Preperation of LHC combination for the weak mixing angle with full Run-2 dataset

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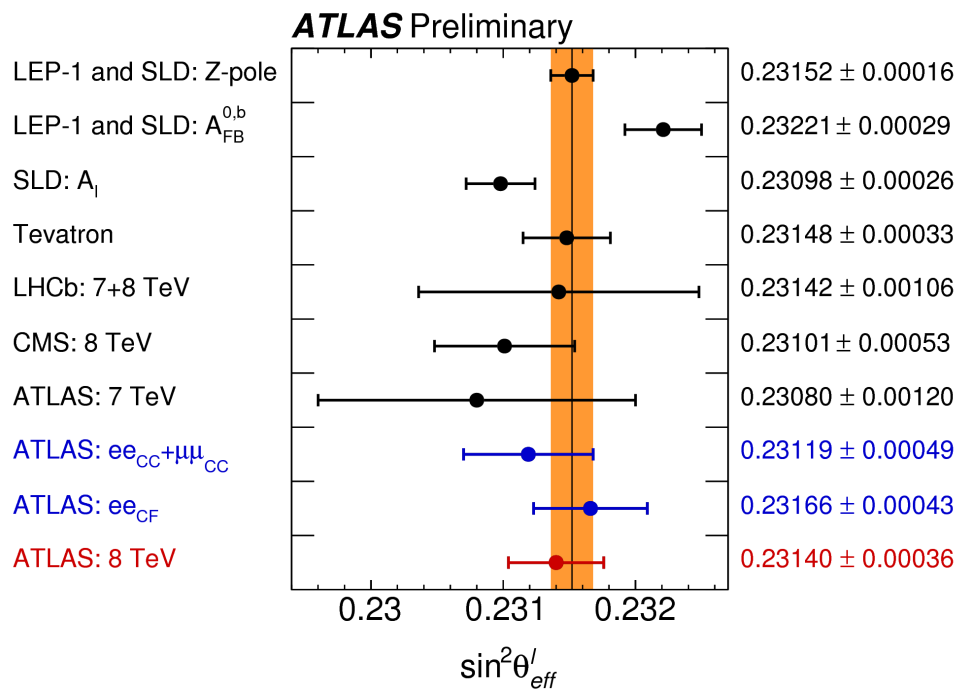
LHC EW WG General Meeting

Dec 17, 2019

Introduction

- Precise measurements of effective leptonic weak mixing angle provide important tests for SM

- Has been measured by ATLAS, CMS and LHCb collaborations with Run1 data



- With x7 integrated luminosity of Run2 data (even with larger √s) LHC can produce much more precise measurement of $\sin^2\theta^l_{eff}$

- It is important that experiments use same or equivalent models to interpret data and treat common uncertainty sources consistently to produce final combined measurement

How it's measured

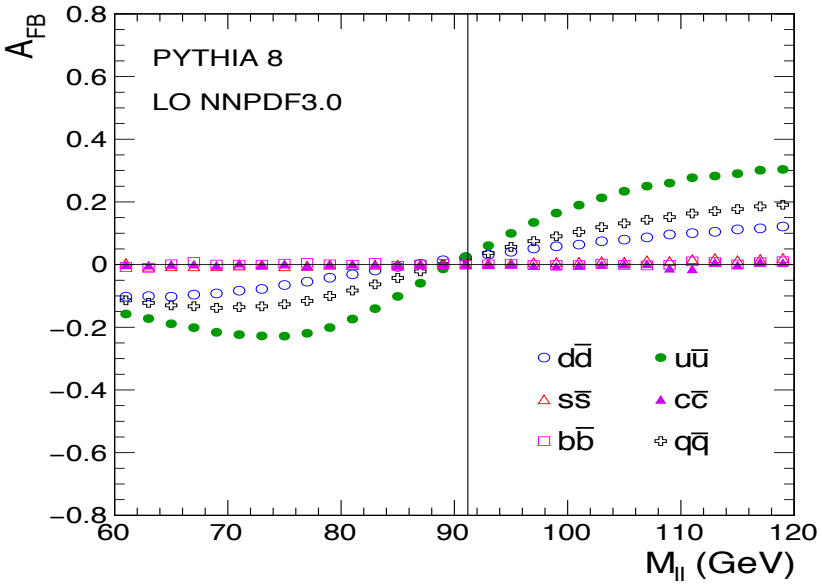
- Measurement relies on A4/A_{FB} present in Drell-Yan dilepton events which is sensitive to $\sin^2\theta^l_{eff}$ near Z peak

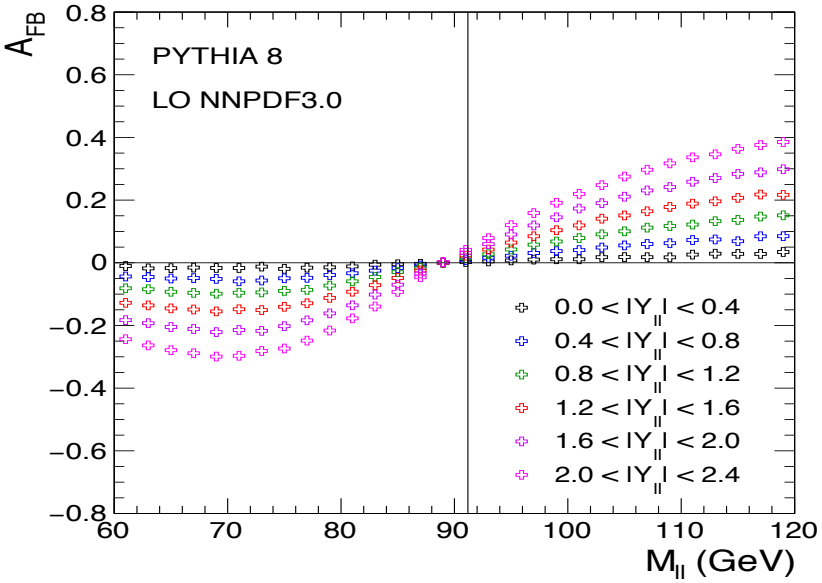
- Significant mass dependence of A_{FB} driven by Z-γ interference

