



A search for $Z' \rightarrow e^+e^-$ using M_{ee} & $\cos\theta^*$ at CDF

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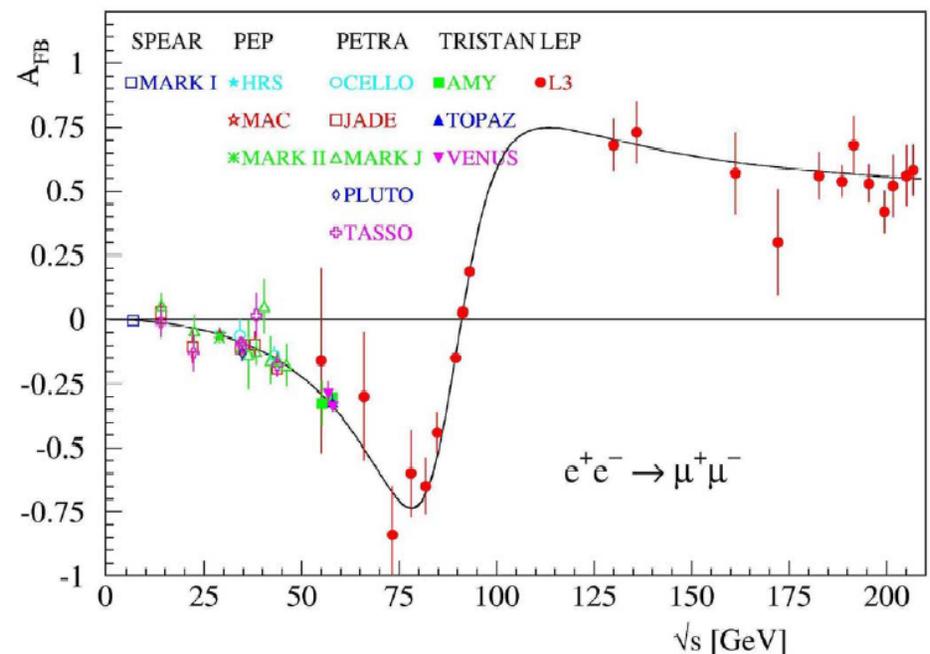
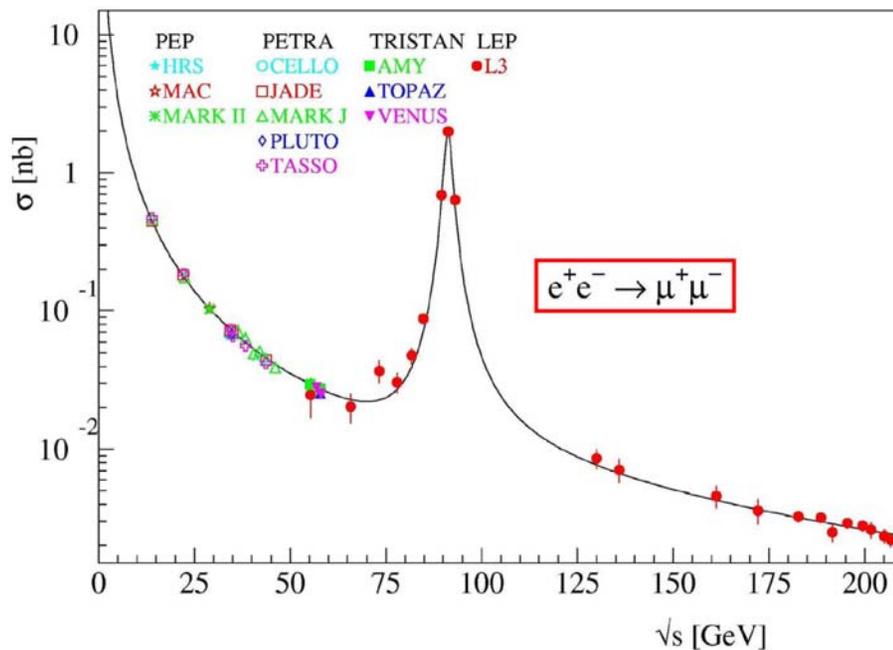
for the CDF collaboration



Past Results from e^+e^-



- Previous experiments have done very precise measurements (LEP, SLC, etc.)
- Need $> 10 \text{ fb}^{-1}$ to compete on $\sin^2(\theta_W)$
- Difficult to compete with LEP II
 - $120 < \sqrt{s} < 207 \text{ GeV}$
- LEP-II has searched for evidence of contact interactions in almost all conceivable channels.

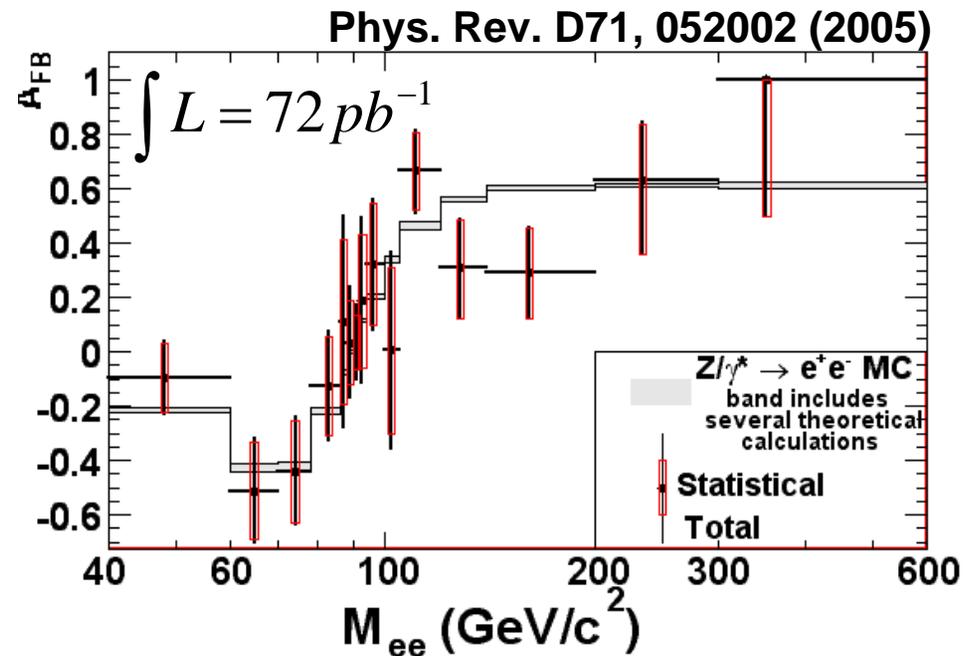
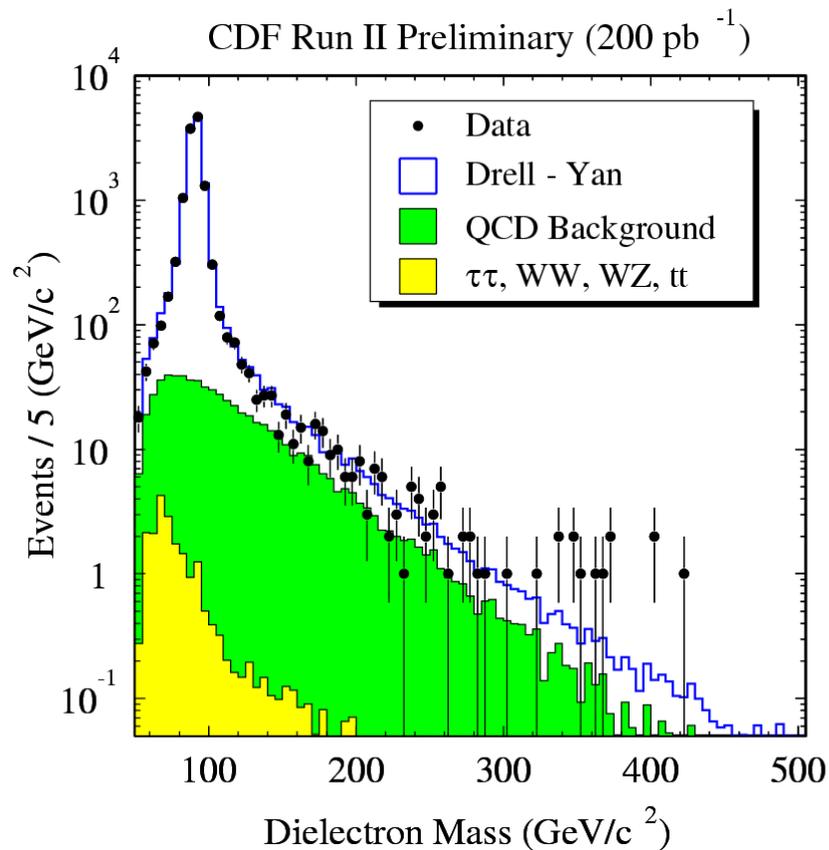




M_{ee} & A_{FB} at Hadron Colliders



- Previous analyses have used just M_{ee} to set limits, and measurement have been made of A_{FB}





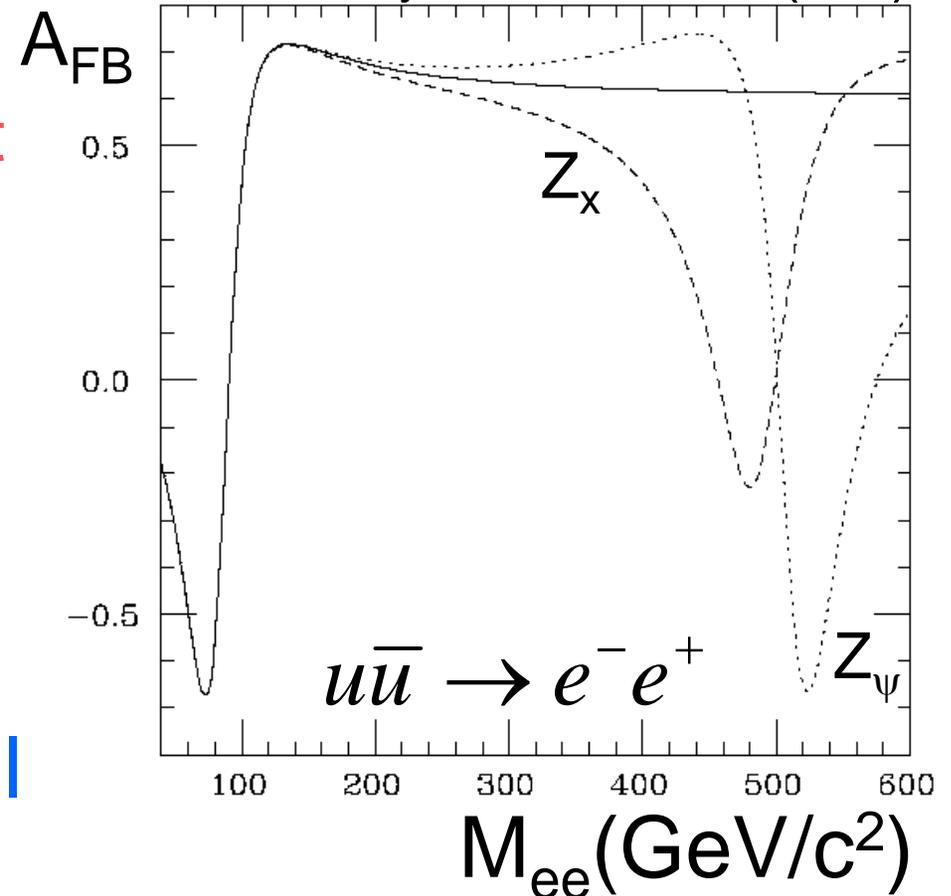
A_{FB} beyond LEP II: Z'



- Looking for symmetries beyond the SM
 - Various models predict new neutral, heavy bosons: Z' 's
- New resonance could interfere with γ and Z .
- Information about the angular distribution will strengthen the search

500 GeV/c^2 Z' :

Rosner, J.L.: Phys. Rev. D 54, 1078 (1996)

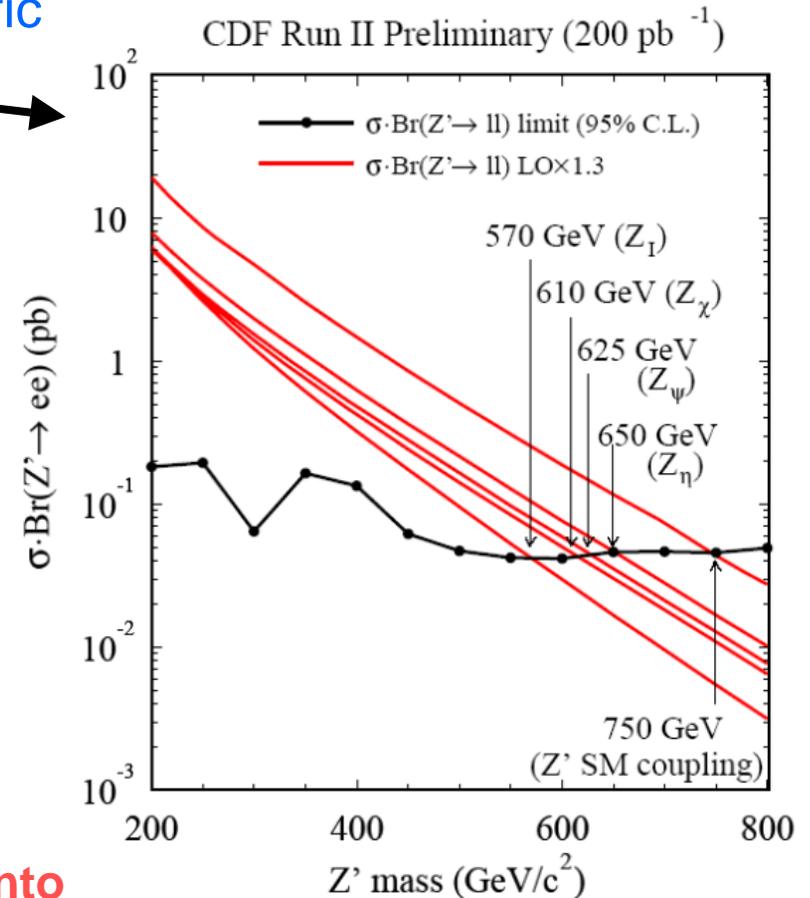




Searching for a Generic Z'



- Previous analyses have focused on specific Z' models
- Simplest Z' extension:
 - Paper by Carena, Daleo, Dobrescu, and Tait
 - Phys.Rev.D70:093009,2004
 - $SU(3)_C \times SU(2)_W \times U(1)_Y \times U(1)_Z$
 - Z'-Z mixing small
 - tightly constrained by LEP
- To fully specify the Z' model, we need:
 - $M_{Z'}$, $\Gamma_{Z'}$, 15 couplings
- Theory constraints 17 parameters to 3
 - Flavor-changing Neutral Currents Constraints
 - No new particles that the Z' can decay into
 - Anomaly cancellations
- Four classes of solutions are found
 - B-xL, q+xu, 10+x5, d-xu





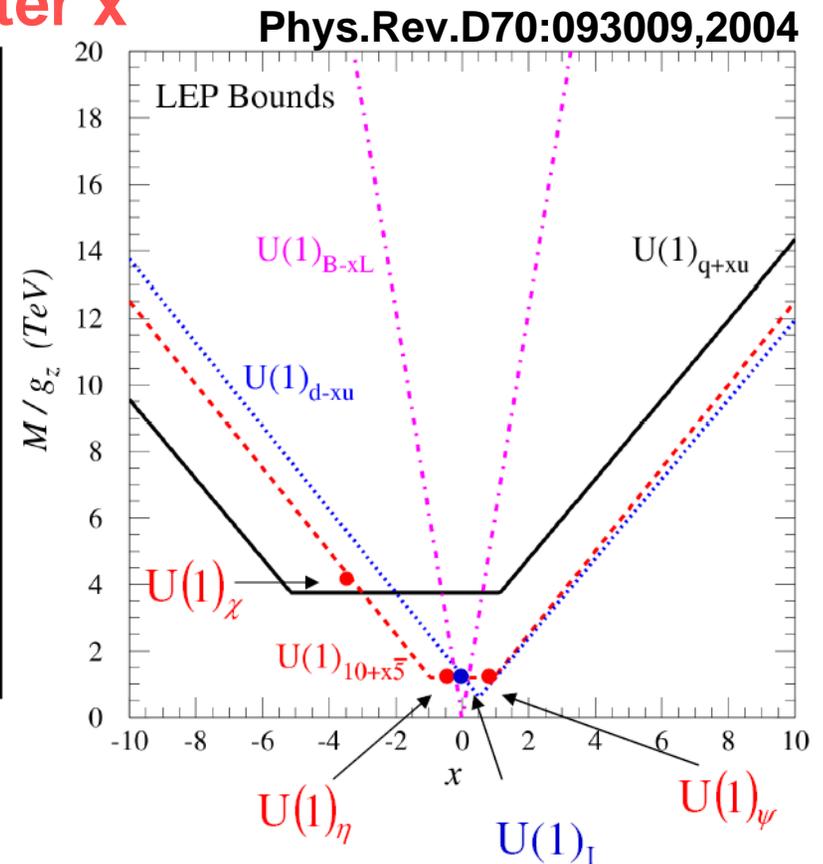
Four classes of models



- Within a class, a Z' model is specified by:

➤ **Mass $M_{Z'}$, strength g_z , parameter x**

	$B-xL$	$q+xu$	$10+x\bar{5}$	$d-xu$
$q_L=(u_L,d_L)$	$+1/3$	$+1/3$	$+1/3$	0
u_R	$+1/3$	$+x/3$	$-1/3$	$-x/3$
d_R	$+1/3$	$(2-x)/3$	$-x/3$	$+1/3$
$l_L=(e_L,\nu_L)$	$-x$	-1	$+x/3$	$(x-1)/3$
e_R	$-x$	$-(2+x)/3$	$-1/3$	$+x/3$



- **E6 motivated models:**

➤ **D-xu models: Z_1 ($x=0$)**

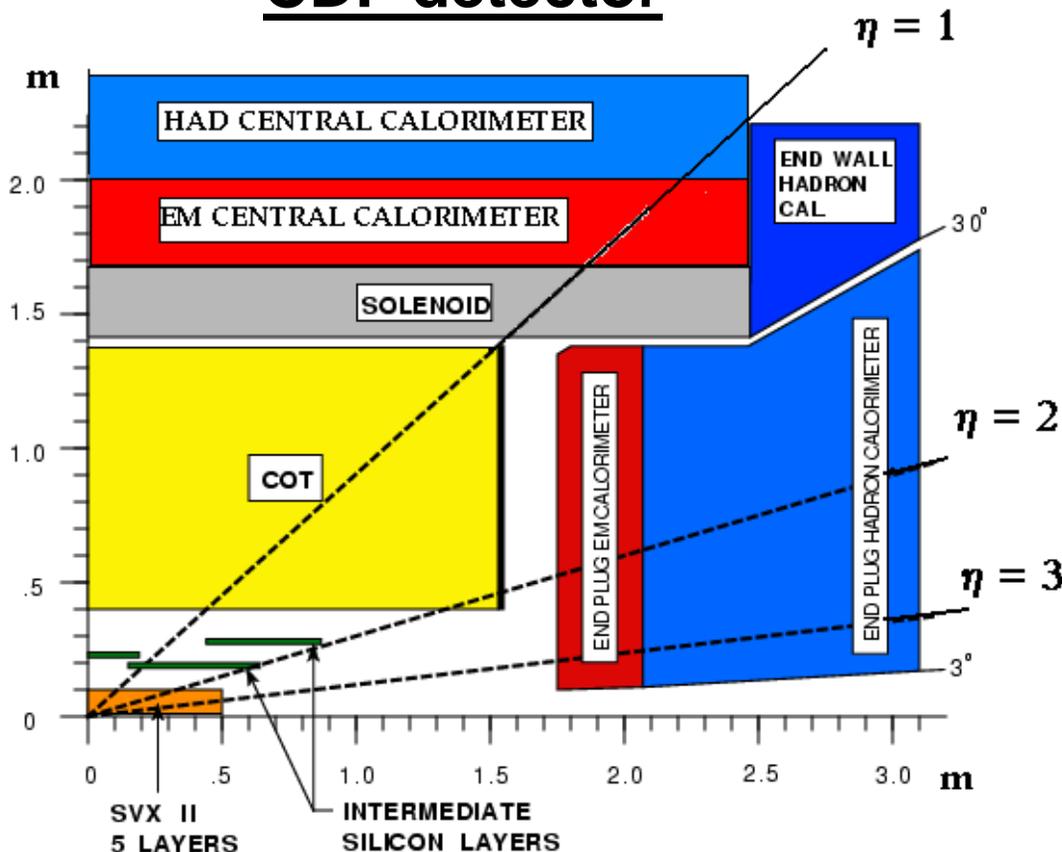
➤ **$10+x5$ models: Z_η ($x=-0.5$), Z_ψ ($x=1$), Z_χ ($x=-3$)**



Z/ γ^* Candidates and CDF



CDF detector



● Selection

➤ **2 high P_T isolated electrons**

- $E_T > 25$ GeV
- Central electrons ($|\eta| < 1$) require a charged track
- Plug electrons ($1 < |\eta| < 3$) have no track requirement

➤ **Central-Central, or Central-Plug pairs**

➤ **Require opposite sign for Central-Central**

● **Sample: 448 pb⁻¹**

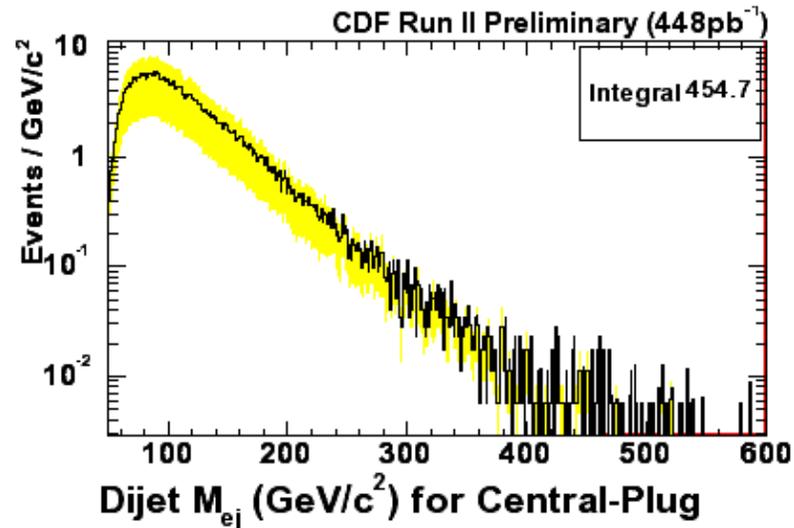
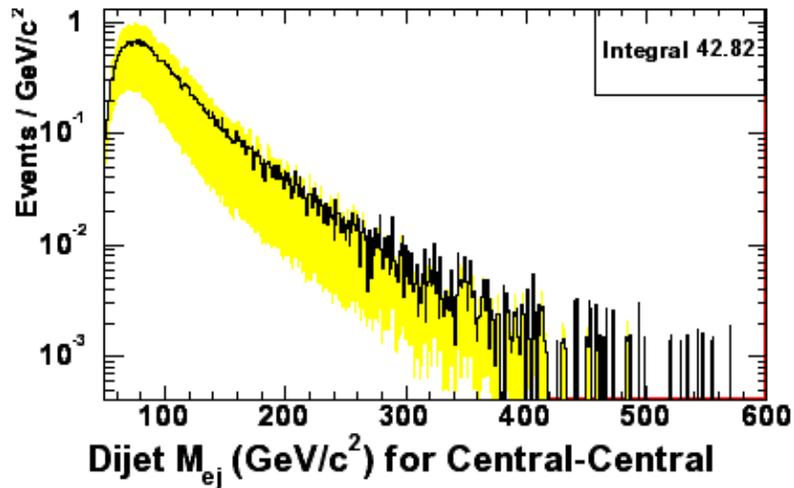
➤ **30745 candidates**



Backgrounds



● Dijet Background



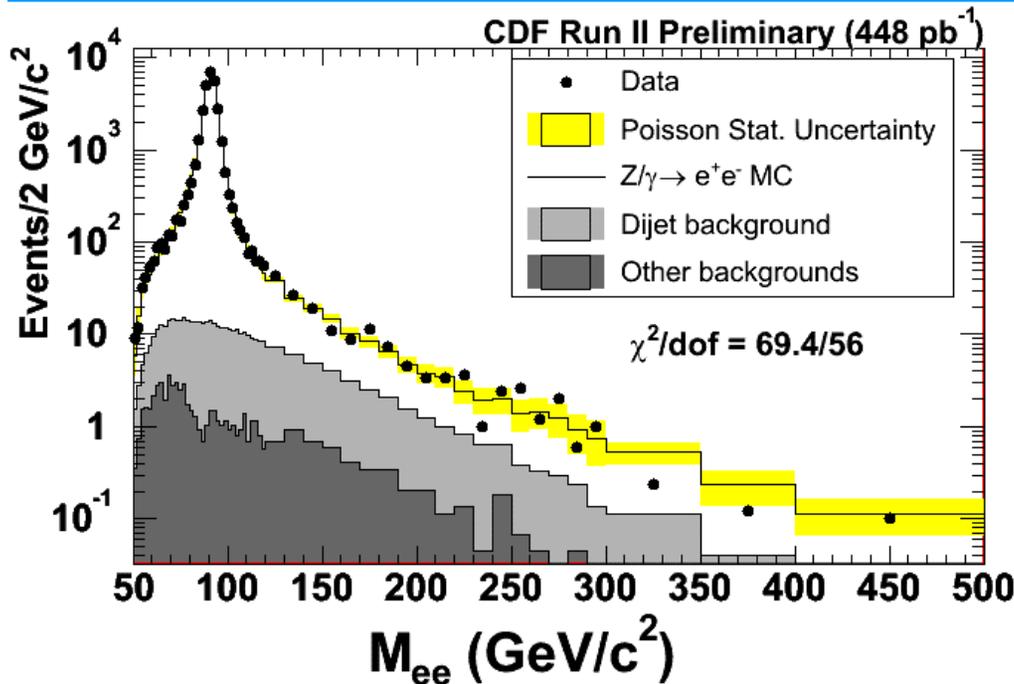
CDF Run II Preliminary (448 pb⁻¹)

Back-ground	Source	# of events	
		C-C	C-P
Dijet	Data	42.5	453
$W \rightarrow e\nu + \gamma$	MC	1.9	48.3
$Z \rightarrow \tau\tau$	MC	11.6	17.6
WZ	MC	6.3	7.9
WW	MC	7.7	9.3
Top	MC	5.1	3.3

- Dijet background estimated using the rate for jet to fake a lepton
- Backgrounds are fit to exponential to estimate cross section at high masses $M > 200$

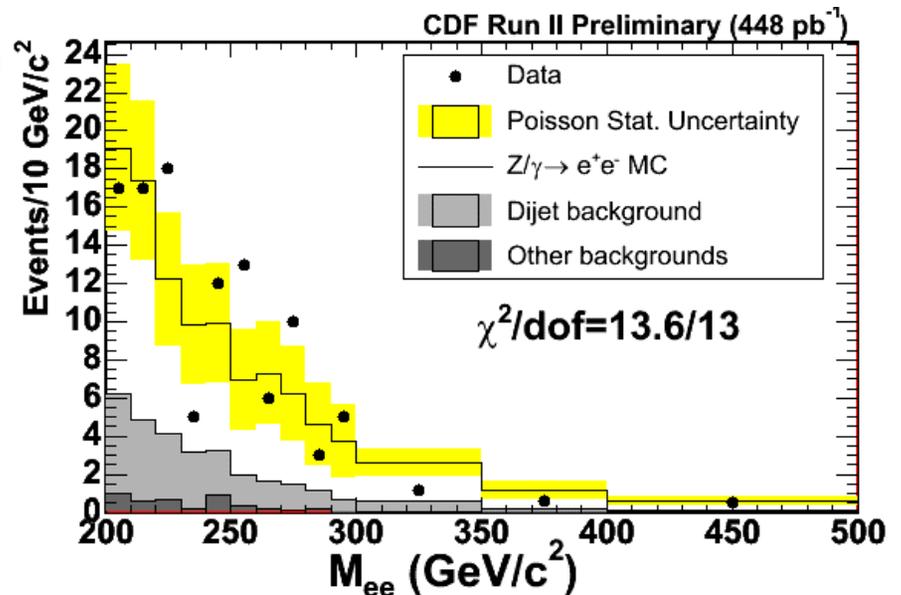


Dielectron Mass Distribution



- Statistical uncertainty shown for the prediction rather than on the data
 - More statistically correct
 - Systematic uncert. not included

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



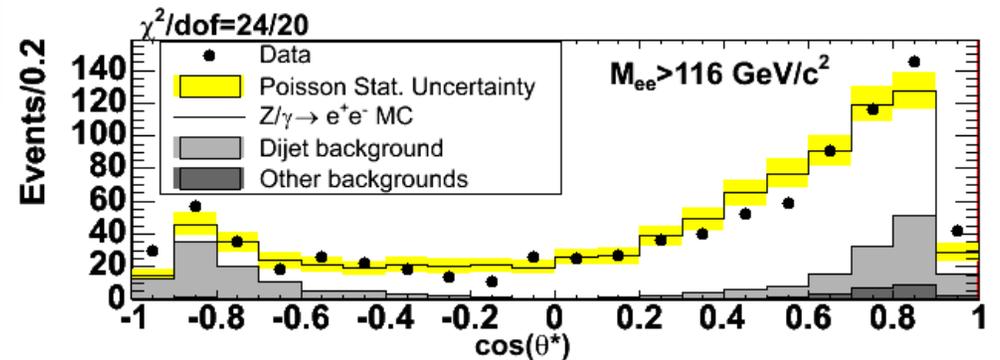
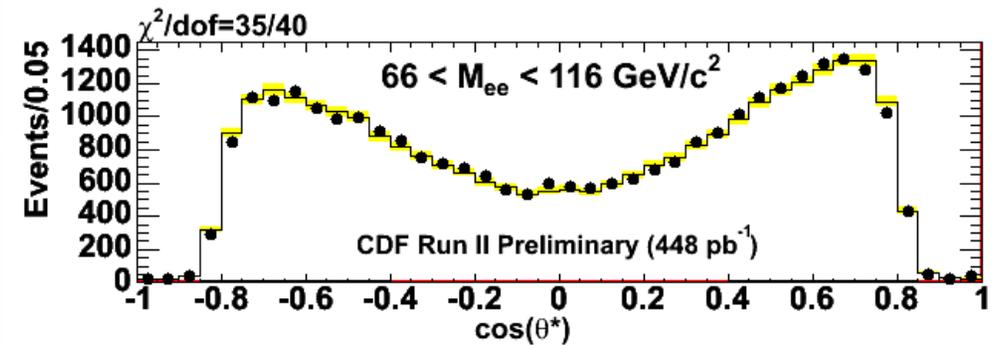
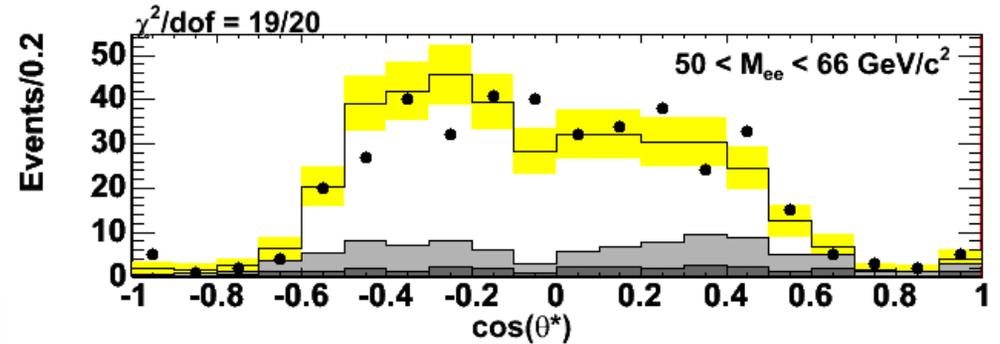
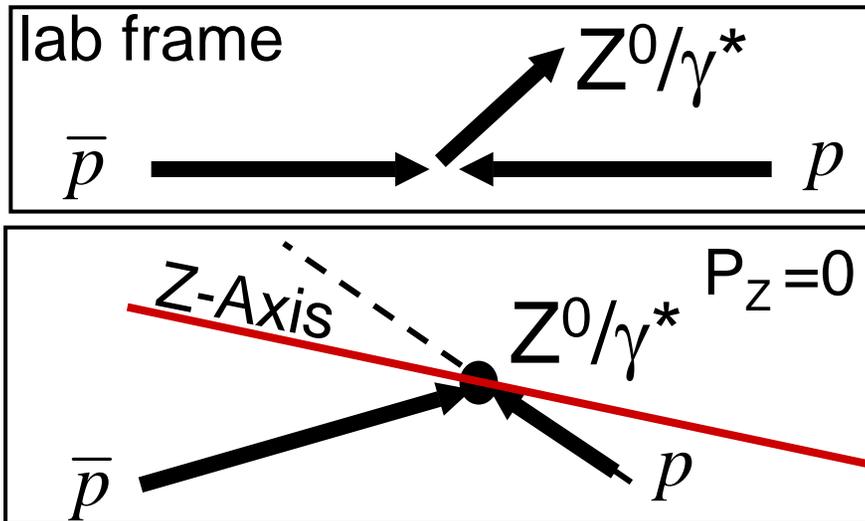


$\cos\theta^*$ Distribution



- $\cos\theta^*$ in Collin-Soper frame

➤ Minimize ambiguity in the incoming quark P_t

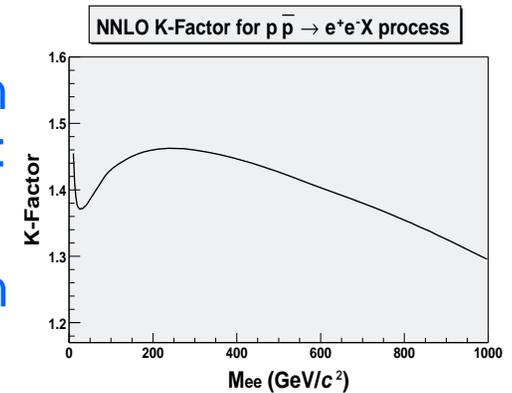




Recipe for building a Z' template

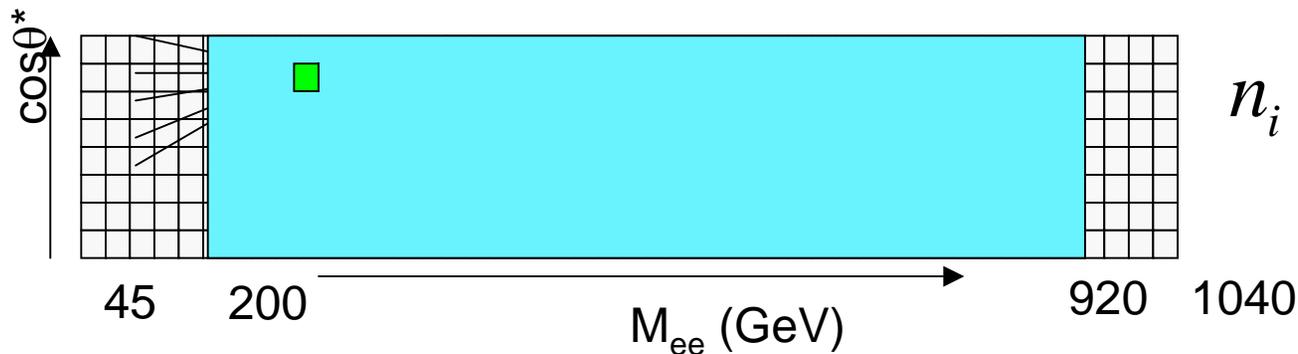


- Pick a Z' model class. Choose $M_{Z'}$, $g_{Z'}$, and x .
- Start with the LO calculation ($d(\text{sigma})/d(M)d(\cos\theta)$), and compute cross section in each $(M_{ee}^{\text{gen}}, \cos\theta^*)$ bin
- Account for the NNLO correction by multiplying each bin with a mass-depended k-factor (ZPROD from C.D.D.T.):
 ↗ **Obtain “NNLO” $(M_{ee}^{\text{gen}}, \cos\theta^*)$ template**
- Factor in the A matrix and luminosity (448 pb^{-1}) to obtain the expected $(M_{ee}^{\text{reco}}, \cos\theta^*)$



↗ **Acceptance is parameterized based on γ^* Monte Carlo sample flat in M_{ee}**

- 10 GeV M bins, and 8 $\cos\theta$ bins



$$n_i = \sum_{j=1}^{N_{bins}} A_{ij} N_j$$



Test Statistics



- Test between two hypotheses:
 - **H1: Data is described by $Z'/Z/\gamma$ and backgrounds**
 - **H2: Data is described by SM Z/γ and backgrounds**
- Poisson probabilities:

$$P(\text{data} | H1) = \prod_{i=1}^{N_{bins}} P^i = \prod_{i=1}^{N_{bins}} \frac{e^{-n_i^{H1}} \cdot (n_i^{H1})^{d_i}}{d_i!}$$

- Test statistics $Q = -2 \ln[P(\text{data}|H1)/P(\text{data}|H2)]$

$$Q = \text{const} - 2 \cdot \sum_{i=1}^{N_{bins}} d_i \ln \frac{n_i^{H1}}{n_i^{H2}}$$



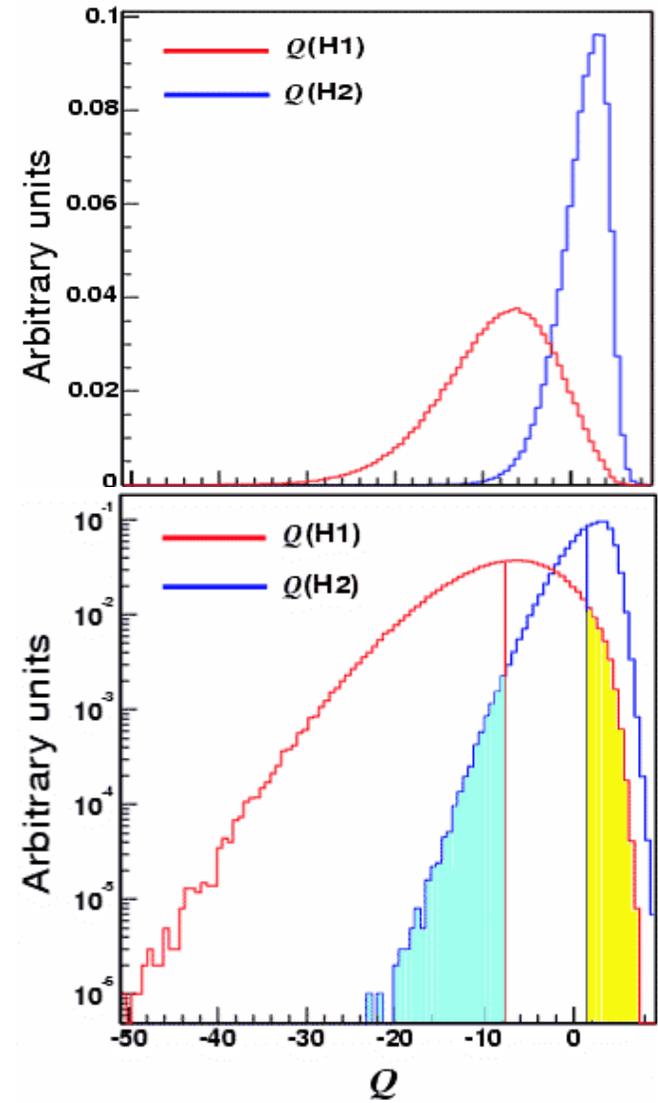
Pseudo Experiment



- Distributions of Q in the H1 and H2
- The separation defines sensitivity between H1 and H2
 - **B-xL model. $M_{Z'}$ =440 GeV, g_2 =0.03, x =10**
- For a measured Q_o , CL_s is given by

$$CL_s(Q_o) = \frac{\text{Prob}(Q < Q_o/H1)}{\text{Prob}(Q < Q_o/H2)}$$

- Median CL_s in H2 hypothesis (SM) defines exclusion (<5%)
- $CL_s = 2 \cdot$ yellow area.
 - **$CL_s < 0.05$ excluded at 95% Confidence Level**





Sequential Z' limits



- Sequential Z' is Z' model with same couplings as Standard Model Z boson
 - **Pretty difficult to get from theory, but easy to generate in Pythia**
 - **Useful for making comparisons**
- New limit on Z'_{SM} (expected: 850 GeV)
 - **Adding $\cos\theta$ is equivalent to adding 25% more data!**

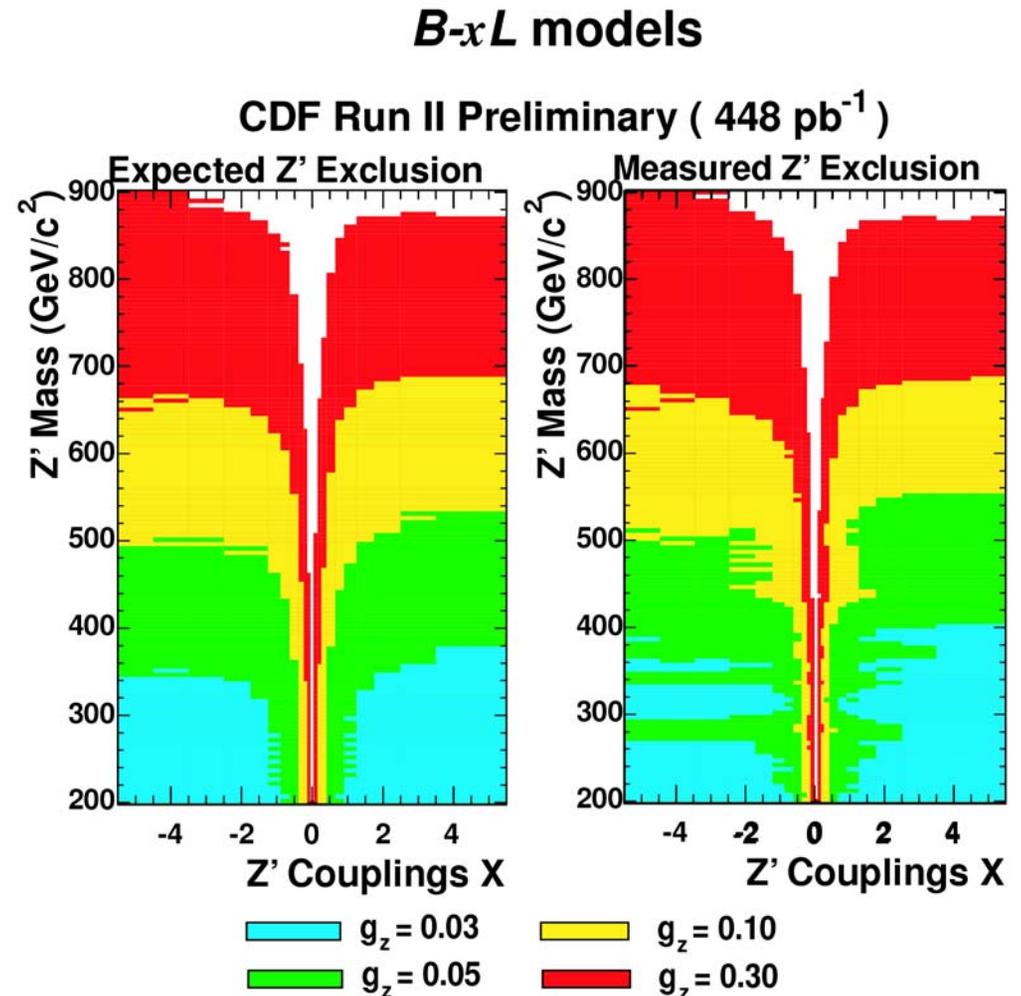
	CDF e^+e^- 448 pb⁻¹	CDF $ee + \mu\mu$ ~200 pb⁻¹	D0 ee 200 pb⁻¹
Limits On Z'_{SM}	845 GeV	825 GeV	780 GeV



B-xL Model Lines



- Finding a limit for a Z' model
 - Expected is drawn from pseudo-experiments
- Values for g_z , x chosen with guidance from theorists
 - CDF seems to be more sensitive than LEP II when g_z is smaller
- $A_{FB}(M_{Z'}) = 0$ for all x
- Input from community is greatly appreciated



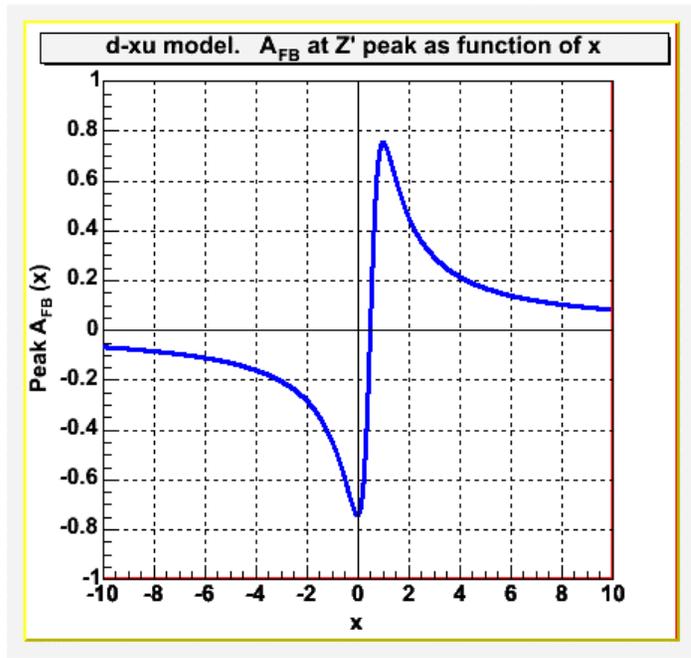
Carena, Daleo, Dobrescu, Tait, PRD 70, 093009 (2004)



d-xu Model Lines

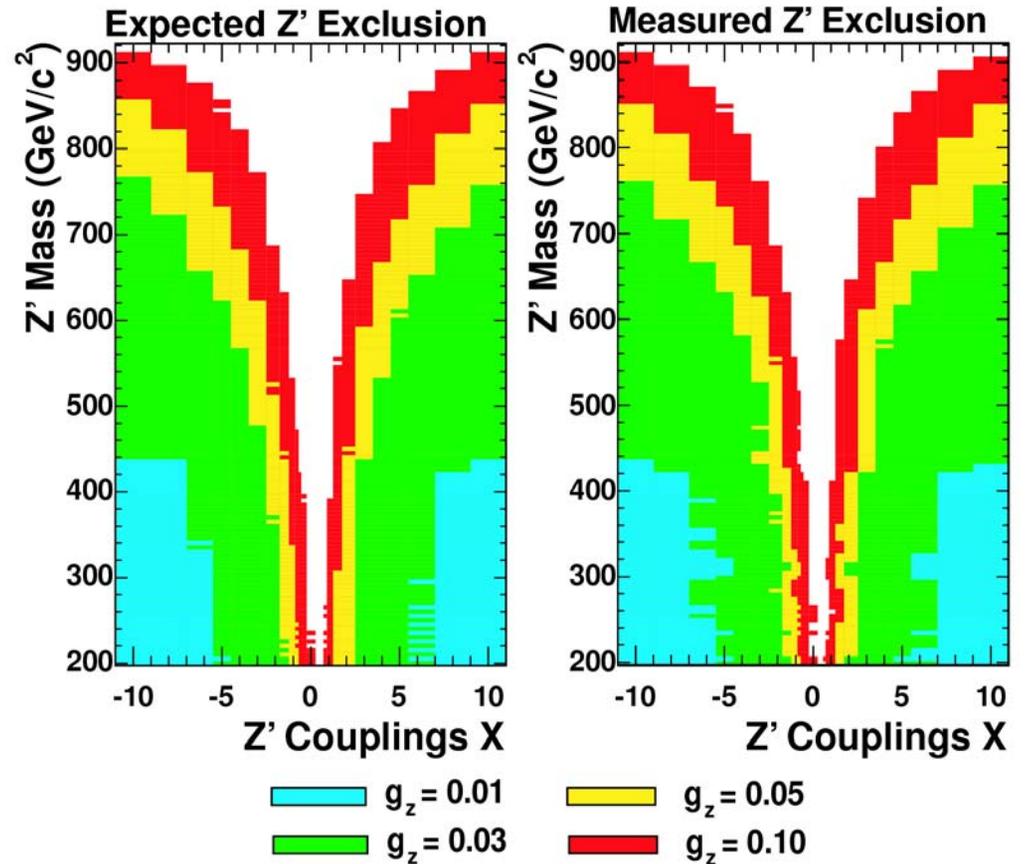


- E6 Models:
 - $\nearrow Z_1, x=0, g_z = 0.667$
- $A_{FB}(M_{Z'})$:



d-xu models

CDF Run II Preliminary (448 pb⁻¹)



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

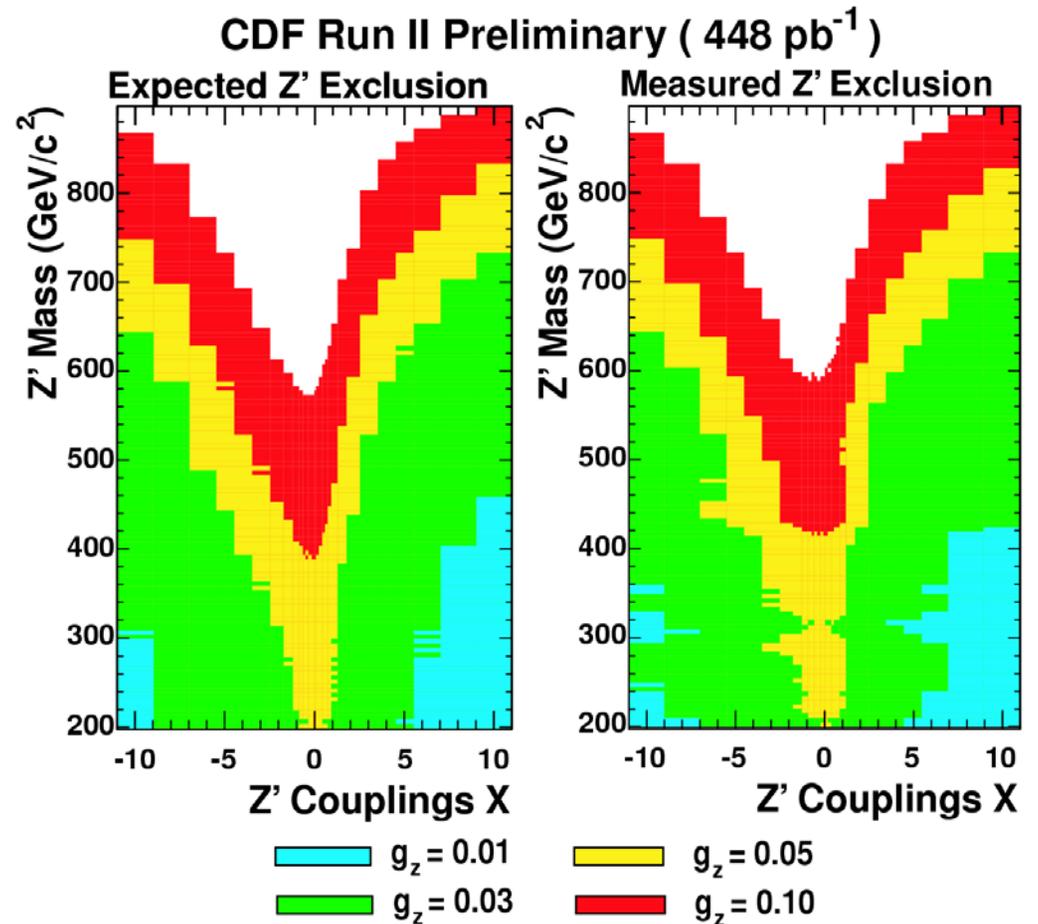
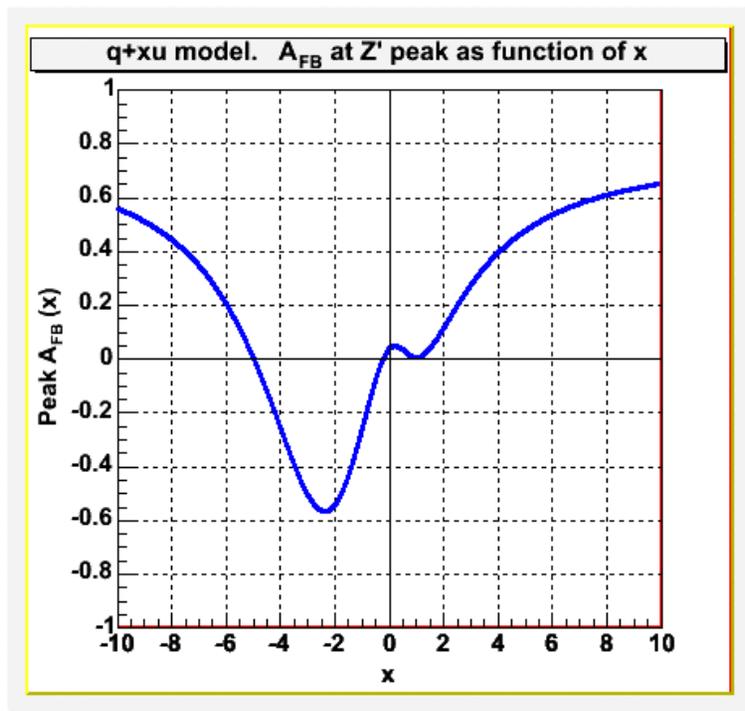


Q+ xu Model Lines



$q + xu$ models

- $A_{FB}(M_{Z'})$:



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



10+x5 Model lines



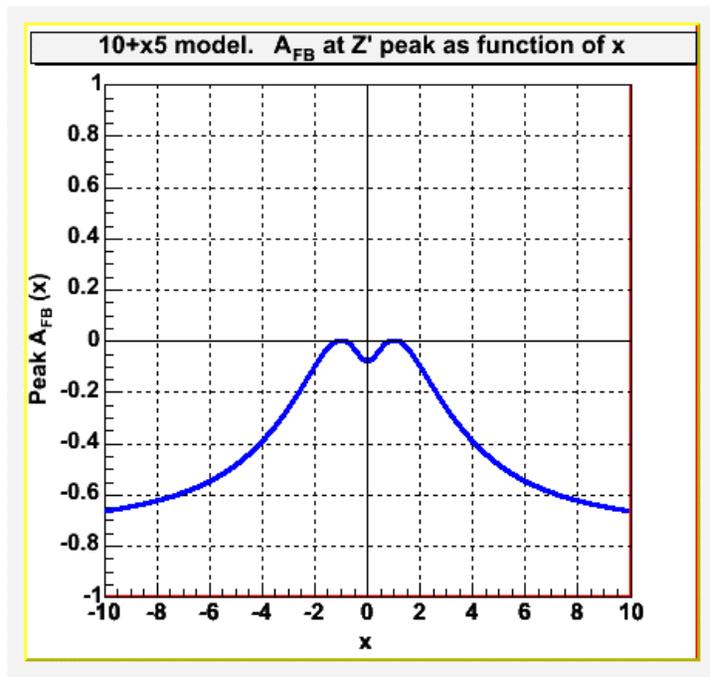
E6 Models:

↗ Z_η : $x=-0.5$, $g_z = 0.344$

↗ Z_ψ : $x=1$, $g_z = 0.272$

↗ Z_χ : $x=-3$, $g_z = 0.211$

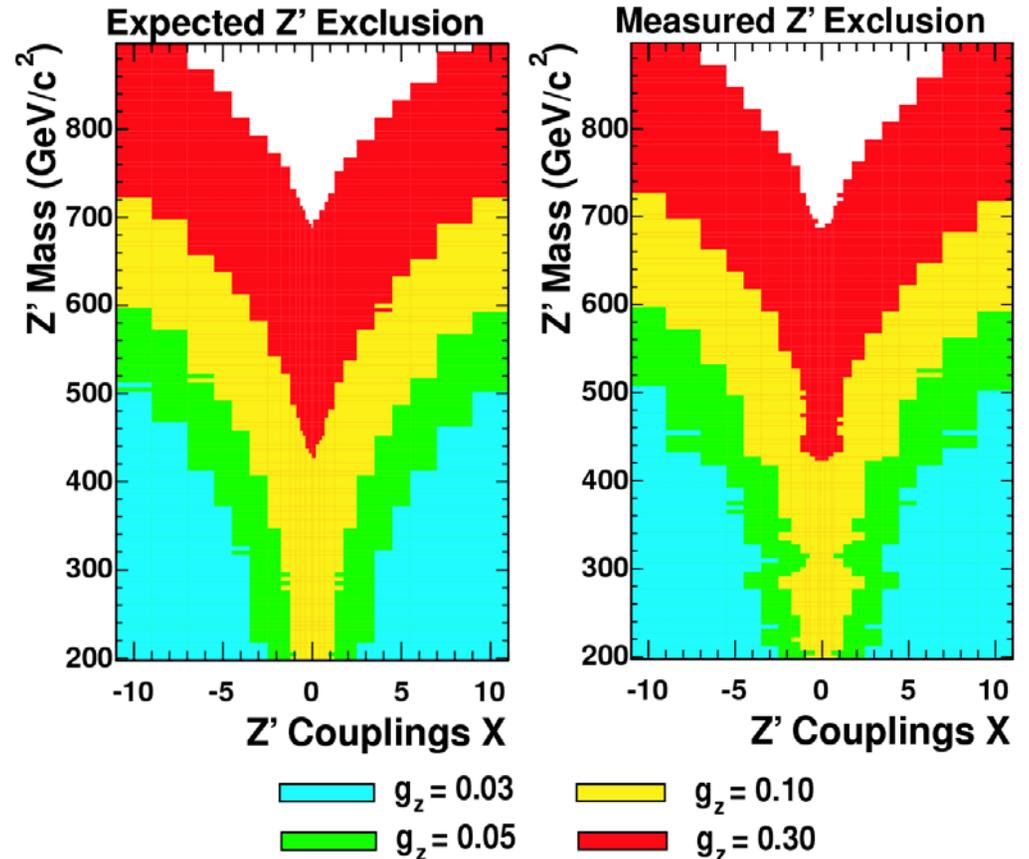
$A_{FB}(M_{Z'})$:



Gregory Veramendi

10+x5 models

CDF Run II Preliminary (448 pb⁻¹)



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

Search for Z' bosons

PHENO '05, May 3rd, 2005 p. 18



Conclusions



- Increased sensitivity
 - More than twice the luminosity of previous D0 and CDF results
 - Increased sensitivity by using angular distribution
 - New method for determining limits: CL_s
- Data consistent with Standard Model
- New limits on Z'
 - New best limit on Sequential Z'_{SM} from hadron collider experiment
 - First limits on generic Z' models
- Publish this summer...