

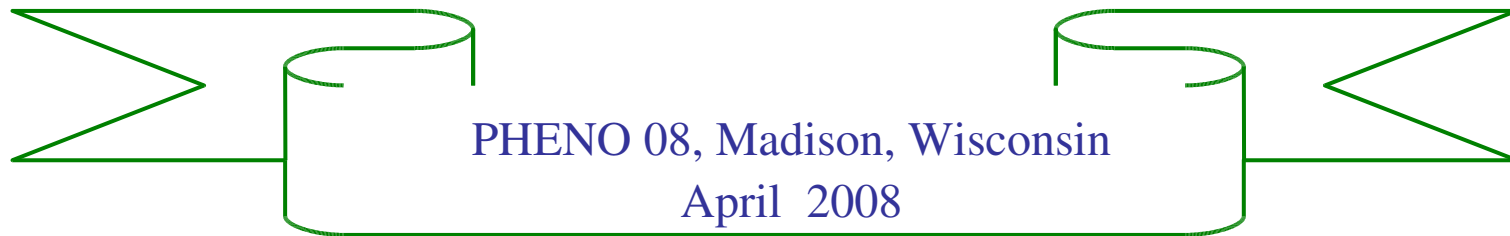




# Search for Large Extra Dimensions at CDF

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*for*

*CDF Collaboration*



- Large extra dimensions
- Direct graviton production
  - $\gamma + \emptyset$  (  with  $2 \text{ fb}^{-1}$  )
  - jet +  $\emptyset$  (  with  $1 \text{ fb}^{-1}$  )
  - combination
- Outlook



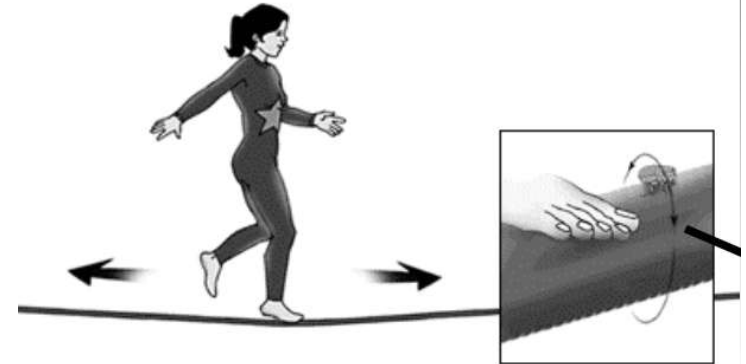
# Large Extra Dimensions

Extra dimensions (ED) are predicted by string theories

- Can stabilize the Higgs mass
- Provide a dark matter candidate

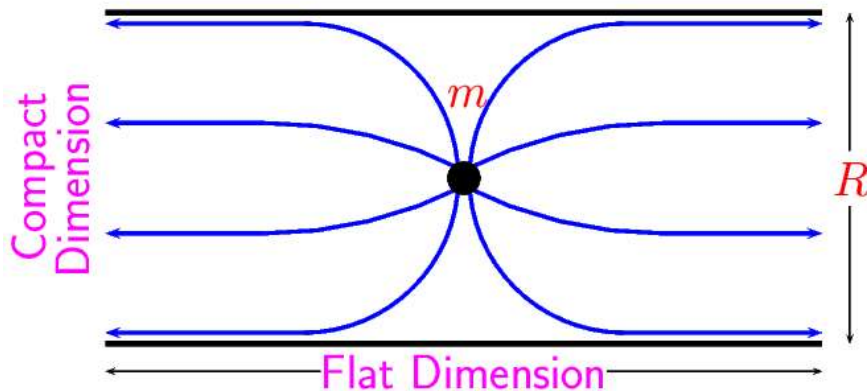
ED should not be visible to us

- Compactification is a solution
- Only gravity propagates in 3+d



Each point has additional dimension(s) attached to it  
Fundamental scale ( $M_D$ )  $\geq$  TeV

$$R \sim 0.1\text{mm} \quad (1\text{ fm}) \text{ for } d=2 \quad (6)$$



$$V(r) = G_N \frac{m_1 m_2}{r} = \frac{1}{(M_{Pl})^2} \frac{m_1 m_2}{r}$$

$$r \ll R \quad V(r) \sim \frac{1}{(M_D)^{n+2}} \frac{m_1 m_2}{r^{n+1}}$$

$$r > R \quad V(r) \sim \frac{1}{(M_D)^{n+2}} \frac{m_1 m_2}{R^n} \frac{1}{r}$$

$$(M_{Pl})^2 \sim R^n (M_D)^{2+n}$$



# LED at the Tevatron

Direct production

- $\gamma + \emptyset$  ( $\gamma + \text{MET} + \text{nothing else}$ )
- **jet** +  $\emptyset$  (jet + MET + not much else)

