High Mass Resonances Decaying to Leptons and Photons at the Tevatron

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on behalf of the CDF and D0 Collaborations

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Outline

Searches are motivated by the BSM physics models

→ A model can predict several signatures

Analysis start with the experimental signature

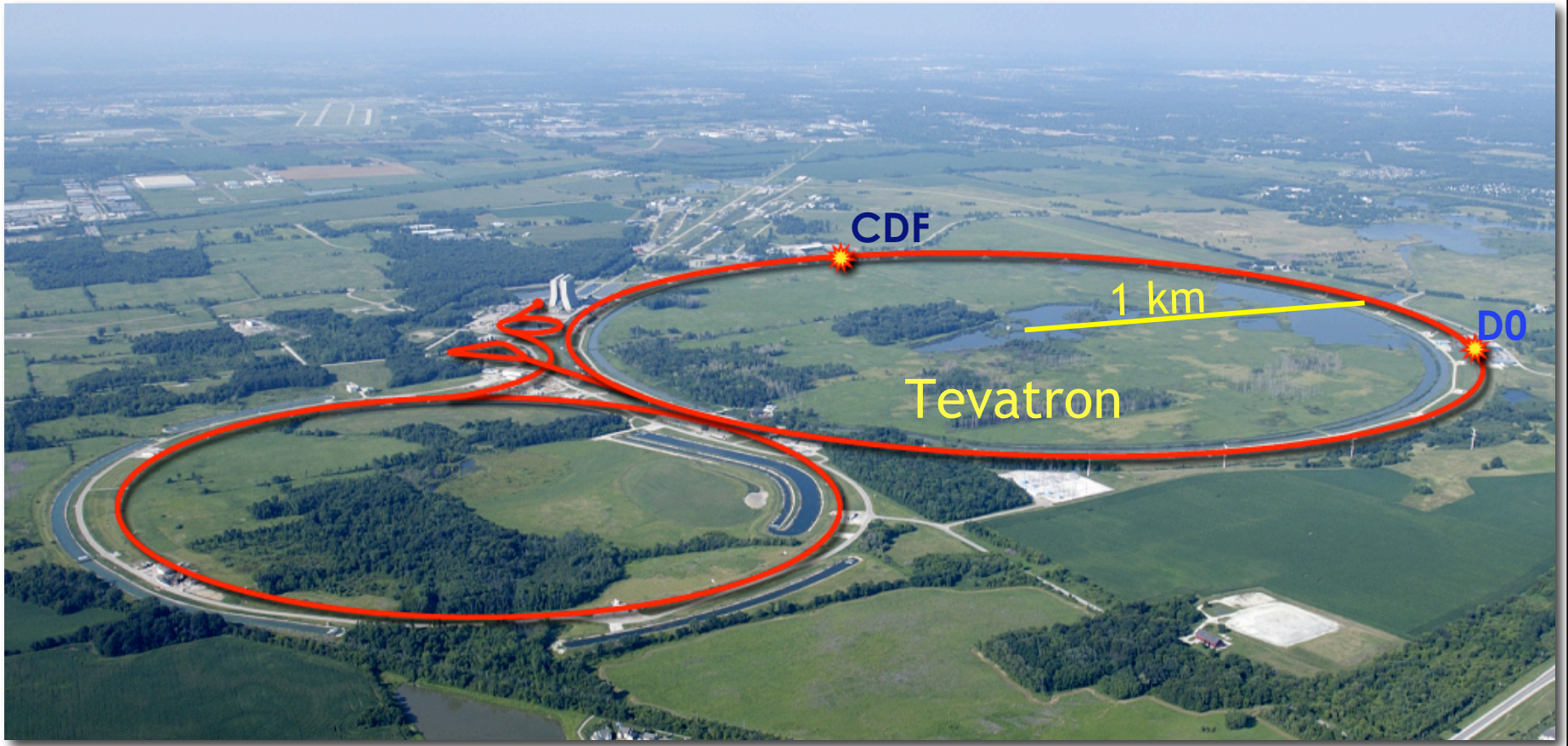
→ One signature can constrain several models

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
- Surpass
- Two mu
  efficien

