Searches for New Physics in Photon and Jets Final States

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Rencontres de Moriond
Electroweak and Unified Theories
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Overview

- Searches for new physics at the Tevatron with jets and photons in the final states.
- Recent results from D0 and CDF with integrated luminosities of ~300 pb^{-1} to 1 fb^{-1}
- Topics covered:
  - Large extra dimensions, Leptoquarks
  - SUSY (Sbottom, GSMB, squark/gluinos, stopped gluinos)
  - Signature based searches for new physics
  - MSSM Higgs to $\tau\tau$

Large Extra Dimensions

- SM particles confined to 3+1 dimensions
- Gravitons can propagate in extra dimensions

Arkani-Hamed, Dimopoulos, Dvali (ADD)

N "large" extra dimensions

$M^2_{Pl} \sim M_D^{N+2} R^N$

M_S fundamental Planck scale (possibly O(TeV))

N = 1 excluded (R ~ 108 km)

N = 2, R ~ 1 mm (precision experiments)

N >= 3 Can be only tested at colliders

Here: direct graviton production:

$q\bar{q} \rightarrow gG$, $qg \rightarrow qG$, or $gg \rightarrow gG$

In all cases graviton G escapes detector.

Signature: single jet plus missing E_T

Selection:

single high E_T jet trigger in central calorimeter $|\eta| < 1.0$

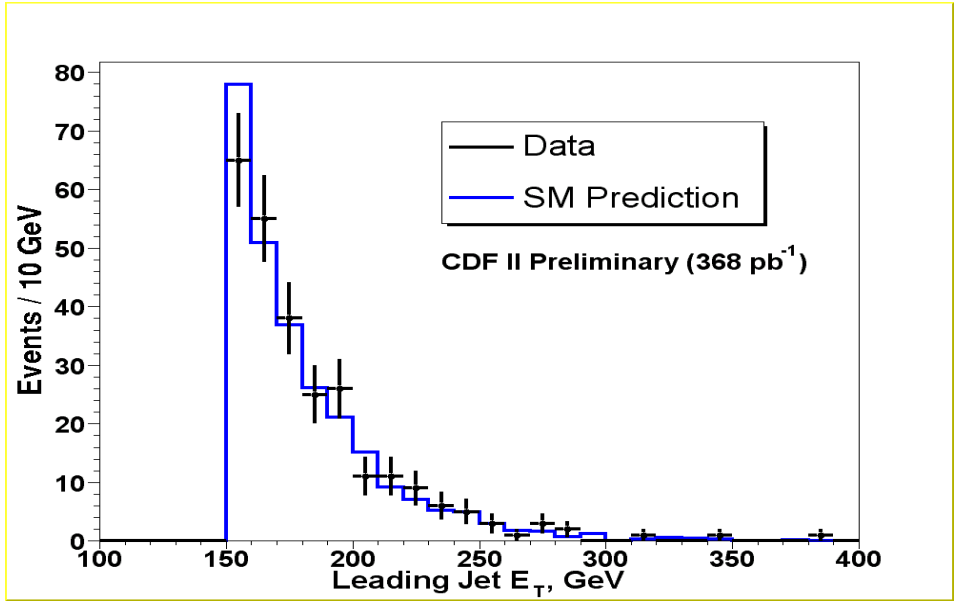
Leading jet $E_T > 150$ GeV (2nd jet < 60 GeV)

