Searches at the Tevatron for Physics Beyond the Standard Model

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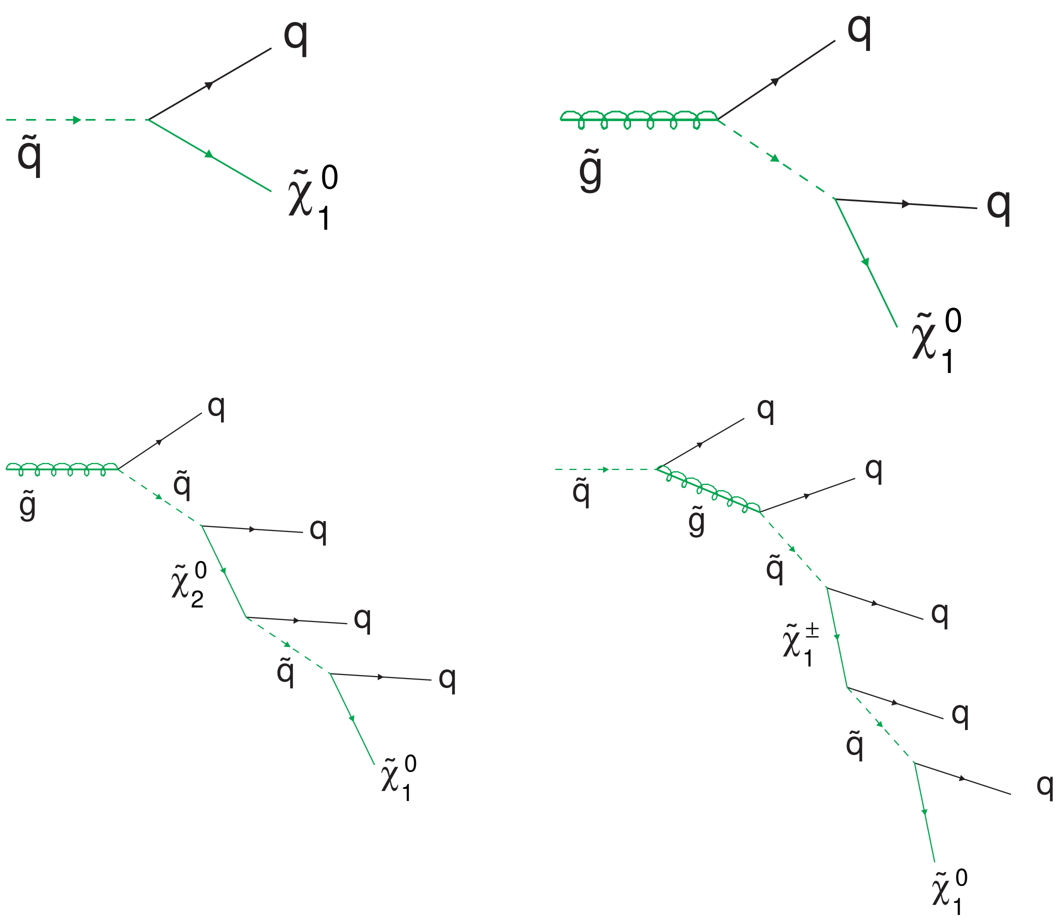
Outline

- Squarks and Gluinos
- High Mass $e\nu$
- Large Extra Dimensions
- Photon Lepton Events
- Sleuth

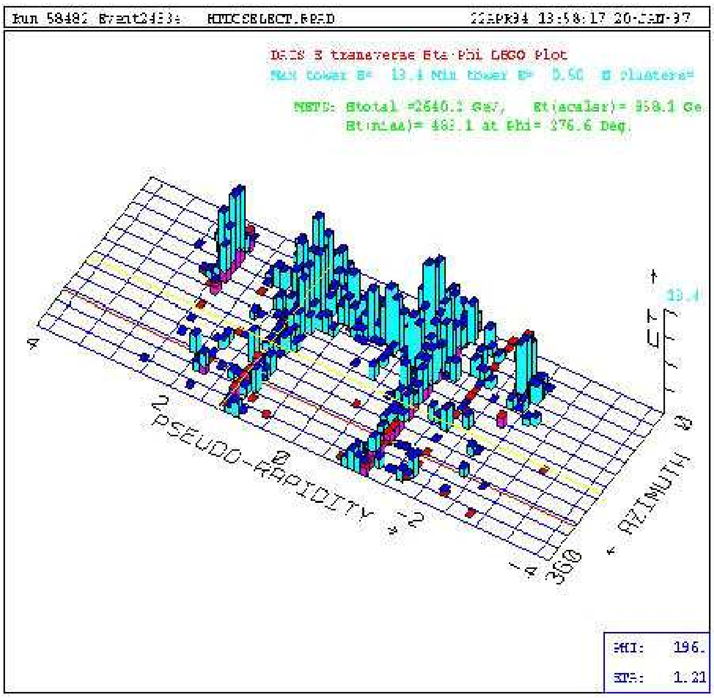
Squarks and Gluinos (CDF)

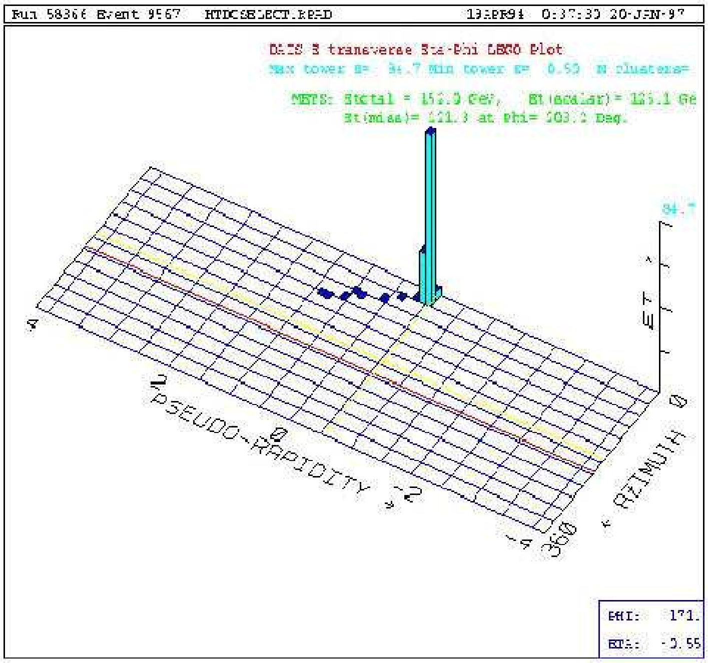
- Strong $\tilde{q}\bar{\tilde{q}}$, $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$ production
- Possible decay modes include



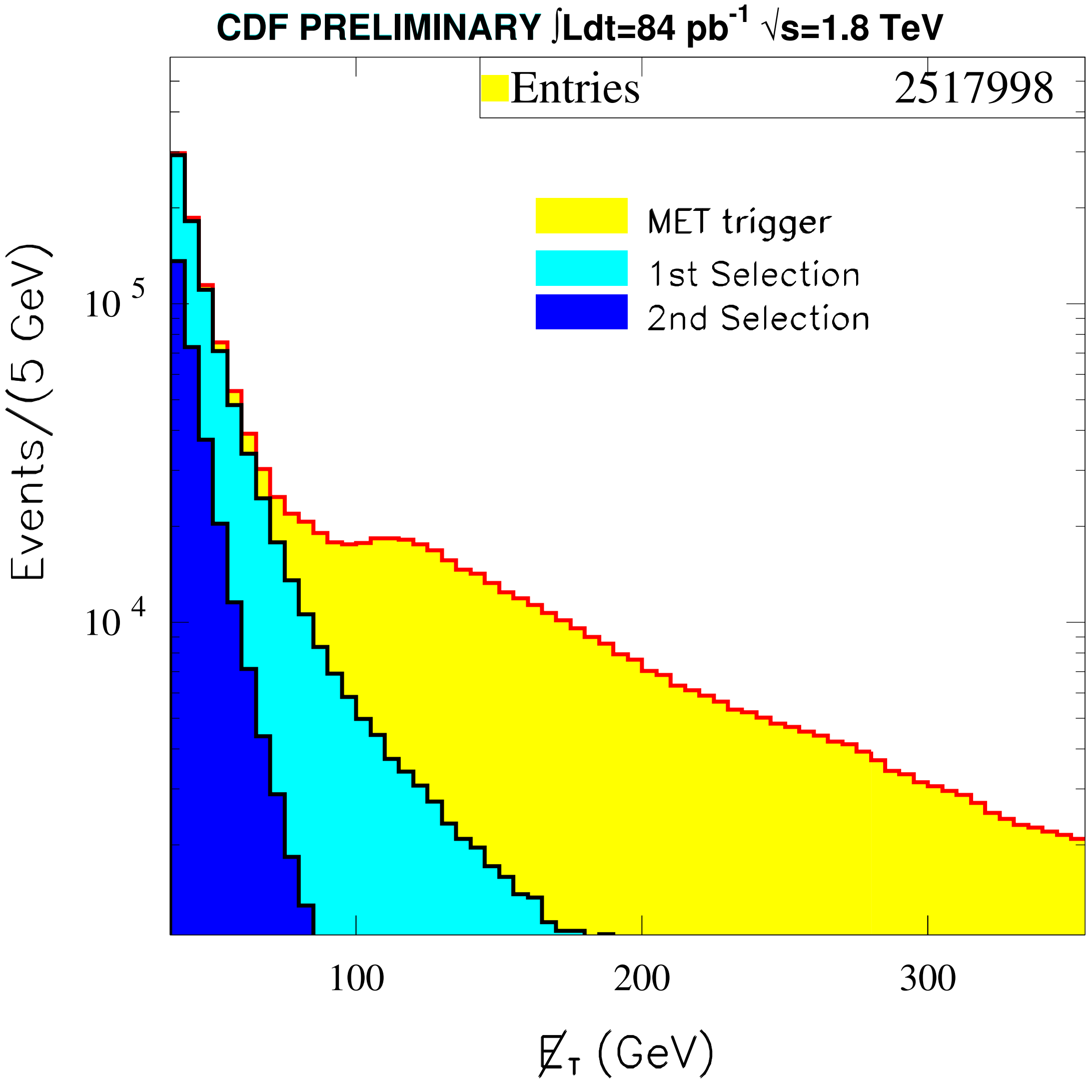
→ signature: $\not{E}_T$ + 3 or more jets

