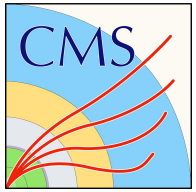

Inclusive production of vector bosons in CMS

Itana Bubanja
On behalf of CMS Collaboration

University of Montenegro and Universite libre de Bruxelles

21st Lomonosov Conference on Elementary Particle Physics

Moscow, August 2023

Introduction

- High rates of W, Z production at the LHC

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- The most recent CMS results

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- “Clean” and well understood final state

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- High rates of W, Z production at the LHC
- The most recent CMS results
- “Clean” and well understood final state
- Highly important analyses:
  - Partonic structure of protons
  - improving and developing theory predictions
  - Probe for pQCD as well as npQCD in different regions
  - EWK parameters, putting limits, coupling constant calculations…

Differential Z boson production cross-section

JHEP 12(2019)061

- Data: 2016
- Luminosity: 35.9 fb^{-1}
- Inclusive fiducial and differential production cross sections as a function of pT (also φ^*, and |y|)

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- Two opposite charged isolated leptons
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- Lepton pT > 25 GeV
- Lepton |η| < 2.4

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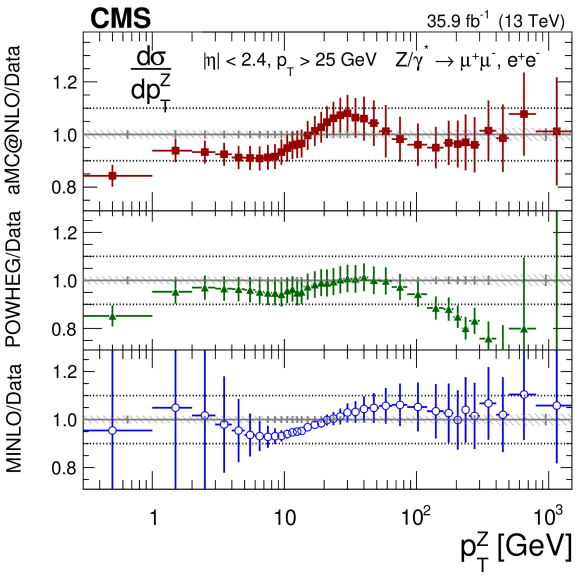
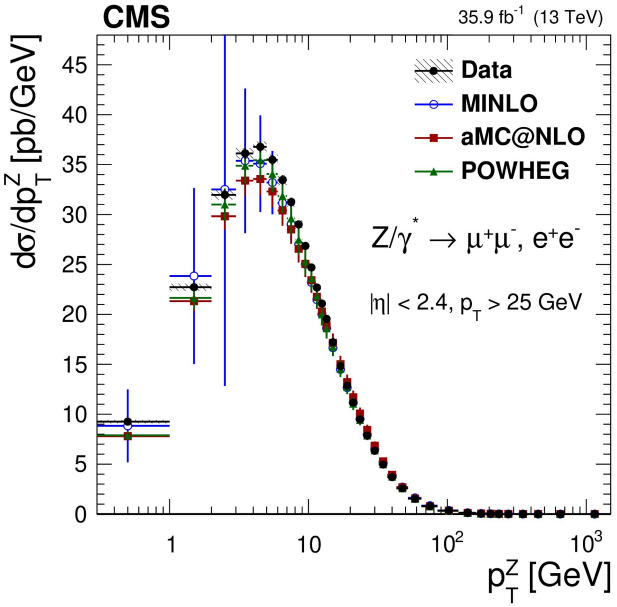
Theoretical predictions:

- MadGraph
- POWHEG & POWHEG-MINLO
- FEWZ
- Parton branching TMD
- GENEVA
- RESBOS

Differential Z boson production cross-section

JHEP 12(2019)061

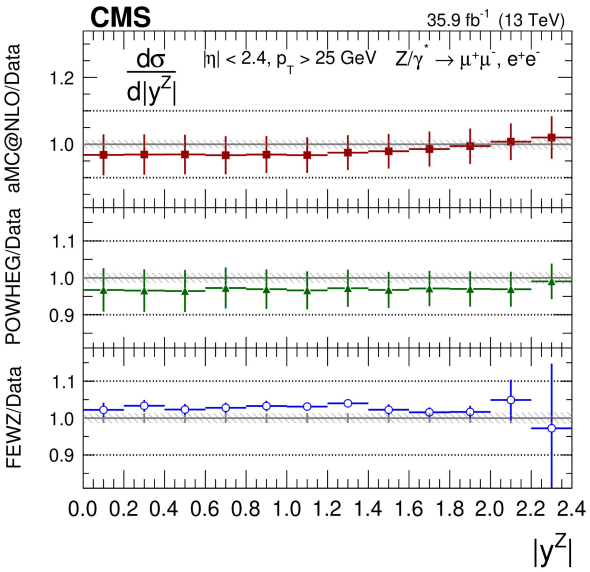


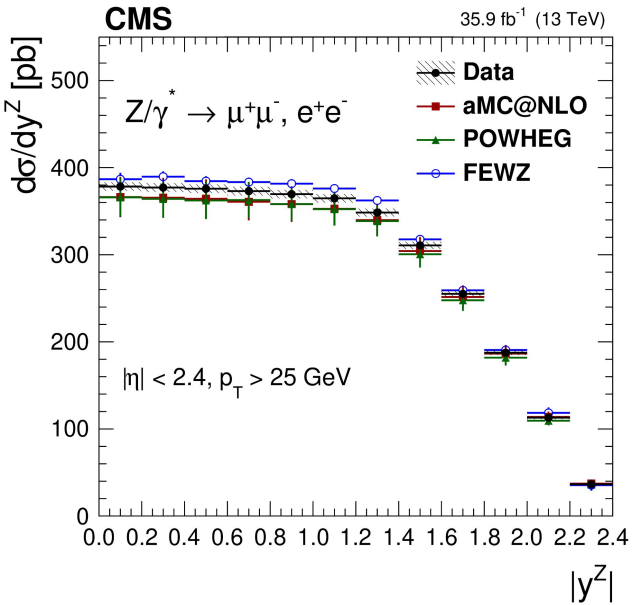


- The predictions are consistent with the measurements within the theoretical uncertainties.
- The POWHEG prediction at high pT, above 100 GeV, disagree with data.

