

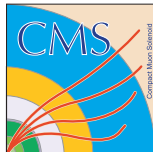
Drell-Yan Measurements with the CMS experiment

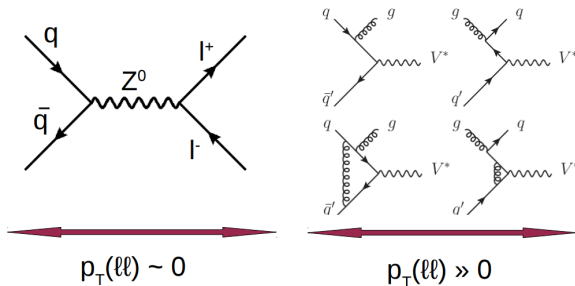
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JINR, Dubna

July 30, 2020

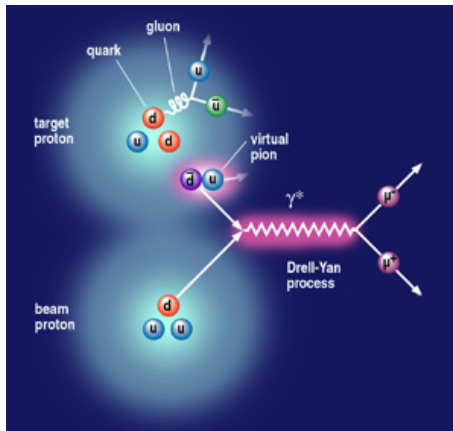




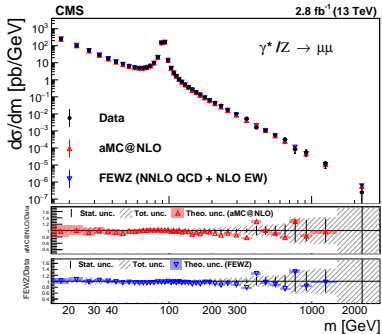
- Testing Standard model (SM)
- Constraining parton distribution functions (PDFs)
- Extracting parameters ($\sin^2\theta_W$, A_{FB} , angular coefficients etc.)
- Background evaluation for BSM models
- Testing different Monte Carlo models
- Testing production mechanism dynamics
- **Precision measurements with a hadron collider!**

The Drell-Yan process

- The production of lepton pairs in pp-collisions is described by the s-channel exchange of γ^*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

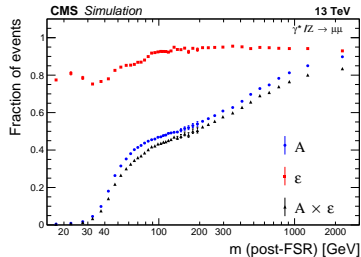
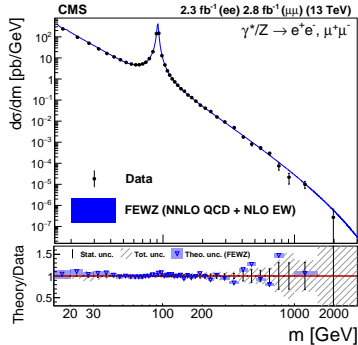


Drell-Yan differential cross section at 13 TeV

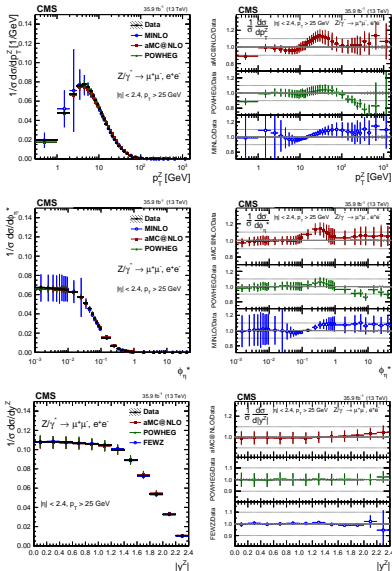


- Measured at 7, 8 and 13 TeV
- At 13 TeV measured in the invariant mass range from 15 to 3000 GeV using 2.8 fb^{-1} of 2015 data

