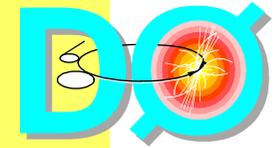




# Search for new physics in photon and jet final states



*Michel Jaffré*



*on behalf of the CDF and D0 collaborations*



*43<sup>rd</sup> Rencontres de Moriond*

*Electroweak interactions and Unified theories session*

# Outline

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- ✓  $\gamma\gamma/ee$  : Randall-Sundrum graviton
- ✓  $\gamma\gamma + \text{MET}$  : SUSY GMSB
- ✓ Single  $\gamma$  : Large extra dimension
- ✓ Anomalous  $\gamma\gamma + \text{MET}$  production
  
- ✓ Multijets + MET: SUSY
  - ✓ Squarks and gluinos
  - ✓ Stop
- ✓ Di-jet mass resonance

# Tools for photon ID

## ☺ Photon pointing

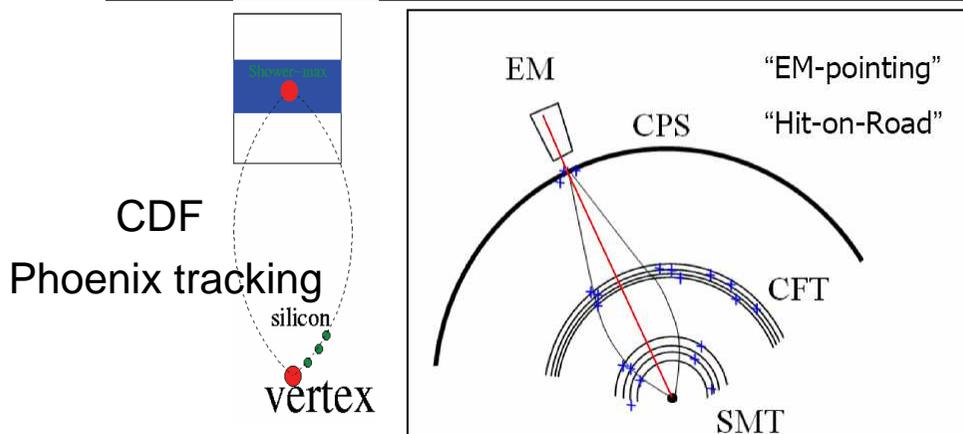
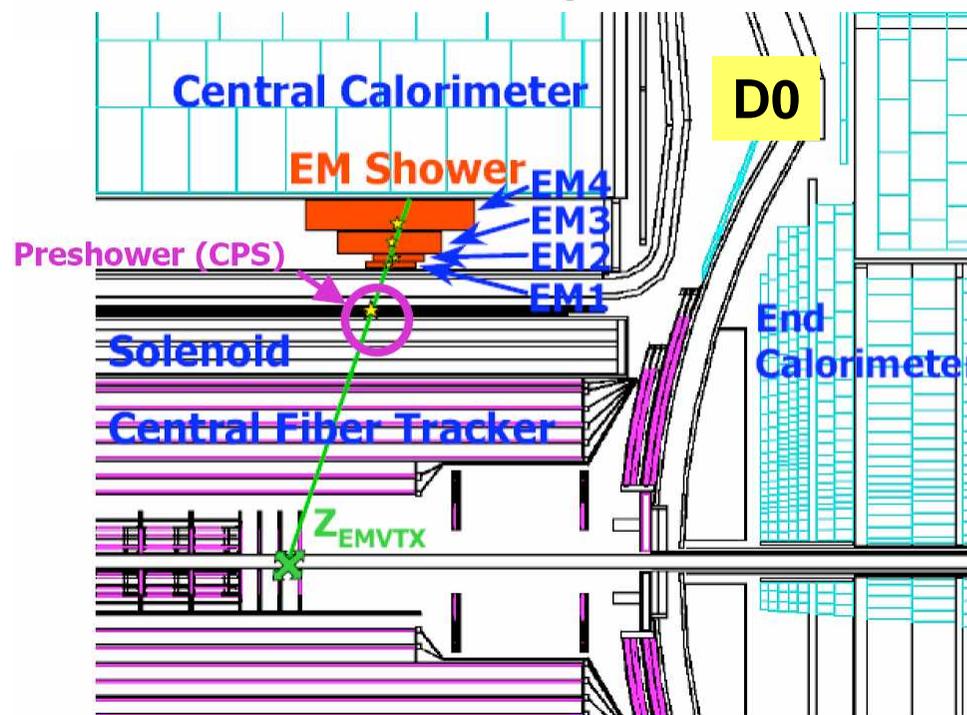
Several interactions/crossing  
 Tevatron inter. region  $\sigma_z \sim 28$  cm  
 MET is affected if PV shifted

Use of preshower (CPS)  
 Resolution on  $Z_{\text{vtx}} \sim 2$  cm

## ☺ Hits on the road (D0)

### Phoenix tracking (CDF)

Increases track efficiency  
 i.e. reduce  $e \rightarrow \gamma$  misid

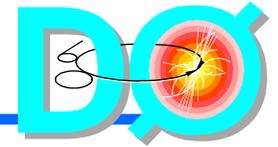


## ☺ CDF EM timing system

Cosmic rejection (muon  
 bremsstrahlung)

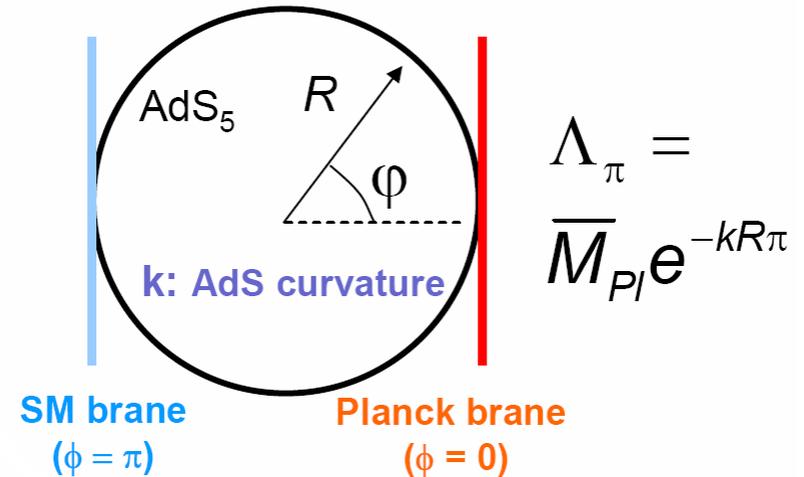


# Search for a $\gamma\gamma$ resonance: Randall-Sundrum

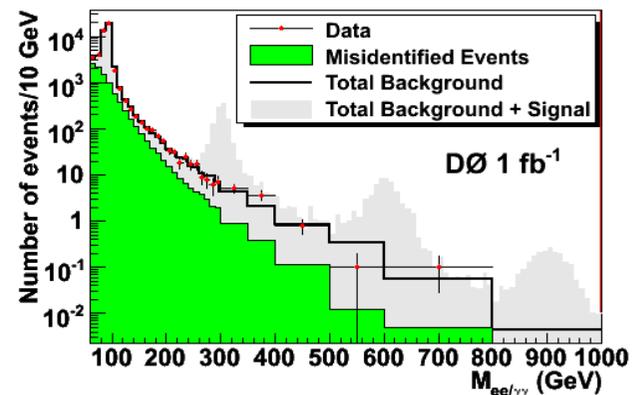


- One extra spatial dimension (as small as  $1/M_{\text{planck}}$ ) with a warped geometry
- Only the graviton is allowed to propagate in this extra dimension
- KK tower of graviton states are coupled to boson and fermion pairs (through the E-p tensor).
- **Model of RS depends on 2 parameters :**
  - $M_1$  the mass of the lowest KK excited mode
  - $\kappa/\bar{M}_{\text{Planck}}$  dimensionless coupling cst to SM fields where  $0.01 < \kappa/\bar{M}_{\text{Planck}} < 0.1$

