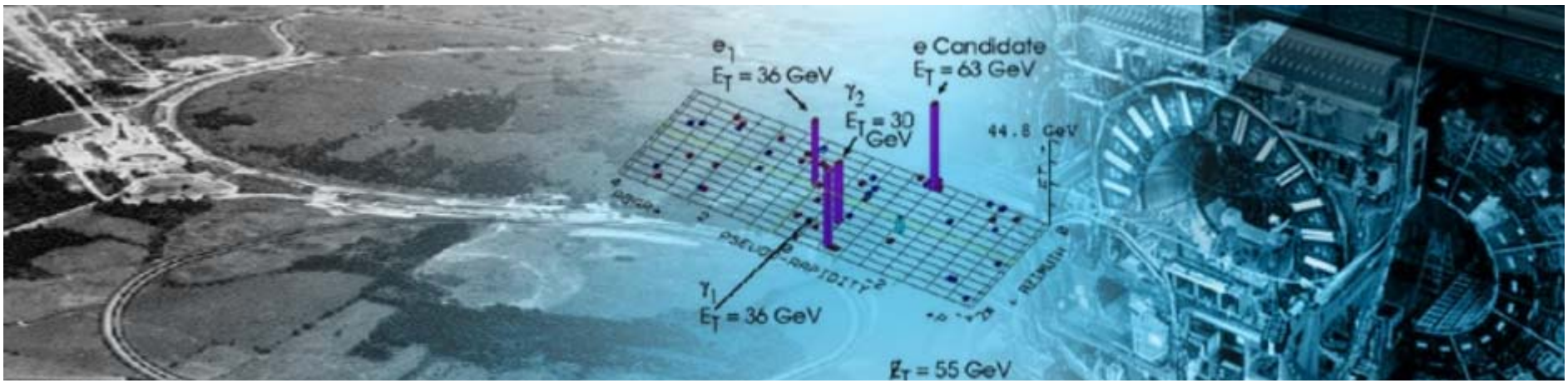


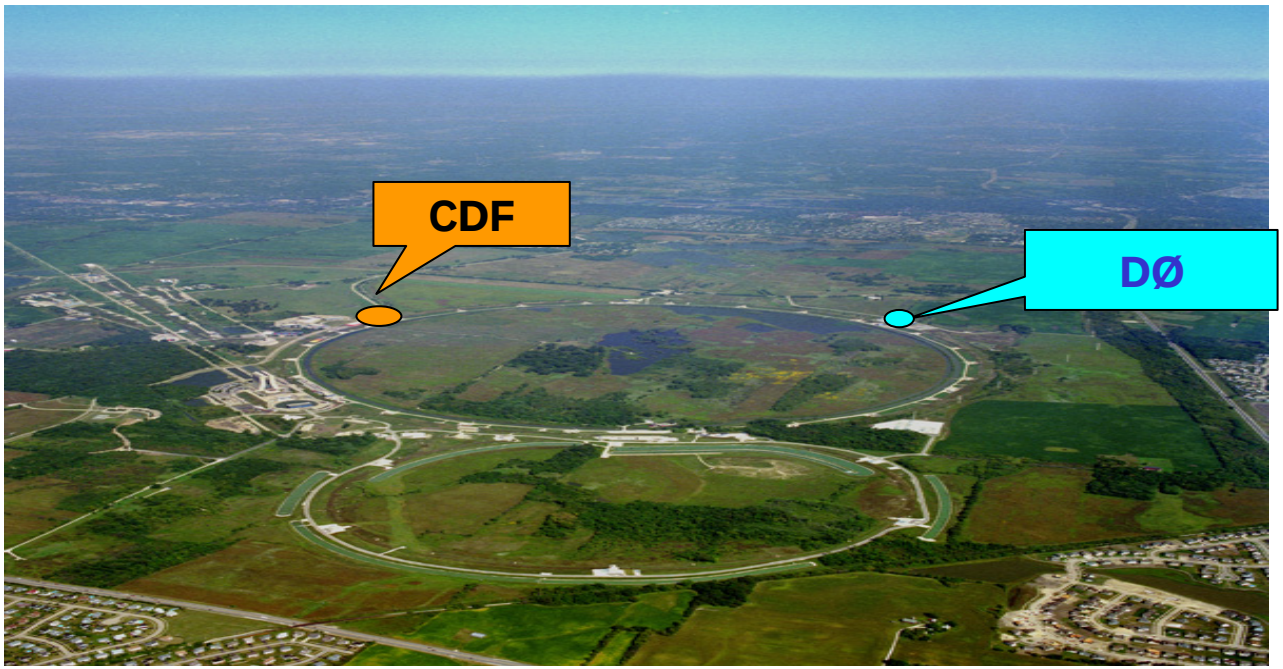
Non SUSY Searches at the Tevatron

DongHee Kim

Kyungpook National University

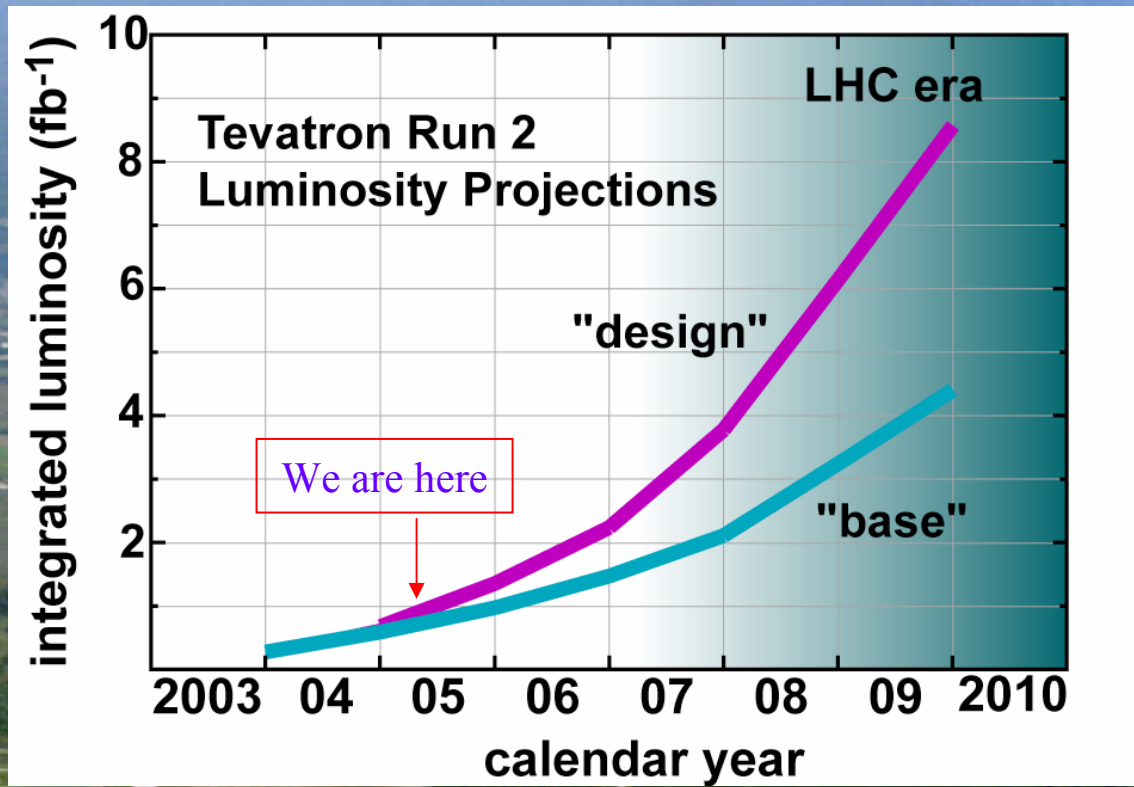
for the CDF and D0 collaborations

Fermilab Tevatron



- Proton-Antiproton Collider with sqrt(s) = 1.96 TeV
- run the Tevatron till 2009
- World Energy Frontier before LHC

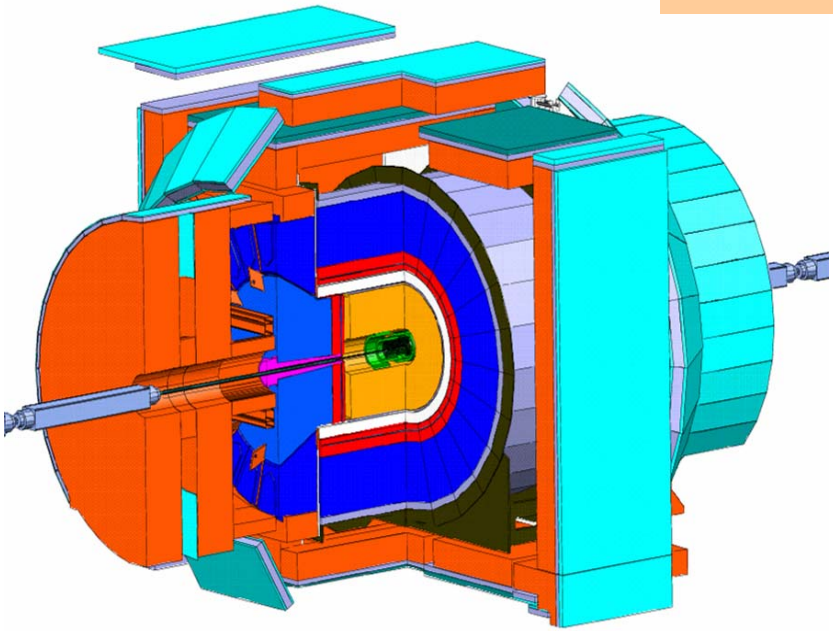
Tevatron Luminosity Profile

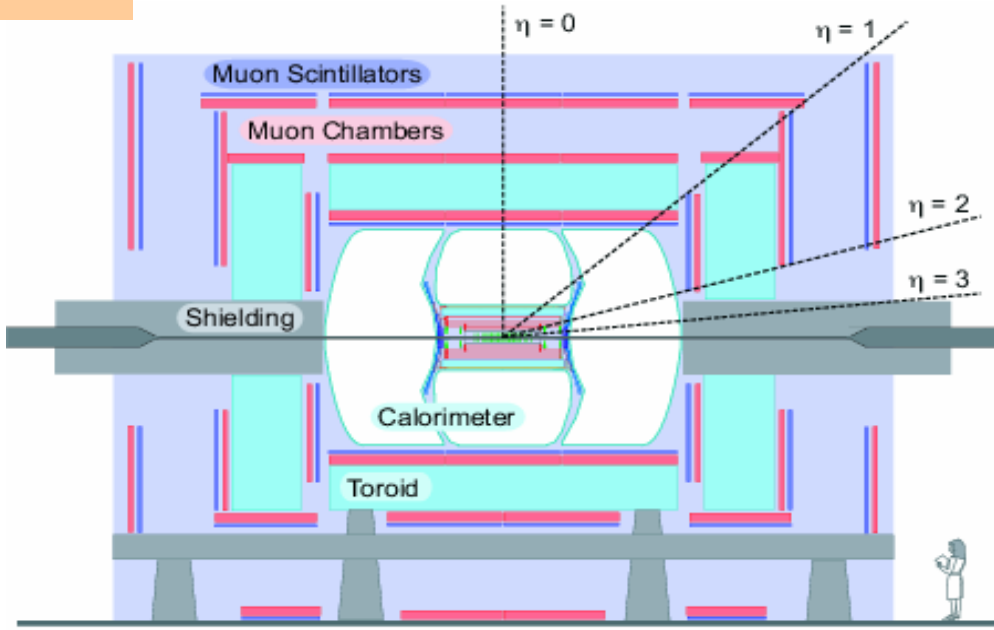


- So far, ~ 800 pb-1 to tape for both CDF and D0
- Total Luminosity till 2009 : Base ~ 4.5 fb^{-1}, Design ~ 8 fb^{-1}

CDF & DZero Experiments

RUN II

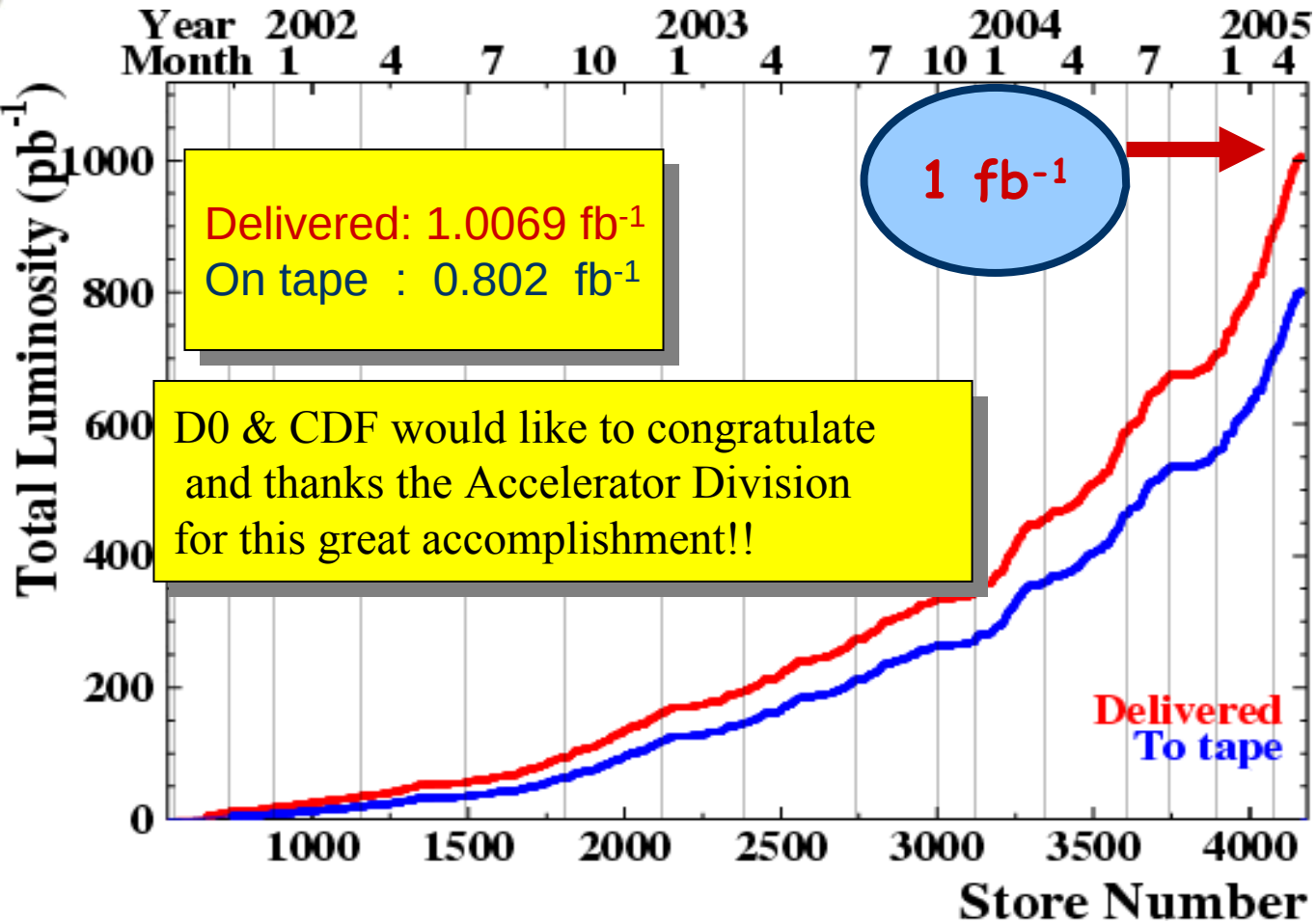




- Extended spatial e, μ coverage
- New plug calorimeter improves also MET measurement
- Improved MET triggers
- Added triggers to identify leptons at early stage

- New silicon and fiber tracker
- Solenoid (2 Tesla)
- Upgrade of muon system
- Upgrade of Trigger/DAQ

Run II Integrated Luminosity



As of May 23, '05,

1 fb^{-1} data delivered !!

