ATLAS and CMS forward-backward charge asymmetry and $\sin^2\theta_{eff}^{lepton}$ measurements in Z production

Anna Di Ciaccio
University of Roma Tor Vergata and INFN
On behalf of the ATLAS and CMS collaborations

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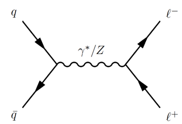
Motivations for A_{FB} measurement

- DY A_{FB} charge asymmetry in Z/γ^* production
  - Provides a consistency test of the Standard Model
    - parity violating properties of the EW interactions
    - test of vector and vector-axial couplings of EW interactions

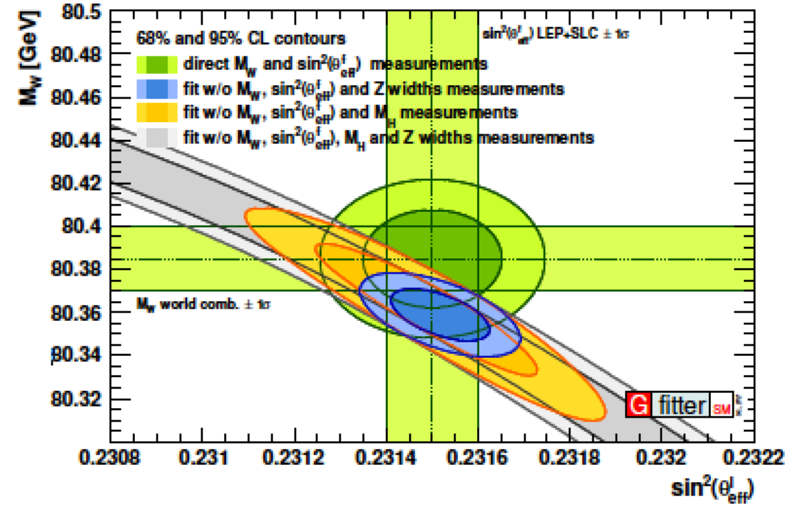
$$q\bar{q} \rightarrow Z/\gamma^* \rightarrow \ell^+\ell^-$$



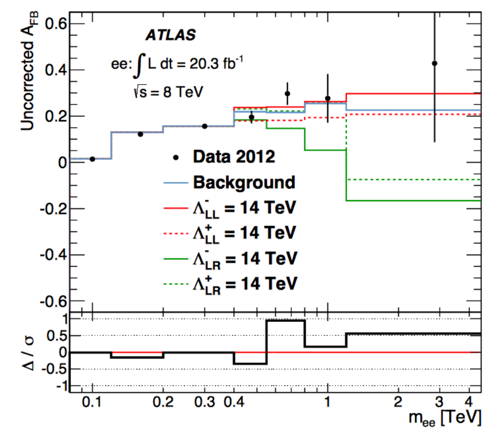
- Around the Z-pole
  - Extraction of the weak effective mixing angle
    - $A_{FB} = f(\sin^2\theta_{eff})$
    - $\sin^2\theta_{eff}$ and M_W precision measurements probe for new physics

- At high mass
  - Sensitive to many scenarios of physics beyond the Standard Model
  - Deviations from the SM prediction may indicate the existence of new neutral gauge bosons

- Precision tests of the SM were possible thanks to the excellent performance of the ATLAS and CMS detectors in Run 1



M_W vs $\sin^2(\theta^l_{eff})$ for the direct measurement compared to the fit including direct M_H measurement



Eur. Phys. J. C. 74:3134

A_{FB} and weak mixing angle measurements

- A_{FB} is measured in the DY Z/γ^* production $q\bar{q} \rightarrow Z/\gamma^* \rightarrow \ell^+\ell^-$
  - The LO differential cross-section at parton level is :

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

θ is the angle of the neg. lepton relative to the quark momentum in the di-lepton rest frame.

- Linear term leads to a charge asymmetry A_{FB} in the distribution of the polar angle θ of the lepton:

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{\int_0^1 \frac{d\sigma}{d\cos\theta} d\cos\theta - \int_{-1}^0 \frac{d\sigma}{d\cos\theta} d\cos\theta}{\int_0^1 \frac{d\sigma}{d\cos\theta} d\cos\theta + \int_{-1}^0 \frac{d\sigma}{d\cos\theta} d\cos\theta} = \frac{N_F - N_B}{N_F + N_B} = \frac{3B}{8A}$$

$\cos\theta > 0$: Forward event
$\cos\theta < 0$: Backward event

- the weak mixing angle is related to the vector coupling g_v and can be extracted by A_{FB} at the M_z scale.
- $\sin^2\theta_w$ at three level is defined as: 1- m_w^2/m_z^2 . Including higher order EW corrections the tree level expression of the couplings g_v and g_A are modified. The $\sin^2\theta_{eff}$ is related to the EW coupling g_v by the relationship:

$$\bar{g}_V^f = \sqrt{\rho_f}\left(T_f^3 - 2Q_f\sin^2\theta_{\rm eff}\right), \quad \text{with} \quad \sin^2\theta_{\rm eff} = \kappa_f\sin^2\theta_W$$

- The EW corrections are absorbed into ρ_f and κ_f.

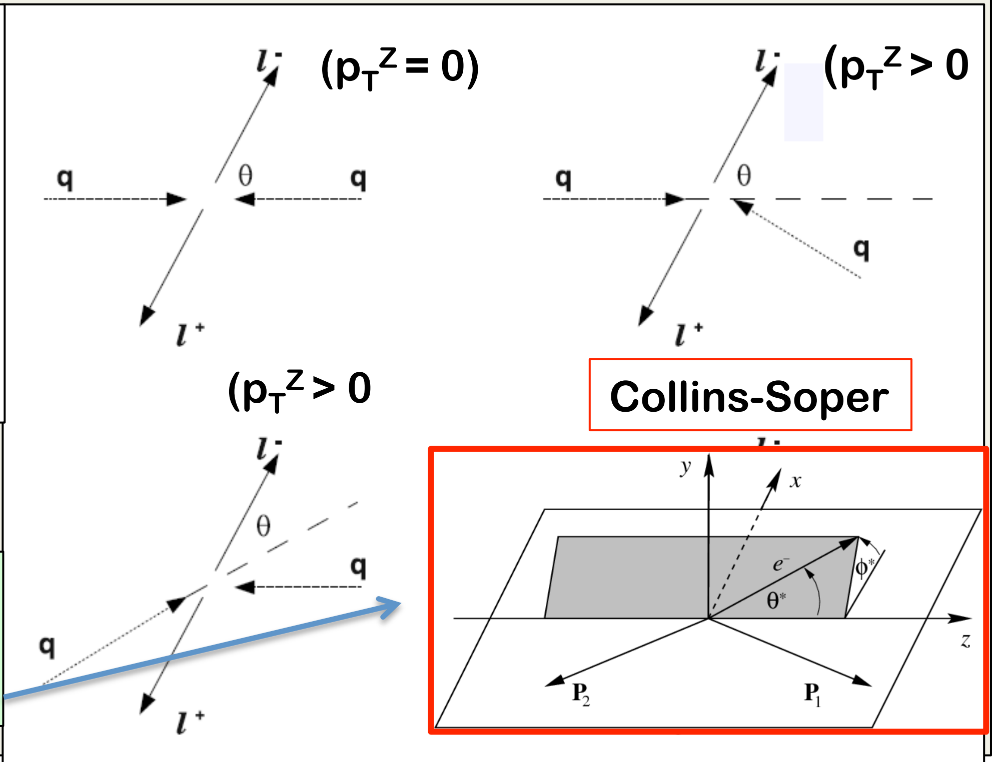
Measurement of A_{FB} in pp collisions

- The definition of the angle θ is ambiguous when the transverse momentum of the lepton pair in the lab frame is not negligible ($p_T^Z>0$)
- The Collins-Soper dileptons reference frame resolves this ambiguity
- θ^*_{CS} is defined as the angle between the lepton momentum and a symmetric axis with respect to the incoming partons

$$\cos\theta^*_{CS} = \frac{p_{z,\ell\ell}}{|p_{z,\ell\ell}|}\frac{2(p_1^+p_2^- - p_1^-p_2^+)}{m_{\ell\ell}\sqrt{m_{\ell\ell}^2 + p_{T,\ell\ell}^2}}$$

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

θ^*_{CS} is the angle between the lepton momentum and the axis that bisects the direction of one proton and the direction opposite to the other proton in the c.m. frame of the dileptons

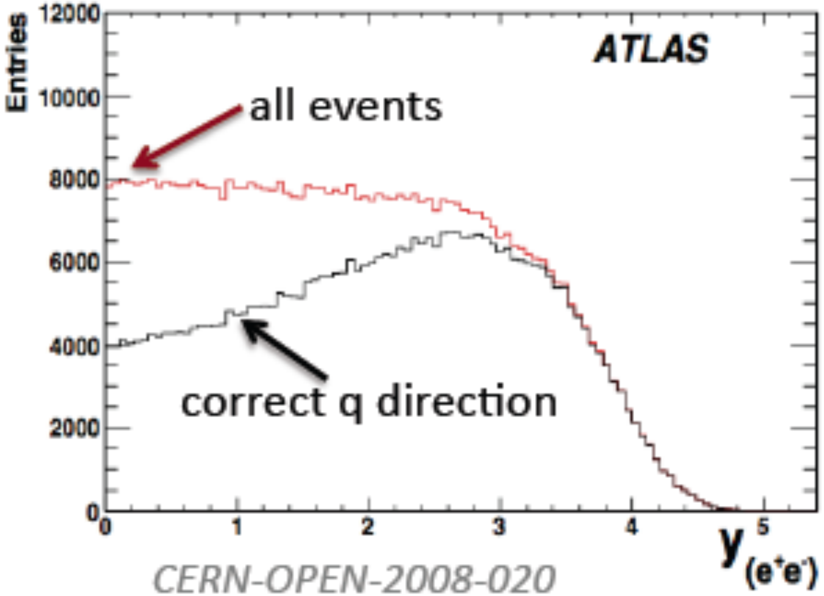


Dilution at LHC

- Because of the symmetric pp collisions at LHC the quark directions is unknown, the sign of $\cos\theta^*_{CS}$ is then ambiguous
  - Assume that the valence quark is carrying more momentum than the antiquark that should come from the parton sea

  → measure the longitudinal boost of the dilepton system and assume that this is in the direction of the valence quark
  - This assumption is sometimes not correct and produces a significant dilution
    - Reduction of the measured asymmetry AFB

- Mistagging probability depends on dilepton system rapidity and mass
  - Less important for lepton pairs with high rapidity
    - In this case, if one of the partons has high x, i.e. it is most likely a quark



CERN-OPEN-2008-020

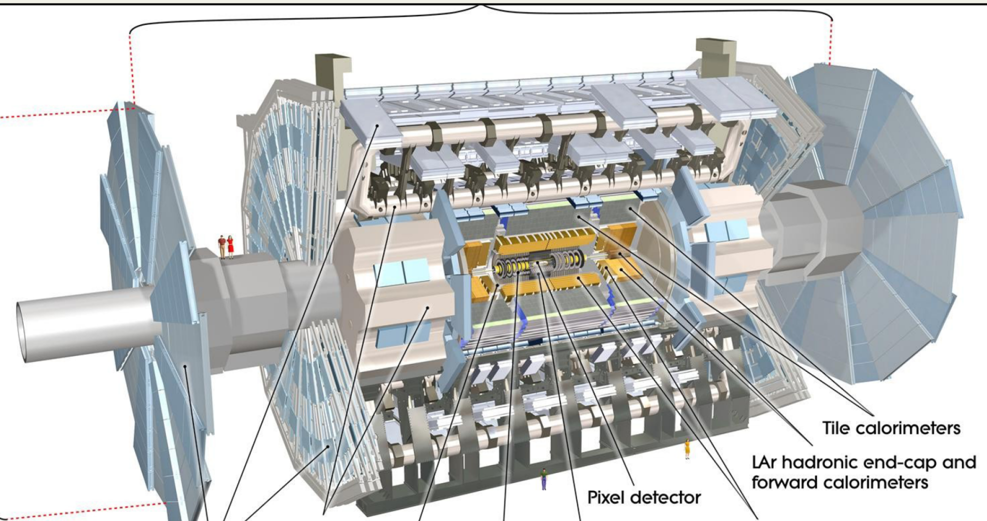
Both ATLAS and CMS experiments are exploiting the capabilities of their forward calorimetry to detect electrons with rapidities up to ≈5

Electron and muon ID with the ATLAS detector

Measurement of the forward-backward asymmetry of electron and muon pair-production in *pp* collisions at $\sqrt{s}$= 7 TeV with the ATLAS detector (arXiv:1503.03709,accepted by JHEP)

- Analysis uses 4.8 fb^{-1} of 7 TeV data

- Measuring *Z* decays in two electron final state topologies (central-central, CC and central-forward, CF) and in the muon final state



- Central electrons $|\eta| < 2.47$ tracking via Inner detector + calorimeters (em. Lar + had. Tile)
- Forward electrons $2.5 < |\eta| < 4.9$ calorimetric info only Lar, Tile and forward Cal ($3.1 < |\eta| < 4.9$)

Central and Forward electron E_T>25 GeV

- Muons $|\eta| < 2.7$ muon spectrometer

P_T>20 GeV

Electron and muon ID with the CMS detector

- The analysis is performed in both dimuons and di-electrons channels
  - Muon final state, 7 TeV, 1.1 fb^{-1} (Phys.Rev. D. 84 (2011) 112002)
    - Extraction of the weak mixing angle
  - Muon and electron final states, 7 TeV, 5 fb^{-1} (Phys. Lett. B 718 (2013) 752)
  - Muons, electrons, and forward electrons, 8 TeV, 19.7 fb^{-1} (CMS-PAS SMP-14-004)

Event selection criteria($Z \to \mu^+\mu^-$):

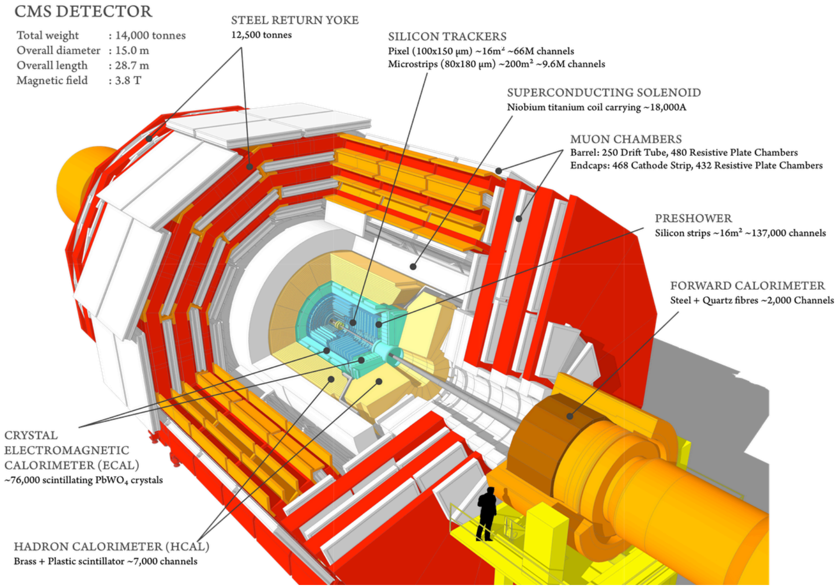
- $p_T > 20$ GeV and $|\eta| < 2.4$ (for both muons)

Event selection criteria($Z \to e^+e^-$):

- $p_T > 20$ GeV and $|\eta| < 2.4$ (for both electrons)

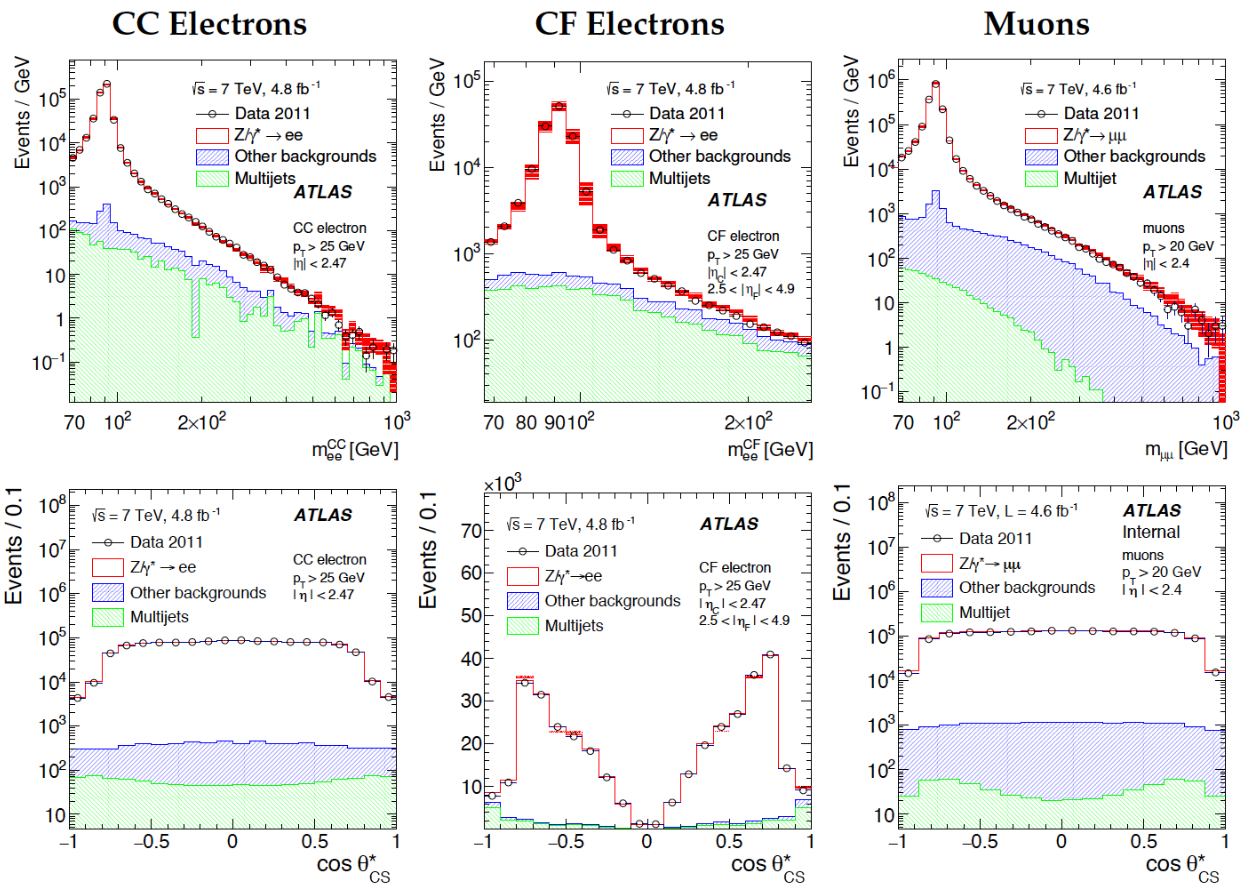
High η event selection:

- Leading e : $p_T > 30$ GeV and $|\eta| < 2.4$
- Sub-leading e : $p_T > 20$ GeV and $3.0 < |\eta| < 5.0$



- A_{FB} results in the two lepton channels (*ee* and $\mu\mu$) for rapidities < 2.4 are combined assuming the systematic uncertainties are uncorrelated

Di-leptons Invariant mass and cos θ^*_{cs} distributions



ATLAS 7 TeV, 4.8fb-1

- Red bands contain all experimental systematic uncertainties
- CC and muon channel measure up to m_{ll}< 1000 GeV. Backgrounds in *Z* peak region ~ 1%
- CF electron only up to m_{ee} < 250 GeV due to large backgrounds. Backgrounds in *Z* peak region ~ 5%

- For CF electrons in linear scale asymmetry is directly visible on the plot

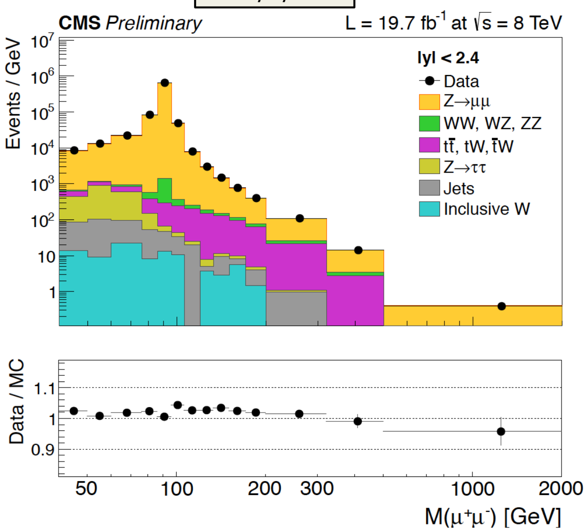
✓ Signal samples simulated with PYTHIA 6.4 (MSTW2008LO) and NLO POWHEG (MC) + PYTHIA6.4 for parton shower

✓ Backgrounds are taken from MC. For QCD multijet and like W+jet background use data-driven methods

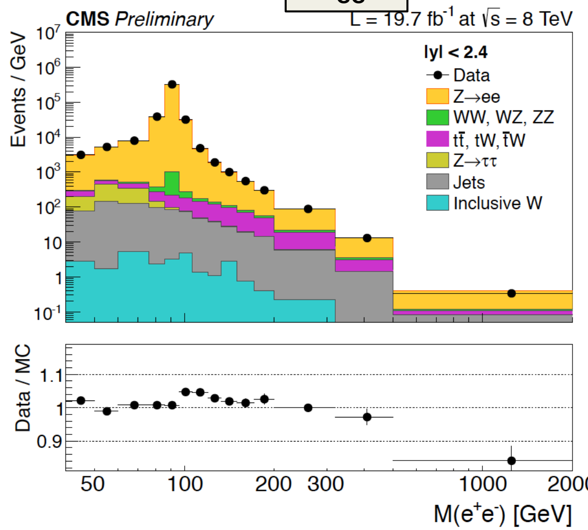
Di-leptons Invariant mass and cos θ^*_{cs} distributions

CMS 8 TeV 19.7fb^{-1}

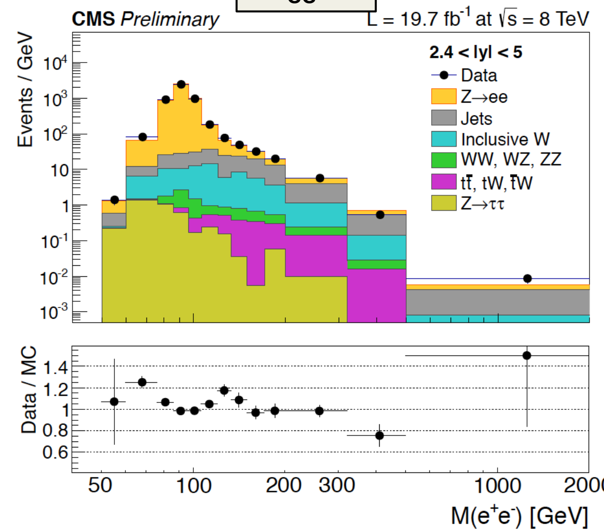
$M_{\mu\mu}$



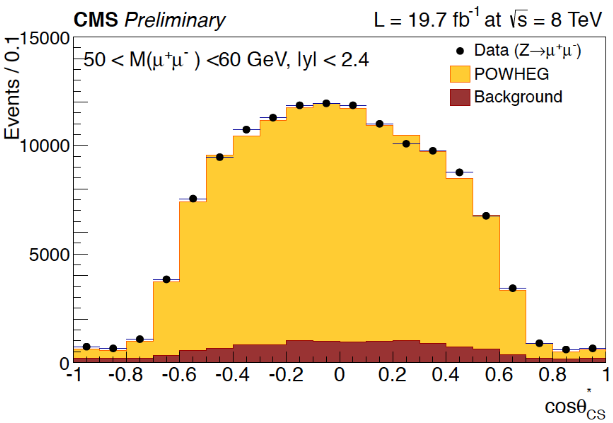
M_{ee}



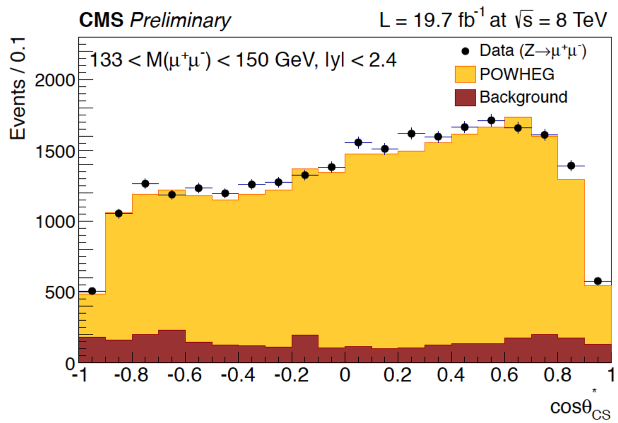
M_{ee}



Cos θ^*



Cos θ^*



Backgrounds estimated with different MC generators:

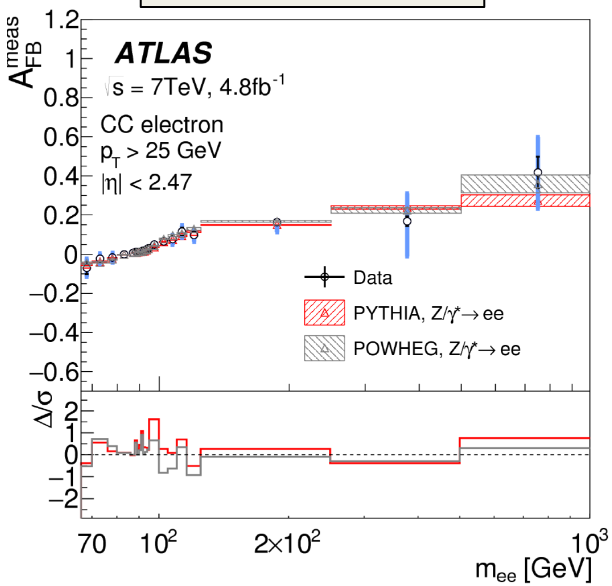
- **$Z \to \tau\tau$, ttbar, tW: POWHEG, PYTHIA6.4 and TAUOLA**
- **WW,WZ, ZZ : PYTHIA6.4 , TAUOLA**
- **Inclusive W : MADGRAPH, PYTHIA6.4 and TAUOLA**
- **QCD dijet background using data driven method**

Detector-level A_{FB} asymmetry

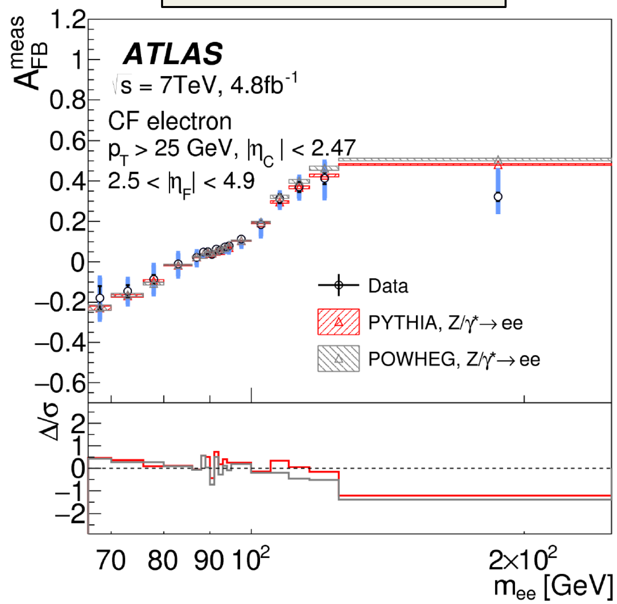
- Calculate A_{FB} from cos θ^*_{CS} distributions at detector level after background subtraction

$$A_{FB} = \frac{N_{\cos\theta^*_{CS}\geq 0} - N_{\cos\theta^*_{CS}<0}}{N_{\cos\theta^*_{CS}\geq 0} + N_{\cos\theta^*_{CS}<0}}$$

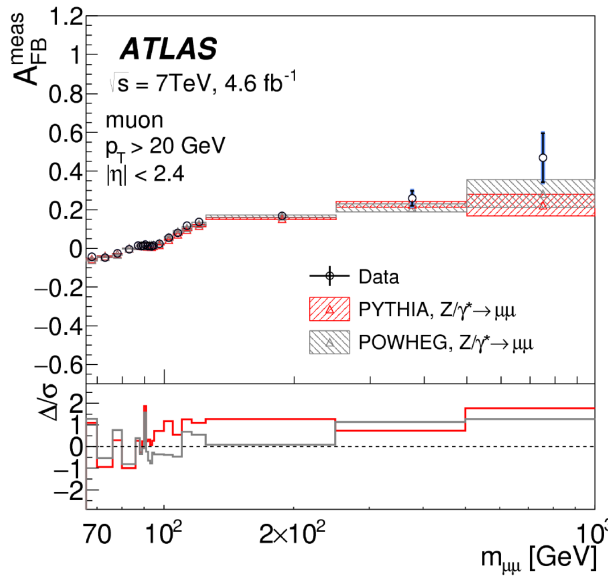
CC electrons



CF electrons



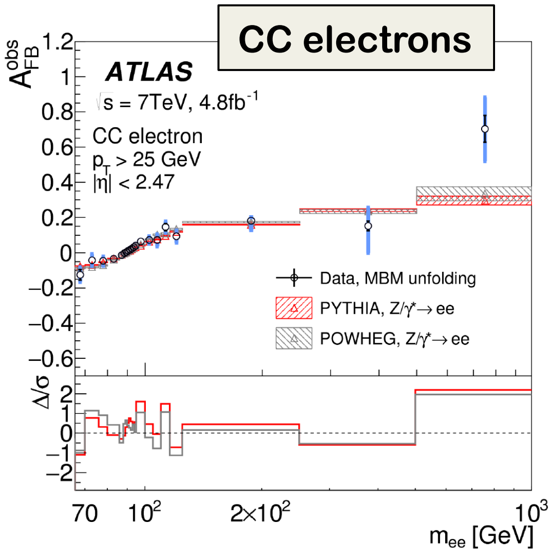
muons

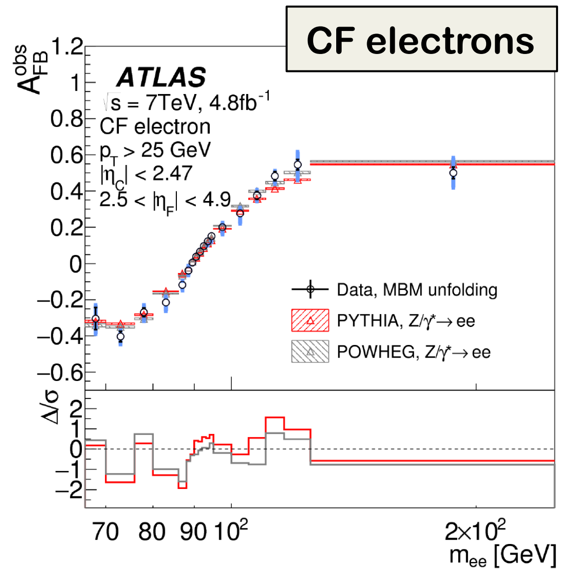


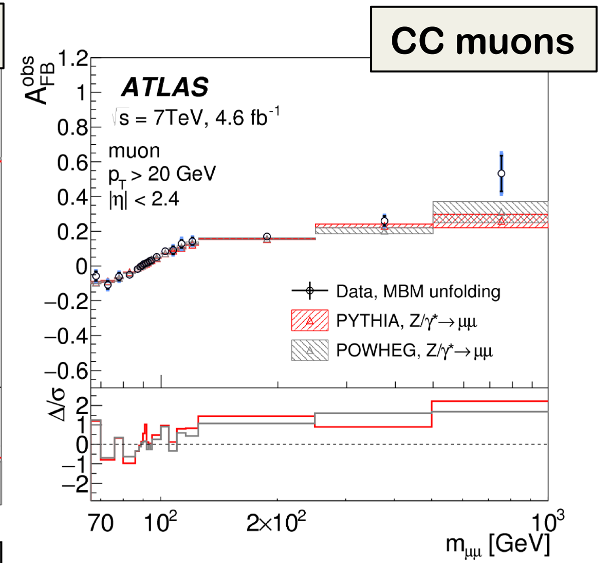
- Good agreement of data with PYTHIA and POWHEG predictions

Unfolding A_{FB} from detector to particle level

- Unfolding A_{FB}^{meas} to particle level using a Bayesian iterative method (RootUnfoldtoolkit) to compare with theoretical predictions
- Response matrix built with Pythia6.4 MC signal samples to correct for 'mass bin migration effects':
  - Detector effects : finite resolution, lepton reconstruction efficiency
  - QED : radiative corrections or real photon in the final-state (FSR) using PHOTOS MC
    - cross-check with SHERPA+PHOTON++ MC
- Additional checks are performed to ensure that PYTHIA LO doesn't bias the results for the unfolding
  - NLO EWK corrections
    - cross-check with HORACE MC
  - NLO QCD effects cross-check with POWHEG simulated sample as pseudo-data and unfolding the asymmetry using the PYTHIA derived response matrix
- All cross-check effects smaller than the statistical uncertainties







- Good agreement of A_{FB}^{obs} and PYTHIA, POWHEG predictions

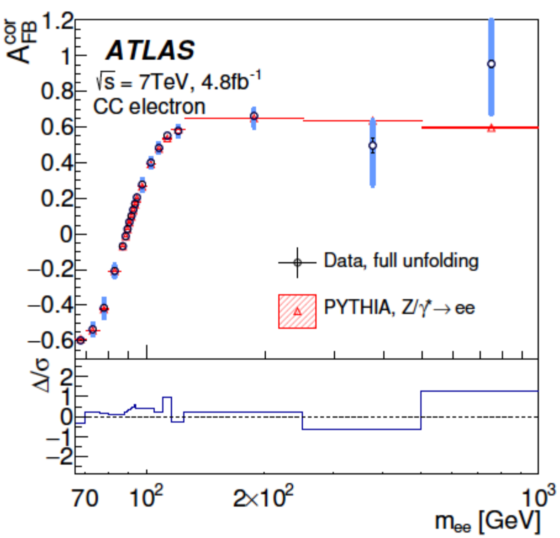
A_{FB} corrected also for dilution and acceptance

Similar unfolding procedure using PYTHIA MC samples to correct also:

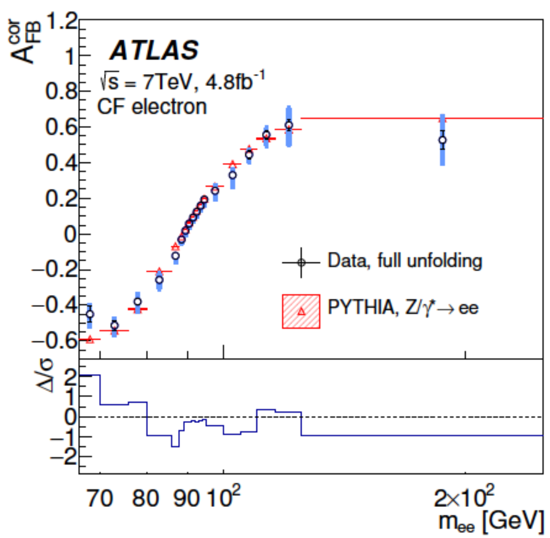
- Dilution effect, geometrical acceptance (extrapolation to the full phase-space)
  - Rely heavily on MC simulation
- Magnitude of the corrections bigger than previous steps
  - Dominated by the PDF systematic uncertainties

The fully corrected spectra for Born-level leptons:

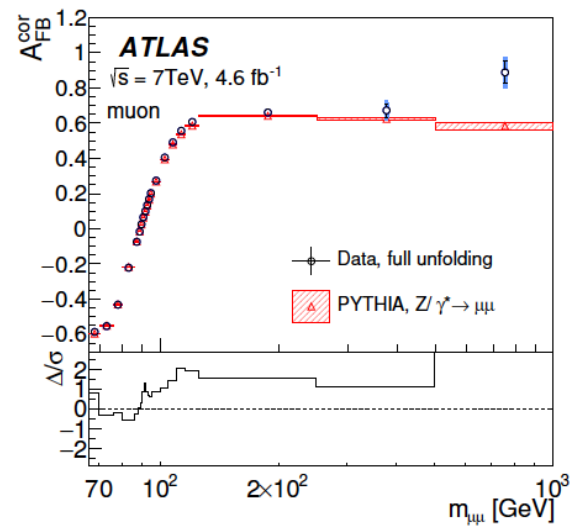
CC Electrons



CF Electrons



Muons



Systematics on A_{FB}^{obs}

CC electrons			
Uncertainty	66–70 GeV	70–250 GeV	250–1000 GeV
Unfolding	$\sim 1\times10^{-2}$	$(2–5)\times10^{-3}$	$\sim 4\times10^{-4}$
Energy scale/resolution	$\sim 7\times10^{-3}$	$(0.5–2)\times10^{-3}$	$\sim 2\times10^{-2}$
MC statistics	$\sim 5\times10^{-3}$	$(0.1–1)\times10^{-3}$	$(3–20)\times10^{-3}$
PDF	$\sim 2\times10^{-3}$	$(1–8)\times10^{-4}$	$(0.7–3)\times10^{-3}$
Other	$\sim 1\times10^{-3}$	$(0.1–2)\times10^{-3}$	$(5–9)\times10^{-3}$

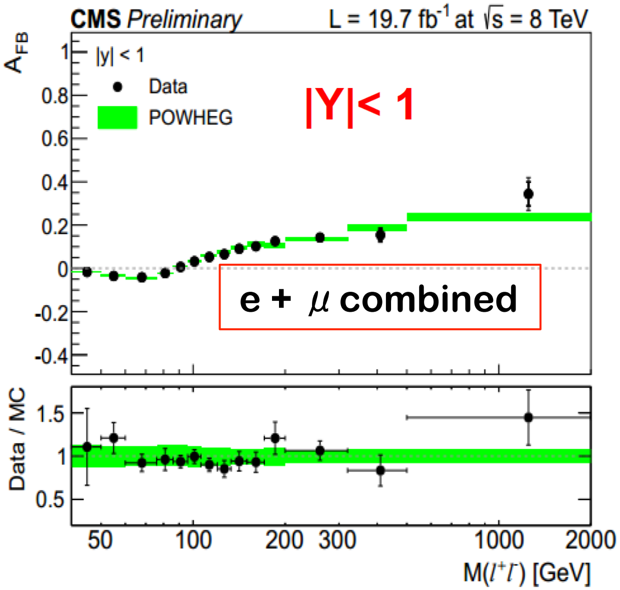
CF electrons			
Uncertainty	66–70 GeV	70–250 GeV	250–1000 GeV
Unfolding	$\sim 2\times10^{-2}$	$(0.5–2)\times10^{-2}$	–
Energy scale/resolution	$\sim 1\times10^{-2}$	$(0.5–7)\times10^{-2}$	–
MC statistics	$\sim 1\times10^{-2}$	$(1–7)\times10^{-3}$	–
Background	$\sim 3\times10^{-2}$	$(0.5–1)\times10^{-2}$	–
PDF	$\sim 4\times10^{-3}$	$(2–6)\times10^{-4}$	–
Other	$\sim 1\times10^{-3}$	$(1–5)\times10^{-4}$	–

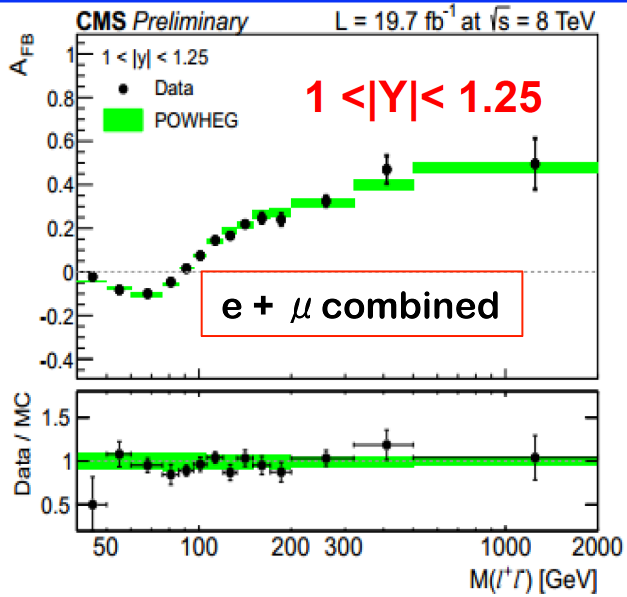
Muons			
Uncertainty	66–70 GeV	70–250 GeV	250–1000 GeV
Unfolding	$\sim 1\times10^{-2}$	$(1–4)\times10^{-3}$	$\sim 5\times10^{-4}$
Energy scale/resolution	$\sim 8\times10^{-3}$	$(3–6)\times10^{-3}$	$\sim 5\times10^{-3}$
MC statistics	$\sim 5\times10^{-3}$	$(0.1–1)\times10^{-3}$	$(2–30)\times10^{-3}$
PDF	$\sim 2\times10^{-3}$	$(1–8)\times10^{-4}$	$(0.3–3)\times10^{-3}$
Other	$\sim 1\times10^{-3}$	$(0.5–1)\times10^{-3}$	$(3–10)\times10^{-3}$

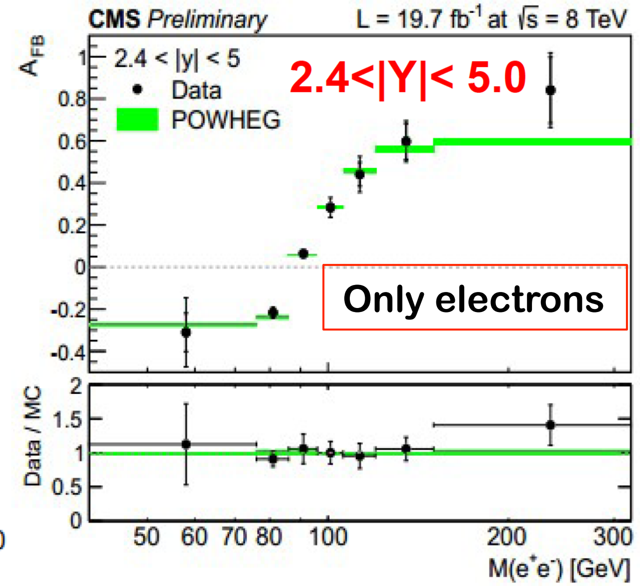
Sources of uncertainties:

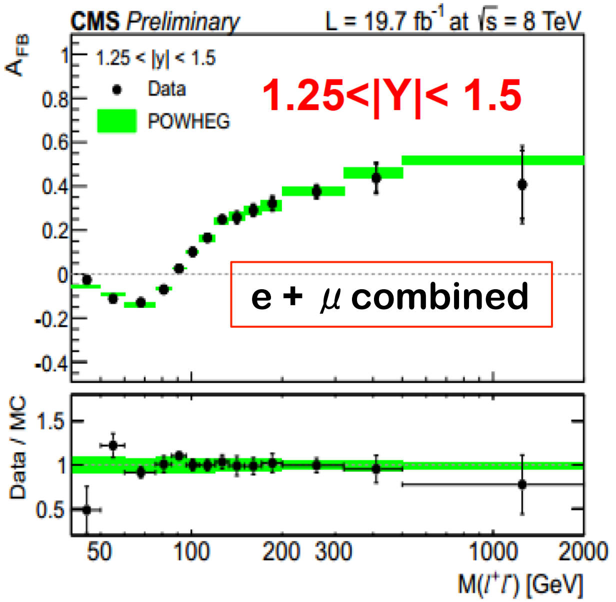
- Unfolding uncertainties from data reweighting and response matrix statistics
- Energy scale and resolution
- Background uncertainty (negligible in CC electrons and muons)
- PDF uncertainties from CT10 error set.
  - For each error set the MC sample is reweighted, the response matrix calculated and unfolding is repeated
  - The results quoted at 68% CL
- No single dominating uncertainty overall

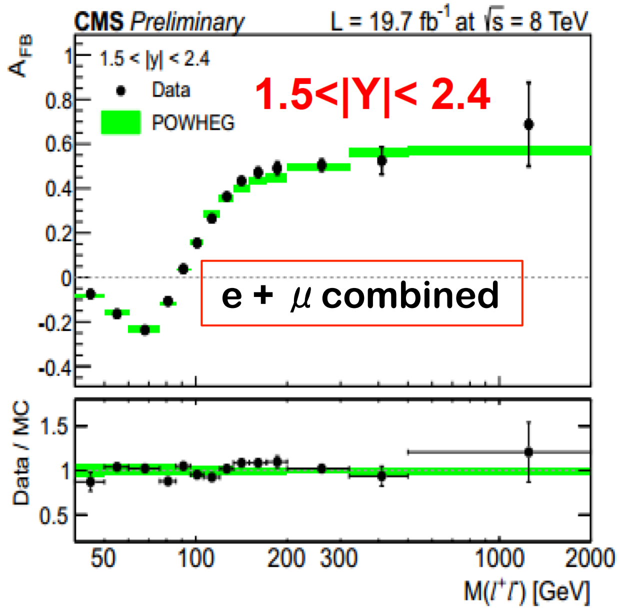
Unfolded CMS asymmetry (e+ μ combined) at 8 TeV











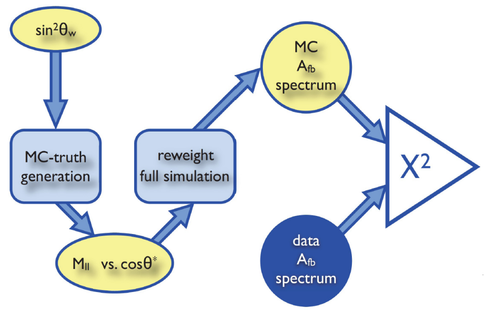
- A_{FB} corrected for detector resolution, efficiency, final state QED radiation (FSR) using Bayesian method
  - No correction for dilution applied

Results in good agreement with Powheg(NLO)+CT10

Extraction of the effective weak mixing angle

ATLAS:

- Measure the A_{FB} in bins of $M_{\ell\ell}$ with two central electrons (CC), one central and one forward electron (CF) and two muons in the mass range 70-250 GeV.
- Produce 17 Pythia MC templates for A_{FB} for different values of $\sin^2\theta_{eff}^{lep}$
  - Use a re-weighting technique to obtain fully simulated samples
- Extract $\sin^2\theta_{eff}^{lep}$ by a χ^2 comparison between data and MC templates with different values of $\sin^2\theta_{eff}^{lep}$



$$\chi^2 = \sum_{i=1}^{N} \frac{(data_i - MC_i)^2}{\sigma(data_i)^2 + \sigma(MC_i)^2 + \sigma(sys_i)^2}$$

CMS :

- $\sin^2\theta_{eff}$ measurement only for di-muon events. Multivariate likelihood analysis using variables :
  - $\cos\theta^*_{CS}$, di-lepton invariant mass and di-lepton rapidity
- Use of an analytical prediction for the differential cross section, convoluted with analytical parametrization for PDFs using CTEQ6. Introduce detector effects into the model.
- Perform unbinned maximum likelihood fit ($\sin^2\theta_{eff}$ left as a free parameter) to extract the weak mixing angle

ATLAS results for $\sin^2\theta_{eff}^{lep}$

	$\sin^2\theta_{eff}^{lept}$
CC electron	$0.2302 \pm 0.0009(\text{stat.}) \pm 0.0008(\text{syst.}) \pm 0.0010(\text{PDF}) = 0.2302 \pm 0.0016$
CF electron	$0.2312 \pm 0.0007(\text{stat.}) \pm 0.0008(\text{syst.}) \pm 0.0010(\text{PDF}) = 0.2312 \pm 0.0014$
Muon	$0.2307 \pm 0.0009(\text{stat.}) \pm 0.0008(\text{syst.}) \pm 0.0009(\text{PDF}) = 0.2307 \pm 0.0015$
El. combined	$0.2308 \pm 0.0006(\text{stat.}) \pm 0.0007(\text{syst.}) \pm 0.0010(\text{PDF}) = 0.2308 \pm 0.0013$
Combined	$0.2308 \pm 0.0005(\text{stat.}) \pm 0.0006(\text{syst.}) \pm 0.0009(\text{PDF}) = 0.2308 \pm 0.0012$

Combination of channels by quadratic error weighting

- **Experimental uncertainties taken as completely uncorrelated**
- **Theoretical uncertainties (PDF, higher order EW and QCD corrections) taken as completely correlated**
- **Combination errors dominated by PDF uncertainties**
  - **A_{FB} depends from the flavor and charge of the initial partons**

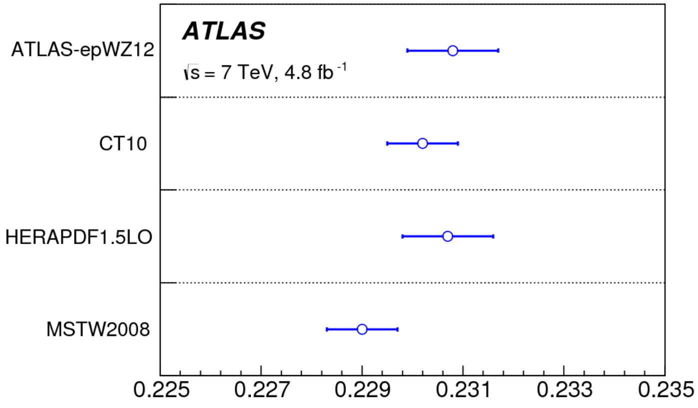
Uncertainty source	CC electrons $[10^{-4}]$	CF electrons $[10^{-4}]$	Muons $[10^{-4}]$	Combined $[10^{-4}]$
PDF	10	10	9	9
MC statistics	5	2	5	2
Electron energy scale	4	6	–	3
Electron energy resolution	4	5	–	2
Muon energy scale	–	–	5	2
Higher-order corrections	3	1	3	2
Other sources	1	1	2	2

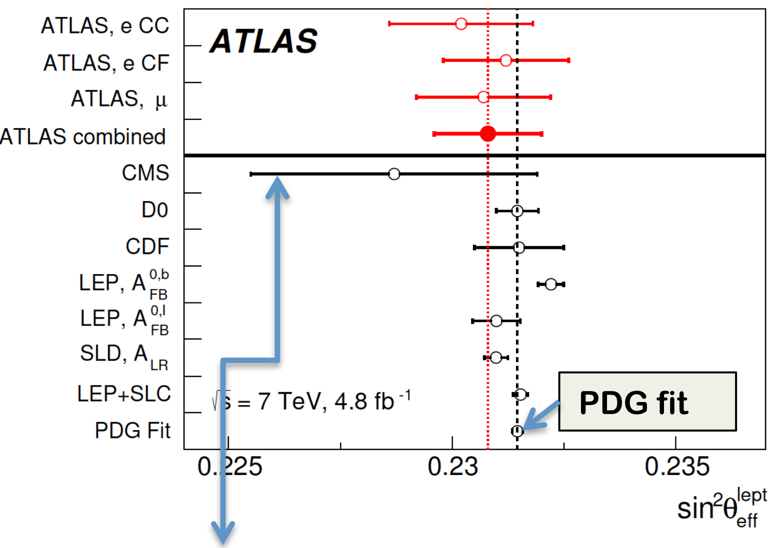
- **For this measurement a LO version of ATLAS-epWZ12 PDF was used**
  - **Extracted by W,Z production ATLAS data at 7 TeV and from HERA data**
- **Uncertainty evaluated from ATLAS-epWZ12 PDF error set**

  (Phys.Rev.Lett. 109 (2012) 012001)

  arXiv:1203.4051)

Results on $\sin^2\theta_{eff}^{lep}$ and A_μ determination





$$\sin^2\theta_{eff} = 0.2287 \pm 0.0020\ (\text{stat.}) \pm 0.0025\ (\text{syst.})$$

Study the effect of different PDFs set on $\sin^2\theta_{eff}^{lep}$

- Good agrement between ATLAS-epWZ12 and HERAPDF1.5LO set
- CT10 (NLO) set
- By choosing MSTW2008 $\sin^2\theta_{eff}^{lep}$ shifts down by ~ -0.002
- Need of further precision measurements to constrain PDFs

Determination of Muon Asymmetry Parameter A_μ:

- can be estimated from measured value of $\sin^2\theta_{eff}^{\mu}$.
- Assuming the SM expression for A_q and

$$\sin^2\theta_{eff}^{q} = \sin^2\theta_{eff}^{\mu} = \sin^2\theta_{eff}^{lept}$$

$$A_\mu = \frac{2(1-4\sin^2\theta_{eff}^{lept})}{1+(1-4\sin^2\theta_{eff}^{lept})}$$

- We obtain :

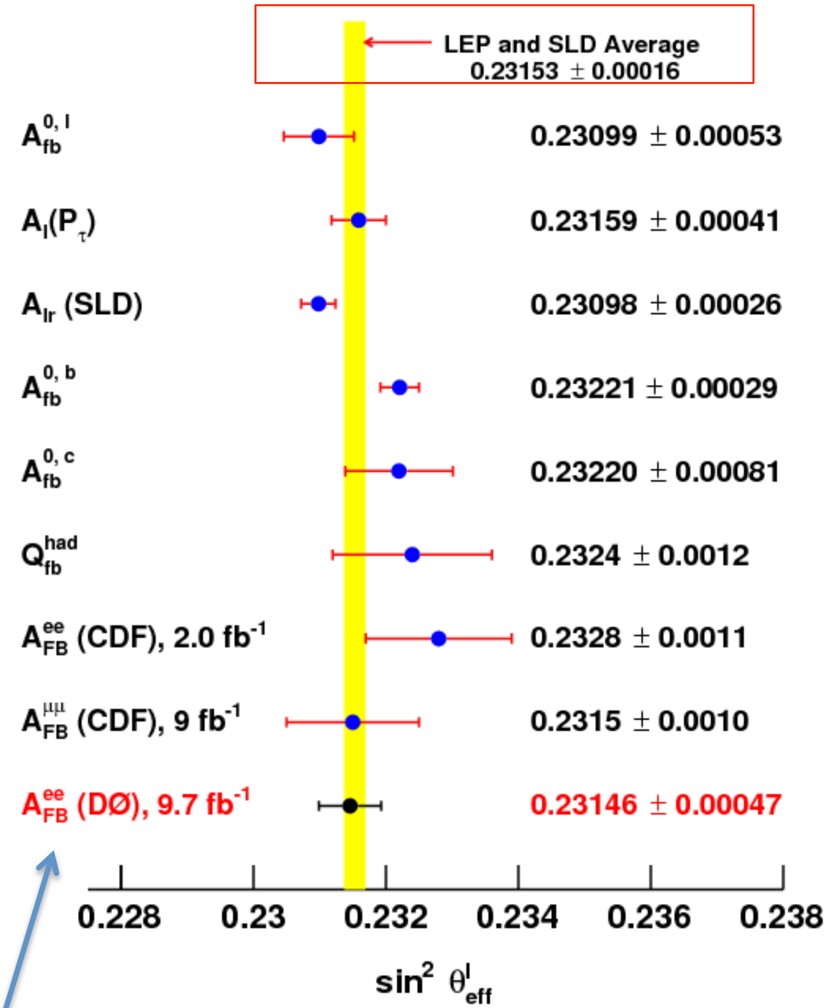
$$A_\mu = 0.153 \pm 0.007(\text{stat.}) \pm 0.009(\text{syst.}) = 0.153 \pm 0.012(\text{tot.})$$

- In agreement with the measured value from SLD (0.142±0.015) Phys.Rept.427:257-454,2006 arXiv:hep-ex/050900

TeVatron $\sin^2\theta_{eff}^{lep}$ measurements

Arie Bodek's plenary talk

- **Tevatron A_{FB} measurement complementary to LHC**
  - ppbar collider is ideal for asymmetry measurements
- **Both CDF and D0 both measured $\sin^2\theta_{eff}^{lep}$ from the A_{FB} in Z/γ^* production to lepton pairs**
  - D0 : dielectron (5 fb^{-1}, 9.7 fb-1)
  - CDF : dielectrons (2.0fb^{-1} , dimuon 9.2 fb^{-1})
- **Latest D0 A_{FB} measurement with di-electrons (9.7fb^{-1})**
  - extended acceptance and new energy calibration method.
  - Extract $\sin^2\theta_{eff}$ by fitting raw A_{FB} to MC PYTHIA templates with different $\sin^2\theta_W$ values
    - No unfolding: MC is carefully corrected to describe the data
    - PDF uncertainty estimated reweighting the PDF set in MC with the NNPDF2.3 set
- D0 (ee, 9.7 fb-1): $\sin^2\theta^{\ell}_{eff} = 0.23146 \pm 0.00047$
- CDF ($\mu\mu$, 9.2 fb-1): $\sin^2\theta^{\ell}_{eff} = 0.2315 \pm 0.00100$



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$\sin^2\theta_{eff}$ comparison between experiments at the Z scale

	$\sin^2\theta^{lept}_{eff}$	Δ/σ (wrt LEP+SLC)
ATLAS	0.2308 ± 0.0012	-0.6
CMS [6]	0.2287 ± 0.0032	-0.9
D0 [5]	0.23146 ± 0.00047	-0.1
CDF [4]	0.2315 ± 0.0010	-0.03
LEP, $A^{0,b}_{FB}$ [3]	0.23221 ± 0.00029	–
LEP, $A^{0,l}_{FB}$ [3]	0.23099 ± 0.00053	–
SLC, A_{LR} [3]	0.23098 ± 0.00026	–
LEP+SLC [3]	0.23153 ± 0.00016	–
PDG global fit [46]	0.23146 ± 0.00012	-0.4

pp: ATLAS, CMS

ppbar: D0, CDF

e^+e^-: LEP, SLC

S.Farry's talk

Preliminary LHCb result from Z A_{FB} 0.2314 ± 0.0011

- LHC not yet competitive with Tevatron
  - Limited mainly by PDF uncertainty
- Tevatron results approaching LEP/SLD
  - The D0 result is the most precise measurement for light quark interactions
  - ppbar has much smaller dilution !

Conclusions

- **ATLAS and CMS have measured the forward-backward charge asymmetry A_{FB} from Z/γ^* decays for pp collisions at 7 and 8 TeV in electron and muon channels.**
  - **The results are in good agreement with the SM predictions**

- **These measurements has been used by both experiments to extract the effective weak mixing angle $\sin^2\theta_{eff}^{lept}$**
  - **Good agreement with the results with e^+e^- colliders (LEP, SLD) and TeVatron**
    - **Important source of uncertainty is the knowledge of PDFs.**
      - **Reduction possible using future electroweak measurements from LHC from new final analysis from Run1 and Run2 (W, Z cross sections, rapidity distributions, asymmetry, etc)**

backup

Signal and background modelling

ATLAS :

- Signal samples simulated with PYTHIA 6.4 (MSTW2008LO) and NLO POWHEG (MC) + PYTHIA6.4 for parton shower
  - QED final state radiation simulated using PHOTOS
  - Normalized to cross section at NNLO using PHOZPR (MSTW2008 NNLO PDF).
  - K factor applied at generator level
    - A_{FB} not affected by this LO-to-NNLO rescaling
- Backgrounds estimated from MC simulations
  - Z --> $\tau\ \tau$: PYTHIA 6.4
  - Dibosons : HERWIG 6.510 (MRSTMCal PDFs)
  - Top quark pair-production MC@NLO 4.01 (CTEQ6L1) + HERWIG for parton shower
- Multijet and W+jets backgrounds estimated together from data-driven methods

CMS :

- Signal samples from POWHEG (NLO) + PYTHIA6.4 for parton shower with Z2 tune (CT10 NLO PDF)
- Backgrounds estimated from different MC generators:
  - Z→ $\tau\ \tau$, ttbar, tW: POWHEG, PYTHIA6.4 and TAUOLA
  - WW,WZ , ZZ and QCD multijets : PYTHIA6.4 and TAUOLA
  - Inclusive W : MADGRAPH, PYTHIA6.4 and TAUOLA
- The MC samples include multiple interactions to simulate pile-up
- QCD dijet background estimated using data driven method

Extraction of Asymmetry Parameter A_μ

- The value of $A_{FB}^{0,\ell}$ around the Z pole can be written in term of the parameters A_ℓ and A_q

$$A_{\rm FB}^{0,\ell} = \frac{3}{4} A_q A_\ell$$

  - A_ℓ, A_q are directly related to the electroweak vector and axial-vector couplings and to the weak mixing angle. For the $Z/\gamma^* \to \mu\mu$ channel

$$A_{q/\mu} = \frac{2 g_{\rm V}^{q/\mu} g_{\rm A}^{q/\mu}}{(g_{\rm V}^{q/\mu})^2 + (g_{\rm A}^{q/\mu})^2} = \frac{2 g_{\rm V}^{q/\mu} / g_{\rm A}^{q/\mu}}{1 + (g_{\rm V}^{q/\mu} / g_{\rm A}^{q/\mu})^2}$$

$$g_{\rm V}^{q/\mu} / g_{\rm A}^{q/\mu} = 1 - 4|Q_{q/\mu}| \sin^2\theta_{\rm eff}^{q/\mu}$$

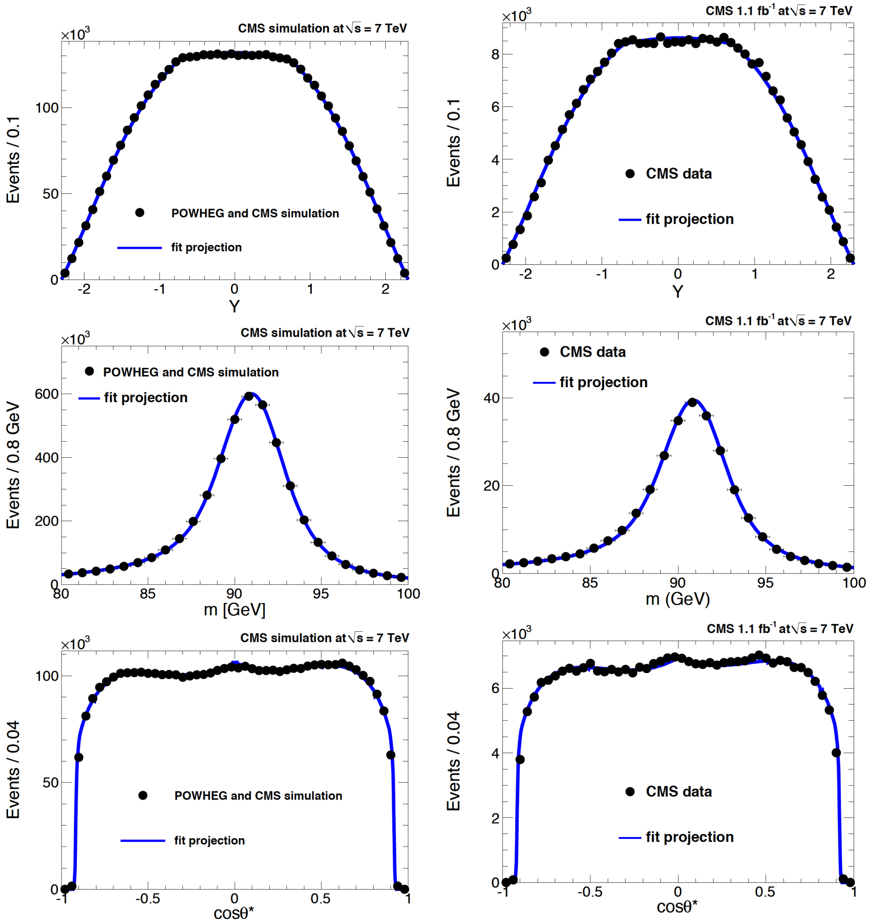
- Assuming the Standard Model expression for A_q, $\sin^2\theta_{\rm eff}^{q} = \sin^2\theta_{\rm eff}^{\mu} = \sin^2\theta_{\rm eff}^{\rm lept}$ and using the measured value of $\sin^2\theta_{\rm eff}^{\mu}$ we get:

$$A_\mu = 0.153 \pm 0.007({\rm stat.}) \pm 0.009({\rm syst.}) = 0.153 \pm 0.012({\rm tot.})$$

- Compatible with and similar precision as the most precise measurement of A_μ = 0.142 ± 0.015 from SLD (Phys.Rept.427:257-454,2006)

CMS $\sin^2\theta_{eff}^{lep}$ measurement

- $Z \rightarrow \mu\mu$, 7 TeV, 1.1 fb^{-1}



$$\sin^2\theta_{\text{eff}} = 0.2287 \pm 0.0020\ (\text{stat.}) \pm 0.0025\ (\text{syst.})$$

source	correction	uncertainty
PDF	–	±0.0013
FSR	–	±0.0011
LO model (EWK)	–	±0.0002
LO model (QCD)	+0.0012	±0.0012
resolution and alignment	+0.0007	±0.0013
efficiency and acceptance	–	±0.0003
background	–	±0.0001
total	+0.0019	±0.0025

PDF uncertainty: performed with different PDF sets

- **CT10, MSTW,NNPDF**

FSR modeled with different MC:

NLO EWK: ZFITTER

NLO QCD: bias assigned to cover the effect of assumed LO models

Systematics on A_{FB}

(a) Muon channel

	$\|y\|$ bins			
Systematic Uncertainty	0 – 1	1 – 1.25	1.25 – 1.5	1.5 – 2.4
Background	0.062	0.080	0.209	0.051
Momentum correction	0.006	0.015	0.020	0.022
Unfolding	0.001	0.003	0.004	0.003
Pileup reweighting	0.002	0.004	0.003	0.004
Efficiency scale factors	< 0.001	0.002	0.003	0.005
PDF	0.001	0.004	0.008	0.047
QED FSR	<0.001	0.001	0.001	0.002

(b) Electron channel

	$\|y\|$ bins				
Systematic Uncertainty	0 – 1	1 – 1.25	1.25 – 1.5	1.5 – 2.4	2.4 – 5
Background	0.064	0.015	0.008	0.004	0.033
Energy correction	0.011	0.015	0.012	0.012	0.123
Unfolding	0.005	0.007	0.006	0.004	0.001
Pileup reweighting	0.003	0.002	0.002	0.001	0.007
Efficiency scale factors	<0.001	< 0.001	< 0.001	< 0.001	0.008
Forward η(e) scale factor	-	-	-	-	0.002
Forward normalization	-	-	-	-	0.060
PDF	0.002	0.004	0.005	0.008	0.014
QED FSR	<0.001	0.001	0.001	0.001	0.002

- **Major source of uncertainties:**
  - **background estimation**
- **Other sources:**
  - **electron energy correction, muon momentum correction**
  - **unfolding procedure.**
  - **PDF choice (CT10 and NNPDF2.0 error sets)**
  - **QED FSR modeling**