Searches for Extra Dimensions and Z' Bosons at DØ

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On behalf of the DØ Collaboration

Overview

- **Introduction**
- **The Fermilab Tevatron and DØ**
- **Signatures at the Tevatron**
- **The diEM and dielectron searches**
- **The dimuon searches**
- **Summary and conclusions**

Introduction

- The Standard Model does a wonderful job
- Extensively tested and probed
  - W and Z bosons predicted and found at the correct masses!
  - Top quark predicted and found!
- Still wrought with problems/questions
  - Fine tuning
  - Hierarchy problem
    - Very large difference between the couplings of SM and gravity
  - Running coupling constants

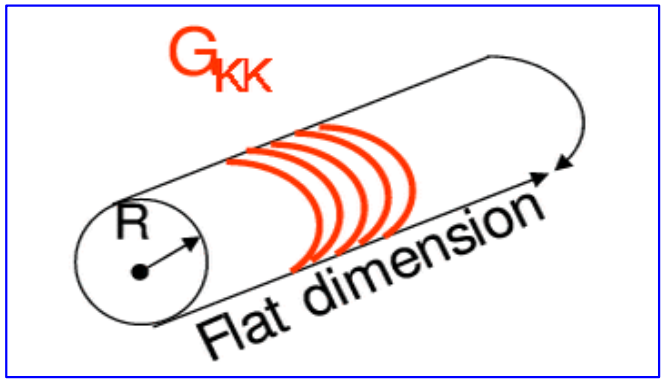
Introduction

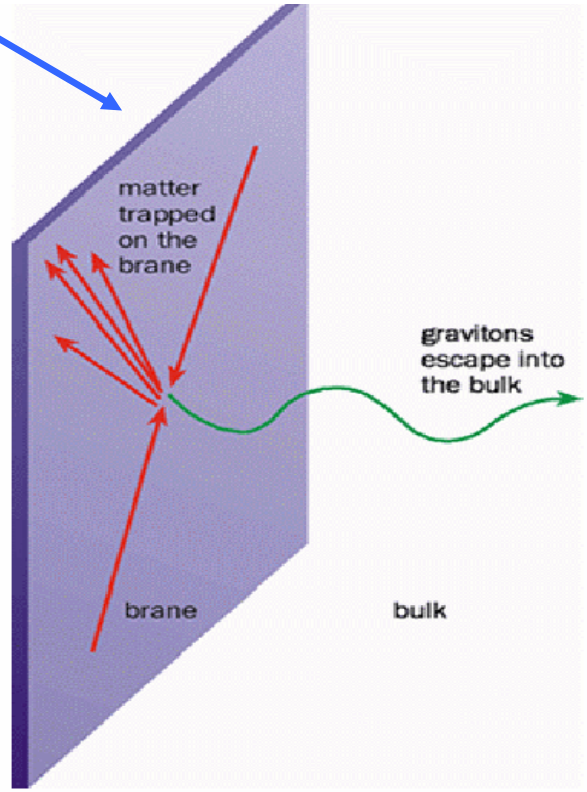
- One possible solution/extension:
  - Add to the gauge sector of the SM
  - Often these give rise to new neutral gauge bosons (Z') which may have sub-TeV masses
  - Grand Unified Theories (GUT)
    - SU(5), SO(10), E_6

- Another possiblity: Extra Dimensions:
  - TeV^{-1} Extra Dimensions (TeV^{-1} ED)
    - Matter resides on a p-brane (p>3)
    - Chiral fermions are confined to 3D part of the p-brane
    - SM gauge bosons can propagate in the extra space
    - Get Kaluza-Klein (KK) states of the SM gauge bosons

Introduction

- More Extra Dimensions:
  - Large Extra Dimensions (LED):
    - Graviton is only particle that propagates in extra dimensions
    - The other SM fields are localized to 3-brane
    - Gravity's "apparent" weakness is due to the extra space gravity can travel in
    - Get many KK graviton states



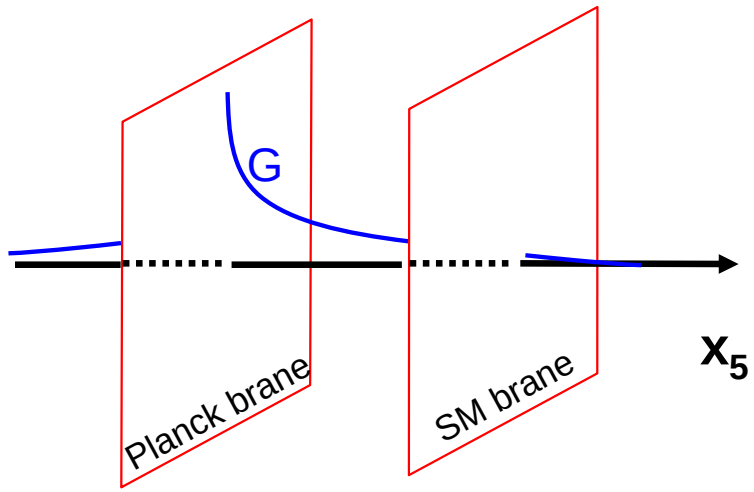


- KK states have very small mass splitting (1 keV - 0.1 GeV)

Introduction

- **More Extra Dimensions:**
  - **Randall-Sundrum (RS ED)**
    - **One extra dimension**
    - **Warped metric damps gravities effects on the SM brane**

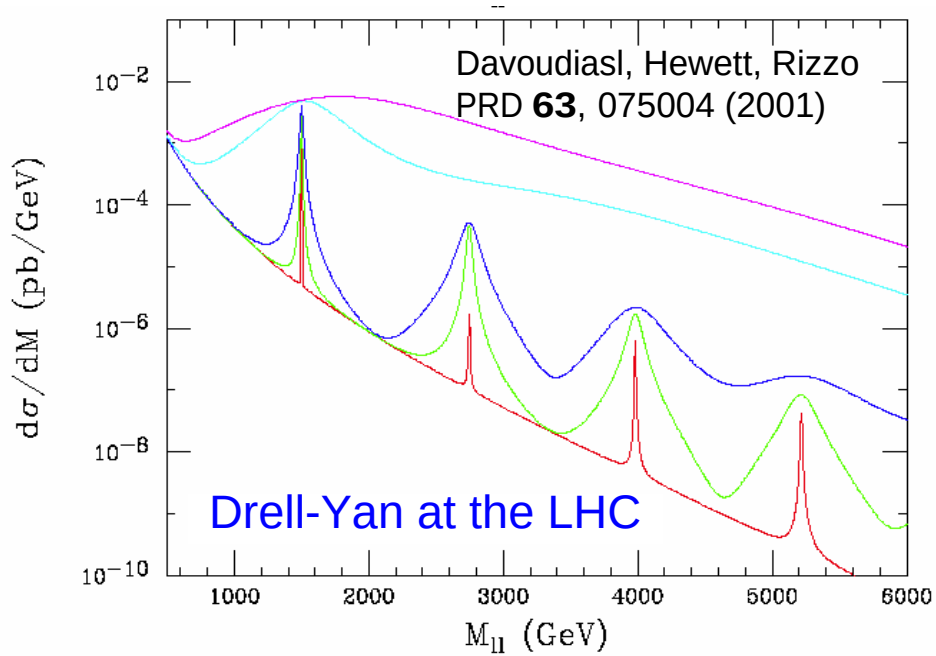
$$ds^2 = e^{-2\sigma(\phi)}\eta_{\mu\nu}dx^\mu dx^\nu - r_c^2 d\phi^2$$
$$\sigma(\phi) = kr_c|\phi|$$



