# The Forward-Backward Asymmetry in Drell-Yan Process with the CMS Experiment

The Physics of the Dimuons at the LHC, 23–24 Jun 2022, JINR, Dubna, Russia

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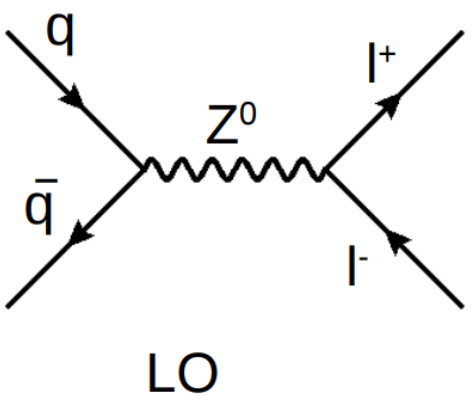
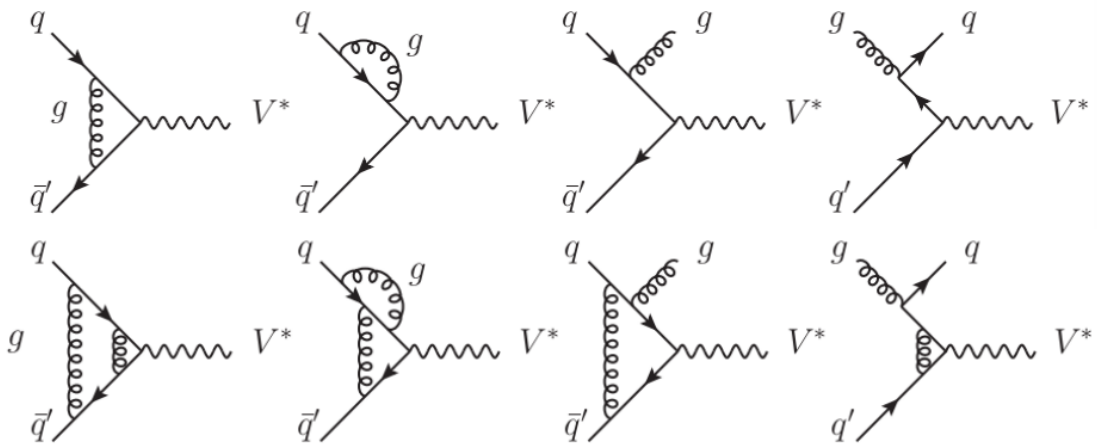
JINR, Dubna

June 23, 2022

# Motivation



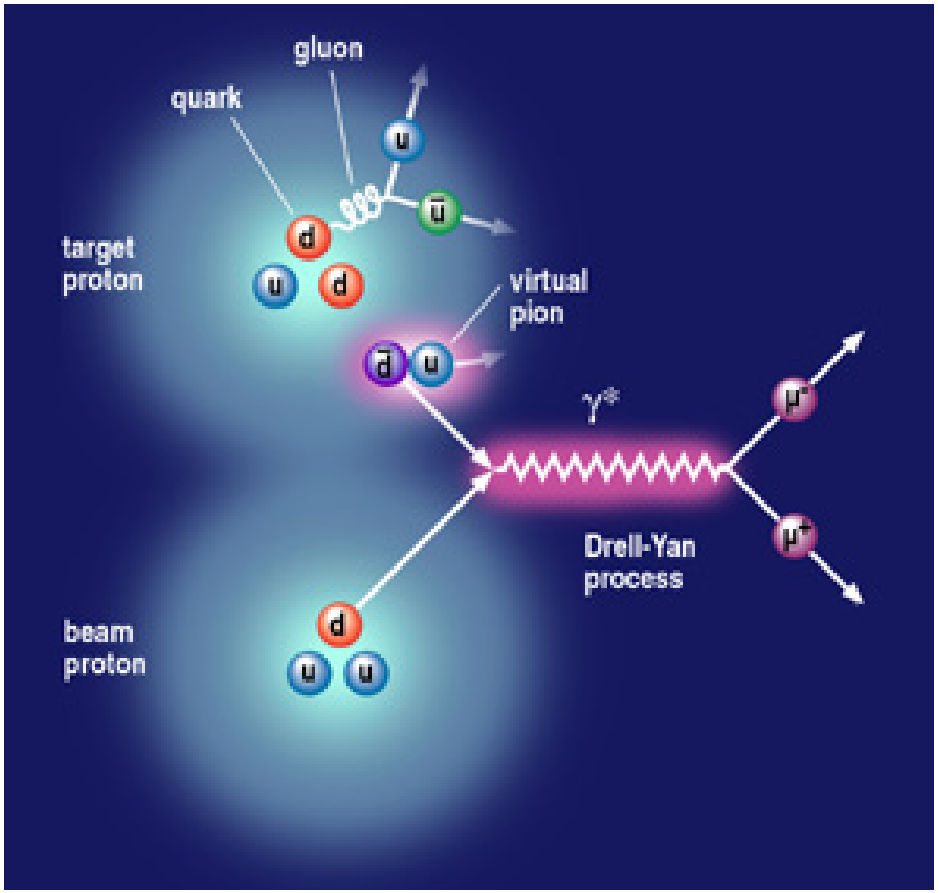

$p_T(\ell\ell) \sim 0$

$p_T(\ell\ell) \gg 0$

- Testing Standard model (SM)
- Constraining parton distribution functions (PDFs)
- Extracting parameters
- Background evaluation for BSM models
- Testing different Monte Carlo models
- Testing production mechanism dynamics
- Precision measurements with a hadron collider!

