Searches for Gauge-Mediated Supersymmetry

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for the DØ Collaboration

Outline

- Gauge-Mediated SUSY
- DØ detector
- Charged long-lived particles
- Di-photon plus missing E_T analysis
- Summary

Gauge-Mediated SUSY

- Alternative to gravity mediated SUSY
  - SUSY breaking occurs at scale Λ much lower than GUT (10 – 100 TeV)
  - Mediated by new gauge fields – "messengers"
  - Gravitino is very light (<keV) and is LSP
- Lifetime of NLSP is a free parameter
  - All SUSY particles cascade to NLSP, so if R-parity is conserved all final states have two NLSPs
- NLSP can be neutralino or stau:
  $\chi_1^0 \to \gamma G$ or $\tau_1^+ \to \tau^+ G$
  - If neutralino is higgsino-like then it can also decay to hG and ZG
  - Gravitino is weakly interacting and is registered as missing transverse energy (MET)

Typical Final States

	prompt decays	inside detector	outside detector
Stau	multiple τ + MET	tracks with kinks	muon-like highly ionising slow moving particles
Neutralino	$\gamma\gamma$ + MET	non-pointing photon(s)	mSUGRA-like
Higgsino	γ bb + MET, γZ+MET	Non-pointing b-jets, detached Z	mSUGRA-like

- Many of the final states are predicted by other models (extra dimensions, 4th generation quarks, etc...)

mGMSB

- Model Parameters:
  - Λ - mass parameter (effective scale of SUSY breaking)
  - M_m - messenger mass scale
  - N_5 - number of messenger fields
  - $\tan\beta = <\phi_1>/<\phi_2>$
  - $\text{sign}\ \mu = \pm 1$ - sign of higgsino mass term
  - C_{grav} - determines NLSP lifetime
- Gaugino masses proportional to N_5, scalar masses proportional to $\text{sqrt}(N_5)$
- Snowmass slope E:
  - Λ – varies
  - $M_m = 2 \cdot \Lambda$
  - $N_5 = 1$
  - $\tan\beta = 15$
  - $\text{sign}\ \mu = +1$

  Neutralino NLSP
- Snowmass slope D:
  - Λ – varies
  - $M_m = 2 \cdot \Lambda$
  - $N_5 = 3$
  - $\tan\beta = 15$
  - $\text{sign}\ \mu = +1$

