# *High Mass Resonances Decaying to Leptons and Photons at the Tevatron*

**Oliver Stelzer-Chilton**

TRIUMF

**on behalf of the CDF and D0 Collaborations**

34th International Conference on High Energy Physics
Philadelphia, PA, July 29th – August 5th, 2008

# *Outline*

Searches are motivated by the BSM physics

→ A model can predict several signatures

Analysis start with the experimental signature

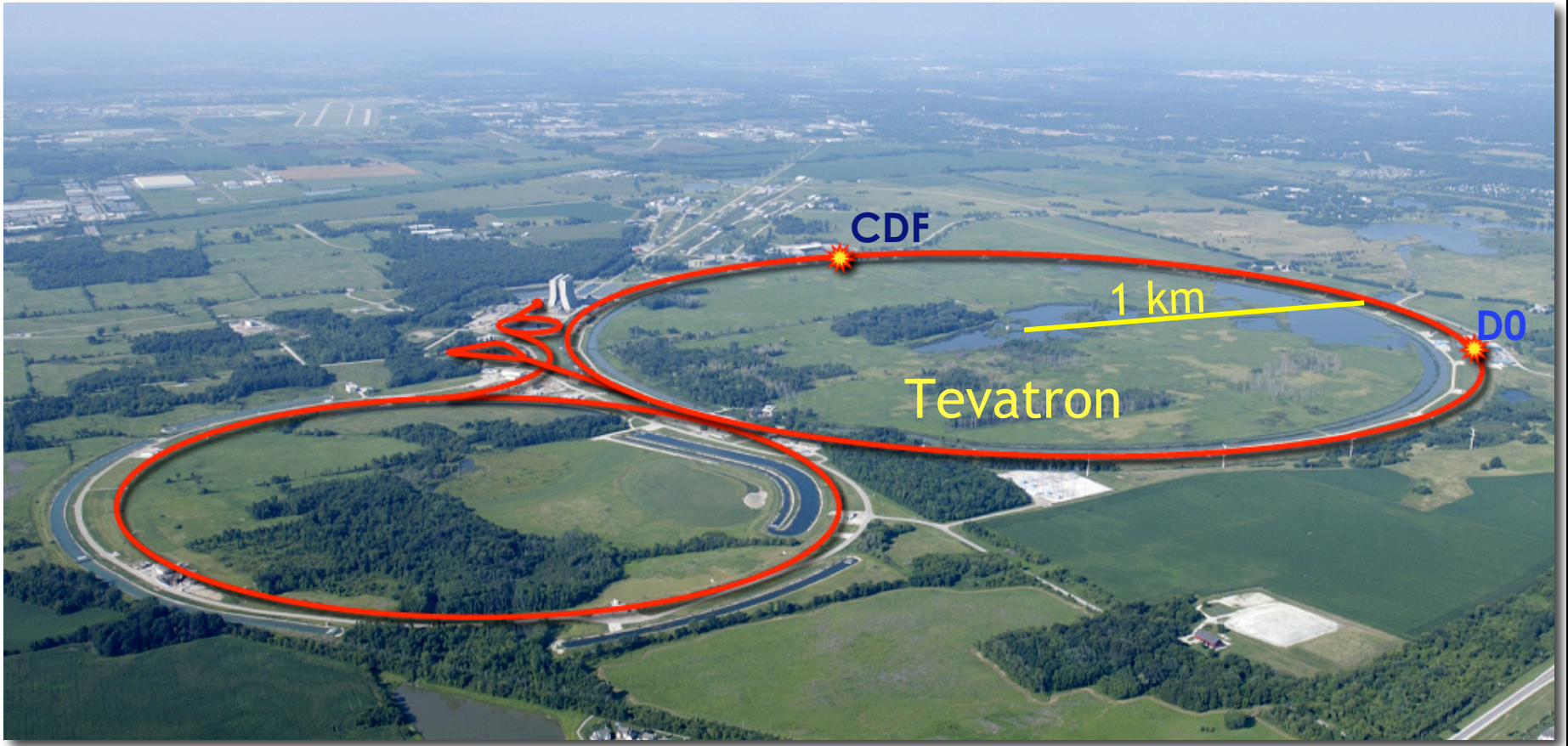
→ One signature can constrain several models

Signatures and Models in this talk:

| | | |
|---|---|---|
| Z' bosons | ⟷ | ee, μμ |
| W' bosons | ⟷ | eν |
| Extra Dimensions | ⟷ | ee, γγ, μμ |
| Excited electrons (compositness) | ⟷ | eγ |

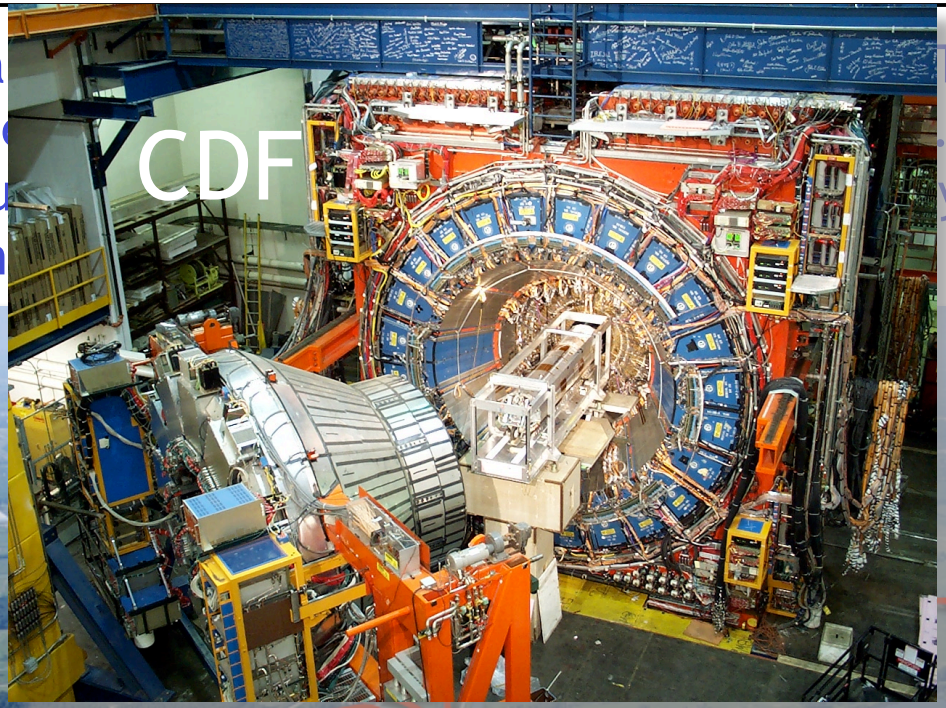
# *CDF and DØ at the Tevatron*

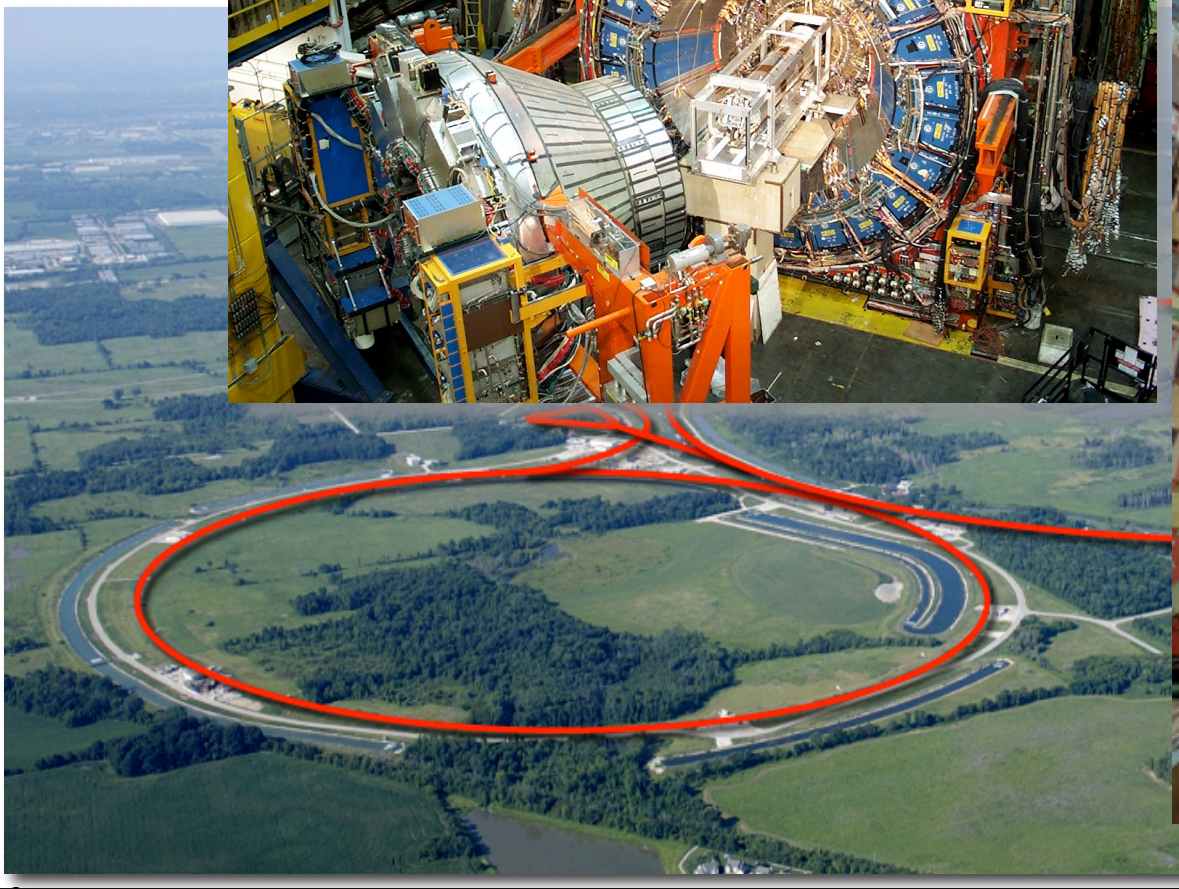
- Fermilab's Tevatron Run II $p\bar{p}$ collider at 1.96 TeV
- Surpassed design luminosity (record Inst. lum. 3.18 $10^{32}$ [$cm^{-2}sec^{-1}$])
- Two multi-purpose detectors (CDF,D0) in highly efficient data taking mode since 2002



