Investigation of the Drell-Yan process and precise electroweak measurements in the CMS experiment

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Introduction

Electroweak (EW) processes emerge with the interaction of EW bosons in the Standard model (SM) described by diagrams of production or exchange of EW gauge bosons. They are an important part of physics studied at the Large Hadron Collider (LHC) since EW processes can be well predicted in theory using NLO (next-to-leading) order for electroweak processes and up to NNLO (next-to-next-to-leading) order for quantum chromodynamics (QCD), also constraining Parton distribution functions (PDF), which are important to make predictions for the higher energies. Besides, the search for beyond SM physics requires knowledge of the backgrounds of EW processes.

Electroweak Mixing Angle

In Particle Physics, the Glashow-Weinberg-Salam (GWS) model of the electroweak (EW) interactions describes the fundamental parameters. One of these important parameters is θ_W, referred as the Weak Mixing Angle. This parameter probes the mixing of W and B fields and can be defined as,

$$\sin^2\theta_W = 1 - (M_W^2 / M_Z^2)$$

Due to the difference of the Z boson couplings for left-handed and right-handed fermions, an asymmetry is observed in the angular distribution between the oppositely charged leptons produced in Z-boson decays. This asymmetry depends on the weak mixing angle between the neutral states associated to the U(1) and SU(2) gauge groups. Weak mixing angle is same for all leptons because of lepton universality. Additionally, this measurement is an overall test of the electroweak sector. This is also an indirect measurement of the mass of the W-bosons. So, the precise measurement of the weak mixing angle is a study of immense importance.

Previous Results

The most precise measurements by the LEP and SLD experiments differ by 3.2 standard deviations[1]. Later, we have results from Tevatron, and the LHC experiments too (Fig. 1)

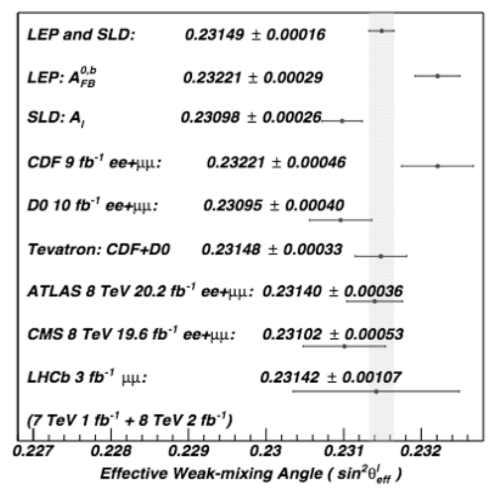

Fig.1 Previous experimental results for effective weak mixing angle measurements

The current precision of the angle corresponds to a precision of 8 MeV on the W mass, which needs a lot of improvement. Main uncertainties in this measurement include uncertainties from background studies, theoretical uncertainties (PDF etc) and higher order corrections. The experimental precision is much worse than the theoretical one (uncertainty ~0.00005).

Analysis Strategy

In general, for the analysis, the Drell-Yan

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processes are considered which is expressed as,
$q(p_1) + \bar{q}(p_2) \rightarrow Z/\gamma^* \rightarrow l^+l^-$
$Z \rightarrow ll$ events are used for the detector calibration. During this process, the presence of both the vector and axial-vector couplings give rise to non-zero forward-backward asymmetry(A_{FB}). Experimentally, this asymmetry is defined within the Collins-Soper frame [2], to reduce the effects of p_T of the incoming quarks. This asymmetry as a function of the dimuon invariant mass is used to determine the weak mixing angle. EW radiative corrections affect the simple LO relations. In the improved Born approximation, some of the higher-order corrections are absorbed into an effective mixing angle. The effective weak mixing angle is based on the ratio of vector and axial-vector coupling (v_f and a_f) as, $v_f/a_f = 1 - 4|Q_f| \sin^2\theta^f_{eff}$, with $\sin^2\theta^f_{eff} = \kappa_f \sin^2\theta_W$, where the flavor-dependent κ_f is determined through EW corrections.

Analysis in CMS

The Run-I measurement is based on pp collisions at $\sqrt{s}$ = 8 TeV recorded by the CMS Experiment in 2012, corresponding to integrated luminosities 18.8 and 19.6 fb^{-1} for the muon and electron channels, respectively (Fig.2).

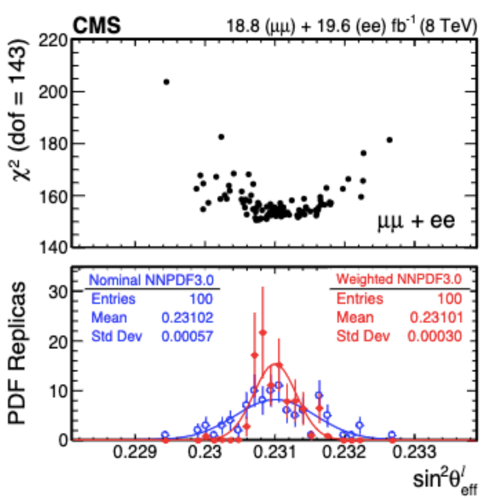

Fig.2 χ^2_{min} vs. the best-fit $\sin^2\theta^l_{eff}$ in 100 NNPDF replicas for the μμ+ee channels

The Run-II measurement ($\sqrt{s}$ = 13 TeV) is ongoing and the forward muon, forward electron channels have been added to increase the statistics.

Prospects at HL-LHC

Prospect of the precise measurements at high luminosity LHC has been predicted by generating Monte-Carlo sample of pp events (corresponding to 3000 fb^{-1} luminosity) from Powheg (NLO matrix element) with NNPDF3.0 PDF and interfaced with Pythia8, FSR ON.

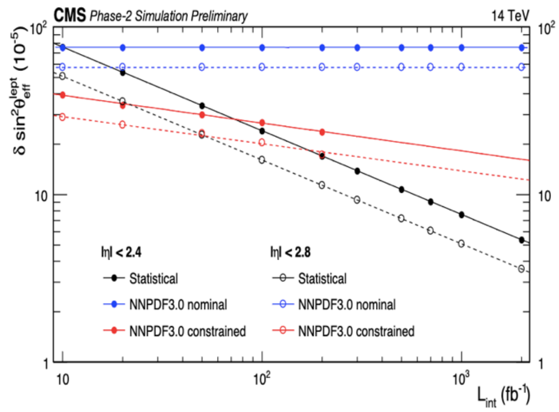

Fig.3 Reduction of uncertainties at HL-LHC

In addition to the increased luminosity, the upgraded part of the muon system extends the η -coverage of the CMS experiment to $|\eta| < 2.8$ for muons. Since the measurement has higher sensitivity in this η-region, both the statistical and systematic uncertainties will be significantly reduced. For HL-LHC (even for > 200 fb^{-1}), with the extended coverage of $|\eta| < 2.8$, the statistical uncertainties are expected to reduce by about 30% and the PDF uncertainties will be reduced by about 20% (Fig.3). It is expected to give very precise results, and also expected to address the long-standing issue of value discrepancy between LEP and SLD.

References

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