DØ Note 3135

Supersymmetry Searches at the TeVatron and HERA: Results and Prospects

- Strategies
- Experimental Issues
- Higgs
- Winos, Zinos
- Squarks, Gluinos
- Stop
- Photon Final States
- Futures
- Hera
- Conclusions

RECENT RESULTS

- H. E. Montgomery
- LHCC SUSY Workshop,
- Oct. 30, 1996

Tevatron Phenomenology

* SUSY particles are pair-produced
  ASSUMPTION: R-PARITY CONSERVATION

* Squarks, gluinos strongly produced
  cascade --- charginos, neutralinos,
  final state includes 2 LSP's

* Charginos, neutralinos weakly produced,
  cascade decays
  final state includes 2 LSP's

* lighter top squark mass lighter than top?
  if also lighter than lightest chargino
  and W + LSP, 100% BF —> c + LSP

* Proportion of leptonic final states depends
  on slepton masses relative to chargino &
  neutralino masses

Tevatron Strategies

Search topologies:

- squark/gluino
  - multi jets + missing E_T
  - dilepton + $\geq$ 2 jets + missing E_T
  - (SUSY baryon decays) FT. EXPERIMENT
- top squark
  - 2 jets + missing E_T
  - (lepton + jets + missing E_T)
- chargino/neutralino
  - 3 leptons + missing E_T
- charged Higgs
  - τ + jets + missing E_T

Backgrounds!

- Tot. cross section 80 mb
- Normal Events have few jets
- Few Events have lots of jets
- Few events have leptons

  (few 10^-4 rejection of jets)

- --> Missing E_T Spectrum

  CRITICAL !

  – Resolution
  – Mismeasurement
  – Misassignment of Vertex (MI)

  • CUT AROUND JET DIRECTIONS

  • RECHECK VERTEX.

- Expected Signals... ~1 pb

$\not{E}_T$ → background.

Higgs Limits

DØ • Bosonic Higgs (lepton BR low) $WH \to \gamma\gamma$

Mass greater than 73.5 GeV

DØ • Associated Production $WH \to b\bar{b}$

Xsec* BR LT 50 - 10 pb, 95% CL

CDF • Charged Higgs

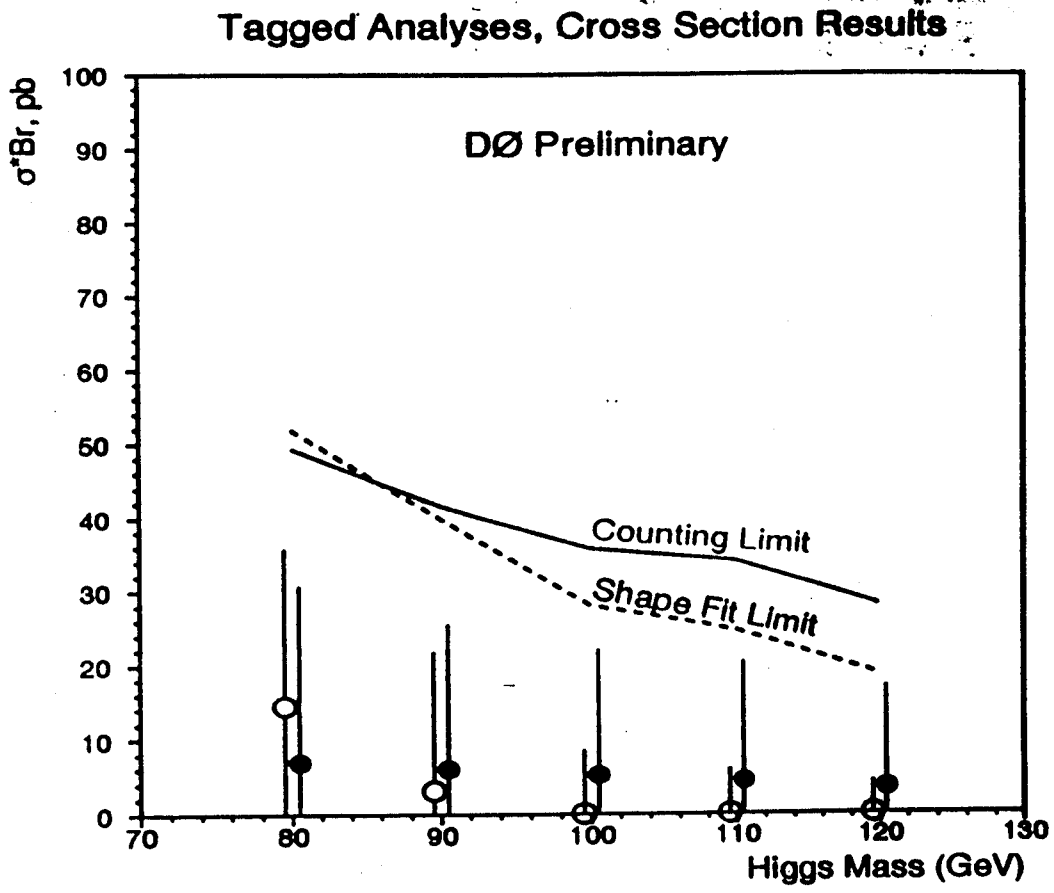
M_H > 130 GeV, Large tan Beta

Associated Higgs Production

Analysis: require W --> eν or μν;
>= 2 jets, $|\eta| < 2$, $E_T > 15$ GeV
soft muon tag on at least one jet

Counting experiment: observe 27 evts, calculate
25 + - 3 from bkgs

Dijet mass fits (using SM H^0 MC for signal template)

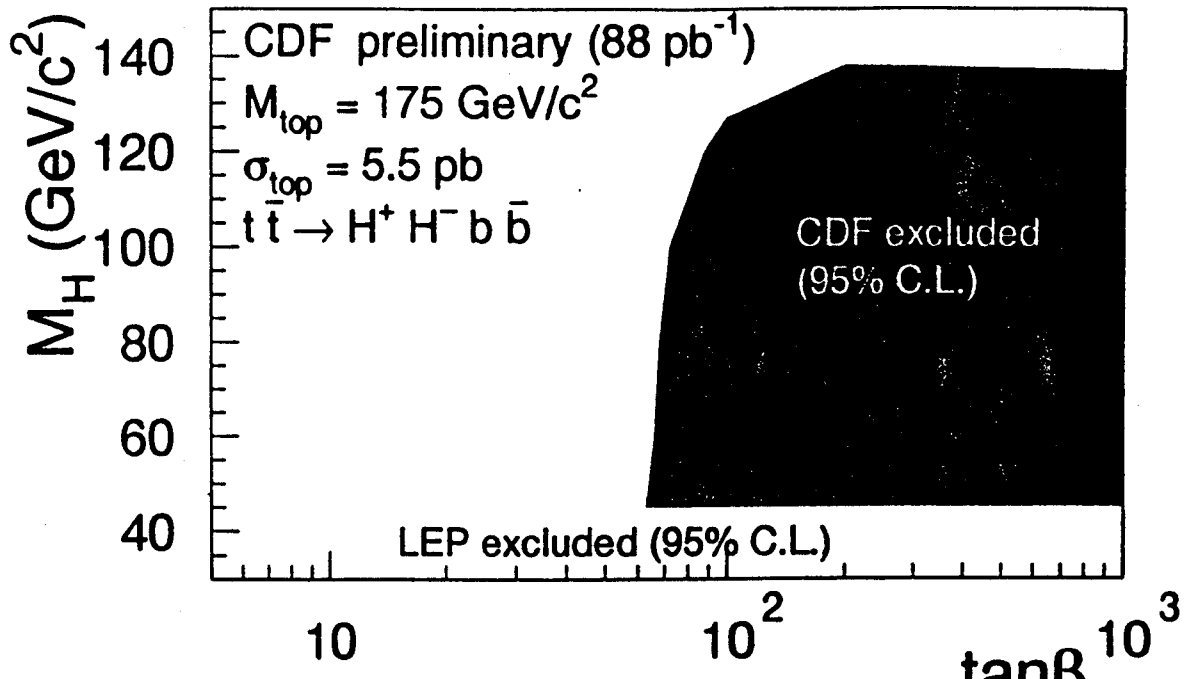


Charged Higgs Search

large tan β $t \to H^+ b$, $H^+ \to \tau \nu$

CDF

SIGNATURE τ jj $e\mu\tau$ +



REQUIRE τ (narrow jet $E_T > 10$ GeV
$n_{ch} = 1, 3$
isolation, $M < 1.8$ GeV)

Candidates: 8 events each with 3 jets

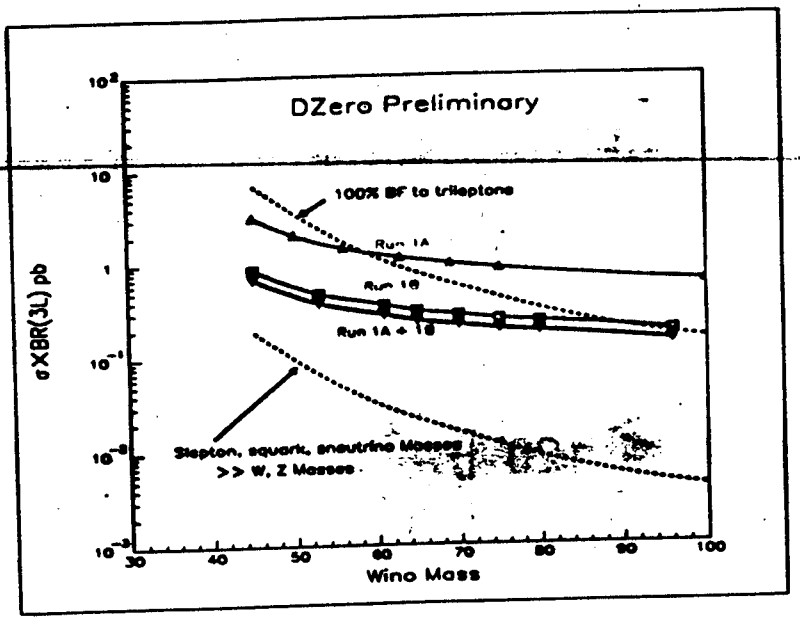
Background: 8.5 ± 1.7 ev.

$M_{H^+} < 140$ GeV for large tan β

Chargino/Neutralino Searches

D0 trilepton search:

$\mathcal{L} \cong 107\ pb^{-1}$

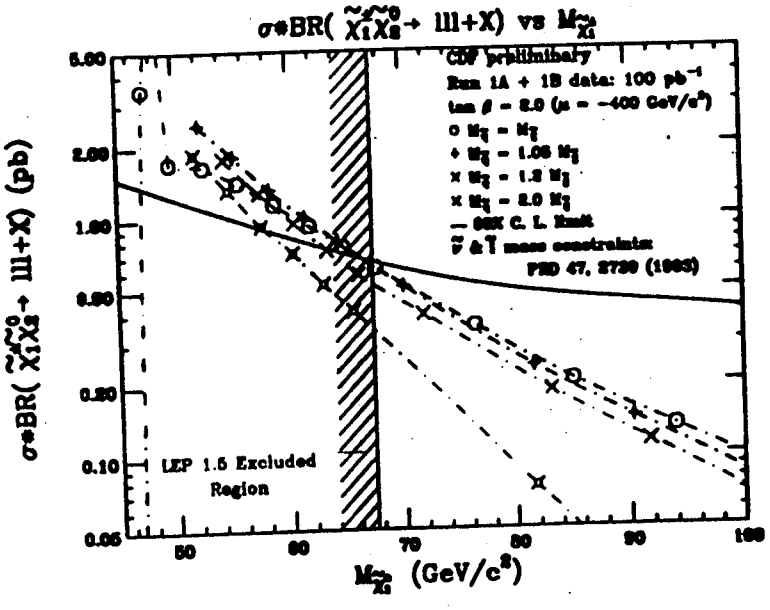


4 channels:

eee, eeμ, eμμ, μμμ

CDF trilepton search:

$\mathcal{L} \cong 110\ pb^{-1}$



CDF → $M_{\tilde{\chi}_1^{\pm}} > 68$ GeV

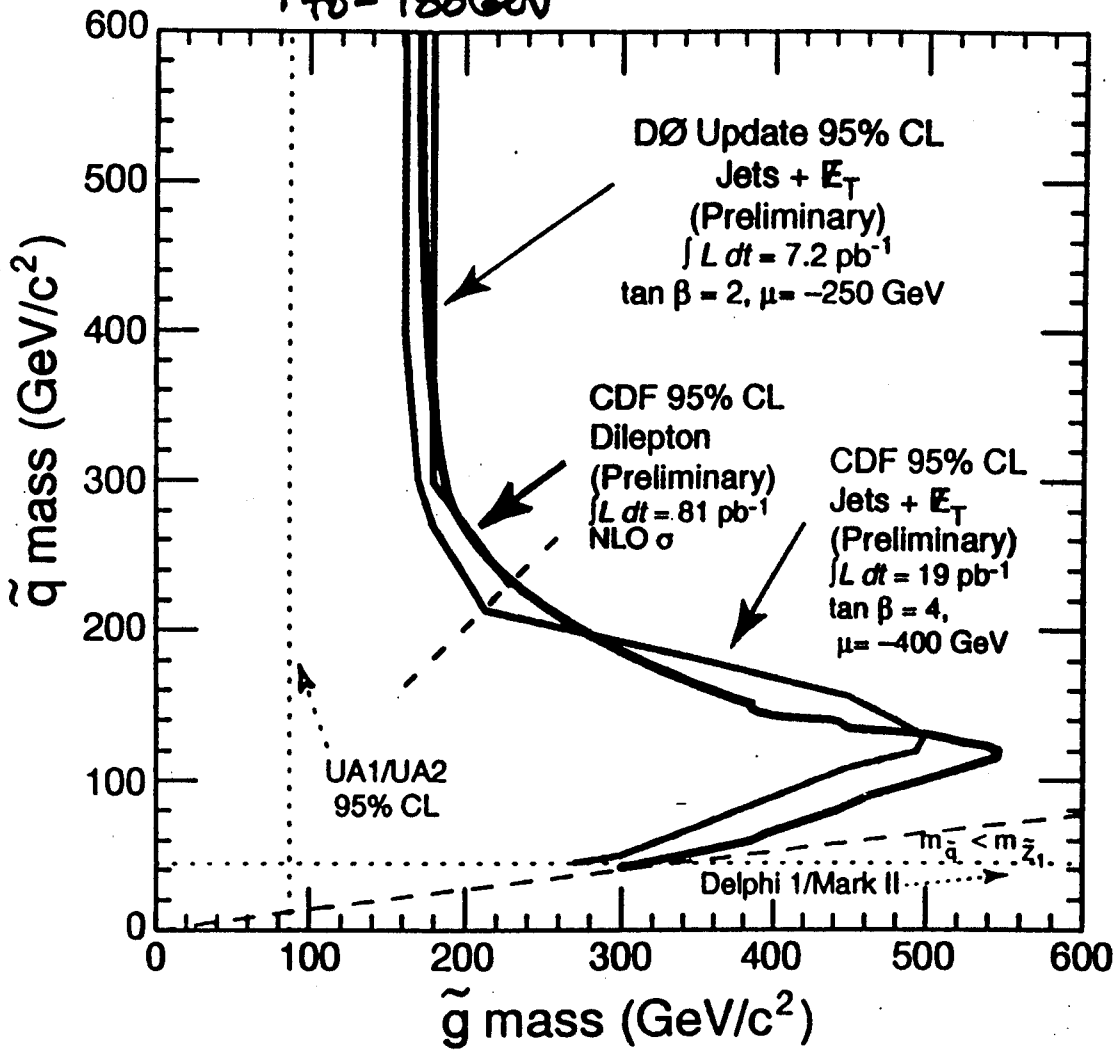
Squark and Gluino Searches

Model framework: SUGRA-inspired MSSM

CDF jets + missing Et - 1992-93 data (19 pb^{-1})
D0 jets + missing Et - 1992-93 data (7 pb^{-1})
CDF 2 lepton + 2 jets + missing Et - 1994-95 data (81 pb^{-1})

Run 1a or

170 - 180 GeV



$M_{\tilde{q}} = M_{\tilde{g}} < 230$ GeV

Squark and Gluino Searches

Model framework: consistent SUGRA

D0 2 electron + 2 jets + missing Et - 1994-95 data (93 pb^{-1})

$2e$, $E_T > 15$ $\eta < 2.5$

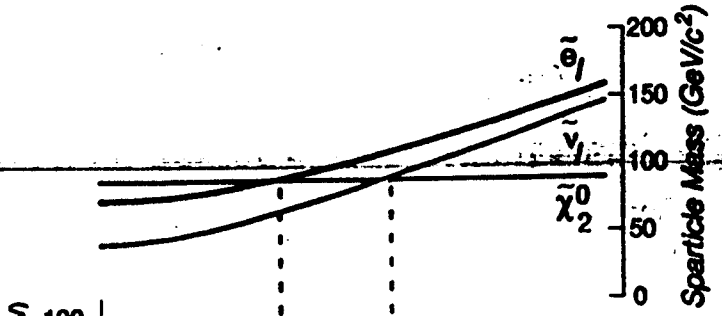
$2j$, $E_T > 20$

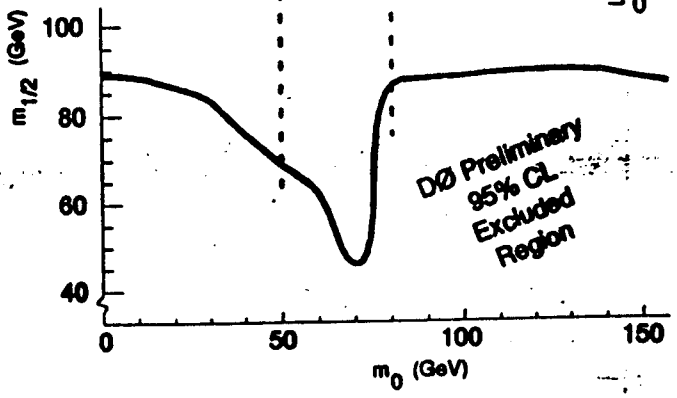
$\not{E}_T > 25$

$\neq M_Z$

2 events

bgd 3 ± 1.3

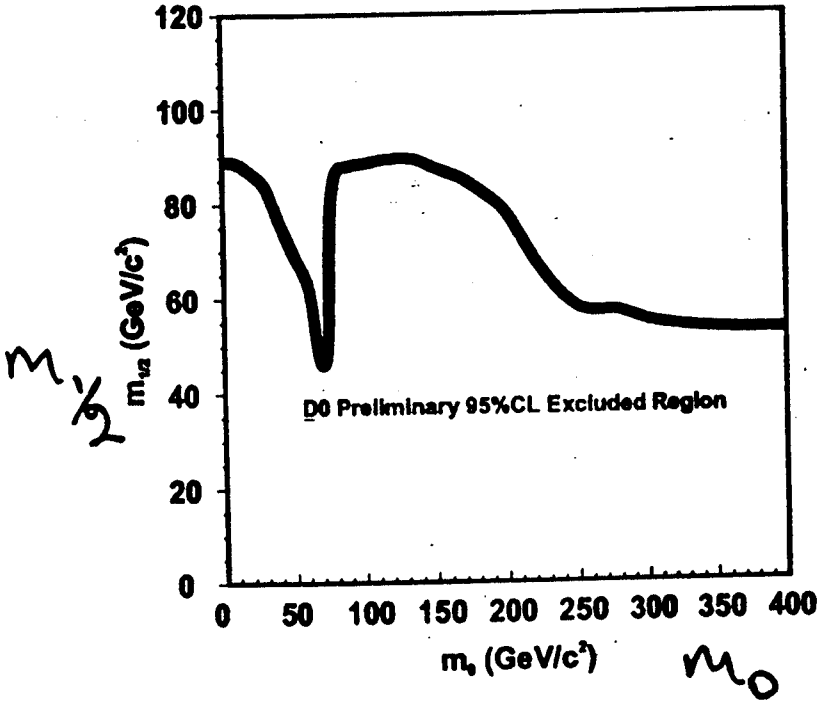




$A_0 = 0$

$\tan\beta = 2$

μ −ve



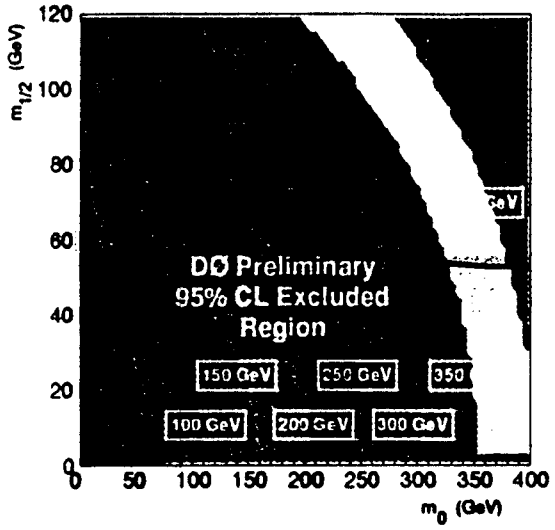
$m_{1/2}$ m_0

Squark and Gluino Searches

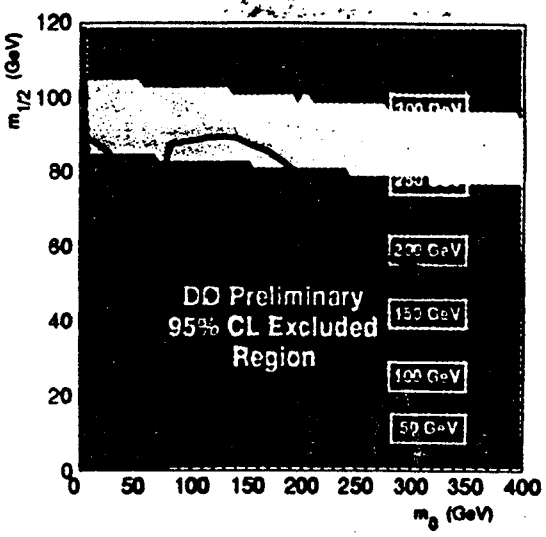
Model framework: consistent SUGRA

D0 2 electron + 2 jets + missing Et - 1994-95 data (93 pb^{-1})