TeV
3.18 10^{32} [$cm^{-2}sec^{-1}$])
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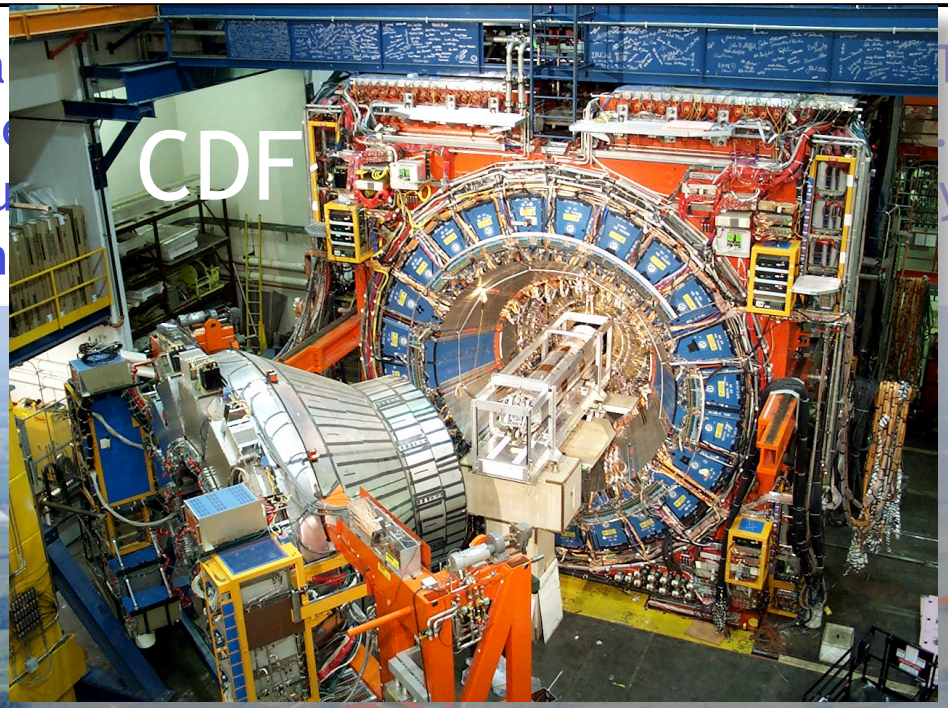
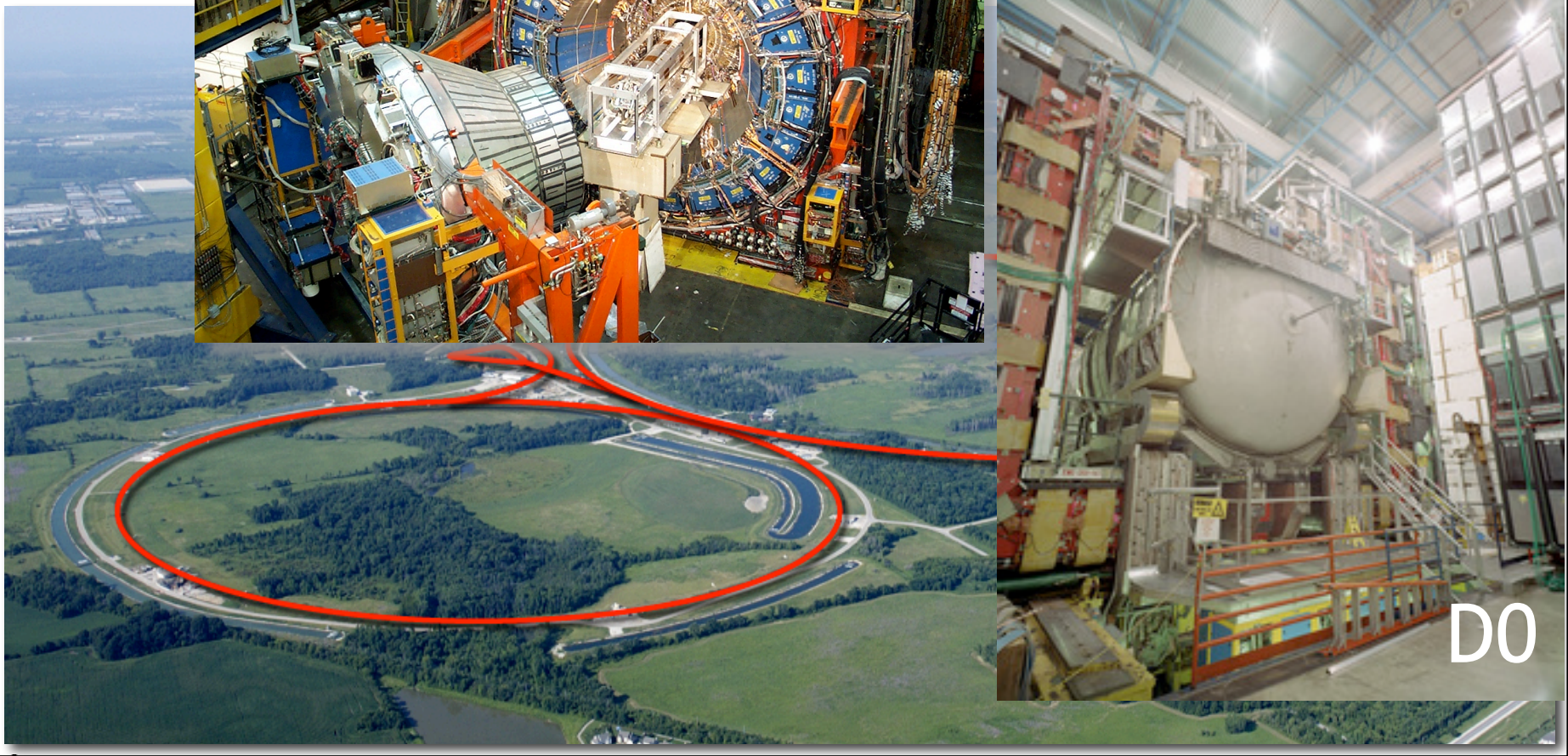
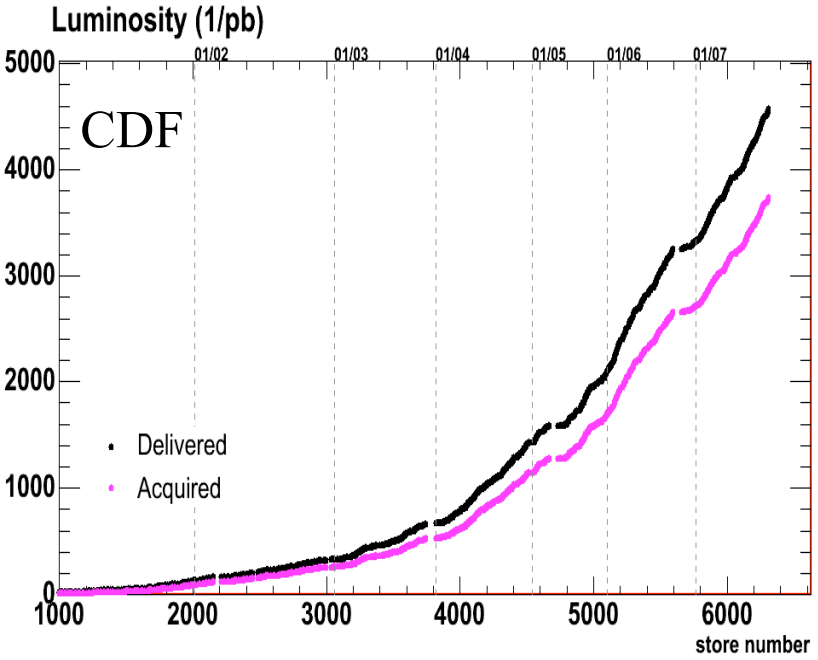
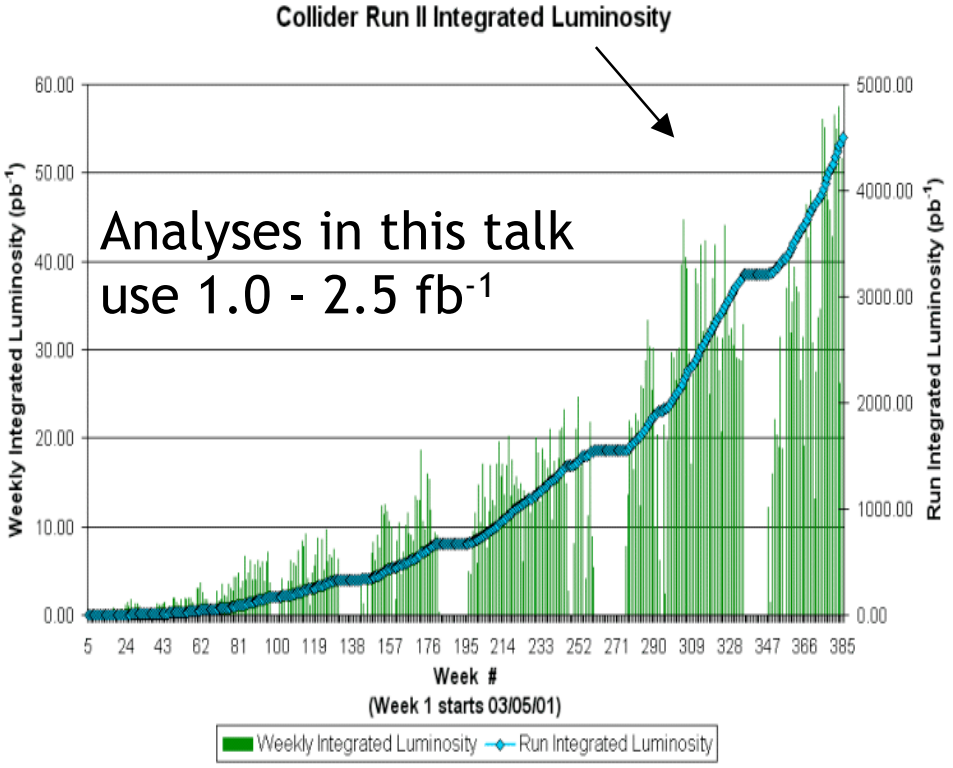




CDF and DØ at the Tevatron

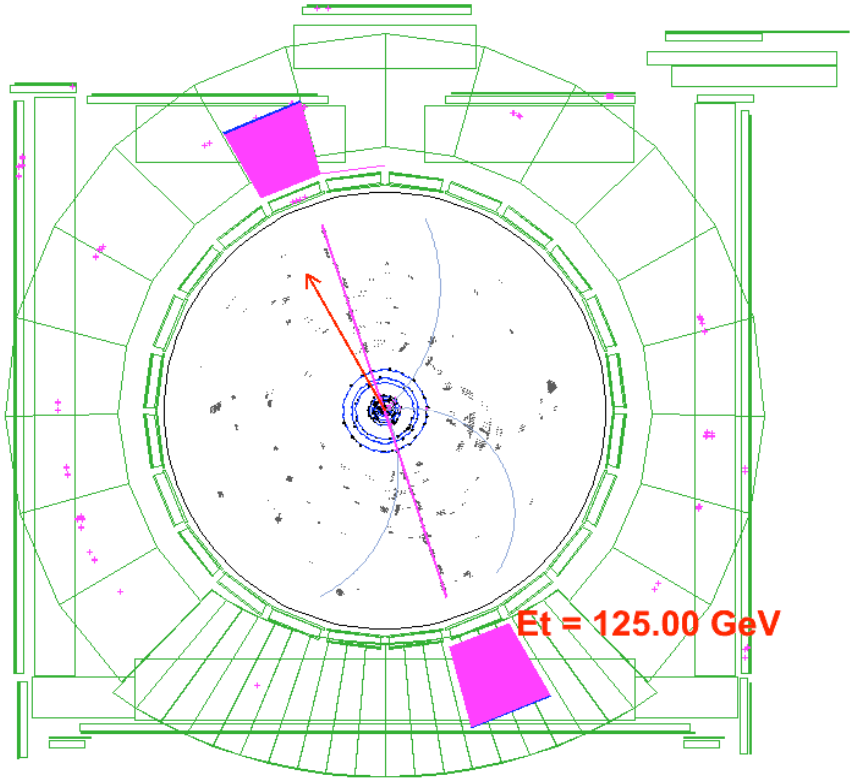
- *CDF and DØ are running well*
- Tevatron delivered ~4.5 fb^{-1} and is performing extremely well ~58 pb^{-1} / week!

