Measurement of $\sin^2\theta_{eff}^{lept}$

Using 2012 8 TeV dataset (~ 19/fb)

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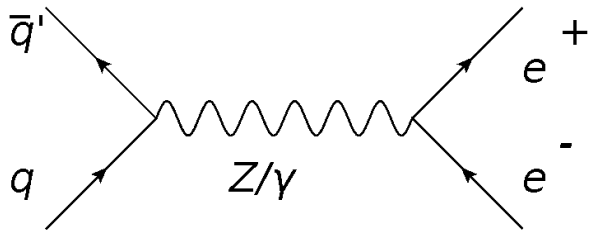
Representing the CMS collaboration

6 Jul 2017, 10:30 15m

Room Volpi (Palazzo del Casinò)

Dilepton production Hadron colliders



The axial and vector neutral currents interfere

Weak neutral current strength related to $\sin^2\theta_{eff}$

$\sin^2\theta_W = \sin^2\theta_W^{\text{on-shell}} = 1 - M_w^2 / M_z^2$

$\sin^2\theta_{eff}^{lept} = \mathrm{Re}[\kappa_l(M_z^2, \sin^2\theta_w)]\sin^2\theta_w$

$\hookrightarrow \approx 1.037$

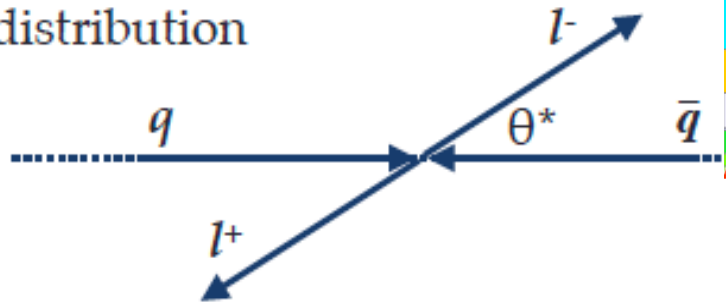
With a known Higgs mass, Standard Model is over constrained.
A measurement of $\sin^2\theta_{eff}$ is equivalent to a measurement of M_w

±0.00050 error in $\sin^2\theta$w is equiv. to ±25 MeV error in Mw (indirect)

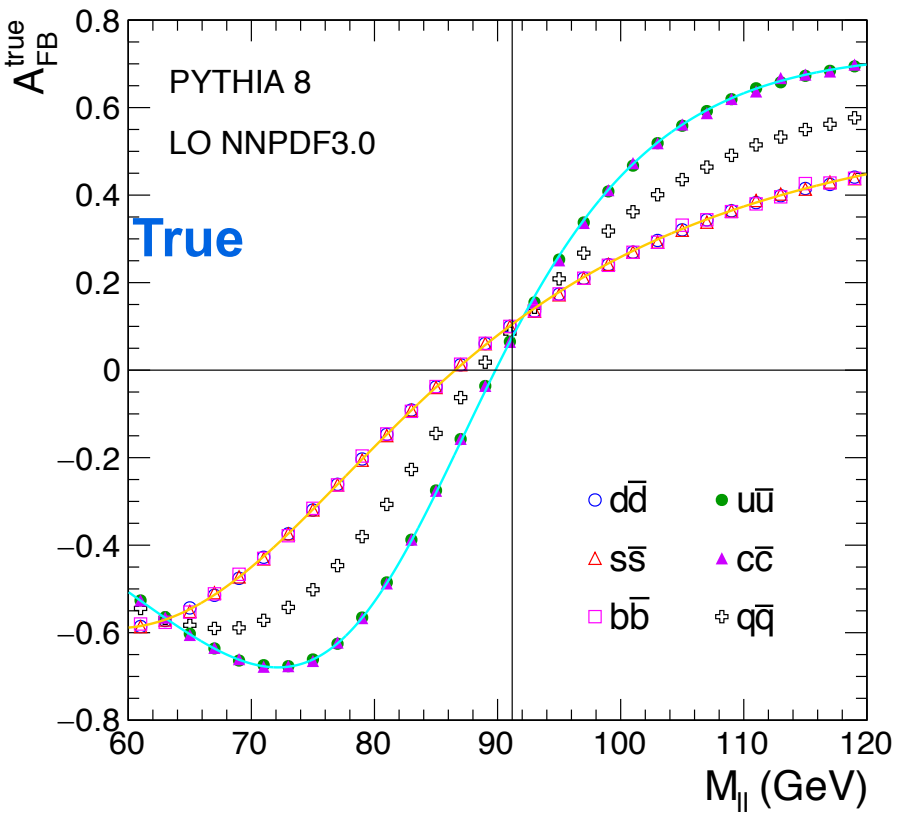
This new CMS measurement has a total error of ± 0.00052

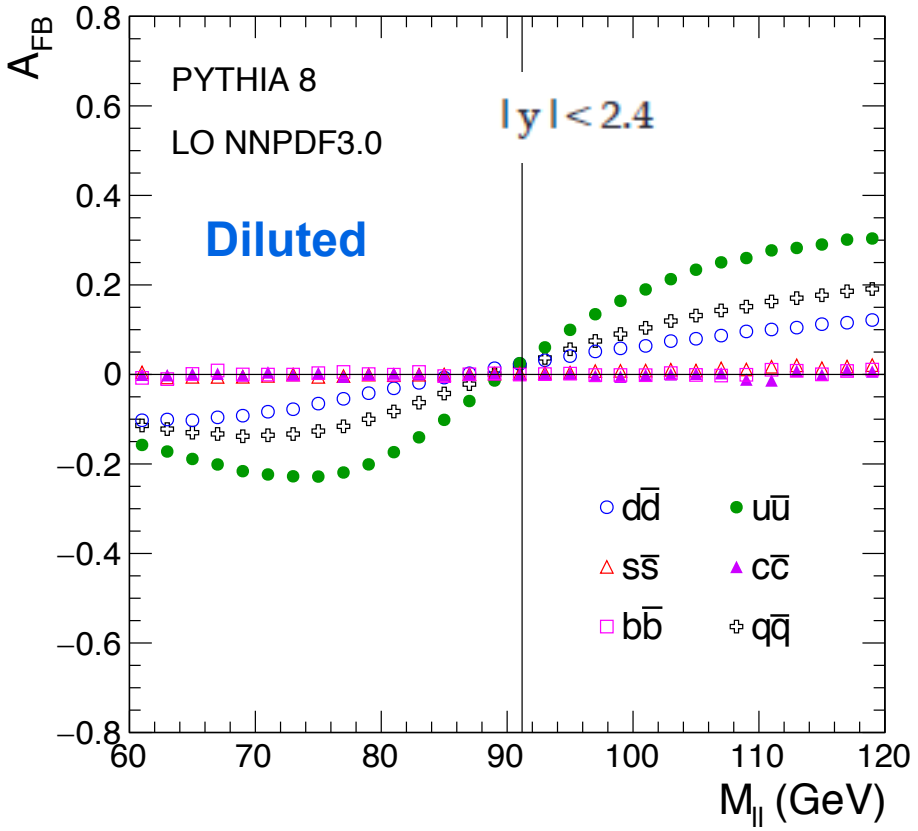
All errors reported in this talk are quoted to five decimal places.

