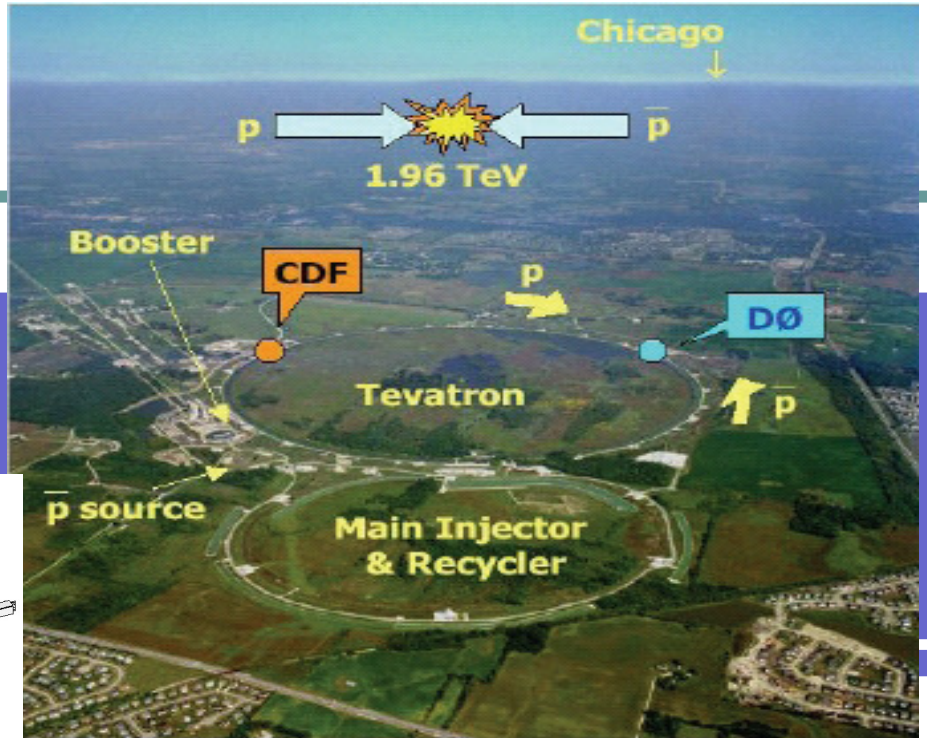
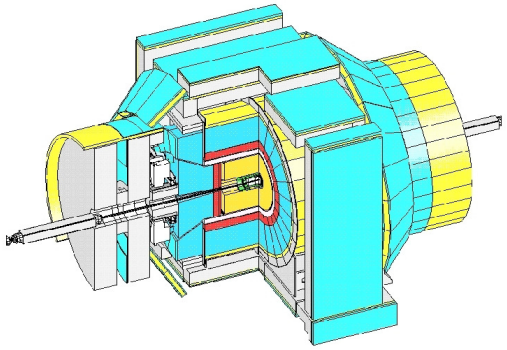
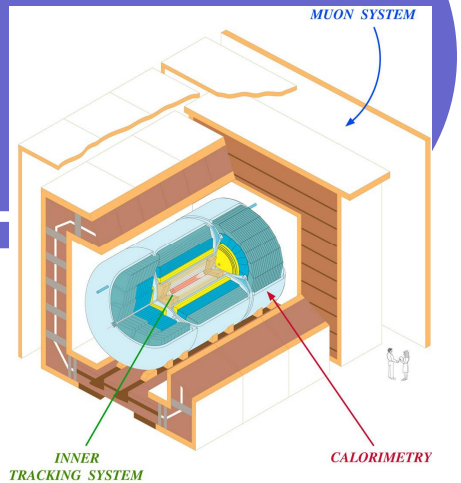


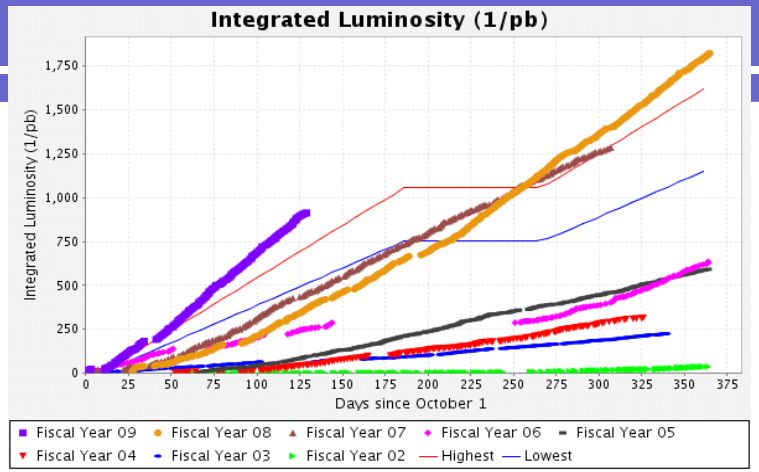




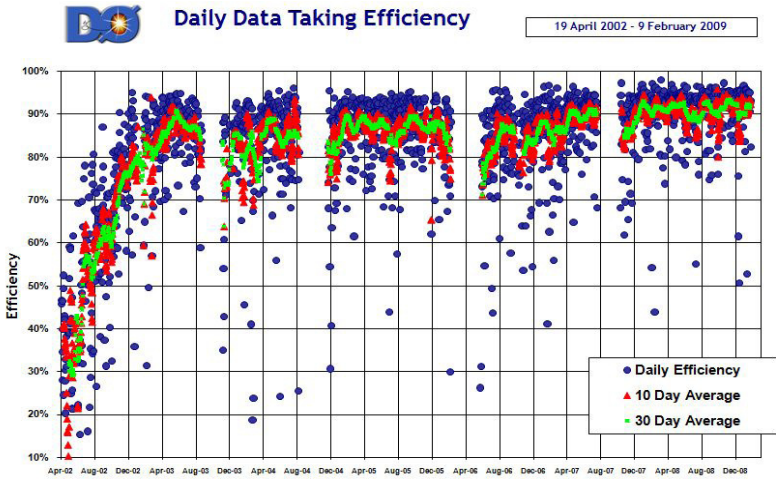
Non-SUSY Exotics Searches at the Tevatron

Alan Jonckheere - Fermilab

The Accelerator is running fantastically well.



And the Experiments aren't doing badly either.



Introduction

- The Standard Model of High Energy Physics is widely believed to be the correct low energy approximation to reality => But it's also clearly incomplete.
- There are many possible extensions to the SM. Super Symmetric (SUSY) models being the favorite ones at the moment. Those have been discussed by Miguel Vidal.
- This talk is somewhat a grab bag of searches motivated by all sorts of models, and some model independent.