Differential Z boson production cross-section

JHEP 12(2019)061

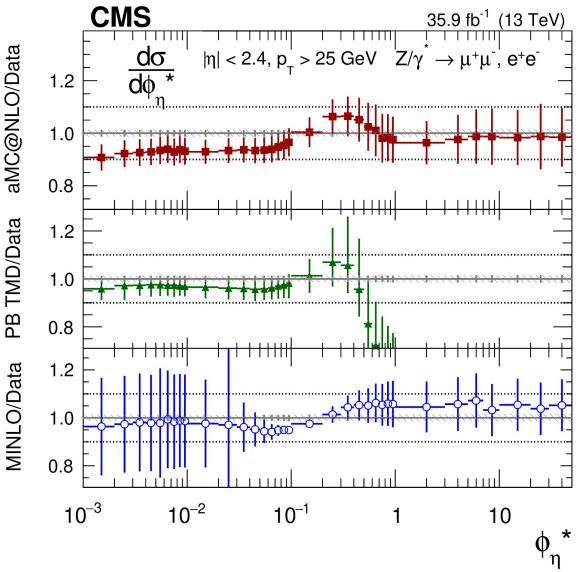


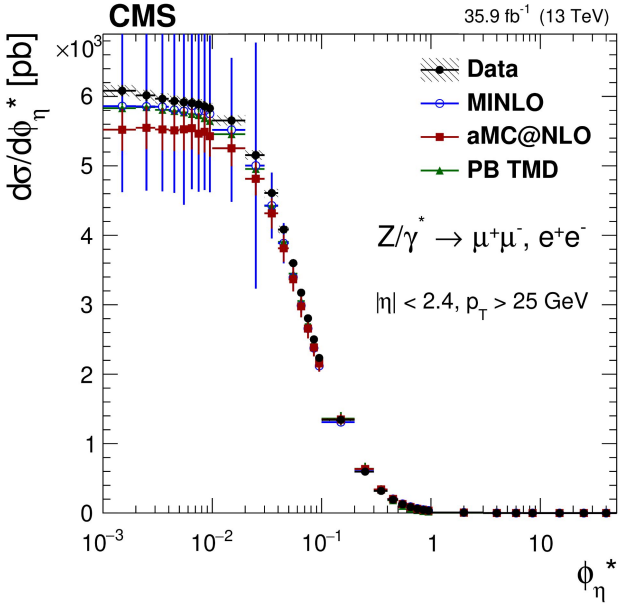


- The MadGraph5 aMC@NLO and POWHEG - consistent with the data within the theoretical uncertainties.
- The FEWZ prediction with the NNPDF 3.1 PDF set - within 5% of the measurement over the entire $|y_Z|$ range

Differential Z boson production cross-section

JHEP 12(2019)061





- The predictions are consistent with the measurements within the theoretical uncertainties and describe data well at low pT.
- PB TMD predictions deviate from data at high pT.

Differential Z boson production cross-section

JHEP 12(2019)061

- The measured cross section values agree with the theoretical predictions within uncertainties.
- The predicted values are :
  - **$\sigma_{Z\to ll}$ = 682 ± 55 pb with MadGraph5 aMC@NLO**
  - **$\sigma_{Z\to ll}$ = 719 ± 8 pb with fixed order FEWZ**

Cross section	$\sigma\,\mathcal{B}$ [pb]						
$\sigma_{Z\to\mu\mu}$	694	±	6	(syst)	±	17	(lumi)
$\sigma_{Z\to ee}$	712	±	10	(syst)	±	18	(lumi)
$\sigma_{Z\to\ell\ell}$	699	±	5	(syst)	±	17	(lumi)

Measurement of the mass dependence of the pT of lepton pairs in Drell-Yan production in pp collisions at $\sqrt{s}$ = 13 TeV

Eur. Phys. J. C 83 (2023) 628

- Data: 2016
- Luminosity: 36.3 fb^{-1}
- pT of the pair (also φ^{*})
- Five mass bins: 50-1000 GeV
- Di-electron and di-muon channels combined

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Theoretical predictions:

- Madgraph5_aMC@NLO
- MiNNLO
- Cascade
- Artemide
- Geneva

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Predictions

	ME	Resum	MC	comments
MadGraph5_aMC@NLO	$Z + 0, 1, 2j$ NLO	PS	MC	Baseline for LHC experiments
MiNNLO	NNLO	PS	MC	
arTeMiDe	LO	TMD $\simeq N^3LL$	Analytic	no QED FSR Valid for $p_T < 0.2 m_{\ell\ell}$
CASCADE	$Z + 0j$ or $Z + 1j$ at NLO	PB-TMD	MC	no MPI
Geneva	NNLO	$N^3LL'_{q_T}$	MC	

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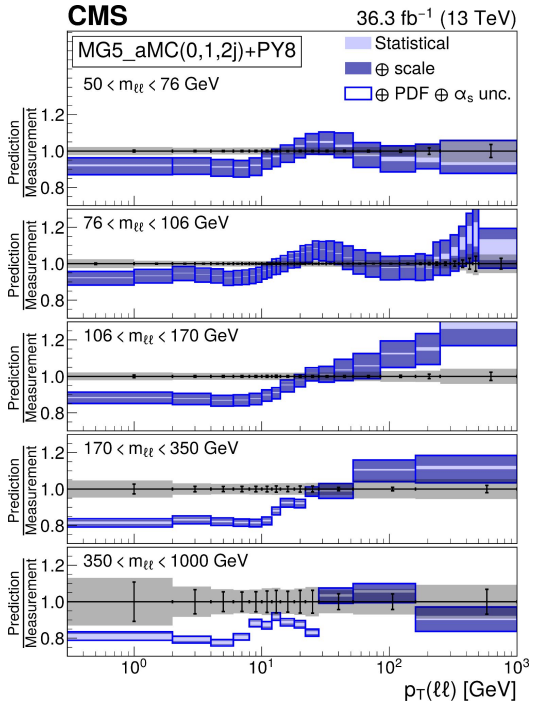

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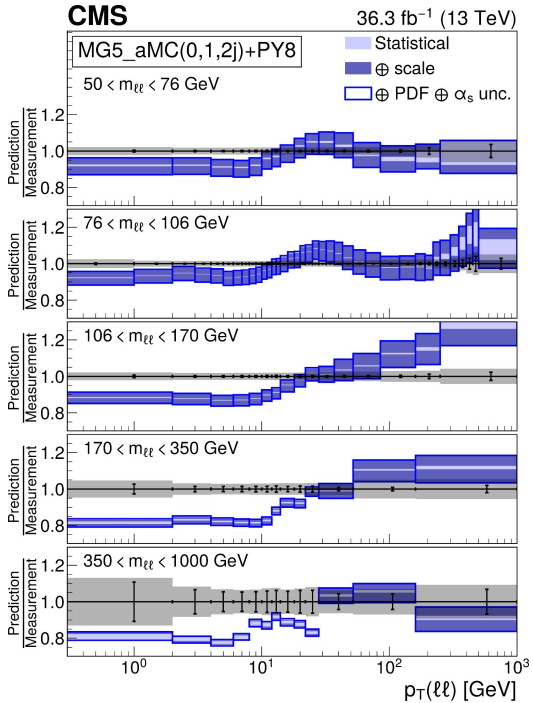