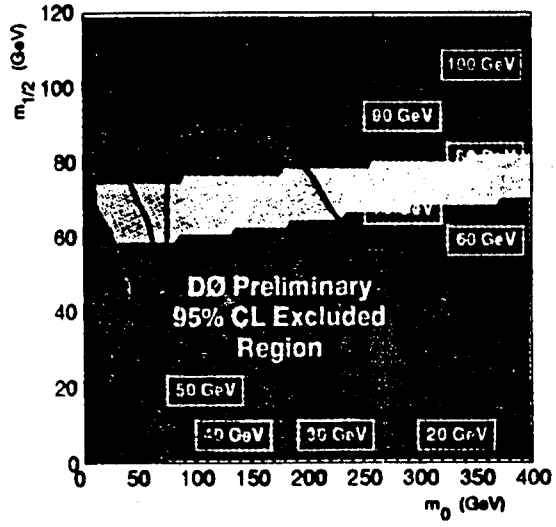
Left Up Squark Mass Contours



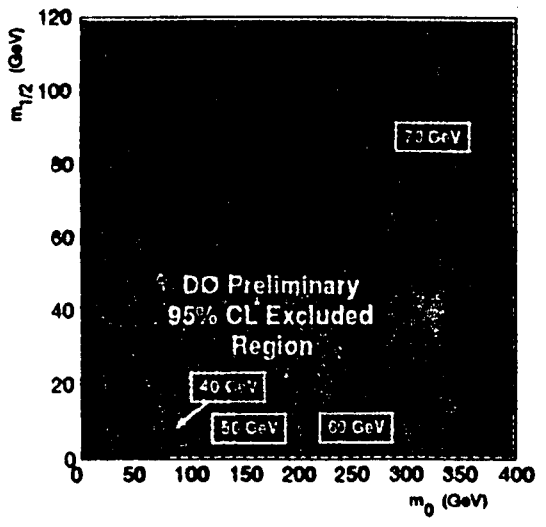
Gluino Mass Contours



Lightest Chargino Mass Contours



Light Neutral Higgs Mass Contours



Top Squark Search

D0 top squark search: 2 jets + missing Et

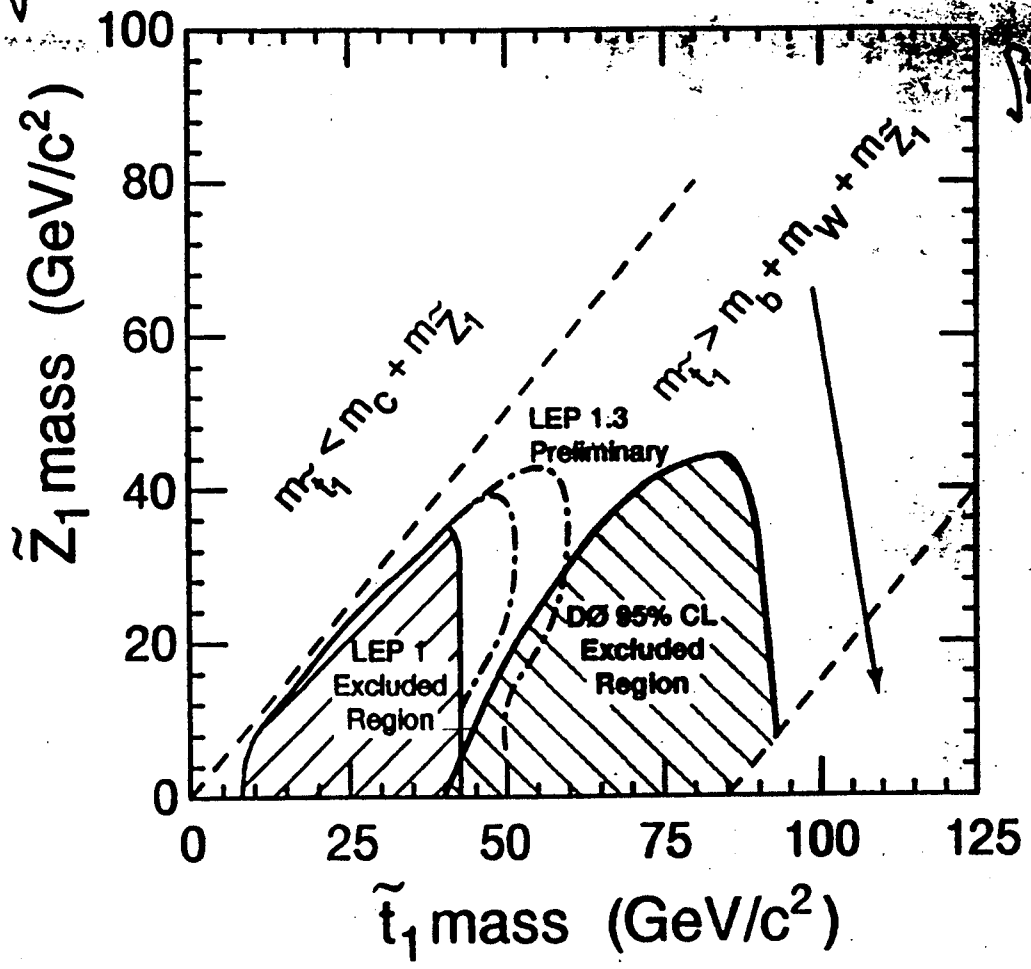
3 candidates; bkg = 3.5 ±1.2

$\tilde{t} \to c\,\tilde{\chi}_1^0$

jet $\not{E}_T$

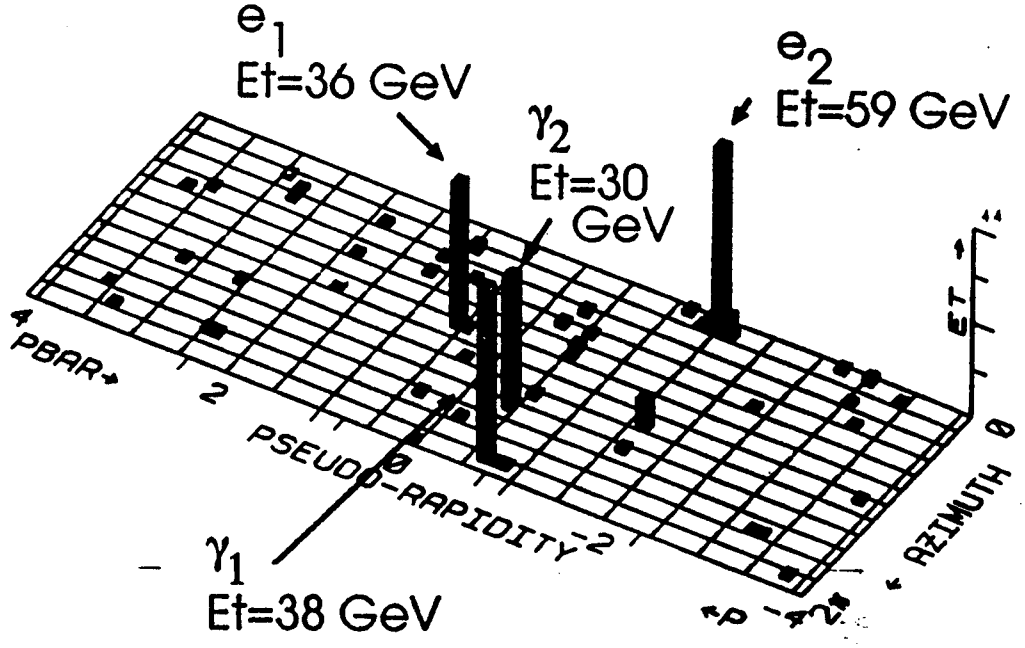
$m_{\tilde{t}} < m_t$?

Assume $m_{\tilde{t}} < m_W + m_b + m_{LSP}$



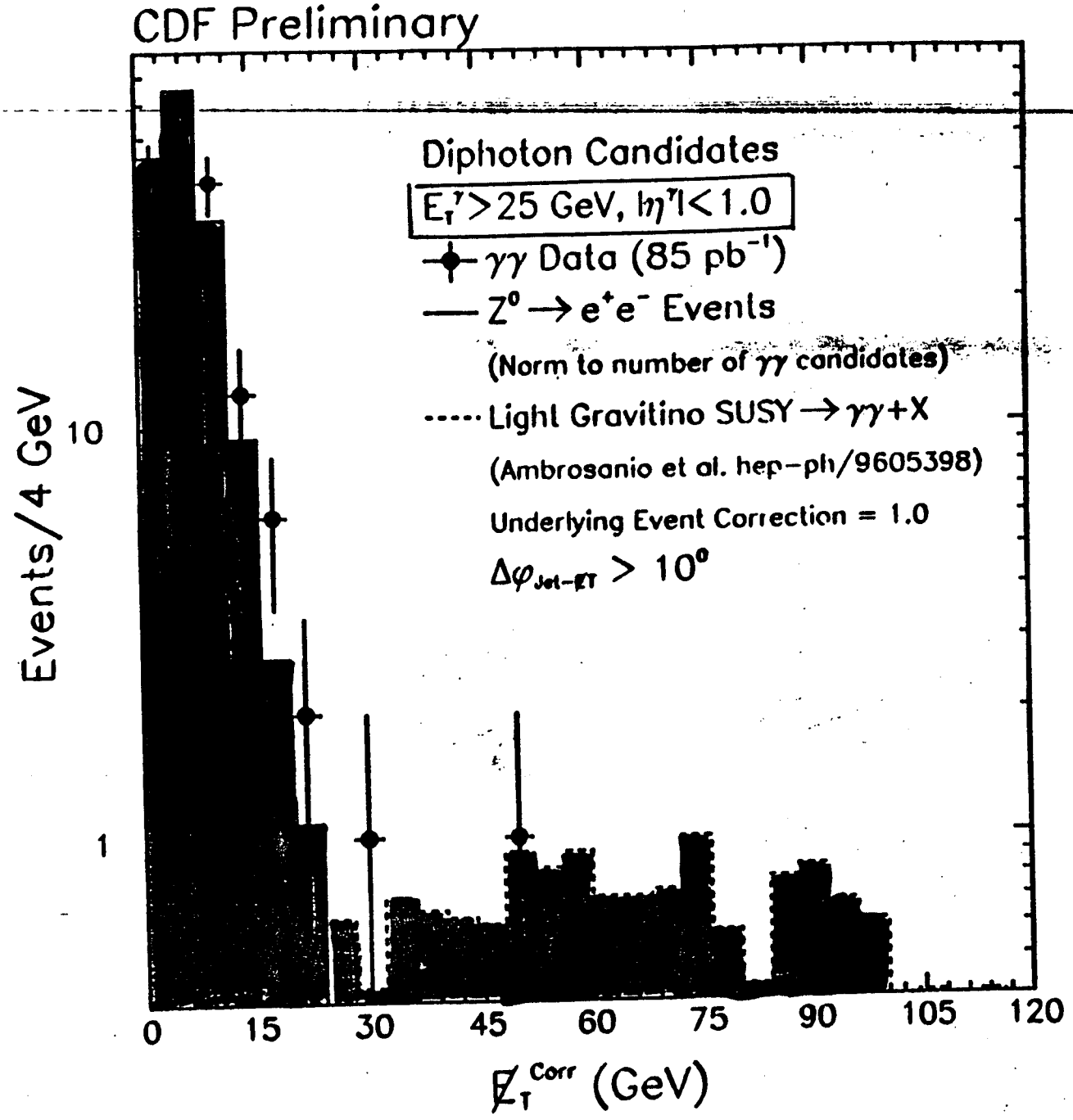
CDF Event

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

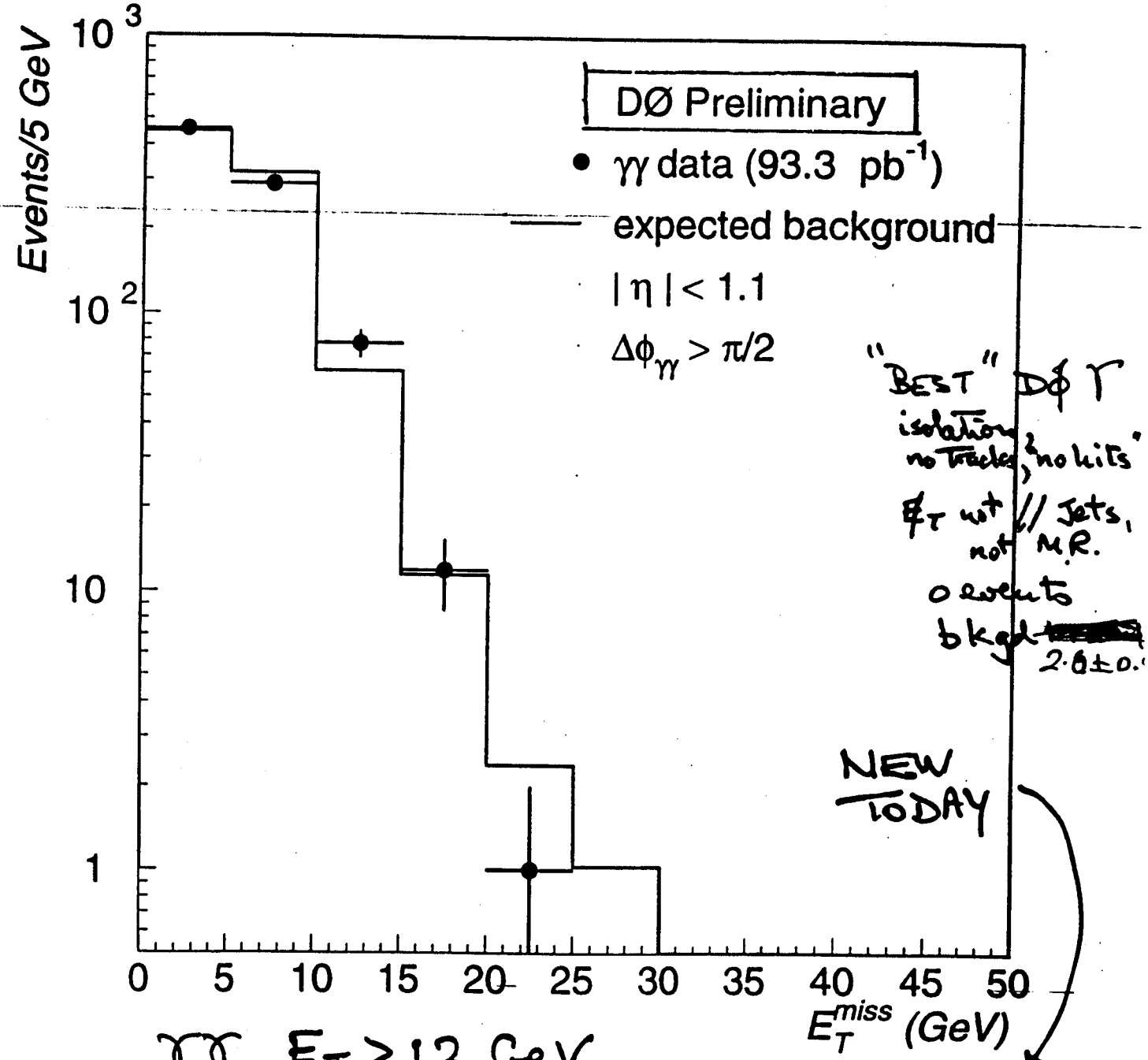


$\not{E}_t$=53 GeV ↖ NOT SHOWN

CDF diphoton + missing E_T search



D0 diphoton + missing E_T search



"BEST" DØ γ
isolation, no tracks, no hits
$\not{E}_T$ not // Jets, not M.R.
0 events
bkgd 2.0±0.

NEW TODAY

$\gamma\gamma$ $E_T > 12$ GeV
$\eta < 1.1$
$\not{E}_T > 25$ GeV
~ MODEL INDEP

→ < 181 fb
95% CL.

15

hep-ph/9605398
May 1996

Search for supersymmetry with a light gravitino at the Fermilab Tevatron and CERN LEP colliders

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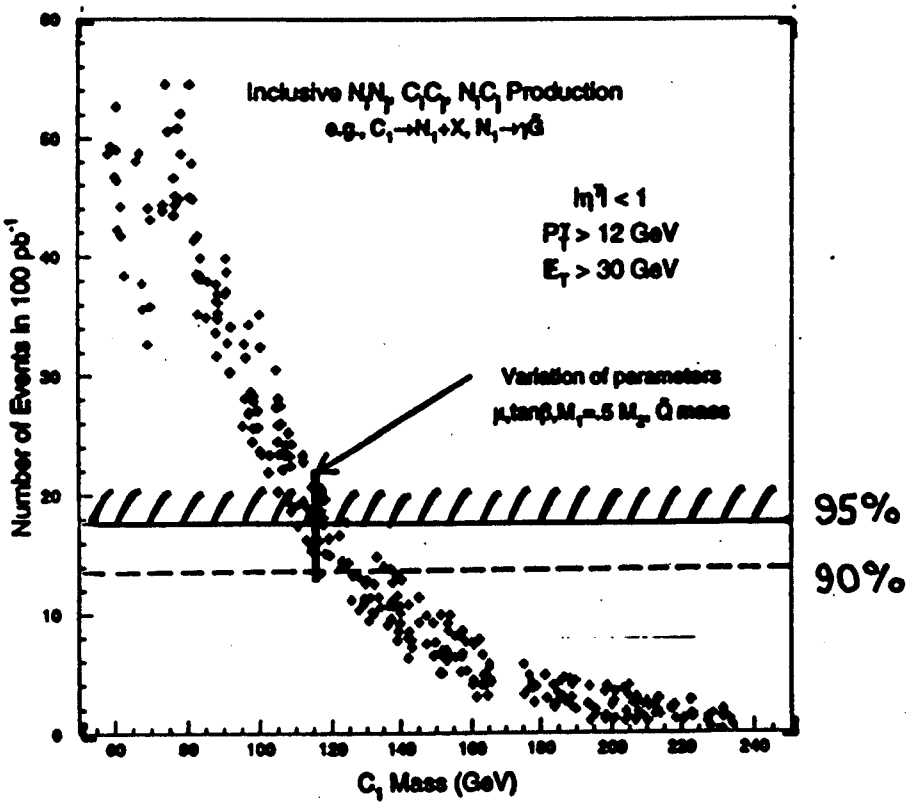
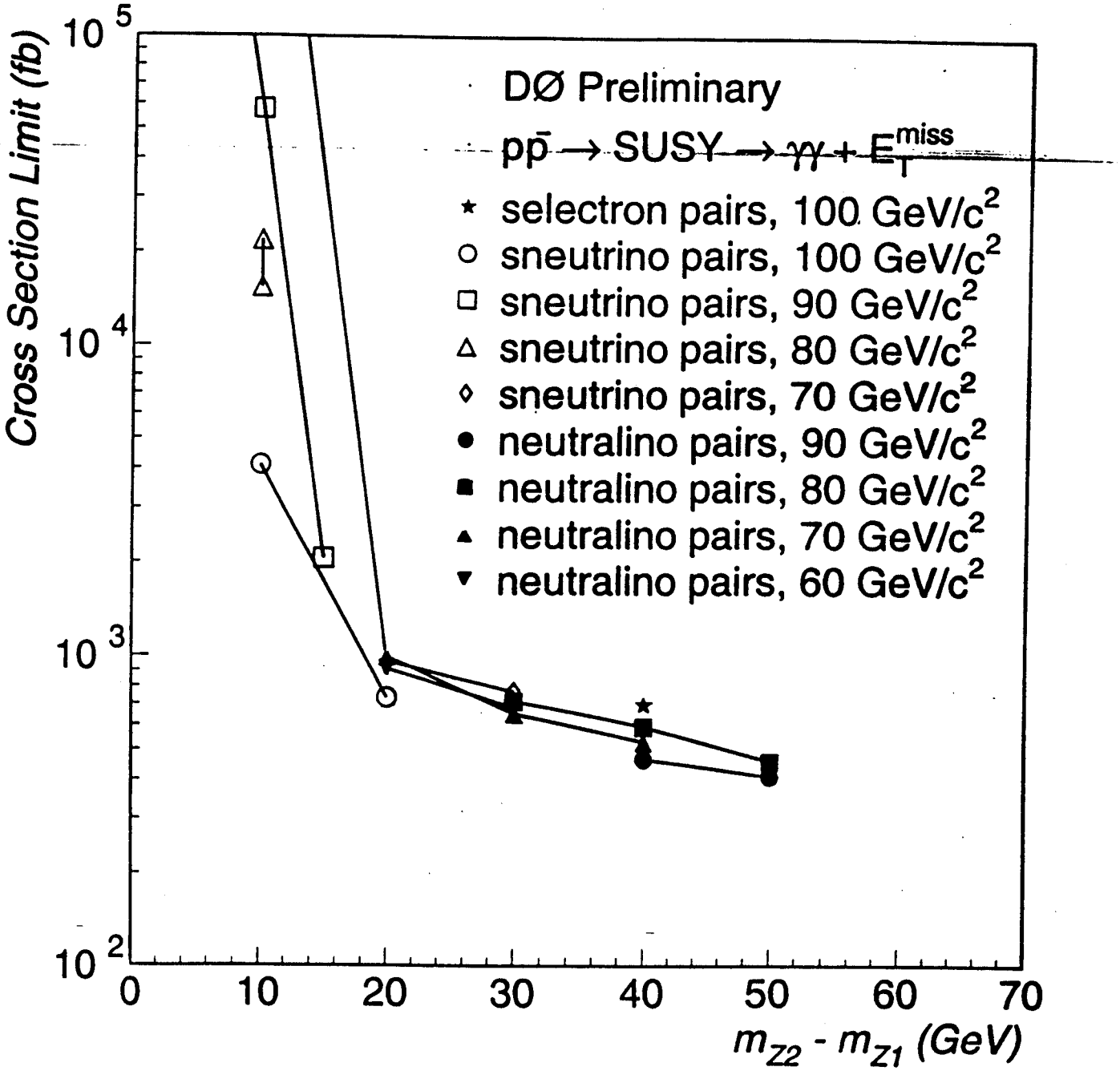
Randall Physics Laboratory, University of Michigan,
Ann Arbor, MI 48109-1120

