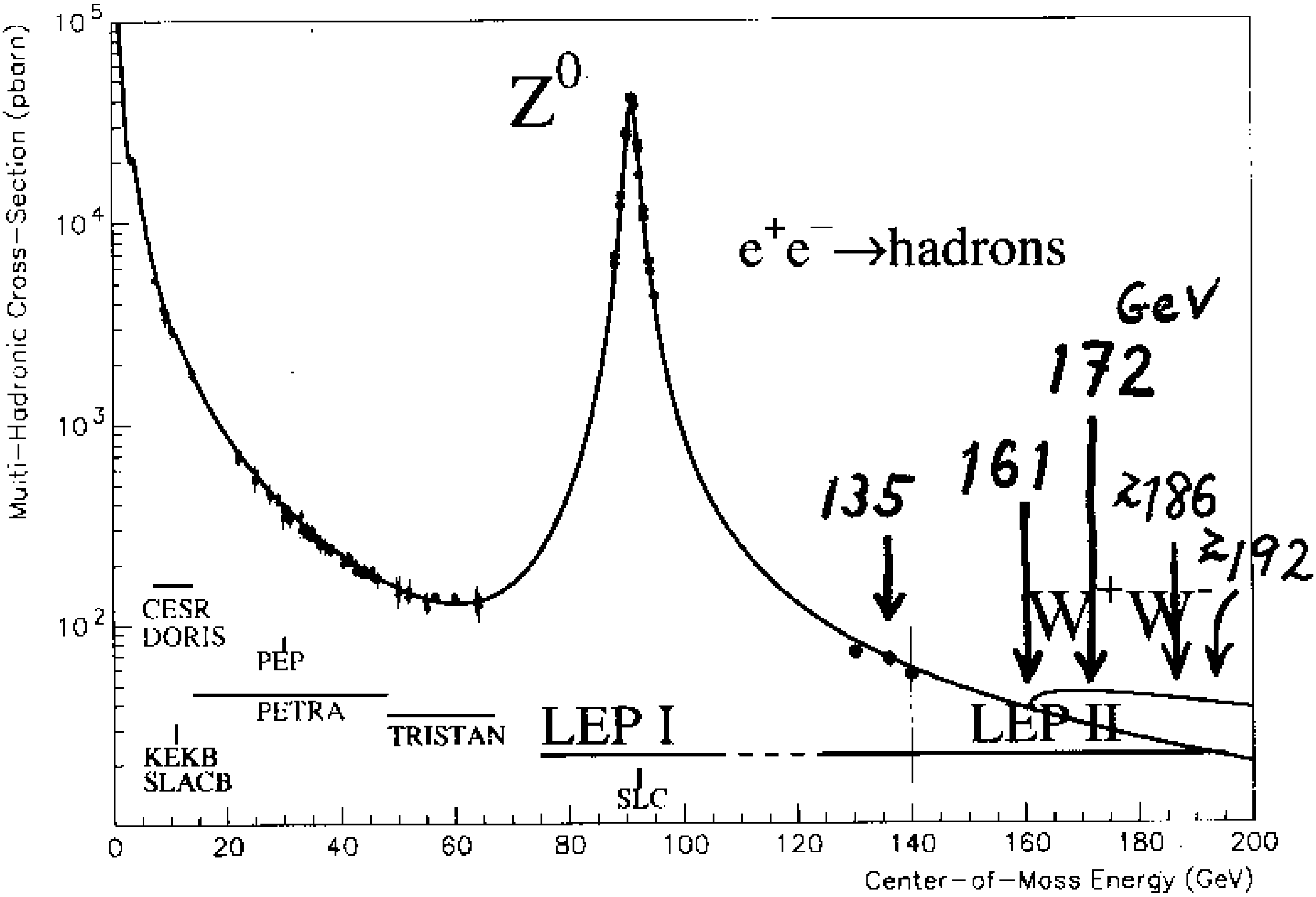
Dark Matter: Implications from LEP Experiments

T. Mori / Univ. Tokyo / OPAL

@ RESCEU Symposium 26-Nov-96

- Neutrinos ν
- SUSY DM
  - $\tilde{\nu}$
  - $\tilde{\chi}$
  - $\tilde{G}$
- Prospect

LEP2 RUNS



'95 130-140 GeV ~6 pb^{-1}/expt

"LEP1.5"

'96 161 GeV ~11 pb^{-1}/expt

first W^+W^-

172 GeV ~10 pb^{-1}/expt

ended last week

LEPC last week

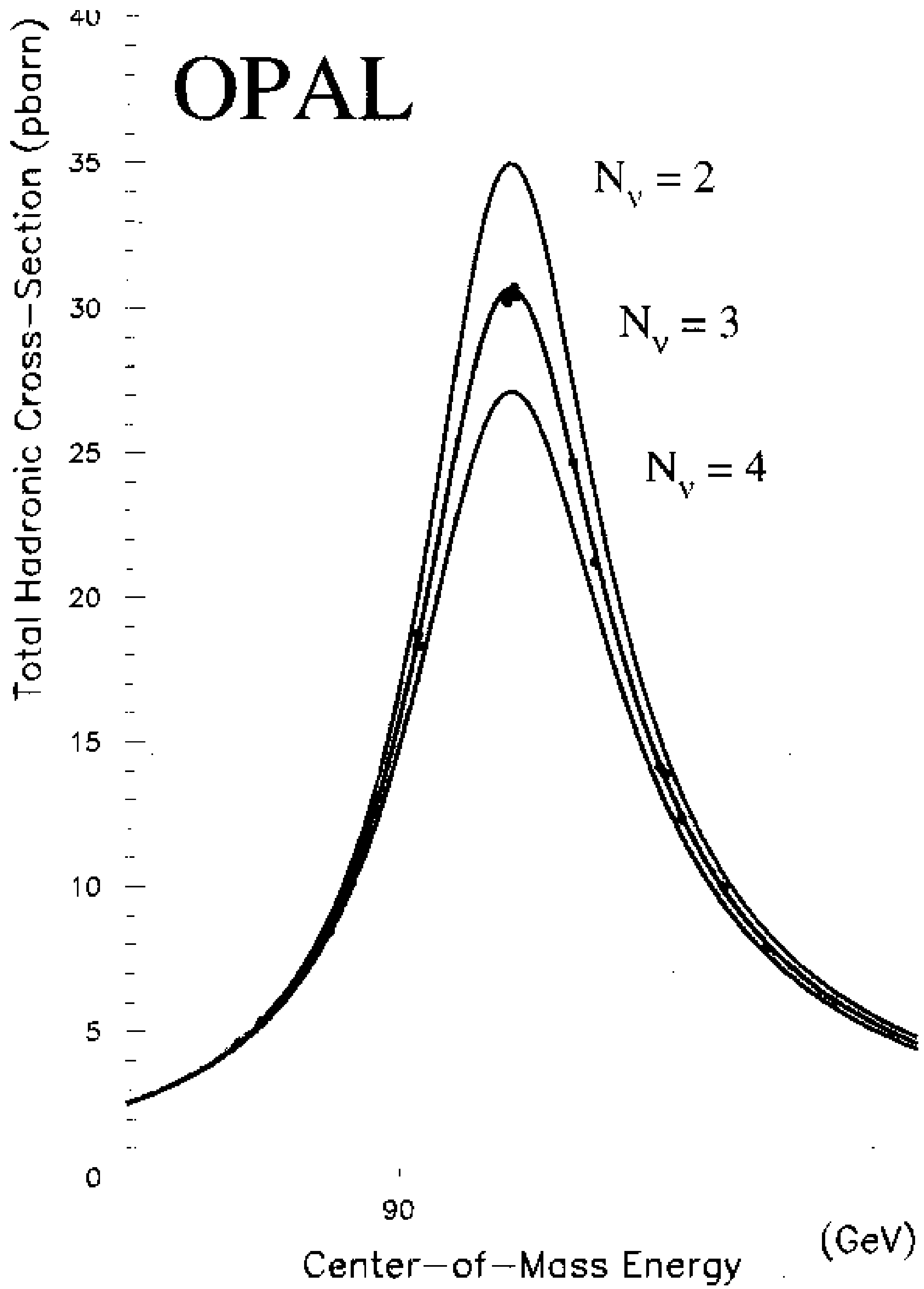
'97 186~188 GeV ~100 pb^{-1}/expt

(⊕ 161 GeV ?)

"enough for
| SUSY, Higgs
| 4jet peak

'98~ ≳ 192 GeV

$$\Gamma = \Gamma_{q\bar{q}} + \Gamma_{\ell^+\ell^-} + N_\nu \Gamma_\nu \qquad \sigma_{peak} \propto \frac{\Gamma_e \Gamma_f}{\Gamma^2}$$



$$N_\nu = 2.989 \pm 0.012$$

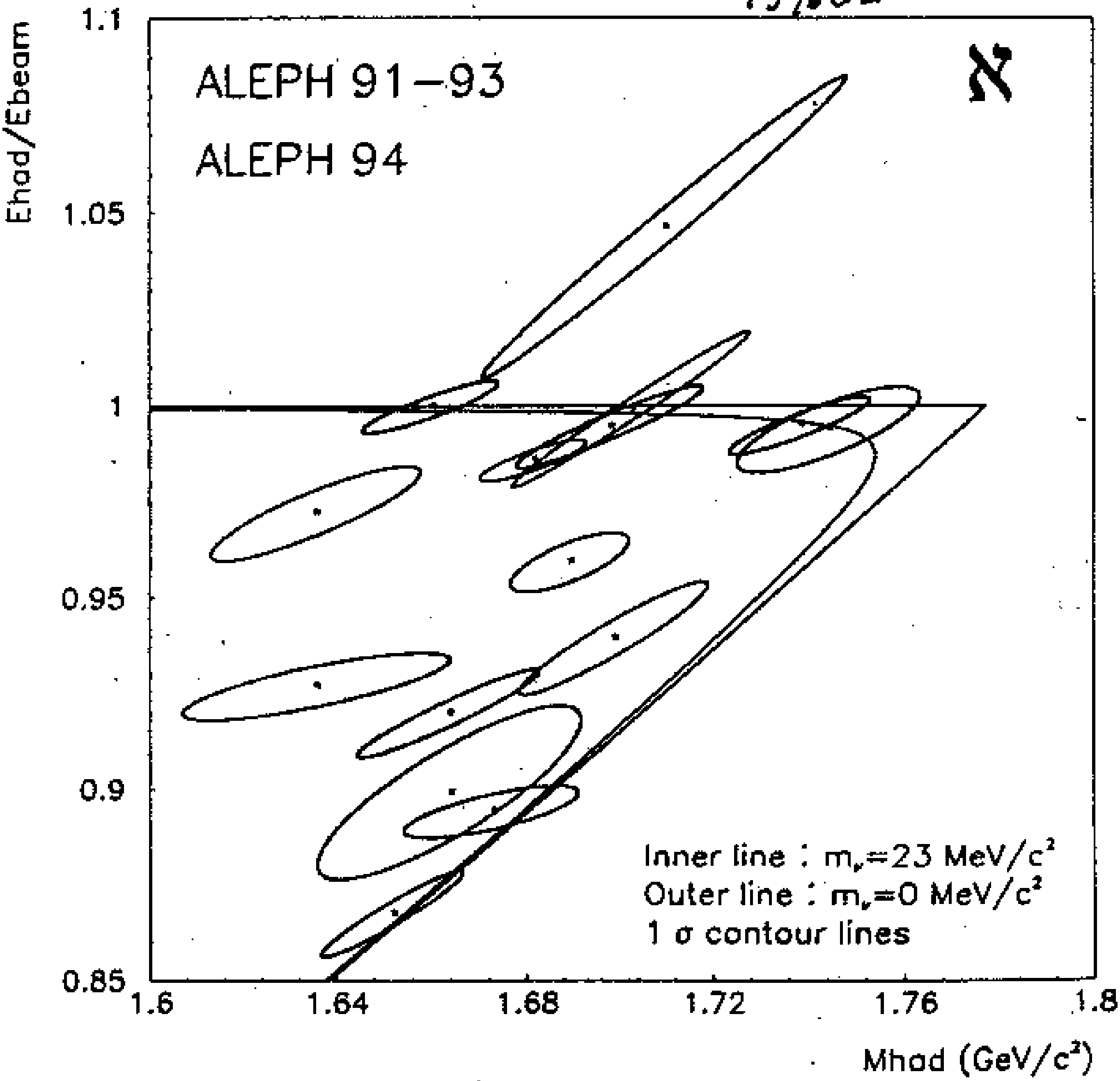
preliminary @ Warsaw '96

ν_τ Mass From LEP

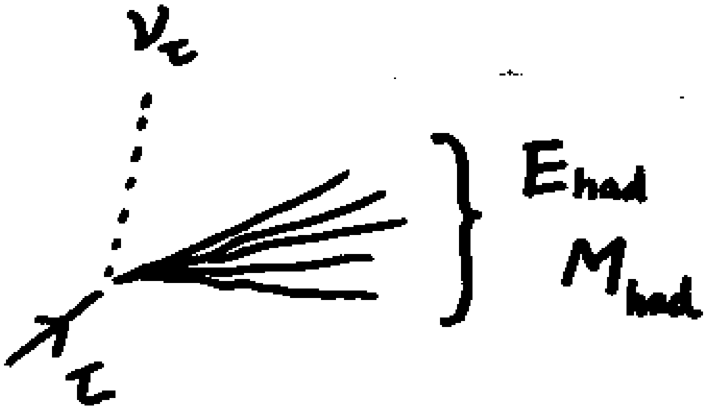
$M_{\nu_\tau} < 29.9$ MeV OPAL

< 23.1 MeV ALEPH

95% CL



3, 5-prongs



SUSY Dark Matter

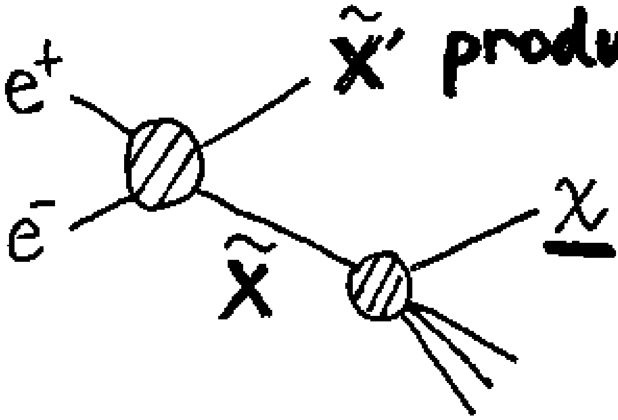
- Why SUSY?
- SUSY naturally predicts DM

