Search for Gauge-Mediated Supersymmetry

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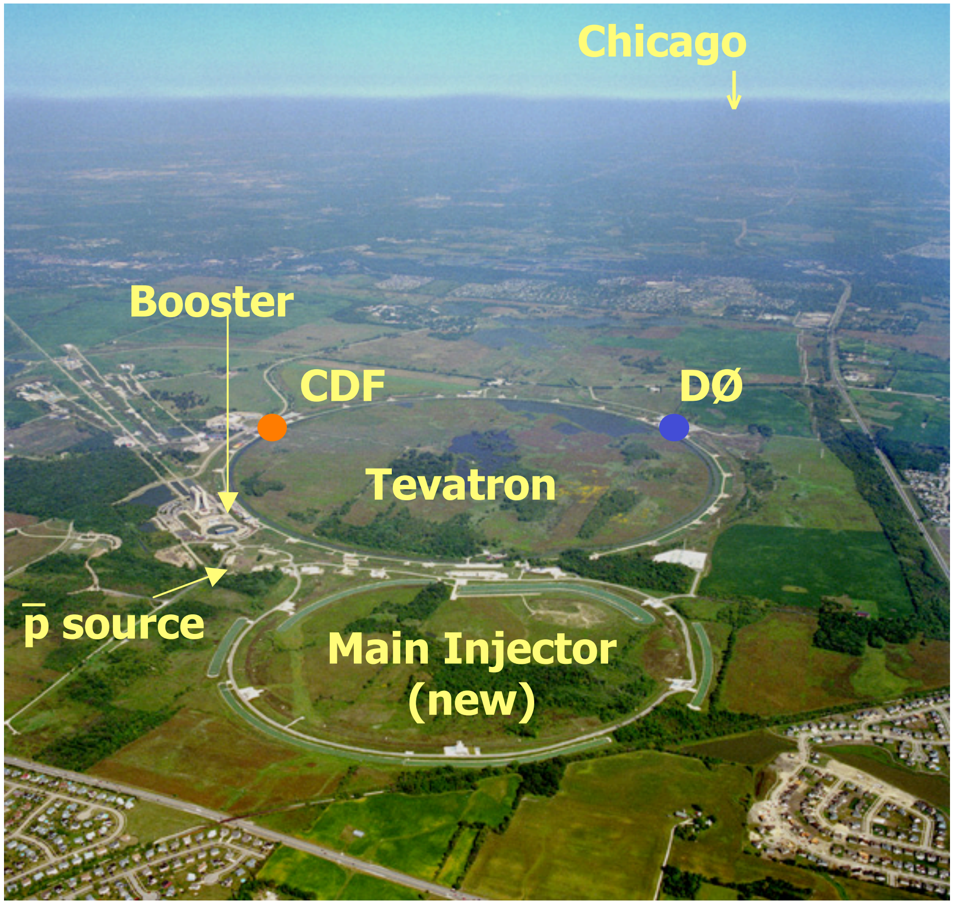
Tevatron Collider