Search and Signature

Search	Signature
W'	**eν**
Z' (sequential Z', Zψ,Zη,Zχ,Zι)	**ee, μμ, ττ**
Compositeness(excited electron)	**e γ**
Leptoquarks	**(ll, lν, νν) + jet jet**
Extra Dimension (LED, TeV^{-1}ED & WarpedED)	**ee, μμ, ττ , γγ, jet + MET**
Monopole	**Exclusive trigger(TOF & Tracker)**
Technicolor	**ee, μμ, lνbb**

This search is mostly only based on ~ 200 pb^{-1} data

Search for High Mass Resonances

- New particles like massive gauge bosons predicted in many extensions to the standard model
  - ✓ Spin –1, Sequential Z', $Z\psi$, $Z\eta$, $Z\chi$,$Z\iota$ from E(6) Model, Techni-mesons ρ_T, ω_T
  - ✓ Spin – 2, Randull-Sundrum(RS) Graviton
  - ✓ Spin - 0, RPV Sneutrino($\tilde{\nu}$)

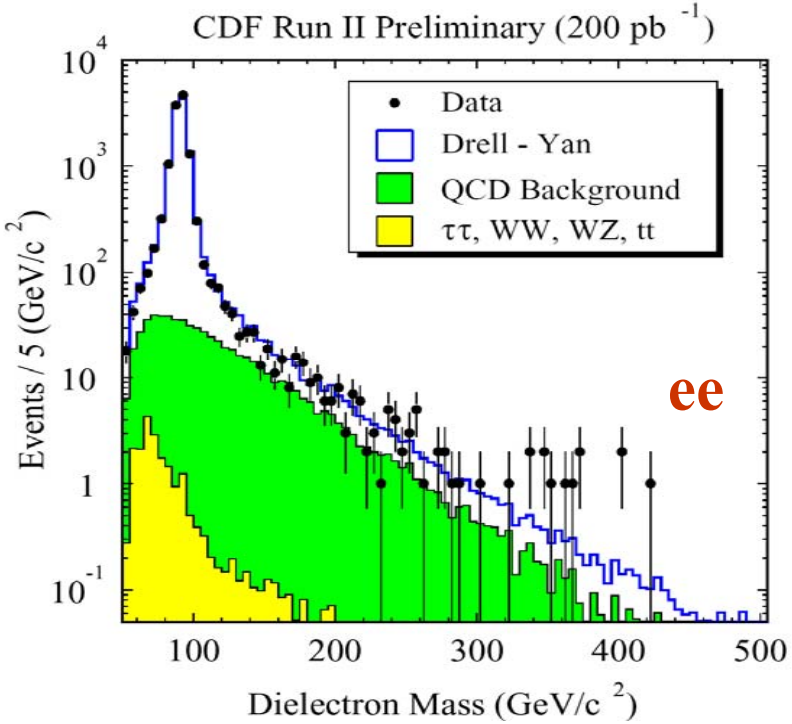
- Looking for resonances decaying to leptons provides very clean signature even in a hadron collider

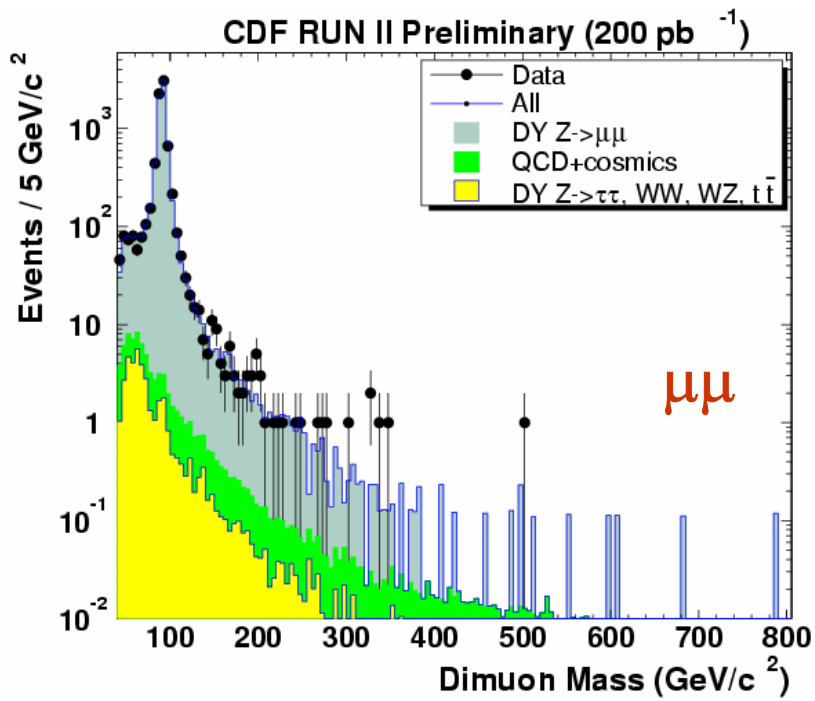
- For the these(ee, μμ) channel, search X directly by comparing observed and expected background invariant mass distribution
  - ✓ Experimental sensitivities for the particles are different according to the spin of X which determines the angular distribution of the decayed dileptons.
  - ✓ Obtain 95% CL upper limit of $\sigma(X_{ll})$ on $p\bar{p} \rightarrow X \rightarrow ll$ as a function of M_{ll} for the each spin value

Dilepton Channel

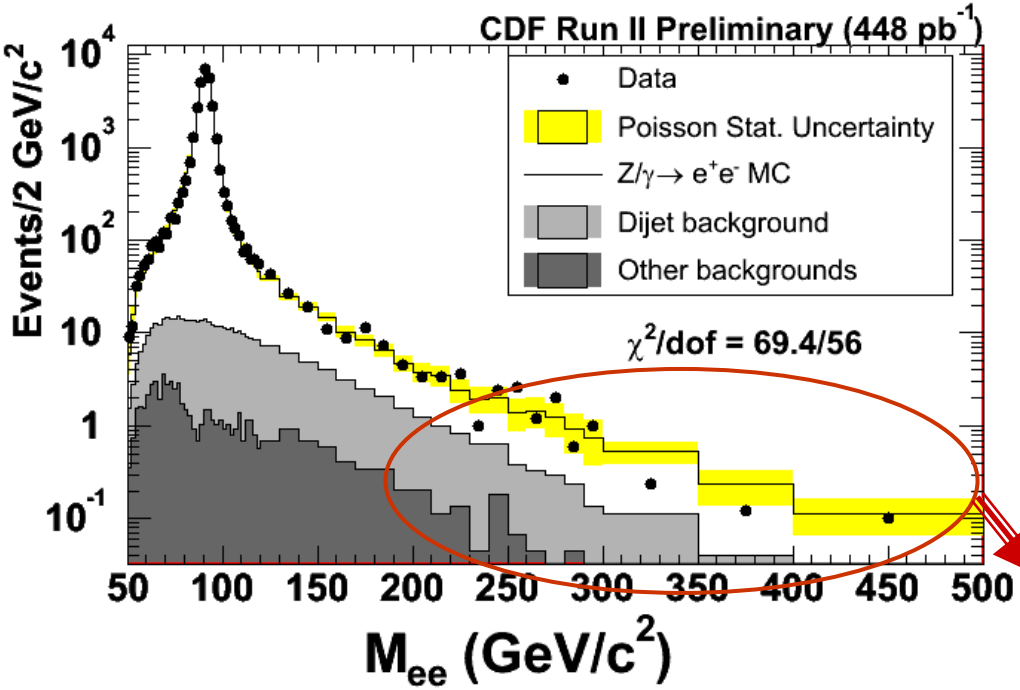
Dilepton(ee, μμ) Mass Distribution

- 200 pb^{-1}
- Inclusive lepton trigger : E_T (P_T) > 18 GeV
- Offline, E_T(P_T) > 25(20) GeV
- Central-Central, Central-Plug used
- Z^0 mass cut
- Backgrounds : Drell-Yan dominant, t-tbar, W-pair etc…

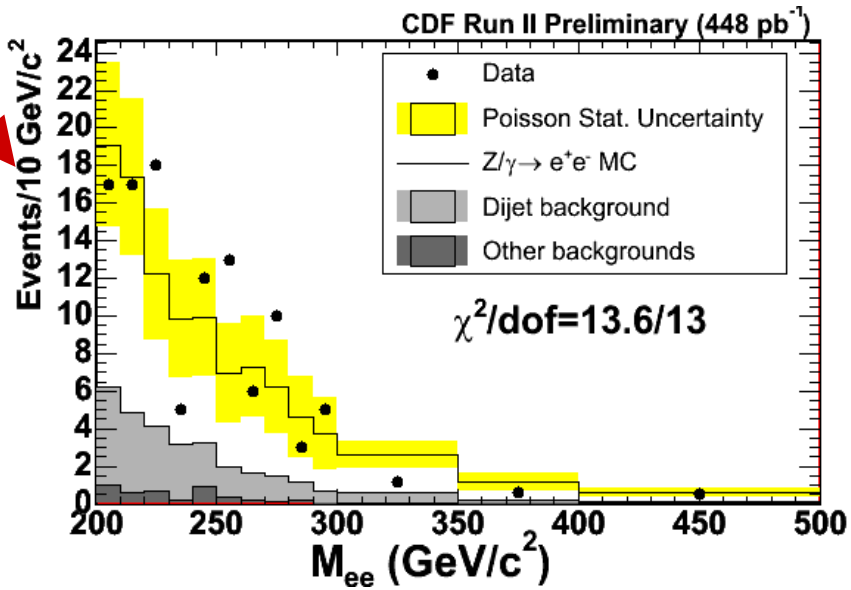




Z'→ee (448 pb^{-1})



- Statistical uncertainty shown for the prediction rather than on the data
  - ✓ More statistically correct
  - ✓ Systematic uncertainties not shown
- cosθ* distribution also assures

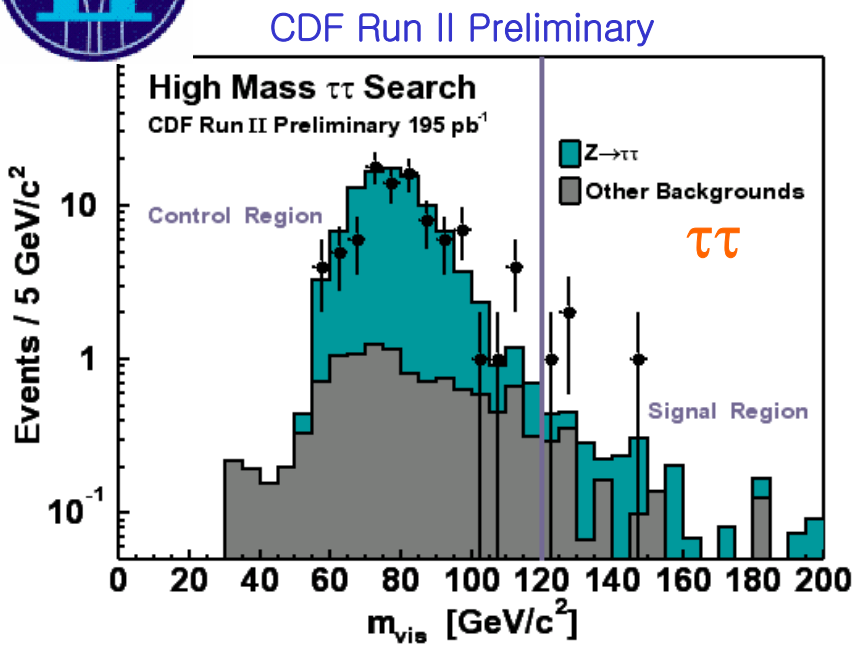


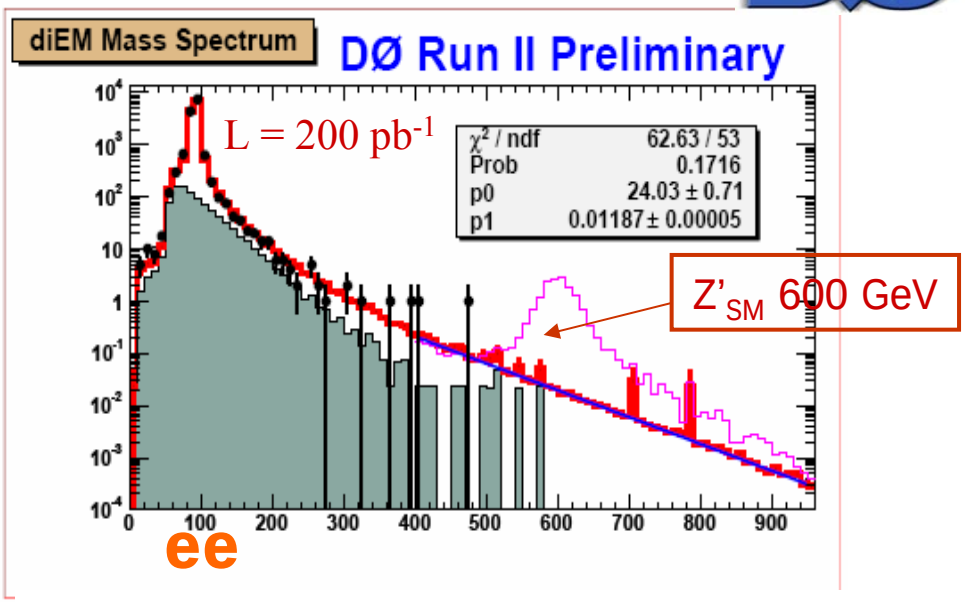
- Very good agreement between data and prediction for full mass region and high mass signal region.
  - ✓ Number of events in Signal Region

