Exotic Searches at the Tevatron

Gustaaf Brooijmans

Columbia University
in the City of New York

On behalf of the CDF and DØ Collaborations

Hadron Collider Physics, May 23rd, 2006

Outline

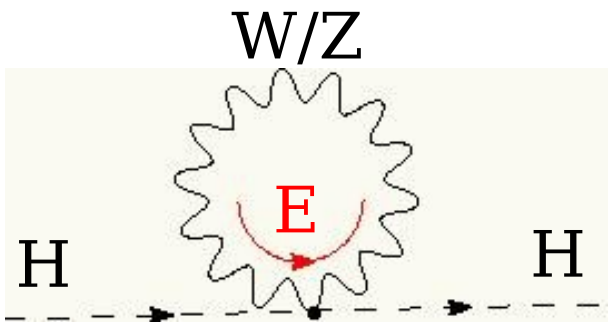
- Why exotics?
- New gauge bosons
  - Dilepton Resonances
  - Leptoquarks
- Large Extra Dimensions
- Exotic resonances
- Excesses from the past
- Conclusions

Why Exotics?

- Among models of physics beyond the standard model, SUSY theories are certainly the best understood (and most studied)
  - They solve many “theoretical” issues (quadratic divergences in Higgs mass, unification of forces, dark matter candidate, radiative EWSB, ...)
  - They don't address (or worsen) certain “experimental” issues (3 generations?, masses?, charges?, spin?, ...)
- Other models are “exotic”
  - Maybe not so bad

Heavy Gauge Bosons

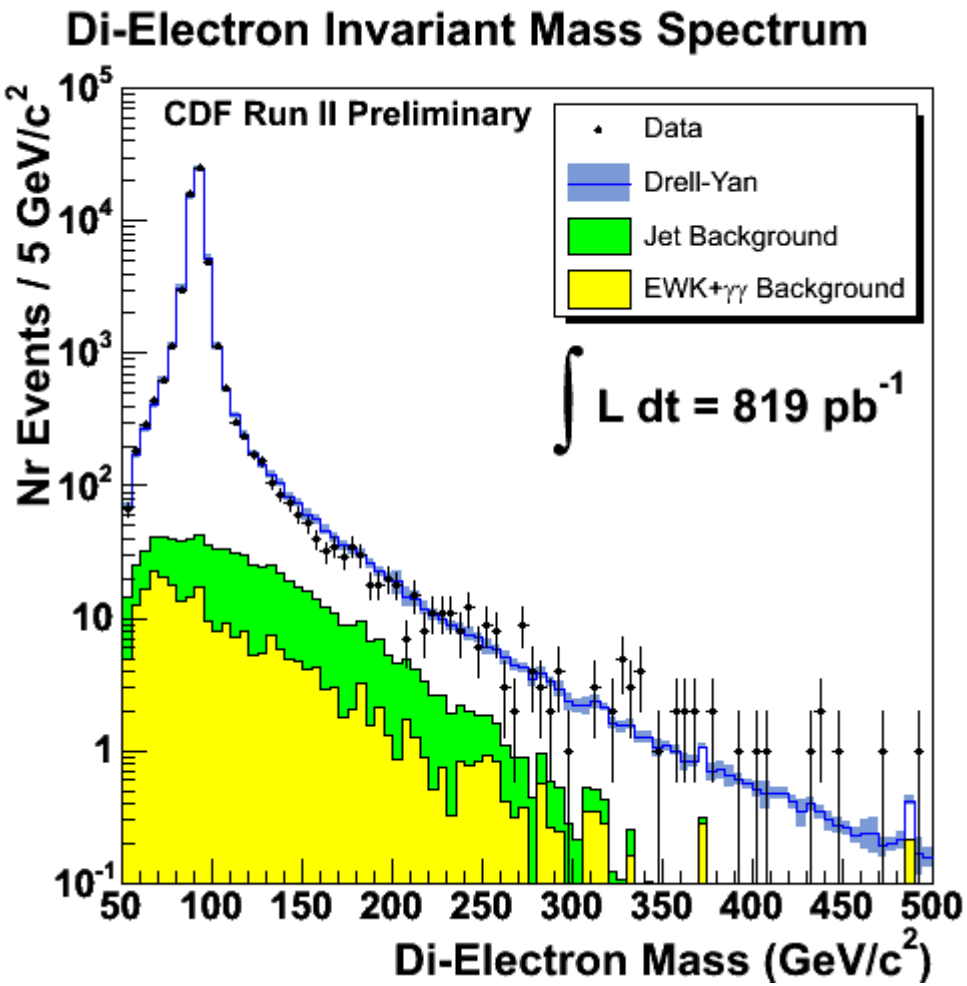
- Predicted in many models
  - Little Higgs:
    - Quadratic divergences in radiative corrections to the Higgs mass are addressed "individually":

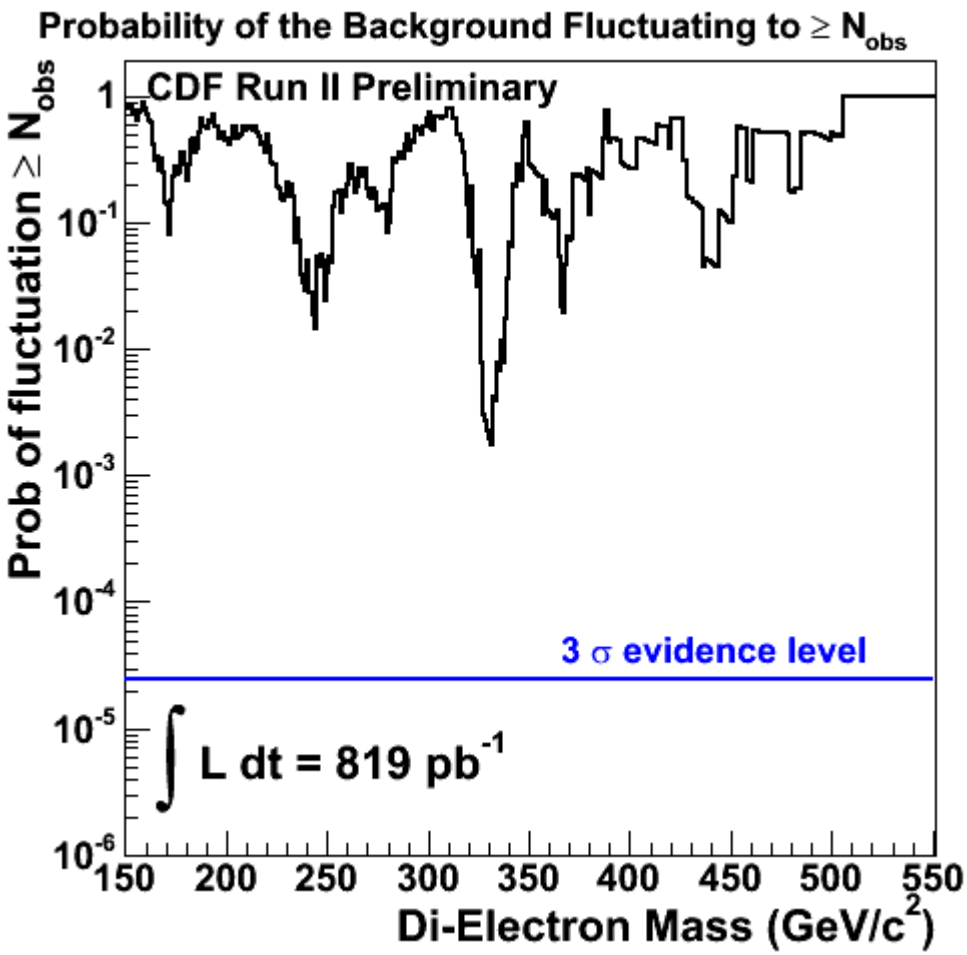


  - L-R symmetry, GUTs
  - Extra dimensions
    - Kaluza-Klein excitations of the gauge bosons if allowed to propagate in extra dimensions
    - Similar signatures from graviton resonances (Randall-Sundrum models)

Dielectrons

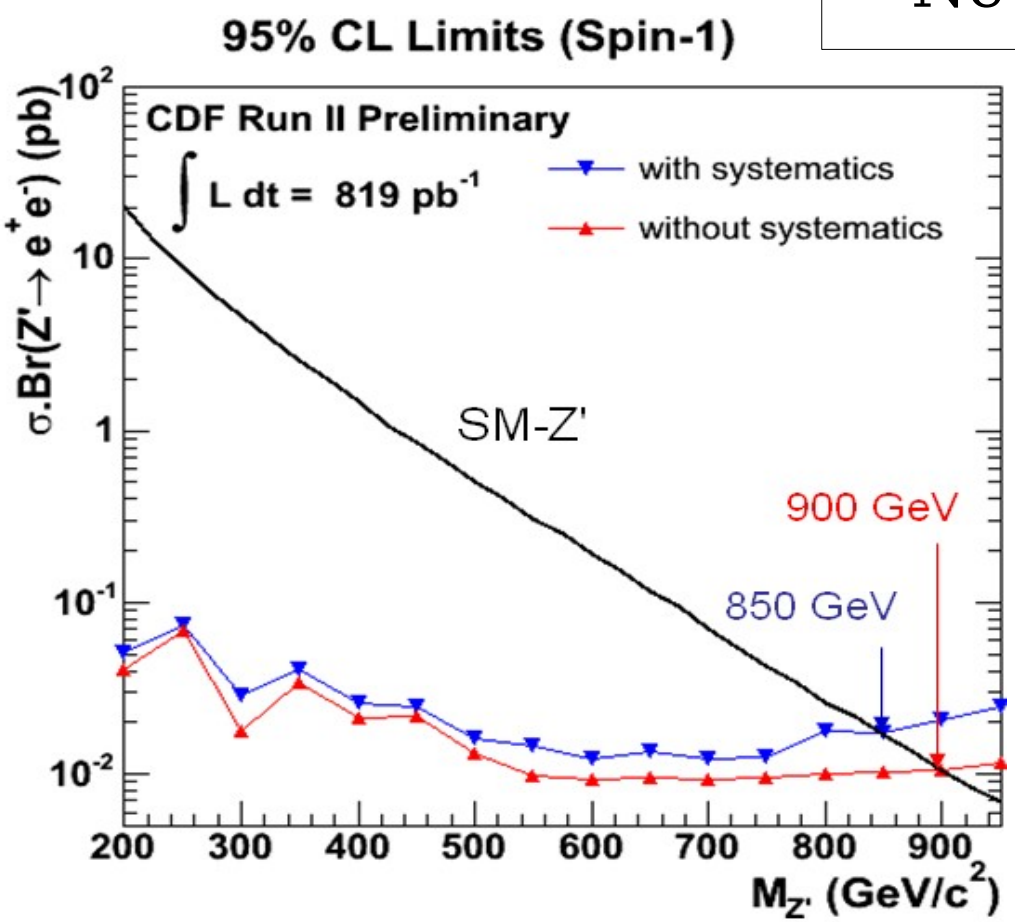
- CDF result using 819 pb^{-1}:



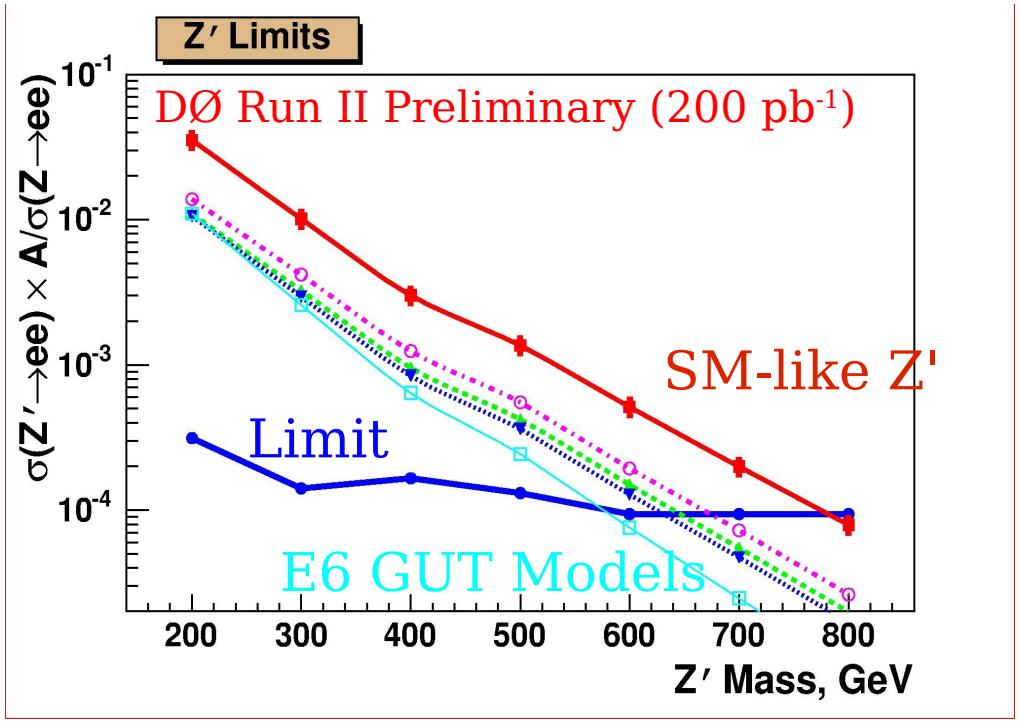


- Limits

New CDF Result

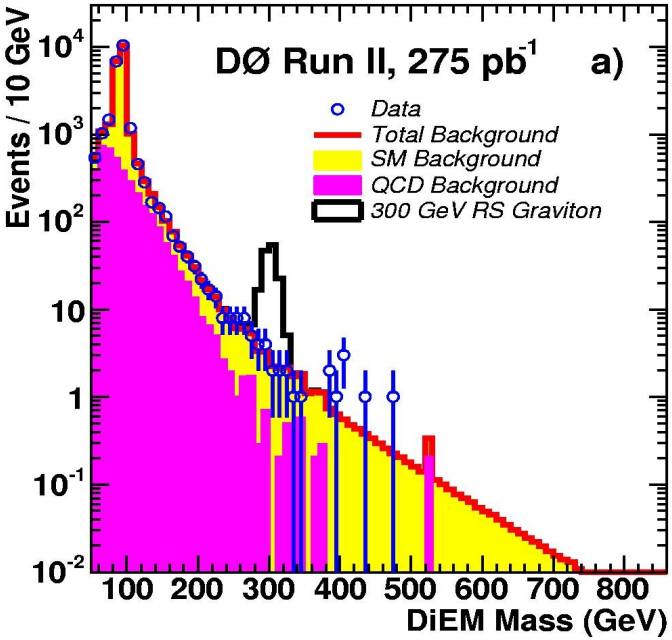


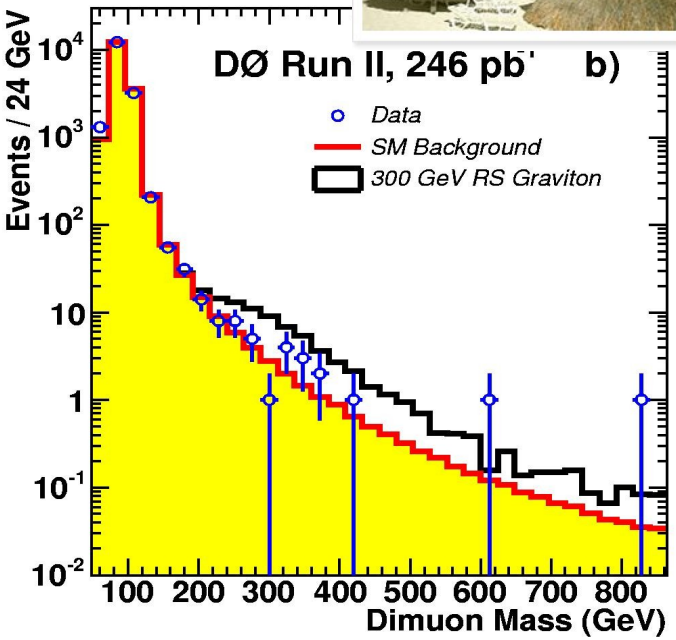
2004 DØ Result

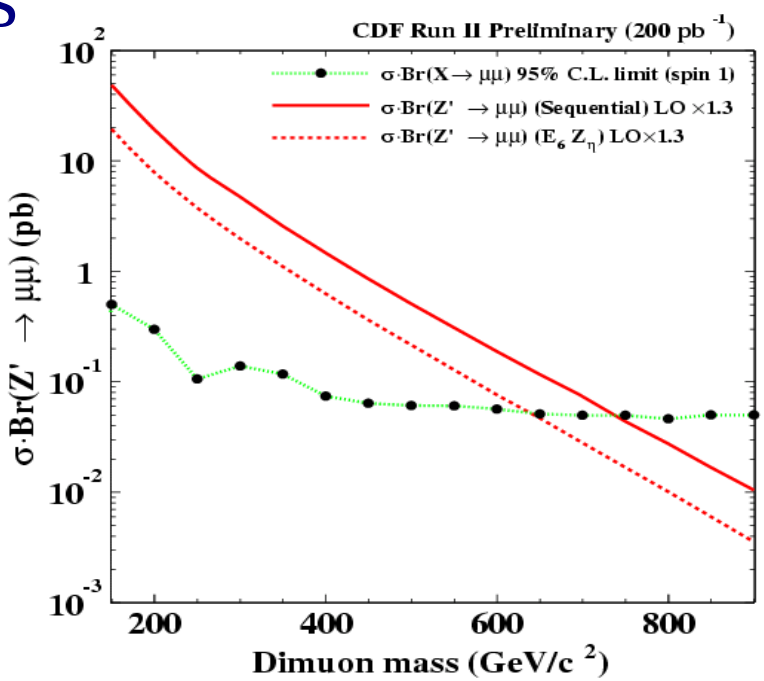


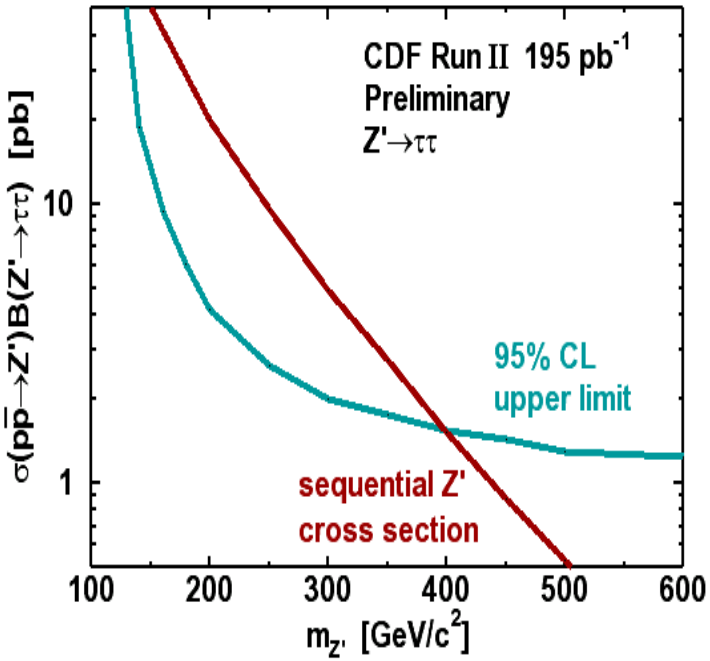
Dimuons, Diphotons and Ditaus

- At high energy, energy resolution is much better for electrons (calorimeter vs tracker)
- Tau detection efficiency is lower than e/μ



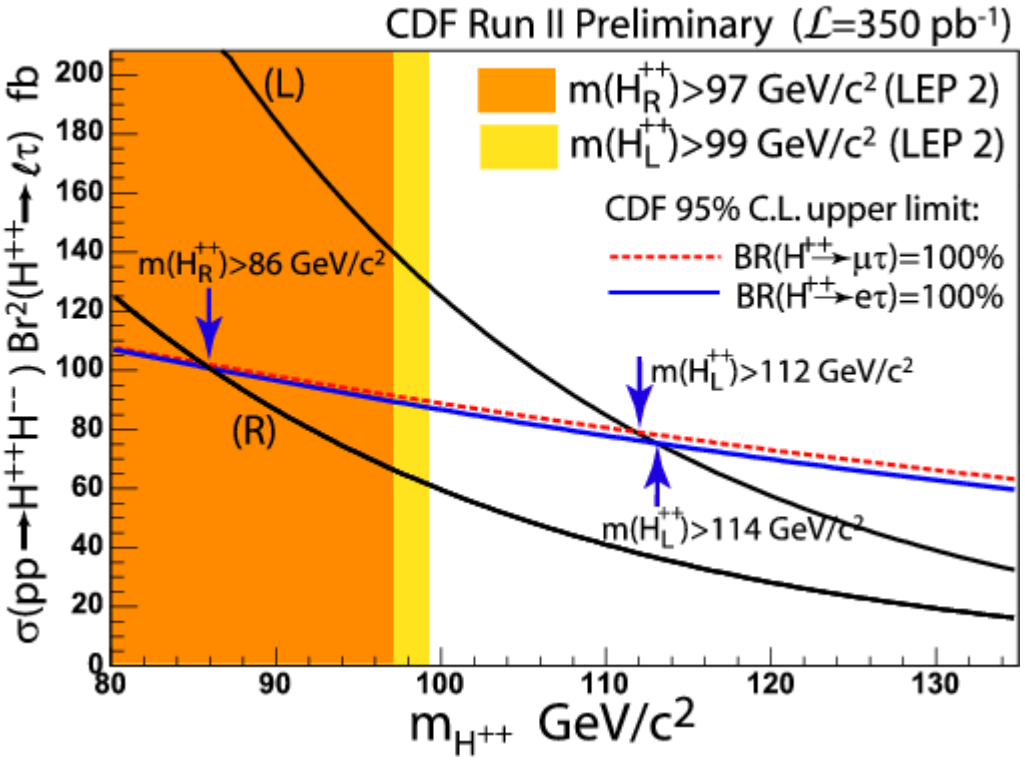




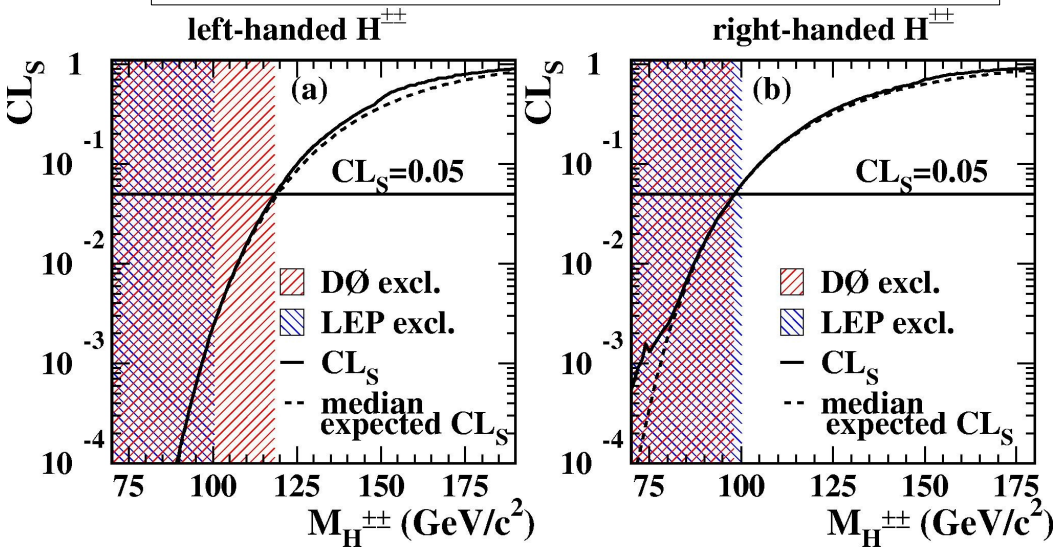


Doubly Charged Higgs

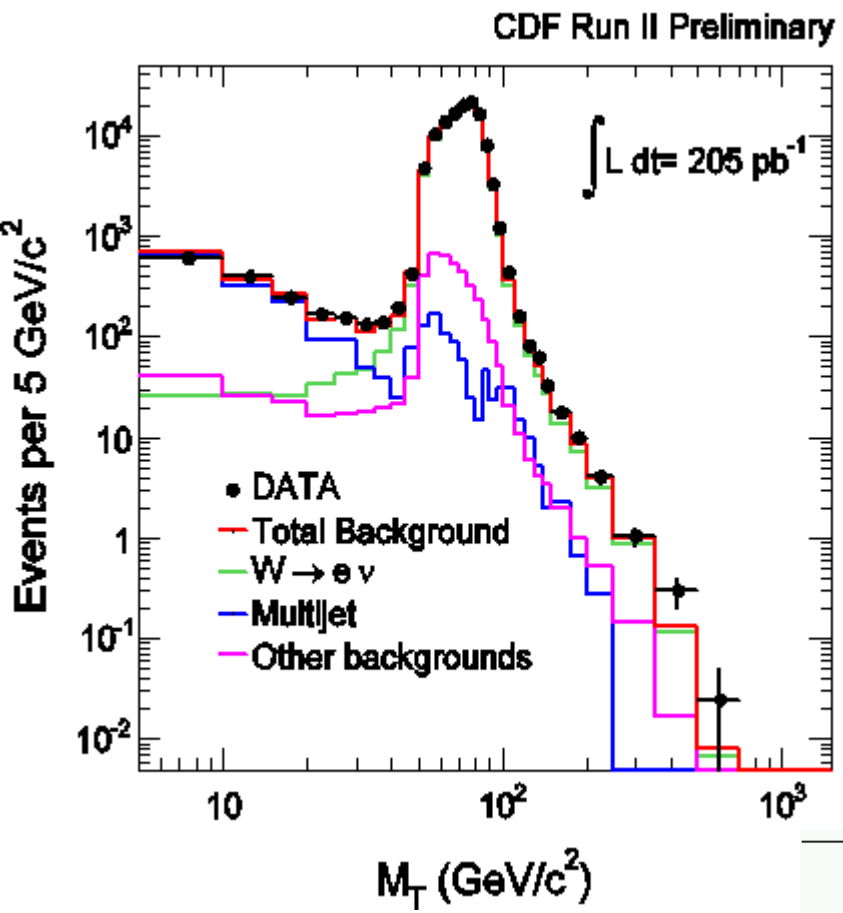
- Exist in models with Higgs triplets (like LR sym.)
- Recent CDF search in H^{++} -> $e\tau$ and $\mu\tau$ channels
  - H^{++} assumed to be pair-produced, so require at least three leptons -> backgrounds are very small, and no events are observed



"Old" DØ result in dimuon channel (113 pb^{-1})



W' -> eν



CDF: $M_{W'} > 788$ GeV/c^2
@ 95% CL (SM couplings)

