Searches for New Physics at the Tevatron in Photon and Jet Final States

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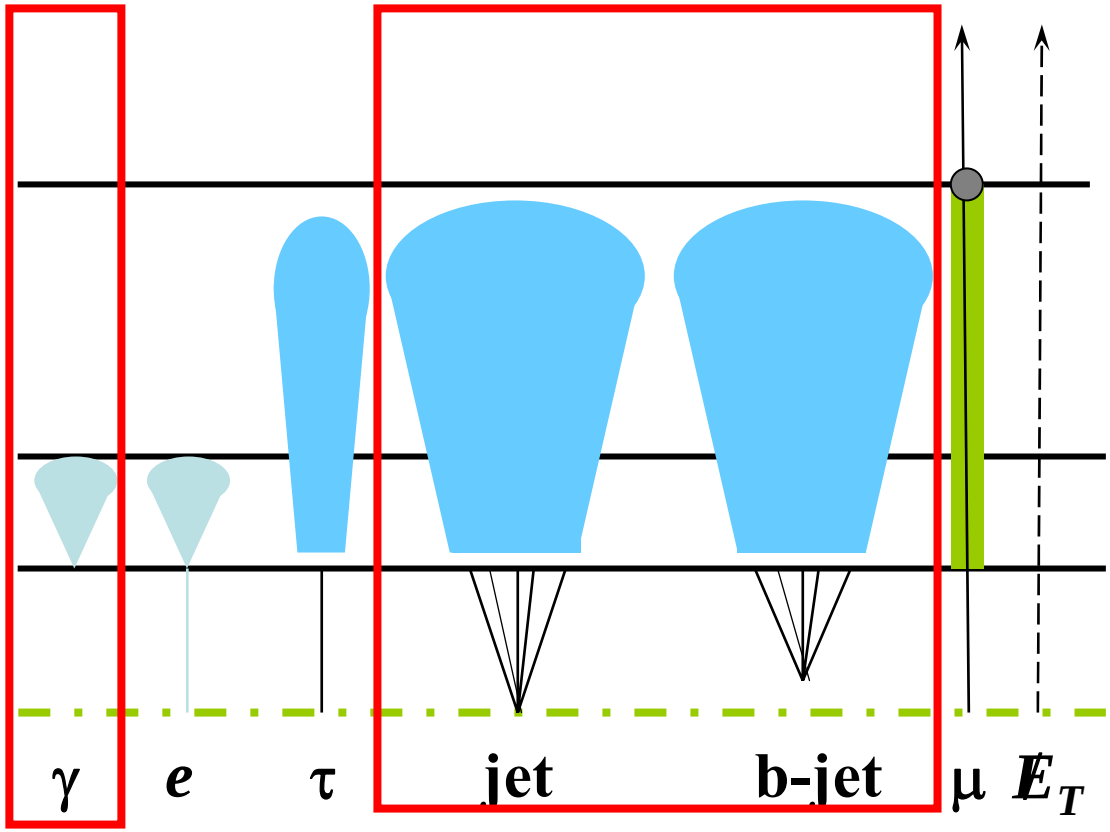
Rencontres de Moriond EW 2009

The Magnificent Seven Objects



Muon Chamber

Hadronic Layers

Calorimeter

EM Layers

Tracking system

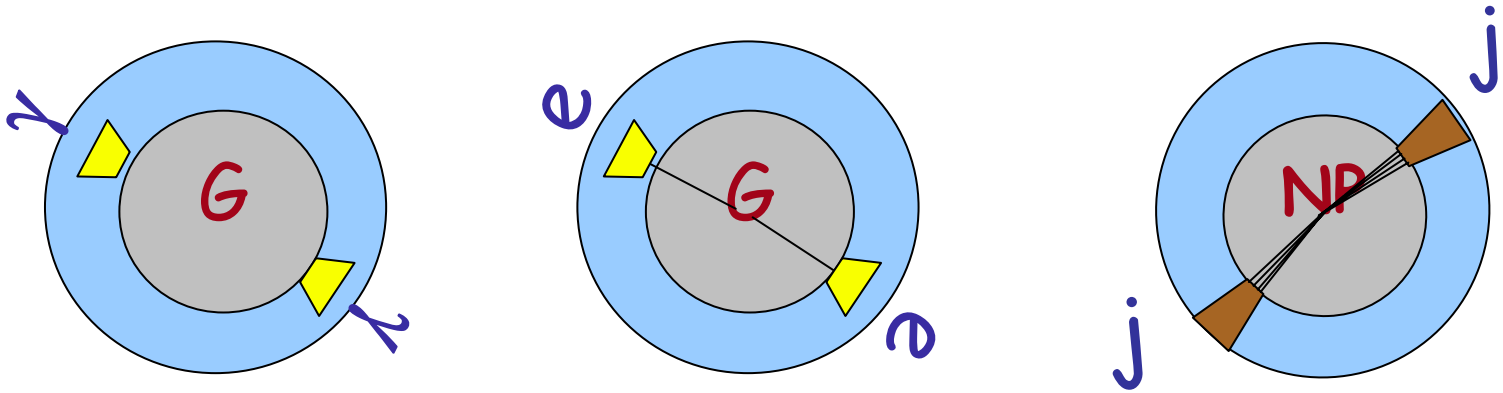
Beam Axis

This talk will focus on the searches in “photon + X” or “jet/b-jet + X” final states.

Analyses Breakdown

- 2 Electrons/Photons or 2 Jets
  - Extra Dimension
  - Quark Compositeness
- Jets + Leptons
  - Leptoquarks
  - RS Graviton, W', Z'
- Photons or b-Jets + Missing E_T
  - Large Extra Dimension
  - Supersymmetry
- Photons + Jets + X (not included in this talk)
  - Signature-based search

What Could We Do with Two Objects?



1. Invariant Mass
2. Angular Distributions

$\sigma_{\text{modified}} = f_{SM} + f_{NP}$,

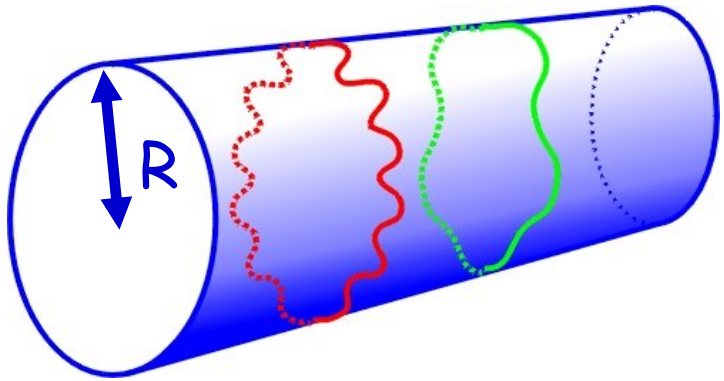
where for

Large Extra Dimension $f_{NP} = h(F/M_S^4)$

Quark Compositeness $f_{NP} = h(\lambda/\Lambda^2)$

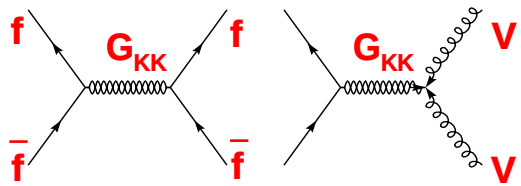
TeV^{-1} Extra Dimension $f_{NP} = h(1/M_c^2)$

Large Extra Dimension (LED) 101



- Aim to solve hierarchy between EW (1 TeV) and Plank scales (10^{16} TeV)
- n_d extra large spatial dimensions which are compactified on a scale R
- SM fields confined to 4-dim, graviton propagates in the (4+ n_d) bulk
- Mass splitting small enough to integrate all KK modes (meV-MeV)

Virtual Graviton Exchange



$$\sigma_{\text{modified}} = f_{SM} + f_{NP},$$

$$\text{where } f_{NP} = h(F/M_s^4)$$

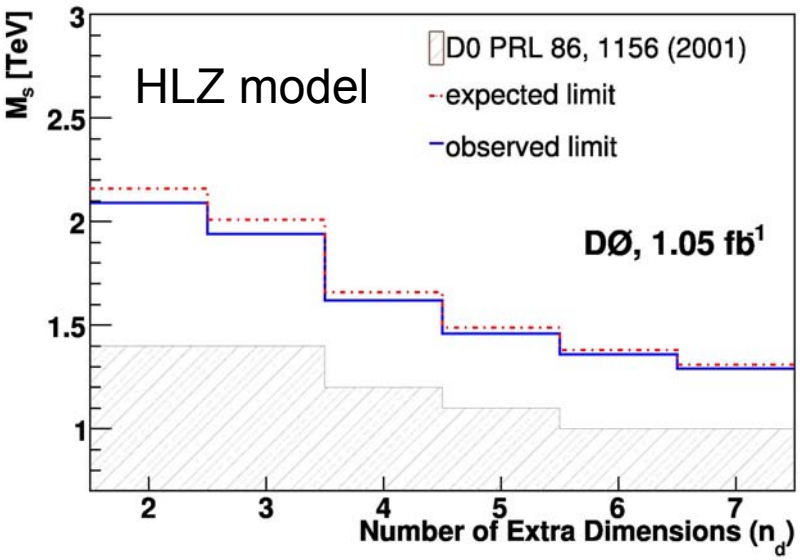
M_s: theory cutoff

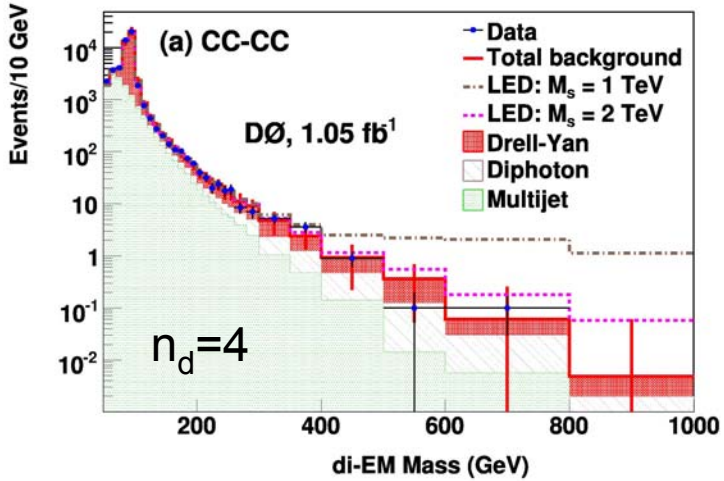
(~ fundamental Plank scale M_D ~ TeV)

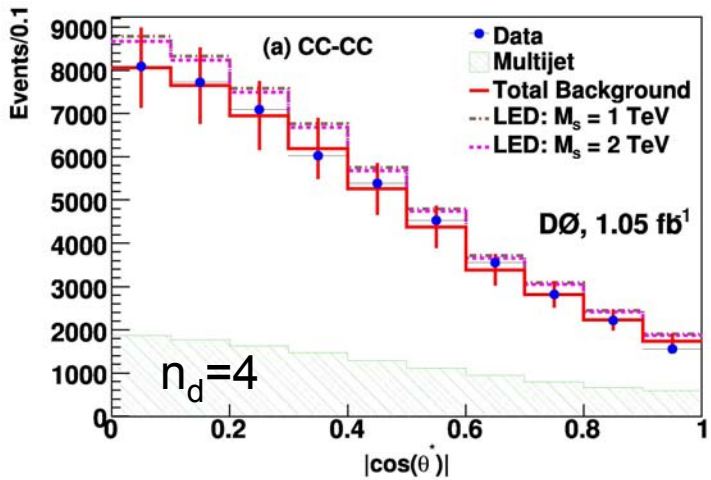
LED in ee, γγ

1.1/fb

- Sensitive to theory cutoff M_s
- Look for deviations in the 2D di-EM mass and $|\cos\theta^*|$ distributions







GRW: $M_s > 1.62$ TeV

HLZ: $M_s > 2.09$ (1.29) TeV for n_d=2 (7)

