Non-SUSY Searches at the Tevatron

Michael Eads

University of Nebraska – Lincoln
on behalf of the CDF and DØ Collaborations

Overview

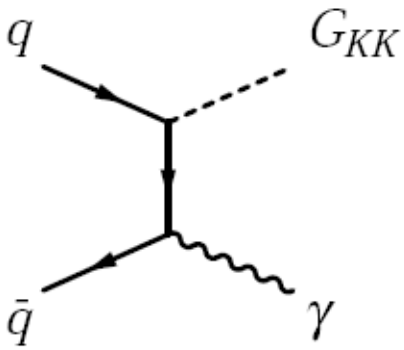
- CDF and DØ have a wide variety of results in non-supersymmetry related searches
  - Extra dimensions
  - Extra gauge bosons
  - Resonance searches
  - Excited Leptons
- I will concentrate on extra dimension searches and resonance searches
- Most results use at least 1 fb^{-1} of data, several results use up to (and over) 2 fb^{-1}

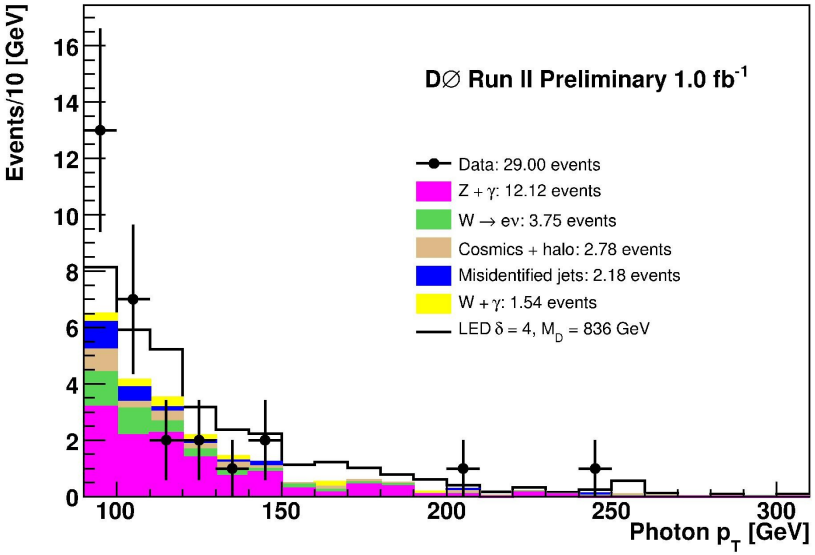
Extra Dimensions

- This is one method of explaining why gravity is so much weaker than the other forces ("hierarchy problem")
- In ADD models, the SM particles are confined to our usual 3 spacial dimensions, while gravity can propagate in extra dimensions
  - Gravity propagates in $4+\delta$ dimensions, where δ is the number of extra dimensions
  - This renders the effective Planck scale small, even though the fundamental mass scale can be close to the weak scale
- "Large" extra dimensions (LED) must be compactified to have escaped detection by precision gravity experiments
  - Any particle that travels in these extra dimensions will have quantized momentum, resulting in a tower of energy states known as Kaluza-Klein (KK) modes

LED in Monophotons (I)

- Uses 1.0 fb^{-1} of data
- A Kaluza-Klein graviton is produced in association with a photon. The graviton escapes detection, leaving a monophoton signature in the detector
- Require a photons with p_T > 90 GeV with $|\eta|$<1.1 and MET > 70 GeV
- Use "photon pointing" to require a vertex to within 10cm
  - Use to reject instrumental backgrounds (cosmics, beam halo, misidentified jets)

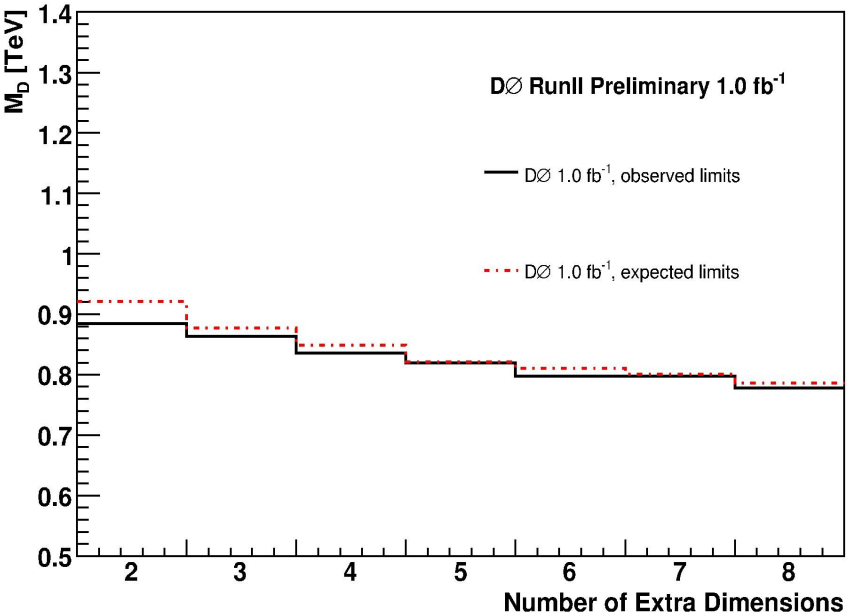




Dominant background is irreducible Z(→νν)+γ

LED in Monophotons (II)

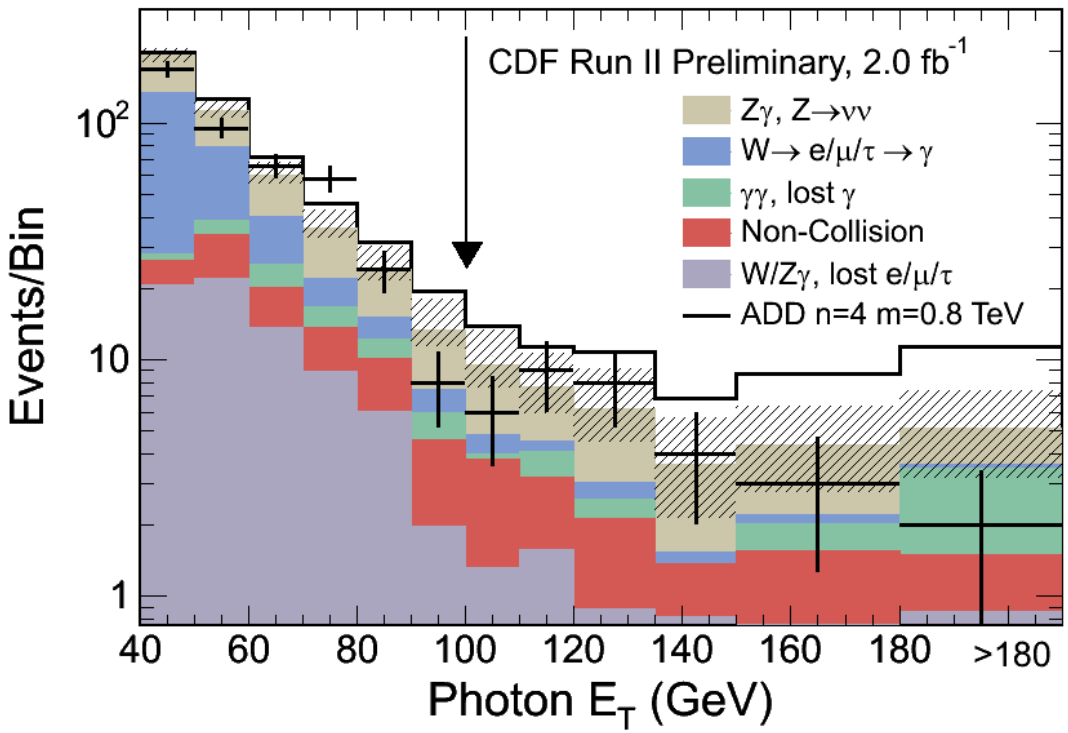
- Final sample is 29 events in data, with 22.37 ±2.50 total expected background events
- No significant excess is observed, so limits are set on the number and size of extra dimensions



Number of extra dimensions	*95% CL Limit on Fundamental Mass Scale (M_D) (GeV)*
2	884
3	864
4	836
5	820
6	797
7	797
8	778

Photon + MET (I)

- Uses 2.0 fb^{-1} of data
- Require a single photon above 50 GeV and missing transverse energy above 50 GeV. Veto on jets and tracks over 10 GeV

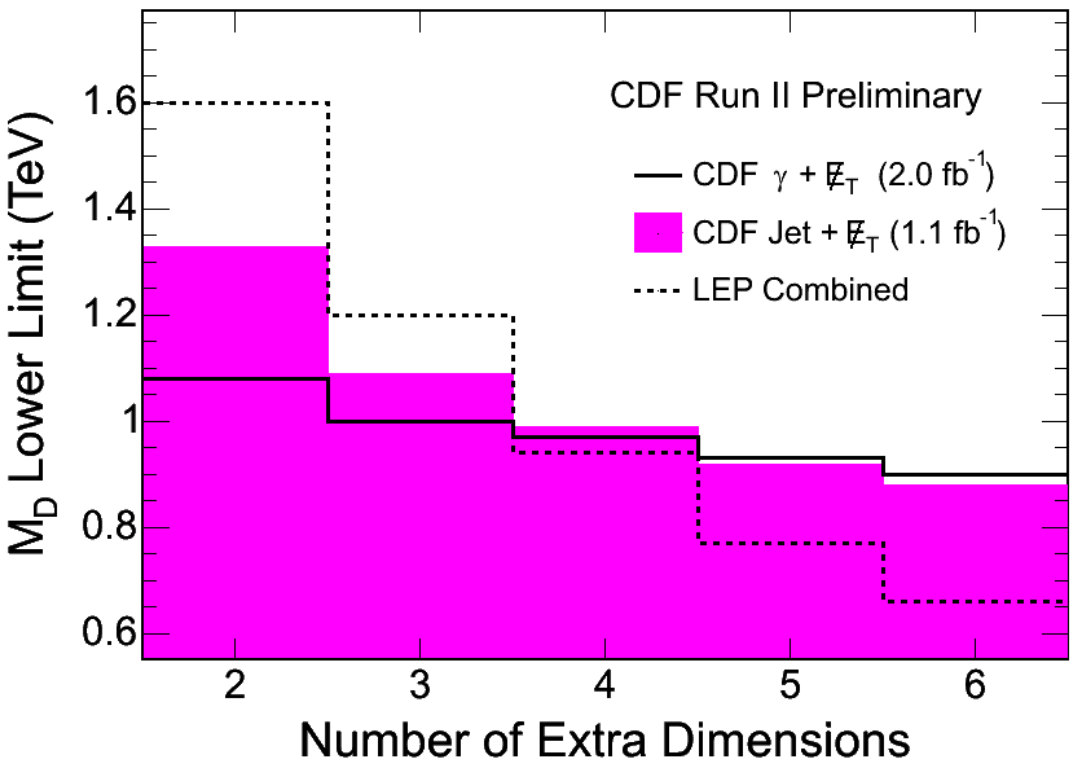


Optimized cut for extra dimensions search

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

Photon + MET (II)

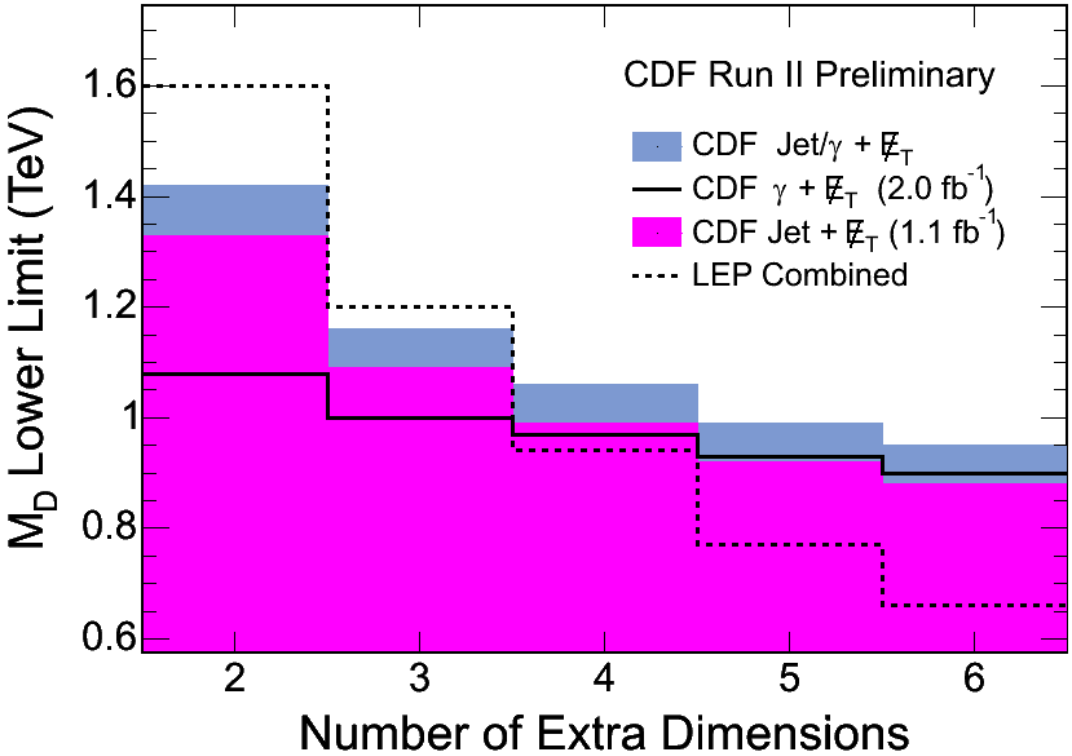
- No excess of single photon + MET events is observed, so limits are set on the cross section and on M_D, the fundamental mass scale