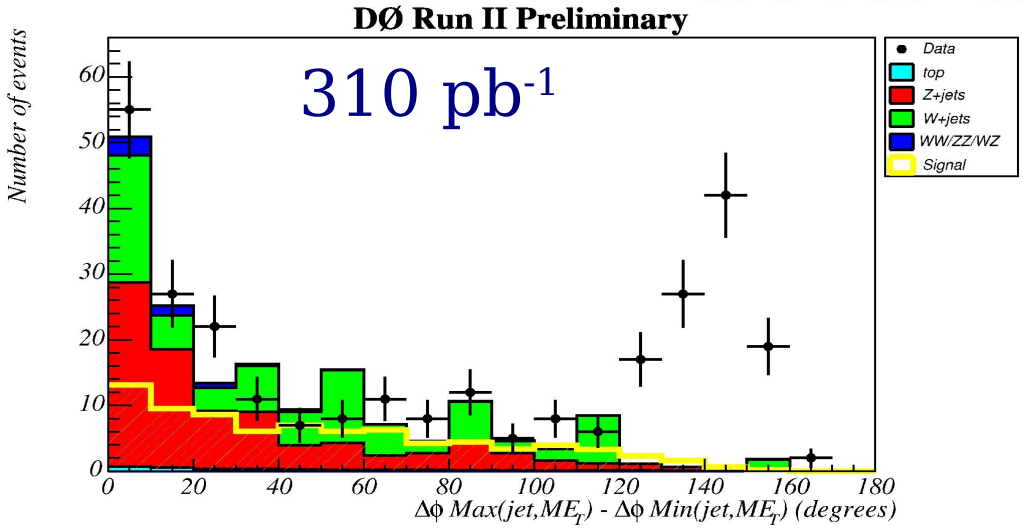
	Events in Each M_T Bin (GeV/c^2)				
	200 - 250	250 - 350	350 - 500	500 - 700	700 - 1000
$W \to e\nu$	30.8 ± 5.7	17.0 ± 4.0	3.52 ± 1.70	0.27 ± 0.45	0.00 ± 0.00
Multijet	2.7 ± 6.1	0.0 ± 3.3	0.00 ± 0.29	0.00 ± 0.01	0.00 ± 0.00
Other Backgrounds	5.2 ± 1.0	3.0 ± 0.9	0.51 ± 0.22	0.06 ± 0.08	0.00 ± 0.03
Total Background	38.7 ± 8.9	20.0 ± 5.9	4.03 ± 1.97	0.33 ± 0.53	0.01 ± 0.03
Data	41	21	9	1	0

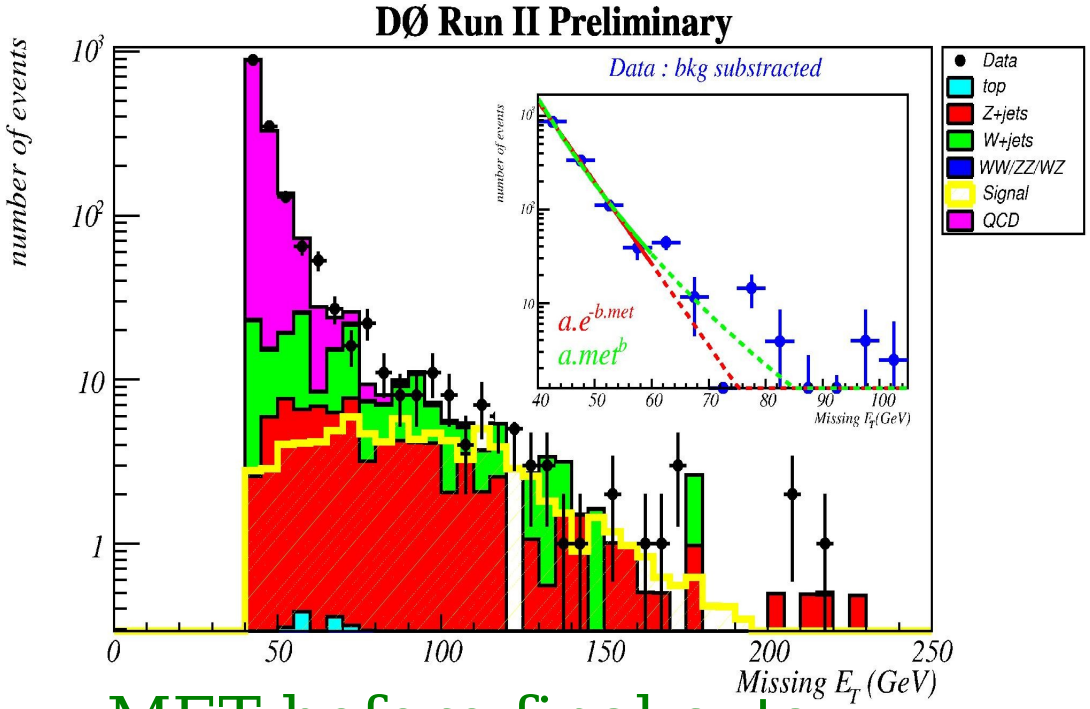
Leptoquarks

- Natural consequence of unification of quarks and leptons into a single multiplet
  - Logically expected to have mass close to the unification scale, but in some models they can be substantially lighter
- Usually consider three leptoquarks, one per generation
  - Assumed to be unstable and decay to quark+lepton
  - Branching ratio to charged lepton + quark = β
- At hadron colliders, pair production through strong interaction, single production is model dependent (because of quark-lepton coupling)

LQ -> qν :Acoplanar Jets (DØ)

- Search for LQ decaying to quark+neutrino suffers from substantial QCD backgrounds
  - Require exactly 2 acoplanar jets
  - Non-QCD SM background dominated by Z -> νν + 2 jets
- M_{LQ} > 136 GeV/c^2 @ 95% CL

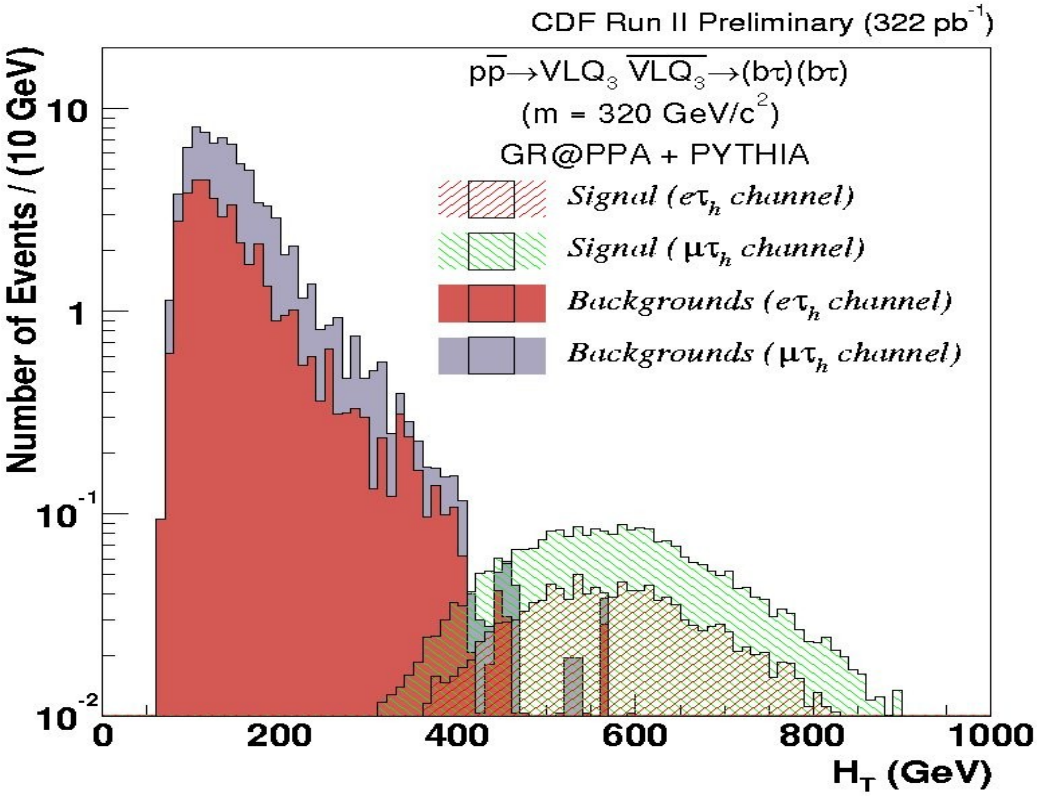


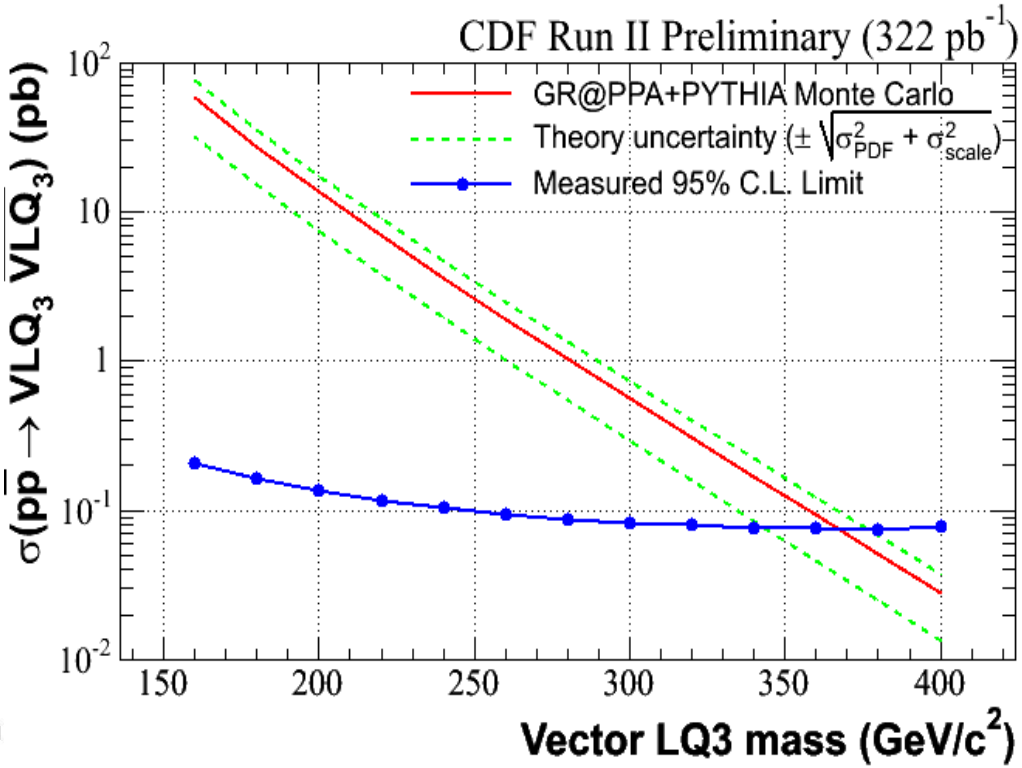


MET before final cuts

Vector LQ3 -> bτ (CDF)

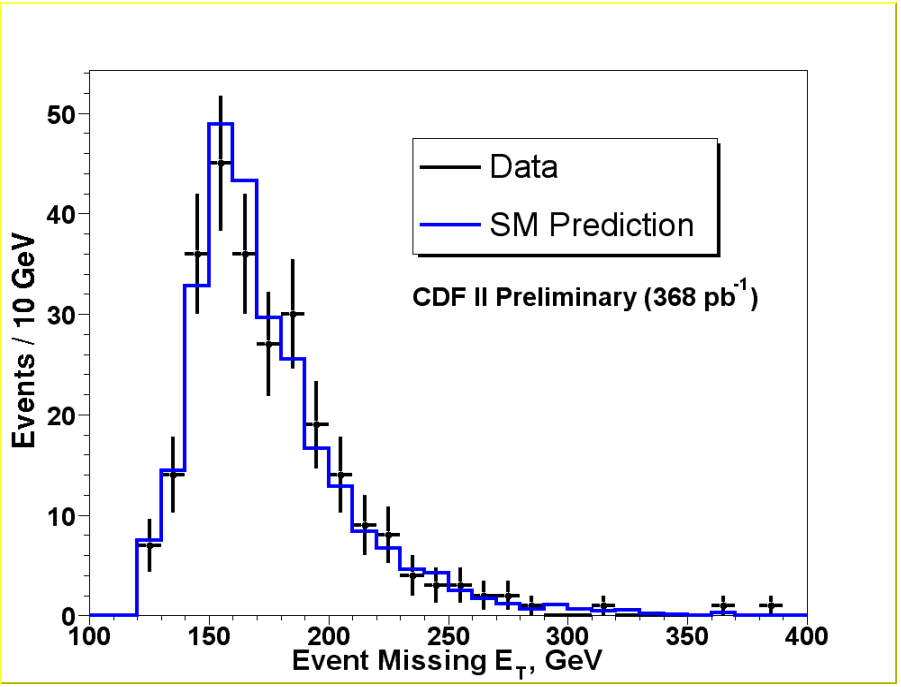
- Dijet + ditau signature, with one tau decaying leptonically and the other hadronically
  - Number of jets and H_T (including lepton E_T and MET) are main discriminating variables