- Standard CMS prediction for Run 2 data
- Good overall agreement - 20 % of disagreement only in highest mass ranges

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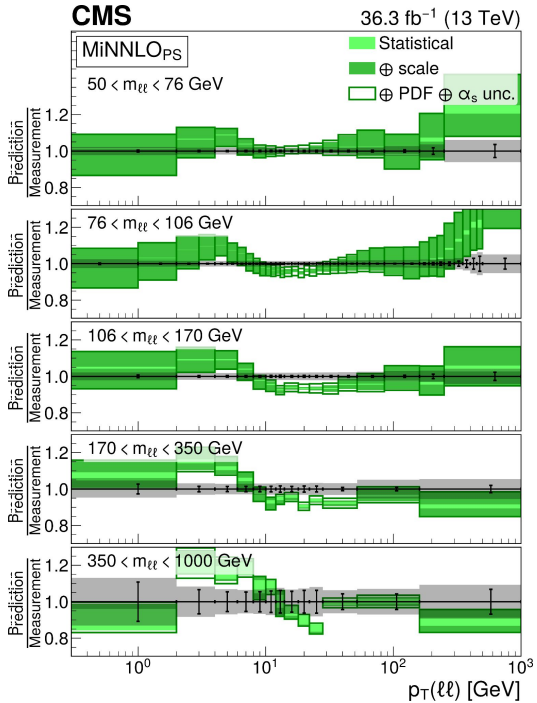

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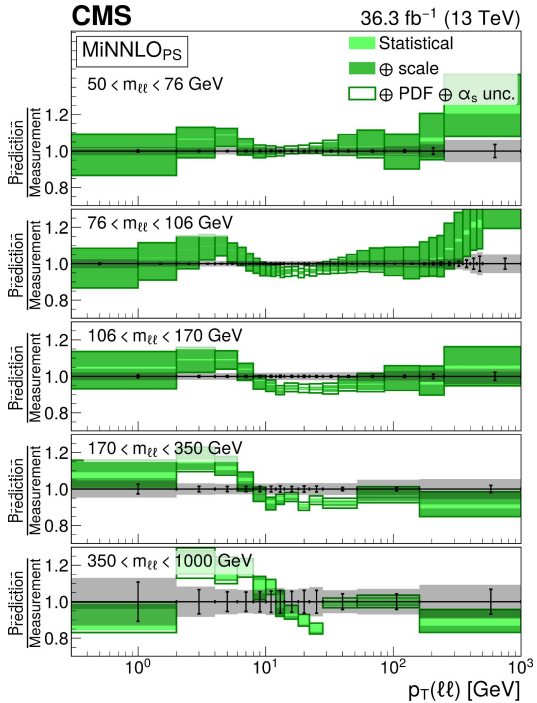

- Good description of high pT
- The best agreement among all the considered predictions

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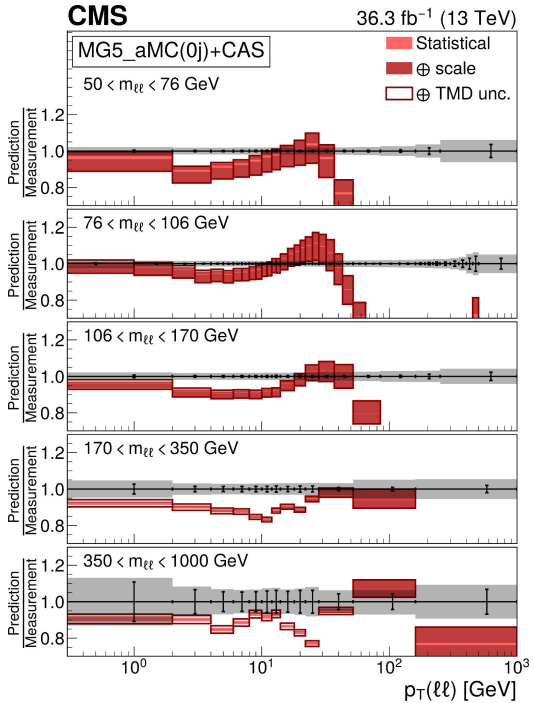

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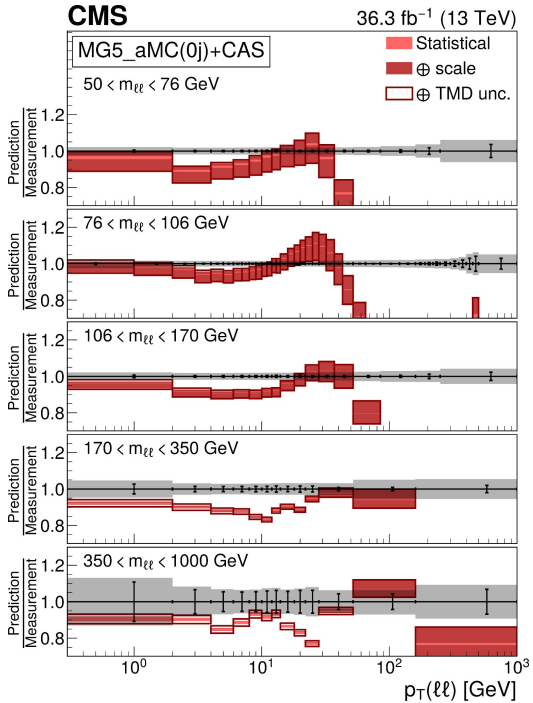

- Good description of moderate pT region
- high pT region miss higher fixed-order calculations.