Introduction

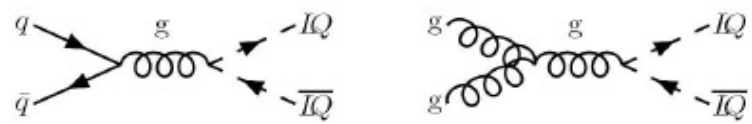
- Limiting our consideration to analyzes that use > 1 fb^{-1} of data (available Aug 06 and later) and not counting SUSY searches, searches for rare B states or other such searches, I count 30 published and preliminary results from the two experiments.
- Impossible to do justice to them all.
  - Leptoquarks
  - Large Extra Dimension
  - Technicolor
  - High Mass Resonances

Leptoquarks

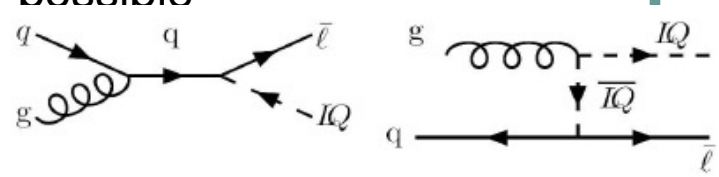
- Connect the Quark ↔ Lepton sectors
  - Compositeness
  - SUSY in RPV scenarios
  - Grand Unified Theories
  - Extended Technicolor
  - …
- Color triplets
  - Non-zero lepton (L) and baryon (B) numbers
  - Fractional charge Q=1/3, 2/3, 4/3, 5/3, …
  - Scalar (spin 0) α M_{LQ}
  - Vector (spin 1) α anomalous couplings λ_G κ_G also
- At hadron colliders, pair production through SM gauge couplings dominate.
- Bounds on Lepton number conservation, etc imply transitions between generations are highly suppressed or absent.

Dominant diagrams for

M_{LQ}> 100GeV/c^2



Single LQ production possible



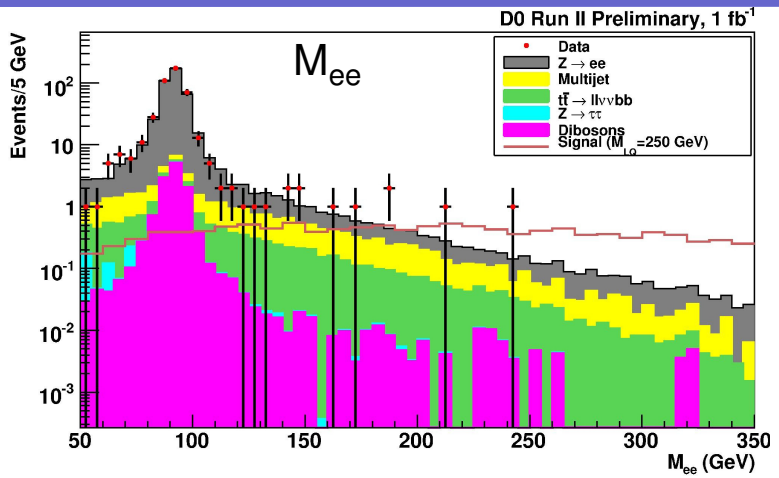
β=Br(LQ→ $l^{\pm}$q) (1-β)=Br(LQ→νq)

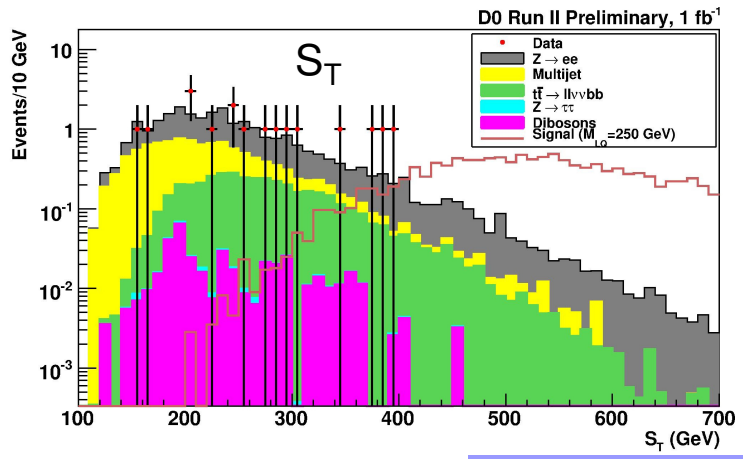
σxBr(l^+l^-qq) α β^2

σxBr($\nu\nu$qq) α $(1-\beta)^2$

σxBr($l\nu$qq) α $2\beta(1-\beta)$

Leptoquarks – 1st Gen





$LQ_1LQ_1 \rightarrow eejj$

$1.0 fb^{-1}$

- 2 "tight" electrons: pT > 25 GeV; $|\eta| < 1.1$ or $1.5 < |\eta| < 2.5$; DCA < 1cm from primary vertex
- 2 R=0.5 cone jets; > 0.5 from em object; leading jet > 25GeV; $|\eta|<2.5$
- M(ee) > 110GeV : S_T (sum of Scalar E_T of e+e+j+j) > 400 GeV
- 0 data events left: Bg = 1.5 ± 0.1 (stat) ± 0.12 (syst)
- Set limit on $\langle M_{ej} \rangle$ where the assignments are made to minimize the LQ-LQ mass difference.

http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/NP/N62/

Leptoquarks – 1st Gen

- Scalar LQ
- Minimal Coupling (MC) $\kappa_G=1$ $\lambda_G=0$
- Yang-Mills (YM) $\kappa_G=0$ $\lambda_G=0$
- Minus-Minus (MM) $\kappa_G=-1$ $\lambda_G=-1$
- σ_{obs}(MC)=0.015pb, $\sigma_{obs(YM,MM)}$=0.013pb