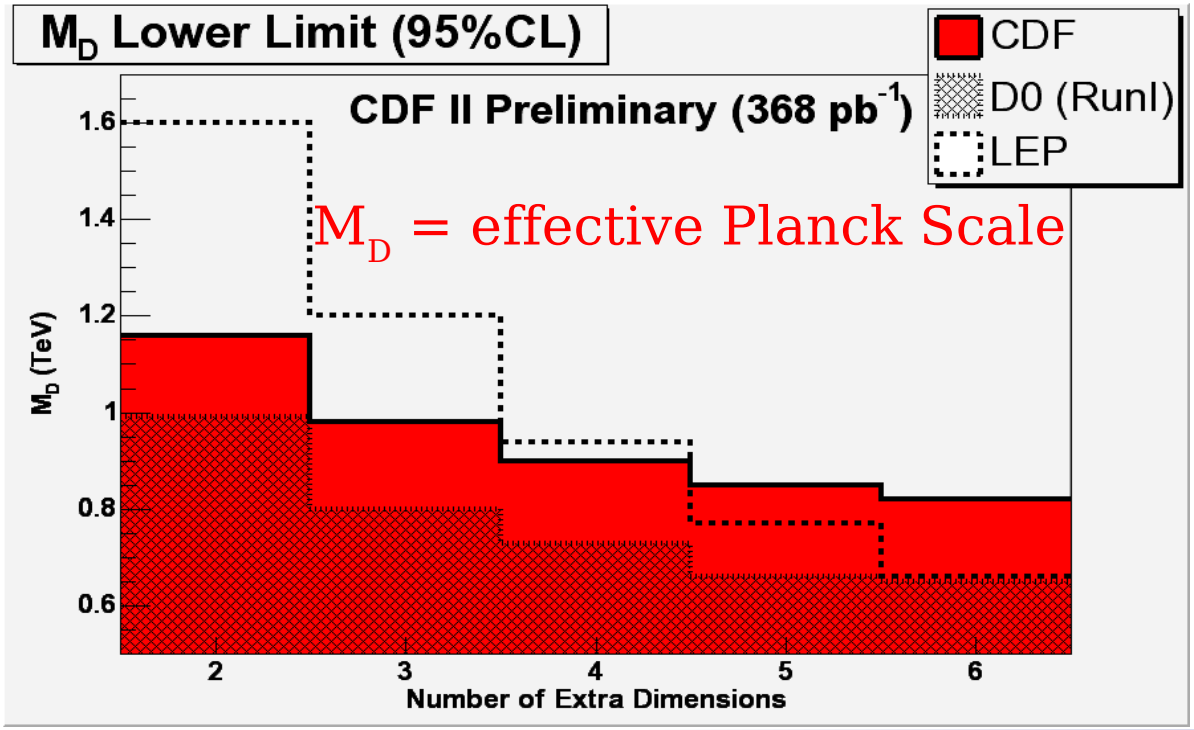




Large Extra Dimensions

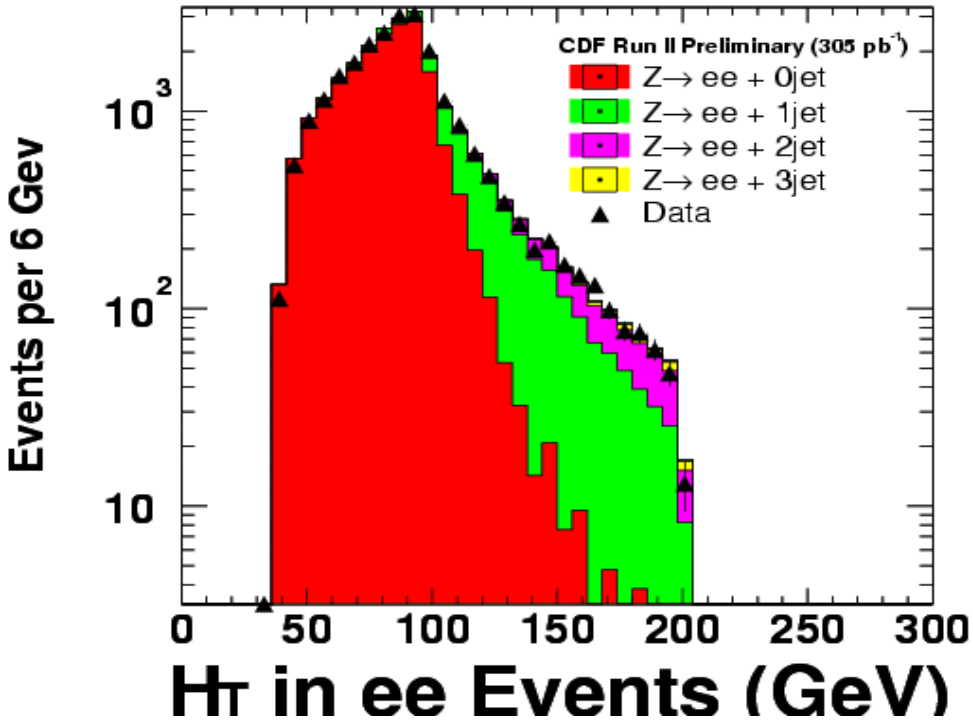
- In the original Arkani-Hamed, Dimopoulos and Dvali model have a "tower" of KK excitations of the graviton
  - Coupling is small, but the number of states is very large, so can produce a graviton which immediately disappears in the bulk
    - Excess of events with a high E_T jet and lots of MET
    - Dominant backgrounds are Z -> νν + jets and W -> lν + jets

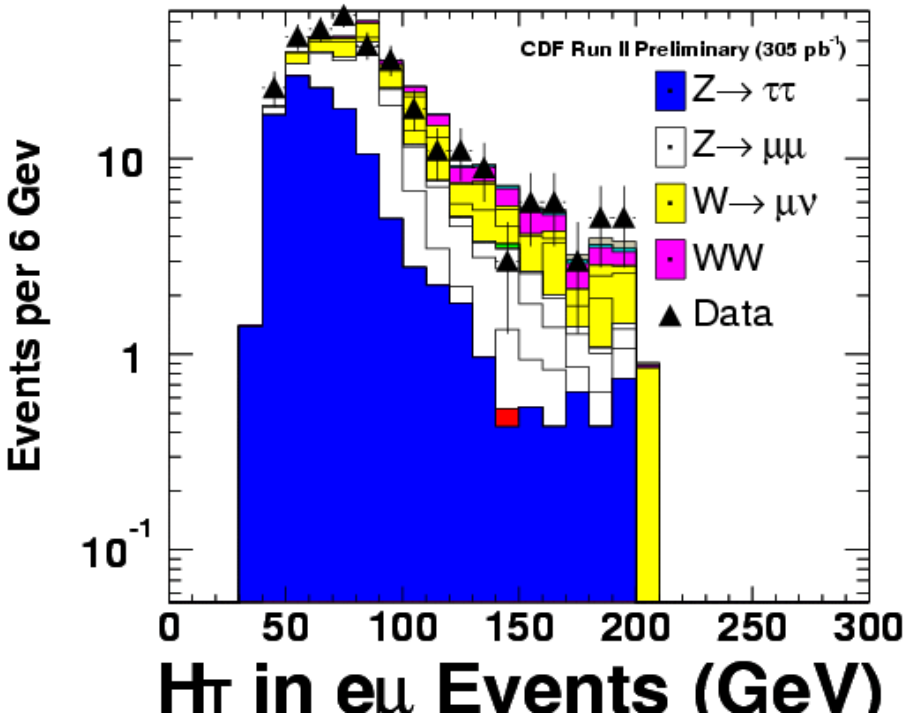




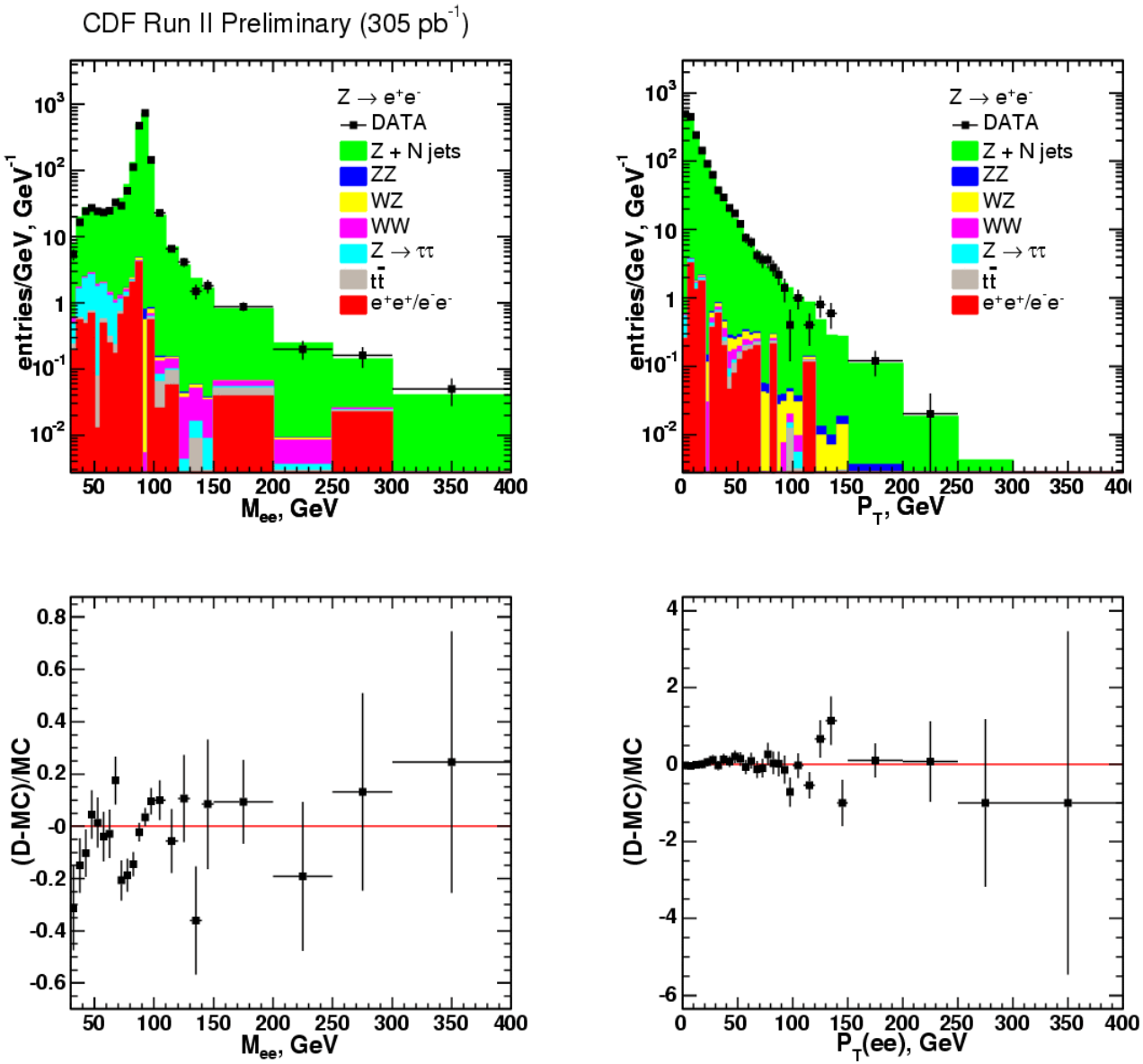
Resonances -> Z + X

- CDF analysis uses H_T as main discriminating variable. The control region is $H_T < 200$ GeV, and the signal region has $H_T > 400$ GeV, incl. 2 jets with $E_T > 50$ GeV
  - No events, set limit on a 300 GeV/c^2 RH down-type quark: $\sigma < 1.3$ pb @ 90% CL (see hep-ph/0206116 for model)

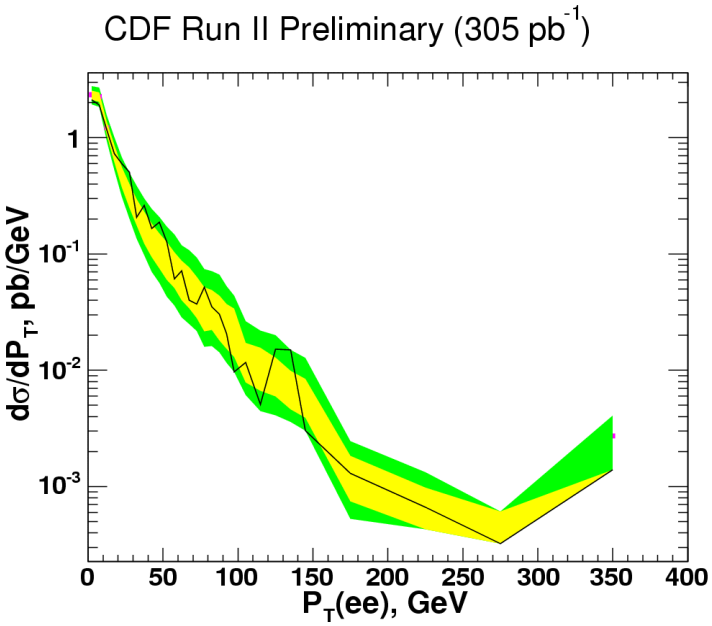




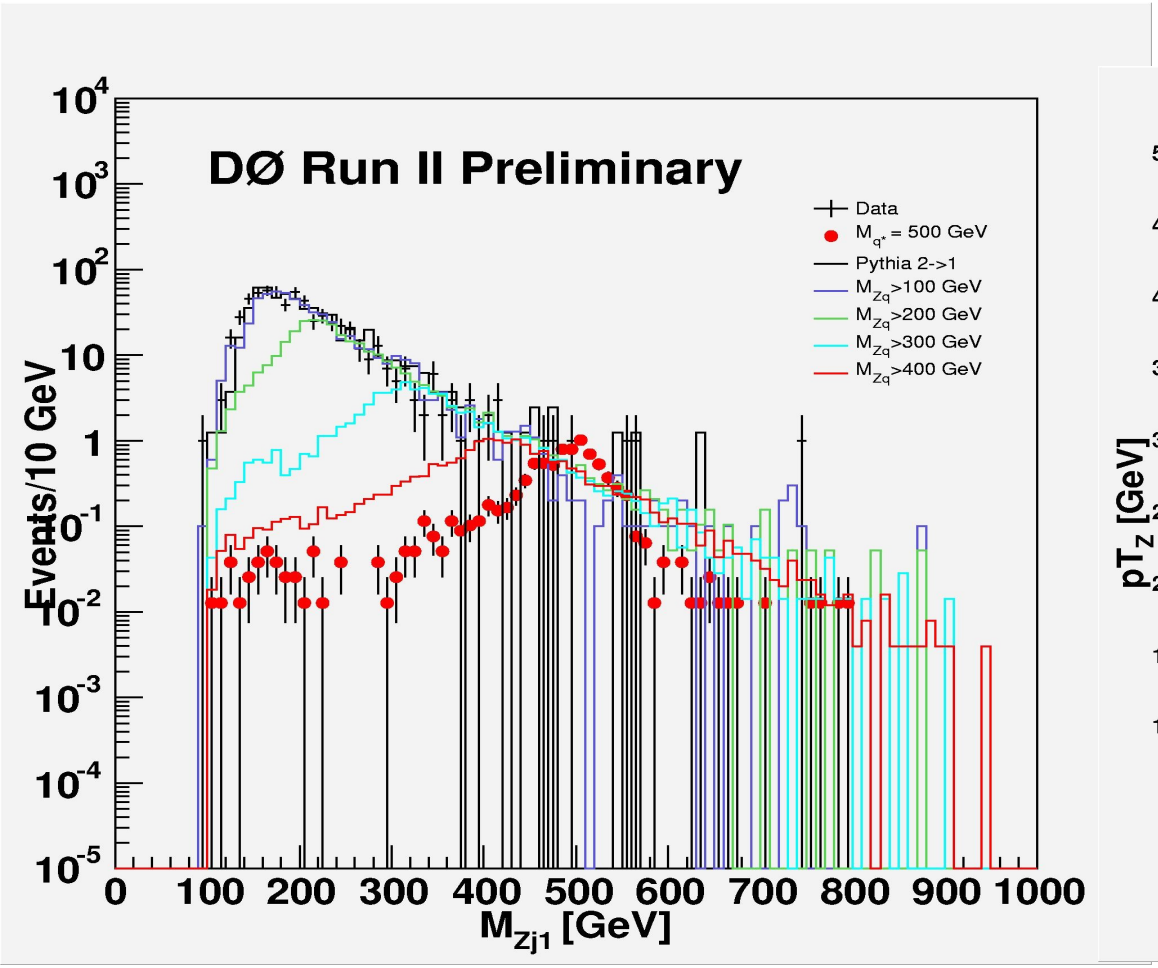
- Can also look at Z p_T distribution (still CDF):