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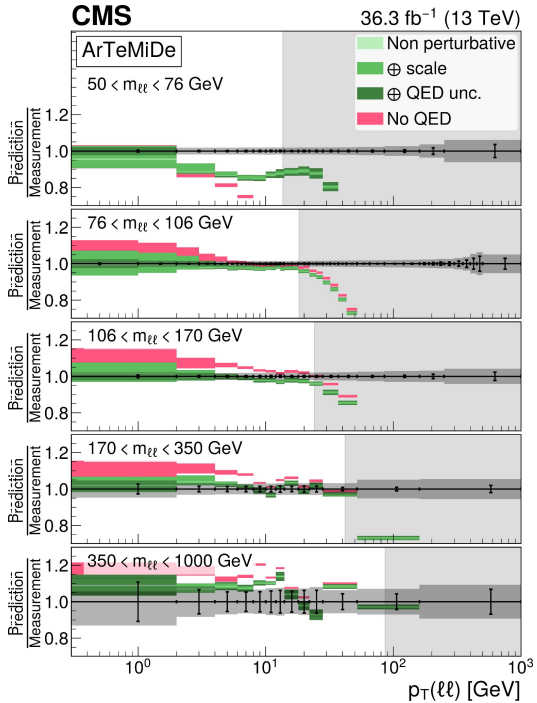

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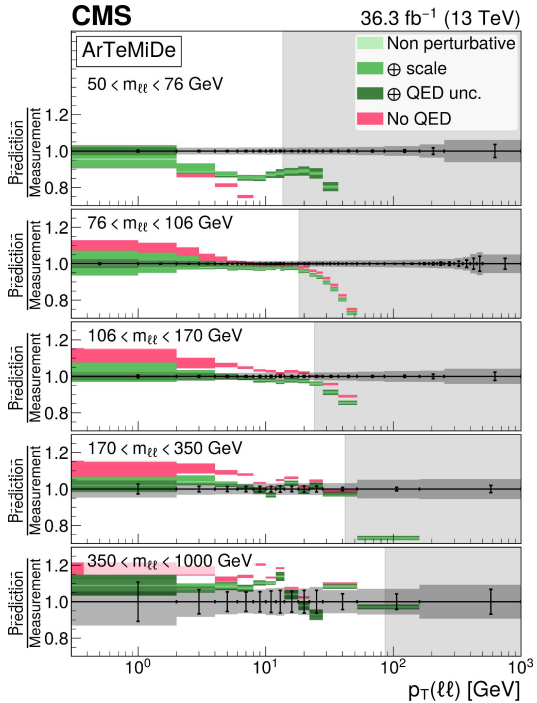

- Low-pT region in a very good agreement with data for all mass bins
- Prediction with and without QED FSR corrections

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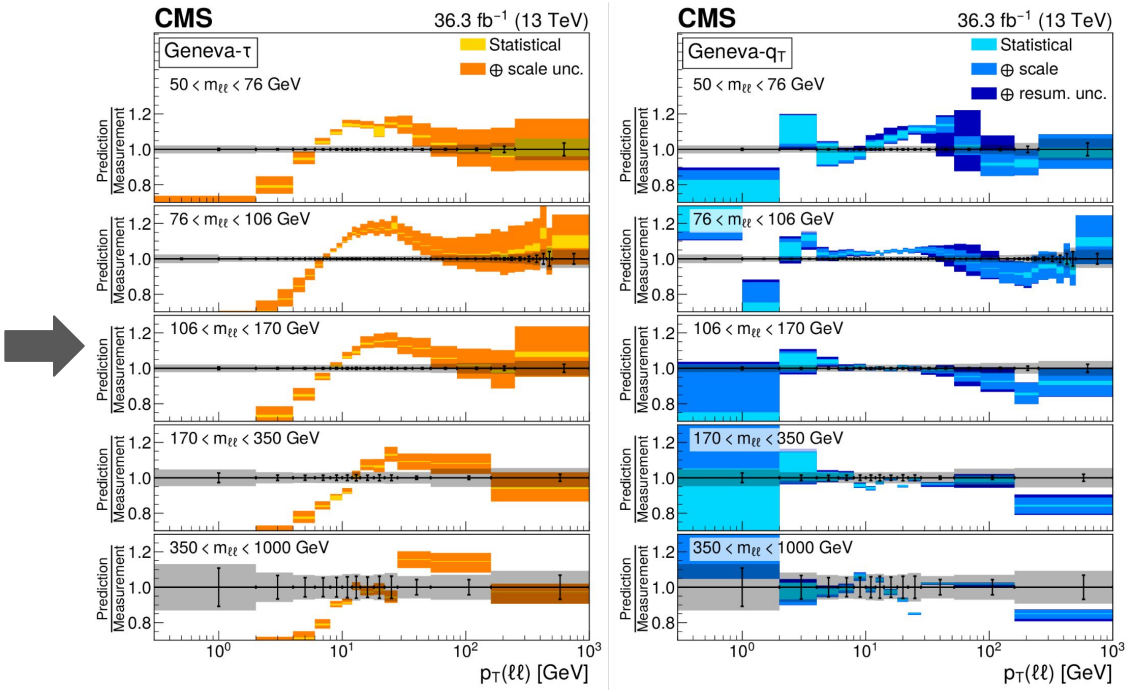

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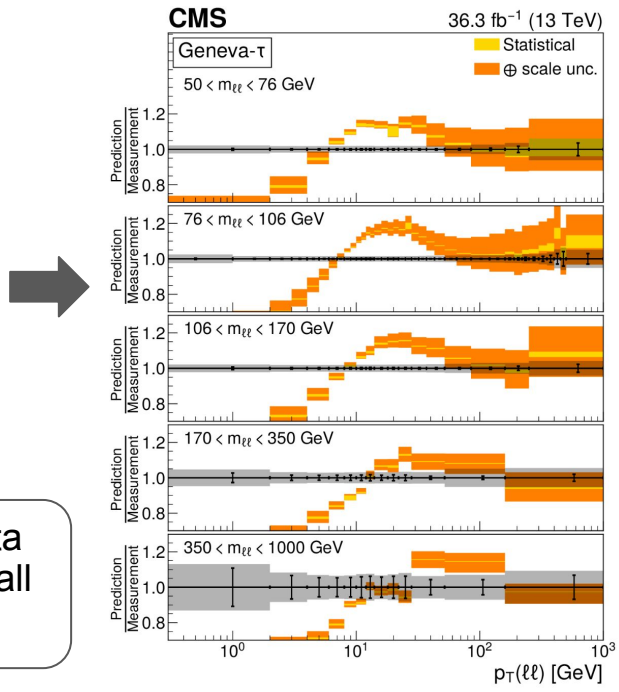

