Disclaimer

DØ Note
2380

DØ Searches for SUSY

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- Thumbnail Sketch of SUSY
- Overview of Run 1a Analyses
- Overview of Run 1b Analyses
- Triggering Issues
- Miscellany
- Conclusions : What We've Found So Far...

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Supersymmetry (SUSY) is a fundamental space-time symmetry which relates fermions and bosons. SUSY QFTs eliminate mass divergences, unify running coupling constants.

The Minimal Supersymmetric Standard Model

Standard Model States		SUSY Partners	
Particle	Spin	Sparticle	Spin
q	$\frac{1}{2}$	$\tilde{q}_L, \tilde{q}_R$	0,0
l	$\frac{1}{2}$	$\tilde{l}_L, \tilde{l}_R$	0,0
ν	$\frac{1}{2}$	$\tilde{\nu}$	0
g	1	$\tilde{g}$	$\frac{1}{2}$
γ	1	$\tilde{Z}_1$ (*)	$\frac{1}{2}$
Z°	1	$\tilde{Z}_2$	$\frac{1}{2}$
$W^\pm$	1	$\tilde{Z}_3$	$\frac{1}{2}$
h	1	$\tilde{Z}_4$	$\frac{1}{2}$
H	1	$\tilde{W}_1$	$\frac{1}{2}$
A	1	$\tilde{W}_2$	$\frac{1}{2}$
$H^\pm$	1		

$\tilde{t}$

Features

- Conserved multiplicative quantum number ("R parity") $\rightarrow$ sparticles are pair produced.
- Lightest SUSY Particles (LSP*) has no strong or EM interactions $\rightarrow$ Events signatures with missing $\not\!\!E_T$.
- Sparticles should exist with mass below the TeV scale, or fine tuning comes back to haunt us.

Pre-Run 1a limits

(From the SUSY-93 Proceedings)

Gluino :	$m_{\tilde{g}} > 130$ GeV	[CDF]
Squark :	$m_{\tilde{q}} > 150$ GeV	[CDF]
Stop :	$m_{\tilde{t}} > 45$ GeV	[LEP]
Charginos :	$m_{\tilde{W}_1} > 45$ GeV	[LEP]
Neutralinos :	$m_{\tilde{Z}_1} > 20\ \mathrm{GeV}, \tan\beta > 3$	[LEP]
	$m_{\tilde{Z}_2} > 51\ \mathrm{GeV}, \tan\beta > 3$	[LEP]
Higgs (SUSY) :	$m_h > 43$ GeV	[LEP]
	$m_A > 20 - 40$ GeV	[LEP]
	$m_{H^\pm} > 42$ GeV	[LEP]

DØ Run 1a Analyses

- Squark/Gluinos → Jets + $\not{E}_T$

  Chang-Kee Jung Marc Paterno Horst Wahl Mark Gorforth Adam Lyon

  Status : PRL under review (Jung and Paterno).

- Wino Zino → Trileptons

  James White Andrew White Lee Sawyer Mark Sosebee

  Status : PRL being written (Sawyer and Sosebee). Review committe formed

- Stop → Jets + $\not{E}_T$

  Dan Claes

  Status : Analysis in progress.

General Search Strategy

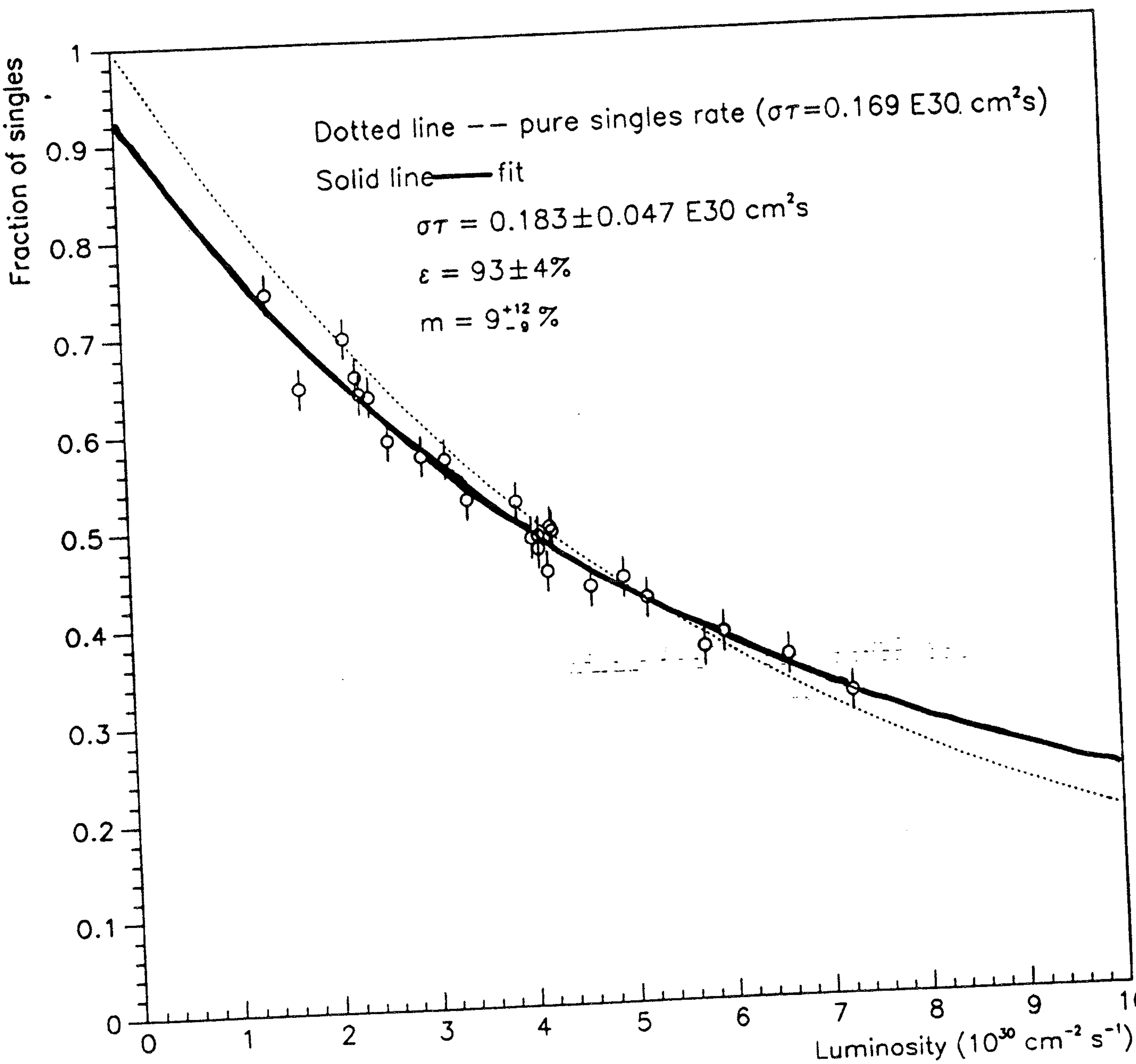
- Experimental Signature:
  - LSP does not interact – produces ME_T
  - Multiple jets (3 or more)
  - No leptons
- Major Backgrounds:
  - Missing E_T from W and Z + jets
    - $W \rightarrow e\nu, \mu\nu, \tau\nu$
    - $Z \rightarrow \nu\nu, \mu\mu, \tau\tau$
    - Reject leptons to remove these
  - Missing E_T from mismeasured QCD multijets
    - Demand large Missing E_T
    - Reject jet-Missing E_T correlation

$\tilde{q}, \tilde{g}$ → multilepton analysis started $\sigma \lesssim 1$ pb.

MULT_INT algorithm

- [illegible]
- Scalar E_T of event
- # vertices found by TRACKING

Fraction of events identified as single interaction as a function of instantaneous luminosity



This cut reduces our data set to:

7.1 +/- 0.9 pb^{-1} single interaction equivalent luminosity

Analysis Results

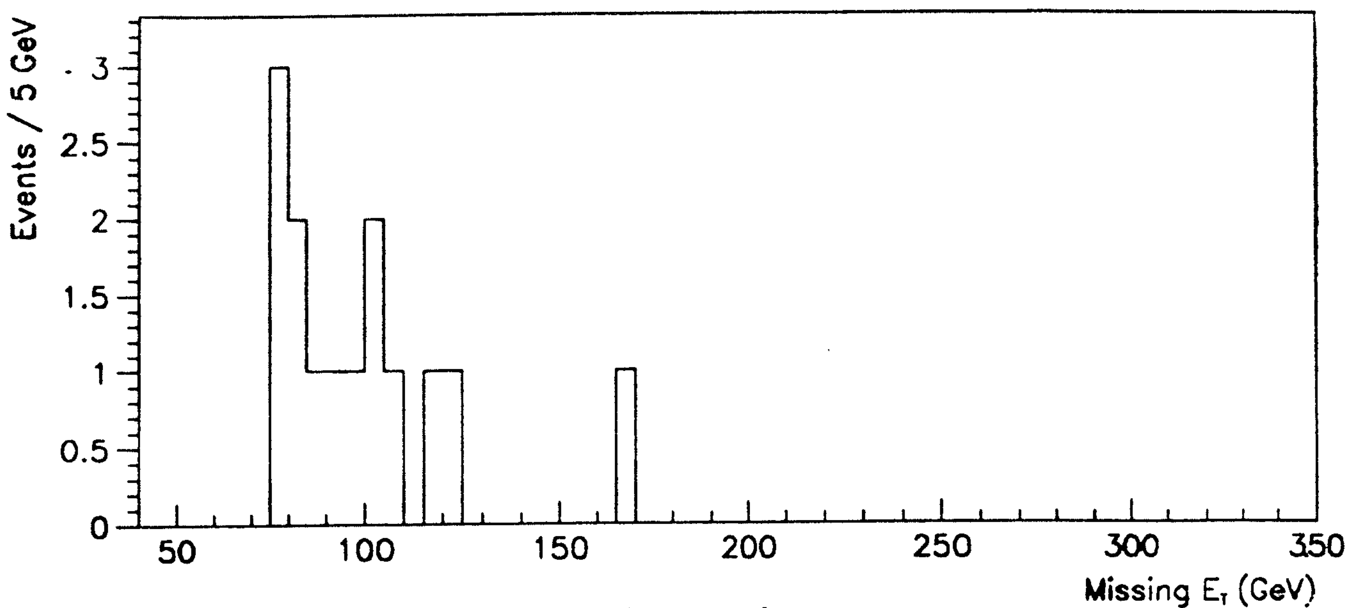
Cut	# of events passing
trigger/offline filter	9625
single interaction	3730
$ME_T > 75$ GeV	107
3 jets $E_T > 25$ GeV	47
leading jet not in ICR	45
reject jet- ME_T correlation	30
reject electrons & muons	25
reject noise jets	
scan: 1 cosmic muon, 2 vertex errors	**14**