- At LHC definition of forward/backward based on sign of y_{ll} boost
  - only valence quarks contribute
  - large rapidity-dependent dilution

- PDFs have the dominant systematic uncertainty; In this measurement we constrain them in situ

- A proper way of combined $\sin^2\theta^l_{eff}$ extraction is a simultaneous fit of A4 (y, m) measurements from all experiments





Basic plan

- Each LHC experiment measures A4 in the way best suited to the experiment itself (which observable, selections, etc) with a negligible theory uncertainty

- But interpretation in terms of $\sin^2\theta^l_{\mathrm{eff}}$ induces the dominant theory uncertainties (mostly PDFs but also QCD and EW) which are fully correlated between the experiments.
  => need common interpretation tools.

Preparation of full run-2 combination (ATLAS/CMS/LHCb) for $\sin^2\theta_{eff}^l$

- **YR will hopefully contain a section as below which would really be useful as a concrete example of how the weak mixing angle measurements of the three experiments could be combined with a proper correlation treatment of all common theoretical uncertainties**

Goal of pseudo-data exercise

- **Focus on dominant theoretical uncertainties: use one interpretation model as an example of how to deal properly with all sources of correlated theoretical uncertainties**
- **Goal is to provide guidelines in Yellow Report of how experimental data should be published such that an LHC-wide combination could be obtained swiftly once all experiments will have published their individual results.**

Table 3: Summary of the theoretical uncertainties for the dimuon and dielectron channels, as discussed in the text.

CMS

Modeling parameter	Muons	Electrons
Dilepton p_T reweighting	0.00003	0.00003
μ_R and μ_F scales	0.00011	0.00013
POWHEG MINLO Z+j *vs.* Z at NLO	0.00009	0.00009
FSR model (PHOTOS *vs.* PYTHIA 8)	0.00003	0.00005
Underlying event	0.00003	0.00004
Electroweak $\sin^2\theta^{\ell}_{\mathrm{eff}}$ *vs.* $\sin^2\theta^{\mathrm{u,d}}_{\mathrm{eff}}$	0.00001	0.00001
Total	0.00015	0.00017

Goal of pseudo-data exercise

ATLAS

- Table below needs further breakdown!!

Channel	ee_{CC}	$\mu\mu_{CC}$	ee_{CF}	$ee_{CC} + \mu\mu_{CC}$	$ee_{CC} + \mu\mu_{CC} + ee_{CF}$
Total	65	59	42	48	34
Stat.	47	39	29	30	21
Syst.	45	44	31	37	27
	Uncertainties in measurements				
PDF (meas.)	7	7	7	7	4
p_T^Z modelling	< 1	< 1	1	< 1	< 1
Lepton scale	5	4	6	3	3
Lepton resolution	3	1	3	1	2
Lepton efficiency	1	1	1	1	1
Electron charge misidentification	< 1	0	< 1	< 1	< 1
Muon sagitta bias	0	4	0	2	1
Background	1	1	1	1	1
MC. stat.	25	22	18	16	12
	Uncertainties in predictions				
PDF (predictions)	36	37	21	32	22
QCD scales	5	5	9	4	6
EW corrections	3	3	3	3	3

Table 8: Expected measurement uncertainties in $\sin^2\theta_{\text{eff}}^{\ell}$ and their breakdown, based on MMHT14 pseudo-data. The values are given in units of 10^{-5}, assuming an effective value of $\sin^2\theta_W = 0.23152$. The uncertainties are broken down separately for those arising from the A_4 measurements and from the predictions. The PDF uncertainties are treated as uncorrelated between the A_4 measurements and the predictions (see text).

Pseudo-data exercise

- **Preparatory step towards combined Run2 measurement**
- **Based on MC simulation only**

- **Each experiment**
  - **generates pseudo-data** for full Run-2 integrated luminosity
    — mainly to mimic real efficiencies and momentum resolution
    (no backgrounds or any experimental systematics are considered yet)
  - **unfolds** A_4 in agreed y and m bins
  - **extracts** $\sin^2\theta^l_{\mathrm{eff}}$ **± stat, pdf (**theo & exp may also be added later)
  - **provides**
    - *pseudo-measured* $A_4(m, y)$ + stat. covariance matrix
    - *true* $A_4(m, y)$ for common generator settings and variations

