Background is 3 times bigger (smaller) for $M_{top} = 100$ (200) GeV


Events/0.5 GeV/SSC Year
Two Photon Invariant Mass (GeV)
80
100
120
140
160