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EWK physics prospects for the HL-LHC

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The Large Hadron Collider (LHC) has been successfully delivering proton-proton collision data at the unprecedented center of mass energy of 13 TeV. An upgrade is planned to increase the instantaneous luminosity delivered by high luminosity LHC (HL-LHC), aiming to deliver a total of about 3000/fb of data to the ATLAS and CMS detectors. To cope with the expected data-taking conditions the ATLAS and CMS experiments are planning major upgrades of the detector. In this contribution we present an overview of the physics reach expected for electroweak measurements and searches at the HL-LHC for the CMS and ATLAS experiments. The prospects for high-precision measurements and study of rare processes are presented.

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1. Introduction

The upcoming HL-LHC project is expected to collect about 3000-4000 fb^{-1} of data compared to the 350 fb^{-1} to be collected during the first three runs of the LHC. This comes at the cost of significant pile-up increase, reaching 200 vertices per bunch crossing, which means a factor of 5 increase compared to the Run 3 conditions. Higher pile-up results in the increased rate of fake tracks, higher radiation exposure of the detector and leads to the degradation of the calorimeter resolution. Another consequence is the increased volume of data that has to be processed online.

In order to maintain at least the existing performance for all the physics objects and cope with the increased number of vertices a number of detector characteristics has to be improved. Specifically, it means better association of particles to vertices, including the track information into triggering, timing discrimination, increased detector acceptance and granularity. A brief description of these upgrades for the ATLAS [1] and CMS [2] detectors is presented in the following section.

The section on precision electroweak measurements contains information on the prospects for the measurement of two important parameters of the Standard Model (SM), namely the mass of the W boson (m_W) and the Weinberg angle $\sin^2\theta_W$.

The section on the electroweak rare processes describes the prospects on the searches for a rare SM process — the massive triboson production (VVV).

2. Planned upgrades for the ATLAS and CMS detectors

Both the ATLAS and CMS detectors are subject to substantial upgrades [3–6]. The trackers of both experiments have to get an extended coverage, reaching $|\eta| < 4$. Hardware trigger will use the information from the tracker in both ATLAS and CMS. The ATLAS Inner Detector is to be completely replaced with an all-silicon high-granularity tracker [7–9]. The CMS tracker has to get its silicon strips and pixels replaced, improving the granularity and functionality [10]. The Muon trigger systems of both experiments will have most of the front-end electronics replaced and the trigger rate improved. Both experiments have to obtain timing detectors that would cover forward (ATLAS) or central and forward (CMS) regions [11, 12]. The high-granularity Timing detector for the ATLAS experiment is to have a time resolution of about 30 ps per track and cover the forward region of $2.4 < |\eta| < 4$ [13]. The minimum Ionizing Particle timing detector of CMS is also expected to have a time resolution of 30 ps per track, but will have a full coverage of central and forward regions at $|\eta| < 4$. The front-end electronics of both experiments' calorimeters have to be replaced, enhancing the read-out frequency to 40 MHz [14–17].

The ATLAS Trigger/DAQ system will be getting full detector information and offer a hardware selection rate of 1 MHz, providing tracking information for software selection at 10 kHz [18]. The CMS hardware trigger rate for tracks is to reach 40 MHz, ensuring a Particle Flow selection rate of 750 kHz and software selection output at 7.5 kHz [19].

3. Electroweak precision measurements

The experimental uncertainty for the mass of the W boson is still considerably larger that the theoretical uncertainty from SM fit (see Figure 1). Reducing the experimental uncertainty on m_W

to the level of 10 MeV would allow to test the SM and improve the precision of the SM theoretical predictions.

With Parton Density Function (PDF) uncertainties being dominant in the measurement of the W boson mass, the main source of improvement would come from the extended tracker coverage in η, leading to much better PDF constraints. This measurement would not benefit from the full HL-LHC statistics, as it would require a special low pile-up run. Figure 1 shows the dependence of the measurement uncertainty on the integrated luminosity of this supposed low pile-up run. The rightmost column shows possible gain from the Large Hadron Electron Collider (LHeC) project, that would help to reduce the PDF uncertainty down to about 2 MeV.

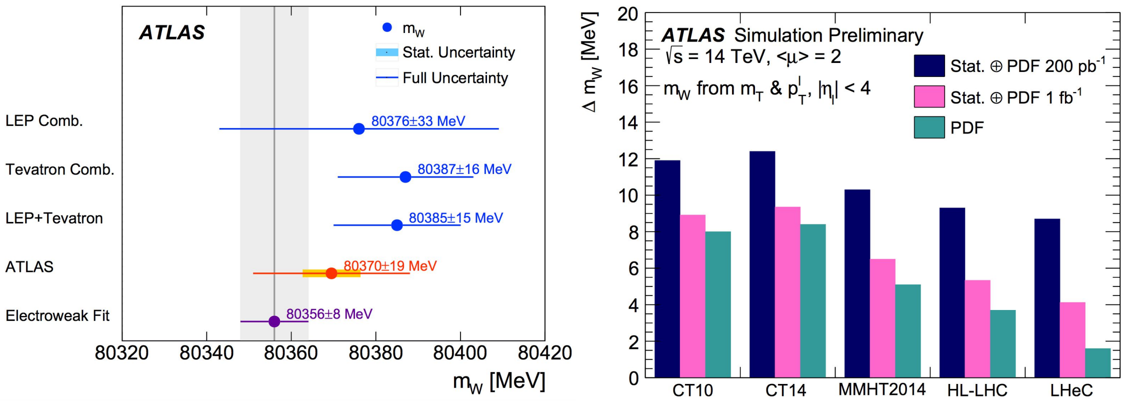

Figure 1: Current W boson mass measurements (left) [20]. Expected measurement error with different PDF sets and integrated luminosity (right) [21].

