Searches in Photon and Jet States

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For the CDF and DØ Collaborations

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Rencontres de Moriond
Electroweak Interactions and Unified Theories
La Thuile

Introduction

- New physics may appear at colliders as events with high transverse momentum (p_T) objects, including photons or quark/gluon jets
- Two complementary search approaches

  Signature based: - Combinations of final state particles
  - Sometimes "inclusive" (e.g. $\gamma\gamma$+X)
  - Model-independent

  Model based: - Optimized for sensitivity to a particular model
- Specific topics

  SUSY: Gauge Mediated SUSY Breaking, split-SUSY, minimal-Supergravity

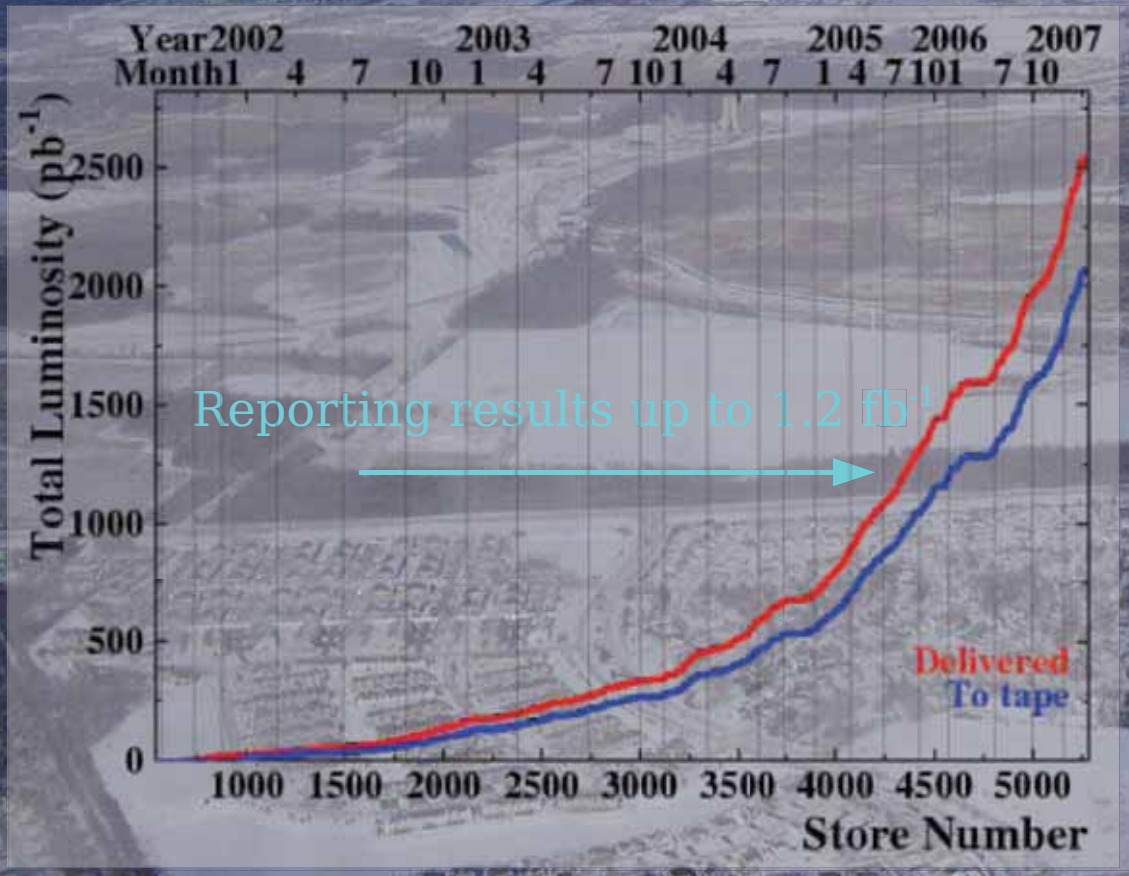
  Leptoquarks: 2nd and 3rd generation leptoquarks

  4th generation: b'

  Large extra dimensions: Gravitons

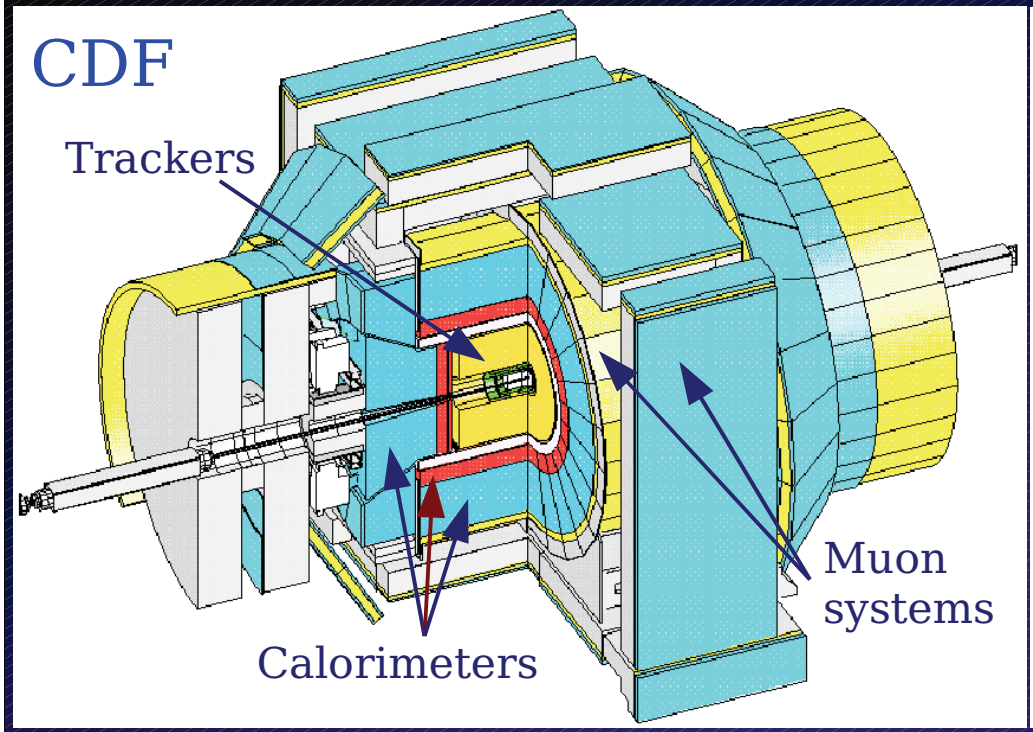
Tevatron

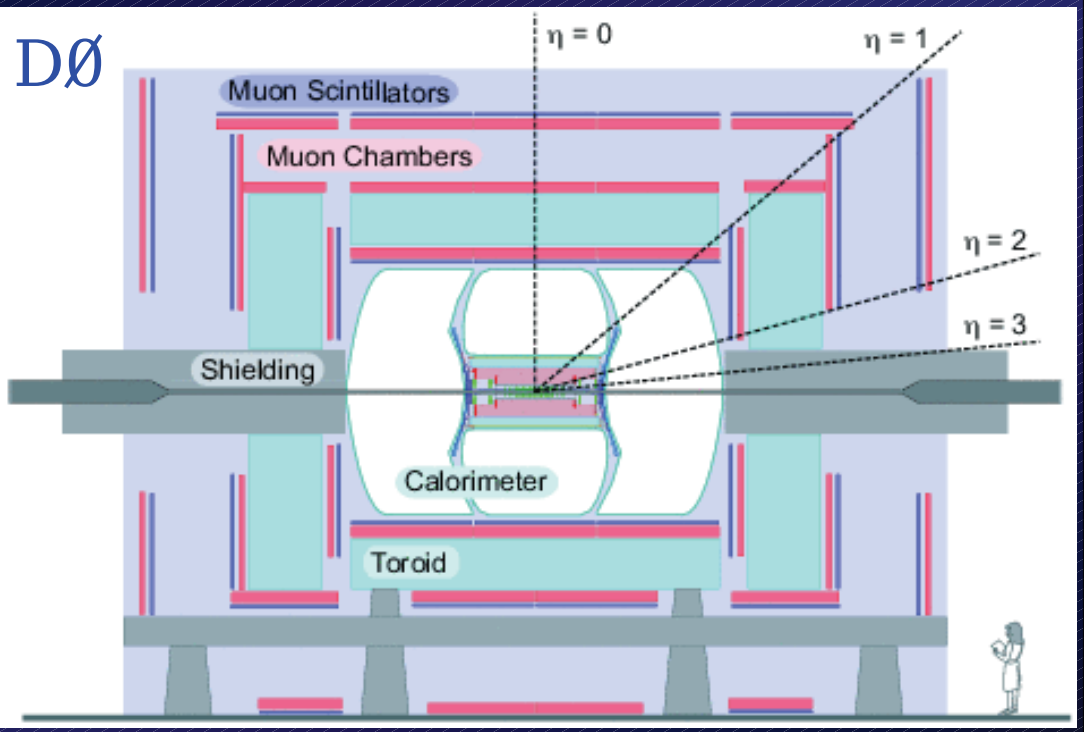
- $p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV
- Record initial instantaneous luminosity = 292×10^{30} $s^{-1}cm^{-2}$
- Peak antiproton accumulation rate = 22.6 mA/hr



