New Particle Searches at LEP

(Extra-dimension will be covered in Session VIII)

[0] Introduction

[1] SUSY

[2] Non-SUSY

[3] Conclusion

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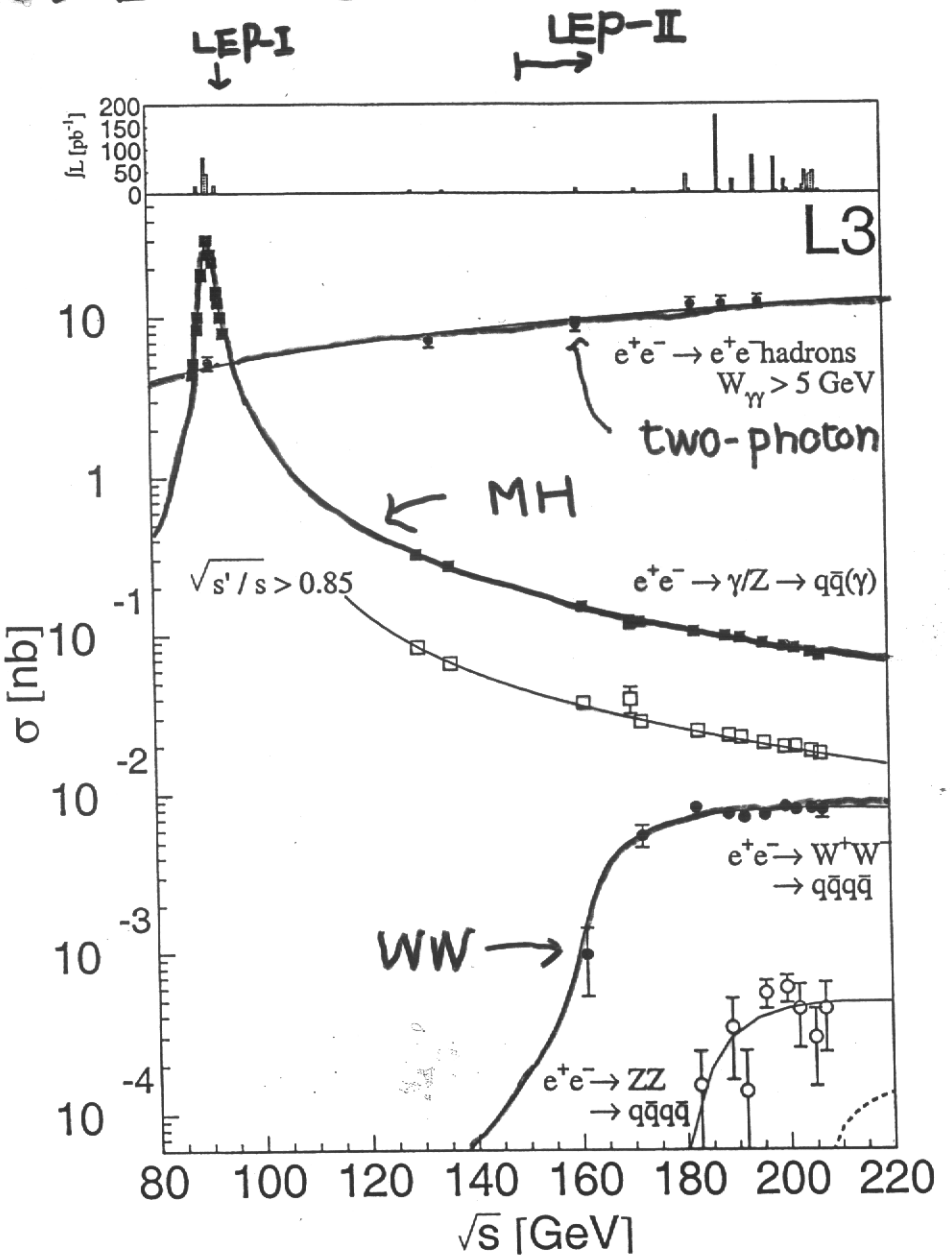
[0] Data set



$\sqrt{s}$ & Luminosities

	'98	'99	'00
$\sqrt{s}$ (GeV)	189	192-202	206-209
$\mathcal{L}$ (pb^{-1})	~180	~220	~220

$\Sigma \sim 620\ pb^{-1}$ /exp.

- Preliminary for '00
- LEP-wide Combined results

($\mathcal{L} \sim 2.5\ fb^{-1}$)

Introduction of SUSY

SUSY is broken symmetry.

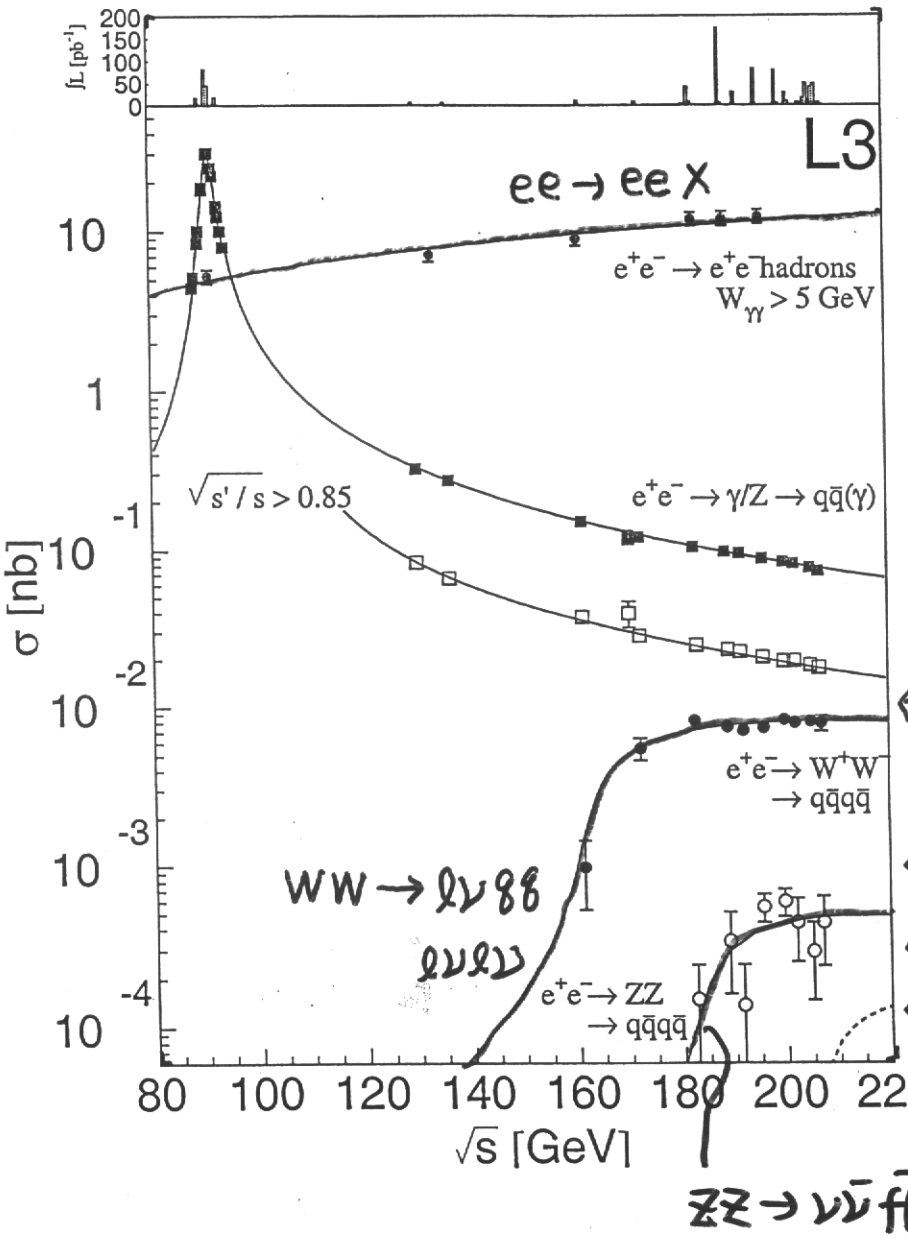
- Gravity-Mediation ("MSSM")
  - $\tilde{\chi}_1^0$ is LSP. ($m\tilde{\chi}_1^0 = 1 \sim 10^2$ GeV)
  - $\not{E}$ is experimental signature if R conserved.
  - $\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^0\tilde{\chi}_2^0$, $\tilde{\ell}^+\tilde{\ell}^-$, $\tilde{t}\tilde{t}$, $\tilde{b}\tilde{b}$ promising
  - M_2, m_0, μ, $\tan\beta$, A_0 (5-parameters)
- Gauge-Mediation ("GMSB")
  - $\tilde{G}$ is LSP (Light ev~keV)
  - $\not{E}$ or/and γ is experimental signature.
  - $\tilde{\ell}^\pm$ or $\tilde{\chi}_1^0$ NLSP
    $\tilde{\chi}_1^0\tilde{\chi}_1^0$ $\tilde{\ell}\tilde{\ell}$ promising channel
  - $\sqrt{F}$, M_m, Λ, $\tan\beta$, N_m, sign(μ)
- Anomaly-Mediation ("AMSB") ← excluded by g-2 ??
  - $M_1 \sim M_2 \rightarrow m\tilde{\chi}_1^\pm \sim m\tilde{\chi}_1^0$

- We perform model independent study using "Model" as Guide.
- Then interpretation has been done.

Promising Event topologies

	MSSM	GMSB	AMSB
① 1 or 2 γ + $\not{E}$	○ ($\tilde{\chi}_1^0\tilde{\chi}_2 \hookrightarrow \tilde{\chi}_1^0\gamma$)	◎ ($\tilde{\chi}_1^0\tilde{\chi}_1^0$, $\tilde{\chi}_1\tilde{G}\cdots$)	
② Acoplaner Lepton + $\not{E}$	◎ ($\tilde{\ell}^+\tilde{\ell}^-$)	◎ ($\tilde{\ell}^+\tilde{\ell}^-$)	
③ Long-lived heavy Particle	○ (Higgsino)	◎ (Large $\sqrt{F}$)	◎
④ WW/Z-like + $\not{E}$	◎ ($\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^0\tilde{\chi}_2^0$)		
⑤ γ + X + $\not{E}$	○ (Higgsino)	○ ($\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^0\tilde{\chi}_2$) $\hookrightarrow \tilde{\chi}_1^0 \searrow \tilde{\gamma}\tilde{G}$	◎
⑥ Acoplaner Jet + $\not{E}$	◎ ($\tilde{t}\tilde{t}$, $\tilde{b}\tilde{b}$)		
⑦ Many Lepton + Jet	◎ (R-violation)		

σ of SUSY & BG



← two-photon (BG for small Δm)
~10^4 Pb

← W^+W^- (BG for Large Δm)
~10 Pb

← $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ $\sigma \sim (1-10)\beta$ (Pb)

← $\tilde{\chi}_j^0 \tilde{\chi}_i^0$ $\sigma \sim (0.2-2)\beta$ (Pb)

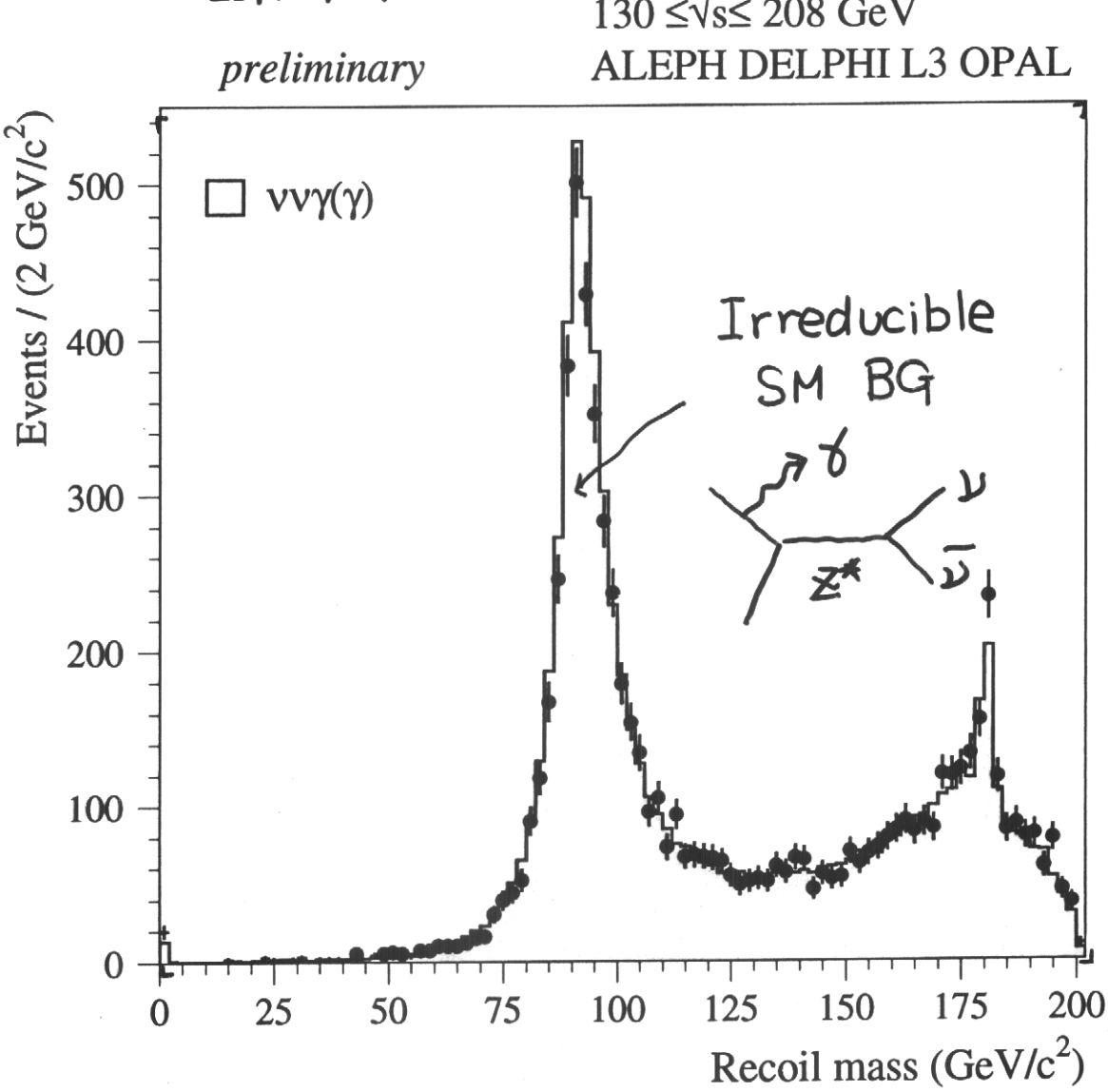
← $\tilde{f}^+ \tilde{f}^-$ $\sigma \sim (0.2-2)\beta^3$ (Pb)

