



# Search for new physics at the Tevatron

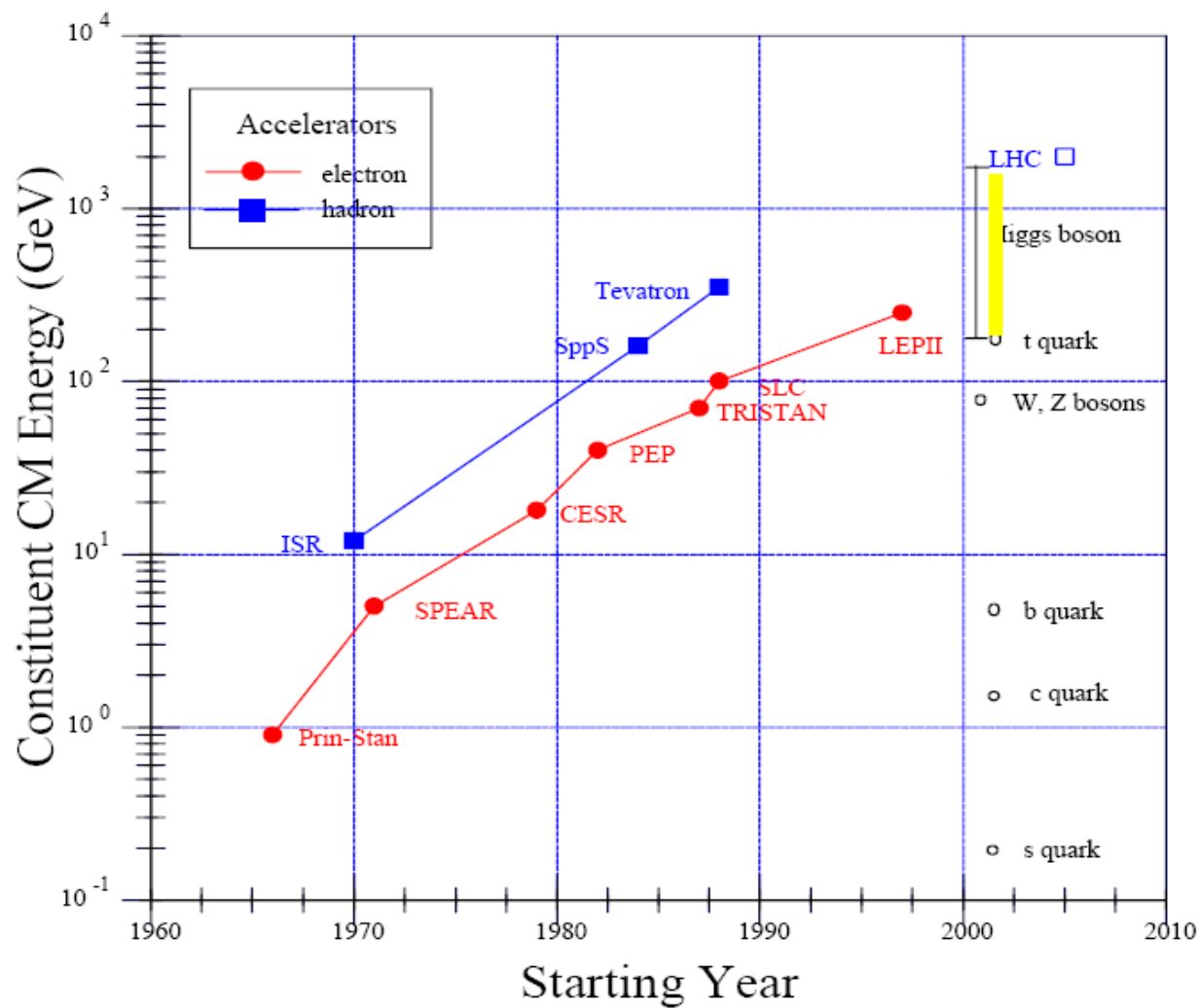


Pedro Mercadante  
SPRACE/UFABC

On behalf of DZero and CDF collaborations



# Past and Present Accelerators





# TeV Energy Scale



- Why is the TeV scale special?
  - It is the scale of EW symmetry breaking
  - We don't know how masses are generated
  - In the Standard Model the Higgs mechanism is evoked
- New Physics Beyond Standard Model?
  - Supersymmetry
  - Extra Dimensions
  - Other models



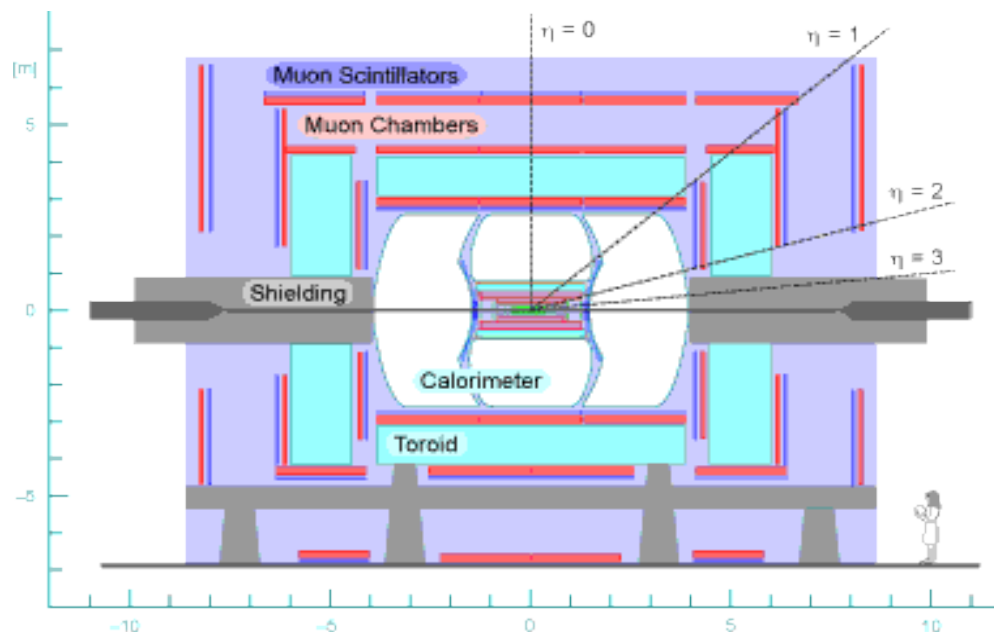
# Tevatron Run II



- Detectors
  - Good coverage
  - Good particle identification
    - $e$
    - muon
    - Jets
    - Missing  $E_T$
    - ...