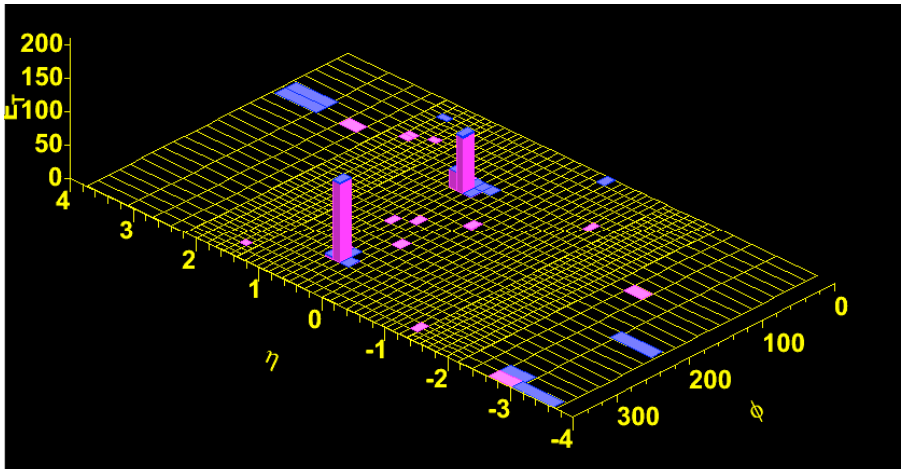




Analysis Strategy

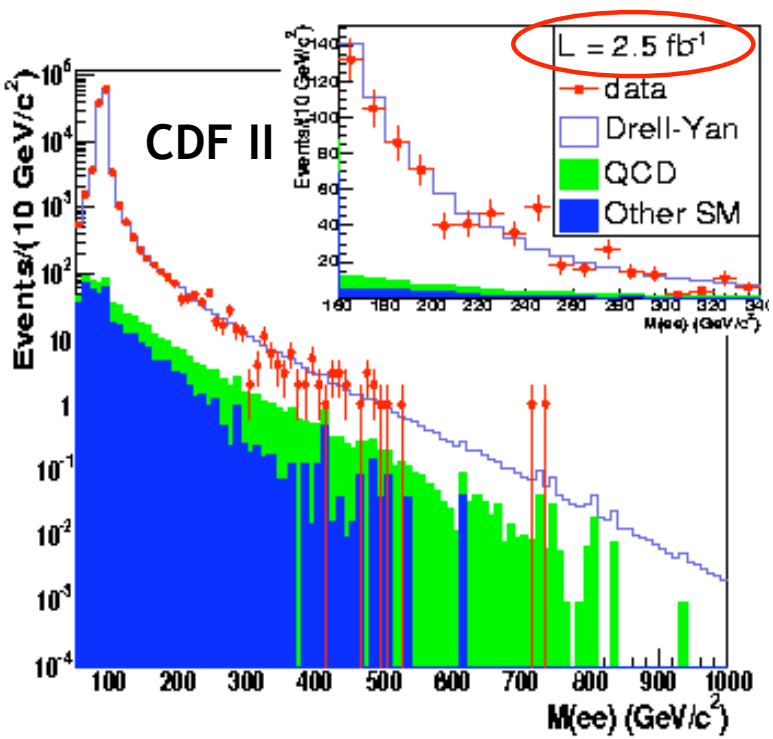
- Model Standard Model background processes
  - → Generally QCD from data
  - → Remaining SM backgrounds from MC
- Select clean high-p_T leptons and construct invariant mass



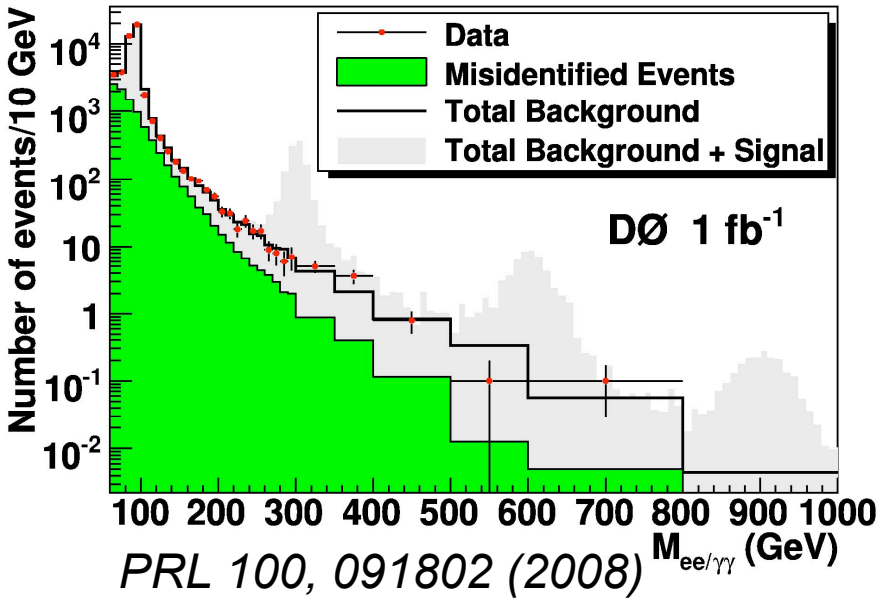


- Look for any excesses in the high mass spectrum

High Mass ee, γγ Spectrum



Largest sample

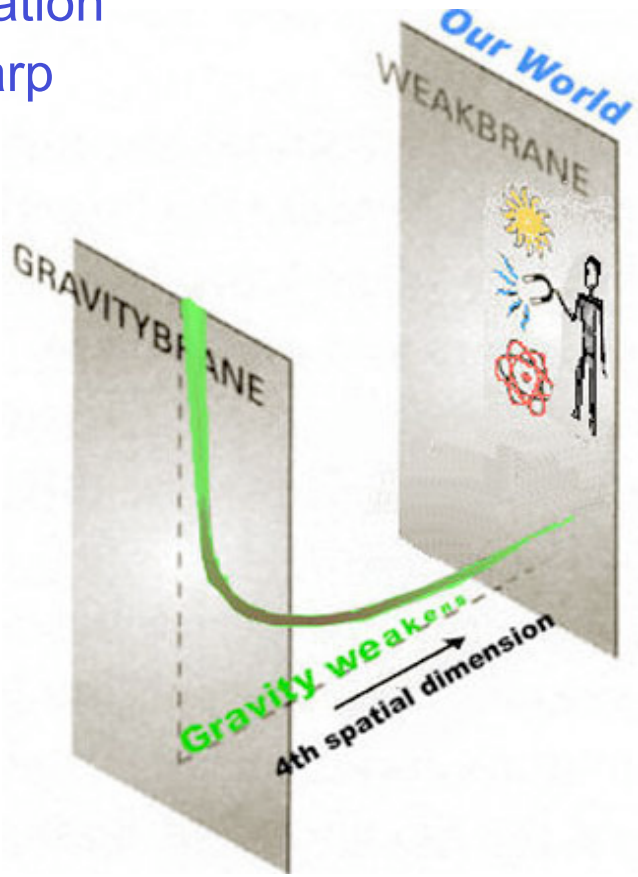


PRL 100, 091802 (2008)

- CDF: Sees excess (3.8 σ) for M_{ee}= 228 –250 GeV/c^2
  → p-value = 0.6% to see such an excess in 150-1000 GeV/c2
  → Significances in sub-samples: 2.9 σ(CC) and 2.7 σ(CF)
- D0: no excess

Model: Randall-Sundrum Graviton

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

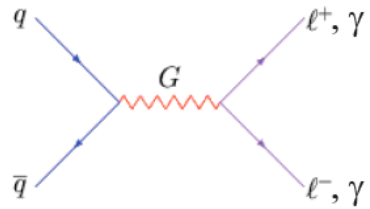


- Two branes, TeV and Planck
  → Gravitons live everywhere
  → SM confined to TeV brane

