Search for Extra Dimensions at Hadron Colliders

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Outline

- Extra Dimensions phenomenology
- Results from experiments at TeVatron
- Future at LHC (See also L. Vacavant's talk)
- Conclusions

Abstract # 419, 488, 596, 609

Extra Dimensions

– Standard Model works surprisingly well, but:

  * Why is $M_{\mathsf{Pl}} \sim 10^{16} \times M_{\mathsf{EW}}$?
  * Gravity ?
  * Dark matter ?
  * ...

$\Rightarrow$ Does gravity propagate in more than four dimensions ?

  * If n compact extra dimensions with radius $\sim R$

$\rightarrow$ $R \sim \frac{1}{M_{\mathsf{S}}}(M_{\mathsf{Pl}}/M_{\mathsf{S}})^{2/n}$

  * Take $(4+n)$ dimensional Planck scale $M_{\mathsf{S}} = M_{\mathsf{Pl}}^{(4+n)} \sim M_{\mathsf{EW}}$

$\Rightarrow$ For $n \geq 3$, $R \lesssim 1$ nm: not excluded by gravitational experiments !

Extra Dimensions Phenomenology

- Arkani-Hamed, Dimopoulos, Dvali (ADD): "large" Extra Dimensions
  - $*$ At high energy, many graviton excitations
  - $\Rightarrow$ Increase of collision cross sections
- Randall, Sundrum (RS): one "small" Extra Dimension, "warped" by exponential factor $e^{-2kr_c\phi}$
  - $*$ At high energy, single graviton excitations
  - $\Rightarrow$ Spin-2 resonance production in collisions

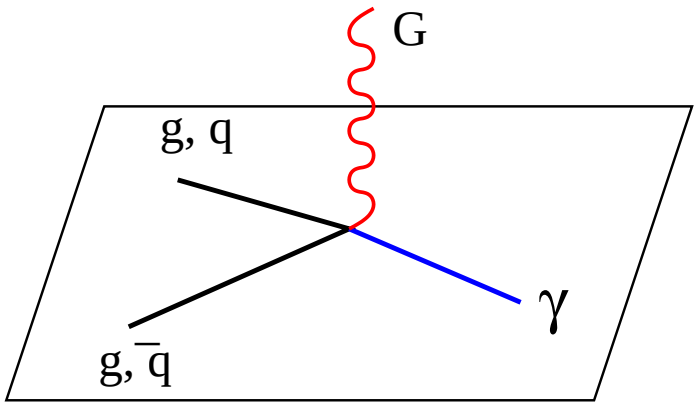
$\Rightarrow$ Look for signs of Extra Dimensions in collider experiments !

Experimental Signatures

Graviton emission:

⇒ Anomalous production of

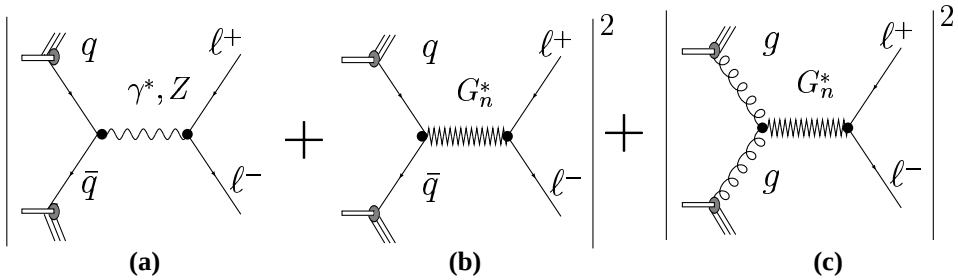
* Jets $+ \not{E}_T$
* $\gamma + \not{E}_T$



Graviton exchange:

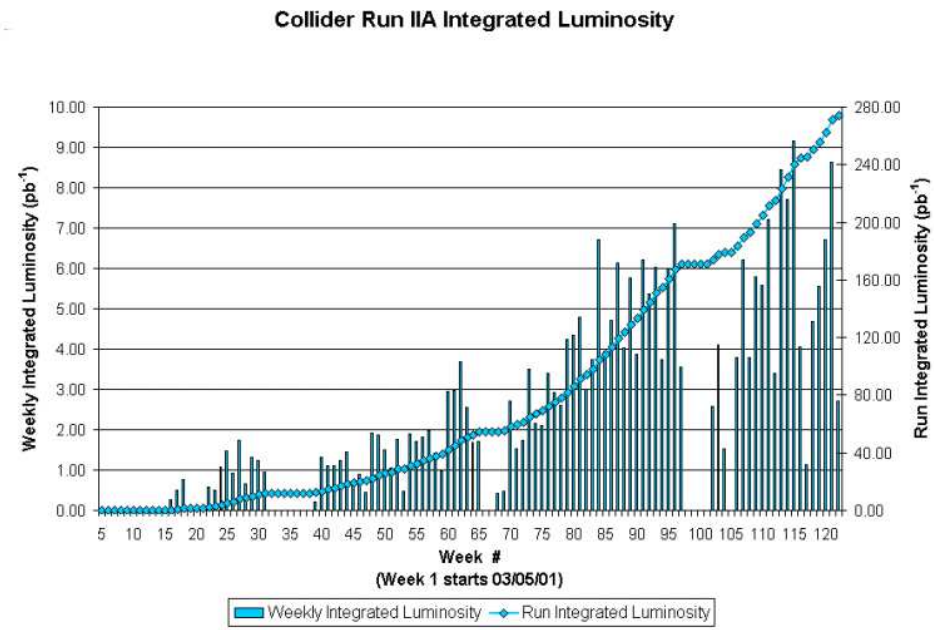
⇒ Anomalous production of

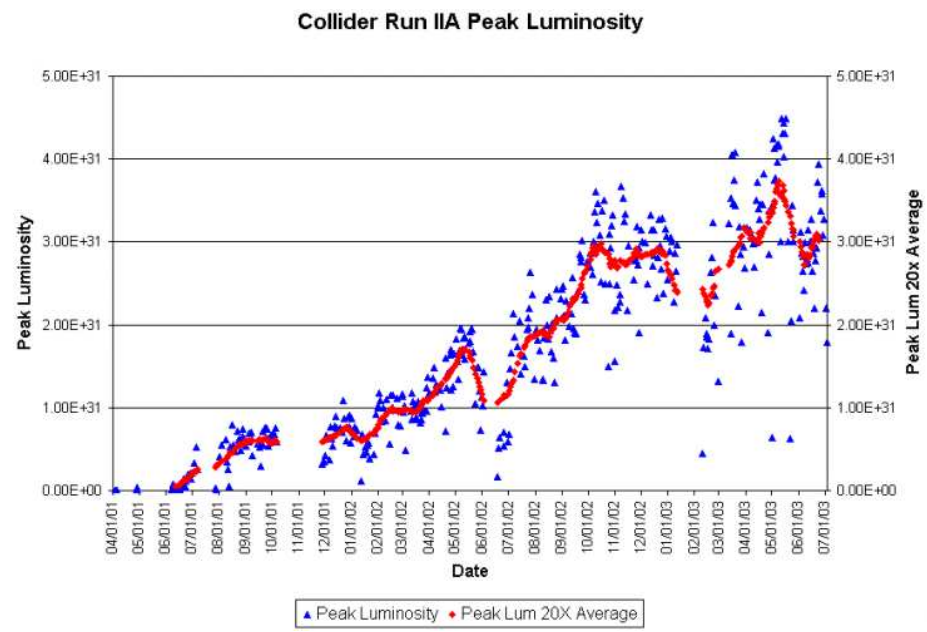
* Di-leptons
* Di-γ's



TeVatron

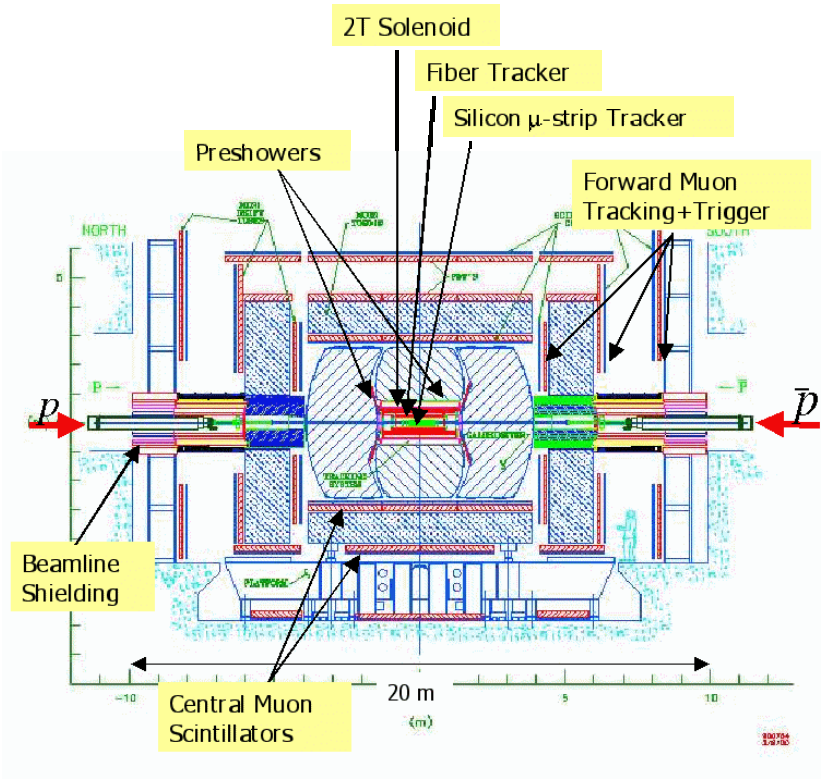
- $p\bar{p}$ Collider
  - $\sqrt{s} = 1.8$ TeV (Run I)
  - $\sqrt{s} = 1.96$ TeV (Run II)
- Higher luminosity and cross sections in Run II