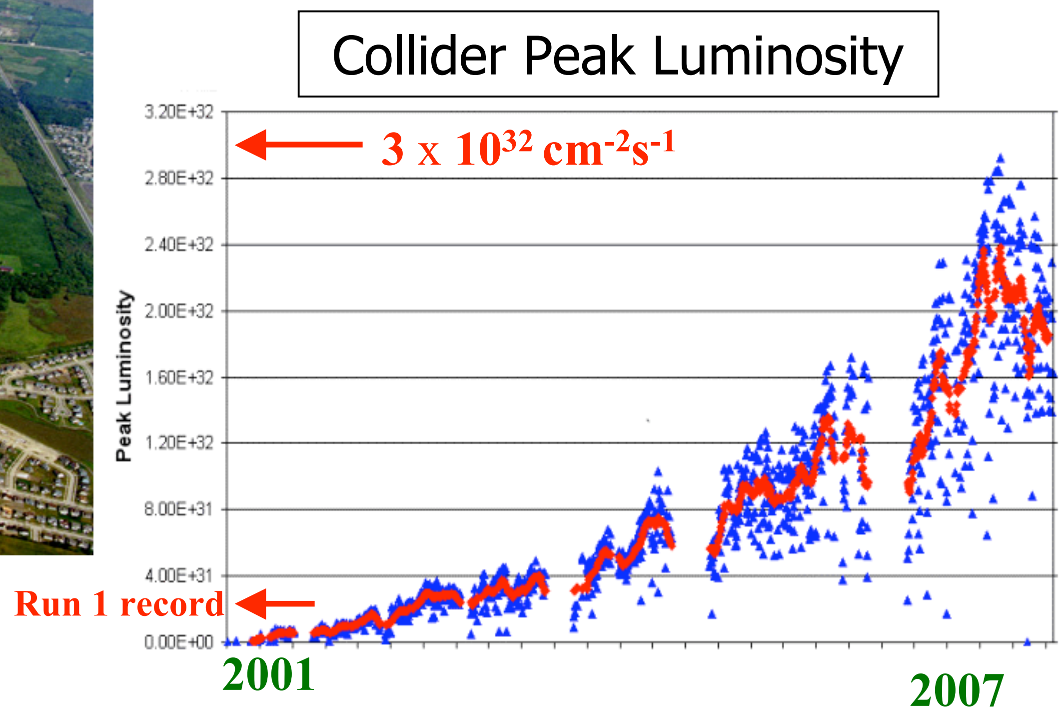
1992-95

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

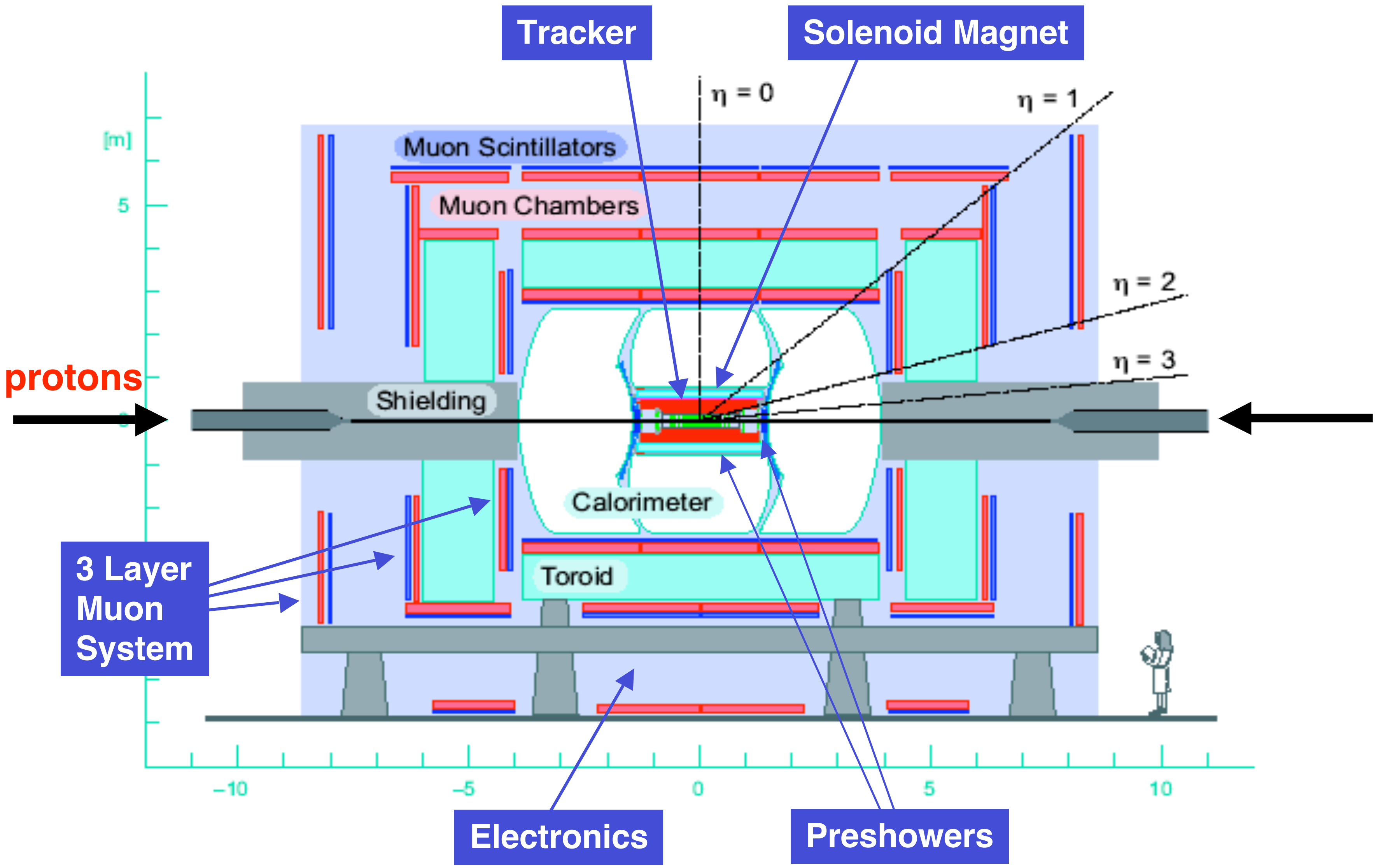
2001-2009 Run 2: major upgrades

higher E_{CM} = 1.96 TeV

~3 fb^{-1} recorded, expect ~8 fb^{-1} in 2009



DØ Detector


Tracker
Solenoid Magnet
η = 0
η = 1
η = 2
η = 3
[m]
5
0
Muon Scintillators
Muon Chambers
protons
Shielding
Calorimeter
Toroid
3 Layer Muon System
−10
−5
0
5
10
Electronics
Preshowers