PRL 102, 051601 (2009)

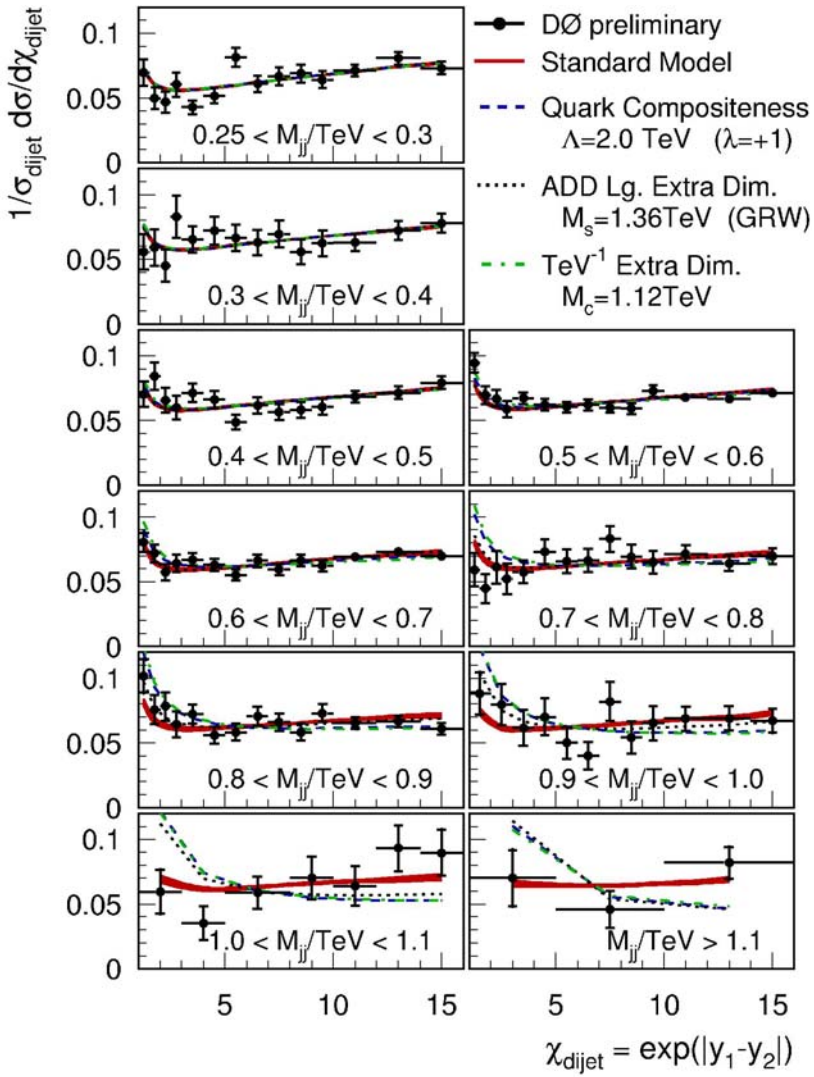
New Physics in dijet Events

0.7/fb

- Shape of the dijet angular distributions as a function of dijet mass
  - Sensitive to new physics at high mass
  - Insensitive to theoretical uncertainties (e.g. renormalization scale)

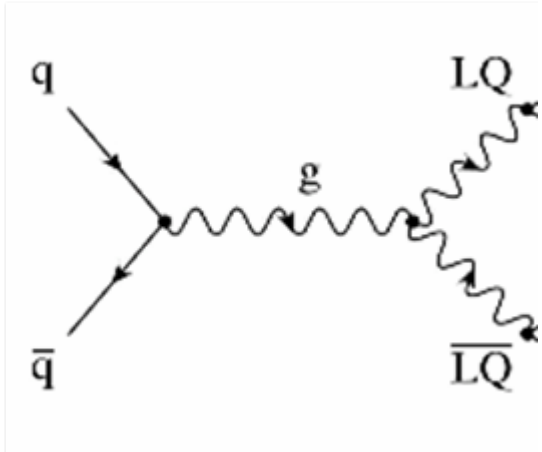
$$\chi_{dijet} = \exp(|y_1 - y_2|) \approx \frac{1+\cos\theta^*}{1-\cos\theta^*}$$

- Quark Compositeness ($q^* \rightarrow qg$)
  - Λ > 2.46 (2.42) TeV for λ = +1 (-1)
- ADD Large Extra Dimension
  - GRW: M_s > 1.54 TeV
- TeV^{-1} Extra Dimension
  - X-section modified due to the exchange of virtual KK excitations of SM Gauge Bosons
  - Compactification scale M_c > 1.35 TeV



Leptoquarks 101

- Couples directly to a quark and a lepton
- Predicted by
  - GUT
  - Extended Technicolor
  - R-parity violating SUSY
  - Compositeness
- Spin-0 or spin-1 (only scalars today)
- Charge Q = 1/3, 2/3, 4/3, 5/3
- Focus on pair production
  - qq or gg
  - Cross-section only depends on M_{LQ}
- Couples to a single generation
- Common variable to distinguish signal from background: S_T
  - Scalar sum p_T of 4 objects



$$\beta \equiv BR(LQ \to \ell j)$$

$$\sigma(\nu\nu jj) \propto (1-\beta)^2$$

$$\sigma(\ell\ell jj) \propto \beta^2$$

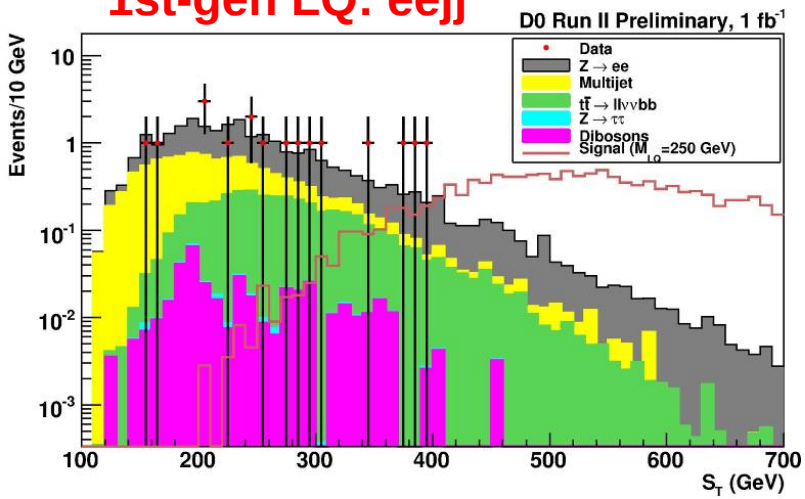
$$\sigma(\ell\nu jj) \propto 2\beta(1-\beta)$$

Leptoquarks in eejj, μμjj, μ$\not{E}_T$jj, ττbb

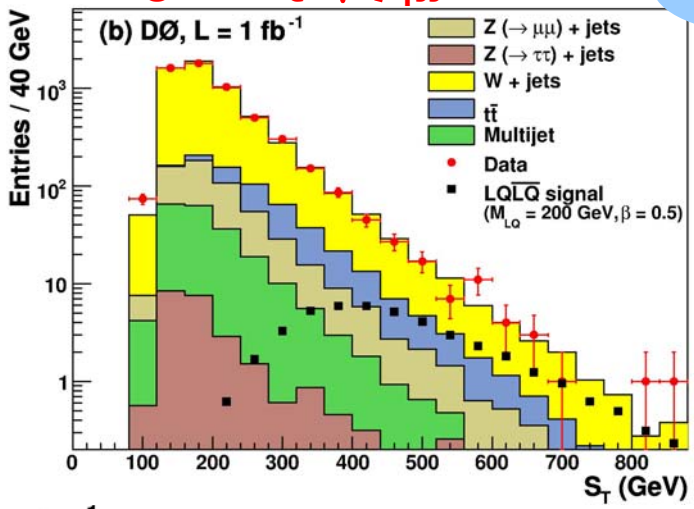
1.0/fb

1st-gen LQ: eejj

$M_{LQ}^{\beta=1} > 292\ \mathrm{GeV}/c^2$

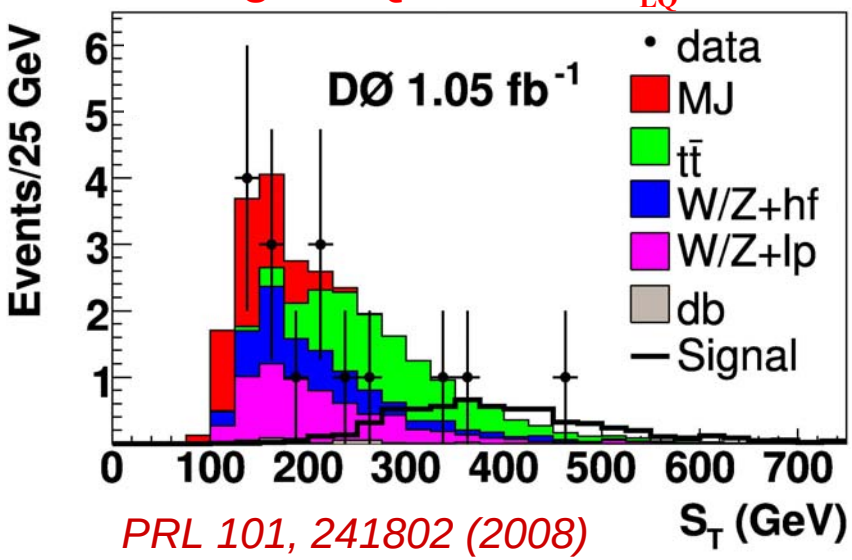


2nd-gen LQ: μ$\not{E}_T$jj

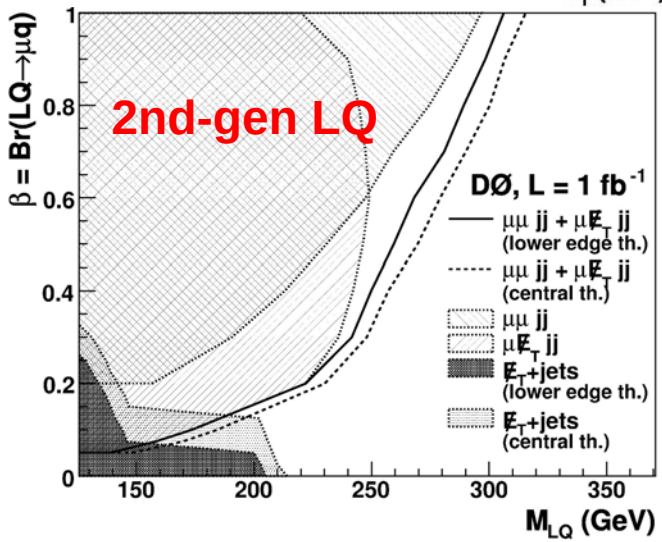


3rd-gen LQ: ττbb

$M_{LQ}^{\beta=1} > 210\ \mathrm{GeV}/c^2$



PRL 101, 241802 (2008)

