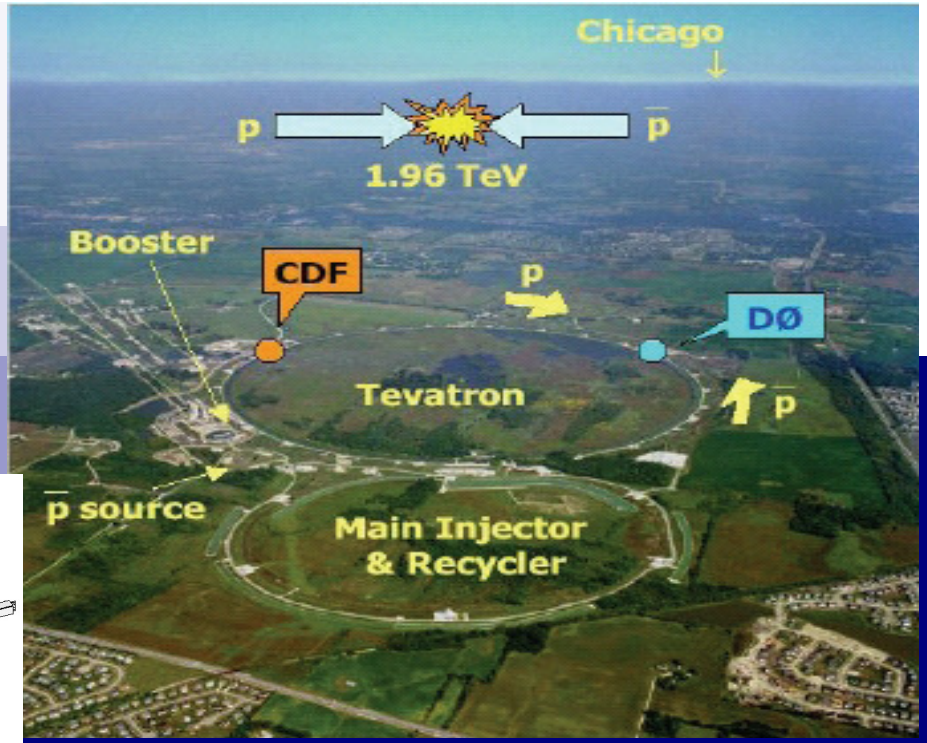
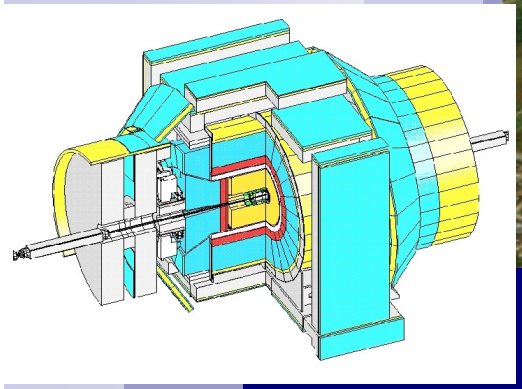
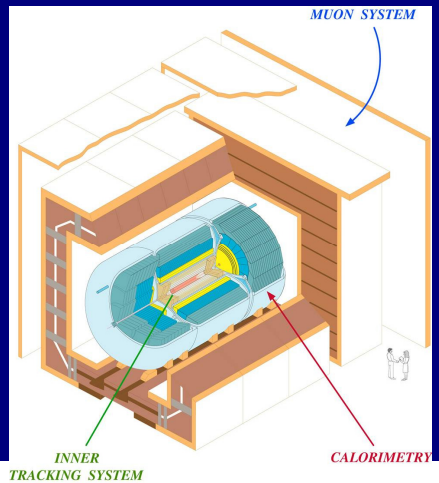






Search for Physics Beyond the Standard Model (Non-SUSY) at the Tevatron

Alan Jonckheere - Fermilab

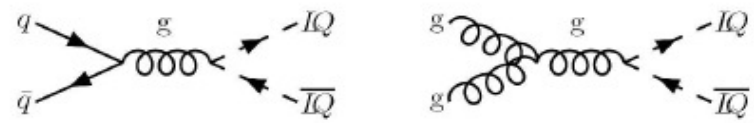
Introduction

- Standard Model of High Energy Physics (SM)
  - correct low energy approximation to reality
  - also clearly incomplete.
- Many possible extensions
- Beyond the Standard Model (BSM) searches
  - motivated by all sorts of models
  - Many model “independent”
  - Super Symmetric (SUSY) models = favorite
    - Discussed by Miguel Vidal
- Count 30 published and preliminary results
  - > 1 fb^{-1} of data (available Aug 06 and later)
  - Not counting SUSY searches, rare B states etc
- This talk will cover only
  - Leptoquarks
  - Large Extra Dimension
  - Technicolor
  - High Mass Resonances

Leptoquarks

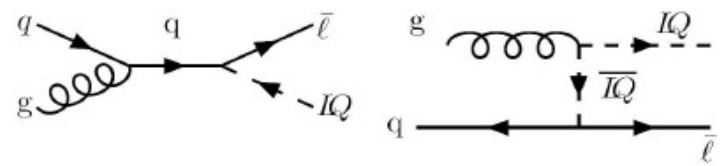
Dominant diagrams for

M_{LQ}> 100 GeV/c^2



- 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
  - Q = 1/3, 2/3, 4/3, 5/3, …
  - Scalar (spin 0) α M_{LQ}
  - Vector (spin 1) α λ_G κ_G as well
- Bounds on Lepton number conservation, fcnc, etc → suppression of transitions between generations
- β=Br(LQ→ $l^{\pm}$q) (1-β)=Br(LQ→νq)