Gauge-Mediated SUSY Breaking

- Alternative to gravity mediated SUSY breaking
  - 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
  - Dark Matter is a mix of the gravitino and the lightest "messenger"
- 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:
  $\chi_1^0 \rightarrow \gamma G$ or $\tau_1^+ \rightarrow \tau^+ G$
  - 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, γ Z+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

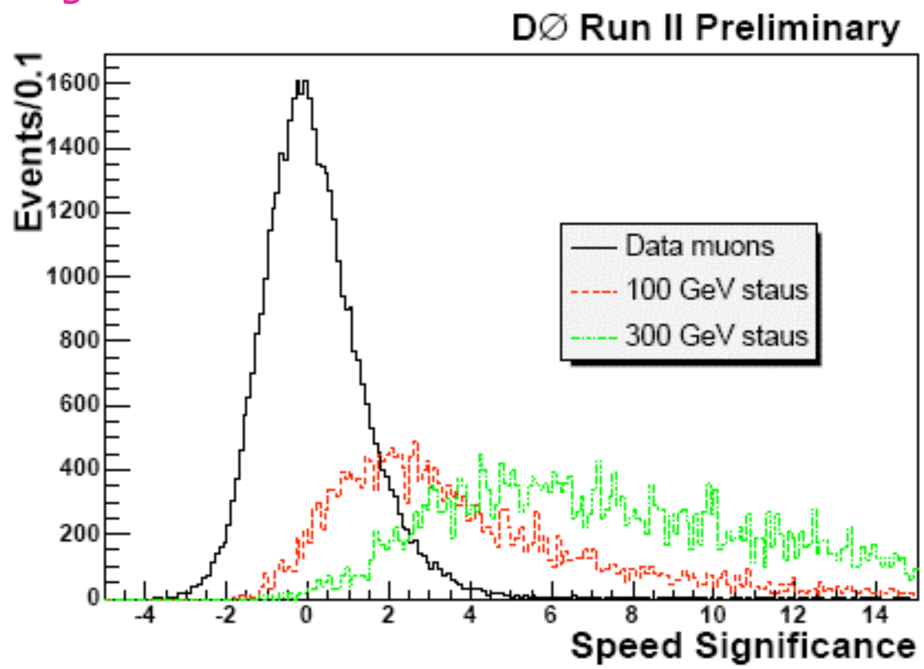
- Model Parameters:
  - Λ - mass parameter (effective scale of SUSY breaking)
  - M_m - messenger mass scale
  - N_5 - number of messenger fields
  - $\tan\beta = \langle\phi_1\rangle/\langle\phi_2\rangle$
  - sign $\mu = \pm 1$ - sign of higgsino mass term
  - C_{grav} - determines NLSP lifetime
- Gaugino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

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

  } Stau NLSP

Charged Massive "Stable" Particles

- **"Old"** analysis - 0.35 fb^{-1}, update is in the works…
- Exist in many models in addition to GMSB: AMSB, stable stop, R-hadrons…
- Appear in the detector as a "slow muons"
- Study exclusive pair production of CMSP's
  - require two muons in event
  - measure muon speed with scintillator counters (counter resolution ~ 2 to 4 ns)
  - speed resolution depends on detector region and number of reconstructed hits -> construct "speed significance"



- Main background: Drell-Yan
- Use low-mass di-muons (<120 GeV) to calibrate speed significance
- Look for excess in high mass di-muons

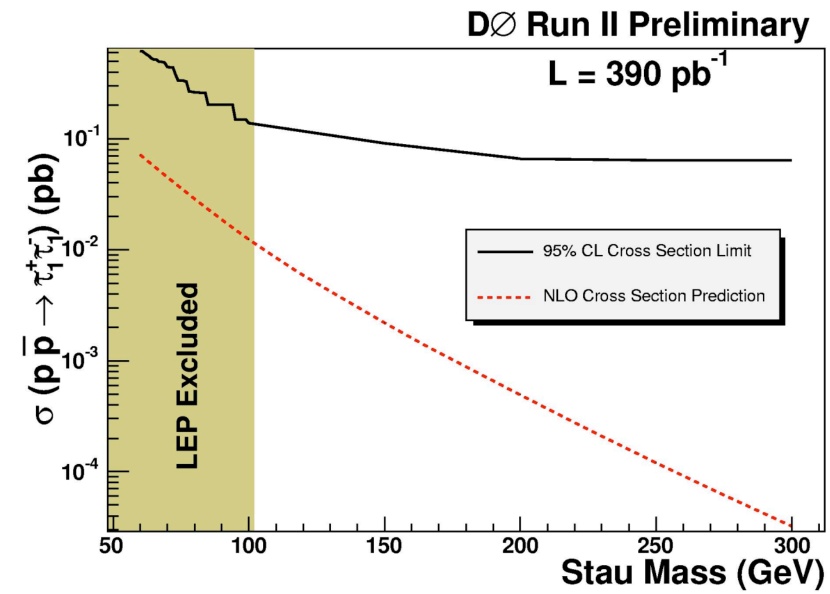
Data agrees with SM expectation…

Charged Massive "Stable" Particles

- No excess, set limits

GMSB line (Snowmass slope D)

