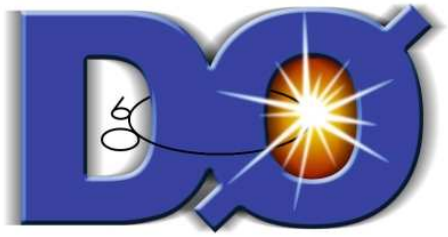


Search for Exotic Particles and Extra Dimensions at the Tevatron Collider

Sharon Hagopian
Florida State University
for the DØ and CDF Collaborations

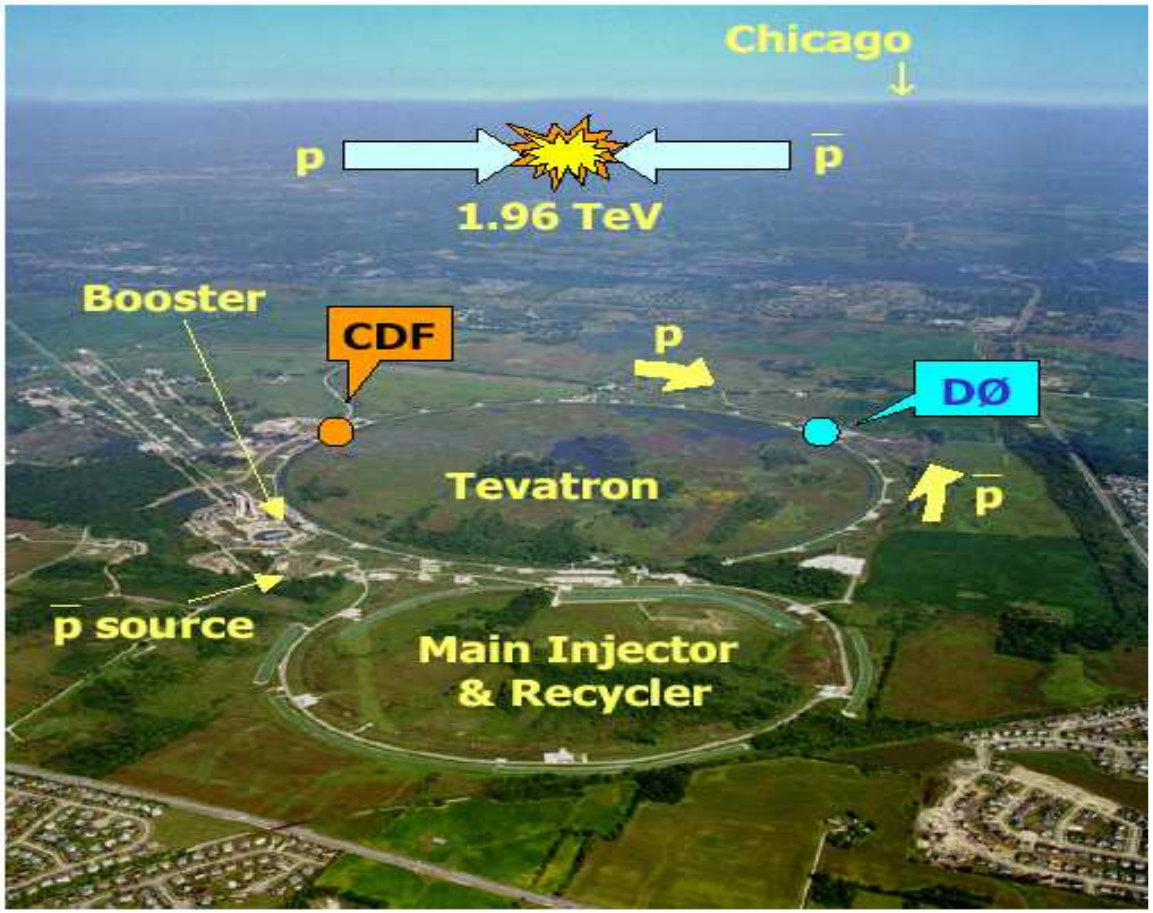
Outline

- Tevatron and the Detectors
- Data Samples
- Backgrounds
- Search for Leptoquarks
- Search for High Mass Particles
- Search for Evidence of Extra Dimensions

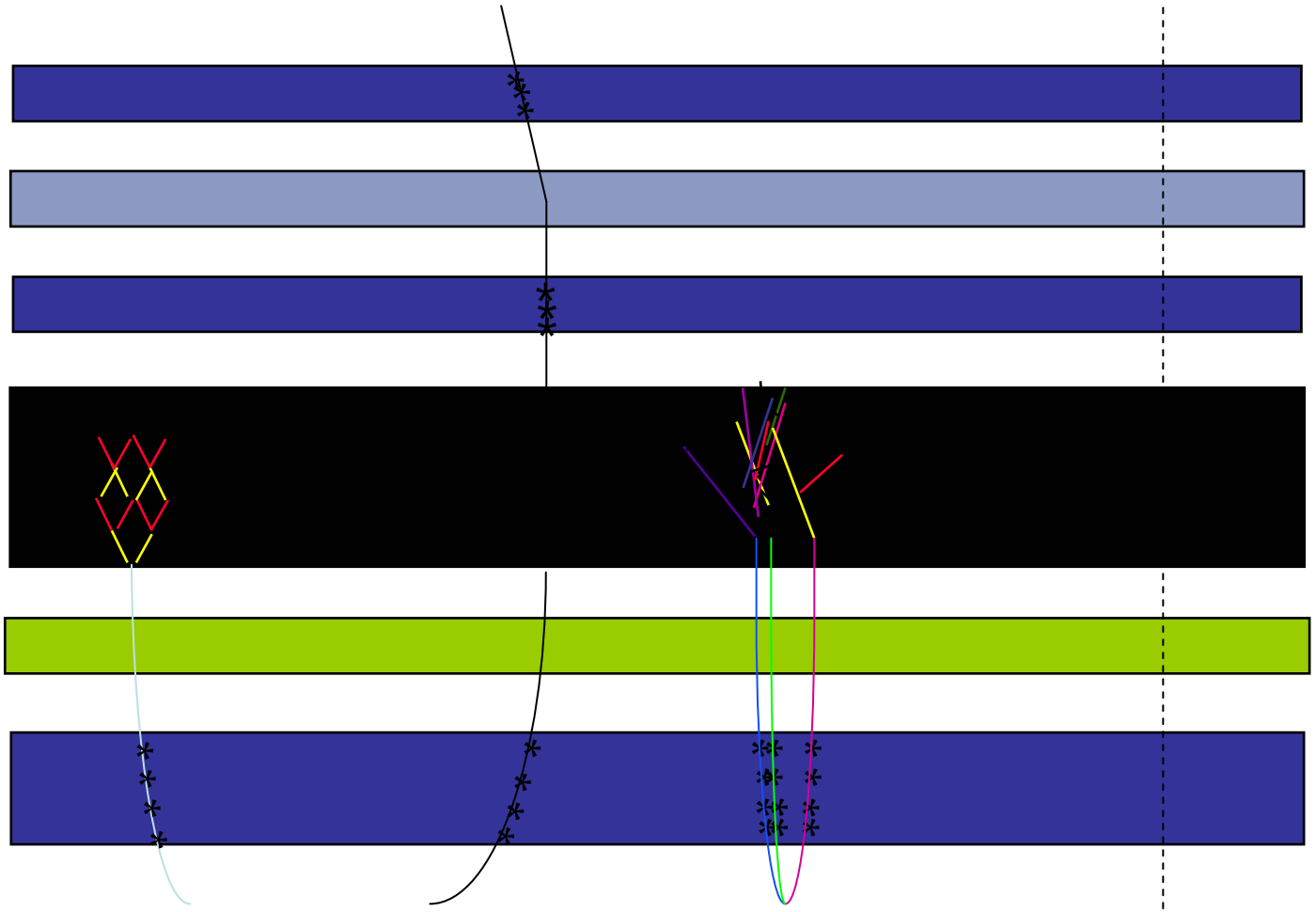
Fermilab Tevatron

- Proton-antiproton collider
- Highest energy Accelerator
  - 1.96 TeV
  - Analyses here use 200-250 pb^{-1} of data gathered over 1½ years

Great place to look for new physics!

