



ATLAS



JOHANNES GUTENBERG  
UNIVERSITÄT MAINZ

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

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R. Caputo

(Universität Mainz)

Snowmass: Seattle Energy Frontier Workshop

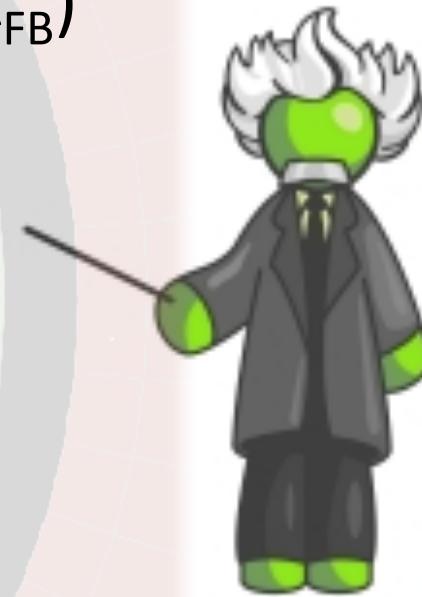
*on behalf of the ATLAS collaboration*

30 June 2013

ATLAS-CONF-2013-046

# 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  $\sin^2(\theta_{W}^{\text{eff}})$ 
  - template extraction using raw  $A_{FB}$
- Conclusions

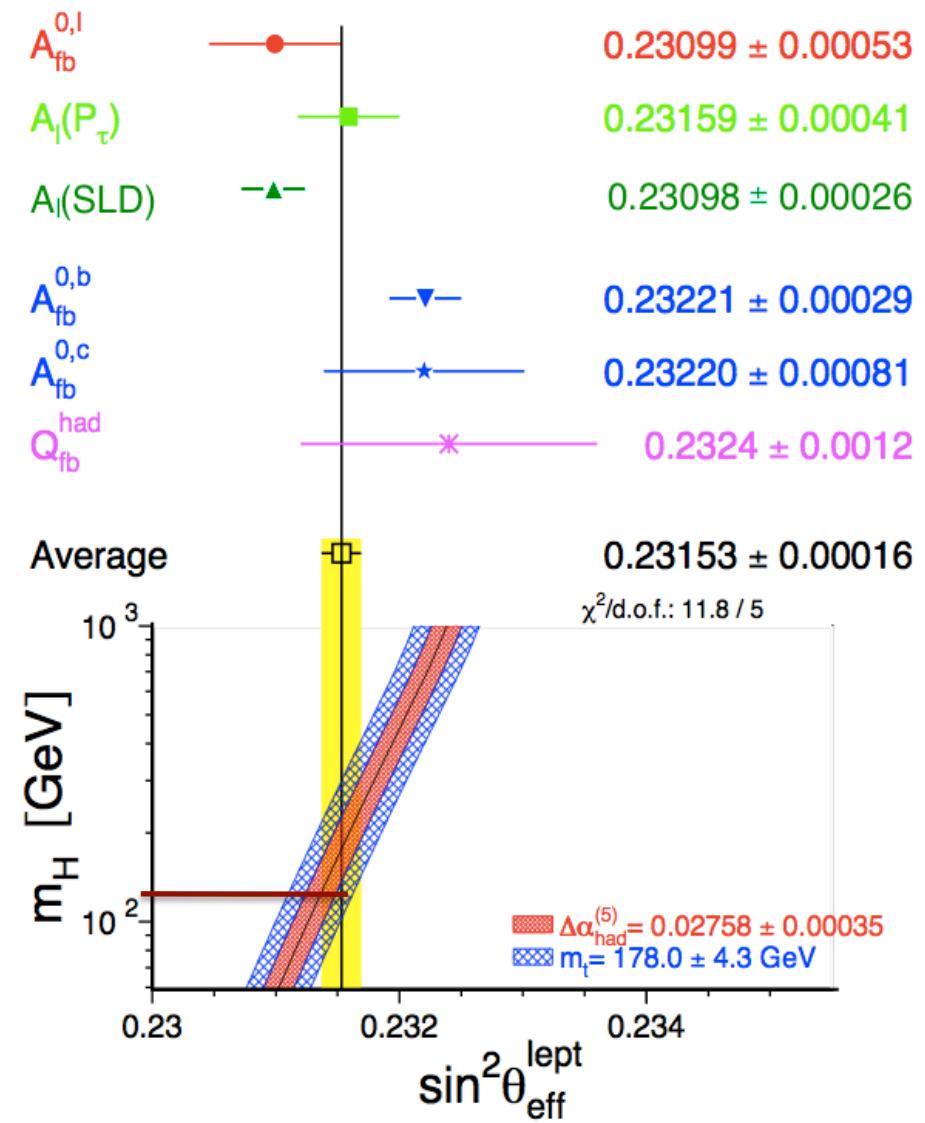


# Motivation

- Reminder:

$$\sin^2(\theta_{\text{eff}}^\ell) = 1 - \frac{m_W^2}{m_Z^2}$$

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



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

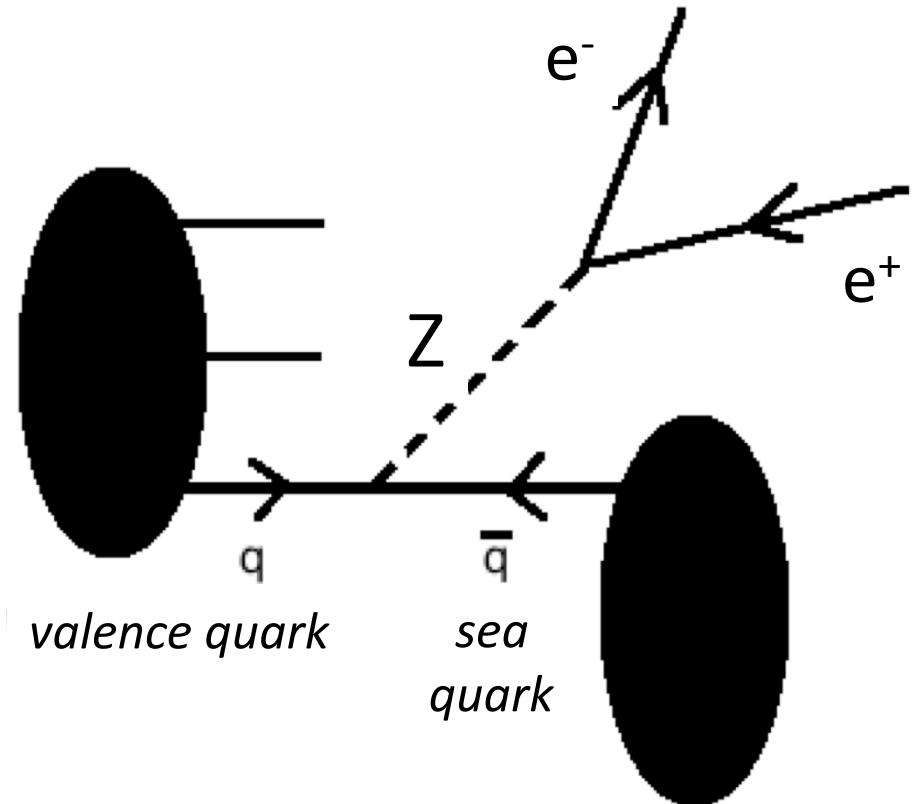
# Measurement Principle

- Asymmetry ( $A_{FB}$ ) in  $Z/\gamma^*$ 
  - vector/axial couplings
  - parity violations in EW interactions

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

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

- Define parameters
  - $\cos(\theta) > 0 \rightarrow$  Forward ( $N_F$ )
  - $\cos(\theta) < 0 \rightarrow$  Backward ( $N_B$ )
- pp colliders: incoming quark direction
  - determined by sign of  $y(\ell\ell)_z$
  - misidentified quark
    - dilution (reduction)  $A_{FB}$