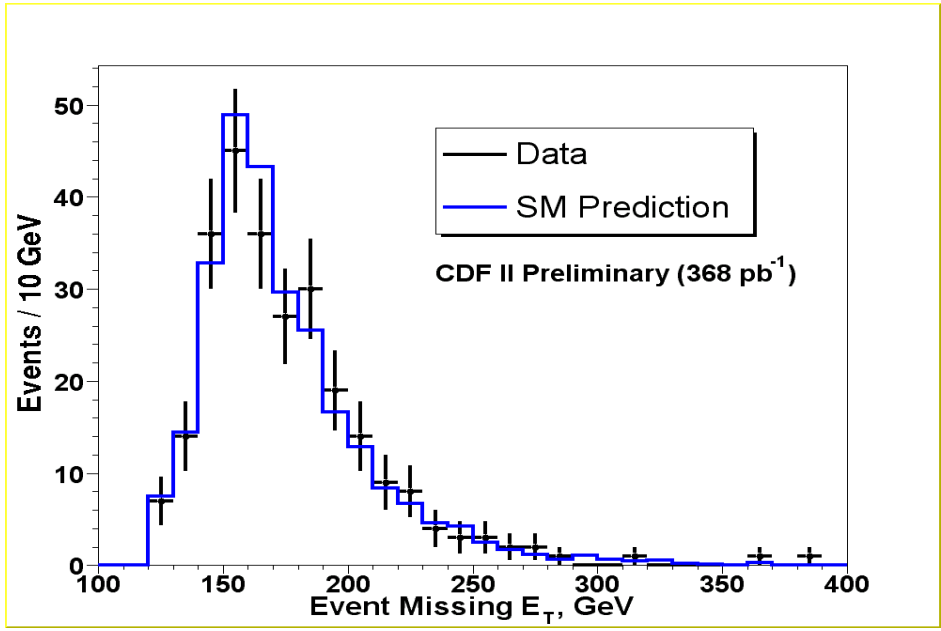
Missing $E_T > 120$ GeV

$\Delta R(\text{Jet,MET}) > 0.3$

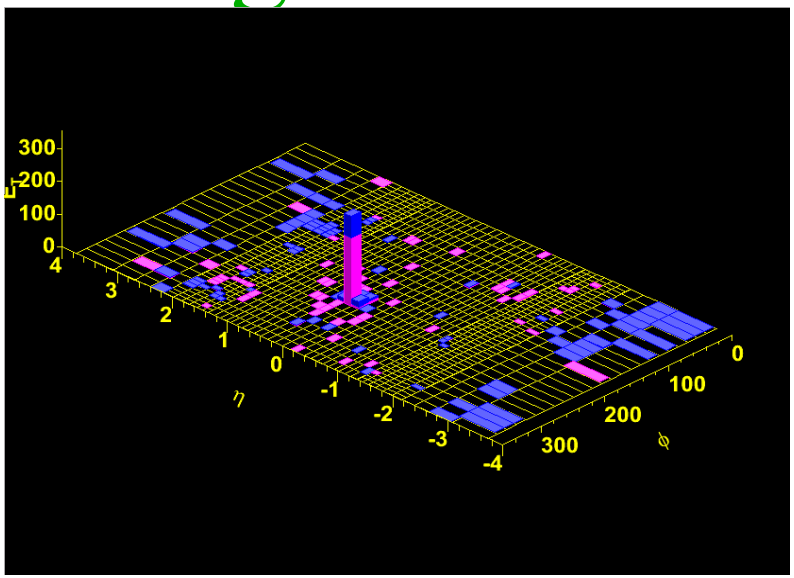
Large Extra Dimensions: Jet + MET

- Largest (irreducible) bg is $Z \rightarrow \nu\nu$ + jets
- $W \rightarrow l\nu$ + jets where lepton is lost
- Data driven way to estimate bg:
  - Measure $Z \rightarrow ll$ + jets ($ll = ee, \mu\mu$)
  - Apply analysis cuts taking 2 leptons into account (e.g. for missing ET)
    - 2 cross section measurements
  - Use Z BF into leptons and neutrinos to estimate $Z \rightarrow \nu\nu$ + jets
  - Measure $W \rightarrow l\nu$ + jets
    - Divide by ratio R (theory) of W+jets/Z+jets cross section
    - Uncertainties smaller than for individual cross sections.





Large Extra Dimensions: Jet + MET



E_T = 384 GeV, ME_T = 390 GeV

L = 368 pb^{-1}
Events
Expected: 265 ± 30
Observed: 263

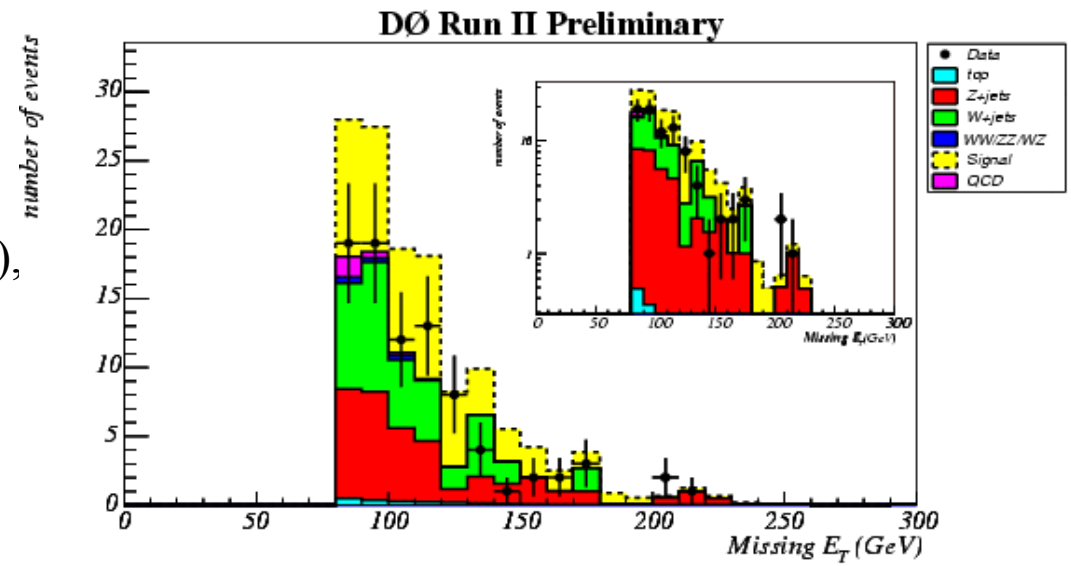
$$R^n = \frac{1}{(8\pi)}\left(\frac{M_{pl}}{M_D}\right)^2 \frac{1}{M_D^n}$$

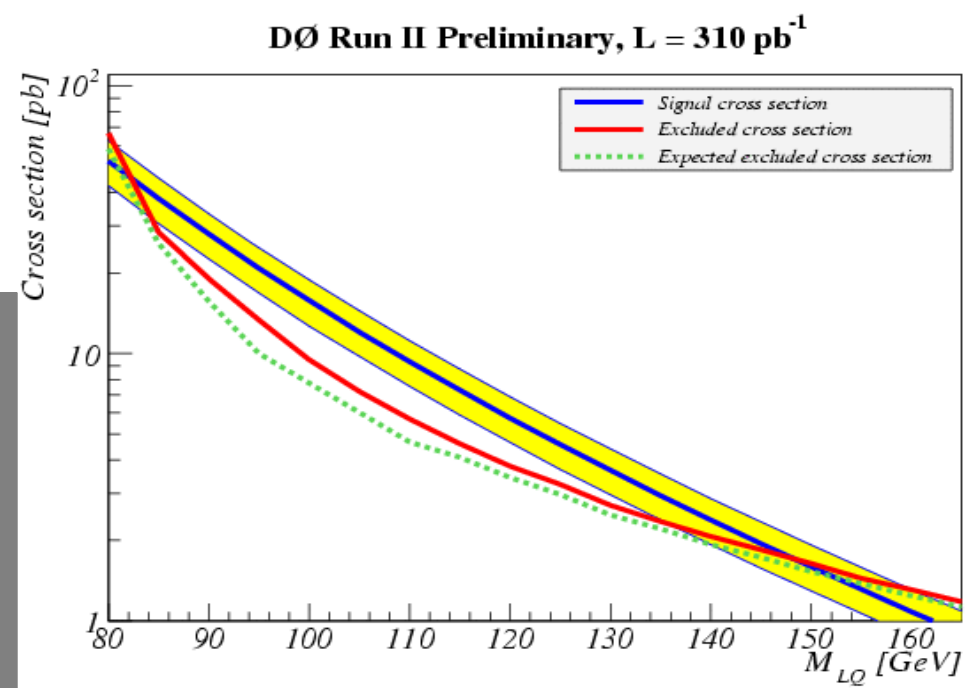
n	M_D (K=1.0)	M_D (K=1.3)	Run I (K = 0)	Run I (K = 1.3)	LEP Avg
2	1.09 TeV/c^2	1.16	1.00	1.06	1.60
3	0.93	0.98	-	-	1.20
4	0.87	0.90	0.77	0.80	0.94
5	0.82	0.85	-	-	0.77
6	0.80	0.83	0.71	-	0.66

Scalar Leptoquarks in Acoplanar Jet Topology

- Predicted by many BSM models. Carry both quark and lepton quantum numbers, and have fractional charges.
- Decay into quark and charged lepton with branching fraction β or quark and neutrino (1-β), here β = 0. LQ → qν
- Pair produced at Tevatron.
- Signature: pair of acoplanar jets and ME_T
  - Exactly 2 jets, p_T > 60, 65 GeV, Δϕ < 165°
  - H_T > 40 GeV, ME_T > 80 GeV
  - Main backgrounds: Z → νν+jj, W → lν + jj