  Lightest Neutralino χ ~ LSP

  R parity conservation

- Signatures of SUSY at LEP

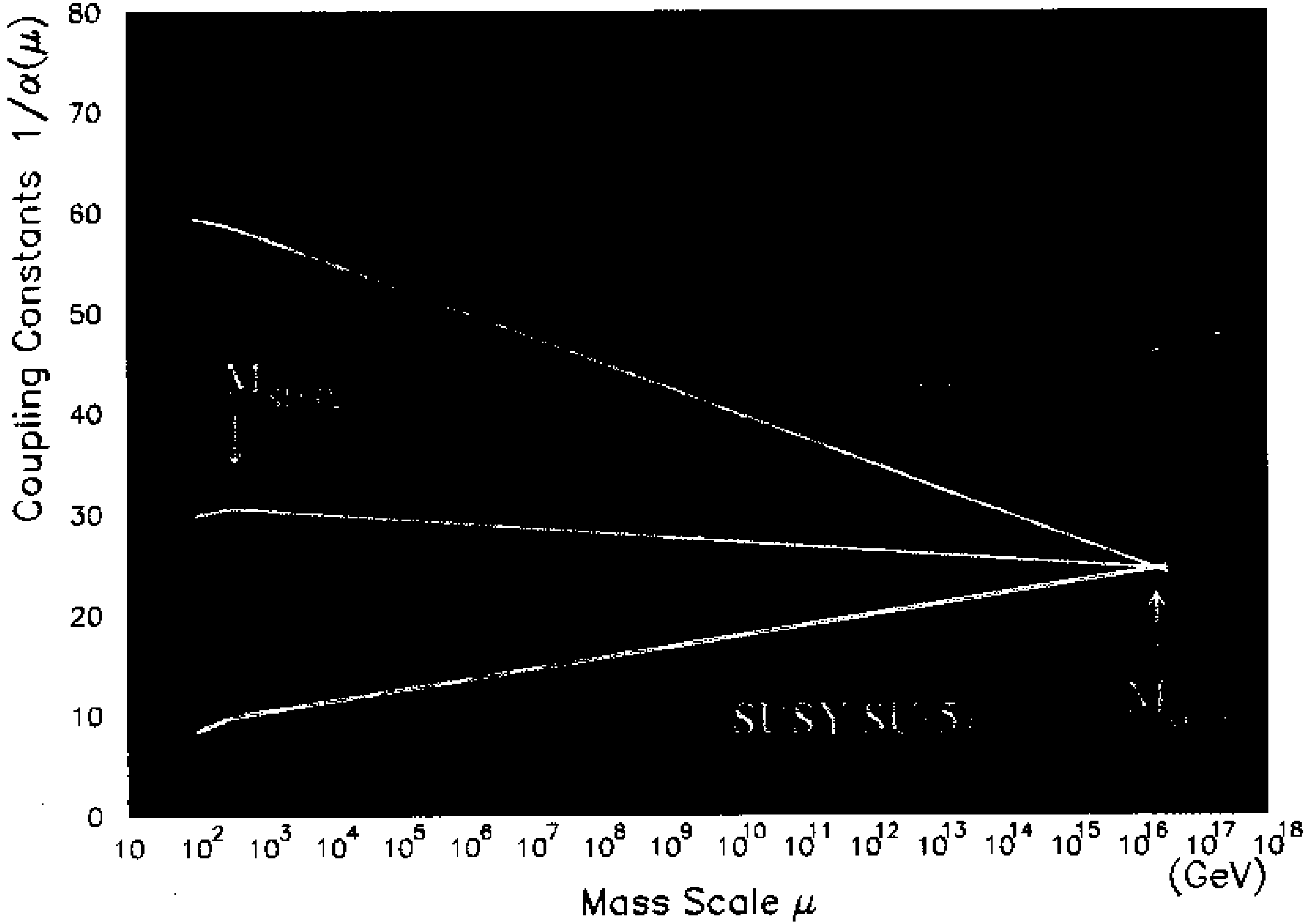
  - Z width $\Delta\Gamma$?
  - Direct Production



$\tilde{\chi}'$ produced in pairs

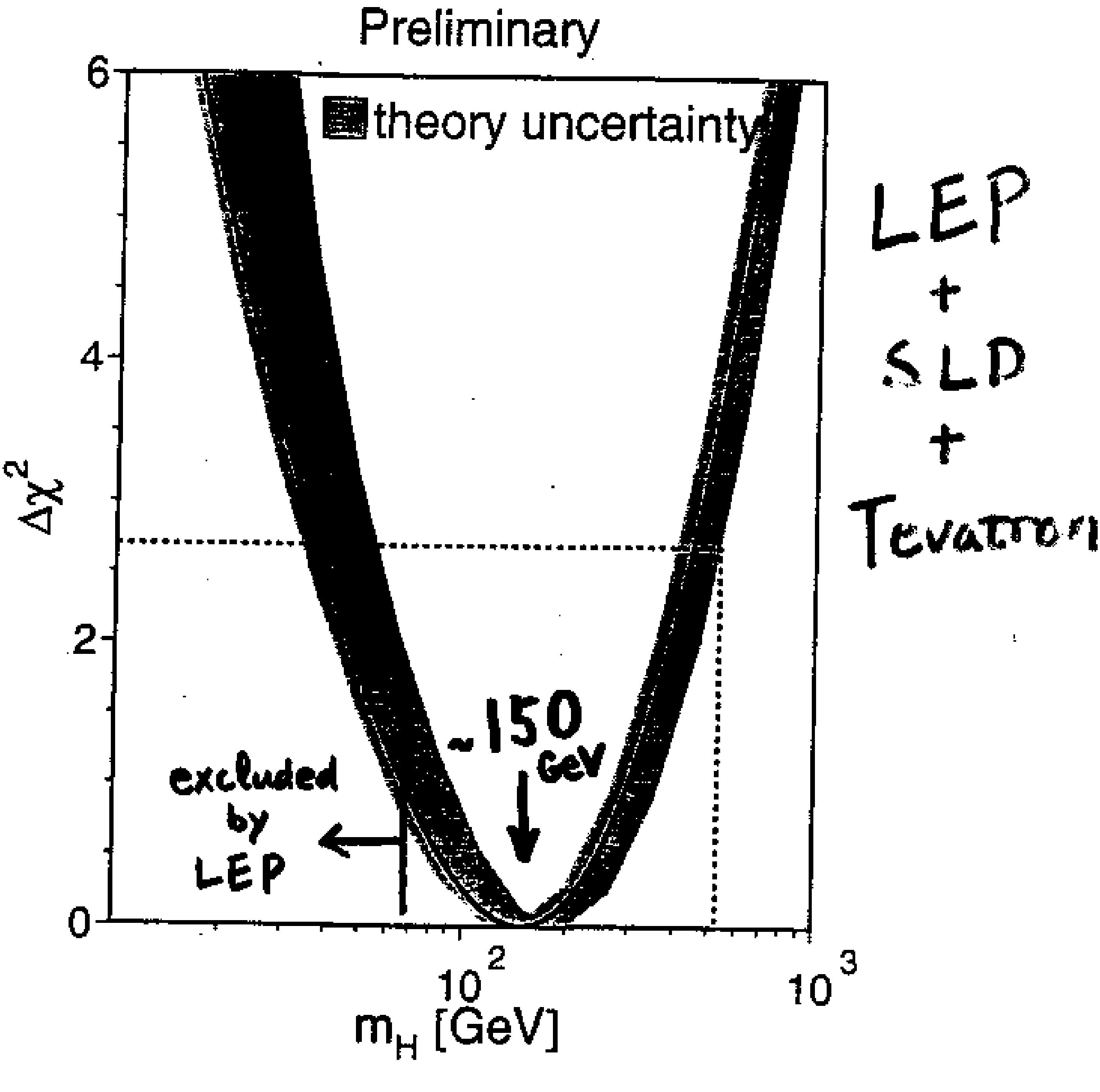
χ missing E

Kinematics depends on $\Delta m = M_{\tilde{\chi}'} - M_{\chi}$



Coupling Constants $1/\alpha(\mu)$
0
10
20
30
40
50
60
70
80
10
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
(GeV)
Mass Scale μ

m_H limit?



95% CL upper limit: **550 GeV.**

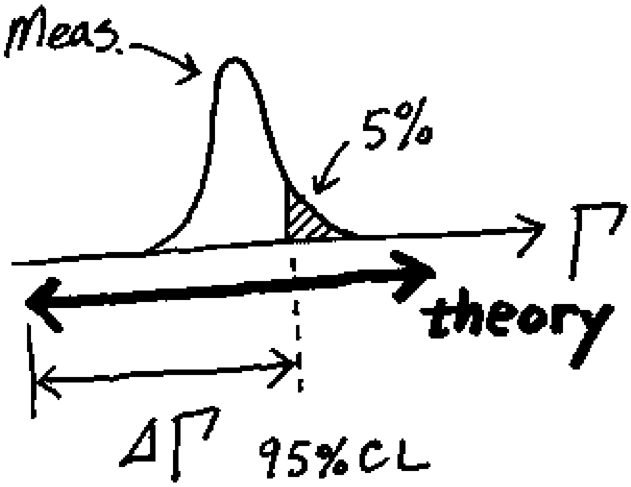
@ Warsaw '96

Z^0 width

$$\underbrace{\Gamma_Z = \Sigma \Gamma_{q\bar{q}} + \Sigma \Gamma_{\ell^+\ell^-}}_{\text{measured}} + \Gamma_{inv}$$

$$\begin{cases} \Gamma_Z = 2494.6 \pm 2.7 \text{ MeV} \\ \Gamma_{inv} = 499.5 \pm 2.0 \text{ MeV} \end{cases}$$

