Electroweak precision measurements

LHCP2021: 9th Edition of the Large Hadron Collider Physics Conference, 7-12 June 2021, Paris Virtual World

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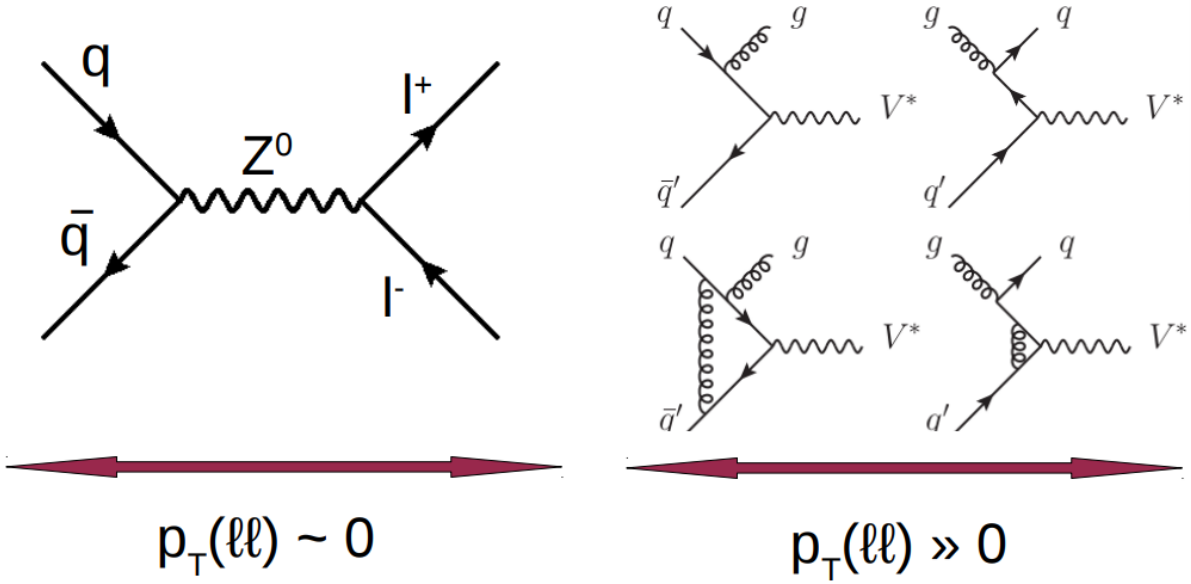
JINR, Dubna

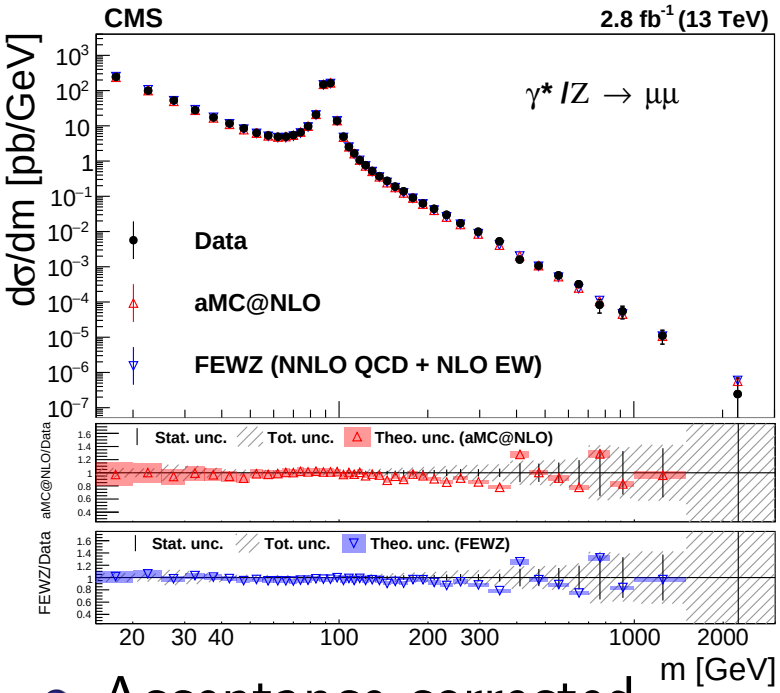
June 9, 2021

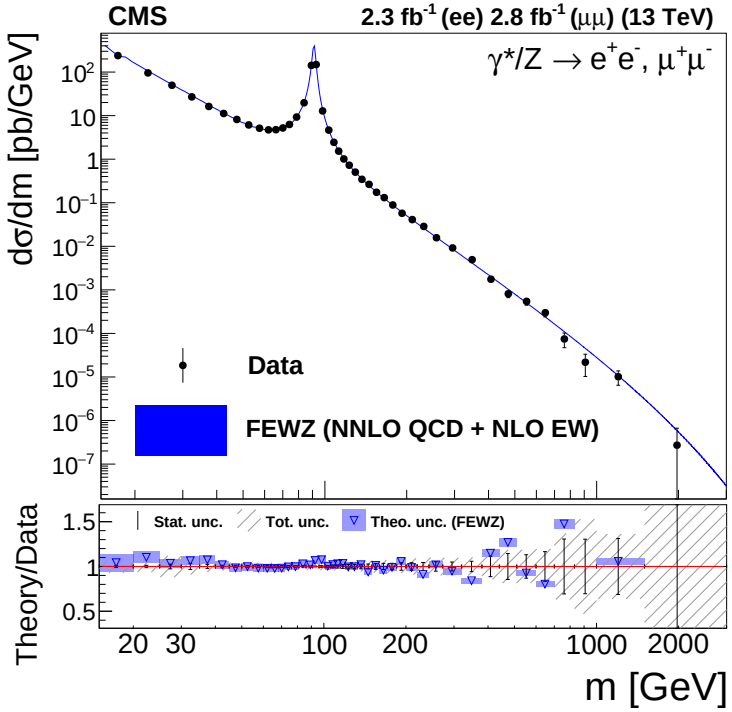
Motivation



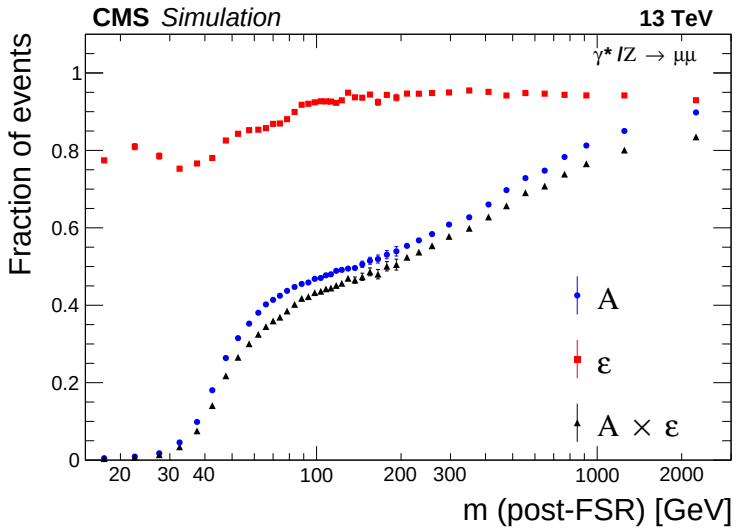
- Testing Standard model (SM)
- Constraining parton distribution functions (PDFs)
- Extracting parameters
- Background evaluation
- Testing different Monte Carlo models
- Testing production mechanism dynamics
- Precise measurements with a hadron collider!