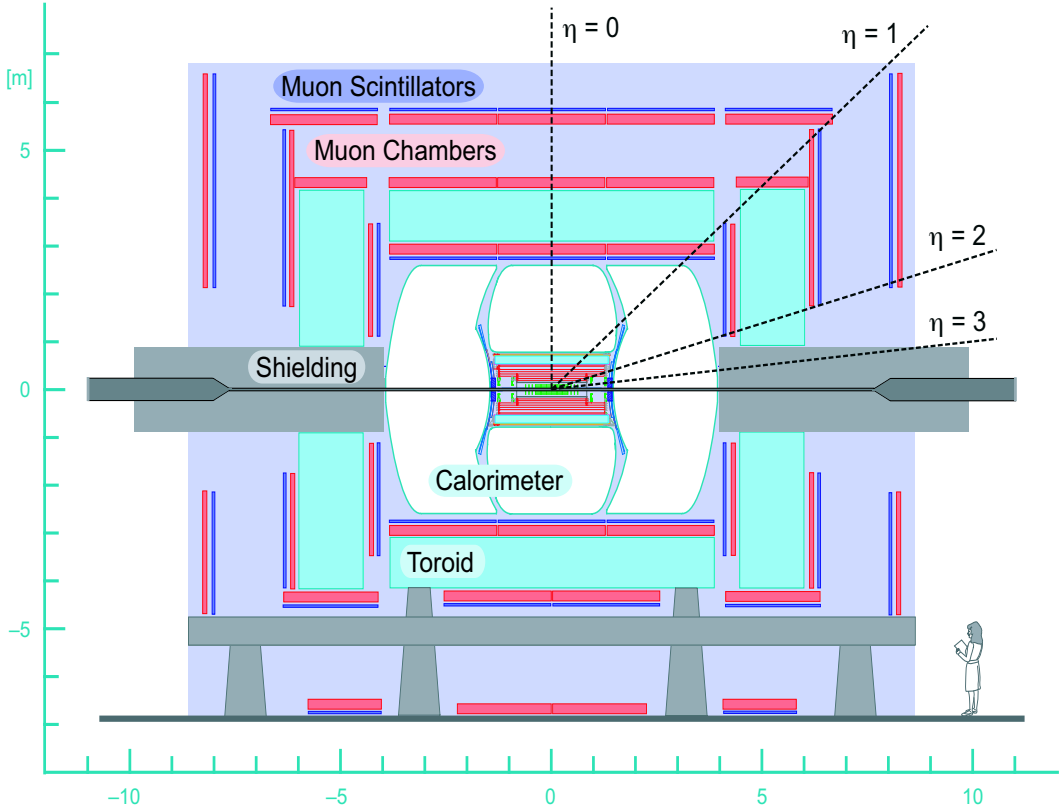


Detector Cartoon

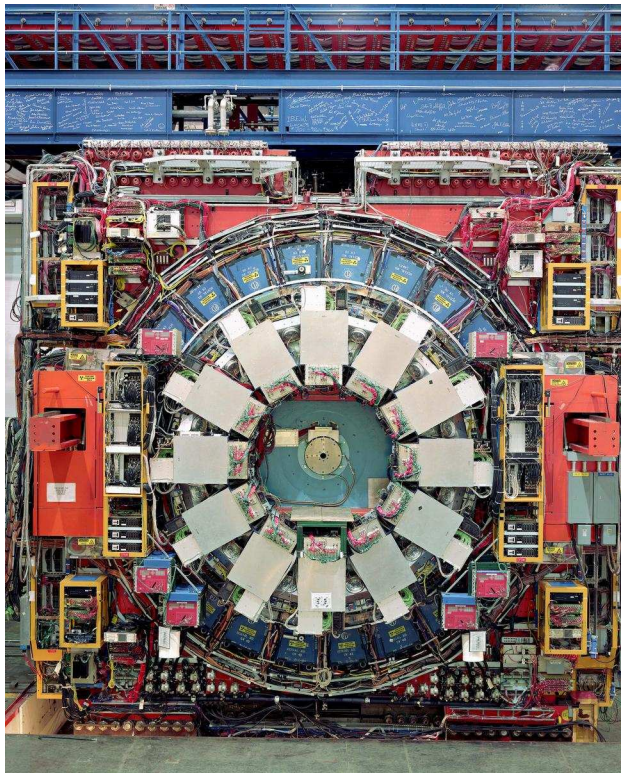


Detectors at the Tevatron

DØ



CDF



Look for particles at large angle to the beam

Measure missing energy in plane transverse to the beam

Method

- To overcome the large multijet background choose events with special characteristics such as electrons or muons in the final state
- Select specific samples to perform searches
- Understand standard model backgrounds in order to search for new physics
- Make interpretations using various models

Data Samples

- Dielectron

  Two high p_T electrons (one central)
- Diphoton

  Same as dielectron, but no associated tracks
- Electron+jets – one central high p_T electron

  + two or more high E_T jets
- Dimuon

  Two high p_T muons (one central)
- Muon+jets – one central high p_T muon

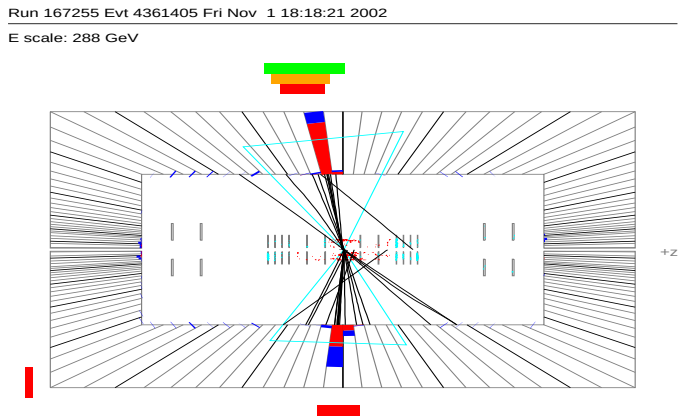
  + two or more high E_T jets

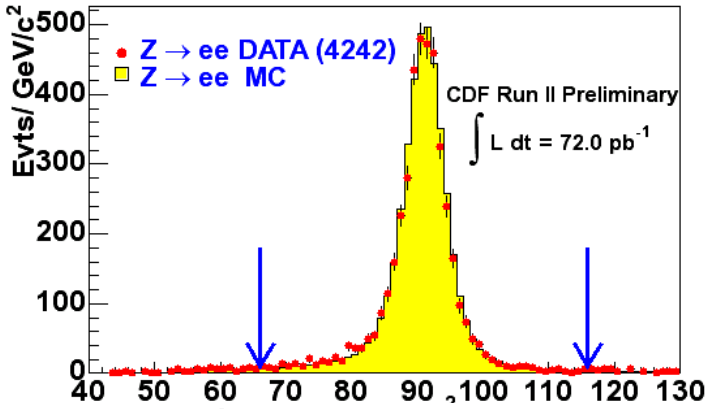
Main Backgrounds

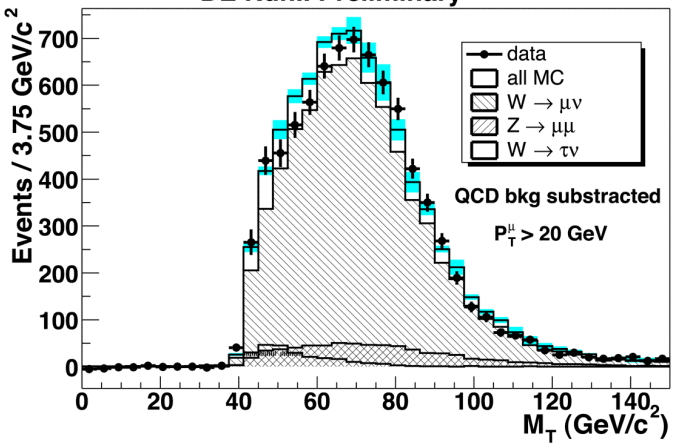
- Multijets produced by strong interactions can have real or fake e, μ

- W and Z production by electroweak interactions. Need to be understood and modeled or measured.

- Drell-Yan dilepton production via intermediate Z/γ^* state







Leptoquark Phenomenology

- Leptoquarks (LQ)
  - fractional electric charge
  - color charge
  - baryon and lepton number
  - can be scalar or vector particles
  - fundamental gauge bosons or composite

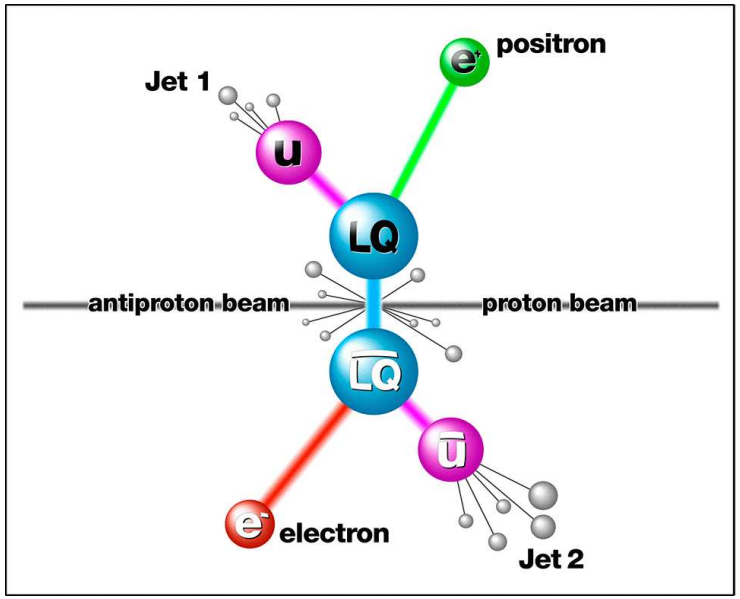
First Generation $\begin{pmatrix} u \\ d \end{pmatrix} \leftrightarrow LQ_1 \leftrightarrow \begin{pmatrix} e \\ \nu_e \end{pmatrix}$

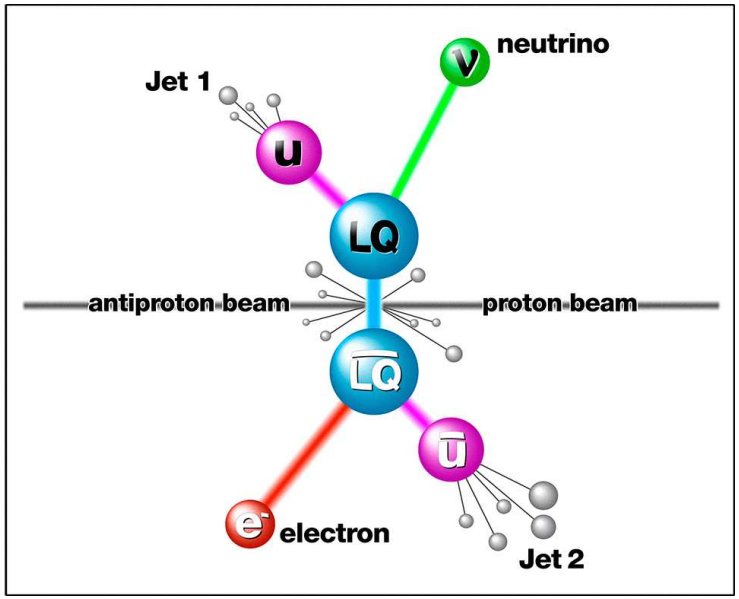
Second Generation $\begin{pmatrix} s \\ c \end{pmatrix} \leftrightarrow LQ_2 \leftrightarrow \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}$

Third Generation $\begin{pmatrix} t \\ b \end{pmatrix} \leftrightarrow LQ_3 \leftrightarrow \begin{pmatrix} \tau \\ \nu_\tau \end{pmatrix}$