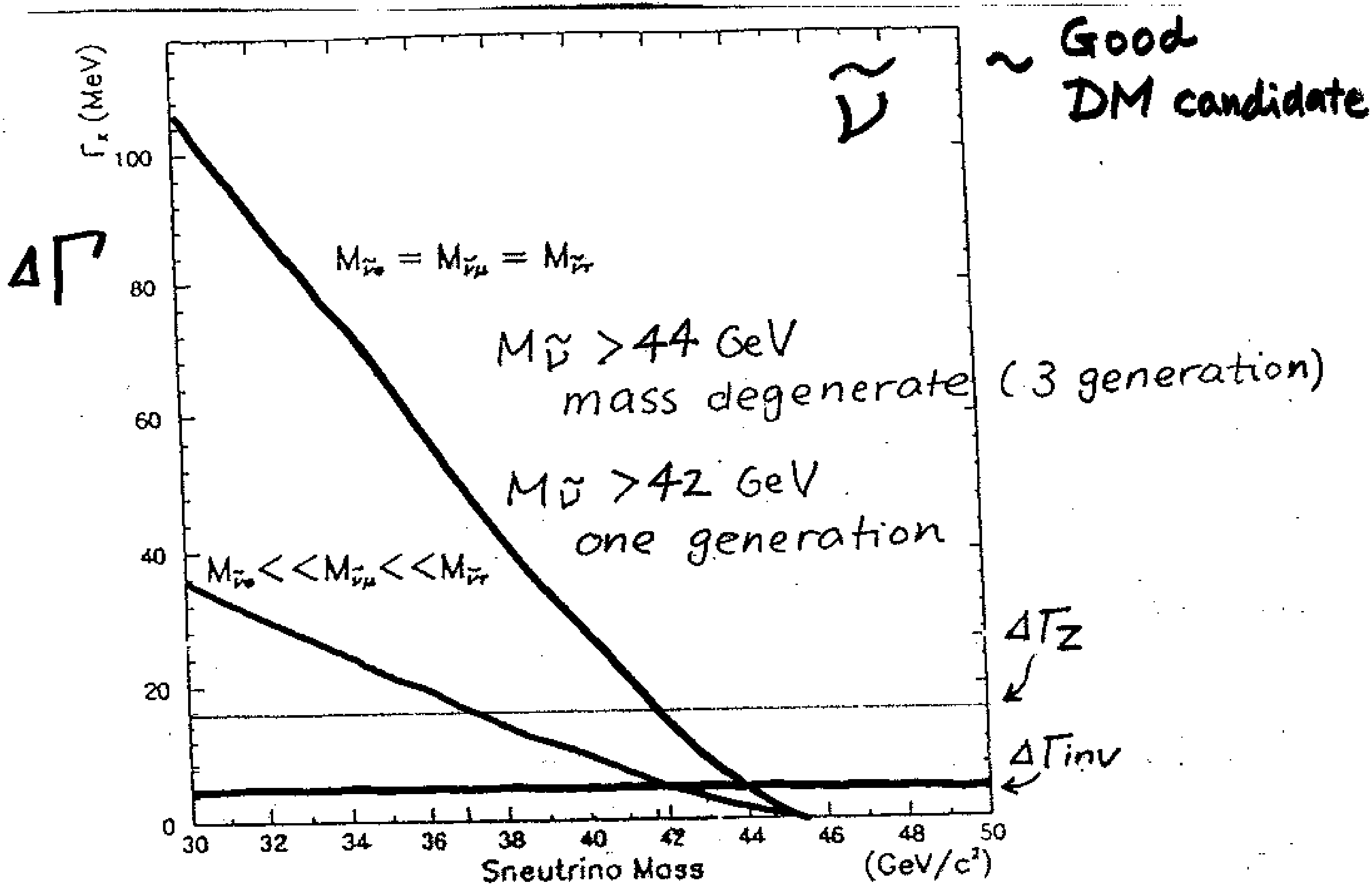
plenary @ Warsaw '96



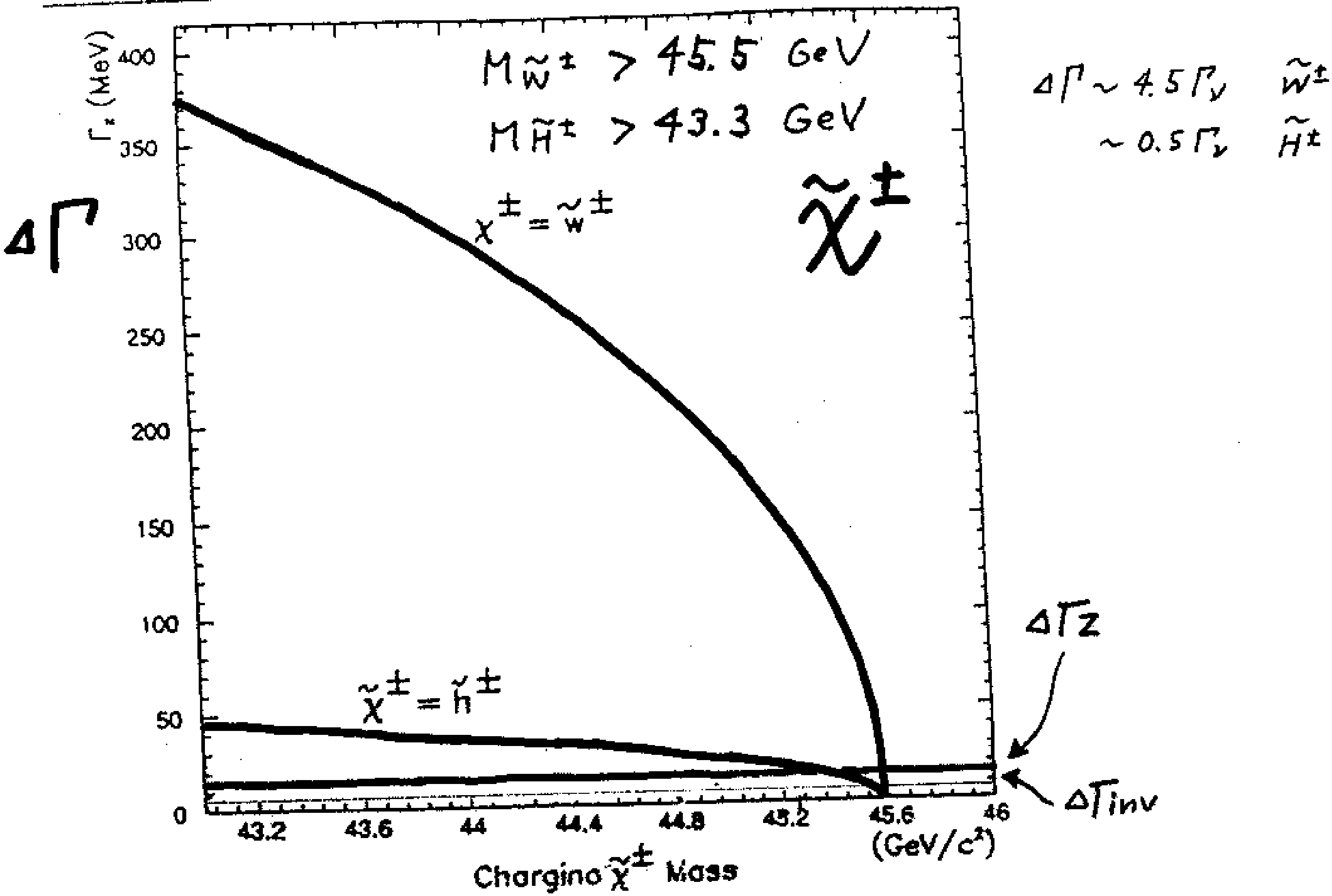
possible excess: $\Delta\Gamma$

$$\Delta\Gamma_Z \lesssim 16 \text{ MeV}$$

$$\Delta\Gamma_{INV} \lesssim 5.5 \text{ MeV}$$

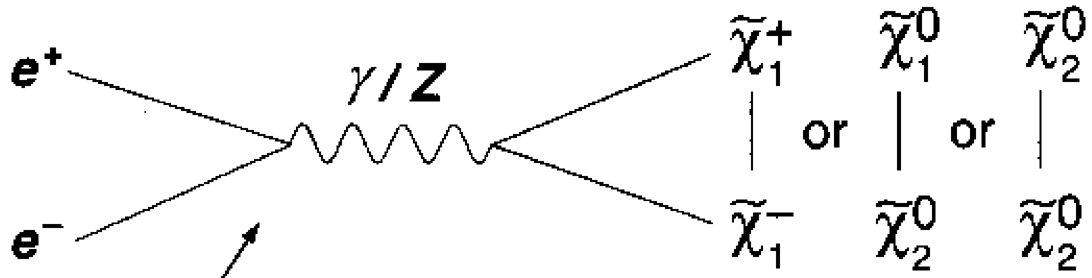


$\tilde{\nu}$ ~ Good DM candidate
$\Delta\Gamma$
Γ_Z (MeV)
$M_{\tilde{\nu}_e} = M_{\tilde{\nu}_\mu} = M_{\tilde{\nu}_\tau}$
$M_{\tilde{\nu}} > 44$ GeV
mass degenerate (3 generation)
$M_{\tilde{\nu}} > 42$ GeV
one generation
$M_{\tilde{\nu}_e} << M_{\tilde{\nu}_\mu} << M_{\tilde{\nu}_\tau}$
$\Delta\Gamma_Z$
$\Delta\Gamma_{inv}$
Sneutrino Mass
(GeV/c²)

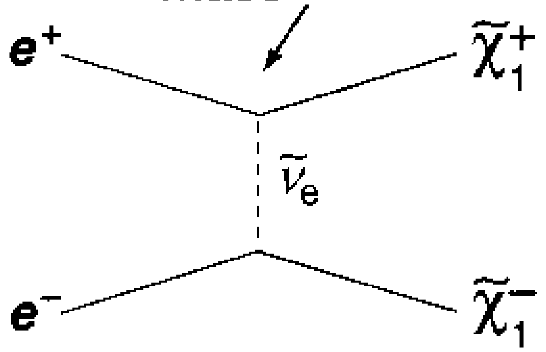


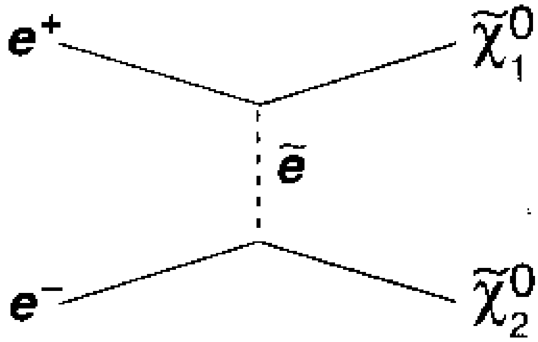
$\Delta\Gamma$
Γ_x (MeV)
400
350
300
250
200
150
100
50
0
$M_{\tilde{W}^\pm} > 45.5$ GeV
$M_{\tilde{H}^\pm} > 43.3$ GeV
$\tilde{\chi}^\pm$
$\chi^\pm = \tilde{w}^\pm$
$\tilde{\chi}^\pm = \tilde{h}^\pm$
$\Delta\Gamma_Z$
$\Delta\Gamma_{inv}$
43.2
43.6
44
44.4
44.8
45.2
45.6
46
(GeV/c²)
Chargino $\tilde{\chi}^\pm$ Mass
$\Delta\Gamma \sim 4.5\,\Gamma_\nu$ $\tilde{W}^\pm$
$\sim 0.5\,\Gamma_\nu$ $\tilde{H}^\pm$

Chargino/Neutralino Production



\+ Destructive interference, worse for small sneutrino mass



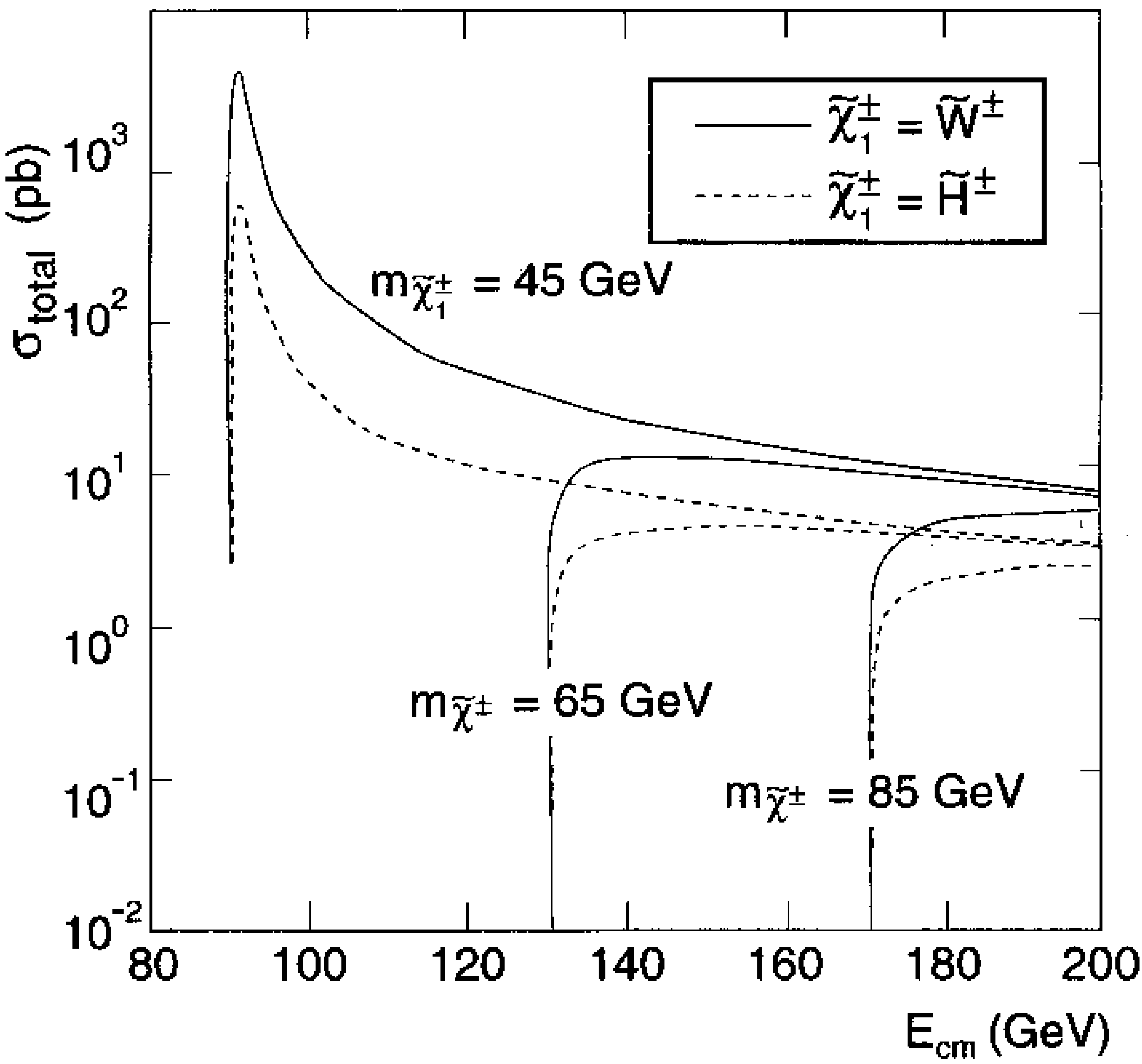


couplings and

e.g., $\sigma(e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^-) = f(m_{\tilde{\chi}}, \underline{m_{\tilde{\nu}_e}}, M, \mu, \tan\beta)$

