



Non-SUSY Exotics Searches at the Tevatron

Sasha Pronko

Fermilab

For CDF and DØ Collaborations

Overview

o In this talk

- Emphasize on new results since summer 07 based on $\sqrt{L} \geq 1 \text{ fb}^{-1}$ of data

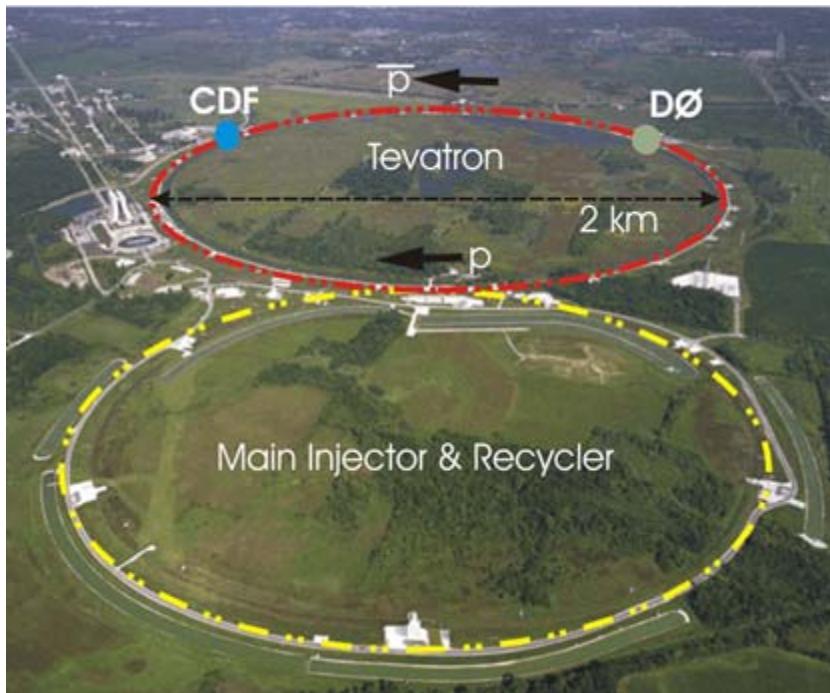
o Model-inspired

- Theory driven
- Model-dependent optimization of event selection
- Set limits on model parameters

o Signature-based

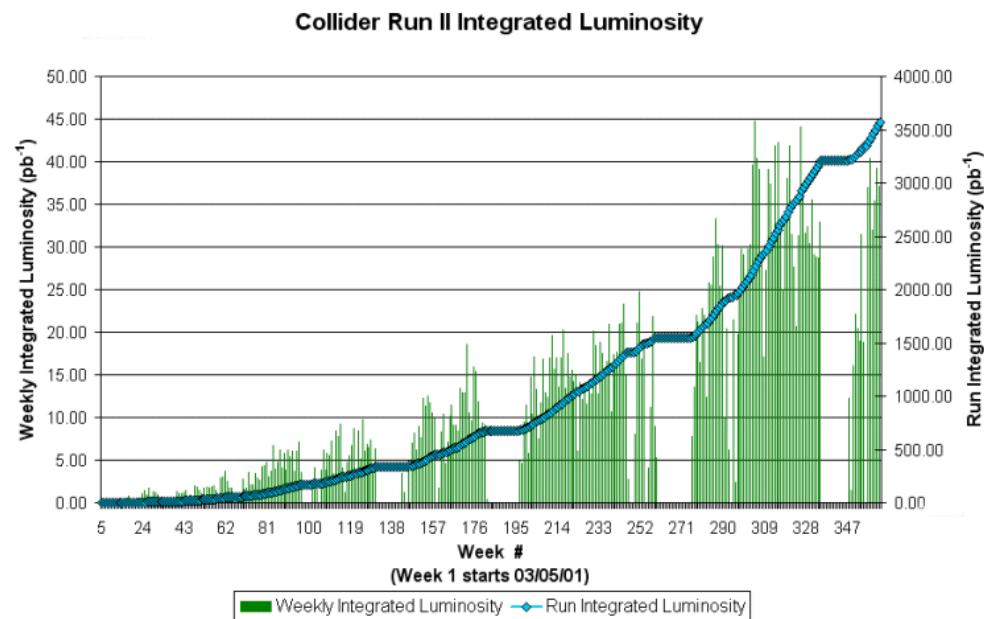
- Signature driven
- Optimize selection to reduce backgrounds
- Event count; event kinematics

Tevatron in Run II

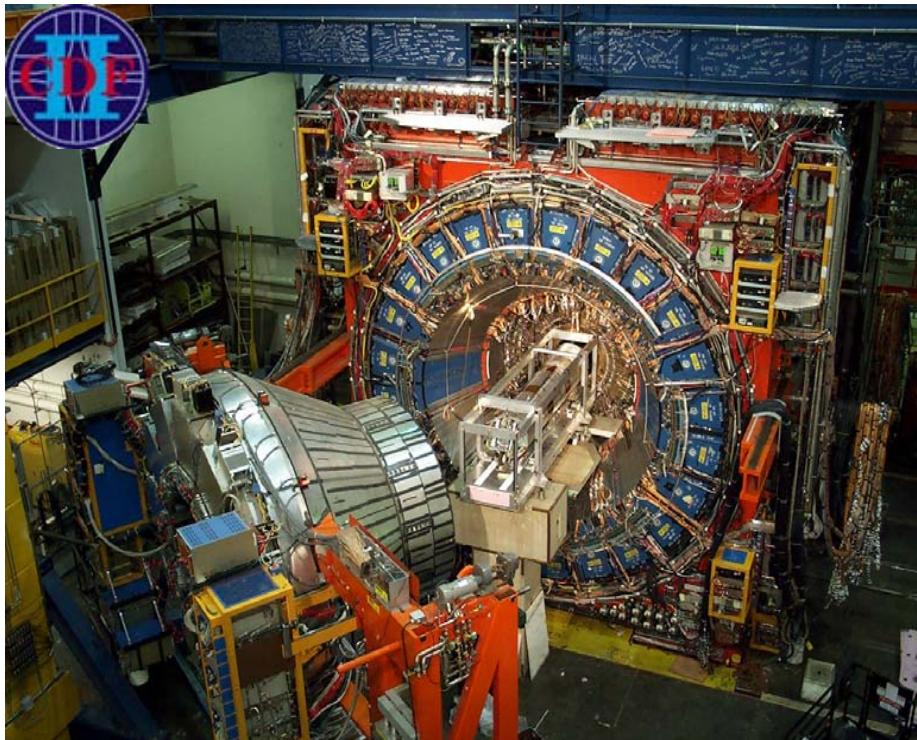


- o **36×36 bunches**
- o **Collisions every 396 ns**
- o **Two experiments: CDF & DØ**

- o **Proton-antiproton collisions at $\sqrt{s}=1.96$ TeV**
- o **Delivered luminosity**
 - Current: 3.7 fb^{-1} per experiment
 - Goal by 2009: $5-8 \text{ fb}^{-1}$



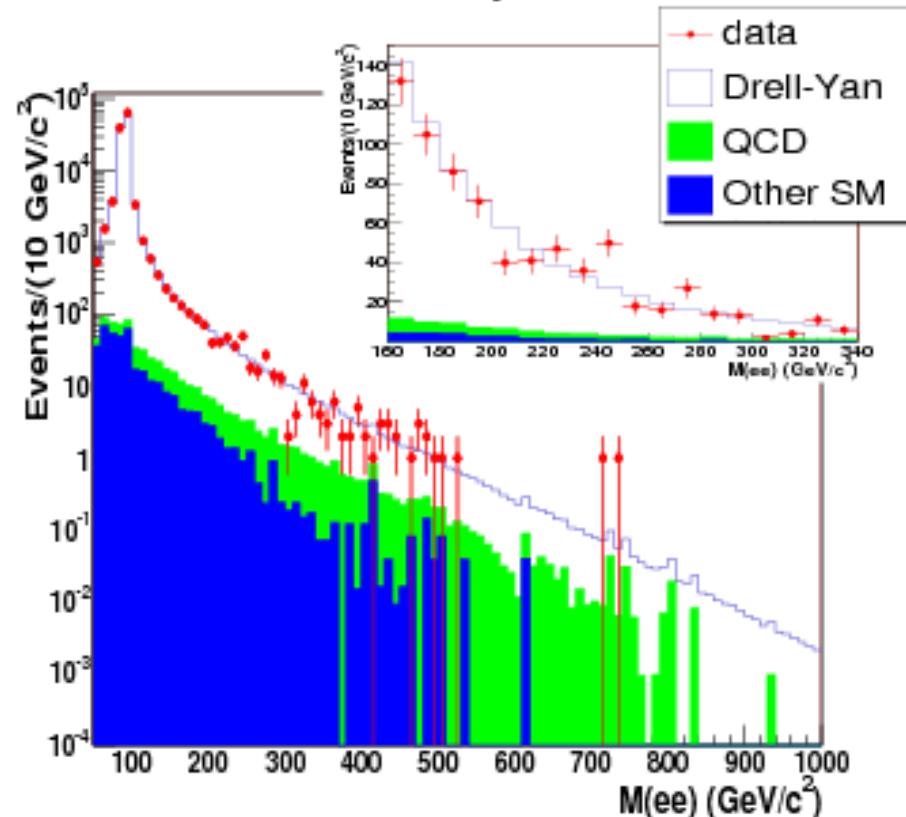
CDF and DØ Experiments



- o Multipurpose detectors — classic design
 - “silicon”, central tracker, solenoid, calorimeter, muon chambers
- o Operating well: 80-90% efficiency
- o Broad physics program
 - QCD, EWK, top, B-physics, Higgs searches, searches for new physics