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

Photon/jet + MET

- LED models can also produce a signal of one or more high p_T jets with MET
- Combine with the 1.0 fb^{-1} jet+MET search to improve the limit

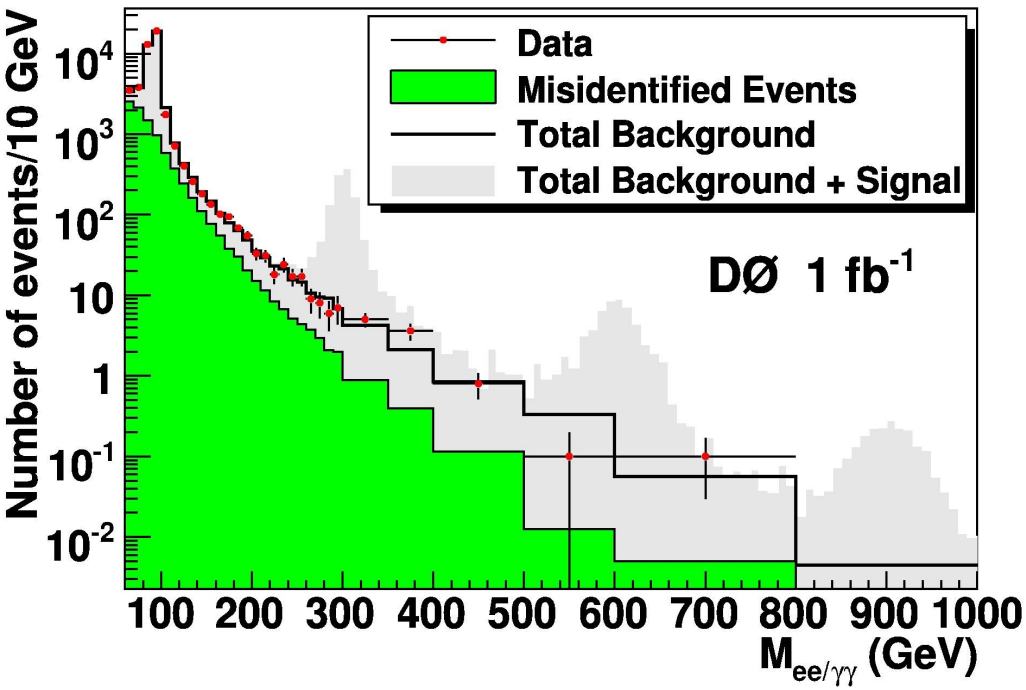


CDF RunII Preliminary, Jet/γ+$\not\!\!E_T$		
N LED	σ^{95}_{obs} fb	M_D^{obs} GeV
2	26.3	1420
3	38.7	1160
4	46.9	1060
5	52.7	990
6	56.7	950

Randall-Sundrum Gravitons (I)

PRL **100**, 091802 (2008)

- In Randall-Sundrum (RS) ED models, the SM particles are confined to a 3-brane and gravity originates at another 3-brane. Only gravitons propagate in the bulk between these branes
- Use 1.0 fb^{-1} of data to search for KK excitations of the graviton that decays to a pair of electrons or photons
- Require two electromagnetic calorimeter clusters with $p_T > 25$ GeV and $|\eta| < 1.1$

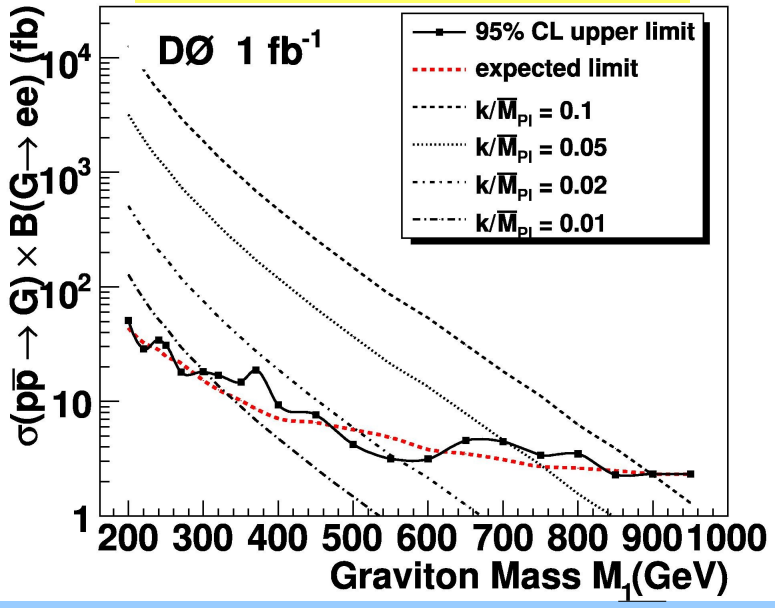


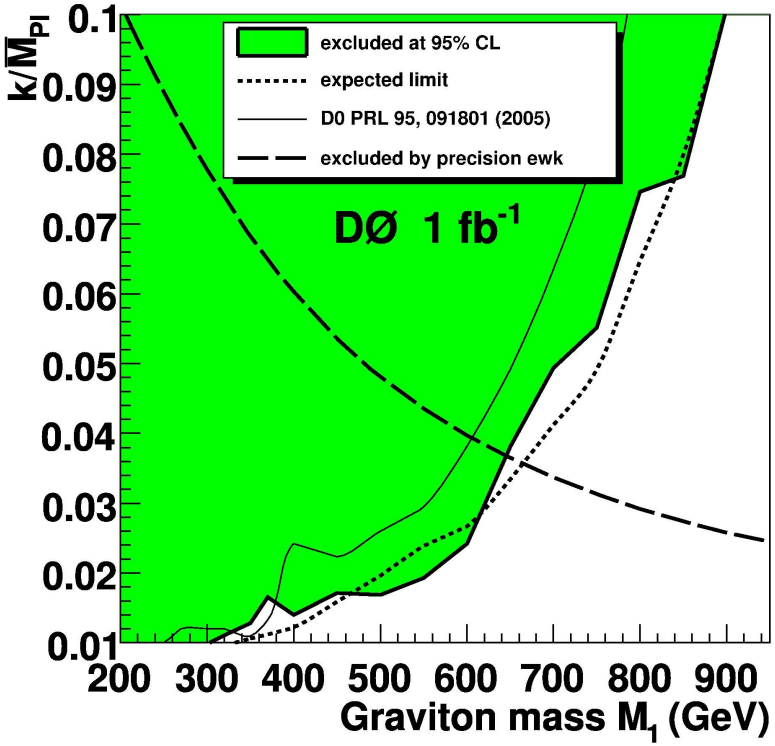
Misidentified events have jets faking electrons/photons. The shape of this background is estimated from data by inverting selection cuts.

Randall-Sundrum Gravitons (II)

- Count events in a sliding window (varies from 20 to 220 GeV) in the invariant mass distribution (optimized from simulation) for graviton masses from 200 to 950 GeV
  - observe 88 to zero events, consistent with background

PRL **100**, 091802 (2008)



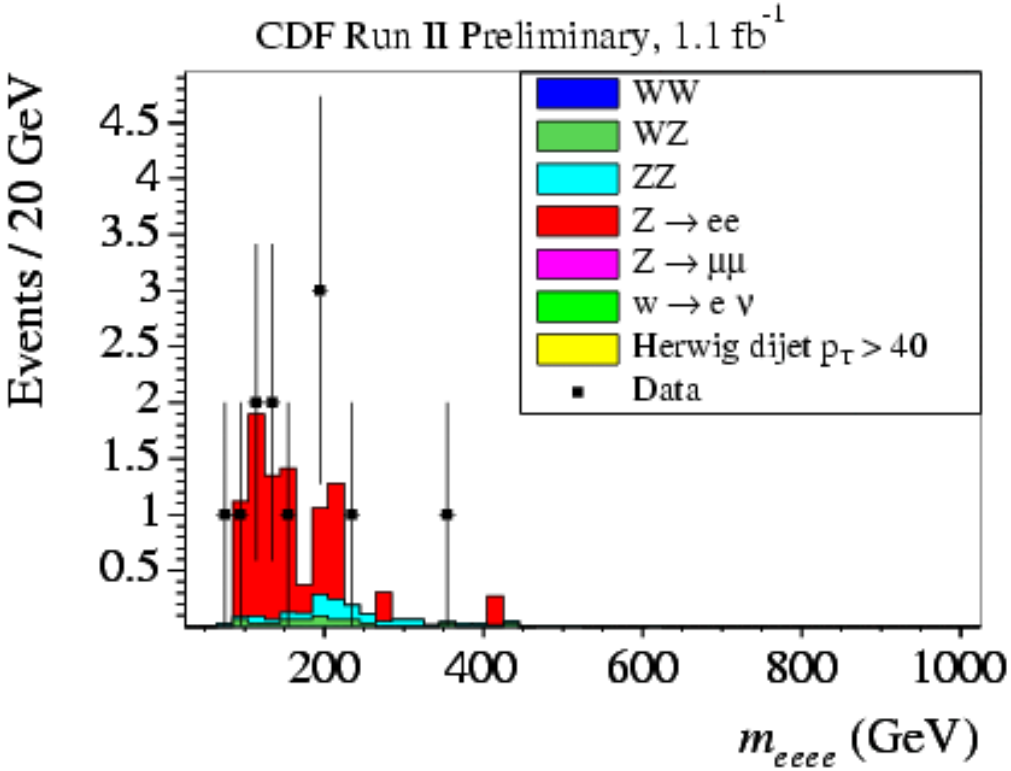


Exclude below 900 GeV for k/M_{pl} = 0.1

CDF limit is 889 GeV with 1.13fb^{-1}

RS Gravitons in ZZ (I)

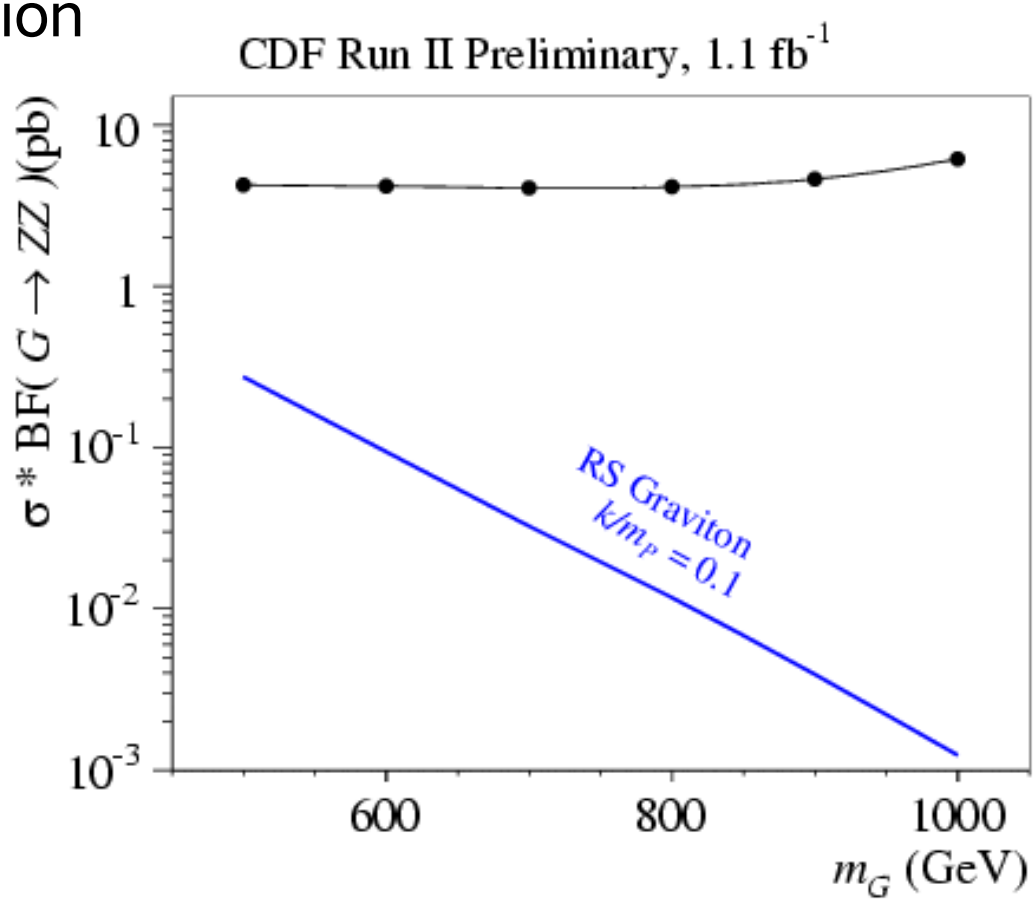
- Search for a new particle decaying to two Z bosons, which both decay to electrons
- Optimize electron selection to maximize sensitivity
  - Factor of 2-4 better than standard selection
- Estimate background from data
  - Use low-mass *eeee* events and events with hadronic fakes, extrapolate to signal region



arXiv: 0801.1129, submitted to PRD

RS Gravitons in ZZ (II)