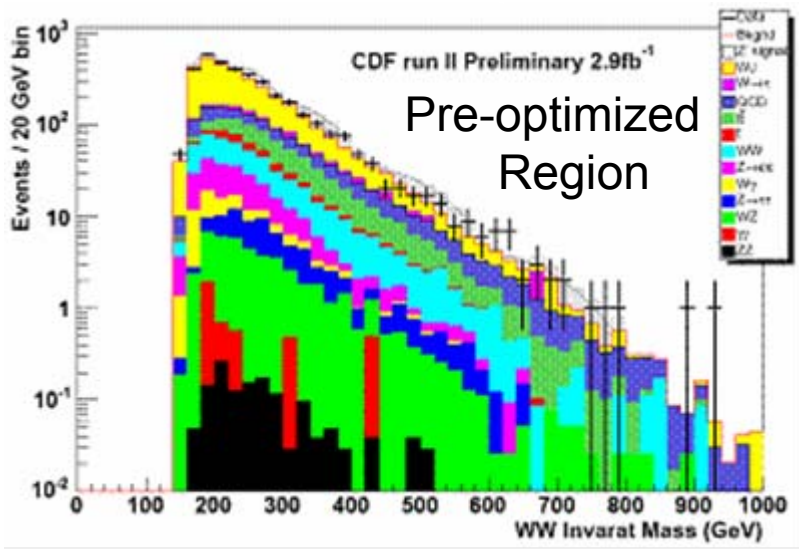


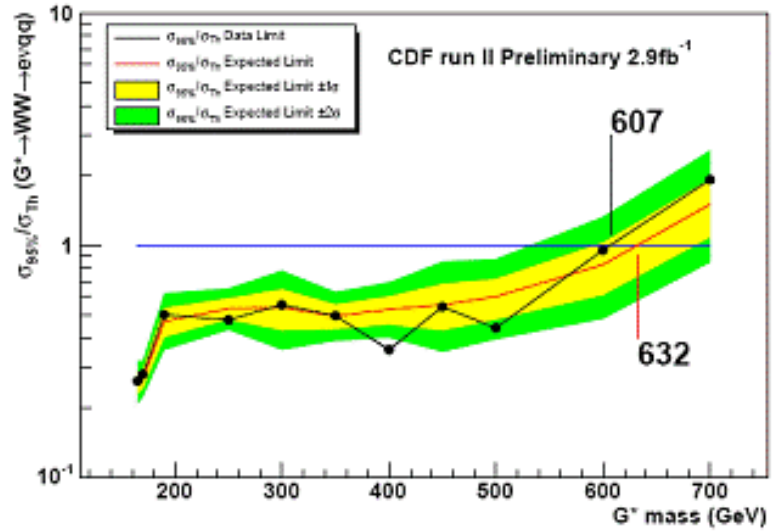
Phys. Lett. B 671, 224 (2009)

New Physics in WZ, WW (jj+l $\not\!\!E_T$)

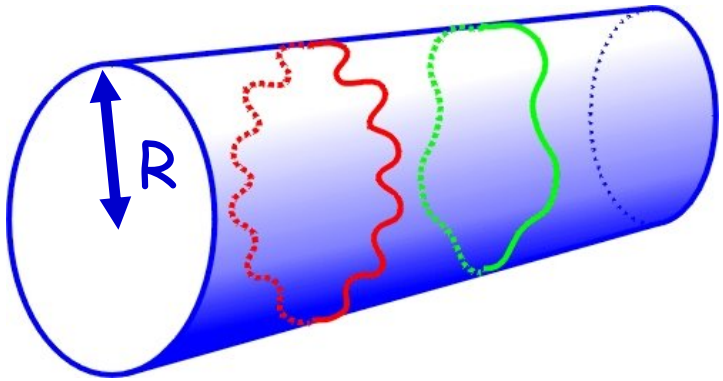
2.9/fb

- WZ or WW resonance in lepton + jets channel
  - BR(W/Z→jj) > 6 BR(W/Z→lν, ll)
  - 2 or 3 jets
- Optimize the requirements on ME_T, E_T of lepton, and each jet for each mass point
- Limits on various resonances
  - RS Graviton > 607 GeV/c^2
  - W' 284-515 GeV/c^2 excluded
  - Z' 247-545 GeV/c^2 excluded
- First time to look for RS Graviton, W', and Z' in WZ, WW resonances





Large Extra Dimension (LED) 102



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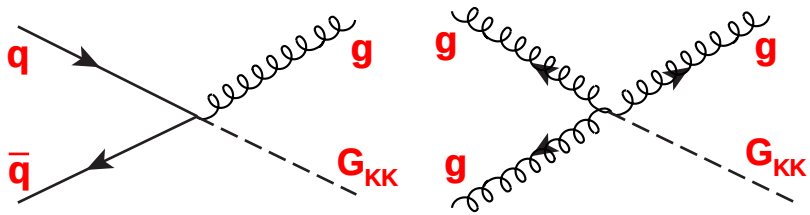
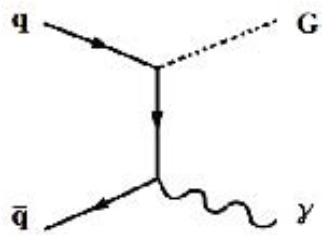
Real Graviton Emission



Probe fundamental Plank scale M_D

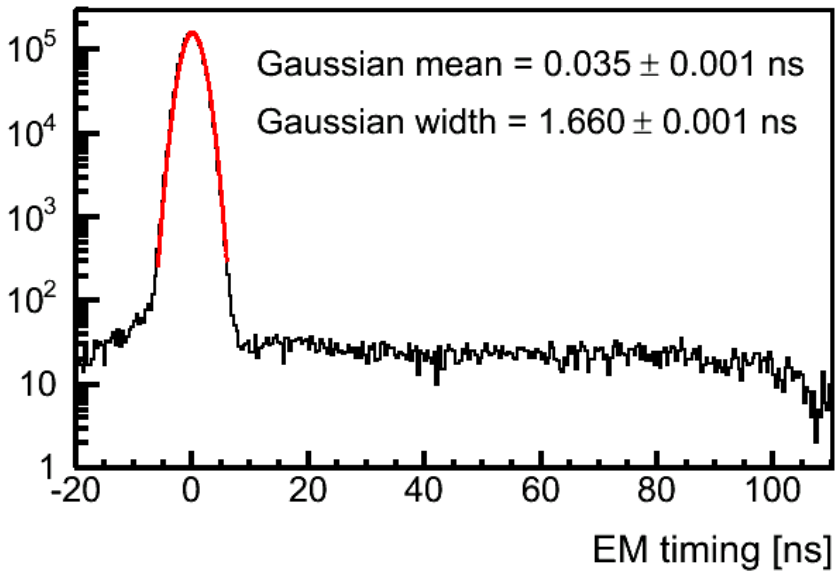


LED in Mono-photon + $\not\!\!E_T$

How to suppress cosmic rays and beam halos?

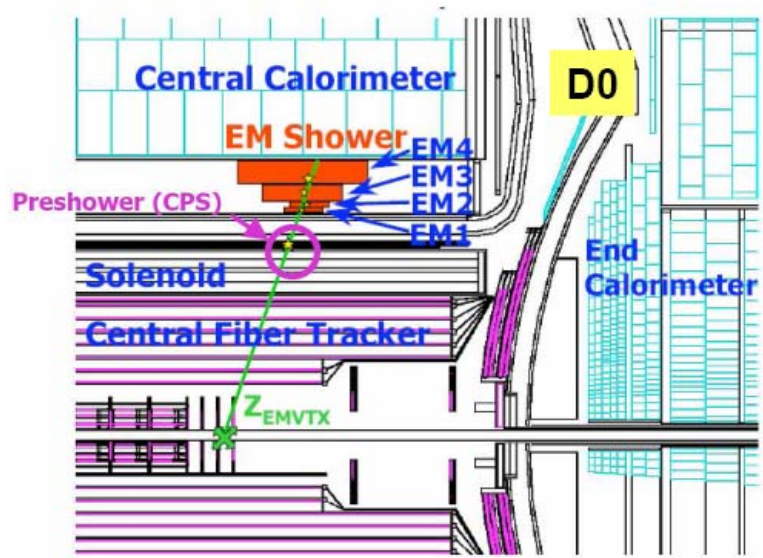
CDF 2.0 fb^{-1}

- Photon timing in ECAL
- Topological cuts
  - Low-pt track multiplicity, angle between muon hit and photon, energy deposition in the calorimeter



D0 2.7 fb^{-1}

- 5 Measurements in ECAL
- Impact parameter from the primary vertex
  - Cut on z distance
  - Estimate remaining background with x-y distance



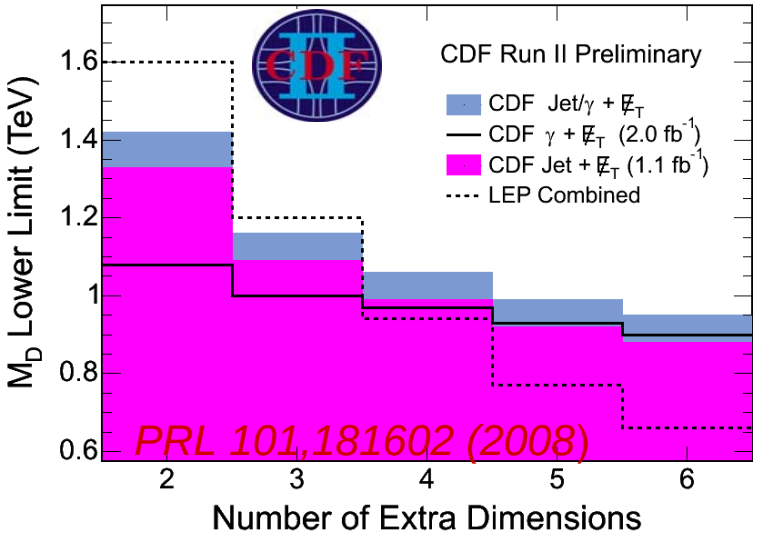
LED in Mono-photon + $\not\!\!E_T$

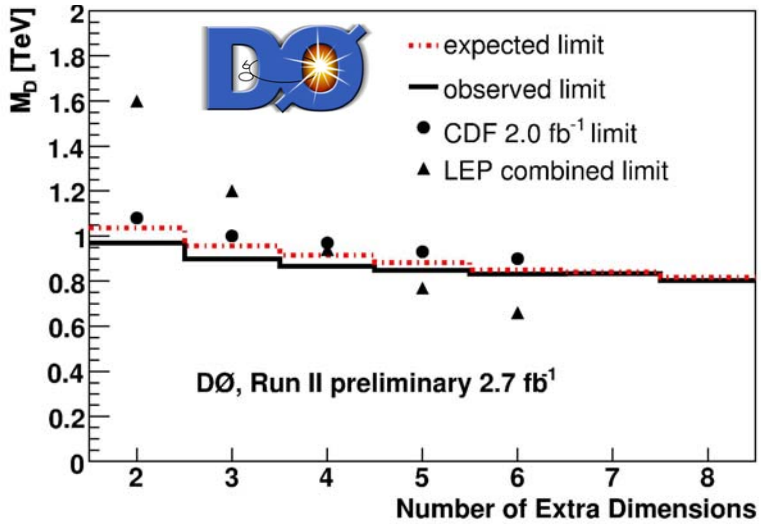
For n=6 ***M_D: Plank mass in 4+n-dim***

CDF γMET: $M_D > 900$ GeV/c^2

D0 γMET: $M_D > 831$ GeV/c^2

Channel	CDF (2.0 fb^{-1}) MET > 50	D0 (2.7 fb^{-1}) MET > 70
Z $\gamma \rightarrow \nu\nu\,\gamma$	25.2 ± 2.8	29.5 ± 2.5
Non-collision	9.8 ± 1.3	6.6 ± 2.3
Fake Photons	--	3.1 ± 1.5
W $\rightarrow$ lepton$\rightarrow \gamma$	3.6 ± 0.4	8.5 ± 1.7
W $\gamma \rightarrow$ lost lepton$\rightarrow \gamma$	5.0 ± 1.4	2.2 ± 0.3
$\gamma\,\gamma \rightarrow \gamma$	2.3 ± 0.6	--
Total	46.7 ± 3.0	49.9 ± 4.1
Data	40	51