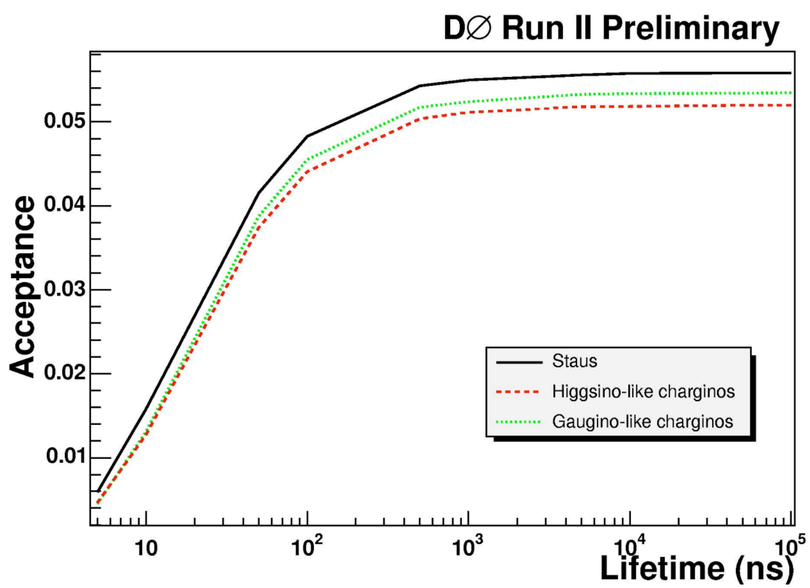
$M=2\Lambda$, $N_5=3$, $\tan\beta=15$, sign $\mu > 0$