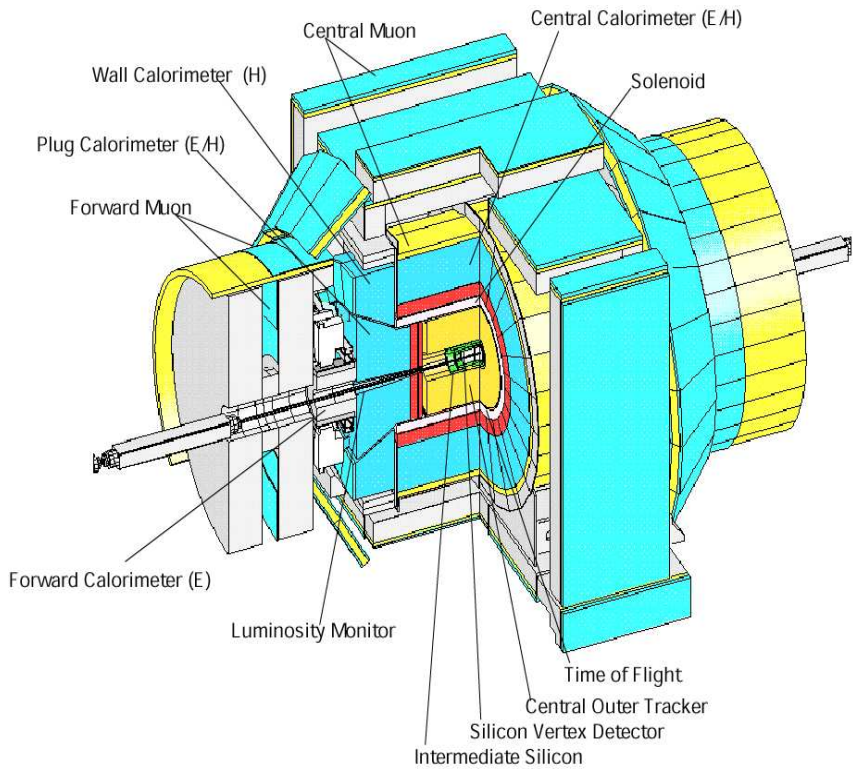


Run II Detectors

Major upgrades from Run I



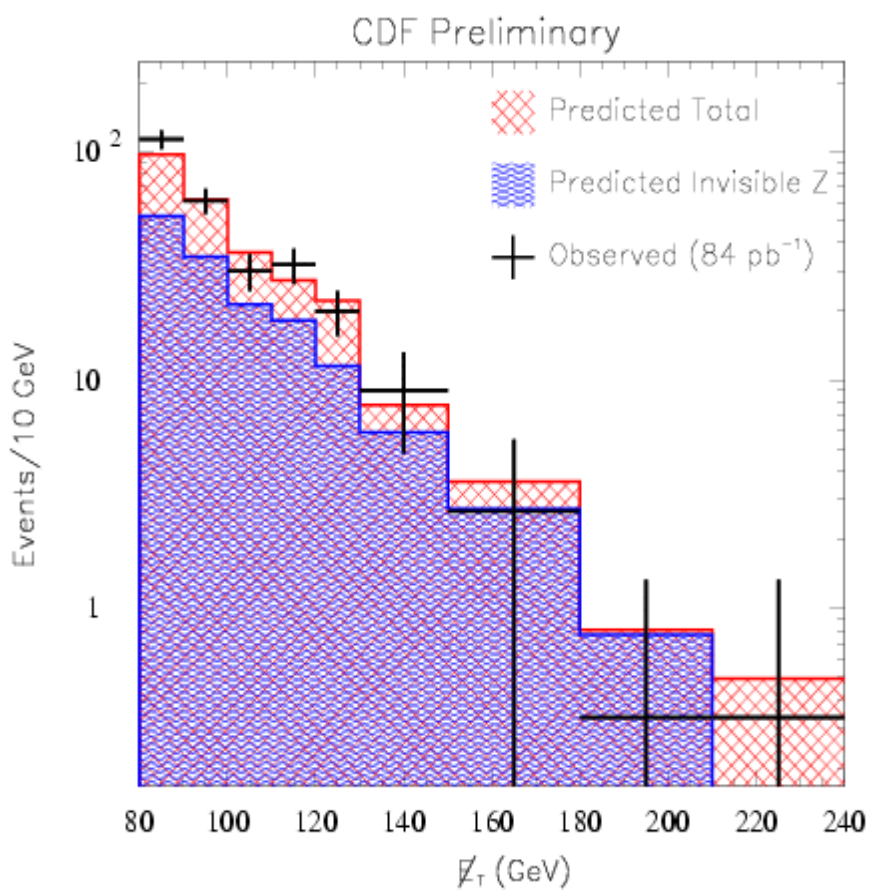
CDF



DØ

ADD Graviton Emission: Jets + $\not{E}_T$ (CDF, Run I)

- Relatively large cross section
- Background from Z ($\rightarrow \nu\bar{\nu}$) + jets production



Consistent with no signal

$\Rightarrow$ Lower limits on M_S (in GeV):

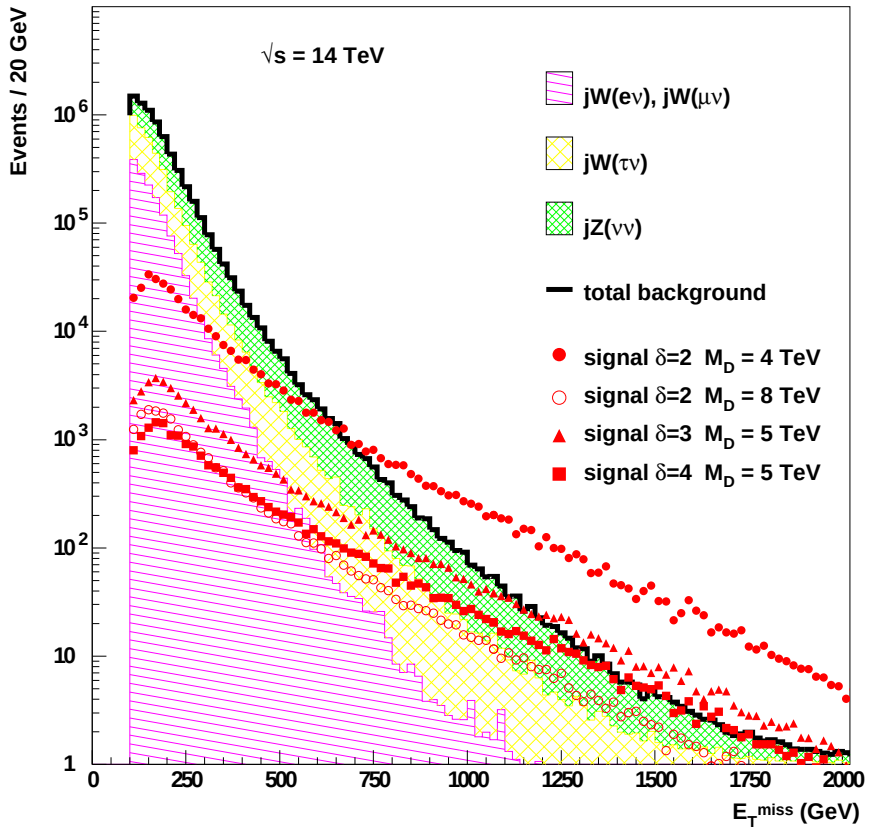
n	2	4	6
	1000	770	710

Likewise for $\gamma + \not{E}_T$:

n	4	6	8
	549	581	602

ADD Graviton Emission: Jets + $\not{E}_{\mathrm{T}}$ (ATLAS)

- $\sqrt{s} = 14$ TeV, 100 fb^{-1}
- More background sources



Discovery potential !

- $E_{\mathrm{T}}^{\mathrm{jet}} > 1$ TeV
- ≥ 100 signal events
- Significance > 5

$\Rightarrow$ Mass scale M_{D} reach (in TeV):

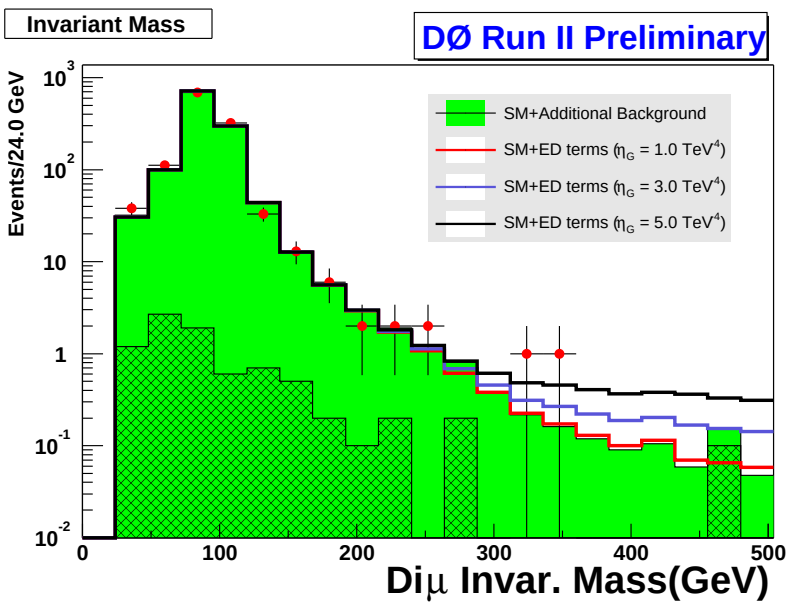
n	2	3	4
	9.1	7.0	6.0

ADD Graviton Exchange: Di-μ, Di-γ

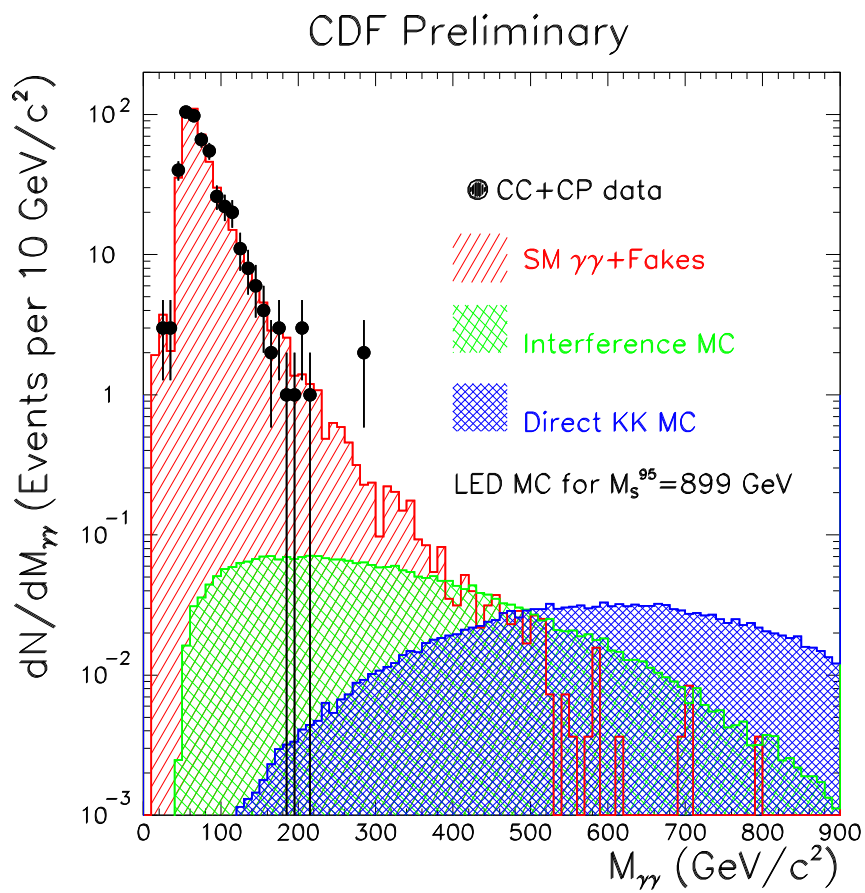
$$\sigma = \sigma_{\mathrm{SM}} + \sigma_{\mathrm{int}}\eta_G + \sigma_{\mathrm{KK}}\eta_G^2, \qquad \eta_G = \mathcal{F}/M_{\mathrm{S}}^4$$