$Q=1/3$, $T_3=-1/2$, $\lambda_{eff}=e$

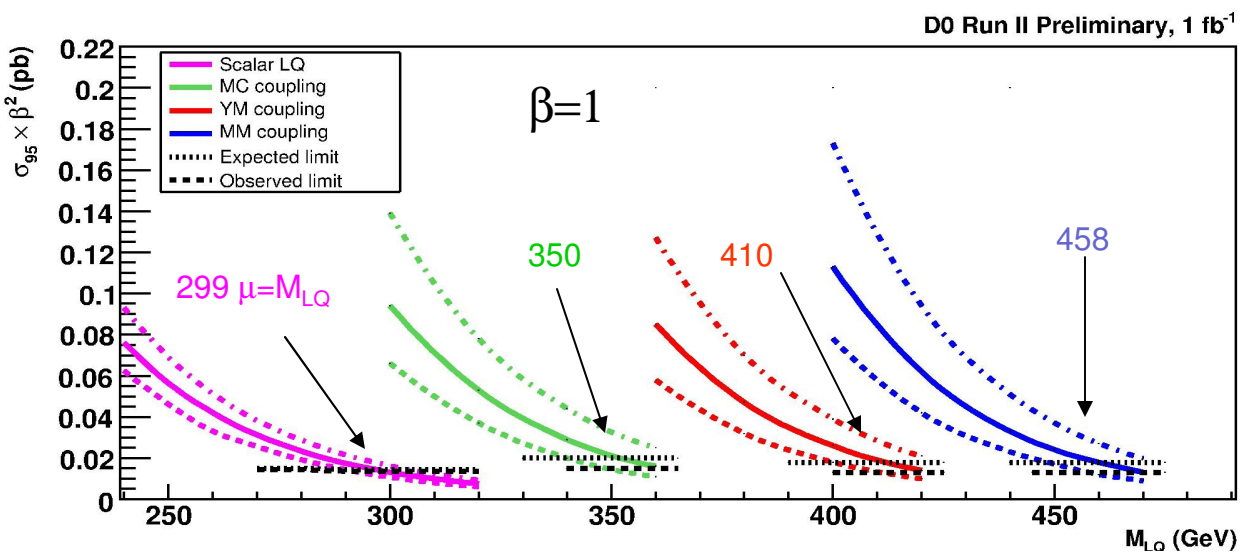
Top : $\mu = M_{LQ}/2$

Mid : $\mu = M_{LQ}$

Bot : $\mu = 2M_{LQ}$

$LQ_1LQ_1 \rightarrow eejj$

1.0 fb^{-1}

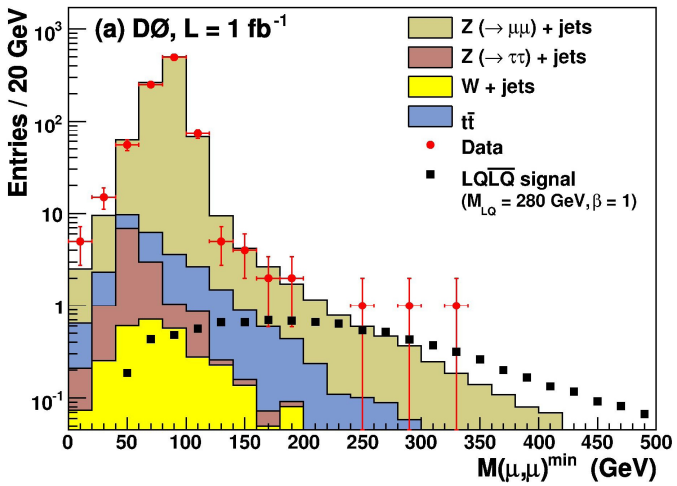


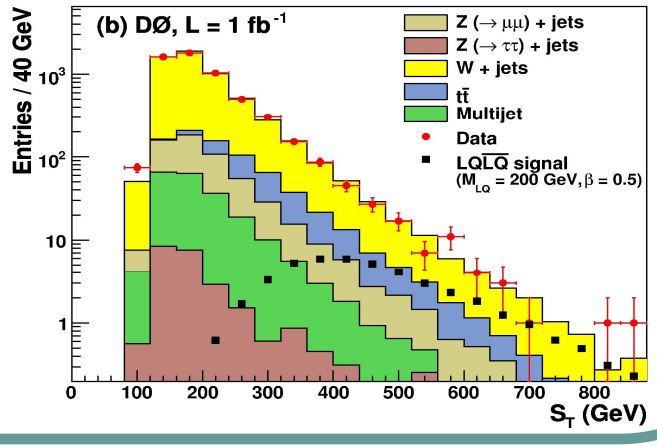
Leptoquarks - 2nd Gen

1.0 fb^{-1}

- Overview: $\rightarrow \mu\mu jj$ $\beta=1.0$
  - **2 jets:** E_T > 25GeV, $|\eta|$<2.5
  - **2 μ :** E_T > 20 GeV
  - S_T = Sum(E_T $\mu+\mu+j+j$) > 200 GeV
  - 6 kNN inputs S_T, M($\mu\mu$), M($\mu_i j_j$)
- Overview: $\rightarrow \mu\nu jj$ $\beta=0.5$
  - **2 jets:** ET > 25GeV, $|\eta|$<2.5
  - **1 μ :** ET > 20 GeV: MEt > 30 GeV
  - $M_T(\mu\nu)$ > 200 GeV
  - S_T = Sum(E_T $\mu+\nu+j+j$) > 200 GeV
  - **6 kNN** inputs: S_T, M_T(Met|j,j,μ), M(μ|j,j)

kNN=k Nearest Neighbor





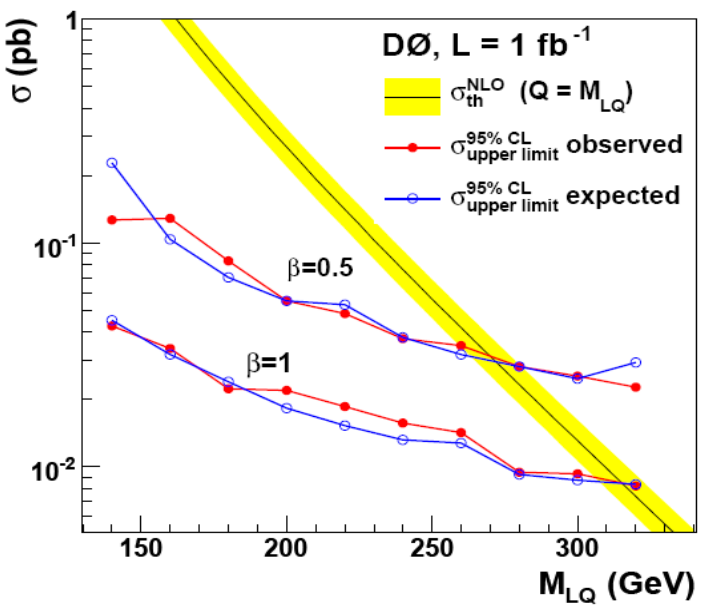
Leptoquark – 2nd Gen

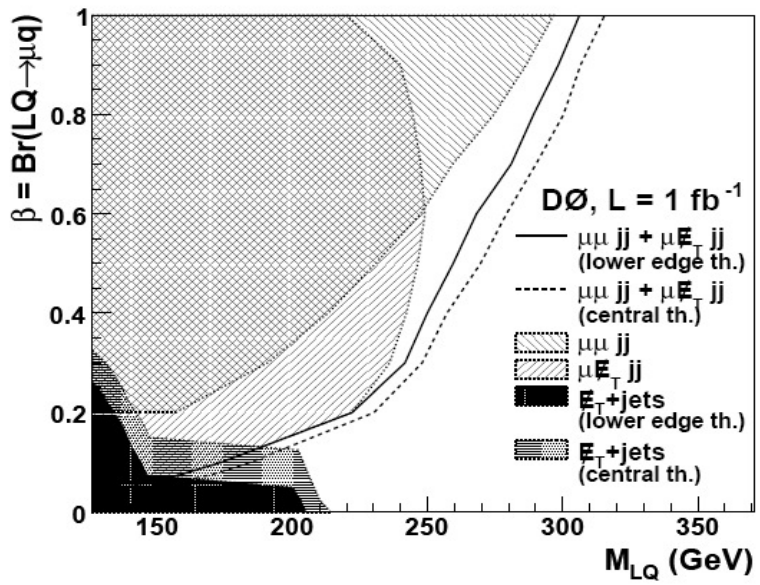
- PLB 671, 224 (2009)

1.0 fb^{-1}

M_{LQ} > 316 GeV (β=1)
M_{LQ} > 270 GeV (β=0.5)