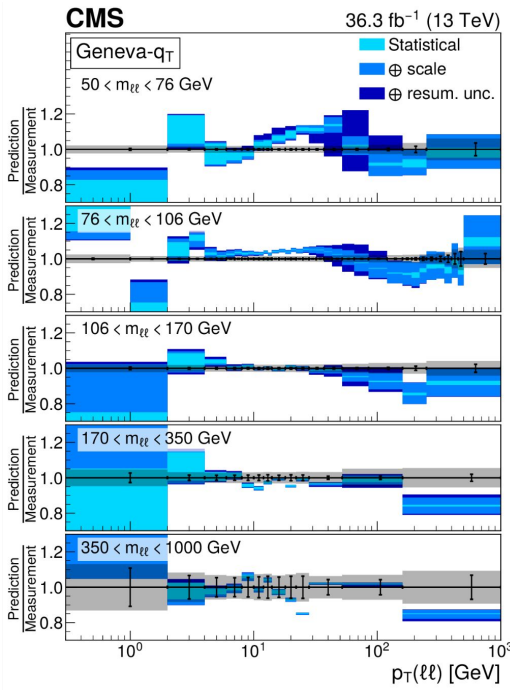

- Significant improvement in data description for Geneva qT for all the distributions

Measurement of the mass dependence of the pT of lepton pairs in Drell-Yan production in pp collisions at √s = 13 TeV

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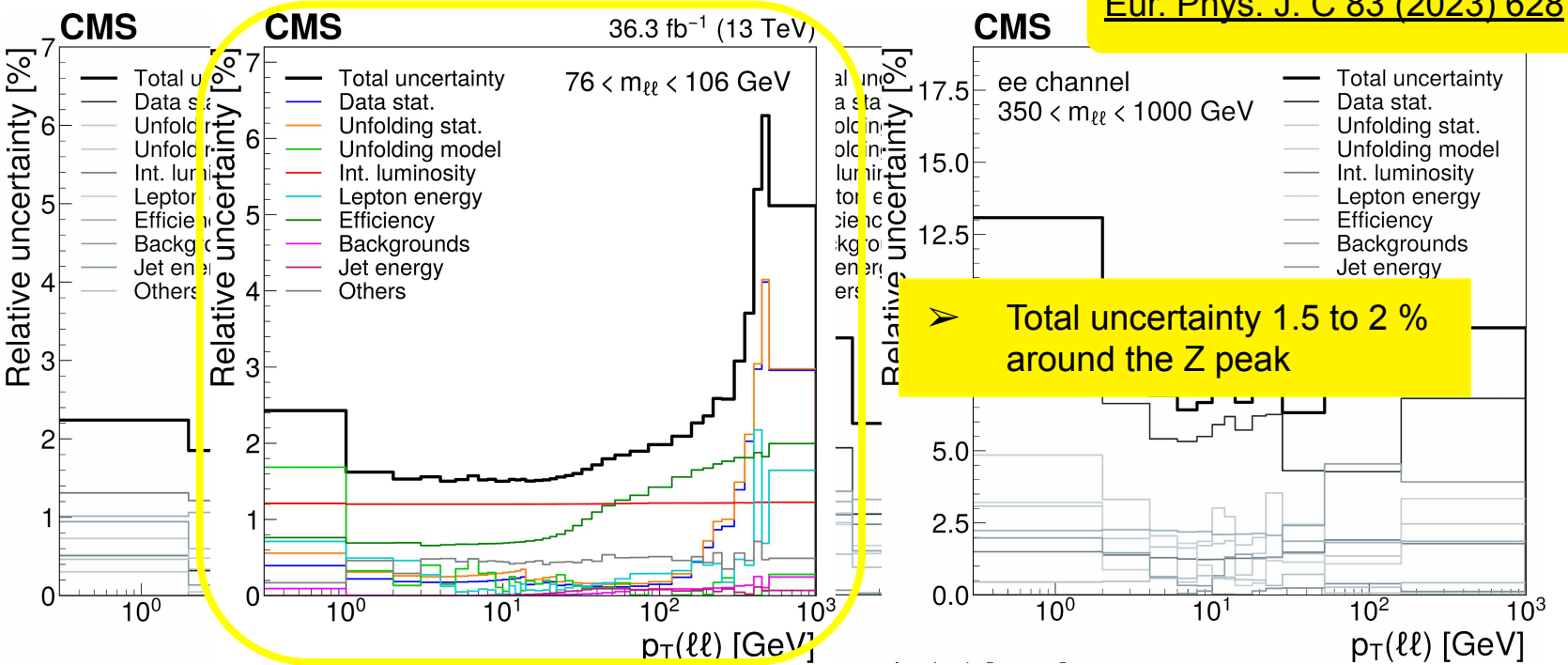

- Total uncertainty 1.5 to 2 % around the Z peak

Drell-Yan forward-backward asymmetry at high dilepton masses

JHEP 08 (2022) 063

- Data: 2016, 2017, 2018
- Luminosity: 138 fb^{-1}
- Asymmetry(A_{FB}) and the angular coefficient (A_0) as a function of lepton pair mass
- Masses larger than 170 GeV in 7 mass ranges
- Di-electron and di-muon channels combined

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- Leading electron **pT(2016/2017/2018) > 29/38/35 GeV** and subleading **pT > 15 GeV**
- Muons: **|η| < 2.4**, electrons: **|η| < 2.5**

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- The difference between the dimuon and dielectron asymmetries - a test of lepton flavor universality
- To set limits on the presence of additional gauge bosons

Drell-Yan forward-backward asymmetry at high dilepton masses

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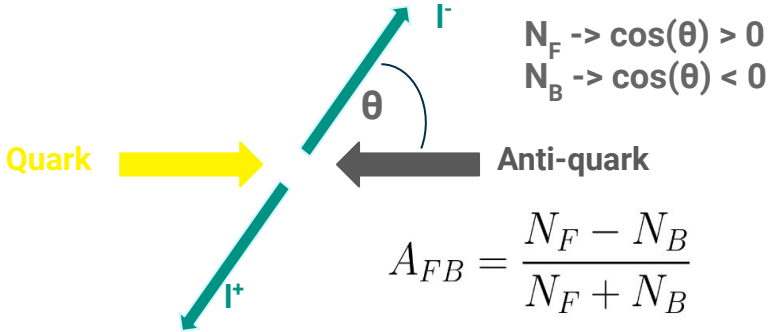


N_F -> cos(θ) > 0
N_B -> cos(θ) < 0

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

- Measure the **angle** between **final state lepton** and **initial quark**

$$\frac{d\sigma}{d\cos\theta} \propto \frac{3}{8}\left[1 + \cos^2\theta + \frac{A_0}{2}\left(1 - 3\cos^2\theta\right) + A_4\cos\theta\right]$$

