Other BSM Searches at the Tevatron

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on behalf of the CDF and D0 collaborations

Hadron Collider Physics Symposium, Galena, Illinois, USA
May 29, 2008

What I Will Cover in This Talk

- **15 non-SUSY, non-Higgs BSM results from 1-2.5 fb^{-1} of data**
- **Signature-based**
  - Final-state driven
    - Objects: **e, μ, τ, MET, jet, b-jet, γ**
  - Examine event counts and kinematic distributions
  - Standard model is known. Look for any deviations everywhere
- **Model-inspired**
  - Theory driven
  - Standard model and new physics known
  - Set limit on model parameters
    - Large Extra Dimension
    - Randall-Sundrum Graviton, Extended Gauge Bosons
    - Leptoquark
    - Maximal Flavor Violation, Technicolor, 4th generation

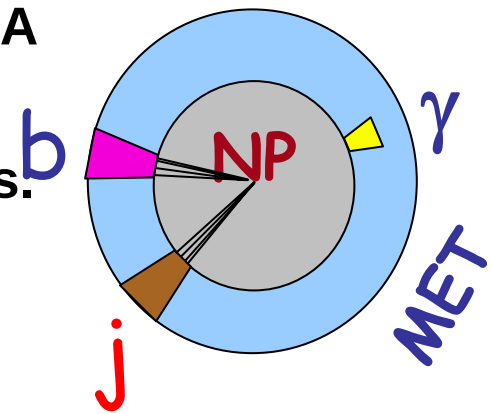
Signature-based

Anomalous γ b MET+ X in 2.0 fb^{-1}

NEW !

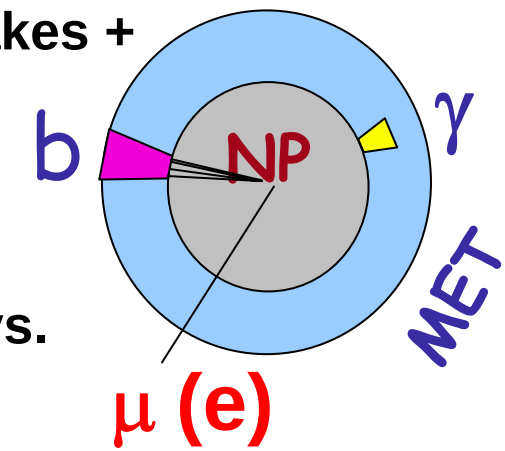
- X = jets, background mostly fakes
- GMSB, mSUGRA
- No excess

637±139 (exp) vs. 617 (obs)

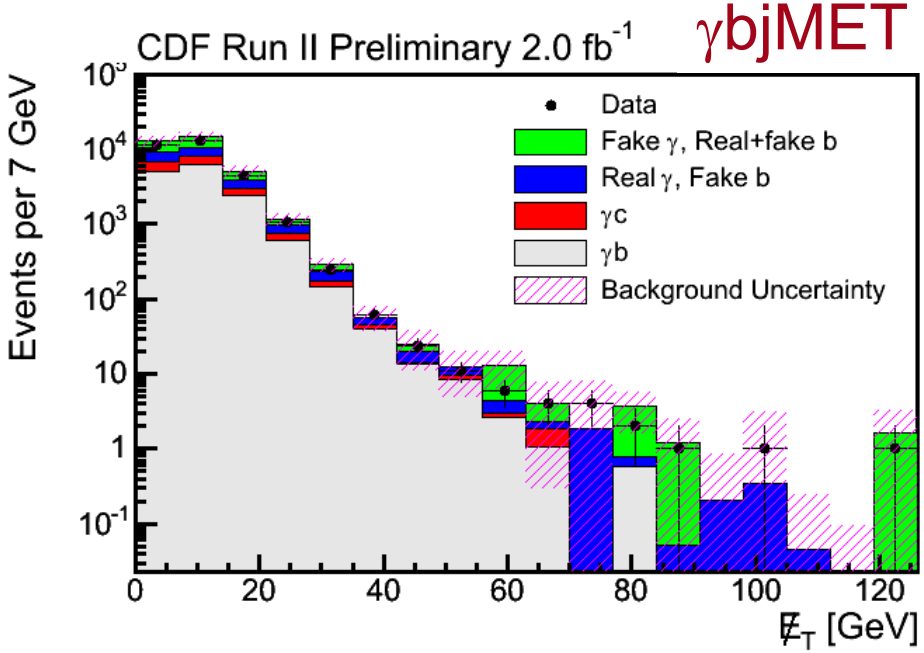


- X = e or μ, backgrounds: fakes + $t\bar{t}\gamma$
- MSSM
- No excess

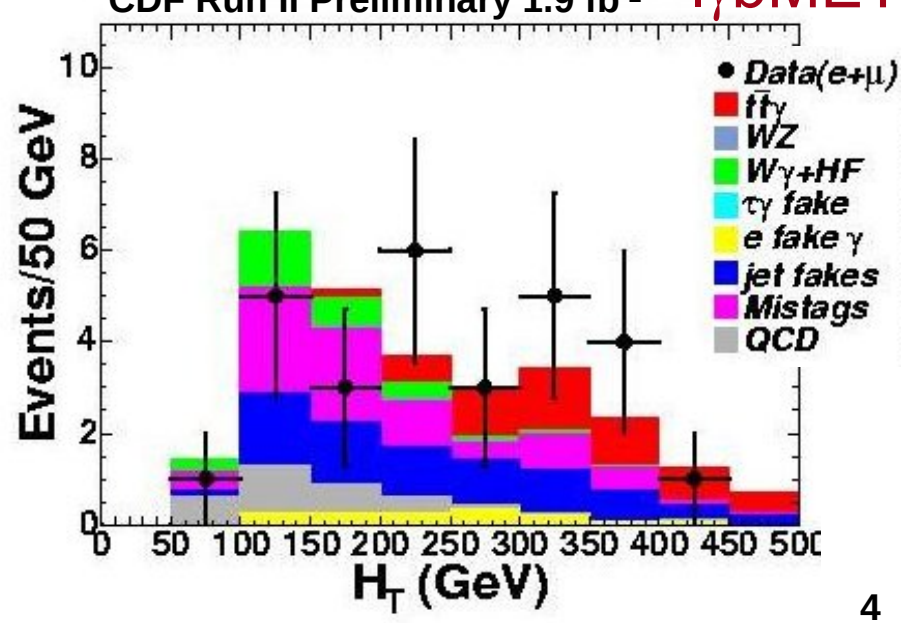
27.9±3.6 (exp) vs. 28 (obs)



γbjMET



lγbMET



Anomalous γ b MET+ X in 2.0 fb^{-1}

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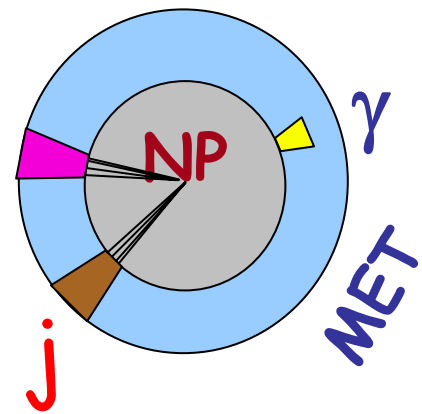
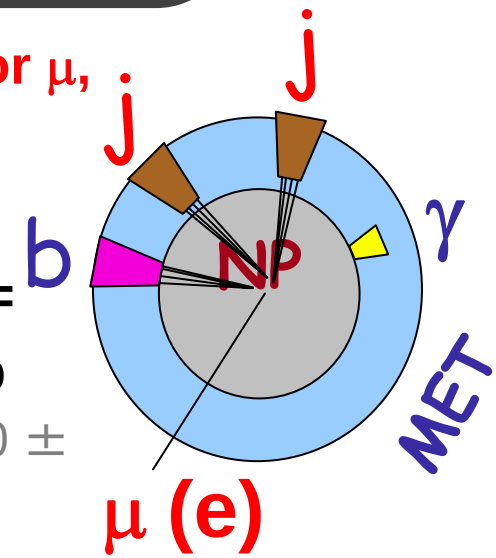
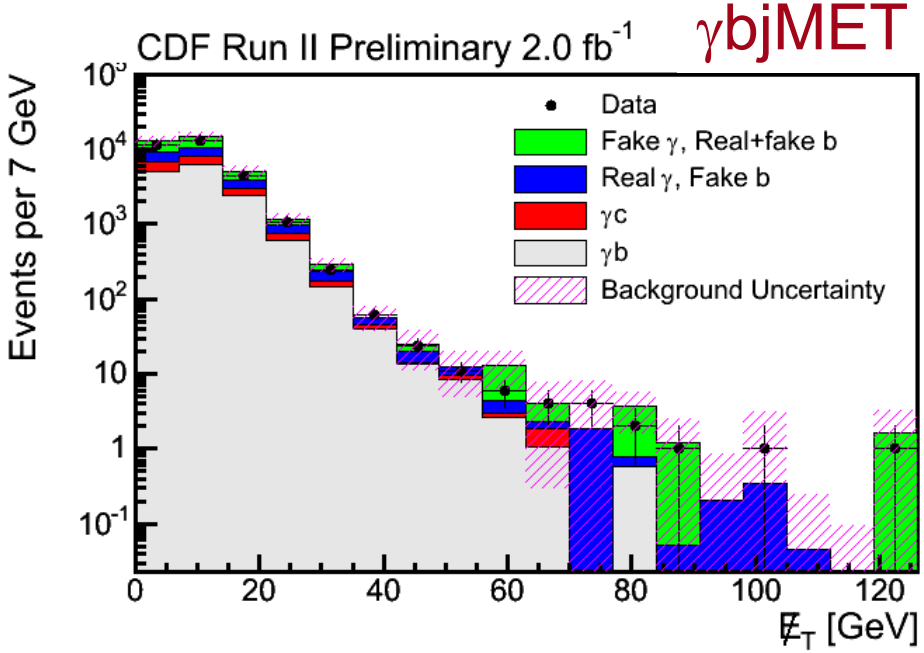


- X = ≥2 jets + e or μ, H_T>200, mostly fakes + $t\bar{t}\gamma$
- Measure $\sigma(t\bar{t}\gamma)$ = 0.15 ± 0.08 pb
  - NLO σ = 0.080 ± 0.012 pb

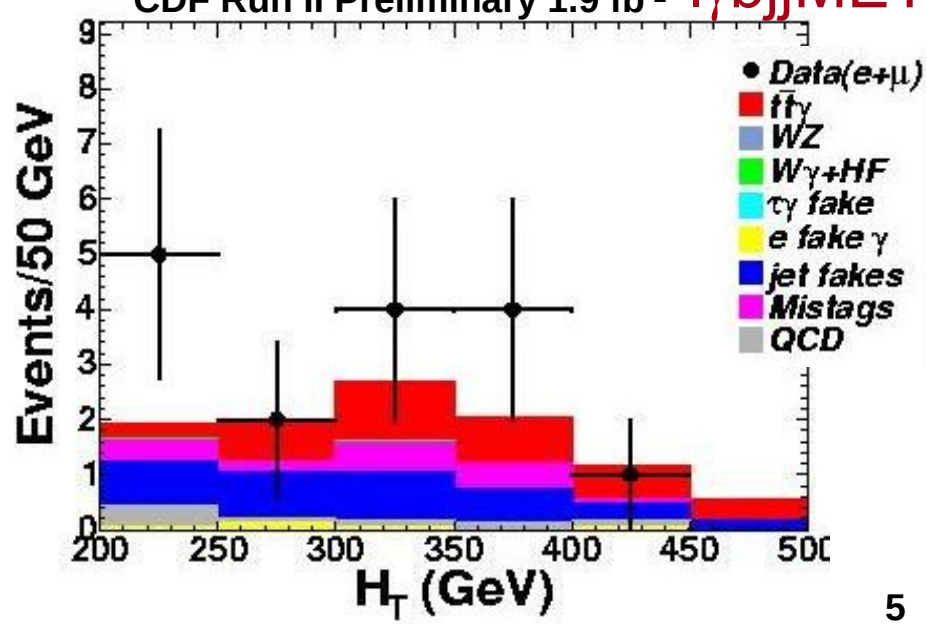
Baur, Petriello



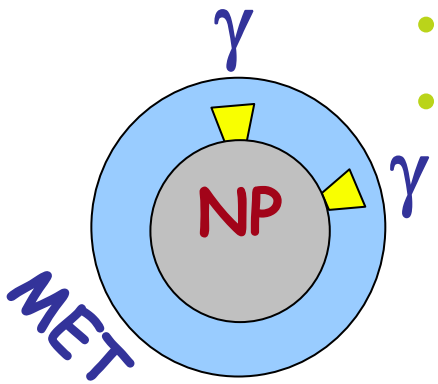
γbjMET



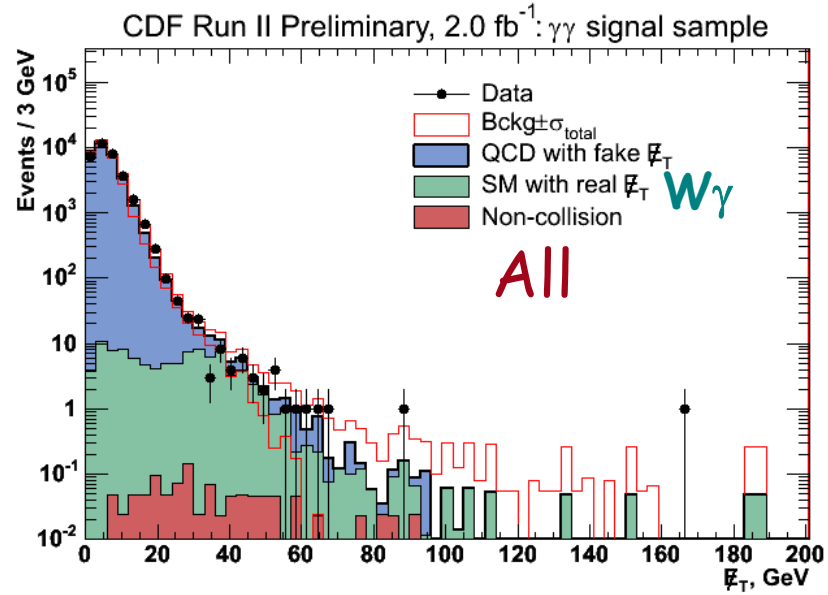
lγbjjMET

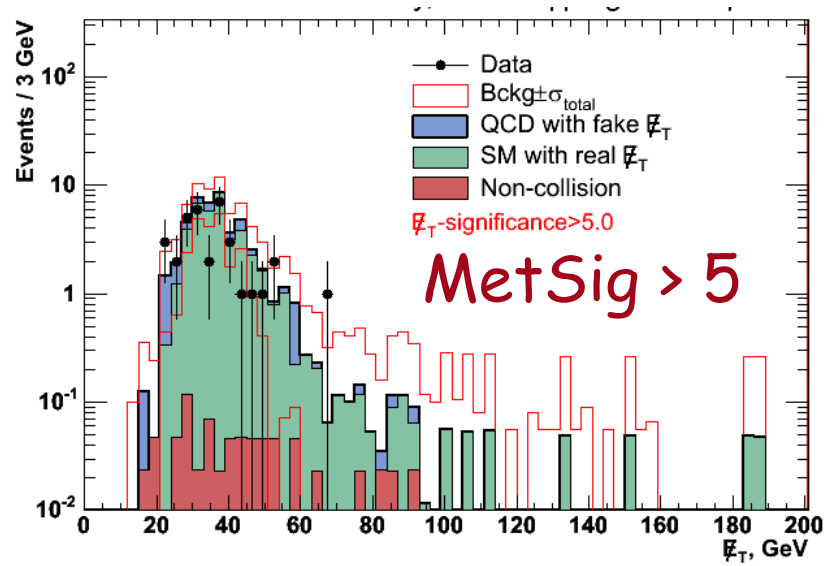


Anomalous $\gamma\gamma$ MET in 2.0 fb^{-1}



- SUSY, Higgs
- Build a "MET resolution model" to calculate MET significance

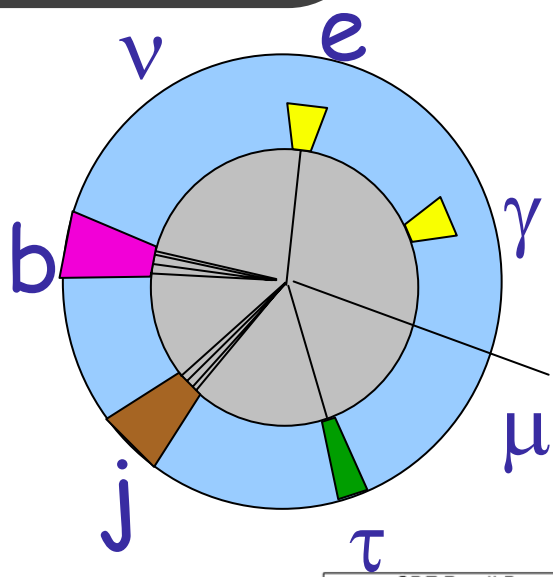




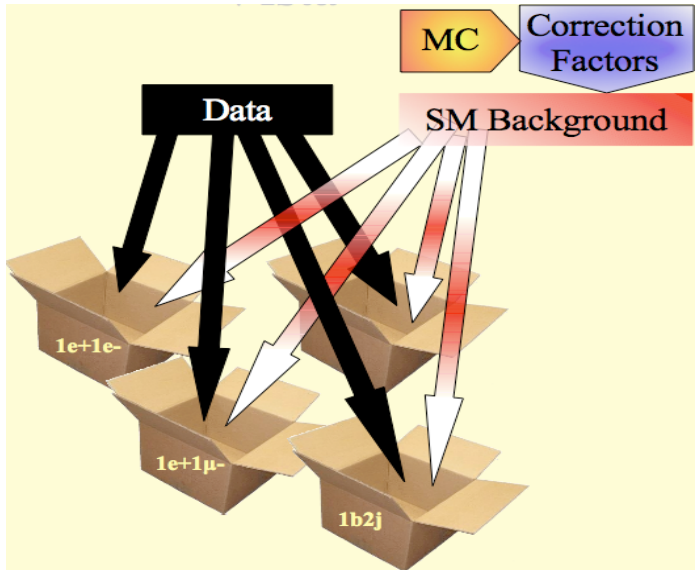
	MetSig > 3.0	MetSig > 4.0	MetSig > 5.0
EWK	53.6 ± 8.9	47.3 ± 8.0	41.6 ± 7.0
QCD	52.1± 11.5	15.4 ± 3.8	6.2 ± 2.7
Non-collision	0.90 ± 0.32	0.85 ± 0.30	0.80 ± 0.27
Total	106.6 ± 14.5	63.6 ± 8.9	48.6 ± 7.5
Observed	120	52	34

Global Search in 2.0 fb^{-1}: Vista

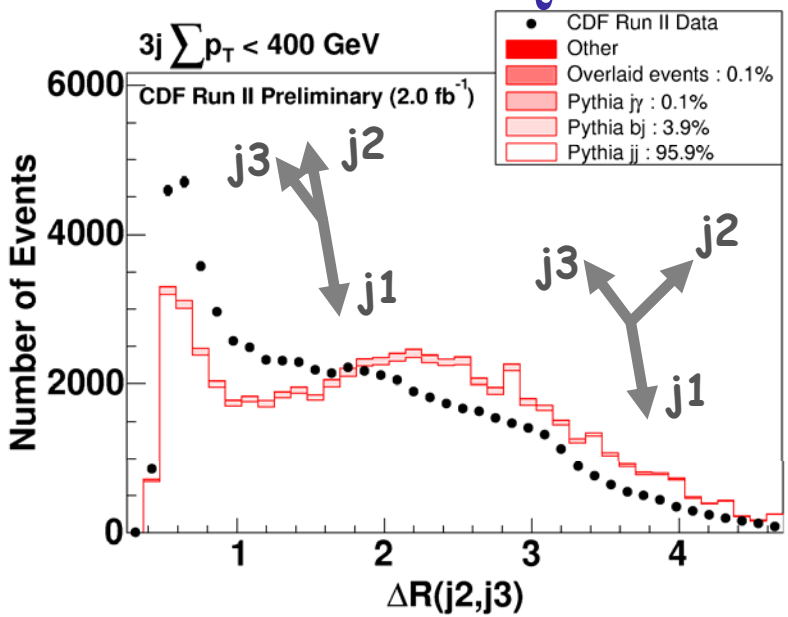
- **Identify physics objects with p_T > 17 GeV**
- **No significant discrepancy in population**
- **Most discrepant distributions are due to difficulty in modeling soft jet emission**



~400 exclusive final states. Compare populations and kinematic distributions.

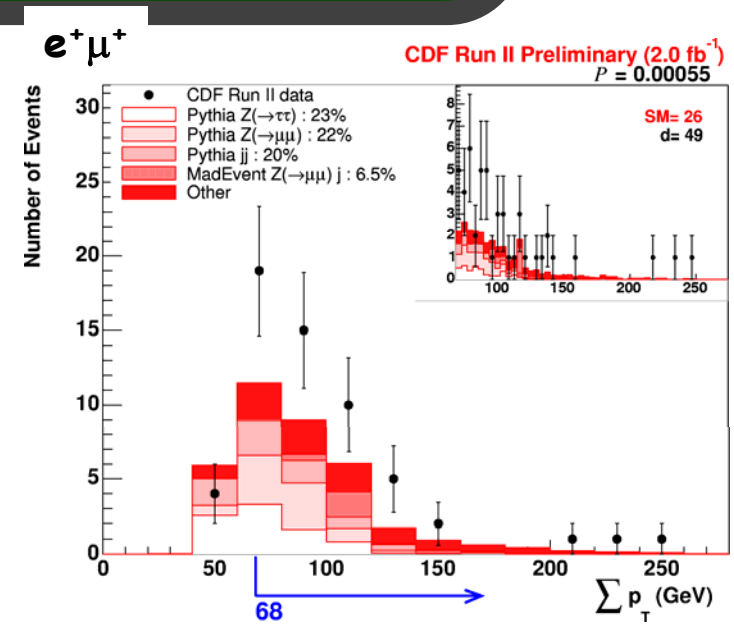


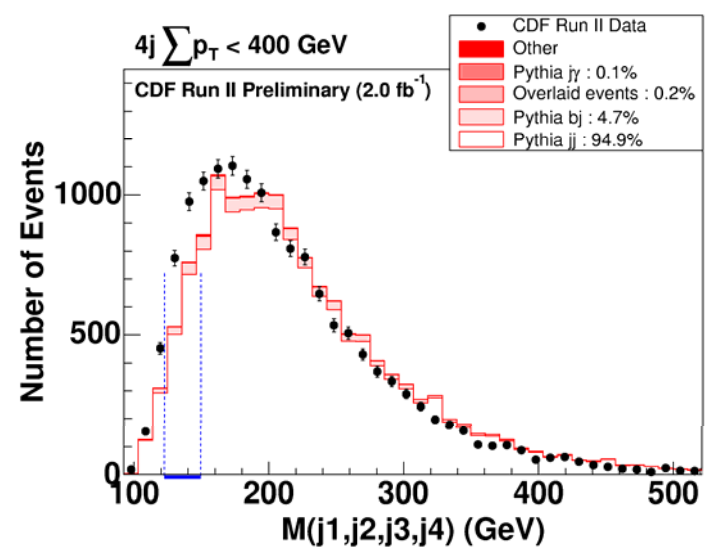
Final State	Data	Background	σ
$be^{\pm}\not{p}$	690	817.7 ± 9.2	-2.7
$\gamma\tau^{\pm}$	1371	1217.6 ± 13.3	$+2.2$
$\mu^{\pm}\tau^{\pm}$	63	35.2 ± 2.8	$+1.7$



Global Search: Sleuth / Bump Hunter

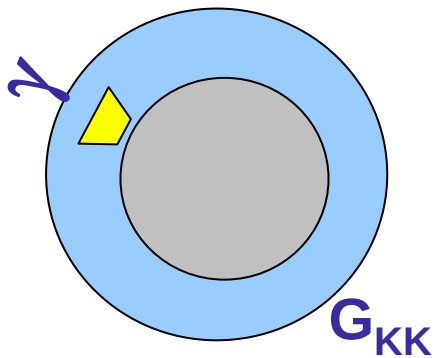
- **Sleuth**
  - Search for excess at high sum- p_T
  - The p-value of the most discrepant excess after taking into account trials factor is 8%
- **Bump Hunter**
  - Search for resonances in invariant mass
  - Search window: 2 X detector mass resolution
  - ~5000 mass distributions
  - Other requirements
    - ≥ 5 data events
    - Verify sideband agree better than the center
  - The only significant bump found is attributed to the ΔR discrepancy in Vista
- **No new physics found**





arXiv: 0805.0742, 0712.2534, 0712.1311

Large Extra Dimension in γ+ MET



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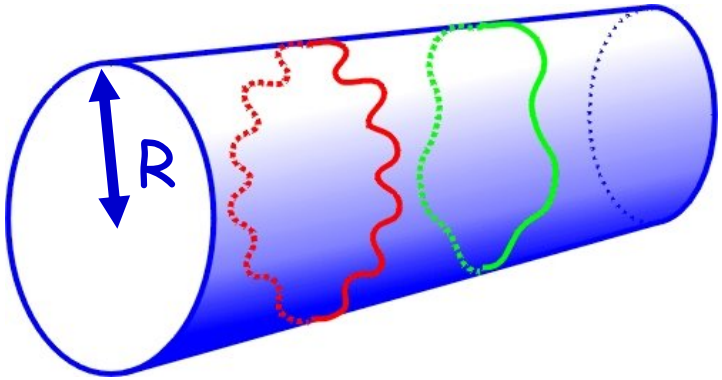
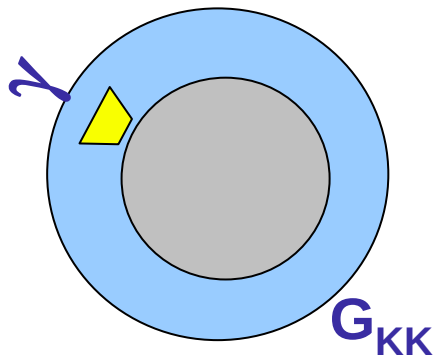




- **Arkani-Hamed, Dimopoulos, Dvali (ADD) model** $q\bar{q} \rightarrow \gamma\, G_{KK}$
  - Aim to solve hierarchy between EW (1 TeV) and Plank scales (10^{16} TeV)
  - n extra large spatial dimensions which are compactified on a scale R
  - SM fields confined to 4-dim, gravtion propagates in the (4+n) bulk
  - Predict fundamental Plank scale M_D at 1 TeV
  - Relate Plank masses in 4-dim to that in (4+n)-dim

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

  - For n ≤ 8, mass splitting small enough to integrate all KK modes (meV-MeV)
  - Kaluza-Klein graviton: stable, non-interacting → MET

Large Extra Dimensions in γ + MET

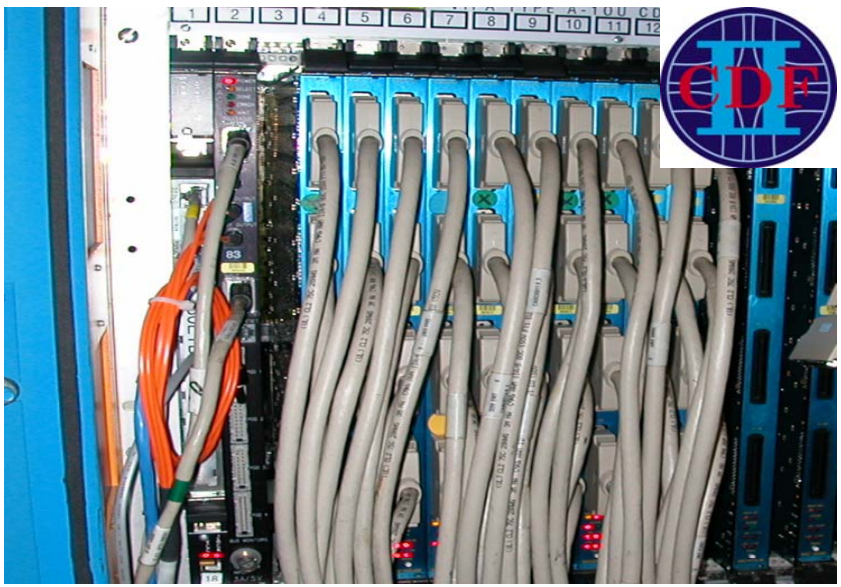
How to suppress cosmics and beam halos?