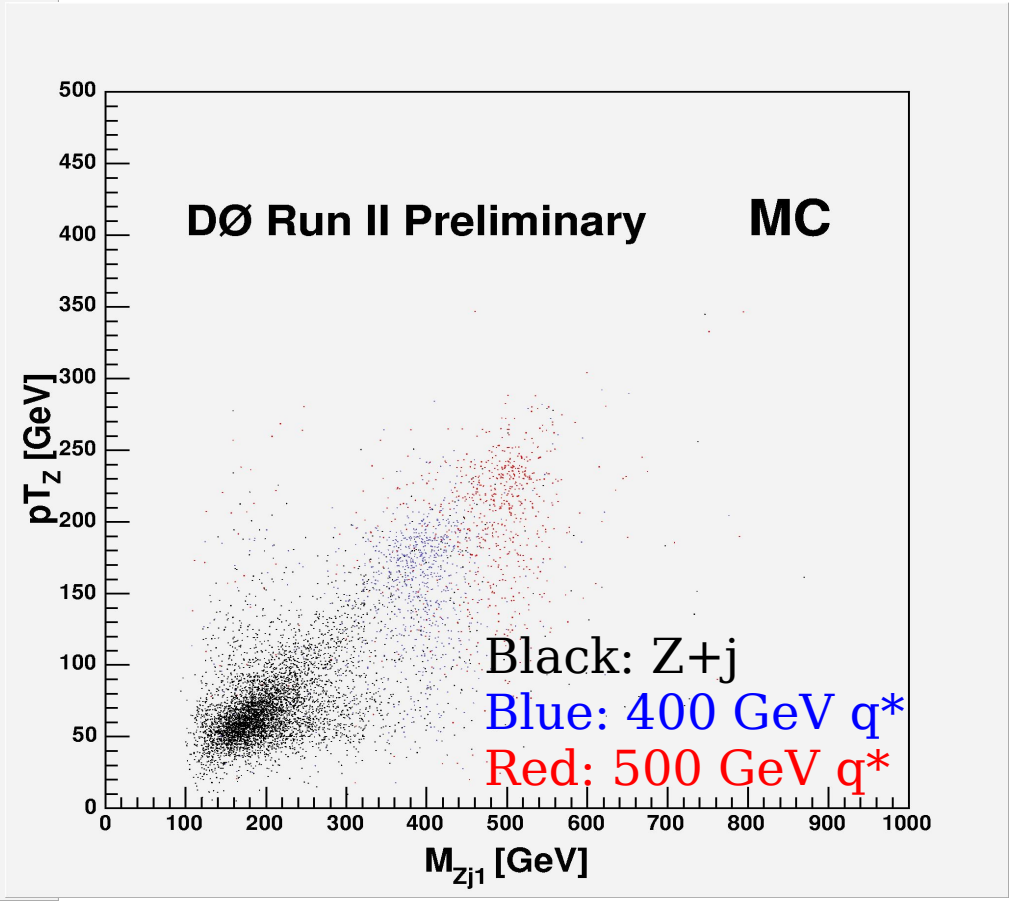


Leads to limit on anomalous cross-section



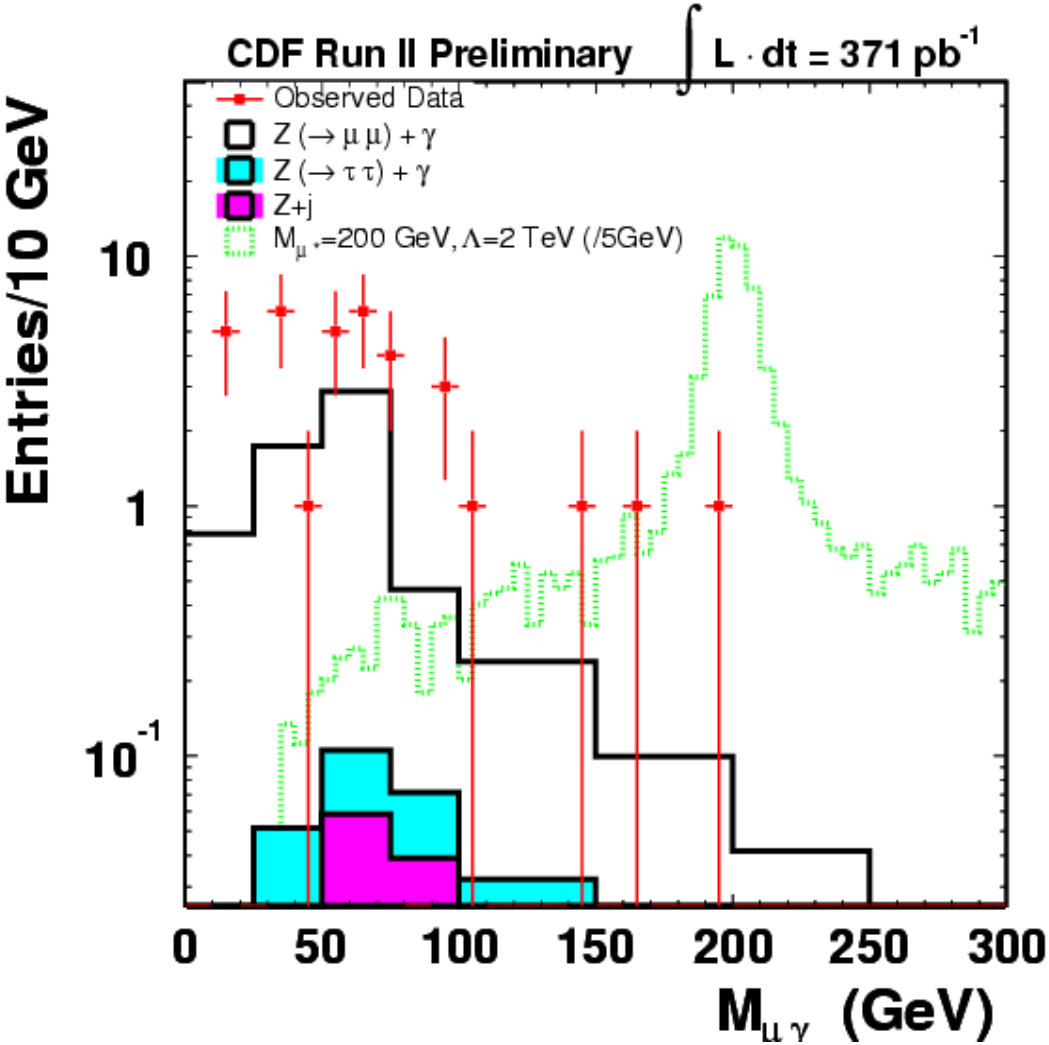
- DØ searches for a resonance in the Z-jet mass spectrum (380 pb^{-1}) , then look at p_{TZ} vs m_{Zj}
  - No excess, limit set on mass of an excited quark at m_{q*} > 520 GeV/c^2 @ 95% CL (model of PRD 42, 8158)

