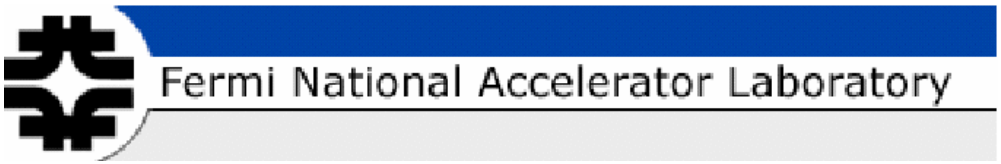
Non-SUSY Searches at Tevatron



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for the CDF and D0 collaborations

DIS2006 (Apr 20 ~ 24, 2006, Tsukuba)

Outline (Search & Signature)

New Gauge Bosons Z' , W'

(sequential Z', Zψ,Zη,Zχ,Zι)

- ee, μμ, ττ, eν

Compositeness

- ee, μμ

New Fermions

(t', μ*, q*) - lν + jets, μμγ, ee+jet

Extra Dimension

(LED, TeV-1ED, & WarpedED)

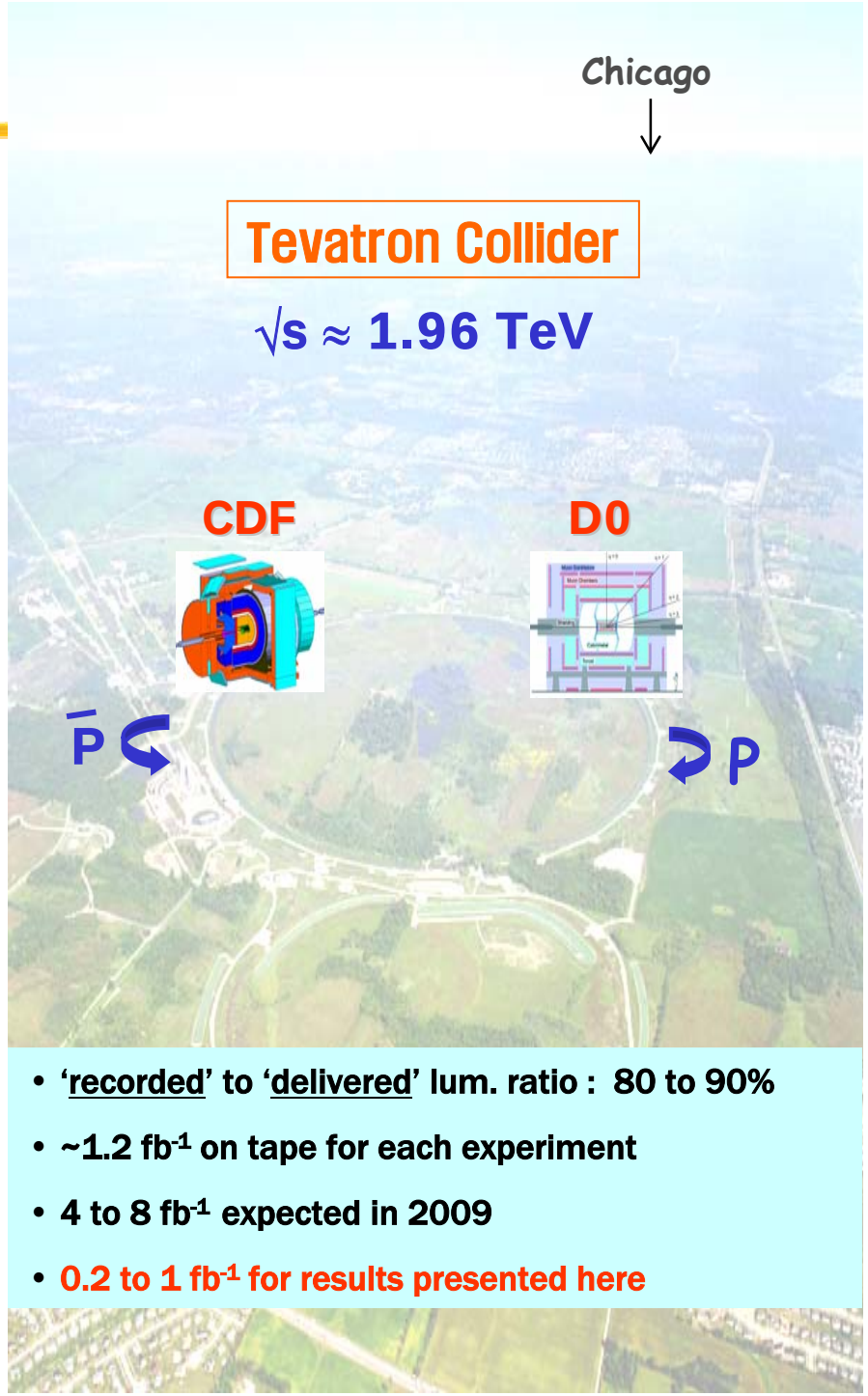
- ee, μμ, γγ, jet + ME_T

Leptoquarks

- (ll, lν, νν) + jet jet

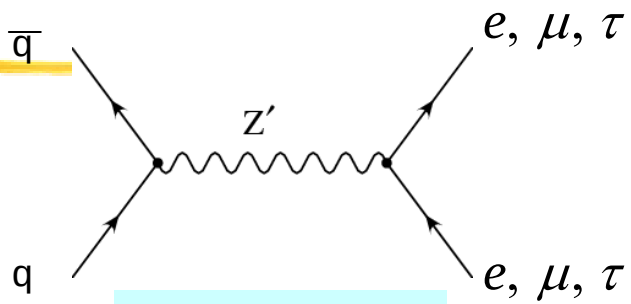
Anomalous Diphoton+X Production

- X = e, μ, γ



- '<u>recorded</u>' to '<u>delivered</u>' lum. ratio : 80 to 90%
- ~1.2 fb^{-1} on tape for each experiment
- 4 to 8 fb^{-1} expected in 2009
- 0.2 to 1 fb^{-1} for results presented here

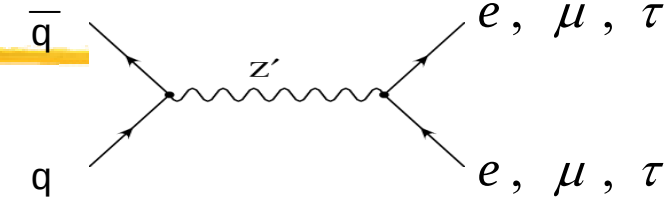
Z' (heavy neutral gauge boson)

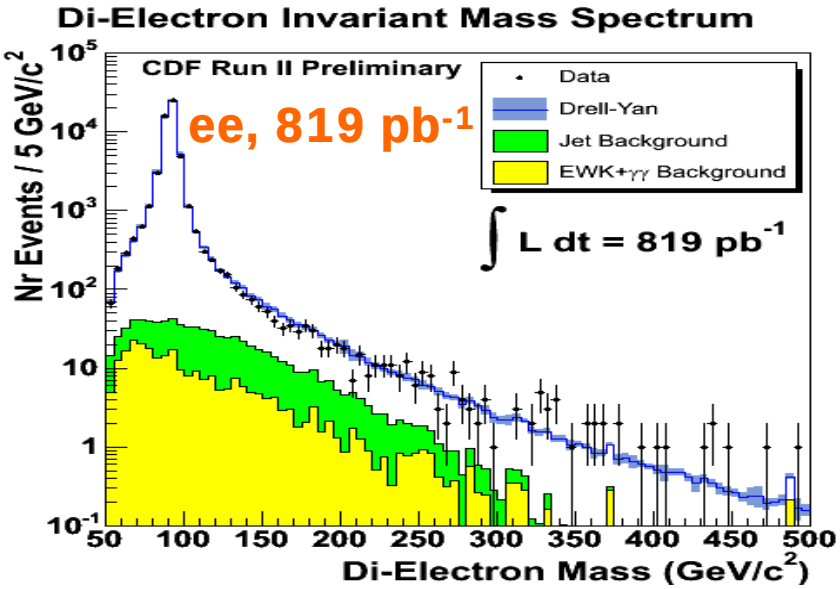


Dilepton Channel

- The majority of extensions to the SM predict new gauge interactions, many of which naturally result in the prediction of neutral bosons, such as a highly massive " Z' " particle : Sequential Z' (SM coupling), $Z\psi$, $Z\eta$, $Z\chi$, $Z\iota$ in GUT E(6) Model
- Generated from $q\,\overline{q}$ annihilation from $p\,\overline{p}$ collision at 1.96 TeV
- Looking for resonances decaying to leptons provides very clean signature even in a hadron collider
- Search X ($p\overline{p} \rightarrow X \rightarrow ll$) directly by comparing observed and expected background invariant mass distribution
  - Background contributions (Drell-Yan, QCD, cosmic, $\tau^+\tau^-$, tt, WW, WZ)

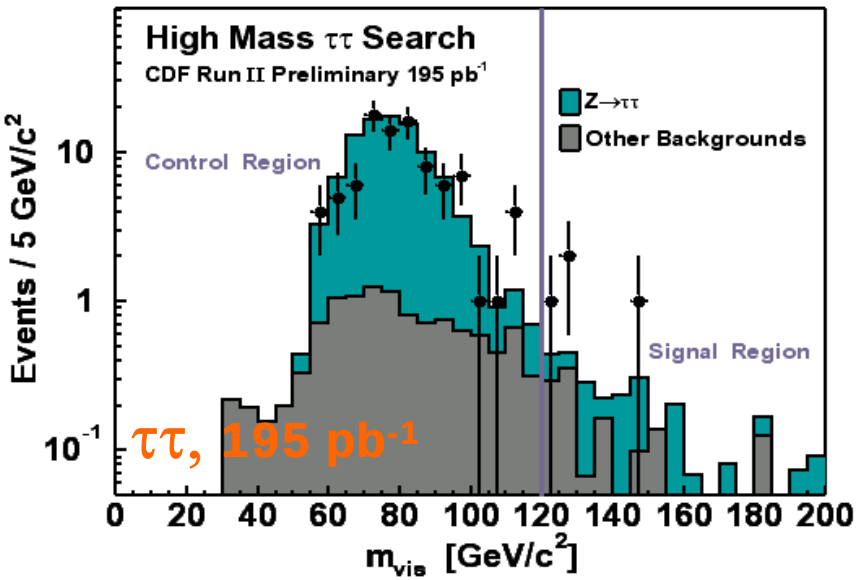
Dilepton Mass Dist.