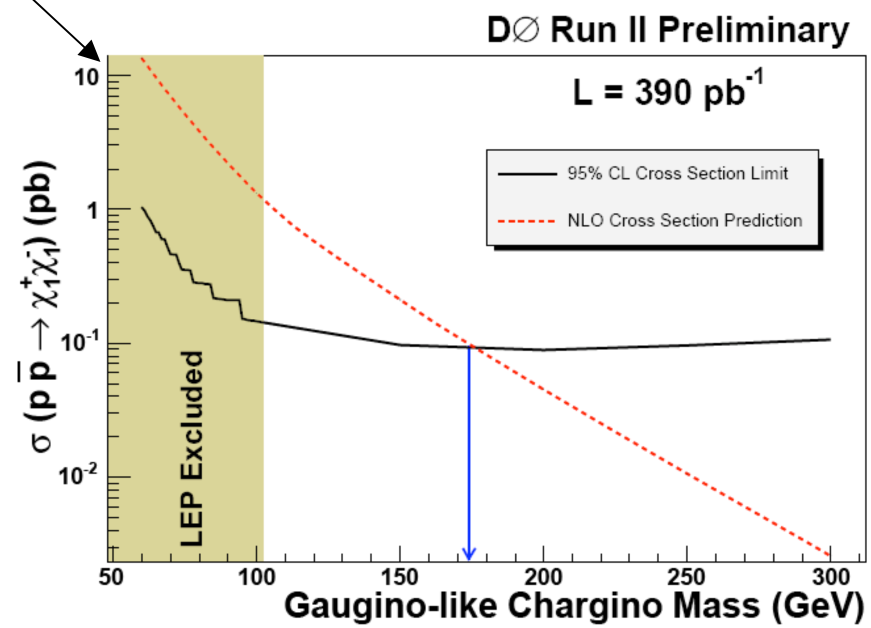


AMSB Gauginos

$M_1=3M_2$, $M_3=500$, $\mu=10$ TeV

$\tan\beta = 15$, M(squark) = 800 GeV

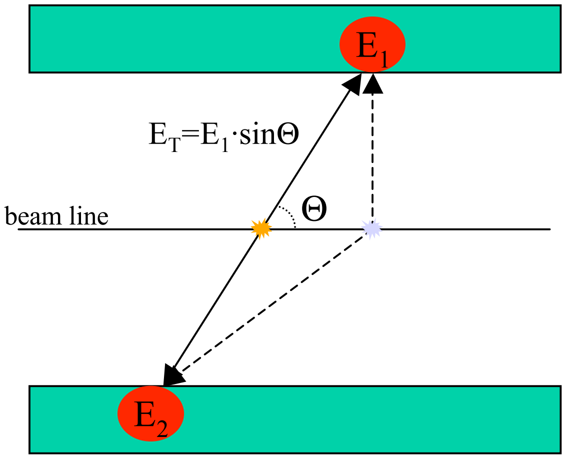




Di-photon Data Analysis

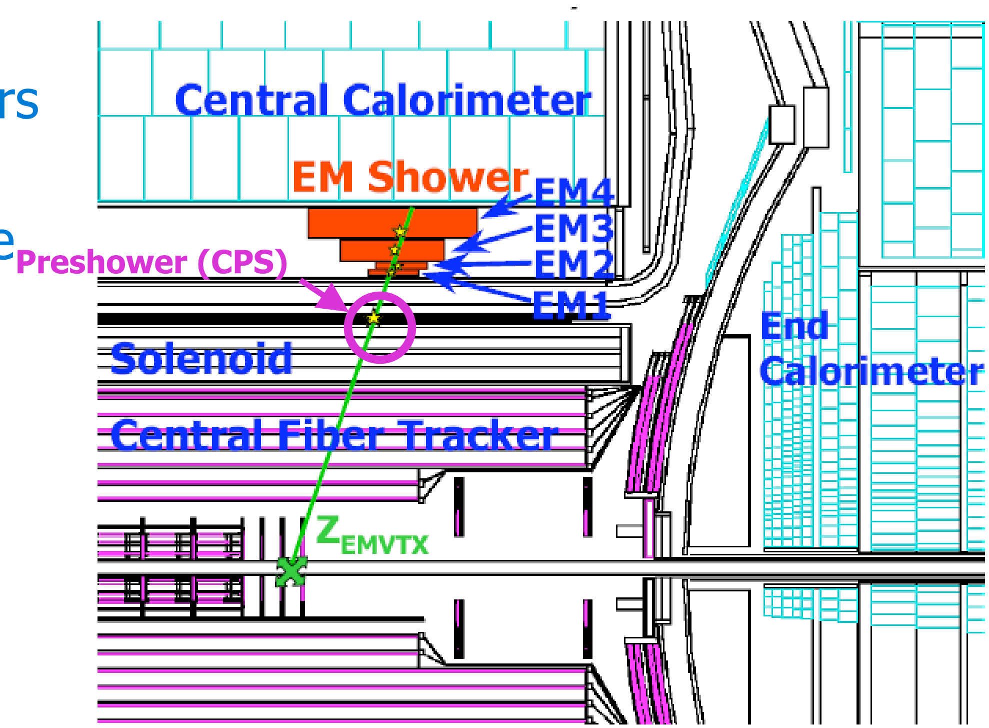
- Data collected in the Run IIa: 1.1 fb^{-1}
- Photon and electron identification:
  - Calorimeter cluster with > 95% energy in EM calorimeter
  - Isolated in calorimeter $(E_{TOT}^{R=0.4} - E_{EM}^{R=0.2})/E_{EM}^{R=0.2} < 0.07$
  - Scalar sum of track p_T in $0.05<R<0.4$ annulus around the direction of the cluster is less than 2 GeV
  - Shower shape is consistent with photon
  - Cluster is electron if there is a central track match (or an electron-like hit pattern in the tracker) and is a photon otherwise
- Event selection
  - Two photons, $E_T>25$ GeV and $|\eta| < 1.1$
  - $\Delta\varphi$ (jet, MET) < 2.5 – for leading jet (if present) - to remove events with mismeasured missing E_T
  - use photon pointing to eliminate mis-vertexing

Photon Pointing & Vertex Selection



- There can be several interactions per event
- Vertex distribution RMS ~ 28 cm
- MET is significantly affected if the vertex is shifted by >10 cm
- Which vertex did the photons come from?

- DØ has four longitudinal EM layers and a preshower
- Fit a straight line through the five points (obtain resolution of each layer using $Z \to ee$ events)
- Z_{VTX} resolution ~ 2 cm (verified with $Z \to ll\gamma$ events)
- In the analysis require at least one photon to have CPS cluster



Backgrounds

- Physics backgrounds are small: $W\gamma\gamma$, $Z\gamma\gamma$ - COMPHEP MC
- All instrumental backgrounds can be determined from data