L = 310 pb^{-1}
Events expected: $75.2^{+10.1+10.7}_{-9.7-12.2}$
Events observed: 86
M_{LQ} > 136 GeV

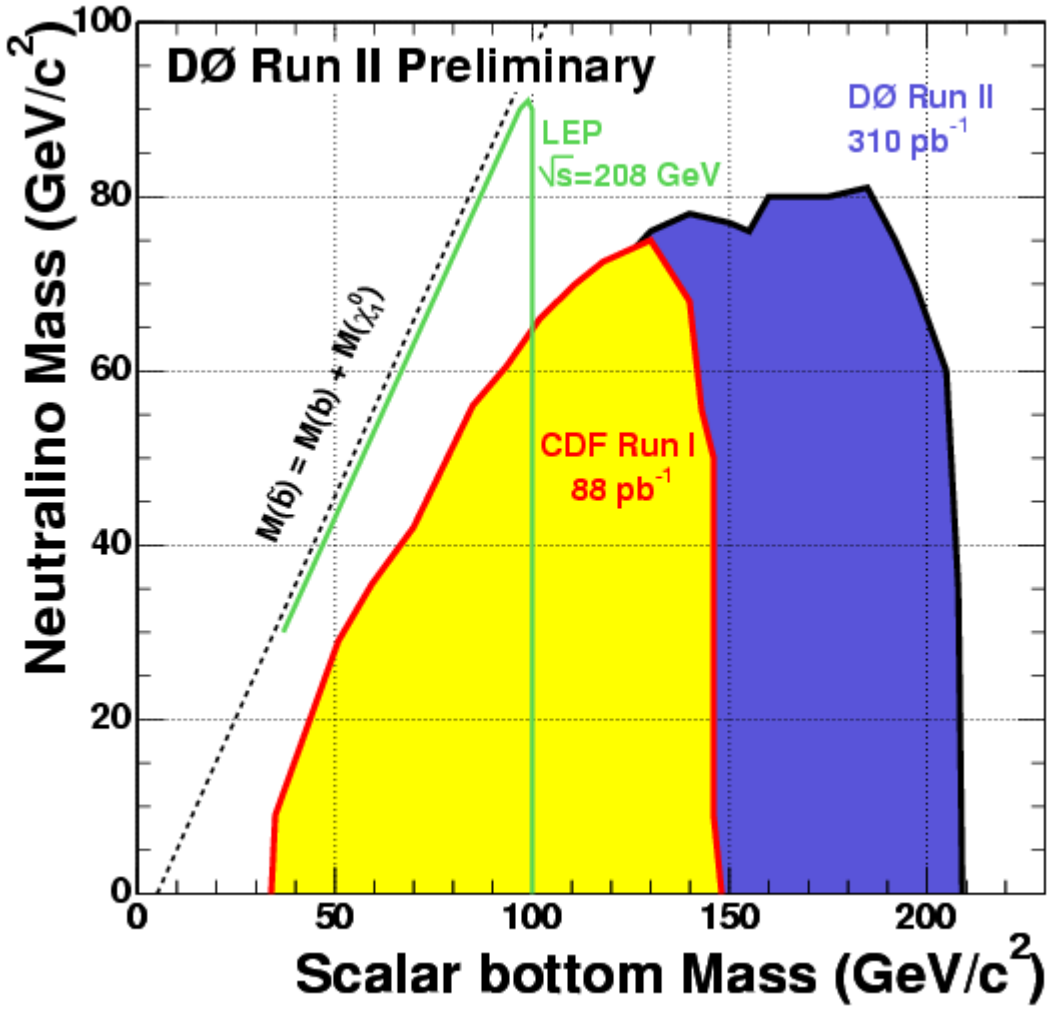




Direct Production of Scalar Bottom Quark

- Direct pair production of scalar bottom quark.
  - Decays into b quark and lightest neutralino (assumed to be LSP)
  - two acoplanar **b** jets and missing ET
- Main backgrounds
  - $Z/W \rightarrow l\nu + j$, $l\nu + jj$
  - $WW, WZ, ZZ \rightarrow l\nu jj$, $t\bar{t}$
- Selection
  - $H_T > 40$, $ME_T > 60$ GeV
  - Jet 1 $p_T > 40$ GeV, Jet 2 $p_T > 20$
  - >1 b-tagged jet

L = 310 pb^{-1}
Events expected: 19.1 ±0.7
Events observed: 22
after single b-tagging



Squarks/Gluinos to Jets and MET

- Large production cross-section
- Large backgrounds: multi-jets, W+jets, Z+jets
- $m(\tilde{g}) > m(\tilde{q})$ (low m_0)
  - acoplanar di-jets
  - Background: $Z \rightarrow \nu\nu + 2j$, ...
- $m(\tilde{q}) > m(\tilde{g})$ (large m_0)
  - >= 4 jets events
  - Background: ttbar, QCD
- intermediate m_0: >= 3 jets
  - Background: $W \rightarrow \tau\nu + 2j$, $t\bar{t}$