- Tevatron has delivered >2.5 fb^{-1}
- Both CDF and DØ have collected >2 fb^{-1}

CDF and DØ Detectors





- Tracking, calorimetry (electromagnetic & hadronic), muon systems
- Identify and reconstruct: e, μ , τ, hadrons, photons, jets
- Calculate missing transverse energy ($\not\!\!E_T$)

photon: shower in EM calorimeter with no associated track

jet: cluster of energy deposited in EM+hadronic calorimeters

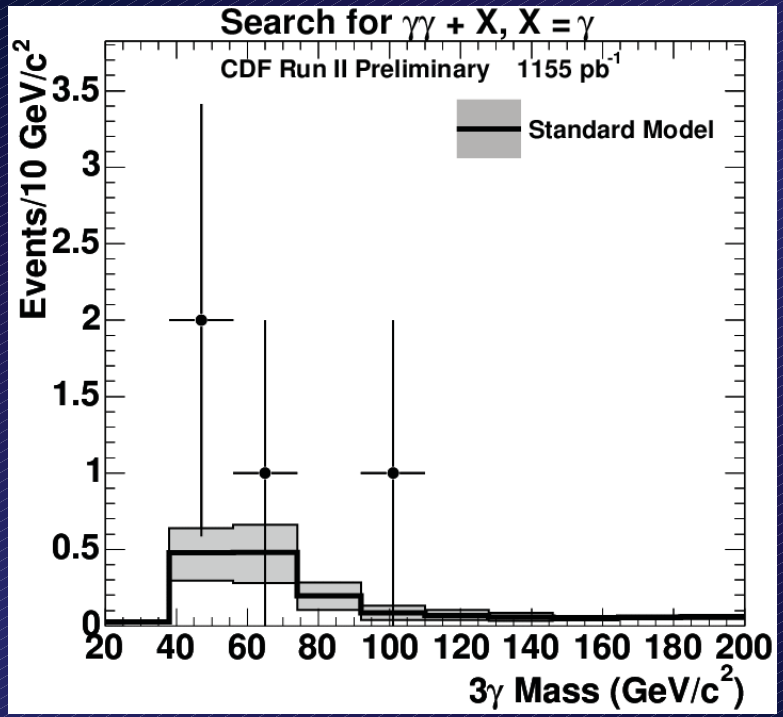
Searches in $\gamma\gamma$+ {e, μ, γ, $\not\!\!E_T$}

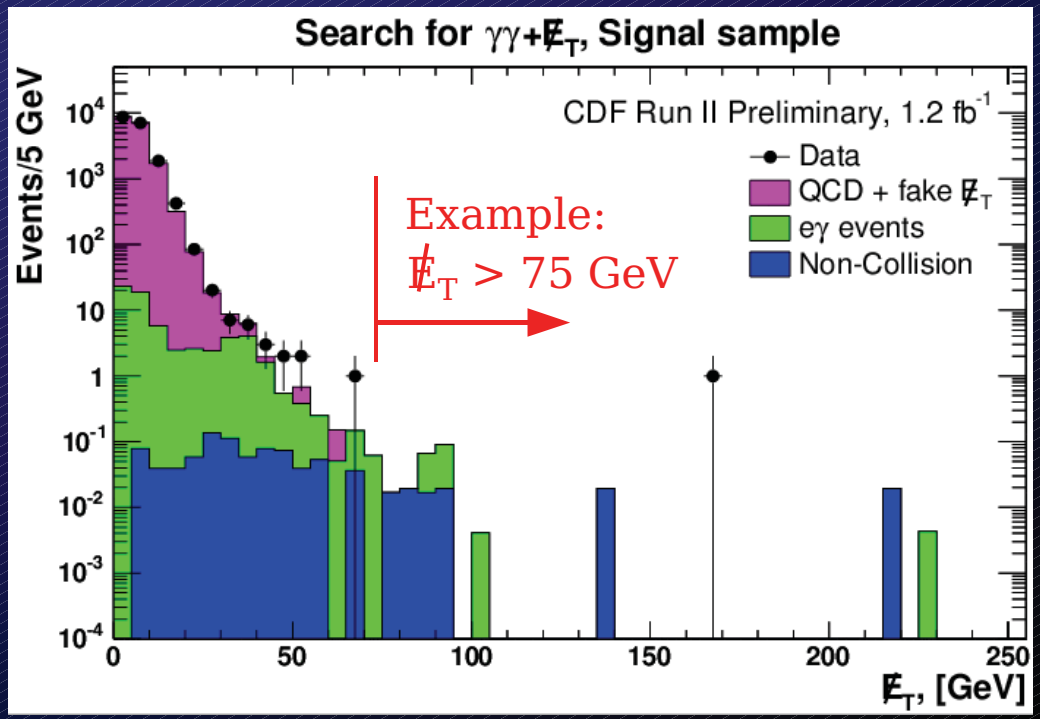
Using 1.0-1.2 fb^{-1}

- Motivated by anomalous Run I ee+$\gamma\gamma$+$\not\!\!E_T$ event
- Signature based
- $\chi_2^0 \to \gamma\chi_1^0$, $X^* X^* \to \gamma X\ \gamma X$, b'b', fermiphobic Higgs, ...

	$\gamma\gamma\gamma$	$\gamma\gamma\not\!\!E_T$	$\gamma\gamma$e	$\gamma\gamma\mu$
SM	2.2	0.24	6.8	0.7
Data	4	1	3	0

- Consistent with standard model (SM)

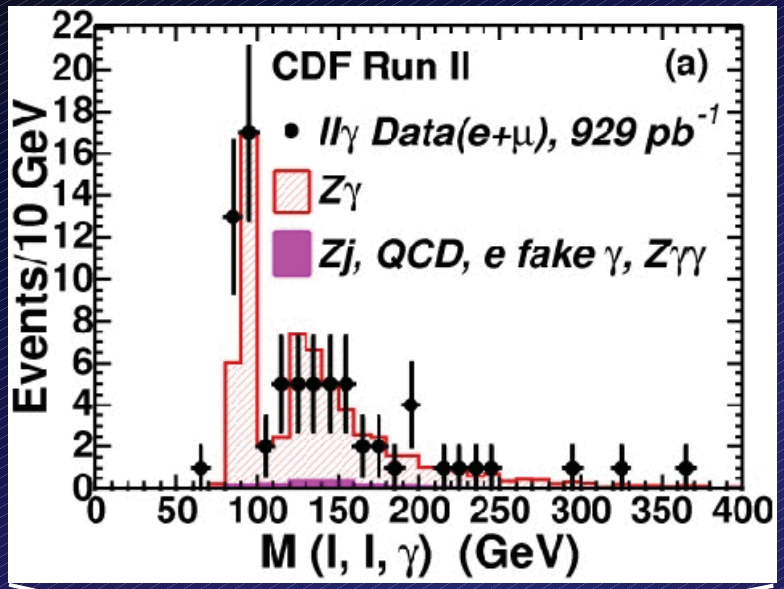


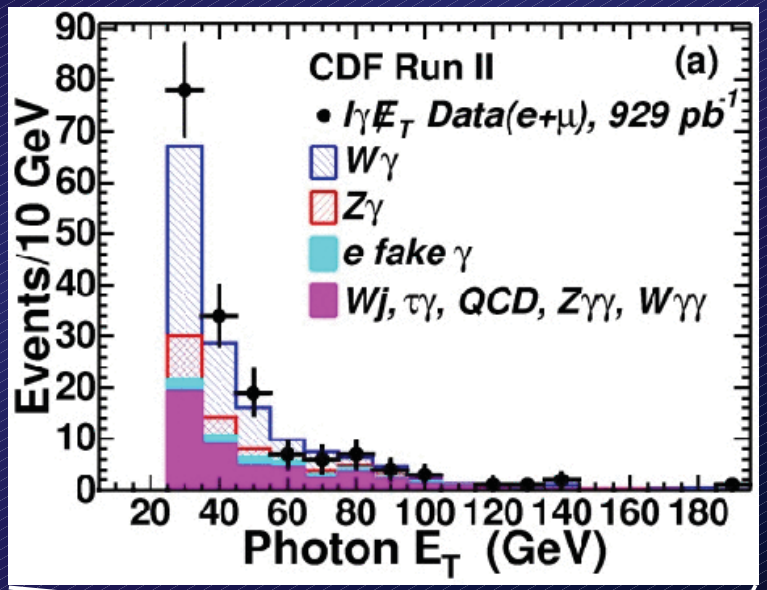


Searches in lγ + {l, γ, $\not\!\!E_T$}

0.9 fb^{-1}

- CDF Run I found 2.7σ excess in lγ$\not\!\!E_T$ (expected 7.6 ± 0.7, observed 16)
- Signature based: $p_T(\gamma)$ and p_T(e or μ) > 25 GeV/c





	eeγ	μμγ	eμγ + X	eγγ	μγγ	eγ$\not\!\!E_T$	μγ$\not\!\!E_T$
SM (dominant)	39 ± 5 (Zγ)	26 ± 3 (Zγ)	1.0 ± 0.3 (Zγ)	0.5 ± 0.1 (e fakes γ)	0.1 ± 0.1 (j fakes γ)	95 ± 8 (Wγ)	56 ± 7 (Wγ)
Data	53	21	0	0	0	96	67

