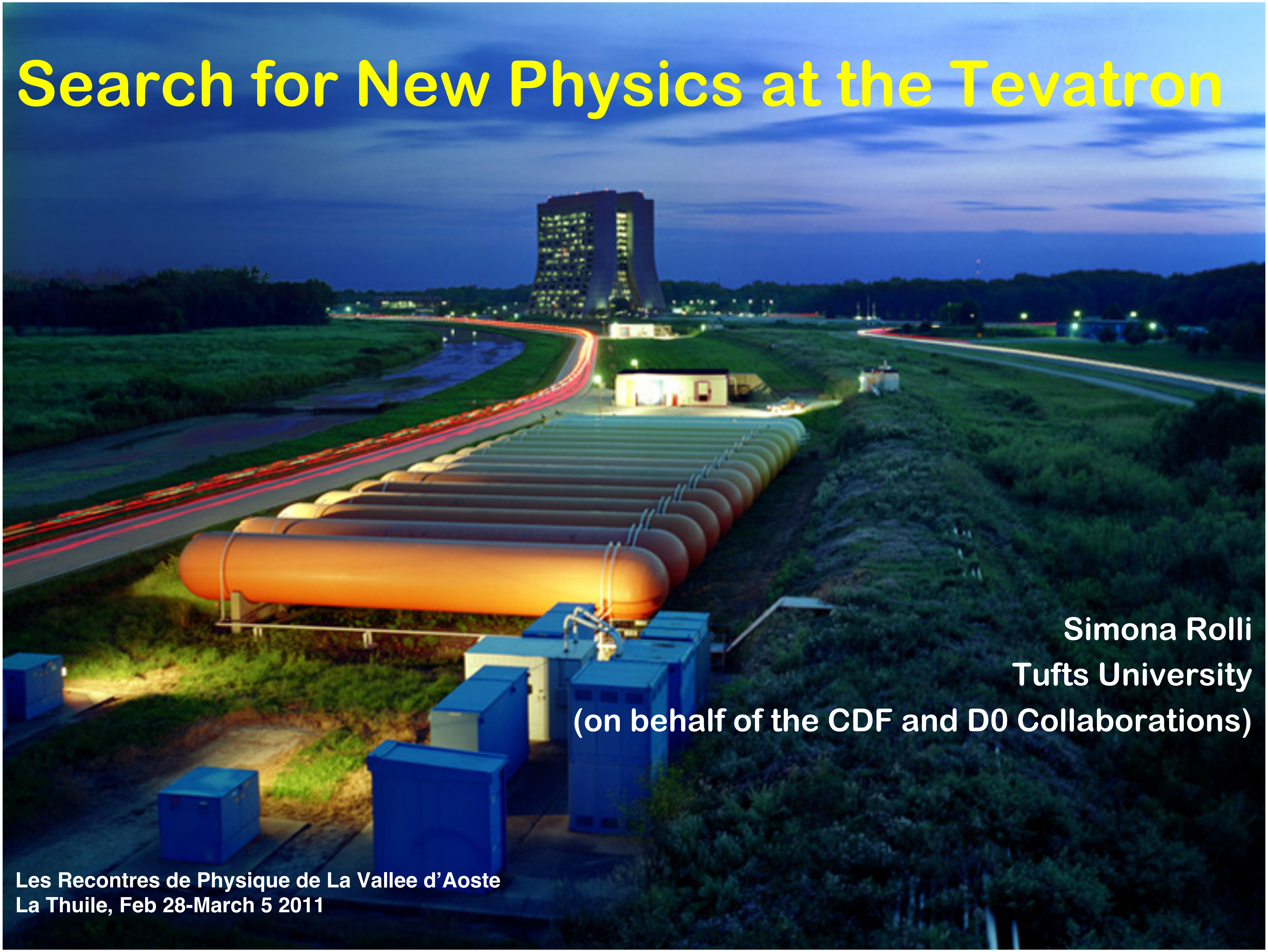
Search for New Physics at the Tevatron

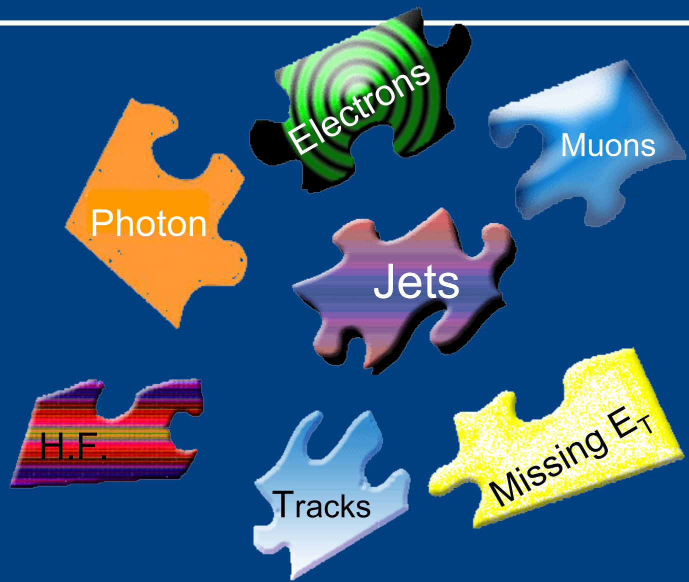


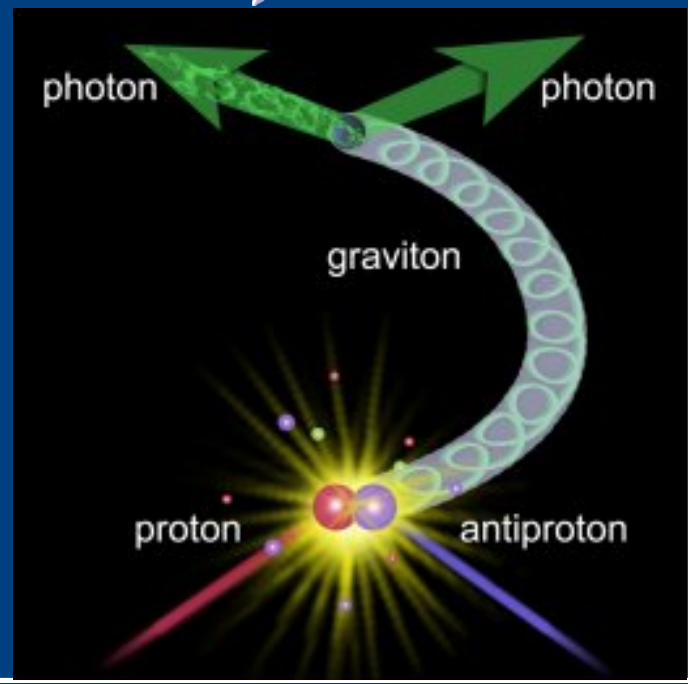
Simona Rolli
Tufts University
(on behalf of the CDF and D0 Collaborations)

Les Recontres de Physique de La Vallee d'Aoste
La Thuile, Feb 28-March 5 2011

Outline

- The Tevatron
  - Status and records
- Latest Results
  - Dilepton/diphotons resonances
  - Dibosons resonances
  - Complex final states (MET, jets, h.f.)
  - Signature-based searches
- Final remarks and conclusions

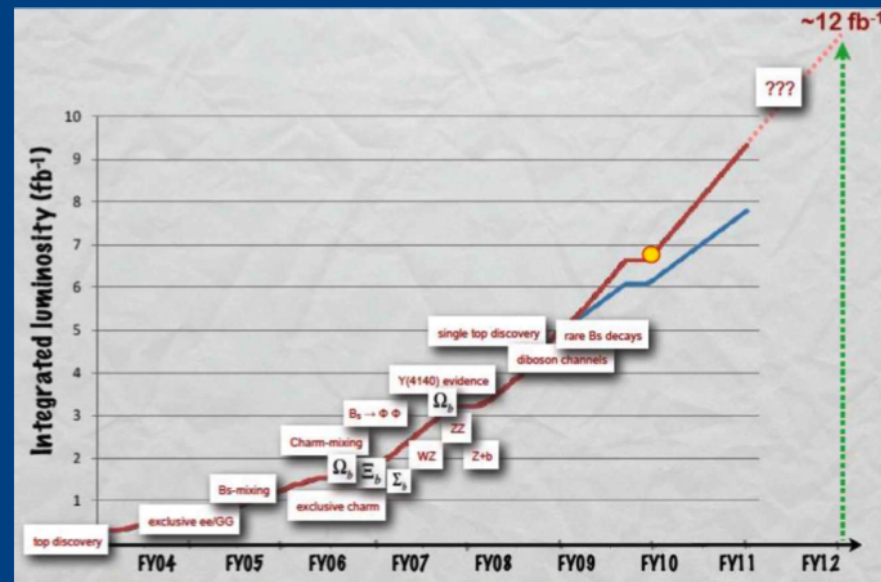




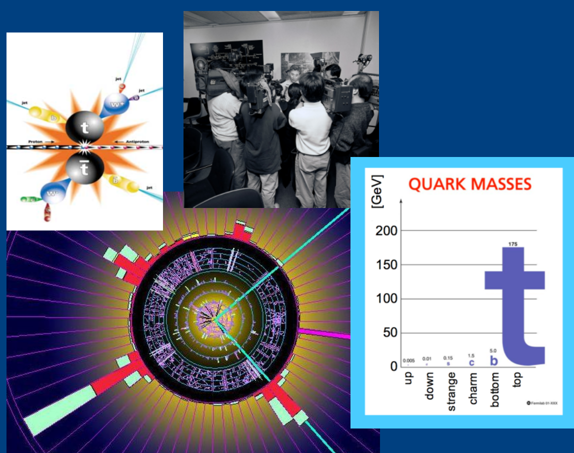
The Fermilab Tevatron

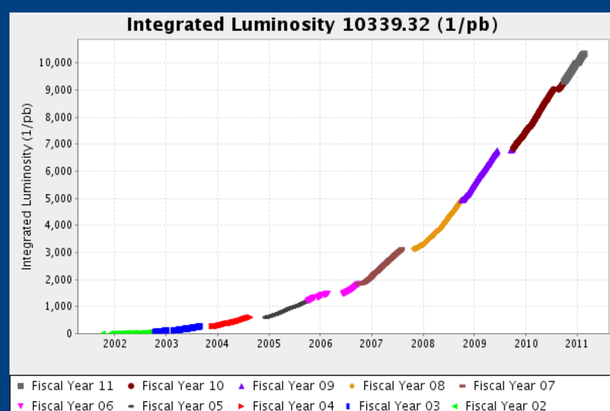
The Fermilab Tevatron is …

…a Discovery Machine!



Top Quark Discovery (1995)





Today the collider experiments have collected 125 times more data than what we used to discover the top quark

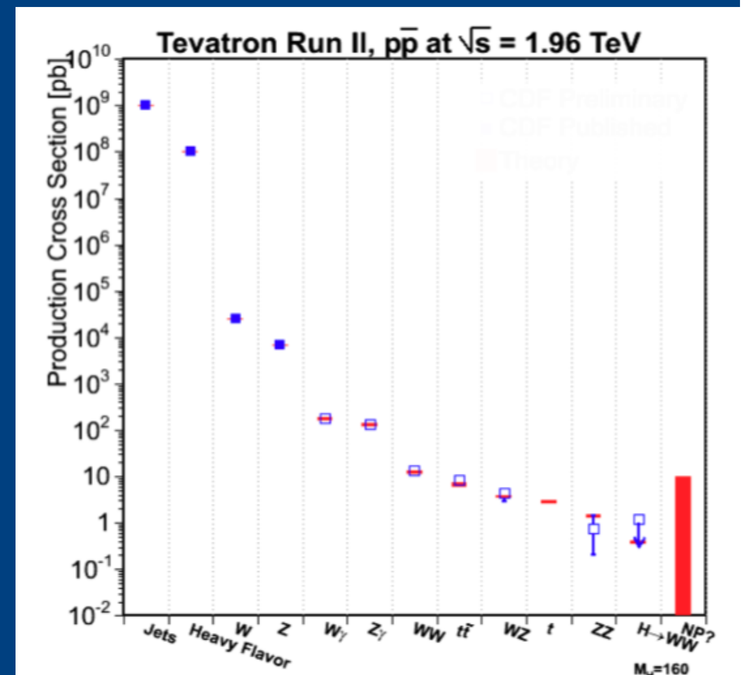
Many new luminosity records set!

The Tevatron Research Program

Precision Measurements & New Discoveries

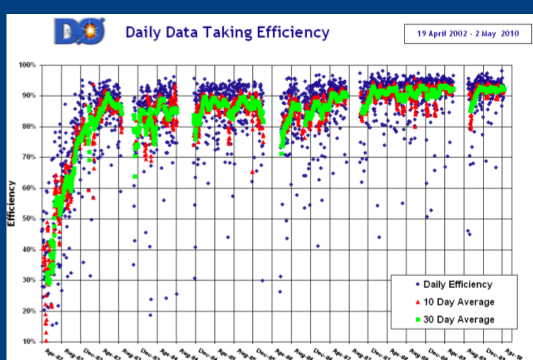
- Mixing, CKM constraints and CP violation
- Heavy flavor spectroscopy
- New Heavy barions states
- Tests of Quantum Chromodynamics
- Precise Measurements of the Top quark and W boson mass
- Top Quark Properties
- Diboson production and SM gauge couplings
- New Exclusive/diffractive processes
- …..