DØ Run II, Di-μ channel, 30 pb^{-1}

- $p_{\mathrm{T}} > 15$ GeV, $M_{\mu\mu} > 40$ GeV
- Background:
  - Drell-Yann (MC)
  - Heavy quark decay (data)



CDF Run I, 87-100 pb^{-1}

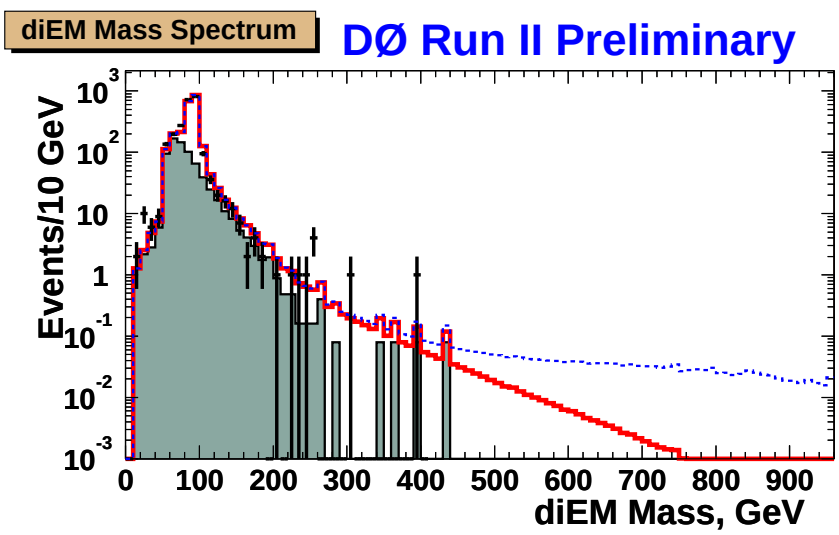


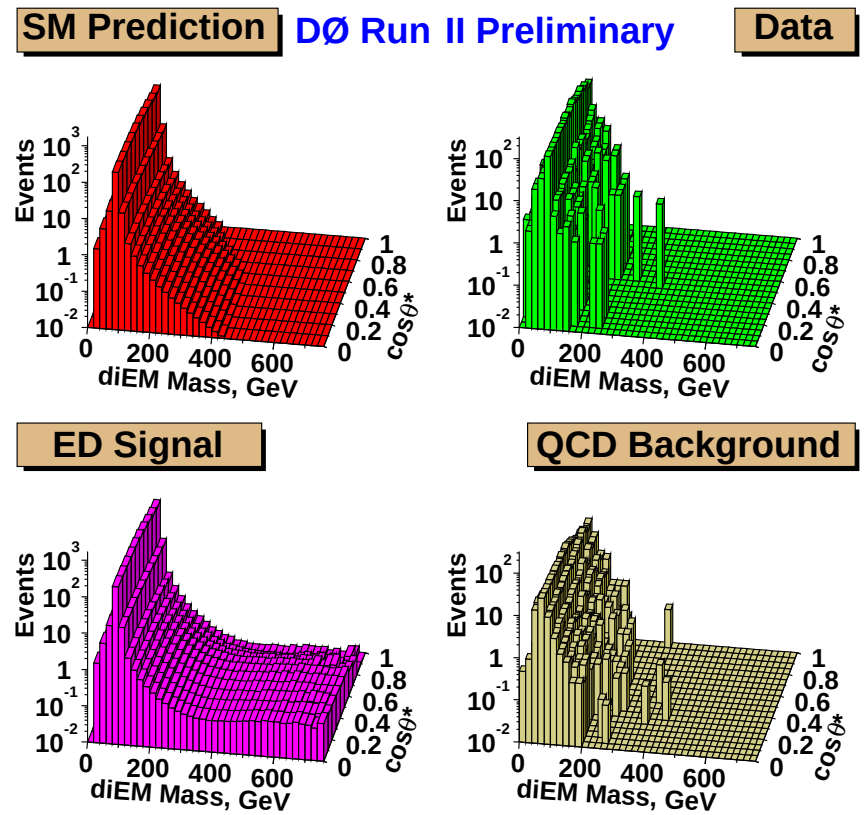
ADD Graviton Exchange: Di-EM

DØ Run II, 50 pb^{-1}

- $E_{\mathrm{T}} > 25$ GeV, $\not{E}_{\mathrm{T}} < 25$ GeV
- Background:
  - Drell-Yan, di-γ (MC)
  - fake EM from QCD (data)

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}M\,\mathrm{d}\cos\theta^*} = f_{\mathrm{SM}} + f_{\mathrm{int}}\eta_G + f_{\mathrm{KK}}\eta_G^2$$