without true MET *-fake MET*

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

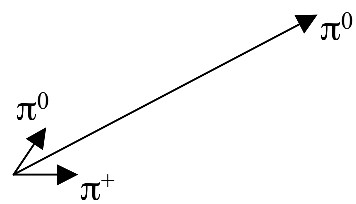
largest

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 with No Genuine MET

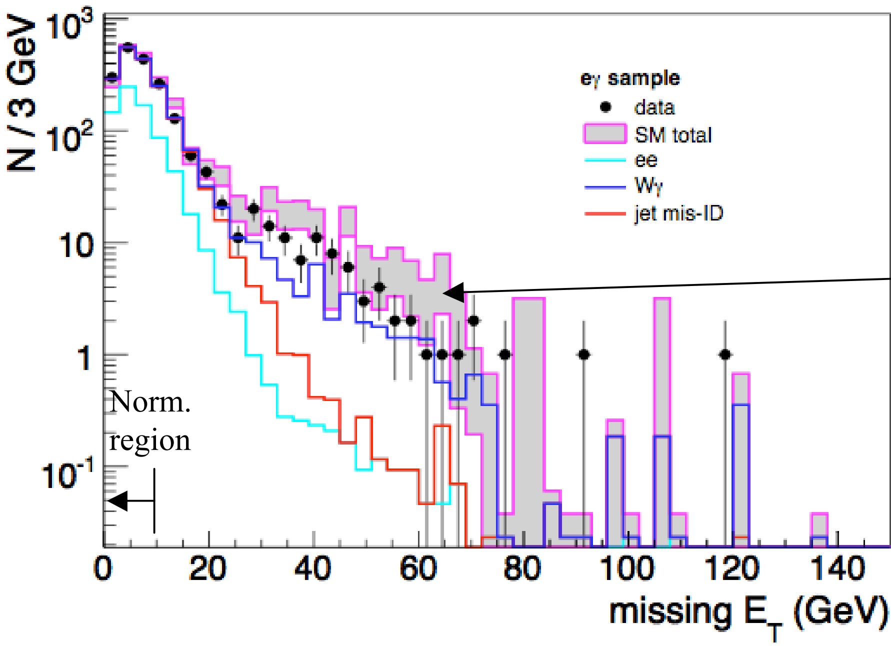
- Need to know the shape of MET distribution for them
  - and normalize to data with low MET
- MET resolution is dominated by the energy resolution of the photons
  - to first order, the shape does not depend on whether the photons are real or faked by jets
  - still, there is a small difference due to the fact that when jet fakes a photon, the photon's energy is less than original parton;s energy
- Take $\gamma\gamma$ shape from $Z \rightarrow ee$
- Take fake shape from a sample that is the same as signal sample except both photons fail shower shape cut (*hh sample*)
- Take relative contribution that fits data best
  - 60±20% of real $\gamma\gamma$
  - agrees with MC expectation for $\gamma\gamma$
  - purity cross-checked by looking at shower shape in the preshower (not used for photon ID)



fluctuated jet: most energy is carried by π^0

Backgrounds with Genuine MET

- Always involve electron - photon mis-identification
  - can determine using eγ events and known mis-identification rate
- Select eγ events using the same kinematical cuts as γγ
  - Contributions from
    - Z→ee (one lost track) - get contribution from di-EM mass fit
    - QCD (jets faking electron and photon) - subtract using shape of hh sample
    - the processes we want to measure (Wγ, Wj, WZ, tt, etc)

