Forward-backward asymmetry in Z->μμ and determination of the effective weak mixing angle

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On behalf of the LHCb collaboration

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LHCb detector

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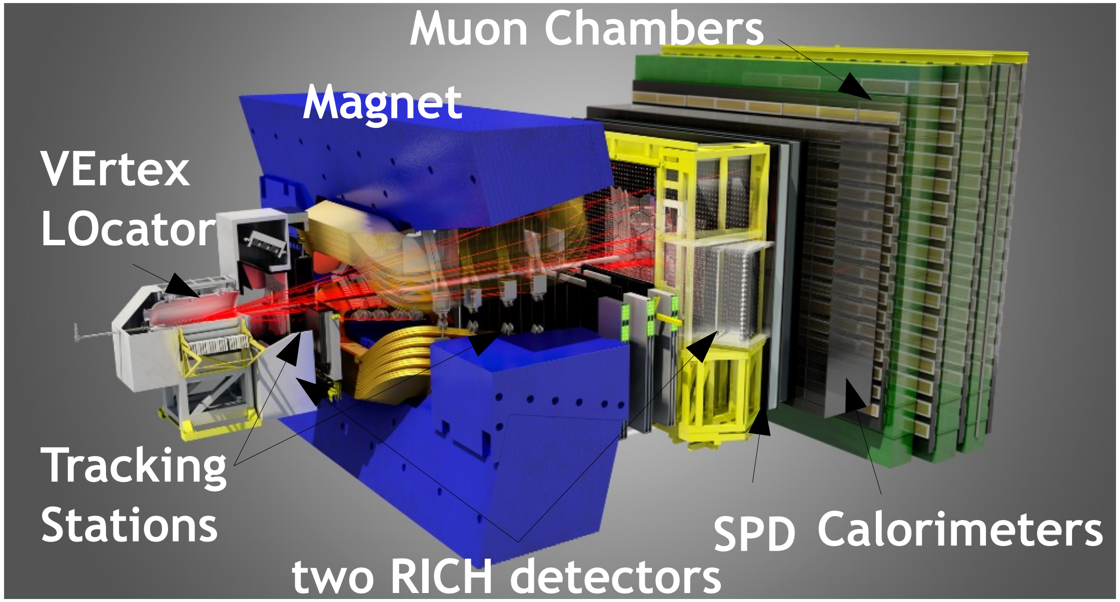
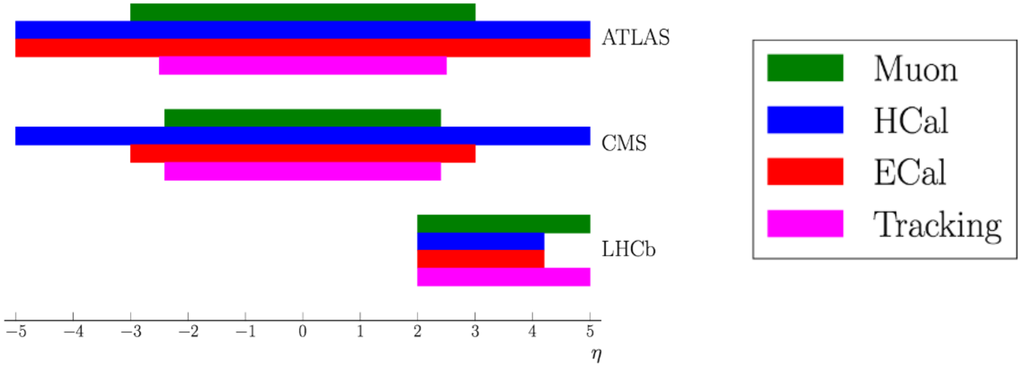




- **LHCb** is a forward spectrometer designed for B physics.
- It covers a **unique acceptance** within the LHC experiments ($2 < \eta < 5$).
- Momentum resolution: 0.4% at 5 GeV and 0.6% at 100 GeV.
- Impact parameter resolution of 13-20 μm at high P_T
- Muon ID efficiency: 97% with 1-3% $\mu \rightarrow \pi$ mis-identification.
- Measurements in the **Electroweak** sector are possible (**Stephen's talk**).