- **Coupling determined by**

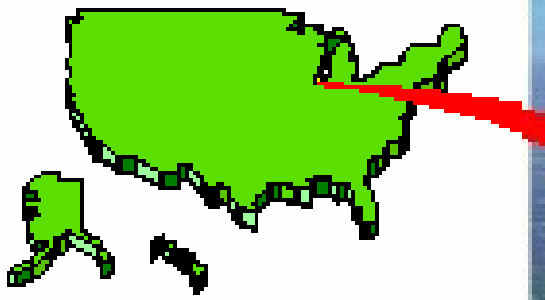
$$k/\overline{M}_{Pl}$$

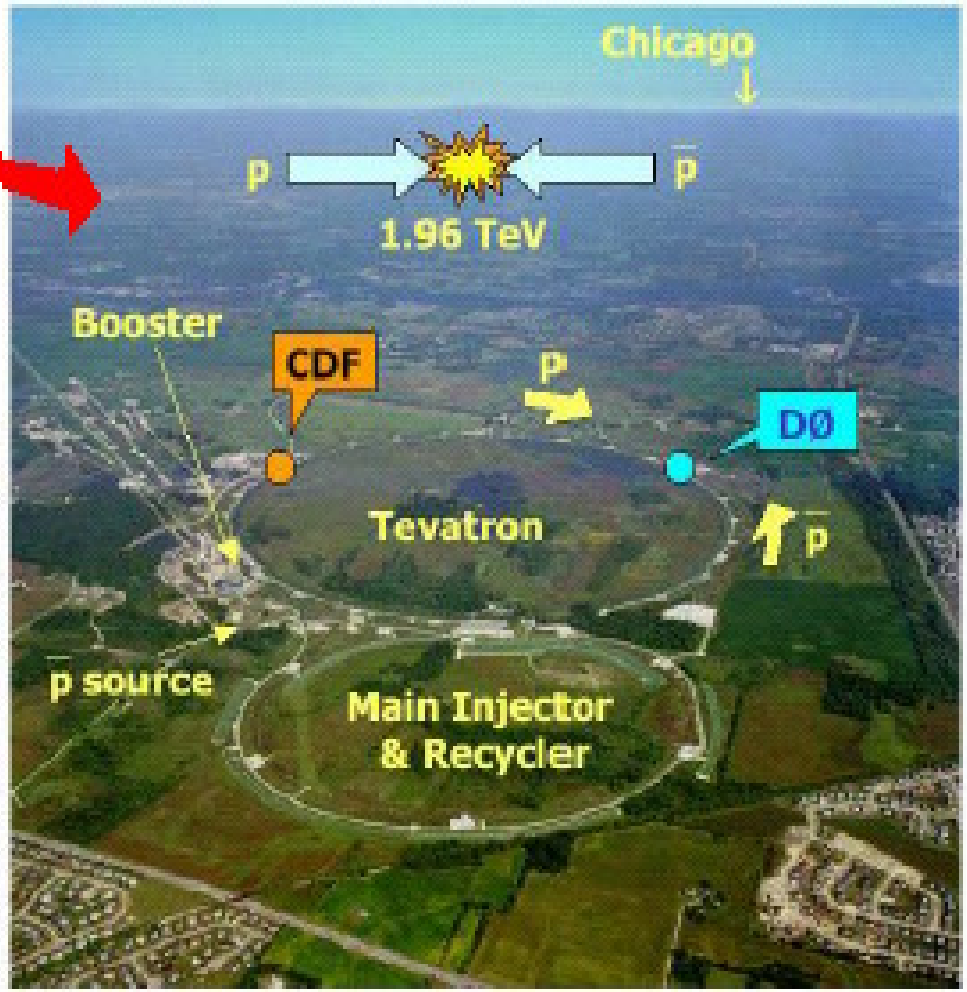
- **Again KK modes of the graviton yield interesting behavior**
- **Repeating resonances**



The Tevatron and DØ

Fermilab's Tevatron Accelerator

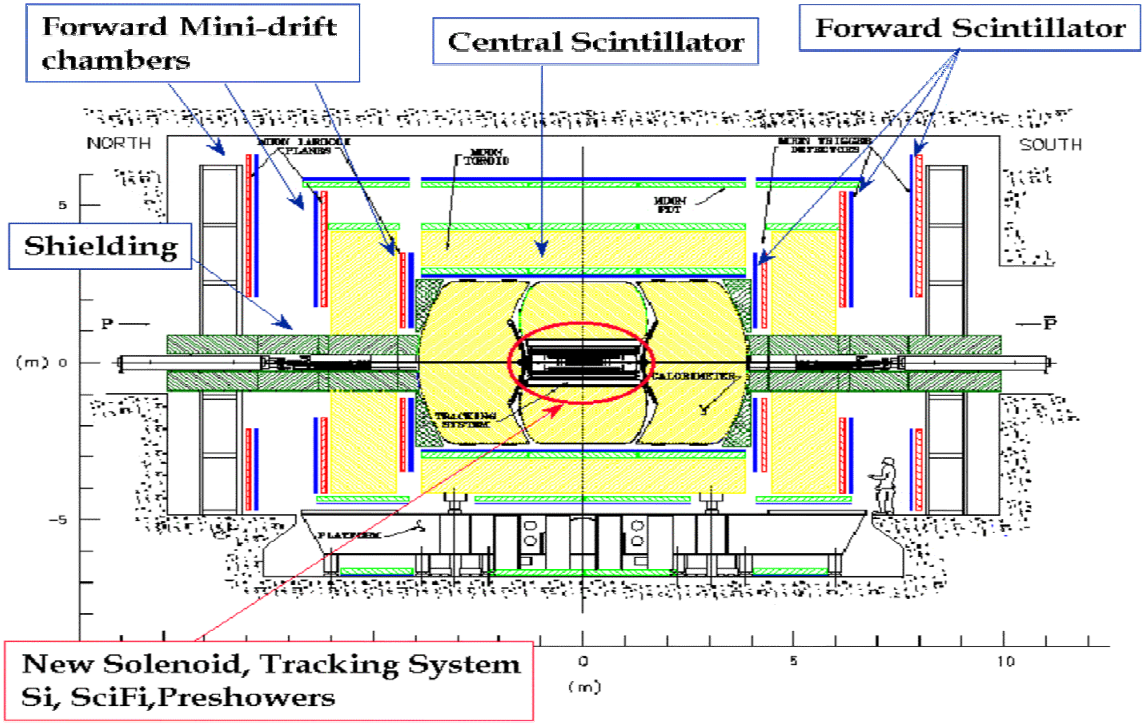


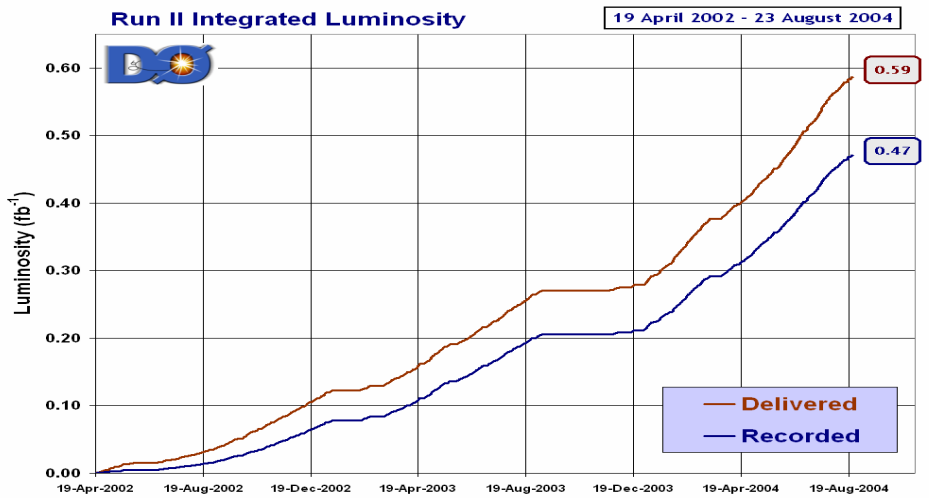


Run II: Proton antiproton collisions started in 2001 at $\sqrt{s}$ = 1.96 TeV

The Tevatron and DØ

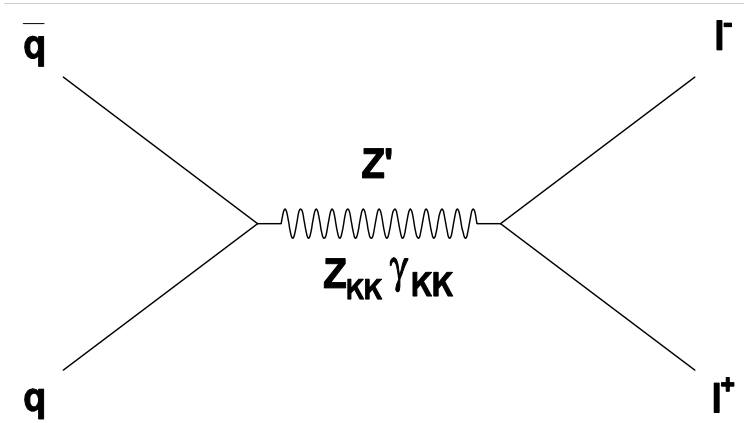
- **The DØ Detector**
  - **Jets**
    - **Calorimeter**
    - **Coverage: $|\eta| < 4$**
  - **Electrons and photons**
    - **EM calorimeter**
    - **Tracking system**
    - **Coverage: $|\eta| < 3$**
  - **Muons**
    - **Tracking system**
    - **Muon system**
    - **Coverage: $|\eta| < 2$**
  - **Missing Energy**
    - **Calorimeter corrected for muons and electrons**
  - **Luminosity used for the following studies is 200-250 pb^{-1}**