$$ds^2 = \exp(-2kR|\phi|) \eta_{\mu\nu} dx^\mu dx^\nu - R^2 d\phi^2$$



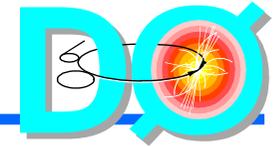
- CDF looked at  $\gamma\gamma$  and  $ee$  final states
- DØ looked at  $\gamma\gamma/ee$  final states
- $\text{Br}(G \rightarrow \gamma\gamma)/\text{Br}(G \rightarrow ee) = 2$



Photon:  
 $E_T > 25 \text{ GeV}$   
 $|\eta| < 1.1$

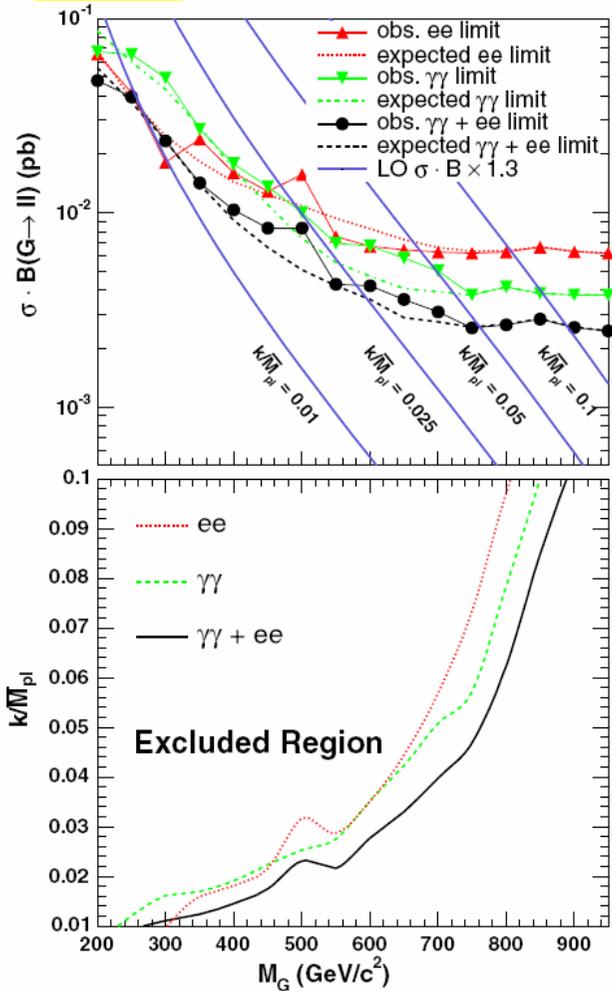


# RS graviton



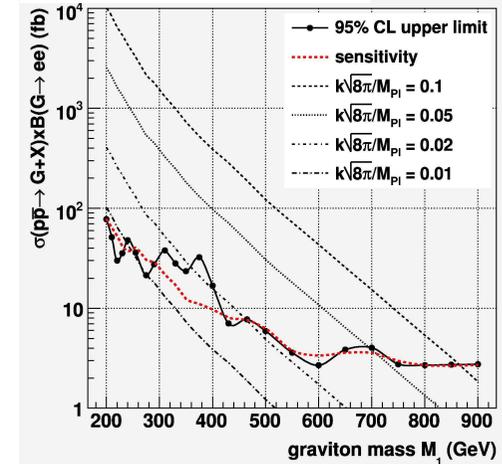
**CDF**

*PRL 99 171802 (2007)*



**D0**

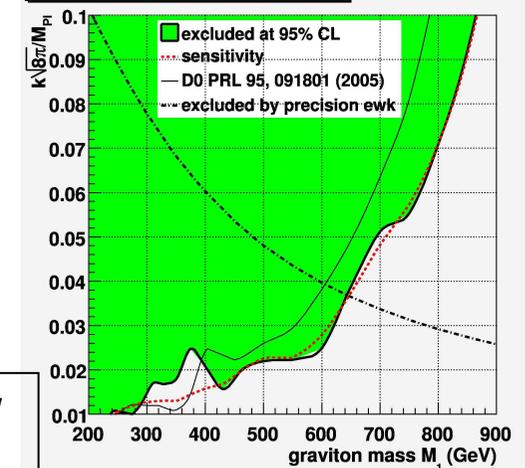
*Accepted by PRL*



Mass limits for $\kappa/\overline{M}_{\text{Pl}} = 0.1$	
CDF $1.3 \text{ fb}^{-1}$	D0 $1.0 \text{ fb}^{-1}$
<b>889 GeV</b>	<b>900 GeV</b>

*CDF update for  $e^+e^-$  with  $2.5 \text{ fb}^{-1}$   
 $\Rightarrow M_1 > 907 \text{ GeV}$*

**D0 Run II Preliminary,  $1.1 \text{ fb}^{-1}$**



# Search in $\gamma\gamma$ +MET: GMSB

## ☞ Gauge mediated SUSY Breaking

- New gauge fields called “messengers”
- Gravitino is LSP ( mass  $< \text{keV}$ ), weakly interacting  $\rightarrow$  MET
- NLSP is neutralino  $\tilde{\chi}_1^0 \rightarrow \gamma G$
- the “Snowmass Slope SPS 8” model with 1 parameter  $\Lambda$  (effective scale of SUSY breaking),
- Neutralino lifetime short enough to see the decay

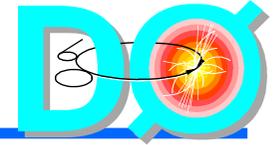
$$\begin{aligned} N5 &= 1 \\ M_m &= 2\Lambda \\ \tan\beta &= 15 \\ \mu &< 0 \end{aligned}$$

## ☞ Final state is : $\gamma\gamma$ + MET

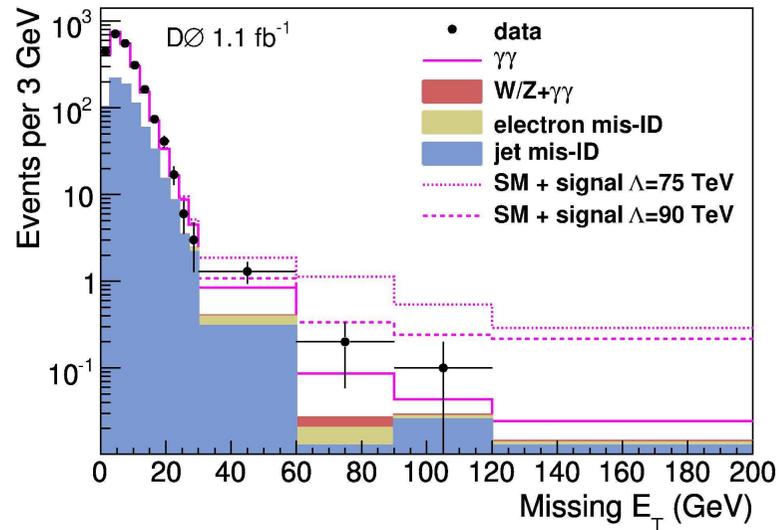
☞ Physics bckg :  $W(\rightarrow lv) \gamma\gamma$ ,  $Z(\rightarrow \nu\nu) \gamma\gamma$