Weinberg angle

- **The Weinberg angle θ_w** is a fundamental parameter of the electroweak lagrangian**, not predicted by the theory:**

$$\mathcal{L}_{\mathrm{EW}} = \sum_{\psi} \bar{\psi}\gamma^{\mu} \left(i\partial_{\mu} - g' \frac{1}{2} Y_{\mathrm{W}} B_{\mu} - g \frac{1}{2} \boldsymbol{\tau} \mathbf{W}_{\mu} \right) \psi$$

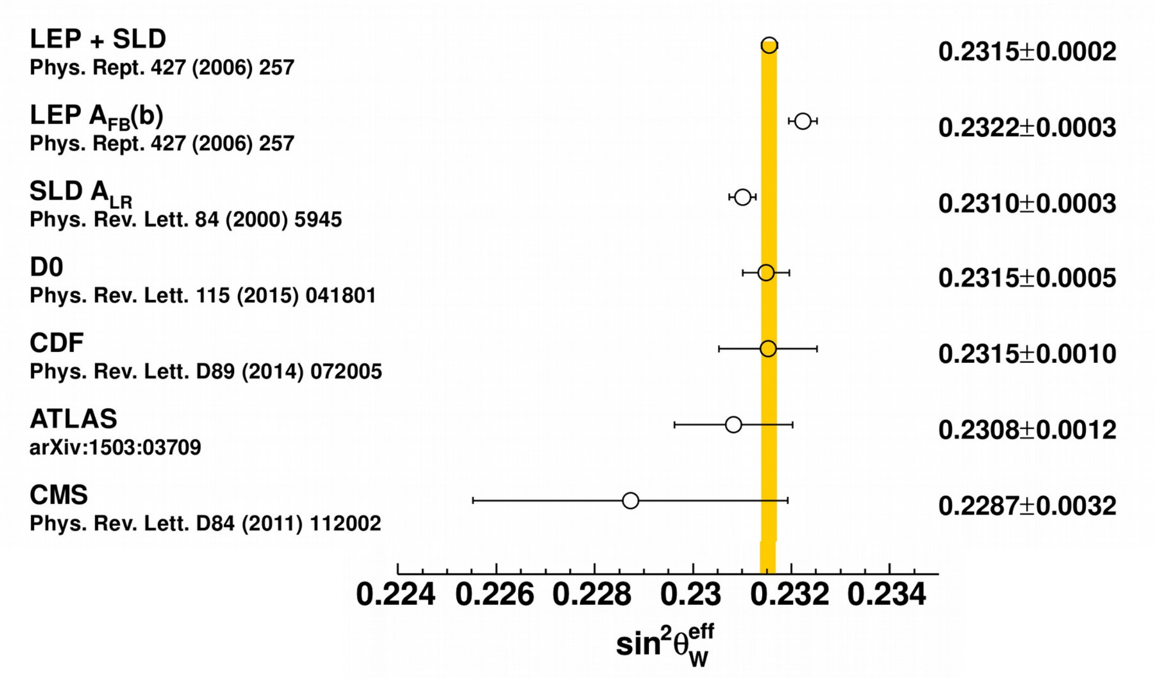
$$\sin\theta_W = \frac{g'}{\sqrt{g^2 + g'^2}}$$

- The Z couplings differ for left- and right-handed fermions. This difference leads to an **asymmetry in the angular distribution of negative and positive leptons**.

- **$\sin^2\theta^{eff}_w$** is defined in function of the axial and vector-axial couplings of the Z to the fermions and it is proportional to **$\sin^2\theta_w$**.