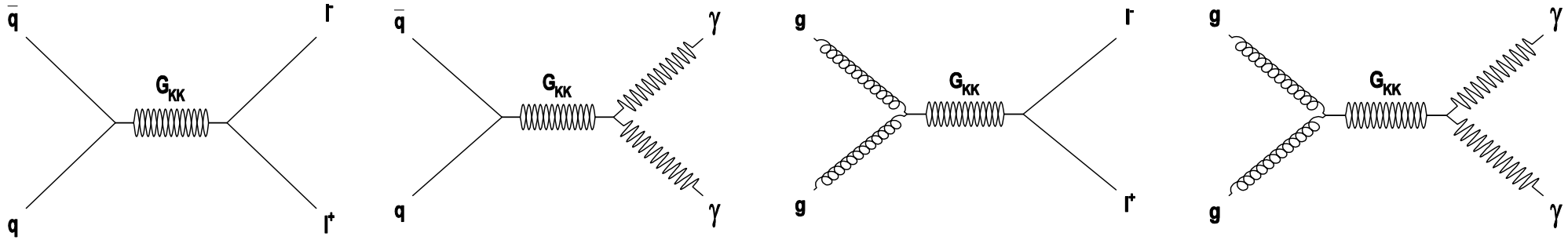


Signals at the Tevatron

- **Diagrams for Z' and TeV^{-1} EDs:**



- **Diagrams for LEDs and RS EDs:**



- **Note: graviton couples to boson final states (i.e. photons, …)**
- **Final state objects tend to have very high momentums**

Signals at the Tevatron

Physics	Final States Explored
Z'	Dielectron and Dimuon
TeV^{-1} EDs	Dielectron
LEDs	Dielectron + Diphoton and Dimuon (Also direct graviton production: see Patrice Verdier's talk Tuesday 8:45 am)
RS EDs	Dielectron + Diphoton

- **In general look for deviations in the high mass (M > 200 GeV) Drell-Yan spectrum**
- **For Z' and RS EDs:**
  - **Signals will be resonances ("bump hunting")**
- **For LEDs and TeV^{-1} EDs:**
  - **Look for general deformations of the spectrum**
  - **Enhancements or destructive interference effects**

Dielectron and DiEM Selections

DiEM and dielectron data selections:

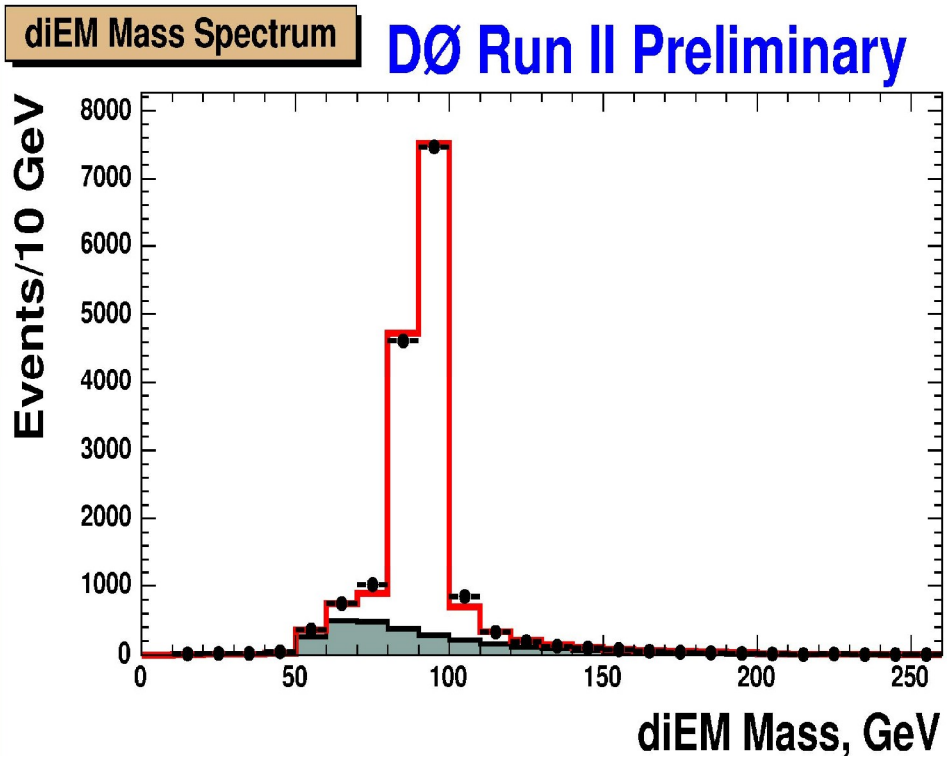
- **Define diEM = two electromagnetic objects in the calorimeter (*e* or γ)**
- **Select 2 EM objects (shower shapes, EM fraction, …)**
- **E_T > 25 GeV**
- **$|\eta_d| < 2.5$**
- **18,118 events in final diEM data set**
- **Dielectron selections:**
  - **diEM + matched track**
  - **15,602 in final dielectron data set**

Dominant backgrounds:

- **Drell-Yan + Z (Estimated from Monte Carlo)**
- **QCD (Estimated from data)**

Tevatron data from 2002-2003

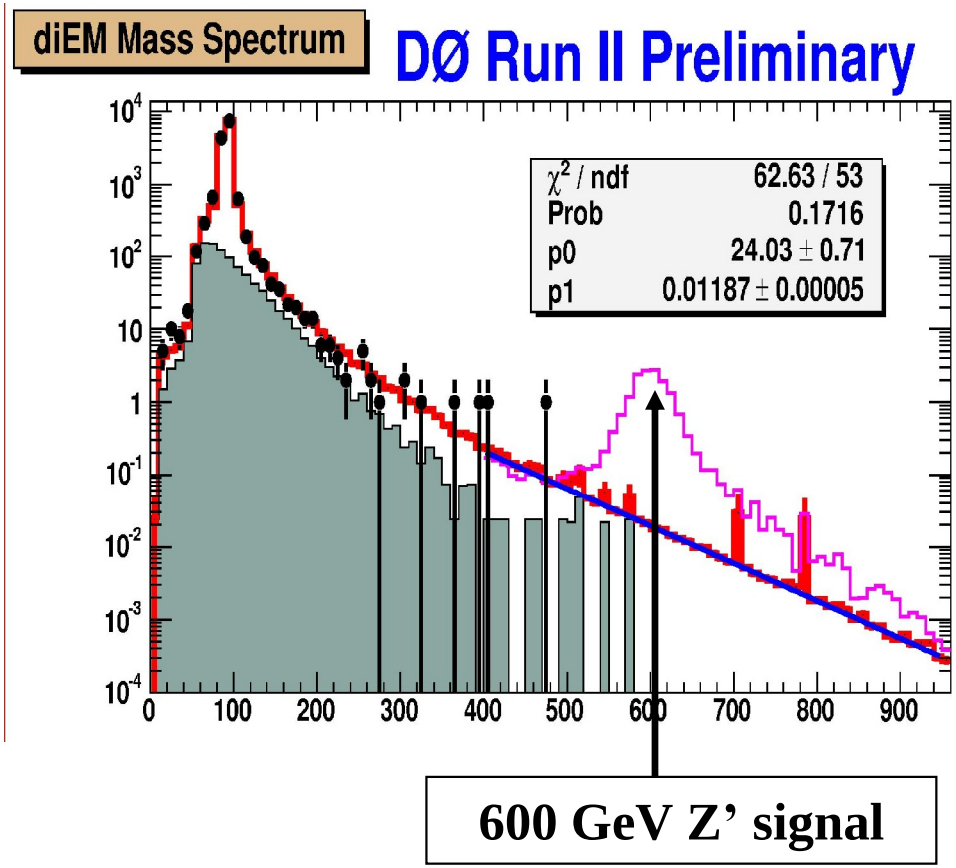
Luminosity ~ 200 pb^{-1}



Dielectron: Z' Bosons

- Use mass distribution with an optimized counting window

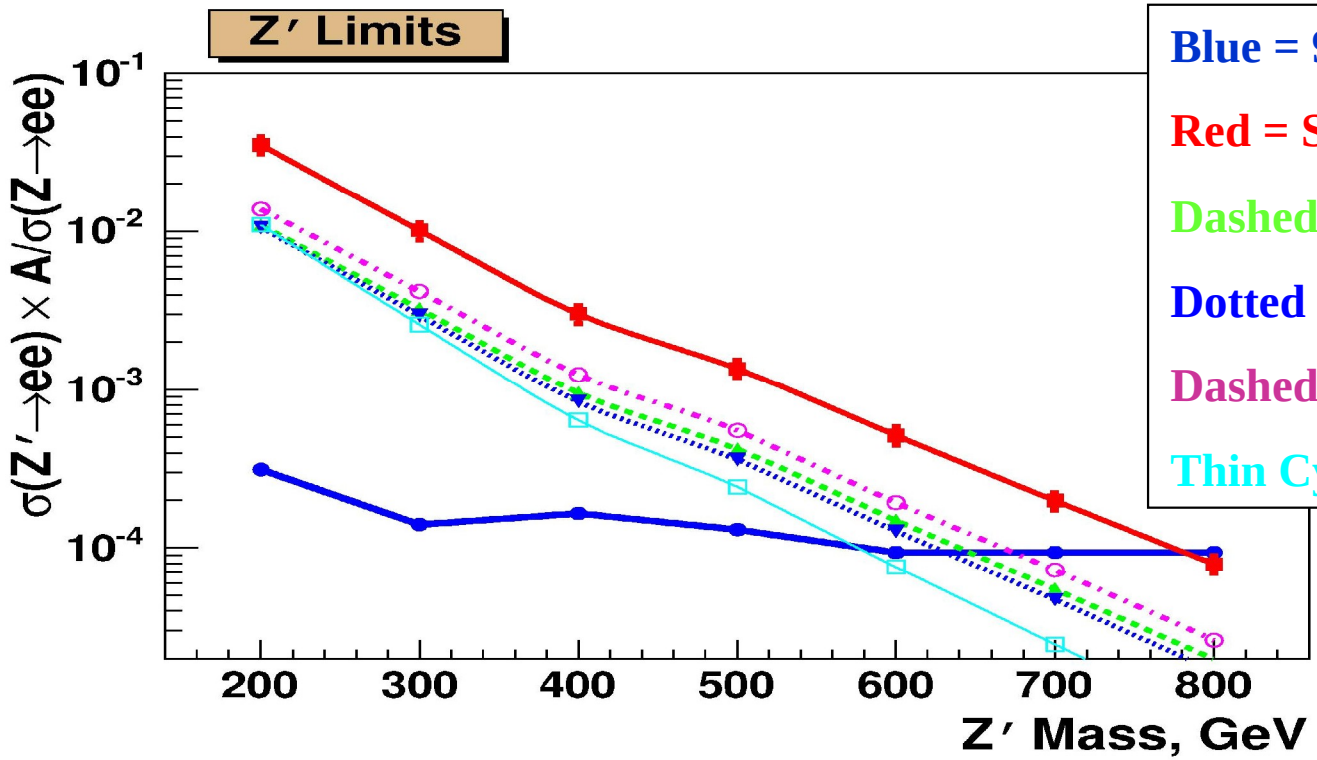
Mass	Window	Data	BK
200	190-210 GeV	32	28.6 ± 2.9
300	280-320 GeV	3	5.9 ± 0.59
400	380-420 GeV	2	1.19 ± 0.12
500	450-550 GeV	1	0.86 ± 0.09
600	540-660 GeV	0	0.31 ± 0.03
700	620-780 GeV	0	0.16 ± 0.02
800	700-900 GeV	0	0.09 ± 0.01



- Completely consistent with no signal!

Dielectron: Z′ Bosons

- **Limit setting: Bayesian approach with systematic uncertainties of 19%**



Blue = 95% C.L. Experimental Limits

Red = SM-like Z'

Dashed Green = E_6 ψ

Dotted Blue = E_6 χ

Dashed Magenta = E_6 η

Thin Cyan = E_6 I

- **SM-like Z' Mass limit = 780 GeV!**
- **CDF (200 pb^{-1} , dielectron) : 750 GeV**
- **Our 780 GeV limit is world's best for a direct search!**

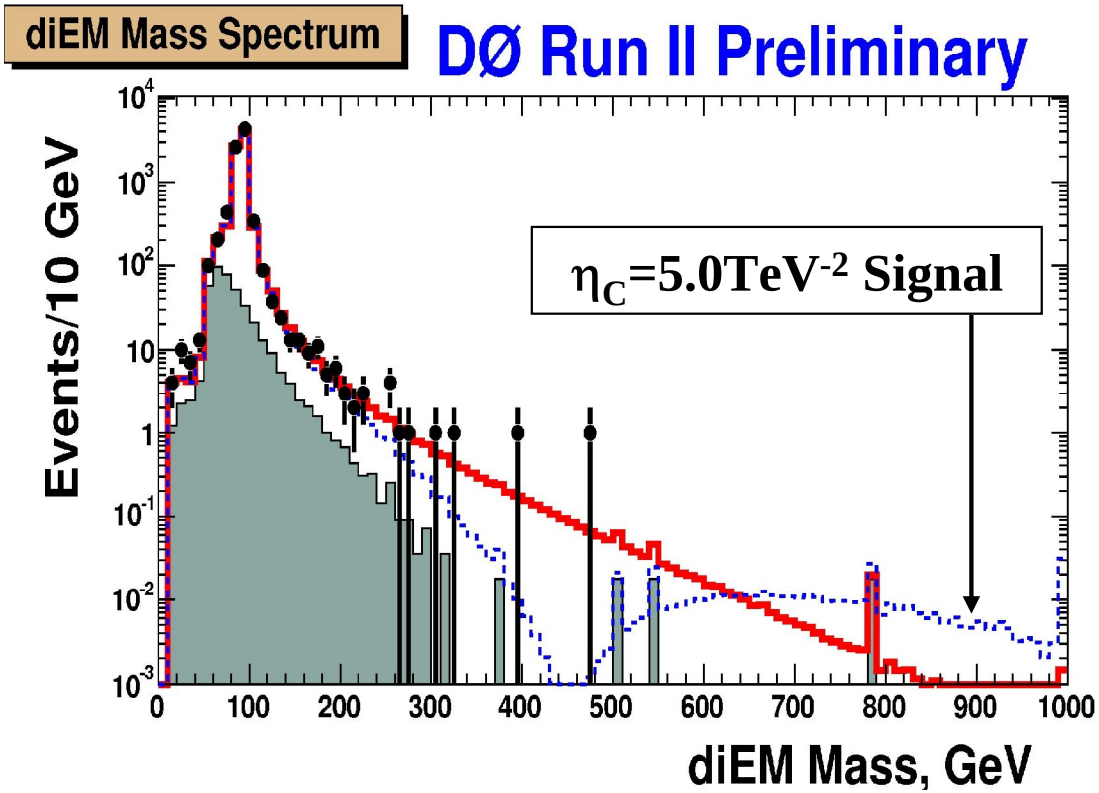
Dielectron: TeV^{-1} ED

- **Fit the 2D distributions**

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

- **Find η_C to be (0.90 ± 0.97) TeV^{-2}**
- **Not strong evidence for TeV^{-1} EDs!**
- **Proceed to find limits:**

Source of systematics	Uncertainty
K-factor	10%
Choice of p.d.f	5%
E_T dependence on ε	5%
MC to Data normalization	2%
Total	12%



