

Search for Extra Dimensions at the Tevatron

Oriol Saltó

IFAE - Barcelona

for the CDF and D0 collaborations

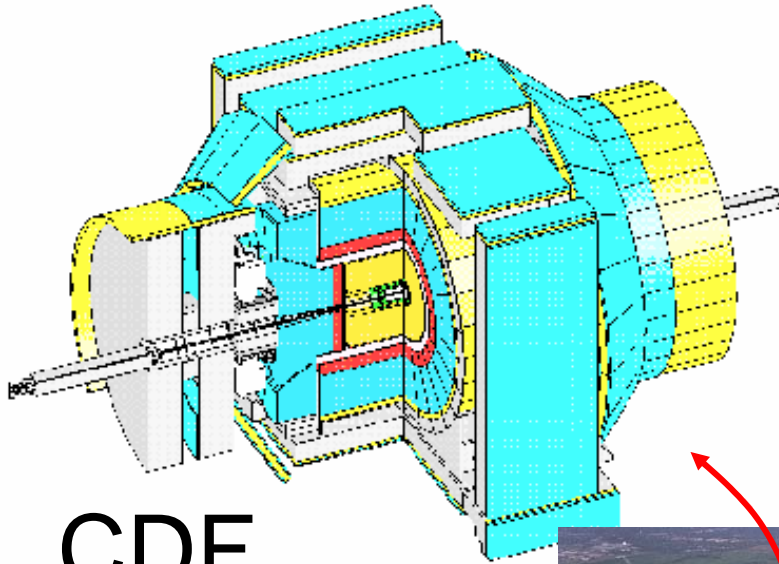
5th Eurogdr Supersymmetry

Barcelona, November 2005

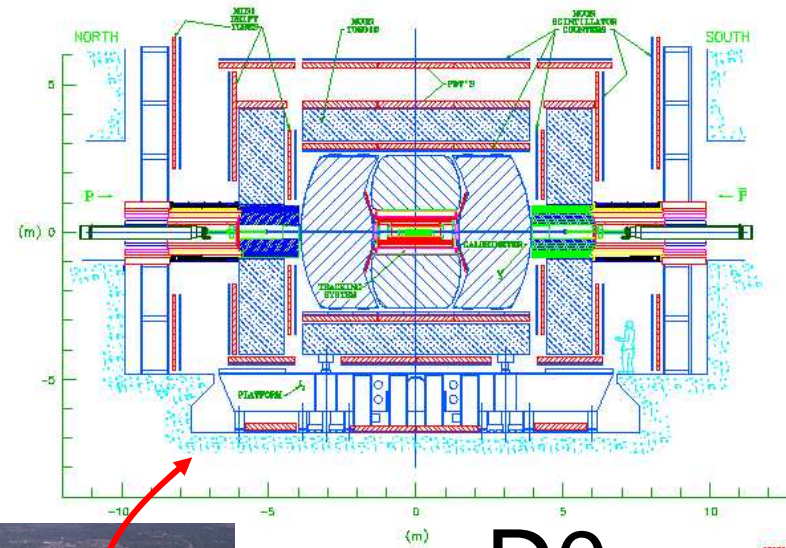
Outline

- Tevatron and the CDF and D0 detectors
- Virtual Graviton searches
- Direct Graviton searches
- Models of Extra Dimensions
 - Randall-Sundrum (RS) gravitons
 - Searches for RS Gravitons
 - Large Extra Dimensions (LED)
 - Searches for LED
 - TeV^{-1} Extra Dimensions
 - Searches for TeV^{-1} ED
- Summary

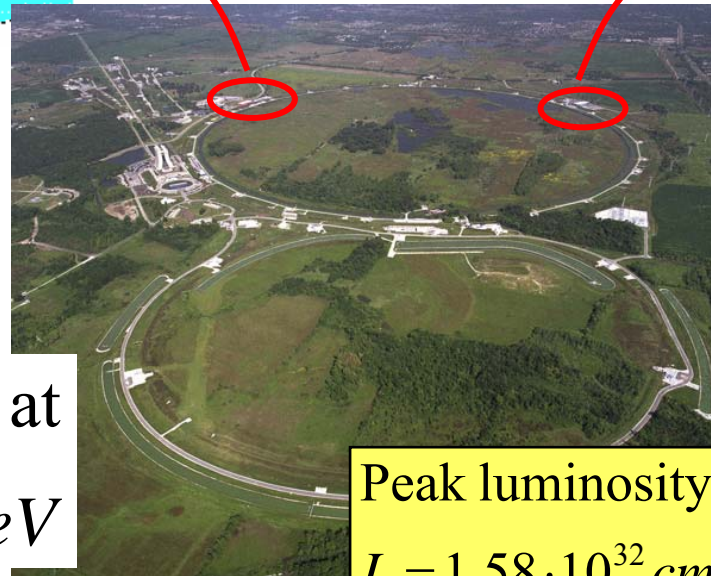
Tevatron and the CDF and D0 detectors



CDF



D0



$p\bar{p}$ collider at
 $\sqrt{s} = 1.96\text{TeV}$

Peak luminosity world record
 $L = 1.58 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

Virtual Graviton searches

- Drell-Yan and diphoton production are sensitive to the presence of additional Graviton contributions at high masses

$$\sigma = \sigma_{SM} + \eta_G \sigma_{int} + \eta_G^2 \sigma_{KK}$$

- The effects of the ED are parametrized by

$$\eta_G = F/M_S^4$$

$$F = 1 \text{ (GRW)}$$

$$F = \frac{2}{n-2}; \text{ for } n > 2 \text{ (HLZ)}$$

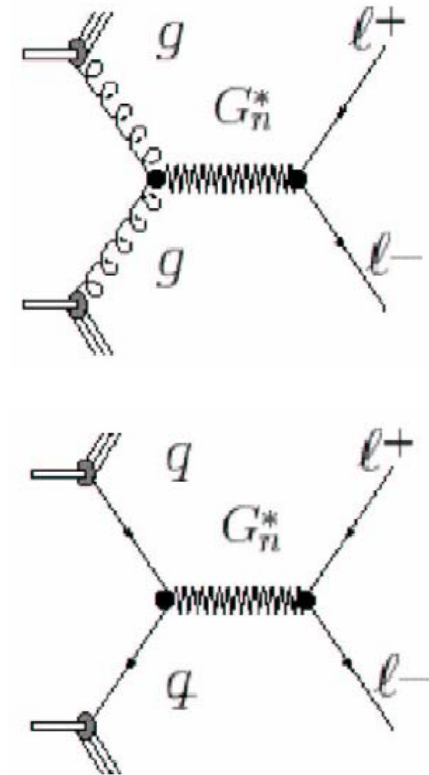
$$F = \frac{2\lambda}{\pi}; \text{ with } \lambda = \pm 1 \text{ (Hewett)}$$