- Observe 12 *eeee* events, none in signal region (m_{eeee} > 400 GeV), expect 0.028 ±0.009 ±0.011 background events in signal region



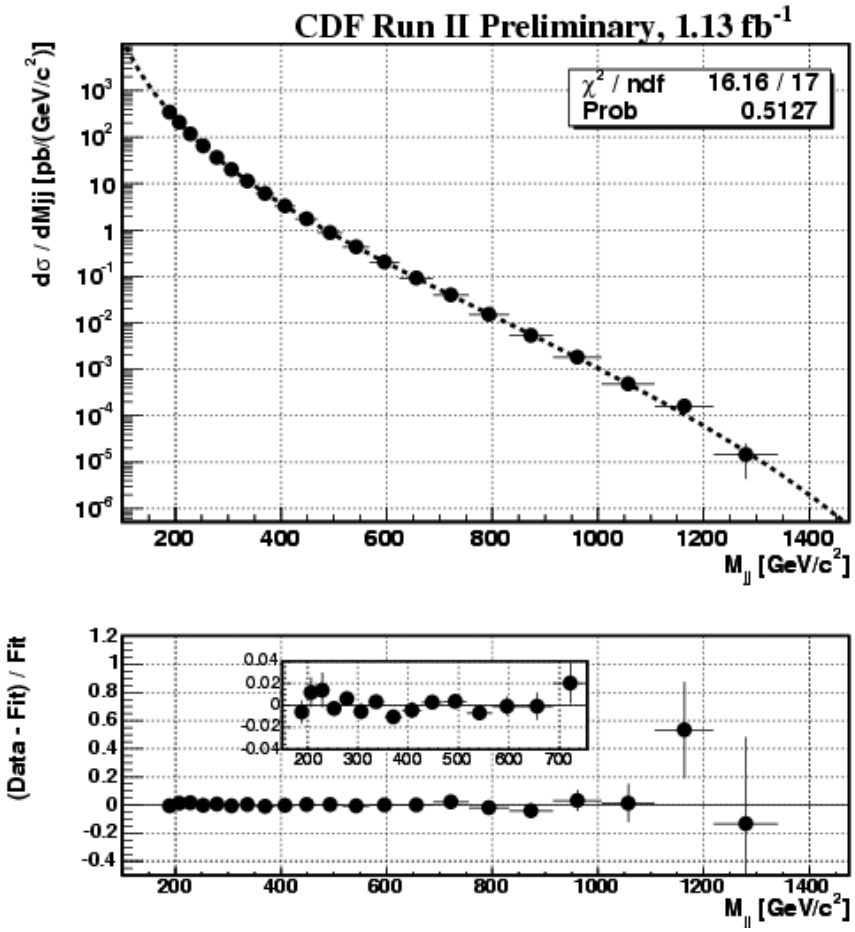
arXiv: 0801.1129, submitted to PRD

Resonance Searches

- There are a wide variety of models that predict new particles that would decay to quarks, leptons, or gauge bosons
  - KK states in ED models, excited quarks or leptons, new gauge bosons, etc...
- The general strategy for these searches is to look for deviations from the SM in invariant mass distributions (dilepton mass, dijet mass, diboson mass, etc...)
  - A good, old-fashioned “bump hunt”

Dijet Resonance Search (I)

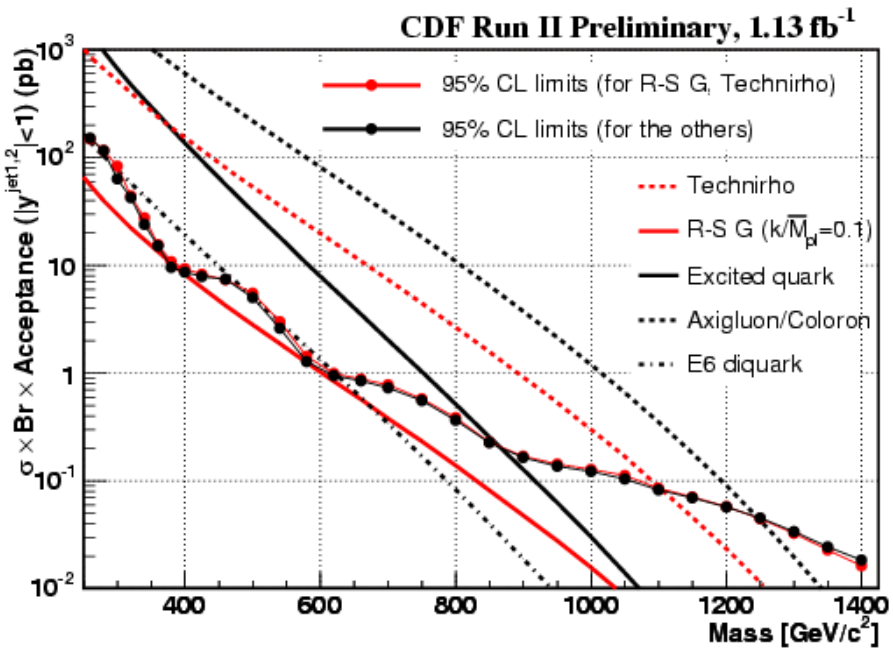
- Use 1.13 fb^{-1} of data
- Choose events with two high-p_T jets with rapidity less than 1.0. Look for an excess in the dijet mass spectrum for masses above 180 GeV
- Possible signals include excited quarks, W', Z', and Randall-Sundrum gravitons
- Find functional form of of dijet spectrum in pythia and herwig, fit to data. Look for "bumps" in the data minus fit plot

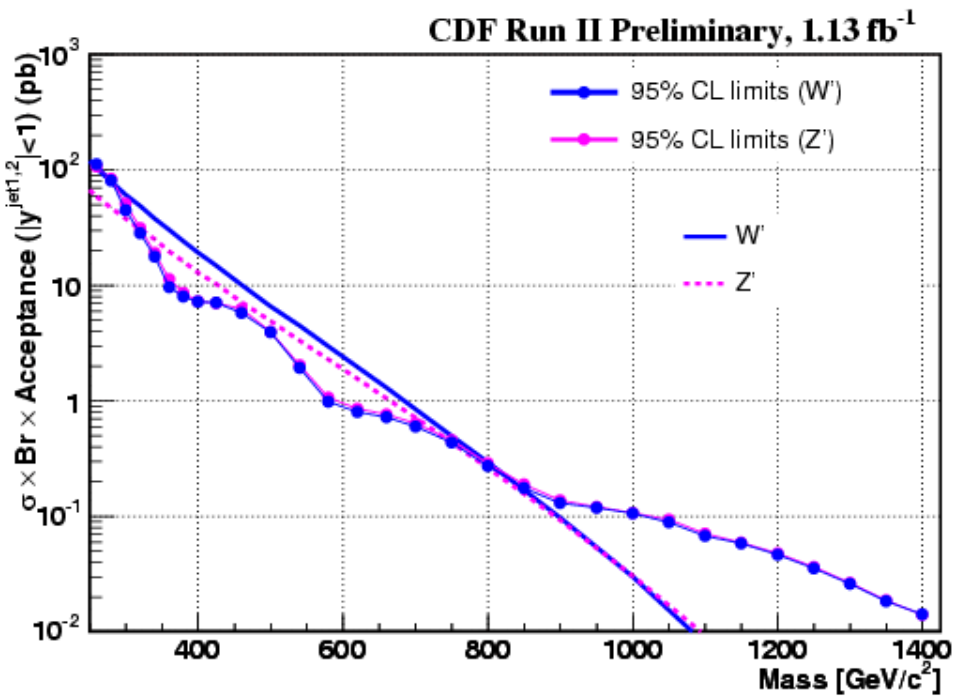


$$\frac{d\sigma}{dm} = p_0(1-x)^{p1} / x^{p2+p3\log(x)}, \quad x = m/\sqrt{s}$$

Dijet Resonance Search

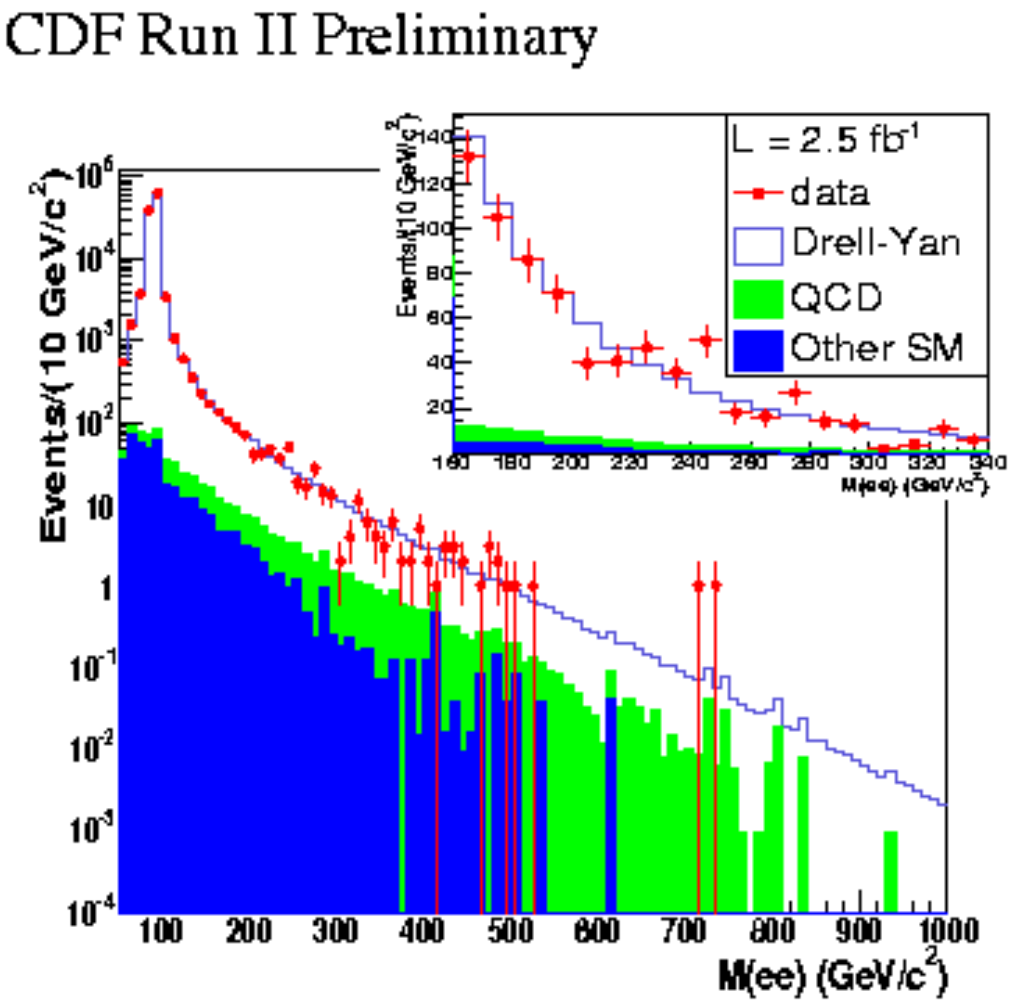
- No significant resonant structure is observed, so limits are set on various models
- Excludes (at 95% CL) excited quarks from 260-870 GeV, W' from 280-840 GeV, and Z' from 320-740 GeV