(1) Single γ + Emiss (GMSB, MSSM)

$\tilde{\chi}_1^0 \tilde{G} \to (\gamma \tilde{G}) \tilde{G}$ $\quad\quad$ $\tilde{\chi}_1^0 \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 (\gamma \tilde{\chi}_1^0)$

$\gamma \tilde{G}$

$\gamma_{ISR} \tilde{G} \tilde{G}$

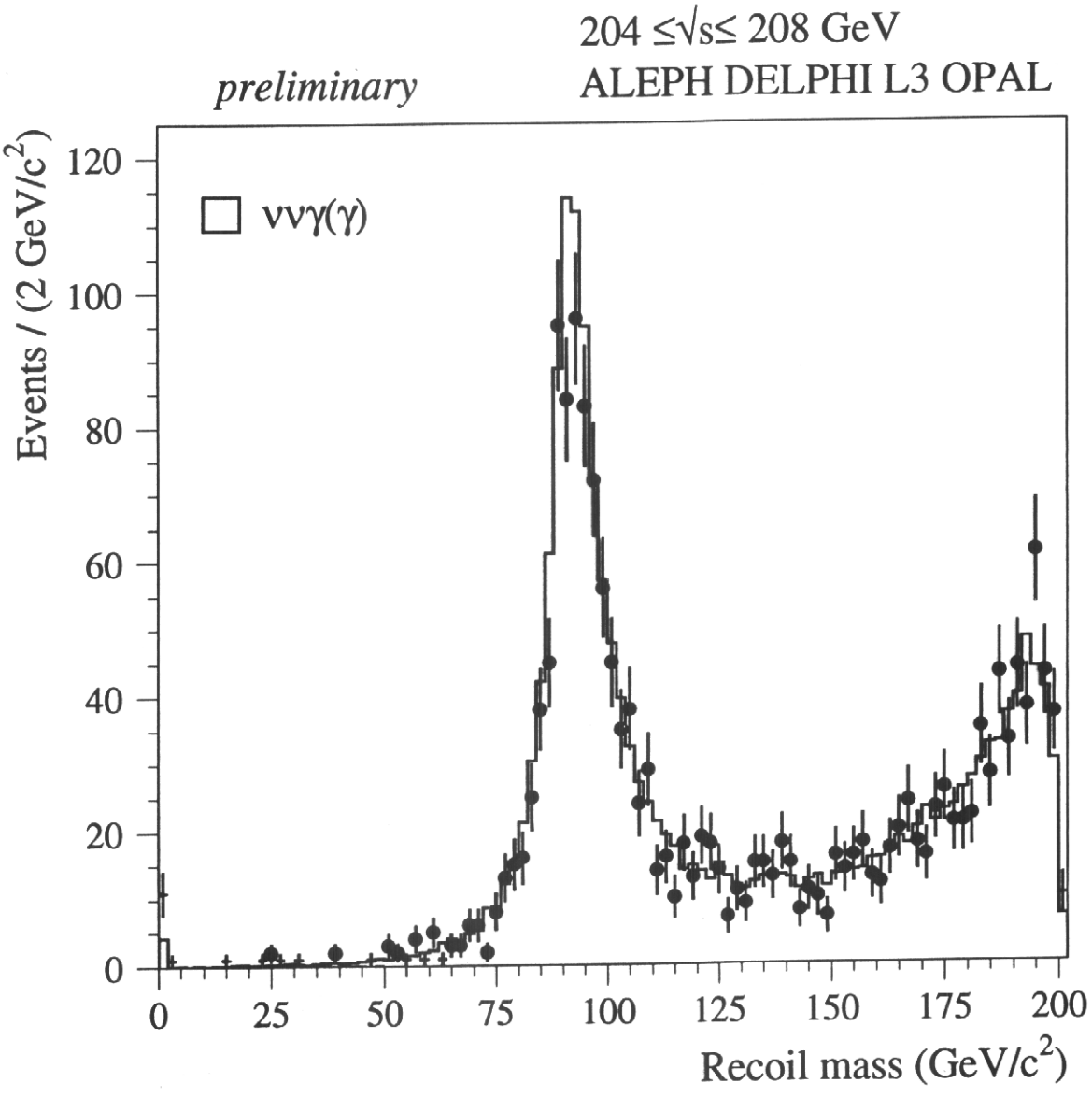


~ Invariant Mass of missing particles.

Total # of Data agrees with SM BG.

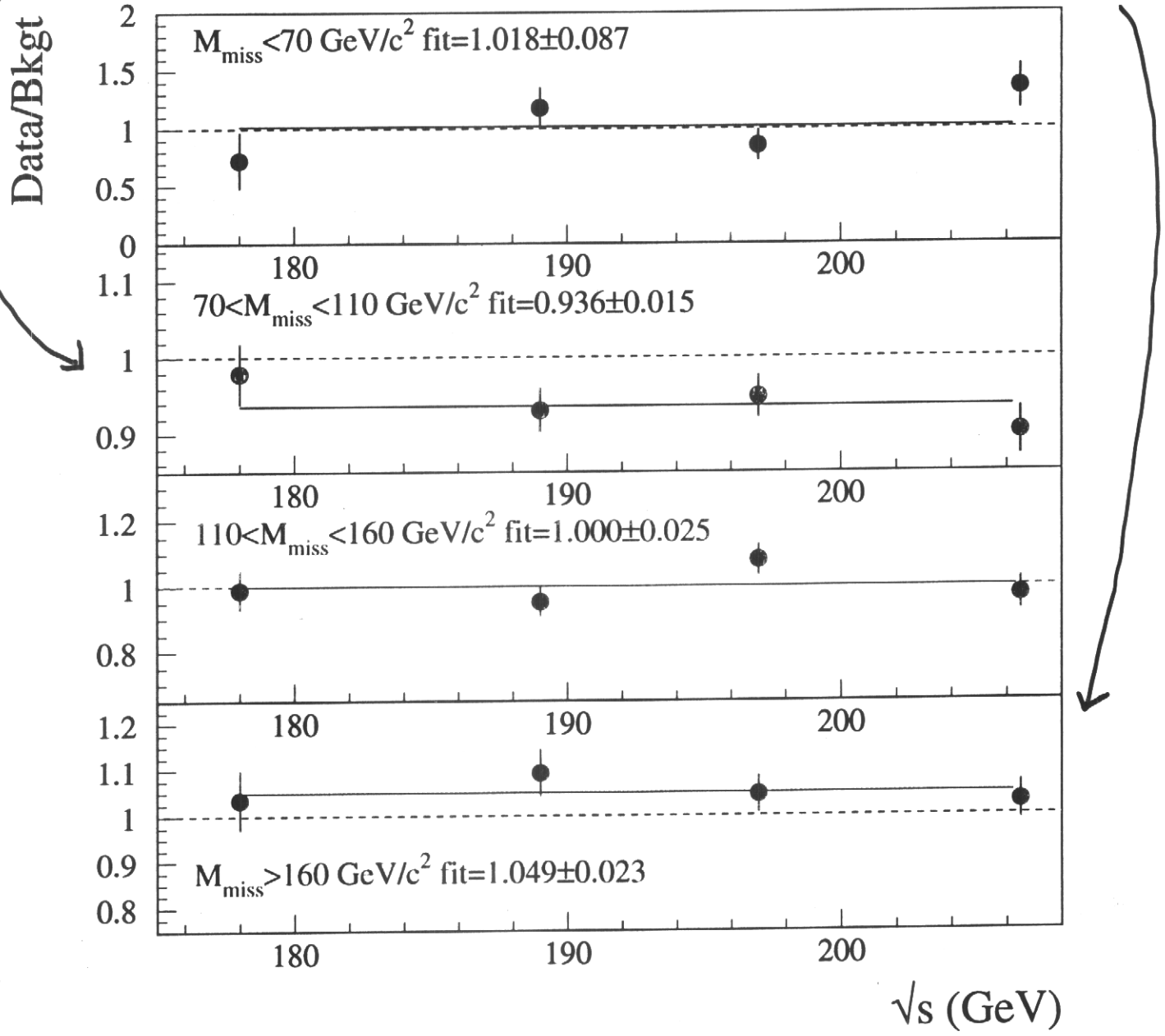
→ NO excess

ONLY '00 data


204 ≤√s≤ 208 GeV
ALEPH DELPHI L3 OPAL
preliminary
νν̄γ(γ)
Events / (2 GeV/c²)
Recoil mass (GeV/c²)
0
20
40
60
80
100
120
0
25
50
75
100
125
150
175
200

But differential cross-section has discrepancies (~ 6%)

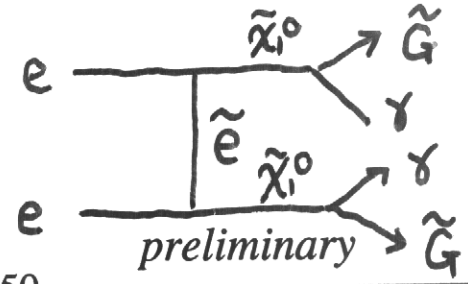
- Deficit at Z^0 peak
- excess at tail

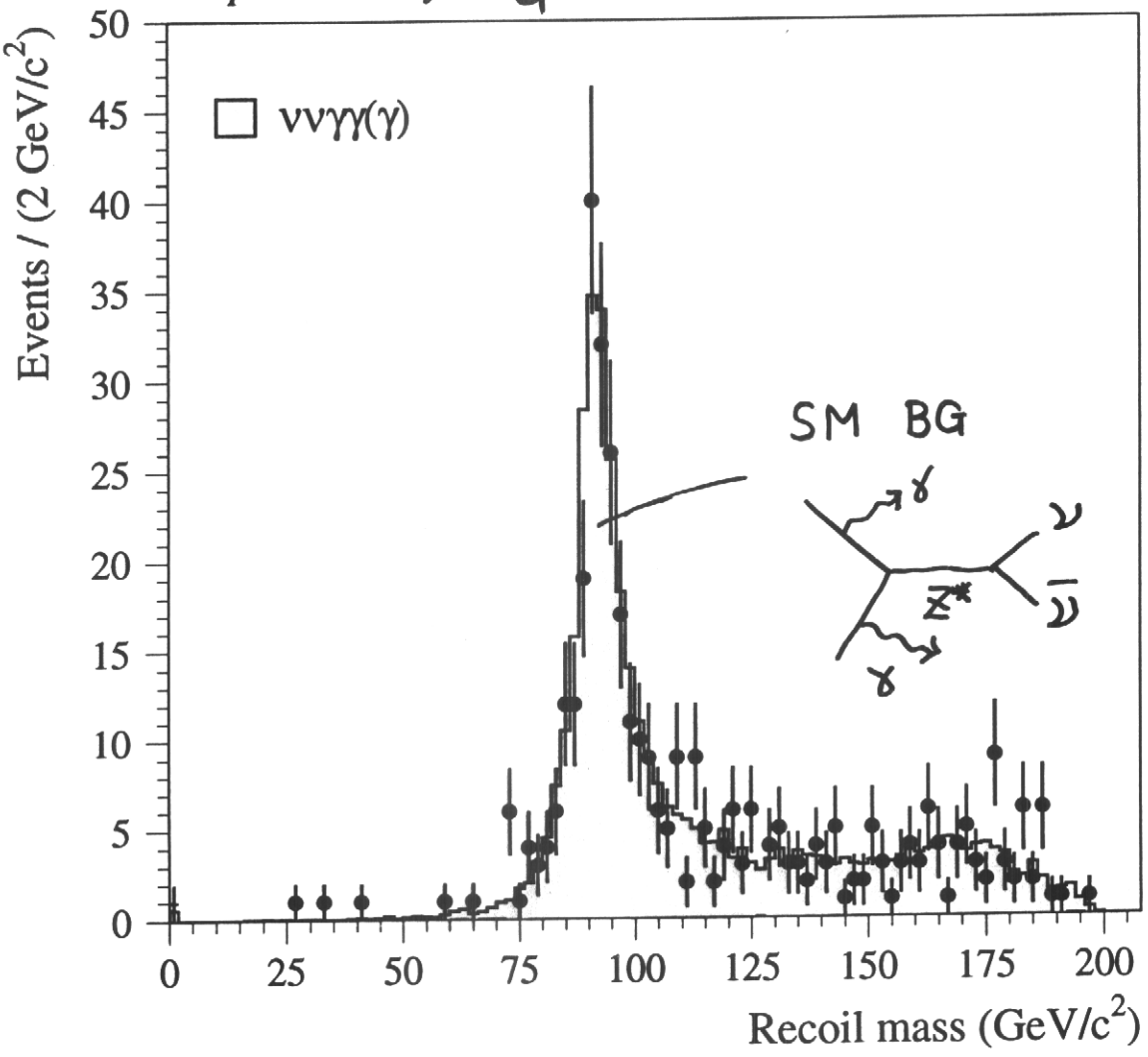


- Koral Z is used for these study. except for OPAL.
- KK2f is in agreement with Nunugpv and Data.