- CDF searches:

- dilepton channel ($ee + \mu\mu$)
- diphoton channel

- D0 searches:

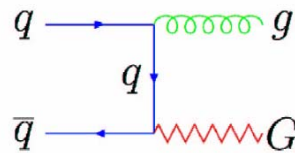
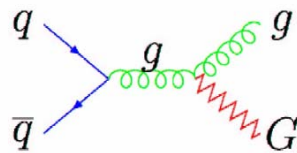
- diEM channel ($ee + \gamma\gamma$)
- dimuon channel



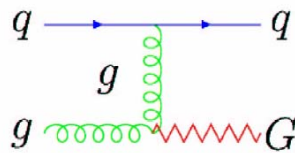
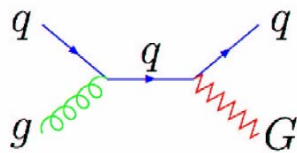
Direct Graviton searches

- A Graviton is emitted recoiling against a quark or a gluon
 - The Graviton escapes to the Extra Dimensions leaving a signal of missing transverse energy (MET)
 - The parton produces a jet (monojet signature)

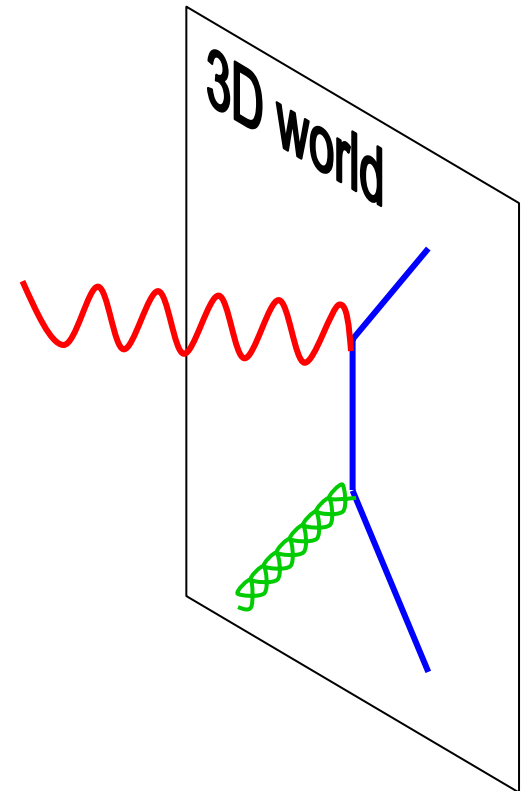
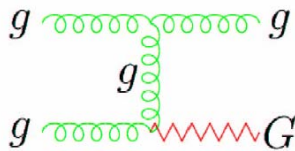
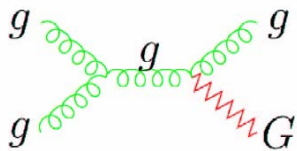
$$q\bar{q} \rightarrow gG$$



$$qg \rightarrow qG$$

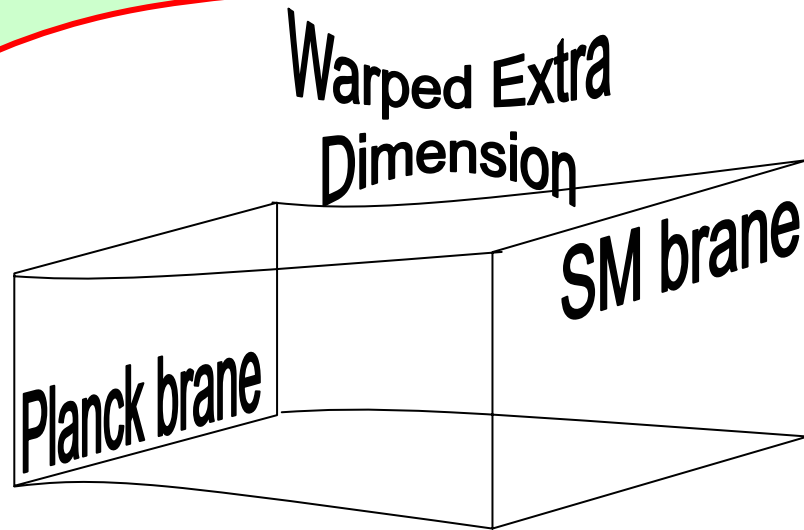


$$gg \rightarrow gG$$



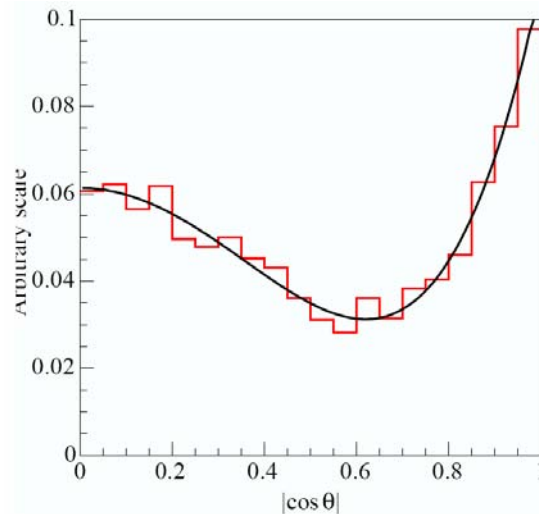
- CDF and D0 searches:
 - jet + MET signature

Randall-Sundrum (RS) Gravitons

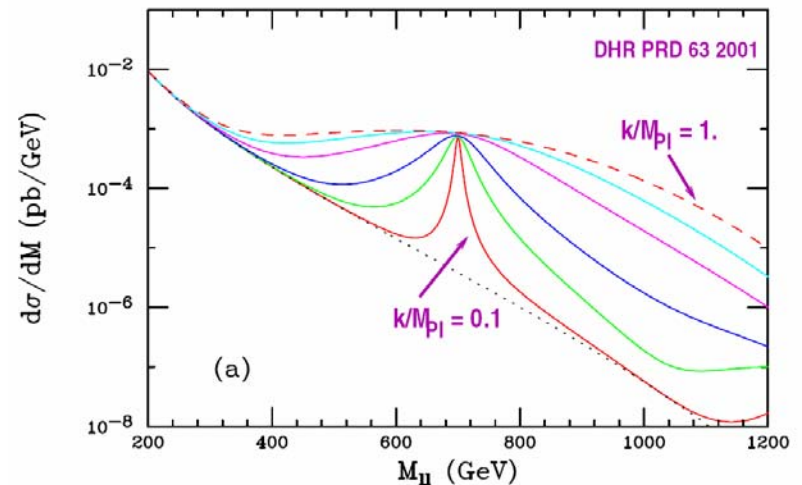


Graviton is a spin-2 boson.