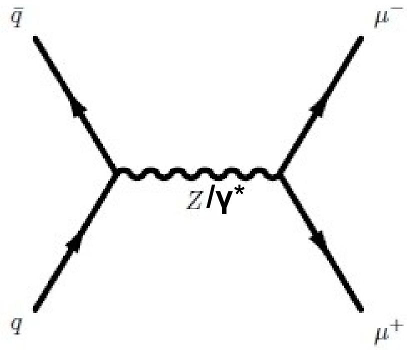
A bit of history

- $\sin^2\theta^{eff}_W$ was precisely measured at **LEP** in the 90s, by studying the Z asymmetry to fermions.
- Also another electron-positron collider, **SLAC**, performed the measurement with the detector **SLD**.
- A little puzzle appears at this point: **these two measurements, the most precise in the world, differ for 3σs.**

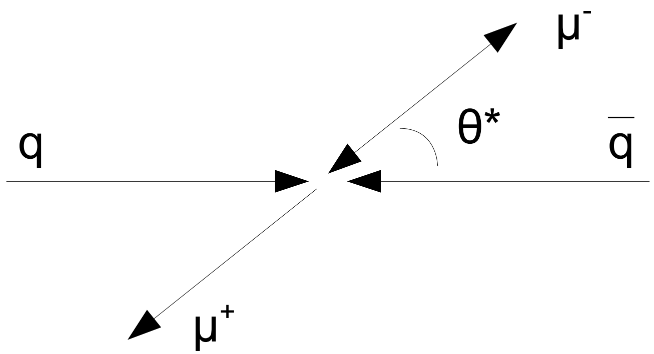


- $\sin^2\theta^{eff}_W$ was also measured at hadron colliders by D0, CDF, ATLAS and CMS.

Measuring the Z asymmetry at LHCb



- **LHCb** measured the Z asymmetry in the process **$q\bar{q} \rightarrow Z/\gamma^* \rightarrow \mu\mu$**



Colin-Soper Frame (dimuon rest frame)

- The **Z angular distribution** is given by $$\frac{d\sigma}{d\cos\theta^*} = A(1+\cos^2\theta^*) + B\cos\theta^*$$

The asymmetry arises from this term!

θ^* ⟶ angle of the negative charged lepton in the Colin-Soper frame

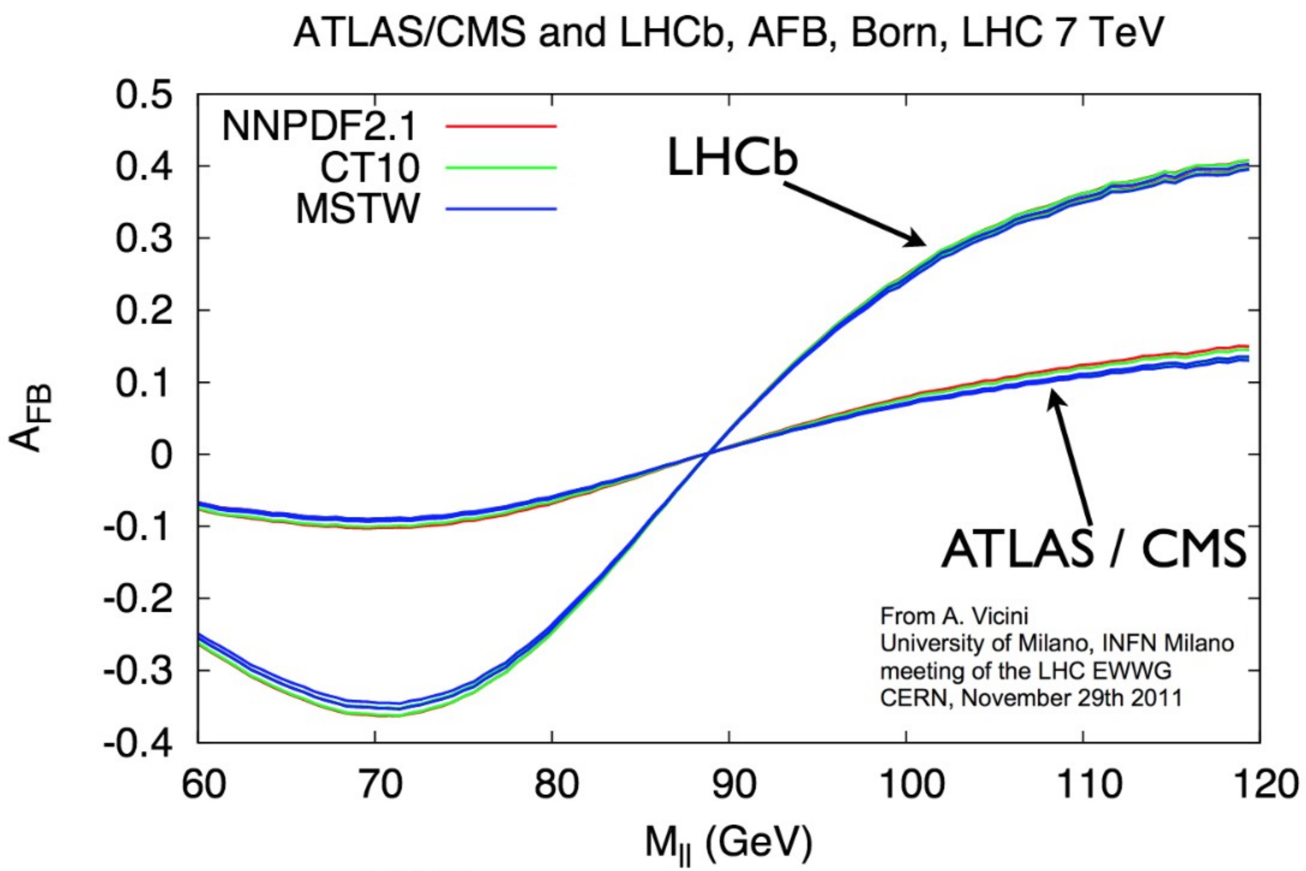
A,B ⟶ depend on dimuon mass, quarks color charge and couplings