☞ Largest Instrumental bckg (e or jet misid to  $\gamma$ )

- with real MET :  $W(\rightarrow e \nu) \gamma$ ,  $W(\rightarrow e\nu) \text{ jet}$
- with no real MET : QCD ( $\gamma\gamma$ ,  $\gamma \text{ jet}$ , jet jet)

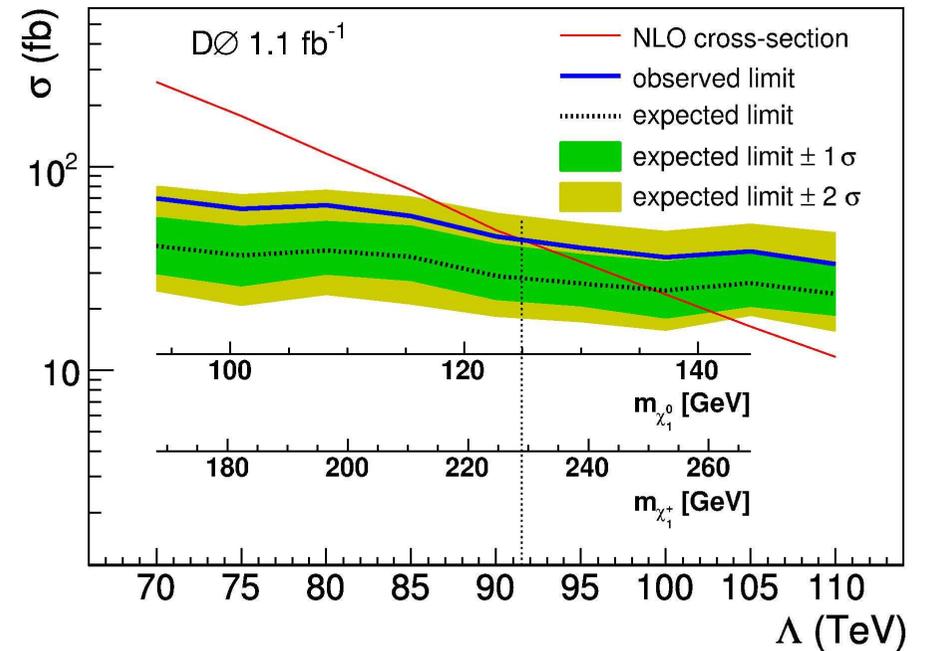


2  $\gamma$  with  $E_T > 25$  GeV  
 $|\eta| < 1.1$



MET cut	>60GeV
# events observed	3
# events expected	$1.6 \pm 0.4$

“Snowmass Slope SPS 8” benchmark model



$\Lambda > 91.5$  TeV at 95% CL

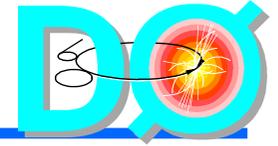
$M(\chi_1^0) > 125$  GeV

$M(\chi_1^+) > 229$  GeV

*Phys. Lett.* **B659**, 856 (2008).



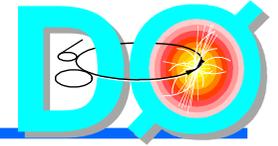
# Single $\gamma$ + MET : Large Extra Dimensions



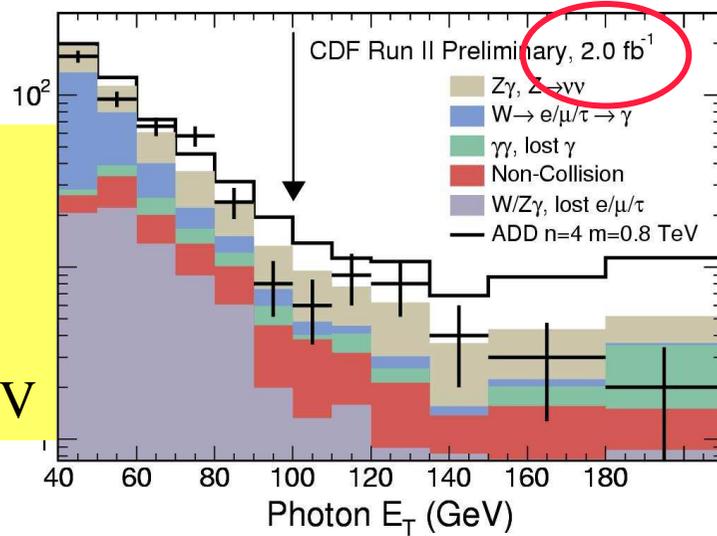
- ADD model may have noticeable effects at the Tevatron
  - Compactified extra space  $R \approx \frac{1}{M_D} \left( \frac{M_{Planck}}{M_D} \right)^{2/n}$  with  $M_D \approx 1$  TeV
  - Direct graviton production :  $q\bar{q} \rightarrow G \gamma$
- SM background :  $Z + \gamma \rightarrow \nu\bar{\nu} + \gamma$  irreducible
- Instrumental bkgd
  - $W + \gamma \rightarrow l \nu + \gamma$  lepton escapes detection
  - $W \rightarrow e \nu$  mis id of electron
  - $W + \text{jet} \rightarrow l \nu + \text{jet}$  mis id of jet
  - Cosmics + Halo
    - ( D0 : use photon pointing,  $\mu$  detectors
    - ( CDF : timing of EM system,  $\mu$  detectors



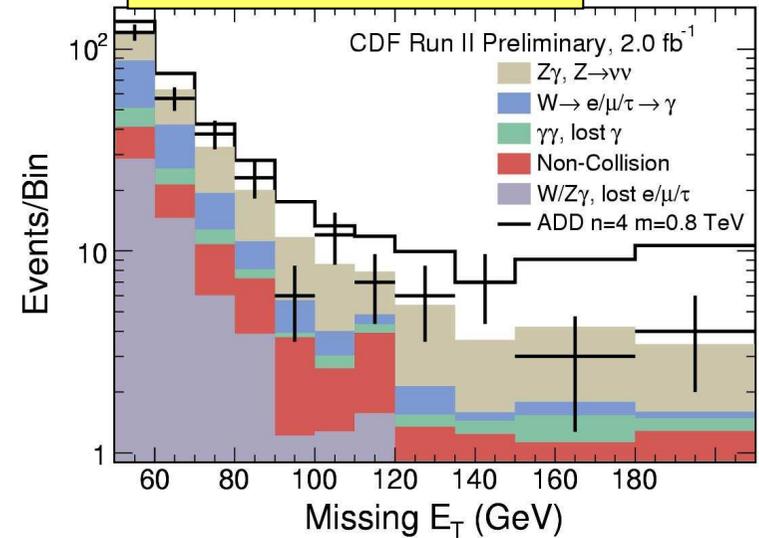
# Single $\gamma$ + MET: LED (II)



