ATLAS Status Report

Trevor Vickey
on behalf of the ATLAS Collaboration

November 30, 2022
LHCC Open Session — CERN
Outline

Run-2 Physics Highlights

Run-3 Data-taking and Results

Phase-II Upgrades Progress
Happy 30th Birthday ATLAS!

Interactive timeline can be found online: https://atlas.cern/about#history

‘ATLAS 30 Years’ video online: https://videos.cern.ch/record/2296611
Recent Run-2 Physics Highlights

A candidate event in the search for invisible Higgs boson decays using the vector-boson-fusion signature of two forward jets

Since the last LHCC meeting, ATLAS has submitted 27 new publications and released 8 new conference notes
Evidence for off-shell Higgs Boson Production

- Predicted Higgs width of 4.1 MeV is much smaller than the detector resolution
- This 4ℓ and 2ℓ 2ν ZZ combination exploits the independence of off-shell cross section on \( \Gamma_H \) and relies on identical on-shell and off-shell Higgs couplings to determine \( \Gamma_H \) from measurements of \( \mu_{\text{off-shell}} \) and \( \mu_{\text{on-shell}} \)

\[
\sigma_{gg\to H\to VV} \sim \frac{g^2_{ggH} g^2_{HZZ}}{m_H \Gamma_H} \qquad \sigma_{gg\to H\to VV} \sim \frac{g^2_{ggH} g^2_{HZZ}}{m_{ZZ}^2}
\]

\( \mu_{\text{off-shell}} = 0 \)

3.2σ obs (2.4σ exp) exclusion of \( \mu_{\text{off-shell}} = 0 \)

\( \Gamma_H = 4.6^{+2.6}_{-2.5} \text{ MeV} \)
Searches for Invisible Higgs Boson Decays

- Statistical combination of searches for $H \rightarrow$ invisible decays in 139 fb$^{-1}$ of Run-2 data
- Result combined with Run-1 data at $\sqrt{s} = 7$ TeV and 8 TeV
- Upper limit on the branching ratio of 0.107 (0.077) at the 95% confidence level is observed (expected)
- σ_{WIMP-nucleon} limits for scalar (blue), Majorana (red) and fermion (black) WIMP scenarios are also derived
- These are the strongest limits to date, and surpass the performance we thought was possible at the LHC
Search for Heavy Resonances in $W^+W^-\rightarrow e\nu\mu\nu$

- Searched across a wide mass range (200 GeV - 6 TeV) using $W^+W^-\rightarrow e\nu\mu\nu$ final state
- No significant excess over the Standard Model expectations in 139 fb$^{-1}$ of $\sqrt{s}=13$ TeV pp data
- Set exclusion limits on $\sigma \times BR(H \rightarrow W^+W^-)$ for Georgi-Machacek (GM) model
- Also limits on: Higgs-like narrow width scalar (NWA), Randall-Sundrum, spin-1 heavy vector triplet, spin-2 graviton

### Table

<table>
<thead>
<tr>
<th>Model</th>
<th>Obs. limit [GeV]</th>
<th>Exp. limit [GeV]</th>
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<td>Radion, ggF</td>
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<td>HVT scenario A, ggF</td>
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<td>HVT scenario B, ggF</td>
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<td>2200</td>
</tr>
</tbody>
</table>

### Figures

- **ATLAS Preliminary**
  - $\sqrt{s} = 13$ TeV, 139 fb$^{-1}$
  - $H \rightarrow WW \rightarrow e\nu\mu\nu$ (GM, VBF, $H_5 \rightarrow WW\rightarrow e\nu\mu\nu$)
  - 95% CL limit on $\sigma B(R(H \rightarrow WW)/B(R(W^+W^-))$
  - $m_H$ vs. $m_T$ (GeV)
  - $m_T$ vs. data/prediction

- **ATLAS Preliminary**
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  - NWA, ggF, $H \rightarrow WW\rightarrow e\nu\mu\nu$
  - 95% CL limit on $\sigma B(R(H \rightarrow WW)/B(R(W^+W^-))$
  - $m_H$ vs. $m_T$ (GeV)
  - $m_T$ vs. data/prediction
Measurement of the VH (H → WW*) Cross Section