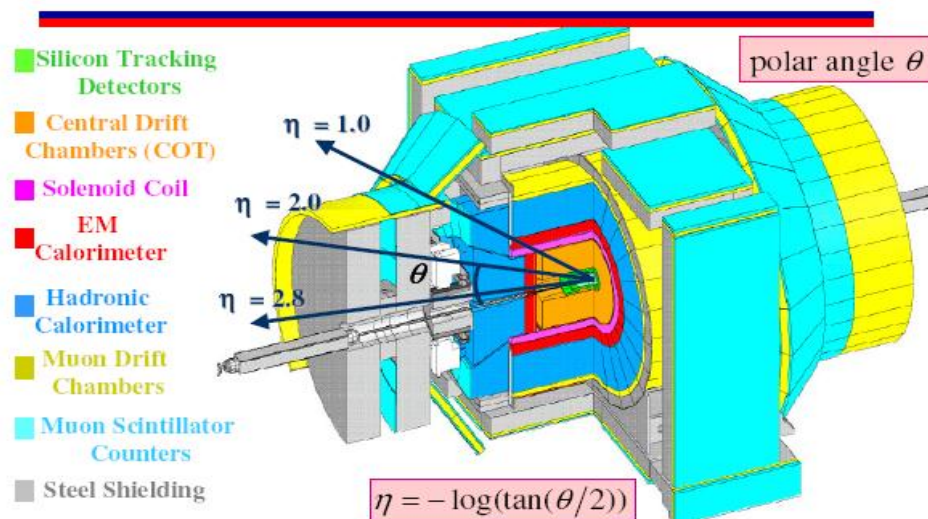


## DZero Detector



Good eta coverage  
 $-2 < \eta < 2$

## CDF Detector

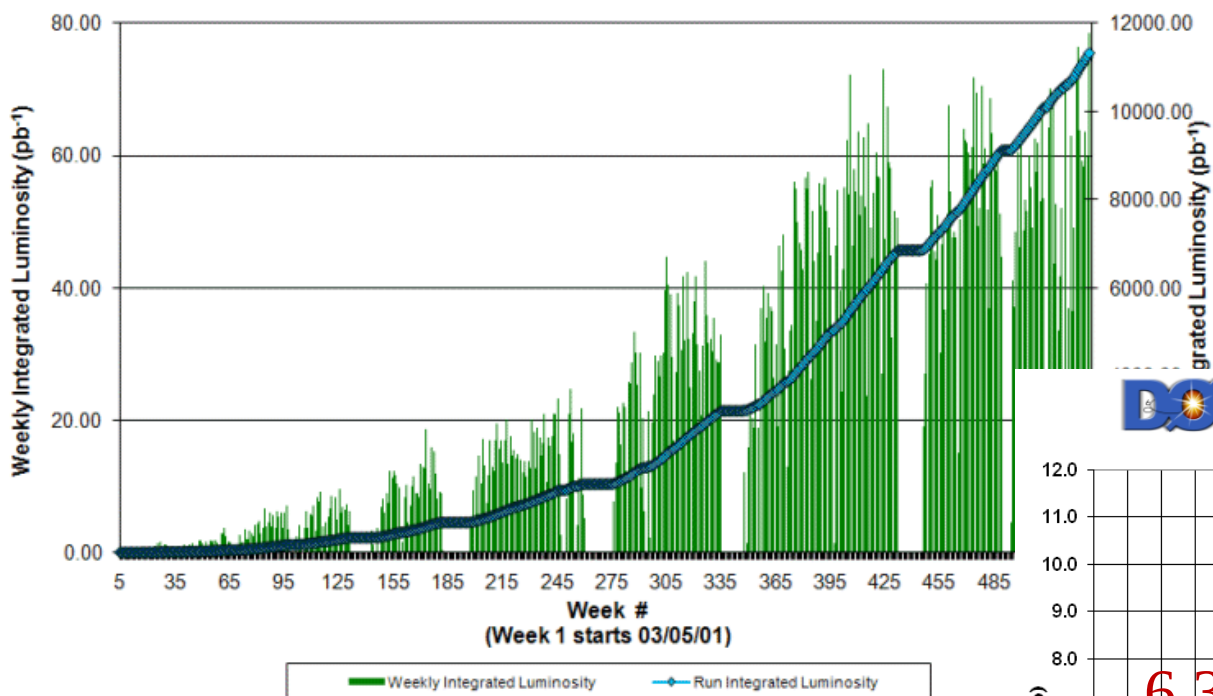




# Integrated Luminosity

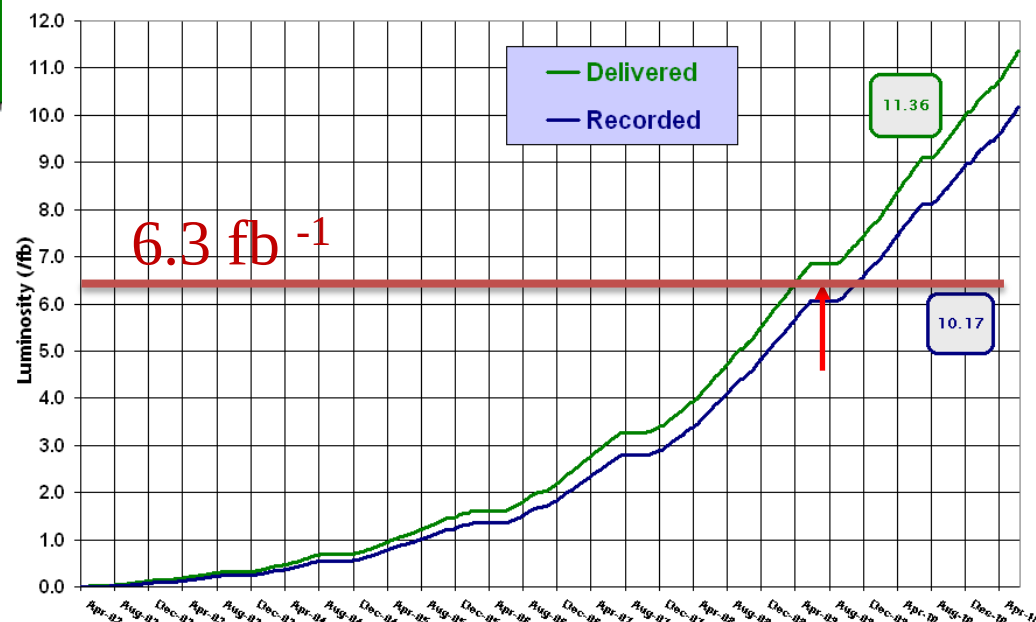


Collider Run II Integrated Luminosity



Run II Integrated Luminosity

19 April 2002 - 26 June 2011



D0 and CDF have large datasets  
and well understood reconstructed  
objects  Look at more  
complex final states



# Supersymmetry



## The MSSM

Minimal supersymmetric model

- Two Higgs doublet SM + Superpartners
- $\mu$  parameter
- $\tan \beta$
- Superpotential

### Soft Terms

- Scalar Masses ( $m_0$ )
- Gauginos Masses ( $m_{1/2}$ )
- Trilinear (A) Parameter
- Bilinear (B) Parameter

$$W = \mu H_d H_u + f_l L H_d E + f_d Q H_d D + f_u Q H_u U \\ + \lambda L L E + \lambda' L Q D + \lambda'' L Q D + \varepsilon L H_u$$



# Supersymmetry

## Which SUSY?



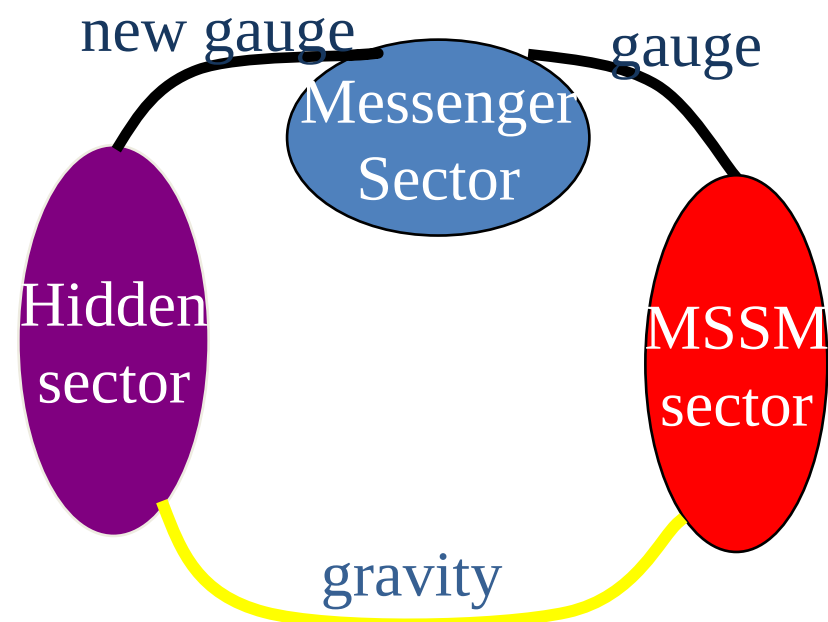
- mSUGRA (Constrained MSSM)

$m_0, m_{1/2}, \tan \beta, A, \text{sign } \mu$

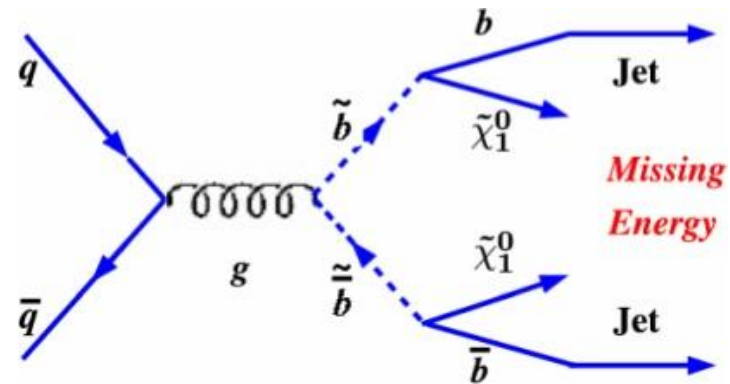
- gluino + squark
- gluino + sbottom
- trilepton

- AMSB and GMSB

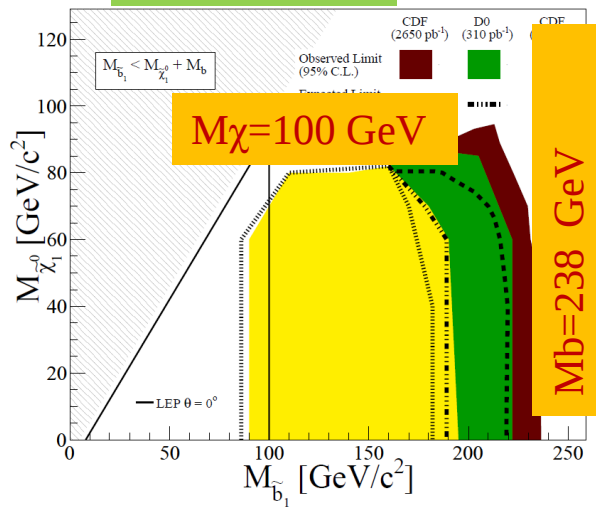
- R parity Violation Models



- Search: Sbottom production
- B-Jets + missing  $E_T$ 
  - Missing  $E_T > 40$  GeV
  - 2 Jets;  $p_T > 20$  GeV
  - Lepton veto



$L=2.65 \text{ fb}^{-1}$

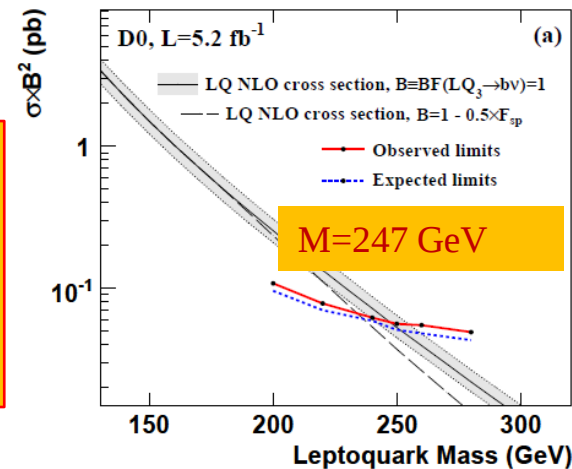
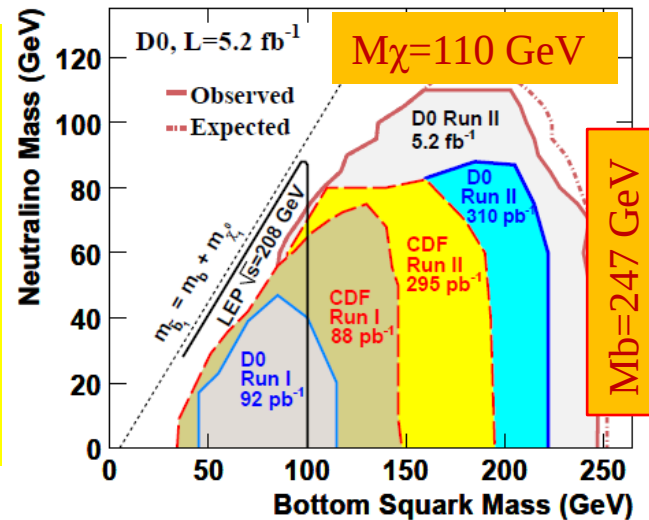