  Stau NLSP

Tevatron Collider

1992-95

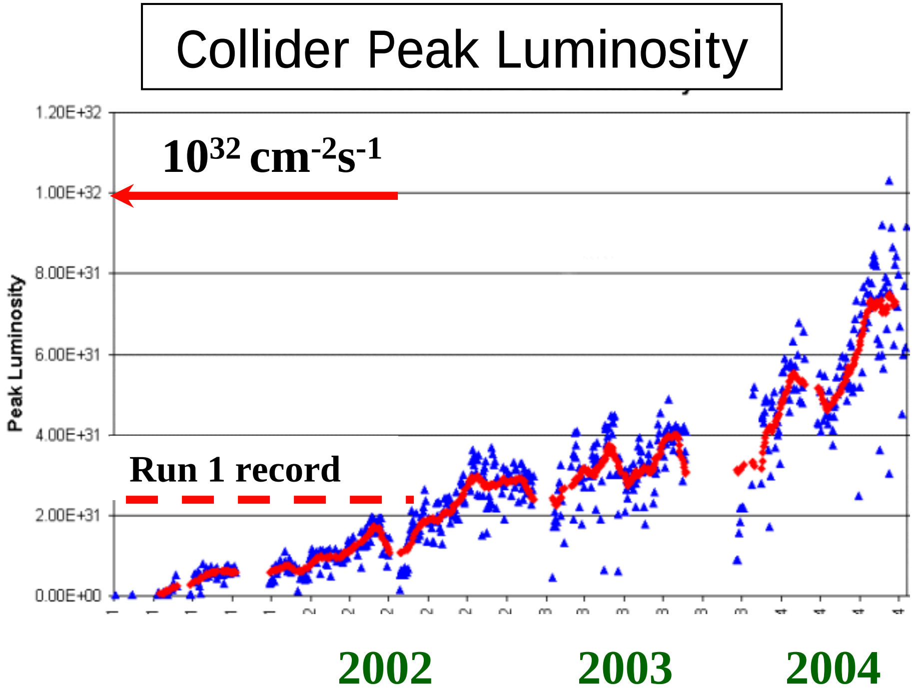
Run 1: 100 pb^{-1}, 1.8TeV

2001-? Run 2: major upgrades

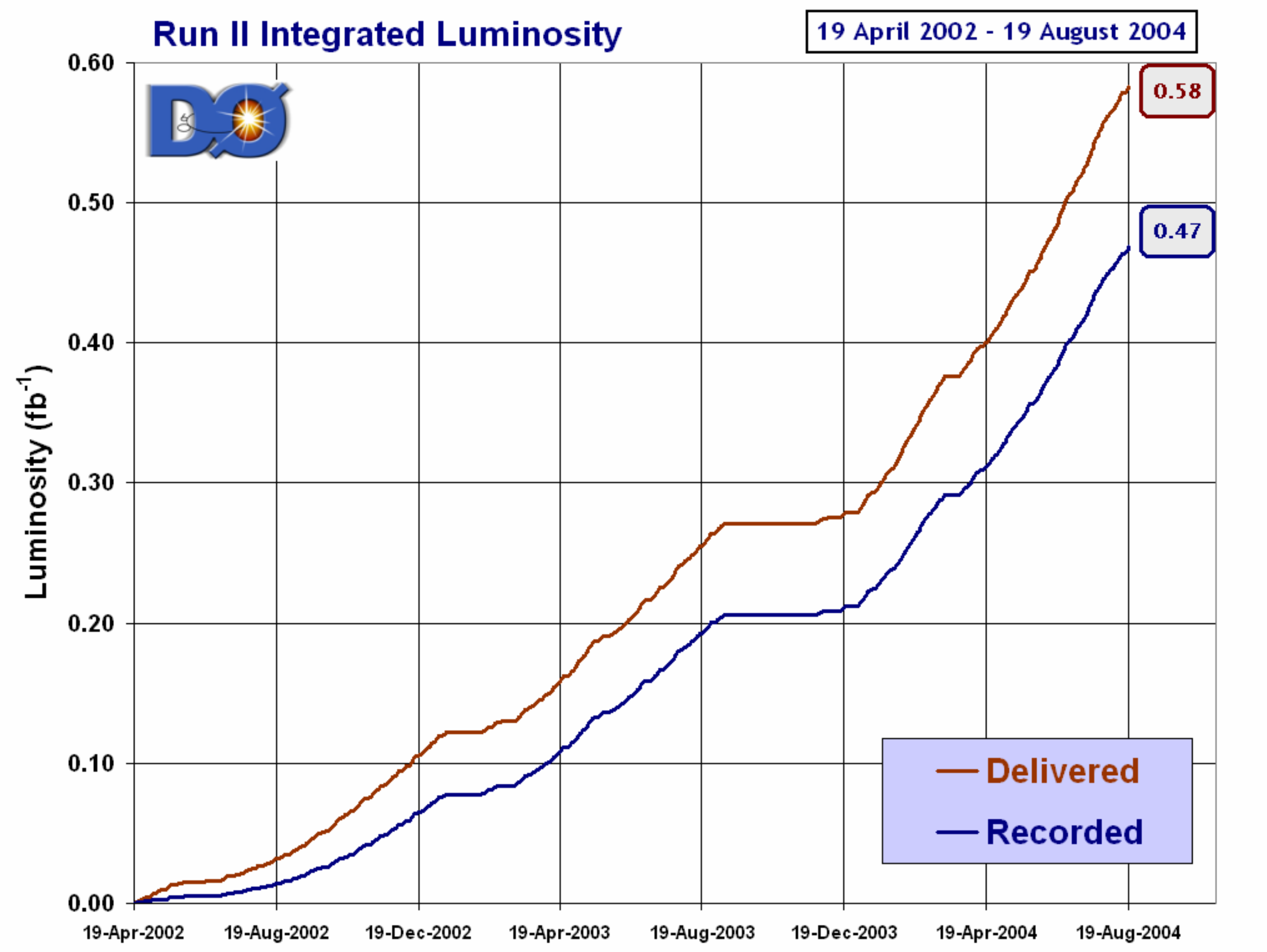
higher E_{CM} = 1.96 TeV

Upgrades yet to come:

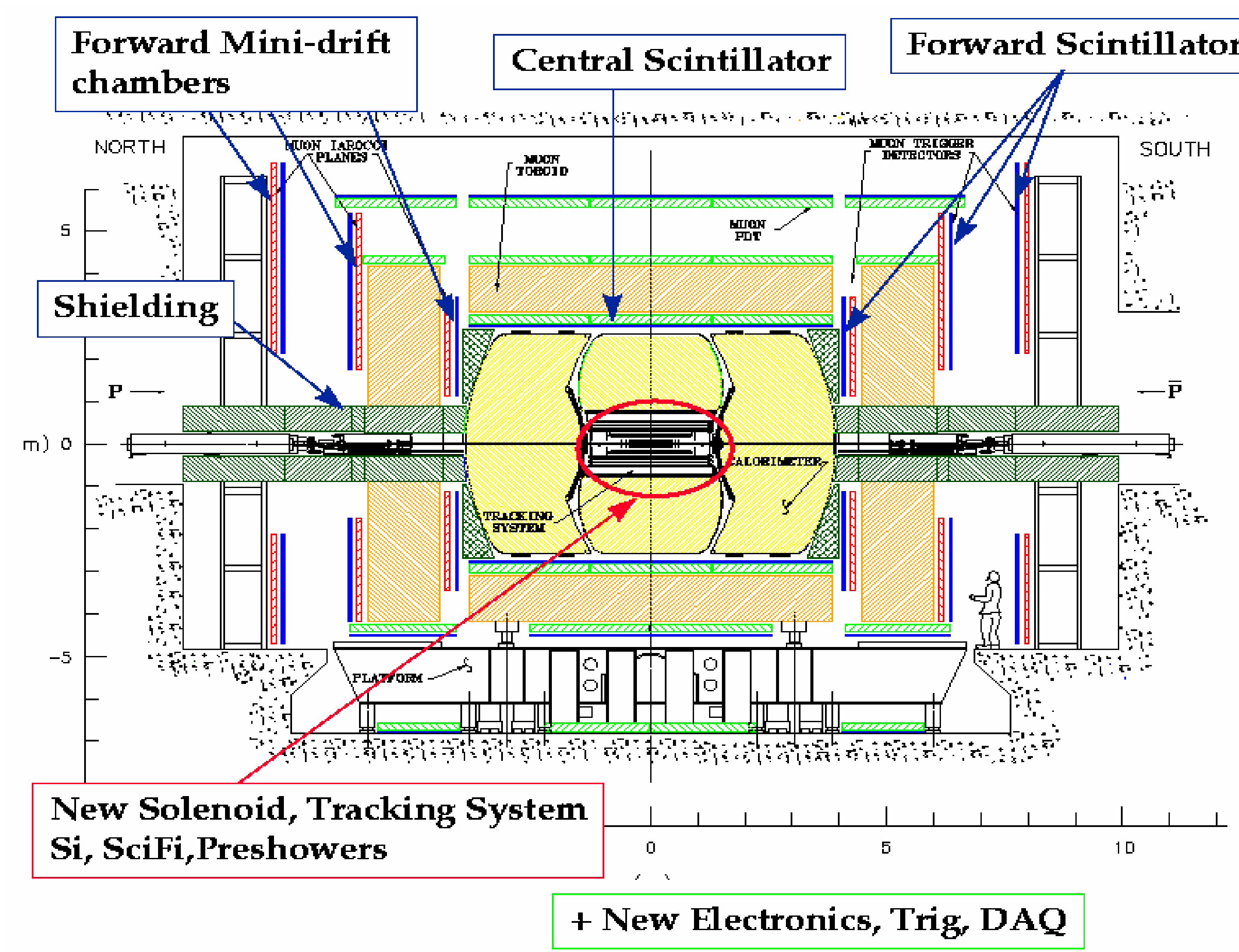
- trigger
- silicon Layer 0 (D0)



