The Measurement of A_{FB} in Electron-Positron Pairs

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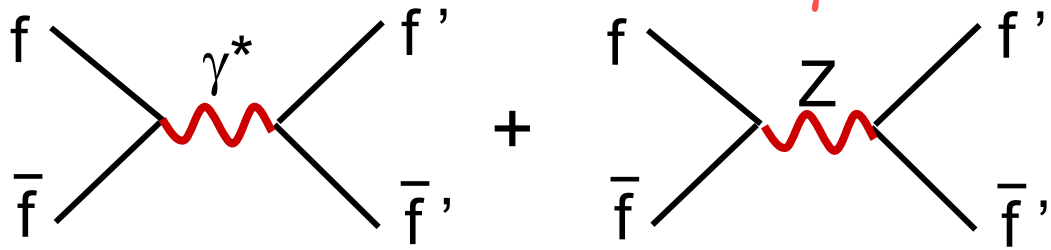
for the CDF Collaboration

Outline

- A Brief History of A_{FB}
- Signal and Background
- Acceptance
- Results

A_{FB}

- Interference between Z and γ^* exchanges

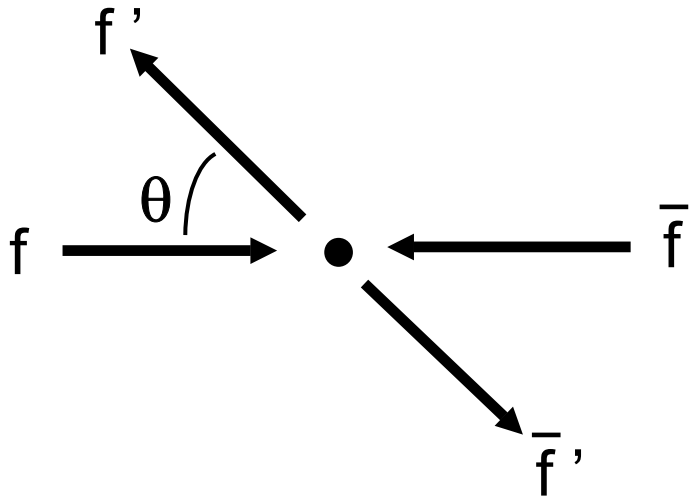


f = e, quarks

- θ-dependent cross sections

$d\sigma$ / $d\cos\theta$ = 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} = 3B / 8A**
- **Directly probing the couplings**

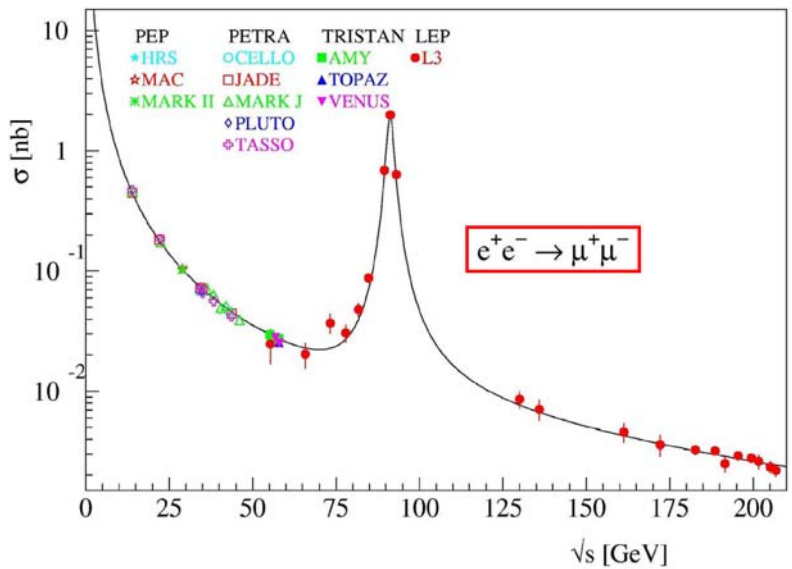
- Reduces systematics
  - Luminosity, efficiencies and acceptance

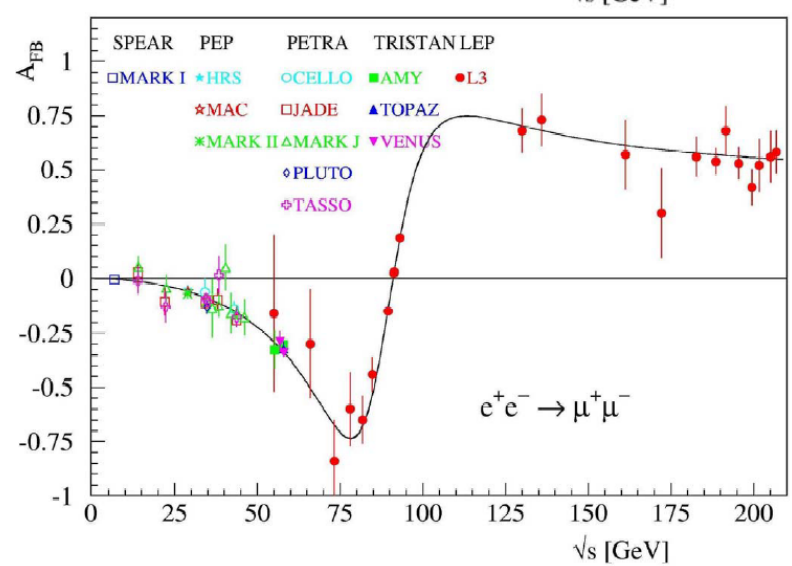
A_{FB} at e^+e^- Colliders

- CESR
- PEP
- PETRA
- TRISTAN
- SLC
  - measure $\sigma_{L,R}$ using polarized e beams

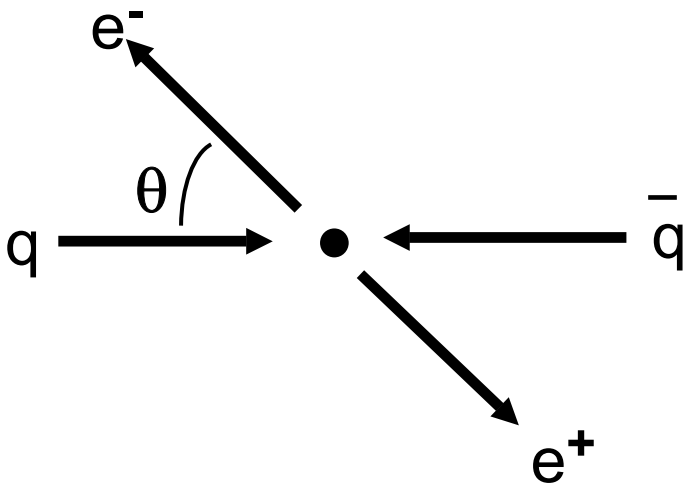
$$A^0_{LR} = \left(\frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \right) = A^0_e$$

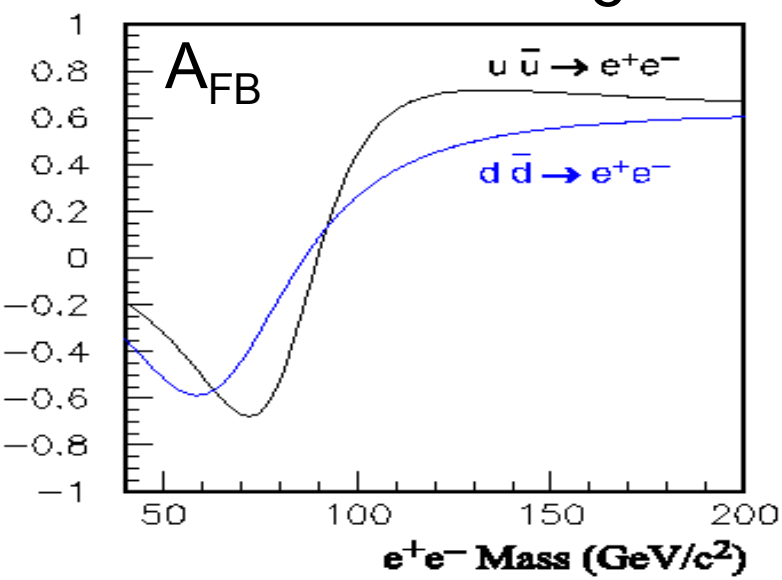
- LEP
  - Tevatron needs >10 fb^{-1} to compete



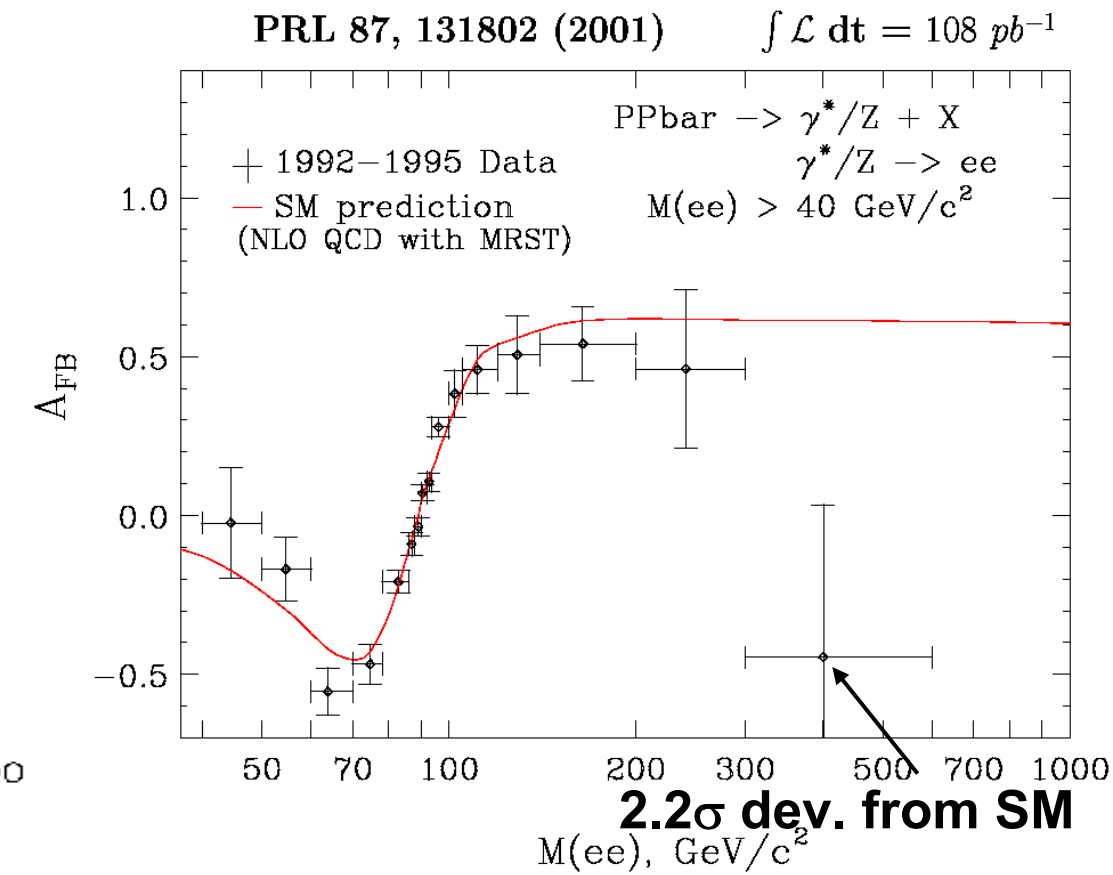


A_{FB} at Hadron Colliders





CDF Run I (~110 pb^{-1})