Experimental limits on rare decays and flavor changing neutral currents imply that leptoquarks don't mix generations

Leptoquark Pair Production





Production Cross section of LQ pairs know from Strong Interaction Theory

Reconstruct mass of parent LQ from angles and momenta of e or ν and jet

Leptoquark Decays

Parameterized by branching fraction beta into charged lepton:

$\beta = BF(e+q)$

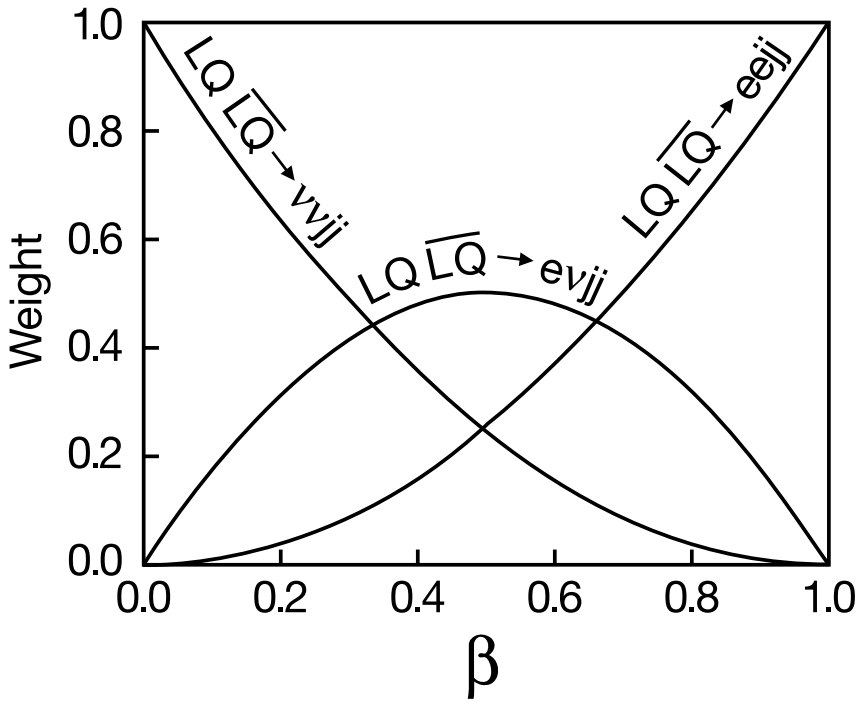
$1-\beta = BF(\nu+q)$

For $\beta=0.5$

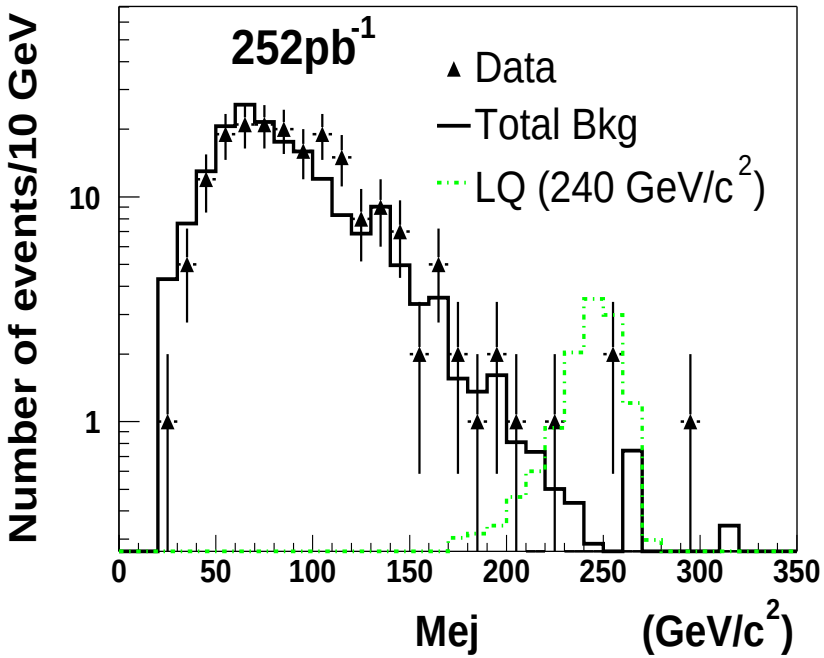
50% evjj

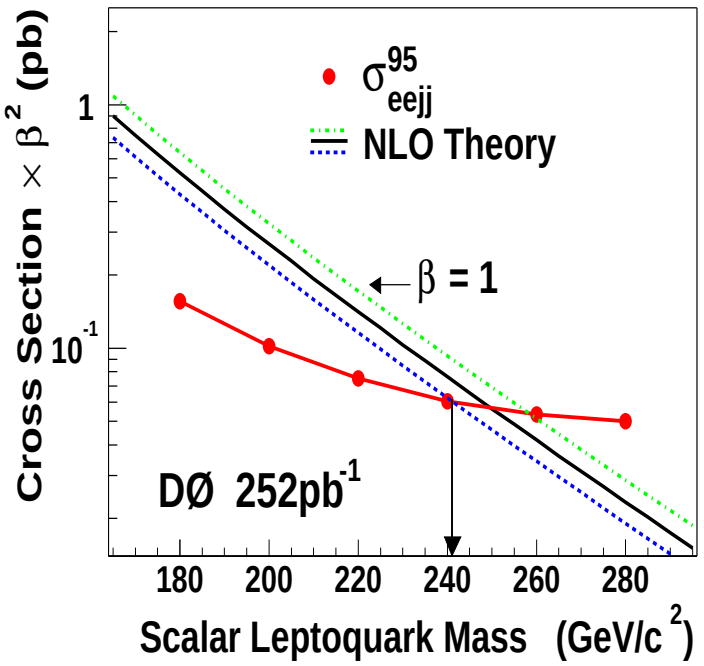
25% eejj

25% vvjj



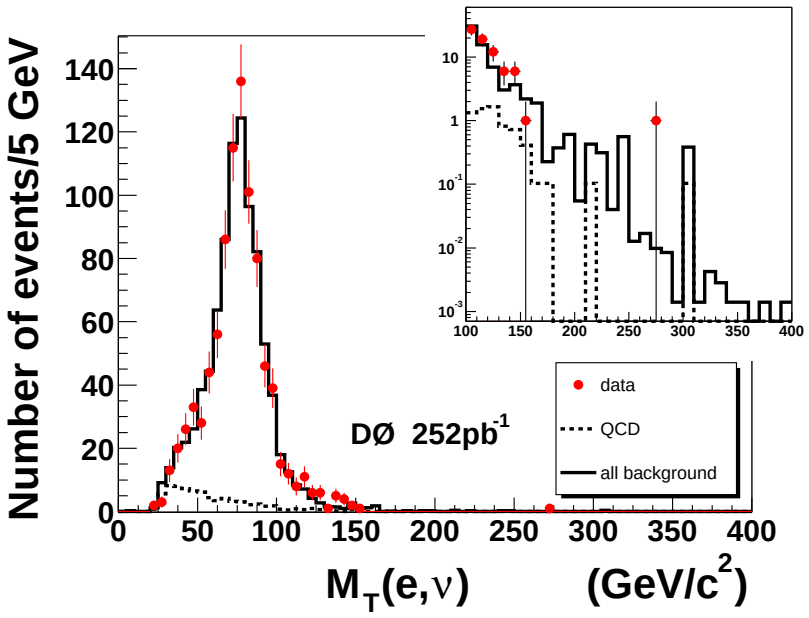
Search for LQ in eejj