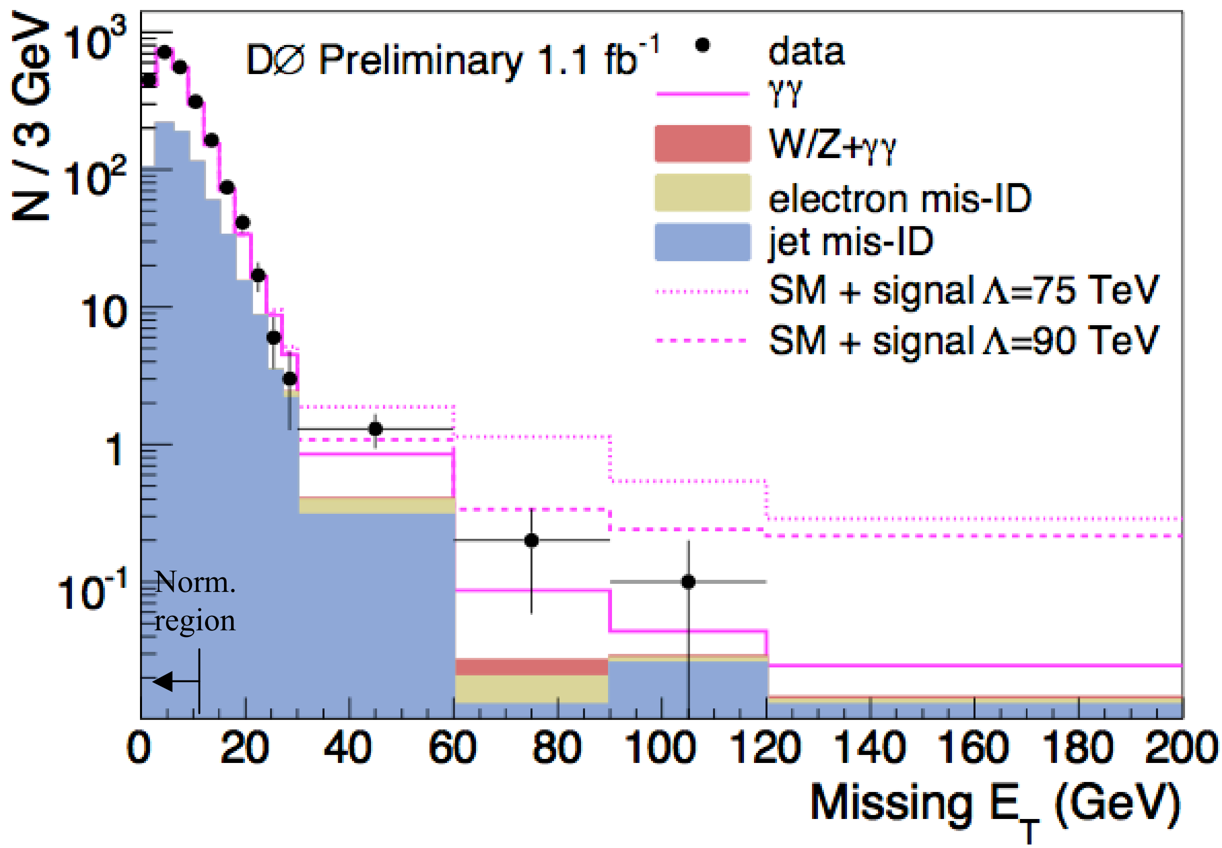


also serves as a cross-check of QCD subtraction method:

grey area is Z+QCD+Wγ MC + Wj obtained from data

error is dominated by j→γ fake rate (correlated between bins)

MET in γγ Sample

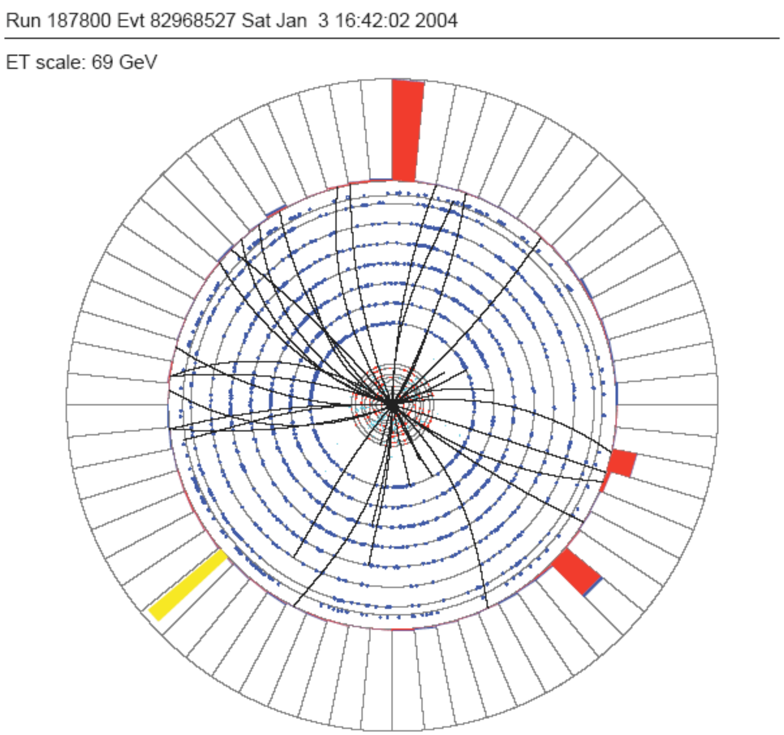


- Signal MC: ISAJET for masses and branchings, PYTHIA for event generation, full detector simulation plus real zero-bias events overlay to simulate multiple interactions per crossing

