Physics with Di-electron Final State at CDF

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Hadron Collider

- Tevatron ($p\bar{p}$ @1.96 TeV)
  - 1995 – now
  - CDF & D0
  - Discovered top quark
  - SM precision measurement
  - Constrain/Search for new physics

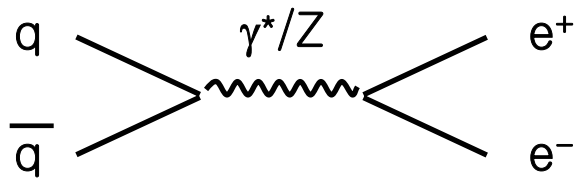
- LHC (pp @ 14 TeV)
  - 2007 –
  - Search for SM Higgs
  - Search for new physics
    - SUSY, ED, Z', etc.

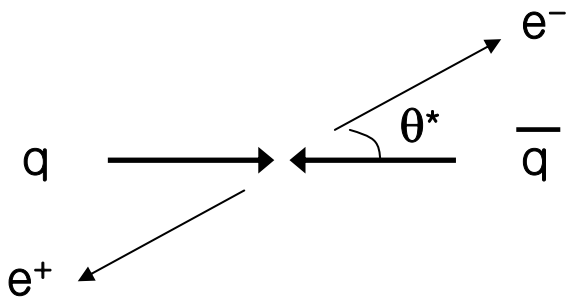
Electroweak Physics

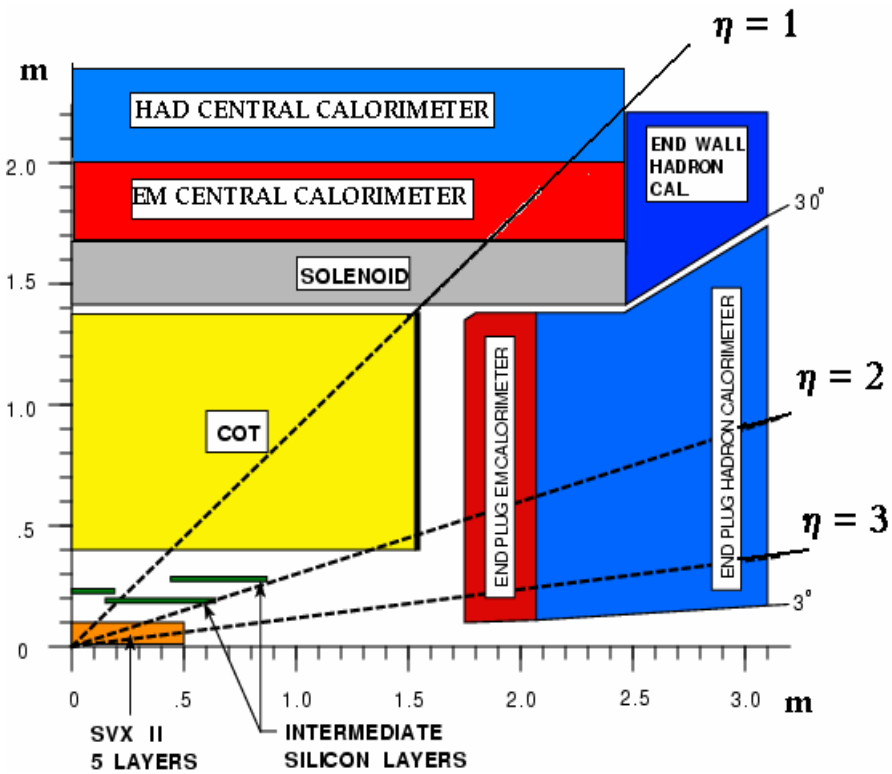
- Successfully tested so far.
- Problems:
  - Electroweak symmetry breaking mechanism
    - Higgs may be the answer.
  - Light Higgs mass requires new physics at ~1TeV.
    - Nothing discovered so fat though.
- What we can do at hadron colliders:
  - Search for the Higgs.
  - Precision measurements.
    - Measure the coupling constants and Weinberg angle.
  - Direct Search for new gauge bosons.

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'.







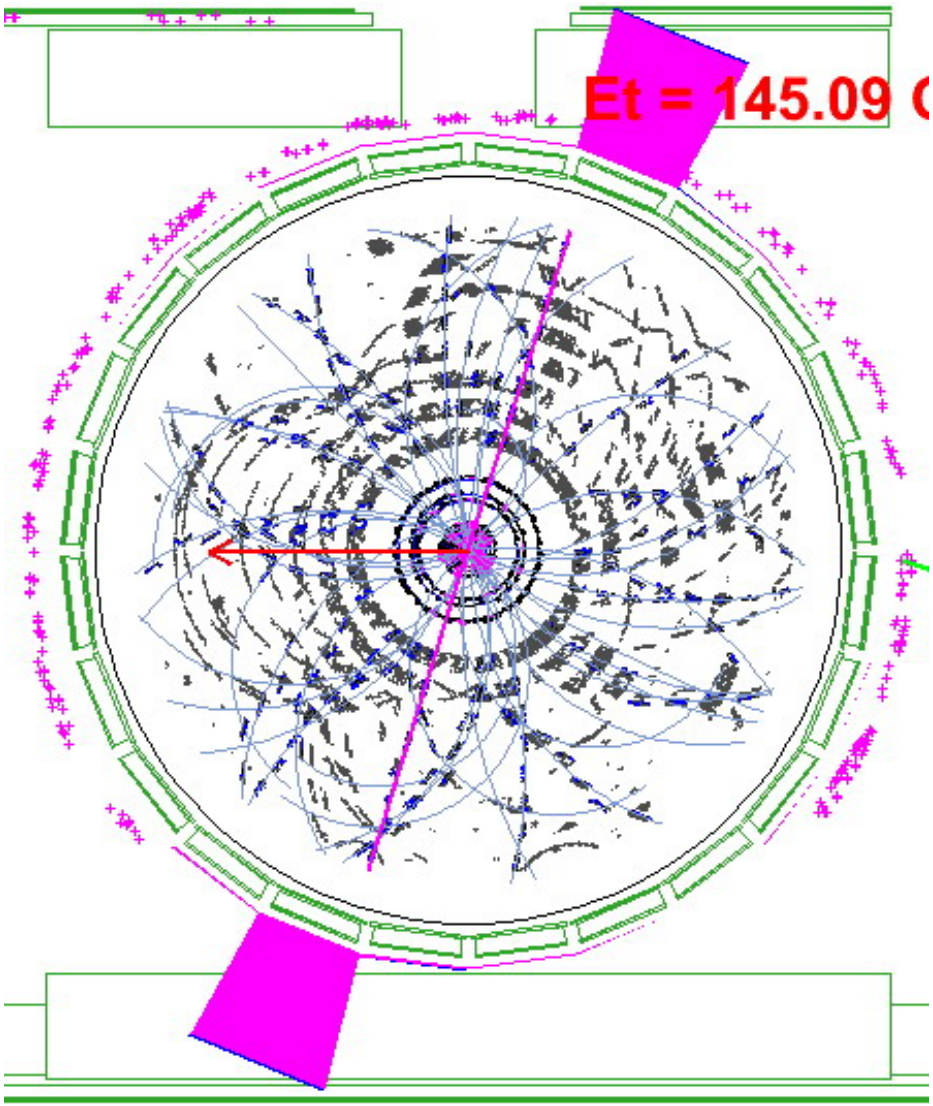
Electron Reconstruction at CDF

- Electromagnetic Calorimeter
  - 480 towers of lead/scintillator layers.
  - Measure the Energy deposit of the shower.

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

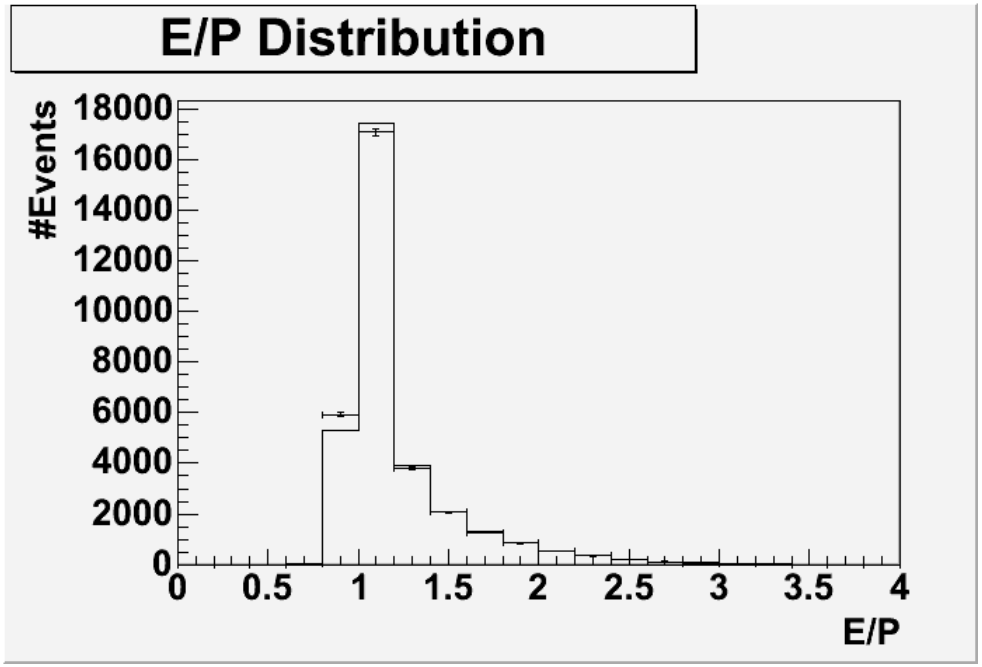
- Central Outer Tracker
  - Wires in an Argon gas chamber.
  - Magnetic field of 1.4 T by Solenoid.
  - Momentum is measured from the curvature.

$$\Delta P_T / P_T = 1.5 \times 10^{-3} P_T [GeV / c]^{-1}$$



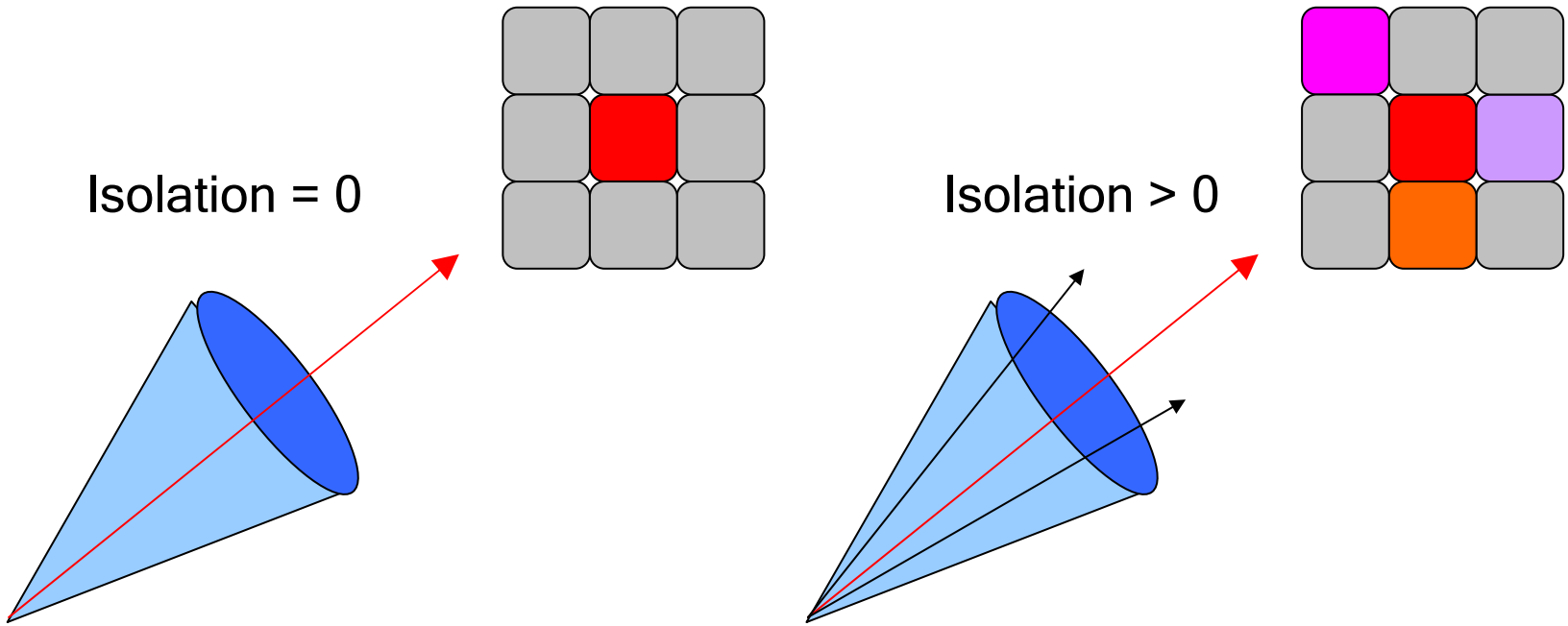
Electron Reconstruction (cont'd)

- Reconstruction Algorithm
  - Initiated by calorimeter.
  - Track must match the position.
  - Momentum (P) must match the energy (E)
- E/P peaks at ~1.0
  - E/P tail shows material effect.
  - Useful for material systematic study.



Electron Reconstruction (cont'd)

- Isolation
  - Most signal electrons are well isolated. (Jet fakes are not.)

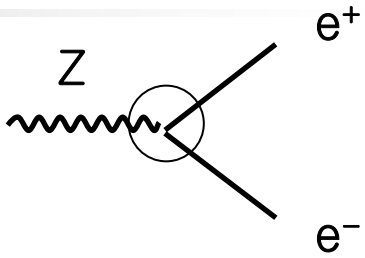


Z Forward-backward Asymmetry

- An Electroweak precision measurement

Z Forward-backward Asymmetry

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



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

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

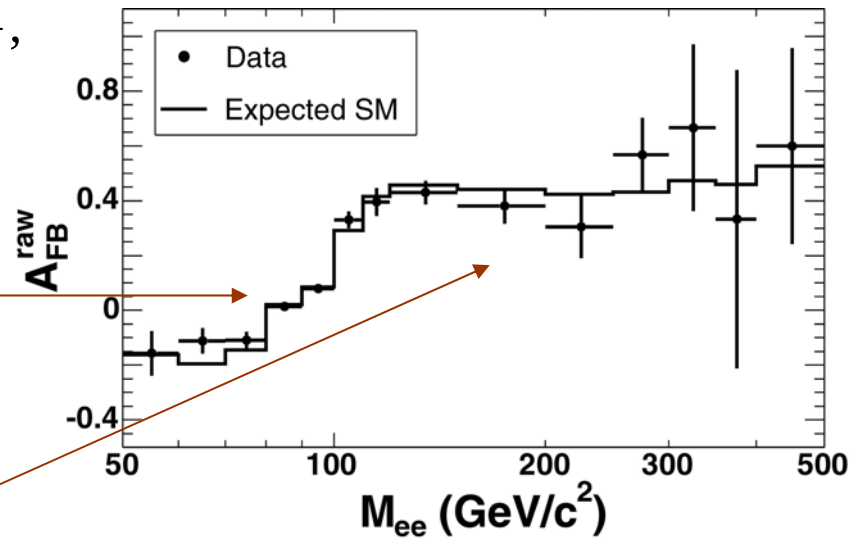
$$B = \frac{3}{2} g_A^q g_A^l (Q_l Q_q \,\mathrm{Re}(\chi(s)) + 2 g_V^q g_V^l \,|\chi(s)|^2),$$

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

$$A_{FB} = \frac{B}{A}.$$

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

$$A_{FB} \propto g_A^l g_A^q$$

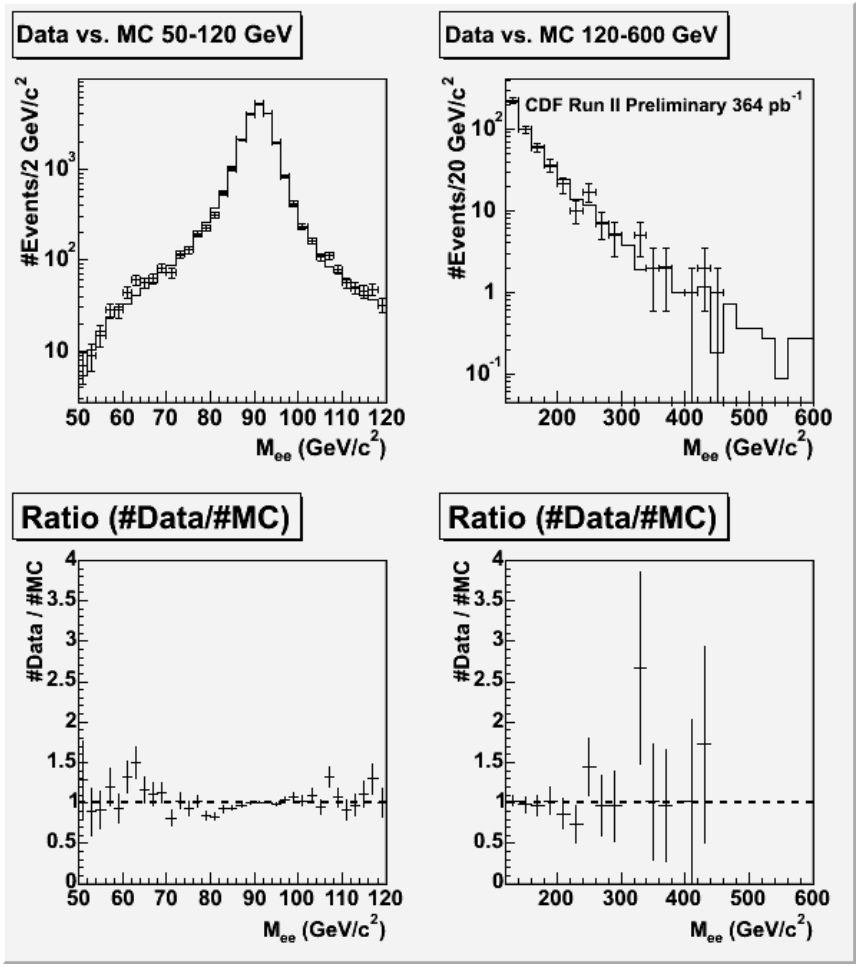


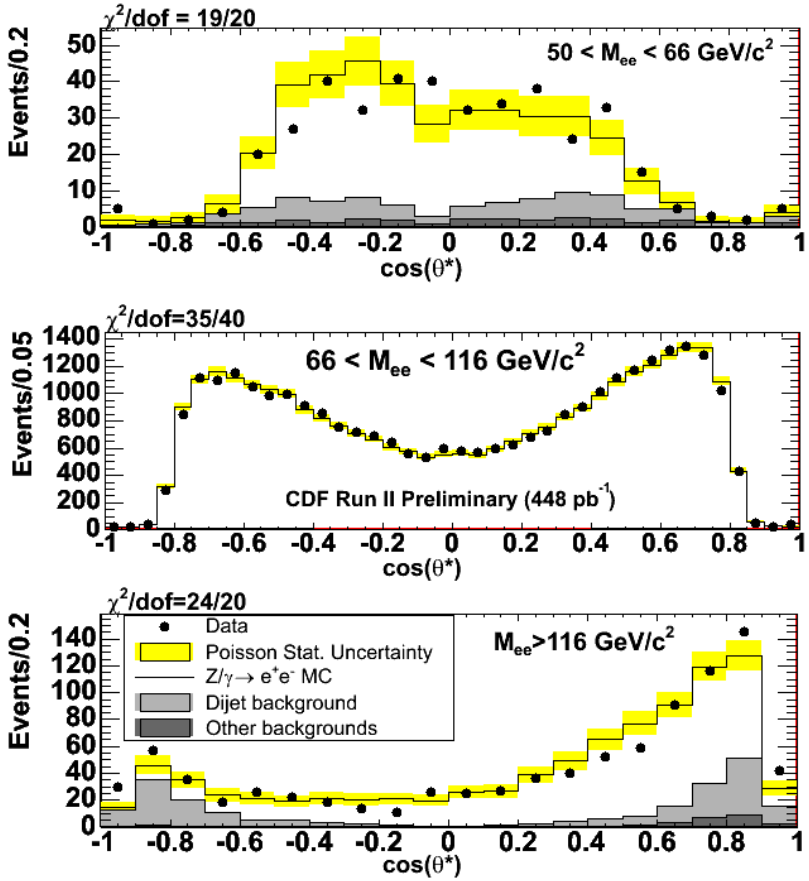
Event Selection

The cuts are designed to achieve flat efficiency in E_T.

- Fiduciality
- $E_T > 25$ GeV
- Central region ($|\eta|<1$)
  - Ratio of hadronic energy to electromagnetic energy ($E_{had}/E_{em} < 0.055 + 0.00045 * E$)
  - $E/p < 2.5 + 0.015 * E_T$ ($E_T < 100$ GeV)
  - Isolation ($< 3 + 0.02 * E_T$ GeV)
  - Lateral shower profile ($L_{shr} <0.2$)
  - Track – shower matching
- Plug region ($1<|\eta|<3$)
  - $E_{had}/E_{em} < 0.05 + 0.026 * \log(E/100)$
  - Isolation ($<1.6 + 0.02\ E_T$ GeV)
  - Shower profile ($\chi^2_{PEM} < 25$)

M_{ee} and $\cos\theta^*$ Distribution





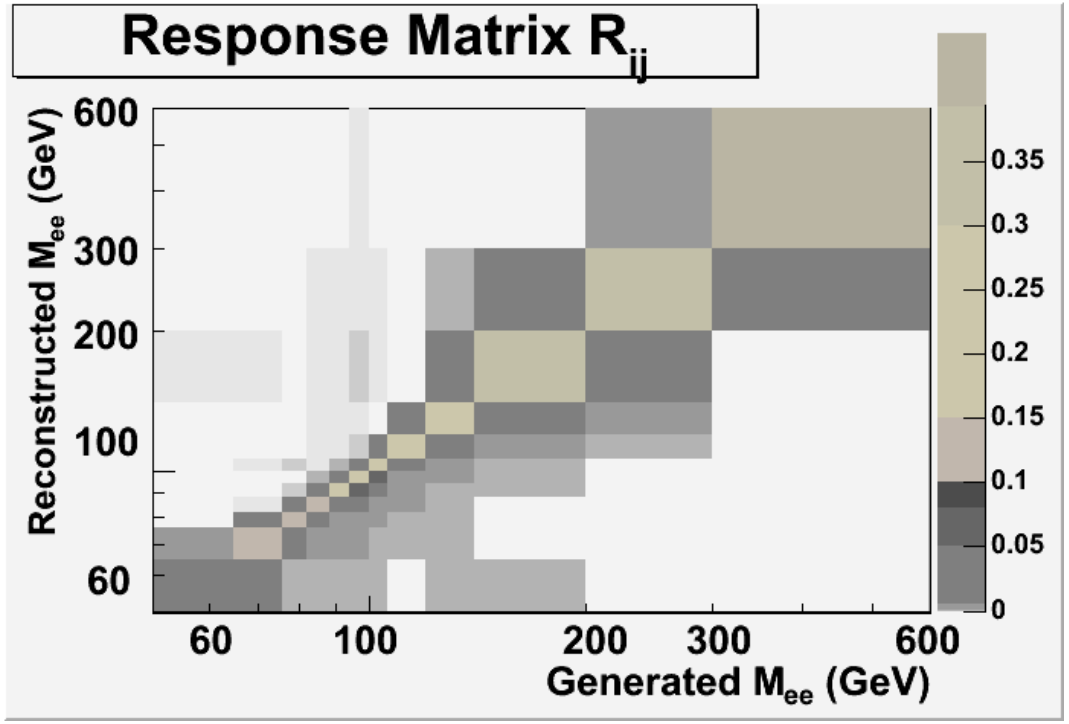
Matrix Inversion

- 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:

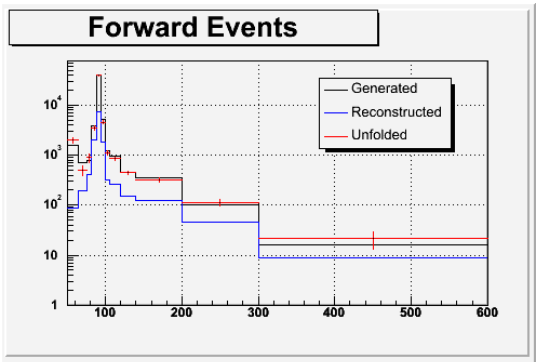
  $\mu = R^{-1}\nu$.
- With BG:

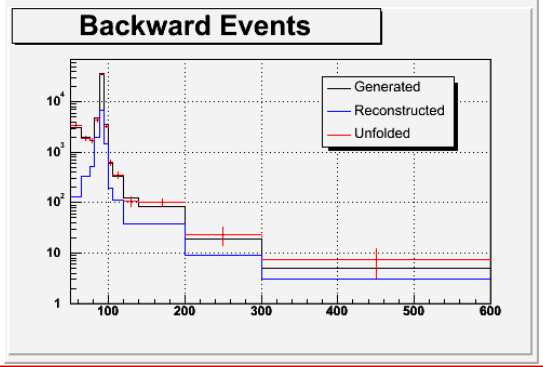
  $\mu = R^{-1}(\nu-\beta)$.

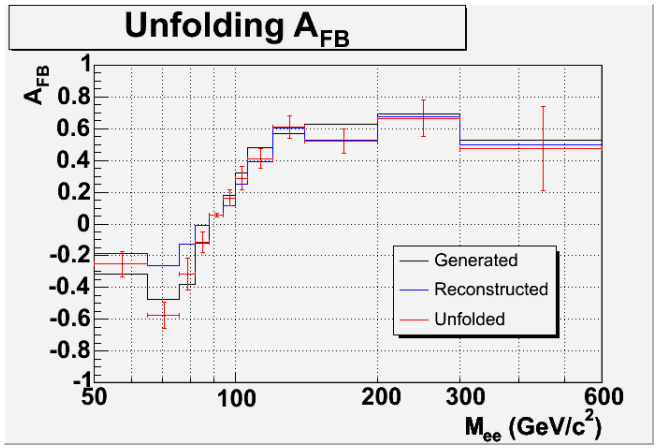


Unfolding; An Example

- Forward and backward events are unfolded separately and then the physics A_{FB} is calculated.
  - Two R's are constructed from forward and backward events.
- An example:





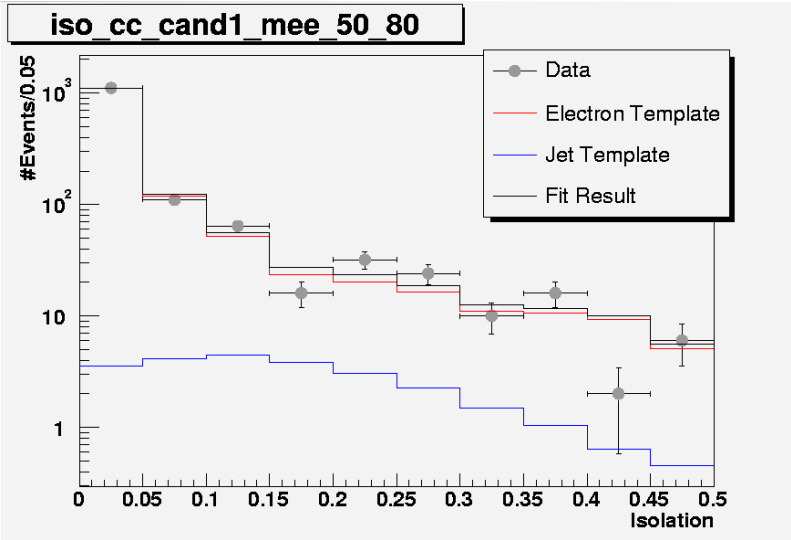


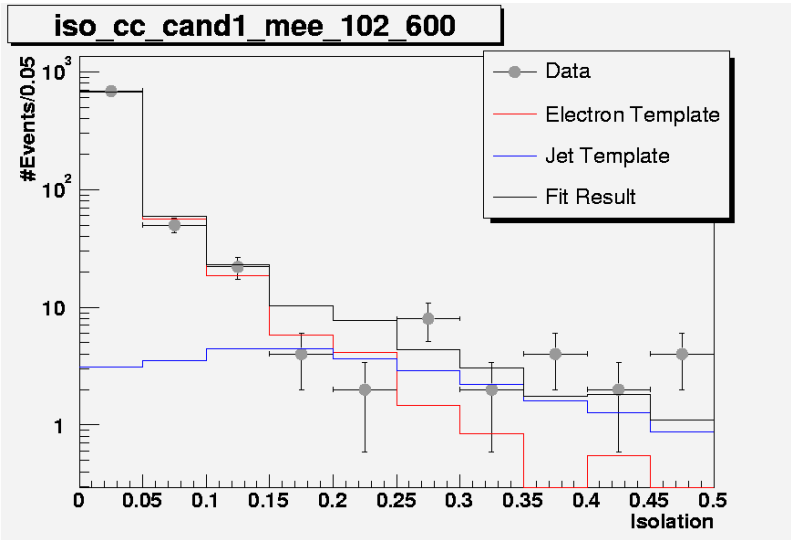
$$A_{FB}^{i} = \frac{\mu_i^F - \mu_i^B}{\mu_i^F + \mu_i^B}, \text{where } \mu_i^{F,B} = R_{ij}^{-1} \nu_j^{F,B}$$

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

Background Estimation

- Jet fake background is estimated by fitting the isolation distribution.
- Electron template : From the data at the pole with tight cuts.
- Jet template : Select jet like events from the EM calorimeter triggered sample.





Background Estimation (cont'd)

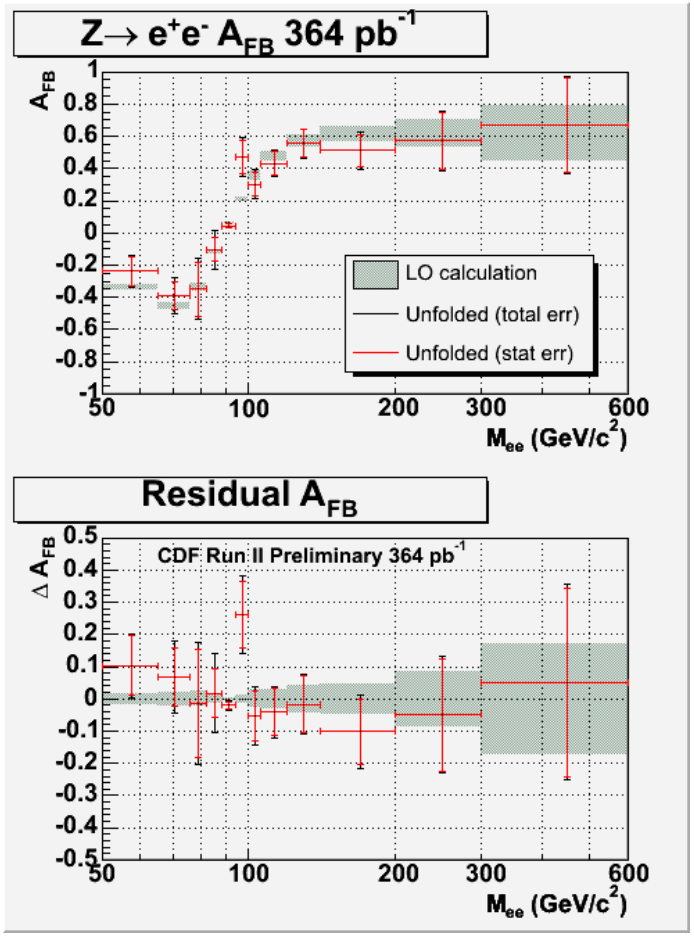
- Electroweak backgrounds are estimated from Monte Carlo.

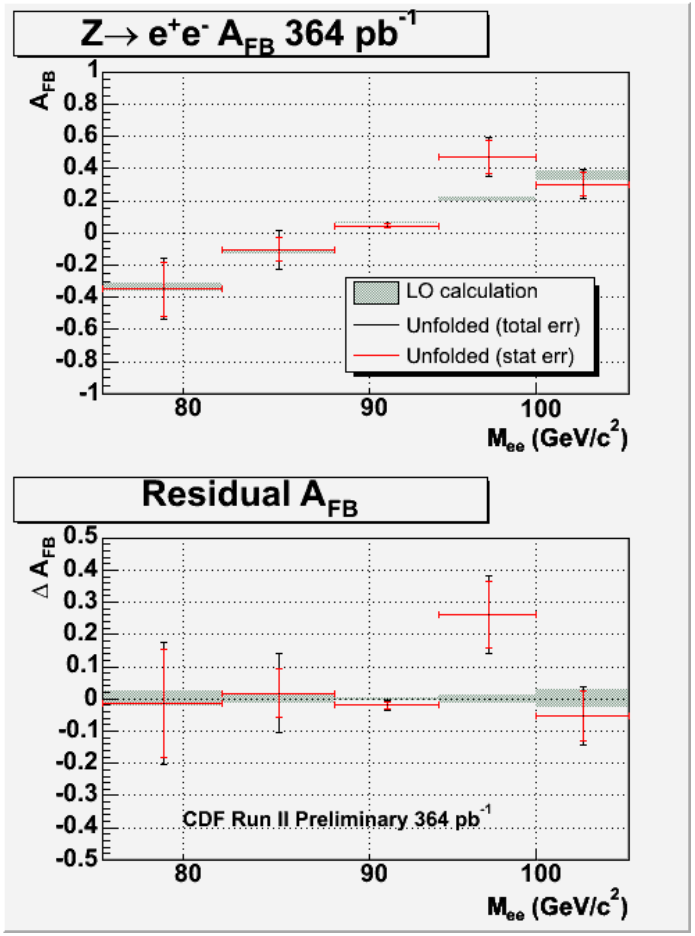
- Summary:

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

Result

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





A_{FB} Uncertainty Summary

bin	Mass (GeV)	A_{FB} (Data)	A_{FB} (LO)	Stat. (MC)	Energy scale	Energy Resol.	PDF	Material	Background	Response matrix	Total Syst.	Total Uncert.
1	50-65	-0.236	-0.380	0.085	0.009	0.020	0.003	0.015	0.018	0.015	0.036	0.092
2	65-76	-0.389	-0.430	0.081	0.010	0.006	0.002	0.060	0.016	0.026	0.068	0.106
3	76-82	-0.348	-0.244	0.117	0.017	0.047	0.001	0.041	0.008	0.065	0.092	0.149
4	82-88	-0.102	-0.134	0.064	0.030	0.063	0.003	0.062	0.002	0.023	0.096	0.116
5	88-94	0.044	0.062	0.011	0.002	0.005	0.001	0.008	0.000	0.002	0.010	0.015
6	94-100	0.471	0.192	0.103	0.028	0.033	0.002	0.037	0.001	0.030	0.064	0.121
7	100-106	0.303	0.320	0.073	0.018	0.014	0.001	0.033	0.005	0.028	0.049	0.088
8	106-120	0.432	0.484	0.067	0.011	0.007	0.000	0.026	0.012	0.016	0.035	0.076
9	120-140	0.555	0.590	0.070	0.005	0.015	0.000	0.018	0.018	0.011	0.032	0.077
10	140-200	0.512	0.602	0.069	0.004	0.009	0.000	0.041	0.030	0.011	0.053	0.087
11	200-300	0.571	0.583	0.122	0.006	0.016	0.001	0.022	0.030	0.019	0.045	0.130
12	300-600	0.668	0.682	0.214	0.000	0.034	0.001	0.049	0.012	0.028	0.067	0.224

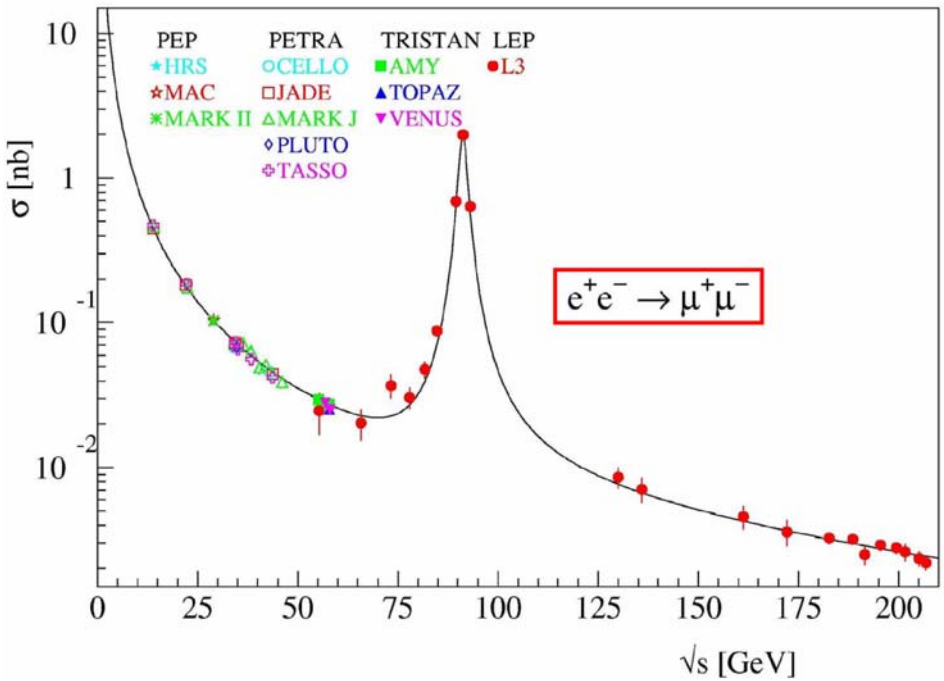
A Search for Z’

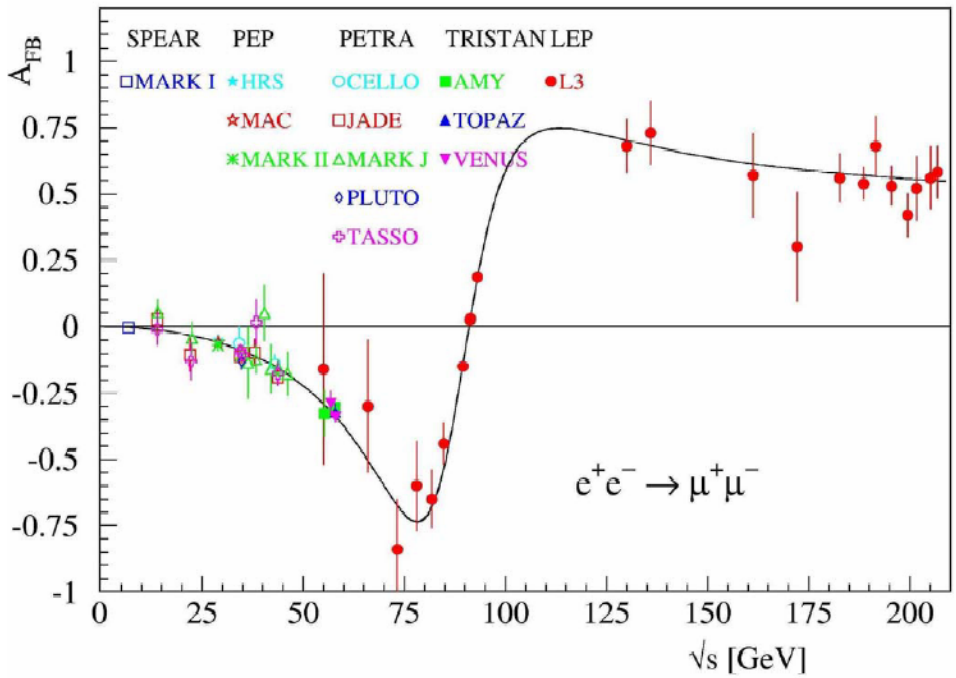
Z', An Extra Neutral Gauge Boson

- Heavier copy of the Z boson.
- Predicted in many extensions of SM.
  - E6 GUT, Little Higgs, etc.
- Tevatron is the high energy frontier.
- May be the first new physics at LHC.

Searching for Z'

- Direct searches at LEPII restricted to M_{ee} <207 GeV
- Tevatron can extend the direct search closer to 1 TeV
- Z' can show up as a peak, or
- Z' can be detected through ee angular distribution





Z' Parameterization

- Four classes of solutions satisfy the theory constraints.
  - Within a class, Z' is specified by three parameters.
    - $M_{Z'}$ (Z' mass)
    - g_Z (strength)
    - x (coupling)

	b-xL	q+xu	10+x5	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
$l_L=(e_L,v_L)$	-x	-1	+x/3	(x-1)/3
e_R	-x	-(2+x)/3	-1/3	+x/3

CDDT, Phys.Rev.D70:093009,2004

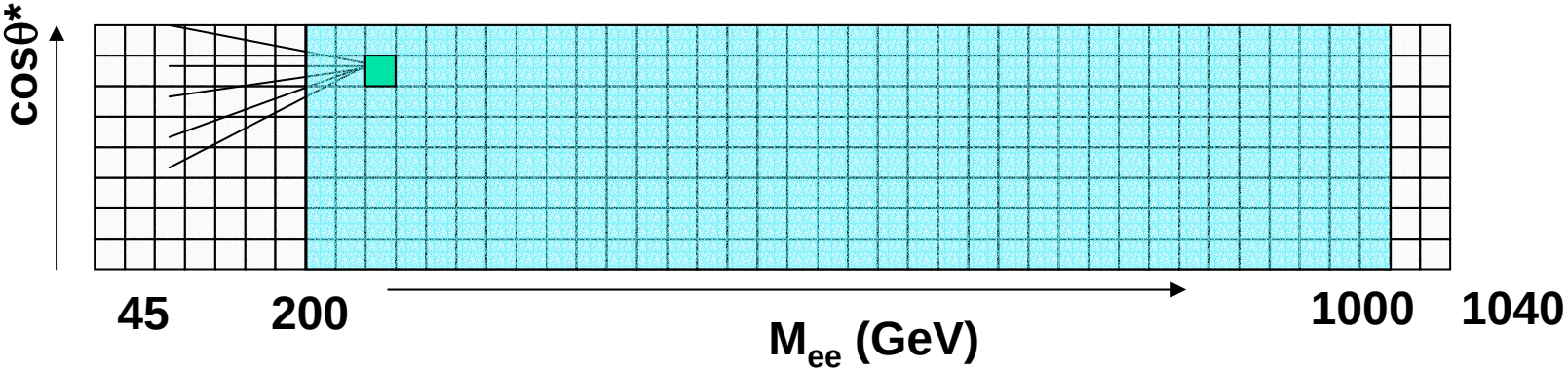
- E6 motivated models are included.
  - d-xu gives Z_I with x=0
  - 10+x5 gives $Z\eta$ (x=-0.5), $Z\psi$ (x=1), $Z\chi$ (x=-3).

Dealing with Many Models

- Solution:
  - Start with a LO calculation
  - Include a NNLO mass dependent K-factor
  - Then parameterize the simulation in terms of (M_{ee}, $\cos\theta^*$)
- Parameterization obtained running Pythia (~7 million events)
  - Tweak switches to generate in steps of 5 GeV, from 45-1045 GeV.

n_i* = sim. events in bin *i ***N_j* = gen. events in bin *j***

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



Test Statistic

- CL_s method used in Higgs searches at LEP
- Test between two hypotheses:
  - H1: Data is described by Z'/Z/γ and backgrounds
  - H2: Data is described by SM Z/γ and backgrounds

- Poisson probabilities:

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

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

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

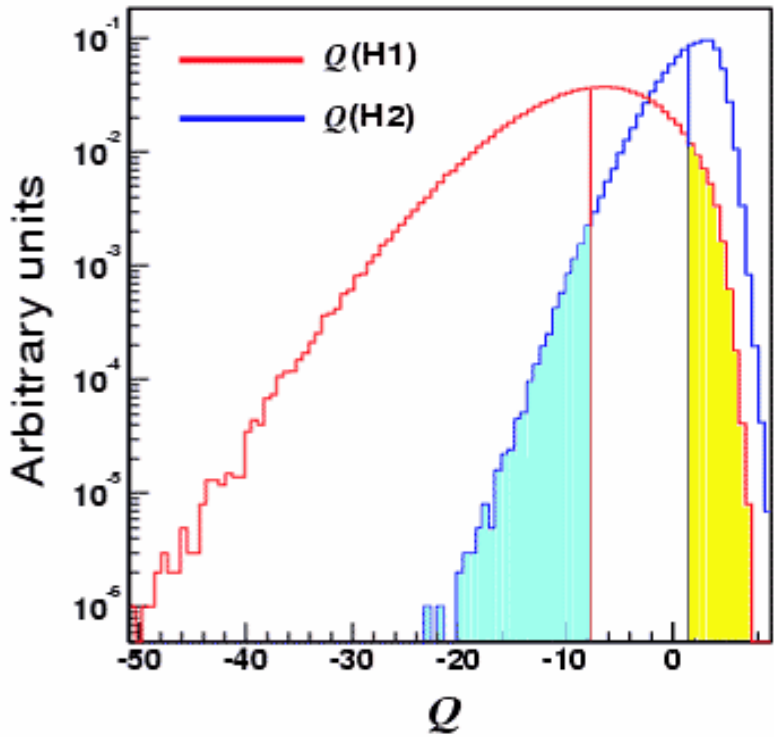
Pseudo-Experiments

- Throw pseudo-exp. assuming either H1 or H2. Get Q distribution in each case
- The separation defines sensitivity between H1 and H2
  - B-xL model. Example: $M_{Z'}$=440 GeV, g_z=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·yellow area.
  - CL_s < 0.05 excluded at 95% C.L.



Systematic Uncertainties

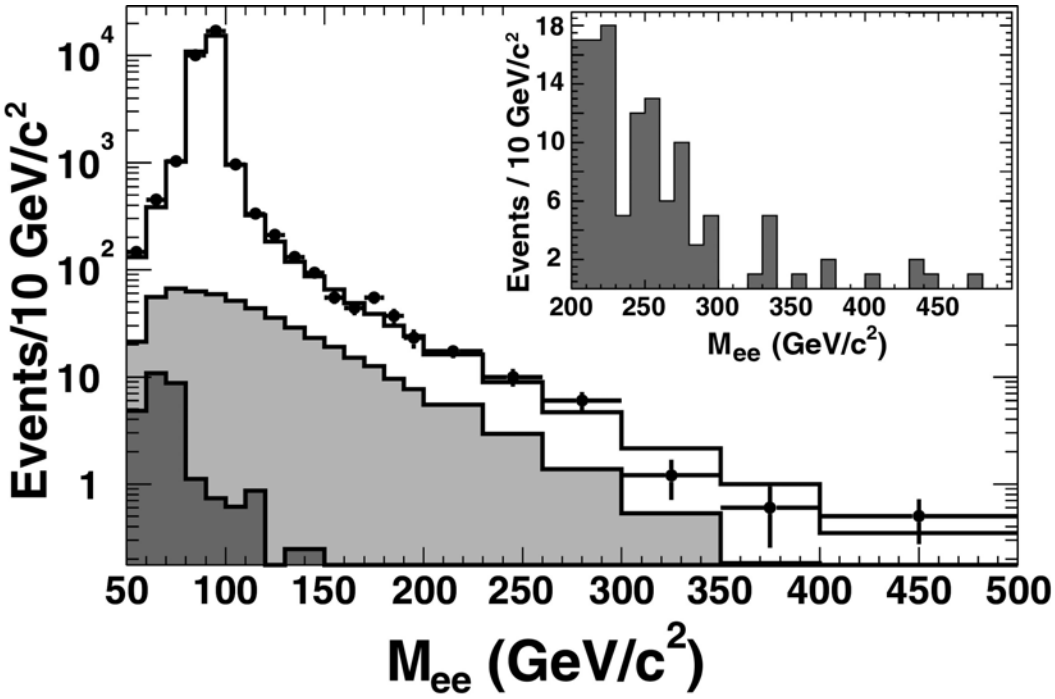
- Luminosity and lep trigger + ID:
  - Luminosity: 6%
  - Acceptance and efficiency uncertainties: 5%
  - The smearing matrix reproduces full simulation down to 3%
  - Found a 4% difference in the high mass region between our LO calculation and LO Pythia.
  - $6\% \oplus 4\% \oplus 3\% \oplus 5\% = 9.3\%$.

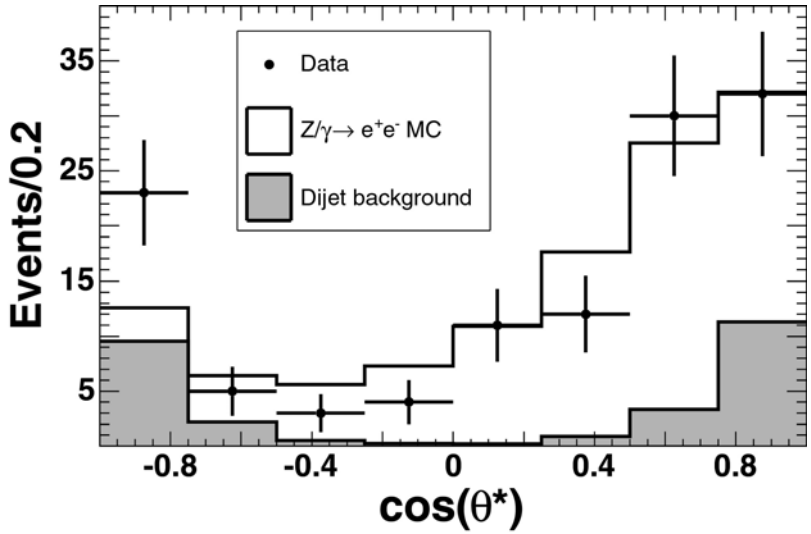
- Electron energy scale and resolution
  - Shifts of 3% for the scale in the central and plug regions
  - Calorimeter resolutions varies by 3% in both central and plug

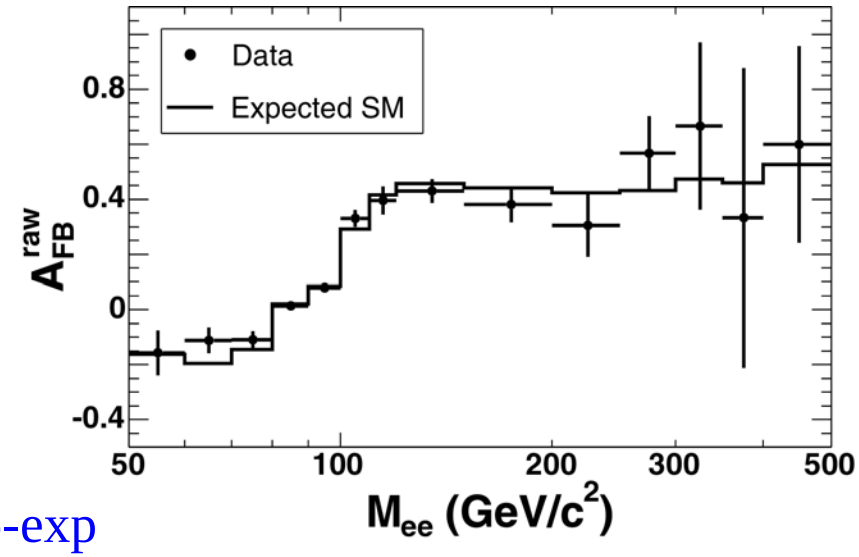
- Uncertainties in the background estimations
  - Use jet-electron fake rates. At least 50% uncertainty

- Pdf uncertainty found to have a small effect.

Data versus SM







Very good agreement with SM:

Data has larger P(data|SM) than 87% SM pseudo-exp

95% C.L. Limits

SEQUENTIAL Z': 855 GeV (825). Mass alone needs 35% more L.

$E6Z'$ Model	Z_χ	Z_ψ	Z_η	Z_I	Z_N	$Z_{\rm sec}$
Exp. limit (GeV/c^2)	735	725	745	650	710	675
Obs. limit (GeV/c^2)	740	725	745	650	710	680

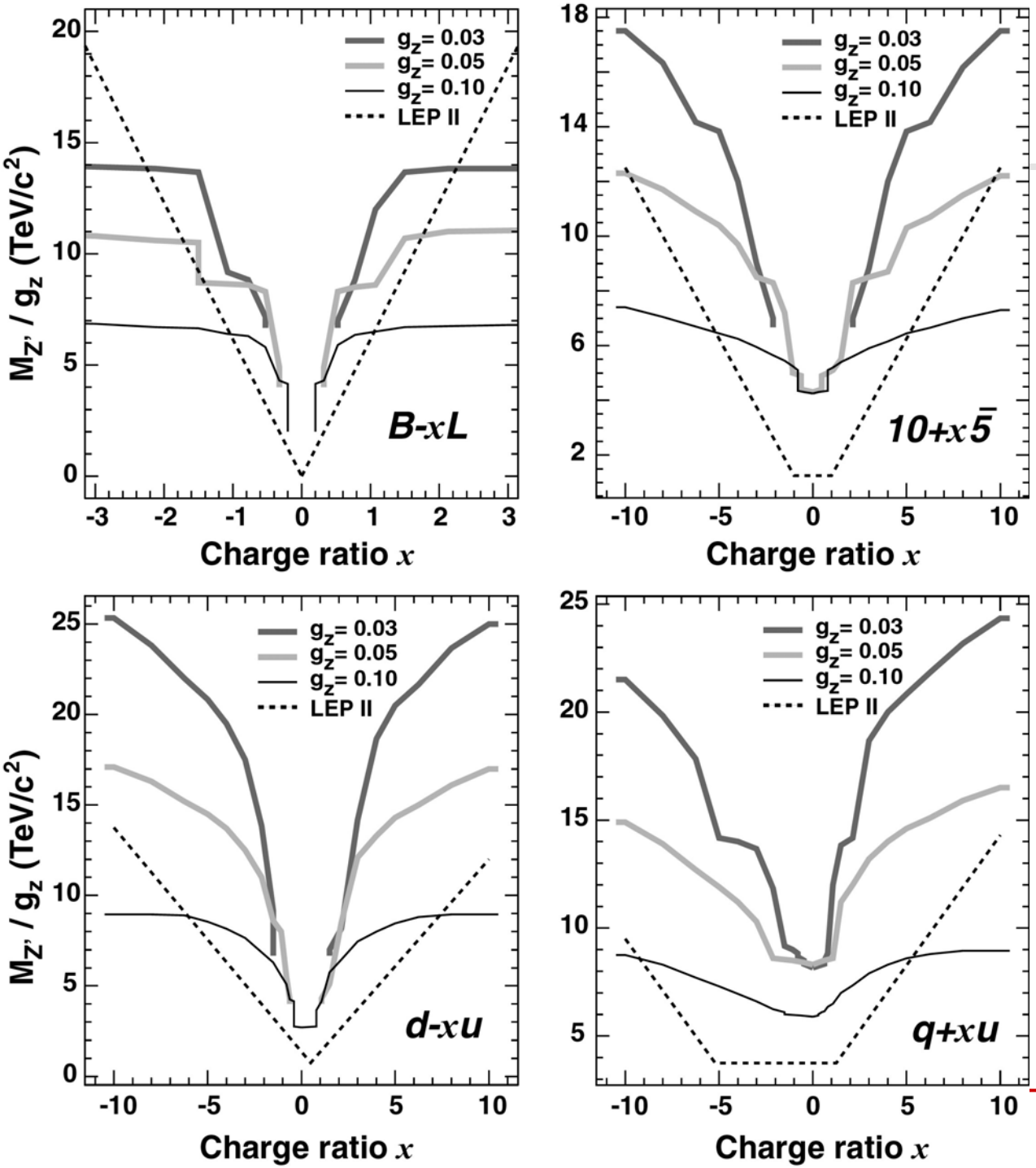
690 675 720 615

Mass alone:

5% more L.

Littlest Higgs Z'	$\cot\theta_H$=0.3	$\cot\theta_H$=0.5	$\cot\theta_H$=0.7	$\cot\theta_H$=1.0
Exp. $M_{Z'_H}$ limit (GeV/c^2)	625	765	835	910
Obs. $M_{Z'_H}$ limit (GeV/c^2)	625	760	830	900

725 805 885



CDDT general Z':

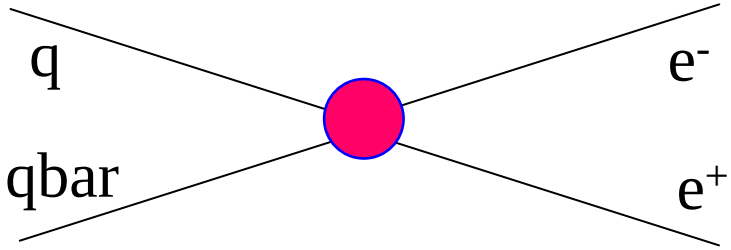
Comparisons to LEP

- better for |x|<1
- better for small g_z

Contact Interactions?

- If the CI scale is >> 1TeV, we can detect it through distortions of the $M_{ee}/\cos\theta^*$ spectrum

$$\sum_q \sum_{i,j=L,R} \frac{4\pi\eta}{\Lambda_{ij}^2} \bar{e}_i \gamma^\mu e_i \bar{q}_j \gamma_\mu q_j$$



Interaction	LL	LR	RL	RR	VV	AA
Λ_{qe}^+ limit (TeV/c^2)	3.7	4.7	4.5	3.9	5.6	7.8
Λ_{qe}^- limit (TeV/c^2)	5.9	5.5	5.8	5.6	8.7	7.8

Surpass LEP and D0 eeqq results

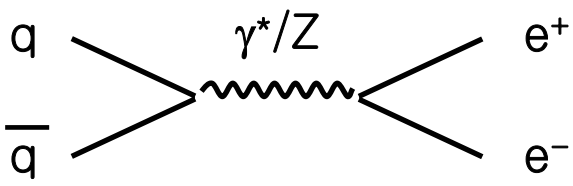
Surpass D0

Conclusion

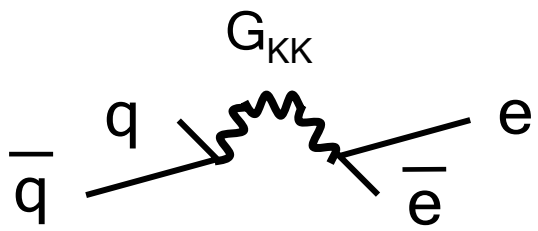
- A_{FB} is measured with 364 pb^{-1} of data by matrix inversion.
  - Good agreement with SM (χ^2/ndof = 10.2/12)
  - Will be updated with ~1 fb^{-1} data.
  - Coupling constants will be measured from A_{FB}.
- Z' limit is measured with mass & angular distributions.
  - Good agreement with SM (87%)
  - Will be updated with ~1 fb^{-1} data.
  - First limits of generic Z' in the ($M_{Z'}$,g_Z, x) space.
  - Limits on eeqq contact interactions.
  - Best limits in many cases.
  - Submitted to PRL. (hep-ex/0602045)
  - If discovered, coupling will be measured.

- BACKUP

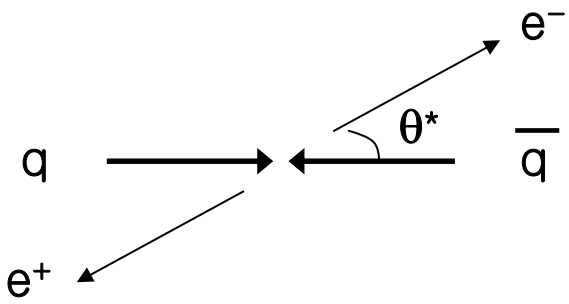
Di-electron Final State



- Clean signal, low background.
  - Well isolated high-pt electrons.
  - SM background (Drell-Yan) is very low at high mass.



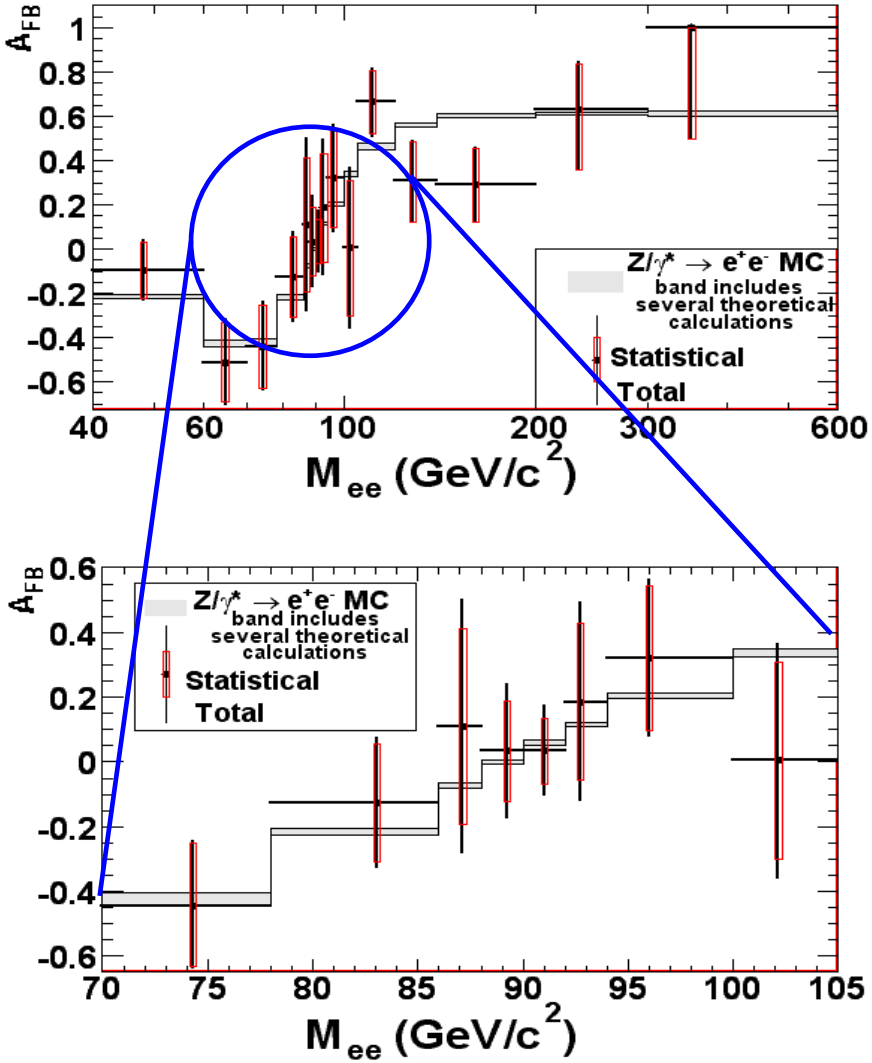
- Di-electron invariant mass
  - Search for new resonance Z'.
  - Search for Extra Dimensions.



- Angular distribution
  - Probe V-A nature of weak interaction.
  - Search for Z' or ED.

Previous Result

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



Datasets & Presentations

- Dataset
  - bhel0d Goodrun v7 (364 pb^{-1})
    - ELECTRON_CENTRAL_18
    - ELECTRON70_L2_JET
- Monte Carlo
  - 12M Z->ee (new with -1/6 X_0 material in the plug).
  - ztop4i (Z->$\tau\tau$)
  - hewk9d (Wγ)
  - atopaa (W+jet)
  - wewkfe (W+jet/γ)
  - ttopkl (ttbar)
  - wewk5d (WW)
  - wewk6d (WZ)
- Note
  - CDF 7107 (BG estimation, old)
  - CDF 7997 (BG estimation)
  - CDF 7998 (A_{FB} measurement)

- Presentations

2003.11.12	ETF	Dijet BG
2004.3.29	ETF	Dijet BG
2004.9.30	EWK	Dijet BG
2005.2.3	EWK	Unfolding
2005.5.10	W/Z	Dijet BG
2005.5.12	EWK	Unfolding
2005.6.1	Collaboration	Unfolding
2005.11.8	W/Z	PDF syst.
2005.11.21	W/Z	Energy syst.
2005.12.13	W/Z	Dijet BG
2005.12.20	W/Z	Dijet BG
2006.1.3	W/Z	Dijet BG
2006.1.10	W/Z	Systematics
2006.1.26	EWK	Update
2006.2.7	W/Z	Systematics
2006.2.14	W/Z	Systematics
2006.2.23	EWK	Full Status
2006.2.28	W/Z	Jet BG
2006.3.7	W/Z	Jet BG
2006.3.9	EWK	Pre-Blessing
2006.3.28	W/Z	Jet BG

Selection Cuts (S. Harper, CDF7527)

- Motivated by the high Et physics.

Variable	Central	Plug
Fiducial	Fid = 1 or 2	1.18 < |e| < 3.0
E_T	> 25 GeV	> 25 GeV
|Track Z_0|	≤ 60 cm	-
P_T	> 15 GeV (Et < 100 GeV), > 25 GeV (Et > 100 GeV)	-
E_{had}/E_{em}	≤ 0.055 + 0.00045 x E	≤ 0.05 + 0.026 x log(E/100)
Isol (GeV)	≤ 3 + 0.02 Et	≤ 1.6 + 0.02 Et
E/p	≤ 2.5 + 0.015 Et (Et<100 GeV)	-
|ΔX|	< 3 cm	-
|ΔZ|	< 5 cm	-
L_{shr}	< 0.2	-
χ^2_{PEM3x3}	-	25

- Opposite charge required for CC.
- No charge ID for plug leg, opposite charge is assumed for CP.

Data-MC After Energy Scale Correction

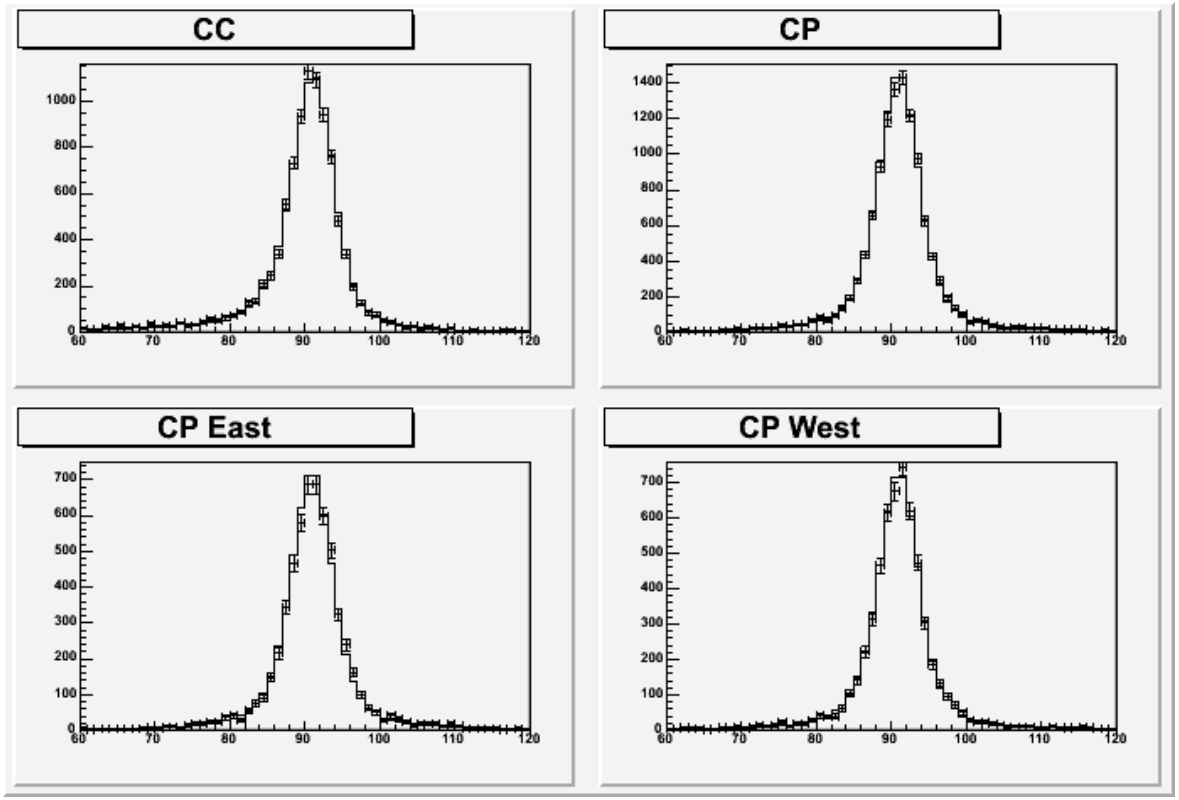
- Agrees within the fit errors.
- Mean

	Data	MC
CC	91.0 ± 0.04	91.0 ± 0.04
CP(E)	91.1 ± 0.05	91.0 ± 0.05
CP(W)	91.0 ± 0.05	91.0 ± 0.04

- Width

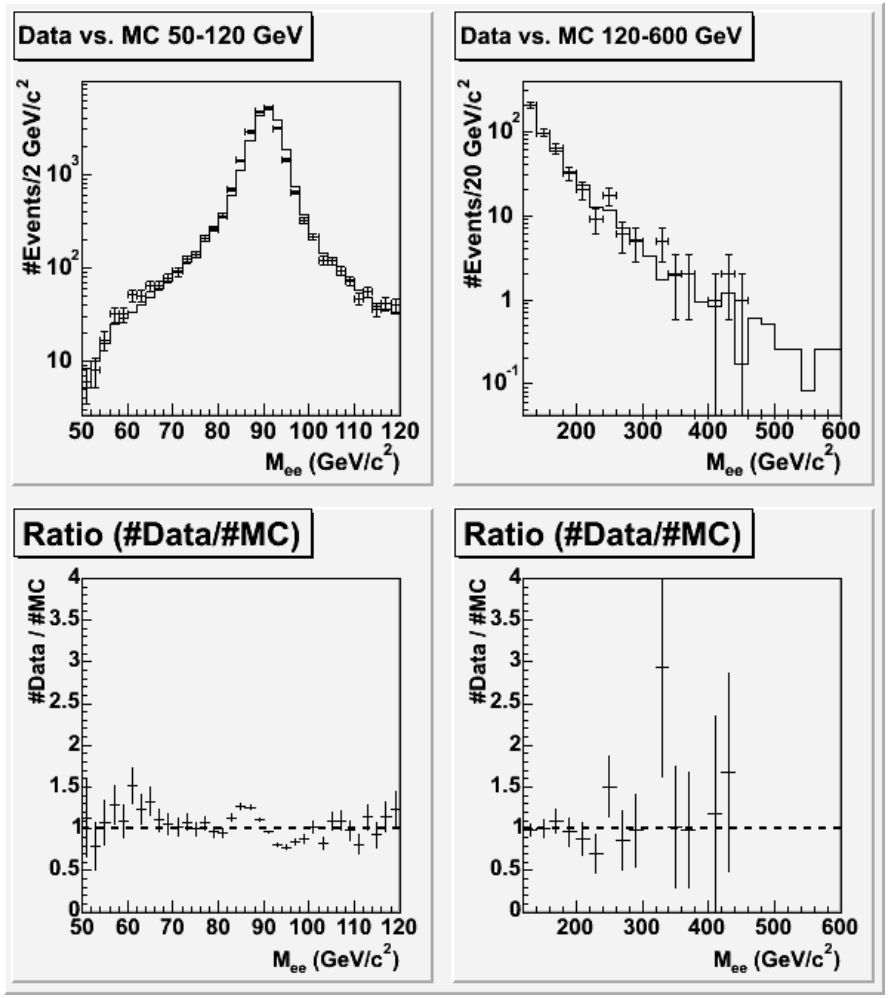
	Data	MC
CC	2.99 ± 0.04	3.03 ± 0.04
CP(E)	3.07 ± 0.05	3.08 ± 0.05
CP(W)	2.97 ± 0.05	2.97 ± 0.05

- Following CDF 7687.
- Fitting to Gaus 86-98 GeV.

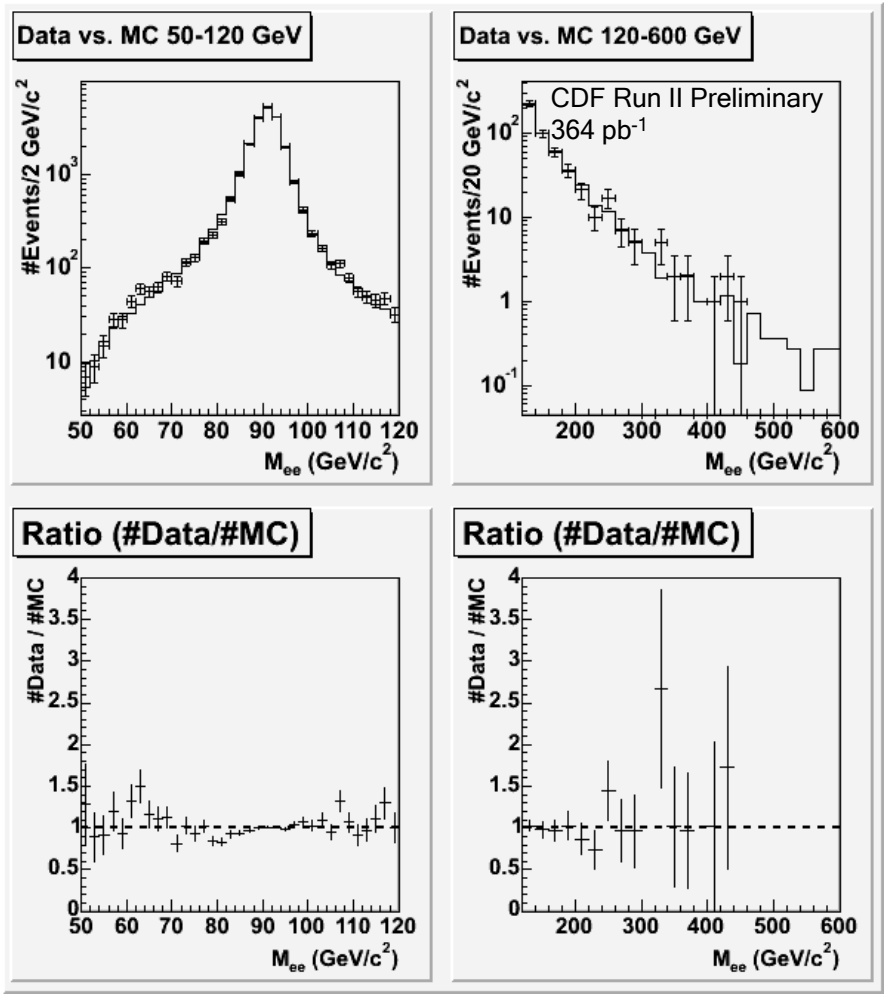


Data vs. MC

- Before the correction



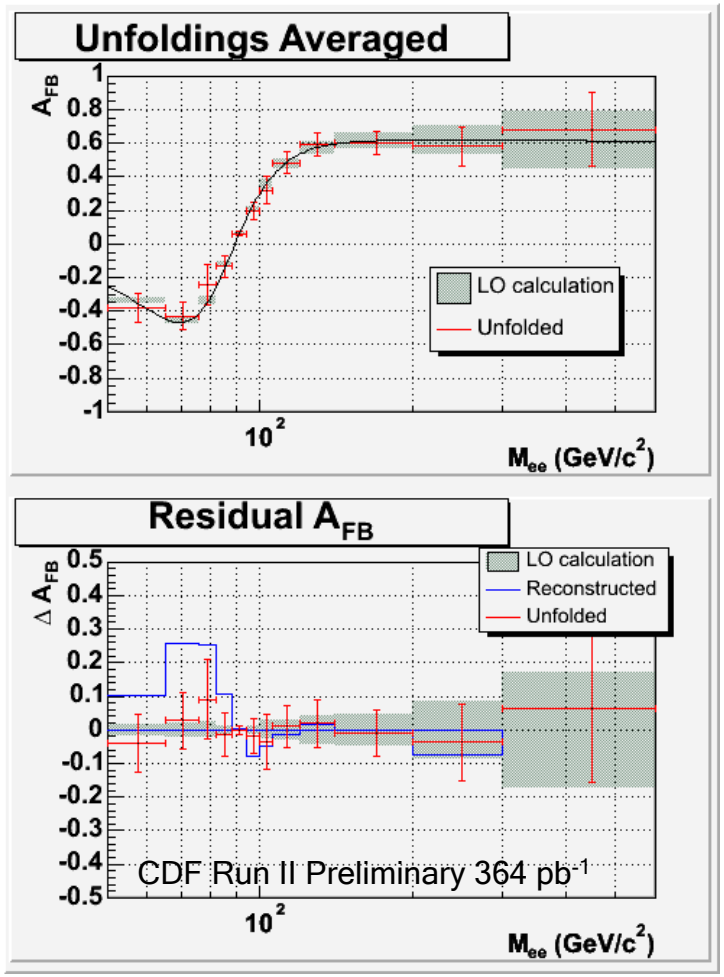
- After the correction



Pseudo Experiments

- 11 Pseudo Experiments (PE's) averaged.

Bin	Mass (GeV)	Average A_{FB}	Stat. Err.
1	50-65	0.380	0.087
2	65-76	-0.430	0.083
3	76-82	-0.244	0.118
4	82-88	-0.134	0.066
5	88-94	0.062	0.011
6	94-100	0.192	0.052
7	100-106	0.320	0.082
8	106-120	0.484	0.062
9	120-140	0.590	0.070
10	140-200	0.602	0.067
11	200-300	0.583	0.116
12	300-600	0.682	0.221



Jet Background Estimation

- Fitting the isolation shape with electron/jet templates.
  - Fitter available in ROOT (class TFractionFitter).
    - R. Barlow and C. Beeston, Comp. Phys. Comm. 77 (1993) 219
  - W+jet included in the estimation : removed from MC study.
  - Fitting below and above the pole.
    - No sensitivity around the pole -> Interpolate from the dijet mass shape.
  - CC : Two legs are combined and fit once.
  - CP : Fit central and plug legs separately. Central leg is used for the analysis and plug leg is added to the systematics.
- Dijet mass shape is normalized to the fits.
  - W+jet is rejected by MET < 15 GeV.
  - Flat A_{FB} is assumed.

Electron- and Jet-templates

- Electron template : Data at the pole with tight cuts.
  - Shape change due to the detector effect is accounted for from the MC, as function of the mass region. (Systematic effect is calculated form the difference with the extra material MC.)
  - Triggers are required as in the candidates (ELECTRON_18 and ELECTRON70).
- Jet template : Electron-jet sample selected from the high pt electron sample bhel0d.
  - Central and plug shapes are obtained separately.
  - Plug leg jet template is obtained from Z_NOTRACK triggered events.
    - This may have introduced a bias, and the difference is added to the systematics.

Electron Template Cuts (CC)

Variable	Fitting Leg	Control Leg
Fiducial	Fid = 1 or 2	Fid = 1 or 2
E_T	> 25 GeV	> 25 GeV
|Track Z_0|	≤ 60 cm	≤ 60 cm
P_T	> 15 GeV (Et < 100 GeV), > 25 GeV (Et > 100 GeV)	> 10 GeV (Et < 100 GeV), > 25 GeV (Et > 100 GeV)
E_{had}/E_{em}	≤ 0.055 + 0.00045 x E	≤ 0.05
Isol	-	≤ 0.8 * (3 + 0.02 Et)
E/p	≤ 2.5 + 0.015 Et (Et <100)	≤ 2.5 + 0.015 Et (Et <100)
|ΔX|	< 3 cm	< 3 cm
|ΔZ|	< 5 cm	< 3 cm
L_{shr}	< 0.2	< 0.18

- Opposite charge and ass region 81 GeV < M_{ee} < 101 GeV.
- Tighter cuts for the control leg to increase purity.

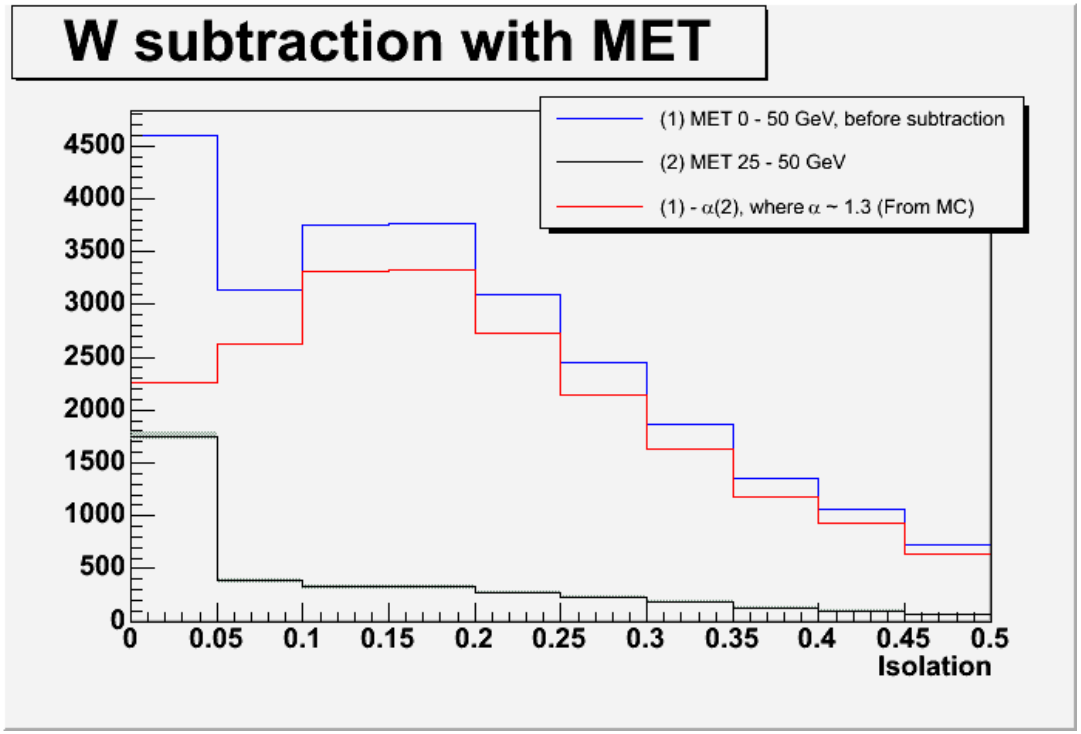
Jet Template Cuts (central)

Variable	Central (EmObject)	Plug (CdfJet)
Fiducial	Fid = 1 or 2	-
E_T	> 25 GeV	> 25 GeV
|Track Z_0|	$\leq$ 60 cm	-
P_T	> 15 GeV (Et < 100 GeV), > 25 GeV (Et > 100 GeV)	-
E_{had}/E_{em}	$\leq$ 0.055 + 0.00045 x E	> 0.125
Isol (GeV)	-	-
E/p	$\leq$ 2.5 + 0.015 Et (Et < 100)	-
$\|\Delta X\|$	< 3 cm	-
$\|\Delta Z\|$	< 5 cm	-
L_{shr}	< 0.2	-

- Z removed by requiring no more than 1 EmObj with EmEt > 15 GeV.
- W subtracted from MET distribution. (next slide)

W Subtraction for Jet Template

- Events with MET > 25 GeV are regarded as W's.
- The W shape is multiplied by a factor to compensate for the low MET events from the W's.

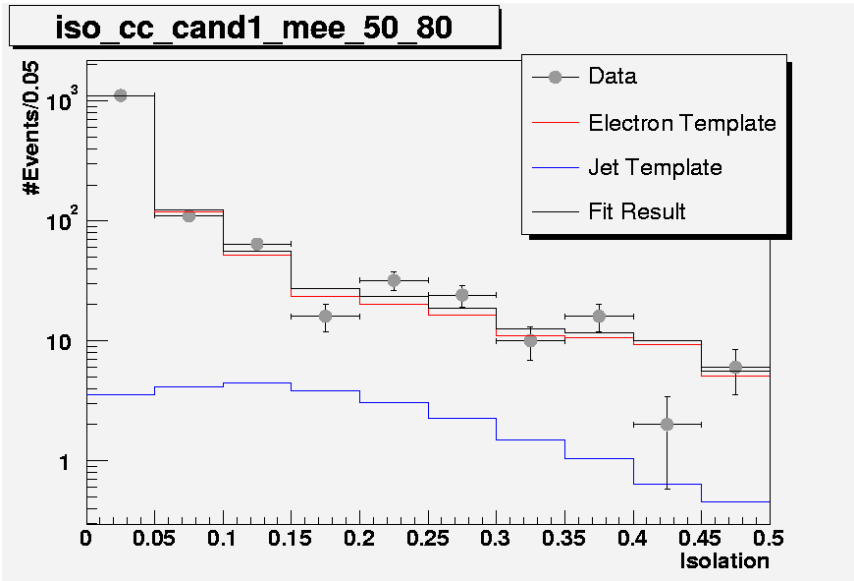


- Selecting with MET < 15 GeV and applying no W subtraction gives identical result (within uncertainty).

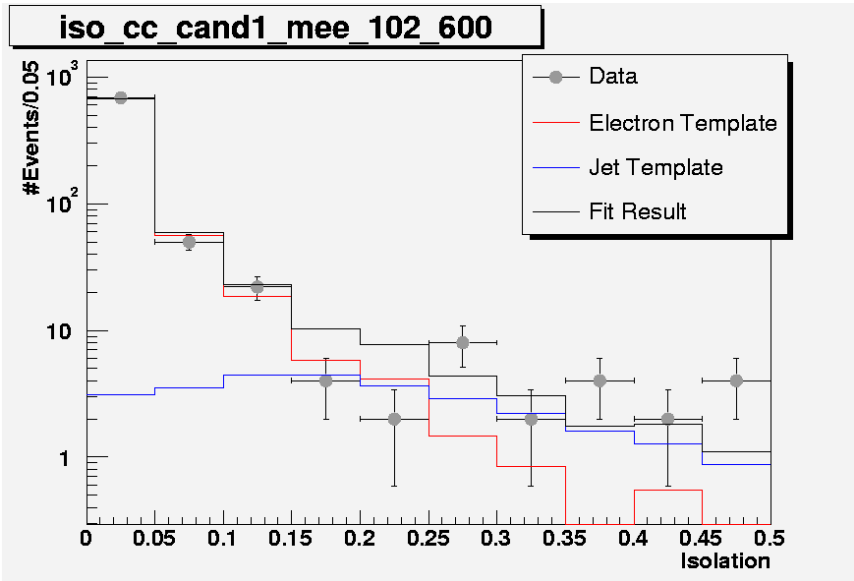
Jet BG in CC

- The fit result is summed in the signal region with isolation < 0.1.
- The ratio of jet template vs. total gives background rate.

- 50-80 GeV



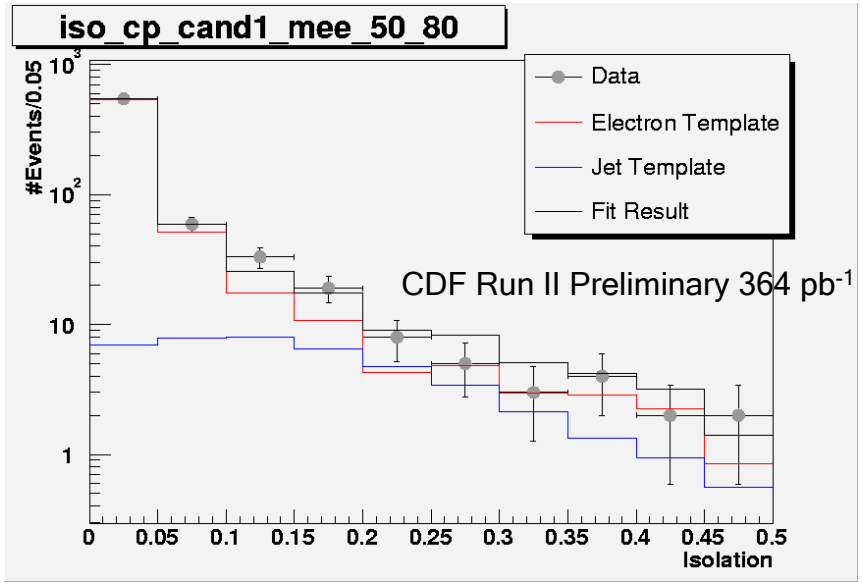
- 102-600 GeV



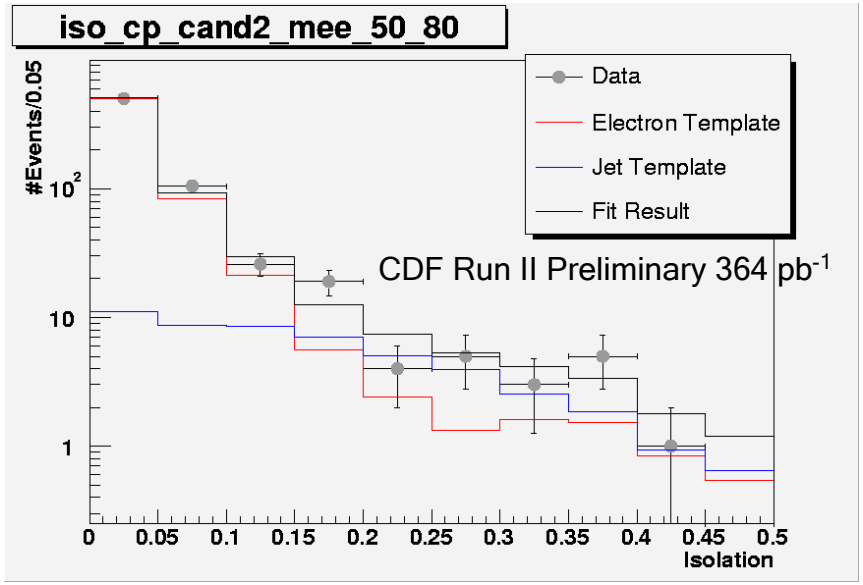
CP Fits Below the Pole

- 50-80 GeV

- Fit with central leg



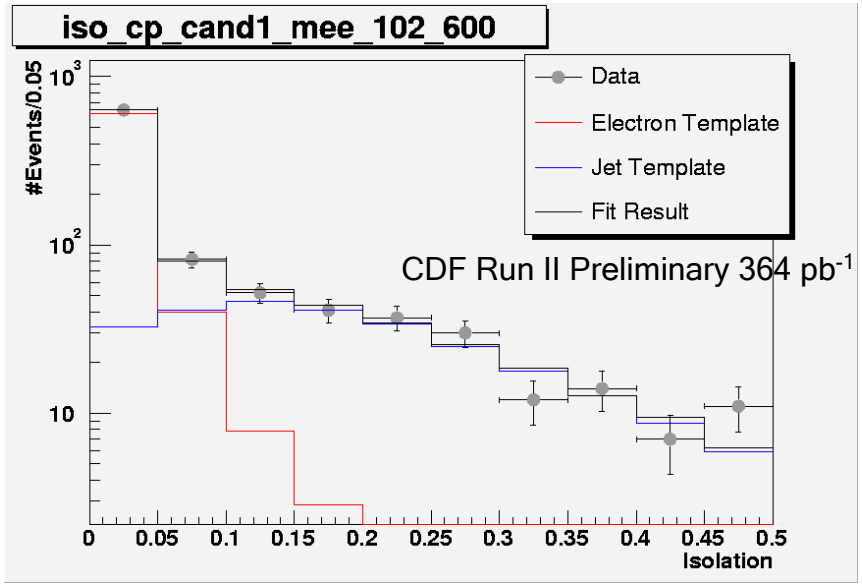
- Fit with plug leg



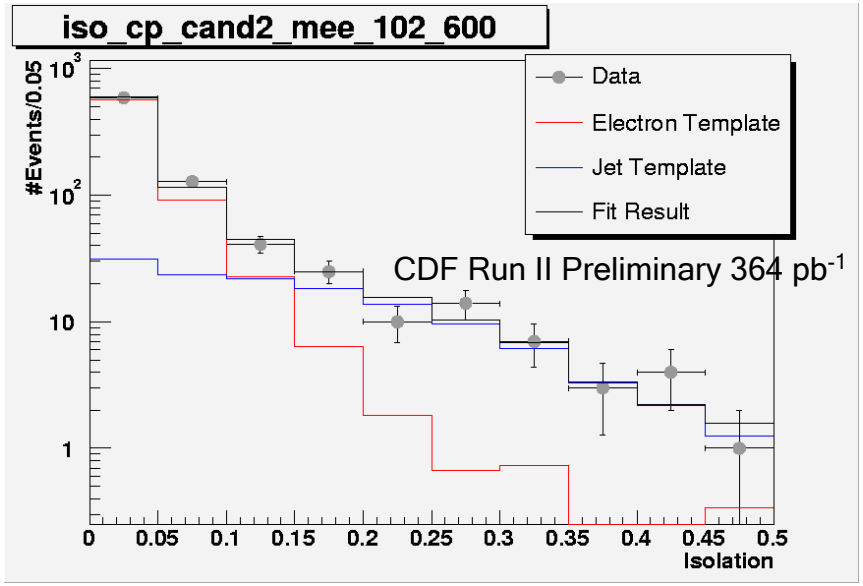
CP Fits Above the Pole

- 102-600 GeV

- Fit with central leg



- Fit with plug leg



Jet Background Fit Summary (1)

- Mass regions were varied to make sure the robustness.
- Expected behavior (The further from the pole, the more the Bg.)
- W+jet will be subtracted from this results.
- (#BG)/(#Total) (%)

	Mass (GeV)	CC Two legs combined	CP	
			Fit with Central leg	Fit with Plug leg
Below Pole	50-74	0.97 +- 0.45	4.55 +- 1.29	6.12 +- 1.72
	50-76	0.62 +- 0.52	3.08 +- 1.04	4.38 +- 1.34
	50-78	0.86 +- 0.52	2.90 +- 0.91	4.85 +- 1.18
	50-80	0.62 +- 0.50	2.39 +- 0.77	3.39 +- 0.90
Above Pole	102-600	0.90 +- 0.25	10.2 +- 0.74	7.93 +- 1.06
	104-600	1.02 +- 0.28	11.0 +- 0.80	8.82 +- 1.17
	106-600	1.23 +- 0.33	11.7 +- 0.87	9.76 +- 1.28
	108-600	1.25 +- 0.35	12.2 +- 0.93	9.87 +- 1.36

Measurements are not independent to each other.

Jet Background Fit Summary (2)

- Same table, but shown in the numbers of BG's.
- W+jet will be subtracted from this table.

	Mass (GeV)	CC Two legs combined	CP	
			Fit with Central leg	Fit with Plug leg
Below Pole	50-74	3.47 +- 1.60	11.5 +- 3.27	15.5 +- 4.36
	50-76	2.51 +- 2.13	10.4 +- 3.53	14.9 +- 4.54
	50-78	4.36 +- 2.65	12.9 +- 4.04	21.6 +- 5.26
	50-80	3.82 +- 3.07	14.4 +- 4.65	20.5 +- 5.43
Above Pole	102-600	3.31 +- 0.92	73.0 +- 5.26	56.7 +- 7.61
	104-600	3.26 +- 0.90	70.9 +- 5.16	56.9 +- 7.54
	106-600	3.37 +- 0.89	66.9 +- 4.97	55.7 +- 7.32
	108-600	3.00 +- 0.83	62.9 +- 4.80	50.8 +- 7.01

W+jet Subtraction from the Jet BG

- A fraction of W+jet events are estimated by the isolation fit method.
- We subtract from the fit and estimate the BG form MC.
- In CC we just subtract ½ of total W+jet estimated.
- In CP we find that 92% of W+jet BG has the electron in the central.
  - The fit with the central leg is not much sensitive to W+jet.
- Here we show the W+jet subtraction.

	50-80 GeV			108-600 GeV		
	CC	CP		CC	CP	
		central leg	plug leg		central leg	plug leg
fit result	3.82 +- 3.07	14.4 +- 4.65	20.5 +- 5.43	3.00 +- 0.83	62.9 +- 4.80	50.8 +- 7.01
weighted W+jet	0.5 +- 0.4	0.5 +- 0.2	5.7 +- 2.6	0.7 +- 0.5	0.7 +- 0.3	8.0 +- 3.1

- The uncertainty of W+jet is added to the systematics of BG estimation.

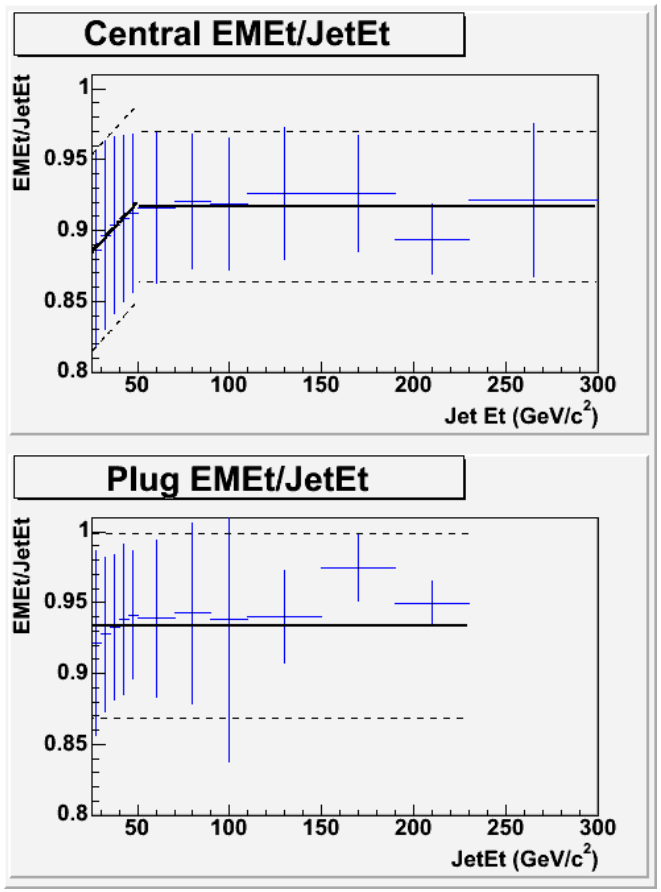
(*) CC is weighted by 0.5 and CP by 0.08 (central leg) or 0.92 (plug leg).

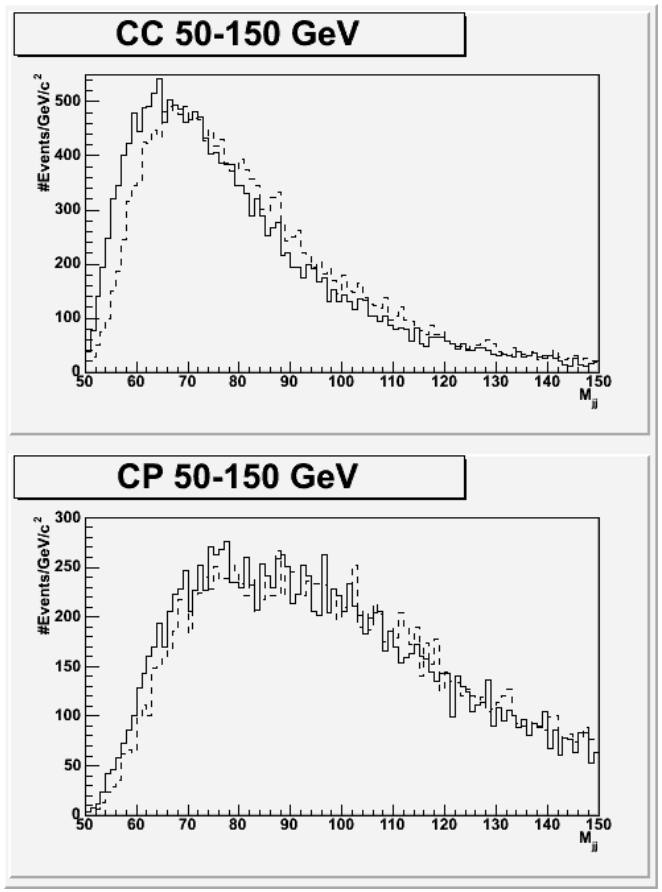
Dijet Mass Shape

- Dijet Mass shape is normalized to the fit result.
  - W+jet is subtracted before the normalization.
- Goal :
  - Interpolate the Bg in the Z pole region.
  - Obtain the Bg mass profile.
  - Confirm the jet mass shape with the isolation fits. (next next slide)
- Selection from the high pt electron sample:
  - No more than 1 Em Object with Em Et > 10 GeV.
  - At least one jet with Jet Et > 10 GeV and with $\Delta\phi$ from the Em Object > 0.53.
  - MET < 15 GeV (W+jet rejection).
  - Jet100 data shape is added for the high mass region statistics.
  - Shape is corrected for jet-em clustering difference. (next slide)

Clustering Correction for Jets

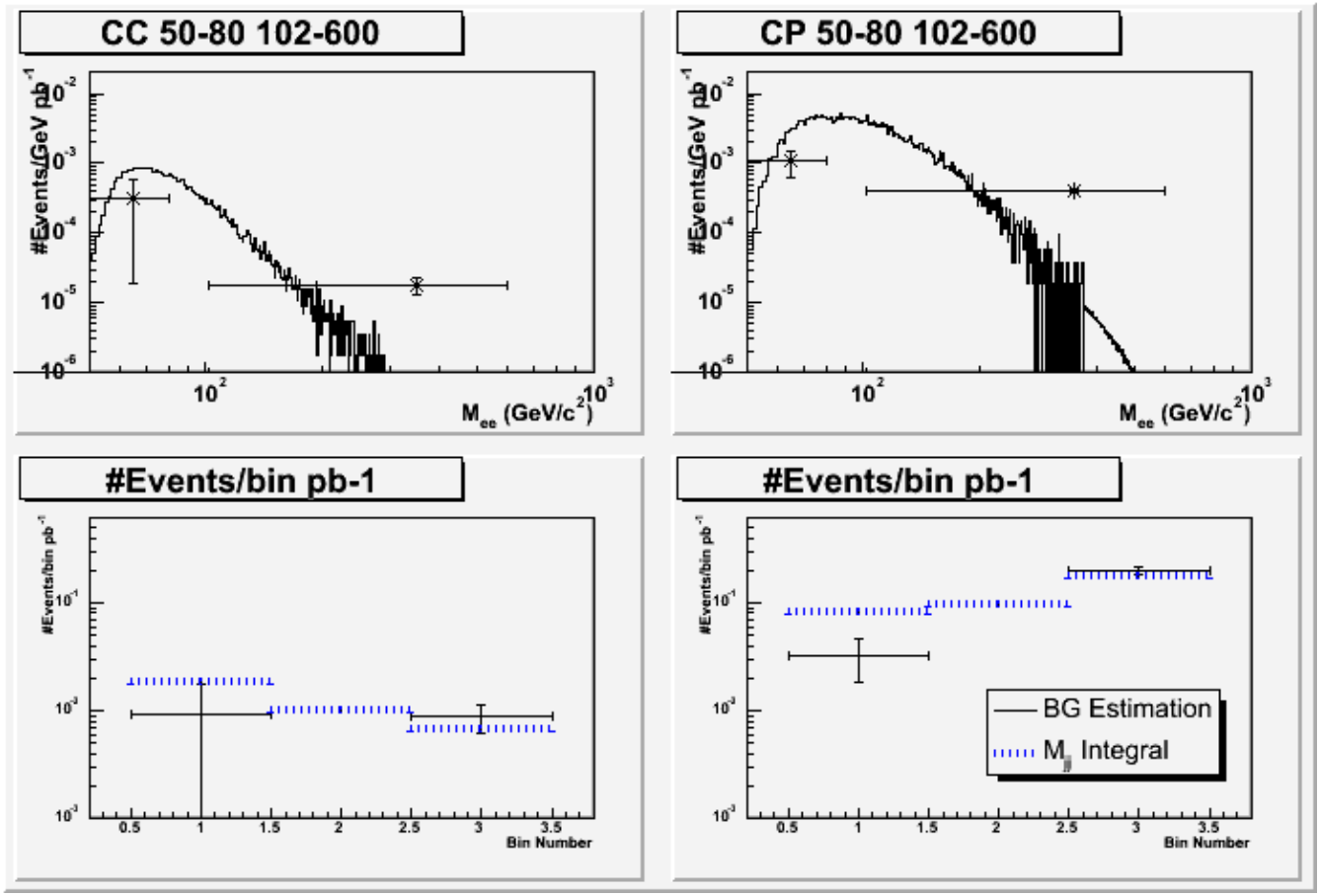
- Correction is found from electron sample, by reading matching jet.
- Solid line is the distribution after the correction.





Jet Mass Shape Normalized

- The isolation fit describes the dijet mass shape within uncertainty.



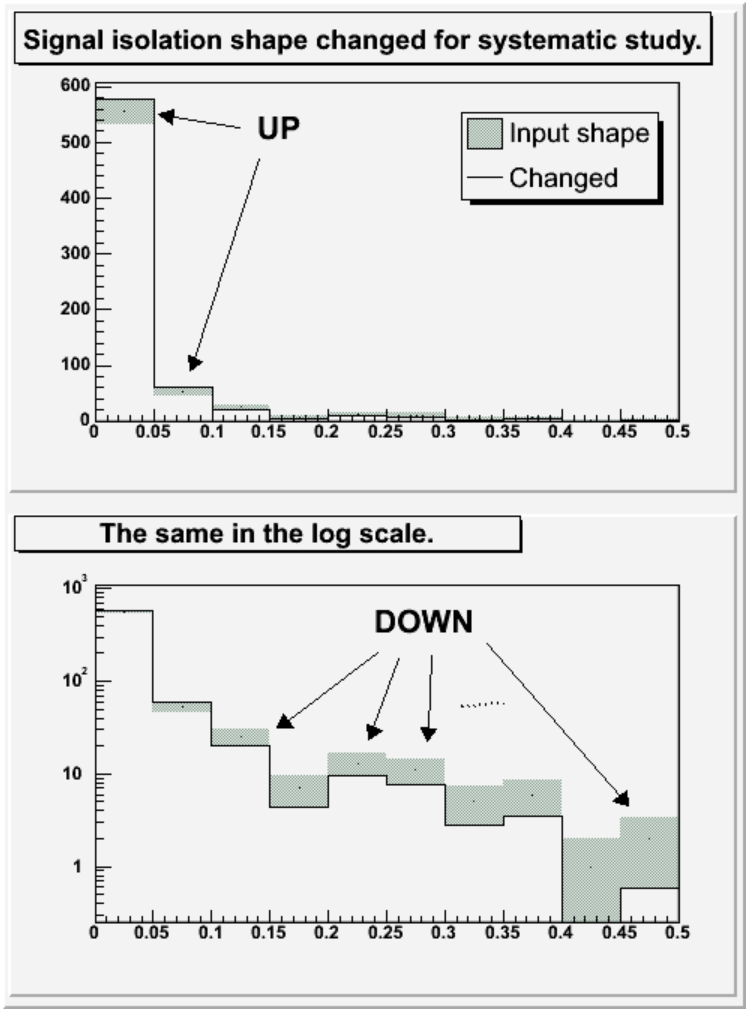
Systematics in Dijet BG

- Twisted the templates (sig, bg shapes. next slide) and w subtraction in bg shape. (1-3)
  - 1 sigma up(down) in the signal region, 1 sigma down(up) in other region for the maximum effect.
- Applied tighter cuts (next next slide) on both legs of signal template for purity, at the risk of cut-cut correlation. (4)
- Material effect on the isolation shape. (5,6)
- Fit with the plug leg of CP events. (7)
- Uncertainty of the W+jet subtraction. (8)

#BG from in 50 - 600 GeV		Stat.	(1) Electron template	(2) Jet template	(3) W subtraction	(4) tight cuts on electron temp.	(5) material central	(6) material plug	(7) plug leg of CP	(8) W+jet subtraction	total syst.	total (stat+syst)
CC	10.6	+3.6	+1.7	+0.4	-2.8	+0.4	+0.4	+0.8	N/A	+1.8	+3.3	+5.0
		-3.6	-1.4	-0.4	+1.9	-0.4	-0.4	-0.8	N/A	-1.8	-3.8	-5.3
CP	128	+9.6	+1.0	+4.5	-2.7	+3.0	+1.0	+1.0	+18	+1.0	+19.0	+21.2
		-9.6	-1.1	-4.4	+1.4	-3.0	-1.0	-1.0	-18	-1.0	-19.1	-21.4

Changing the Templates for Syst.

- Input template shape were changed by 1 sigma.
- Signal region (iso < 0.1) is changed to the opposite direction from other bins.
- Trying two possible directions (up/down and down/up).



Tighter cuts for the BG Syst. (CC)

Variable	Fitting Leg	Control Leg
Fiducial	Fid = 1 or 2	Fid = 1 or 2
E_T	> 25 GeV	> 25 GeV
|Track Z_0|	≤ 60 cm	≤ 60 cm
P_T	> 15 GeV (Et < 100 GeV), > 25 GeV (Et > 100 GeV)	> 10 GeV (Et < 100 GeV), > 25 GeV (Et > 100 GeV)
E_{had}/E_{em}	≤ 0.055	≤ 0.045
Isol	-	≤ 0.6 * (3 + 0.02 Et)
E/p	≤ 2.5 + 0.015 Et (Et <100)	≤ 2.5 + 0.015 Et (Et <100)
|ΔX|	> -3 cm, < 1.5 cm	> -3 cm, < 1.5 cm
|ΔZ|	< 3 cm	< 3 cm
L_{shr}	< 0.18	< 0.15
χ^2_{strip}	< 10	< 10

- Opposite charge and ass region 81 GeV < M_{ee} < 101 GeV.
- Tighter cuts can remove more BG but can have correlatio with iso.

EWK BG

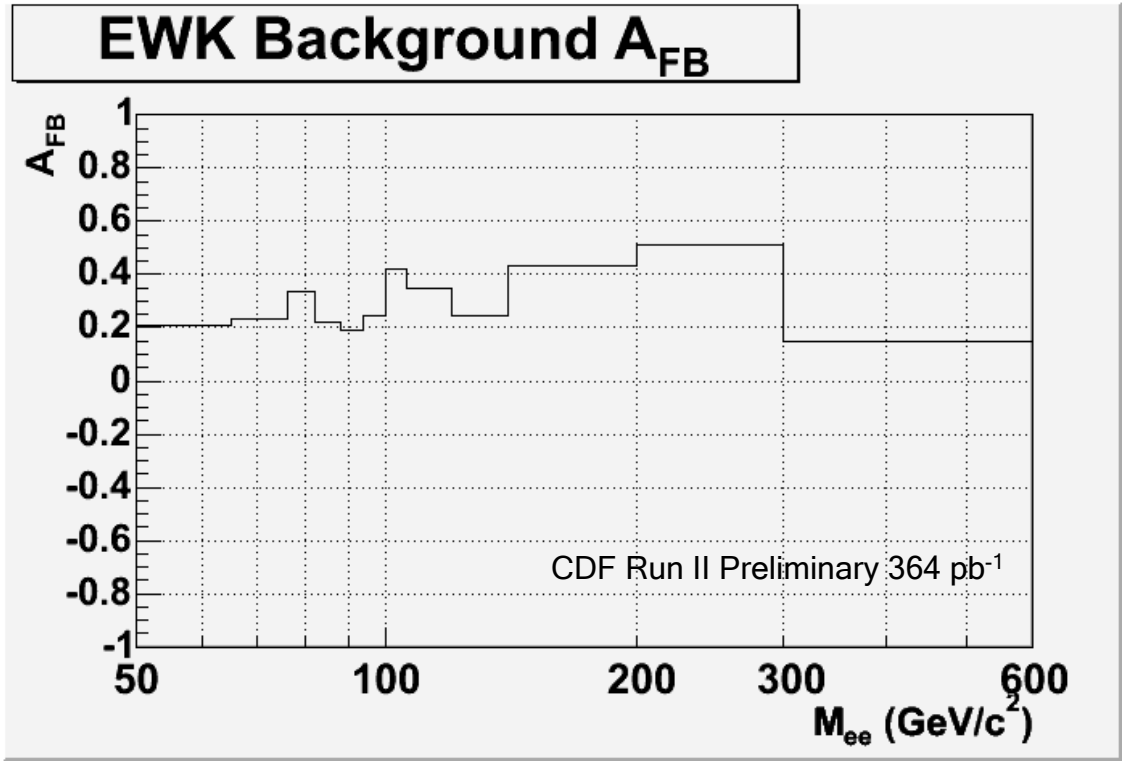
- Uncertainty is from the Poisson in MC, luminosity and the PDF error shown in the theory paper.
- Took the calculation with CTEQ5L as standard.

		σBr (pb)	CC	CP	Total	uncertainty
wewk5d	WW->ll$\nu\nu$	1.39	5.9	6.5	12.4	0.6
wewk6d	WZ (Z->ee)	0.41	5.6	6.4	12.0	0.6
wewkfe	W->eν+γ/jets	2744	3.7	70.5	74.3	6.1
ttopkl	ttbar incl.	5.5	3.2	1.9	5.1	0.3
atopaa	W+parton	682	2.5	22.4	24.8	5.8

- W+parton sample (atopaa) is used for W+jet subtraction form the isolation fit.
- wewkfe (Pythia W->eν+γ/jets) is used.

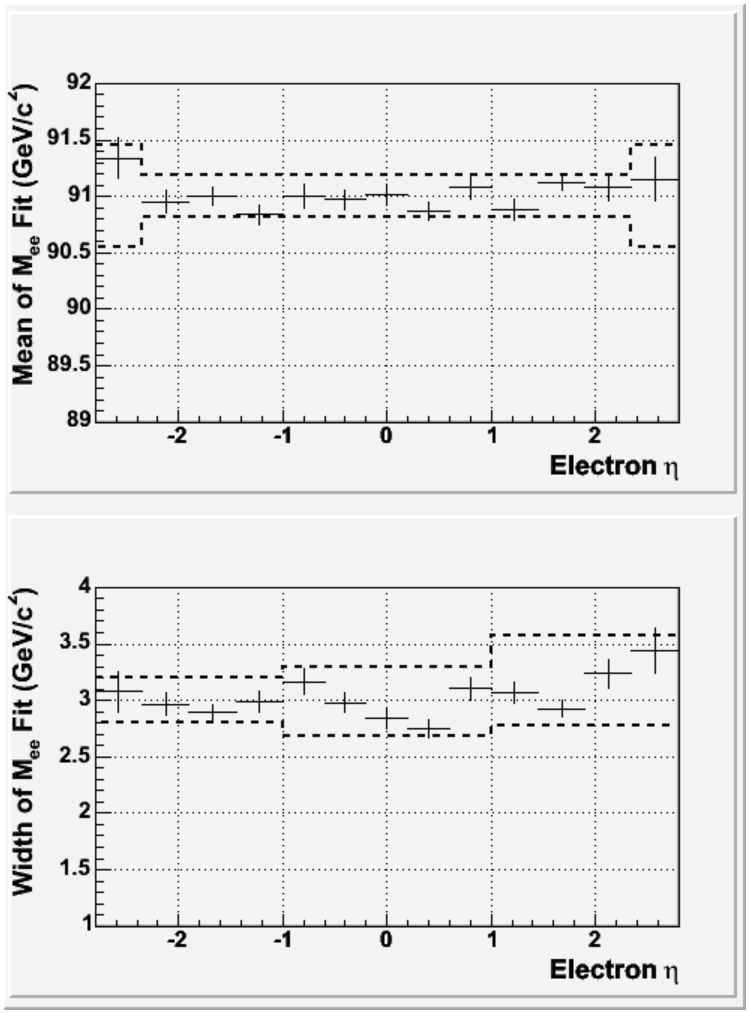
A_{FB} in EWK BG

- Angular asymmetry in EWK BG is accounted for in the subtraction.



Energy Scale and Resolution Uncert.

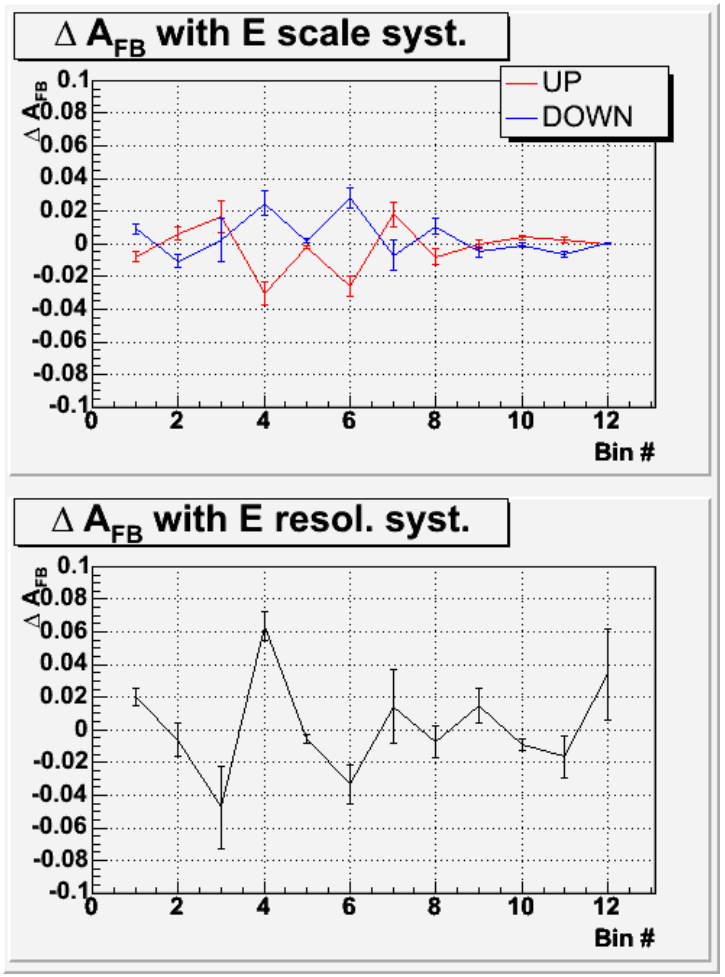
- Energy Scale
  - $|\eta| < 2.35$: $\pm 0.2\%$
  - $|\eta| > 2.35$: $\pm$ 0.8%
- Resolution
  - Central width : $\pm$ 0.3 GeV
  - Plug (W) width : $\pm$ 0.2 GeV
  - Plug (E) width : $\pm$ 0.4 GeV
- May be able to constrain more.



Energy Scale Systematics

- Pulled 16 pseudo experiments from the (1)scale-up, (2)scale-down and (3)width-varied pools.
- Keep the same matrix and only change the PE's (Testing for a mismatch).
- Average of 11 PE's, with error = RMS/sqrt(11-1).

Bin#	Mass (GeV)	Scale up	Scale down	Width varied
1	50 - 65	-0.008	0.009	0.020
2	65 - 76	0.006	-0.010	-0.006
3	76 - 82	0.017	0.003	-0.047
4	82 - 88	-0.030	0.025	0.063
5	88 - 94	-0.002	0.002	-0.005
6	94 - 100	-0.026	0.028	-0.033
7	100 - 106	0.018	-0.007	0.014
8	106 - 120	-0.008	0.011	-0.007
9	120 - 140	-0.000	-0.005	0.015
10	140 - 200	0.004	-0.001	-0.009
11	200 - 300	0.003	-0.006	-0.016
12	300 - 600	-0.000	0.000	0.034



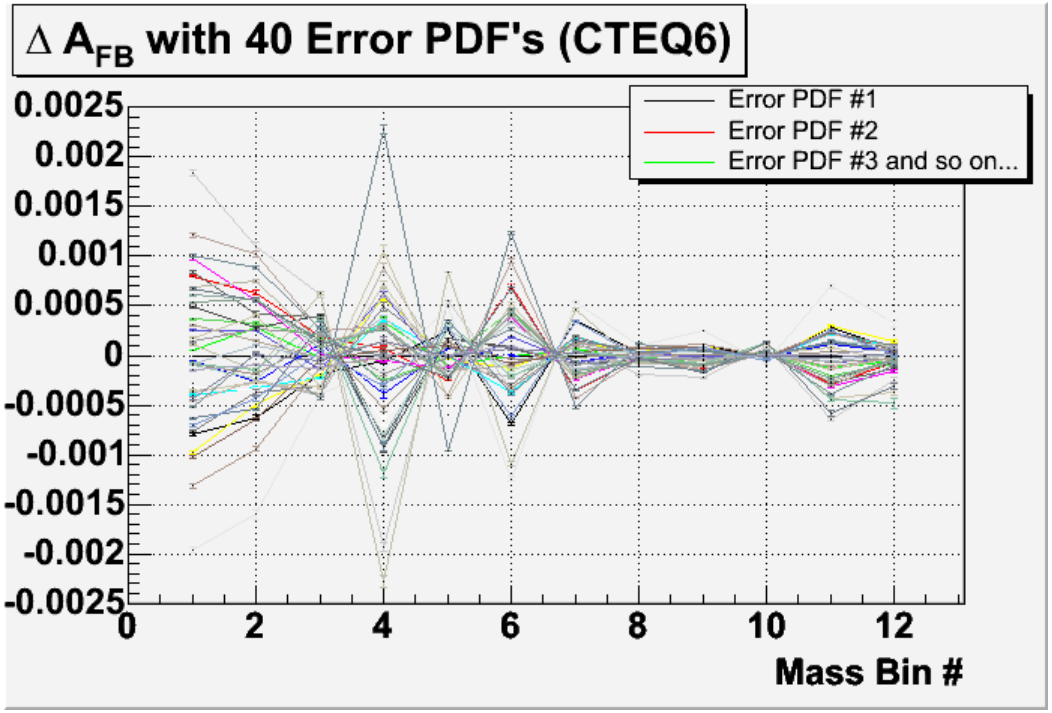
BG Systematics on A_{FB}

- Unfolding of A_{FB} with BG subtraction level by 1σ up.
- Jet BG and EWK BG.
  - Averaged over 11 PE's.

Bin	Mass (GeV)	ΔA_{FB}
1	50-65	0.010
2	65-76	0.010
3	76-82	0.005
4	82-88	0.001
5	88-94	0.000
6	94-100	0.001
7	100-106	0.003
8	106-120	0.006
9	120-140	0.012
10	140-200	0.016
11	200-300	0.015
12	300-600	0.010

PDF Systematics

- 40 response matrices (R) were created by re-weighting the MC events.
- 11 pseudo experiments were prepared. (ν)
- For each 11 PE's, 40 R's were applied and results are averaged.
- Plot : Deviation on A_{FB} in each mass bins.



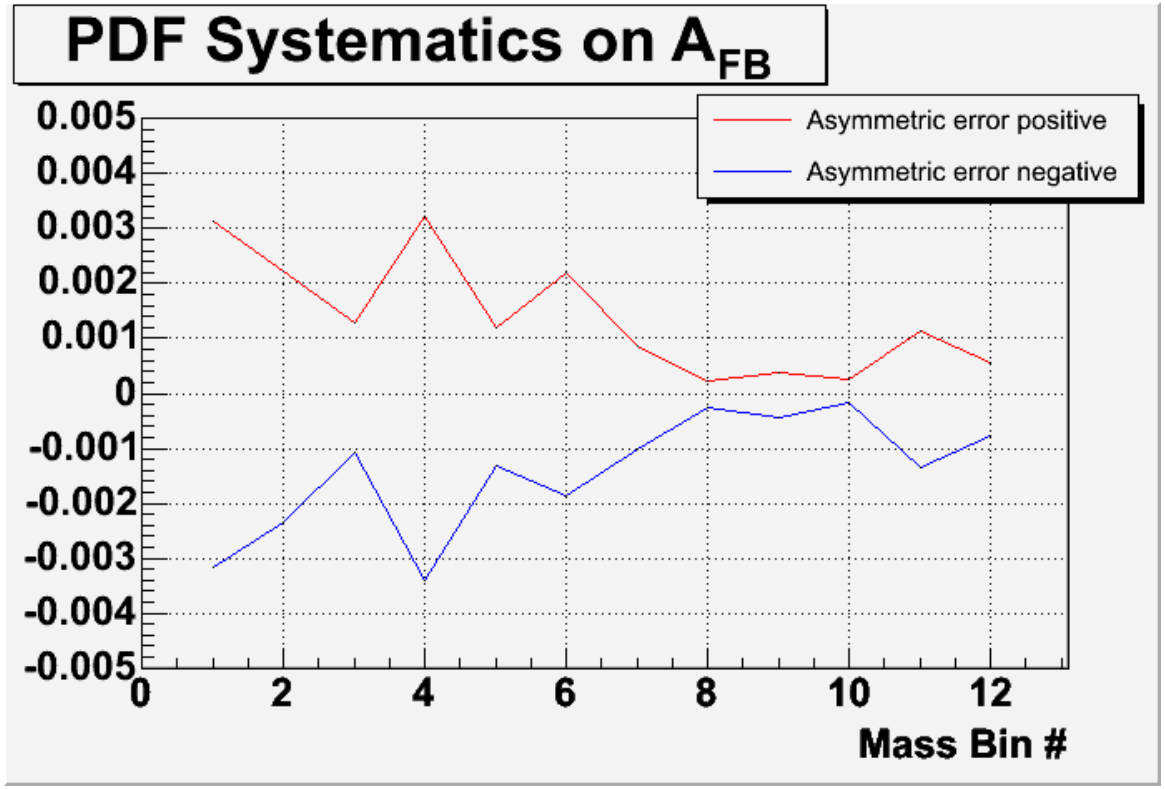
bin 1	50-65
bin 2	65-76
bin 3	76-82
bin 4	82-88
bin 5	88-94
bin 6	94-100
bin 7	100-106
bin 8	106-120
bin 9	120-140
bin 10	140-200
bin 11	200-300
bin 12	300-600

PDF Systematics Summed

- 40 uncertainties are added following EWK recommendation.
  - +/- symmetric within precision.

PDF uncertainty summary

bin 1	+0.003	-0.003
bin 2	+0.002	-0.002
bin 3	+0.001	-0.001
bin 4	+0.003	-0.003
bin 5	+0.001	-0.001
bin 6	+0.002	-0.002
bin 7	+0.001	-0.001
bin 8	+0.000	-0.000
bin 9	+0.000	-0.000
bin 10	+0.000	-0.000
bin 11	+0.001	-0.001
bin 12	+0.001	-0.001



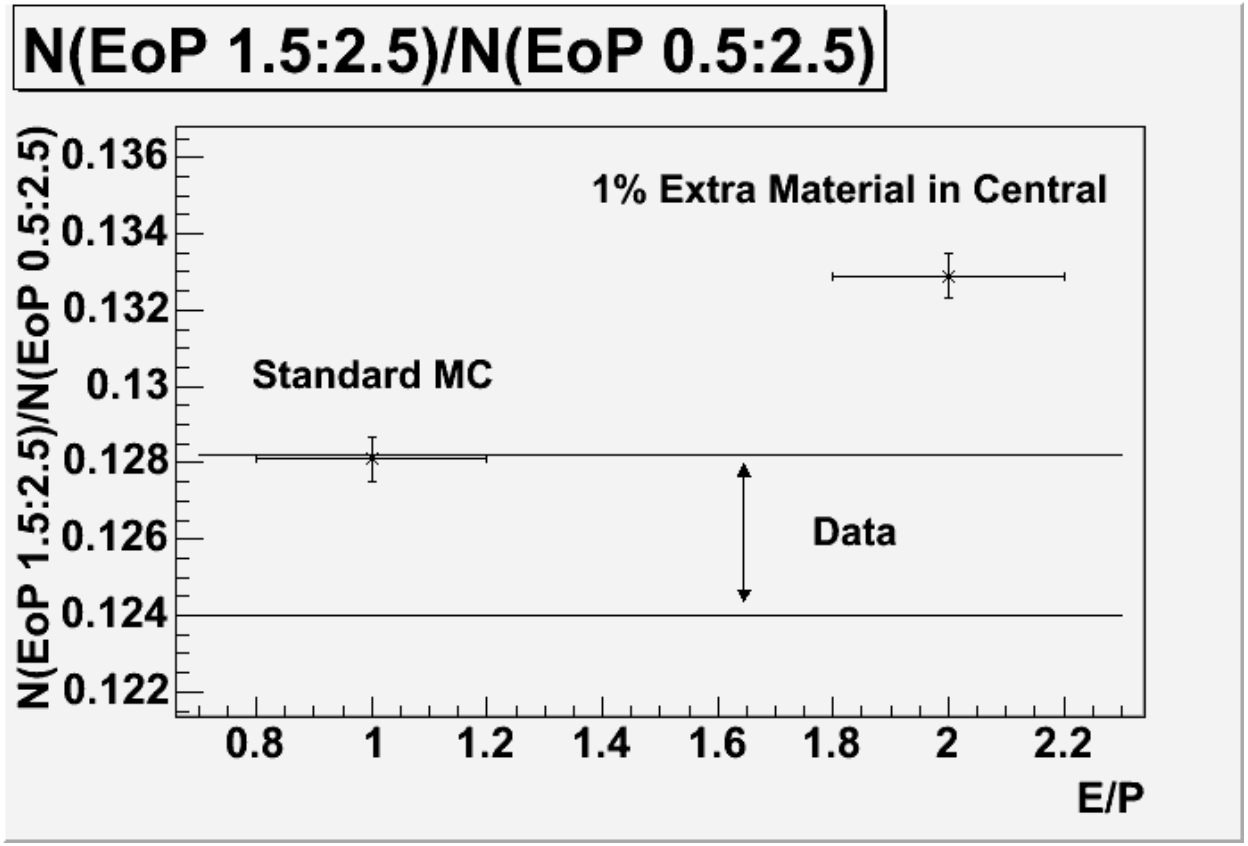
Material Systematics

- 2M hepg used in common.
- Null MC.
  - Simulated with 0% (central) and -1/6 (plug) of X0.
- Extra material in the central.
  - 1% (central) and -1/6 (plug) of X0.
- Extra material in the plug.
  - 0% (central) and -1/6+1/6 (plug) of X0.
- 11 PE's from null MC were unfolded with three response matrices.
  - The differences in A_{FB} in each bins were averaged.
  - Incorporates charge mid-id uncertainty.

Bin	Mass (GeV)	Central	Plug	Total
1	50 - 65	0.015	0.003	0.015
2	65 - 76	0.021	0.056	0.060
3	76 - 82	0.027	0.031	0.041
4	82 - 88	0.025	0.056	0.062
5	88 - 94	0.006	0.006	0.008
6	94 - 100	0.035	0.014	0.037
7	100 - 106	0.033	0.003	0.033
8	106 - 120	0.000	0.026	0.026
9	120 - 140	0.016	0.007	0.018
10	140 - 200	0.018	0.037	0.041
11	200 - 300	0.010	0.020	0.022
12	300 - 600	0.046	0.015	0.049

E/p and the Extra Material

- Number of electrons in the radiation region is compared.
- Number in 1.5 < E/p < 2.5 / Number in 0.5 < E/p < 2.5.



Data Unfolded (table)

		RAW					Unfolded			
Bin	Mass (GeV)	#Forward	#BG Forward	#Backward	#BG Backward	A_{FB} (bg subtracted)	#Forward	#Backward	A_{FB}	Stat. Err. (data)
1	50-65	97	9.6	120	7.6	**-0.125**	1875.6	3036.1	**-0.236**	0.085
2	65-76	207	15.8	284	12.7	**-0.173**	704.9	1603.2	**-0.389**	0.084
3	76-82	330	9.5	394	7.3	**-0.094**	486.5	1006.4	**-0.348**	0.163
4	82-88	1791	8.9	1817	7.5	**-0.008**	3153.1	3871.7	**-0.102**	0.074
5	88-94	6935	12.6	6295	10.1	**0.048**	39087.9	35762.7	**0.044**	0.011
6	94-100	1853	8.3	1348	6.8	**0.158**	3229.1	1160.2	**0.471**	0.102
7	100-106	333	8.5	169	6.0	**0.331**	1215.4	649.6	**0.303**	0.075
8	106-120	288	18.6	130	13.3	**0.395**	843.5	334.2	**0.432**	0.067
9	120-140	166	14.9	58	11.9	**0.532**	453.0	129.7	**0.555**	0.072
10	140-200	140	22.7	53	14.7	**0.508**	300.3	97.0	**0.512**	0.078
11	200-300	45	7.5	15	4.1	**0.550**	91.0	24.8	**0.571**	0.135
12	300-600	10	0.8	3	0.7	**0.600**	21.4	4.3	**0.668**	0.236

A_{FB} Uncertainty Summary

bin	Mass (GeV)	A_{FB} (Data)	A_{FB} (LO)	Stat. (Data)	Stat. (MC)	RMS of MC Stat error	Energy scale	Energy Resol.	PDF	Material	Background	Response matrix	Total Syst.	Total Uncert.
1	50-65	-0.236	-0.380	0.085	0.085	0.004	0.009	0.020	0.003	0.015	0.018	0.015	0.036	0.092
2	65-76	-0.389	-0.430	0.084	0.081	0.008	0.010	0.006	0.002	0.060	0.016	0.026	0.068	0.106
3	76-82	-0.348	-0.244	0.163	0.117	0.010	0.017	0.047	0.001	0.041	0.008	0.065	0.092	0.149
4	82-88	-0.102	-0.134	0.074	0.064	0.004	0.030	0.063	0.003	0.062	0.002	0.023	0.096	0.116
5	88-94	0.044	0.062	0.011	0.011	0.000	0.002	0.005	0.001	0.008	0.000	0.002	0.010	0.015
6	94-100	0.471	0.192	0.102	0.103	0.010	0.028	0.033	0.002	0.037	0.001	0.030	0.064	0.121
7	100-106	0.303	0.320	0.075	0.073	0.004	0.018	0.014	0.001	0.033	0.005	0.028	0.049	0.088
8	106-120	0.432	0.484	0.067	0.067	0.004	0.011	0.007	0.000	0.026	0.012	0.016	0.035	0.076
9	120-140	0.555	0.590	0.072	0.070	0.005	0.005	0.015	0.000	0.018	0.018	0.011	0.032	0.077
10	140-200	0.512	0.602	0.078	0.069	0.007	0.004	0.009	0.000	0.041	0.030	0.011	0.053	0.087
11	200-300	0.571	0.583	0.135	0.122	0.013	0.006	0.016	0.001	0.022	0.030	0.019	0.045	0.130
12	300-600	0.668	0.682	0.236	0.214	0.086	0.000	0.034	0.001	0.049	0.012	0.028	0.067	0.224

Electron Template Cut (CP, central)

Variable	Fitting Leg (central)	Control Leg (plug)
Fiducial	Fid = 1 or 2	1.18 < |e| < 3.0
E_T	> 25 GeV	> 25 GeV
|Track Z_0|	≤ 60 cm	-
P_T	> 15 GeV (Et < 100 GeV), > 25 GeV (Et > 100 GeV)	-
E_{had}/E_{em}	≤ 0.055 + 0.00045 x E	≤ 0.05
Isol (GeV)	-	≤ 0.8 * (1.6 + 0.02 Et)
E/p	≤ 2.5 + 0.015 Et (Et < 100)	-
|ΔX|	< 3 cm	-
|ΔZ|	< 5 cm	-
L_{shr}	< 0.2	-
χ^2_{PEM3x3}	-	10
5by9U	-	0.65
5by9V	-	0.65

- 81 GeV < M_{ee} < 101 GeV

Electron Template Cuts (CP, plug)

Variable	Control Leg (central)	Fitting Leg (plug)
Fiducial	Fid = 1 or 2	1.18 < |e| < 3.0
E_T	> 25 GeV	> 25 GeV
|Track Z_0|	≤ 60 cm	-
P_T	> 15 GeV (Et < 100 GeV), > 25 GeV (Et > 100 GeV)	-
E_{had}/E_{em}	≤ 0.055	≤ 0.05 + 0.026 x log(E/100)
Isol (GeV)	≤ 0.8 * (3 + 0.02 Et)	-
E/p	≤ 2.5 + 0.015 Et (Et < 100)	-
|ΔX|	< 3 cm	-
|ΔZ|	< 3 cm	-
L_{shr}	< 0.18	-
χ^2_{strip}	< 10	-
χ^2_{PEM3x3}	-	25

- 81 GeV < M_{ee} < 101 GeV

Jet Template Cuts (plug)

Variable	Central (CdfJet)	Plug (EmObject)
Fiducial	-	$1.18 < \|\eta\| < 3.0$
E_T	> 25 GeV	> 25 GeV
E_{had}/E_{em}	> 0.125	< 0.05 + 0.026 x log(E/100)
Isol (GeV)	-	< 1.6 + 0.02 * Et
χ^2_{PEM3x3}	-	< 25

- Z removed by requiring no more than 1 EmObj with EmEt > 15 GeV.
- W subtracted from MET distribution.

Data-MC Before Energy Scale Correction

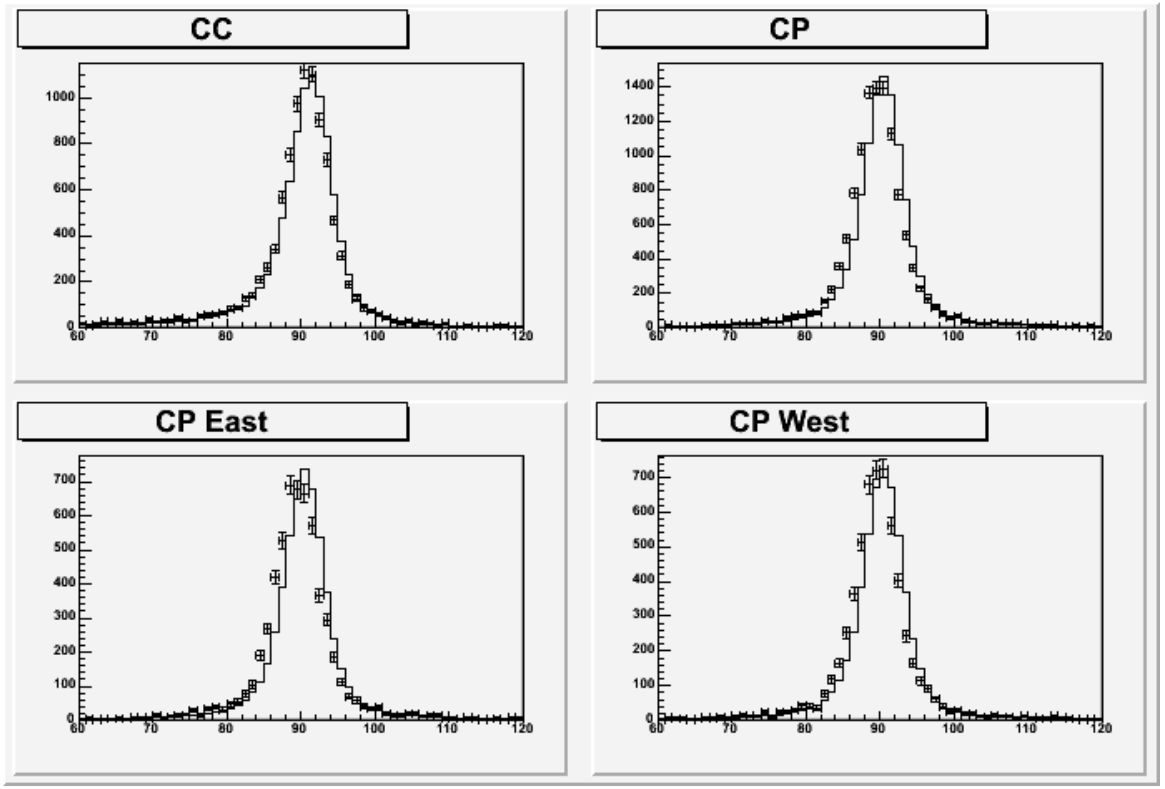
- Following CDF 7687.
- Fitting to Gaus 86-98 GeV.
- Data

	Mean	Width
CC	90.9	2.96
CP(E)	89.5	3.25
CP(W)	89.6	3.03

- MC

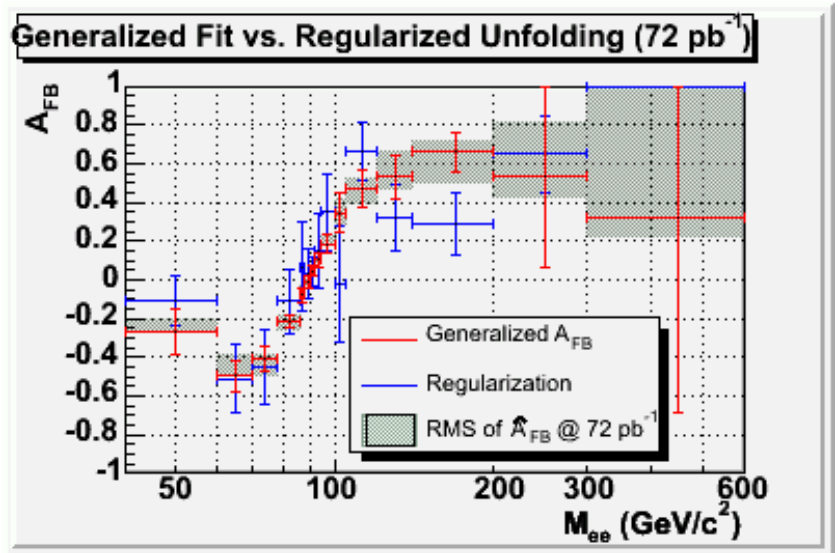
	Mean	Width
CC	91.3	3.01
CP	90.5	2.90

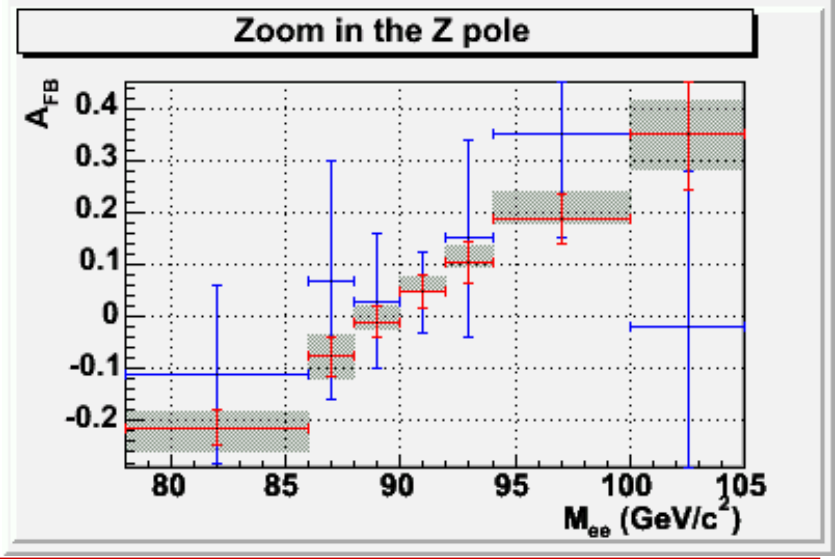
Scale Factors		CEM	PEM(E)	PEM(W)
E Scale	Data	1.001	1.034	1.030
	MC	0.997	1.014	1.014
E Reslution	MC		1.018	1.010

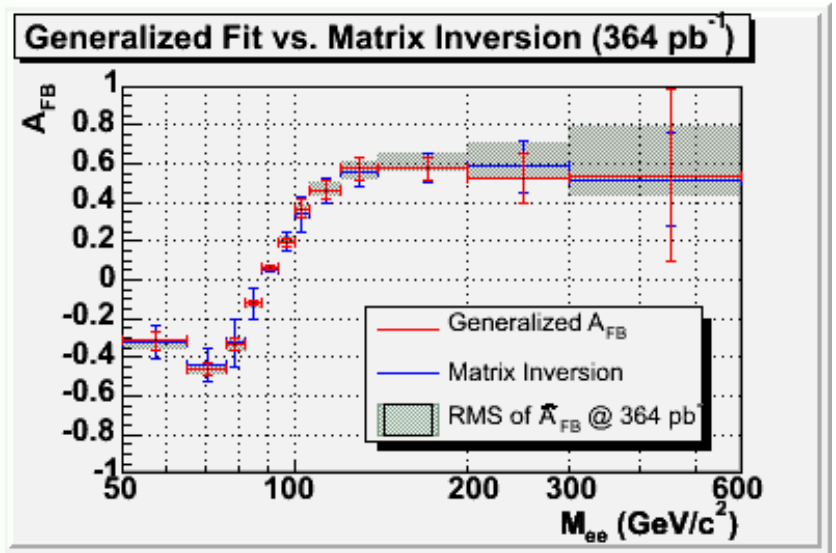
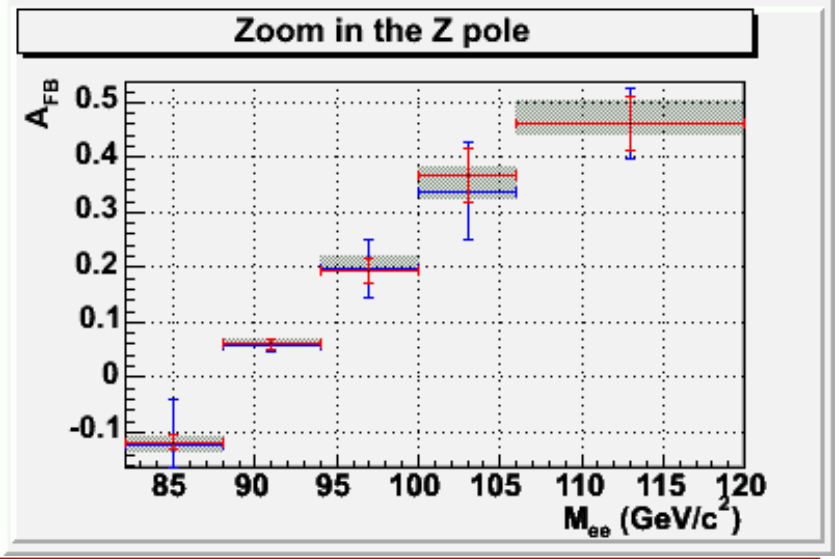


Generalized A_{FB} vs. Previous Result

- Comparison to the previous Run II result @ 72 pb^{-1}.
- Red : Generalized A_{FB} by fitting cos(θ*).
  - 10 PE (pseudo experiment) 's assuming 72 pb^{-1}.
  - Errors are averaged.
  - No background.
- Blue : Regularized unfolding.
  - Run II analysis with 72 pb^{-1}.
  - With background.





Generalized A_{FB} vs. Matrix Inversion

- Comparison of the two new methods that we are developing.
  - No background.
  - Assume 364 pb^{-1}.
  - Errors from the PE's are averaged.
- Red : Generalized A_{FB} by fitting cos(θ*). 11 PE's.
- Blue : Unfolding with matrix inversion. 4000 PE's.
- Generalized fit seems to win.