→ signal and bkg. enhanced by  $\alpha_{\text{QCD}} / \alpha_{\text{QED}}$

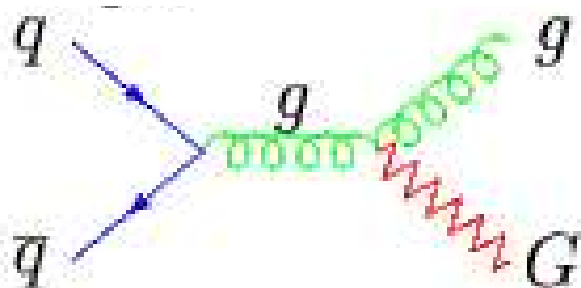
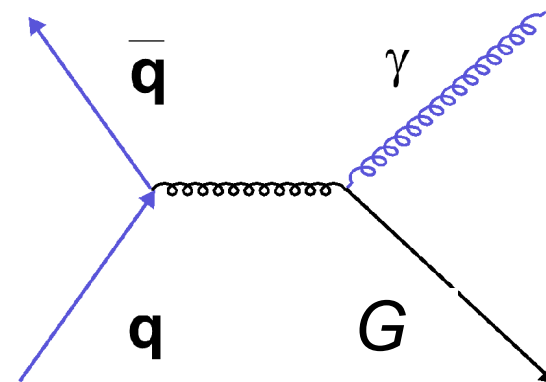
$$\sigma \sim 1/M_D^{2+n}$$

## $\gamma + \emptyset$ selection:

- central  $\gamma$   $E_T > 90$  GeV,  $|\eta| < 1$
- No jets  $E_T > 15$  GeV, tracks  $P_T > 10$  GeV

## jet + $\emptyset$ selection:

- Leading jet  $E_T > 150$  GeV
  - ✓ 2<sup>nd</sup> leading jet  $E_{T(2)} < 60$  GeV
- MET  $> 120$  GeV, away (in  $\phi$ ) from any jet
- No isolated tracks ( $P_T > 10$  GeV)

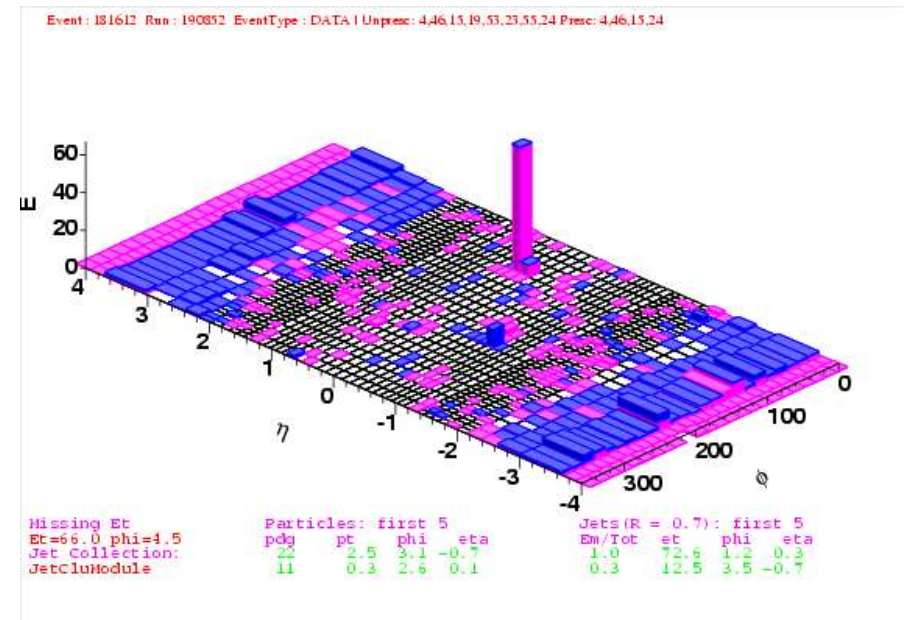




# $\gamma + \cancel{\chi}$ Signature

Many models predict something interesting in  $\gamma + \cancel{\chi}$

- Large Extra Dimensions
- SUSY Gravitinos
- Long Lived Heavy Particles
- $Z\gamma$  couplings
- ...