$\cos\theta^*$ (in the CM frame) reflects spin configuration



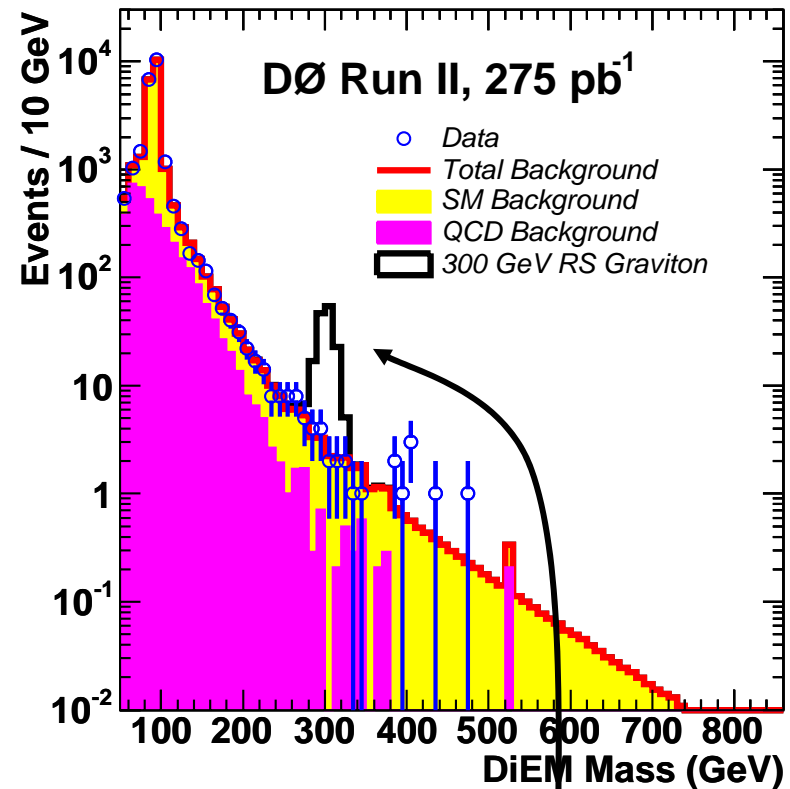
- Gravity originates (fundamental Planck scale) in the Planck brane
- Graviton wave function is highly suppressed in the SM brane
- Planck scale apparently higher in the SM brane
- Free parameters: M_G k/M_{Pl}



Gravitons appear as narrow resonances in the mass spectrum

D0 search for RS graviton production in the diEM channel

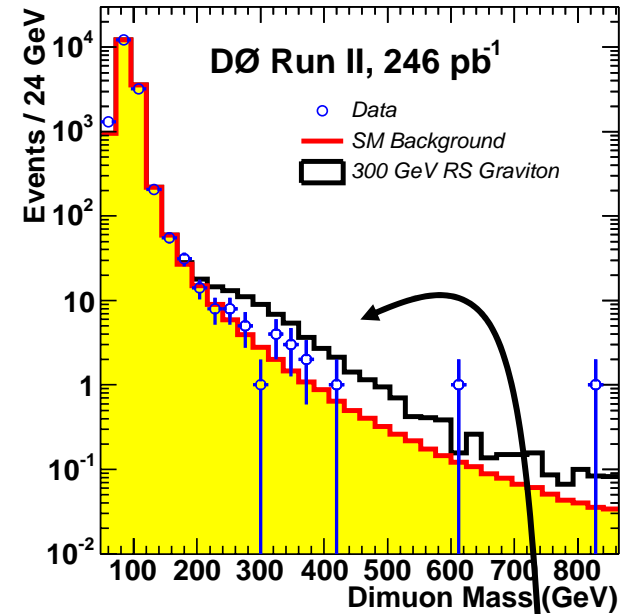
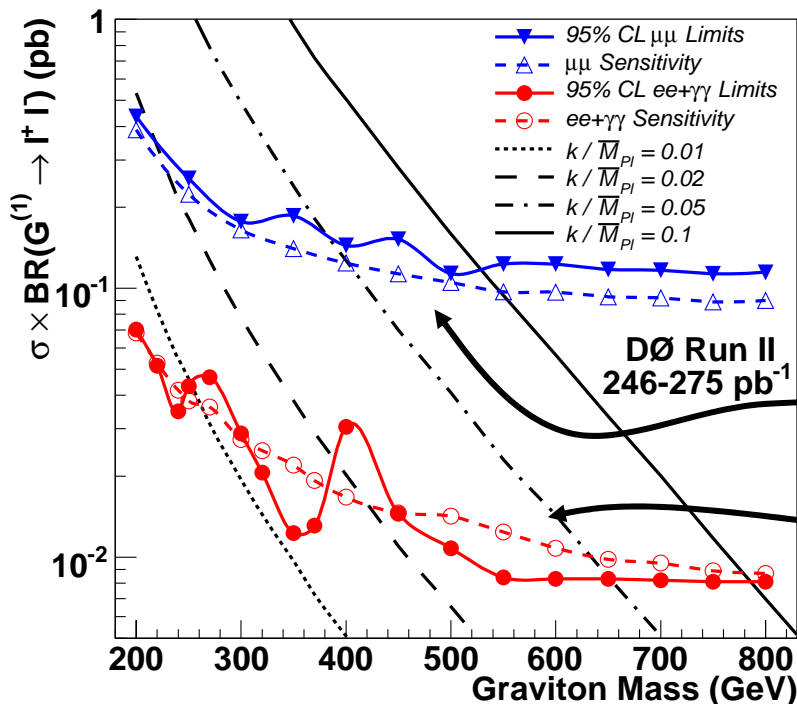
- ee and $\gamma\gamma$ channels combined in the diEM channel
- Requiring:
 - 2 isolated EM objects with $E_T > 25$ GeV
- Backgrounds:
 - DY production
 - direct diphoton production