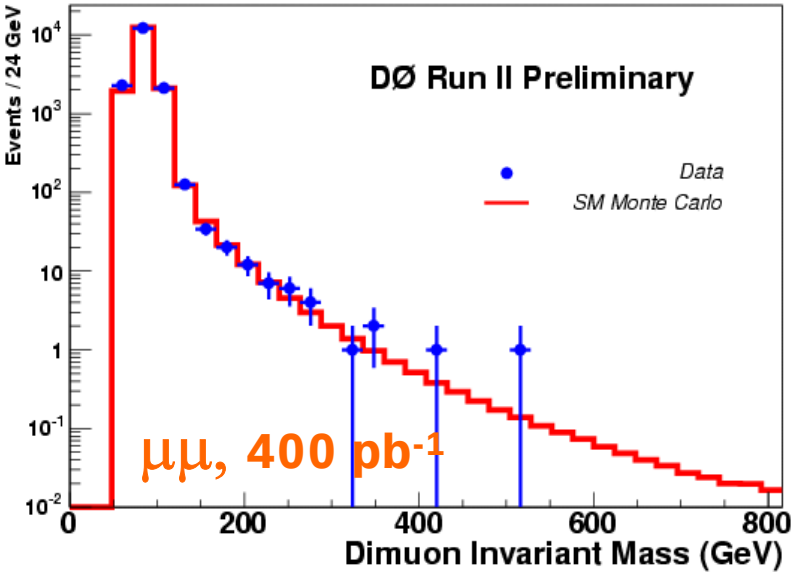




- Very good agreement between data and prediction for full mass region and high mass signal region.

Both D0 and CDF have no significant Excess





Z' Limits (95% CL)

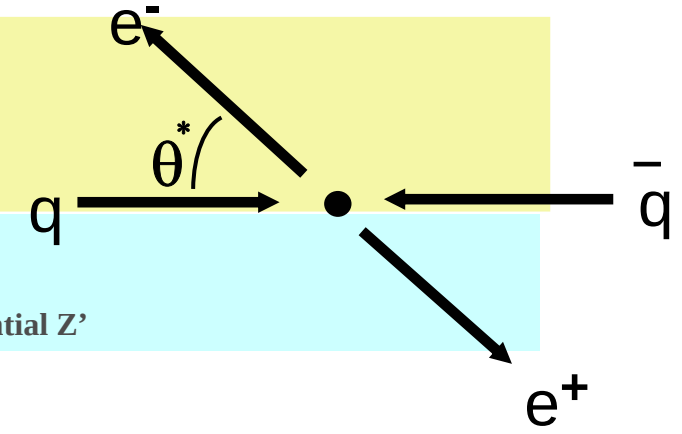
(unit : GeV)

Sequential Z' (SM Couplings)	ee	μμ	ee+μμ	ττ
CDF (820 pb^{-1})	850			
CDF with cosθ* (450 pb^{-1})	845			
CDF (200 pb^{-1})	750	735	815	394
DØ (200 – 250 pb^{-1})	780	690		
E6	Z_I	Z_χ	Z_ψ	Z_η
CDF with cosθ* (**ee,** 450 pb^{-1})	625	720	690	715
CDF (**ee+μμ,** 200 pb^{-1})	615	675	690	720
DØ (**ee,** 200 pb^{-1})	575	640	650	680

- Search for decays : $Z' \rightarrow e^+e^-$
  - Use dielectron mass M_{ee} and cosθ*
  - $\int L\,dt = 450$ pb^{-1}

θ* : **Scattering angle in Collin-Soper frame**

Adding cosθ* is equivalent to adding 25% more data for the sequential Z'



Compositeness

- Look for effects due to preons, the fundamental constituents of quarks and leptons
- The effects are parameterized in terms of Λ, the compositeness scale
- the search compared invariant mass and scattering angle of data with SM expections,

Λ : compositness scale (TeV)

- $$\frac{d^2\sigma}{dM\, d\cos\theta^*} = f_{SM} + \frac{I}{\Lambda^2} + \frac{C}{\Lambda^4}$$

where 'I' and 'C' are input from theory and express the possiblity of constructive / destructive interference

CDF (ee, 450 pb^{-1})

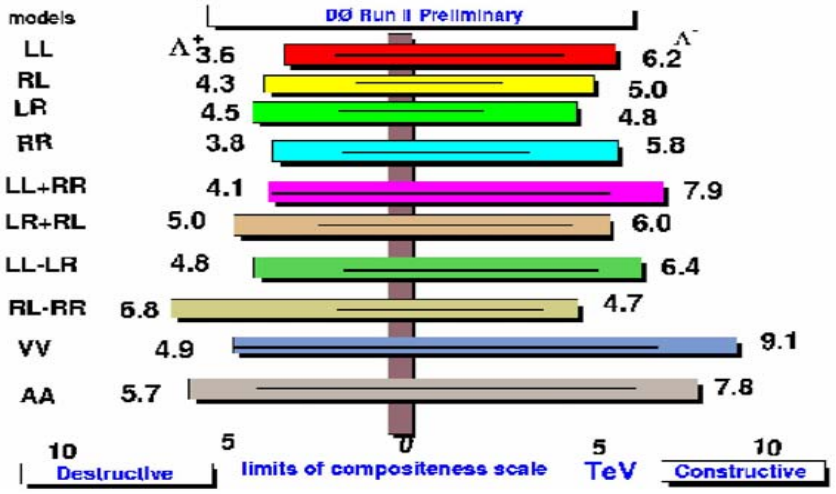
Interaction	LL	LR	RL	RR	VV	AA
Λ^+_{qe} limit (TeV/c^2)	3.7	4.7	4.5	3.9	5.6	7.8
Λ^-_{qe} limit (TeV/c^2)	5.9	5.5	5.8	5.6	8.7	7.8

- No excess wrt SM -> limits (95% CL) on the models

D0 (μμ , 400pb^{-1})

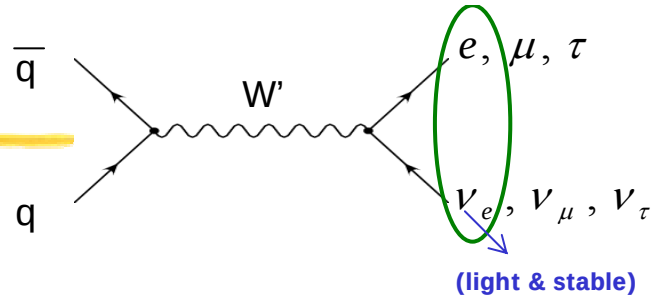
Model	Λ^+(TeV)	Λ^-(TeV)
LL	4.19	6.98
RR	4.15	6.74
LR	5.32	5.10
RL	5.31	5.17
LL+RR	5.05	9.05
LR+RL	6.45	6.12
LL-LR	4.87	7.74
RL-RR	5.07	7.41
VV	6.88	9.81
AA	5.48	9.76

D0 (ee, 270 pb^{-1})



ee and μμ combination in progress

W'

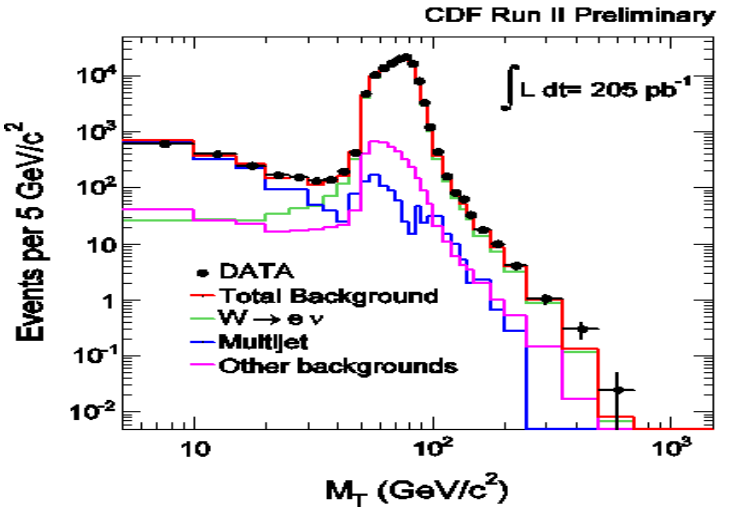


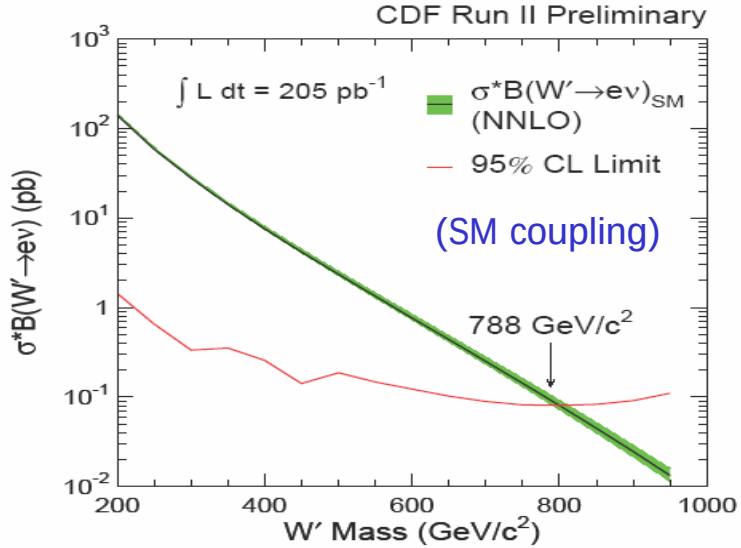
- Additional charged heavy vector boson
  - Left–Right Symmetric Model: $SU(2)_L \times SU(2)_R \times U(1)_Y$ ($SU(2)_R \longrightarrow$ W')
- High P_T e + ME_T
  - Compare M_T distribution

Highest M_T events at 524 GeV/c^2

  - No excess over background

	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	0.00 ± 0.03
Data	41	21	9	1	0



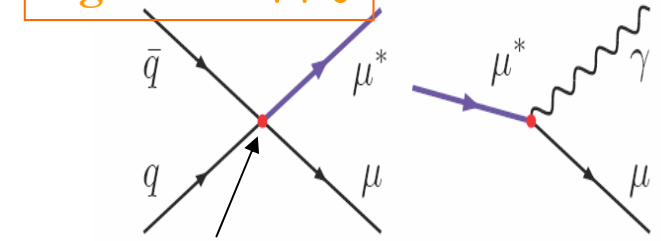


Limit: $M(W'_{SM}) > 788$ GeV/c^2

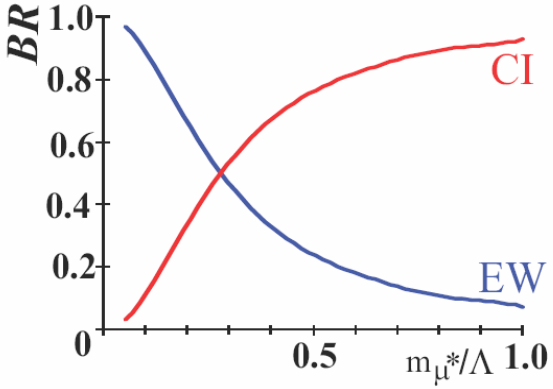
Run I results : $M(W'_{SM}) >$ 754 GeV/c^2 CDF