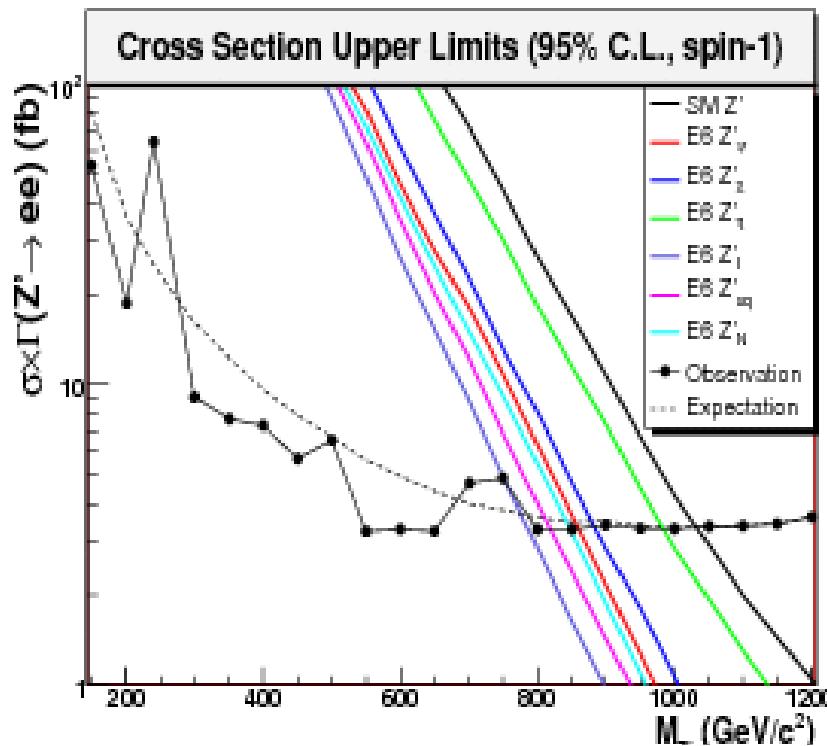
- o Many models with di-lepton resonance
 - E_6 Z's
 - RS graviton
- o Analysis overview
 - 2.5 fb^{-1} (largest dataset!!)
 - CC ($|\eta_{1,2}| < 1$) or CF ($|\eta| < 2$) e^+e^- pair with $E_T > 25 \text{ GeV}$
 - Search region: $150\text{-}1000 \text{ GeV}/c^2$
 - Dominant background is Drell-Yan
- o Results
 - 3.8σ excess in $M(e^+e^-)$ for $[228;250] \text{ GeV}/c^2$
 - 3.1σ excess with tighter cuts
 - $P=0.6\%$ to see 3.8σ deviation anywhere in $[150;1000] \text{ GeV}/c^2$
 - Both CDF & DØ didn't see anything significant in $\sim 1 \text{ fb}^{-1}$
 - Seen in both CC & CF e^+e^- pairs

CDF Run II Preliminary



- o Set World best limits on masses of Z's from E₆

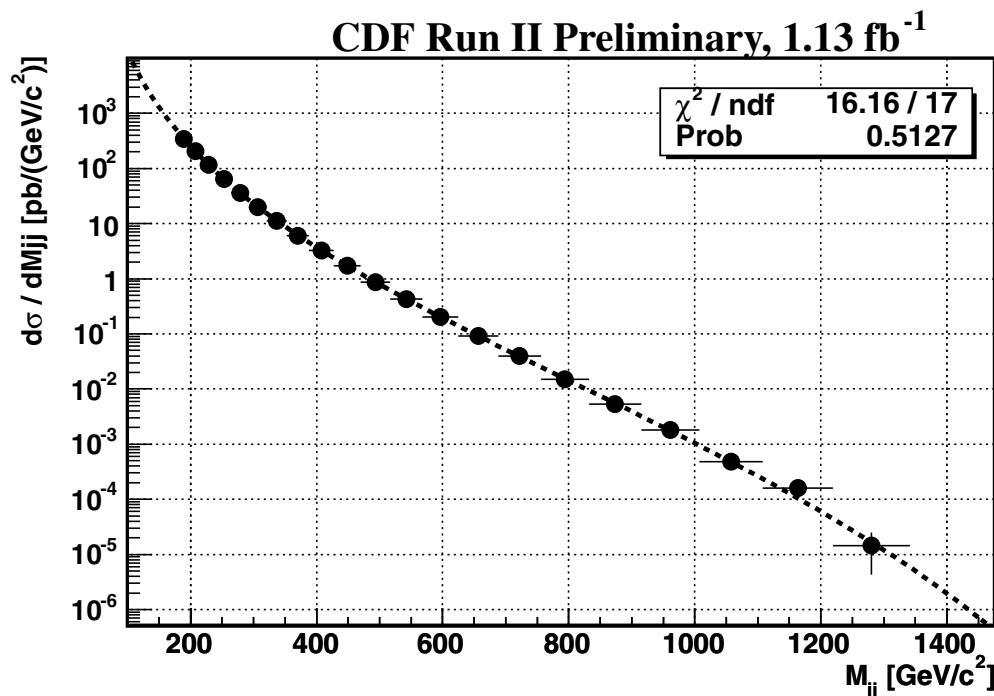
CDF Run II Preliminary



Work in progress
on updating lower
mass limit for RS
graviton

Z' Model	Z'_{SM}	Z'_{ψ}	Z'_{χ}	Z'_{η}	Z'_{I}	Z'_{sq}	Z'_{N}
Exp. Limit (GeV/c^2)	1031	855	880	982	775	811	842
Obs. Limit (GeV/c^2)	1032	859	883	983	752	819	847

- o Many Models with new particles decaying into di-jets
 - Axigluons, excited quarks, color octet technirhos, W'/Z', di-quarks in E₆, RS gravitons, etc.
- o Analysis at a glance
 - 1.1 fb⁻¹; N_{jet} ≥ 2; |y| < 1.0; M_{jj} > 180 GeV/c²
 - Fit mass spectrum by smooth function
 - test with Herwig, Pythia, and NLOJET++
 - look for excess over fit function

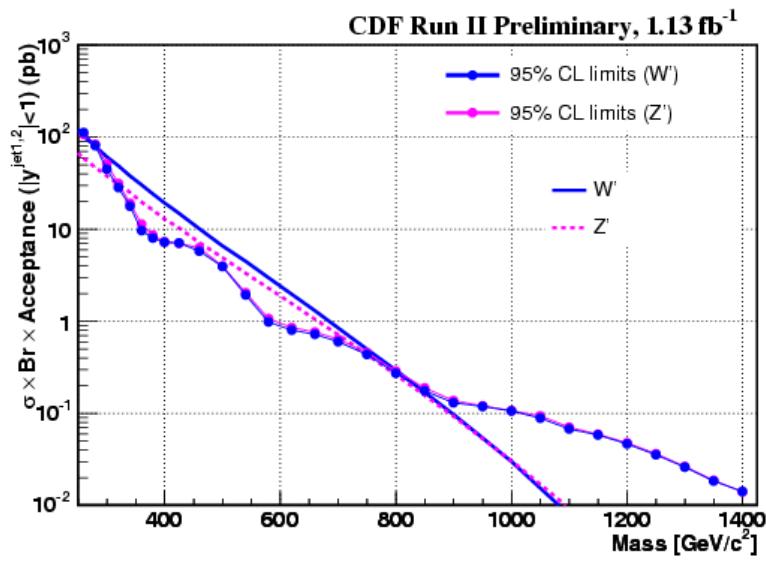
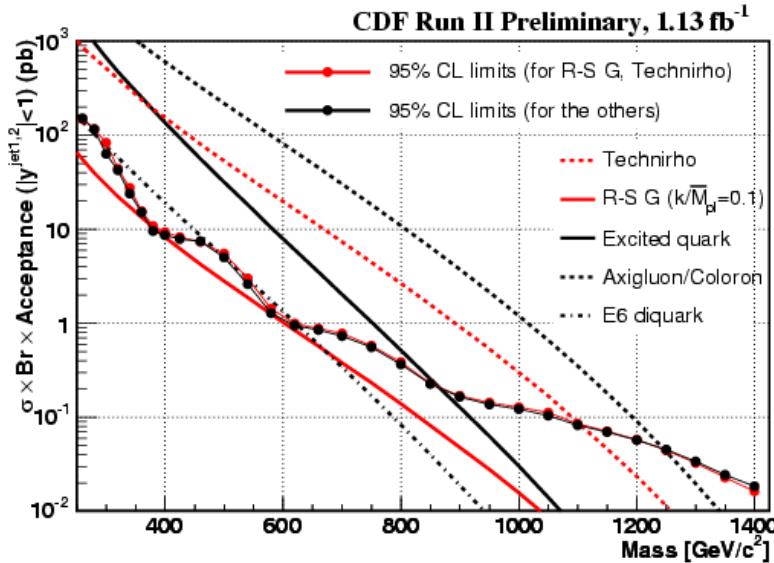


$$\frac{d\sigma}{dm} = p_0 (1-x)^{p_1} / x^{p_2 + p_3 \log(x)}, \quad x = m / \sqrt{s}$$

Search for High Mass Di-jet Resonances

- No excess observed
 - Set 95% CL limits
 - World best limits

Observed mass exclusion	Model
260-870 GeV/c^2	Excited quark
260-1110 GeV/c^2	Color-octet technirho
260-1250 GeV/c^2	Axigluon & coloron
260-630 GeV/c^2	E_6 diquark
260-840 GeV/c^2	W' (SM couplings)
260-740 GeV/c^2	Z' (SM couplings)



- o Long-lived particles decaying into Z

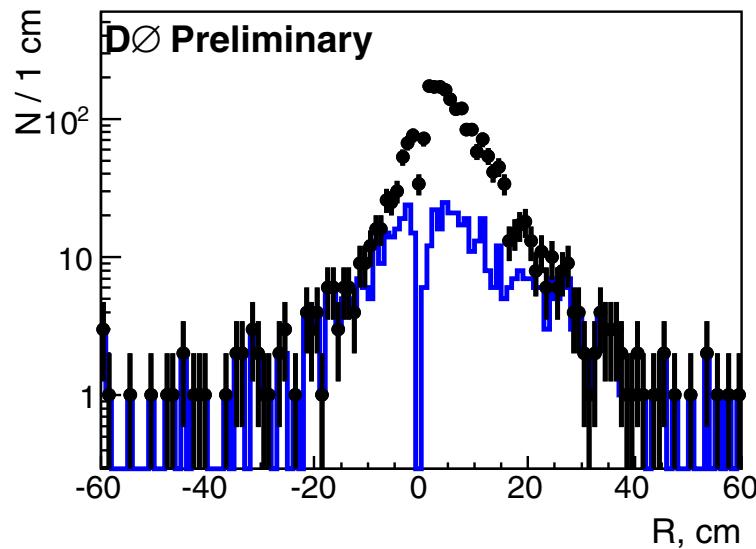
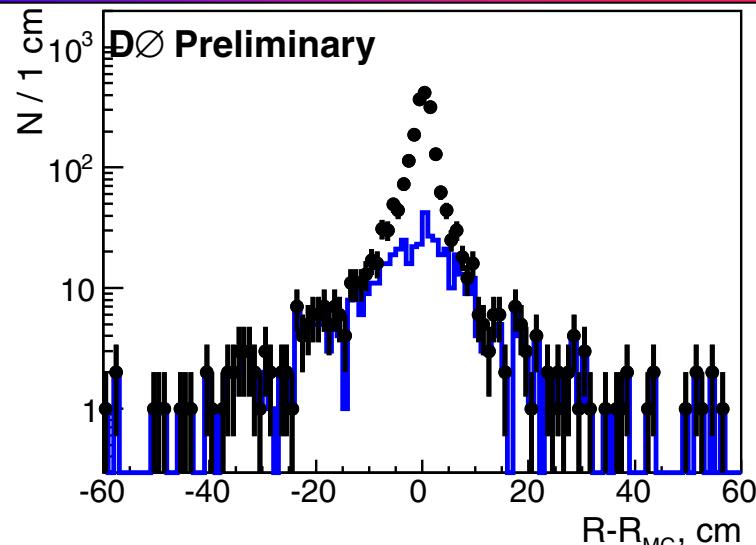
- GMSB
- Hidden valley models
- Extended Higgs sector
- 4th generation quarks