$LQ_2LQ_2 \rightarrow \mu\mu jj$
$LQ_2LQ_2 \rightarrow \mu\nu jj$

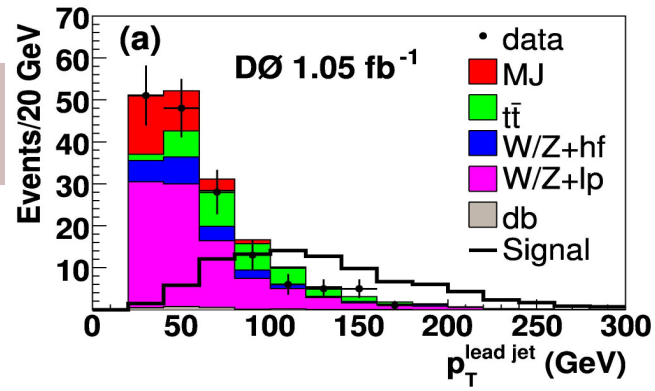


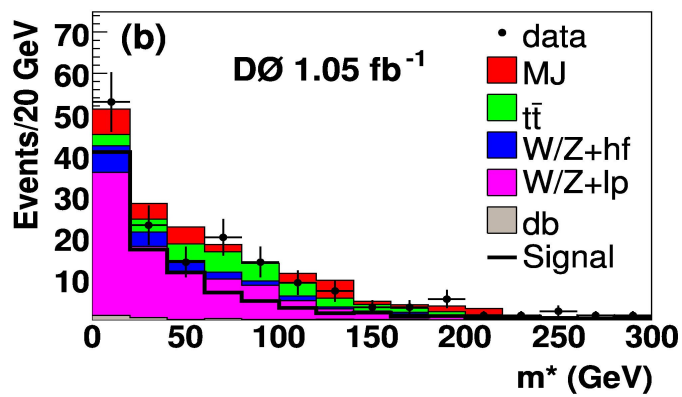


Leptoquark – 3rd GEN

- PRL 101, 241802 (2008)
- Charge 2/3 & 4/3
- $\tau \rightarrow \mu\nu\nu$ and $\tau \rightarrow h^{\pm}\nu$
  final state: b+b+μ+τ+MEt
- Bkg
  - W/Z + light jets (48%)
  - Top (15%)
  - QCD (13%)
  - W/Z + heavy flavors (10%)
- Selection
  - 2 τ candidates
    - τ_1: 1 isolated μ, E_T >15 GeV, $|\eta|$<2.0
    - τ_2: vis E_T > 15-20 GeV
      NN-based τ id (tracks + Cal info)
    - m^* < 60 GeV
  - 2 Jets
    - $E_T(j)$ > 20 GeV, $|\eta|$ < 2.5
    - **B-tagged** (optimized NN)

$LQ_3LQ_3 \rightarrow \tau\tau bb$
1.05 fb^{-1}



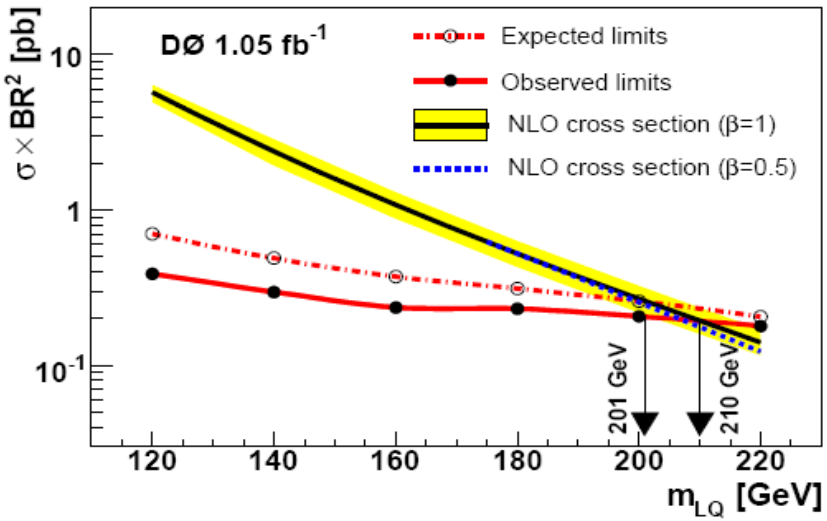


m^* is related to the W mass

Leptoquark – 3rd Gen

- Result:
  - Use S_T and sub-samples (1 b-tag and ≥ 2 b-tags) to set limits
  - Q=2/3 LQ → tν opens up just at this limit.
    - Phase space suppression calculated assuming $\beta = 0.5$, M_{top}= 175GeV

$LQ_3LQ_3 \rightarrow \tau\tau bb$
1.05 fb^{-1}



M_{LQ} > 210 GeV
β=1.0:central theory:2/3&4/3
M_{LQ} > 207 GeV
β=0.5: central theory: 2/3
M_{LQ} > 201 GeV
95% low theory: all

Leptoquarks – Any Gen

- Phys. Lett. B 668, 357 (2008)
- 2 jets: E_T>35GeV; $|\eta|$<0.8 (central)
- E_T^{miss} > 75 GeV
- H_T and E_T^{miss} optimized for low and high M_{LQ}

LQ LQ $\rightarrow \nu\nu jj$

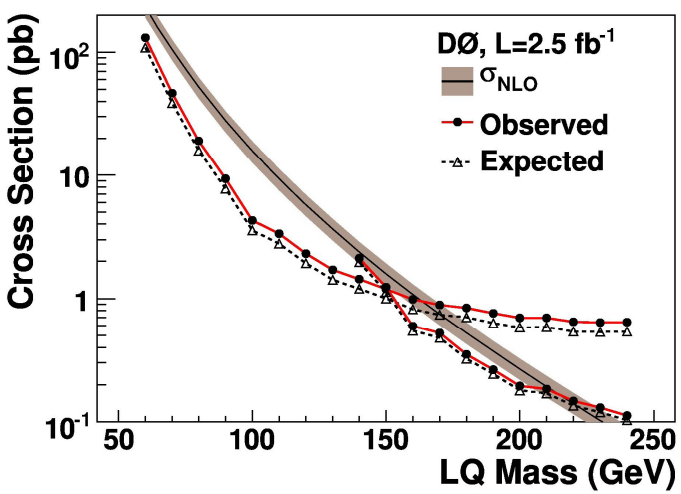
2.5 fb^{-1}

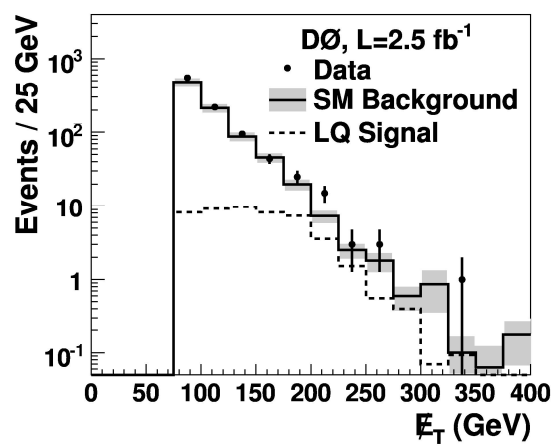
Bkg: $Z \rightarrow \nu\nu$ + jets

$W \rightarrow l\nu$ +jets (lepton veto)