Simple hard signature

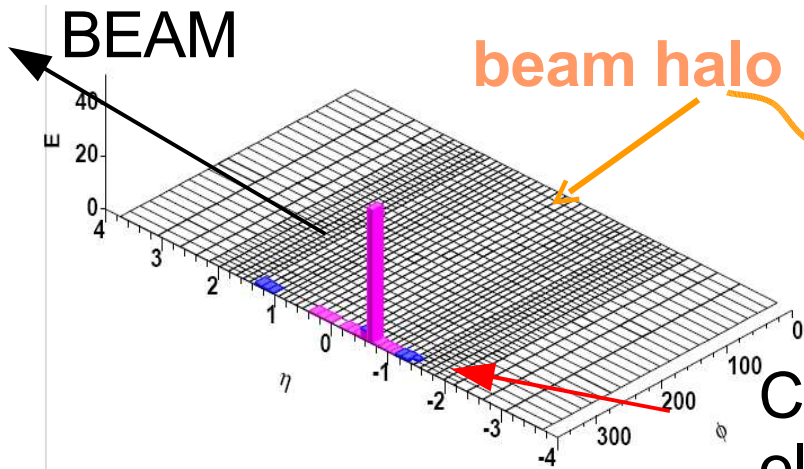
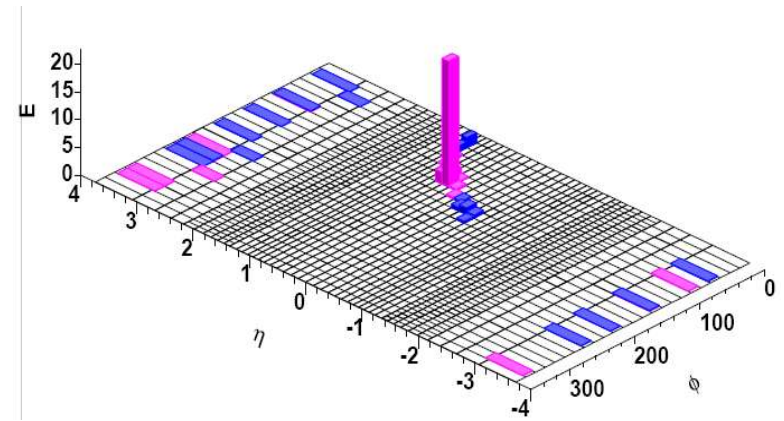
- cosmic rays (cut using timing, ID, topology)
- beam effects (cut using topology)
- detector effects