Harder to Produce



Harder to Observe

We are still probing the Terascale, as the integrated luminosity of our datasets increases



Are we on the verge of a new discovery?

CDF and D0 are running at ~90% efficiency

Signatures and Physics Objects

Many processes: several signatures

Leptons-only final states

- e/μ identification well understood
- τ id a little more complex
- Straightforward and highly efficient approach to search for anomalies

- **...** + Missing Energy and Photons
  - Wealth of models and exotic processes
  - Need accurate understanding of detector effects
- ... + Jets and heavy flavors
  - More complex signatures
  - Maintaining high $S/\sqrt{B}$

When a signature-based approach is advocated, final results are generally interpreted in terms of specific models (typical case dilepton searches, MET + jets)

When the analysis is model driven and results are presented as testing of a specific model, there is always a check on control regions, defined in terms of the process signature (blind analyses)

The two approaches have been pursued in a balanced and complementary way

Dilepton Final States

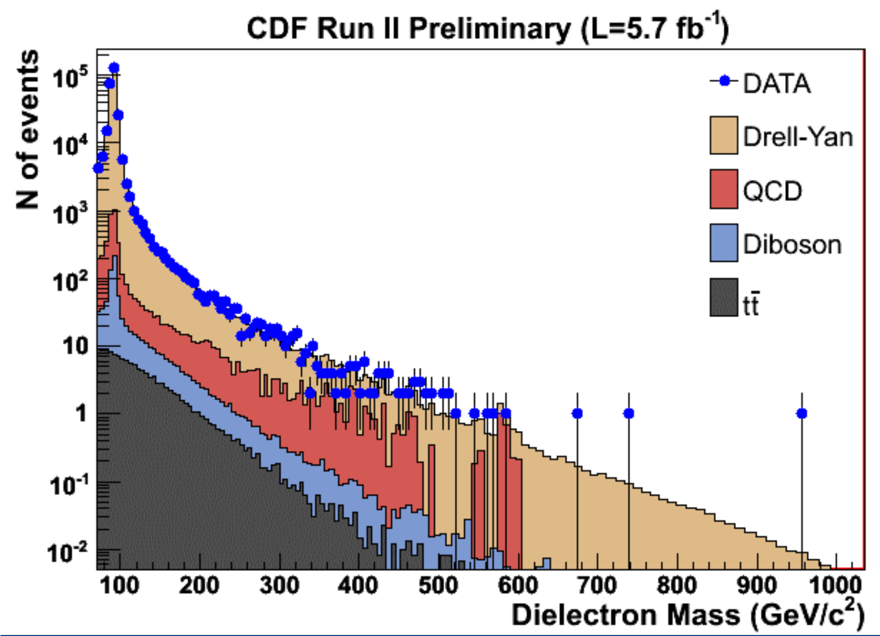
CDF: 5.7fb^{-1}
D0: 5.4fb^{-1}

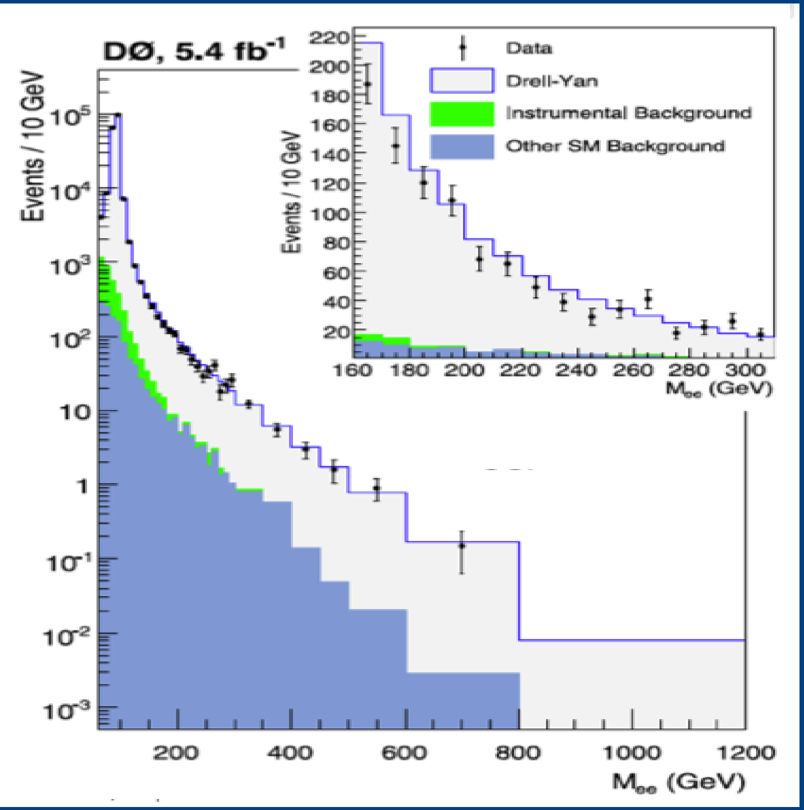
Old-fashioned mass bump hunt..

-Z production and decay into ee/$\mu\mu$ precisely measured
-Lepton ID/Reco and Trigger efficiencies high and very well understood
-Background low and easily determined (QCD fakes)
-Clean events

PLB 695, 88 (2011)

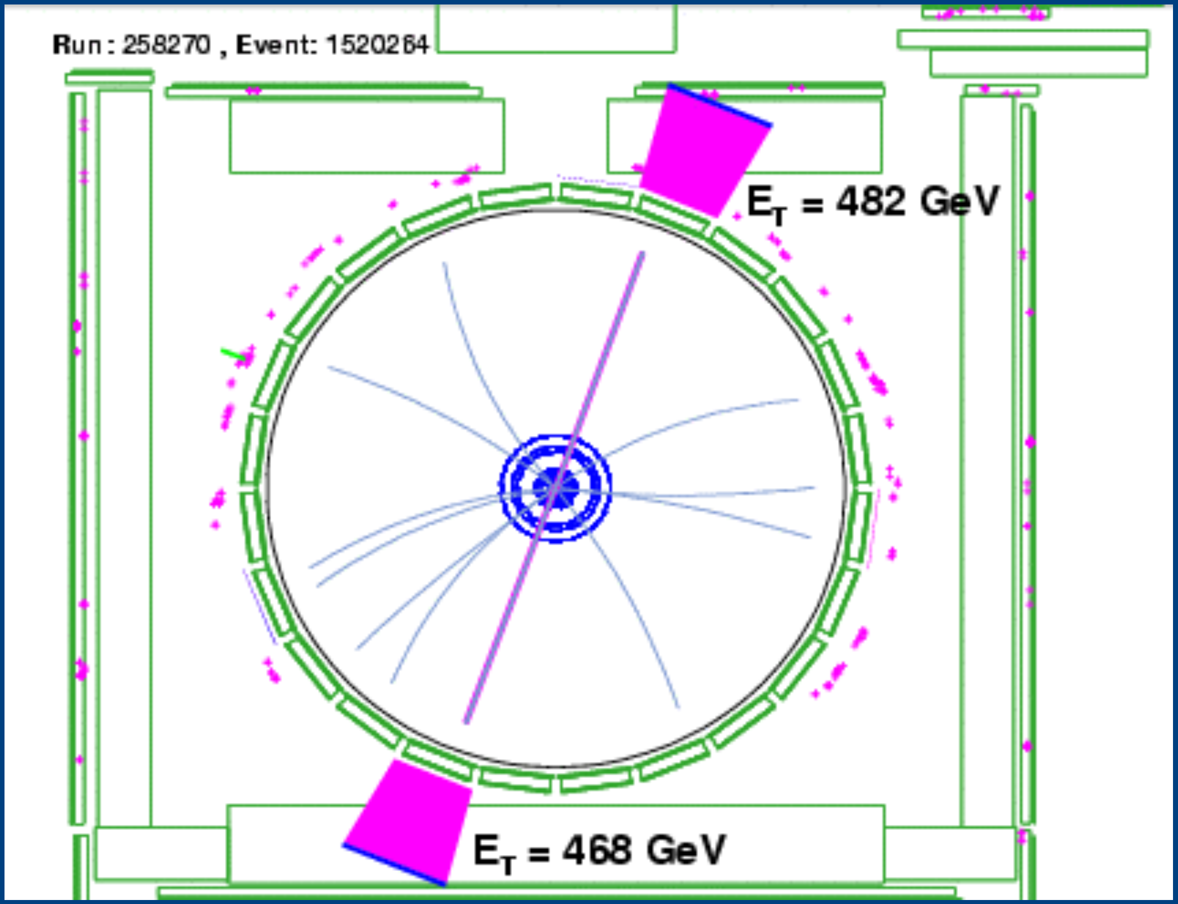
CDF Public Note 10405





Dilepton Highest Mass Event!

$M(ee) = 960\ GeV/c^2$

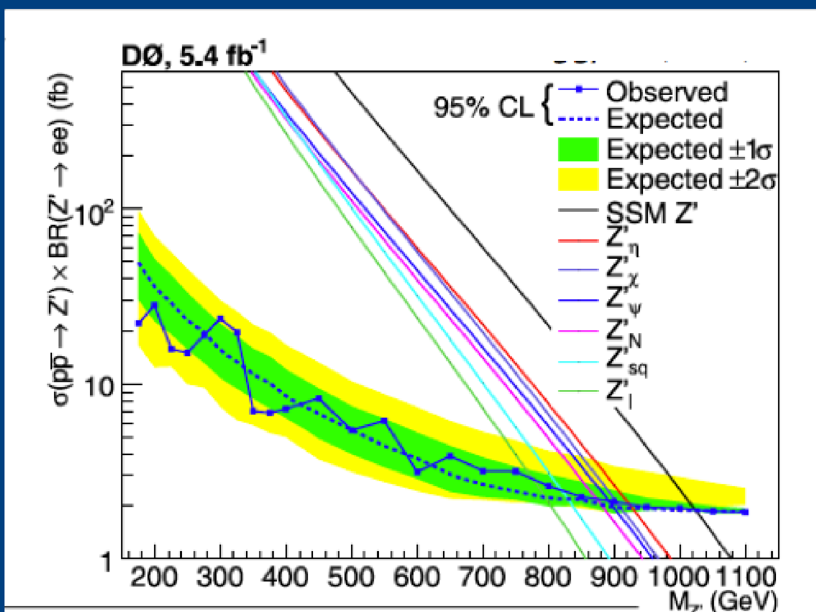


the highest dilepton event ever recorded!

Limits On New Particles

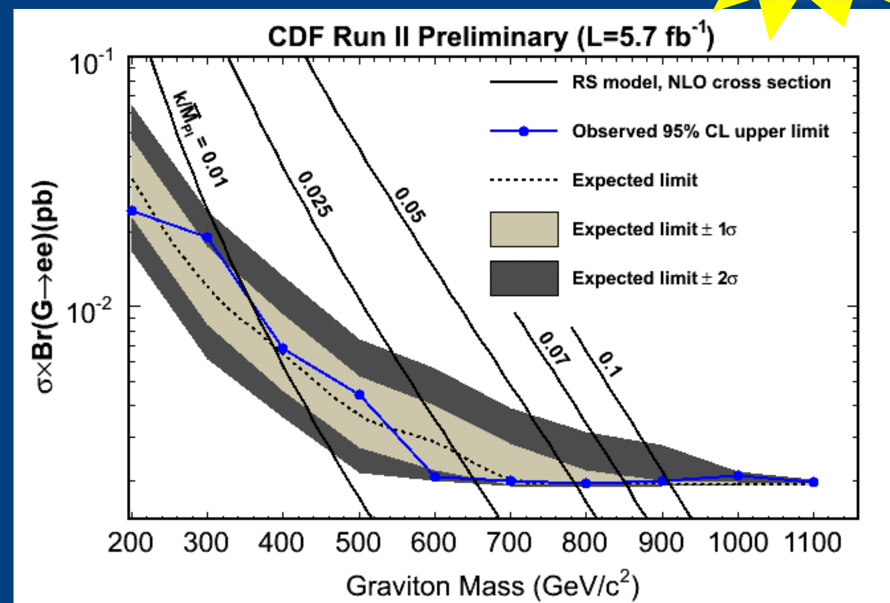
Once the data spectrum is well understood in terms of SM background, from MC, the acceptances for resonant states for different spin particles are derived (Z', RS Graviton) and the expected number of BSM events is calculated. In the absence of an excess of data, 95% CL limits on production cross-sections and mass of the particles are set.

PLB 695, 88(2011)



M(Z_{SSM}) > 1023 @ 95% CL
Best limit in this channel!