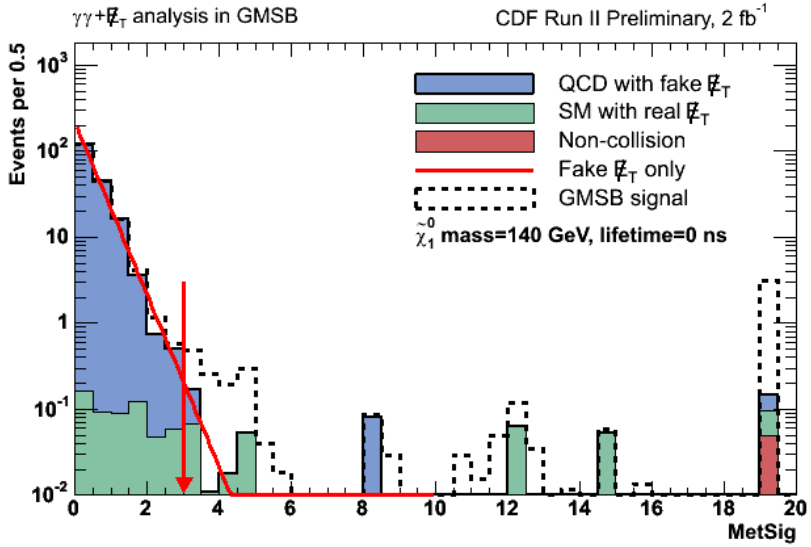


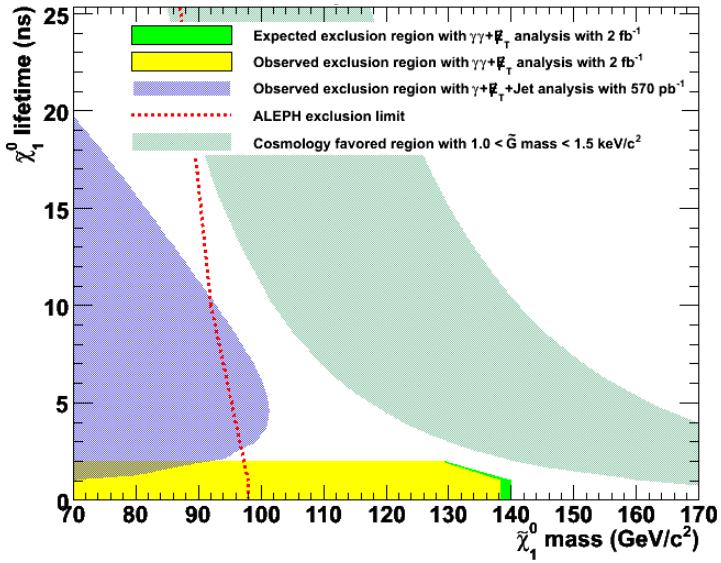
GMSB in $\gamma\gamma$ + ME_T

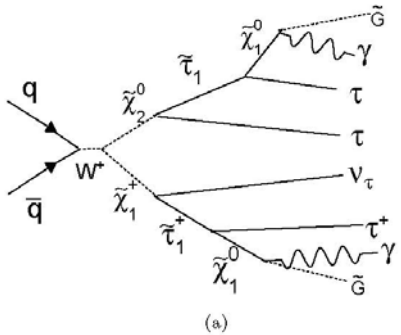
2.0/fb

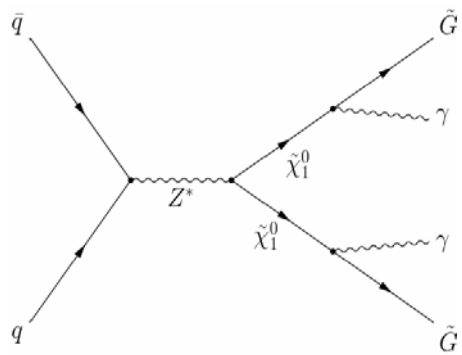
- Gauge-mediated SUSY breaking
  - Messengers coupled to the source of SUSY breaking and SUSY particles
  - LSP is gravitino
  - NLSP neutralino $\tilde{\chi}_1^0 \to \gamma\tilde{G}$
- Focus on low-lifetime neutralino
- Optimize on MetSig, H_T, $\Delta\phi(\gamma_1,\gamma_2)$
- Obs: 1 evt, Exp: 0.62 ± 0.29 evt

$$M(\tilde{\chi}_1^0) > 138\ \text{GeV/c}^2 \text{ for } \tau(\tilde{\chi}_1^0) = 0\ \text{ns}$$

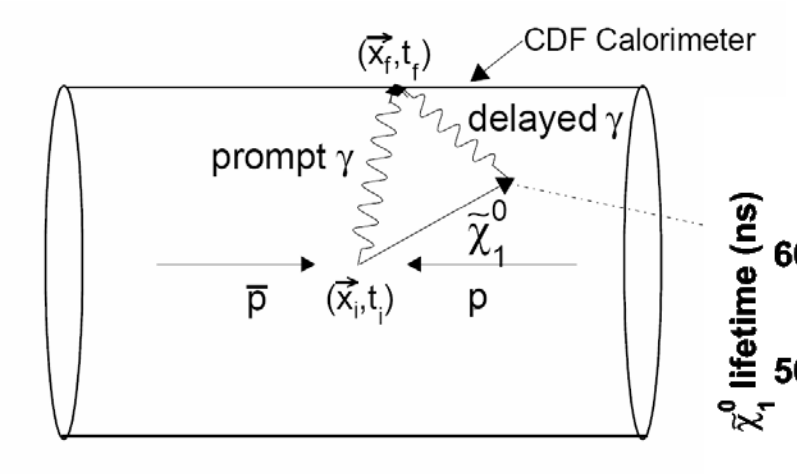




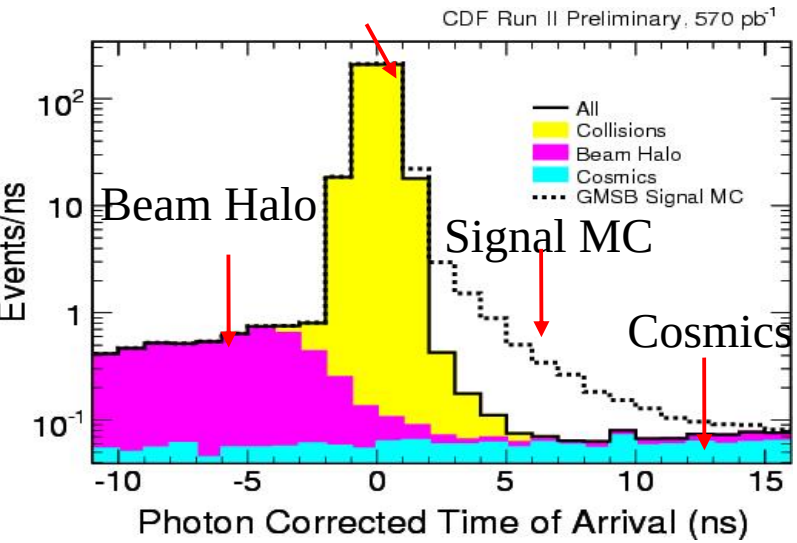


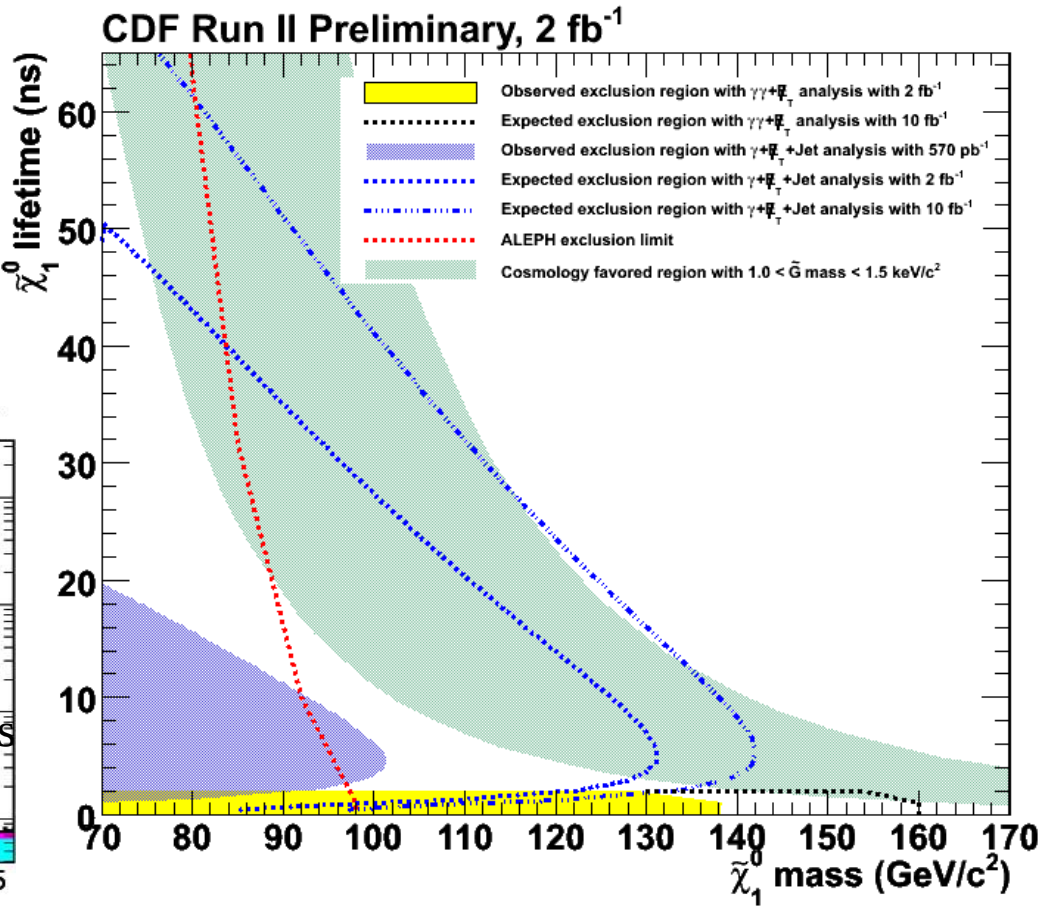


GMSB in the Future



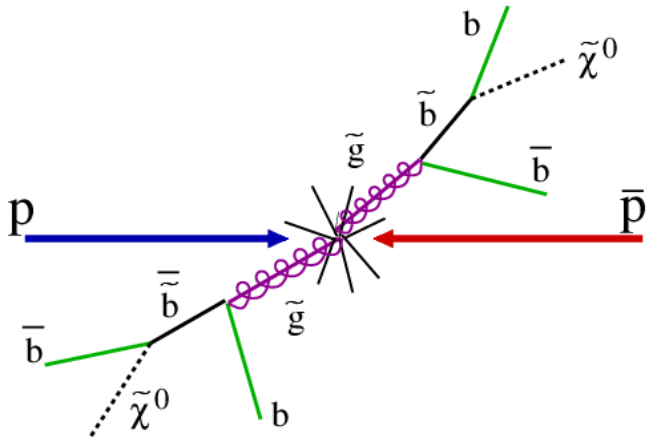
Standard Model

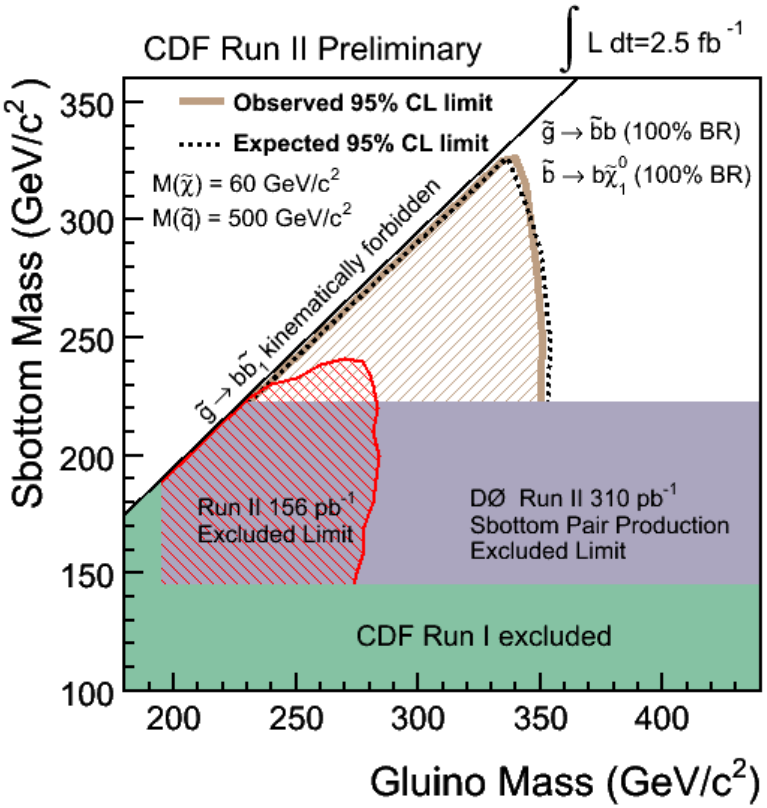




$\tilde{b}$ from $\tilde{g}$ Decay (bbbb + ME_T)