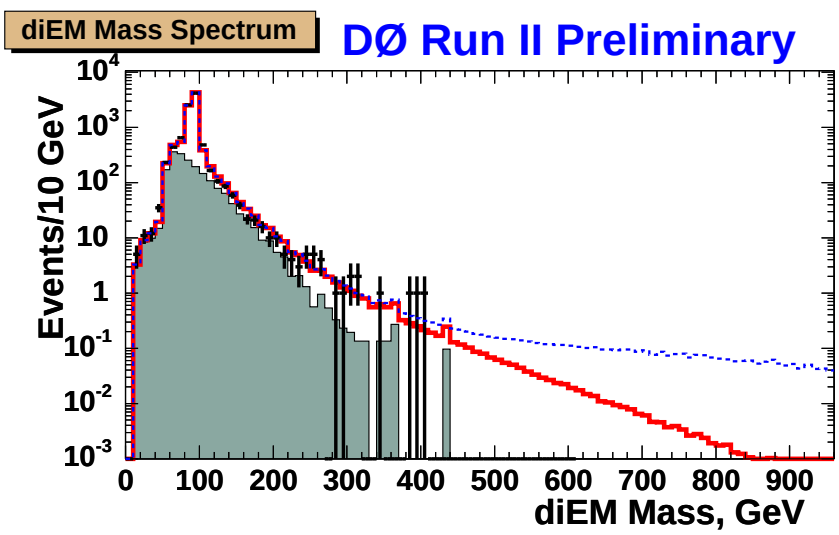


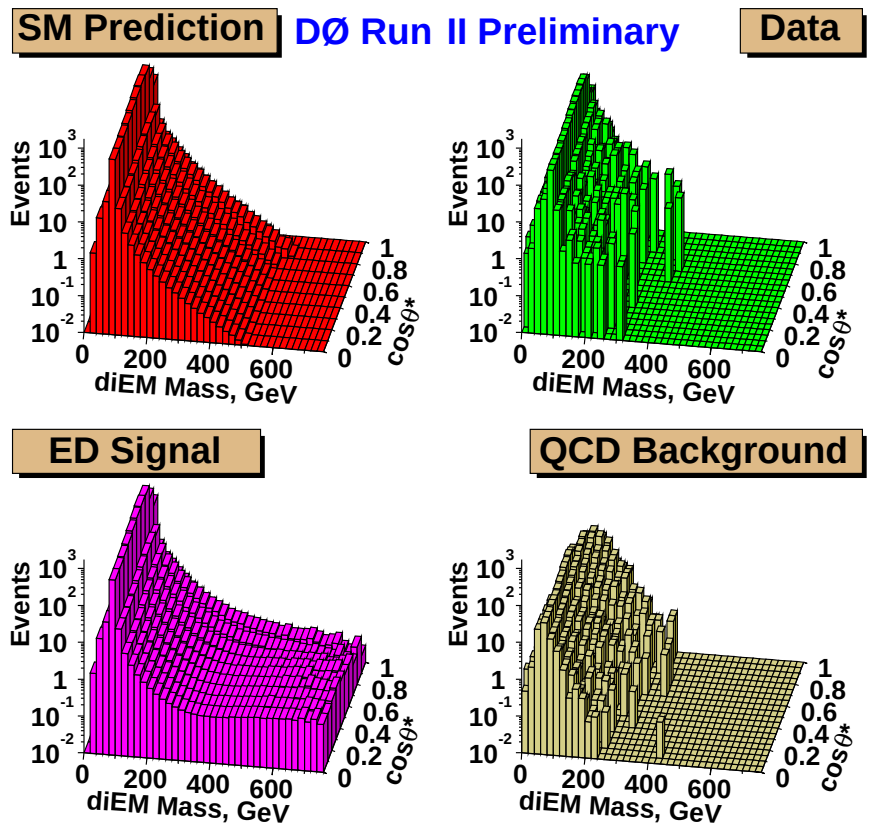
ADD Graviton Exchange: Di-EM

DØ Run II, 120 pb^{-1}

- $E_{\mathrm{T}} > 25$ GeV
- Background:
  - ∗ Drell-Yan, di-γ (MC)
  - ∗ fake EM from QCD (data)

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}M\,\mathrm{d}\cos\theta^*} = f_{\mathrm{SM}} + f_{\mathrm{int}}\eta_G + f_{\mathrm{KK}}\eta_G^2$$





ADD Graviton Exchange: Results

No signal observerd $\Rightarrow$ Fit to SM + graviton expectation, extract limits

DØ Run II

Lower limits on M_S (in TeV):

	GRW	HLZ		Hewett
		$n = 2$	$n = 7$	$\lambda = +1$
di-EM	1.12	1.16	0.89	1.00
di-μ	0.79	0.68	0.63	0.71

CDF Run I

Lower limits on M_S (in GeV):

	Hewett	
	$\lambda = -1$	$\lambda = +1$
ee	826	808
$\gamma\gamma$	899	797
di-EM	939	853

- Di-EM: $\eta_G = 0.0 \pm 0.27$ TeV^{-4}
- Di-μ: $\eta_G = 0.02 \pm 1.35$ TeV^{-4}

ADD Graviton Exchange: Results

No signal observerd $\Rightarrow$ Fit to SM + graviton expectation, extract limits

DØ Run II

Lower limits on M_S (in TeV):

	GRW	HLZ		Hewett
		$n = 2$	$n = 7$	$\lambda = +1$
di-EM	1.28	1.42	1.01	1.14
di-μ	0.79	0.68	0.63	0.71

CDF Run I

Lower limits on M_S (in GeV):