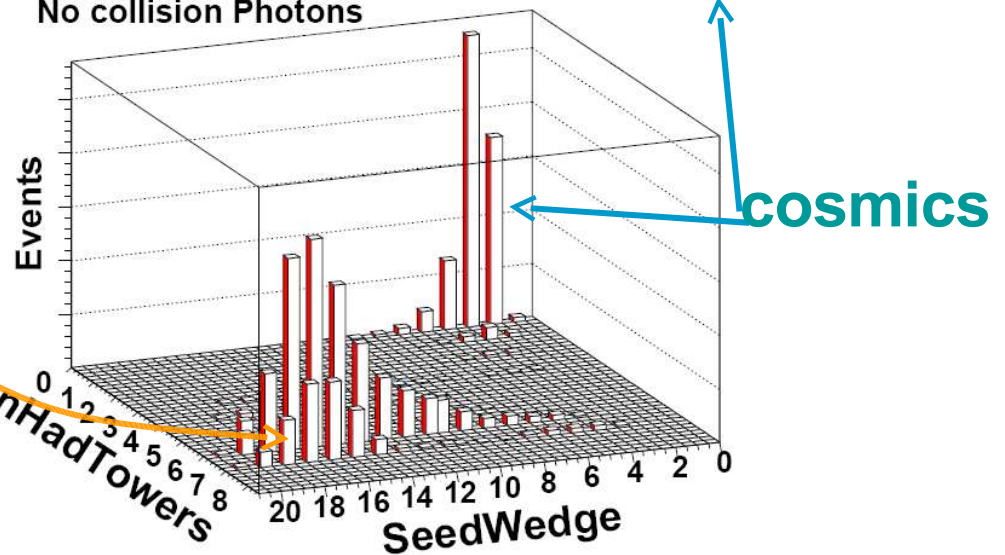


# Non-Collision Backgrounds

- From the beam – beam halo (BH) (muons)
- From outer space – cosmic (muons)
- Look different in cal
  - long traces for BH (mostly at  $\phi = 0$ )
  - a few towers for cosmics



No collision Photons



Count towers in the same wedge  
electromagnetic (pink)  
hadronic (blue)

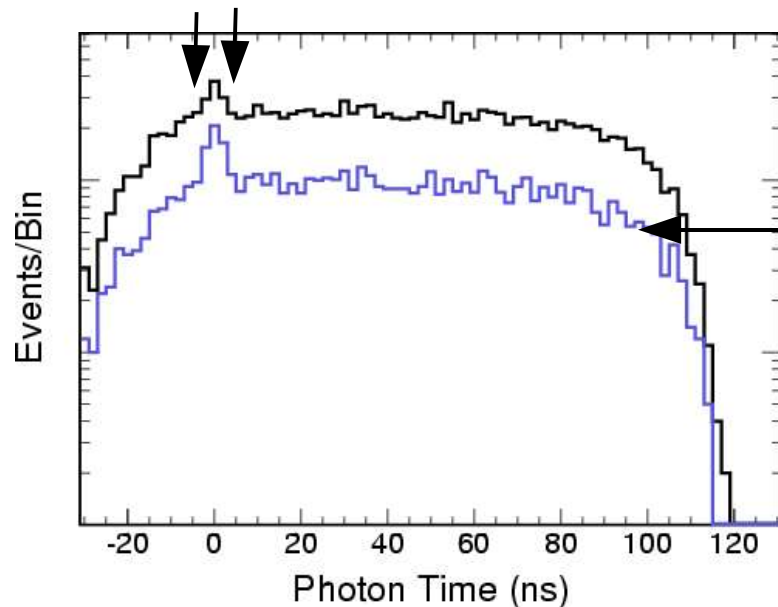




# Cosmic Rejection

## Hopeless without timing

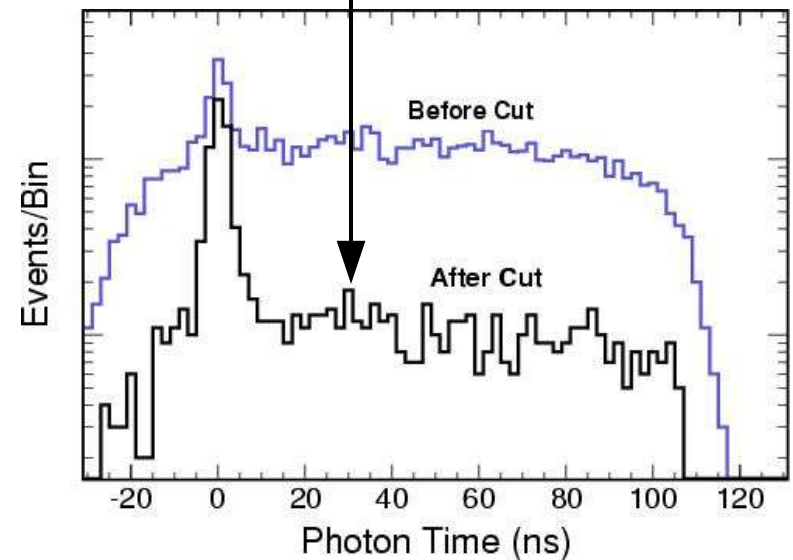
Photon in time ( $2\sigma$ ) :  $\sim 20$  reduction