- Consistent with standard model

GMSB SUSY in $\gamma\gamma + \not\!\!E_T$

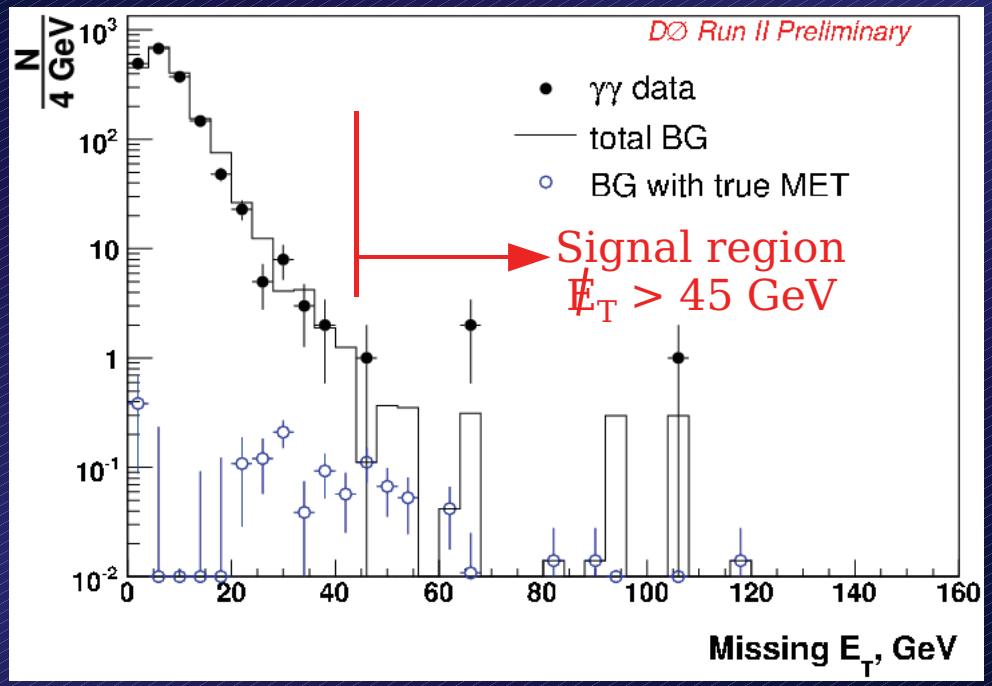
760 pb^{-1}

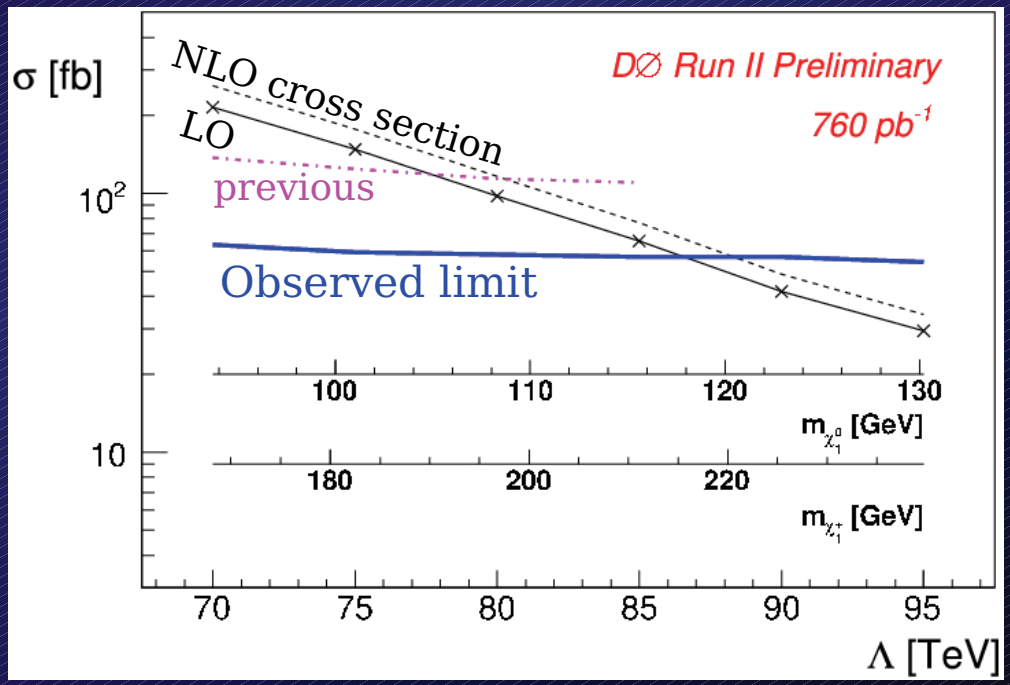
- 2 neutralinos from SUSY decays $\rightarrow \gamma\tilde{G}\,\gamma\tilde{G} \rightarrow$ 2 photons + $\not\!\!E_T$
- Λ = SUSY breaking scale parameter (other parameters are fixed)
- Neutralino lifetime assumed to be short (prompt photons)

Leading backgrounds are instrumental:

Without real $\not\!\!E_T$: QCD with photons or jets mis-identified as photon

With real $\not\!\!E_T$: $W \rightarrow e\nu + \gamma$ (or jet), e (and jet) mis-identified as photon





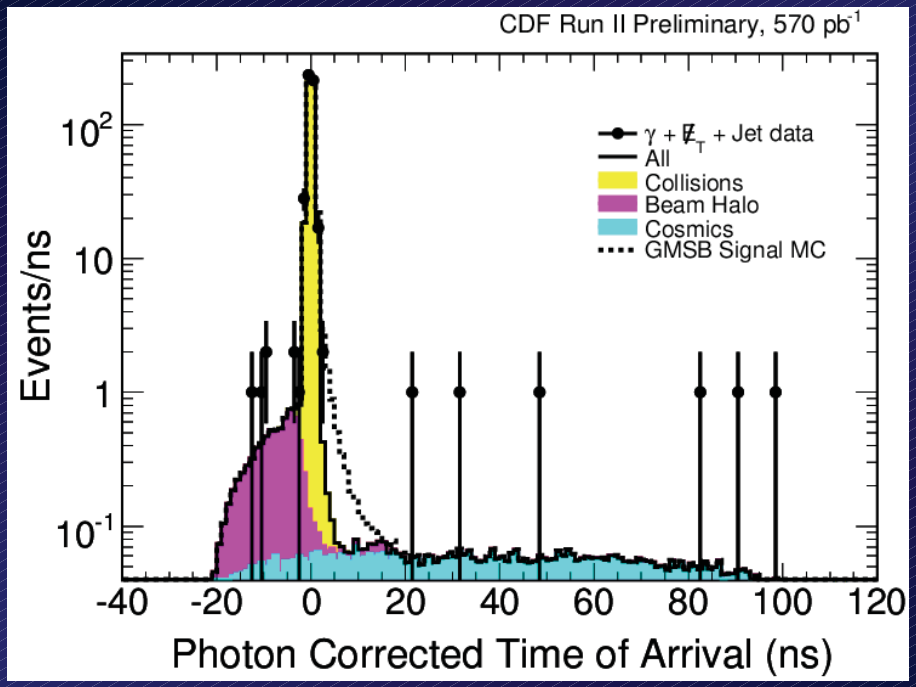
- Expect 2.1 ± 0.7, observe 4
- 95% C.L. limits:
  m(neutralino) > 120 GeV/c^2
  m(chargino) > 220 GeV/c^2