→ We set various Limits after switching MC.

(2) $2\gamma + E_{miss}$ (GMSB)





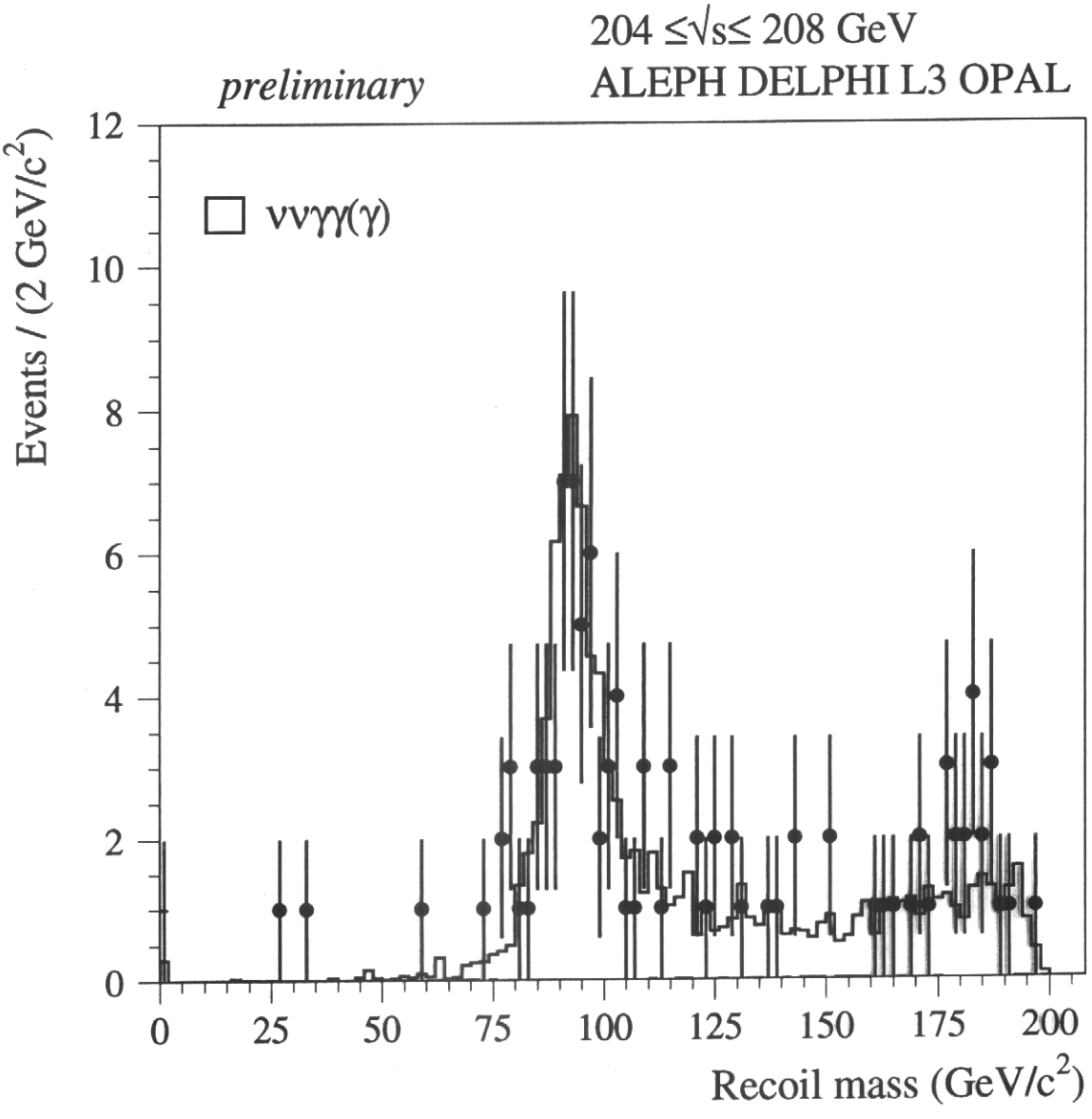
No excess

↓

Limit on $\tilde{\chi}_1^0$-mass

as a function of $\tilde{e}$-mass

ONLY Y2K data

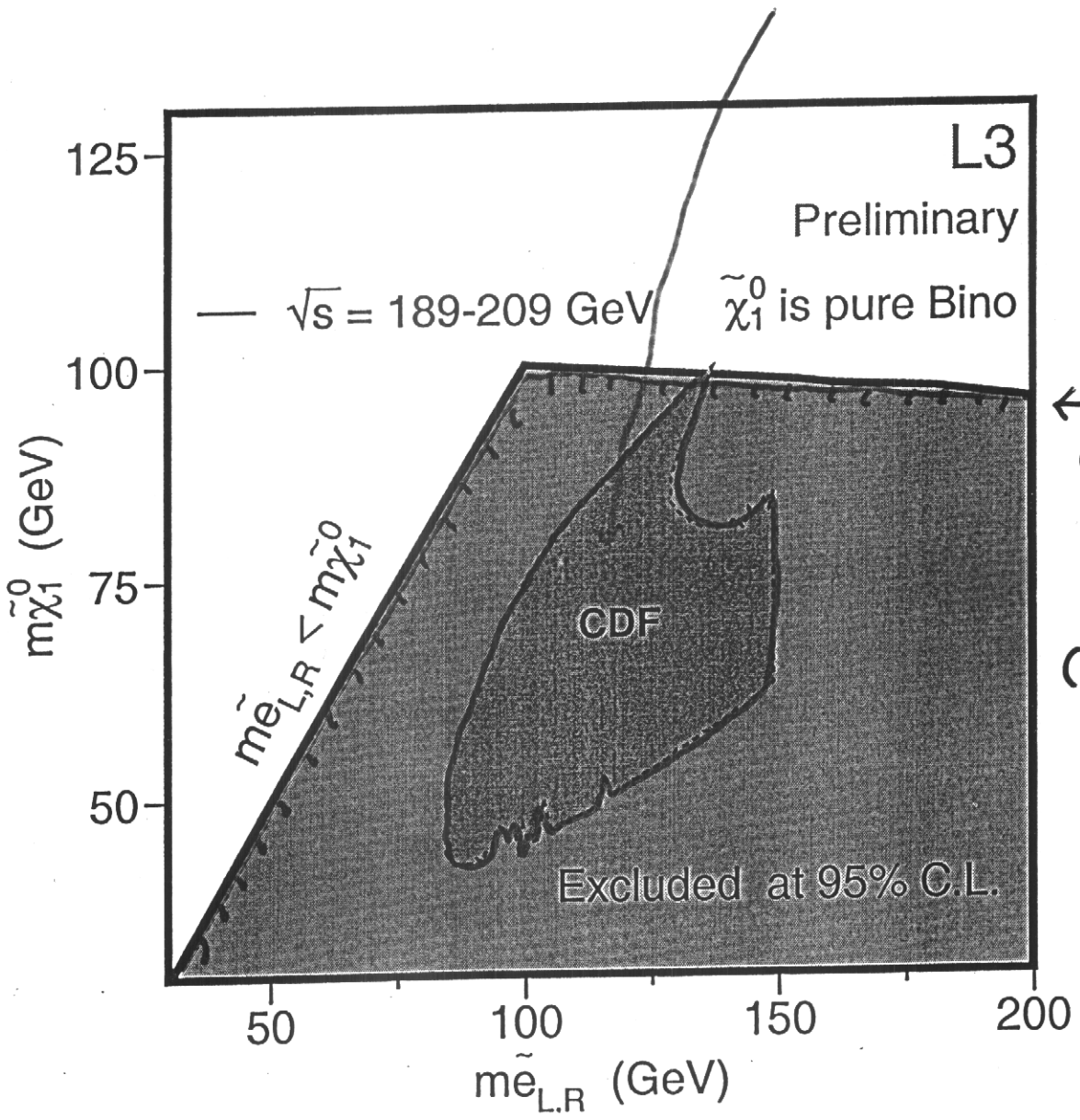


CDF: $e^+e^-\gamma\gamma + \not{E}_T$

promising explanation

$q\bar{q} \to \tilde{e}^+\tilde{e}^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$

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

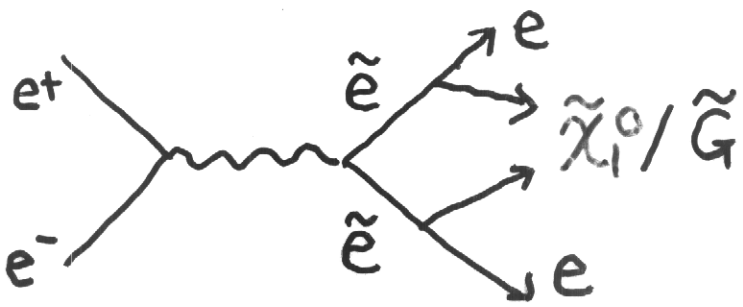


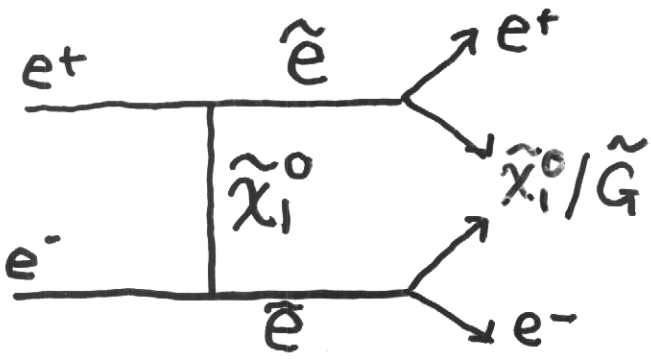
$\leftarrow m\tilde{\chi}^0 > 95$ GeV ($m\tilde{e} <$ 200GeV)

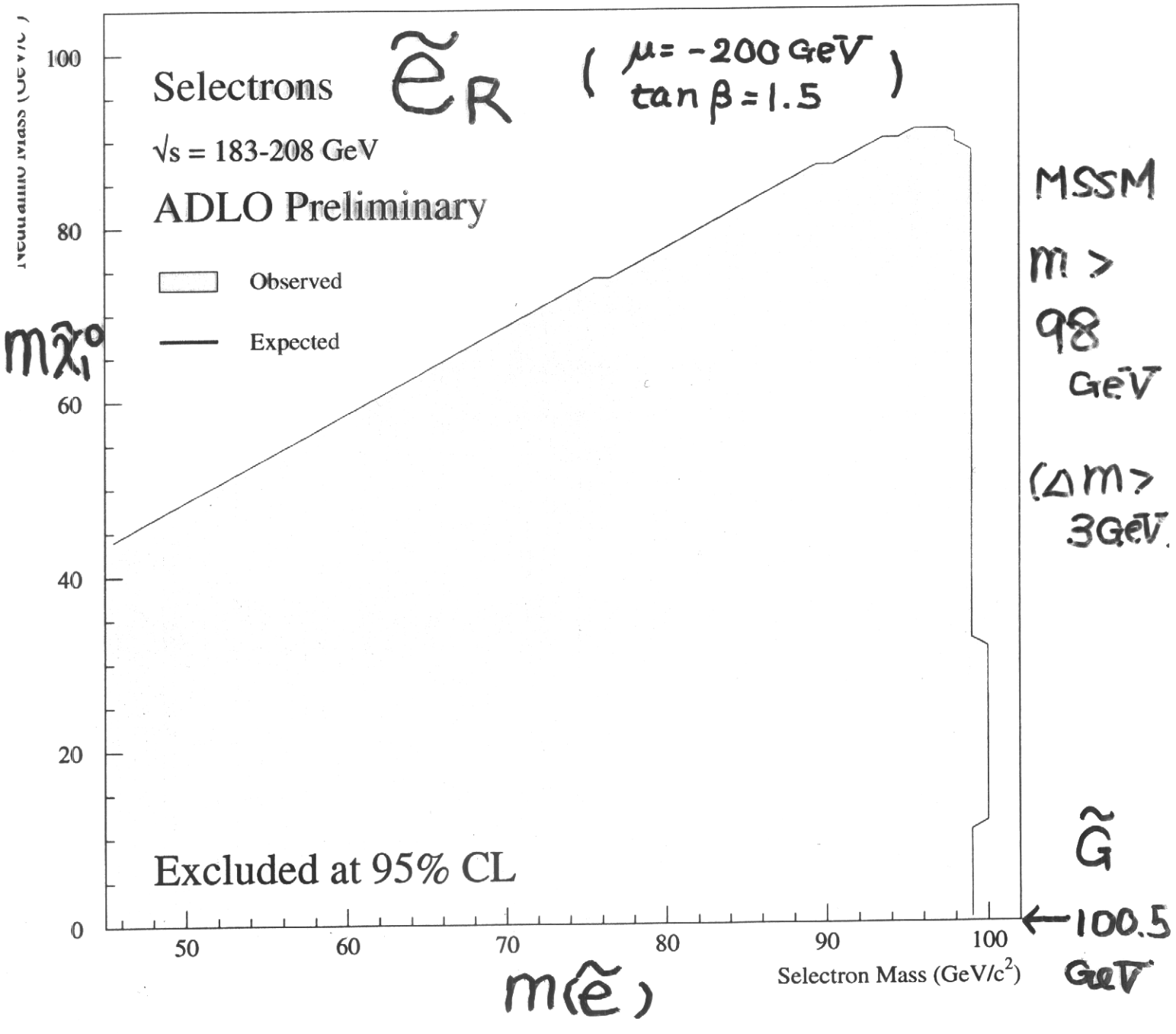
The hypothesis is ruled out !!!