CDF

PRL 105, 081802 (2010)

D0

PRL105,191802,(2010)

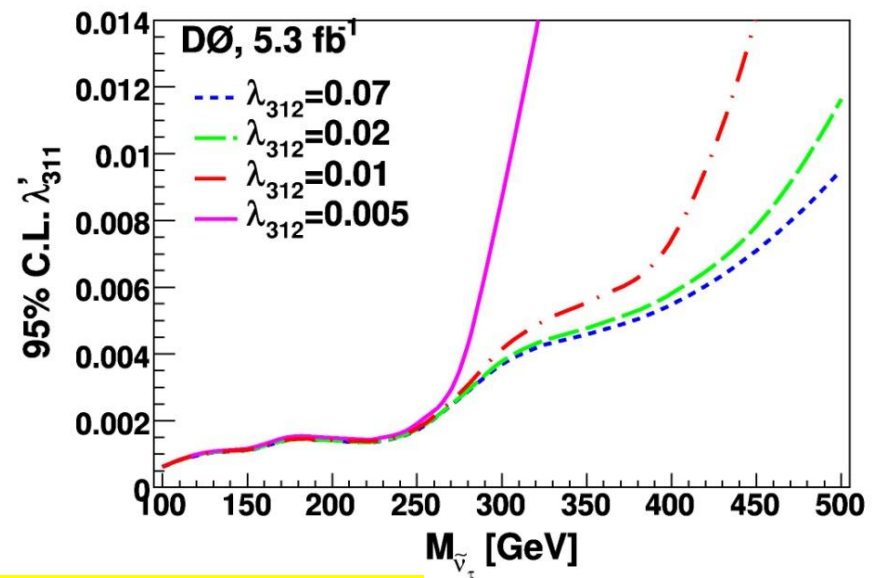
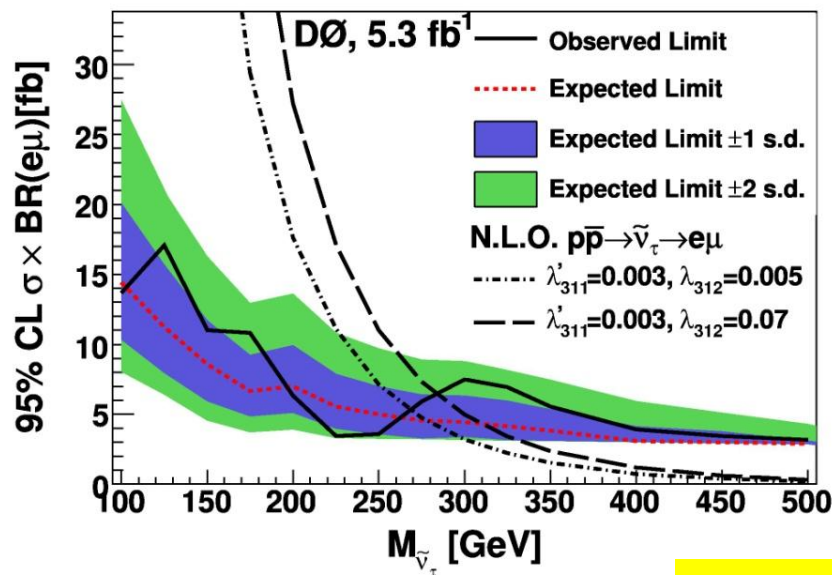
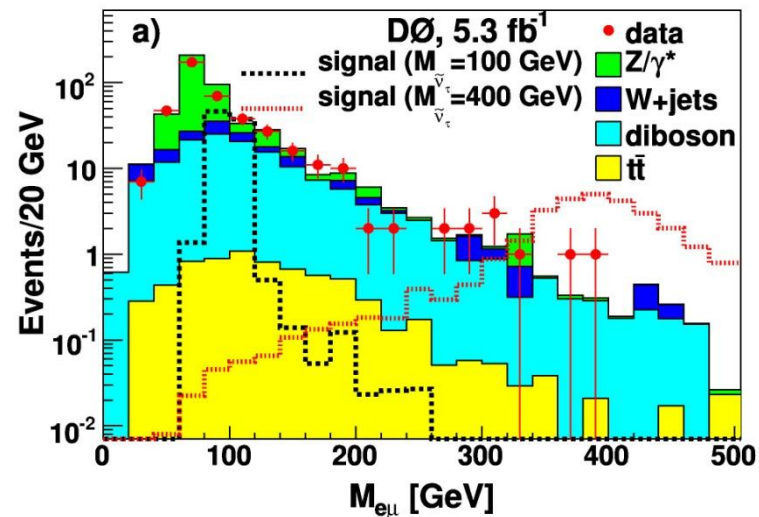


SUSY interpretation

Leptoquark Interpretation

# R-Parity Violation

- Search: Sneutrino ( $\lambda'_{311}, \lambda_{312}$ )
- Muon + Electron
  - Muon  $p_T > 20$  GeV
  - Electron  $E_T > 30$  GeV
  - jet veto  $p_T > 25$  GeV



DØ PRL, 105, 191802 (2010)



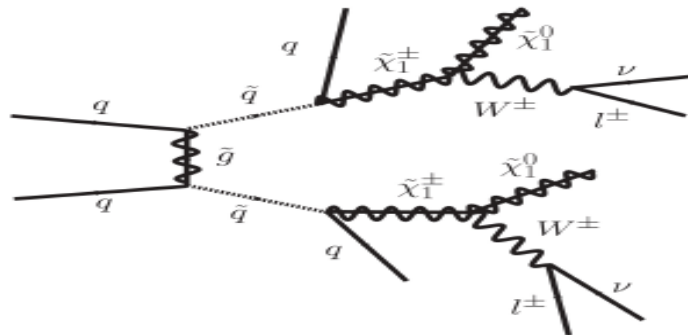
# Like Sign di leptons



- lepton  $p_T > 20$  GeV

SUSY interpretation

- 2 jets

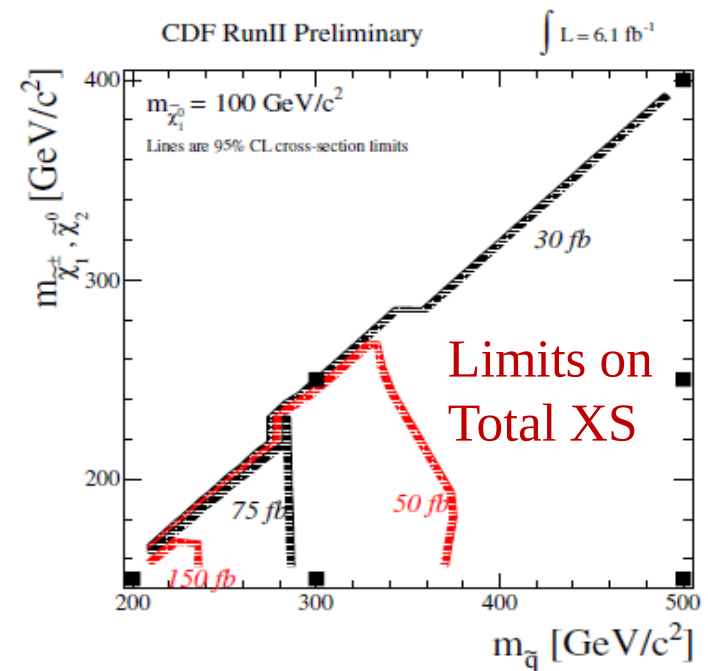
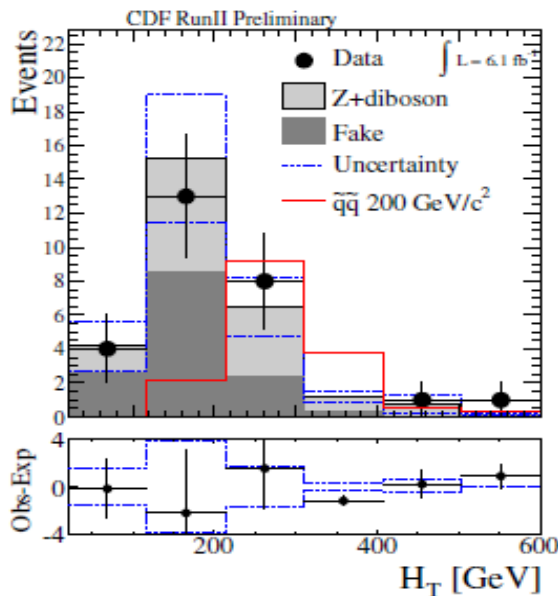