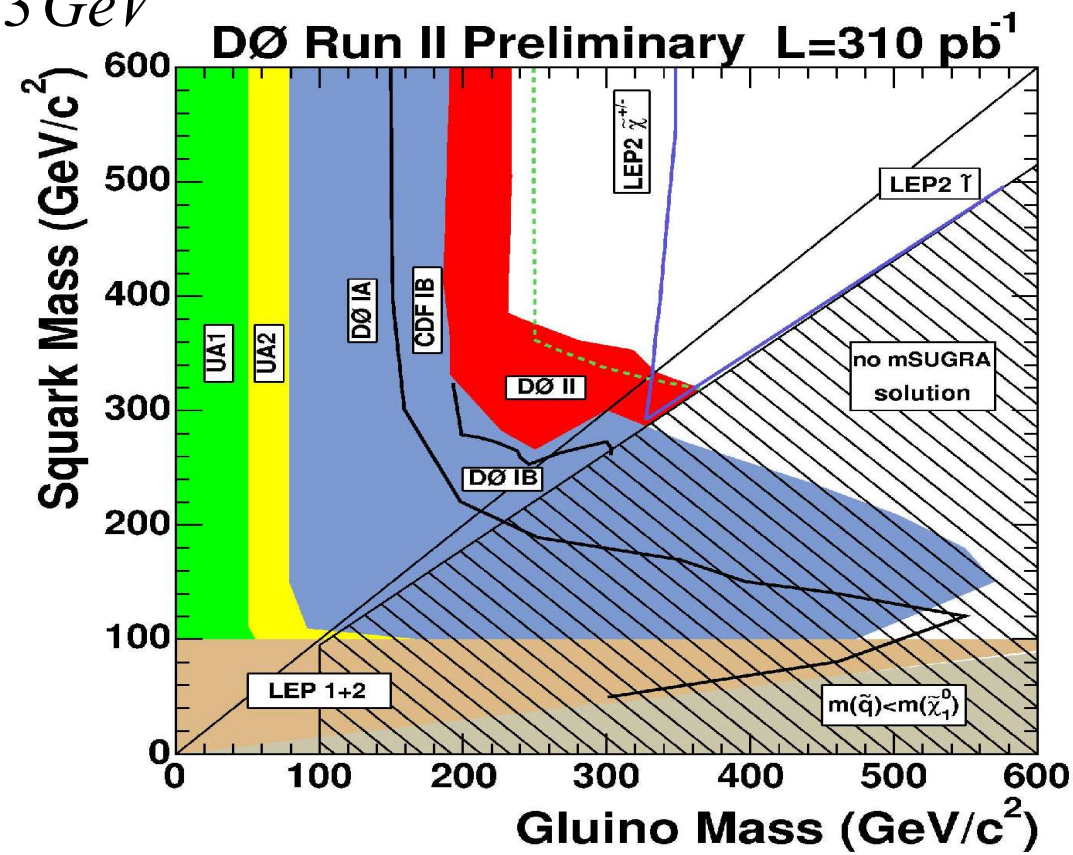
Squark/Gluinos to Jets and MET

No excess observed, limits in mSUGRA tan $\beta = 3$, $A_0 = 0$, $\mu < 0$

$m_0 = 25$ GeV $\quad m(\tilde{q}) > 318\, GeV$

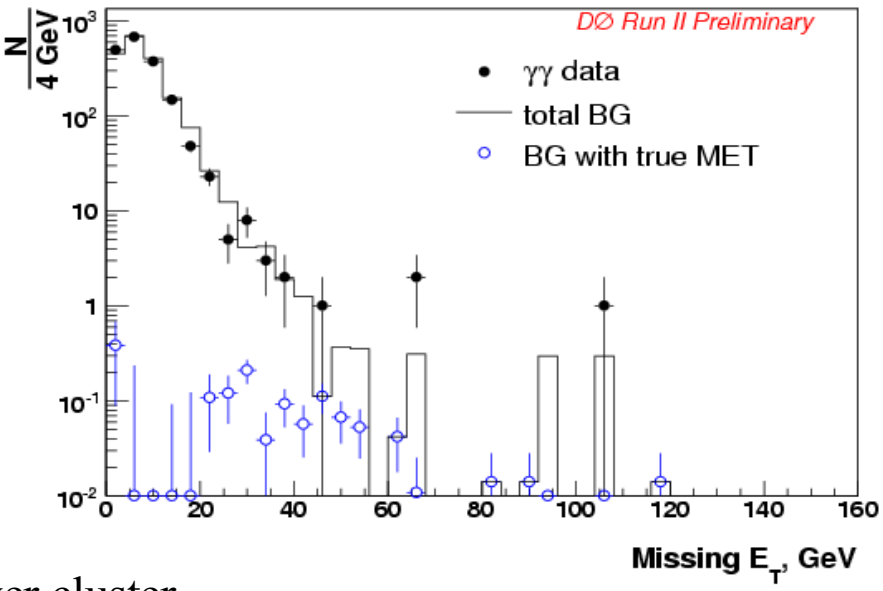
$m_0 = 500$ GeV $\quad m(\tilde{g}) > 233\, GeV$

intermediate: $m(\tilde{q}), m(\tilde{g}) > 333\, GeV$



Gauge-mediated Supersymmetry Breaking

- Pair production of superpartners, R parity conserved
- Decay into NLSP (here: neutralino)
  - which decays into photon and gravitino (LSP)
- Signal:
  - Two high energetic photons plus missing ET
- Selection:
  - Two photons, E_T > 25 GeV, at least one has preshower cluster
  - Primary vertex consistent with photon pointing
    - photon vertex resolution ~2cm
  - ME_T > 45 GeV
- Physics background negligible
- Others: W (-> eν) γ, W (-> eν) j, where jet is misidentified as photon

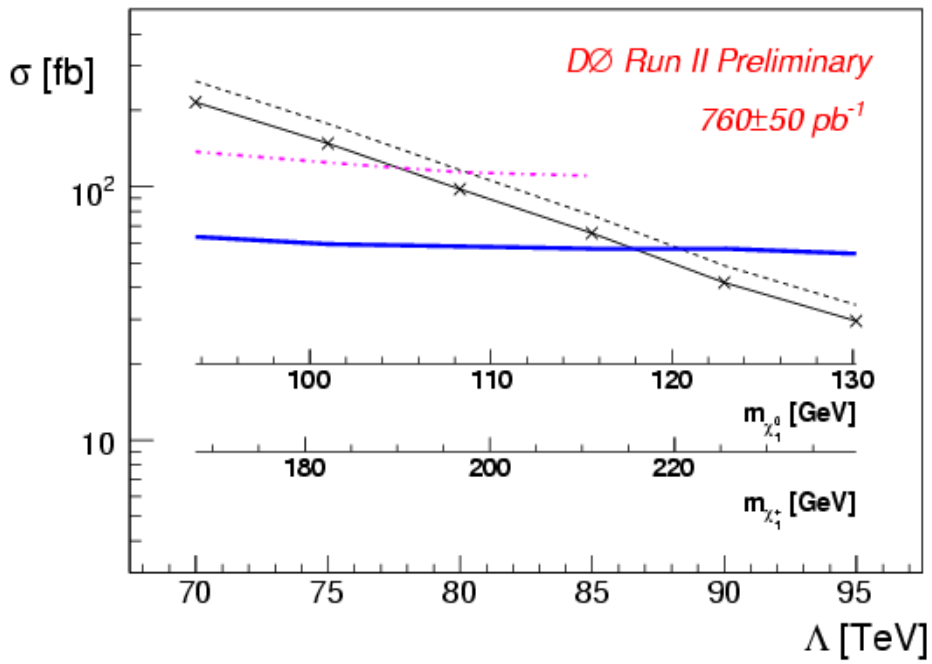


Snowmass slope SPS8

Λ : eff. scale of SUSY breaking

Lifetime of neutralino assumed to be short enough to result in prompt decay to photons.