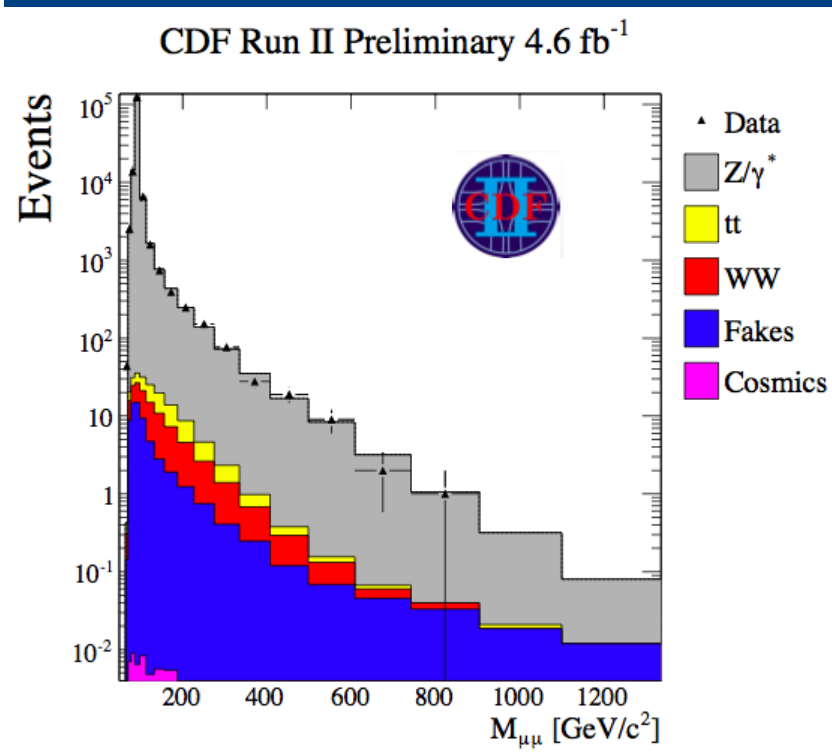
CDF Public Note 10405 New!



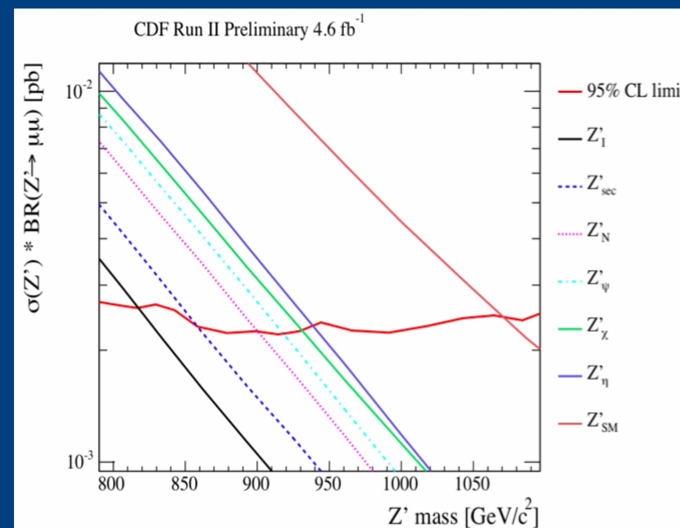
M(RSG) > 907 @ 95%CL
927 with fixed k-factor

Dimuons Final State

CDF has looked for bumps in the X→μμ final state: no excess is observed.



CDF:4.6fb^{-1}



Model	Mass Limit (GeV/c^2)
Z'_I	817
Z'_{sec}	858
Z'_N	900
Z'_ψ	917
Z'_χ	930
Z'_η	938
Z'_{SM}	1071

arXiv:1101.4578 (accepted by PRL)

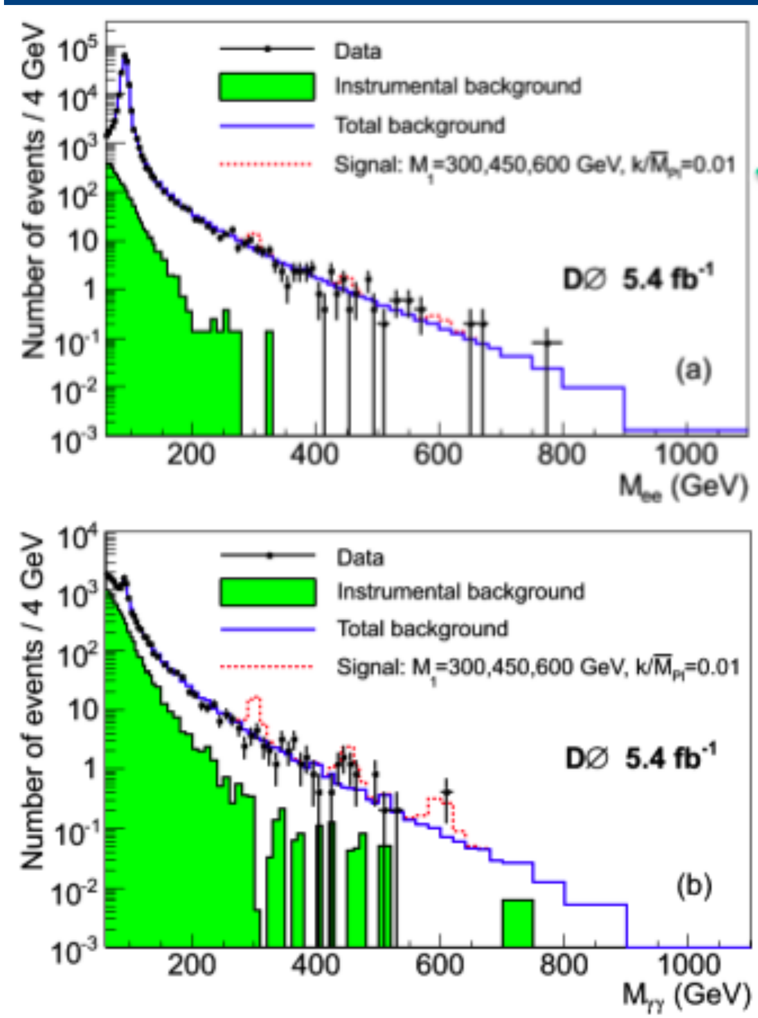
Limits are derived for other scenarios (2.3fb^{-1})

Sneutrino: up to 866 GeV/c^2 (λ^2BR = 0.01),

RS graviton: up to 921 GeV/c^2 (K/M_{PL} = 0.1)

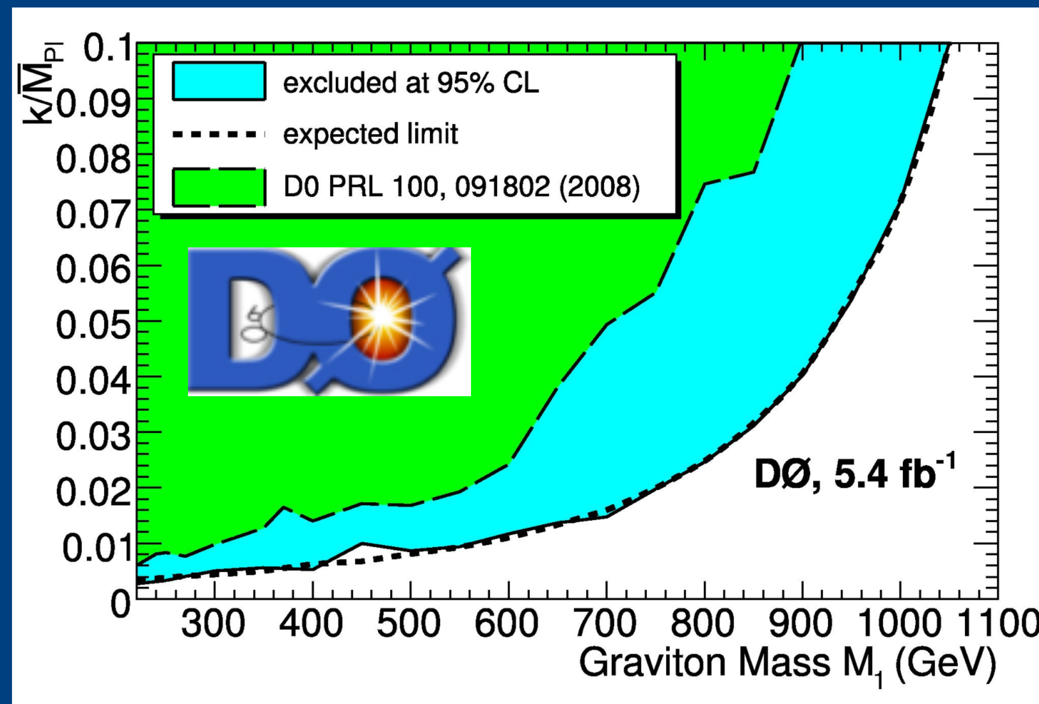
Best limit in this channel!

Diphotons & Dielectrons Final States



Graviton KK excitation mass limits:

560-1050 GeV/c^2 for $0.01 \leq k/M_{PL} \leq 0.1$

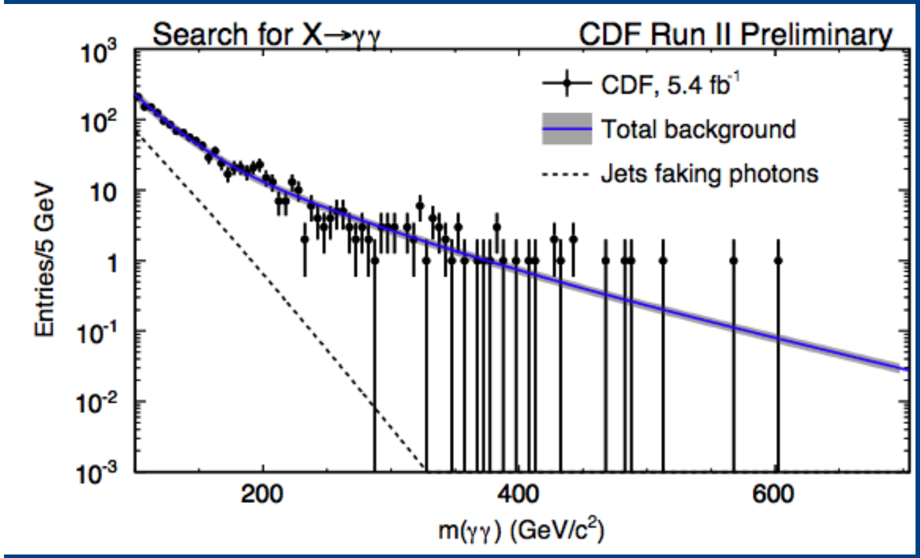


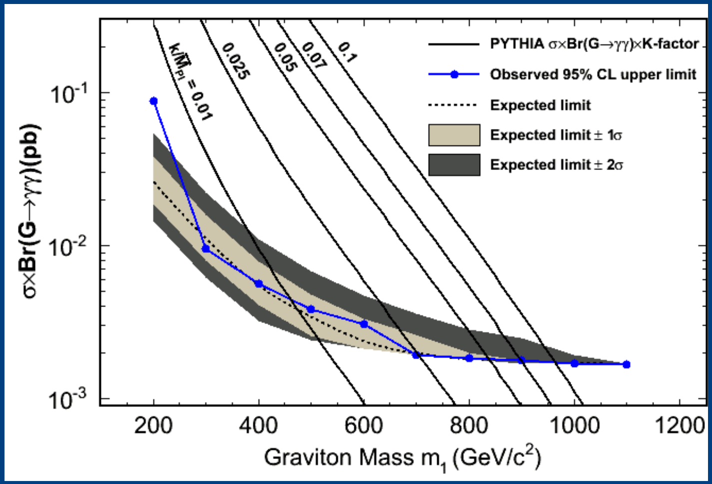
PRL 104, 241802 (2010)

Small excess at 450 GeV/c^2 (diphoton) - 2.3σ significance

Diphotons

CDF:5.4fb^{-1}

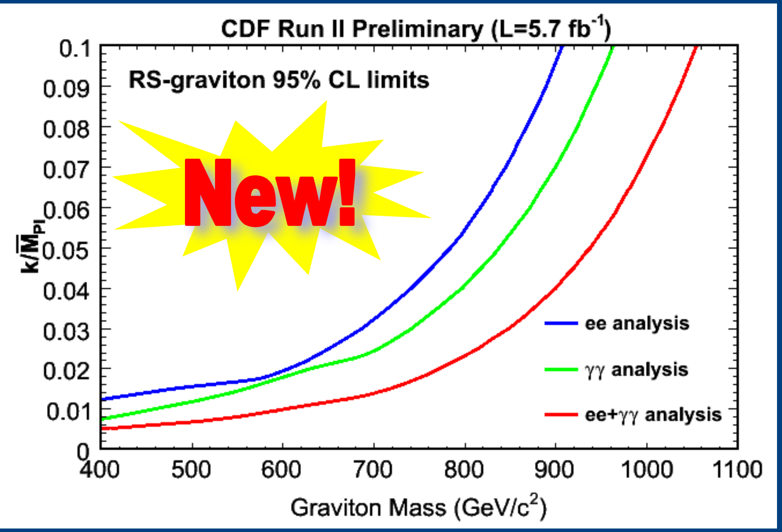




M(RSG) > 963 GeV/c^2 k/M$_{PL}$ = 0.1

Best limit in this channel!