CDF RunII Preliminary  $\int \mathcal{L} dt = 6.1 \text{ fb}^{-1}$

| Process                        | Total $\ell\ell$ | $\mu\mu$       | $ee$           | $e\mu$          |
|--------------------------------|------------------|----------------|----------------|-----------------|
| $t\bar{t}$                     | $0.1 \pm 0.0$    | $0.0 \pm 0.0$  | $0.0 \pm 0.0$  | $0.1 \pm 0.0$   |
| $Z \rightarrow ee$             | $15.7 \pm 2.7$   | $0.0 \pm 0.0$  | $15.7 \pm 2.7$ | $0.0 \pm 0.0$   |
| $Z \rightarrow \mu\mu$         | $8.7 \pm 2.0$    | $0.0 \pm 0.0$  | $0.0 \pm 0.0$  | $8.7 \pm 2.0$   |
| $Z \rightarrow \tau\tau$       | $2.2 \pm 0.9$    | $0.0 \pm 0.0$  | $1.3 \pm 0.6$  | $1.0 \pm 0.6$   |
| $WZ$                           | $24.7 \pm 1.3$   | $7.0 \pm 0.4$  | $5.1 \pm 0.3$  | $12.7 \pm 0.7$  |
| $WW$                           | $0.2 \pm 0.1$    | $0.0 \pm 0.0$  | $0.1 \pm 0.1$  | $0.1 \pm 0.0$   |
| $ZZ$                           | $3.5 \pm 0.2$    | $0.9 \pm 0.1$  | $0.8 \pm 0.1$  | $1.7 \pm 0.1$   |
| $W(\rightarrow e\nu)\gamma$    | $7.8 \pm 1.7$    | $0.0 \pm 0.0$  | $7.8 \pm 1.7$  | $0.0 \pm 0.0$   |
| $W(\rightarrow \mu\nu)\gamma$  | $7.8 \pm 1.7$    | $0.0 \pm 0.0$  | $0.0 \pm 0.0$  | $7.8 \pm 1.7$   |
| $W(\rightarrow \tau\nu)\gamma$ | $0.6 \pm 0.4$    | $0.0 \pm 0.0$  | $0.3 \pm 0.3$  | $0.3 \pm 0.3$   |
| Fakes                          | $51.6 \pm 24.2$  | $8.2 \pm 5.3$  | $22.1 \pm 8.9$ | $21.3 \pm 10.6$ |
| Total                          | $123.0 \pm 24.6$ | $16.1 \pm 5.4$ | $53.3 \pm 9.5$ | $53.6 \pm 10.9$ |
| Data                           | 145              | 14             | 66             | 65              |

CDF

CDF/PHYS/EXO/PUBLIC/10465

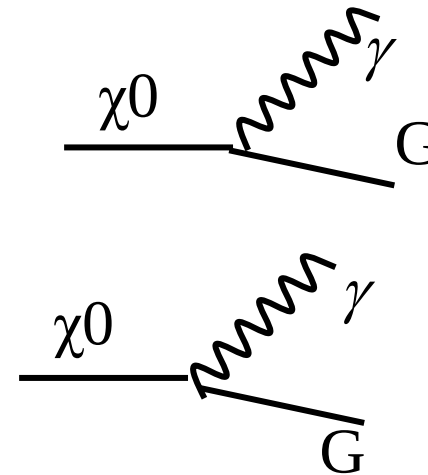




# GMSB

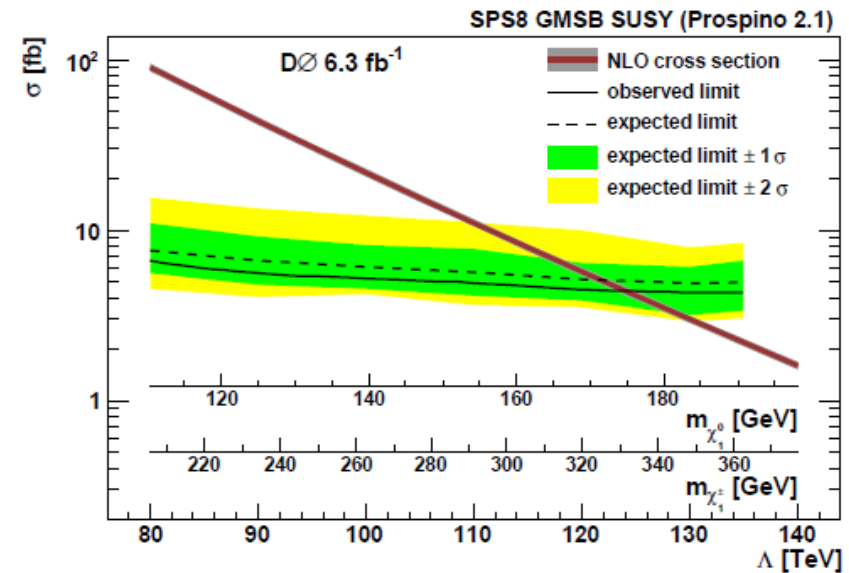
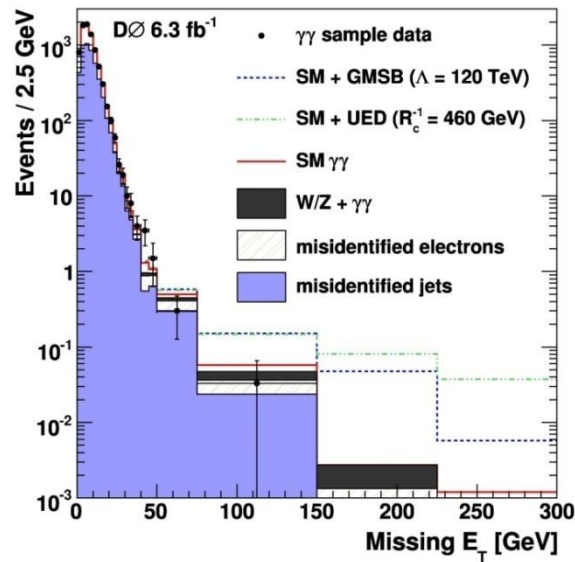


- GMSB: NLSP Neutralino (LSP: light Gravitino)
- Search: Di photon channel
  - Photon  $p_T > 20$  GeV
  - Missing  $E_T$



D0

PRL, 105, 221802 (2010)



SUSY interpretation

$$M_{\chi} < 175 \text{ GeV}$$

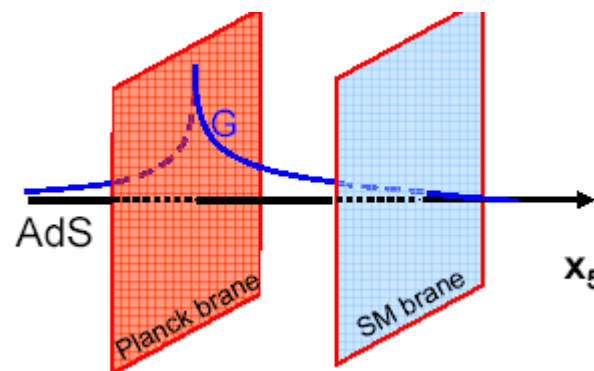
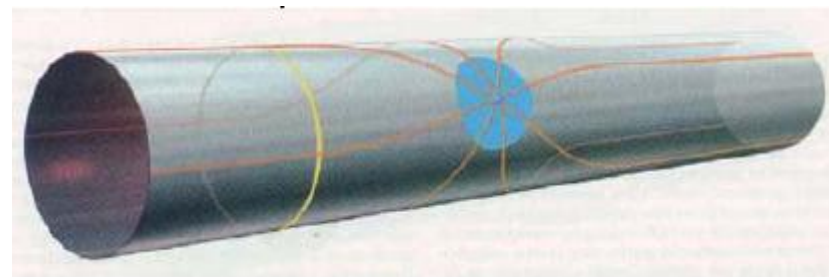


# Extra Dimensions

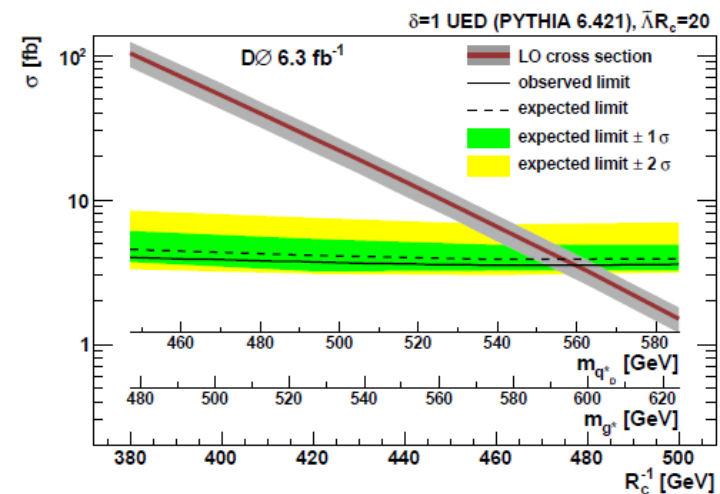
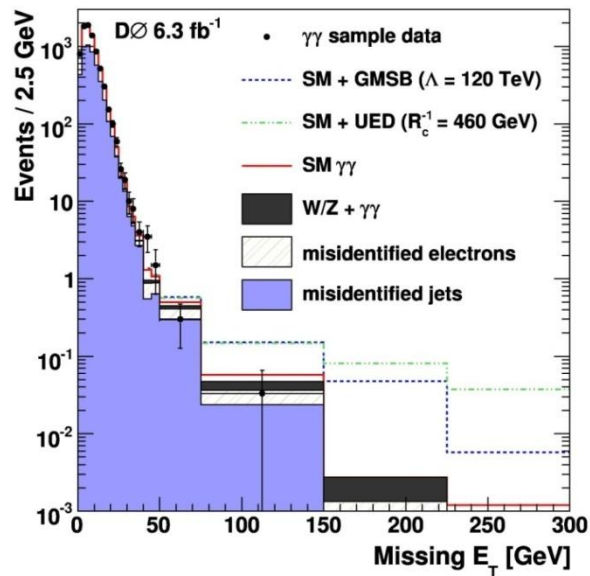
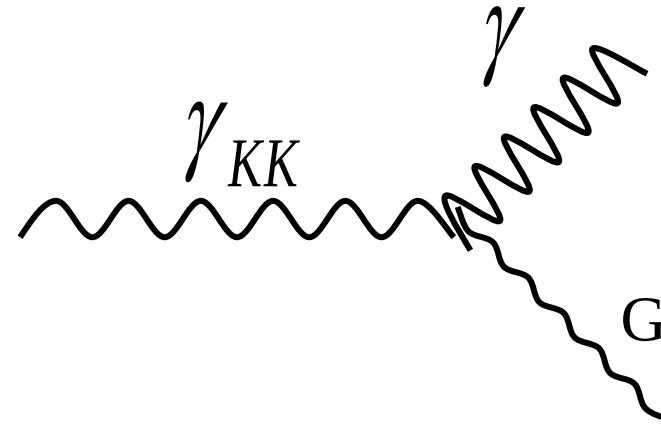
## Are there new extra Dimension?