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Z production cross section at 13 TeV



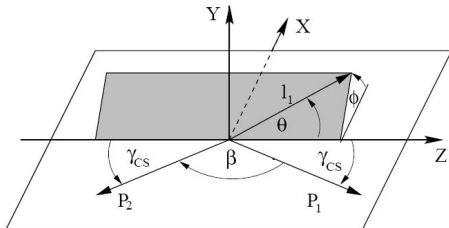
Source	$Z \rightarrow \mu\mu$ (%)	$Z \rightarrow ee$ (%)
Luminosity	2.5	2.5
Muon reconstruction efficiency	0.4	—
Muon selection efficiency	0.7	—
Muon momentum scale	0.1	—
Electron reconstruction efficiency	—	0.9
Electron selection efficiency	—	1.0
Electron momentum scale	—	0.2
Background estimation	0.1	0.1
Total (excluding luminosity)	0.8	1.4

Cross section	σB [pb]
$\sigma_{Z \rightarrow \mu\mu}$	694 ± 6 (syst) ± 17 (lumi)
$\sigma_{Z \rightarrow ee}$	712 ± 10 (syst) ± 18 (lumi)
$\sigma_{Z \rightarrow \ell\ell}$	699 ± 5 (syst) ± 17 (lumi)

- p_T , ϕ_{η}^* , Y are measured using both electrons and muons
- 35.9 fb^{-1} of 13 TeV 2016 data used
- JHEP 12 (2019) 061

Angular Coefficients

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



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

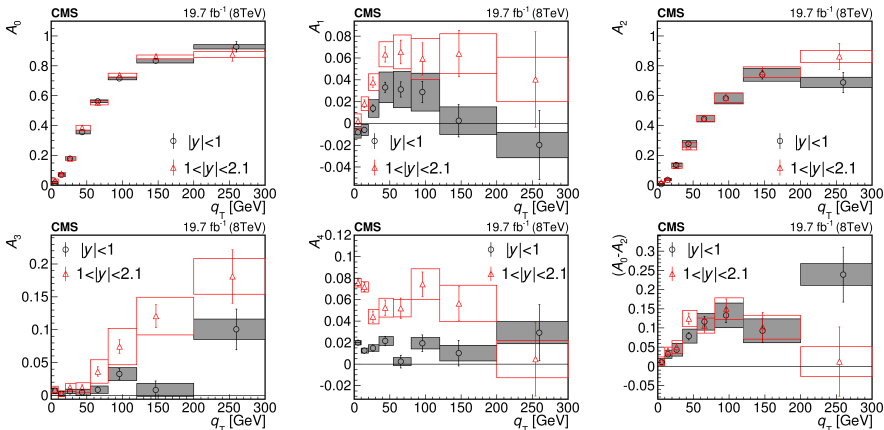
where θ^* and ϕ^* are the polar and azimuthal angles of μ^- in the Collins-Soper frame.

If integrate over ϕ^* :

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

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

Angular Coefficients at 8 TeV



Measured at 8 TeV for the invariant mass range from 60 to 120 GeV using 19.7 fb^{-1} of data as a function of p_T and rapidity.