Half A Femtobarn of Data!



DØ Detector

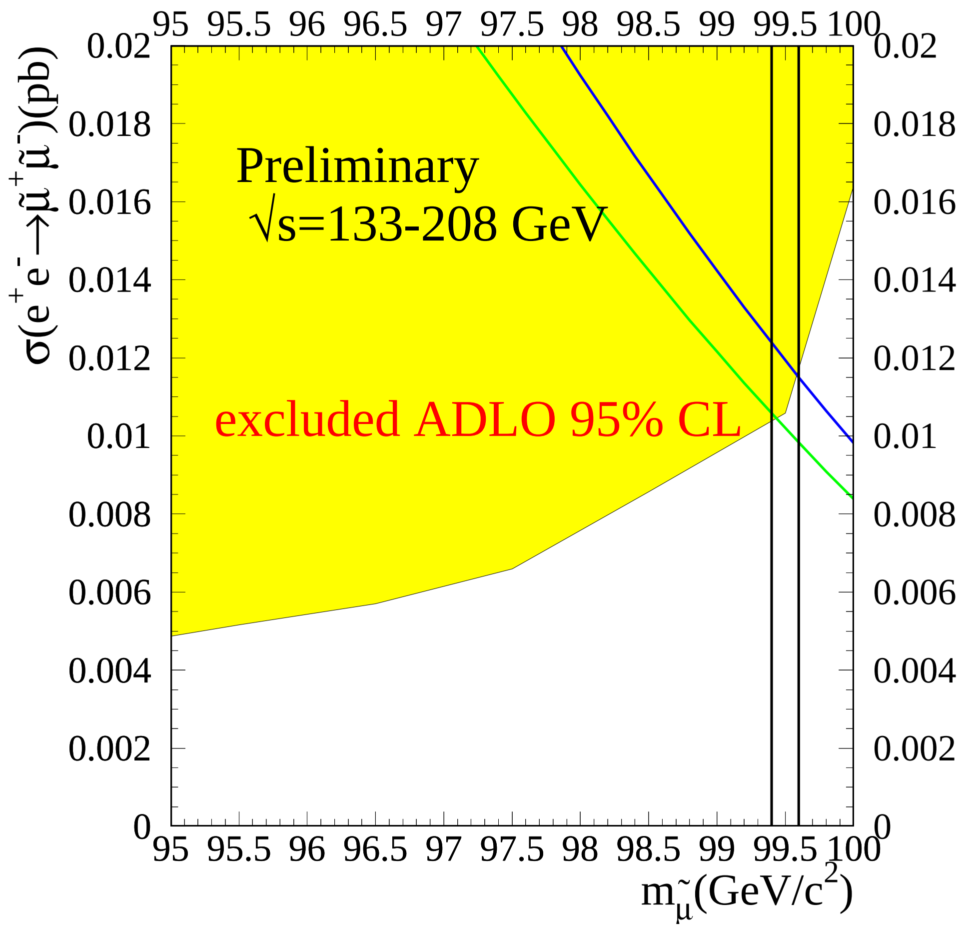


Forward Mini-drift chambers
Central Scintillator
Forward Scintillator
Shielding
NORTH
SOUTH
MUON IAROCCI PLANES
MUON TOROID
MUON TRIGGER DETECTORS
MUON PDT
CALORIMETER
TRACKING SYSTEM
PLATFORM
P
P̄
5
0
-5
10
New Solenoid, Tracking System
Si, SciFi,Preshowers
+ New Electronics, Trig, DAQ

Search for Charged Long-Lived Particles

Charged Long-Lived Particles

- Slow, weakly interacting and highly ionizing
- LEP experiments set the best existing limit on GMSB sleptons M(stau) > 99.5 GeV
- At Tevatron
  - Stau pair-production (similar to Drell-Yan)
  - Cascade decays of gauginos

