JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Measurement of the A_{FB} in NC DY Processes with ATLAS

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(Universität Mainz)

XXI International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS)

on behalf of the ATLAS collaboration
25 April 2013

ATLAS-CONF-2013-043

FSP 101 ATLAS

PRISMA

Overview

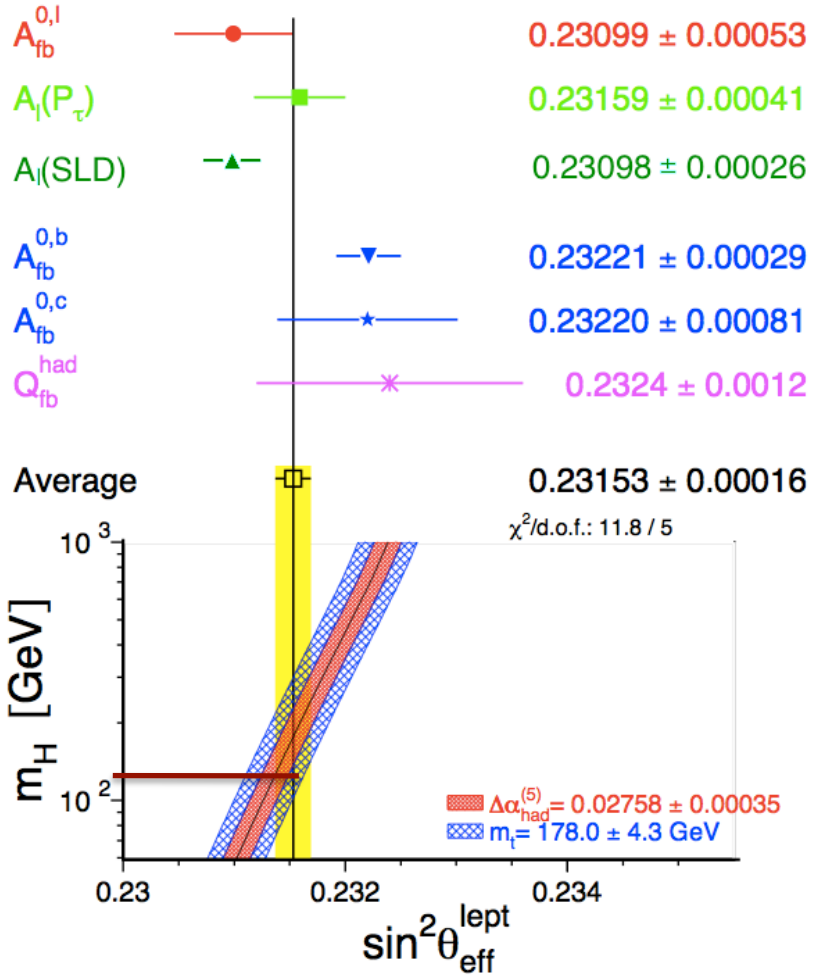
- Motivation
  - electroweak physics and the Weinberg angle
- Measurement Principle
  - *Z* forward-backward asymmetry (A_{FB})
- Event Selection
  - 3 channels: 2 electron, 1 muon
  - resulting A_{FB} distributions
- Unfolding A_{FB} spectra
- Measurement of $\sin^2(\theta^{eff}_W)$
  - template extraction using raw A_{FB}
- Conclusions

Motivation

- Reminder:

$$\sin^2(\theta_W) = 1 - \frac{m_W^2}{m_Z^2}$$

- Comparison of $\sin^2(\theta^{\ell}_{\text{eff}})$
  - measured at many different Q
  - SLC: lepton couplings
  - LEP: quark couplings
- Standard Model prediction
  - function of Higgs mass
- Physical observable
  - $\sin^2(\theta^{\ell}_{\text{eff}})$ to forward-backward asymmetry
    - shift in the distribution



Phys. Rept. 427 (2006) 257–454, arXiv:0509008 [hep-ex] 27 Feb 2006

Measurement Principle

- Asymmetry (A_{FB}) in Z/γ*
  - vector/axial couplings
  - parity violations in EW interactions

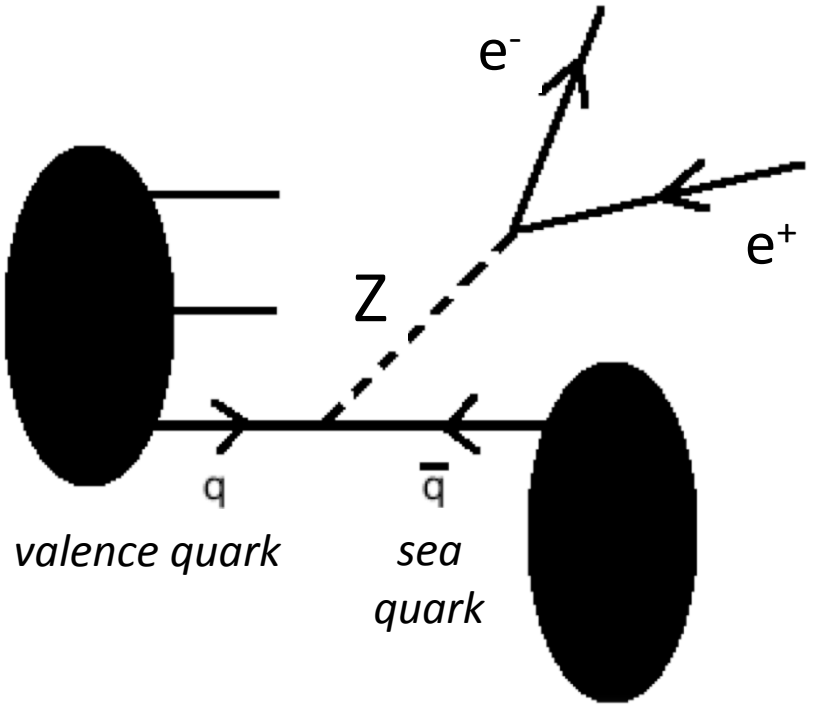
$$\frac{d\sigma}{d\cos\theta} = \frac{4\pi\alpha^2}{3s}\left[\frac{3}{8}A(1+\cos^2\theta) + B\cos\theta\right]$$

θ: defined in $q\bar{q}$ resp $\ell^+\ell^-$ rest frame

- Define parameters
  - cos(θ)>0 → Forward (N_F)
  - cos(θ)<0 → Backward (N_B)

$$\cos(\theta^*_{CS})$$

- pp colliders: incoming quark direction
  - determined by sign of $y(\ell\ell)_z$
  - misidentified quark
    - dilution (reduction) A_{FB}



$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

Measurement Principle

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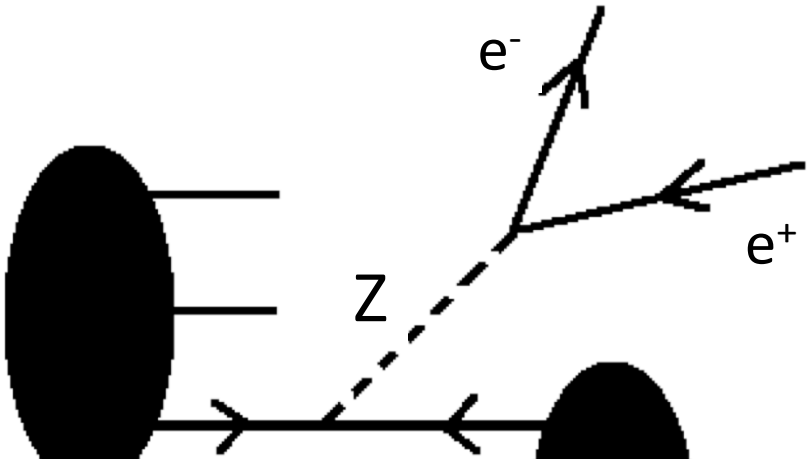