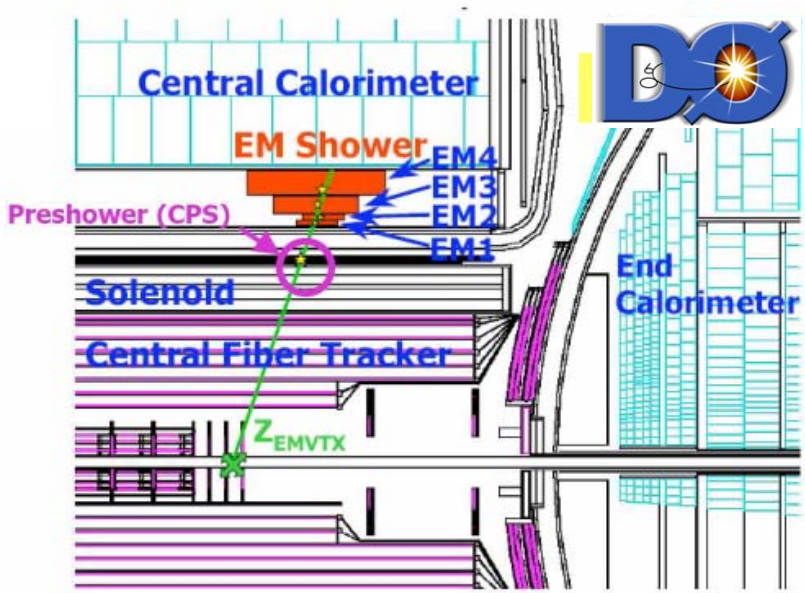
CDF **2.0 fb^{-1}**

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

D0 **1.0 fb^{-1}**

- **EM object pointing from the EM CAL to the beam line**
- **Cut on the distance between photon vertex and the primary vertex (using tracks)**





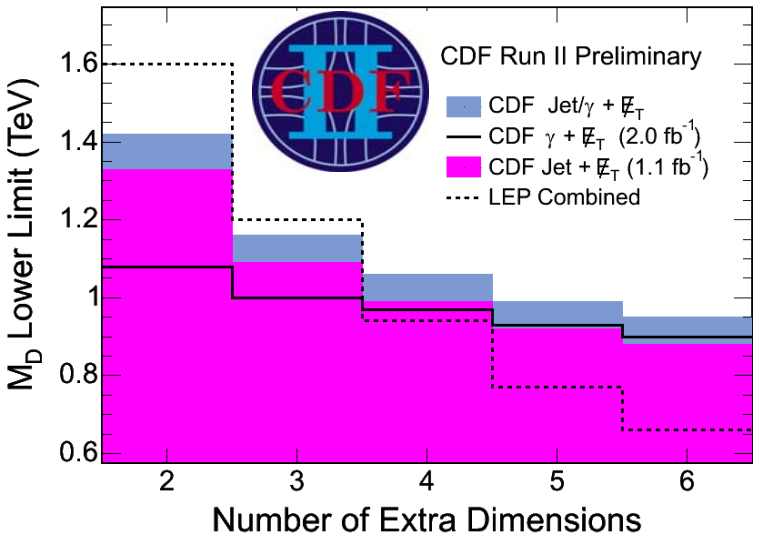
Large Extra Dimensions in γ + MET

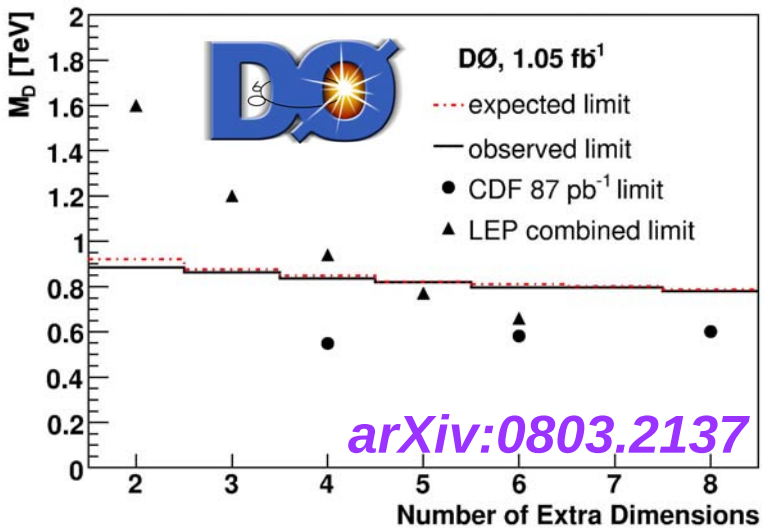
For n=6 *M_D: Plank mass in 4+n-dim*

CDF γMET: M_D > 900 GeV/c^2

D0 γMET: M_D > 797 GeV/c^2

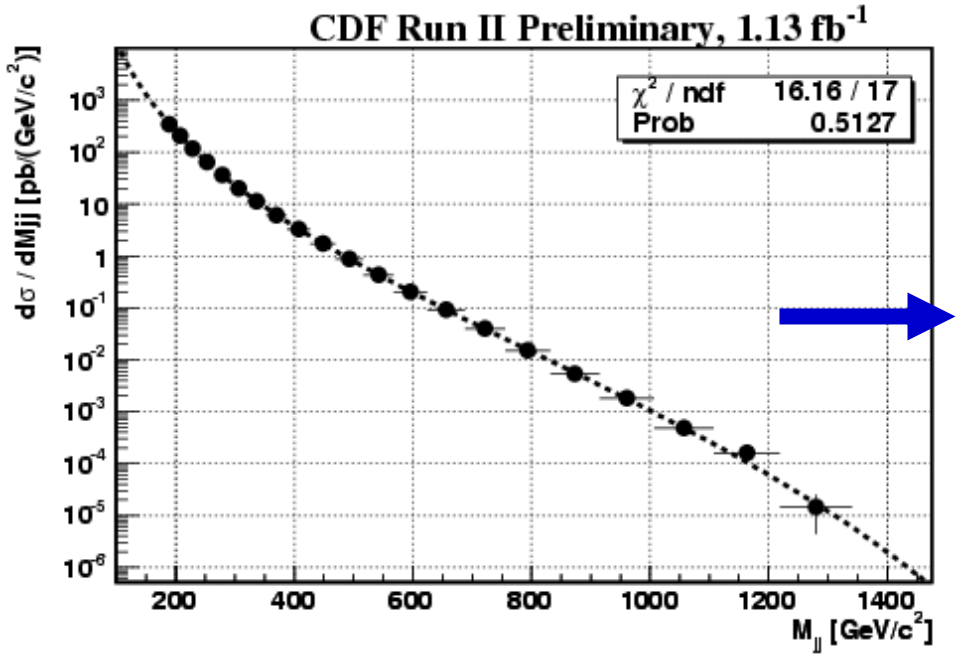
Channel	CDF (2.0 fb^{-1}) MET > 50	D0 (1.1 fb^{-1}) MET > 70
Z $\gamma \to \nu\nu\gamma$	25.2 ± 2.8	12.1 ± 1.3
Non-collision	9.8 ± 1.3	2.8 ± 1.4
Fake Photons	--	2.2 ± 1.5
W → lepton→ γ	3.6 ± 1.2	3.8 ± 0.3
W γ → lost lepton→ γ	5.0 ± 1.4	1.5 ± 0.2
γ γ → γ	2.3 ± 0.6	--
Total	46,3 ± 3.0	22.4 ± 2.5
Data	40	29

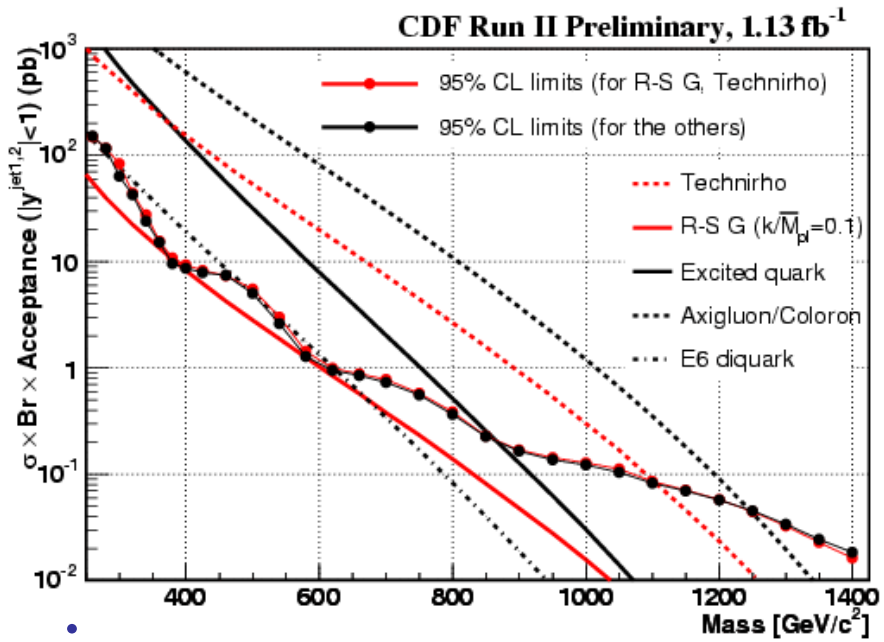




Extended Gauge Bosons and Randall-Sundrum Gravitons

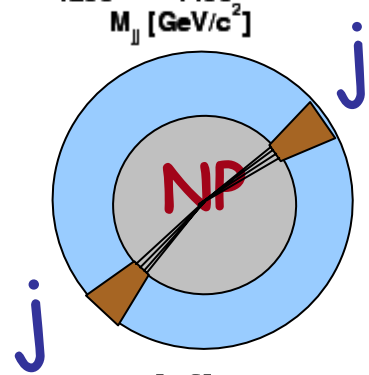
Dijet Resonances in 1.1 fb^{-1}





- **Extension of QCD σ(jj)**

$$X \rightarrow q\bar{q}, gg, qg$$



- **Find excess above background fit**

$$\frac{d\sigma}{dm} = p_0(1-x)^{p_1} / x^{p_2+p_3\log(x)}, \quad x = m/\sqrt{s}$$

World's best limit

Model	Excluded mass
axigluon, coloron	260-1250
E6 diquark	260-630
Color octet Techni- ρ	260-1100
Excited q	260-870

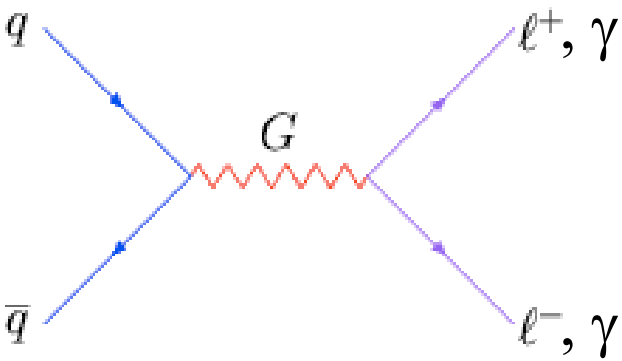
High-mass ee, γγ Resonances

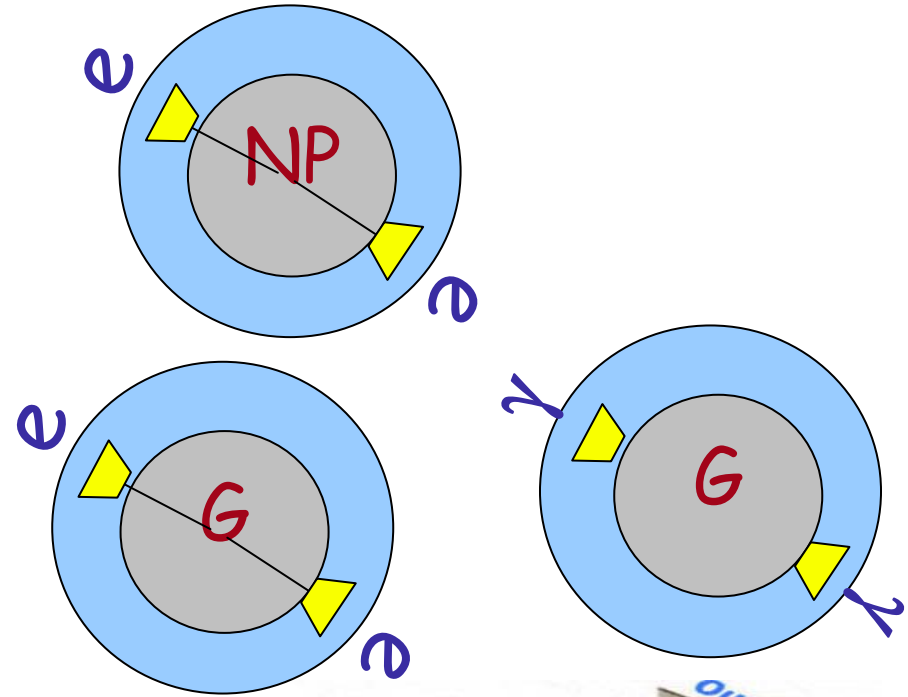
CDF **2.5 fb^{-1} (largest dataset)**

- **NP→ ee**
  - NP = E6 Z', Sequential Z', RS Graviton

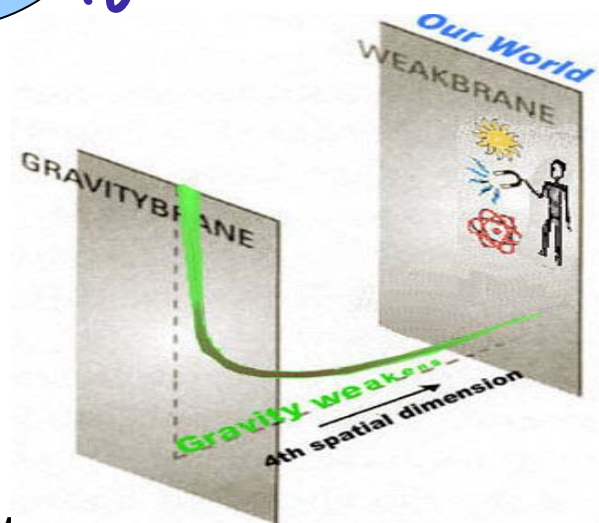
D0 **1.0 fb^{-1}**

- **Randall-Sundrum Graviton**

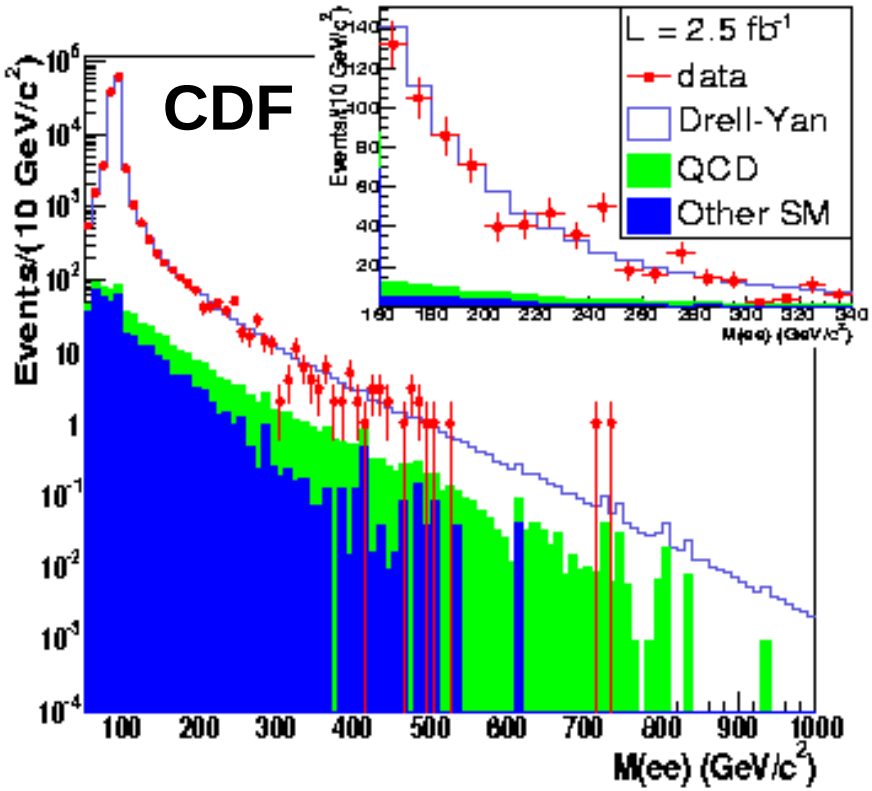


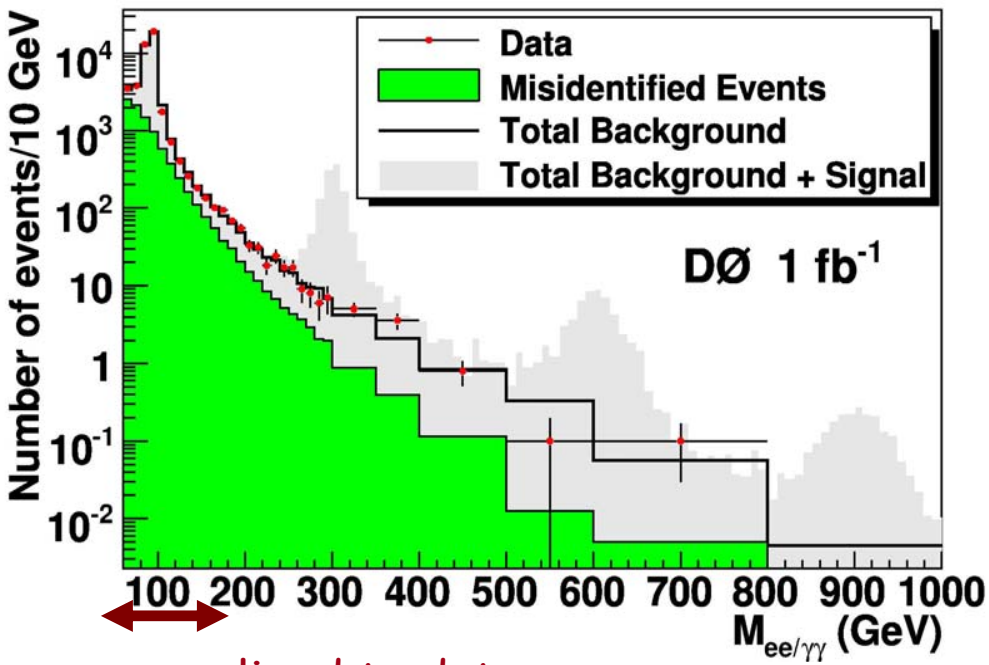


- First massive Kaluza-Klein excitation
- Warped extra dimension, exponential warp factor solves hierarchy problem
- Two branes, TeV and Planck. Gravitons live everywhere, SM confined to TeV brane.



High-mass ee, γγ Spectrum





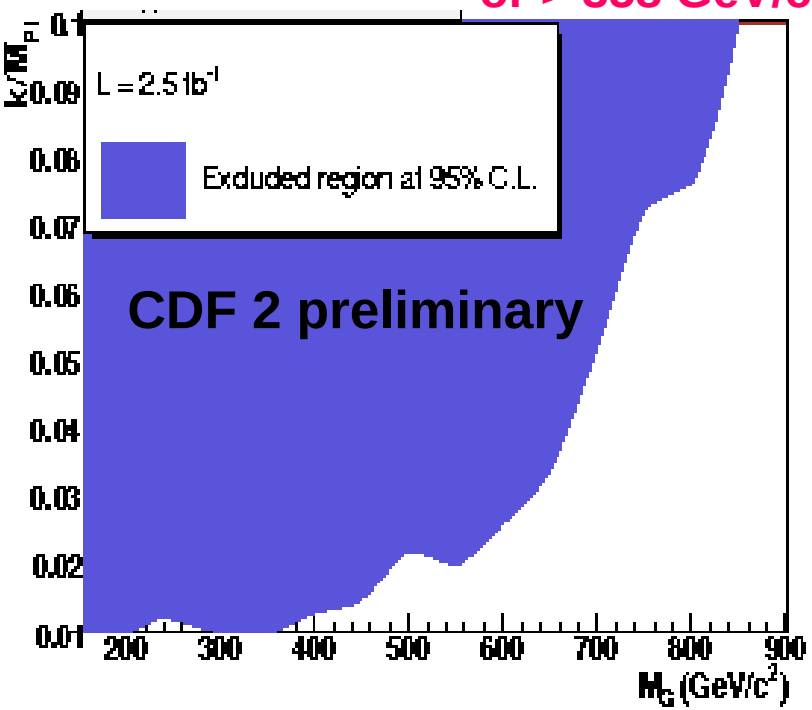
normalized to data

- **CDF: Large excess (3.8 σ) for M_{ee} = 228 – 250 GeV/c²**
  - P value = 0.6% to see a 3.8 σ excess in 150-1000 GeV/c²
  - Significances in sub-samples: 2.9 σ (CC) and 2.7 σ (CF)
- **D0: no excess**

RS Graviton → ee, γγ

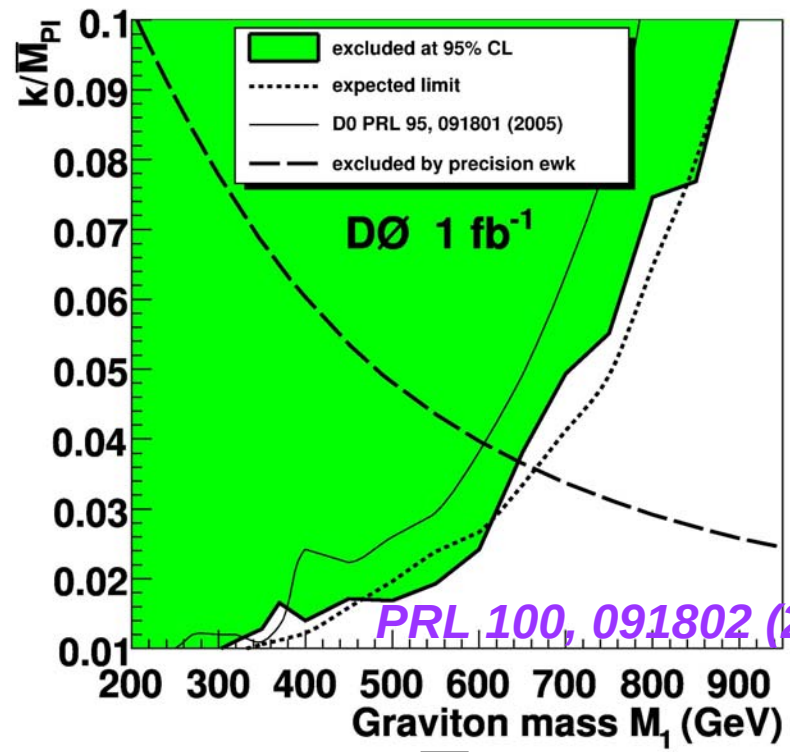
For $k/\overline{M}_{pl}$=0.1, M_1 >850 GeV/c^2

For $k/\overline{M}_{pl}$=0.01, 236< M_1 <257 GeV/c^2 or > 358 GeV/c^2



For $k/\overline{M}_{pl}$=0.1, M_1 >900 GeV/c^2

For $k/\overline{M}_{pl}$=0.01, M_1 >300 GeV/c^2

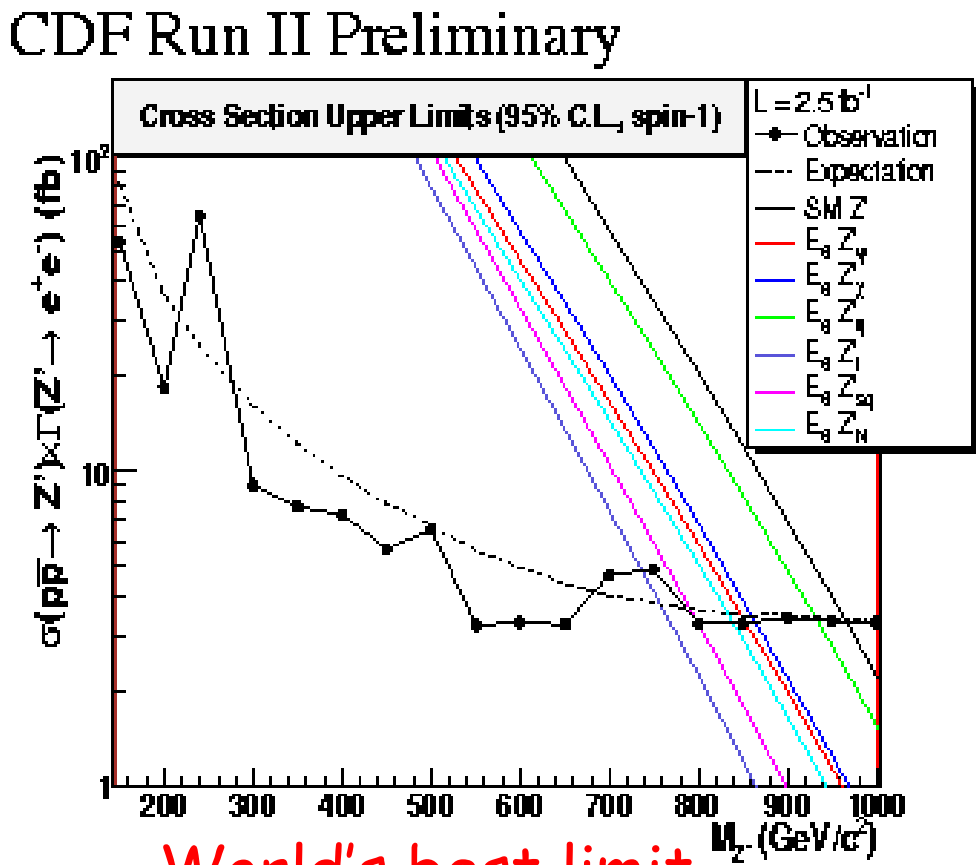


PRL 100, 091802 (2008)