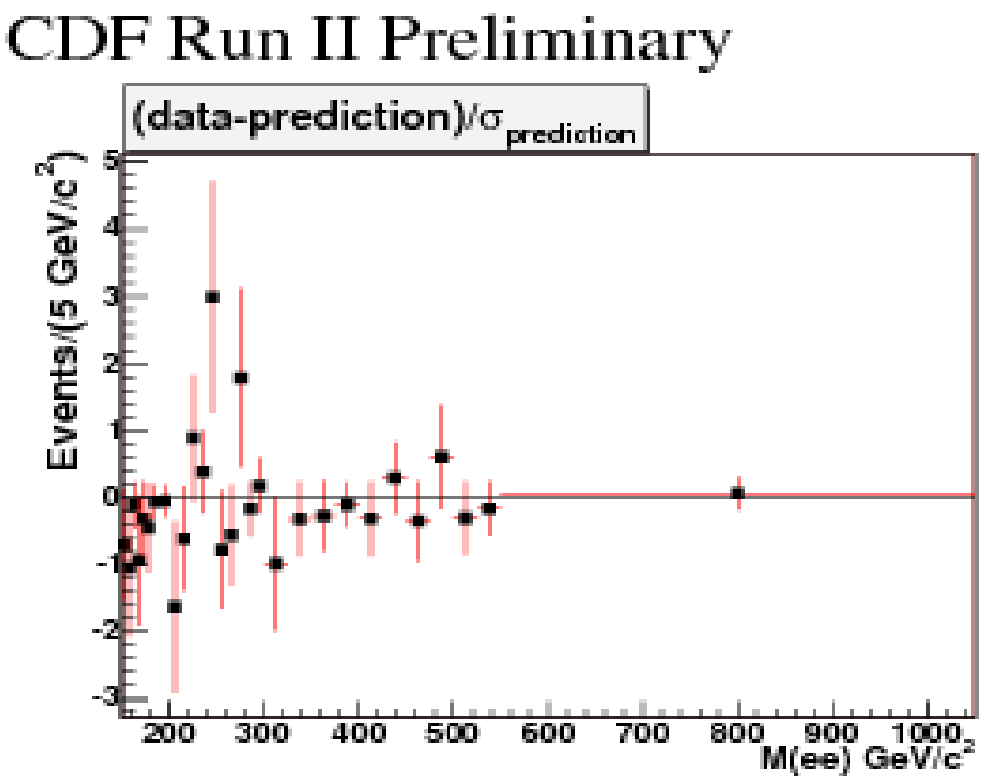
Dielectron Resonance Search (I)

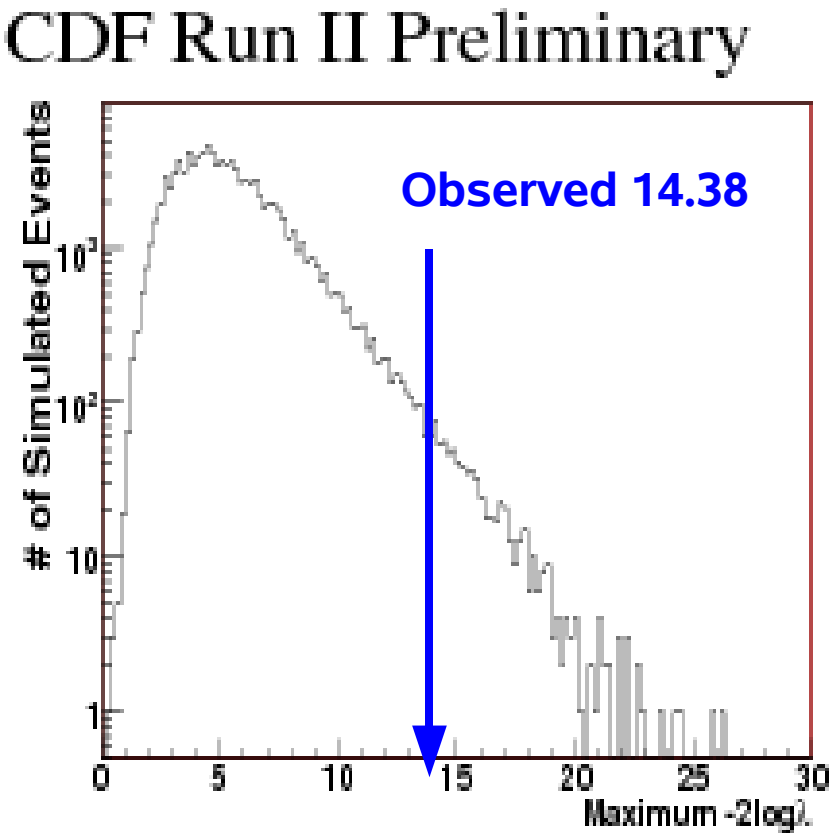
- Uses 2.5 fb^{-1}
- Require two electrons with p_T > 25 GeV and $|\eta|$ < 2 (at least one electron in central region)
- Dominant backgrounds are SM dielectron production, and dijets and W+jets with the jets misidentified as electrons
- Look for excesses in the dielectron mass distribution above 150 GeV



Dielectron Resonance Search (II)

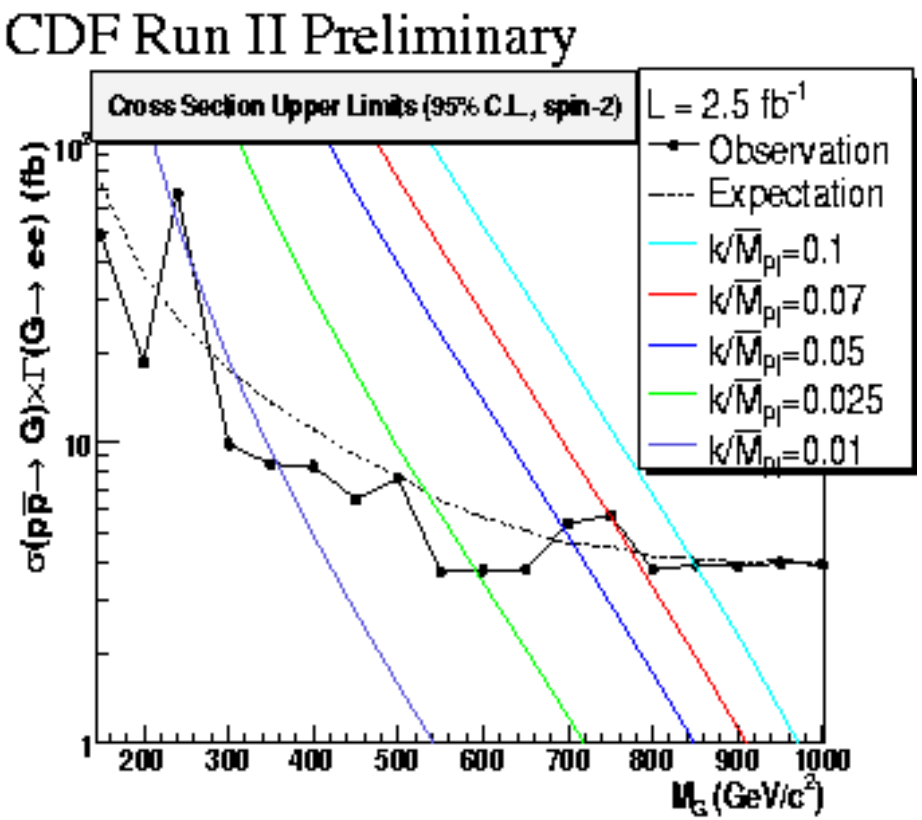
- The largest discrepancy shown by an unbinned maximum likelihood ratio is 3.8σ in the range 228 – 250 GeV
  - 0.6% probability of seeing this size discrepancy in the range 150-1000 GeV

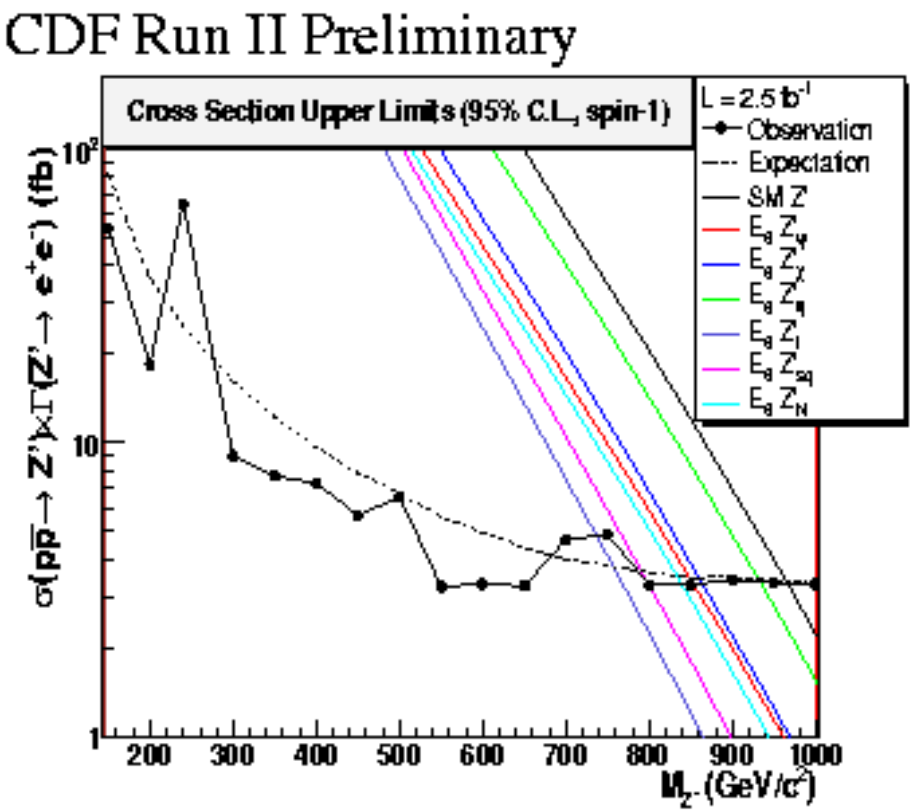




Dielectron Resonance Search (III)

- Limits are set on RS Gravitons and Z' bosons





Exclude (at 95% CL) RS Gravitons below 850 GeV for $k/\overline{M}_{pl}$ = 0.1

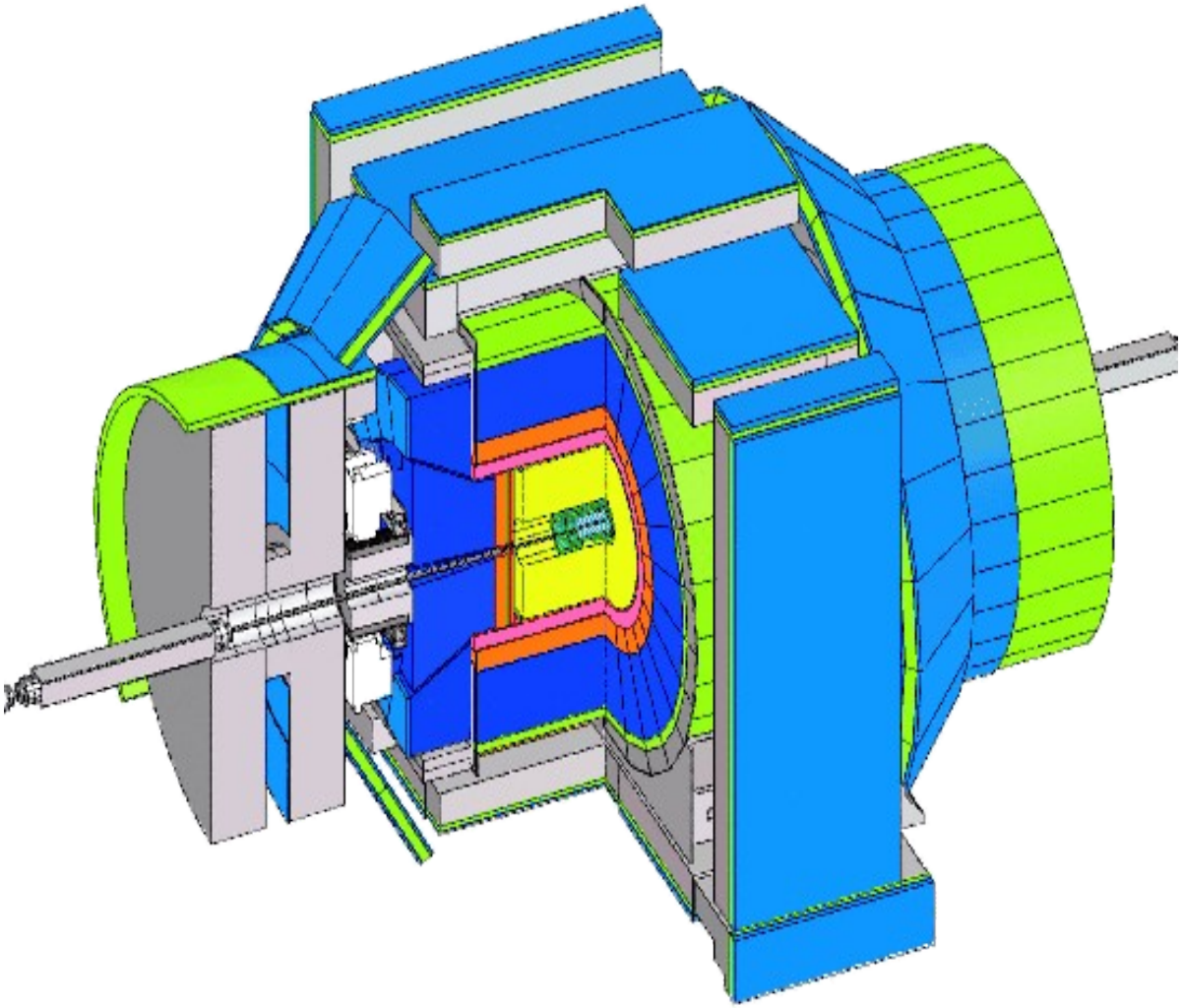
Exclude (at 95% CL) Z' with SM coupling below 966 GeV