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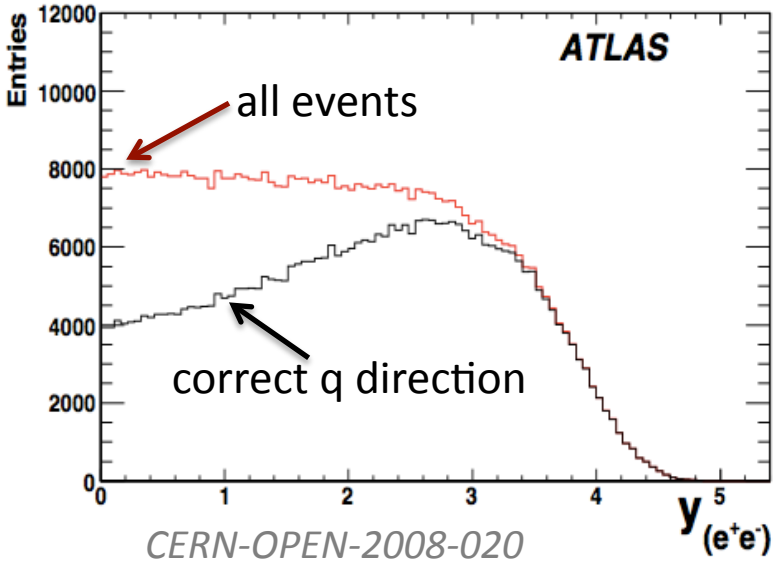


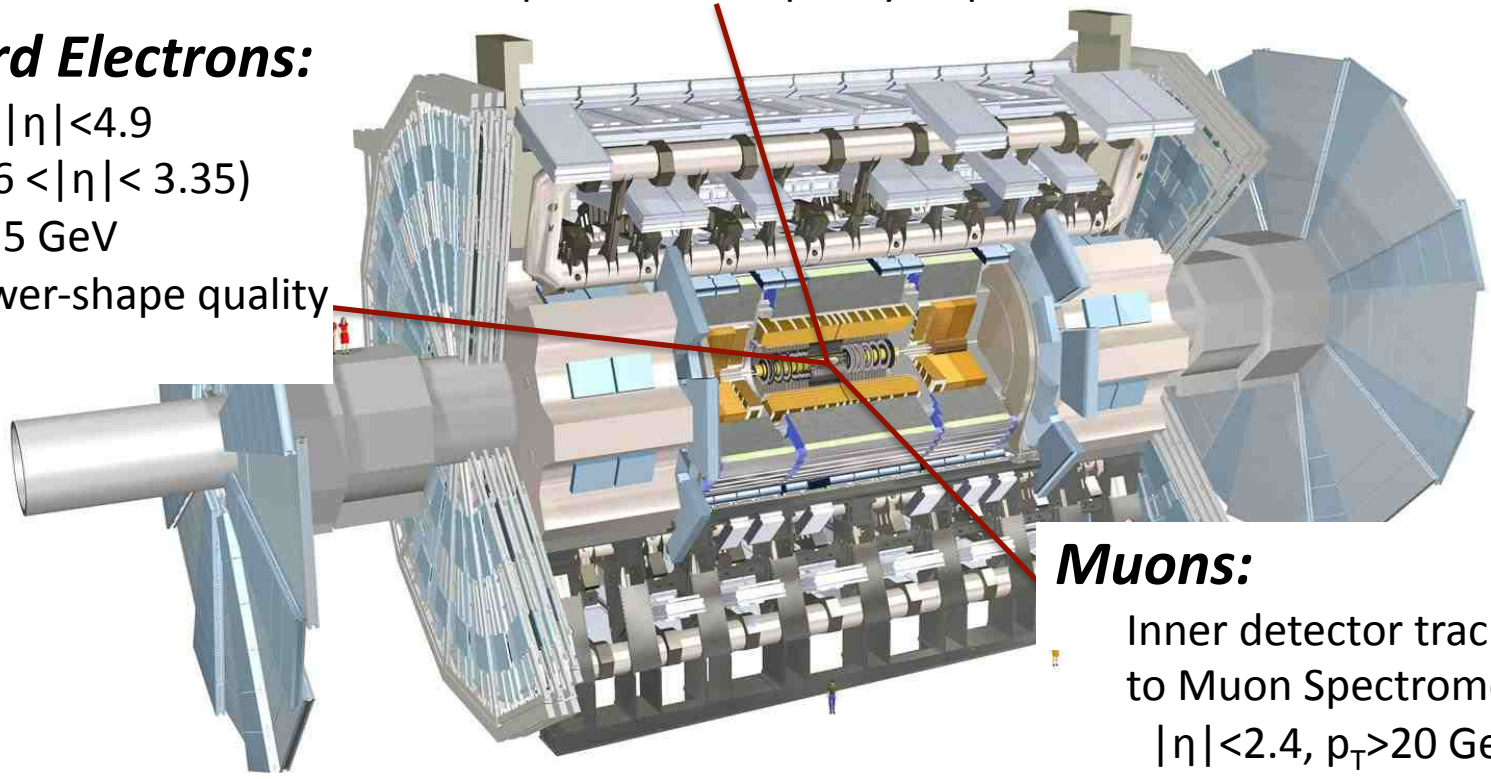
Lepton Reconstruction

Central Electrons:

$|\eta|<2.47$ (excluding $1.37<|\eta|<1.52$), $E_T>25$ GeV
shower-shape and track quality requirements

Forward Electrons:

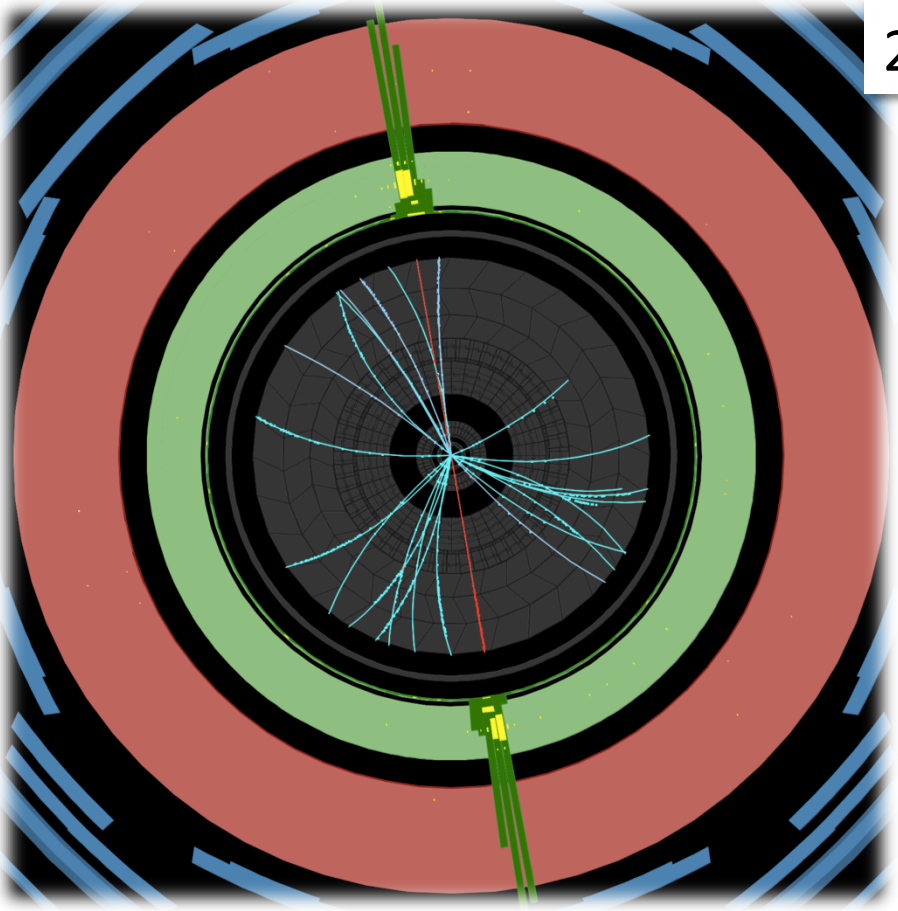
$2.5<|\eta|<4.9$
$(3.16<|\eta|<3.35)$
$E_T>25$ GeV
shower-shape quality



Muons:

Inner detector track matched to Muon Spectrometer
$|\eta|<2.4$, $p_T>20$ GeV
relative isolation<0.1
(within cone $\Delta R(0.2)$)

Event Selection



2011 data $\sqrt{s}$=7 TeV $\int Ldt = 4.8\, fb^{-1}$.