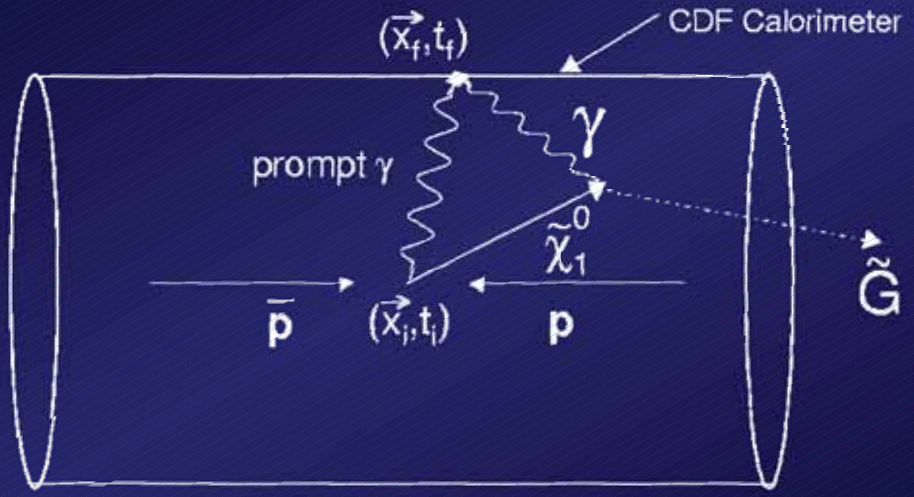
Delayed Photons

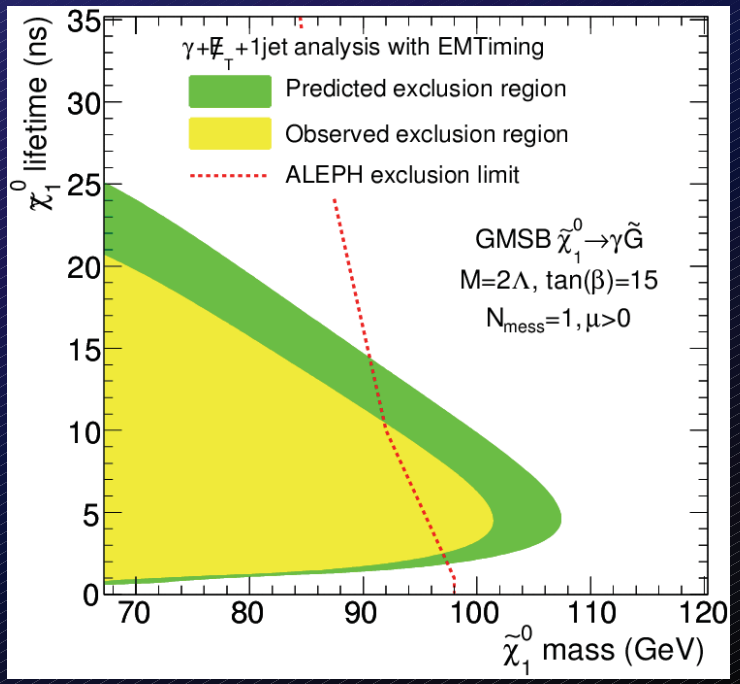
Using 570 pb^{-1}

- Heavy, neutral, long-lived particles decaying to photons (e.g. GMSB: Neutralino$\rightarrow \gamma\tilde{G}$)
- Use γ+$\not\!\!E_T$+jet channel
- EM Calorimeter timing system

  Signal region: 2 < t < 10 ns







- Expect 1.3 ± 0.7, observe 2

Stopped Gluinos

Using 350 pb^{-1}

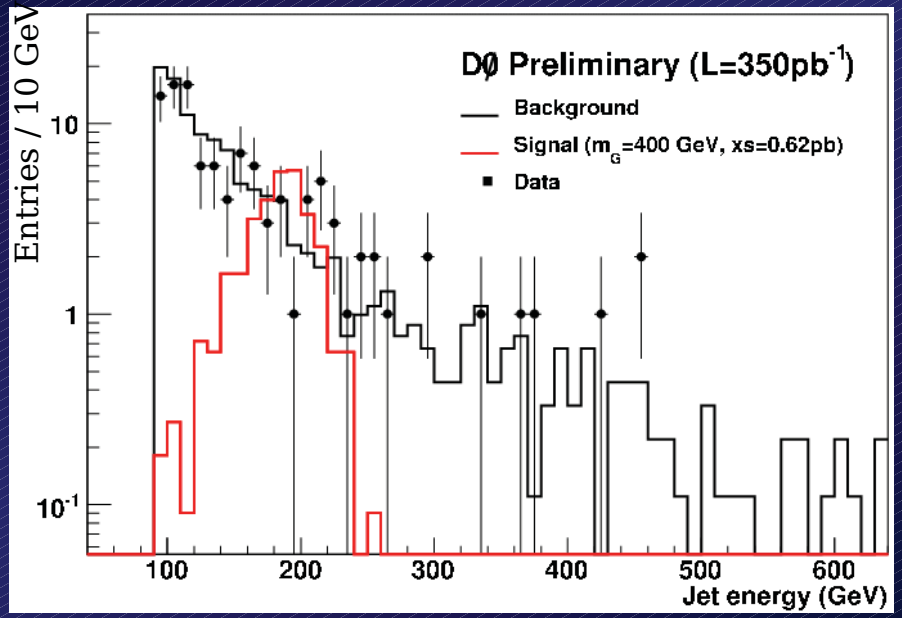
- Long lived gluinos
  - Predicted by split-SUSY
  - Have time to hadronize, and stop in calorimeter
  - Decay during a later beam-crossing
- Decay: "stopped gluino" $\rightarrow g\chi_1^0$
  - Signature: jet + $\not\!\!E_T$
  - Require one jet with E > 90 GeV in otherwise empty event
- Signal efficiency = 5-10%

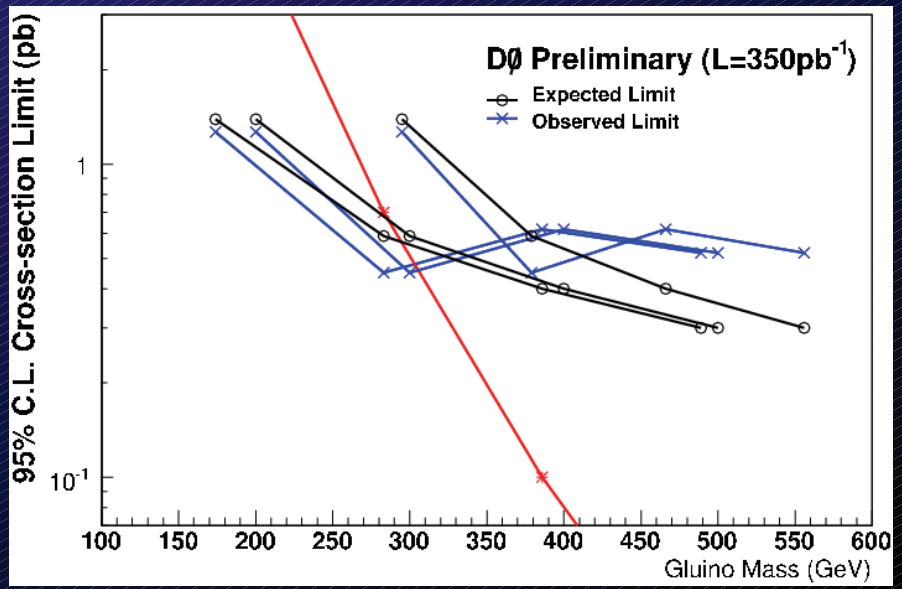
Background from cosmic muons:

Jets are narrow for muons (vs. wide for signal)
Require wide showers, with no muon