Expected signal for a 300 GeV RS Graviton

D0 search for RS graviton production in the dimuon channel

- Requiring:
 - 2 isolated muons with $p_T > 15$ GeV/c
- Backgrounds:
 - DY production
 - cosmic rays

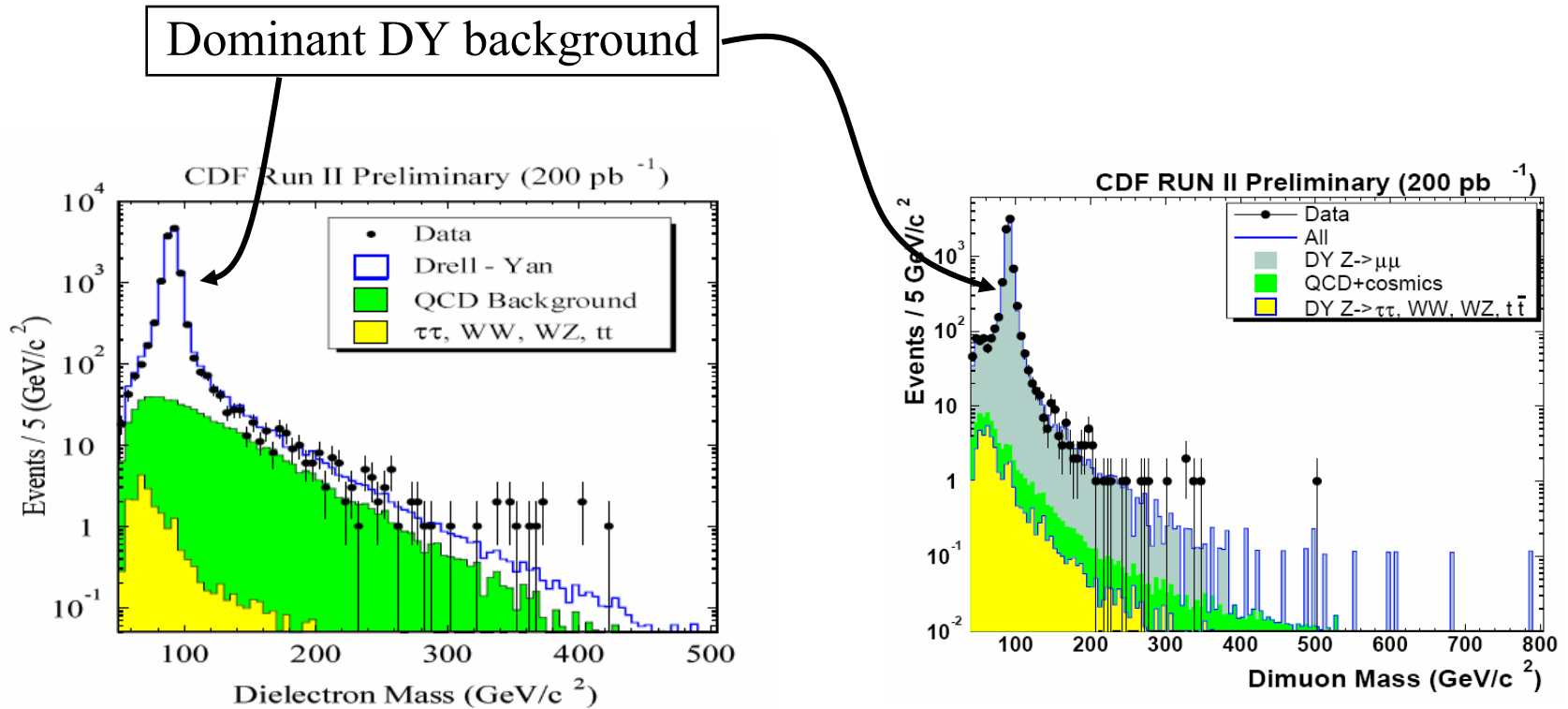


RS Graviton signal
Less resolution in the muon measurements.
Worse limits

Limits on the cross section of RS Graviton decaying to EM objects

CDF search for RS graviton production in the dilepton channel (I)

- ee and $\mu\mu$ channels combined in the dilepton channel

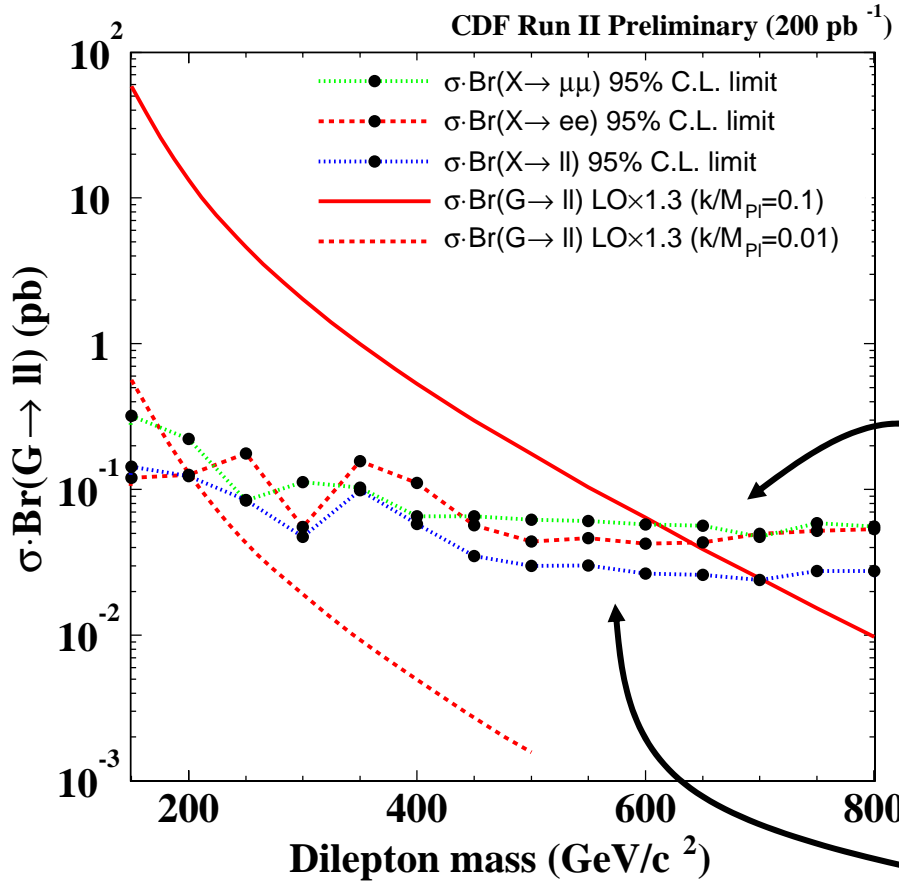


Requirements:

isolated electrons
with $E_T > 25 \text{ GeV}$

isolated muons with
 $p_T > 20 \text{ GeV}/c$

CDF search for RS graviton production in the dilepton channel (II)