- **Set limit on M_1 and the coupling to the SM fields, $k/\overline{M}_{pl}$**
  - K: warp factor which gives the ED curvature
  - Reduced Plank scale

$$B(G_{RS} \to \gamma\gamma) = 2 \cdot B(G_{RS} \to ee)$$

Limits on Masses of Z' Bosons



World's best limit

Model	Z'_{SM}	Z'_{Ψ}	Z'_{χ}	Z'_{η}	Z'_{I}	Z'_{sq}	Z'_{N}
Exp	965	849	860	932	757	791	834
Obs	966	853	864	933	737	800	840

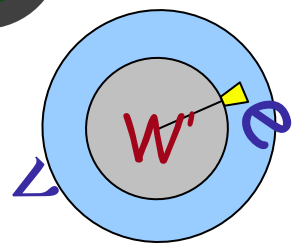
W'→e$\bar{\nu}$ in 1.0 fb^{-1}

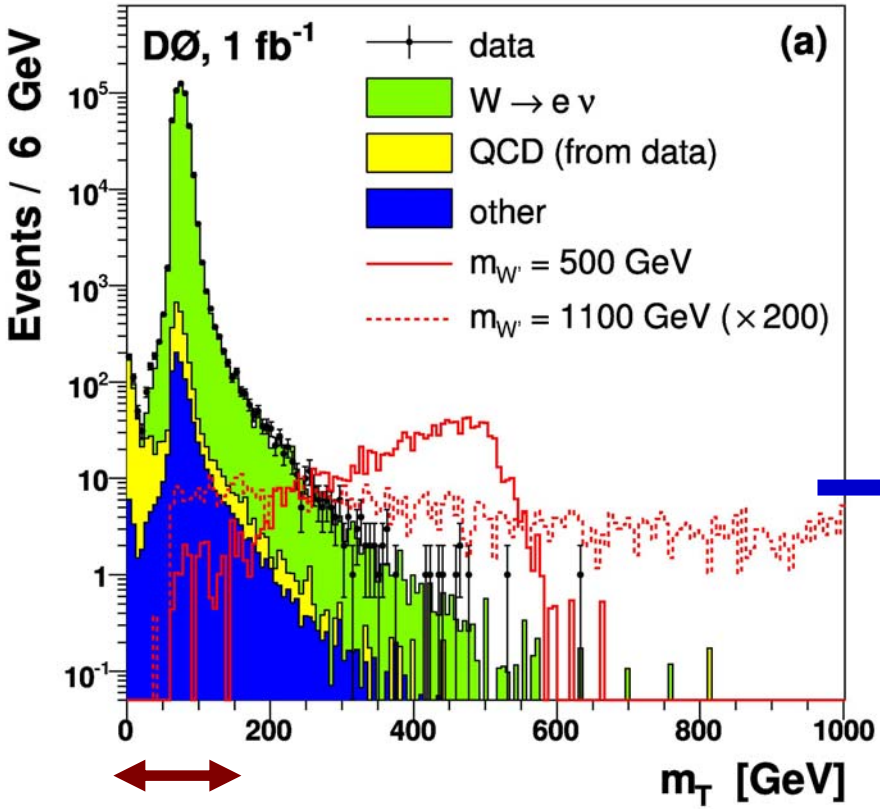
- E6, L-R symmetric model, Altarelli Reference Model
- No excess seen

- Set limit using M_T

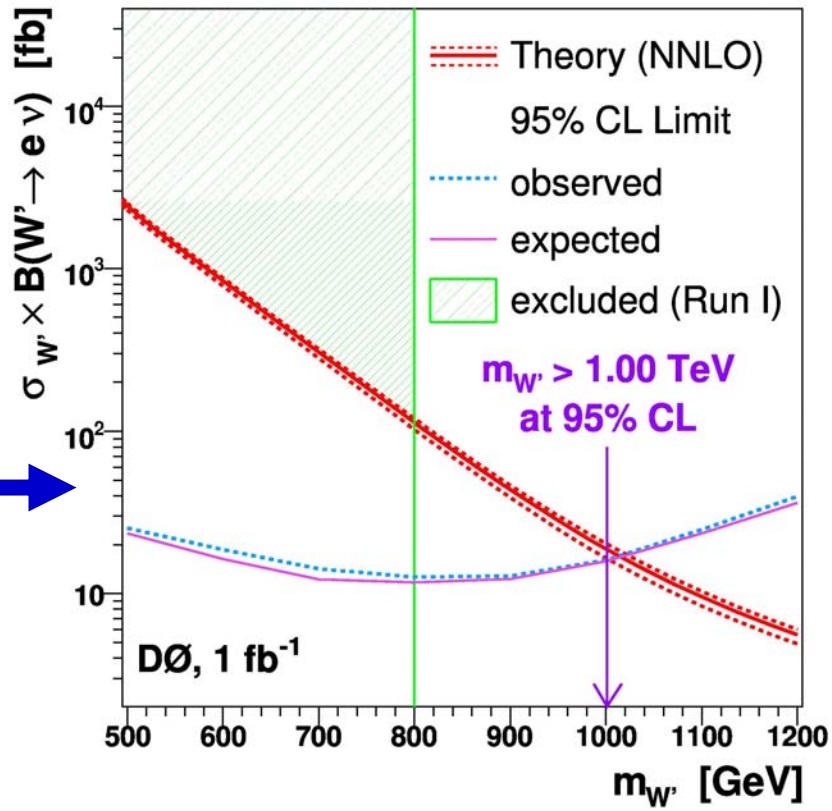
World's best limit

M(W') > 1.0 TeV/c^2



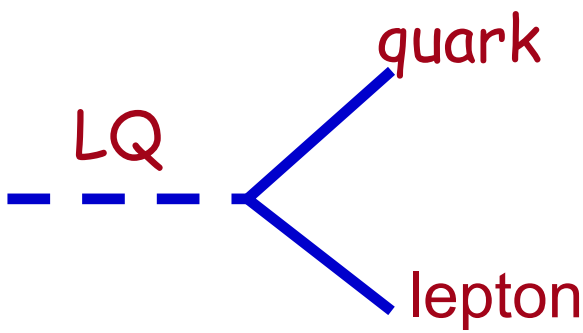


normalized to data



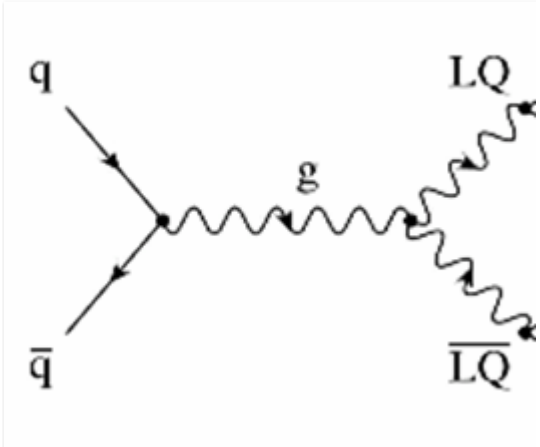
PRL 100, 031804 (2008)

Pair Production of Scalar Leptoquarks



Leptoquarks

- **Couples directly to a quark and a lepton**
- **Carry both a baryon and a lepton number**
- **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**
- **Couples to a single generation**
- **Focus on pair production**
  - qq or gg
  - Cross-section only depends on M_{LQ}



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

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

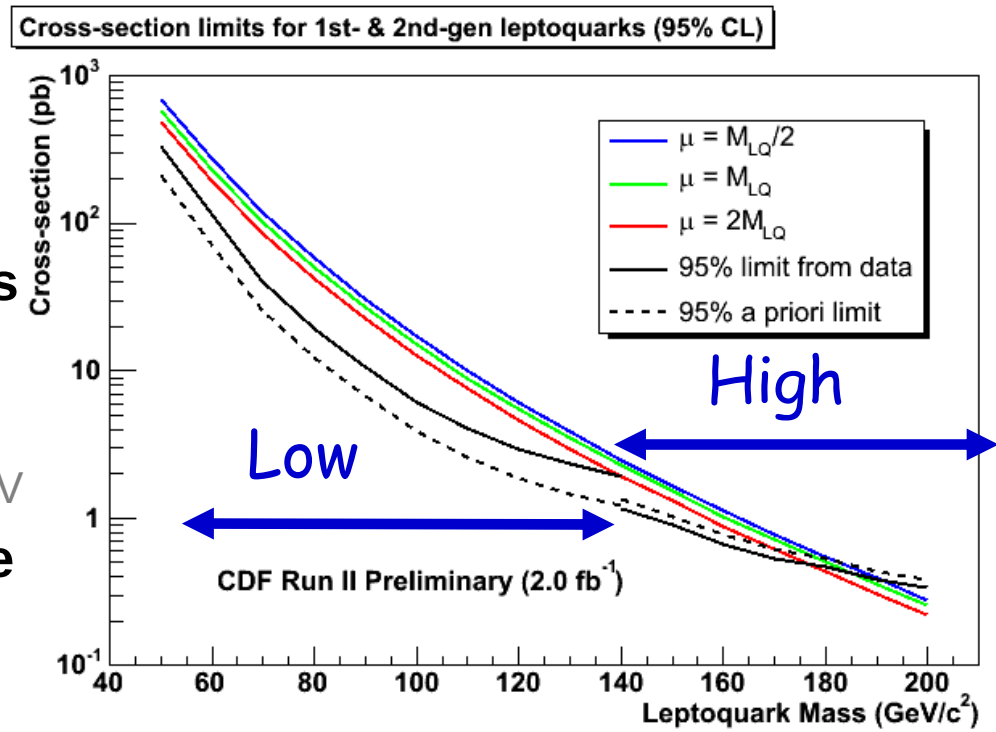
$$\sigma(\ell\ell jj) \propto \beta^2$$

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

Scalar LQs to dijet + MET in 2.0 fb^{-1}

- **Started as signature-based**
  - Leptoquark
  - Little Higgs (T-parity conserved)
  - UED (K-parity conserved)
  - MSSM (R-parity conservd)
- **Veto lepons and 3rd energetic jets**
- **Two kinematic regions**
  - Low: $\Sigma E_T(j) > 125$ GeV, MET > 80 GeV
  - High: $\Sigma E_T(j) > 225$ GeV, MET > 100 GeV
- **Data-driven background estimate**
  - $Z \rightarrow \nu\nu$ + jets
  - $W \rightarrow l\,\nu$ +jets with missing lepton
- **Set limits on 3 generations of LQs with Q=1/3, 2/3, β = 0**

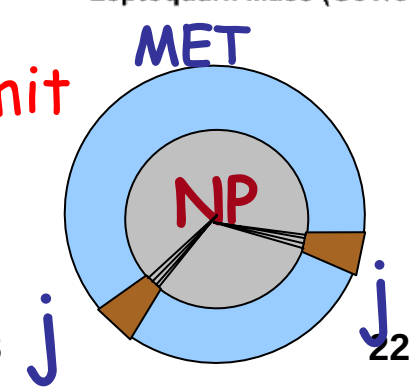
$$LQ\overline{LQ} \rightarrow \nu\, q\, \bar{\nu}\, \bar{q}$$



World's best limit

For m= $2M_{LQ}$, $M(LQ_1)$ or $M(LQ_2)$ > 177 GeV/c^2

$M(LQ_3)$ > 167 GeV/c^2

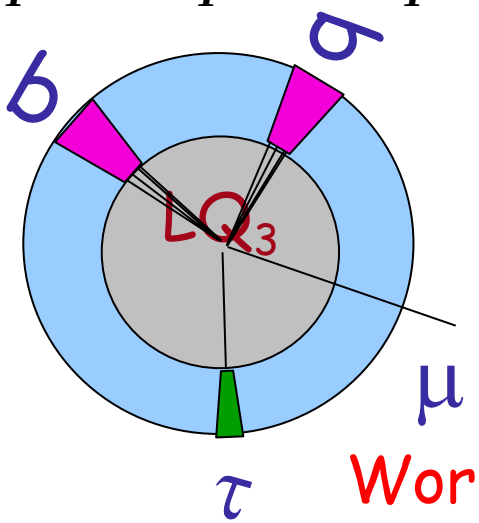


3rd-Gen Scalar LQs to ττbb in 1.1 fb^{-1}

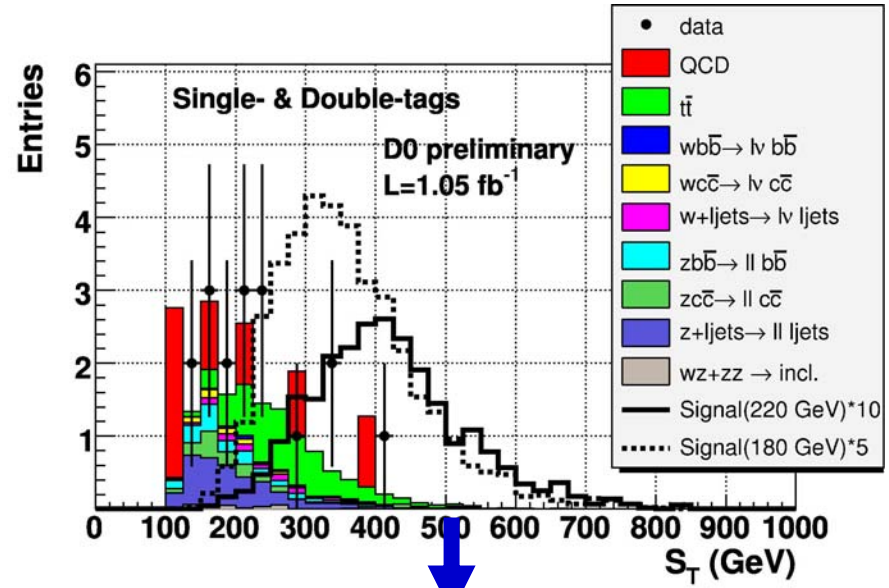
$$LQ_3\,\overline{LQ_3} \rightarrow \tau^- b\,\tau^+ \bar{b}$$

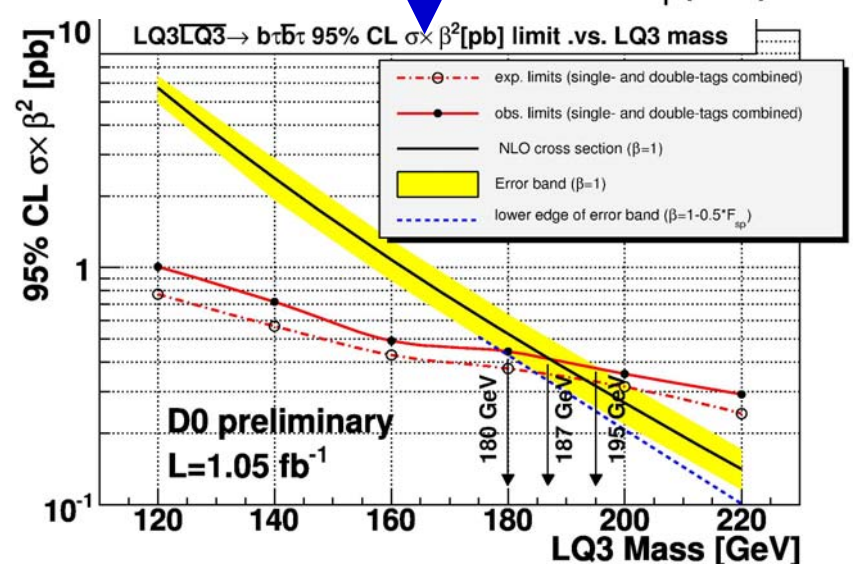
$$\tau_1 \rightarrow \mu\,\bar{\nu}\,\nu\,,\ \tau_2 \rightarrow \nu + hadrons$$

$$S_T = E_T^{\tau_1} + E_T^{\tau_2} + E_T^{j_1} + E_T^{j_2}$$



World's best limit





- **For m= 2M$_{LQ}$, M(LQ$_3$) > 180 GeV/c^2**
  - Charge= 4/3, 2/3 LQ, β = 1
  - For Q =2/3, LQ→ t ν is allowed, only suppressed by phase space
  - BR(LQ→τb) = 1 – 0.5 * Fsp

Other Models

Same-sign Top Pairs in 2.0 fb^{-1}

NEW !

By S. Bar-Shalom, A. Rajaraman

- **In Maximum Flavor Violation, a new scalar couples to quarks in an opposite way of CKM matrix**

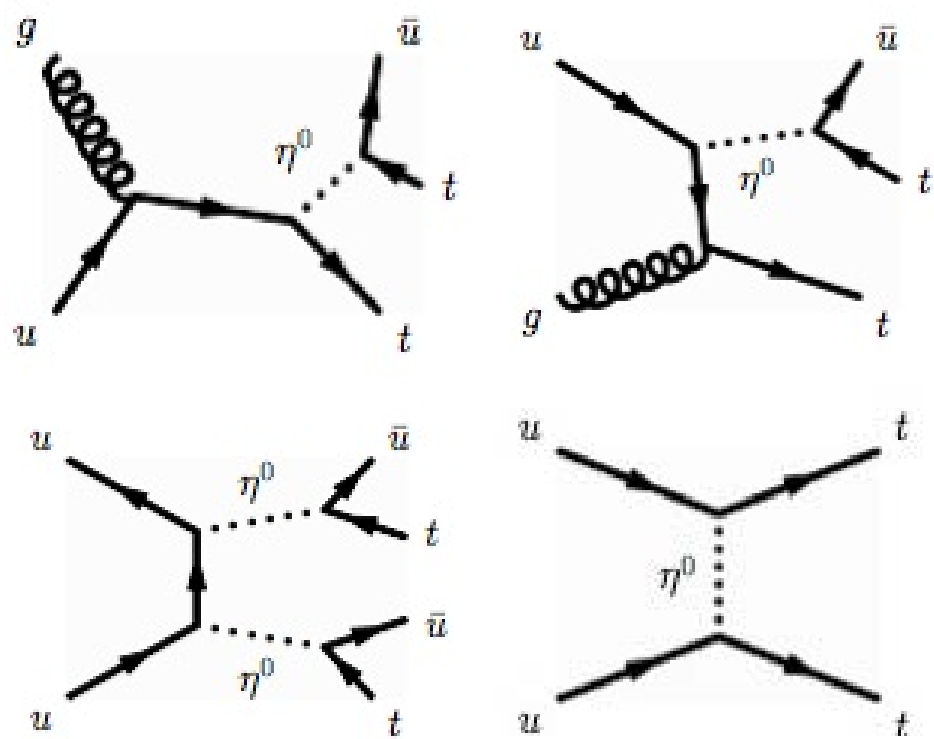
$$\Phi_{FV} \equiv \left(\eta^{+}, \eta^{0}\right)$$

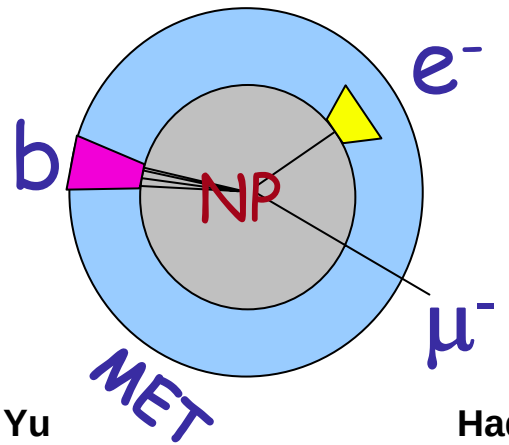
$$\xi_{i3}, \xi_{3i} \sim V_{tb} \quad for \;\; i = 1 \; or \; 2$$

$$\xi_{33} \sim V_{td}$$

- **Scenario** $m(\eta^{+}) >> m(\eta^{0})$

$$\xi = \xi_{13} = \xi_{31} >> \xi_{23,32} >> \xi_{33}$$



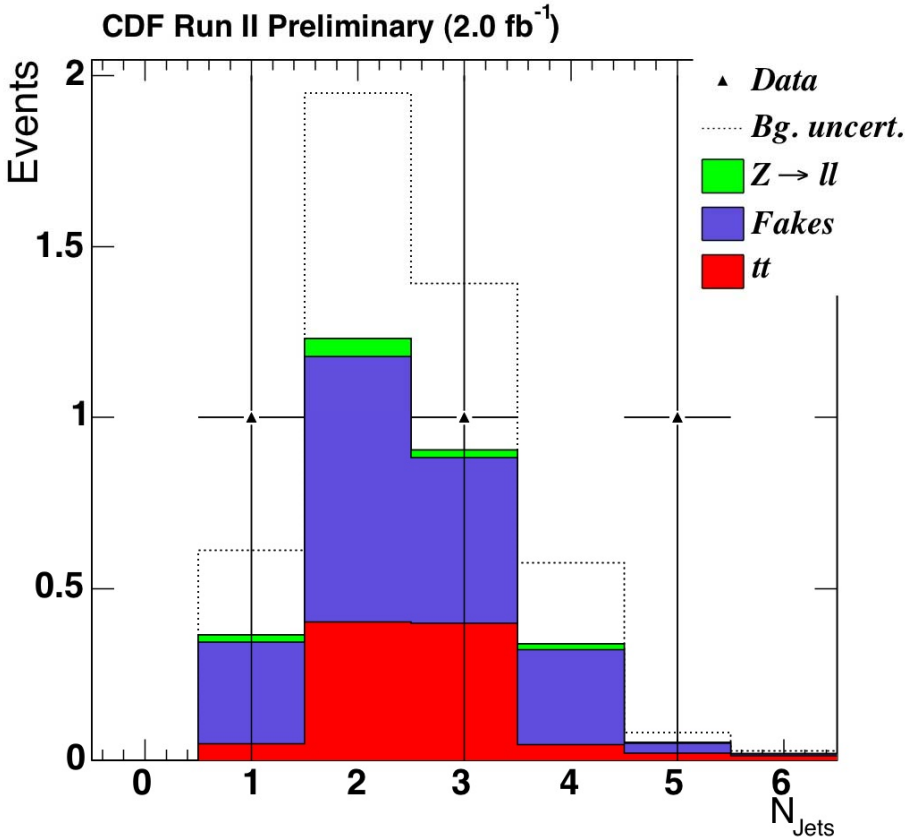


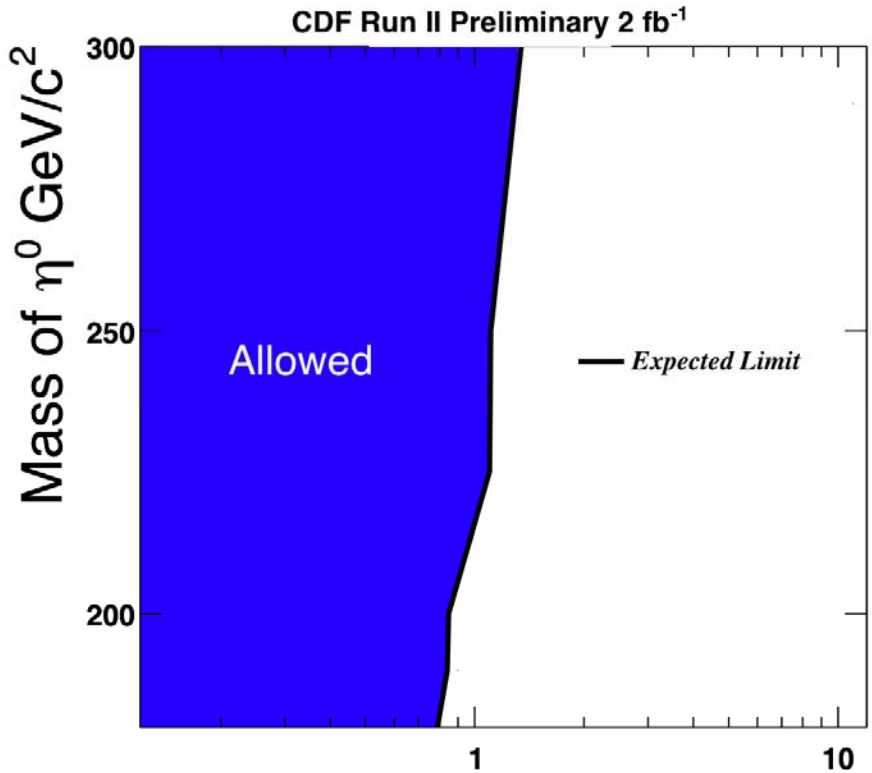
$$p\bar{p} \rightarrow \ell^{\pm}\ell^{\pm}\not{E}_T bb \; + \textbf{ n jets}$$

arXiv/0711.3193 *arXiv/0803.3795*

Same-sign Top Pairs in 2.0 fb^{-1}

NEW !