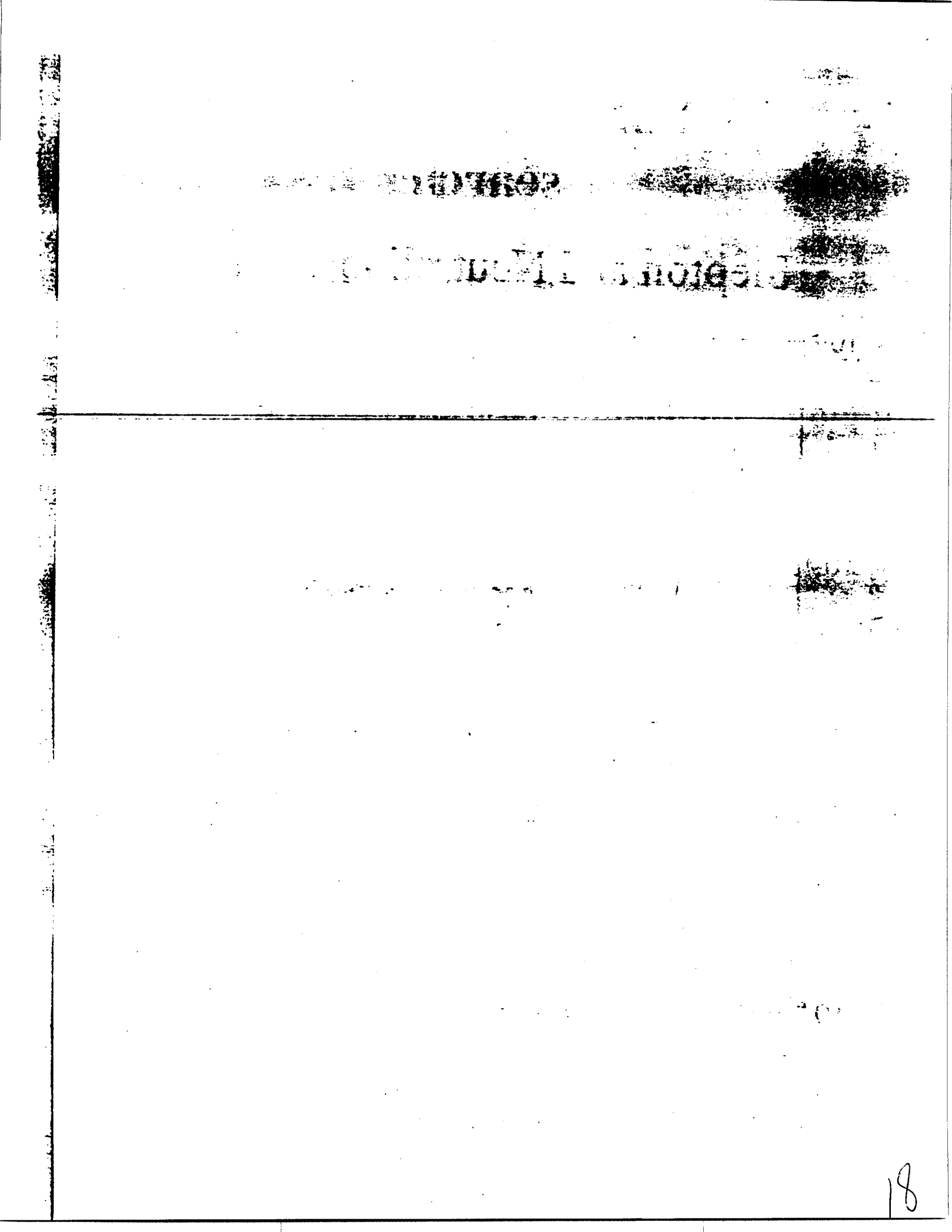
S. Mrenna[5]
High Energy Physics Division, Argonne National Laboratory,
Argonne, IL 60439

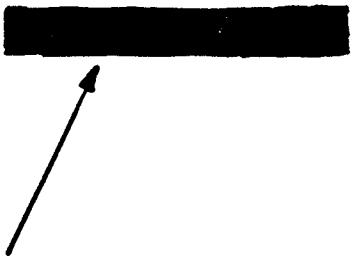


D0 diphoton + missing E_T search

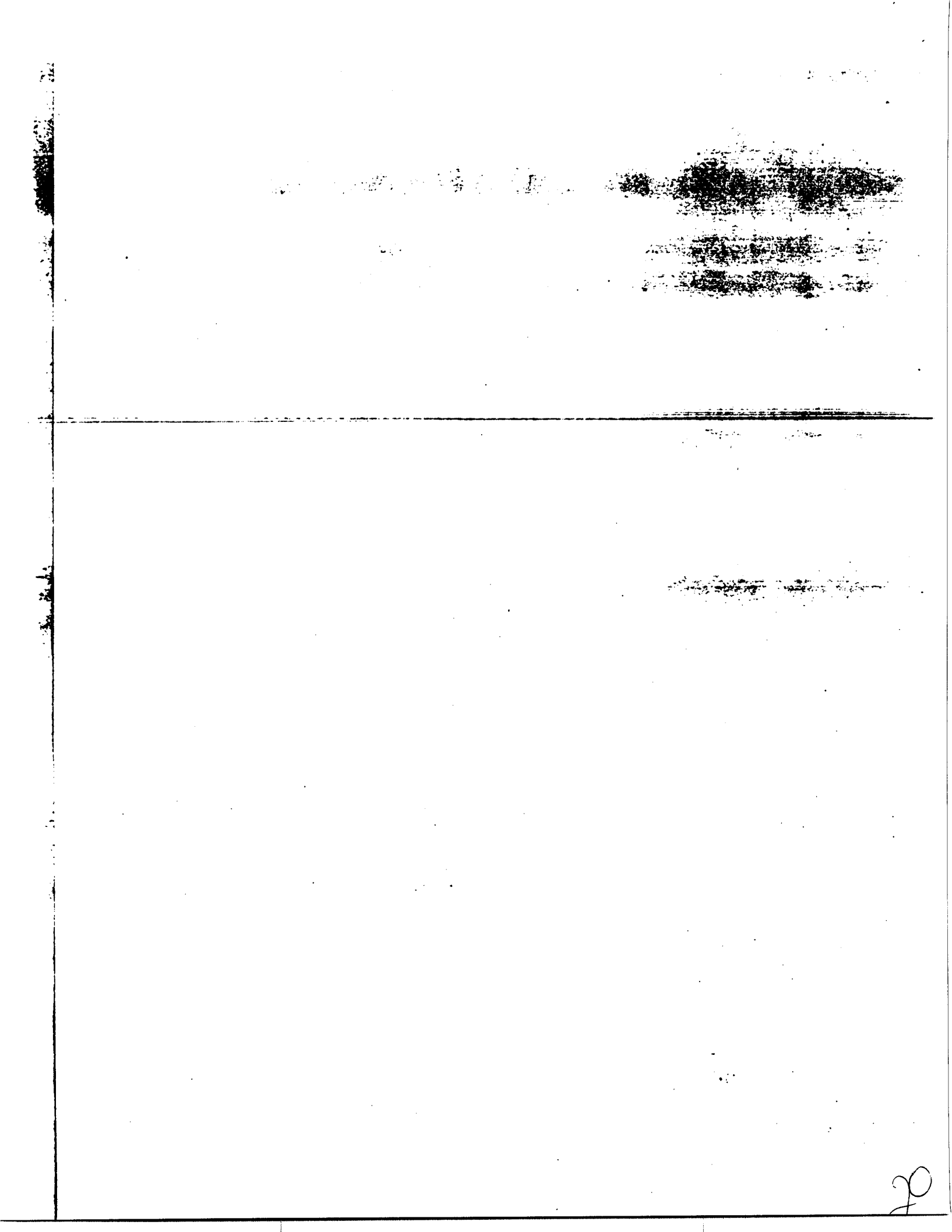
- Slepton and Neutralino Limits





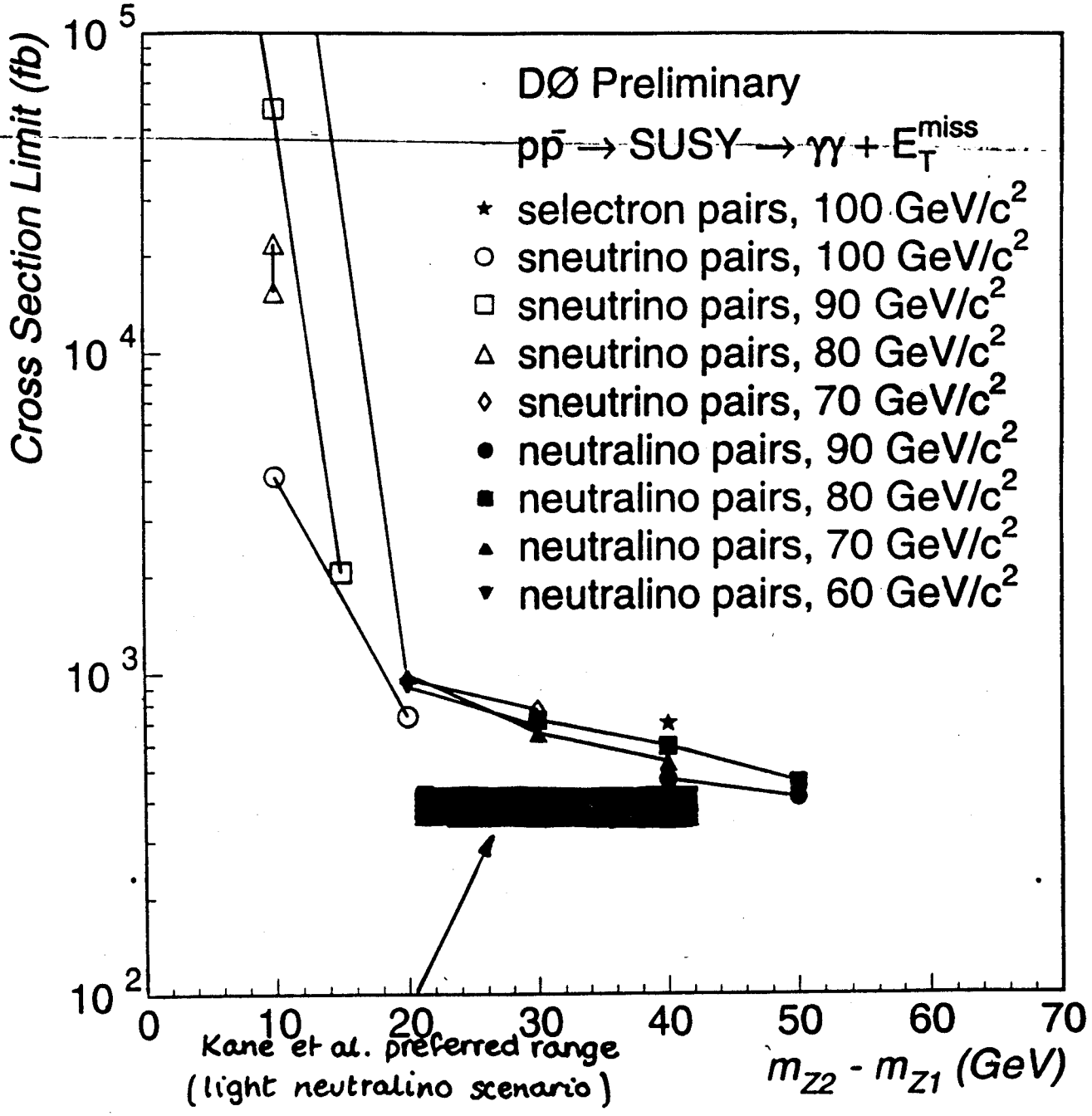


Kane et al. preferred range
(light neutralino scenario)



D0 diphoton + missing E_T search

- Slepton and Neutralino Limits



et

TeVatron Prospects

- **Run 2 , Start 1999**
  - **2 TeV**
  - **Detector Upgrades**
  - **Better Coverage**
  - **Better Vertex Tagging**

  2 fb ^ -1

- **TeV 33, 2003-2006 ?**

  WHENEVER LHC GETS UP TO SPEED.