Beam-induced background successfully removed

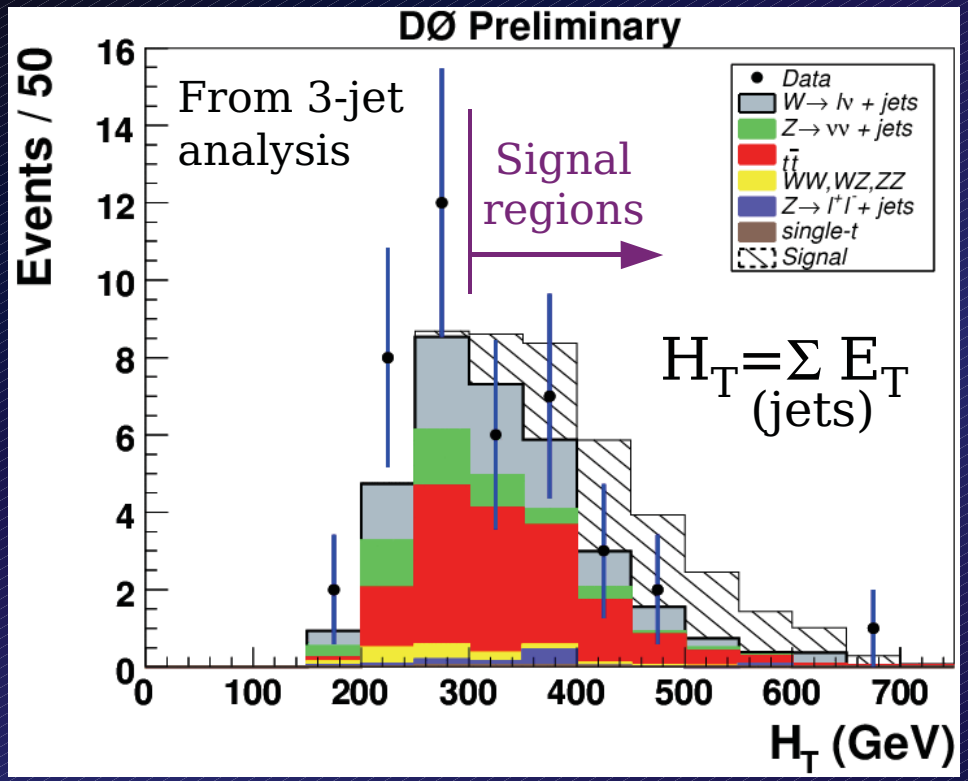
- Set limits for signal vs. jet energy, translate to gluino mass limits
- Exclude m(gluino) < ~270 GeV/c^2 for example with m(χ_1^0) = 50 GeV/c^2

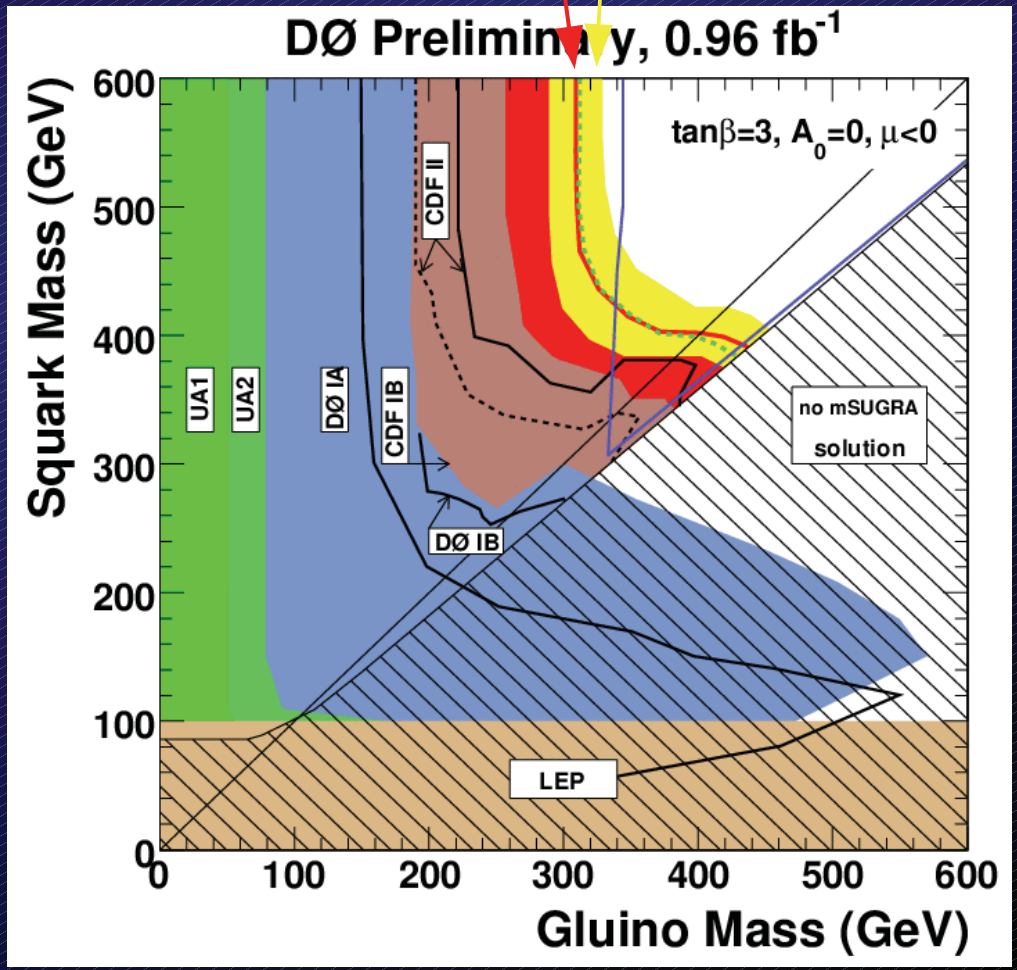




Squarks and Gluinos Using 960 pb^{-1}

- Probe mSUGRA scenarios: pair production ($\tilde{q}\tilde{q}$, $\tilde{q}\tilde{g}$, $\tilde{g}\tilde{g}$)
- Decays ($\tilde{q}\rightarrow q\chi_1^0$, $\tilde{g}\rightarrow q\tilde{q}\chi_1^0$) give 2,3,4 jets + $\not\!\!E_T$
- 3 analyses combined





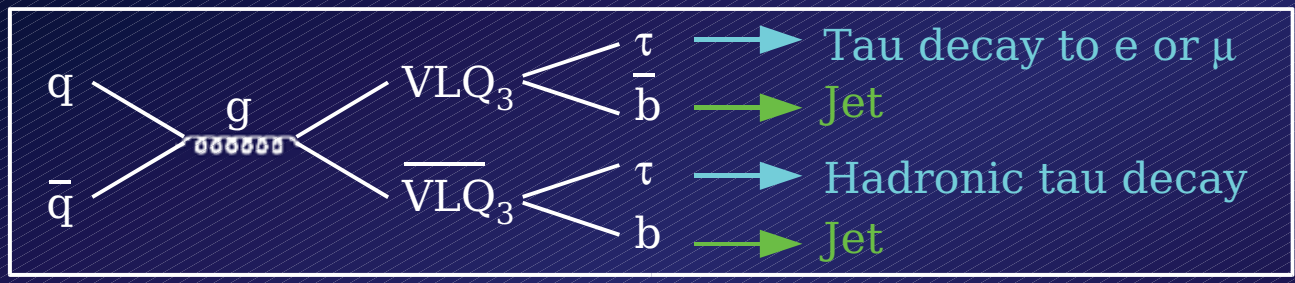
- m($\tilde{q}$) > 375, m($\tilde{g}$) > 289 GeV
- Details in Young Scientist Forum talk by Samuel Calvet

3rd Gen. Vector Leptoquarks 322 pb^{-1}

- Link between quark and lepton sectors?

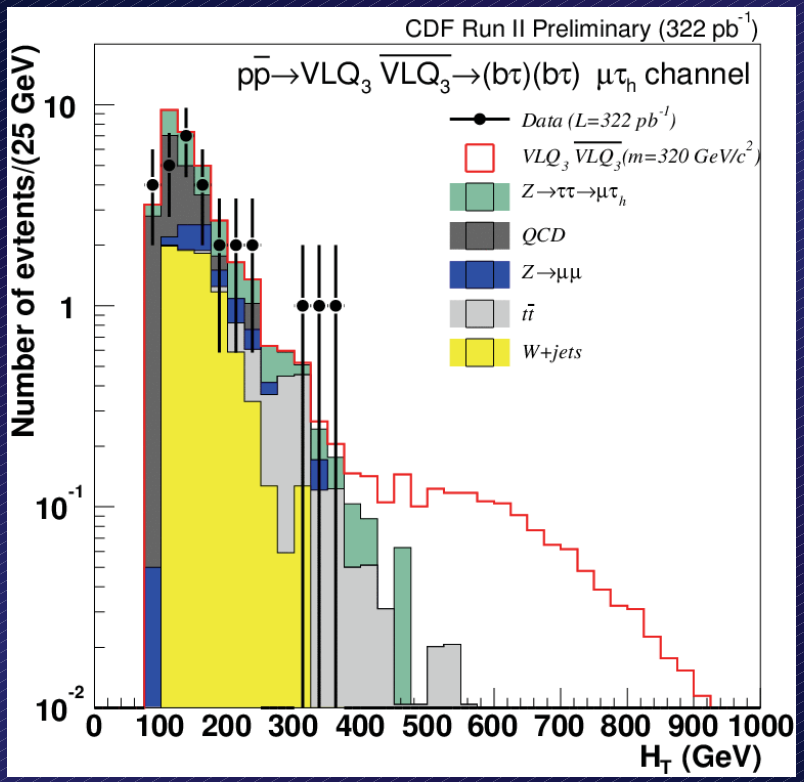
SU(5) GUT? Superstrings?
SU(4) Pati-Salam? Technicolor?