Single LQ production possible

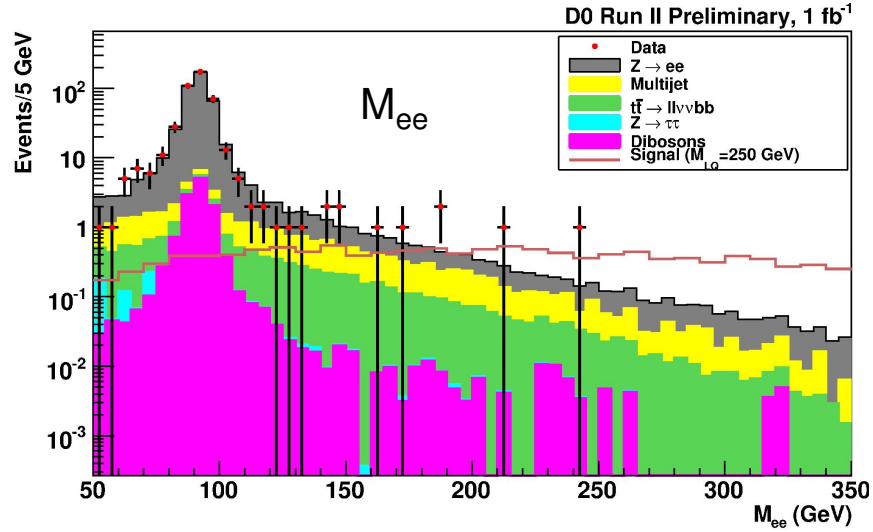


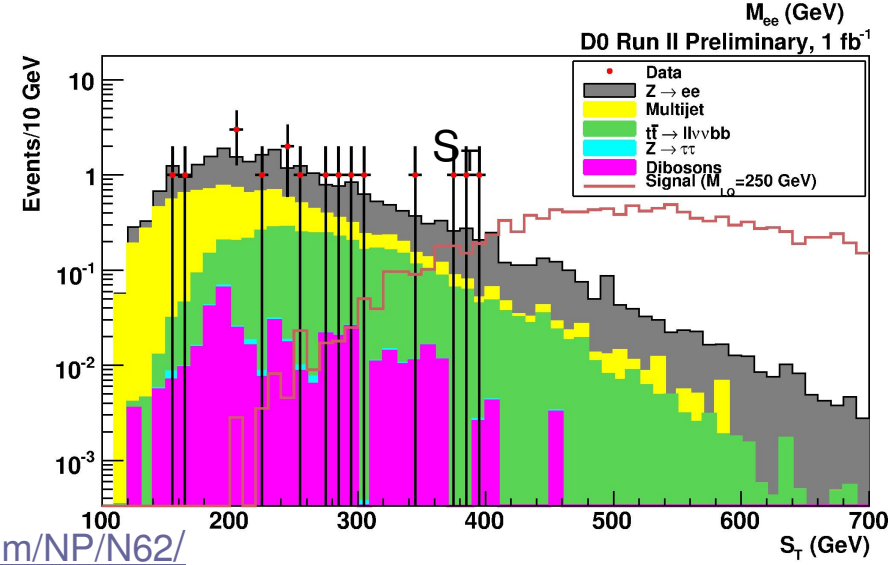
Leptoquarks - 1st Gen

$LQ_1LQ_1 \rightarrow eejj$

1 fb^{-1}

- 2 "tight" electrons
  - $p_T > 25$ 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 (Σ Scalar E_T of e+e+j+j) > 400 GeV
- $\rightarrow$ 0 data events
  - Bkg = 1.5 $\pm$ 0.1 (stat) $\pm$ 0.12 (syst)
- Set limit on $\langle M_{ej} \rangle$
  - 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) = 0.015 pb, $\sigma_{obs(YM,MM)}$= 0.013 pb

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

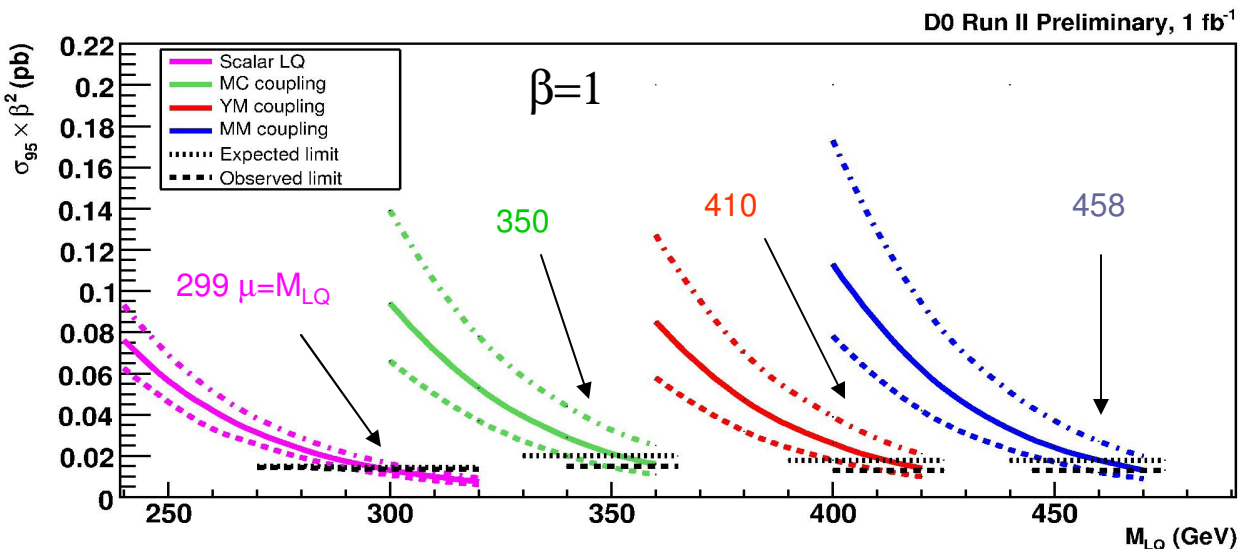
Top : $\mu = M_{LQ}/2$

Mid : $\mu = M_{LQ}$

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

$LQ_1LQ_1 \rightarrow eejj$

1 fb^{-1}

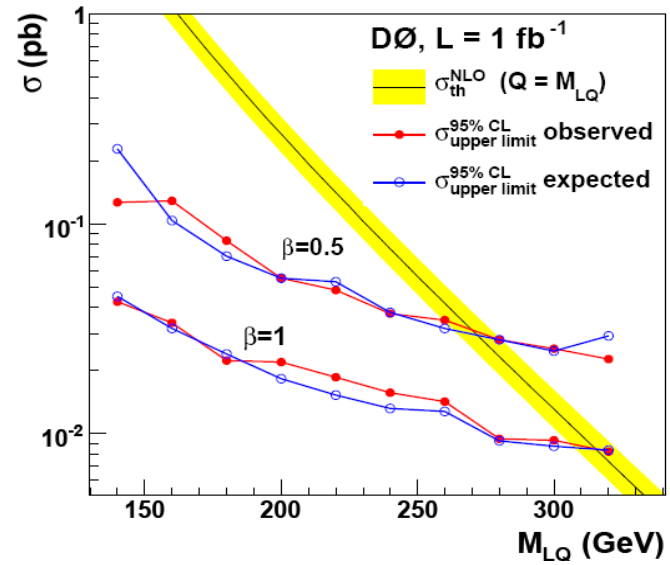


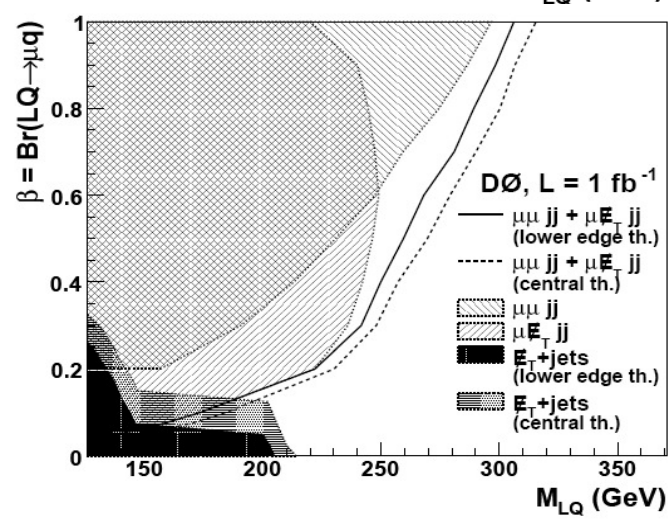
Leptoquarks - 2nd Gen

1 fb^{-1}

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

- PLB 671, 224 (2009)
- Overview: $\rightarrow \mu\mu jj$
  - **2 jets:** E_T > 25 GeV, $|\eta|$<2.5
  - **2 μ :** E_T > 20 GeV
  - $\mathbf{S_T}$ = Sum(E_T μ+μ+j+j) > 200 GeV
  - **NN** inputs S_T, M(μμ), M($\mu_i j_j$)
- Overview: $\rightarrow \mu\nu jj$
  - **2 jets:** ET > 25 GeV, $|\eta|$<2.5
  - **1 μ :** ET > 20 GeV
  - **MEt** > 30 GeV: $\mathbf{M_T(\mu\nu)}$ > 200 GeV
  - $\mathbf{S_T}$ = Sum(E_T μ+ν+j+j) > 200 GeV
  - **NN** inputs: S_T, M_T(Met|j,j,μ), M(μ|j,j)





