Asymmetries in $W^{\pm}$ and Z^0/γ^* Production at the TeVatron

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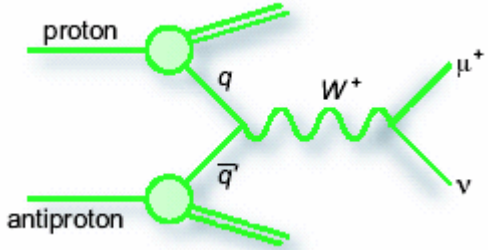
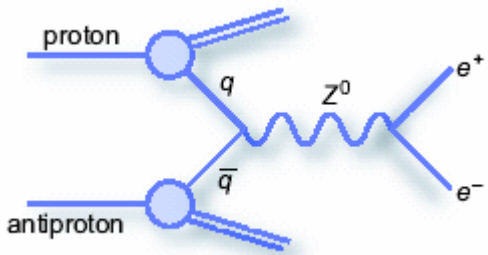
For the CDF and D0 Collaborations

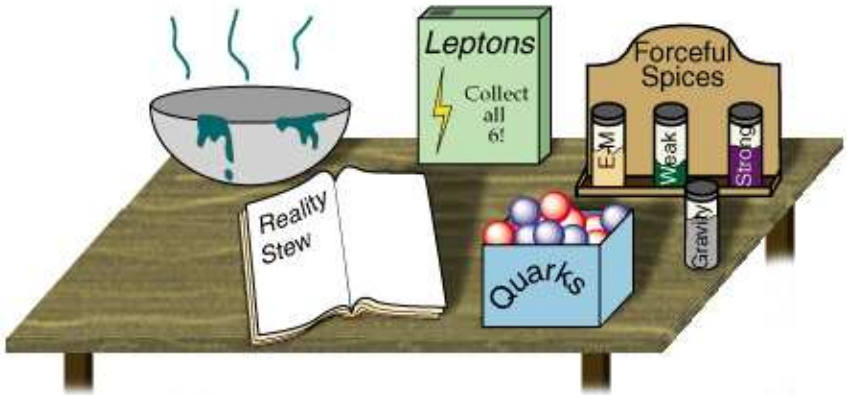
EWK "Spectroscopy"

- Lots of interesting physics in production of $W^{\pm}$ and Z^0 bosons at the Tevatron!
  - § Rapidity Spectrum: $d\sigma/dy$
    - o quark PDF constraints
      - o Direct impact on M_W
  - § Polar Angle Spectrum: $d\sigma/d\cos\theta$
    - o In Z's vs. M_{ee}
      - o A_{FB}, $\sin^2\theta_W$
      - o quark, lepton couplings
    - o In W's vs. p_T
      - o Tests QCD predictions
  - § Boson p_T Spectrum: $d\sigma/dp_T$
    - o Tests QCD predictions
      - o Direct impact on M_W



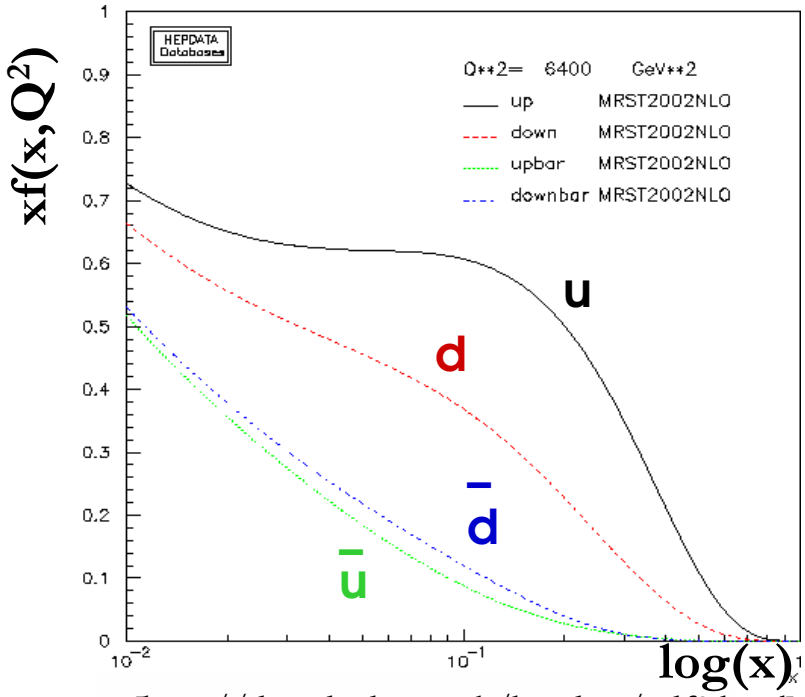
W Charge Asymmetry





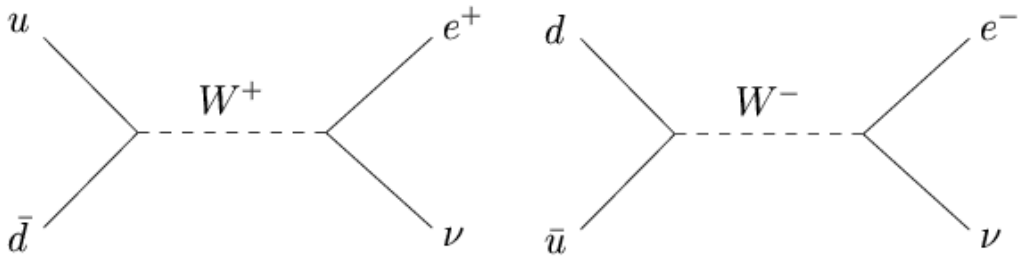
$W^{\pm}$ Charge Asymmetry

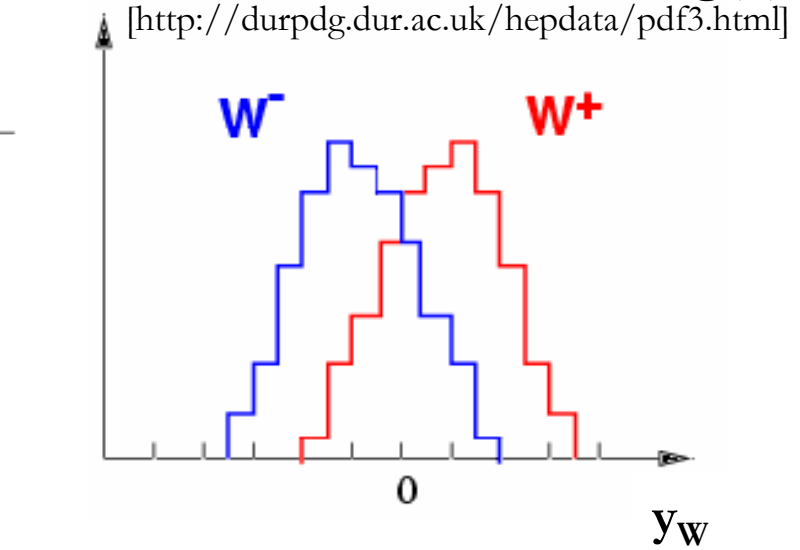
$$A(y_W) = \frac{d\sigma_+/dy_W - d\sigma_-/dy_W}{d\sigma_+/dy_W + d\sigma_-/dy_W} \approx \frac{u(x1)d(x2) - d(x1)u(x2)}{u(x1)d(x2) + d(x1)u(x2)}$$



[http://durpdg.dur.ac.uk/hepdata/pdf3.html]

u quark carries higher fraction of p momentum!



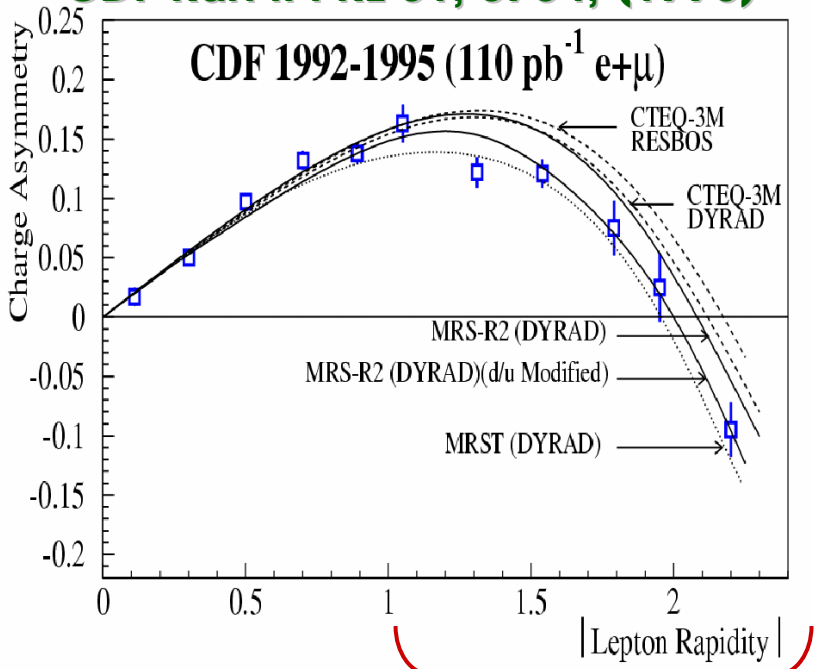


Measurement of the W charge asymmetry constrains PDF's of the proton.

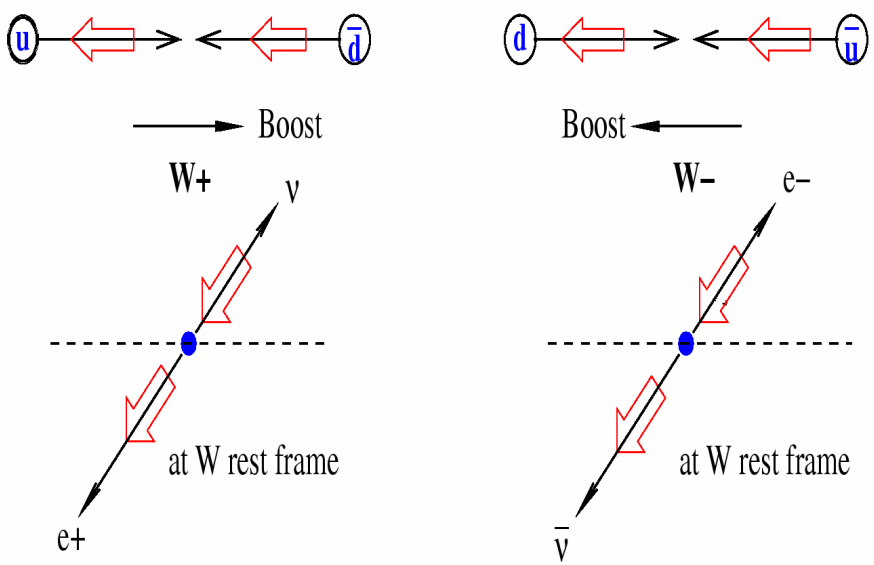
Lepton Charge Asymmetry

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

CDF Run I: PRL 81, 5754, (1998)



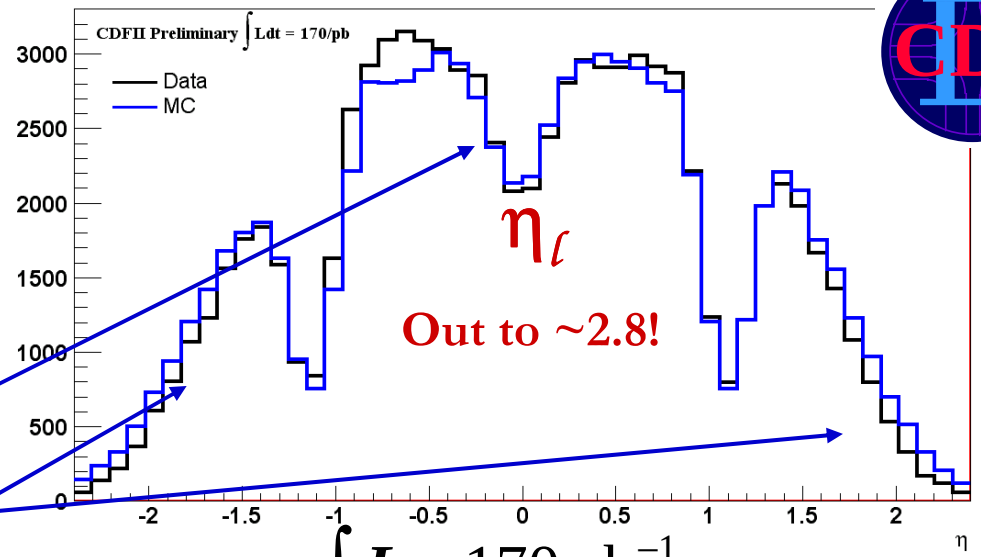
Least constrained at high η!



- Leptonic W decay involves ν → p_z^{ν} is unmeasured.
- Use experimentally more direct $\ell^{\pm}$ direction to measure $A(\eta_\ell)$.
  - § This convolves W production asymmetry with V-A decay distribution.
  - § Sensitivity to the ratio of PDFs for u and d quarks, u(x)/d(x).

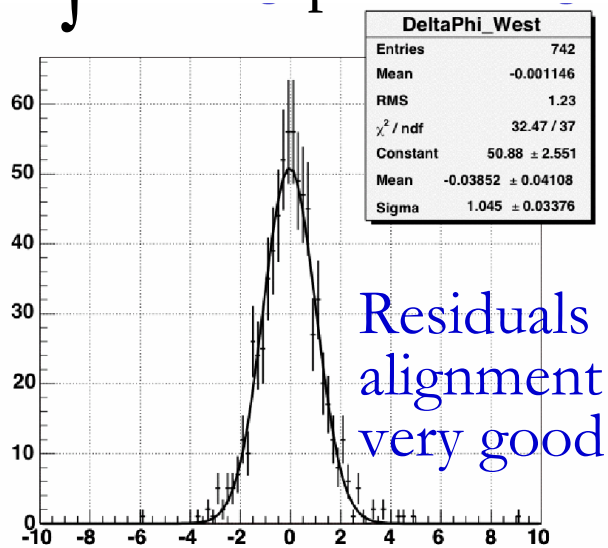
Event Selection

- $W^{\pm} \rightarrow e^{\pm} \nu$ Candidates
  [E_T, ME_T > 25GeV,
  50 GeV < M_T < 100 GeV]
  - § Central: 49214 events
  - § Forward: 28806 events



$$\int L = 170\ \mathrm{pb}^{-1}$$

- Charge ID in forward region is key!
  - § Use new silicon tracker and forward calorimeters.
  - § Align forward calorimeters with tracks from central tracker.
    - o *Global* offsets, rotations.
    - o *Internal* misalignments.

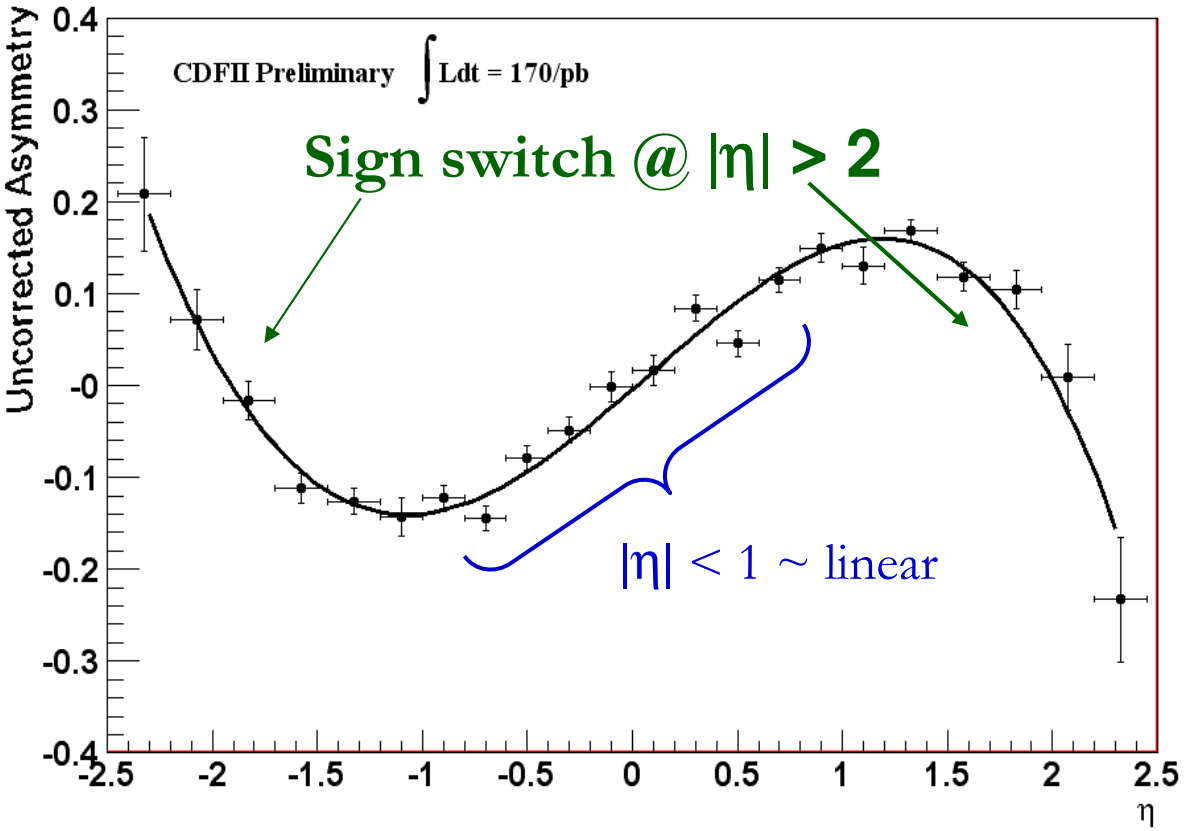


Residuals after alignment look very good.

Global Δϕ (mRad)

Raw Asymmetry

Shape is convolution of $\mathcal{A}(y_W)$ and V-A



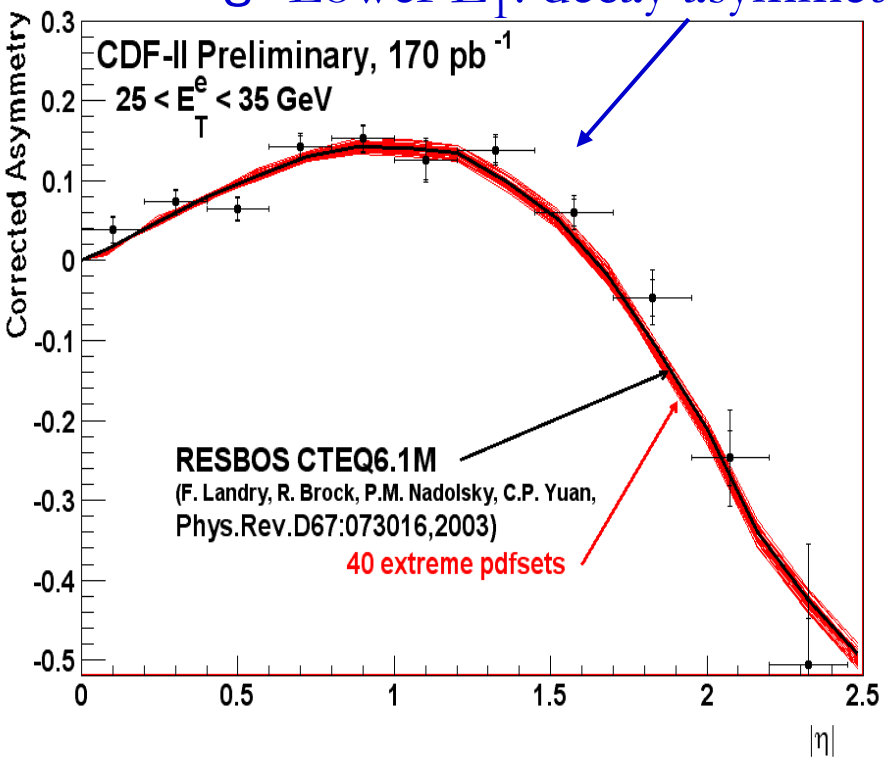
Curve is just to guide the eye.

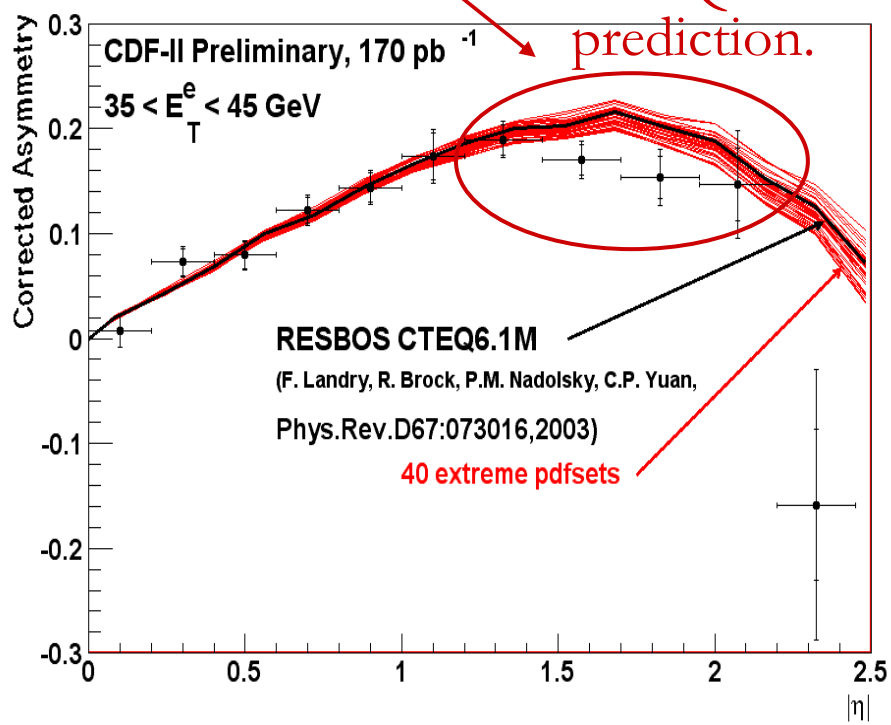
- Corrections to extract true asymmetry:
  - § Charge misidentification rate.
  - § Background subtraction.
    - o Both bias the asymmetry low → dilution.
    - o Measured in each η bin.
    - o Uncertainties in corrections go directly in $\mathcal{A}$.

Corrected W Charge Asymmetry

- Gain sensitivity to W production asymmetry $\mathcal{A}(y_W)$ with E_T dependence.
  - § Higher E_T: electron direction closer to W direction. Production asymmetry enhanced.
  - § Lower E_T: decay asymmetry enhanced

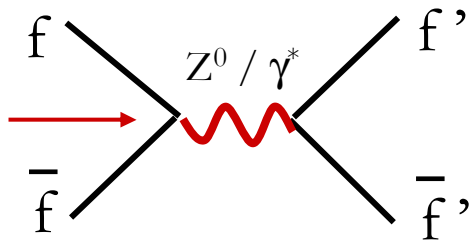
Data lower than existing CTEQ prediction.

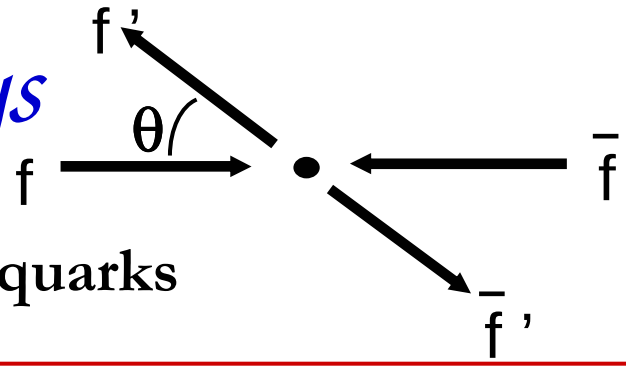




A_{FB} in $Z^0/\gamma^* \rightarrow e^+e^-$ Decays

$$J^{Zf} \sim \bar{f}(g_V^f + g_A^f \gamma_5) f$$
$$J^{\gamma^* f} \sim Q_f$$





f = e, quarks

$$d\sigma / d\cos\theta = A(1+\cos^2\theta) + B\cos\theta$$

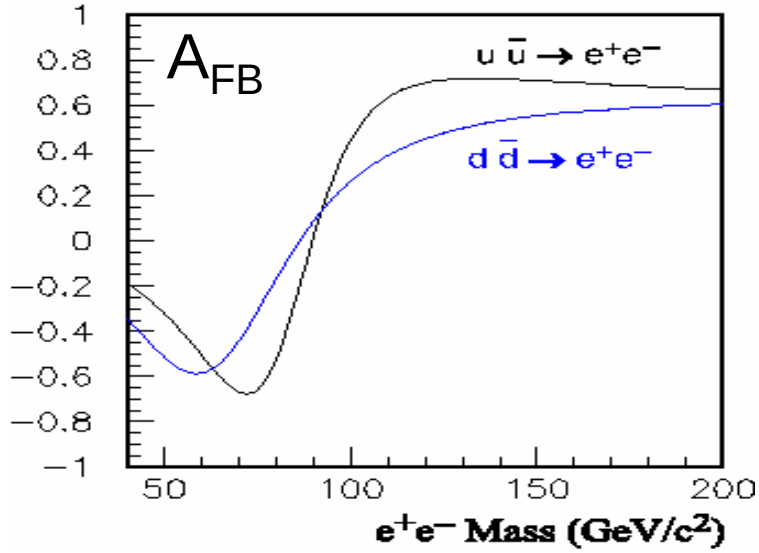
$$A_{FB} = \frac{d\sigma(\cos\theta > 0) - d\sigma(\cos\theta < 0)}{d\sigma(\cos\theta > 0) + d\sigma(\cos\theta < 0)}$$

$$A_{FB} = \frac{3B}{8A}$$

- **Vector (V) and Axial-vector (A) couplings give rise to A_{FB}.**
- **Interference between Z^0 and γ^* exchanges.**
- **Different combinations of V and A couplings contribute to $d\sigma/d\cos\theta\, dM_{ee}$.**

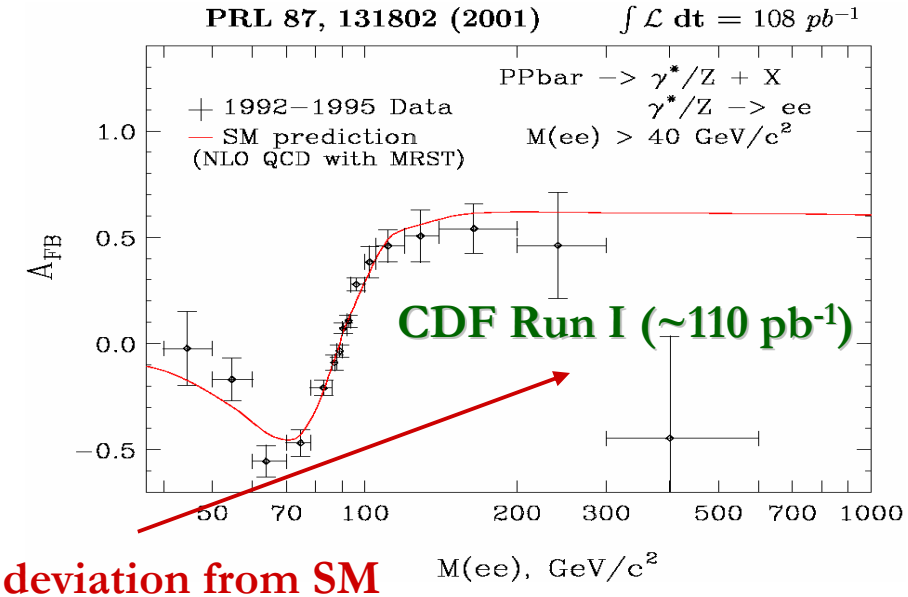
  § **A_{FB} direct probe of relative strengths of coupling between Z^0 and quarks.**

  § **Mass dependence is sensitive to u and d quarks separately.**



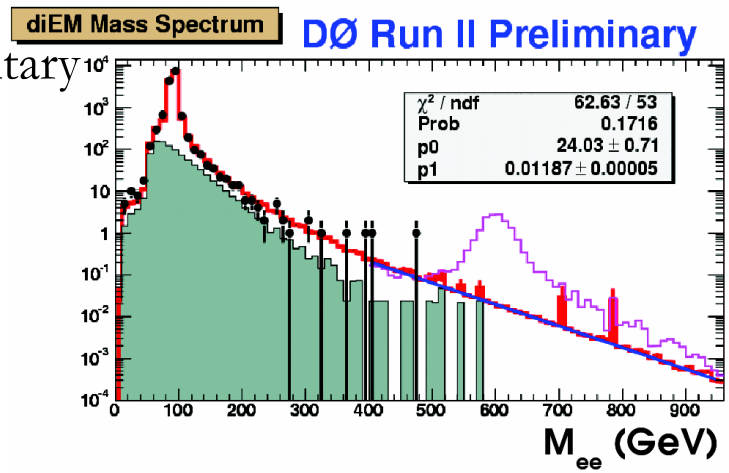
A_{FB} Beyond LEPII

- Interesting for M_{ee} above LEP II energies.
- New interactions → deviations of A_{FB} and $d\sigma/dM$ from SM predictions.
  - § **Various models predict new neutral, heavy bosons: Z´s**
- New resonance could interfere with γ and Z.
- Complementary to direct searches → excess in total cross section.

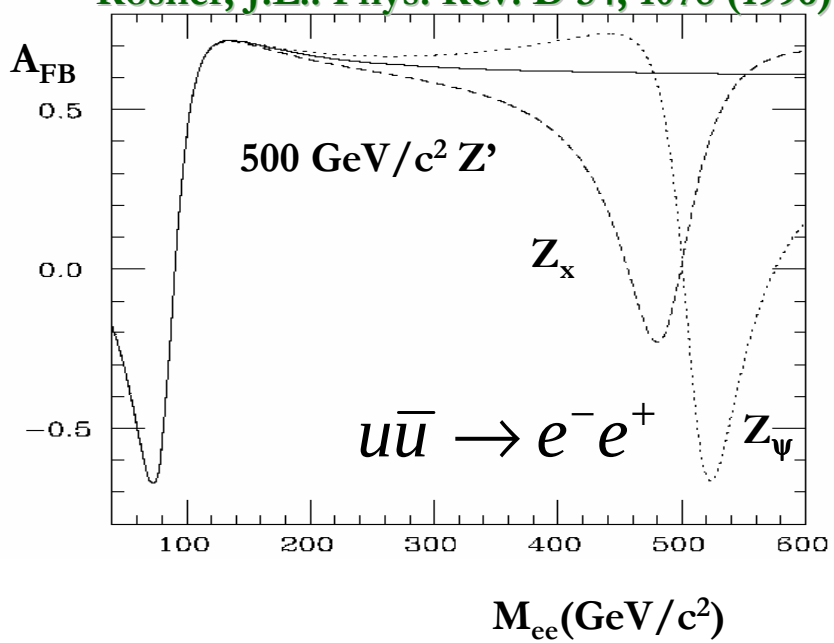


2.2 s deviation from SM

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



200 pb^{-1} of Z→ee

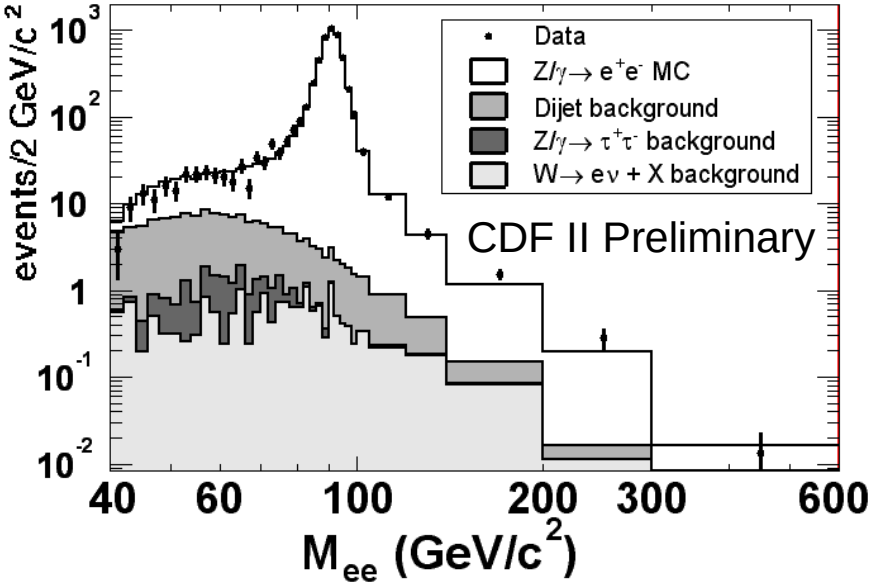


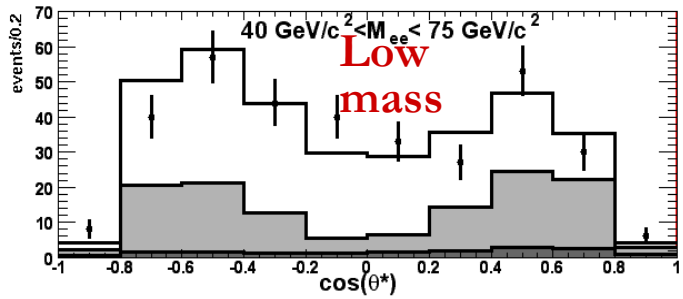
Calculating A_{FB}

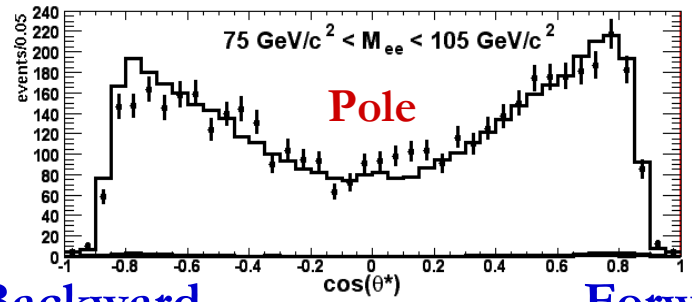
$$A_{FB} = \frac{d\sigma(\cos\theta^* > 0) - d\sigma(\cos\theta^* < 0)}{d\sigma(\cos\theta^* > 0) + d\sigma(\cos\theta^* < 0)}$$

- 5211 Candidate $Z^0 \rightarrow e^+e^-$ events
  - § 2 isolated electrons E_T>20 GeV
  - § 1892 Central-Central
  - § 3319 Central-Forward

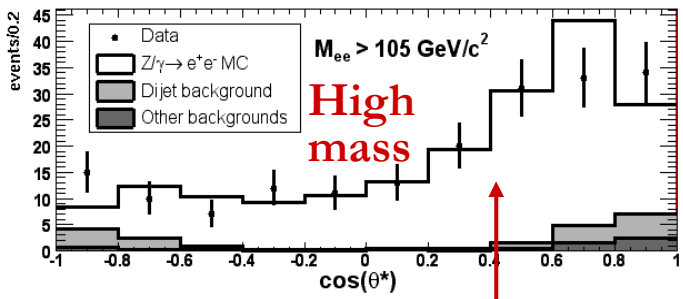
$$\int L = 72\ \text{pb}^{-1}$$







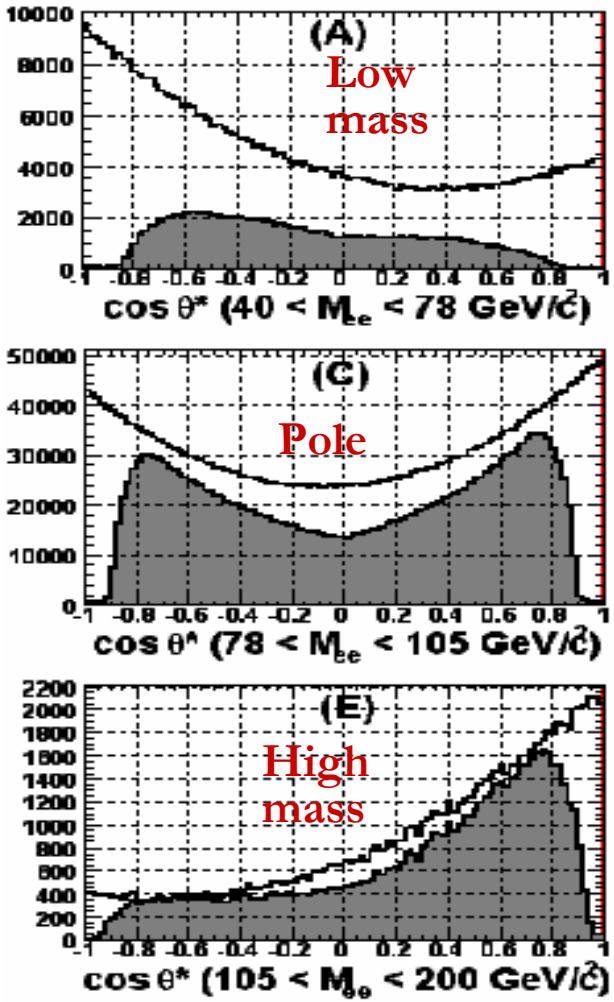
Backward Forward



A_{FB} is largest

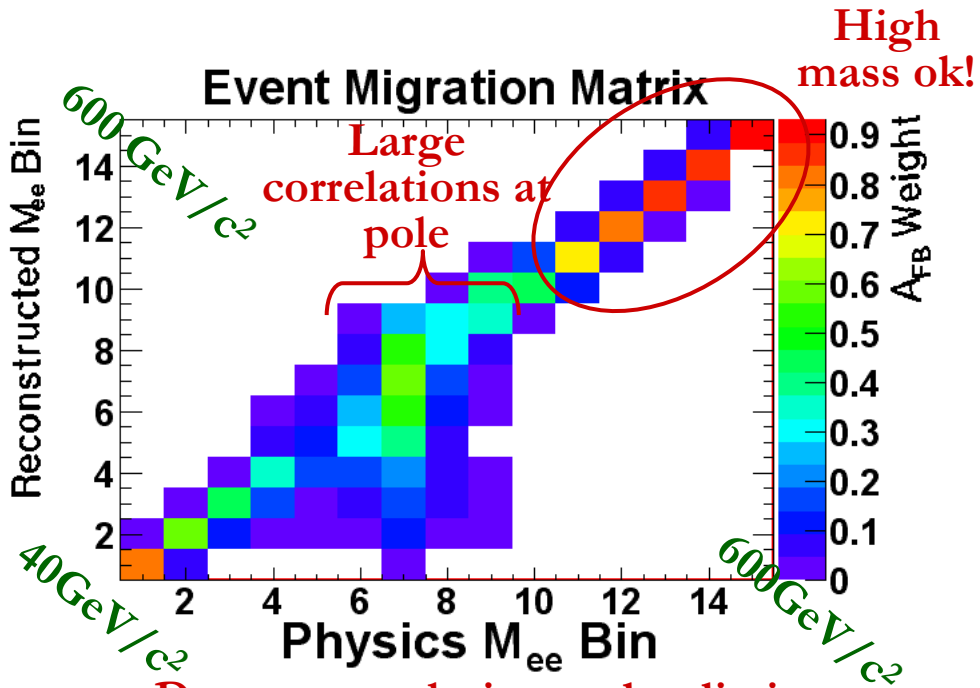
- Backgrounds:
  - § Central-Central: 1%
  - § Central-Forward: 5%
  - § Dijet background dominant

Acceptance Corrections



Kin. and geom. cuts sculpt the cosθ* distrib., esp. in forward region.

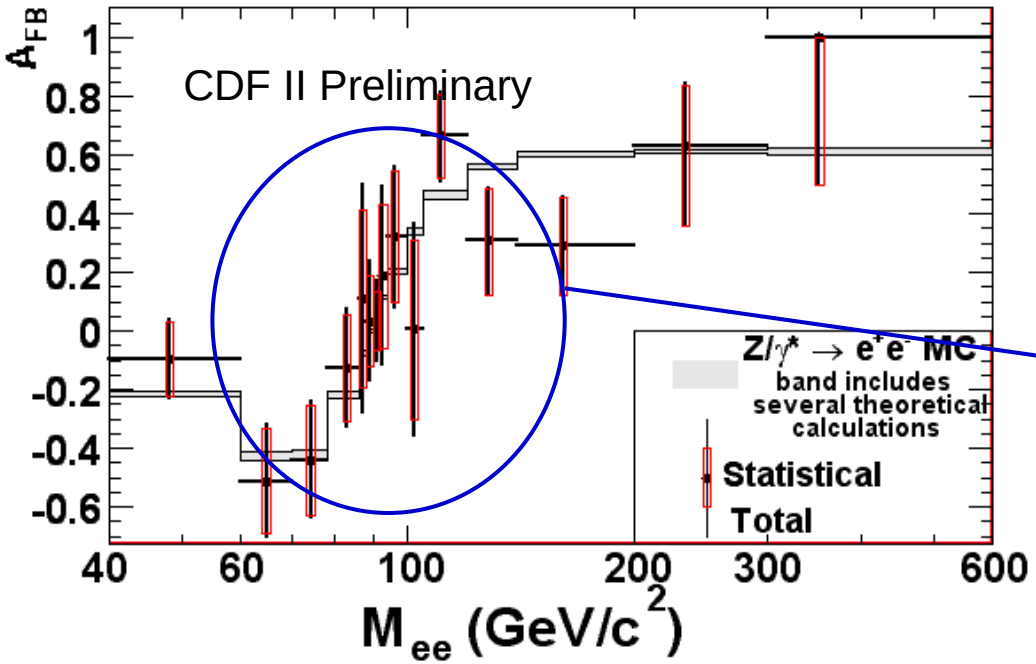
- Unconstrained unfolding analysis
  - § Acceptance and event migration parameterized to transform A_{FB}^{phys} to A_{FB}^{raw}.
  - § Use maximum log likelihood method to compare to data at the detector level.



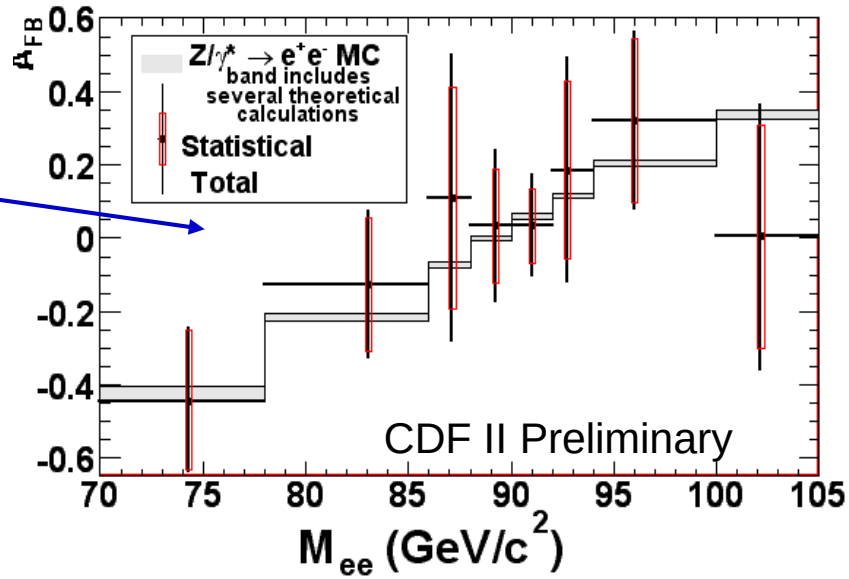
Detector resolution and radiative effects → event migration.

Unconstrained Fit with Smoothing

- Result fitting A_{FB}
  - § Large statistical uncertainties
  - § No SM assumptions about A_{FB}!



- Systematic uncertainties small compared to statistical:
  - § Energy Scale, Resolution
  - § Detector Material
  - § Backgrounds



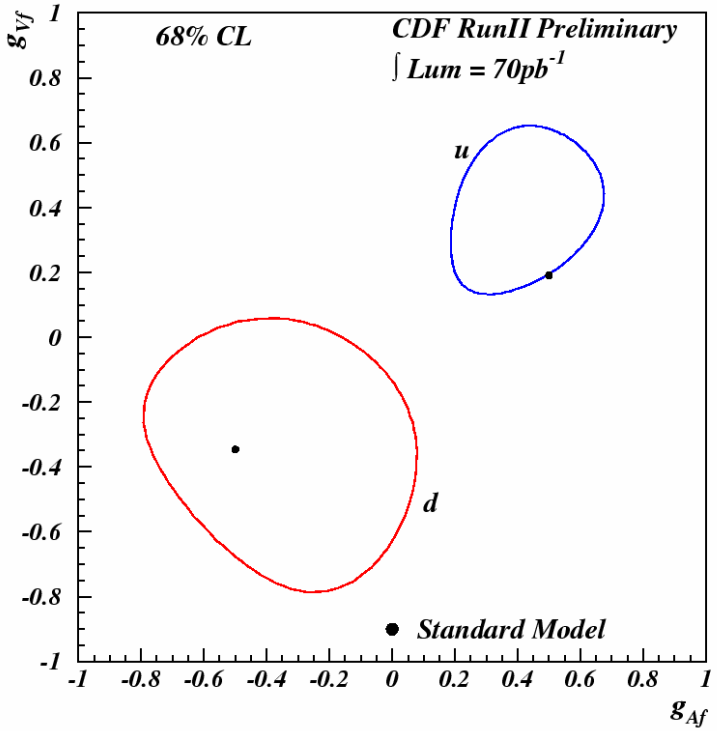
- All results consistent with SM.
- Not useful for non-SM physics near Z pole.
- Nothing new above the pole yet.

Couplings Results

Quark Couplings:

$\chi^2 / \text{ndf} = 10.66/11$

	CDF Run II	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



$$\sin^2\theta_W = 0.2238 \pm 0.0046(\text{stat}) \pm 0.0020(\text{syst})$$

$\chi^2/\text{ndf} = 12.71/14.0$

Electron Couplings:

$\chi^2 / \text{ndf} = 12.5/13$

	CDF Run II	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

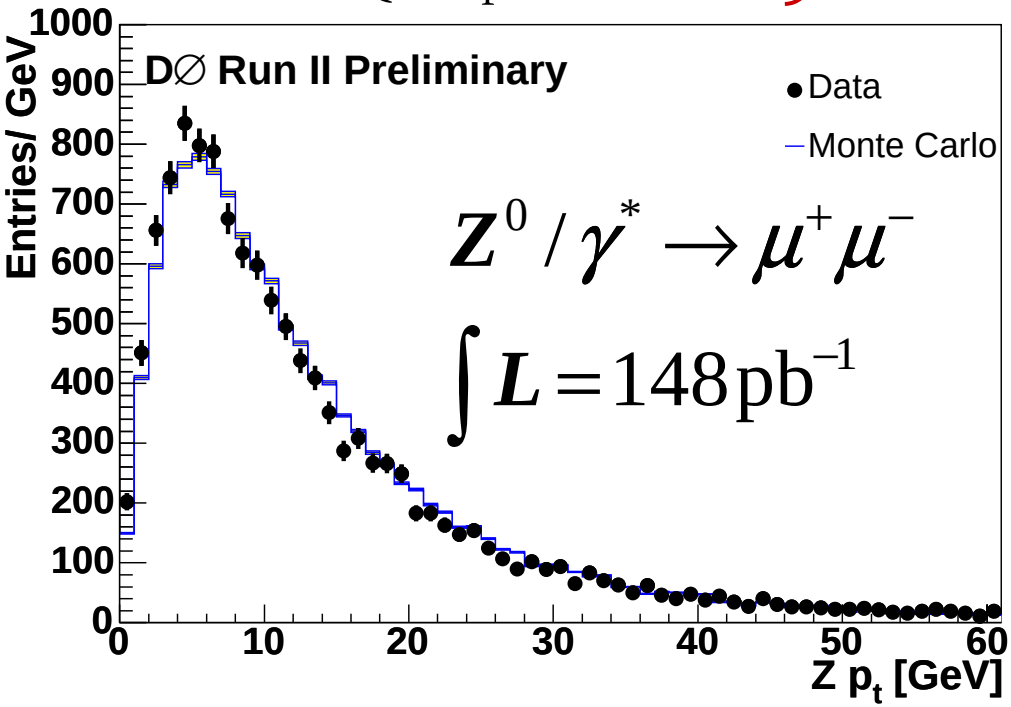
Summary

- CDF has a new measurement of the lepton charge asymmetry in $W \rightarrow e\nu$ decays.
  - § Look at data at large E_T and large η.
  - § Uncertainty on PDFs could be reduced by inclusion of this data in global fits.
  - § *First* Run II measurement of W charge asymmetry!
- We also measure A_{FB} vs. M_{ee} in $Z \rightarrow ee$ events.
  - § Unfolded A_{FB} with out SM assumptions.
  - § Fit for Z couplings.
  - § Nothing new above the Z pole yet.

Future

- $d\sigma/dy$ measurements in Z's will further constrain PDF uncertainties.
- $d\sigma/dp_T$ in both W's and Z's will further test QCD predictions.

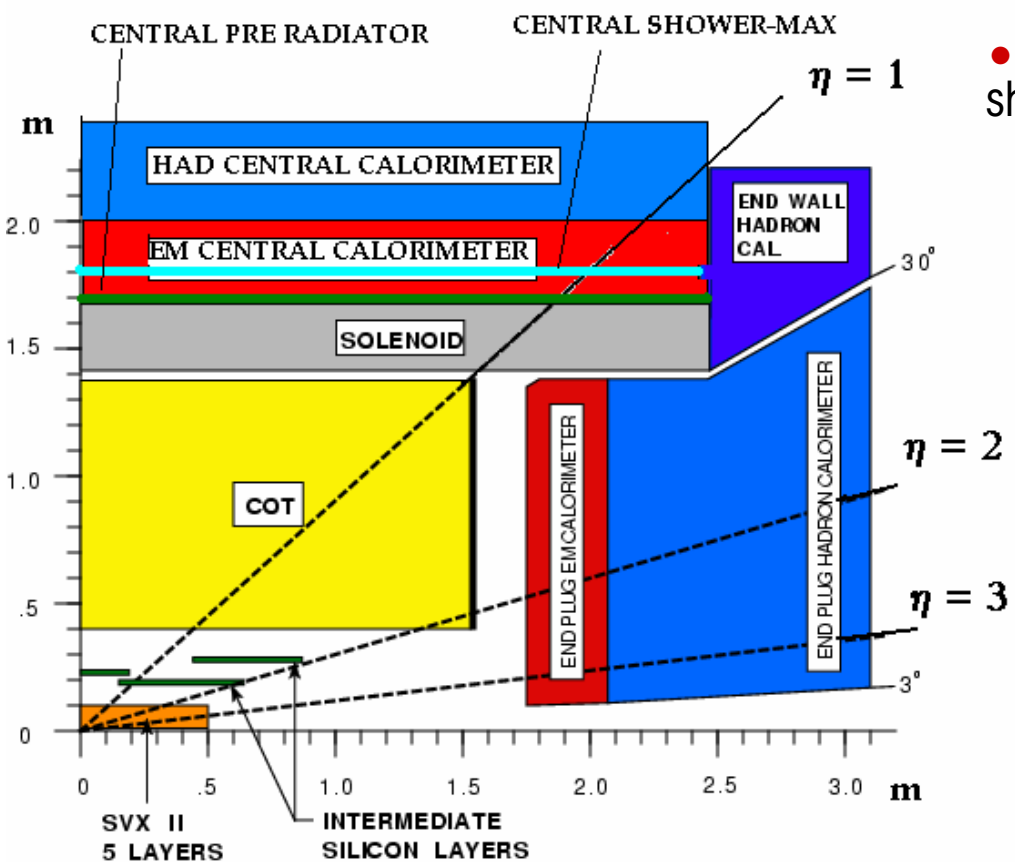
} Important for M_W!



Backup

Phoenix (Calorimeter-Seeded) Tracking

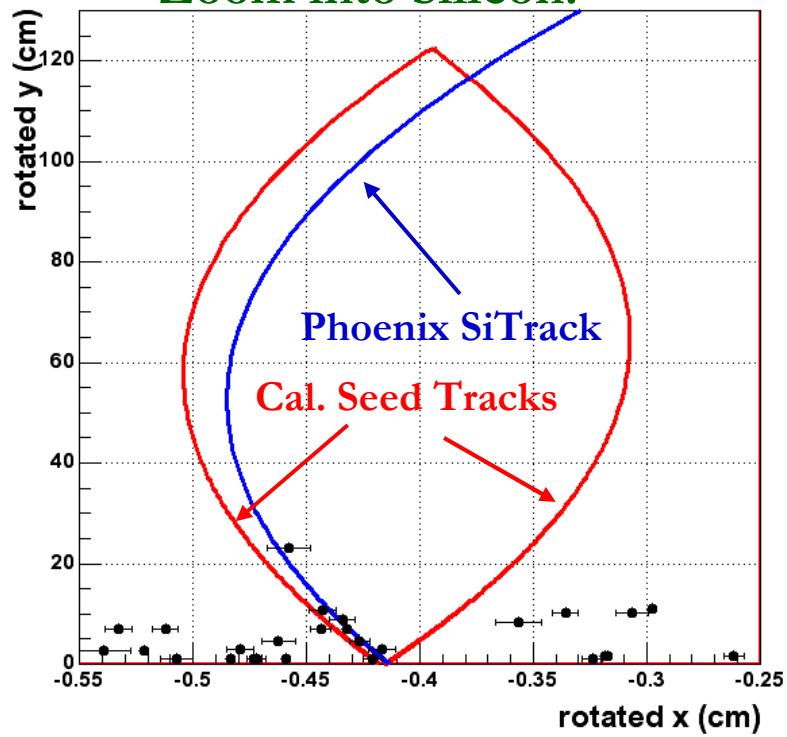
Use both central and <u>forward</u> electrons! $|\eta| < 2.8$



Two points and a curvature define a helix:

- Primary collision vertex position.
- Fitted position of calorimeter shower maximum.

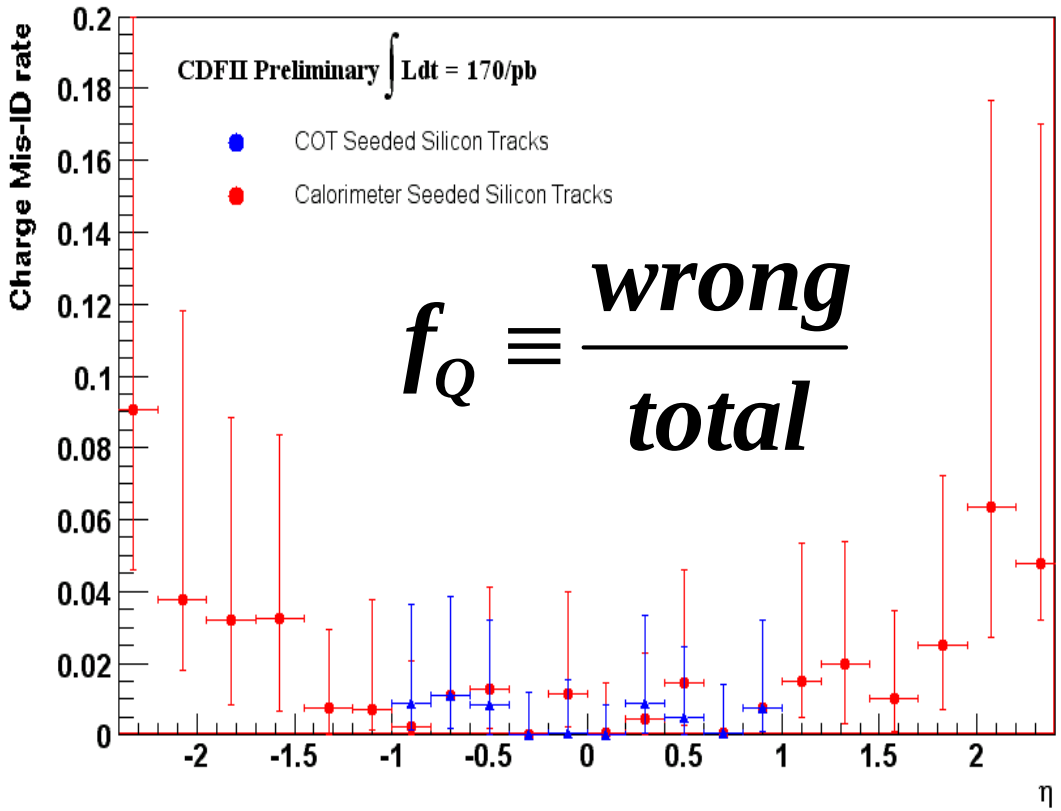
Zoom into Silicon:



Charge Misidentification Rate

- Charge mis-ID rate, f_Q:
  - § Residual misalignments in silicon and plug shower maximum detectors.
  - § Measured in data using $Z^0 \rightarrow e^+e^-$ events, with one leg in the central tracker (COT).
  - § Measured in each η bin.
  - § Uncertainties in f_Q directly go in $\mathcal{A}$.
  - § Monte Carlo predicts f_Q<1% even at η=2 → naïve.

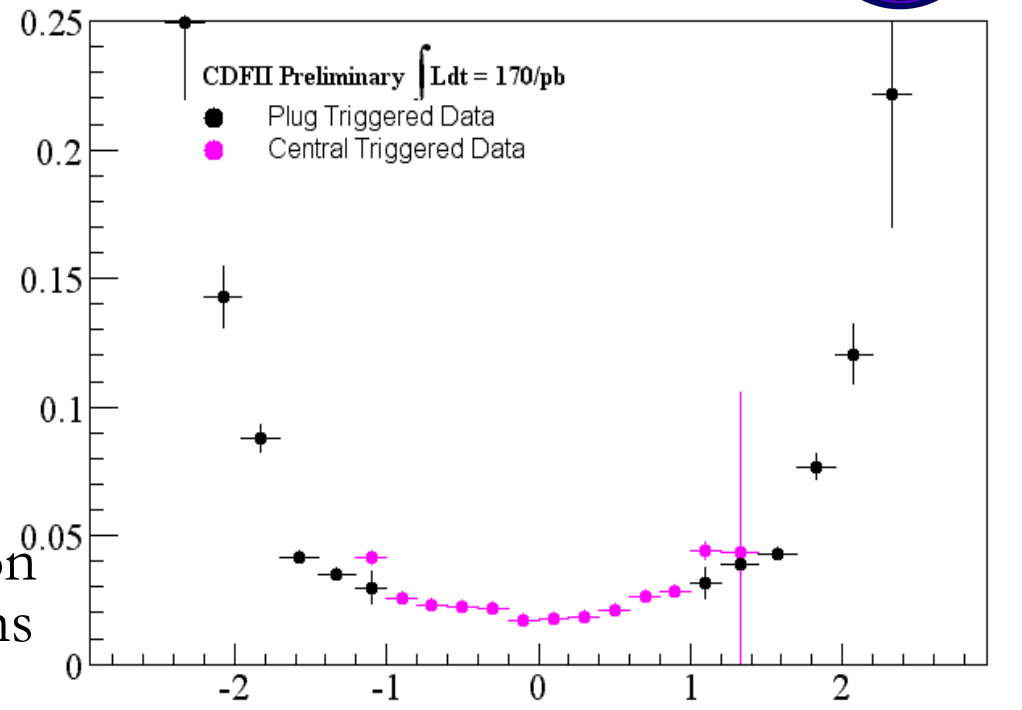
$$A_{true} = \frac{A_{meas}}{1 - 2 f_Q}$$



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

Background Corrections

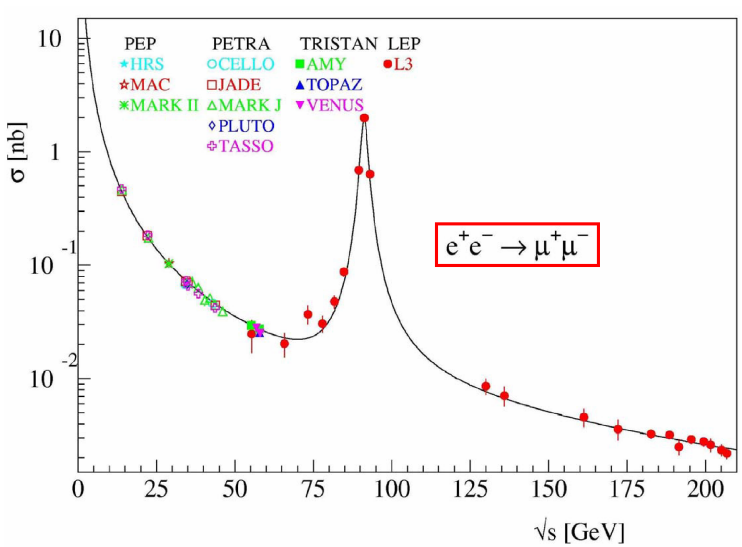
- We correct $\mathcal{A}$ for backgrounds:
  - § $W \rightarrow \tau\, \nu \rightarrow e\, \nu\nu$, $Z \rightarrow e\, e$
    - o Measured from Monte Carlo
    - o Asymmetric
  - § QCD Jets
    - o Measured from data
      - o Use Calorimeter Isolation (e) and ME_T distributions (ν) projected into signal region.
      - o Isolation correlated with other selection criteria.
      - o Estimate is upper limit.
    - o Biases $\mathcal{A}$ toward 0.

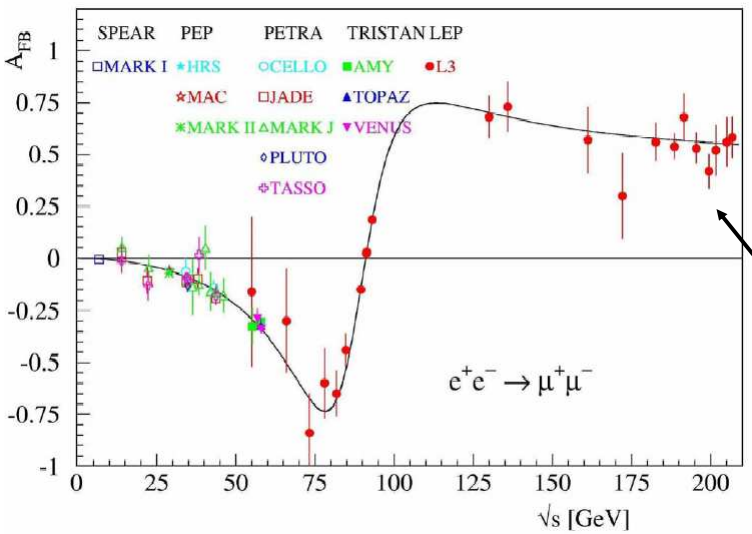


Bkg vs. Eta

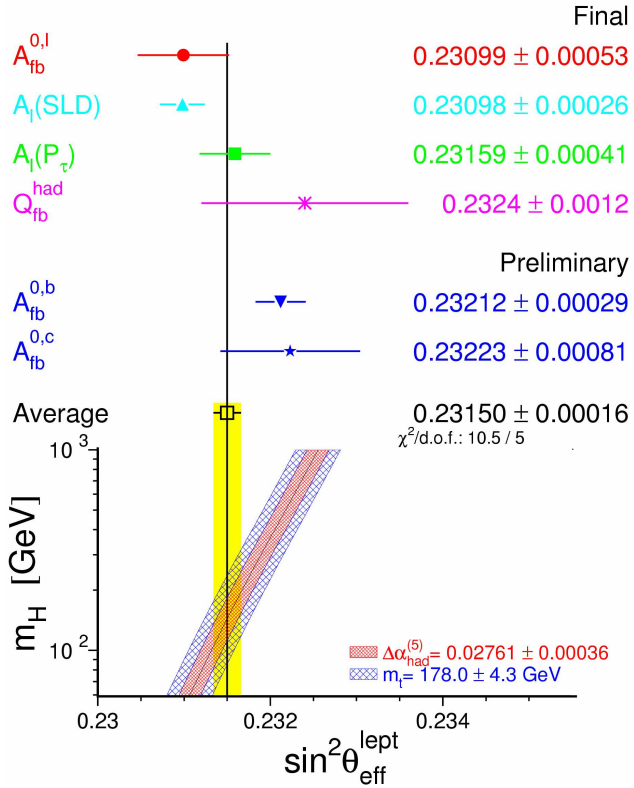
QCD background is upper limit → use 0.5% ± 0.25% → gives full coverage.

Past Results from e+e-





- Previous experiments have done very precise measurements (LEP, SLC, etc.)
- Need > 10 fb^{-1} to compete on $\sin^2(\theta_W)$

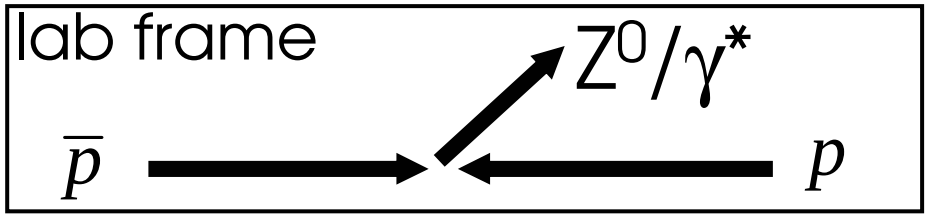


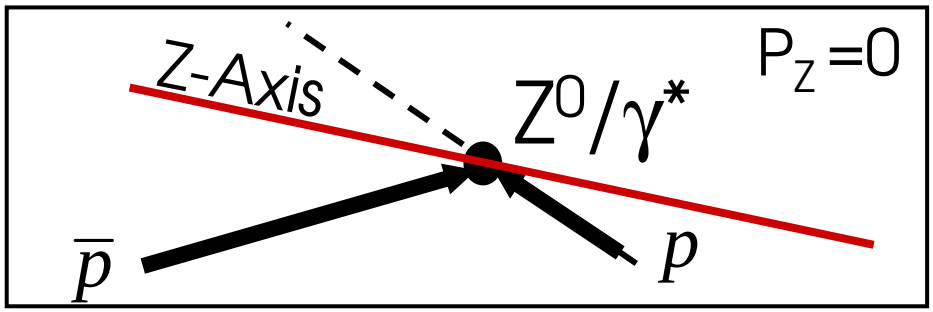
- Difficult to compete with LEPII
  - § 120<√s<207 GeV

Calculating A_{FB}

- $\cos\theta^*$ in Collins-Soper frame (minimize ambiguity in the incoming quark p_T)

$$A_{FB} = \frac{d\sigma(\cos\theta^* > 0) - d\sigma(\cos\theta^* < 0)}{d\sigma(\cos\theta^* > 0) + d\sigma(\cos\theta^* < 0)}$$





$$A_{FB} = \frac{\dfrac{N^+ - N^+_{Bkgrnd}}{a^+} - \dfrac{N^- - N^-_{Bkgrnd}}{a^-}}{\dfrac{N^+ - N^+_{Bkgrnd}}{a^+} + \dfrac{N^- - N^-_{Bkgrnd}}{a^-}}$$

a : Forward/Backward Acceptance & Efficiency

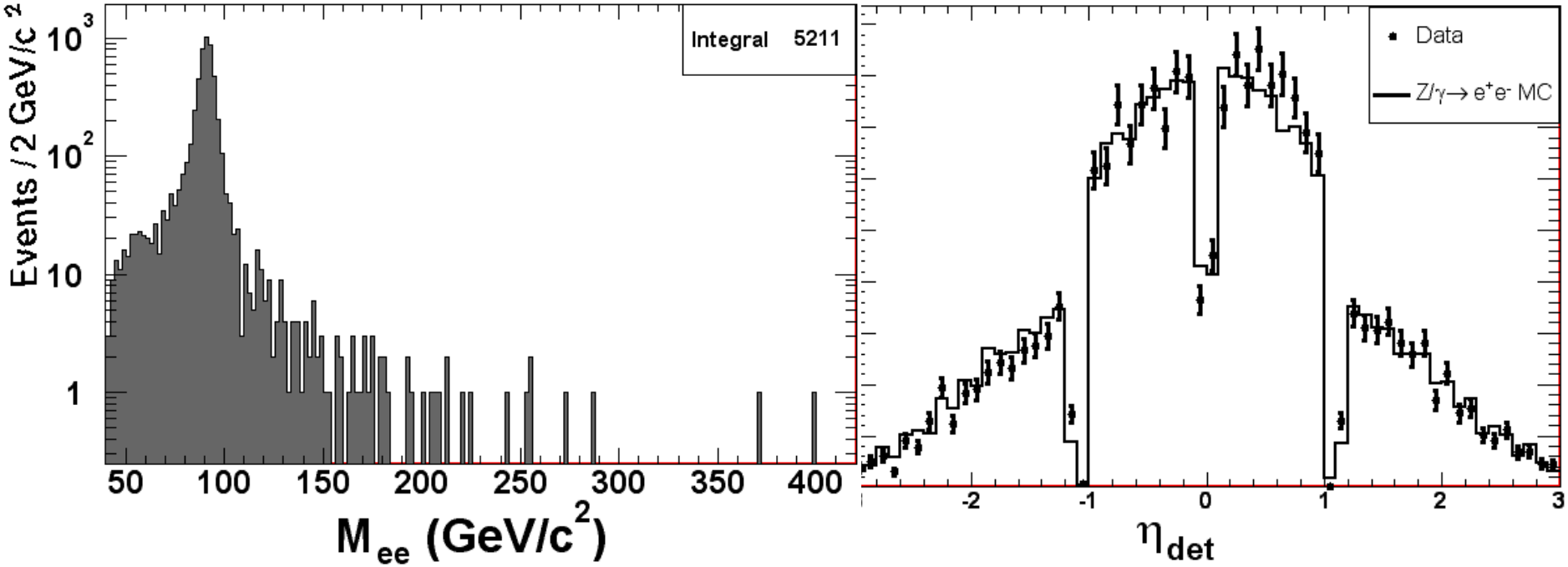
$N^{\pm}$: Forward/Backward Candidates

- $\cos\theta^* > 0 \equiv$ Forward
- $\cos\theta^* < 0 \equiv$ Backward

Correct A_{FB}^{raw} to obtain A_{FB}^{phys} →compare to theory:

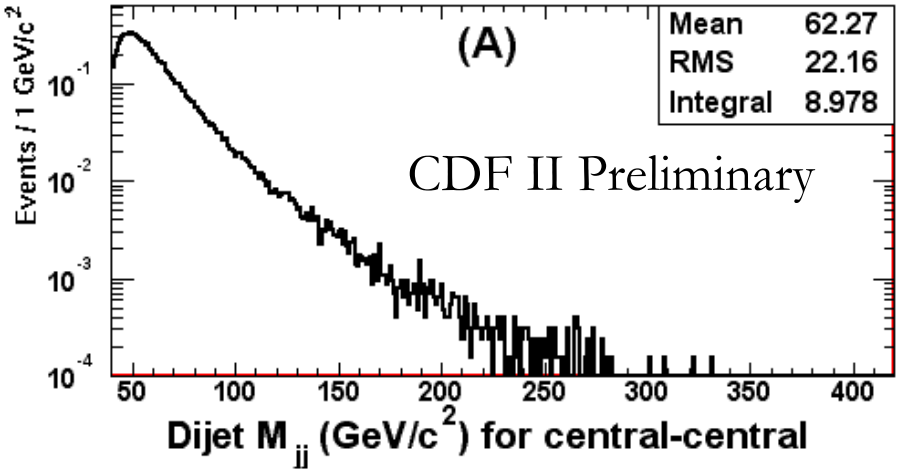
$$a^{\pm} = \underbrace{(a^{\pm})_{geom} * (a^{\pm})_{kin}}_{\text{Sculpt } \cos\theta^* \text{ dist.}} * \underbrace{(a^{\pm})_{res} * (a^{\pm})_{rad}}_{M_{ee} \text{ bin migration}} * (\varepsilon^{\pm})_{ID}$$

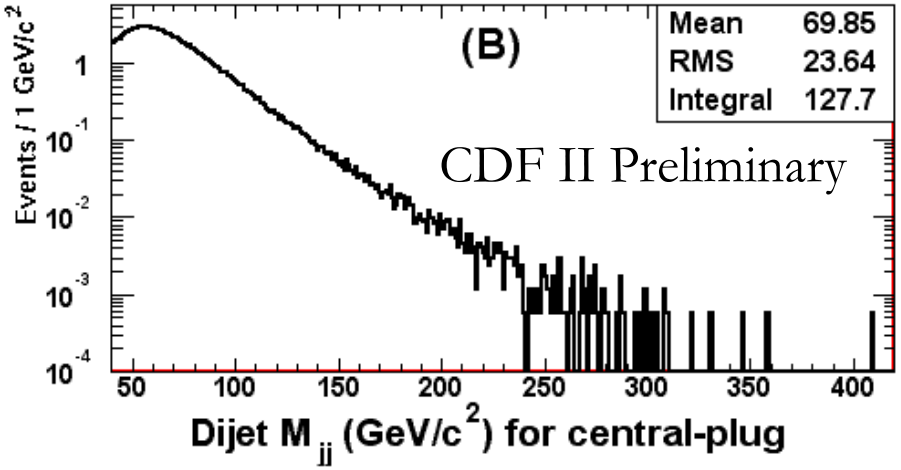
M_{ee} and η for $Z \rightarrow ee$



Backgrounds for Z/γ^*

- Dijet dominant



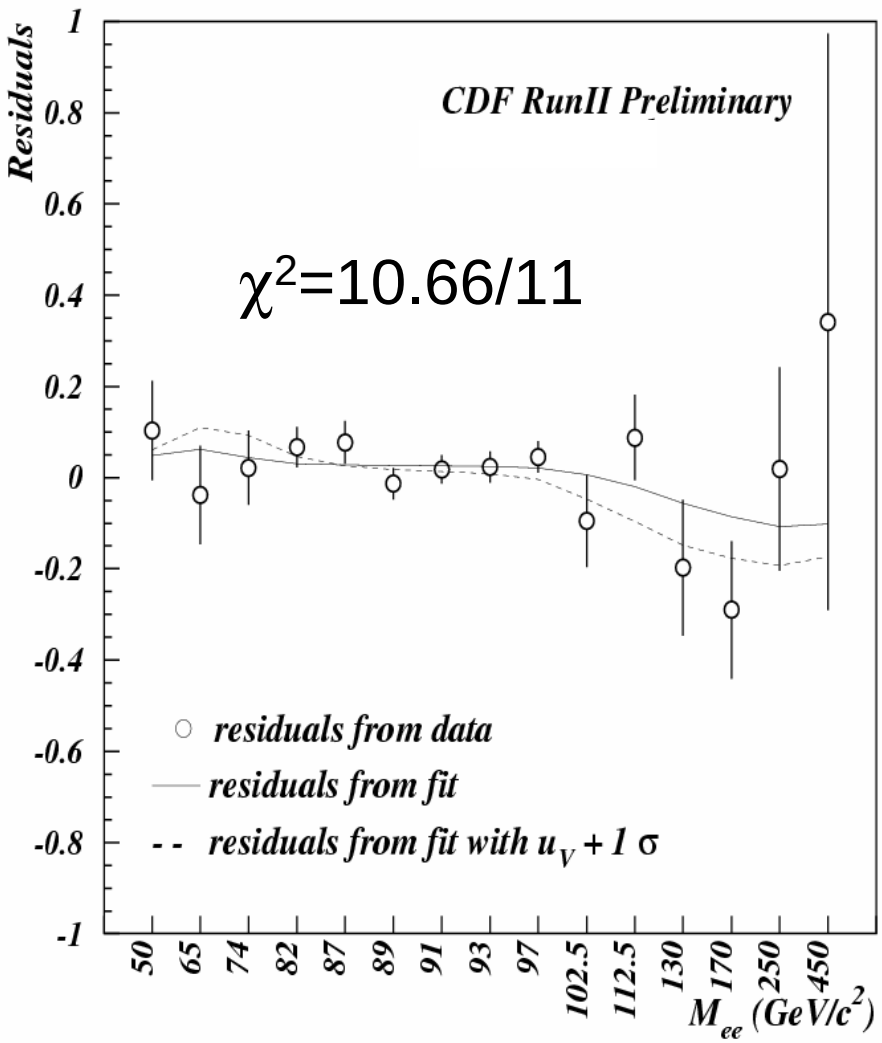


Background Summary

Source	# of events	
	C-C	C-P
Dijet	9	128
Wà eν+X	1.8	25
Zà ττ	5.6	7.2
WZ	1.4	1.7
WW	1.5	1.8
Top	1.1	0.7

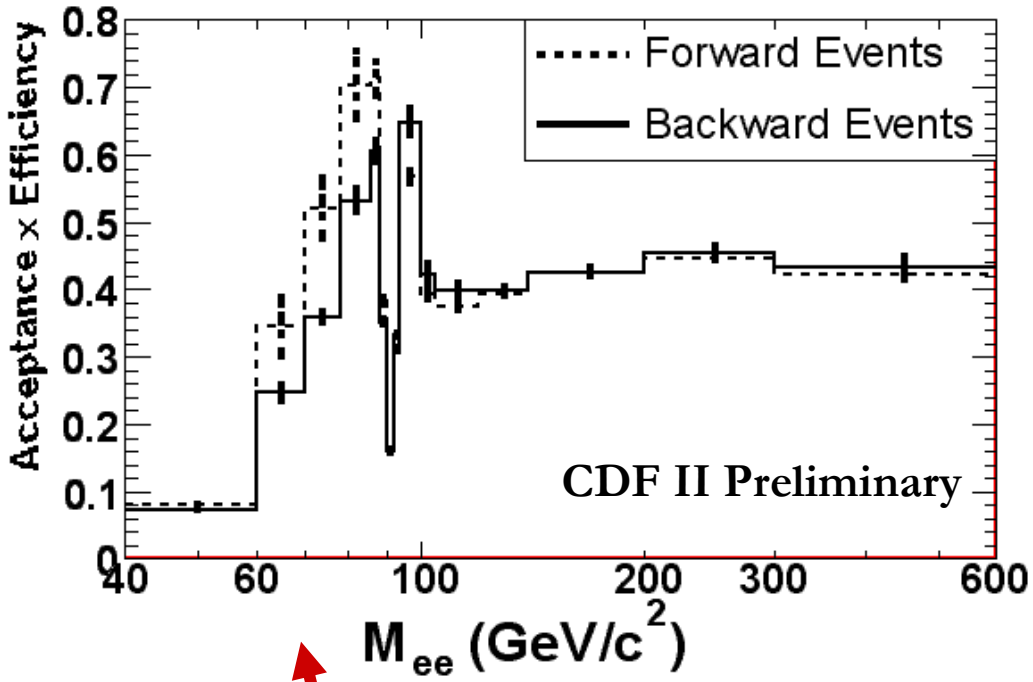
Fitting for Z Couplings

- Fit at Raw A_{FB} Level
  - § Test A_{FB} is smeared
- χ^2 show good agreement with SM



Acceptance*Efficiency

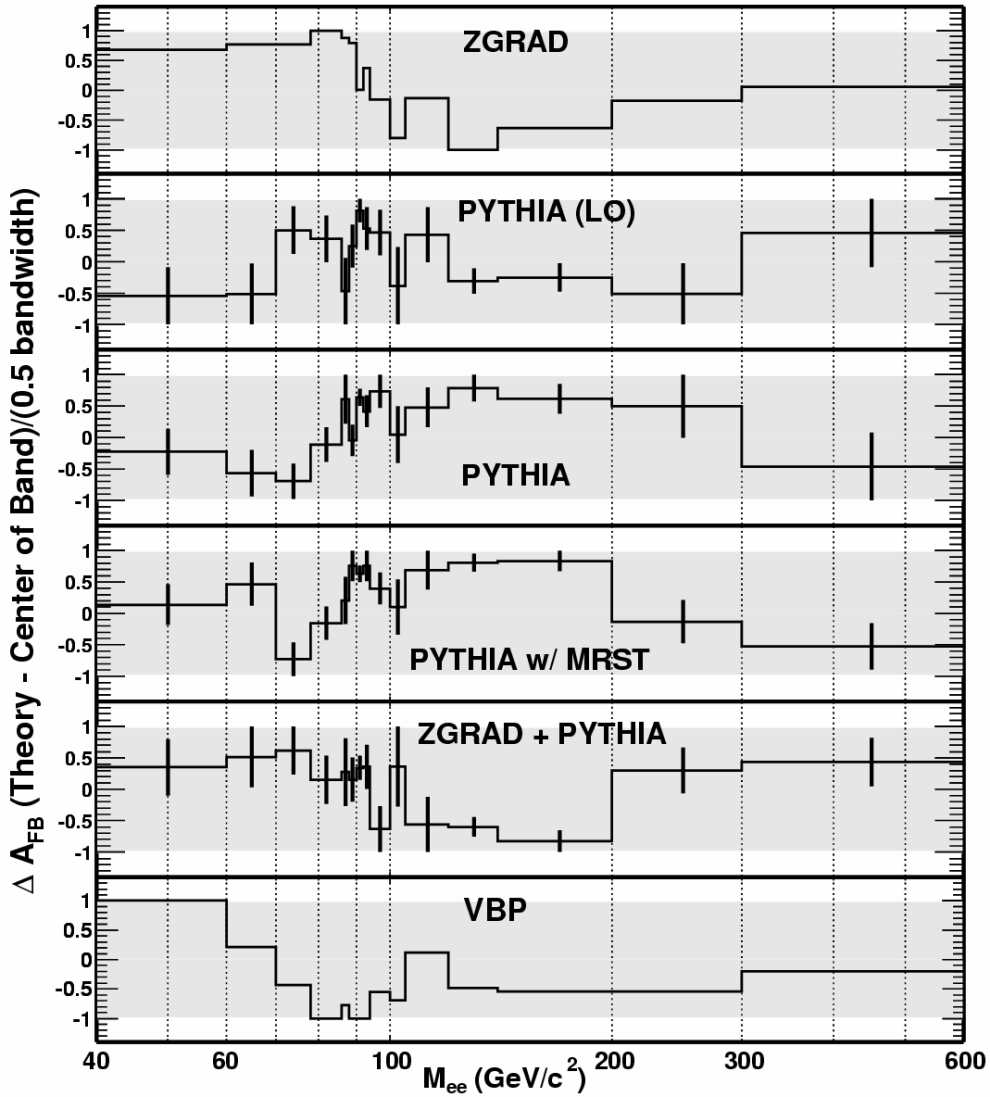
- Correction Factors:
  - § Energy Resolution
  - § Kinematic and Fiducial cuts
  - § Radiation from FSR and Brems
  - § Electron ID efficiency
- Assumes SM
  - § Allow Z couplings to float



Couplings fit used as input A_{FB}

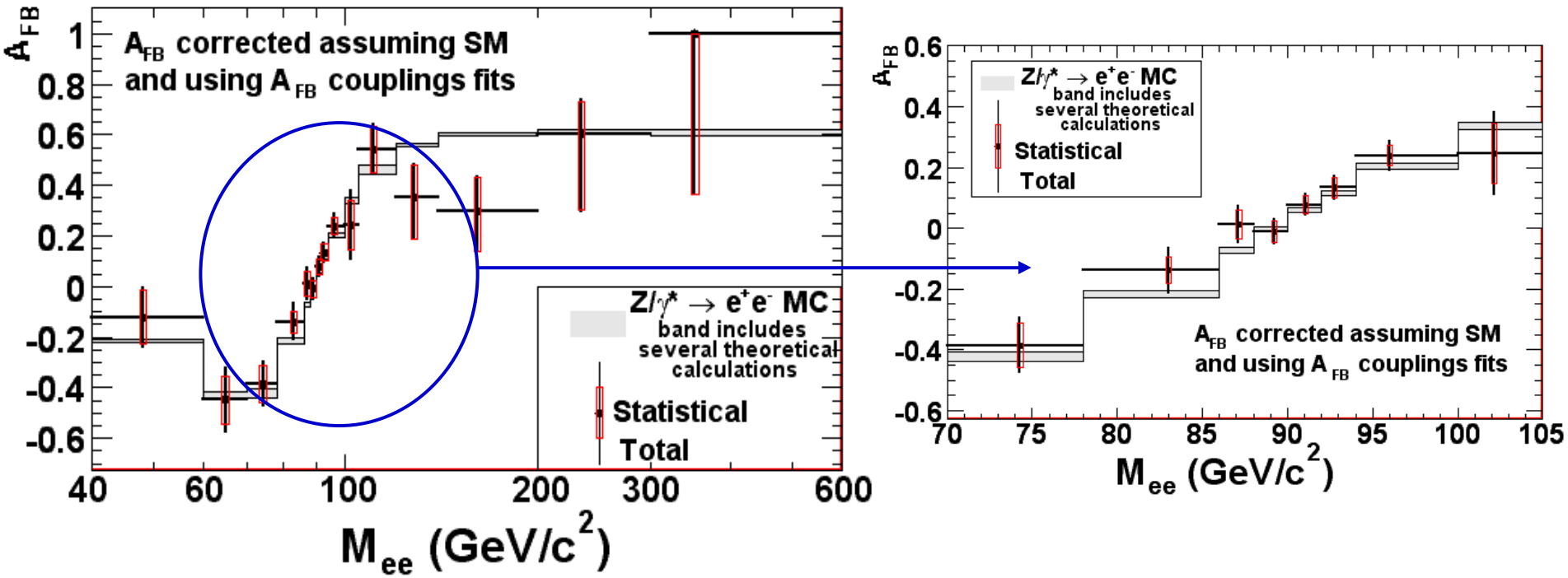
Theory Band

- Different MC's:
- VPB
  - § g resummation
- ZGRad
  - § O(α) EW corr.
- Pythia
  - § Parton shower (QED+QCD)
- Nothing w/ NLO QCD & O(α) EW
- Indicates size of effects
  - § PDF's, ISR…



SM with Measured Z^0 couplings

Using couplings fit as input A_{FB} gives:



- All results consistent with SM.
- Not useful for non-SM physics near Z pole
- Nothing new above the pole yet.