# The Drell-Yan process

- The production of lepton pairs in pp-collisions is described by the s-channel exchange of $\gamma^{\star}Z$
- Theoretical calculations are well established up to NNLO order
- Comparison of Data and MC provide stringent tests of QCD and significant constraints on the evaluated PDFs
- DY is a major background for $t\bar{t}$ and diboson measurements as well as for searches for new physics



# This program was initiated by Dubna in 2002

- Many theoretical reasons:
  - Verification of Standard Model with Drell-Yan processes
  - Hunting for new physics beyond SM (extra gauge models, extra dimensions etc)
- Why muons?
  - Because it is Compact MUON Solenoid where Dubna group plays important role since conceptual design through PhTDR up to physics analysis
  - Strong B-field and long lever arm (from IP and tracker to Muon system) for precise momentum estimation
  - high precision muon detectors with redundant muon trigger
- It's JINR physics program priority - search for new physics in di-muon channels at the invariant mass region uncovered so far by other accelerators

# CMS Analysis Note

*The content of this note is intended for CMS internal use and distribution only*

**April 10, 2006**

## Study of Drell-Yan Di-muon Production with the CMS Detector

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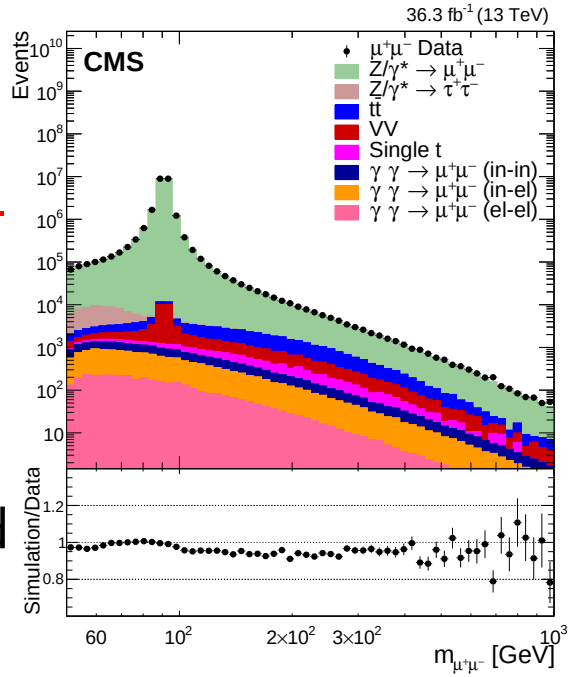
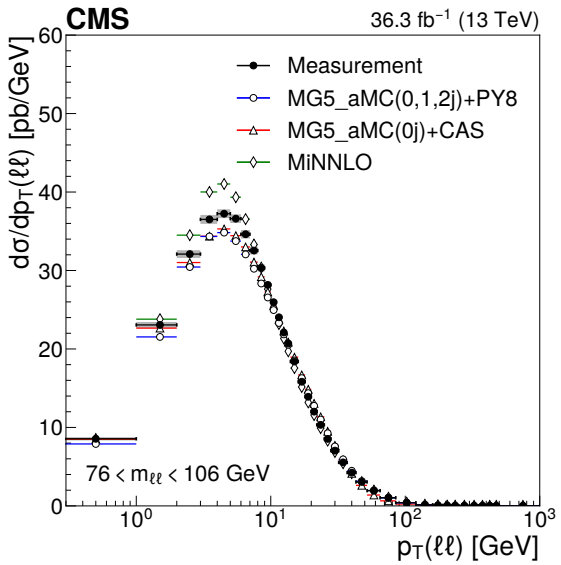
**Abstract**

# Double Differential Drell-Yan x-section at 13 TeV

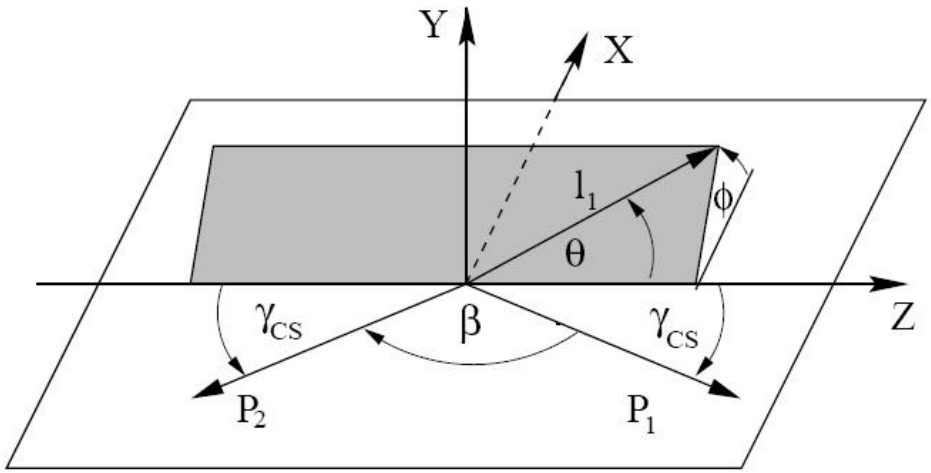
- Double differential invariant mass and $p_T/\phi^\star$ cross section measured at 13 TeV using $36.3 fb^{-1}$ Submitted to Eur. Phys. J. C, SMP-20-003
- Measured in 50 to 1000 GeV mass range and 0 to 2.4 absolute dilepton rapidity
- Measurements are compared to NNLO and NLO predictions
- Results are in good agreement with SM



# Angular Coefficients

The lepton angular distribution of the Drell-Yan process in the $\gamma/Z$ rest frame (Collins-Soper frame) can be expressed as follows:




$$\frac{d^2\sigma}{dcos\theta^\star d\phi^\star} \propto (1+cos^2\theta^\star) + A_0\frac{1}{2}(1-3cos^2\theta^\star) + A_1 sin(2\theta^\star)cos\phi^\star + A_2\frac{1}{2}sin^2\theta^\star cos(2\phi^\star) + A_3 sin\theta^\star cos\phi^\star + A_4 cos\theta^\star + A_5 sin^2\theta^\star sin(2\phi^\star) + A_6 sin(2\theta^\star)sin\phi^\star + A_7 sin\theta^\star sin\phi^\star$$