Lepton pair cuts

- ≥2 good leptons
  - 2 central electrons: CC
  - 1 central+1 forward electron: CF
  - 2 muons
- Invt. Mass > 66 GeV
  - CC and muon: <1000 GeV
    - asymmetry largest at high invt. mass
    - opposite sign
  - CF: <250 GeV

Phys.Lett. B700 (2011) 163-180

Signal and Backgrounds

Monte Carlo Signal

- Z->ee/μμ: PYTHIA interfaced with PHOTOS
- NLO contributions estimated with HORACE (NLO EWK) and MCFM (NLO QCD)

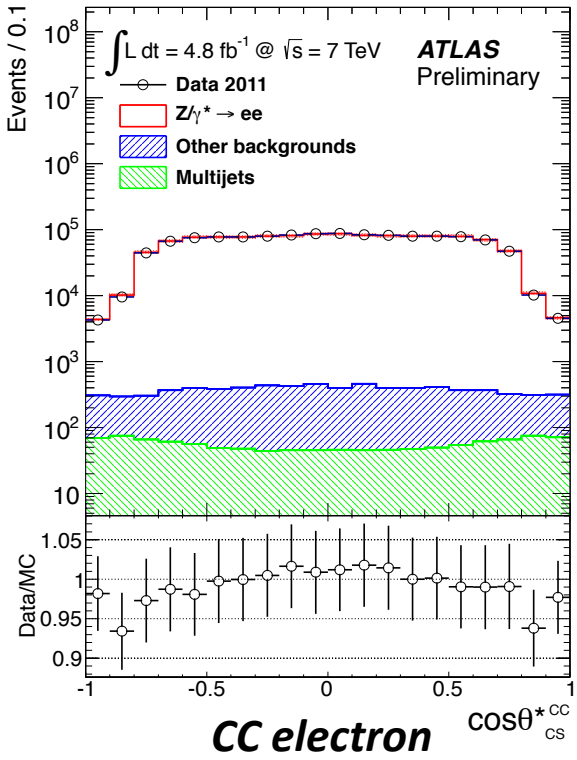
Monte Carlo Background Estimation

- diboson(WW/ZZ/WZ): HERWIG
- tt: MC@NLO
- Z->ττ: PYTHIA/PHOTOS

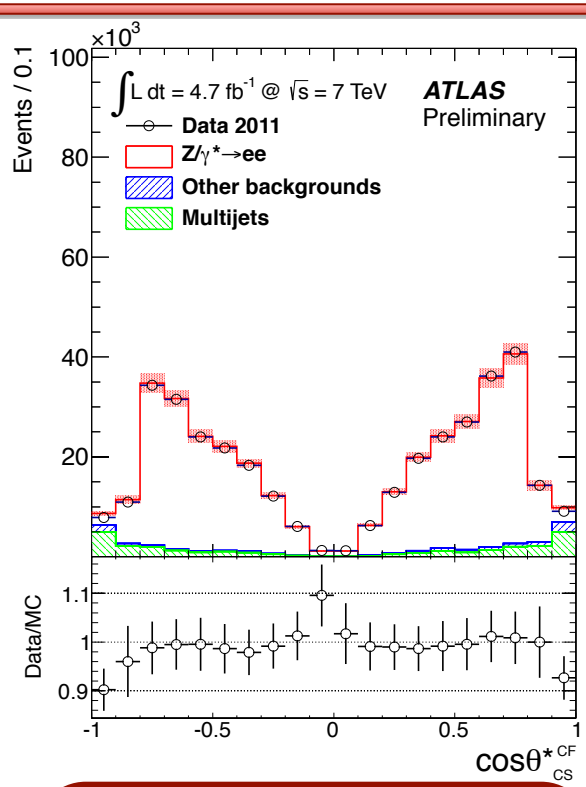
Data Driven Background Estimation

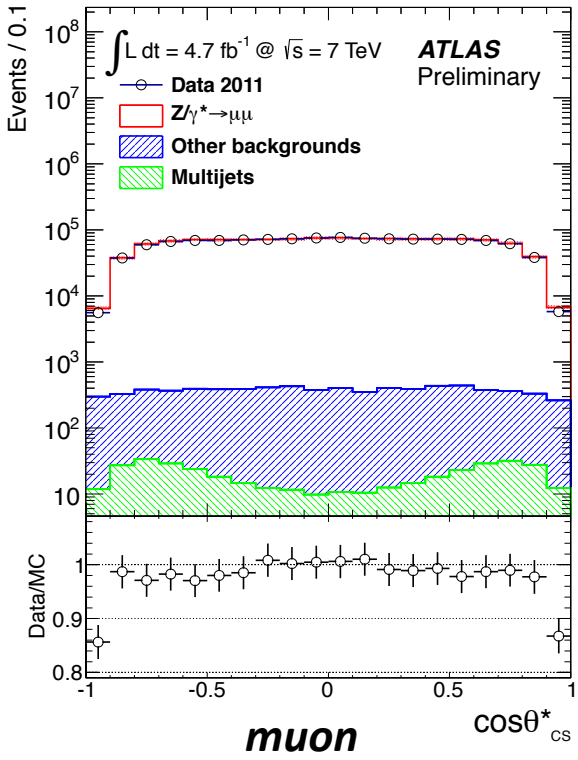
- Multijets
  - invert selection: create background enhanced sample
  - Dominated by dijets (W+jets also included)

$\cos(\theta^*_{CS})$ Distributions



CC electron





muon

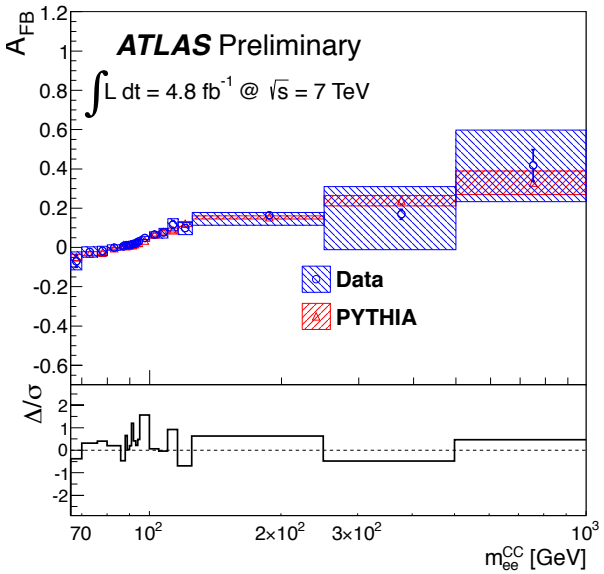
Integrate $\cos(\theta^*_{CS})$>0, <0
in mass bins
to determine N_F and N_B

CF electron channel
forward e: 2.5<|η|<4.9
Asymmetry visible already
suffers less from dilution