(3) Scalar Leptons (MSSM, GMSB)

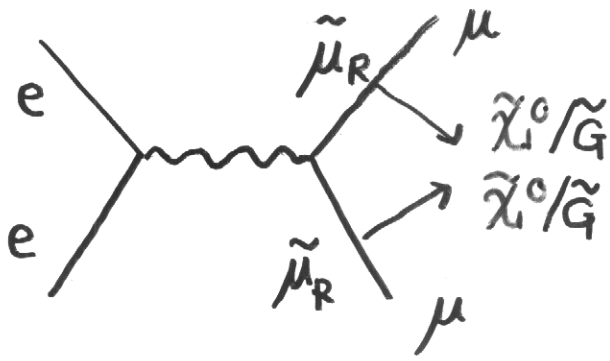
- $m(\tilde{\ell}_R) < m(\tilde{\ell}_L)$
- $\sigma(\rightarrow \tilde{\ell}_R \tilde{\ell}_R) < \sigma(\rightarrow \tilde{\ell}_L \tilde{\ell}_L)$ ⇨ $\tilde{\ell}_R$







$\tilde{\mu}$

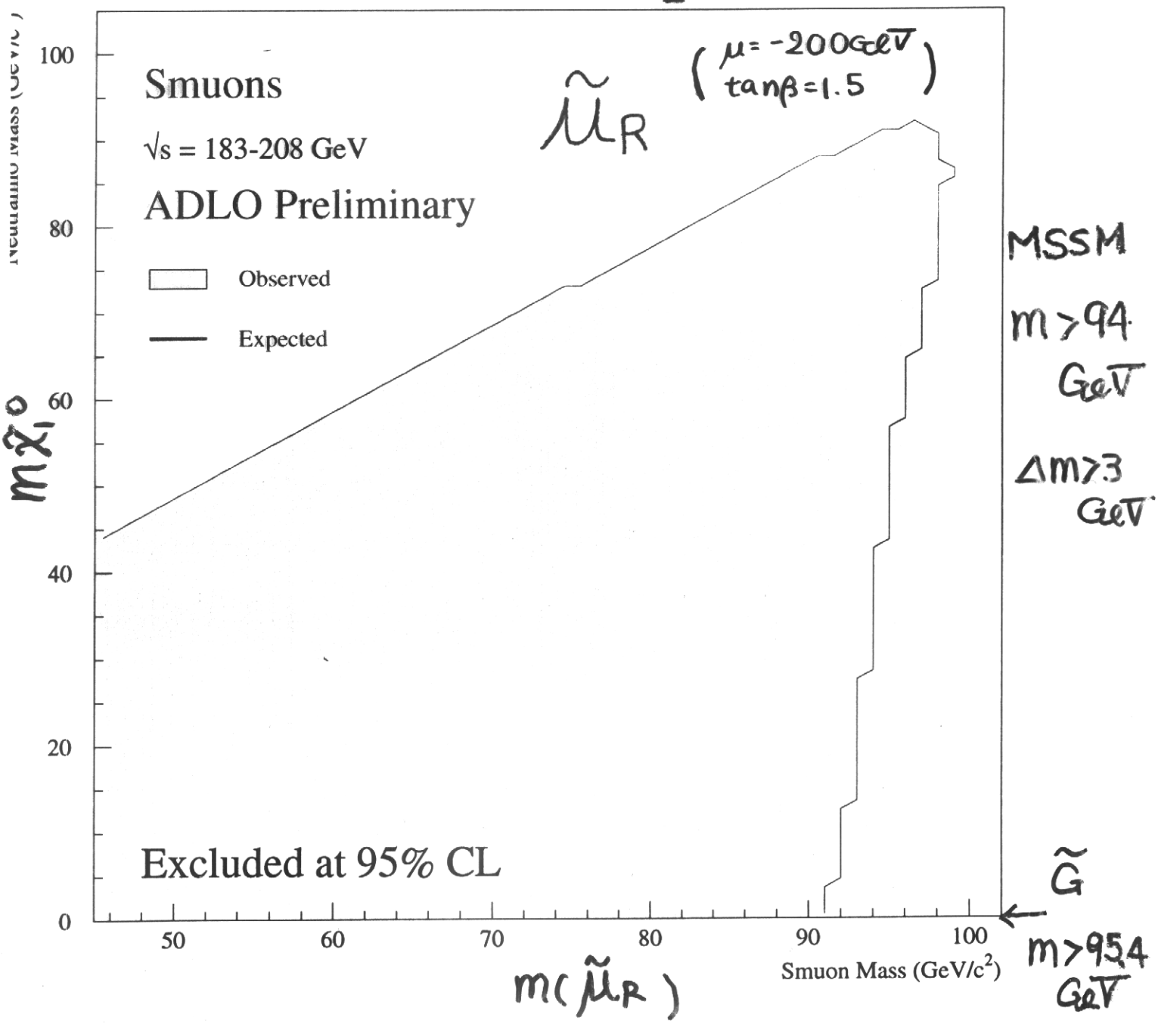


⇨ NO excess

σ : independent on SUSY Parameter

But $Br(\tilde{\mu} \to \mu \tilde{\chi}_1^0)$ depend slightly

$\tilde{\mu} \to \mu \tilde{\chi}_2^0 \to \mu(\tilde{\chi}_1^0 X)$ ⇨ $\varepsilon = 0$

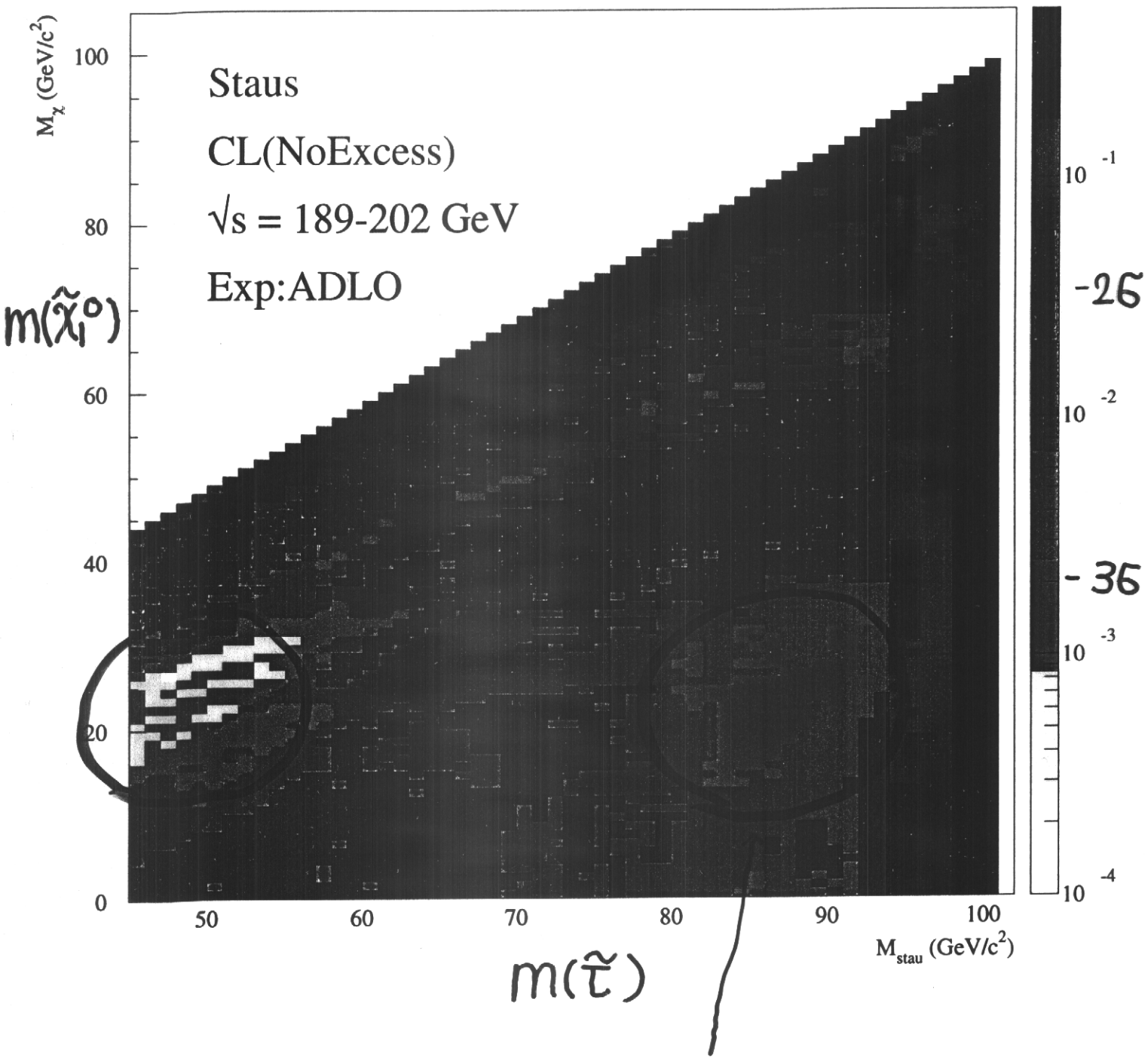


$\tilde{\tau}$

("MSSM" "GMSB" for large tanβ)

In '98+'99 data

- Excess (>3σ) was found
- All 4 experiments contribute.



Best fit $\begin{cases} m\tilde{\tau} = 85\,GeV \\ m\tilde{\chi}_1^0 = 22\,GeV \end{cases}$

$\tilde{\chi}_1^0 + \nu$ escape from detection, → Kinematic reconstraction difficult.

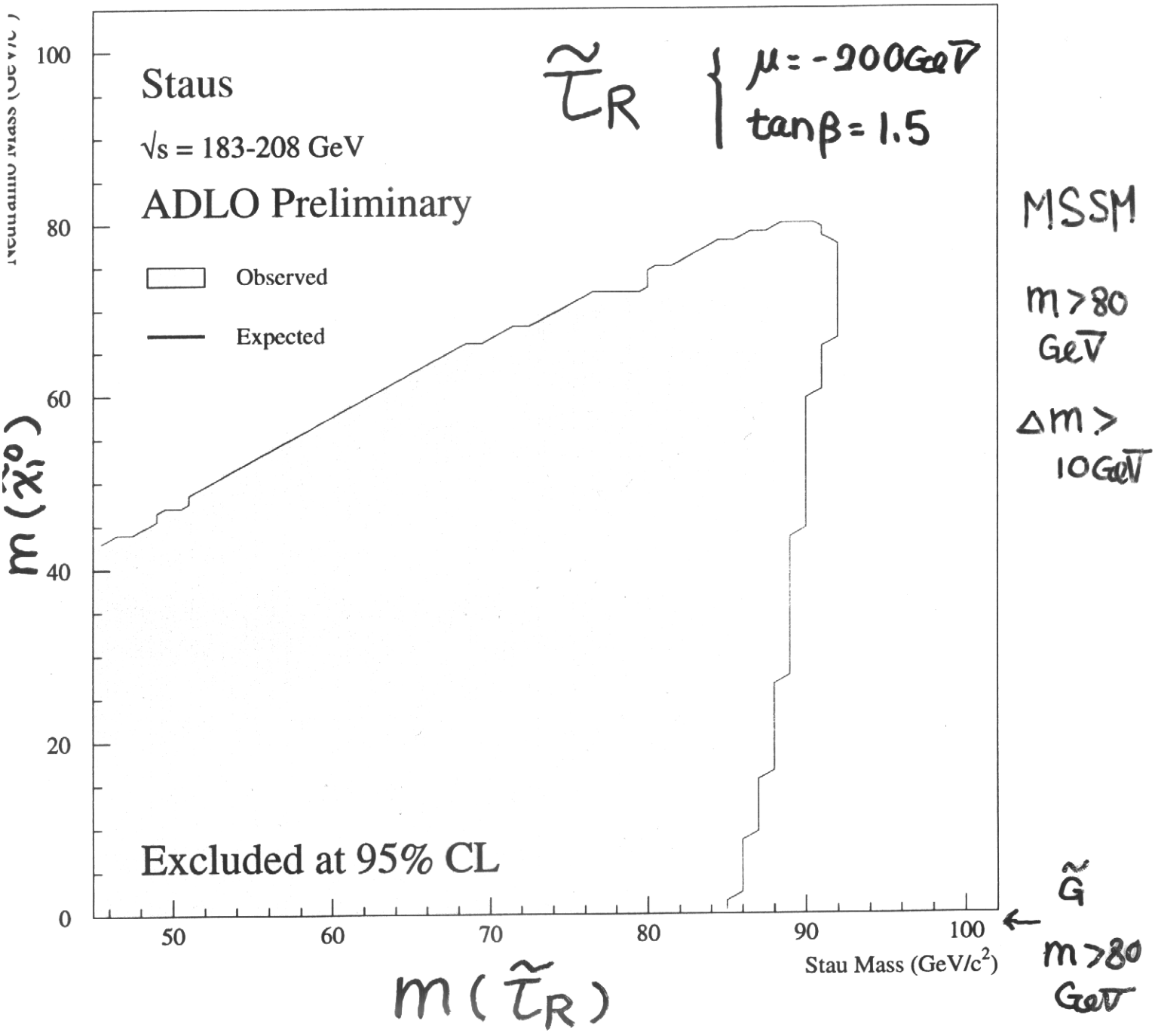
But

Data in '00 is in perfect agreement with SM BG.