RS Graviton mass limit at
95% CL

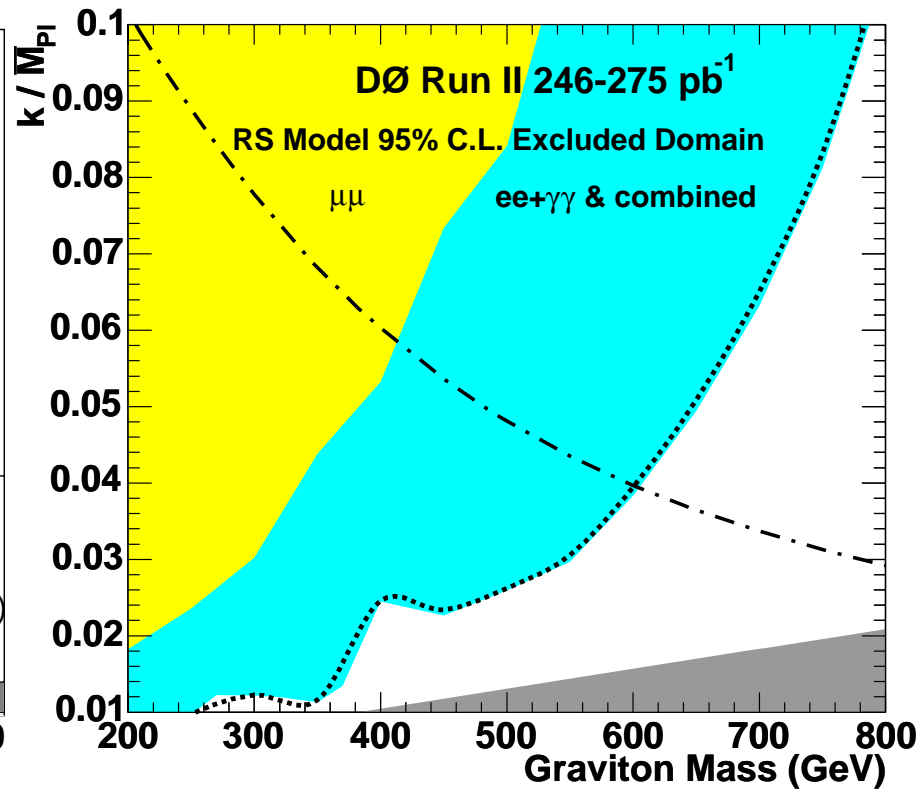
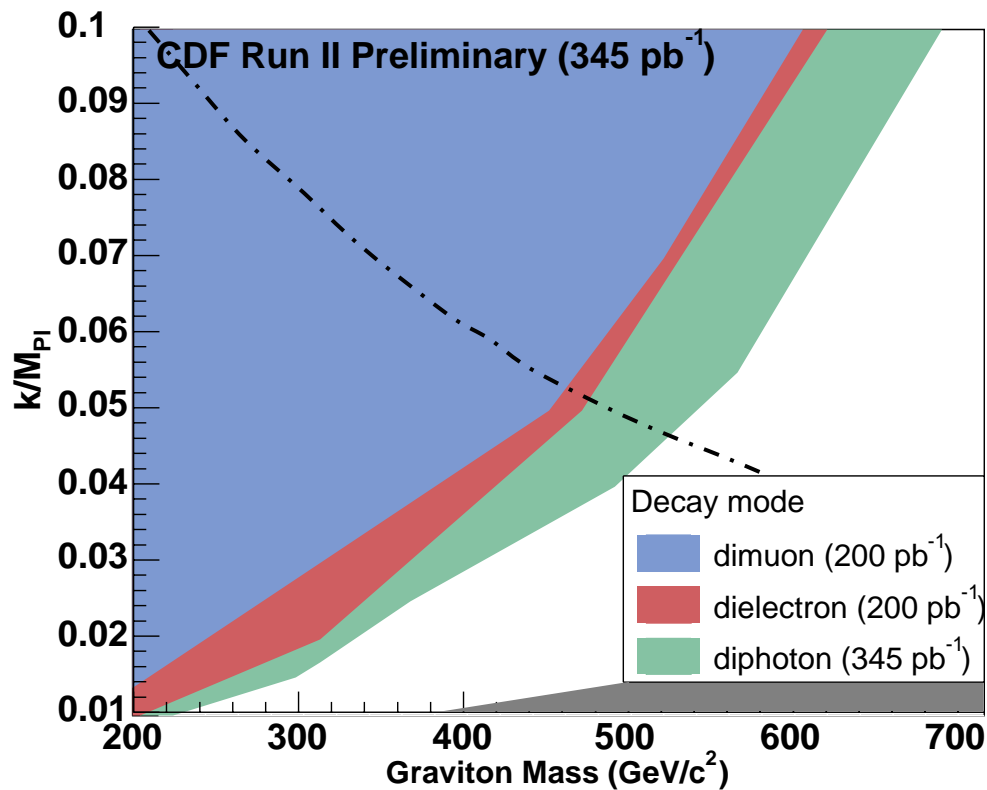
k/M_{Pl}	M_G (GeV/c ²)
0.1	700
0.05	525
0.01	200