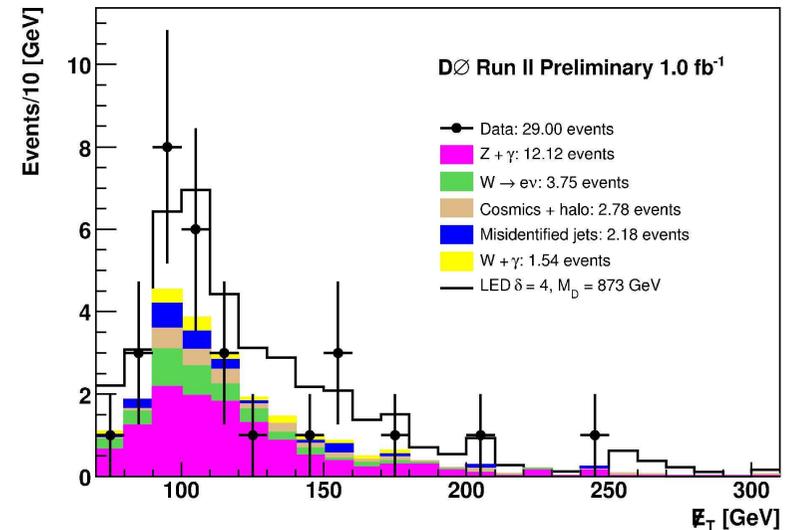
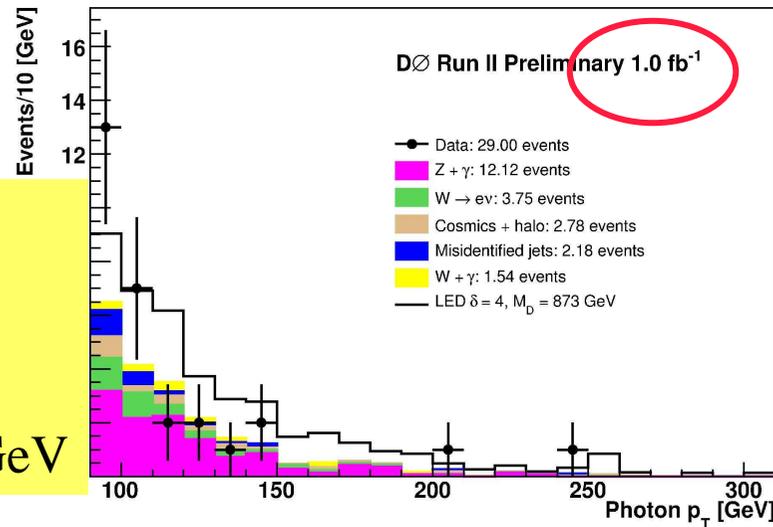
$E_T(\gamma) > 18 \text{ GeV}$   
 $|\eta| < 1.$   
 $\text{MET} > 50 \text{ GeV}$   
 No jet with  $E_T > 15 \text{ GeV}$



Photon  $E_T > 50 \text{ GeV}$

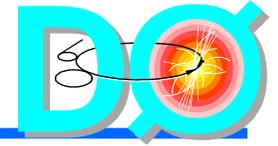


$E_T(\gamma) > 90 \text{ GeV}$   
 $|\eta| < 1.1.$   
 $\text{MET} > 70 \text{ GeV}$   
 No jet with  $E_T > 15 \text{ GeV}$



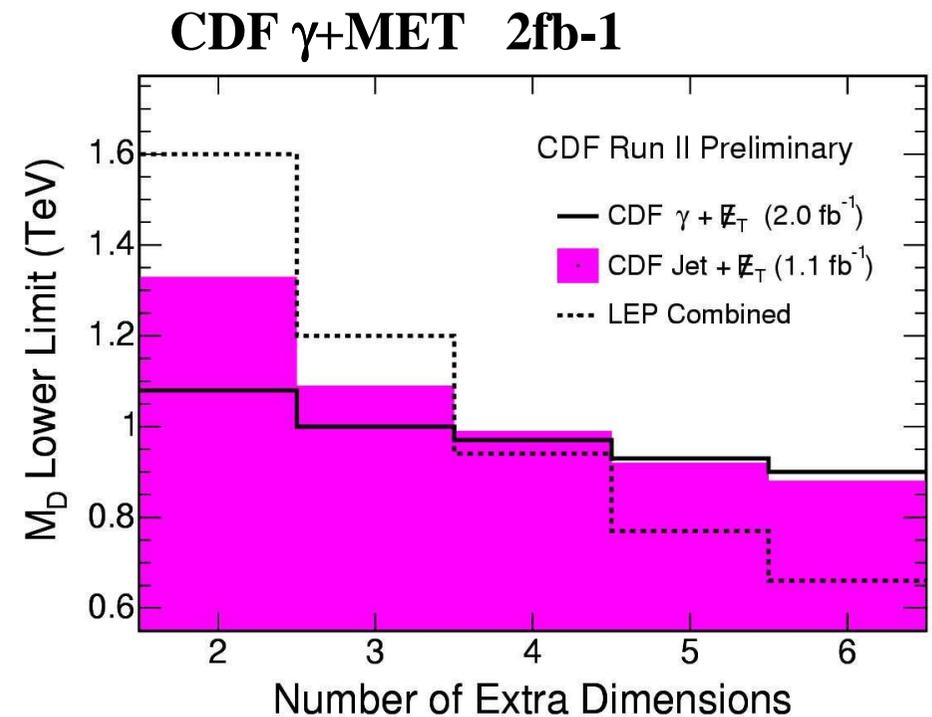


# Single $\gamma$ + MET: LED (III)



*Photon  $E_T > 90$  GeV*  
*No Jet with  $E_T > 15$  GeV*

	CDF	D0
Luminosity	2.0 fb <sup>-1</sup>	1.0 fb <sup>-1</sup>
MET cut	50 GeV	70 GeV
Channel		
<b>Cosmics + Halo</b>	<b>9.8 ± 1.3</b>	<b>2.8 ± 1.4</b>
Fake photons	-	2.2 ± 1.5
W → l → γ	3.6 ± 0.4	3.8 ± 0.3
Wγ → lost lepton + γ	5.0 ± 1.4	1.5 ± 0.2
γγ → γ	2.3 ± 0.6	-
<b>Zγ → ννγ</b>	<b>25.2 ± 2.8</b>	<b>12.1 ± 1.3</b>
Total	46.7 ± 3.0	22.4 ± 2.5
Data	40	29





# Anomalous production of $\gamma$ +MET

- **Signature based search**

Expected in many models

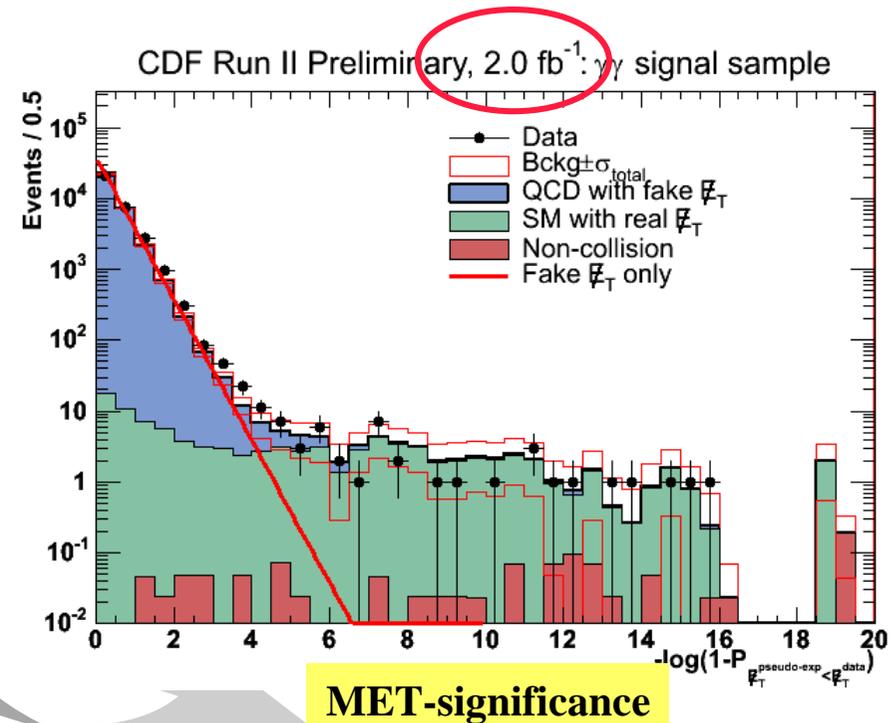
Famous Run I  $e e \gamma \gamma + \text{MET}$  event