Drell-Yan differential cross section at 13 TeV



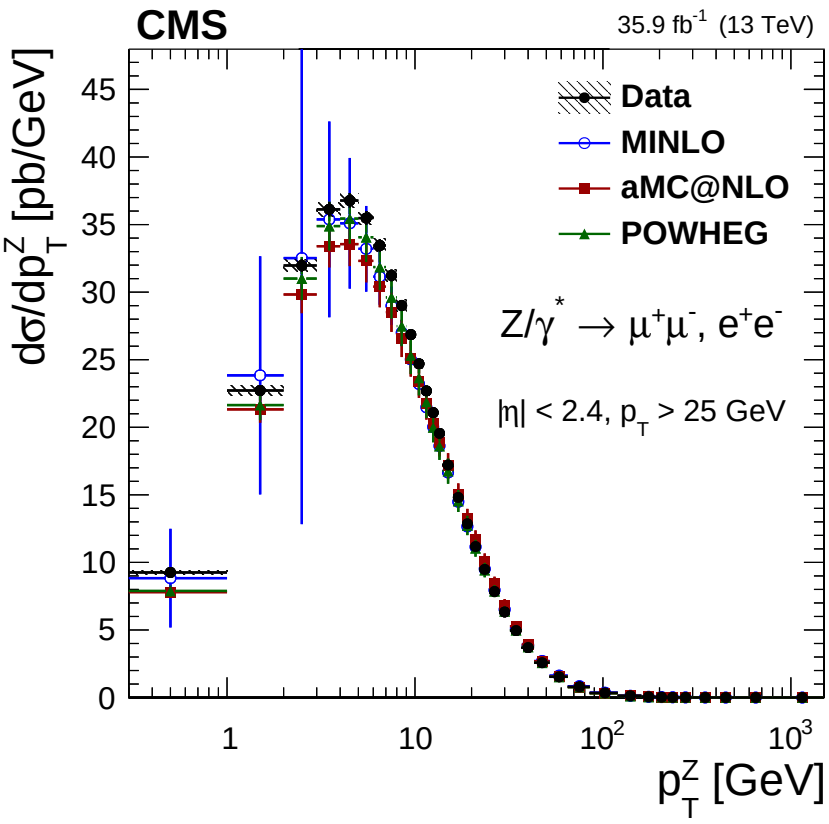


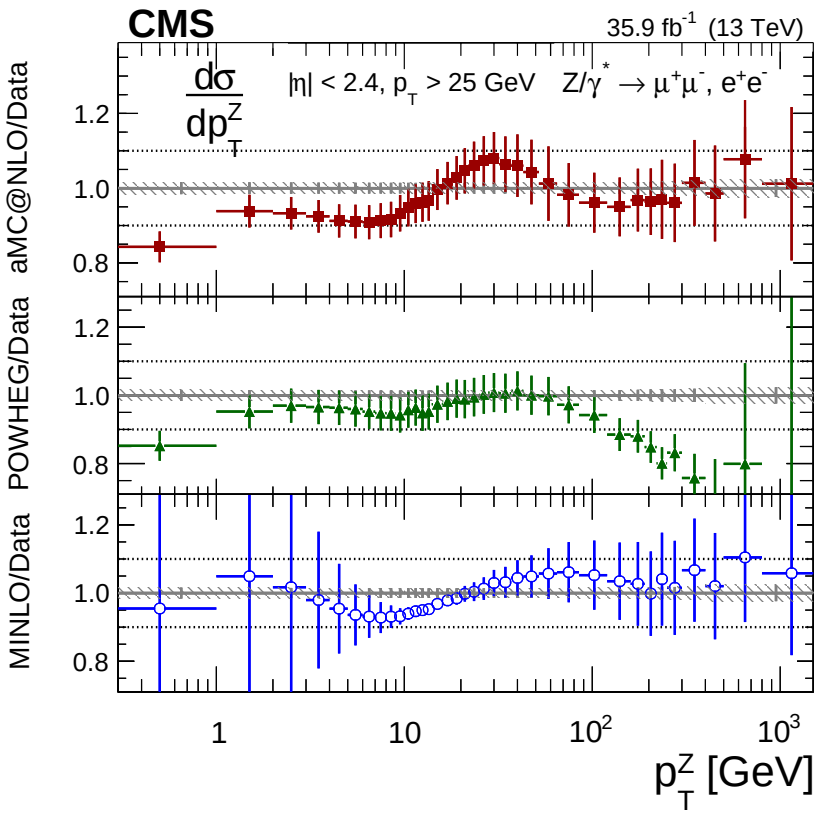
- Acceptance corrected
- From 15 to 3000 GeV using 2.8 fb^{-1} of data
- PDF, Background and FSR are dominant systematics at high mass



JHEP 12 (2019) 059

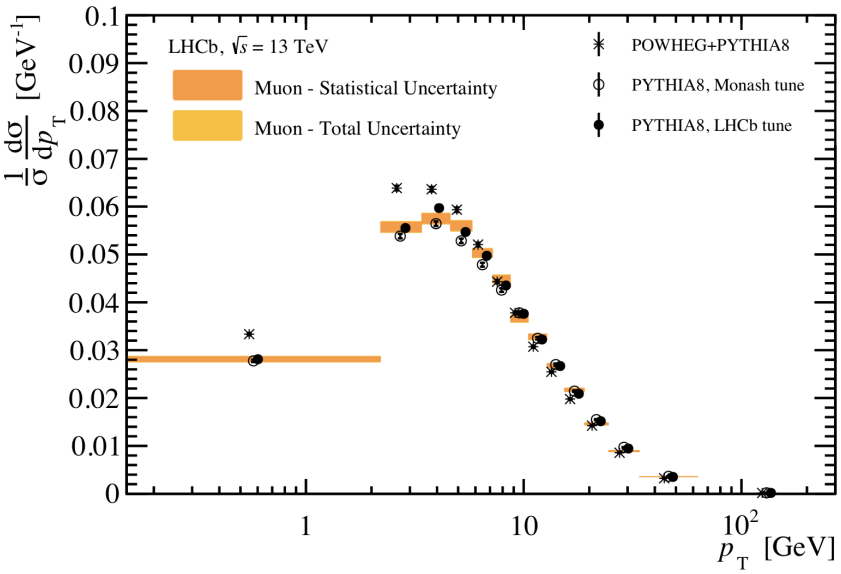
Inclusive Z production cross section at 13 TeV (CMS)

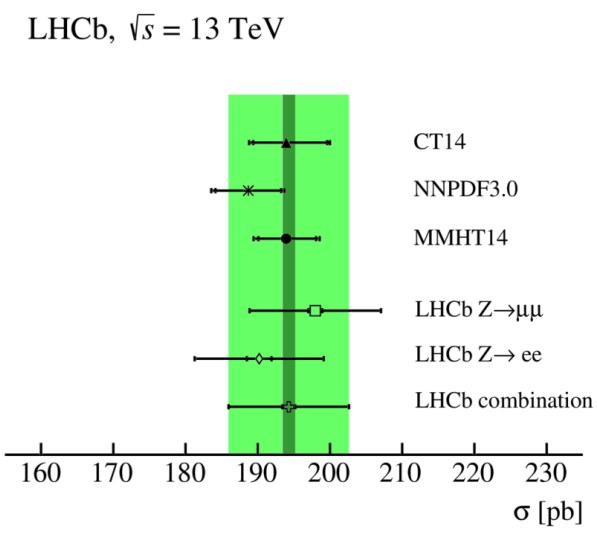




- CMS-SMP-17-010, JHEP 12 (2019) 061 $Z \to \ell\ell$
- Inclusive/differential measurements at Z peak
- $d\sigma/dp_T$ in dielectron and dimuon
- 35.9 fb^{-1} of 13 TeV 2016 data used

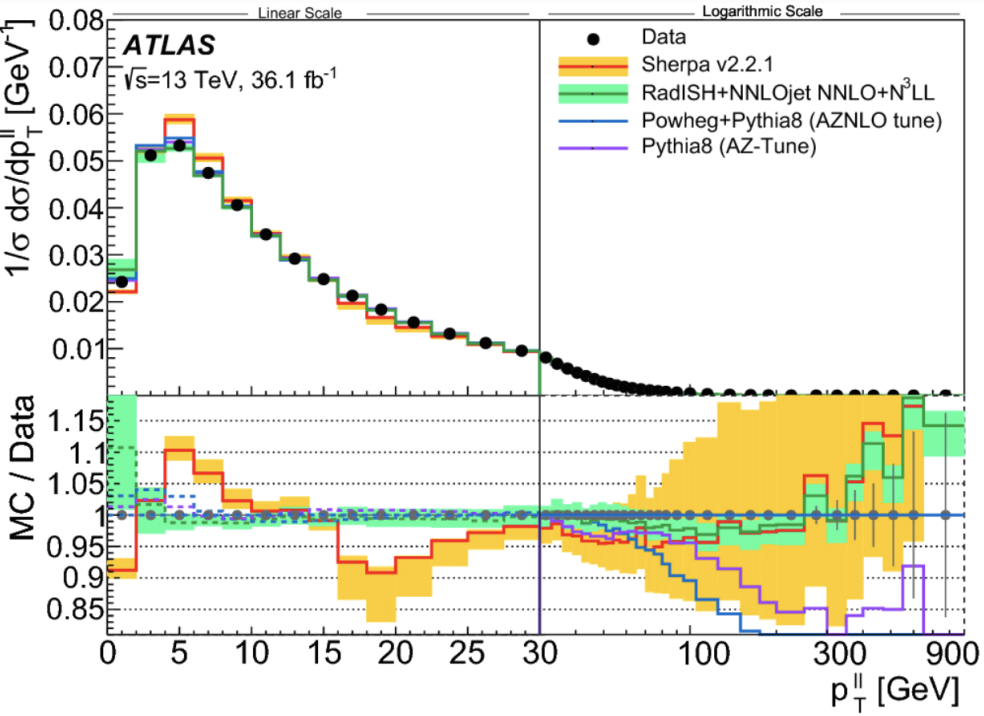
Forward inclusive Z production cross section at 13 TeV (LHCb)