# *CDF and DØ at the Tevatron*

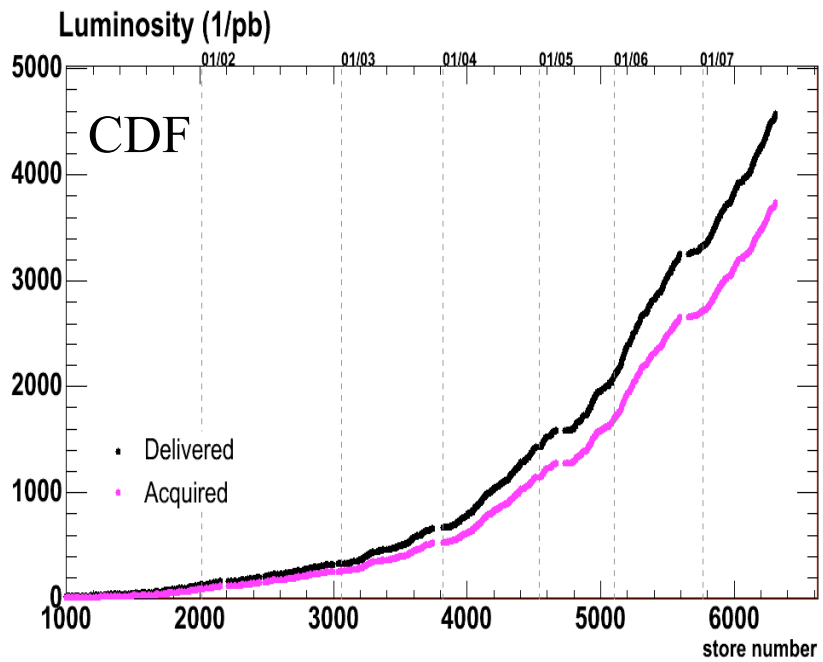
- Fermila TeV
- Surpass 3.18 $10^{32}$ [$cm^{-2}sec^{-1}$])
- Two mu y
  efficien

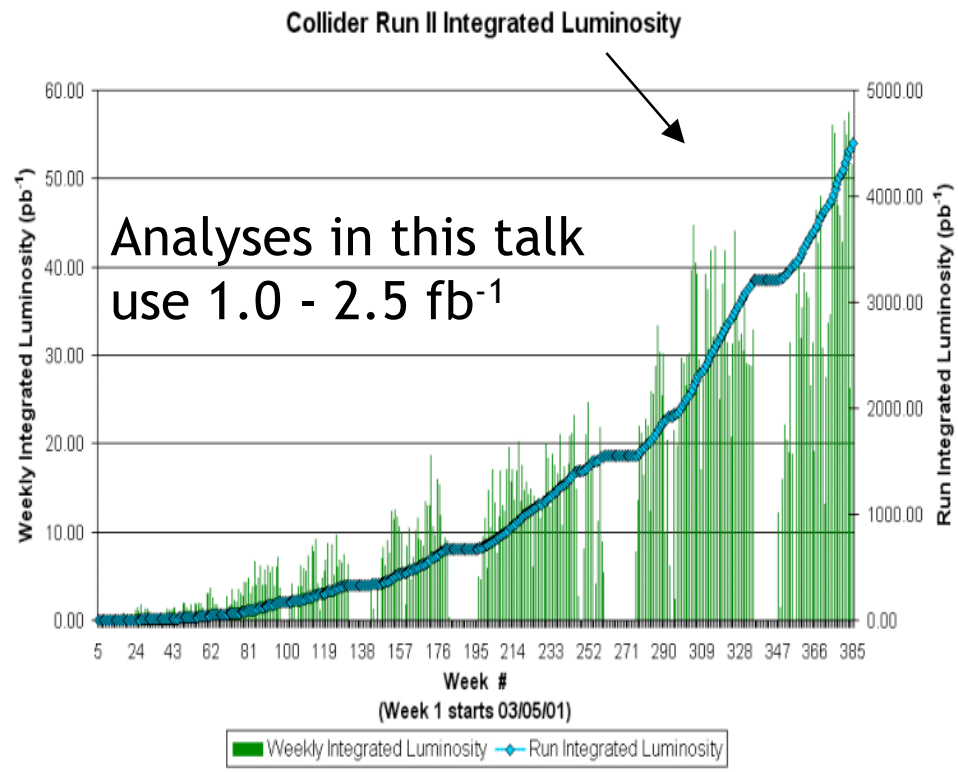


# *CDF and DØ at the Tevatron*

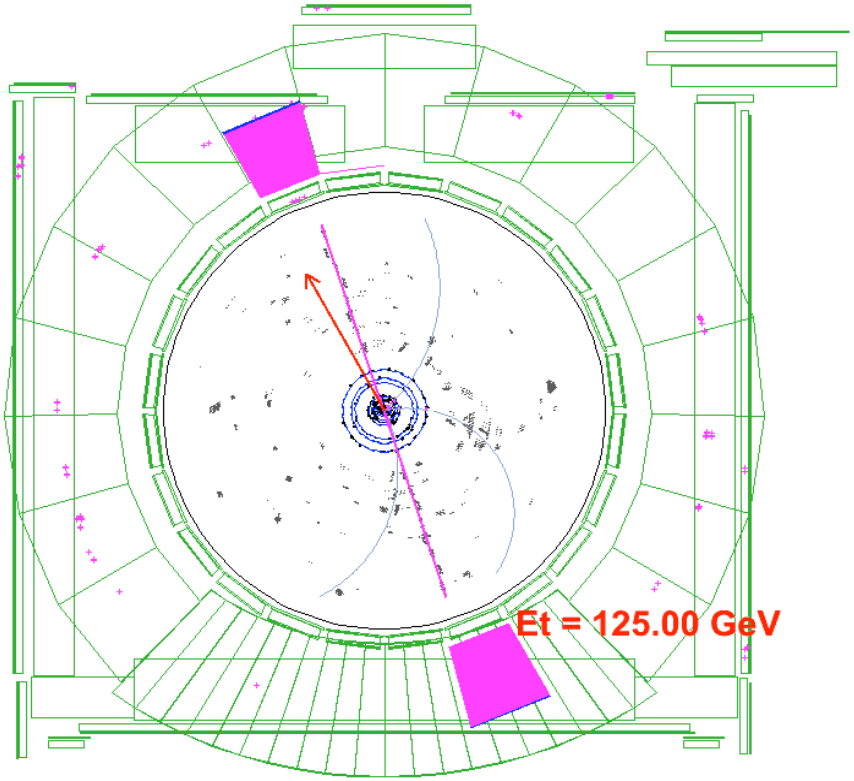
- *CDF and DØ are running well*
- Tevatron delivered ~4.5 $fb^{-1}$ and is performing extremely well ~58 $pb^{-1}$ / week!