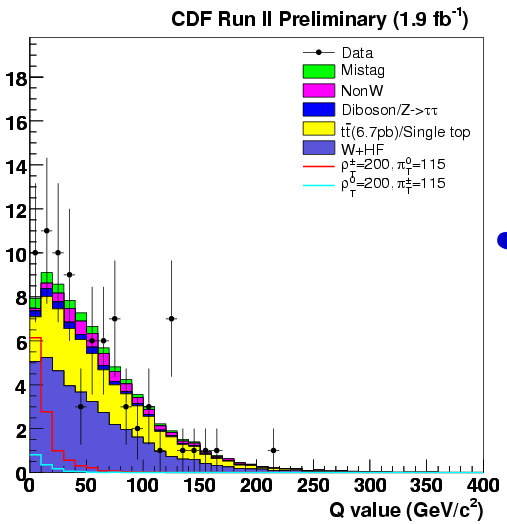


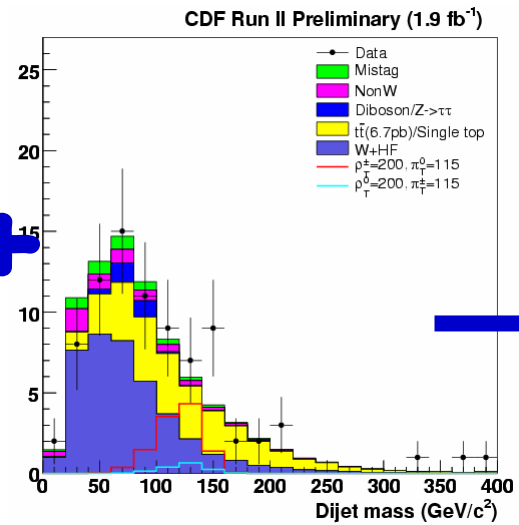


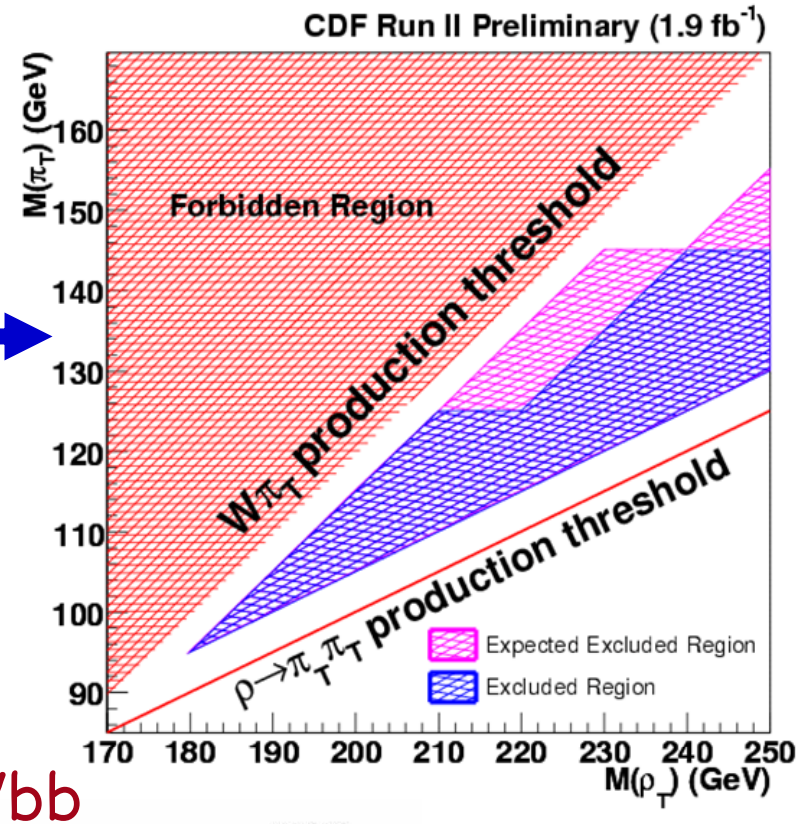
For $m_{\eta 0}$ ~ 200 GeV, ξ<0.85

- For ξ ~ 1 & $m_{\eta 0}$ ~ 200 GeV, 11 MxFV events expected
- No excess. 2.9±1.8 (exp) vs. 3 (obs)

Technicolor $\rho^{\pm}$ and ρ^{0} in 1.9 fb^{-1}

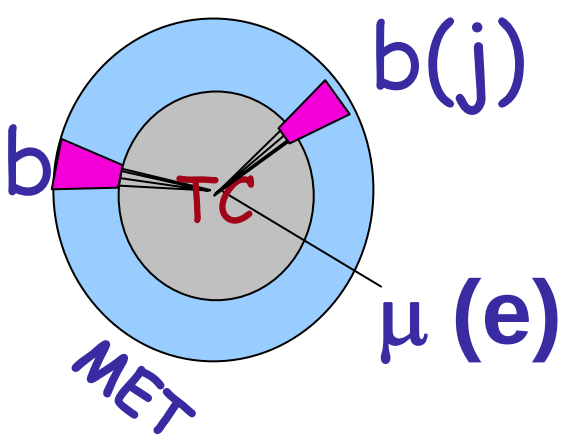




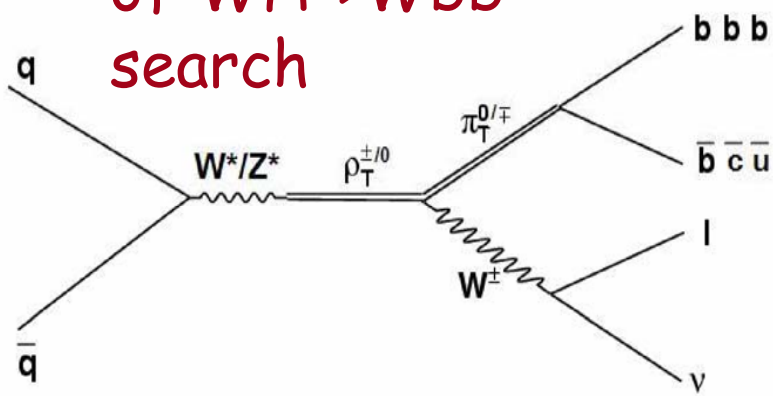


$$Q = M_{\rho_T} - M_{\pi_T} - M_W$$

M(bj)



Extension of WH->Wbb search

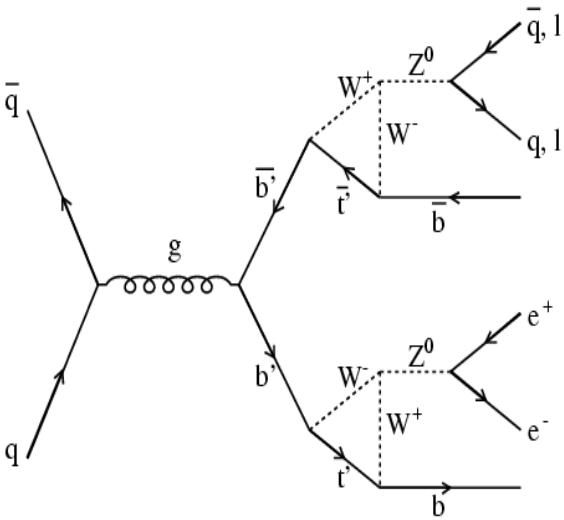


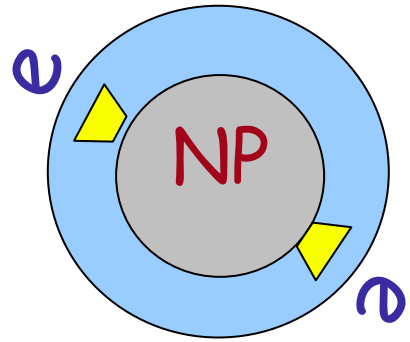
Technicolor Straw Man
Phys. Rev. D60 075007

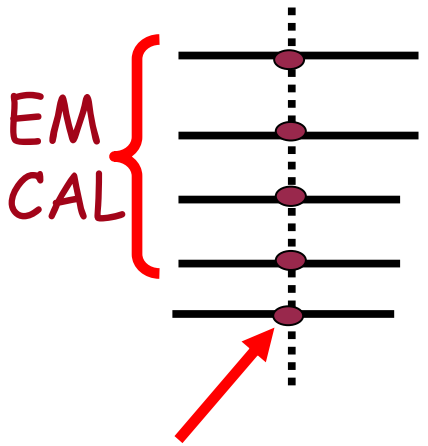
See poster by Y. Nagai

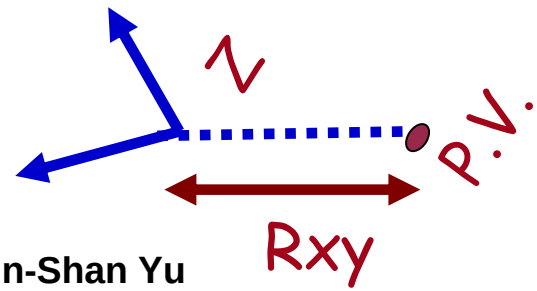
Long-lived Particles → Z + X in 1.1 fb^{-1}

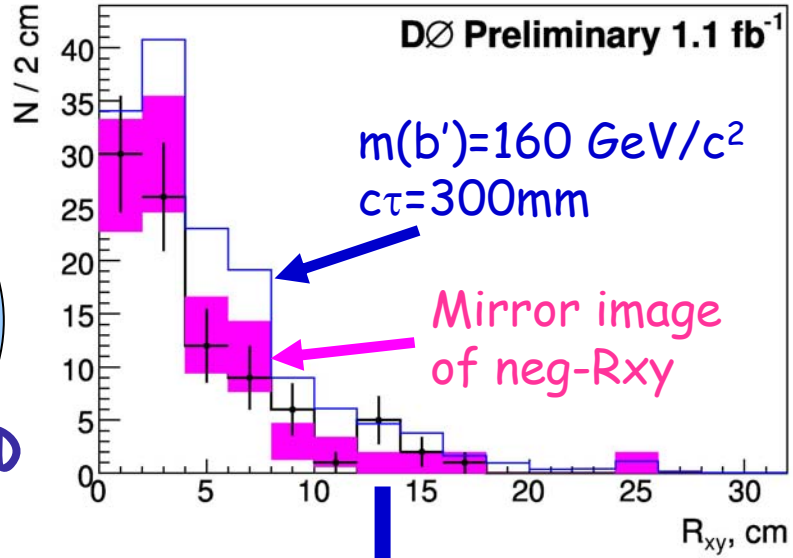
- **Predicted by several models**
  - Long-lived 4th generation b' quark
  - GMSB
  - Extended Higgs sector
  - Hidden-valley model

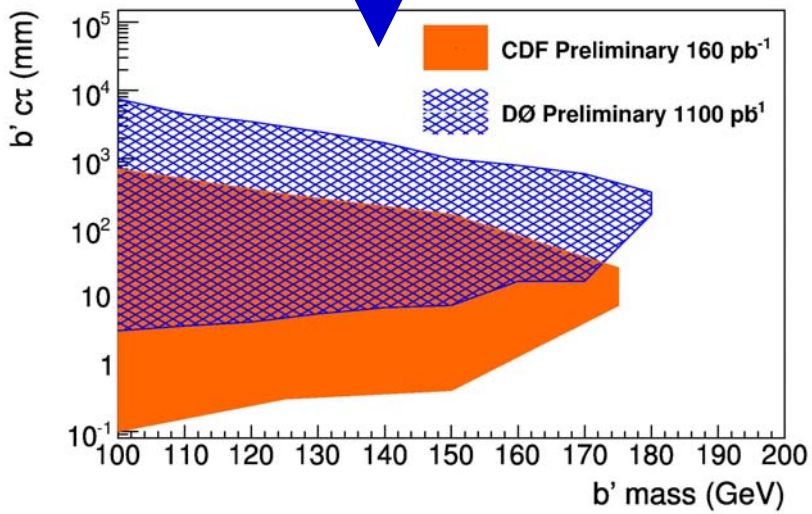




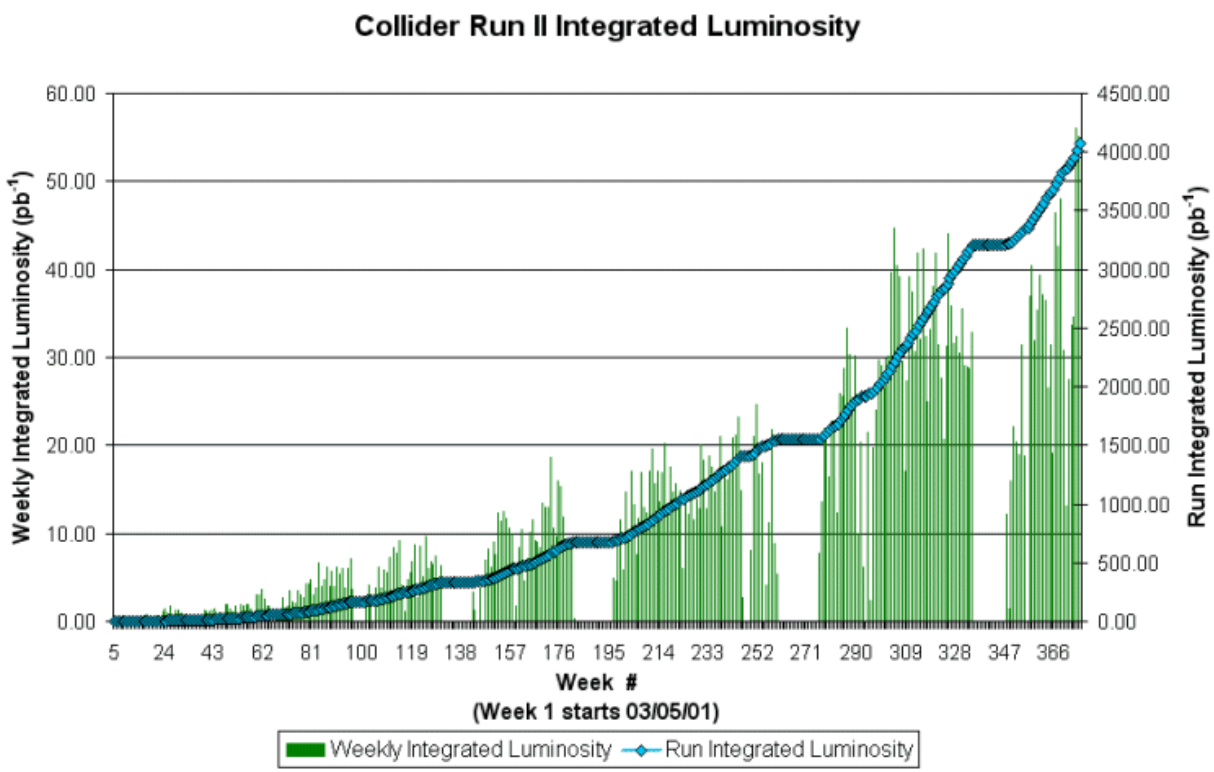








Conclusion



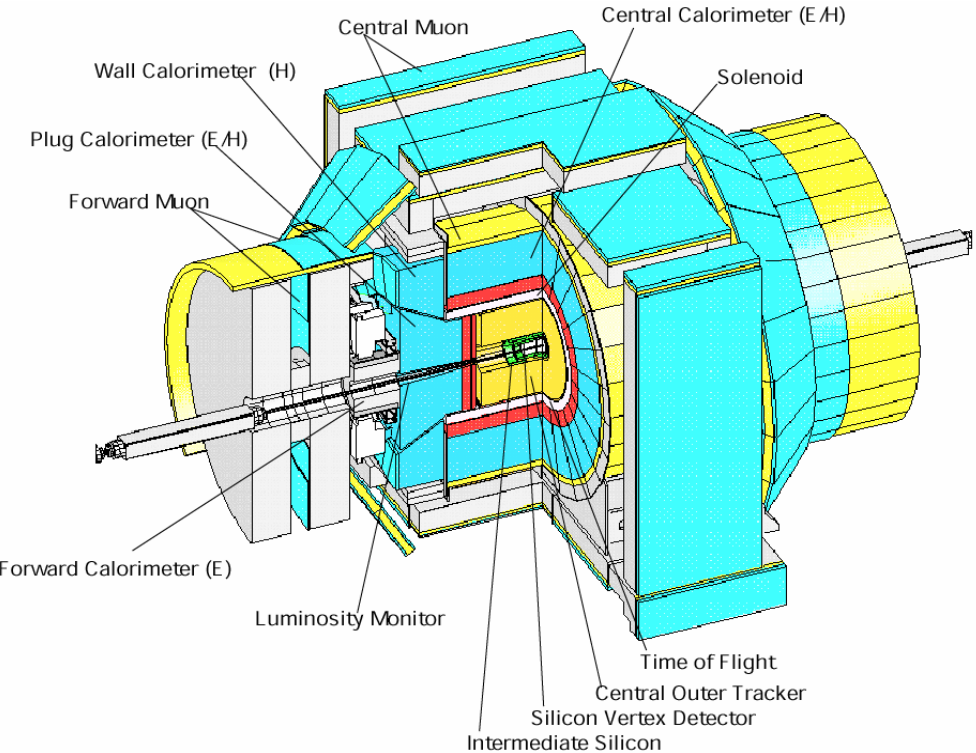
- **Both CDF and D0 have broad programs to look for evidence of new physics**
- **No significant excess in 1-2.5 fb^{-1} of data**
  - But some indications of new physics may be understood with more data
- **More data are coming!**

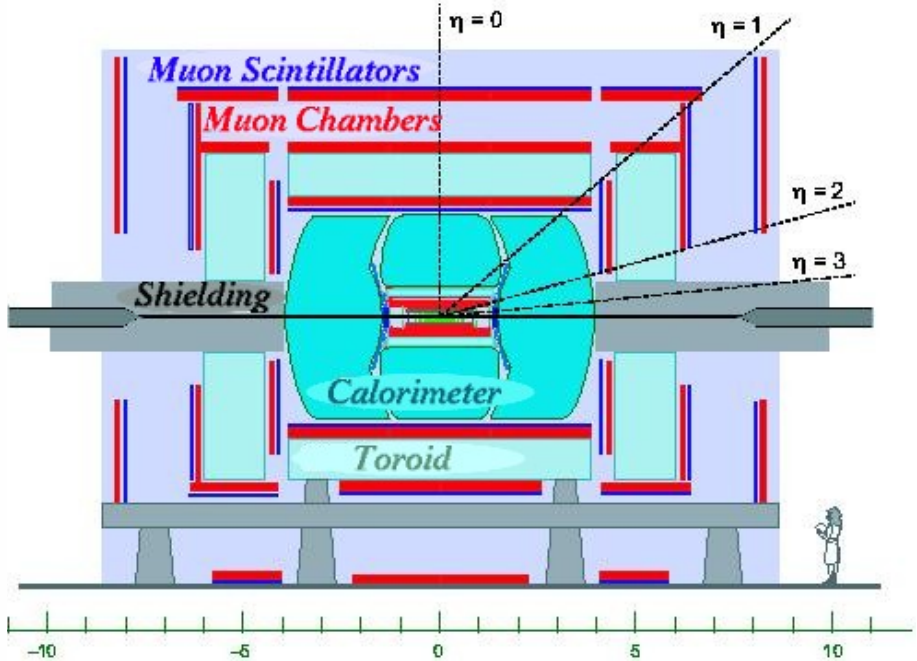
What We Want to Cover

Every BSM model and those not yet thought of

Backup Slides

Detectors





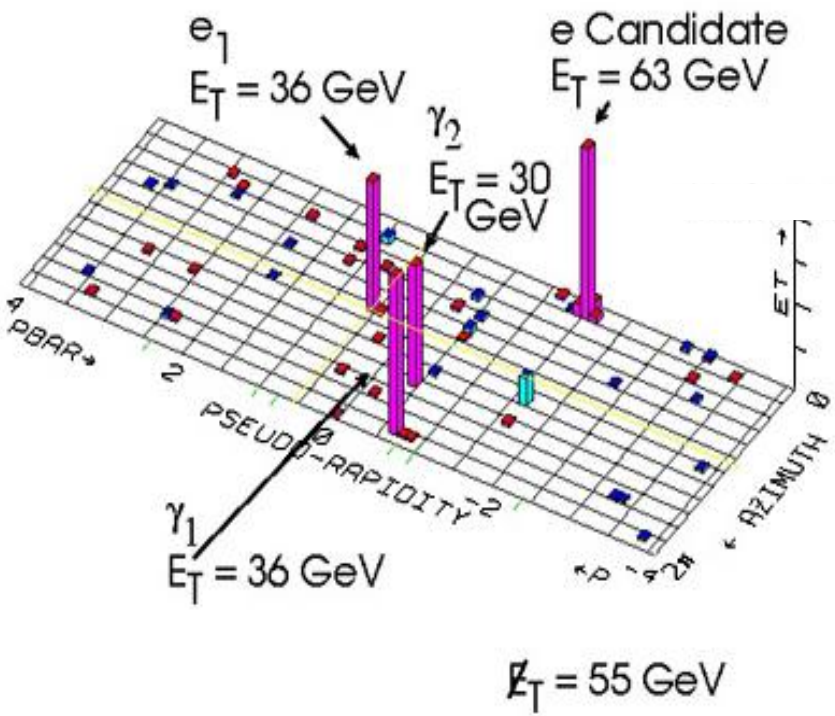
- **Multi-purpose detector: tracking chamber, EM (ECAL) and Had calorimeters (HCAL), and muon chamber**

Why Photons?

- **CDF Run I $\mu\gamma$+MET excess**
  - 86 pb^{-1}
  - 11 observed
  - 4.2 ± 0.5 expected
  - ***PRL 89, 041802 (2002)***

- **CDF Run I ee$\gamma\gamma$+MET event**
  - 86 pb^{-1}
  - Dominant SM from WW$\gamma\gamma$:

  8×10^{-7} events
  - Total Bg: 10^{-6} events
  - ***PRL 81, 1791 (1998)***



Mee= 163 GeV/c^2
Mee$\gamma\gamma$= 232 GeV/c^2
Mee$\gamma\gamma$MET=307 GeV/c^2

A hint of new physics?

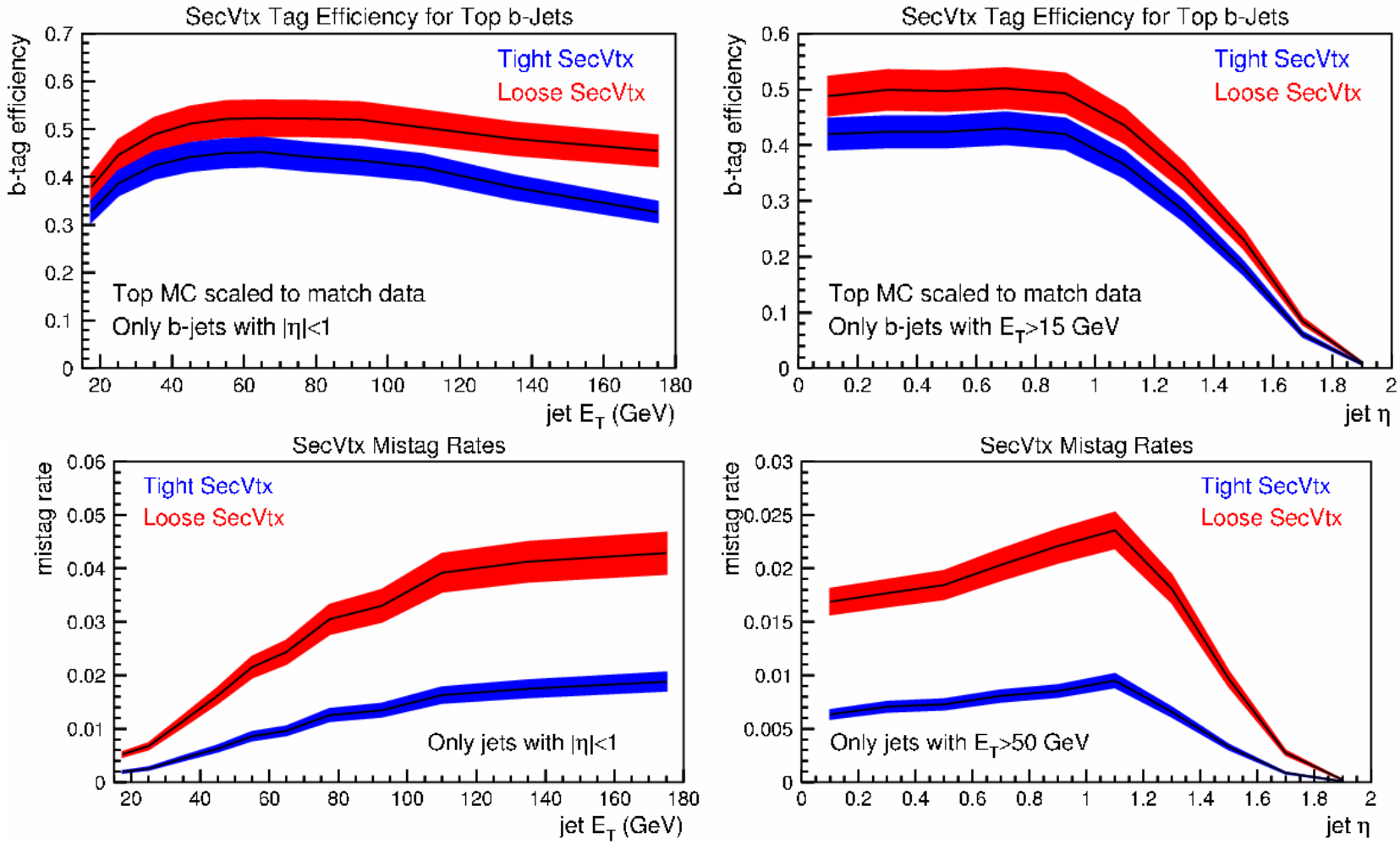
Anomalous Production of γ b MET+ X

NEW !