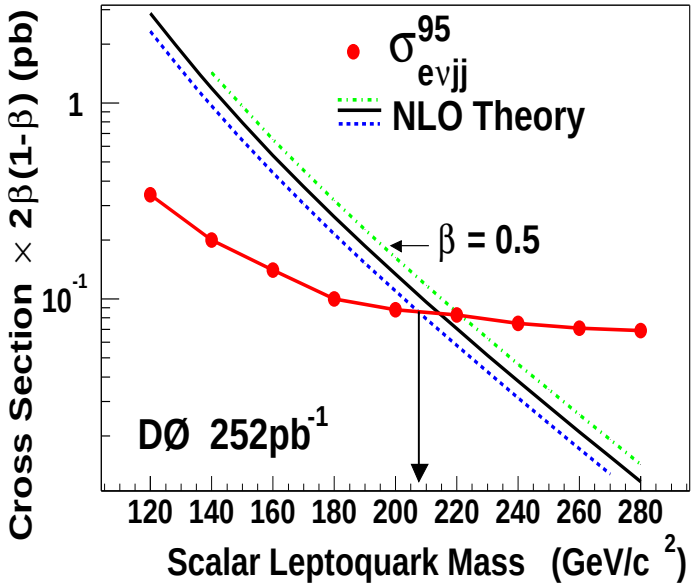




For β=1.0 $M(LQ_1) > 241$ GeV/c^2

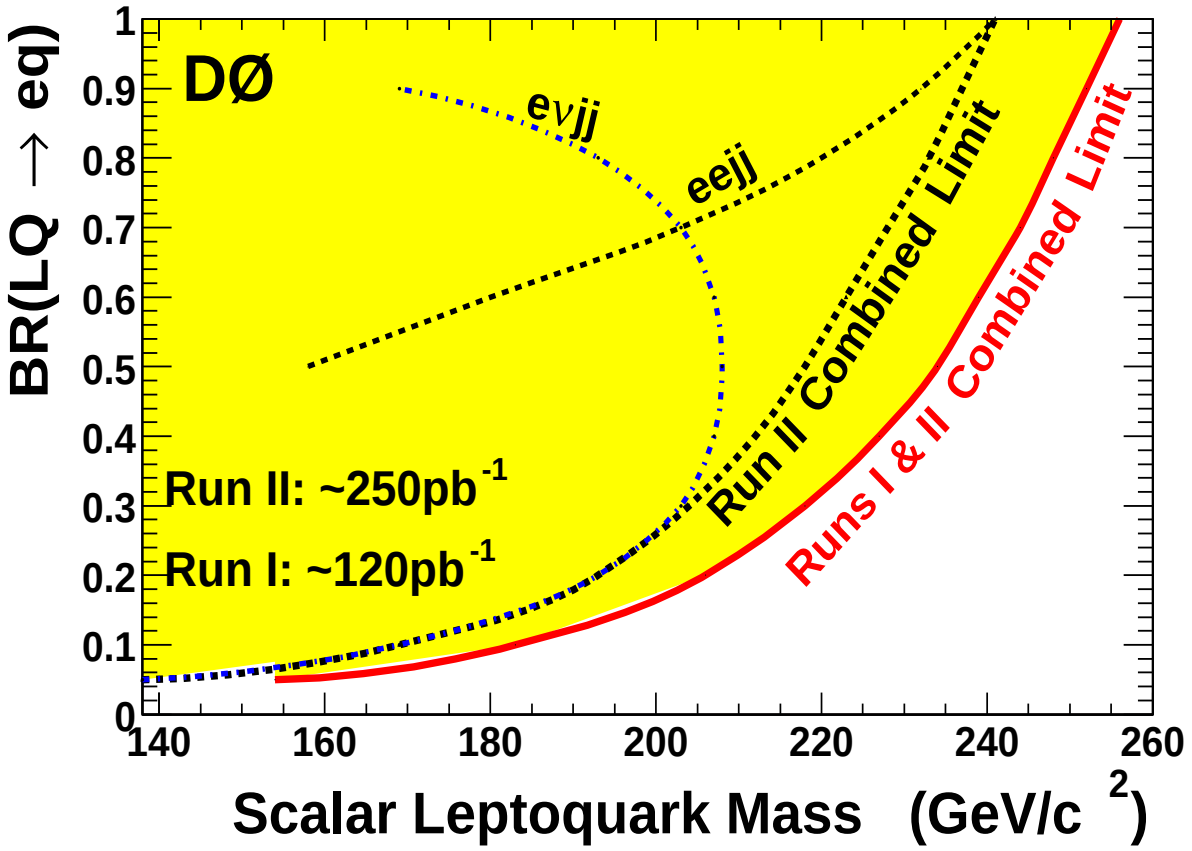
Search for LQ in eνjj





For β=0.5 M(LQ1) > 208 GeV/c^2

LQ1 Mass Exclusion Contour



For β=1.0

DØ Run I & II, MLQ1 > 256 GeV/c^2

CDF Run II, MLQ1 > 235 GeV/c^2

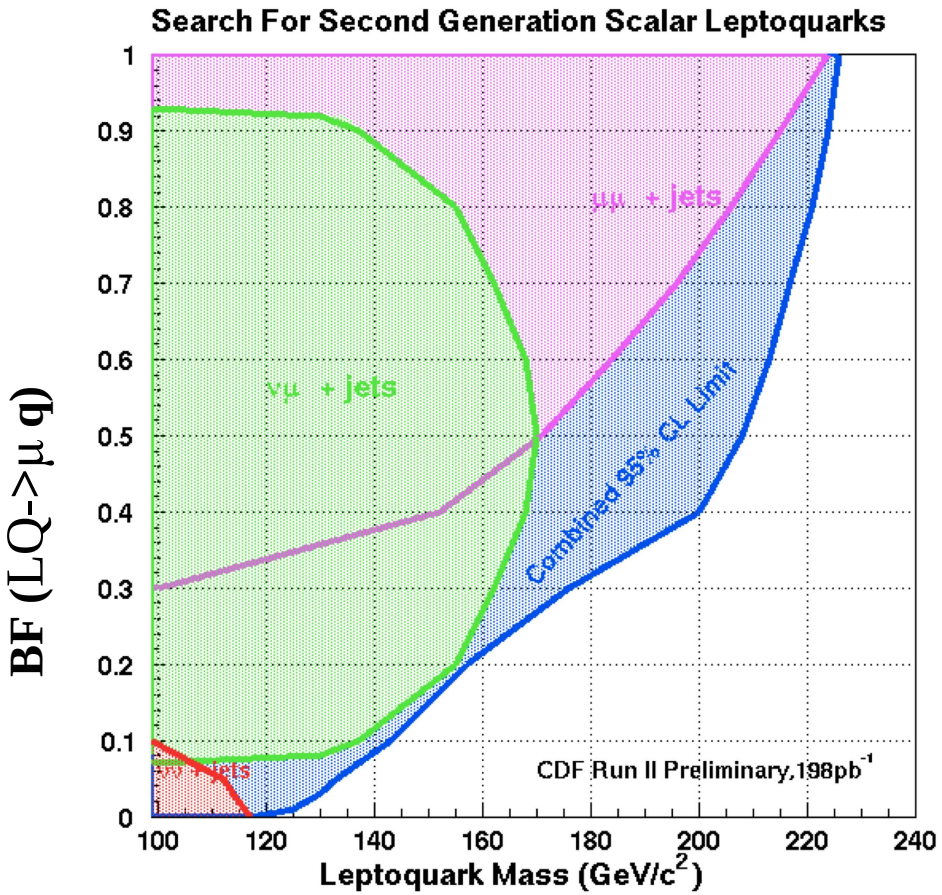
CDF Pair production of 2nd generation leptoquarks

μμjj and μνjj final states

~200 pb^{-1}

β=1.0 $M(LQ_2)$>~225 GeV

β=0.5 $MLQ_2)$>~210 GeV



W´ and Z´ Introduction

- W´ and Z´ are additional heavy vector bosons

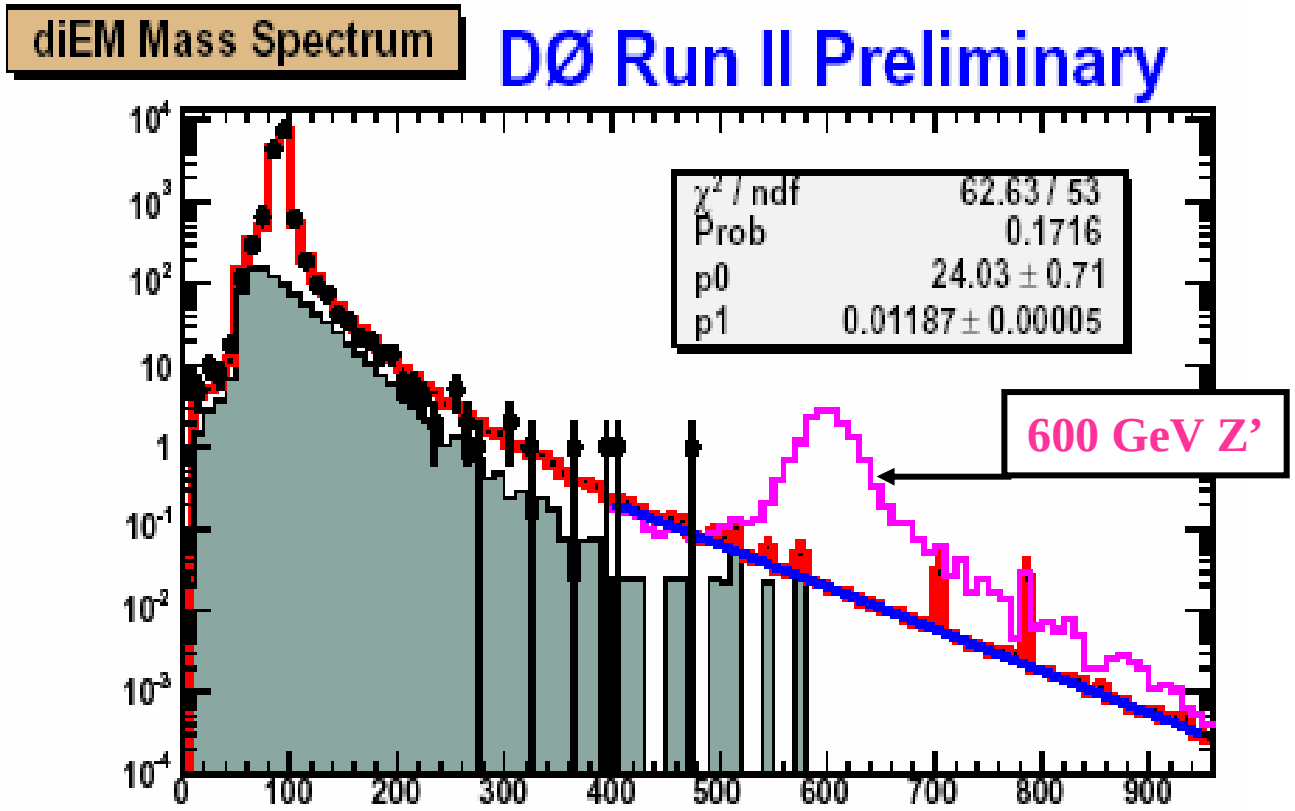
Appear in theories based on extensions of the gauge group