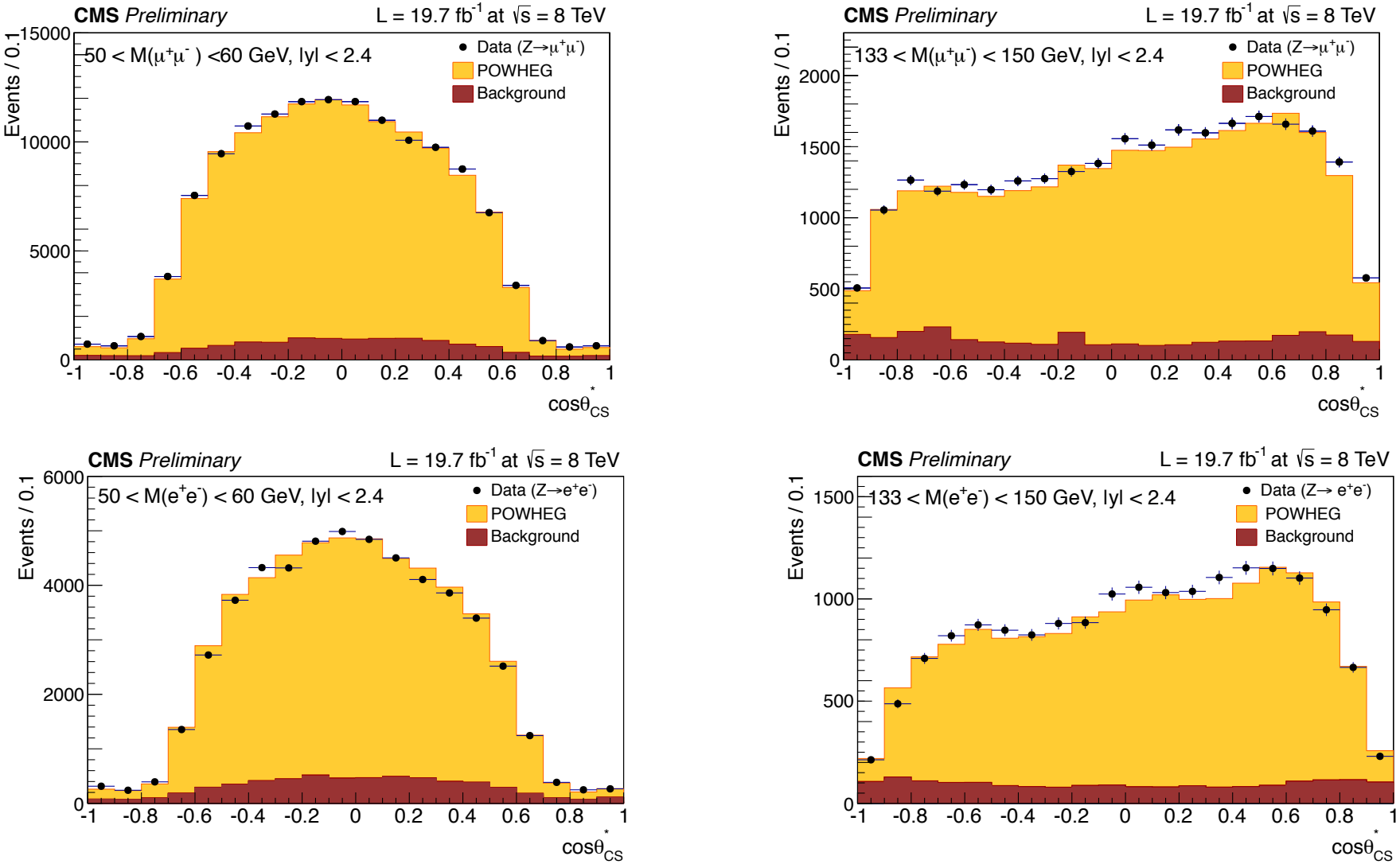
, where $\theta^\star$ and $\phi^\star$ are the polar and azimuthal angles of $\mu^-$ in the Collins-Soper frame.

If integrate over $\phi^\star$:

$$\frac{d\sigma}{dcos\theta^\star} \propto \frac{3}{8}(1+cos^2\theta^\star) + A_{FB}cos\theta^\star$$

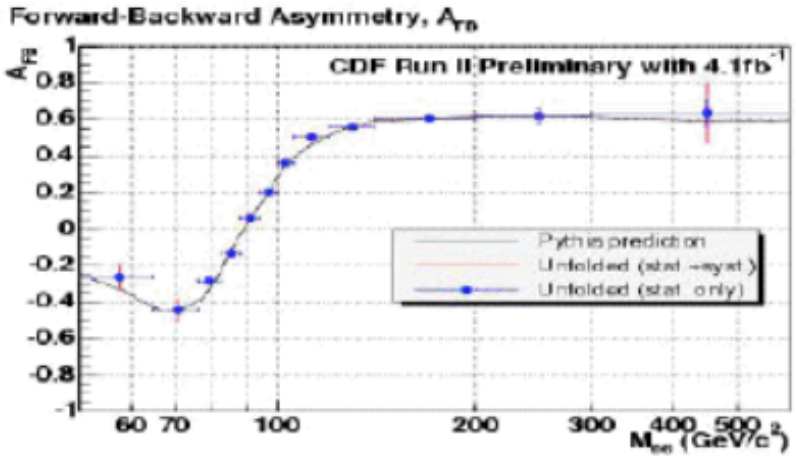
, where $A_{FB}$ is the Forward-Backward Asymmetry.

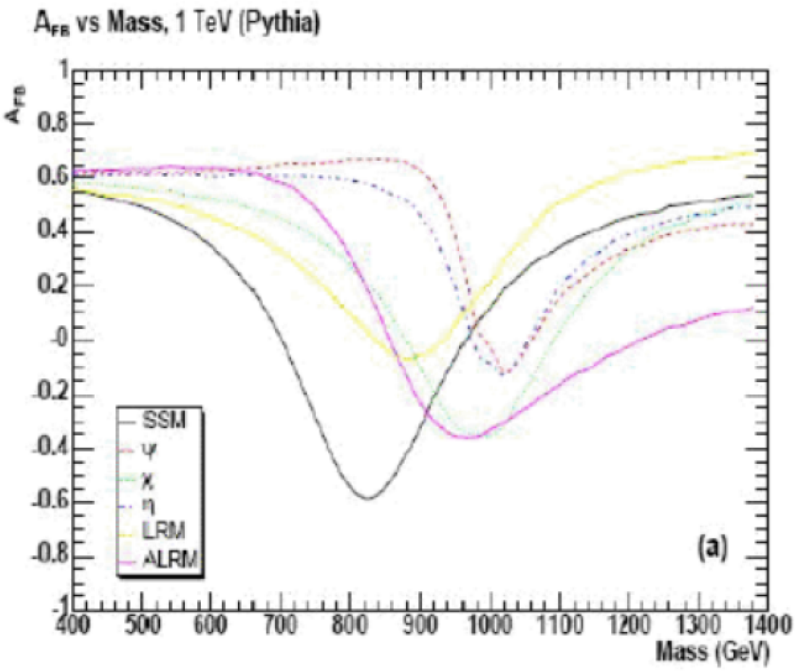
# The $cos\Theta^{\star}_{CS}$ distribution