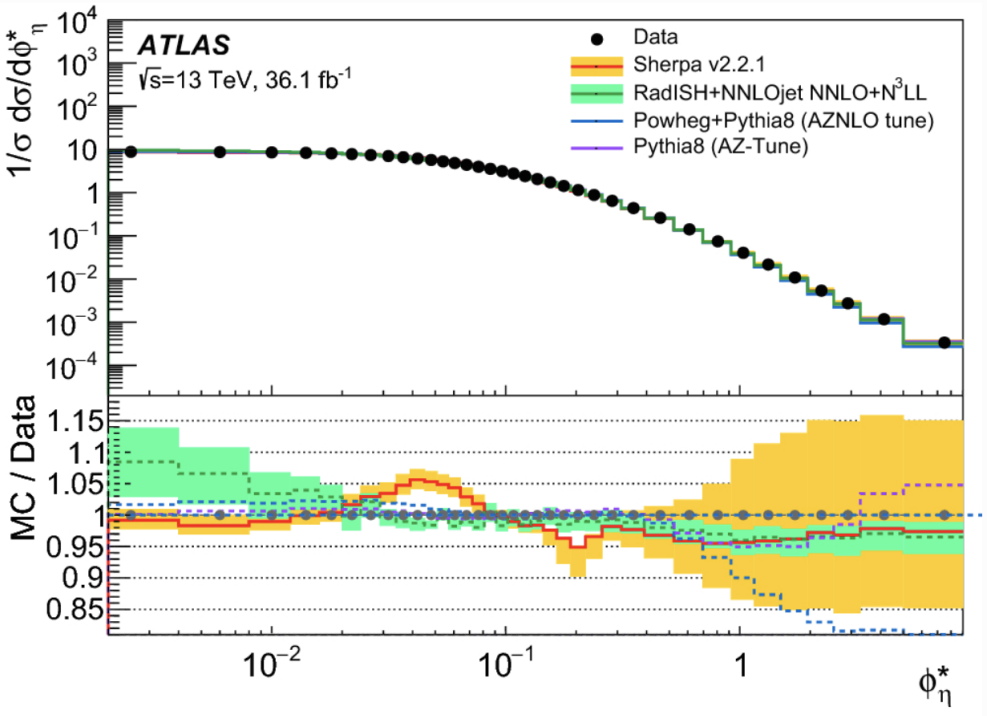




- JHEP 09 (2016) 136 $Z \to \ell\ell$
- Inclusive/differential measurements at Z peak
- forward region $2.0 < \eta < 4.5$
- $d\sigma/dp_T$ in dielectron and dimuon channels
- 294 fb^{-1} of 13 TeV data used
- $\sigma_Z^{\ell\ell} = 194.3 \pm 0.9 \pm 3.3 \pm 7.6\ pb$

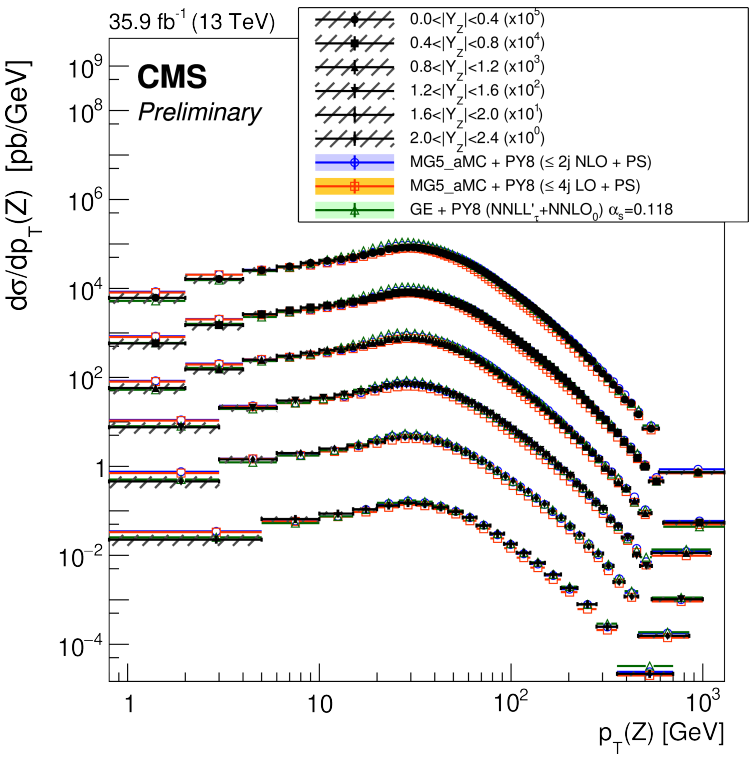
Z p_T measurement at 13 TeV (ATLAS)

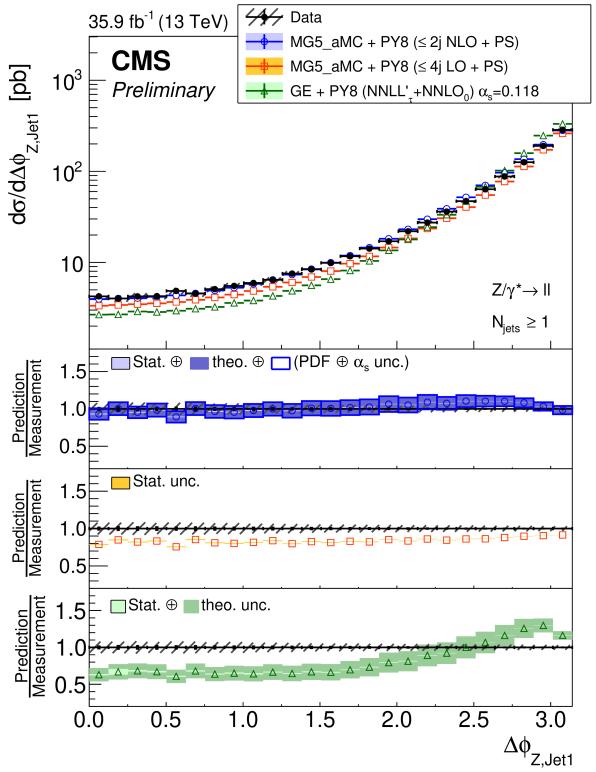




- Inclusive differential measurements at Z peak
- 36.1 fb^{-1} of 13 TeV
- Differential $d\sigma/dp_T^Z$ and $d\sigma/d\phi^\star$
- Eur. Phys. J. C 80, 616 (2020)
- New LHCb measurement also expected soon

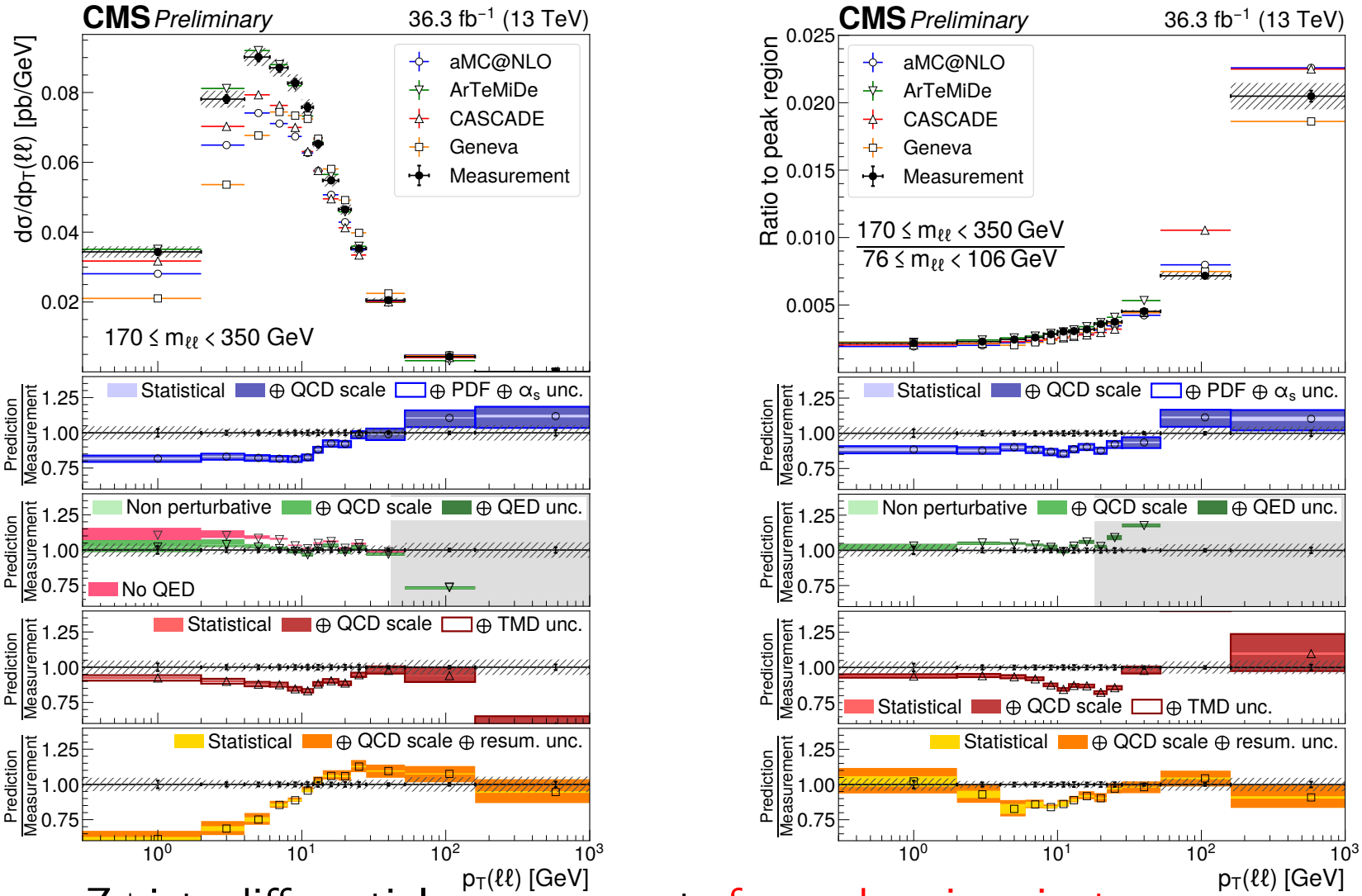
Differential Z+jets cross section at 13 TeV (CMS)