Gauge-mediated Supersymmetry Breaking (2)



- $L = 760\ pb^{-1}$
- Events
  - Expected: 2.1 ± 0.7
  - Data: 4
- Limits
  - $\Lambda > 88.5$ TeV @ 95% CL
  - $m(\chi^0_1) > 120$ GeV
  - $m(\chi^+_1) > 220$ GeV

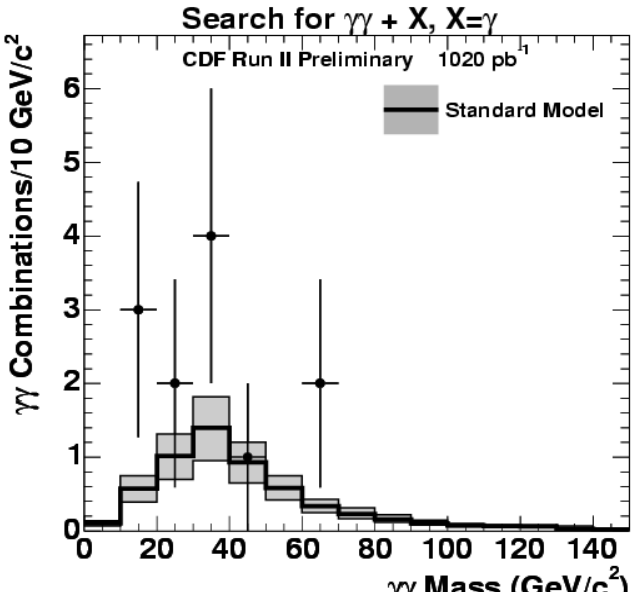
This improves significantly on the previous combined Run II limit $m(\chi^+_1) > 209$ GeV from D0 and CDF

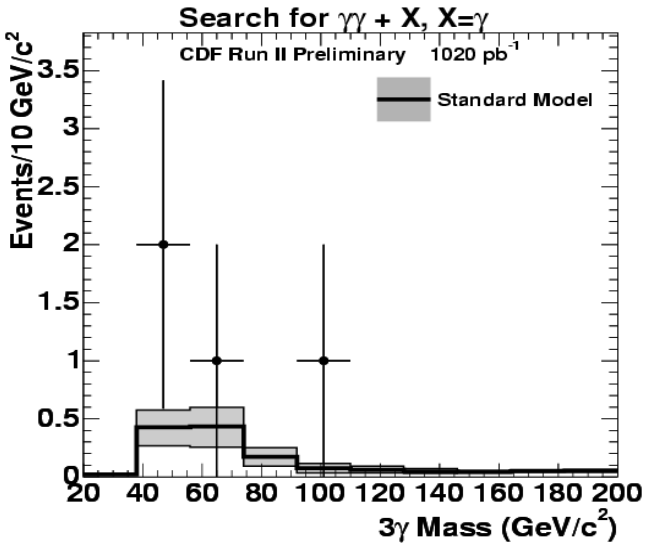
Search for Anomalous $2\gamma + X$ Production

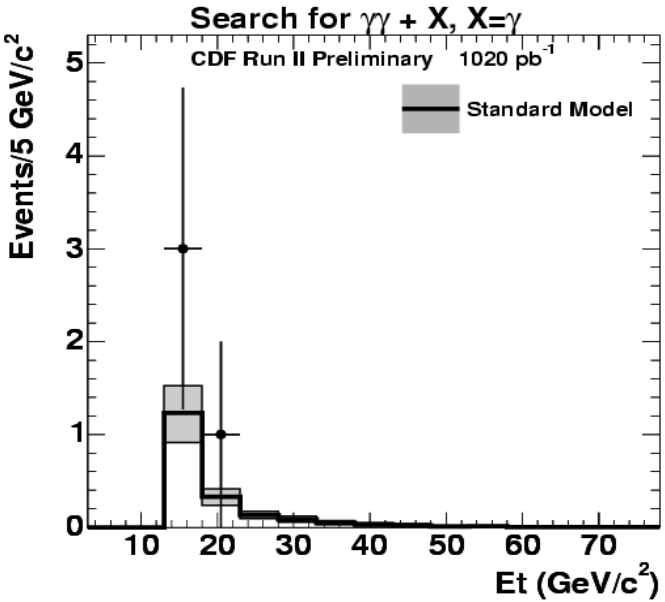
- Search for events with 2 photons and additional identified object (electron, photon or muon): GMSB, fermiophobic Higgs, ...
  - Compare observed event counts with Standard Model predictions and kinematic distributions.
- Basic Selection:
  - 2 central photons (isolated EM clusters in calorimeter and tracking system), $E_T > 13$ GeV
  - Vertex with $|z| < 60$ cm
  - Backgrounds: $Z\gamma\gamma$, $W\gamma\gamma$, Fake $l + \gamma\gamma$, $l\gamma$ + jet/e $\rightarrow \gamma$
- Electrons: central, $E_T > 20$ GeV,
  - $L = 683$ pb^{-1}, expect: 4.49, observe: 2 events
- Muons: central, $P_T > 20$ GeV,
  - L = 683 pb-1, expect: 0.47 events, no events observed

Search for Anomalous 2γ + X Production (2)

- 3rd Photon: same cut as for first two photons
- Background:
  - true triphoton events: 0.7 ±0.1
  - jet fakes a photon: 1.2 ± 0.6
- Expect: 1.9 ± 0.6
- Observed: 4