We can not confirm "$\tilde{\tau}$"-excess.

⇨ Including new data

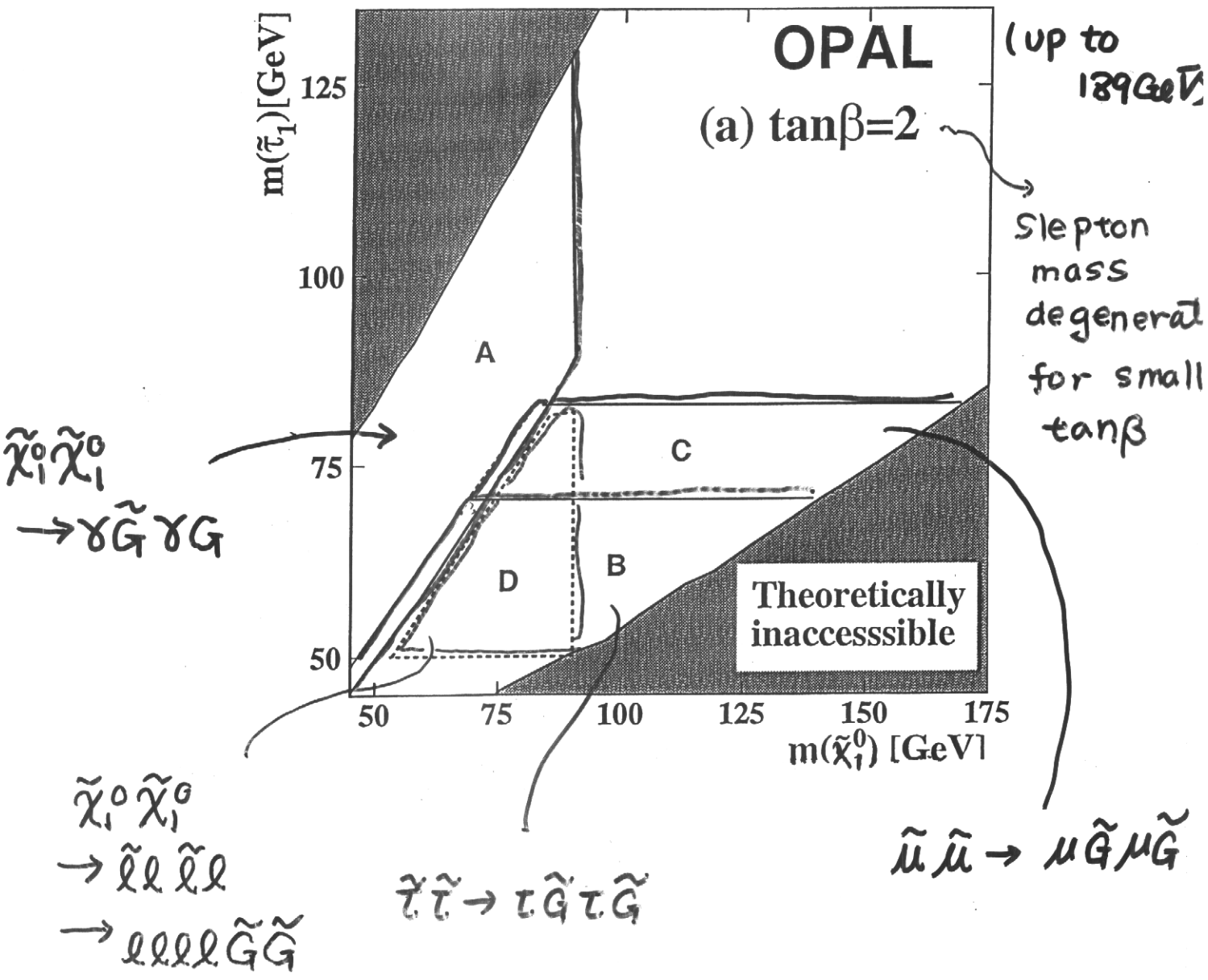
significance is reduced to 2σ.



Parameter Scan in GMSB

- Derive absolute limits by scanning on GMSB parameters

$m_{\tilde{\ell}} > 83\,GeV$, $m_{\tilde{\chi}_1^0} > 85\,GeV$ ($\tan\beta=2$)



$\tan\beta \gg 1$ $\Delta m (m_{\tilde{\tau}} - m_{\tilde{\mu}})$ is large

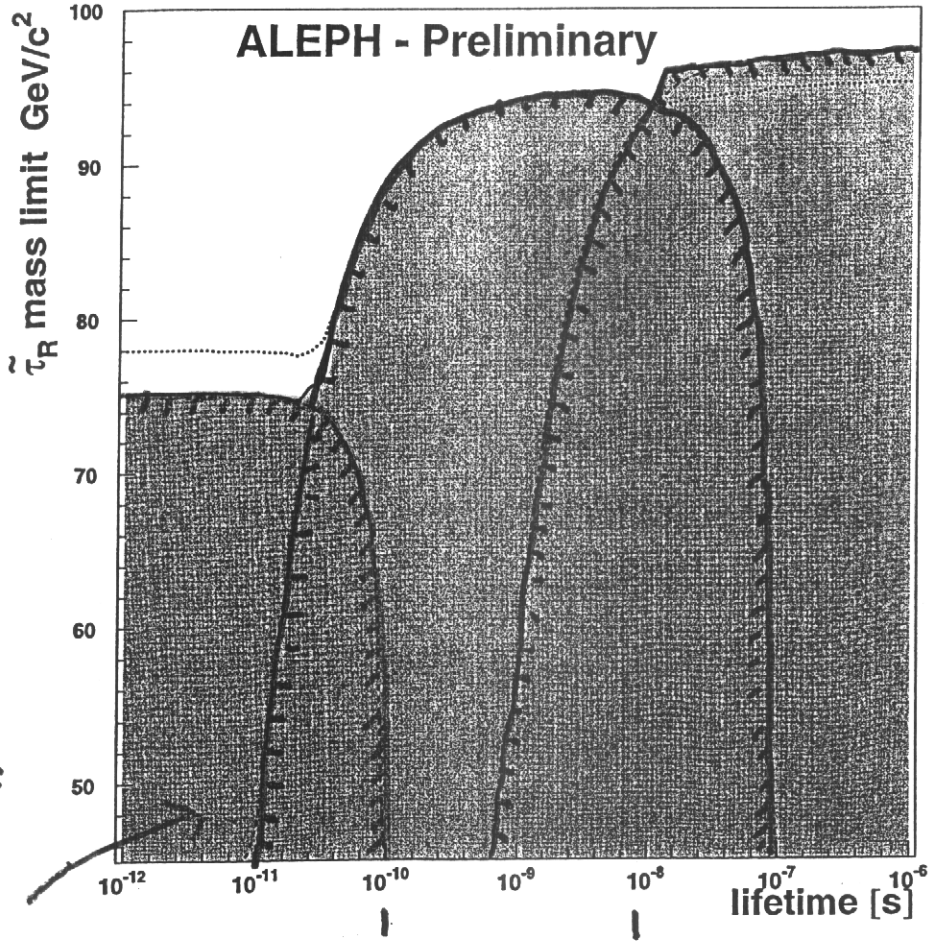
$m_{\tilde{\tau}} > 69\,GeV$ $m_{\tilde{\chi}_1^0} > 76\,GeV$

$\tilde{\tau}$ - pair with any Lifetime (GMSB)

$\sqrt{F} > O(100\,TeV)$

↳ Life time of NLSP is sizable

decay point { far from vertex
outside of detector



$C\gamma\tau \sim O(1cm) \quad \sim O(1m)$

$\sqrt{F} \sim O(100TeV) \quad \sim O(10^3 TeV)$

$m_{\tilde{G}} \sim O(1eV)$

Large IP track search + Kink track search

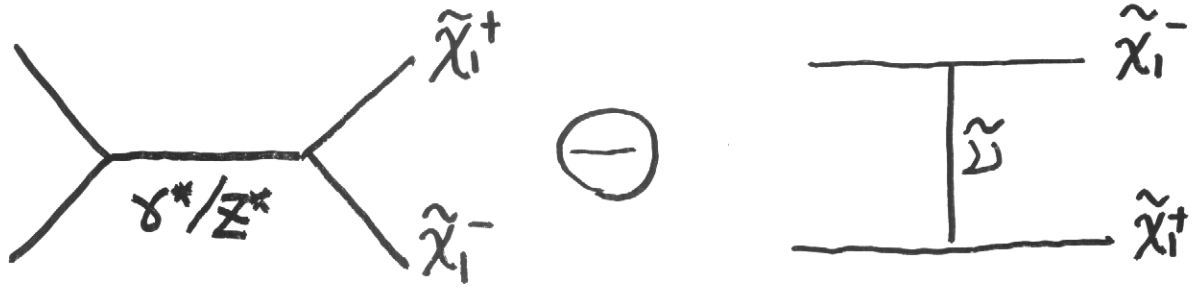
Heavy Stable Particle search

NO signal

"Standard" 2012 $\tilde{\tau}\tilde{\tau}$

(4) $\tilde{\chi}_1^{\pm}$ / $\tilde{\chi}_i^0\tilde{\chi}_j^0$ (MSSM)

$m_{\tilde{\nu}}$ plays important role in $\tilde{\chi}_1^+\tilde{\chi}_1^-$.

① 

Negative interference of s- and t - channel

② $Br(\tilde{\chi}_1^+ \to \ell^+\nu\tilde{\chi}_1^0)$ depends on $\tilde{\ell}$-mass

<u>Large m_0</u> (Heavy $\tilde{\nu}, \tilde{\ell}$)

- σ Large
- $Br(\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 W^*) \sim 100\%$

<u>Small m_0</u> (Light $\tilde{\nu}, \tilde{\ell}$)

- σ small
- $Br(\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 \ell\nu)$ ↑↑

Lower-limit on m_0 is obtained from

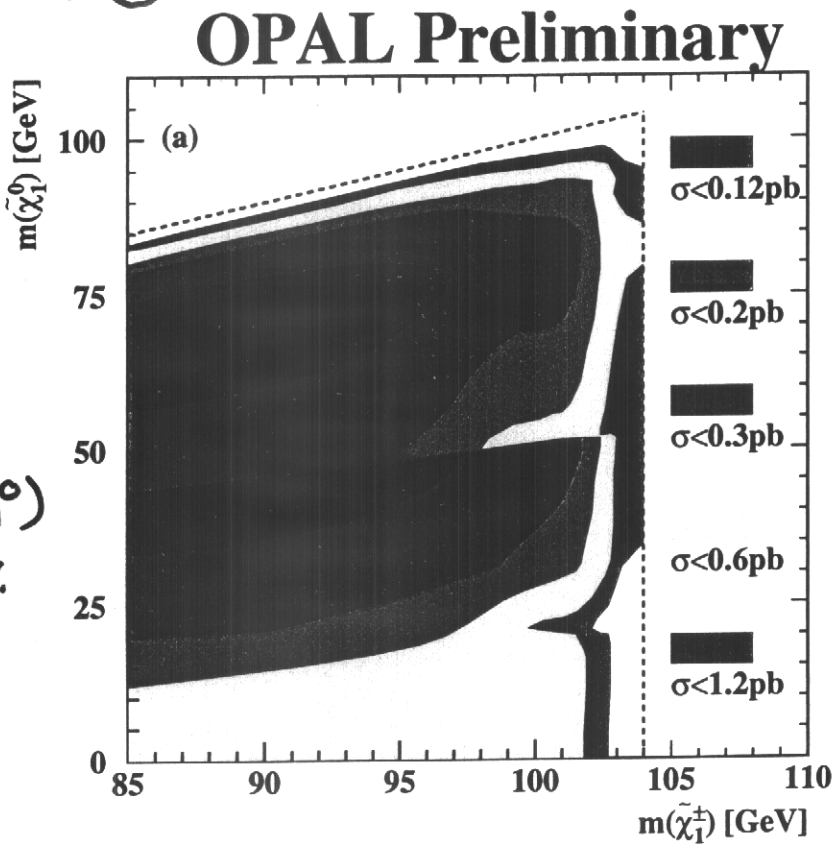
- LEP-I invisible width $m_{\tilde{\nu}} > 45$
- $\tilde{\ell}$-searches

No excess was found in all 4 exp.