Backgrounds

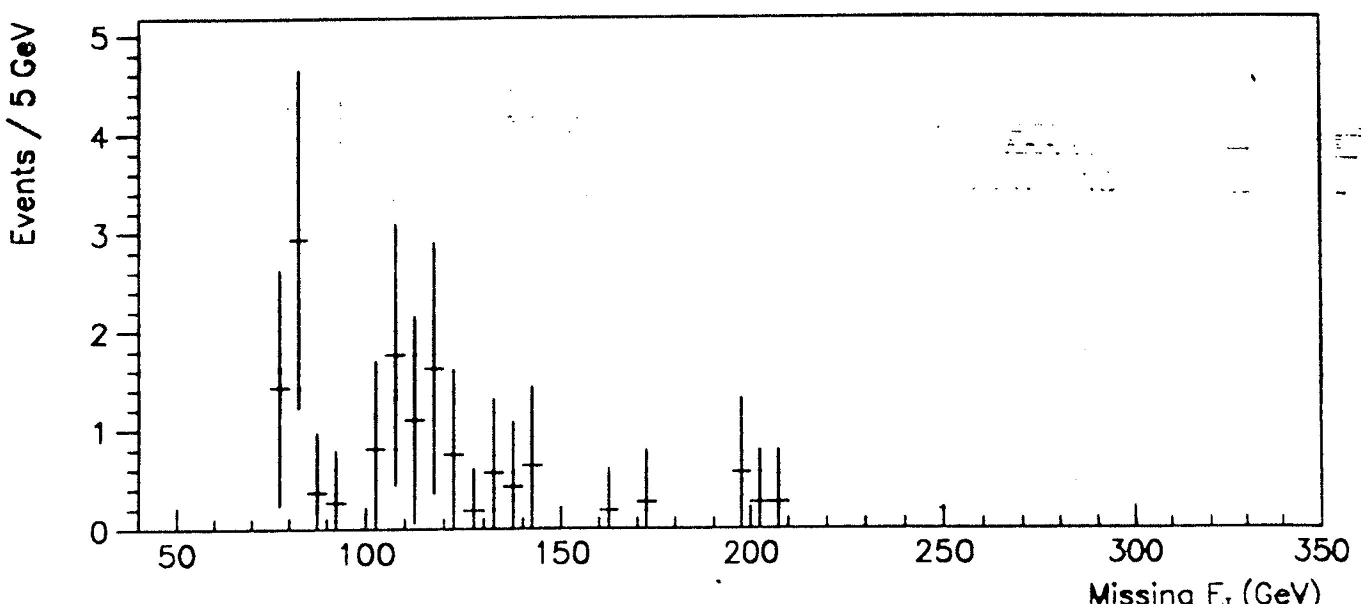
- W/Z + jets:
  - analyzed with VECBOS/ISAJET generator, GEANT-based detector simulation
  - total of <u>16.7±1.7 [+7.0/-6.6]</u> events expected
  - Dominant backgrounds
    - $W \rightarrow \mu\nu$ (5.1 events)
    - $Z \rightarrow \nu\nu$ (4.6 events)
    - $W \rightarrow \tau\nu$ (4.0 events)
    - $W \rightarrow e\nu$ (2.3 events)
    - all others (0.8 events)

Fit $\not{E}_t$ spectrum of set of single jet triggers then determined fraction of events passing 3-jet requirement as a function of $\not{E}_T$ Extrapolated

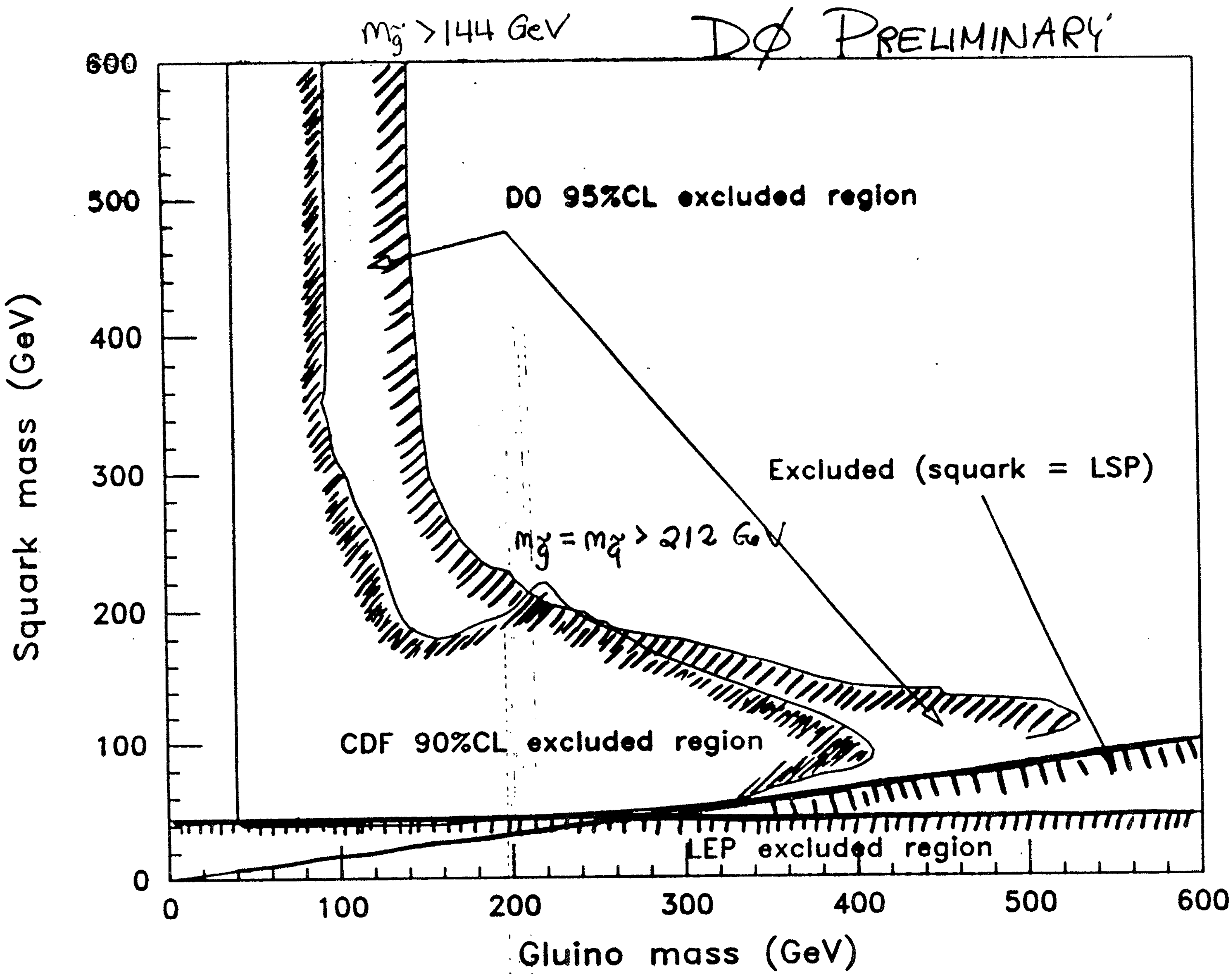
- QCD with "fake" ME_T
  - analyzed from low E_T jet triggers
  - total of 0.42±0.37 events
- Combined total of <u>17.1 ±1.7[+7.0/-6.6]</u> events expected
- Number of events in data (14) consistent with SM - <u>no excess seen</u>



Final candidates



Sum of W/Z backgrounds



$m_{\tilde{g}} > 144$ GeV
DØ PRELIMINARY
DO 95%CL excluded region
Excluded (squark = LSP)
$m_{\tilde{g}} = m_{\tilde{q}} > 212$ GeV
CDF 90%CL excluded region
LEP excluded region
Squark mass (GeV)
Gluino mass (GeV)
0
100
200
300
400
500
600

Data Analysis

Collider Run Ia   Reco v11.19 / CaFix Energy Corr

SUSY Triggers: Missing_Et, Jet_Miss

Most Data:
Hardware: $\not{E}_T > 30$ GeV 1 jet tower E>3 GeV
Software: $\not{E}_T > 35$ GeV
$\int L_{\text{single interaction}}\, dt = 7.2\ \text{pb}^{-1}$

SSY Offline Stream:	
3 Jets, $\not{E}_T > 25$ GeV	8,666
Probable Single Interaction	3,348
Jets: $E_T \geq 20$ GeV, R=0.5, $\lvert\eta\rvert \leq 3.5$	
2nd/1st Cell Energy Fraction > 10%	3,022
# Cells E > 1 GeV ≠ 1 or 2	2,677
Coarse Hadronic Fraction < 40%	2,530
ICD Fraction < 50%	1,571
5% < EM Fraction < 90%	1,561
Isolated missing E_T	
All Jets:	
$\pi/32 < \lvert \phi_{\text{missing ET}} - \phi_{\text{jet i}} \rvert < 31/32\ \pi$	1,019
$\Psi = [\ (\pi-\Delta\phi_{\text{jet1}})^2 + \Delta\phi_{\text{jet2}}^{\ 2}\ )^{1/2} > 0.5$	735
4 or 5 jets, $\not{E}_T > 50$ GeV	**16**

W and Z Backgrounds

VecBos Monte Carlo - W. Geile
DØGeant 3.14, Reco v11.19, Trigger Sim

$W \to e\nu$ + 4 jets	0.98 ± 0.07 stat ± 0.24 sys
$W \to \mu\nu$ + 4 jets	0.59 ± 0.13 stat ± 0.15 sys
$W \to \tau\nu$ + 3 jets	1.2 ± 0.10 stat ± 0.15 sys
$Z \to \nu\nu$ + 3 jets	0.95 ± 0.09 stat ± 0.23 sys
$Z \to \mu\mu$ + 3 jets	0.16 ± 0.02 stat ± 0.04 sys
Total W/ Z	**3.9 ± 0.19 stat ± 0.46 sys Events**

QCD Background Estimate

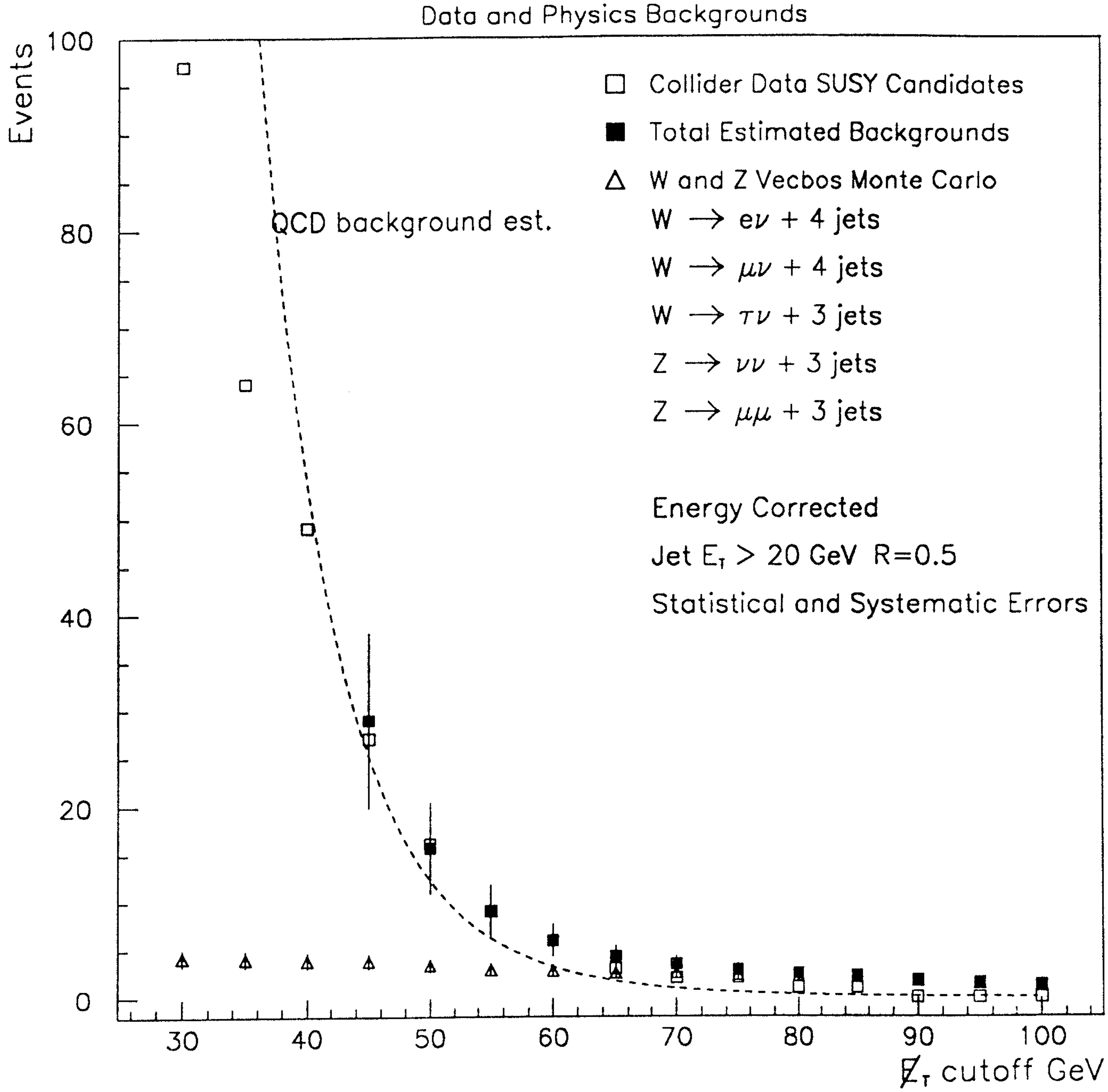
QCD Jet_Min Trigger: Hardware 1 jet tower E>3 GeV
Software 1 jet E_T>15 GeV R=0.3