Extraneous Energy

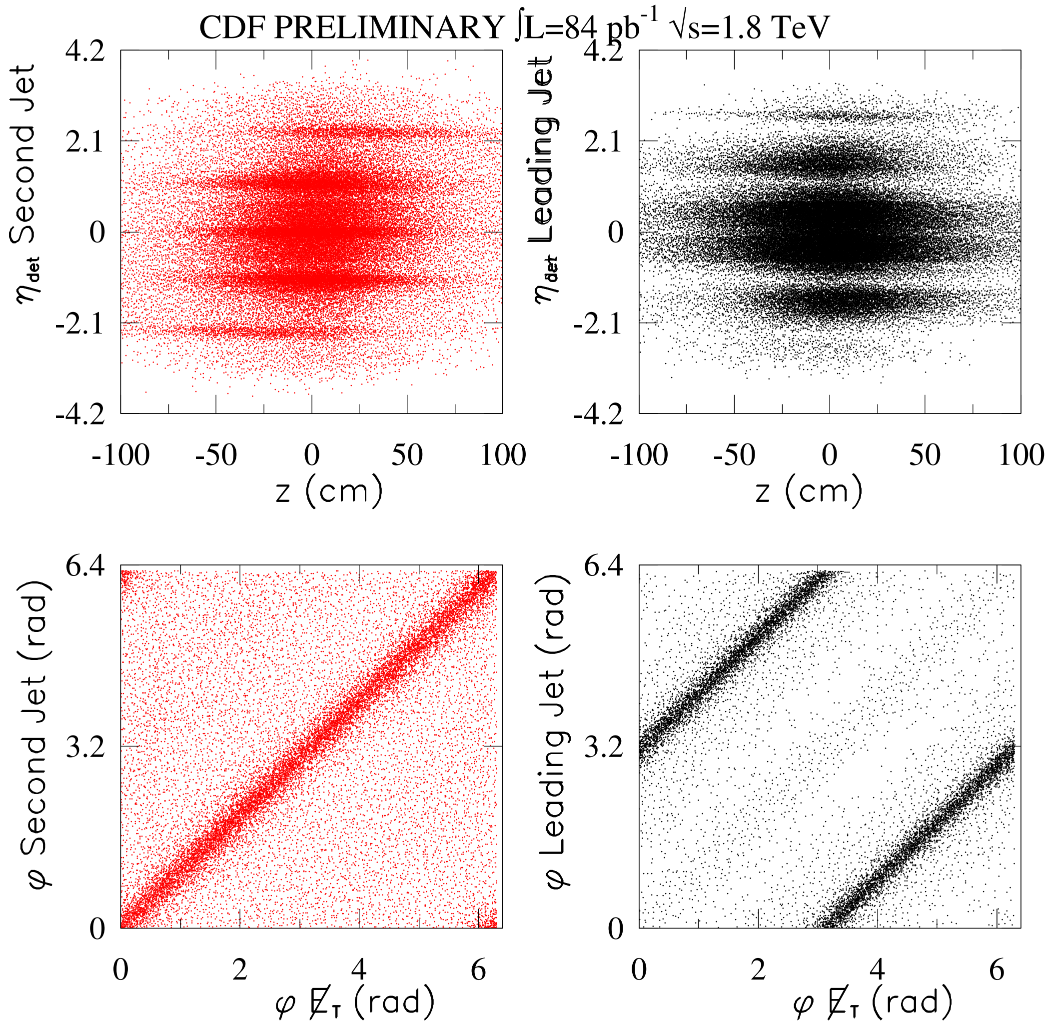




$\not{E}_T$ After Cleanup

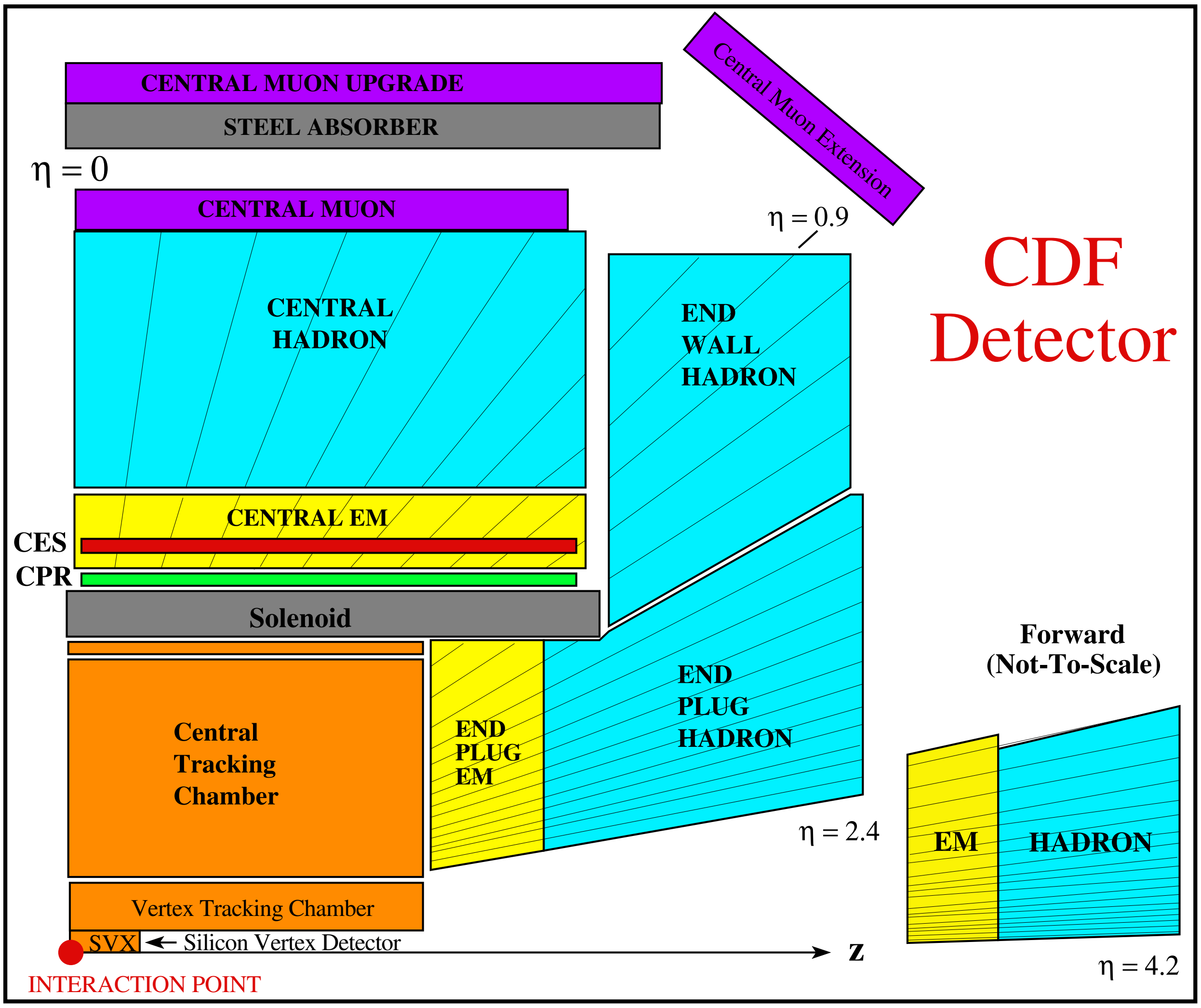


Lost Energy

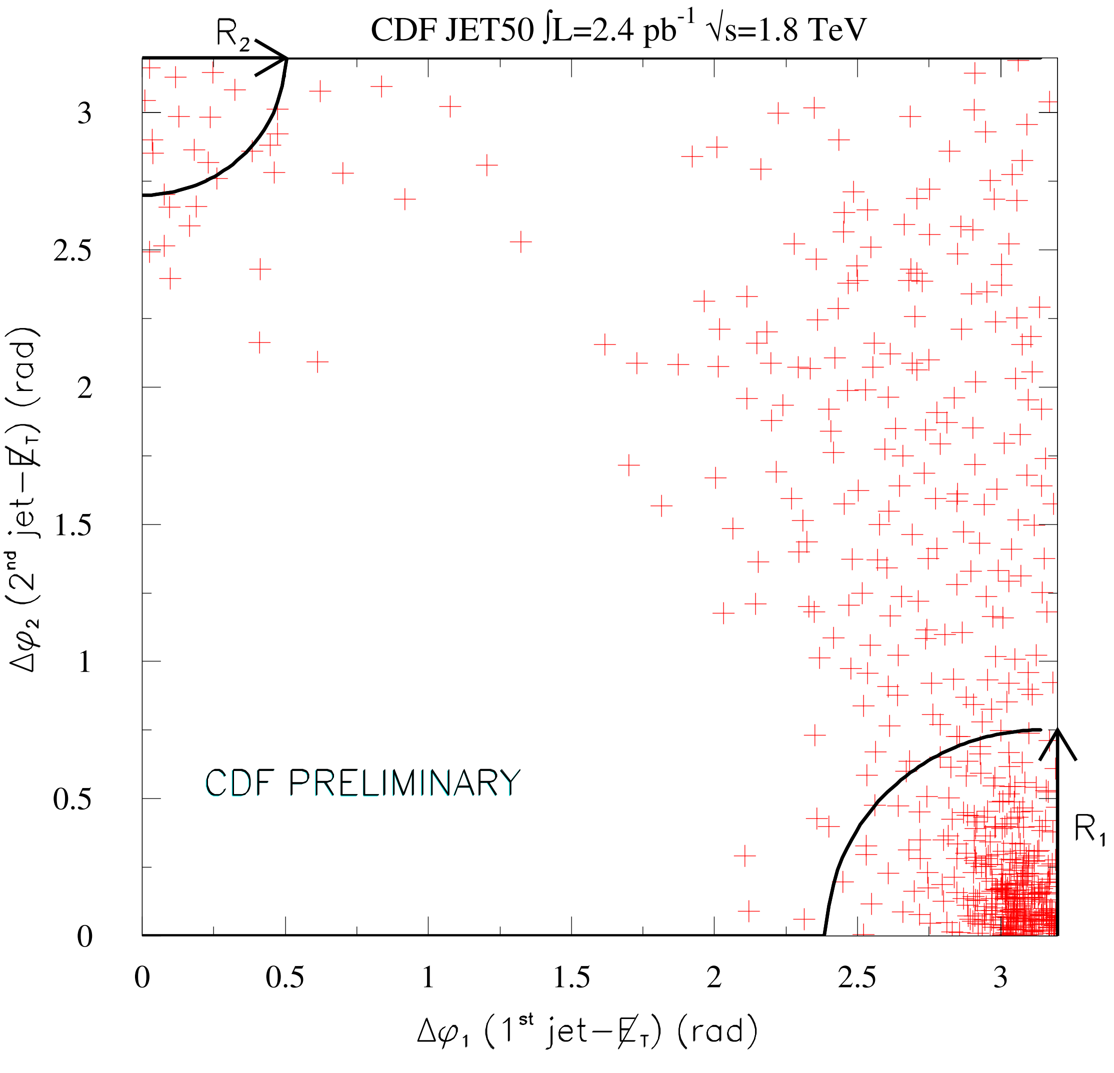


CDF PRELIMINARY ∫L=84 pb-1 √s=1.8 TeV
η_det Second Jet
η_det Leading Jet
4.2
2.1
0
-2.1
-4.2
-100
-50
0
50
100
z (cm)
φ Second Jet (rad)
φ Leading Jet (rad)
6.4
3.2
0
2
4
6
φ E̸_T (rad)

Quadrant of CDF



Lost Energy (cont.)



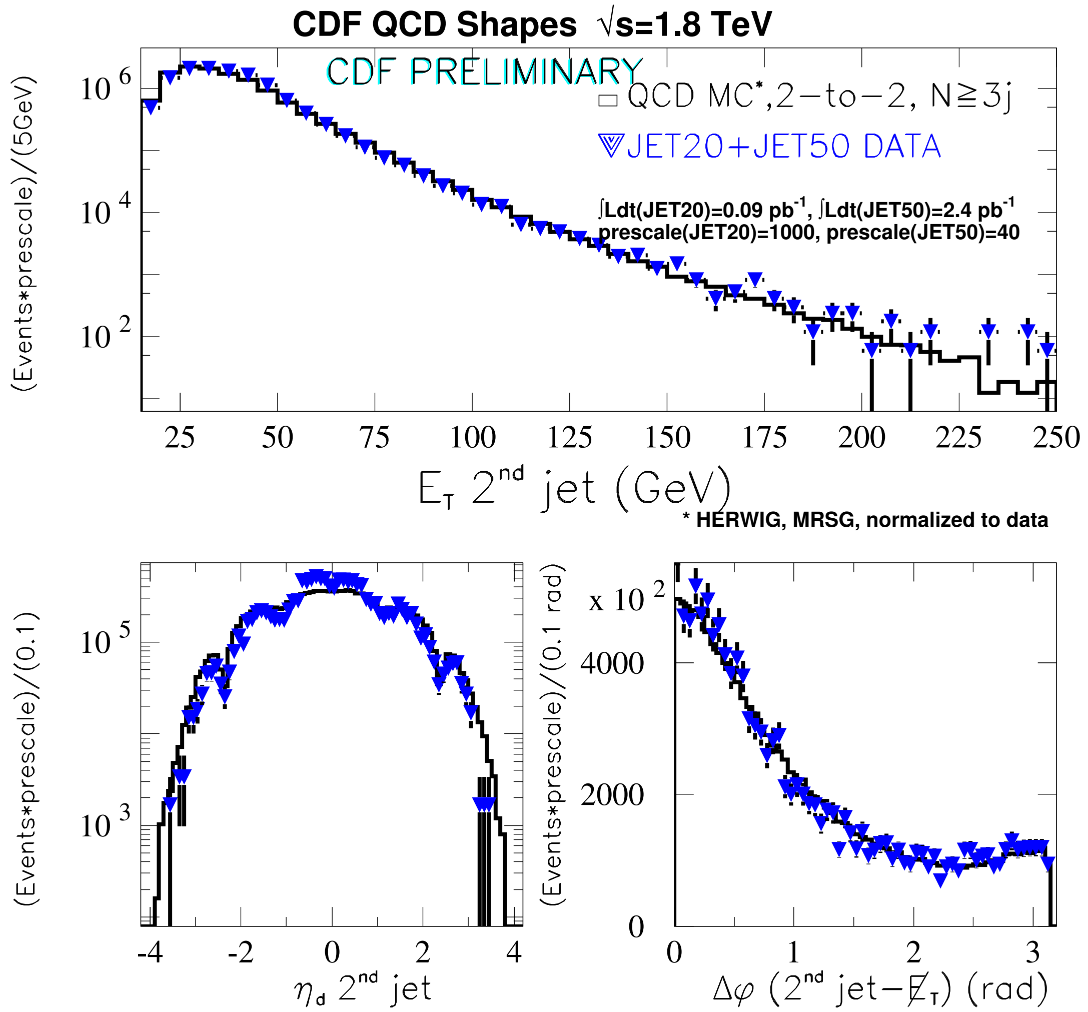
Event Selection

- Three or more jets
  - 1st highest $E_T > 70$ GeV
  - 2nd highest $E_T > 30$ GeV
  - 3rd highest $E_T > 15$ GeV
  - one of the leading 3 within $|\eta < 1.1|$
  - neither of leading two consistent with electron shower
- No isolated tracks with $p_T > 10$ GeV$/c$
- $\not{E}_T > 70$ GeV
- $H_T = E_T^{j2} + E_T^{j3} + \not{E}_T > 150$ GeV

Backgrounds

Source	Background
$Z \to \nu\overline{\nu}$	12.7 ± 1.5
$Z \to \mu^+\mu^-$	$.2 \pm 0.1$
$W \to e\nu$	4.0 ± 0.6
$W \to \mu\nu$	3.4 ± 0.5
$W \to \tau\nu$	7.0 ± 1.2
$t\bar{t}$	6.9 ± 1.3
WW	$.6 \pm 0.1$
WZ	$.2 \pm 0.0$
ZZ	$.1 \pm 0.0$
single t	$.2 \pm 0.0$
Total Electroweak	35.3
Multijet	40.7
Total	76.0 ± 12.8