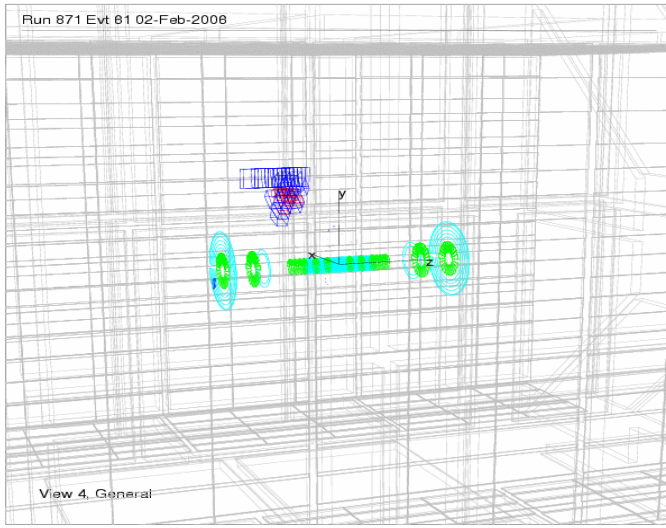
Stopped Gluinos: Motivation

N. Arkani-Hamed et al., Nucl. Phys.B 709, 3 (2005) [arXiv:hep-ph/0409232].

- Split-Supersymmetry
  - SUSY scalars are heavy (~GUT-scale) compared to fermions.
  - Gluino decays are suppressed => long lifetime
    - lifetime determined by SUSY scalar mass scale (M_{SUSY})
    - long-lived gluinos can hadronize into (charged) R-hadrons: colorless bound states of gluinos and other quarks and gluons
  - If $M_{SUSY} > 10^{16}$ GeV, R-hadrons can be pair produced at the Tevatron and live long enough to reach the D0 calorimeter
- Gluinos can loose their momentum through ionization and come to rest in the calorimeter ("stopped gluinos")
- Finally decay into jet (from gluon) and missing ET (from neutralino = LSP).

Stopped Gluinos: Signal

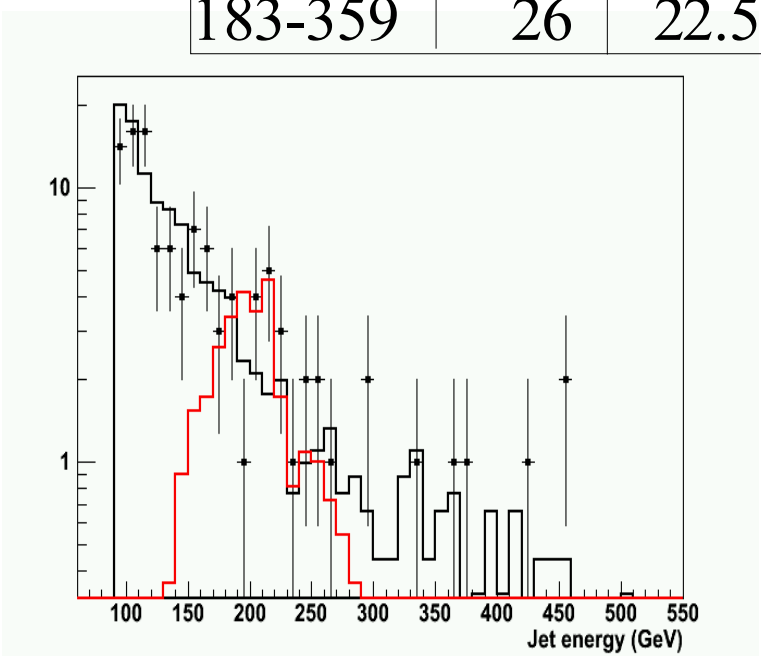
- Signal:
  - More than 75% of gluinos in $|\eta| < 1.0$, angular distribution flat
  - Gluon (jet) energy: $E = (M_g^2 - M_{LSP}^2)/2M_g$
- Background
  - Cosmic muons that shower in the calorimeter
  - Beam-halo muons
  - Others small: Cosmic neutrons, cosmic neutrinos.
- Selection
  - Decay *not* associated with $p\,\bar{p}$ interaction !
    - "Diffractive" gap triggers: luminosity counters do not fire, but jets in Level 1 calorimeter trigger
  - Exactly one jet in event, $E > 95$ GeV. Width in η and $\phi > 0.08$
  - *No* primary vertex ! No (high quality) muons.

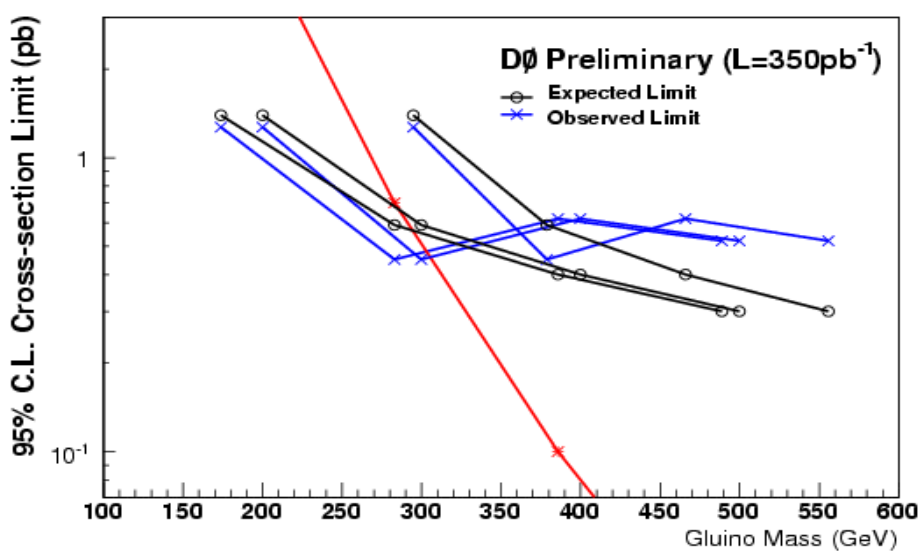


Stopped Gluinos: Results

- No excess over expected background observed
- Can set upper limit on gluino $\sigma \times BR(\tilde{g} \rightarrow g\,\tilde{\chi}_1^0)$ depending on LSP mass.

Jet E	Data	Bg.	Expected:	Obs. Limit	Gluino Mass (GeV) LSP=50	90	200
105-159	55	57.53	1.90 pb	1.76 pb	174	200	295
124-217	46	47.96	0.71	0.68	283	300	379
153-299	41	32.12	0.46	0.73	386	400	466
183-359	26	22.55	0.42	0.54	489	500	556