$\int L_{single\ interaction}\, dt = 3.9\ nb^{-1}$ 773,919 events

Same cuts applied to sample as with data, no $\not{E}_T$cut
63 events

Plot Et distribution, fit tail to curve
$f(x) = P_1\, e^{P2 * sqrt(x)}$ x = missing E_T
Scale Luminosity

Expect 12.3 ± 1.5 stat ± 4.0 sys events


Data and Physics Backgrounds
Events
Collider Data SUSY Candidates
Total Estimated Backgrounds
W and Z Vecbos Monte Carlo
$W \rightarrow e\nu$ + 4 jets
$W \rightarrow \mu\nu$ + 4 jets
$W \rightarrow \tau\nu$ + 3 jets
$Z \rightarrow \nu\nu$ + 3 jets
$Z \rightarrow \mu\mu$ + 3 jets
QCD background est.
Energy Corrected
Jet E_T > 20 GeV R=0.5
Statistical and Systematic Errors
$\not{E}_T$ cutoff GeV
0
20
40
60
80
100
30
40
50
60
70
80
90
100

Results: Data: 16 events

Backgrounds: 16.2 ± 1.5 stat ± 4.0 sys events

15 Signal Events @ 95% C.L.

ISASUSY/ISAJET Monte Carlo - H. Baer, X. Tata

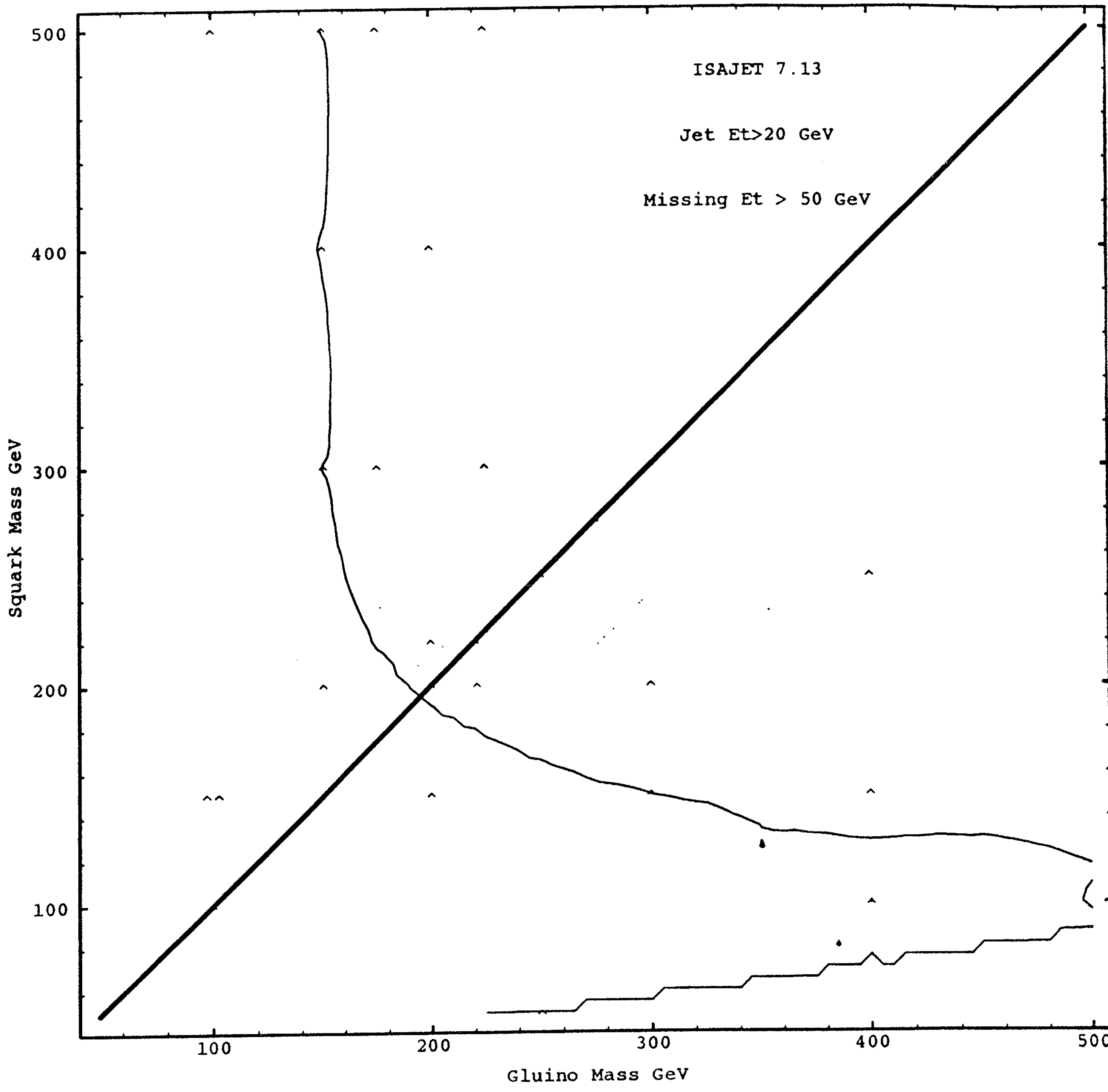
DØGeant Detector and Trigger Simulation

$\tan\beta = 2$; $\mu = -250$ GeV

$m_{\tilde{q}} = 500$ GeV $m_{\tilde{g}} = 149$ GeV

$m_{\tilde{q}} = m_{\tilde{g}} = 195$ GeV

SUSY Limit   4 or 5 jets + Missing Et



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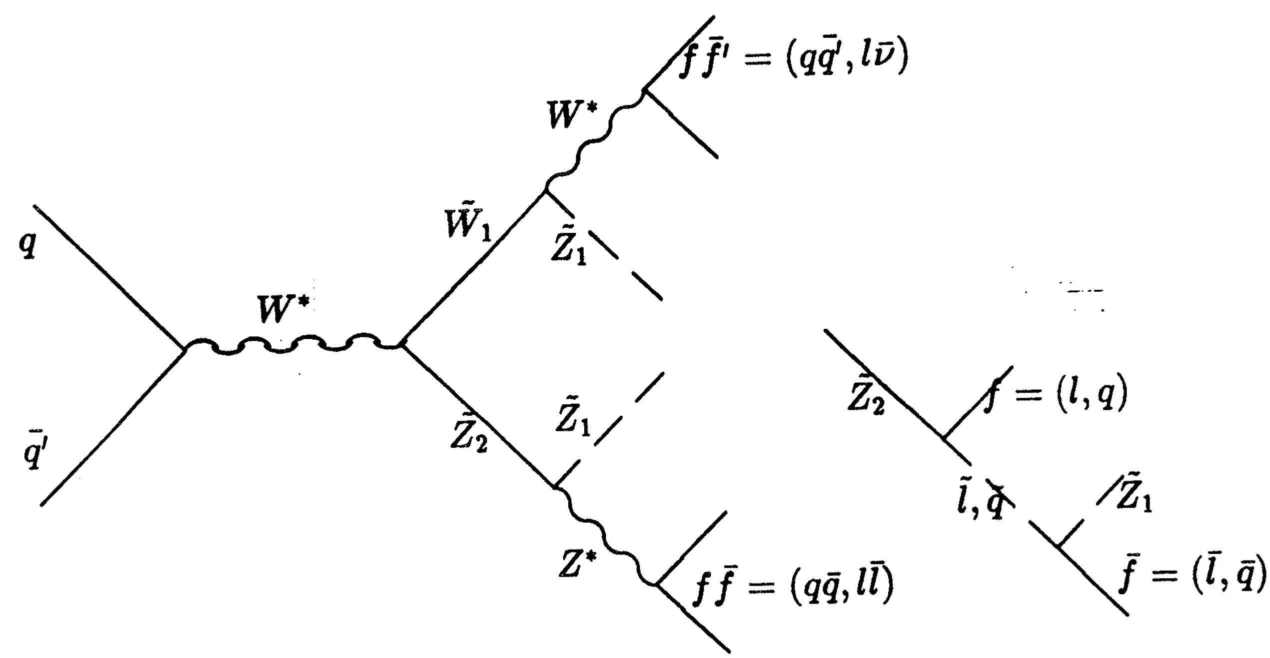
The Search for Gaugino Production

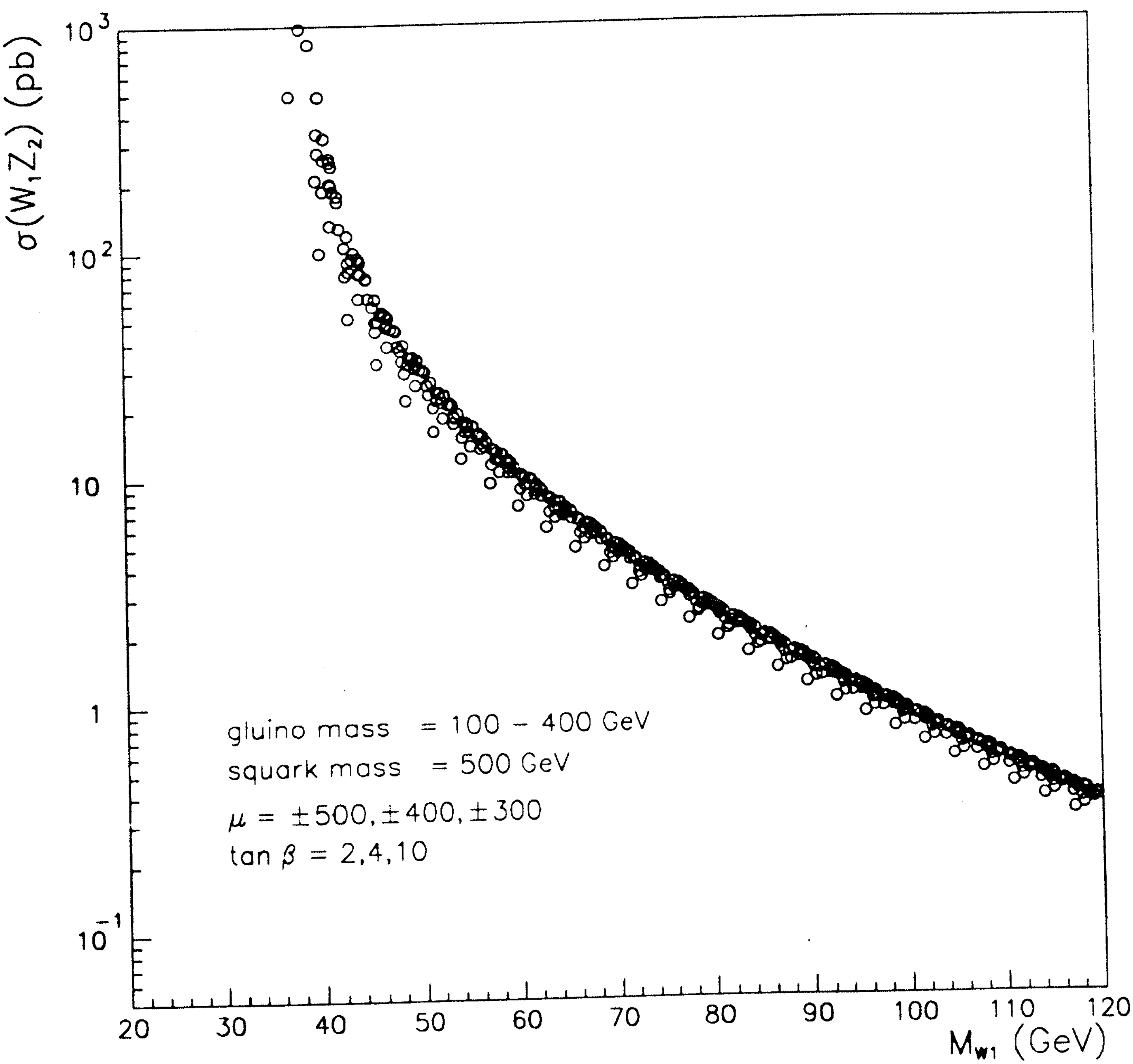
Largest cross-section is pair produuction of the lightest chargino ($\tilde{W}_1$) and second lightest neutralino ($\tilde{Z}_2$).



Production cross sections are 100-1 pb for $M_{\tilde{W}_1}$ = 47-100 GeV .

Branching fractions depend on model parameters, *e.g.*slepton mass for slepton mediated $\tilde{Z}_2$ decay.