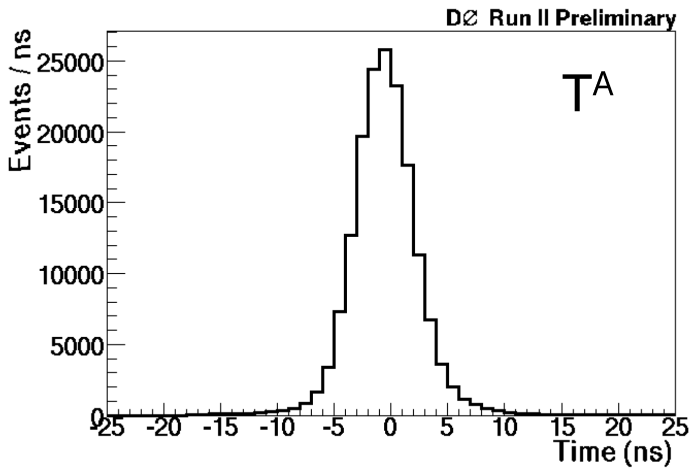


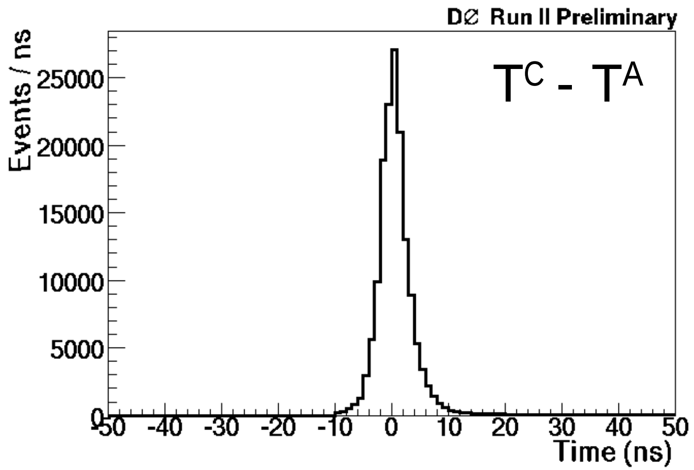
Data Sample and Trigger

- Data are collected with a dimuon trigger
  - 220 ± 14 pb^{-1}
- Muon trigger gate ~24 to 60 ns
  - made as tight as possible to reject non-prompt muons
- If particle is too slow it will not give a trigger – low efficiency to staus from cascade decays
- Assume that staus decay outside of the muon system
- Look for back-to-back pairs of “slow muons”

Data Pre-selection

- Require two good muons
- At least one muon with $p_T > 20$ GeV and central track
- Not consistent with cosmics
  - muon track points to primary vertex
  - muons not back-to-back in pseudorapidity: $|\eta_1+\eta_2| > 0.15$
  - Inner scintillator times $|T_1^A - T_2^A| < 10$ ns
  - Outer scintillator hits occur at later times than inner scintillator $|T^C - T^A| > -10$ ns





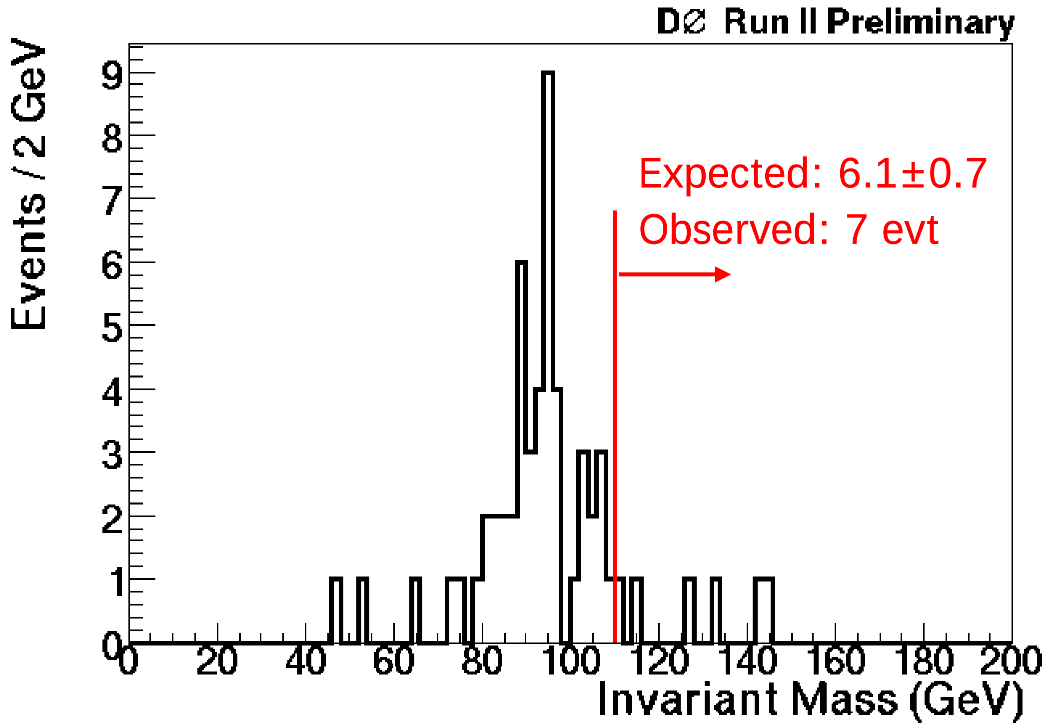
Data Selection

- Timing Cuts
  - $T^A > 2.5$ ns
  - $T^C > 4$ ns
  - $T^C – T^A > 3.5$ ns
- Back-to-back in azimuth
  - $\Delta\varphi > 1.0$
- Invariant mass
  - Anti-Z cut: m>110 GeV

- Background is real muons with large measured times
- Two samples to determine fraction of real muons passing timing cuts: Z candidates and muons with $p_T < 20$ GeV
- The measured (η-dependent) fraction is then applied to the number of events in the pre-selected sample

Cut	*Expected*	*Observed*
Preselection		*78,617*
Timing	*103±2±11*	*104*
$\Delta\varphi$	*61.7±1.2 ±6.6*	*57*
Invariant Mass	*6.1 ±0.1 ±0.7*	*7*