Phys.Rev.D83:011102,2011



Combined with dielectron channel gives the most stringent limits to date

604-1055 GeV/c^2 for $0.01 \leq k/M_{PL} \leq 0.1$ (variable k-factor)

1089 for k/M$_{PL}$ for fixed k-factor

CDF Public Note 10405

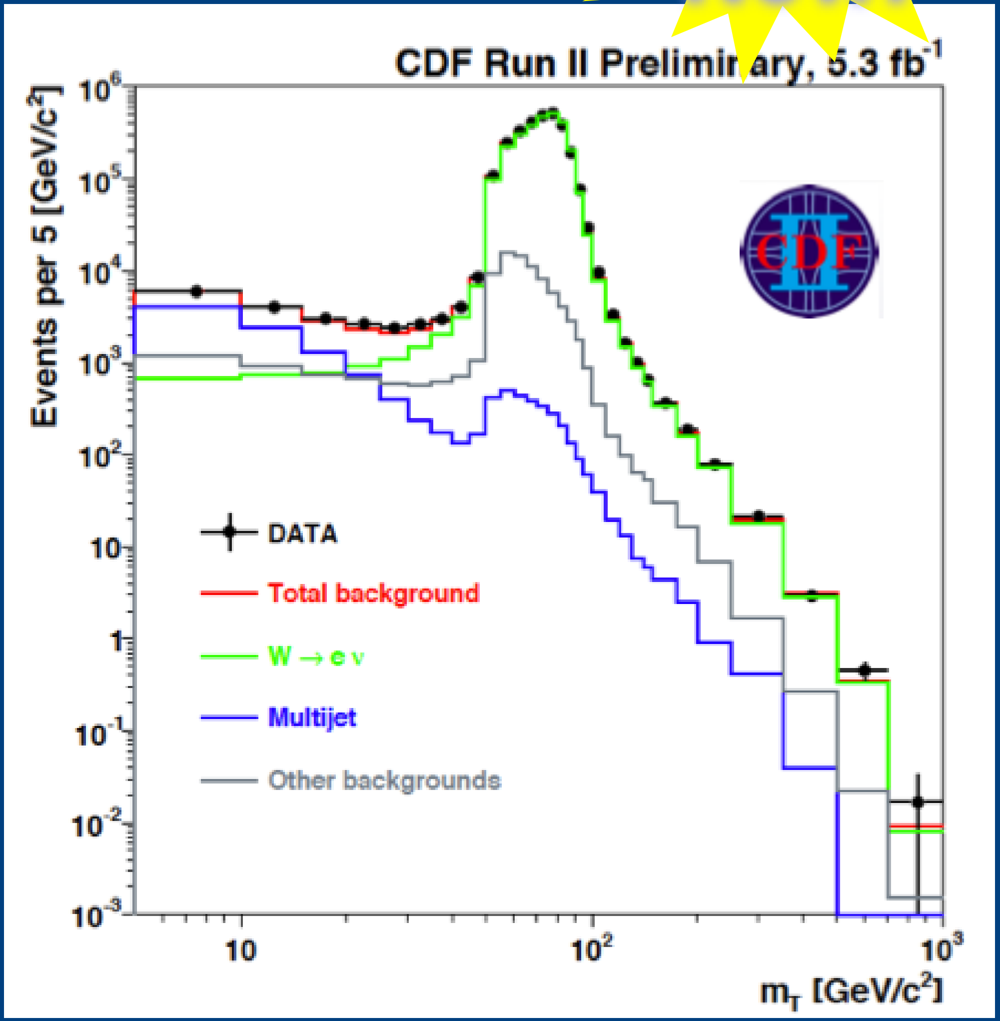
W’

Search for heavier versions of the EW gauge boson: simple final state with lepton and neutrino

Pushing the envelope by going up to energies far from benchmarks! Understanding of the SM tails very important.

No excess observed- 95% CL limit $m_{W'} > 1.1$TeV

New!



Phys.Rev.D83:031102,2011

Diboson Production

•Diboson production is one of the least tested areas of the SM

•The triple gauge vertices are sensitive to physics beyond the SM

•SM diboson production share many characteristics and represent background to Higgs and SUSY searches

- WW+WZ

  D0: σ (WW+WZ) = 20.2 4.5 pb evidence at 4.4σ

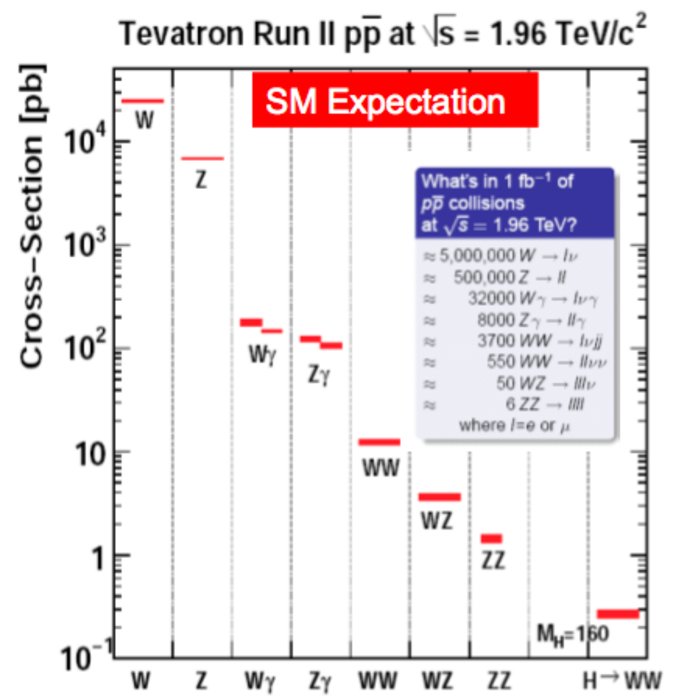
  CDF: σ (WW+WZ) = $16.5^{+3.3}_{-3.0}$ observation at 5.4σ

- WW+WZ+ZZ

  CDF: σ (WW + WZ+ ZZ) = 18.± 2.8(stat) ±2.4(sys) ±1.1(lum)pb

  SM prediction = 16.8 ± 0.5 pb (MCFM+CTEQ6M)

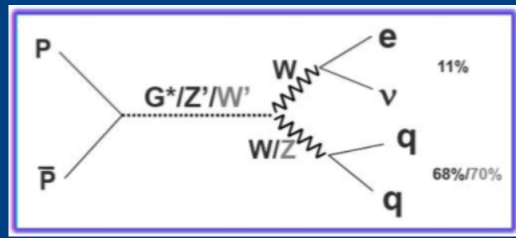
  observation at 5.3σ significance



note: this is σ, not σ×BR

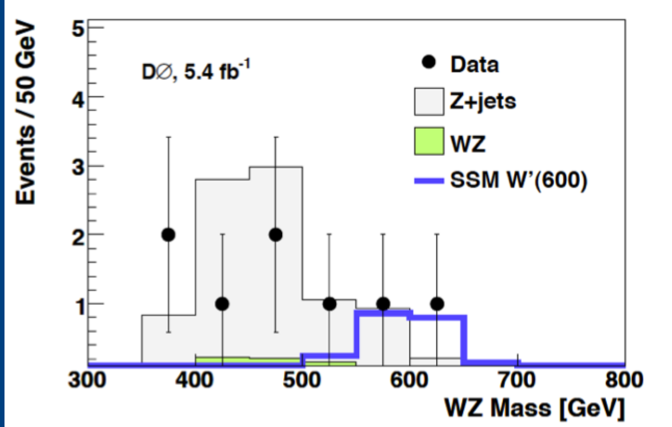
Diboson Resonances:WW/WZ

lνjj, lljj, lllν



Search sensitivity increased with high mass/low mass regions properly optimized

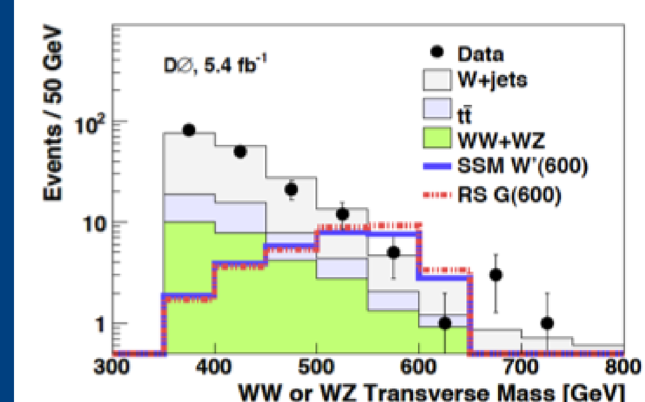
llj(j)

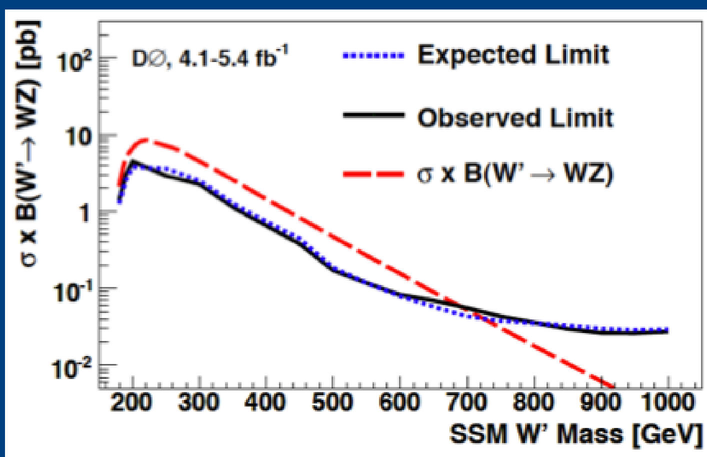


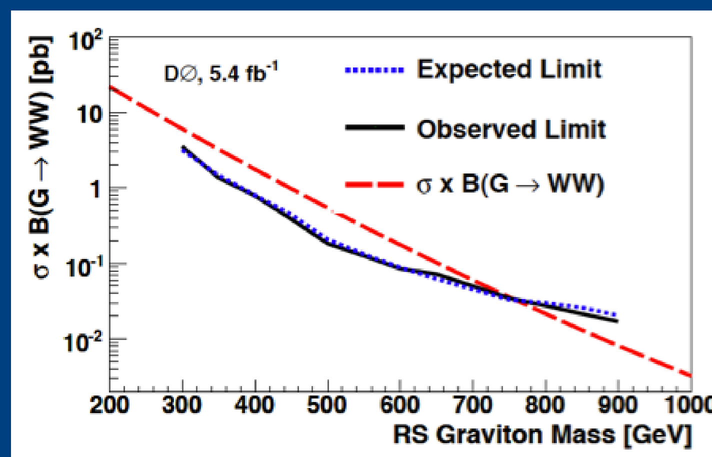
arXiv.org:1011.6278

4.1-5.4 fb^{-1}

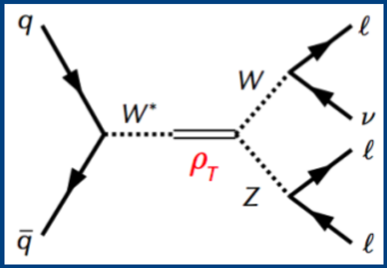
lνj(j)



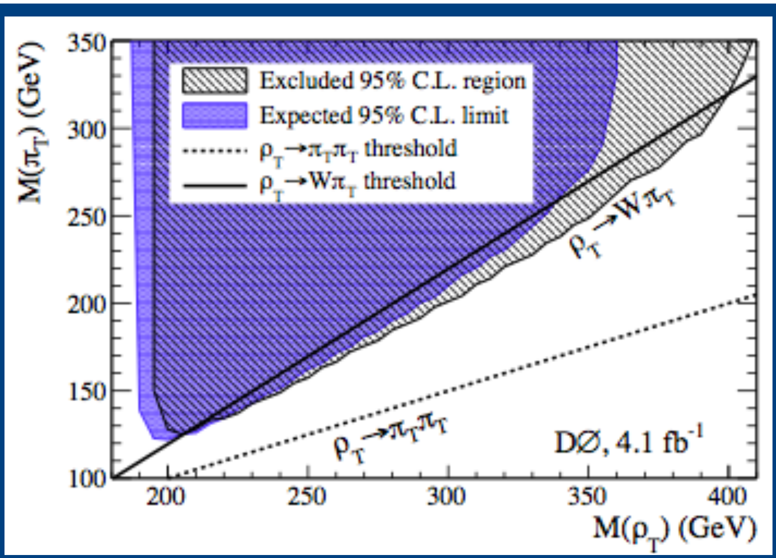




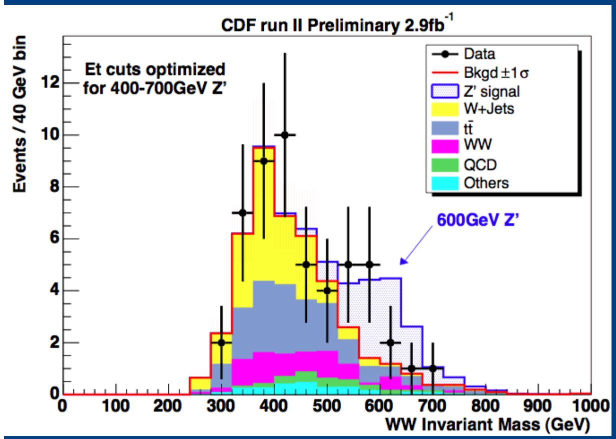
Dibosons Resonances (cont'd)