  - **2 TeV**
  - **Detector Upgrades**

  10 - 30 fb^-1

A Tractable TeV33 Scenario

- Tevatron becomes 1. 10^{33} cm^{-2} sec^{-1}
- Luminosity Leveling

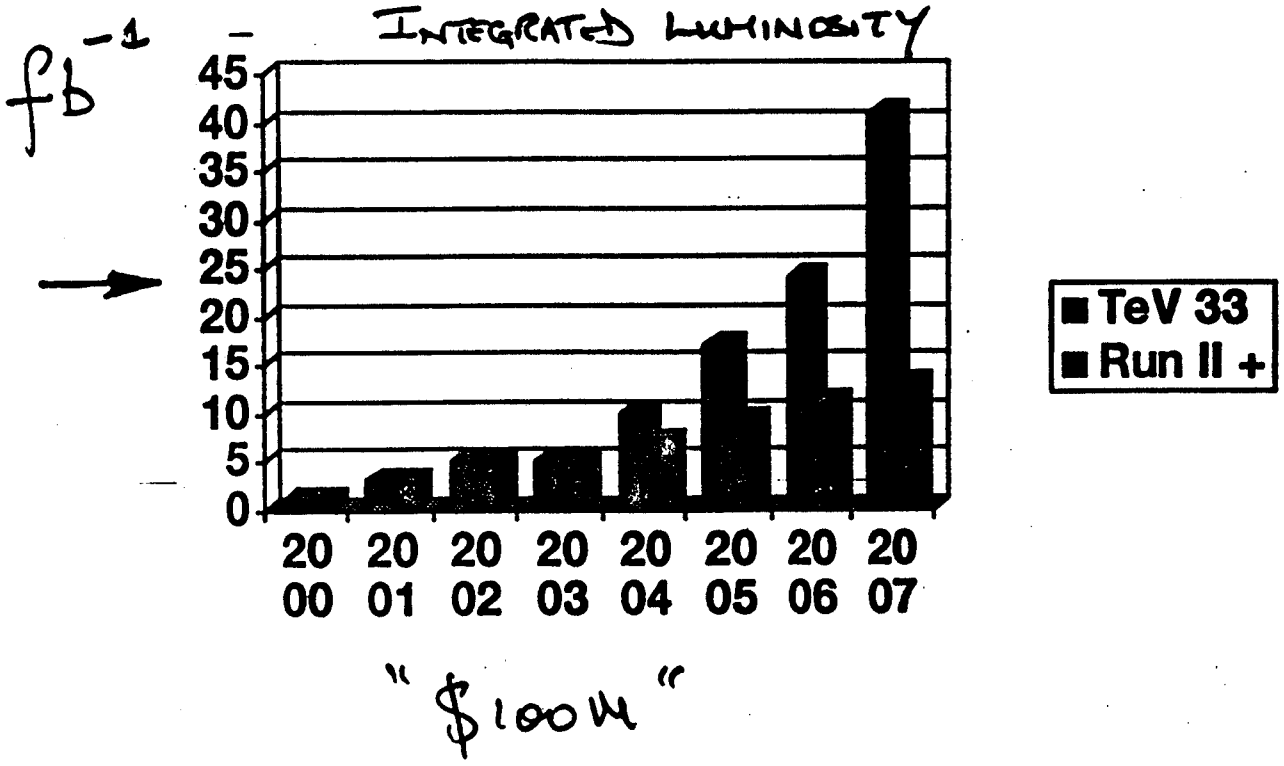
  Detectors 5. 10^{32} cm^{-2} sec^{-1}

  Penalty 70%
- 1 Year Shutdown

  Replace Silicon +++
- 1 Real Year gives (100*AP(10^{31})) pb^{-1}

  (July 1994-95 AP~1* 10^{31})

AP ≡ "Average Peak"



"$100M"

Tevatron Higgs Prospects

- **Associated WH Production** KANE, HRENNA, WILLENBROCK

  H--> b-bbar , double vertex tag

  - **5 fb^-1 M_H < 80 GeV**
  - **10 fb^-1 M_H < 100 GeV**
  - **25 fb^-1 M_H < 120 GeV**

Issues Di-Jet Mass resolution including gluon radiation

Analysis Optimization

TEVATRON HIGGS

STEVE KUHLMANN

$WH \to l\nu b\bar{b}$ DOUBLE TAGGED.

2 TeV

$10\,fb^{-1}$

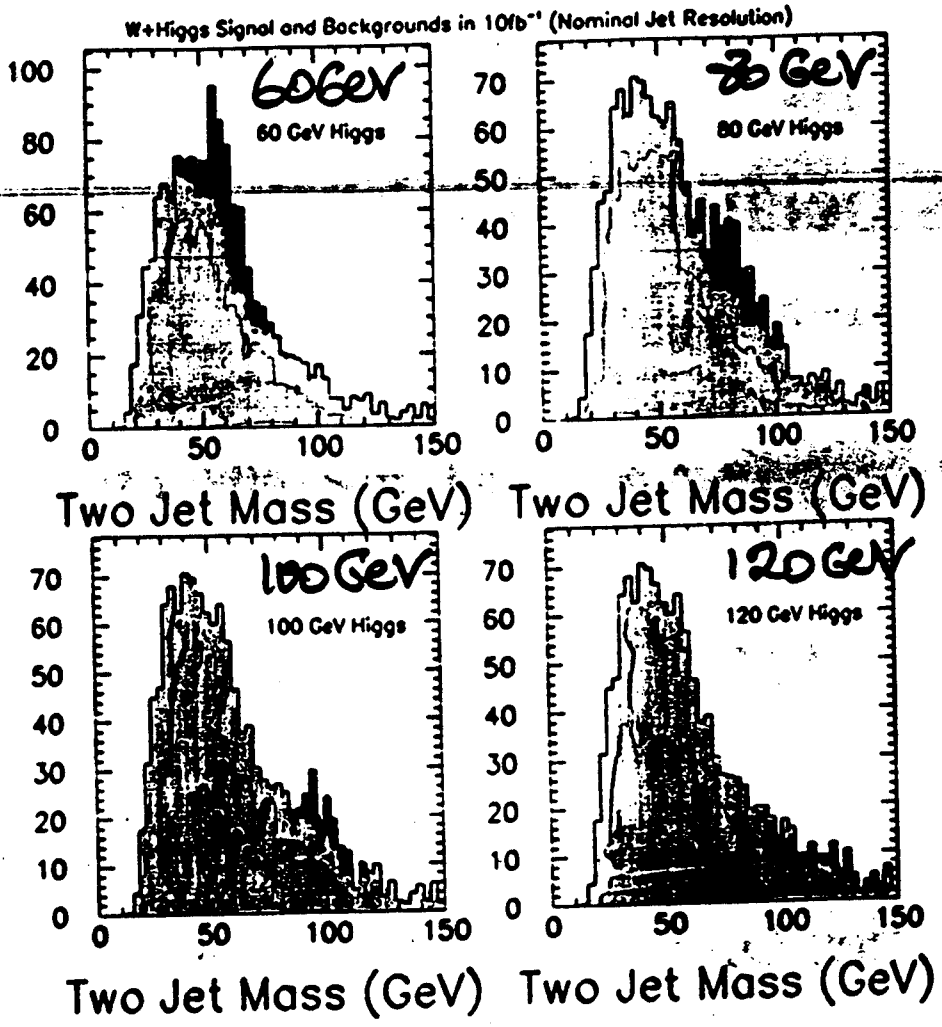
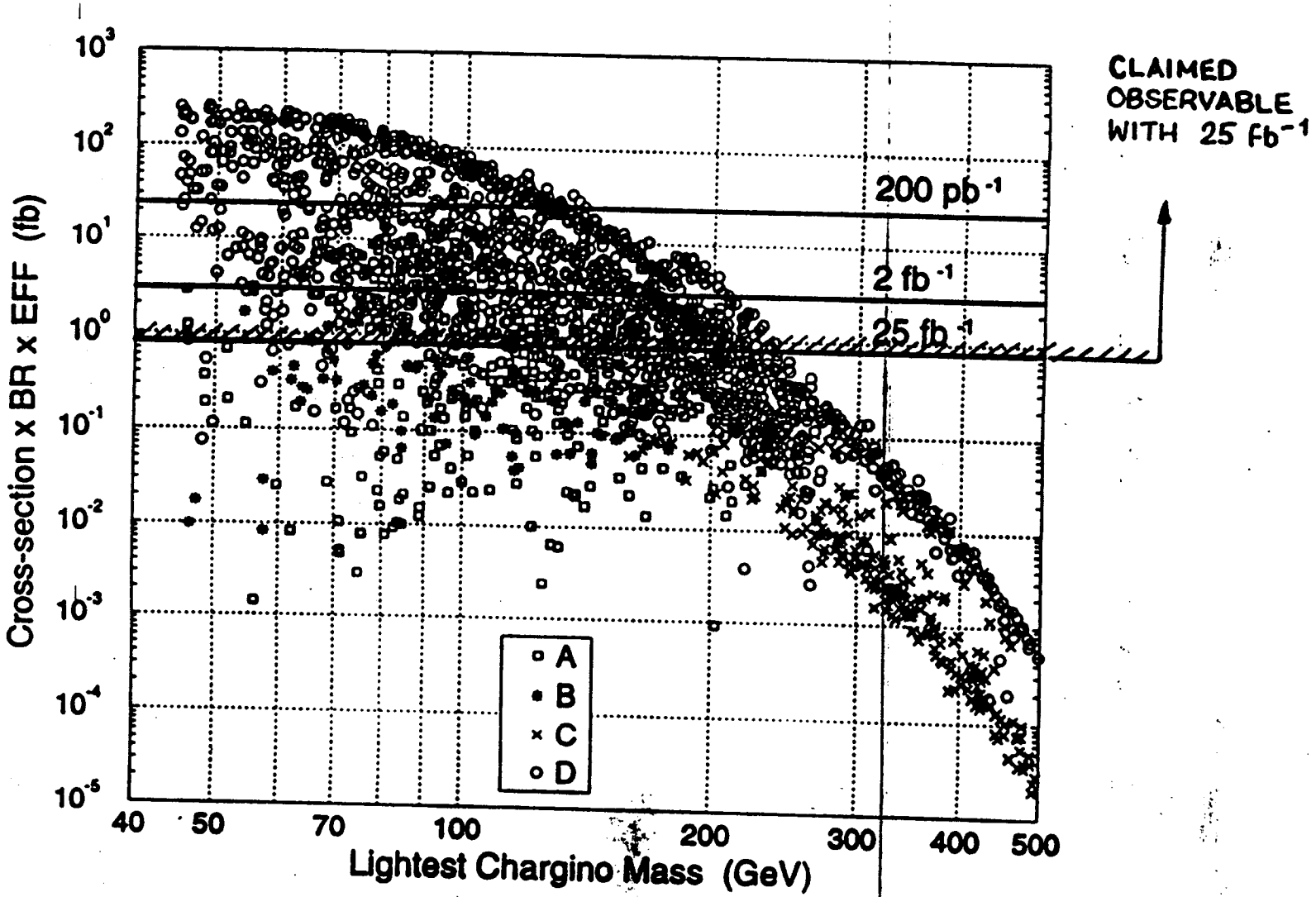


Figure 5.12: The signal+background mass distributions for the WH process with 10 fb^{-1} of data at 2 TeV. The solid line is signal+background, the dashed line the sum of all backgrounds.