- Using the full Run-2 data set and the H → WW* → ℓνℓν and H → WW* → ℓνjj decay modes
- The WH and ZH signal strength measurements are compatible at a level of 2.1σ
  - Individually they agree with the Standard Model at the level of 1.8σ and 1.2σ, respectively

\[
\sigma_{WH} \times BR_{H \rightarrow WW^*} = 0.13^{+0.08}_{-0.07} \text{(stat.)}^{+0.05}_{-0.04} \text{(syst.)} \text{ pb}
\]

\[
\sigma_{ZH} \times BR_{H \rightarrow WW^*} = 0.31^{+0.09}_{-0.08} \text{(stat.)} \pm 0.03 \text{(syst.)} \text{ pb}
\]
Search for New Physics in $H \to \gamma\gamma$ Events

- Looking for production of $H + X$ where $H \to \gamma\gamma$; general search, as there are many different ‘X’s
- Search performed on 139 fb$^{-1}$ of $\sqrt{s} = 13$ TeV pp data
- Examine a total of 22 final states categorized by the objects produced in association with the Higgs boson
Inclusive Photon Production at $\sqrt{s} = 13$ TeV

- Cross sections measured as functions of the photon $E_T$ in different regions of photon pseudorapidity
- The photons are required to be isolated by means of a fixed-cone method with two different cone radii
- Improvements provide a more in-depth test of the theoretical predictions from next-to-leading-order QCD predictions (JETPHOX and SHERPA) and next-to-next-to-leading-order QCD calculations (NNLOJET)

Measured differential cross sections (R=0.2 and 0.4)

Ratio of NLO and NNLO QCD calculations from NNLOJET (R=0.2) to measured cross sections
Run-3 Data-taking
Integrated Luminosity and Data-taking Efficiency

- Total integrated luminosity from $\sqrt{s} = 13.6$ TeV pp collisions delivered to ATLAS in 2022: just over 40 fb$^{-1}$
- NB: Delivered and recorded (~38 fb$^{-1}$) for 2022 just above the 2016 totals
- The ATLAS data-taking efficiency for 2022 was 92.8%
Average Pile-up in 2022

- Average pile-up in 2022: ~40.9 interactions per bunch crossing, about 20% higher than Run-2
- Fills with $\mu$ in the high-end tail are challenging: systems exert ‘busy’ more often, then readout must recover
- Deadtime (~4%) at higher $\mu$ adds up, resulting in a slightly lower recording efficiency compared to Run-2

Luminosity-weighted Pile-up Distributions

ATLAS Online

- 2015-18: $<\mu> = 33.7$
  - $\sqrt{s} = 13$ TeV, 147 fb$^{-1}$
- 2022: $<\mu> = 40.9$
  - $\sqrt{s} = 13.6$ TeV, 38 fb$^{-1}$

ATLAS Online Luminosity

- LHC Delivered All
- LHC Delivered Stable
- ATLAS Ready Recorded

November 25-26, 2022
Stable Beams: ~16 h
Leveling: ~6 h
Efficiency: 96.9%
2022 Data Quality

- Good Run Lists (GRLs) are being made which identify the luminosity blocks in 13.6 TeV runs that are suitable for data analysis.
- So far, the available GRLs cover 47% of the 2022 data recorded by ATLAS.
- Different GRLs for analyses depending on trigger availability.
  - Efficiency of data passing most generous good GRLs is 96%.
  - Best efficiencies at ~98% during the most recent periods (sub-periods within October 1st-20th range).
- Currently estimate ~0.7% recoverable in reprocessing.

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Fraction of data assessed as good quality</th>
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<tbody>
<tr>
<td>July 19 - August 6, 2022</td>
<td>92%</td>
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<tr>
<td>August 6 - August 23, 2022</td>
<td>97%</td>
</tr>
<tr>
<td>October 1 - October 20, 2022</td>
<td>96%</td>
</tr>
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ATLAS Phase-I Upgrade Program

- Muon
  - New Small Wheels (NSW)

- NSW Readout System

- Liquid Argon Calorimeter electronics boards

- Trigger and Data Acquisition System

- New Muon Chambers at the center of ATLAS

- ATLAS Forward Proton (AFP)
Phase-I Commissioning: LAr Calorimeter

- Phase-I LAr Digital Trigger system is fully operational with items activated in the Level-1 (L1Calo) and High-Level Trigger (HLT) menus.
- Energies sent to L1Calo Feature Extractors (FEXes).
- Experts investigating a few low-rate instabilities linked to FELIX.
- Data continuously looked at to improve the reliability of the system.
Phase-I Commissioning: L1-Calo