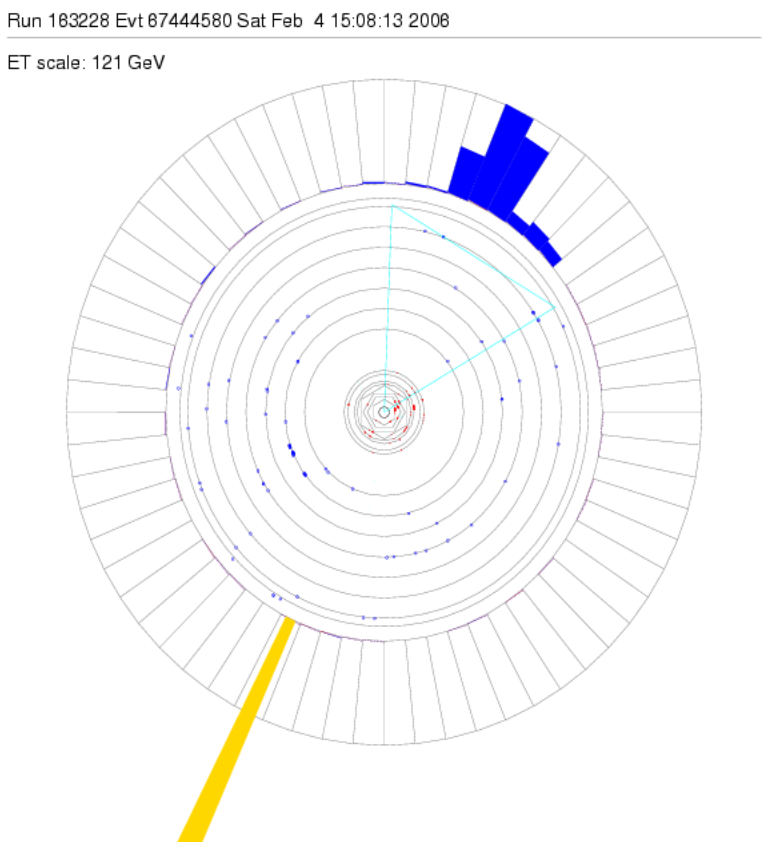


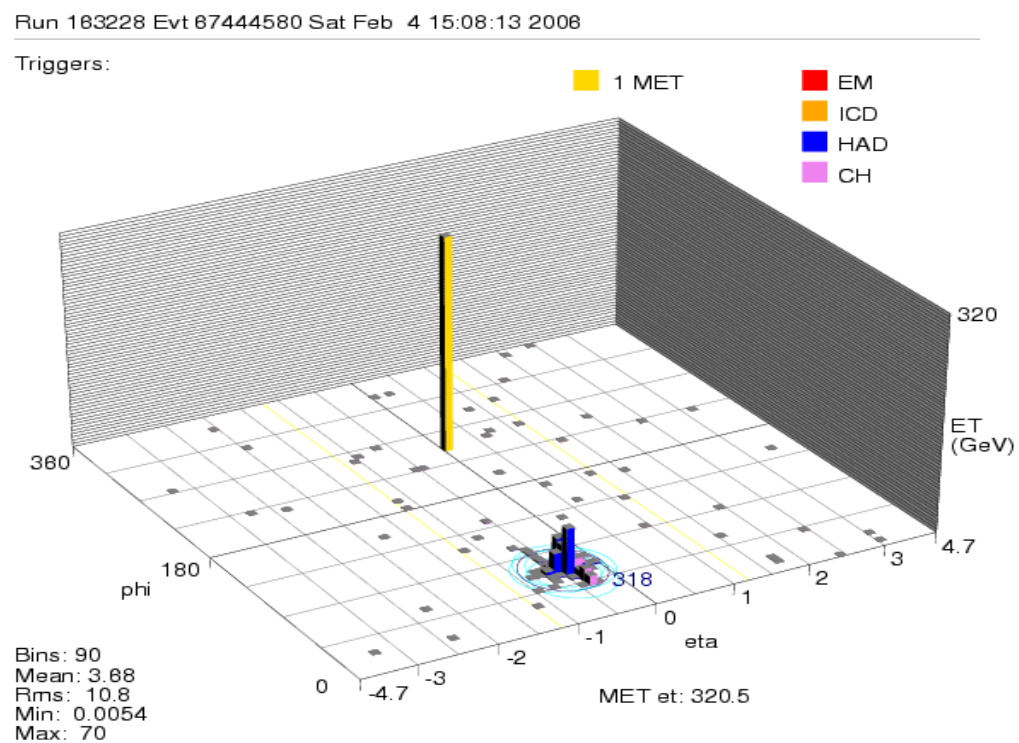


Stopped Gluinos: Data Event

MET: 320 GeV
Jet: 318 GeV

Notice: no tracks for jet...