- **Met resolution model**

particle E resolution is Gaussian

Fake MET is due soft unclustered E (UE, MI) and jet E mis-measur<sup>t</sup>

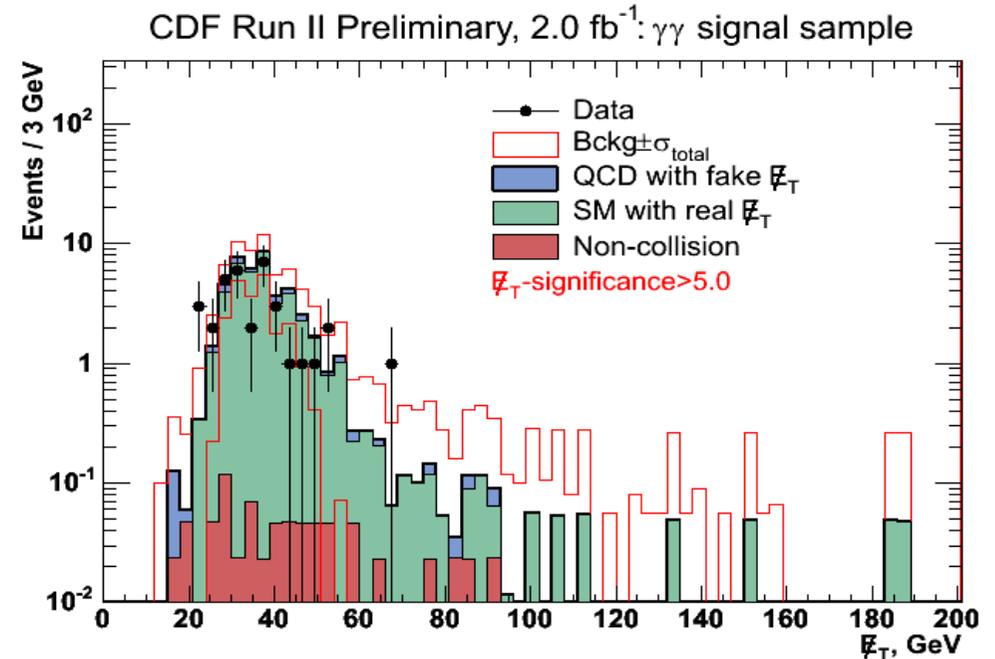
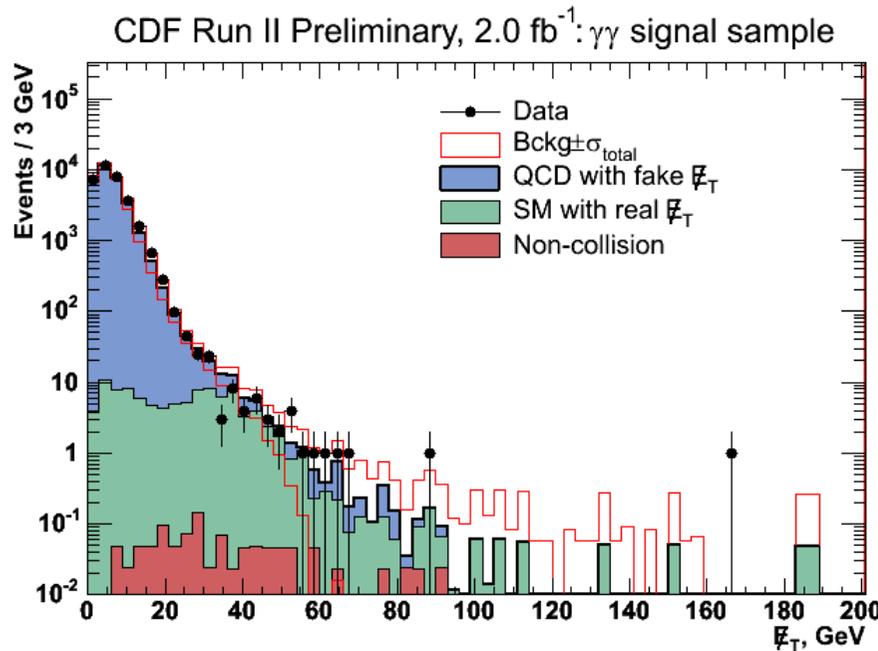
- Isolated photons with  $|\eta_{\gamma_{1,2}}| < 1.0$ ;  
 $E_T(\gamma_{1,2}) > 13 \text{ GeV}$



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



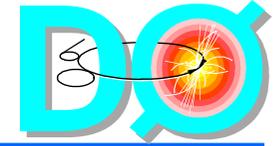
# Anomalous production of $\gamma\gamma$ +MET+X (II)



QCD background (no MET) is almost gone with MET significance >5 cut  
Keeping high efficiency for an eventual signal  
Checked with  $W\gamma \rightarrow l\nu\gamma$  events: eff.=72%



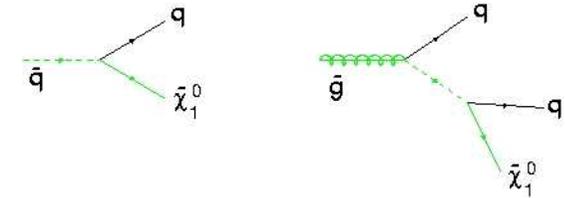
# Jets + MET : squarks – gluinos



- **Pair production :**

- 1<sup>st</sup> + 2<sup>nd</sup> squark generation (+ sbottom for D0)
- Stop prod. not considered

$$\begin{aligned}
 p\bar{p} &\rightarrow \tilde{q}\tilde{q} & p\bar{p} &\rightarrow \tilde{g}\tilde{g} \\
 p\bar{p} &\rightarrow \tilde{q}\tilde{g} & p\bar{p} &\rightarrow \tilde{q}\tilde{q}
 \end{aligned}$$