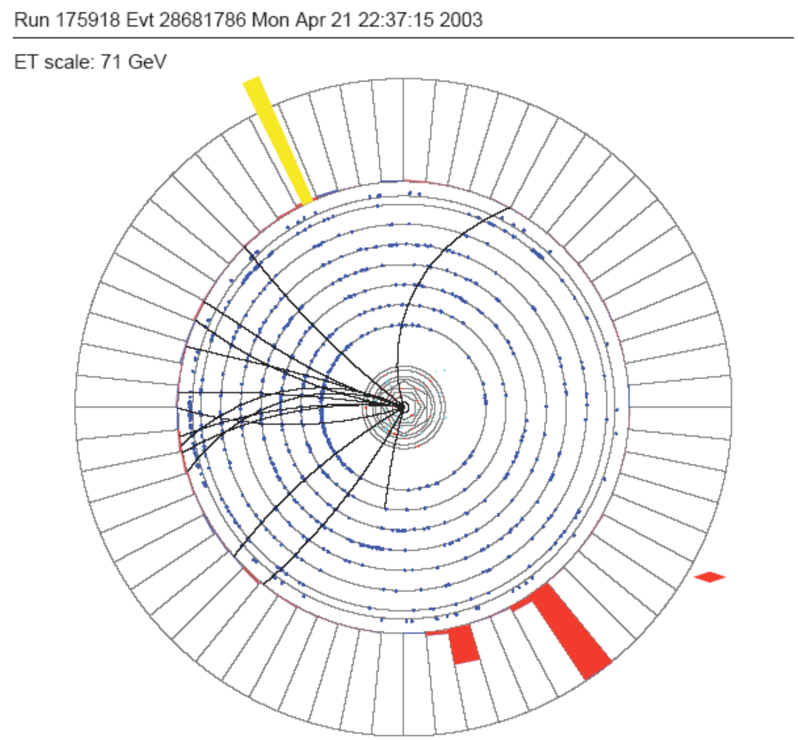
Two Highest MET Events

ME_T=63 GeV, $E_T(\gamma)$ = 69, 27 GeV

plus electron with E_T = 23 GeV



ME_T=105 GeV, $E_T(\gamma)$ = 82, 33 GeV

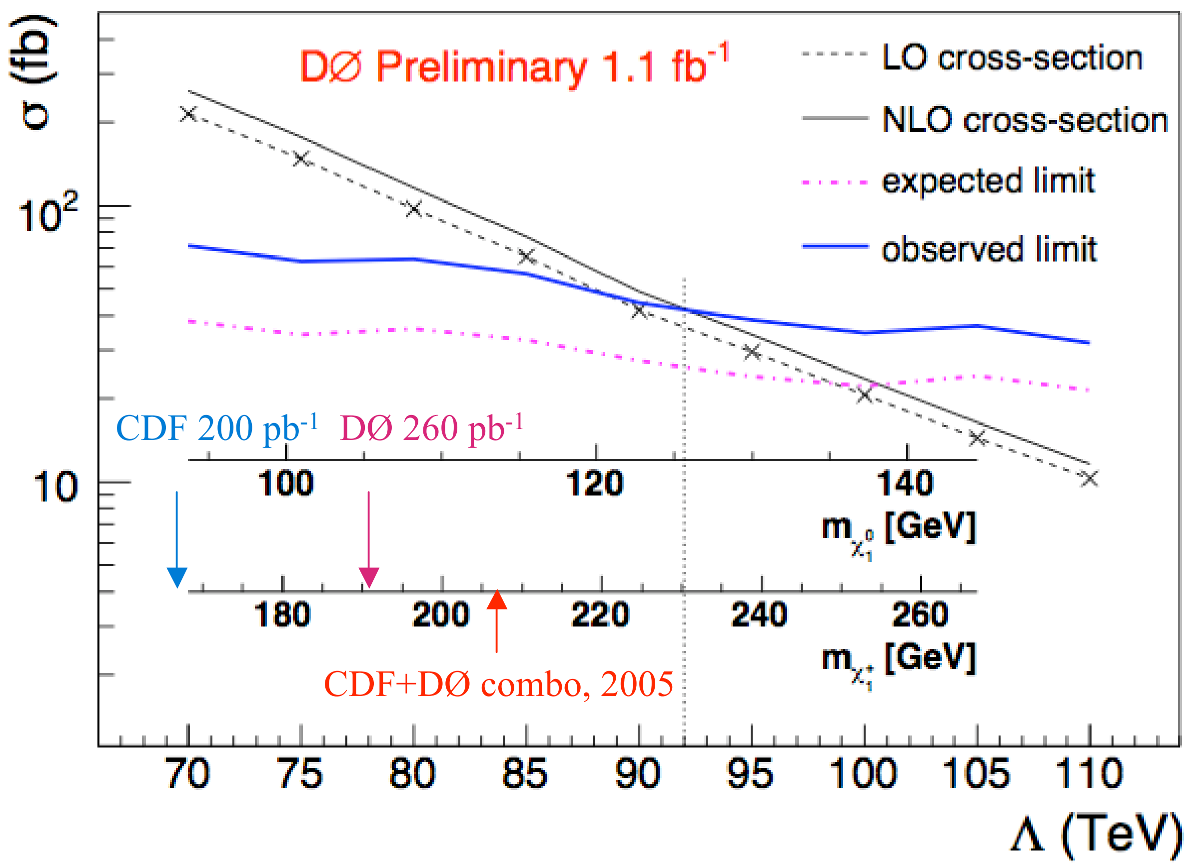


Expect ~0.15 events from $W\gamma\gamma$ with $E_T(\gamma)$>25 GeV

Expect ~0.1 event from $Z\gamma\gamma$ with $E_T(\gamma)$>25 GeV

Limit Setting

- Since data agrees with the MC proceed to limit-setting
- Use CLS method - takes into acount shape of the distributions



@ 95% CL:

$\Lambda > 92$ TeV

$m(\chi_1^0) > 126$ GeV

$m(\chi_1^+) > 230$ GeV

Summary and Outlook

- Still no sign of SUSY, although some interesting events are showing up…
- Not the end of the story - have more than twice the data on tape, will get ~8 fb^{-1} by the end of 2009

Stay tuned!