phase space, kinematics

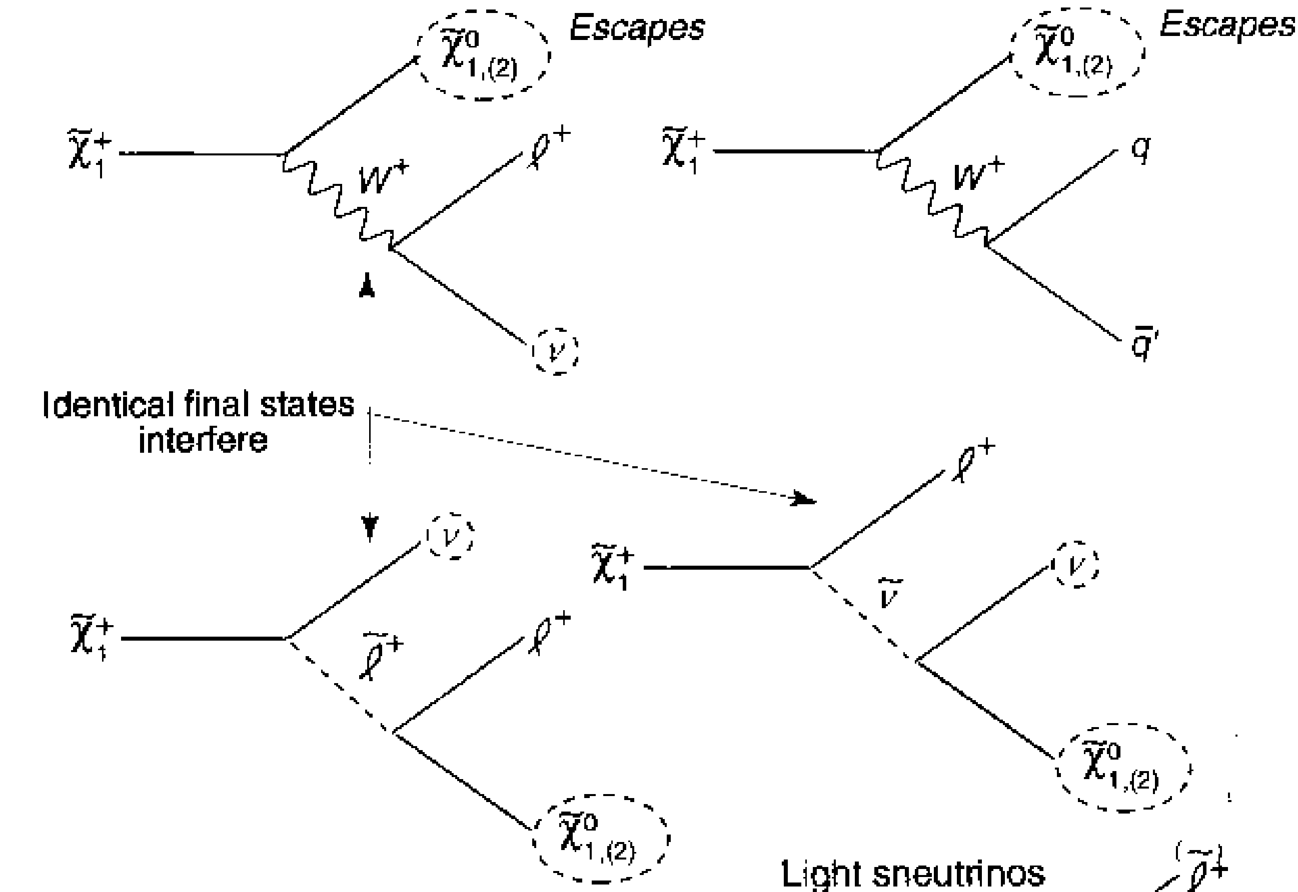
R.V.K.

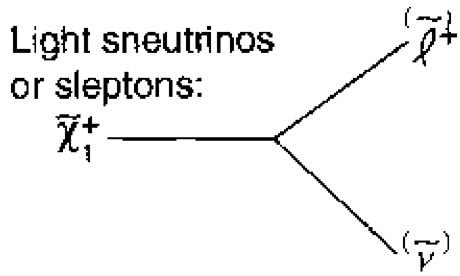


σ_{total} (pb)
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
80
100
120
140
160
180
200
E_{cm} (GeV)
$\tilde{\chi}_1^\pm = \tilde{W}^\pm$
$\tilde{\chi}_1^\pm = \tilde{H}^\pm$
$m_{\tilde{\chi}_1^\pm}$ = 45 GeV
$m_{\tilde{\chi}^\pm}$ = 65 GeV
$m_{\tilde{\chi}^\pm}$ = 85 GeV

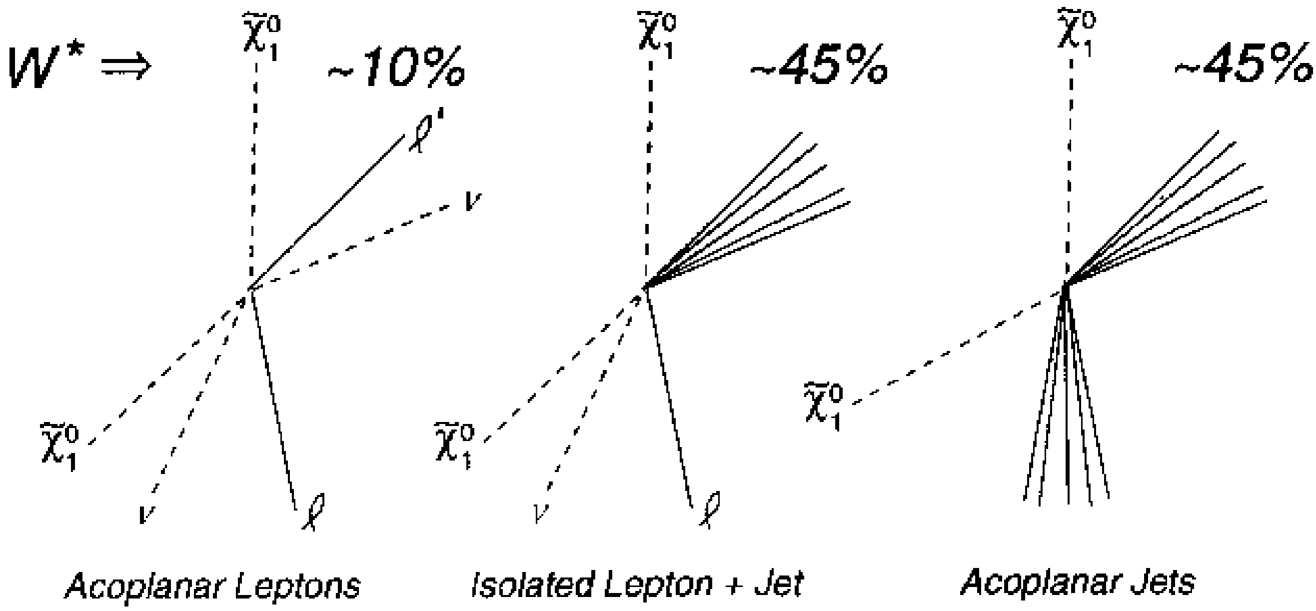
R.v.k.

Chargino Decay



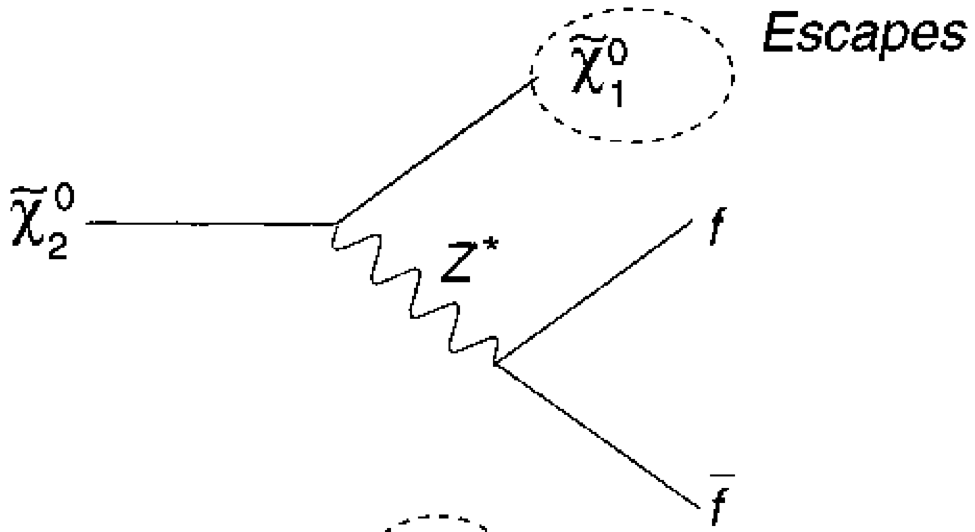


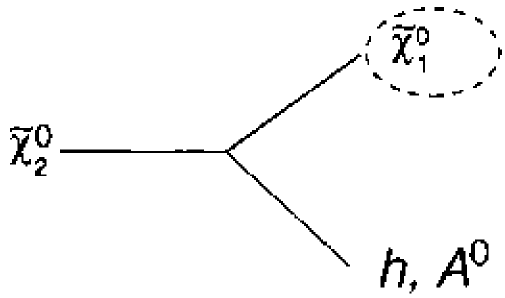
Topologies

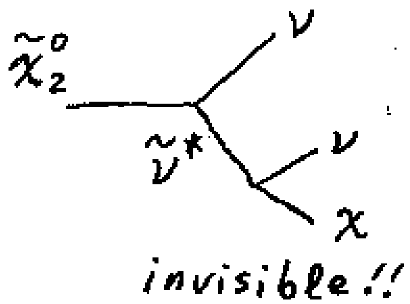


R.v.K.

Neutralino Decay







Topologies

$e^+e^- \rightarrow \tilde{\chi}_2^0\, \tilde{\chi}_1^0 \rightarrow \tilde{\chi}_1^0\, \tilde{\chi}_1^0\, f\bar{f} \qquad f = q, \ell, \nu$

Missing energy + Acoplanar leptons
Acoplanar jets
Monojets

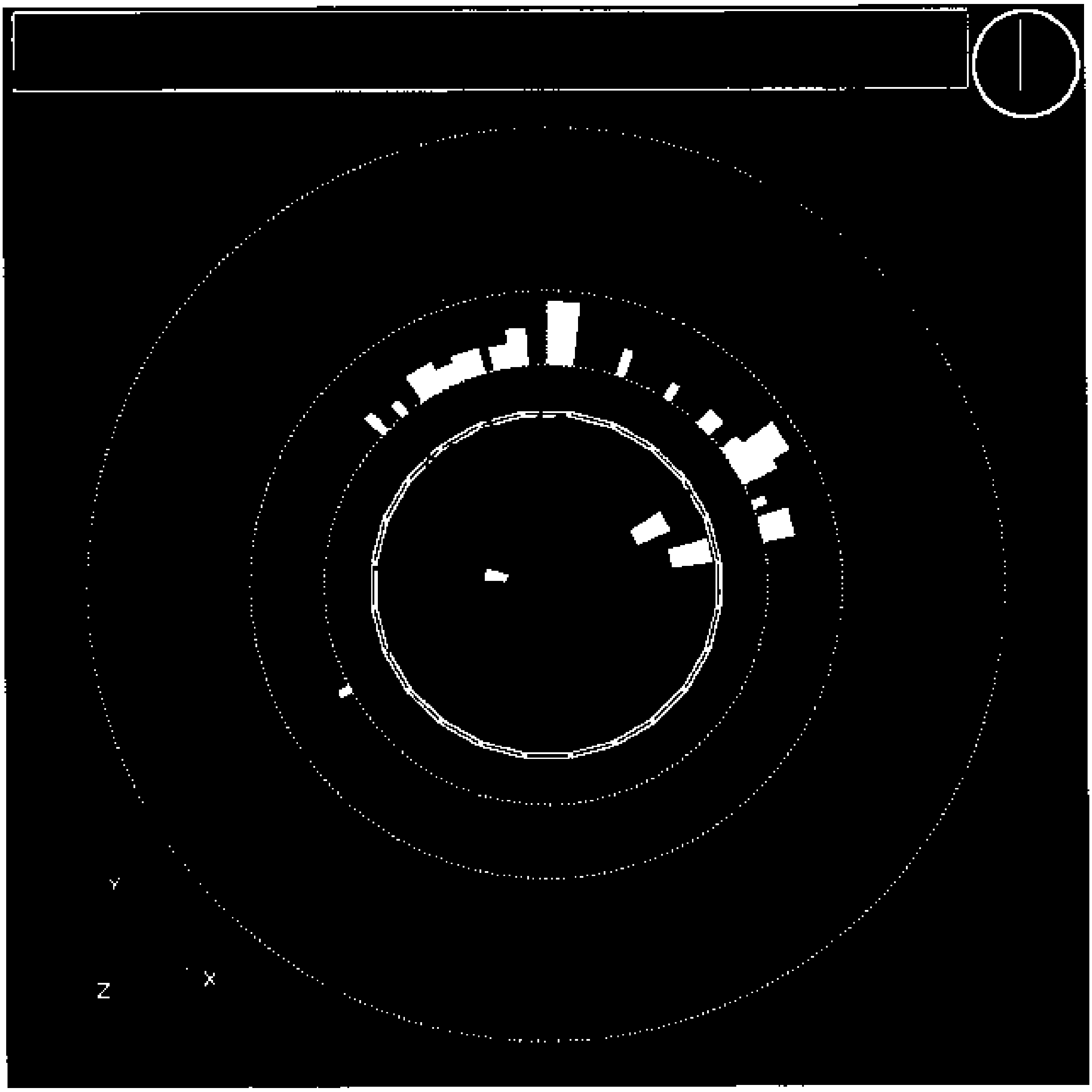
$e^+e^- \rightarrow \tilde{\chi}_2^0\, \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\, \tilde{\chi}_1^0\, f\bar{f}f'\bar{f}' \qquad f = q, \ell, \nu$

Add multiple isolated leptons
and acoplanar jets
Monojets

R.v.K.