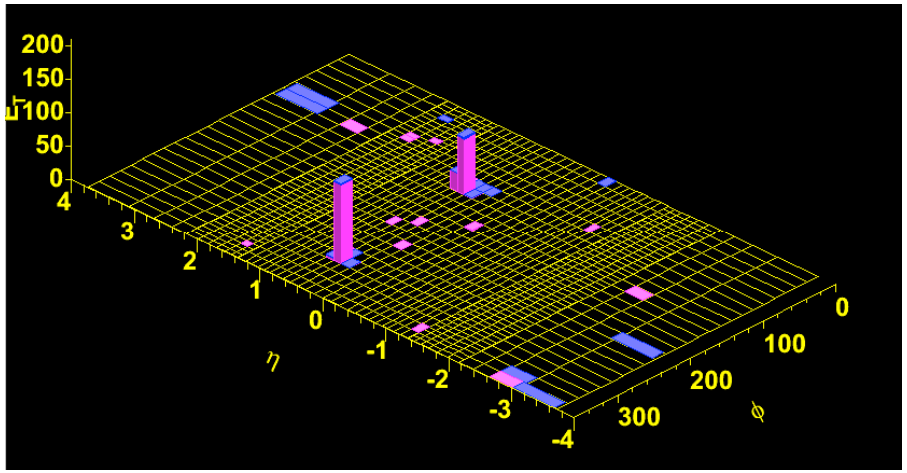


# Analysis Strategy

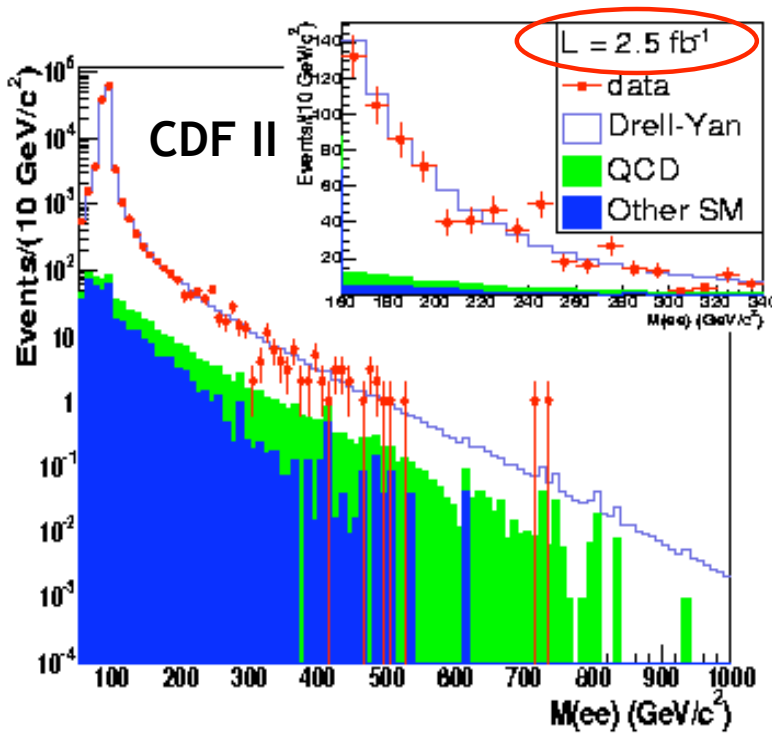
- Model SM background processes
  - → Generally QCD from data
  - → Remaining SM backgrounds from MC
- Select clean high-$p_T$ leptons and construct invariant mass



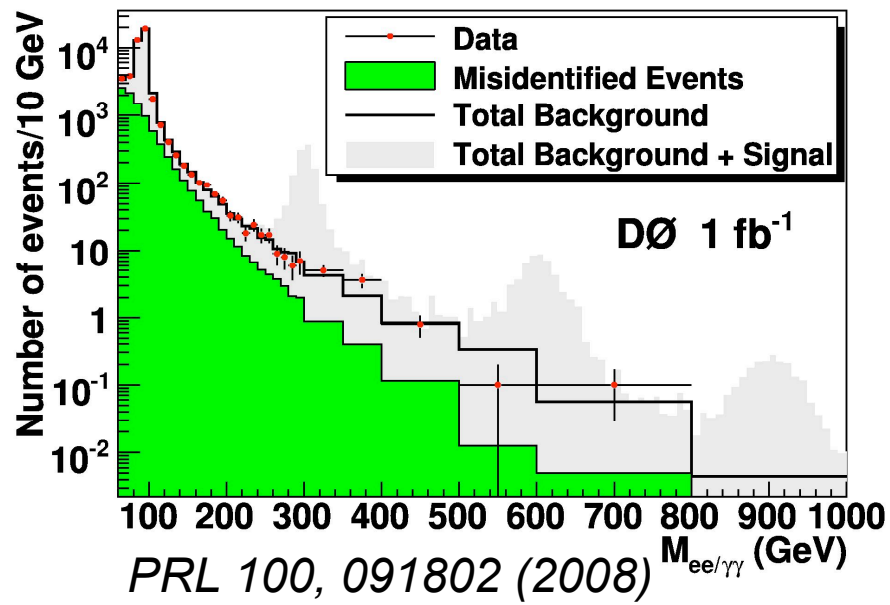




- Look for any excesses in the high mass spectrum

# High Mass ee, $\gamma\gamma$ Spectrum




Largest sample



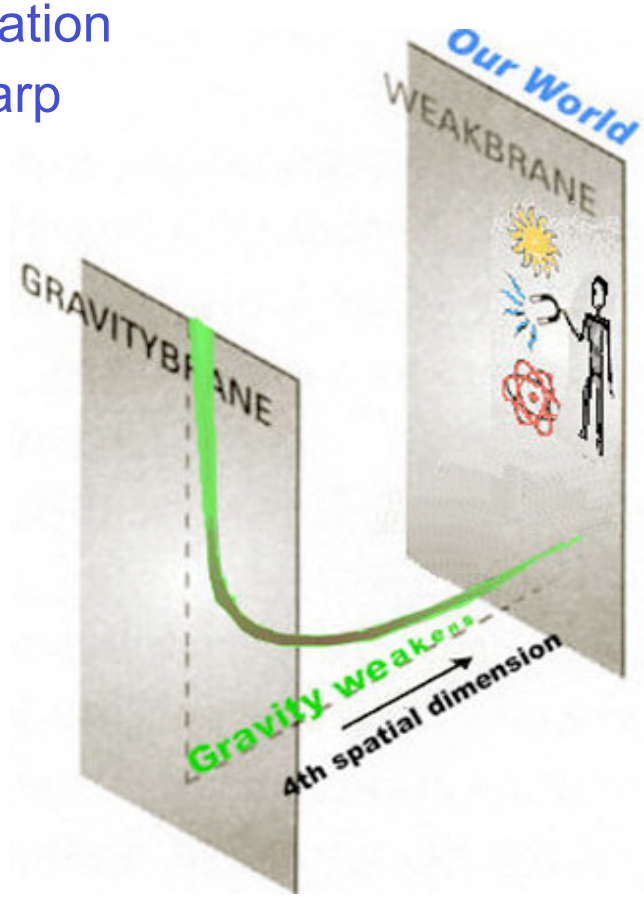

*PRL 100, 091802 (2008)*

- CDF: Largest excess at $M_{ee}$= 228 –250 GeV/$c^2$
  → p-value = 0.6% to see such an excess in 150-1000 GeV/c2

- D0: no excess

# *Model: Randall-Sundrum Graviton*

- Potential solution to hierarchy between Planck and weak scale
  → Randall-Sundrum model of gravity unification
  → Warped extra dimension, exponential warp factor solves hierarchy problem

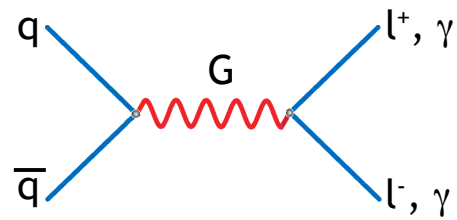


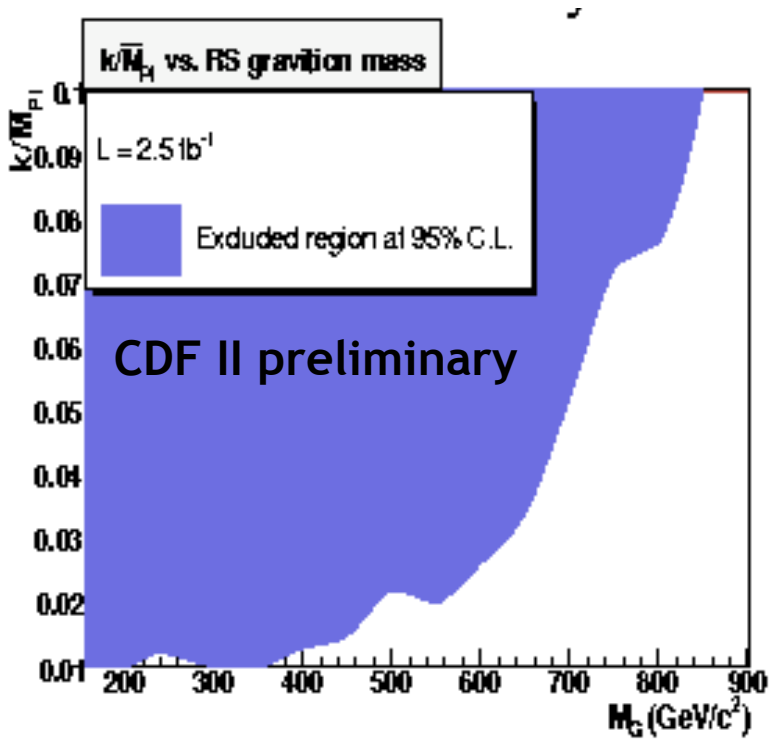

- Two 3-branes, TeV and Planck
  → Gravitons live everywhere
  → SM confined to TeV brane

- Prediction:
- Excited states of graviton wave function has big overlaps
  → Massive gravitons with electroweak-strength couplings to SM particles on our brane