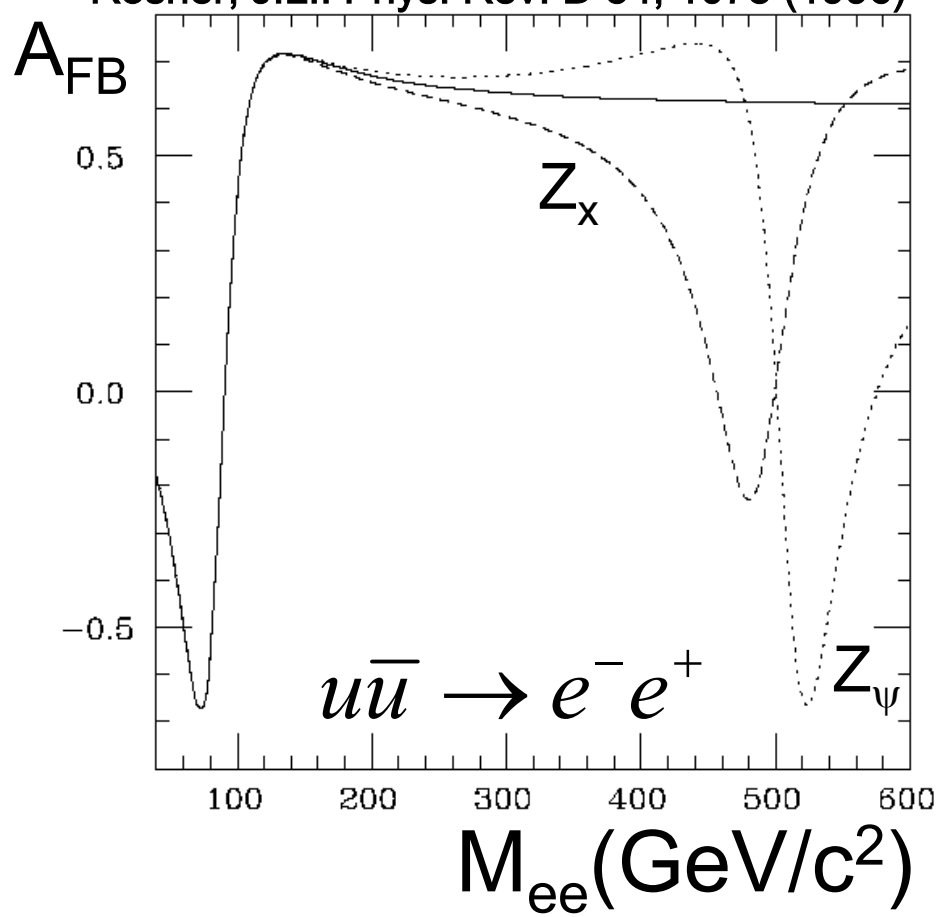
2.2σ dev. from SM

A_{FB} beyond LEPII: Z´,etc...

- Looking for symmetries beyond the SM
  - ↗Various models predict new neutral, heavy bosons: Z´s
- New resonance could interfere with γ and Z.
- Complementary to cross-section search (see Muge's talk)

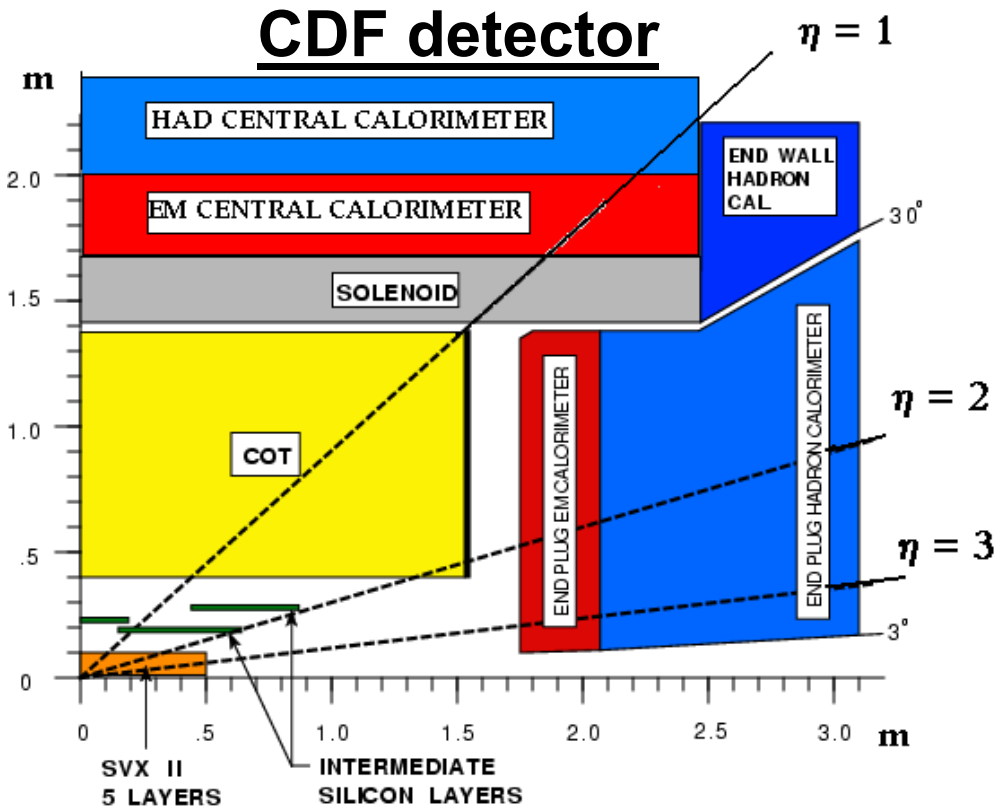
500 GeV/c^2 Z':

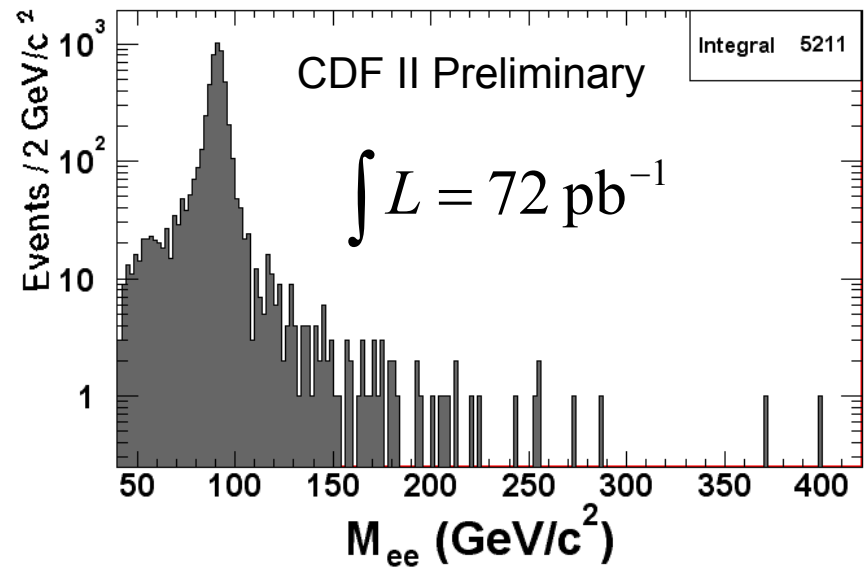
Rosner, J.L.: Phys. Rev. D 54, 1078 (1996)

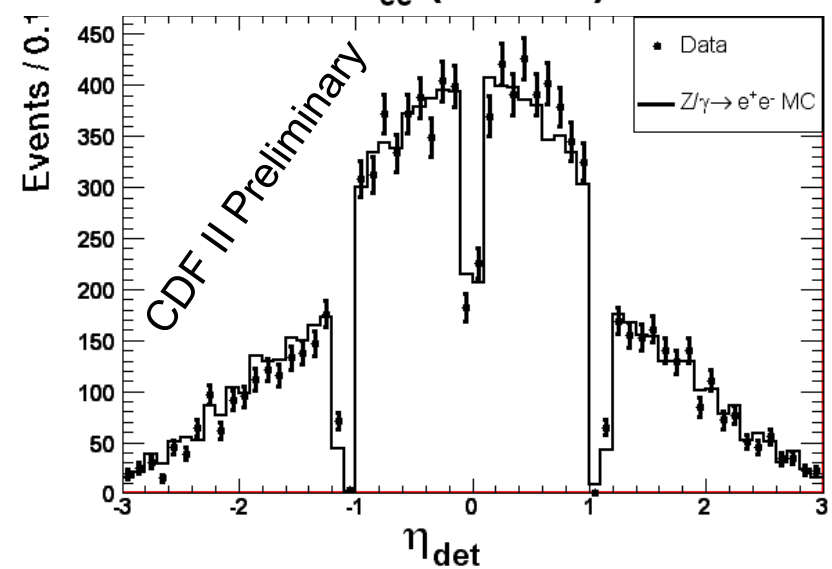


Z/γ^* Candidates and CDF

- Selection (5211 candidates)
  - ↗ 2 high P_T isolated electrons
    - E_T > 20 GeV

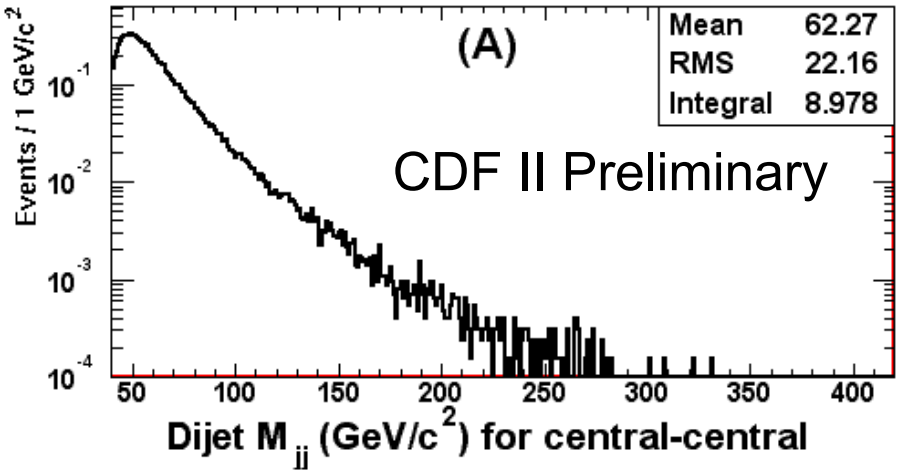


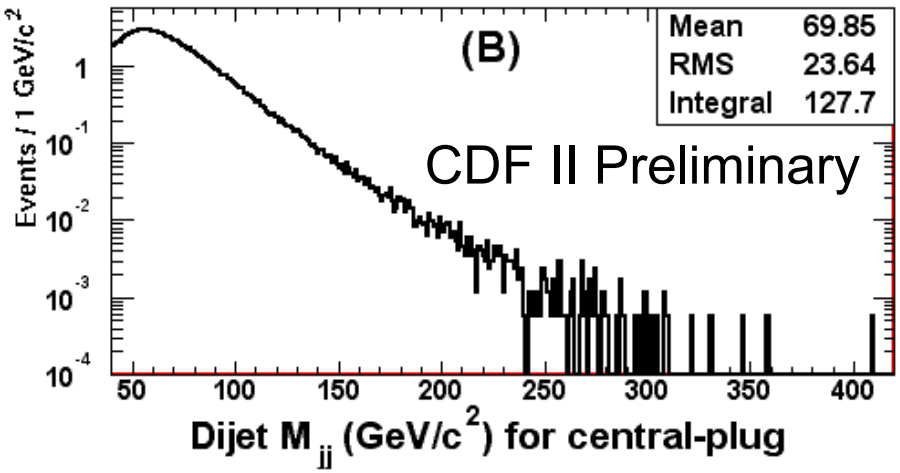




Backgrounds for Z/γ^*

- Dijet dominant

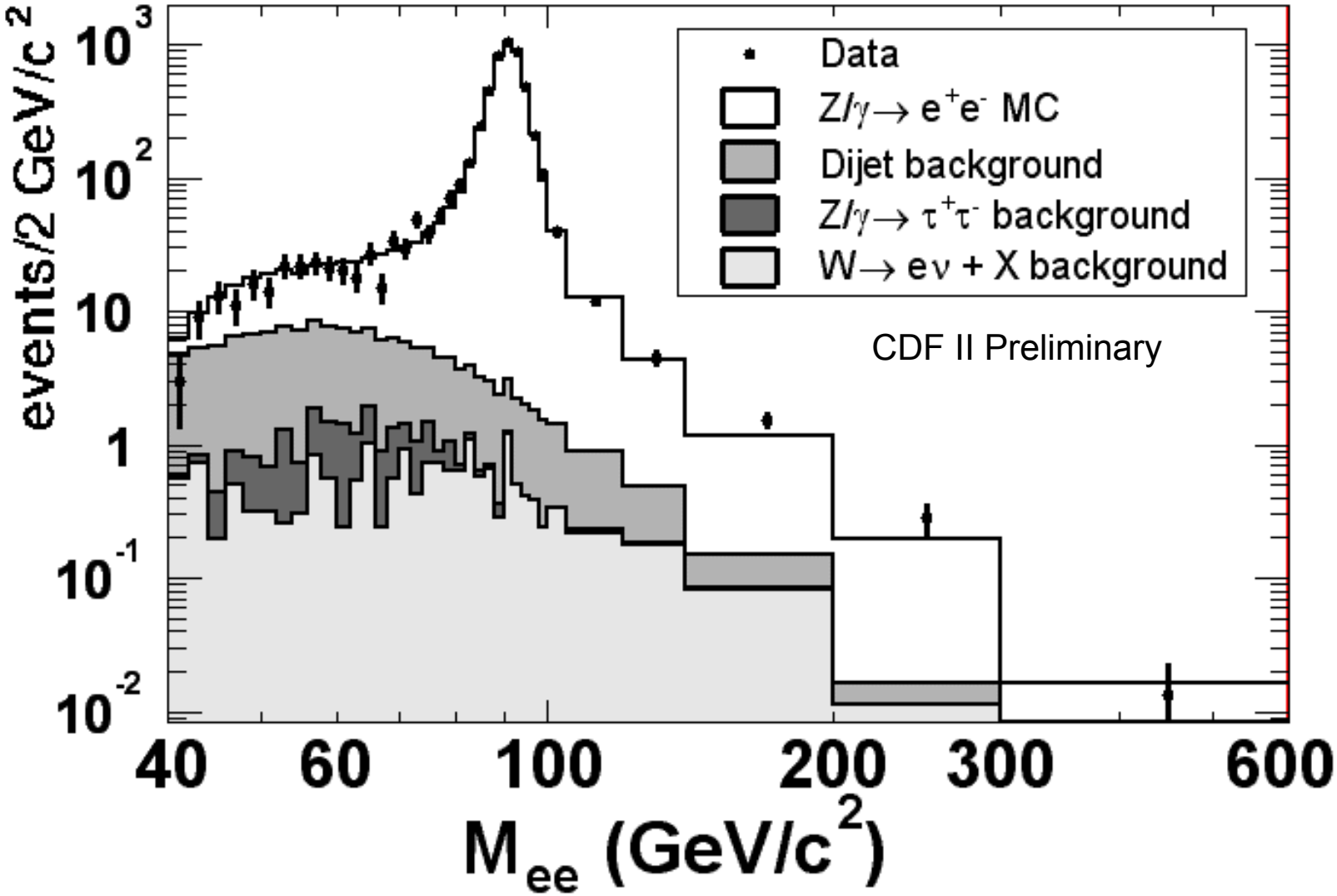




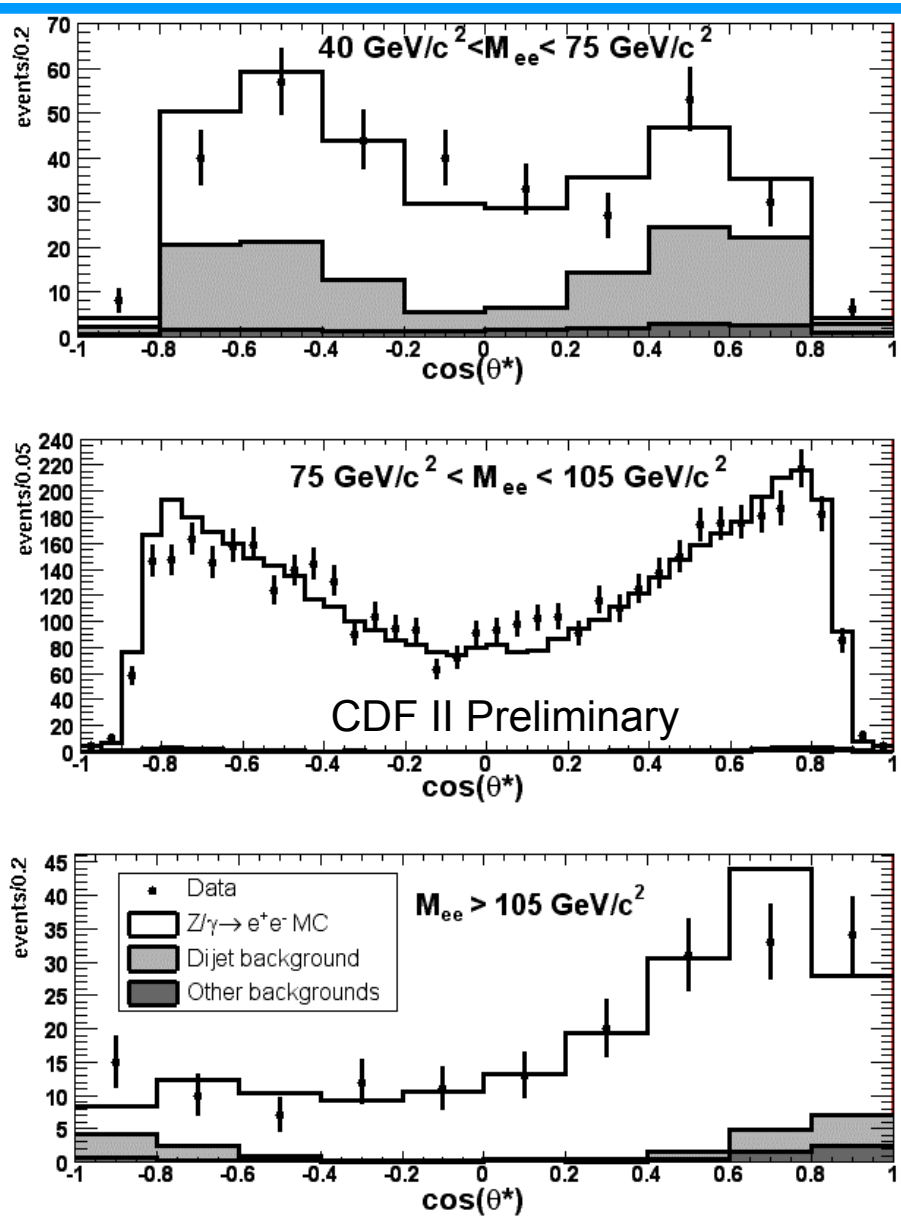
Background Summary

Source	# of events	
	C-C	C-P
Dijet	9	128
$W \rightarrow e\nu + X$	1.8	25
$Z \rightarrow \tau\tau$	5.6	7.2
WZ	1.4	1.7
WW	1.5	1.8
Top	1.1	0.7

Data-MC Comparisons

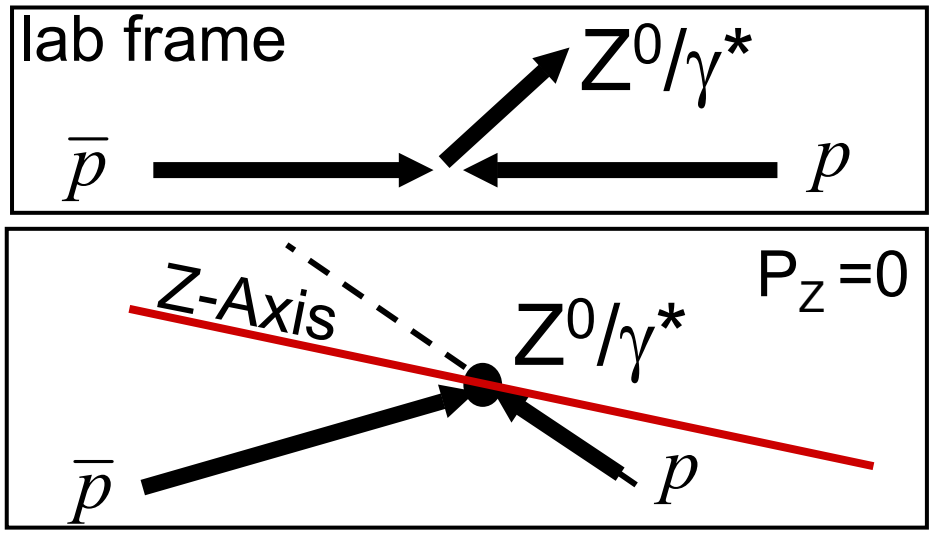


Data-MC: Cos(θ^*)



Calculating A_{FB}

- $\cos\theta^*$ in Collin-Soper frame
  - Minimize ambiguity in the incoming quark Pt



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

- Calculating A_{FB}:

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

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

a : Forward/Backward Acceptance & Efficiency

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

Acceptance:Event Loss

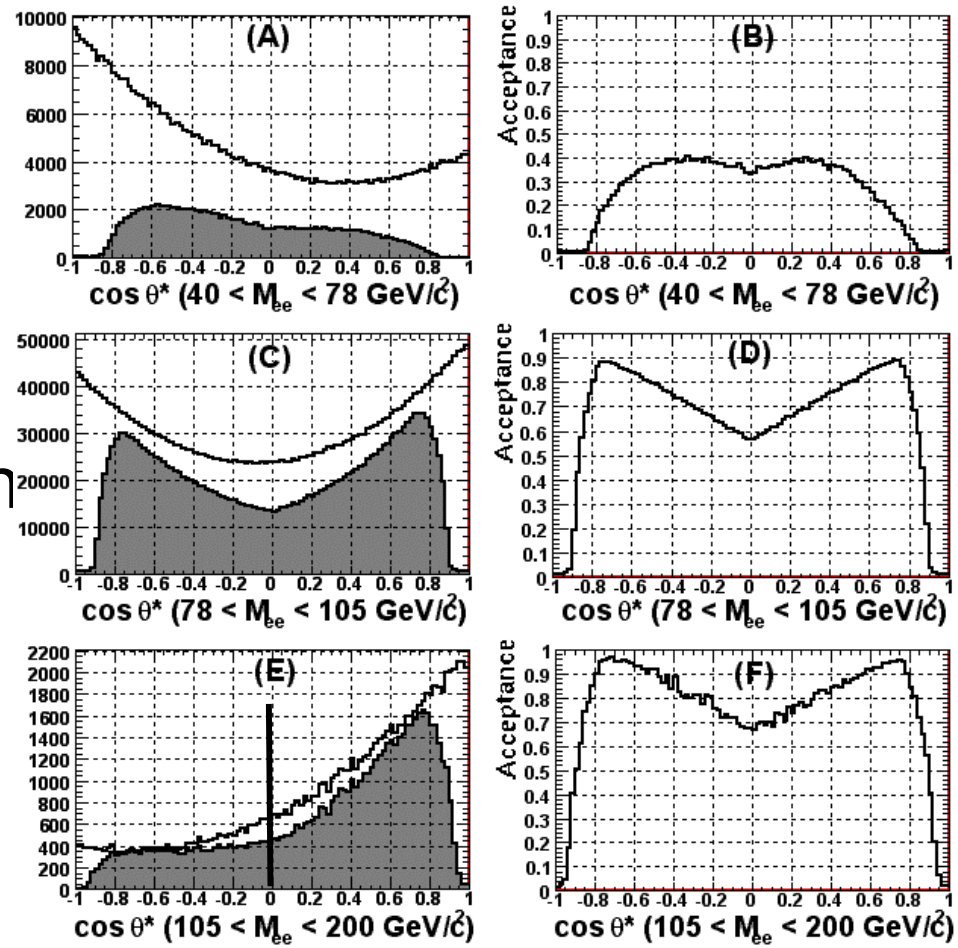
- Generator Level:
- Acceptance is symmetric, but distribution is not
- Grey:
  - $|\eta_1| < 1, |\eta_1| < 3$,
  - $E_T > 20$ GeV
- Tends to shift A_{FB} in a bin

Raw Distr. Acceptance

Low Mass

Pole Region

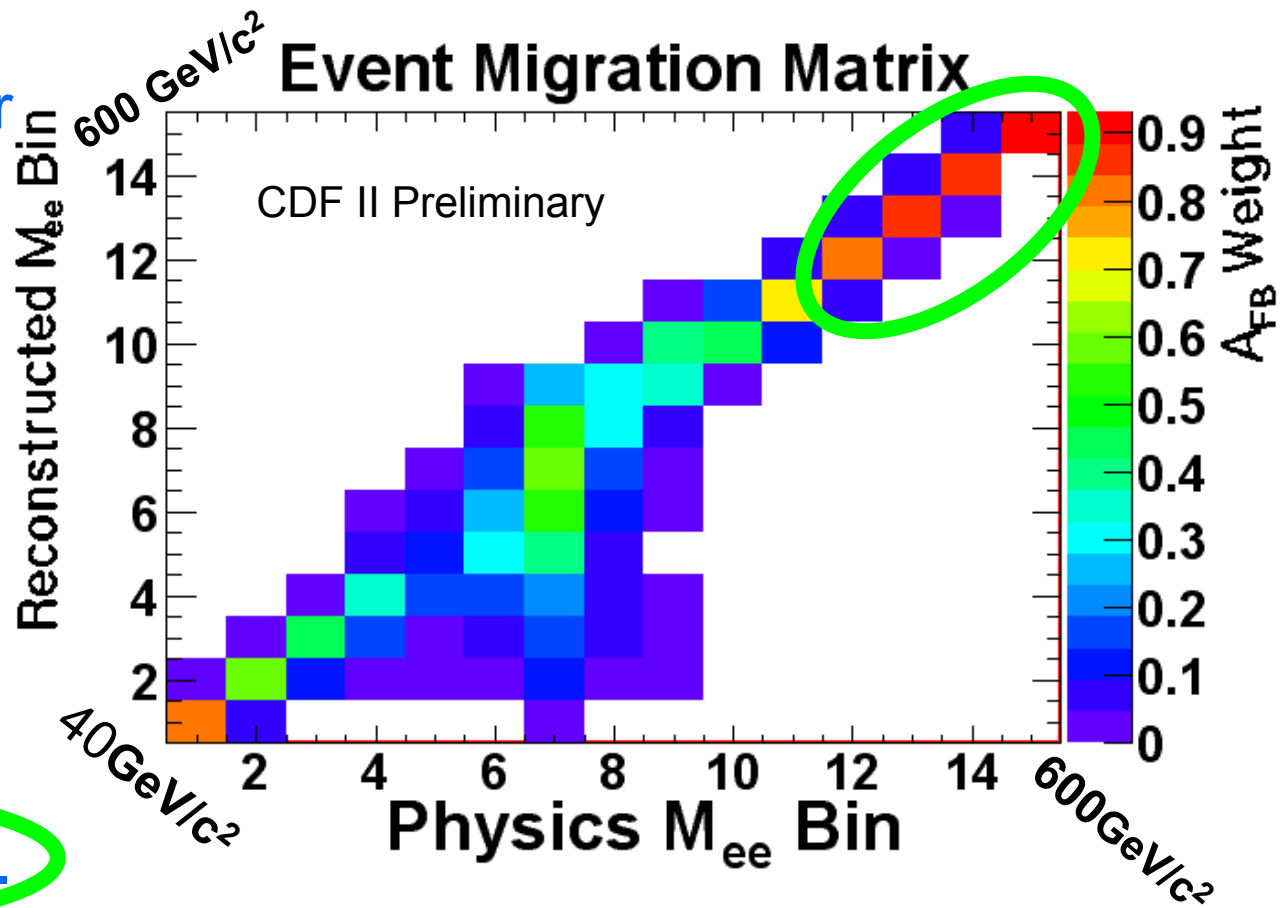
High Mass



Acceptance:Event Migration

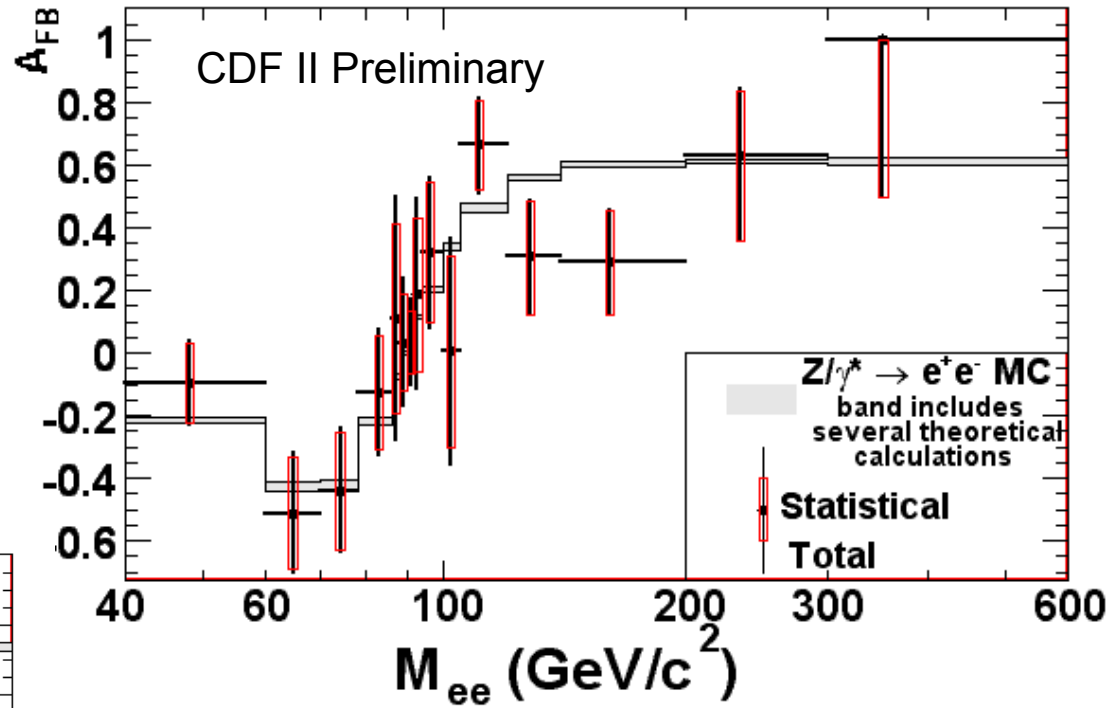
- Event Migration Matrix
- Large correlations between bins near Z pole
- Unfolding Problem
  - **Invert Matrix by fitting for A_{FB}**
    - Large variances
  - **Correction factors**
    - Biases result
- High Mass O.K.

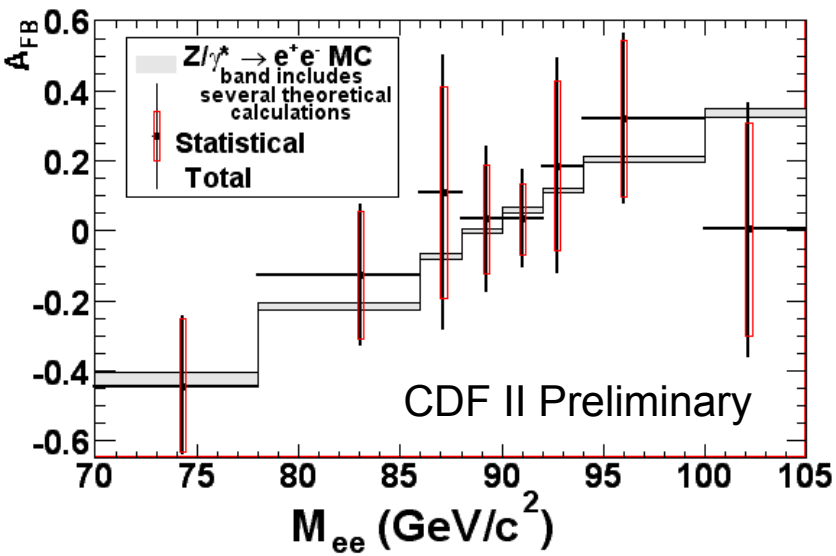
Sum A_{FB} in Rows:



Fit with smoothing

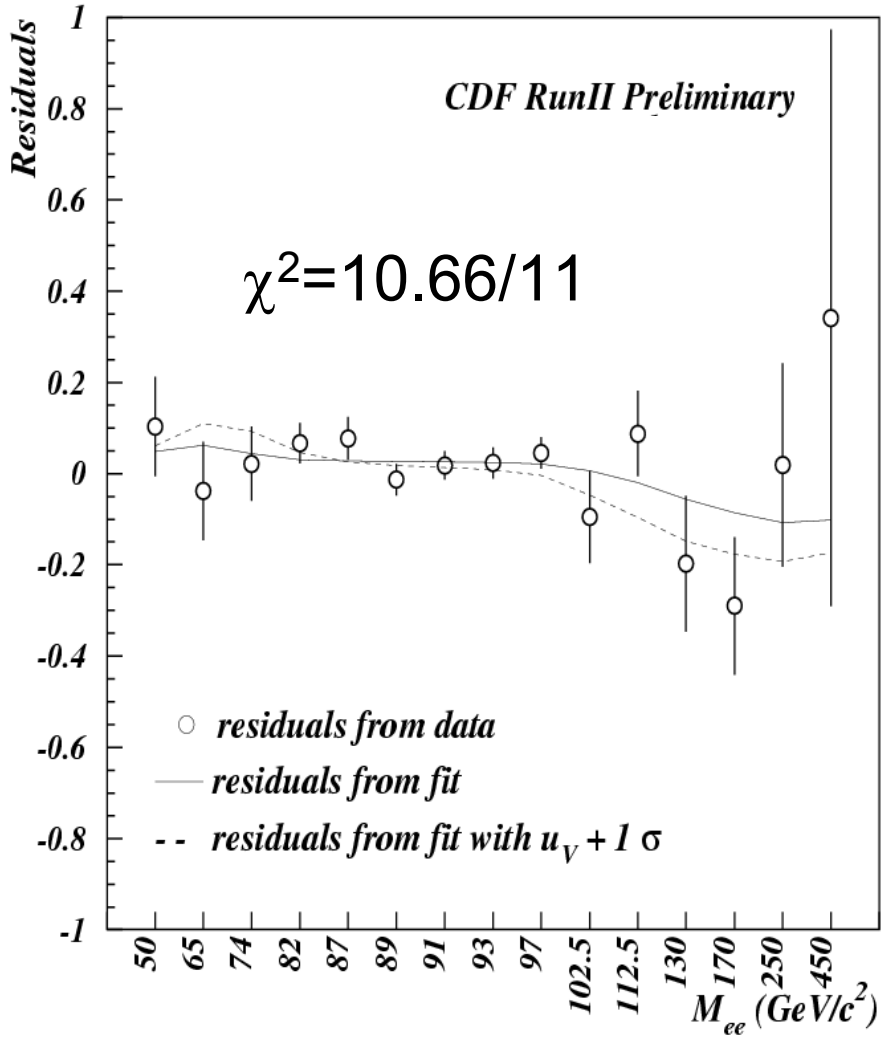
- Result fitting A_{FB}
  - Large uncertainties
  - Tikhonov regularization
    - Only in bins with correlations