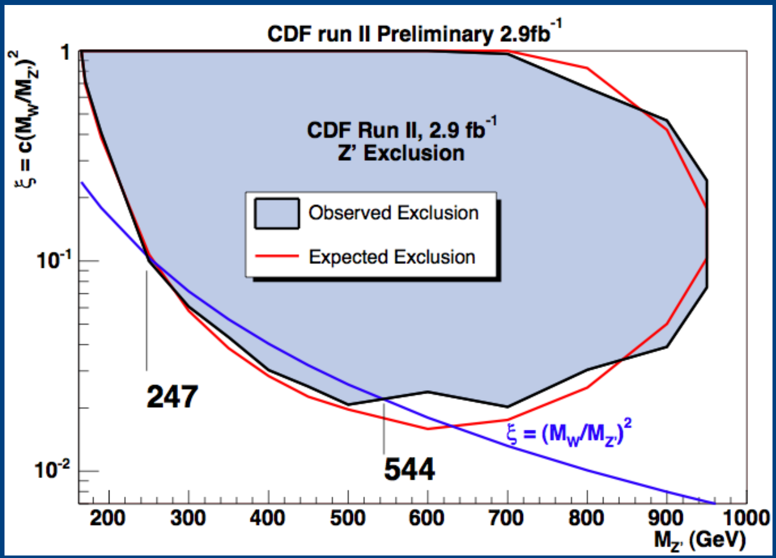


Phys. Rev. Lett. **104**, 061801 (2010)



Technicolor scenario with
$m(\rho_T) < m(\pi_T) + M(W)$
Excluded mass 208-408 GeV/c^2 @ 95% CL

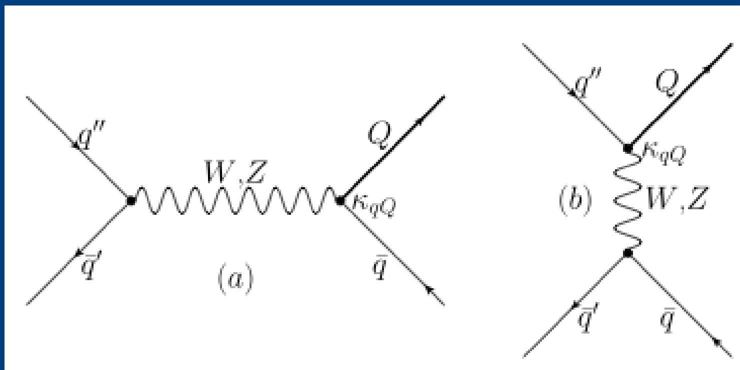




The gauge coupling strength $g^* \cos\theta_W$ for W and Z is replaced by $\xi^* g^* \cos\theta_W$ for Z', where $\xi = c^*(M_W/M_{Z'})^2$ is a suppression factor set by the Z' mass ($M_{Z'}$) and a free parameter c

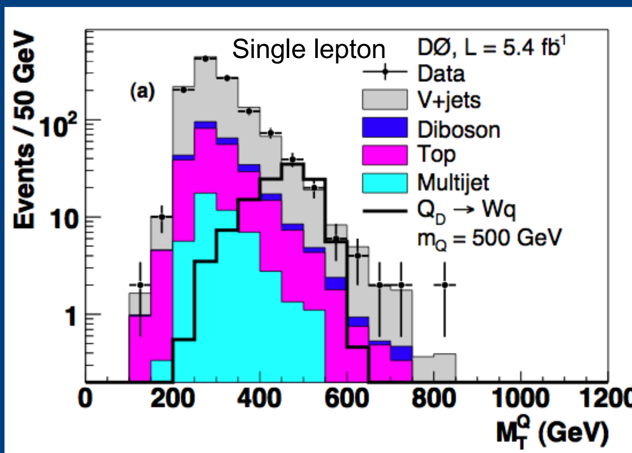
Phys.Rev.Lett.104:241801,2010

Vector-like Quarks

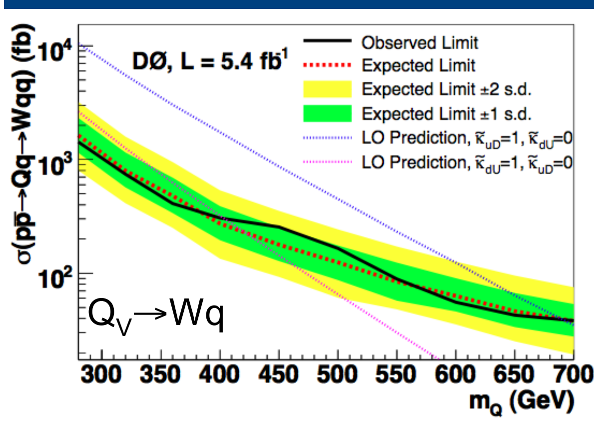


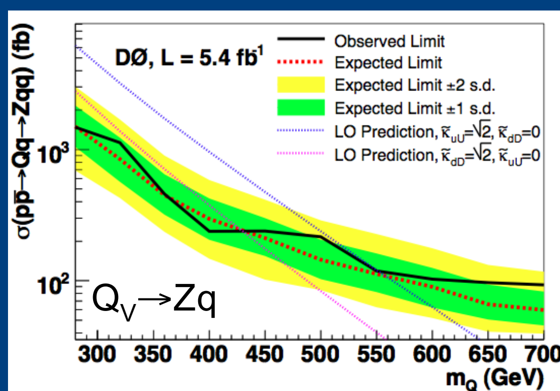
Q decays into W/Z +q
Final state comprising
Lepton(s), MET and at least 2 jets

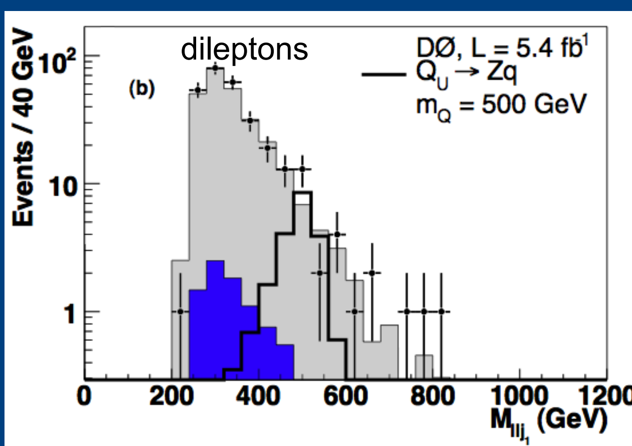
5.4 fb^{-1}



Use M_T(Q) (lepton plus MET)and Mllj masses and search for evidence of the Q_v decay.







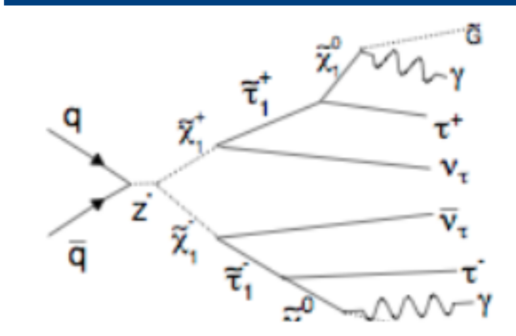
PRL 106, 081801 (2011)

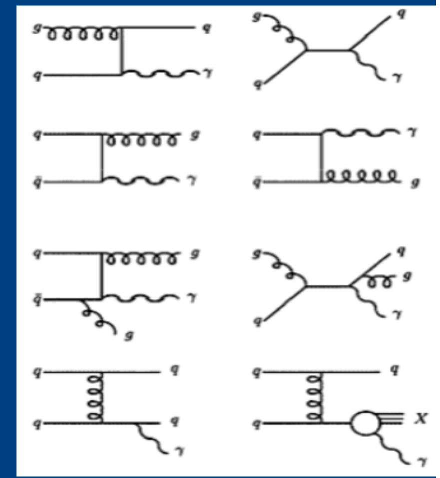
More Complex Topologies

γ + jets

New! 4.8 fb^{-1}

Several processes can give rise to anomalous production of γ+Jet

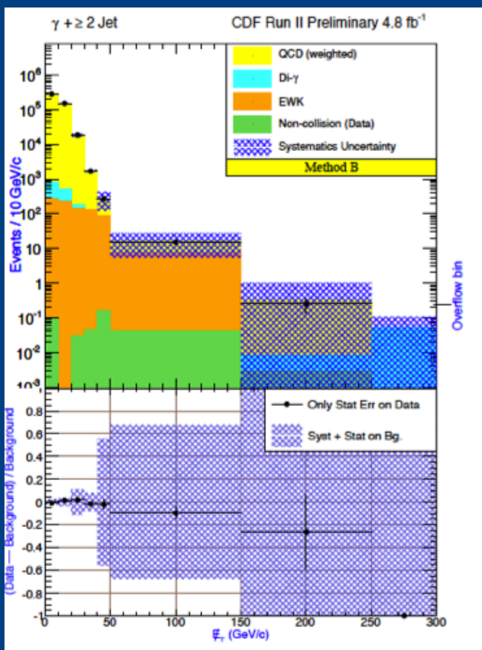


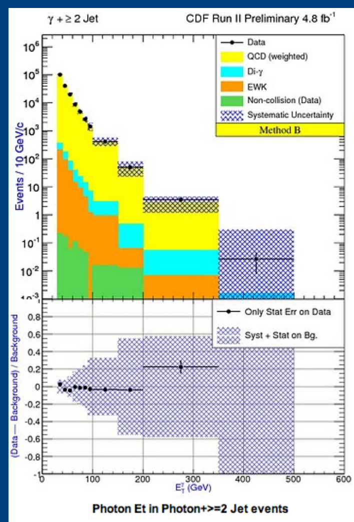


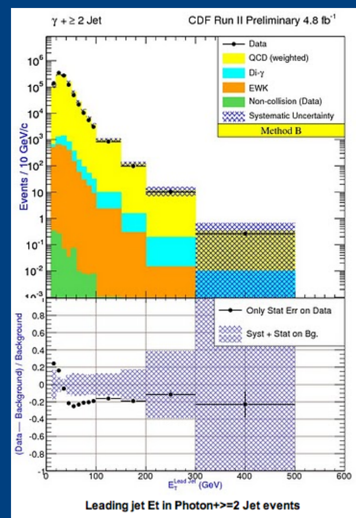
Various SM processes also contribute!

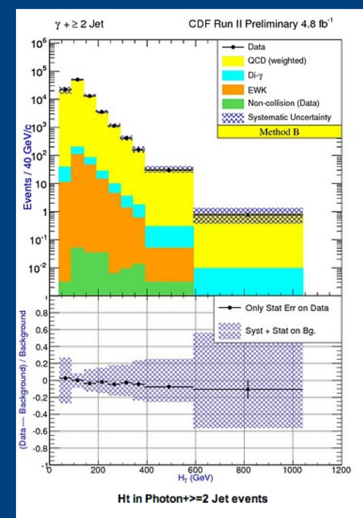
Searching for an excess (shape discrepancy) over the background predictions which will indicate new physics.

Scan kinematic plots photon E_T, invariant mass of photon and jet/s, missing transverse energy etc. for an excess.