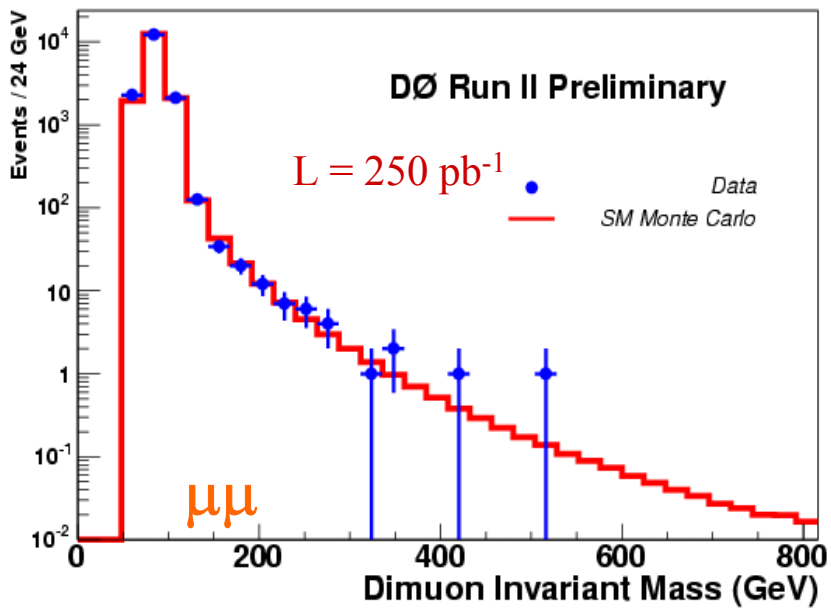
	Data	Predicted
M>200	120	125 ± 11$_{stat}$

No Significant Excess

Dilepton Mass Distribution



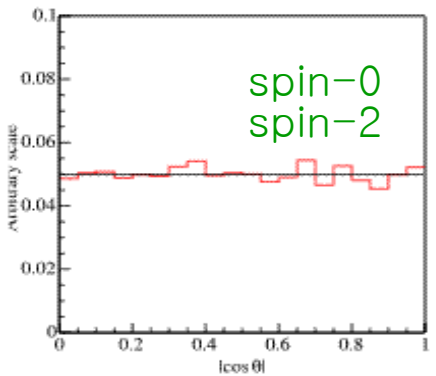


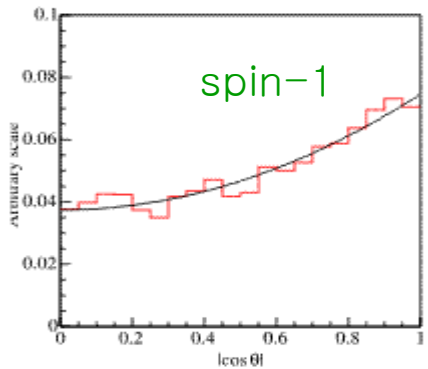


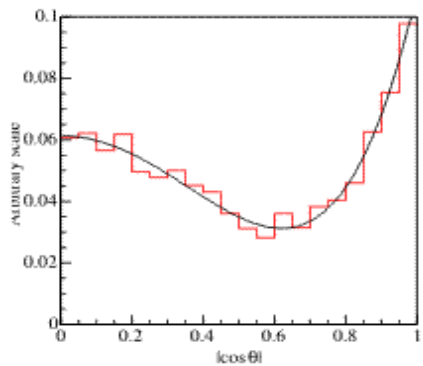
Both D0 and CDF have no significant Excess

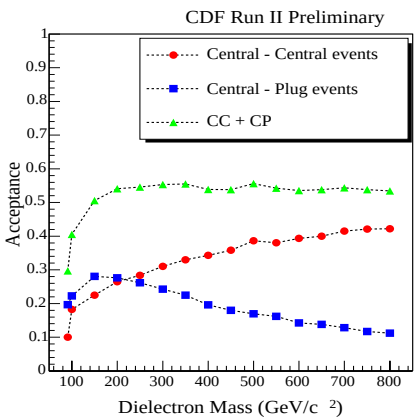
Spin dependent Acceptance

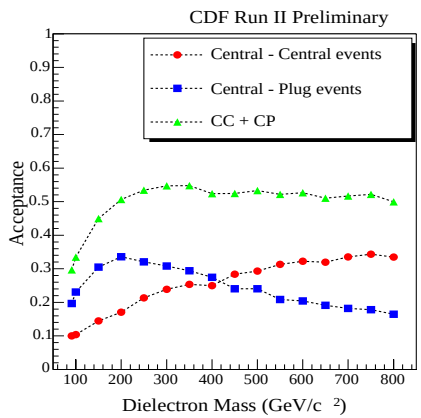
- Angular Distribution(and so Acceptance) depends on the spin of the decaying particle
- Geometric & Kinematic acceptance for each spin by MC(Pythia & CTEQ5L)

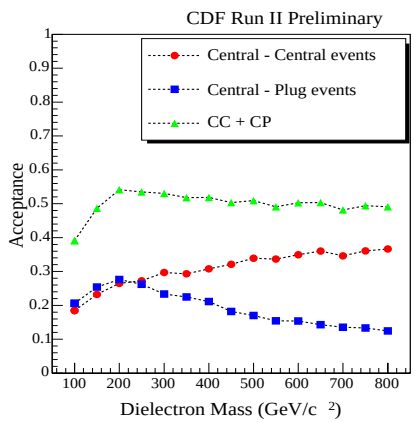






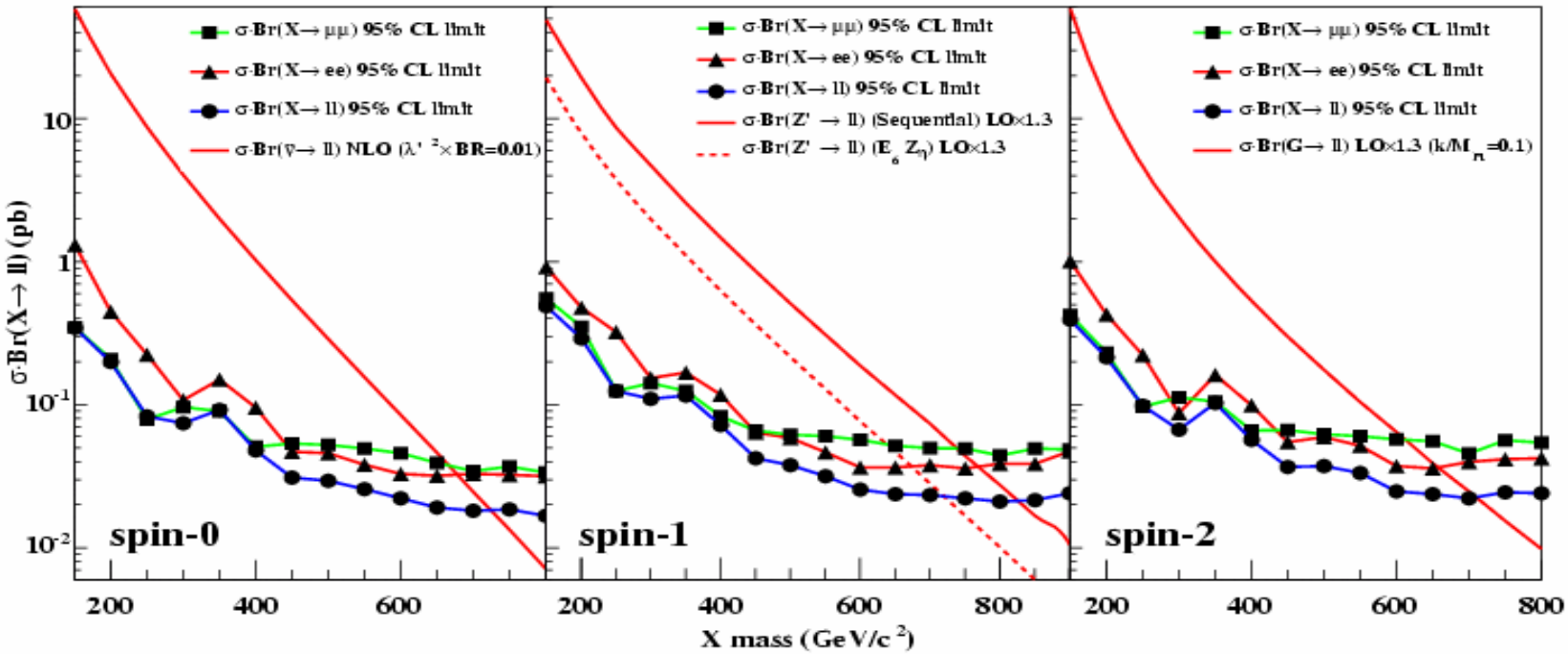






Total dilepton efficiencies ~ 50% for $M_X > 400$ GeV/c^2

σ*BR Limits (X→ ee or μμ)



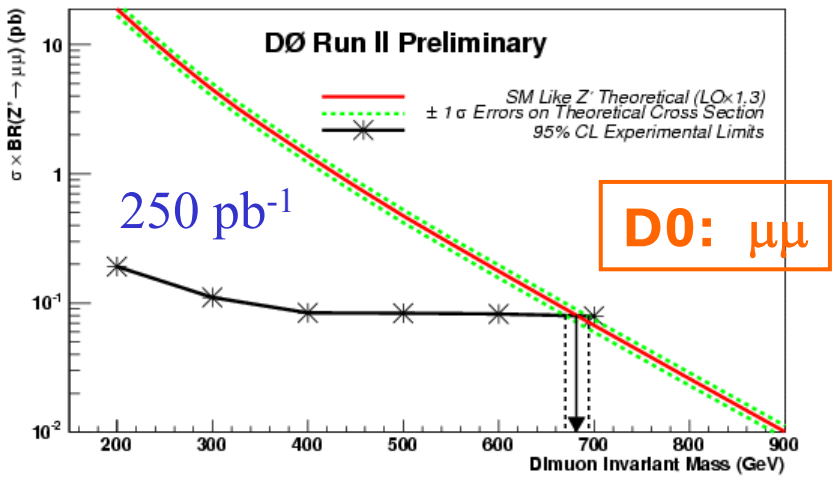
σ*Br(X→ μμ) 95% CL limit

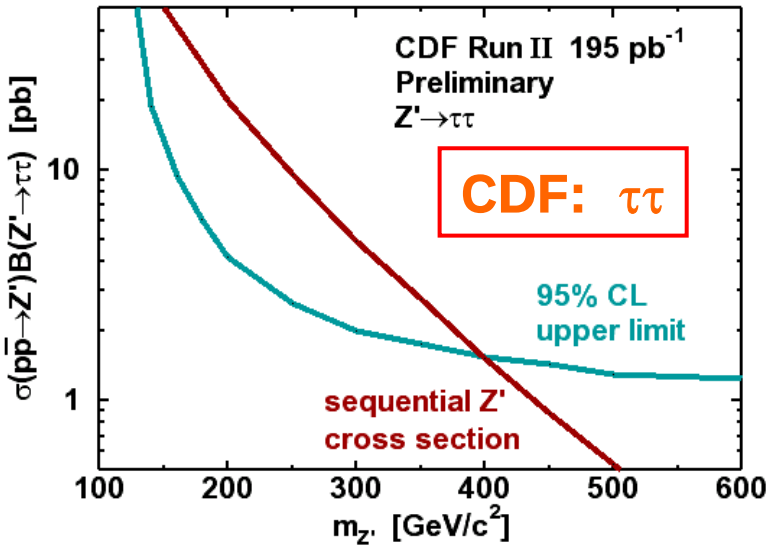
σ*Br(X → ee) 95% CL limit

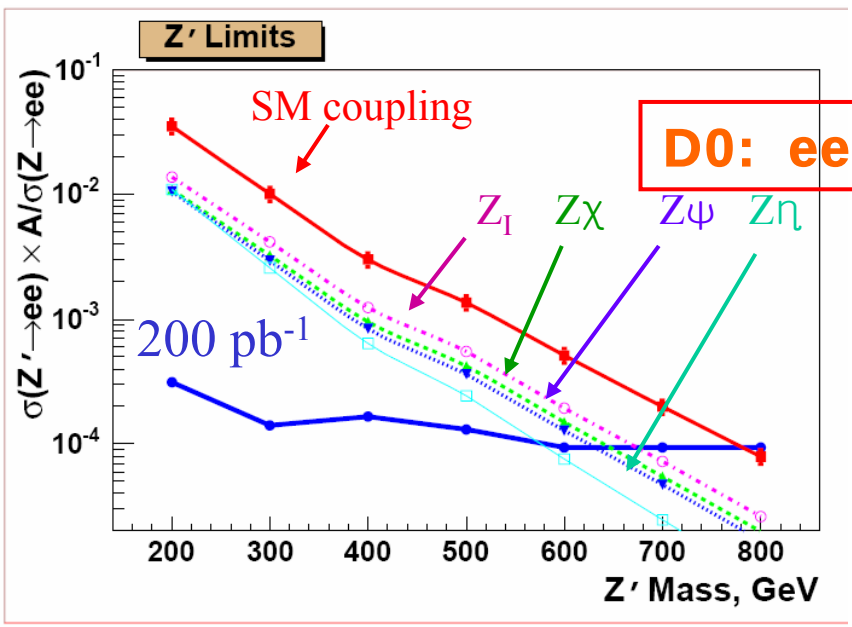
ee, μμ combined limit

- σ*Br limit ~25 fb for all spins for the high mass region (M_{ll} > 600 GeV)
- These curves can be compared with many models
- Reminder: **spin-1**: all the heavy Z, Technimeson, **2**: RS graviton, **0**: RPV sneutrino