dibosons, ttbar

M_{LQ}>205 GeV, β=0



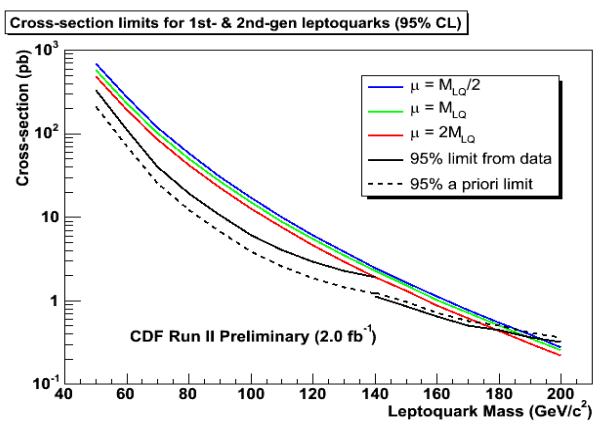


Leptoquarks Any Gen

Limit on all 3 generations : β=0, Q=1/3, 2/3

- Met + dijets
- Veto isolated leptons, 3rd jet
- 2 kinematic regions
  - Low: H_T>125 GeV, E_T^{miss}>80 GeV
  - High: H_T>225 GeV, E_T^{miss}>100 Gev

M_{LQ1}, M_{LQ2}>179GeV, M_{LQ3}>169GeV



LQ LQ → ννjj

2.0fb^{-1}

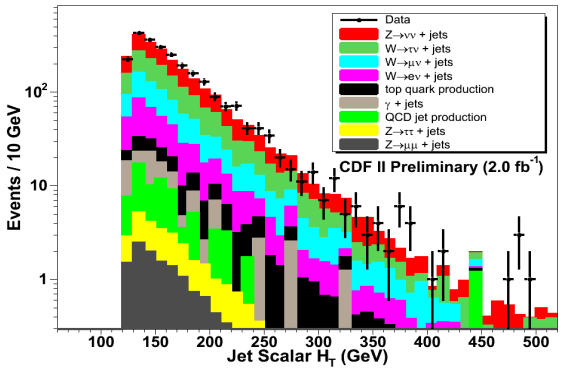
Bkg: Z → νν + jets (34%)

W → τν + jets (29%)

W → μν + jets (11%)

Z → ll + jets (1%)

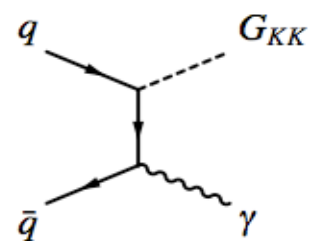
QCD, top… (8%)



http://www-cdf.fnal.gov/physics/exotic/r2a/20080403.dijetmet/dijet_mssm_lq/dijet_met_2fb.html

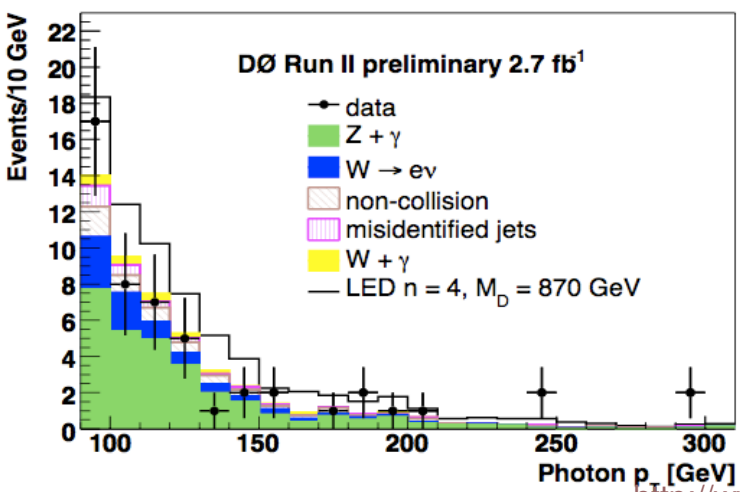
Large Extra Dimensions

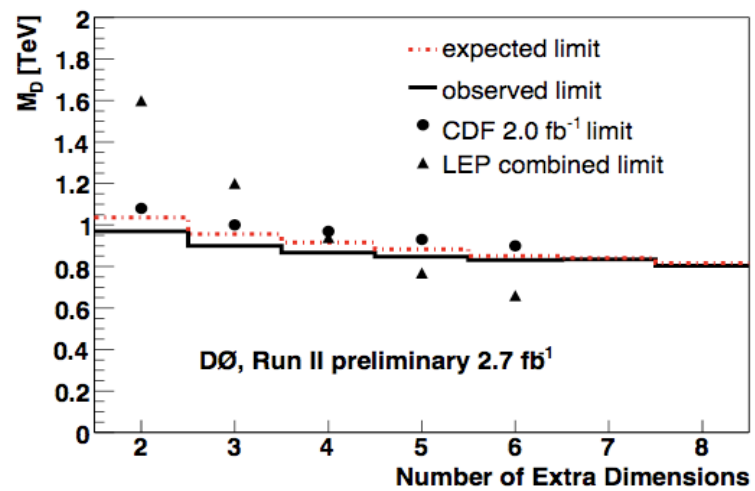
- Solution to the Hierarchy Problem?
- Arkani-Hamed, Dimopoulos and Dvali (ADD)
- Analysis overview
  - $|\eta|<1.1$; $E_T(\gamma)>90$GeV; MEt>70GeV
  - no jet with $E_T>15$GeV
  - no isolated track with $P_T>6.5$GeV
  - cosmics veto
  - EM shower pointing to primary vertex ($\delta z<10$ cm, $\sigma\sim2$cm)



2.7 fb^{-1}

$M_{Pl}^2 \sim R^n M_D^{n+2}$





http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/NP/N63/

Large Extra Dimensions

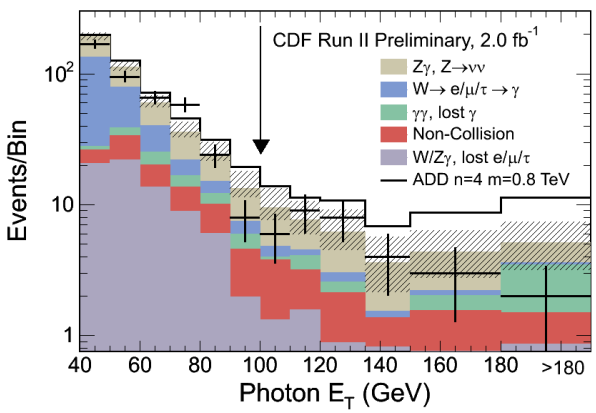
- PRL 101:181602 (2008)
- Overview
  - $E_T^{\gamma} > 90$ GeV; MEt > 50 GeV
  - No jet with $E_T > 15$ GeV
  - No tracks with $P_T > 10$ GeV