3 reconstructed tracks:  $\sim 3$

Cosmic Rejection Cut:  $\sim 10$

**All cuts – 600 times reduction!**

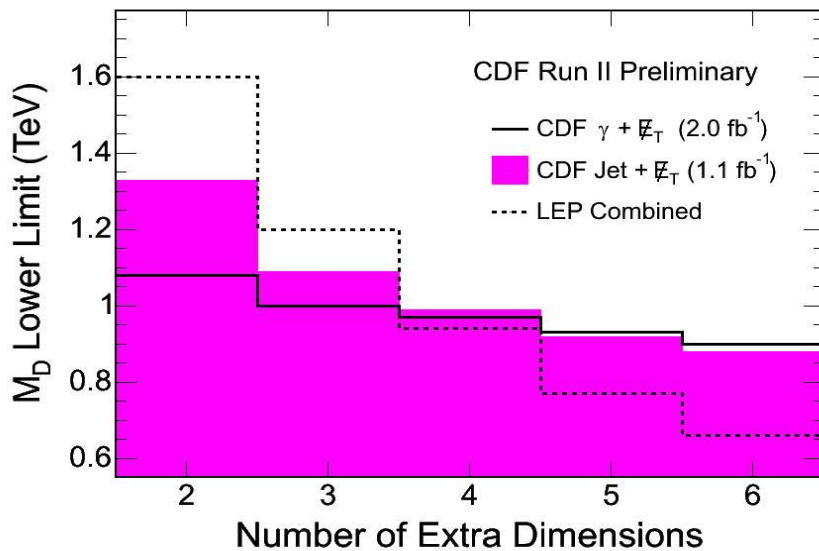
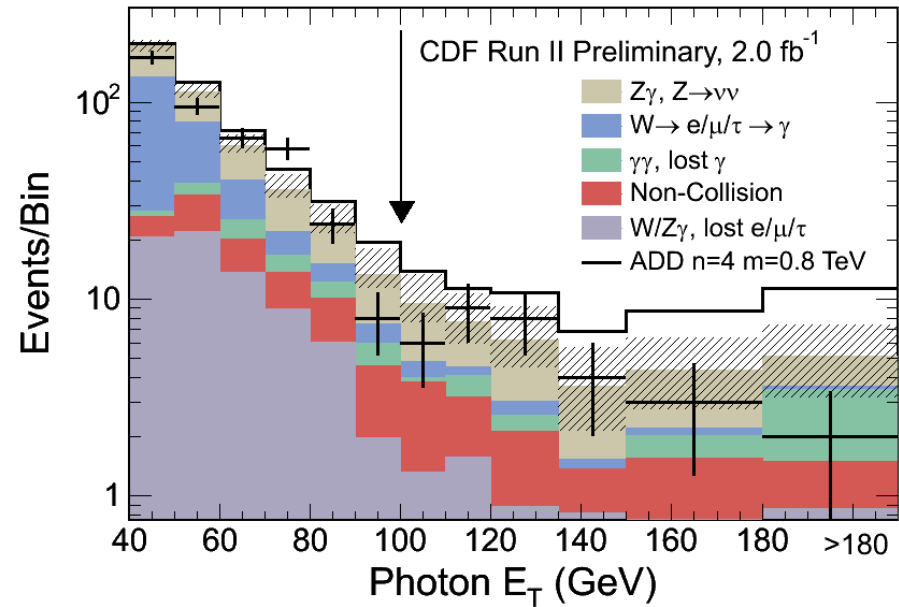