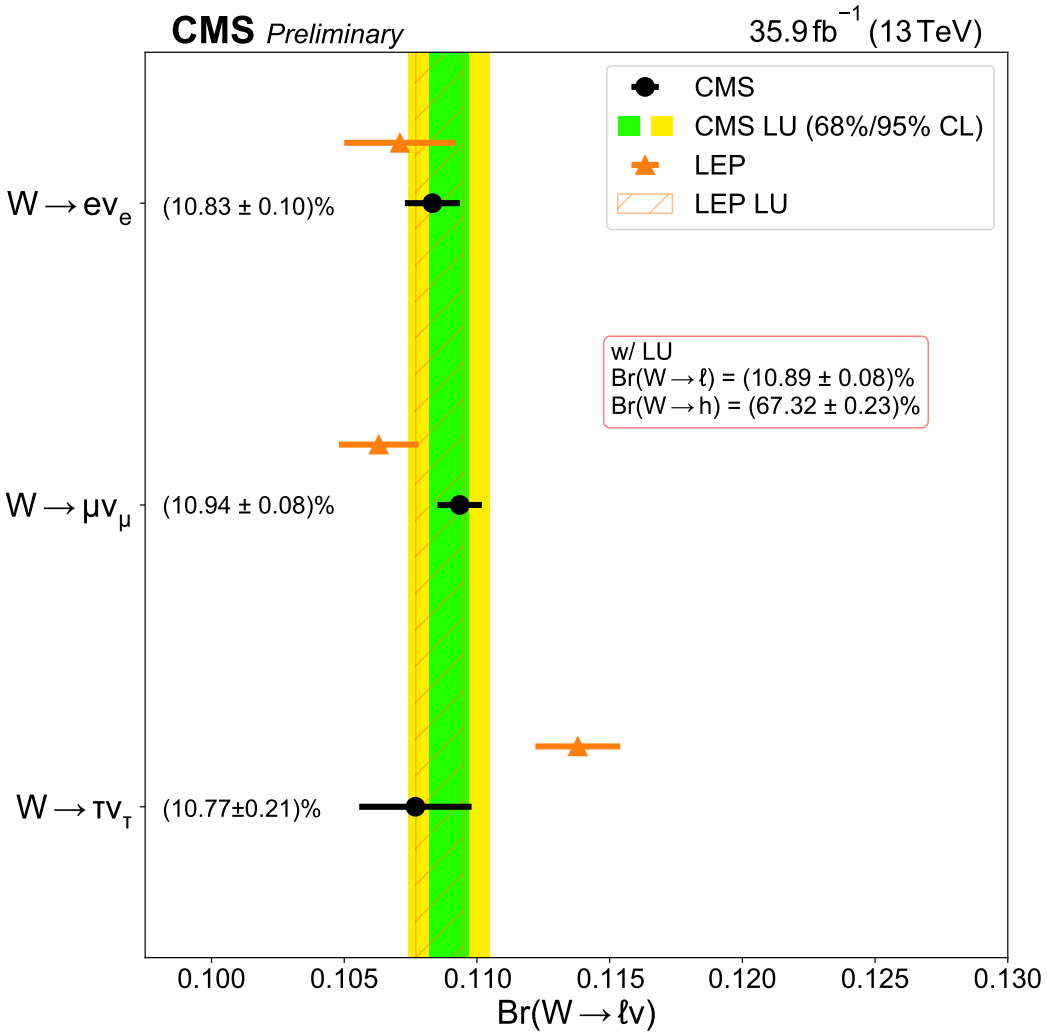
- Differential measurements at Z peak focusing on Z+jets
- 35.9 fb^{-1} of 13 TeV 2016 data used
- Double differential $d\sigma/dp_T^Z dY^Z$
- Differential $d\sigma/d\Delta\phi_{Z,Jet1}$
- NLO MG5_aMC, LO MG5_aMC, and GENEVA
- CMS-PAS-SMP-19-009

Differential in mass Z cross section at 13 TeV



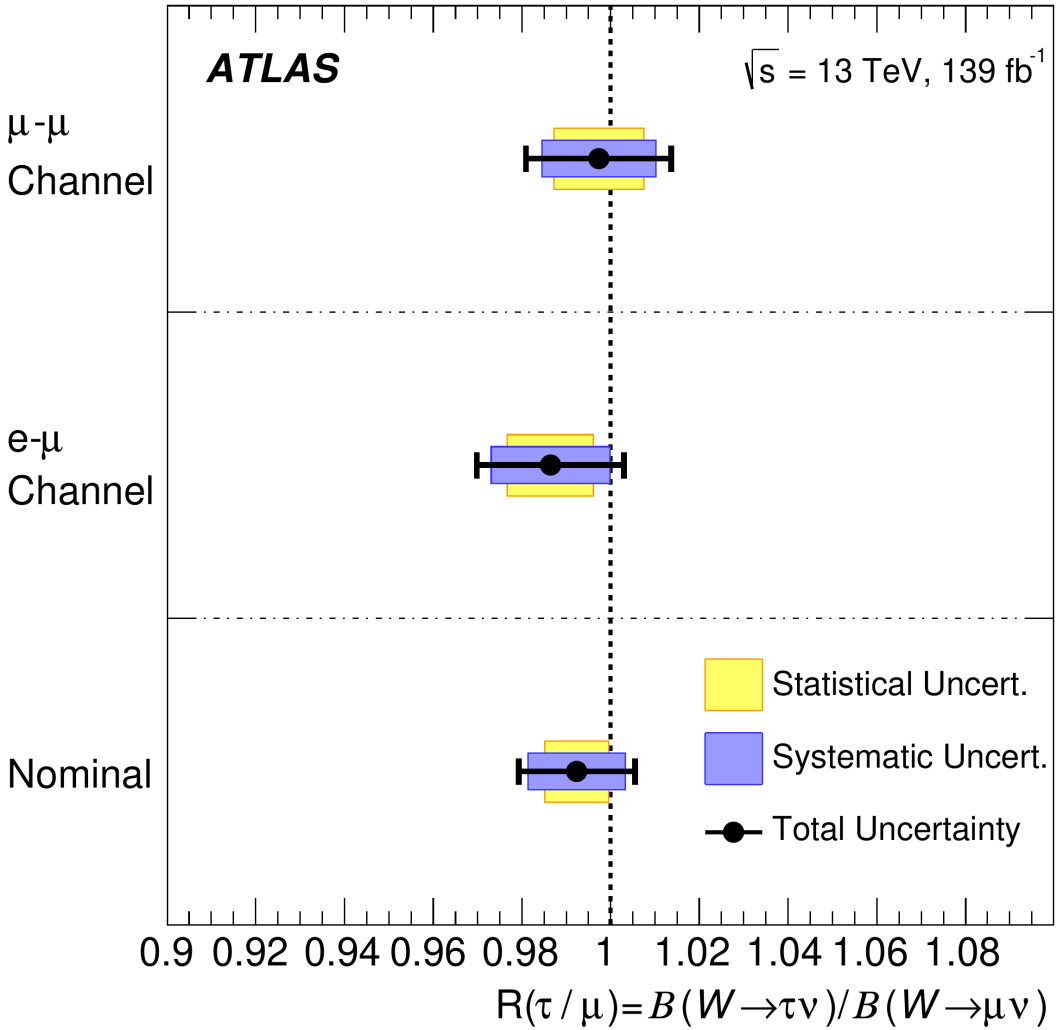
- Z+jets differential measurements focused on invariant mass
- Gluon compton scatering important at high p_T and invariant mass
- $m_{\ell\ell}$ =[50, 76, 106, 170, 350, 1000] GeV CMS-PAS-SMP-20-003

The W boson decay branching fractions at 13 TeV (CMS)