W$_1$ Z$_2$ production cross section vs. W$_1$ mass

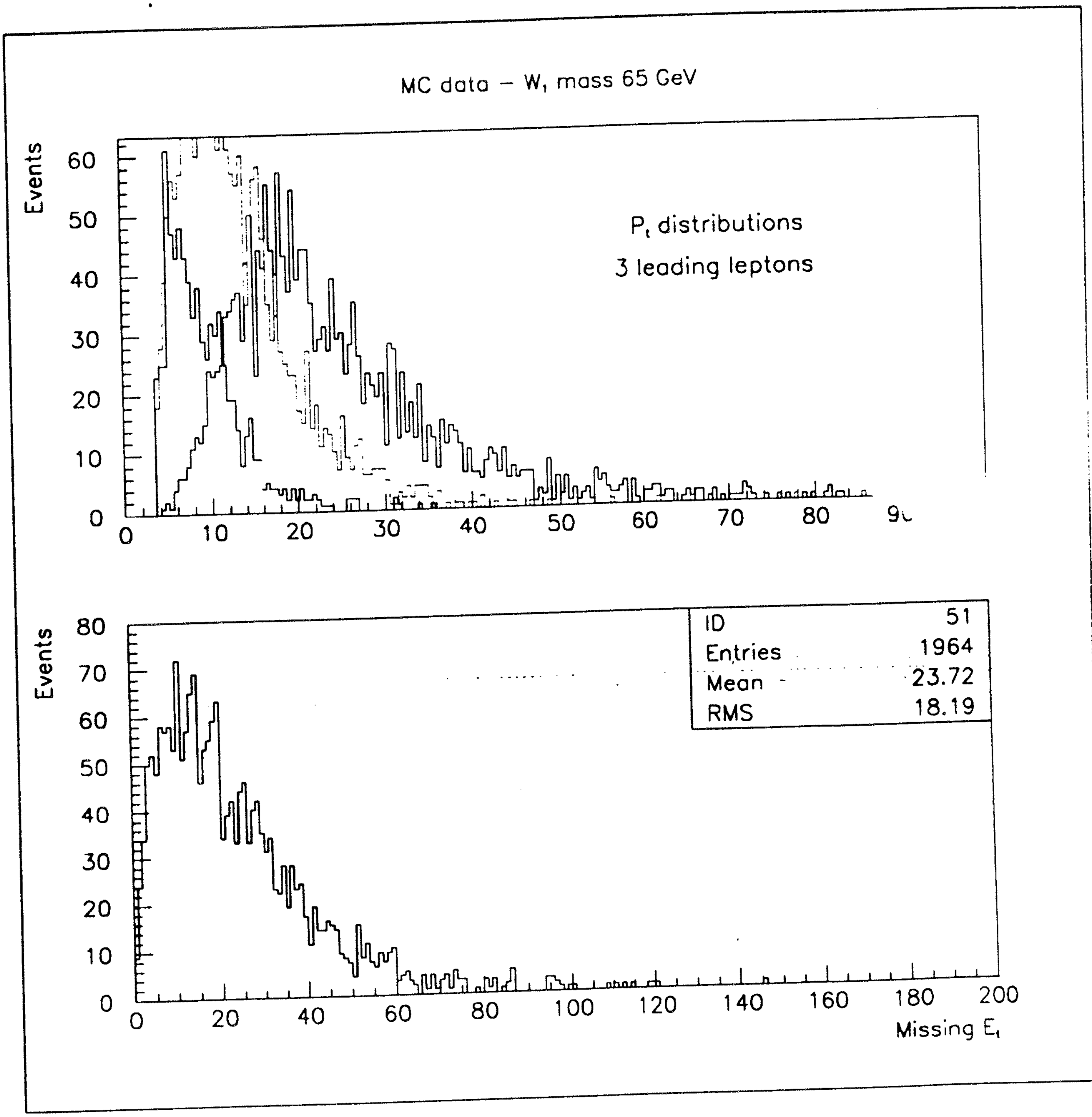


Event Signatures

$\tilde{W}_1 \rightarrow$	$\tilde{Z}_2 \rightarrow$	Final State
$q\bar{q}'\tilde{Z}_1$	$q\bar{q}\tilde{Z}_1$	4 jets + $\not{E}_T$
$l\nu\tilde{Z}_1$	$q\bar{q}\tilde{Z}_1$	Lepton + 2 jets + $\not{E}_T$
$q\bar{q}'\tilde{Z}_1$	$l\bar{l}\tilde{Z}_1$	2 leptons + 2 jets + $\not{E}_T$
$l\nu\tilde{Z}_1$	$l\bar{l}\tilde{Z}_1$	3 leptons + $\not{E}_T$ (***)

The trilepton signal should be the easiest to discrimninate from background. Other channels have large QCD backgrounds. Primary backgrounds to the trilepton search should be

- Physics backgrounds (*e.g.*, WZ pair production) - very small
- Misidentifcation backgrounds, *e.g.*, $Z \rightarrow l^+l^- + \gamma$, where the γ converts, $Z \rightarrow \tau\bar{\tau}$ + jet where the jet is misidentified, etc.


MC data – W, mass 65 GeV
Events
P_t distributions
3 leading leptons
0
10
20
30
40
50
60
70
80
90
Events
ID 51
Entries 1964
Mean 23.72
RMS 18.19
0
20
40
60
80
100
120
140
160
180
200
Missing E_t

Analysis

channel	eee	$ee\mu$	$e\mu\mu$	$\mu\mu\mu$
Triggers	ELE_2_HIGH ELE_HIGH	MU_ELE ELE_HIGH	MU_MAX MU_ELE	MU_MAX MU_2_HIGH
$\int \mathcal{L}dt\ (pb^{-1})$	12.1	12.1	12.1	9.0

A subsample of the RGE stream was preselected. Filtered events were then required to have $N_e + N_\mu \geq 3$

Filtered data set represents approx. 2800 events

Offline impose tighter cuts on physics objects.

- *Electrons* : $\chi^2 \leq 150(200)$, Iso. $\leq 0.15(0.20)$, EM fraction ≥ 0.9, No. CD tracks = 1 or 2.

- *Muons* : Define a "best" and "good" muon
  - "Best" : IFW4 = 0 or 1, Tight impact parameters, CD track match, Calorimeter confirmation from MTC, Float $T_0 < 100$.
  - "Good" : IFW4 = 0 or 1, Looser impact parameters, No CD track match, Calorimeter confirmation from MTC, Float $T_0 < 100$.
  - In each case, muons required to be isolated from jets ($dR > 0.5$).

Results

	eee	$ee\mu$	$e\mu\mu$	$\mu\mu\mu$
Filter Events	17	53	243	2489
Events with 3 leptons (tighter offline cuts)	6	3	4	7
$\not{E}_T > 10$	0	-	-	-
Number of forward e's ≤ 1	-	0	-	-
$\mu\mu$ pair invariant mass ≥ 5 GeV	-	-	1	3
$\angle\phi(\mu\mu) < 170°$ $\angle\theta(\mu\mu) < 160°$	-	-	0	0
Candidates	0	0	0	0

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SEARCH FOR LIGHT STOP SQUARK

If kinematically possible $\tilde{t}_1 \to b\tilde{W}_1$

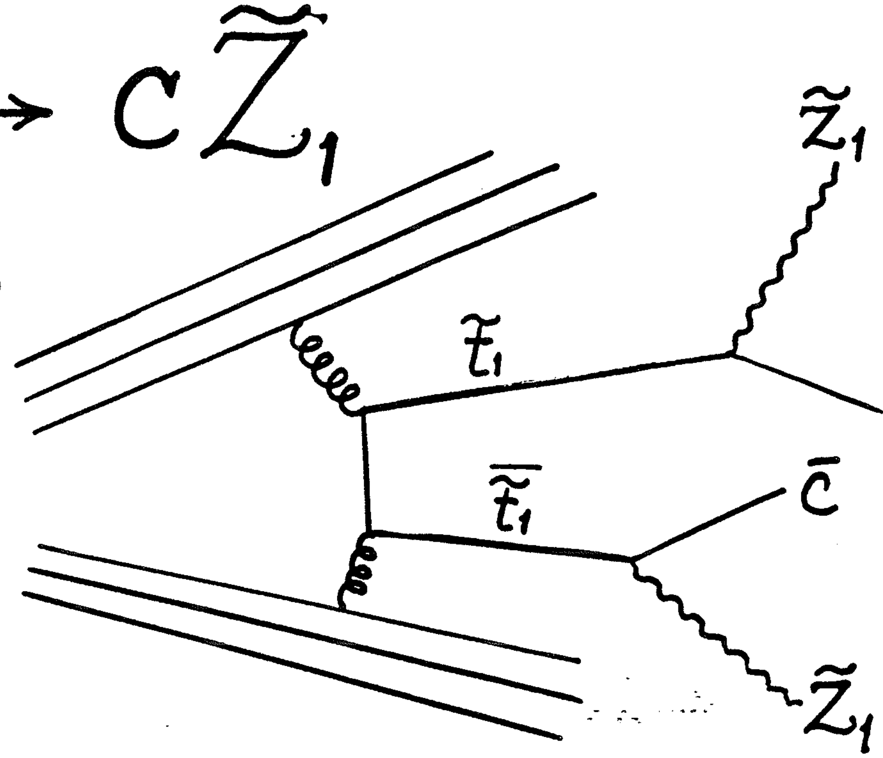
thru the direct S-top pair production channel where:

production cross section fixed by QCD in terms of $m_{\tilde{t}_1}$

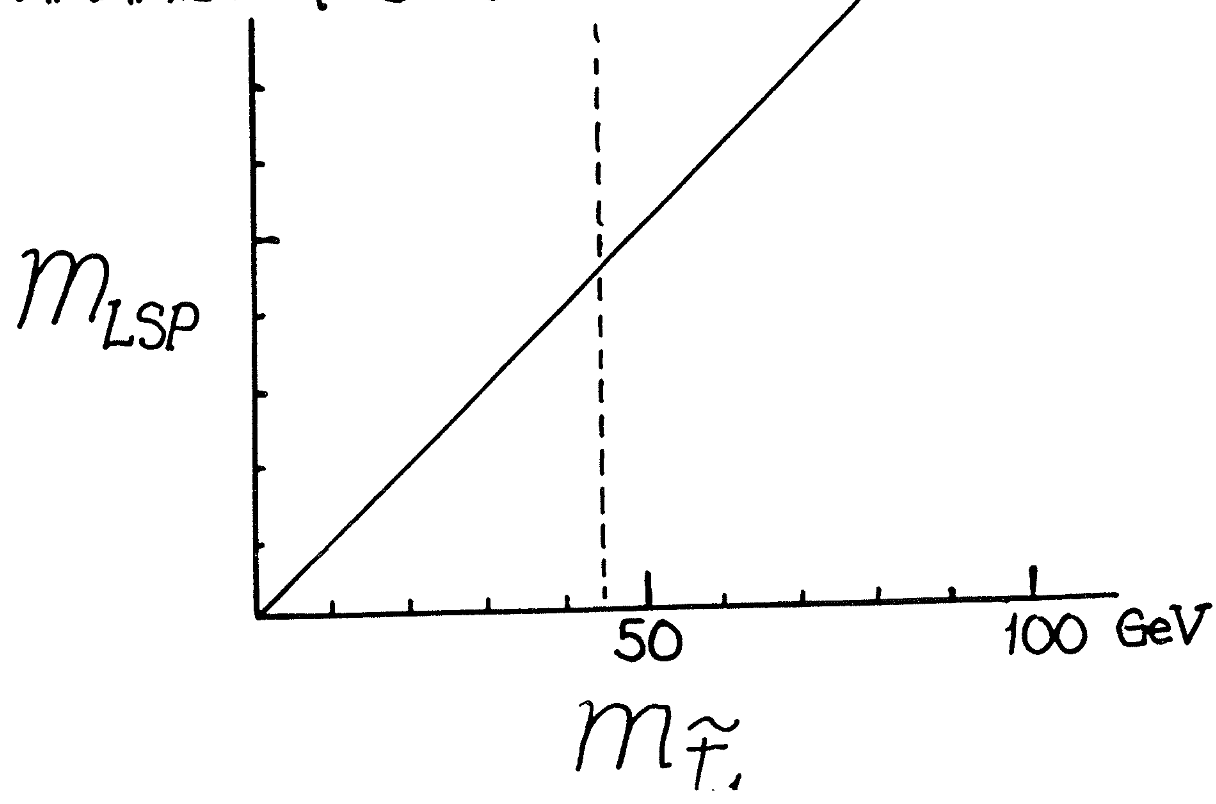
$$\tilde{t}_1 \longrightarrow c\tilde{Z}_1$$