Conclusion

- While I could only touch on a few analyses, both collaborations have performed many other searches
  - Excited fermions, technicolor, leptoquarks, generic signature-based searches
- Both CDF and DØ currently have about 3 fb^{-1} of recorded data, so expect more results (and updates to existing results) soon
- For all public results, visit
  - http://www-cdf.fnal.gov/physics/physics.html
  - http://www-d0.fnal.gov/Run2Physics/WWW/results.htm

Backup Slides

CDF Detector



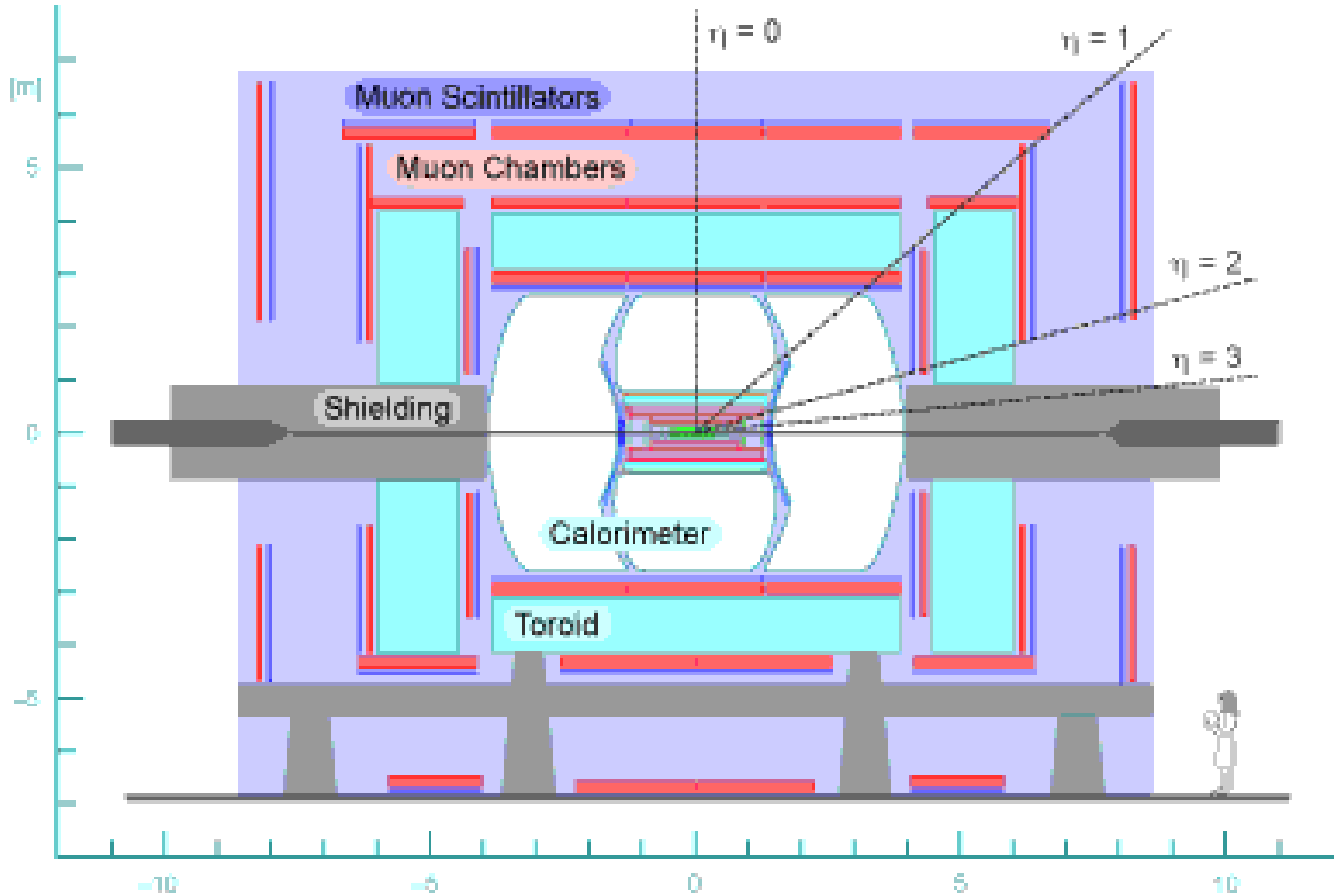
Electron acceptance:
$|\eta| < 2.0$

Muon acceptance:
$|\eta| < 1.5$

Silicon tracking:
$|\eta| < 2.0$

Calorimetry:
$|\eta| < 3.6$

DØ Detector



Electron acceptance:
$|\eta| < 3.0$

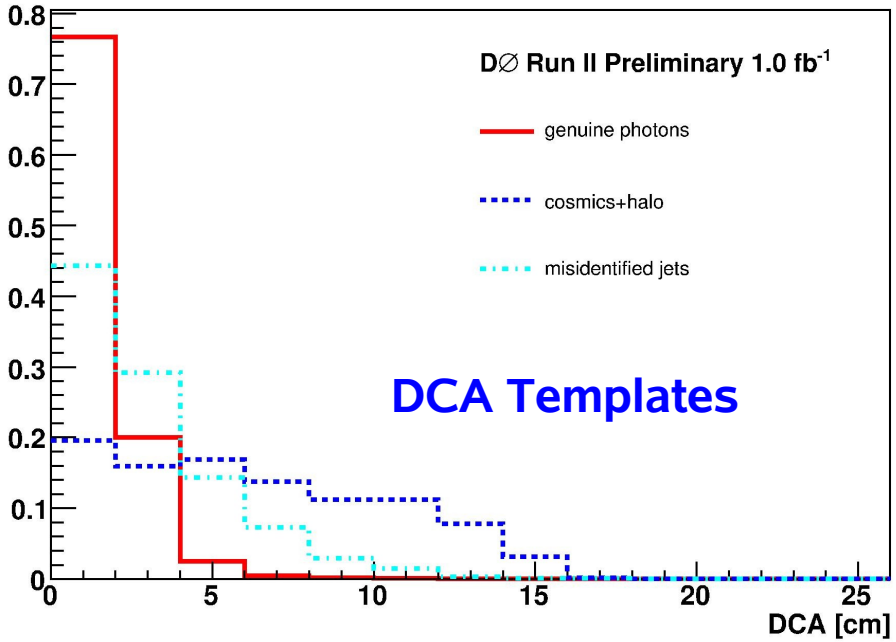
Muon acceptance:
$|\eta| < 2.0$

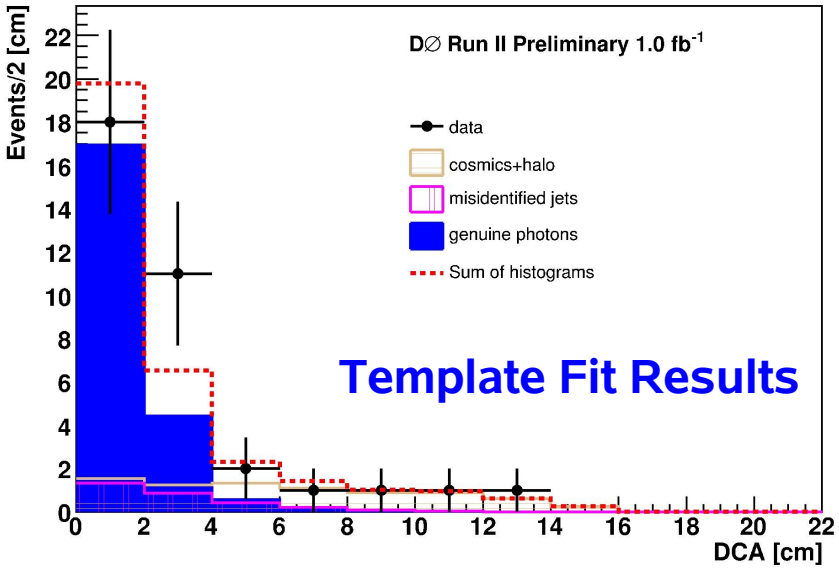
Silicon tracking:
$|\eta| < 3.0$

Calorimetry:
$|\eta| < 4.2$

Photon Pointing

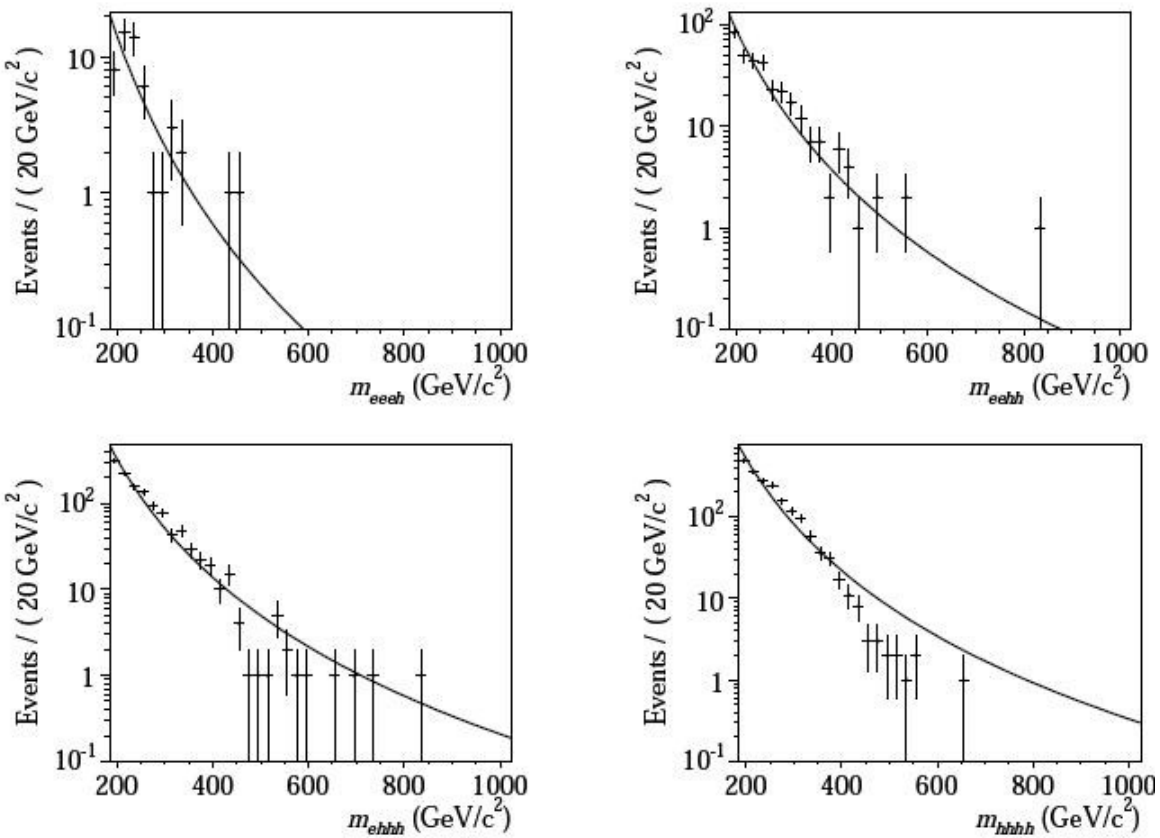
- Due to fine segmentation of calorimeter, can extrapolate photon back to beam line and calculate distance-of-closest-approach (DCA)
- Mis-identified jets, cosmics, and beam halo have wider DCA distributions than signal
- Fit DCA templates to get data composition