- **Combined analysis**
  - compatibility checks and combined fit

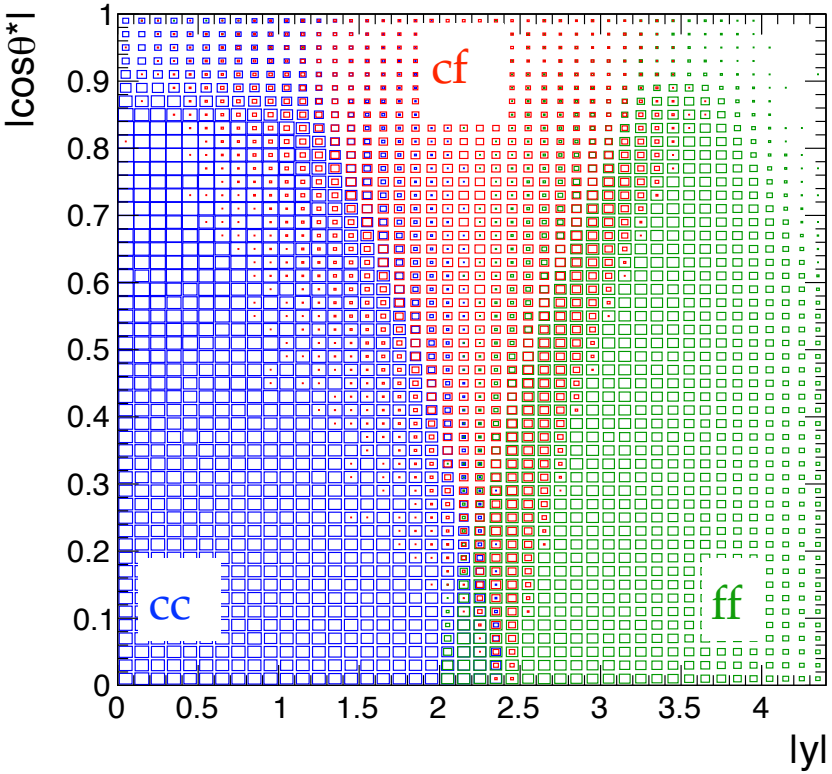
Pseudo-data

- Pseudo-data generated for L_{int}=**140/fb**

- ATLAS/CMS expect about
  ~140 M selected events for CC uu and ee events in channel
  ~10 M selected ee events in CF channel

- LHCb will have about
  ~ 1M forward uu events

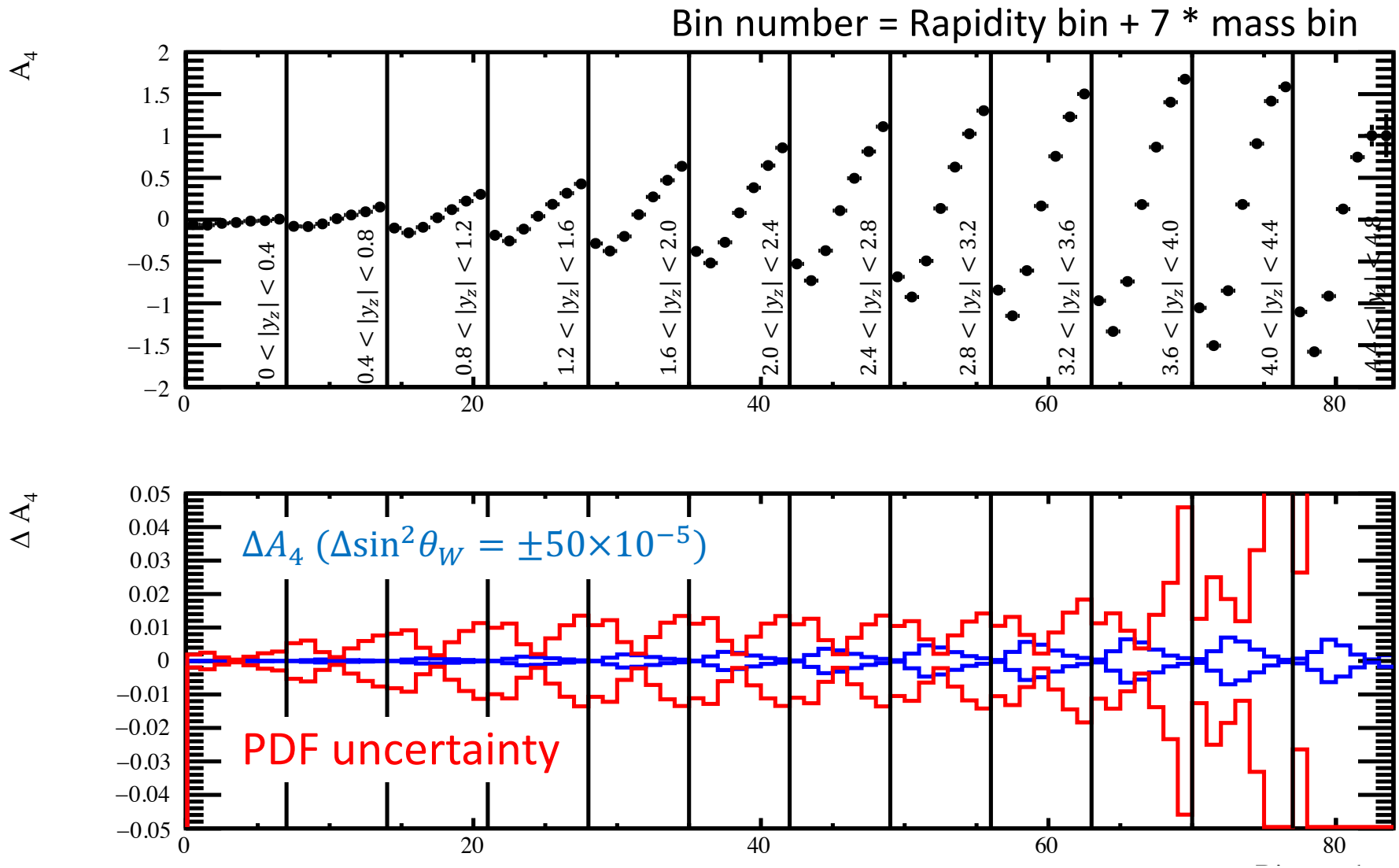
- Significant overlap in rapidity
  between ATLAS/CMS CF ee pairs
  and LHCb uu pairs



Setup

- Observable: **Born level** $A_4(m,y)$
- (N)**LO EW, NLO** (+PS) **QCD** generated with **Powheg+Pythia8**
- $\sin^2\theta^l_{\mathrm{eff}}$ **: 0.23150** (± 0.00050 to compare variations)
- **PDF: NNPDF31**_nnlo_hessian_pdfas
- **6 (11) equal** $|y|$ **bins** with width of 0.4
- **7** m **bins**: 50, 66, 76, **86, 96**, 106, 116, 150 GeV