- o Analysis overview

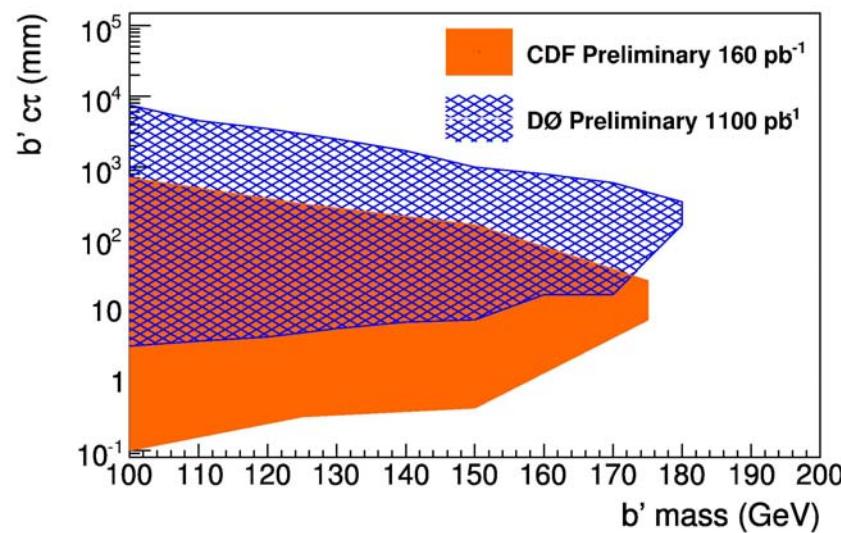
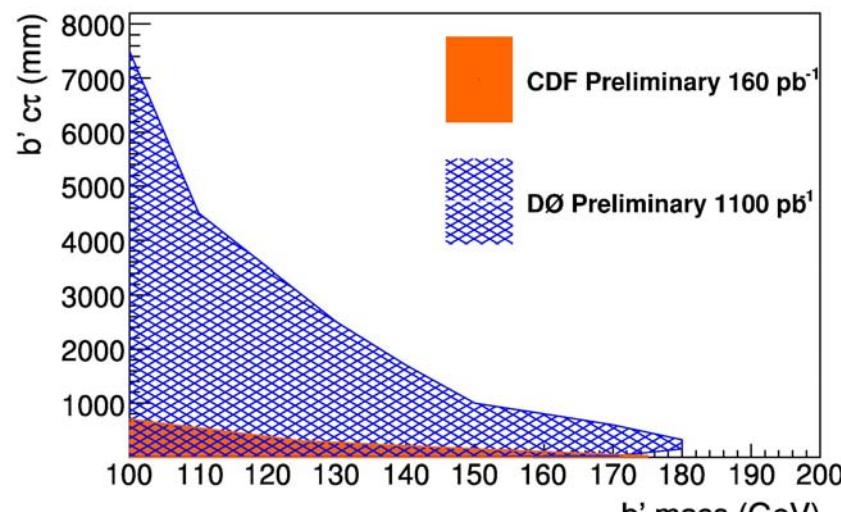
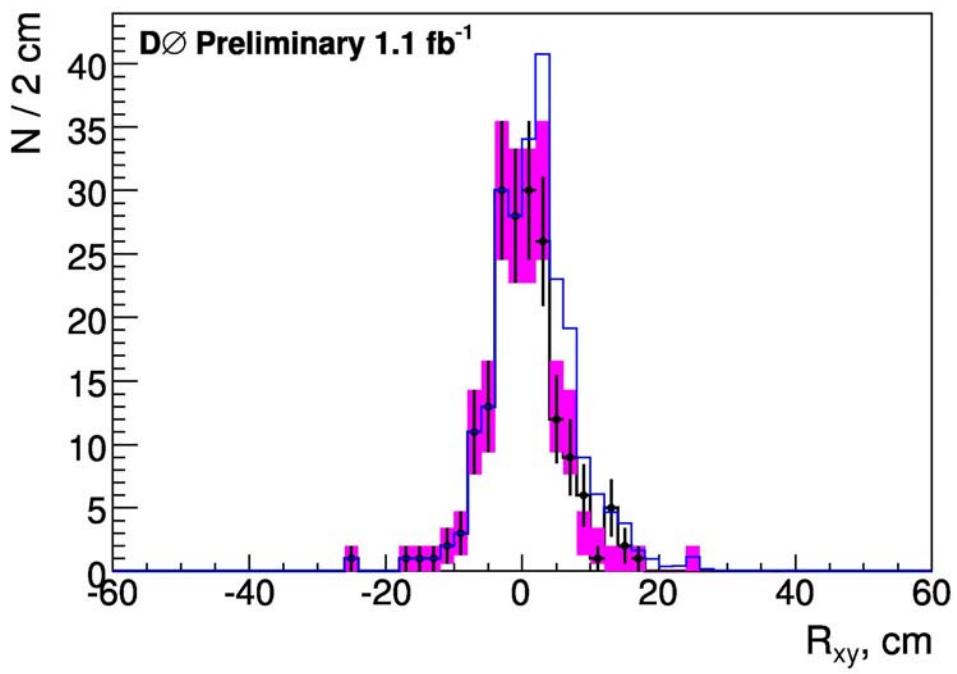
- 1.1 fb^{-1} ; $M_{ee} > 75 \text{ GeV}/c^2$; two central EM objects
- EM pointing to reconstruct decay vertex
 - $\sim 2 \text{ cm}$ resolution

- o Example of vertex reconstruction in (xy)-plane using EM pointing

- For b' with $M=160 \text{ GeV}/c^2$ & $c\tau=300 \text{ mm}$
- New Physics would show up as excess in $R>0.0$

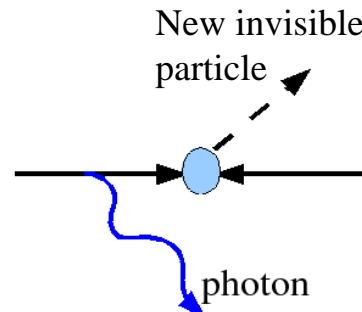


- No excess in positive R_{xy} is observed
 - Set limit on b' mass and lifetime



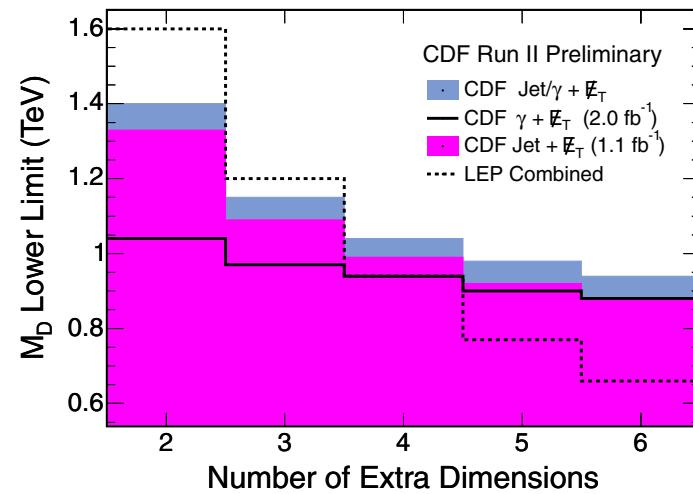
o Motivation

- Rare signature in SM
- ISR photon can be only trace of exotic process



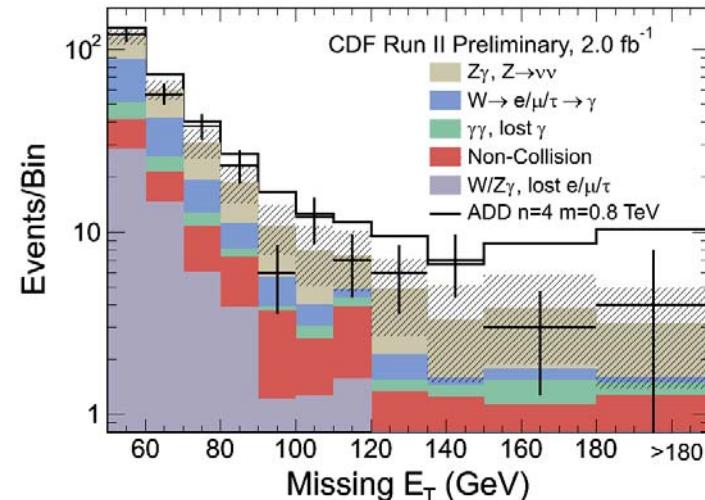
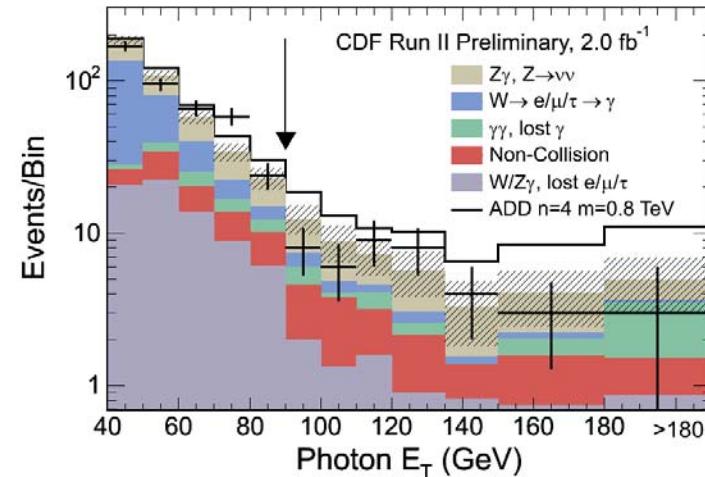
o Analysis