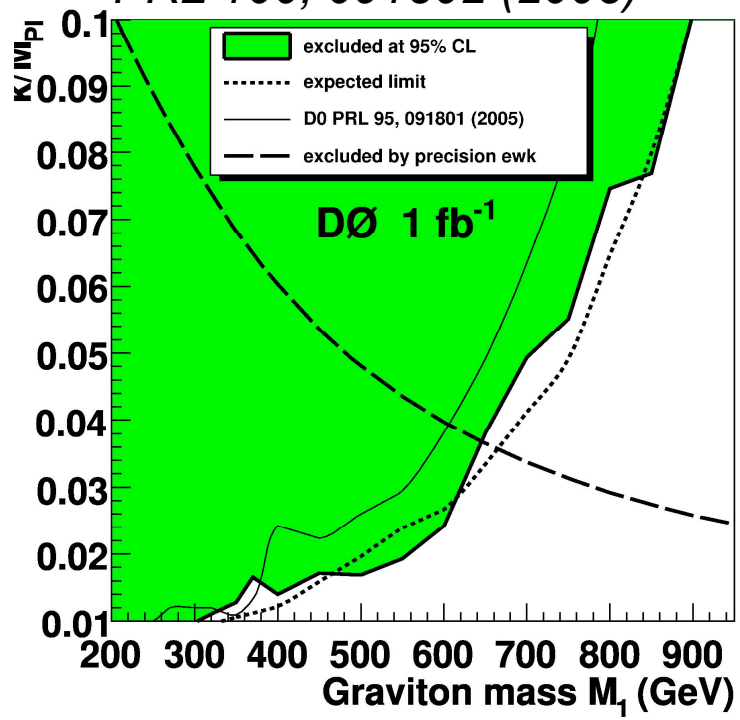
# High Mass ee, $\gamma\gamma$ Spectrum - Limits on RS Graviton

- Limits set as a function of $k/M_{PL}$:
  → coupling constant to SM fields




*PRL 100, 091802 (2008)*




- $k/M_{PL}$=0.1, $M_{G*}$>850 GeV
- $k/M_{PL}$=0.01, $M_{G*}$>358 GeV

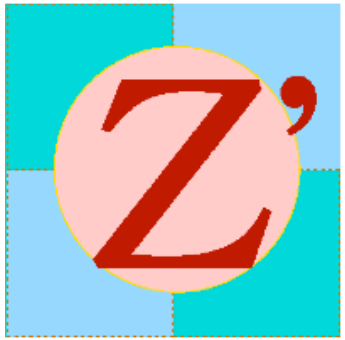
- $k/M_{PL}$=0.1, $M_{G*}$>900 GeV
- $k/M_{PL}$=0.01, $M_{G*}$>300 GeV

# *Model: Z' Bosons*

- Di-lepton resonances have a strong track record for discovery
  → J/ψ, Υ, Z
  → Motivation continues at higher energy

- Unification of forces in GUT theories typically based on extended gauge groups e.g. SO(10), E6

  Symmetry-breaking of larger gauge group to SM groups generates additional U(1) gauge groups → Z' bosons

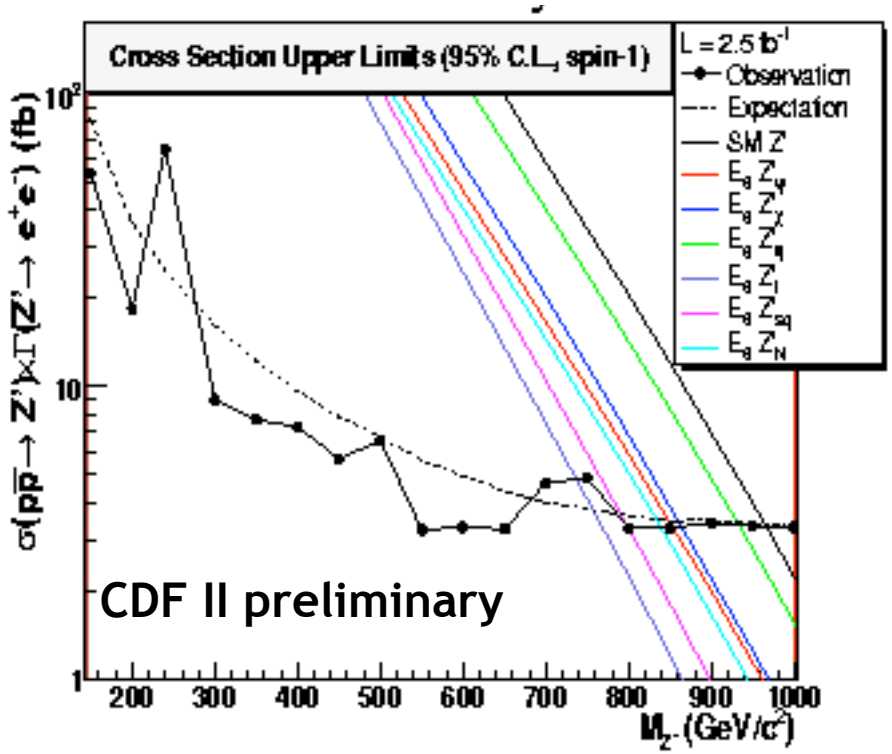



- Long lasting 3.2σ discrepancy in the electroweak precision fits from $A_{LR}$ and $A^{b}_{FB}$

  If interpreted as a hint of new physics, could be explained by mixing of the SM Z with a heavier Z' (M. Chanowitz)

# High Mass ee Spectrum - Limits on Z' Bosons

- Limits set with SM couplings and in E6 Model
- E6 $\rightarrow$ SO(10) x $U(1)_\Psi$
  $\rightarrow$ SU(5) x $U(1)_\chi$ x $U(1)_\Psi$
- Mass eigenstate:
  $Z'(\theta) = Z'_\Psi \cos\theta + Z'_\chi \sin\theta$
- $\theta$: Mixing angle, determines the coupling

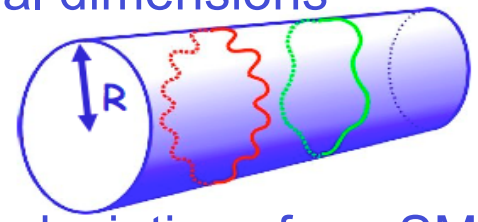



95% C.L. Mass Limits (GeV/$c^2$)

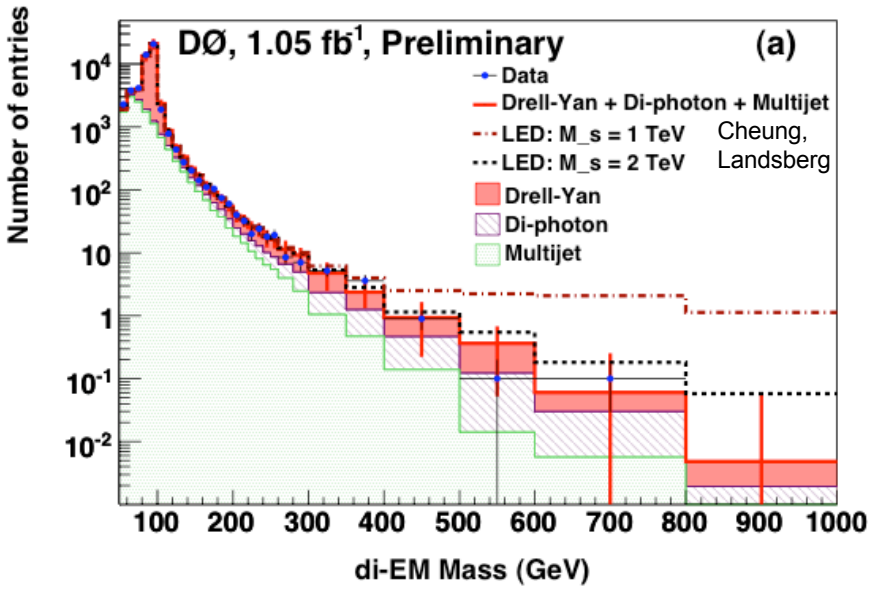
| Model | $Z'_{SM}$ | $Z'_\Psi$ | $Z'_\chi$ | $Z'_\eta$ | $Z'_I$ | $Z'_{sq}$ | $Z'_N$ |
|---|---|---|---|---|---|---|---|
| Exp | 965 | 849 | 860 | 932 | 757 | 791 | 834 |
| Obs | 966 | 853 | 864 | 933 | 737 | 800 | 840 |

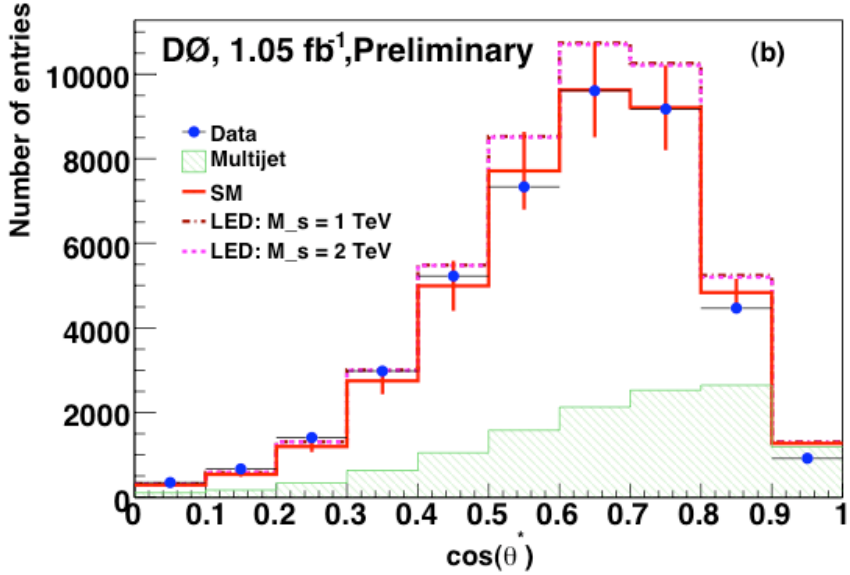
# *High Mass ee, $\gamma\gamma$ Spectrum*