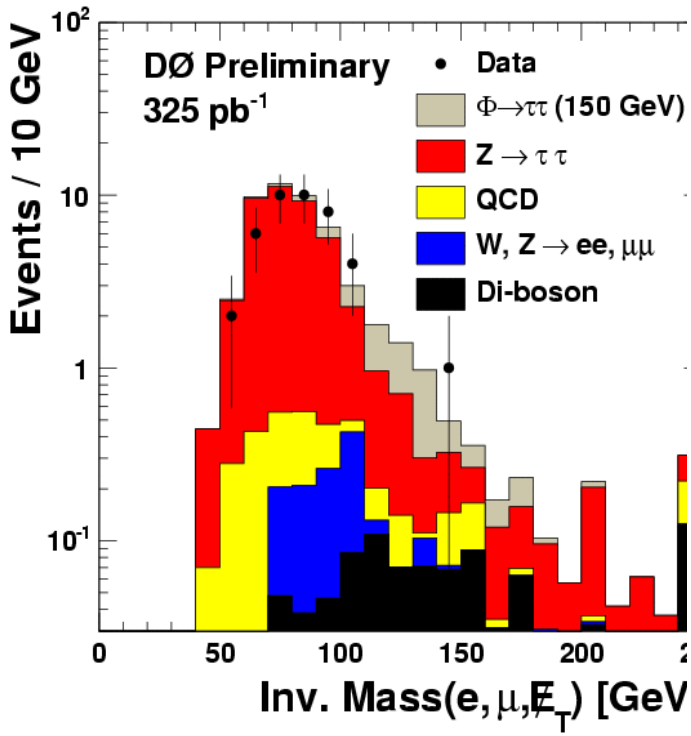
MSSM $\Phi \rightarrow \tau\tau$

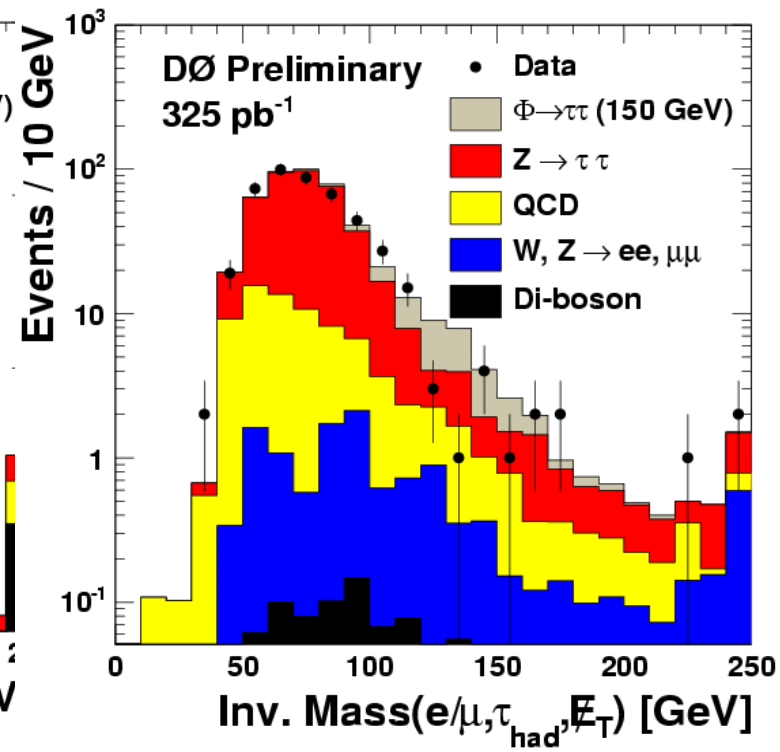
- In MSSM models with large tan β, sizable cross sections for final states with high P_T taus are predicted.
- Assume that at least one tau decays leptonically
  - $e\tau_h$, $\mu\tau_h$ and $e\mu$ final states

τ identification using neural network

Signal should stand out in "visible mass":

Main backgrounds:
$Z \rightarrow \tau\tau$
QCD
$W,Z \rightarrow ee, \mu\mu$





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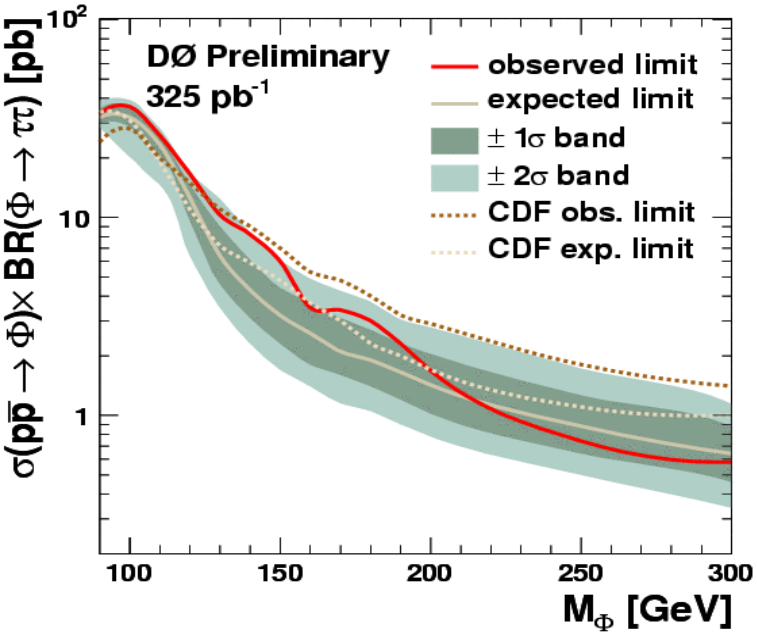
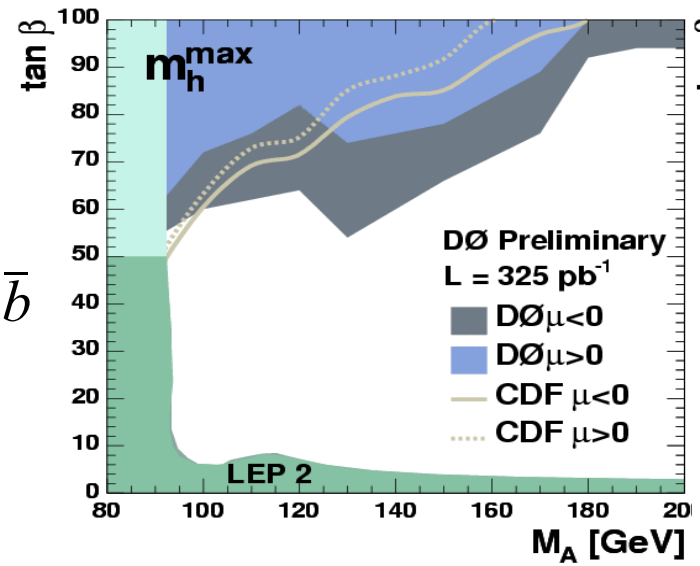
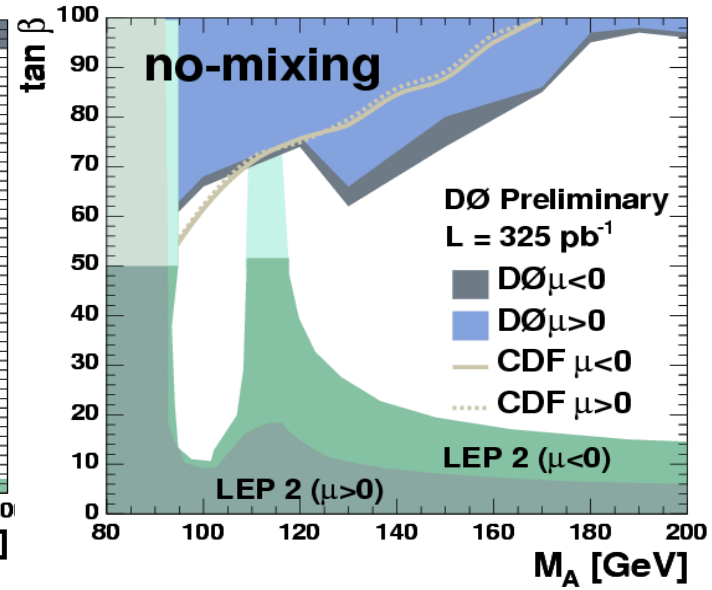


No excess observed in L = 325 pb^{-1}
$\sigma \times BR$ as function of Higgs mass

Channel:	eτ	mτ	eμ
Expected:	427.3±55	576.3±61.5	43.5±5.3
Data:	484	575	41

Combination with $\phi \rightarrow b\bar{b}$ limits.





Summary

- Recent results for a wide variety of BSM physics were presented
  - Many are world best limits
  - Others are approaching previous limits from LEP
- First results with data taken last year
  - With luminosities of 760 pb^{-1} to 1 fb^{-1}
- Many more results with ~1 fb^{-1} are in the pipeline
  - Stay tuned for Moriond QCD and spring conferences