Excited Muon (μ*)

signature : μμγ

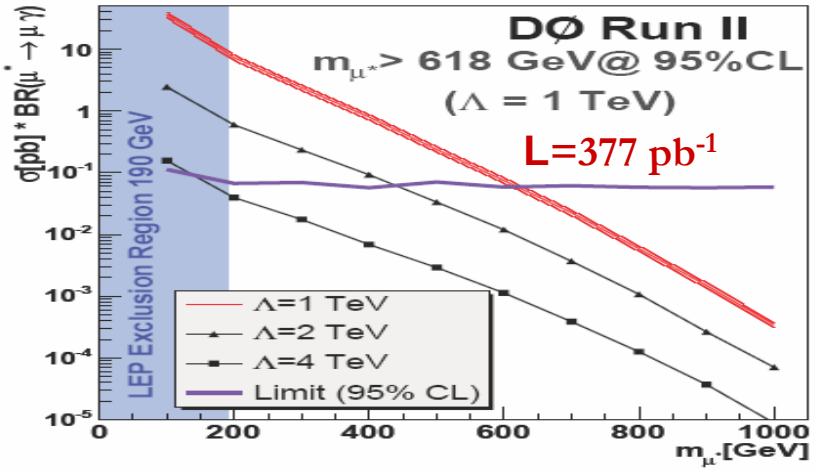


Contact Interaction (CI)

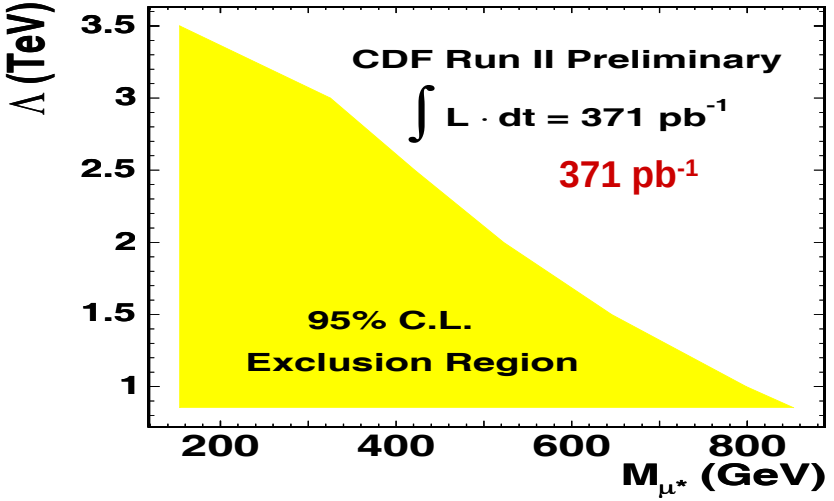


EW decays: μ* -> μ + gauge boson
CI decays: μ* -> μ + ff

Three parameters:
- m_{μ^*}
- BR(μ* -> μγ)
- Λ: compositness scale



m_{μ^*} > 618 GeV Λ=1 TeV



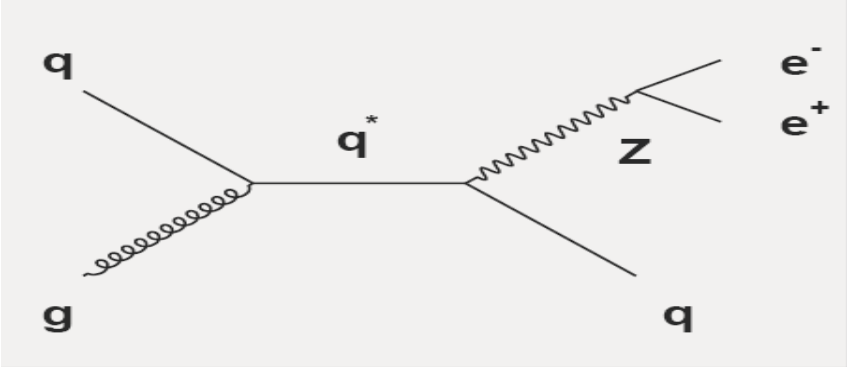
m_{μ^*} > 800 GeV Λ=1 TeV

CI decay taken into account in the calculation of BF(μ* −>μγ)

Assume that decays via contact interactions can be neglected, only EW decays

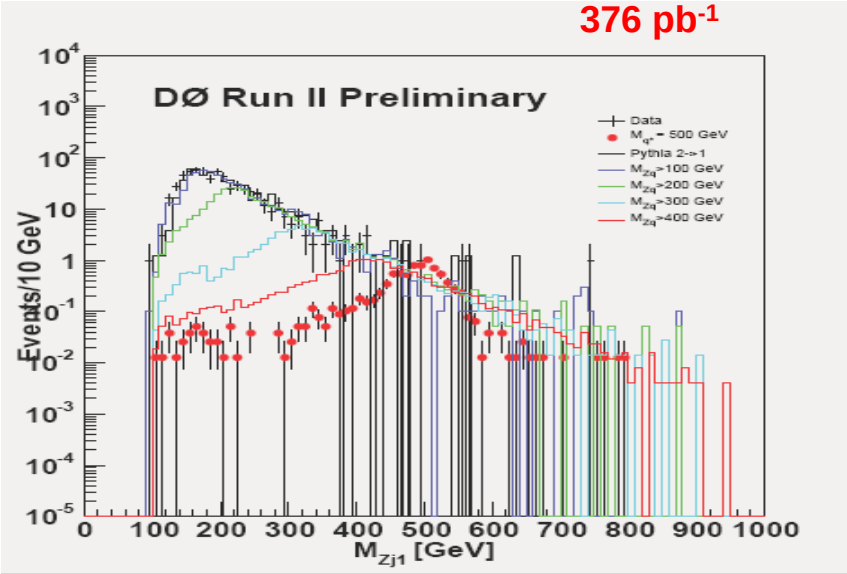
Excited Quark (q*)

signature : Z(ee)+jet

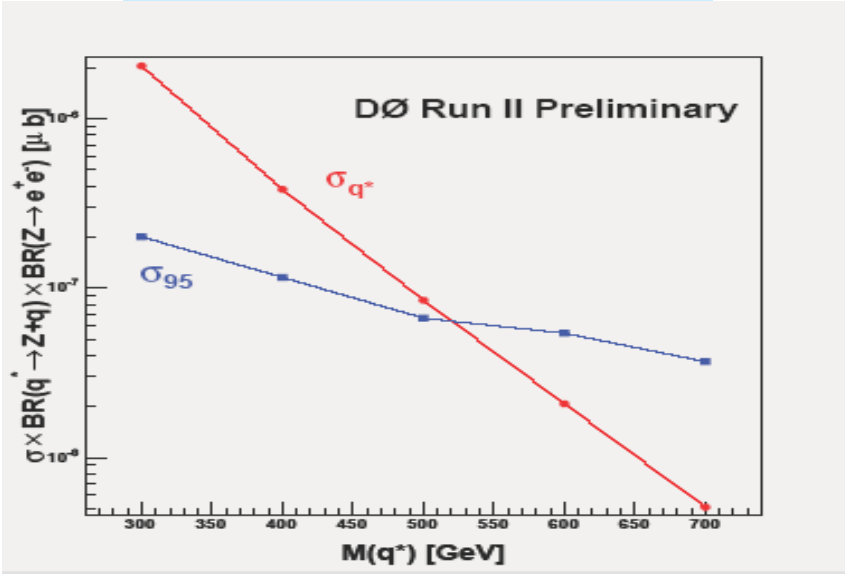


- Heavy resonances decaying into a quark and a gauge boson may signal the existence of excited quarks and thereby indicate a possible substructure
- Low BR(Z->ee), but the high luminocity offered in RunII present preliminary results for the first time on this final state