- Model to solve the hierarchy problem
  Large Extra Dimensions: Arkani-Hamed, Dimopoulos, Dvali (ADD)
  → Gravity propagate in $n_d$ additional compactified spatial dimensions
  → $[M_{Pl}]^2 \sim R^{n_d} [M_s]^{n_d+2}$, Effective Planck scale: $M_s$



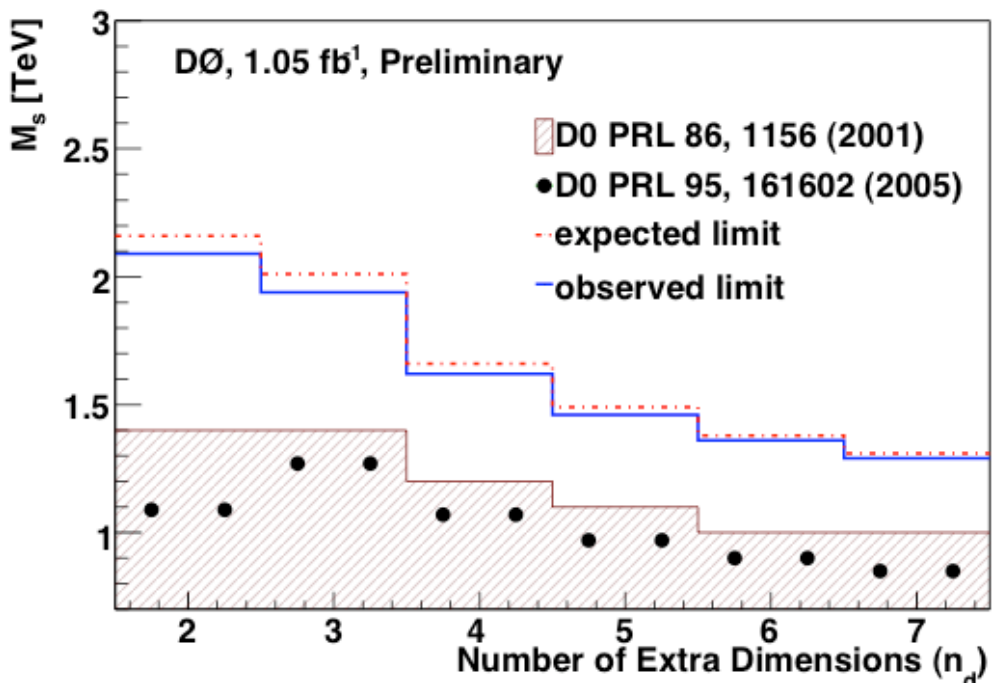

- Examine 2D distribution, invariant mass and cos(θ*) for deviations from SM




- Data consistent with Standard Model Backgrounds

# *High Mass ee, $\gamma\gamma$ Spectrum - Limits on $M_s$*

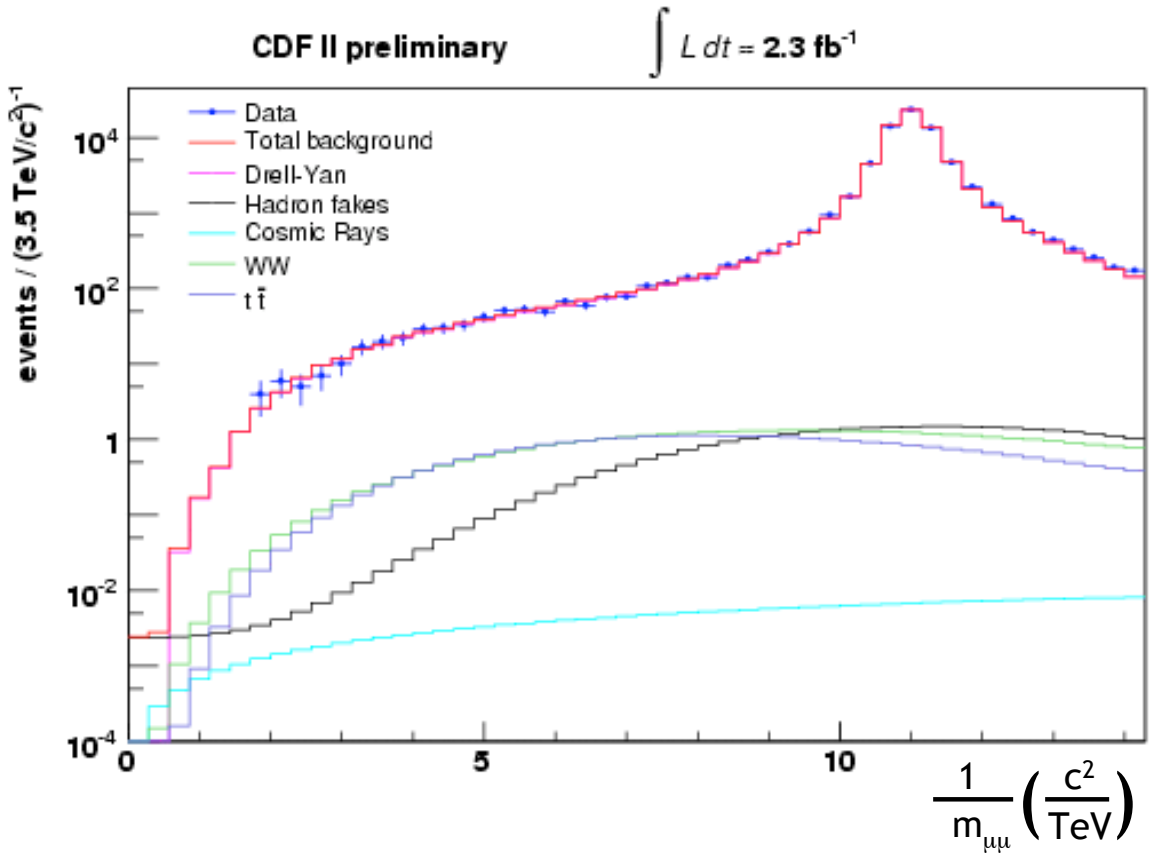



- Limits on $M_s$ ranging from 1.29 - 2.09 TeV for number of extra dimensions ranging from $n_d$ = 7 to $n_d$ = 2 (HLZ)

*…world's best limit*

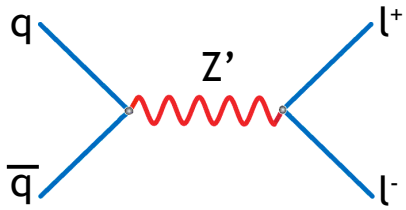
# *High Mass $\mu\mu$ Spectrum*

- Perform search in $1/m_{\mu\mu}$ in which detector resolution is ~const
  → Resonances have all the same width in entire mass range




- Data consistent with Standard Model backgrounds

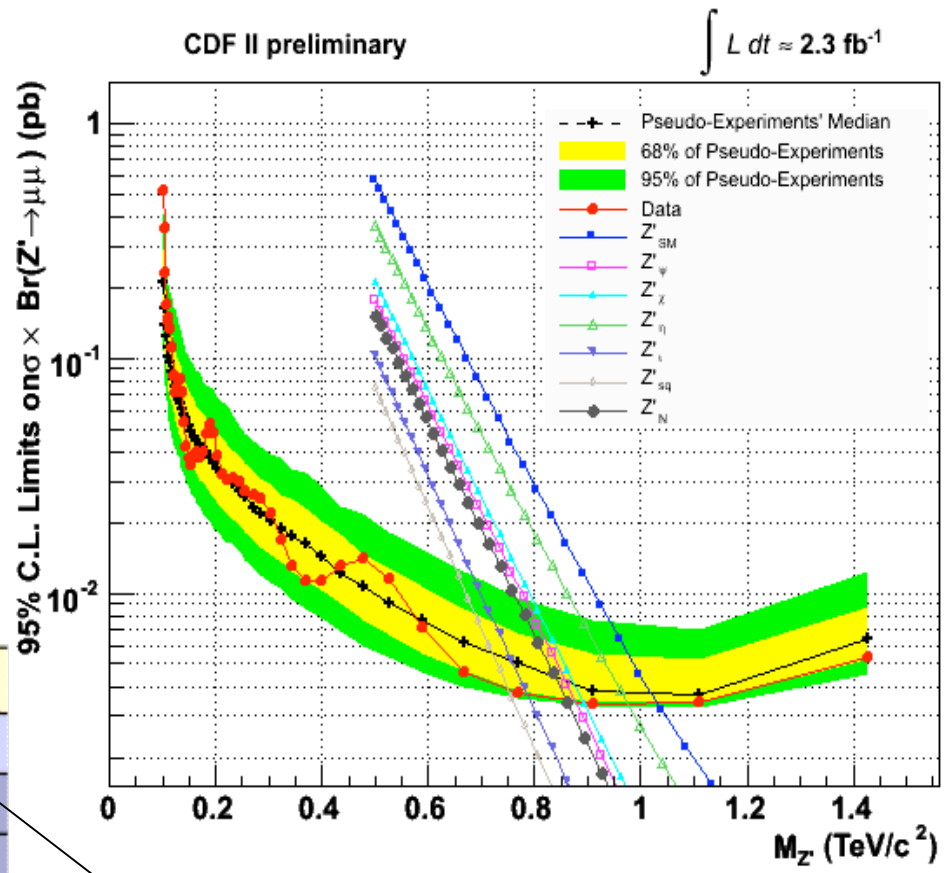
# *High Mass $\mu\mu$ Spectrum - Limits on Z' Bosons*