$\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^0$ Candidate

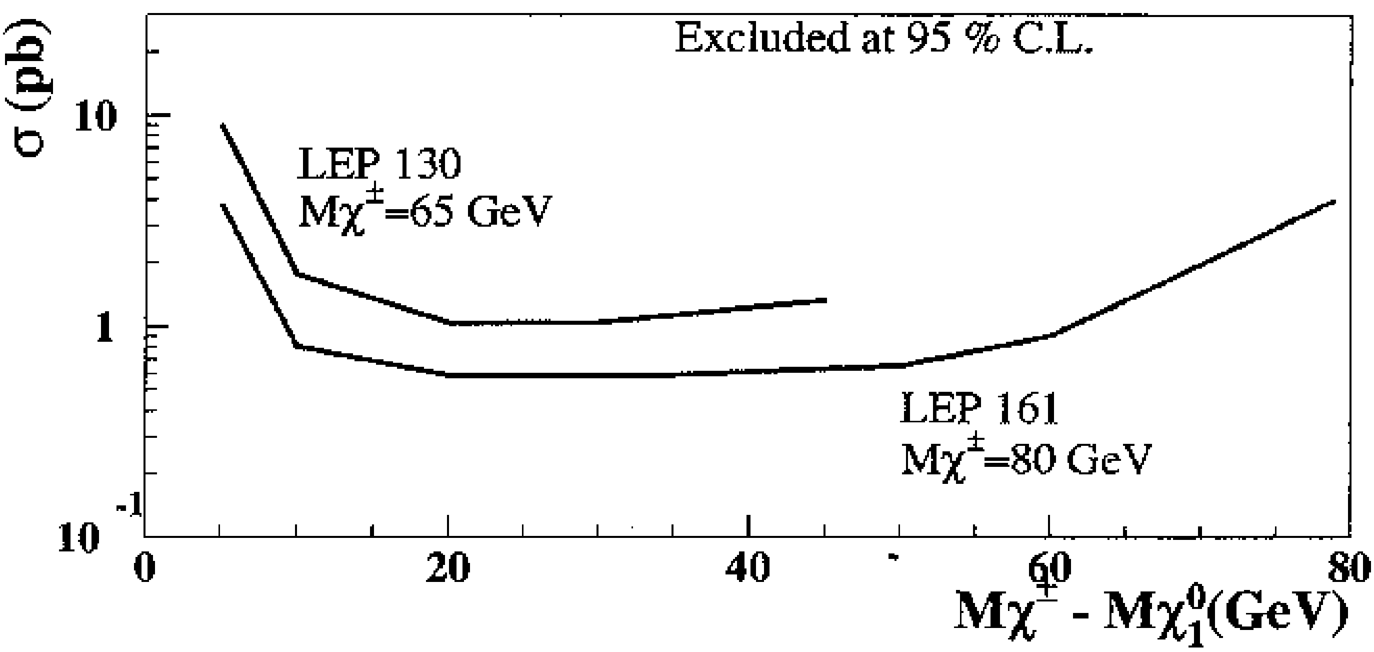
161 GeV

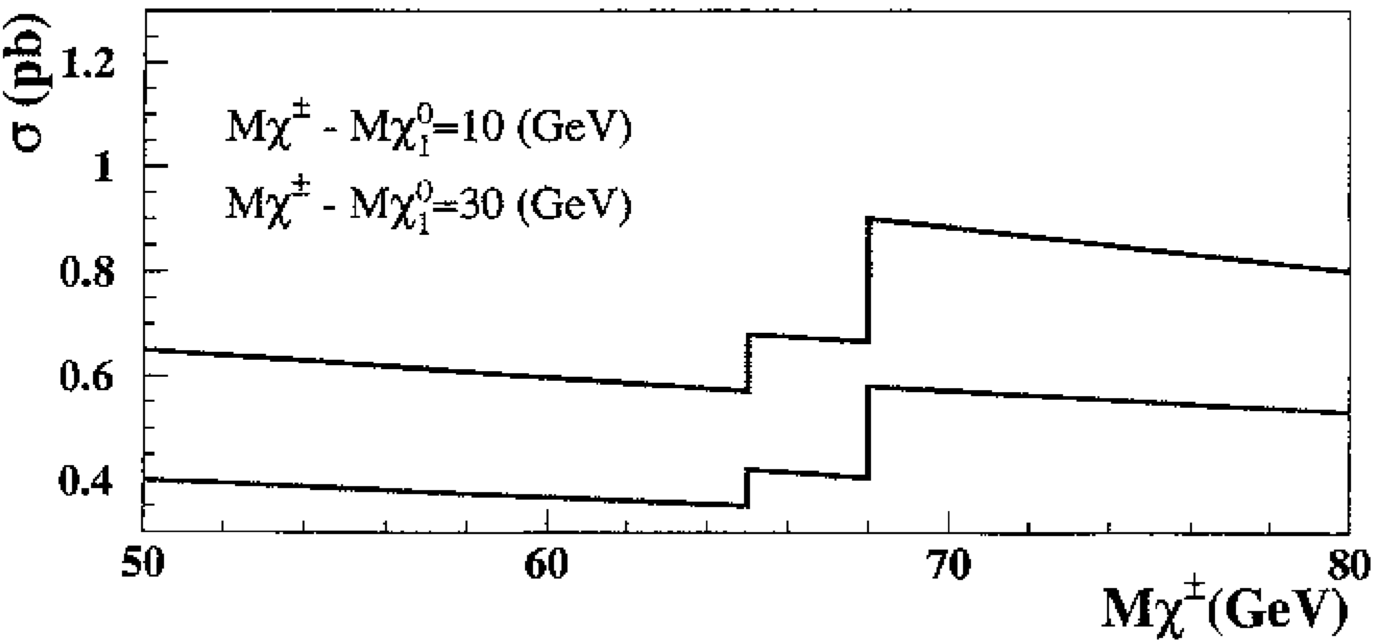


- Recoil mass $= 99$ GeV, visible energy $= 55$ GeV
- Missing transverse momentum $= 39$ GeV
- Also selected as: $\mathrm{L}^+\mathrm{L}^-$, $\tilde{\mathrm{t}} \to \mathrm{b}\ell^+\tilde{\nu}$, ...

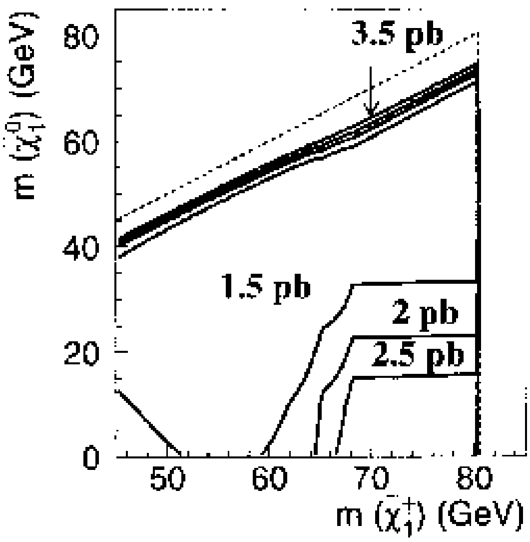
Upper Limit on Chargino Cross Section

L3

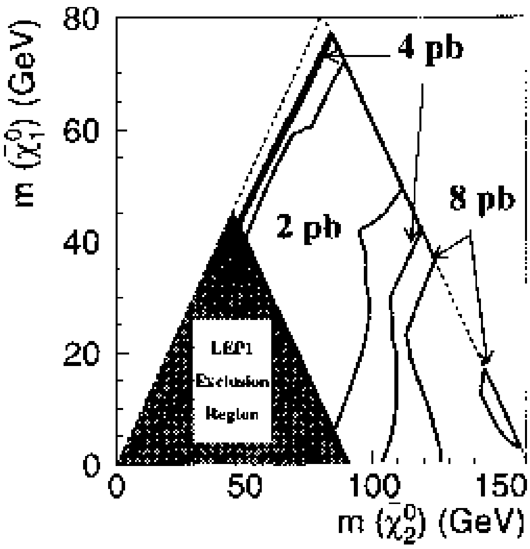




161GeV **Cross-section Limits** OPAL

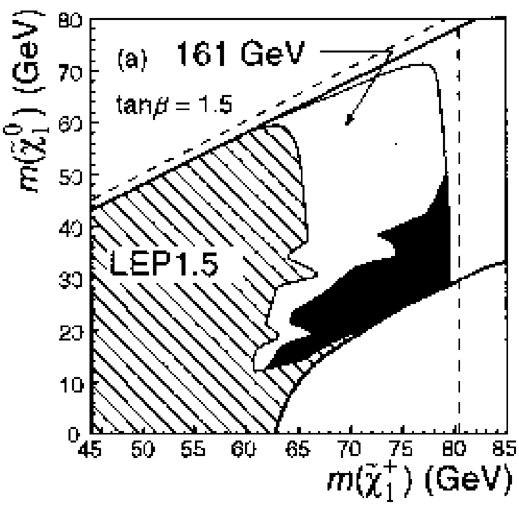


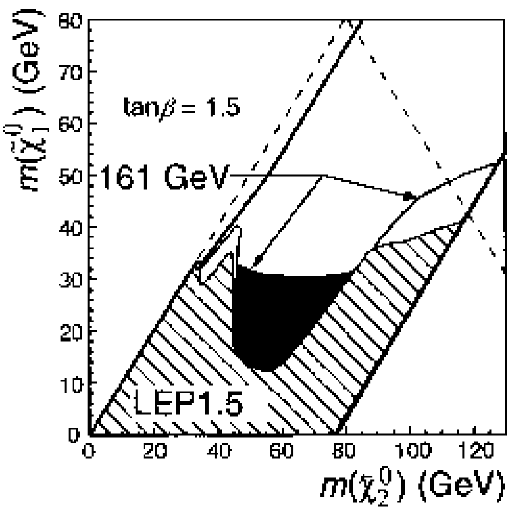
$\tilde\chi_1^\pm \to \tilde\chi_1^0 W^\pm$ 100%



$\tilde\chi_2^0 \to \tilde\chi_1^0 W^\pm$ 100%

MSSM Mass Limits





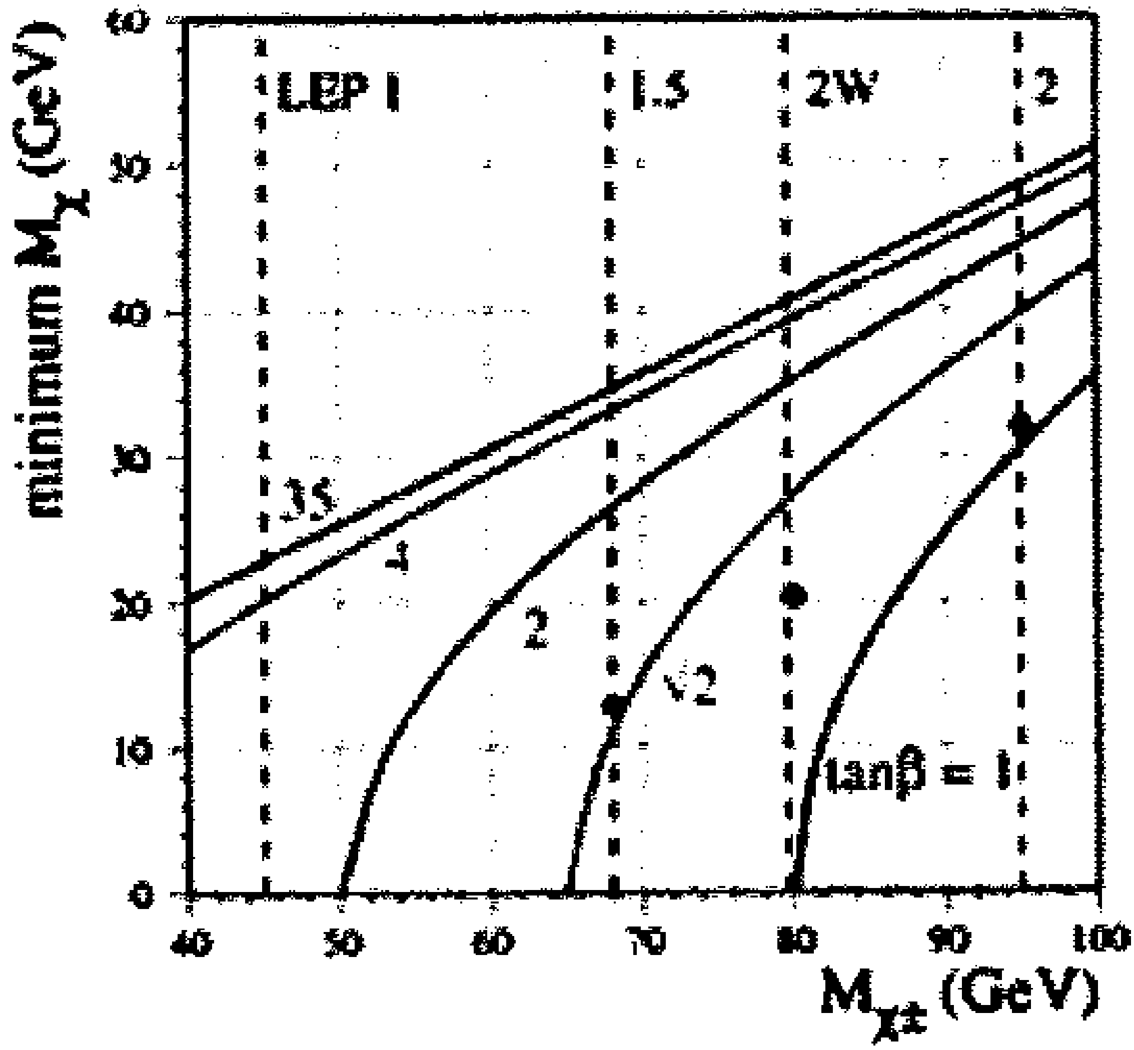
m($\tilde\chi_1^\pm$) > 78.5 GeV	$m_0 > 1$ TeV
m($\tilde\chi_1^\pm$) > 62.0 GeV	m_0 minimal