M_{Zq} resonant



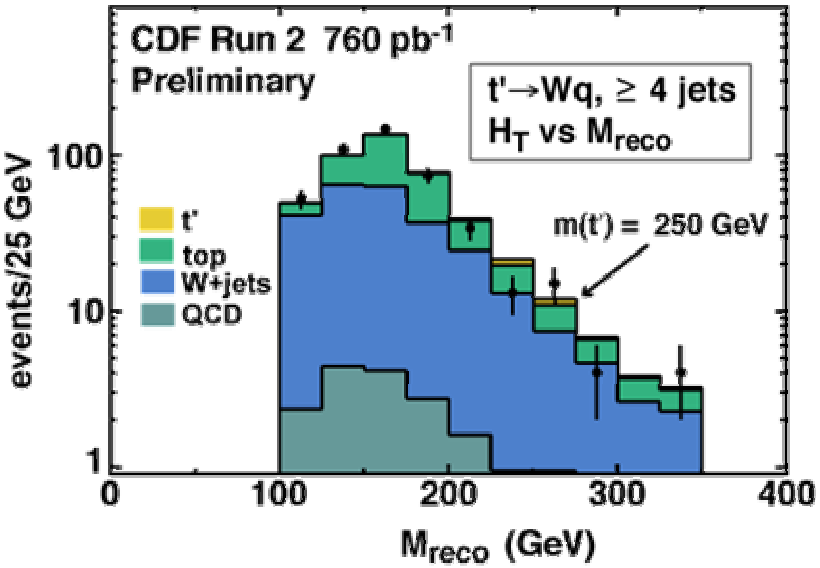
$M_{q^*} > 520$ GeV @ 95% CL

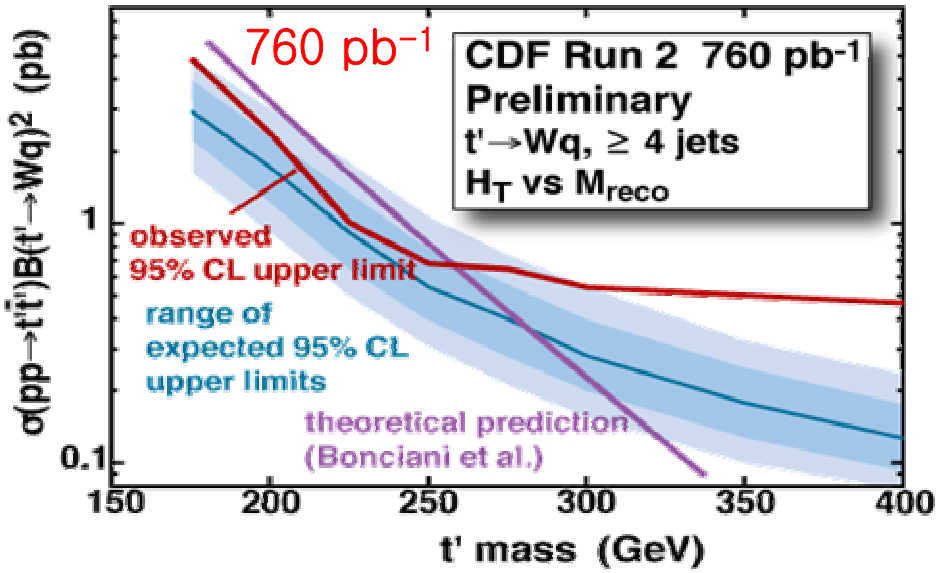


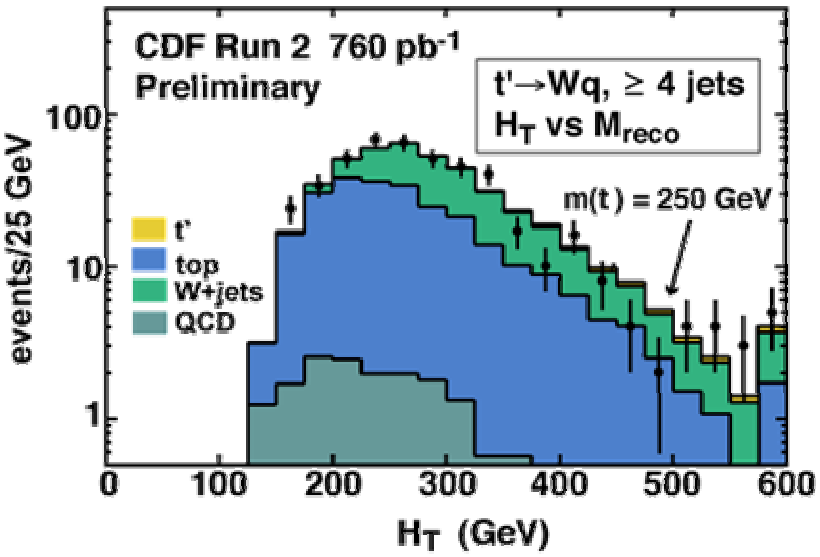
4th Generation Quark (t')

signature : 1ν + 4jets

- heavy top (t') quark pair production decaying to Wq final states (t' -> Wq)
- signature : lepton + ME_T + jets
- reconstruct the mass of the t' quark
- 2D-fit of the observed (H_T , M_{reco}) distribution to discriminate signal from SM backgrounds
- exclude SM 4th generation t' quark with mass below 258 GeV at 95% CL







Extra Dimensions (ED)

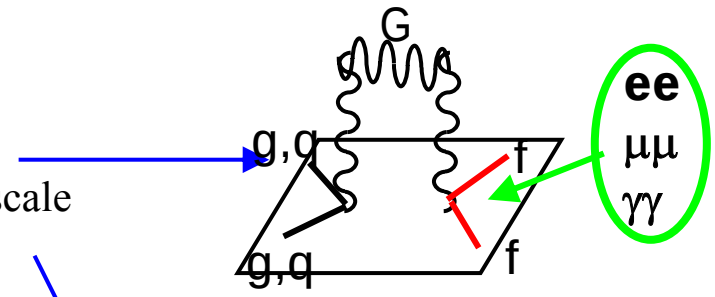
Alternatives to SUSY for resolving the hierarchy problem ($M_{EW} << M_{Plank}$?)
In this model, gravition can propagate in additional spatial dimensions

- Models with n extra spatial dimensions

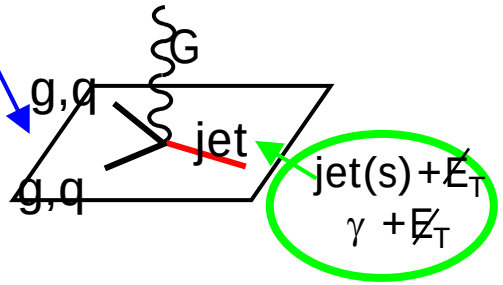
✓ Large ED(LED) :
n>0 (n>2) compactified
$M^2_{Pl} \sim R^n M_D^{n+2}$, M_D: string scale

✓ 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



Graviton Exchange



Graviton Emission

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

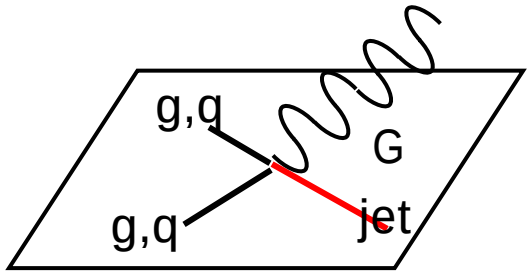
At the Tevatron, searched
- LED : **ee, μμ, γγ, jet+MET**
- TeV^{-1}ED : **ee**
- RS : **ee, μμ, γγ**

LED (graviton emission) : Jet + ME_T

Direct production of graviton

qq, qg, gg-> gG, qG :

a single energetic jet + large ME_T



heavy G escapes to extra D

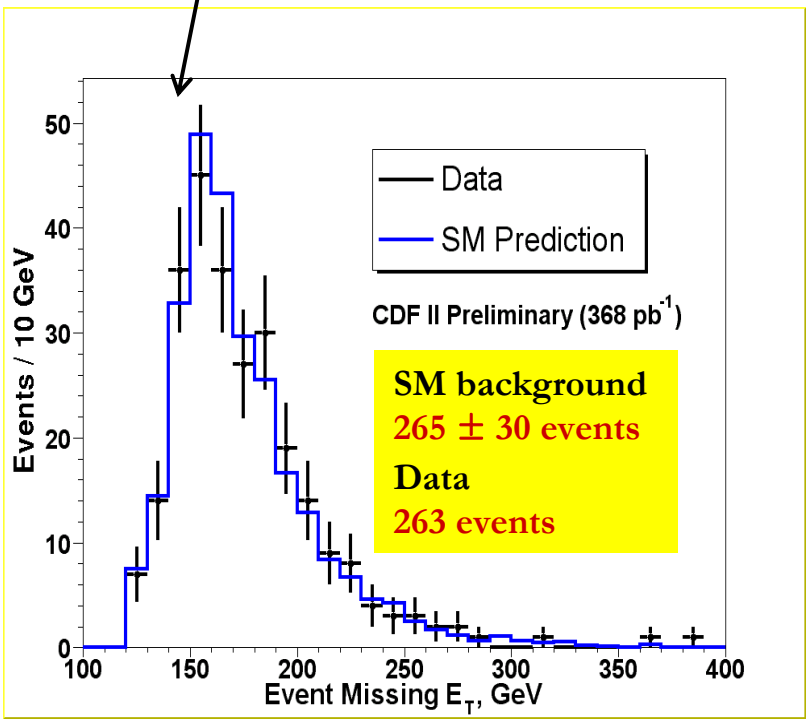
⇩

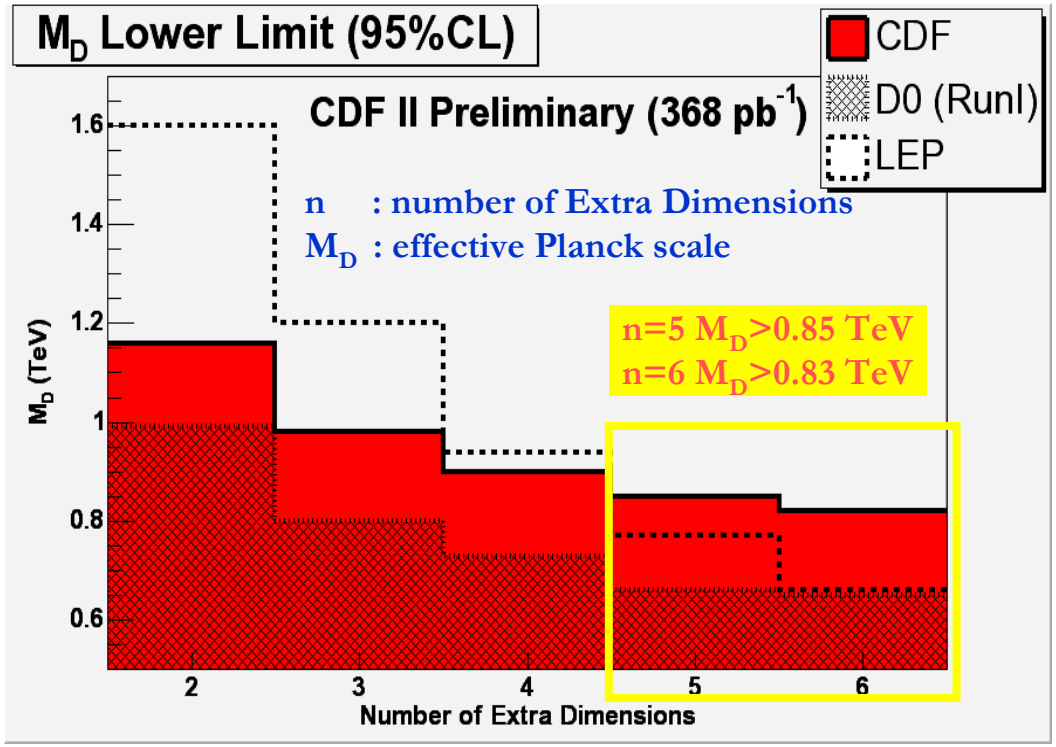
large MET

⇩

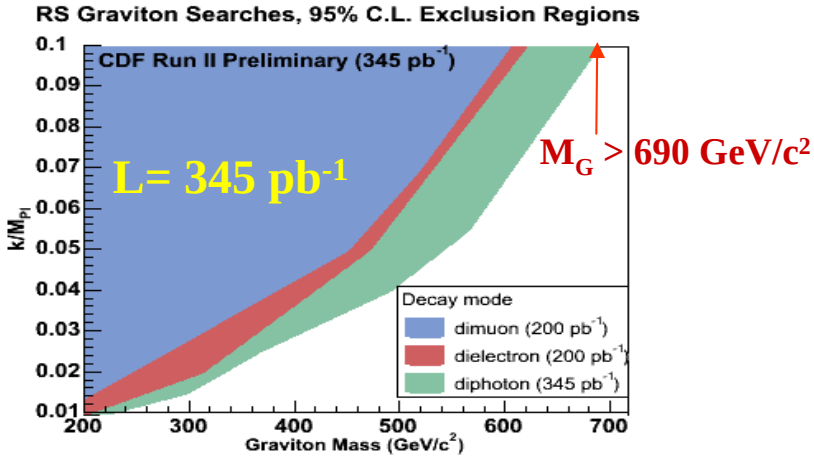
recoil jet very energetic

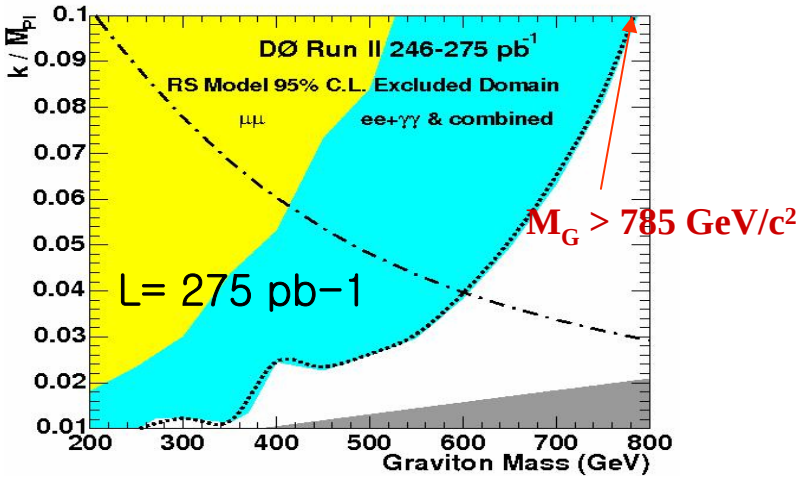
L ~ 368 pb^{-1}
One central jet p_T > 150 GeV
ME_T > 120 GeV