The $cos\Theta^{\star}_{CS}$ distribution for $\mu^+\mu^-$ (top) and $e^+e^-$ (bottom) events. The left (right) plots correspond to the events in $50 < M < 60\ GeV$ ($133 < M < 150\ GeV$)

# Application of $A_{FB}$




**Measurement of the $A_{FB}$ can provide:**

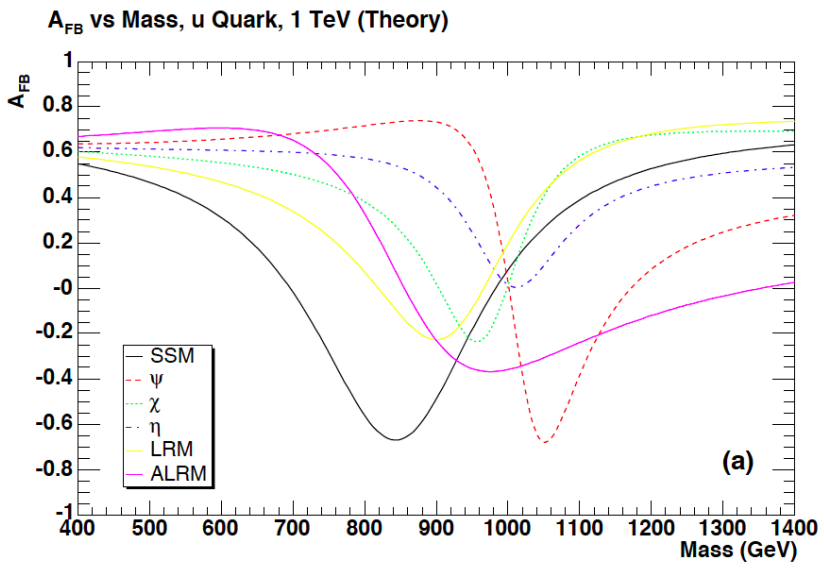
- Test of the SM in the new energy region
- Provide at the Z-pole a precise measurement of $\sin^2\theta_W$

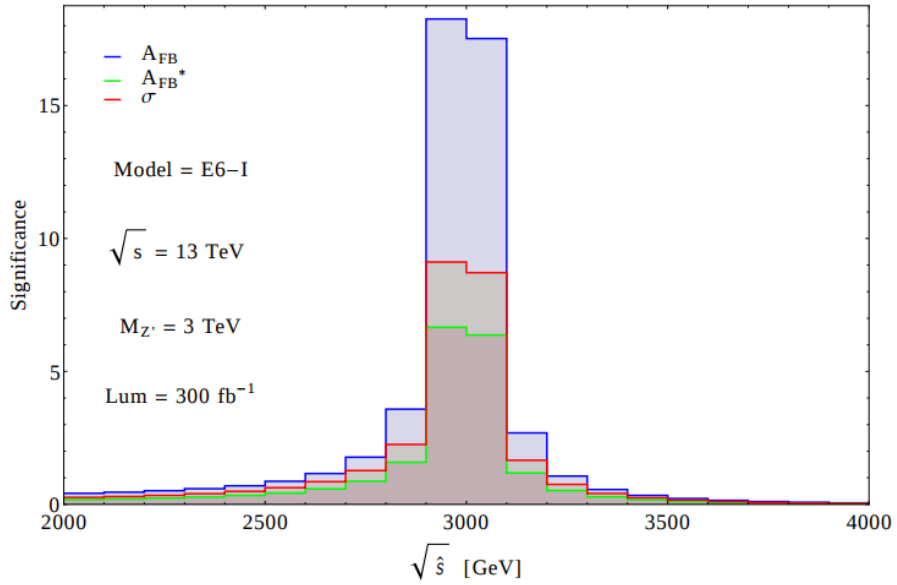
**Deviations from the SM predictions for $A_{FB}$ may indicate the existence of:**

- A new neutral gauge boson
- Quark-lepton compositeness
- Existence of supersymmetric particles
- Extra dimensions, etc.