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

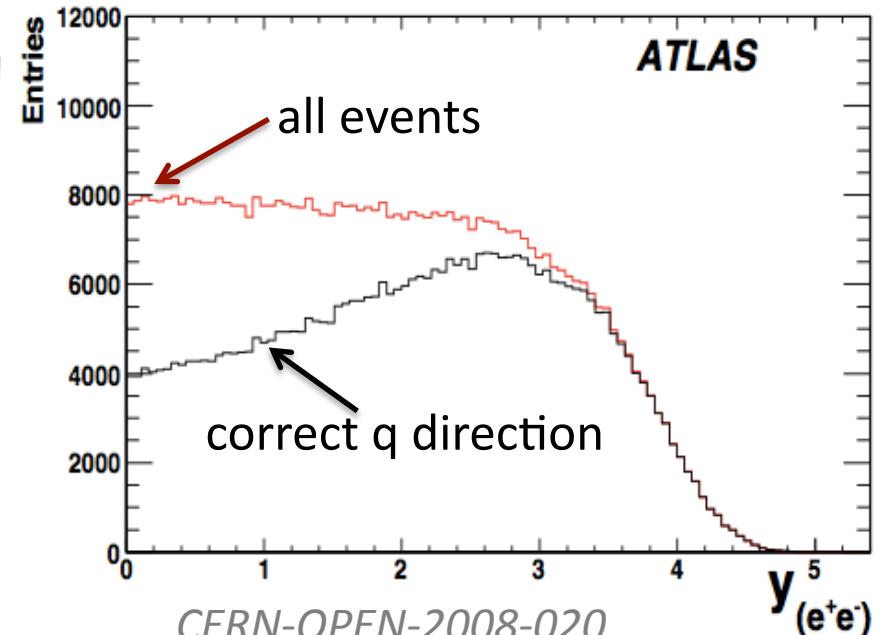
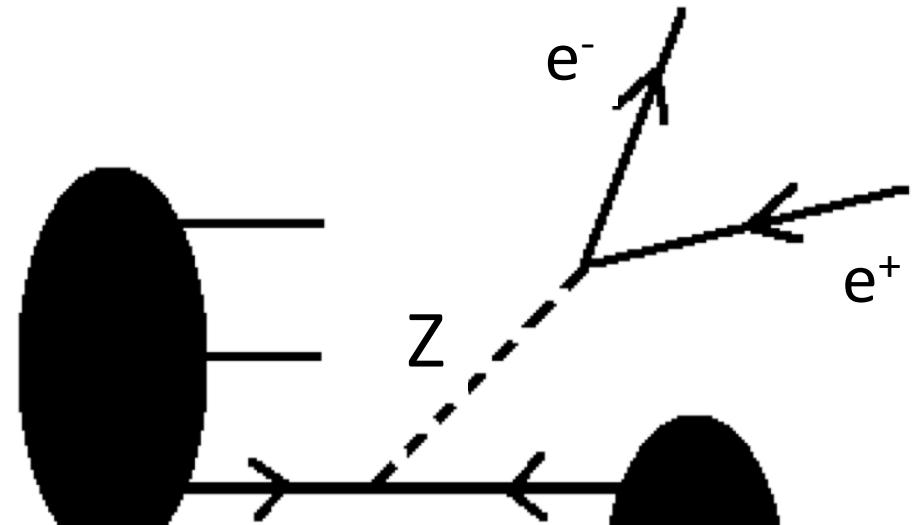
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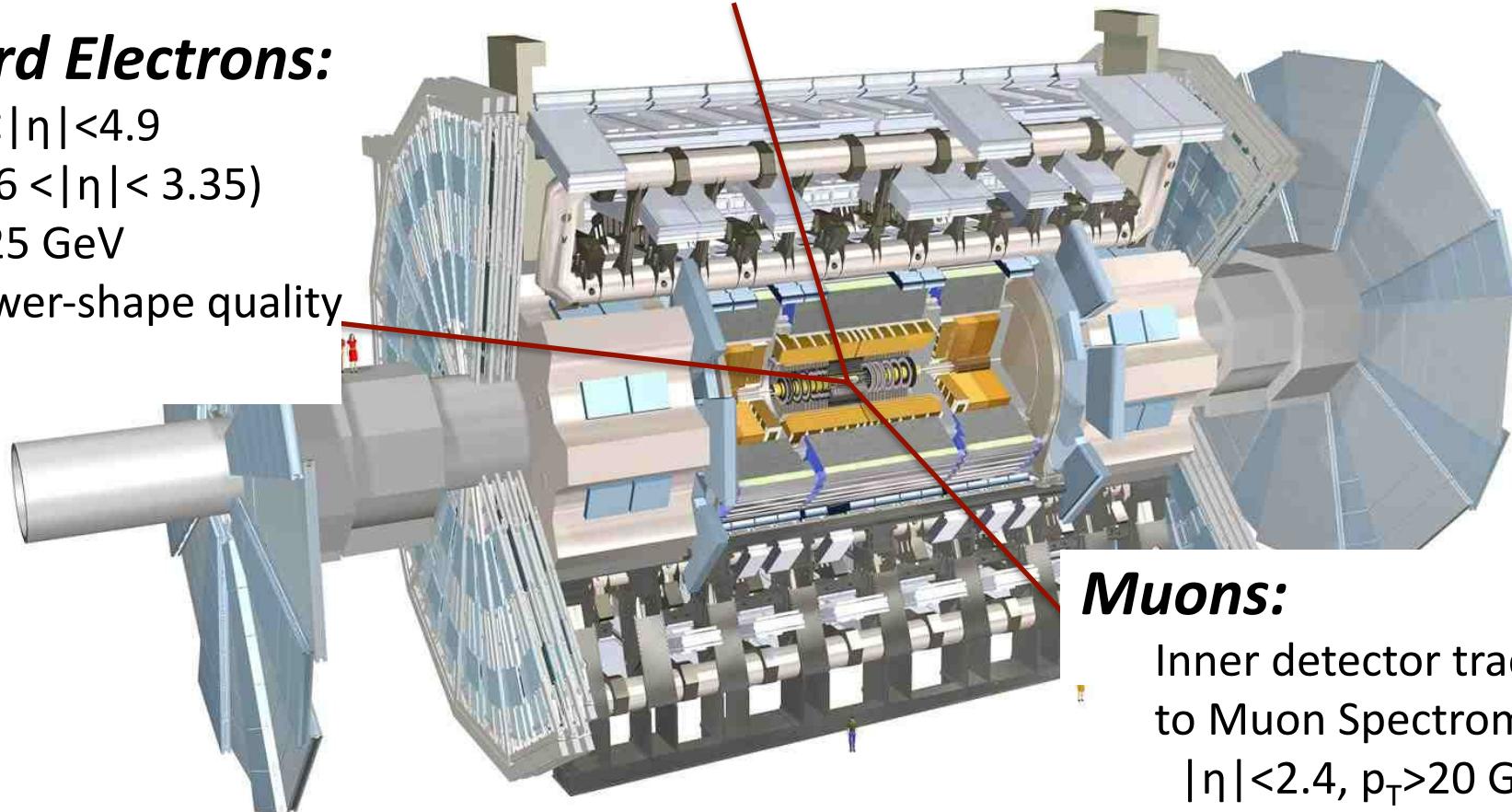
# Lepton Reconstruction

## *Central Electrons:*

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

## *Forward Electrons:*

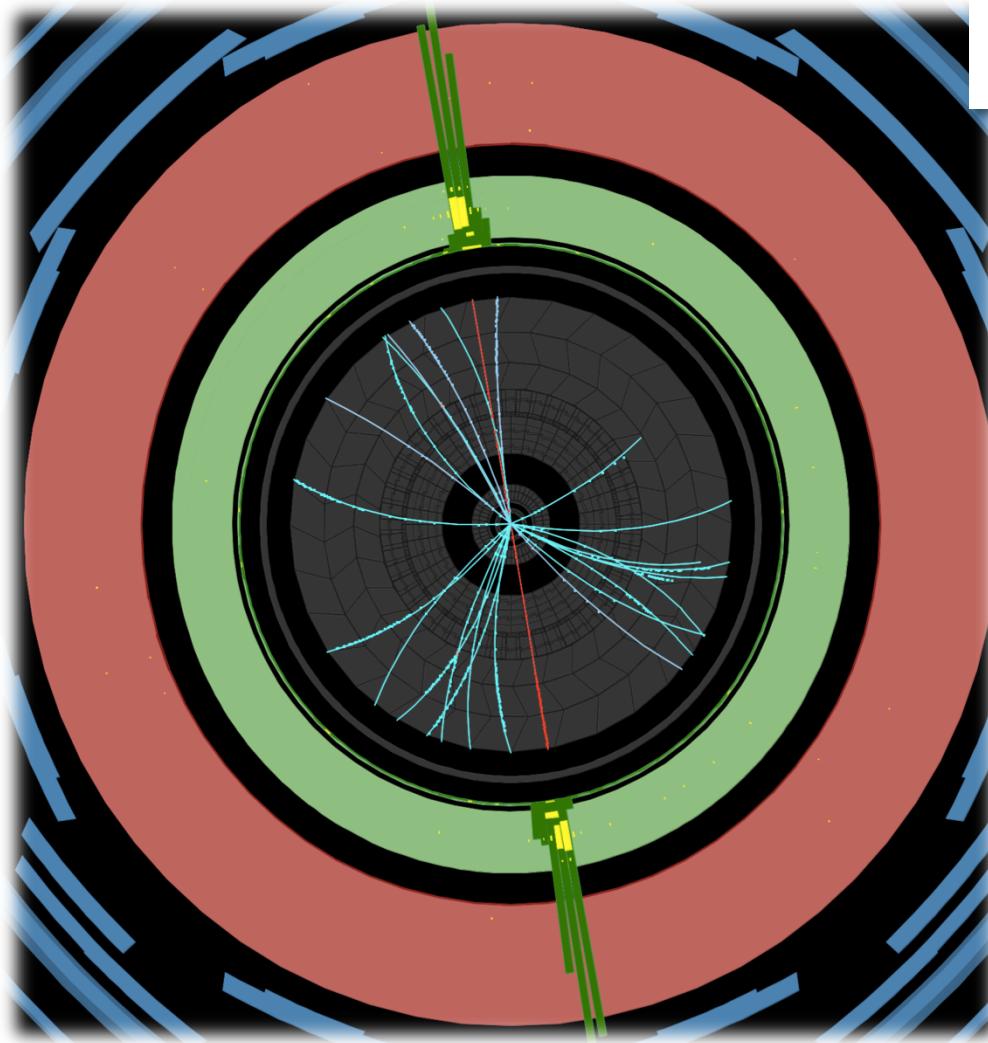
$2.5 < |\eta| < 4.9$   
 $(3.16 < |\eta| < 3.35)$   
 $E_T > 25$  GeV  
shower-shape quality



## *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  $\sqrt{s}=7 \text{ TeV}$   $\int Ldt = 4.8 fb^{-1}$

## Lepton pair cuts

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

# Signal and Backgrounds

## Monte Carlo Signal

- $Z \rightarrow ee/\mu\mu$ : PYTHIA interfaced with PHOTOS
- NLO contributions estimated with HORACE (NLO EWK) and MCFM (NLO QCD)

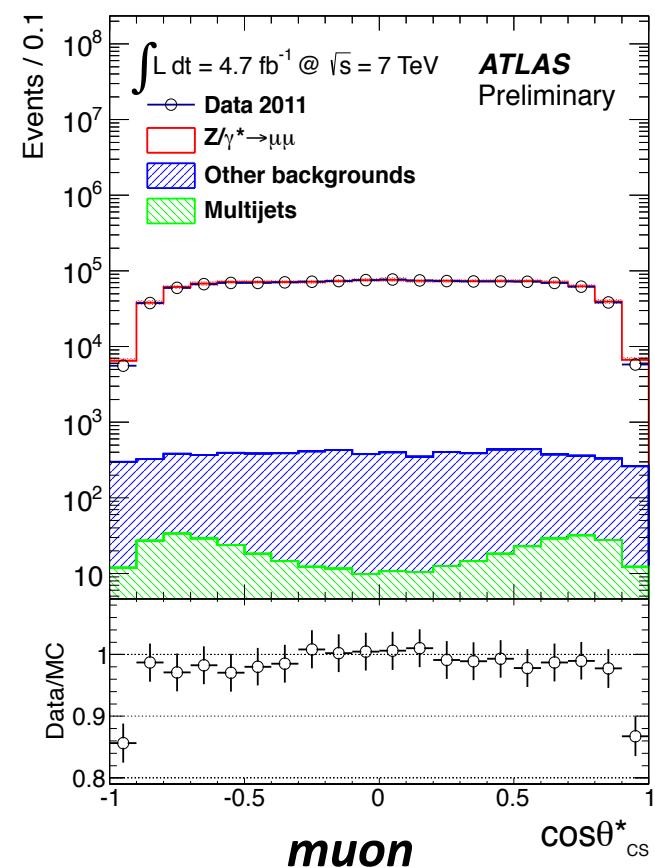
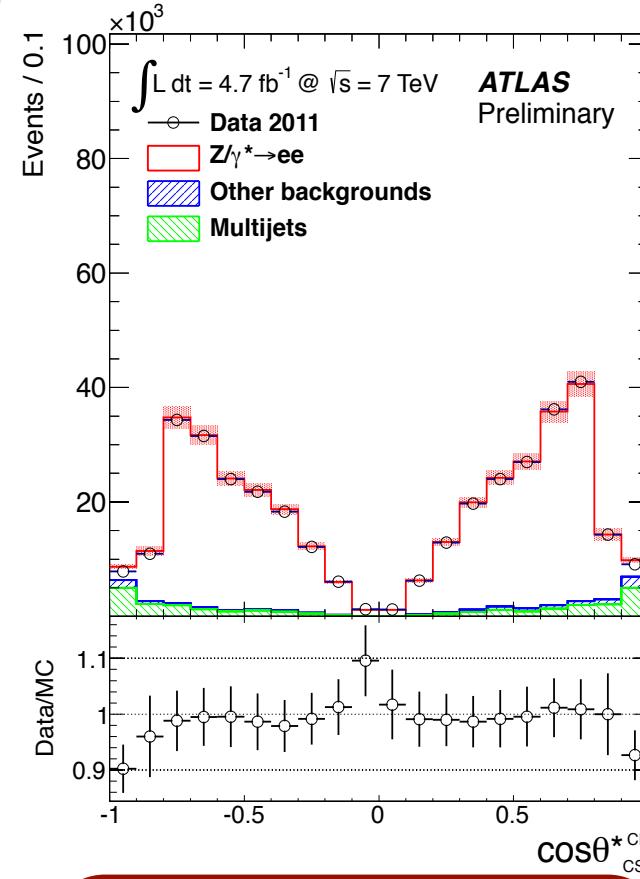
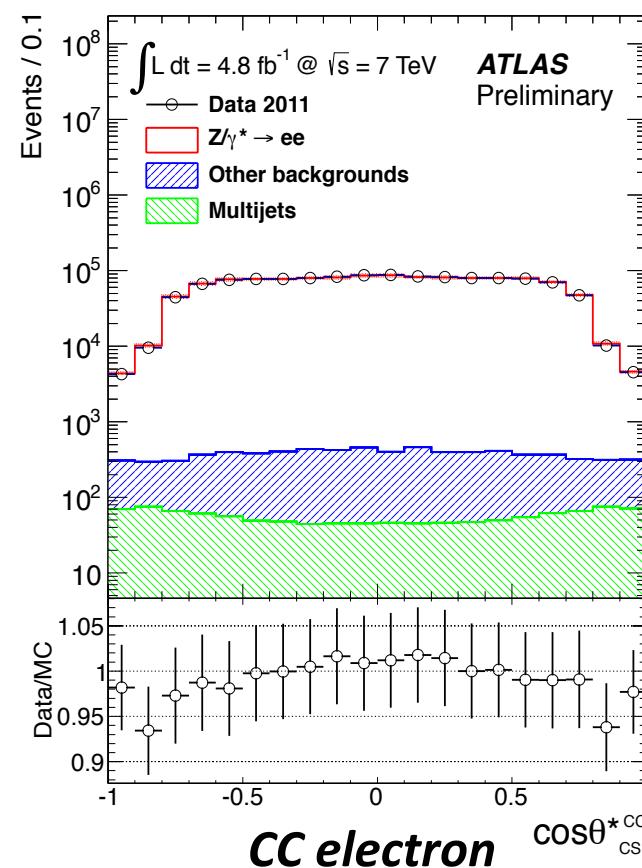
## Monte Carlo Background Estimation

- diboson(WW/ZZ/WZ): HERWIG
- $t\bar{t}$ : MC@NLO
- $Z \rightarrow \tau\tau$ : PYTHIA/PHOTOS

## Data Driven Background Estimation

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

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



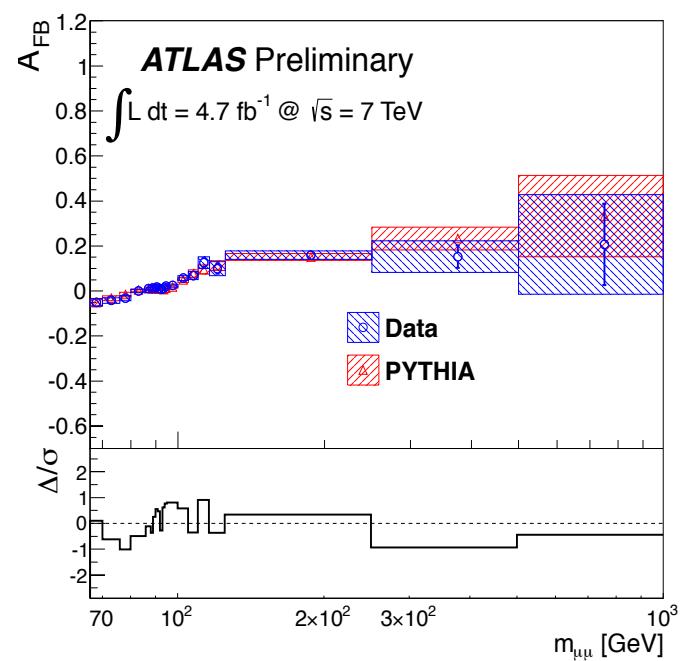
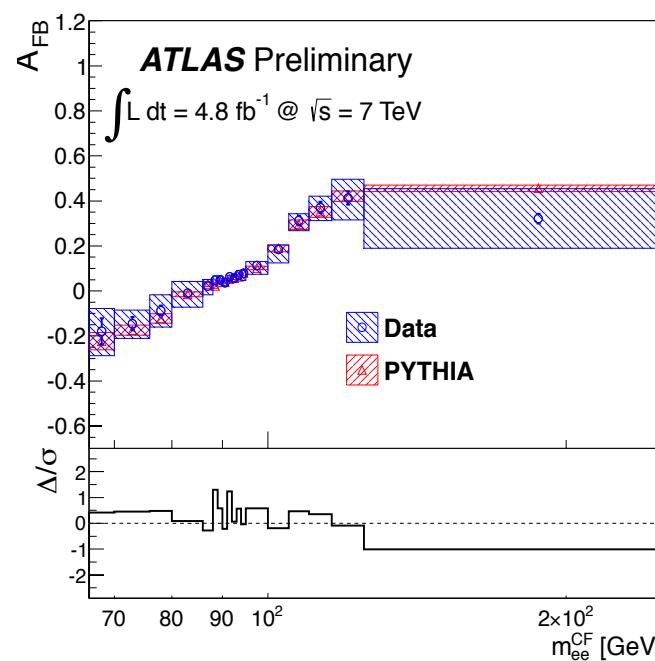
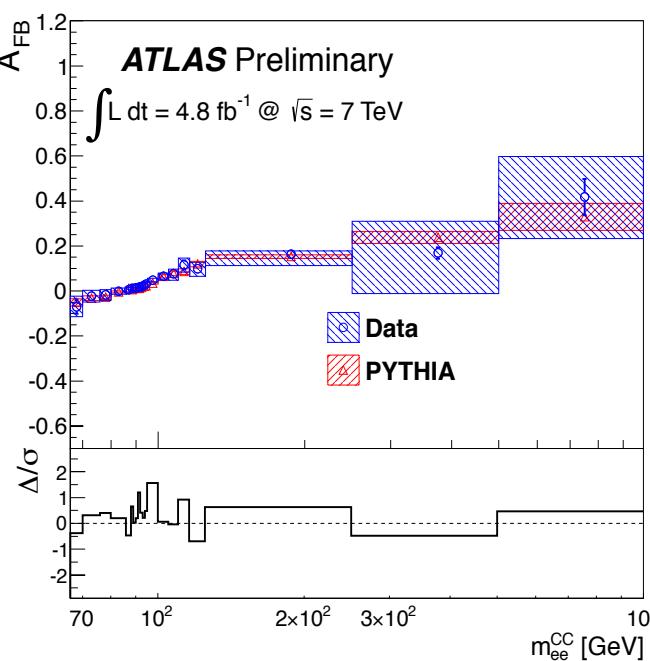
Integrate  $\cos(\theta^*_{\text{CS}}) > 0, < 0$   
in mass bins  
to determine  $N_F$  and  $N_B$

**CF electron channel**  
forward e:  $2.5 < |\eta| < 4.9$   
Asymmetry visible already  
suffers less from dilution

Reminder:

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

# Raw $A_{FB}$ Spectra



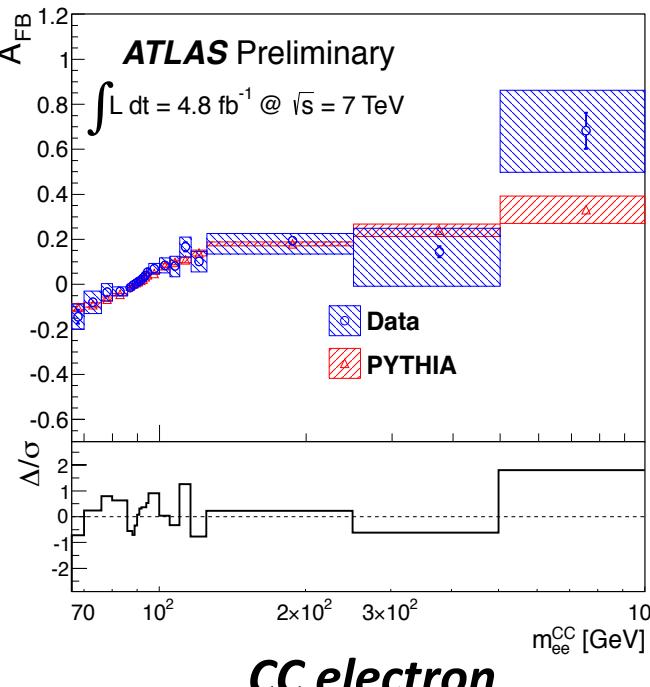
$\Delta = (\text{data}-\text{MC})$   
 $\sigma = \text{total uncertainty}$

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

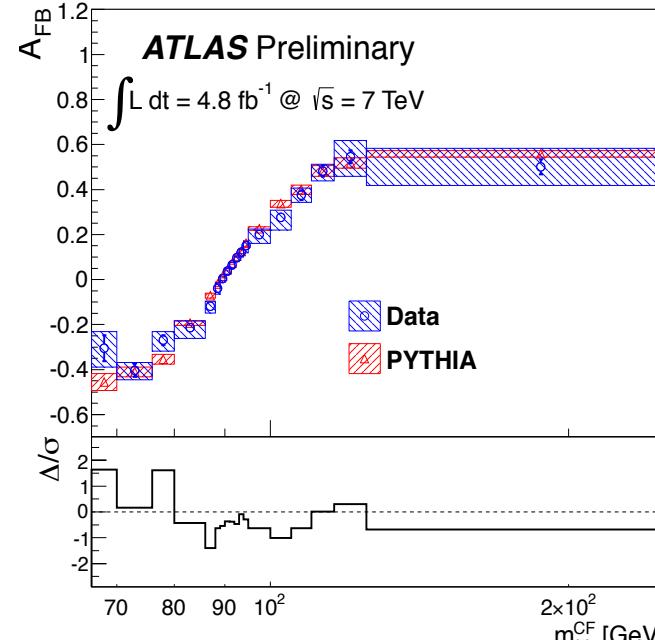
*Reminder:*

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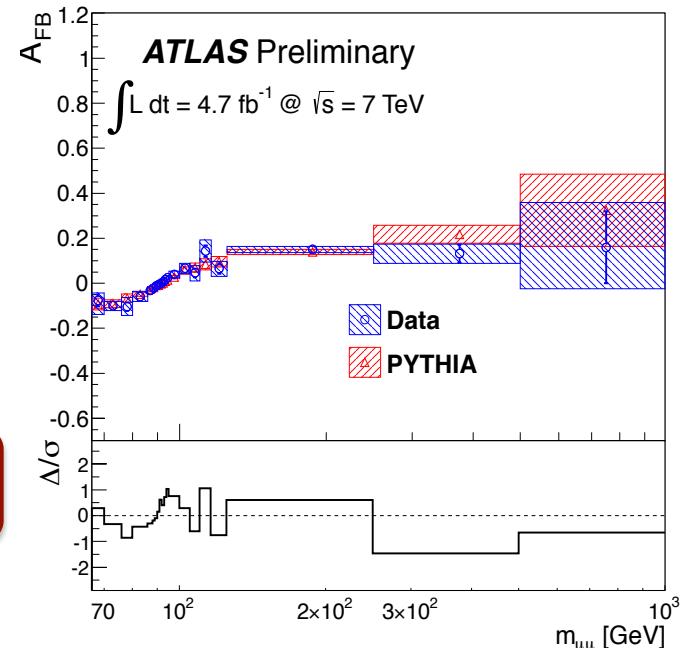
# Unfolding the $A_{FB}$ Spectra: Mass-bin-Migration



dramatic effect in low mass bins, big impact from 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





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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

**Default:**

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

Create templates for each of these  $A_{FB}$  distributions

- $A_{FB}$  reconstruction as before

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

- $A_{FB}$  range 70-250 GeV

# Combination

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

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

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

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

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

**ATLAS Preliminary**

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

PDF and higher-order systematic  
 uncertainties correlated

# Systematic Uncertainties

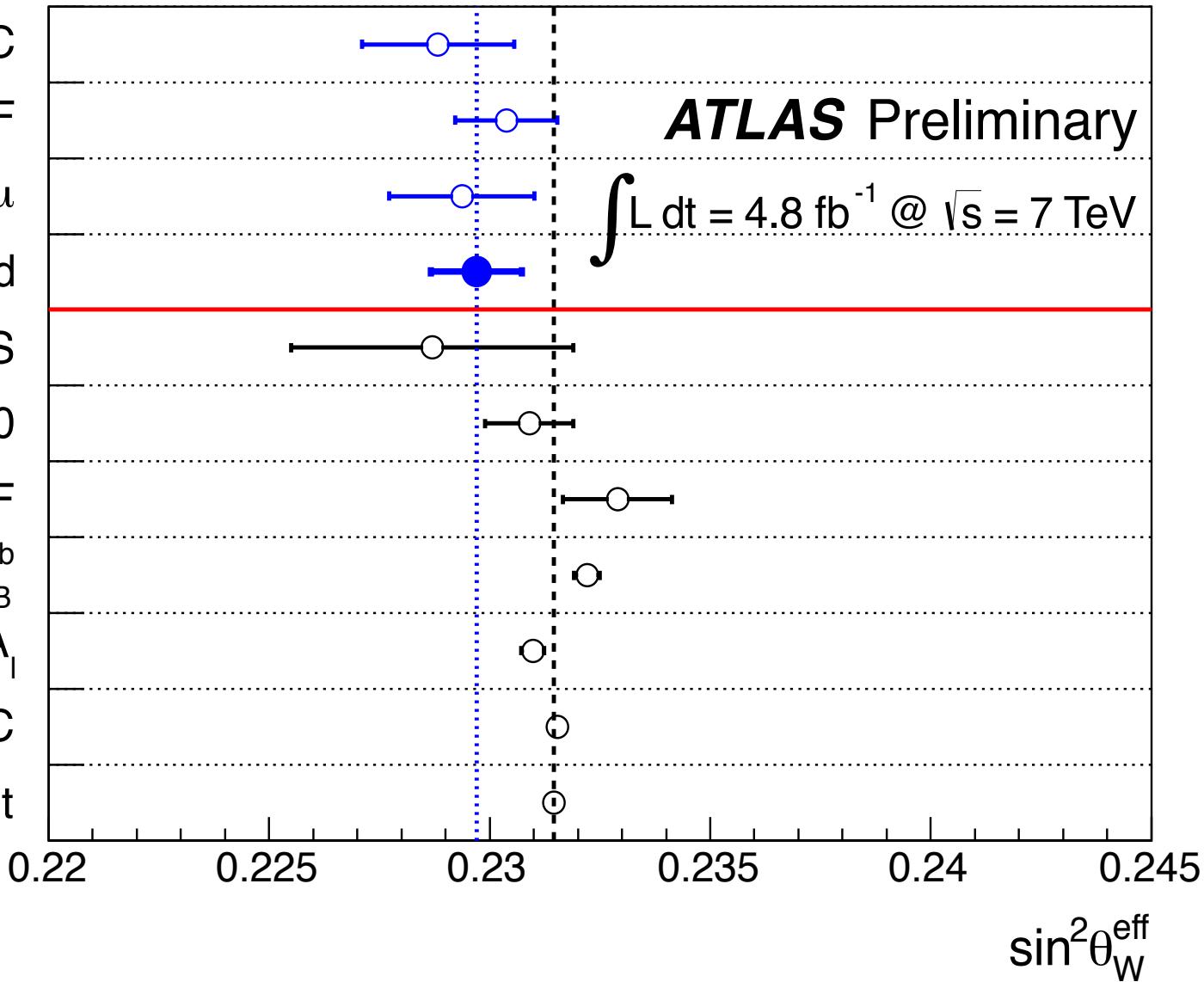
**ATLAS Preliminary**

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

ATLAS, e CC  
 ATLAS, e CF  
 ATLAS,  $\mu$   
 ATLAS combined  
 CMS  
 D0  
 CDF  
 LEP,  $A_{FB}^{0,b}$   
 SLD,  $A_I$   
 LEP+SLC  
 PDG Fit



# Summary and Conclusions

- First ATLAS Measurement of  $A_{FB}$ 
  - ATLAS 2011 data  $\sqrt{s}=7 \text{ TeV} \int L dt = 4.8 fb^{-1}$
  - 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/ $\mu$  in the measurement of  $\sin^2\theta_W^{\text{eff}}$  at a hadron collider
  - As precise as best hadron collider results

# Outlook

- Limited by PDF uncertainty (central)
  - 4x MC stats for paper (in production)
- Limited by Energy scale/smearing (forward)
  - forward electrons difficult, best for  $\sin^2\theta_W^{\text{eff}}$
  - methods to reduce for 2012 underway
- 4x statistics in 2012
  - help constrain energy scale/smearing



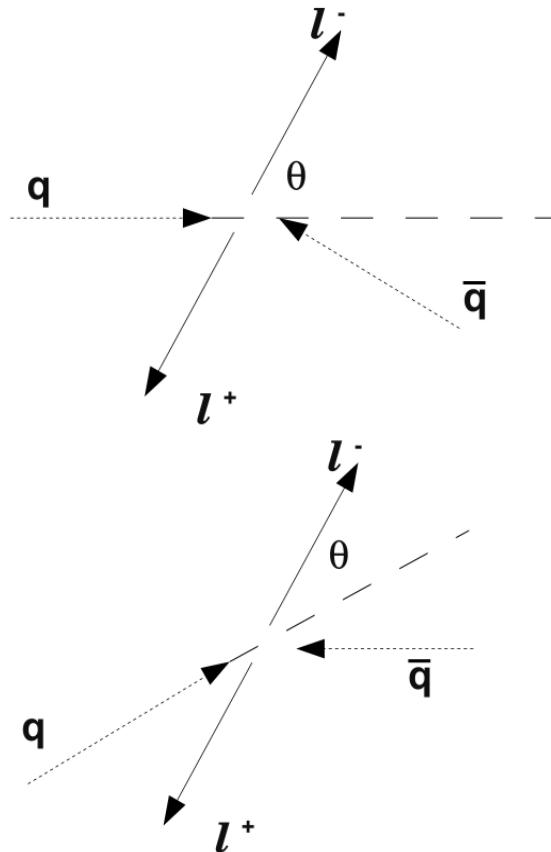
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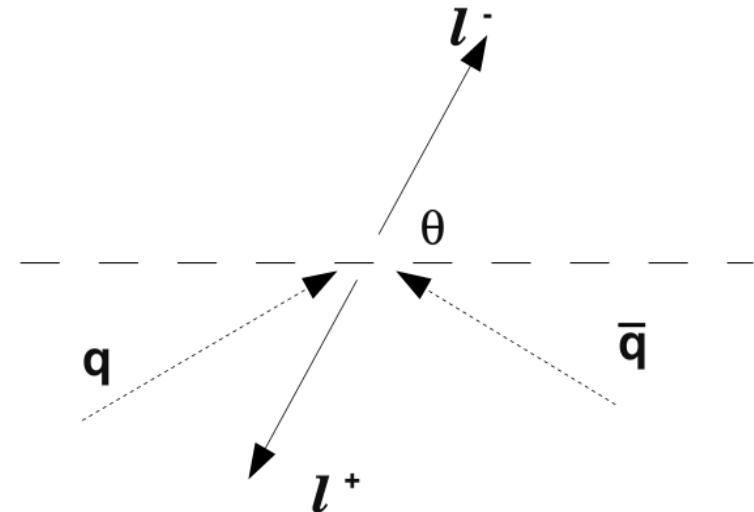
# BACKUPS

# 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

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

# Signal and Backgrounds

## Monte Carlo Signal

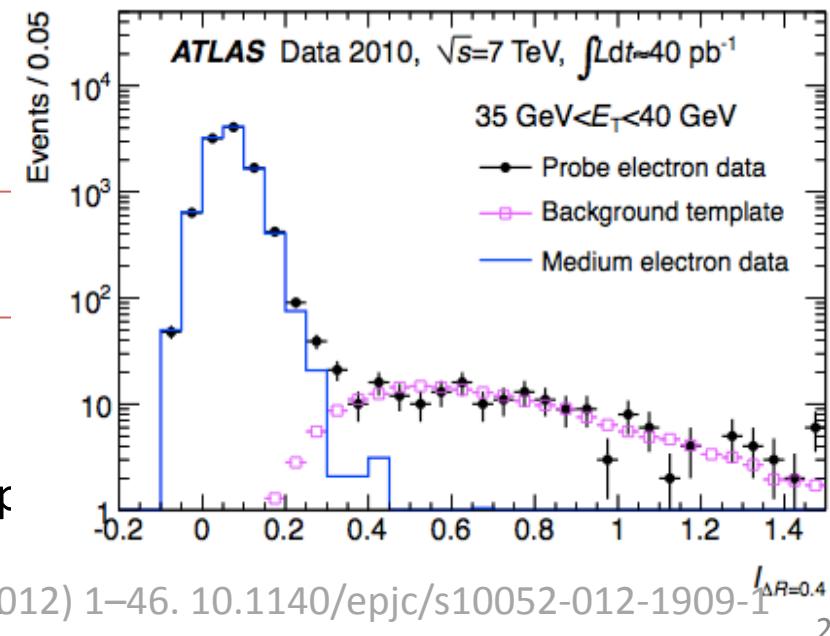
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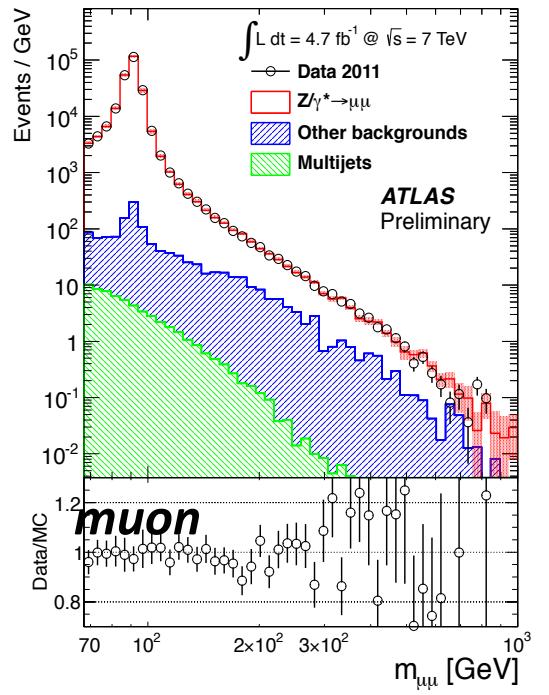
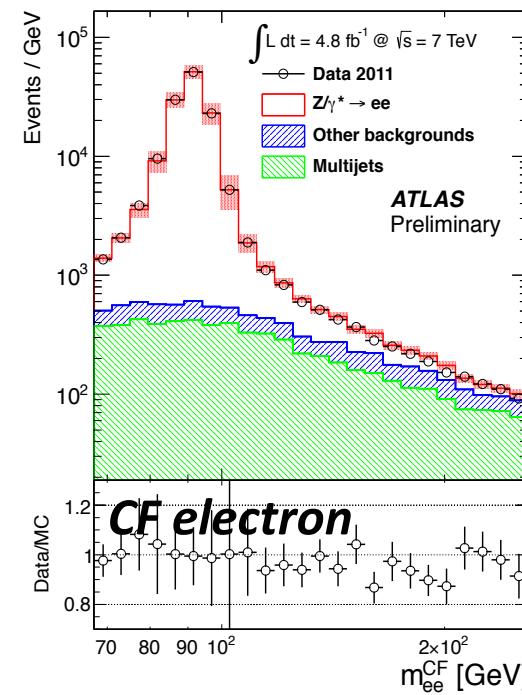
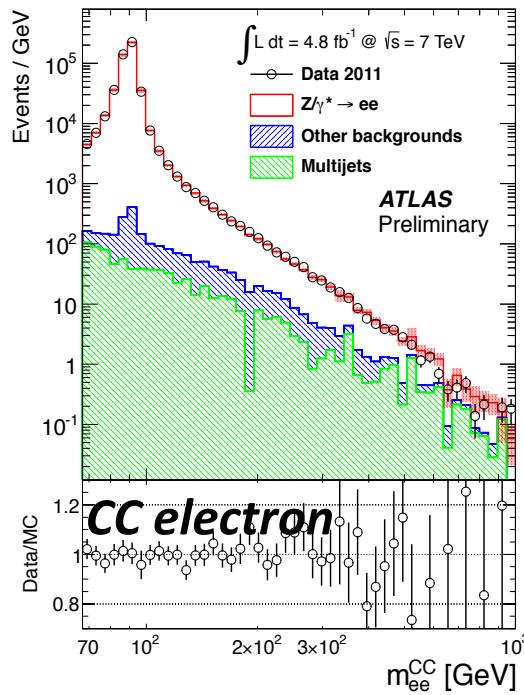
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## Data Driven Background Estimation