- 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



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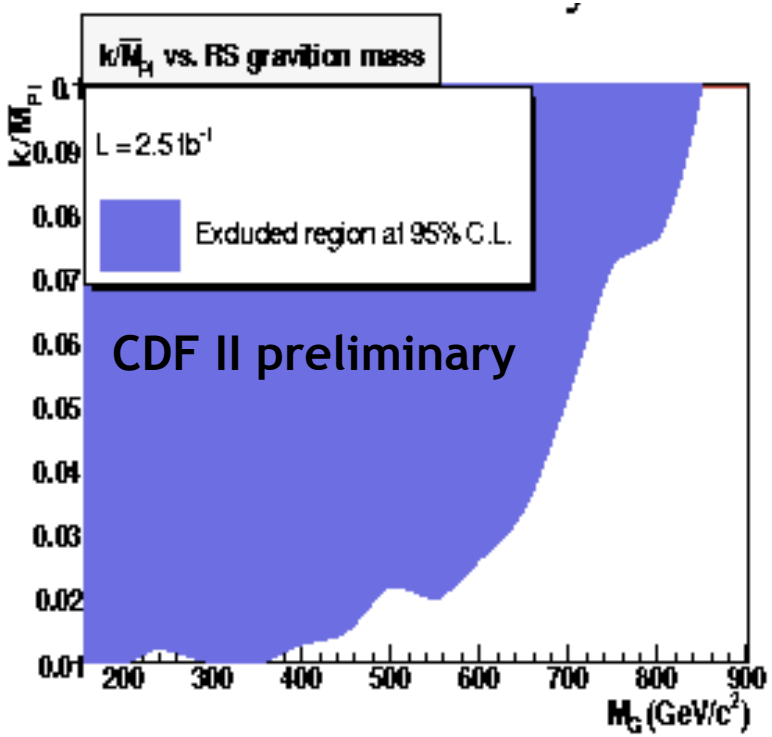
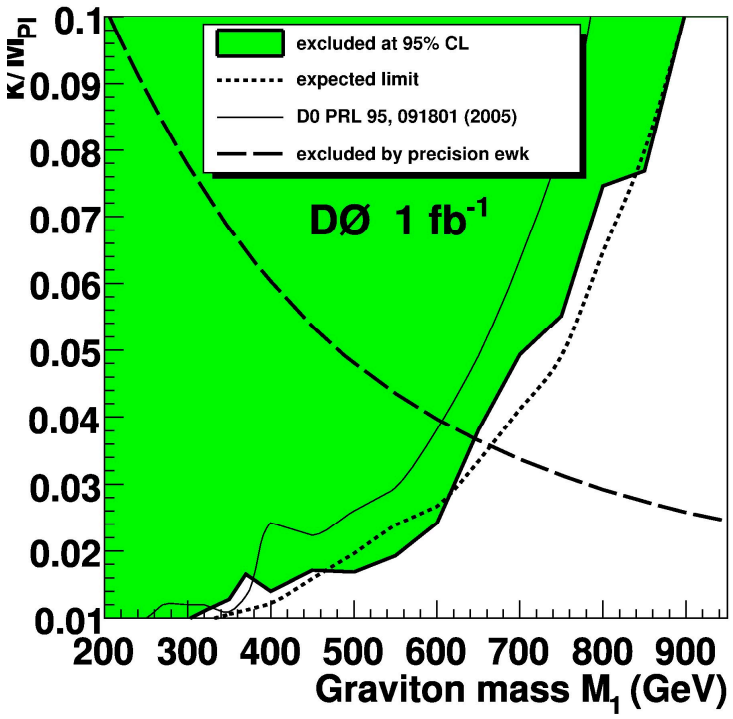




- k/M_{PL}=0.1, M_{G^*}>850 GeV
- k/M_{PL}=0.01, M_{G^*}>358 GeV

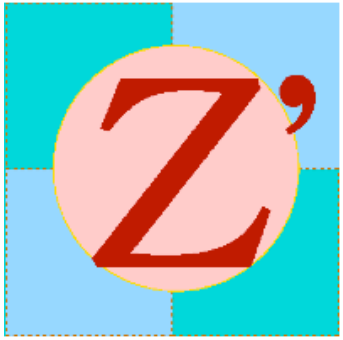
- k/M_{PL}=0.1, M_{G^*}>900 GeV
- k/M_{PL}=0.01, M_{G^*}>300 GeV

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

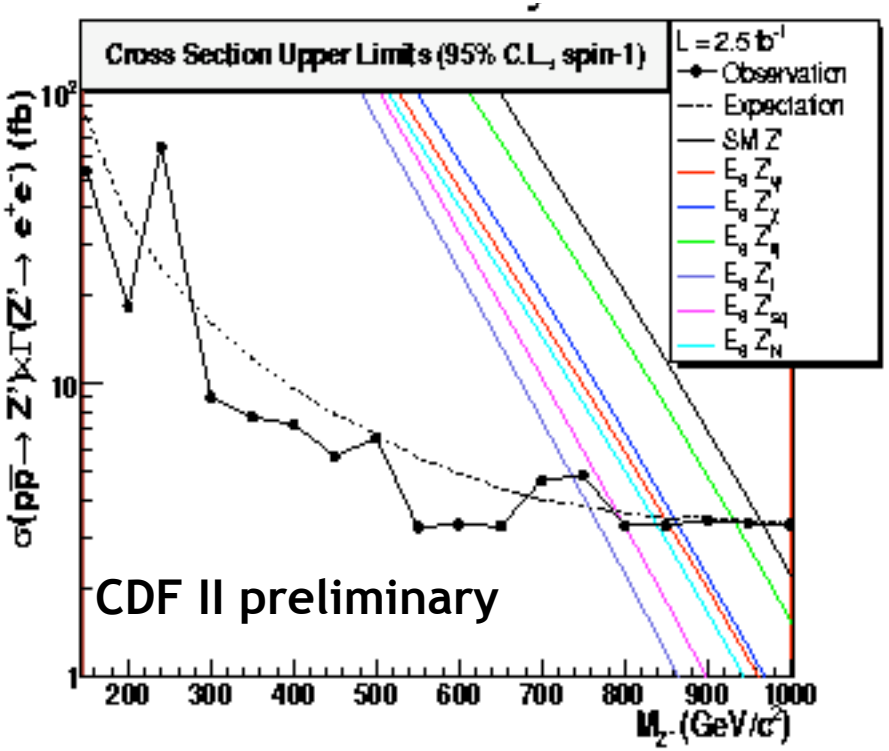


- Long lasting 3.2σ discrepancy in the electroweak precision fits from A_{LR} and A^{b}_{FB}

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

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:
  $Z'(\theta) = Z'_\Psi \cos\theta + Z'_\chi \sin\theta$
- θ: Mixing angle, determines the coupling

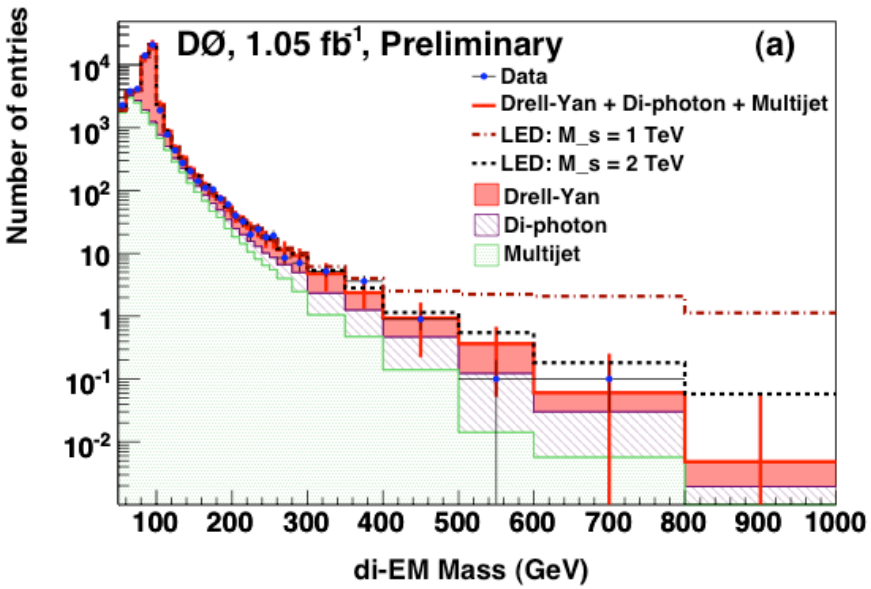


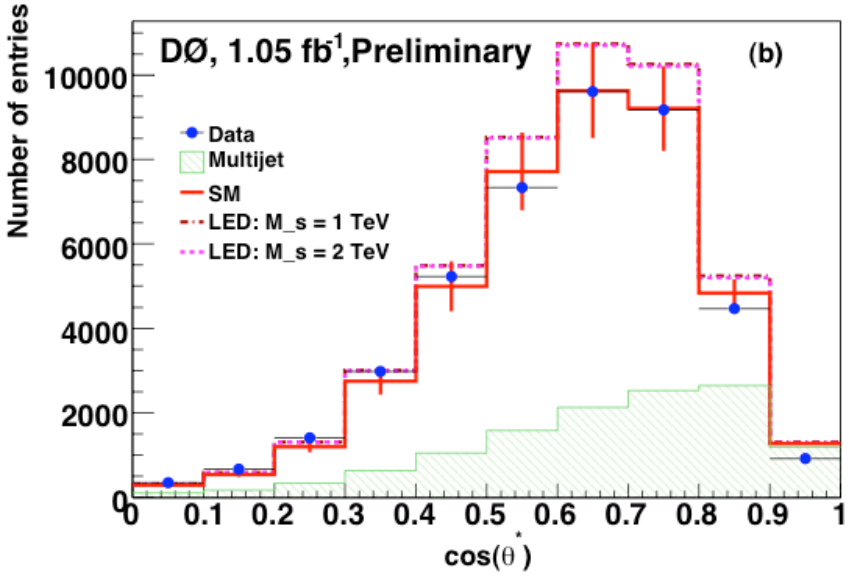
Model	Z'_{SM}	Z'_Ψ	Z'_χ	Z'_η	Z'_I	Z'_{sq}	Z'_N
Obs	965	849	860	932	757	791	834
Exp	966	853	864	933	737	800	840