- Limits set with SM couplings and in E6 Model
- Approaching kinematic limit for some models

CDF II preliminary L = 2.3 fb$^{-1}$

| Model | Mass Limits, 95% CL (GeV/c$^2$) |
|---|---|
| Z' (SM) | 1030 |
| Z' (η) | 975 |
| Z' (χ) | 892 |
| Z' (ψ) | 878 |
| Z' (N) | 861 |
| Z' (ι) | 789 |
| Z' (sq) | 754 |

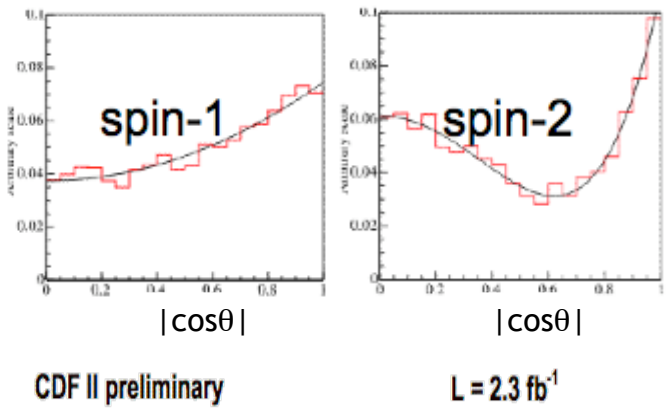



- For the first time beyond the the one TeV mark

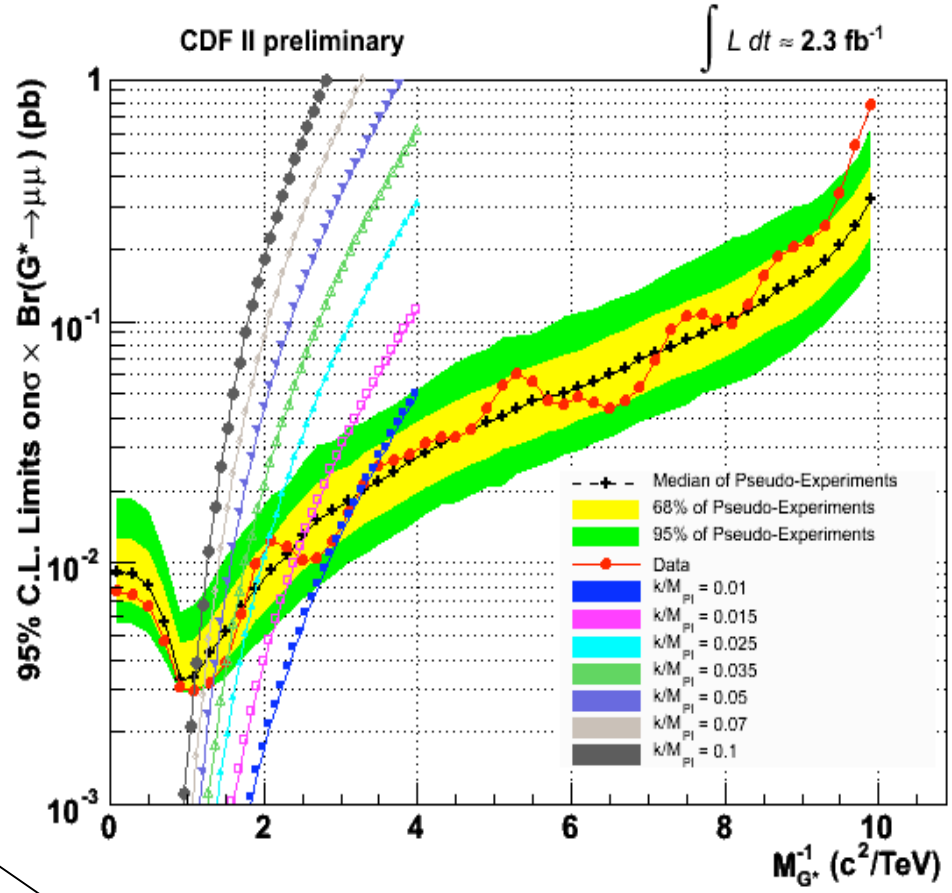
*...world's best limit*

# *High Mass $\mu\mu$ Spectrum - Limits on RS Graviton*

- Angular distribution and therefore acceptance depends on spin of the decaying particle



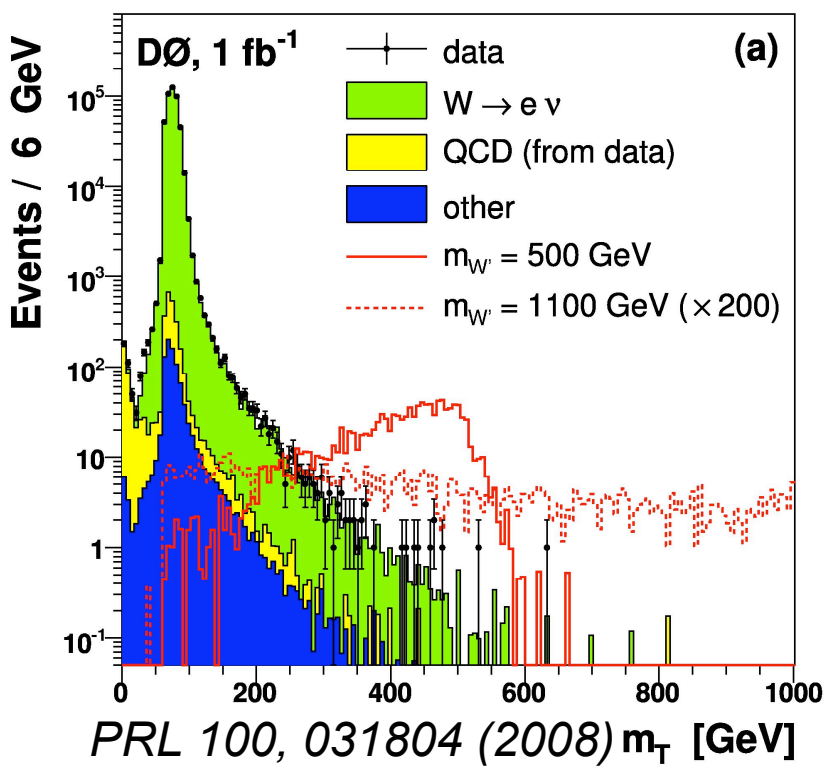

| Graviton $k/M_{Pl}$ | Mass Limit, 95% CL (GeV/$c^2$) |
|---|---|
| 0.1 | 921 |
| 0.07 | 824 |
| 0.05 | 746 |
| 0.035 | 651 |
| 0.025 | 493 |
| 0.015 | 409 |
| 0.01 | 293 |



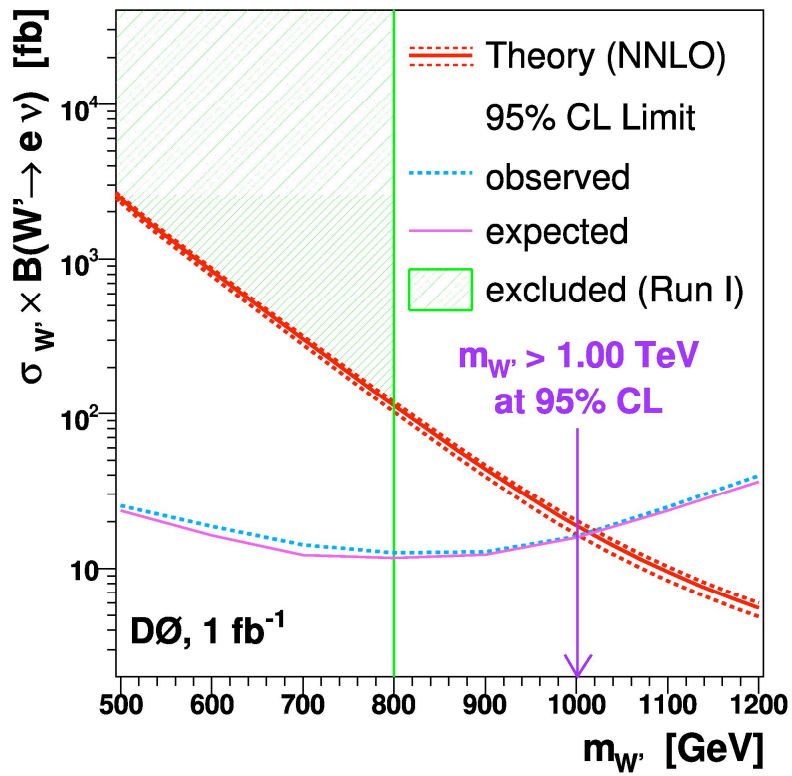

*…world's best limit*

# *High Transverse Mass eν Spectrum - Limit on W' Bosons*

- W' introduced in L-R symmetric Model: $SU(2)_R \rightarrow W_R$, GUT e.g. E6
- No excess seen