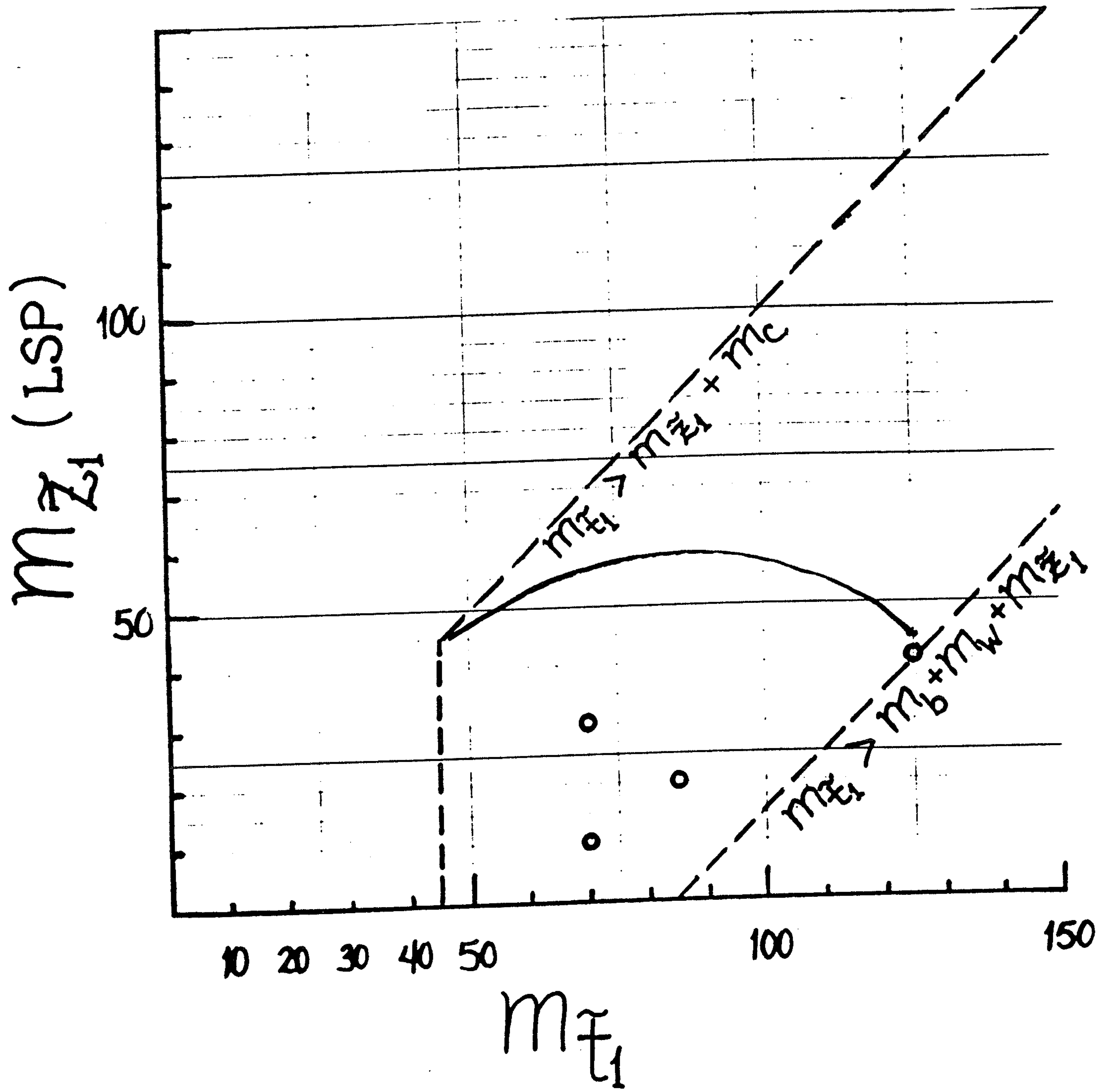
signal would be 2 acollinear jets plus $\not{E}_T$

$\tilde{t}_1\bar{\tilde{t}}_1$ production via gluon fusion & $q\bar{q}$ annihilation



PARAMETER SPACE TO BE PROBED:





o ISAJET 7.00 s-bottom production

$\not{E}_t > 55\text{-GeV}$

$Et_{jet1} > 45\text{-GeV}$ $Et_{jet2} > 25\text{-GeV}$

$Et_{\mu} < 5.0\text{-GeV}$ $Et_{el} < 20$ $Et_{\gamma} < 20\text{-GeV}$

$10^\circ < \Delta\phi(j_1, j_2) < 165^\circ$

$10^\circ < \Delta\phi(j_1, \not{E}_t) < 130^\circ$

Run 1a single interaction Missing Et triggers 1 candidate

Signal:

	SURVIVORS from 2000-evt sample	Eff	Expected In ~7/pb
70-GeV STOP	28	1.4%	8
85-GeV STOP	38	1.9	4.4
125-GeV STOP	107	5.4	1.6

DØ Run 1b Analyses

- Squark/Gluinos $\rightarrow$ Jets + $\not\!\!E_T$

  Adam Lyon

- Squark/Gluinos $\rightarrow$ Leptons + Jets + $\not\!\!E_T$

  Kaushik De Elizabeth Gallas Jim Linnemann Rich Genik
  Naba Mondal H. C. Shankar

- Wino Zino $\rightarrow$ Trileptons

- Wino Wino $\rightarrow$ Dileptons

  Doug Norman Taylor Goss Djoko Wirjawam

- Stop $\rightarrow$ Jets + $\not\!\!E_T$

  Gouliang Wang

- Stop $\rightarrow$ Leptons + b Jets

  Sue Blessing Amber Boehnlein

- R-Parity Violating SUSY

  V. Narasimham Nirmalya Parua

- Charged Higgs

  Chiaki Yanagisawa

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Run 1b Squark/Gluino Search

Major problem : How do we perform a Missing E_T search with high multiple interaction rates ?

Question is two-fold :

- How do multiple interactions affect the signal ?
- How do multiple interactions affect the background ?

Preliminary studies begun by Adam Lyon. Looks at $\tilde{q}/\tilde{g}$ + Min Bias events, and $Z^{\circ}\rightarrow ee$ + Min Bias events.

For signal events, selection of hard scattering vertex seems relatively insensitive to multiple interactions.
→ Recipe (still to be verified) :

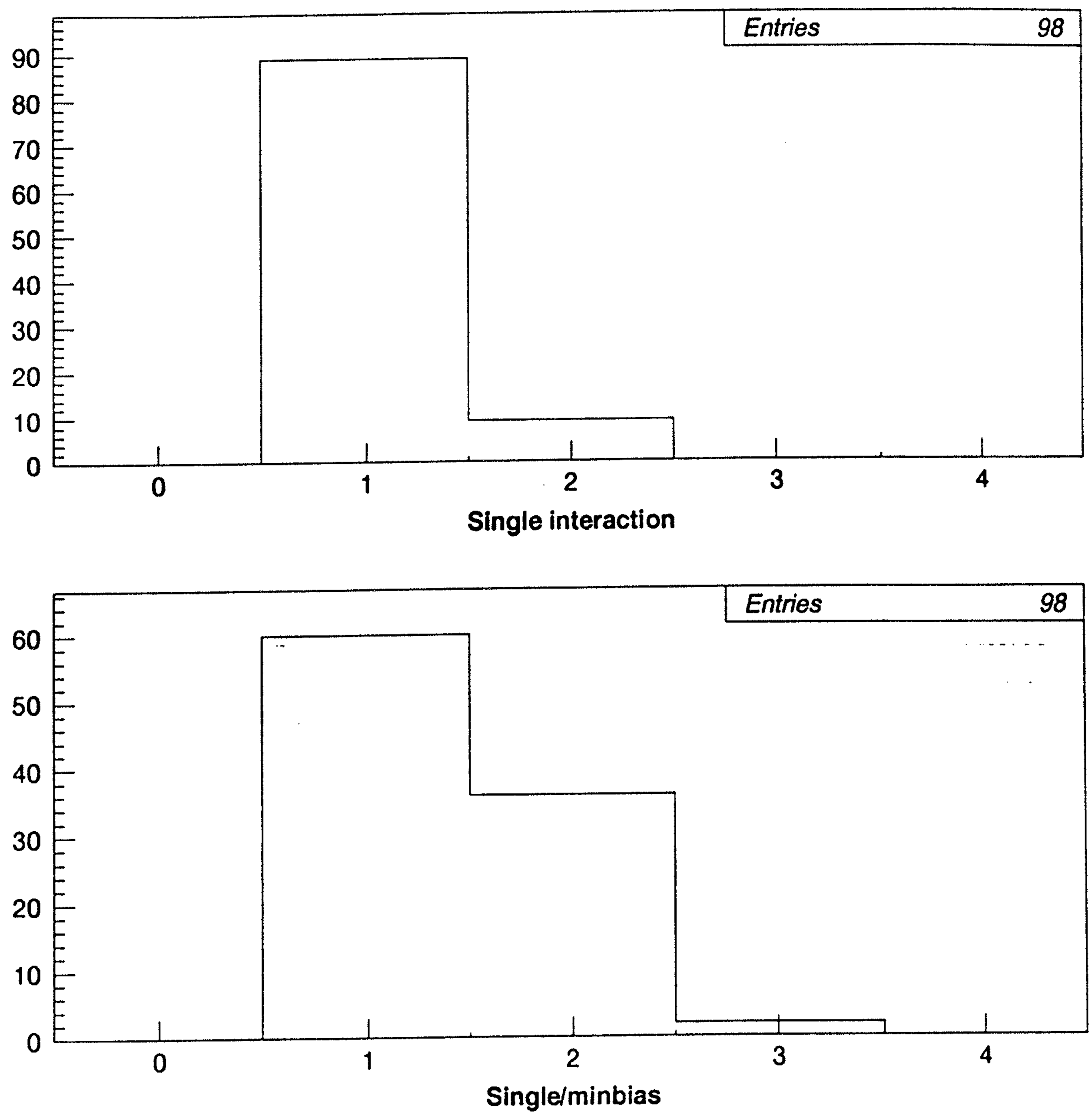
1 Get list of event vertices from tracking,,

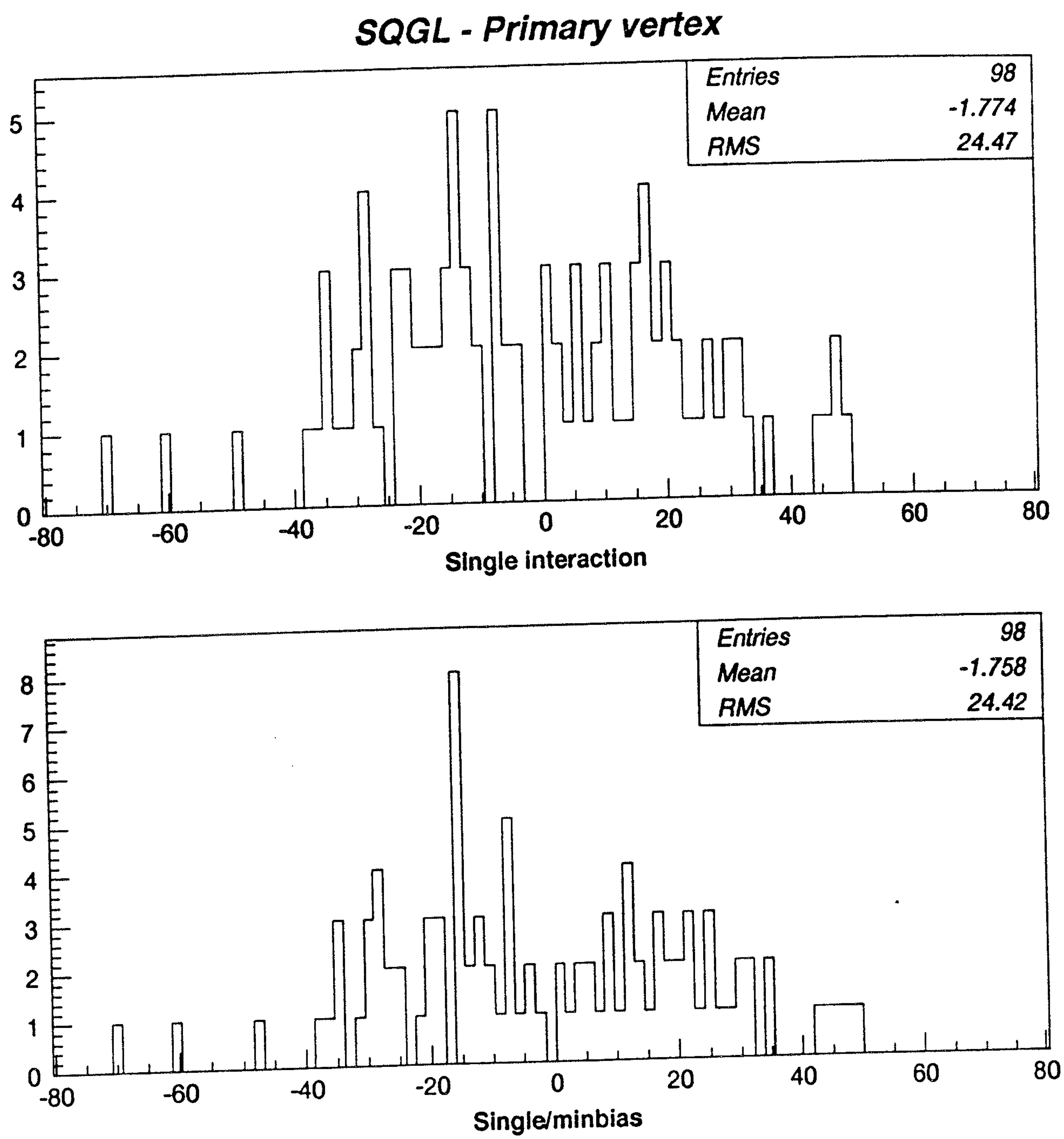
2 Choose hard scatter interaction with jets,