Z' LIMITS (spin-1)







SM Couplings	ee	μμ	ee+μμ	ττ
CDF :	750	735	815	394
DØ:	780	680		

E_6	Z_I	Zχ	Zψ	Zη	
CDF:	610	670	690	715	(ee+μμ)
DØ:	575	640	650	680	(ee)

Very new limit CDF

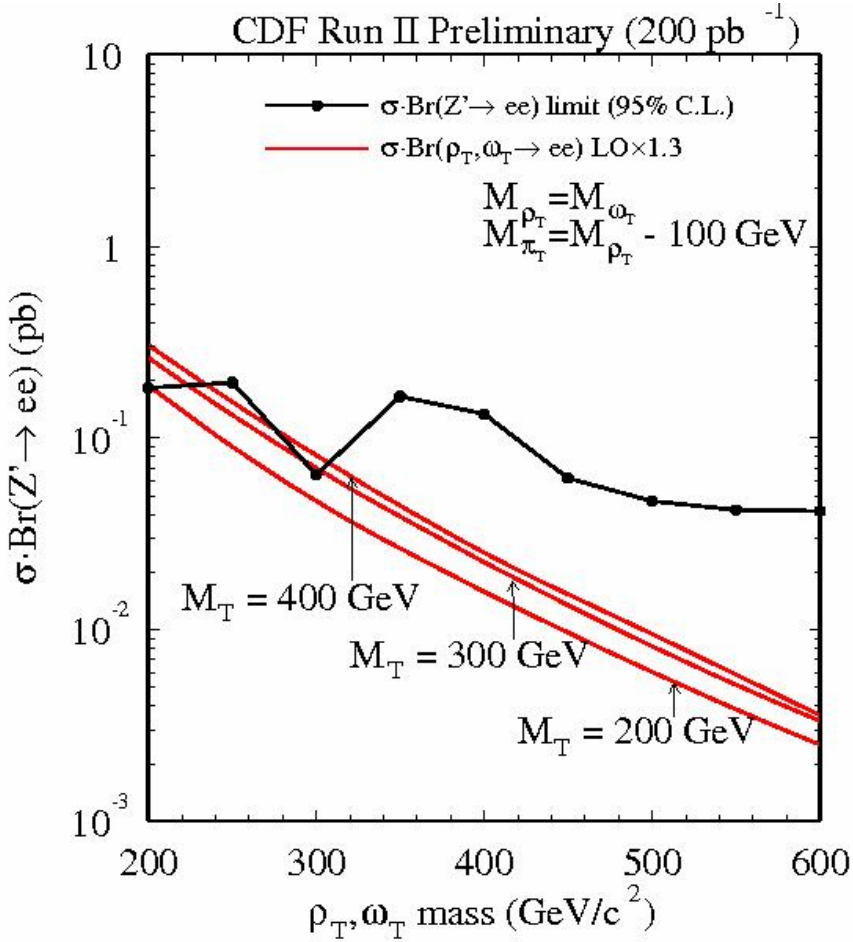
ee Z'_{SM}>845 GeV with 448 pb^{-1}

Technicolor (spin-1)

Spin-1 ee + μμ

- From the spin-1 dilepton result, mass bounds are also obtained for ρ_T and ω_T for different M_T.

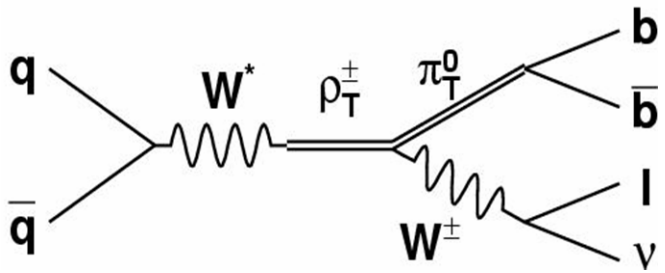
- M_T is a parameter in the Straw-man TC model which affects the production cross section and the decay rates.

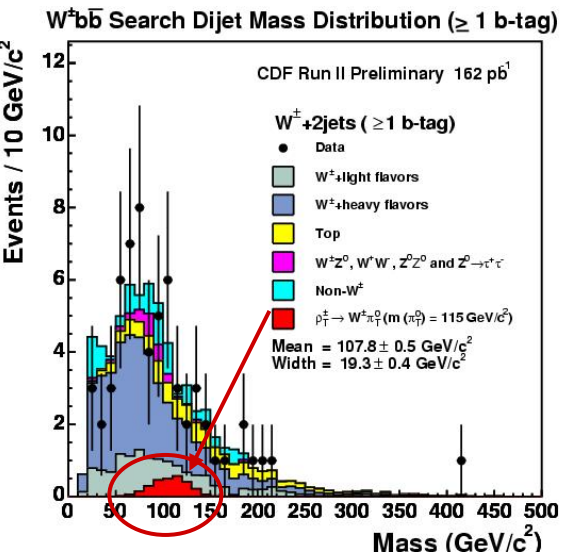


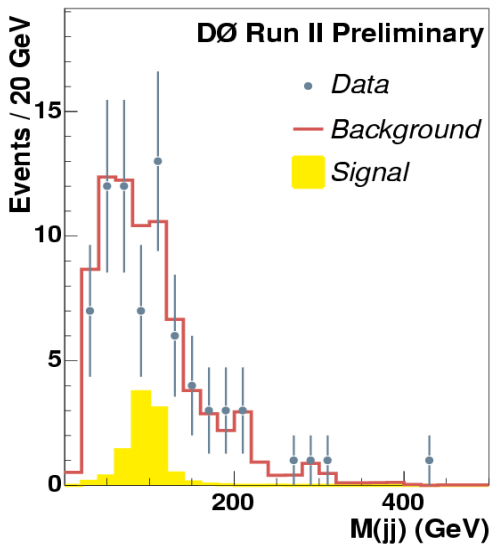
M_T	mass limit	(GeV/c^2)
500	320	
400	315	
300	310	
200	225	

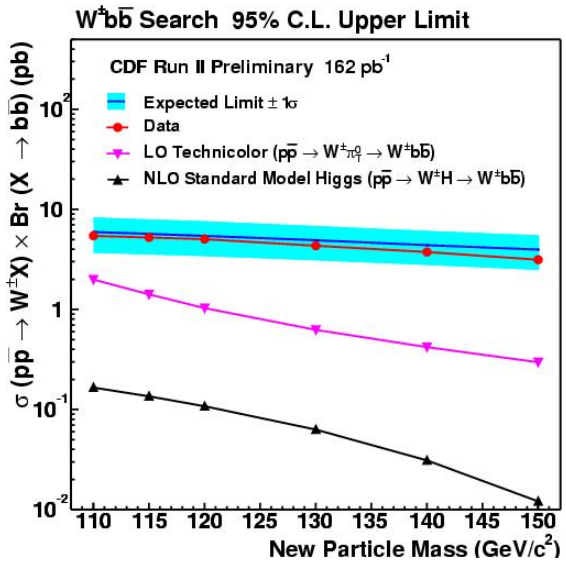
Technicolor

- Can search for Technicolor in many signatures
- This search explores same signature as SM Higgs (lνbq)



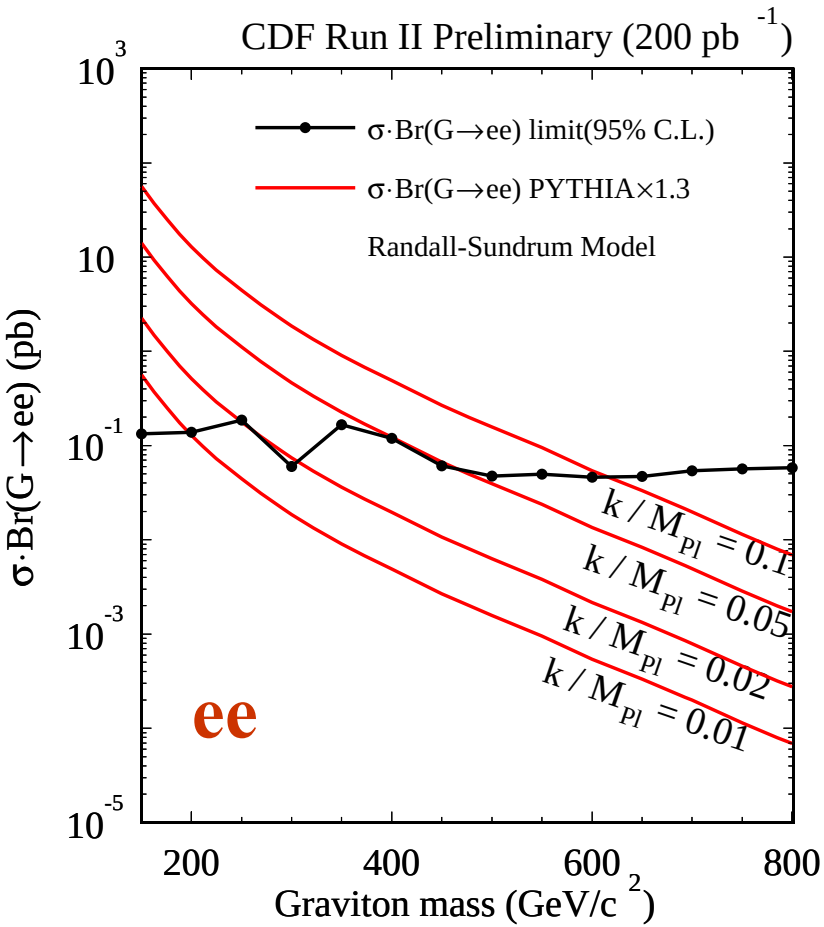


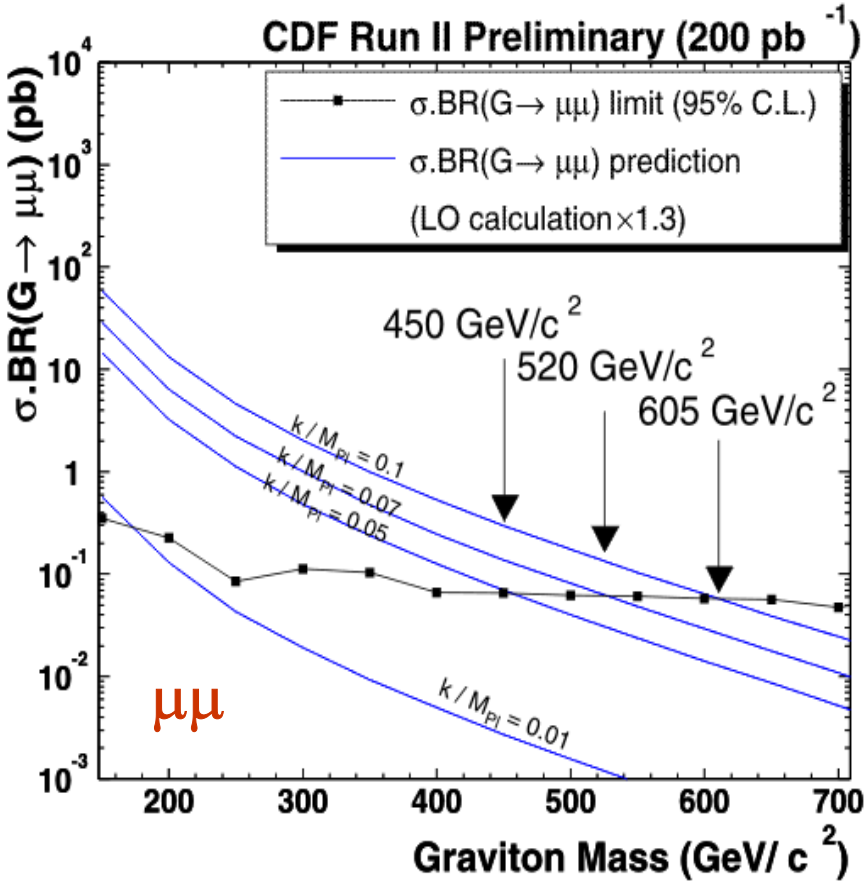




note: We had mass bounds on this channel in Run I.
Run II cross section limit is better than Run I.
The theoretical prediction was revised downwards.