- The **forward-backward asymmetry:** $$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

N_F : number of forward decays ($\cos\theta^* > 0$)
N_B : number of backward decays ($\cos\theta^* < 0$)

Measuring the Z asymmetry at LHCb

- **A_{FB} prediction at 7 TeV**, for ATLAS, CMS and LHCb acceptance:

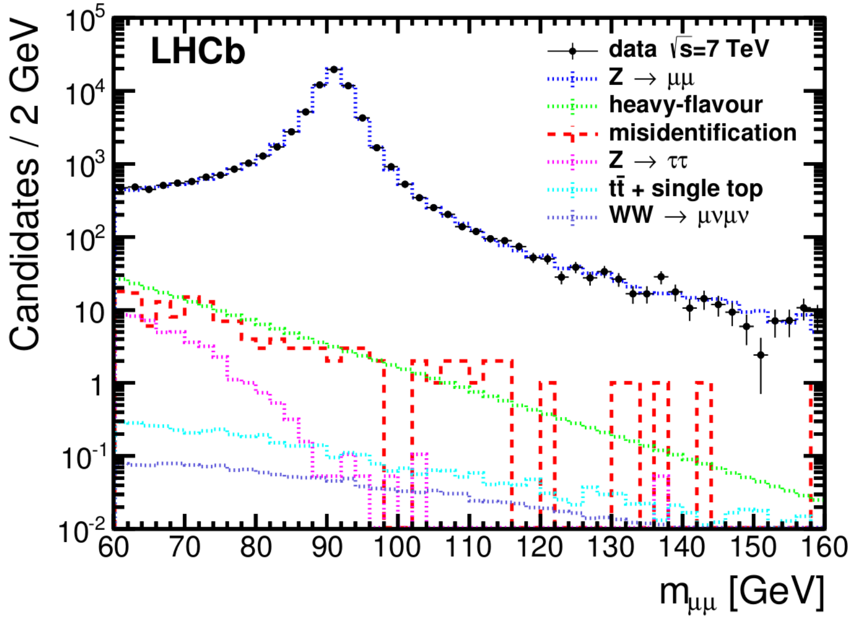


- **At high rapidities A_{FB} is enhanced**, and there is an increased sensitivity to $\sin^2\theta^{eff}_W$ respect to low rapidities: due to PDFs the high-x parton tend to be the quark and not the anti-quark.