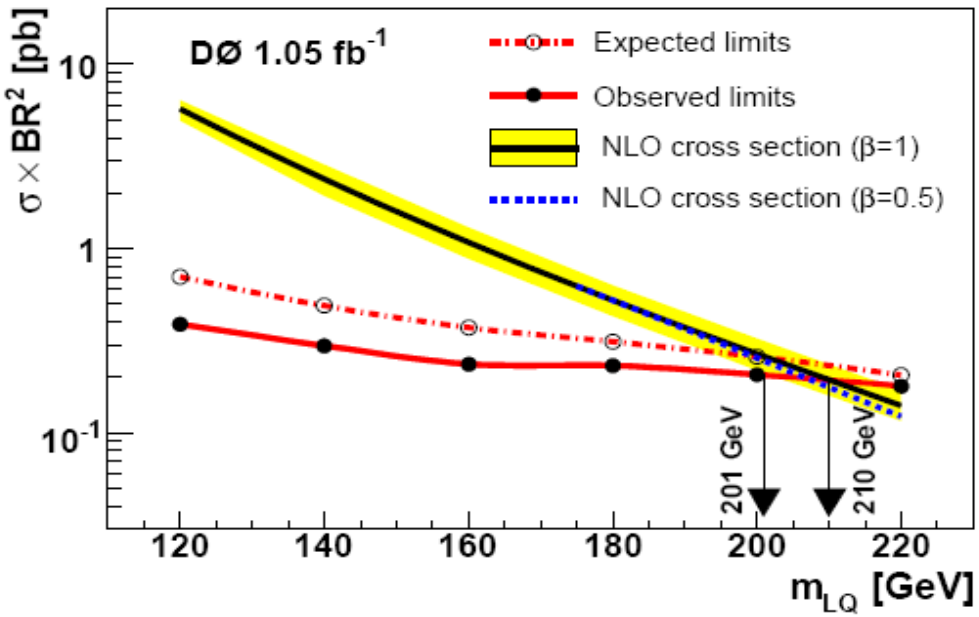
M_{LQ} > 316 GeV (β=1)
M_{LQ} > 270 GeV (β=0.5)

Leptoquarks - 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, |η|<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)
- **Result**
  - **S_T : 1** and **2** b-tags sub-samples
  - **Q=2/3** LQ → tν opens up at the limit
    - **Phase space suppression assumes β = 0.5, m_{top} = 175GeV**

M_{LQ} > 210 GeV
β=1.0: Q = 2/3&4/3
M_{LQ} > 207 GeV
β=0.5: Q = 2/3

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



Leptoquarks - Any Gen

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

LQ LQ $\rightarrow \nu\nu jj$

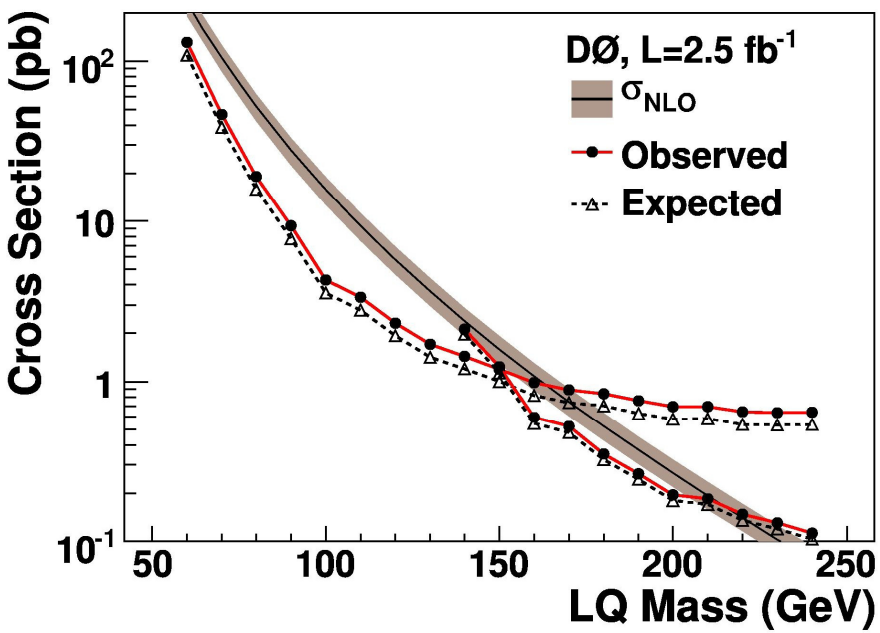
2.5 fb^{-1}

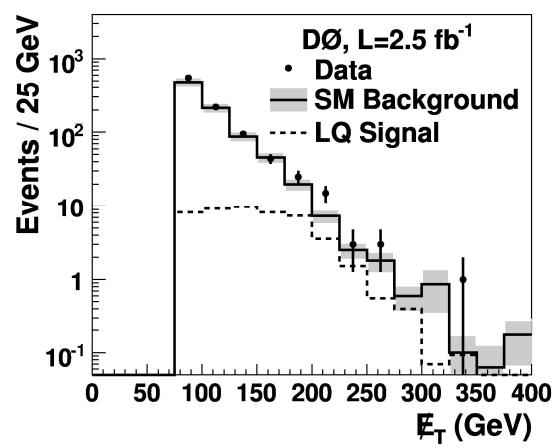
Bkg: $Z \rightarrow \nu\nu$ + jets

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

dibosons, ttbar

M_{LQ}>205 GeV, β=0





Leptoquarks - Any Gen

Limit on all 3 generations : $\beta=0$, 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}>179 GeV, M_{LQ3}>169 GeV

LQ LQ $\rightarrow \nu\nu jj$

2.0fb^{-1}

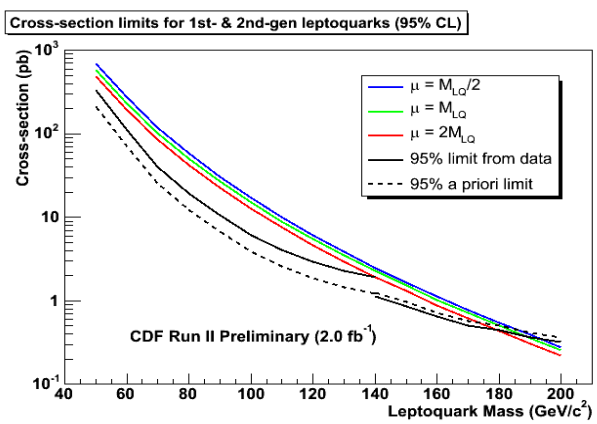
Bkg: $Z \rightarrow \nu\nu$ + jets (34%)

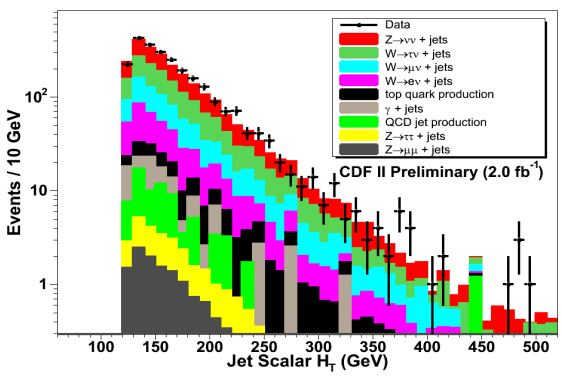
$W \rightarrow \tau\nu$ + jets (29%)