In case of BSM physics $A_{FB}$ can help to determine it's nature

# $A_{FB}$ Measurements



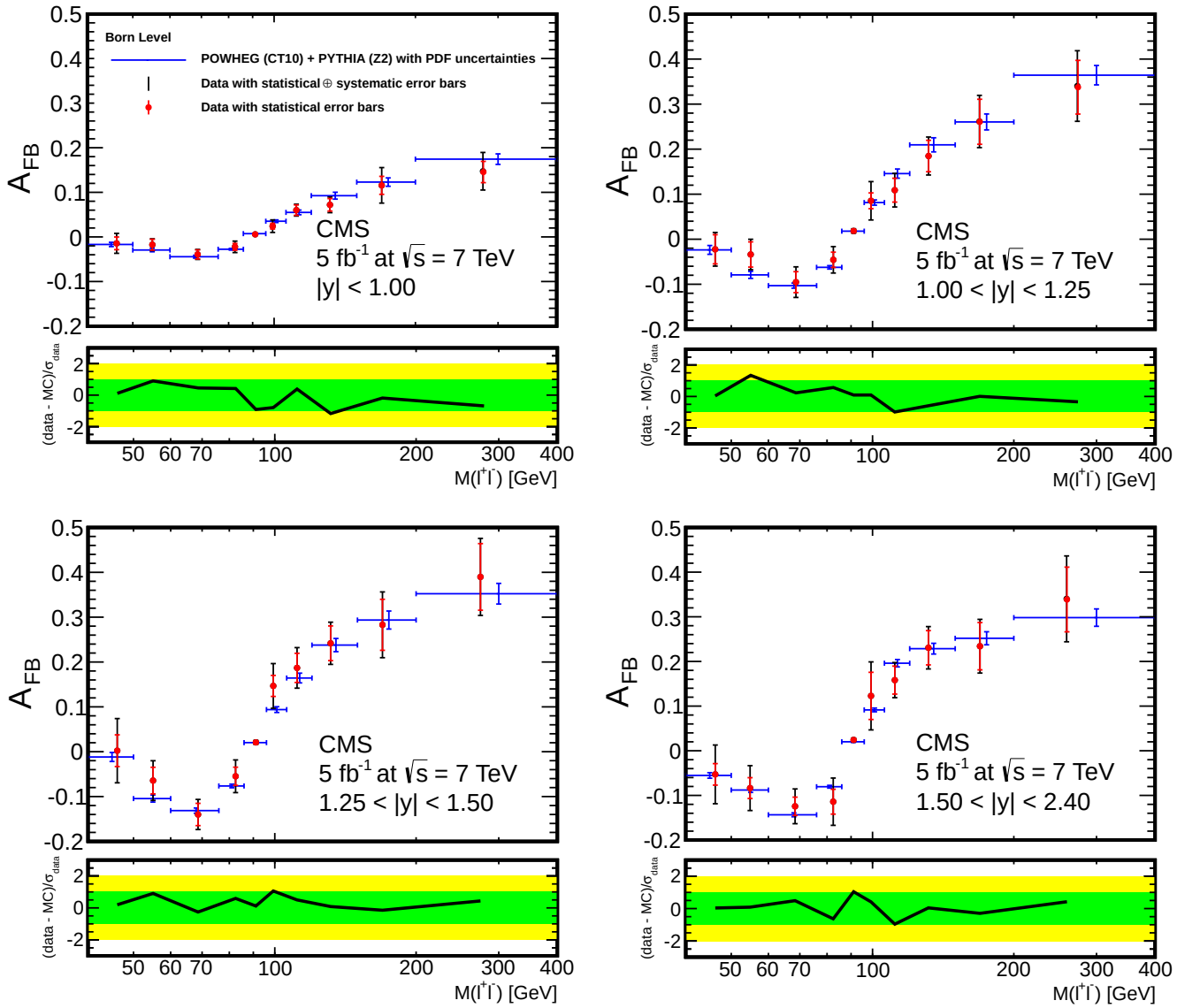




Usually considered as a way to discriminate between different $Z'$ models

For some of the $Z'$ models $A_{FB}$ sensitivity is larger then the one of the invariant mass spectra studies.

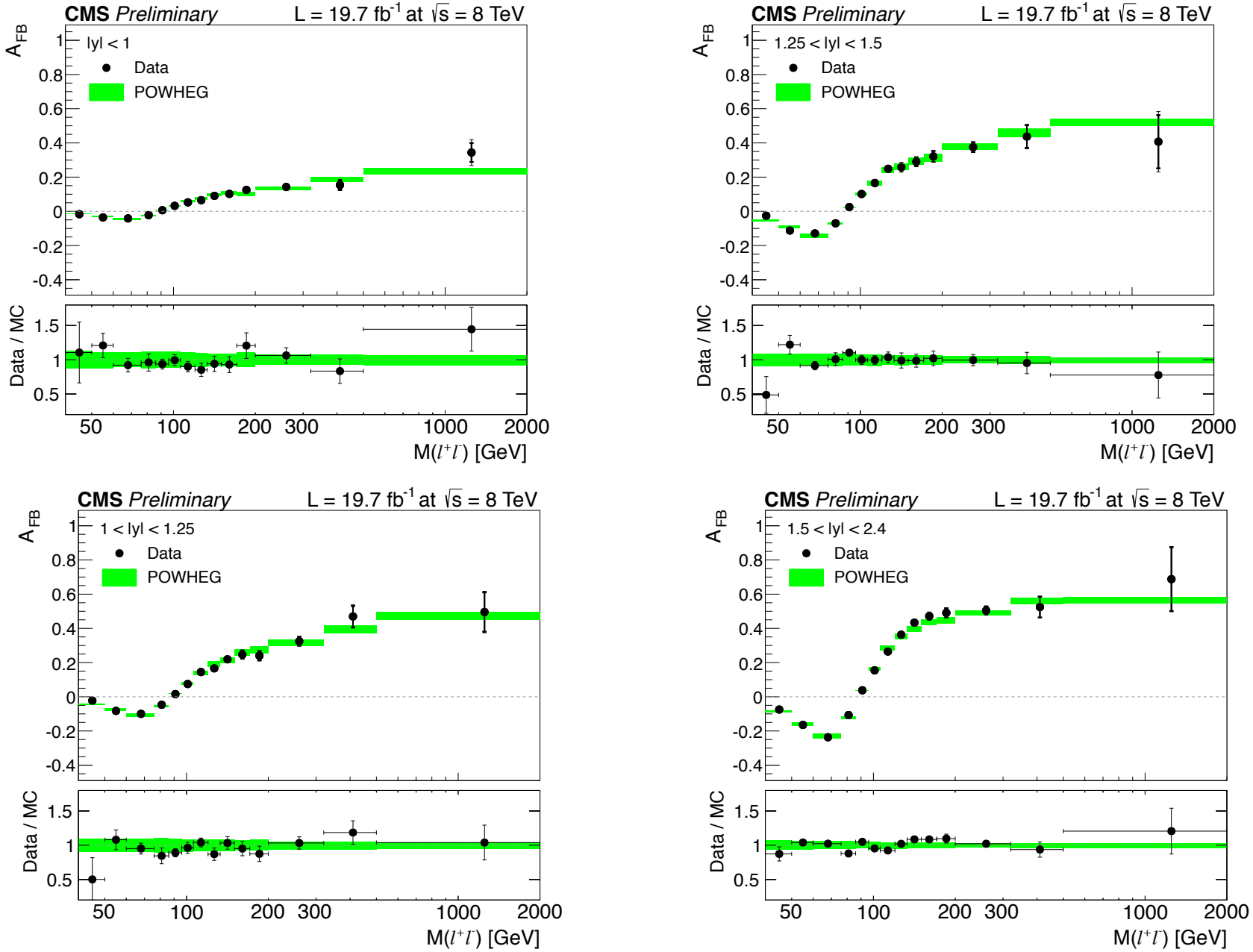
Can also provide additional information for non-resonant signals.
JHEP01(2016)127