Upper limit on σ

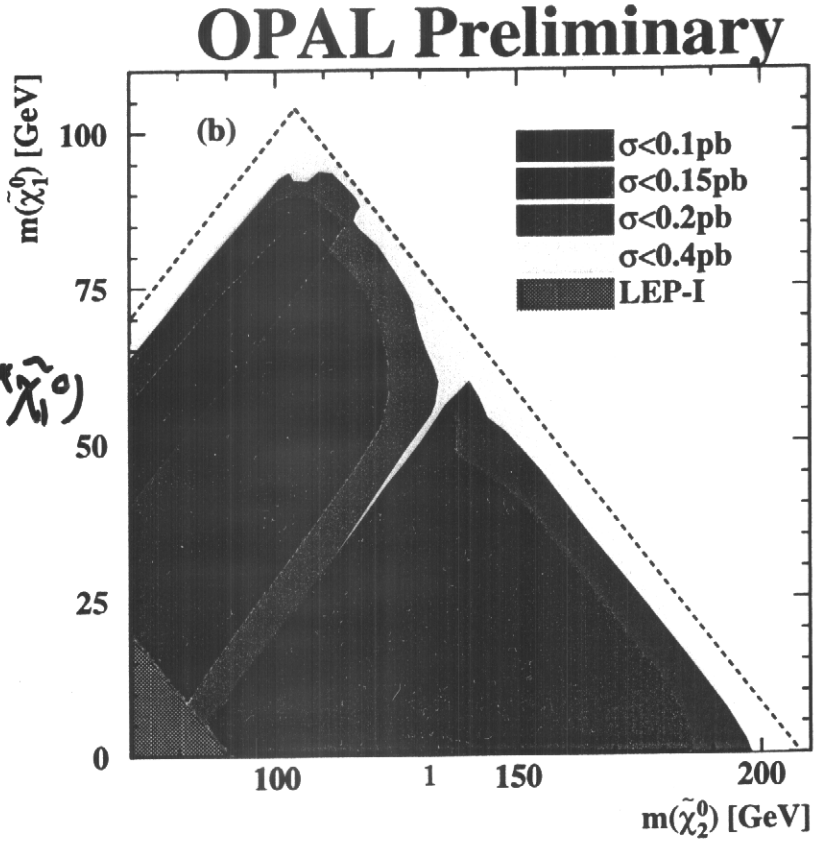
$\tilde{\chi}_1^+\tilde{\chi}_1^-$

$Br(\tilde{\chi}_1^\pm \to W^*\tilde{\chi}_1^0) = 100\%$



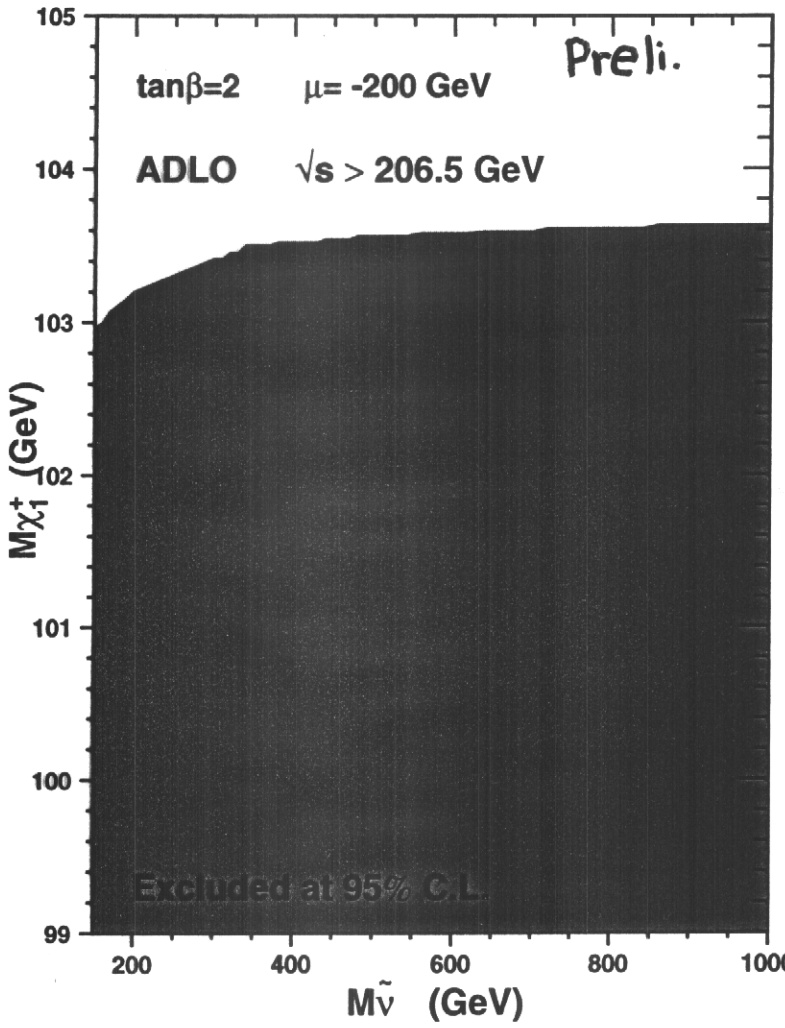
$\tilde{\chi}_1^0\tilde{\chi}_2^0$

$Br(\tilde{\chi}_2^0 \to Z^*\tilde{\chi}_1^0) = 100\%$



Derive " absolute mass limit " within MSSM

Lower-limit on $\tilde{\chi}_1^{\pm}$ mass as function of $\tilde{\nu}$-mass



← $m_{\tilde{\chi}_1^{\pm}} >$ 103.5 GeV

(For $m_{\tilde{\nu}} >$ 300 GeV)

Large m_0 case

small m_0 case

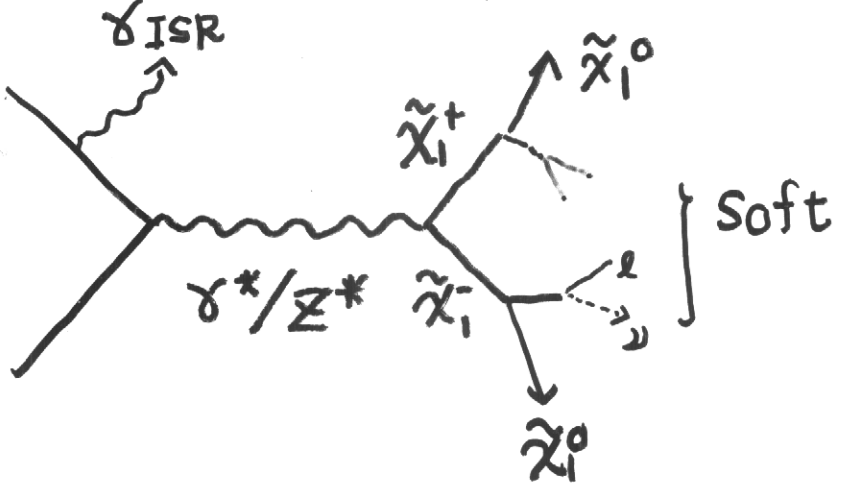
$m_{\tilde{\chi}_1^{\pm}} > 98.6$ GeV (for all $\tan\beta$, μ, ...)

$\Delta m > 3$ GeV

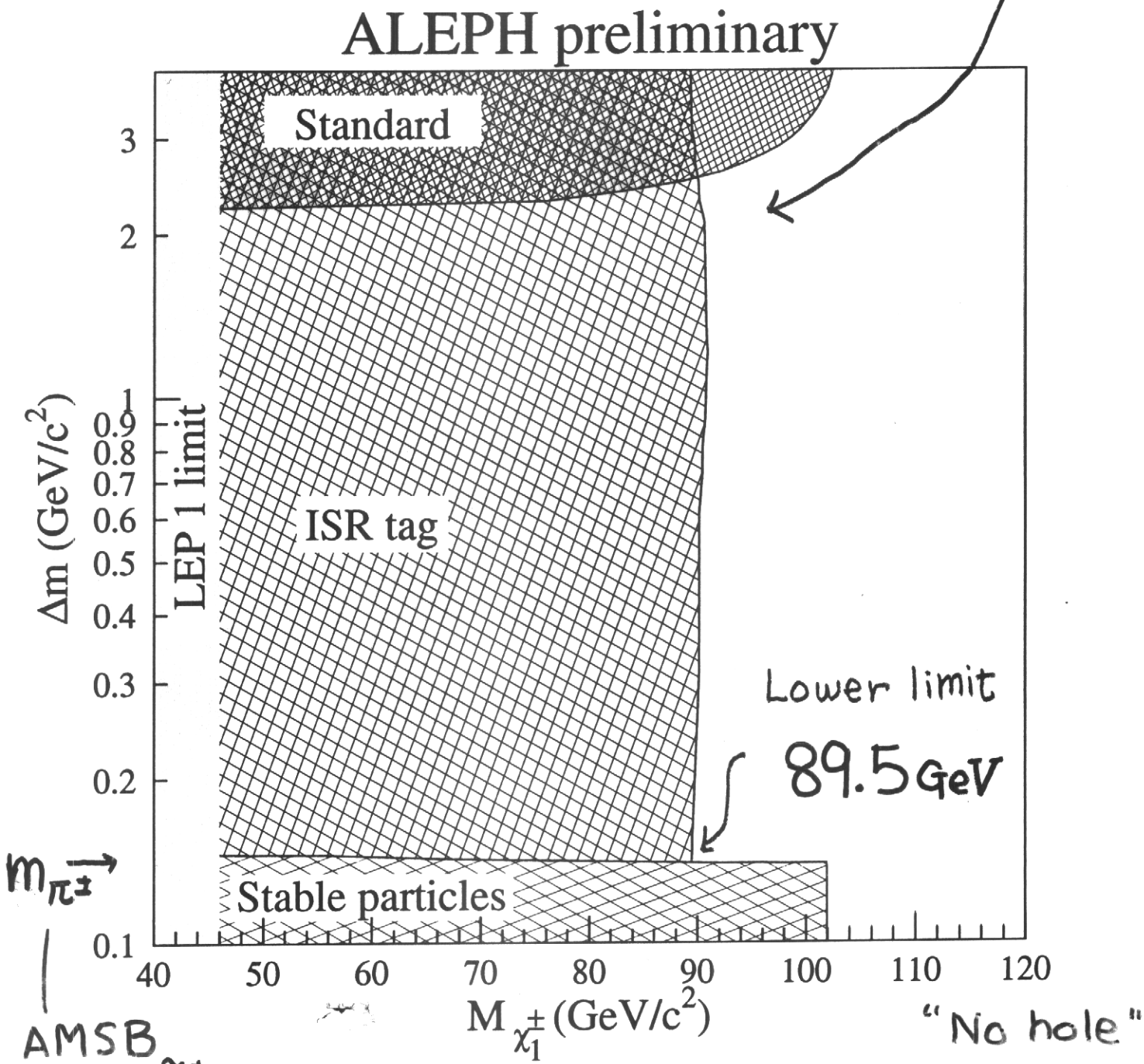
DELPHI

(Preliminary result)

If $\Delta m < 3\,GeV$ no sensitivity in "standard" search



γ_{ISR}-tag covers $\gamma + X +$ missing search



$m_{\pi^\pm}$

AMSB

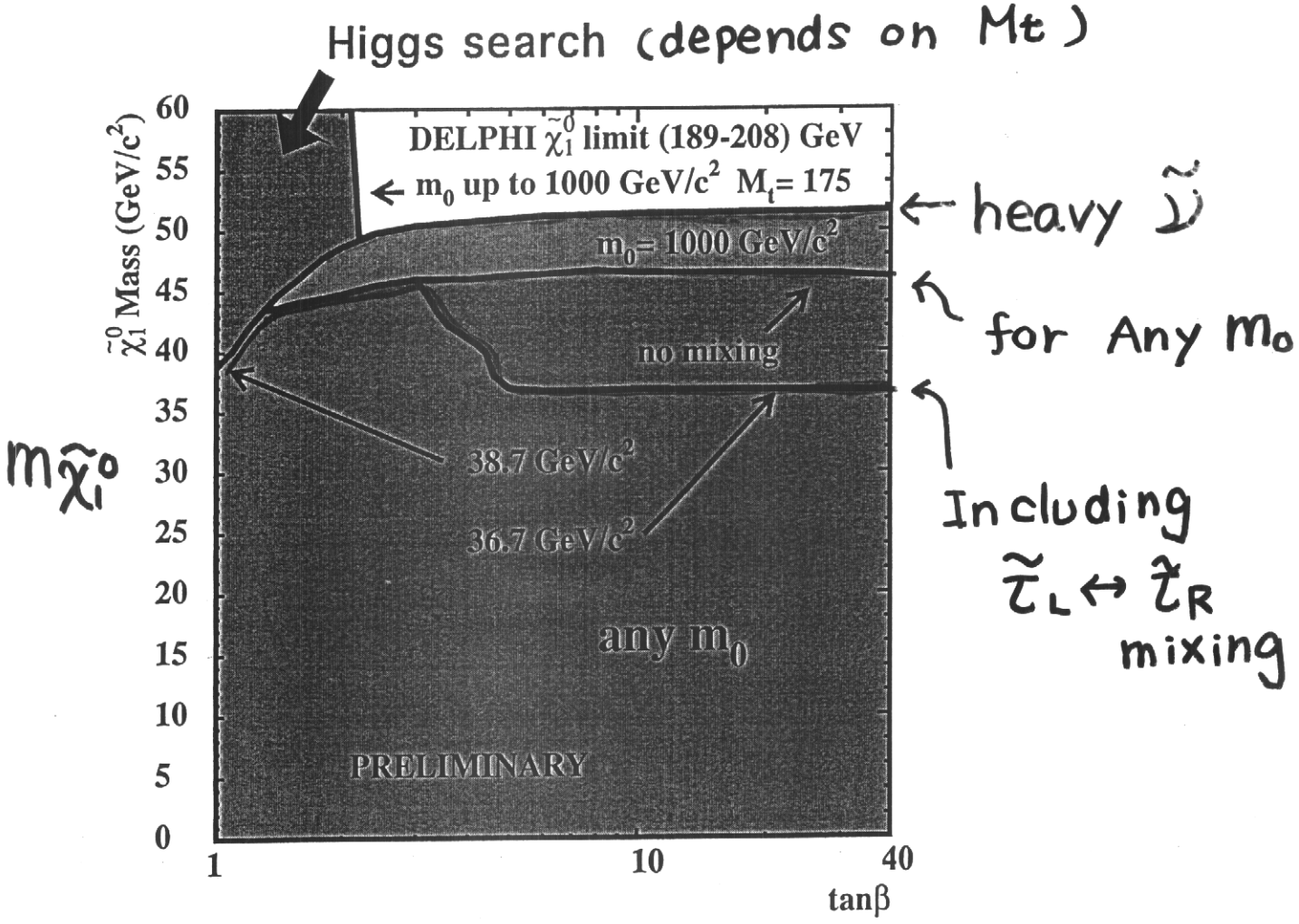
"No hole"

$\tilde{\chi}_1^\pm$ can not decay inside of Detector.