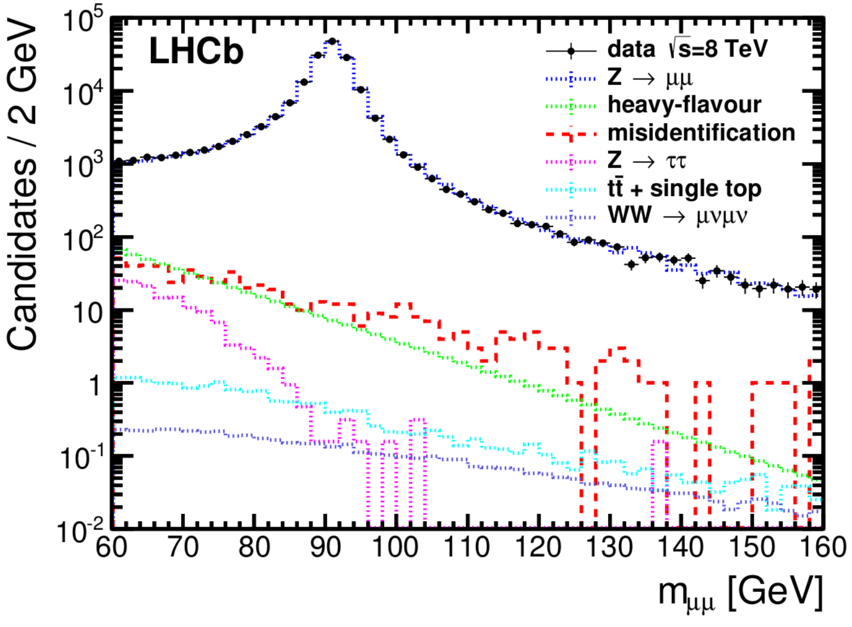
Z -> μμ selection

- **Inclusive Z → μμ cross section measurement paper: arXiv:1505.07024**
- **Trigger selection**: one muon with P_T > 10 GeV.
- **Offline selection**: → Two muons with P_T > 20 GeV and 2< η < 4.5
  → Dimuon invariant mass in [60,160] GeV window.

Dimuon mass (7 TeV data)



Dimuon mass (8 TeV data)



Unfolding the asymmetry

- **The raw asymmetry A_{FB}^{raw}, is corrected for**:
  - Efficiency on trigger, track reconstruction and muon identification (almost negligible).
  - Detector mis-alignment → curvature/momentum bias that shifts the Z peak.
- **The true asymmetry A_{FB}** is obtained from the measured asymmetry through a Bayesian unfolding technique.
- Finally data are corrected for background contaminations, by using the simulation (also this is negligible).

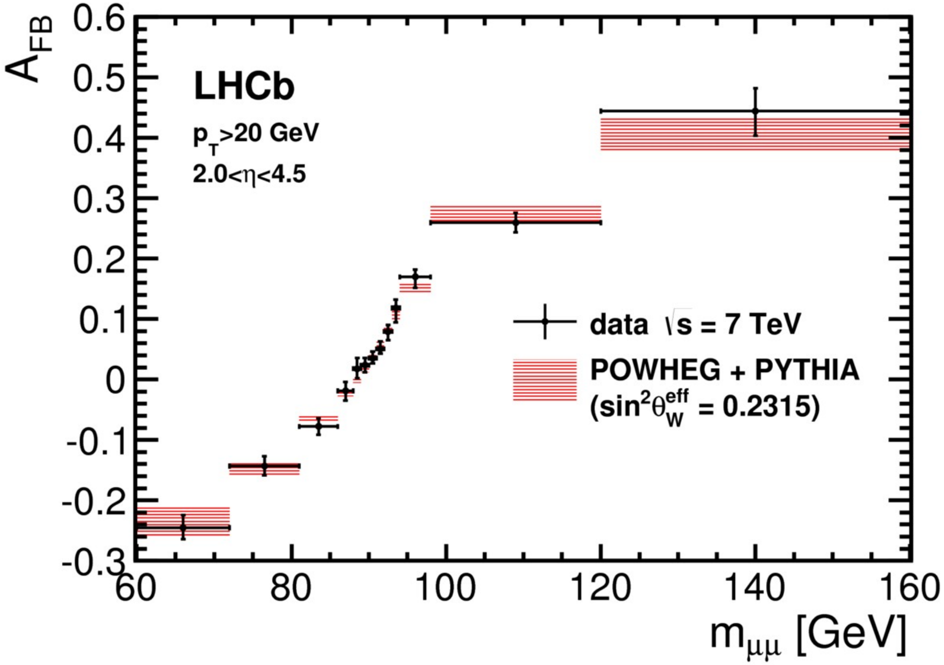
Source of uncertainty	$\sqrt{s} = 7\,\mathrm{TeV}$	$\sqrt{s} = 8\,\mathrm{TeV}$
curvature/momentum scale	0.0102	0.0050
data/simulation mass resolution	0.0032	0.0025
unfolding parameter	0.0033	0.0009
unfolding bias	0.0025	0.0025