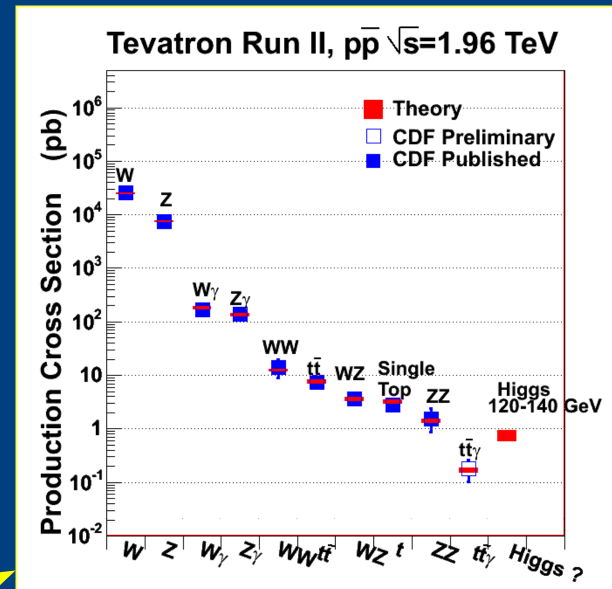
CDF Public note 10355

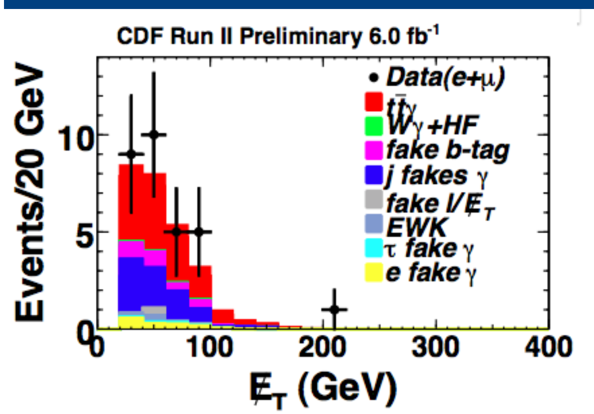
More Complex Topologies

γ+ MET + b-jet + lepton

6.0 fb^{-1}

- Sensitive to the same kind of new physics as the more general final state.
- Leading background is Standard Model t-tbar + γ.
- Pleasant synergy,
  search for deviation from the Standard Model,
  and measurement of the ratio of the cross
  section: γ-ttbar/ ttbar.

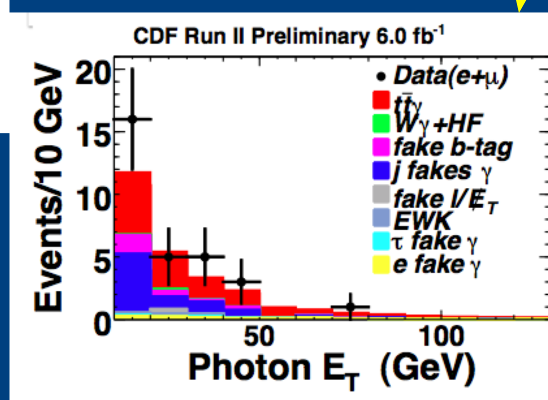




Possibly the smallest cross-section measured!

New!

CDF Public Note 10270



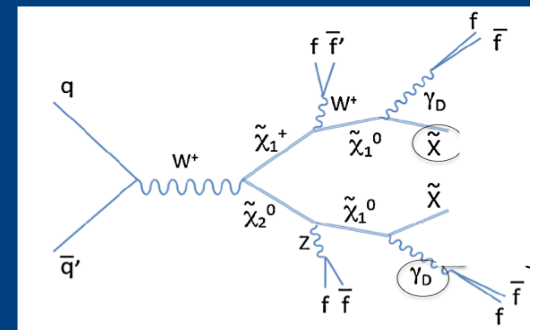
No excess observed,
σ(ditop+γ) =0.18 ±0.07 pb

R(ttγ/tt) = 0.024 ± 0.009

More Complex Topologies

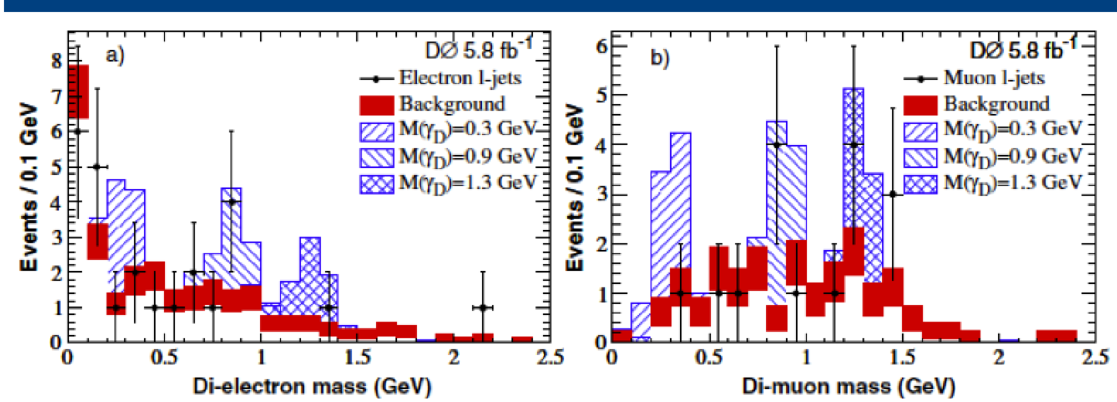
MET+*leptonic jets*

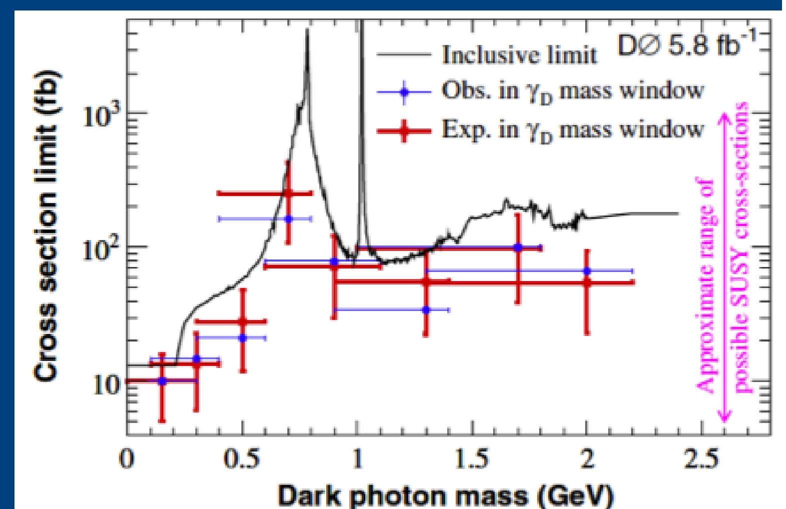
5.8 fb^{-1}



- Very exotic SUSY models :
  - hidden sector weakly coupled to SM particles
  - Force carrier in the hidden sector: dark photon
  - Dark photon decays to highly collimated SM particles
- Signature: two *leptonic* jets and MET

- Leptonic jet - regular lepton + additional track(s) of opposite charge near the lepton





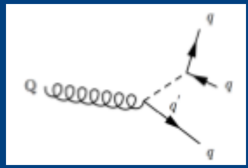
efficiency times acceptance varies over range of masses due to hadronic decays.

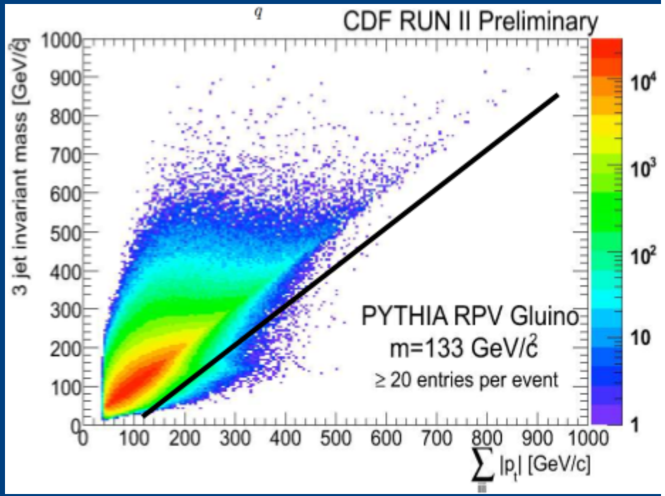
PRL, 105, 211802 (2010)

Multijets Resonances

3.2 fb^{-1}

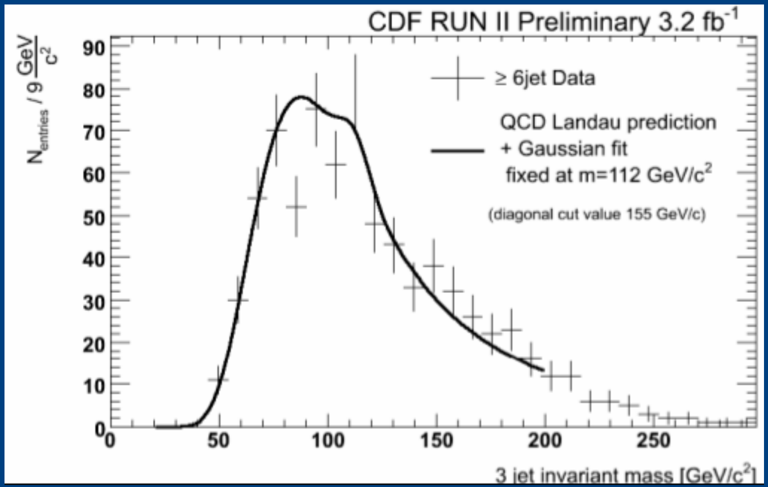
Model independent search for pp→QQ→3j + 3j = 6 jets



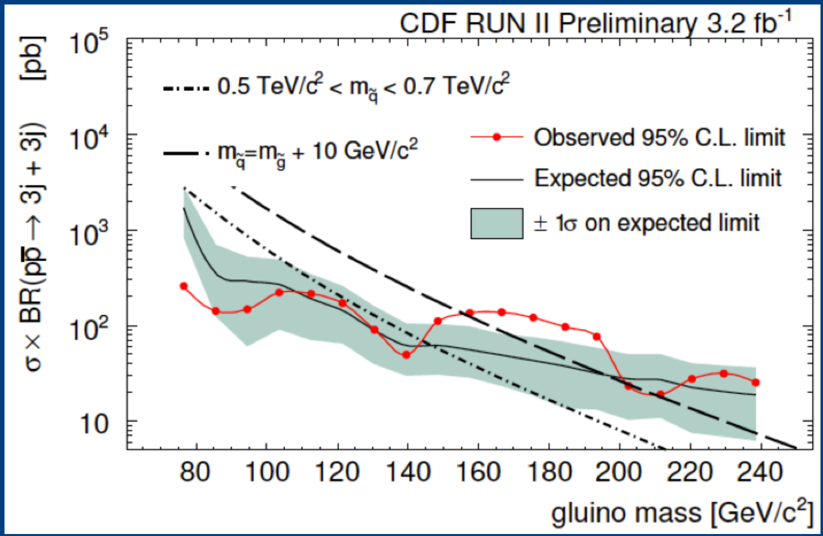


Start with 6 jets selection
- separate three-jet combinations that are potentially correlated using diagonal cut
- optimize for each mass point

QCD background parameterized from 5-jet events
Set limit on RPV gluino scenario
Exclude mass below 144 GeV/c^2

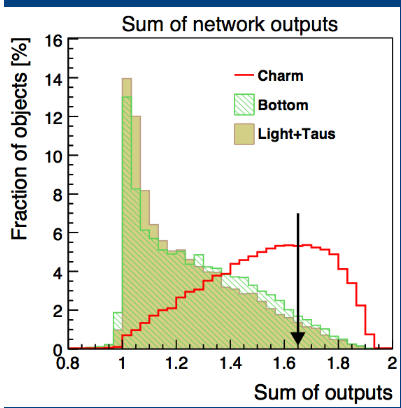


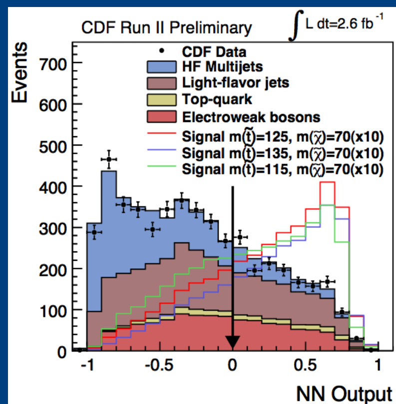
CDF Public Note 10256

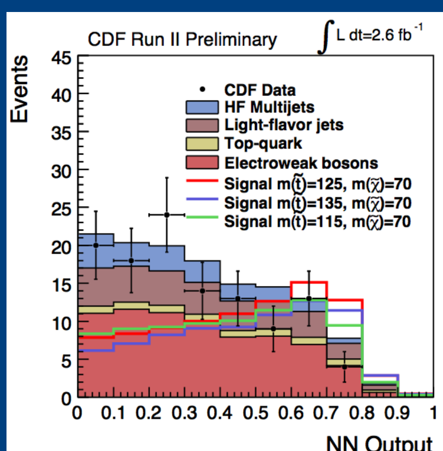


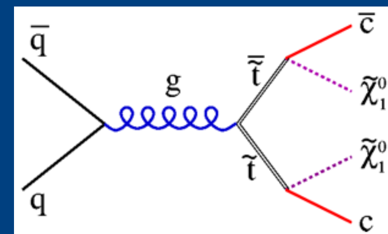
MET + c-jets: Stop to Charm-Neutralino

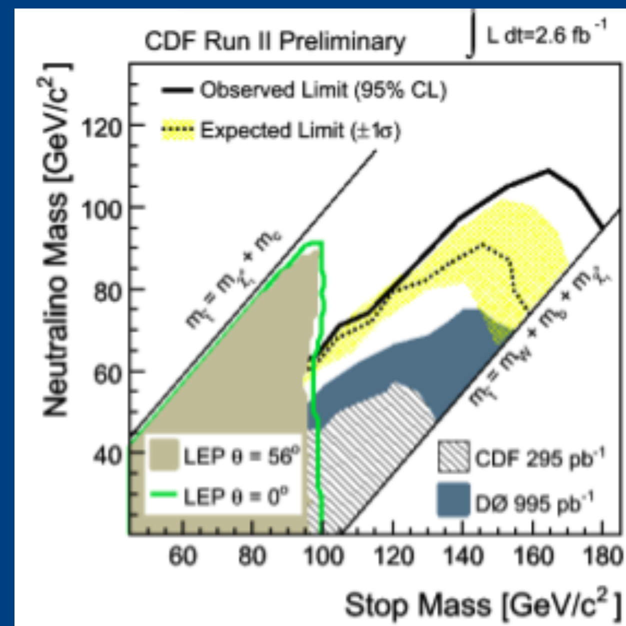
Optimization process using a Neural Network (NN) plus a flavour saparator (CHAOS) to reduce the background contribution.