Fitting for Z Couplings

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

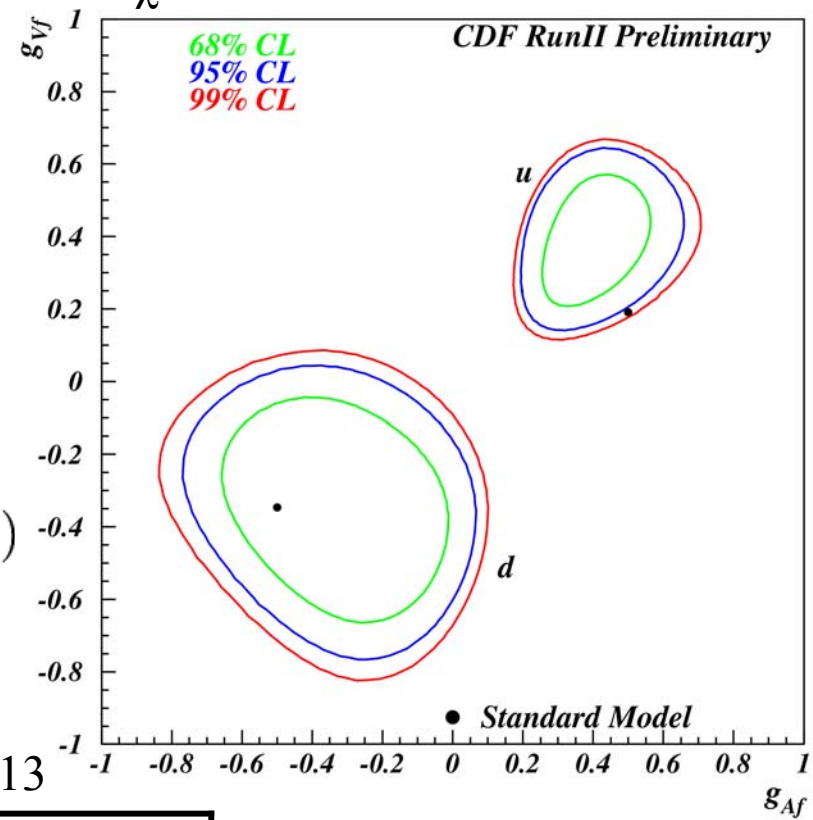


Couplings Results

Quark Couplings

	This Study	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

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



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

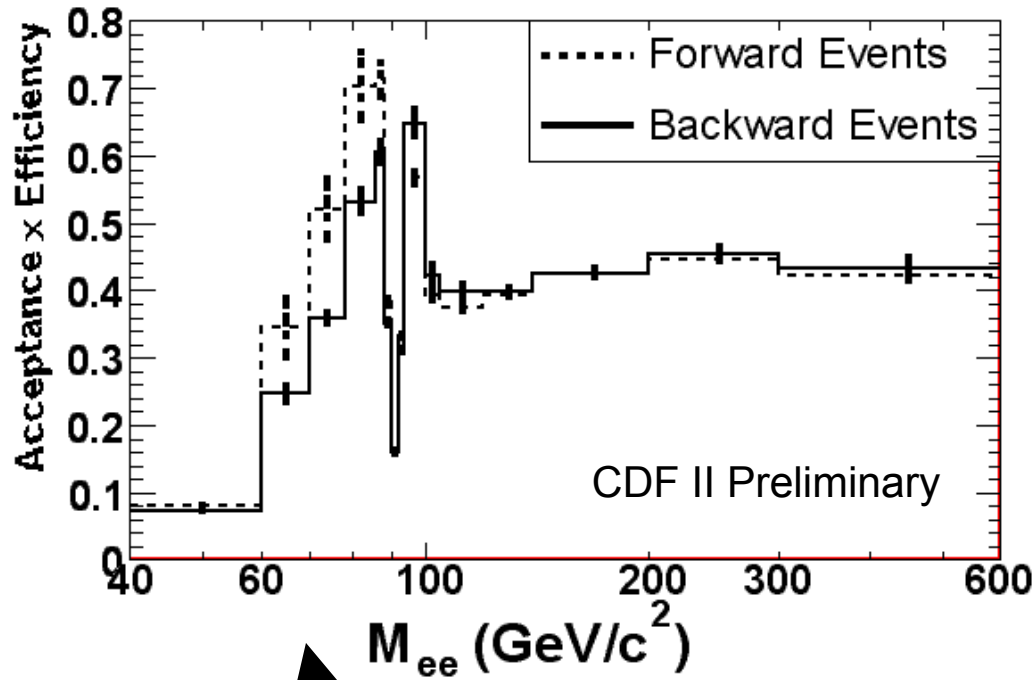
$\chi^2/\mathrm{ndf} = 12.71/14.0$

Electron Couplings: $\chi^2/\mathrm{ndf} = 12.5/13$

	This study	SLD+LEP	SM prediction
e_V	**-0.056±0.018**	**-0.03816±0.00047**	**-0.03816 ± 0.00047**
e_A	**-0.536±0.190**	**-0.50111±0.00035**	**-0.5064 ± 0.0001**

Acceptance*Efficiency

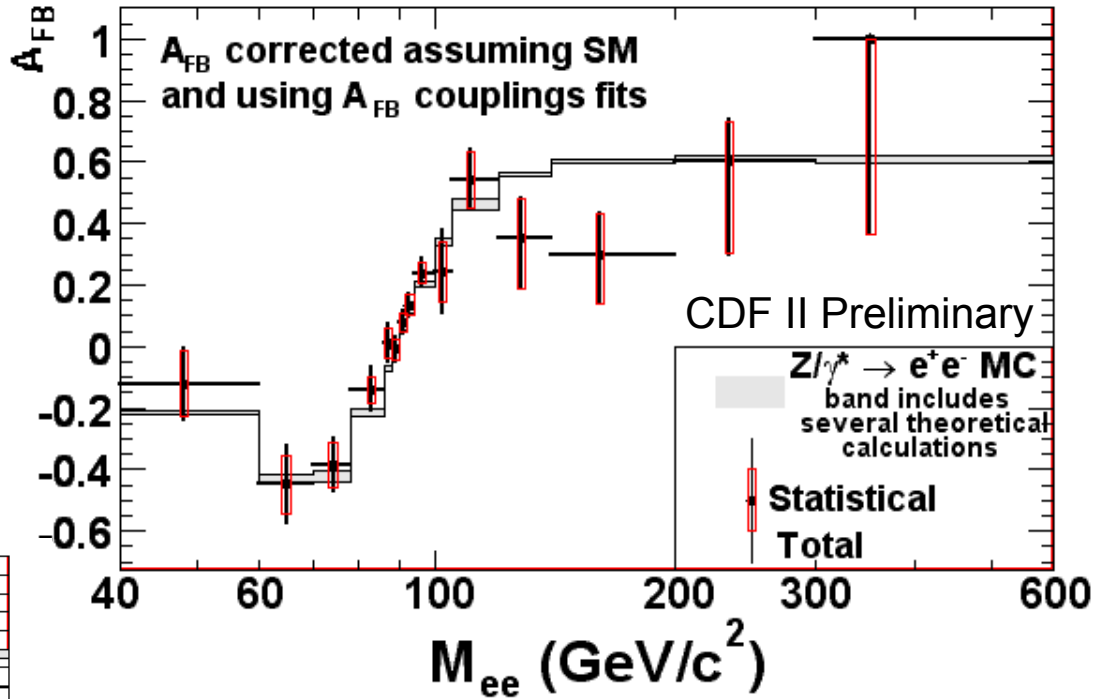
- Correction Factors:
  - Energy Resolution
  - Kinematic and Fiducial cuts
  - Radiation from FSR and Brems
  - Electron ID efficiency
- Assumes SM
  - Allow Z couplings to float

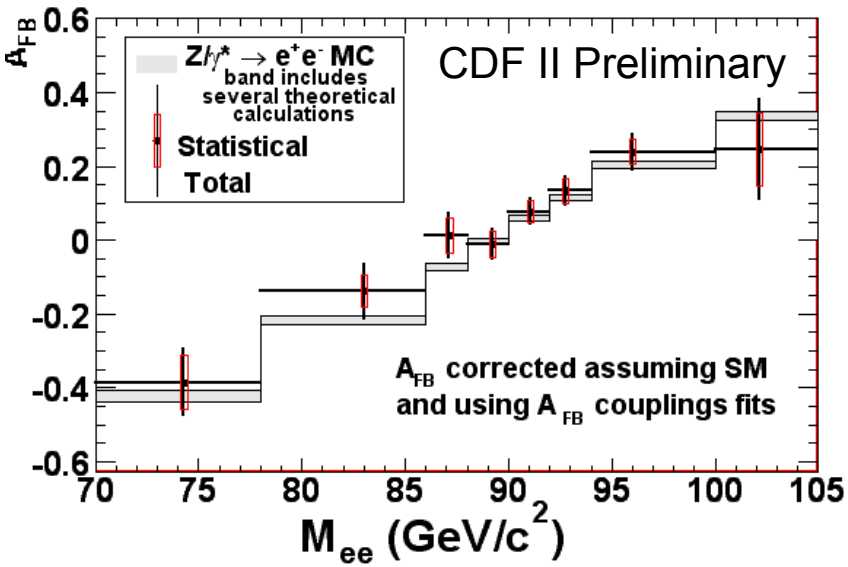


Couplings fit used as input A_{FB}

SM w/ measured Z couplings

- Result with correction factors
  - ↗ **Not useful for non-SM physics near Z-pole**





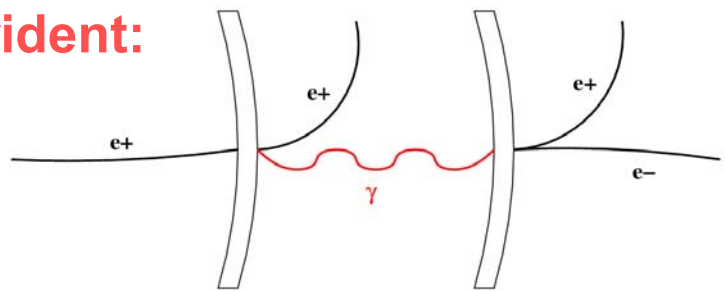
Conclusions

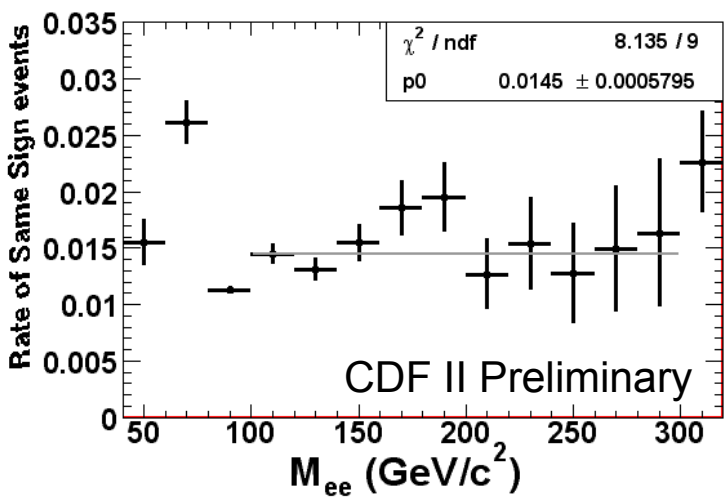
- Unfolding Problem near Z pole
  - **Fit for couplings using uncorrected A_{FB}**
  - **Good agreement with current world ave.**
  - **Contribute to Z-quark couplings in future?**
- High mass not affected by smearing
- Nothing new above pole, yet…
- PRD on its way…

Backup Slides

Understanding the detector

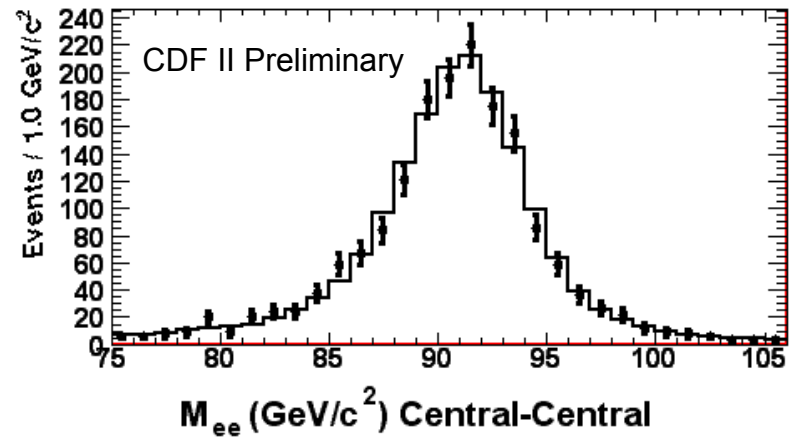
- Radiation Effects: Charge ID
  - Get M_{ee} dependence from MC
  - two effects: "tridents", $\sigma(p_T)$
  - Trident:

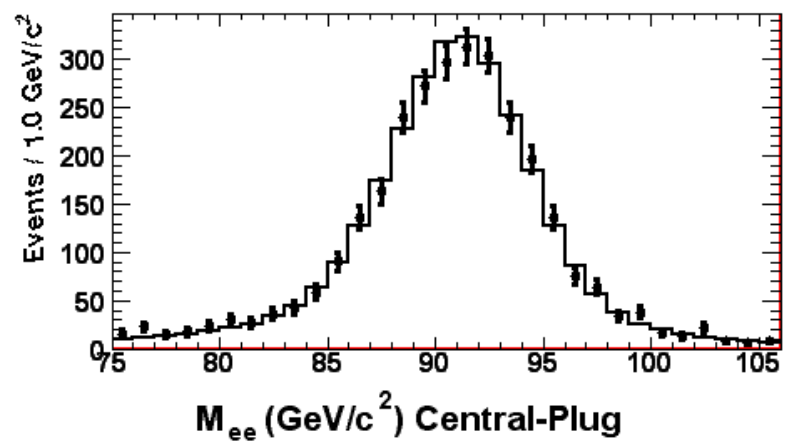




MisID rate (trident):0.7%

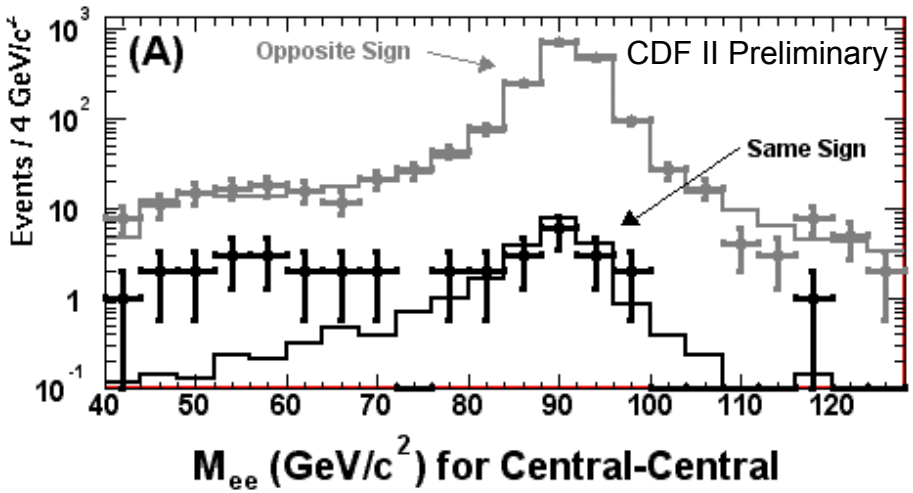
- Energy Scale and Resolution

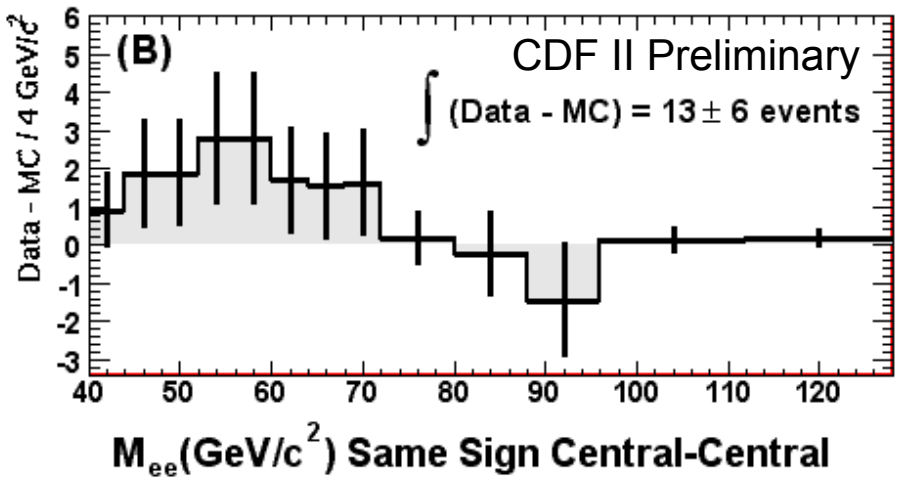




Cross-Check: SS vs OS

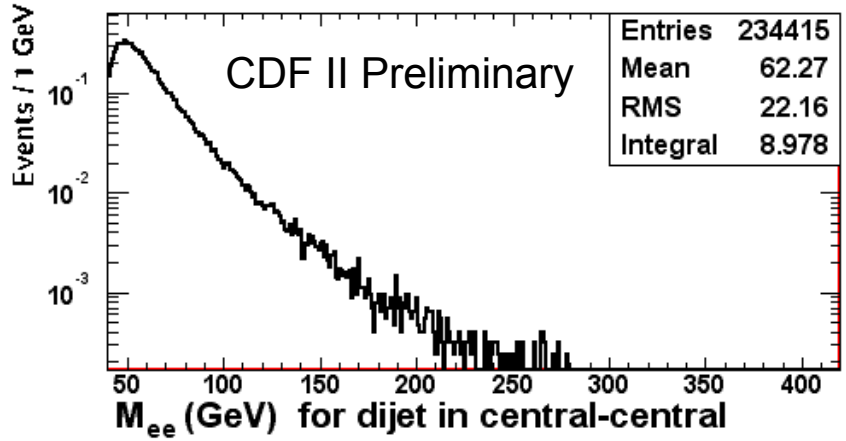
- SS vs. OS
  - ↗ **CC : Find 36 SS events in our sample**
    - Have to worry about Material → Tridents
- Subtracting peak from MC
  - ↗ **$13 \pm 6_{(stat)} \pm 4_{(sys)}$ events**
- Checks both radiation in Simulation and background estimation

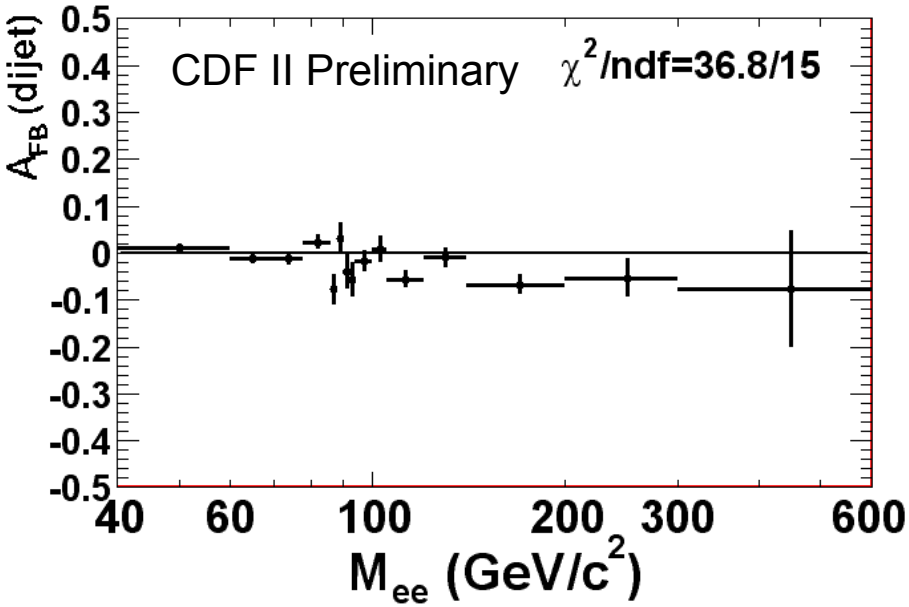


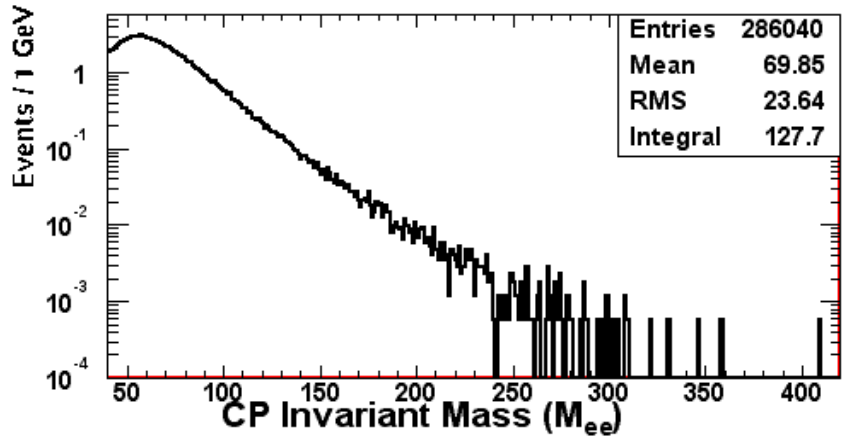


Dijet background

- From Data
  - M_{ee} from jet sample
  - A_{FB} from background sample
    - $A_{FB} \sim 0$



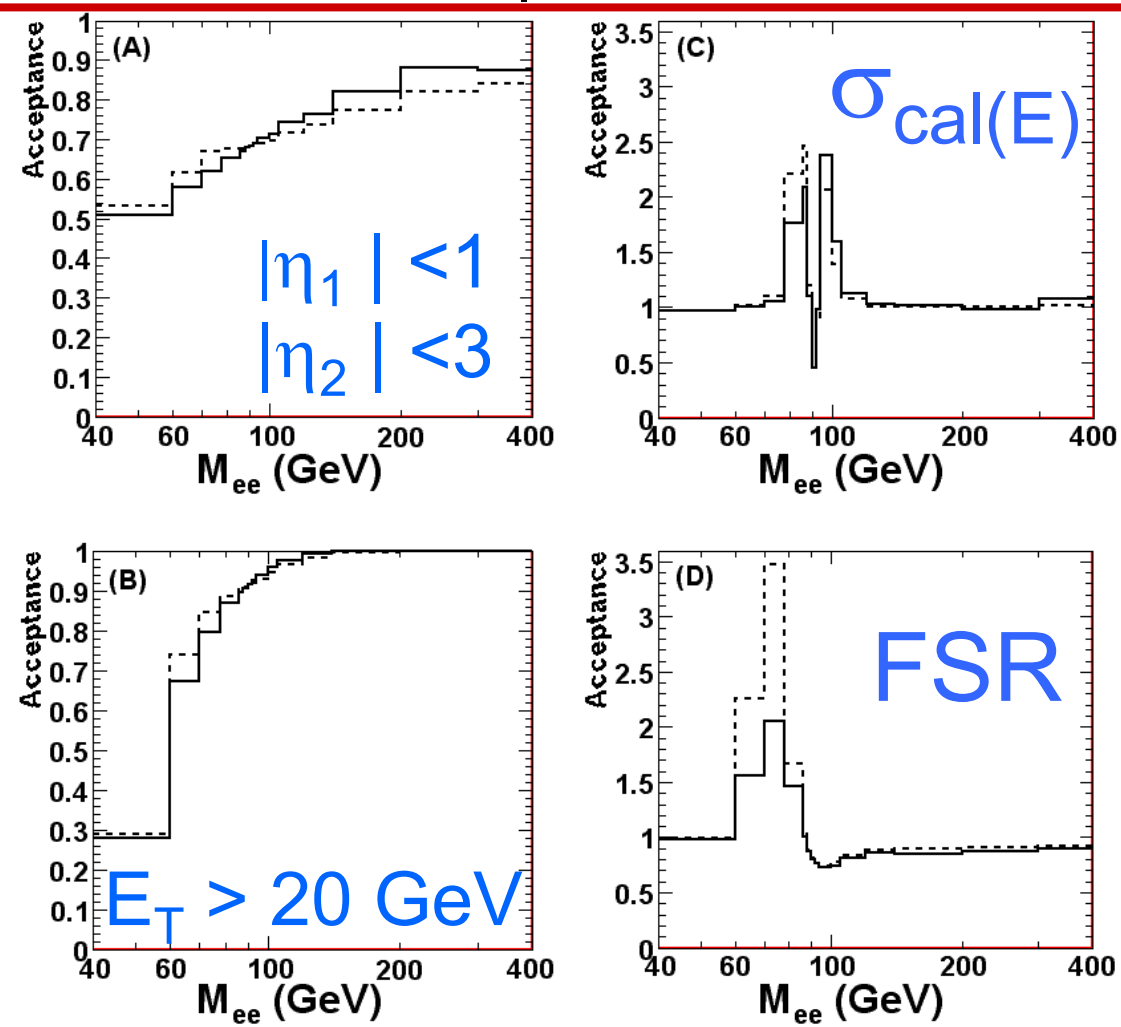




Acceptance

- Generator Level Studies:
- **Event Loss:**
  - A: Fiducial Cuts
  - B: Kinematic Cuts
- **Event Migration:**
  - C: E_T Smearing
  - D: FSR Corrections

Line: backward | Dashed: forward



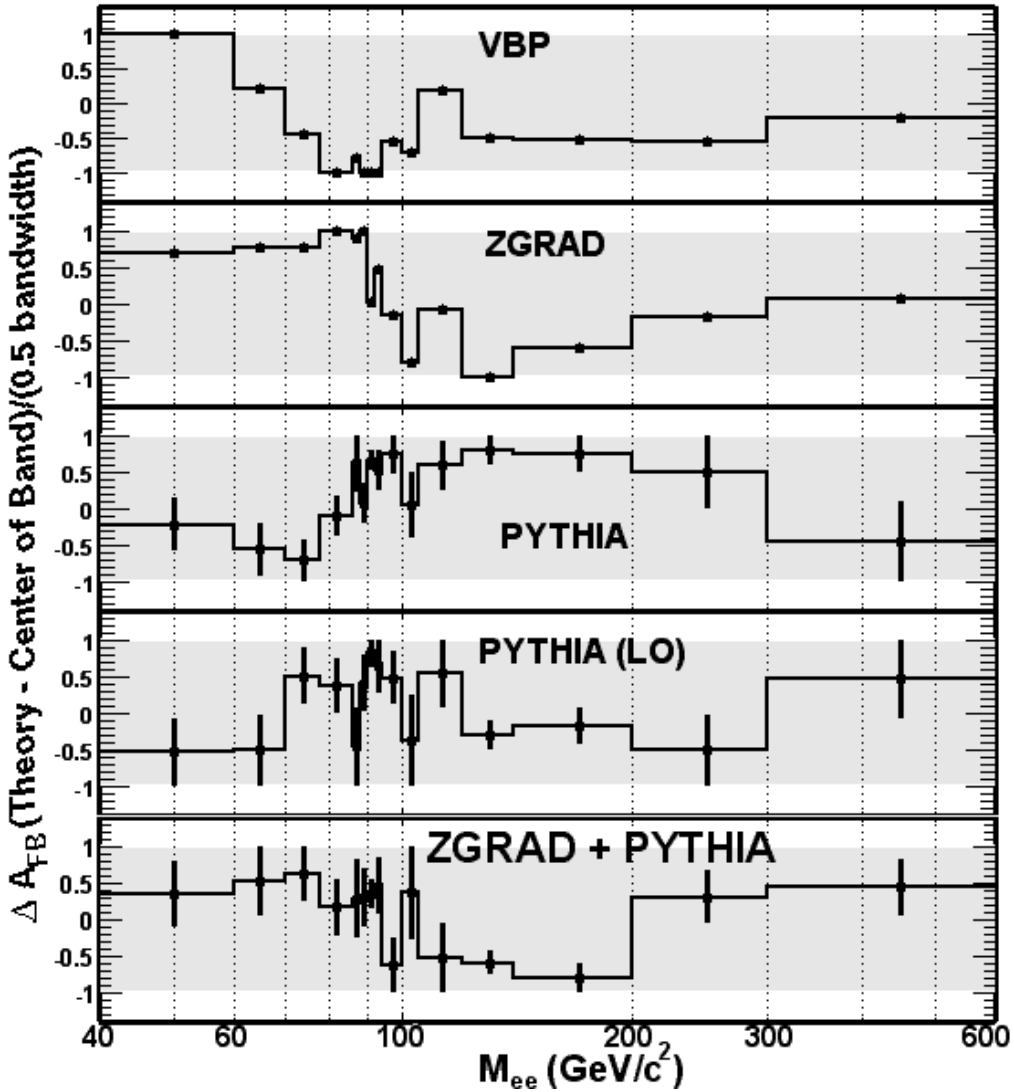
Correlations in Couplings

The correlation matrix :

	u_V	u_A	d_V	d_A
u_V	1.000	0.193	0.675	-0.078
u_A	0.193	1.000	-0.324	0.332
d_V	0.675	-0.324	1.000	-0.535
d_A	-0.078	0.332	-0.535	1.000

Theory Band

- Number of MC's
- VPB
  - ↗g resummation
- ZGRad
  - ↗O(α) EW corr.
- Pythia
  - ↗Parton shower (QED+QCD)
- Nothing w/ NLO QCD & O(α) EW



Systematics

- Energy Scale
  - Central: ±0.5%
  - Plug: ±1%
- Energy Resolution
  - Central: +0.5 GeV
  - Plug: +1.5 GeV
- Material
  - Central: ±0.015 X_o Copper
  - Plug: ±1/6 X_o Iron
- Background
  - QCD: $\pm\sigma_{\text{fake rate}}$
  - Montecarlo: $(6_{lum} \oplus 5_{accept} \oplus X_{theory})\%$

- Checked(negligible):
  - A_{FB}(dijet)
  - A_{FB}(W+X)
  - Fiducial acceptance
  - Charge mis-ID
  - Trigger efficiency

- For SM plot:
  - A_{FB} input from couplings measurement

Fitting for A_{FB}

- Parameterization takes $f(A_{FB}^{physics}) \rightarrow A_{FB}^{raw}$
- Construct -log(likelihood): binomial function

$$P(A_{FB}^{raw}) = \binom{N}{N_F} \cdot (1 + A_{FB}^{raw})^{N_F} \cdot (1 - A_{FB}^{raw})^{N_B} \cdot (\tfrac{1}{2})^{N_F + N_B}$$

$$\alpha = -N_F \cdot \log(1 + A_{FB}^{raw}) - N_B \cdot \log(1 - A_{FB}^{raw}) + C$$

- Some bins poorly constrained…
- Add smoothing function $\propto \dfrac{d^2 A_{FB}(M_{ee})}{dM_{ee}^{\ 2}}$

$$\alpha' = -\log(P(A_{FB}^{raw})) + \lambda \cdot S[f_{true}(M_{ee})]$$

- Choose λ such that $\alpha' = \alpha + 0.5$

Add Smoothing

- Using Tikhonov regularization

$$S[f_{true}(M_{ee})] = \int \left(\frac{d^2 f_{true}(M_{ee})}{dM_{ee}^{\ 2}} \right)^2 dy$$

- We assume parabolic form for $f_{true}(M_{ee})$
  - ↗**Solve for three adjacent bins**
- New likelihood:

$$\alpha' = -\log(P(A_{FB}^{raw})) + \lambda \cdot S[f_{true}(M_{ee})]$$

- Choose λ such that $\alpha' = \alpha + 0.5$

Parameterizing Acceptance

- Define 4 15x15 matrices:
  - Efficiency for bin i to end up in bin j

$$R^{ij}_{FF} = \frac{N^j_F(sim)}{N^i_F(gen)}, R^{ij}_{FB} = \frac{N^j_B(sim)}{N^i_F(gen)}$$

$$R^{ij}_{BF} = \frac{N^j_F(sim)}{N^i_B(gen)}, R^{ij}_{BB} = \frac{N^j_B(sim)}{N^i_B(gen)}$$

- Mean # of events in bin i:

$$N^i_{F/B}(gen) = N^i_{Tot}(gen)(\tfrac{1}{2} \pm \tfrac{1}{2} A^i_{FB})$$

- Number of raw/detector level events:

$$N^j_F(raw) = \sum_i^{15} \left(R^{ij}_{FF} \cdot N^i_F(gen) + R^{ij}_{FB} \cdot N^i_B(gen) \right)$$

$$N^j_B(raw) = \sum_i^{15} \left(R^{ij}_{BF} \cdot N^i_F(gen) + R^{ij}_{BB} \cdot N^i_B(gen) \right)$$