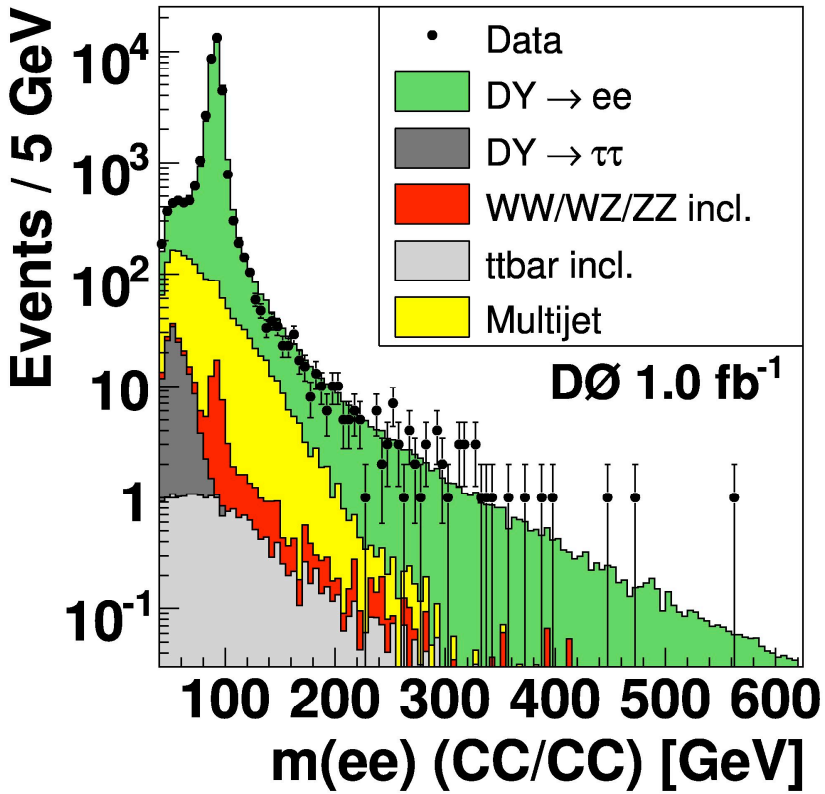

*PRL 100, 031804 (2008)*

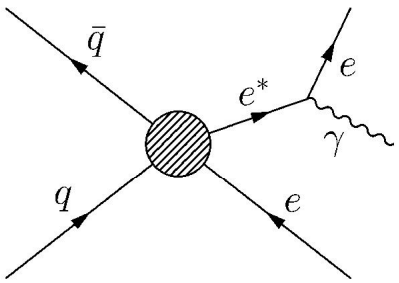



- Assume generic Altarelli Model, e.g. SM coupling, SM CKM Matrix
  → M(W') > 1.0 TeV *...world's best limit*

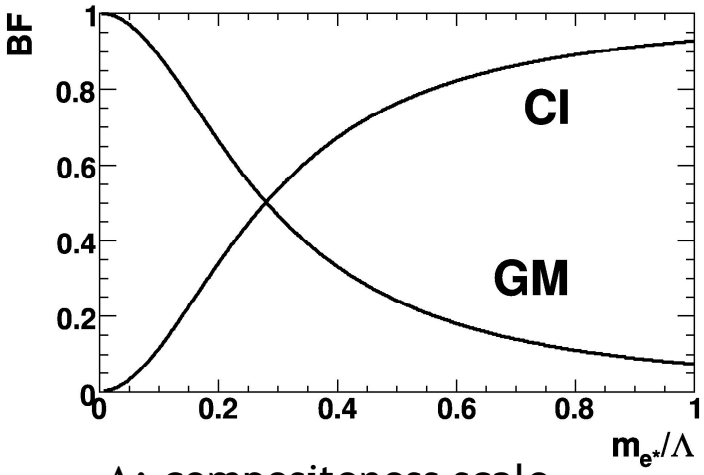
# *High Mass eγ Spectrum*

- Search for compositness of electron predicts excited state to explain apparent mass hierarchy of the quark and lepton doublets
- Coupling of excited states either through novel strong interaction, described by contact interaction (CI), or gauge mediated (GM)



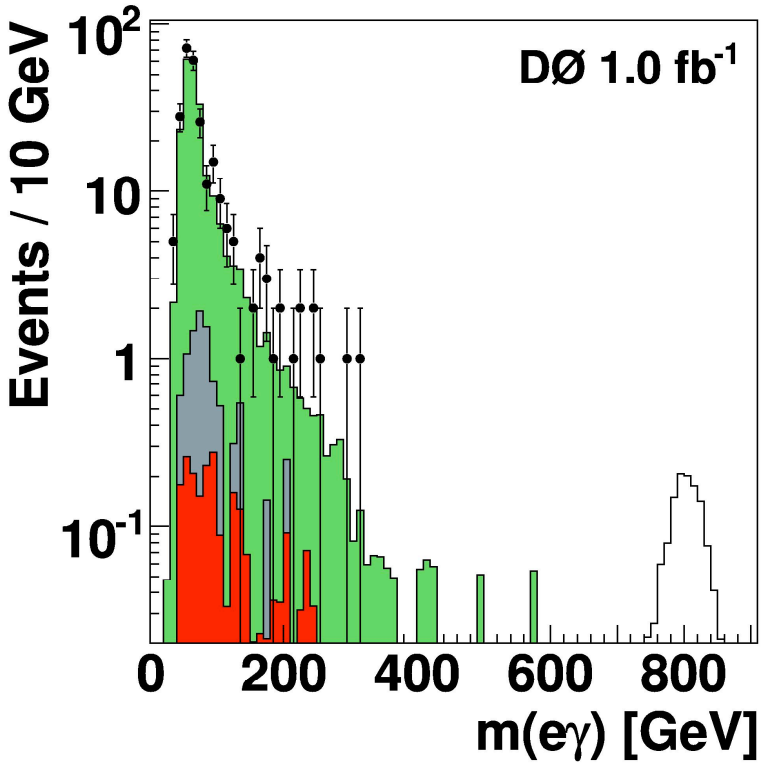




*arXiv:0801.0877*



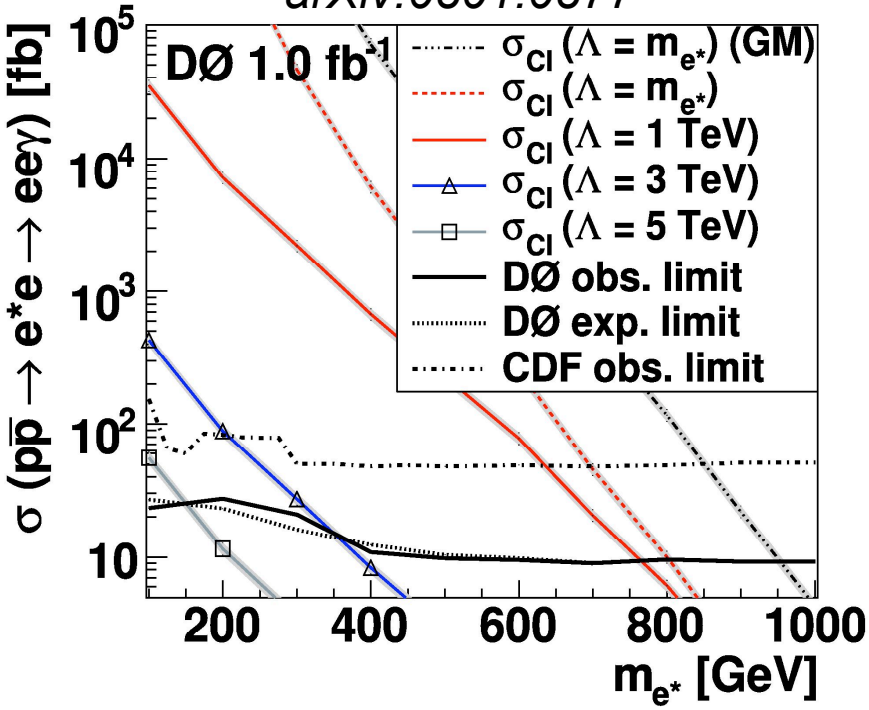

Λ: compositeness scale

# *High Mass eγ Spectrum - Limits on Excited Electrons*




- For m(eγ) combination, choose value closest to the e* canadiate
- For $m_{e^*}$<300 GeV, the lower $E_T$ electron is predominantly the decay electron

*arXiv:0801.0877*




- For contact interaction scale $\Lambda$ = 1 TeV
  → exclude $m_{e^*}$<756 GeV

*...world's best limit*

# *Conclusion*

- CDF and D0 have an extensive program to look for resonances in the high mass lepton and photon final states

- No significant excess in 1-2.5 $fb^{-1}$ of data
  → Largest excess in CDF di-electrons, p-value: 0.6%

- Derived mass limits for Z', W', RS Gravitons, LED and e* are the world's best!