RS Graviton (Spin -2)





Coming Full Extra Dimension results later

Extra Dimensions (ED)

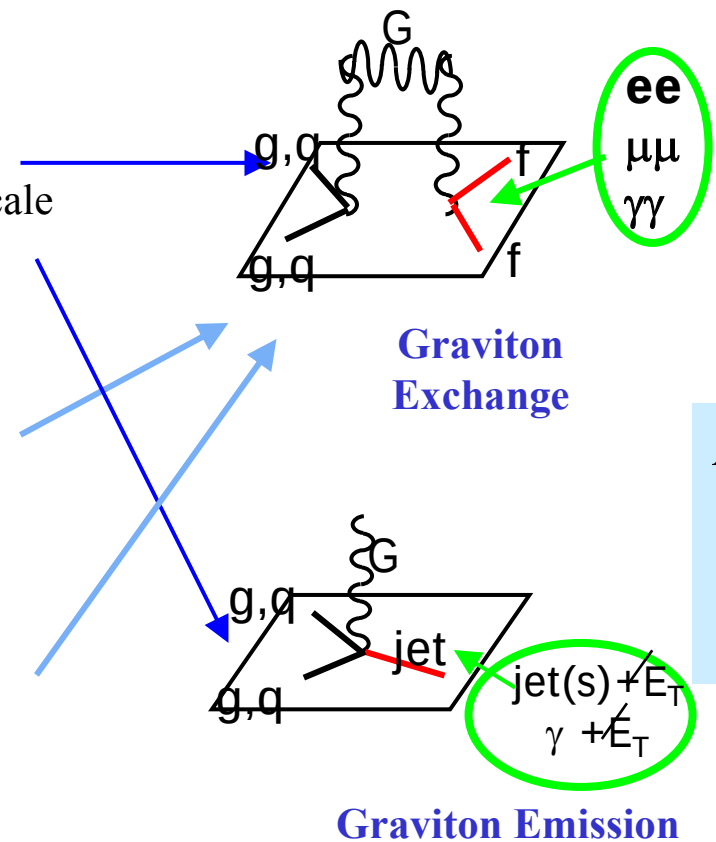
Alternatives to SUSY for resolving the hierarchy problem ($M_{EW} << M_{Plank}$?)
In this model, gravition can propagate in additional spatial dimensions

- Models with n extra spatial dimensions

✓ Large ED(LED) :
n>0 (n>2) compactified
$M^2_{Pl} \sim R^n M_s^{n+2}$, M_s: string scale

✓ TeV^{-1} ED :
n>=1 (n=1)
M_c: compactification scale
Gauge Boson Exchange

✓ Warped ED (RS):
n=1, highly curved
k/M_{Pl}, k: curvature scale



Signature		Model
Graviton Exchange	ll, γγ	LED, RS
Graviton Emission	Jets + MET	LED
Boson Exchange	dielectron	TeV^{-1}ED

At the Tevatron, searched
LED : ee, μμ, γγ, jet+MET
TeV^{-1}ED : ee
RS : ee, μμ, γγ

LED – graviton exchange

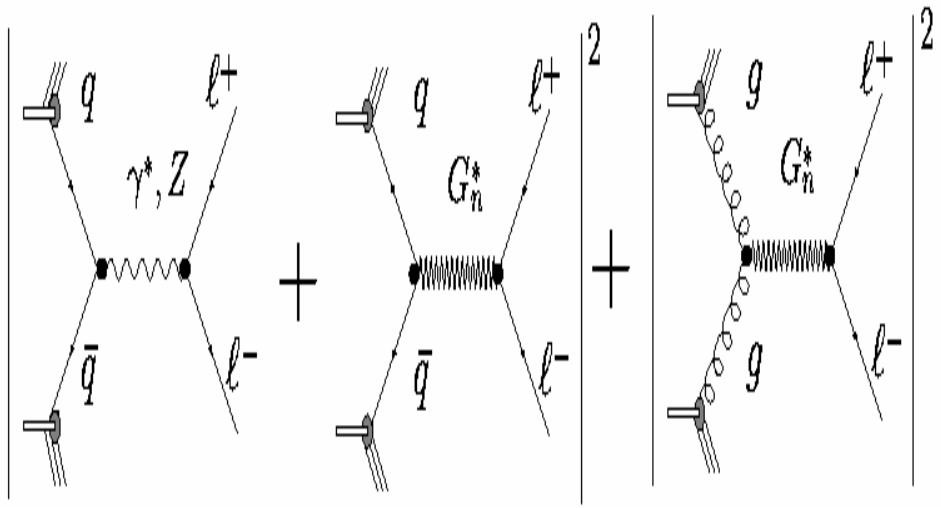
- Gravity effect is parametrized by η_G

$$\frac{d^2\sigma}{dM\, d\cos\theta^*} = f_{SM} + f_{\text{int}}\eta_G + f_{KK}\eta_G^2$$

ee, γγ invariant

Scatt. angle

Functions of M & cosθ* determined by theory



η_G: effective x-section parameter $(=F/M_S^4)$

F is a model dependent dimensionless parameter ~ 1

- ✓ GRW: F = 1
- ✓ HLZ: F = log(Ms2/M2), n =2
- ✓ F = 2/(n-2), n > 2
- ✓ Hewett: $F = 2\lambda/\pi$, $\lambda = \pm 1$

DØ Search Strategy:

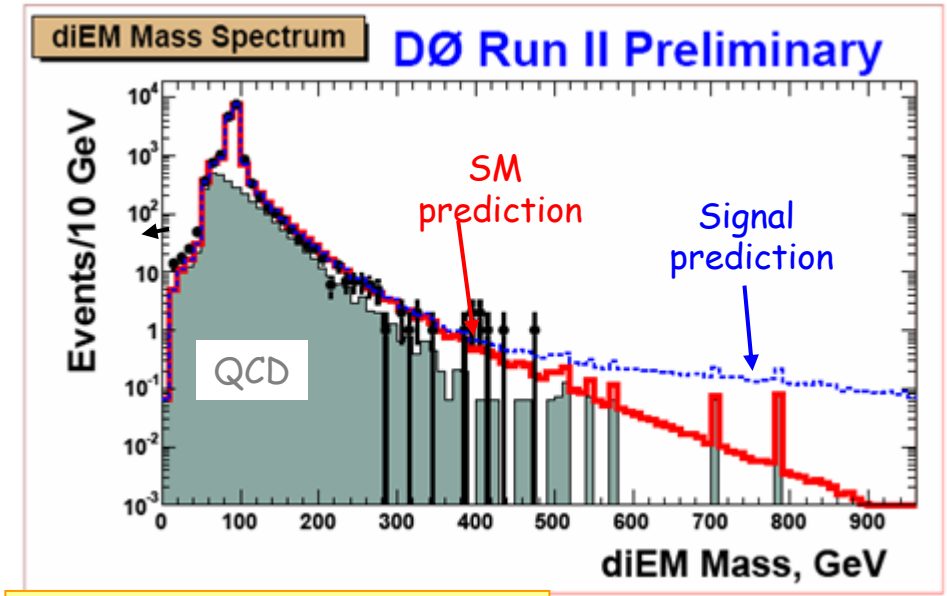
→ Combine ee & γγ to diEM signature

→ Fit distribution of M vs cosθ* of Data – SM

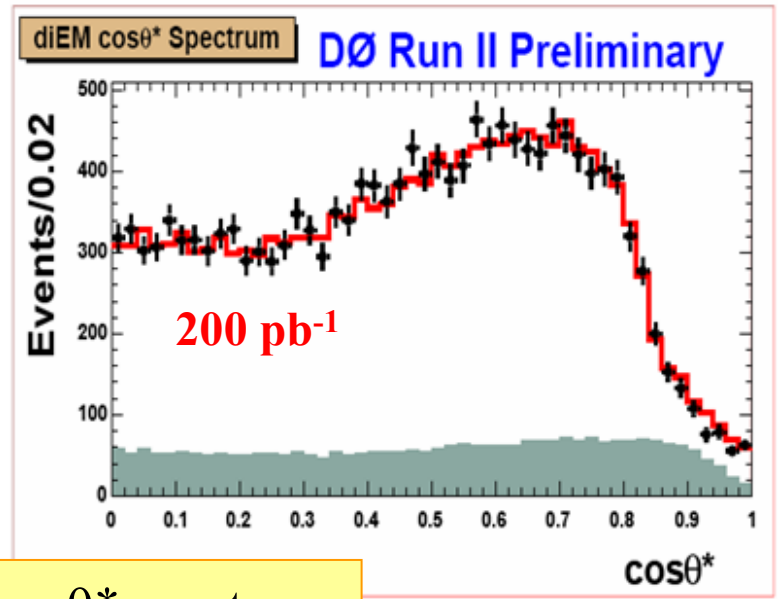
→ Extract η_G from the fit for different models

→ Translate η_G into Ms limit

LED (ee + γγ): graviton exchange



ee + γγ mass spectrum



cosθ* spectrum

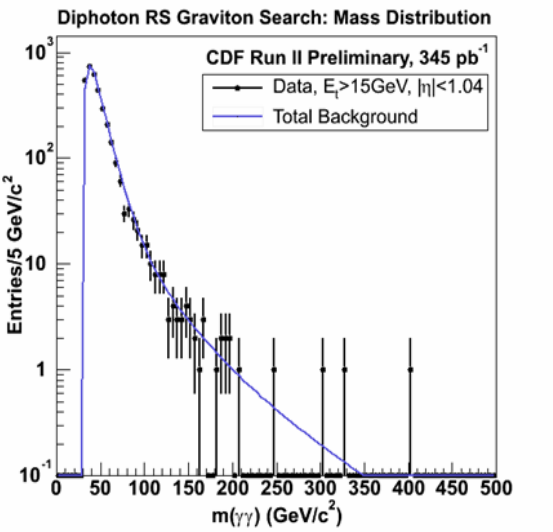
- Fit M_{ee},$M_{\gamma\gamma}$ and $\cos\theta^*$ → Data consistent with background expectation
- Bayesian likelihood fitting → set 95% CL on η_G
- 95% CL mass limits on Fundamental Planck Scale(Ms) (in TeV)

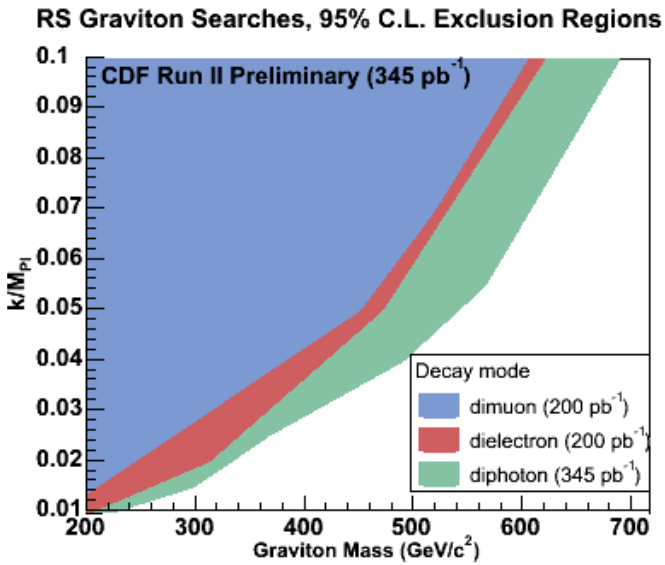
	GRW	HLZ for n =					Hewett
		2	3	4	5	6	7	λ = +1
DØ RunII	1.36	1.56	1.61	1.36	1.23	1.14	1.08	**1.22**
DØ RunI + Run II	1.43	1.67	1.70	1.43	1.29	1.20	1.14	**1.28**

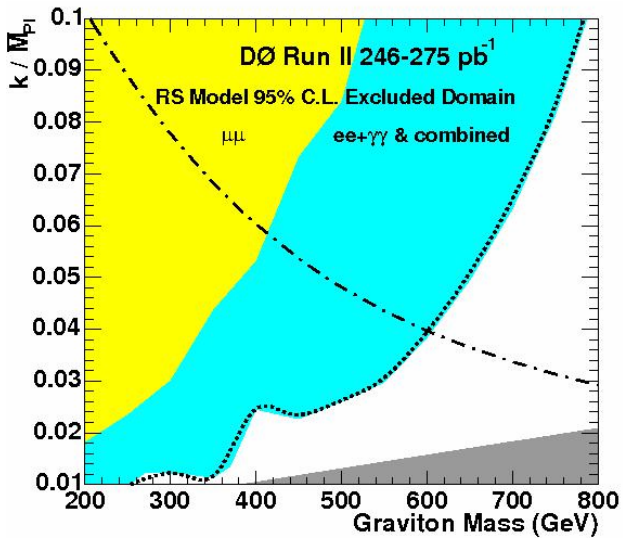
CDF w/ ee channel w/ 200 pb^{-1} →

1.11 for GRW

Randall-Sundrum Graviton (ee+μμ+γγ)

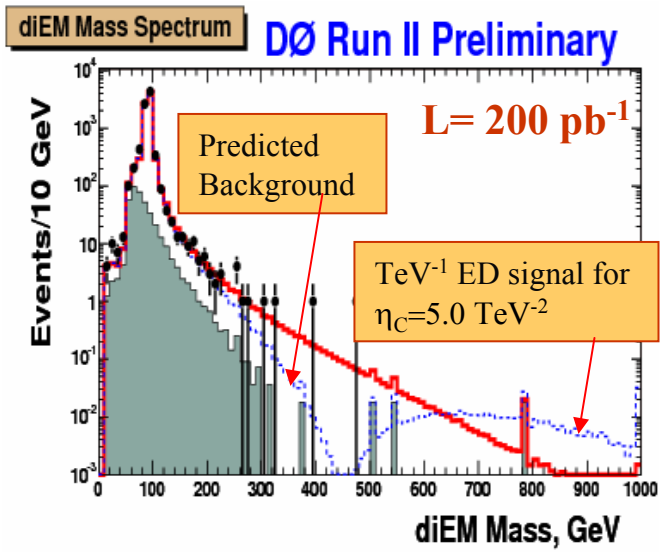


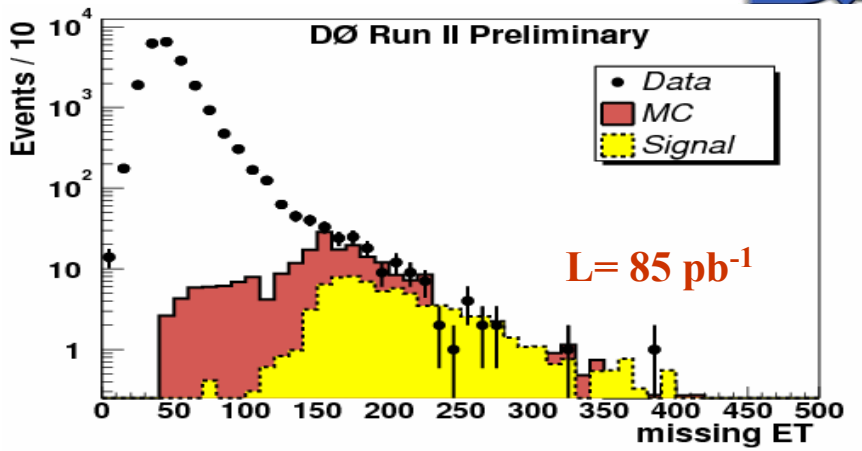




- ee + μμ has largest acceptance at low mass
- γγ has largest acceptance at high mass BR(G→γγ) = 2 * BR(G→ee)
- Randall-Sundrum gravitons are excluded by these data in the plane of coupling (k/M_{Pl}) versus effective graviton mass. e.g. for k/M_{Pl}=0.05 masses less than 640 GeV are ruled out at 95% C.L..