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

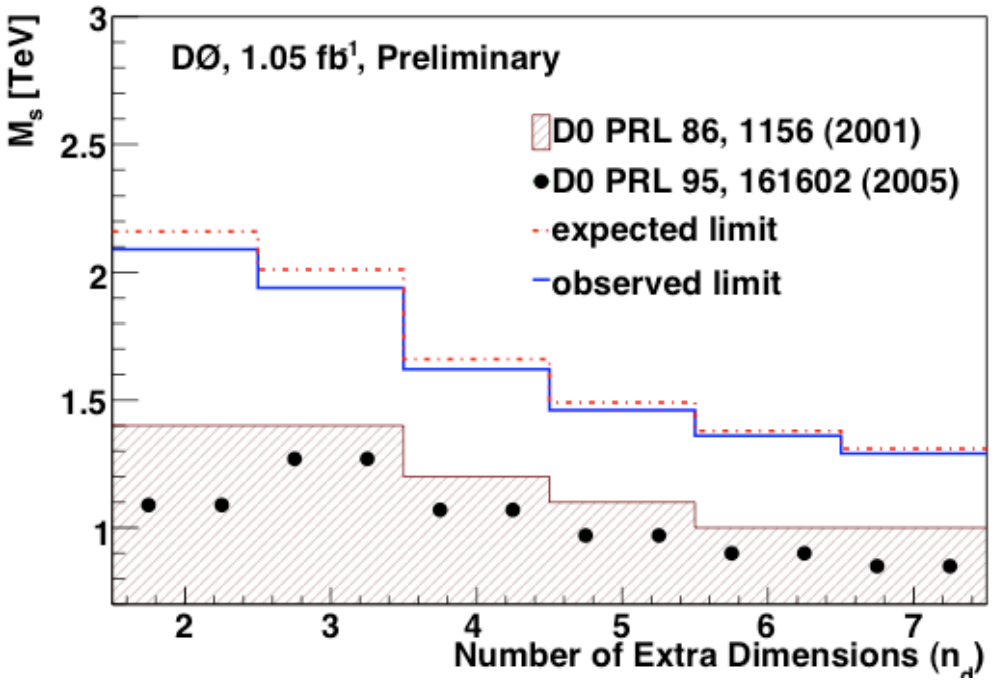
- Examine 2D distribution, invariant mass and cos(θ*) for deviations from SM





- Data consistent with Standard Model Backgrounds

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

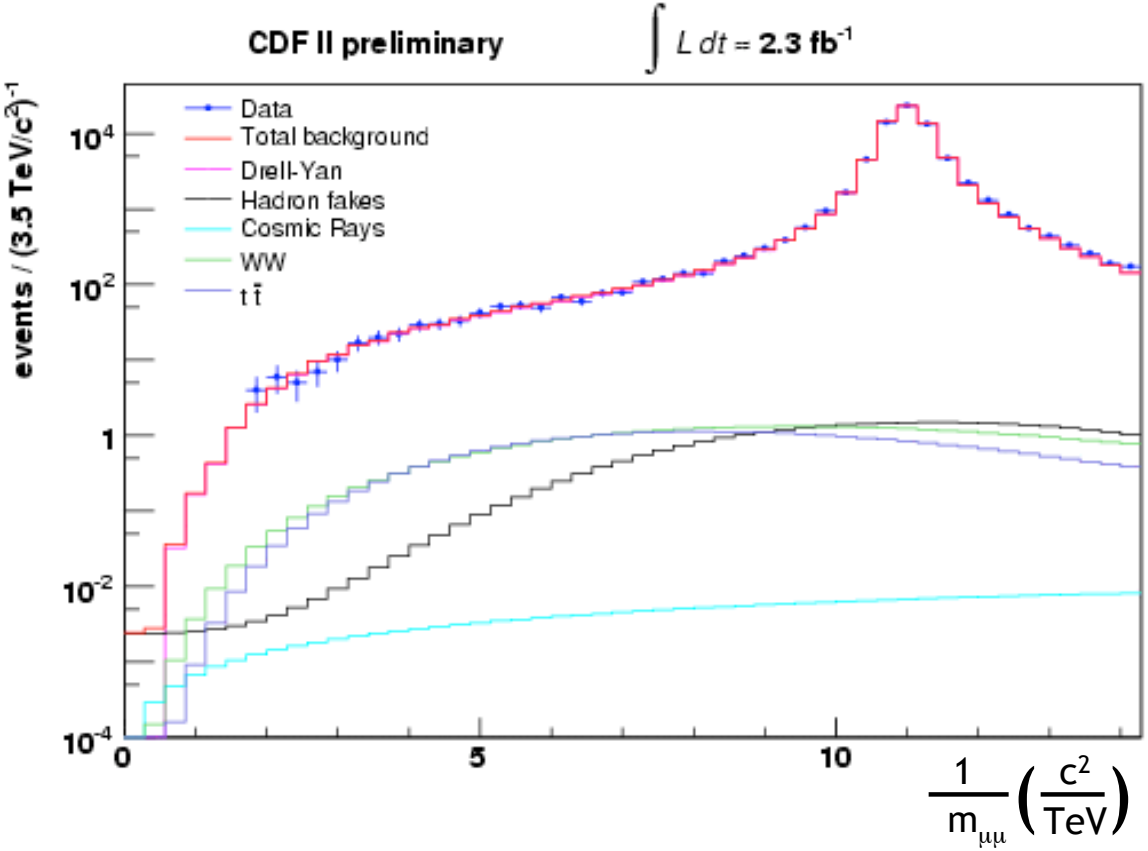


- Limits on M_s ranging from 1.29 - 2.09 TeV for number of extra dimensions ranging from $n_d = 7$ to $n_d = 2$

…world's best limit

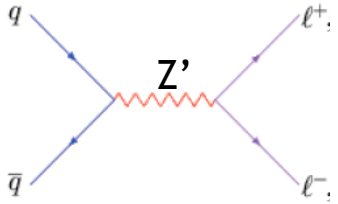
High Mass μμ Spectrum

- 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

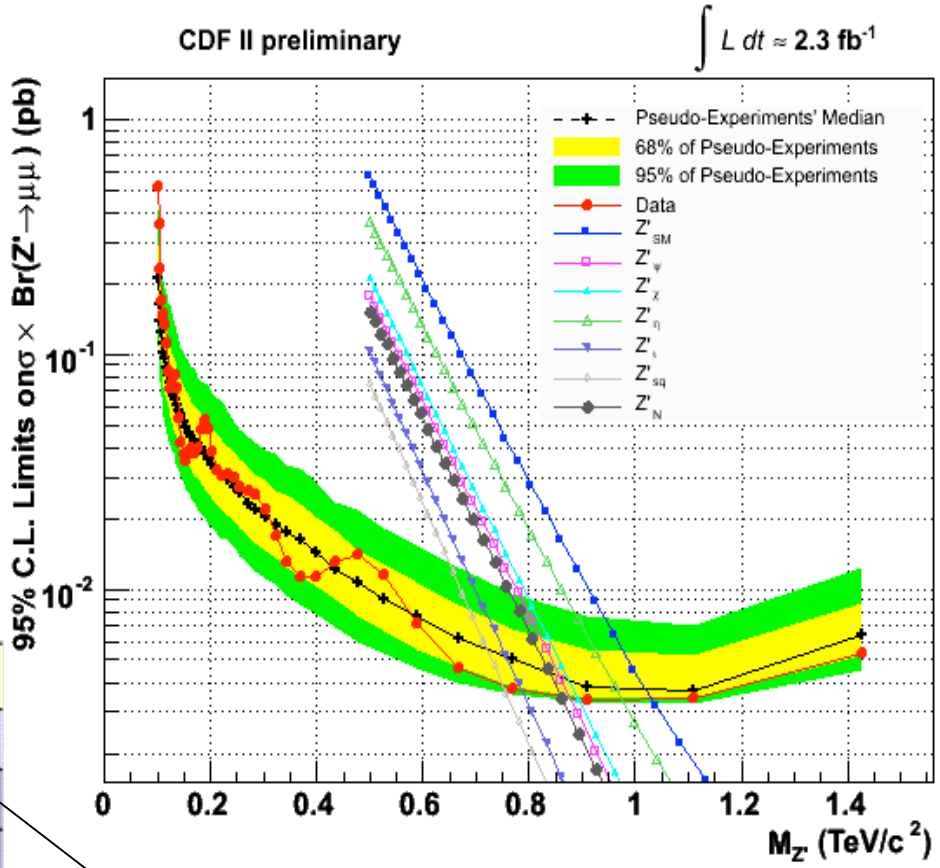
High Mass μμ Spectrum - Limits on Z' Bosons