Similar limits on the RS Graviton cross section from ee and $\mu\mu$ channels

Dilepton combined limits

Tevatron exclusion regions for the RS model

RS Graviton Searches, 95% C.L. Exclusion Regions

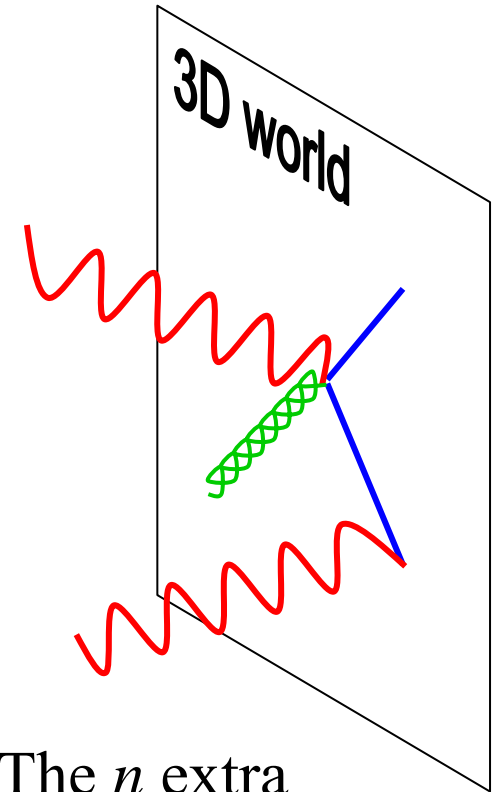


Large Extra Dimensions (LED)

- SM particles are confined in our 3D world
- Gravitons can propagate in a $(3+n)$ dimensional space
- Then gravity appears weaker in the 3D world
- Consequently with an apparent higher Planck scale:

$$M_{Pl}^2 \approx R^n \cdot M_S^{2+n}$$

for $n = 2$ with $R \sim 1\text{mm}$, $M_S \sim \text{EWK scale}$



The n extra dimensions are compactified with a radius R

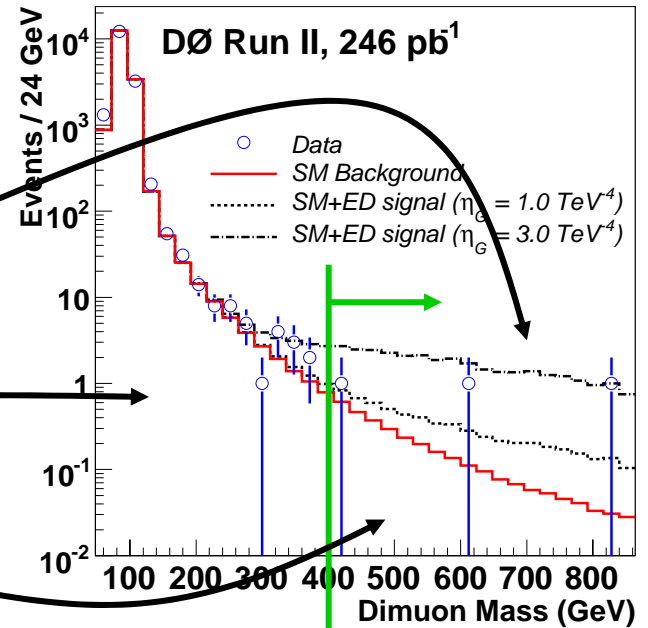
D0 search for LED in the dimuon channel

- Requiring
 - 2 isolated muons with $p_T > 15$ GeV/c

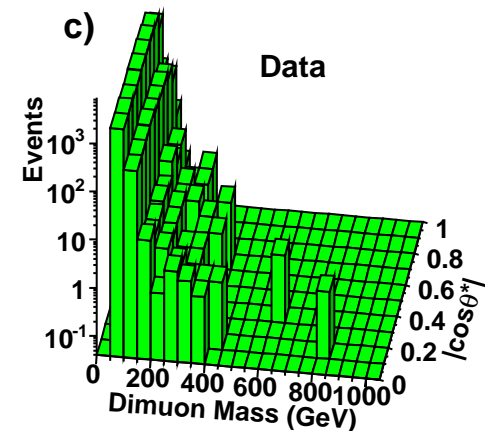
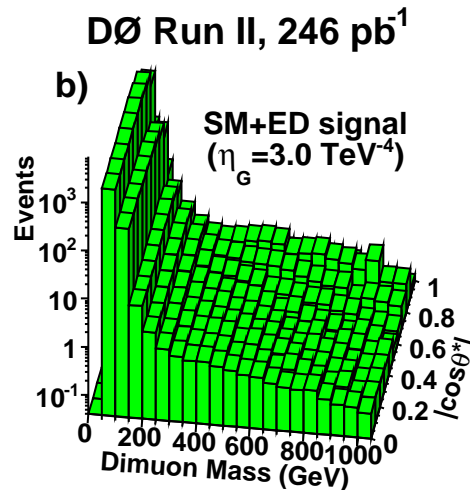
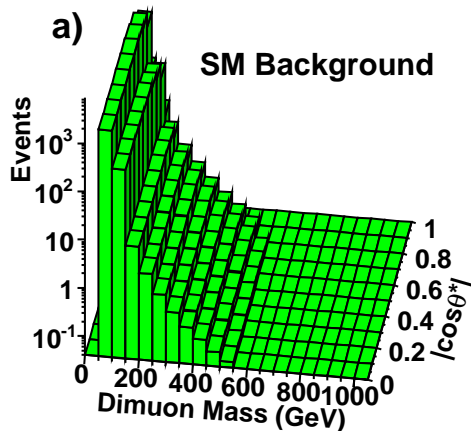
Expected signal:
excess at higher masses

DY background
(other backgrounds
are negligible)

3 events with $M_{mm} > 400$ GeV/c²
(background expectation: 4 events)