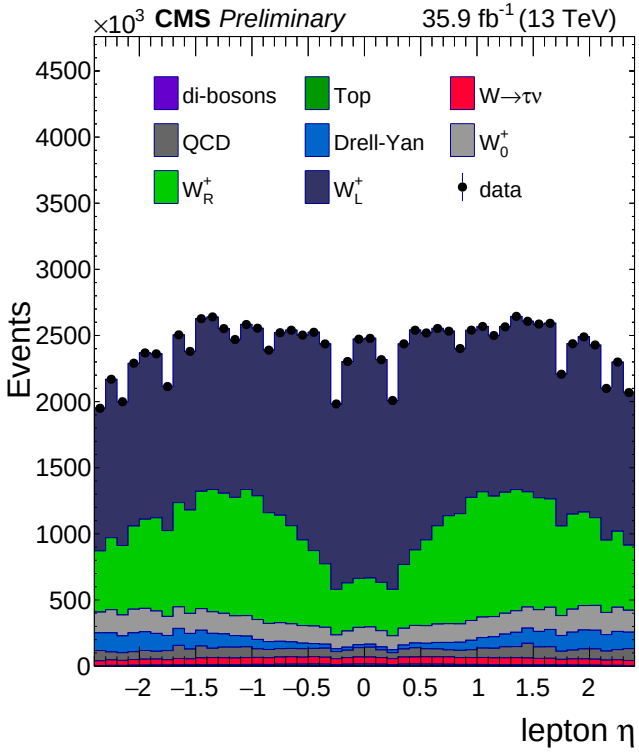
- The leptonic and inclusive hadronic decay branching fractions of the W boson are studied using 35.9 fb^{-1} of 13 TeV data
- W boson decaying into electron, muon, and tau lepton amount to $(10.83 \pm 0.1)\%$, $(10.94 \pm 0.08)\%$ and $(10.77 \pm 0.21)\%$
- Results support the hypothesis of lepton universality for the weak interaction
- CMS-PAS-SMP-18-011

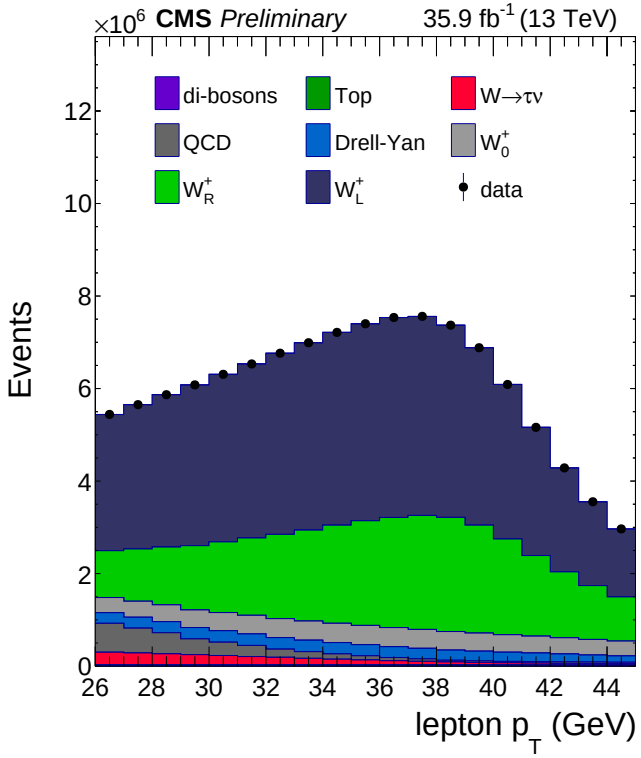
The W boson decay branching fractions at 13 TeV (ATLAS)

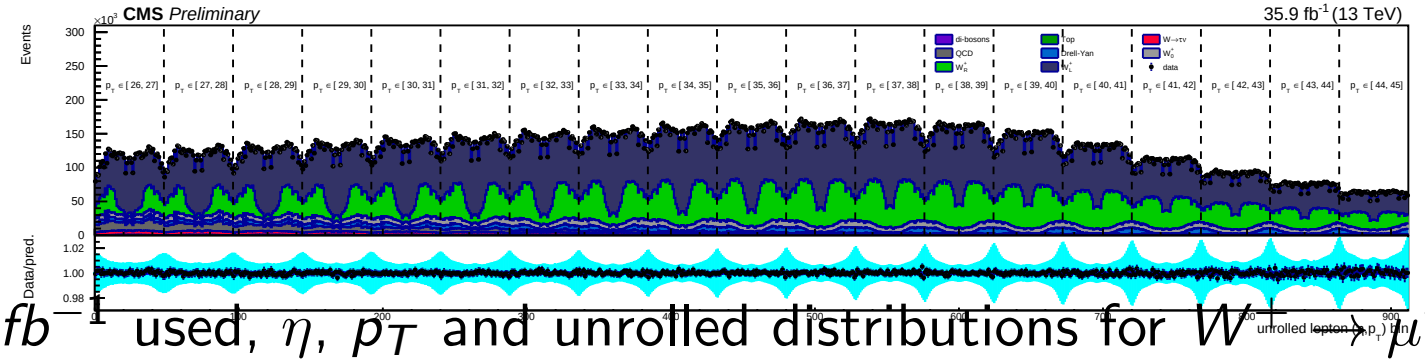


- Test of the universality of τ and μ lepton couplings in W-boson decays from $t\bar{t}$ events using 139 fb^{-1} of 13 TeV data
- One of the most precis measurements available
- Results support the hypothesis of lepton universality for the weak interaction
- CERN-EP-2020-139

W rapidity, helicity and differential xsection at 13 TeV (CMS)