- 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' (I)	789
Z' (sq)	754

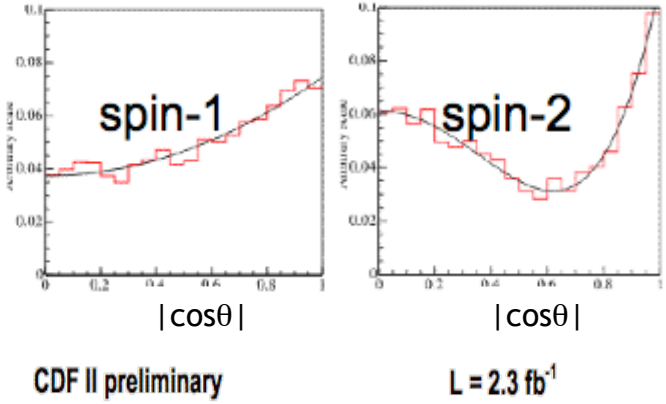


- For the first time beyond the the one TeV mark

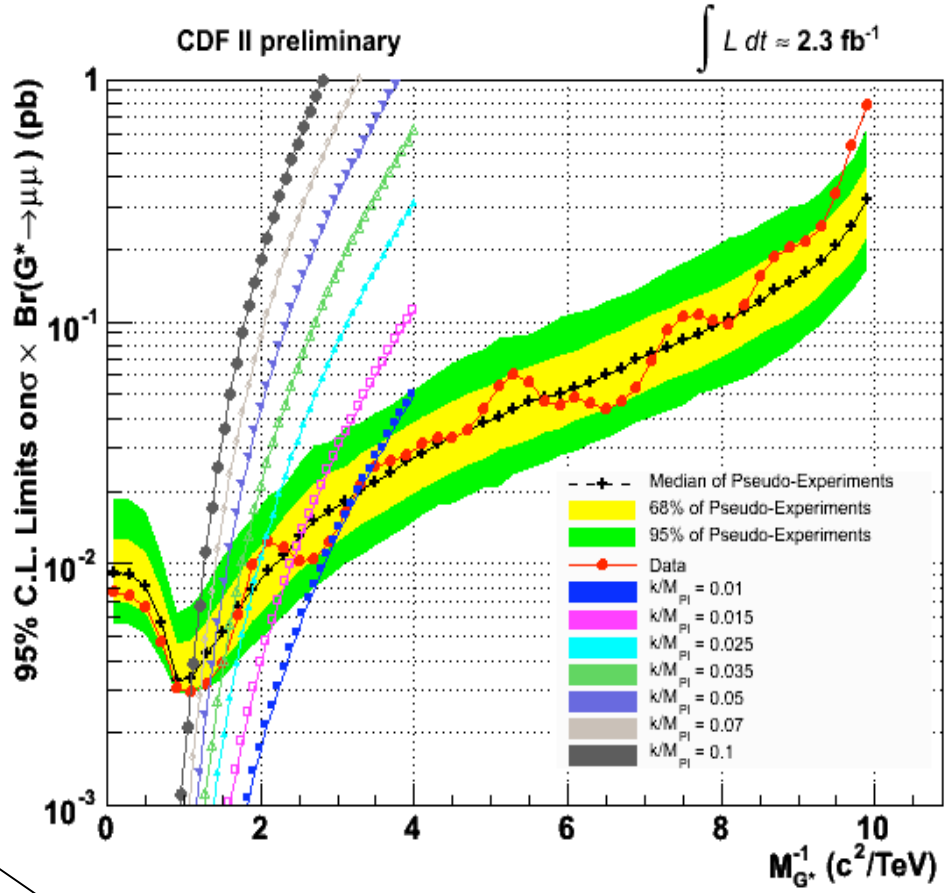
…world's best limit

High Mass μμ Spectrum - Limits on RS Graviton

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



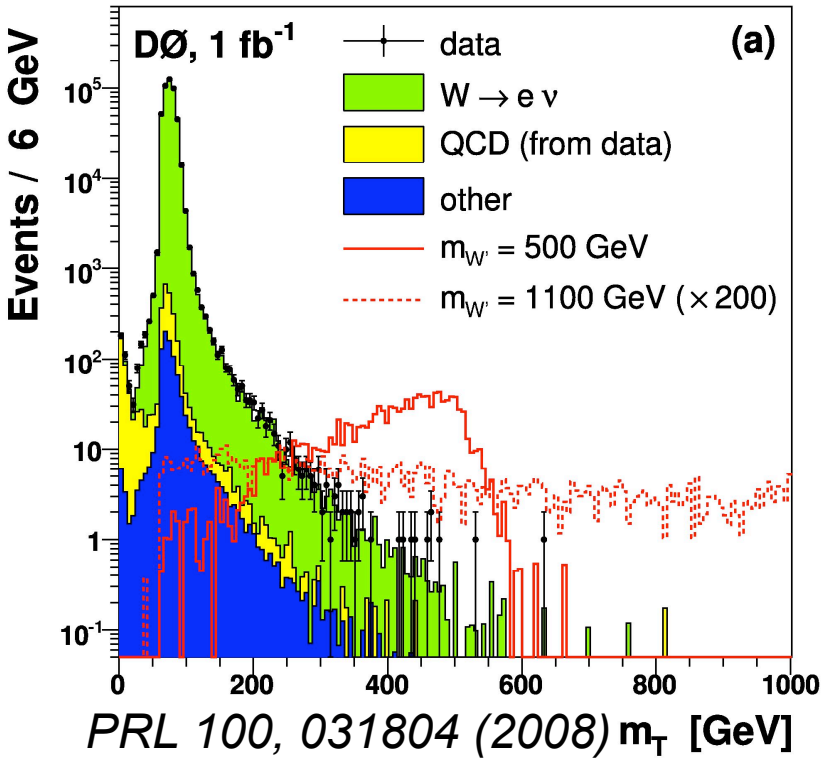
Graviton k/M_{Pl}	Mass Limit, 95% CL (GeV/c^2)
0.1	921
0.07	824
0.05	746
0.035	651
0.025	493
0.015	409
0.01	293