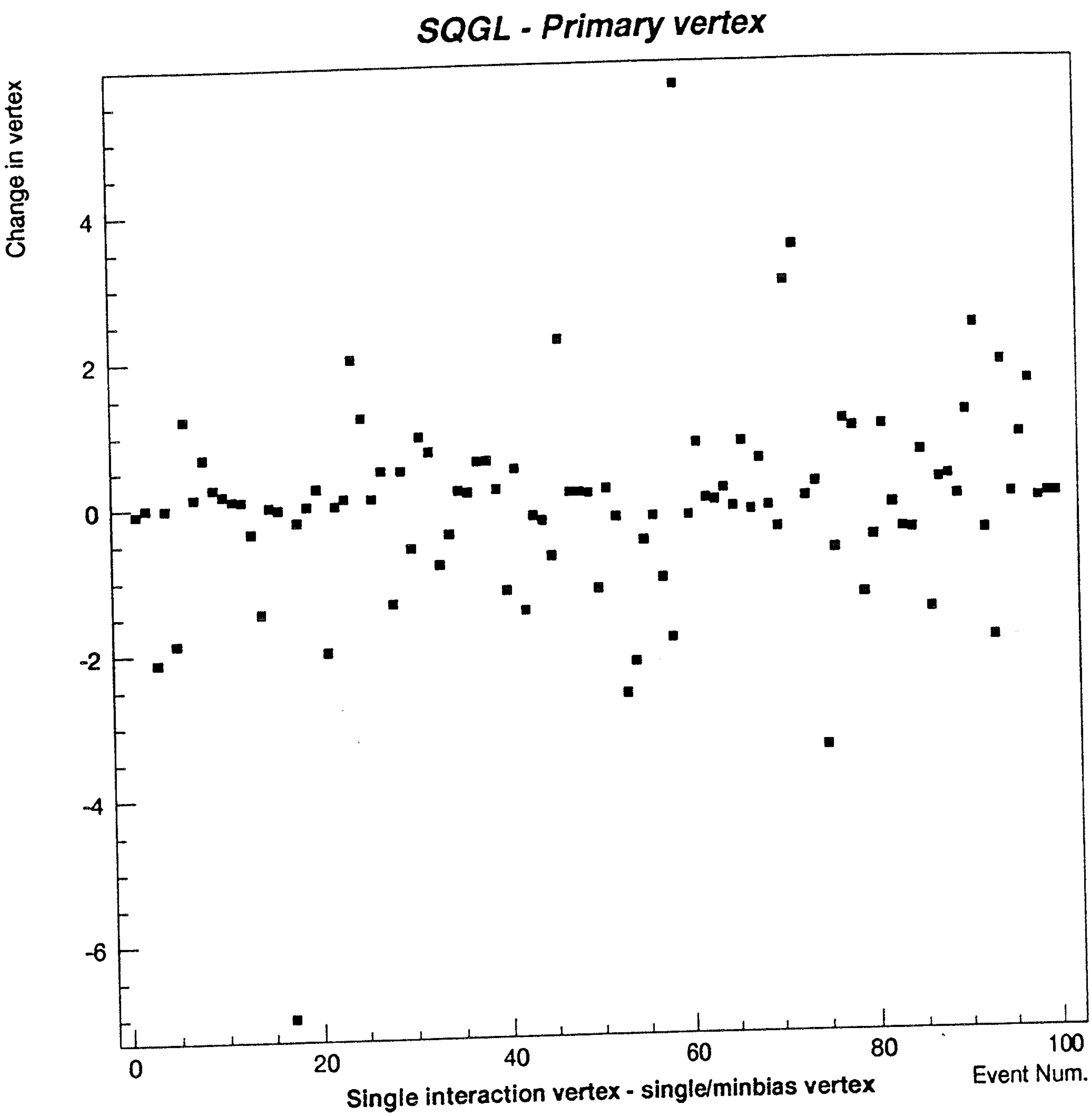
3 Cut on events where the RECO primary vertex is displaced from the jet vertex.

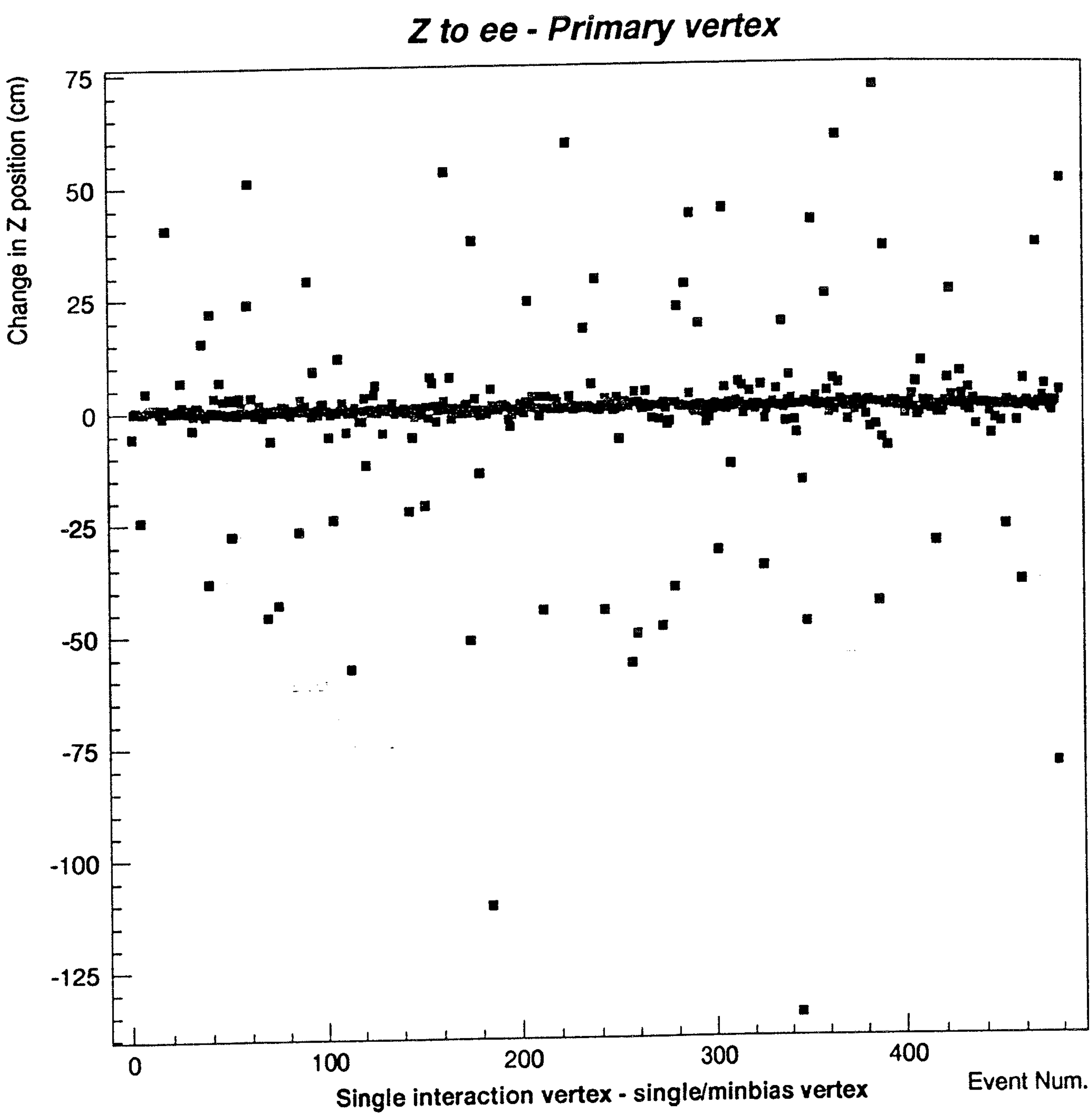
Should at least be better than cutting out all multiple interaction events.