- Vector and axial couplings result in A_{FB} of $\cos\theta^*$ distribution
- A_{FB} near Z peak sensitive to leptonic $\sin^2\theta_{eff}$
- Mass dependence from Z/γ^* interference
- Observable A_{FB} in pp collisions based on ll boost
- A_{FB} dependence on PDFs:

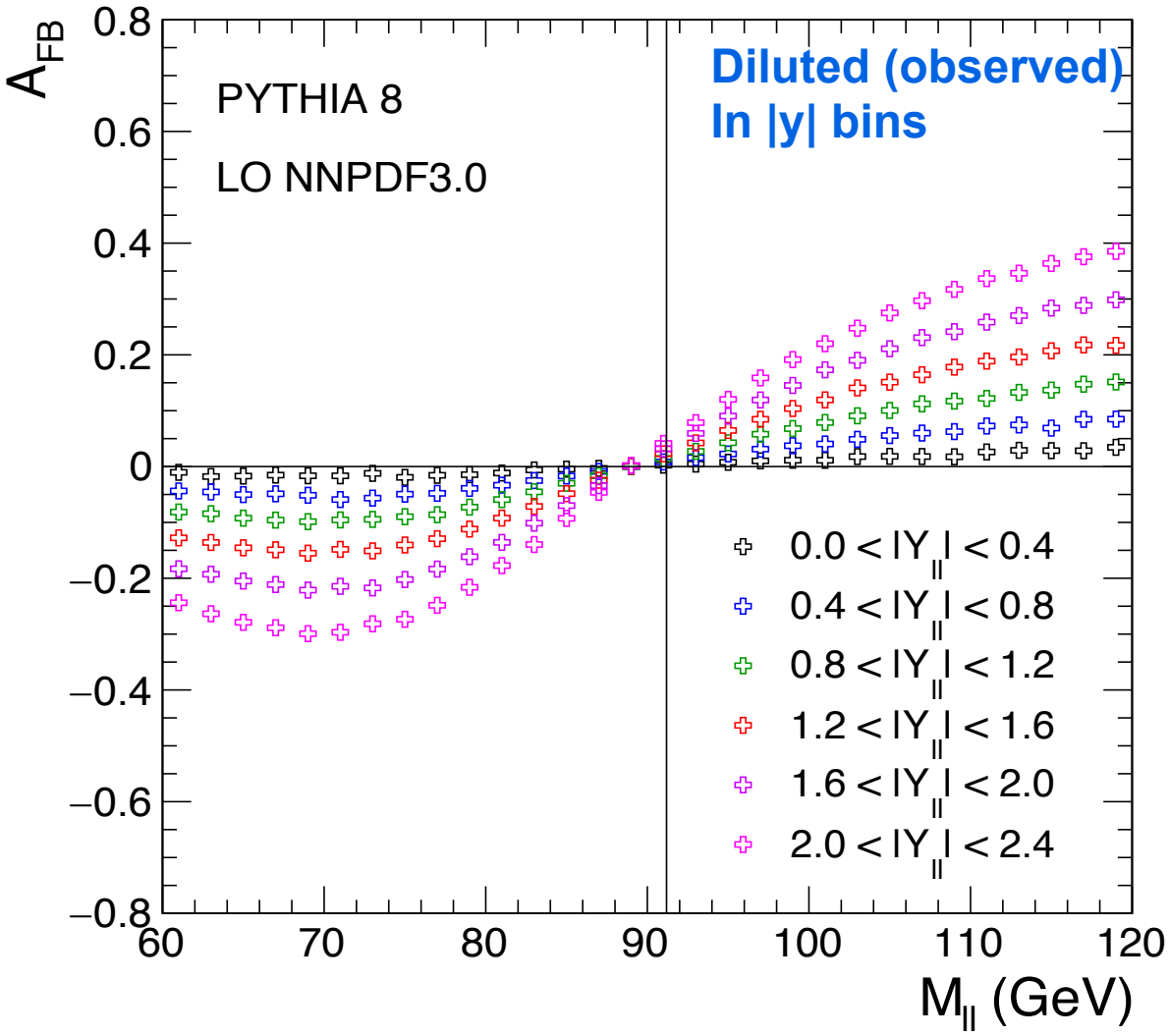


1. Fraction of valence u vs. d
2. Dilution (y dependent) from high x antiquarks





- 6 bins of $|y|$: 0.0, 0.4, 0.8, 1.2, 1.6, 2.0, 2.4
- 12 bins of m: 60, 70, 78, 84, 87, 89, 91, 93, 95, 98, 104, 112, 120



Dilution (y dependent). Therefore bin data in rapidity.

Extract $\sin^2\theta_{eff}$ by fitting the observed A_{FB} to templates generated with different values of $\sin^2\theta_{eff}$

- Fit A_{FB} distribution in bins of m and $|y|$ with different $\sin^2\theta_{eff}$ templates

A precision measurement using three new techniques:

1: Precise lepton momentum/energy scale (and modeling resolution)
Reduces contribution to $\Delta\sin^2\theta_{eff}$ to ±0.00008

A. Bodek et al., "Extracting Muon Momentum Scale Corrections for Hadron Collider Experiments", *Eur. Phys. J.* **C72** (2012) 2194, doi:10.1140/epjc/s10052-012-2194-8, arXiv:1208.3710.

2: Angular Event weighting method for A_{FB} analyses:
systematic errors in acceptance & efficiency cancel: $\Delta\sin^2\theta_{eff}$ ±0.00008

A. Bodek, "A simple event weighting technique for optimizing the measurement of the forward-backward asymmetry of Drell-Yan dilepton pairs at hadron colliders", *Eur. Phys. J.* **C67** (2010) 321–334, doi:10.1140/epjc/s10052-010-1287-5, arXiv:0911.2850.

3: New PDF constraints using the same Drell Yan Data above and below the Z peak. Reduced contribution to $\Delta\sin^2\theta_{eff}$ from ±0.00054 to ±0.00030) [a]

A. Bodek, J. Han, A. Khukhunaishvili, and W. Sakumoto, "Using Drell-Yan forward-backward asymmetry to reduce PDF uncertainties in the measurement of electroweak parameters", *Eur. Phys. J.* **C76** (2016), no. 3, 115, doi:10.1140/epjc/s10052-016-3958-3, arXiv:1507.02470.

±0.00050 error in $\sin^2\theta$w is equiv. to ±25 MeV error in Mw (indirect)

Precise Lepton Energy/Momentum

New technique used for both $\mu^+\mu^-$ and e^+e^- for both data and MC. Used in CDF and CMS for muons and electrons.

Step I : Remove the correlations between the scale for the two leptons by getting an initial calibration using Z events and requiring that the **mean $<1/P_T>$** of each lepton in bins of η, Φ and charge be correct.

Step II: The Z mass used as a reference scale. The Z mass as a function of η, Φ, (and charge for $\mu^+\mu^-$) of each lepton be correct (done in bins of η, Φ).

- **Reference scale for muons:** Expected Z mass (post FSR) smeared by resolution (with acceptance cuts). (J/Ψ and ϒ are also used for tuning dE/dx).

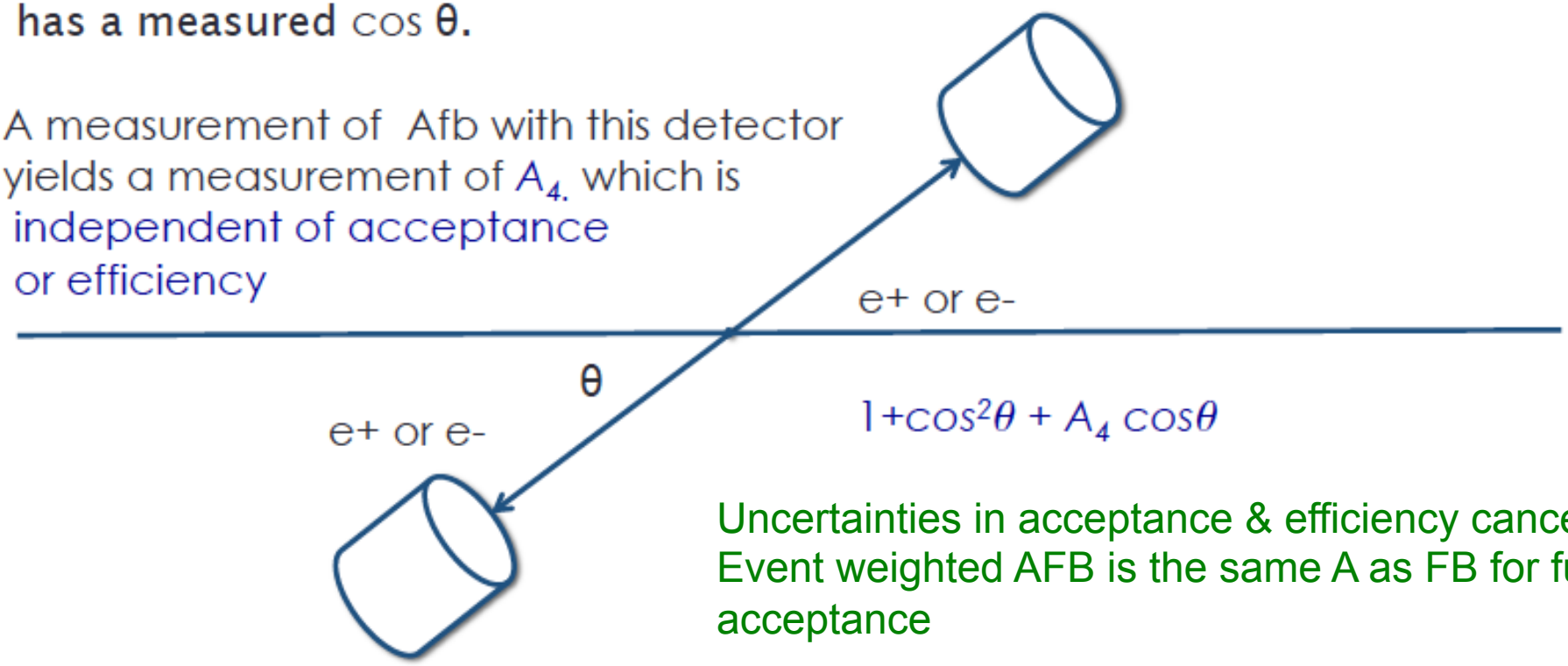
- **Reference scale for electrons:** Expected Z mass post FSR with FSR photons clustered to form a dressed electron) smeared by resolution (with acceptance cuts).

- Usually, both data and MC are misaligned (or mis-calibrated for electrons)
  Corrections must be apply to both data and MC to agree with the Z reference scale.

Angular event weighting method (used in CMS and CDF)

Imagine a detector with acceptance for only one value of cos θ. **Each event has a measured** cos θ.

A measurement of Afb with this detector yields a measurement of A_4, which is independent of acceptance or efficiency

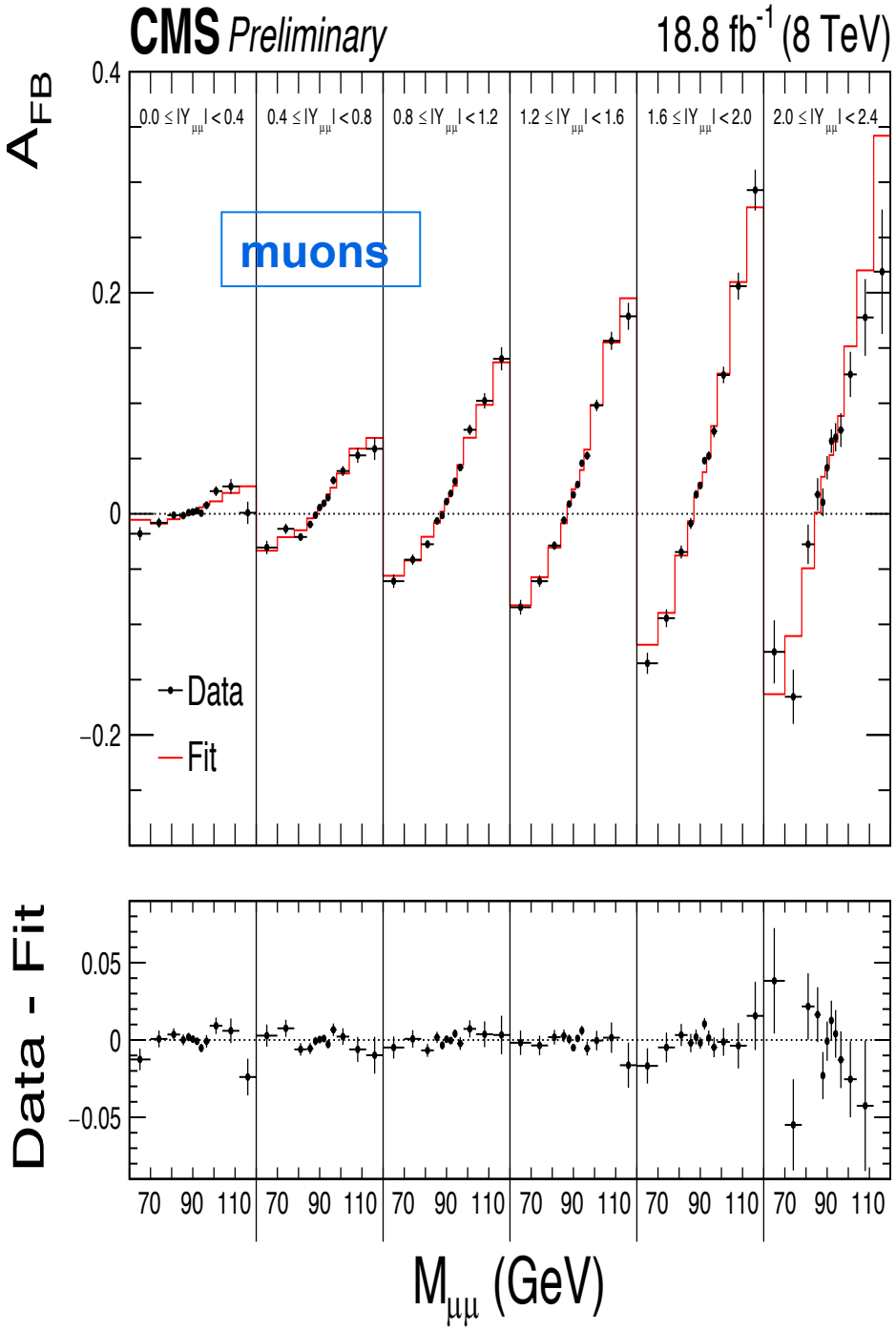


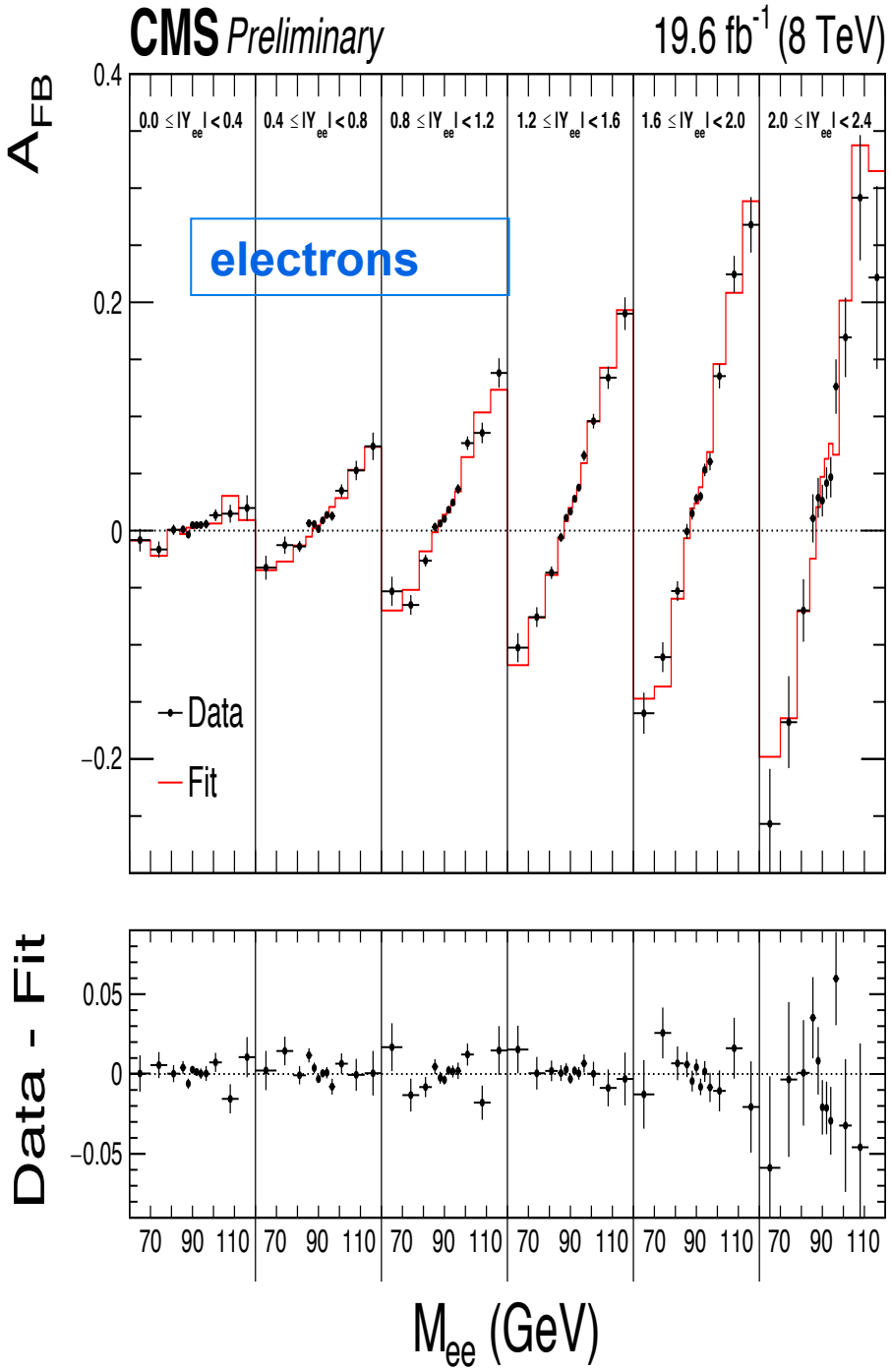
Uncertainties in acceptance & efficiency cancel
Event weighted AFB is the same A as FB for full acceptance

cos θ=1 yields best measurement of A_4. cos θ=0 yields no measurement of A_4

We can combine measurements of A_4 with different detectors at different values of by weighting events. Events with cos θ=0 have zero weight. Events with cos θ=1 have maximum weight. → obtain smaller statistical error.

Afb (all cos θ) = (3/8) A_4 → No acceptance corrections needed.


CMS Preliminary
18.8 fb-1 (8 TeV)
AFB
0.0 ≤ |Yμμ| < 0.4
0.4 ≤ |Yμμ| < 0.8
0.8 ≤ |Yμμ| < 1.2
1.2 ≤ |Yμμ| < 1.6
1.6 ≤ |Yμμ| < 2.0
2.0 ≤ |Yμμ| < 2.4
muons
Data
Fit
Data - Fit
Mμμ (GeV)


CMS Preliminary
19.6 fb-1 (8 TeV)
AFB
0.0 ≤ |Yee| < 0.4
0.4 ≤ |Yee| < 0.8
0.8 ≤ |Yee| < 1.2
1.2 ≤ |Yee| < 1.6
1.6 ≤ |Yee| < 2.0
2.0 ≤ |Yee| < 2.4
electrons
Data
Fit
Data - Fit
Mee (GeV)

channel	statistical uncertainty
muon	0.00044
electron	0.00060
combined	0.00036

Combined ± 0.00036 (stat)

Source	muons	electrons
MC statistics	0.00015	0.00033
Lepton momentum calibration	0.00008	0.00019
Lepton selection efficiency	0.00005	0.00004
Background subtraction	0.00003	0.00005
Pileup modeling	0.00003	0.00002
Total	0.00018	0.00039

Combined ± 0.00018 (syst)

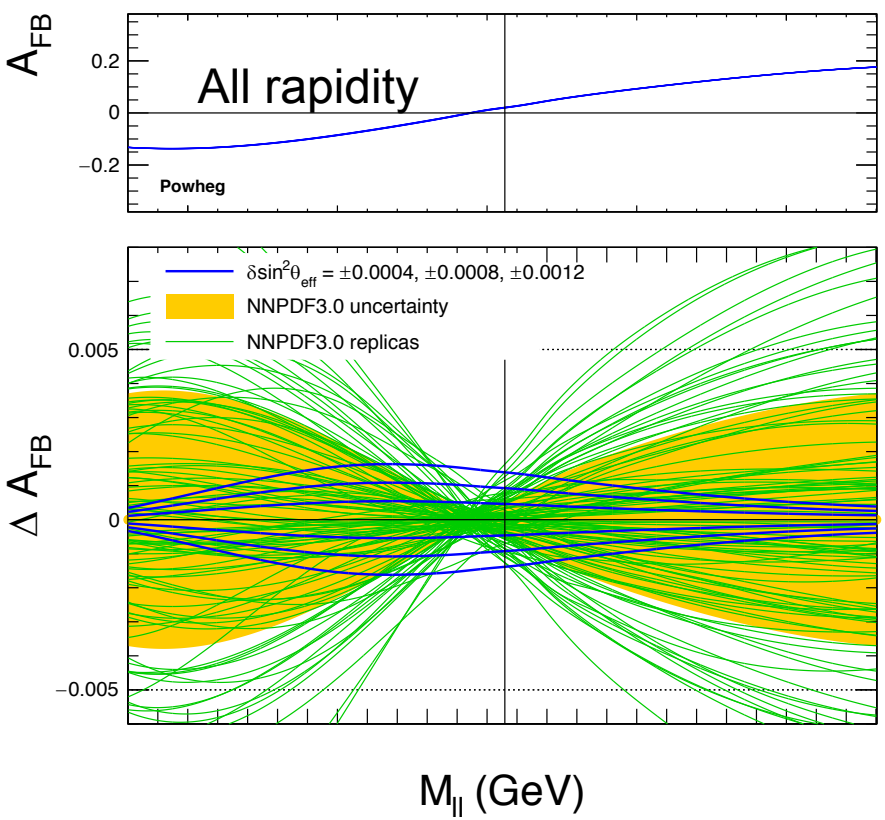
model variation	Muons	Electrons
Dilepton p_T reweighting	0.00003	0.00003
QCD $\mu_{R/F}$ scale	0.00011	0.00013
POWHEG MiNLO Z+j vs NLO Z model	0.00009	0.00009
FSR model (PHOTOS vs PYTHIA)	0.00003	0.00005
UE tune	0.00003	0.00004
Electroweak ($\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}} - \sin^2\theta_{\mathrm{eff}}^{\mathrm{u,d}}$)	0.00001	0.00001
Total	0.00015	0.00017

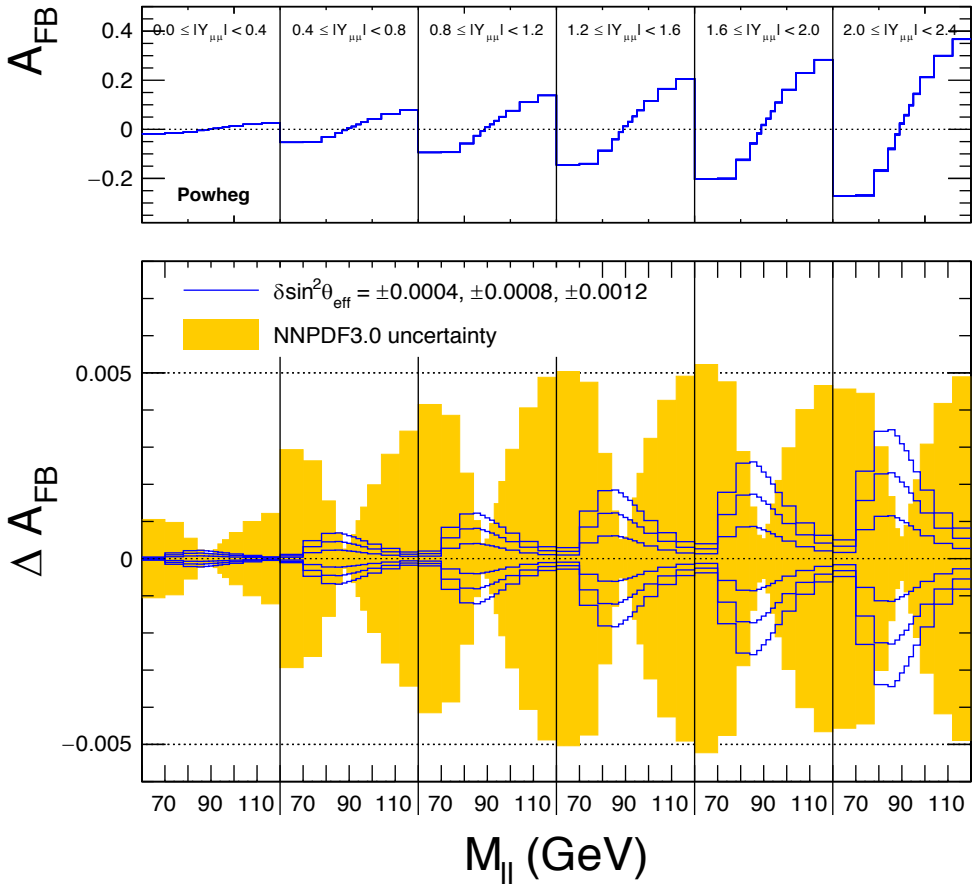
Combined ± 0.00016 (theory)

$$\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}} = 0.23101 \pm 0.00036(\mathrm{stat}) \pm 0.00018(\mathrm{syst}) \pm 0.00016(\mathrm{theory})$$