E6 model predicts a Z´

Left-Right symmetric models predict a W´

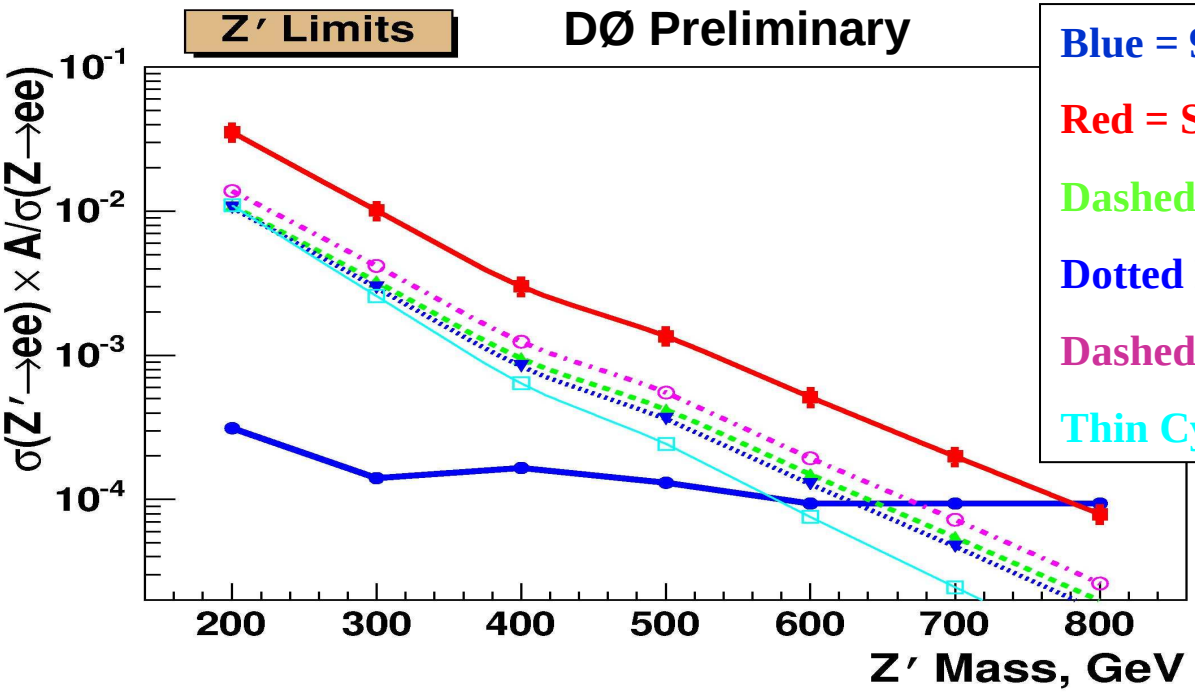
Search for Z´ in ee

Integrated luminosity of 200 pb-1



Dielectron Invariant Mass (GeV/c^2)

Search for Z´ in ee



Blue = 95% C.L. Experimental Limits

Red = SM-like Z'

Dashed Green = E_6 ψ

Dotted Blue = E_6 χ

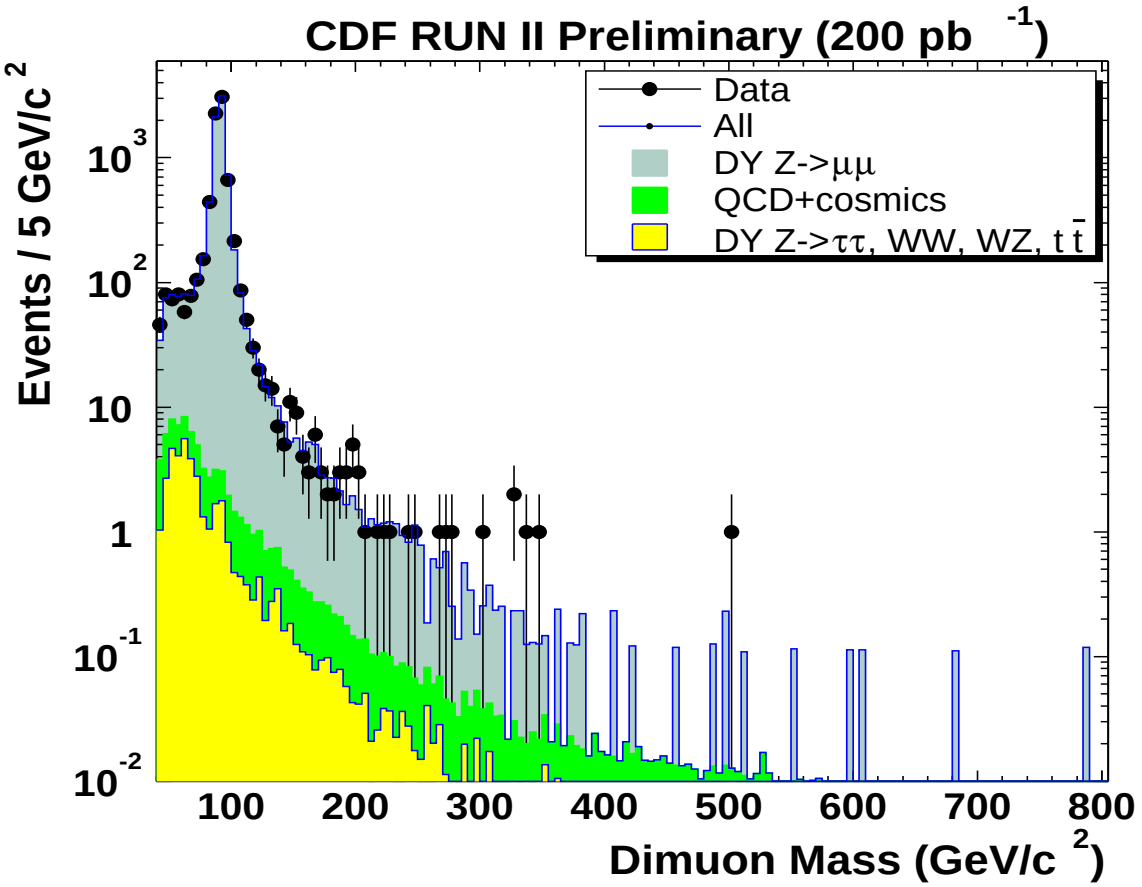
Dashed Magenta = E_6 η

Thin Cyan = E_6 I

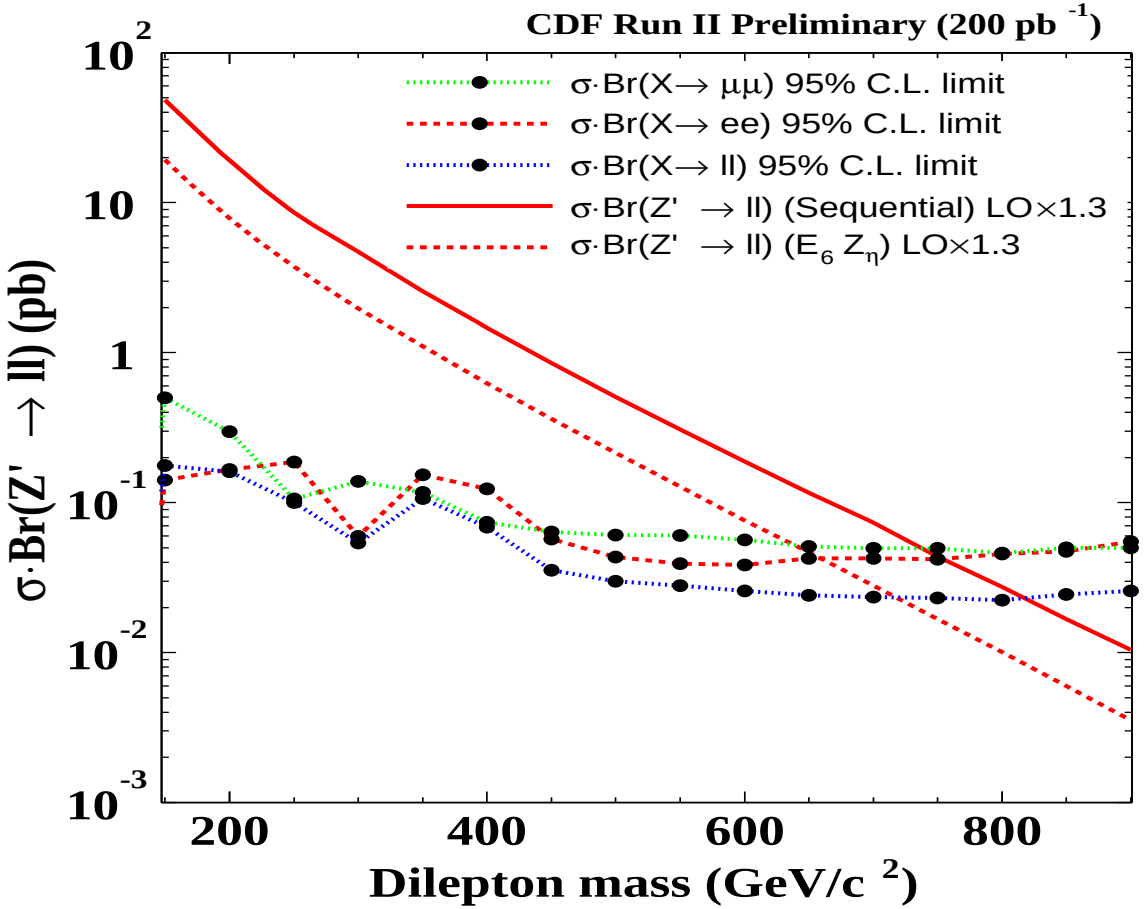
DØ SM-like couplings, Z' Mass limit = 780 GeV

CDF (200 pb^{-1} , dielectron) : 750 GeV

CDF Mass μμ

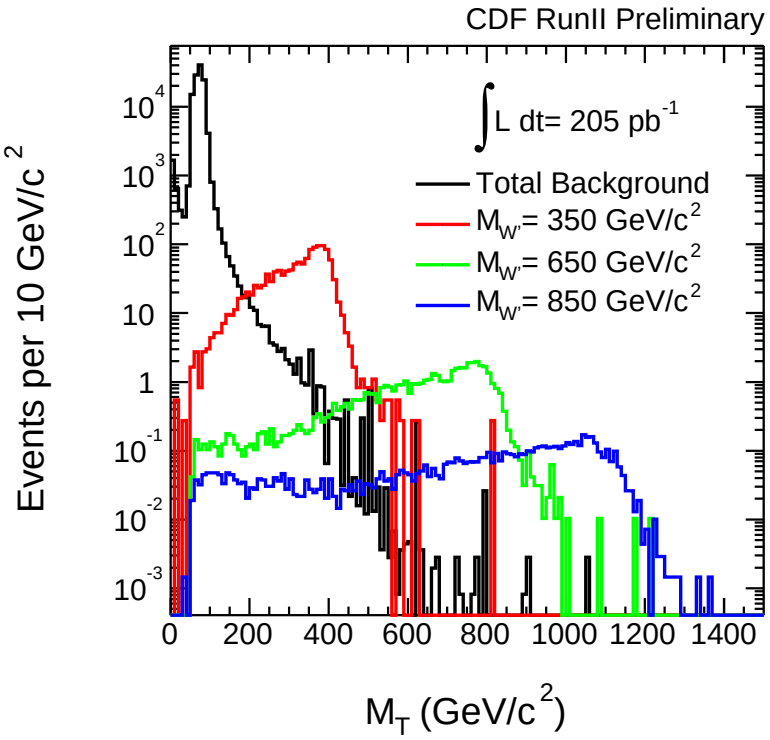

CDF RUN II Preliminary (200 pb -1)
Data
All
DY Z->μμ
QCD+cosmics
DY Z->ττ, WW, WZ, t t̄
Events / 5 GeV/c 2
10 3
10 2
10
1
10 -1
10 -2
100
200
300
400
500
600
700
800
Dimuon Mass (GeV/c 2)