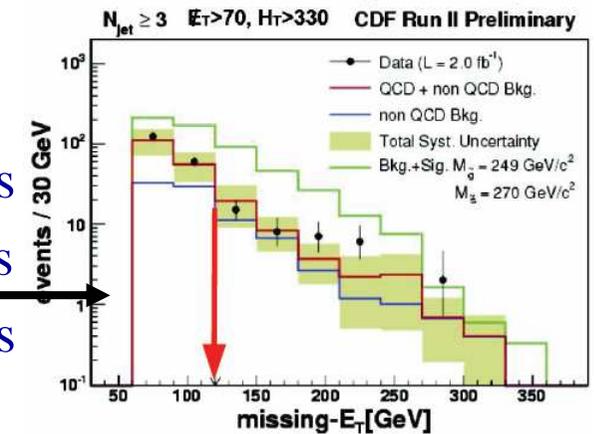
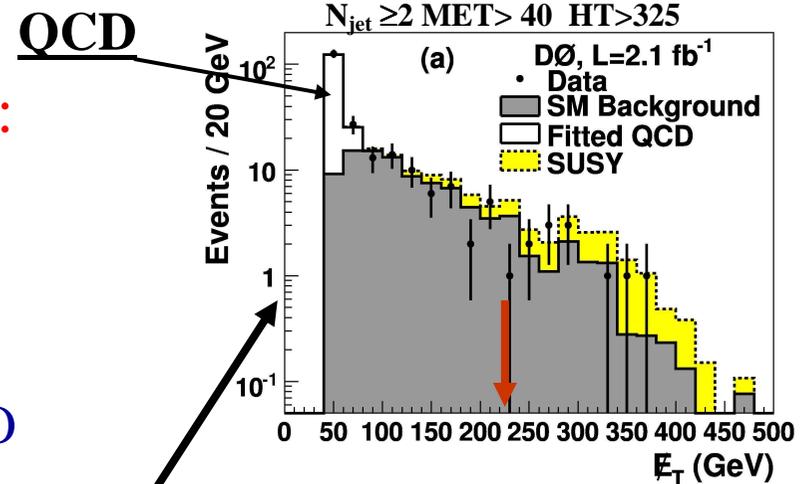


- **mSUGRA with conservation of R-parity :**

- $A_0=0, \mu<0, \tan\beta=3(\text{D0}), 5(\text{CDF})$
- RGE ■ D0 → Suspect+SDECAY
  - CDF → ISASUSY
- NLO cross-section calculated with PROSPINO

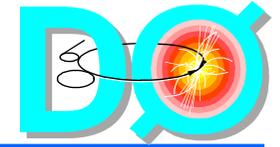
- **3 analysis → 3 topologies**

- 2 leading pT jets are acoplanar and central
- 1. Small  $m_0$  : ( $m(\text{squark}) < m(\text{gluino})$ ) at least 2 jets
- 2. Intermediate  $m_0$  : ( $m(\text{squark}) = m(\text{gluino})$ ) at least 3 jets
- 3. Large  $m_0$  : ( $m(\text{squark}) > m(\text{gluino})$ ) at least 4 jets
- Cuts on MET and HT are optimised for each topology

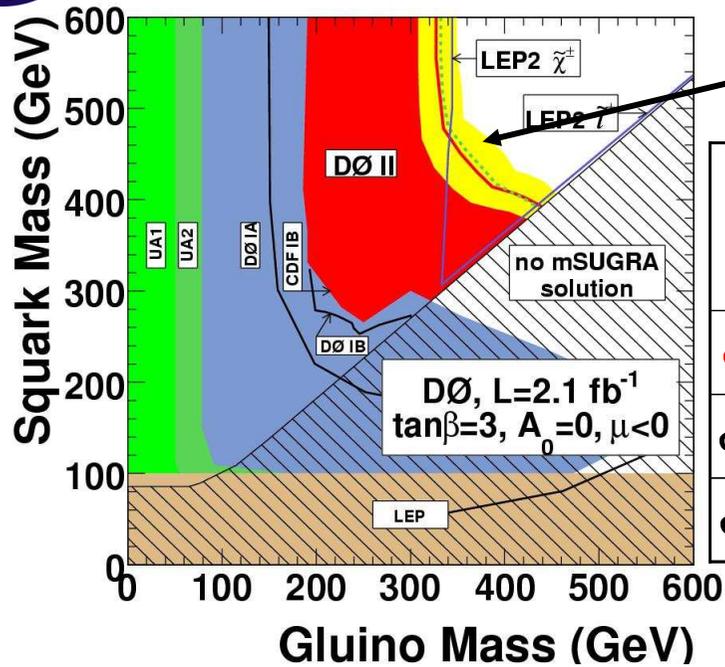




# Squark + gluinos (II)

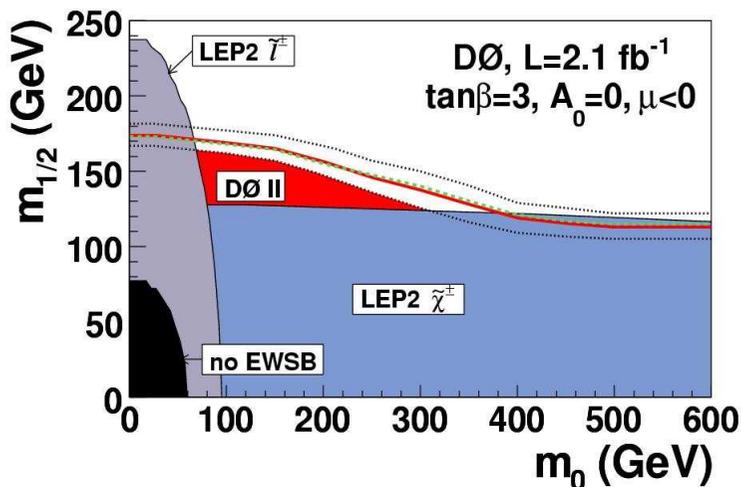


Phys. Lett. B660, 449 (2008)

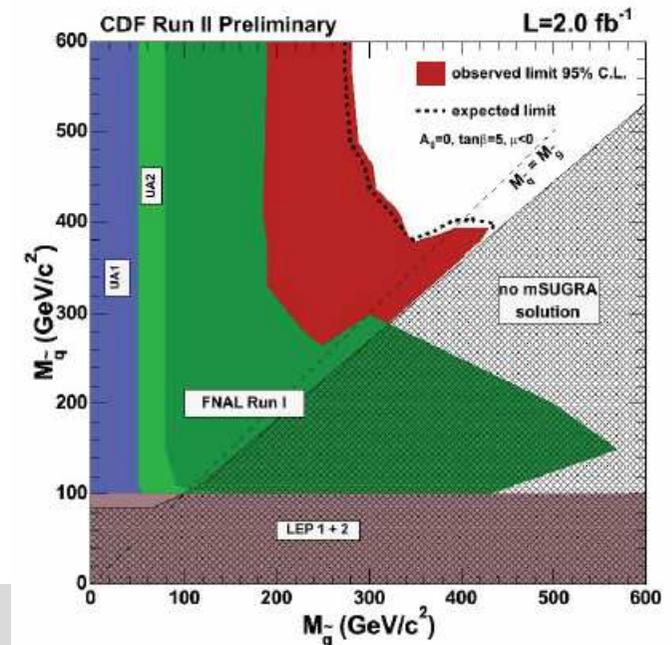


Yellow band shows the effect of PDF and factorisation/renormalisation scales uncertainties

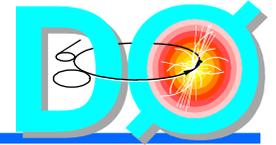
	M(gluino)		M(squark)	
	obs.	exp.	obs.	exp.
$\sigma(\text{min})$	308	312	379	377
$\sigma(\text{nom})$	327	332	392	391
$\sigma(\text{max})$	349	354	406	404