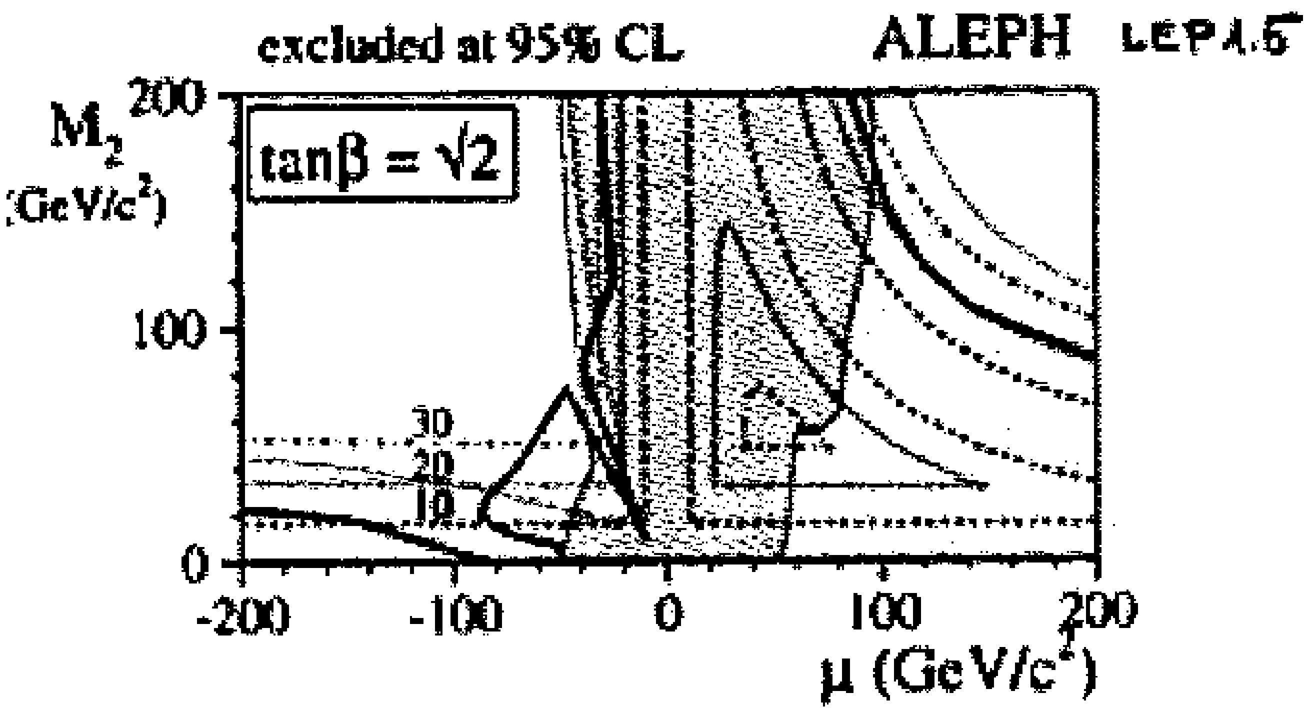
@ 95% c.l.

assuming $\Delta M > 10$ GeV, $\tan\beta = 1.5$

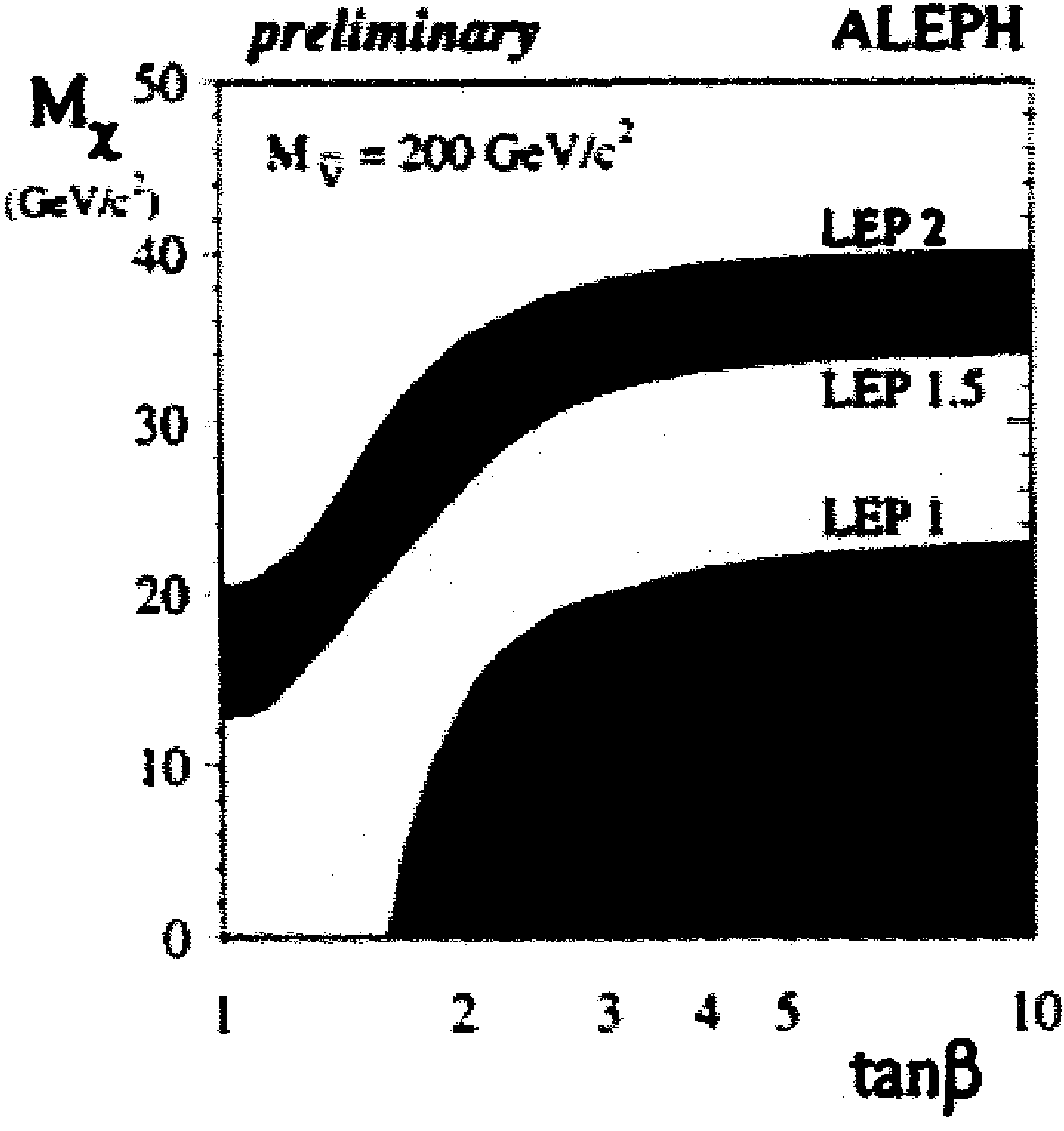
M. Schmitt

$\chi^{\pm}$ limits → χ^{0} limits





$M_\chi > 20.4\ \mathrm{GeV}/c^2$ at 95% CL



Oct 8, 1996

Combine all LEP expts

→ a new WG

172 GeV Physics Results

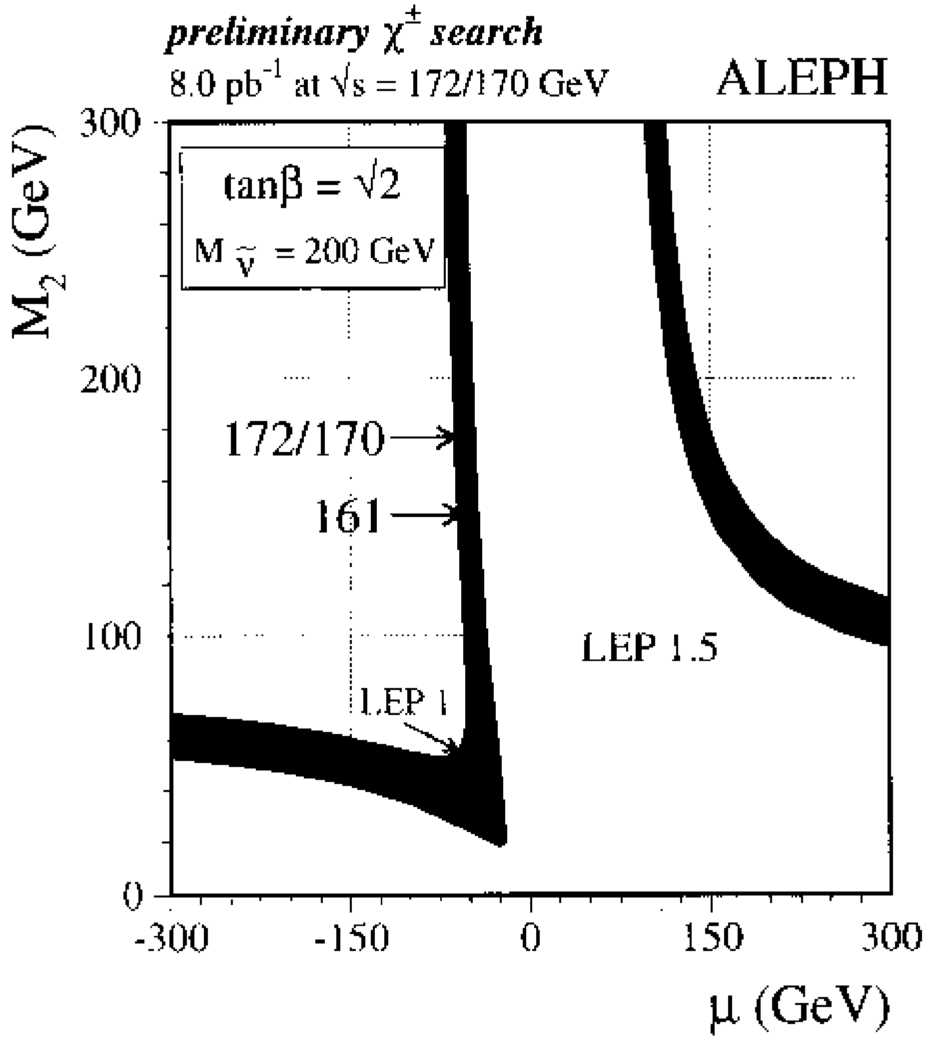
Chargino search:

- Run on 8 pb^{-1} at 170 and 172 GeV

NO CANDIDATES

→ Upper limit on cross sections ~ 0.6 pb
for "typical" ***ΔM = 20 - 60 GeV***

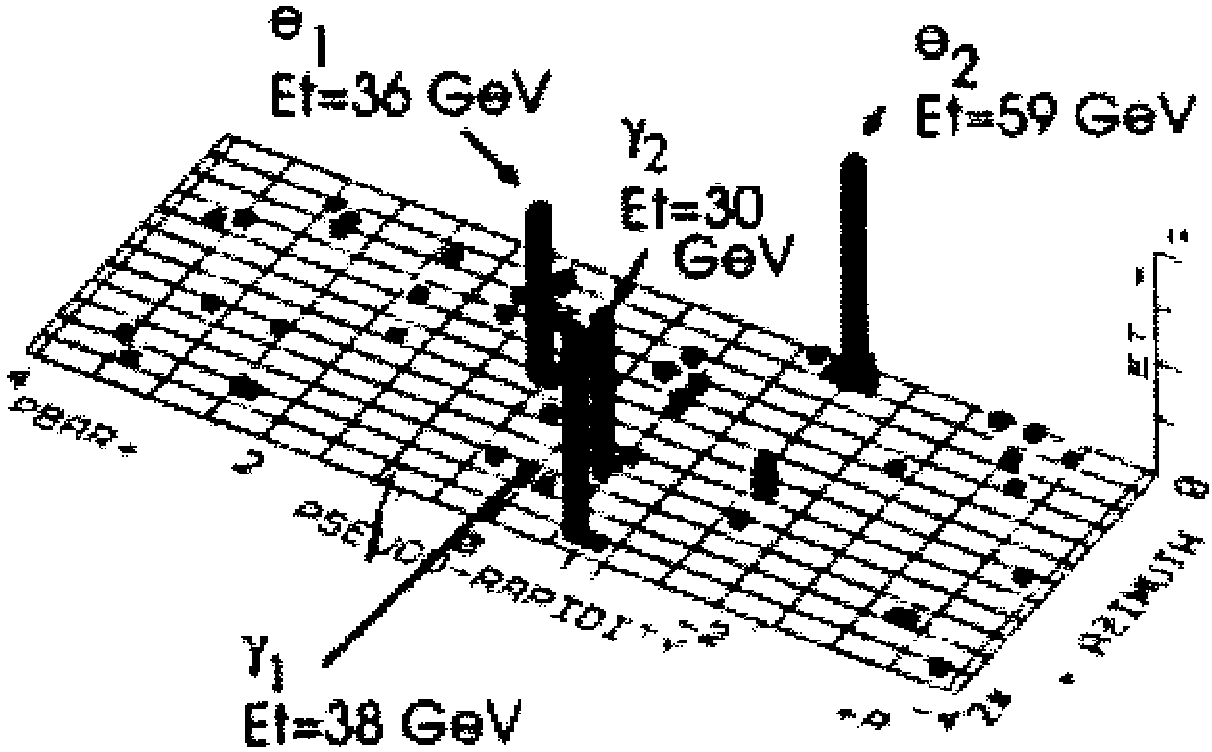
→ ***$M\chi^{\pm} \geq 84$ GeV/c^2 95% C.L.–M_ν > 200 GeV/c^2***



Light gravitino ($\tilde{G}$) ~ LSP

CDF Event

Event: $2\,e + 2\,\gamma + \not{E}_t$



$\not{E}_t$=53 GeV ~ NOT SHOWN

$$p\bar{p} \to \tilde{e}\tilde{e} \to e\chi e\chi \to ee\gamma\gamma\tilde{G}\tilde{G}$$

$$\chi^{+}\chi^{+} \to e\nu\chi e\nu\chi \to ee\gamma\gamma\nu\nu\tilde{G}\tilde{G}$$

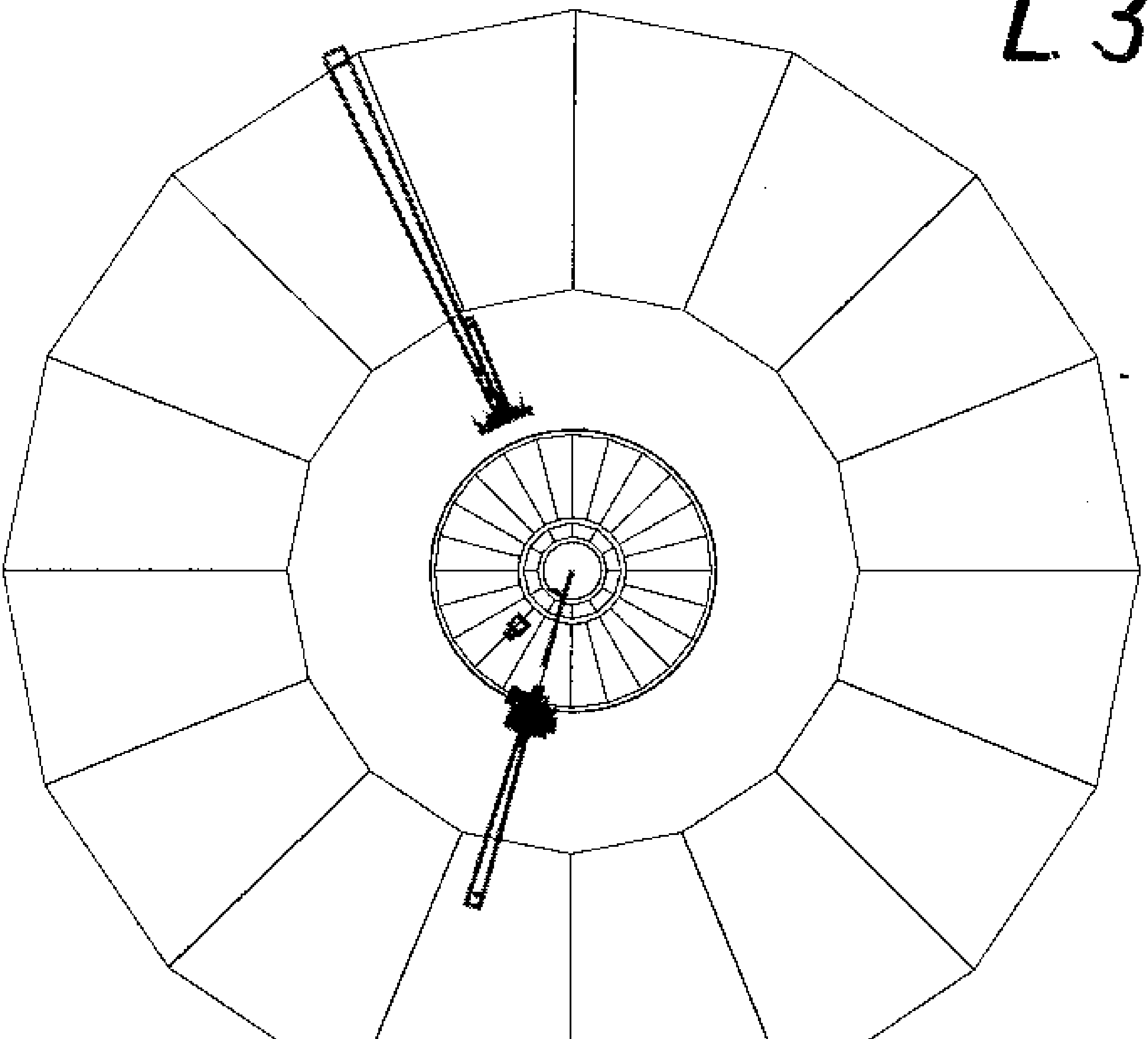
$e^+e^- \to \chi\chi \to \gamma\gamma\tilde{G}\tilde{G}$

Multiphoton Events with Missing Energy

Might be a sign of supersymmetry (neutralinos)

$E_{\gamma 1} = 36.2$**GeV**, $E_{\gamma 2} = 19.8$**GeV**

L3



161 GeV

$e^+e^- \rightarrow \nu\bar{\nu}\gamma(\gamma)$

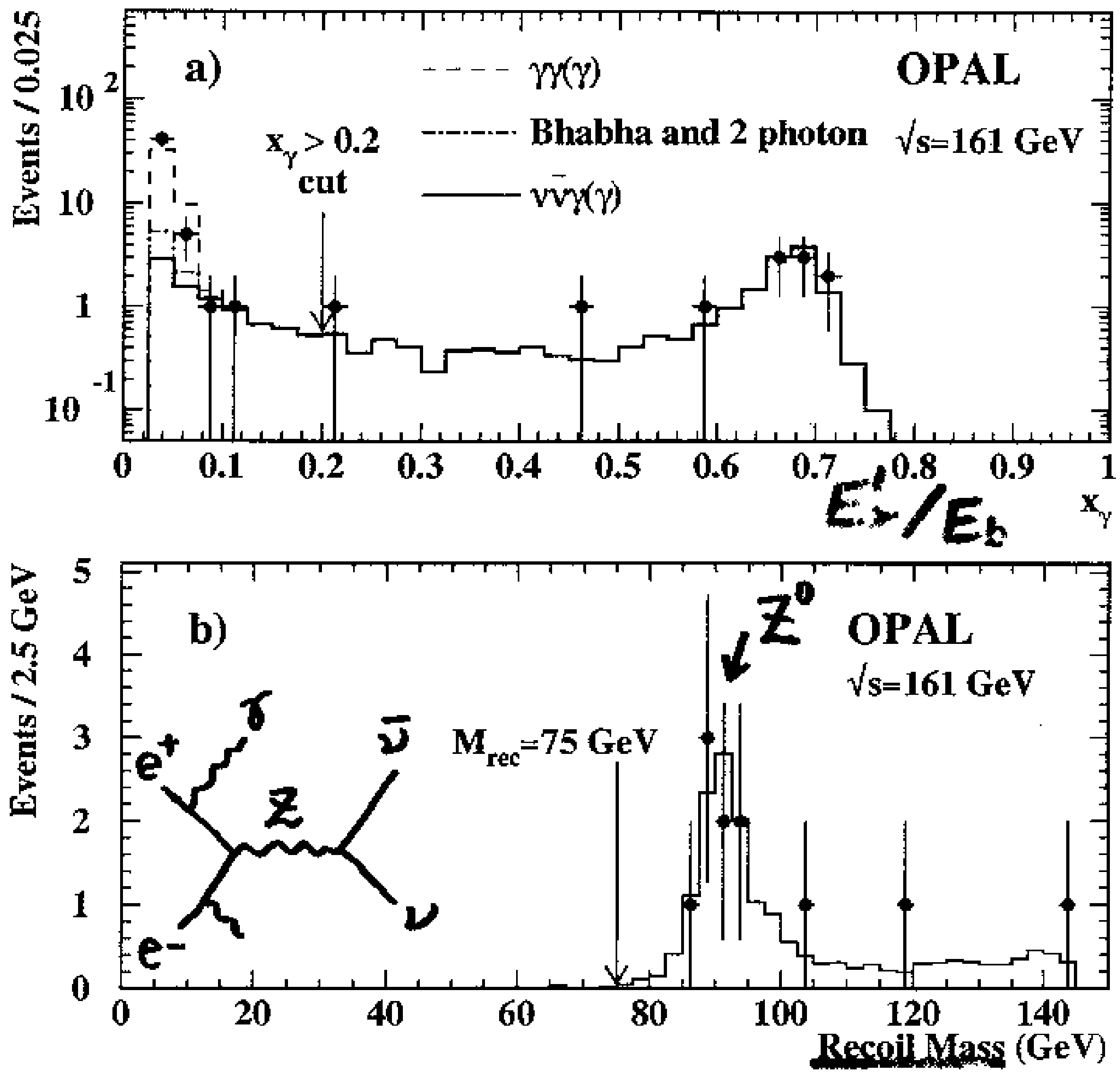


Figure 2: a) The x_γ distribution for the most energetic photon in events selected by topology A without the x_γ cut in order to show the expected background contributions at low x_γ. The data are the points with error bars, the solid line is the expected contribution from $e^+e^- \rightarrow \nu\bar{\nu}\gamma(\gamma)$ and the broken lines are the additional contribution from other Standard Model backgrounds. The Monte Carlo contributions are normalised to the 10.0 pb^{-1} of the data. b) The recoil mass distribution for selected events in topology A. The points with error bars are the data and the histogram is the expectation from the $e^+e^- \rightarrow \nu\bar{\nu}\gamma(\gamma)$ Monte Carlo normalised to the 10.0 pb^{-1} of the data.