Cosmics are still 20% of the total background



# $\gamma + \emptyset$ Results

CDF RunII Preliminary, 2.0 fb <sup>-1</sup>		
Channel	$\gamma E_T > 50$ GeV	$\gamma E_T > 90$ GeV
$W \rightarrow e \rightarrow \gamma$	$47.3 \pm 5.1$	$2.6 \pm 0.4$
$W \rightarrow \mu/\tau \rightarrow \gamma$	$19.1 \pm 4.2$	$1.0 \pm 0.2$
$W\gamma \rightarrow \mu\gamma \rightarrow \gamma$	$33.1 \pm 10.2$	$1.7 \pm 1.2$
$W\gamma \rightarrow e\gamma \rightarrow \gamma$	$8.0 \pm 3.0$	$0.8 \pm 0.7$
$W\gamma \rightarrow \tau\gamma \rightarrow \gamma$	$17.6 \pm 1.6$	$2.5 \pm 0.2$
$\gamma\gamma \rightarrow \gamma$	$18.9 \pm 2.3$	$2.3 \pm 0.6$
cosmics	$36.4 \pm 2.5$	$9.8 \pm 1.3$
$Z\gamma \rightarrow \nu\nu\gamma$	$99.7 \pm 9.5$	$25.2 \pm 2.8$
Total	$280.1 \pm 15.7$	$46.7 \pm 3.0$
Data.	280	40

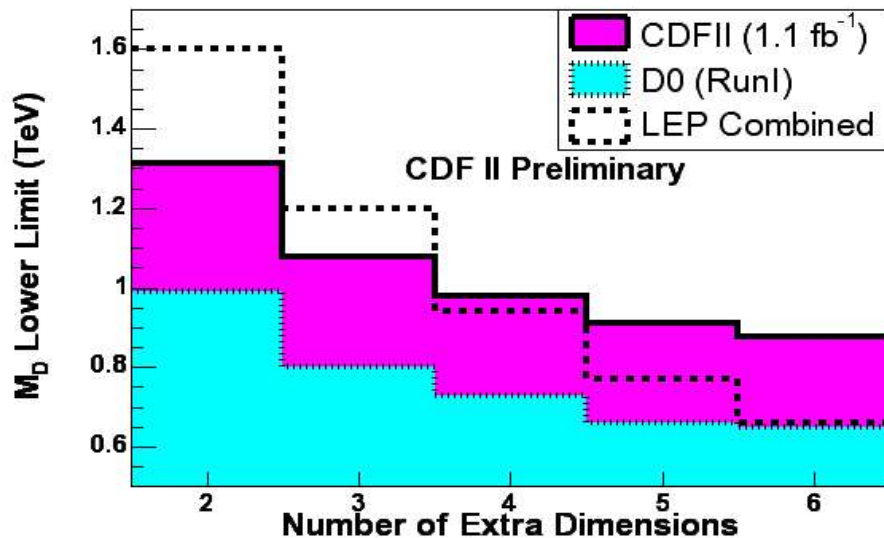
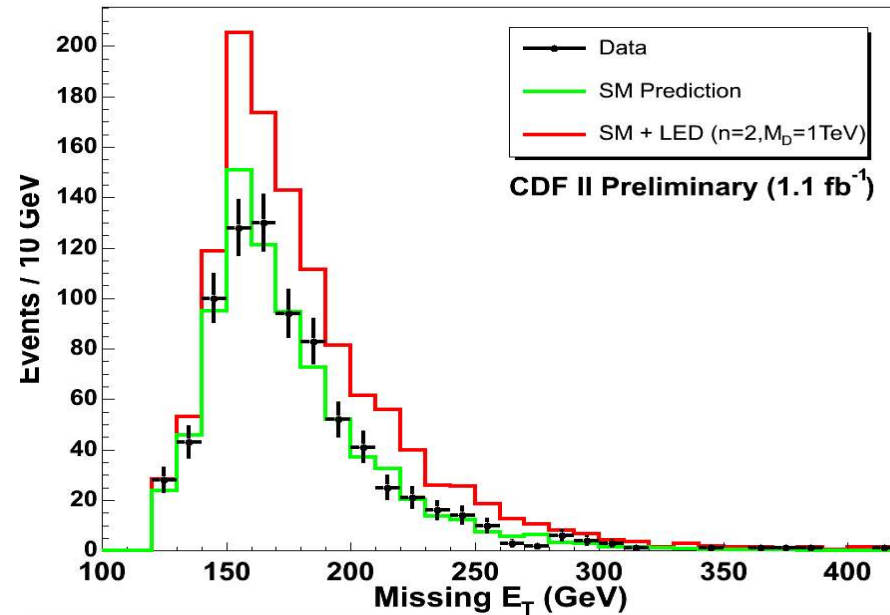