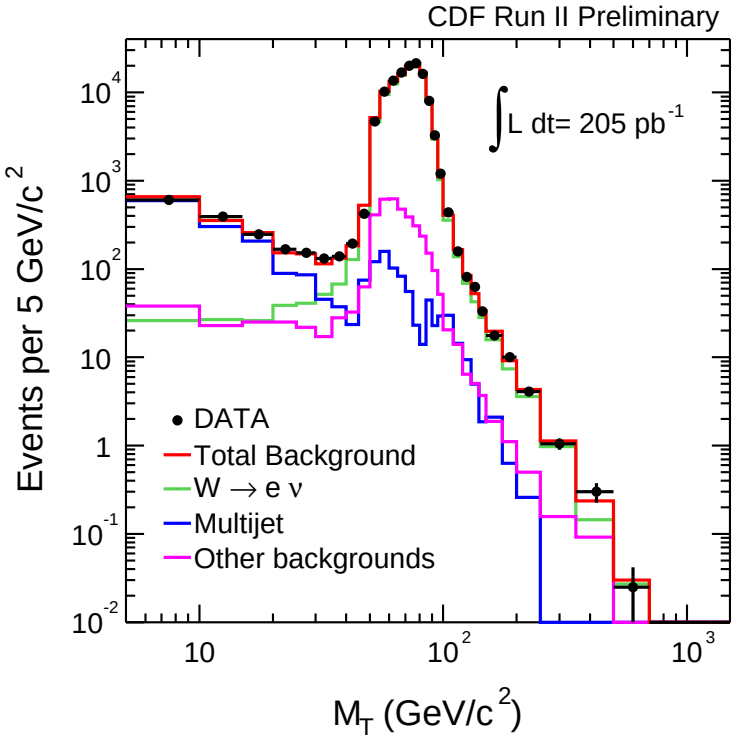
CDF Combined ee and μμ Z´ limits



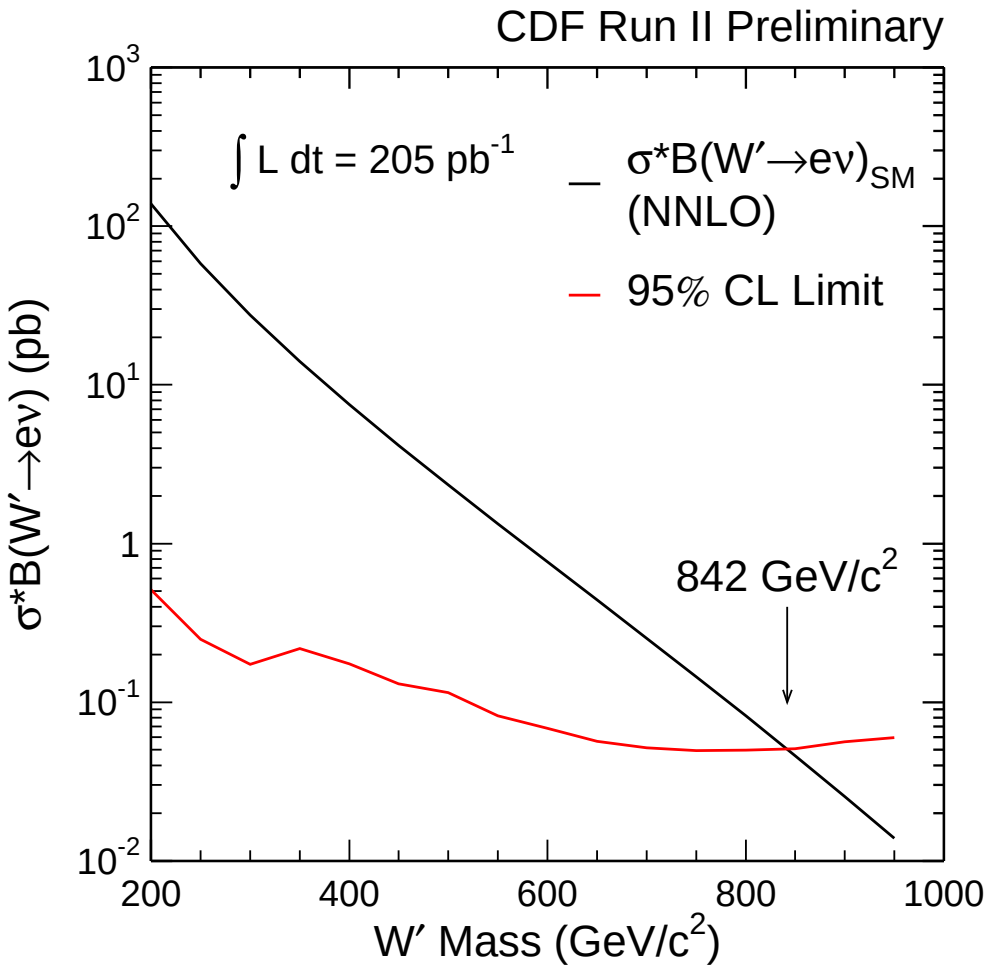
SM-like couplings Z' Mass limit = 815 GeV/c^2

Search for W´ in e ν





W´ Limit



Limit: M(W´$_{SM}$)> 842 GeV/c²

Extra Dimensions

We live in a world of 3 space + 1 time dimensions, called the SM brane by string theorists

String theories, which combine gravity and quantum effects, postulate 6 or 7 more dimensions

These extra dimensions can explain things that are mysterious, such as why gravity is weak, since it can propagate in the extra dimensions

Some model have extra dimensions large enough to be seen in experiments (between ≈ 100 μm and ≈ 1 fm)

Models of Extra Dimensions

In a talk “Phenomenology Beyond the Standard Model,” Joseph Lykken states:

There are over 3,000 papers discussing extra dimension models. He summarizes the current status in two bullets:

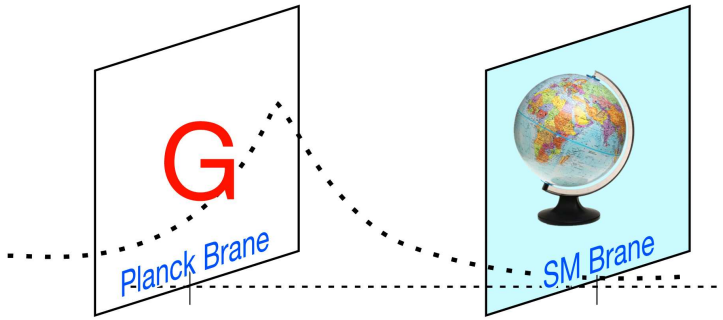
- **There are too many models**
- **None of them are any good**

Lykken: hep-ph/0503148

RS Model

Randall-Sundrum Model

Gravitons propagate in a single extra dimension, which has a special warped metric that damps gravity's effect on the SM brane