- 2 fb^{-1} ; $|\eta_\gamma| < 1.0$; $E_T(\gamma) & \text{MET} > 50 \text{ GeV}$; no jet with $E_T > 15 \text{ GeV}$; no trk with $P_T > 10 \text{ GeV}$; in time; 3 low P_T tracks
- Cosmic rejection: EM timing system ($\sigma \approx 0.7 \text{ ns}$)



**Optimize for LED:
 $E_T(\text{pho}) > 90 \text{ GeV}$**

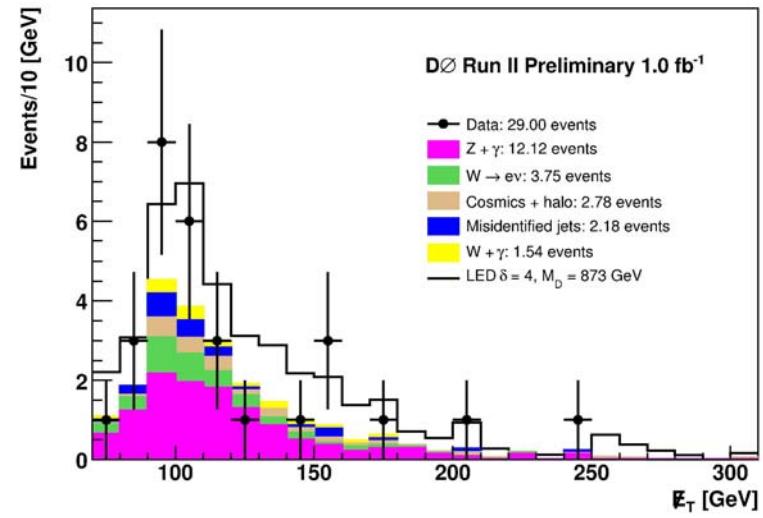
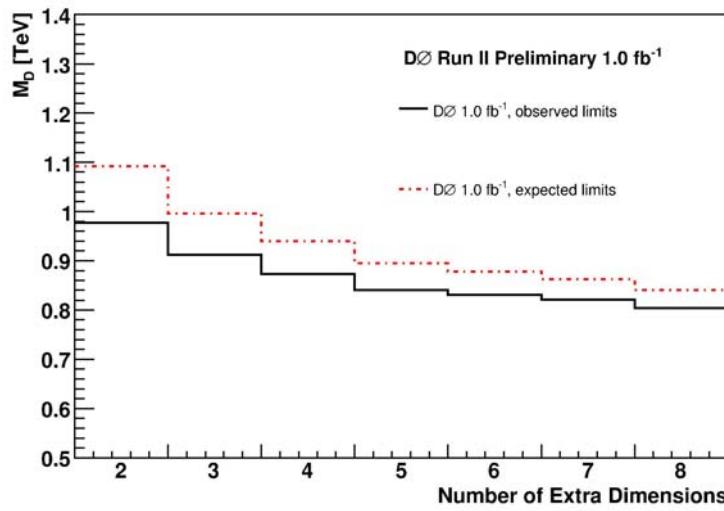
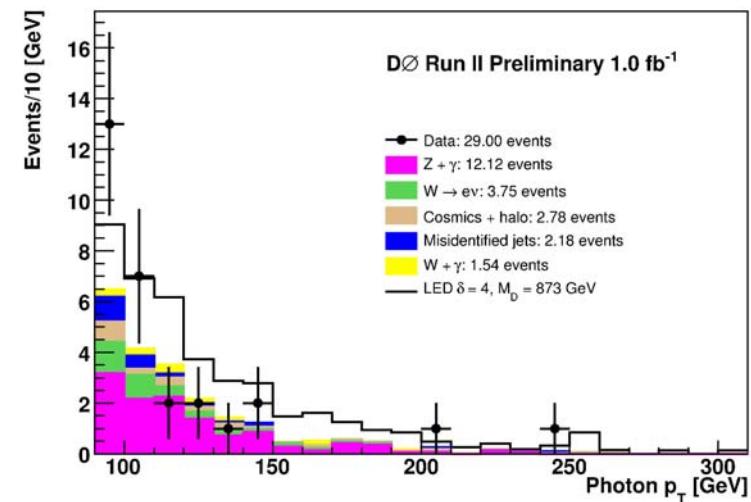
**Combination of
jet+MET & γ +MET**



- o LED provides solution for hierarchy problem

- o Analysis overview

- Almost same cuts as in CDF analysis
- 1 fb^{-1} ; $|\eta_\gamma| < 1.1$; $E_T(\gamma) > 90 \text{ GeV}$; $\text{MET} > 70 \text{ GeV}$; no jet with $E_T > 15 \text{ GeV}$; no isolated trk with $P_T > 6.5 \text{ GeV}$; cosmics veto
- EM shower pointing to reconstruct photon vertex ($\Delta z < 10 \text{ cm}$, $\sigma \sim 2 \text{ cm}$)



Anomalous Production of $\gamma\gamma + \text{MET}$

- o $\gamma\gamma + \text{MET} + X$ signature in many models

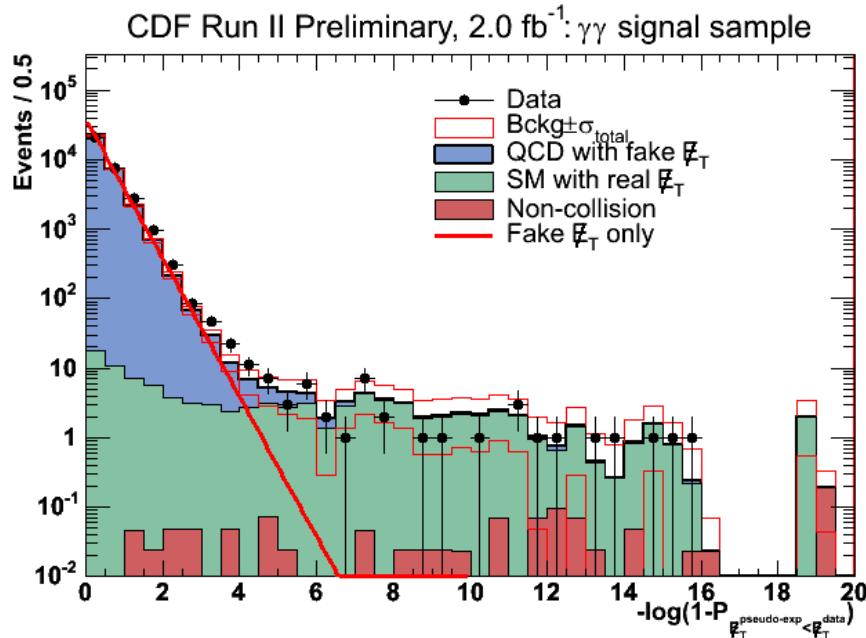
SUSY: $\gamma\gamma + E_T$, $\gamma\gamma + \text{jets} + E_T$, $\gamma\gamma + ll + E_T$

Technicolor: $\gamma\gamma + ll + E_T$

Higgs: $\gamma\gamma + l + E_T$

UED(6DSM): $\gamma\gamma + m^*l + E_T$

- o "Met Resolution Model" to calculate MET-significance & evaluate fake MET



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

MET-significance is evaluated based on jet & un-clustered energy resolution

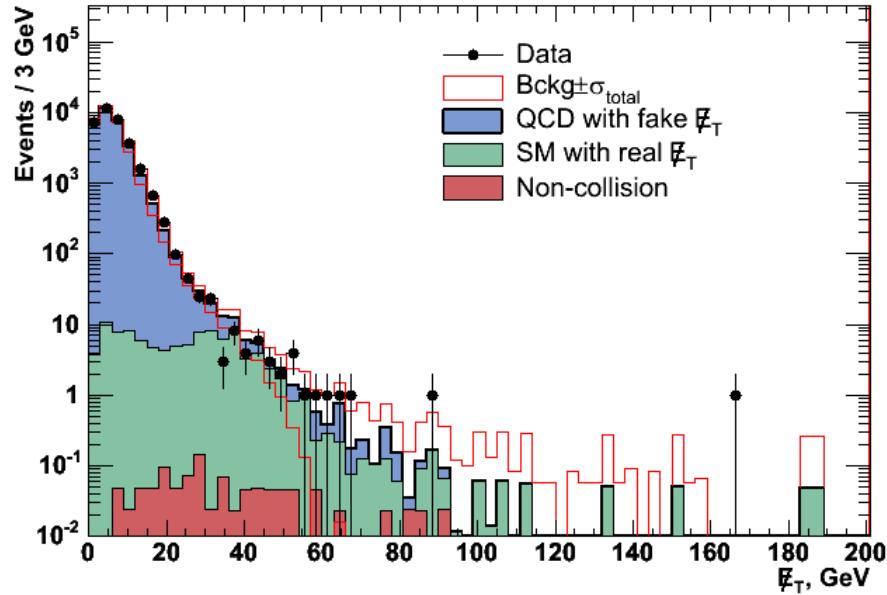
Sig>1: 10.0% level
 Sig>2: 1.0% level
 Sig>3: 0.1% level