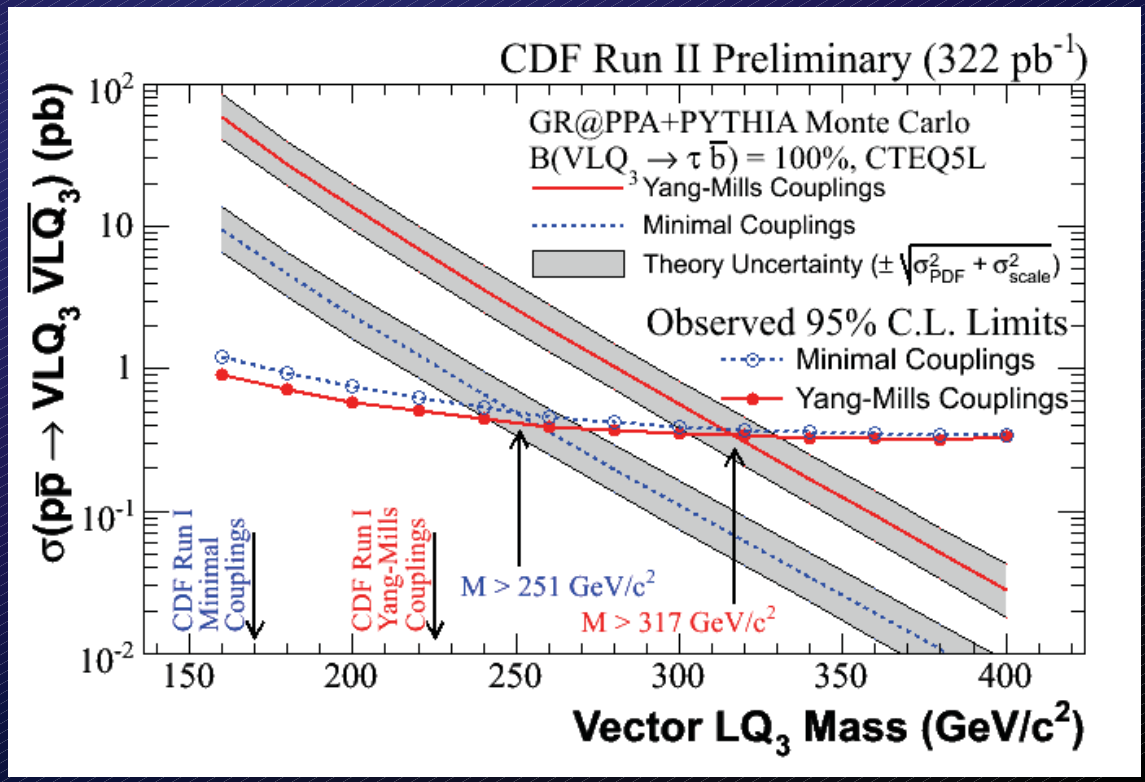
- Vector LQ_3:
  - Spin=1
  - Fractional charge (-2/3)
  - Carry lepton and baryon quantum numbers



$H_T = \Sigma E_T(\text{jets}) + P_T(\mu) + P_T(\tau) + \not\!\!E_T$

- $m(VLQ_3) > 317$ GeV/c^2 at 95% C.L.





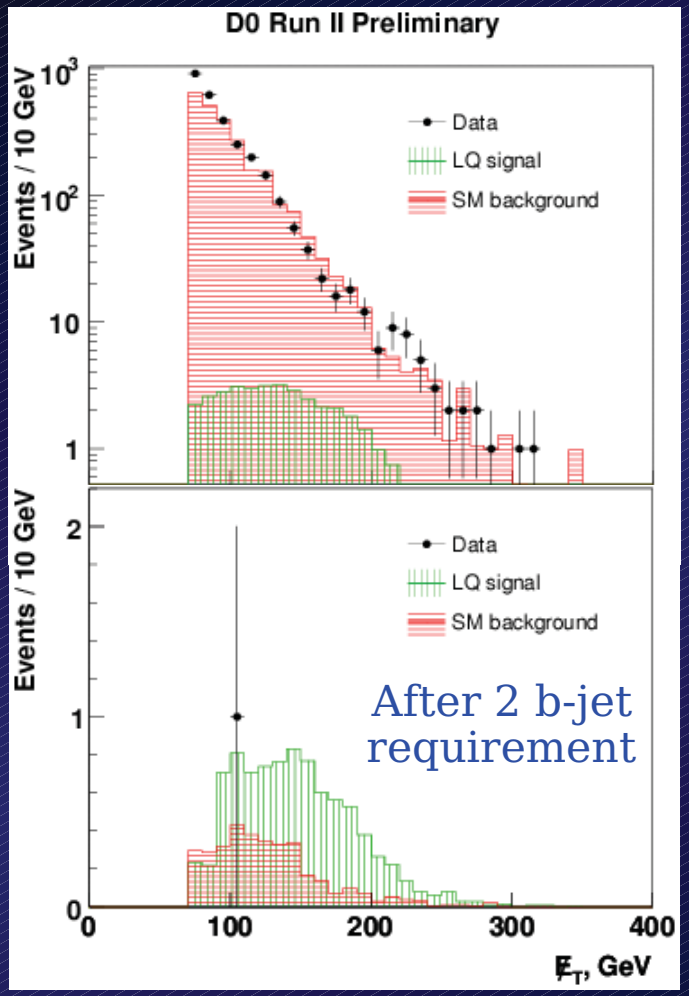
3rd Gen. Scalar Leptoquarks

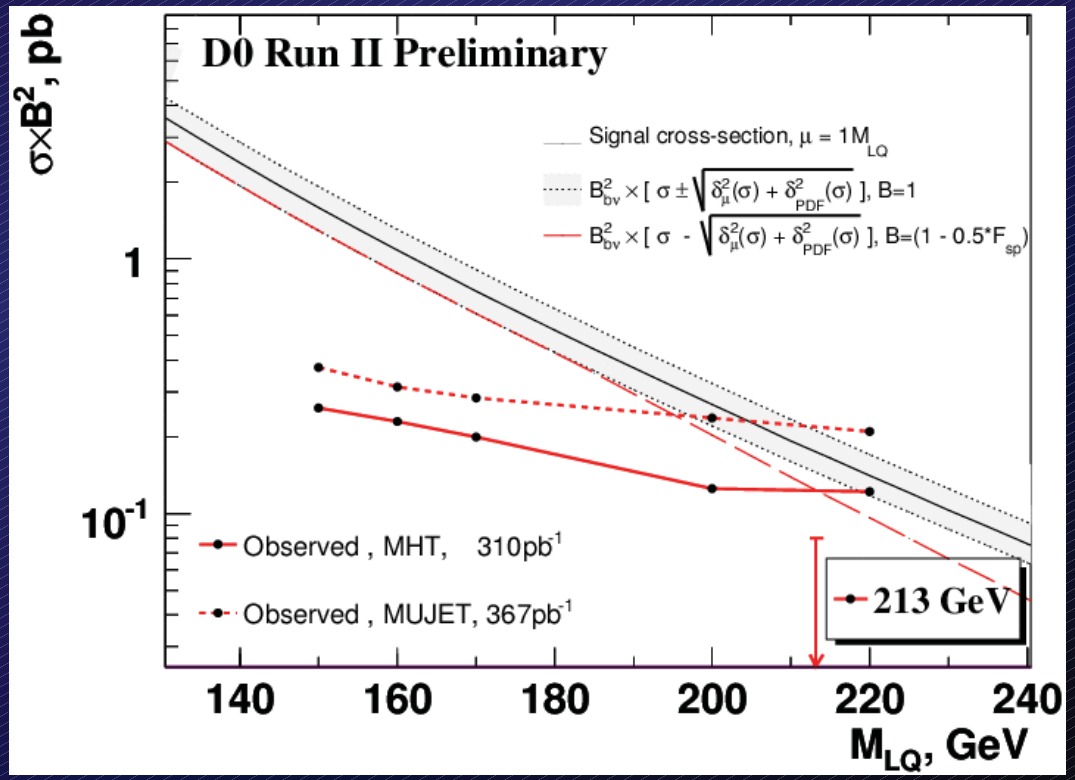
310 pb^{-1}

- Scalar (spin=0) LQ, pair produced
- Search for $SLQ_3 \rightarrow \nu_\tau b$, charge 1/3
- Channel: $\nu_\tau \bar{\nu}_\tau b\bar{b}$, signature: $\not\!\!E_T$ + 2 b-jets

