Search for Large Extra Dimensions at CDF

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for
CDF Collaboration

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- Large extra dimensions
- Direct graviton production
  - $\gamma + \not{\emptyset}$
  - jet + $\not{\emptyset}$
  - combination
- Outlook

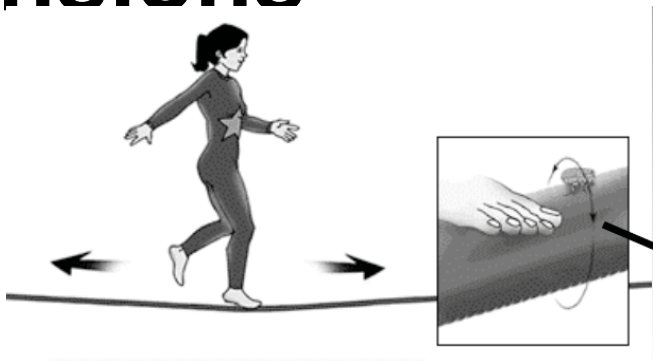
Large Extra Dimensions

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

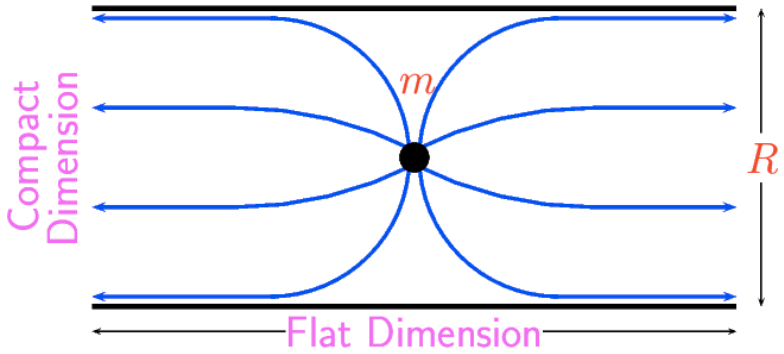
- Compactification is a solution
- Only gravity propagates in 3+d



Each point has additional dimension(s) attached to it

Fundamental scale (M_D) ≥ TeV

R ~ 0.1mm (1 fm) for d=2 (6)



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

r << R $$V(r) = \frac{1}{(M_D)^{n+2}} \frac{m_1 m_2}{r^{n+1}}$$

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

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

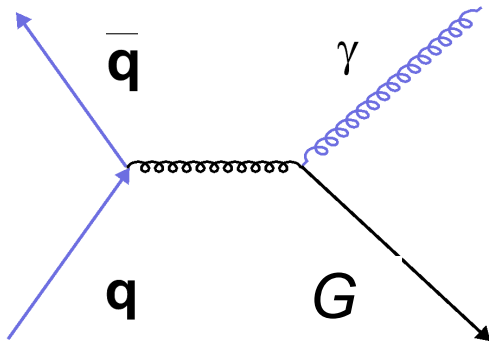
LED at the Tevatron

Direct production

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

- **γ + ∅ (γ + MET +** nothing else)
- **jet + ∅ (**jet + **MET +** not much else)

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

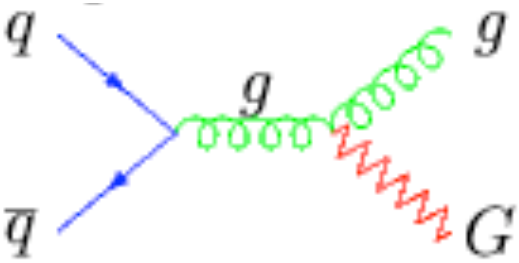


γ + ∅ selection:

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

jet + ∅ selection:

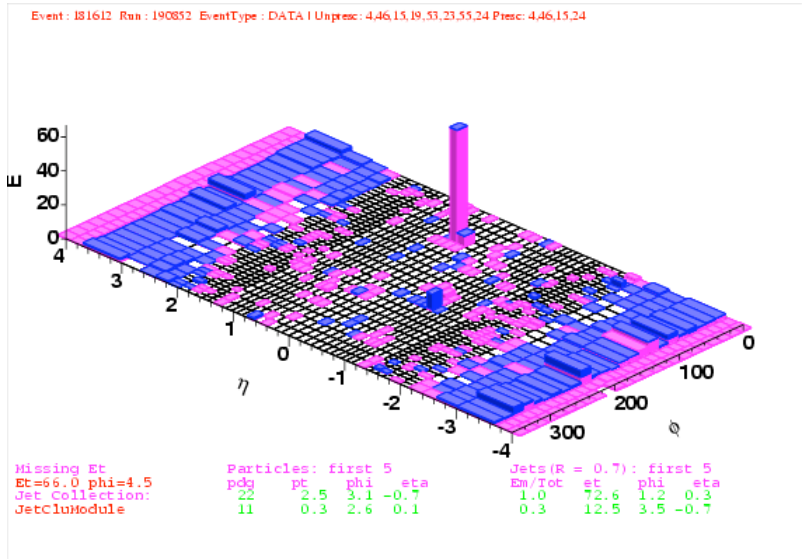
- Leading jet E_T > 150 GeV
  - ✓ 2nd leading jet $E_T(2) < 60$ GeV
- MET > 120 GeV, away (in φ) from any jet
- No isolated tracks (P_T > 10 GeV)



