ATLAS Phase II Upgrade

Description: The High Luminosity LHC (HL-LHC) is expected to begin operating in 2024, providing proton-on-proton collisions at a center of mass energy of ~14 TeV and a levelled instantaneous luminosity of 5×10^{34} cm^{-2} s^{-1}. The aim of the program is to deliver a total of 3000 fb^{-1} to ATLAS over the course of Phase II. This represents an order-of-magnitude increase in the data sample that will significantly enhance the physics reach of the ATLAS experiment, further exploiting our investments in the LHC project to date. The primary detector challenges in the HL-LHC environment are to maintain high performance in vertex and track reconstruction, lepton identification and heavy flavor tagging. These will be addressed via three fundamental detector improvements: a complete replacement of the current tracking system; an upgraded Trigger and Data Acquisition (TDAQ) architecture that will cope with increasing rates; and new radiation-hard readout electronics using state-of-the art technologies for the tracker, calorimeter and muon detector systems. A new all-silicon tracker design has been developed that makes use of modern sensors and radiation-tolerant ASIC technology which, along with its improved geometrical acceptance and reduced upstream material, provides superior performance when compared to the current tracker, even at the anticipated 200 interactions-per-crossing in the HL-LHC environment. The upgraded detector readout systems and TDAQ architecture are motivated by the desire to maintain low trigger thresholds and adequate bandwidth in order to maximize physics acceptance. The computing and software of the experiment must also evolve to meet the needs of the upgraded detector systems.

Science: The high luminosity at the HL-LHC extends the energy scales that can be accessed in high energy boson-boson scattering, allows enhanced studies of the electroweak symmetry breaking mechanism, and enables extended probes for new physics predicted by models such as SUSY and extra dimensions well into the multi-TeV region. The range of new physics signatures includes: searches for high mass gauge bosons (requiring good lepton momentum resolution up to high transverse momenta); reconstruction of complex SUSY cascade decays (requiring triggering on, and reconstruction of, low p_T leptons, and identification of heavy flavors); and searches for resonances in $t\bar{t}$-pairs (requiring reconstruction of leptons and heavy flavors in highly boosted topologies). The discovery of the Higgs boson will pave the way forward to measure its properties with the highest possible precision for testing the validity of the Standard Model and to search for new physics at the energy frontier. The large data sample will allow the measurement of the Higgs couplings to other particles to a precision of 5% to 30%. The increased data set will also enable probes of rare decays: $H \to \mu\mu$; vector boson fusion production of $H \to \gamma\gamma$ and $H \to \tau\tau$; and associated Higgs production with a top-pair, such as $t\bar{t}H$ with $H \to \gamma\gamma$. These additional channels increase the precision with which the fermion couplings can be measured, and improve the limits on new physics that can be set from loops in, for example, $gg \to H$ and $H \to \gamma\gamma$. The full luminosity will also allow the Higgs self-coupling to be studied for the first time, in channels such as $HH \to \tau\tau bb$ and $HH \to \gamma\gamma bb$.

Collaboration and Funding: ATLAS is a global experiment. The U.S. physicists come from 44 U.S. institutes, including four national laboratories, and comprise about 20% of the ATLAS collaboration, which consists of 2,500 physicists from 178 institutions in 38 countries. U.S. ATLAS is currently funded by both the DOE and the NSF; we anticipate this funding model to continue for the Phase II upgrade.

Cost: The total estimated "Core value" construction cost (essentially M&S costs only, excluding basic infrastructure, labor and contingency) of the ATLAS Phase II upgrade is 250 - 300 MCHF (over the period FY15-22). The potential U.S. share will be driven by the areas of U.S. interest and expertise, as well as the fraction of U.S. physicists in ATLAS. Assuming a 20% share, we estimate the U.S. portion of the Phase II upgrade to be ~$200-300M (AY$), based on scaling the U.S. share of total Core cost for the Phase I ATLAS upgrade, which includes labor and contingency.

Science Classification and Readiness: The science to be produced by the ATLAS Phase II Upgrade is *absolutely central* to the U.S. and world high energy physics program. The European strategy group has recently classified the LHC upgrades as their top priority. ATLAS has just published a Letter of Intent for the Phase II upgrade. The U.S. is actively engaged in pursuing the R&D for the new silicon tracker and the upgrade of the readout electronics. The Upgrade, although ready for CD-0, still has significant R&D to carry out, and we therefore classify the state of construction readiness as requiring *significant scientific/engineering challenges to resolve before initiating construction*.