TeV^{-1} ED and LED (graviton emission)



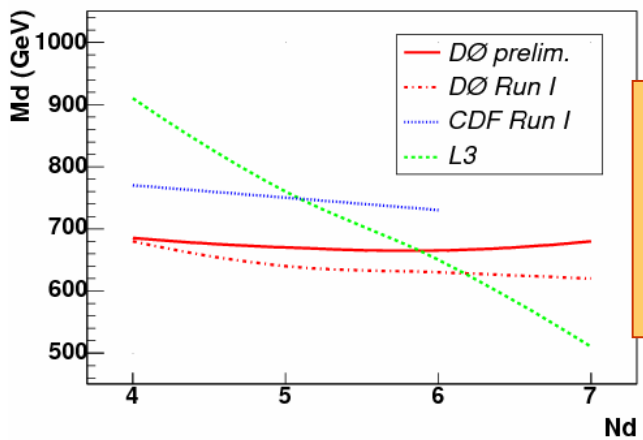


- TeV^{-1} ED : Gauge Boson Exchange
- Limited by statistics, not by systematics
- set Limit on M_C via η_C (replacement of η_G)
- Lower Limit on compactification scale:

  $M_C > 1.12$ TeV at 95% CL
- World Limit(incl. LEP indirect search limit) :

  $M_C > 6.8$ TeV at 95% CL

- LED : Graviton Emission
- jet + MET channel
- MET > 150 GeV , High p_T jet (p_T > 150 GeV/c)
- Backgrounds : Z+jets, W+jets & QCD
- limited by jet energy scale uncertainty



Lower Limit on M_d

for # of extra dimension n_D

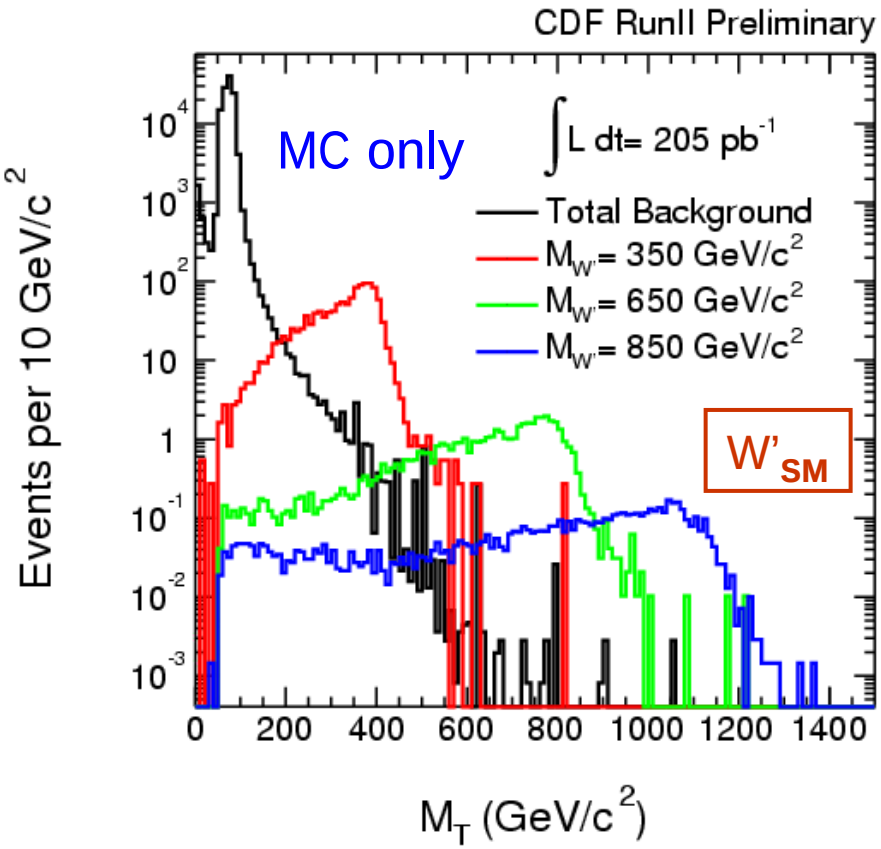
W'(→ eν) search

- Additional Charged Heavy Vector Boson : W'
- from theories based on extension of the gauge group
- Left-Right Symmetric SM :

  $SU(2)_L X SU(2)_R X U(1)_Y$
- assuming ν to be light and stable

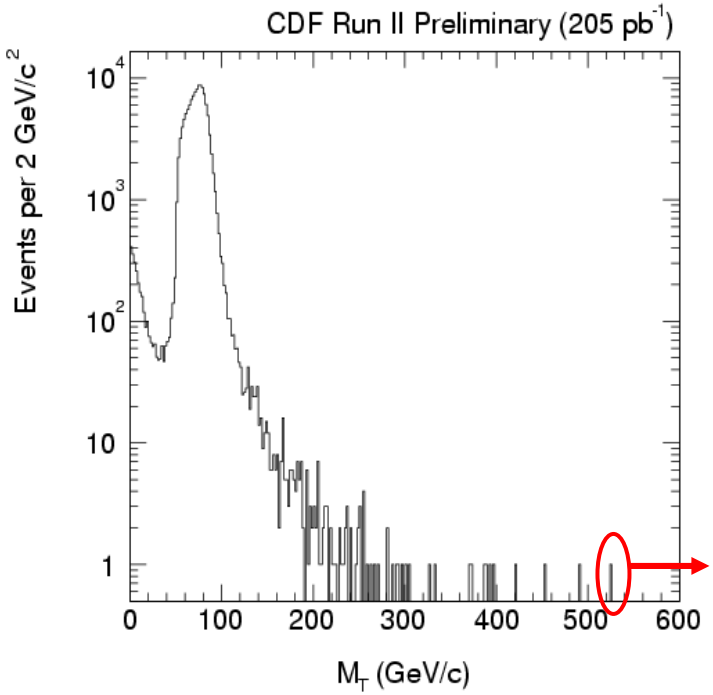
- high p_T electron + high MET
  - ✓ one isolated electron $p_T > 25$
  - ✓ MET > 25
  - ✓ for QCD rejection
    - ✓ $0.4 < p_T/MET < 2.5$
  - ✓ veto dilepton events

    (Drell-Yan, Diboson, $t\bar{t}$)

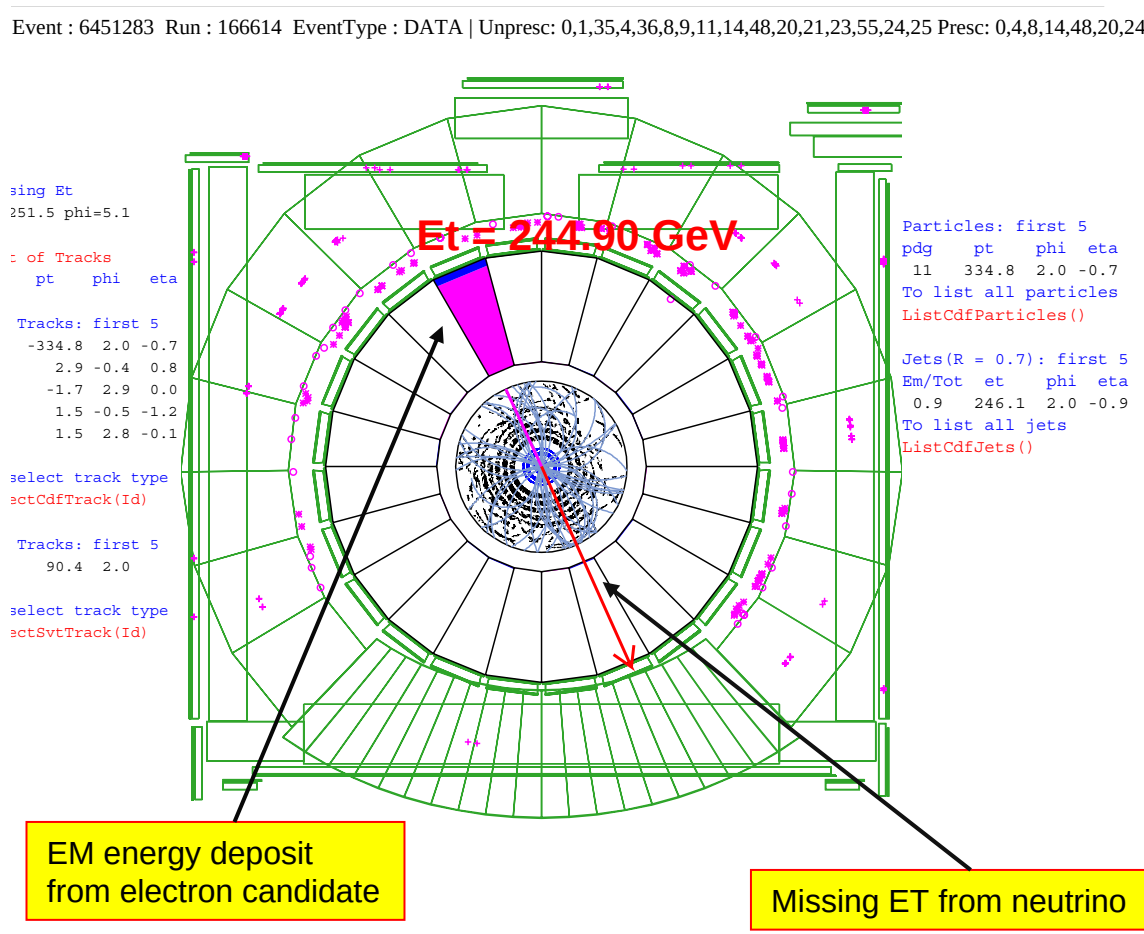


Transverse Mass distribution(MC)

W' search (cont.)

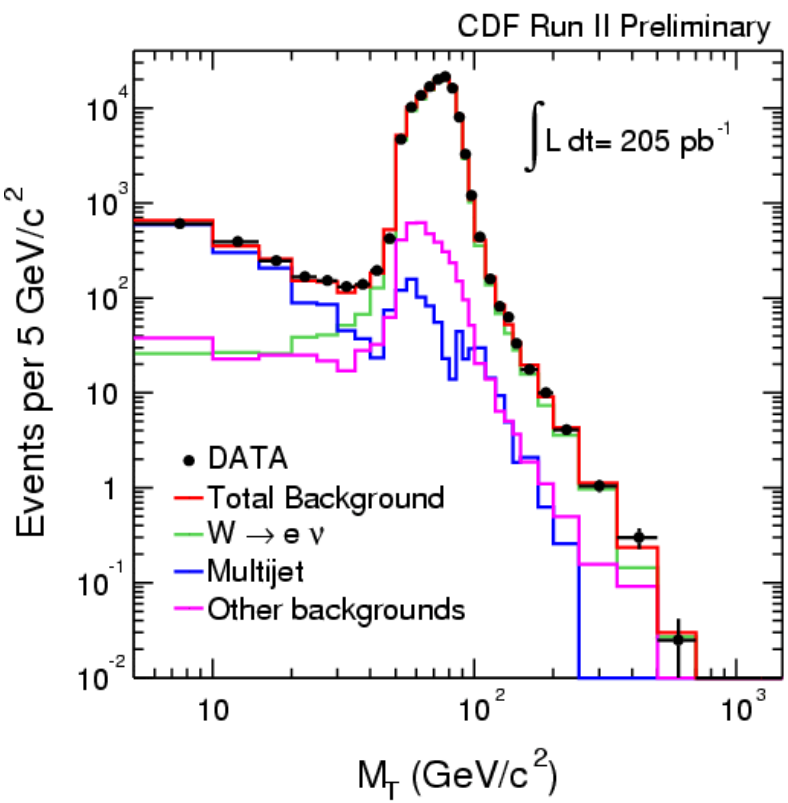


M_T Distribution of Data



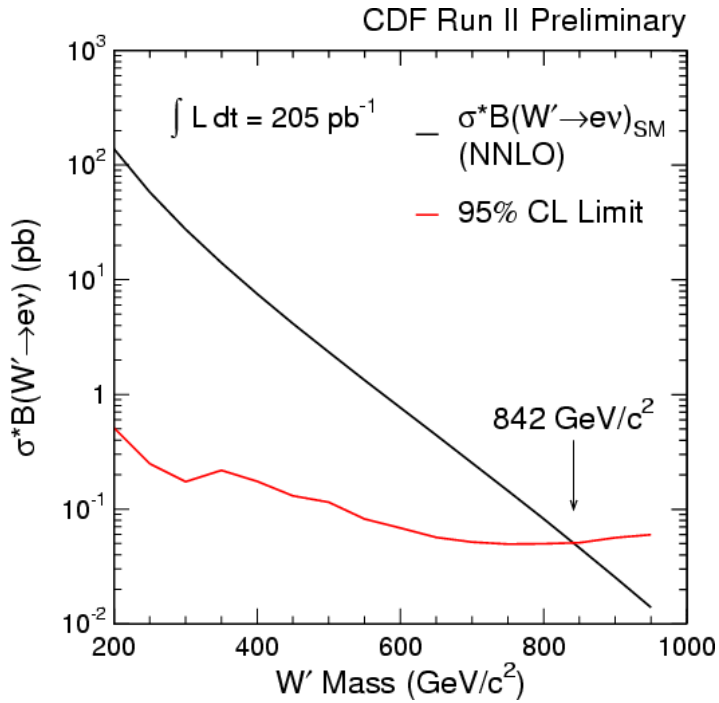
Highest M_T events at 524 GeV/c^2

W' search (cont.)