The two most precise measurement of $\sin^2\theta_W$ at LEP and SLD are 3 standard deviations apart. Figure 2 demonstrates that the HL-LHC measurement would allow to halve the existing uncertainty of ATLAS measurement. The systematic uncertainty is dominated by the PDFs, constraining the PDFs with LHeC results would allow to reduce the uncertainty by a factor of 4.5. Similar considerations are presented in the CMS proposal [22].

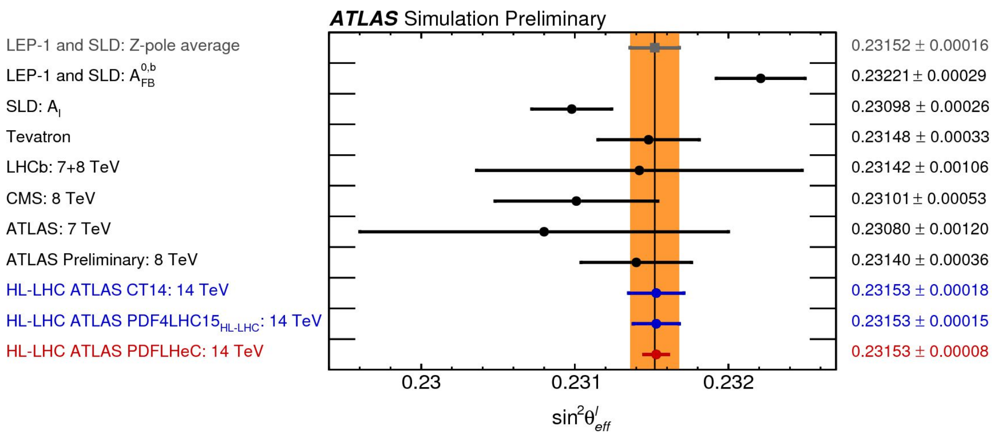

Figure 2: Existing $\sin^2\theta$ measurements and prospects for HL-LHC [23]. The last two lines demonstrate the effect of PDF constraints from full HL-LHC luminosity and LHeC experiment correspondingly.

4. Rare electroweak processes

The HL-LHC project is to collect about 10 times more integrated luminosity compared to the previous LHC runs. This would allow to perform a precise measurement of rare processes that are hard to observe using the data available at the moment. The production of three massive bosons is an example of such a rare process. The massive tri-boson production is sensitive to triple and quartic gauge couplings, thus provides a test for the Standard Model. Besides that, it allows to study Higgs-mediated and radiative processes.

The ATLAS search for tri-boson production has used 79.8 fb^{-1} of integrated luminosity collected at 13 TeV and resulted in observing the combined WVV channels with a signal significance of 4.1σ (with 3.1σ expected) [24], using leptonic and hadronic decay channels. The CMS search for $W^{\pm}W^{\pm}W^{\mp}$ in leptonic final states has shown a signal significance of 0.6σ (1.8σ expected) [25]. A more recent CMS study that has used a larger integrated luminosity of 137 fb^{-1} has claimed the observation of heavy triboson production in leptonic final states with significance for the combined VVV production signal of 5.7σ (5.9σ expected) [26]. The ATLAS experiment prospects for HL-LHC luminosity predict an observation of WWW production in the leptonic final states with a significance of 6.7σ and the evidence for WWZ and WZZ channels at the level of 3.0σ (see Table 1). The prospects are assuming standard cuts thus a better signal significance could be expected using more advanced signal extraction techniques.

Channel	Z_σ at 3000 fb^{-1} (4000 fb^{-1})
WWW $\rightarrow 3l\ 3\nu$	0SFOS: 6.7 (7.0)
	1SFOS: 1.0 (1.0)
	2SFOS: 0.7 (0.7)
WWW $\rightarrow 2l\ 2\nu\ 2j$	$e^{\pm}e^{\pm}$: 0.8 (0.8)
	$e^{\pm}\mu^{\pm}$: 1.2 (1.2)
	$\mu^{\pm}\mu^{\pm}$: 1.8 (1.8)
WWZ $\rightarrow 4l\ 2\nu$	SFOS: 0.1 (0.1)
	DFOS: 3.0 (3.1)
WWZ $\rightarrow 3l\ 3\nu\ 2j$	0.3 (0.3)
WZZ $\rightarrow 5l\ 1\nu$	SFOS: 3.0 (3.4)
WZZ $\rightarrow 4l\ 2j$	DFOS: 0.1 (0.1)
WZZ $\rightarrow 3l\ 3\nu$	0.03 (0.03)
WZZ $\rightarrow 3l\ 1\nu\ 2j$	0.04 (0.04)

Table 1: Expected signal significance for the VVV processes at HL-LHC luminosity [27].

5. Conclusions

The prospects for the HL-LHC measurements demonstrate promising opportunities from using the full HL-LHC dataset. The upgrades for the two experiments should allow to cope with the challenges of the increased luminosity and pile-up.

Improved statistics and acceptance coverage of the upgraded detectors would allow to improve the precision of the Standard Model measurements and investigate rare processes in much greater detail. Substantial progress is expected on the side of theoretical modelling. Advanced analysis methods that would include multivariate analysis might bring further improvement in precision.

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