- Multijets
  - invert selection: create background enhanced sample
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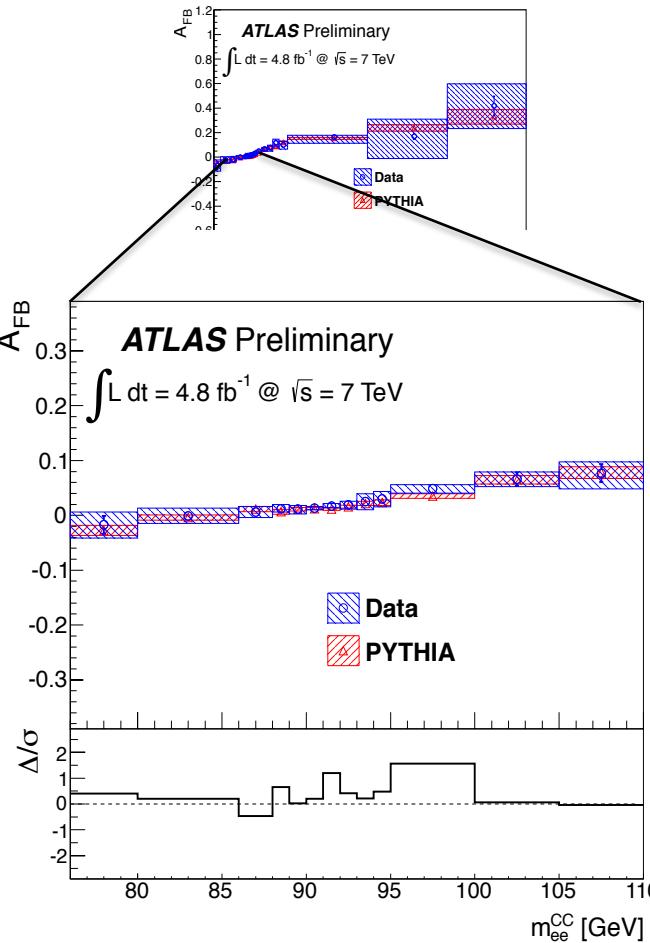


# $m_{\parallel}$ Distributions

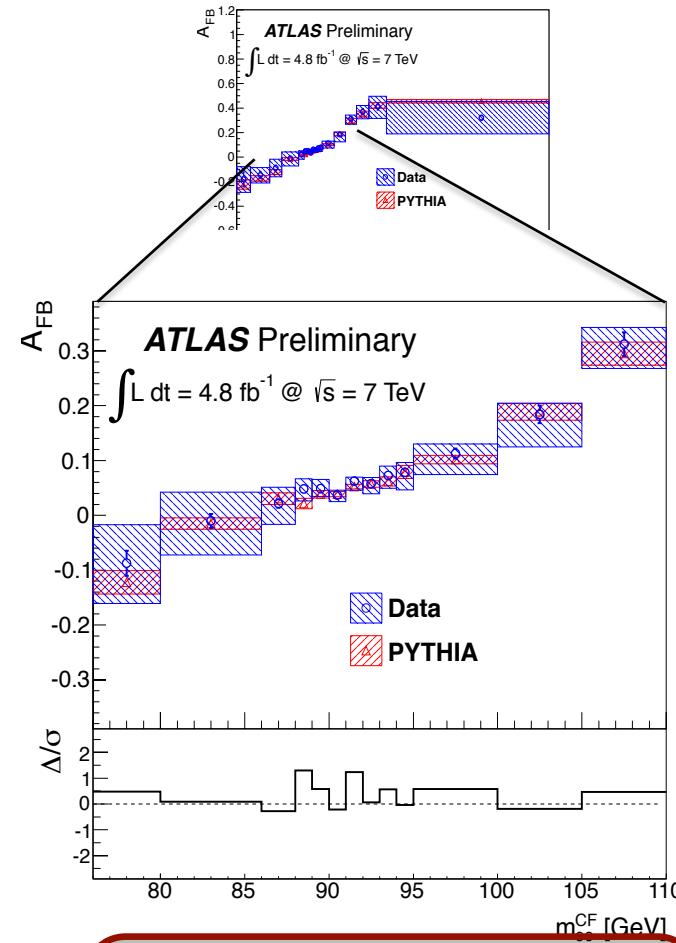


Good data/MC agreement through full invariant mass range  
 full range used because AFB is a function of dilepton  
 invariant mass

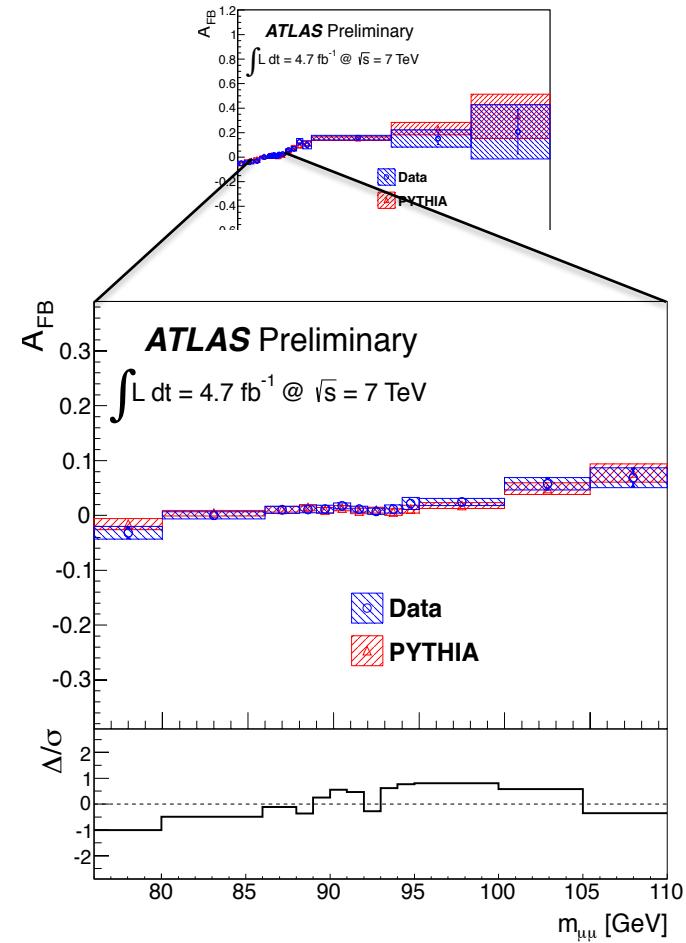
# Raw $A_{FB}$ Spectra: Zoomed



*CC electron*



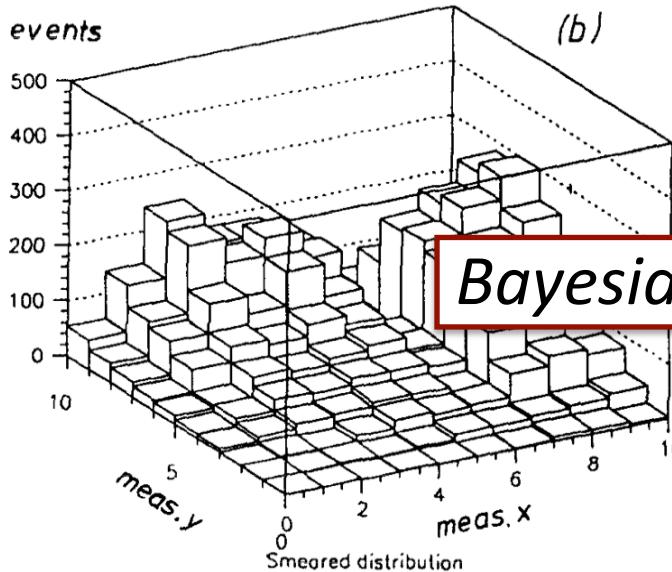
***CF electron channel***  
 asymmetry larger since  
 dilution less of an effect



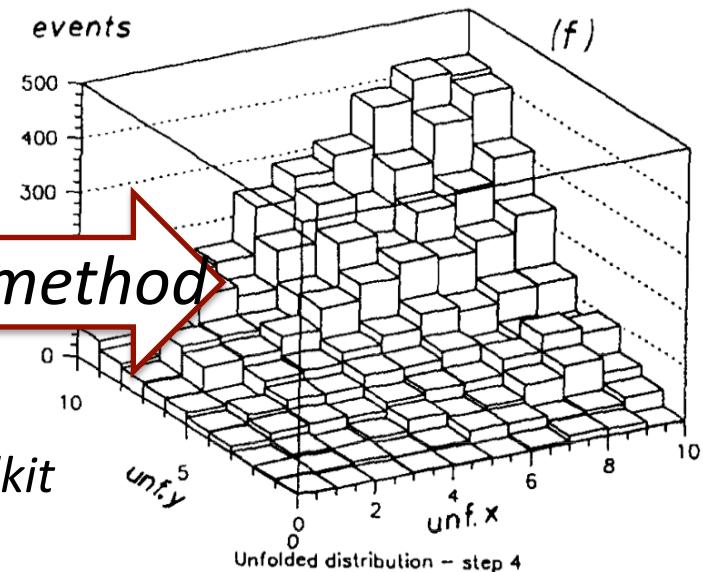
*muon*

# Unfolding

*Smeared*



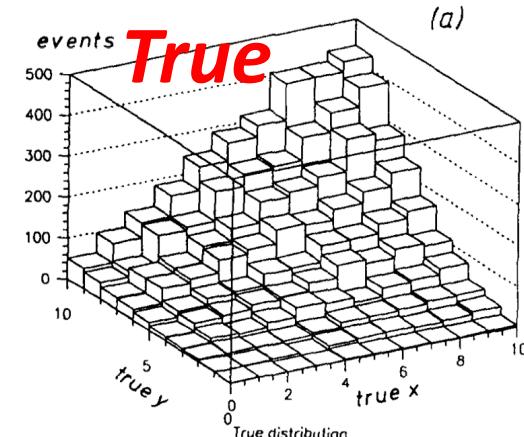
*Unfolded*



*Bayesian iterative method*

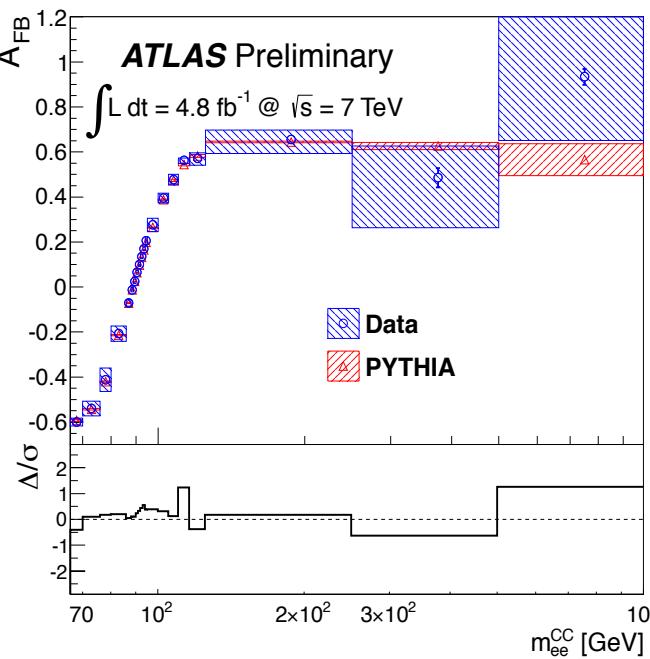
RooUnfold toolkit

- 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

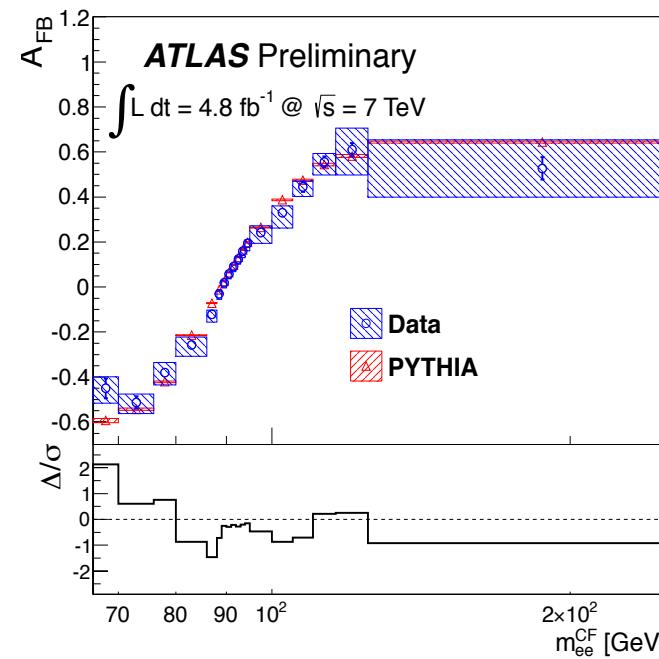


D'Agostini, arXiv:1010.0632v1  
[physics.data-an] 4 Oct 2010

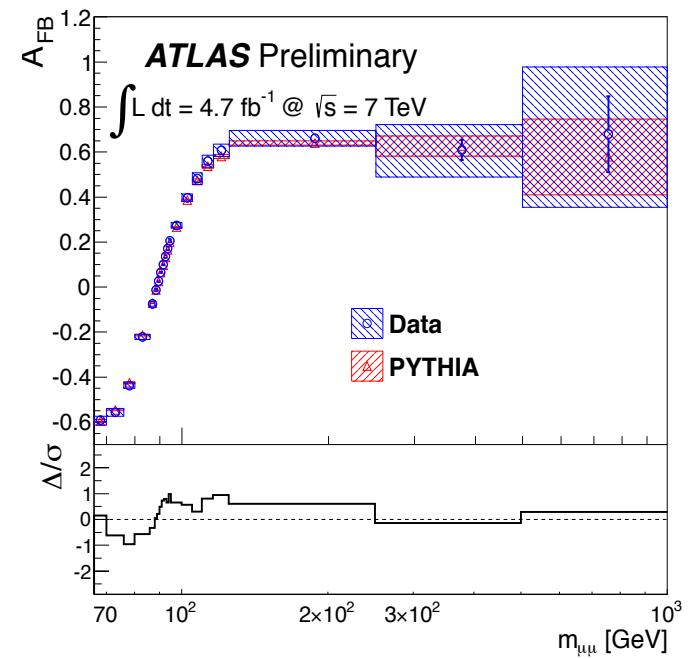
# Unfolding the $A_{FB}$ Spectra: A Leading Order Interpretation



electron CC



electron CF



muon

Unfolding for mass-bin-migration, acceptance and dilution

# Our Results and World Averages

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