CDF RunII Preliminary, 2.0 fb <sup>-1</sup>			
N LED	$\alpha$ (%)	$\sigma_{obs}^{95}$ fb	$M_D^{obs}$ GeV
2	7.2	84.7	1080
3	7.2	84.7	1000
4	7.6	80.4	970
5	7.3	82.7	930
6	7.2	84.4	900



# Jet + $\cancel{\gamma}$ Results

Background	Expected Events
$Z \rightarrow \nu \nu$	$390 \pm 30$
$W \rightarrow \tau \nu$	$187 \pm 14$
$W \rightarrow \mu \nu$	$117 \pm 9$
$W \rightarrow e \nu$	$58 \pm 4$
$Z \rightarrow ll$	$6 \pm 1$
QCD	$23 \pm 20$
$\gamma$ Jet	$17 \pm 5$
Non-Collision	$10 \pm 10$
<b>Total Predicted</b>	<b><math>808 \pm 62</math></b>
<b>Data Observed</b>	<b>809</b>



n	$M_D$ (TeV)	R(mm)
2	$> 1.31$	$< 0.279$
3	$> 1.08$	$< 3.15 \times 10^{-6}$
4	$> 0.98$	$< 1.01 \times 10^{-8}$
5	$> 0.91$	$< 3.20 \times 10^{-10}$
6	$> 0.88$	$< 3.16 \times 10^{-11}$

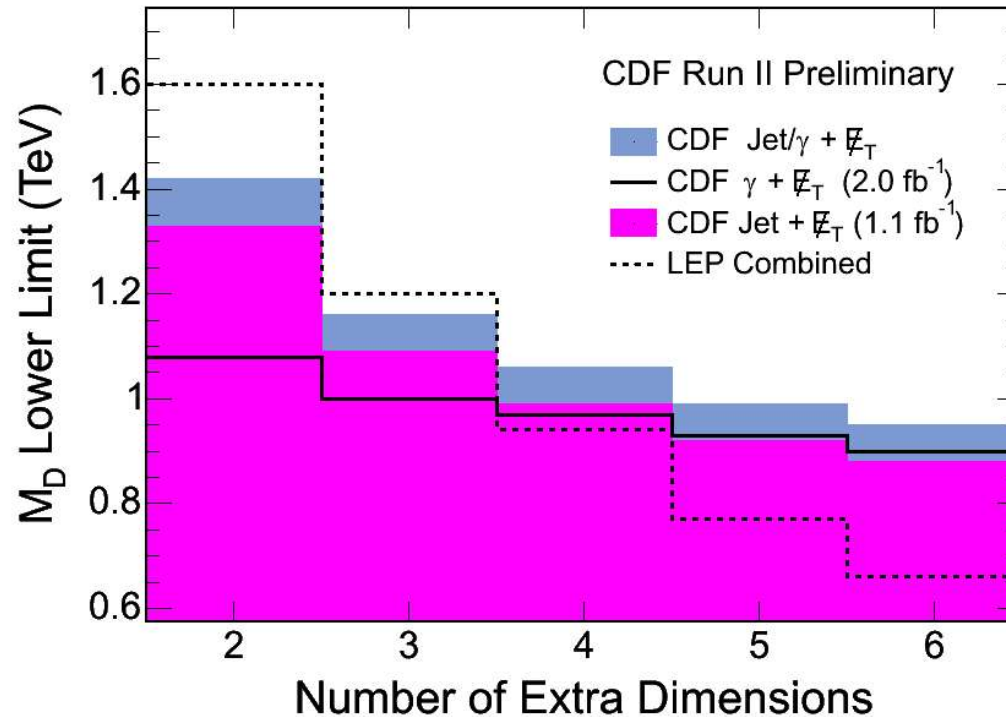
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# Combined Limits



- Limits from jet+ $\cancel{\gamma}$  and  $\gamma$ + $\cancel{\gamma}$  combined give better sensitivity
- Similar sensitivity in jet+ $\cancel{\gamma}$  and  $\gamma$ + $\cancel{\gamma}$  for  $d > 3$
- Tevatron combination is en course
- NB: from Newton law tests  $M_D > 3.6 \text{ TeV}$  for  $d = 2$



# Outlook

- Direct production of LED graviton is explored
  - Sensitivity to the fundamental mass scale is  $M_D \sim 1$  TeV in direct production
- Looking forward to more data