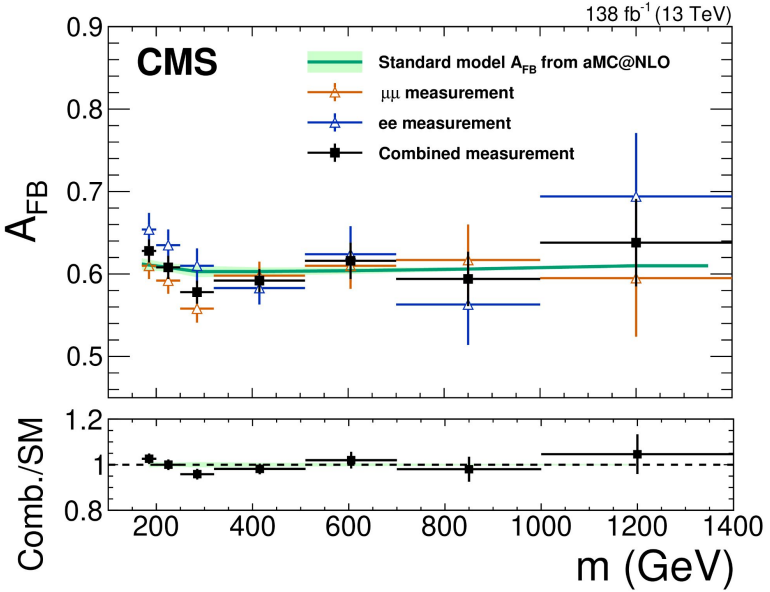
- A_0 and A_4 are the standard dimensionless constants parameterizing the angular distribution of the DY process
- The angular coefficients A_0 and A_4 vary as functions of the mass (m), transverse momentum (pT), and rapidity (y) of the dilepton system

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B},$$

Drell-Yan forward-backward asymmetry at high dilepton masses

JHEP 08 (2022) 063

- The results for the template fits to data to extract A_{FB} in different mass bins
- Test of lepton flavor universality - the difference between the dimuon and dielectron A_{FB} - **agreement with zero to within 2.4 standard deviations**
- Measured asymmetry **0.612 ± 0.005 (stat) ± 0.007 (syst)**



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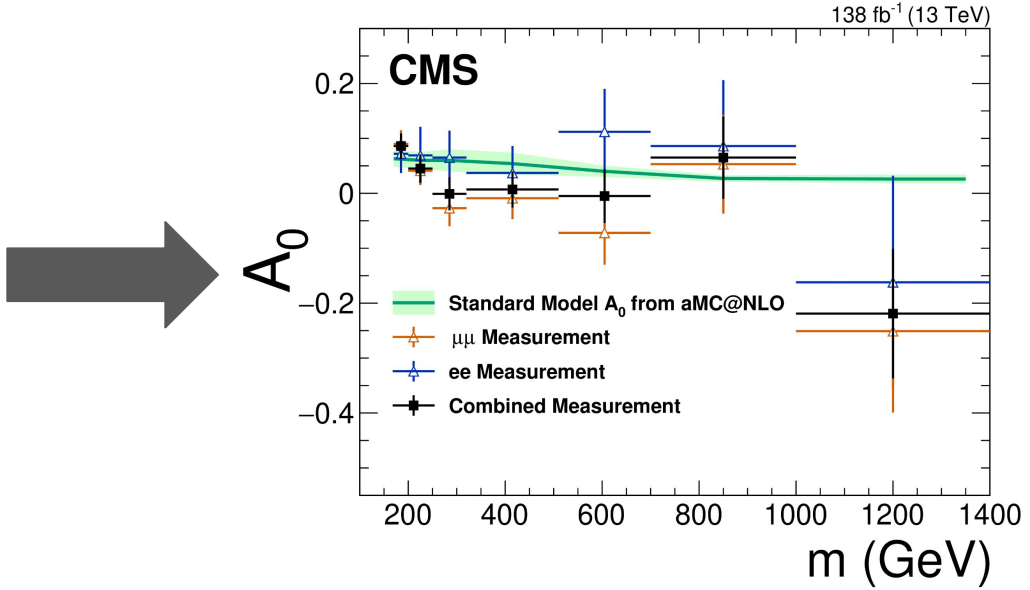
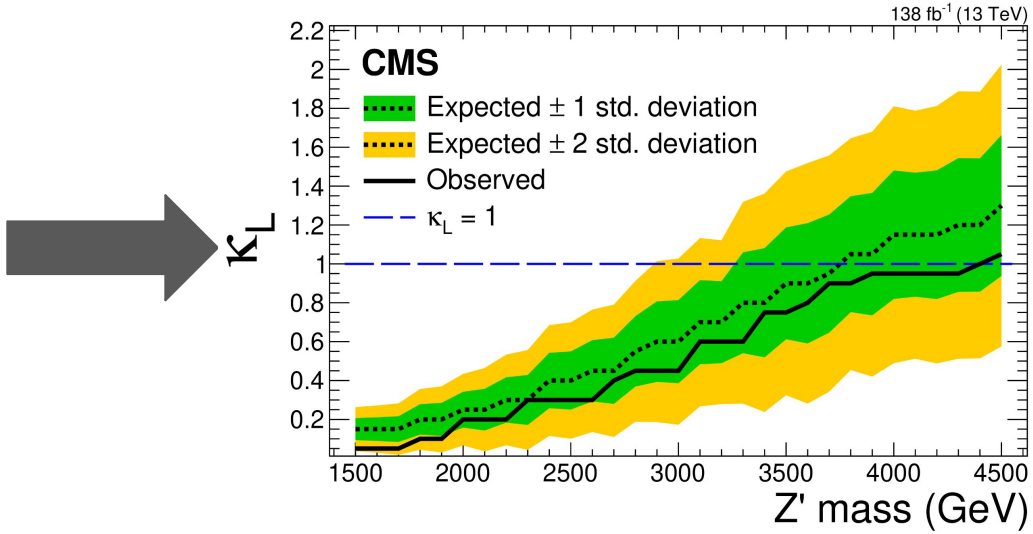
- Measured angular coefficient is **0.047 ± 0.005 (stat) ± 0.013 (syst)**
- Measurements of A_0 probe **higher-order corrections in perturbative QCD.**