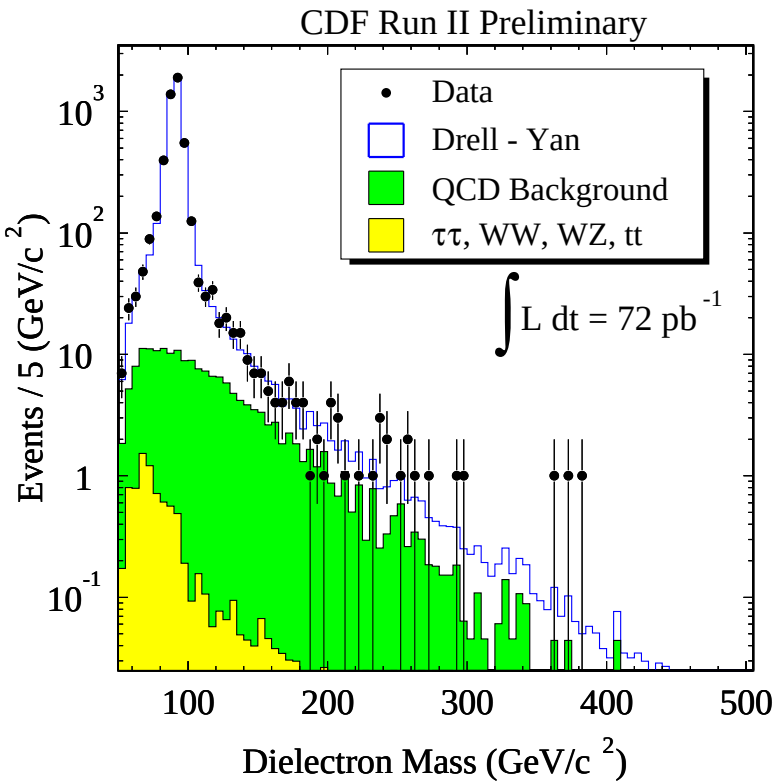
	Hewett	
	$\lambda = -1$	$\lambda = +1$
ee	826	808
$\gamma\gamma$	899	797
di-EM	939	853

- Di-EM: $\eta_G = 0.0 \pm 0.15$ TeV^{-4}
- Di-μ: $\eta_G = 0.02 \pm 1.35$ TeV^{-4}

RS Resonance Production (CDF, Run II)

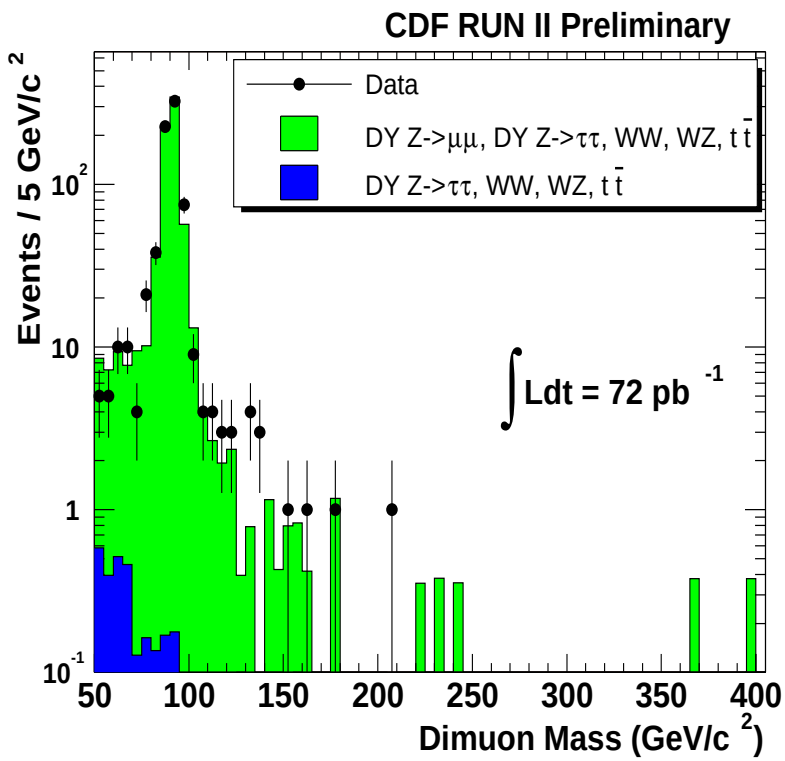
Di-electron channel, 72 pb^{-1}

– $E_T > 25$ GeV, $\not{E}_T/\sqrt{\Sigma E_T} < 2.5$



Di-μ channel, 72 pb^{-1}

– $p_T > 20$ GeV, Cosmic rejection



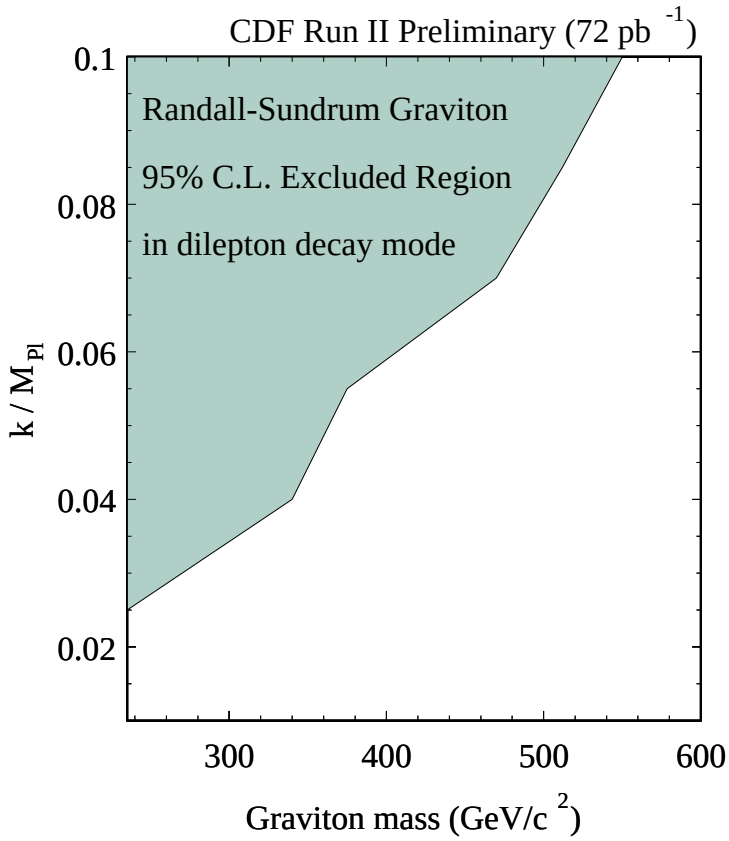
Consistent with no signal $\Rightarrow$ RS graviton mass limits (in GeV):