Leading backgrounds:
W + jets, Z + jets, top

Leading systematics:
Jet energy scale, b-tag eff., SM cross sections



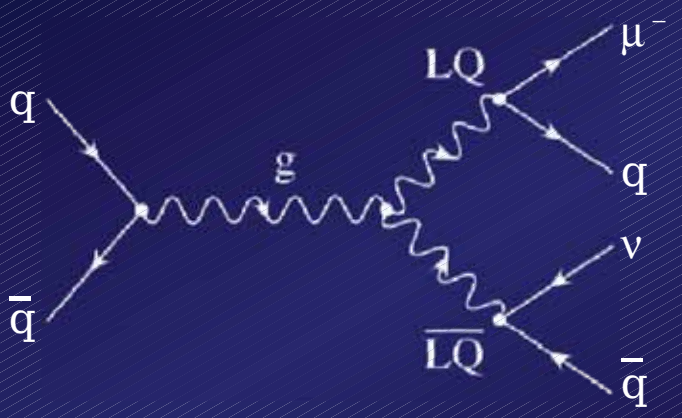


- $m(SLQ_3) > 213$ GeV/c^2 at 95% C.L.
  (> 219 if no $SLQ_3 \rightarrow \tau t$)

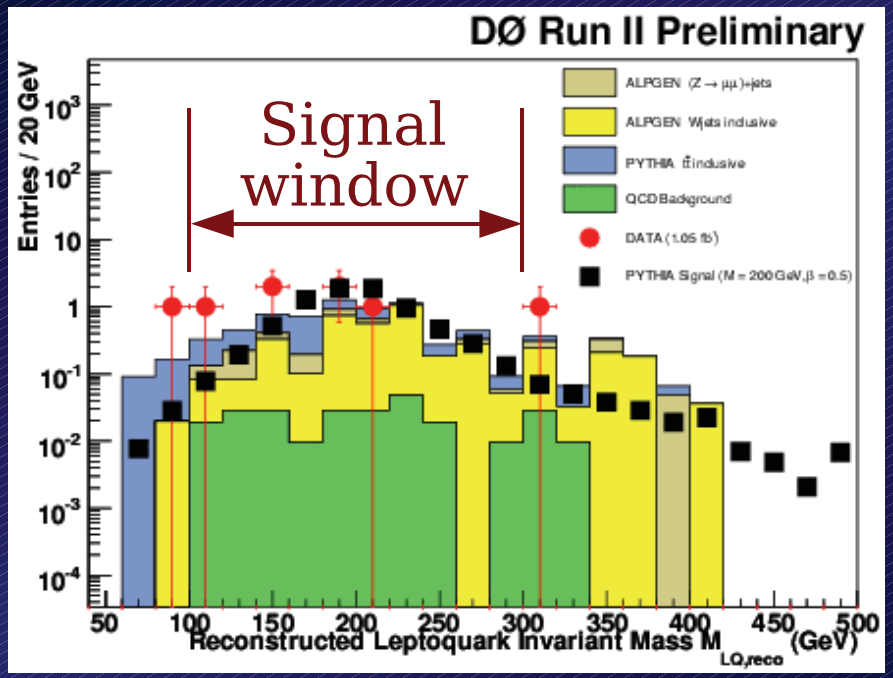
2rd Gen. Scalar Leptoquarks

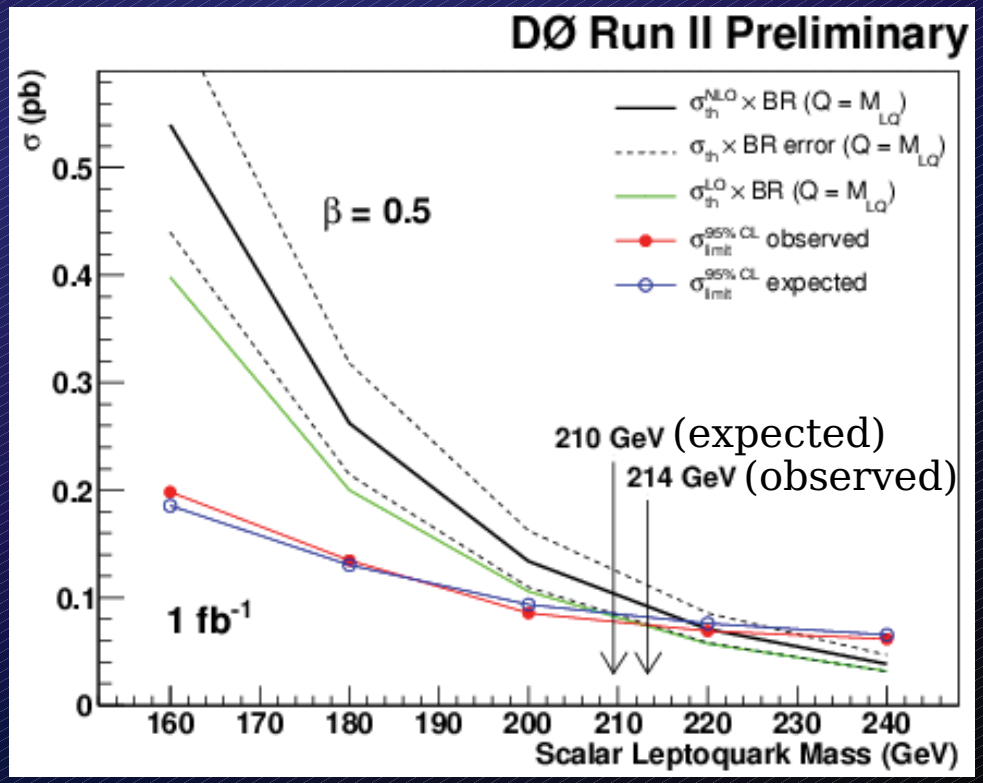
1 fb^{-1}

- Assume $\beta \equiv Br(SLQ_2 \rightarrow \mu q) = 0.5$
- Search for SLQ_2 $SLQ_2 \rightarrow \mu q\, \nu q$
- Signature: μ + 2 jets + $\not\!\!E_T$



- Reduce W($\rightarrow \mu\nu$)+jets and QCD:
  $M_T(\mu\nu) > 160$ GeV/c^2
- Require reconstructed SLQ_2 mass (μ ,jet) to be within 100 GeV/c^2 of expected mass





- Expect 6.4 ± 1.1, observe 6
- m(SLQ_2) > 214 GeV/c^2 at 95% C.L.

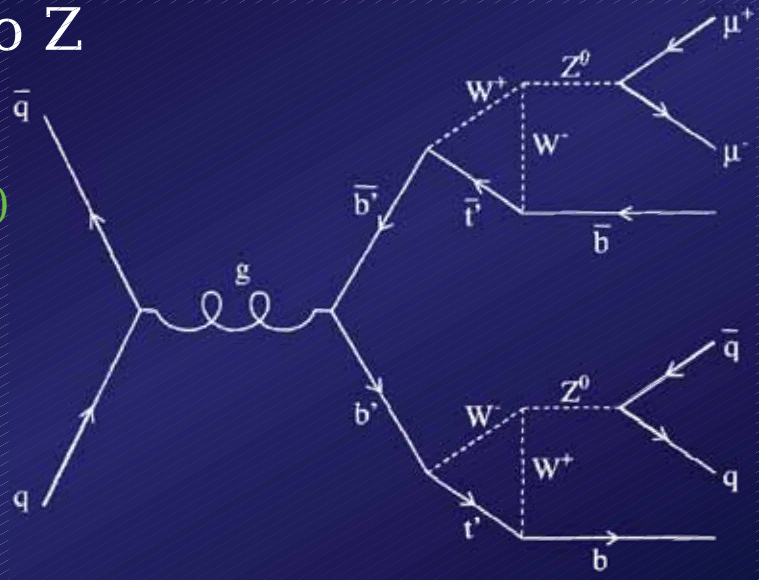
Search for b'