	Events in Each M_T Bins (GeV/c^2)				
	200 - 250	250 - 350	350 - 500	500 - 700	700 - 1000
$W \to e\nu$	35.8 ± 4.3	19.5 ± 2.5	4.34 ± 0.99	1.08 ± 0.73	0.0 ± 0.0
Jets	2.6 ± 6.3	0.0 ± 3.4	0.0 ± 0.31	0.0 ± 0.0	0.0 ± 0.0
Other Backgrounds	5.0 ± 0.7	3.2 ± 1.2	2.76 ± 3.26	0.12 ± 0.04	0.04 ± 0.02
Total Background	43.3 ± 7.6	22.7 ± 4.5	7.10 ± 3.66	1.20 ± 0.77	0.04 ± 0.02
Data	41	21	9	1	0

- No evidence of W' existing
- Set limits on σ*Br(W'→eν) assuming SM coupling strength
- use binned likelihood fitting method
- Dominant systematics : PDF and electron energy scale

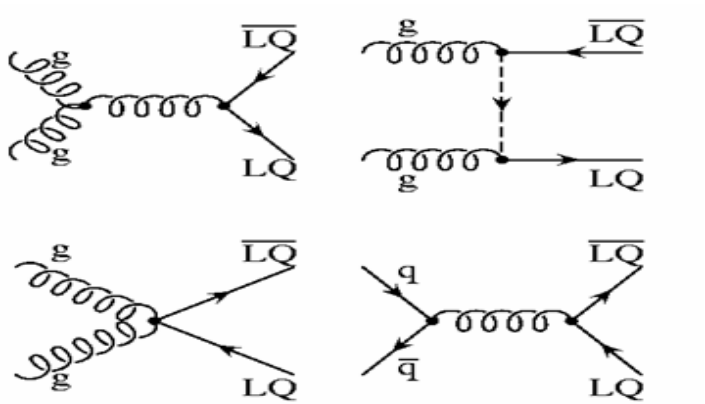


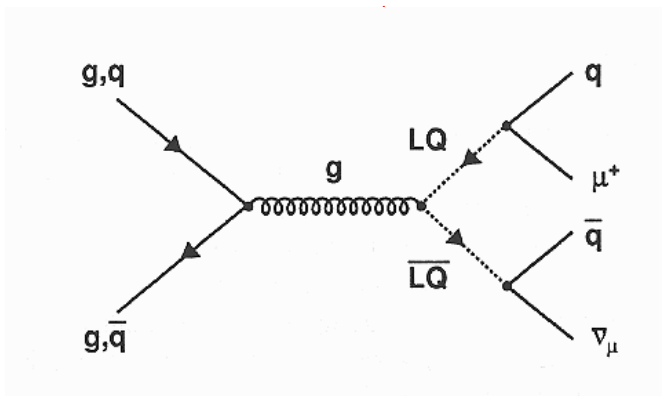
Limit: $M(W'_{SM}) > 842$ GeV/c^2

Run I results : $M(W'_{SM}) >$ 754 GeV/c^2 CDF

Leptoquarks(LQ)

- Color-triplet particles coupled both quarks and leptons
  - ✓ Predicted in many extensions of SM(GUT, Superstring, compositeness, technicolor etc..)
  - ✓ Carry both lepton and color quantum numbers
- Couple only to fermions of same generation due to no FCNC & helicity supp. decay
- At the Tevatron, pair-produced by gg fusion or q qbar annihilation
- Decay channel is controlled by β = **BR (LQ→lq)**

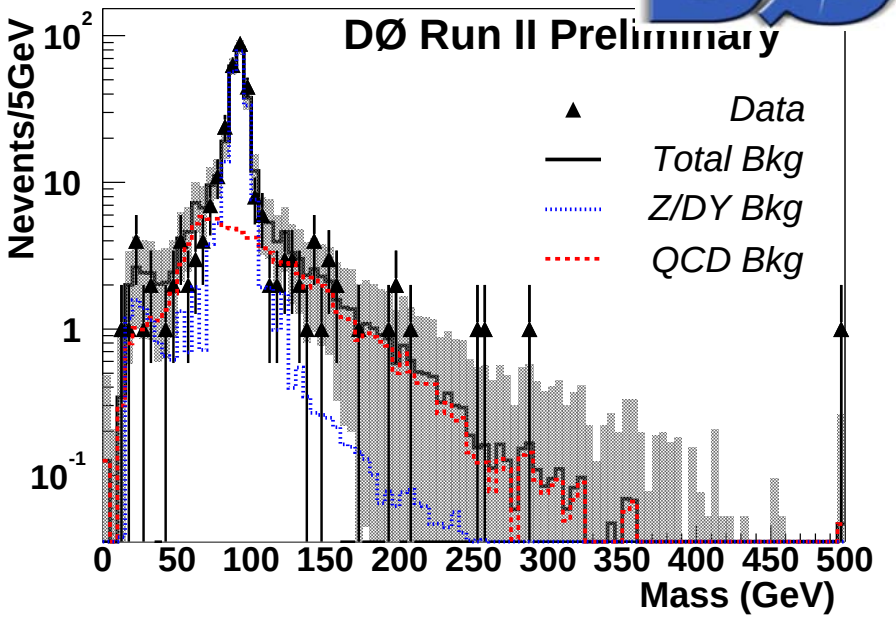


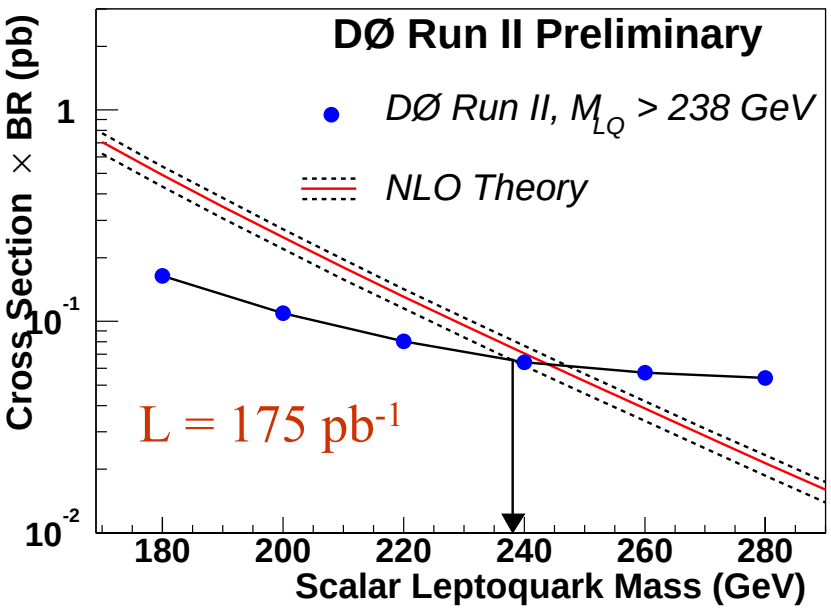


Search of each generation LQ in channels
(example: For 1st, eejj, evjj, *vv*jj)

1st generation LQ : eejj channel

- **Background**
  - ✓ Drell-Yan/Z + jets,
  - ✓ QCD (with 2 fakes EM)
  - ✓ t tbar



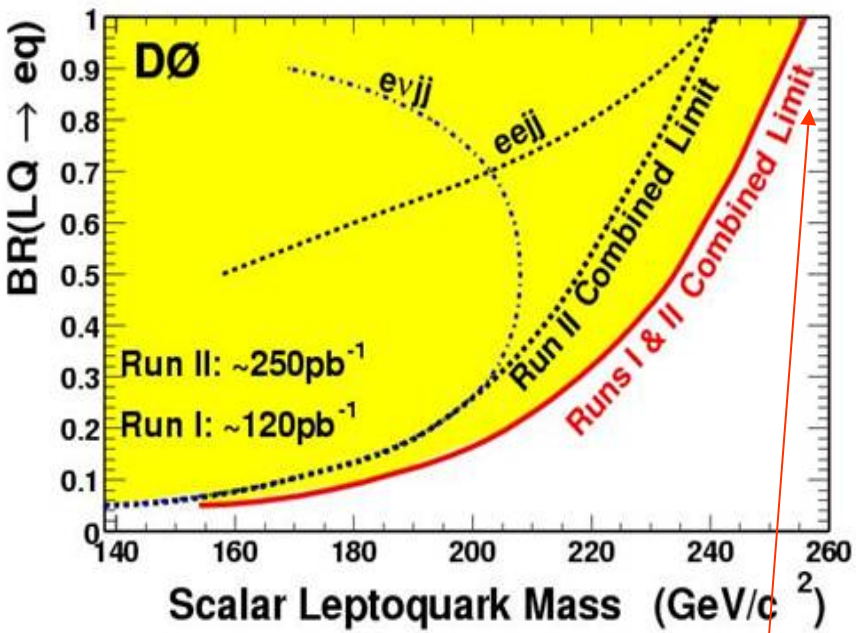


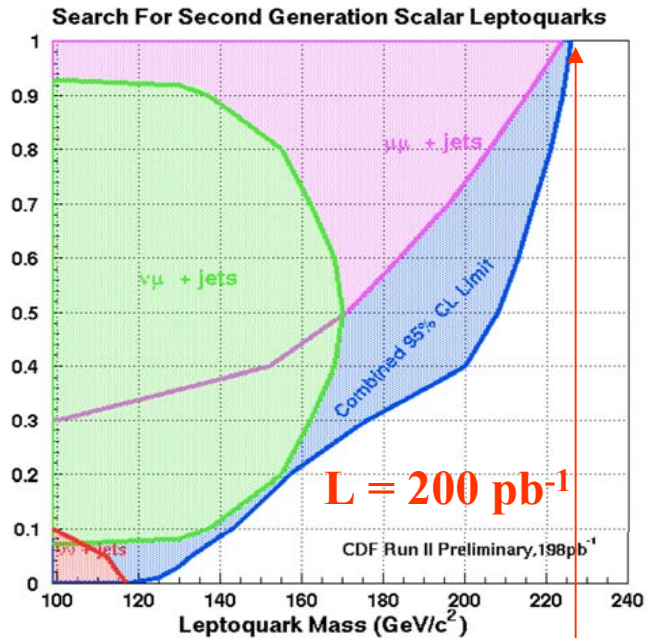
- **Selections**
  - ✓ Electrons : E_T > 25 GeV
  - ✓ Jets : E_T > 20 GeV, $|\eta|$<2.4
  - ✓ Z veto
- ✓ Signal Efficiency = 12 – 33 %

1st & 2nd Generation LQ

Channels: *eejj*, *evjj*, (*vvjj*)

μμjj *μνjj* *νvjj*



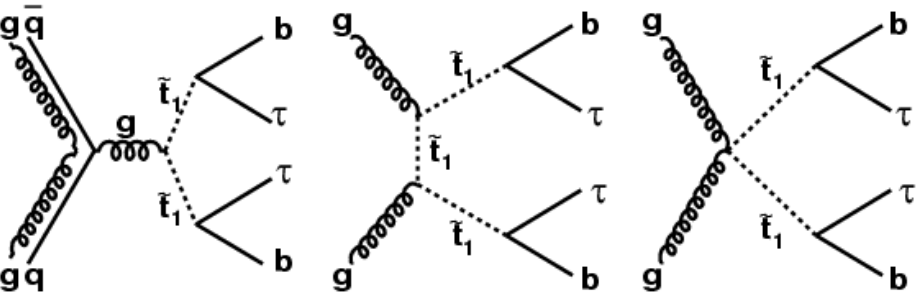


For β =1,
D0: Run I + II, $M_{LQ} > 256$ GeV/c^2
CDF: Run II, $M_{LQ} > 235$ GeV/c^2

for β =1,
CDF: Run II, $M_{LQ} > 224$ GeV/c^2
D0: Run I, $M_{LQ} > 200$ GeV/c^2

3rd generation LQ

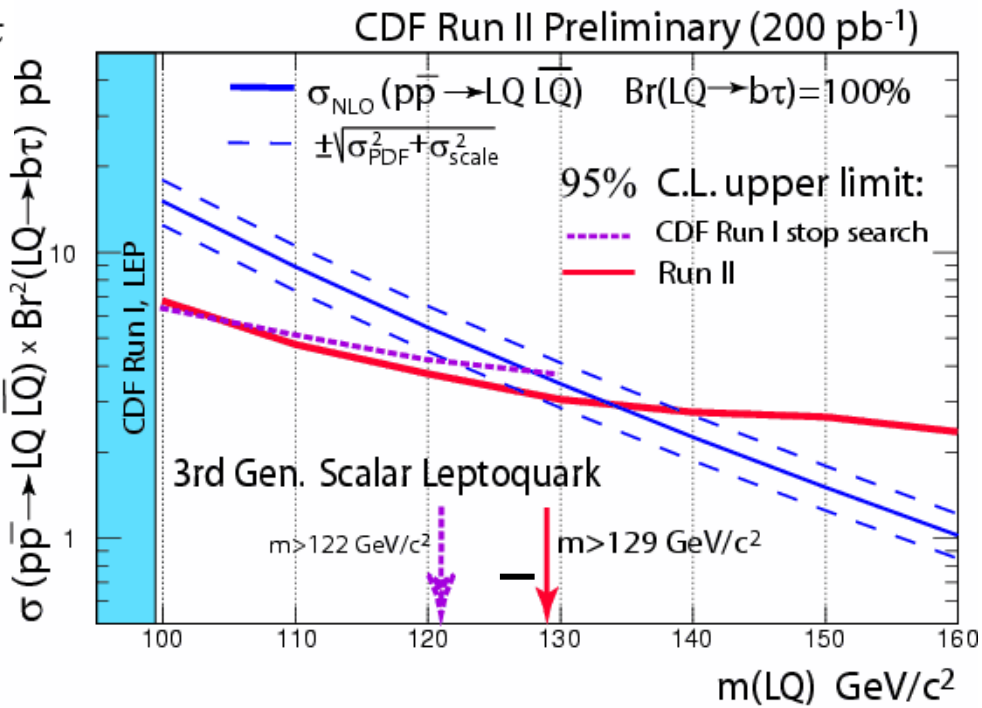
channel: $\tau_l\tau_h jj$ (one leptonic, one hadronic decayed τ's)



final state: $\tau\tau bb$, same as the RPV Stop search signature

- $\tau_l + \tau_h$
- $n_{jet} >= 2$
- $Y_T = P_T(l) + P_T(\tau_\eta) + \not{E}_T > 85$ GeV/c
- $M_T(l, \not{E}_T) < 35$ GeV/c^2 :removing W