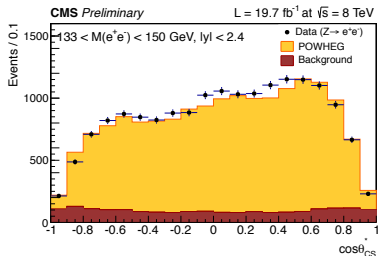
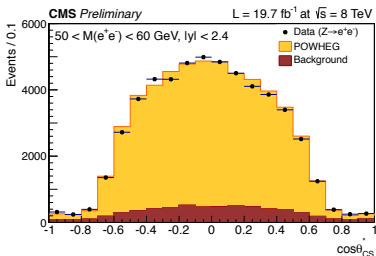
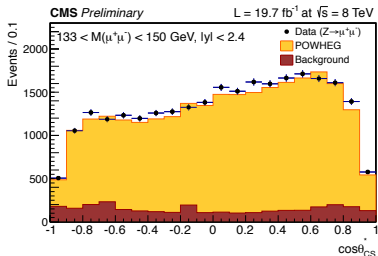
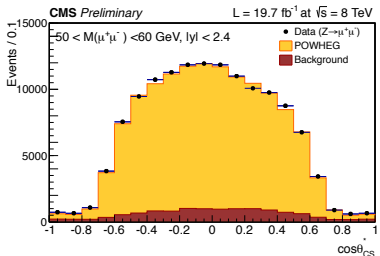
Phys. Lett. B Vol. 750, 2015, pp. 154-175

- At LO only A_4 is non-zero (proportional to the A_{FB})
- $A_0 \sim A_2$ – Lam-Tung relation ($A_0 = A_2$; C. S. Lam, W. K. Tung, Phys. Lett. B 80, 228 (1979) and/or Phys. Rev. D 21 (1980) 2712) violated at high p_T
- $A_0 - A_2$ related to the Z-boson polarisation
- $A_3 - A_6$ sensitive to V-A contributions
- A strong rapidity dependence observed

Can extend the measurement by:

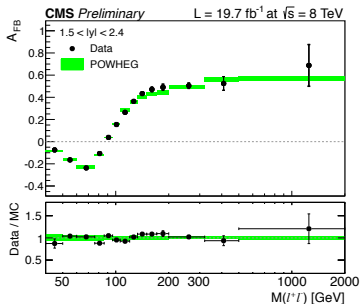
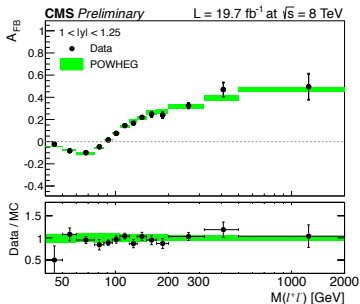
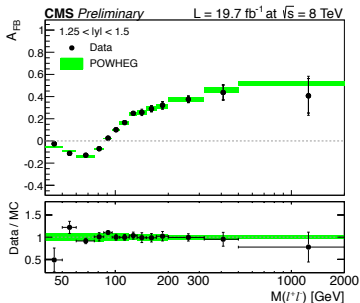
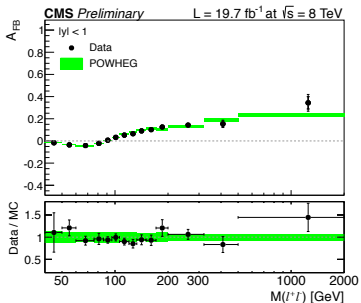
- measuring coefficients outside of the Z peak
- introducing additional coefficients ($A_i \cos^4 \theta$ will be sensitive to graviton contributions)
- measuring coefficients for qg and $q\bar{q}$ production mechanisms separately

The $\cos\Theta_{CS}^*$ distribution

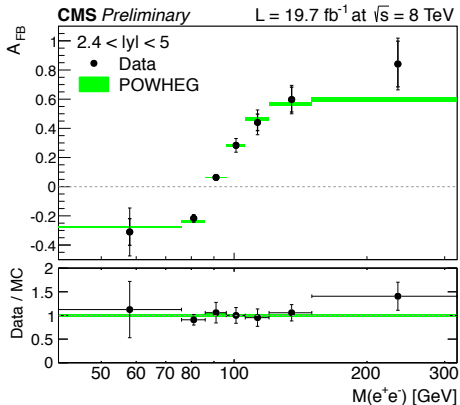


The $\cos\Theta_{CS}^*$ distribution for $\mu^+\mu^-$ (top) and e^+e^- (bottom) events. The left (right) plots correspond to the events in $50 < M < 60$ GeV ($133 < M < 150$ GeV)