Tests of Multijet Background Model

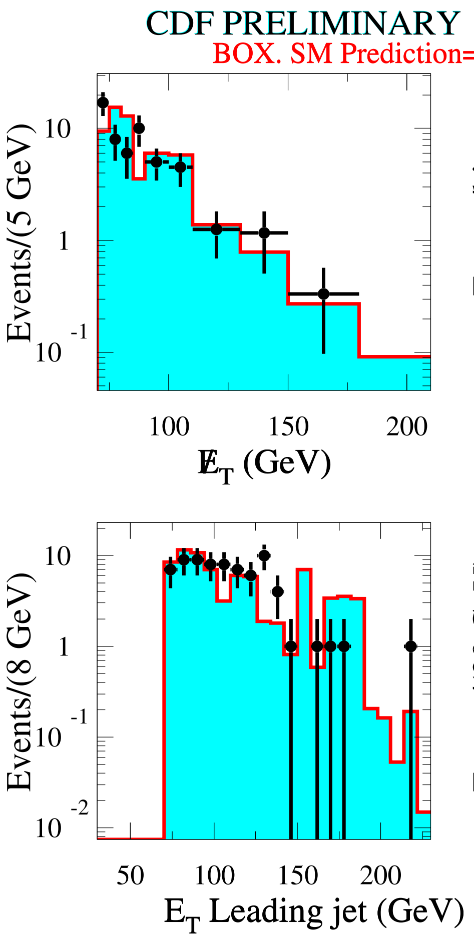


Control Samples with $\not{E}_T + \geq 3$ jets

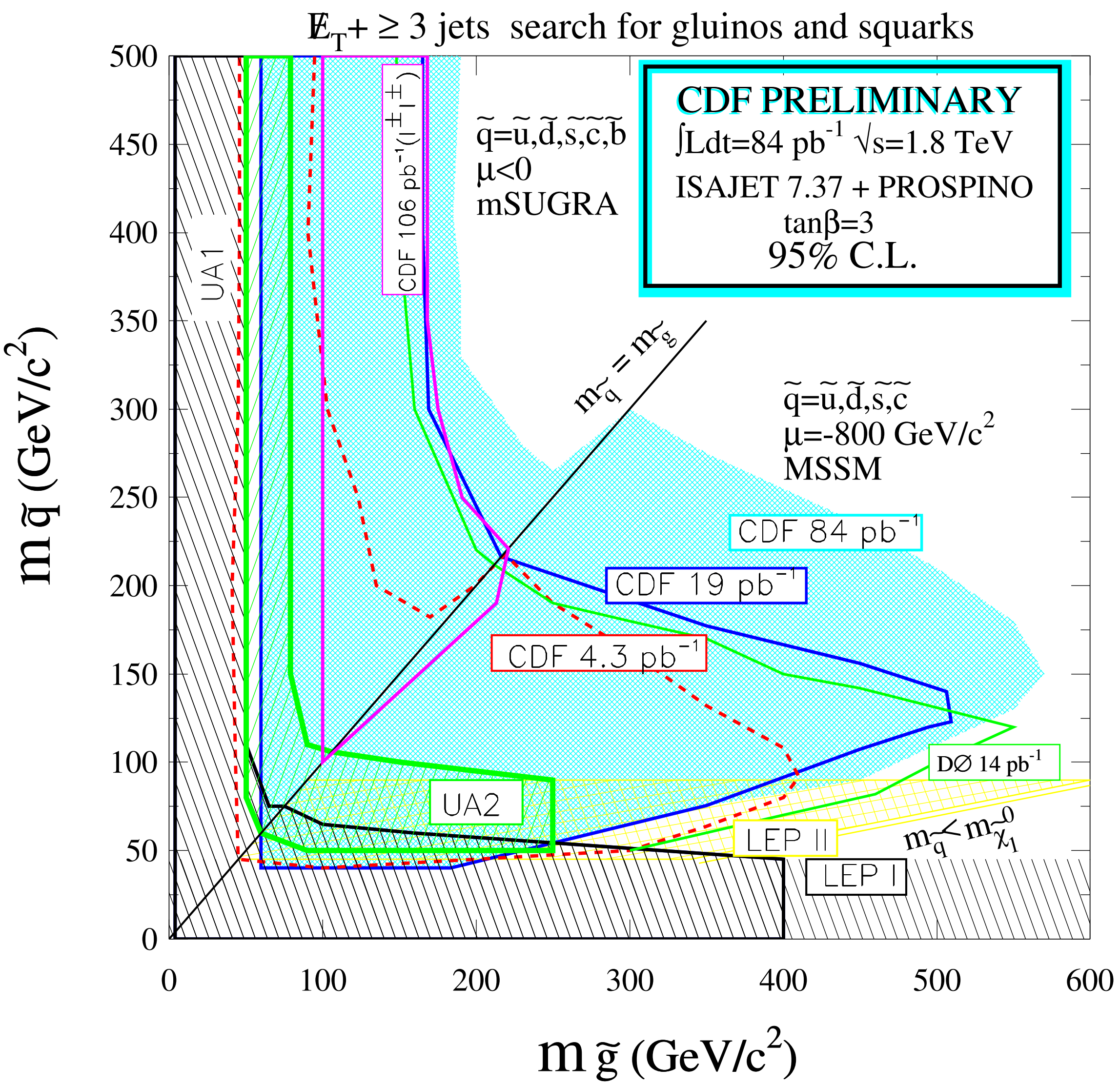
	Description	EWK	QCD	All	Data
1	$\not{E}_T \geq 70, H_T \geq 150, N_{trk}^{iso} > 0$	13.9	6.26	20.2±4.7	10
2	$\not{E}_T \geq 70, H_T < 150, N_{trk}^{iso} = 0$	2.3	6.26	8.6±4.5	12
3	$35 < \not{E}_T < 70, H_T > 150, N_{trk}^{iso} = 0$	1.95	134.6	136.5±27.8	134
4	$\not{E}_T > 70, H_T < 150, N_{trk}^{iso} > 0$	1.73	0	1.73±0.3	2
5	$35 < \not{E}_T < 70, H_T > 150, N_{trk}^{iso} > 0$	13.95	9.39	23.34±5.7	24
6	$35 < \not{E}_T < 70, H_T < 150, N_{trk}^{iso} = 0$	4.9	413.16	418.1±68.8	410
7	$35 < \not{E}_T < 70, H_T < 150, N_{trk}^{iso} > 0$	3.3	28.17	31.4±10.2	35
8	$\not{E}_T > 70, H_T > 150, N_{trk}^{iso} = 0$	35.3	40.69	76.02±12.8	?
9	$35 < \not{E}_T < 70, H_T < 150$	8.2	441.3	449.5±72	445

Results

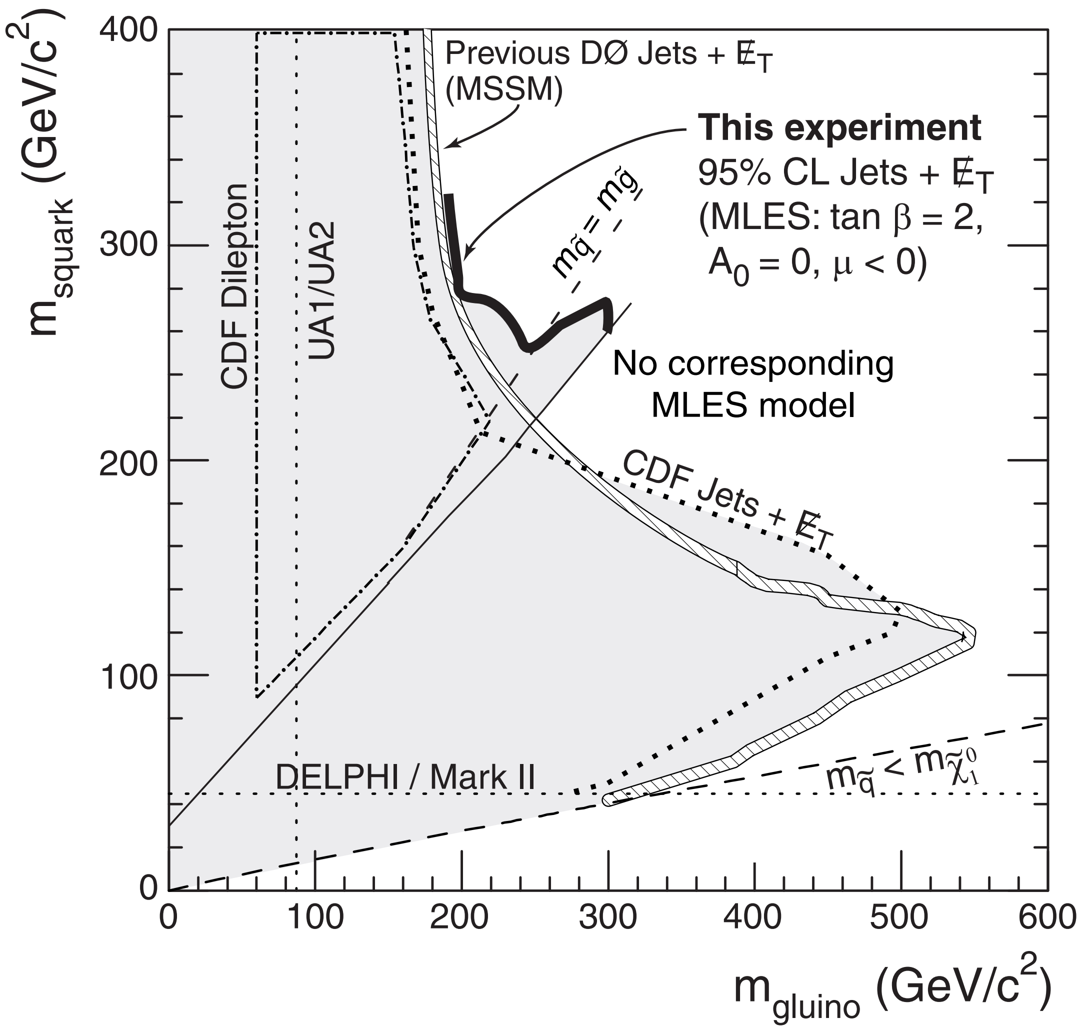
$\not{E}_T$ (GeV)	H_T (GeV)	Expected	Observed
70	150	76.0 ± 12.8	74
90	160	32.7 ± 6.7	31
110	230	3.7 ± 0.5	5
110	170	10.6 ± 1.0	14



CDF Limits on Squarks and Gluinos

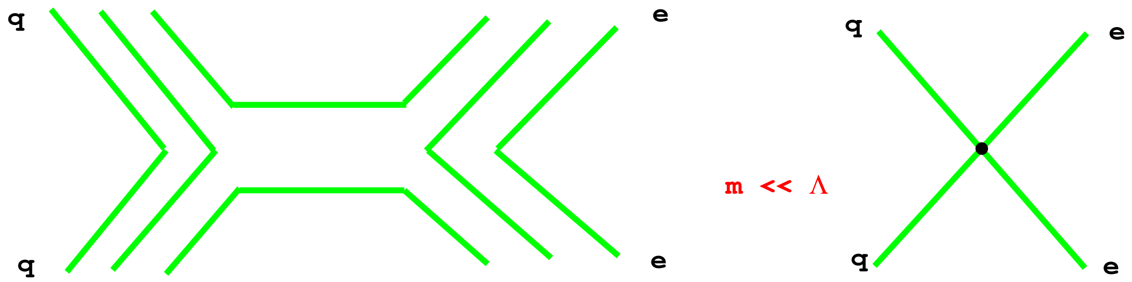


DØ Limits on Squarks and Gluinos



High Mass $e\nu$ Events (CDF)