- **$\eta_{95\%}$ = 2.63 TeV^{-2} (Bayesian)**

$$\eta_C = \frac{\pi^2}{3M_C^2}$$

- **M_C > 1.12 TeV**

Dielectron: TeV^{-1} ED

- **Fit the 2D distributions**

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

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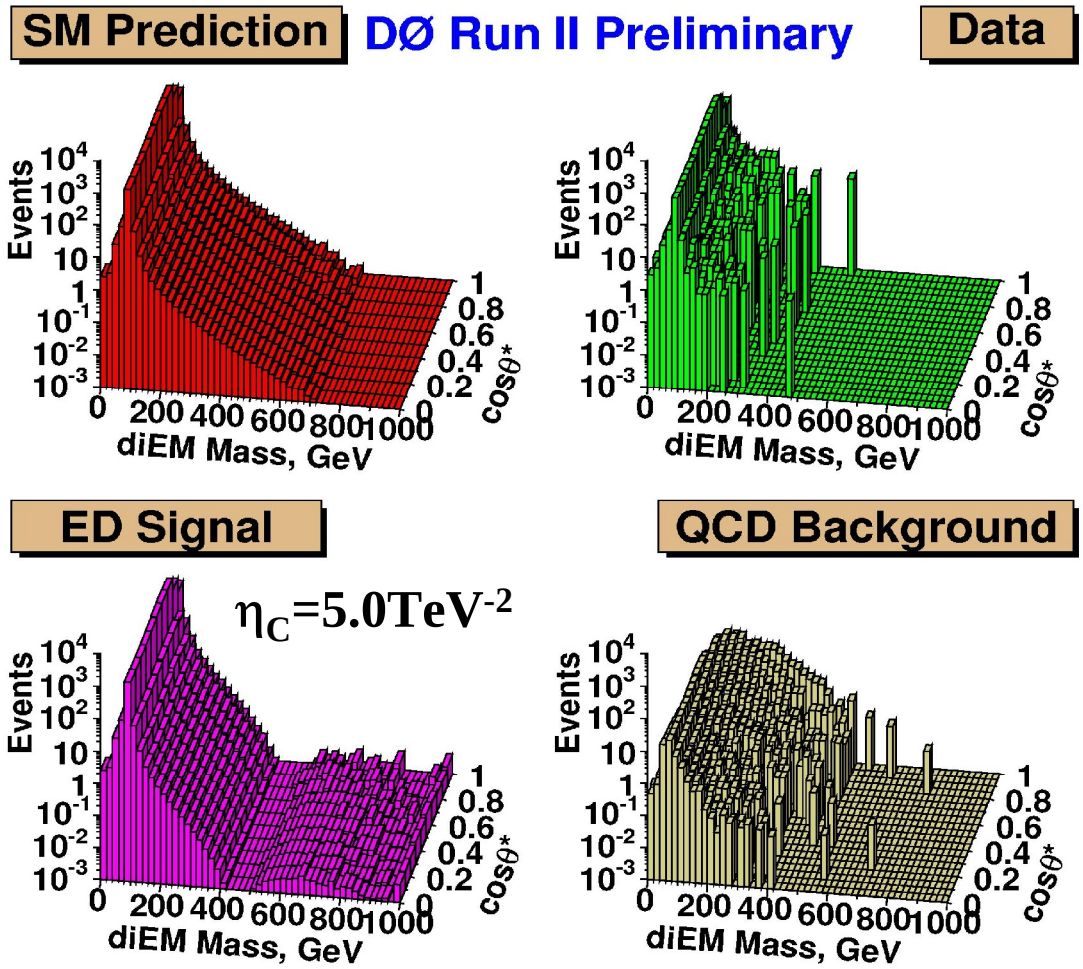


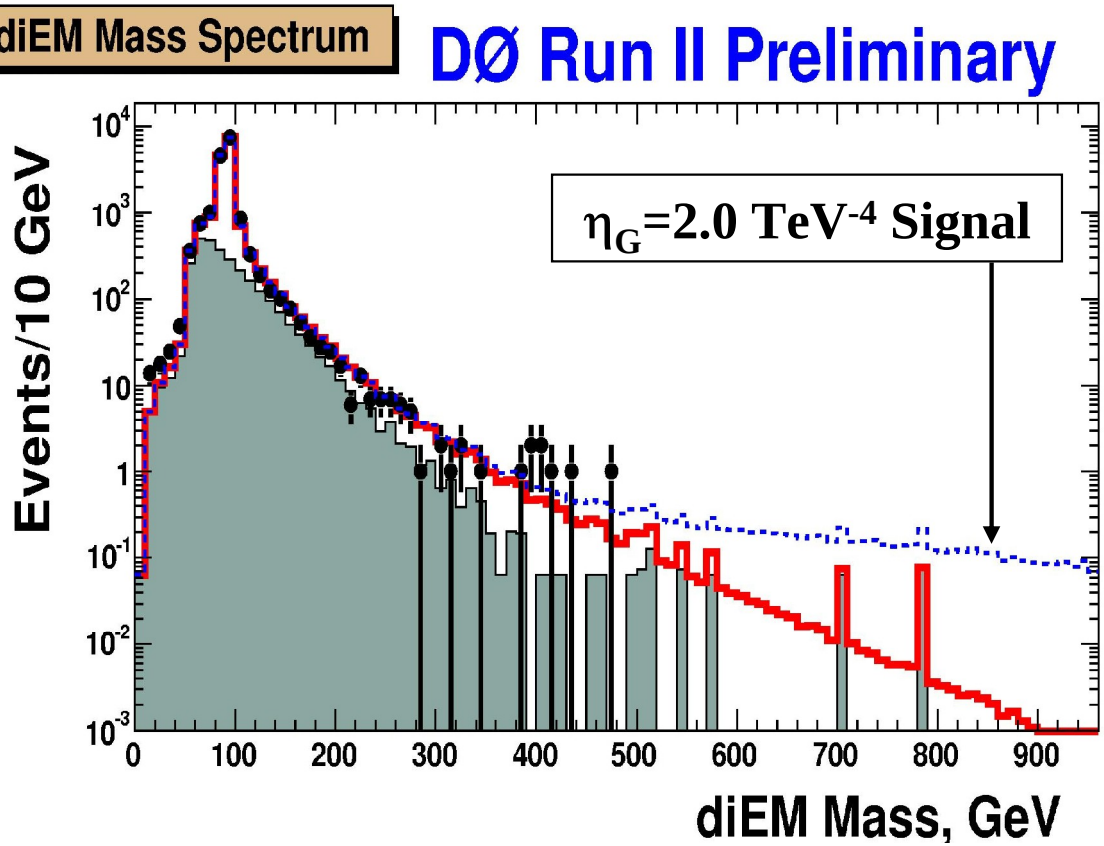
DiEM: LED

- Fit the 2D distributions

$$\sigma = \sigma_{SM} + \eta_G \sigma_4 + \eta_G^{\,2} \sigma_8$$

- Find η_G to be (0.00 + 0.12) TeV^{-4}
- No evidence for LEDs!
- Proceed to find limits:

Source of systematics	Uncertainty
K-factor	10%
Choice of p.d.f	5%
E_T dependence on ε	5%
MC to Data normalization	2%
Total	12%



- $\eta_{95\%}$ = 0.24 TeV^{-4} (Bayesian)
- M_S > 1.43 TeV

$$\eta_G = \frac{1}{M_S^4}(GRW)$$

- This is the world's best limit to date!