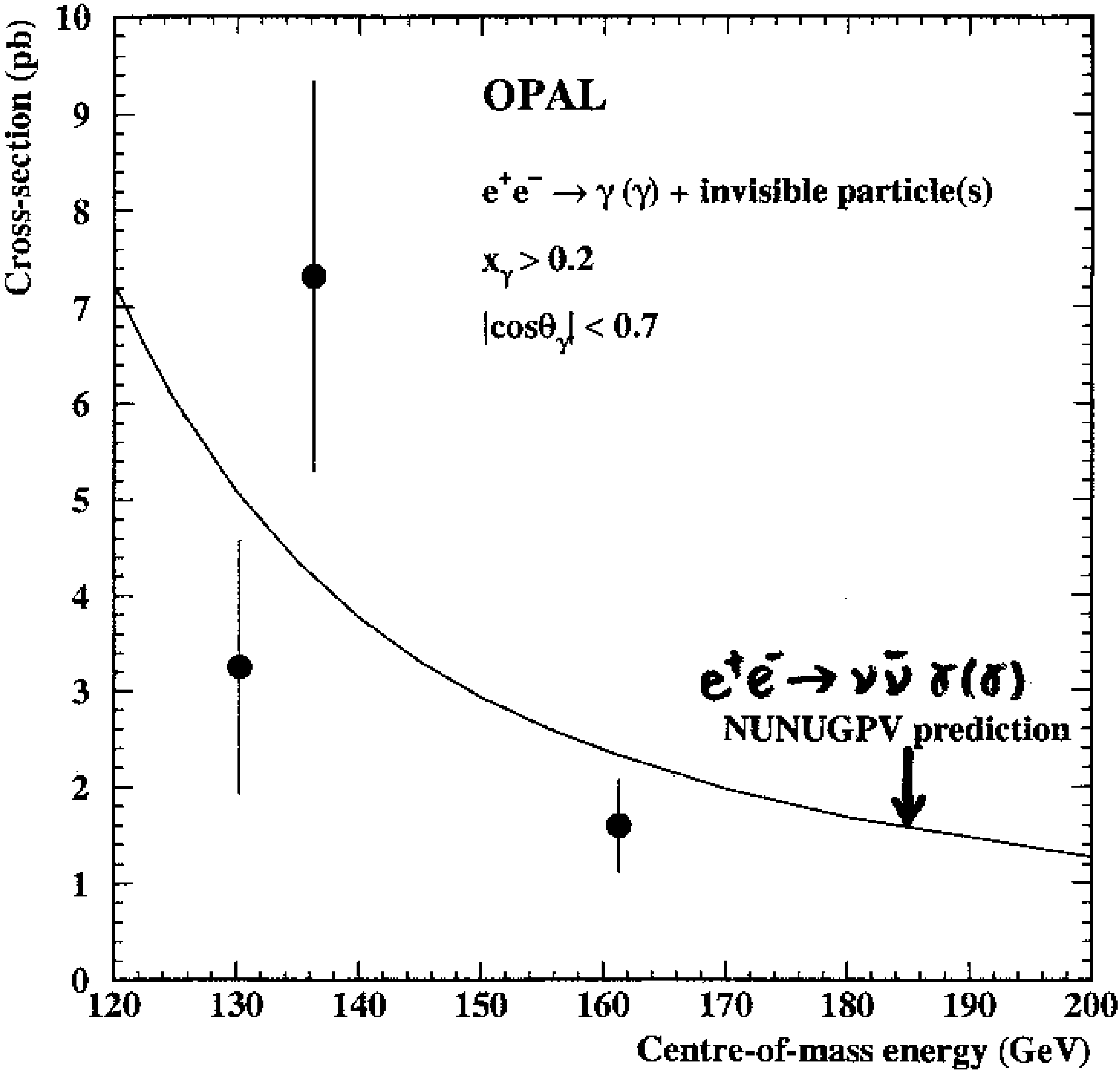
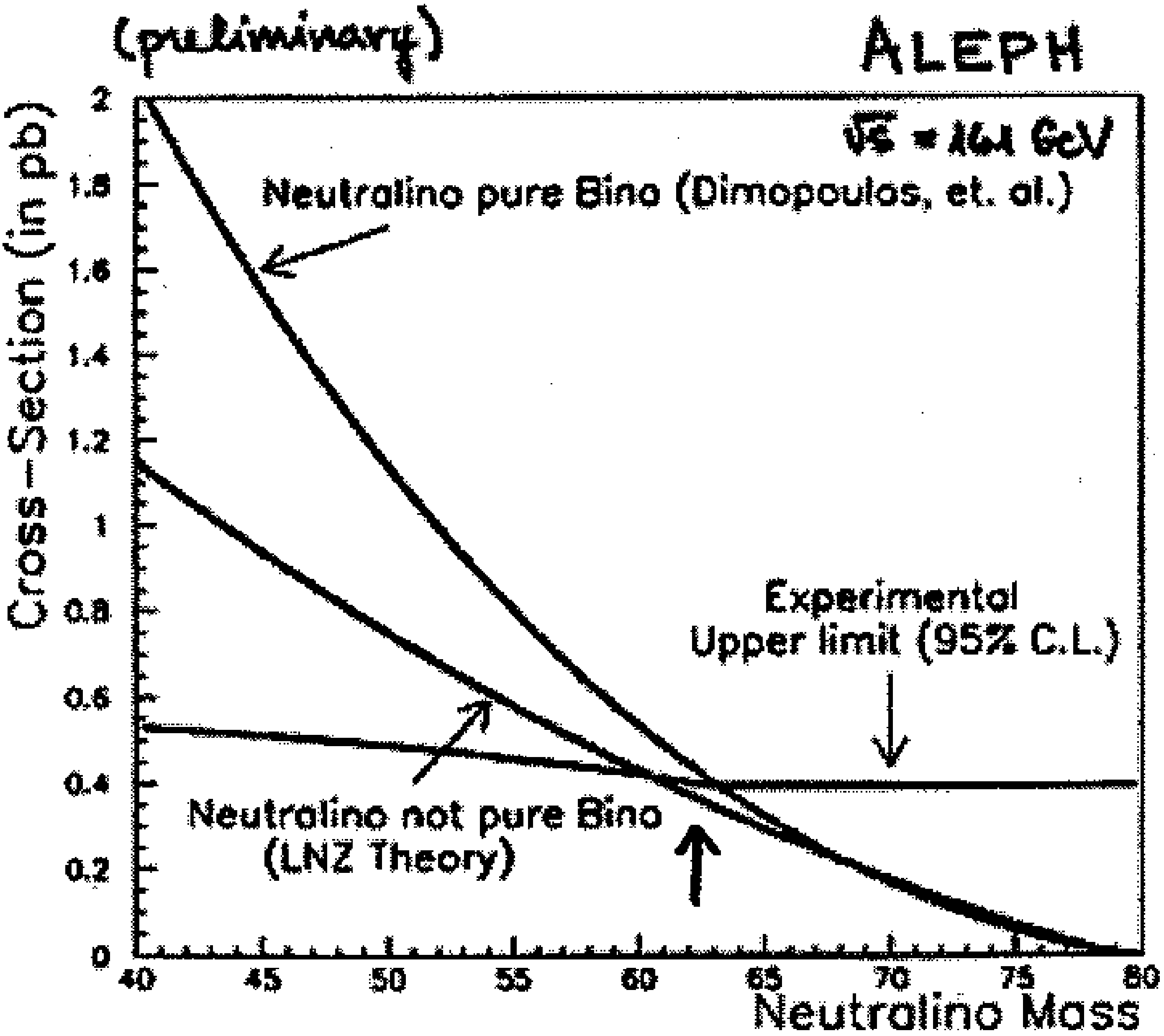


Figure 1: The measured cross-section for $e^+e^- \to \gamma(\gamma)$ + invisible particle(s) versus centre-of-mass energy. The data points with error bars are OPAL measurements from this paper and from the analysis at centre-of-mass energies of 130 and 136 GeV. The curve is the Standard Model prediction for the process $e^+e^- \to \nu\bar{\nu}\gamma(\gamma)$.

upper limit on cross section

$e^+e^- \to \gamma\gamma\tilde{G}\tilde{G}$

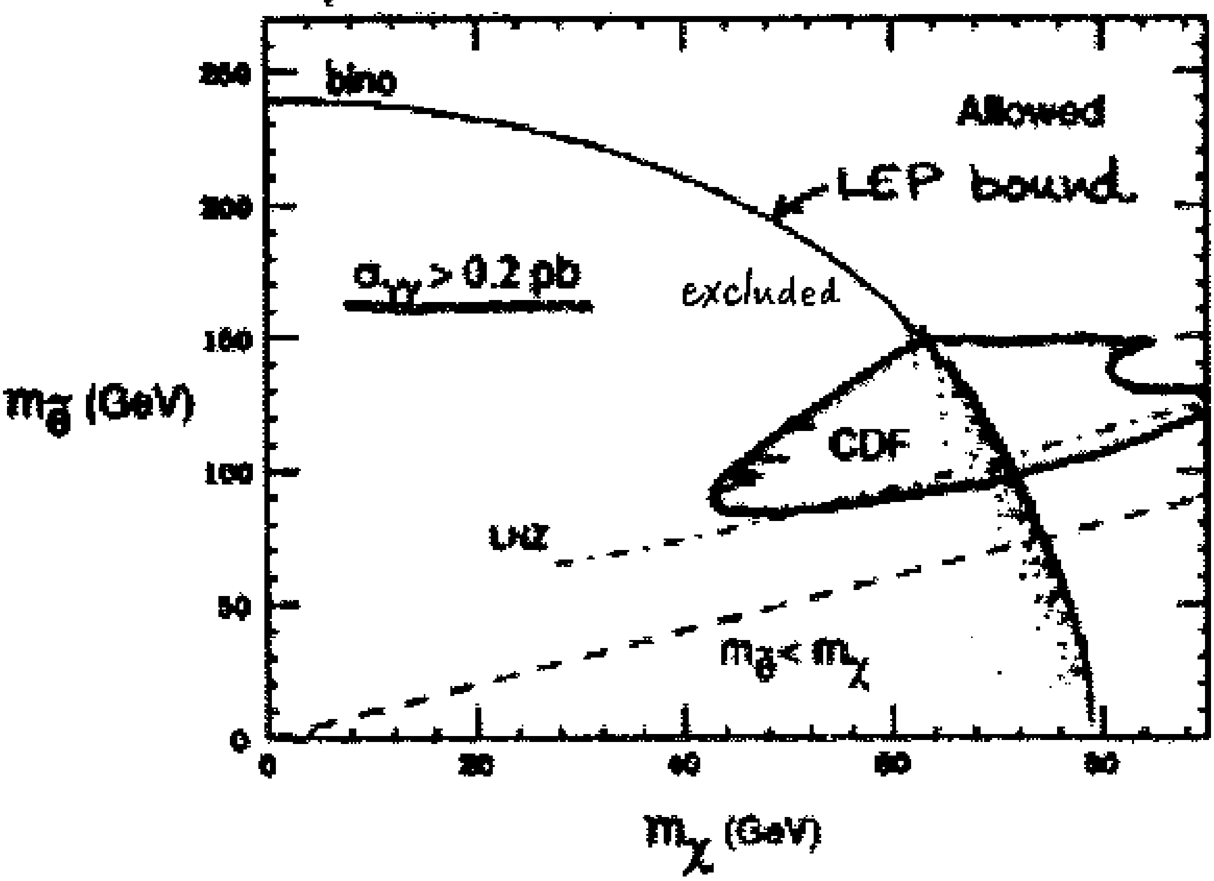


Impact on CDF event

All 4 LEP experiments have presented upper limits on acoplanar γ's.

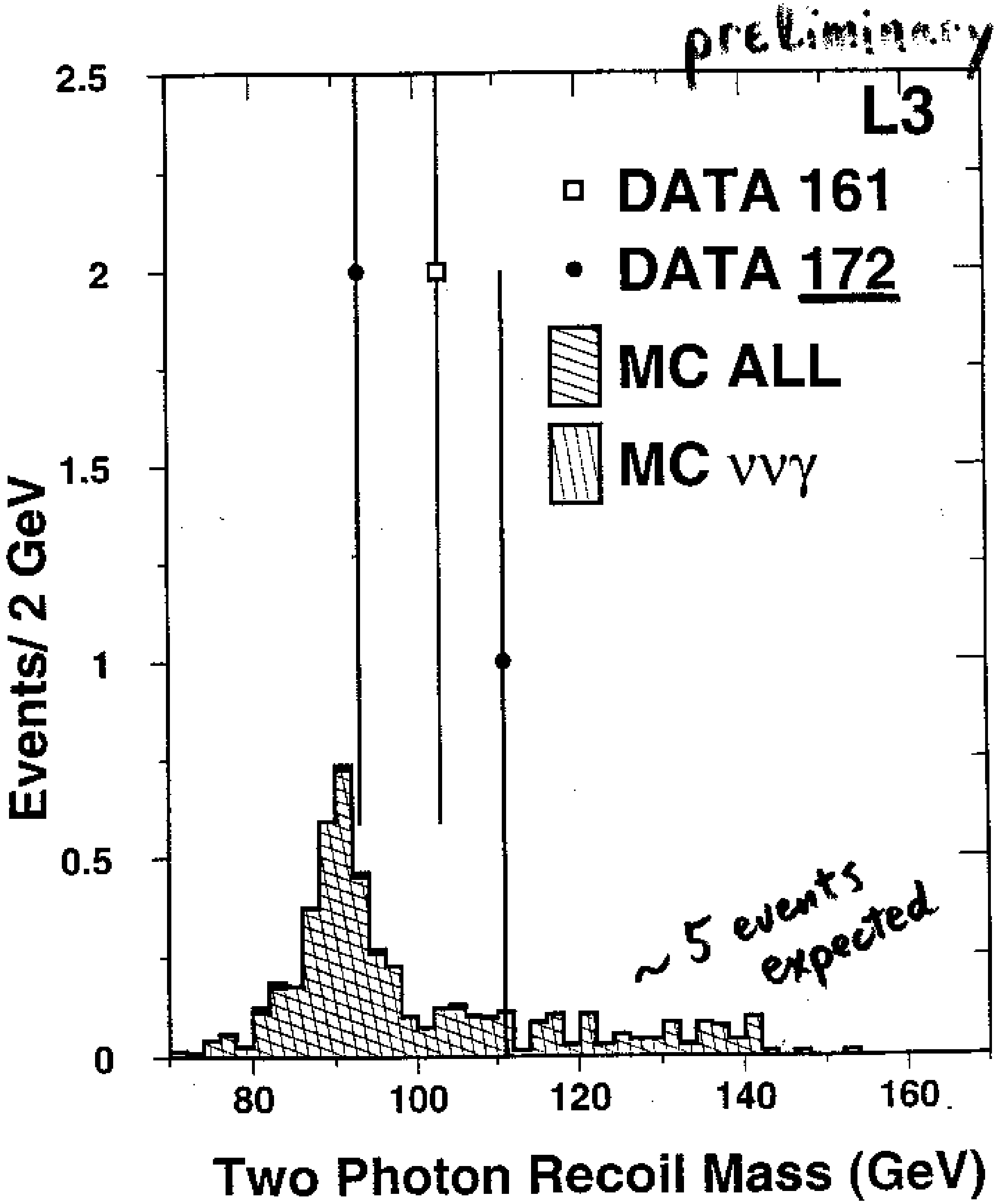
approx combined result: **0.2 pb**

Ellis, Lopez, Nanopoulos



This region is consistent with the kinematics of the CDF event.

$$p\bar{p} \to \tilde{e}\tilde{e} \to ee\chi\chi \to ee\gamma\gamma\tilde{G}\tilde{G}$$



preliminary
L3
DATA 161
DATA 172
MC ALL
MC ννγ
~ 5 events expected
Events/ 2 GeV
2.5
2
1.5
1
0.5
0
80
100
120
140
160
Two Photon Recoil Mass (GeV)

Conclusion

- LEP^2 gives tighter constraints on SUSY DM
- Better to find evidence of SUSY than to play around with parameters to get tighter limits

→ New High-energy [illegible] might find a clue