Look for graviton resonances in dielectron, diphoton and dimuon

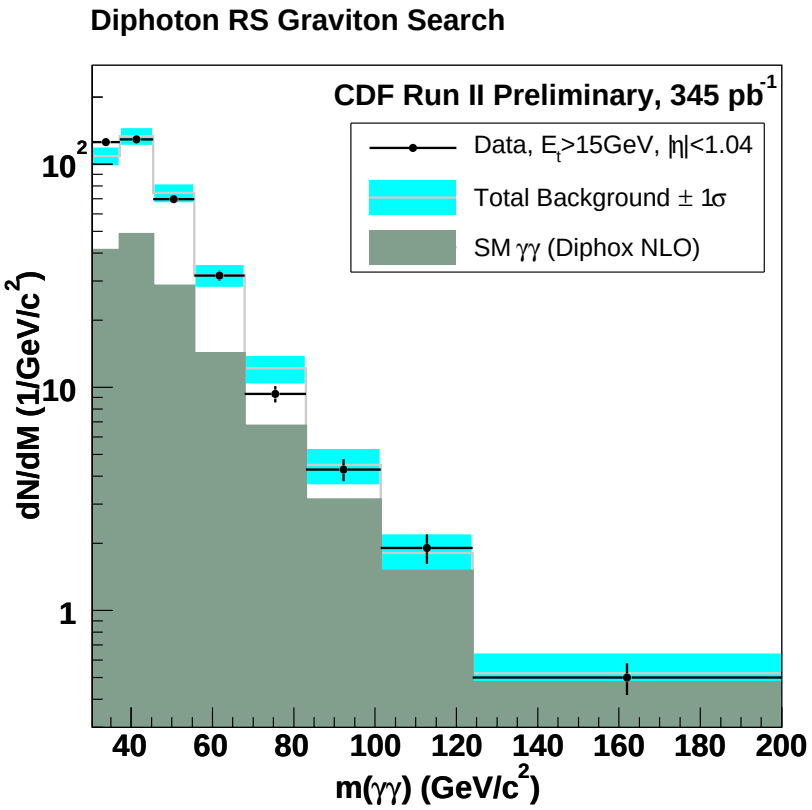
Randall and Sundrum: hep-ph 9905221

Randall-Sundrum Graviton

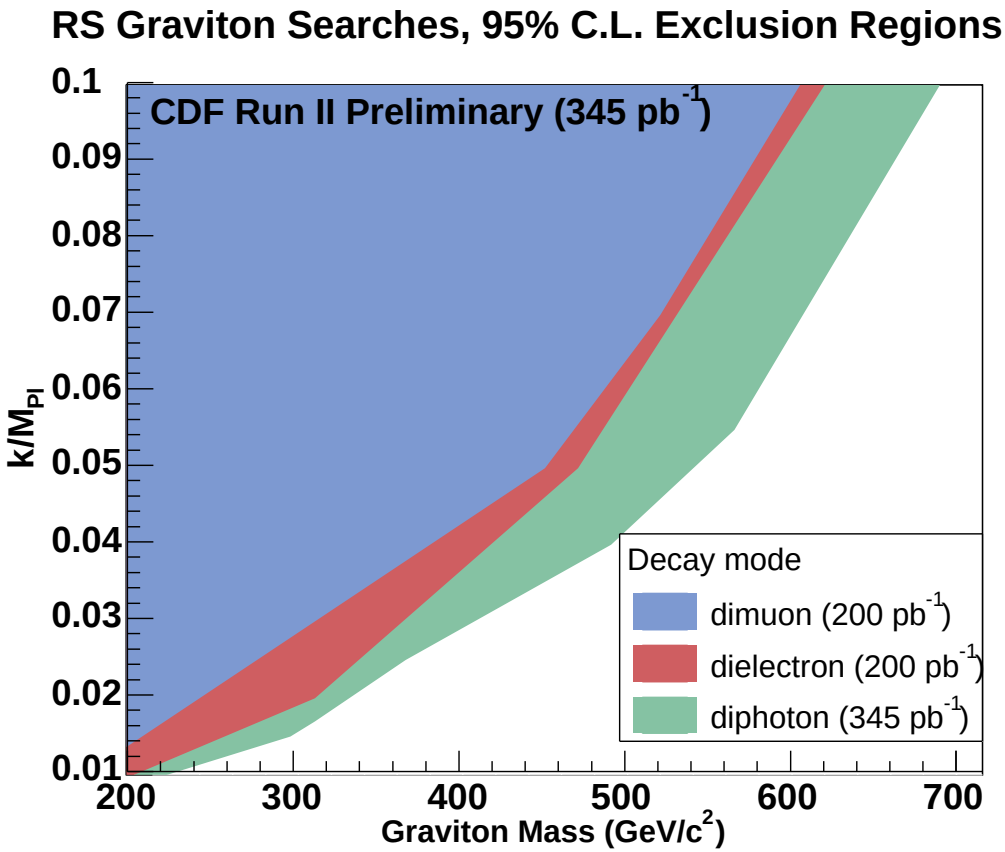
Diphoton RS graviton search

Most of the sensitivity
is in diphotons

BR(G->$\gamma\gamma$) = 2$*$ BR(G->ee)



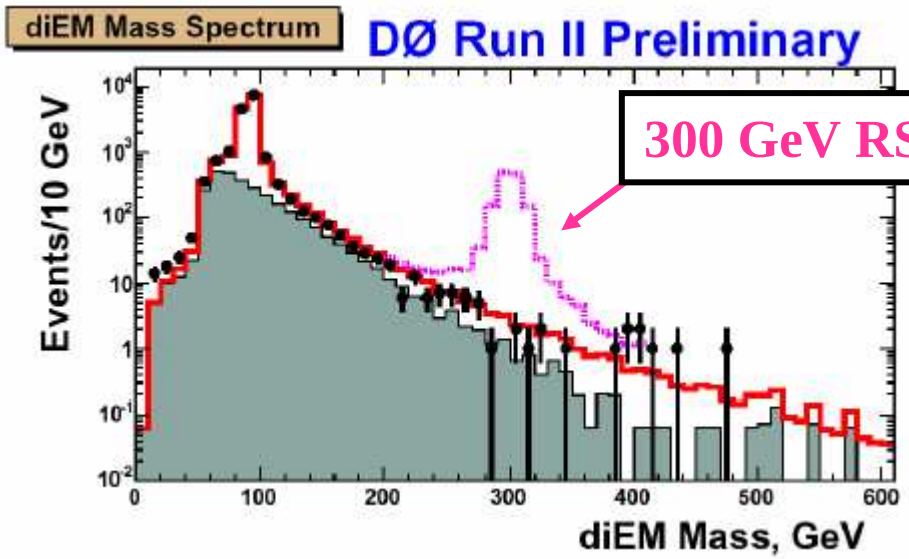
Limits on RS graviton mass



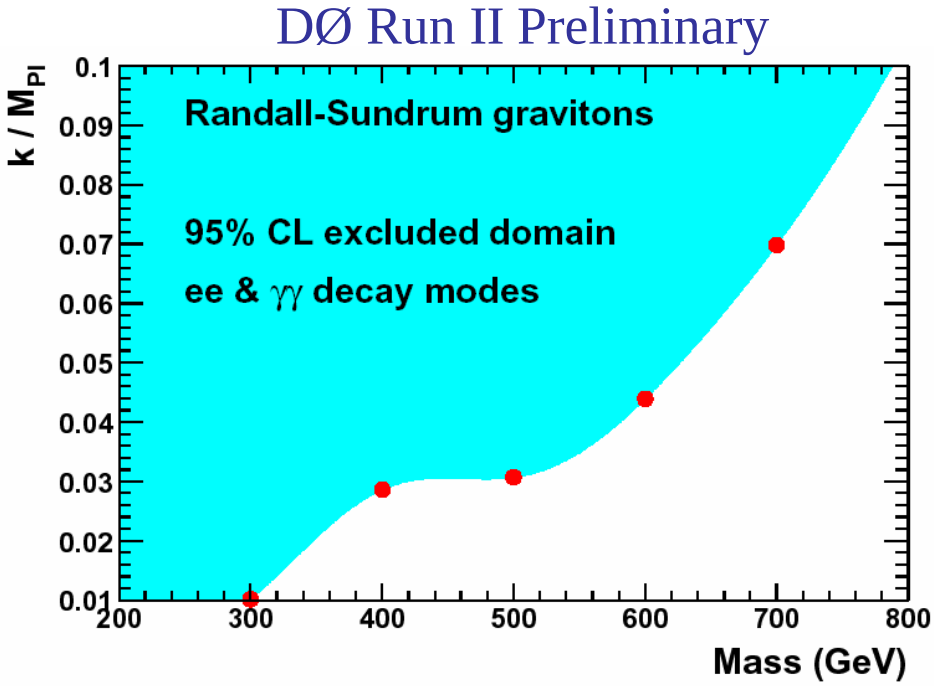
Two model parameters: Mass and coupling (κ/MPl)

For κ/MPl = 0.1: M > 690 GeV/c^2

Randall – Sundrum gravitons



diEM = dielectron + diphoton



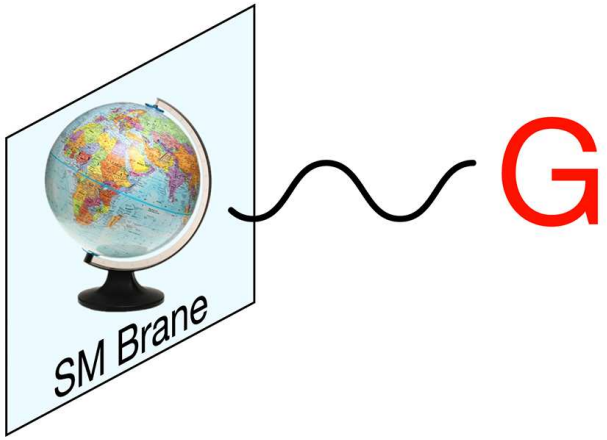
For $\kappa/M_{Pl} = 0.1$: $M > 785$ GeV

ADD Model

Arkani-Hamed, Dimopoulos,
Dvali Model

Gravity freely propagates in the many large extra dimensions (n=2-7).

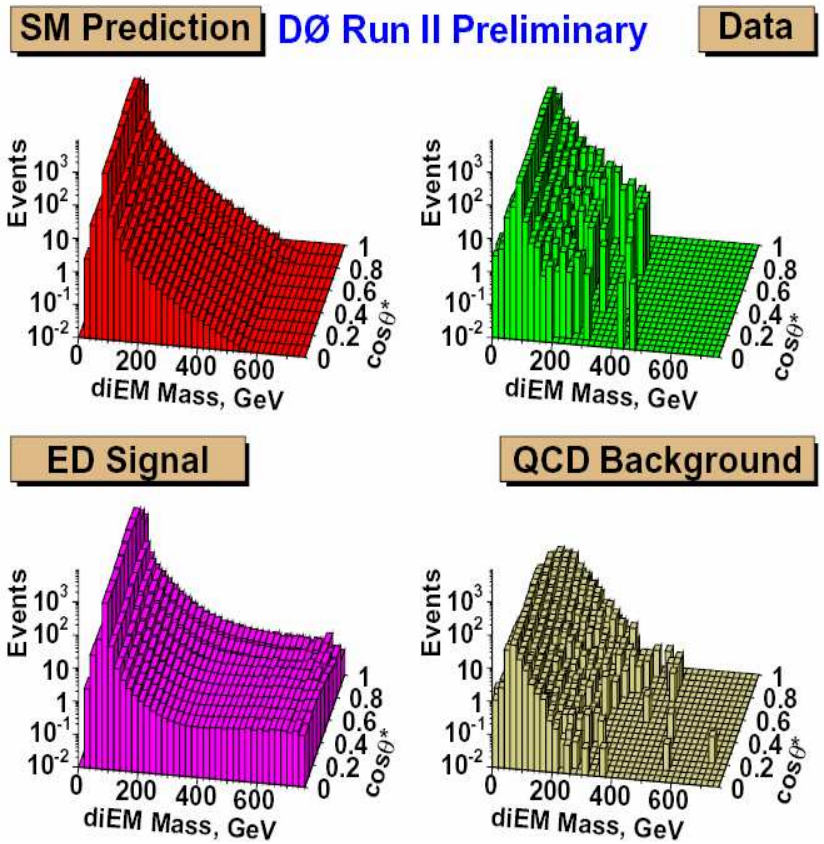
Search for enhanced dielectron, diphoton and dimuon production via a virtual graviton