▸ MSSM

Lower-limit on $\tilde{\chi}_1^0$ mass can be obtained using results of $\tilde{\chi}^\pm$, $\tilde{\chi}_1\tilde{\chi}_2$, $\tilde{l}^\pm$ search

$\tilde{\chi}_1^0$ is good candidate of DM.



absolute Limit on $\tilde{\chi}_1^0$ mass

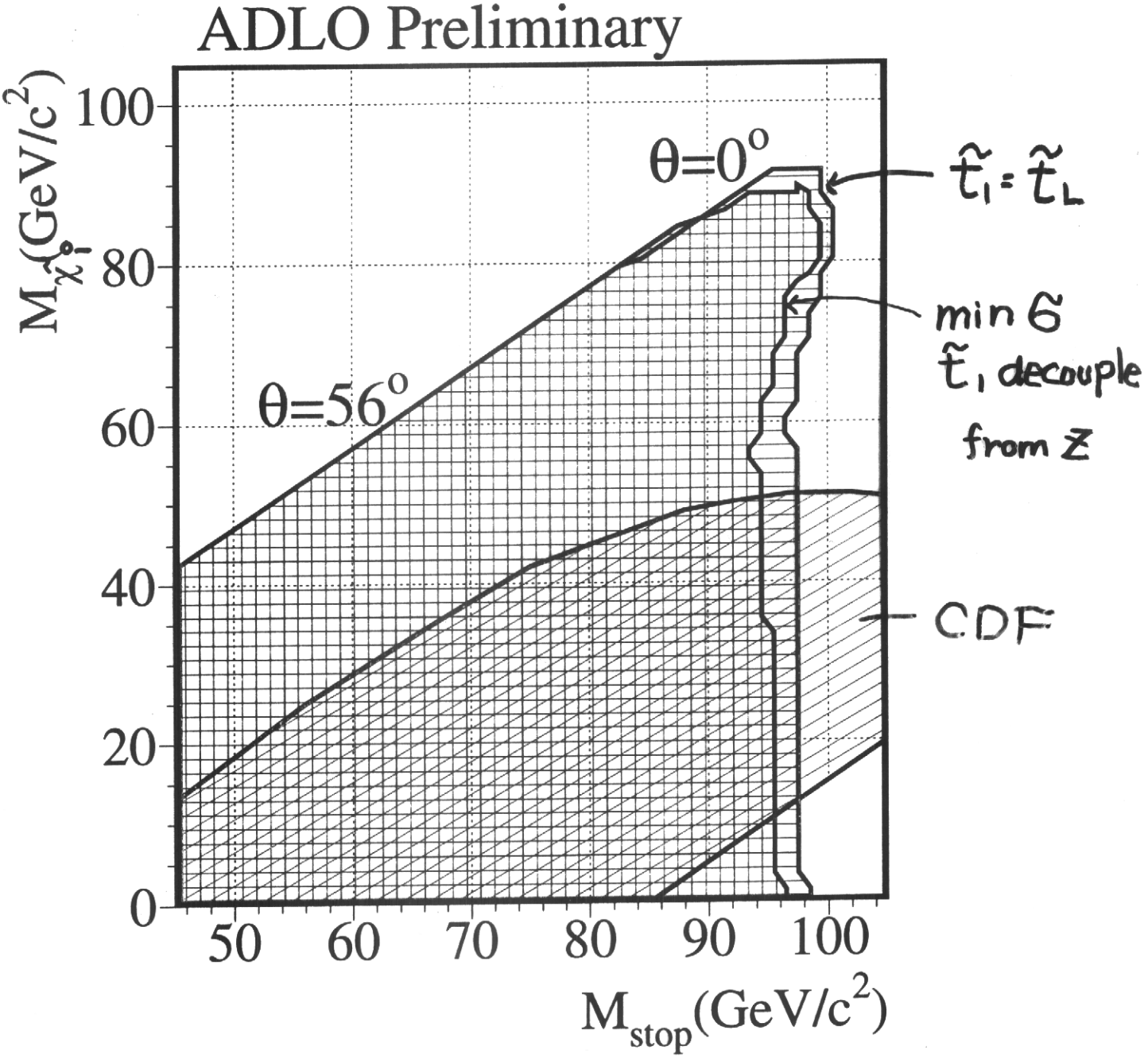
38.7 GeV (for large m_0)

36.7 GeV (Any m_0)

(5) $\tilde{t}_1$ (MSSM) Leading contribution to Δm_h^2

FC $\tilde{t} \to c + \tilde{\chi}_1^0$ ($m_{\tilde{\chi}} > m_{\tilde{t}}$)

No signal was found.

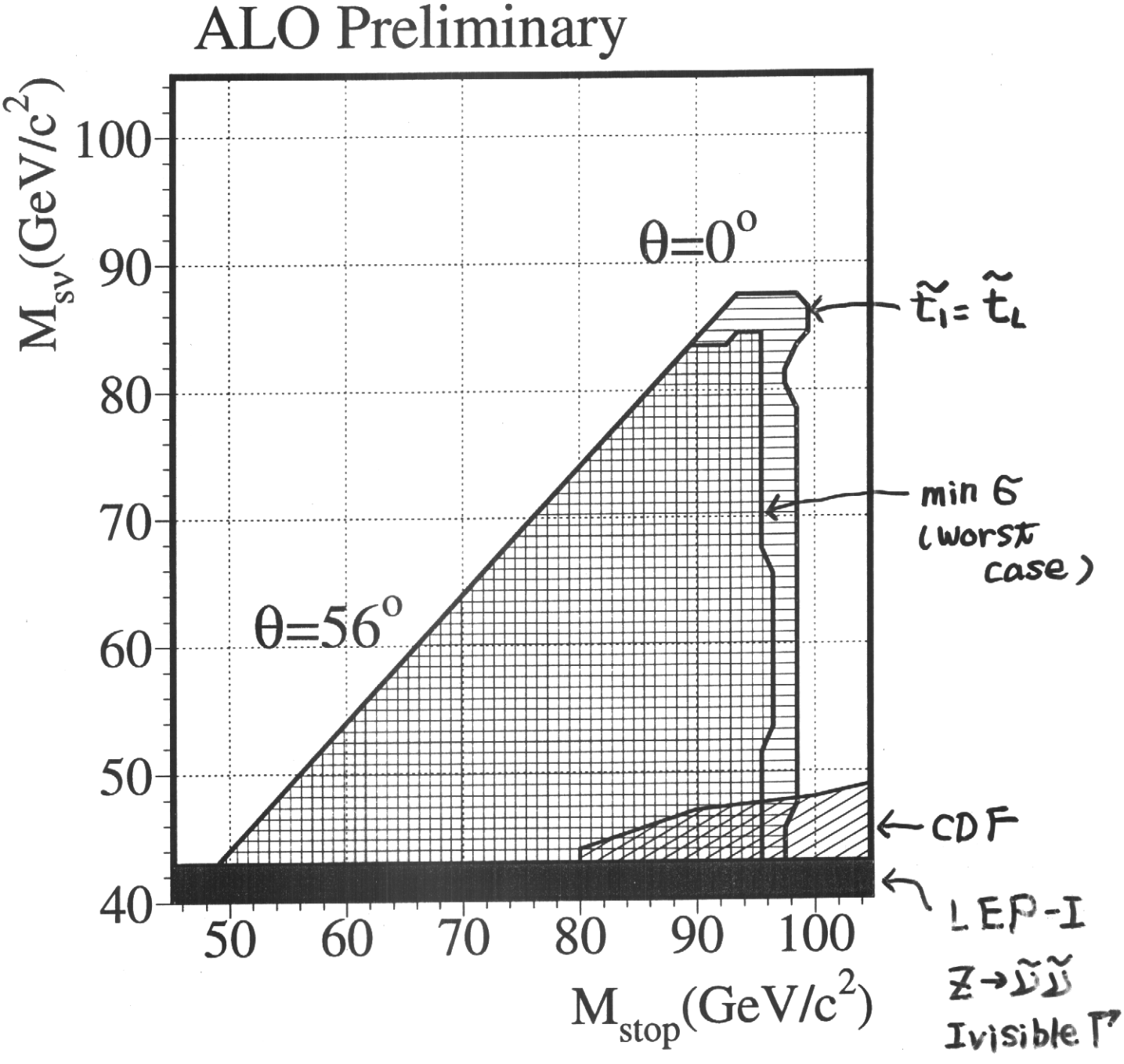


$m_{\tilde{t}_1} >$ 96 GeV (θ=0)
93 GeV (θ=56°)
$\Delta m > 5$ GeV

IF($m_{\tilde{\nu}} < m_{\tilde{t}} - m_b$)

$\tilde{t}_1 \to b \ell^+ \tilde{\nu}$ dominant process

No evidence was found.



$m_{\tilde{t}} >$ 97 GeV ($\theta = 0°$)

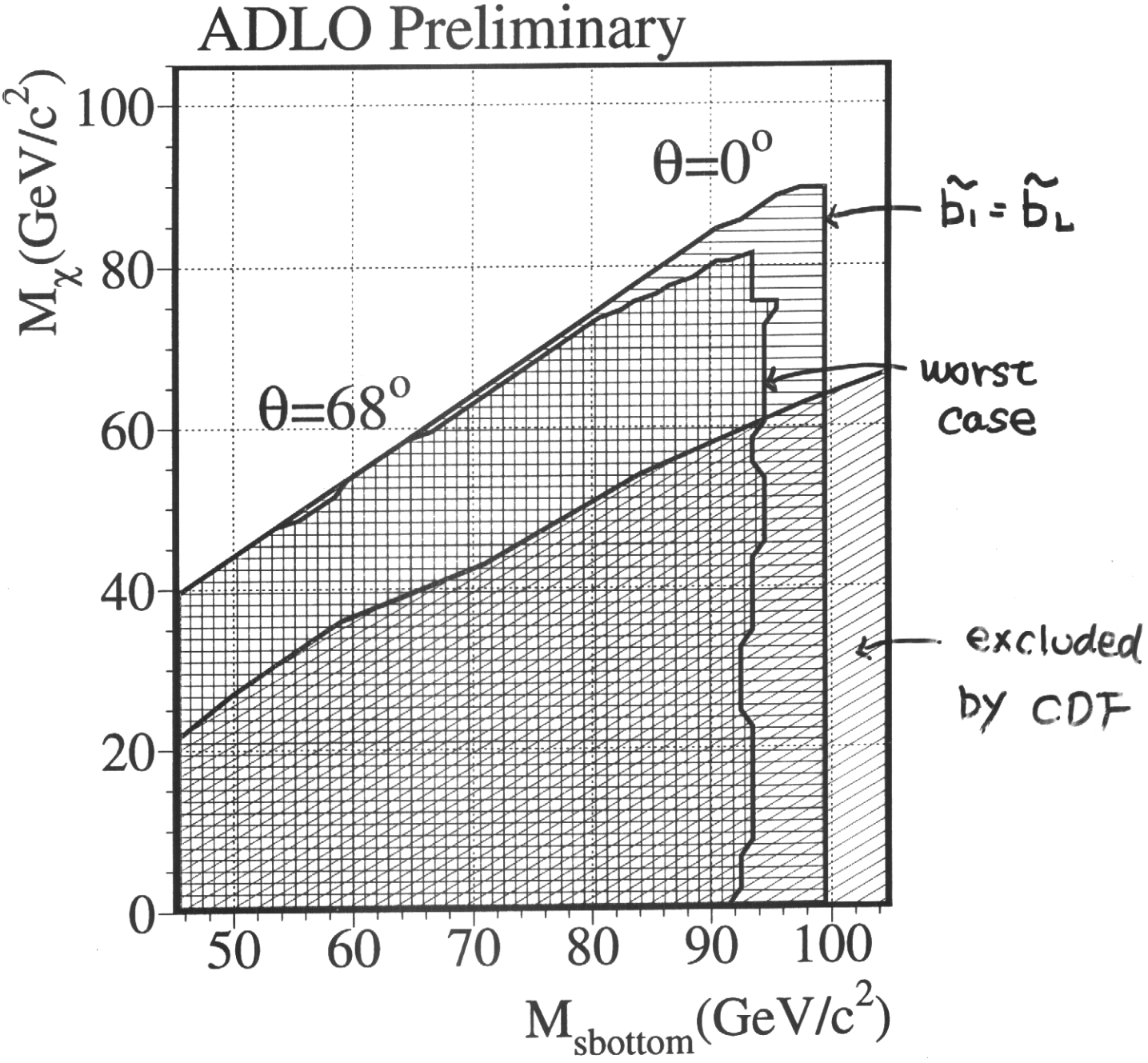
94 GeV ($\theta = 56°$)

$\Delta m > 10$ GeV

$\tilde{b}_1$ (Large tanβ MSSM)

$ee \to \tilde{b}_1 \bar{\tilde{b}}_1 \to b\bar{b}\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$ Acoplanar b-jets

No evidence



$m_{\tilde{b}_1} > 99$ GeV ($\theta=0$)

92 GeV ($\theta=68°$) (worst)

$\Delta m > 10$ GeV

(6) $\tilde{g}$ as LSP (DELPHI)

Some models predict "$\tilde{g}$ is LSP."

$\tilde{g}$ is stable, but carries colour charge.

↓

$\tilde{g}$ fragments into $\tilde{R}$-hadron.