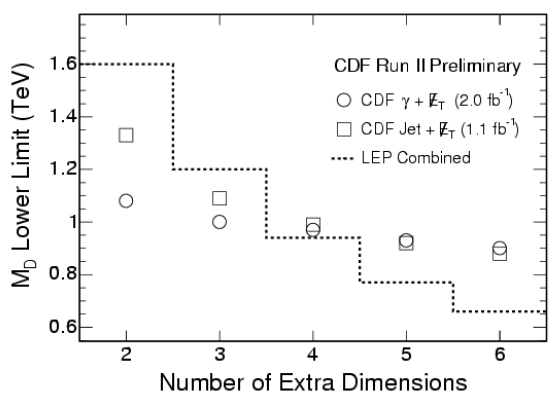
CDF RunII Preliminary, 2.0 fb^{-1}			
N LED	α (%)	σ^{95}_{obs} fb	M_D^{obs} GeV
2	7.2	84.7	1080
3	7.2	84.7	1000
4	7.6	80.4	970
5	7.3	82.7	930
6	7.2	84.4	900

2.0 fb^{-1}

Combined with Mono-jet analysis

$\rightarrow M_D > 1040$ GeV at n=4.

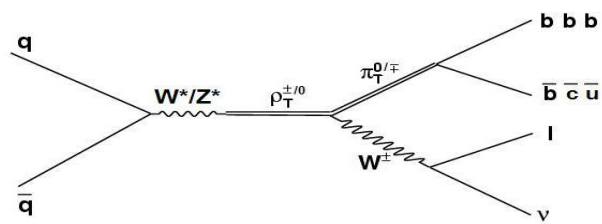


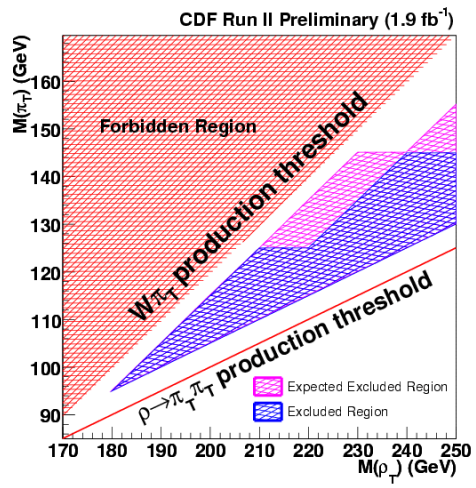


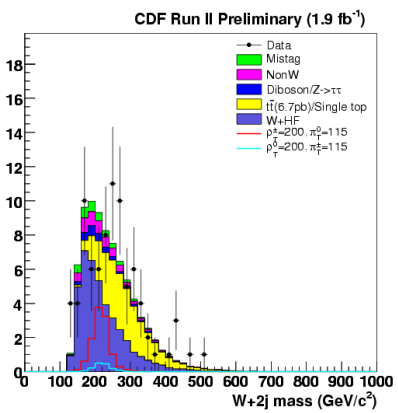
Technicolor

1.9 fb^{-1}

- jets; > 20 GeV, $|\eta| < 2.0$
  - 2 silicon b-tagged
  - 1 silicon, 1 jet prob
  - 1 silicon /w NNtg
- Central iso e or μ, Plug iso e; P_T>20GeV
- Met > 20 GeV (Central)
- Bkg: Wbbar, ttbar, …
- Limit: $m(W+2j):m(2j):Q=m(\rho_T)-m(\pi_T)-m(W)$







M(W)+m(2j)

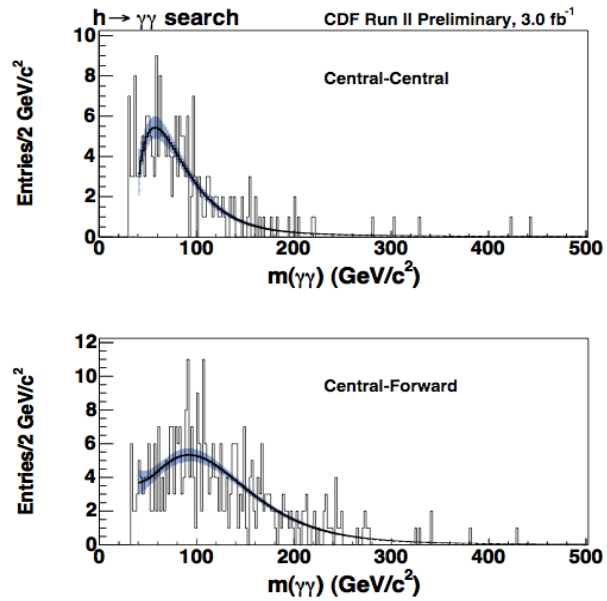
2 silicon tags

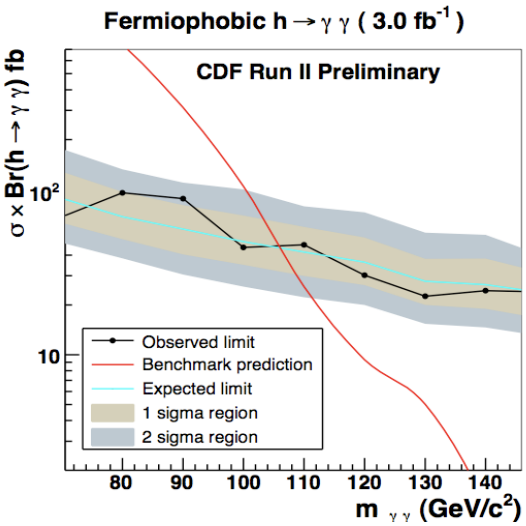
http://www-cdf.fnal.gov/physics/new/hdg/results/technicolor_080411/note/Tech1.9fb_public.pdf

Fermiophobic Higgs

- SM boson coupling, lepton coupling = 0
  - Gluon fusion forbidden -> x4 lower cross section
- 2 isolated c-c or c-p γ: $E_T^{\gamma} > 15$ GeV
- $M_{\gamma\gamma} > 30$ GeV/c^2; $P_T^{\gamma\gamma} > 75$ GeV
- Fit $M_{\gamma\gamma}$ with smooth function.