# The combined $A_{FB}$ distribution at 7 TeV

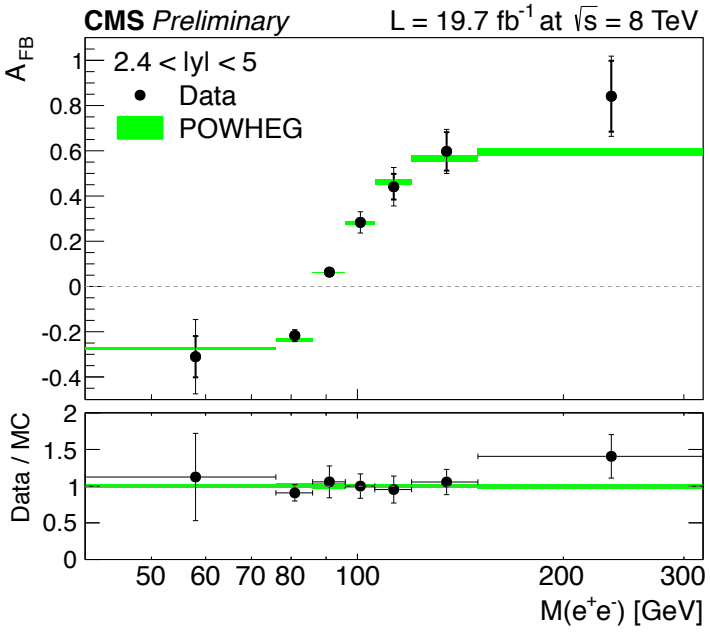


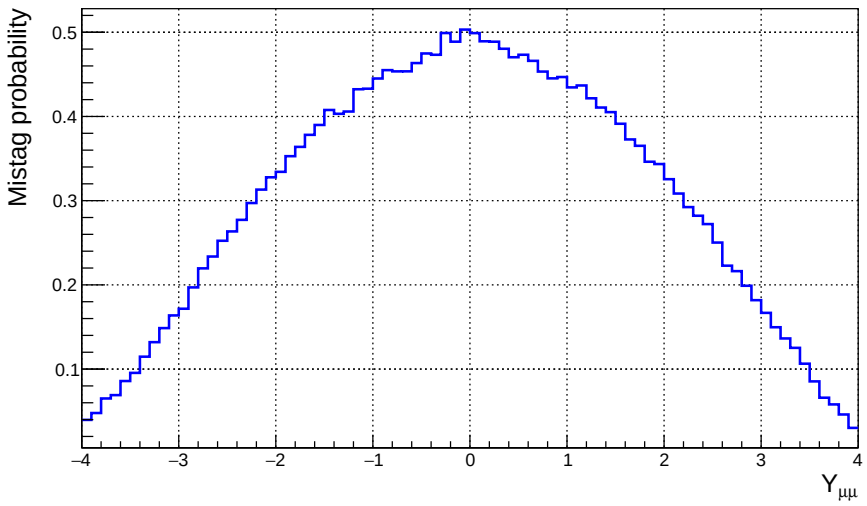

EWK-11-004, PLB 718 (2013) 752-772

# The combined $A_{FB}$ distribution at 8 TeV



# The unfolded $A_{FB}$ distribution for $2.4 < |Y| < 5$ at 8 TeV

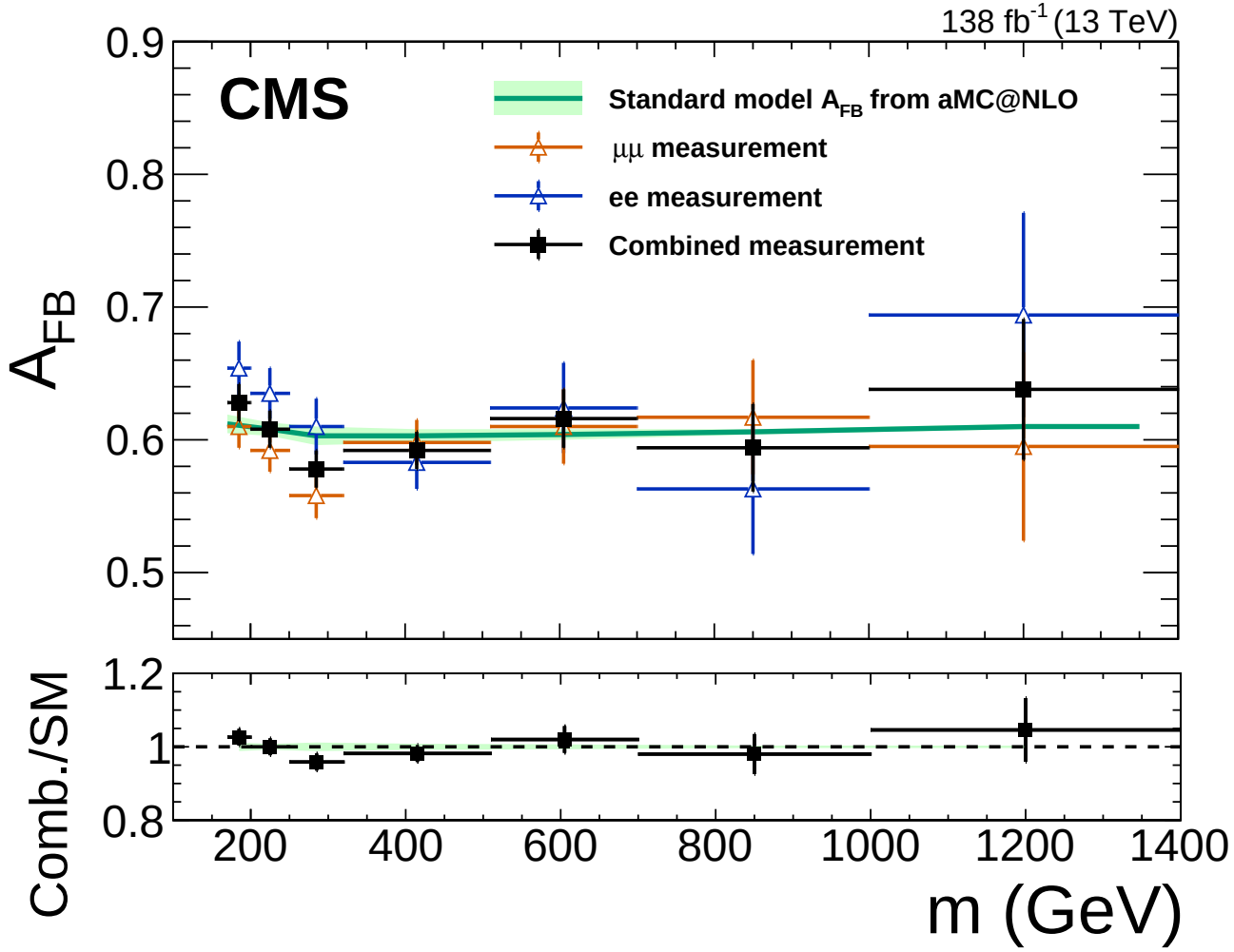



- Measured at 7 and 8 TeV 13 TeV analysis ongoing
- Mass range from 40 to 2000 GeV
- Rapidity range of up to 5
- Increased acceptance will improve measurement
