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

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on behalf of ATLAS, CMS, LHCb $\sin^2\theta_{\text{eff}}$ measurement groups

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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 $\sqrt{s}$) LHC can produce much more precise measurement of $\sin^2\theta^l_{\text{eff}}$
- 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 $A_4/A_{FB}$ 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-$\gamma$ 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 $A_4$ ($y$, $m$) measurements from all experiments
Basic plan

- Each LHC experiment measures $A_4$ in the way best suited to the experiment itself (which observable, selections, etc) with a negligible theory uncertainty.

- But interpretation in terms of $\sin^2 \theta_{\text{eff}}$ induces the dominant theory uncertainties (mostly PDFs but also QCD and EW) which are fully correlated between the experiments.

$\Rightarrow$ need common interpretation tools.
Preparation of full run-2 combination (ATLAS/CMS/LHCb) for $\sin^2\theta_{\text{eff}}$.

- 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>
<thead>
<tr>
<th>Modeling parameter</th>
<th>Muons</th>
<th>Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dilepton $p_T$ reweighting</td>
<td>0.00003</td>
<td>0.00003</td>
</tr>
<tr>
<td>$\mu_R$ and $\mu_F$ scales</td>
<td>0.00011</td>
<td>0.00013</td>
</tr>
<tr>
<td>POWHEG MINLO Z+j vs. Z at NLO</td>
<td>0.00009</td>
<td>0.00009</td>
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<tr>
<td>FSR model (PHOTOS vs. PYTHIA 8)</td>
<td>0.00003</td>
<td>0.00005</td>
</tr>
<tr>
<td>Underlying event</td>
<td>0.00003</td>
<td>0.00004</td>
</tr>
<tr>
<td>Electroweak $\sin^2 \theta_{\text{eff}} \ell$ vs. $\sin^2 \theta_{\text{eff}}^\text{ud}$</td>
<td>0.00001</td>
<td>0.00001</td>
</tr>
<tr>
<td>Total</td>
<td>0.00015</td>
<td>0.00017</td>
</tr>
</tbody>
</table>
Table 8: Expected measurement uncertainties in $\sin^2 \theta_{\text{eff}}^e$ 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 $\sin^2 \theta_{\text{eff}} \pm \text{stat, pdf}$ (theo & exp may also be added later)
  • provides
    • pseudo-measured $A_4(m, y) + \text{stat. covariance matrix}$
    • true $A_4(m, y)$ for common generator settings and variations

• Combined analysis
  • compatibility checks and combined fit
Pseudo-data

- Pseudo-data generated for $L_{\text{int}}=140/\text{fb}$

- 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
  ~1 M 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
- $\sin^2 \theta_{\text{eff}} : 0.23150 \pm 0.00050$ 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
Bin number = Rapidity bin + 7 * mass bin

$\Delta A_4$ ($\Delta \sin^2 \theta_W = \pm 50 \times 10^{-5}$)

PDF uncertainty
A4 is measured by fitting \( \cos \theta \) distributions in reco \((y,m)\) bins with \( \cos \theta \) 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
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 $A_4 = a s^2 w + b$ for each point in mass, rapidity.
• Above shown for linear and constant term $a, b$ for one EV.
• Parametrizing $A_4$ measurement inputs with prediction inputs, one should recover the result:

$$s^2 w = 0.23150 \pm 0.00010 \text{(stat)} \pm 0.00019 \text{(pdf)} = 0.23150 \pm 0.00022 \text{(tot)}$$
LO vs NLO EW Powheg

\[ A_4 \]

- Zew with ew off
- Zew with ew on
- ewkZnoew
- ewkZwiew
- nomZmod
- Z

\[ \Delta \]

- Zew with ew off
- Zew with ew on
- ewkZnoew
- ewkZwiew
- nomZmod
- Z

ibin(iy,im)
POWHEG

ewkZnoew: ewkZ with EW OFF
ewkZwiew: ewkZ with EW ON
nomZmod: nominal Z Powheg process with adjusted mZ and gZ
— LHC sin$^2\theta_{\text{eff}}$ 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
Below is first comparison of CMS pseudo-data with those from ATLAS, but not yet with rigorously same input parameters.