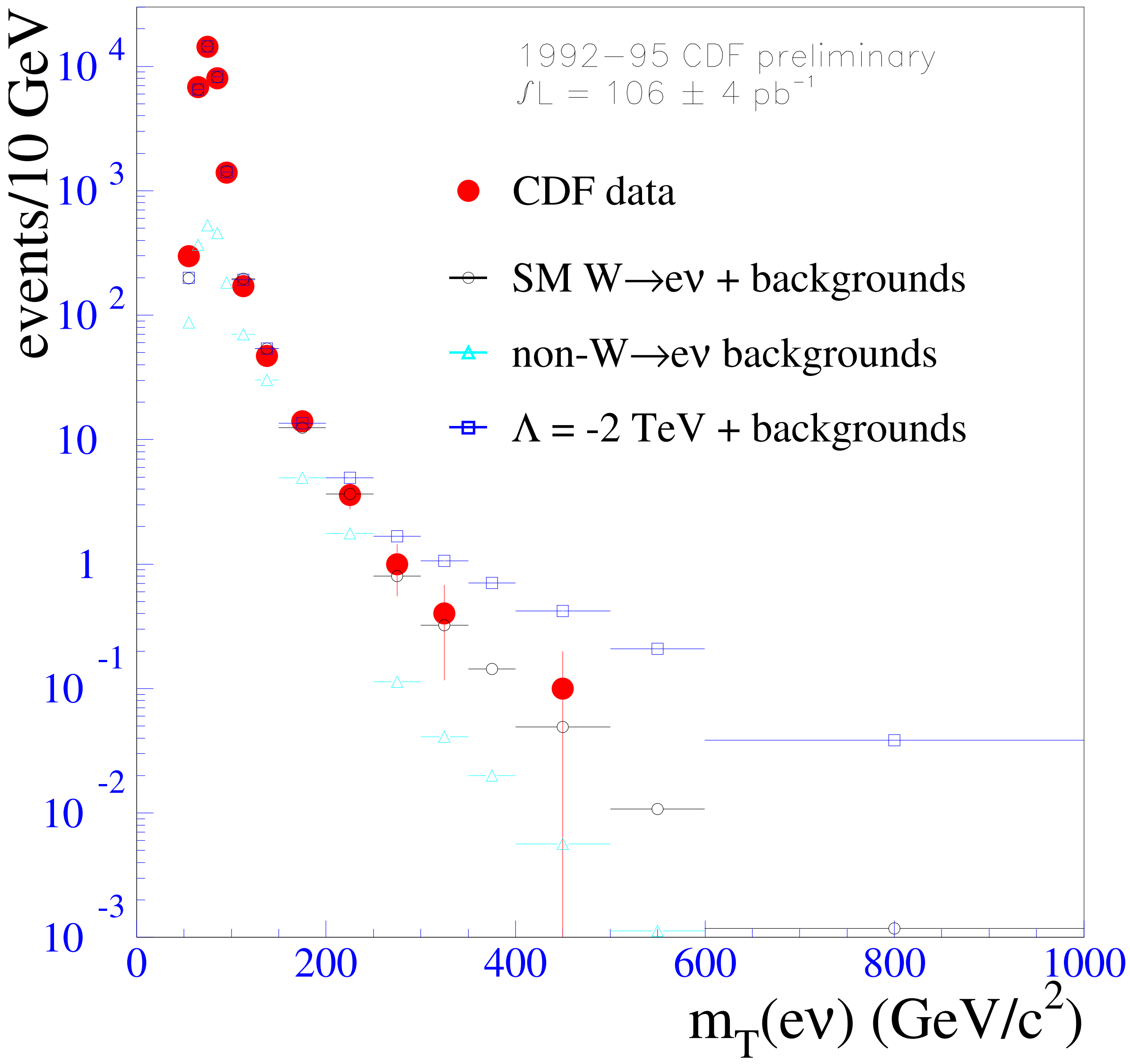
- Composite quarks and leptons with common constituents



Effective 4-fermion contact interaction increases cross section at high mass above standard model W production (Eichten, Lane & Peskin, PRL 50 (1983))

- $W' \to$ Jacobian peak at high transverse mass

$e\nu$ Transverse Mass

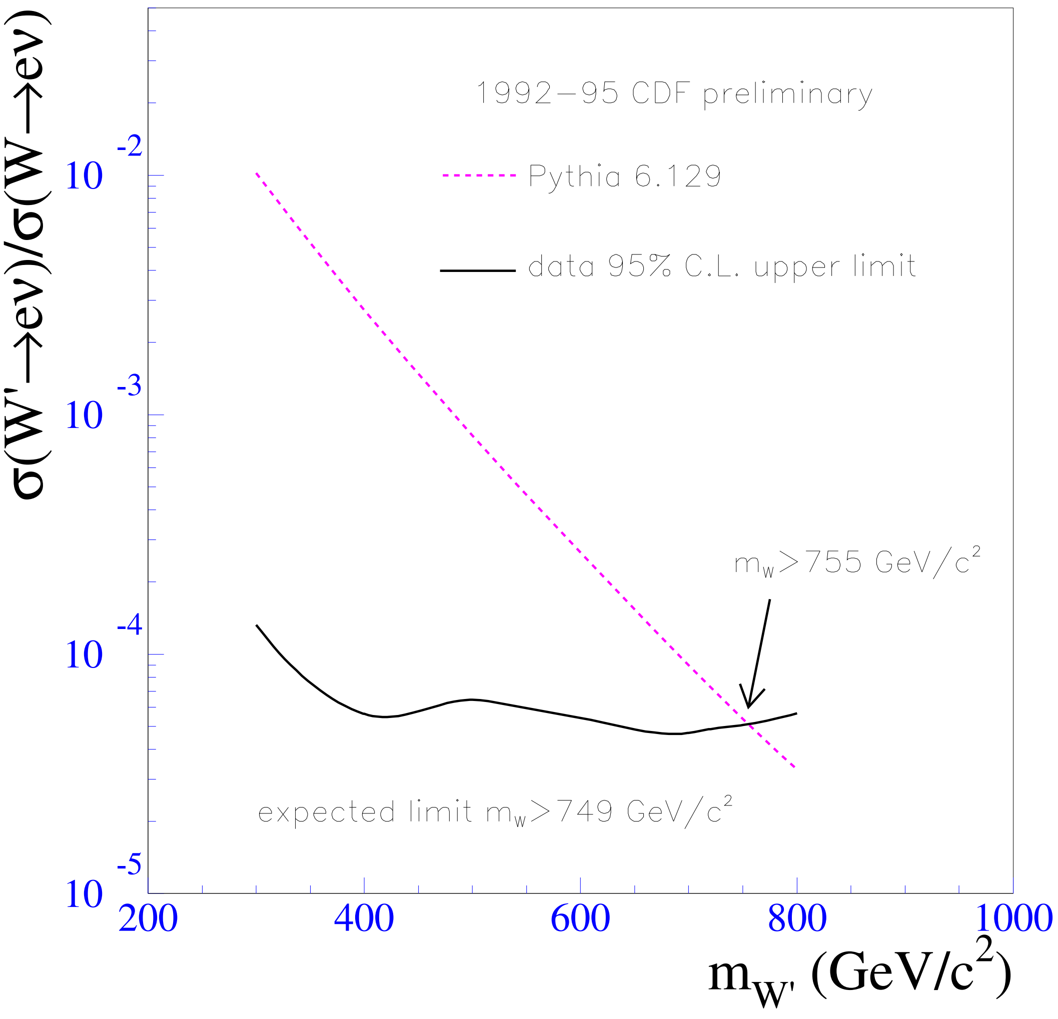


Limits on Models

- Compositeness scale:

$$\Lambda > 2.81 \text{ TeV at } 95\% \text{ C.L. (positive interference)}$$
$$\Lambda > 2.71 \text{ TeV at } 95\% \text{ C.L. (negative interference)}$$

- W' production:



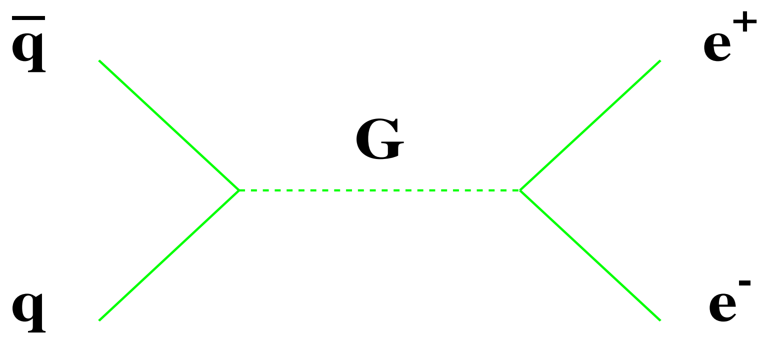
Extra Dimensions (DØ)

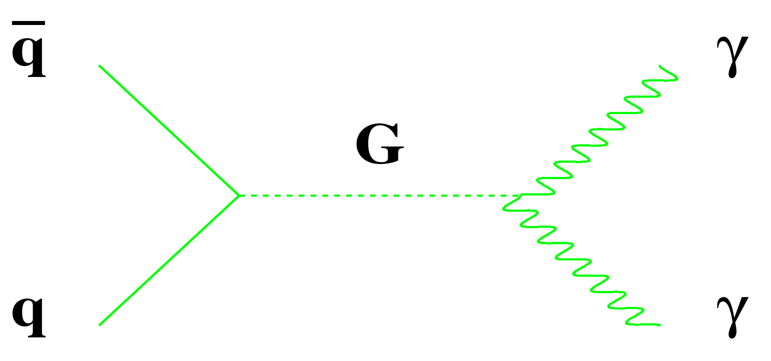
- Suppose gravitons propagate in n extra dimensions of size $R \sim \frac{1}{M_S}(M_{Plank}/M_S)^{2/n}$, with $M_S \sim 1$ TeV.

  At high energy, the large number of graviton modes compensates the coupling weakness and leads to observable particle interactions.

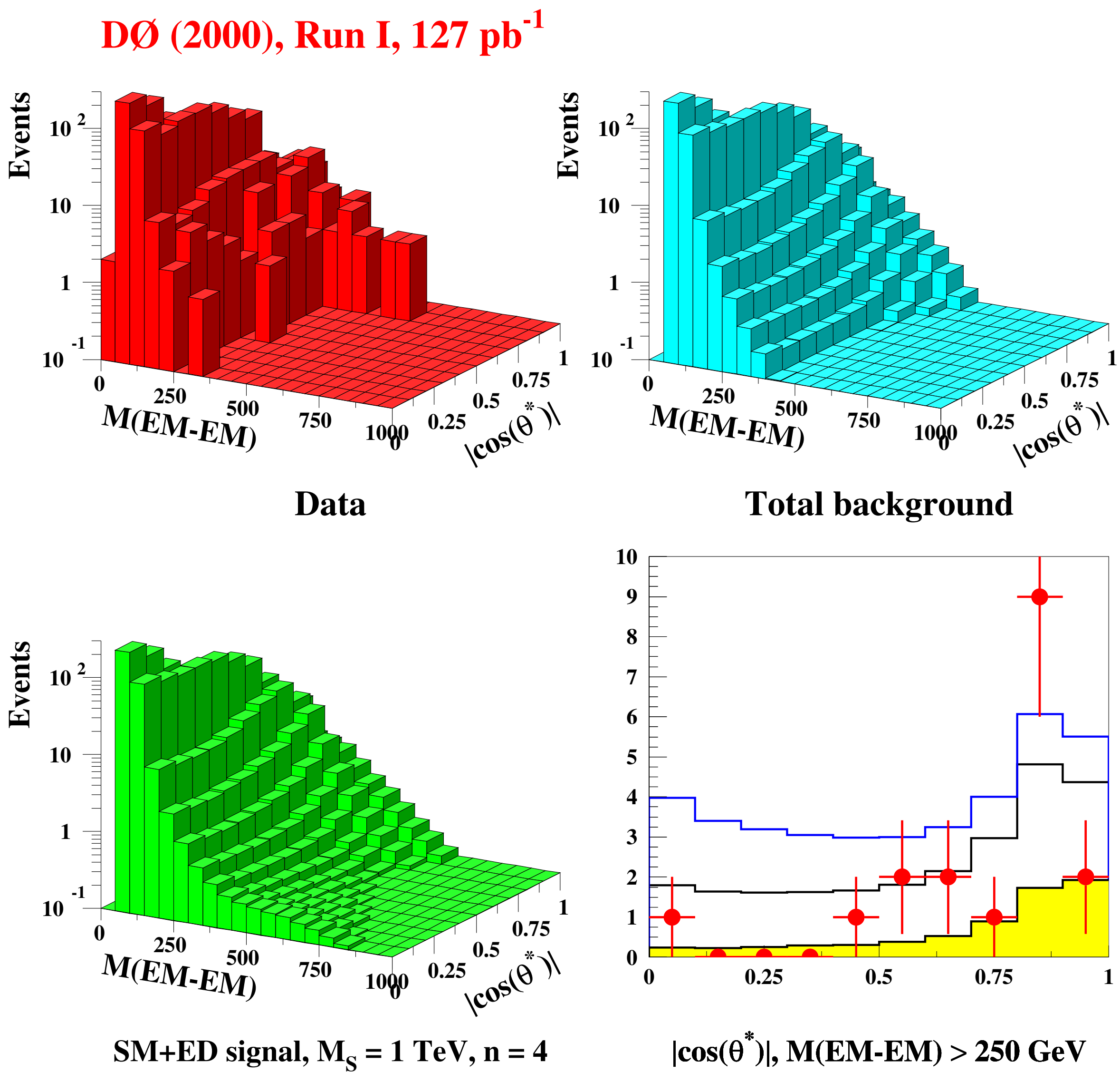
  Arkani-Hamed, Dimopoulos & Dvali, PLB429, 263, (1998); Hewett, PRL82, 4765 (1999); Giudice, Rattazzi & Wells, Nucl Phys B544, 3 (1999); Han, Lykken & Zhang, PRD59, 105006 (1999)

- Look for effect of

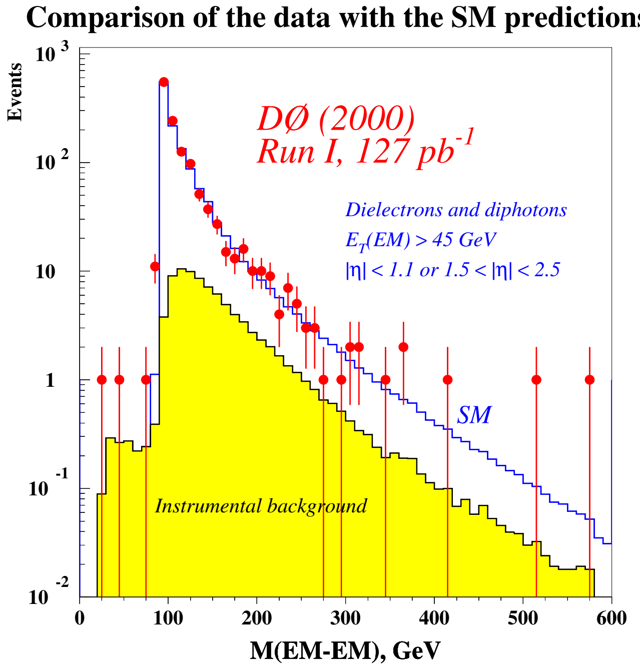


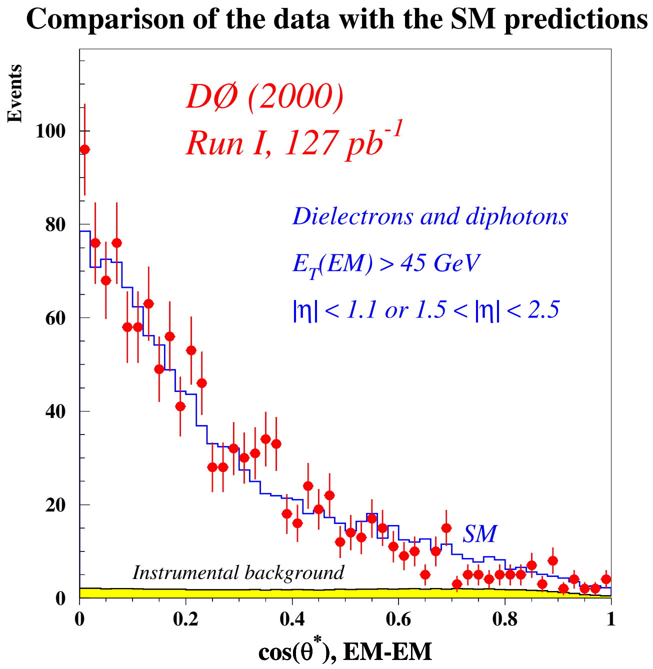


Signal Characterstics

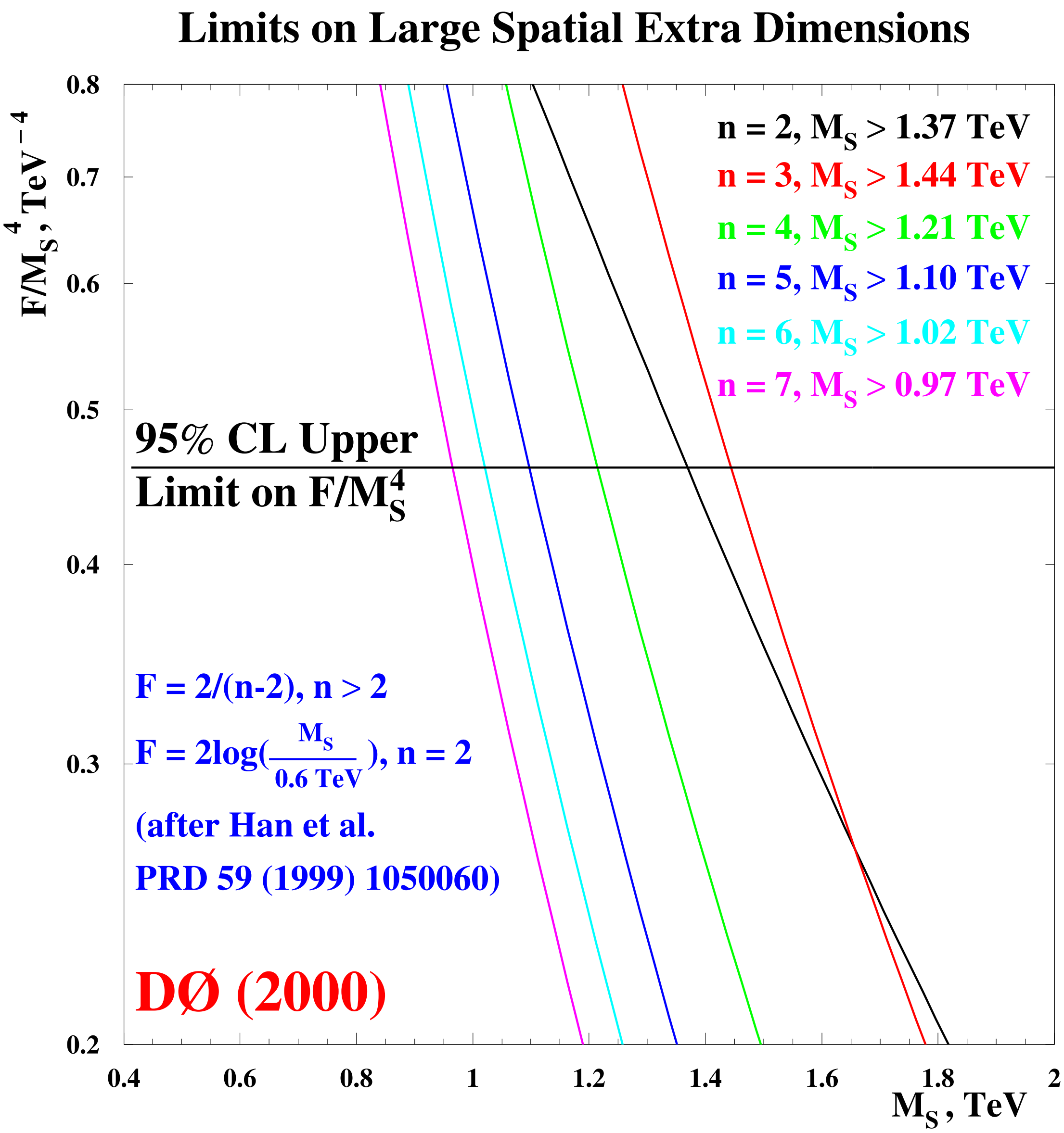


Data Compared to SM Background





Limits on Extra Dimensions



Data Driven Searches

- Look for discrepencies between data and standard model predictions without limiting focus to a specific model of new physics
- For any specific process, not as sensitive as a dedicated search
- But sensitive to unanticipated signals, and economical for covering signatures of many models and variations

Photon + Lepton Search (CDF)

- Look for cousins of the CDF $ee\gamma\gamma \not{E}_T$ event
- Predetermined categories:

Photon-Lepton Results

CDF Preliminary (86 pb^{-1})

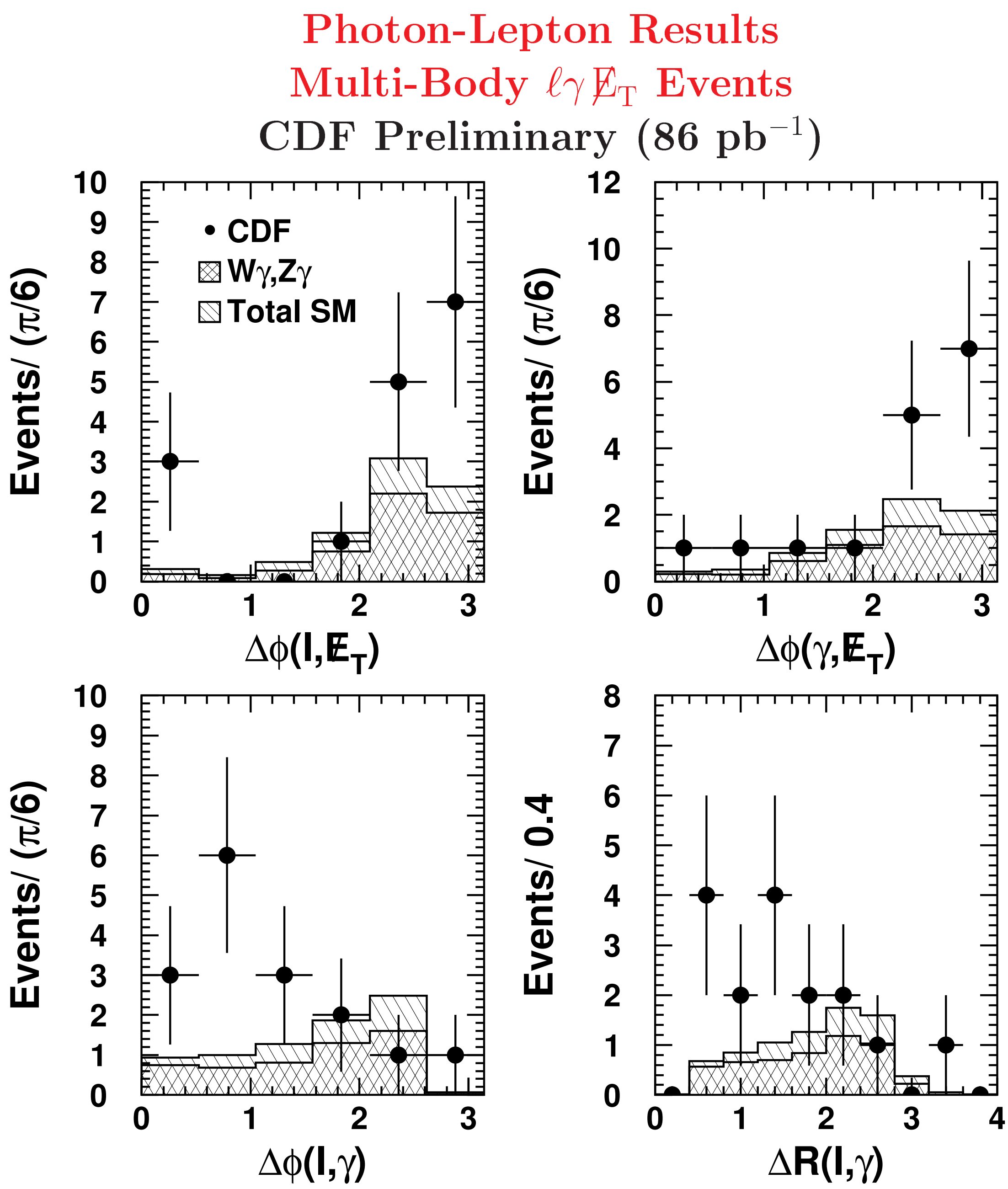
Category	Predicted μ_{SM}	Observed N_0	$P(N \geq N_0 \vert \mu_{SM})$ %
All $\ell\gamma X$	—	77	—
Z-like $e\gamma$	—	17	—
Two-Body $\ell\gamma X$	24.9 ± 2.4	33	9.3
Multi-Body $\ell\gamma X$	20.2 ± 1.7	27	10.0
Multi-Body $\ell\ell\gamma X$	5.8 ± 0.6	5	61.0
Multi-Body $\ell\gamma\gamma X$	0.02 ± 0.02	1	1.5
Multi-Body $\ell\gamma \not{E}_T X$	7.6 ± 0.7	16	0.7

$l\gamma + \not{E}_T$ Subsample

Photon-Lepton Results
Multi-Body $\ell\gamma\not{E}_T$ Events
CDF Preliminary (86 pb^{-1})

Process	$e\gamma\not{E}_T$	$\mu\gamma\not{E}_T$	$\ell\gamma\not{E}_T$
W+γ	1.93 ± 0.26	1.99 ± 0.27	3.92 ± 0.47
Z+γ	0.32 ± 0.05	0.96 ± 0.15	1.27 ± 0.17
ℓ+jet, jet $\rightarrow \gamma$	1.06 ± 0.20	1.00 ± 0.18	2.06 ± 0.38
$Z \rightarrow ee, e \rightarrow \gamma$	0.10 ± 0.04	-	0.10 ± 0.04
Hadron+γ	-	0.18 ± 0.11	0.18 ± 0.11
π/K Decay+γ	-	0.10 ± 0.11	0.10 ± 0.11
b/c Decay+γ	< 0.01	< 0.01	< 0.01
Mean Rate μ_{SM}	3.41 ± 0.34	4.23 ± 0.46	7.64 ± 0.71
CDF Data N_0	5	11	16
$P(N \geq N_0 \mid \mu_{SM})$	0.26	0.0054	0.0072

$l\gamma + \not{E}_T$ Angle Distributions



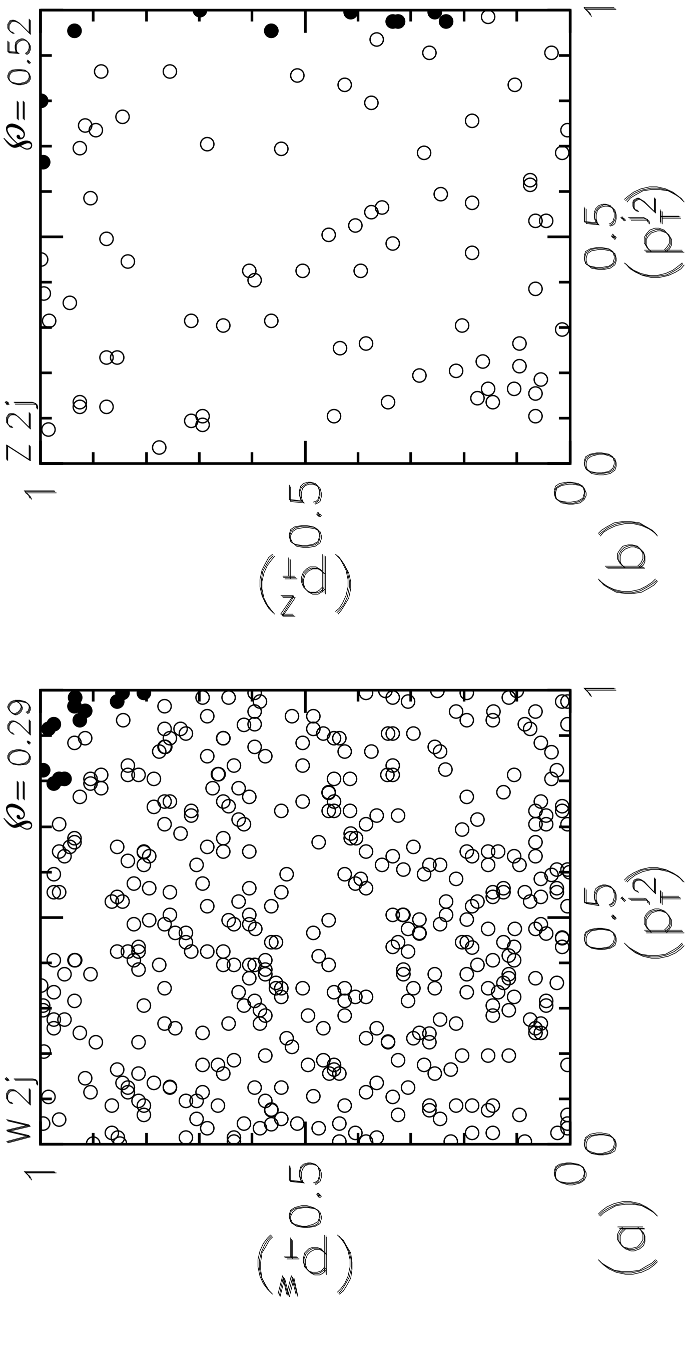
Sleuth (DØ)

- Identify e, μ, γ, jets, $\not\!\!E_T$, W, Z
- Categorize events by the number and type of objects, e.g. $e\gamma jj$
- Assume new physics will produce higher p_T objects

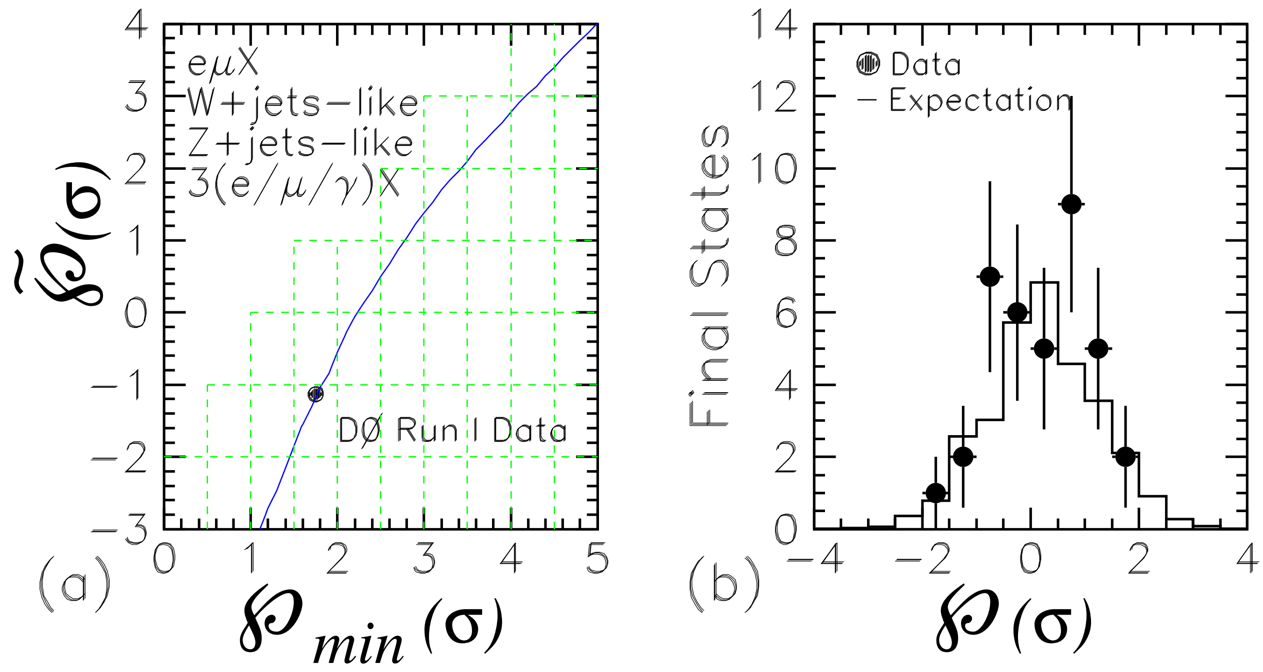
If the final state includes	then consider the variable
$\not\!\!E_T$	$\not\!\!E_T$
one or more charged leptons	Σp_T^l
one or more electroweak bosons	$\Sigma p_T^{\gamma/W/Z}$
one or more jets	$\Sigma' p_T^j$

- For each final state, cluster the events in the parameter space to locate the region with the highest excess of data above background, and calculate the probability P for finding an excess more improbable than the one observed.
- Note $P_{\min}$, the lowest final state P, and calculate the probability of $P_{\min}$ coming out less than it did, taking into account the number of final states examined.

Sleuth Clustering



Sleuth Results (cont.)



Conclusions

- No positive results
- But Run II collisions are only weeks away. A substantial portion of the favored parameter space for SUSY (and LED) will be within reach.
- Backgrounds are the central issue in every search. How will we know if a signal is real? Blind searches, many control samples build confidence in estimates, even for difficult signatures such as jets + $\not\!\!E_T$.
- General searches are a vital complement to dedicated searches for specific processes. Sleuth is a systematic and comprehensive example of one.

Sleuth Results

Final State	Bkg	Data	$\mathcal{P}$
	$e\mu X$		
$e\mu\not\!\!E_T$	48.5±7.6	39	0.14 ($+1.08\sigma$)
$e\mu\not\!\!E_T\ j$	13.2±1.5	13	0.45 ($+0.13\sigma$)
$e\mu\not\!\!E_T\ 2j$	5.2±0.8	5	0.31 ($+0.50\sigma$)
$e\mu\not\!\!E_T\ 3j$	1.3±0.3	1	0.71 (-0.55σ)
	W+jets-like		
$W\,2j$	400 ± 53	441	0.29 ($+0.55\sigma$)
$W\,3j$	77 ± 10	67	0.23 ($+0.74\sigma$)
$W\,4j$	14.3 ± 2.3	15	0.53 (-0.08σ)
$W\,5j$	1.8 ± 0.4	1	0.81 (-0.88σ)
$W\,6j$	0.25 ± 0.07	1	0.22 ($+0.77\sigma$)
$e\not\!\!E_T\ 2j$	11.6 ± 1.7	7	0.76 (-0.71σ)
$e\not\!\!E_T\ 3j$	2.5 ± 0.6	5	0.17 ($+0.95\sigma$)
$e\not\!\!E_T\ 4j$	0.80 ± 0.24	2	0.13 ($+1.13\sigma$)
	Z+jets-like		
$Z\,2j$	98 ± 19	85	0.52 (-0.05σ)
$Z\,3j$	13.2 ± 2.7	12	0.71 (-0.55σ)
$Z\,4j$	1.9 ± 0.5	1	0.83 (-0.95σ)
$ee\,2j$	32 ± 4	32	0.72 (-0.58σ)
$ee\,3j$	4.5 ± 0.6	4	0.61 (-0.28σ)
$ee\,4j$	0.64 ± 0.20	3	0.04 ($+1.75\sigma$)
$ee\not\!\!E_T\ 2j$	3.7 ± 0.8	2	0.68 (-0.47σ)
$ee\not\!\!E_T\ 3j$	0.45 ± 0.13	1	0.36 ($+0.36\sigma$)
$ee\not\!\!E_T\ 4j$	0.061 ± 0.028	1	0.06 ($+1.55\sigma$)
$\mu\mu\,2j$	0.50 ± 0.15	2	0.08 ($+1.41\sigma$)
	$3(\ell/\gamma)X$		
eee	2.6 ± 1.0	1	0.89 (-1.23σ)
$Z\gamma$	4.3 ± 0.7	3	0.84 (-0.99σ)
$Z\gamma j$	1.03 ± 0.31	1	0.63 (-0.33σ)
$ee\gamma$	2.2 ± 0.4	1	0.88 (-1.17σ)
$ee\gamma\not\!\!E_T$	0.26 ± 0.10	1	0.23 ($+0.74\sigma$)
$e\gamma\gamma$	10.7 ± 2.1	6	0.66 (-0.41σ)
$e\gamma\gamma j$	2.3 ± 0.7	4	0.21 ($+0.81\sigma$)
$e\gamma\gamma\,2j$	0.37 ± 0.15	1	0.30 ($+0.52\sigma$)
$W\gamma\gamma$	0.21 ± 0.08	1	0.18 ($+0.92\sigma$)
$\gamma\gamma\gamma$	2.5 ± 0.5	2	0.41 ($+0.23\sigma$)
$\tilde{\mathcal{P}}$			0.89 (-1.23σ)