($\tilde{R}^{\pm}$, $\tilde{R}^{0}$)

- $\tilde{R}^{\pm}$ (Charged): high $\frac{dE}{dx}$ in TCP

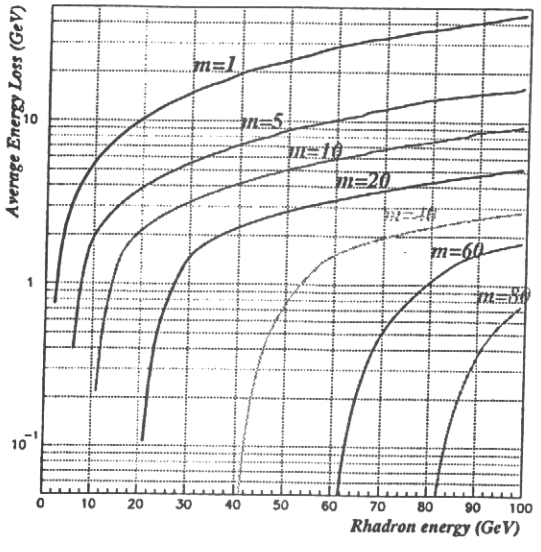
  (since β of $\tilde{R}^{\pm}$ is small)

- $\tilde{R}^{0}$ (Neutral): Some E deposits in calorimeters.

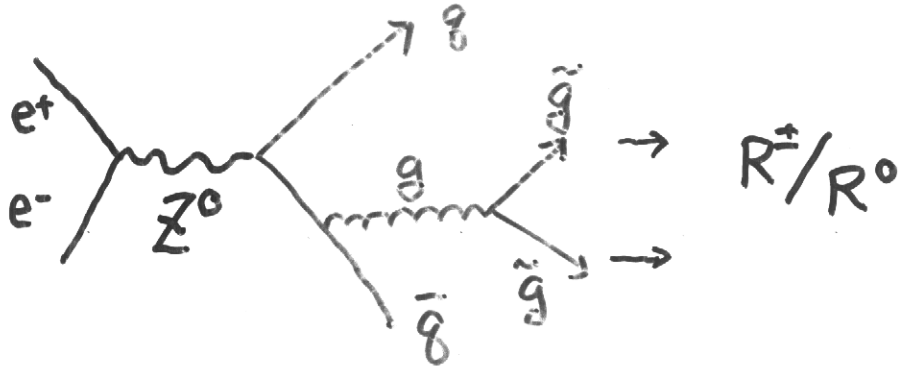
  but not all.

  ↳ Some $\not{E}$

  (since $\tilde{R}^{0}$ is heavy. Energy Loss becomes small)

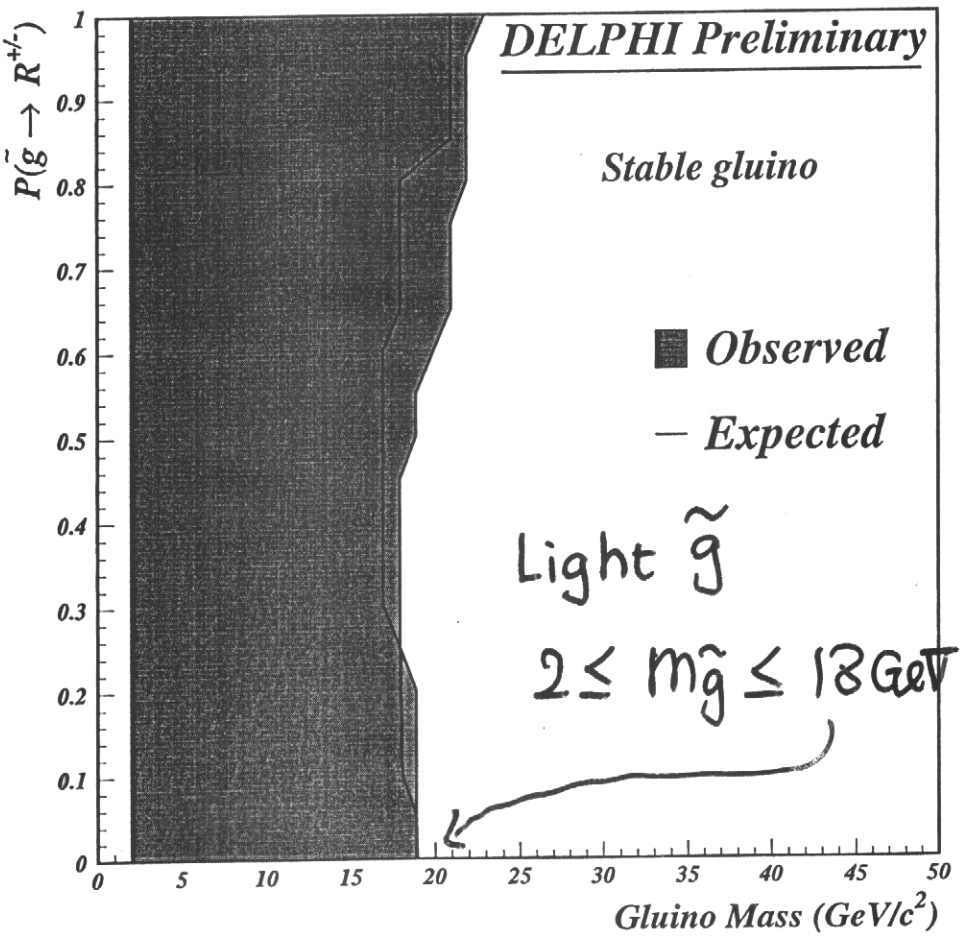


at LEP-I



Event topology :

- 2 jet + 2 high $\frac{dE}{dx}$ track
- 2 jet + high $\frac{dE}{dx}$ track + Isolated E + $\not{E}$
- 2 jet + 2 Isolated $E_{cluster}$ + $\not{E}$



at LEP-I (Z^0-pole)

Light $\tilde{g}$

$2 \leq m_{\tilde{g}} \leq 18$ GeV Excluded

(7) If R is vaiolated

$$\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

→ LSP ($\tilde{\chi}_1^0$) decays into SM fermions.

For example, $\tilde{\chi}_1^+ \tilde{\chi}_1^-$

λ: 6ℓ, $4\ell + \not{E}$, $2\ell + \not{E}$, $4q + 4\ell + \not{E}$,
$4q + 5\ell + \not{E}$, $6\ell + \not{E}$

λ': $4q + 2\ell$, $4q + 1\ell + \not{E}$, $4q + \not{E}$,
$8q + 2\ell$, $8q + 1\ell + \not{E}$, $8q + \not{E}$
$6q + 3\ell + \not{E}$, $6q + 2\ell + \not{E}$, $6q + 1\ell + \not{E}$
$4q + 4\ell + \not{E}$, $4q + 3\ell + \not{E}$, $4q + 2\ell + \not{E}$

λ'': $6q$, $8q + 1\ell + \not{E}$, $6q + 2\ell + \not{E}$, $10q$

⇨ 18 topologies !!!

e^+e^- is clean system,
→ we have checked almost all topologies

⇨ No edivence

[2] Non-SUSY

(1) Excited Lepton $\ell^{\pm *}$

(2) 4-th generation Lepton $L^{\pm}, L^{0}$

(3) Lepto-quark

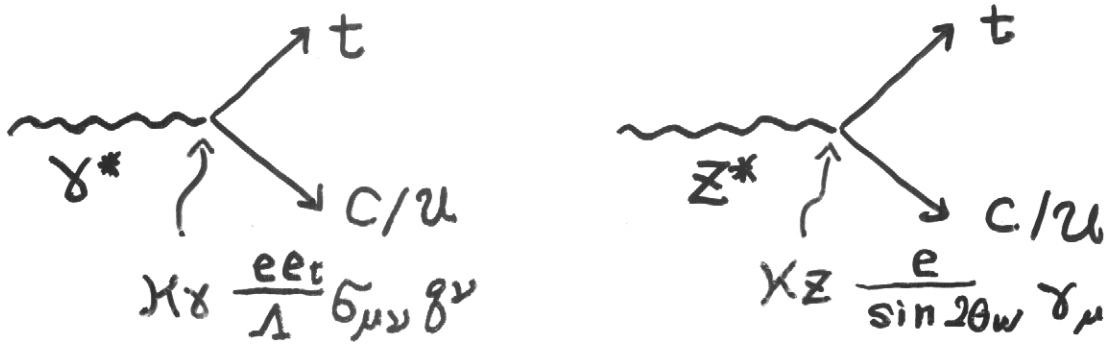
(4) Technicolour

(5) Flavour-Changing

- Single top production
- exotic decay of b, c

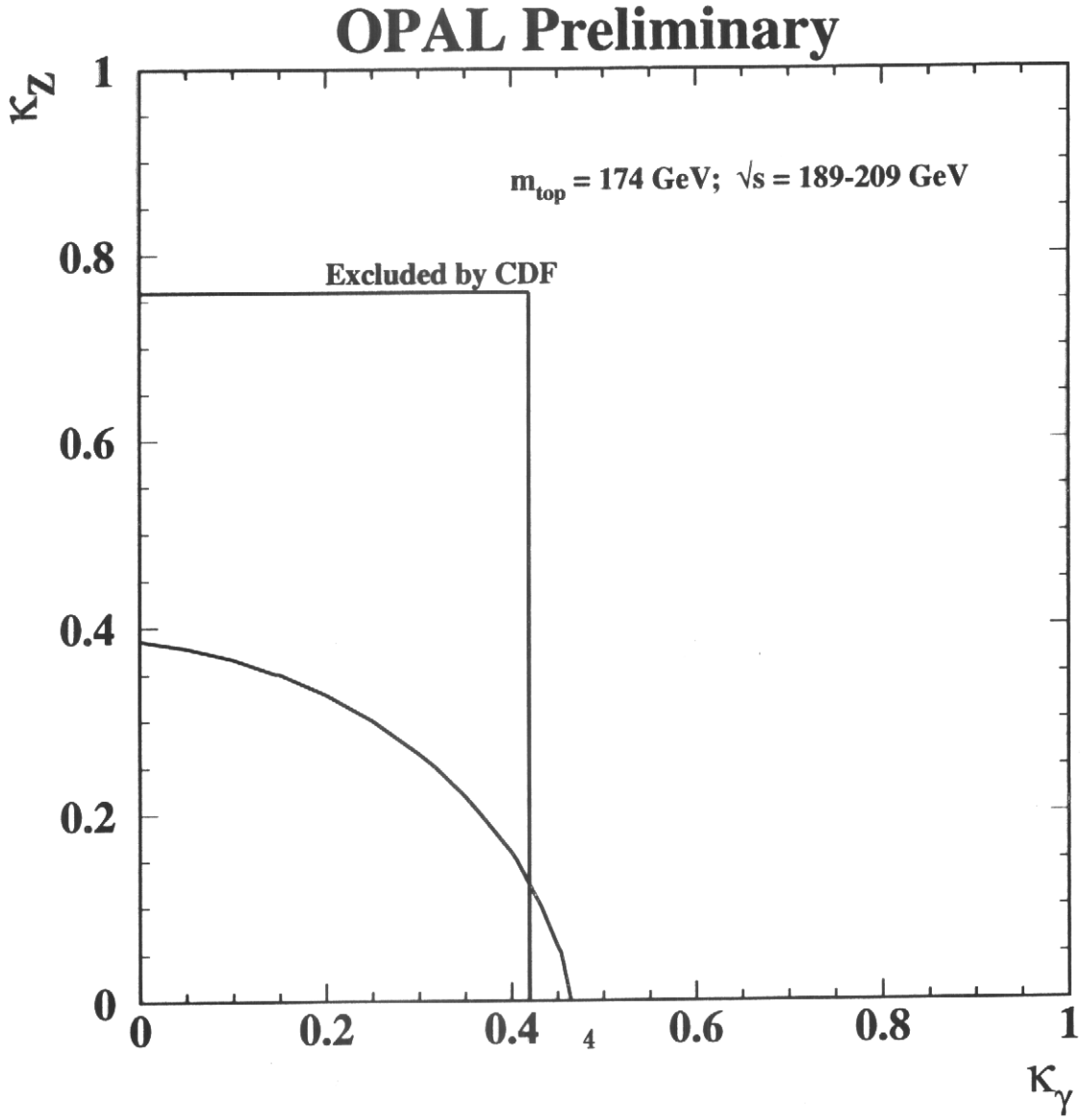
No evidence was observed.

FCNC vertex



$\kappa_\gamma \frac{e e_t}{\Lambda} \sigma_{\mu\nu} q^\nu$ $\kappa_Z \frac{e}{\sin 2\theta_W} \gamma_\mu$

- LEP-II Single top production.
- Tevatron & LHC FC Decay of Top



Conclusion

- New particles and phenomena are searched for.

  Not only Susy but also Technicolour, 4-th gen. Lepton, excited Lepton, FCNC. ....

  Almost all possible topologies are covered.

- No excess above 2.5 σ was found unfortunately.

- Derive Lower-Limit on mass (GeV)

$\chi_1^\pm$	98.6 ($\Delta m > 3$)	103.5 ($m_{\tilde{\nu}} > 300$)	
$\tilde{\chi}_1^0$	36.7 (All)	38.7 (")	
$\tilde{e}^-$	98 ($\Delta m > 3$)	76	(GMSM Large $\tan\beta$)
$\tilde{\mu}^-$	94 (")		
$\tilde{\tau}^-$	80 ($\Delta m > 10$)		
$\tilde{t}_1$	93 ($\Delta m > 5$)		
$\tilde{b}_1$	92 ($\Delta m > 10$)		

MSSM