The combined A_{FB} distribution at 8 TeV

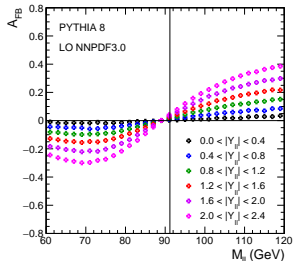
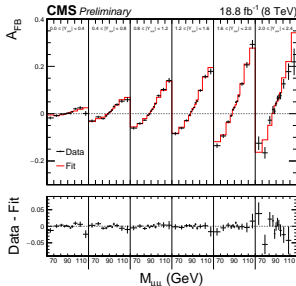
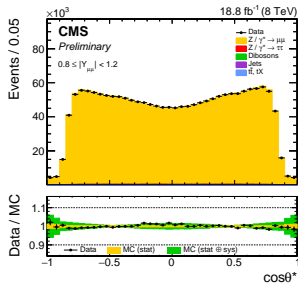


The unfolded A_{FB} distribution for $2.4 < |Y| < 5$ at 8 TeV

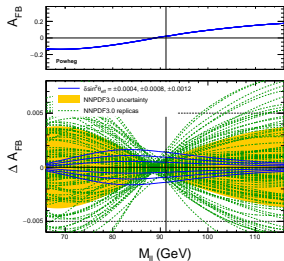


- Measured at 7 and 8 TeV.
- At 8 TeV ([EPJC 76 \(2016\) 325](#)):
 - mass range from 40 to 2000 GeV,
 - rapidity range of up to 5,
 - increased acceptance improves measurement,
 - measurements are in agreement with SM predictions.

Weak mixing angle using A_{FB} at 8 TeV



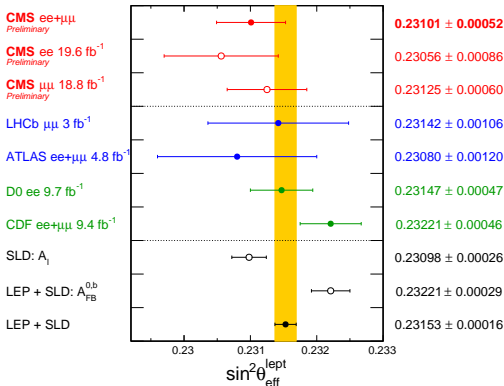
- $\sim 19 \text{ fb}^{-1}$ of 8 TeV data used
- The statistical and systematic uncertainties are significantly reduced with respect to 7 TeV analysis
- Fit of experimental A_{FB} with theory (at NLO)



Eur. Phys. J. C 78 (2018) 701

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

- One of the most precise measurements
- PDF are constrained in-situ
- $\sin^2\theta_{eff}^{lept} = 0.23101 \pm 0.00036(stat) \pm 0.00018(syst) \pm 0.00016(theory) \pm 0.00030(pdf)$
- Can reach better precision than LEP+SPD after LHC and CMS upgrade



CMS-PAS-FTR-17-001

L_{int} (fb $^{-1}$)	$\delta_{stat} [10^{-5}]$		$\delta_{npdf3.0}^{nominal} [10^{-5}]$		$\delta_{npdf3.0}^{constrained} [10^{-5}]$	
	$ \eta < 2.4$	$ \eta < 2.8$	$ \eta < 2.4$	$ \eta < 2.8$	$ \eta < 2.4$	$ \eta < 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	

- High precision measurements (including weak mixing angle) available
- Some channels are analyzed at 13 TeV (Z cross sections, DY differential invariant mass cross section)
- SM predictions tested (weak mixing angle, A_{FB} , DY Angular Coefficients, Lam-Tung relation)
- These measurements provide invaluable constraining power on PDFs