



Searches for BSM (non-SUSY physics) at the Tevatron

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collaborations
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Searches for Exotic Physics

► Motivation:

- Search for anomalous behavior in the data
- Provide non-susy and non-higgs explanations to open questions in the Standard Model (SM)
 - Are quarks and leptons composite particles?
 - Do extra dimensions exist?
 -

► General Search Strategies

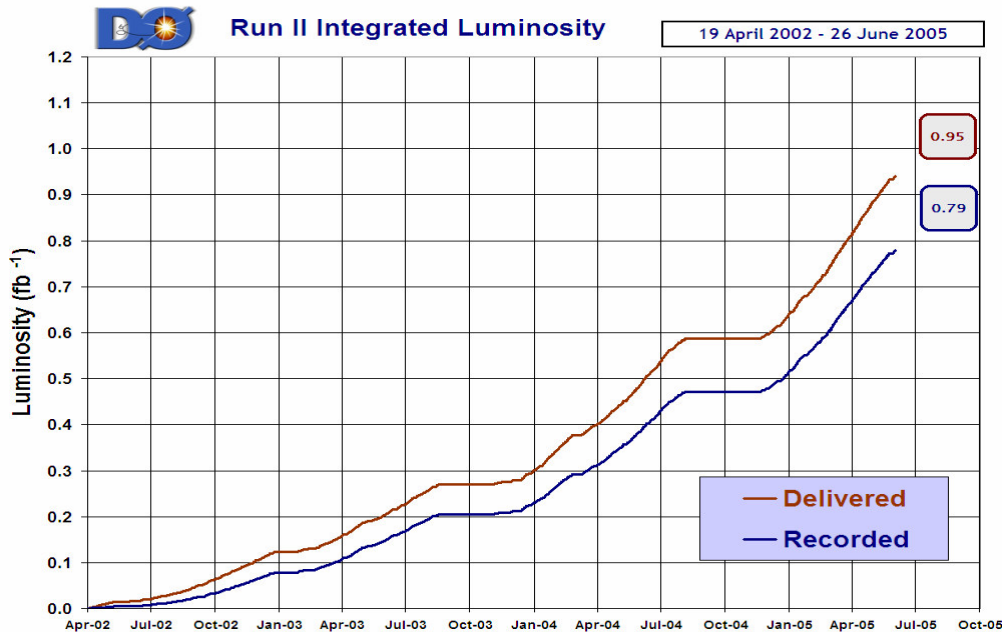
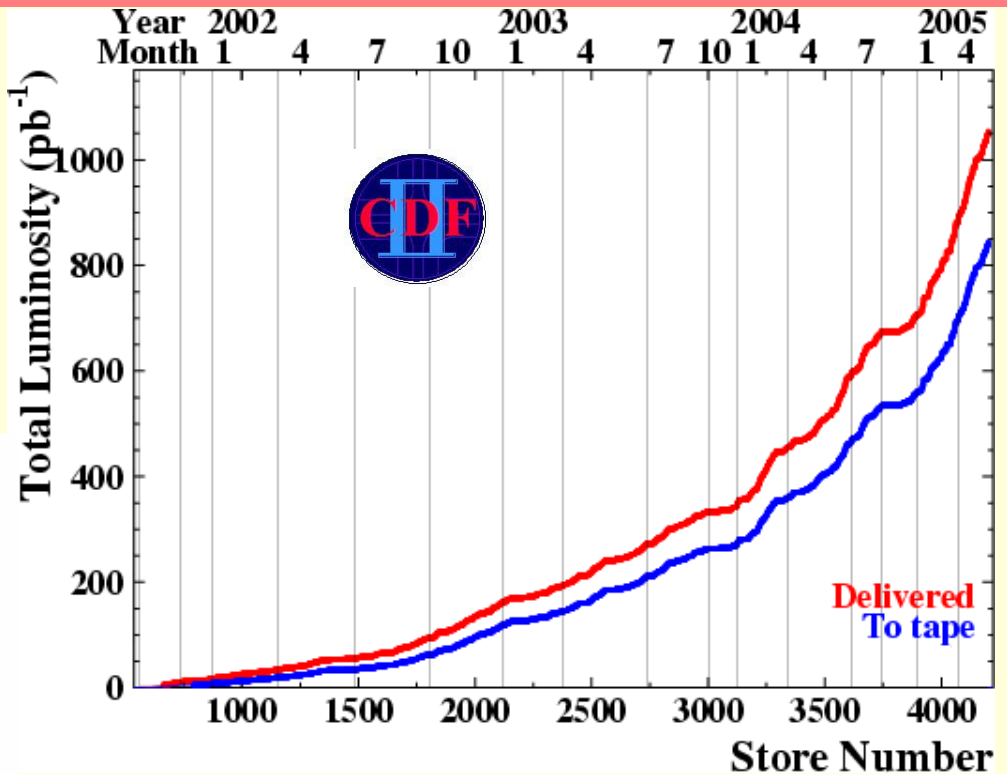
- Thorough understanding of SM and detector backgrounds
 - Monte Carlo for SM backgrounds
 - Data (where possible) for understanding mis-identification rates
- Understand model signal acceptances
- Optimize analyses for signal, not according to model, prior to looking in the signal region of the data

Searches for New Physics

Search	Signature
Z'	$ee, \mu\mu, \tau\tau$
Large Extra Dimensions	$ee, \mu\mu, \tau\tau, \gamma\gamma$
Lepton-Quark Compositeness	$ee, \mu\mu, \tau\tau$
Randall-Sundrum Graviton	$ee, \mu\mu, \tau\tau, \gamma\gamma$
W'	$e\nu$
Excited Electrons	$ee\gamma$
Leptoquarks	$jj + (\ell\ell, \ell\nu_\ell, \nu_\ell\nu_\ell)$

Run II Data Summary

- Tevatron has delivered $\sim 1.05 \text{ fb}^{-1}$ to CDF
- CDF has collected about $\sim 0.85 \text{ fb}^{-1}$ of data



- Tevatron has delivered $\sim 0.95 \text{ fb}^{-1}$ to D0
- D0 has collected about $\sim 0.79 \text{ fb}^{-1}$ of data

► Results shown today are based on data samples of $\sim 0.2 - 0.45 \text{ fb}^{-1}$

Dilepton Searches

High Mass Dilepton Searches

Motivations:

- ▶ Small source of background:
 - Irreducible SM Z/γ^* (well understood)
 - γ +jet and multijet events

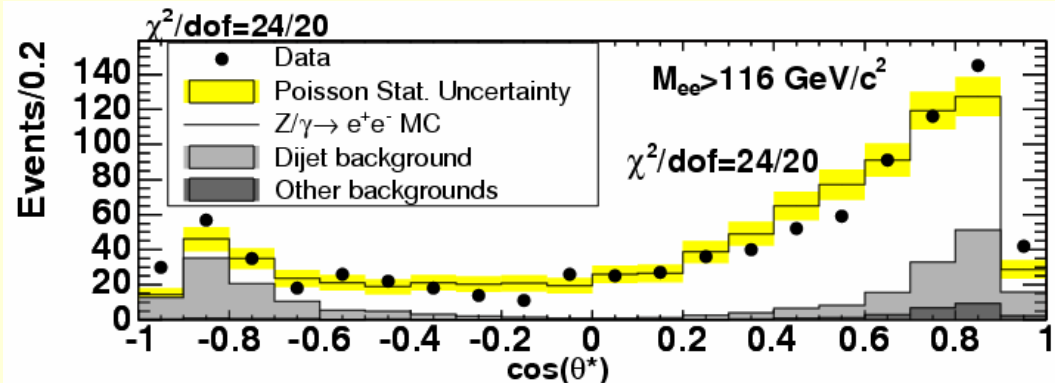
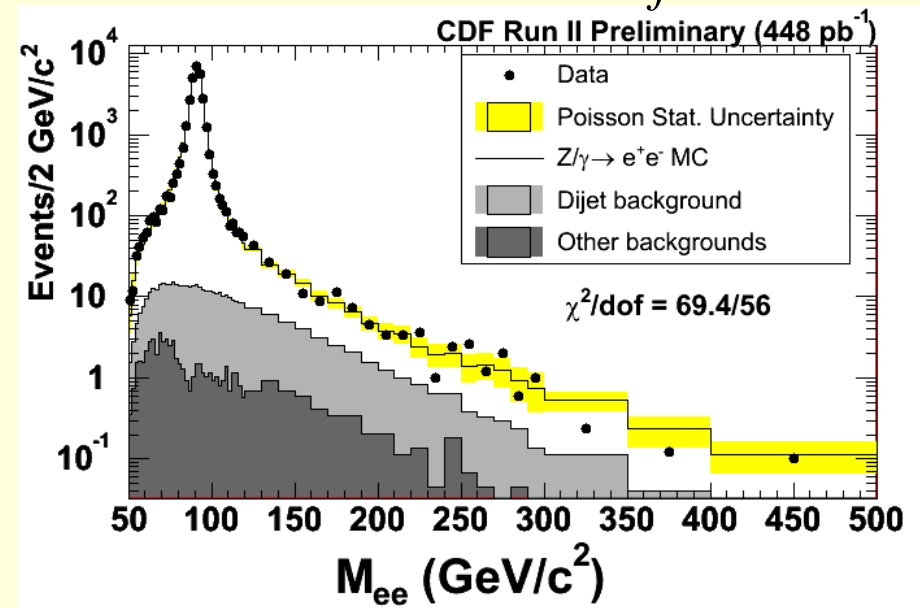
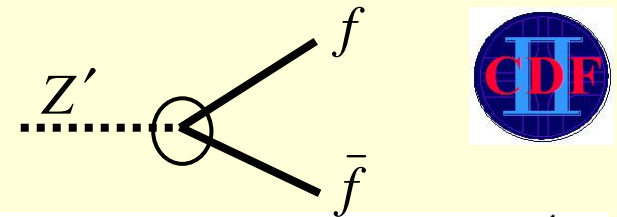
- ▶ Results applicable to many theories
 - Extended Gauge Theories (Z')
 - Technicolor
 - Lepton-quark compositeness
 - Large extra dimensions/effective Planck scale
 - Randall-Sundrum Gravitons



Z' Searches

$Z' \rightarrow e^+e^-$ Search

- ▶ Most extensions to SM predict new gauge interactions
 - Most give neutral or singly charged bosons
- ▶ Search for decays: $Z' \rightarrow e^+e^-$
 - Use dielectron mass M_{ee} and $\cos\theta^*$
 - Dataset: 448 pb⁻¹
- ▶ Adding angular information helps:
 - At 448 pb⁻¹: use $\cos\theta^* \equiv +25\%$ data (seq. Z')
- ▶ No evidence of signal:
 - Set 95% C.L. limits:



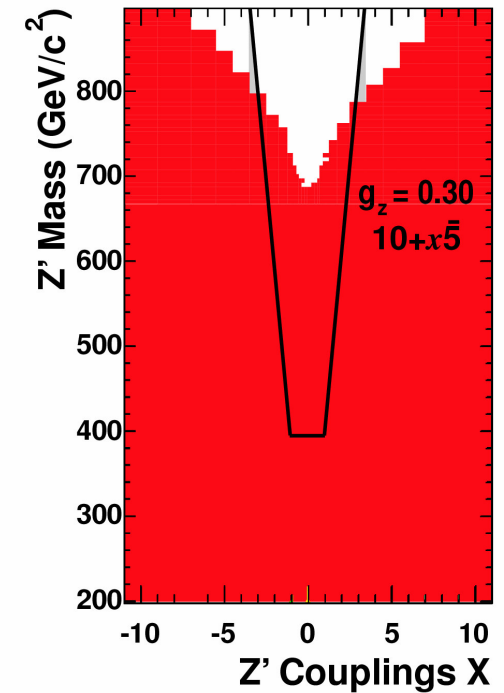
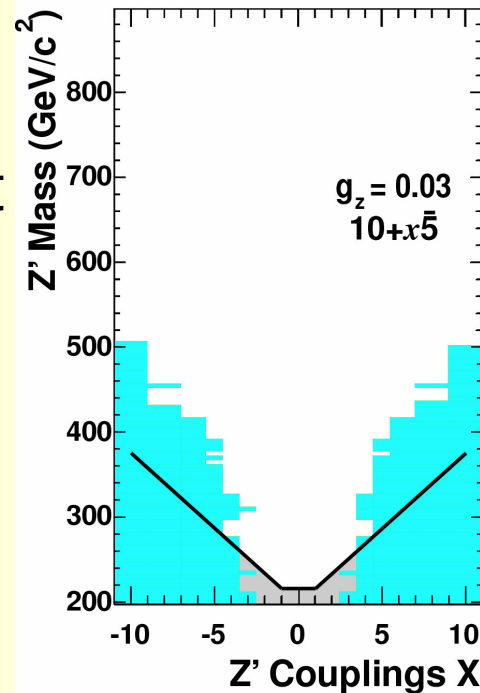
Z' Model	M_Z Limit (GeV)
Seq. Z'	845
E6 Z_χ	720
E6 Z_ψ	690
E6 Z_η	715
E6 Z_1	625

$Z' \rightarrow ee$ Results



- ▶ General formalism for Z' :
 - 4 general model classes that are each defined by 3 parameters (*Carena et al*):
 - Mass $M_{Z'}$
 - Strength $g_{Z'}$
 - Parameter x
- ▶ Below black curves are the LEP II exclusion regions:
 - LEP II \rightarrow indirect search via contact interactions

CDF Run II Preliminary (448 pb⁻¹)

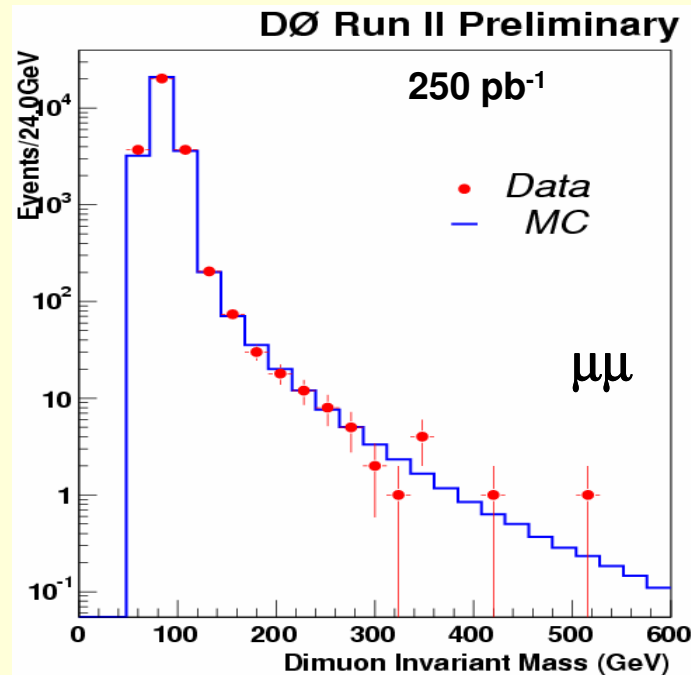
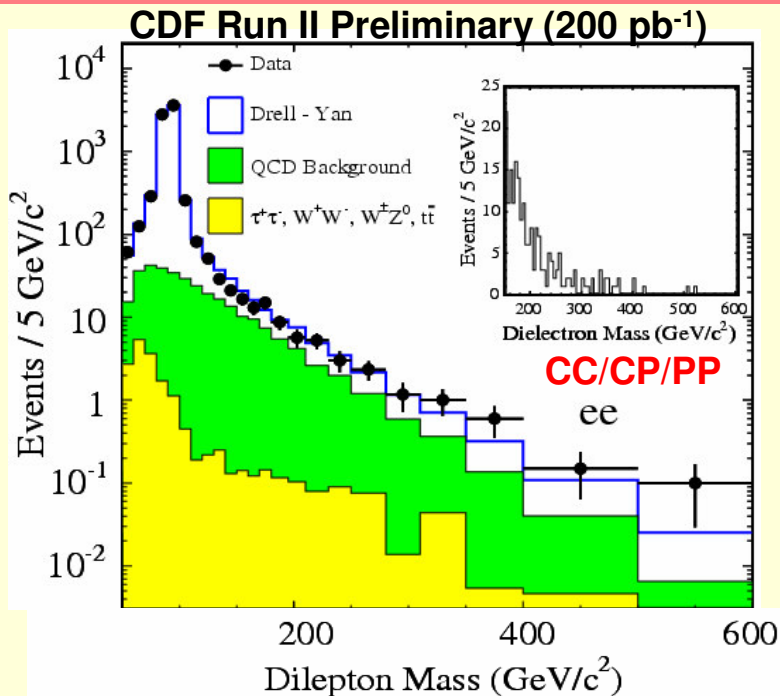


- ▶ This general approach uses M_{ee} and $\cos\theta$ and allows future models to be easily checked

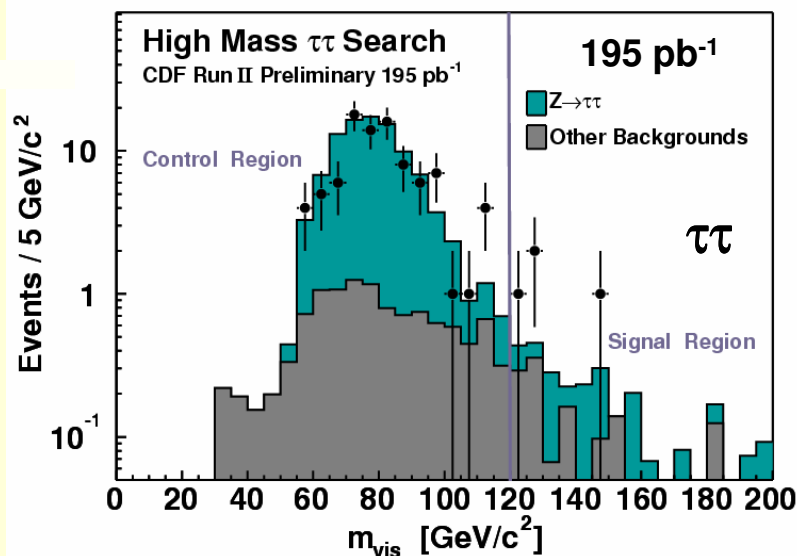
Carena, Daleo, Dobrescu, and Tait
(PRD 70:093009, 2004)

“Traditional” Z' Searches

More Z' Results



Visible mass (m_{vis}) formed from the visible decay products and \cancel{E}_T in the event

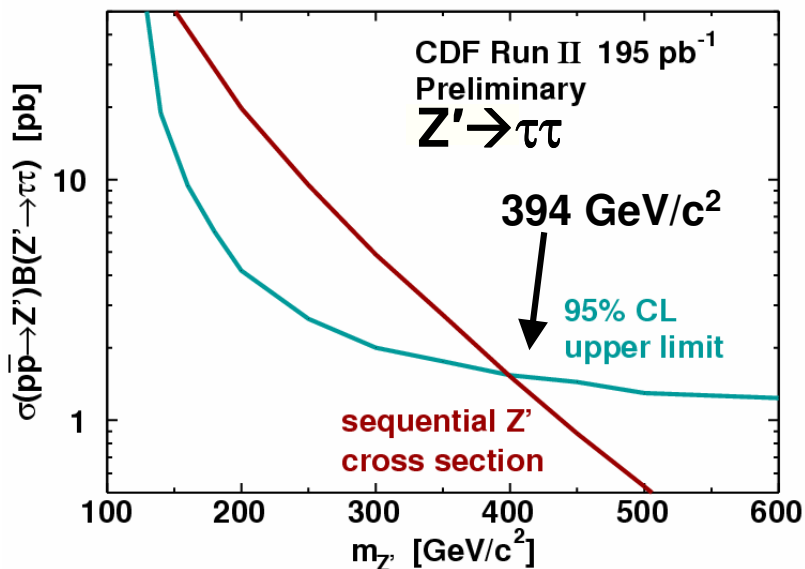
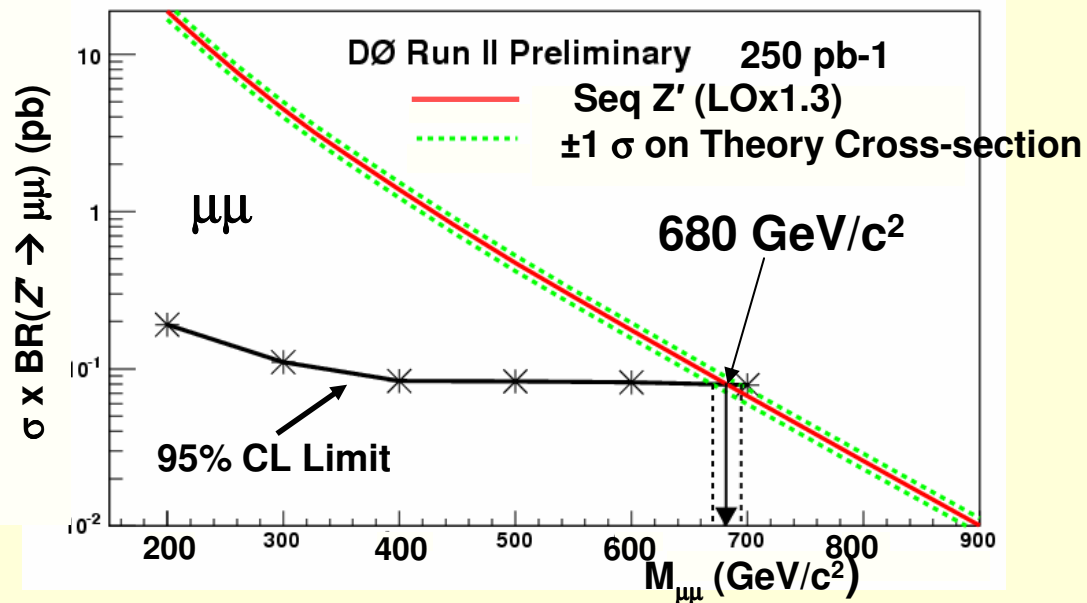
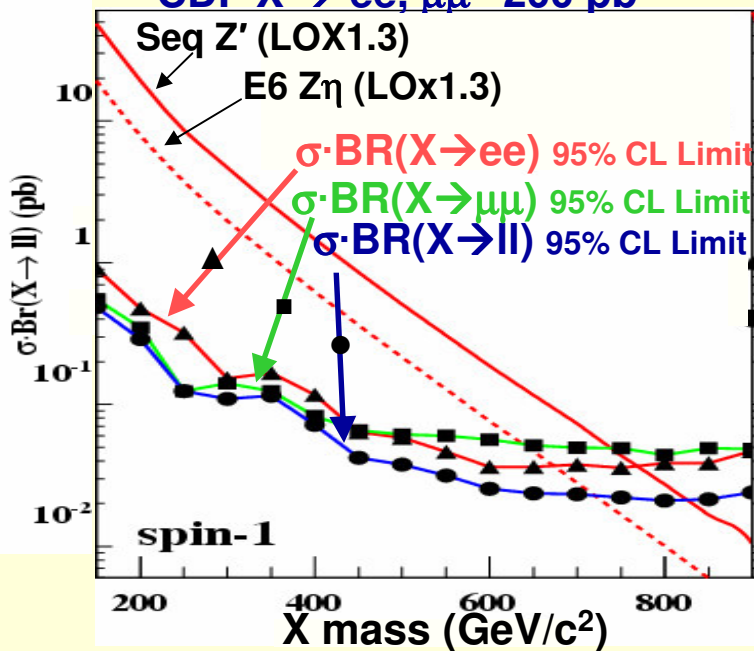


No excess observed in the lepton channels
→ Set limits

More Z' Results



CDF $X \rightarrow ee, \mu\mu$ 200 pb⁻¹



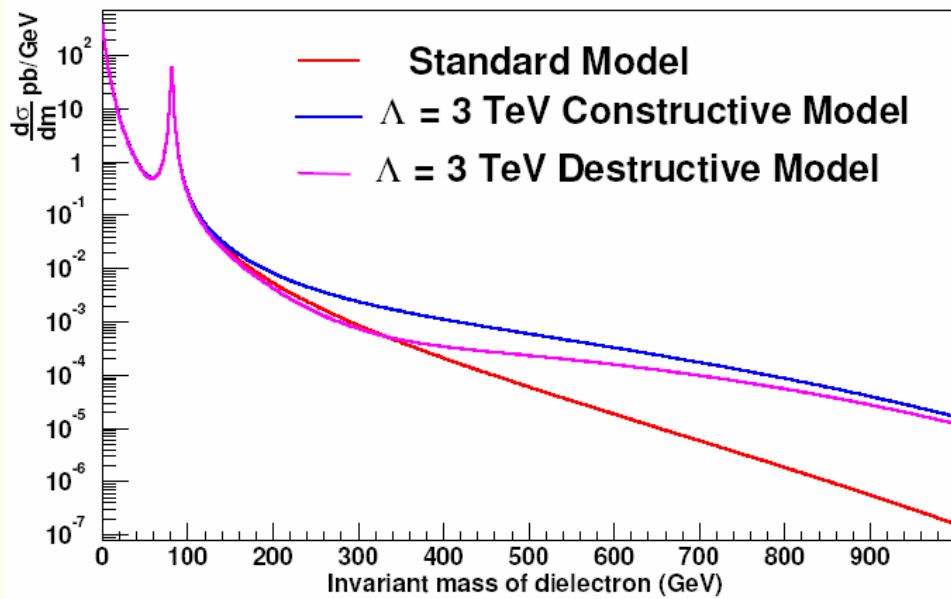
Seq Z' (GeV)	ee	$\mu\mu$	ee+ $\mu\mu$	$\tau\tau$	
CDF:	750	735	815	394	(200/pb)
CDF with $\cos\theta$:	845				(448/pb)
D0:	780	680			(200 – 250 /pb)
E ₆	Z ₁	Z χ	Z ψ	Z η	
CDF:	615	675	690	720	(ee+ $\mu\mu$)
CDF with $\cos\theta$:	625	720	690	715	(ee)
D0:	575	640	650	680	(ee)

Search for Quark-Lepton Compositeness

Quark-Lepton Compositeness

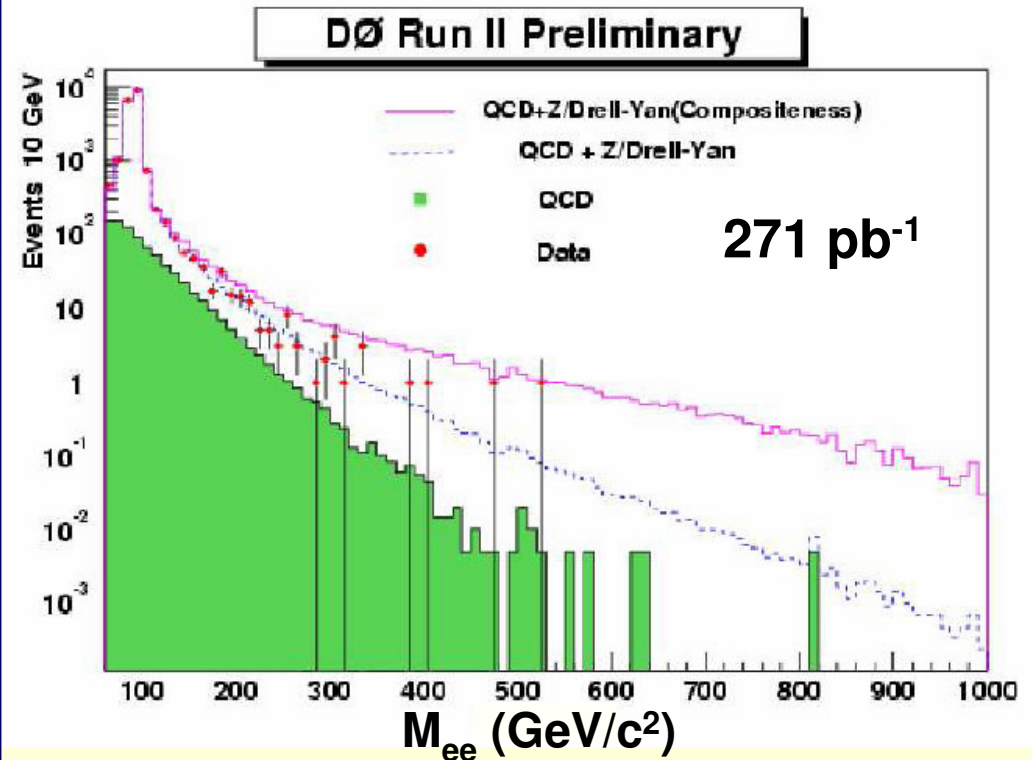
- ▶ Composite models depend on dilepton invariant mass and the compositeness scale Λ

$$\blacksquare \frac{d\sigma_T}{dM} = \frac{d\sigma_{sm}}{dM} + \frac{I}{\Lambda^2} + \frac{C}{\Lambda^4}$$



- ▶ Look for excess in the tail of dilepton distributions

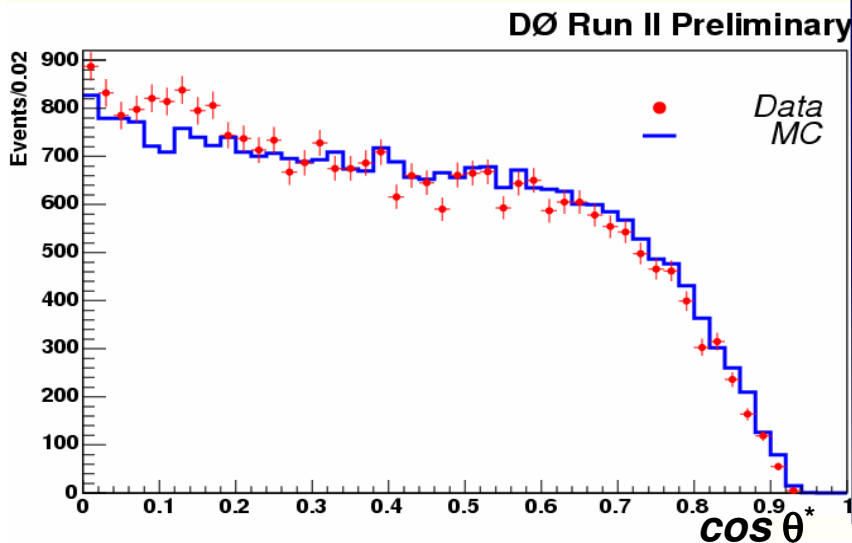
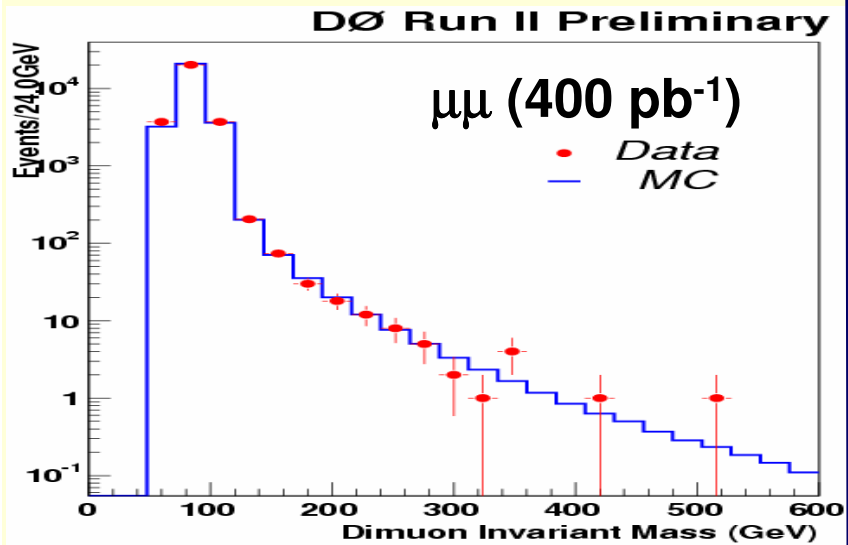
- ▶ Results for ee search:



Quark-Lepton Compositeness



► Results for $\mu\mu$ search:



► Limits for ee ($271/\text{pb}$) and $\mu\mu$ ($400/\text{pb}$):

Model	Λ^- (TeV)		Λ^+ (TeV)	
	ee	$\mu\mu$	ee	$\mu\mu$
LL	6.2	6.9	3.6	4.2
RR	5.8	6.7	3.8	4.2
LR	4.8	5.1	4.5	5.3
RL	5.0	5.2	4.3	5.3
LL+RR	7.9	9.0	4.1	5.0
LR+RL	6.0	6.1	5.0	6.4
LL-LR	6.4	7.7	4.8	4.9
RL-RR	4.7	7.4	6.8	5.1
VV	9.1	9.8	4.9	6.9
AA	7.8	5.5	5.7	5.5

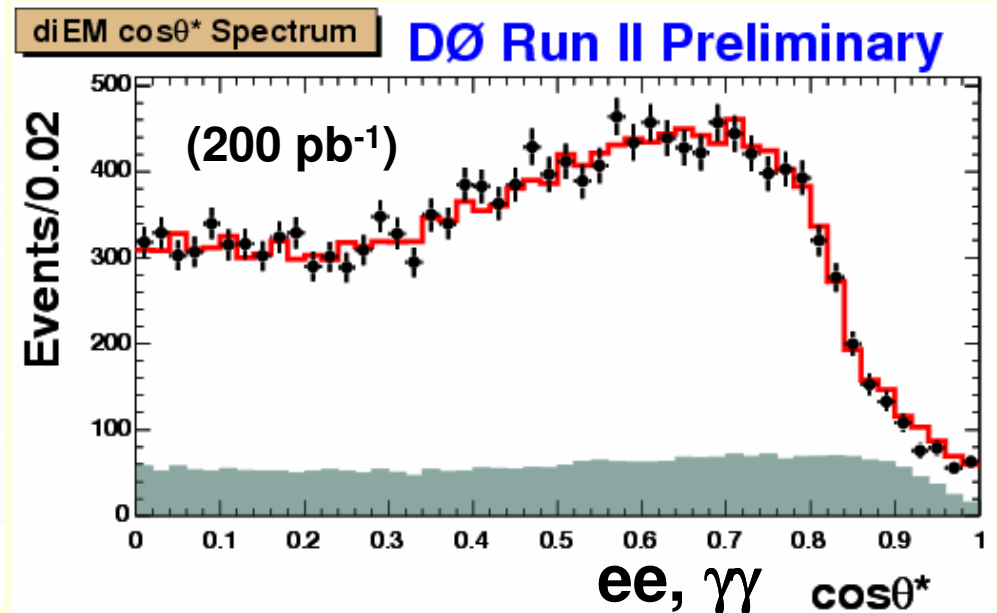
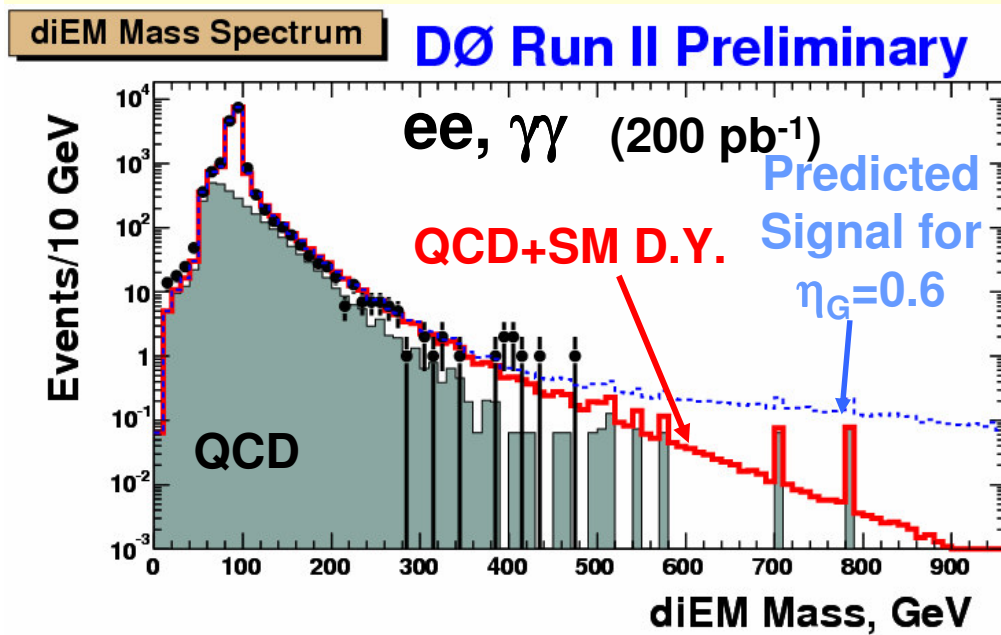
S. Eidelman et al., Phys. Lett. B592, 1 (2004) 2005 update

Extra Dimensions

Large Extra Dimensions ($ee, \gamma\gamma$ channels)



- ▶ Non-susy alternative to the “hierarchy” problem ($M_{EW} \ll M_{Planck} ?$)
 - **Large ED (ADD)** Arkani-Hamed, Dimopoulos, Dvali Phys Lett B429 (98)
 - increase in cross-section at high mass



Large Extra Dimensions (ee, $\gamma\gamma$ channels)



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

- $\eta_G = F/M_s^4$
 - F is a model dependent dimensionless parameter of order 1
 - M_s is the UV cutoff = $M_{PL(4+n \text{ dim})}$

Limits on Fundamental Planck Scale, in TeV

Fit M_{ee} , $M_{\gamma\gamma}$ and $\cos\theta^*$ to extract $\eta_G^{95\%}$

	for $\lambda > 0$ <small>+0.12</small>	for $\lambda < 0$ <small>+0.08</small>
η_G (TeV ⁻⁴)	0.00 ^{-0.00}	-0.08 ^{-0.18}
$\eta_G^{95\%}$ (TeV ⁻⁴)	< 0.292	> -0.432

	GRW: F=1	Hewett: F = 2 λ / π , $\lambda = \pm 1$	HLZ: F=log(M_s^2/M^2), n=2 F=2/(n-2), n>2					
		$\lambda = +1 / -1$	n=2	3	4	5	6	7
D0 Run II	1.36	1.22 / 1.10	1.56	1.61	1.36	1.23	1.12	1.08
D0 Run I + Run II	1.43	1.28 / NA	1.67	1.70	1.43	1.29	1.20	1.14

Randall-Sundrum Gravitons



■ **Randall-Sundrum Graviton**

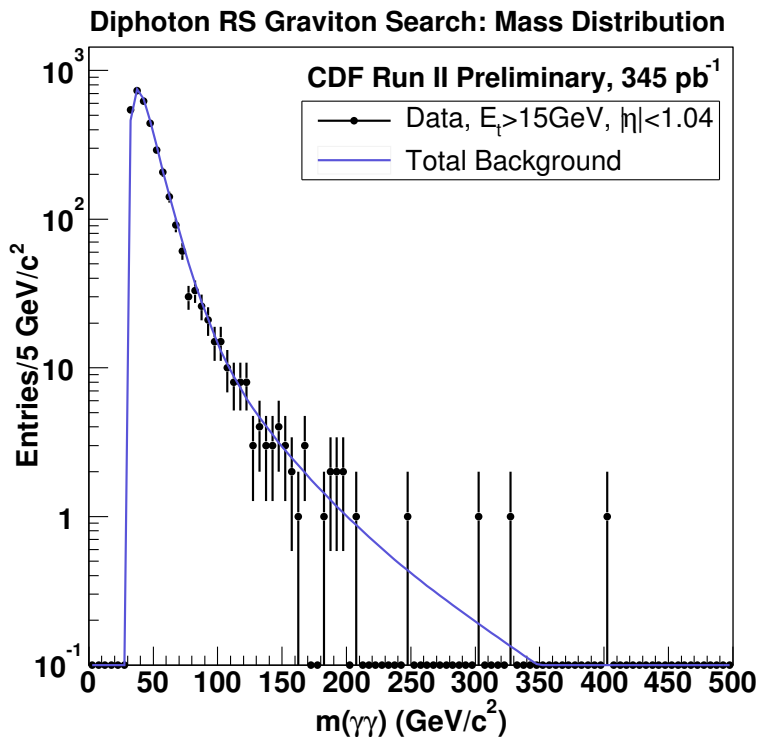
Warped ED (RS):

Randall, Sundrum
Phys Rev Lett 83 (99)

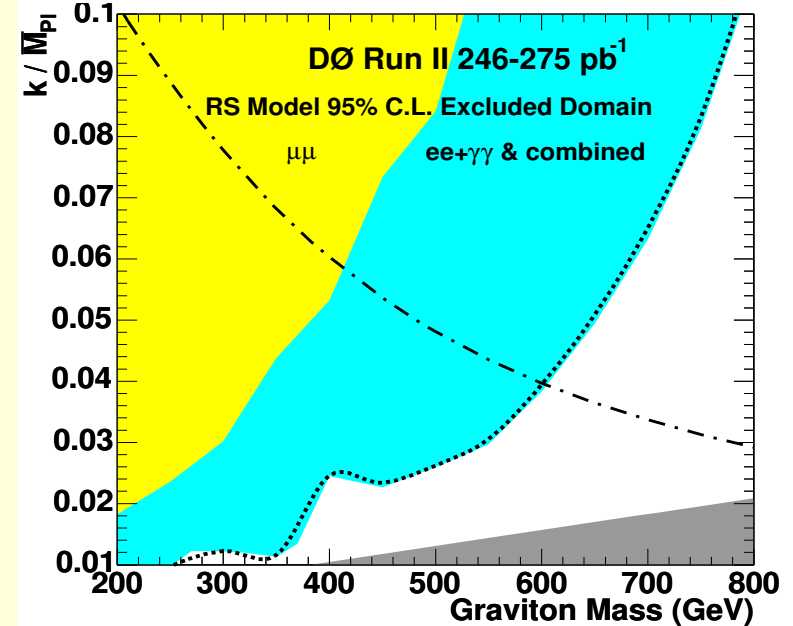
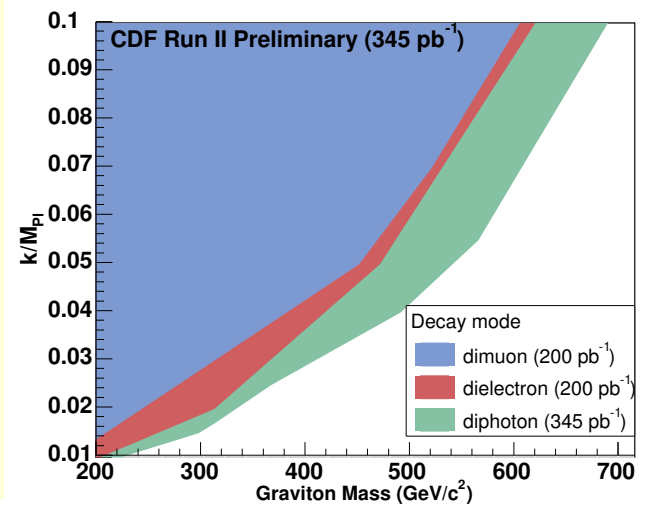
- $n=1$, highly curved
- k/M_{Pl} , k : curvature scale

$\sigma \sim (k/M_{Pl})^2$

Searching for resonance in mass spectra which depends on k/M_{Pl}



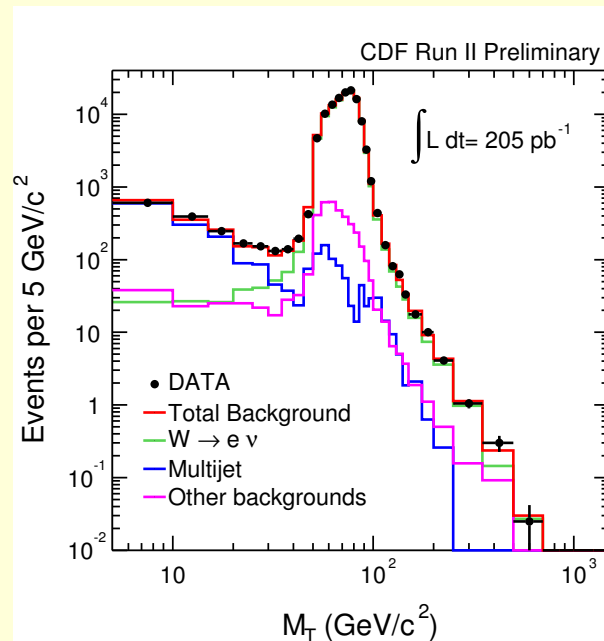
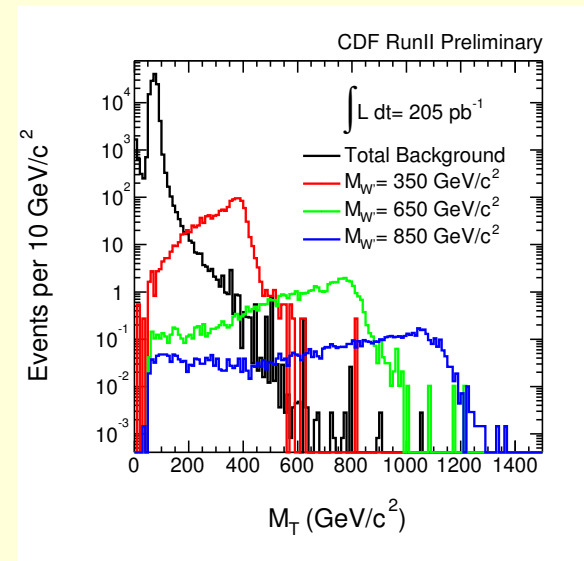
RS Graviton Searches, 95% C.L. Exclusion Regions



W' Search

Charged Heavy Vector Boson (W')

- ▶ $W' \rightarrow e\nu$ appear in theories based on the extension of the gauge group
- ▶ e.g. Left-right symmetric models: $SU(2)_R \rightarrow W_R$
- ▶ Neutrino from W' decay is assumed light and stable
- ▶ Final state signature:
 - high p_T electron+ high missing E_T

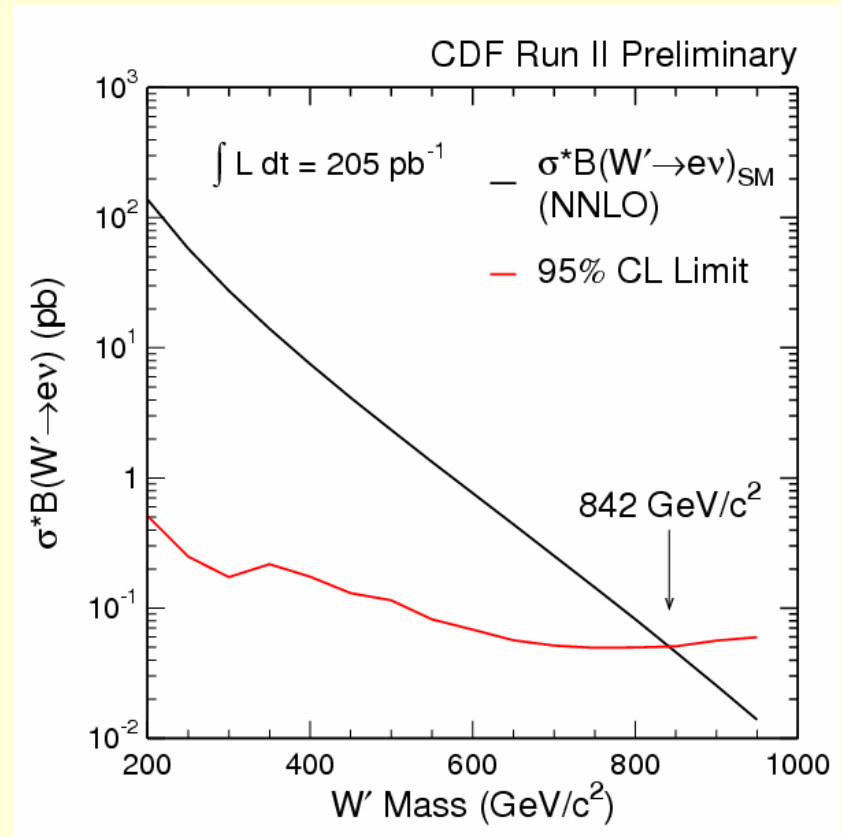


Demonstrates sound understanding of detector missing E_T



Charged Heavy Vector Boson (W')

- ▶ No signal observed above SM expectation
 - Set limits on W' production rate using a binned likelihood fitting
- ▶ Primary systematics are M_T dependent:
 - event rate: PDF $\sim 14\%$
 - shape: electron energy scale $\sim 16\%$



- ▶ Limit $M(W'_{\text{SM}}) > 842 \text{ GeV}/c^2$
 - Compared to Run I result of $M(W'_{\text{SM}}) > 754 \text{ GeV}/c^2$

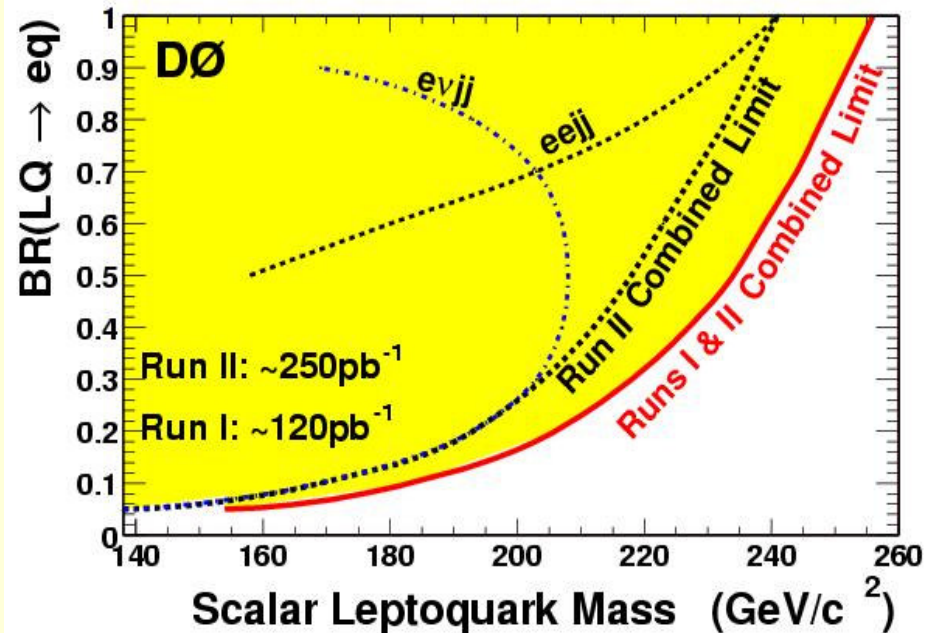


Leptoquarks

Leptoquarks

- ▶ Many extensions of the SM assume **additional symmetry** between **leptons** and **quarks**
- ▶ Leptoquarks
 - Carry both **Lepton** and **Baryon numbers**
 - **Couple** to **quarks** and **leptons** of the **same generation**
 - Three generations
- ▶ **Pair produced** at the Tevatron
- ▶ Decay controlled by $\beta = \text{BR}(\text{LQ} \rightarrow lq)$
- ▶ Signature:
 - $lljj, lvjj, \nu\nu jj$
- ▶ Signal
 - Resonance in M_{jj} spectrum

Generation 1: $eejj, evjj$

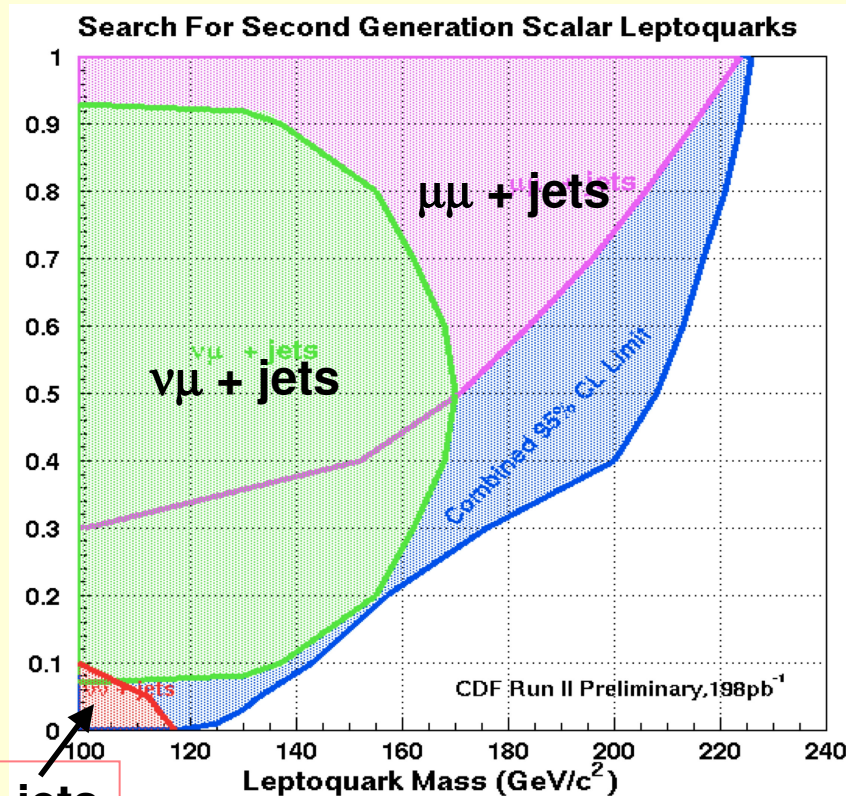
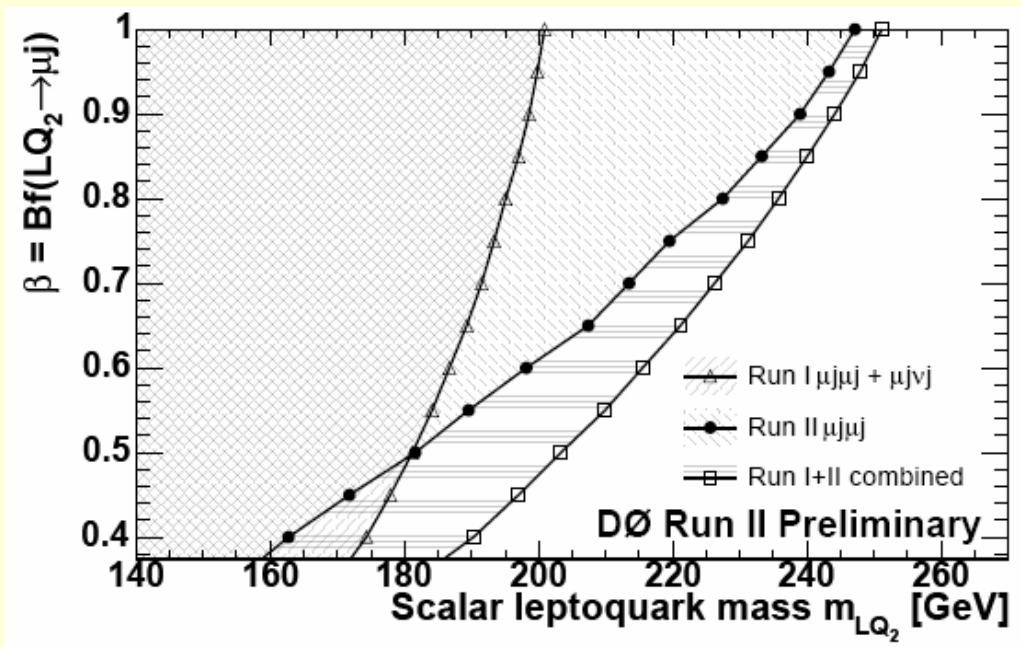


- ▶ For $\beta=1$:
 - D0: Run I + II, $M_{\text{LQ}} > 256 \text{ GeV}/c^2$
 - CDF: Run II, $M_{\text{LQ}} > 235 \text{ GeV}/c^2$ (200/pb)

Leptoquarks



Generation 2: $\mu\mu jj$, $\mu\nu jj$, $\nu\nu jj$



► For $\beta=1$:

- D0: Run I + II, $M_{LQ} > 251 \text{ GeV}/c^2$
- CDF: Run II, $M_{LQ} > 224 \text{ GeV}/c^2$ (200/pb)

$\nu\nu + \text{jets}$

Generation 3: τtb

► For $\beta=1$:

- CDF: Run II, $M_{LQ} > 129 \text{ GeV}/c^2$ (200/pb)

Excited Electrons

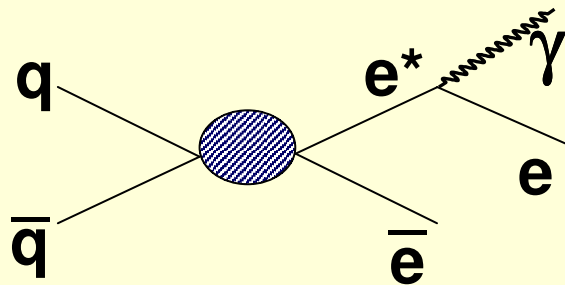
Excited Electrons

- ▶ **The observation of excited states of leptons or quarks would be a first indication of their compositeness**

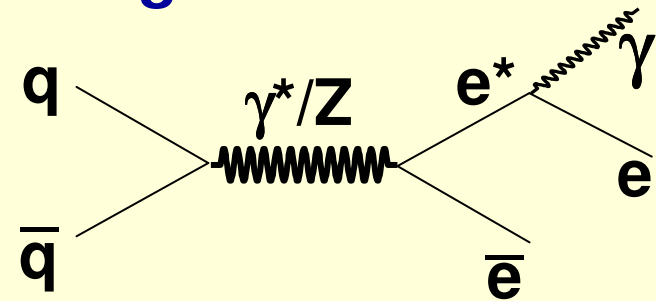
$$p\bar{p} \rightarrow e^* + e \rightarrow e\gamma + e$$

- **Signature: dielectrons + photon**
- **Signal: Resonance in electron+photon mass spectrum**

Contact Interaction Model:



Gauge Mediated Model:

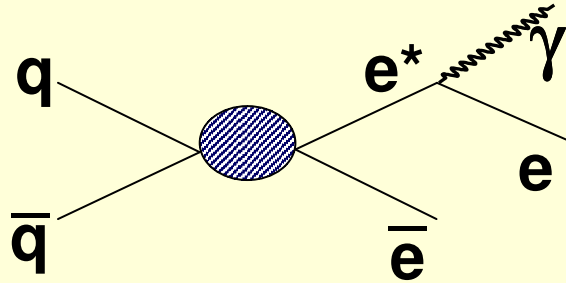


- ▶ Depends on M_{e^*} and Λ
(Compositeness Scale)
U . Baur, et.al., Phys Rev D. V42,3

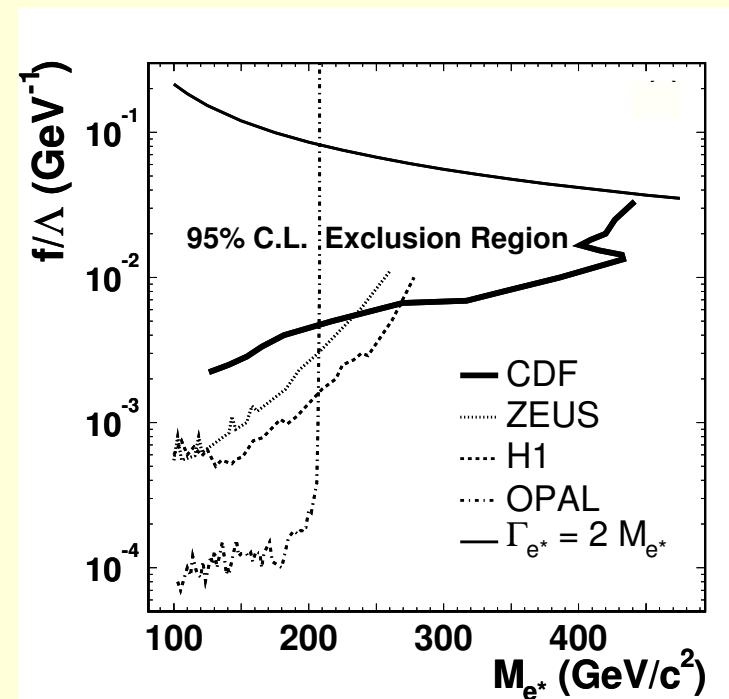
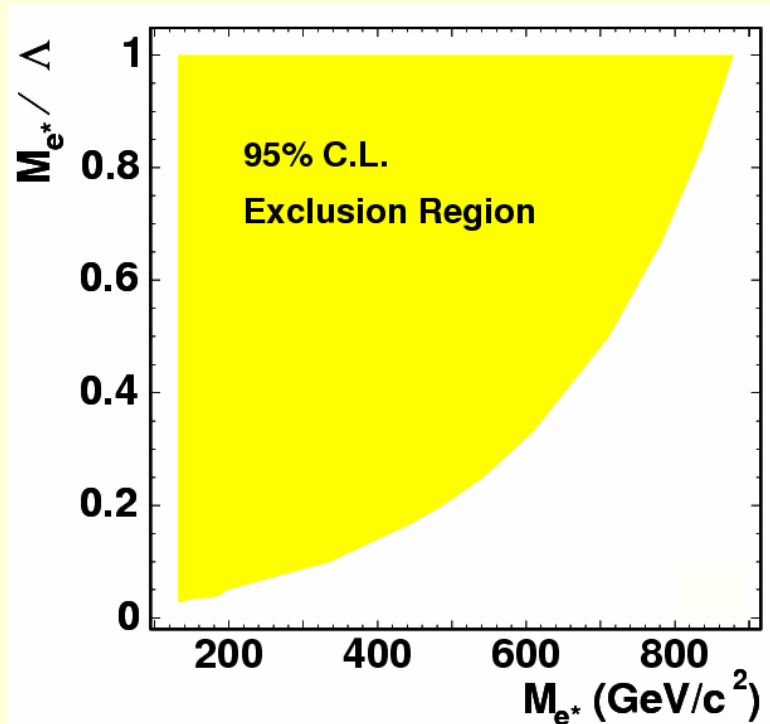
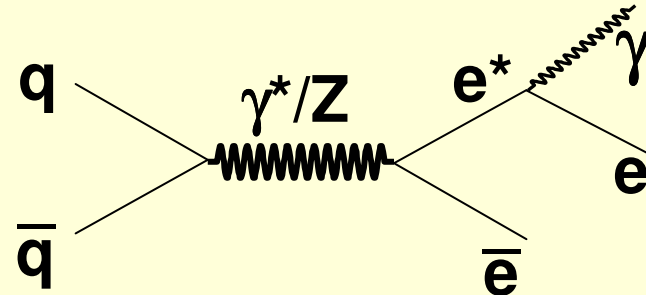
- ▶ Depends on M_{e^*} and f/Λ
K . Hagiwara, et. al., Z.Phys.
C29:115, 1985

Excited Electrons

Contact Interaction Model:



Gauge Mediated Model:



Summary and Conclusions

- ▶ CDF and D0 have many searches for new physics underway
 - Z' , W' , extra dimensions, leptoquarks, excited leptons...
- ▶ No evidence for new physics... yet...
- ▶ Already have a lot of new data to analyze and more on the way!

<http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm> ←



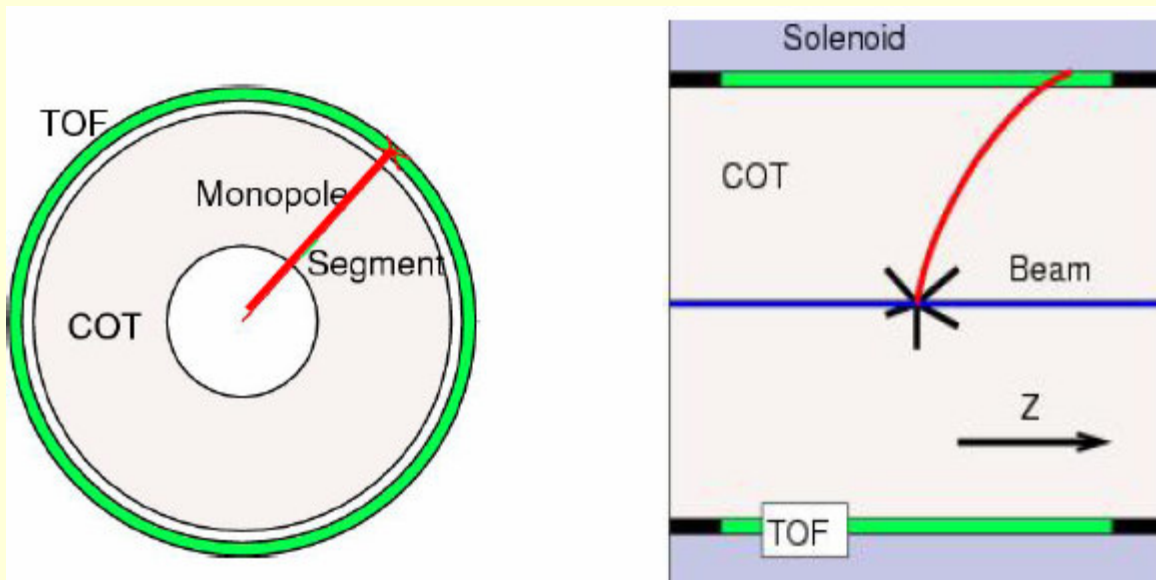
→ <http://www-cdf.fnal.gov/physics/exotic/exotic.html>

▶ BACKUP SLIDES

Dirac Monopoles

Dirac Monopoles

- ▶ Signature:
 - Large pulses in Time of Flight
 - Large ionization in drift chamber
 - No curvature in r - ϕ
 - Curvature in r - z
- ▶ Dedicated trigger for monopoles ($\sim 35 \text{ pb}^{-1}$)



Dirac Monopoles