2.5/fb





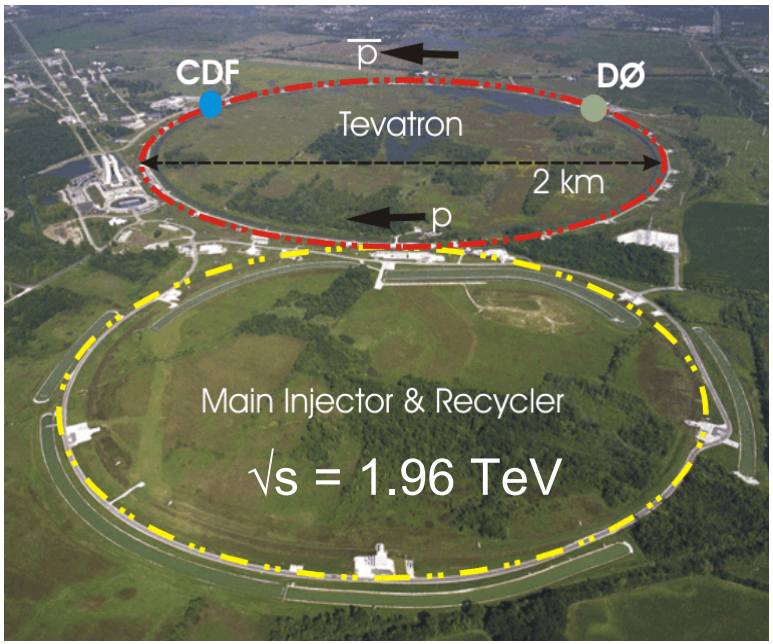
- σ(gluino) ~ 10 σ(sbottom)
  - If sbottom is light enough, mainly produced via gluino decay
  - 4 bjets and large missing energy
  - Complimentary to the search of direct sbottom pair production
- QCD multi-jet background from data
- Require 2 b-tags, large missing E_T
- Apply cuts on NN output to further suppress multi-jet and ttbar backgrounds

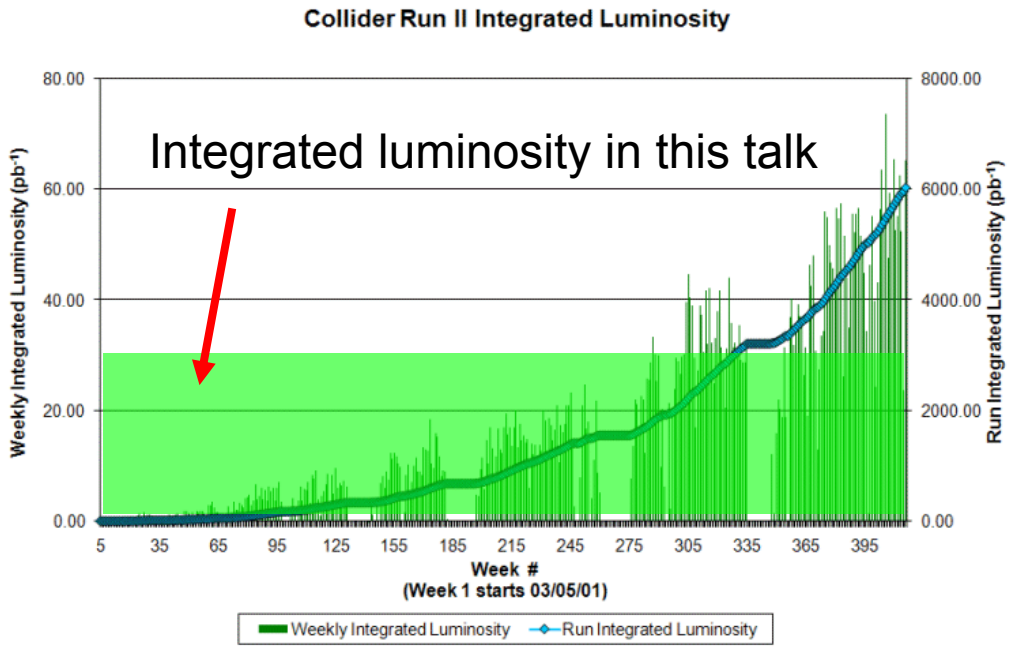
Conclusion and Outlook

- Both CDF and D0 have extensive programs of searches in photons and jets
  - Supersymmetry, Leptoquarks, Compositeness, Extra Dimension, Signature-based
- World's best limits on numerous theory parameters
  - LED M_s, M_D
  - TeV^{-1} ED M_c
  - Mass of scalar Leptoquarks
  - GMSB neutralino mass and lifetime
  - Sbottom mass
- More data means more sensitive to new physics
  - 0.7-2.9/fb today, ~ 5/fb collected
  - ≥ 8.0/fb per exp. by the end of Run II
  - Run until 2009-2010 (proposed to run until 2012, 10-15/fb)

Backup Slides

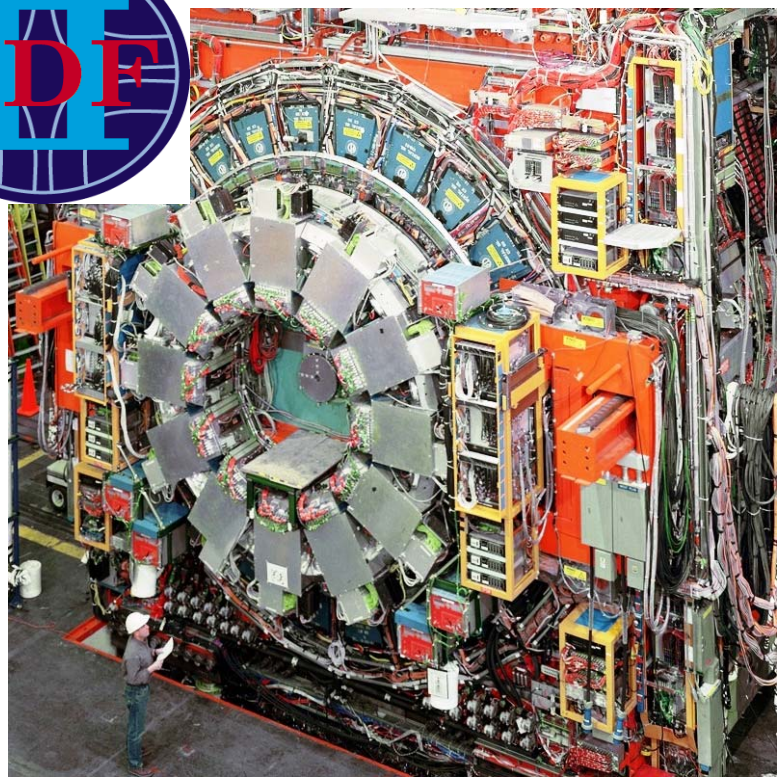
Tevatron Performance





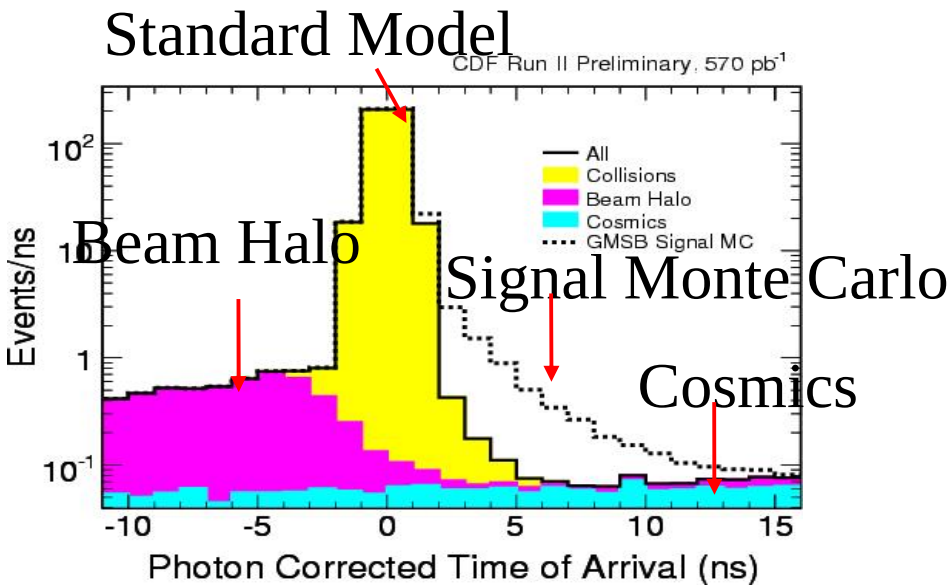
- Both CDF and D0 have 5 fb^{-1} of data on tape (6 fb^{-1} delivered)
- Record initial luminosity: $3.6\times10^{32}\ cm^{-2}s^{-1}$
- Results from 0.7-2.9 fb^{-1} in this talk

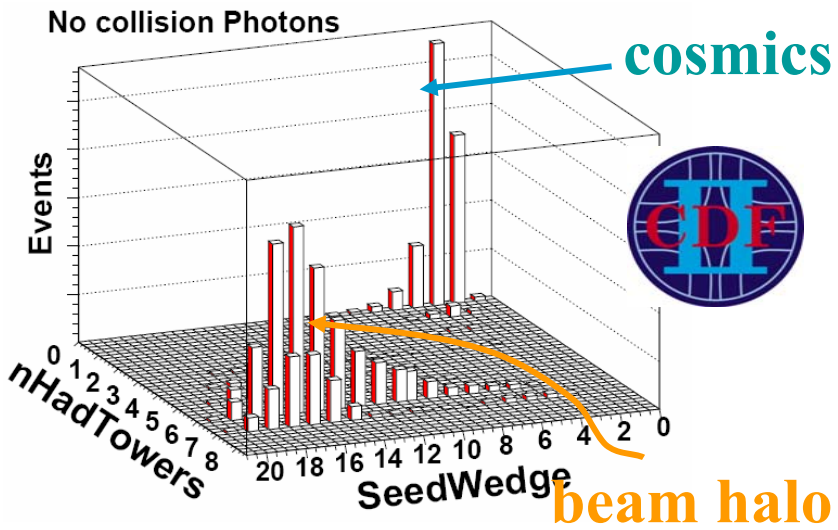
Detectors

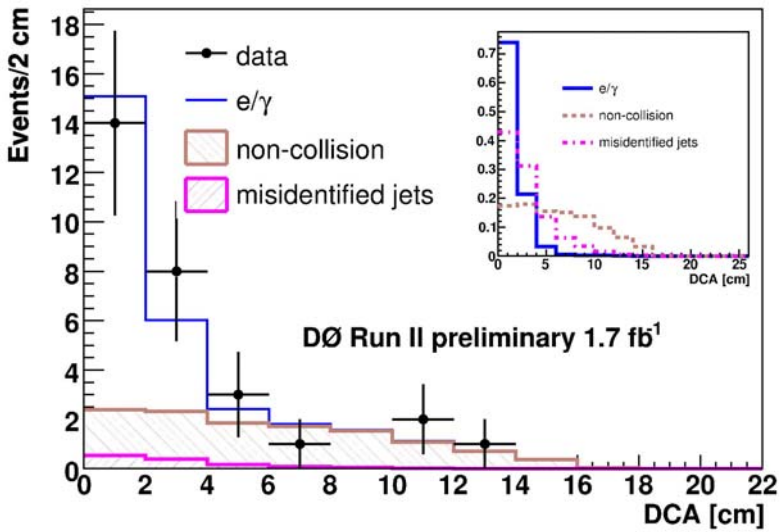


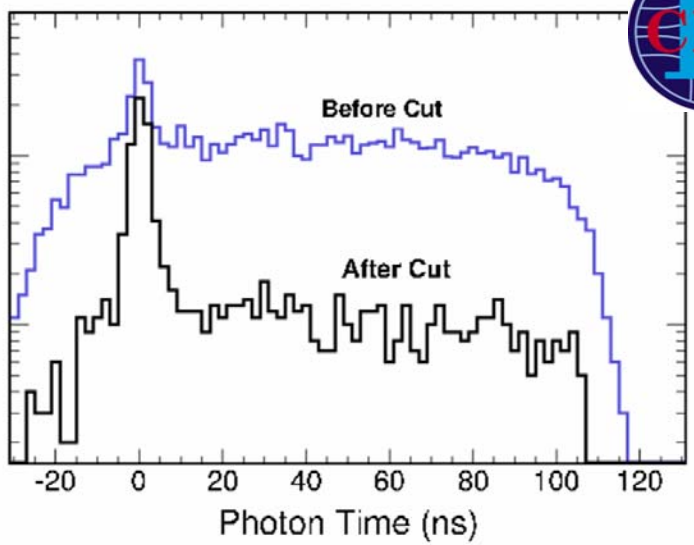
- Multi-purpose detector: tracking system, electromagnetic (ECAL) and hadron calorimeters (HCAL), and muon chamber

Large Extra Dimensions in γ + MET









LED GRW and HLZ Models

$$\left[M_{Pl}\right]^2 = 8\pi \times R^{n_d}\left[M_D\right]^{n_d+2}$$

$$\sigma_{NP} = f_{SM} + \left(\frac{F}{M_S^4}\right) f_{\text{int}} + \left(\frac{F}{M_S^4}\right)^2 f_{NP}$$

$$F = 1\,(\text{GRW})$$

$$F = \ln\left(\frac{M_S^2}{\hat{s}}\right) \text{ for } n_d = 2 \ \ (\text{HLZ})$$

$$F = \frac{2}{n_d - 2} \text{ for } n_d > 2 \ \ (\text{HLZ})$$

$$M_{pl}^2 = 8\pi\, M_D^{n+2} R^n$$

LED Limits in the ee, $\gamma\gamma$ Channels

TABLE III: Observed and expected lower limits at the 95% C.L. on the effective Planck scale, M_s, in TeV.

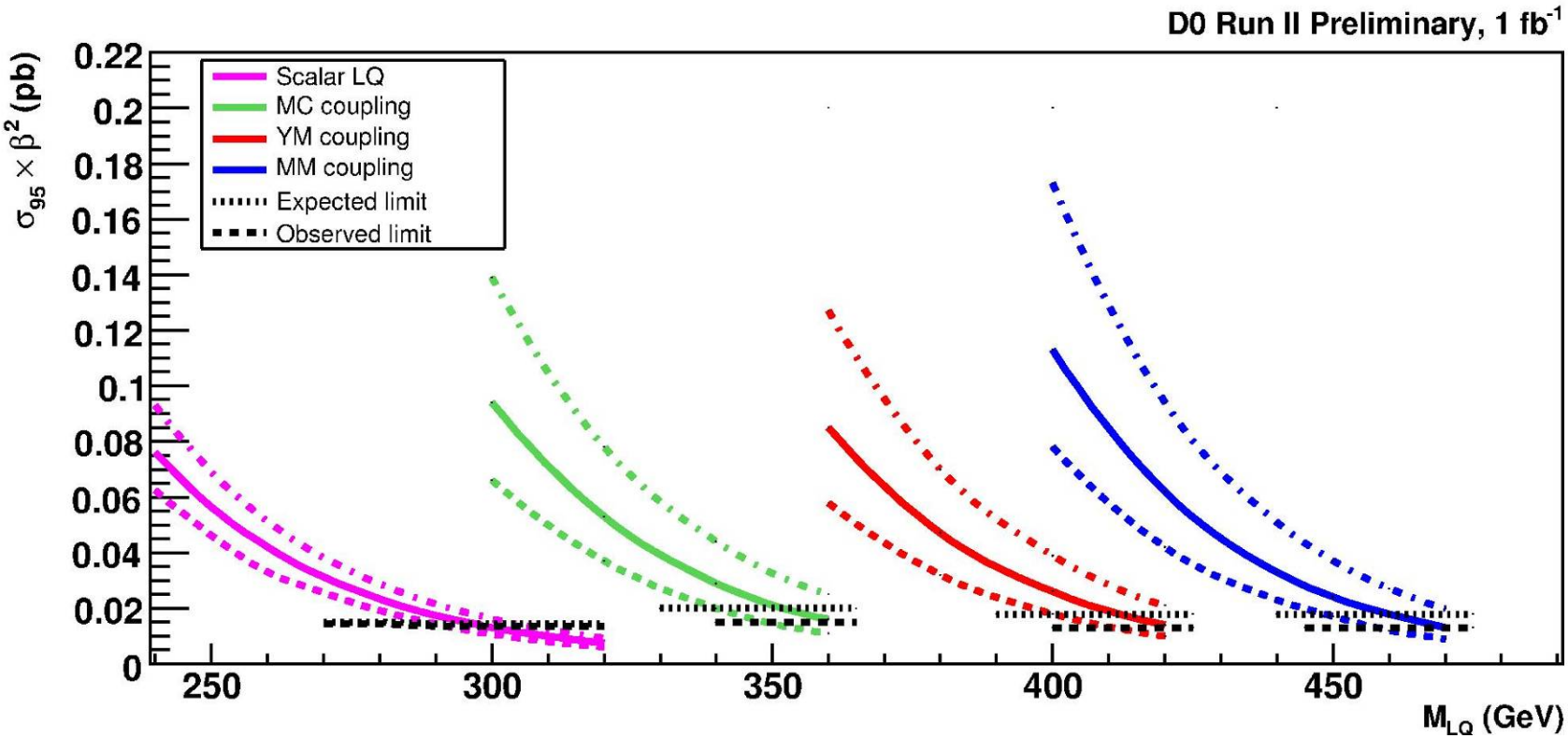
	GRW	HLZ					
		n_d	2	3	4	5	6	7
Obs.	1.62		2.09	1.94	1.62	1.46	1.36	1.29
Exp.	1.66		2.16	2.01	1.66	1.49	1.38	1.31

LED and Compositeness Limits in jj

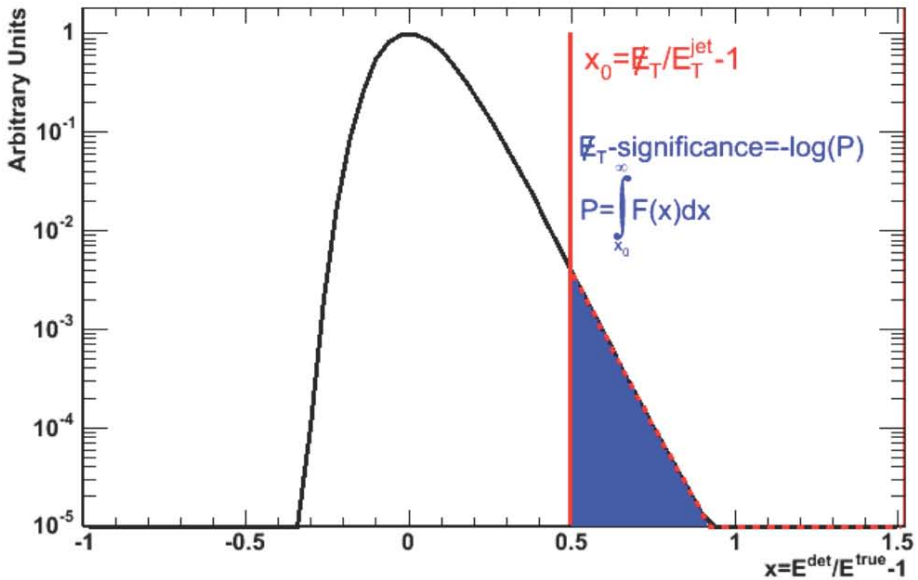
DØ preliminary
95% CL limits on New Physics models from the dijet angular distribution (in TeV)

model (parameter)	χ^2 minimum position	χ^2 minimum depth	Bayesian prior flat in η expected	Bayesian prior flat in η found	Bayesian prior flat in η^2 expected	Bayesian prior flat in η^2 found	frequentist $\chi^2 - \chi^2_{\rm min} = 3.84$ expected	frequentist $\chi^2 - \chi^2_{\rm min} = 3.84$ found	previous limit
Quark Composit. (Λ)									
$\lambda = +1$	5.10	0.02	$2.75\ ^{+0.43}_{-0.35}$	2.58	$2.58\ ^{+0.28}_{-0.29}$	2.39	$2.65\ ^{+0.42}_{-0.35}$	2.46	2.73 [10]
$\lambda = -1$	5.22	0.02	$2.78\ ^{+0.36}_{-0.41}$	2.54	$2.55\ ^{+0.31}_{-0.33}$	2.35	$2.65\ ^{+0.45}_{-0.39}$	2.42	2.49 [10]
TeV^{-1} ED (M_O)	2.17	0.66	$1.64\ ^{+0.23}_{-0.25}$	1.42	$1.51\ ^{+0.16}_{-0.19}$	1.33	$1.57\ ^{+0.33}_{-0.24}$	1.35	1.12 [27]
ADD LED (M_S)									
GRW	∞		$1.49\ ^{+0.12}_{-0.14}$	1.56	$1.44\ ^{+0.10}_{-0.10}$	1.48	$1.47\ ^{+0.16}_{-0.14}$	1.54	1.62 [26]
Hewett $\lambda = +1$	∞		$1.33\ ^{+0.11}_{-0.12}$	1.39	$1.28\ ^{+0.09}_{-0.09}$	1.32	$1.31\ ^{+0.14}_{-0.12}$	1.37	1.22 [25]
Hewett $\lambda = -1$	∞		$1.28\ ^{+0.11}_{-0.09}$	1.35	$1.23\ ^{+0.09}_{-0.08}$	1.29	$1.25\ ^{+0.13}_{-0.09}$	1.33	1.10 [25]
HLZ n=3	∞		$1.77\ ^{+0.14}_{-0.16}$	1.85	$1.71\ ^{+0.11}_{-0.12}$	1.76	$1.74\ ^{+0.19}_{-0.16}$	1.83	1.94 [26]
HLZ n=4	∞		$1.49\ ^{+0.12}_{-0.14}$	1.56	$1.44\ ^{+0.10}_{-0.10}$	1.48	$1.47\ ^{+0.16}_{-0.14}$	1.54	1.62 [26]
HLZ n=5	∞		$1.35\ ^{+0.11}_{-0.12}$	1.41	$1.30\ ^{+0.09}_{-0.09}$	1.34	$1.32\ ^{+0.14}_{-0.12}$	1.39	1.46 [26]
HLZ n=6	∞		$1.25\ ^{+0.11}_{-0.10}$	1.31	$1.21\ ^{+0.08}_{-0.09}$	1.25	$1.22\ ^{+0.14}_{-0.11}$	1.29	1.36 [26]
HLZ n=7	∞		$1.19\ ^{+0.09}_{-0.11}$	1.24	$1.14\ ^{+0.08}_{-0.08}$	1.18	$1.17\ ^{+0.13}_{-0.11}$	1.22	1.29 [26]

Leptoquarks in eejj, μμjj, ττbb



MET Significance



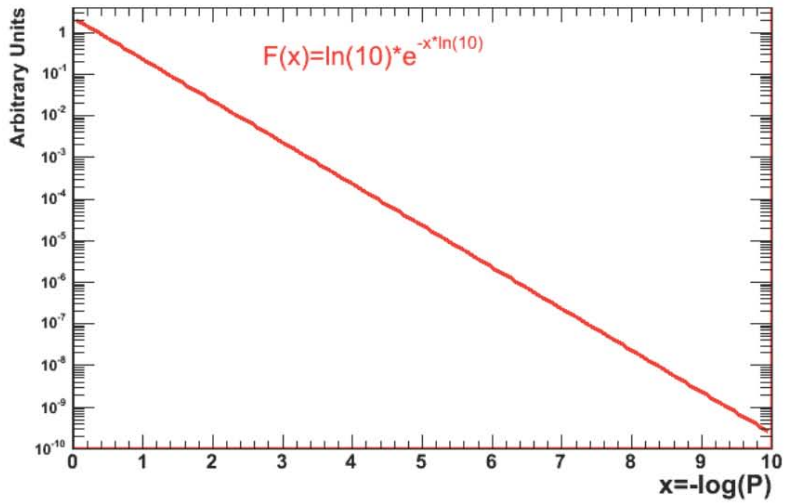
- Takes into account individual jet resolution
- Accounts for relative direction of MET and jet
- Eliminates need for $\Delta\varphi$(MET-jet) cuts

New MET-sig=-log(P) for fake MET:

Simple shape for any distribution F(x)

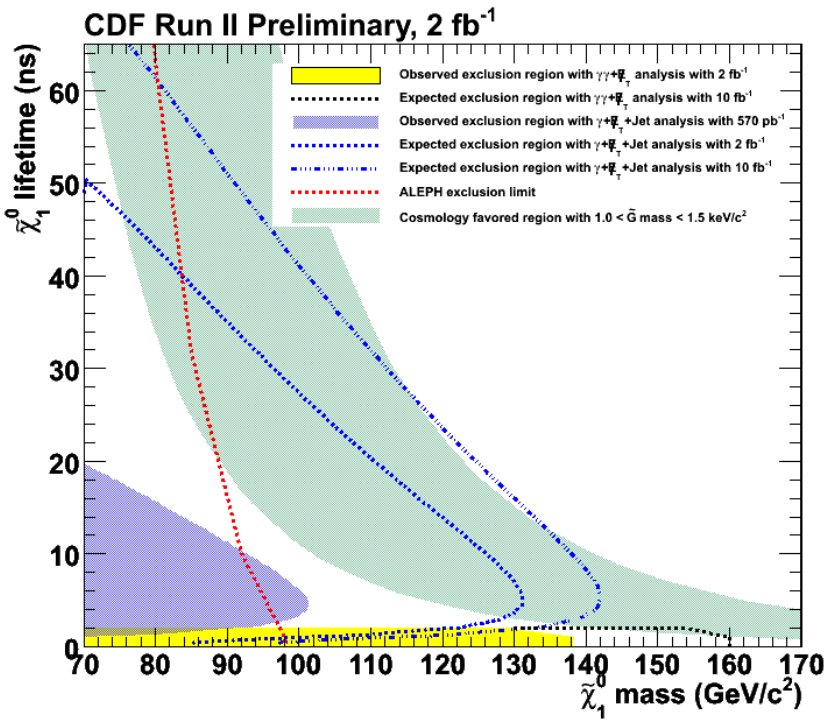
For 10,000 events:

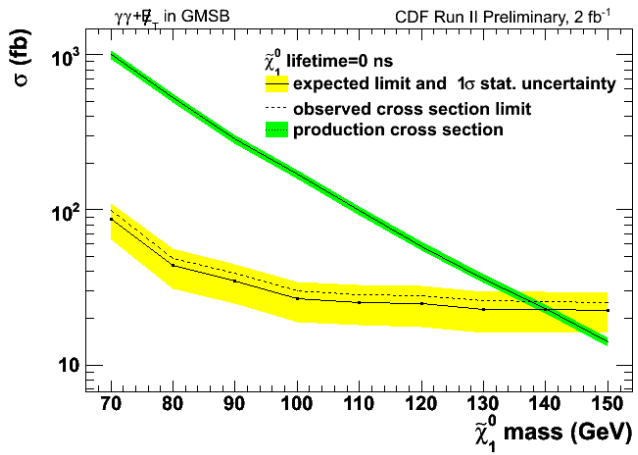
Cut on Sig>1 ⇒ ~1,000 events pass
Cut on Sig>2 ⇒ ~100 events pass
Cut on Sig>3 ⇒ ~10 events pass
Cut on Sig>4 ⇒ ~1 event pass

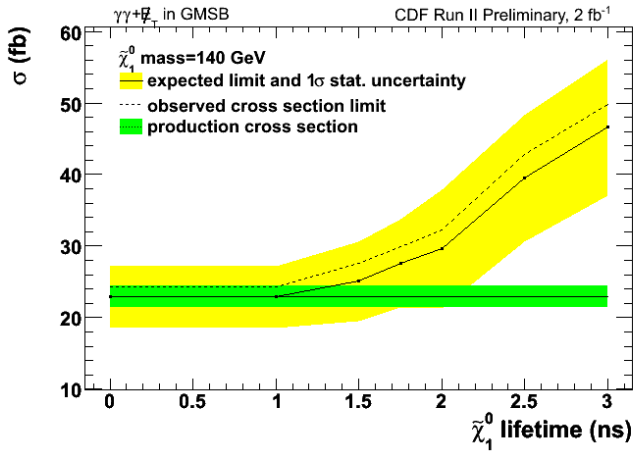


GMSB in $\gamma\gamma$ + Missing E_T

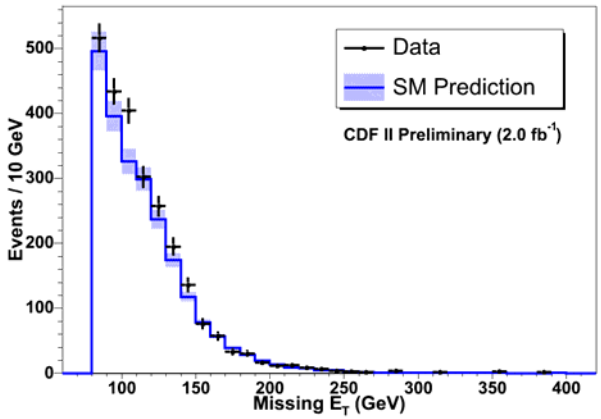
Background Source	Expected Rate±Stat±Sys
Electroweak	0.39±0.14±0.11
QCD	0.10±0.10±0.00
Non-Collision	0.049±0.042±0.028
Tri-Photon	0.00±0.180±0.035
Wrong Vertex	0.081±0.081±0.008
Total	0.62±0.26±0.12

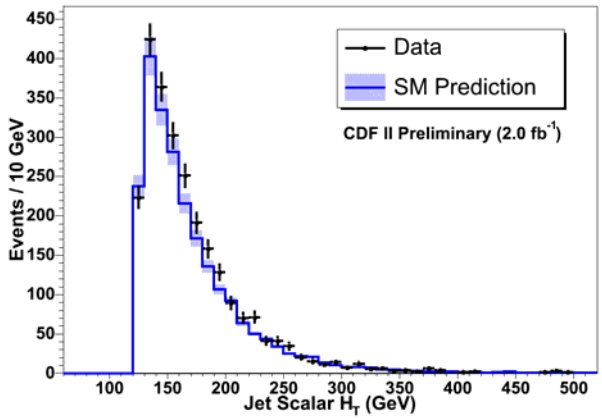


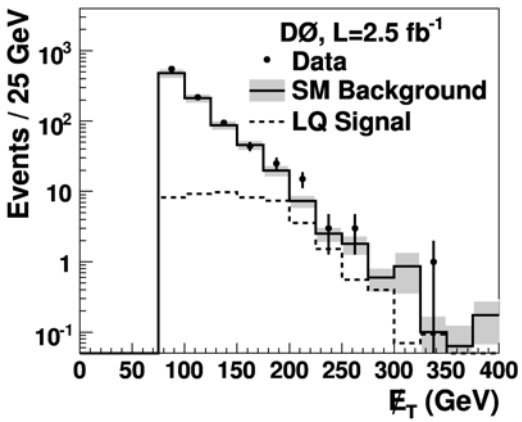


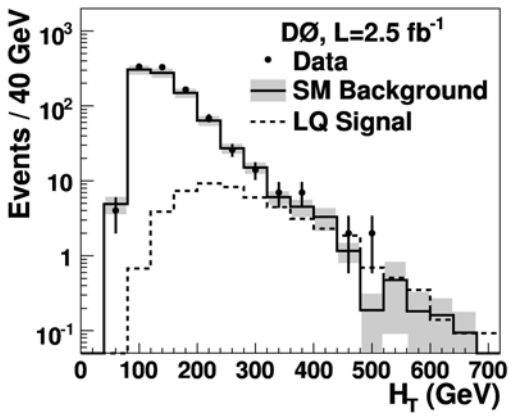


New Physics in dijet + ME_T









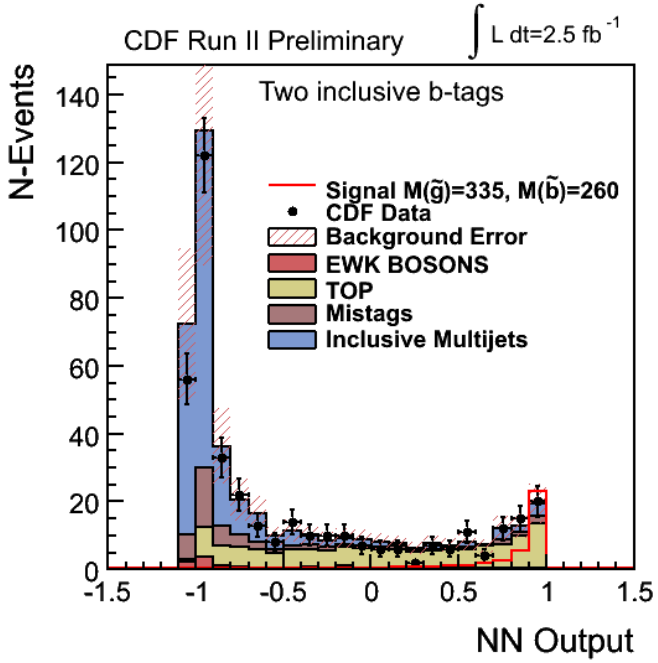
Sbottom from Gluino Decay

CDF Run II Preliminary 2.5 fb^{-1}

Two Inclusive Tags	QCD Region	Lepton Region	Preoptimization Region
W/Z + jets production	10 ± 7	19 ± 14	29 ± 22
Diboson production	0.4 ± 0.1	2 ± 0.6	4 ± 1
Top pair production	18 ± 6	107 ± 34	140 ± 45
Single top production	1 ± 0.2	4 ± 1	6 ± 1
HF QCD Multijets	864 ± 432	23 ± 11	273 ± 136
Light-flavour contamination	238 ± 48	8 ± 2	57 ± 11
Total expected	1132 ± 435	164 ± 38	510 ± 145
Observed	1104	156	455

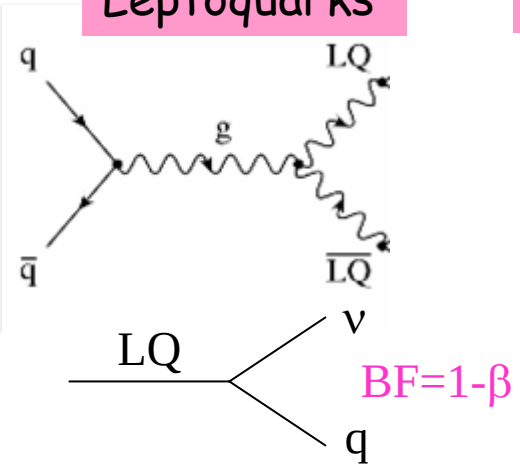
CDF Run II Preliminary 2.5 fb^{-1} (Two Inclusive Tags)