Drell-Yan forward-backward asymmetry at high dilepton masses

JHEP 08 (2022) 063

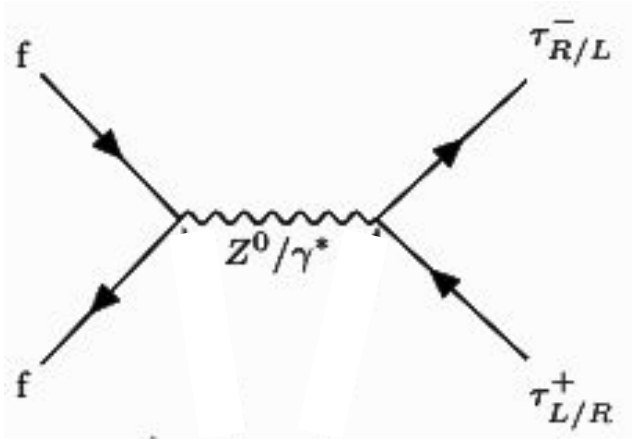
- Combined A_{FB} measurements - limits on the existence of additional gauge bosons.
- For a Z′ boson, in the canonical sequential standard model, the observed (expected) 95% confidence level lower limit on the **Z′ mass is 4.4 TeV (3.7 TeV).**

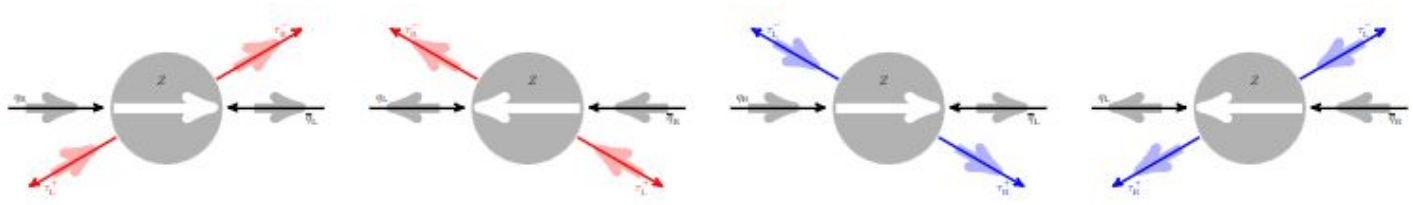


Measurement of the τ lepton polarisation in the Z boson decays

CMS-SMP-PAS-18-010

- Data: 2016
- Luminosity: 36.3 fb^{-1}
- Leptonic and hadronic τ lepton decays in Z→ττ events
- All possible tau decays are covered





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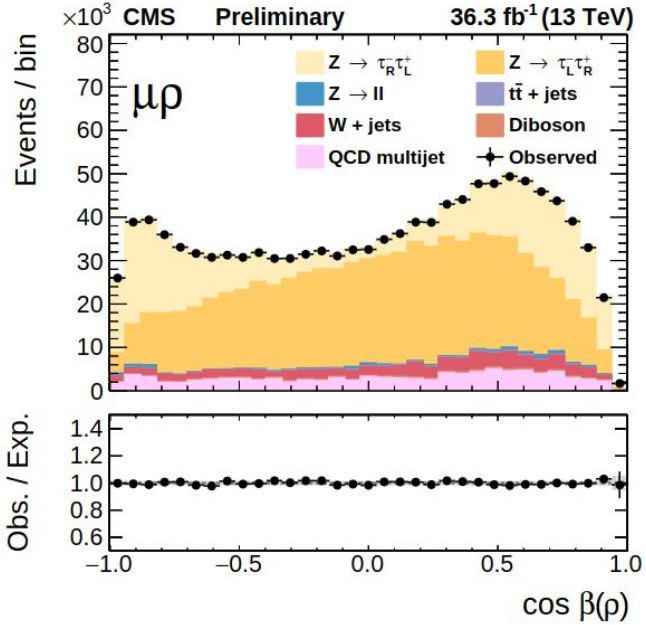
Final state	Trigger	Lepton selection	Additional selection	
$\tau_h\tau_h$	τ_h (35 GeV)τ_h (35 GeV)	$p_T^{\tau_h} > 45(40)$ GeV, $\lvert\eta^{\tau_h}\rvert < 2.1$	Med DeepTau iso	
$\tau_\mu\tau_h$	μ(22 GeV) or μ(19 GeV)τ_h (20 GeV)	$p_T^{\mu} > 23$ GeV, $\lvert\eta^{\mu}\rvert < 2.1$ $p_T^{\mu} > 20$ GeV, $p_T^{\tau_h} > 30$ GeV, $\lvert\eta^{\tau_h}\rvert < 2.3$	$I_{rel}(\mu) < 0.15$ Med DeepTau iso	$m_T^{\mu} < 50$ GeV
$\tau_e\tau_h$	e(25 GeV)	$p_T^{e} > 30$ GeV, $\lvert\eta^{e}\rvert < 2.1$ $p_T^{\tau_h} > 30$ GeV, $\lvert\eta^{\tau_h}\rvert < 2.3$	$I_{rel}(e) < 0.15$ Med DeepTau iso	$m_T^{e} < 50$ GeV
$\tau_e\tau_\mu$	μ(8 GeV)e(23 GeV) or μ(23 GeV)e(12 GeV)	$p_T^{e} > 15$ GeV, $\lvert\eta^{e}\rvert < 2.4$ $p_T^{\mu} > 15$ GeV, $\lvert\eta^{\mu}\rvert < 2.4$ $p_T^{\ell} > 24$ GeV for lead trigger leg	$I_{rel}(e) < 0.15$ $I_{rel}(\mu) < 0.20$	

Measurement of the τ lepton polarisation in the Z boson decays

CMS-SMP-PAS-18-010

- Measure **average polarisation of τ leptons** in Z/γ events
- Z boson couplings are **different for left and right-handed fermions**
- **The spin of τ lepton and spin correlations of τ lepton pairs** can be determined and be used to explore new physics
- Convert polarisation into **effective weak mixing angle $\sin^2\theta_W$**
- **The best sensitivity on Pτ -> μ + ρ** category - a good selection efficiency and a good reconstruction of the optimal observable ω_{vis}
- **The least sensitivity - the fully hadronic decay channel** - high trigger thresholds therefore poor selection efficiency.

$$\langle \mathcal{P}_\tau \rangle = \frac{N(pp \to Z/\gamma \to \tau_R^- \tau_L^+) - N(pp \to Z/\gamma \to \tau_L^- \tau_R^+)}{N(pp \to Z/\gamma \to \tau_R^- \tau_L^+) + N(pp \to Z/\gamma \to \tau_L^- \tau_R^+)}$$



