Physics prospects with the ATLAS detector at the HL-LHC

The ATLAS experiment is preparing for the next approved collider project: the High-Luminosity Large Hadron Collider (HL-LHC) at CERN, scheduled to begin operation in 2027. This new machine will collide proton beams at a center-of-mass energy of 14 TeV and is expected to deliver over 3000 fb^{-1} (3 ab^{-1}) of integrated luminosity to ATLAS, an order of magnitude increase compared to that expected from the LHC at the end of Run 3 (2024). The luminosity increase presents a number of experimental challenges (sharp increase in trigger rates and number of concomitant *pp* interactions in each bunch crossing). Ambitious upgrades of the detector and trigger systems are underway to cope with the extreme conditions anticipated at the HL-LHC [1–7], and a strategy is outlined to develop software and computing capable of processing the data [8–10].

The large HL-LHC dataset and refined capabilities of the detector and trigger systems will significantly improve the precision of key measurements, as well as provide access to rare processes and increase the reach of searches for physics beyond the Standard Model. Of particular importance are Higgs boson coupling measurements, searches for and observations of its rare and invisible decays, direct constraints on the Higgs self-coupling, and the study of longitudinal vector-boson scattering. A list of available and forthcoming studies can be found below, organized according to the relevant Snowmass topical groups. A large number of extrapolations were provided for the CERN Yellow Report for the recently completed European Strategy Update [11], and references to the relevant ATLAS public notes are provided. These results remain valid, with potential updates and new studies expected for Snowmass '21 designated in bold. There are two strategies employed for ATLAS projections: (1) extrapolations based on Run-2 results scaled to the HL-LHC luminosity taking the change in center-of-mass energy, triggers, and expected object-level performance into account, and (2) parametric simulations based on detailed simulations of the upgraded detectors under HL-LHC conditions to provide the expected performance for reconstructed objects. The treatment of theoretical and experimental uncertainties, as well as the upgraded detector performance, are described in Ref. [12].

The ATLAS Collaboration recognizes the importance of the Snowmass process to the HEP community in the US and beyond. In particular, continued strong US participation is critical to the success of the HL-LHC physics program.

Higgs boson properties and couplings (EF01)

- Production modes: ggF, VBF, WH, ZH, $t\bar{t}H$ [13]
- Branching ratios and coupling parameters: $\gamma\gamma$, ZZ, W^+W^-, $\tau^+\tau^-$, $b\bar{b}$, $\mu^+\mu^-$, $Z\gamma$ [13,14]
- Mass: $H \to ZZ^* \to 4\ell$ [13]
- Differential cross sections in $\gamma\gamma$ and 4ℓ final states: Higgs boson p_{T}, η, jet multiplicity, p_{T} of leading jet [15]
- Probing the CP nature of the coupling to τ leptons [16]
- **Sensitivity to differential measurements of $VH(b\bar{b})$ production**
- **$H \to c\bar{c}$ using charm tagging** [17]
- **Pair-production and self-coupling measurements: $HH \to b\bar{b}b\bar{b}$, $b\bar{b}\tau^+\tau^-$, and $b\bar{b}\gamma\gamma$** [18]

Higgs boson as a portal to new physics (EF02)

- Search for additional Higgs bosons in the $\tau^+\tau^-$ final state [19]
- Search for a massive resonance decaying to HH in the $b\bar{b}b\bar{b}$ final state [20]
- **Lepton flavor violating Higgs boson decays**
- **Sensitivity to $H \to$ invisible produced via VBF**

Heavy flavor and top quark physics (EF03)

- Prospects for the measurement of $t\bar{t}\gamma$ [21]
- Sensitivity of searches for the FCNC decay $t \to qZ$ [22]
- Prospects for measuring the top quark mass using $t\bar{t}$ events with $J/\psi \to \mu^+\mu^-$ decays [23]
- **Prospects for the four-top-quark production cross section** [24]
- **Prospects for $t\bar{t}Z$ differential cross section measurements**

EW precision physics and constraining new physics (EF04)

- Search for lepton flavor violation with $\tau \to \mu\mu\mu$ events [25]
- Measurement of the W boson mass [26]
- Measurement of the weak mixing angle in $Z/\gamma^* \to e^+e^-$ events [27]
- $W^\pm W^\pm$ scattering, and extraction of the longitudinal component [28]
- Resonance searches and vector boson scattering in the $WW/WZ \to \ell\nu qq$ final state [29]
- **Electroweak production of WZ/ZZ + 2 jets** [30, 31]
- **Production of three massive vector bosons: WWW, WWZ, WZZ** [32]

Precision QCD (EF05)

- Prospects for jet and photon physics [33]

Hadronic structure and forward QCD (EF06)

- **Prospects for the HL-LHC as a photon collider**

Heavy ions (EF07)

- Bulk properties of Pb+Pb, p+Pb, and pp [34]
- Nuclear parton distributions [35]
- Measurements of jet modifications [36]
- Photon-induced processes in ultra-peripheral collisions [37]

Model specific explorations (EF08)

- Searches for staus, charginos and neutralinos [38]
- Sensitivity to models with two Higgs doublets and an additional pseudoscalar in $4t$ final states [39]
- **Sensitivity to top squark pair production** [40]
- **Sensitivity to winos and higgsinos with compressed mass spectra** [41]
- **Sensitivity to low-mass/electroweak R-parity violating SUSY in multi-jet final states**
- **Fully hadronic EW gaugino production**

More general explorations (EF09)

- Extrapolation of $E_{\mathrm{T}}^{\mathrm{miss}}$ + jet search results [42]
- Sensitivity to long-lived particles with displaced vertices and $E_{\mathrm{T}}^{\mathrm{miss}}$ signature [43]
- Search for Z' and W' bosons in fermionic final states [44]
- Dark-photons decaying to displaced, collimated jets of muons [45]

Dark matter at colliders (EF10)

- Dark matter searches in mono-photon and VBF+$E_{\mathrm{T}}^{\mathrm{miss}}$ [46]
- Search for invisible particles in association with single top quarks [47]
- Dark matter produced in association with heavy quarks [48]

Weak decays of b and c quarks (RF1)

- Prospects for $\mathcal{B}$ $(B_s^0 \to \mu^+\mu^-)$ measurements [49]
- CP-violation measurement prospects in the $B_s^0 \to J/\psi\,\phi$ channel [50]
- $B_d^0 \to K^{*0}\mu\mu$ angular analysis prospects [51]

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