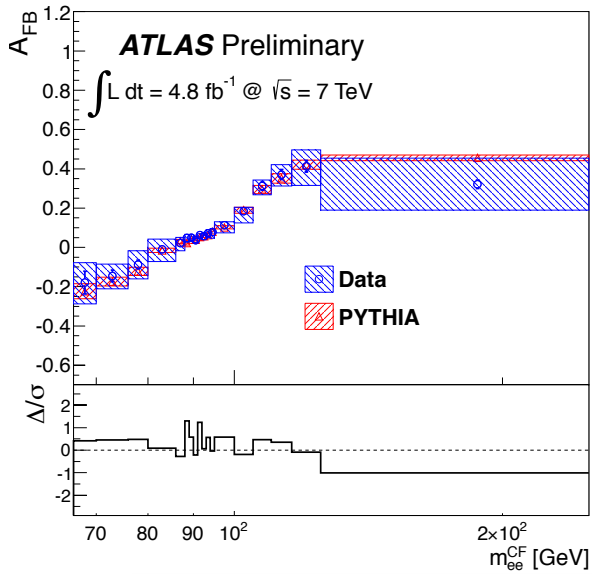
Reminder:

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

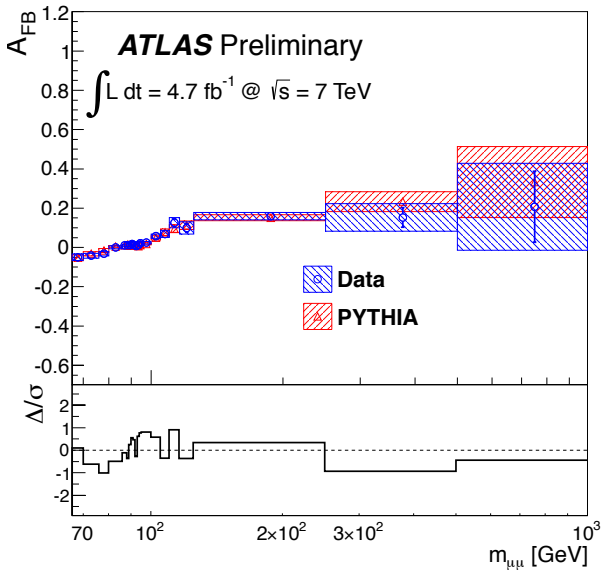
Raw A_{FB} Spectra



CC electron



CF electron channel
forward e: 2.5<|η|<4.9
only go to 250 GeV,
asymmetry spectrum less diluted



muon

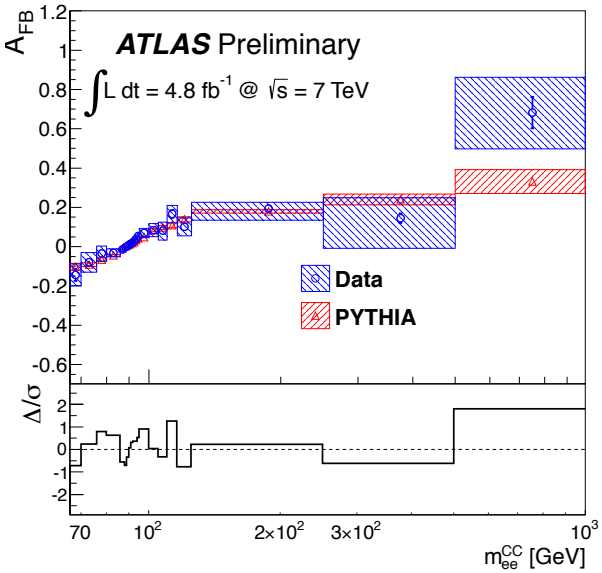
Δ=(data-MC)
σ = total uncertainty

Reminder:

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

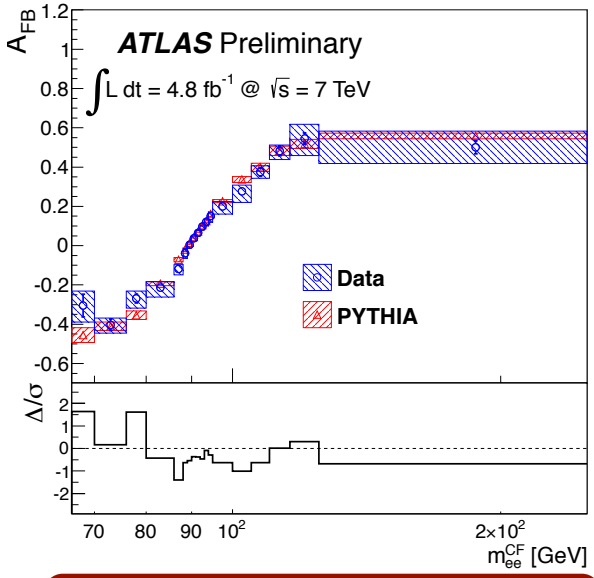
Unfolding the A_{FB} Spectra: Mass-bin-Migration

- Mass-bin-migration
  - Detector effects
    - finite resolution, reconstruction, pileup
      - QED radiative corrections
        - shifts peak to lower invariant masses
        - unfold to *Born*-level: pre- FSR

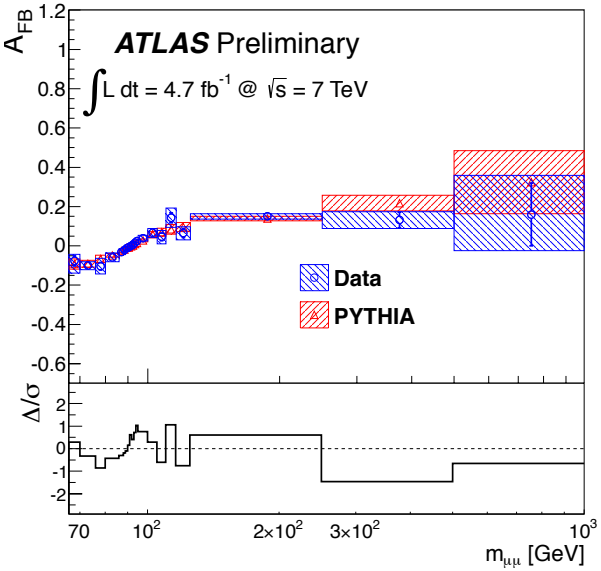


CC electron

dramatic effect in low mass bins, big impact from mass-bin-migration



CF electron



muon

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WEAK MIXING ANGLE MEASUREMENT

Weak Mixing Angle Measurement

Generate events with different $\sin^2(\theta_W^{eff})$

- Reconstruct A_{FB} with each different set of generated events

Create templates for each of these A_{FB} distributions

- A_{FB} reconstruction as before

χ^2 comparison with data to determine most probable $\sin^2(\theta_W^{eff})$

- A_{FB} range 70-250 GeV

Default:

$$\sin^2(\theta_W^{eff}) = 0.232$$

Combination

$\sin^2(\theta_W^{eff})$ *CC electron*

$\sin^2(\theta_W^{eff})$ *CF electron*

$$\sin^2\theta_{W\ \text{electrons}}^{\text{eff}} = 0.2298 \pm 0.0005(\text{stat.}) \pm 0.0009(\text{syst.})$$

$\sin^2(\theta_W^{eff})$ *muon*

systematic uncertainties fully correlated
(except MC stat, energy scale)

ATLAS Preliminary

$$\sin^2\theta_{W\ \text{combined}}^{\text{eff}} = 0.2297 \pm 0.0004(\text{stat.}) \pm 0.0009(\text{syst.})$$

PDF and higher-order systematic uncertainties correlated

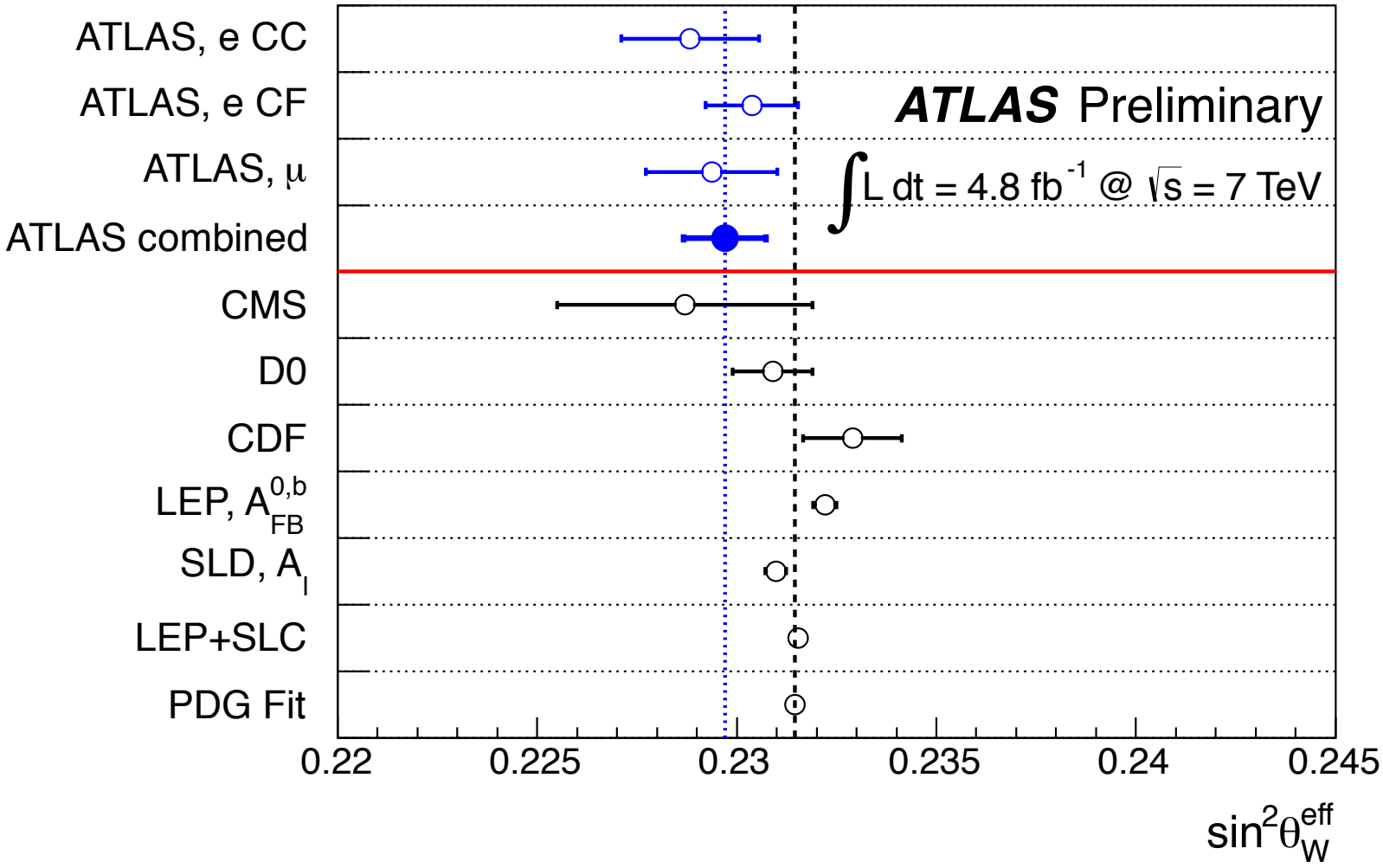
Systematic Uncertainties

ATLAS Preliminary

uncertainty source	CC electron (10^{-4})	CF electron (10^{-4})	muon (10^{-4})	combined (10^{-4})
PDF	9	5	9	7
MC statistics	9	5	9	4
electron energy scale	4	6	–	4
electron energy smearing	4	5	–	3
muon energy scale	–	–	5	2
HO corrections	3	1	3	2
other sources	1	1	2	2

- Dominant systematic is correlated
  - not a large reduction in systematic uncertainty

Results and World Averages



Summary and Conclusions

- First ATLAS Measurement of A_{FB}
  - ATLAS 2011 data $\sqrt{s}$=7 TeV $\int Ldt = 4.8\,fb^{-1}$
  - 3 channels
    - central-central electron, central-forward electron and muon
  - forward region displays reduced effect from dilution
- Measurement of the leptonic weak mixing angle
  - 3 channels and combined results
- First combination of e/μ in the measurement of $sin^2\theta^{eff}_W$ at a hadron collider
  - As precise as best hadron collider results

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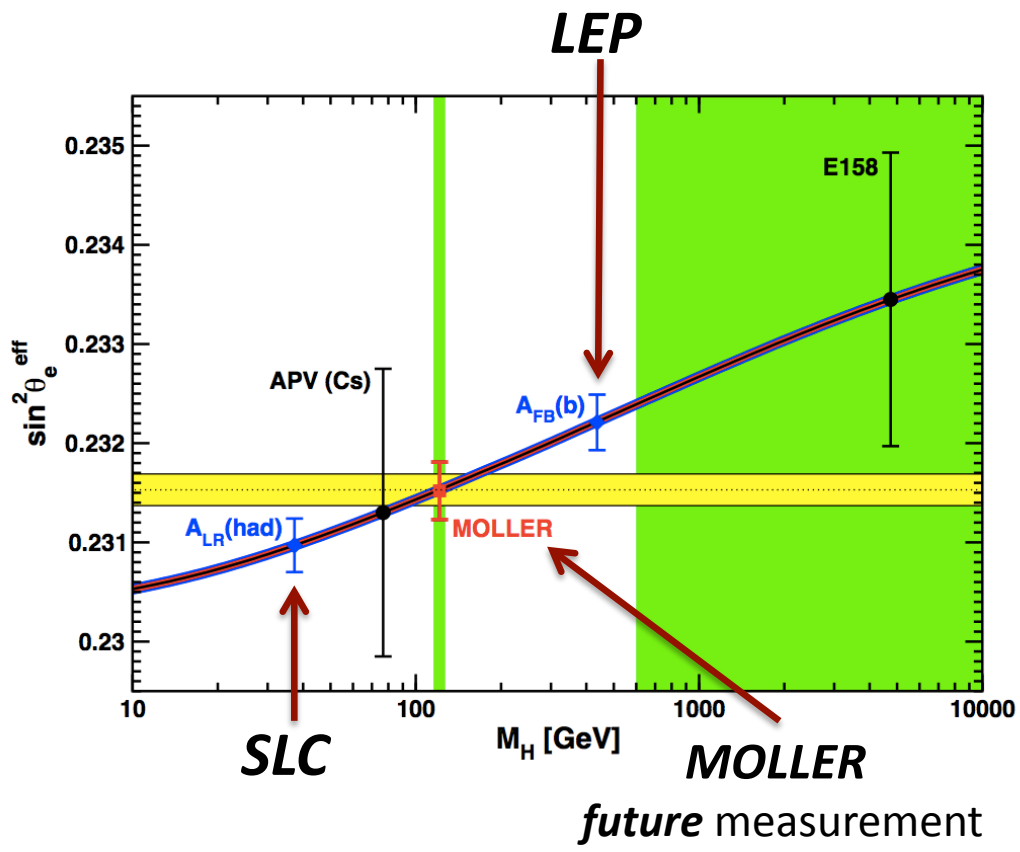
BACKUPS

Motivation

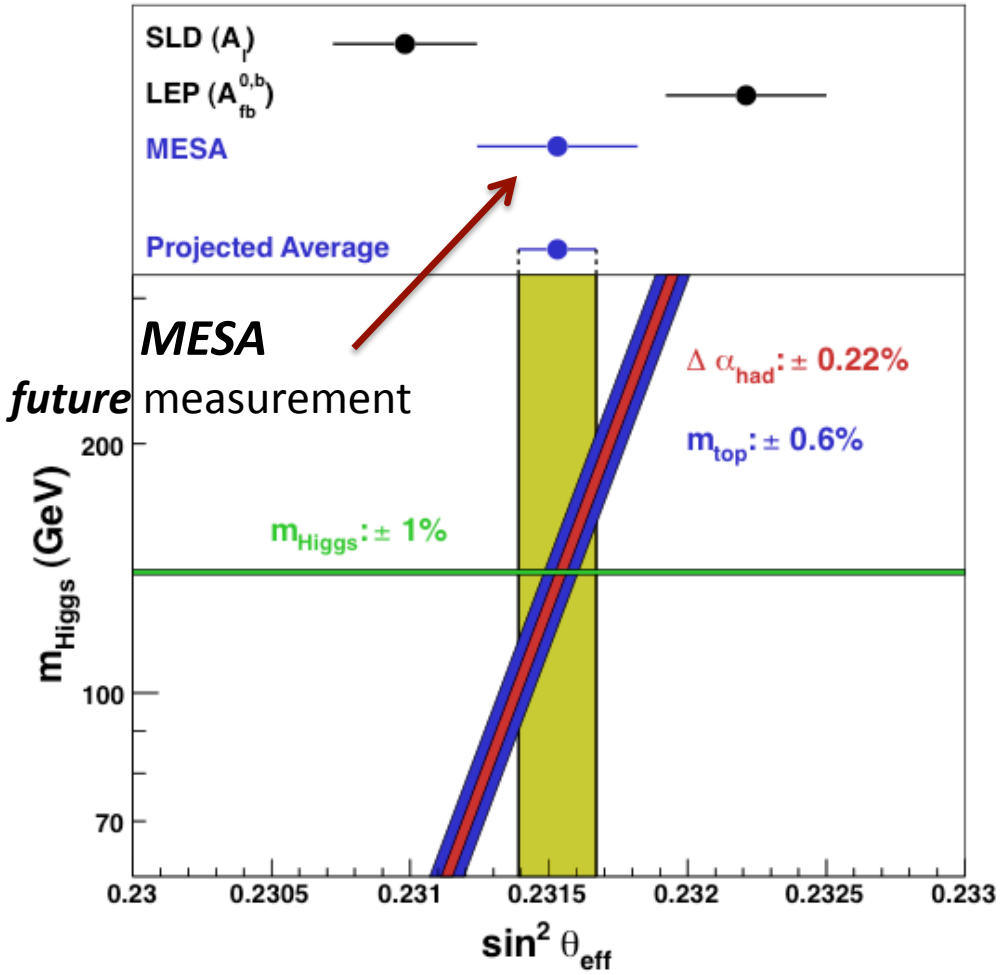


future measurement

- Measurements at different Q
  - LEP 1 and SLC
    - disagreement at ~3σ
  - Low energy (Møller scattering)
    - APV, E158
    - MOLLER (future) polarized e-beams
    - MESA accelerator facility high luminosity e-beams on fixed targets
- Implications
  - running value of Weinberg angle
  - measured value of Higgs mass
  - non-excluded high mass intervals

J. Erler, arXiv:1209.3324v1 [hep-ph] 14 Sep 2012

Motivation



http://www.prisma.uni-mainz.de/area_A.php

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- Implications
  - running value of Weinberg angle
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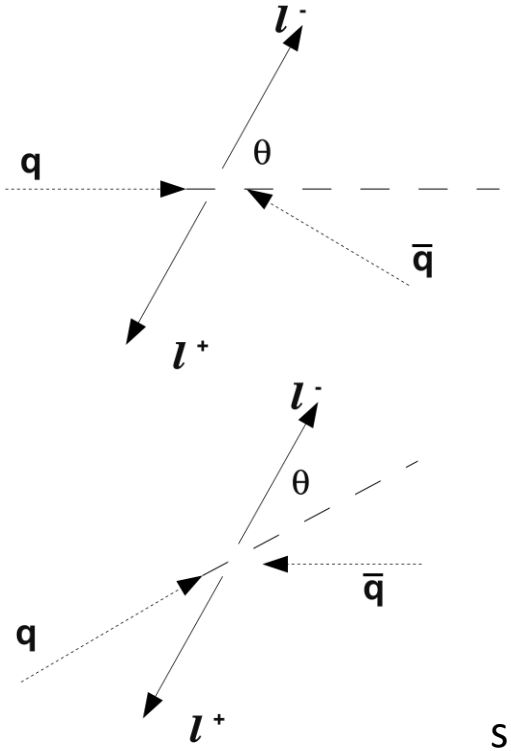
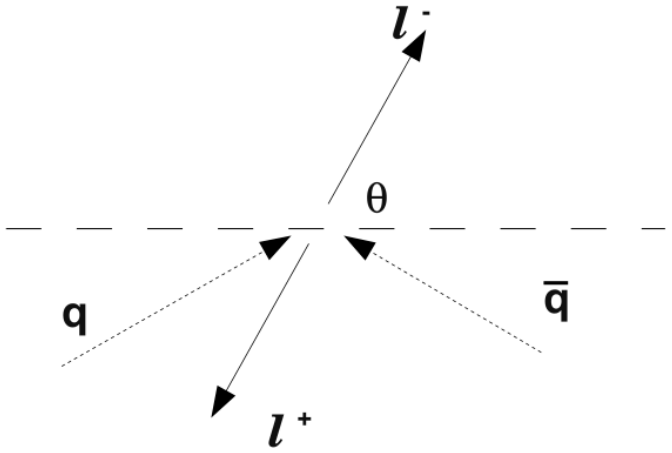
Collins-Soper Frame

- Non-negligible p_T of the lepton pair



- Collins Soper
  - Symmetric axis: incoming partons

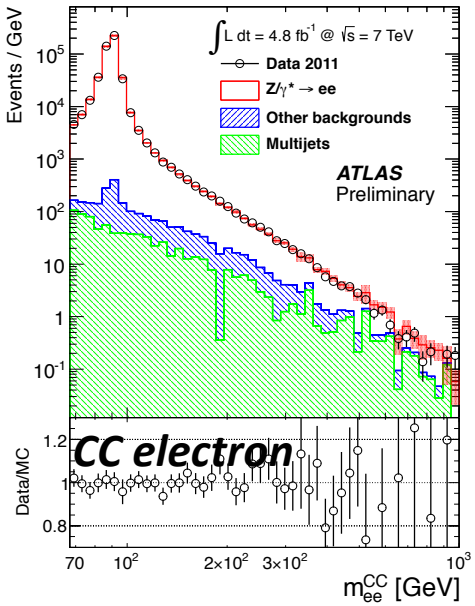


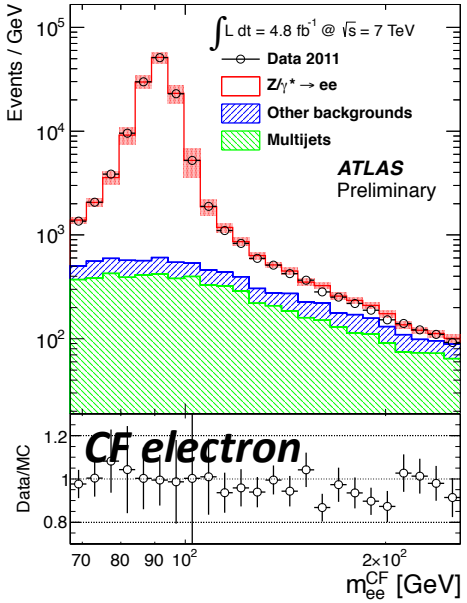
$$\cos\theta^*_{CS} = \frac{p_z(\ell^+\ell^-)}{|p_z(\ell^+\ell^-)|} \frac{2\,(p_1^+ p_2^- - p_1^- p_2^+)}{m(Z/\gamma^*)\sqrt{m(Z/\gamma^*)^2 + p_T(Z/\gamma^*)^2}}$$

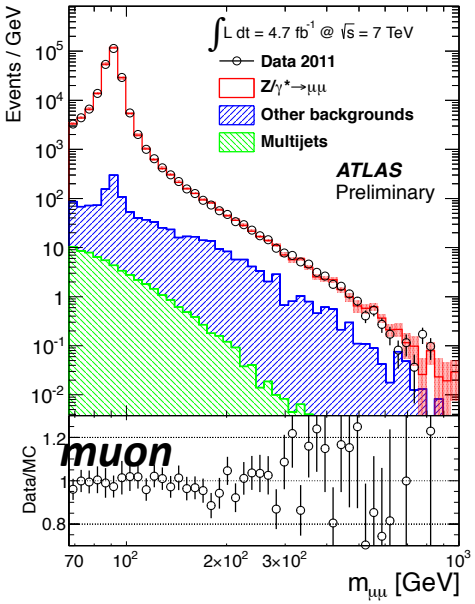
↑ sign is important

$$p_i^{\pm} = \frac{1}{\sqrt{2}}(E_i \pm p_{z,i})$$

m_{ll} Distributions

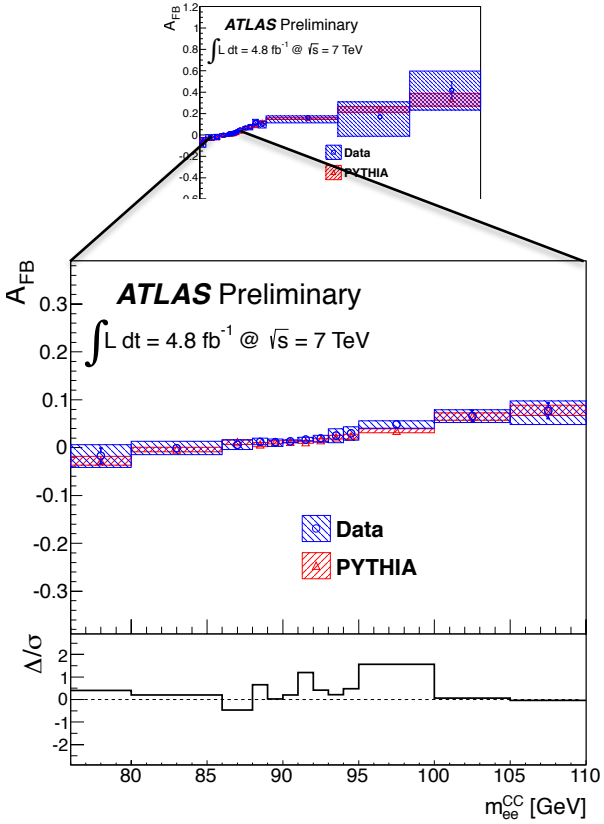




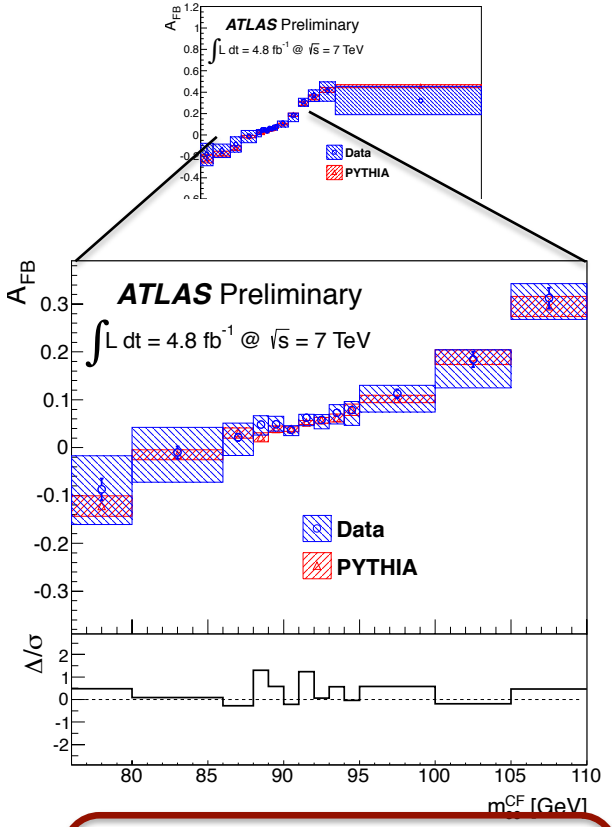


Good data/MC agreement through full invariant mass range
full range used because AFB is a function of dilepton invariant mass

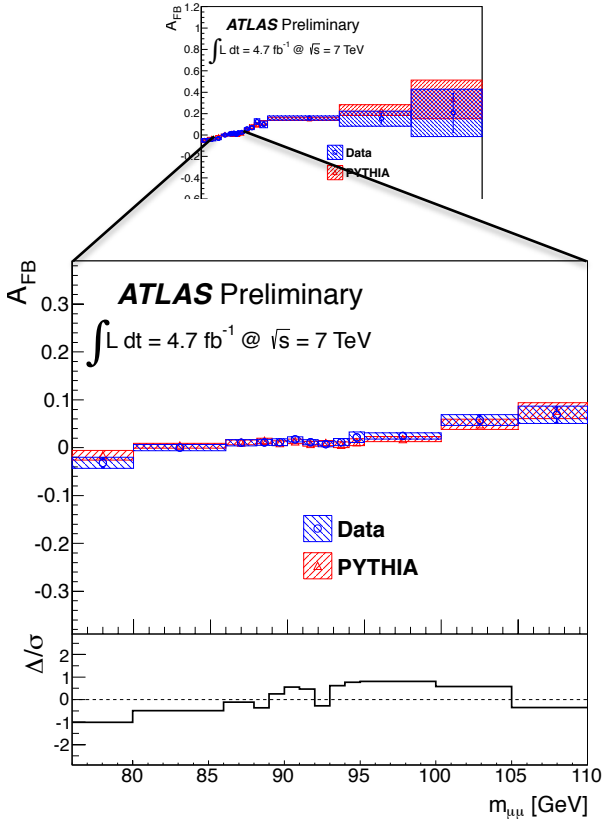
Raw A_{FB} Spectra: Zoomed



CC electron



CF electron channel
asymmetry larger since dilution less of an effect



muon

Systematic Uncertainties

Common

- Parameterization of PDFs
- MC statistics
- Higher Order Corrections (QCD and EWK)
- Unfolding Algorithm