Arkani-Hamed, Dimopoulos and Dvali: hep-ph 9803315

LED in dielectron and diphotons

DØ search in 200 pb^{-1} combines ee and γγ to maximize the sensitivity



Fit of Data to EWSM+QCD+LED(M_s)

Set limits:
M_s > 1.36 TeV
Combine with Run I data
M_s > 1.43 TeV
in the GRW formalism

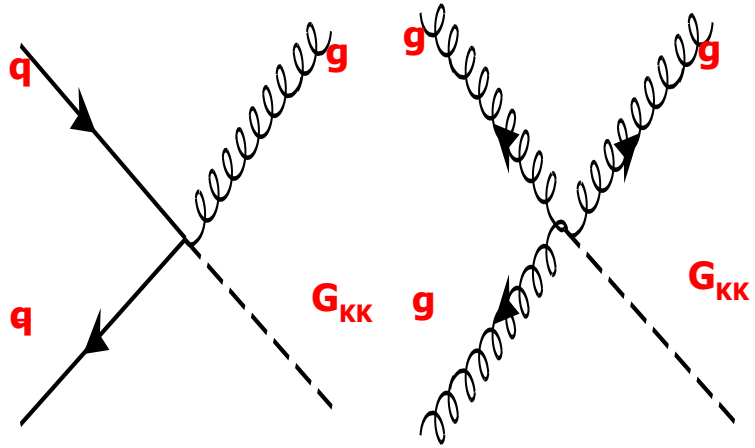
CDF limit in dielectrons
M_s > 1.1 TeV
with 200 pb^{-1} data

D0 limit in dimuons
M_s > 1.1 TeV
with 200 pb-1 data

Giudice, Rattazzi and Wells: hep-ph/9811291

ADD Direct Graviton Production

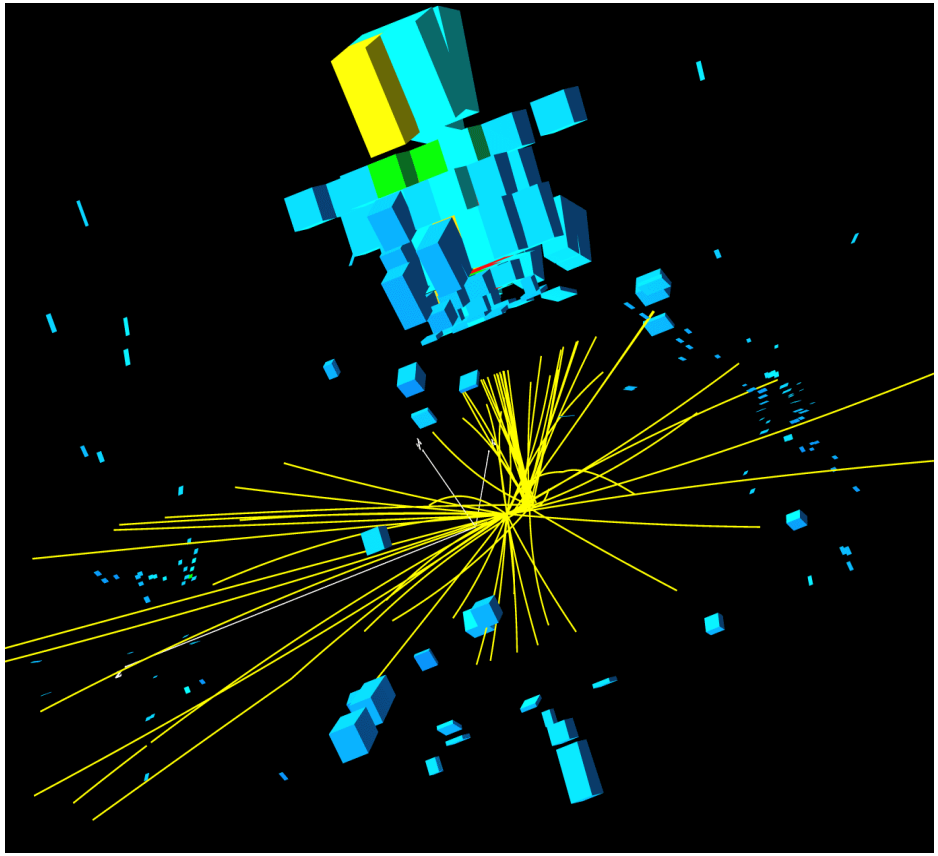
Monojets at hadron colliders

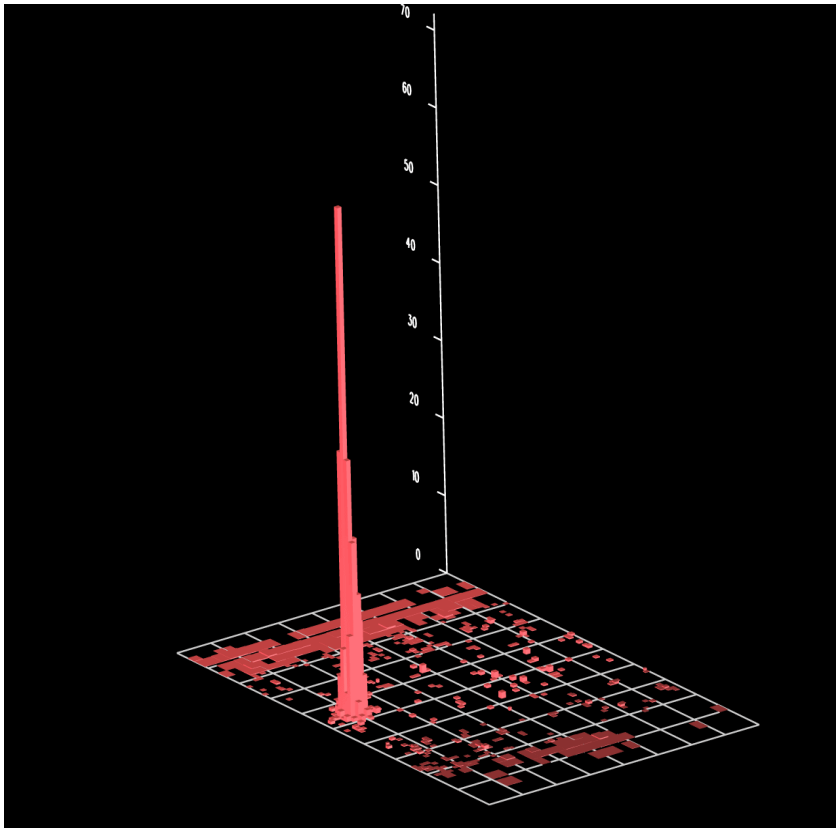


Gravitons can be produced recoiling against a quark or gluon

Gravitons escape and create missing E_T

Monojet Event Display

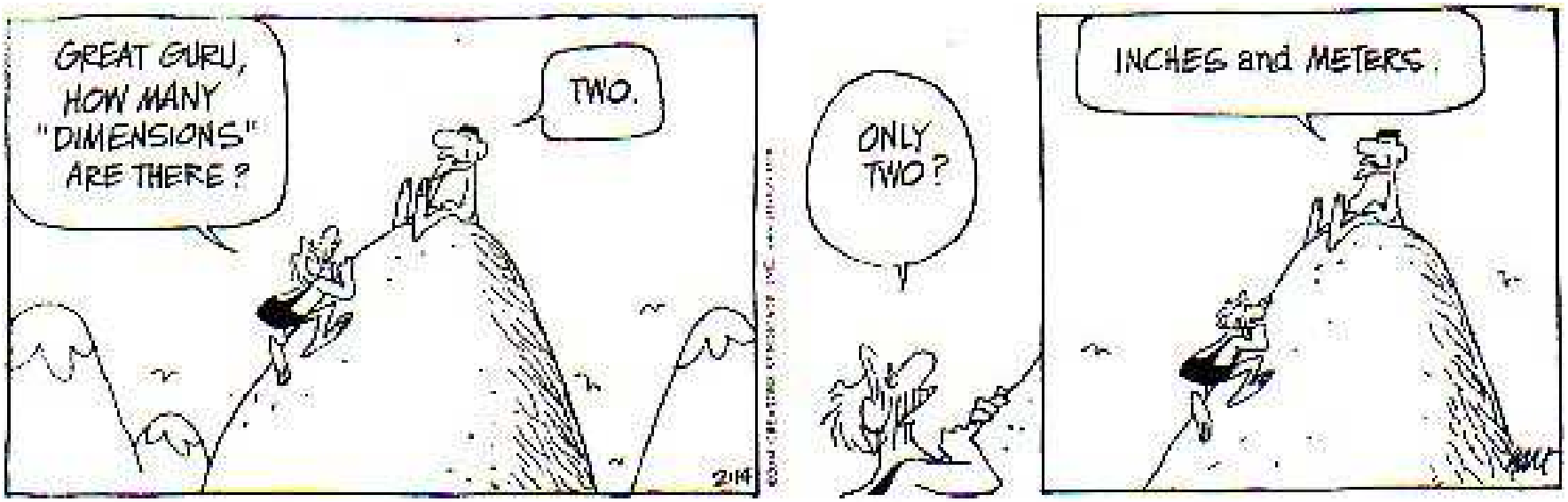




DØ did a preliminary study with 85 pb^{-1} of data
Results on larger sample in near future

Are there extra dimensions?

Ask the Gurus



Summary and Outlook

This was a small sample of the many new Tevatron results

For details of these results and other NP results, see the web pages:

http://www-cdf.fnal.gov/physics/exotic/exotice.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm

Results are updated periodically.

Discoveries may be just around the corner!
Stay tuned!