$W \rightarrow \mu\nu$ + jets (11%)

$Z \rightarrow ll$ + jets (1%)

QCD, top… (8%)

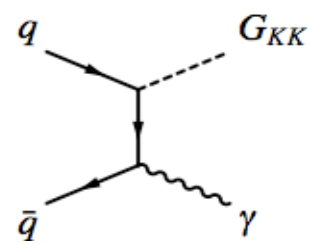




http://www-cdf.fnal.gov/physics/exotic/r2a/20080403.dijetmet/dijet_mssm_lq/dijet_met_2fb.html

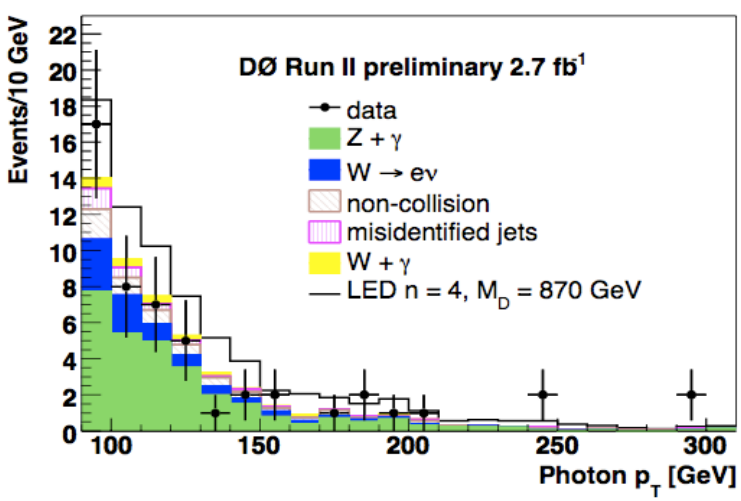
Large Extra Dimensions

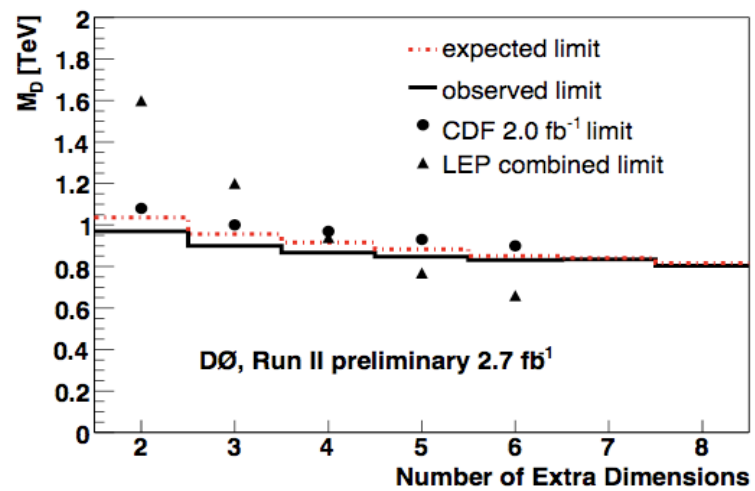
- Solution to the Hierarchy Problem?
- Arkani-Hamed, Dimopoulos and Dvali (ADD)
- Analysis overview
  - $|\eta|<1.1$; $E_T(\gamma)>90$ GeV; MEt>70 GeV
  - no jet with $E_T>15$ GeV
  - no isolated track with $P_T>6.5$ GeV
  - cosmics veto
  - EM shower pointing to primary vertex ($\delta z<10$ cm, $\sigma\sim2$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



2.7 fb^{-1}

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





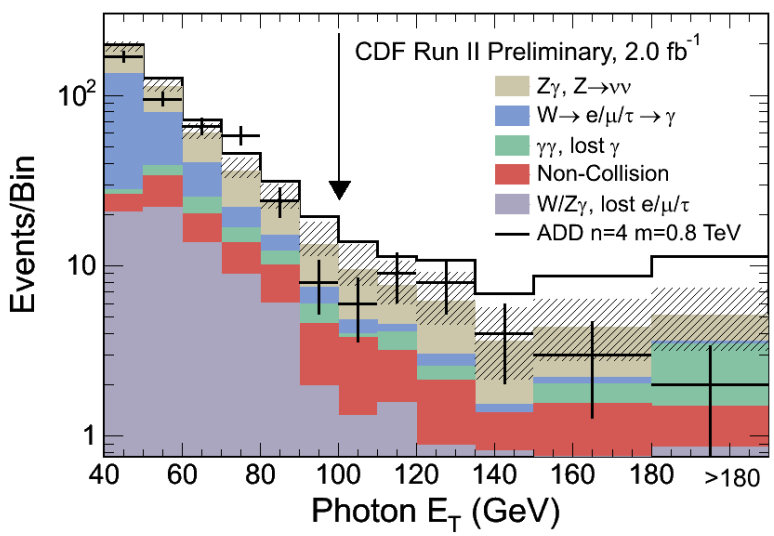
http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/NP/N63/

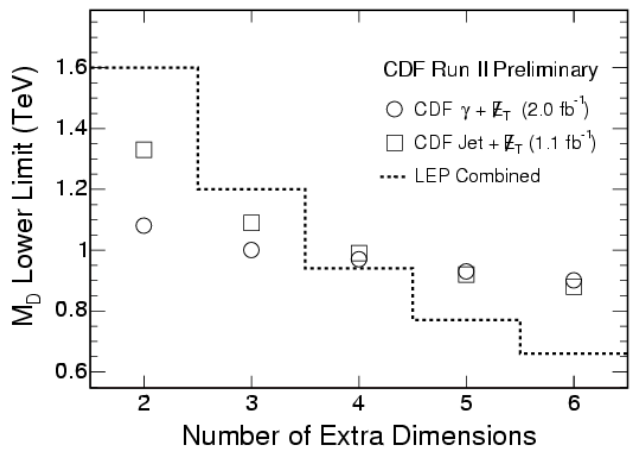
Large Extra Dimensions

- 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_{obs}^{95} 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 fb^{-1}