- Measurements are in agreement with SM predictions

SMP-14-004, EPJC 76 (2016) 325

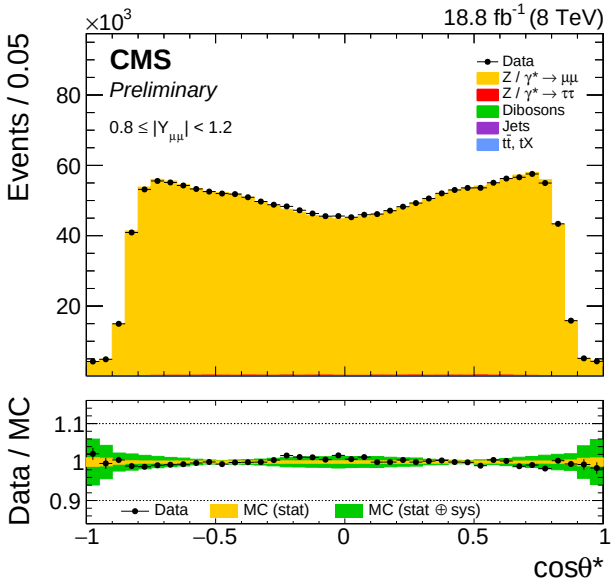
# $A_{FB}$ at high invariant masses with 13 TeV

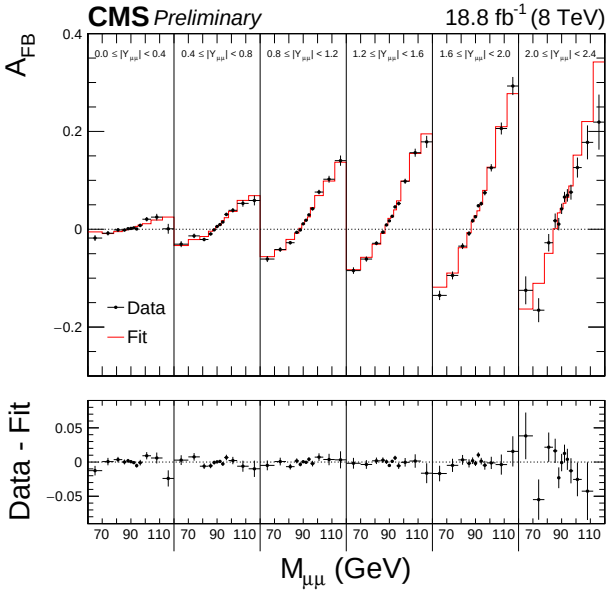


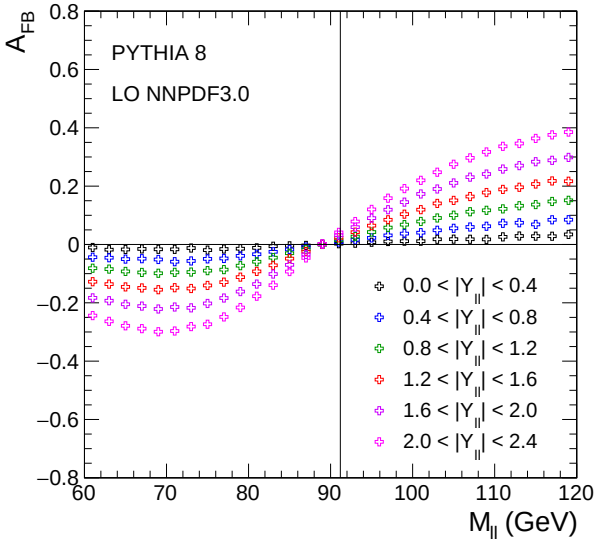

- Measured at masses above 170 GeV using $138 fb^{-1}$ of 13 TeV data
- Template measurement with full correction applyied
- Inclusive measurement yields an asymmetry of $0.599 \pm 0.005(stat.) \pm 0.007(syst.)$
- Limit on SSM $Z'$ set at 4.4 TeV

