Electroweak precision measurements

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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 $Z \rightarrow \ell \ell$
- 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 $Z \rightarrow \ell\ell$

Inclusive/differential measurements at $Z$ peak

forward region $2.0 < \eta < 4.5$

d$\sigma$/d$p_T$ in dielectron and dimuon channels

294 $fb^{-1}$ of 13 TeV data used

$\sigma_{Z}^{\ell\ell} = 194.3 \pm 0.9 \pm 3.3 \pm 7.6 \, pb$
Inclusive differential measurements at $Z$ peak

36.1 $fb^{-1}$ of 13 TeV

Differential $d\sigma/dp_T^Z$ and $d\sigma/d\phi^*$


New LHCb measurement also expected soon
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 $d\sigma/d\Delta\phi_{Z,\text{Jet}1}$

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 scattering important at high $p_T$ and invariant mass

$m_{\ell\ell} = [50, 76, 106, 170, 350, 1000]$ GeV CMS-PAS-SMP-20-003
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 $(10.83 \pm 0.10\%)$, $(10.94 \pm 0.08\%)$ 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 $\tau$ and $\mu$ lepton couplings in W-boson decays from $t\bar{t}$ events using 139 fb$^{-1}$ of 13 TeV data

One of the most precise measurements available

Results support the hypothesis of lepton universality for the weak interaction

CERN-EP-2020-139
W rapidity, helicity and differential x-section at 13 TeV (CMS)

First W helicity measurement at CMS, PRD 102 (2020) 092012
W boson charge asymmetry at 8 TeV (ATLAS)

\[ \sqrt{s} = 8 \text{ TeV}, \ 20.2 \text{ fb}^{-1} \]

20.2 fb\(^{-1}\) of 8 TeV data used \text{Eur. Phys. J. C} 79 (2019) 760
Angular coefficients at 8 TeV (CMS)

Preliminary CMS = 8 TeV at $L = 19.7 \text{ fb}^{-1}$

$1.25 < |y| < 1.5$

$-\mu^+ + \mu^+ \rightarrow \text{Data}(Z)$

$-e^+ + e^- \rightarrow \text{Data}(Z)$

POWHEG

$M(l^+ l^-)$

50 100 200 300 1000 2000

Data / MC

0 0.5 1 1.5 2 2.5

$\rho^2 \sigma_{d \cos \theta^* \, d \phi^*} \propto$

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

Lam-Tung relation violated

Strong $|y|$ and $q_T$ dependence

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
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$A_{FB}$ measurement at 8 TeV (ATLAS)

- Both electrons and muons
- $A_{FB}$ measurement with fine rapidity bins
- The results for $\sin^2\theta_{W}$ obtained using $A_{FB}$ in agreement with those obtained using $A_4$

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

- $\sim 19 \text{ fb}^{-1}$ of 8 TeV data used
- The statistical and systematic uncertainties are significantly reduced
- Fit of experimental $A_{FB}$ with theory
Weak mixing angle using $A_{FB}$ at 8 TeV (CMS, II)

- One of the most precise measurements
- PDF are constrained in-situ

\[ \sin^2 \theta_{\text{eff}}^\text{lept} = 0.23101 \pm 0.00036 \text{(stat)} \pm 0.00018 \text{(syst)} \pm 0.00016 \text{(theory)} \pm 0.00030 \text{(pdf)} \]

- Can reach better precision than LEP+SPD after LHC and CMS upgrade

CMS-PAS-FTR-17-001

Can reach better precision then LEP+SPD after LHC and CMS upgrade

| $L_{\text{int}}$ (fb$^{-1}$) | $|\eta| < 2.4$ | $|\eta| < 2.8$ | $|\eta| < 2.4$ | $|\eta| < 2.8$ |
|-----------------------------|--------------|--------------|--------------|--------------|
| 10                          | 76           | 51           | 75           | 57           |
| 100                         | 24           | 16           | 75           | 57           |
| 500                         | 11           | 7            | 75           | 57           |
| 1000                        | 8            | 5            | 75           | 57           |
| 3000                        | 4            | 3            | 75           | 57           |
| 19 (from [1])               | 43           | 49           | 27           |
| 19 (from [1])               | 44           | 54           | 32           |

CMS-PAS-FTR-17-001
Weak mixing angle using $A_{FB}$ at 8 and 7 TeV (LHCb)

$$\sin^2 \theta_{\text{eff}}^W = 0.23142 \pm 0.00073 \pm 0.00052 \pm 0.00056$$

- 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
- $W$ crosssection and helicity measurements
- $W$ branching 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=MU1IVTNiVWtOaW5pRW52Z0NvVWpHUT09