- Large Extra Dimensions (ADD models)
  - Only gravity propagates in the extra dimensions
  - Direct signal: missing ET from the sum of KK states propagating in the bulk
  - Indirect signal: sum of KK towers modify the production of SM particles
- Universal Extra Dimensions
  - All particles can propagate in the extra dimensions. All particle have new excited states
  - Signals are similar to those of SUSY
- Randall Sundrum models
  - Excited states of gravitons are heavy. Might be produced and decay in pairs of SM particles



- UED (Pair production of KK quarks)
  - Lightest KK particle: Photon
  - If additional Large ED  $\rightarrow$  KK Photon decay Photon+ Graviton
- Search: Di photon channel
  - Photon  $p_T > 20$  GeV
  - Missing  $E_T$



$$R^{-1} < 477 \text{ GeV}$$

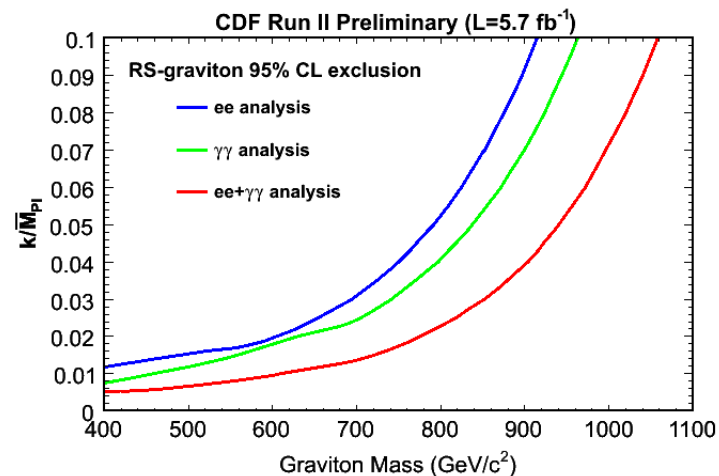
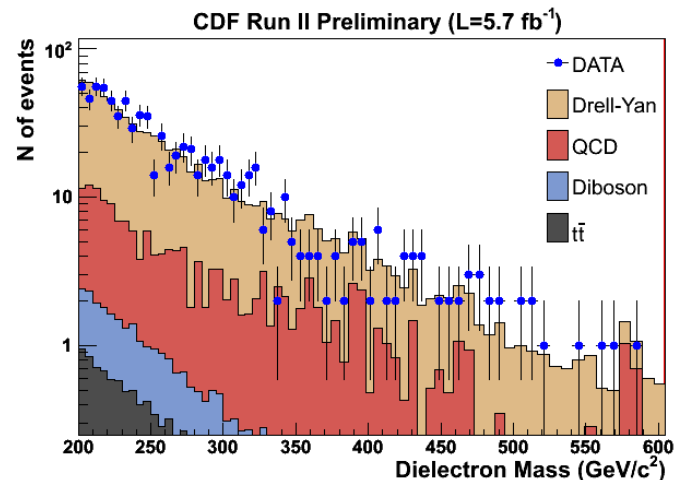
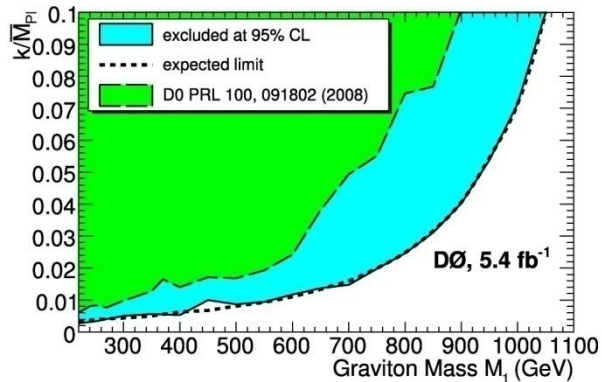
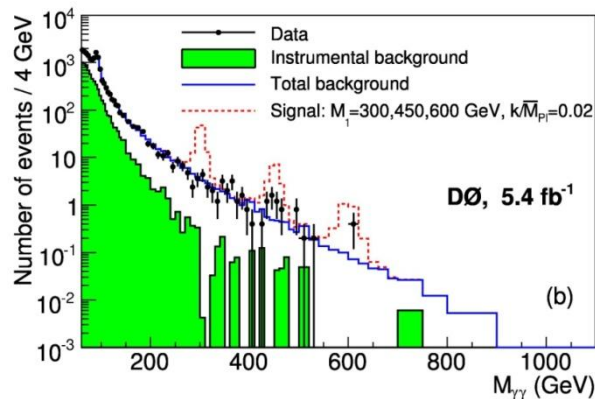
UED interpretation



# Randall Sundrum Gravitons



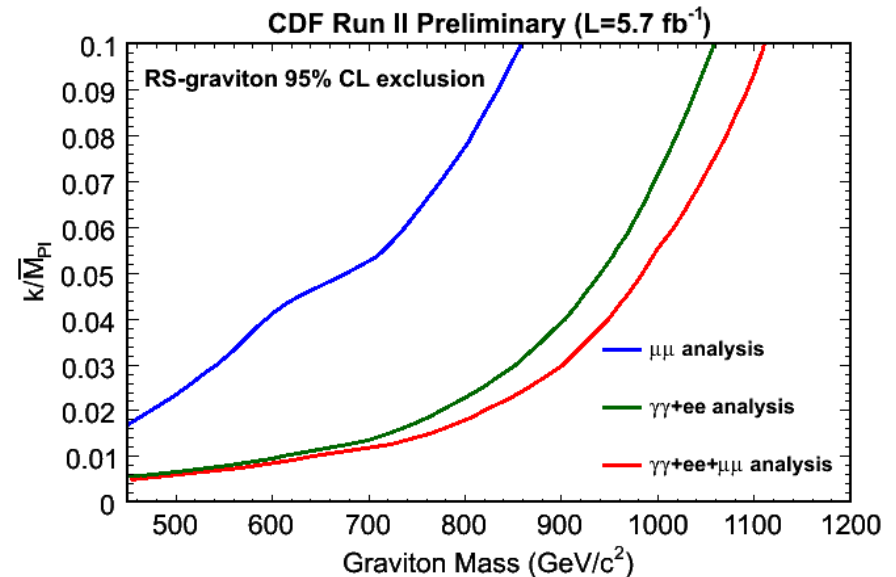
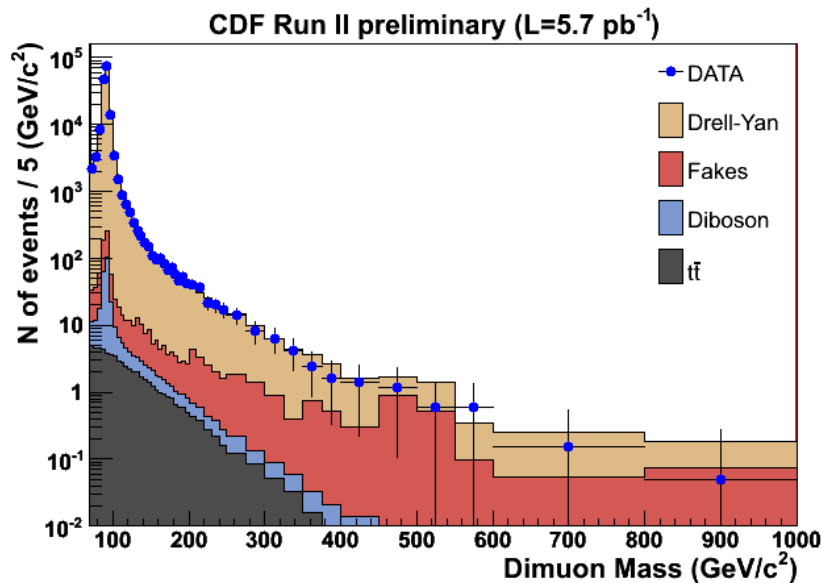
- Production of Graviton Excitation -> Resonant Signal
- Looking for a bump
- Combined results  $ee + \gamma\gamma$



DØ PRL, 104, 241802 (2010)