Region	Large Δm Optimization	Small Δm Optimization
W/Z + jets production	0.1 ± 0.05	0.4 ± 0.3
Diboson production	0.07 ± 0.02	0.1 ± 0.03
Top pair production	1.9 ± 1.0	0.6 ± 0.4
Single top production	0.03 ± 0.01	0.04 ± 0.01
HF QCD Multijets	1.5 ± 0.7	0.6 ± 0.3
Light-flavour contamination	0.9 ± 0.3	0.6 ± 0.1
Total expected	4.5 ± 1.4	2.3 ± 0.8
Observed	5	2
Signal M($\tilde{g}$)=335, M($\tilde{b}$)=260	14.9 ± 5.0	-
Signal M($\tilde{g}$)=335, M($\tilde{b}$)=315	-	8.5 ± 2.8

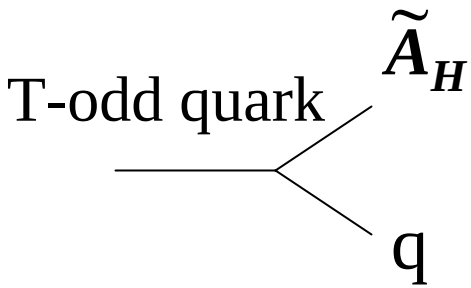


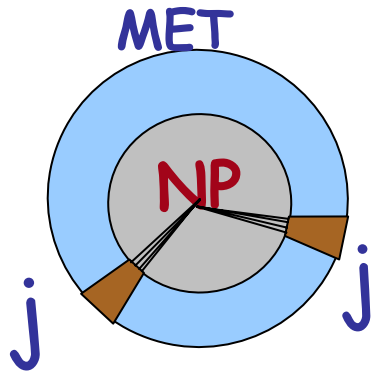
New Physics in dijet + ME_T

Leptoquarks



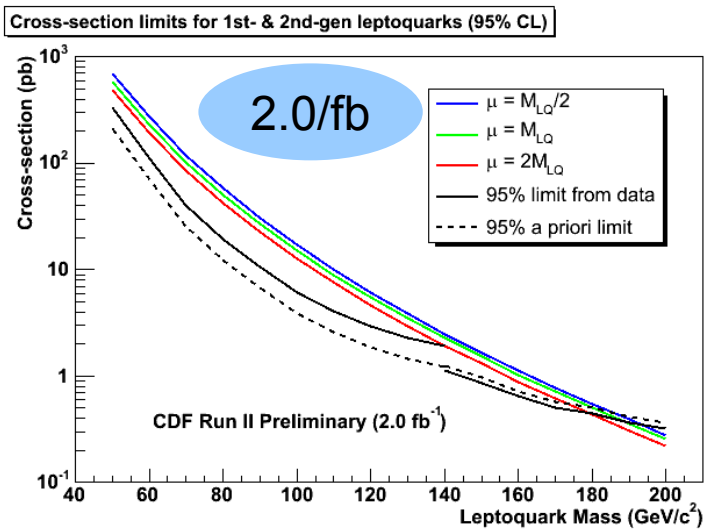
Quarks with odd T-parity

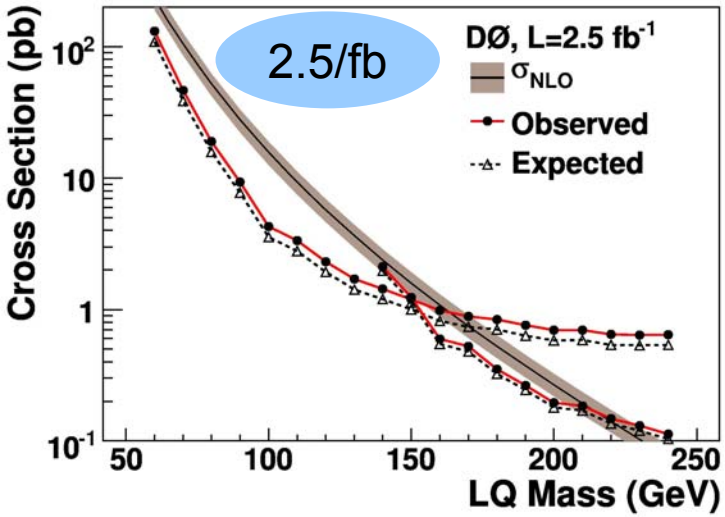


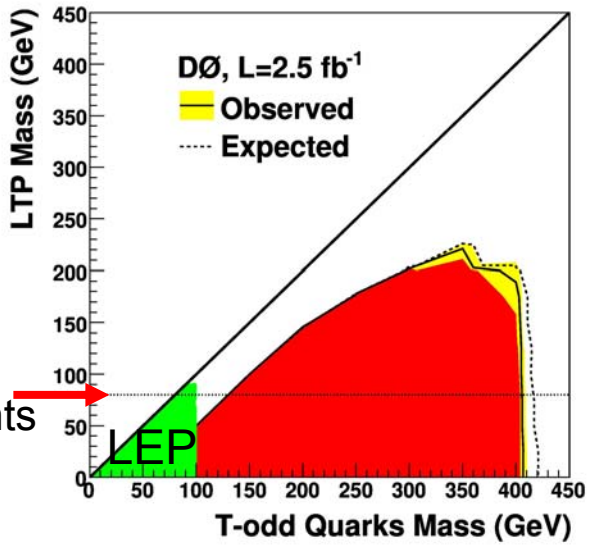


- Predicted by several models
  - Pair production of scalar Leptoquarks
  - Little Higgs (T-parity conserved)
- Similar baseline requirements
  - Exactly two jets, large ME_T, veto isolated tracks, leptons
- Major backgrounds
  - $Z \rightarrow \nu\nu$ + jets
  - $W \rightarrow l\ \nu$ +jets with missing lepton

New Physics in dijet + ME_T







SM precision measurements

- 1st and 2nd Leptoquarks
  - CDF $M(LQ_{1,2}) > 179$ GeV/c^2
  - D0 $M(LQ_{1,2}) > 205$ GeV/c^2
- T-odd quarks
  - Maximum T-quark mass excluded is 404 GeV/c^2

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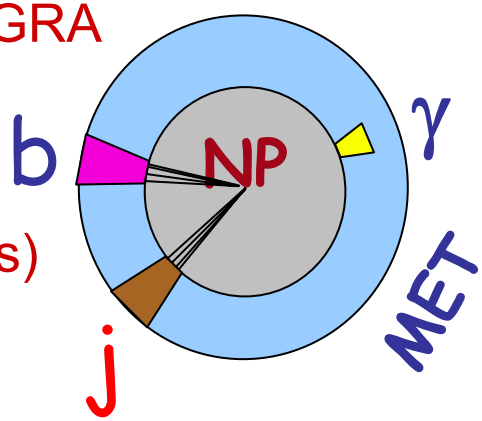
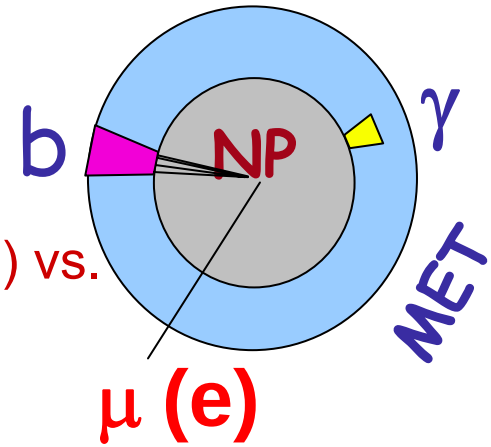
Photons + Jets + X

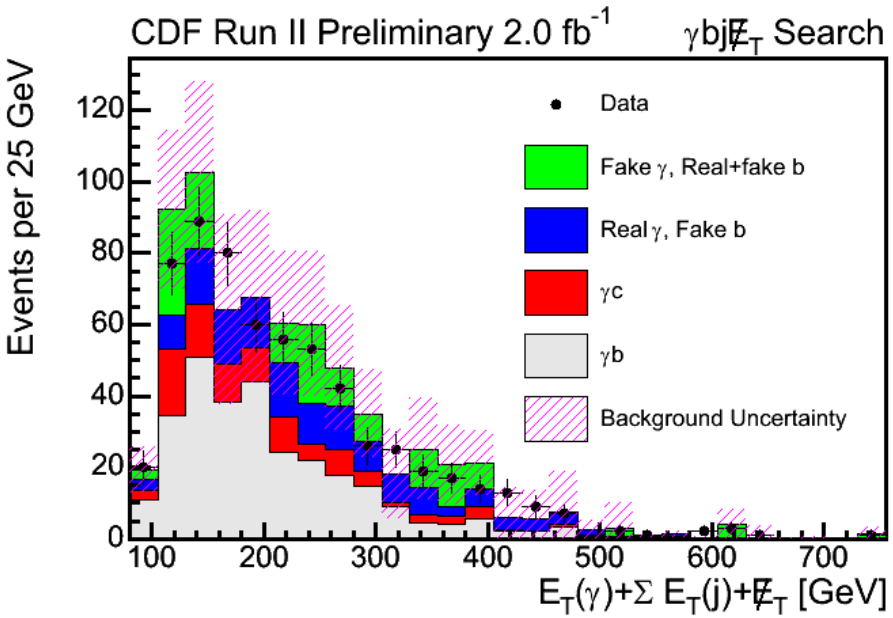
2.0/fb

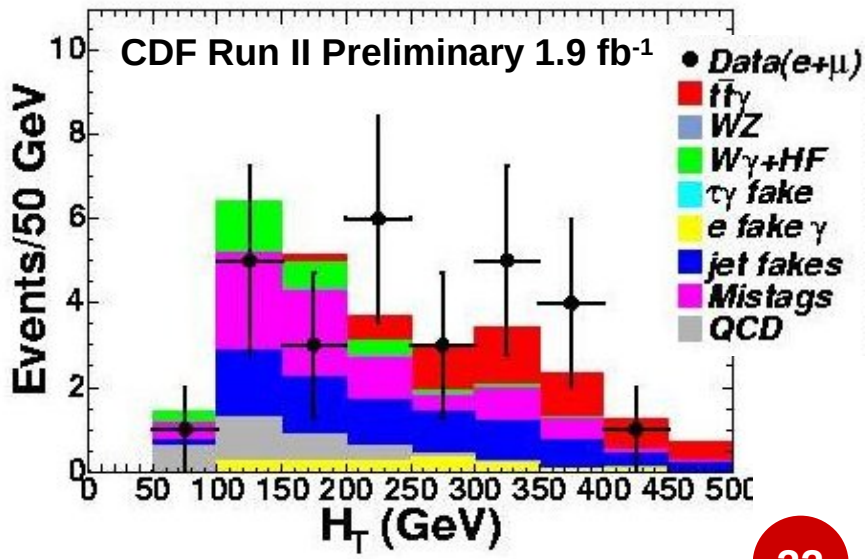
- X = jets, background mostly fakes
- GMSB, mSUGRA
- No excess
- 637±139 (exp) vs. 617 (obs)



- X = e or μ, backgrounds: fakes + ttbarγ
- MSSM
- No excess
- 27.9±3.6 (exp) vs.
- 28 (obs)







Photons + Jets + X

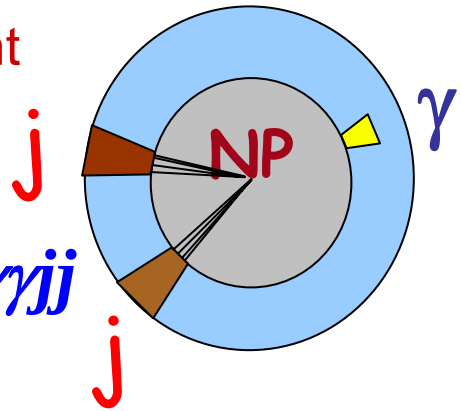
2.0/fb

- Background mostly SM
- MET requirement

under study

$$h \to A^0 A^0 \to \gamma\gamma jj$$

$$\to "\gamma"" j"$$



- X = ≥2 jets + e or μ, large H_T
- Measure σ(ttγ) = 0.15 ± 0.08 pb

NLO prediction = 0.080 ± 0.012 pb from Baur, Petriello