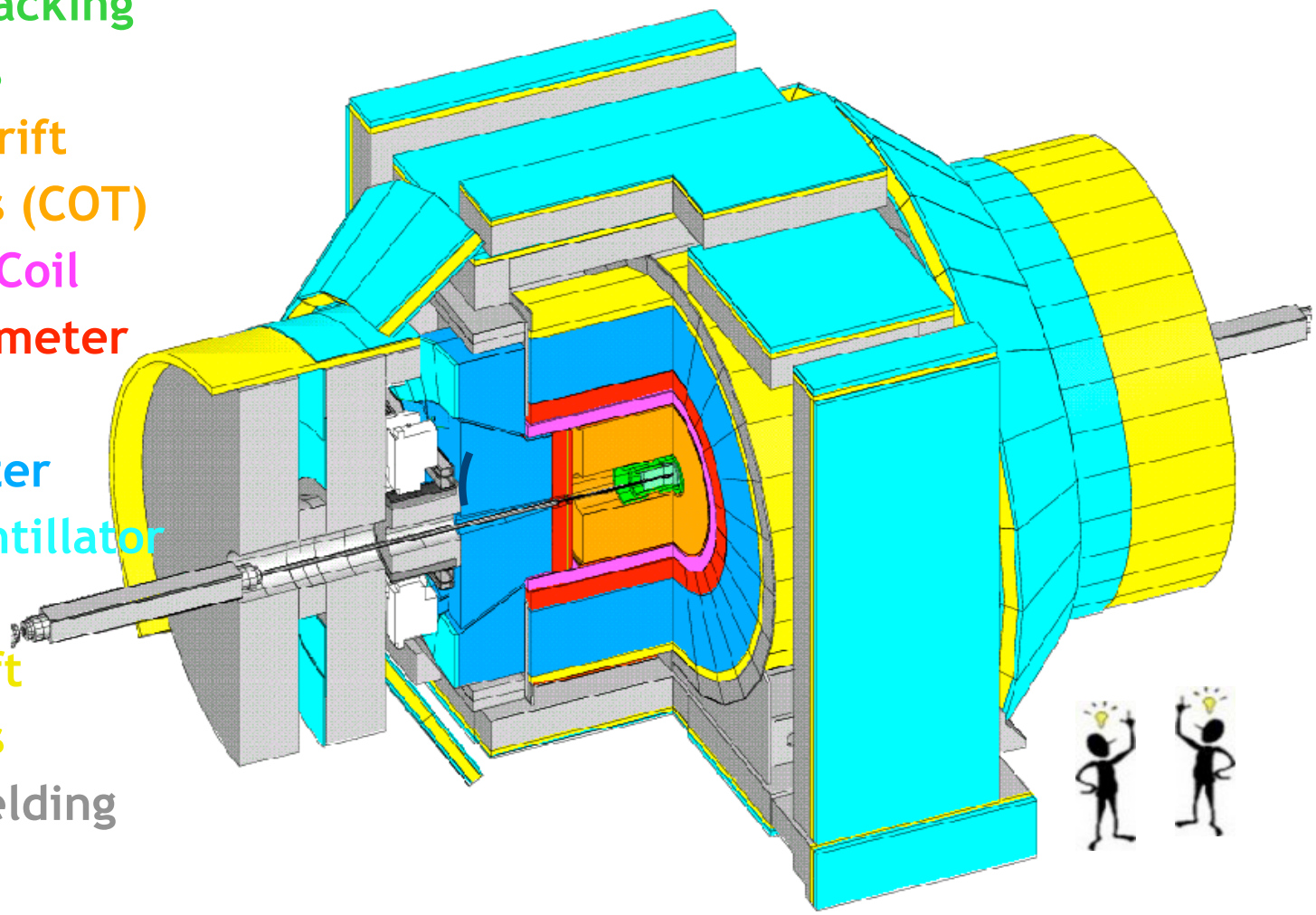
- More data is already on tape and expect a total of 6-8 $fb^{-1}$ for the final Run II dataset!
  → Still room for discoveries

- Details available at:
  → CDF: http://www-cdf.fnal.gov/physics/exotic/exotic.html
  → D0: http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm

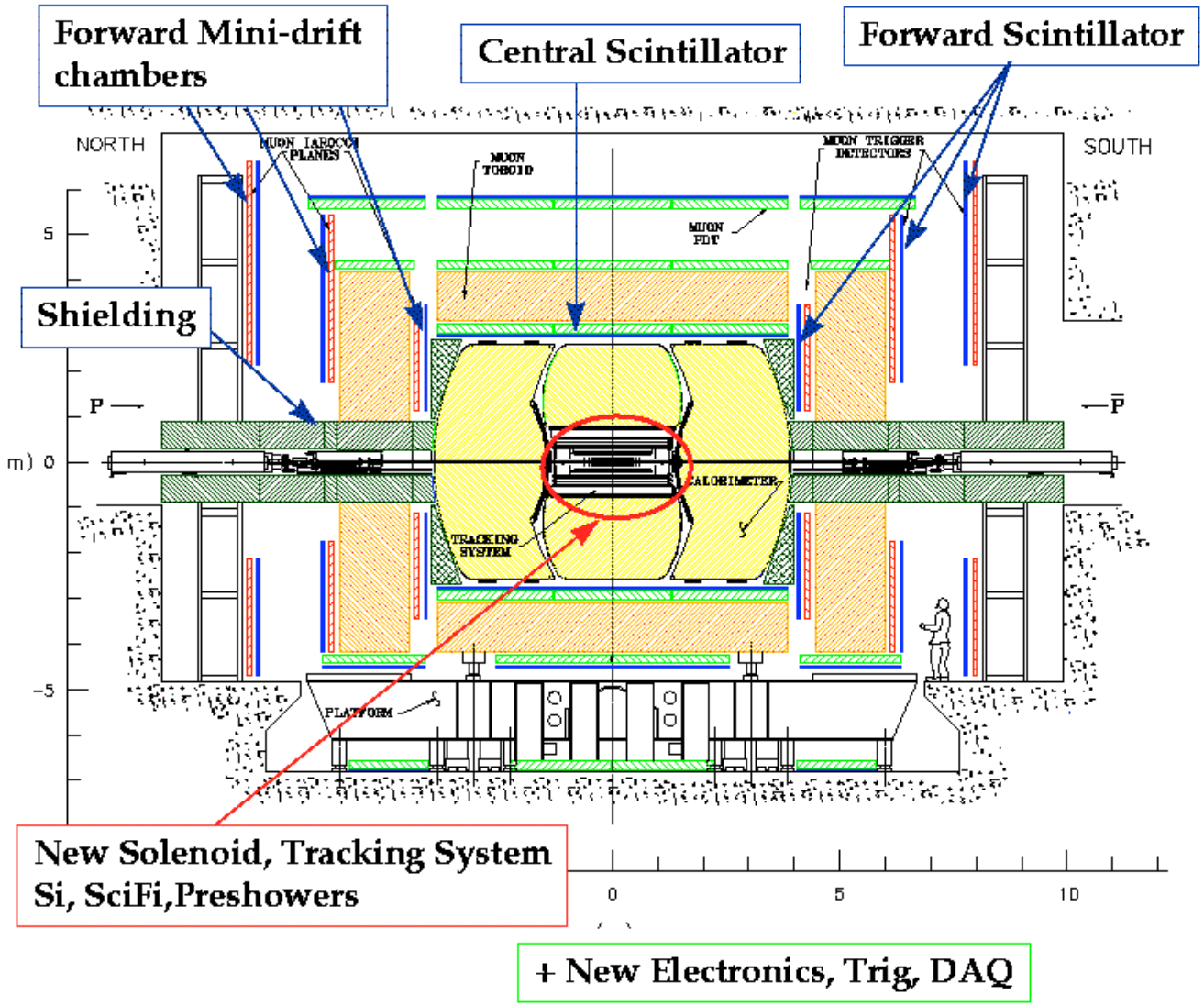
# *Backup*

# CDF

- Silicon tracking detectors
- Central drift chambers (COT)
- Solenoid Coil
- EM calorimeter
- Hadronic calorimeter
- Muon scintillator counters
- Muon drift chambers
- Steel shielding



# DØ


Forward Mini-drift chambers
Central Scintillator
Forward Scintillator
Shielding
NORTH
SOUTH
MUON IAROCCI PLANES
MUON TOROID
MUON TRIGGER DETECTORS
MUON PDT
CALORIMETER
TRACKING SYSTEM
PLATFORM
P
P̄
5
m) 0
-5
0
5
10
New Solenoid, Tracking System
Si, SciFi,Preshowers
+ New Electronics, Trig, DAQ