CDF Note 10405

## Combined results : Dimuon channel



$M < 1111 \text{ GeV}$  for  
 $k/M=0.1$

CDF Note 10479

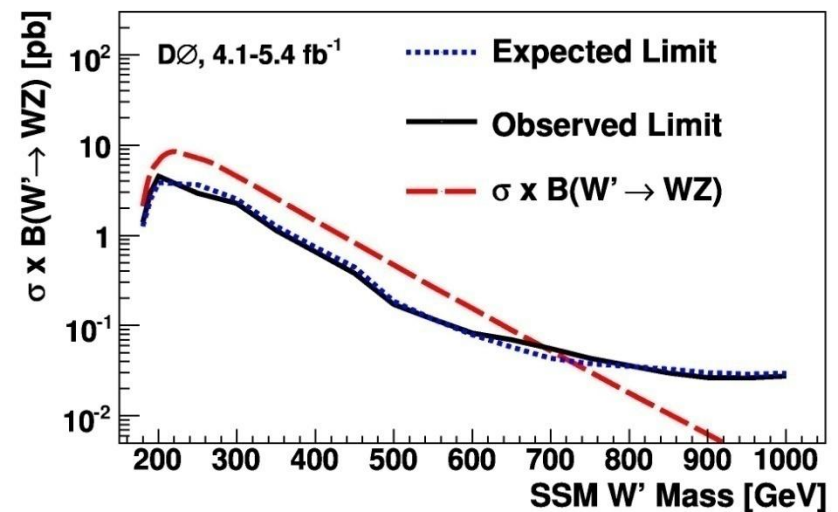
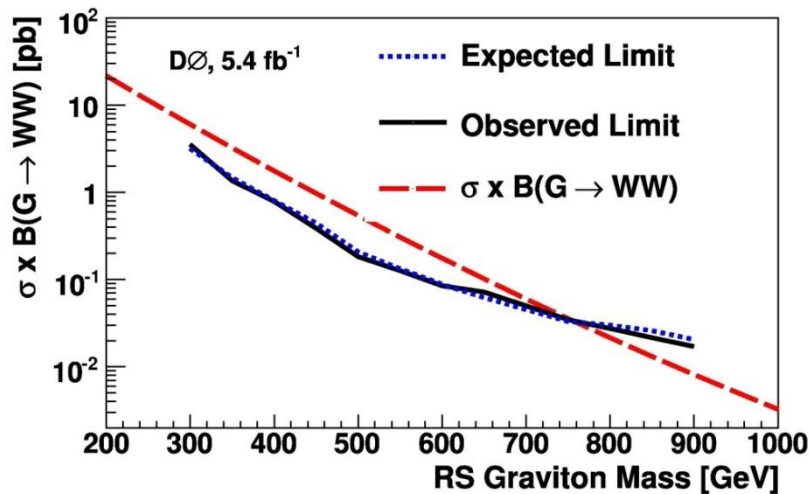
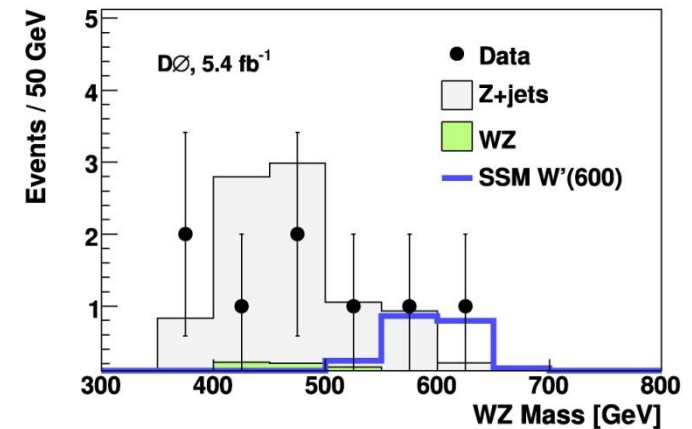
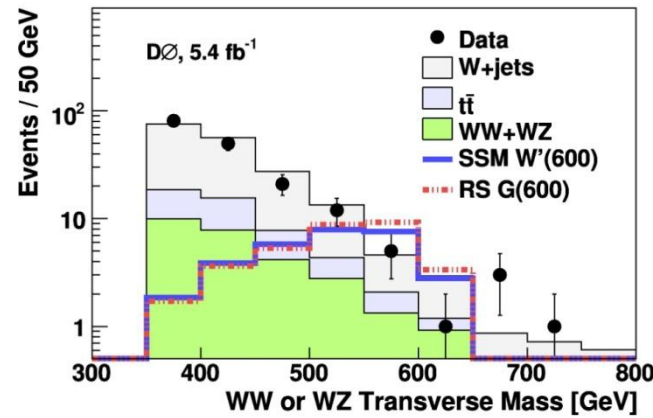


# Randall Sundrum Gravitons (III)

## WW/WZ decays



- Decay to Boson pair
  - Lepton + jet
  - Lepton pair + jet
  - 3 Lepton



PRL 107, 011801 (2011)



# ZZ + missing $E_T$

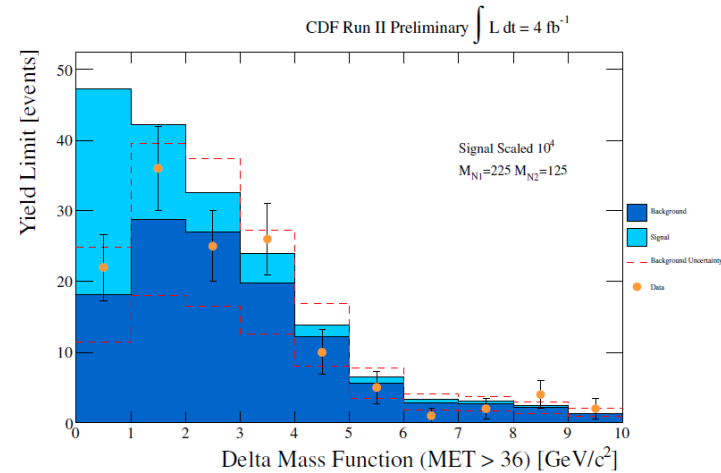


- Heavy  $N_2$  pair production

$$p\bar{p} \rightarrow Z/\gamma^* \rightarrow N_2 N_2 \rightarrow N_1 Z N_1 Z$$

- Z Boson pair + MET
  - 2 lepton  $p_T > 20$  GeV
  - 2 Jets  $p_T > 15$  GeV
  - Missing  $E_T > 40$  GeV

CDF Note 10539

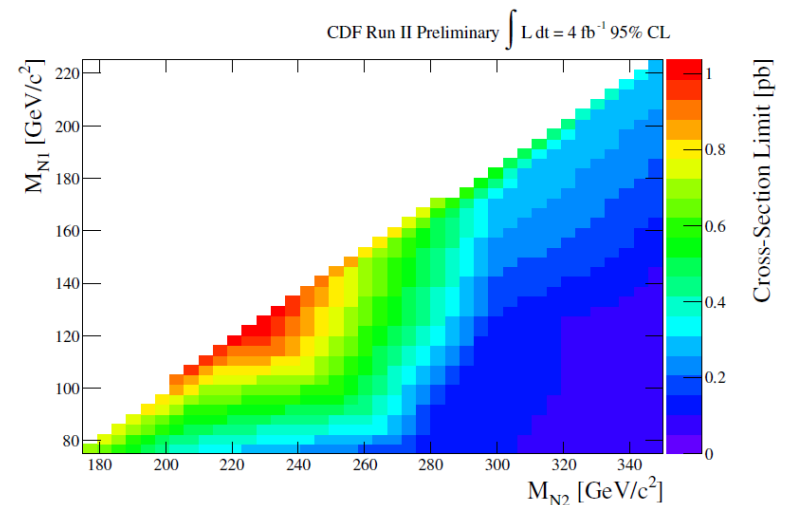


$$\sqrt{\left(\frac{M_{ll} - 91.6}{10}\right)^2 + \left(\frac{M_{ll} - 85.3}{15}\right)^2}$$