$\gamma + \not\emptyset$ Signature

Many models predict something interesting in $\gamma + \not\emptyset$

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

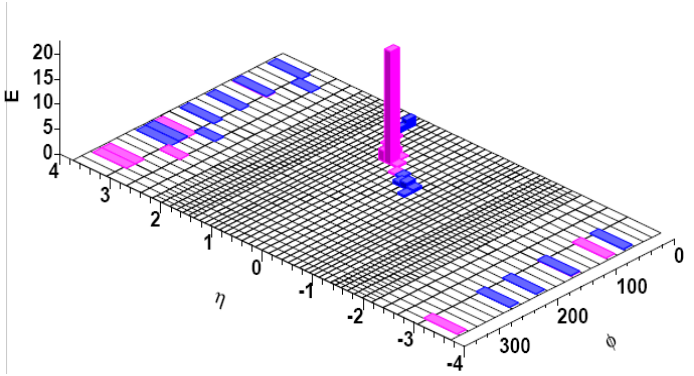


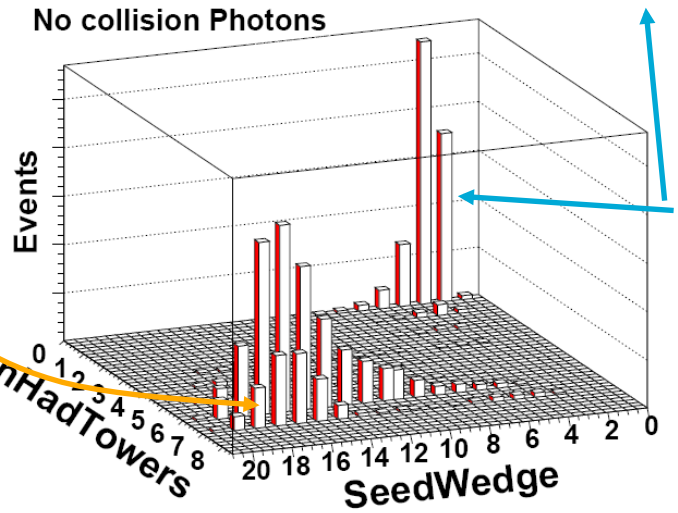
Simple hard signature

- 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 φ = 0)
  - a few towers for cosmics