Anomalous Production of $\gamma\gamma + \text{MET}$

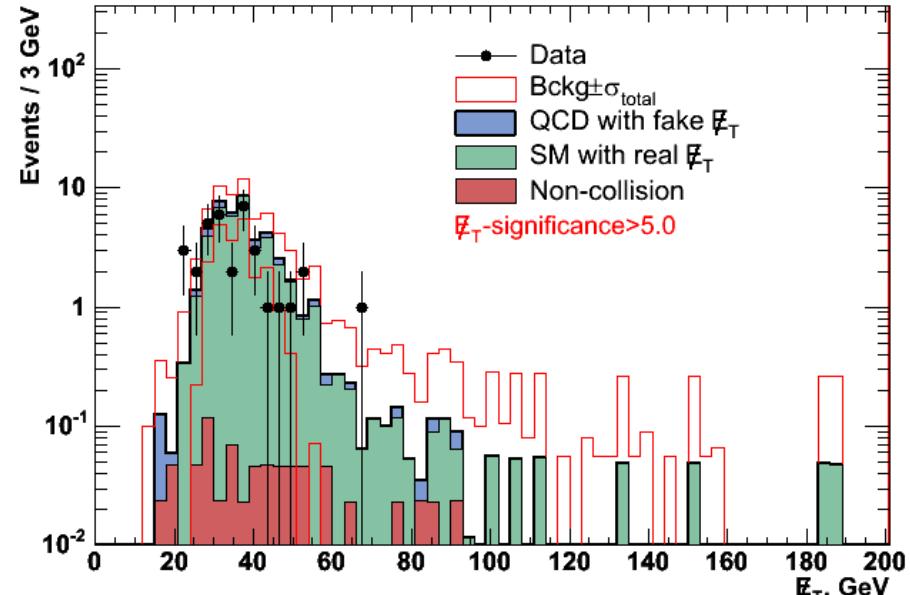
- Example on efficiency of MET-significance cut

Efficiency for $W\gamma \rightarrow e\nu\gamma$	$\text{MetSig} > 3.0$	$\text{MetSig} > 4.0$	$\text{MetSig} > 5.0$
	84%	79%	72%

CDF Run II Preliminary, 2.0 fb^{-1} : $\gamma\gamma$ signal sample

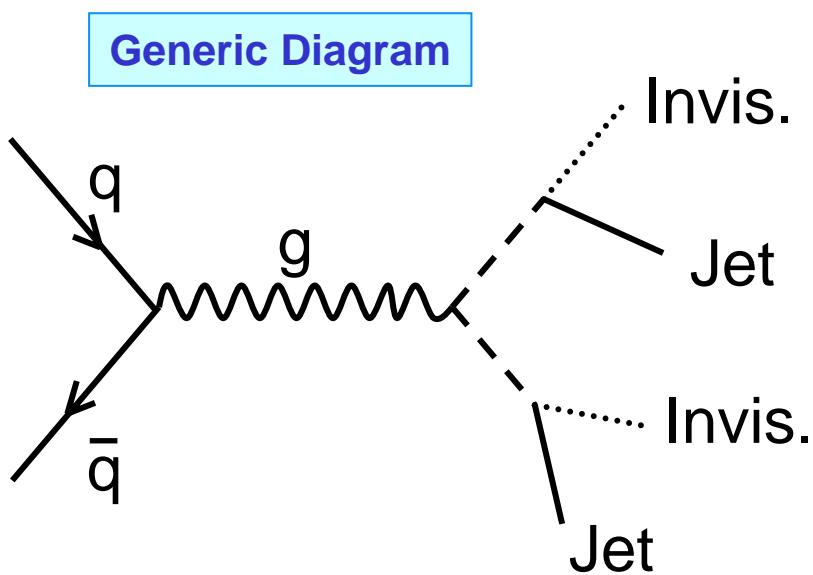


CDF Run II Preliminary, 2.0 fb^{-1} : $\gamma\gamma$ signal sample



MET-significance >5 removes almost all QCD (fake MET), but keeps $\sim 70\%$ of $W\gamma$ (real MET)

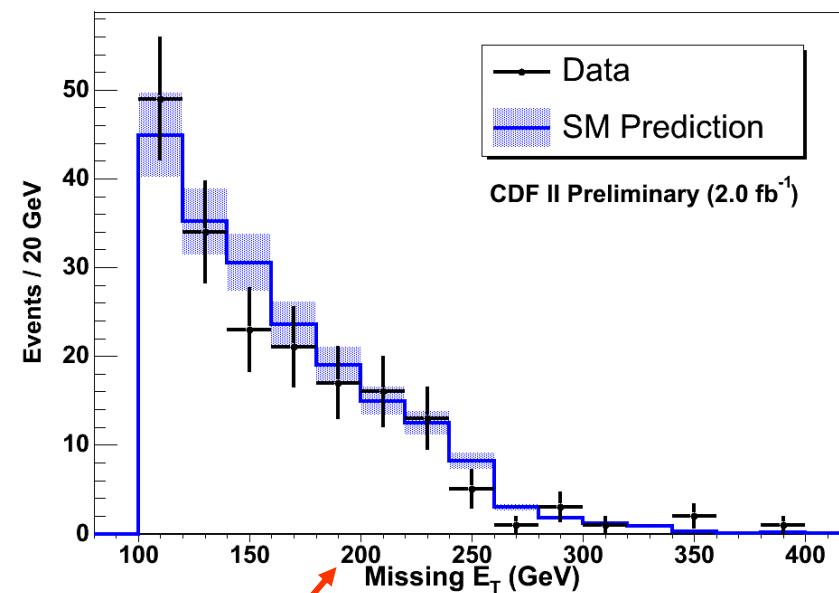
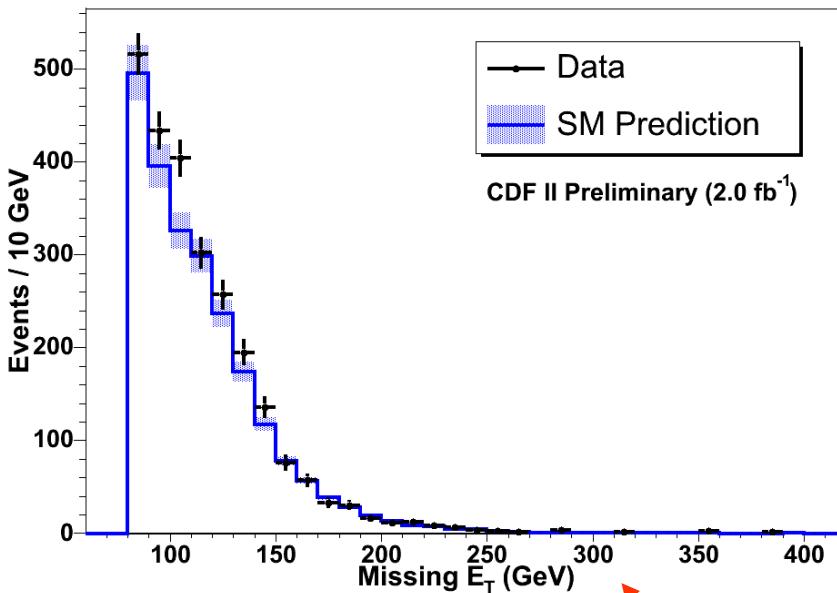
- o Signature of many models
 - MSSM (R-parity conserved)
 - Leptoquark models
 - UED (K-parity conserved)
 - Littlest Higgs models (T-parity conserved)



- o Analysis overview (2 fb^{-1})
 - Signature-based search
 - $N_{\text{jet}}(E_T > 15 \text{ GeV}) = 2$;
 $0.05 < |\eta| < 2.4$;
 - $E_T(\text{jet2}) > 30 \text{ GeV}$; MET-cleanup cuts
 - Two kinematic regions:
 - ✓ $H_T = E_T(\text{jet1}) + E_T(\text{jet2}) > 125 \text{ GeV}$; MET $> 80 \text{ GeV}$
 - ✓ $H_T = E_T(\text{jet1}) + E_T(\text{jet2}) > 225 \text{ GeV}$; MET $> 100 \text{ GeV}$
 - Data driven background estimate

Anomalous Production of jj+MET

- o Data agrees with predicted background
 - Limits on models (e.g., leptoquarks) are coming soon



	$H_T > 125 \text{ GeV}; \text{MET} > 80 \text{ GeV}$	$H_T > 225 \text{ GeV}; \text{MET} > 100 \text{ GeV}$
Total	2312 ± 140	196 ± 29
Observed	2506	186

o Theories with LQ bosons

- Grand unification
- Technicolor
- Compositeness

o Properties of LQ's

- Spin-0,1
- 3 generations (FCNC not seen)
- $Q=1/3, 2/3$ or $4/3$

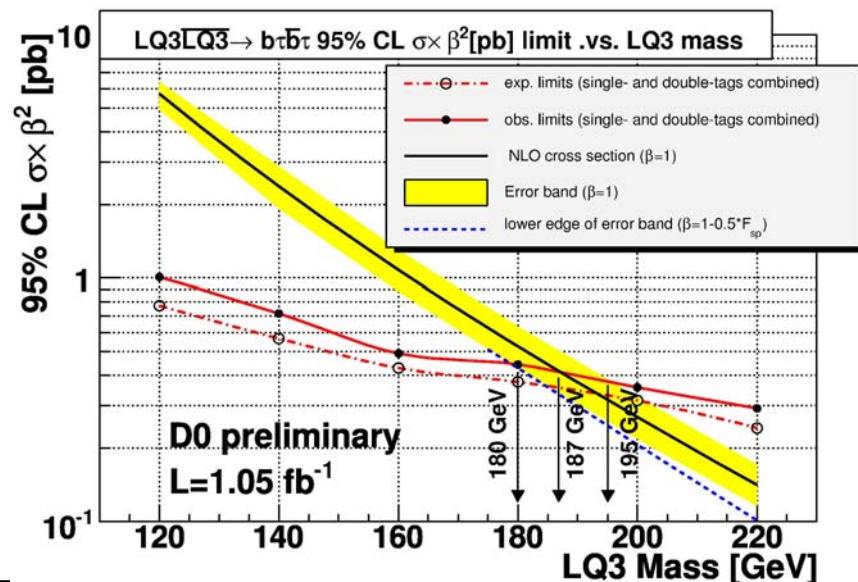
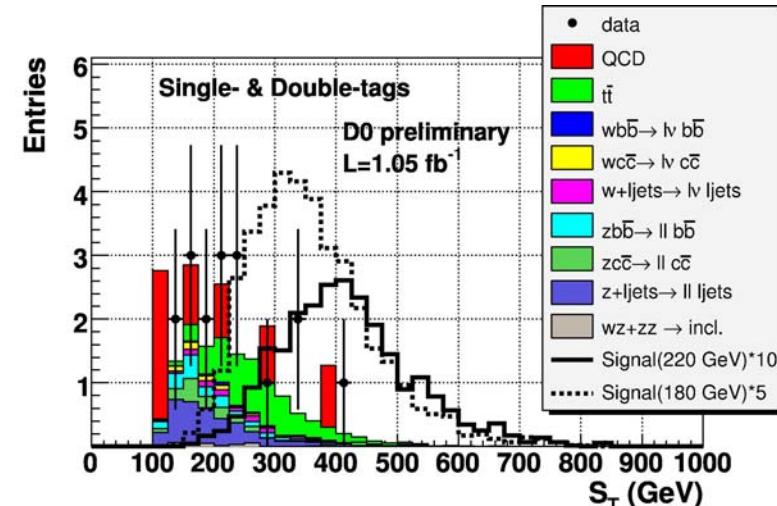
o Analysis overview