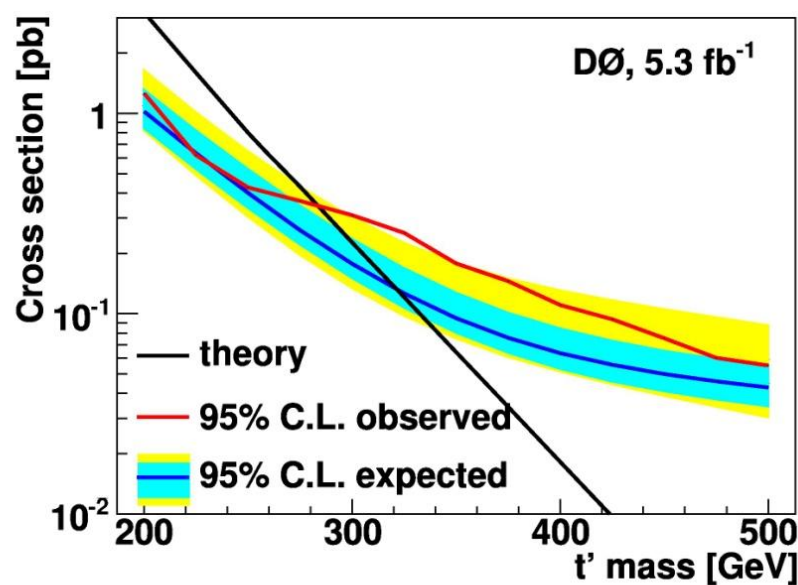
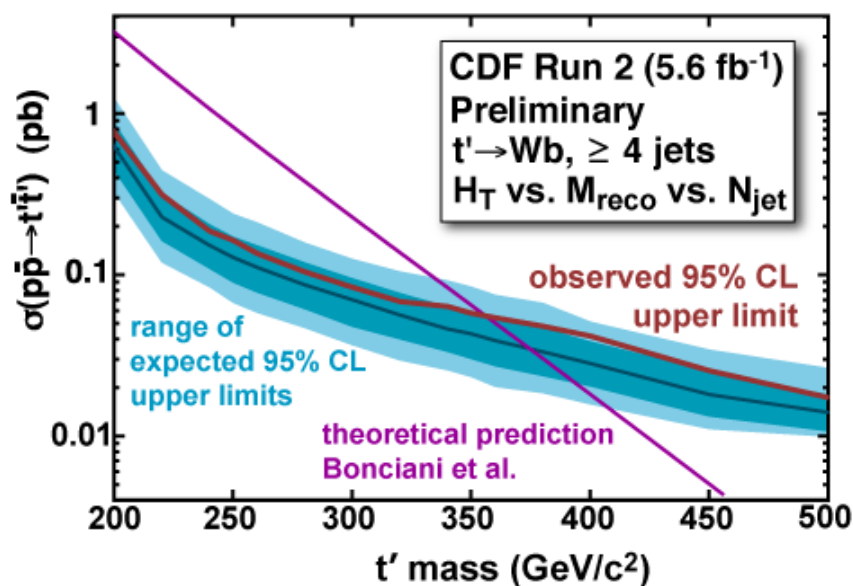
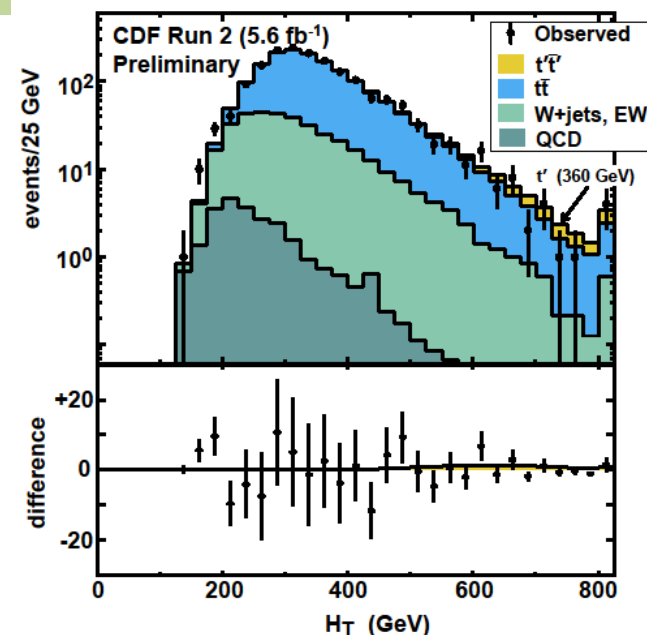
CDF Run II Preliminary  $\int L dt = 4 fb^{-1}$  95% CL

| $M_{N1}$<br>[GeV/c <sup>2</sup> ] | $M_{N2}$<br>[GeV/c <sup>2</sup> ] | Cross-Section [fb] |            | Yield [events] |            |
|-----------------------------------|-----------------------------------|--------------------|------------|----------------|------------|
|                                   |                                   | *Exp. Limit        | Obs. Limit | *Exp. Limit    | Obs. Limit |
| 75                                | 175                               | [243.2, 901.3]     | 701.6      | [10, 38]       | 29         |
| 75                                | 200                               | [107.1, 649.2]     | 368.9      | [5, 28]        | 16         |
| 125                               | 225                               | [332.3, 1182.6]    | 1087.9     | [12, 42]       | 39         |
| 75                                | 225                               | [53.7, 329.2]      | 273.2      | [2, 13]        | 11         |
| 75                                | 275                               | [49.2, 211.5]      | 132.2      | [2, 9]         | 6          |
| 125                               | 300                               | [44.2, 209.6]      | 137.5      | [2, 9]         | 6          |
| 175                               | 300                               | [67.0, 369.7]      | 315.4      | [3, 15]        | 13         |
| 125                               | 350                               | [41.0, 161.6]      | 47.7       | [2, 7]         | 2          |
| 225                               | 350                               | [76.6, 420.0]      | 297.0      | [3, 19]        | 13         |
| 75                                | 350                               | [42.2, 153.7]      | 54.9       | [2, 7]         | 2          |

\* Expected Values shown are the 2 sigma boundaries



- Heavy  $t' \rightarrow Wb$ 
  - 1 lepton  $p_T > 20$  GeV
  - 4 Jets  $p_T > 20$  GeV
  - b tag
  - Missing  $E_T > 20$  GeV





# Charge Asymmetry in Dimuon Like Sign Signal



After background suppression asymmetry is due to CP violation on the B meson mixing

Look at single muon asymmetry in the B meson system. Cancellation of systematics

Result:

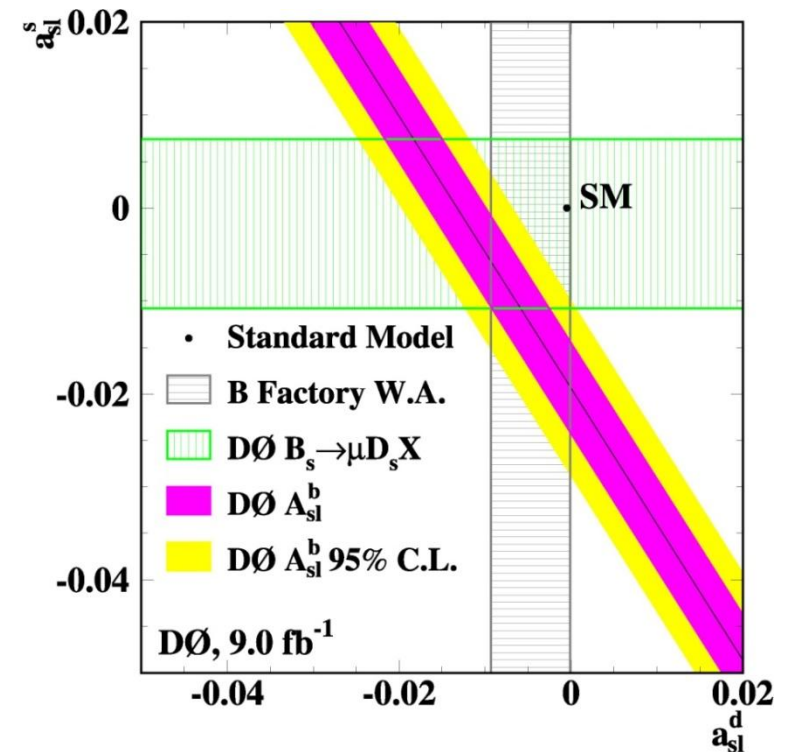
$$A_{sl}^b = -0.00787 \pm 0.00172 \text{ (stat)} \pm 0.00093 \text{ (syst)}$$

SM:

$$A_{sl}^b(\text{SM}) = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}$$

Discrepancy of  $3.9 \sigma$

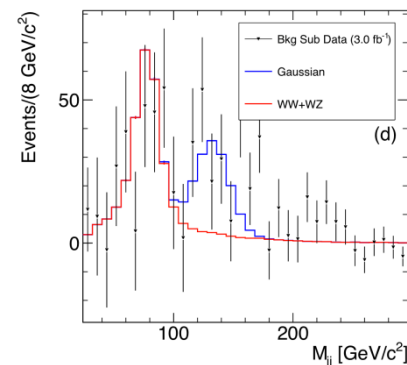
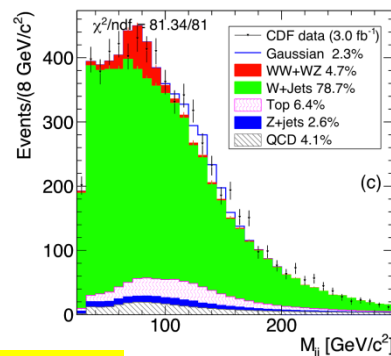
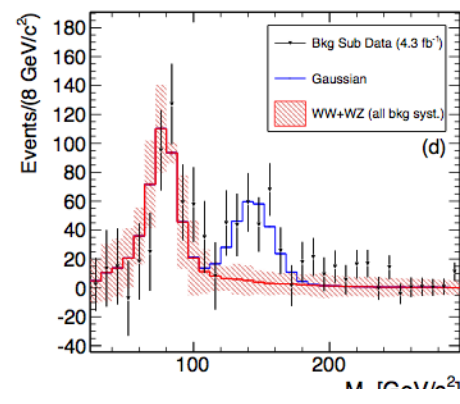
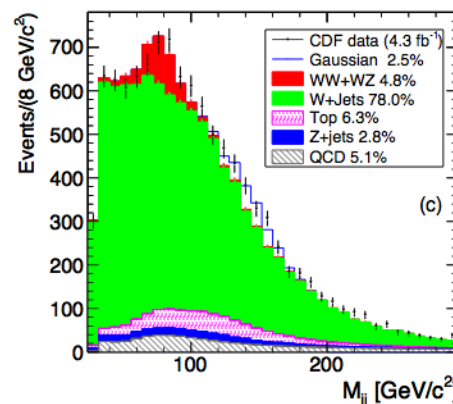
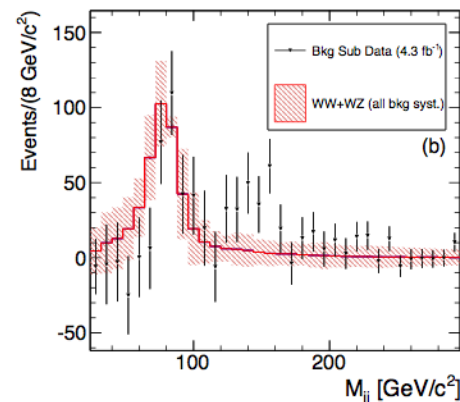
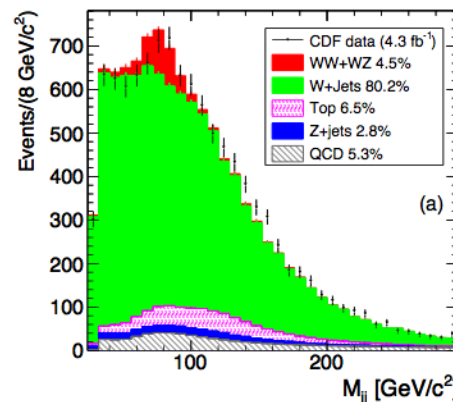
Periodic reversal of D0 solenoid and toroid magnetic field polarities cancels most detector-related asymmetries