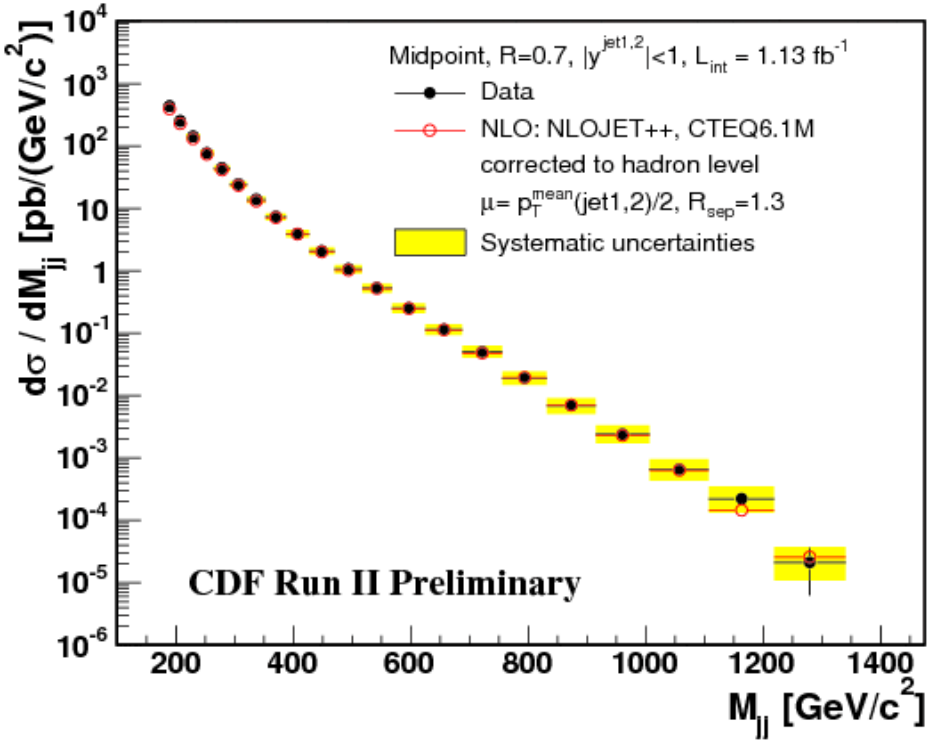
ZZ Background Estimate

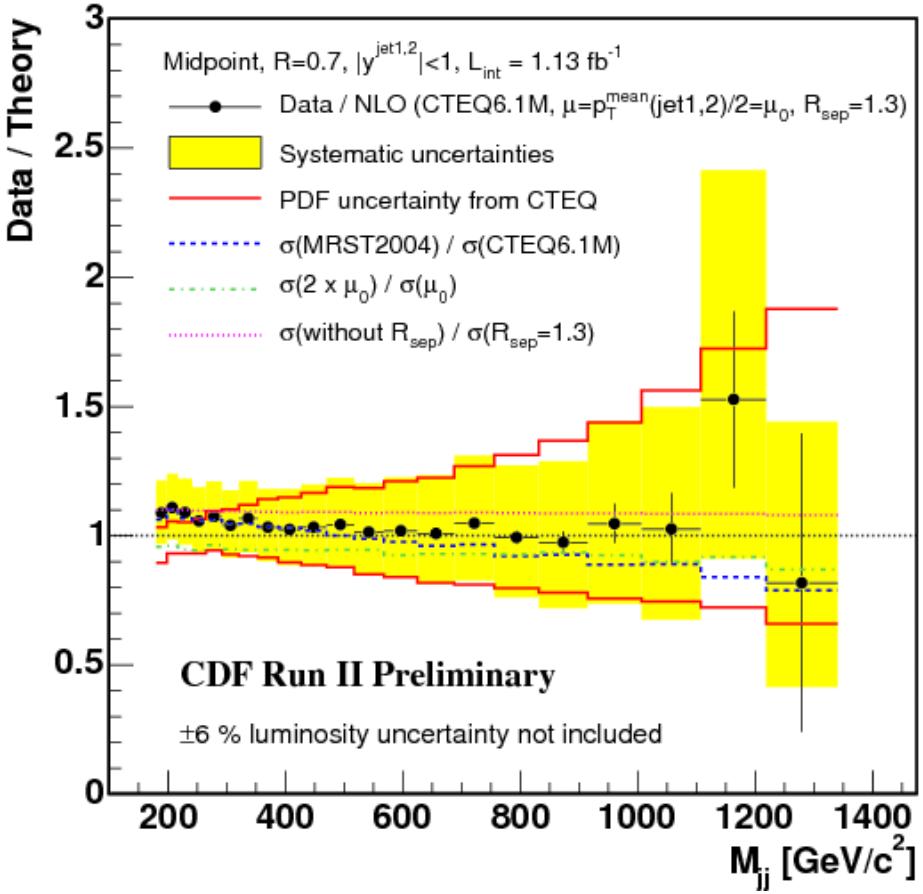
- Dominant background is from jets faking electrons
- Select hadron-enriched samples from electrons that fail E_{HAD}/E_{EM} requirement, no isolation
- Use five control samples – 1, 2, 3, or 4 hadronic fakes, and low-mass (m_{eeee} < 400 GeV) sample
- Do unbinned max likelihood fit (of power law) to all five samples simultaneously



Dijet Mass Spectrum

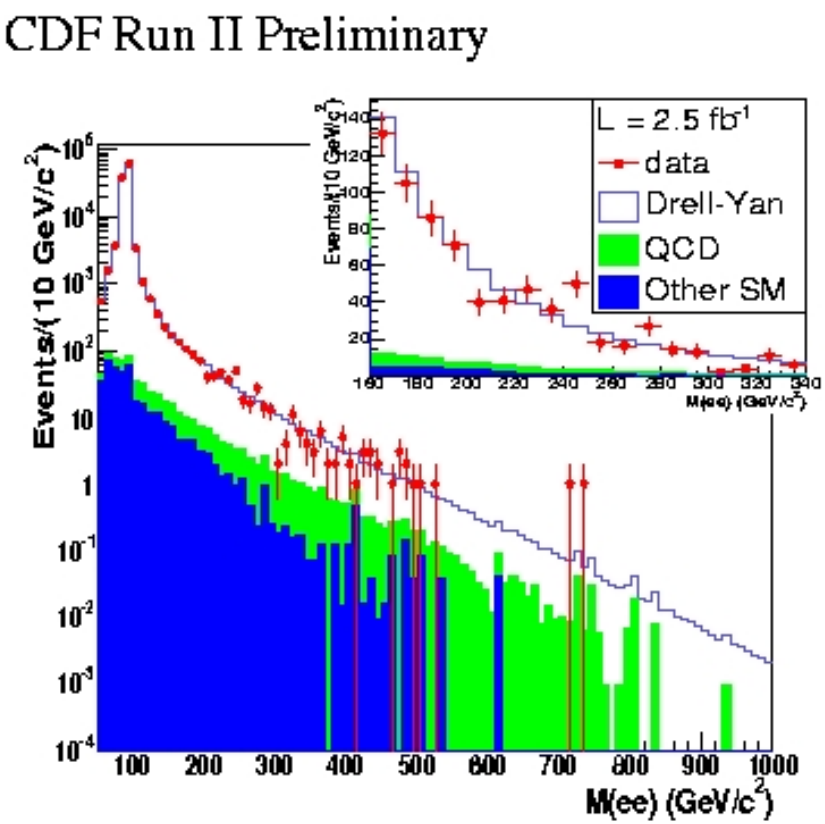
- Results of dijet mass analysis from CDF QCD group using same data sample as the dijet resonance analysis

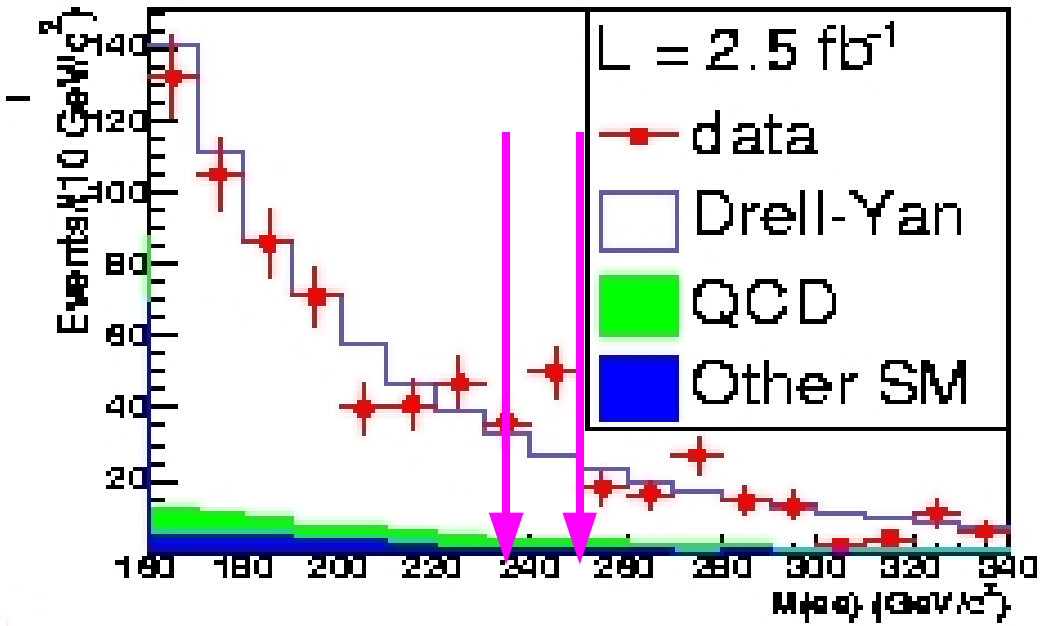




Dielectron Excess

eliminary



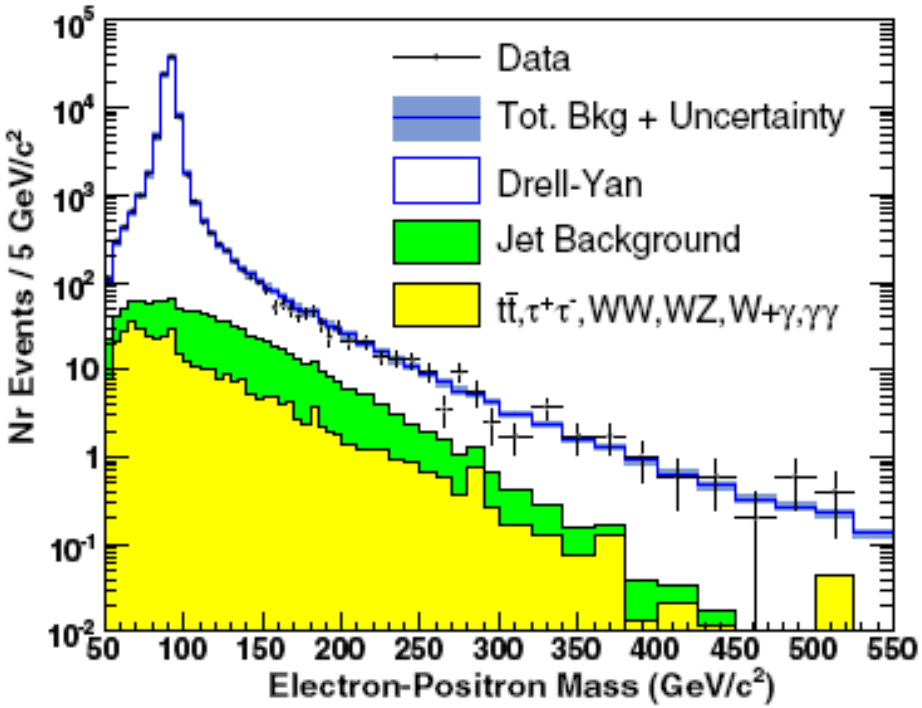


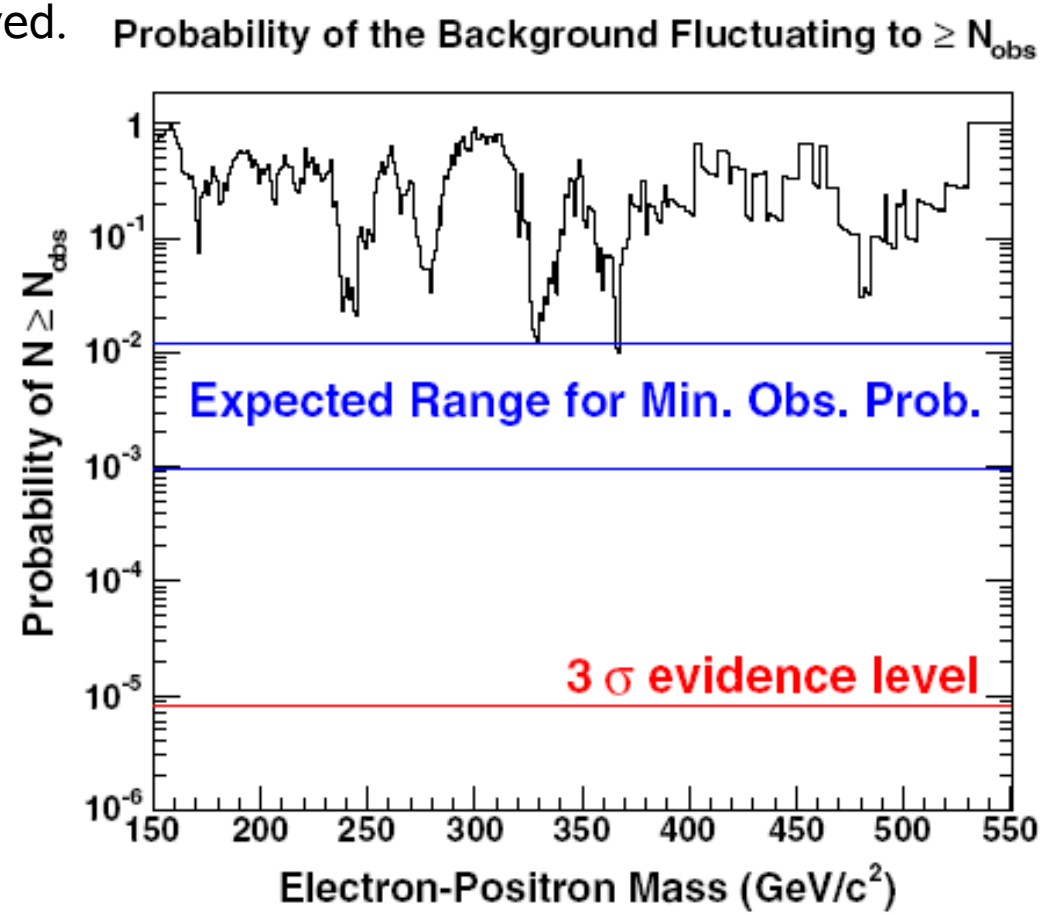
Most discrepant mass range

Mass resolution at 240 GeV about 5.5 GeV
Mass resolution at 500 GeV about 10.5 GeV