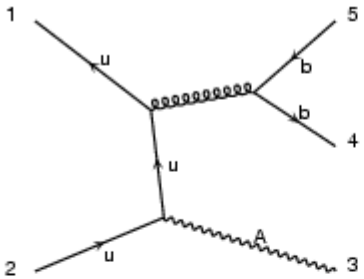
- **X = jets, mostly fakes**
- **Selection in 2.0 fb^{-1} data**
  - $E_T(\gamma) > 25$ GeV, $|\eta| < 1.1$
  - ≥ 2 jets with $E_T > 15$ GeV, $|\eta| < 2.0$
  - ≥ 1 tight b-tag (eff 40%)
  - MET > 25 GeV, $\Delta\phi$(jet $\rightarrow$MET)>0.3
- **No excess in 15 distributions**

- **X = lepton (e, μ)**
- **Selection in 1.9 fb^{-1} data**
  - $E_T(\gamma) > 10$ GeV, MET > 20 GeV
  - ≥ 1 loose b-tag (eff 50%)
  - 1 lepton $p_T > 20$ GeV, $|\eta| < 1.0$
  - $H_T > 200$ GeV, $N_{jets} > 2$ (for $t\bar{t}+\gamma$)
- **Measure $\sigma(t\bar{t}\gamma) = 0.15 \pm 0.08$ pb**
  - NLO $\sigma = 0.080 \pm 0.012$ pb

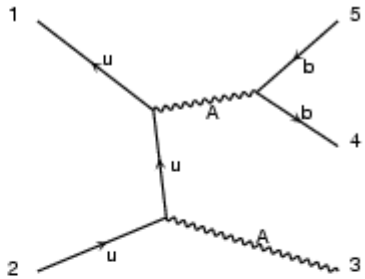
Tight and Loose b-tagging



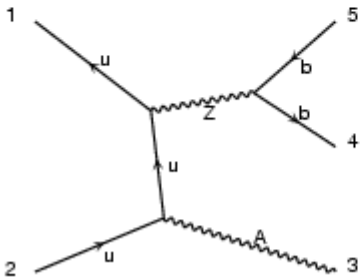
Anomalous Production of γ b j MET



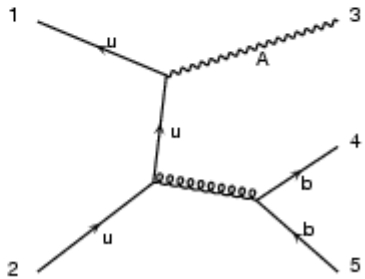
graph 1



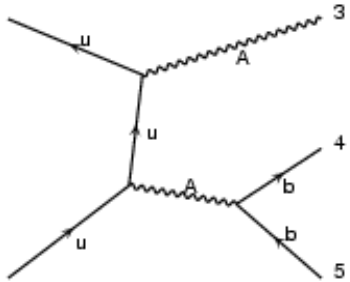
graph 2



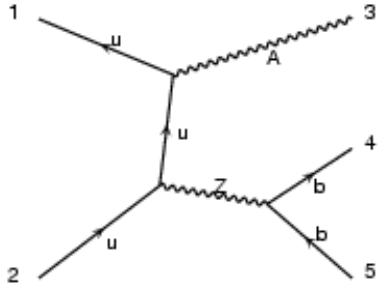
graph 3



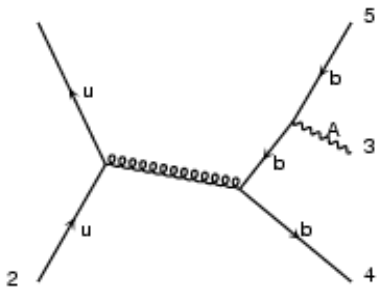
graph 4



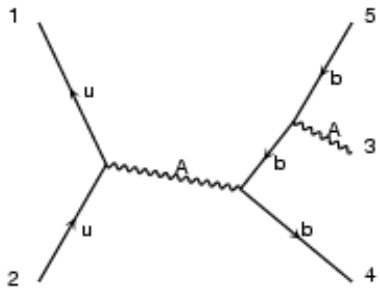
graph 5



graph 6



graph 7

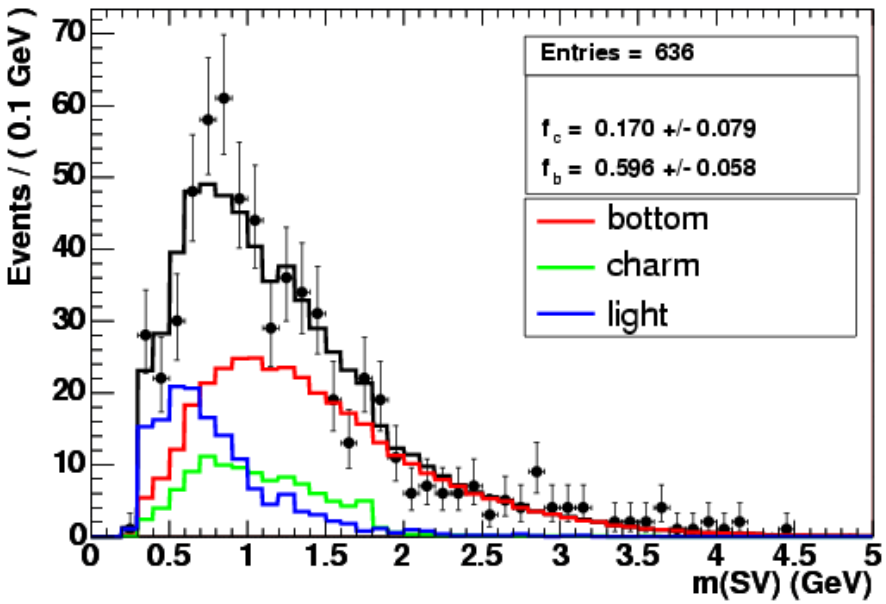


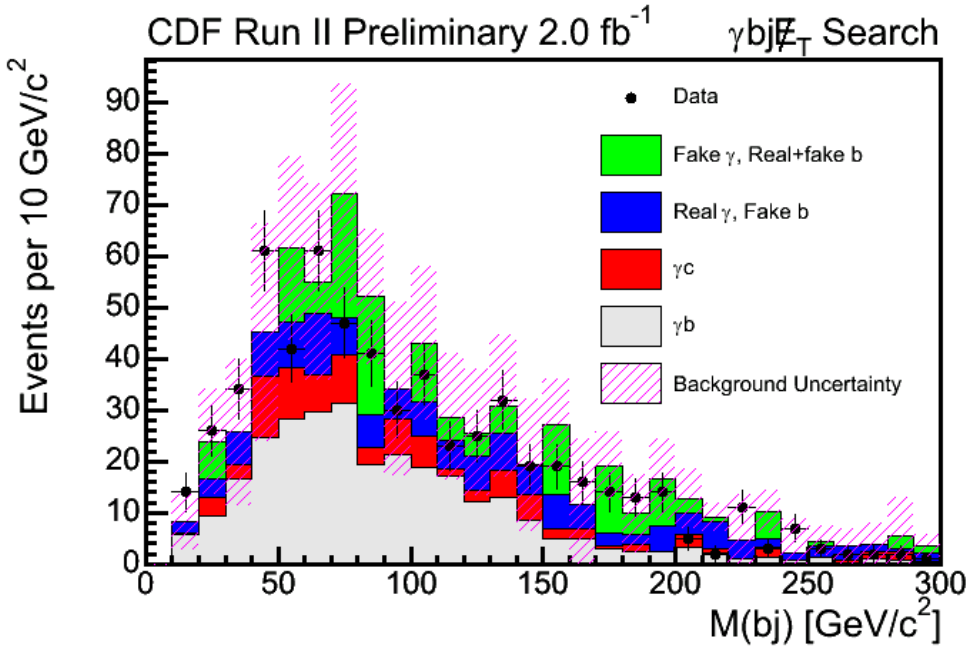
graph 8

Anomalous Production of γ b j MET

$$\tilde{\chi}_i^+ \tilde{\chi}_2^0 \rightarrow (\tilde{t}\bar{b})(\gamma\tilde{\chi}_1^0) \rightarrow (c\bar{b}\tilde{\chi}_1^0)(\gamma\tilde{\chi}_1^0)$$

$$\tilde{\chi}_i \tilde{\chi}_j \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \gamma G\, hG \rightarrow \gamma G\, b\bar{b}G$$





Anomalous Production of γ b j MET

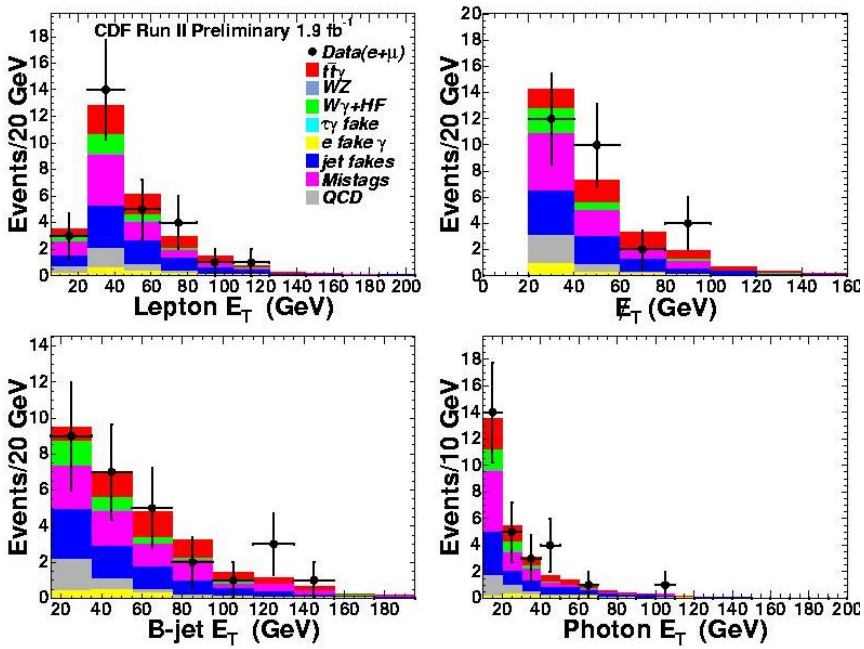
Background Source	Number	Statistical Uncertainty	Systematic Uncertainty
γb	291	7	50
γc	92	25	45
Fake b, real γ	141	6	30
Fake γ	113	49	54
Total	637	54	128

TABLE III: Number of predicted background events in the signal region.

Anomalous Production of γ b MET+ X

NEW !

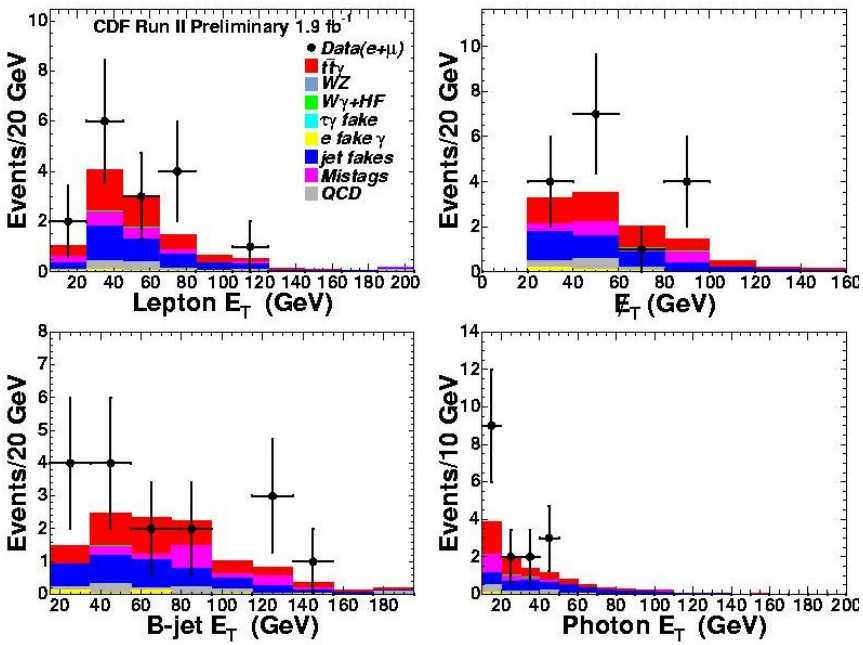
$$t\bar{t} \rightarrow Wb\tilde{t}\tilde{\chi}_i \rightarrow Wbc\tilde{\chi}_i\tilde{\chi}_j \rightarrow Wbc\tilde{\chi}_0\tilde{\chi}_0\gamma + X$$



CDF Run II Preliminary, 1.9fb^{-1}			
Lepton + Photon + $\not{E}_T$ + b Events			
SM Source	$e\gamma b\not{E}_T$	$\mu\gamma b\not{E}_T$	$(e+\mu)\gamma b\not{E}_T$
$t\bar{t}\gamma$ semileptonic	2.06 ± 0.38	1.52 ± 0.28	3.58 ± 0.65
$t\bar{t}\gamma$ dileptonic	1.30 ± 0.23	1.02 ± 0.18	2.32 ± 0.41
$W^{\pm}c\gamma$	0.75 ± 0.16	0.72 ± 0.15	1.47 ± 0.26
$W^{\pm}cc\gamma$	0.08 ± 0.04	0.22 ± 0.06	0.30 ± 0.08
$W^{\pm}bb\gamma$	0.62 ± 0.11	0.42 ± 0.08	1.04 ± 0.17
$Z(\tau\tau)\gamma$	0.13 ± 0.09	0.11 ± 0.08	0.24 ± 0.12
WZ	0.08 ± 0.04	0.01 ± 0.01	0.09 ± 0.04
$\tau \rightarrow \gamma$ fake	0.12 ± 0.01	0.10 ± 0.01	0.22 ± 0.01
Jet faking γ	4.56 ± 1.92	3.02 ± 1.19	7.58 ± 3.11
Mistags	4.11 ± 0.41	3.54 ± 0.37	7.65 ± 0.70
QCD	1.49 ± 0.77	0^{+1}_{-0}	$1.49^{+1.30}_{-0.77}$
$ee\not{E}_T b$, $e \rightarrow \gamma$	1.50 ± 0.28	–	1.50 ± 0.28
$\mu e\not{E}_T b$, $e \rightarrow \gamma$	–	0.45 ± 0.10	0.45 ± 0.10
Predicted	$16.8 \pm 2.2(tot)$	$11.1^{+1.7}_{-1.4}(tot)$	$27.9^{+3.6}_{-3.5}(tot)$
Observed	16	12	28

Anomalous Production of γ b MET+ X

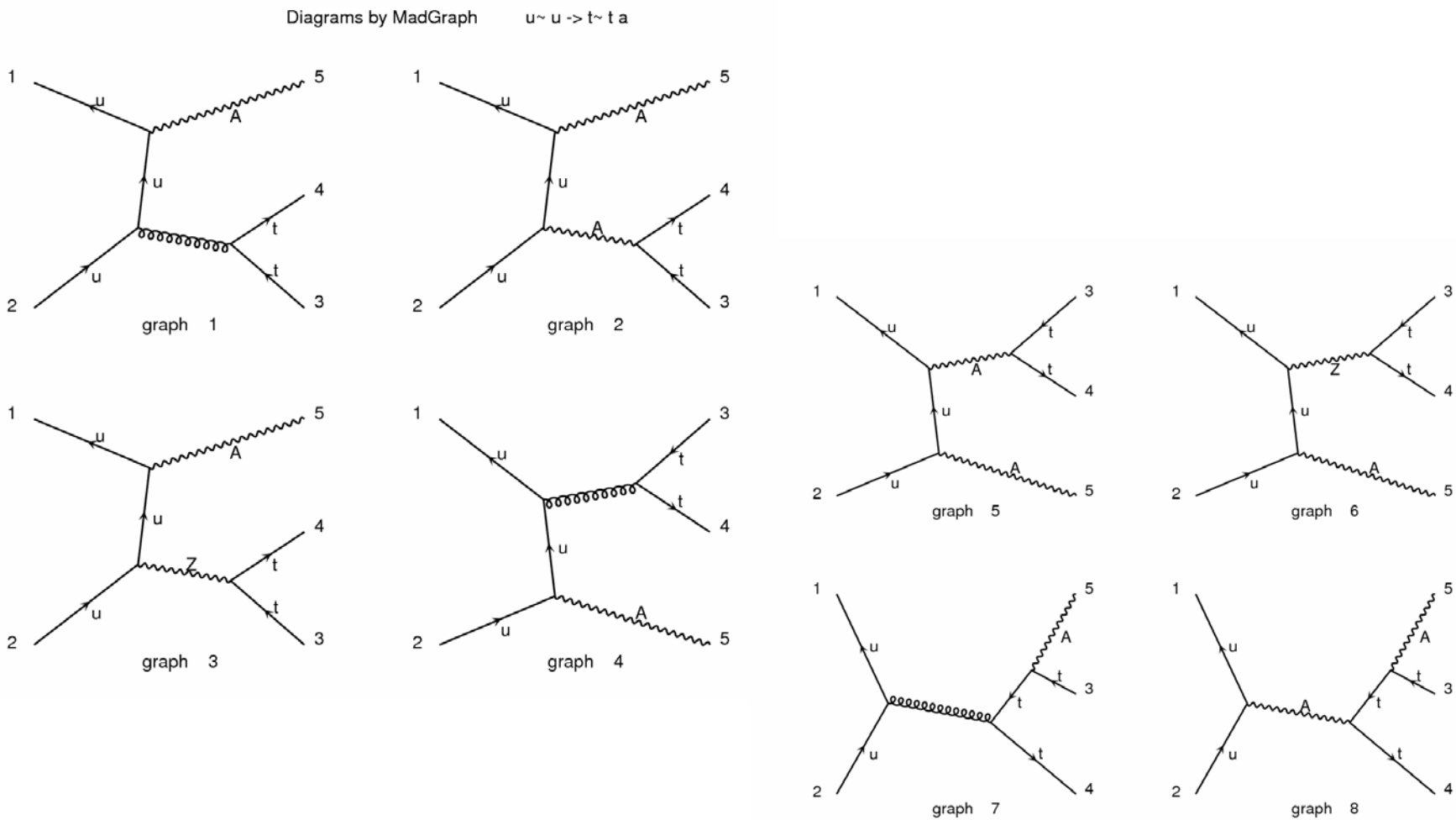
NEW !



CDF Run II Preliminary, 1.9fb^{-1}			
	$t\bar{t}\gamma$		
SM Source	$e\gamma b\not{E}_T$	$\mu\gamma b\not{E}_T$	$(e+\mu)\gamma b\not{E}_T$
$t\bar{t}\gamma(semileptonic)$	1.97 ± 0.36	1.47 ± 0.27	3.44 ± 0.62
$t\bar{t}\gamma(dileptonic)$	0.52 ± 0.10	0.43 ± 0.08	0.95 ± 0.17
$W^{\pm}c\gamma$	$0.0^{+0.02}_{-0}$	$0.0^{+0.02}_{-0}$	$0^{+0.03}_{-0}$
$W^{\pm}cc\gamma$	$0.0^{+0.02}_{-0}$	0.01 ± 0.01	$0.01^{+0.02}_{-0.01}$
$W^{\pm}bb\gamma$	0.06 ± 0.03	0.01 ± 0.01	0.07 ± 0.03
WZ	0.02 ± 0.02	$0.0^{+0.02}_{-0}$	0.02 ± 0.02
$\tau \rightarrow \gamma$ fake	0.08 ± 0.01	0.02 ± 0.01	0.10 ± 0.01
Jet faking γ	2.37 ± 1.22	1.42 ± 0.70	3.79 ± 1.92
B-jet mistags	0.78 ± 0.20	0.83 ± 0.22	1.61 ± 0.31
QCD	0.53 ± 0.46	0^{+1}_{-0}	$0.53^{+1.10}_{-0.46}$
$ee\not{E}_T b$, $e \rightarrow \gamma$	0.34 ± 0.11	–	0.34 ± 0.11
$\mu e\not{E}_T b$, $e \rightarrow \gamma$	–	0.20 ± 0.06	0.20 ± 0.06
Predicted	$6.7 \pm 1.4(tot)$	$4.4^{+1.3}_{-0.8}(tot)$	$11.1^{+2.3}_{-2.1}(tot)$
Observed	8	8	16

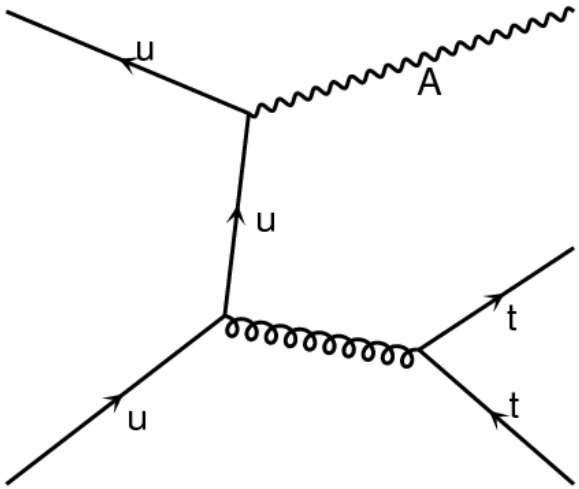
$t\bar{t}\gamma$ Feynman Diagrams

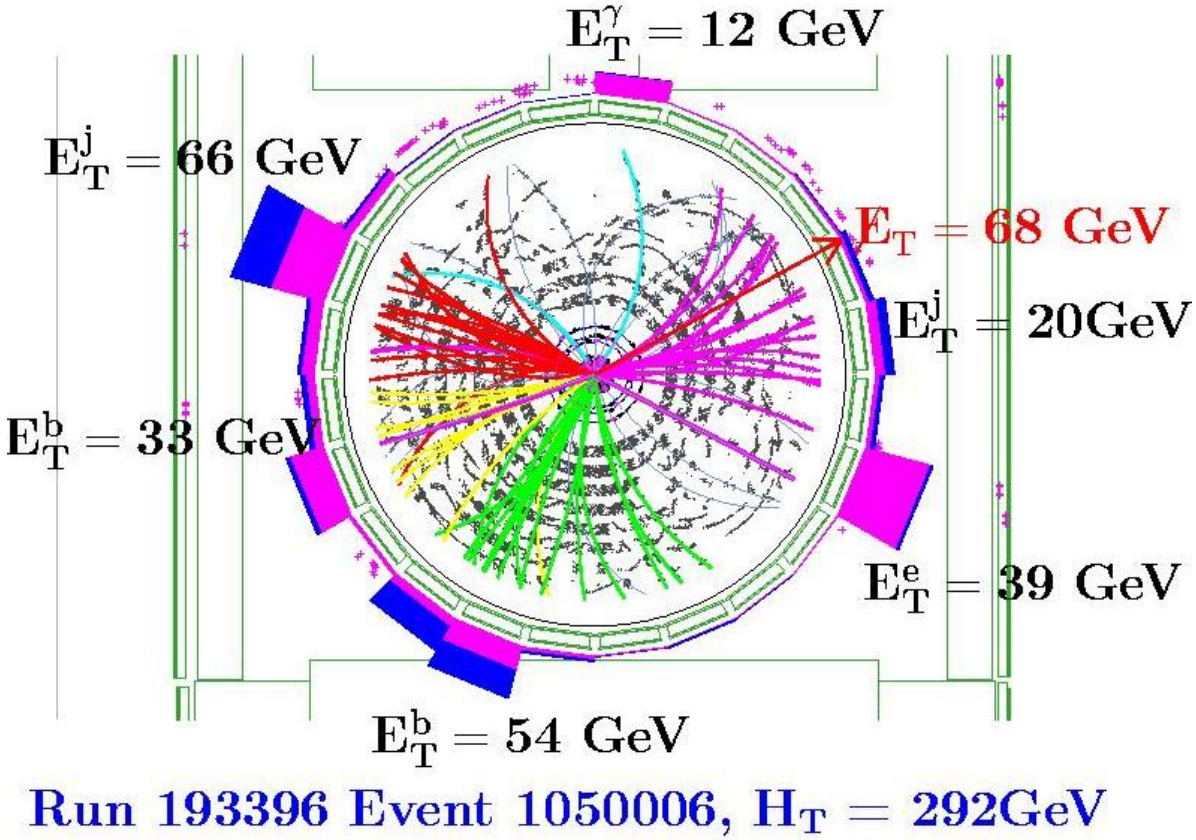
NEW !



A $t\bar{t}\gamma$ Candidate

NEW !

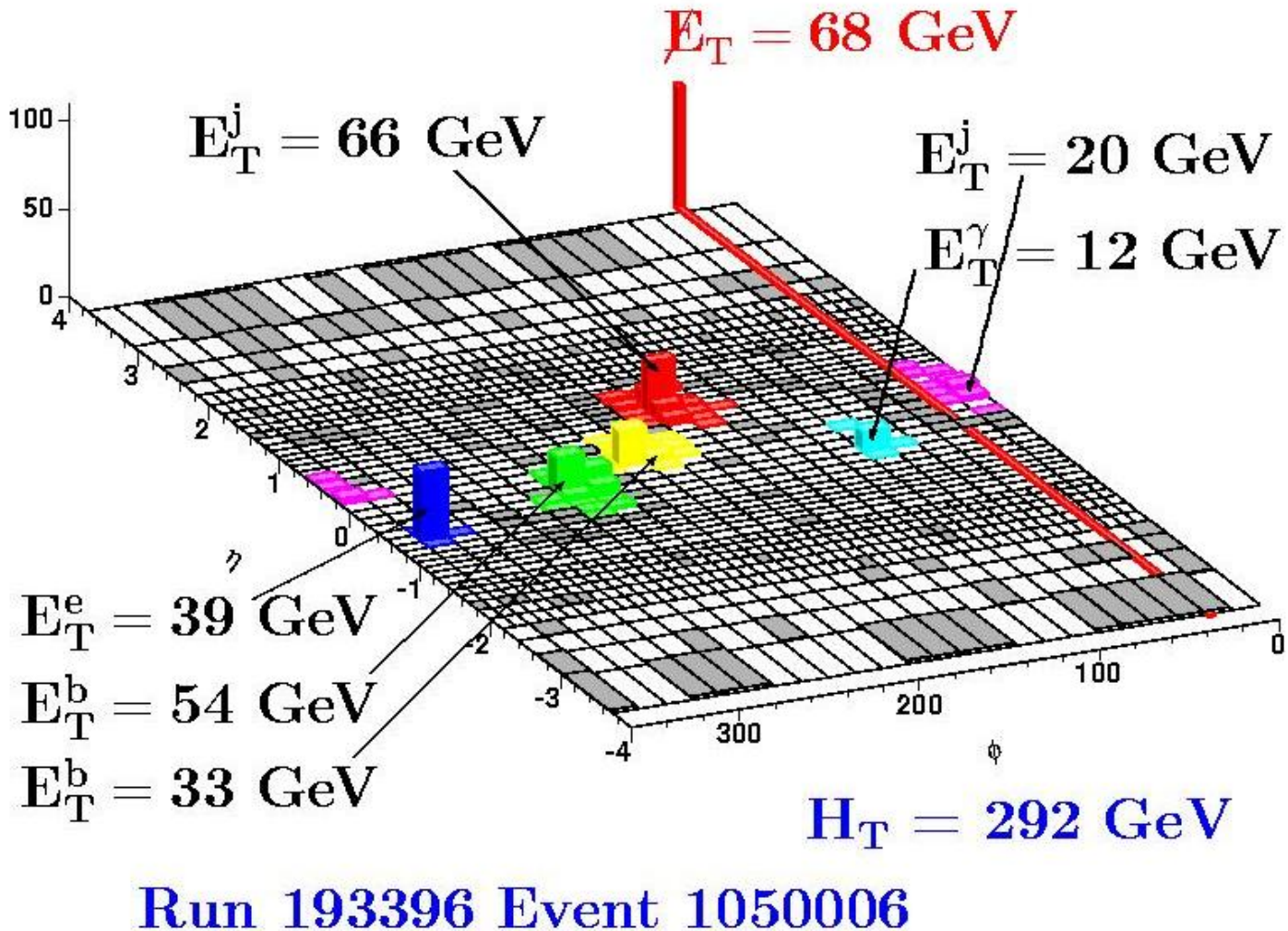




- **2 tags and 4 energetic jets with a low χ^2 (1.03) from a fit to the constrained ttbar system. The reconstructed mass is 166.5 GeV/c^2.**

A $t\bar{t}\gamma$ Candidate

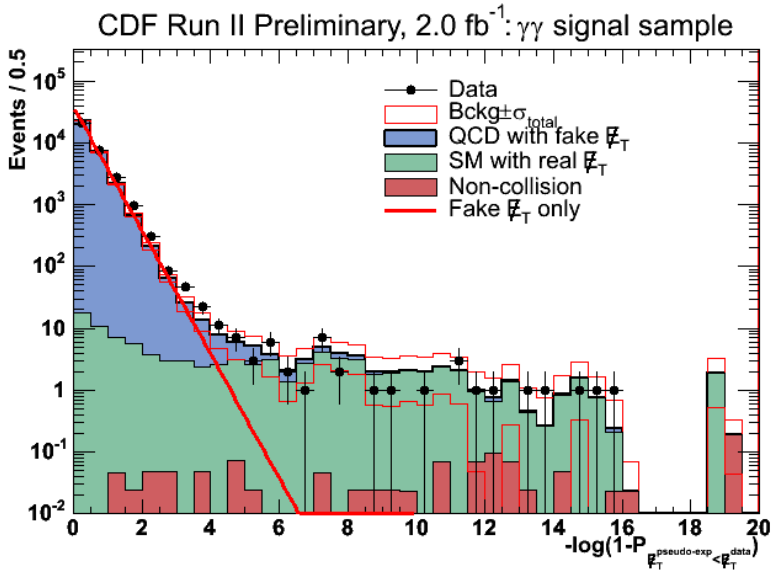
NEW !