- 1.1 fb^{-1} ; tau: vis. $P_T > 15$ or 20 GeV ;
- 2 jets: $E_T > 25, 20 \text{ GeV}$; $|\eta| < 2.6$
- Ele veto, $M_T(\text{MET}, \mu) < 50 \text{ GeV}$
- Two sub-samples: 1 or 2 b-tags

$$p\bar{p} \rightarrow \overline{L}\overline{Q}_3 L Q_3 \rightarrow b\tau b\tau$$

$$\tau \rightarrow \mu\bar{\nu}$$

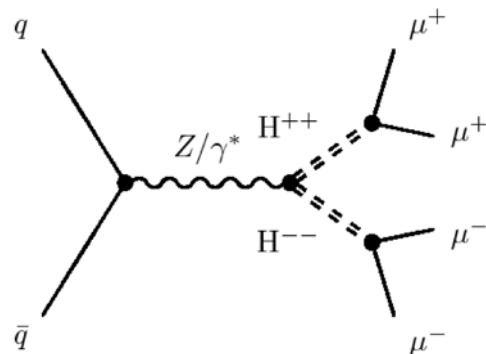
$$\tau \rightarrow \text{hadrons}$$



Search for $H^{++}H^{--} \rightarrow \mu^+\mu^+\mu^-\mu^-$

o Models with H^{++}

- Left-right symmetric models
- Higgs triplet
- Little Higgs

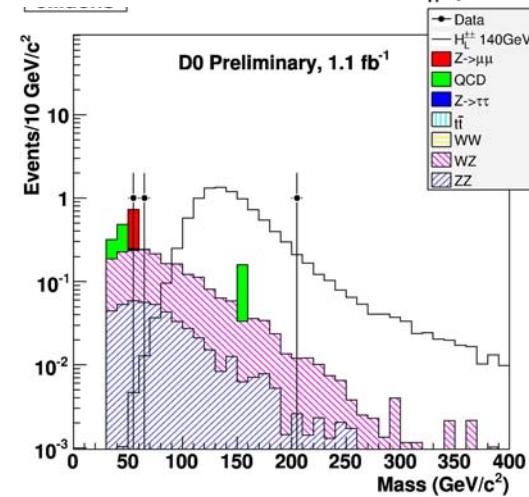
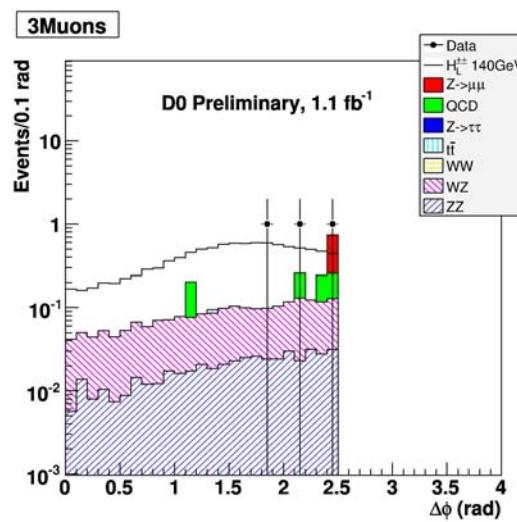
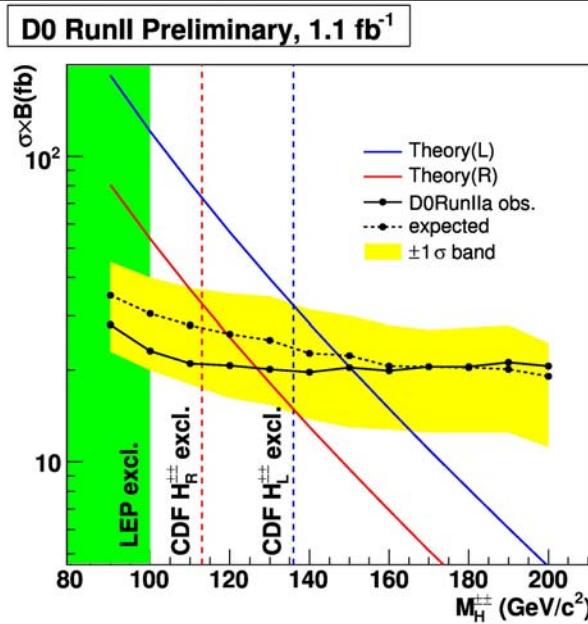


o Analysis Overview

- 1.1 fb^{-1} ; 3 μ 's with: $P_T > 15 \text{ GeV}/c$; $|\eta| < 2.0$
- At least one $\mu\mu$ pair with: $M > 30 \text{ GeV}/c^2$; $\Delta\phi < 2.5 \text{ rad}$

$$M(H_L^{\pm}) > 150 \text{ GeV}$$

$$M(H_R^{\pm}) > 126.5 \text{ GeV}$$



o Fermiophobic Higgs

- Top-color models
- LED theories
- MSSM
 - $H \rightarrow bb$ suppressed by 1-loop SUSY corrections

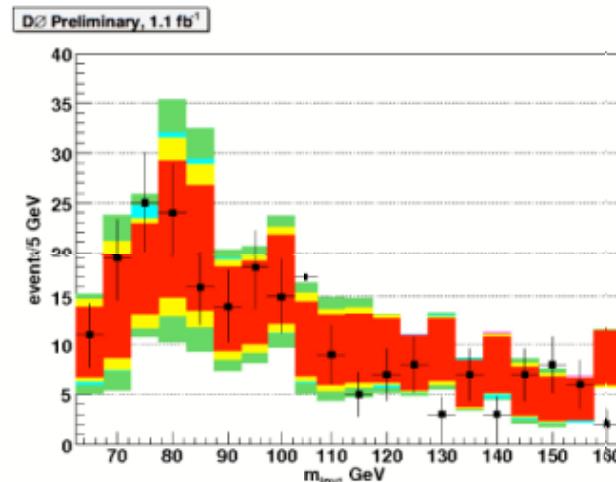
o Analysis overview

- 1.1 fb^{-1} ; 2 γ 's with: $E_T > 25 \text{ GeV}$; $|\eta| < 1.1$; $M_{\gamma\gamma} > 65 \text{ GeV}/c^2$
- Two regions
 - Signal: $q_T > 35 \text{ GeV}$
 - Control: $q_T < 35 \text{ GeV}$
- Background: $\gamma\gamma$, γj , jj

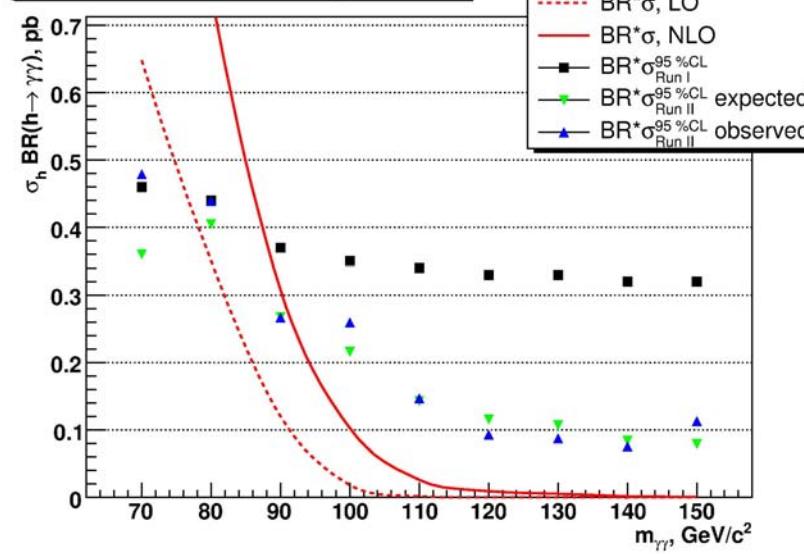
$$p\bar{p} \rightarrow VV \rightarrow h_f \rightarrow \gamma\gamma + X$$

$$p\bar{p} \rightarrow h_f W^\pm (Z) \rightarrow \gamma\gamma + X$$

Result:
 $M(h_f) > 92 \text{ GeV}/c^2$



DZero Run II Preliminary, 1.1 fb^{-1}

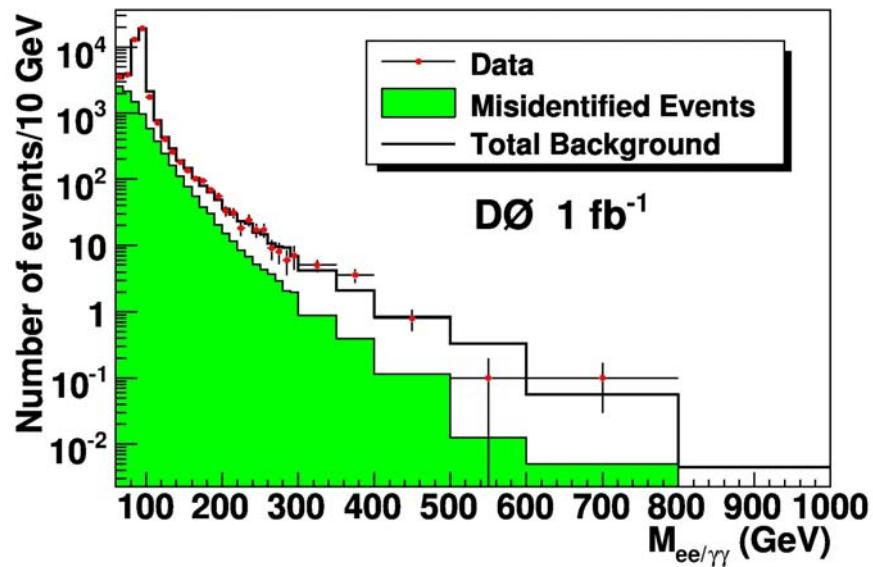
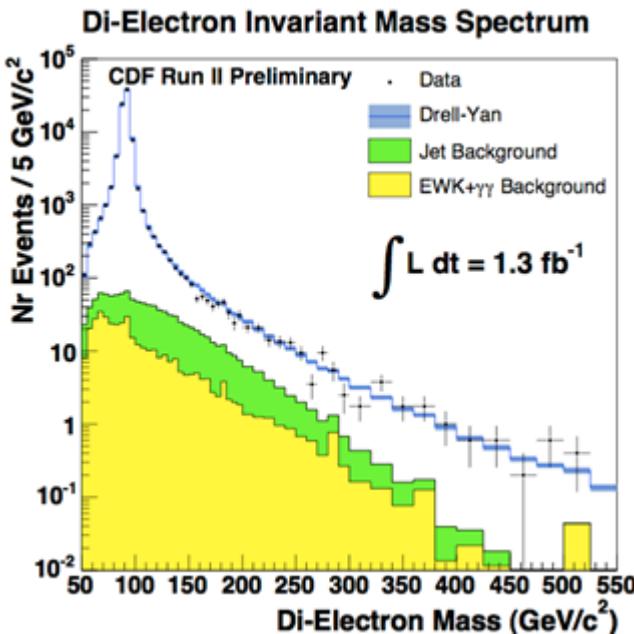