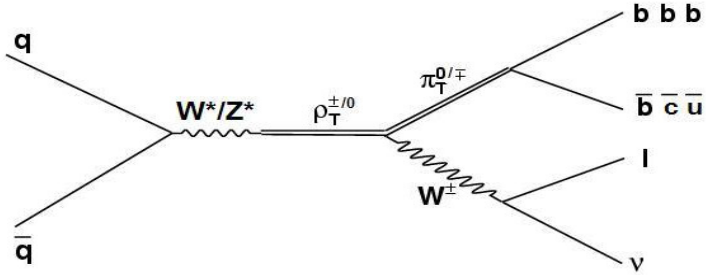
Combined with Mono-jet analysis

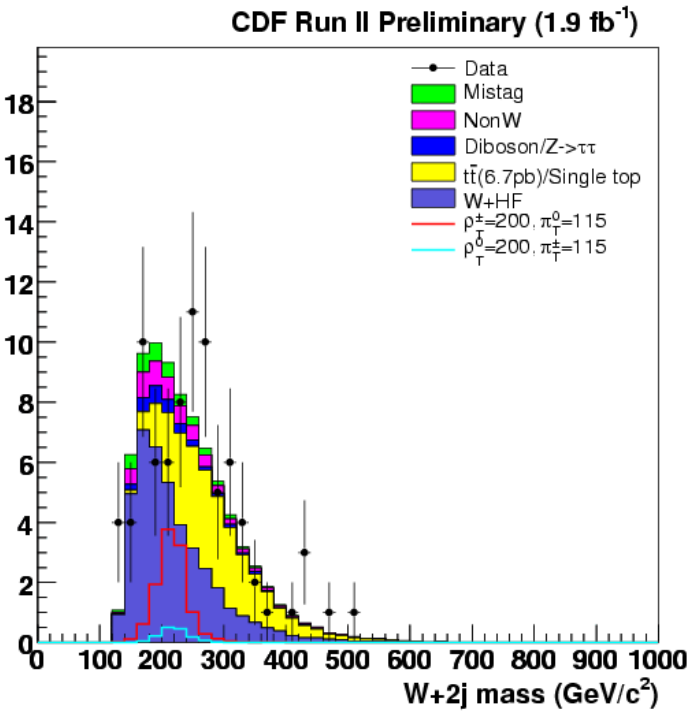
$\rightarrow M_D > 1040$ GeV at n=4

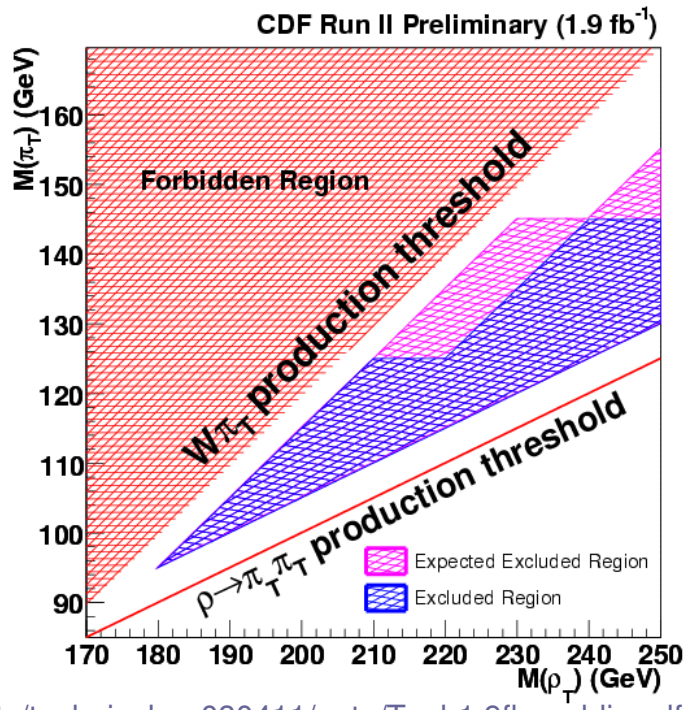
Technicolor

1.9 fb^{-1}

- Alternative to Higgs for EW symmetry breaking
- b-tagged jet; > 20 GeV, $|\eta| < 2.0$
- Central iso e or μ, Plug iso e; P_T>20GeV
- MEt > 20 GeV
- Limit: $m(W+2j):m(2j):Q=m(\rho_T)-m(\pi_T)-m(W)$





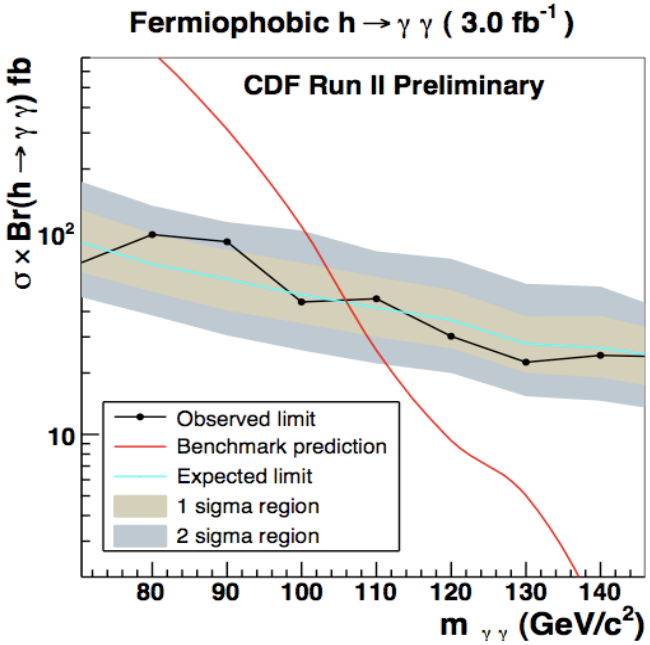


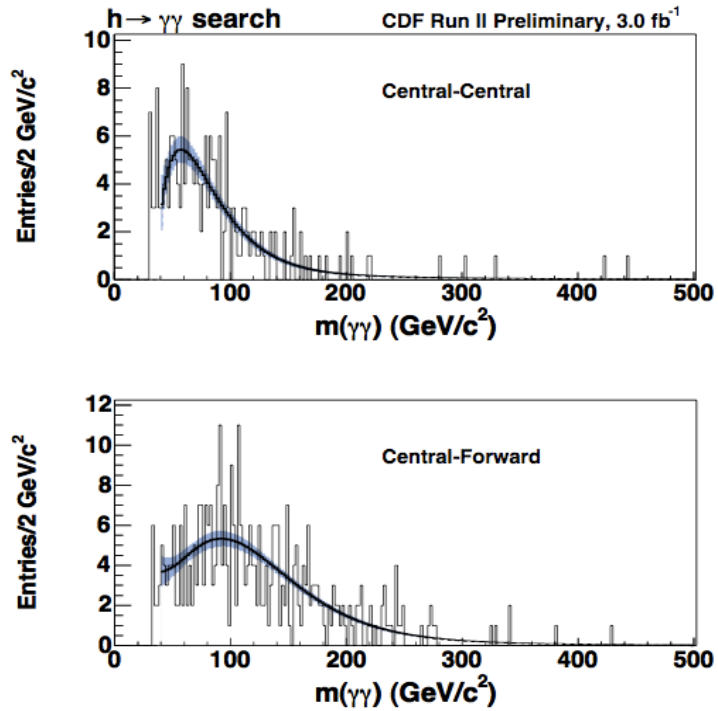
http://www-cdf.fnal.gov/physics/new/hdg/results/technicolor_080411/note/Tech1.9fb_public.pdf

Fermiophobic Higgs

3 fb^{-1}

- 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.