DiEM: LED

- Fit the 2D distributions

$$\sigma = \sigma_{SM} + \eta_G \sigma_4 + \eta_G^{\,2} \sigma_8$$

- Find η_G to be (0.00 + 0.12) TeV^{-4}
- No evidence for LEDs!
- Proceed to find limits:

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Choice of p.d.f	5%
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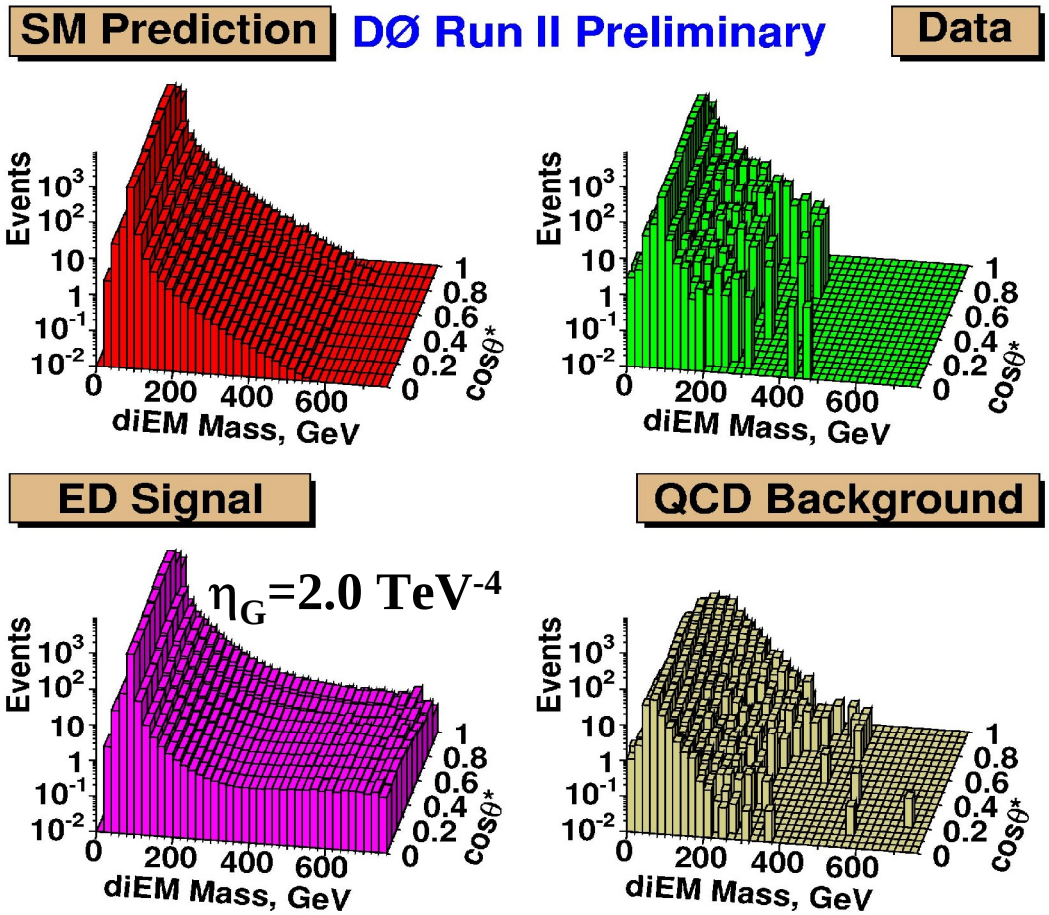
Total	12%



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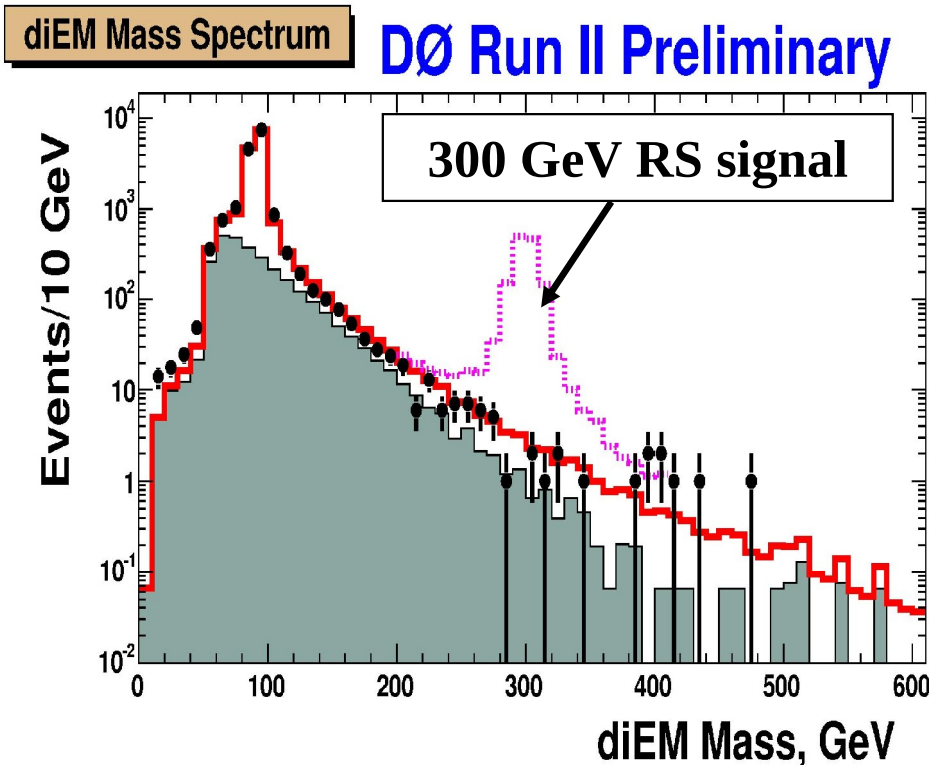
CDF (200 pb^{-1}, dielectron): 1.1 TeV

DiEM: RS ED

- Use mass distribution with an optimized counting window

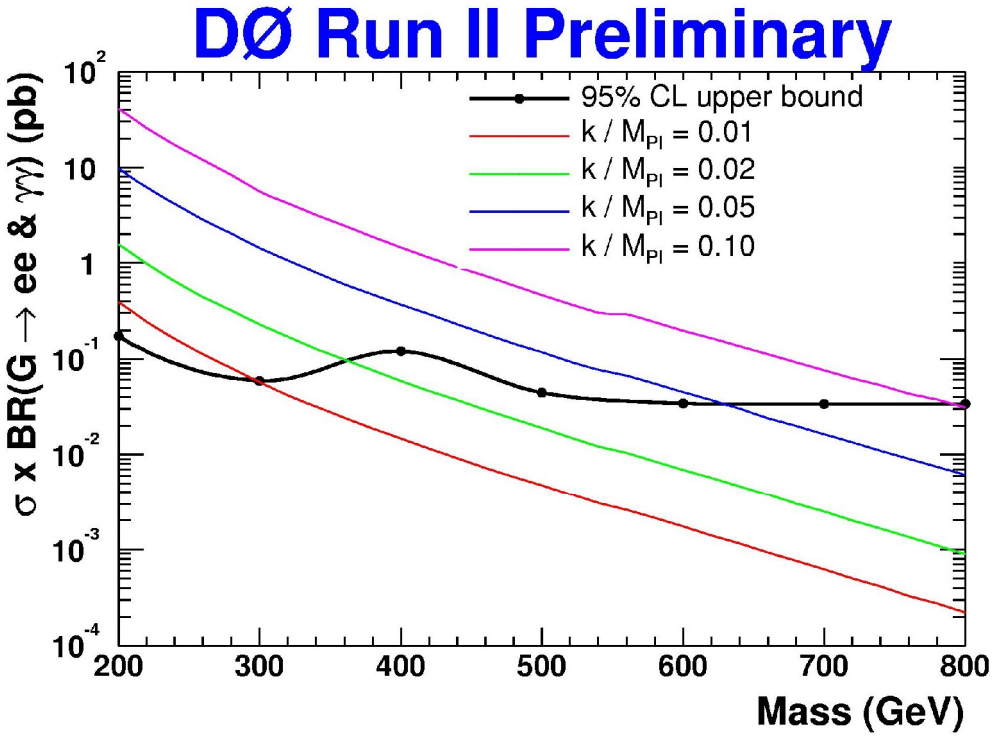
Mass	Window	Data	BK
200	190-210 GeV	49	65.1 ± 6.5
300	280-320 GeV	6	12.7 ± 1.3
400	380-420 GeV	6	2.43 ± 0.24
500	450-550 GeV	1	1.84 ± 0.18
600	540-660 GeV	0	0.64 ± 0.06
700	620-780 GeV	0	0.36 ± 0.04
800	700-900 GeV	0	0.23 ± 0.02