SMP-20-002, Accepted by JHEP

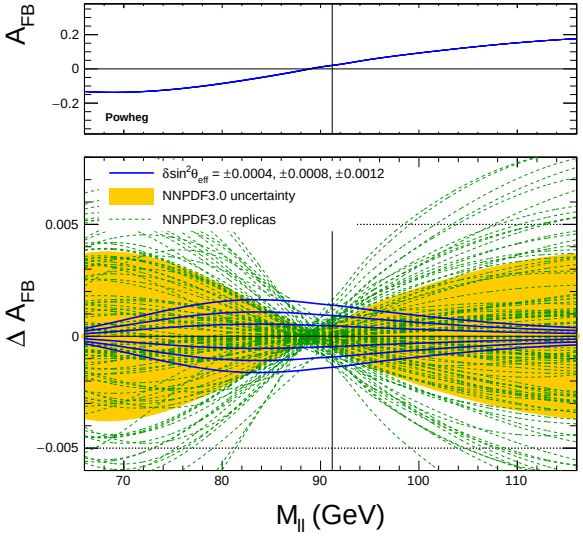
# Weak mixing angle using $A_{FB}$ at 8 TeV



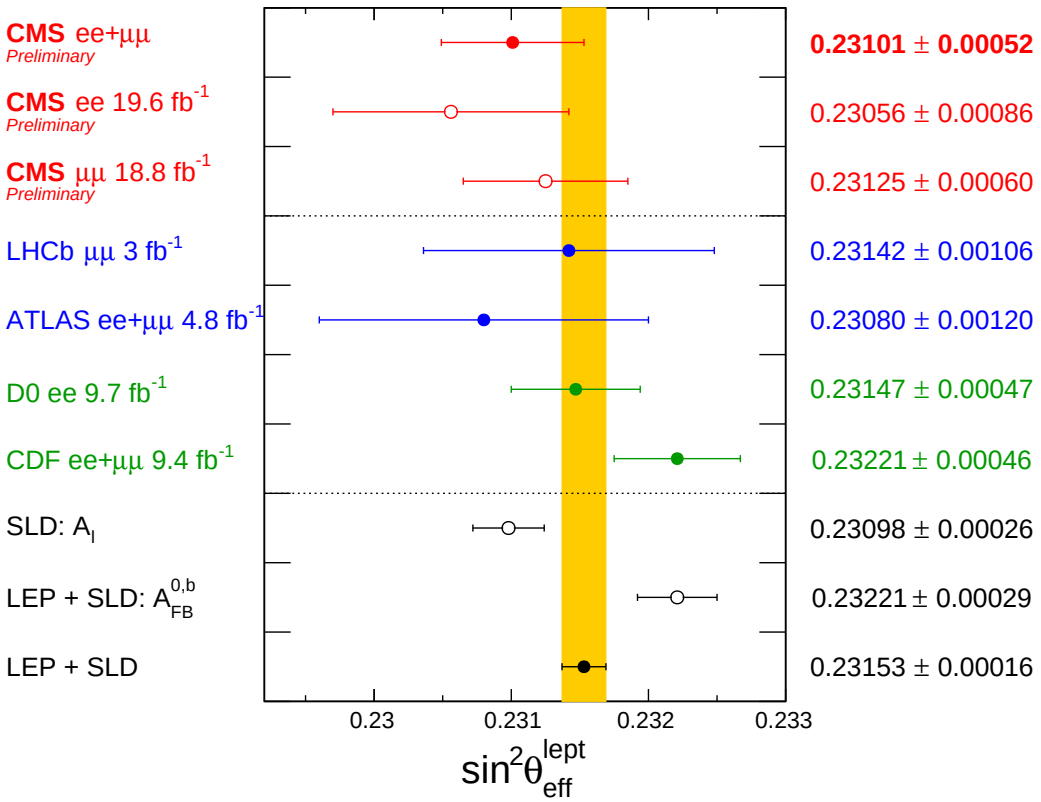




- $\sim 19\ fb^{-1}$ of 8 TeV data used
- The statistical and systematic uncertainties are significantly reduced
- Fit of experimental $A_{FB}$ with theory
- CMS-PAS-SMP-16-007



# Weak mixing angle using $A_{FB}$ at 8 TeV (II)

- One of the most precise measurements
- PDF are constrained in-situ
- $sin^2\theta^{lept}_{eff} = 0.23101 \pm 0.00036(stat) \pm 0.00018(syst) \pm 0.00016(theory) \pm 0.00030(pdf)$
- CMS-PAS-SMP-16-007
- Can reach better precision then LEP+SPD after LHC and CMS upgrade CMS-PAS-FTR-17-001




| $L_{int}$ | $\delta_{stat}[10^{-5}]$ | | $\delta^{nominal}_{nnpdf3.0}[10^{-5}]$ | | $\delta^{constrained}_{nnpdf3.0}[10^{-5}]$ | |
|---|---|---|---|---|---|---|
| ($fb^{-1}$) | $\lvert\eta\rvert < 2.4$ | $\lvert\eta\rvert < 2.8$ | $\lvert\eta\rvert < 2.4$ | $\lvert\eta\rvert < 2.8$ | $\lvert\eta\rvert < 2.4$ | $\lvert\eta\rvert < 2.8$ |
| 10 | 76 | 51 | 75 | 57 | 39 | 29 |
| 100 | 24 | 16 | 75 | 57 | 27 | 20 |
| 500 | 11 | 7 | 75 | 57 | 20 | 16 |
| 1000 | 8 | 5 | 75 | 57 | 18 | 14 |
| 3000 | 4 | 3 | 75 | 57 | 15 | 12 |
| 19 | 43 | | 49 | | 27 | |
| 19 (from [1]) | 44 | | 54 | | 32 | |

# Conclusion

- $A_{FB}$ measurement programm initiated by JINR
- $A_{FB}$ measured at 7, 8 and 13 TeV using 5, 17 and 138 $fb^{-1}$ of data respectively
- Angular Coefficients are measured at 8 TeV the 13 TeV analysis is ongoing
- Measurements are consistent with the Standard Model predictions within uncertainties
- 13 TeV $A_{FB}$ for the first time used to set the limit on SSM $Z'$
- $sin^2\theta_W$ measured using the $A_{FB}$ measurement is amongst the most sencitive ones
- Will be important to measure $A_{FB}$ multidifferentialy with the Run-2 data