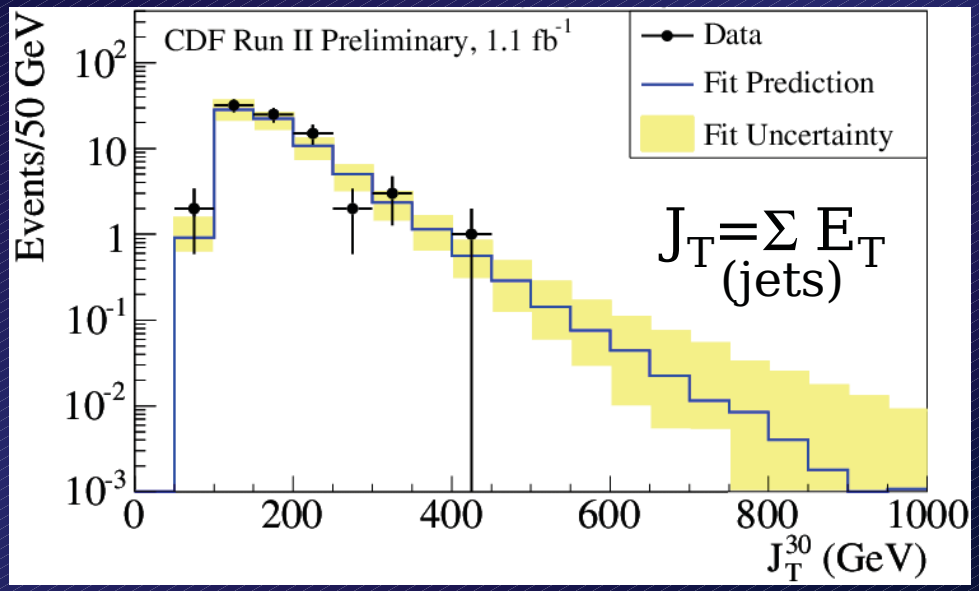
1.1 fb^{-1}

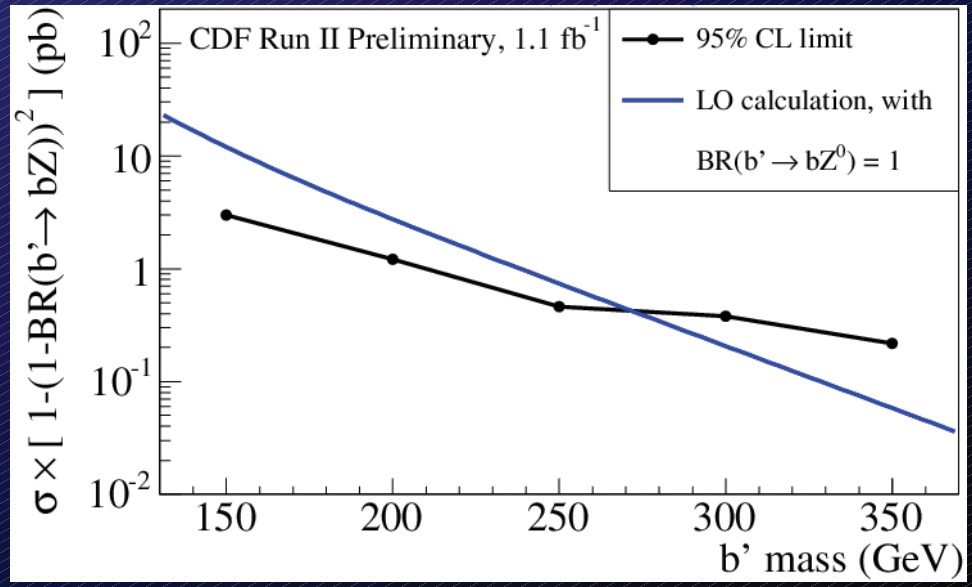
- Search for new particles that couple to Z
- Signature: b' b'$\rightarrow$ bZ bZ$\rightarrow$ bll bqq
  - Reconstruct Z $\rightarrow$ ee or Z $\rightarrow\mu\mu$ (lepton p_T>20 GeV/c)
  - Require ≥3 jets, E_T>30 GeV
  - Require $J_T = \Sigma E_T$(jets) > m(b')

Leading background:

Z + jets (<3 jets region used to predict contribution in ≥3 jets region)







- m(b') > 270 GeV/c^2 at 95% C.L.

Large Extra Dimensions

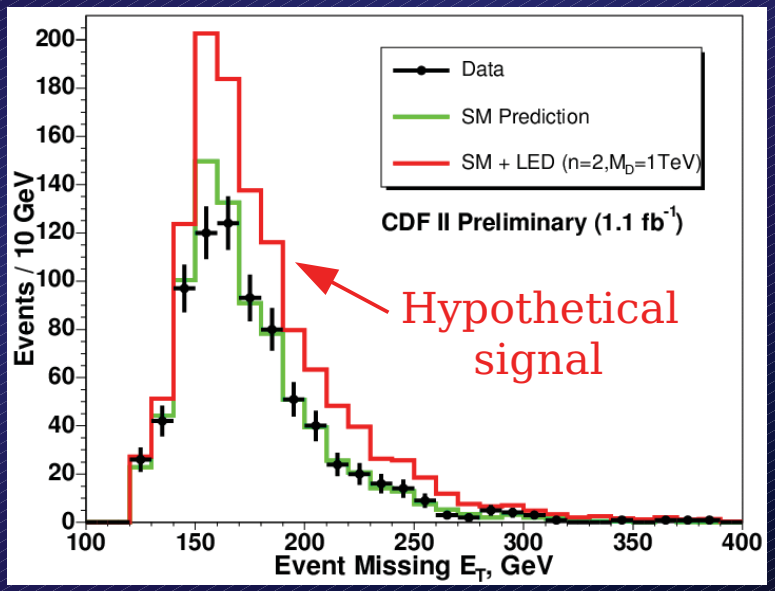
1.1 fb^{-1}

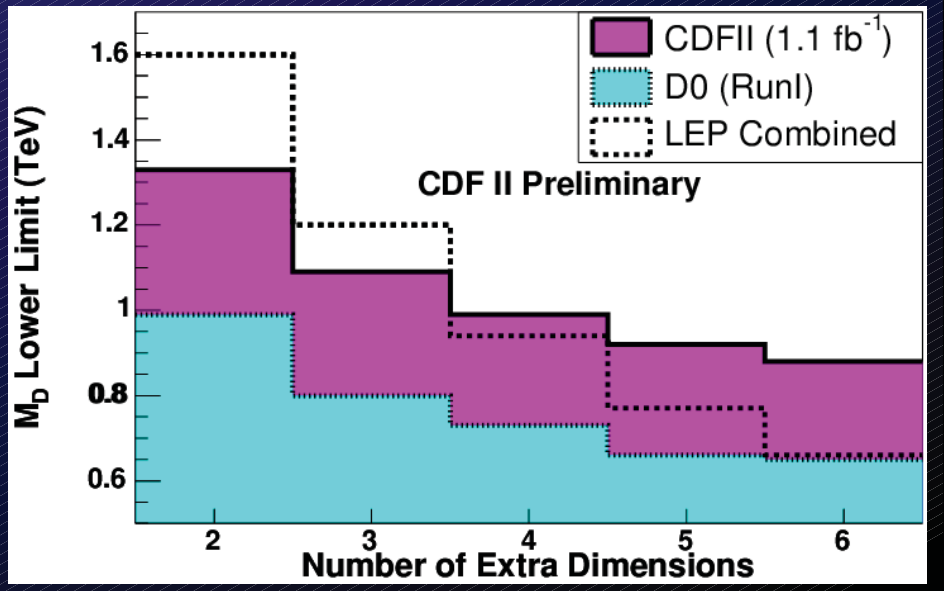
- Gravitons populating 4+n dim. bulk
  (Arkani-Hamed, Dimopoulos, Dvali)
- Direct production:
  $qq \rightarrow gG$, $qg \rightarrow qG$, $gg \rightarrow gG$
- Energetic jet (E_T >150) + $\not\!\!E_T$ (> 120)
- Lower limit on effective Plank scale (M_D)
  $M_{Planck}^{\ 2} \sim R^n M_D^{\ 2+n}$
- Expect 819 ± 71, observe 779

95% C.L. limits

n	M_D (TeV)	R (mm)
2	>1.33	<0.27
3	>1.09	<3.1 × 10^{-6}
4	>0.99	<9.9 × 10^{-9}
5	>0.92	<3.2 × 10^{-10}
6	>0.88	<3.1 × 10^{-11}

Backgrounds:
Z→ νν+jets
W→ lν+jets
QCD





Conclusions

- Searches for new physics at DØ and CDF using photons and jets are constraining a large number of models
- Signature based searches are looking for deviations from Standard Model
- No new physics to report based on current analyses of ≤ 1.2 fb^{-1}
  - Additional analyses and larger data sets are on their way
- Majority of the data from Tevatron Run II remains to be taken!
  - Expect 4-8 fb^{-1} by 2009 ($\times 2$ experiments)