Anomalous Production of γγ MET

Wγ efficiency: MET sig > 3 = 84%
MET sig > 5 = 72%

- **Unclustered energy from zero-jet events in Z and diphoton sample**
  - METx and METy vs. sqrt(Et)
- **Jet energy from Z+jet and dijet samples**
  - Energy hadron/detector ratio-1 in bins of energy and eta

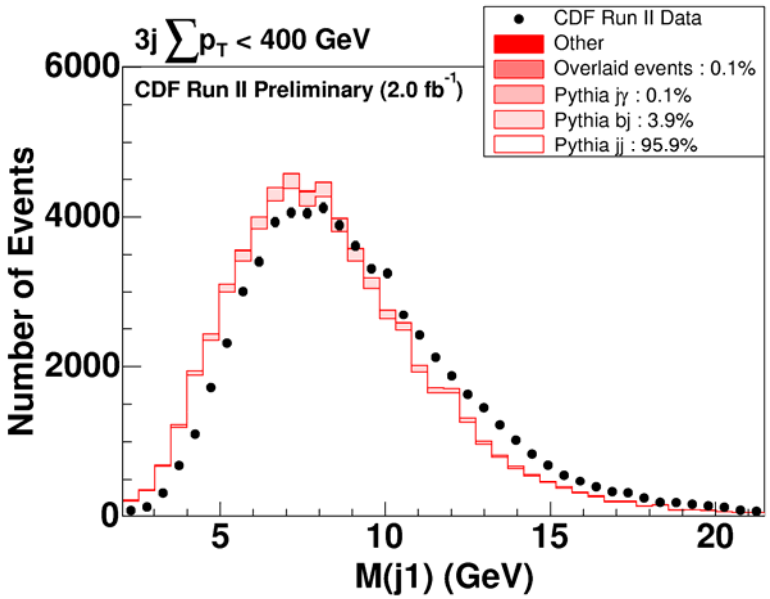


Vista+Sleuth

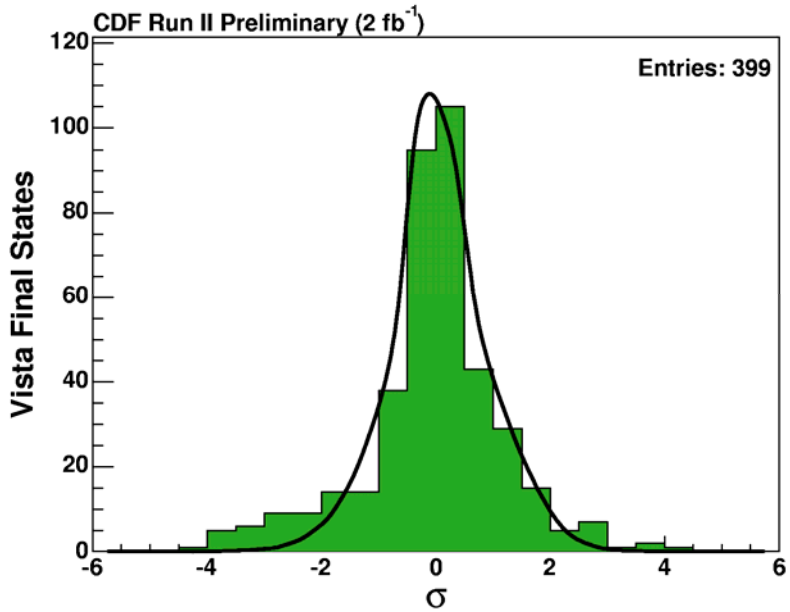
- **Classify events by their object content (final state)**
- **Simulate standard model with Monte Carlo**
- **Global fit to extract correction factors (luminosity, k-factors, mis-id rates, trigger efficiencies, jet energy scale)**
- **Look for anomalies in distributions (bulk)**
- **Look for excesses in high sum E_T distributions**
  - Assumes NP will be at high sum E_T and appear as an excess
- **Order final states by how discrepant they are**
  - Flag interesting states for further study
- **Iterative procedure to identify and account for detector effects**
- **Sensitivity to new physics depends on details of final state**
- **Provides a safety net to avoid missing the obvious**

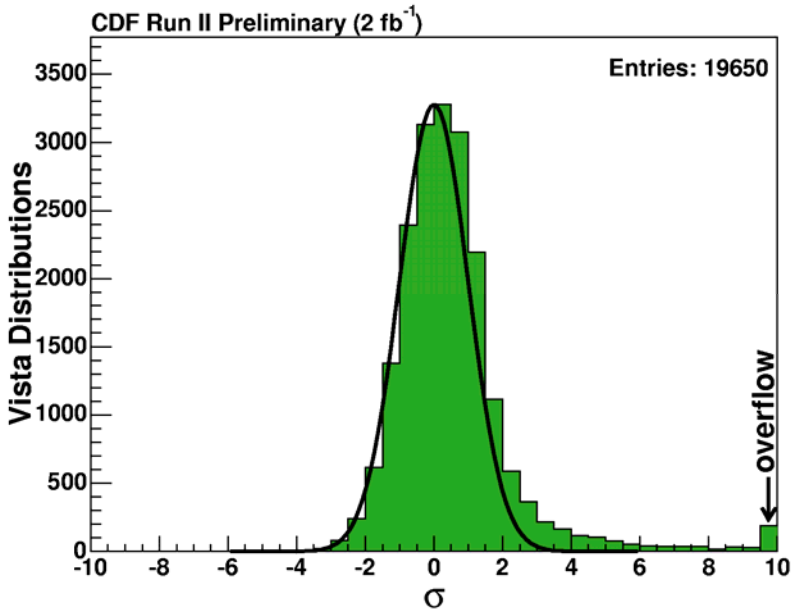
Global Search in 2.0 fb^{-1}: Vista

- **Study bulk features of 2.0 fb^{-1} data**
- **Identify physics objects with p_T > 17 GeV**
- **Partition into ~ 400 exclusive final states**
- **SM background prediction**
  - Primarily Pythia and MadEvent, then cdfSim
  - Determine correction factors by a global fit to all final states, subject to external constraints
    - 43 correction factors for object ID, cross-sections, fake rates
- **Trials factor 1-(1-p)^N**



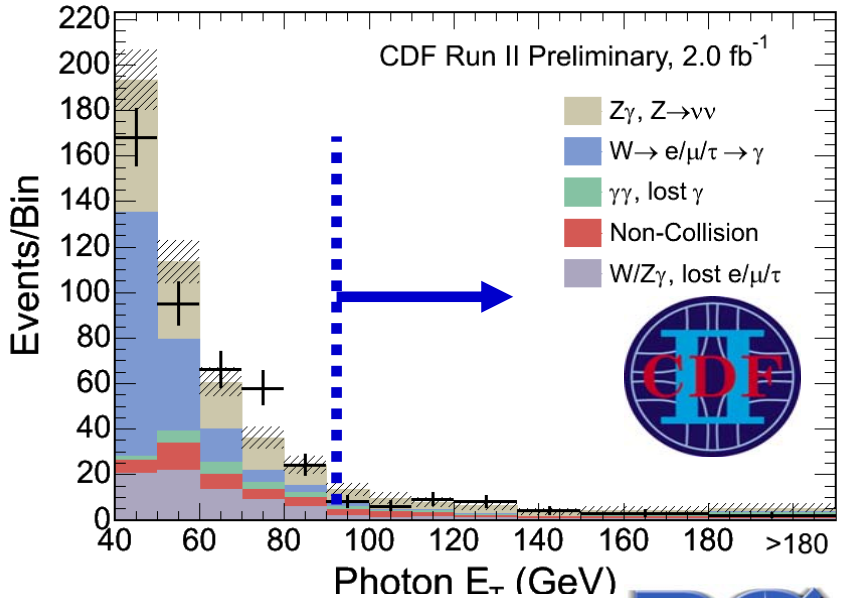
Global Search: Vista

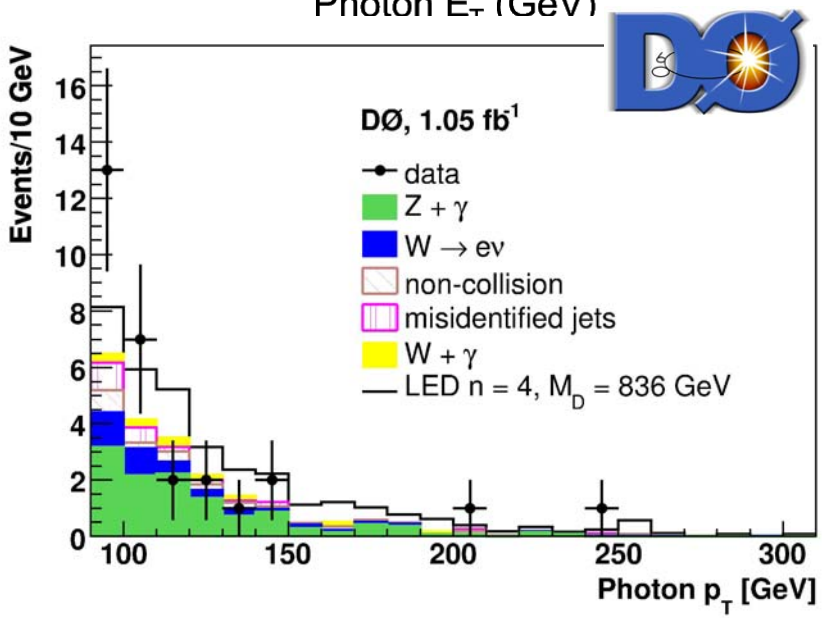




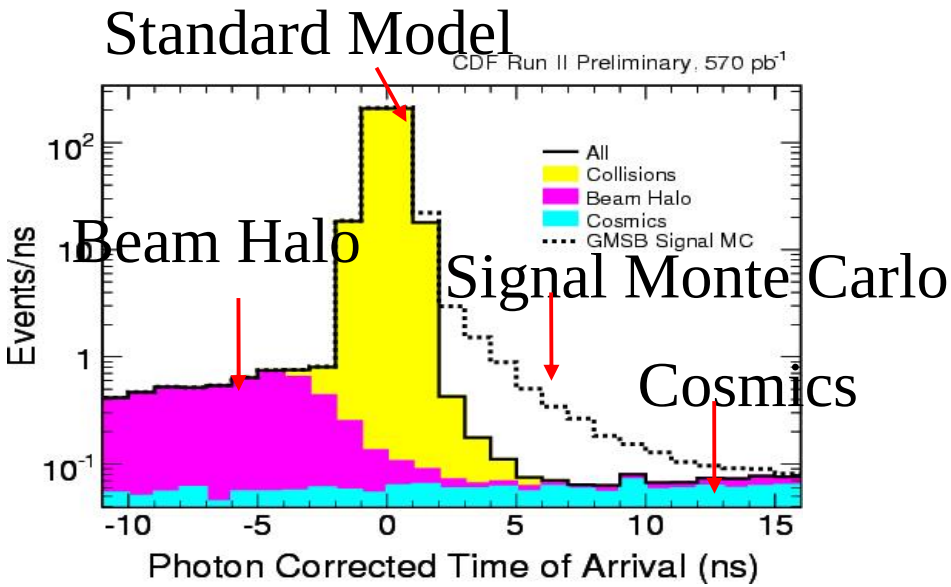
Large Extra Dimensions in γ + MET

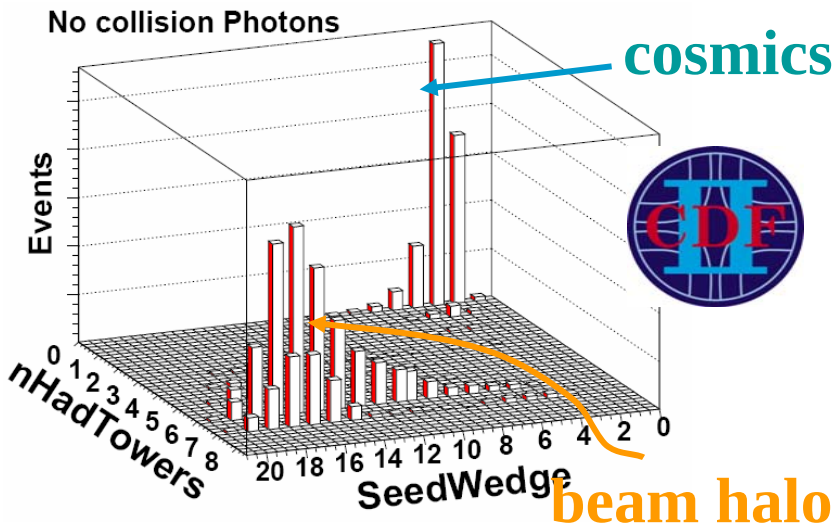
- **CDF: 2.0 fb^{-1}, D0: 1.1 fb^{-1}**
- **Energetic photon and missing E_T**
  - $E_T(\gamma) > 90$ GeV, $|\eta| < 1.1$
  - MET > 50 GeV (CDF), 70 GeV (D0)
- **Veto high p_T jets and tracks**
- **Dominant backgrounds**
  - $Z \rightarrow \nu\nu + \gamma$
  - $W \rightarrow e\nu$ where e is misID as a γ
  - $W \rightarrow l\,\nu + \gamma$ with missing lepton
  - non-collision: cosmics, beam-halo
- **Special strategy to reject non-collision background**

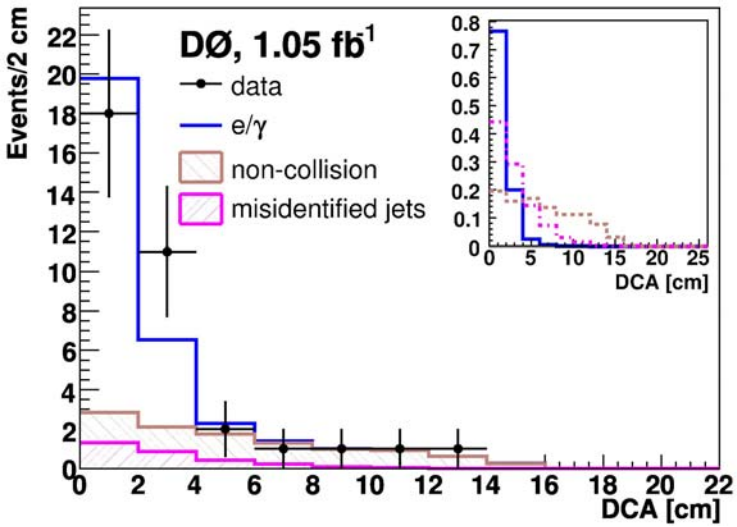


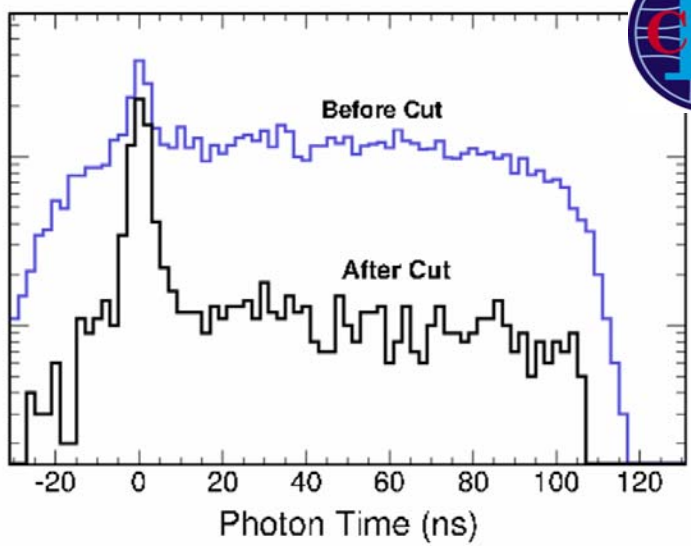


Large Extra Dimensions in γ + MET









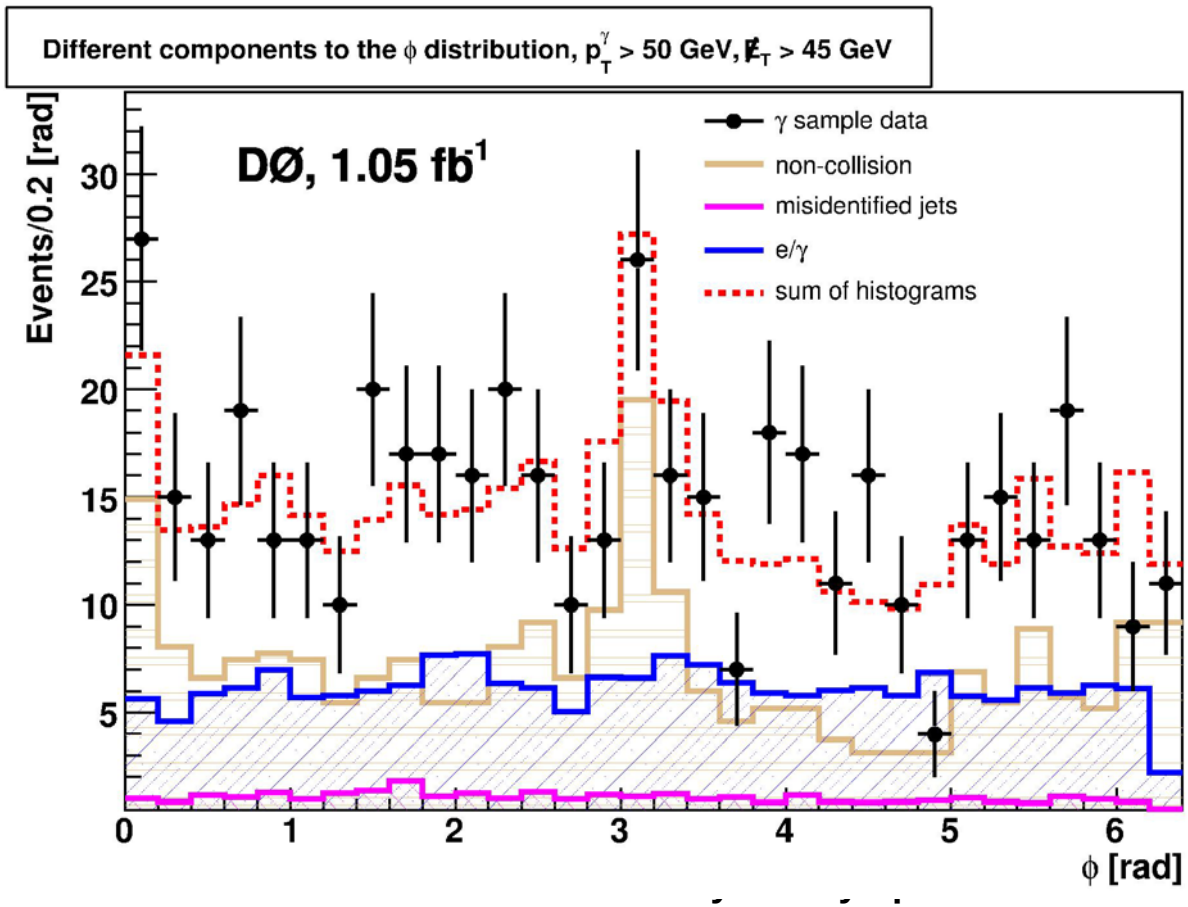
Large Extra Dimensions in γ + MET

Extra-dim (n)	95% CL lower limit on M_D in GeV	
	CDF ($2.0\ fb^{-1}$)	D0 ($1.0\ fb^{-1}$)
2	1080	884
3	1000	864
4	970	836
5	930	820
6	900	797
7		797
8		778

LED in γ + MET

- LEP center of mass energy only 1/5 of MD
- Tevatron twice of MD
- LEP has energy constraint to remove Zγ background

$$\sigma \propto \left(\frac{s}{M_D} \right)^n$$



High-mass ee, $\gamma\gamma$ Resonances

CDF **2.5 fb^{-1} (largest dataset)**

- **X$\rightarrow$ ee**
  - X = E6 Z', RS Graviton
- **an e^+e^- pair**
  - CC ($|\eta| < 1.1$) or CF ($|\eta| < 1.1, 2.0$), $E_T(e) > 25$ GeV
- **Dominant background: Drell-Yan**
  - Normalized with data $76 < M_{ee} < 106$ GeV/c^2 for CC, $81 < M_{ee} < 101$ GeV/c^2 for CF

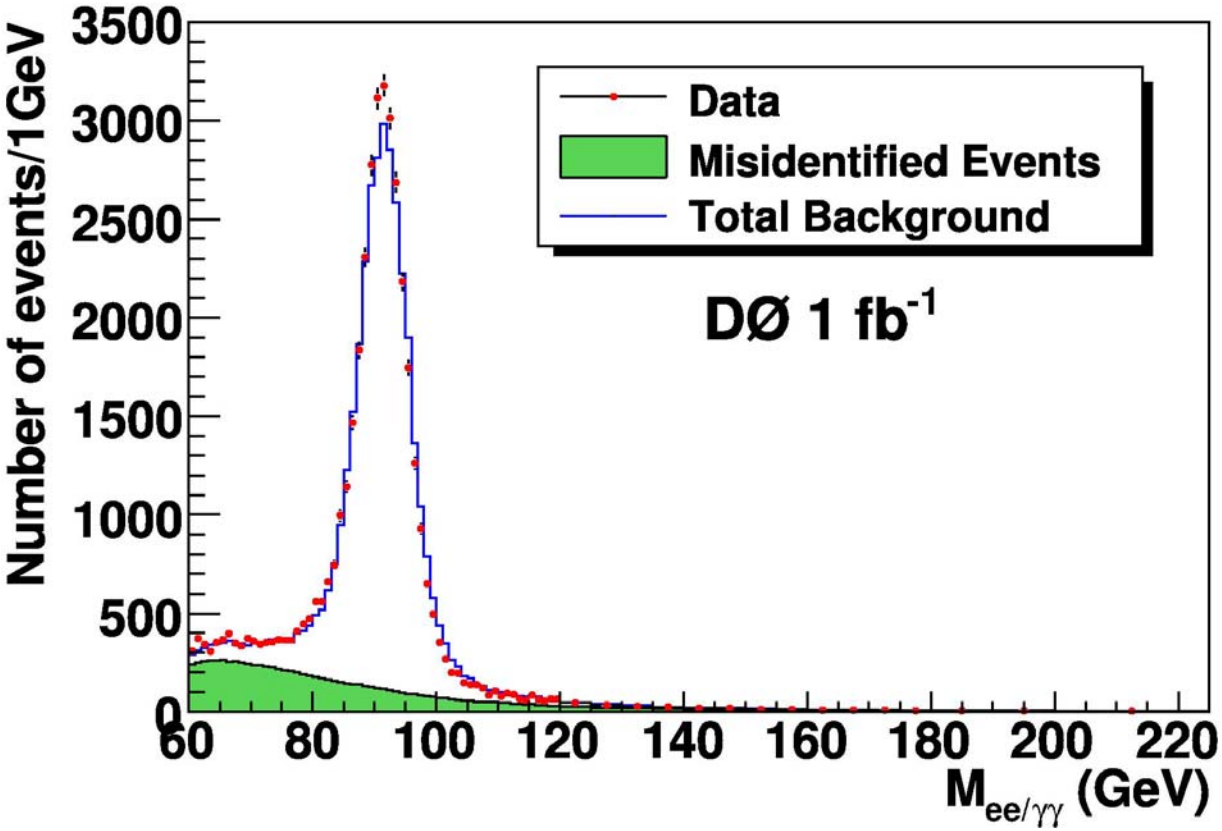
D0 **1.0 fb^{-1}**

- **Randall-Sundrum Graviton**

$$q\bar{q}(gg) \rightarrow G \rightarrow \gamma\gamma, ee$$

  - mass M_1
  - First massive Kaluza-Klein excitation
  - 5-dimensional space
  - Warped space-time metric
- **2 EM objects (both ee, $\gamma\gamma$)**
  - $E_T > 25$ GeV, $|\eta| < 1.1$ each
- **Dominant background: Drell-Yan, direct $\gamma\gamma$ production**
  - Normalized with data $60 < M_{ee,\gamma\gamma} < 140$ GeV/c^2

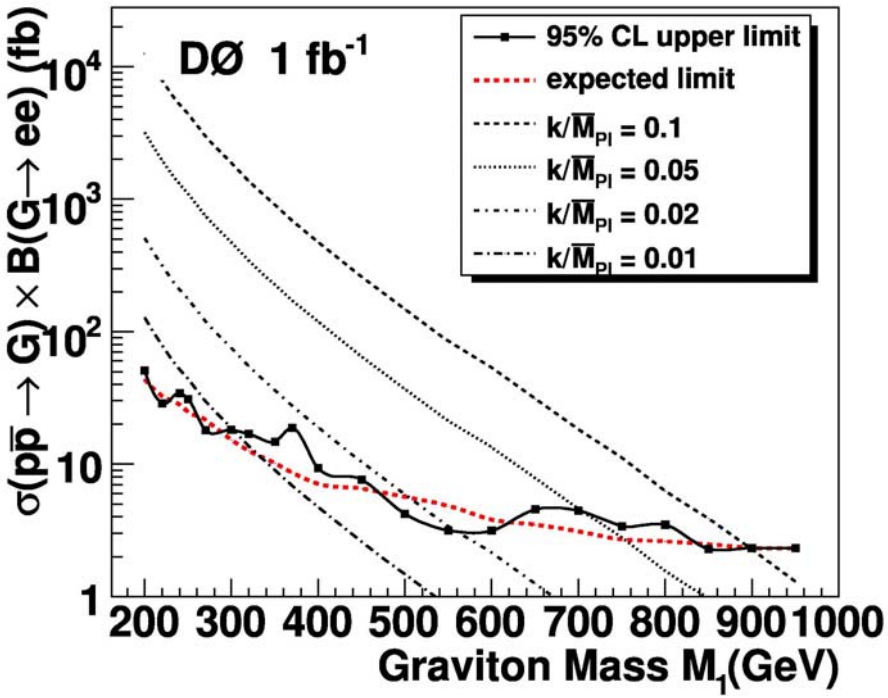
RS Graviton → ee, γγ



RS Graviton → ee, γγ

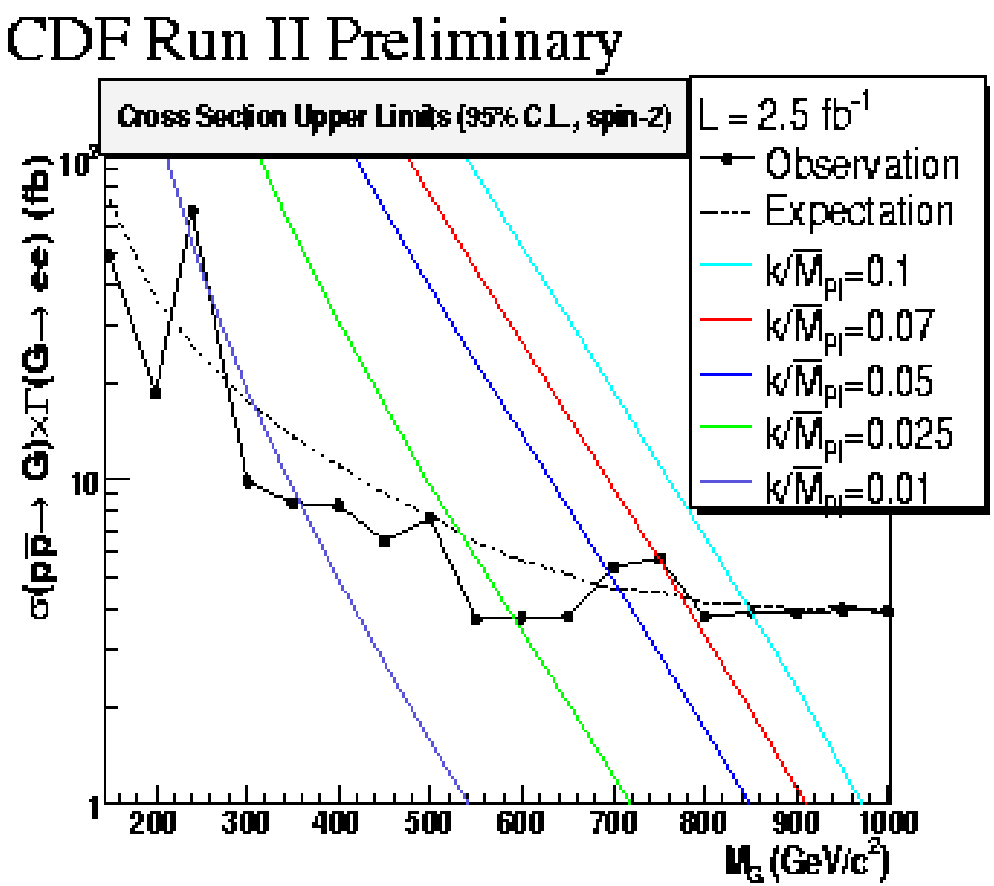
For M1=230-250 GeV/c2, 37.1 ± 3.7 (exp) vs. 41 (obs)