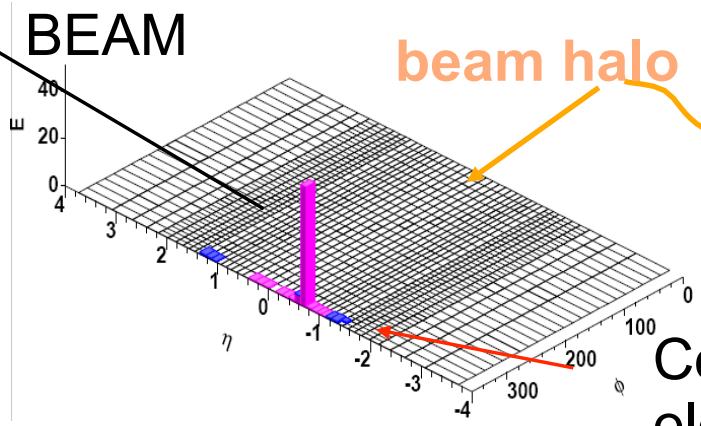




cosmics

BEAM

beam halo

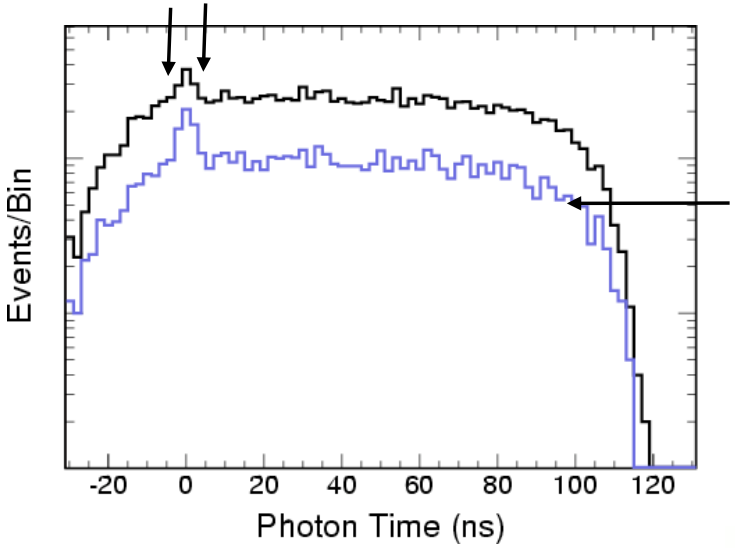


Count towers in the same wedge
electromagnetic(pink)
hadronic (blue)