CDF result on 2.0 fb<sup>-1</sup>  
for tanβ=5  
 $M(\text{gluino}) > 280 \text{ GeV}$



# Jets + MET : light stop



- MSSM :
  - large top-yukawa coupling  $\Rightarrow$  large mixing in 3<sup>rd</sup> generation squarks
  - $\tilde{t}_1$  could be the lightest squark ( even the NLSP)

- Decay via FCNC :

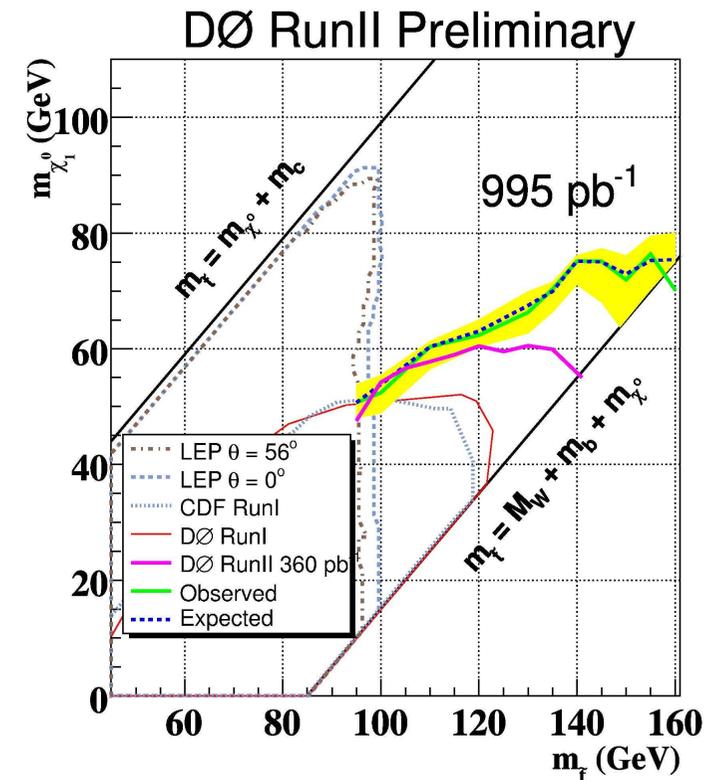
$$Br(\tilde{t}_1 \rightarrow c\chi_1^0) = 100\%$$

if  $m(\text{stop}) < m(b) + m(W) + m(\chi)$

- $\Rightarrow$  2 acoplanar charm jets + MET

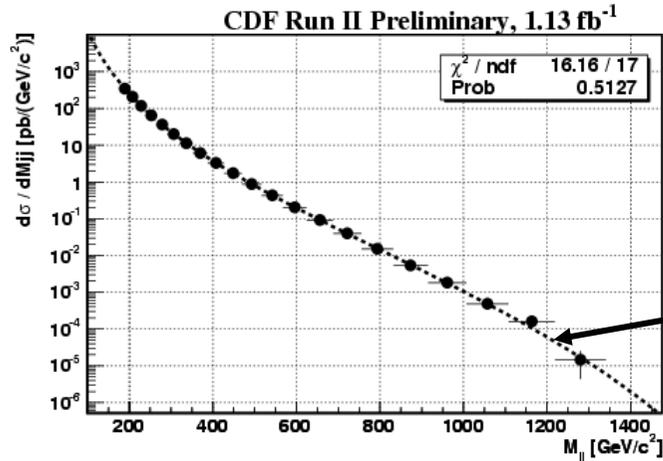
- $E_{T1}, E_{T2} > 40, 20$  GeV
- $|\eta| < 1.5$
- loose heavy flavor tag on  $\geq 1$  jet
- MET  $> 60$  GeV

- $m(\text{stop}) > 149$  GeV for  $m(\chi) = 63$  GeV  
with theoretical uncertainty on Xsection





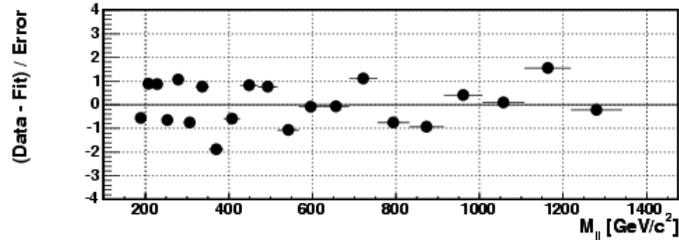
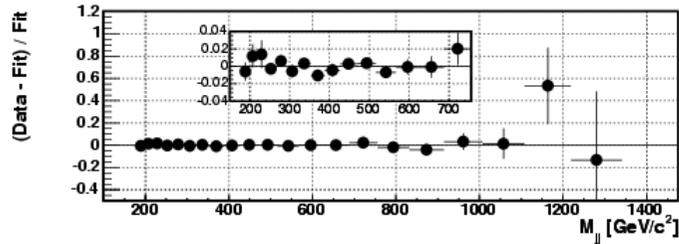
# Search for dijet mass resonances



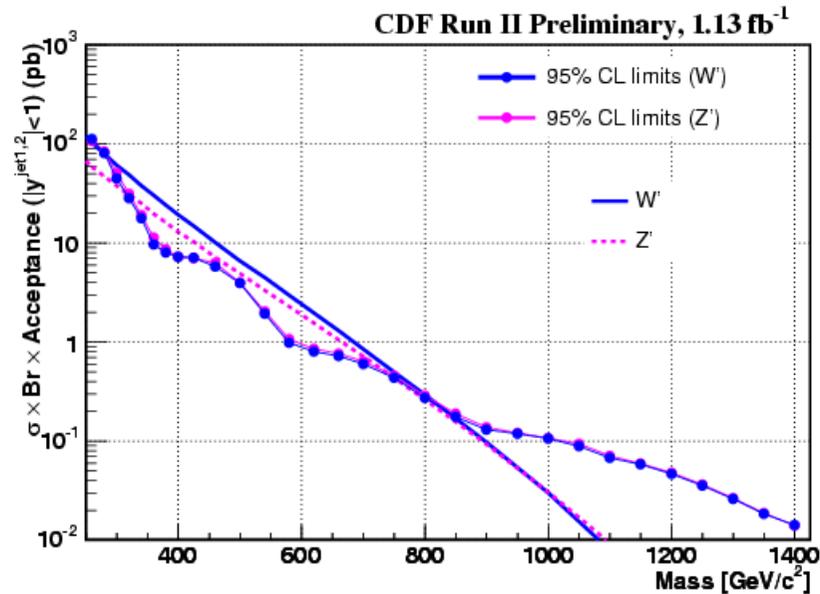
- A large variety of models : excited quark,  $W'$ ,  $Z'$ , RS graviton,.....
- Central jets with mid-point algo.  $R=0.7$

$$\frac{d\sigma}{dm} = p_0 (1-x)^{p1} / x^{p2+p3\log(x)}, \quad x = m/\sqrt{s}$$

- No significant indication of resonant structure is observed.  $\Rightarrow$  95% CL limits



Reconstructed jet-jet mass





## Search for dijet mass resonances (II)

Model description	Observed mass exclusion range (GeV/c <sup>2</sup> )
Excited quark ( $f=f'=f_s=1$ )	260-870
Color octet technirho (top-color-assisted-technicolor (TC2) couplings)	260-1110
Axigluon and flavor universal coloron (mixing of 2 SU(3)'s $\cot(\theta)=1$ )	260-1250
E6 diquark	290-630
W' (SM couplings)	280-840
Z' (SM couplings)	320-740