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

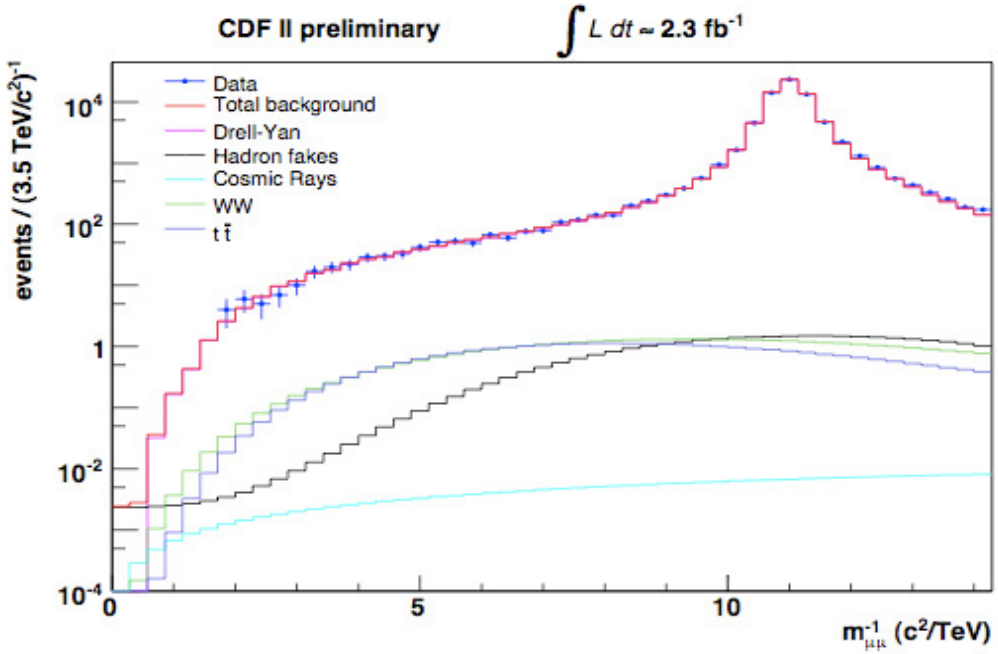
High Mass μμ resonances

Analysis overview

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

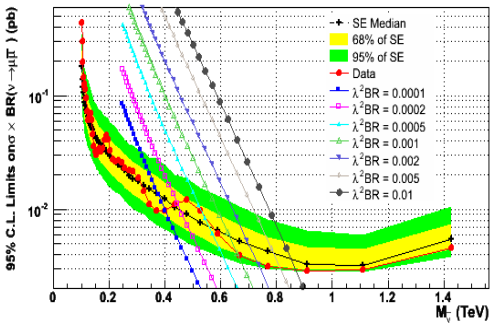
μμ resonances

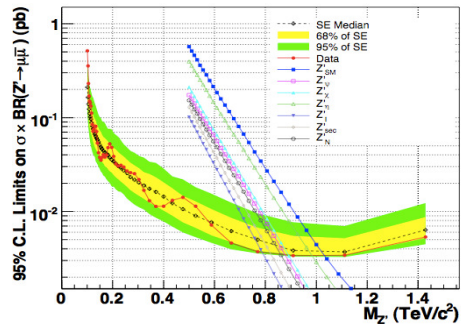
2.3 fb^{-1}

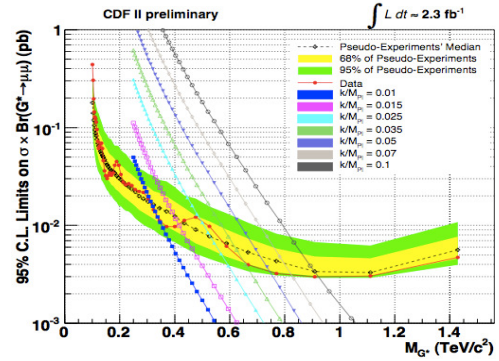


High Mass μμ resonances

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

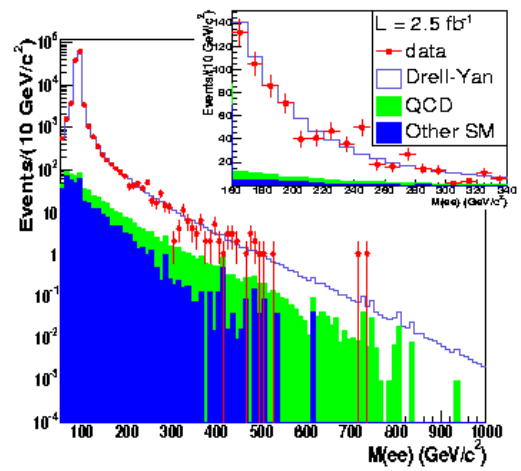
Graviton k/M_{Pl}	Mass Limit, 95% CL (GeV/c^2)
0.1	921
0.07	824
0.05	746
0.035	651
0.025	493
0.015	409
0.01	293

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

High Mass ee resonances

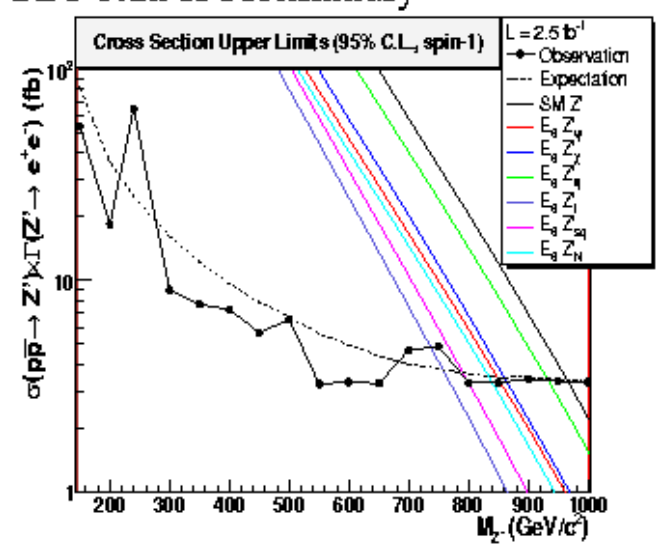
- Phys. Rev. Lett. 102, 031801 (2009)
- Overview
  - 1 central e, 1 central or plug e: $E_T > 25$GeV: $|\eta| < 2.0$
  - Plug e uses calorimeter seeded silicon tracking
- Bkg
  - Drell Yan
  - QCD dijet and W+jets with mismeasured jets
  - $Z/\gamma^* \rightarrow \tau\tau$, ttbar and diboson production