Summary

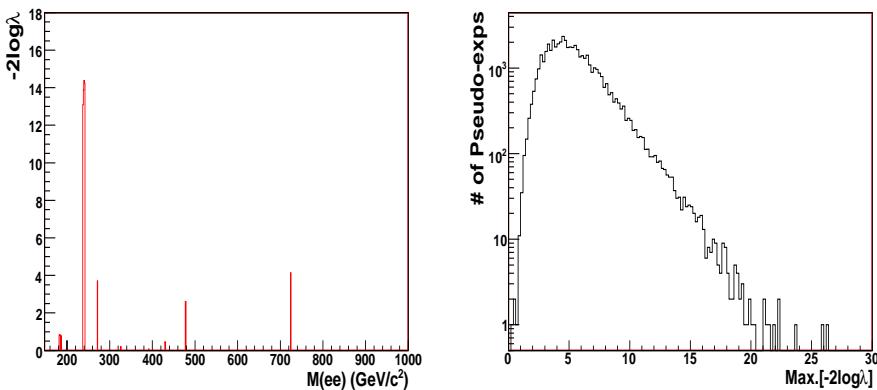
- o CDF and DØ performed many searches for signatures of New Physics beyond the Standard Model
 - SM still prevails
 - CDF observes 3.8σ excess at $M(e^+e^-) \sim 240 \text{ GeV}/c^2$ in 2.5 fb^{-1}
 - More data will tell if is a fluctuation or sign of something new
 - Waiting for DØ result with larger dataset
- o Both CDF & DØ explore new signatures and analysis techniques
 - Increases our potential to see something new
 - New techniques: EM timing; photon pointing; met resolution model
 - New analyses: "delayed" Z's
- o With $\sim 3.7 \text{ fb}^{-1}$ on tape and $2-5 \text{ fb}^{-1}$ still to come, expect more exciting results

Backup slides

Search for High Mass e^+e^- Resonance



CDF Run II Preliminary

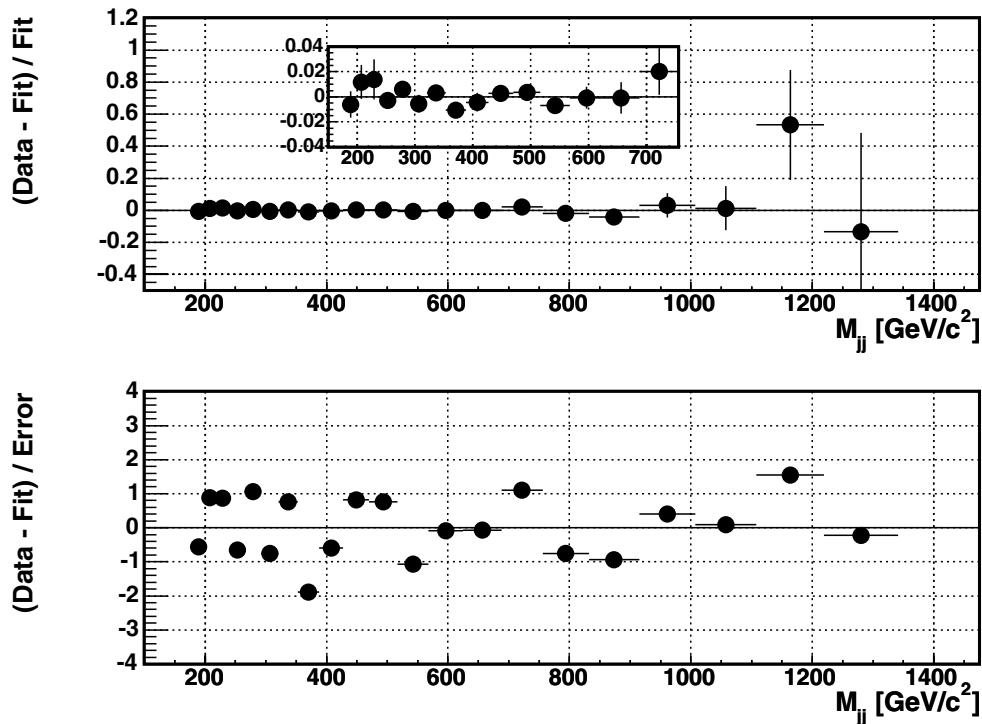


- o **Signal significance investigated**

- See excess in both CC & CP
- Un-binned likelihood ratio
 $\lambda = \max(L_b) / \max(L_{s+b})$ with 1 GeV step
- $P=0.6\%$ to see 3.8σ deviation anywhere in $[150;1000] \text{ GeV}/c^2$

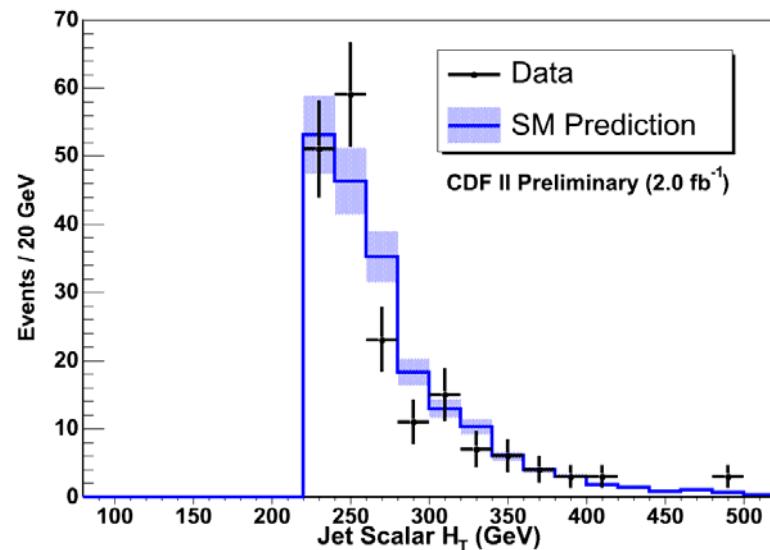
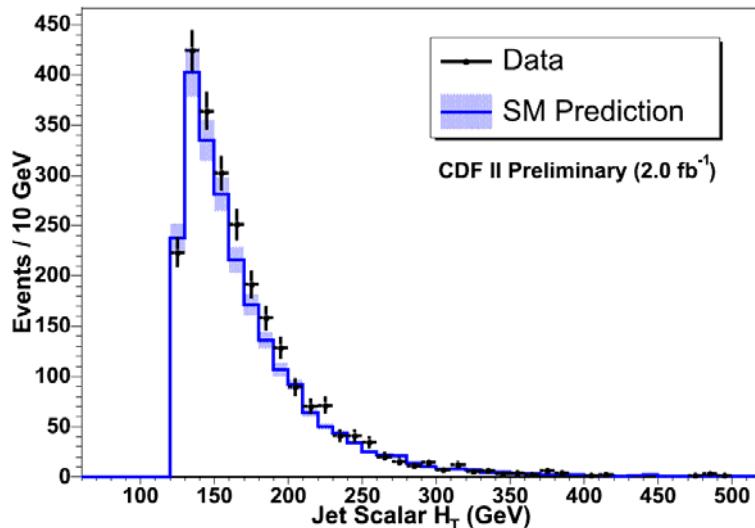
o Analysis at a glance

- 1.1 fb^{-1} ; $N_{\text{jet}} \geq 2$; $|y| < 1.0$; $M_{jj} > 180 \text{ GeV}/c^2$
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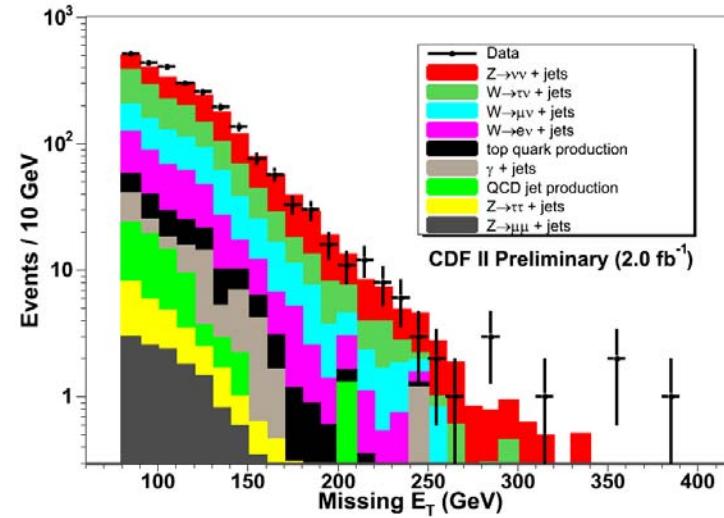


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Anomalous Production of jj+MET