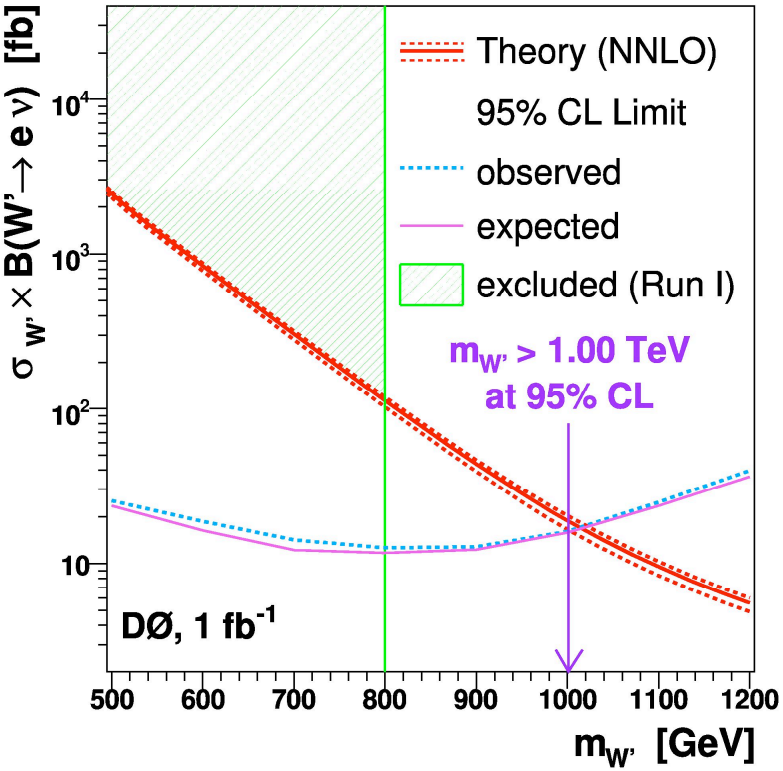


…world's best limit

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

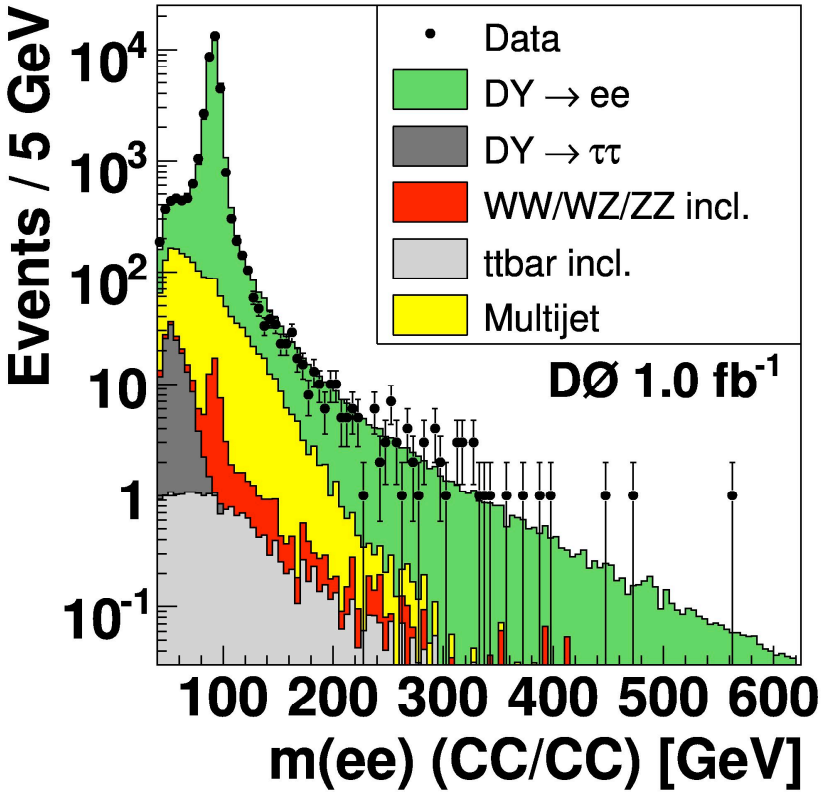


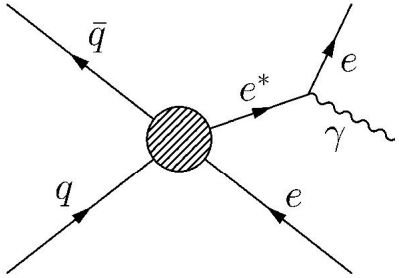


- Assume generic Altarelli Model, e.g. SM coupling, SM CKM Matrix
  → M(W') > 1.0 TeV *…world's best limit*

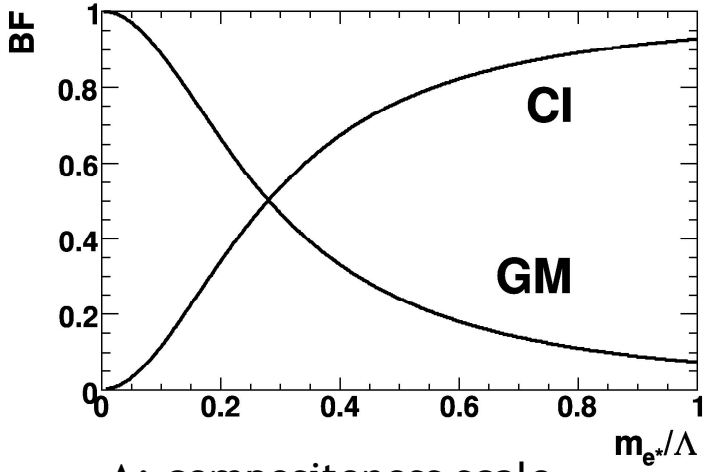
High Mass eγ Spectrum

- 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)



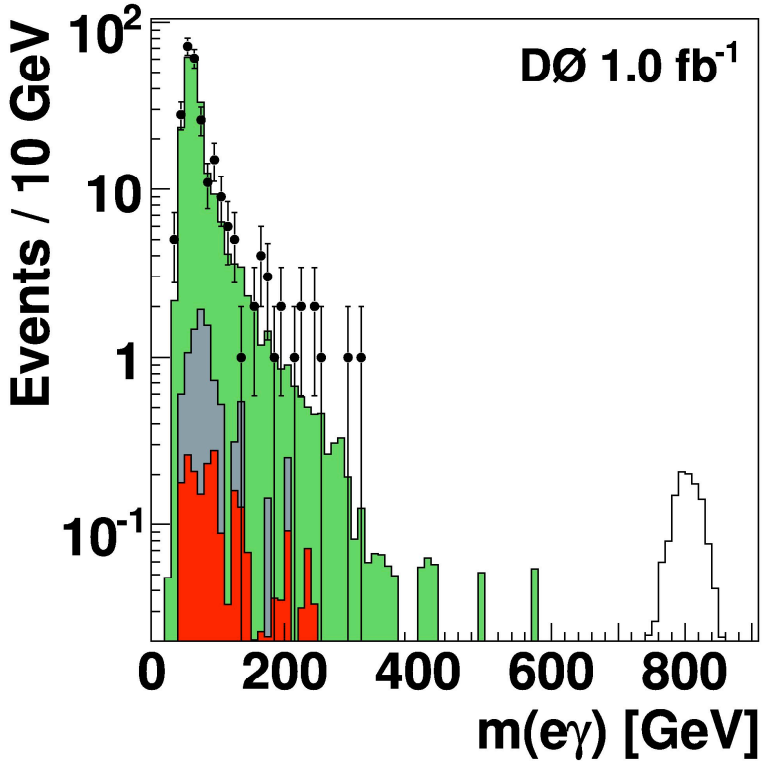


arXiv:0801.0877



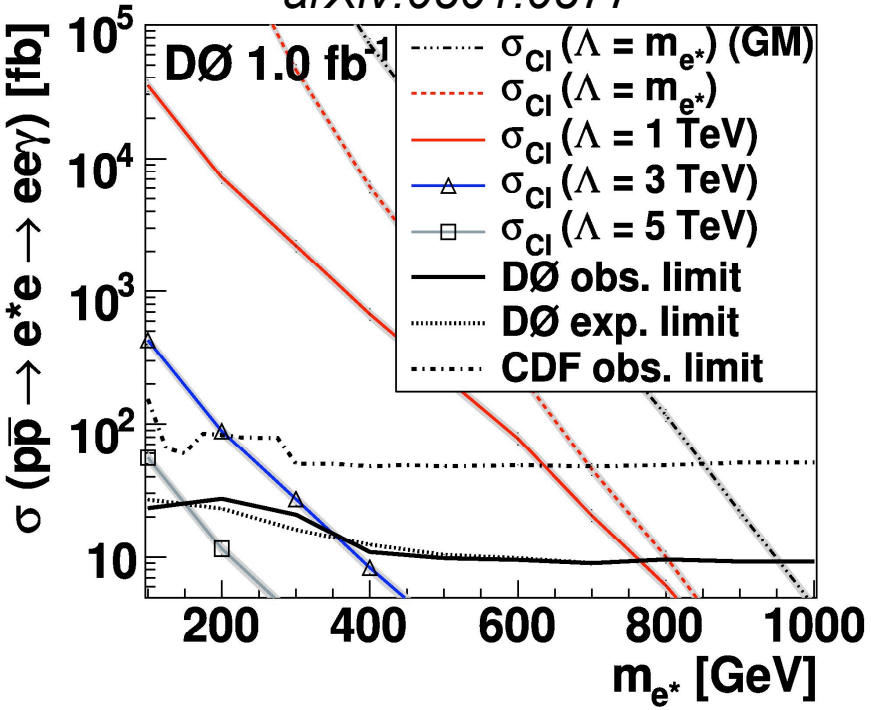
Λ: compositeness scale

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 Λ = 1 TeV
  → exclude m_{e^*}<756 GeV