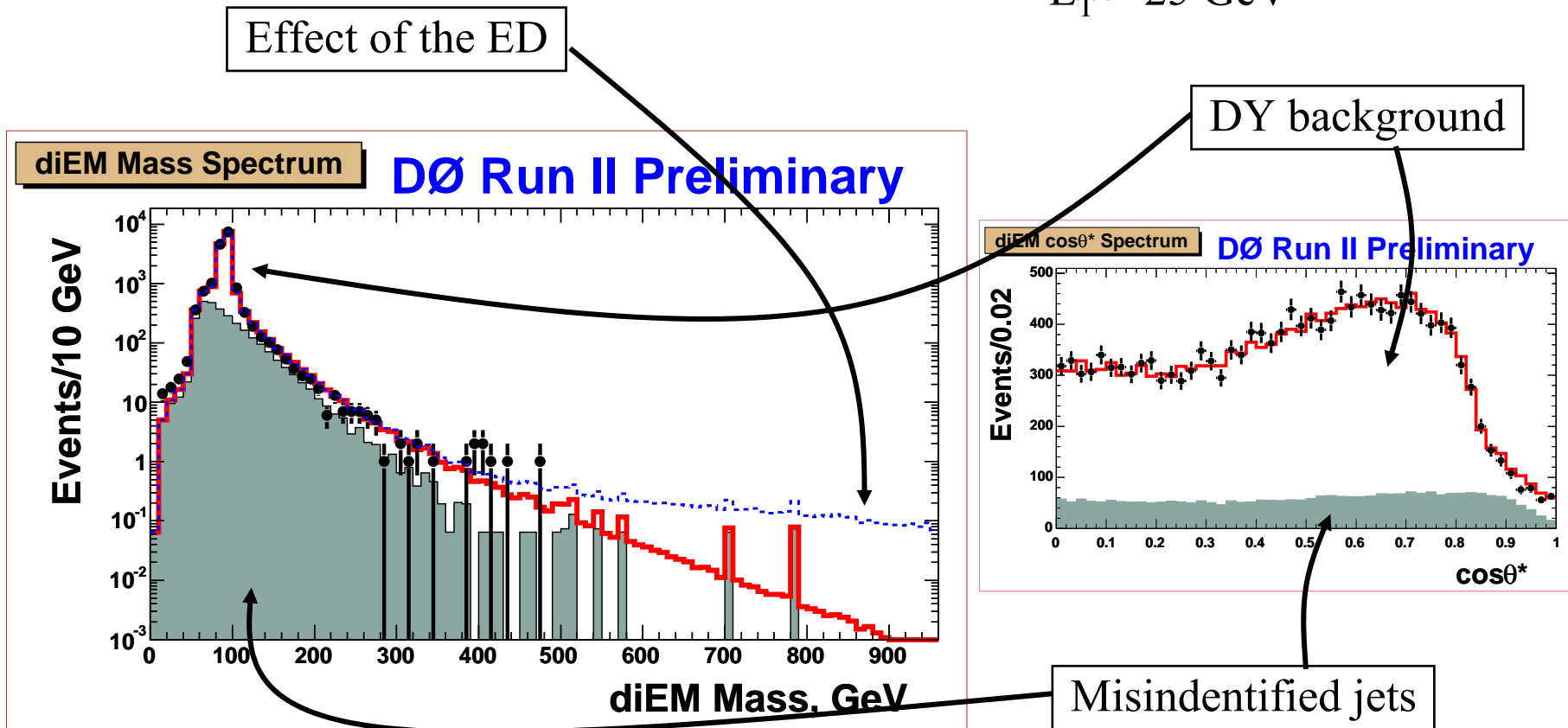


2D fits in
($M, \cos \theta^*$)
to set limits
on η_G



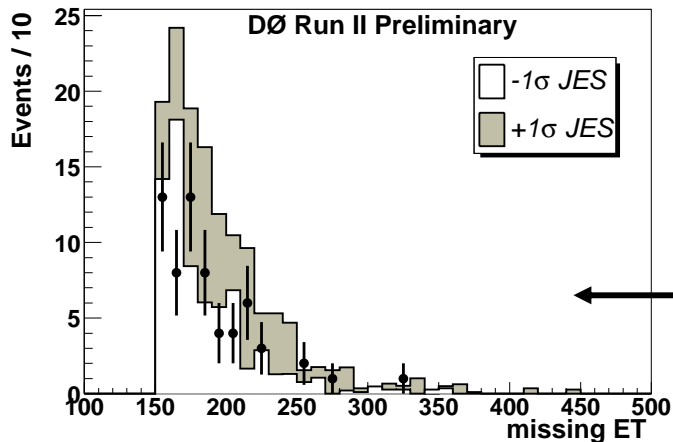
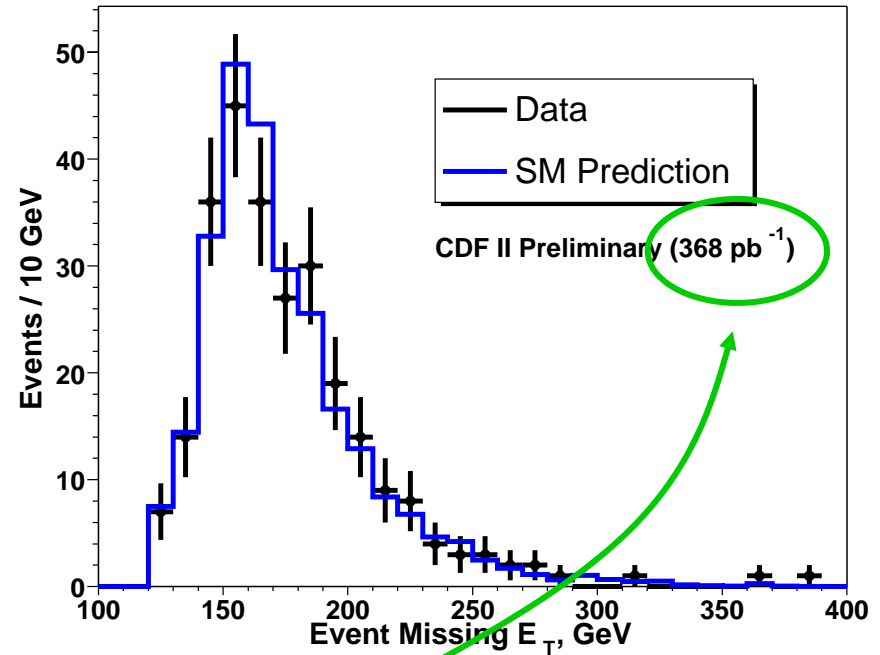
D0 search for LED in the diEM channel

- A search for **LED** combining ee and $\gamma\gamma$ channels
- Requiring
 - 2 isolated EM clusters with $E_T > 25$ GeV



CDF search for LED with jet + MET signature

- Requiring
 - one jet with $E_T > 150$ GeV
 - allows a second jet with $E_T < 60$ GeV
 - $MET > 120$ GeV
- Backgrounds
 - $Z(\rightarrow \nu\nu) + \text{jets}$
 - $W(\rightarrow l\nu) + \text{jets}$
 - QCD dijets mismeasurement