CHARGINOS → TRILEPTONS



- Each point is 1 set of allowed parameters in the 5D space of CMSSM

(Mrenna, Kane, Kribs, Wells. UM-Th-95-14)

Tevatron Future Limits

	Run 2	TeV33
• Squark/gluino reach	~ 390 GeV	> 400 GeV
• Light top squark	~ 120 GeV	
• Chargino neutralino	~ 210 GeV	~250 GeV

TeV 33 Snowmass Analyses

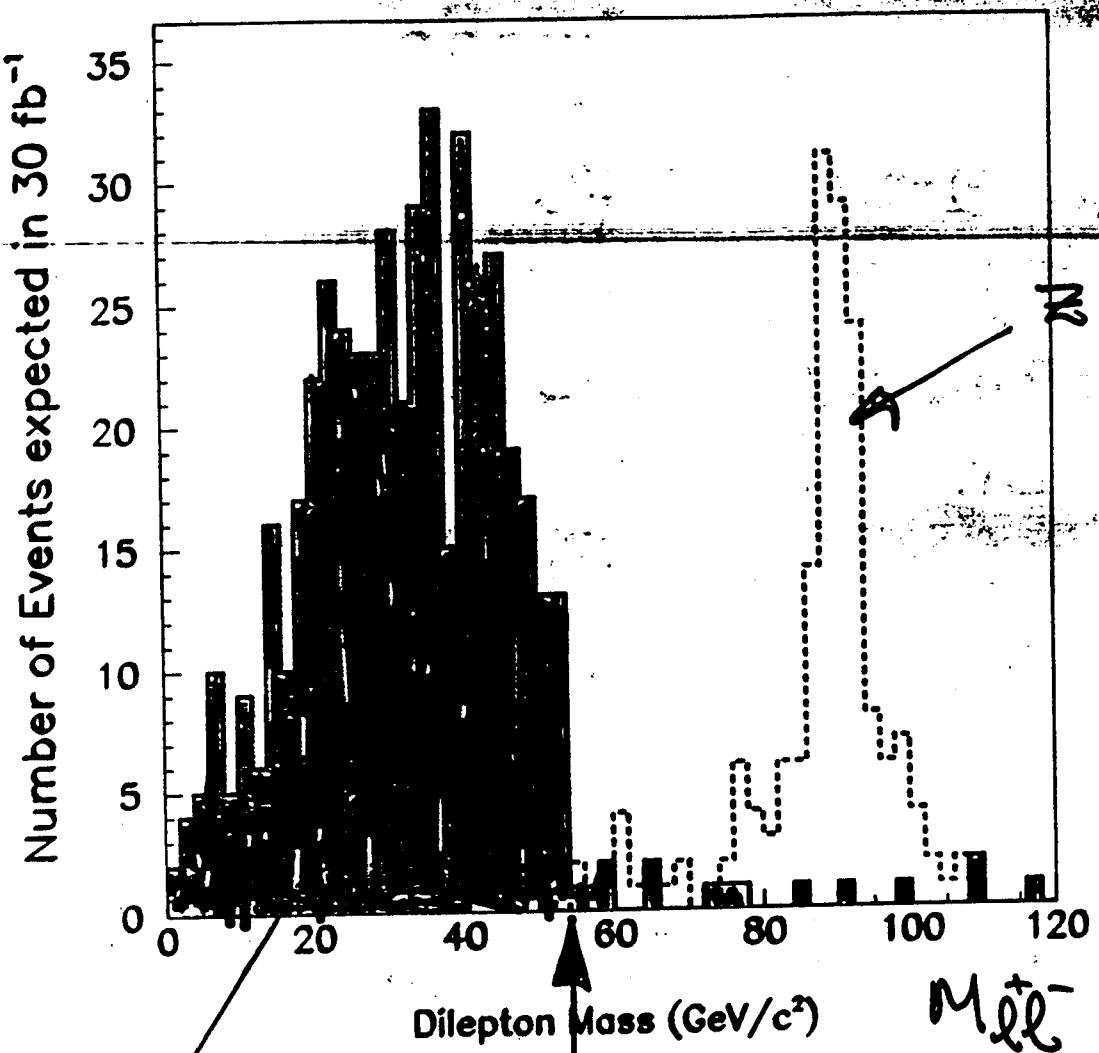
ASSUME 2 TeV, 25 fb^{-1}

	P	Tot. Ev.	m0 GeV	m1/2 GeV	A0	t B	s mu	
	1	*20k*	100	150	0	2	-1	
*	2	*92k*	200	100	0	2	-1	"COMPARISON POINT
	3	*72k*	200	125	0	10	-1	
	4	*162k*	200	130	-400	2	+1	

- DILEPTON SIGNAL IMPORTANT.
- $\tilde{q} \rightarrow \tilde{b}_1 b \rightarrow b \chi_2^0 \rightarrow \chi_1^0 l^+ l^-$
- JETS + $\not{E}_T$

TRILEPTON ANALYSIS

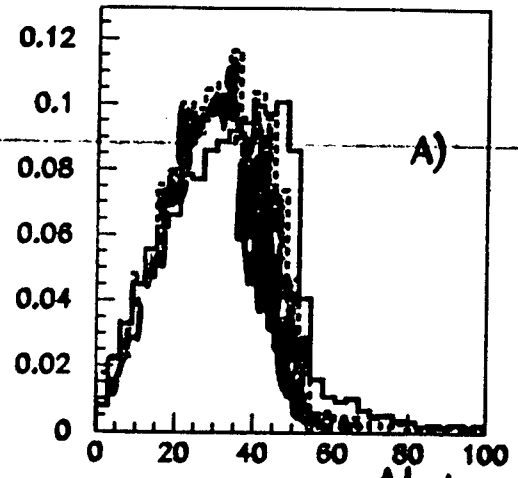
TEV 33, POINT 2 — SNOWMASS 96

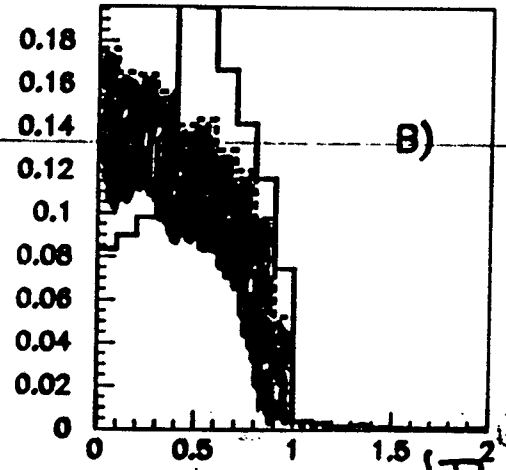


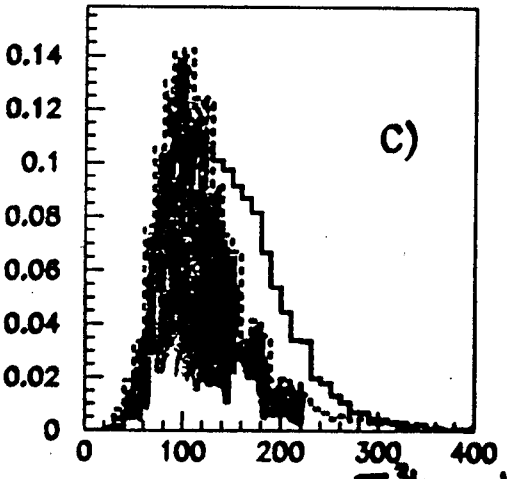
DILEPTON SPECTRUM IS POWERFUL HANDLE IN A VARIETY OF DECAYS.

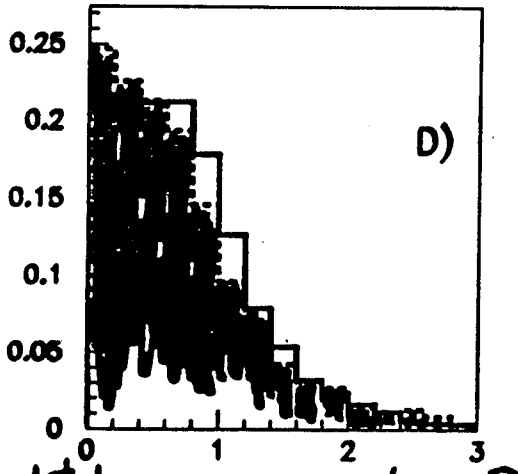
Tev 33: Point 1 vs Point 2.

Snowmass '96









— Point 1

$M_{\tilde{\chi}_2^0} = 135\,GeV$

$M_{\tilde{\chi}_1^0} = 65\,GeV$ (LSP)

$M_{\tilde{\ell}_R} = 121\,GeV$

$M_{\tilde{\nu}} = 138\,GeV$

Point 2

$M_{\tilde{\chi}_2^0} = 976\,eV \longrightarrow Z^* \tilde{\chi}_1^0$, $\tilde{\chi}_1^0 \hookrightarrow \ell^+\ell^-$

$M_{\tilde{\ell}_{R,L}} \gtrsim \sim 200\,GeV$

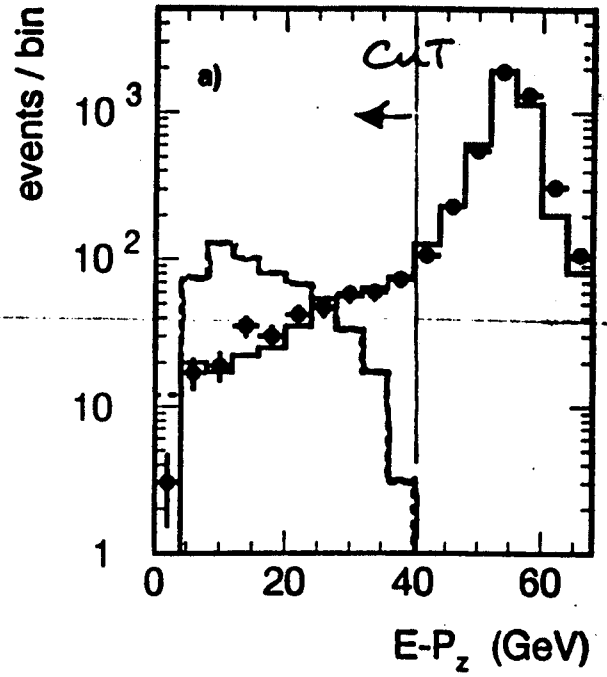
$M_{\tilde{\chi}_1^0} = 45\,GeV$ (LSP)

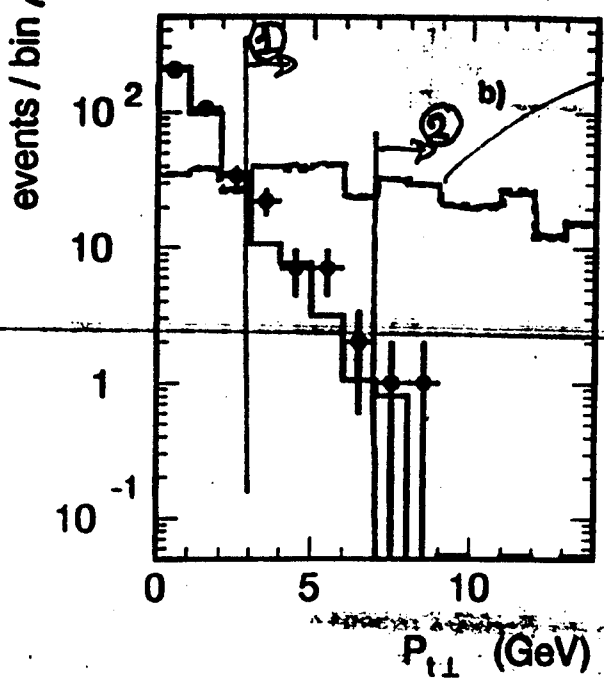
HERA Prospects

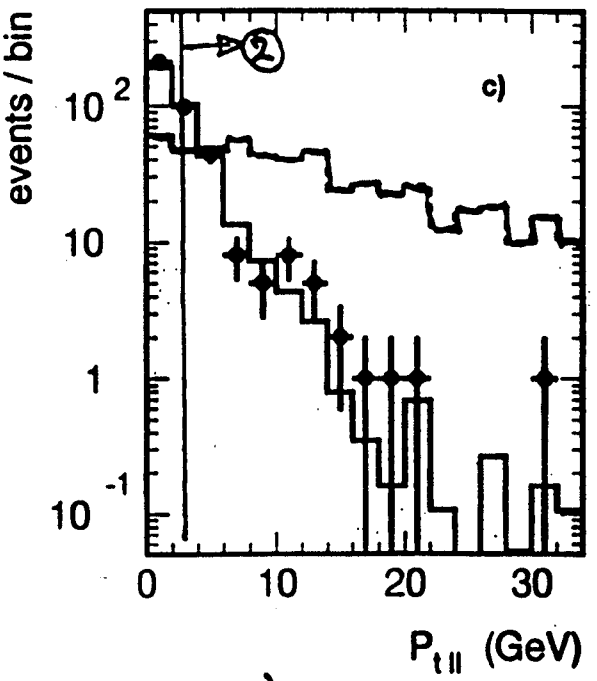
- 250, 500, 1000 pb^-1
- slepton, squark searches
- (light gluinos)
- R_p Violation

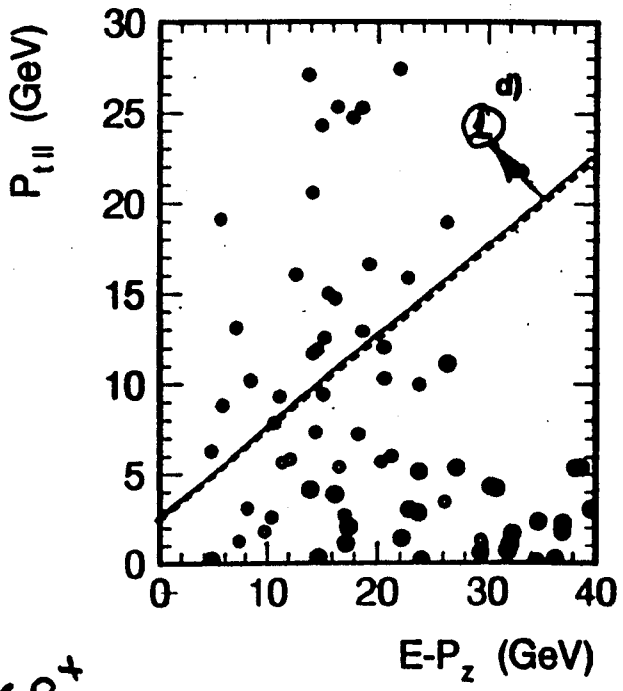
HERA $\tilde{q}$, $\tilde{e}$ SEARCH

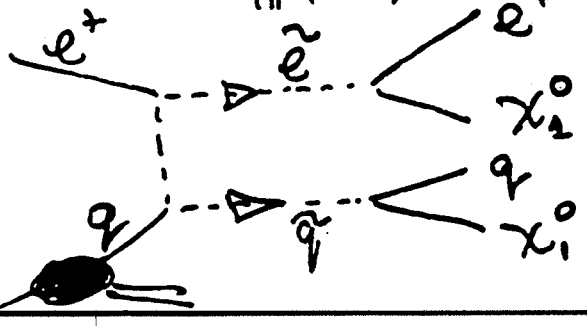
H1, 1996, 6.38 pb^{-1} (94-95 DATA)