…world's best limit

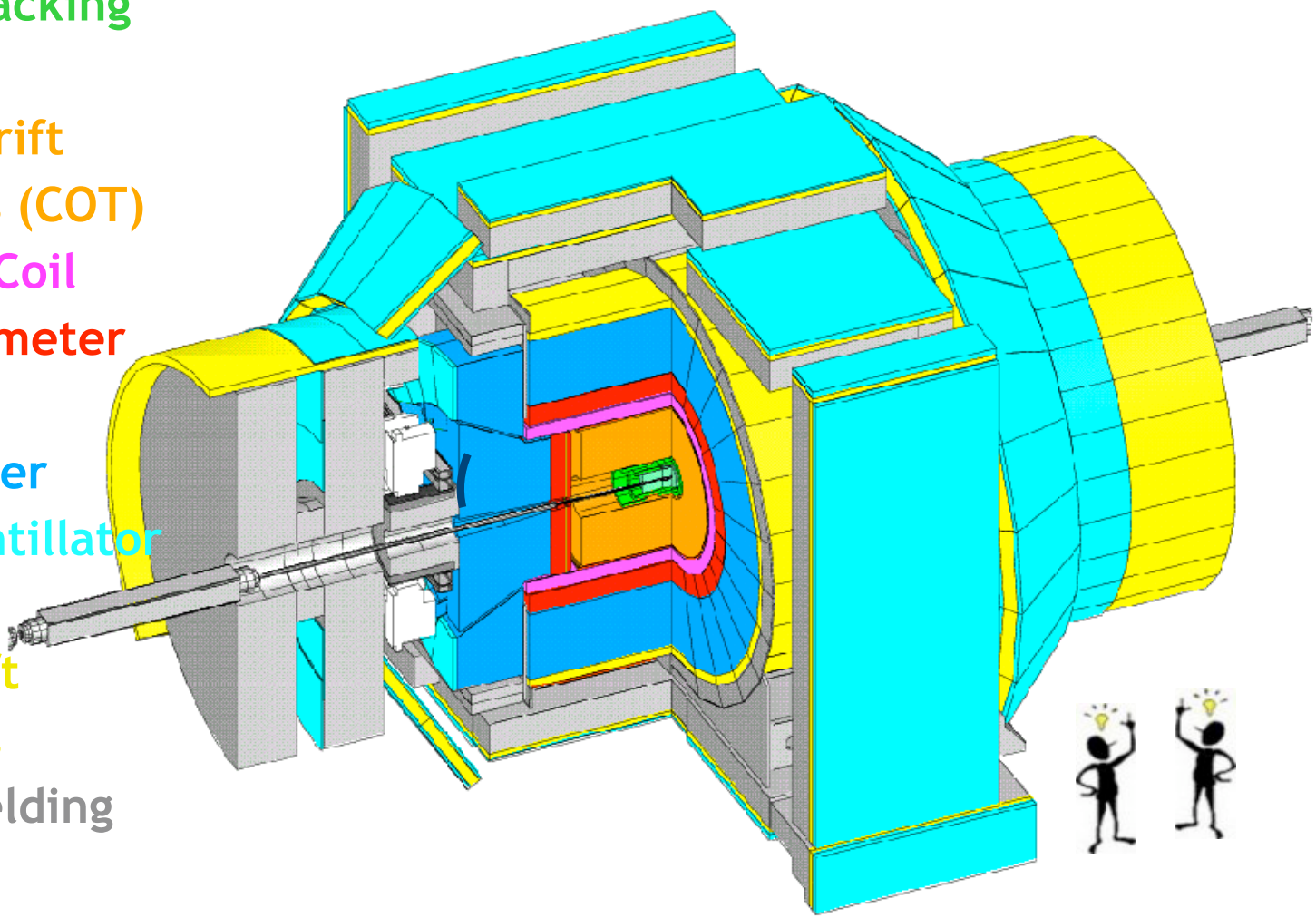
Conclusion

- CDF and D0 have an extensive program to look for resonances in the di-lepton final states
- No significant excess in 1-2.5 fb^{-1} of data
  → Perhaps a hint in CDF di-electrons? p-value: 0.6%
- Derived mass limits for Z', W', RS Gravitons, 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

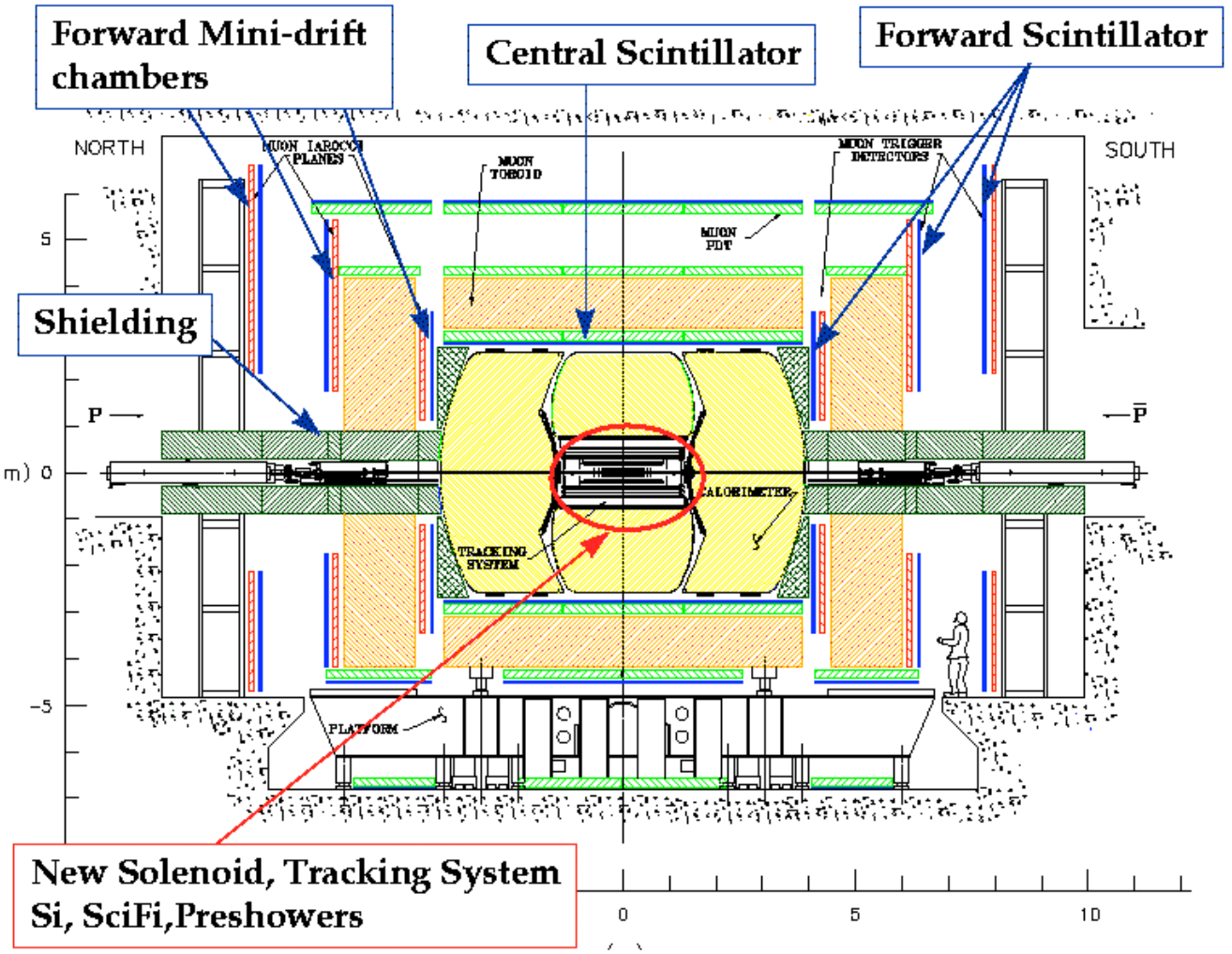
Backup

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
P
$\bar{P}$
CALORIMETER
TRACKING SYSTEM
PLATFORM
New Solenoid, Tracking System
Si, SciFi,Preshowers
+ New Electronics, Trig, DAQ