Data Selection

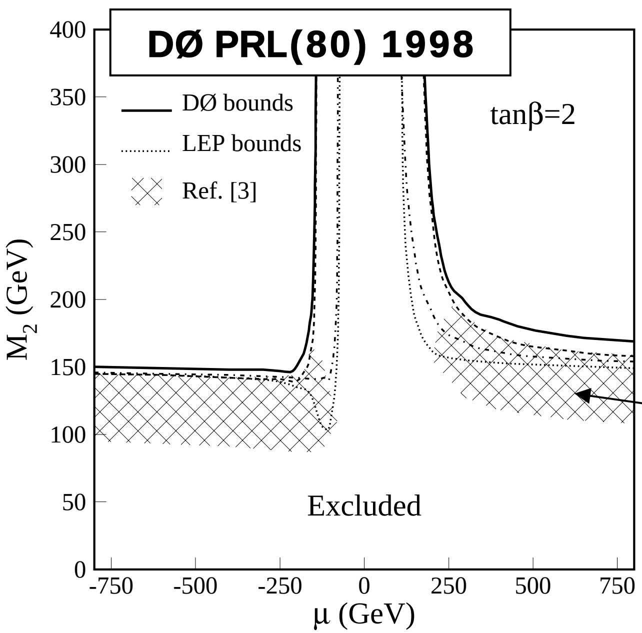


- Cuts are being optimized for best sensitivity vs mass
- Many improvements in store:
  - combined dE/dx and timing likelihood
  - more data!

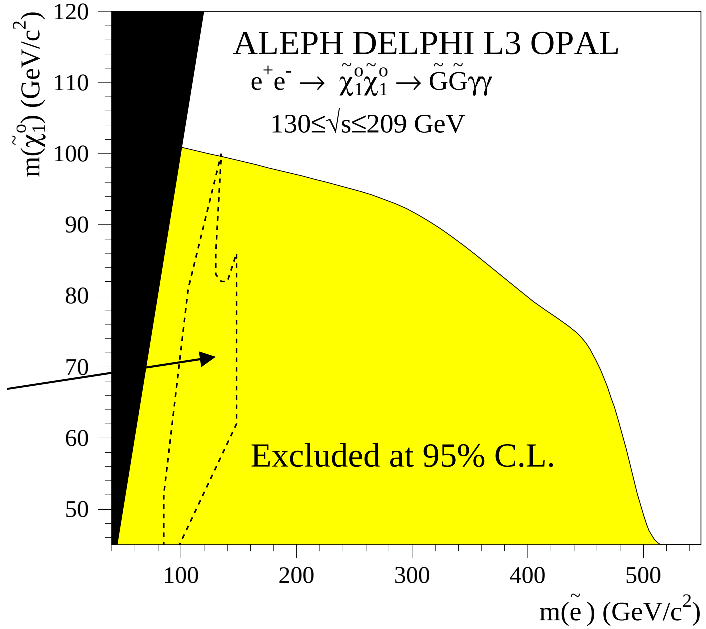
Search for Diphoton Events with Large Missing E_T

Di-photons + MET

- CDF has found an interesting event $\gamma\gamma ee\ E_T$
- DØ found no high MET diphoton events and set lower limit on neutralino mass at $M(\chi_1^0) > 77$ GeV
- In GMSB framework CDF set lower limit on neutralino mass at $M(\chi_1^0) > 65$ GeV
- LEP2 limit is about $M(\chi_1^0) > 100$ GeV



Both GMSB chargino and selectron interpretation of the CDF event are excluded at 95% CL



Di-photon Data Analysis

- Data collected in 2002-2004: 263 ± 17 pb^{-1}
- Photon and electron identification:
  - Calorimeter cluster with > 90% energy in EM calorimeter
  - Calorimeter isolation $\frac{E_{TOT}(R<0.4)-E_{EM}(R<0.2)}{E_{EM}(R<0.2)} < 0.15$
  - Shower shape is consistent with electron
  - Scalar sum of track p_T in $0.05<R<0.4$ annulus around the direction of the cluster is less than 2 GeV
  - Cluster is electron if there is a central track match and is a photon otherwise
- Event selection
  - Two EM objects ($\gamma\gamma$ for signal, $e\gamma$ for background estimate)
  - $E_T>20$ GeV and $|\eta| < 1.1$
  - $\Delta\varphi$ (jet, MET) < 2.5 – for leading jet (if present)
  - $\Delta\varphi$ (EM, MET) > 0.5

Reject events in which MET is likely to have been mismeasured

Backgrounds

- Physics backgrounds are negligible
- All instrumental backgrounds can be determined from data

largest

without true MET *-fake MET*

- QCD: $\gamma\gamma$, γ+j, j+j (jet is faking γ)
- Drell-Yan (lost tracks)

with true MET *-fake γ*

- $W\gamma \rightarrow e\nu\gamma$ (lost track)
  $Wj \rightarrow e\nu j$ (lost track, fake γ)
- $Z \rightarrow \tau\tau \rightarrow ee + X$ (lost tracks)
- $tt \rightarrow ee + X$ (lost tracks)
- WW, WZ, ... (lost tracks)

Backgrounds

without true MET *-fake MET*

- QCD: $\gamma\gamma$, γ+j, j+j (jet is faking γ)
- Drell-Yan (lost tracks)

If jet fakes an isolated EM object, it's because it's fragmented into a leading π^0 and therefore its energy resolution is similar to the EM cluster resolution