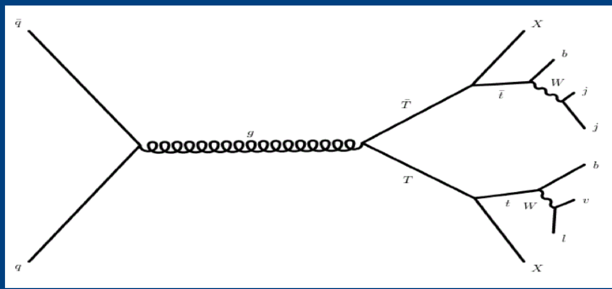






CDF Conf Note 9834

Search for Dark Matter Particles



Exotic 4-th generation quarks t'-> tX, where X is a dark matter candidate

- J.Feng et al, arXiv:1002.3366
- Other scenario: stop -> top + neutralino
- Signature: ttbar + large MET
  - Dominant background, ttbar and W+jets

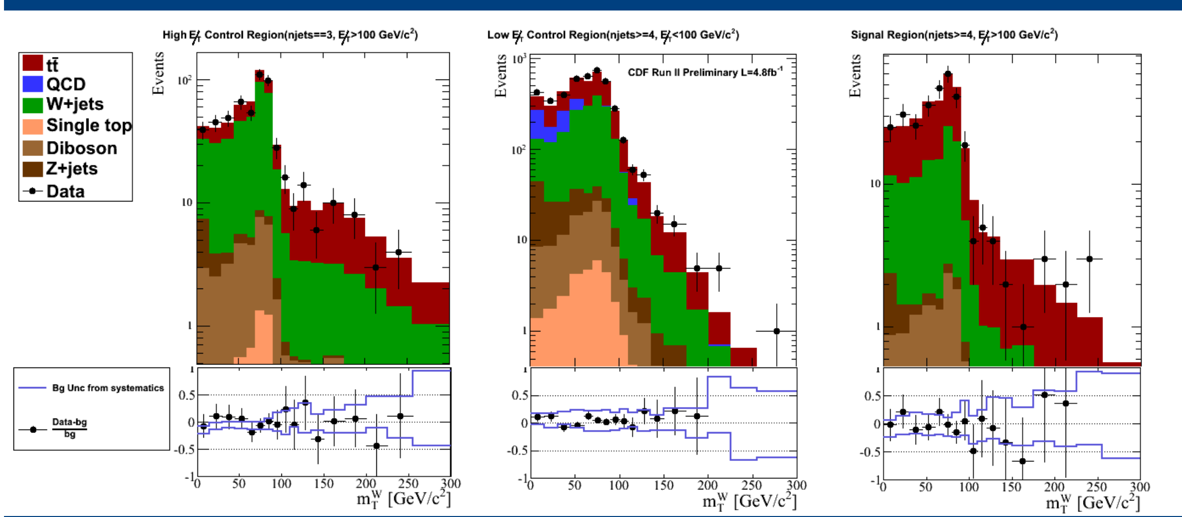
4.8 fb^{-1}

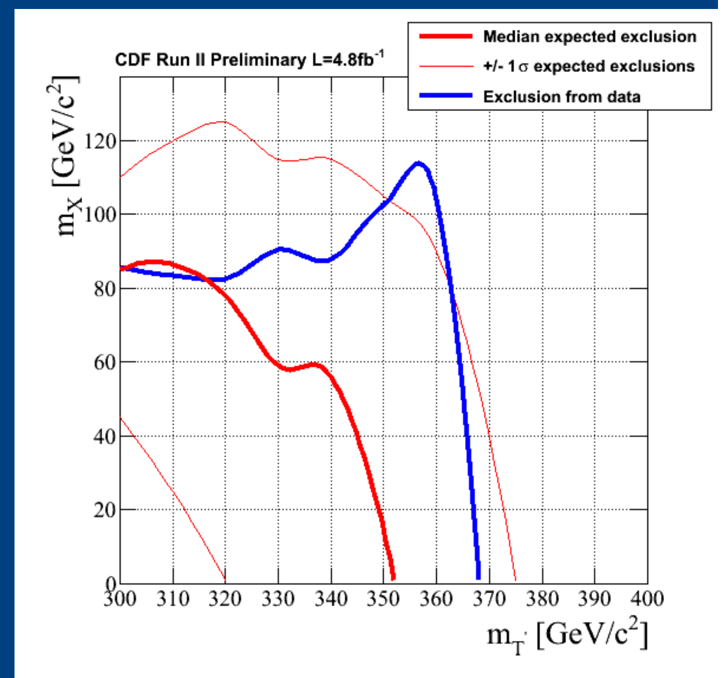
New!

Strategy: fit background + signal transverse mass distribution

Optimize the MET cut for different points

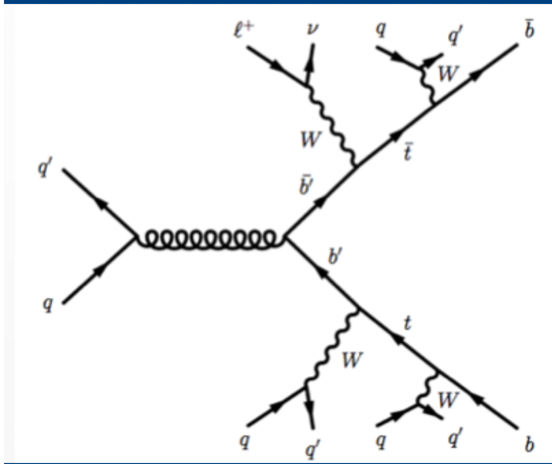
Modeling of background is tested in control regions





CDF Public Note 10374

Search for 4th generation quarks

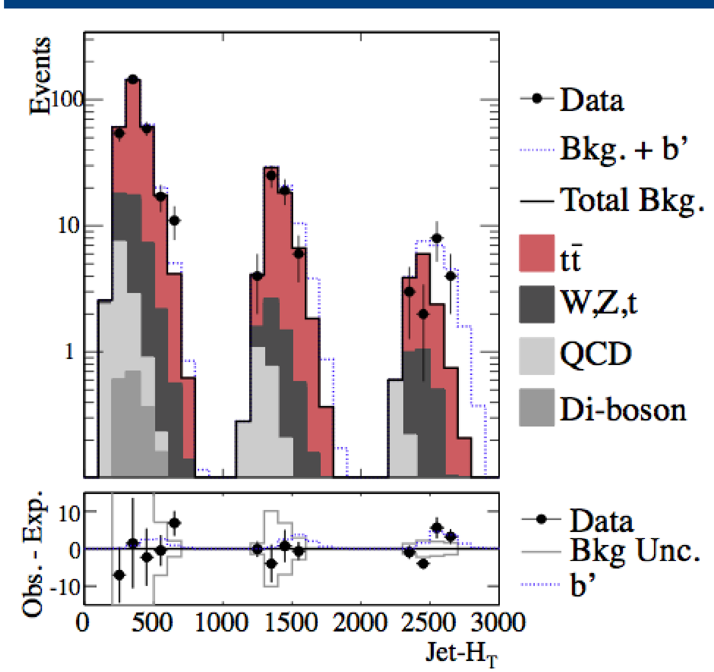


Current limits push 4th generation down-type quark to be above m(top)+m(W)

Final state comprising top and extra W'

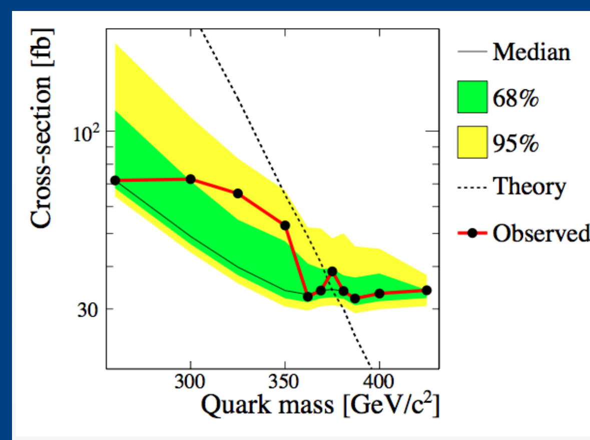
Lepton+jets signature - high acceptance due to hadronic decaying W's

New!



Fit to $H_T = \Sigma(\text{Jet } E_T + \text{lepton } E_T + \text{MET})$

Across different jet multiplicity bins



Exclude b'
below 385 GeV/c^2
@95% CL
Best Limit to date!

arXiv:1101.5728

Conclusions

- The search for new physics at the Tevatron continues…
  - Despite its age, the Tevatron has been performing very well and with increased luminosity records
    - Very Large Dataset!
    - Some limits are still the best!
- The CDF and D0 collaborations are pushing:
  - for better and improved limits on new particles production
    - Small cross-section phenomena now accessible due to large luminosity
    - Hints of something new in B sector (dimuon asymmetry) and Top sector (A_{FB} asymmetry) - separate talks on these topics!
  - To exercise more advanced techniques applicable and being applied at the LHC
- Surprises might still come from Batavia after all….
- More at:
  - http://www-cdf.fnal.gov/physics/exotic/exotic.html
  - http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm

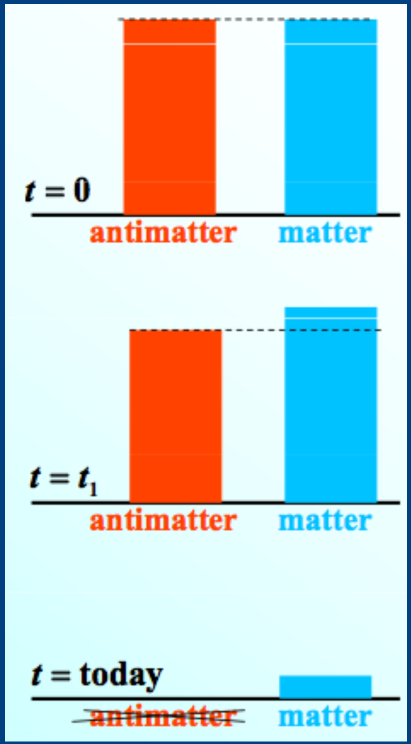
Conclusions (cont'd)

"Just checking."

Backup Slides

Like-sign dimuon asymmetry

Matter-AntiMatter asymmetry
At the beginning of time matter and anti-matter were in equilibrium
Then something happened…
Antimatter completely annihilated..