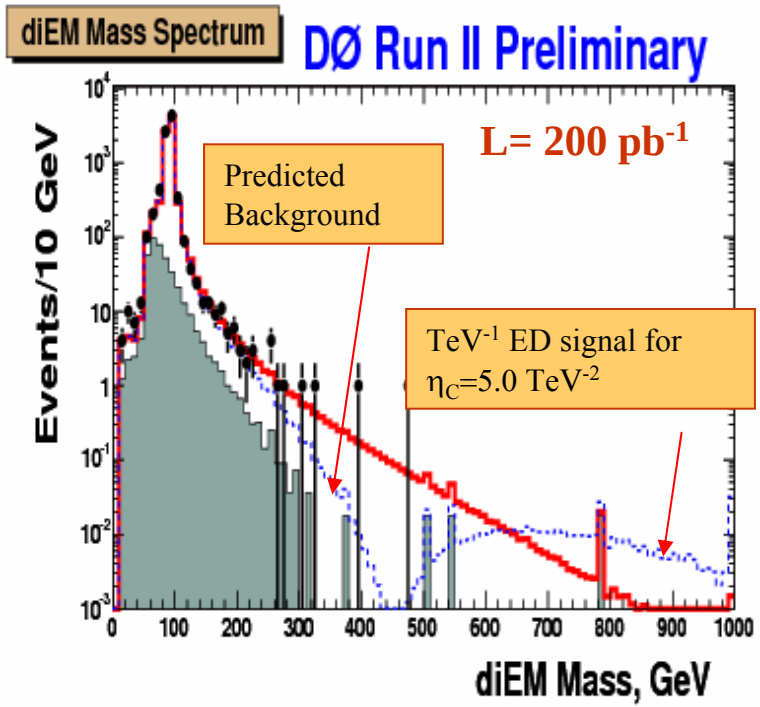


RS Graviton & TeV−1 ED : ee, μμ, γγ





- **RS gravitons are excluded by these data in the plane of coupling (k/M_{Pl}) versus effective graviton mass.**



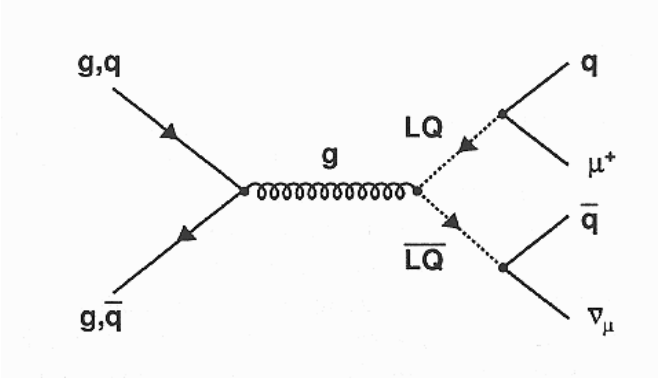
- **TeV^{-1} ED : Gauge Boson Exchange**
- **Set Limit on M_C via η_C**
- **Lower Limit on compactification scale:**

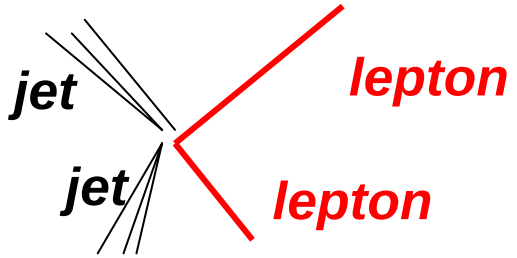
  M_C > 1.12 TeV at 95% CL
- **World Limit(incl. LEP indirect search limit) :**

  M_C > 6.8 TeV at 95% CL

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
- LQs can be scalar (spin=0) or vector (spin=1) : 'SLQ' or 'VLQ'
- 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)**





$(lq)(lq)$

	1st Generation	2nd Generation	3rd Generation
β=1	$LQ\,\overline{LQ}\to e^-e^+q\bar{q}$	$LQ\,\overline{LQ}\to \mu^+\mu^-q\bar{q}$	$LQ\,\overline{LQ}\to \tau^+\tau^-q\bar{q}$
β=0.5	$LQ\,\overline{LQ}\to e^\pm\nu_e q_i q_j$	$LQ\,\overline{LQ}\to \mu^\pm\nu_\mu q_i q_j$	$LQ\,\overline{LQ}\to \tau^\pm\nu q_i q_j$
β=0	$LQ\,\overline{LQ}\to \nu_e\nu_e q\bar{q}$	$LQ\,\overline{LQ}\to \nu_\mu\nu_\mu q\bar{q}$	$LQ\,\overline{LQ}\to \nu_\tau\nu_\tau q\bar{q}$

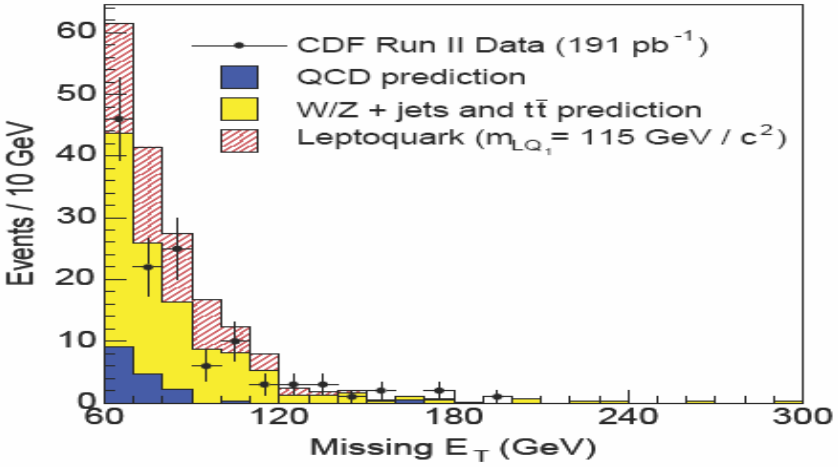
SLQ (β=0)

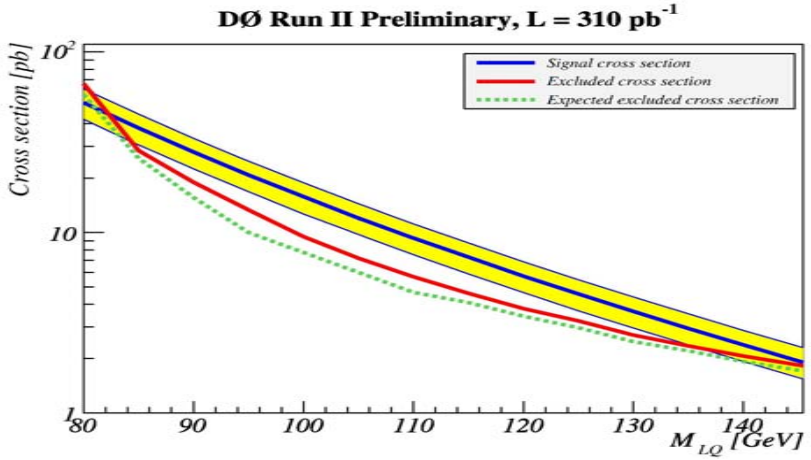
pp -> LQLQ -> ννjj : 2 acoplanar jets + ME_T

Main background :
- Z(νν)+jets
- W(lν)+jets
- QCD multijets

	CDF	DØ
	L ~ 191 pb^{-1}	L ~ 310 pb^{-1}
2 central jets	p_T > 40, 25 GeV	p_T > 60, 50 GeV
MET	> 60 GeV	> 80 GeV
no isolated track, no electron or muon		
cuts on ΔΦ(MET, jet) to remove SM and QCD background		