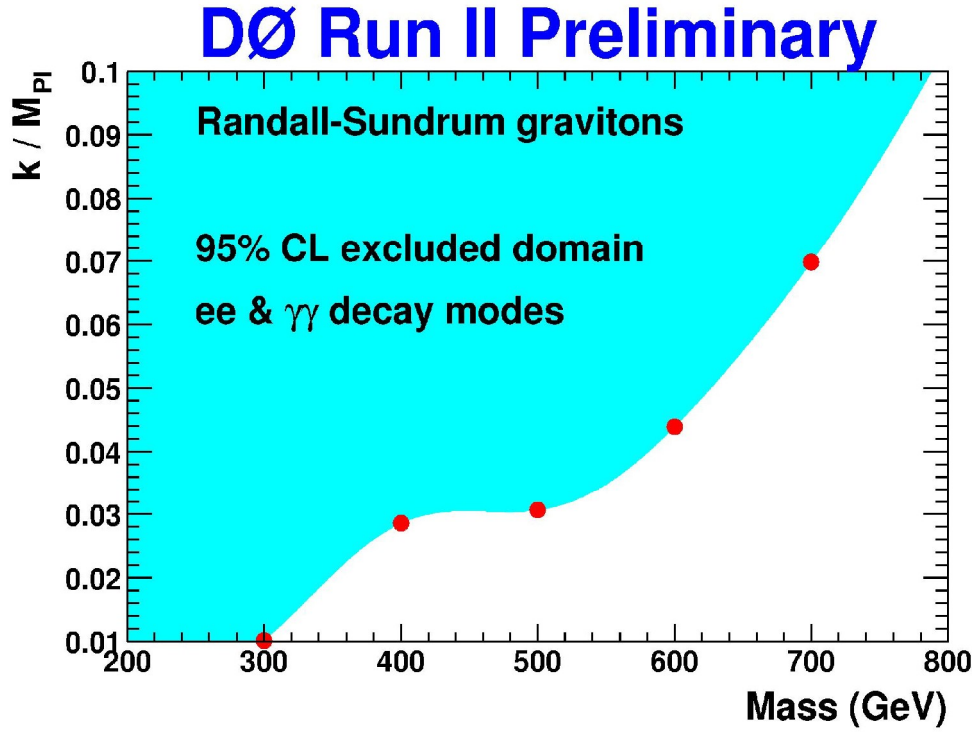


- Completely consistent with no signal!

DiEM: RS ED

- **Limit setting: Bayesian approach with systematic uncertainties of 16%**





- **For k/M_{Pl} = 0.1 mass limit on the RS graviton is 785 GeV!**
- **CDF (200 pb^{-1} , diphoton) : 675 GeV**
- **Our 785 GeV limit is world's best to date!**

Dimuon Selections

Dimuon data selection:

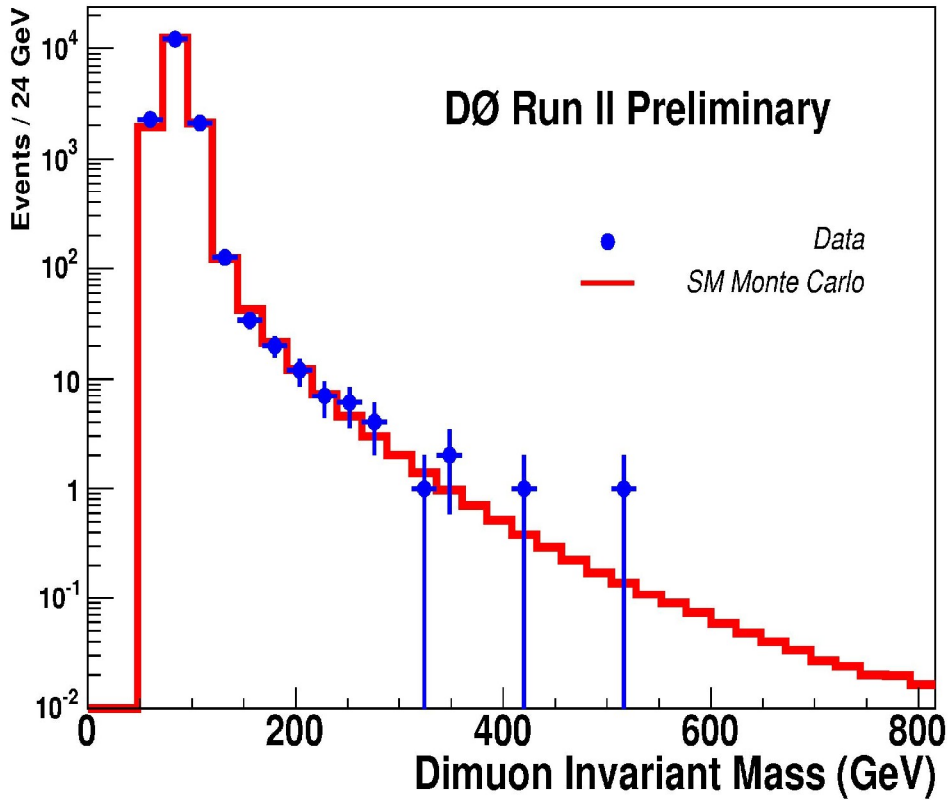
- **At least 2 muons with matched central tracks of p_T > 15 GeV**
- **Data and track quality cuts**
- **Invariant mass > 50 Gev**
- **Cosmic vetoes**
- **Isolation requirements**
- **Final sample contains 16,796 events**

Dominant Backgrounds:

- **Drell-Yan+Z (Modeled by Monte Carlo)**
- **B decays (Eliminated by isolation selections)**
- **Cosmic ray muons (Eliminated by cosmic vetoes)**