1.3 fb^{-1} Dielectron Result

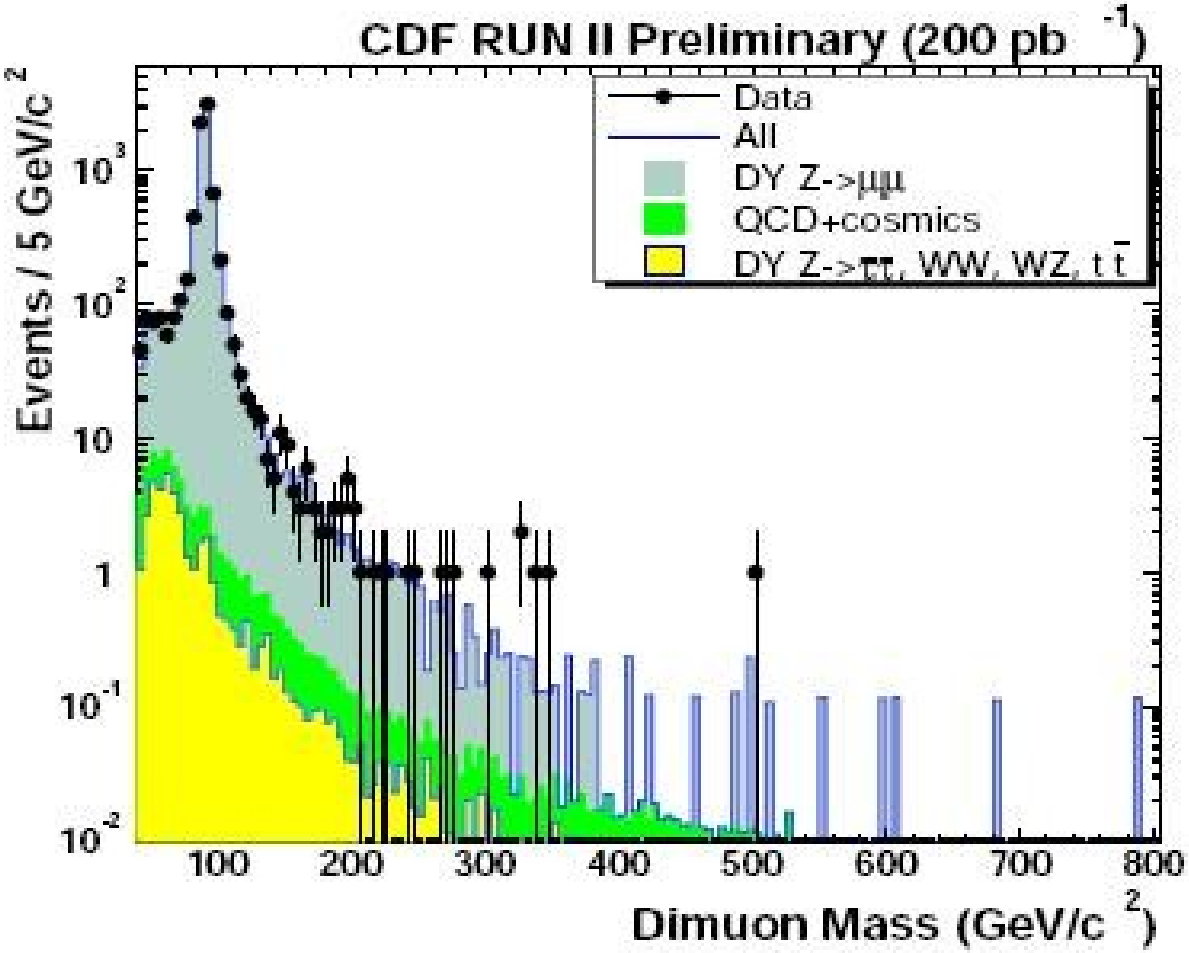
Perform sliding window search. Size of window based on mass resolution. No excess observed.





PRL **99**, 171802 (2007)

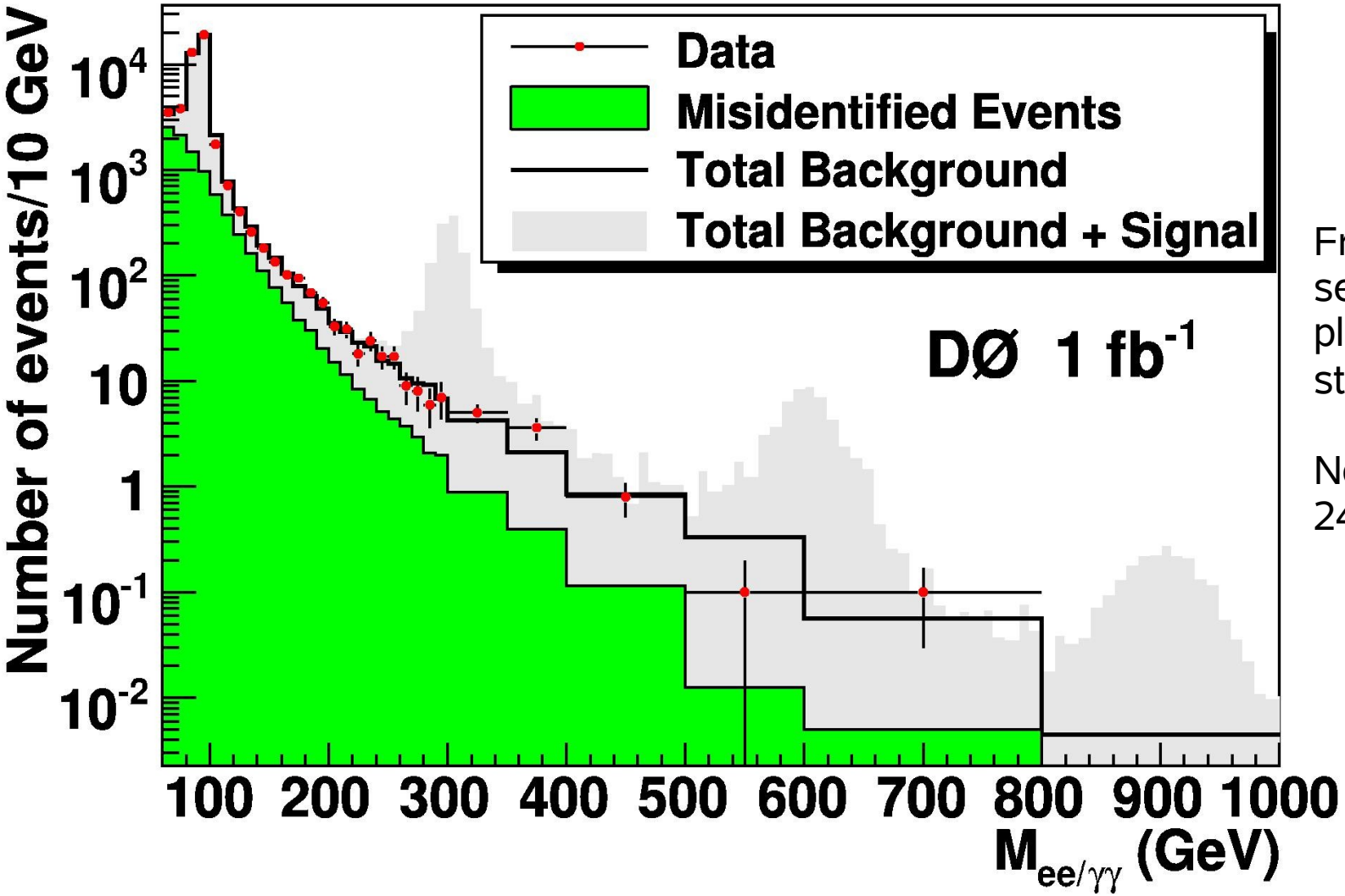
Dimuon Results



PRL **95**, 252001 (2005)

DiEM Results

PRL **100**, 091802 (2008)

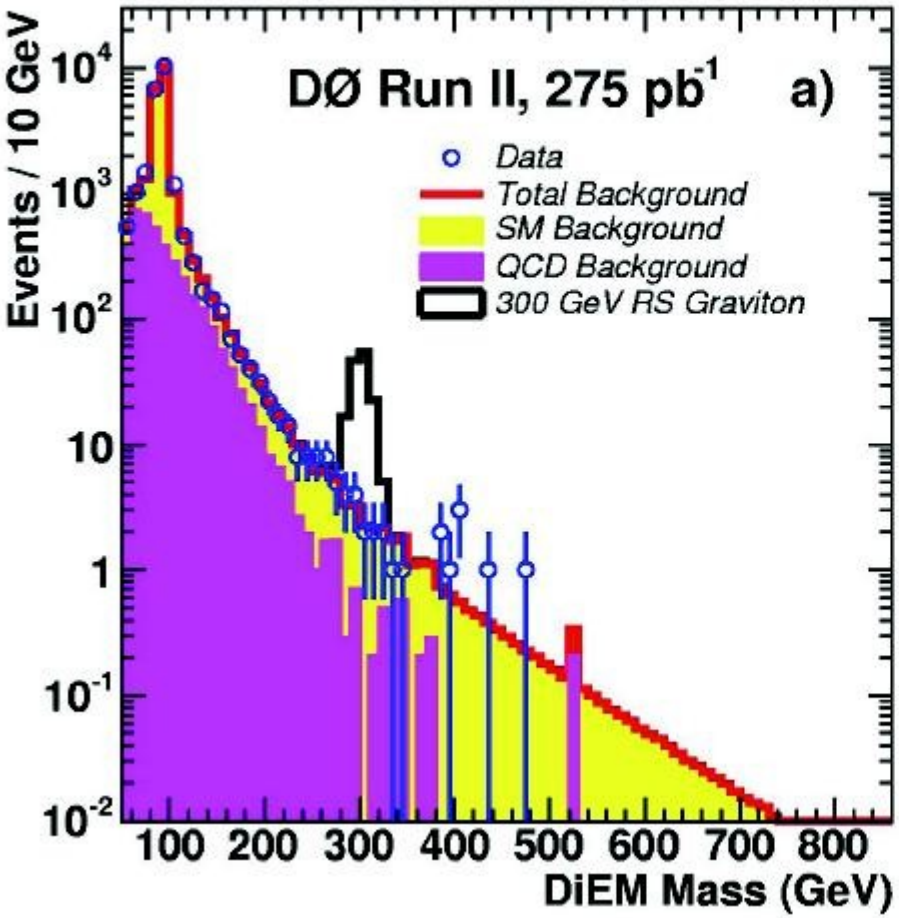


From RS graviton search in dielectron plus diphoton final state with 1 fb^{-1}.