SQGL - Number of verticies

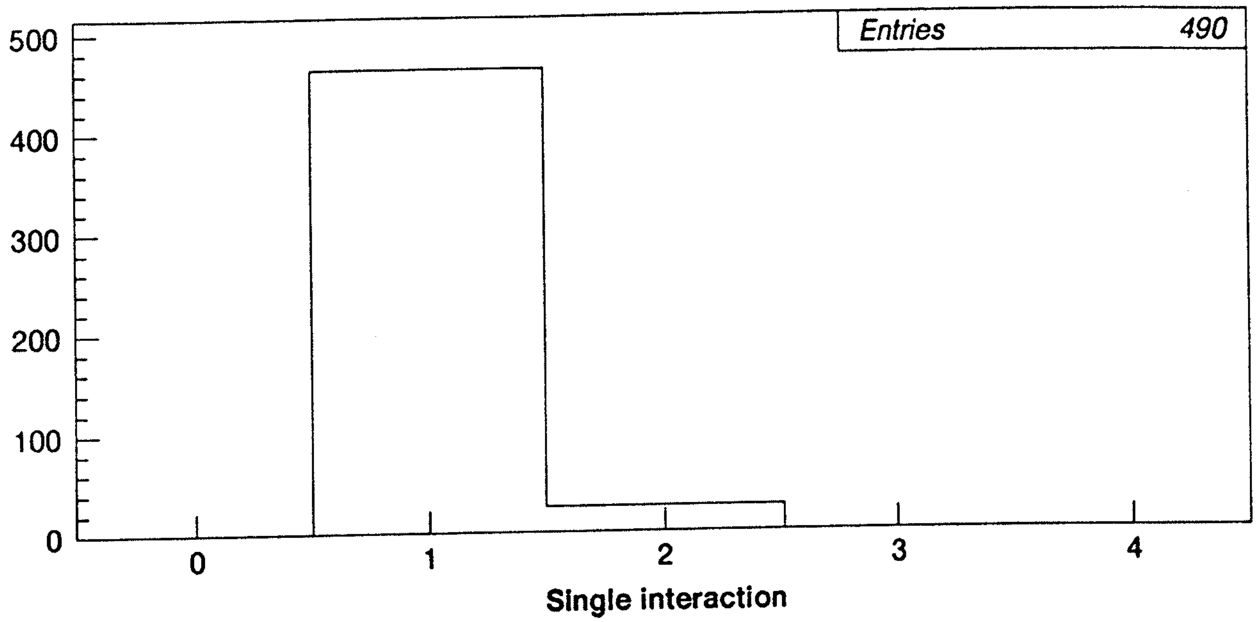


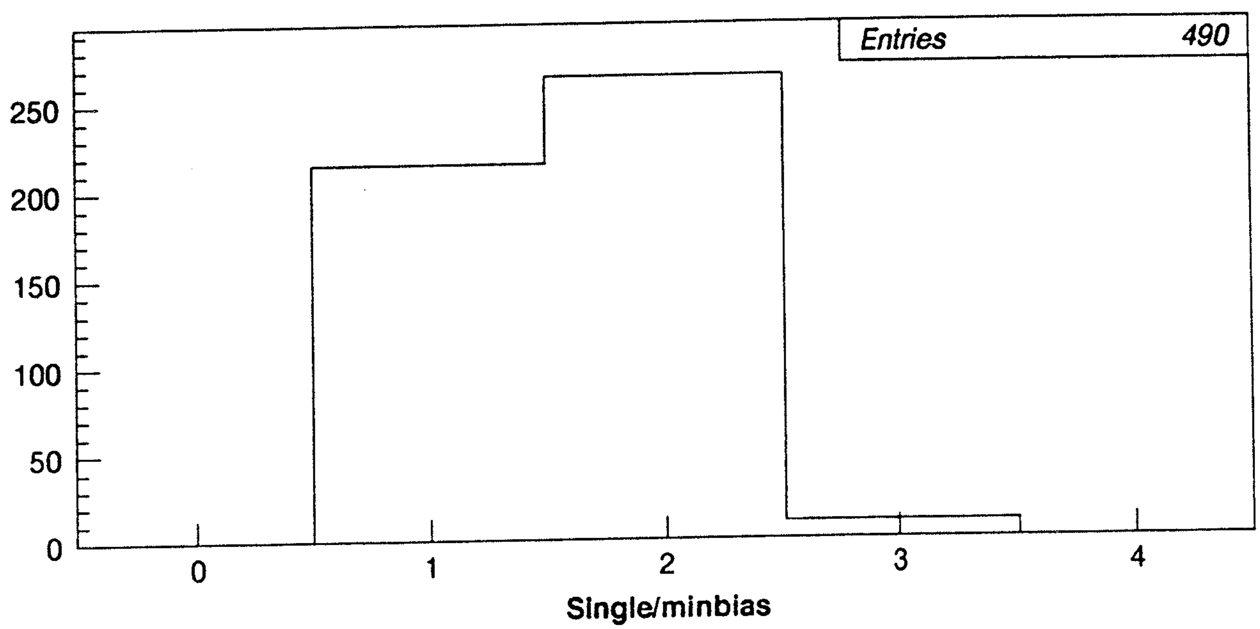

SQGL - Primary vertex
Entries 98
Mean -1.774
RMS 24.47
Single interaction
Entries 98
Mean -1.758
RMS 24.42
Single/minbias


SQGL - Primary vertex
Change in vertex
4
2
0
-2
-4
-6
0
20
40
60
80
100
Event Num.
Single interaction vertex - single/minbias vertex


Z to ee - Primary vertex
Change in Z position (cm)
75
50
25
0
-25
-50
-75
-100
-125
0
100
200
300
400
Event Num.
Single interaction vertex - single/minbias vertex

Z to ee - Number of verticies





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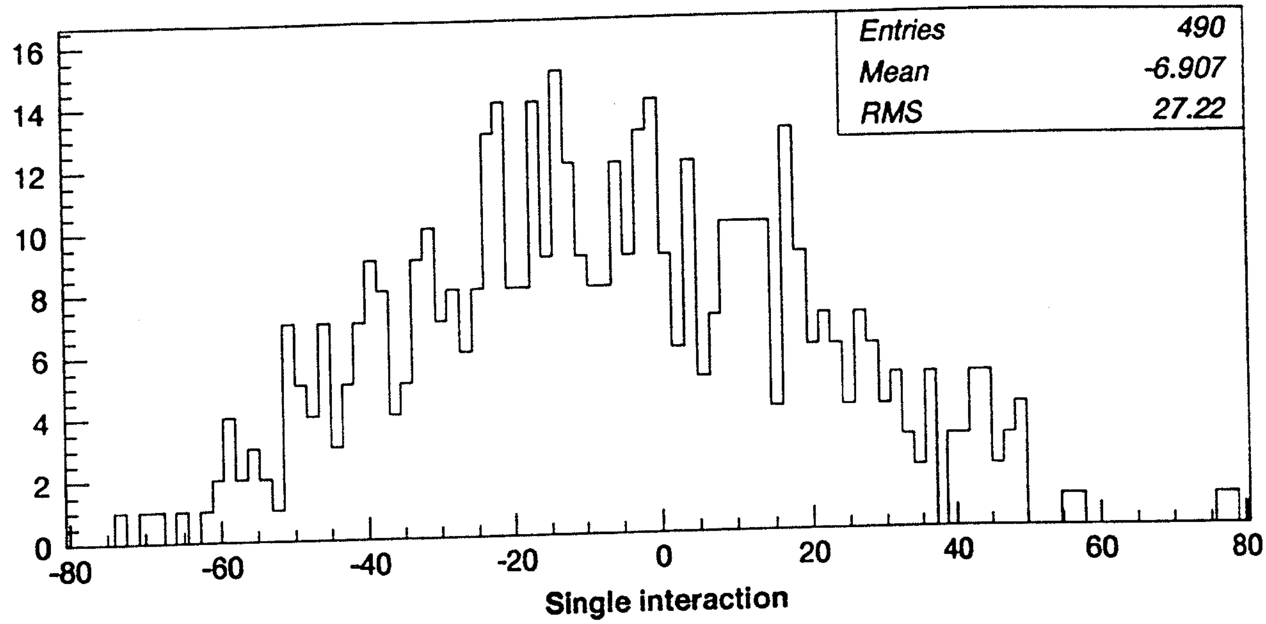
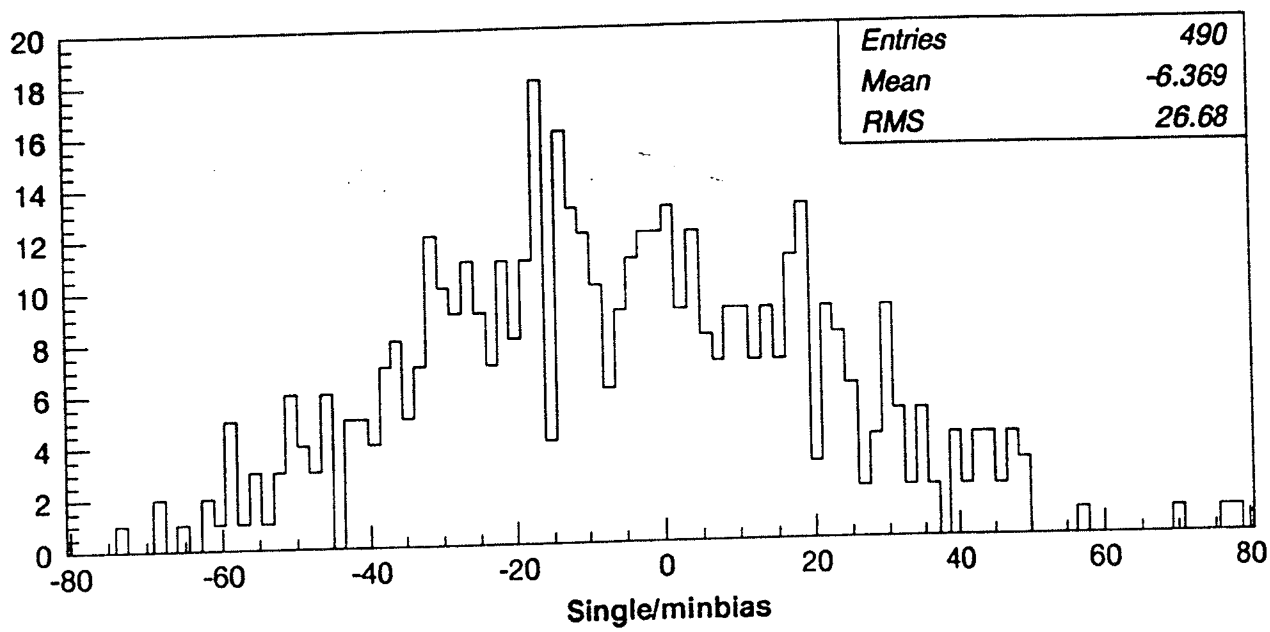
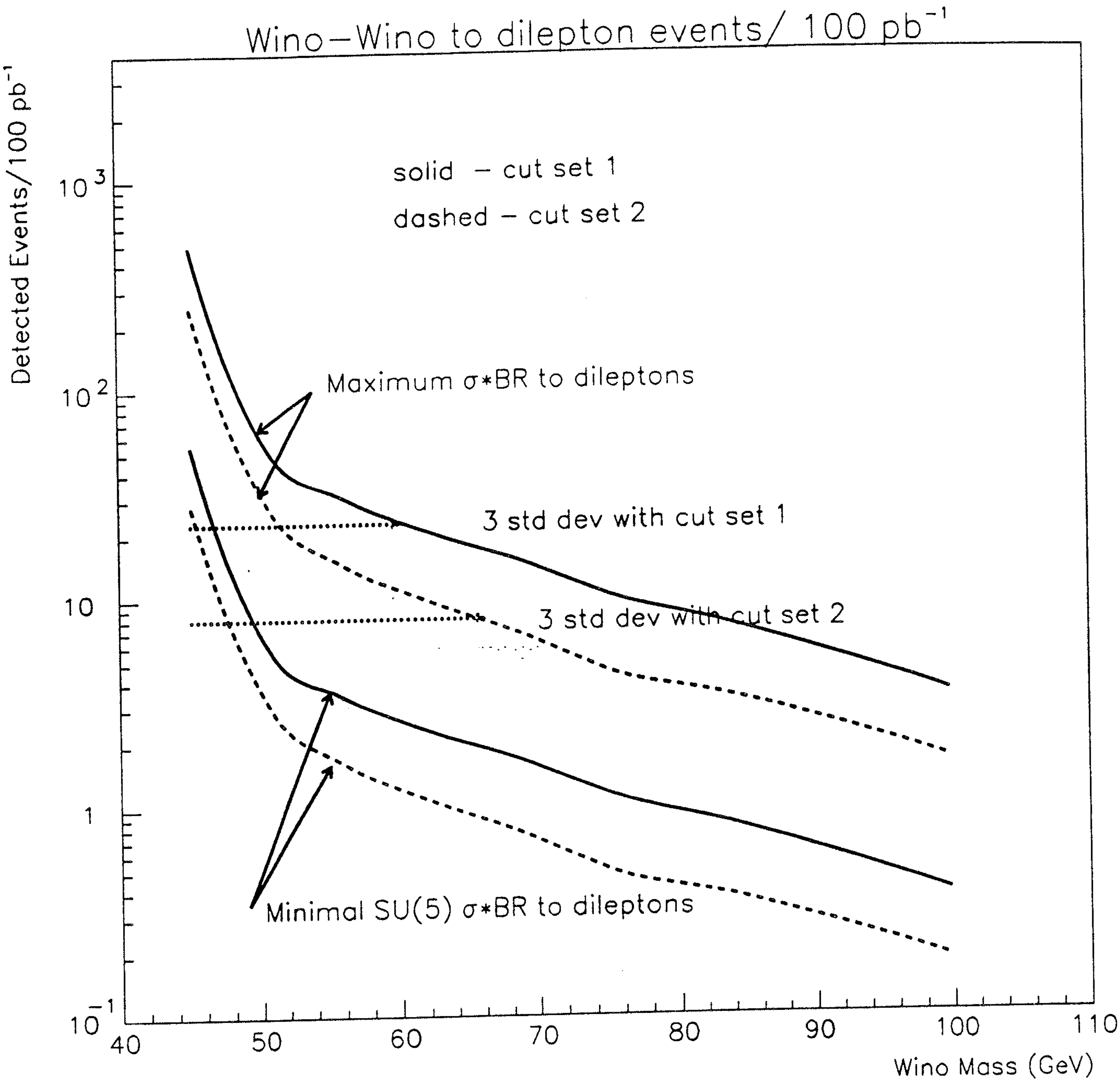
Z to ee - Primary vertex







Wino-Wino to dilepton events/ 100 pb^{-1}
Detected Events/100 pb^{-1}
solid - cut set 1
dashed - cut set 2
Maximum σ*BR to dileptons
3 std dev with cut set 1
3 std dev with cut set 2
Minimal SU(5) σ*BR to dileptons
10^3
10^2
10
1
10^{-1}
40
50
60
70
80
90
100
110
Wino Mass (GeV)