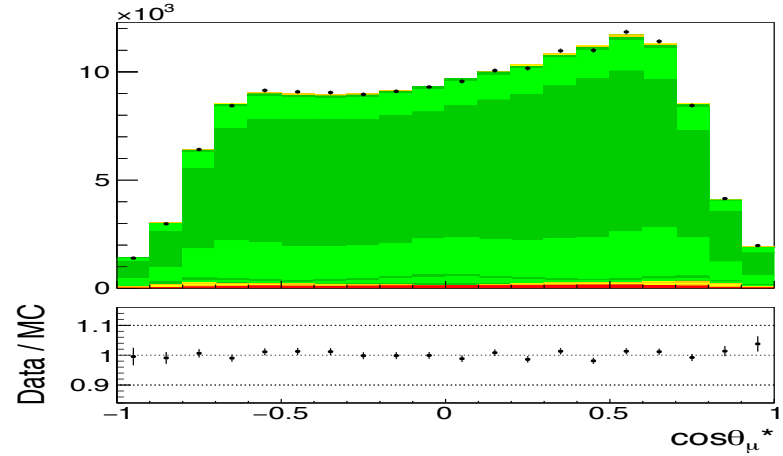
A4(y,m)

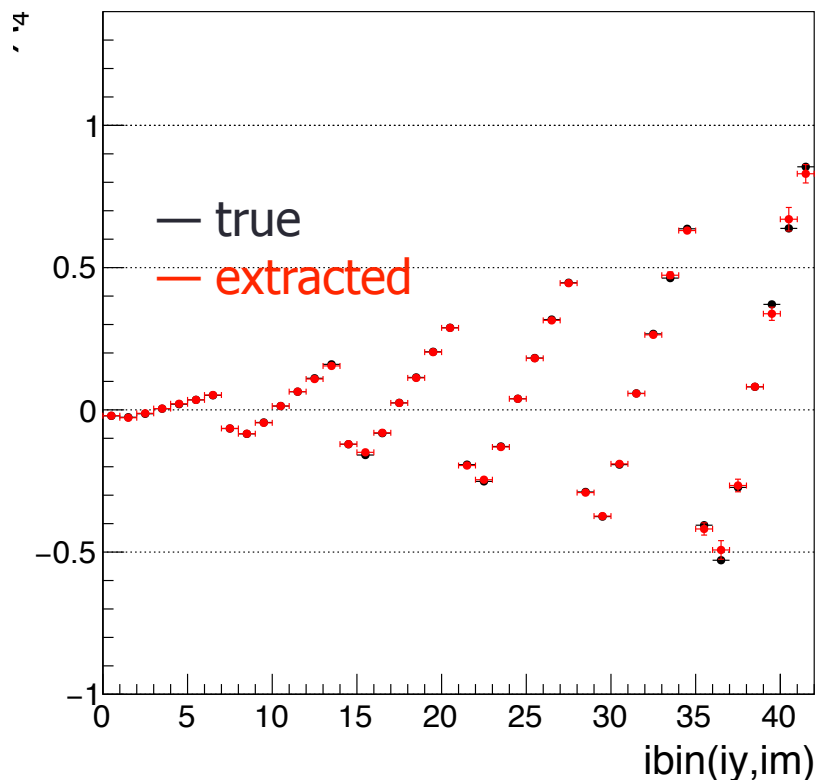

Bin number = Rapidity bin + 7 * mass bin
A_4
ΔA_4
$0 < |y_z| < 0.4$
$0.4 < |y_z| < 0.8$
$0.8 < |y_z| < 1.2$
$1.2 < |y_z| < 1.6$
$1.6 < |y_z| < 2.0$
$2.0 < |y_z| < 2.4$
$2.4 < |y_z| < 2.8$
$2.8 < |y_z| < 3.2$
$3.2 < |y_z| < 3.6$
$3.6 < |y_z| < 4.0$
$4.0 < |y_z| < 4.4$
$4.4 < |y_z| < 4.8$
ΔA_4 ($\Delta \sin^2\theta_W = \pm 50\times10^{-5}$)
PDF uncertainty

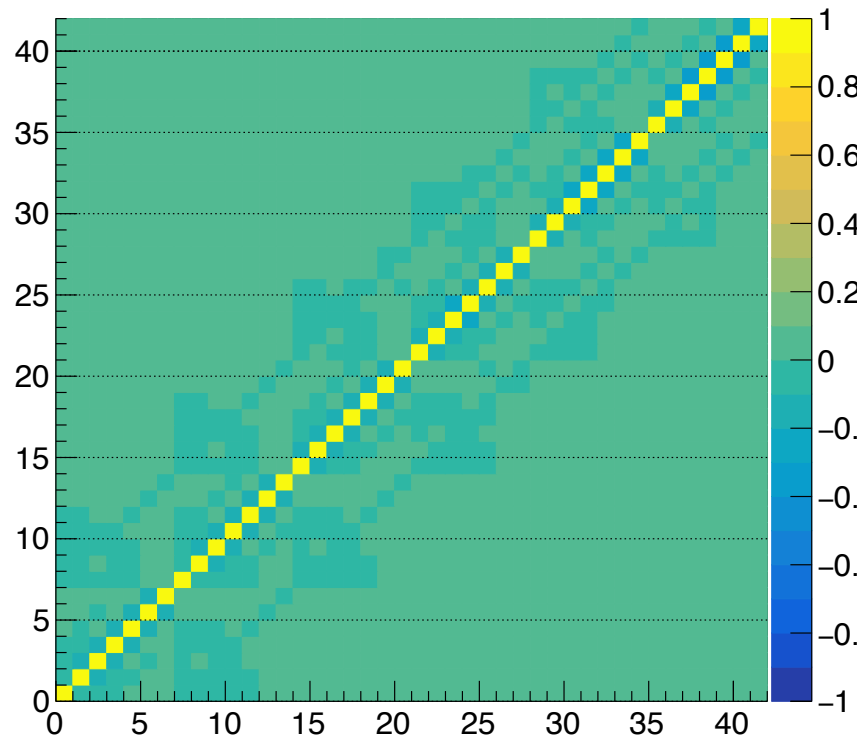
CMS unfolded A4

A4 is measured by fitting cosθ distributions in reco (y,m) bins with cosθ templates from different gen (y,m) bins