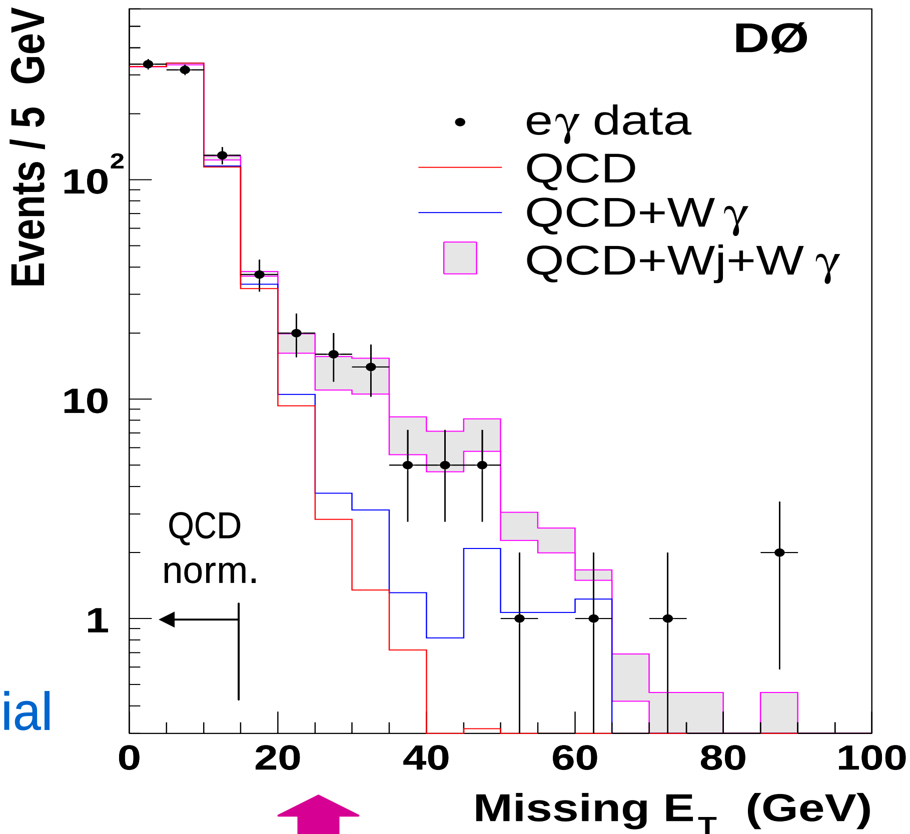
MET resolution is similar for $\gamma\gamma$, γ+jet, e+jet, ee, etc...

- QCD sample: start form the same initial sample; keep the isolation cut, but require both EM clusters to fail the shower shape cut
  - check that MET resolution is independent on shower shape
  - check that MET resolution is the same in QCD and $Z \rightarrow ee$ samples
- Assume that events in $\gamma\gamma$ sample with MET < 15 GeV are dominated by QCD – and estimate QCD background for large MET

Backgrounds

with true MET *-fake γ*

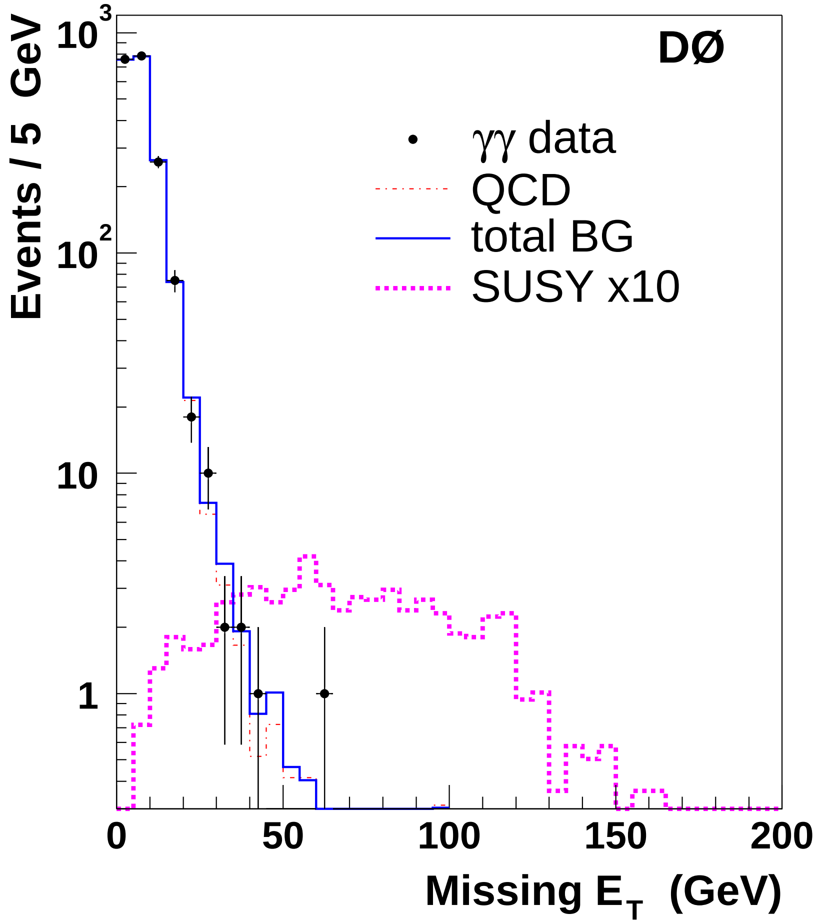
- $W\gamma \to e\nu\gamma$ (lost track)
  $Wj \to e\nu j$ (lost track, fake γ)
- $Z \to \tau\tau \to ee + X$ (lost tracks)
- $tt \to ee + X$ (lost tracks)
- WW, WZ, ... (lost tracks)



- e+γ sample: start from the same initial sample but require one electron and one photon
  - QCD background – subtract as for γγ
  - eγMET events contribution to γγMET: multiply by
    $(1-\varepsilon_{track})/\varepsilon_{track} = 0.068 \pm 0.004$