3.0 fb^{-1}





CDF $M_{Hf} > 106$ GeV/c^2

D0 $M_{Hf} > 100$ GeV/c^2

http://www-cdf.fnal.gov/physics/exotic/r2a/20081030.diphoton_higgs_fermiophobic/HiggsGamGamPub.pdf

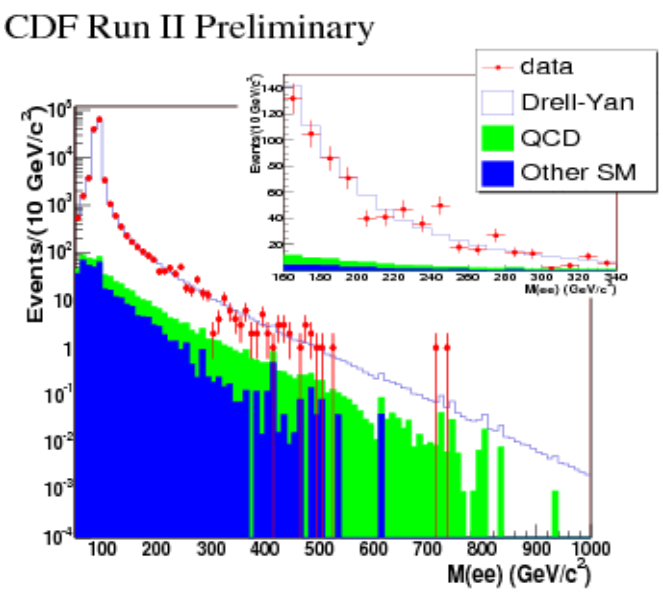
High Mass μμ resonances

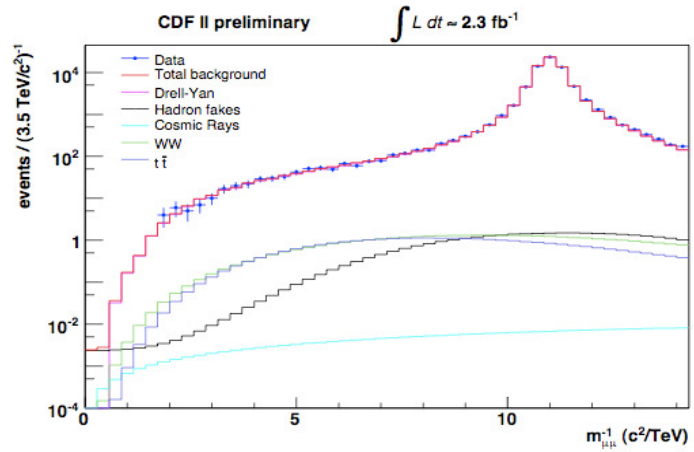
μμ resonances

2.3 fb^{-1}

Analysis overview

- 2 central muons with $P_T > 30$ GeV
- Search region $M_{\mu\mu} > 100$ GeV/c^2
- Dominant Bkg Drell-Yan



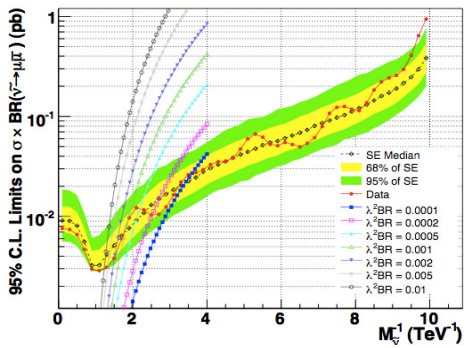


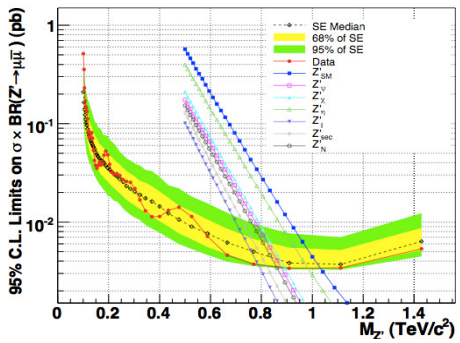
Agree with SM

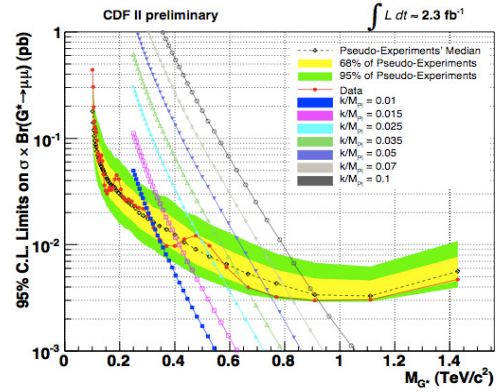
- Spin-0 Sneutrino
- Spin-1 Z'
- Spin-2 RS graviton

High Mass μμ resonances

CDF Preliminary - 2.3 fb^{-1}







Spin 0 - sneutrino

λ^2 • BR	Mass Limit, 95% CL (GeV/c^2)
0.01	866
0.005	810
0.002	731
0.001	662
0.0005	541
0.0002	441
0.0001	397

Spin 1 – Z'

Model	Mass Limits, 95% CL (GeV/c^2)
Z' (SM)	1030
Z' (η)	904
Z' (χ)	892
Z' (ψ)	878
Z' (N)	861
Z' (sec)	821
Z' (ι)	789

Spin 2 - RS Graviton

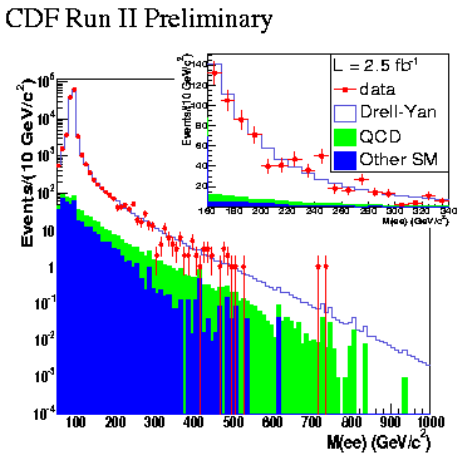
Graviton k/M_{Pl}	Mass Limit, 95% CL (GeV/c^2)
0.1	921
0.07	824
0.05	746
0.035	651
0.025	493
0.015	409
0.01	293

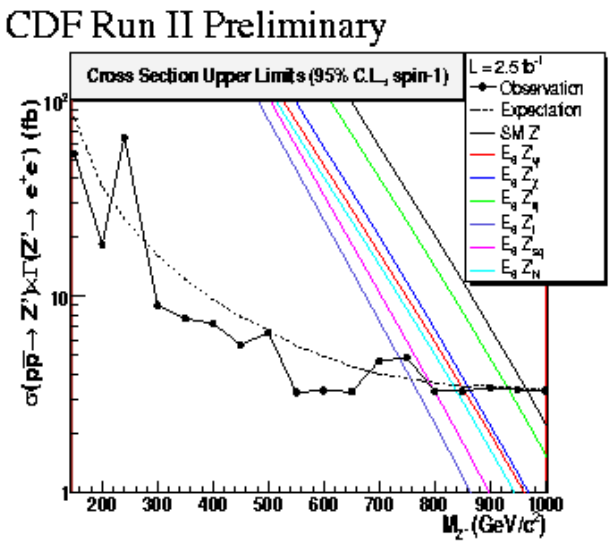
http://lanl.arxiv.org/abs/0811.0053

High Mass ee resonances

2.5 fb-1

- Overview
  - 1 central e, 1 central or plug e: $E_T > 25$GeV: $|\eta| < 2.0$
  - Plug e uses calorimeter seeded silicon tracking
- Bkg
  - Drell Yan
  - QCD dijet and W+jets with mismeasured jets
  - $Z/\gamma^* \rightarrow \tau\tau$, ttbar and diboson production





Spin 1:
SM Z' < 966 GeV excluded (965 expected)
E_6 Z' < 737-933 Gev depending on model

