Drell –Yan Production at the Tevatron

DPF 2004

August 27, 2004

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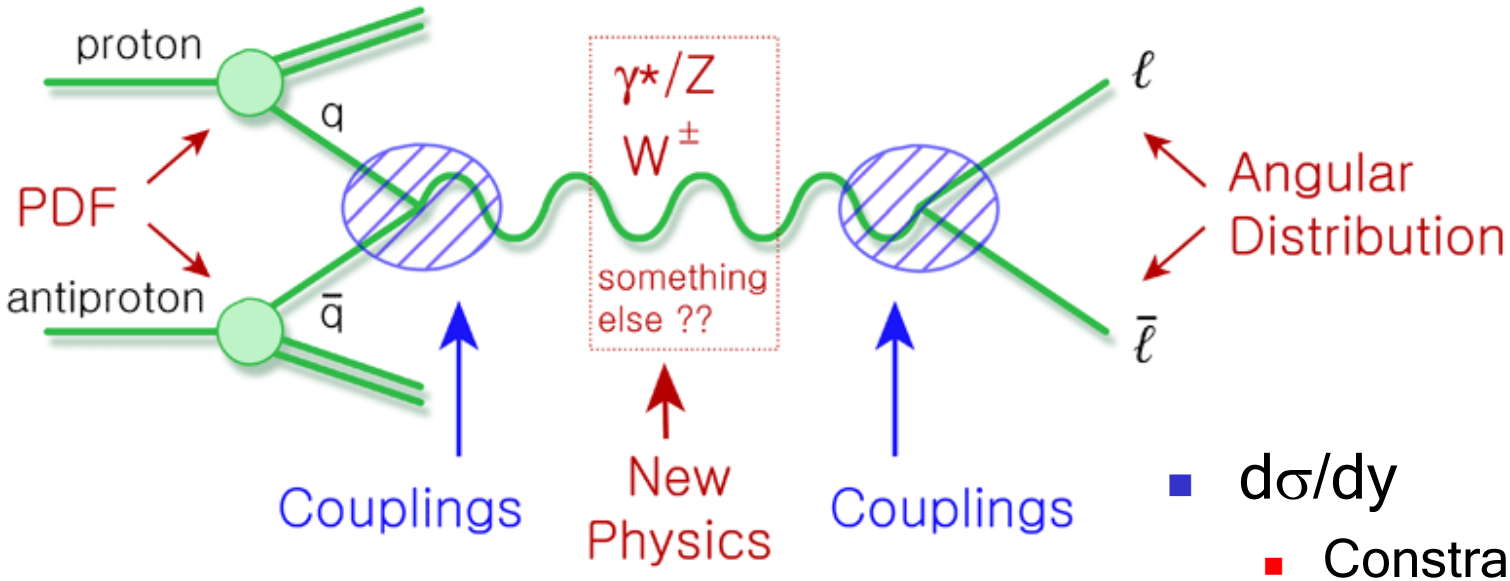
For the CDF and D0 Collaborations

Physics in Drell-Yan Production



- $d\sigma/dy$
  - Constraints for PDF
  - PDF constrains other physics
- $d\sigma/d\cos\theta^*$
  - Charge Asymmetry
  - Z-fermion couplings
  - $\sin^2\theta_W$
  - New Physics
- $d\sigma/dM_{\ell\ell}$
  - Sensitive to New physics at High Mass
  - Z', Extra Dimension, etc.

Forward-Backward Asymmetry in $\gamma^*/Z^0 \rightarrow e^+e^-$

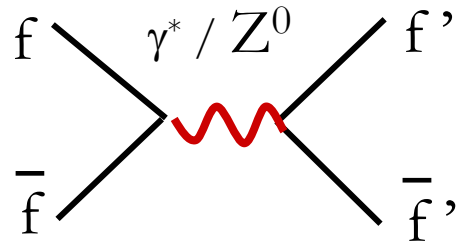
- Vector(V) and Axial-vector(A) nature gives rise to angular asymmetry.

$$\frac{d\sigma}{d\cos\theta^*} = A(1+\cos^2\theta) + B\cos\theta^*$$

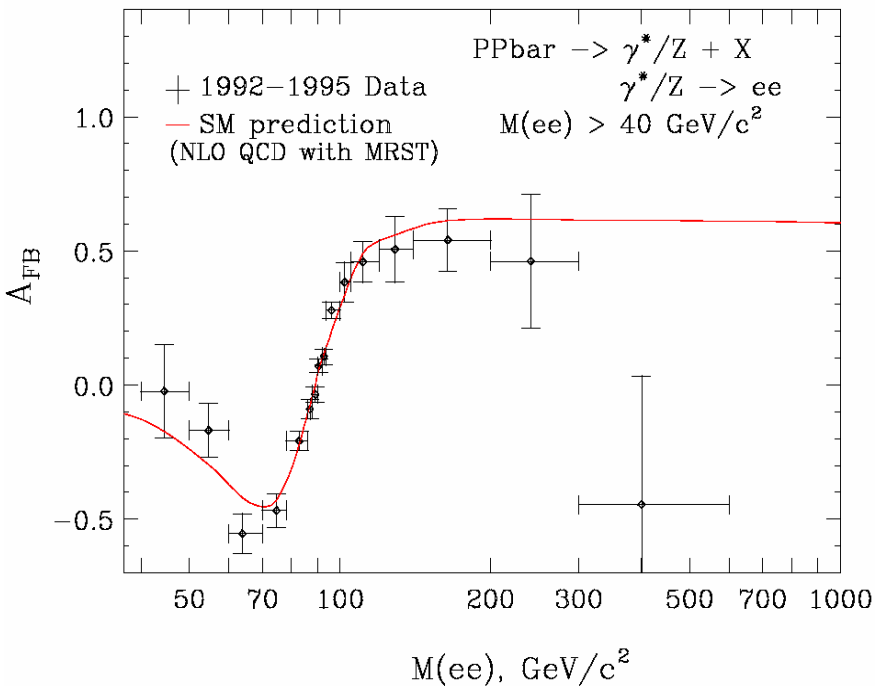
$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{3B}{8A}$$

- New particle may cause deviations in A_{FB} or $d\sigma/dM$
- Contributing helicities vary with mass
  - A_{FB} depends on mass
  - Direct probe of V and A couplings