<u>Cross-check:</u> describe eγ data using prediction for the largest backgrounds:
no genuine MET, Wj (determined from data) and MC prediction for Wγ

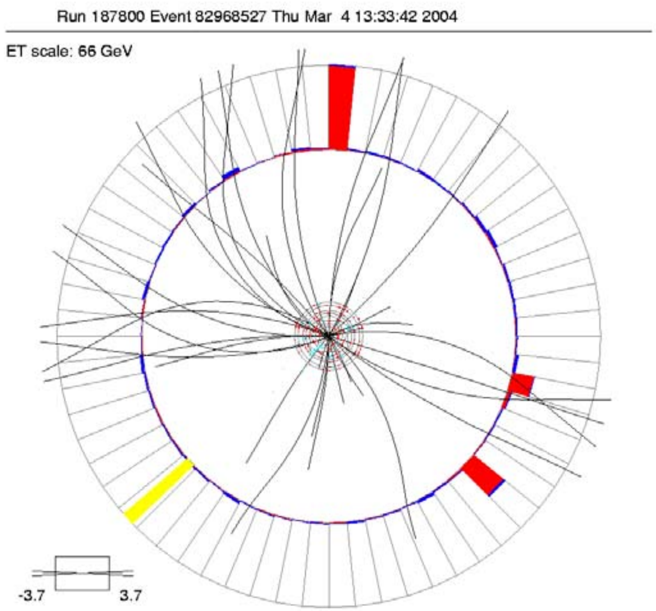
Result



Event with highest MET:

- two photons (E_T = 69 and 27 GeV)
- isolated electron E_T = 24 GeV
- Missing E_T = 63 GeV

cousin of the Run I CDF event?

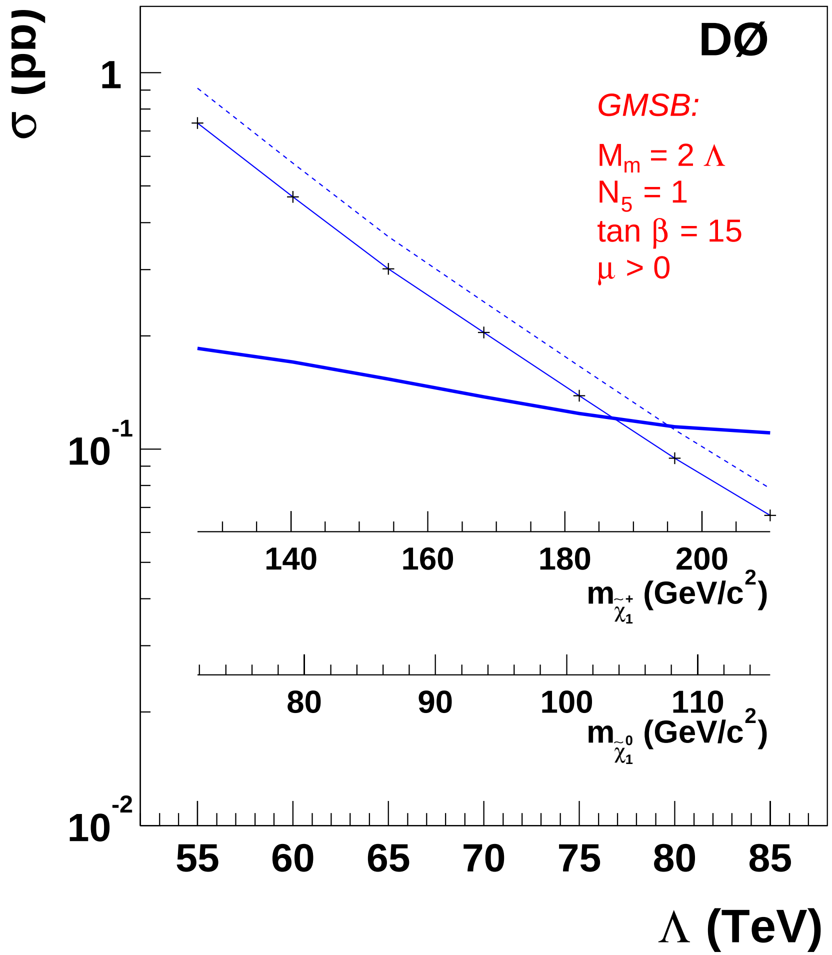


- Observed rates consistent with SM – proceed to set a limit
- MET cut > 40 GeV optimized with signal MC and BG from data
- Expected: 3.7±0.6 events; observed: 2

Upper Limit

- ISAJET 7.58 and PYTHIA 6.202 used for SUSY simulation
- Main production through $\chi_1^+\chi_1^-$ or $\chi_1^\pm\chi_2^0$
- CTEQ5L PDF's and K-factors from Beenakker et al PRL 83, 3780 (1999)
- Total efficiency close to exclusion point is 15%
- Λ > 80 TeV, m(χ_1^0)>108 GeV, m(χ_1^+) > 195 GeV

  Best limits today!
- No strong dependence of the limits on variation of the GMSB parameters



Summary

- Tevatron broke $1 \cdot 10^{32}$ threshold
- 0.5 fb^{-1} on tape
- With about half of the dataset:
  - investigate pair production of charged long-lived massive particles
  - world's best limit on GMSB with neutralino NLSP
  - observe an unusual $e\gamma\gamma$+MET event
- Dataset keeps growing – stay tuned!