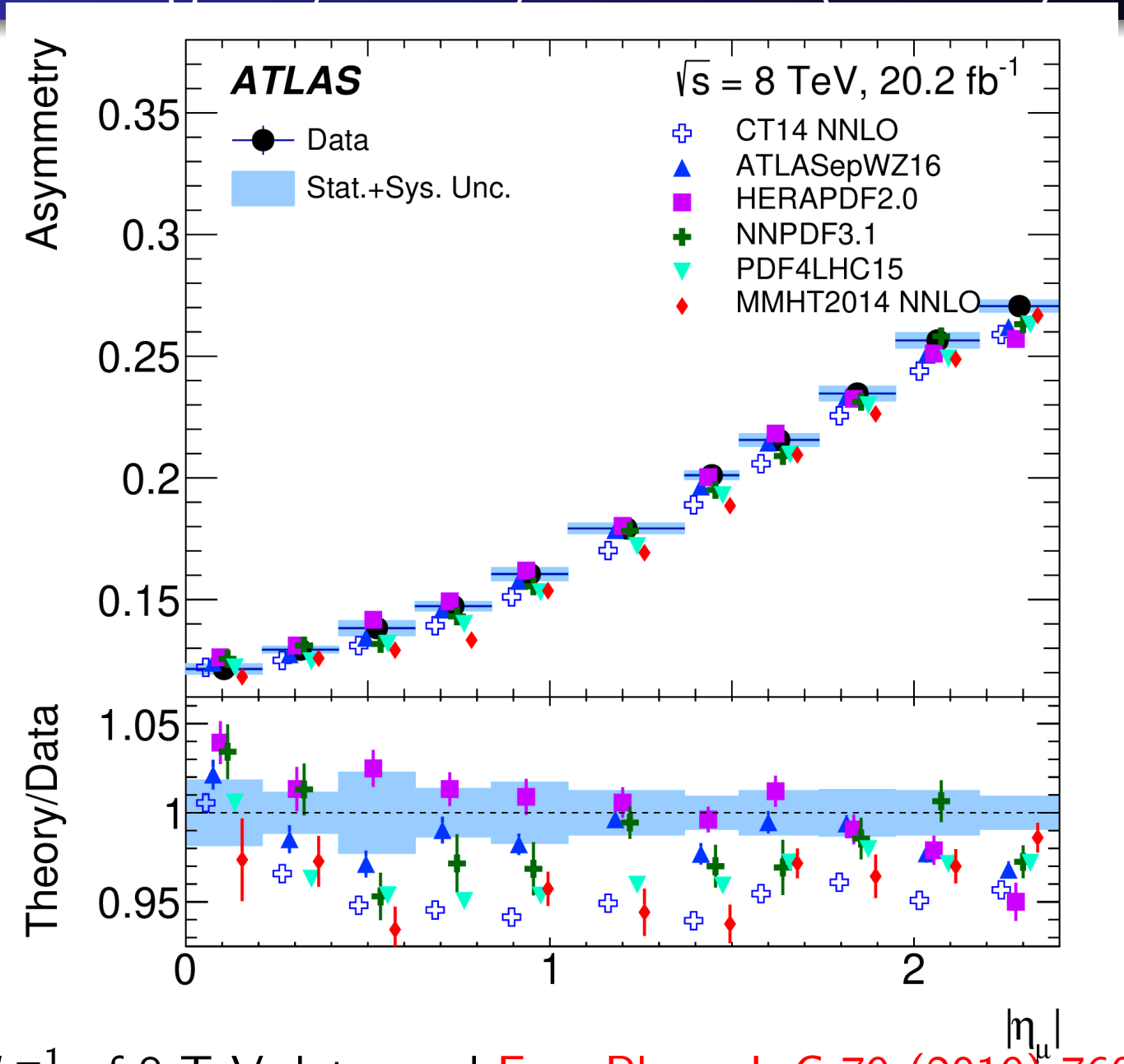




35.9 fb^{-1} used, η, p_T and unrolled distributions for $W^+ \to \mu^+\nu$

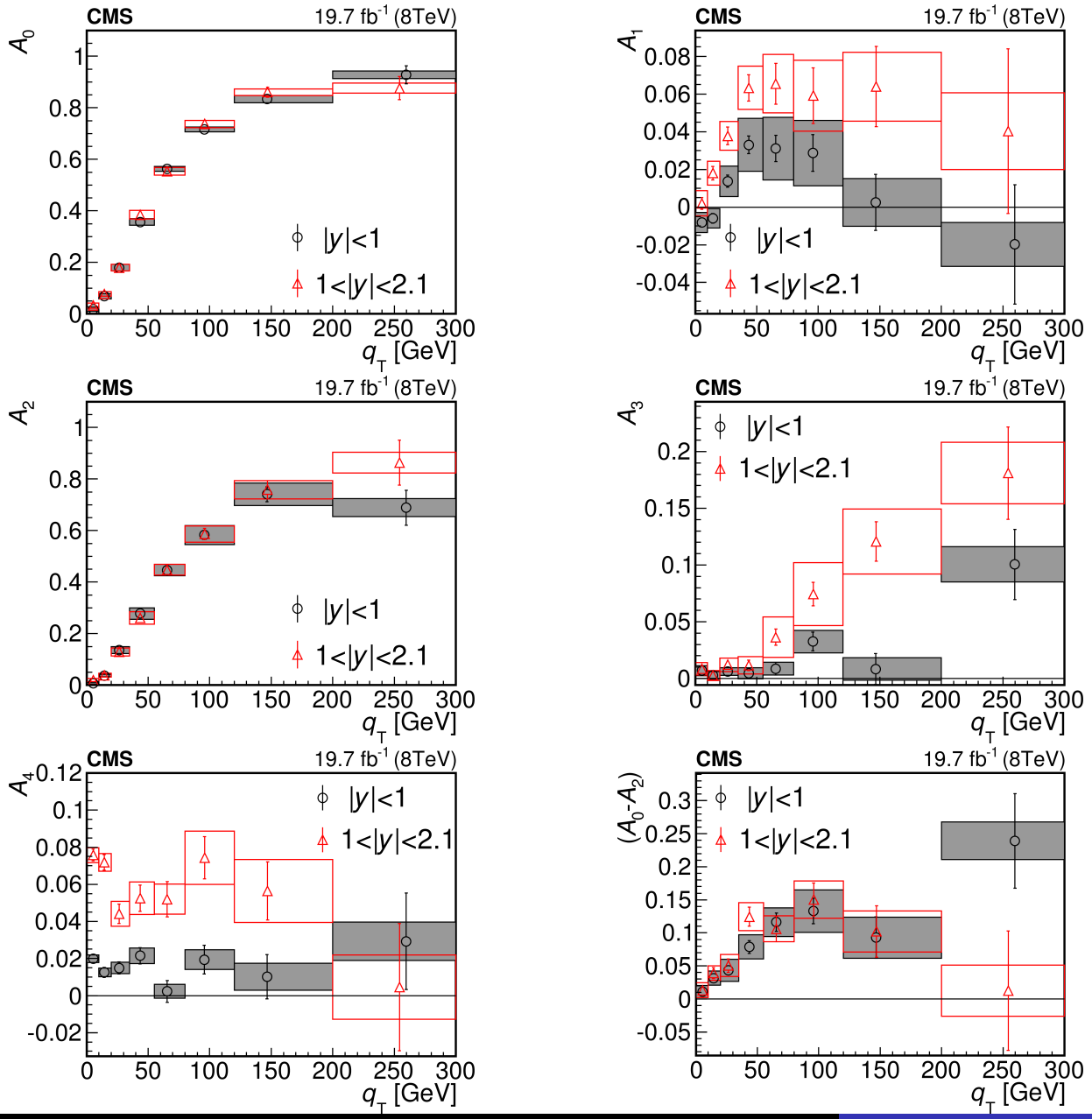
First W helicity measurement at CMS, PRD 102 (2020) 092012

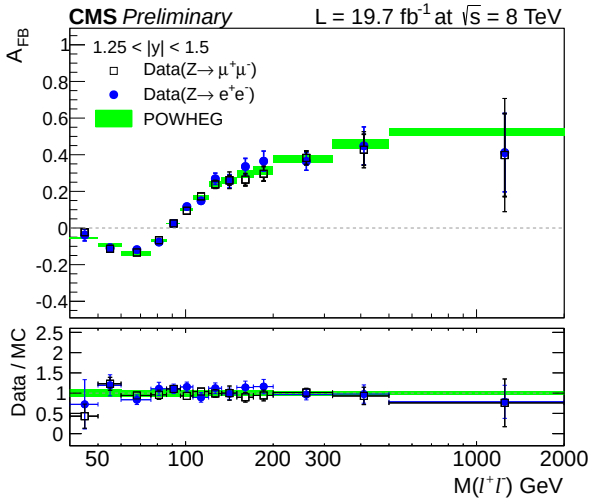
W boson charge asymmetry at 8 TeV (ATLAS)



20.2 fb^{-1} of 8 TeV data used Eur. Phys. J. C 79 (2019) 760

Angular coefficients at 8 TeV (CMS)

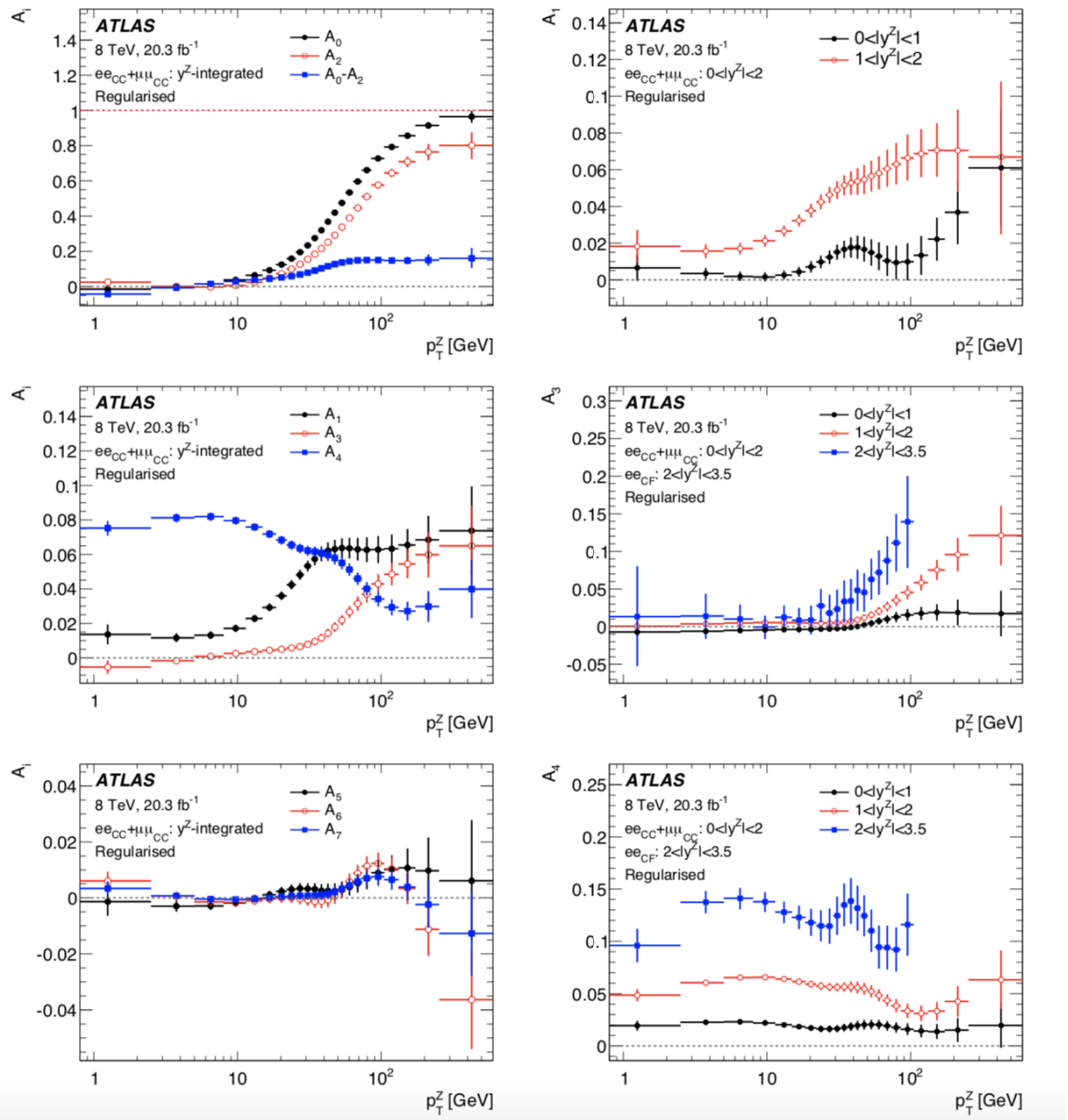




- $\frac{d^2\sigma}{dcos\theta^\star d\phi^\star} \propto (1+cos^2\theta^\star) + A_0\frac{1}{2}(1-3cos^2\theta^\star) + A_1 sin(2\theta^\star)cos\phi^\star + A_2\frac{1}{2}sin^2\theta^\star cos(2\phi^\star) + A_3 sin\theta^\star cos\phi^\star + A_4 cos\theta^\star + A_5 sin^2\theta^\star sin(2\phi^\star) + A_6 sin(2\theta^\star)sin\phi^\star + A_7 sin\theta^\star sin\phi^\star$
- Lam-Tung relation violated
- Strong $|y|$ and q_T dependence