# Conclusion

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- ✓ No surprise yet !!!!!
- ✓ Search for sign of new physics will continue at the Tevatron  
>3fb<sup>-1</sup> of data already recorded
- ✓ Signature based searches in CDF and D0 take over model specific searches

All CDF and D0 results are available on :

<http://www-cdf.fnal.gov/physics/physics.html>

<http://www-d0.fnal.gov/Run2Physics/WWW/results.htm>

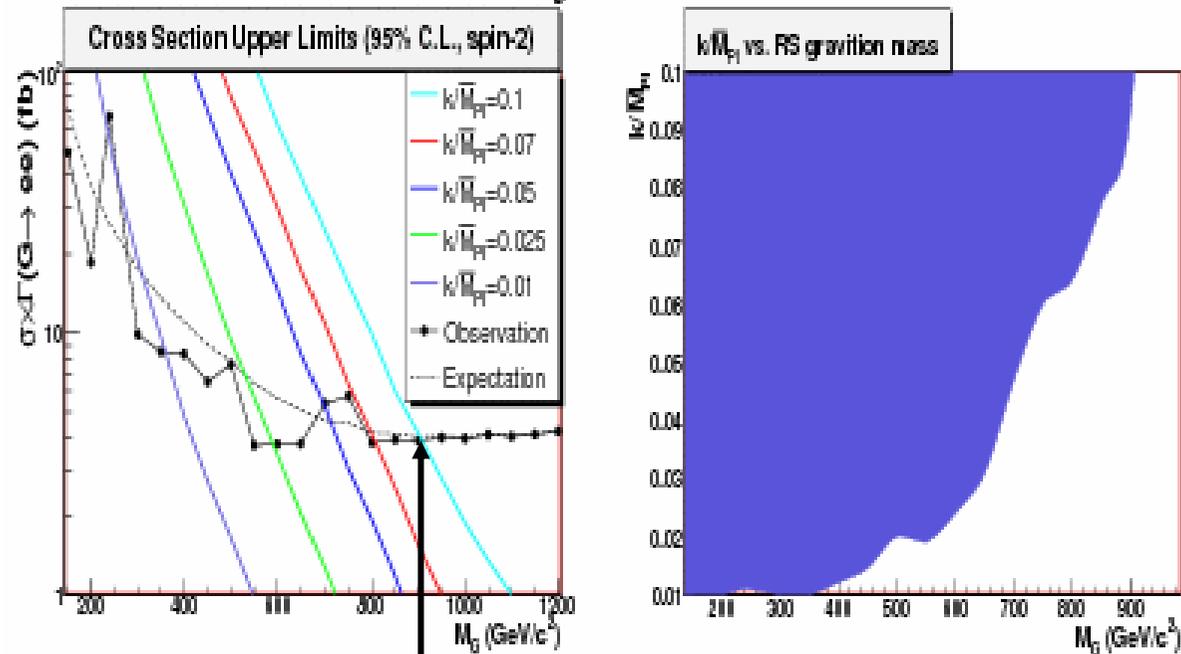
Backup



# Randall-Sundrum in ee

$$\mathcal{L} = 2.5 \text{ fb}^{-1}$$

CDF Run II Preliminary



$M_G > 907 \text{ GeV}/c^2$  for  $\kappa/\bar{M}_{\text{Pl}} = 0.1$



# $\gamma\gamma + e, \gamma\gamma + \mu$

2 central  $\gamma$  ( $|\eta| < 1$ )  $E_T > 13$  GeV  
Phoenix track rejection

$\gamma\gamma + e$

1 electron ( $|\eta| < 2$ );  $E_T > 20$  GeV

$\gamma\gamma + \mu$

1 muon ( $|\eta| < 1$ );  $P_T > 20$  GeV

Background:

SM  $W \gamma\gamma$  and  $Z \gamma\gamma$  (estimated from Madgraph+Pythia+full simulation)

Fakes :  $\text{jet} \rightarrow \gamma$  (0.2% at  $E_T = 13$  GeV)

$e \rightarrow \gamma$  ( $0.4 \pm 0.1\%$ )

$\text{jet} \rightarrow e$  ( $0.04 \pm 0.02\%$ )

isolated track  $\rightarrow \mu$  ( $1 \pm 0.5\%$ )

Bckg :  $e\gamma + (e \rightarrow \gamma)$

Nobs = 1

Nexp =  $3.8 \pm 0.5$

Bckg :  $Z \gamma\gamma$

Nobs = 0

Nexp =  $0.7 \pm 0.1$



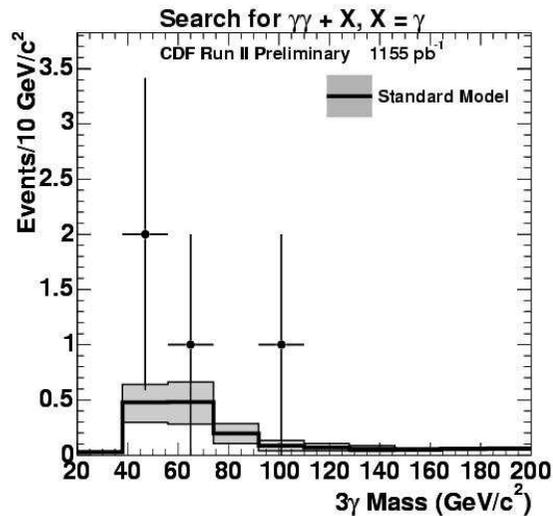
# $\gamma\gamma + \gamma, \gamma\gamma + \tau$

## $\gamma\gamma + \gamma$

Selected events examined for a “non-collision” origin (cosmics, phototube spike,...)

True  $3\gamma$  from MADGRAPH

$\gamma\gamma + \text{jet}$  (faking a  $\gamma$ )



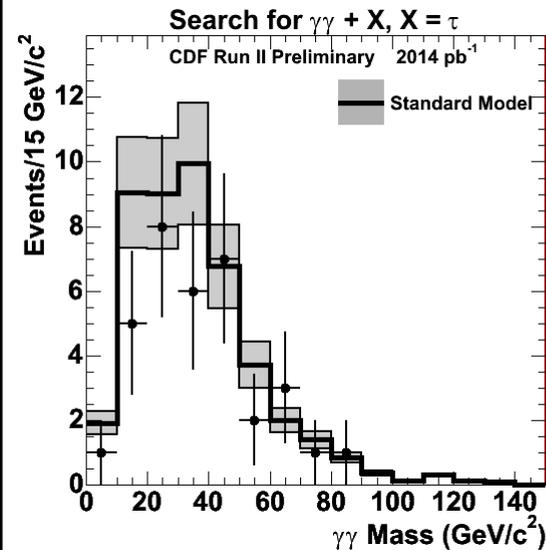
$$N_{\text{exp}} = 2.2 \pm 0.6$$
$$N_{\text{obs}} = 4$$

## $\gamma\gamma + \tau$

Topology dominated by  $\gamma\gamma + \text{jet}$  (faking a  $\tau$ )

Fake rates estimated from inclusive jet trigger sample and controlled in loose selected  $\gamma\gamma$  samples

SM :  $W\gamma$  and  $Z\gamma$  from MADGRAPH



$$N_{\text{exp}} = 46 \pm 10$$
$$N_{\text{obs}} = 34$$