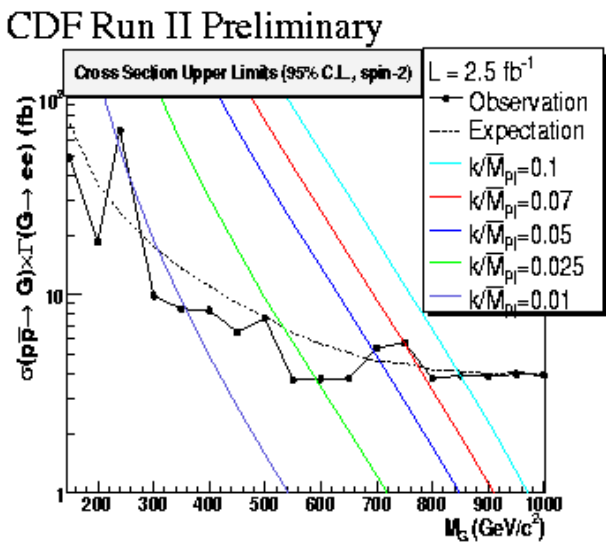
High Mass ee resonances

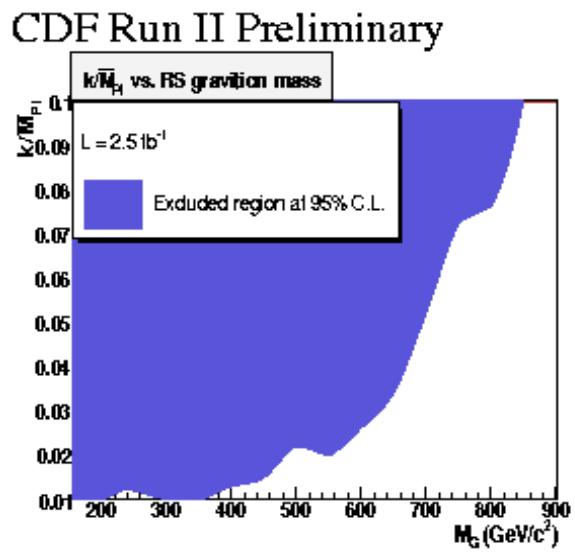
Randal-Sundrum Gravitons

- Spin 2
- k = negative curvature
- M_{Pl} = effective Planck mass

2.5 fb^{-1}

M_G > 850 GeV : k/M_{pl}=0.1





http://www-cdf.fnal.gov/physics/exotic/r2a/20080306.dielectron_duke/pub25/cdfnote9160_pub.pdf

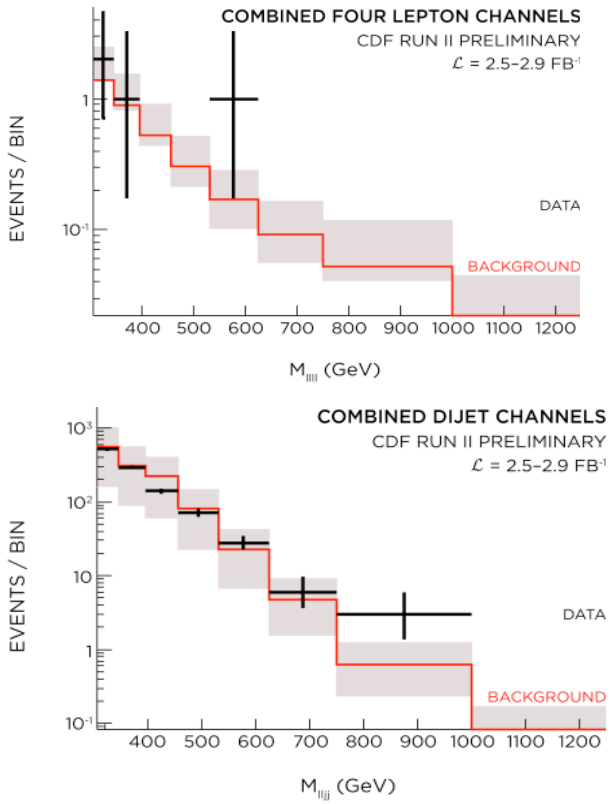
$X \rightarrow ZZ$

2.5-2.9 fb^{-1}

- Signature
  - RS graviton
  - $H \rightarrow ZZ$ ($M_H > 180$ GeV)
  - $ZZ \rightarrow llll$ is clean experimentally
- Overview (2.5-2.9 fb^{-1})
  - eeee, eeμμ, μμμμ : intermediate masses
    - $M_X > 300$ GeV : $\chi^2 < 50$
    - Bkg sideband: evts with 2 or 3 fake leptons

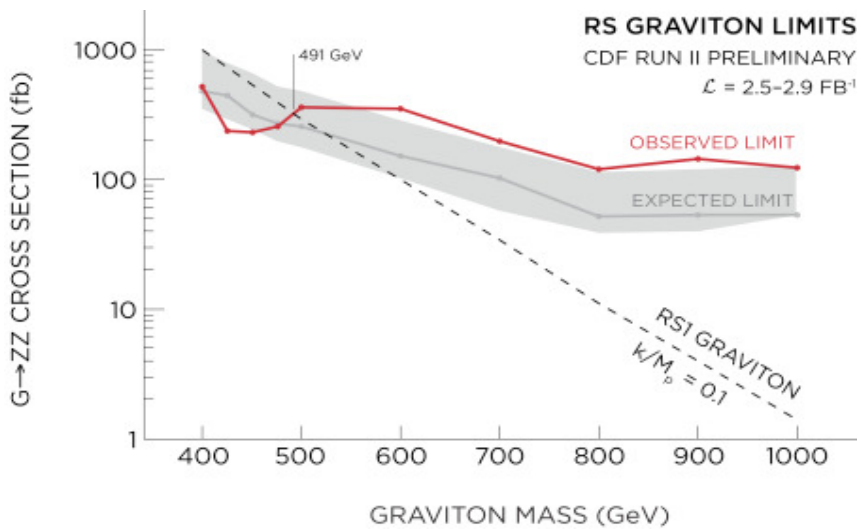
$$\chi^2_{ZZ}=\Sigma_{1,2}(\Delta M_{Zi})^2/(\sigma^2_{Mi}+\sigma^2_{\Gamma})$$

  - eejj, μμjj: very high masses
    - $M_X > 300$ GeV: $65 < M_{jj} < 120$ GeV
    - Bkg sideband: $40 < M_{jj} < 65$: $120 < M_{jj} < 200$ GeV



X → ZZ

2.5-2.9 fb $^{-1}$



RS graviton for k/M_p=0.1 : M > 491 GeV/c^2

http://www-cdf.fnal.gov/physics/exotic/r2a/20081120.ZZ_resonance/public.pdf

Conclusions

- There is a tremendous amount of enthusiasm and resulting activity at both CDF and D0
- New results have been, are and will continue to come out, almost daily.
- The Standard Model is alive and well.
- But we continue to look for anything beyond….

Other results

- Charged Stable Massive Particles
  - http://arxiv.org/abs/0809.4472

1.1 fb^{-1}

- I intend to add others here from both experiments.
- Suggestions welcome!