DATA	124	86
SM	118.3± 14.5	$75.2^{+10.1}_{-9.7}{}^{+10.7}_{-12.2}$



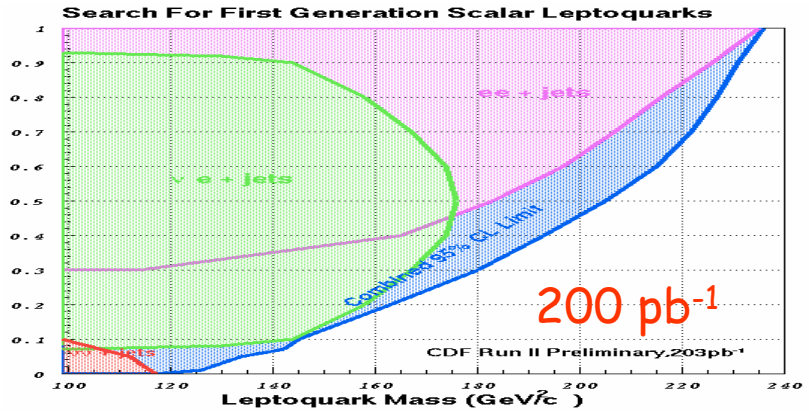


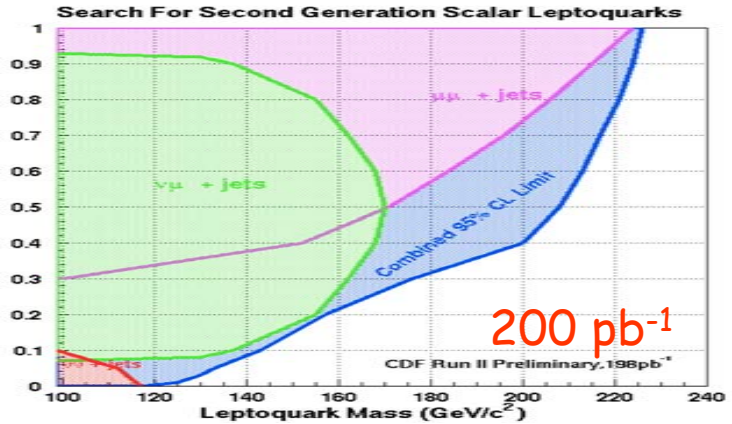
DØ: β = 0 M_{LQ} > 136 GeV @95% CL

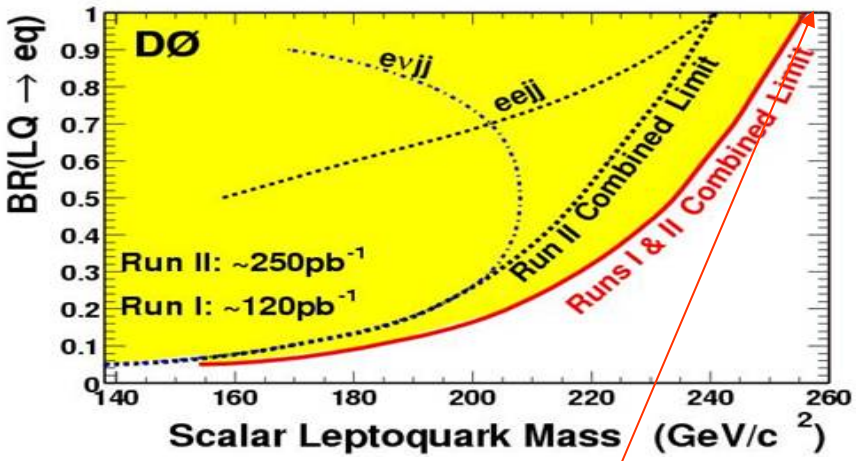
CDF: β = 0 M_{LQ} > 117 GeV @95% CL

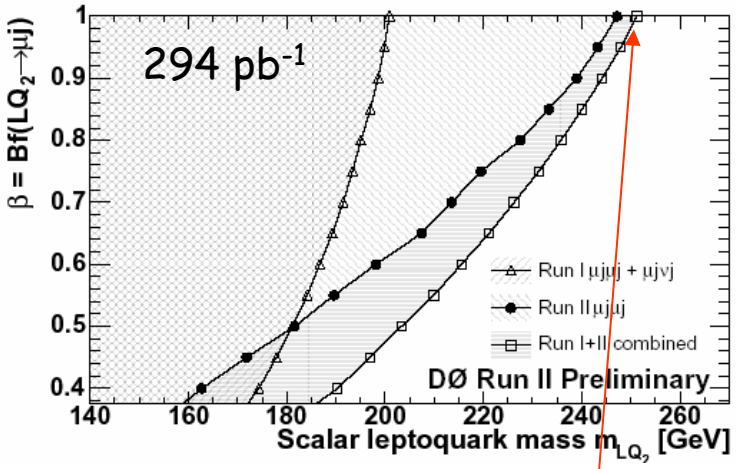
1st and 2nd generation SLQ (combined)

- 1st Gen : eejj,,evjj, νvjj
- 2nd Gen : μμjj,νvjj,μvjj









For β =1, I generation
CDF: Run II, $M_{LQ} > 235$ GeV/c²
D0: Run I + II, $M_{LQ} > 256$ GeV/c²

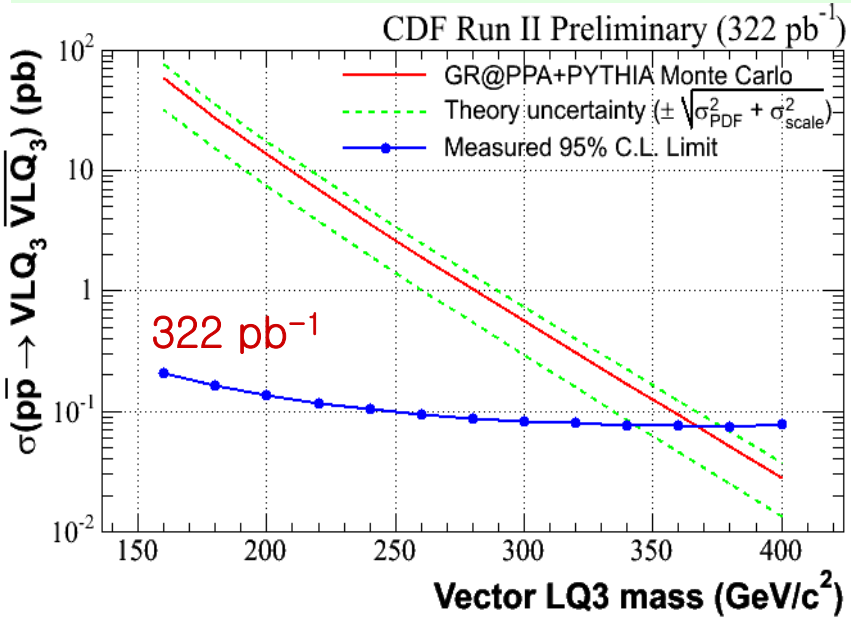
for β =1, II generation
CDF: Run II, $M_{LQ} > 224$ GeV/c²
D0: Run I+II, $M_{LQ} > 251$ GeV/c²

3rd Gen. LQ (Vector & Scalar) (β=1)

Channel : $\tau_l \tau_h$ j j (one leptonic, one hadronic decayed τ's)

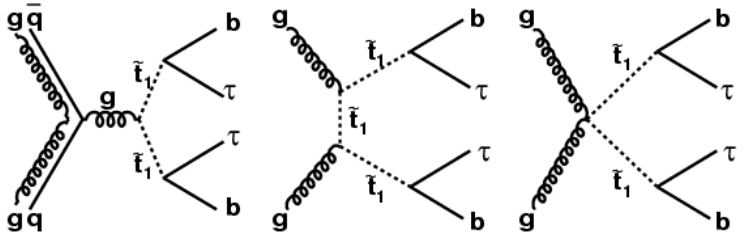
VLQ3 Br (VLQ3 -> τ b) = 100% (β=1)

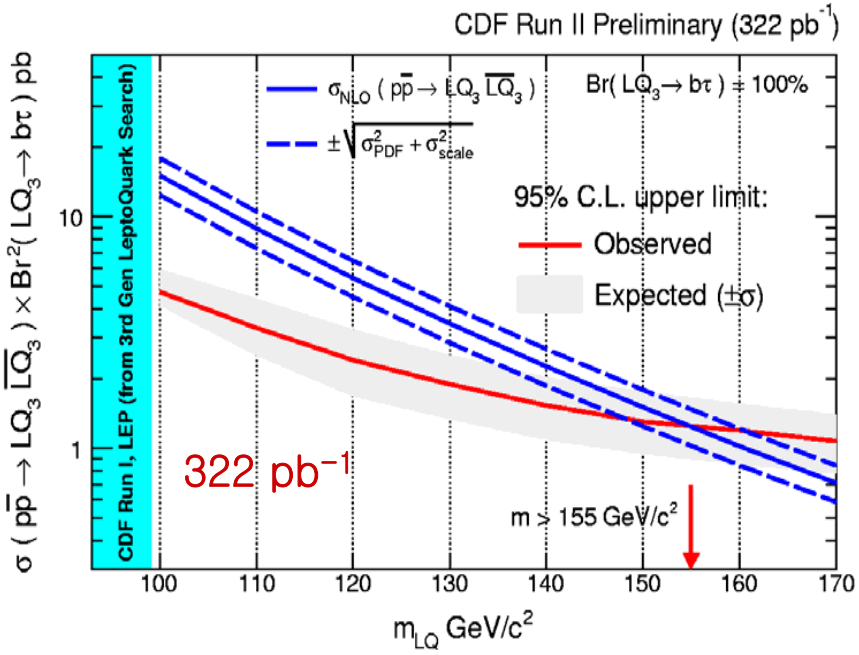
- $\tau_l + \tau_h$ → $P_T(l) > 10$ GeV/c, $P_T(\tau_h) > 15$ GeV/c
- opposite sign of lepton and tau
- $\not\!\!E_T > 10$ GeV
- $H_T = P_T(l) + P_T(\tau_h) + P_T(\text{jet}) + \not\!\!E_T > 400$ GeV/c
- $n_{jet} >= 2$
- removal of conversions, cosmics, and DY



for β=1,
CDF: Run II, $M_{VLQ3} > 344$ GeV/c^2

SLQ3 final state: ττbb, same as the RPV Stop search signature





for β=1,
CDF: Run II, $M_{SLQ3} > 151$ GeV/c^2

Anomalous Diphoton + X Production
(X= e, μ, γ)

- Searches based on the final state signature

diphoton trigger: E_T>12 (isolated), E_T>18 GeV

2 central photons $|\eta| < 1$ E_T >13 GeV

γγ+e,μ	γγ+γ
(L ~ 683 pb^{-1})	(L ~ 1020 pb^{-1})
one electron E_T > 20 GeV **one muon p_T > 20 GeV**	**A third photon** **$|\eta| < 1$ E_T >13 GeV**

Source	electron	muon
$Z\gamma\gamma$	$0.535 \pm 0.014 \pm 0.049$	$0.307 \pm 0.011 \pm 0.028$
$W\gamma\gamma$	$0.117 \pm 0.008 \pm 0.011$	$0.048 \pm 0.005 \pm 0.004$
Fake $l+\gamma\gamma$	$0.093 \pm 0.004 \pm 0.038$	$0.006 \pm 0.005 \pm 0.003$
$l\gamma + \text{jet} \to \gamma$	$0.386 \pm 0.021 \pm 0.220$	$0.093 \pm 0.011 \pm 0.114$
$l\gamma + e \to \gamma$	$3.363 \pm 0.272 \pm 0.760$	$0.017 \pm 0.017 \pm 0.004$
Total	4.49 ± 0.84	0.47 ± 0.12
Data	2	0

γγγ	0.7 ± 0.1
Fakes	1.2 ± 0.6
Total	1.9 ± 0.6
Observed	4

Conclusion

1. **Current results based on 0.2 ~ 1 fb^{-1}**
2. **At present, ~ 1.2 fb^{-1} on tape**
3. **World best Limits on Z', LQ, LEDs etc..**
4. **Second stage of analysis with ~ 1fb^{-1} data**
5. **At the end of 2009, we may have 4 ~ 8 fb^{-1}**
6. **So far, ~ 10% of data analyzed from expected data till 2009**
7. **Expect real discoveries !!??**