Absolute experimental uncertainties on A_{FB}

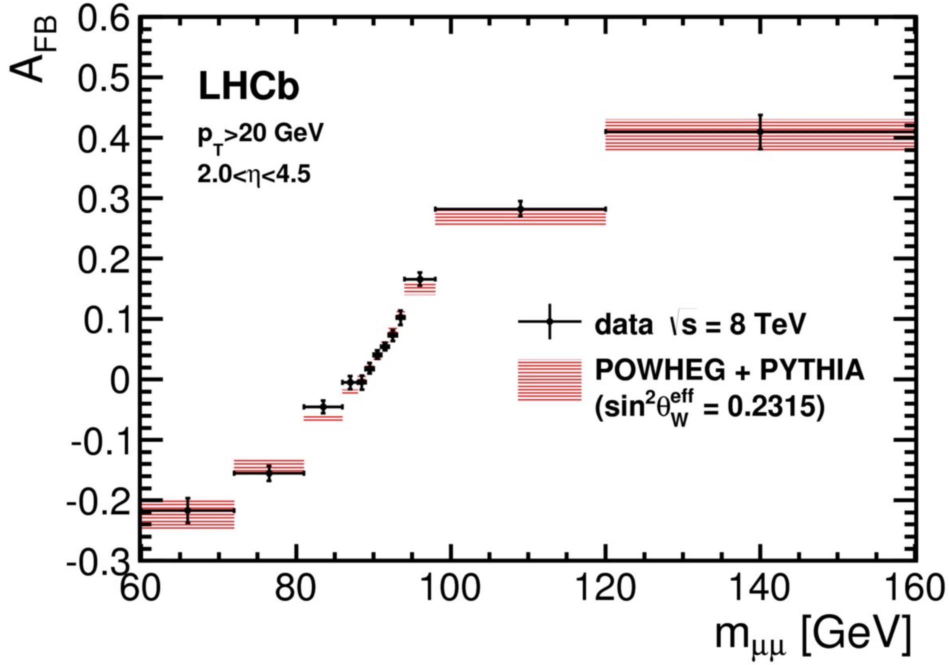
Measured asymmetry

- **True asymmetry A_{FB} at 7 and 8 TeV compared to theory [JHEP 11 (2015) 190]:**