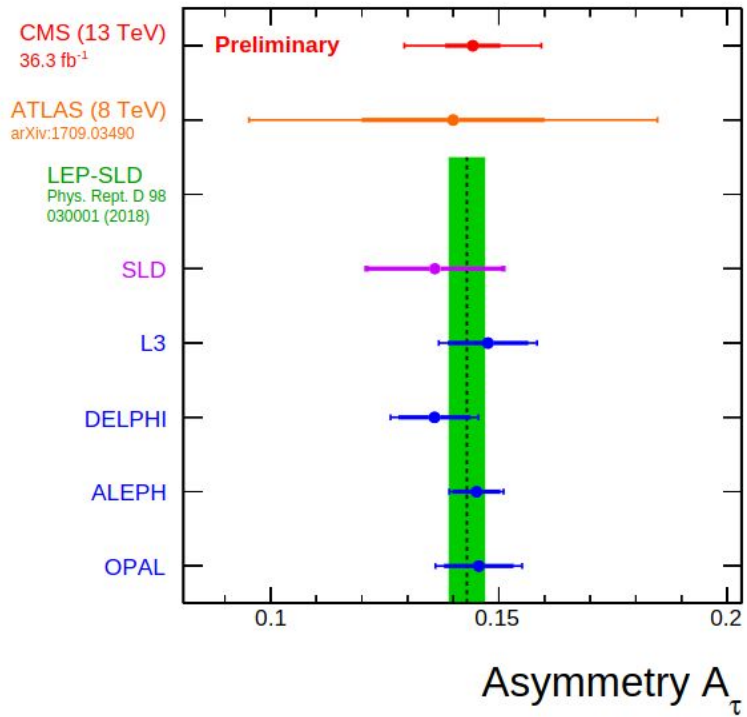
Measurement of the τ lepton polarisation in the Z boson decays

CMS-SMP-PAS-18-010

- The measured value for the τ polarization:
  - **P_τ (Z) = −0.144 ± 0.006 (stat) ± 0.014 (syst) = −0.144 ± 0.015**

In agreement with measurements by the **SLD experiment**, at LEP, and by the **ATLAS experiment** and with **the standard model value** of the lepton asymmetry parameter **A_l= 0.1468 ± 0.0003**

- **More precise than the ATLAS** measurement and **nearly as precise as single LEP** experiments
- The effective weak mixing angle:
  - **$\sin^2 \theta_W^{eff}$= 0.2319 ± 0.0019**



Precision measurement of W boson decay branching fraction

Phys. Rev. D 105, 072008

- Data: 2016
- Luminosity: 35.9 fb^{-1}
- The leptonic and inclusive hadronic decay branching fractions

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- ee and μμ events are rejected if invariant mass is between 75 and 105 GeV
- Electron (muon) **pT > 30 (25) GeV; |η| < 2.5 (2.4)**
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- **Precision measurement**
- The leptonic and inclusive hadronic decay branching fractions
- **Lepton flavor universality (LFU) violation** test
- Features are made for the best isolation of **W → τ decays**

Precision measurement of W boson decay branching fraction

Phys. Rev. D 105, 072008

- Leptonic widths of the W boson **Γ (W → l⁻ν)**
- Hadronic widths of the W boson **Γ (W → qq̄')**
- **Total width Γ_{tot}**

	CMS	LEP
$\mathcal{B}(W \to e\bar{\nu}_e)$	$(10.83 \pm 0.01 \pm 0.10)\%$	$(10.71 \pm 0.14 \pm 0.07)\%$
$\mathcal{B}(W \to \mu\bar{\nu}_\mu)$	$(10.94 \pm 0.01 \pm 0.08)\%$	$(10.63 \pm 0.13 \pm 0.07)\%$
$\mathcal{B}(W \to \tau\bar{\nu}_\tau)$	$(10.77 \pm 0.05 \pm 0.21)\%$	$(11.38 \pm 0.17 \pm 0.11)\%$
$\mathcal{B}(W \to q\bar{q}')$	$(67.46 \pm 0.04 \pm 0.28)\%$	···
	Assuming LFU	
$\mathcal{B}(W \to \ell\bar{\nu})$	$(10.89 \pm 0.01 \pm 0.08)\%$	$(10.86 \pm 0.06 \pm 0.09)\%$
$\mathcal{B}(W \to q\bar{q}')$	$(67.32 \pm 0.02 \pm 0.23)\%$	$(67.41 \pm 0.18 \pm 0.20)\%$

Precision measurement of W boson decay branching fraction

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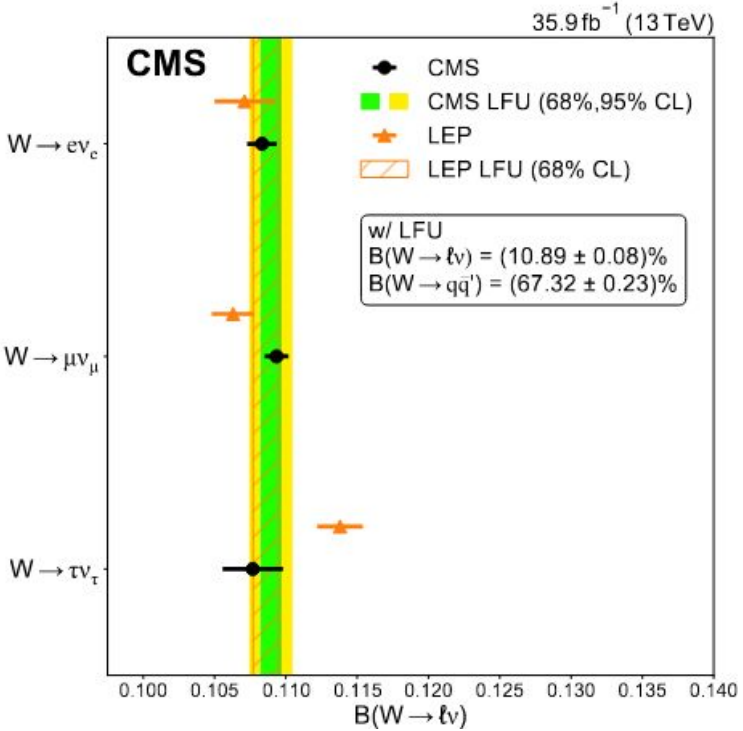
- **Consistent with the LFU** hypothesis for the weak interaction
- **More precise** than previous measurements based on **LEP experiments data** (about 1.5 time)
- **Ratio of hadronic-to-leptonic branching fractions** to the theoretical prediction is used to derive some **standard model parameters**
- Strong coupling constant at the W boson mass scale α_s **= 0.095 ± 0.033**



Summary

- Overview of several current analysis involving Z and W bosons
- Run II data collected by CMS detector in proton-proton collisions at 13TeV
- Better understanding of the QCD and EW
- Important test for new models and some physics concepts
- Putting limits to current physics models