Interference between γ^* and Z^0

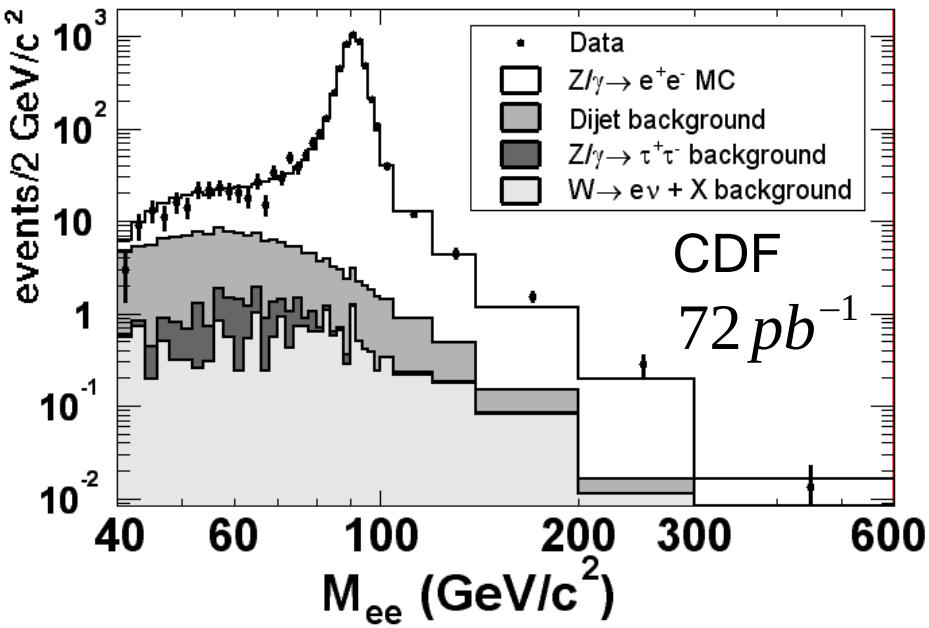


PRL 87, 131802 (2001) $\int \mathcal{L}\,dt = 108\ pb^{-1}$

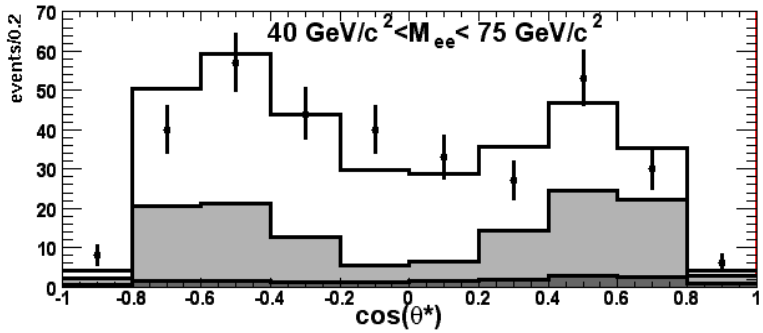


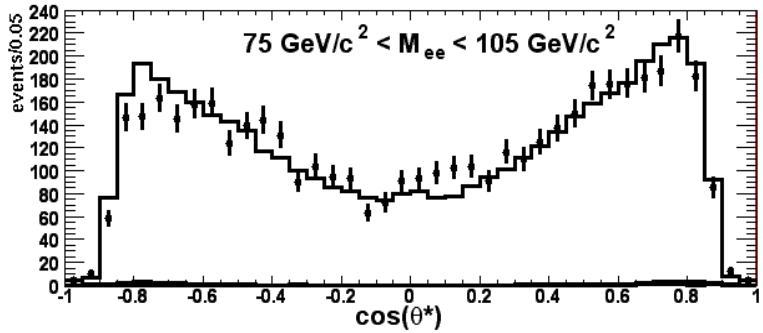
M_{ee} and cosθ* distributions

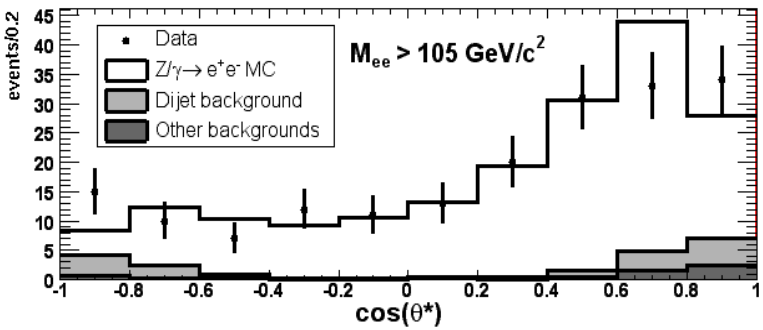
- 5211 $Z \rightarrow e^+e^-$ candidates
  - 2 isolated electrons E_T > 20 GeV



- Backgrounds
  - Fake electron from jets : dominant
  - Electroweak processes
  - t-tbar

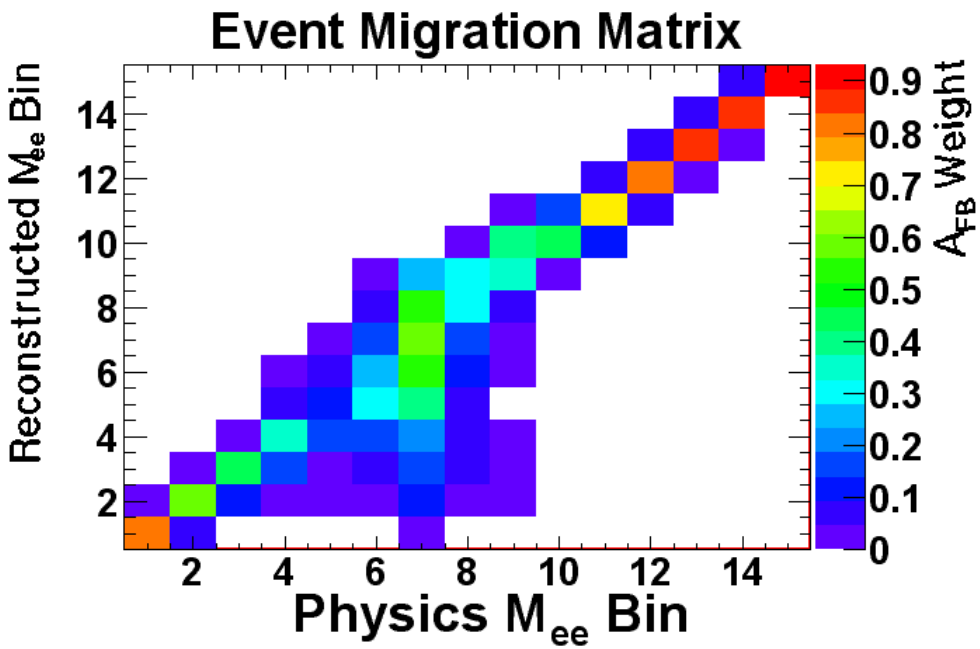


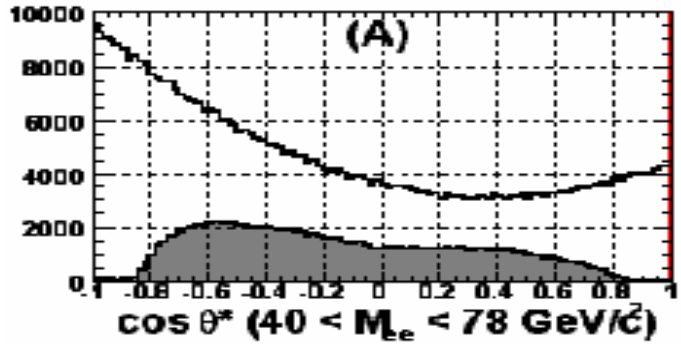


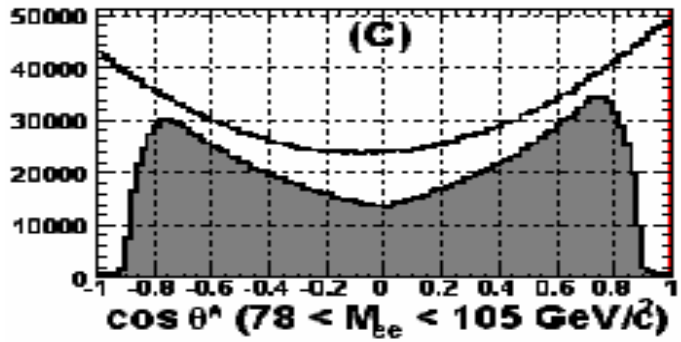


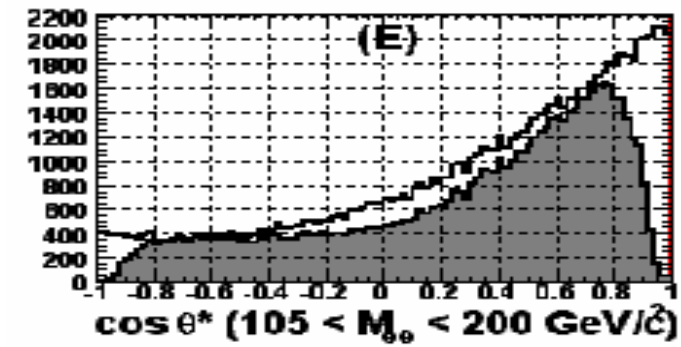
Acceptance Corrections

- A_{FB} gets shifted after reconstruction
  - Reconstructed mass smears out
  - cosθ^* distribution in different mass bins
- Need to correct observed A_{FB}



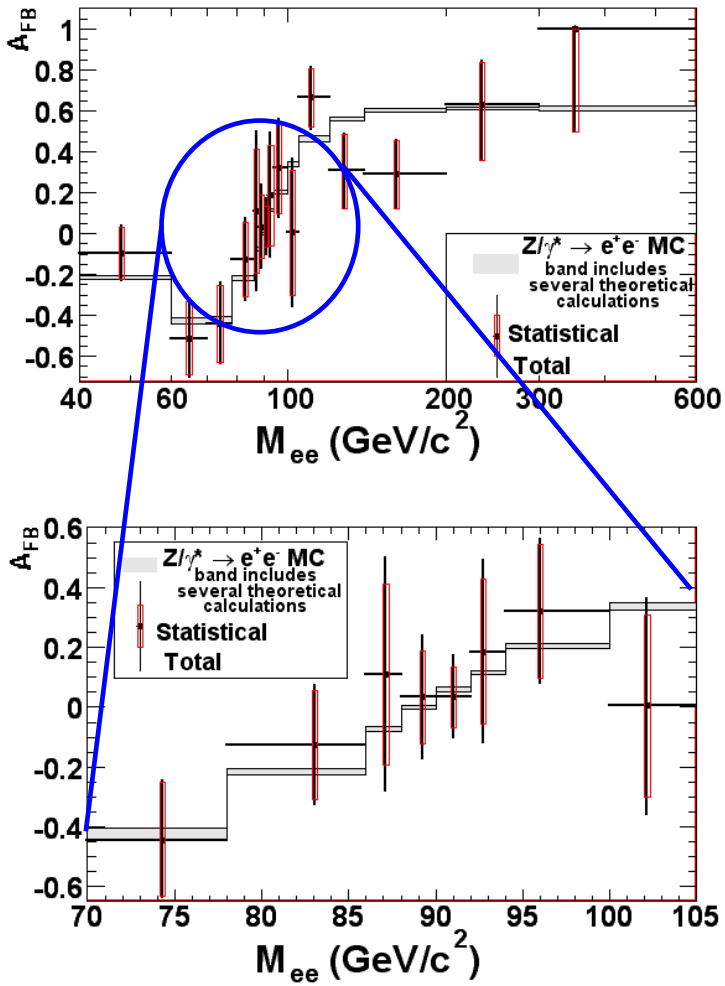






A_{FB} with Unconstrained Fit

- Likelihood fit at raw level
  - No assumptions of A_{FB} prior to the correction (unbiased)
  - Large uncertainties due to large migration in mass
- Statistical error dominates
- Systematic error :
  - Energy scale, resolution
  - Detector material effect
  - Backgrounds