One of conditions (A. Sakharov) required to explain this process – properties of particles and antiparticles must be different (*CP* violation)

CP-violation is naturally included in the SM via the CKM matrix
Many different measurements of CP-violation are in excellent agreement with the SM
However the SM source of CP-violation is not enough to explain the imbalance between matter and antimatter
New sources of CP-violation are required to explain the matter dominance

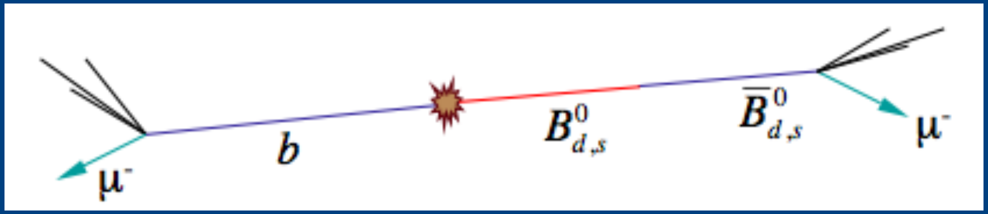
Like-sign dimuon asymmetry: Analysis

Goal of this measurement is to study CP violation in the mixing of the B_d and B_s systems

The magnitude of CP-violation predicted by the SM is negligible

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

Contribution of new physics sources can significantly alter the SM prediction



CP-violation in mixing is measured using the dimuon charge asymmetry of semileptonic b-decays

$$A_{sl}^{b} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

and the inclusive muon charge asymmetry

$$a \equiv \frac{n^{+} - n^{-}}{n^{+} + n^{-}}$$

Semileptonic B decays contribute to both A and a.

$$a = k\, A_{sl}^{b} + a_{bkg}$$

$$A = K\, A_{sl}^{b} + A_{bkg}$$

The correlations in their background uncertainties allow for a very precise measurement

- N_b^{++}, N_b^{--} – number of events with two b hadrons decaying semileptonically and producing two muons of the same charge
- One muon comes from direct semileptonic decay $b \to \mu^- X$
- Second muon comes from direct semileptonic decay after neutral B meson mixing: $B^0 \to \overline{B}^0 \to \mu^- X$

Like-sign dimuon asymmetry: Results

Advantage is taken of the correlated background contributions and obtain A_{sl}^b from their linear combination

$$A' \equiv A - \alpha\, a$$

The coefficient α is chosen as to minimize the uncertainty of A_{sl}^b

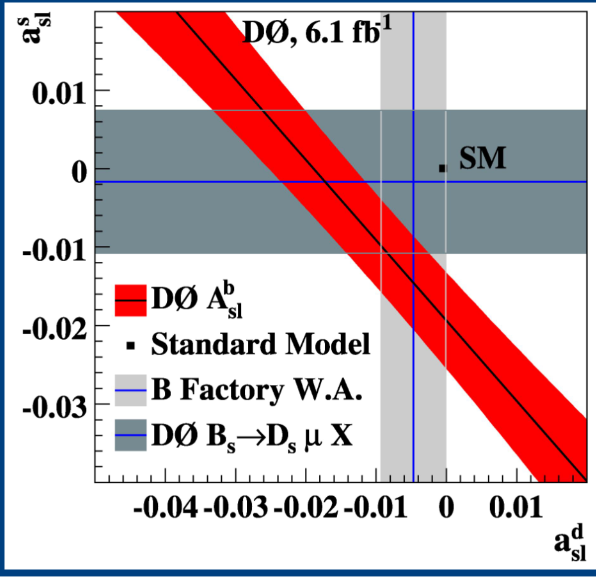
$$A_{sl}^b = (-0.957 \pm 0.251\,(\text{stat}) \pm 0.146\,(\text{syst}))\%$$

3.2σ (99.8% C.L.) disagreement with SM

This analysis measures A^b_{sl} as a linear combination of a^d_{sl} & a^s_{sl}

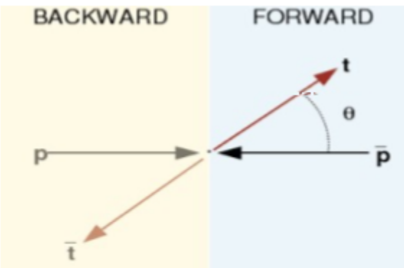
$$A_{sl}^b = 0.506\, a_{sl}^d + 0.494\, a_{sl}^s$$

Which are in agreement with other measurements



Anomalies in Top Sample

- Forward-backward asymmetry

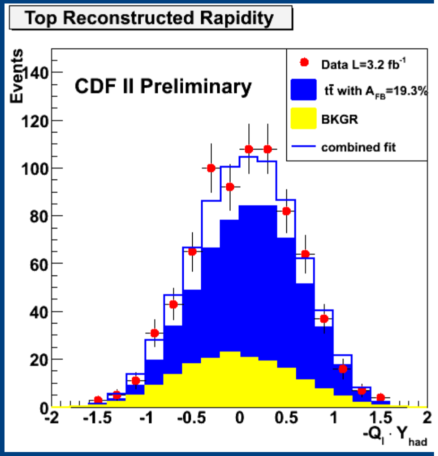


$$A_{fb} = \frac{F - B}{F + B}$$

New physics could give rise to asymmetry (Z', axigluons etc)
Standard Model predicts: A_{FB} = 0.05±0.015 (NLO QCD)

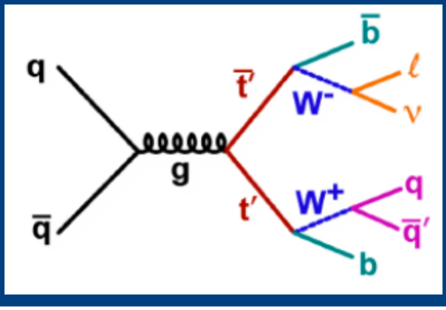
CDF (3.2 fb^{-1}):
Afb = 0.19 ± 0.07 (stat) ± 0.02 (syst)

D0(4.3fb^{-1}):
Afb = 0.08 ±0.04(stat)±0.01(sys)

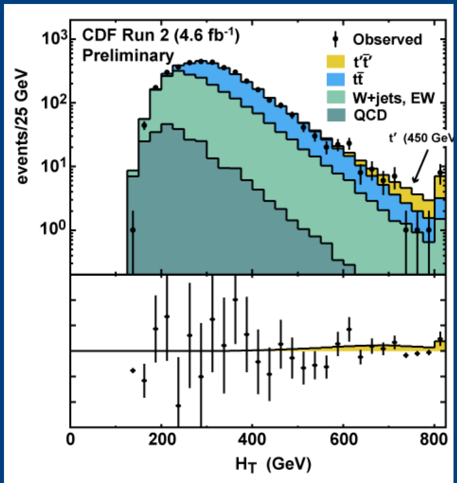


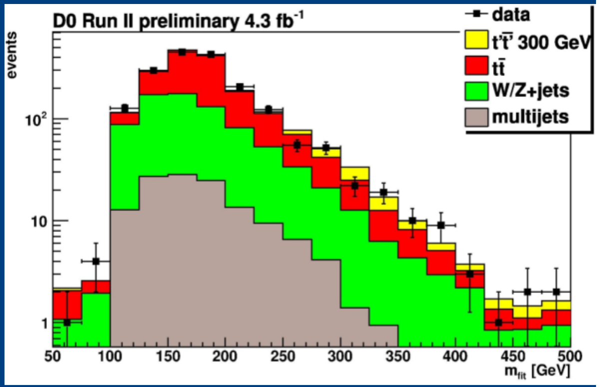
- Apparent heavy top quark events

Search for a heavy t-like quark, decaying to Wb in the same way as top



Less than 2σ significance

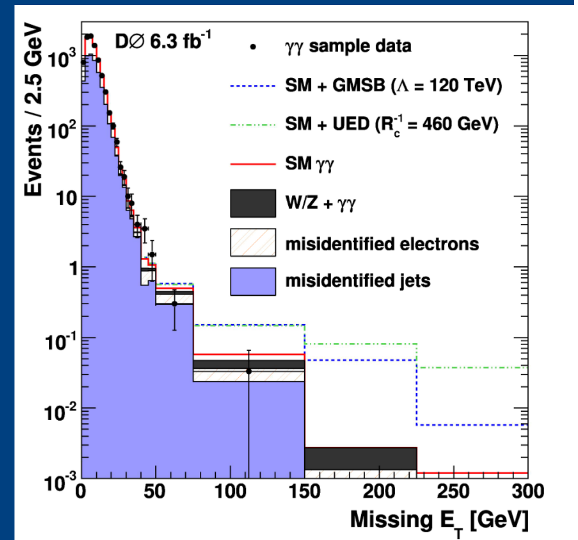




Diphotons + MET

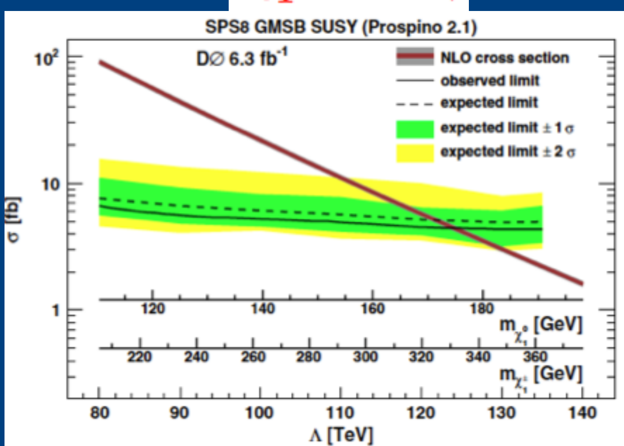
$\gamma\gamma$ + MET events are rare in SM production
An excess of this type of events could mean new physics
Since the events are rare, understanding of the tails is very important. Low MET region used as CR.

Shapes are determined from the data for QCD and $\gamma\gamma$ (using Z→ee) and then fit to low missing ET region



Results interpreted in terms of GMSB and UED

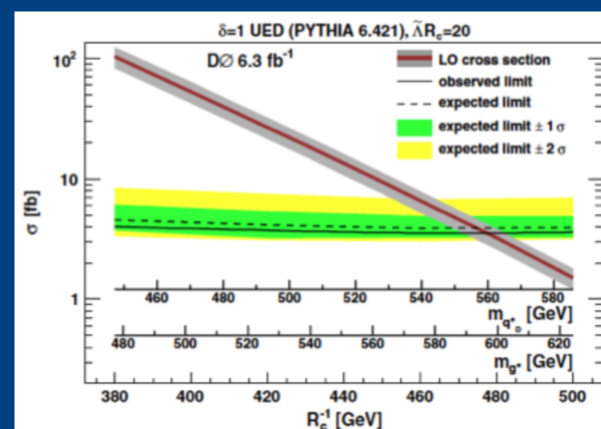
$\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$



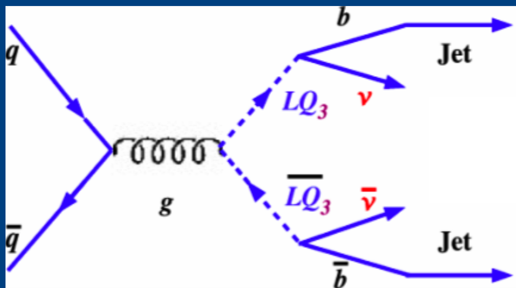
PRL. 105, 221802 (2010)

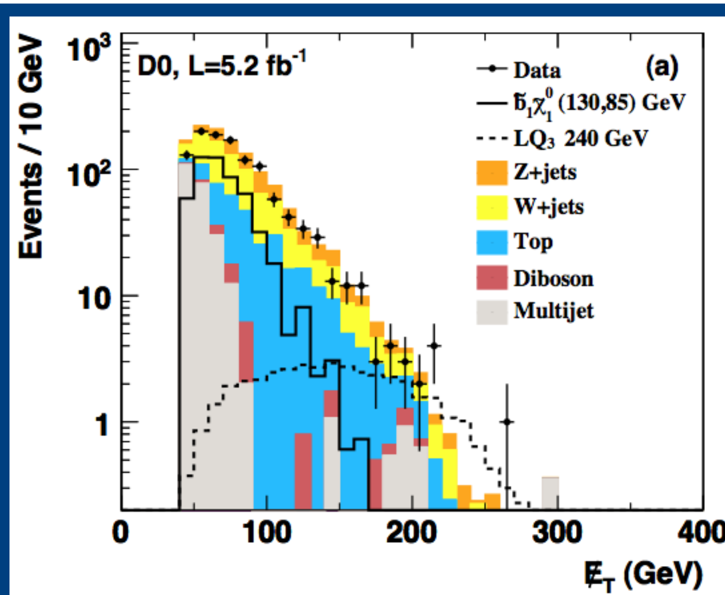
6.3 fb^{-1}

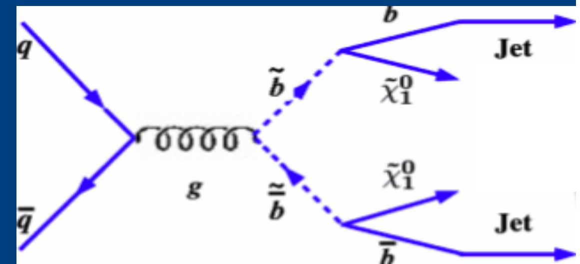
$(\gamma^* \rightarrow G\gamma)$



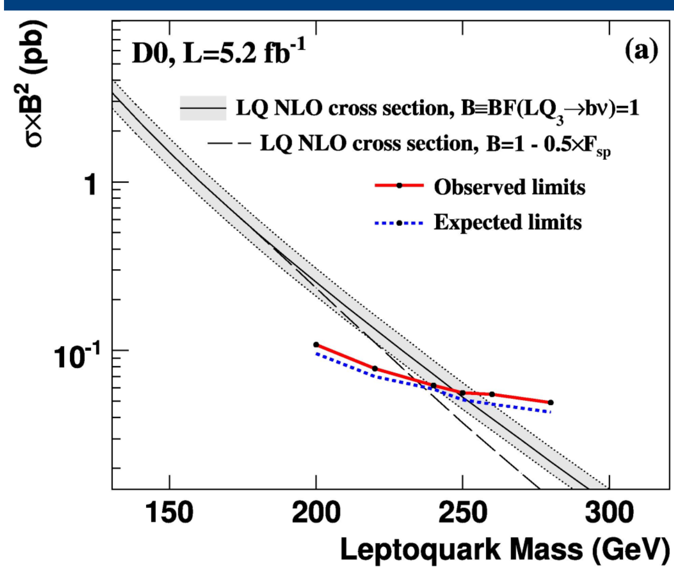
MET + b-jets: LQ and SUSY







Phys. Lett. B **693**, 95 (2010)



5.2fb^{-1}