Backup

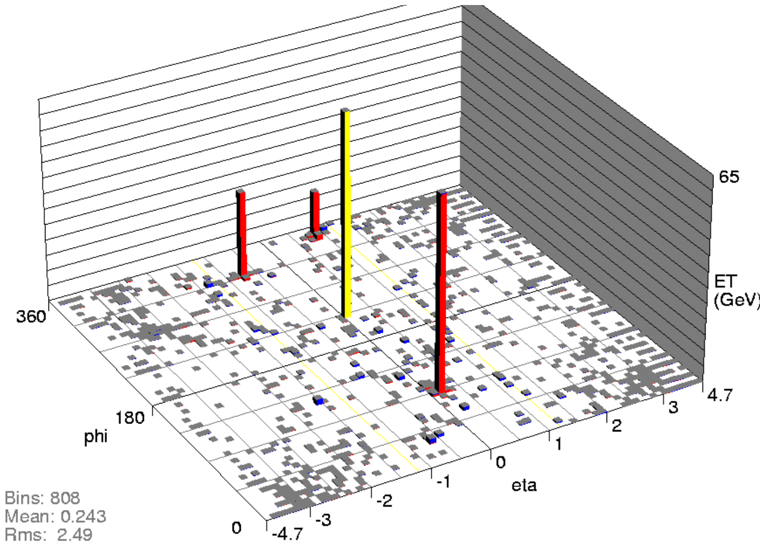
TABLE I: Points on the Snowmass Slope: their cross sections, efficiencies and cross-section limits.

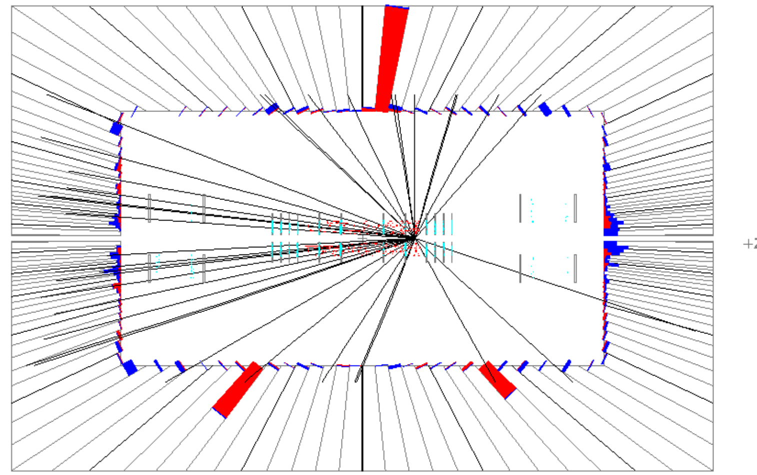
Λ, TeV	$m_{\tilde{\chi}_1^0}$,GeV/c^2	$m_{\tilde{\chi}_1^+}$,GeV/c^2	σ_{TOT}^{LO}, pb	K-factor	Efficiency	95% CL Limit, pb
55	71.8	126.3	0.735	1.236	0.092 ± 0.009	0.184
60	79.1	140.2	0.468	1.227	0.1 ± 0.009	0.170
65	86.4	154.3	0.301	1.217	0.111 ± 0.011	0.153
70	93.7	168.2	0.204	1.207	0.124 ± 0.012	0.137
75	101.0	182.3	0.138	1.197	0.137 ± 0.013	0.124
80	108.2	196	0.094	1.187	0.149 ± 0.014	0.114
85	115.5	209.9	0.066	1.177	0.154 ± 0.015	0.110

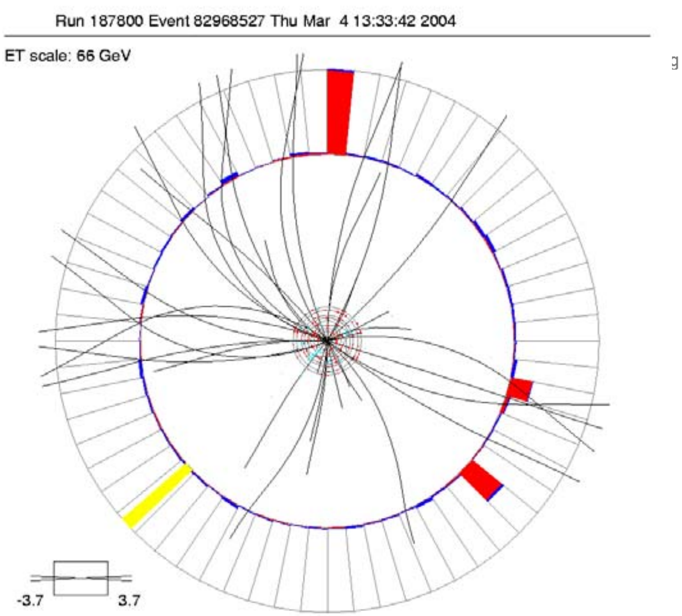
TABLE II: Limits on the Snowmass Slope and two other GMSB models.

Fixed parameters				95% CL lower limits			
M/Λ	$\tan\beta$	N_5	sign(μ)	Λ,TeV	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{\chi}_1^+}$	$m_{\tilde{\chi}_2^0}$
2	15	1	+	79.6	107.7	194.9	195.9
2	5	1	+	79.5	106.0	191.6	193.3
10	5	2	+	44.0	111.4	196.0	198.7

Highest MET Event: Lennox







	pT						
1	69.4						
2	27						
3	23.9		track pT = 15.4				
	m(12) = 86.5		mT(1) = 121.2			Z(vtx) = 31.2	
	m(13) = 71.0		mT(2) = 61.4				
	m(23) = 45.1		mT(3) = 68.5			MET = 63.0	
	m(123) = 120.7						
	pT(12) = 55						
			M_cluster(e,g2,MET) = 112 GeV				
		Definition from Baur *et al* **PRD 48** (1993)					