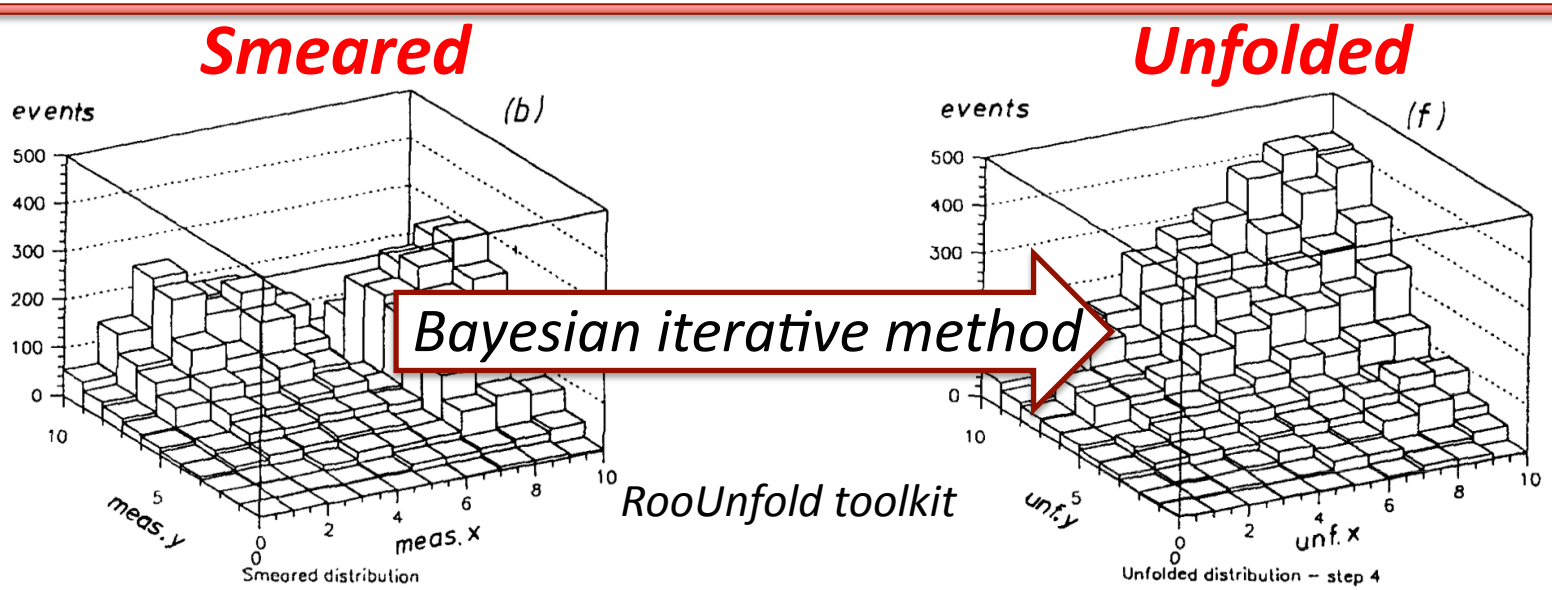
Electron

- Energy Scale/Resolution
- ID (reco, trigger, etc)
- Multijet modeling

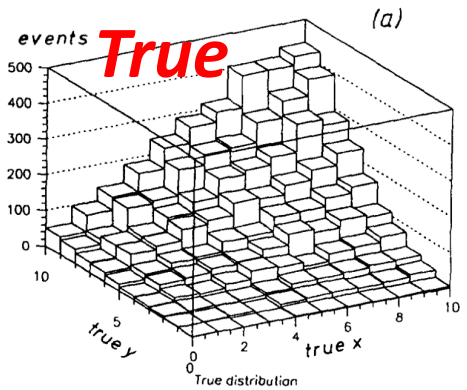
Muon

- Momentum Scale/Resolution
- Alignment
- Smearing

Unfolding

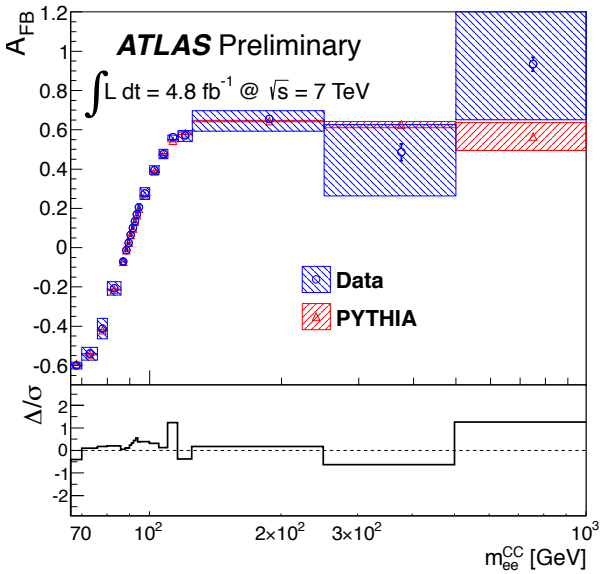


- Mass-bin-migration
  - Detector effects
    - finite resolution, reconstruction efficiencies, pileup
  - QED radiative corrections
    - shifts peak to lower invariant masses
    - unfold to *Born*-level – before FSR

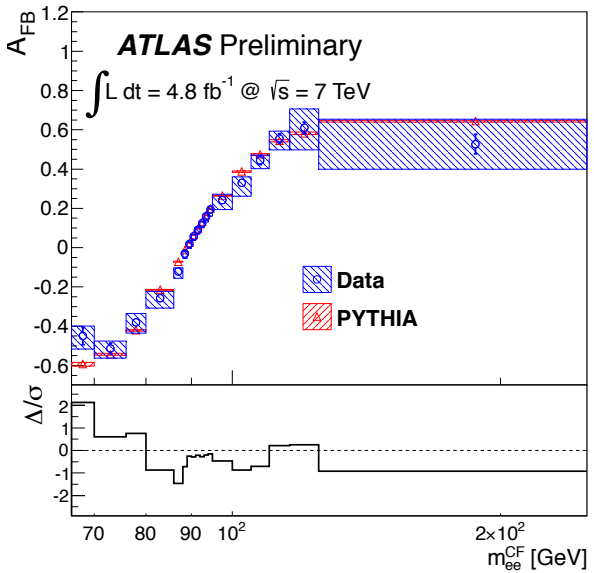


D'Agostini, arXiv:1010.0632v1 [physics.data-an] 4 Oct 2010

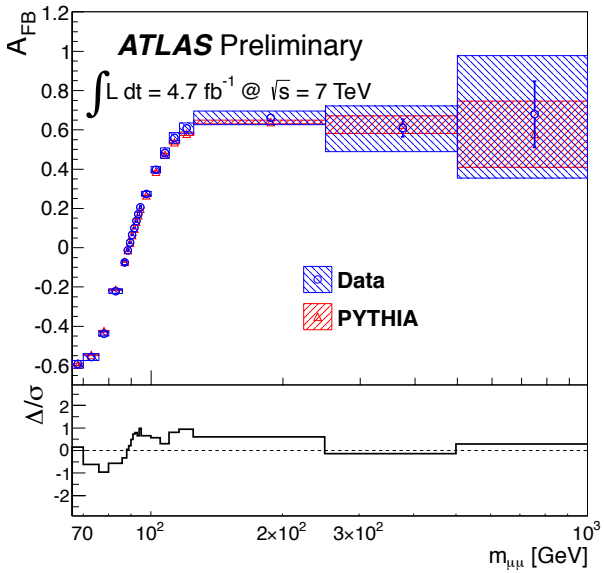
Unfolding the A_{FB} Spectra: A Leading Order Interpretation



electron CC



electron CF



muon

Unfolding for mass-bin-migration, acceptance and dilution

Results from Each Channel

$$\sin^2\theta_W^{\text{eff}} = 0.2288 \pm 0.0009(\text{stat.}) \pm 0.0014(\text{syst.})$$

CC electron

$$\sin^2\theta_W^{\text{eff}} = 0.2294 \pm 0.0009(\text{stat.}) \pm 0.0014(\text{syst.})$$

muon

$$\sin^2\theta_W^{\text{eff}} = 0.2304 \pm 0.0006(\text{stat.}) \pm 0.0010(\text{syst.})$$

CF electron

Our Results and World Averages

	$\sin^2\theta_W^{\text{eff}}$	Δ/σ (wrt LEP+SLC)	Δ/σ (wrt ATLAS)
ATLAS, muons	0.2294 ± 0.0016	-1.3	–
ATLAS, electrons CC	0.2288 ± 0.0017	-1.6	–
ATLAS, electrons CF	0.2304 ± 0.0012	-1.0	–
ATLAS, combined	0.2297 ± 0.0010	-1.8	–
CMS [5]	0.2287 ± 0.0032	-0.9	-0.3
D0 [4]	0.2309 ± 0.0010	-0.6	0.8
CDF [3]	0.2329 ± 0.0012	1.1	2.0
LEP, $A_{\text{FB}}^{0,b}$ [2]	0.23221 ± 0.00029	–	2.3
SLD, A_l [2]	0.23098 ± 0.00026	–	1.2
LEP+SLC [2]	0.23153 ± 0.00016	–	1.8
PDG global fit [29]	0.23146 ± 0.00012	-0.4	1.8