Eur. Phys. J. C (2016) 76: 325

Angular coefficients at 8 TeV (ATLAS)



- Lam-Tung relation violated
- 7 coefficients measured in 3 rapidity bins
- Many theoretical models tested
- Both electrons and muons

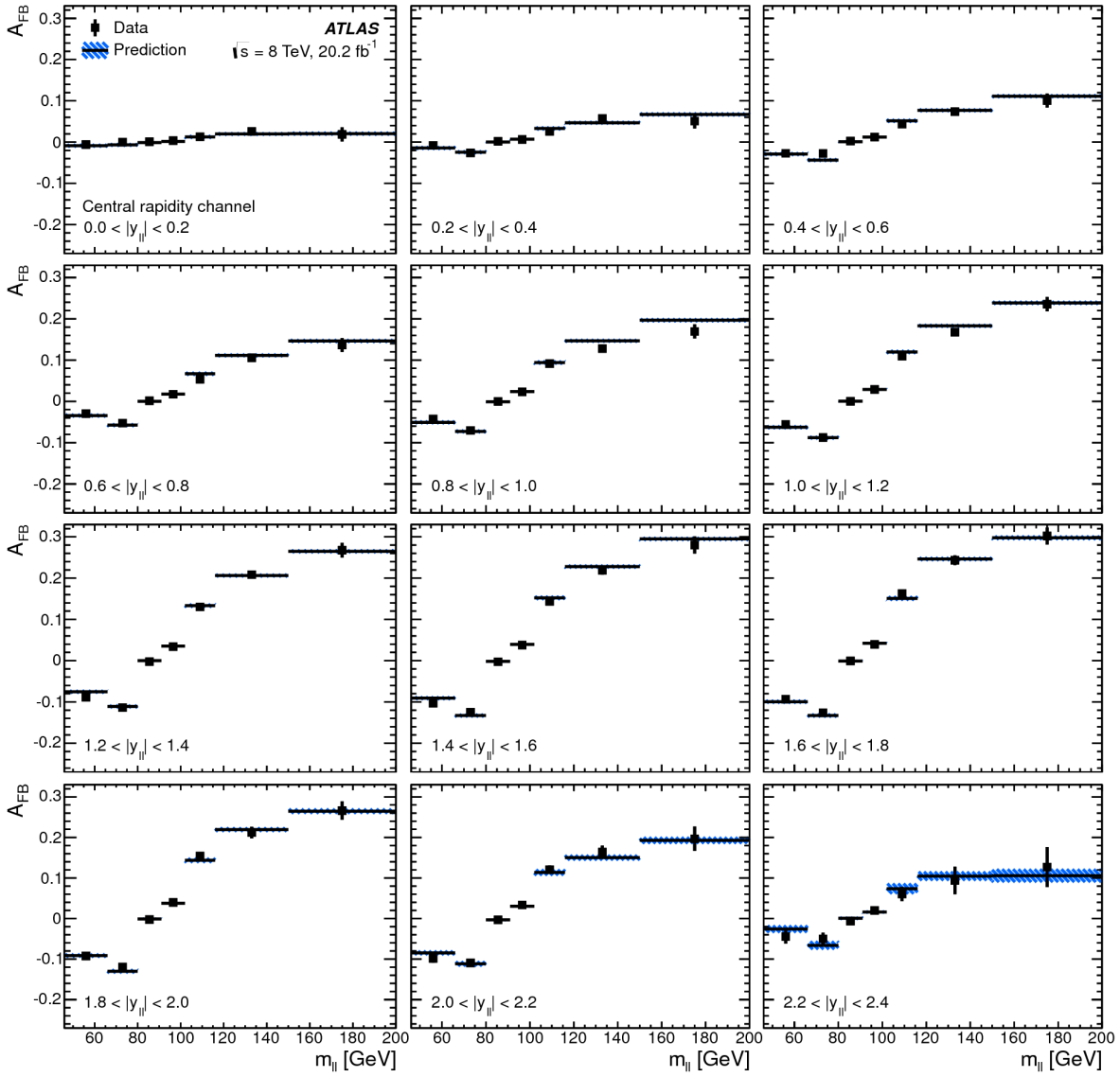
JHEP08(2016)159

Weak mixing angle using A4 at 8 TeV (ATLAS)

Channel	ee_{CC}	$\mu\mu_{CC}$	ee_{CF}	$ee_{CC} + \mu\mu_{CC}$	$ee_{CC} + \mu\mu_{CC} + ee_{CF}$
Central value	0.23148	0.23123	0.23166	0.23119	0.23140
	Uncertainties				
Total	68	59	43	49	36
Stat.	48	40	29	31	21
Syst.	48	44	32	38	29
	Uncertainties in measurements				
PDF (meas.)	8	9	7	6	4
p_{T}^{Z} modelling	0	0	7	0	5
Lepton scale	4	4	4	4	3
Lepton resolution	6	1	2	2	1
Lepton efficiency	11	3	3	2	4
Electron charge misidentification	2	0	1	1	< 1
Muon sagitta bias	0	5	0	1	2
Background	1	2	1	1	2
MC. stat.	25	22	18	16	12
	Uncertainties in predictions				
PDF (predictions)	37	35	22	33	24
QCD scales	6	8	9	5	6
EW corrections	3	3	3	3	3

ATLAS-CONF-2018-037

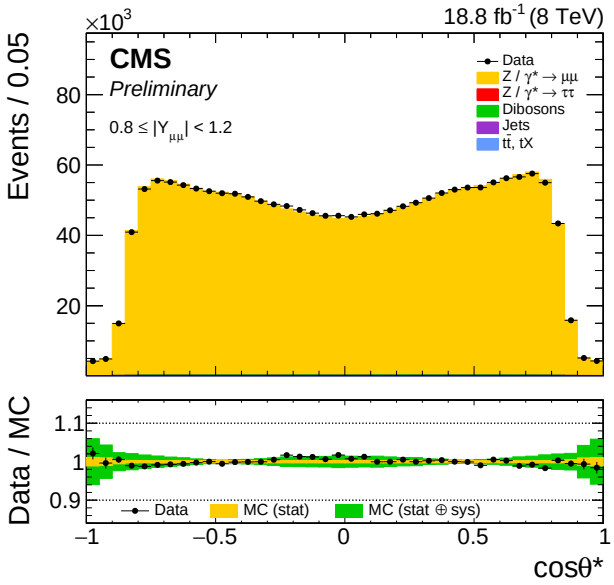
A_{FB} measurement at 8 TeV (ATLAS)

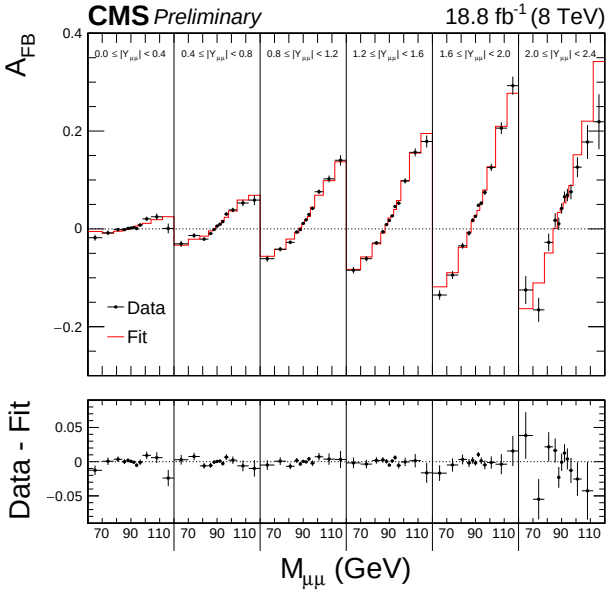


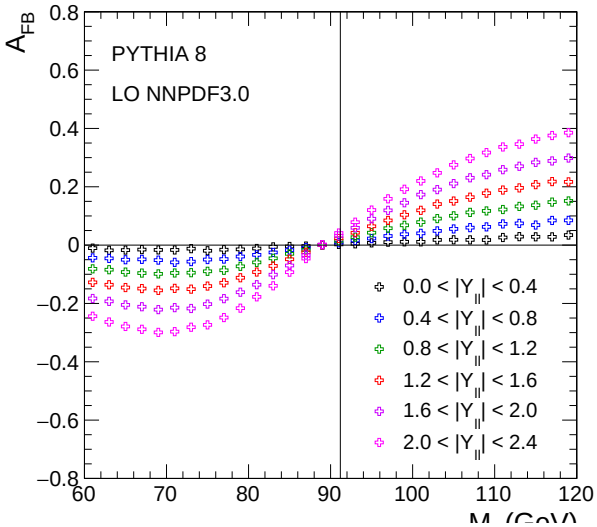
- Both electrons and muons
- A_{FB} measurement with fine rapidity bins
- The results for sin2thatW obtained using AFB in agreement with those obtained using A4