- 6 rapidity bins: 0.0-2.4
- 7 mass bins: 50, 66, 76, **86, 96**, 106, 116, 150 GeV

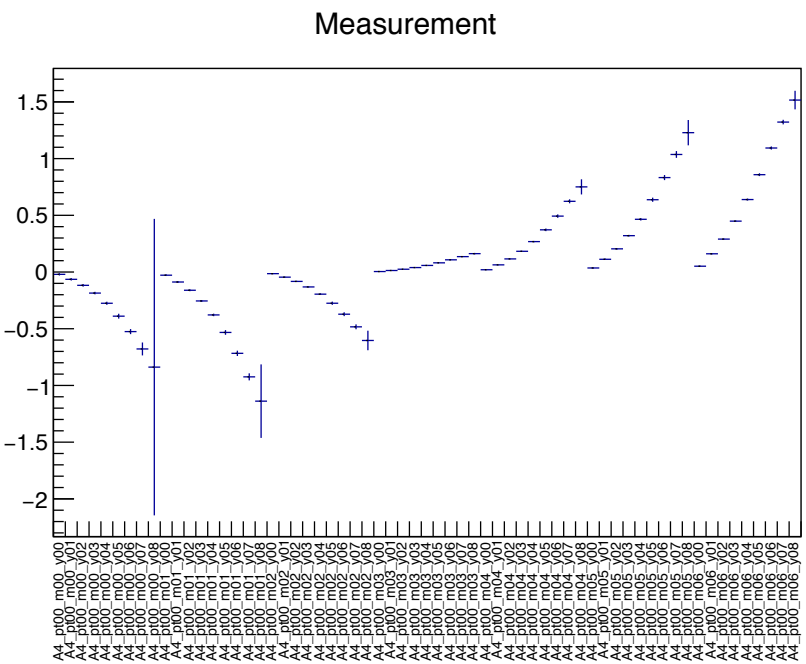


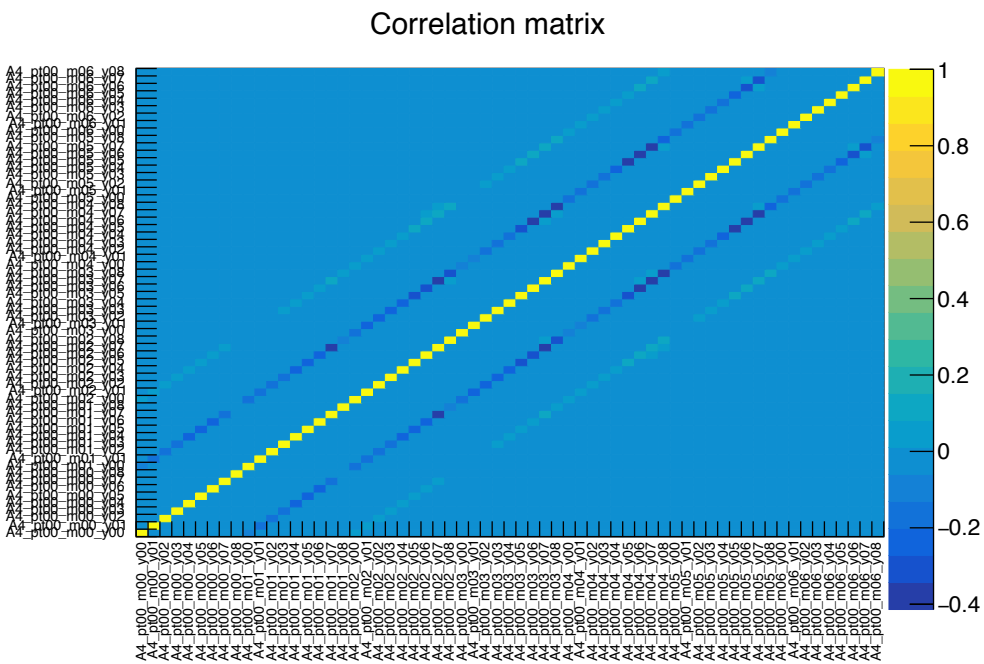




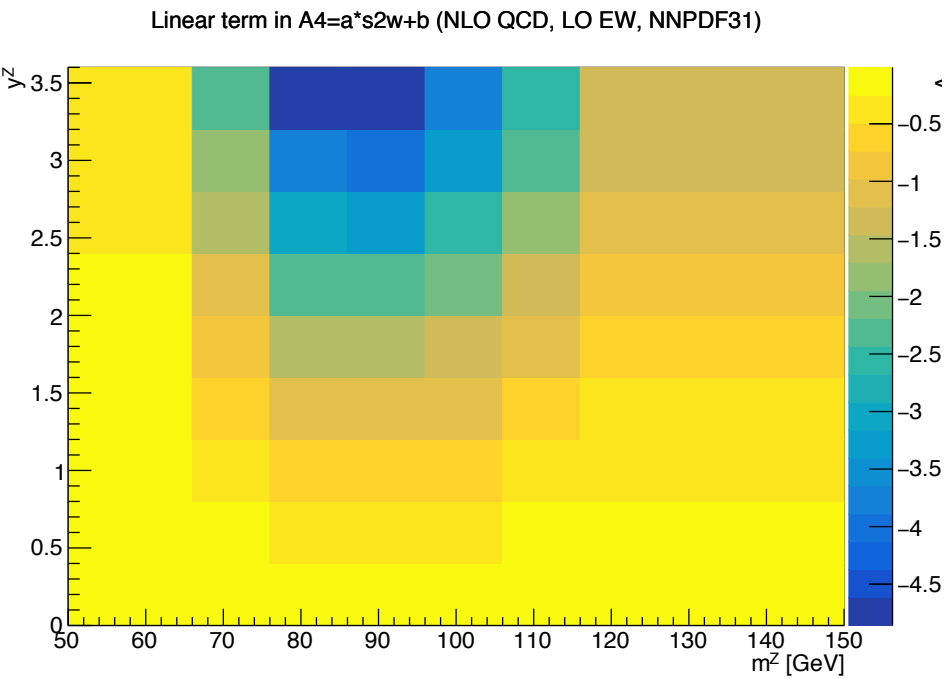
ATLAS pseudo-measurements

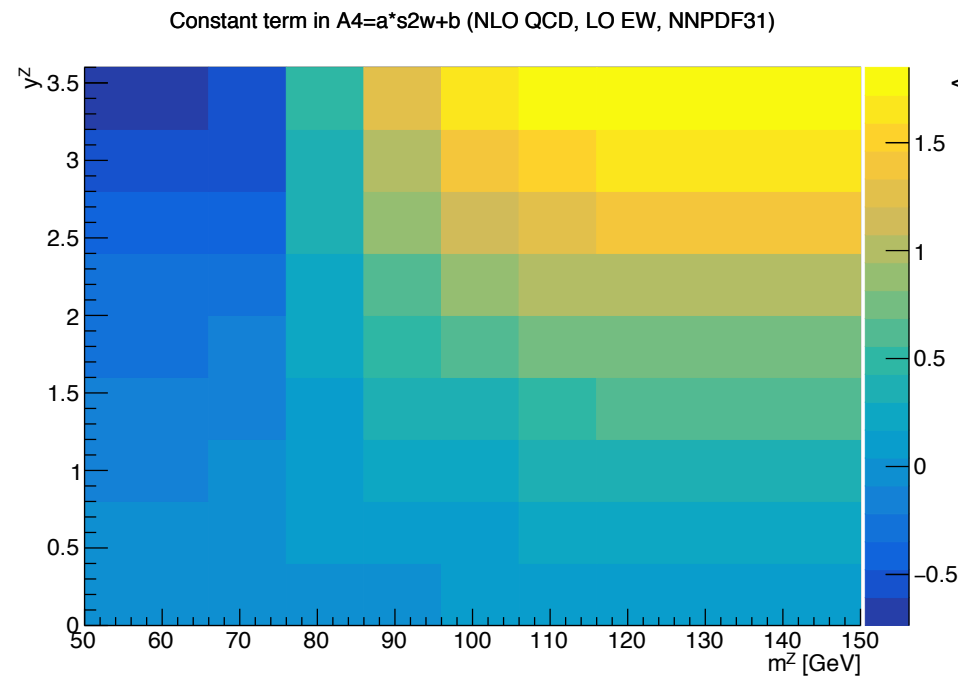
Aaron Armbruster





- Measurement inputs provided in the form of a set of measured A4 values in the specified binning (left) and its covariance matrix (right)
- Full mass range from 50-150 mass range (only 66-116 for previous iteration) for central-central and now with central-forward leptons (eeCC+mumuCC+eeCF combination)

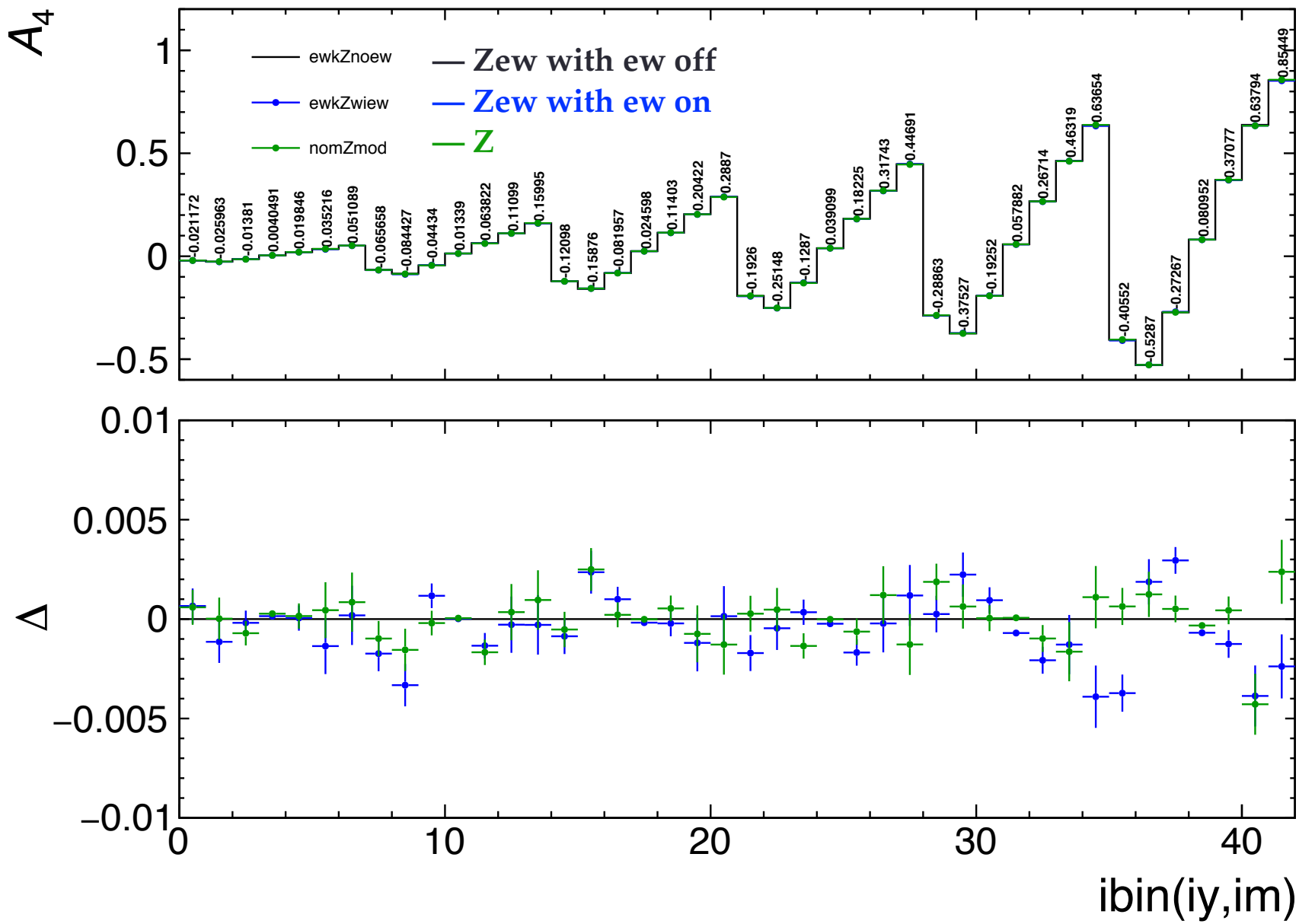




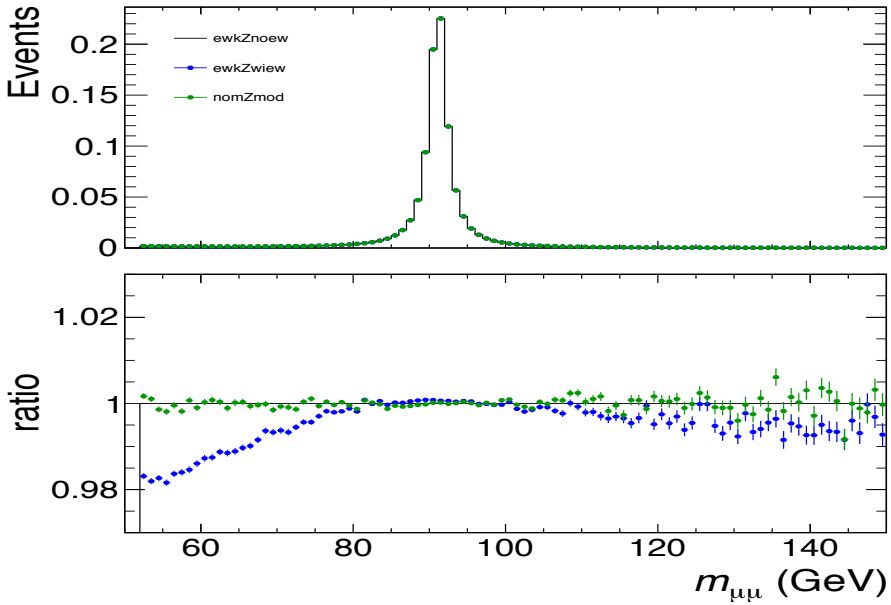
- From this set of predictions, one can produce interpretation curve A4 = a*s2w+b for each point in mass, rapidity
- Above shown for linear and constant term a, b for one EV
- Parametrizing A4 measurement inputs with prediction inputs, one should recover the result:

s2w = 0.23150 +/- 0.00010 (stat) +/- 0.00019 (pdf) = 0.23150 +/- 0.00022 (tot)