Cosmic Rejection

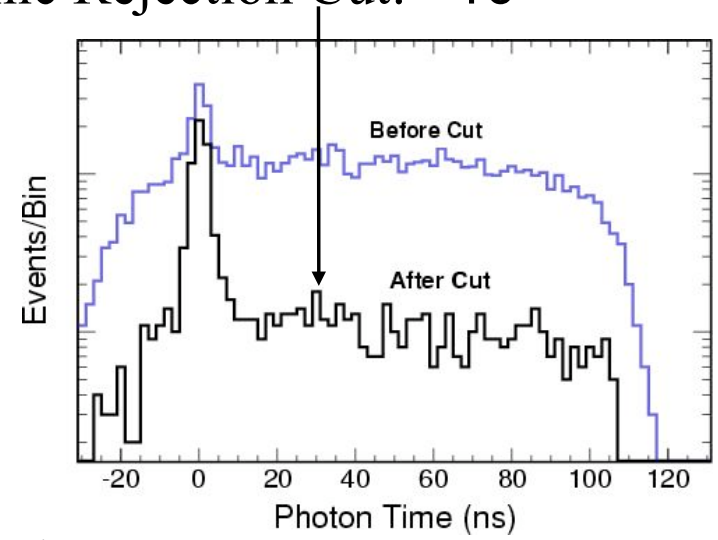
Hopeless without timing

Photon in time (2σ) : ~20 reduction



3 reconstructed tracks: ~3

Cosmic Rejection Cut: ~10

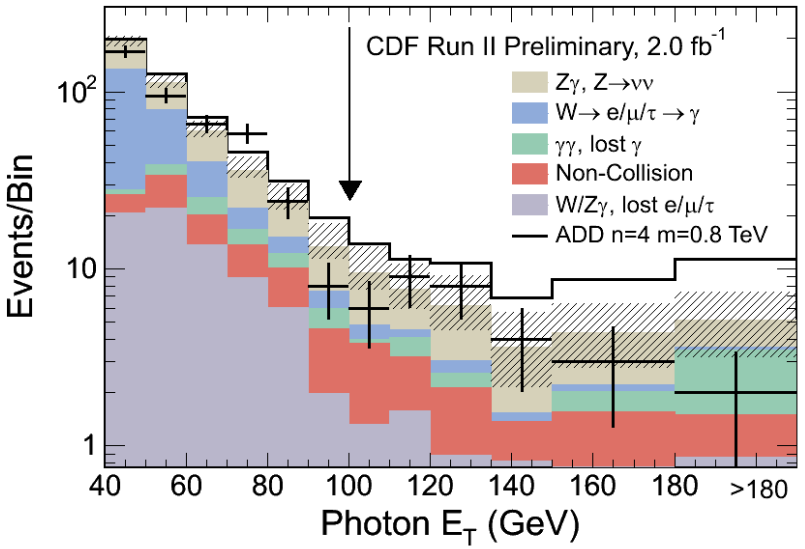


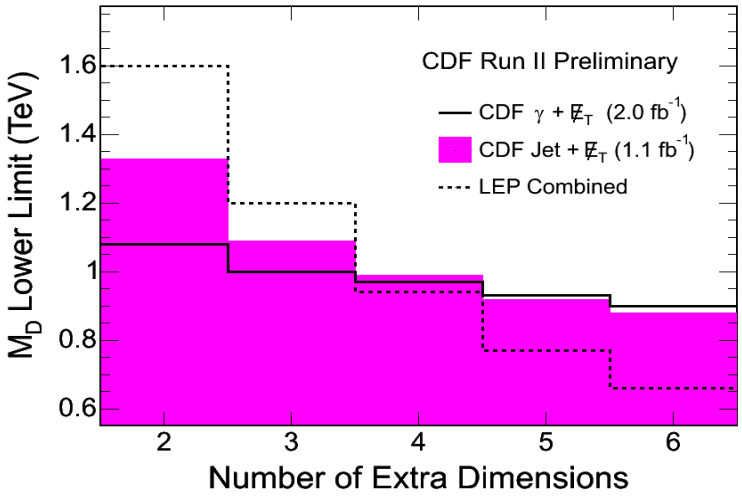
All cuts – 600 times reduction!

Cosmics are still 20% of the total background

$\gamma + \not\varnothing$ Results

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

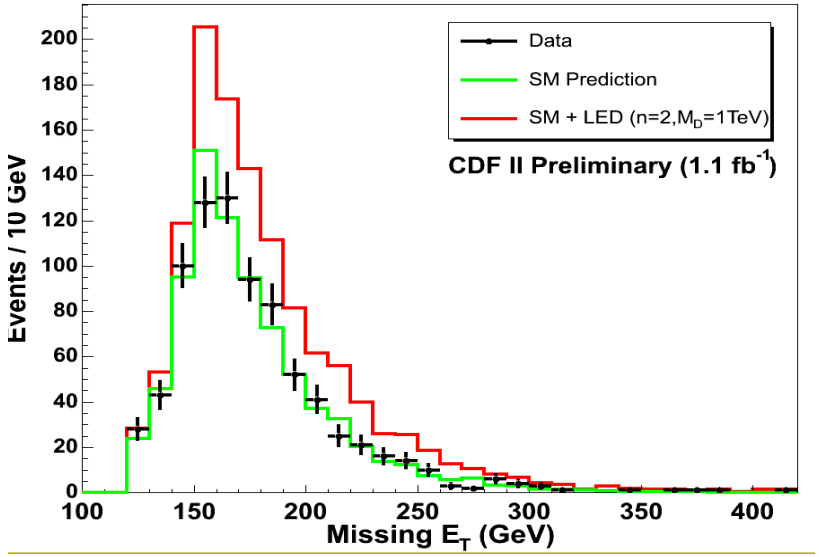


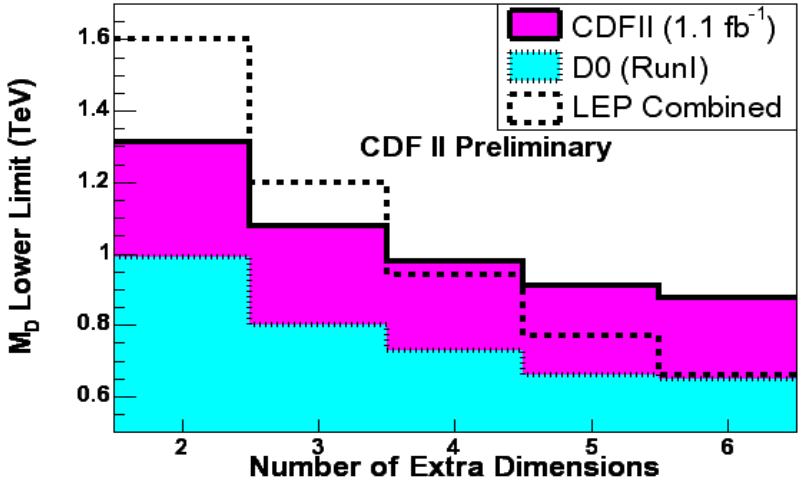


CDF RunII Preliminary, 2.0 fb^{-1}			
N LED	α (%)	σ^{95}_{obs} fb	M_D^{obs} GeV
2	7.2	84.7	1080
3	7.2	84.7	1000
4	7.6	80.4	970
5	7.3	82.7	930
6	7.2	84.4	900