7 TeV



8 TeV



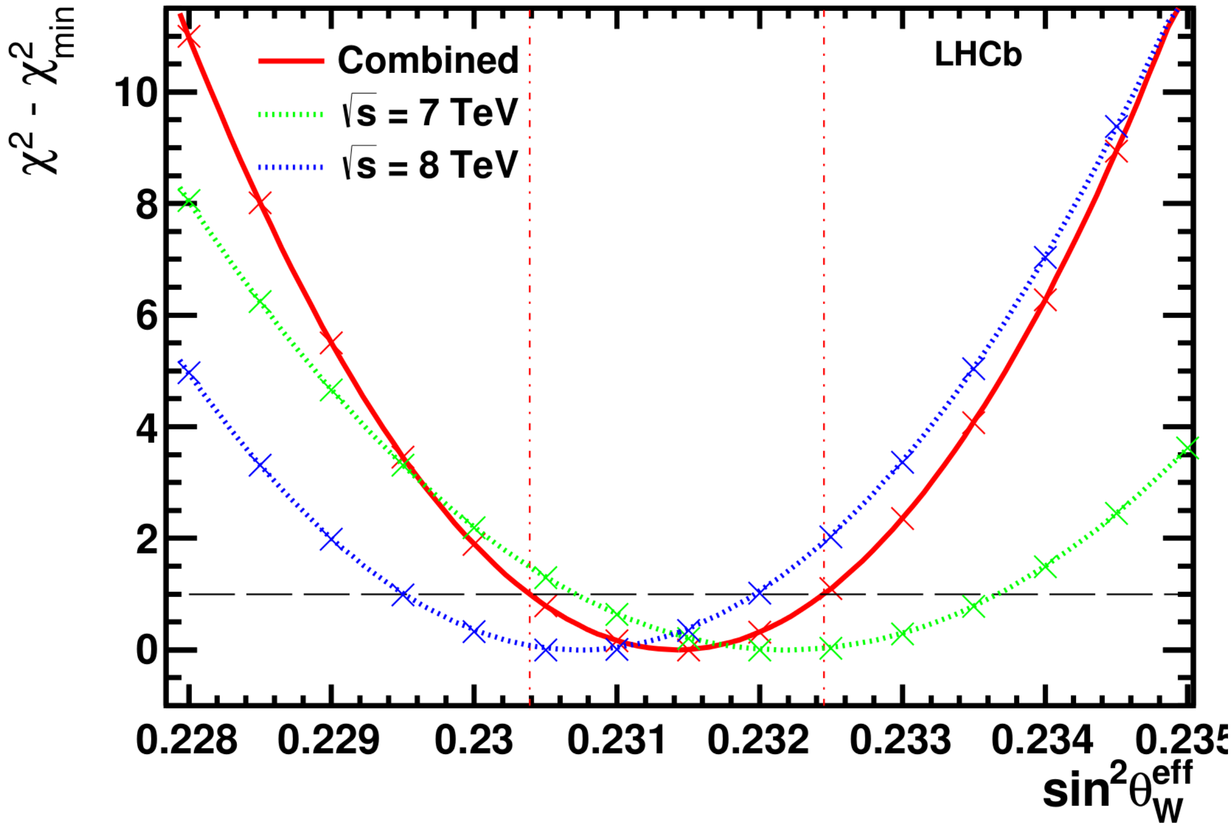
Measuring $\sin^2\theta^{eff}_W$

- **Simulation samples are generated with different values of $\sin^2\theta^{eff}_W$** . The measured one is chosen by comparing the simulations with the measured A_{FB}, using a X^2.
- Simulation is produced using POWHEG-BOX interfaced with Pythia 8, using NNPDF2.3 and setting $\alpha_S(M_Z) = 0.118$. **The result is compatible by using different generators**.
- The systematics in the theoretical prediction are:
  - → Uncertainties in the PDFs
  - → Uncertainty in α_S
  - → Uncertainty on the Final State Radiation
  - → Renormalization and factorization scale uncertainty

Uncertainty	average $\Delta\lvert A_{\mathrm{FB}}^{\mathrm{pred}}\rvert$
PDF	0.0062
scale	0.0040
α_s	0.0030
FSR	0.0016