LO vs NLO EW Powheg



LO vs NLO EW Powheg

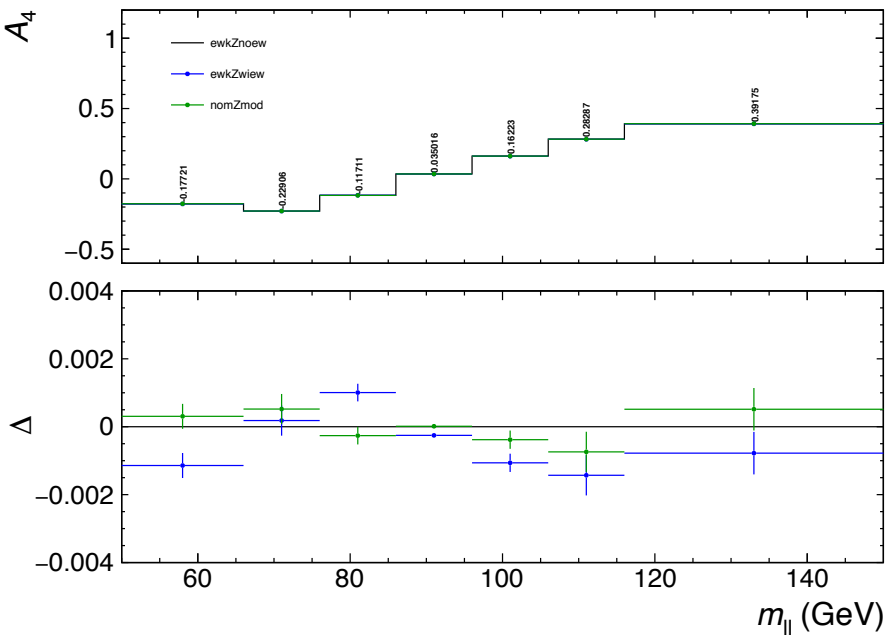


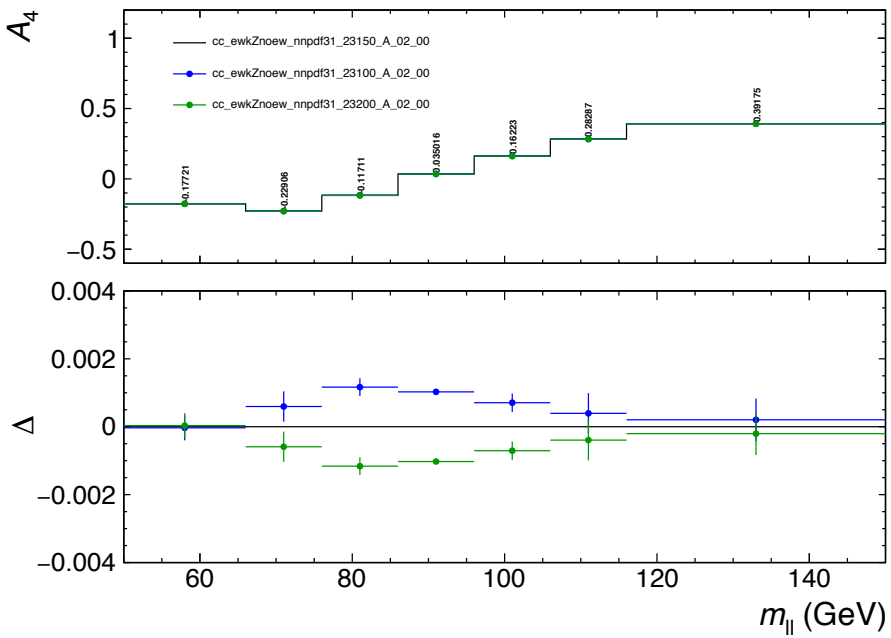
POWHEG

ewkZnoew: ewkZ with EW OFF

ewkZwiew: ewkZ with EW ON

nomZmod: nominal Z Powheg process with adjusted mZ and gZ





Summary

— LHC $\sin^2\theta^l_{\text{eff}}$ combination exercise is in progress

— All three experiments participating, now at various stages

Next:

— finalise individual pseudo-measurements

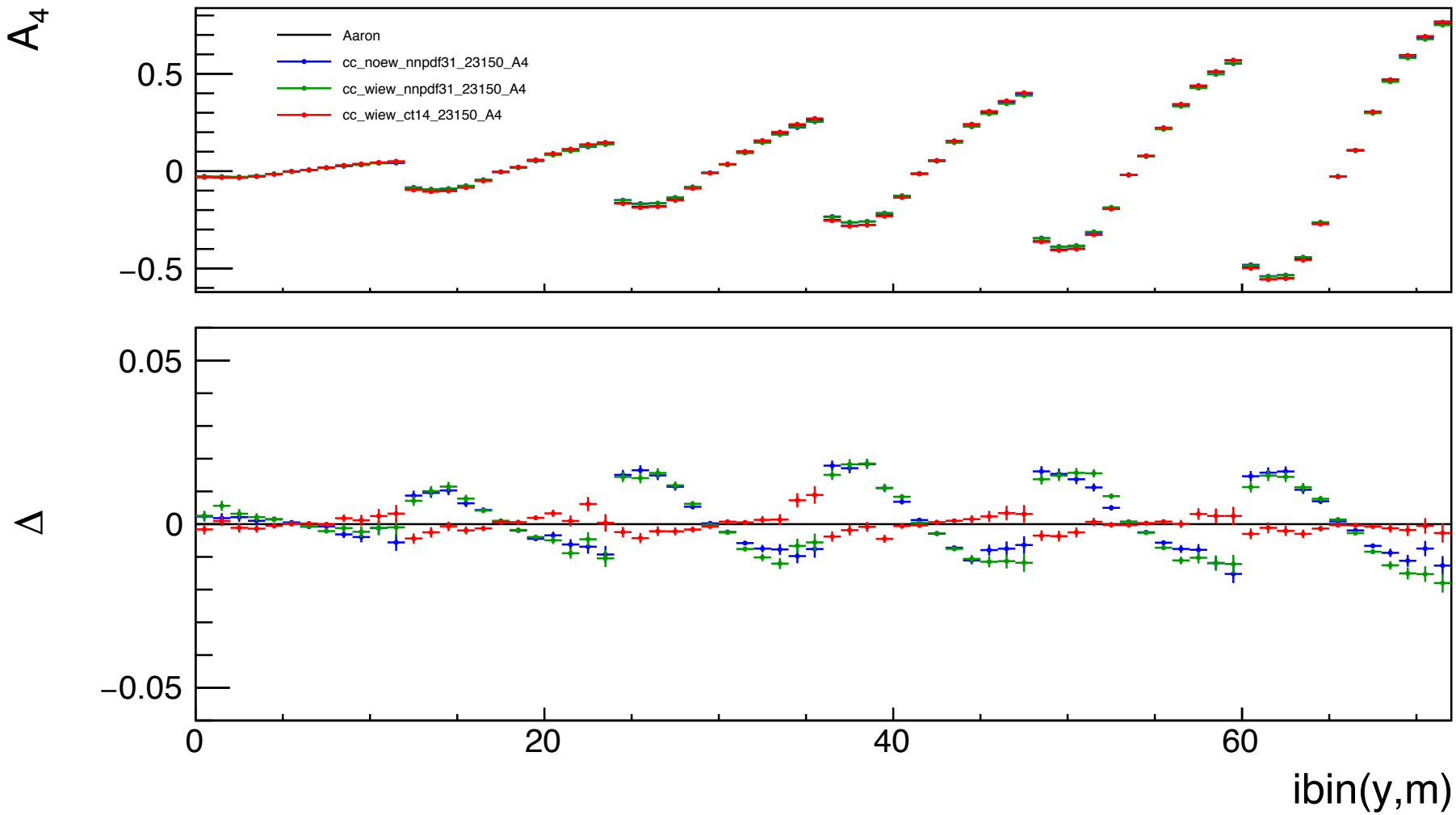
— exchange measurements and perform combined fits

— add theory and maybe approx. experimental uncertainties

Backup

First comparison between ATLAS/CMS pseudodata

- **Below is first comparison of CMS pseudo-data with those from ATLAS, but not yet with rigorously same input parameters**



sinOw variations