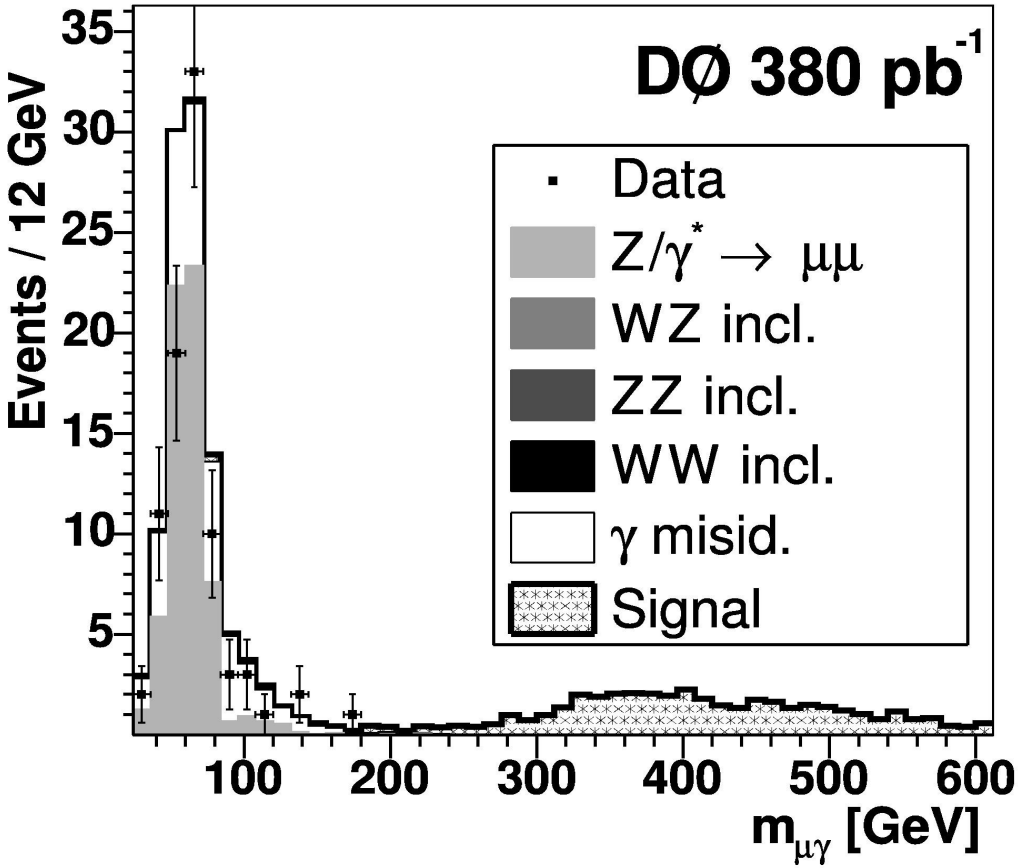




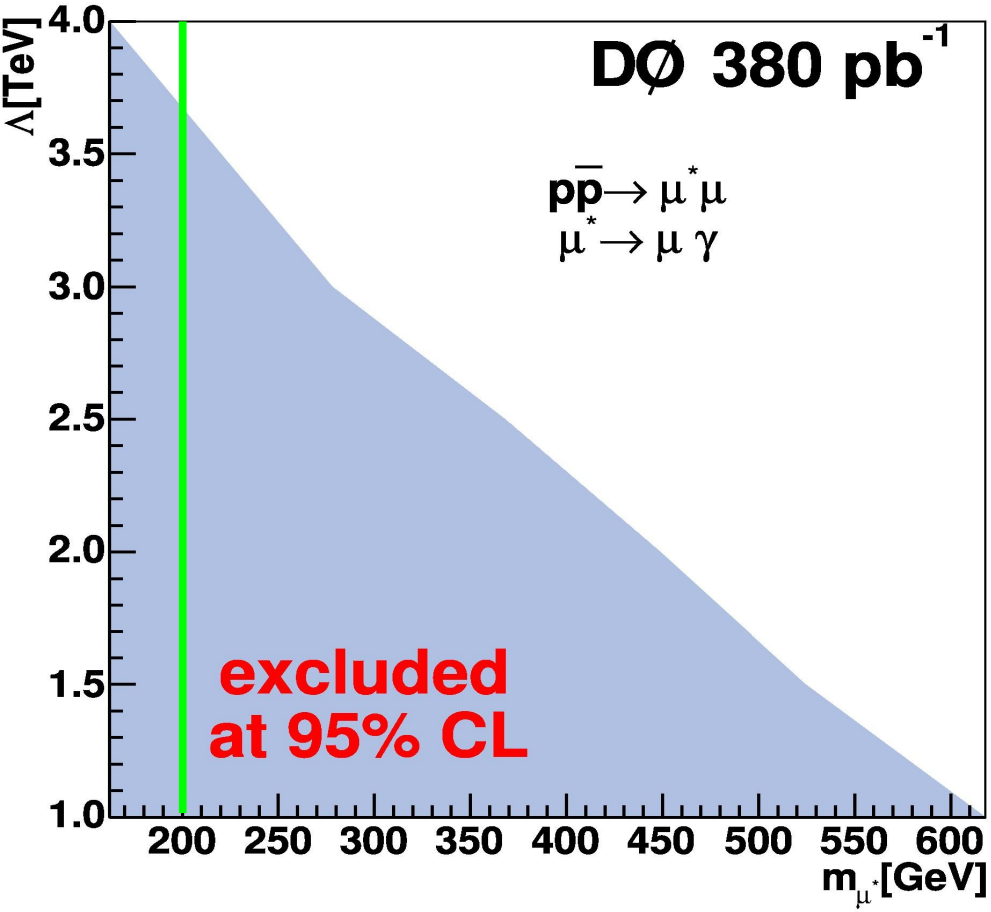
Excited Muons

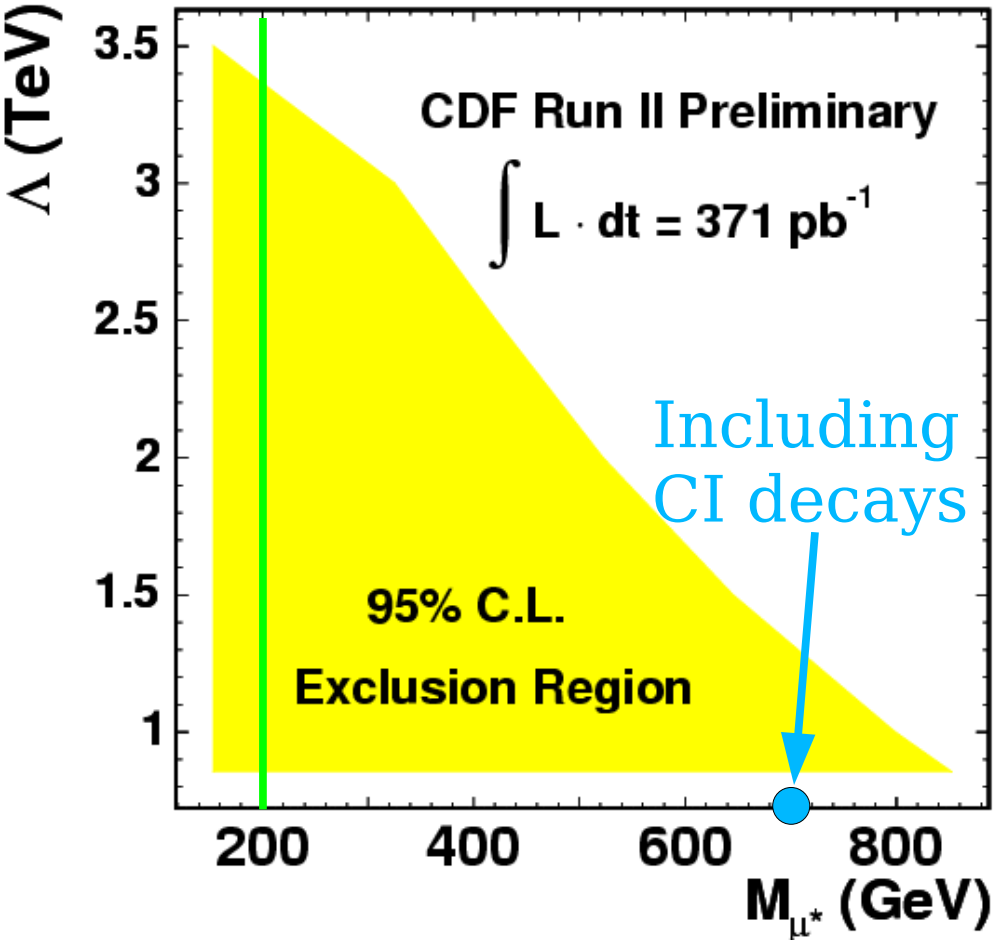
- Search for $\mu\mu^* \rightarrow \mu\mu\gamma$, assume production through contact interaction



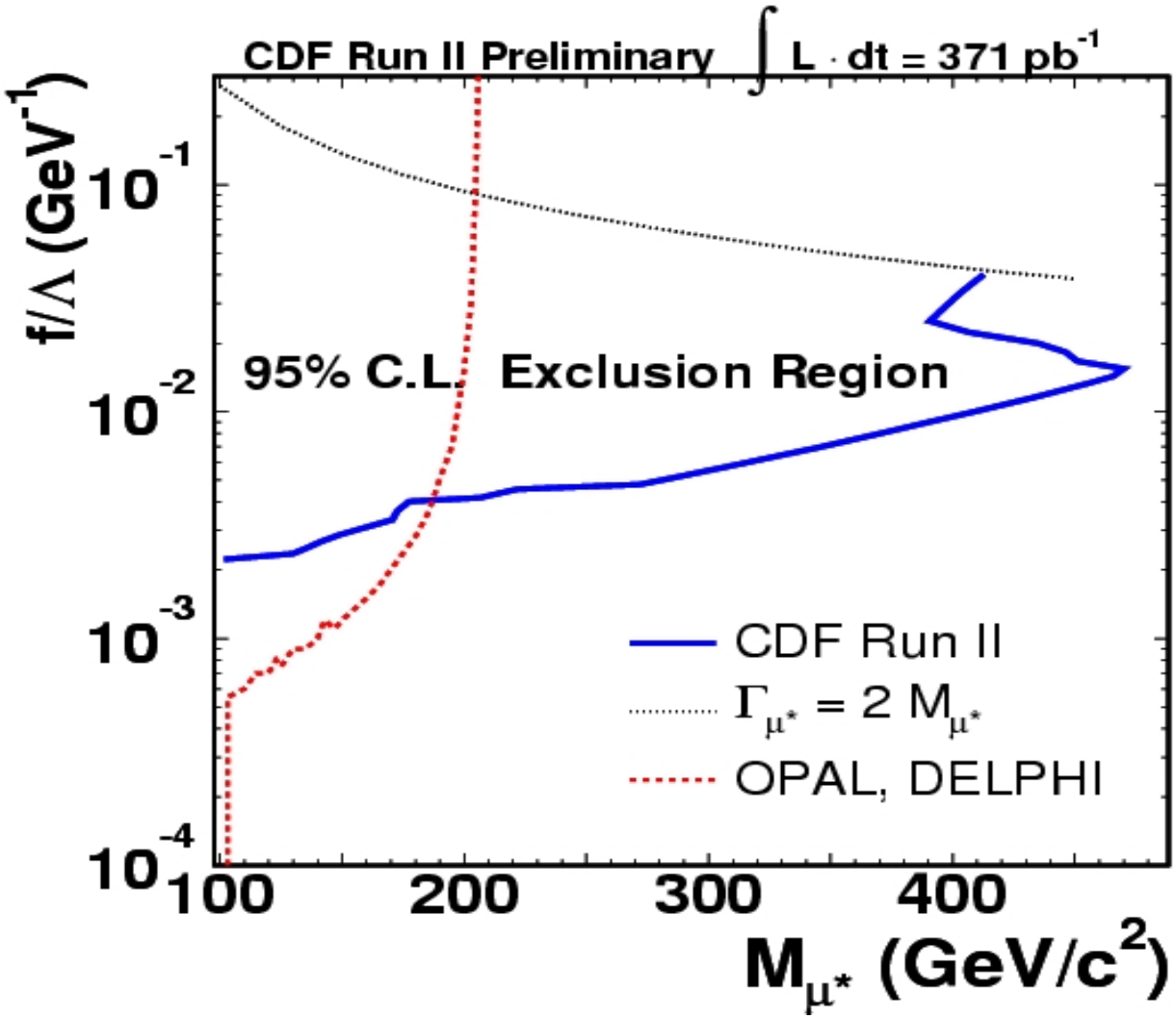


- Limits in terms of mass and scale of contact interaction
  - note: CDF plot assumes gauge mediated decays only, which leads to a better result as $m_{\mu*} \rightarrow \Lambda$



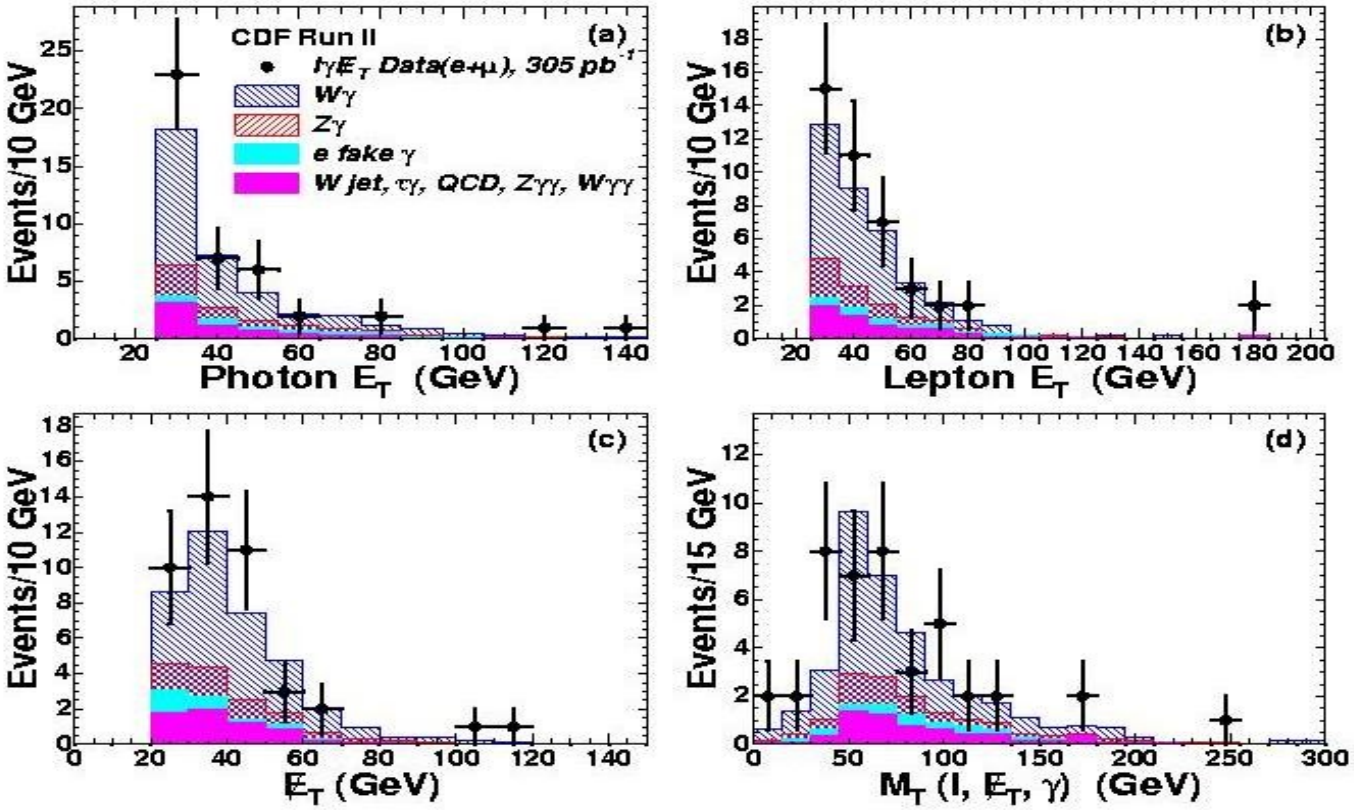


- For comparison with LEP, use a gauge-mediated model with DY-like production of $\mu\mu^*$ (with coupling f/Λ)



Lepton-Photon + X

- In Run I, CDF saw and excess of lepton-photon + MET events (16 observed, 7.6 ± 0.7 expected)
  - New study with 305 pb^{-1} of Run II data (hep-ex/060597)



CDF Run II, 305 pb^{-1}

Lepton+Photon+$\not\!\!E_T$ Events

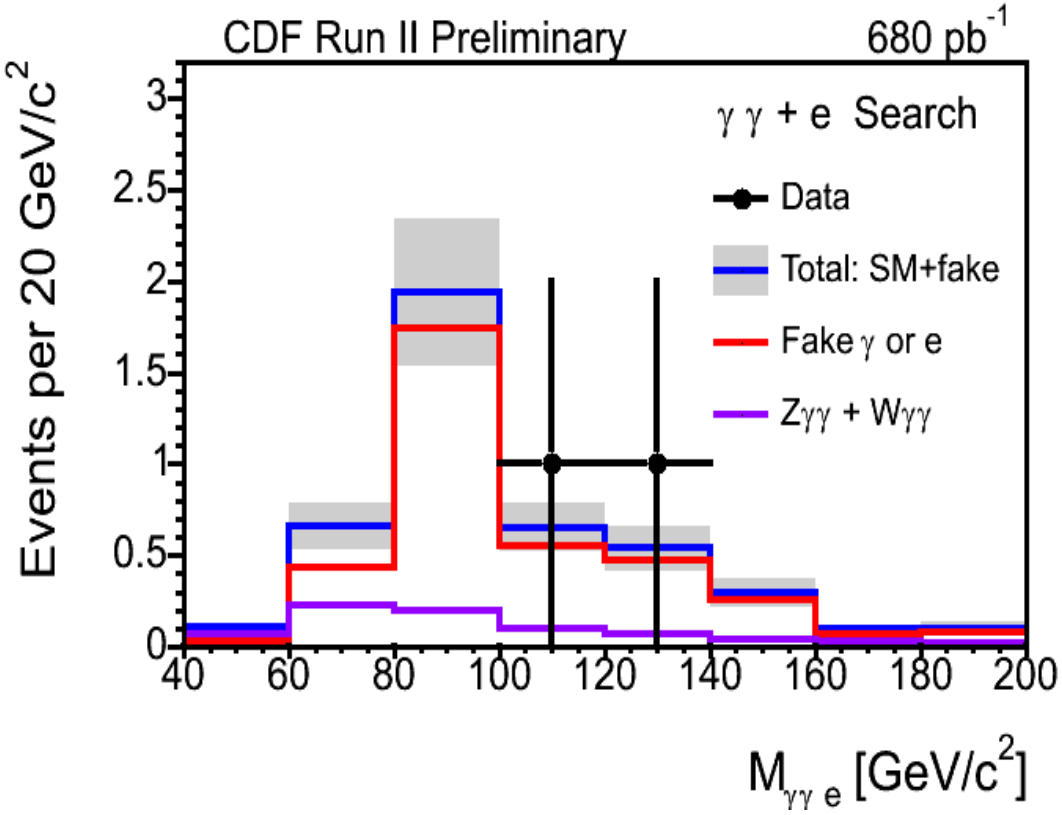
SM Source	$e\gamma\not\!\!E_T$	$\mu\gamma\not\!\!E_T$	$(e+\mu)\gamma\not\!\!E_T$
$W^{\pm}\gamma$	13.70±1.89	8.84±1.35	22.54±2.80
$Z^0/\gamma^* + \gamma$	1.16±0.40	4.49±0.64	5.65±1.03
$W^{\pm}\gamma\gamma, Z^0/\gamma^*+\gamma\gamma$	0.14±0.02	0.18±0.02	0.32±0.03
$W^{\pm}\gamma, Z^0/\gamma^*+\gamma\to\tau\gamma$	0.71±0.18	0.26±0.08	0.97±0.22
$W^{\pm}$+Jet faking γ	2.8±2.8	1.6±1.6	4.4±4.4
$Z^0/\gamma^*\to e^+e^-, e\to\gamma$	2.45±0.33	-	2.45±0.33
Jets faking $\ell + \not\!\!E_T$	0.7±0.7	0.3±0.3	1.0±0.8
Total SM Prediction	**21.7±3.4**	**15.7±2.2**	**37.3±5.4**
Observed in Data	**25**	**17**	**42**