0 Events SURVIVE !

HERA $\tilde{q}, \tilde{e}$ SEARCH

94-95

$\int \mathcal{L} = 6.38\ pb^{-1}$

$M_{\tilde{e}}$ (GeV)

$M_{\tilde{q}}$ (GeV)

$\tan\beta = 1.41$

$\tan\beta = 1.41$

$M_1 = \frac{5}{3} M_2 \tan^2\theta_W$

$\tan\beta, \mu$

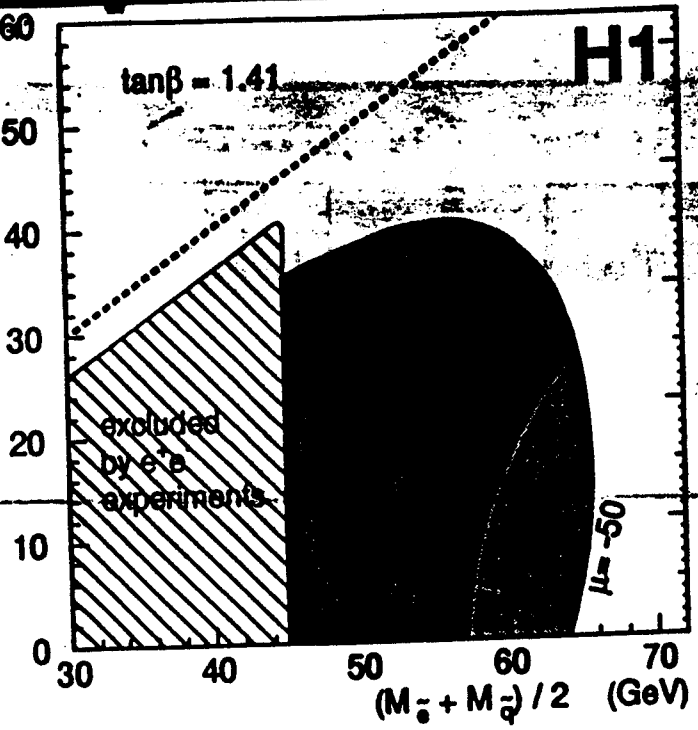


Figure 3: *Excluded regions at 95% confidence level in the plane of $M_{\chi_1^0}$ versus half the sum of $M_{\tilde{e}}$ and $M_{\tilde{q}}$ for $\tan\beta = 1.41$. The dark and light shaded areas are excluded for $\mu = -50$ GeV. The dark shaded area is excluded for all $\mu \leq -50$ GeV. The difference between both is due to decays into other gauginos than the χ_1^0. The diagonal line corresponds to $M_{\tilde{e},\tilde{q}} = M_{\chi_1^0}$. The hatched area is excluded by direct searches for $\tilde{e}$ and $\tilde{q}$ pair production in Z^0 decays [2]. The vertical axis is also labeled in terms of M_2 (see text).*

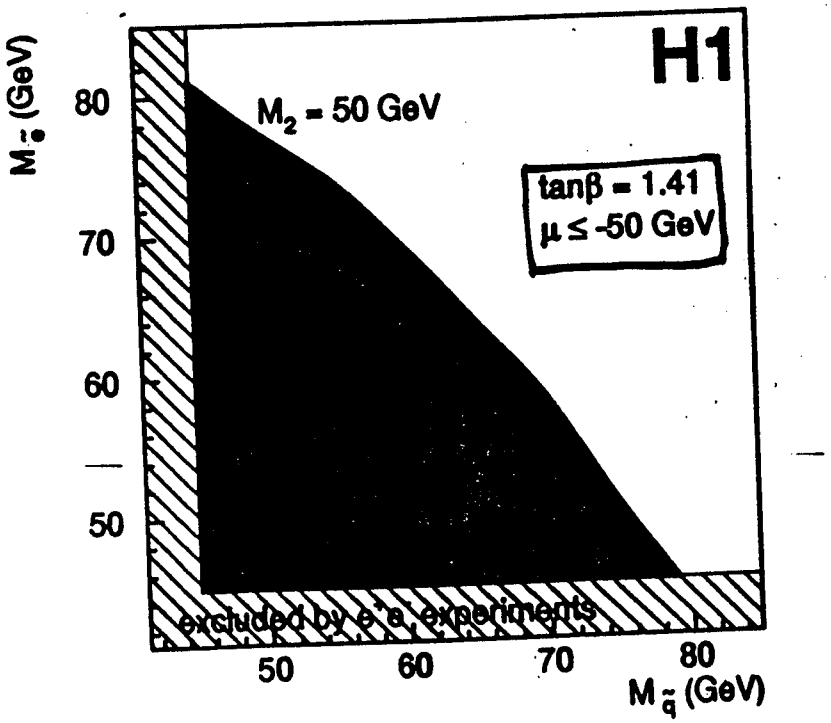
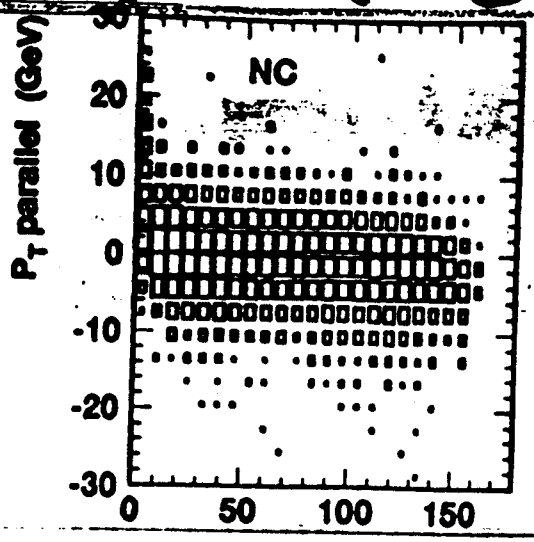
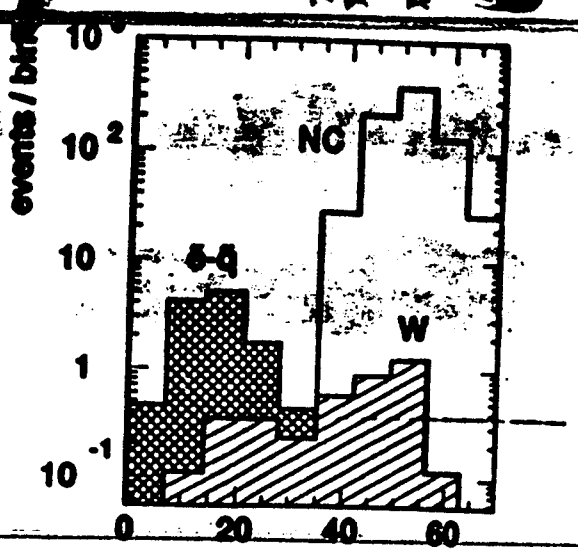
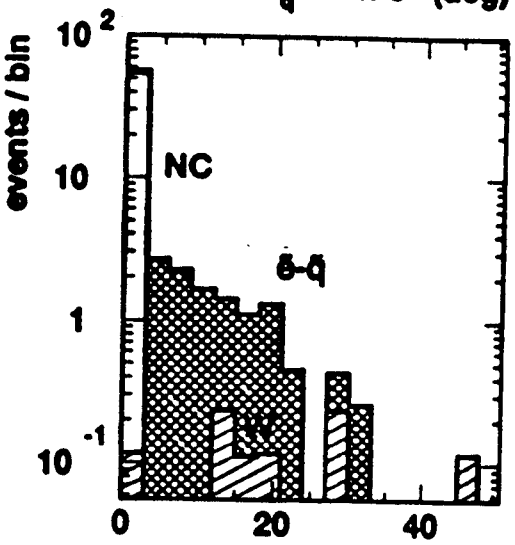


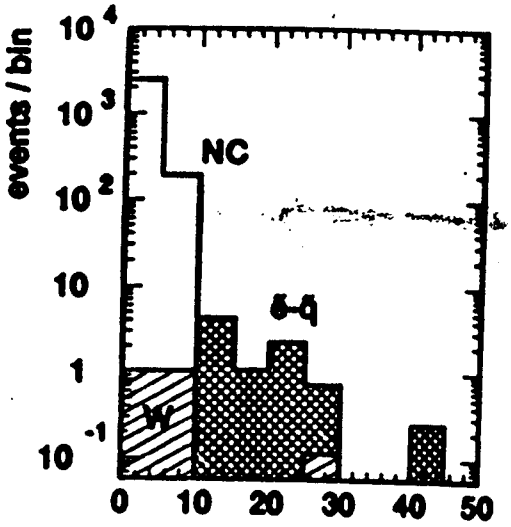
Figure 4: *Exclusion limits at 95% confidence level in the $M_{\tilde{e}}$ versus $M_{\tilde{q}}$ plane for different values of M_2 and $\mu \leq -50$ GeV, $\tan\beta = 1.41$. $M_{\tilde{e}}$ and $M_{\tilde{q}}$ masses below 45 GeV are excluded by searches in Z^0 decays. [2].*

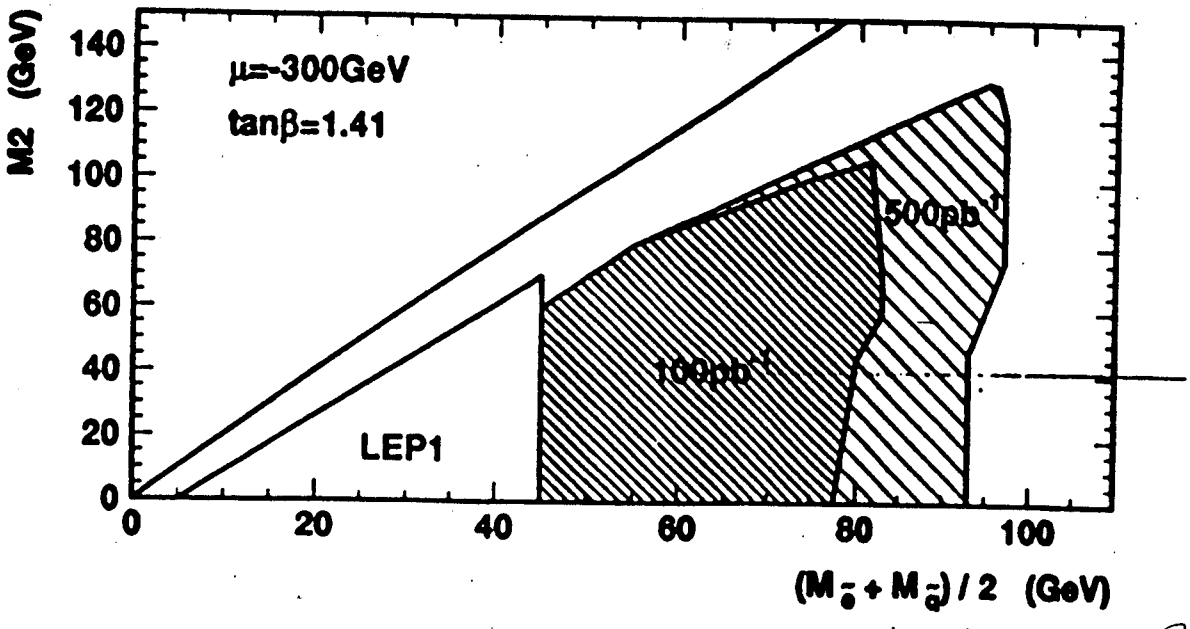
HERA Future $\tilde{e}, \tilde{q}$ LIMITS



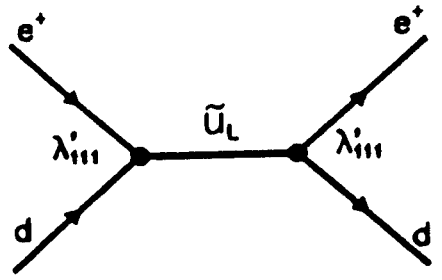




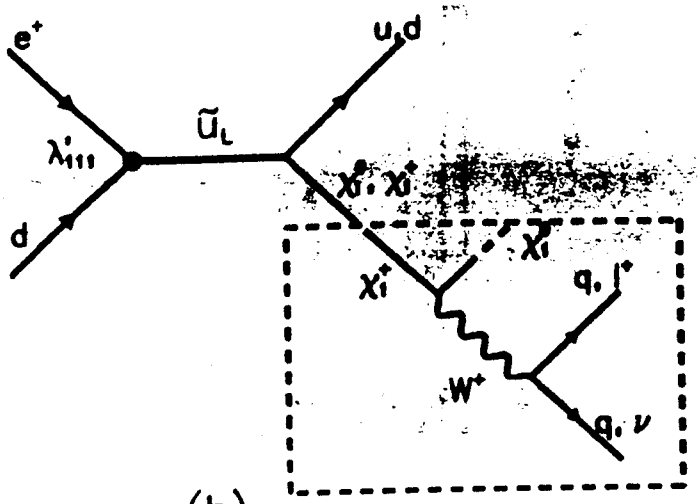




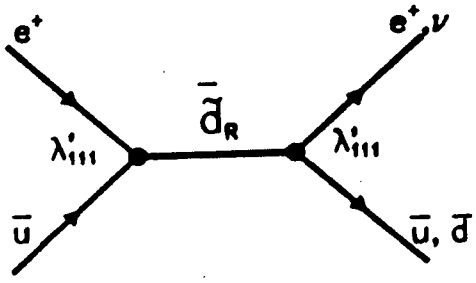
R PARITY VIOLATION PROCESSES AT HERA



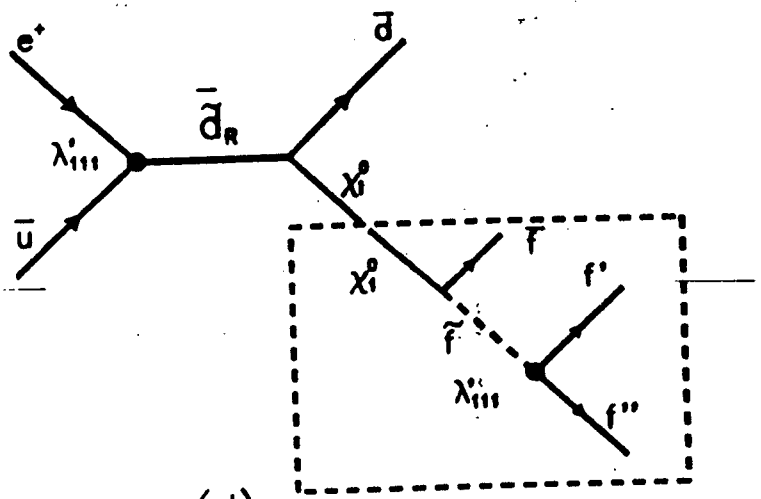
(a)