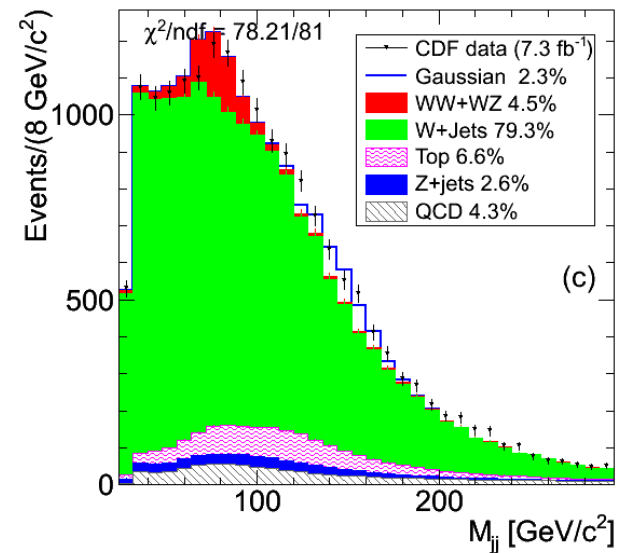
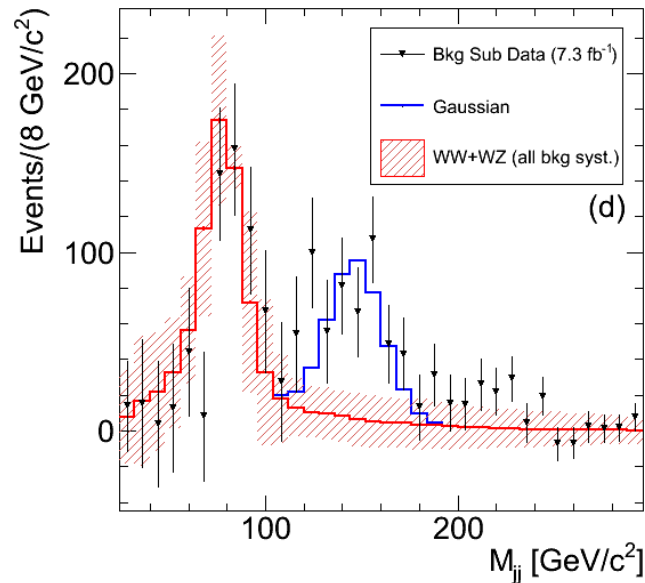


D0 hep-ex: 1106.6308

# CDF W + 2 jets

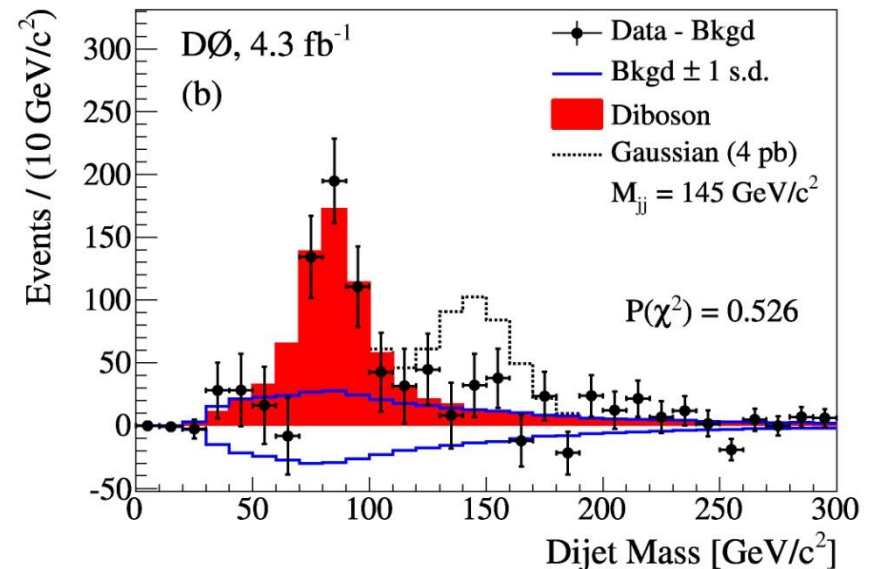
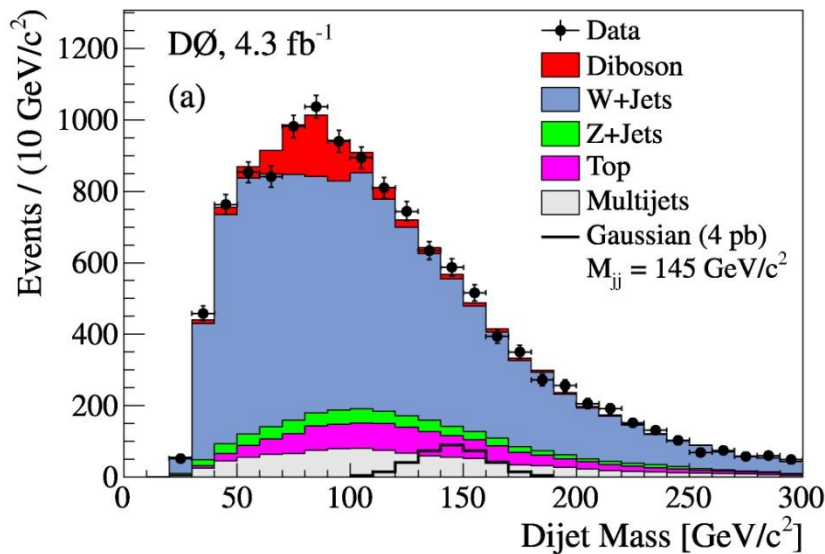
- Invariant mass of two jets
  - lepton  $p_T > 20$  GeV
  - 2 Jets  $p_T > 30$  GeV
  - Dijet  $p_T > 40$  GeV
  - Missing  $E_T > 25$  GeV
- For  $4.3 \text{ fb}^{-1}$  an excess of 3.2 Sigma is found in the 120-160 GeV mass range!
- Additional  $3.0 \text{ fb}^{-1}$  of data: still an excess



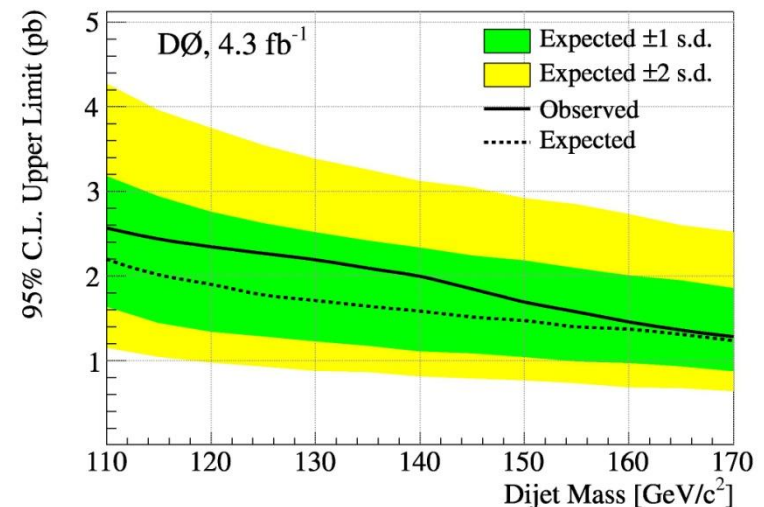


[http://www-cdf.fnal.gov/physics/ewk/2011/wjj/7\\_3](http://www-cdf.fnal.gov/physics/ewk/2011/wjj/7_3)

With new data: larger excess (4.1 standard deviation)  
 consistent with expected from the 4.3 fb<sup>-1</sup>  
 (Consistent with new particle resonance of 4 pb cross section)



- Same selection as CDF
  - No excess observed
  - Limit for new resonance
  - Exclude a resonance at the CDF mass value for 4 pb cross section





# Conclusions



- The Tevatron is looking for complex final states
- At present no evidence in searches for new phenomena is confirmed in both experiments (data for  $4\text{--}6.3 \text{ fb}^{-1}$  )
- CDF excess in the  $W+2\text{Jets}$  events is not confirmed by Dzero
- Hints of new physics from  $b$  mesons
- Tevatron will stop at end of September 2011 with around  $11 \text{ fb}^{-1}$  of data recorded per experiment
- Public webpages:
  - <http://www-cdf.fnal.gov/physics/exotic/exotic.html>
  - <http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm>