Measurement of s2w in CMS

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On behalf of CMS

LHC EW precision sub-group meeting

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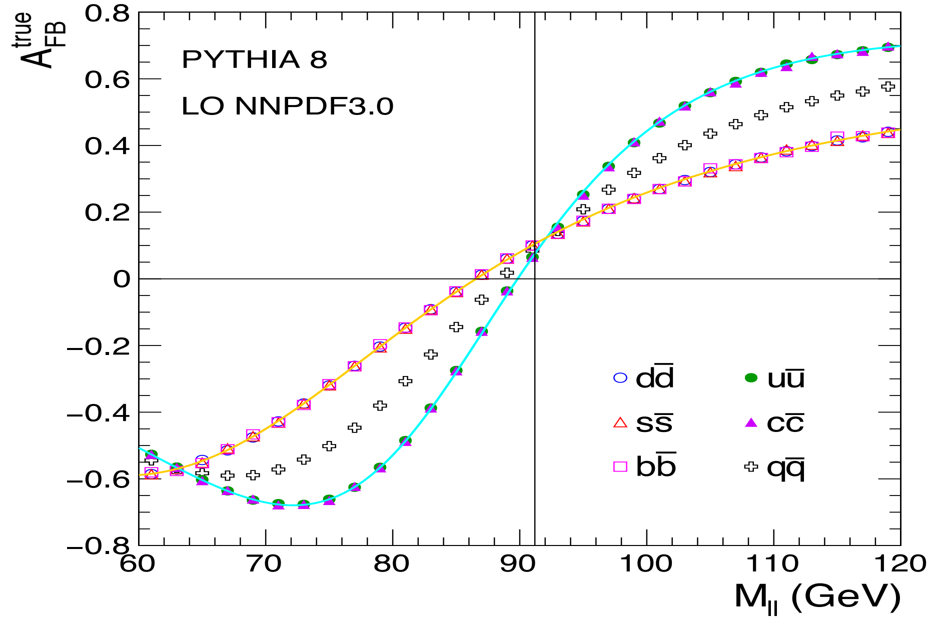
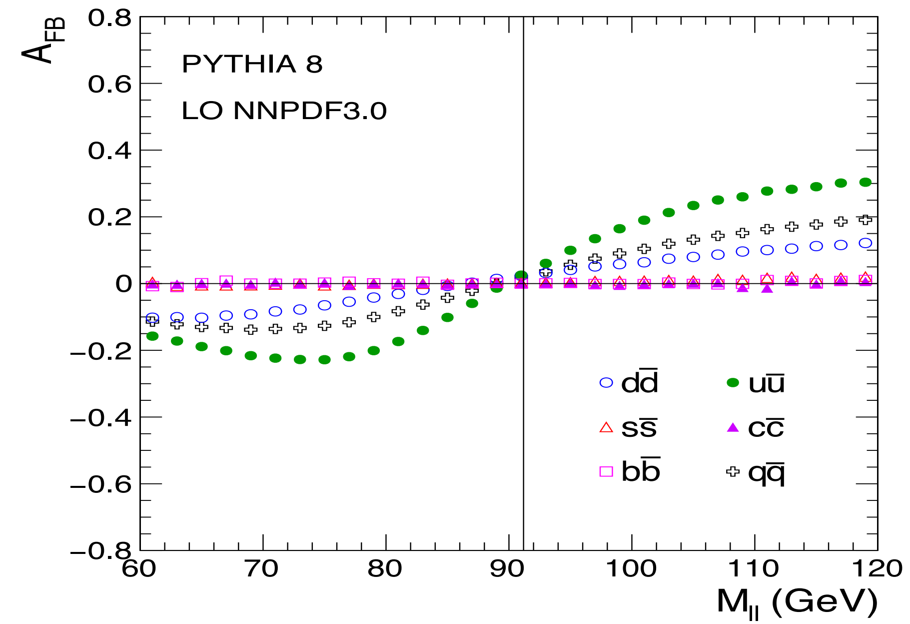
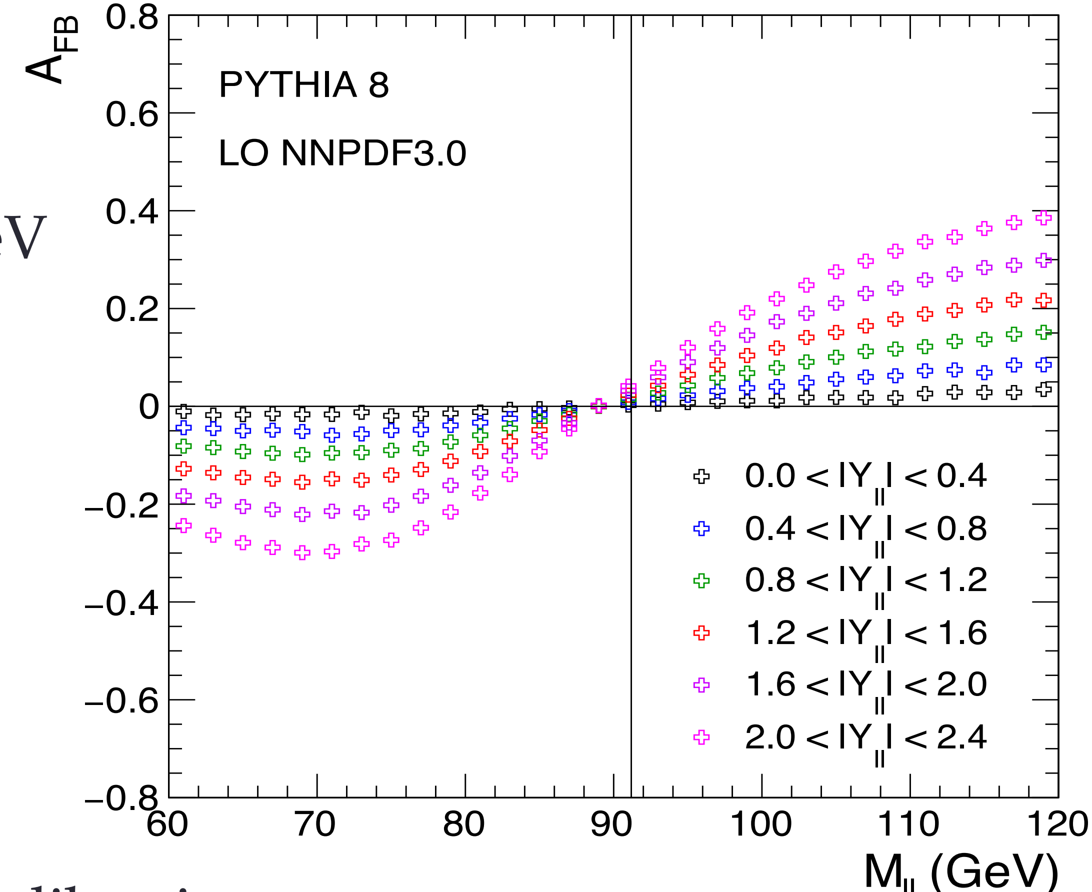
AFB in Drell-Yan events

- A_{FB} in $\cos\theta^*_{CS}$ distribution in dilepton (ee and μμ) events are used to measure $\sin^2\theta_\ell^{eff}$
- Mass dependence of A_{FB} driven by Z-γ interference term
- Definition of forward/backward in pp based on sign of $y_{\ell\ell}$ boost
- Only valence quarks contribute to the measurement
- Large $y_{\ell\ell}$-dependent dilution
- Observed A_{FB} depends on both $\sin^2\theta_\ell^{eff}$ and PDFs





- Fit A_{FB} distribution in bins of mass and $|y_{ee}|$ with POWHEG templates



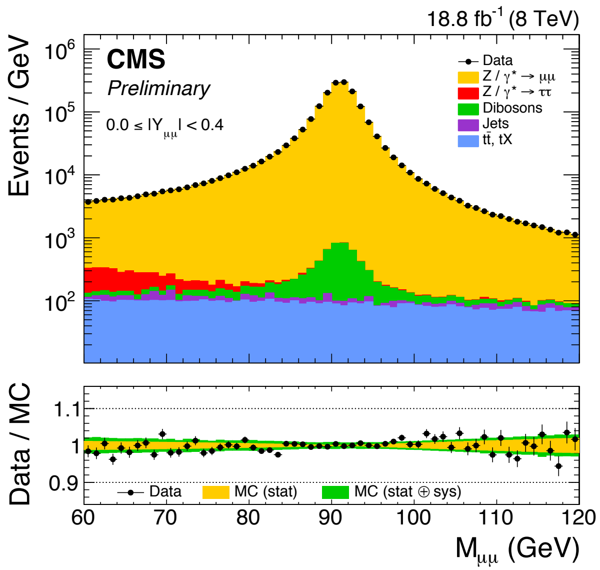
- 12 m_{ee} bins: $60 < m_{ee} < 120$ GeV
- 6 $|y_{ee}|$ bins: $|y_{ee}| < 2.4$
- 2012 8 TeV dataset: 20 fb^{-1}
- ~8M μμ and 5M ee events
- Precise lepton momentum calibration
- Event-weighting technique to calculate observable A_{FB}
- Constrain PDF uncertainties using A_{FB} data

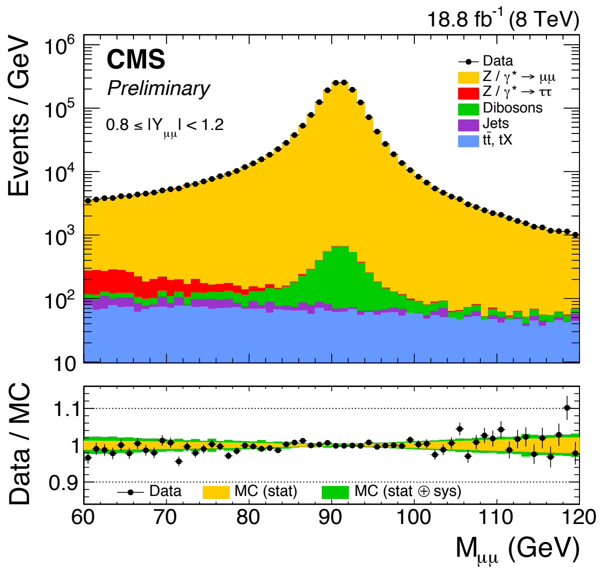
using Z→ ℓℓ events to calibrate lepton momentum scale and resolution

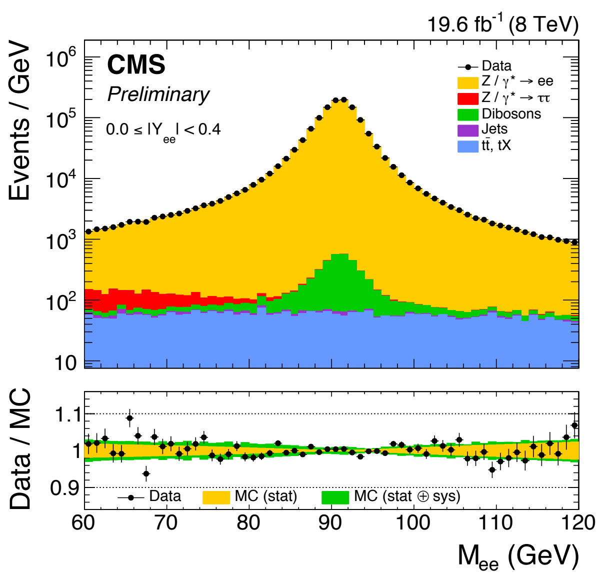
applied to data and simulation such that:

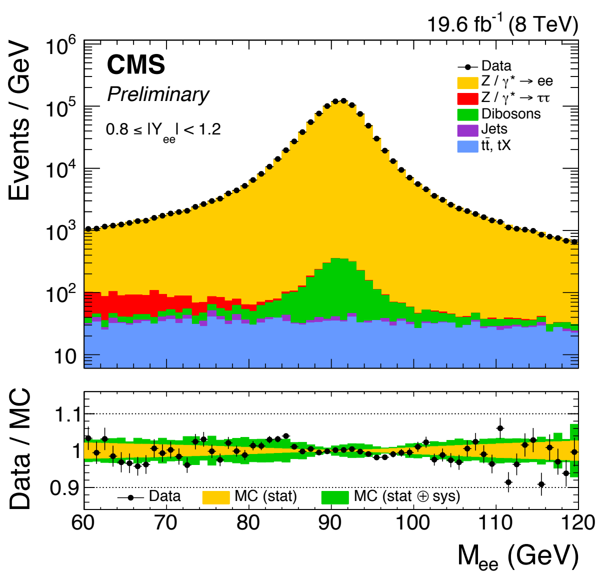
- scale matches true scale based on generated post-FSR (for muons) and dressed (for electron) momenta

- resolution matches reconstruction resolution in data



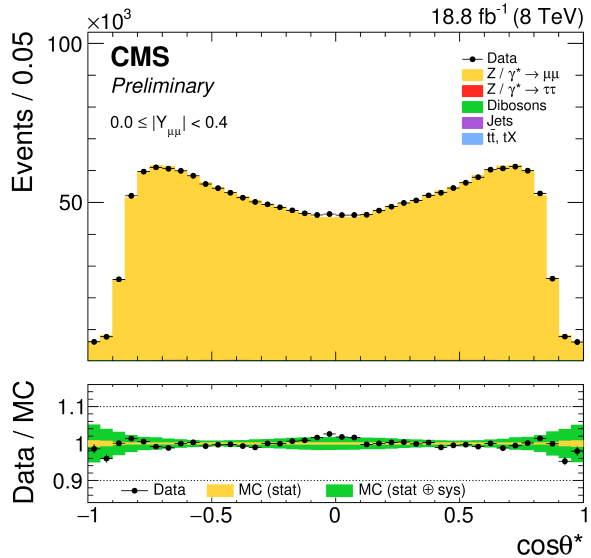


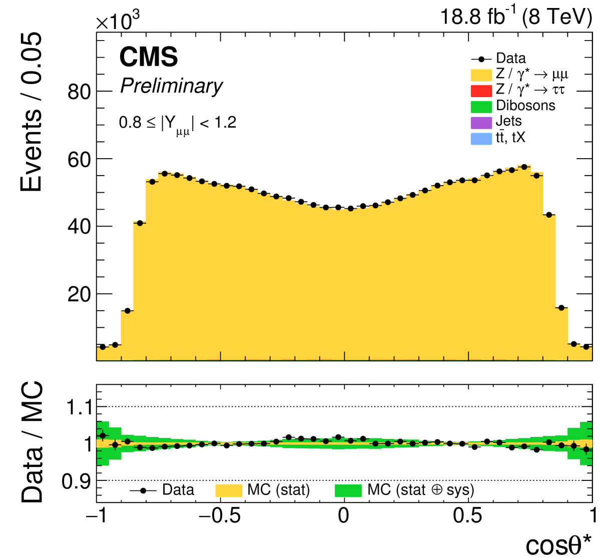


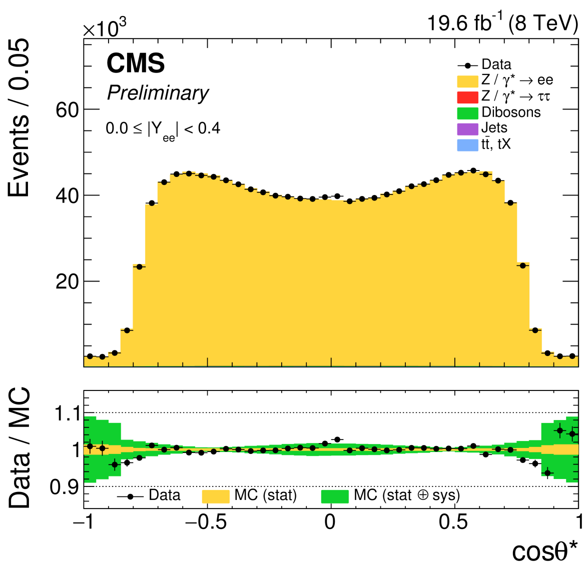


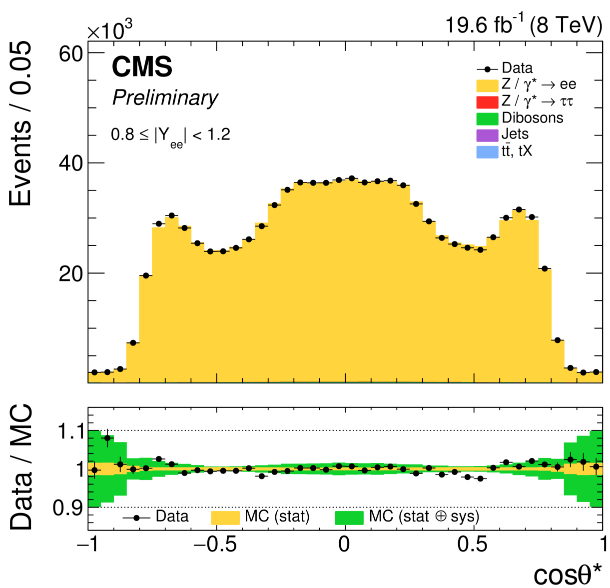
Cosθ distributions

- Observable is weighted A_{FB}
  A. Bodek, Euro. Phys. J. C67, 321(2010)
- Event-weights based on cosθ*
  (0 at cosθ*=0)
- $4\pi\ A_{FB}^{count} = 4\pi\ A_{FB}^{weight}$
  $= \text{fid}\ A_{FB}^{weight}$
- Less sensitive to acceptance
- Smaller statistical uncertainty



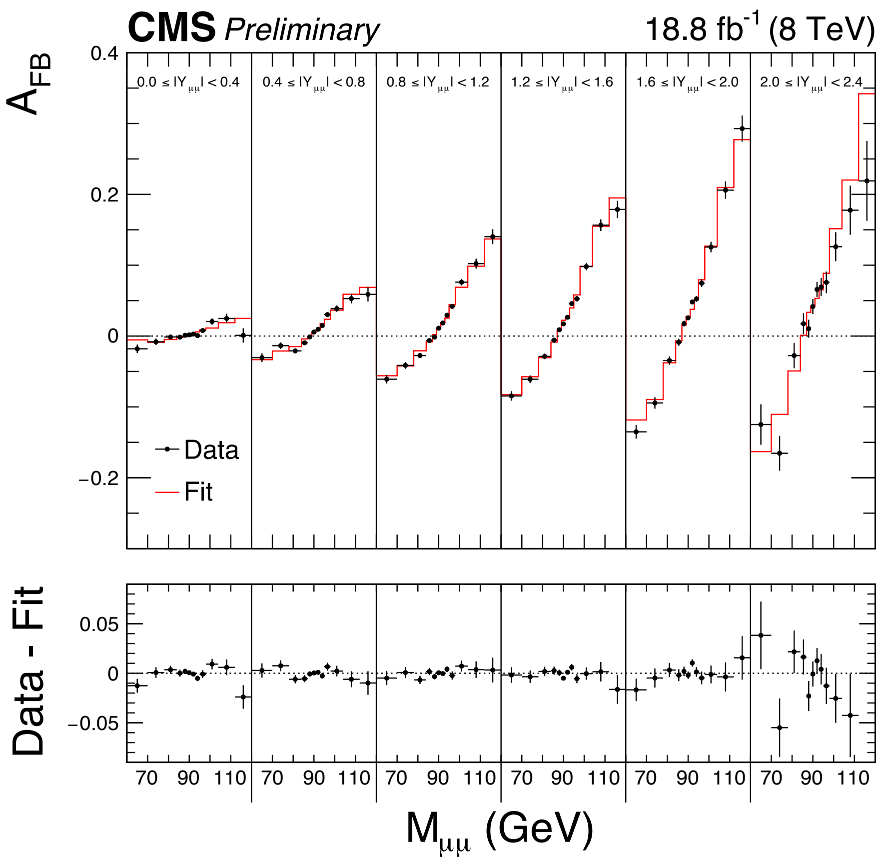


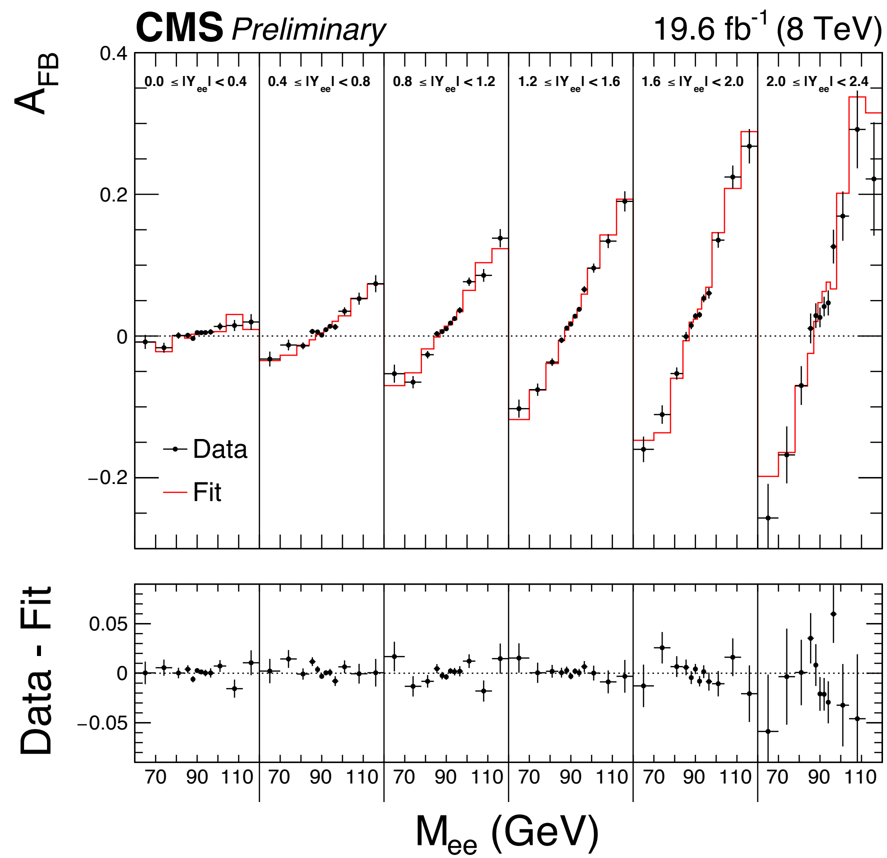




- At large cosθ acceptance sensitive to p_T modeling
- MiNLO has better A_0 modeling and improves description at central cosθ*
- Both have negligible effect on measurement

- Weighted A_{FB} in 6 dimuon rapidity x 12 mass measurement bins





Statistical and systematic uncertainties

- Statistical uncertainties dominate
  - include stat. uncertainties in lepton calibration & efficiencies
  - Evaluated with bootstrapping to take account of correlations

channel	statistical uncertainty
muon	0.00044
electron	0.00060
combined	0.00036

- Experimental uncertainties are small, biggest contribution coming from limited MC statistics, which will reduced for more precise data

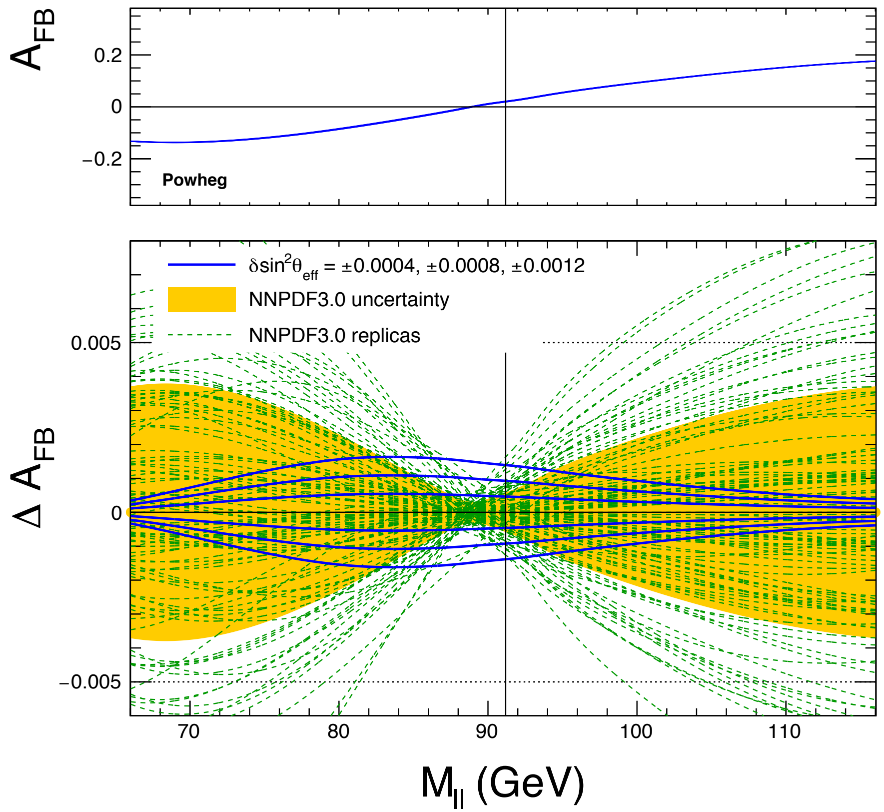
Source	muons	electrons
MC statistics	0.00015	0.00033
Lepton momentum calibration	0.00008	0.00019
Lepton selection efficiency	0.00005	0.00004
Background subtraction	0.00003	0.00005
Pileup modeling	0.00003	0.00002
Total	0.00018	0.00039

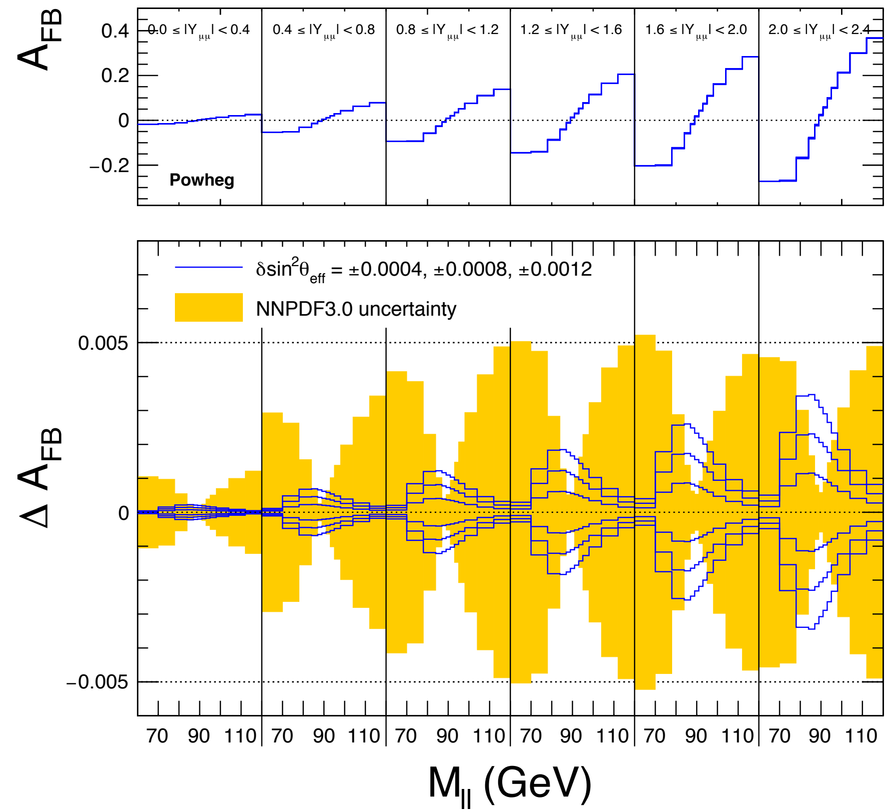
- Largest modeling uncertainty comes from QCD scale variation

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 ($\sin^2\theta^{\text{lept}}_{\text{eff}} - \sin^2\theta^{\text{u,d}}_{\text{eff}}$)	0.00001	0.00001
Total	0.00015	0.00017

PDF reweighting

- Observed A_{FB} is very sensitive to PDFs (size of dilution, ratio of u and d to total)
- Large in low and high masses, small near the peak (+ specific dependence on y)



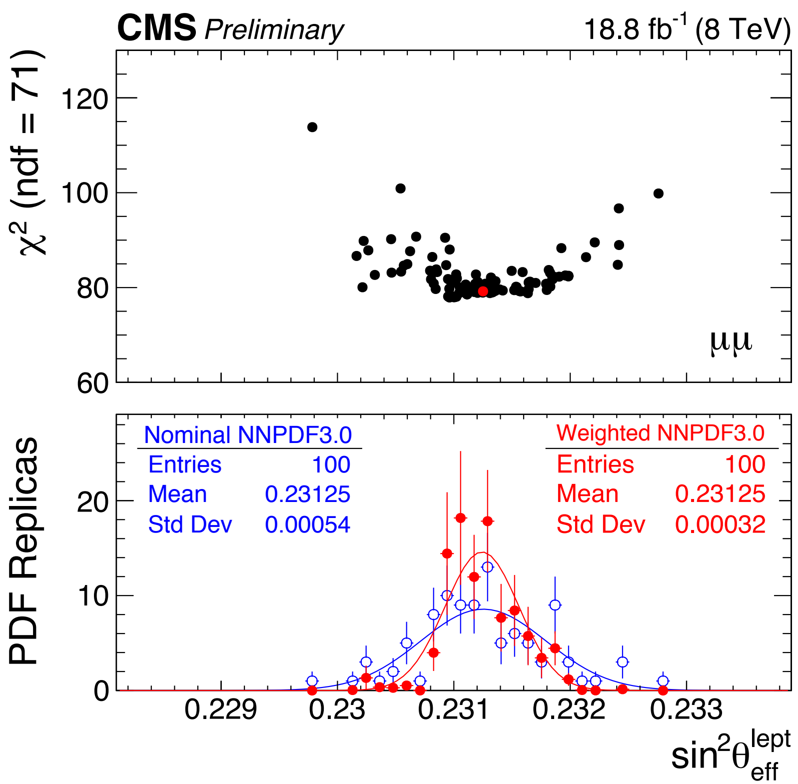


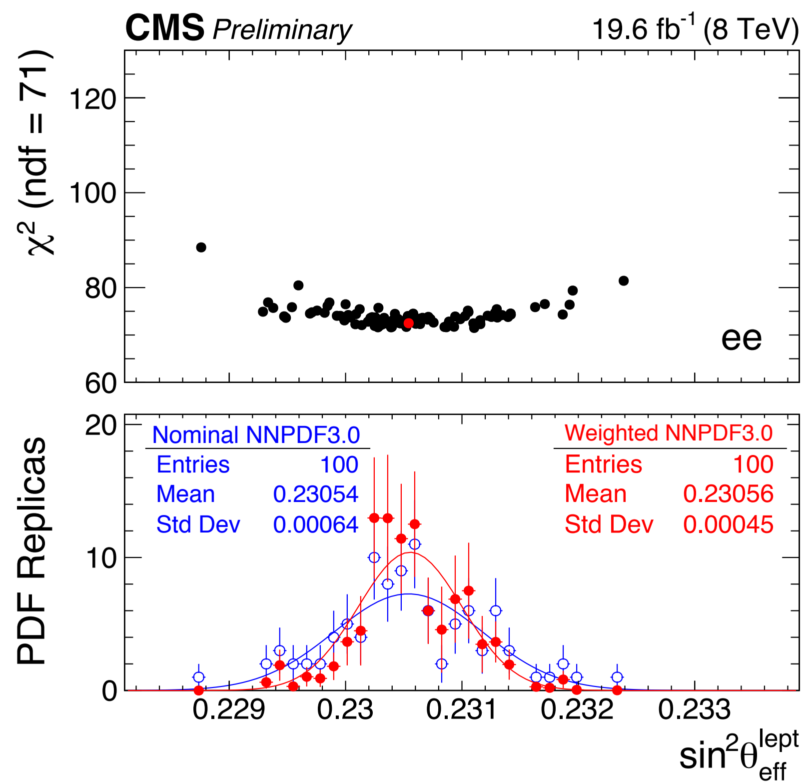
- Perform $\sin^2\theta_{eff}$ fit for each PDF replica (by default we use NNPDF3.0)
- Weight each replica (i) by $w_i(\chi^2_{min})$

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

A. Bodek et al Euro. Phy. J. C76:115 (2016)

PDF uncertainties in μμ and ee channels

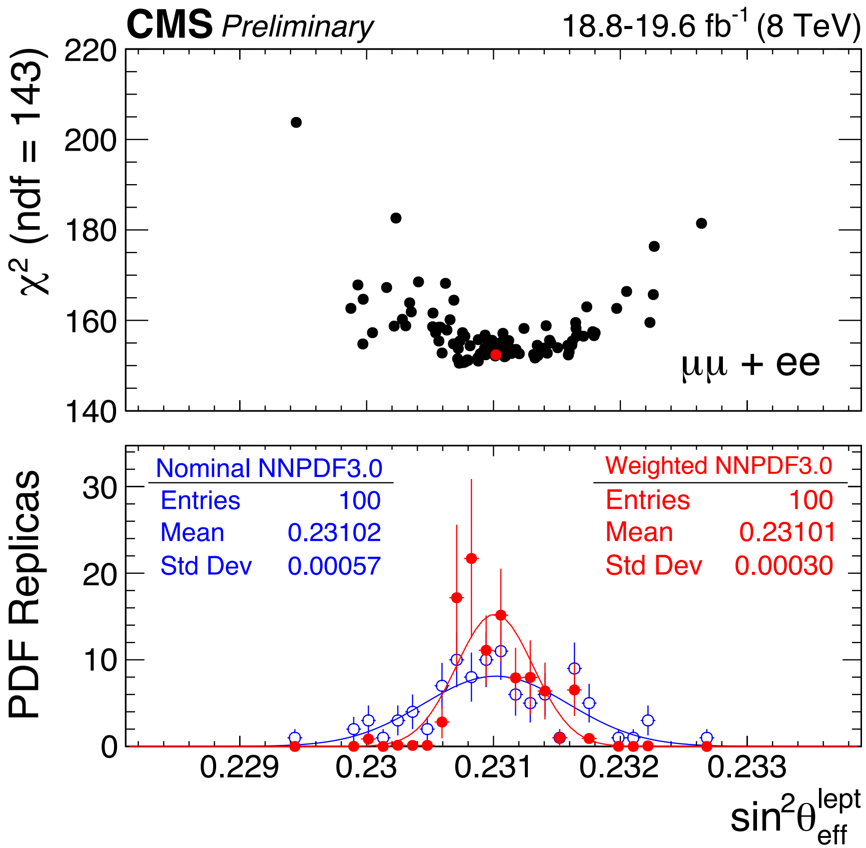




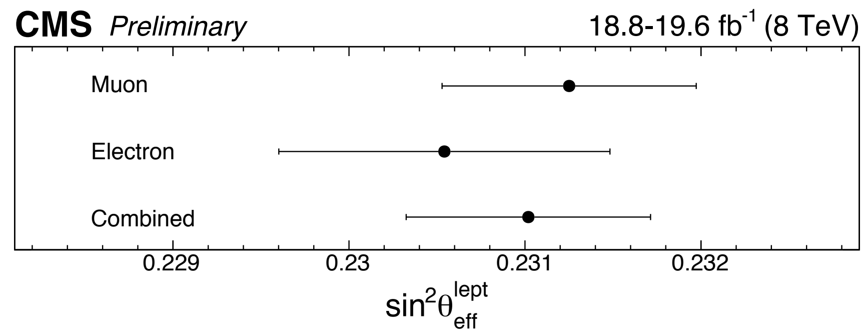
— replicas that poorly describe data (with corresponding best-fit $\sin^2\theta_{eff}$) get smaller weights

— extreme replicas from both sides are disfavored by both dimuon and dielectron data

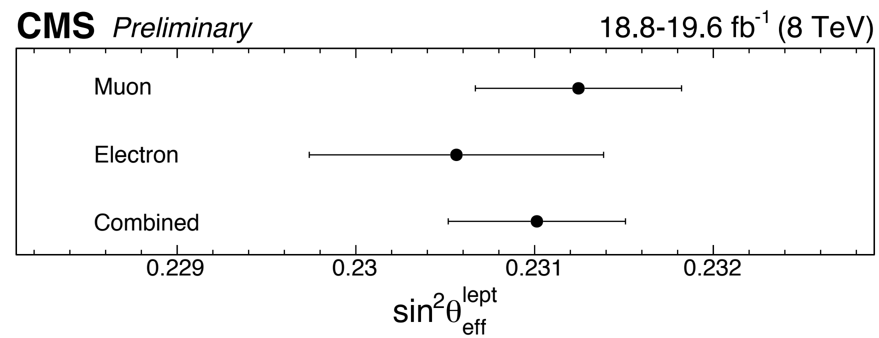
PDF uncertainties



Nominal PDF Errors

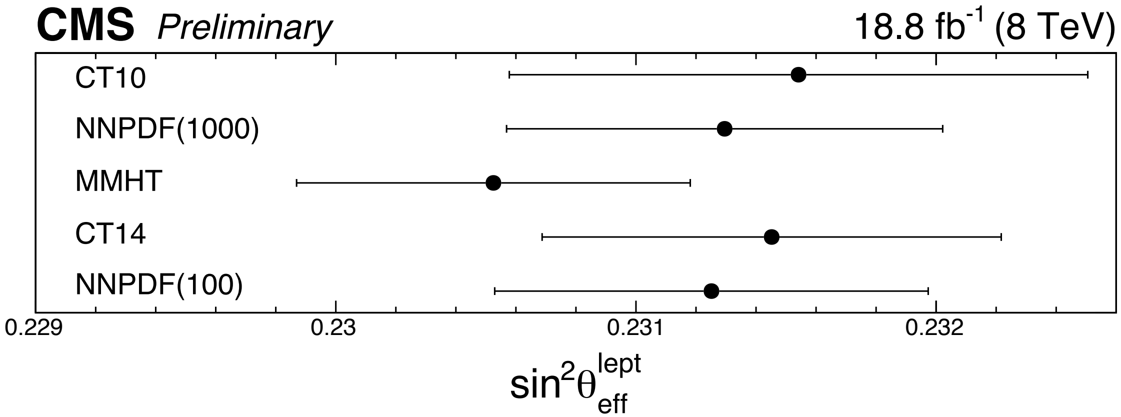


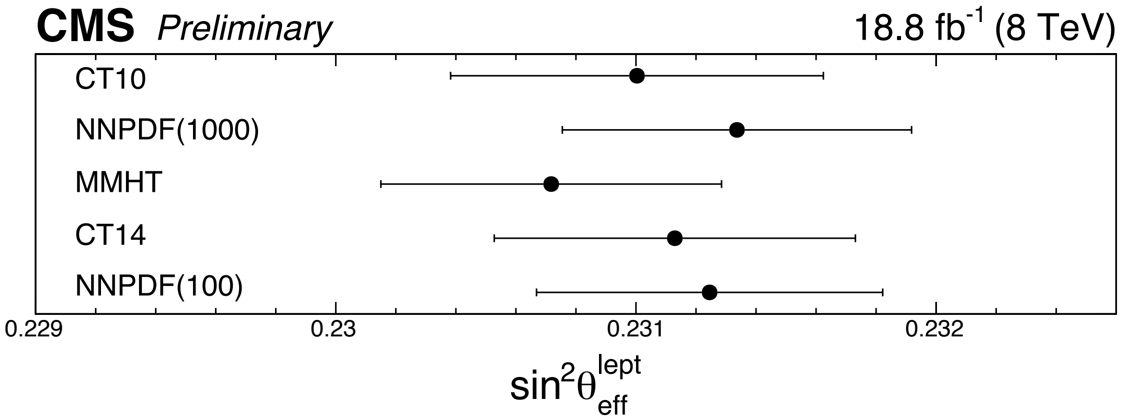
Constrained PDF Errors



- Good consistency between electron and muon results
- PDF uncertainties reduced by about factor of two

Study done with muons





- PDF uncertainties reduce
- Spread of central values reduce

- From Hessian PDFs first generate 1000 replicas:

$$O_i = O_0 + \frac{1}{2}\sum_{k=0}^{n}(O_{2k+1} - O_{2k+2})R_{ik}$$

- then apply same PDF reweighting

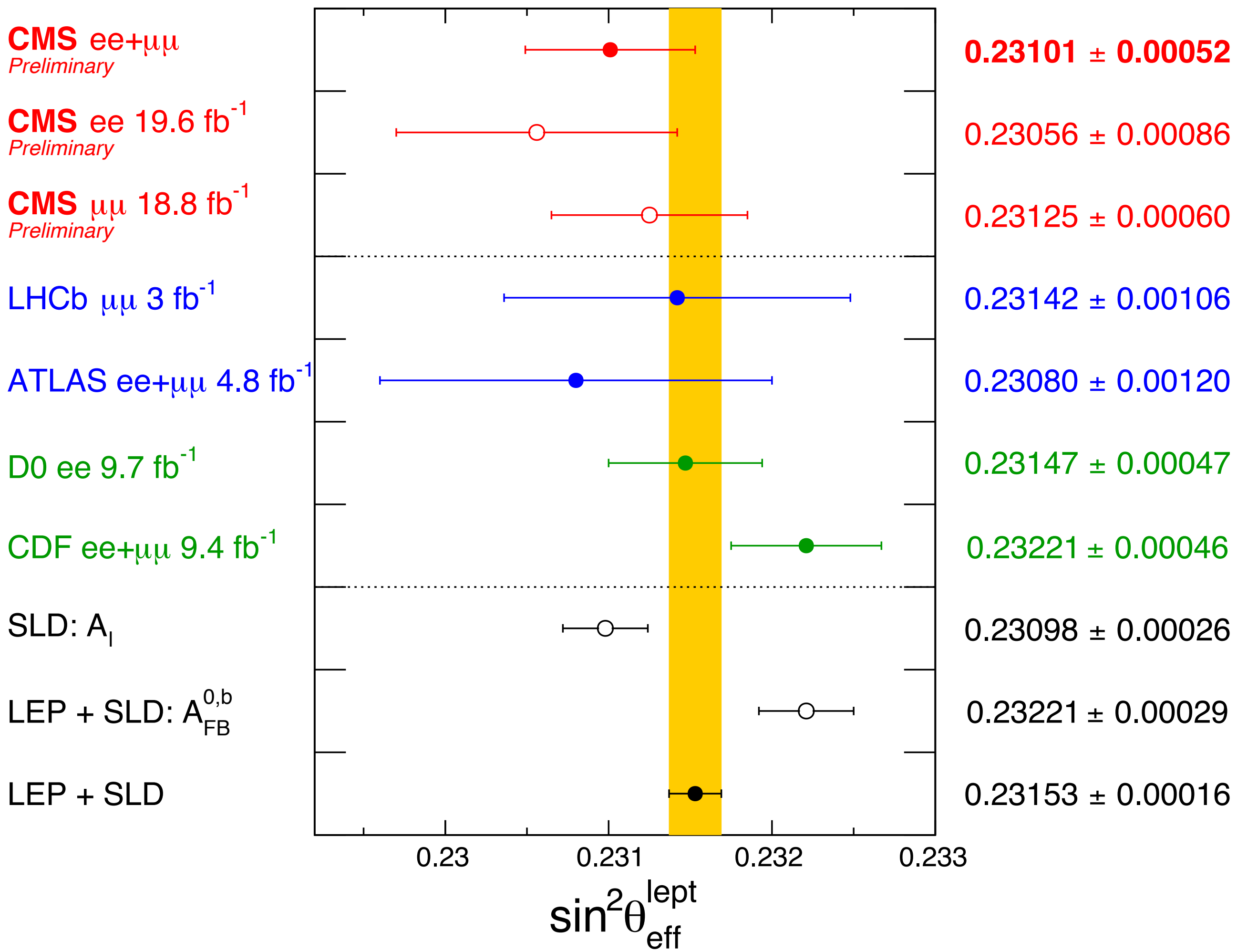
- Also did simultaneous fit for Hessian PDFs using nuisance parameters

- Also performed cross-check for Hessian NNPDFs

=> both central values and uncertainties are ~identical to those obtained with replicas

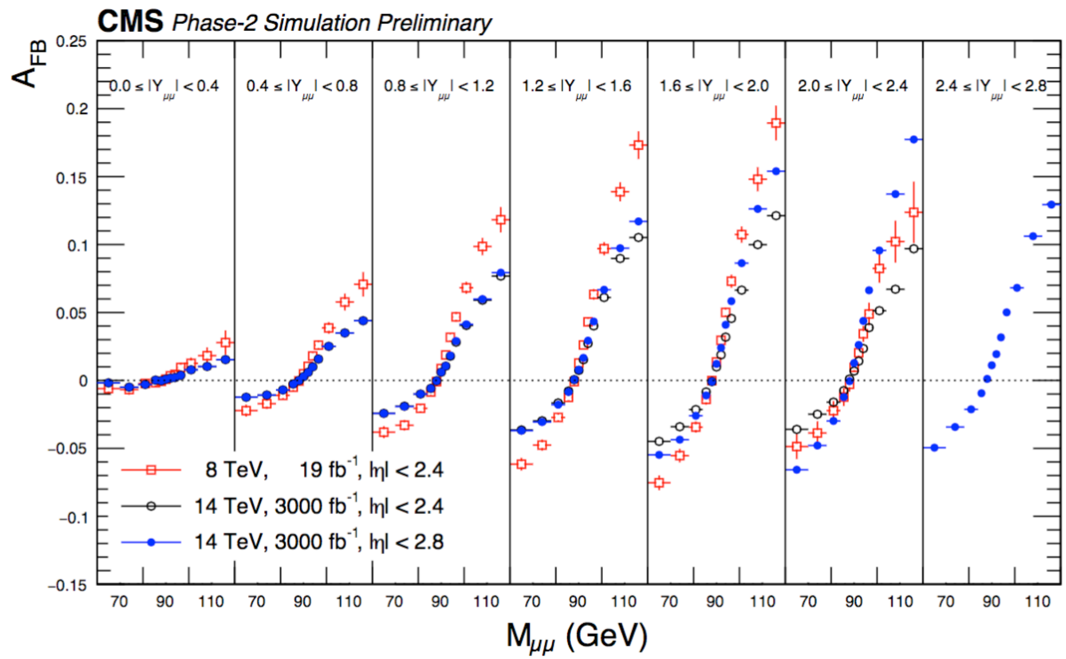
$$\sin^2\theta_{\text{eff}}^{\text{lept}} = 0.23101 \pm 0.00036(\text{stat}) \pm 0.00018(\text{syst}) \pm 0.00016(\text{theory}) \pm 0.00030(\text{pdf})$$

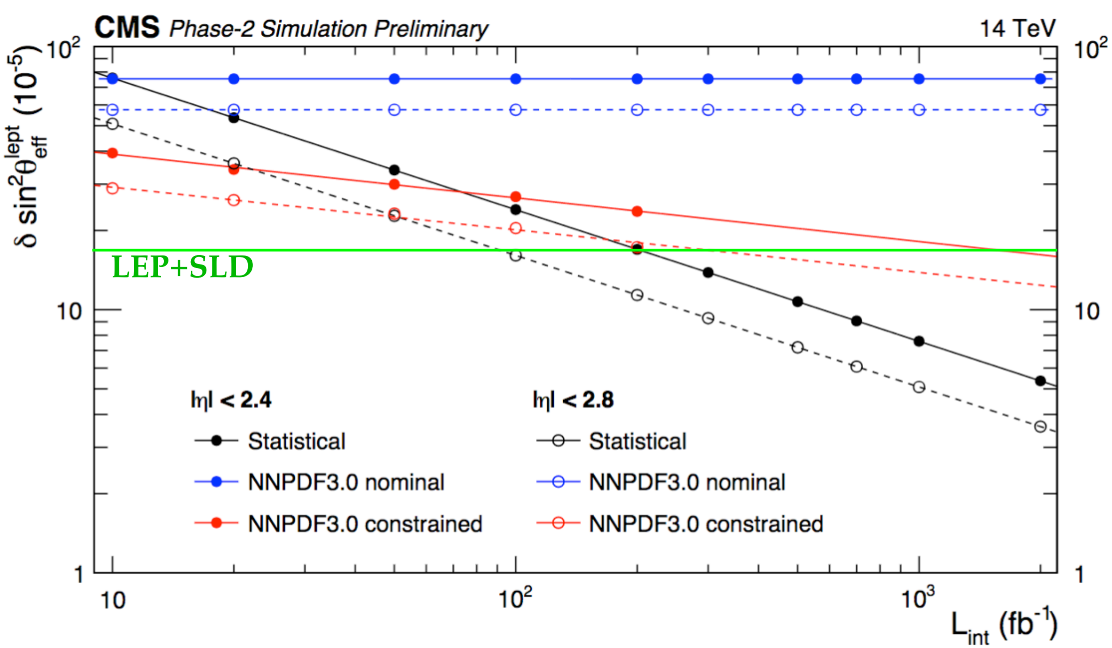
$$\sin^2\theta_{\text{eff}}^{\text{lept}} = 0.23101 \pm 0.00052.$$



- Statistical uncertainties still dominate
- Experimental uncertainties are under control
- Theory uncertainties, dominated by QCD scale variations, are small compared to current statistical errors
- PDF uncertainties constrained significantly using same A_{FB} data

- at 13/14 TeV less contribution from valence quarks
  - smaller observable $|A_{FB}|$ in pp
  - larger statistical and PDF errors if we had same # of events





- But we will have lot more data
- With Run2 data, statistical uncertainty will be <~ half,
- PDF errors will also be reduced
- With HL-LHC data, statistical uncertainty will be negligible, PDF errors can be reduced to improve current knowledge of $\sin^2\theta_\ell^{eff}$

Summary

- Hadron-collider measurements approaching world-average precision
- Current measurements still limited by statistical and PDF errors
- With Run-2 data and onward, PDF uncertainties will dominate
- Constraining PDFs in situ reduces uncertainties significantly
- Can be reduced further when measurements are combined
  - … details to be discussed …