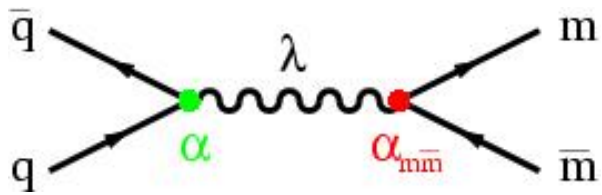
expect 4.8 + 0.7 events,
observed 5 events



for β=1,
CDF: Run II, M_{LQ} > 129 GeV/c^2

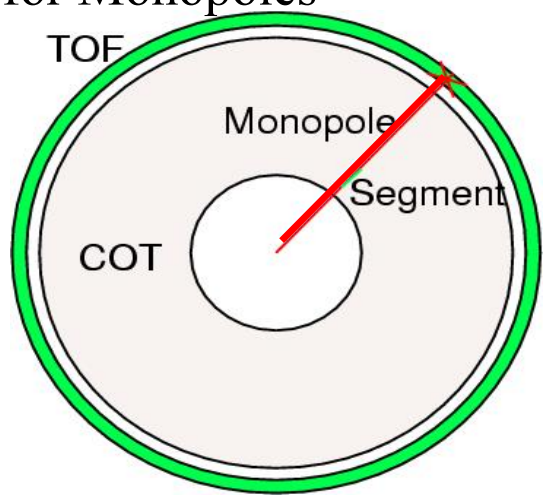
Monopole Search

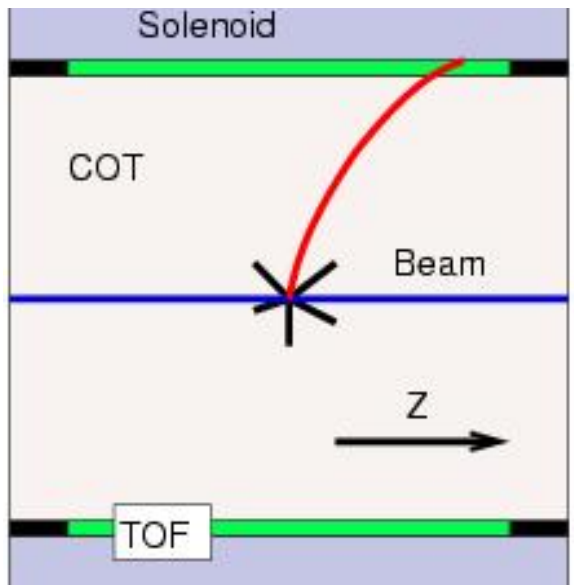
- Magnetic charge is very large.. → Highly Ionizing
  - ✓ Very Large pulses in Time of Flight (TOF)
    - ✓ ~ several hundreds MIPs
  - ✓ Large ionization in drift chamber (COT)
  - ✓ Curvature in r-z instead curvature in r-phi
    - ✓ parabola curves due to relativistic effect



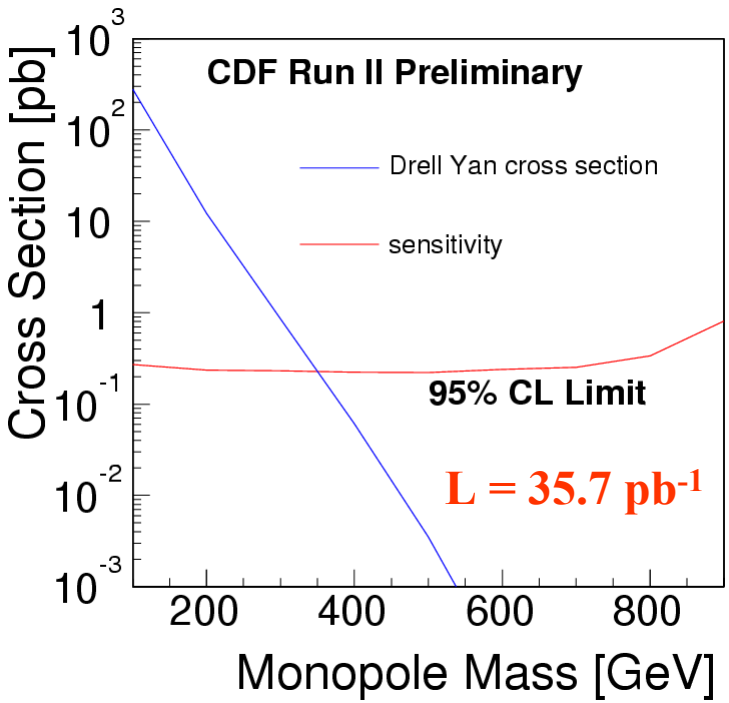
Drell-Yan like monopole pair production

- 'Discovery' can be claimed by one Event !
- Developed a dedicated trigger for Monopoles
  - ✓ requiring larges pulses from both sides of TOF bar
  - ✓ In offline, COT cut

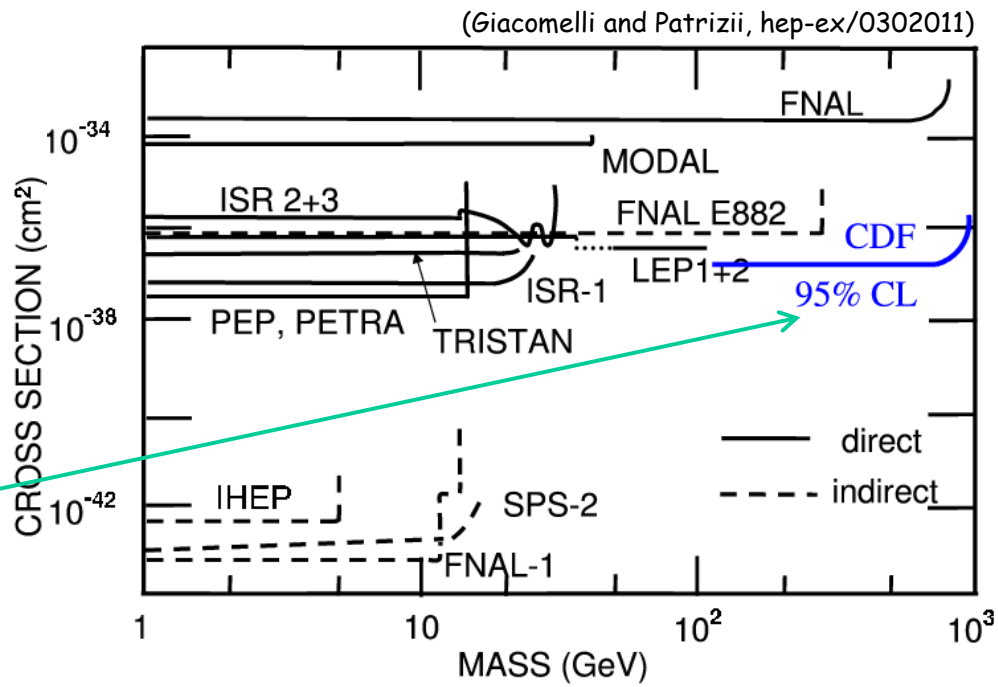




Monopole Search Result



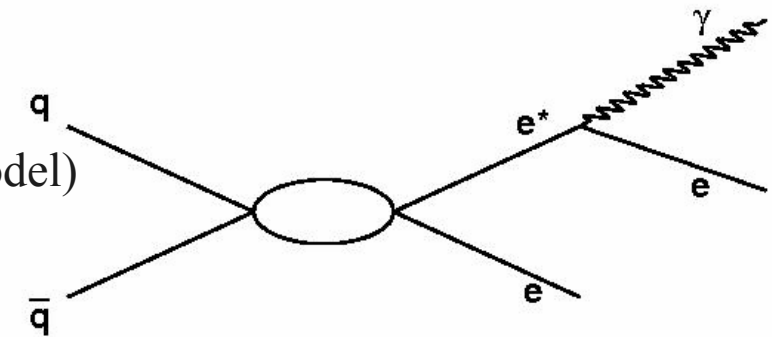
- σ > 0.2 pb (95% CL) for monopole mass between 200 and 700 GeV/c^2
- $M_{Monopole}$ > 360 GeV/c^2 at 95% CL

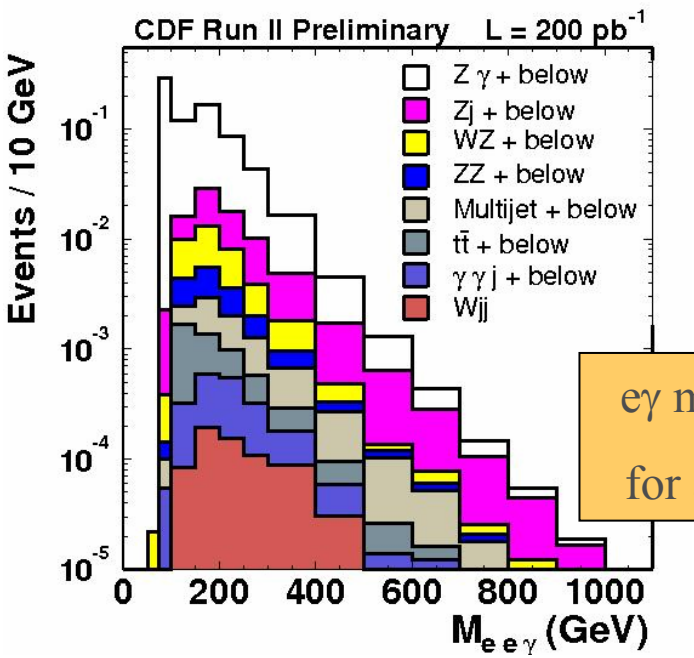


World best limit for large mass monopoles

Compositeness

- p pbar → e* + e → e γ + e
- Expected in many Compositeness models
- σ depends on M_{e*} and compositeness scale Λ.(CI model)
- absence of significant background
  - Zγ, Z+jet, WZ, W+jet etc..





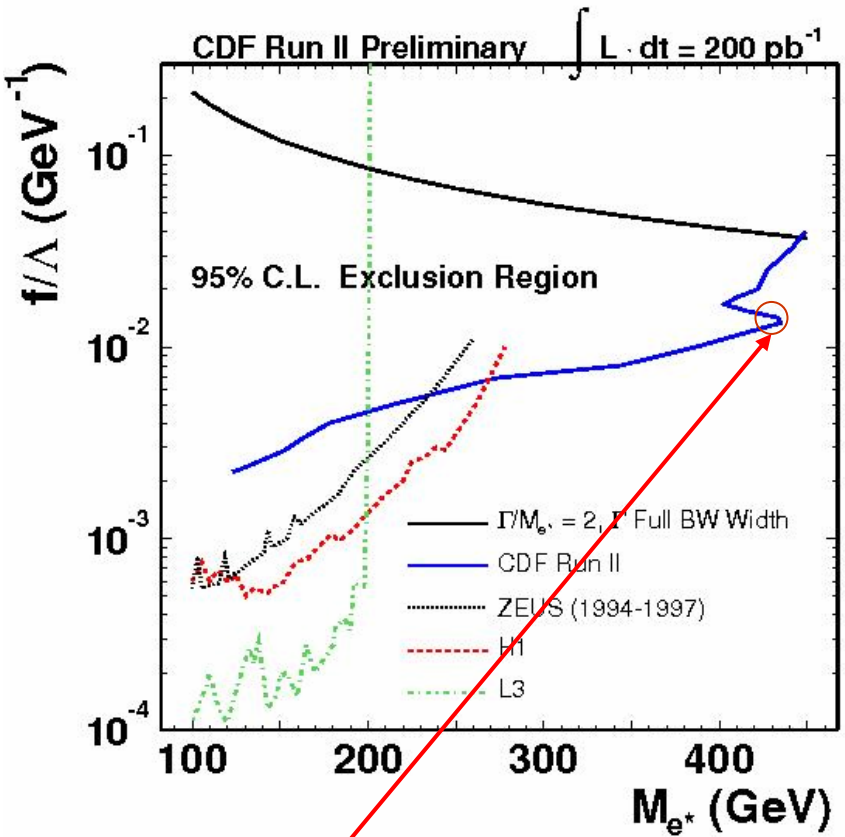
eγ mass distribution for all backgrounds

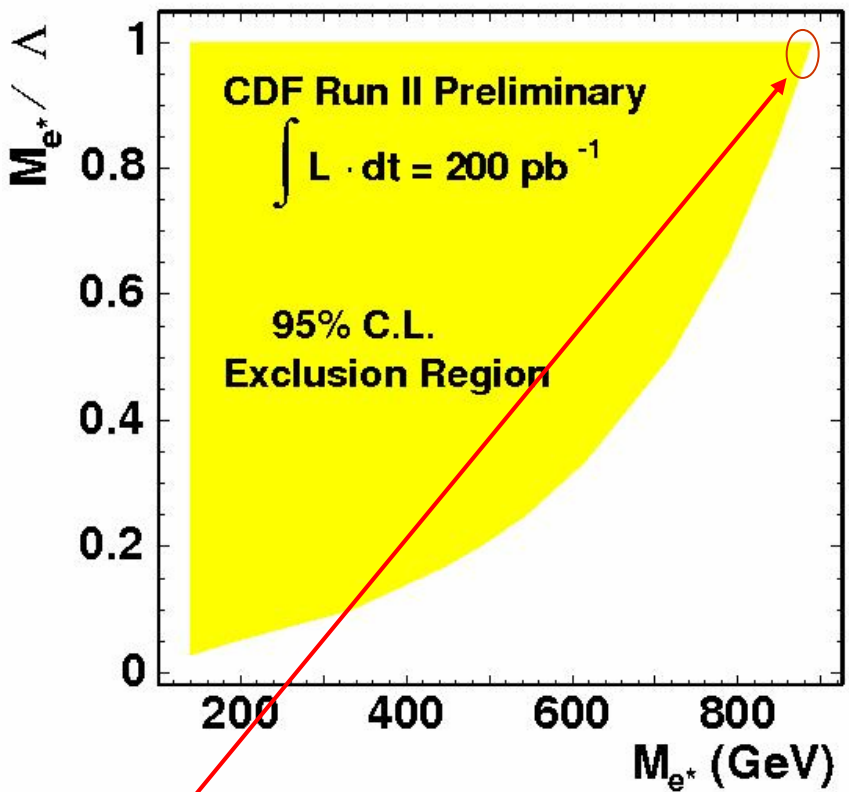
- MC using Pythia for CI and COMPHEP for GM model
- Systematics : Int. Lum(6%), PDF(5%) dominant.
- three candidate events remain but consistent with total background prediction of 3.03+-0.08+-0.4.

Set Limit on e* production

σ*BR Limits (e*→ eγ)

Limits in parameter space of f/Λ (GM model) and M_{e^*} /Λ(CI model)





In GM model, $M_{e^*} > 430$ GeV for $f/\Lambda \sim 0.01$ GeV^{-1} (95% CL)

In Compositeness model, $M_{e^*} > 906$ GeV for $M_{e^*} = \Lambda$ (95% CL)

Conclusion

- **Current results mostly based on 200 ~ 300 pb^{-1}**
- **At present, ~ 800 pb^{-1} on tape**
- **Surpassed sensitivities and results from run 1**
- **World best Limits on Z', LQ, LEDs etc..**
- **Second stage of analysis with ~ 1fb^{-1} data**
- **At the end of 2009, we may have 4 ~ 8 fb^{-1}**
- **So far, only ~ 5% of data analyzed from expected data till 2009**
- **God knows what … about bumps becoming real discoveries !!??**

http://www-cdf.fnal.gov/physics/exotic/exotic.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/np.html