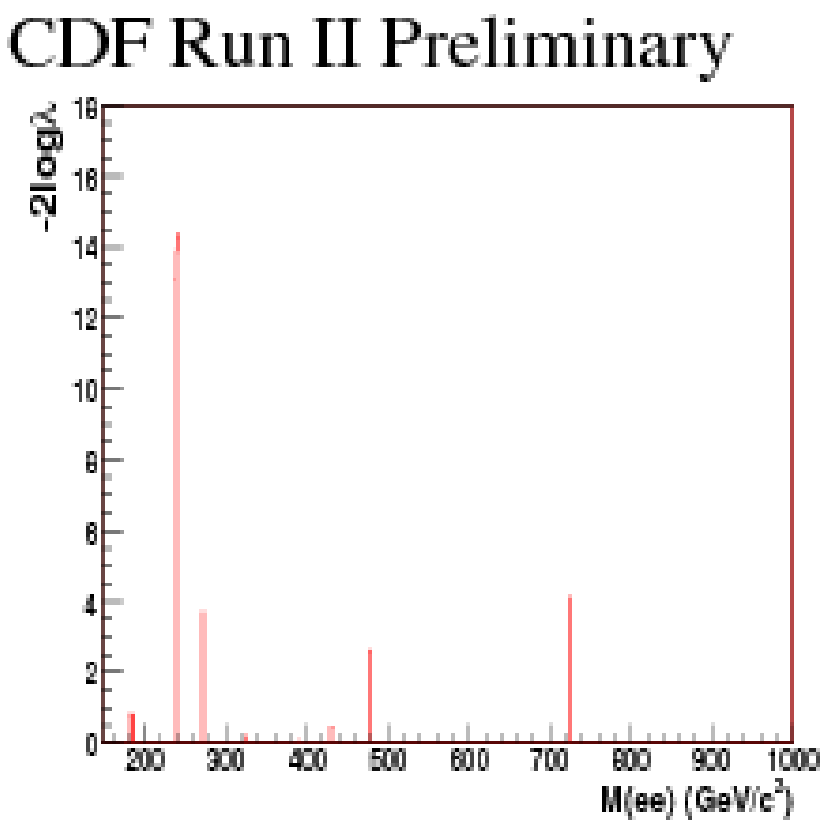
- Graviton wave function suppressed exponentially from the Plank-brane to the SM-brane
- Towers of Kaluza-Klein excitations as the 4-dim manifestation of G propagating in 5-dim space
- Massless zero-mode couples with gravitational strength



High-mass ee Resonances

For M1=228-250 GeV/c2, 67.7 ± 3.2 (exp) vs. 101 (obs)



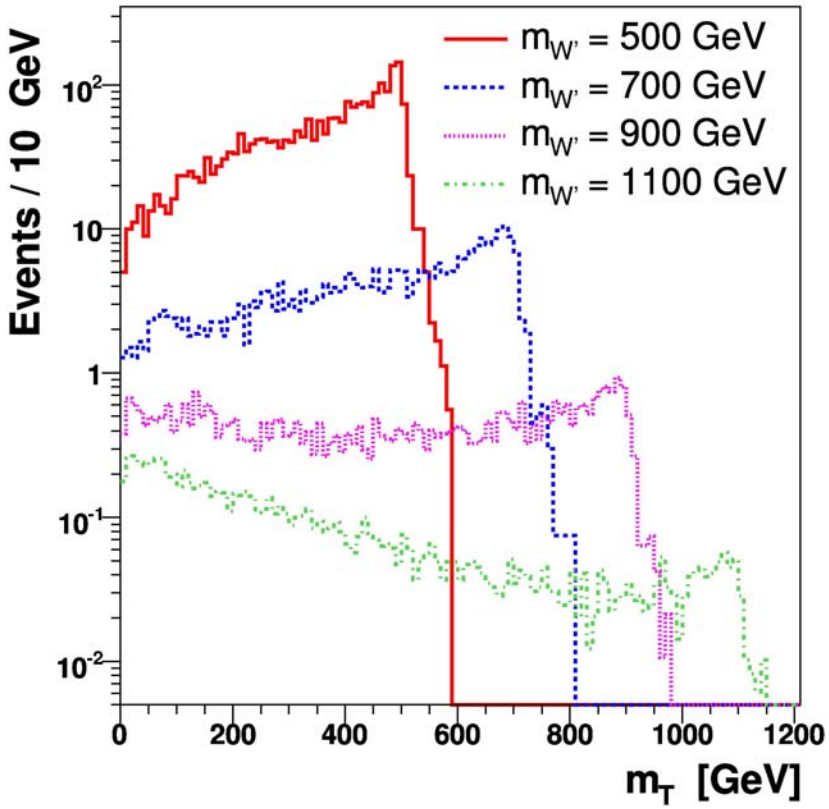


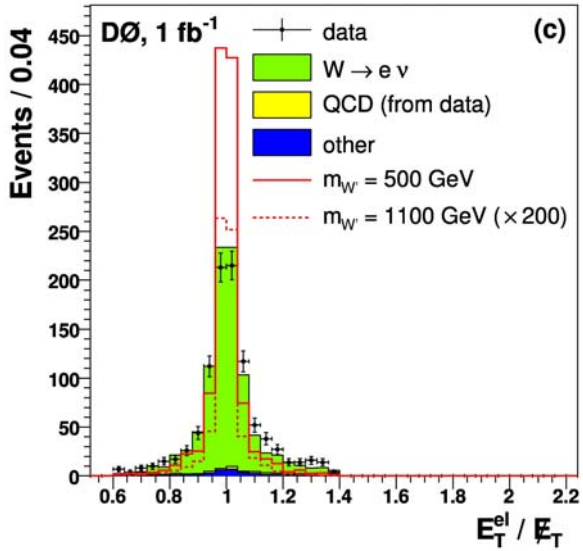
$W' \rightarrow e\bar{\nu}$ in 1.0 fb^{-1}

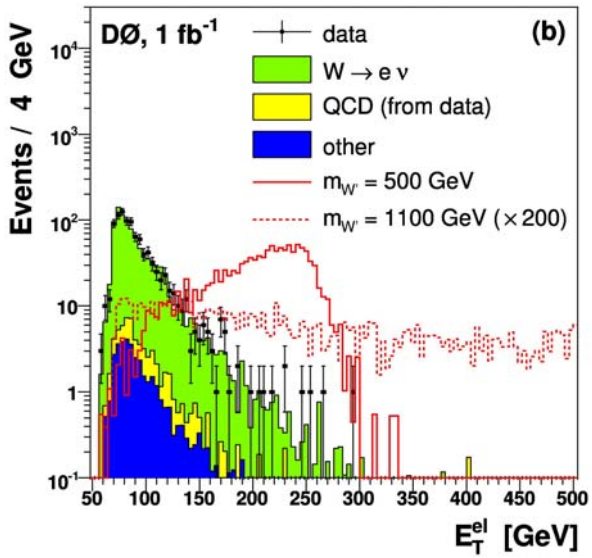
- **1 central electron and large MET**
  - $E_T(e) > 30$ GeV, MET > 30 GeV
  - Additional jet not back-to-back with the electron or MET
  - $0.6 < E_T(e)/MET < 1.4$
- **Transverse mass M_T(MET, e) is a good discriminant**
  - Use $M_T < 30$ GeV/c^2 to estimate QCD background
  - Use $60 < M_T < 140$ GeV/c^2 to obtain overall normalization of EWK background
- **No excess seen**
- **Set limit on W' mass using M_T**
- **Assume**
  - Altarelli Reference Model
  - Couplings to fermions same as SM
  - Same SM CKM matrix
  - No mixing ($W \sim W_1$, $W' \sim W_2$)
  - $W' \rightarrow WZ$ suppressed
  - $\Gamma_{W'} = 4/3 * \Gamma_W * m_{W'}/m_W$

W'→e$\bar{\nu}$

959±92 (exp) vs. 967 (obs)







Dijet Mass Resonances

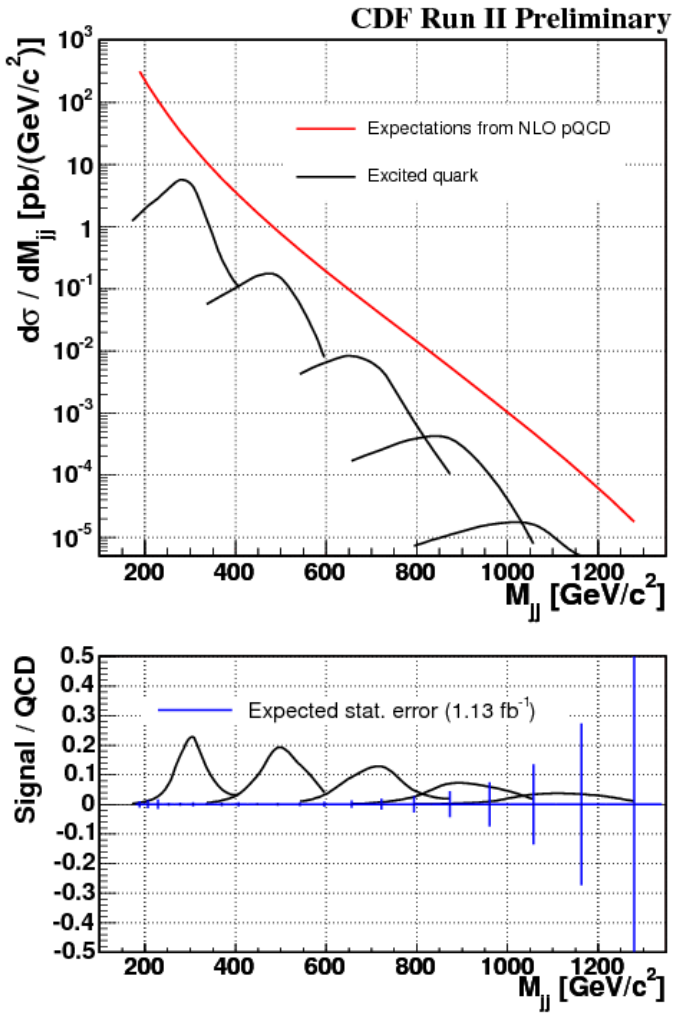
- **Selections in 1.1 fb^{-1} data**
  - ≥ 2 jets, M_{jj} > 180 GeV/c^2, |y| < 1.0
- **Axigluons→qqbar**
  - In chiral color, the unbroken color symmetry SU(3)c of QCD results from the breaking of a larger chiral color group SU(3)L X SU(3)R.
  - This model predicts massive color-octet axial vector gluons
- **Coloron→qqbar**
  - The string gauge group is extended to SU(3)1 X SU(3)2. The extended gauge bosons from each SU(3) mix to form a color-octet of massless gluons and an color-octget of massive colors.
- **E6 diquarks→qq or qbarqbar**
  - Superstring theory in 10 dimension is anomaly free if the gauge group is E8 X E8. The compactification of the extra 6 dimensions can lead to E6 as the grand unification group for the strong and EWK interactions
  - Color-triplet scalar diquarks with charge 1/3 or -1/3 which couples to ud or ubardbar
- **Color-octet technirhos->gg or qqbar**
  - Extended technicolor or topcolor-assisted tenicolor

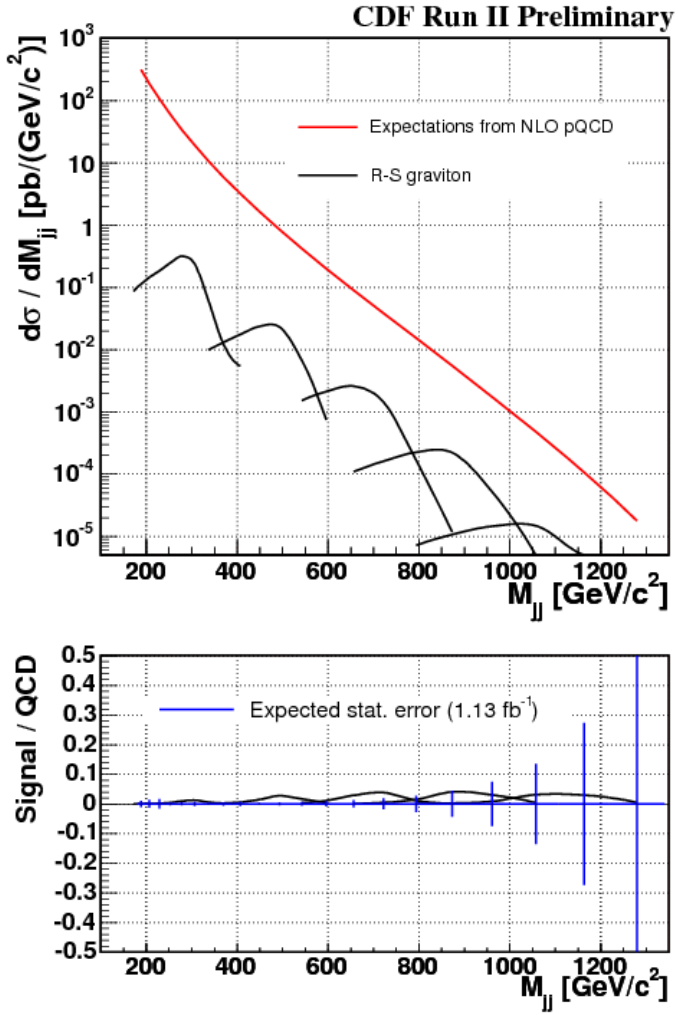
Dijet Mass Resonances

Model Name	X	Color	J^P	Γ / (2M)	Chan
E_6 Diquark	D	Triplet	0^+	0.004	ud
Excited Quark	q*	Triplet	$½^+$	0.02	qg
Axigluon	A	Octet	1^+	0.05	$q\bar{q}$
Coloron	C	Octet	1^-	0.05	$q\bar{q}$
Octet Technirho	ρ_{T8}	Octet	1^-	0.01	$q\bar{q}$,gg
R S Graviton	G	Singlet	2^-	0.01	$q\bar{q}$,gg
Heavy W	W ‘	Singlet	1^-	0.01	$q_1\bar{q}_2$
Heavy Z	Z ‘	Singlet	1^-	0.01	$q\bar{q}$

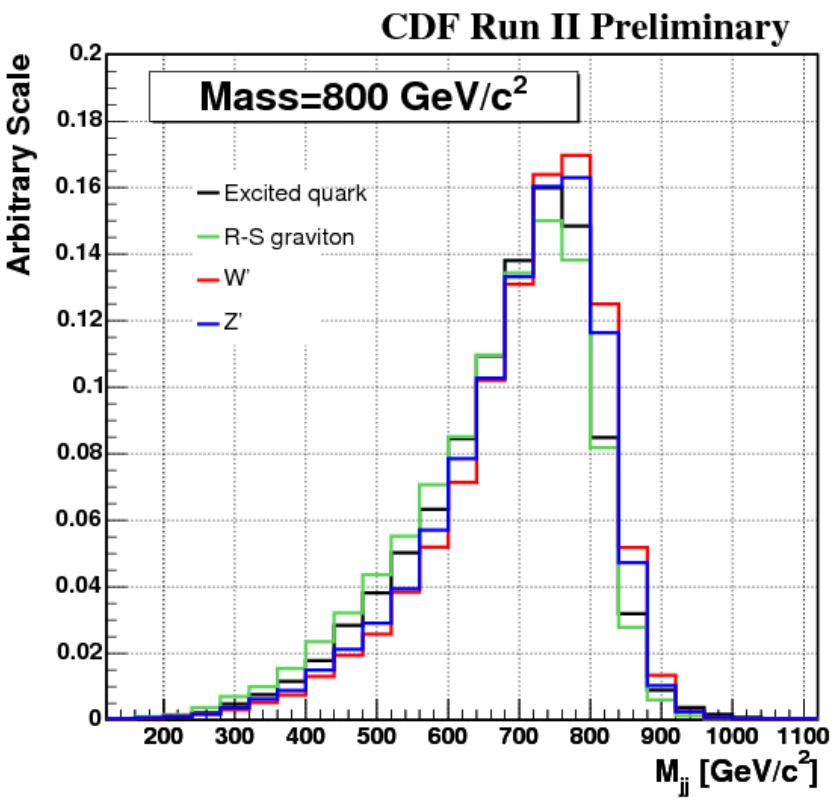
- **Dijet resonances are found in models that try to address some of the big questions of particle physics beyond the SM, the Higgs, or Supersymmetry**
  - Why Flavor ? → Technicolor or Topcolor → Octet Technirho or Coloron
  - Why Generations ? → Compositeness → Excited Quarks
  - Why So Many Forces ? → Grand Unified Theory → W’ & Z’
  - Can we include Gravity ? → Superstrings → E6 Diquarks
  - Why is Gravity Weak ? → Extra Dimensions → RS Gravitions

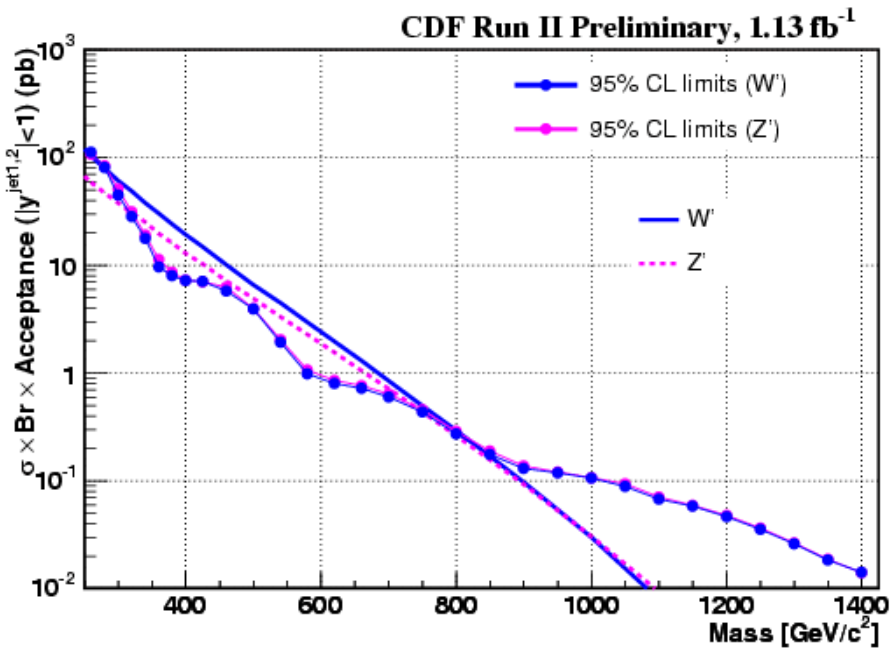
High-mass Dijet Resonances



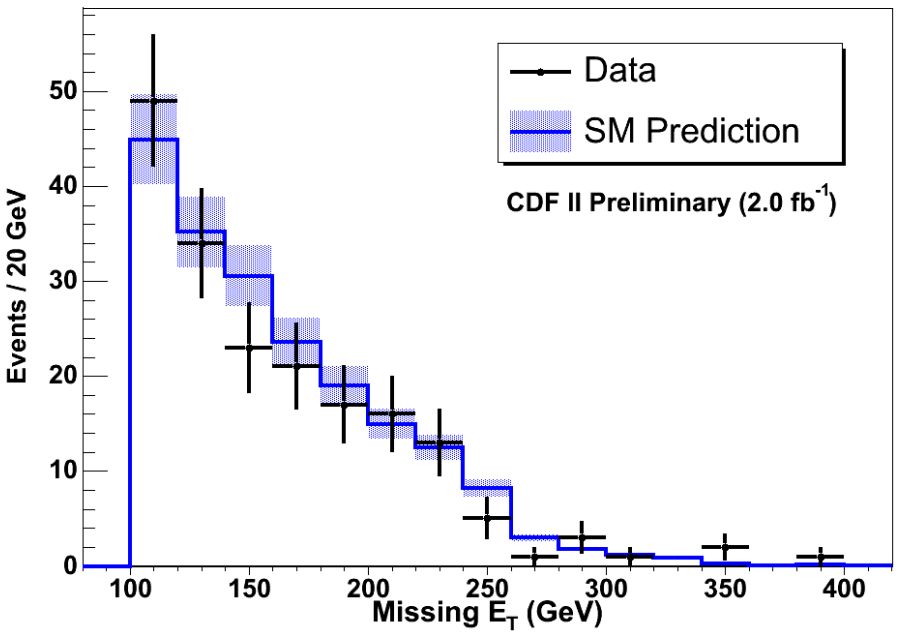


High-mass Dijet Resonances





Anomalous dijet + MET and LQ



- **Started as signature-based**
  - Leptoquark
  - Little Higgs (T-parity conserved)
  - UED (K-parity conserved)
  - MSSM (R-parity conservd)

Selections in 2.0 fb^{-1} data

- 2 jets with $E_T(j) > 30$ GeV, $|\eta| < 2.4$
- No 3rd Jet with $E_T > 15$ GeV
- Veto isolated tracks and EM objects
- Two kinematic regions
  - Low: $\Sigma E_T(j) > 125$ GeV, MET > 80 GeV
  - High: $\Sigma E_T(j) > 225$ GeV, MET > 100 GeV

Data-driven background estimate

- $Z \rightarrow \nu\nu$ + jets
- $W \rightarrow l\ \nu$ +jets with missing lepton

- **Set limits on 3 generations of LQs with Q=1/3, 2/3, β = 0**

Anomalous dijet + MET and LQ

Background	Number of Events
Z -> ν ν	777 +/- 49
W -> τ ν	669 +/- 42
W -> μ ν	399 +/- 25
W -> e ν	256 +/- 16
Z -> l l	29 +/- 4
Top Production	74 +/- 9
QCD	49 +/- 30
Gamma plus Jet	55 +/- 13
Non-Collision	4 +/- 4
Total Predicted	2312 +/- 140
Data Observed	2506

Background	Number of Events
Z -> ν ν	71 +/- 12
W -> τ ν	50 +/- 8
W -> μ ν	33 +/- 5
W -> e ν	14 +/- 2
Z -> l l	2 +/- 0
Top Production	11 +/- 2
QCD	9 +/- 9
Gamma plus Jet	5 +/- 3
Non-Collision	1 +/- 1
Total Predicted	196 +/- 29
Data Observed	186

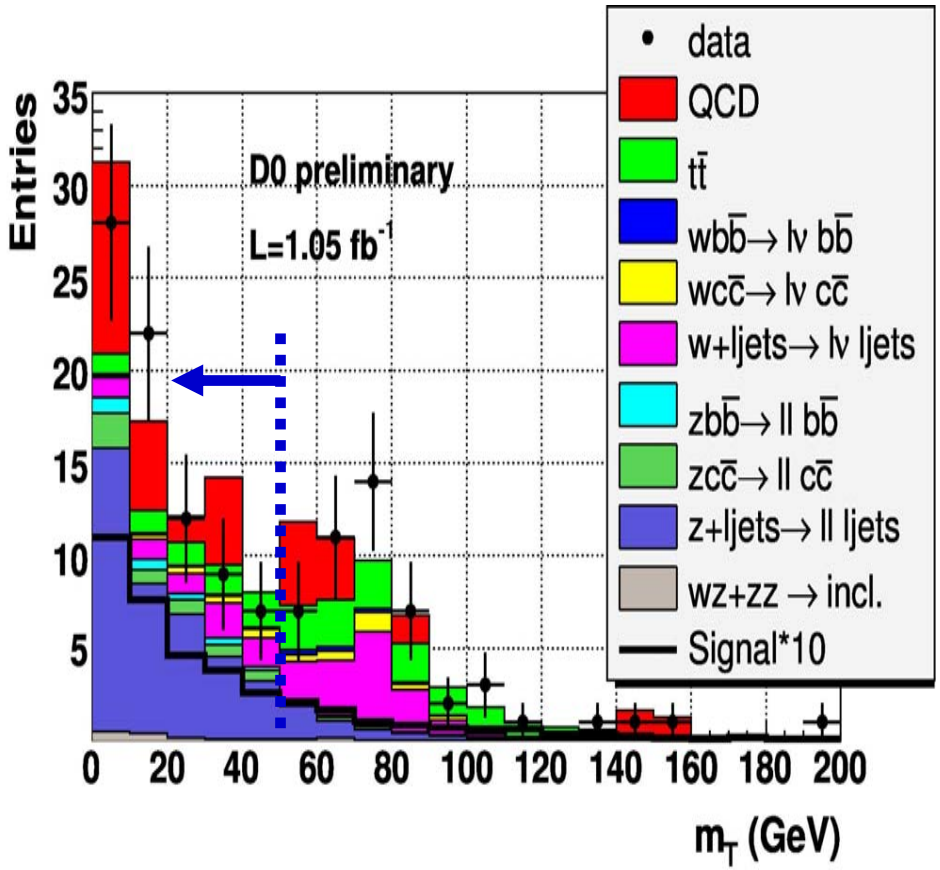
3rd Generation Scalar LQ in ττbb

- Tau visible pt > 15 GeV for 1-prong, 20 GeV for 3-prong
- NN output > 0.9 for 1-prong, > 0.95 for 3-prong
- Mid-Cone jet algorithm, Et> 25, 20 GeV, |eta| < 2.5
- Muon pt > 15 GeV, |eta| < 1.6, tracking and calorimeter isolated
- No tight electron with pt > 12 GeV
- NN input
  - Tau mass
  - Profile of energy deposition
  - Track multiplicity
  - Isolation
- Loose NN b-tagging: output > 0.2, eff = 72.2 %, misID= 5.9 %
- 25-30% systematic uncertainties for the background, 16% for the signal