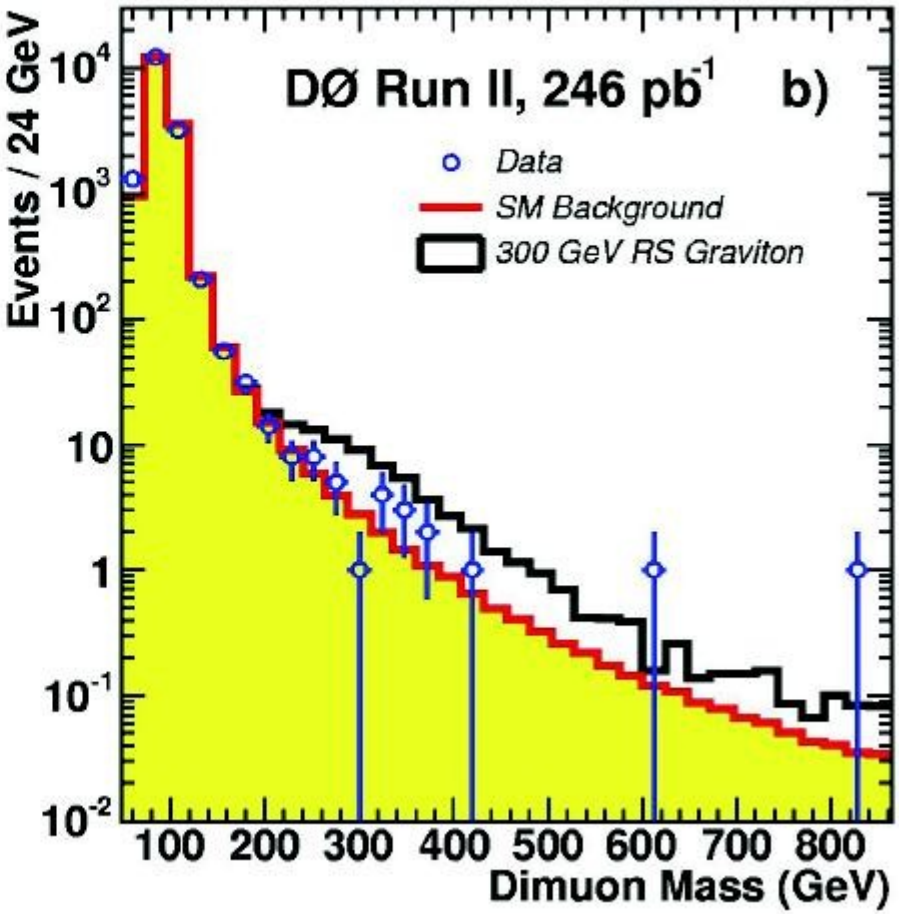
No excess visible at 240 GeV

Dilepton Results

Di-EM channel



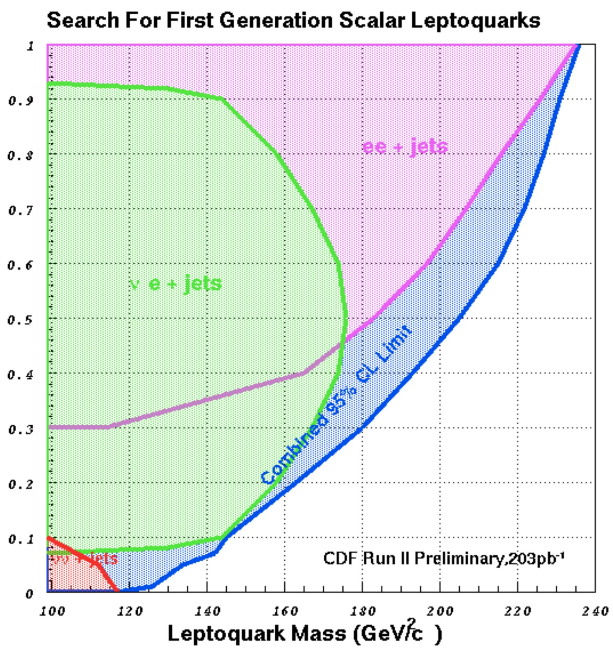
Di-Muon channel



hep-ex/0505018

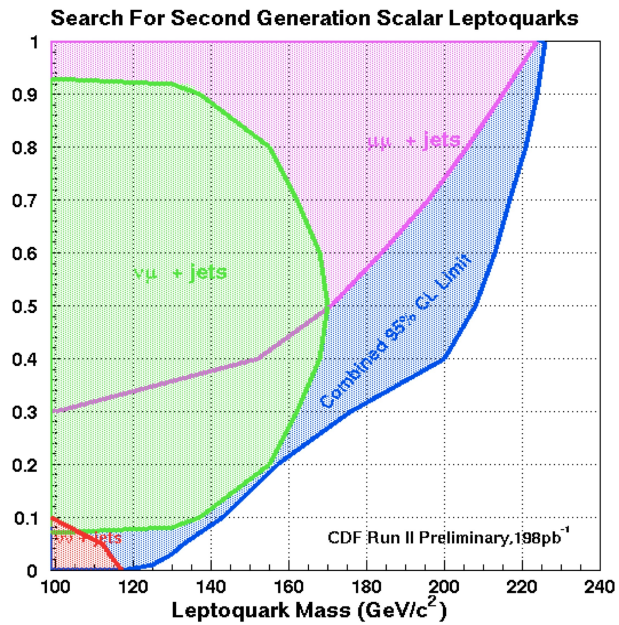
Leptoquark Results

1st generation scalar LQ, 203 pb^{-1}



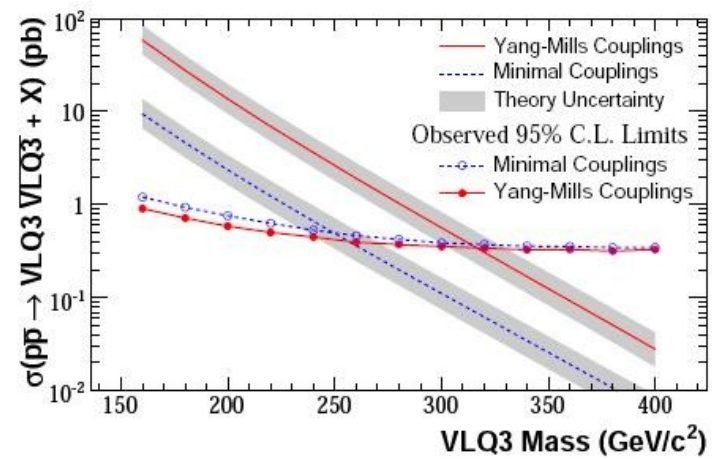
PRD **72**, 051107 (2005)
ejej, ejνj combined
m_{LQ} > 145 GeV (β = 1)

2nd generation scalar LQ, 198 pb^{-1}



PRD **73**, 051101 (2006)
μjμj, μjνj combined
m_{LQ} > 143 GeV (β = 1)

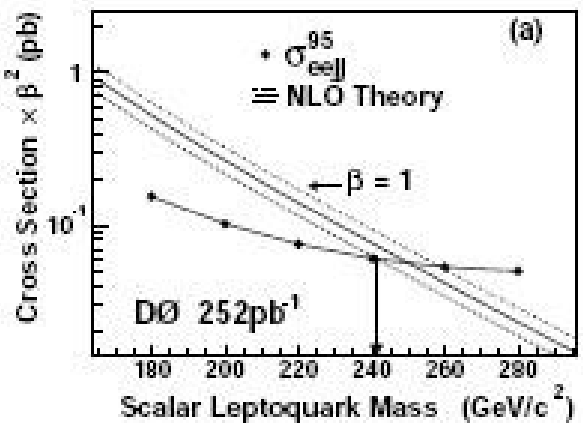
3rd generation vector LQ, 322 pb^{-1}



arXiv: 0706.2832, τbτb
m_{LQ} > 317 GeV (β = 1)

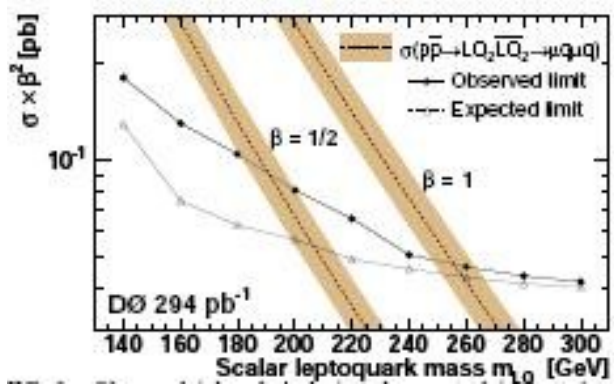
Leptoquark Results

1st generation scalar LQ, 252 pb^{-1}



PRD **71**, 071104 (2005)
m_{LQ} > 241 GeV (β = 1)

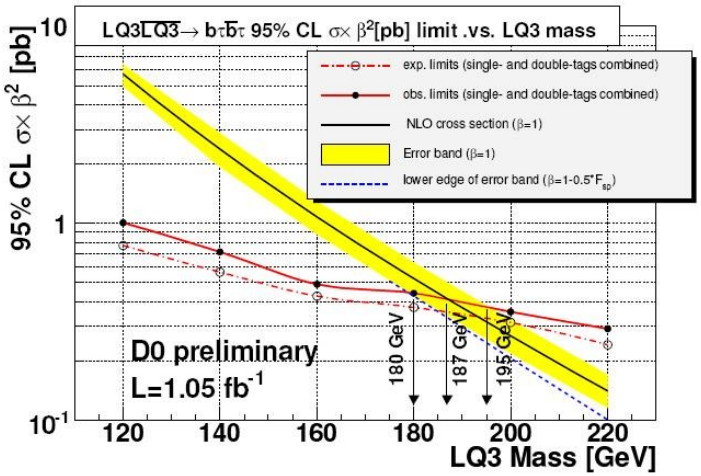
2nd generation scalar LQ, 300 pb^{-1}



PLB **636**, 183 (2006), μjμj
m_{LQ} > 247 GeV (β = 1)

PLB **647**, 74 (2007), μjνj
m_{LQ} > 274 GeV (β = 1)

3rd generation scalar LQ, 0.425 pb^{-1} - 1.05 fb^{-1}

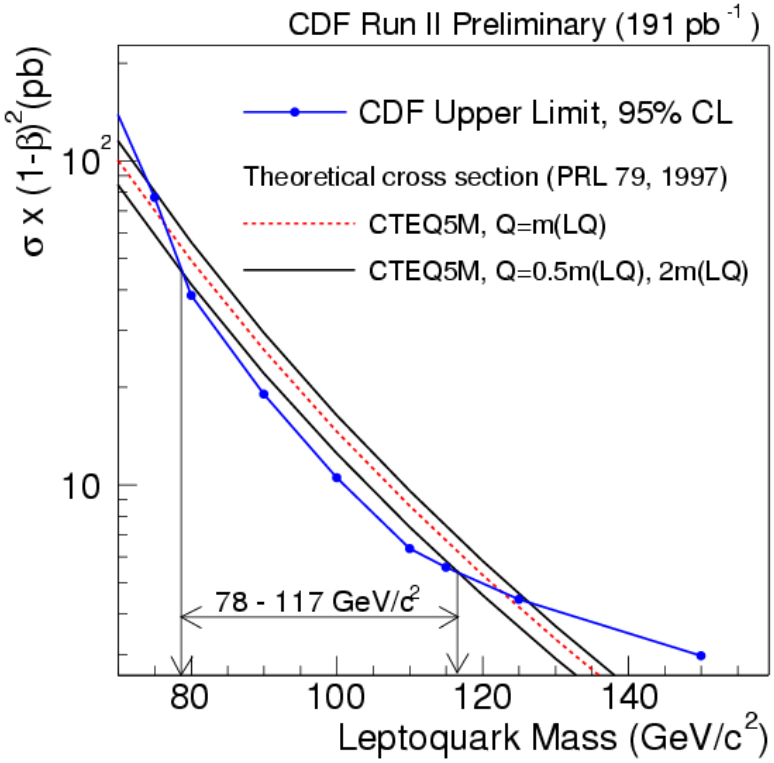


Preliminary, τbτb
m_{LQ} > 180 GeV (β = 1)
1.05 fb^{-1}

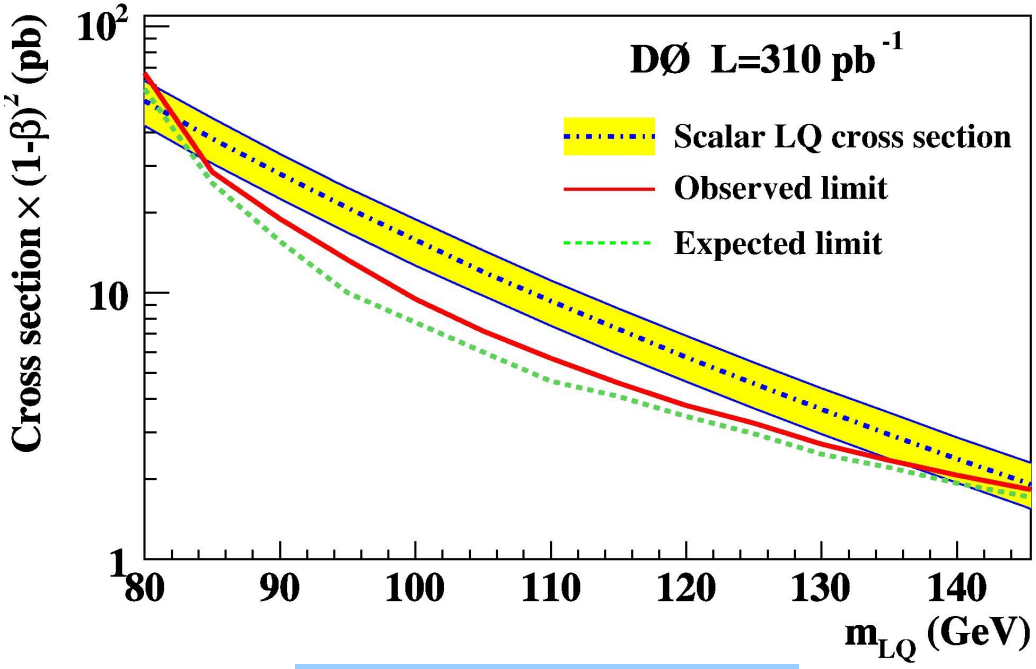
PRL **99**, 061801 (2007), νbνb
m_{LQ} > 229 GeV (β = 0)
425pb^{-1}

Michael Eads
University of Nebraska - Lincoln

Leptoquarks in Dijets+MET



PRD **71**, 112001 (2005)
m_{LQ} > 117 GeV (β = 0)



PLB **640**, 230 (2006)
m_{LQ} > 136 GeV (β = 0)