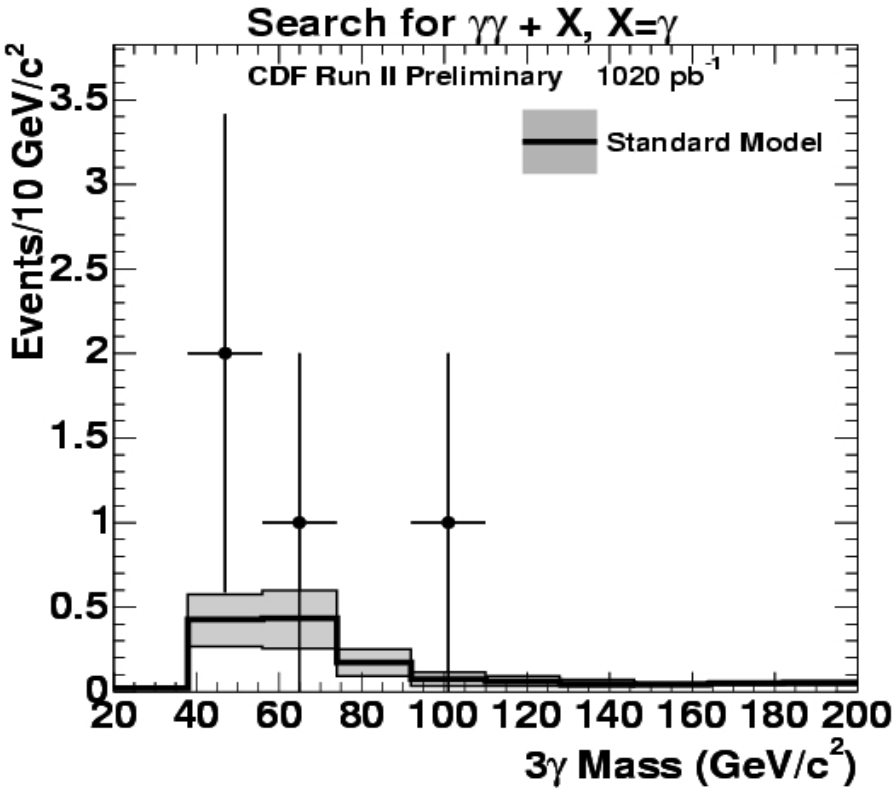
Multi-Lepton+Photon Events

SM Source	$ee\gamma$	$\mu\mu\gamma$	$ll\gamma$
$Z^0/\gamma^* + \gamma$	12.50±1.53	7.81±0.88	20.31±2.40
$Z^0/\gamma^* + \gamma\gamma$	0.24±0.03	0.12±0.02	0.36±0.04
Z^0/γ^*+Jet faking γ	0.3±0.3	0.2±0.2	0.5±0.5
$Z^0/\gamma^*\to e^+e^-, e\to\gamma$	0.23±0.09	-	0.23±0.09
Jets faking $\ell + \not\!\!E_T$	0.6±0.6	1.0±1.0	1.6±1.2
Total SM Prediction	**13.9±1.7**	**9.1±1.4**	**23.0±2.7**
Observed in Data	**19**	**12**	**31**

Diphotons + e/μ/γ

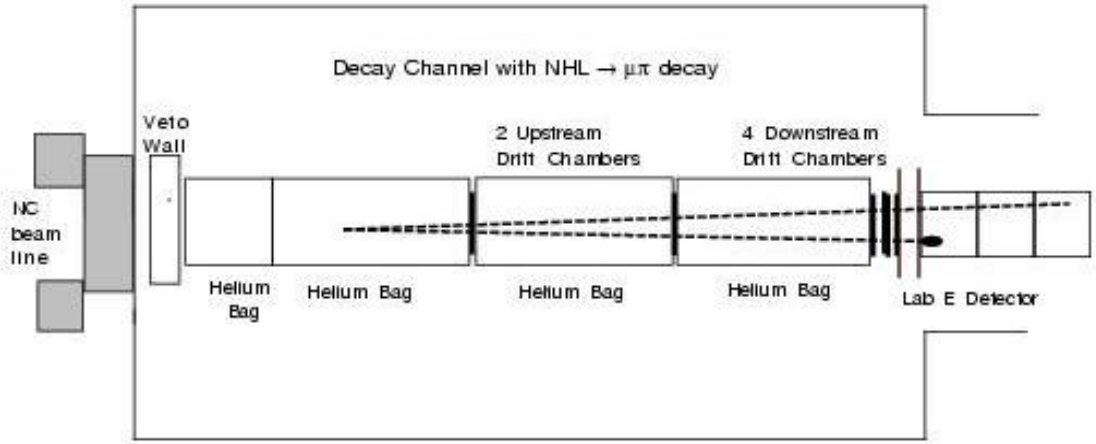
- CDF searches for events with two photons and an electron or muon (700 pb^{-1}), or a photon (1 fb^{-1})
  - Primarily a counting experiment, no excesses above SM expectations



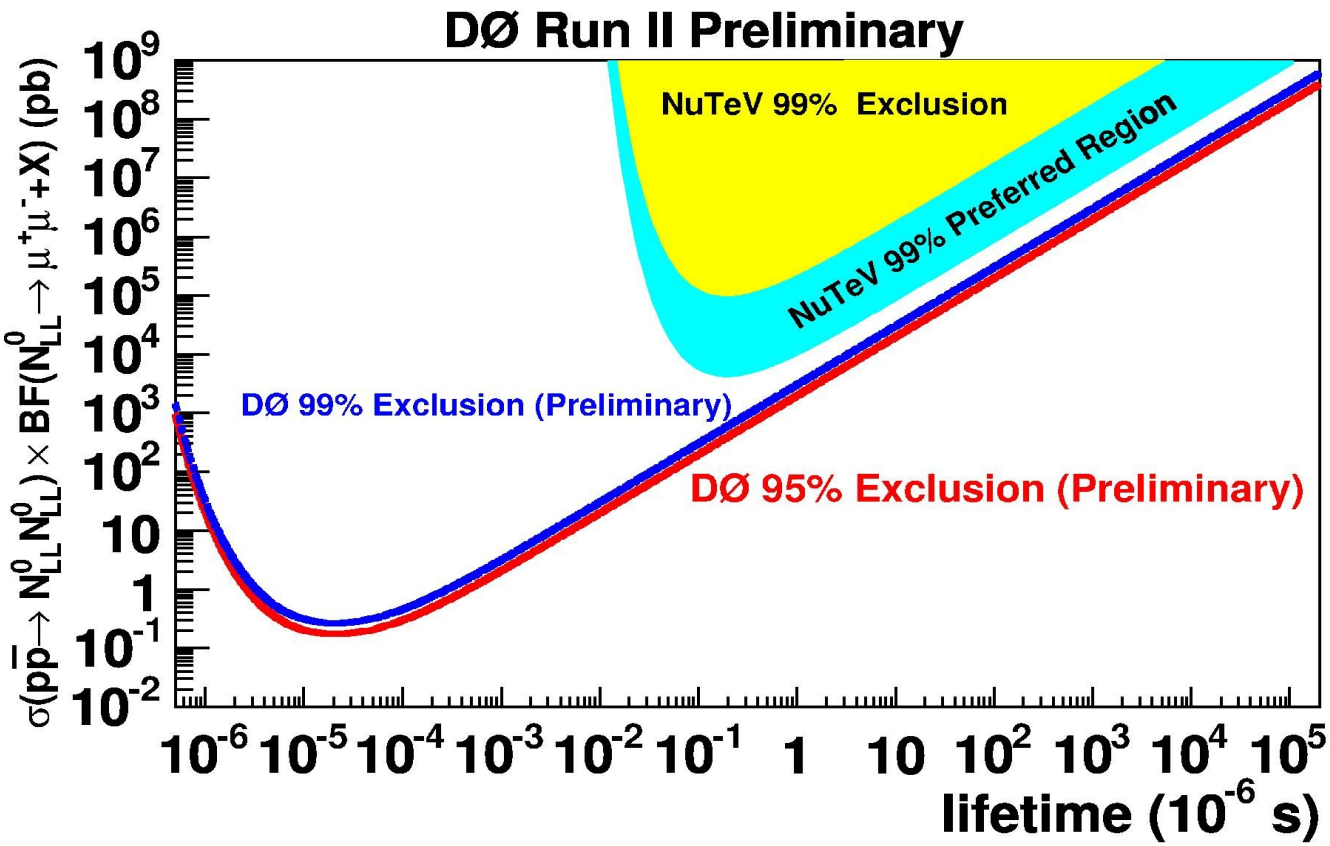


The NuTeV Dimuons

- In 2000, NuTeV reported on a search for neutral heavy leptons decaying to $\mu\mu\nu$ and a few other final states, and reported an excess of 3 events seen vs 0.07 expected in that channel (NuTeV, PRL87(2001) 041801)
- Unlikely to be Neutral Heavy Lepton (not seen in other channels, asymmetry in muon momenta, ...)

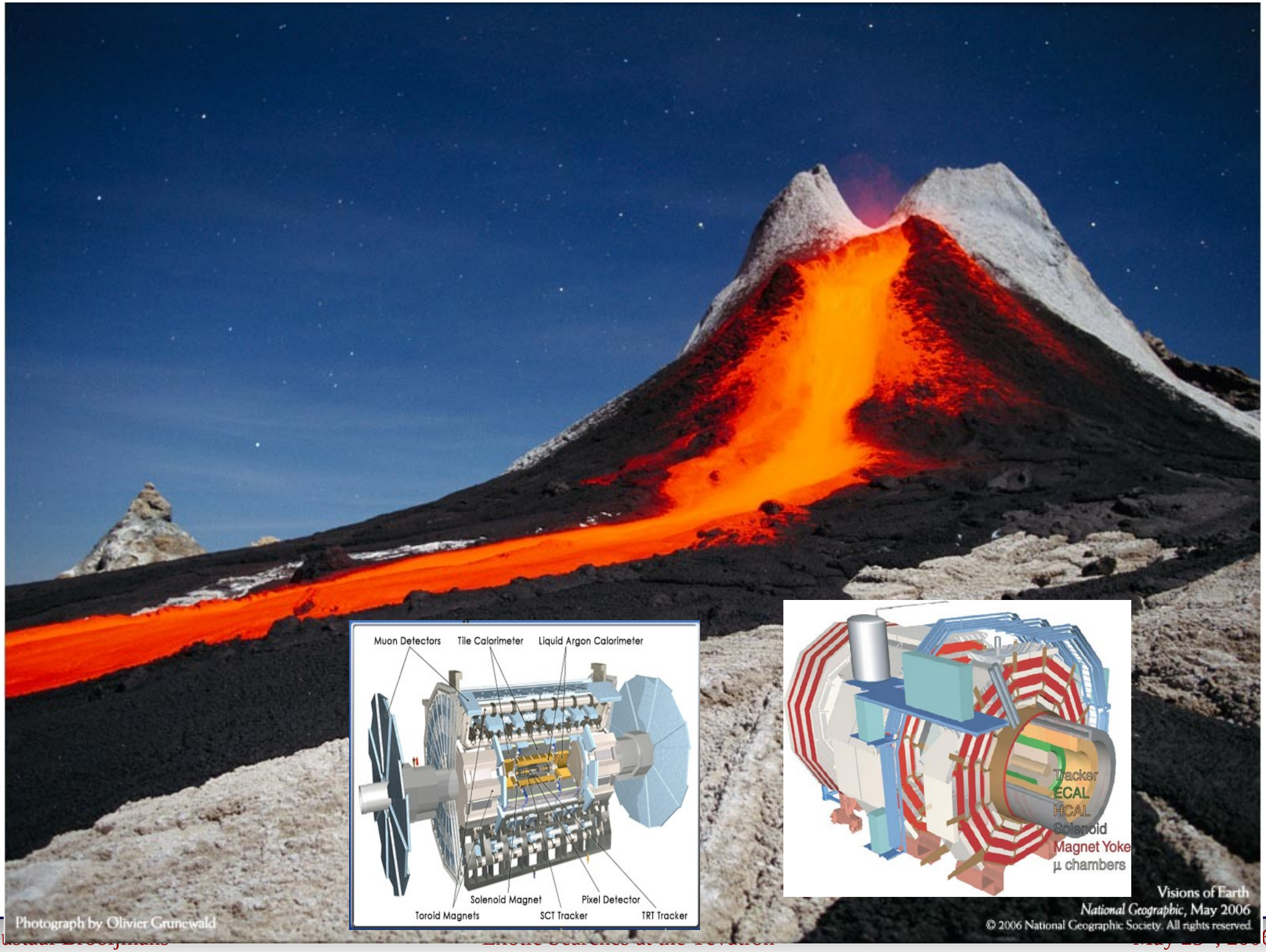


- In DØ, look for a pair of muons with a common vertex between 5 and 20 cm from the beam, calibrate analysis using K_S
  - No signal seen, to compare results make some assumptions about momentum in neutrino beam and convert to Tevatron center of mass