Couplings Results

- Same likelihood fit as used for A_{FB}
- Quark couplings

	CDF	2 fb^{-1} Uncert.	Experimental values (PDG)	SM Prediction
u_L	0.41±0.14	±0.028	0.330±0.016	0.3459±0.0002
u_r	0.01±0.12	±0.024	-0.176±0.008	-0.1550±0.0001
d_L	-0.32±0.26	±0.057	-0.439±0.011	-0.4291±0.0002
d_r	-0.02±0.34	±0.088	-0.023±0.058	0.0776±0.0001

- Electron couplings

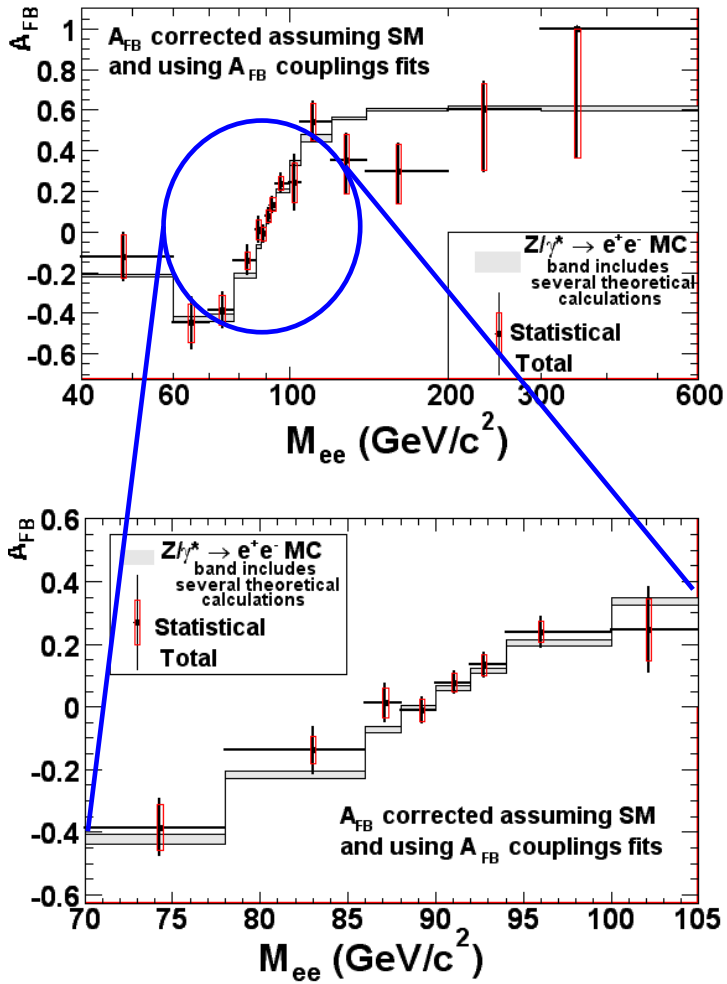
	CDF	SLD+LEP	SM prediction
e_V	-0.056±0.018	-0.03816±0.00047	-0.03816 ± 0.00047
e_A	-0.54±0.19	-0.50111±0.00035	-0.5064 ± 0.0001

- $\sin^2\theta_W$ measured from its relation to the couplings

	CDF	NuTeV	PDG
$\sin^2\theta_W$	0.2238 ±0.0046(stat) ± 0.0020(syst)	0.2364±0.0016	0.23143±0.00015

A_{FB} corrected assuming SM

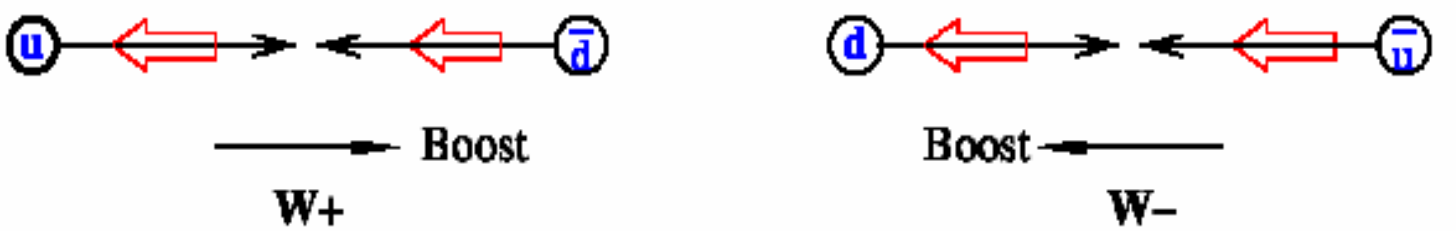
- Couplings fit used as input
- Assumes SM relation between couplings and differential cross section
- Consistent with SM
- Not useful for non-SM physics near Z pole



- D0 result coming soon!

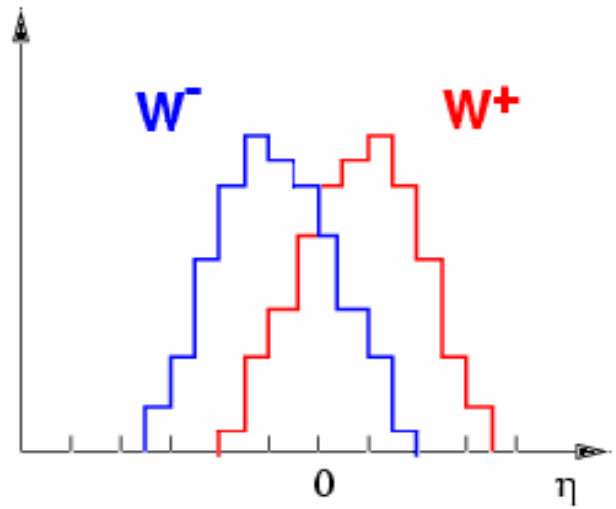
Charge Asymmetry in $W^{\pm} \rightarrow e^{\pm} \nu$

- u quark carries higher fraction of proton momentum



- W charge asymmetry constrains PDF

$$A(y_W) = \frac{d\sigma_+/dy_W - d\sigma_-/dy_W}{d\sigma_+/dy_W + d\sigma_-/dy_W} \approx \frac{u(x1)d(x2) - d(x1)u(x2)}{u(x1)d(x2) + d(x1)u(x2)}$$

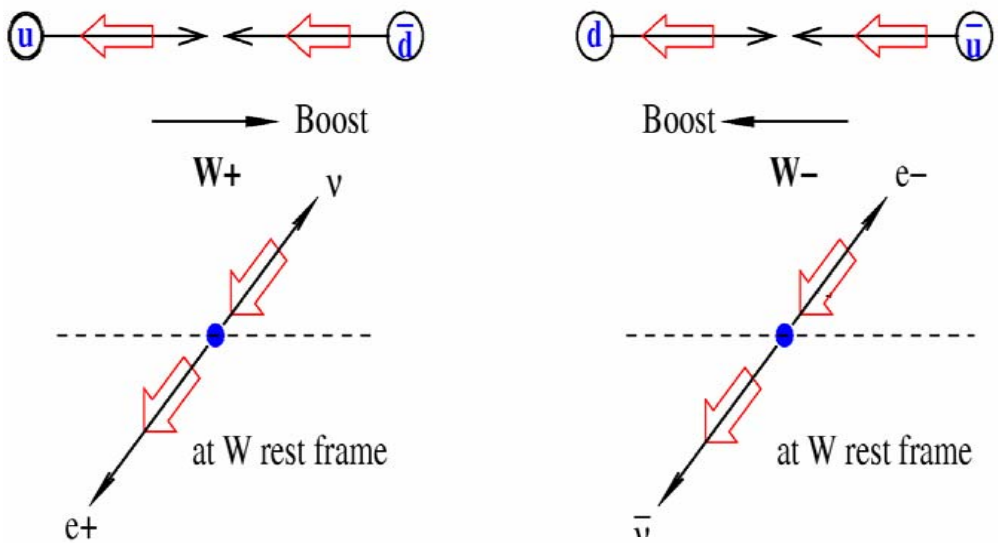


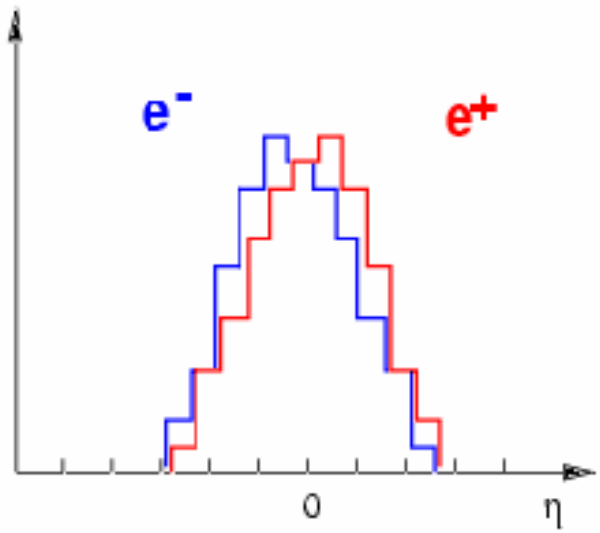
- W rapidity can't be measured directly
  → Ambiguity from neutrino momentum

Lepton Charge Asymmetry

- No ambiguity from neutrino
- V-A decay asymmetry tends to cancel W production asymmetry
- Sensitive to u(x)/d(x)

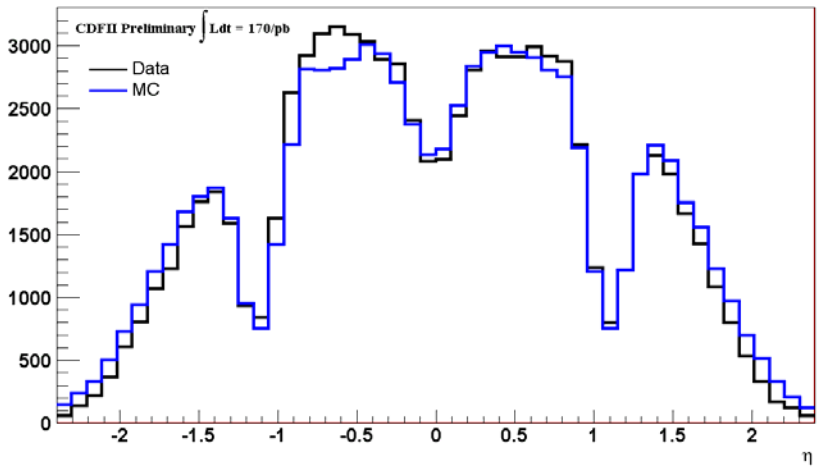
$$A(\eta_l) = \frac{d\sigma_+/d\eta_l - d\sigma_-/d\eta_l}{d\sigma_+/d\eta_l + d\sigma_-/d\eta_l} \sim \frac{d(x)}{u(x)}$$

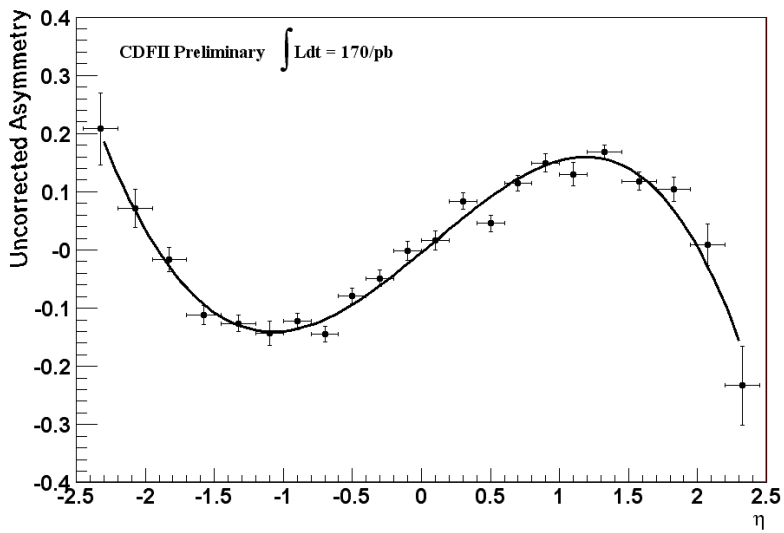




Raw Asymmetry

- $W^{\pm} \rightarrow e^{\pm} \nu$ candidates
  - E_T, missng E_T > 25 GeV
  - 50 GeV < M_T < 100 GeV
  - Central ($|\eta| < 1$) : 49214
  - Forward ($1 < |\eta| < 3$): 28806
- Corrections
  - Charge mis-ID rate
    - Measured from $Z \rightarrow e^+e^-$ data
  - Background subtraction
    - Jet background measured from data
    - Electroweak background measured from MC

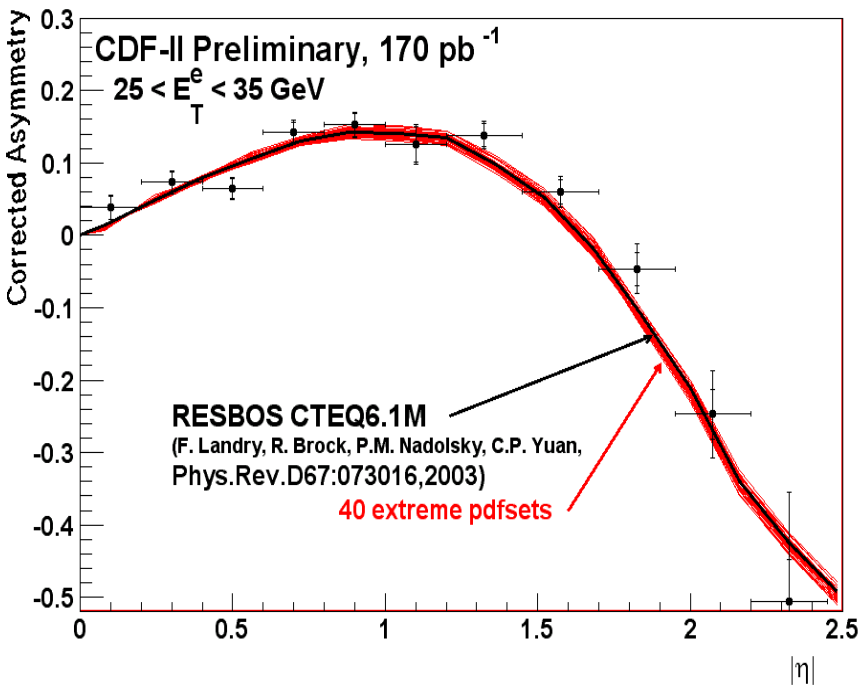


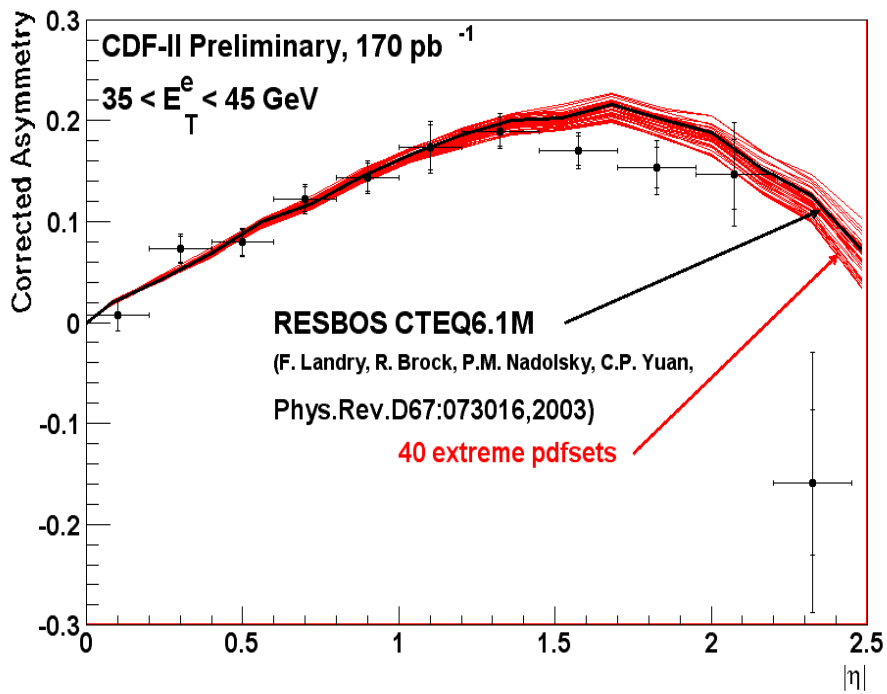


Corrected W charge Asymmetry

Divide E_T region to increase sensitivity

- Lower E_T (25-35 GeV)
  - V-A decay asymmetry enhanced
- Higher E_T (35-45 GeV)
  - Production asymmetry enhanced
  - This analysis may be good input to PDF





- D0 result coming soon!

Search for Exotica in Drell-Yan

- Sequential Z'
  - Reference model with SM-like couplings
  - $M_{Z'}$ is only free parameter
- E6 Model Z'
  - Unification at higher gauge group
  - $E6 \rightarrow (SO(10) \rightarrow SU(5) X U(1)_\chi) X U(1)_\psi$
  - $Z' = Z_\chi \sin\theta_{E6} + Z_\psi \cos\theta_{E6}$
    - $Z\eta$: $\theta_{E6} = \sin^{-1}\sqrt{3/8}$
    - Z_I : $\theta_{E6} = \sin^{-1}\sqrt{5/8}$
- Littlest Higgs Z'
  - Solve fine-tuning and hierarchy by canceling divergences of Higgs mass

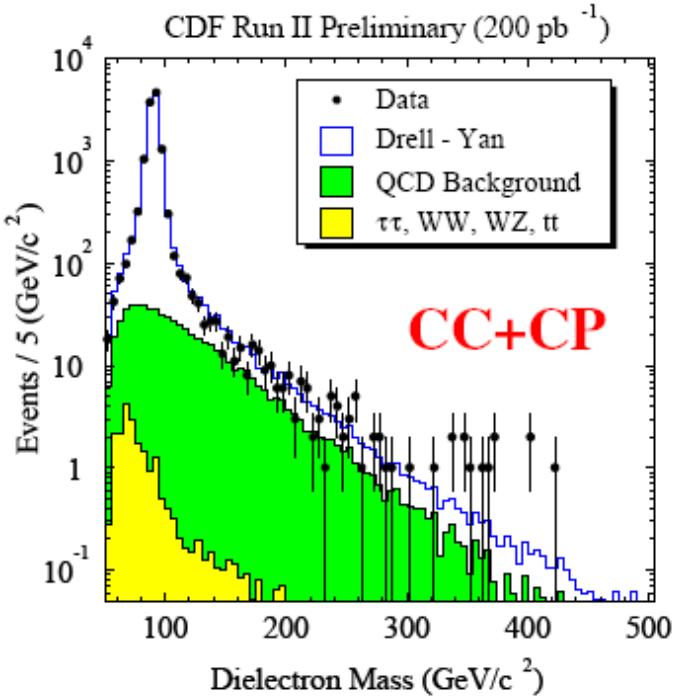
CDF Exotics only.(D0 has separate talk.)

Plots courtesy of Muge Karagoz Unel

- Technicolor ρ_T, ω_T
  - Alternative to Higgs mechanism using strong dynamics
- Extra Dimensions to solve hierarchy problem
  - Randall-Sundrum G
    - 5-D wrapped space-time
  - Large Extra Dimension (ADD)
- RPV sneurtino
  - SUSY with R-parity violation

Comparison to Expectation (ee)

- Two isolated electrons E_T > 25 GeV
  - One electron in $|\eta|<1.0$
  - One electron in $|\eta|<3.0$

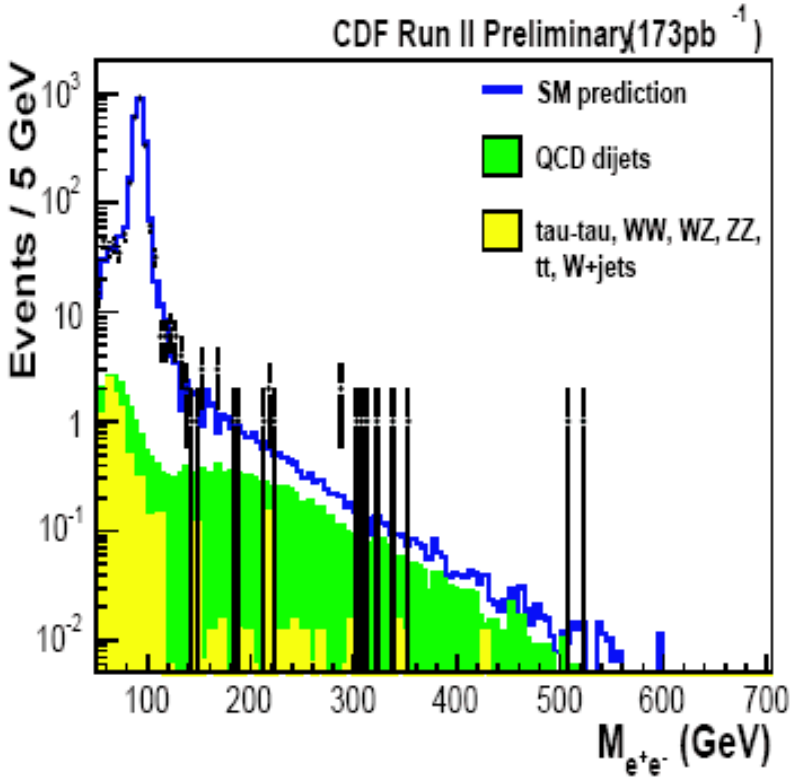


Mass >(GeV/c^2)	N_{exp}	N_{obs}
200	66.9	70
250	25.1	29
300	10.4	14
350	4.7	8
400	2.4	3
450	1.4	0

Total of ~12500 CC+CP candidates in 200 pb^{-1} data

Comparison to Expectation (ee)

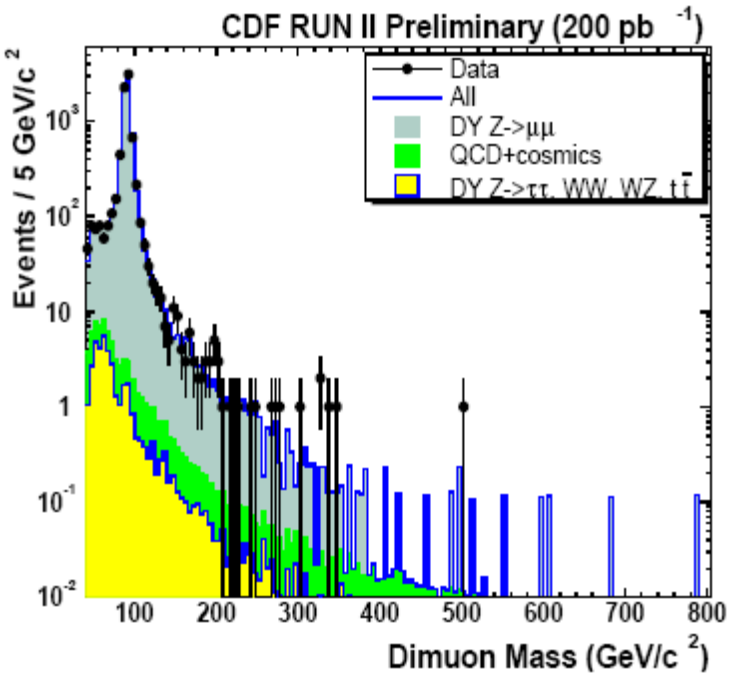
- Two isolated electrons E_T > 25 GeV
  - Two electrons in 1 < |η| < 3



Mass Cut	N_{PRED}	N_{DATA}
0	2414 ± 58	2387
50	2410 ± 58	2381
100	144 ± 6.7	149
150	20.8 ± 3.7	22
200	10.2 ± 2.2	14
250	5.0 ± 1.2	10
300	2.5 ± 0.7	8
350	1.4 ± 0.33	3
400	0.71 ± 0.17	2
450	0.39 ± 0.09	2
500	0.21 ± 0.04	2
550	0.10 ± 0.03	0

Comparison to Expectation ($\mu\mu$)

- Two isolated μ with p_T > 20 GeV
  - μ_1 : $|\eta| < 1.0$
  - μ_2 : $|\eta| < 1.5$



Mass > (GeV/c^2)	N_{exp}	N_{obs}
150	55.25±2.50	58
200	20.88±0.97	18
250	9.44±0.49	9
300	5.22±0.32	6
350	3.23±0.24	1
400	2.28±0.19	1
450	1.79±0.16	1
500	1.24±0.13	1
550	1.03±0.11	0

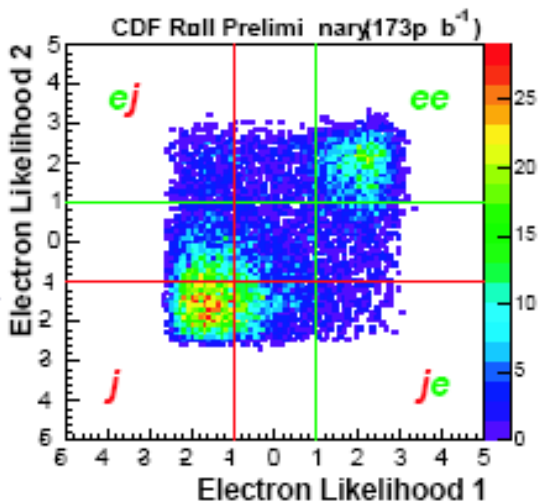
Total of ~ 7500 dimuon candidates in 200 pb^{-1} data

Background Estimation

- Use data to estimate backgrounds and efficiencies as much as possible
- Veto fakes/cosmics mainly by $\not\!\!E_T$ significance and track-timing cuts

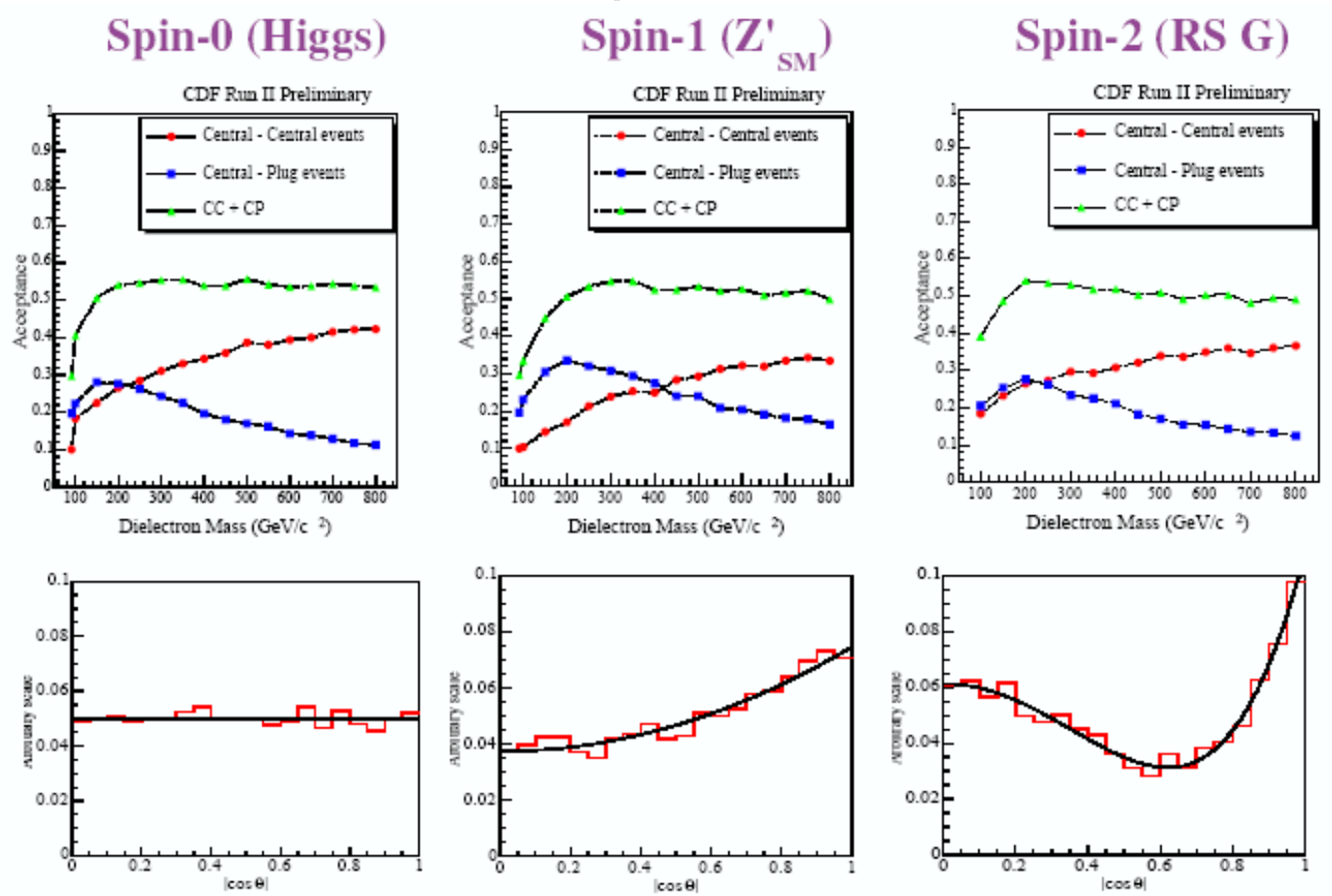
		ee	μμ	Estimation
Direct	Drell-Yan/Z	✓	✓	MC
	WW,WZ, ZZ, Z→ττ, $t\bar{t}$	✓	✓	MC
Fakes	W+n jets, dijets	✓	✓	MC/Data
	cosmic rays		✓	Data

QCD bgrnd estimation for plug electrons

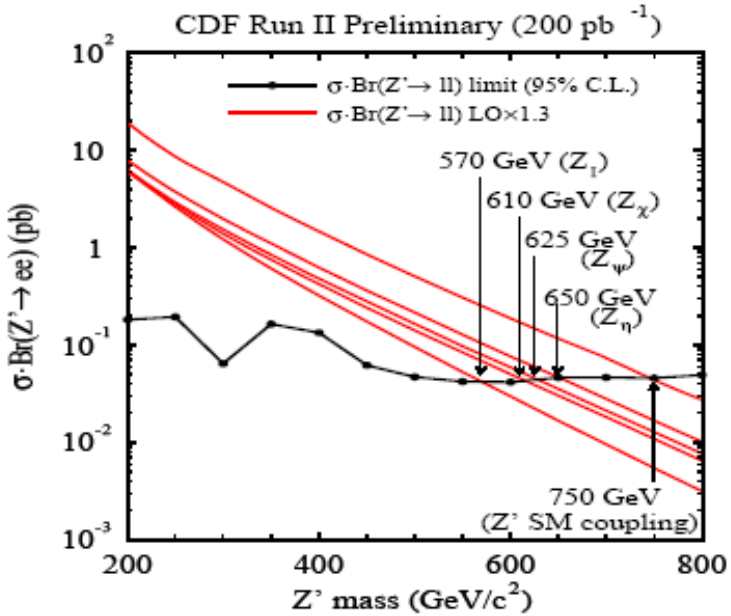


Acceptance Correction

- Difference in angular distribution
  → Variations in Acceptance



Limits on E6 Z'



$ee\ Z'_{SM}$

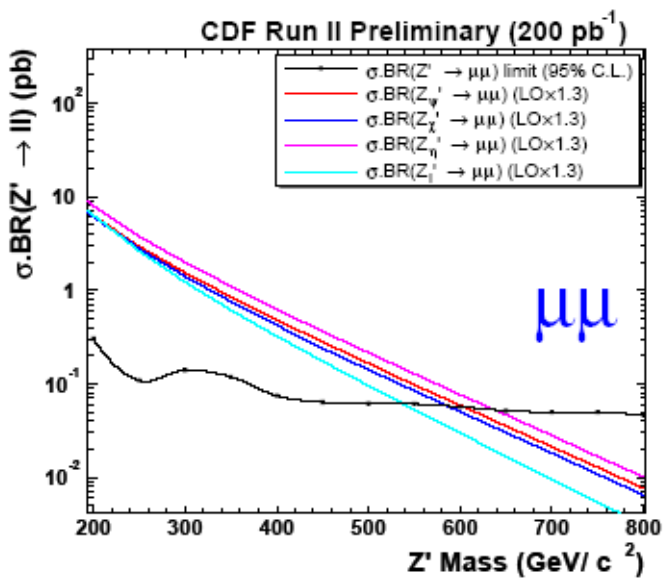
CDF Run II Preliminary

CDF Run	L(pb^{-1})	Mass limit @95%CL
IA ('92-'93)	20	**505**
IB (('94-'95)	90	**640**
IIA (winter '04)	200	**750**

CDF Run II Preliminary

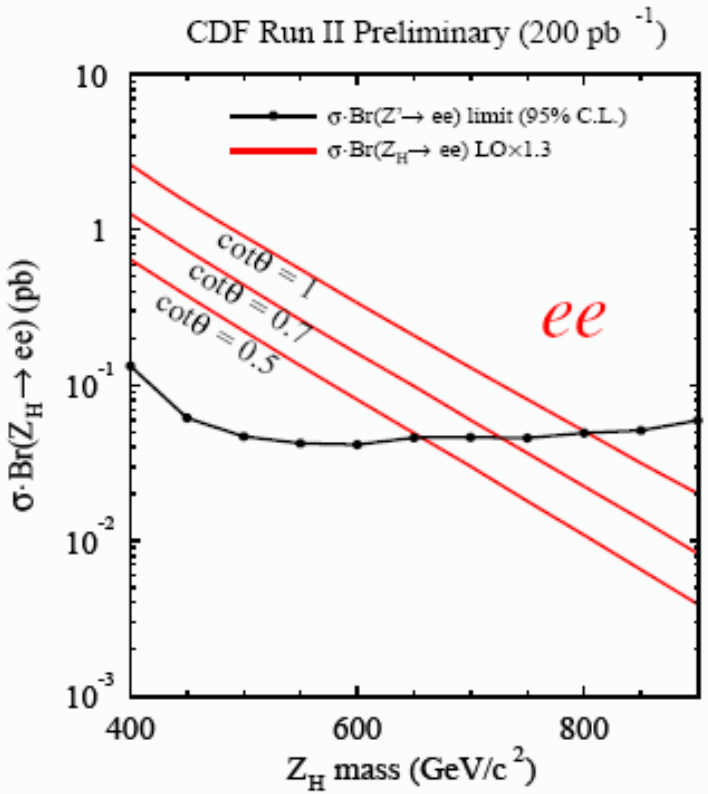
$\mu\mu\ Z'$ Mass limit @95%CL (GeV/c^2)

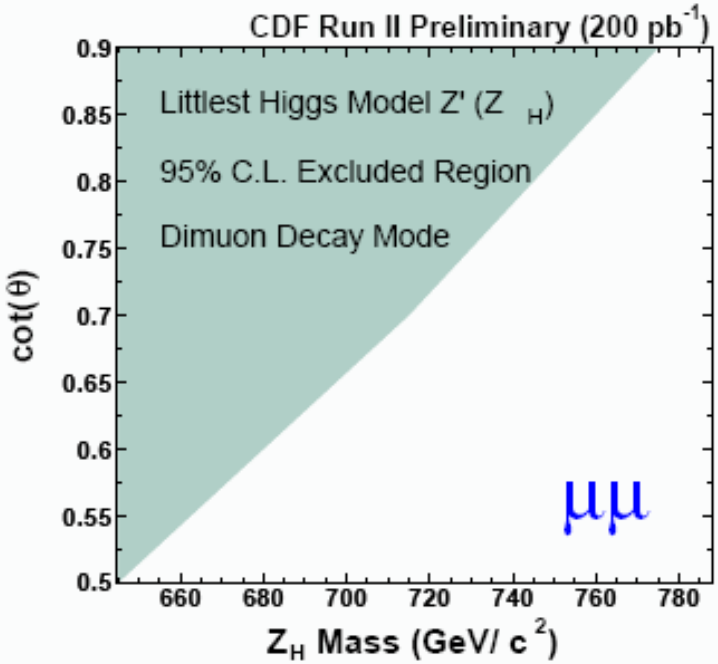
Model	Run I	Run II (winter '04)
Z'_{SM}	590	735
Z_ψ	495	600
Z_χ	500	580
Z_η	520	635
Z_I	480	530



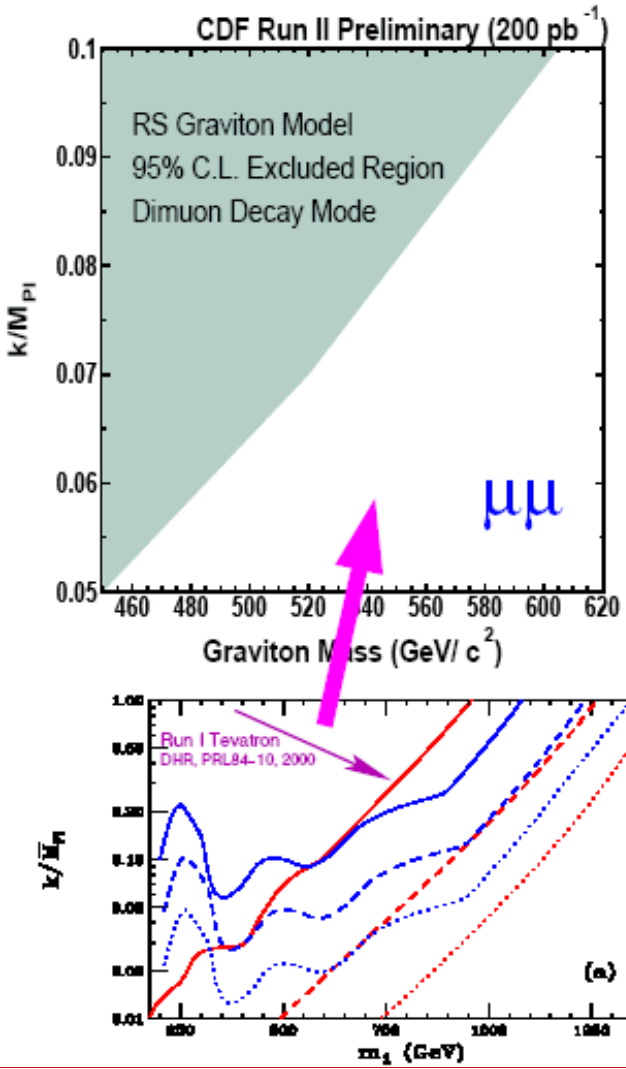
Limits on Littlest Higgs Z'

- *ee:* $M(Z_H) > 800$ GeV/c^2 for $\cot\theta = 1.0$
- μμ: $M(Z_H) > 755$ GeV/c^2 for $\cot\theta = 0.9$



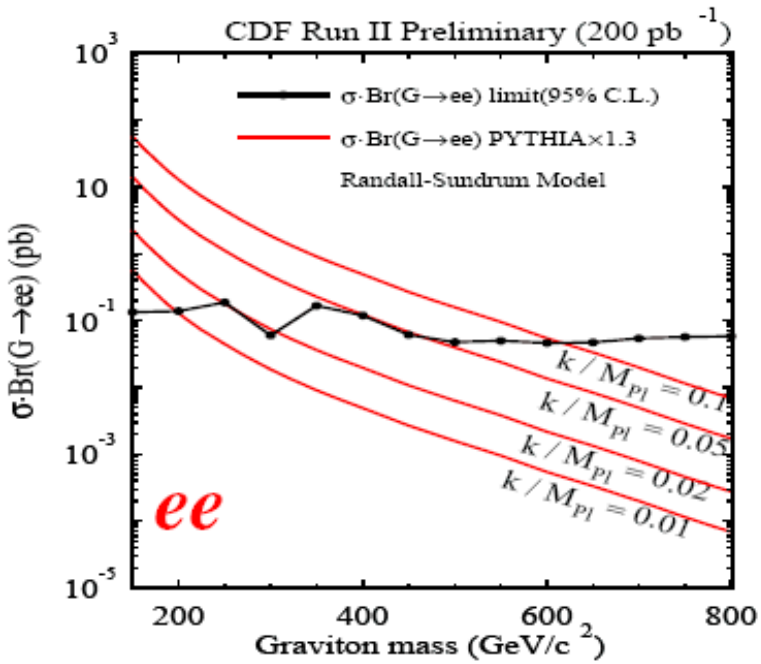


Limits on RS Graviton

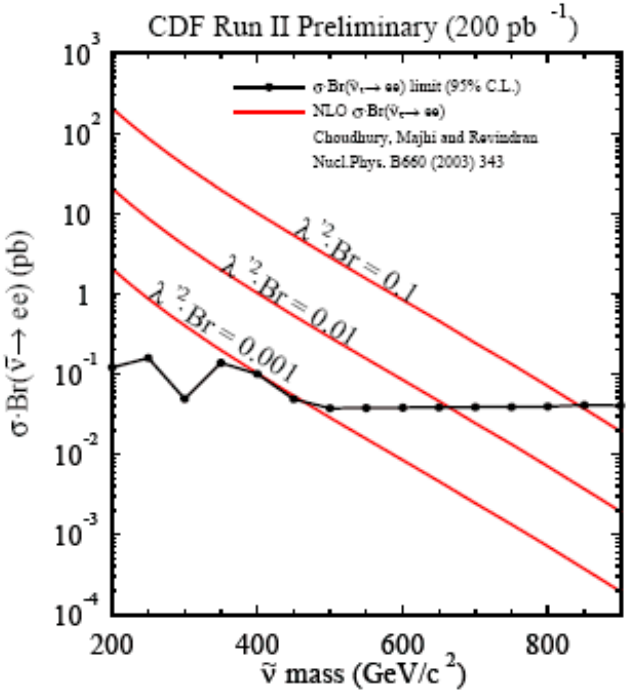


CDF Run II Preliminary

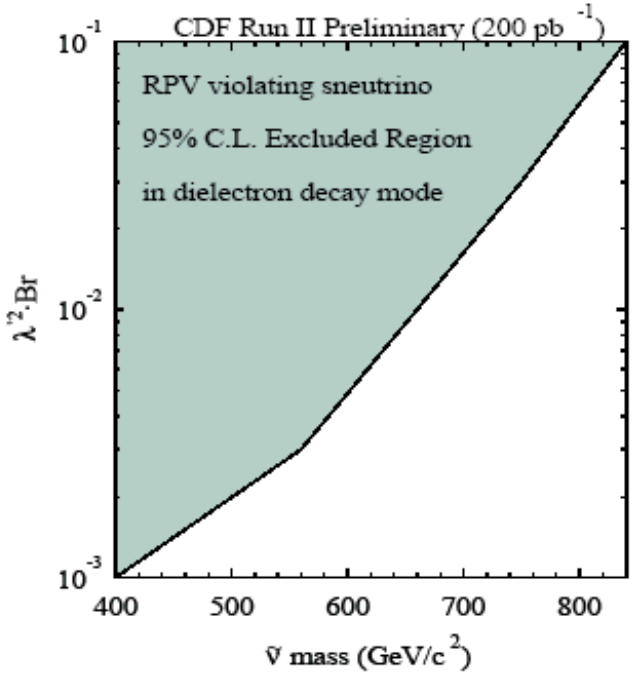
CDF Run	L(pb^{-1})	M_G @95%CL (k/M_{Pl}=0.1)	
		ee	μμ
IIA (winter '04)	200	**620**	**605**



Limits on sneutrino

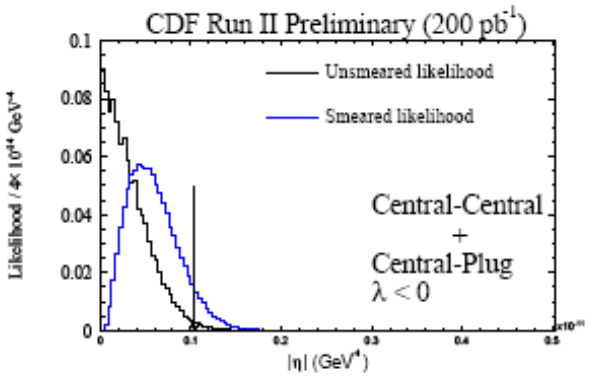


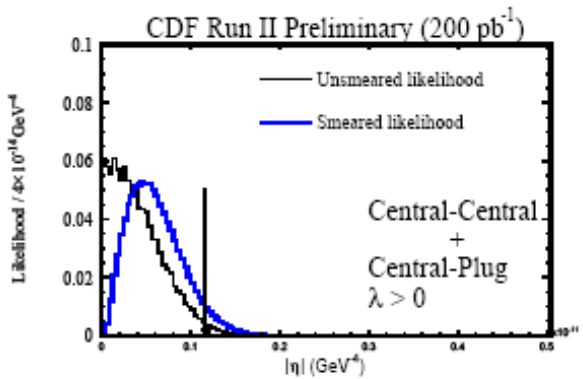
	CC (GeV)	CP (GeV)	CC+CP (GeV)
$\lambda'^2 \cdot Br = 0.1$	830	710	840
$\lambda'^2 \cdot Br = 0.01$	650	550	660
$\lambda'^2 \cdot Br = 0.001$	400	340	400



Limits on ADD Model

- λ conventions : $\frac{2}{\pi}\lambda_{Hewett} = F_{GRW} = F_{HLZ}$, $F_{GRW} = 1$, $F_{HLZ} = \frac{2}{n-2}(n > 2)$





CDF Run II Preliminary (200 pb^{-1})

	η_{95} (10^{-12}GeV^{-4})		Hewett (GeV)		HLZ (GeV)					GRW (GeV)
	$\lambda = -1$	$\lambda = +1$	$\lambda = -1$	$\lambda = +1$	$n = 3$	$n = 4$	$n = 5$	$n = 6$	$n = 7$	
Central-Central	1.05	1.18	987	959	1174	987	892	830	785	1105
Central-Plug	2.23	2.47	818	797	973	818	739	688	650	916
Combined	1.05	1.17	987	961	1174	987	892	830	785	1105

CDF Run I: 780 768

Conclusion

- CDF has measured charge asymmetry in $\gamma^*/Z \rightarrow e^+e^-$
  - Unfolded A_{FB} without SM assumptions
  - Fit for Z couplings
  - Consistent with SM
- Charge asymmetry in $W^{\pm} \rightarrow e^{\pm}\nu$ also measured
  - Increased statistics enables to divide E_T regions
    - Measurement will serve as input to PDF
  - Uncertainty in PDF would be reduced
    - Further constraint will be available with $d\sigma_Z/dy$ analysis
- D0 results are coming soon
- Exotics (CDF only, D0 is on a separate talk)
  - Set upper limits to $\sigma \cdot BR$ of various models beyond SM
  - Surpassed Run I sensitivity
  - Current Tevatron experiments exceed published limits of previous direct searches.

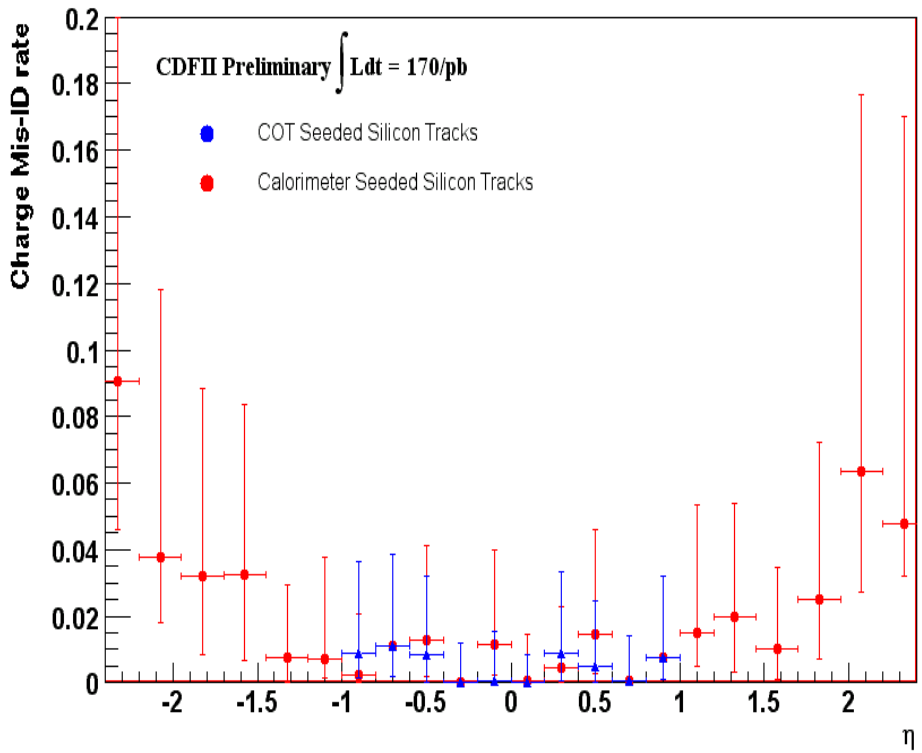
Backup

Charge Mis-ID Correction

- Charge mis-ID biases the asymmetry low
- Measured from $Z \rightarrow e^+e^-$ data
- Cross-checked with central tracker

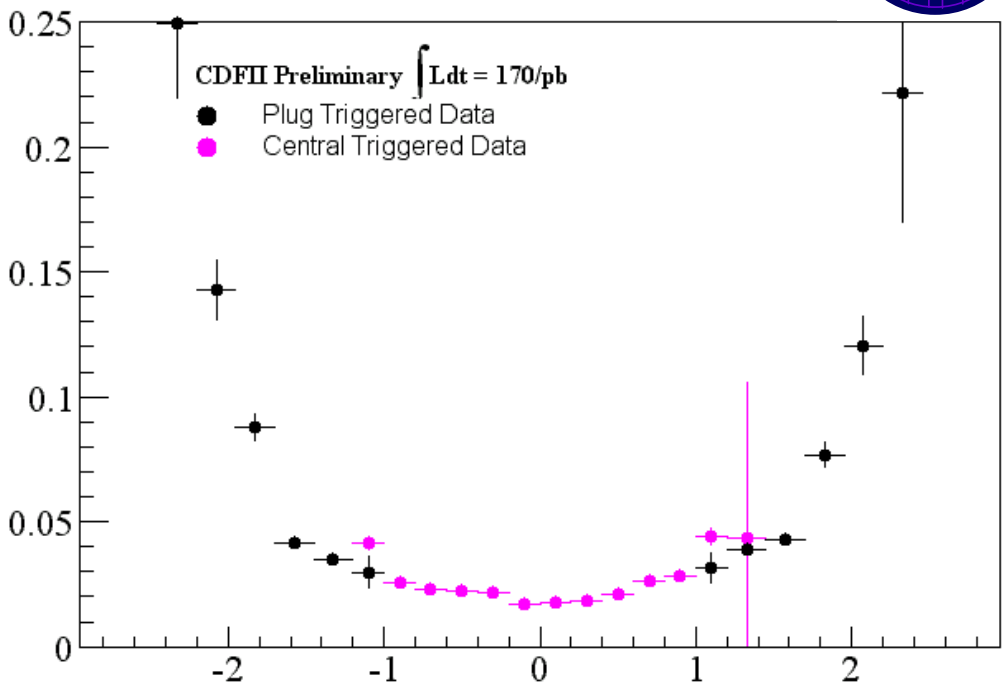
$$f_Q \equiv \frac{wrong}{total}$$

$$A_{true} = \frac{A_{measured}}{1 - 2 f_Q}$$



Background Correction

- Dijet events
  - Charge symmetric
    - Biases A toward 0
  - Measured from data
    - Use Calorimeter Isolation vs. missing ET distibution
    - Estimated is upper limit



Bkg vs. Eta

- $W \rightarrow \tau\ \nu \rightarrow e\ \nu\nu$, $Z \rightarrow e\ e$
  - Charge asymmetric
  - Measured from Monte Carlo

Limits with Likelihood Method

- 95% CL upper limits on $\sigma \cdot BR(X \rightarrow \ell\ell)$ for spin-0,1,2 and lower limits on string scale for LED are placed using binned likelihood method.

$$L(\alpha/\eta) = \prod_i \frac{\mu_i^{n_i} e^{-\mu_i}}{n_i!}$$

- n_i: observed events
- $\mu_i = \alpha N_i^{sig} + N_i^{bgrd}$ *(resonant particles)*
- $\mu_i = N_i^{sig}(\eta) + N_i^{bgrd}$ *(LED spectrum)*

- Likelihoods are used to give the final limits, taking into account the signal and background systematic uncertainties.
- Sources of systematic uncertainties
  - Luminosity (6%)
  - Acceptance (PDF, MC statistics, detector description, etc.)
  - Energy/Momentum scale/resolution
  - Selection efficiencies
  - Background statistics and normalization