Tevatron data from 2002-mid 2004

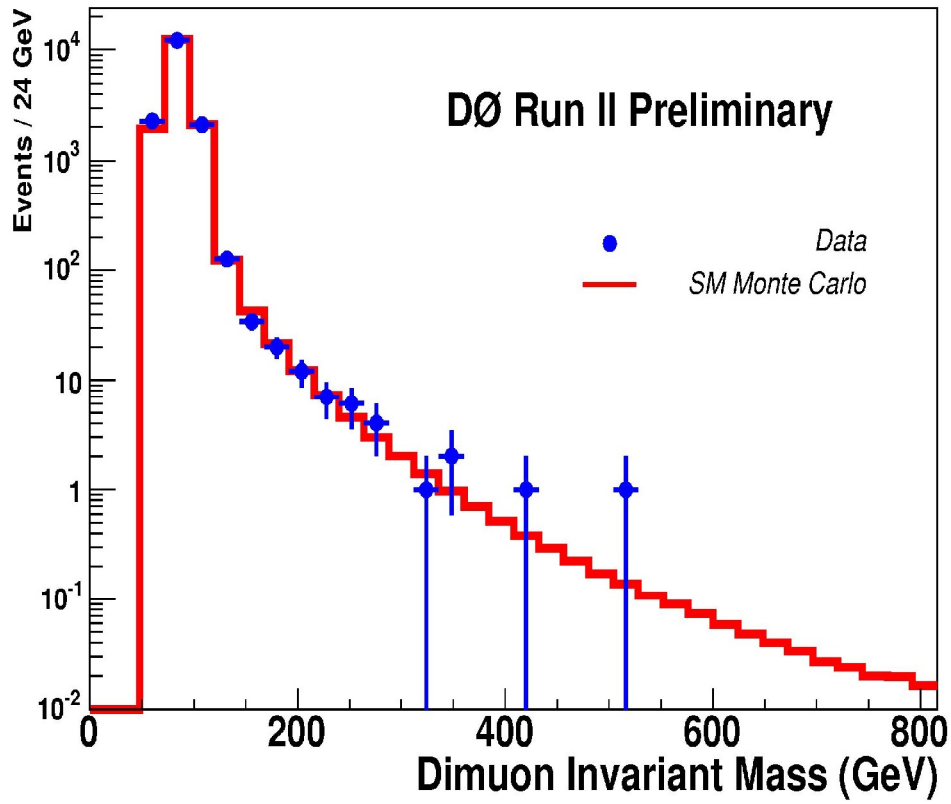
Luminosity ~ 250 pb^{-1}



Dimuon: Z′ Bosons

- Use mass distribution with an optimized counting window

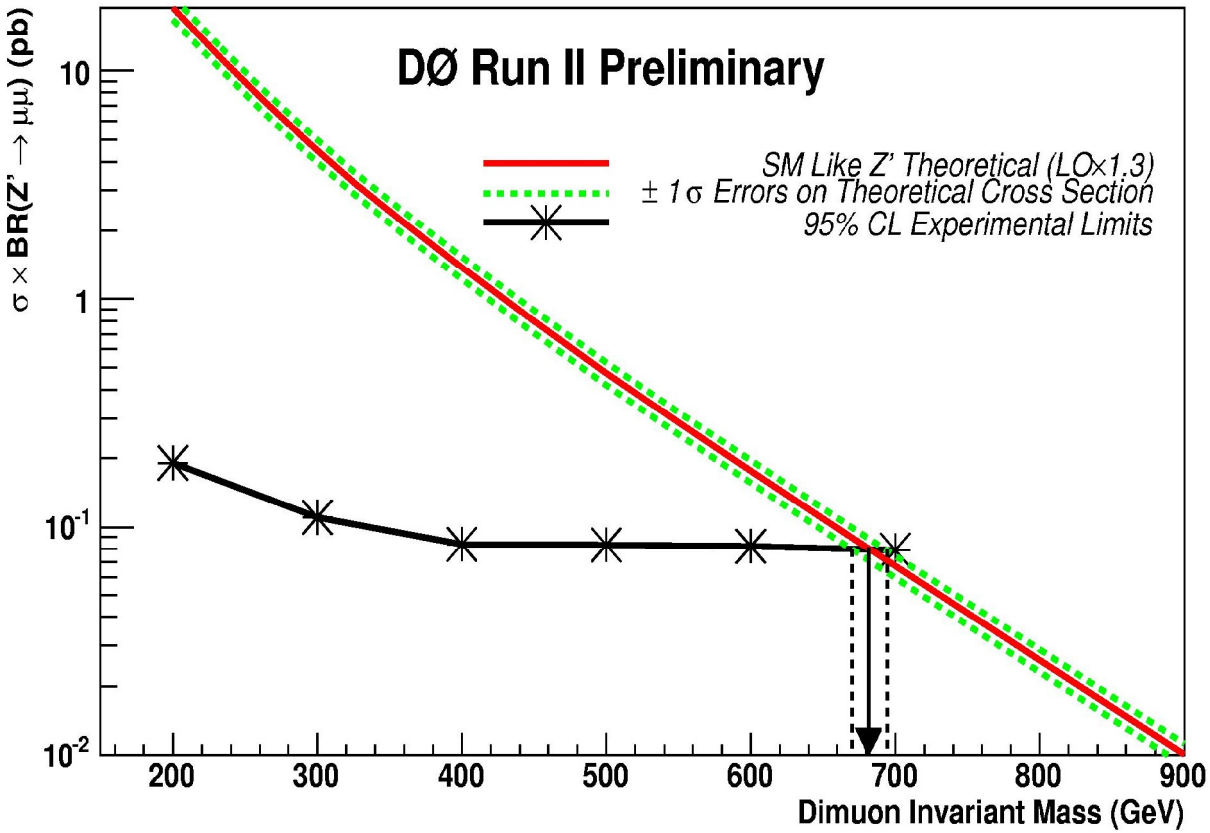
Mass	Window	Data	BK
200	151-1500 GeV	76	91.4 ± 11.9
300	202-1500 GeV	29	30.7 ± 4.0
400	226-1500 GeV	19	20.2 ± 2.6
500	230-1500 GeV	18	18.3 ± 2.4
600	232-1500 GeV	18	18.3 ± 2.4
700	240-1500 GeV	16	15.8 ± 2.1



- Completely consistent with no signal!

Dimuon: Z' Bosons

- **Limit setting: Bayesian approach with systematic uncertainties of 15%**



- **SM-like Z' Mass limit = 680 GeV!**
- **CDF (200 pb^{-1}, dimuon): 735 GeV**

Dimuon: LED

- **Fit the 2D distributions**

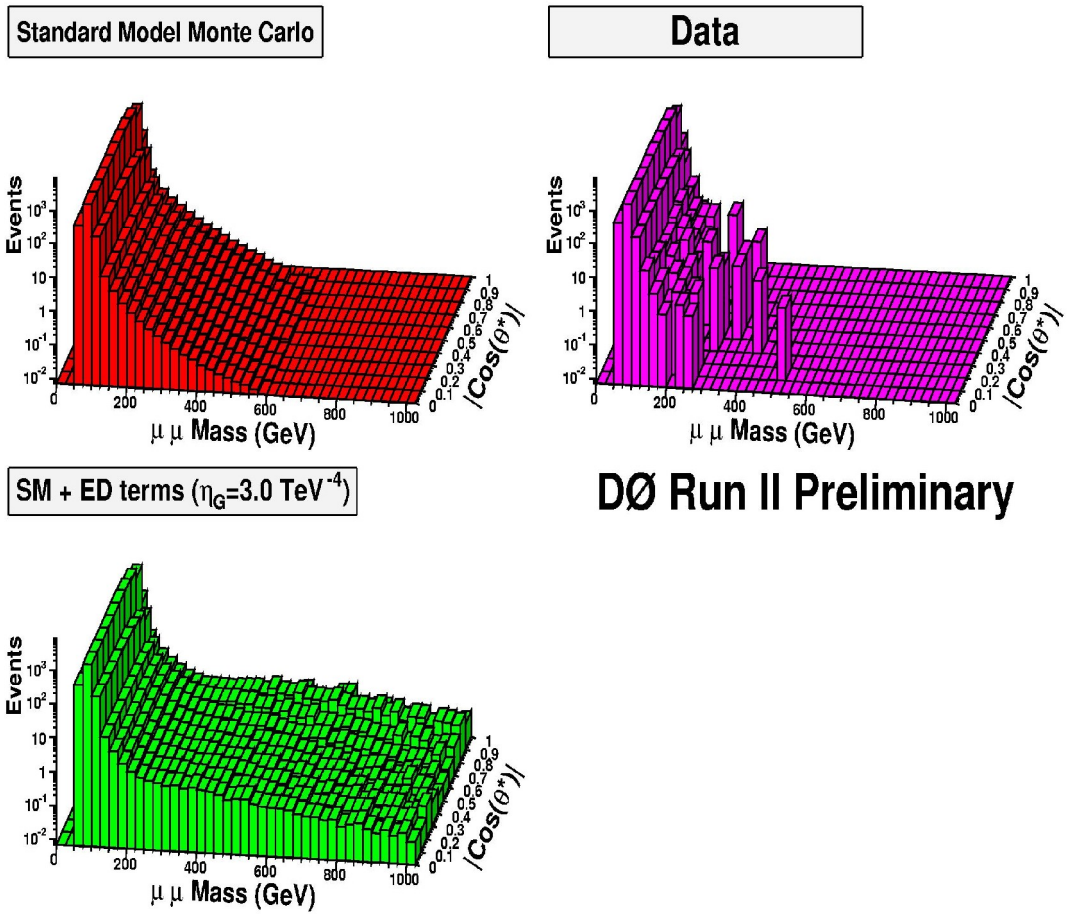
$$\sigma = \sigma_{SM} + \eta_G \sigma_4 + \eta_G^{\,2} \sigma_8$$

- **Find η_G to be (0.00 + 0.32) TeV^{-4}**
- **No evidence for LEDs!**
- **Proceed to find limits:**

Source of systematics	Uncertainty
K-factor	10%
Choice of p.d.f	5%
p_T dependence on ε	5%
Choice of MC p_T smearing	4%
MC to Data normalization	1%
Total	13%

- **$\eta_{95\%}$ = 0.72 TeV^{-4} (Bayesian)**
- **M_S > 1.1 TeV**

$$\eta_G = \frac{1}{M_S^4}(GRW)$$



Summary

- Presented searches for various new physics (Z', LEDs, RS EDs, TeV^{-1} EDs)
- After analyzing 200-250 pb^{-1} of Run II Tevatron data we find no evidence for new "heavy" physics
- Interpret the null results in terms of various limits
- Several of which are the best limits to date

95% CL Limits	Physics	Channel
780 GeV	SM-like Z' Lower Mass Limit	dielectron
1.12 TeV	Lower limit on M_C	dielectron
1.43 TeV (GRW)	Lower limit on M_S	diEM
785 GeV	k/M_{Pl}=0.1 RS Graviton Lower Mass Limit	diEM
680 GeV	SM-like Z' Lower Mass Limit	μμ
1.1 TeV (GRW)	Lower limit on M_S	μμ

- Stay tuned, we still have a lot more data to come!