Conclusions

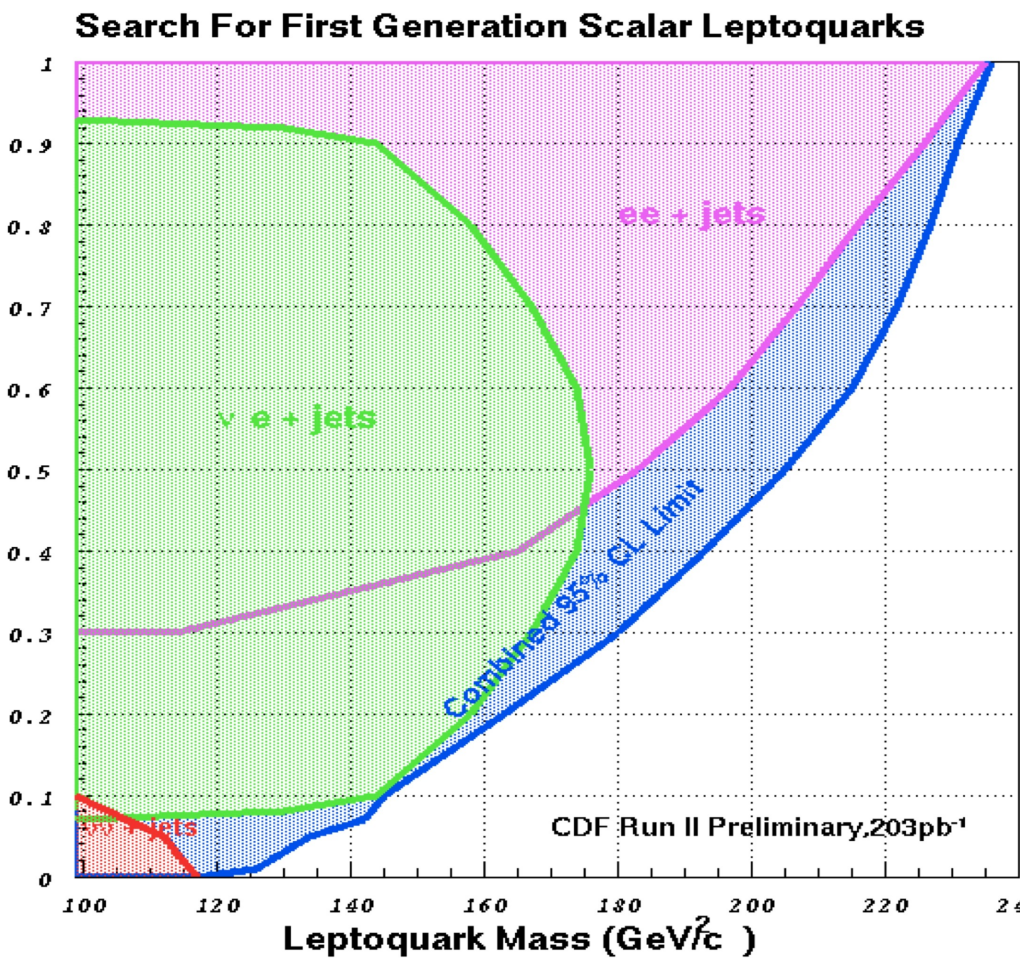
- CDF and DØ are searching for new physics in many channels. Only recent results shown here, many other analyses in progress.
- *Still* nothing interesting
  - And previous excesses demonstrated to be fluctuations
- So far, new physics has remained hidden, but hopefully at the LHC...

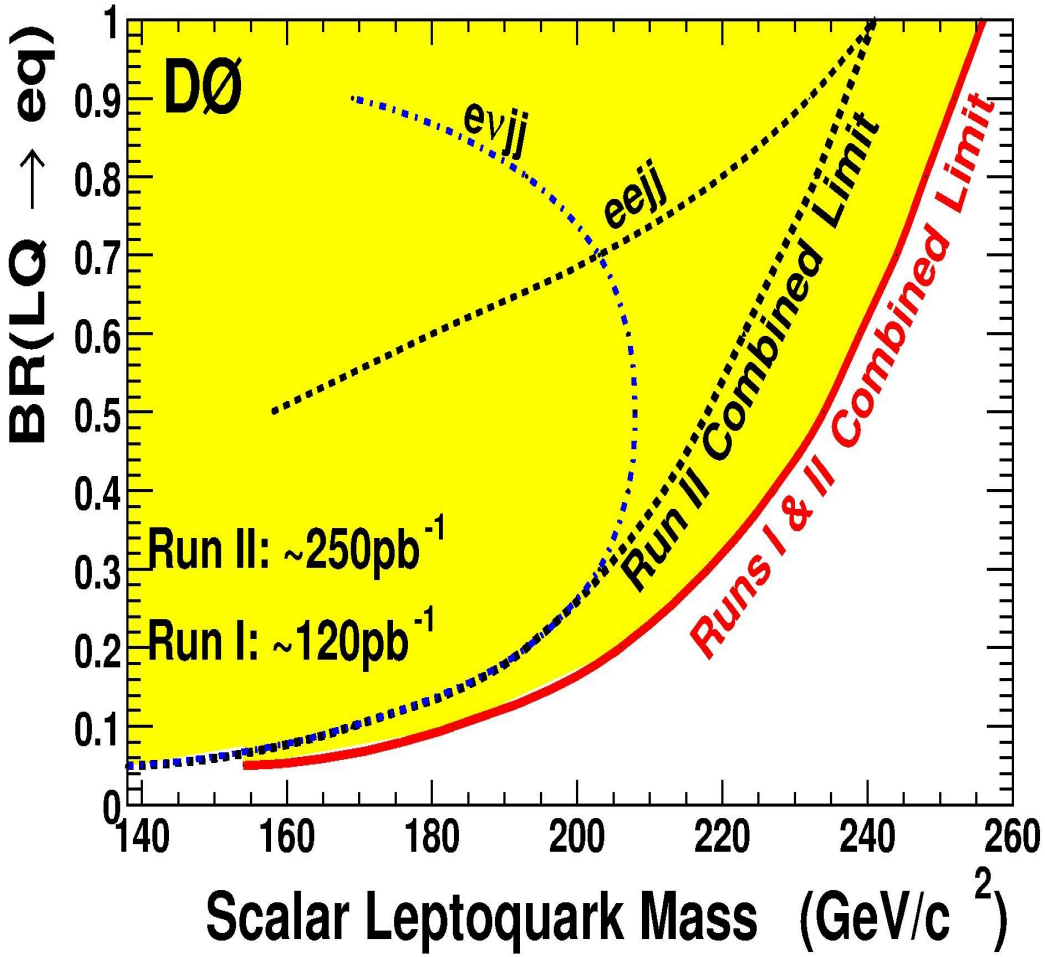
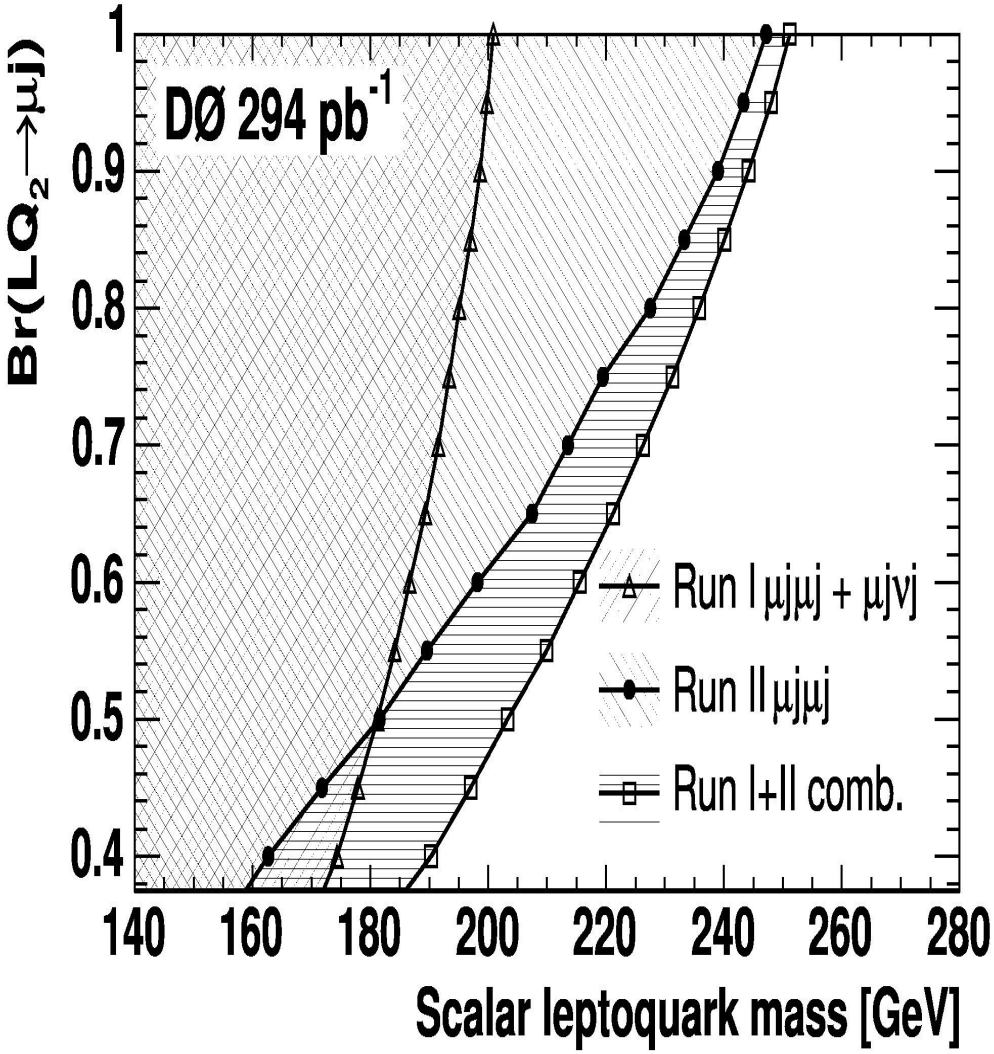
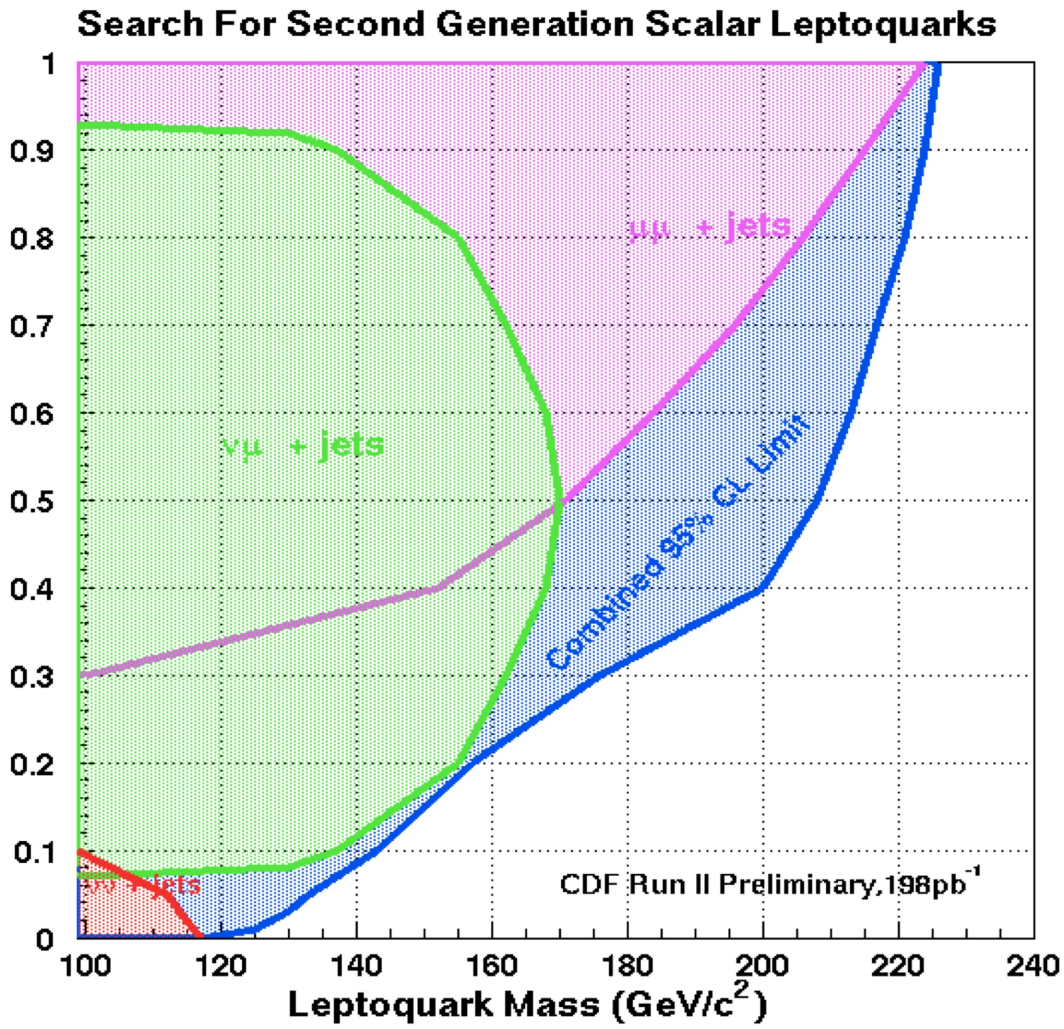

Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Solenoid Magnet
Pixel Detector
Toroid Magnets
SCT Tracker
TRT Tracker
Tracker
ECAL
HCAL
Solenoid
Magnet Yoke
μ chambers
Photograph by Olivier Grunewald
Visions of Earth
National Geographic, May 2006
© 2006 National Geographic Society. All rights reserved.

- Many interpretations of dielectron (and diphoton) results:
  - CDF:
    - Randall-Sundrum graviton mass from search for a diphoton resonance: M_G > 690 GeV for k/M_{Pl} = 0.1 (345 pb^{-1})
    - Sneutrino with RPV decay: m > 725 GeV
  - DØ:
    - Randall-Sundrum Gravitons: M_G > 800 GeV for k/M_{Pl} = 0.1 (260 pb^{-1})
    - Compactification scale for TeV^{-1} extra dimensions from search for KK excitation of gauge bosons: M_C > 1.12 TeV (200 pb^{-1})
    - Fundamental Planck scale in "ADD" large extra dimensions from search for graviton interference in production of dielectron and diphoton final states: M_S > 1.43 TeV (200 pb^{-1} combined with Run I result)
    - Quark-electron compositeness scale from interference of a high scale interaction in Drell-Yan process: Λ > 3.6 – 9.1 TeV (271 pb^{-1}, model dependent)
    - Techni-vector meson masses from search for resonances in dielectrons: m(ρ_T or ω_T) > 367 GeV (200 pb^{-1}, model dependent)

Earlier LQ Results

- First generation:





- Second generation: