A Measurement of the Z Forward-Backward Charge Asymmetry at CDF

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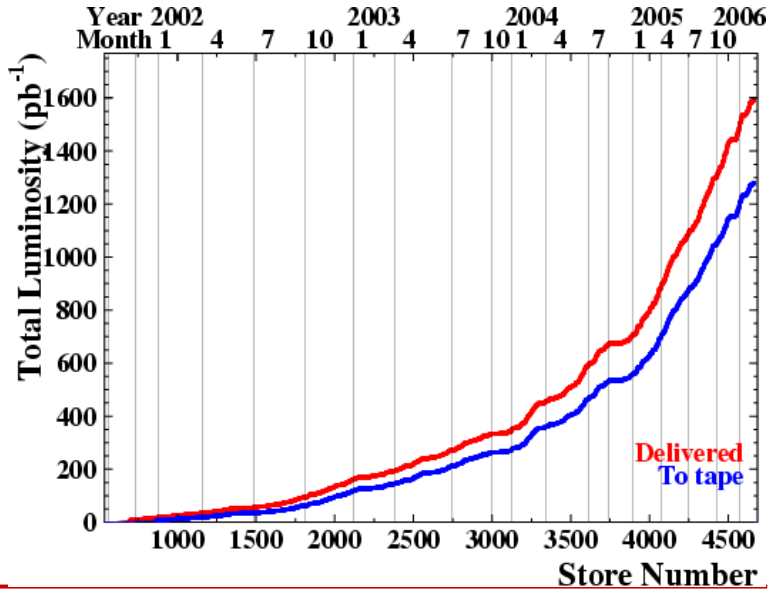
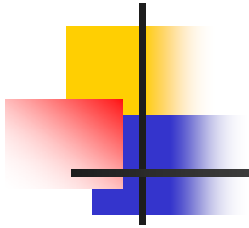
May 15 2006
PHENO 2006

CDF at Tevatron

- Tevatron ($p\bar{p}$ @1.96 TeV)
  - 1985 – now
  - Discovered top quark
  - Recorded 1 fb^{-1} (Jan 2006)
  - SM precision measurement
  - Search for new physics



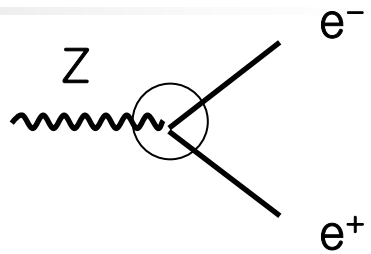


Electroweak Theory of SM

- Successfully tested so far.
- Problems:
  - Electroweak symmetry breaking mechanism.
    - Higgs may be the answer.
  - Loop correction to the Higgs mass requires unnatural fine-tuning.
    - Implication for a new physics at ~1 TeV.
- Precision measurements.
  - Confirm the SM or look for deviation.
- Other efforts:
  - Direct search for the Higgs.
  - Direct search for new gauge bosons.

Z Forward-backward Asymmetry

- Z->e⁺e⁻ vertex: $-i\frac{g}{\cos\theta_W}\gamma^\mu(c^e{}_V - c^e{}_A\gamma^5)$



$$\frac{d\sigma}{d\cos\theta} = \frac{4\pi\alpha^2}{3s}\frac{3}{8}\left[A(1+\cos^2\theta)+B\cos\theta\right],$$

θ : electron scattering angle from the proton direction.

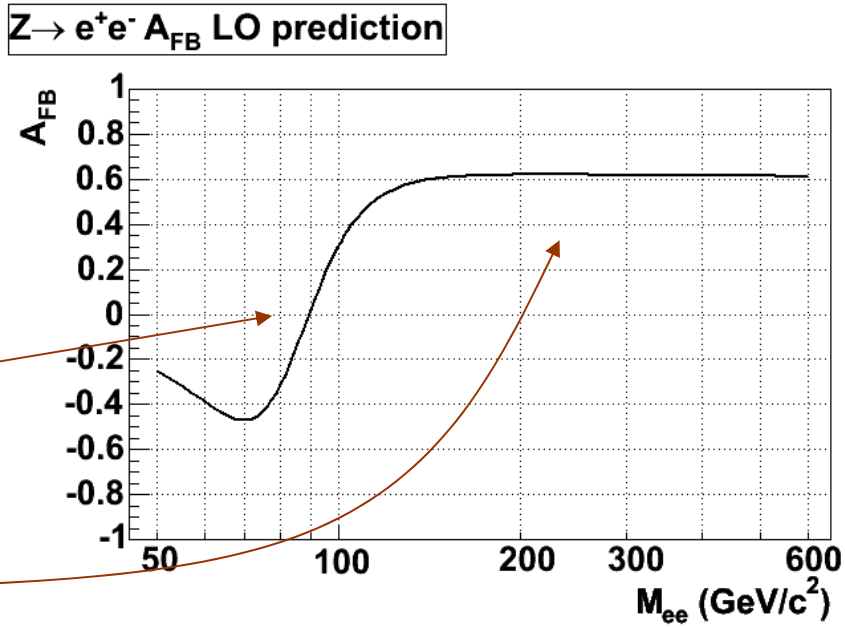
$$A = Q_l^2 Q_q^2 + 2Q_l Q_q g_V^q g_V^l \,\mathrm{Re}(\chi(s)) + g_V^{l\,2}(g_V^{q\,2}+g_A^{q\,2})\,|\chi(s)|^2 + g_A^{l\,2}(g_V^{q\,2}+g_A^{q\,2})\,|\chi(s)|^2,$$

$$B = \frac{3}{2} g_A^q g_A^l (Q_l Q_q \,\mathrm{Re}(\chi(s)) + 2 g_V^q g_V^l \,|\chi(s)|^2),$$

$$\chi(s) = \frac{1}{\cos^2\theta_W \sin^2\theta_W}\frac{s}{s - M_Z^2 + i\Gamma_Z M_Z},$$

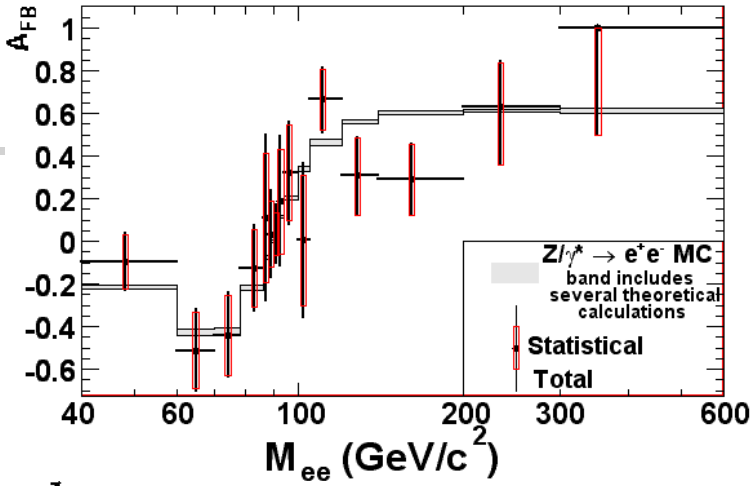
$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{B}{A}.$$

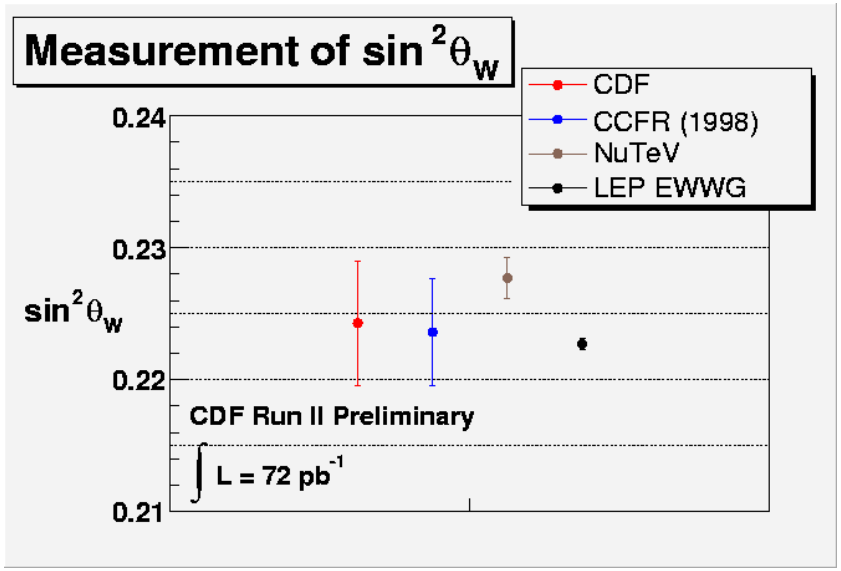
- Near pole: $A_{FB} \propto g_V^l \approx 0$
- Far from the Z pole: $A_{FB} \propto g_A^l g_A^q$

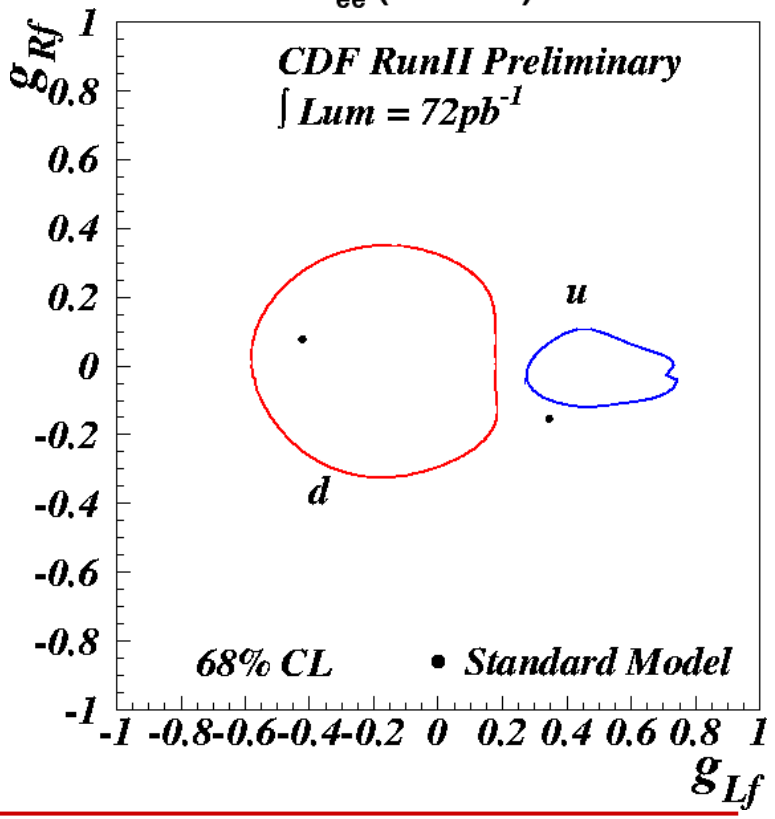


Previous Result

- CDF Run II data with 72 pb^{-1} , Phys. Rev. D71, 052002 (2005).
- Detector effect is unfolded.
- Consistent with SM (χ^2/ndof = 15.7/15)
- Coupling constants and $\sin^2\theta_W$ were also measured.



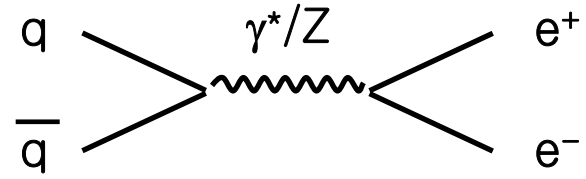


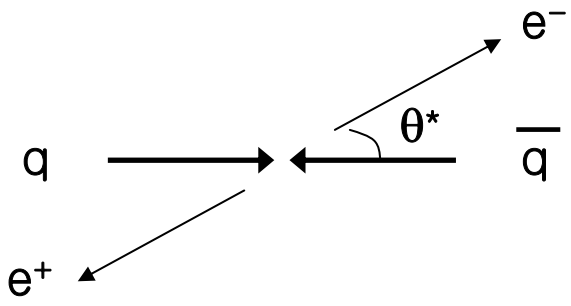


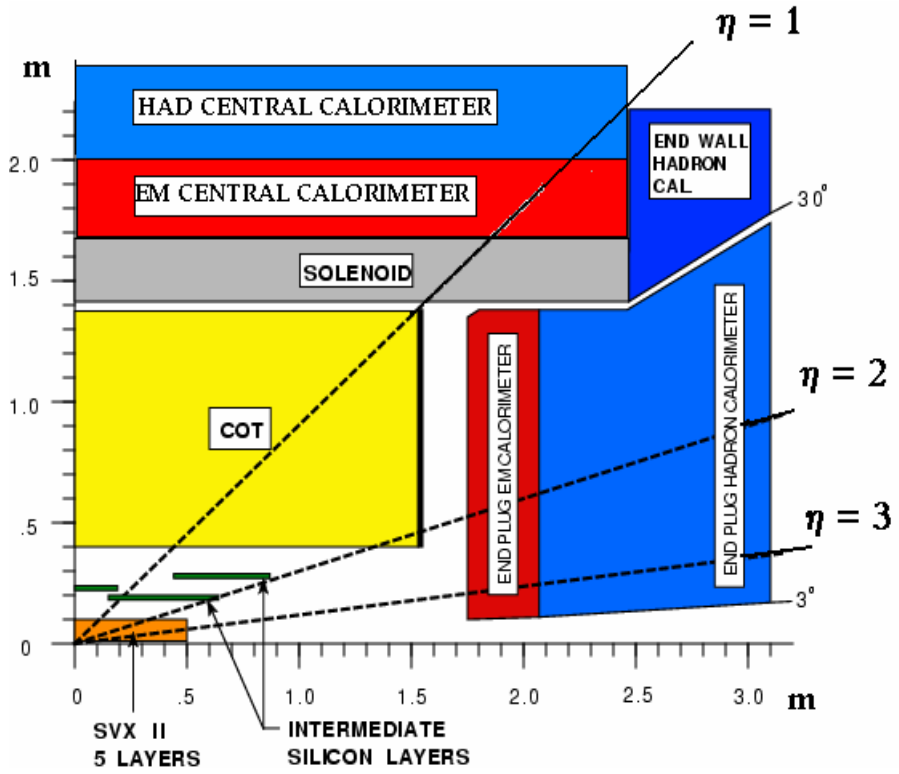
Electron Reconstruction

Di-electron Final State

- Covered up to $|\eta| < 3.0$
- Clean signal, low background.
  - Well isolated high-pt electrons.
  - SM background (Drell-Yan) is well understood.
- Di-electron invariant mass
  - Search for new resonance Z'.
- Angular distribution θ^*
  - Probe V-A nature of weak interaction.
  - Search for Z'.







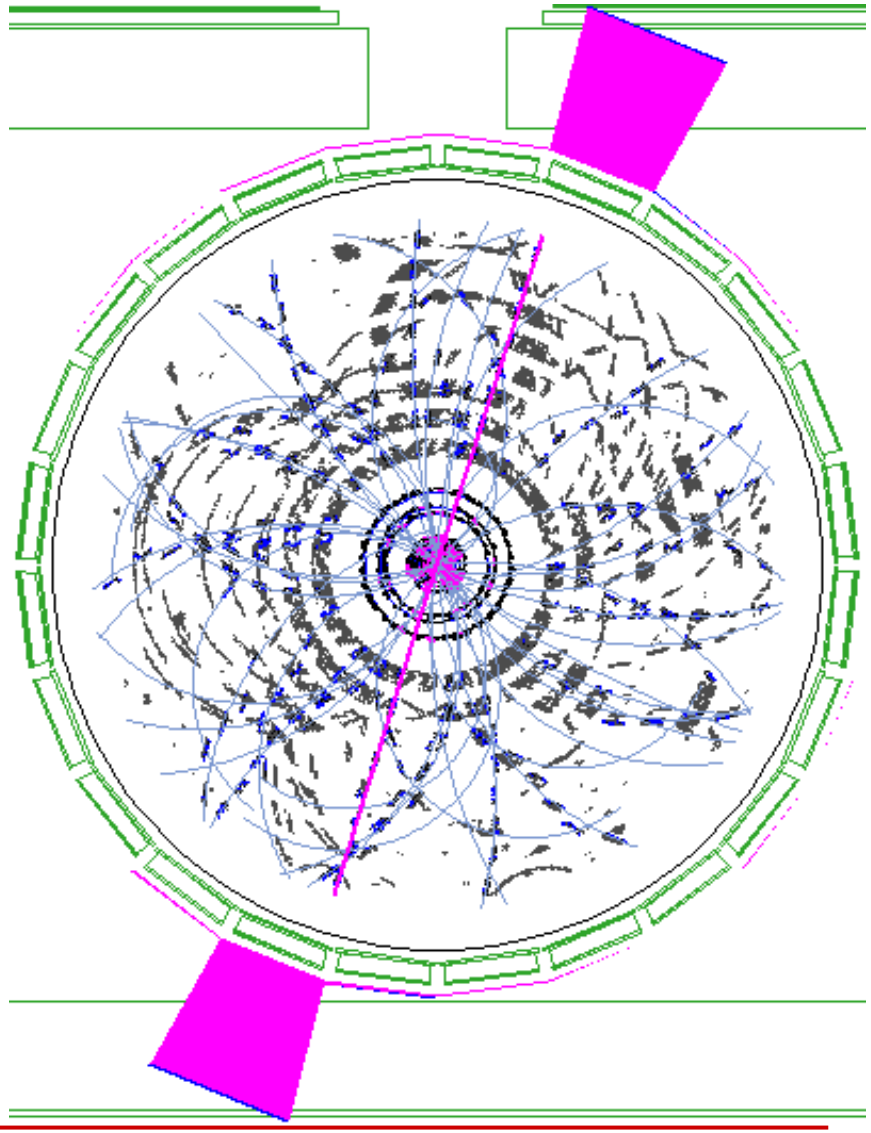
Electron Reconstruction at CDF

- Electromagnetic Calorimeter
  - Towers of lead/scintillator layers.
  - Measure the energy deposition of the shower.

$$\Delta E / E = 1.5\% \oplus 13.5\% / \sqrt{E}$$

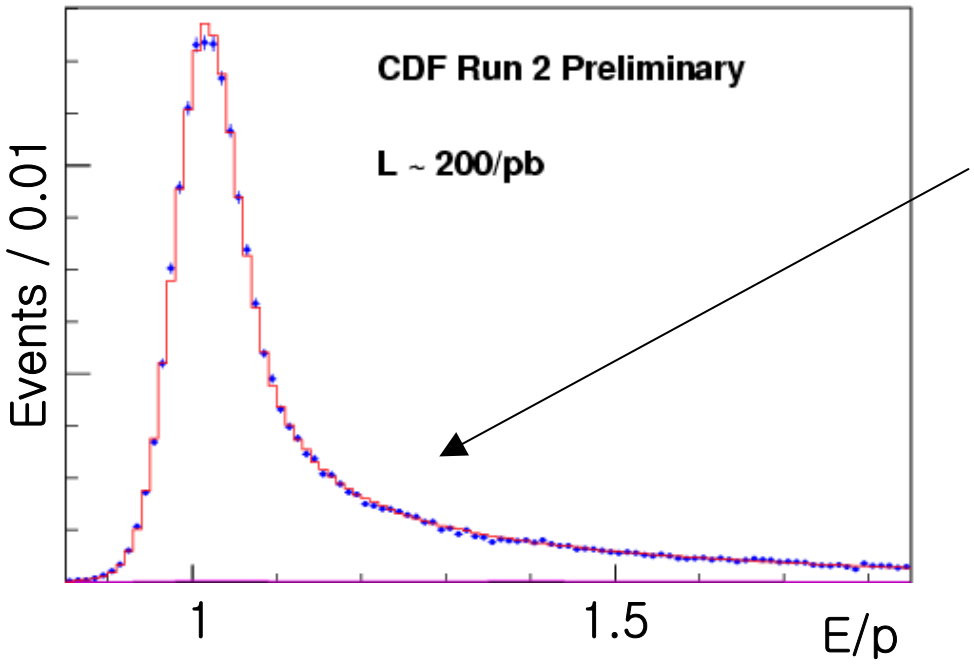
- Central Outer Tracker
  - Argon-ethane wire chamber in 1.4 T magnetic field.
  - Momentum is measured from the track curvature.

$$\Delta P_T / P_T = 0.1\% P_T [GeV/c]^{-1}$$

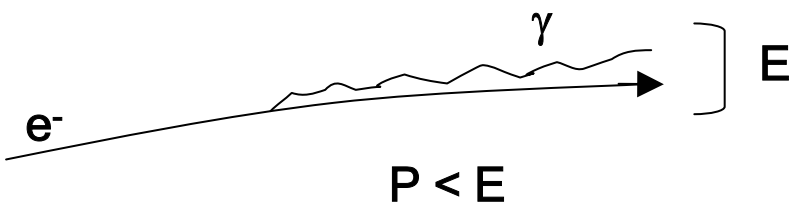


Electron Reconstruction (cont'd)

- Reconstruction Algorithm
  - Seeded by EM cluster in calorimeter.
  - Track must match the position of cluster.
  - Momentum (P) must match the energy (E).
    - Cut on E/P.



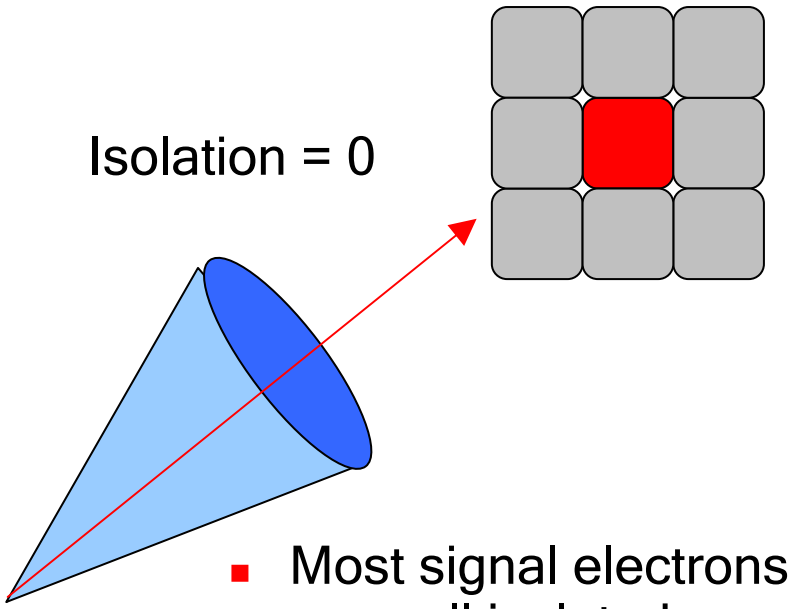
- E/P peaks at ~1.0
  - Detector material causes high tail.



Electron Reconstruction (cont'd)

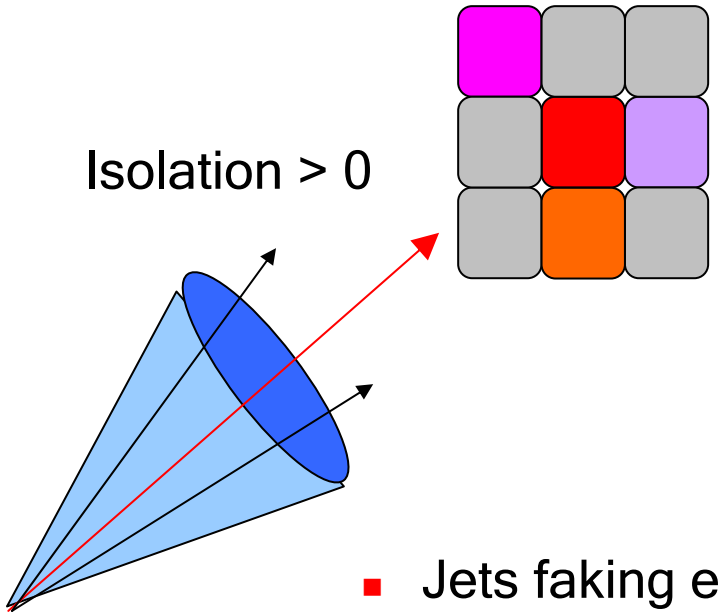
- Isolation = $\dfrac{E^{total} - E^{cluster}}{E^{total}}$
  - E^{total} = Energy in the EM calorimeter in the cone of $\Delta r=0.4$.
  - $E^{cluster}$ = Energy of the electron cluster.

Isolation = 0



- Most signal electrons are well isolated.

Isolation > 0



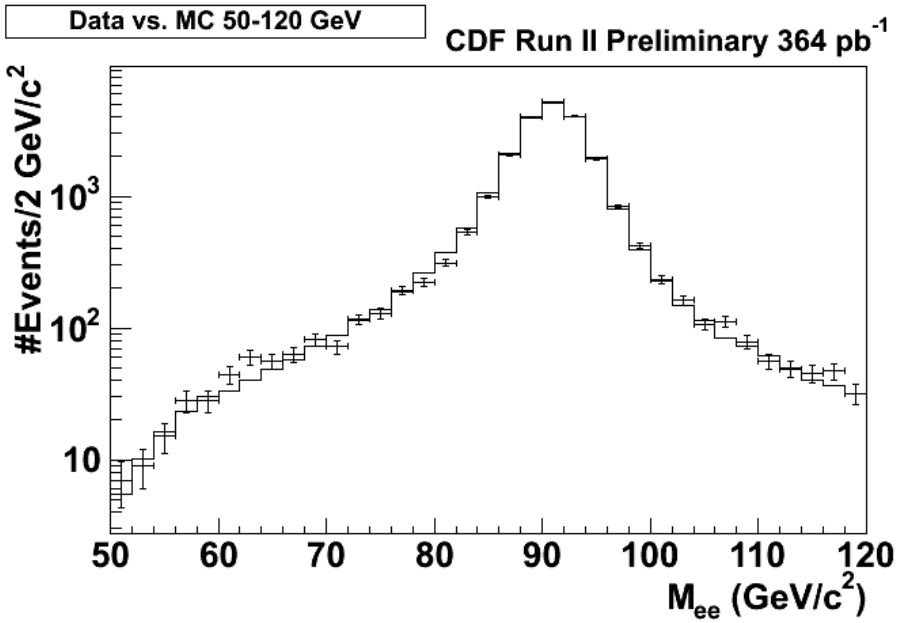
- Jets faking electron are not isolated.

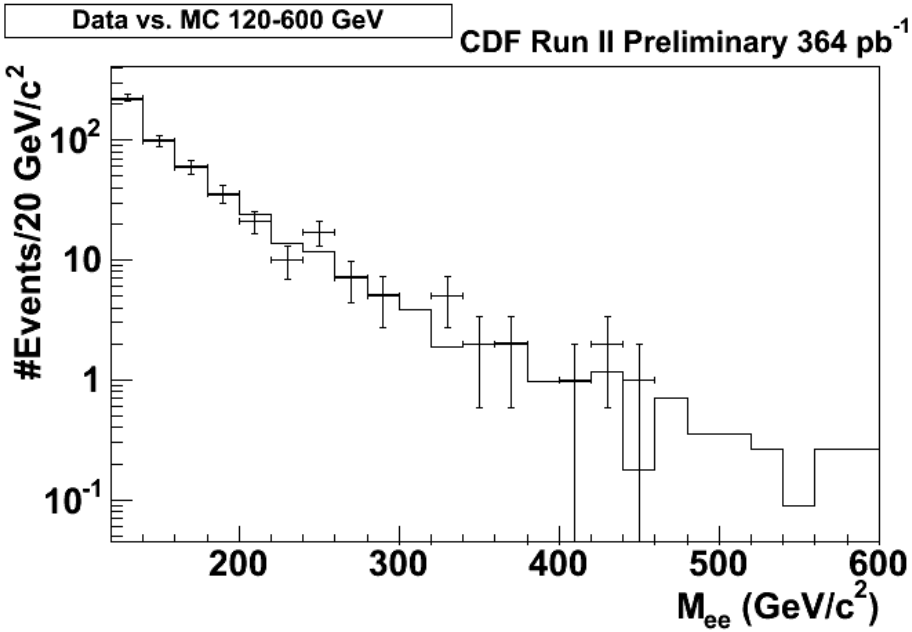
Event Selection

- Kinematic cuts
  - $|\eta| < 3$
  - $E_T > 25$ GeV
  - $P_T > 15$ GeV
- Electron quality cuts (central and forward region)
  - Ratio of hadronic energy to electromagnetic energy.
  - Isolation.
  - Shower shape to be consistent with what we expect for electrons.
- Track quality cuts in the central region ($|\eta| < 1$)
  - $E/p < 2.5 + 0.015 * E_T$.
  - Track – shower position matching.

M_{ee} Data vs. MC

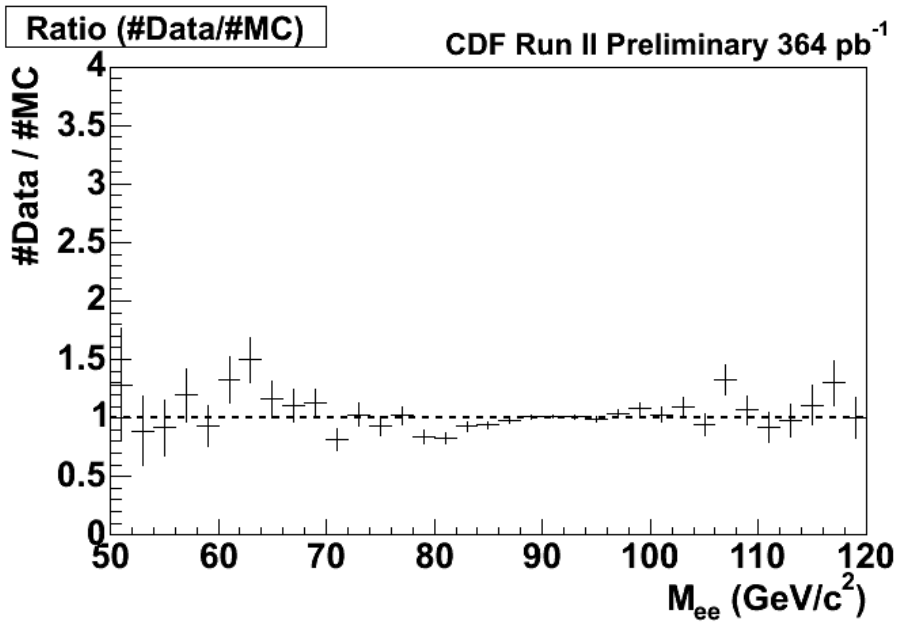
- Mass shape agrees well between data and MC.
  - 50-120 GeV
  - 120-600 GeV



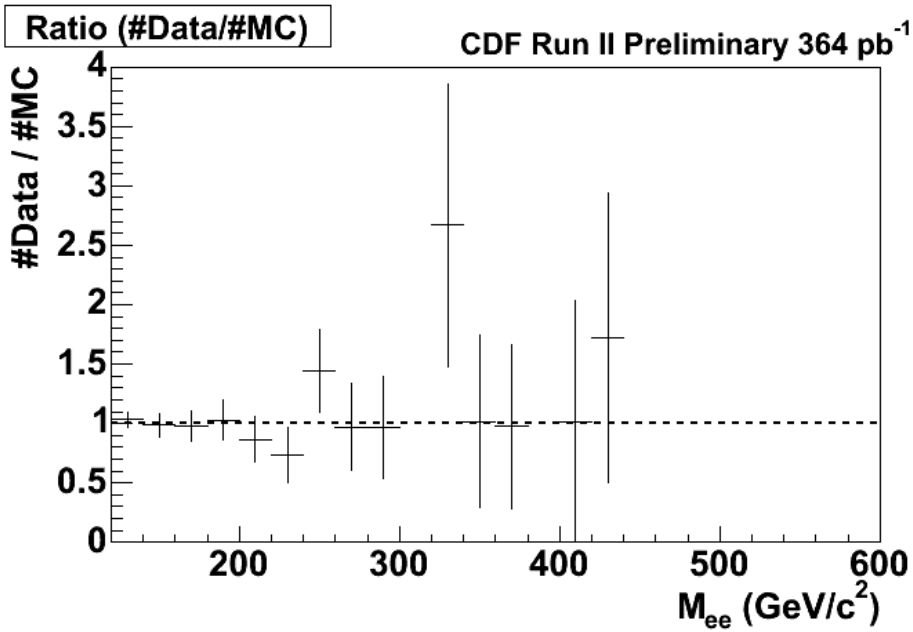


M_{ee} Data vs. MC (Pull)

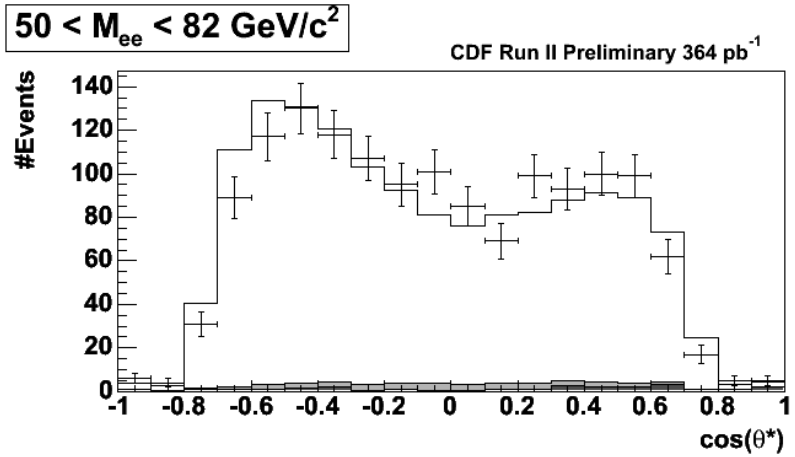
- 50-120 GeV

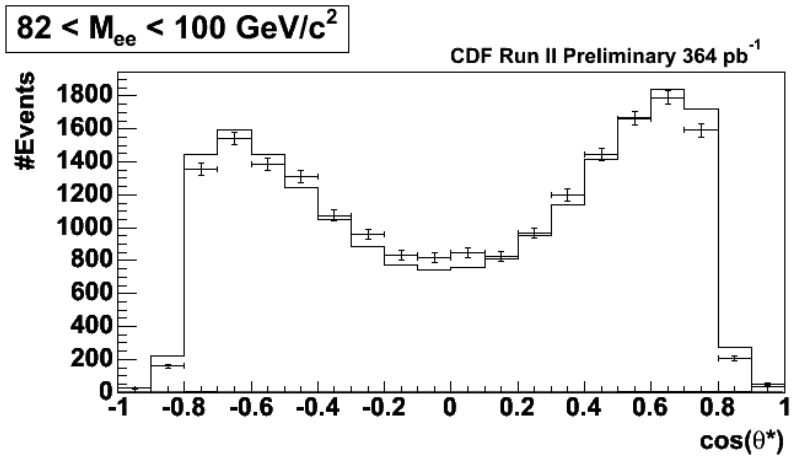


- 120-600 GeV

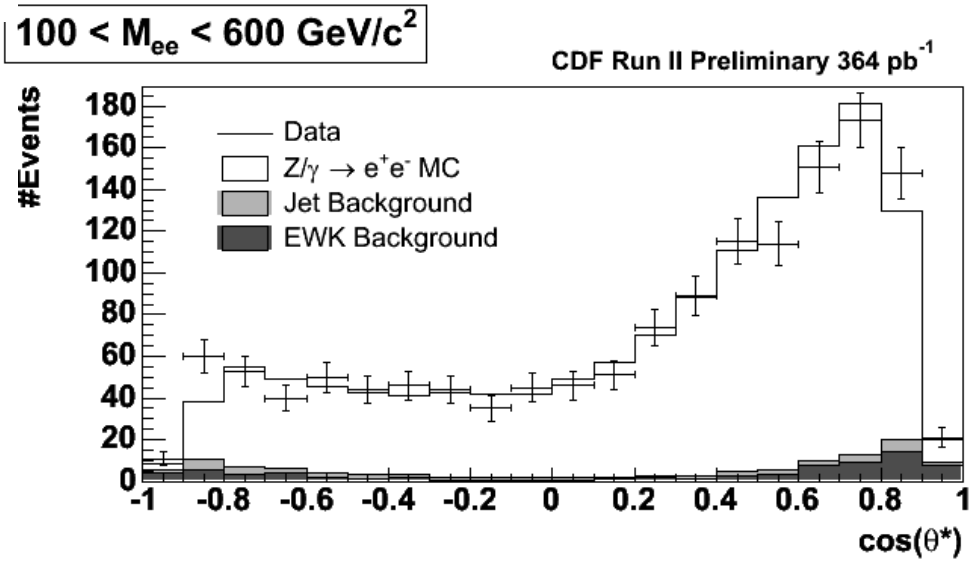


cosθ* Data vs. MC





- cosθ* distribution is shown in three mass ranges:
  - Below the Z pole (50-82 GeV)
  - At the Z pole (82-100 GeV)
  - Above the Z pole (100-600 GeV)



Extracting

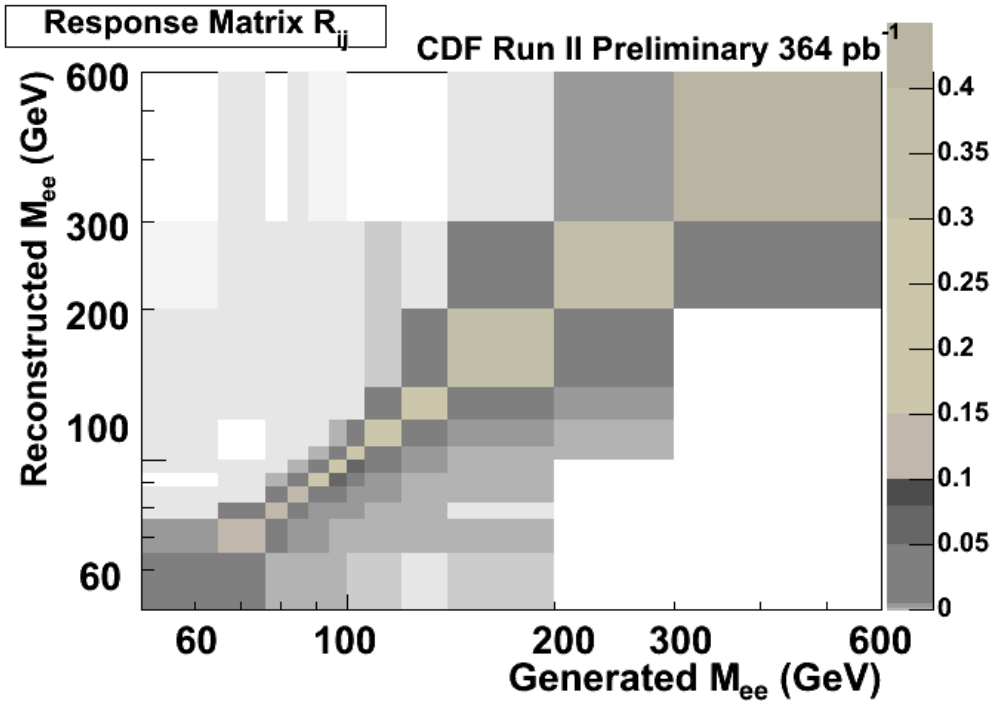
Z Forward-backward Asymmetry

Matrix Inversion

- Detector effect distorts M_{ee} and $\cos\theta^*$.
- Unfolding the effect with matrix inversion.
  - R_{ij} = P(observed in bin i | true value in bin j).
- $\nu = R\,\mu$.
  - μ : true histogram.
  - ν : expected number of observation.
- Unfolding:

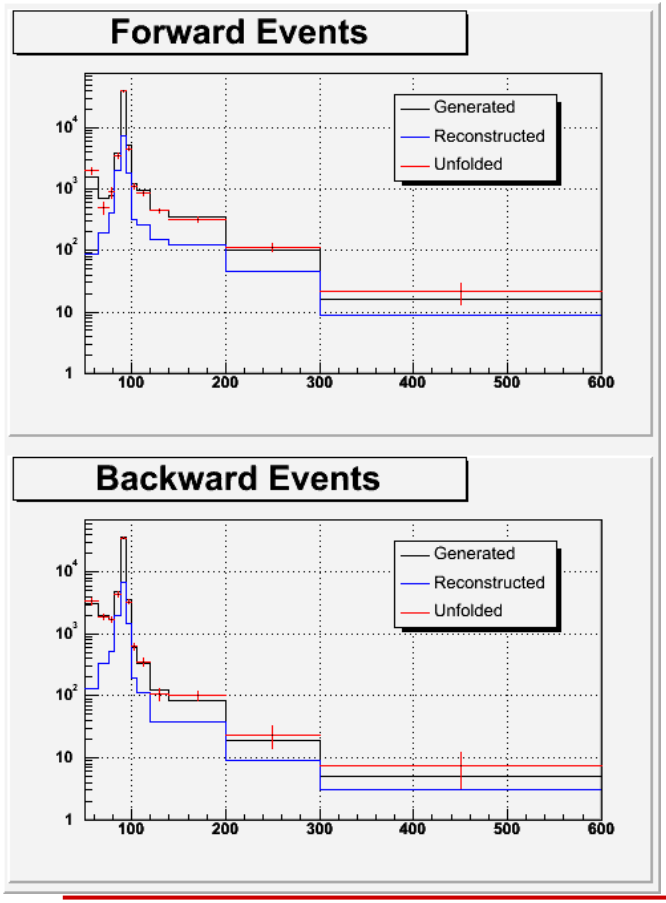
  $\mu = R^{-1}\nu$.
- With BG:

  $\mu = R^{-1}(\nu - \beta)$.



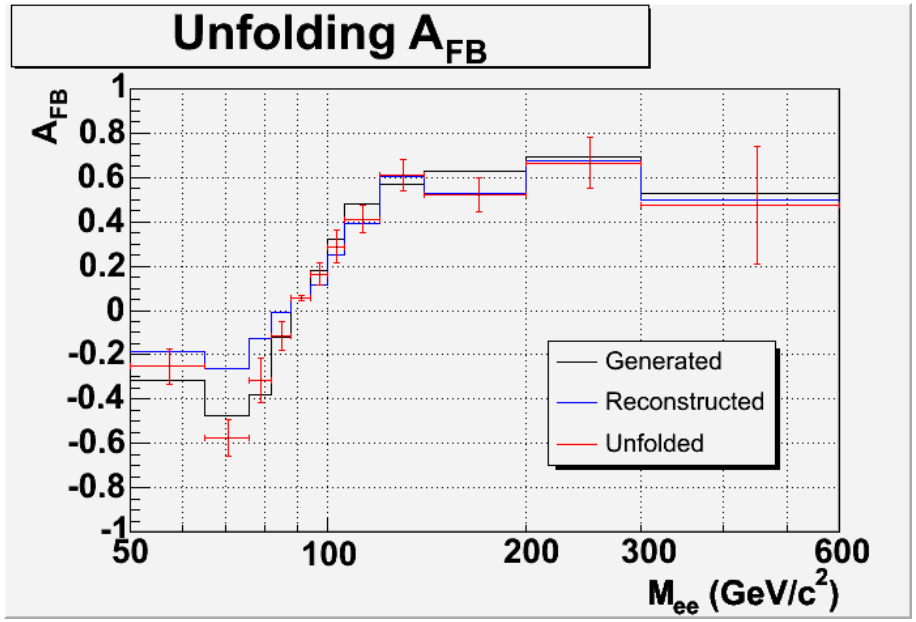
Unfolding; A MC Example

- Forward and backward events are unfolded separately and then the A_{FB} is calculated.



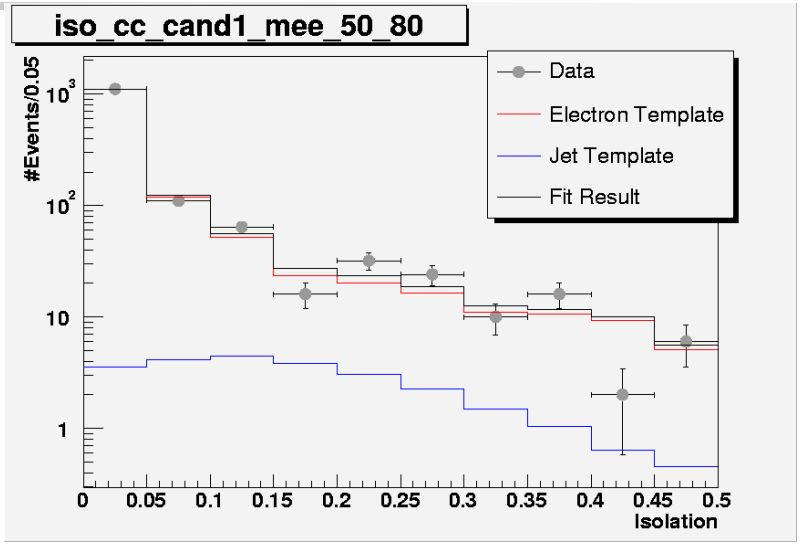
$$A_{FB}^{i} = \frac{\mu_i^F - \mu_i^B}{\mu_i^F + \mu_i^B}, \text{where } \mu_i^{F,B} = R_{ij}^{-1} \nu_j^{F,B}$$

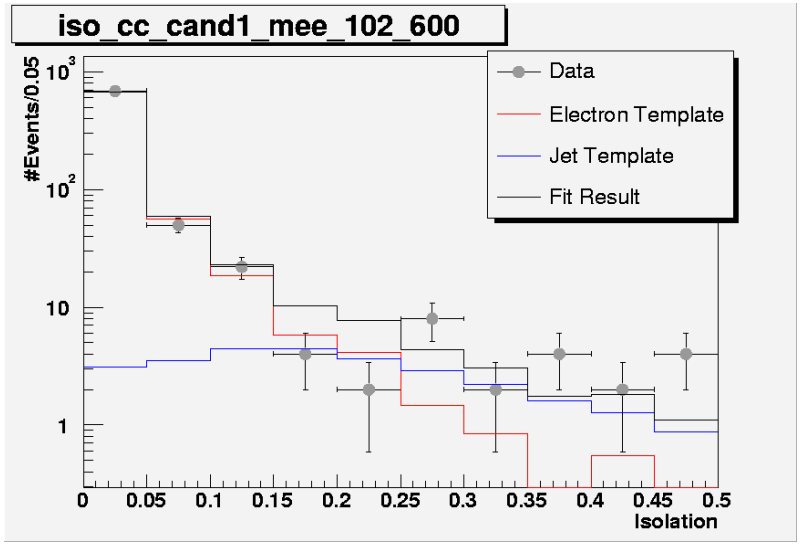
$$\text{Statistical Error}: (\sigma_{\mu_i})^2 = \sum \left[\left(\frac{\partial \mu_i}{\partial \nu_i} \sigma_{\nu_j} \right)^2 + \left(\frac{\partial \mu_i}{\partial R^{-1}_{ij}} \sigma_{R^{-1}_{ij}} \right)^2 \right]$$



Background Estimation

- Jet fake background is estimated by fitting the isolation distribution.
- Electron template :
  - Data at the Z pole with tight cuts.
- Jet template :
  - Jet sample is selected from the EM calorimeter triggered sample by removing W and Z events.





Background Estimation (cont'd)

- Electroweak backgrounds are estimated from Monte Carlo simulations.

- Summary: (CDF Run II Preliminary)

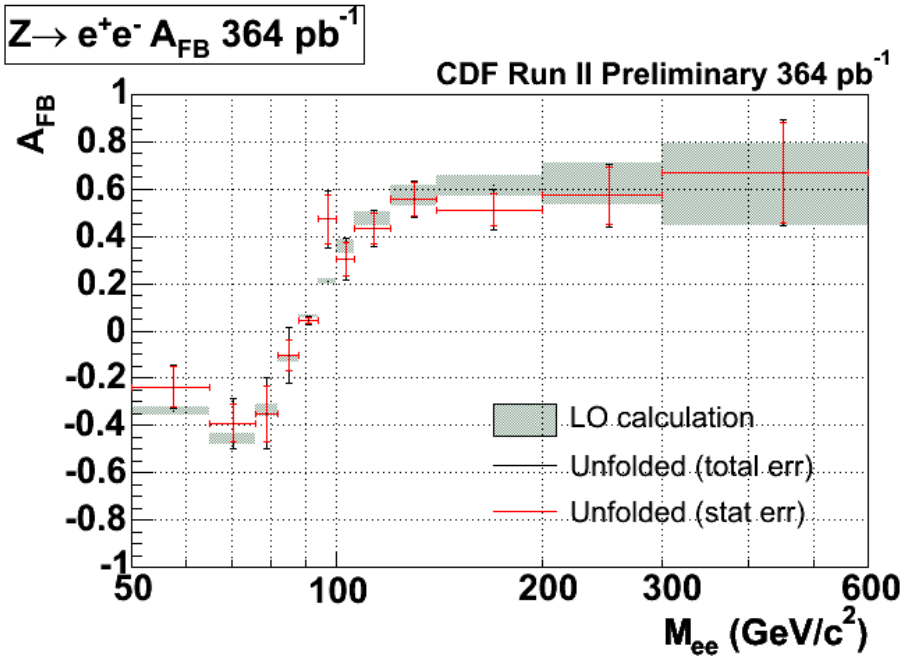
	CC	CP	Total	uncertainty
Data	9455	13455	22910	
Jet Fake	10.6	128	138.6	21.6
W->eν+γ/jets	3.7	70.5	74.3	6.1
WW->ll$\nu\nu$	5.9	6.5	12.4	0.6
WZ (Z->ee)	5.6	6.4	12.0	0.6
ttbar	3.2	1.9	5.1	0.3

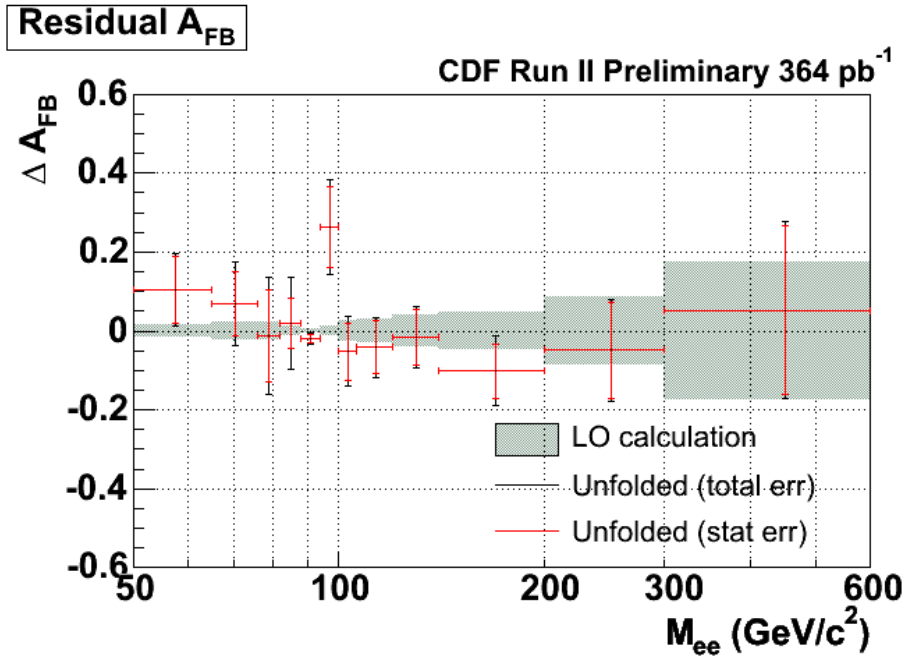
Systematic Uncertainties

- Five sources:
  - Simulation of Detector Material
    - Changes the response matrix.
    - The largest effect.
  - Energy Scale and Resolution
    - Estimated from the Z sample at the pole.
  - Uncertainty in the Background Estimation
  - Limited Statistics in the Response Matrix
  - PDF Uncertainty
    - Estimated from 40 CTEQ6M error PDF sets.
    - The smallest effect.
- Statistical error dominates, except for around the Z pole.

Result

- Consistent with SM (χ^2/ndof = 10.2 / 12)



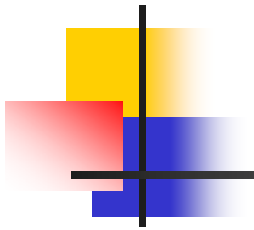


Data Unfolded (table)

Mass (GeV)	RAW					Unfolded		
	#Forward	#BG Forward	#Backward	#BG Backward	A_{FB} (bg subtracted)	#Forward	#Backward	A_{FB}
50-65	97	9.6	120	7.6	-0.125	1875	3036	-0.236
65-76	207	15.8	284	12.7	-0.173	704	1603	-0.389
76-82	330	9.5	394	7.3	-0.094	486	1006	-0.348
82-88	1791	8.9	1817	7.5	-0.008	3153	3871	-0.102
88-94	6935	12.6	6295	10.1	0.048	39087	35762	0.044
94-100	1853	8.3	1348	6.8	0.158	3229	1160	0.471
100-106	333	8.5	169	6.0	0.331	1215	649	0.303
106-120	288	18.6	130	13.3	0.395	843	334	0.432
120-140	166	14.9	58	11.9	0.532	453	129	0.555
140-200	140	22.7	53	14.7	0.508	300	97	0.512
200-300	45	7.5	15	4.1	0.550	91	24	0.571
300-600	10	0.8	3	0.7	0.600	21	4	0.668

A_{FB} Uncertainty Summary

Mass (GeV)	A_{FB} (Data)	Stat.	Energy scale	Energy Resol.	PDF	BG	Response Matrix	Total Syst.	Total Uncert.
50-65	-0.236	0.085	0.009	0.020	0.003	0.018	0.015	0.036	0.092
65-76	-0.389	0.081	0.010	0.006	0.002	0.016	0.026	0.068	0.106
76-82	-0.348	0.117	0.017	0.047	0.001	0.008	0.065	0.092	0.149
82-88	-0.102	0.064	0.030	0.063	0.003	0.002	0.023	0.096	0.116
88-94	0.044	0.011	0.002	0.005	0.001	0.000	0.002	0.010	0.015
94-100	0.471	0.103	0.028	0.033	0.002	0.001	0.030	0.064	0.121
100-106	0.303	0.073	0.018	0.014	0.001	0.005	0.028	0.049	0.088
106-120	0.432	0.067	0.011	0.007	0.000	0.012	0.016	0.035	0.076
120-140	0.555	0.070	0.005	0.015	0.000	0.018	0.011	0.032	0.077
140-200	0.512	0.069	0.004	0.009	0.000	0.030	0.011	0.053	0.087
200-300	0.571	0.122	0.006	0.016	0.001	0.030	0.019	0.045	0.130
300-600	0.668	0.214	0.000	0.034	0.001	0.012	0.028	0.067	0.224



Conclusion

- A_{FB} is measured with 364 pb^{-1} CDF Run II data.
  - Good agreement with SM (χ^2/ndof = 10.2/12)
- Will be updated with ~1 fb^{-1} data.
- Coupling constants will be updated.