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

Using 2012 8 TeV dataset ($\sim 19/\text{fb}$)

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Representing the CMS collaboration

6 Jul 2017, 10:30 15m
Room Volpi (Palazzo del Casinò)
The axial and vector neutral currents interfere

\[ \sin^2 \theta_w = \sin^2 \theta_{\text{on-shell}}^{\text{on-shell}} = 1 - \frac{M_w^2}{M_Z^2} \]

\[ \sin^2 \theta_{\text{eff}}^{\text{lept}} = \text{Re}[\kappa_l(M_Z^2, \sin^2 \theta_w)] \sin^2 \theta_w \]

\( \approx 1.037 \)

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

\( \pm 0.00050 \) error in \( \sin^2 \theta_w \) is equiv. to \( \pm 25 \) MeV error in \( M_w \) (indirect)

This new CMS measurement has a total error of \( \pm 0.00052 \)

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 $Z/\gamma^*$ 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

![Graphs showing $A_{FB}$ vs. $M_{ll}$ for $\cos\theta^*$ distributions for different PDF sets and quark flavors.](image)

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

Extract $\sin^2\theta_{\text{eff}}$ by fitting the observed $A_{FB}$ to templates generated with different values of $\sin^2\theta_{\text{eff}}$.
A precision measurement using three new techniques:

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


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


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


   $\pm 0.00050$ error in $\sin^2 \theta_w$ is equiv. to $\pm 25$ MeV error in $M_w$ (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 $\eta$, $\Phi$ and charge be correct.

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

- **Reference scale for muons:** Expected Z mass (post FSR) smeared by resolution (with acceptance cuts). ($J/\Psi$ and $\Upsilon$ 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 \( \cos \theta \). Each event has a measured \( \cos \theta \).

A measurement of \( A_{fb} \) with this detector yields a measurement of \( A_4 \), which is independent of acceptance or efficiency.

\[
1 + \cos^2 \theta + A_4 \cos \theta
\]

Uncertainties in acceptance & efficiency cancel. Event weighted \( A_{fb} \) is the same \( A \) as \( A_{FB} \) for full acceptance.

\[
\cos \theta = 1 \text{ yields best measurement of } A_4. \quad \cos \theta = 0 \text{ yields no measurement of } A_4
\]

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

\[
A_{fb} \text{ (all } \cos \theta) = \frac{3}{8} A_4 \text{} \Rightarrow \text{ No acceptance corrections needed.}
\]
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<tr>
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<td>muon</td>
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<tr>
<td>electron</td>
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<tr>
<td>combined</td>
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<table>
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<th>Source</th>
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<td>Lepton momentum calibration</td>
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<td>Lepton selection efficiency</td>
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<td>Background subtraction</td>
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<tr>
<td>Total</td>
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<table>
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<td>Dilepton $p_T$ reweighting</td>
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<td>POWHEG MiNLO Z+j vs NLO Z model</td>
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<td>FSR model (PHOTOS vs PYTHIA)</td>
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<td>UE tune</td>
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<tr>
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<tr>
<td>Total</td>
<td>0.00015</td>
<td>0.00017</td>
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$\sin^2 \theta_{\text{eff}}^{\text{lept}} = 0.23101 \pm 0.00036 \text{(stat)} \pm 0.00018 \text{(syst)} \pm 0.00016 \text{(theory)}$
Vary $\sin^2 \theta_{\text{eff}}$ for fixed PDF in GREEN (left), PURPLE (right)
Vary 100 NNPDF replicas for fixed $\sin^2 \theta_{\text{eff}}$ 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 $\sin^2 \theta_{\text{eff}}$ fit for each PDF replica (by default we use NNPDF3.0)

Weight each replica by

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

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**Channel** | **without constraining PDFs** | **with constraining PDFs**  
--- | --- | ---  
Muon | $0.23125 \pm 0.00054$ | $0.23125 \pm 0.00032$  
Electron | $0.23054 \pm 0.00064$ | $0.23056 \pm 0.00045$  
Combined | $0.23102 \pm 0.00057$ | $0.23101 \pm 0.00030$  

**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

<table>
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<th>Channel</th>
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<th>with constraining PDFs</th>
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</thead>
<tbody>
<tr>
<td>Muon</td>
<td>0.23125 ± 0.00048 ± 0.00054</td>
<td>0.23125 ± 0.00048 ± 0.00032</td>
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<tr>
<td>Electron</td>
<td>0.23054 ± 0.00069 ± 0.00064</td>
<td>0.23056 ± 0.00069 ± 0.00054</td>
</tr>
<tr>
<td>Combined</td>
<td>0.23102 ± 0.00040 ± 0.00057</td>
<td>0.23101 ± 0.00040 ± 0.00030</td>
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</tbody>
</table>

**PDF reweighting constraints** reduce PDF error by factor of 2
$\sin^2 \theta_{\text{eff}}^{\text{lept}} = 0.23101 \pm 0.00036(\text{stat}) \pm 0.00018(\text{syst}) \pm 0.00016(\text{theory}) \pm 0.00030(\text{pdf})$

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

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

Results
Additional Slides
With constraints from PDF reweighting the extracted values for different PDF are closer to each other.

PDF reweighting constraints reduce PDF error by factor of 2

Figure 8: Extracted values of $\sin^2 \theta_{\text{eff}}^{\text{lept}}$ from the dimuon data for different PDF sets with nominal (left) and $\chi^2$ reweighted (right) PDF replicas. The error bars include the statistical, experimental and the PDF uncertainties.
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 $\sin^2 \theta_{\text{eff}}^{\text{lept}} = 0.23120$. The solid lines in the bottom panel correspond to six variations of $\sin^2 \theta_{\text{eff}}^{\text{lept}}$ around the central value: $\pm 0.00040$, $\pm 0.00080$ and $\pm 0.00120$. 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.