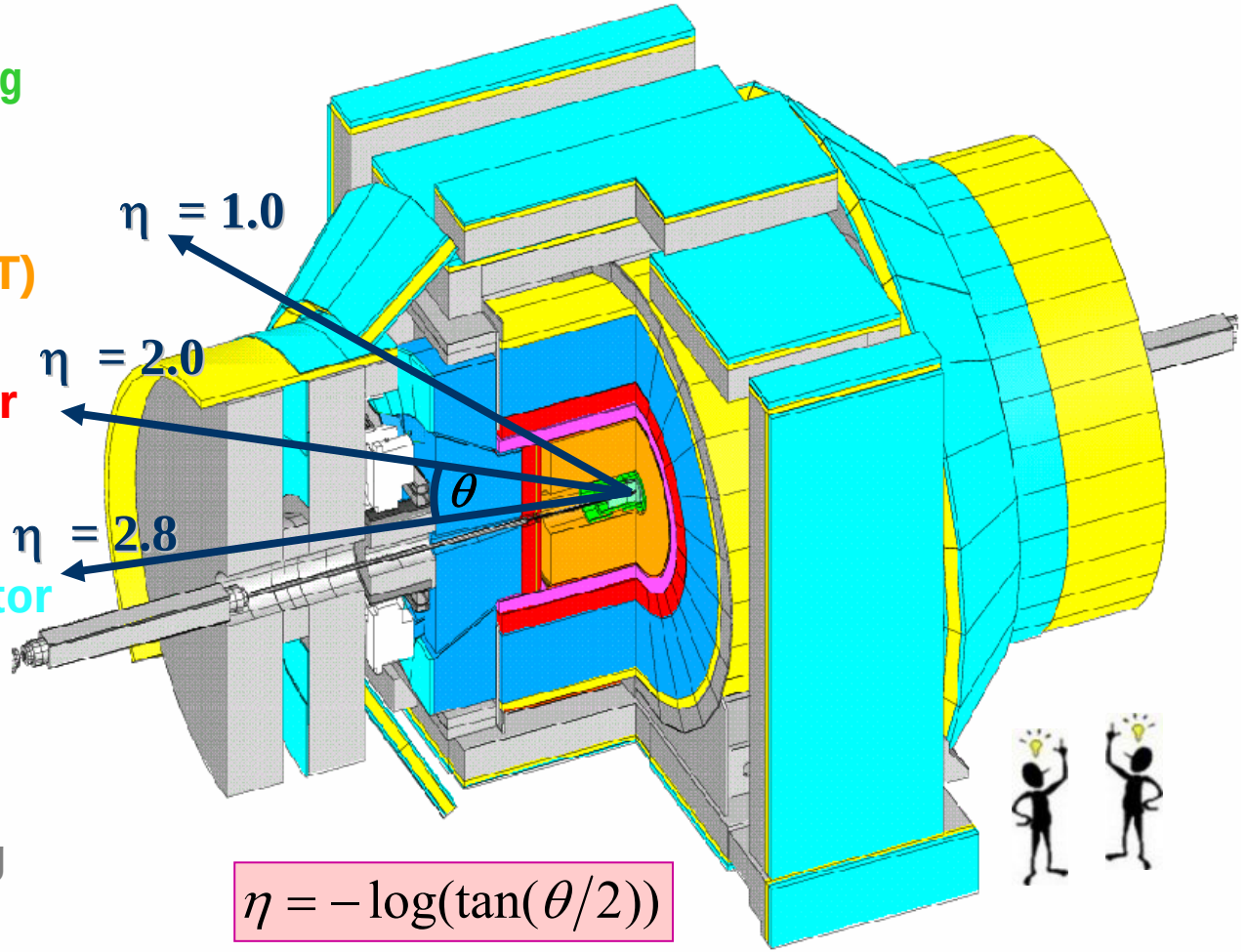
http://www-cdf.fnal.gov/physics/exotic/exotic.html

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

Back up

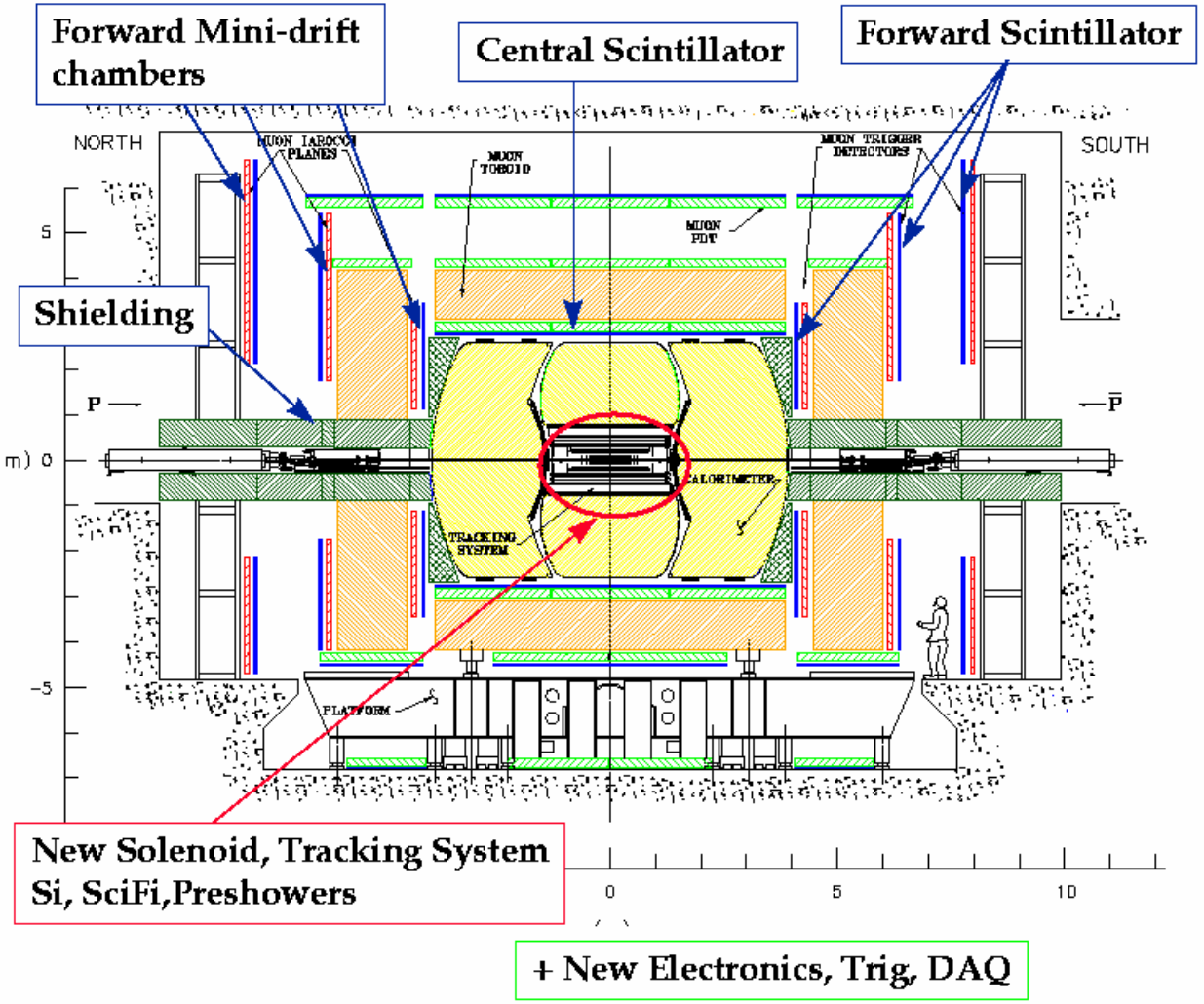
CDF Detector

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



$$\eta = -\log(\tan(\theta/2))$$

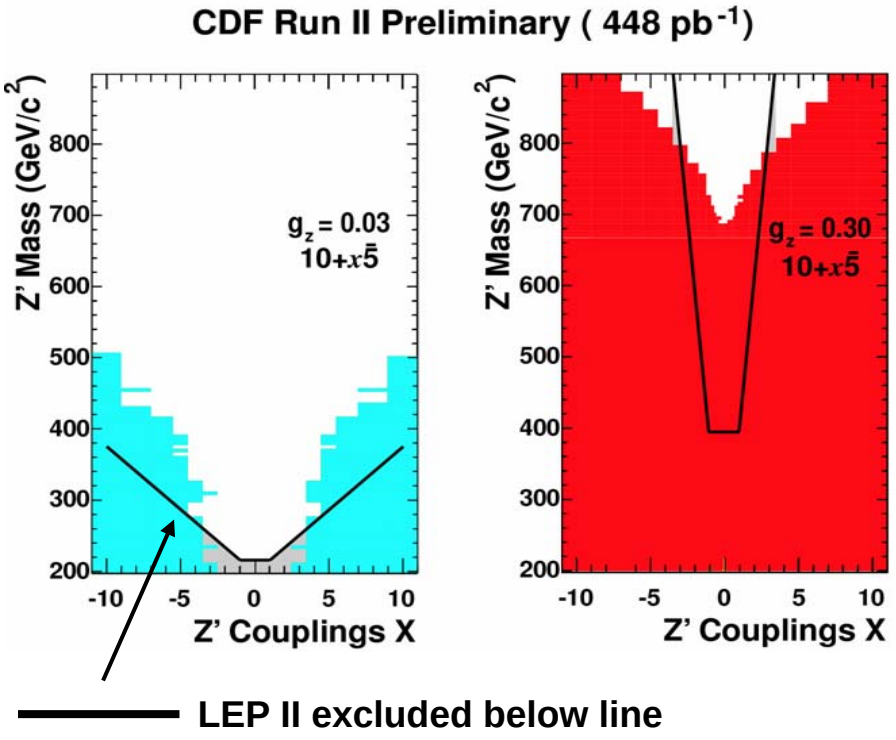
D0 Detector


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

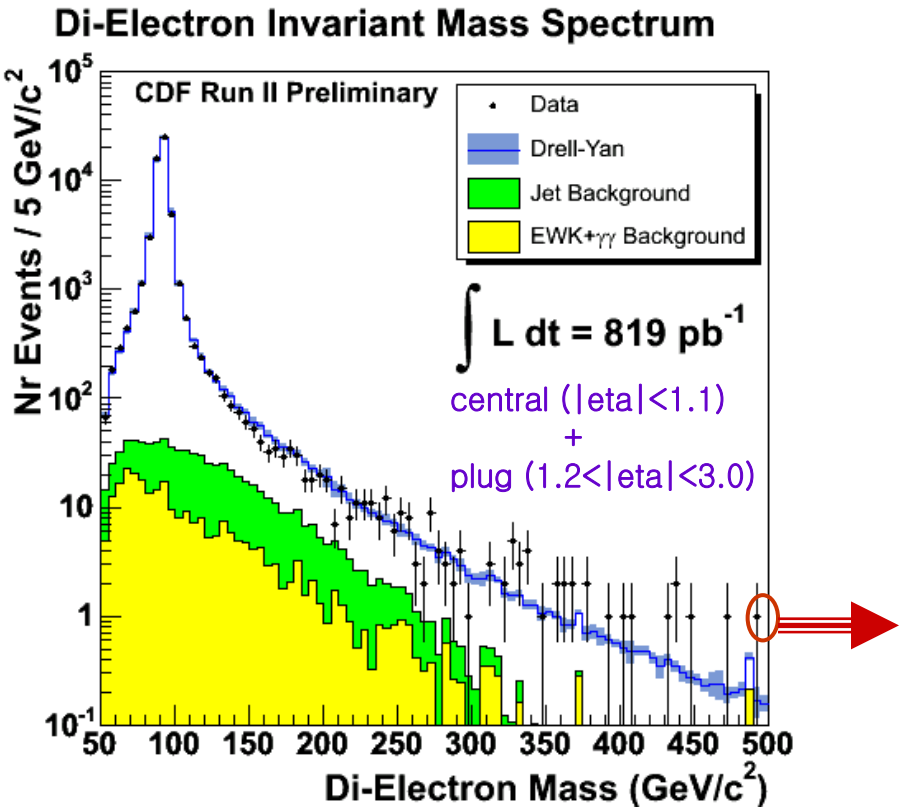
Generic Z' : $Z' \rightarrow e^+ e^-$ @448 pb^{-1}