channel	ee	$\mu\mu$	combined
	535	370	550

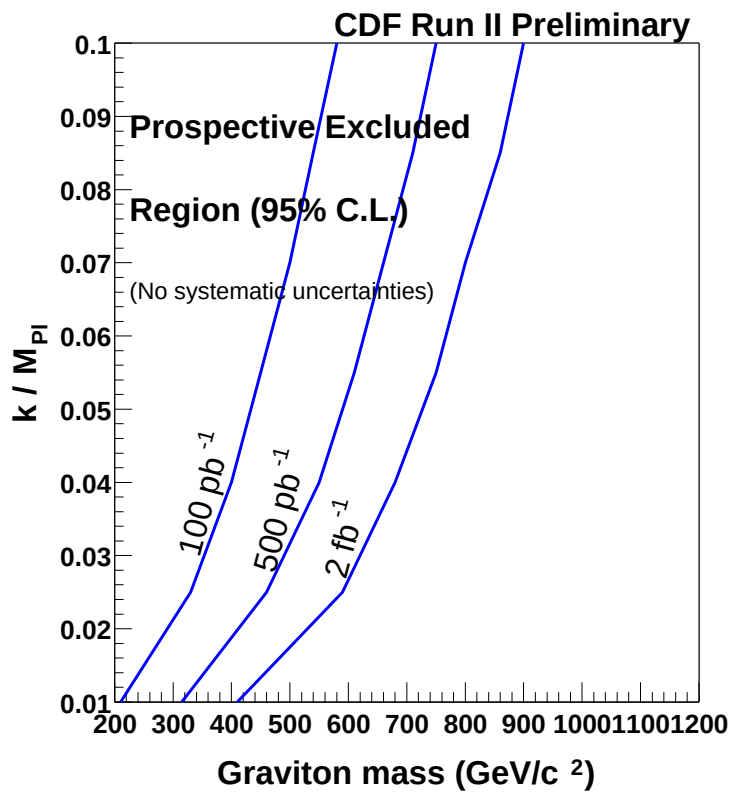
RS Resonance Production (CDF, Run II)

RS graviton mass vs coupling limits

Current:



Expected in Run II (di-electron):

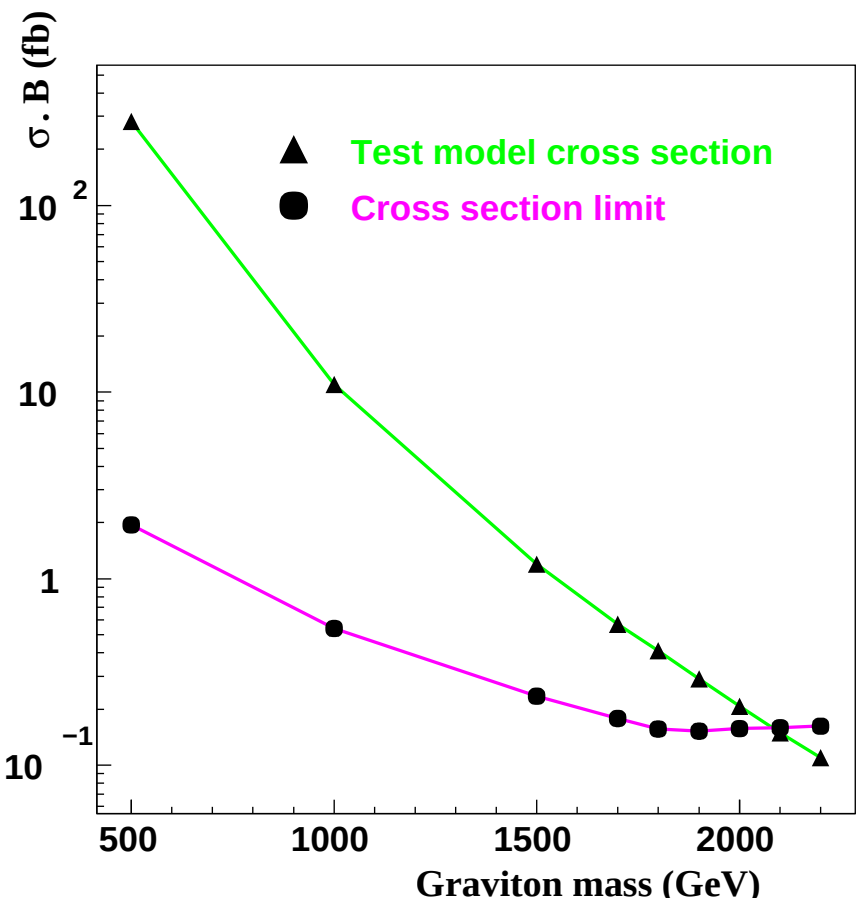


See also Z' search (M.P. Giordani's talk)

RS Resonance Production (ATLAS)

– $\sqrt{s} = 14$ TeV, 100 fb^{-1}

$\Rightarrow$ Cross section limit



$\Rightarrow$ Max. mass $= 2080$ GeV

Conclusion

- Extra Dimensions as a solution to hierarchy (and others)
- No Extra Dimensions found, yet $\Rightarrow$ model limits
- More to expect from TeVatron experiments
- Even more from LHC experiments