CDF Run II Preliminary



2.5 fb-1

CDF Run II Preliminary



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

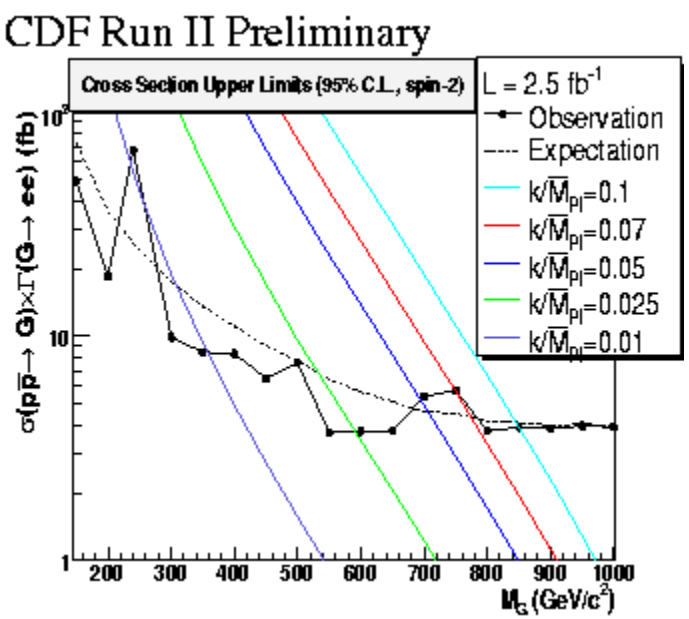
High Mass ee resonances

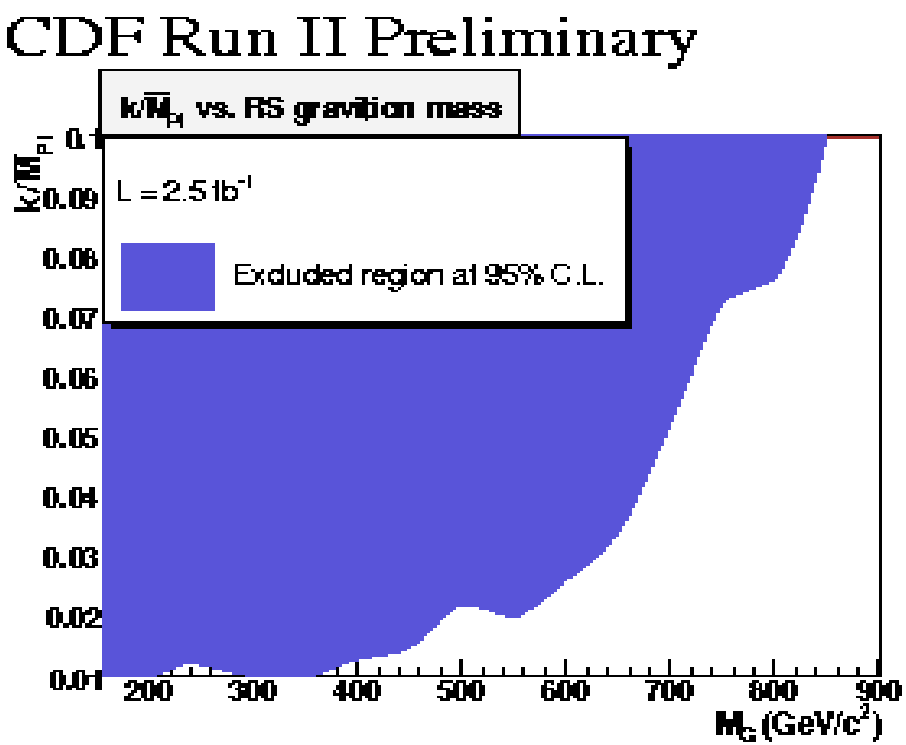
2.5 fb^{-1}

Randall-Sundrum Gravitons

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

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





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

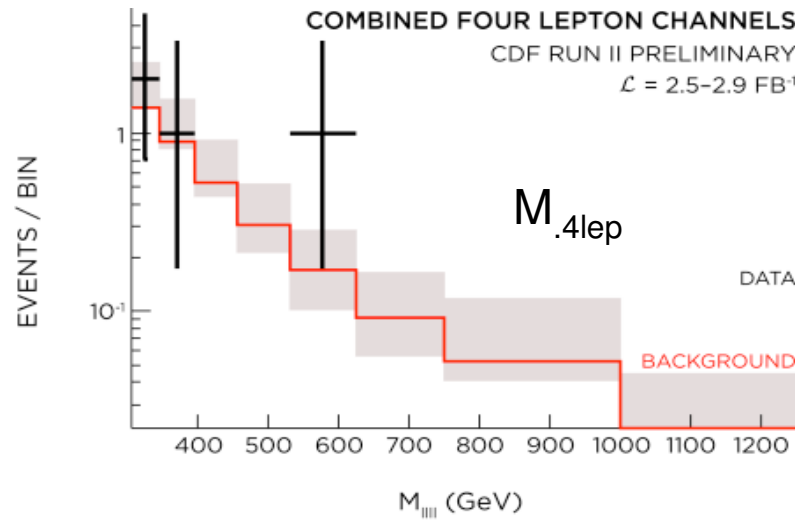
$X \rightarrow ZZ$

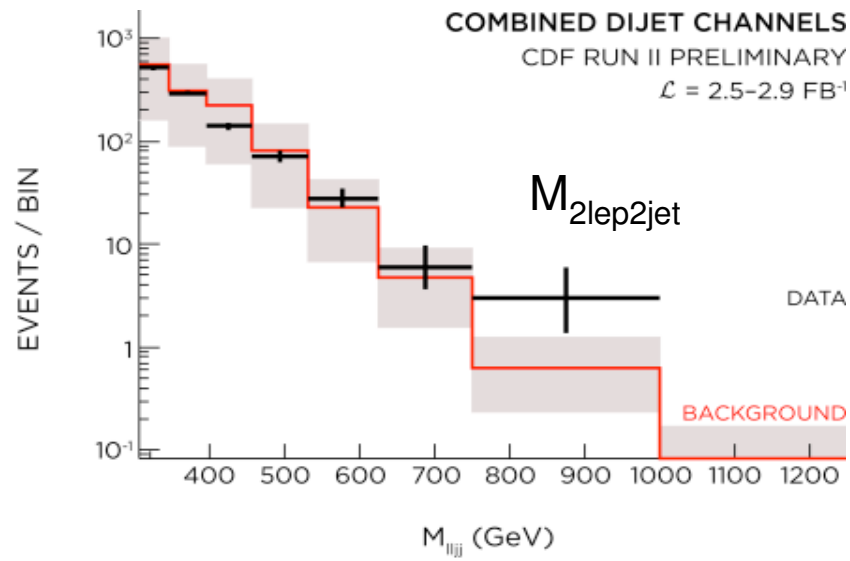
2.5-2.9 fb^{-1}

- Occurs
  - RS graviton
  - $H \rightarrow ZZ$ ($M_H > 180$ GeV)
- Signatures
  - $ZZ \rightarrow llll$ is clean experimentally
  - $ZZ \rightarrow lljj$ higher rate, more bkg
- 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

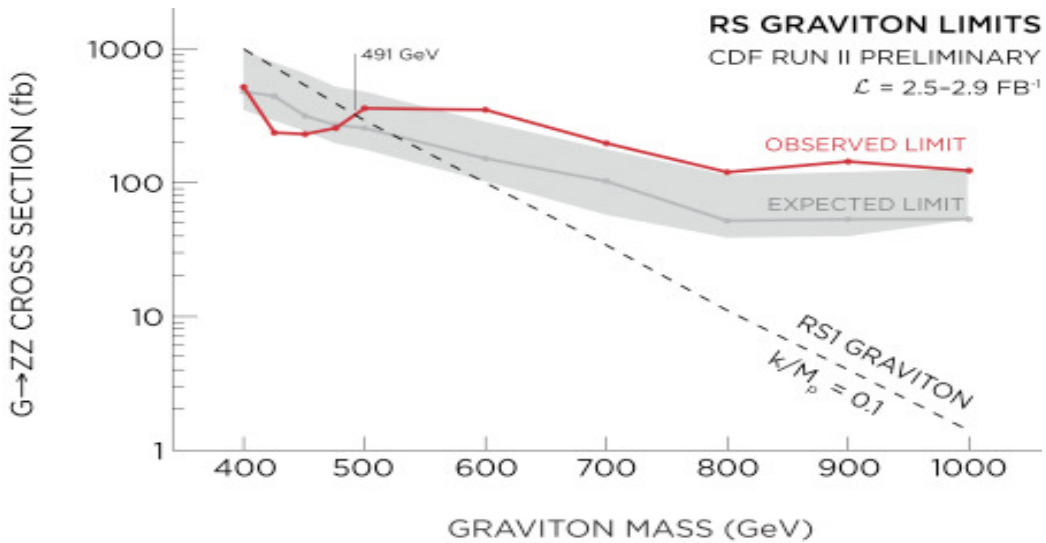
$$\chi^2_{ZZ}=\Sigma_{1,2}(\Delta M_{Zi})^2/(\sigma^2_{Mi}+\sigma^2_{\Gamma})$$

  - 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 $^{-1}$

Other resonance
X → dijets
X → WZ (soon)
X → WW (soon)