$\sin^2\theta^{eff}_W$

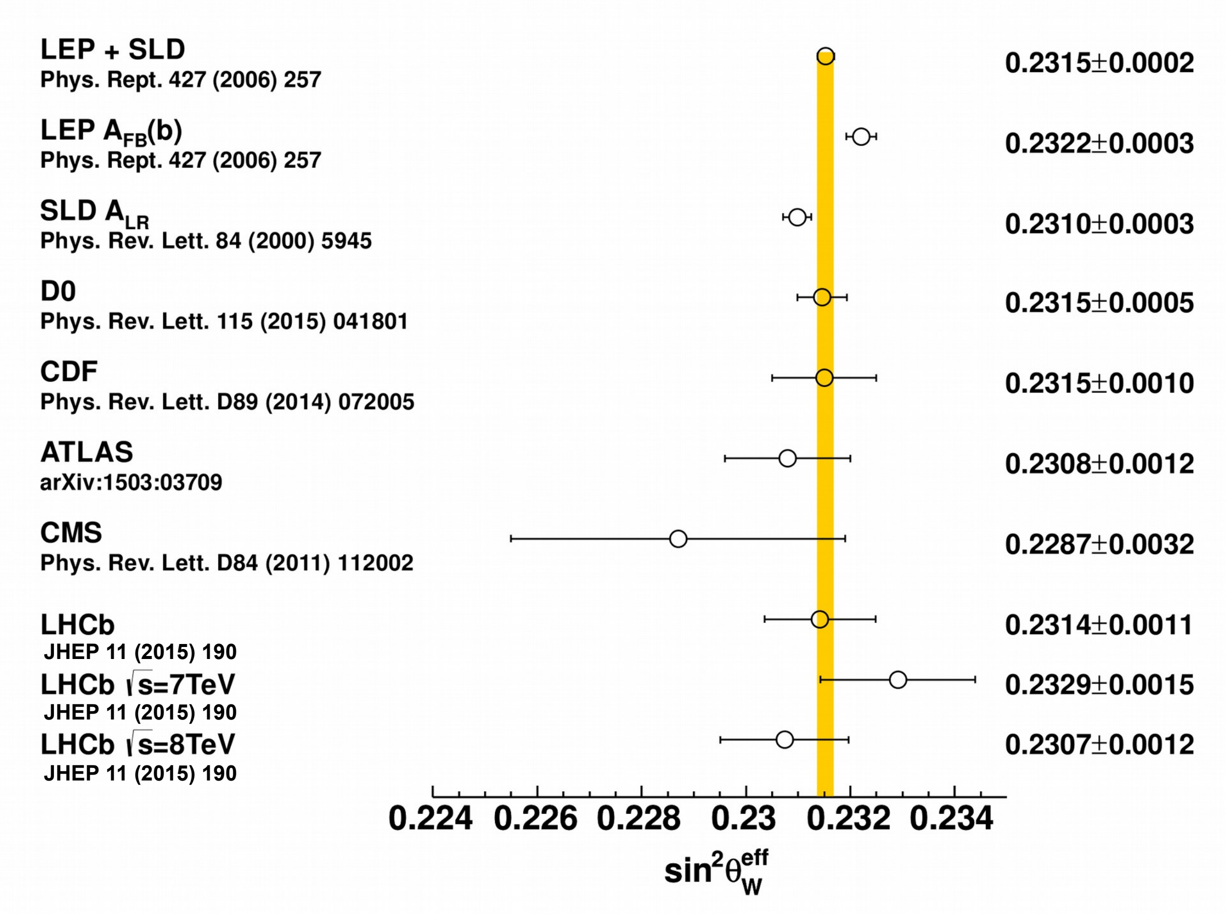
- The combined measurement of $\sin^2\theta^{eff}_W$ for the 7 TeV and the 8 TeV dataset is:



$$\sin^2\theta^{eff}_W = 0.23142 \pm 0.00073\ (\text{stat.}) \pm 0.00052\ (\text{syst.}) \pm 0.00056\ (\text{th.})$$

$\sin^2\theta^{eff}_W$

• The LHCb measurement is consistent with the world average, and it is one of the most precise at hadron colliders.



Conclusions and future

- **$\sin^2\theta^{eff}_W$ has been measured by LHCb, by studying $A^{\mu\mu}_{FB}$:**

  → **$\sin^2\theta^{eff}_W = 0.2329 \pm 0.0015$ (7 TeV)**
  → **$\sin^2\theta^{eff}_W = 0.2307 \pm 0.0012$ (8 TeV)**
  → **$\sin^2\theta^{eff}_W = 0.2314 \pm 0.0011$ (combined)**

- This is the **most precise measurement of $\sin^2\theta^{eff}_W$ at LHC, thanks to LHCb forward acceptance.**

- **The uncertainty on $\sin^2\theta^{eff}_W$ can be reduced in the future**:

  → By taking more data.

  → The **errors on the PDFs will decrease** with the new PDFs sets constrained with LHC data.

  → Events can be weighted (for example as a function of the **Z boson rapidity**) to increase the sensitivity to $\sin^2\theta^{eff}_W$.

- **But with higher energy (14 TeV) the asymmetry dilution at LHCb increases by 5%, for imperfect knowledge of the initial state quark direction.**


Thanks for your attention!
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