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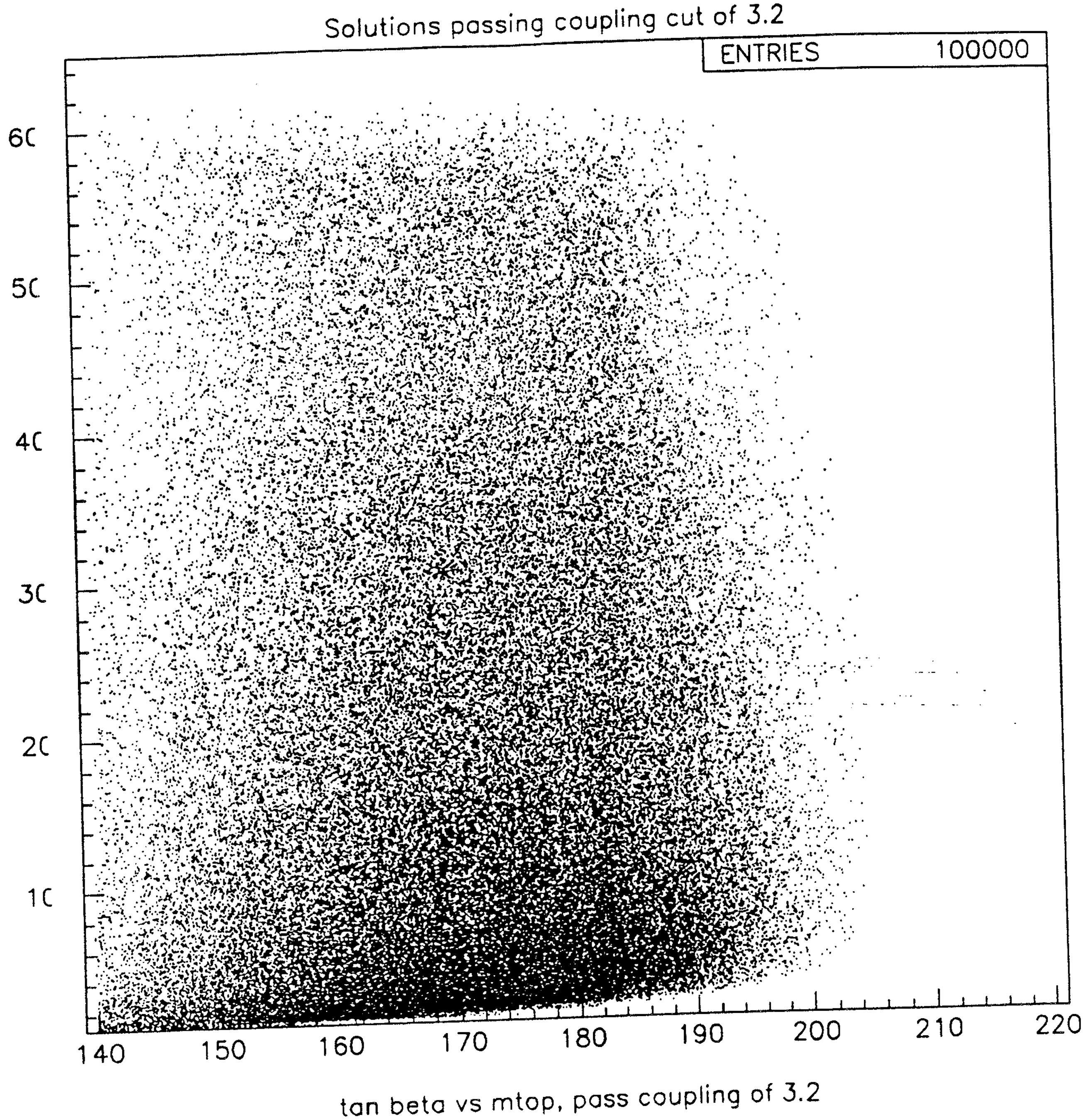
Constraining SUSY

Study begun by Jim Linnemann and Rich Genik to "map" the range of allowed SUSY parameter space, for the purpose of comparing our limits to theoretical predictions.

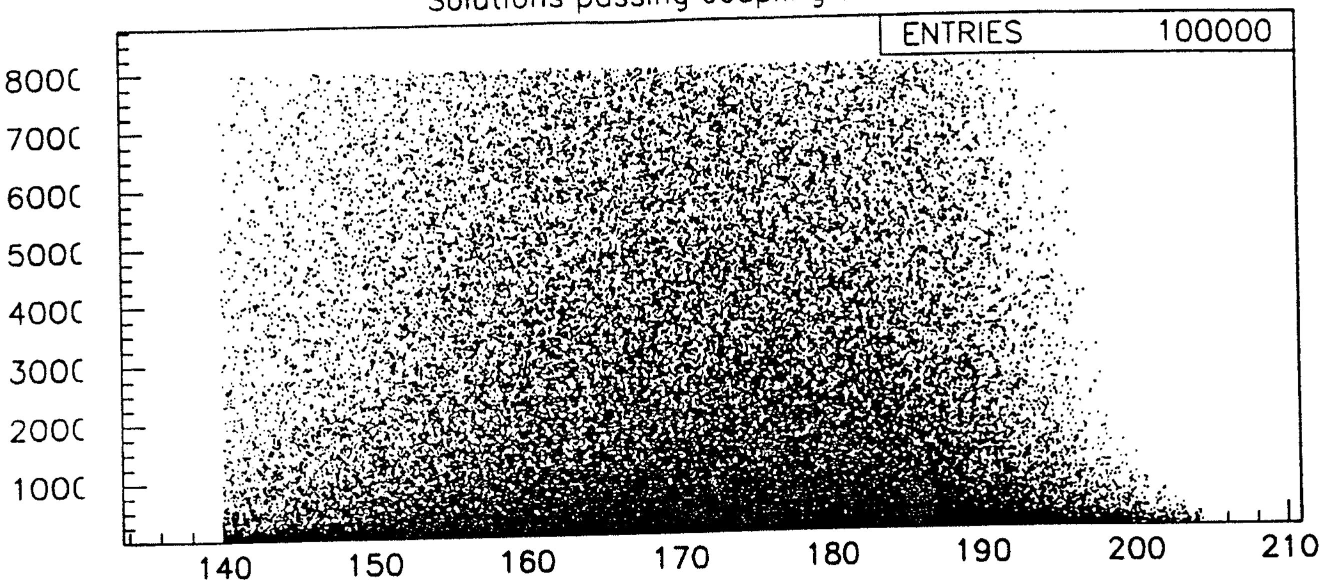
Uses the Univ. of Michigan Theory Group's CMSSM model generator. (Agrees with other theorists...) Produces "solutions" which can be plotted as a function of SUSY parameters, (s)particle masses, etc. Also provides inputs for generators like ISAJET.

Currently performing consistency checks. Have not applied previous experimental limits. Goal is an Ntuple of allowed solutions.

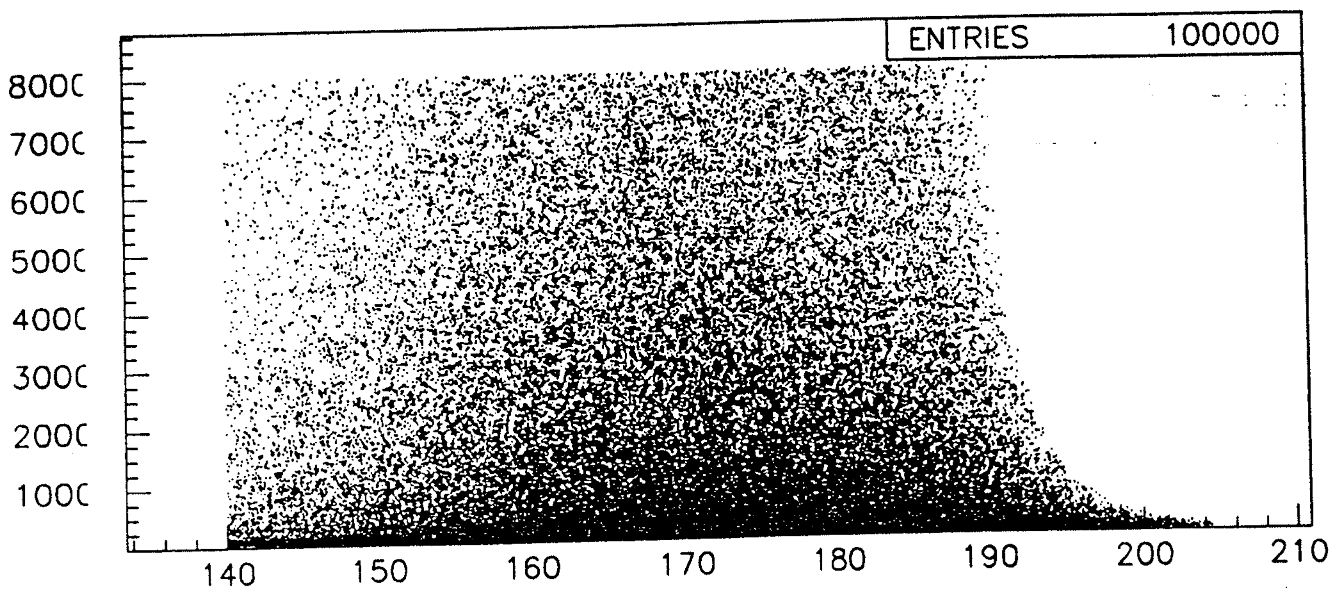
01/11/94 20.18


Solutions passing coupling cut of 3.2
ENTRIES 100000
60
50
40
30
20
10
140
150
160
170
180
190
200
210
220
tan beta vs mtop, pass coupling of 3.2

Solutions passing coupling cut of 3.2



M0 VS MTOP



MHALF VS MTOP

Trigger Issues

Number of SUSY triggers have increased in Run 1b. Previously NEW group trigger were mostly $\not{E}_T$ or *jets* + $\not{E}_T$. New filters added for wino/zino search (plus non-SUSY searches, *cf* Wyatt's talk).

Run 1a NEW Filters (Trigger list 7.2)	Run 1b NEW Filters (Trigger list 10)
SCALAR_ET	GIS_DIJET
MISSING_ET	EM2_2EISTRK_MS
MISS_ET_MON	EISTRK2_MON
JET_3_MISS	SCALAR_ET
JET_MISS_TAU	ELE_JET_1
SCAL_ET_JET	SCALAR_ET_JT
	SCALAR_ET_HT
	EMJET_7
	MISSING_ET
	MISSING_ET_MAX
	JET_3_MISS
	JET_2_MISS
	JET_2_MISS_MON

Concerns :

- MISSING_ET threshold at 40 GeV (Level 1 and Level 2). Probably OK for squark/gluino searches.
- Wino/Zino, Wino/Wino, and $\tilde{t}\rightarrow l$ + *jets* searches suffer from rising lepton p_T thresholds - probably unavoidable.

MEETING

SUSY GROUP

TEVATRON BEYOND 2000

TODAY 1 PM

SNAKE PIT

Conclusions

- All direct searches have failed to discover any new particle states.

- DØ now has the best limit on squark and gluino masses : $M_{\tilde{g}} > 146$ GeV, for heavy squarks; and $M > 205$ GeV, for $M_{\tilde{g}} = M_{\tilde{q}}$

- DØ limit on the $\tilde{W}_1$ mass from Run 1a should be just above the LEP limit. Run 1b could allow discovery of a $\tilde{W}_1$ below 65 GeV or so.

- Given what we know about the (large) mass of the top, the search for its SUSY partner, $\tilde{t}$, is an atractive search channel. Run 1a limits on $m_{\tilde{t}}$ may be in the 70 to 80 GeV range. Run 1b should allow us to exclude much of the allowed parameter space for $\tilde{t} \to jet + \not{E}_T$.

  Alternatively one can look for $\tilde{t} \to b\tilde{W}_1, \tilde{W}_1 \to e\nu\tilde{Z}_1$ or $\mu\nu\tilde{Z}_1$. For the Run 1b analysis, both stops are required to decay to a lepton. Improved b-tagging will allow the single lepton plus b-tagged jet channel be explored.

- Other searches, many of which need a larger data set than Run 1a, are just beginning. A coordinated approach to comparing our limits to theoretical predictions is being studied.

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