1-tag: 14.8±0.5 (exp) vs. 16 (obs)
2-tag: 3.6±0.1 (exp) vs. 1 (obs)

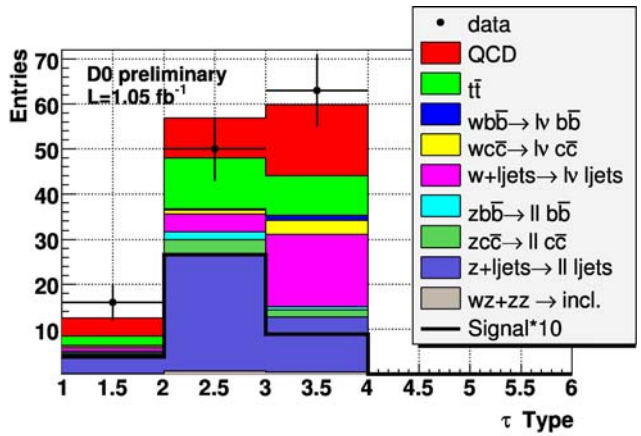
3rd Generation Scalar LQ in ττbb

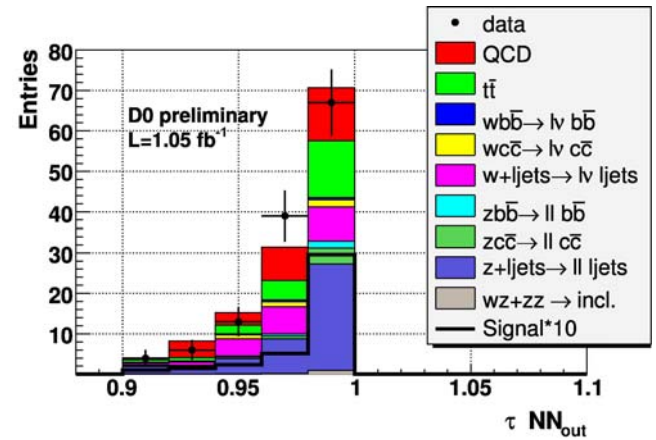
- **Charge= 4/3, 2/3 LQ: M(LQ) > 180 GeV/c2**
  - BR(LQ→τb) =1
- **Charge= 2/3 LQ: M(LQ) > 180 GeV/c2**
  - LQ→ t ν is allowed, only suppressed by phase space, assume the same coupling for both decays
  - BR(LQ→τb) = 1 – 0.5 * Fsp

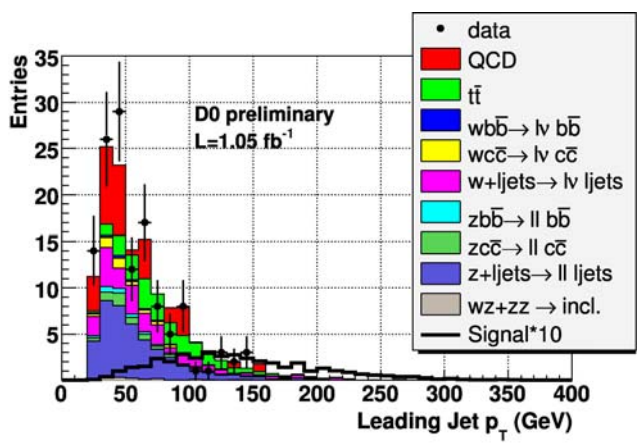


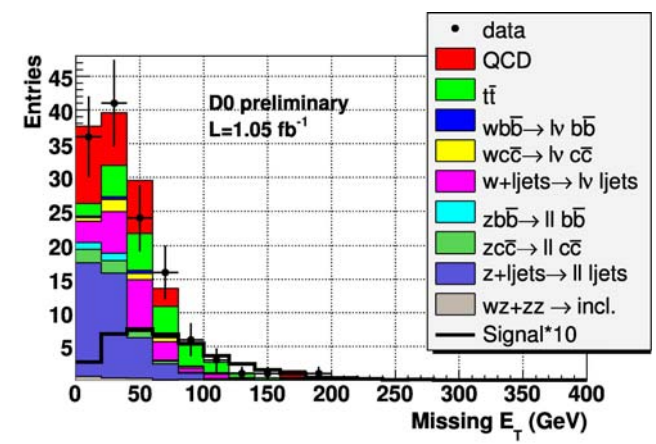
Before b-tagging

3rd Generation Scalar LQ in ττbb







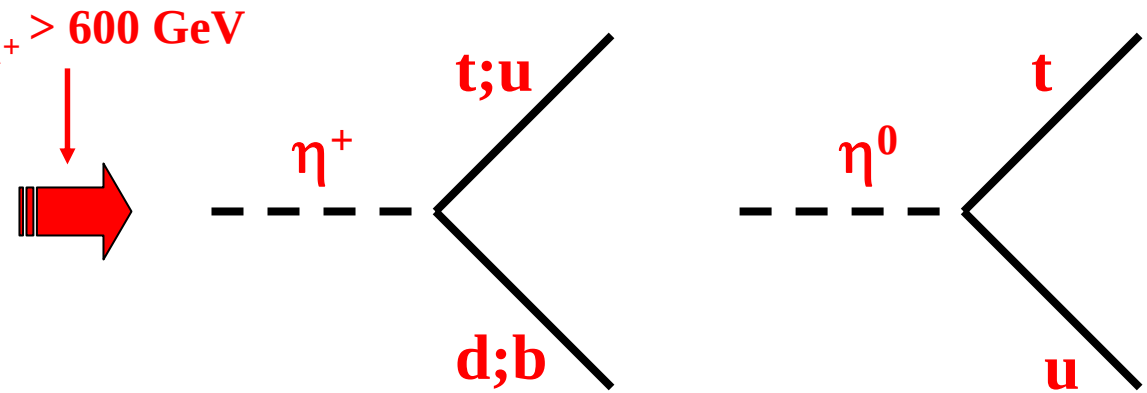


Same Sign Tops

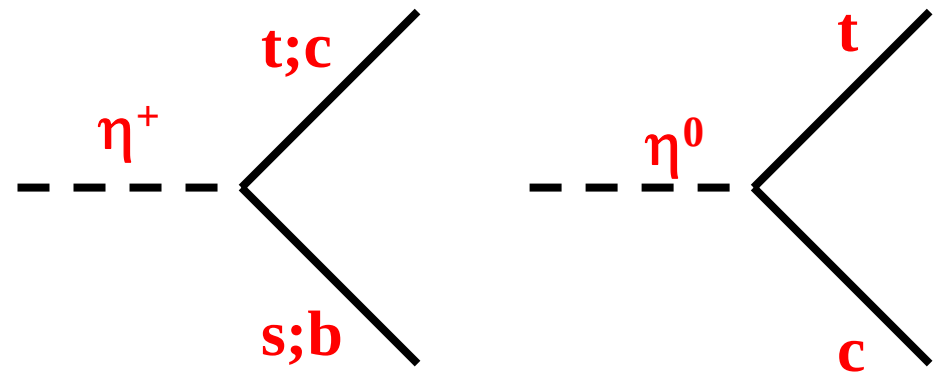
NEW !

A **heavy enough η^+** leads to 2 interesting MxFV textures that are not excluded:

- **$MxFV_1$:** $\xi = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}$ $\Rightarrow$



- **$MxFV_2$:** $\xi = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$ $\Rightarrow$



Same-sign Tops

NEW !

CDF Run II Preliminary (2 fb^{-1})

	M_{η^0} [GeV/c^2]	180	190	200	225	250	300
tt	σ [pb]	0.50	0.45	0.41	0.33	0.27	0.19
	ϵ [%]	0.5	0.5	0.5	0.5	0.5	0.5
	N	4.4	4.3	3.8	2.6	2.1	0.9
$tt\bar{u}$	σ [pb]	0.54	0.50	0.42	0.28	0.22	0.10
	ϵ [%]	0.5	0.5	0.5	0.5	0.5	0.5
	N	4.8	4.0	4.0	3.1	2.4	1.7
$tt\bar{u}\bar{u}$	σ [pb]	0.68	0.45	0.38	0.17	0.06	0.02
	ϵ [%]	0.5	0.5	0.5	0.5	0.5	0.5
	N	5.8	3.6	3.3	1.4	0.5	0.2
Total $N(l^{\pm}l^{\pm}b\not{E}_T)$		14.9	11.9	11.0	7.1	5.0	2.7

CDF Run II Preliminary (2 fb^{-1})

Source	ee	$\mu\mu$	$e\mu$	ll
$Z \to ll$	0.01	0.03	0.04	0.1 ± 0.1
tt	0.27	0.26	0.42	0.9 ± 0.1
$W + jets$	0.60	0.71	0.50	1.8 ± 1.8
Total	0.9	1.0	1.0	2.9 ± 1.8
Data	0	1	2	3

CDF Run II Preliminary (2 fb^{-1})

Mass	180	190	200	225	250	300
$\xi <$ (95% CL)	0.79	0.85	0.85	1.11	1.12	1.32

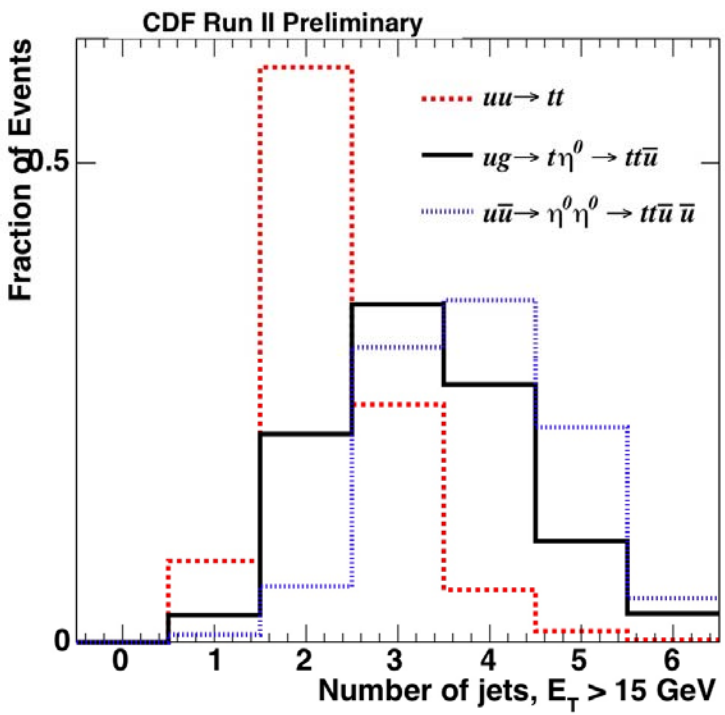
$$ug \to t\eta^0 \to tt\bar{u} + h.c.$$

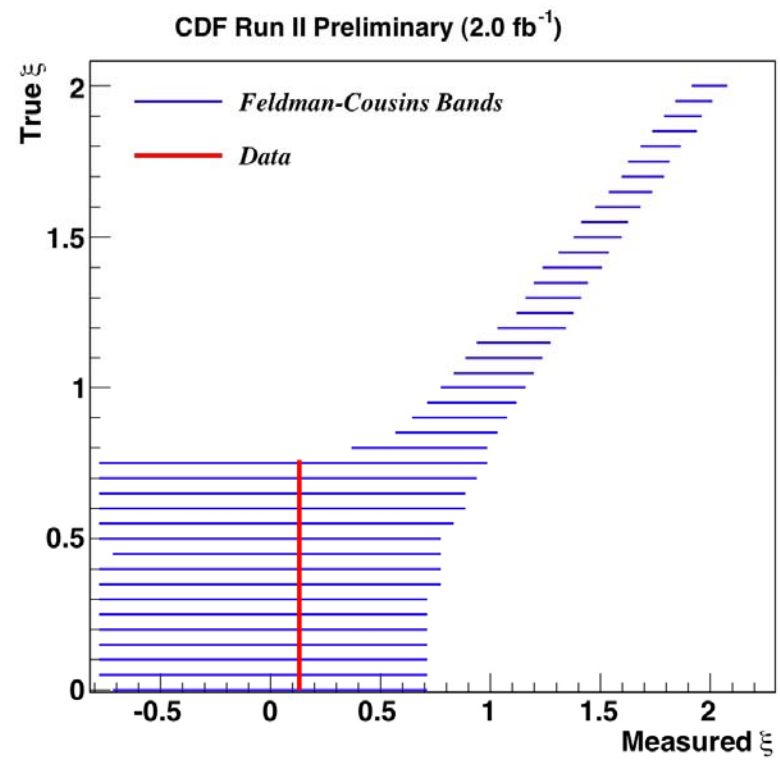
$$u\bar{u} \to \eta^0\eta^0 \to tt\bar{u}\bar{u} + h.c.$$

$$uu \to tt + h.c.$$

Same-sign Tops

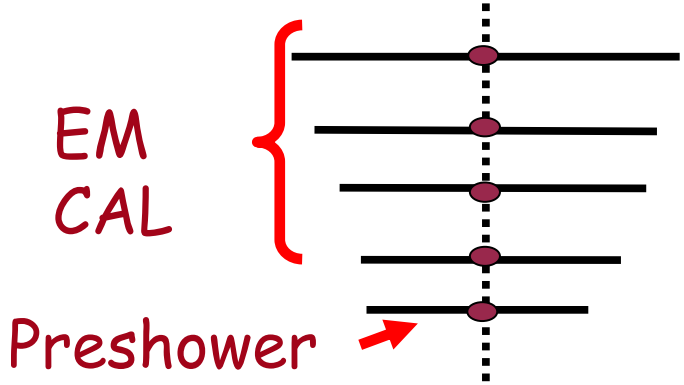
NEW !

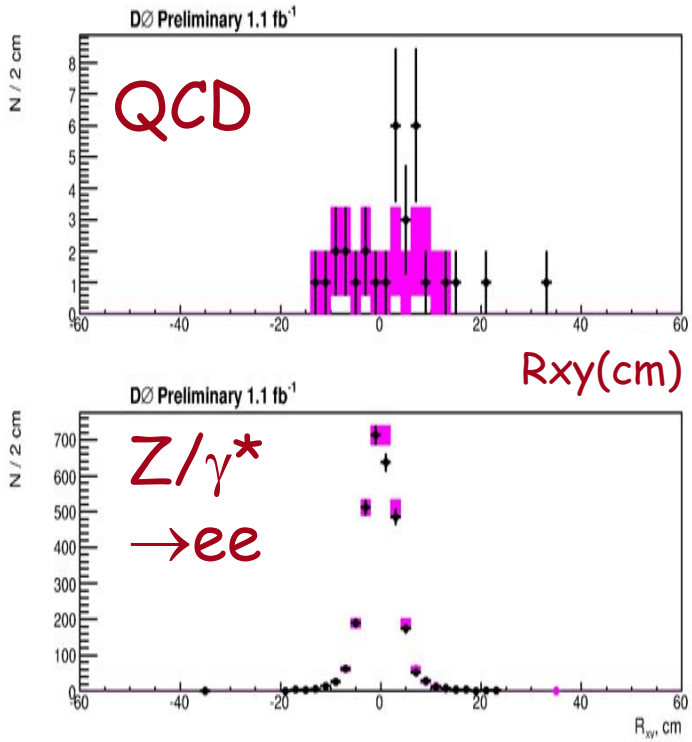




Heavy Long-lived Particles → Z + X

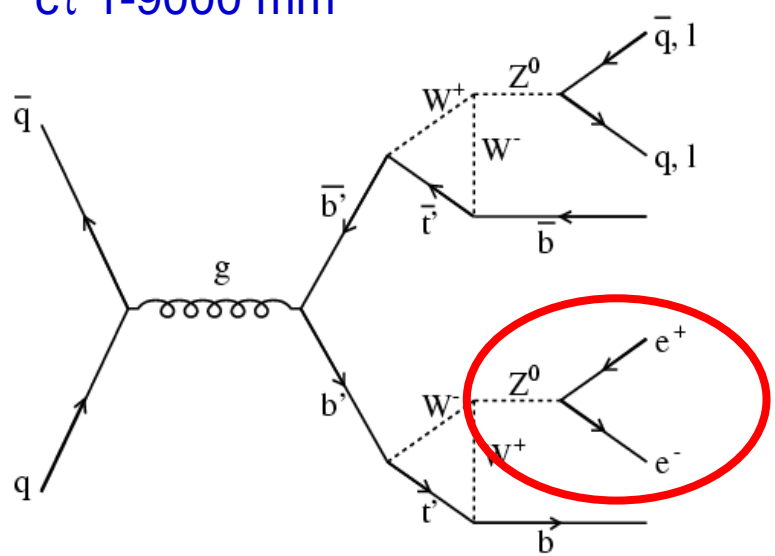
- **Predicted by several models**
  - Long-lived 4th generation b' quark
  - GMSB
  - Extended Higgs sector
  - Hidden-valley model
- **1.1 fb^{-1}, displaced Z →ee + X**
- **2 EM objects matched to clusters in the preshower**
  - E_T > 20 GeV, $|\eta|$ < 1.1 each
  - No matched track to suppress DY
  - M_{ee} > 75 GeV/c^2
- **2-D Vertexing in the transverse plane**
  - EM object trajectory from 5 points (4 in EM CAL, 1 in Preshower)
  - Vertex radius Rxy: 2 cm resolution

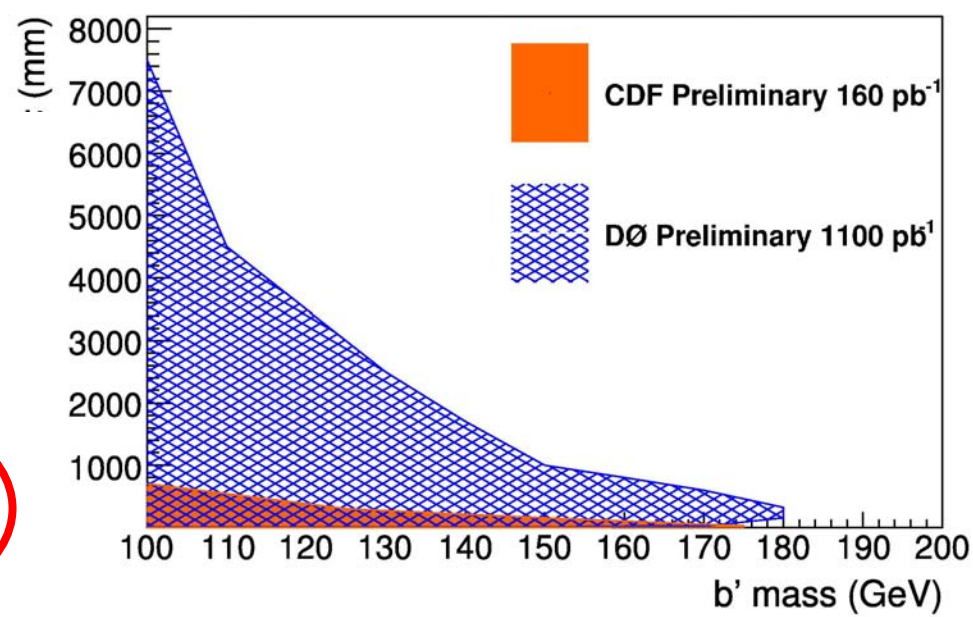




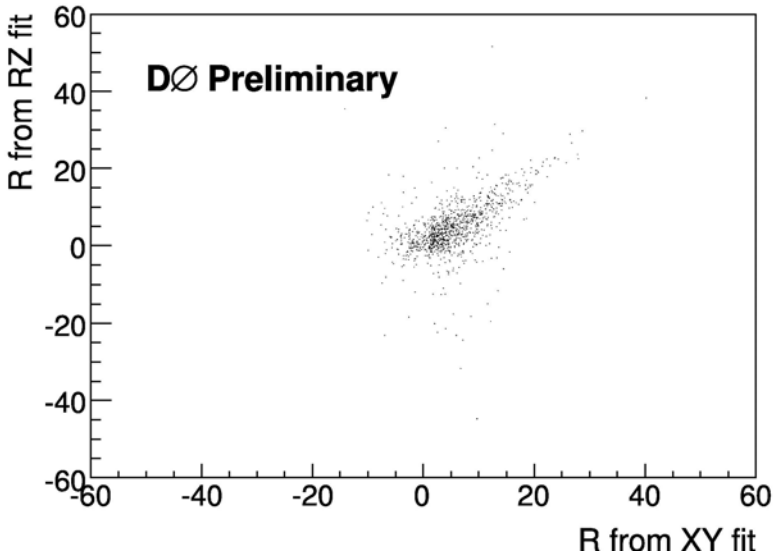
Heavy Long-lived Particles → Z + X

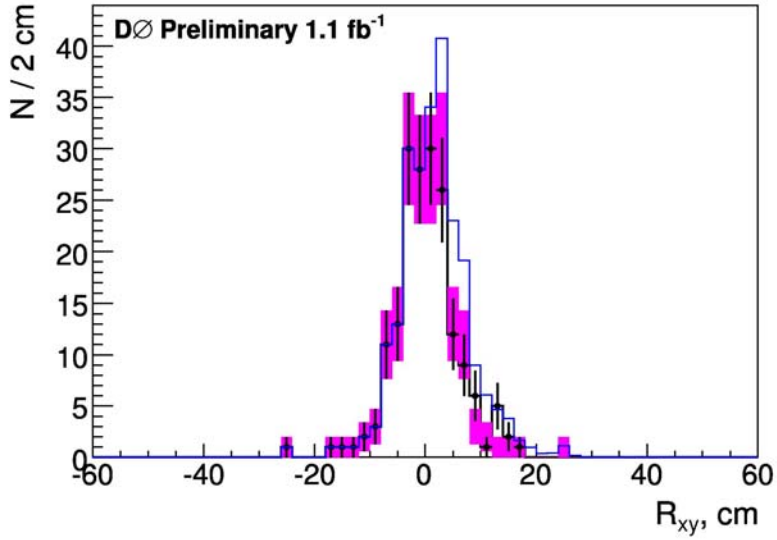
- **Background has symmetric Rxy**
- **Use neg-Rxy in data to estimate background in pos-Rxy**
- **No excess found**
- **Set Limit on b' mass and lifetime**
  - Discriminant: pos-Rxy
  - Mass 100-190 GeV/c^2
  - $c\tau$ 1-9000 mm





Heavy Long-lived Particles → Z + X



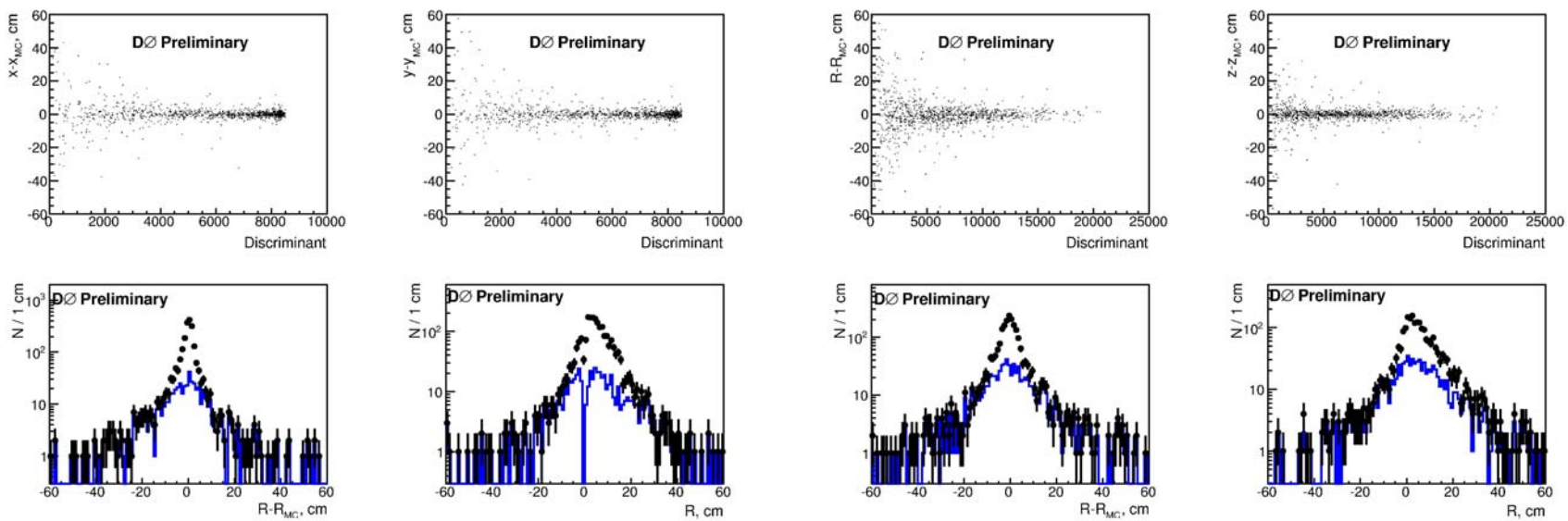


- **Calor. iso fraction < 7%**
- **Track iso < 2 GeV/c**
- **Mee calculated using z position from r-z vertexing**
- **Determinant ($\Delta X_1 \Delta Y_2 - \Delta X_2 \Delta Y_1$) > 4000 cm^2**

Heavy Long-lived Particles → Z + X

2-D vertexing in r-ϕ plane

2-D vertexing in r-z plane



Blue histograms are from almost-parallel electron pair

Technicolor $\rho^{\pm}$ and ρ^{0}

- **Technicolor Straw Man Model**
  - M(V) = M(A) = 200 GeV/c2
  - Q of up-type quark = 1
  - Mixing angle between isotriplet technipion interaction and mass eigenstates as $\sin\chi=1/3$
  - M(W) + M(techni-pion) < M(techni-rho) < 2 M(techni-pion)
- **Excluded region**

M(ρT) [GeV/c2]	M(πT) excluded region at 95% CL
180	95
190	105
200	105-115
210	115-125
220	115-125
230	125-135
240	125-145
250	135-145

Technicolor $\rho^{\pm}$ and ρ^{0}

Njet	2jet	3jet
Pretag Events	32242	5496
Mistag	3.88±0.35	2.41±0.24
$Wb\bar{b}$	37.93±16.92	14.05±5.49
$Wc\bar{c}$	2.88±1.25	1.52±0.61
$t\bar{t}$(6.7pb)	19.05±2.92	54.67±8.38
Single top(s-ch)	6.90±1.00	2.28±0.33
Single top(t-ch)	1.60±0.23	1.43±0.21
WW	0.17±0.02	0.15±0.02
WZ	2.41±0.26	0.68±0.07
ZZ	0.06±0.01	0.06±0.01
$Z->\tau\tau$	0.25±0.04	0.19±0.03
nonW QCD	5.50±1.00	2.56±0.48
Total Bkg	80.62±18.75	79.99±10.92
m($\rho^{\pm}$,π^{0})=(200,115) GeV	11.24±0.98	Control region
m(ρ^{0},$\pi^{\mp}$)=(200,115) GeV	1.50±0.16	Control region
Observed Events	83	88

2 tight b-tags