Largest data sample used in Tevatron searches for ED

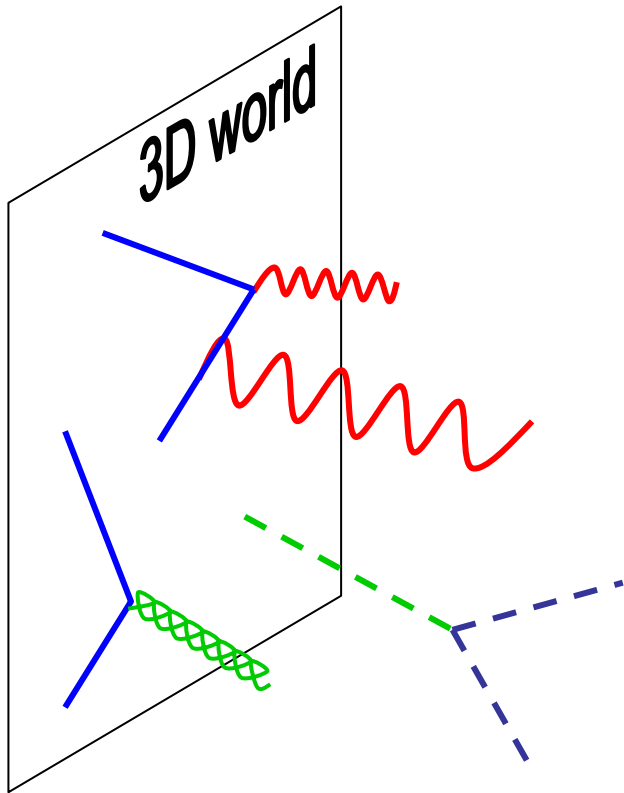
Agreement with previous D0 search using 85 pb^{-1}

Tevatron limits for LED

		D0	CDF	D0 + RunI
GRW		1.36		1.43
	$n = 2$	1.56	1.16	1.67
	$n = 3$	1.61	0.98	1.70
HLZ	$n = 4$	1.36	0.90	1.43
	$n = 5$	1.23	0.85	1.29
	$n = 6$	1.14	0.83	1.20
	$n = 7$	1.08		1.14
Hewett	$\lambda = +1$	1.22		1.28
	$\lambda = -1$	1.10		

Lower limits for M_S in TeV at 95% CL

TeV⁻¹ Extra Dimensions



- Fermions are confined into the 3D brane
- All gauge bosons also propagate in the n Extra Dimensions
- It predicts KK excitations for all the gauge bosons with masses

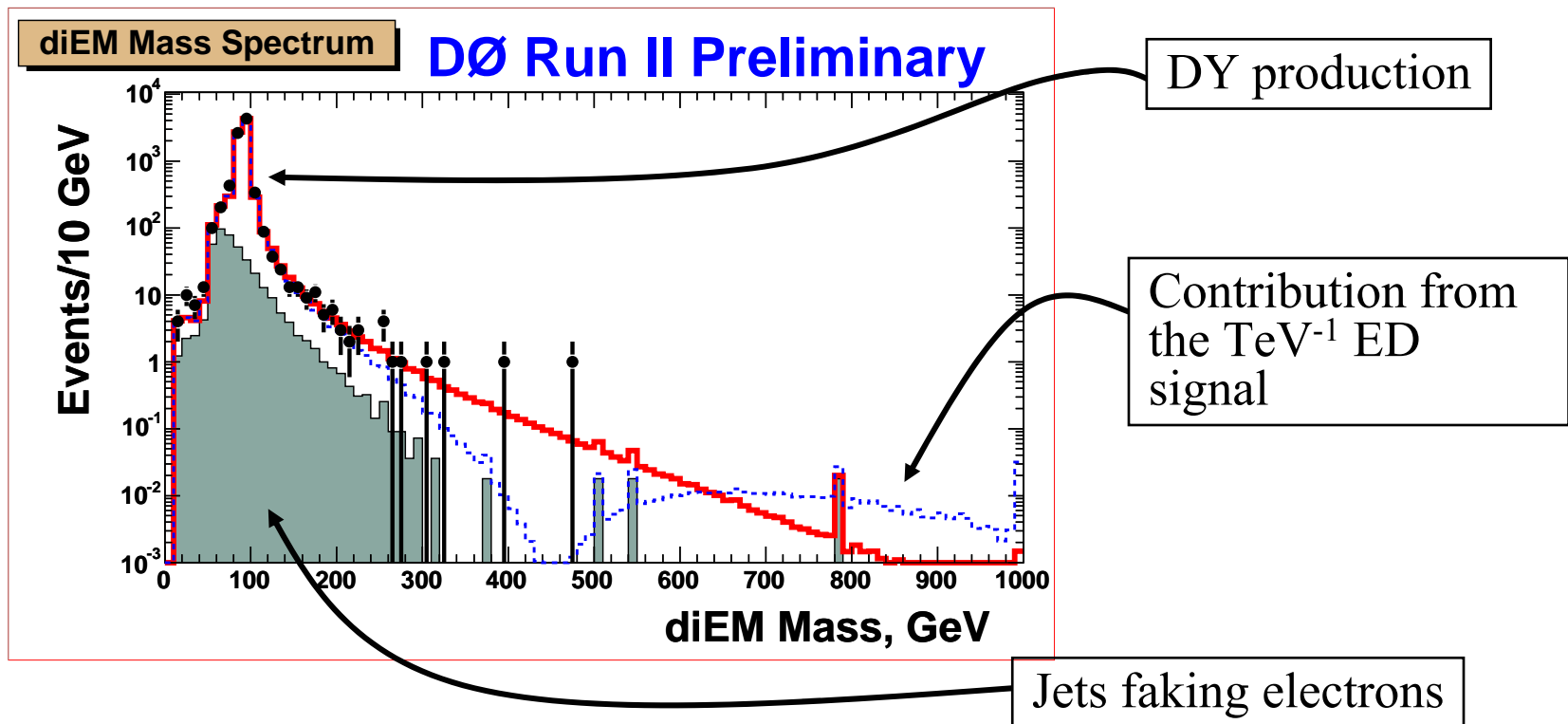
$$M_i = \sqrt{M_0^2 + \frac{i^2}{R^2}} \quad \text{with } R = M_C^{-1}$$

- SM gauge bosons are the zeroth mode of the KK towers

D0 search for LED and TeV^{-1} ED in the dielectron channel

- Does not require isolation but requires at least one EM cluster with a matching track

- Limits on TeV^{-1} ED (@ 95% CL)
 - $\eta_G < 0.65$ TeV-4
 - $M_C > 1.12$ TeV



Summary

- CDF and D0 Experiments carry out a complete program on searches for ED considering different models and final states
- No evidence for ED has been found yet. Tevatron experiments have made available competitive limits
- Results from 1 fb^{-1} improved analyses coming next winter