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

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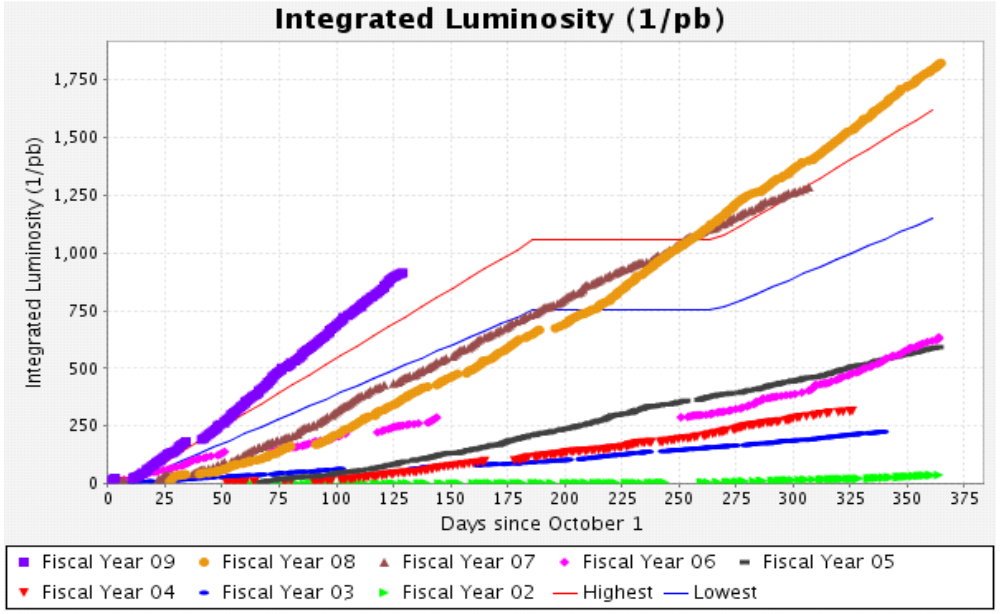
- New results have been and will continue to come out, almost daily.
- The Standard Model is alive and well.
- But we continue to look for anything beyond….

Other results

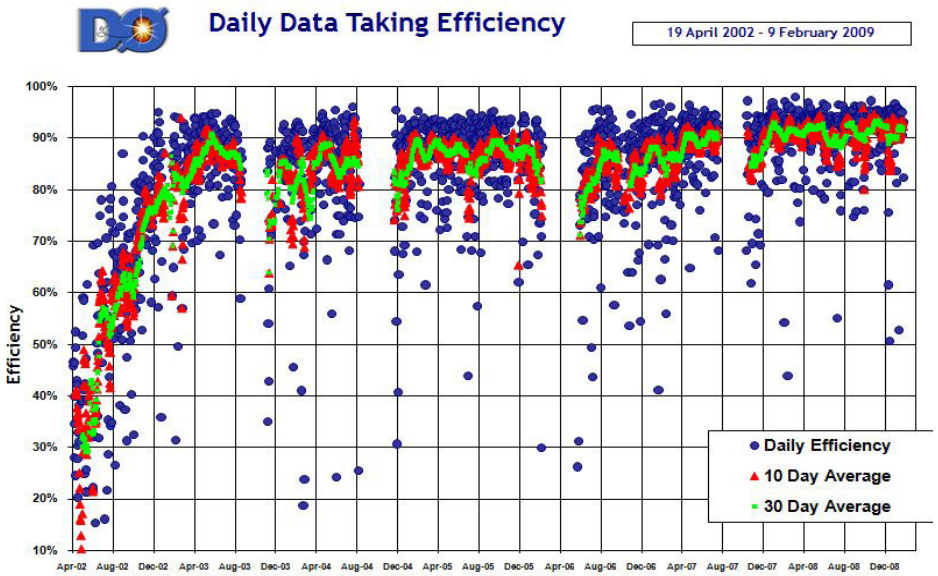
- Charged Long Lived Massive Particles
  - http://arxiv.org/abs/0809.4472 D0
- Model Independent Search
  - http://xxx.lanl.gov/abs/0805.0742 CDF
- The experiments Results pages – contain many more
  - http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm
  - http://www-cdf.fnal.gov/physics/exotic/exotic.html

Backup Slides

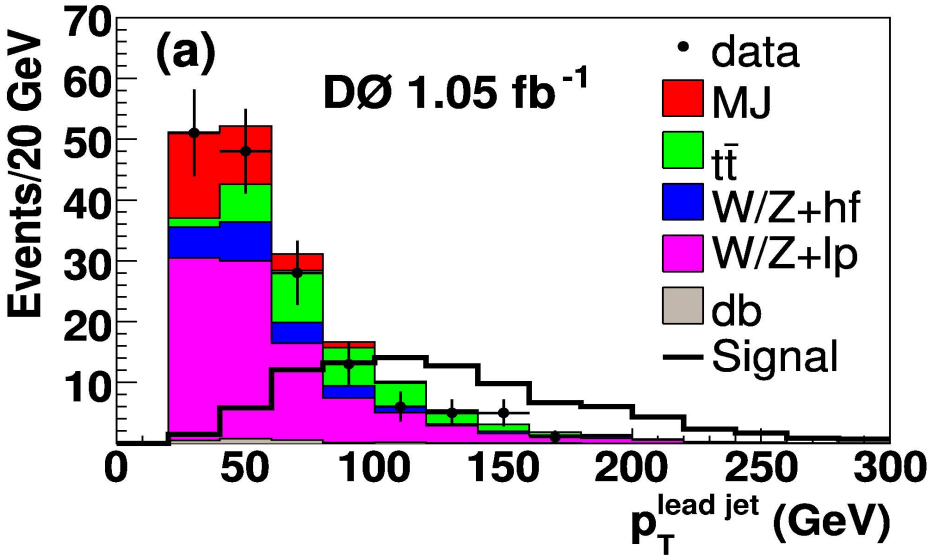
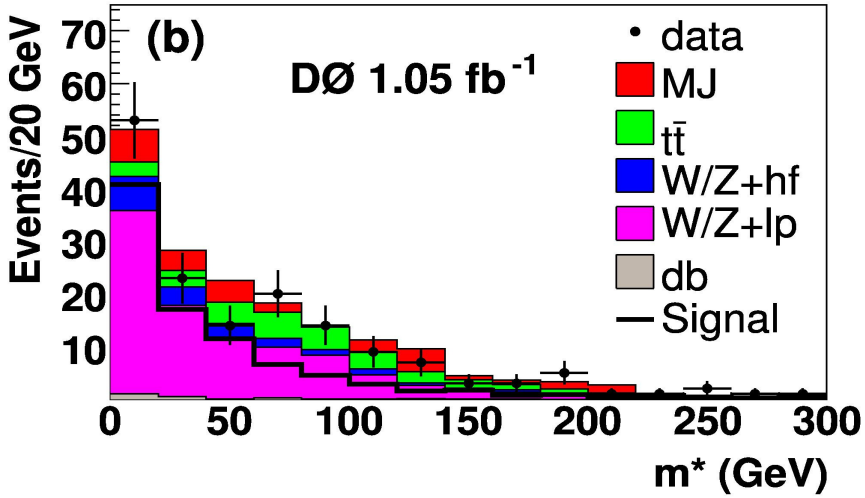


The Accelerator is running fantastically well.

And the Experiments aren't doing badly either.



Leptoquarks - 3rd Gen



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