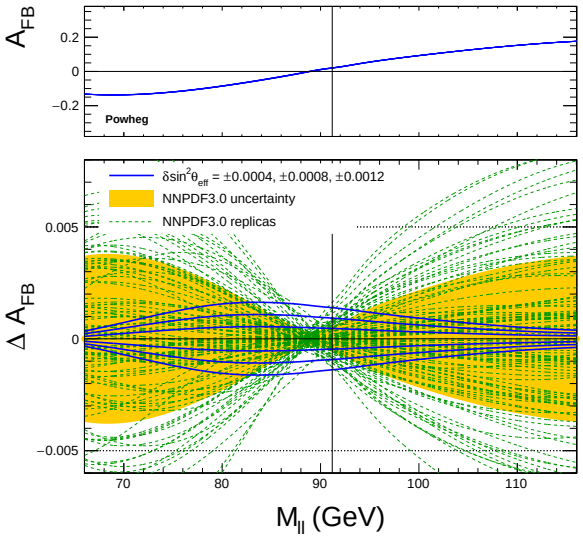
J. High Energ. Phys. 2017, 59

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





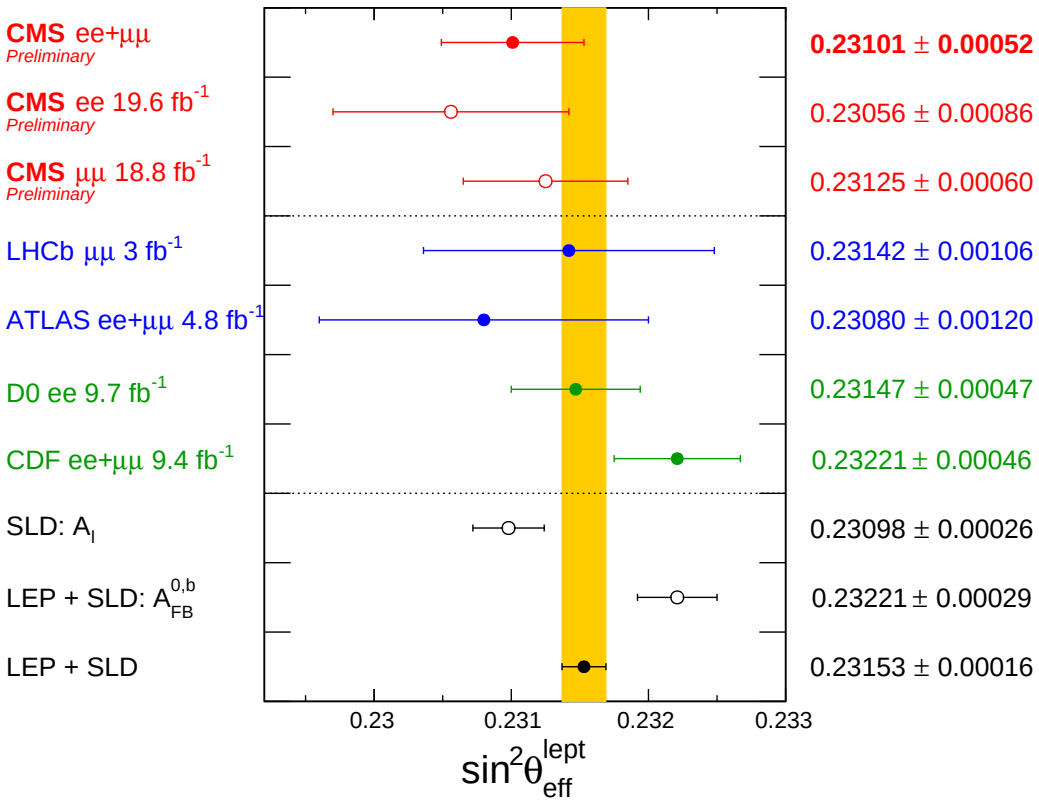




- $\sim 19\ fb^{-1}$ of 8 TeV data used
- The statistical and systematic uncertainties are significantly reduced
- Fit of experimental A_{FB} with theory
- CMS-PAS-SMP-16-007, Eur. Phys. J. C 78 (2018) 701

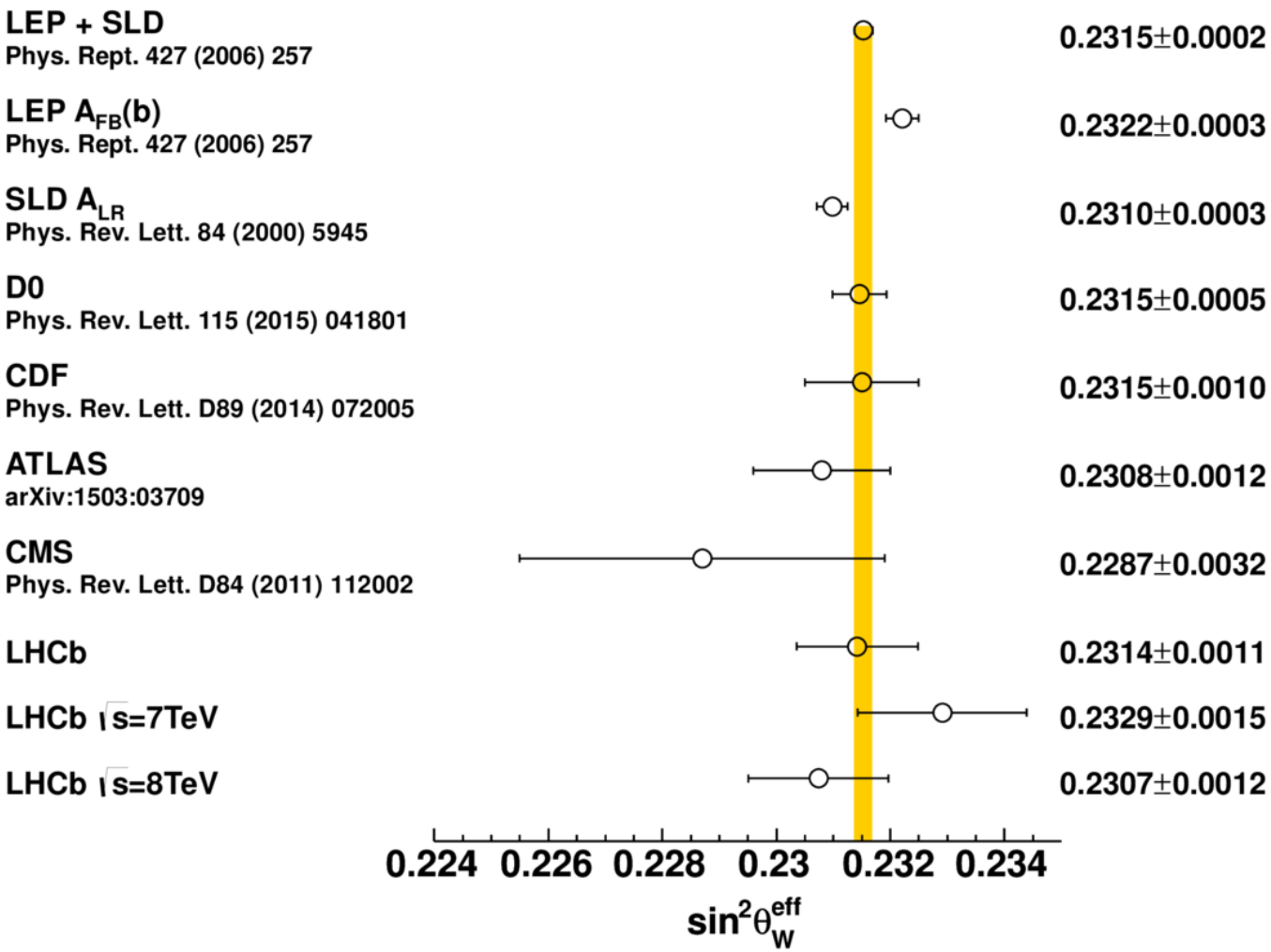
Weak mixing angle using A_{FB} at 8 TeV (CMS, II)

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

Weak mixing angle using A_{FB} at 8 and 7 TeV (LHCb)



- $sin^2\theta_W^{eff} = 0.23142 \pm 0.00073 \pm 0.00052 \pm 0.00056$
- Forward region (low dilution) $2.0 < \eta < 4.5$
- JHEP11(2015)190

Conclusion

- High precision measurements
- Some channels are analyzed at 13 TeV
- SM predictions tested
- PDFs constrained
- W xsection and helicity measurements
- W brenching fractions supporting lepton universality
- High precision weak mixing angle measurements
- Multidifferential Drell-Yan production cross section measurements
- More info at Results on vector boson (+jet) production and W mass and angular coefficients measurements ATLAS-CMS-LHCb

Zoom Link for Followup discussion:
https://cern.zoom.us/j/4137426540?pwd=MU1IVTNiVWtOaW5pRW52Z