Jet + ∅ Results

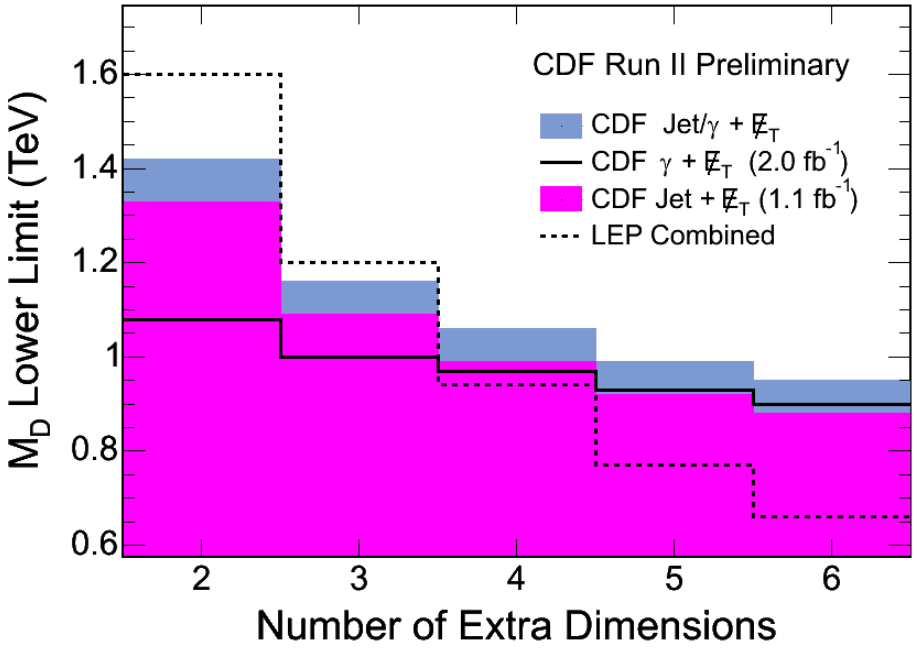
Background	Expected Events
$Z \rightarrow \nu\,\nu$	390 ± 30
$W \rightarrow \tau\nu$	187 ± 14
$W \rightarrow \mu\nu$	117 ± 9
$W \rightarrow e\,\nu$	58 ± 4
$Z \rightarrow l\,l$	6 ± 1
QCD	23 ± 20
γ Jet	17 ± 5
Non-Collision	10 ± 10
Total Predicted	808 ± 62
Data Observed	809





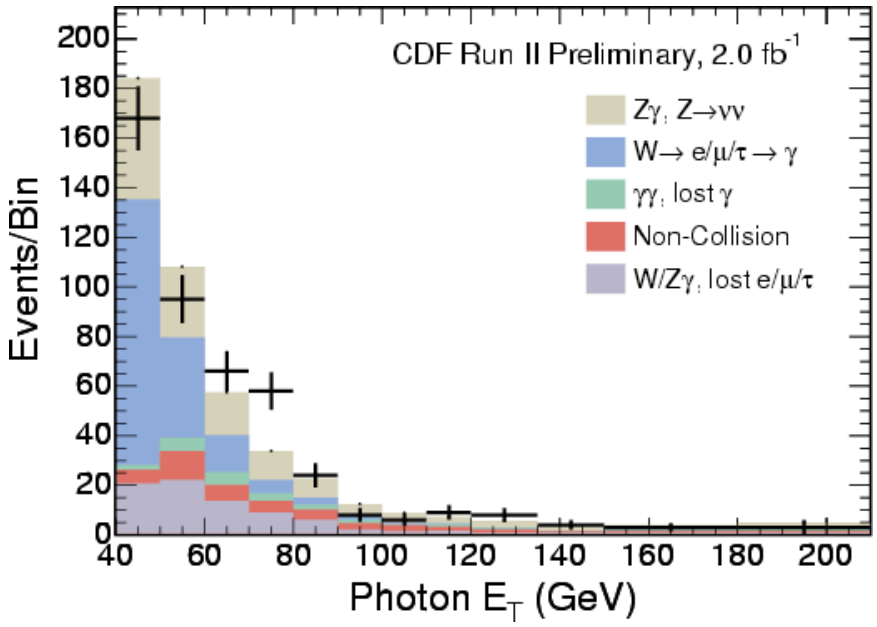
n	M_D (TeV)	R(mm)
2	> 1.31	< 0.279
3	> 1.08	$< 3.15 \times 10^{-6}$
4	> 0.98	$< 1.01 \times 10^{-8}$
5	> 0.91	$< 3.20 \times 10^{-10}$
6	> 0.88	$< 3.16 \times 10^{-11}$

Combined Limits



- Limits from jet+∅ and γ+∅ combined give better sensitivity
- Similar sensitivity in jet+∅ and γ+∅ for d > 3
- Tevatron combination is en course
- NB: from Newton law tests M_D > 3.6 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