- 2004 paper by *Carena et al* defines 4 general model classes (*PRD70:093009,2004*):
  - B−xL, q+xu, 10+x5, d−xu
  - Within each class, Z' defined by: mass $M_{Z'}$, strength g_z, parameter x

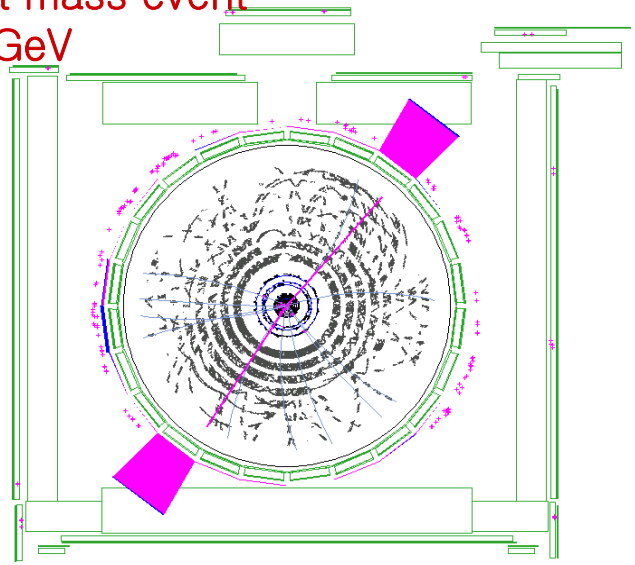
- Comparisons to LEP 2 possible:
  - q+xu, 10+x5, d−xu more exclusion than LEP II
  - As well as LEP II for B−xL
  - More sensitive than LEP to low g_z couplings

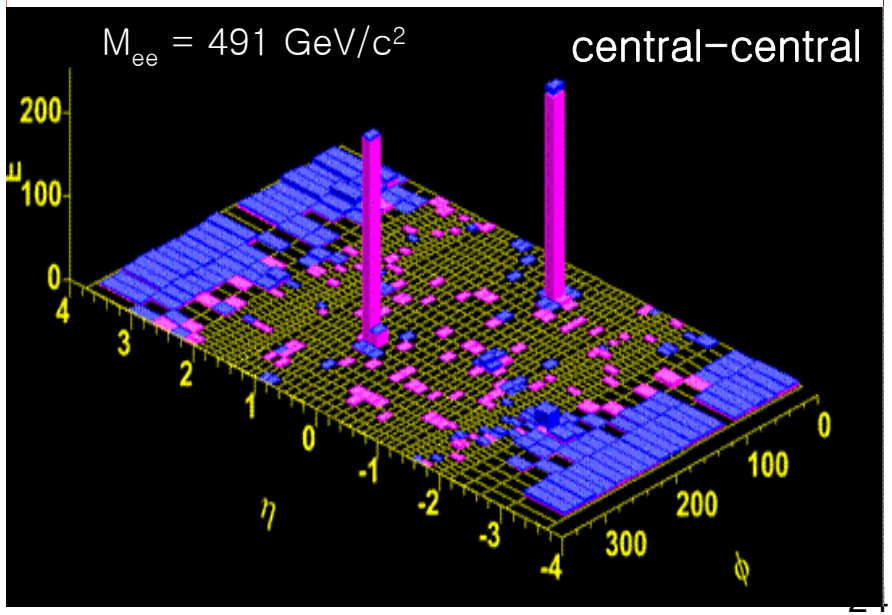


Z'→ee (819 pb^{-1})



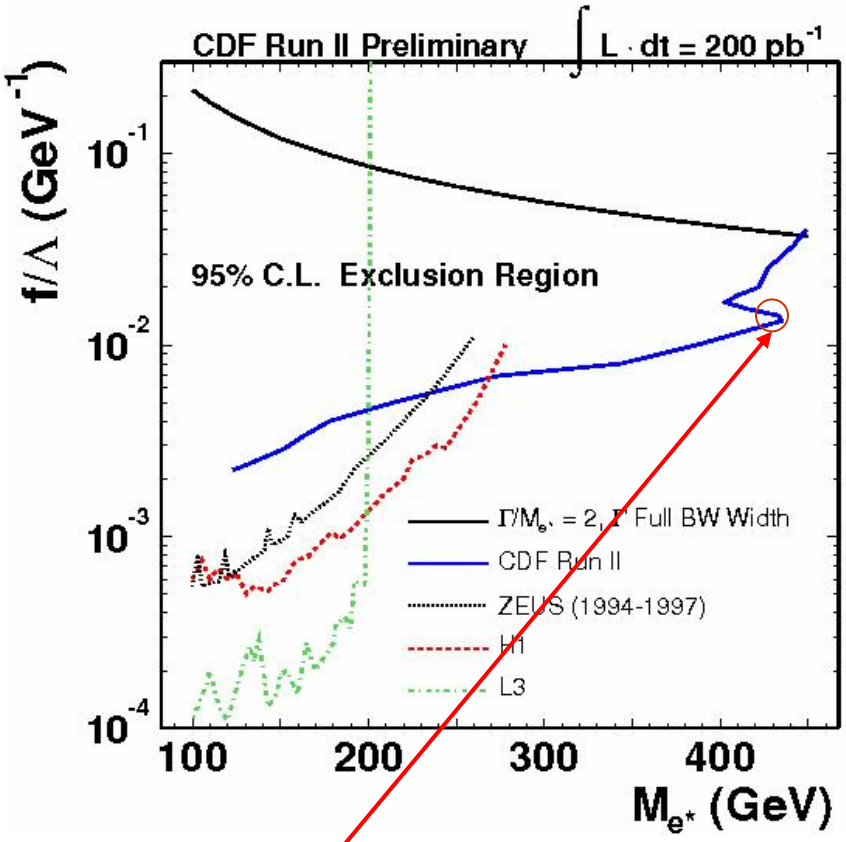
highest mass event
at 491GeV

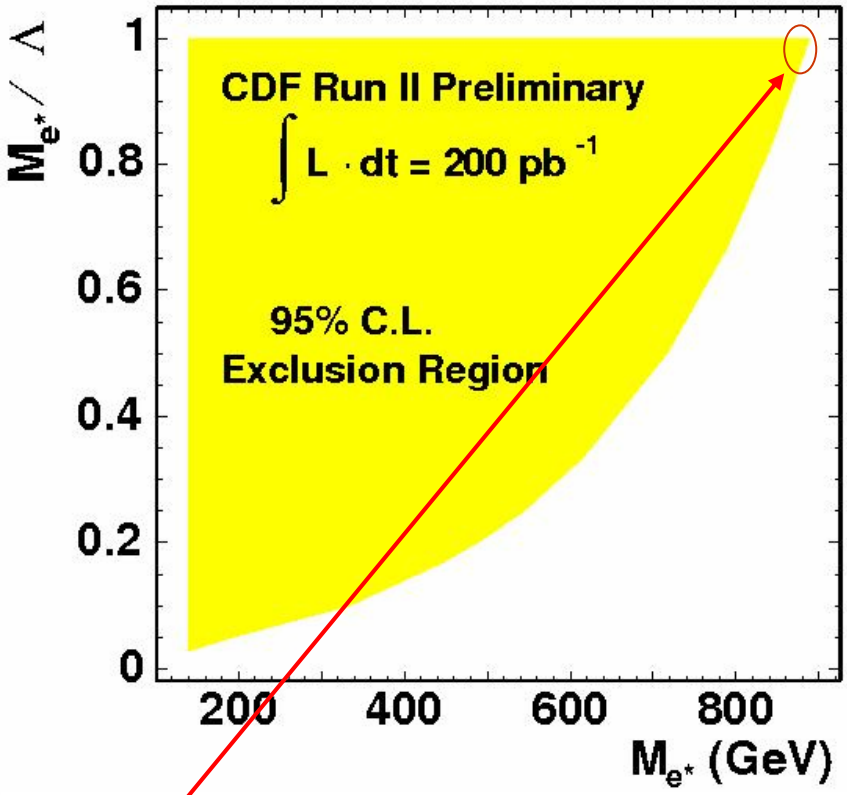




Limits for e*→ eγ

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)

LED (graviton exchange) : ee + γγ

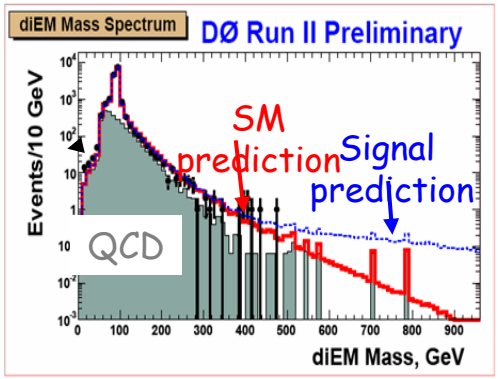
• Gravity effect is parametrized by η_G

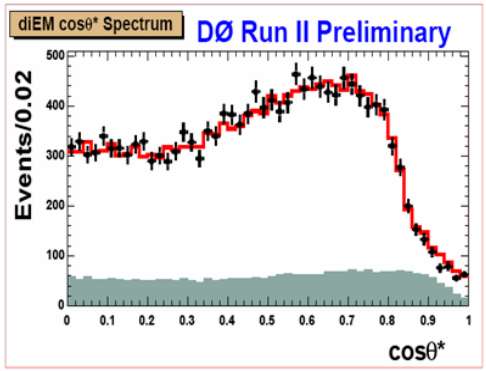
$$\frac{d^2\sigma}{dM\,d\cos\theta^*} = f_{SM} + f_{\text{int}}\eta_G + f_{KK}\eta_G^2$$

ee, γγ invariant

Scatt. angle

Functions of M & cosθ* determined by theory





- 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(M_D) (in TeV)

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

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 λ/π, λ = ±1

L (pb^{-1})	Final state	GRW [1]	HLZ[2]						Hewett[3]
			n=2	n=3	n=4	n=5	n=6	n=7	Λ=+1/λ=-1
200 CDF	ee	1.10	-	1.31	1.10	0.999	0.929	0.879	0.987/0.959
246 D0	μμ	1.07	1.09	1.27	1.07	0.97	0.90	0.85	0.96/0.93
275 D0	ee+γγ	1.48	1.74	1.76	1.48	1.33	1.24	1.17	1.32/1.21

RunI+RunII