(b)



(c)



(d)

HERA R_p SIGNATURES

Channel	χ_1^0 nature	Decay processes	Signature
S1	$\tilde{\gamma},\tilde{Z},\tilde{H}$	$\tilde{q} \xrightarrow{\lambda'} e^+ q'$	High P_T e^+ + 1 jet
S2	$\tilde{\gamma},\tilde{Z},\tilde{H}$ $\tilde{H}$	$\tilde{d}_R \xrightarrow{\lambda'} \nu_e \bar{d}$ $\tilde{q} \longrightarrow q \chi_1^0$	Missing P_T + 1 jet
S3	$\tilde{\gamma},\tilde{Z}$ $\tilde{\gamma},\tilde{Z},\tilde{H}$ $\tilde{\gamma},\tilde{Z}$	$\tilde{q} \longrightarrow q \chi_1^0 \xhookrightarrow{\lambda'} e^+\bar{q}'q''$ $\tilde{u}_L \longrightarrow d \chi_1^+ \xhookrightarrow{\lambda'} e^+ d\bar{d}$ $\tilde{u}_L \longrightarrow d \chi_1^+ \hookrightarrow W^+\chi_1^0 \xhookrightarrow{\lambda'} e^+\bar{q}'q''$	High P_T e^+ + multiple jets
S4	$\tilde{\gamma},\tilde{Z}$ $\tilde{\gamma},\tilde{Z}$	$\tilde{q} \longrightarrow q \chi_1^0 \xhookrightarrow{\lambda'} e^-\bar{q}'q''$ $\tilde{u}_L \longrightarrow d \chi_1^+ \hookrightarrow W^+\chi_1^0 \xhookrightarrow{\lambda'} e^-\bar{q}'q''$	High P_T e^- (i.e. wrong sign lepton) + multiple jets
S5	$\tilde{\gamma},\tilde{Z}$ $\tilde{\gamma},\tilde{Z}$ $\tilde{\gamma},\tilde{Z},\tilde{H}$ $\tilde{H}$	$\tilde{q} \longrightarrow q \chi_1^0 \xhookrightarrow{\lambda'} \nu\bar{q}'q'$ $\tilde{u}_L \longrightarrow d \chi_1^+ \hookrightarrow W^+\chi_1^0 \xhookrightarrow{\lambda'} \nu\bar{q}'q'$ $\tilde{u}_L \longrightarrow d \chi_1^+ \xhookrightarrow{\lambda'} \nu u\bar{d}$ $\tilde{u}_L \longrightarrow d \chi_1^+ \hookrightarrow W^+\chi_1^0 \hookrightarrow q\ \bar{q}'$	Missing P_T + multiple jets
S6	$\tilde{H}$	$\tilde{u}_L \longrightarrow d \chi_1^+ \hookrightarrow W^+\chi_1^0 \hookrightarrow l^+\ \nu$	High P_T e^+ or μ^+ + missing P_T + 1 jet
S7	$\tilde{\gamma},\tilde{Z}$	$\tilde{u}_L \longrightarrow d \chi_1^+ \hookrightarrow W^+\chi_1^0 \xhookrightarrow{\lambda'} e^\pm\bar{q}'q''$	High P_T $e^\pm$ + high P_T e^+ or μ^+ + missing P_T + multiple jets
S8	$\tilde{\gamma},\tilde{Z}$	$\tilde{u}_L \longrightarrow d \chi_1^+ \hookrightarrow W^+\chi_1^0 \xhookrightarrow{\lambda'} \nu\bar{q}'q'$	High P_T e^+ or μ^+ + missing P_T + multiple jets

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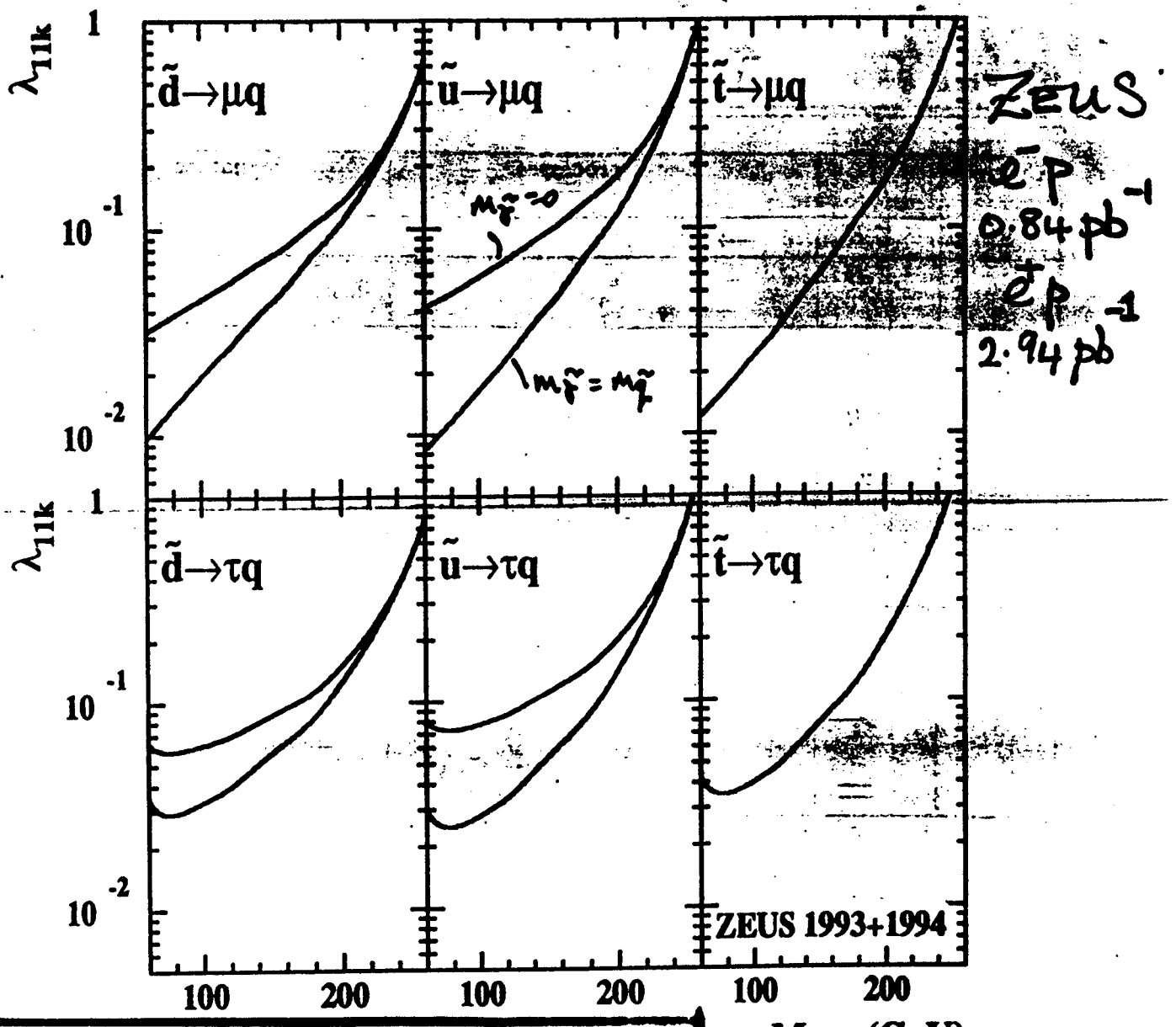
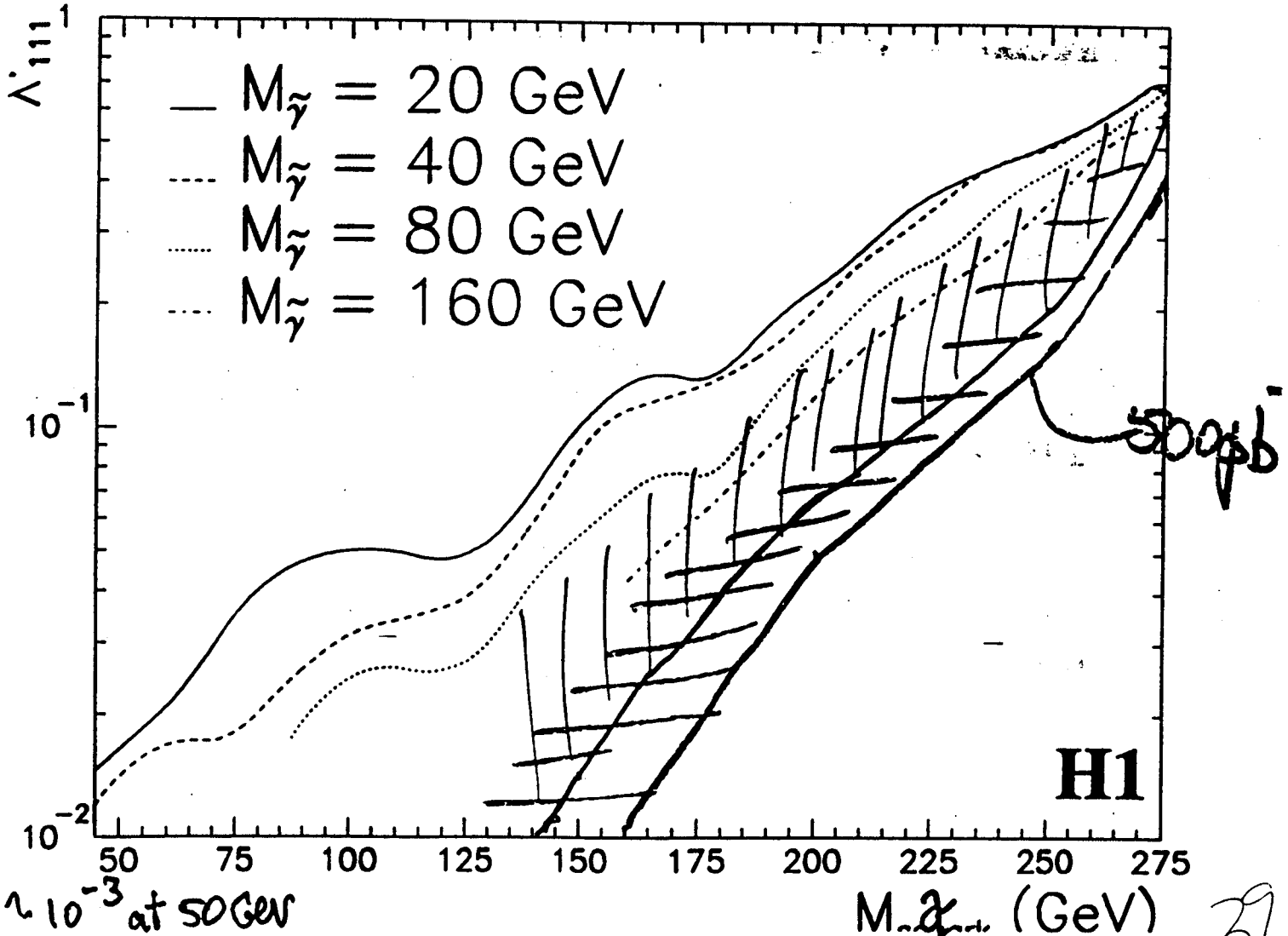


HERA R_p SUSY

95% C.L. limits on lepton flavour violation via production of R_P–violating squarks in ep reactions. The curves represent the coupling limits for R_P–violating squarks decaying to μ and τ, respectively. It is assumed that the $(eq\tilde{q})$ coupling at the production vertex (λ_{11k}) is equal to the coupling λ_{lqk} at the decay vertex $(l = \mu, \tau)$. The upper curves are for zero photino mass and the lower curves are for the photino mass equal to the squark mass. In the case of $\tilde{t}$, only R_P–violating decays are considered and it is assumed that the stop mixing angle is given by $\cos^2\theta_t = 0.5$. The results are based on 0.84 pb^{-1} e^-p and 2.94 pb^{-1} e^+p data collected in the years 1993 and 1994 with the ZEUS detector.

HERA $\not{R}_p$ FUTURES.

— ····	etc	H1	e^+p	$2.83\ pb^{-1}$
—	'HERA'		e^+p	$100\ pb^{-1}$
—	'HERA'		e^+p	$500\ pb^{-1}$



Conclusions

- **Tevatron Collider has significant Limits on SUSY**
- **Run 2 with 2 fb^-1 1999-2002**
- **TeV33 10-30 fb^-1 2004-2006**
- **HERA can play**
- **Something Significant for LHC to beat** OR CONFIRM ?

THANKS TO: CDF, DØ, TEV33 AT SNOWMASS, TEV2000 HERA UPGRADE WG, #1, ZEUS (VIA WWW)....