Vary $\sin^2\theta_{eff}$ for fixed PDF in **GREEN (left)**, PURPLE (right)
Vary 100 NNPDF replicas for fixed $\sin^2\theta_{eff}$ in ORANGE

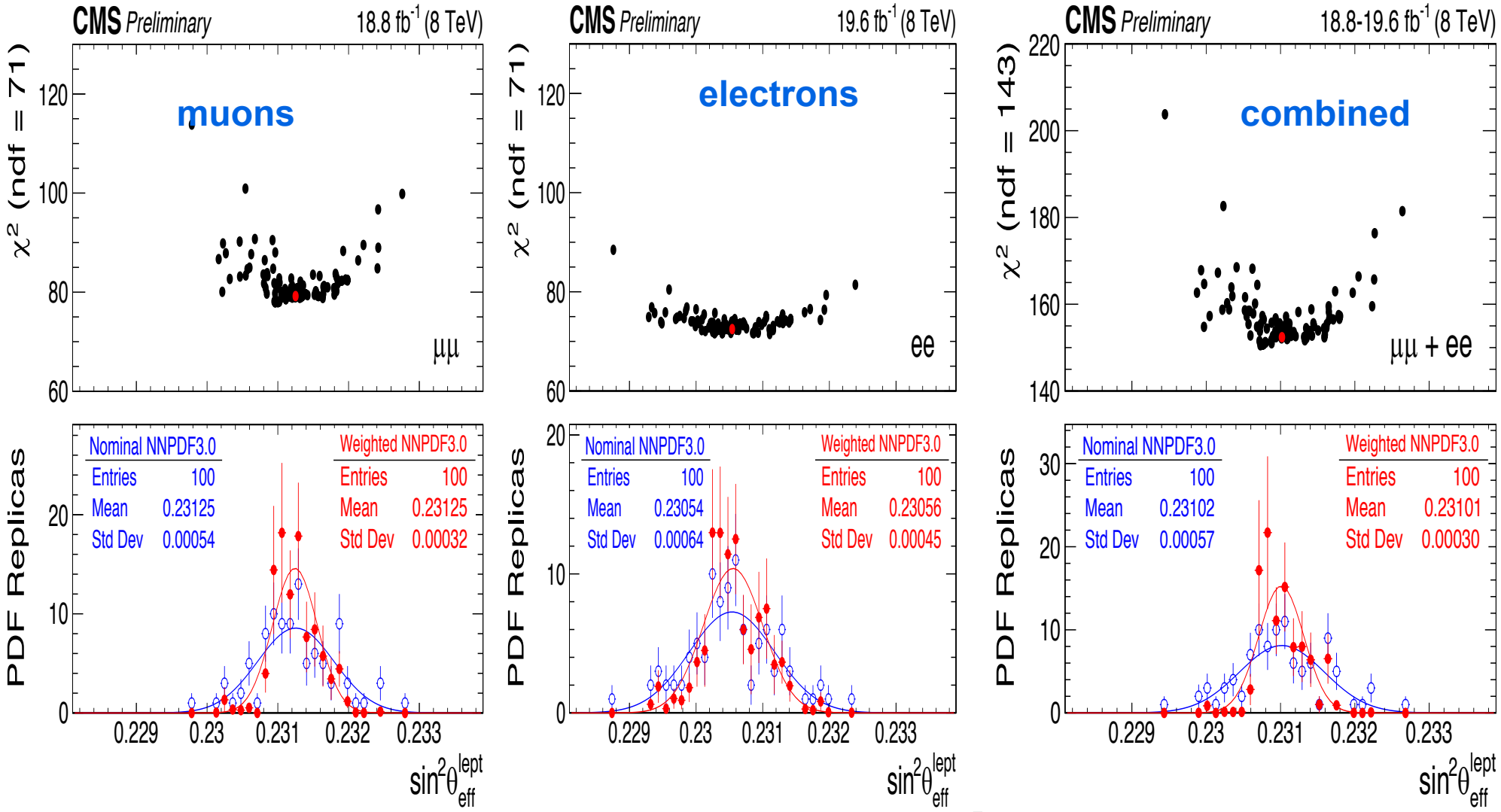
- Observed A_{FB} is very sensitive to PDFs
- Large in low and high masses, small near the peak (+ specific dependence on Y)





- Perform $\sin^2\theta_{eff}$ fit for each PDF replica (by default we use NNPDF3.0)
- Weight each replica by

$$w_i = \frac{e^{-\frac{\chi^2}{2}}}{\frac{1}{N}\sum_{i=1}^{N} e^{-\frac{\chi^2}{2}}}$$

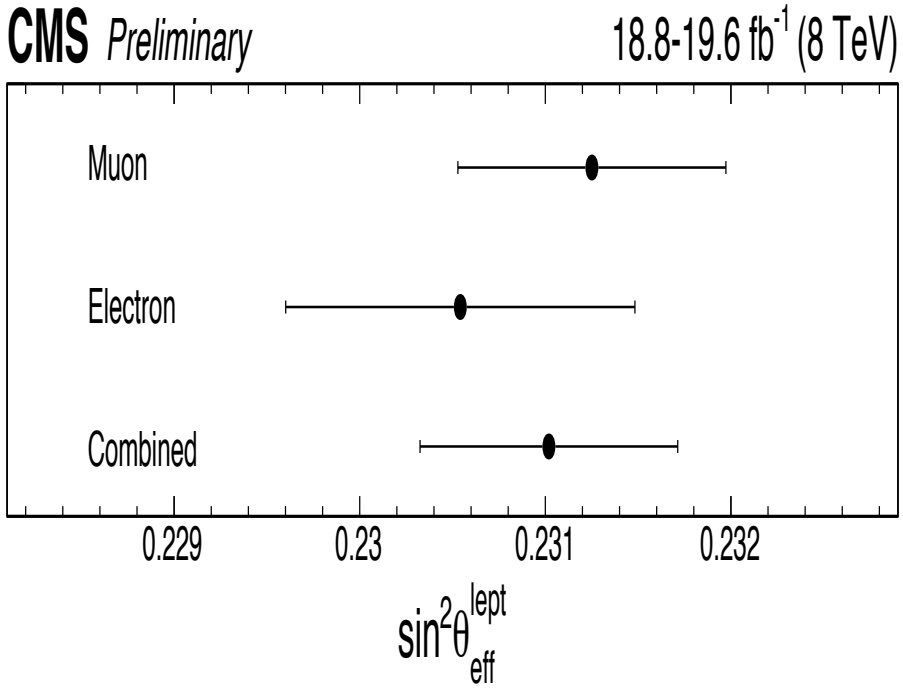


Channel	without constraining PDFs	with constraining PDFs
Muon	0.23125 ± 0.00054	0.23125 ± 0.00032
Electron	0.23054 ± 0.00064	0.23056 ± 0.00045
Combined	0.23102 ± 0.00057	0.23101 ± 0.00030

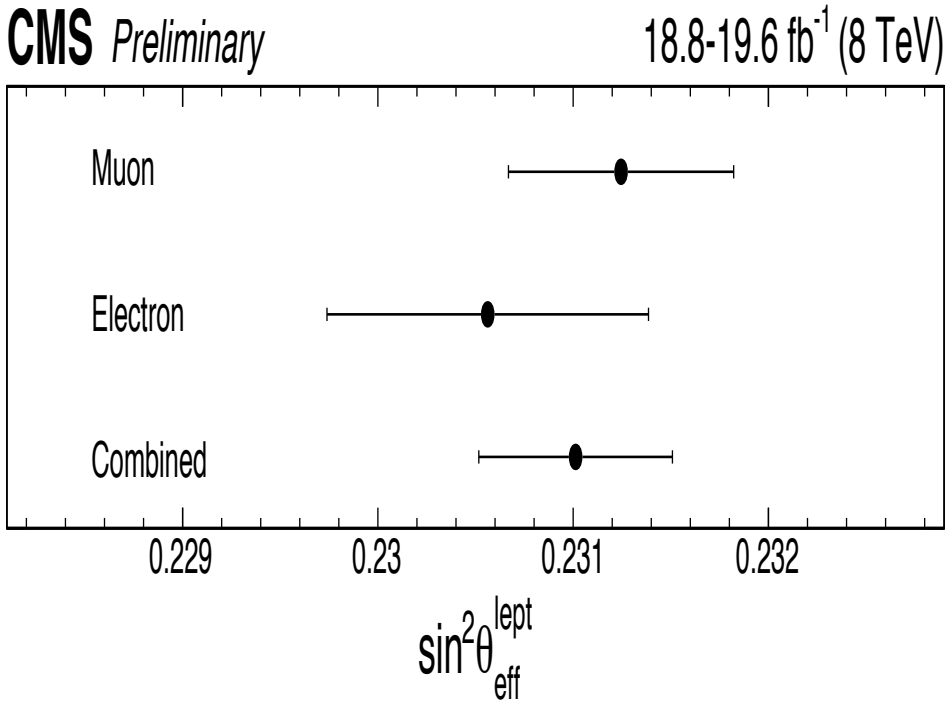
PDF reweighting constraints reduce PDF error by factor of 2

With larger statistical samples and new analysis techniques (including **precise lepton scale calibration, angular event weighting** and **additional PDF constraints**) the errors are significantly reduced.

PDF nominal



With PDF re-weighting constraints



Channel	without constraining PDF	with constraining PDFs
Muon	$0.23125 \pm 0.00048 \pm 0.00054$	$0.23125 \pm 0.00048 \pm 0.00032$
Electron	$0.23054 \pm 0.00069 \pm 0.00064$	$0.23056 \pm 0.00069 \pm 0.00054$
Combined	$0.23102 \pm 0.00040 \pm 0.00057$	$0.23101 \pm 0.00040 \pm 0.00030$

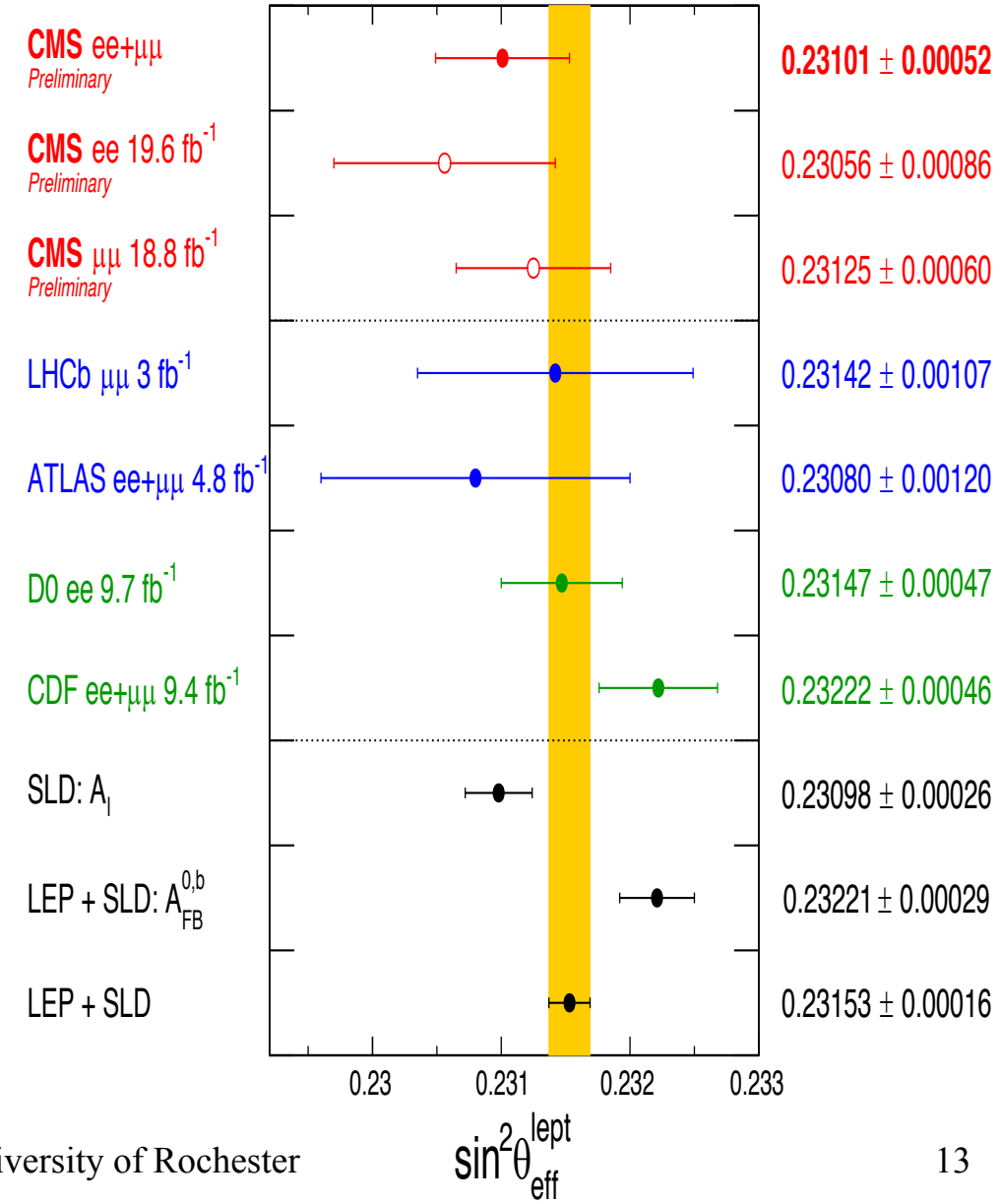
PDF reweighting constraints reduce PDF error by factor of 2

$$\sin^2\theta_{\text{eff}}^{\text{lept}} = 0.23101 \pm 0.00036(\text{stat}) \pm 0.00018(\text{syst}) \pm 0.00016(\text{theory}) \pm 0.00030(\text{pdf})$$

$$\sin^2\theta_{\text{eff}}^{\text{lept}} = 0.23101 \pm 0.00052.$$

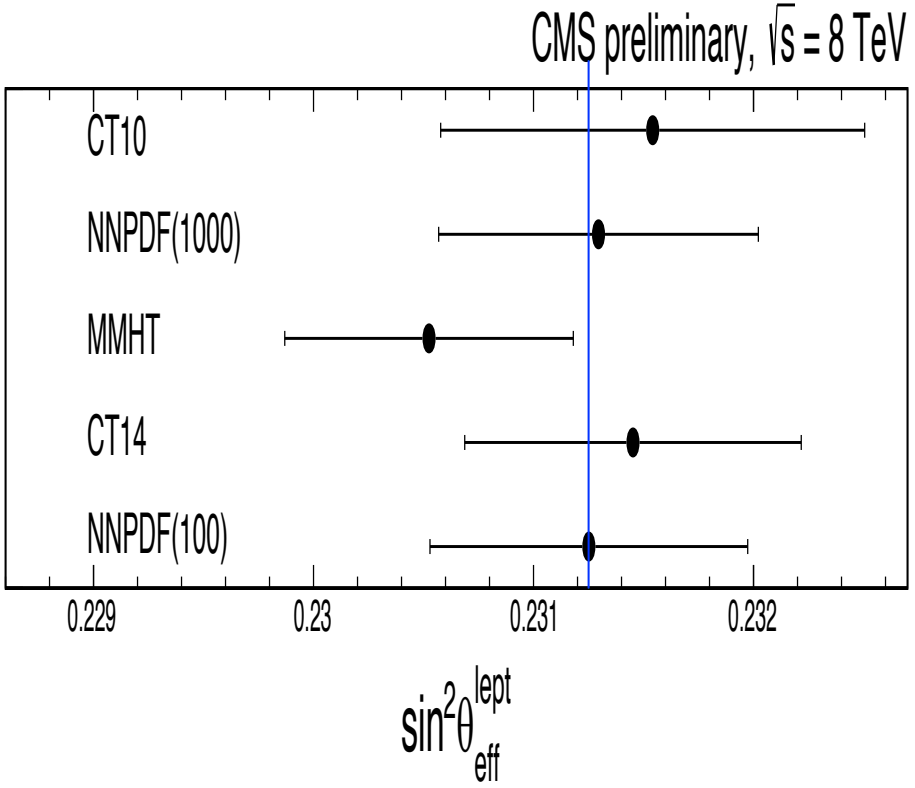
Results

- Measured $\sin^2\theta_{\text{eff}}$ 8 TeV μμ and ee
- Statistical uncertainty dominates
- Followed by PDF (reduced with reweighting by ~50%)
- Experimental uncertainties small
  - MC statistics (dominates)
  - lepton calibration
  - lepton selection efficiencies
  - background estimate
  - pileup
- Modeling errors dominated by QCD

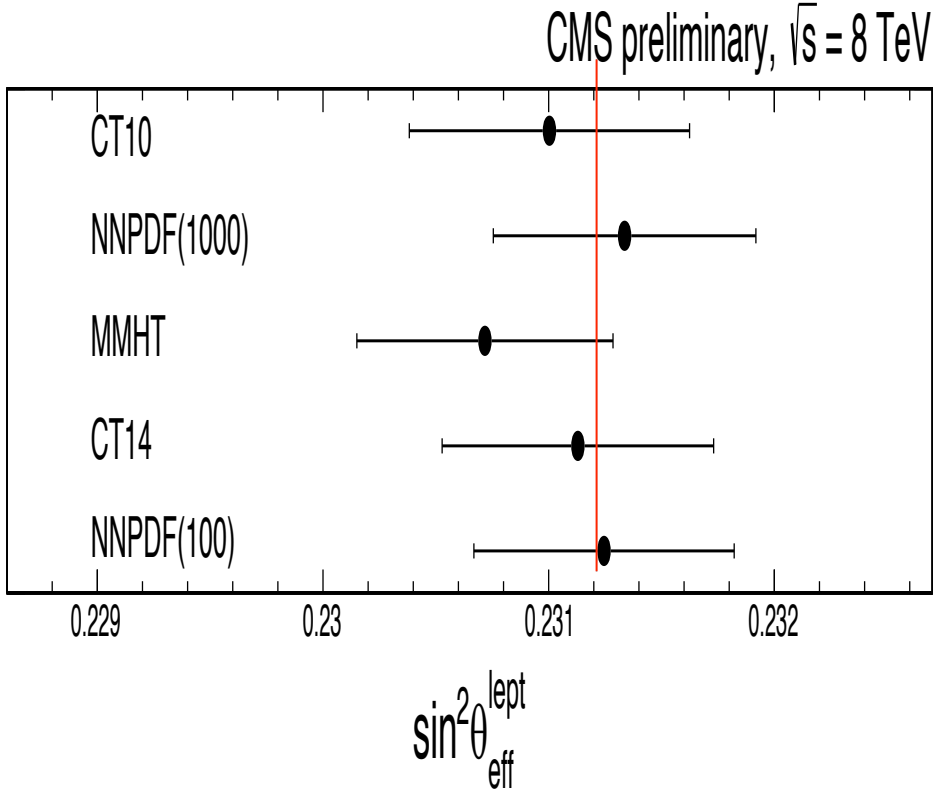


Additional Slides

PDF nominal



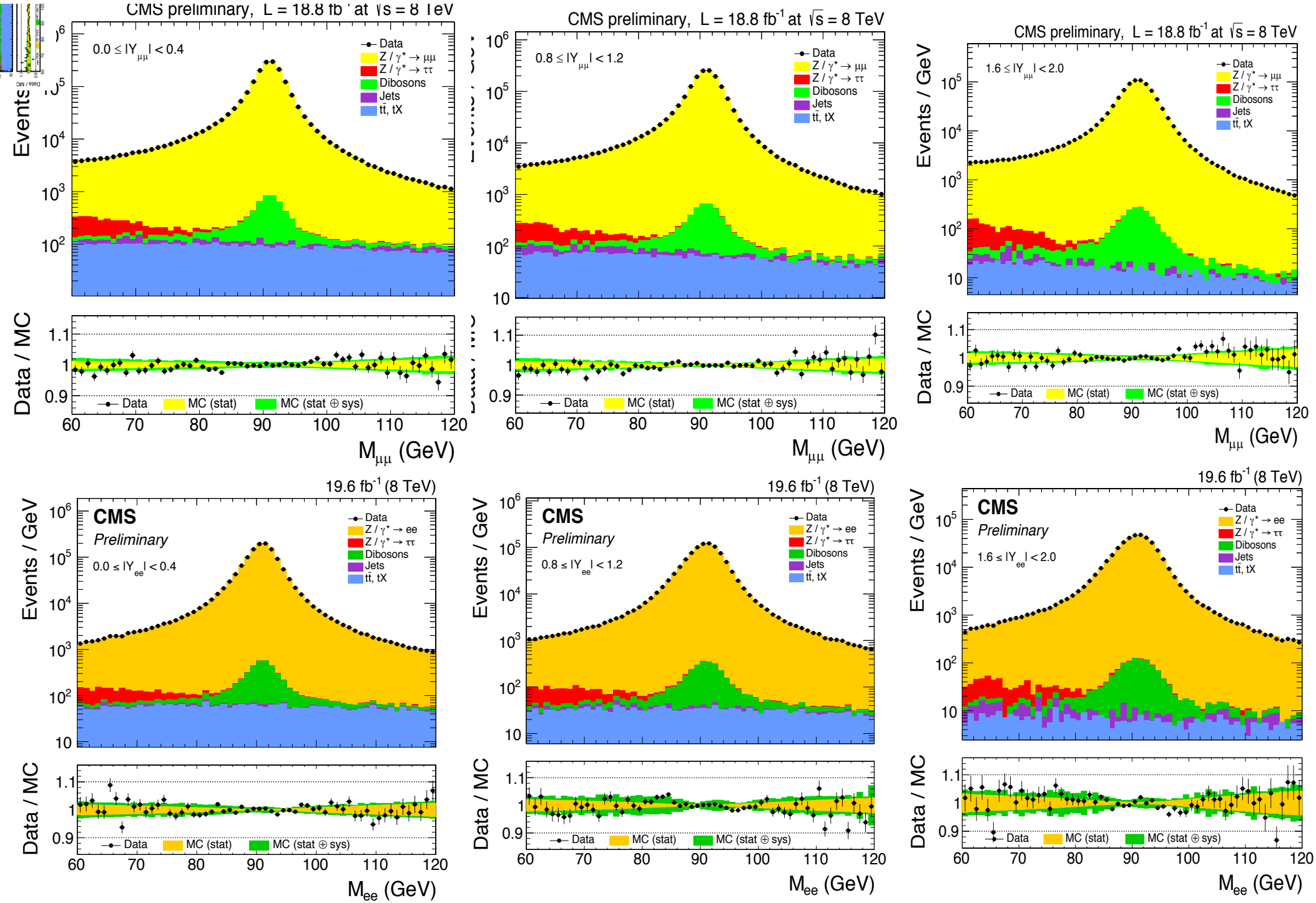
With PDF re-weighting constraints



PDF reweighting constraints reduce PDF error by factor of 2

With constraints from PDF reweighting the extracted values for different PDF are closer to each other

Figure 8: Extracted values of $\sin^2\theta^{\text{lept}}_{\text{eff}}$ from the dimuon data for different PDF sets with nominal (left) and χ^2 reweighted (right) PDF replicas. The error bars include the statistical, experimental and the PDF uncertainties.


CMS preliminary, L = 18.8 fb-1 at √s = 8 TeV
0.0 ≤ |Yμμ| < 0.4
0.8 ≤ |Yμμ| < 1.2
1.6 ≤ |Yμμ| < 2.0
Data
Z / γ* → μμ
Z / γ* → ττ
Dibosons
Jets
tt̄, tX
Events / GeV
Data / MC
Data
MC (stat)
MC (stat ⊕ sys)
Mμμ (GeV)
19.6 fb-1 (8 TeV)
CMS
Preliminary
0.0 ≤ |Yee| < 0.4
0.8 ≤ |Yee| < 1.2
1.6 ≤ |Yee| < 2.0
Z / γ* → ee
Mee (GeV)

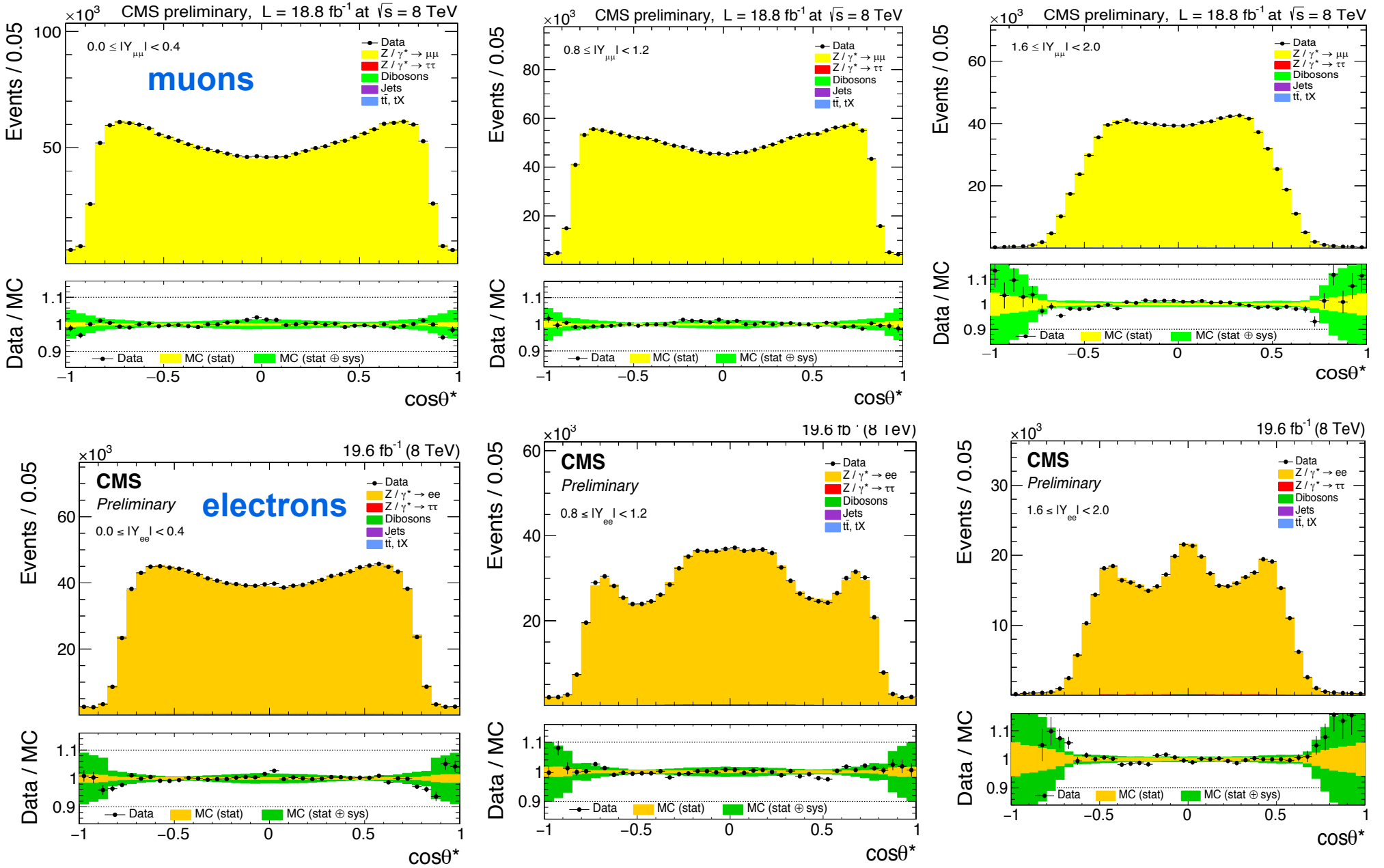


Figure 3: The muon (top) and electron (bottom) $\cos\theta^*$ distributions in three representative rapidity bins: $|Y_{ll}| < 0.4$ (left), $0.8 < |Y_{ll}| < 1.2$ (middle), and $1.6 < |Y_{ll}| < 2.0$ (right).

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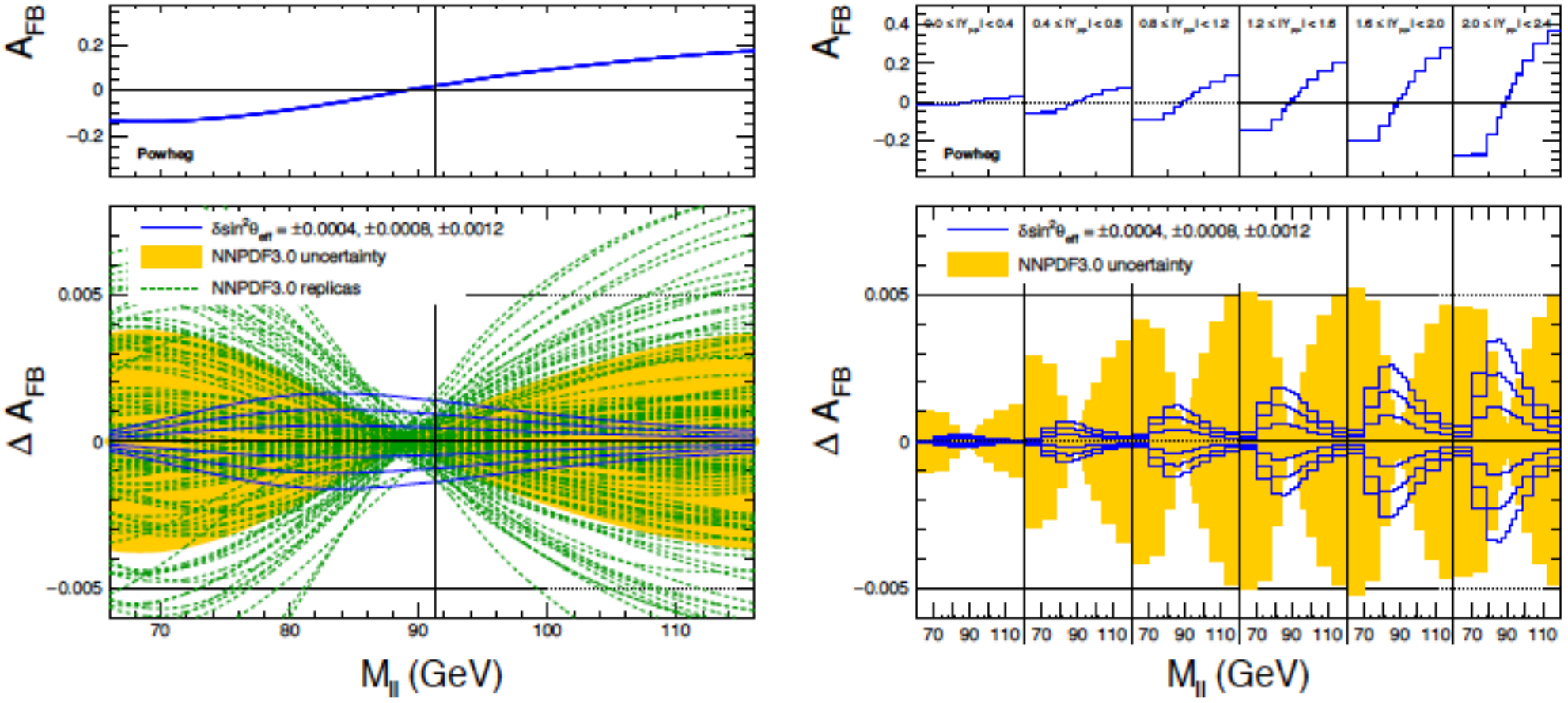

Figure 5: Distribution of A_{FB} as a function of mass integrated over rapidity (left) and in six rapidity bins (right) for $\sin^2\theta^{\mathrm{lept}}_{\mathrm{eff}} = 0.23120$. The solid lines in the bottom panel correspond to six variations of $\sin^2\theta^{\mathrm{lept}}_{\mathrm{eff}}$ around the central value: ± 0.00040, ± 0.00080 and ± 0.00120. The dashed lines correspond to A_{FB} predictions for 100 NNPDF3.0 replicas. The shaded band illustrates the standard deviation over the NNPDF3.0 replicas.