- o Data agrees with predicted background





Anomalous Production of jj+MET

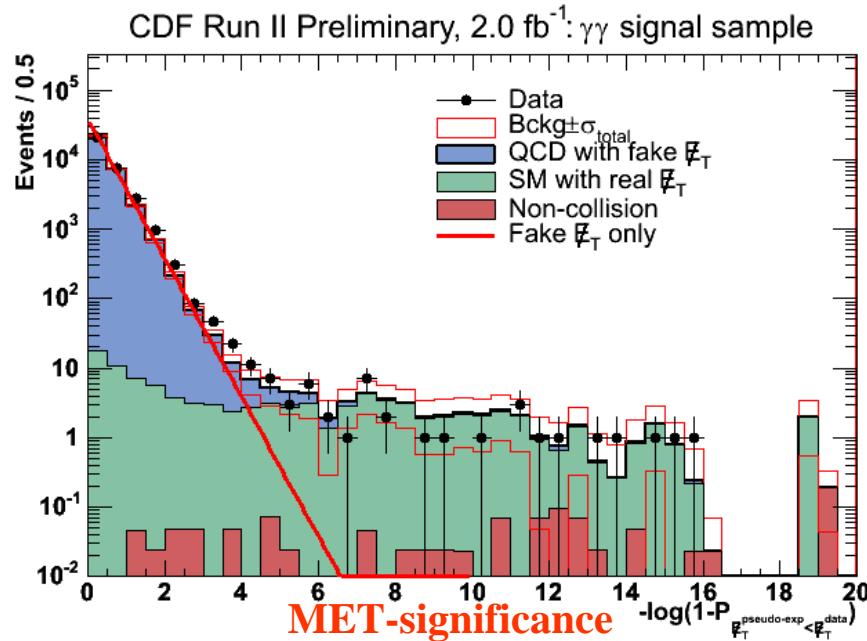
o Data driven background estimates

Background	$H_T > 125 \text{ GeV};$ $\text{MET} > 80 \text{ GeV}$	$H_T > 225 \text{ GeV};$ $\text{MET} > 100 \text{ GeV}$
$W + \text{jets} \rightarrow l\nu + \text{jets}$	1324 ± 51	97 ± 10
$Z + \text{jets} \rightarrow \nu\nu + \text{jets}$	777 ± 49	71 ± 12
$Z + \text{jets} \rightarrow ll + \text{jets}$	29 ± 4	2 ± 0
QCD	49 ± 30	9 ± 9
$\gamma + \text{jets}$	55 ± 13	5 ± 3
top	74 ± 9	11 ± 2
non-collision	4 ± 4	1 ± 1
Total	2312 ± 140	196 ± 29
Observed	2506	186

Anomalous Production of $\gamma\gamma + \text{MET}$

o Analysis overview

- $2 \text{ fb}^{-1}; |\ln_{\gamma_1,2}| < 1.0; E_T(\gamma_{1,2}) > 13 \text{ GeV}$
- Data driven background estimate
- Met Resolution Model to predict fake MET & select events based on MET-significance
- Two control regions
 - $Z \rightarrow e^+e^-$; non-ISO $\gamma\gamma$



	MetSig>3.0	MetSig>4.0	MetSig>5.0
Non-collision	0.90 ± 0.32	0.85 ± 0.30	0.80 ± 0.27
QCD (fake MET)	52.1 ± 11.5	15.4 ± 3.8	6.2 ± 2.7
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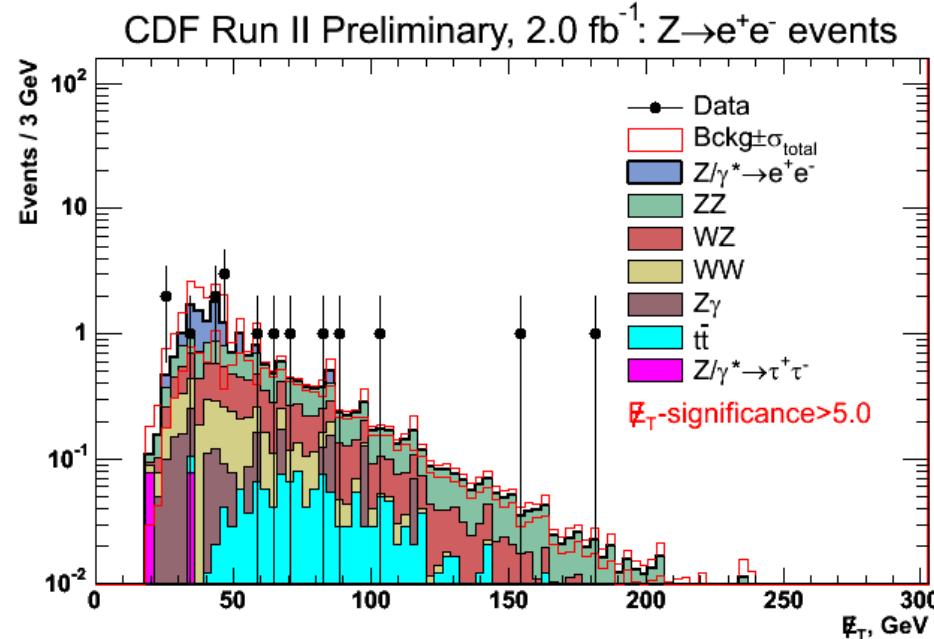
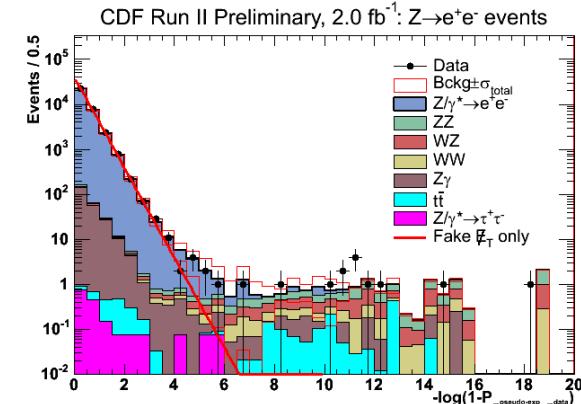
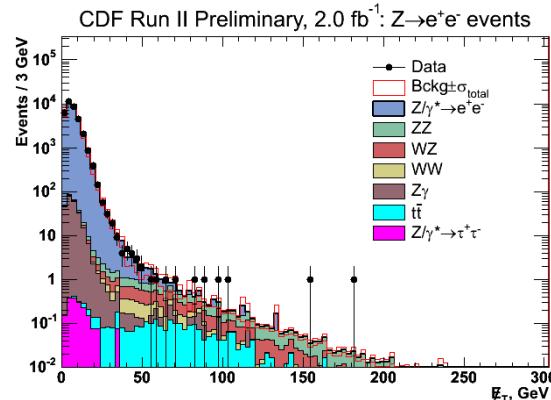
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Sig>1: 10.0% level
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 Sig>3: 0.1% level

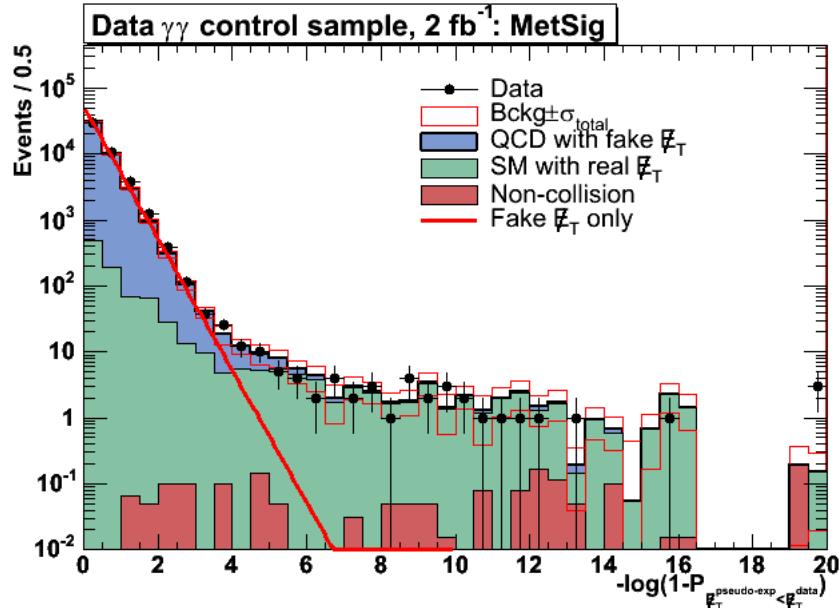
Anomalous Production of $\gamma\gamma + \text{MET}$

	MetSig>3	MetSig>5
$Z \rightarrow \tau\tau$	0.23 ± 0.13	0.15 ± 0.11
$t\bar{t}\text{bar}$	1.45 ± 0.08	1.40 ± 0.08
$Z + \gamma$	2.72 ± 0.37	1.43 ± 0.27
WW	2.97 ± 0.07	2.57 ± 0.06
WZ	5.44 ± 0.04	4.97 ± 0.04
ZZ	6.53 ± 0.06	5.94 ± 0.06
Fake MET	46.1 ± 2.1 $\pm 10.0(\text{syst})$	4.0 ± 0.6 $\pm 2.8(\text{syst})$
Total	65.4 ± 2.1	20.5 ± 0.7
Data	61	16

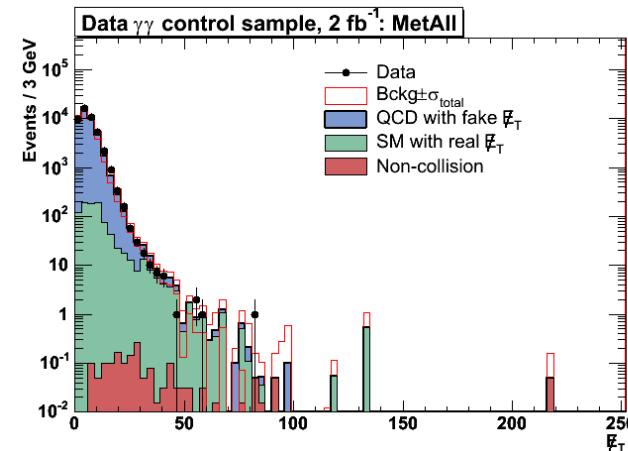
- o $Z \rightarrow e^+e^-$ control region
 - $86 \text{ GeV} < M_Z < 97.5 \text{ GeV}$
- o Only statistical uncertainties on background prediction



Anomalous Production of $\gamma\gamma + \text{MET}$



o Non-ISO $\gamma\gamma$ control sample
(~5% of real $\gamma\gamma$)



	MetSig>3.0	MetSig>4.0	MetSig>5.0
Non-collision	1.29 ± 0.47	1.20 ± 0.43	0.85 ± 0.38
QCD (fake MET)	61.3 ± 16.5	15.6 ± 5.1	4.2 ± 3.5
EWK (real MET)	68.5 ± 11.4	55.1 ± 9.9	43.6 ± 8.3
Total	131.1 ± 20.1	71.9 ± 11.1	48.7 ± 9.0
Data	126	63	41