- Phase-I L1Calo system is fully installed
  - electron, jet, global Feature Extractors (eFEX, jFEX, gFEX), and L1Topo Tile Rear Extension module (TREX) are integrated with the calorimeters and are routinely included in readout during physics runs
  - eFEX, jFEX, gFEX, L1Topo providing Level-1 trigger-objects to ATLAS, seeding (with pre-scale) the relevant HLT chains
  - Full Phase-I trigger is under validation using data from collisions, ready to be activated in 2023

Correlation of electron \( E_T \) Legacy L1Calo versus eFEX
• Both sides of NSW routinely included in data-taking
• Significant effort and progress on DAQ stability
• Trigger integration is progressing
  • First monitoring of trigger signals from MMG and STG pads established via End-cap Sector Logic

• During YETS will investigate Versatile Link Transceiver (VTRx) issues, and work to improve cooling stability
• Problematic ICS low-voltage power distribution channels
  • Field-effect transistor (FET) identified as the failing component; repaired boards reworked to slow down the slew rate, and further tests are on-going
Phase-I Commissioning: L1-Muon

- Further progress on L1-Muon End-cap Sector Logic:
  - Trigger and readout logic validated
  - Excellent end-cap muon trigger efficiency
  - Muon TGC-BW (Big Wheel) and TGC-EI (End-cap Inner station) integrated
  - BIS78: interface tested, mapping to be started

L1-Muon Barrel:
- Completed integration and validation of readout and trigger paths
- Low barrel efficiency found at beginning of data taking:
  - Re-programming of the barrel trigger logic has allowed a good recovery of barrel trigger efficiency (despite increasing number of RPC gas leaks)
Trigger Overview and Phase-I Trigger Activation

- Primary focus was on production data-taking at $1.9 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$, $\mu=55$ and 3 kHz of full-event-building, plus trigger-level analysis at 5.5 kHz
- HLT chains seeded by Phase-1 items enabled for the first time on November 15th
  - Exercised full-chain activation of Phase-I seeded electron, tau and jet chains at a low rate
  - Hardware L1 decision, online decoding of Phase-I readout in the HLT, seeding of chains at the HLT, and offline monitoring of Phase-I seeded chains during prompt reconstruction

Representative rates for some unprescaled triggers

Cumulative trigger stream rates as a function of time for a fill August 2022
High-Level Trigger Fast Track Finding

- Improvements to the speed of online full-scan “fast track finding” were needed to use particle-flow online.
- Around 25% of HLT CPU is spent on full-scan tracking.
- Use of a new seed-finding algorithm saved an additional 12%, with only a small loss to per-track efficiency.
van der Meer Beam Separation Scans

- van-der-Meer (vdM) scan programme was carried out from November 9th - 12th
- Many thanks to the LHC operators for the great support, flexibility and the professional work
- All parts of the program were executed successfully: on-axis, off-axis and 2D-grid scans, as well as the second attempt at the Length Scale Calibration (LSC)
Heavy Ion Test Run

Lead ions colliding at a centre-of-mass energy per nucleon pair of 5.36 TeV in ATLAS on November 18, 2022
• Control Room operates with an 8 member shift crew; some desks struggled to find shifters early in 2022
• By the end of 2022, shifter coverage improved; we feel this is a positive sign for operation in 2023
• Operations in 2023 will begin with two periods of “milestone” running

Photo credits: Clara Nellist
Summary of YETS Planning

- Most systems operating smoothly; majority of the intermittent data-taking issues are resolved quickly
- Now preparing for annual maintenance activities during YETS

**TRT** No increase in number of active gas leaks; will investigate front-end cooling leaks during YETS

**LAr** YETS allows access to front-end crates, so will change a few boards and one low-voltage power supply

**RPC** Considering start of installation of new gas inlet consolidation technique during YETS to improve leaks

**TileCal** During YETS will investigate air leak in the Cesium system, resolve a cooling system leak, and carry out interventions on problematic modules
Summary of YETS Planning

- Most systems operating smoothly; majority of the intermittent data-taking issues are resolved quickly
- Now preparing for annual maintenance activities during YETS

**TGC** Chamber replacement during YETS to address individual high-voltage issues

**NSW** During YETS will carry out investigations on cooling, low-voltage power supplies and VTRx issues

**ALFA** YETS attempt at refurbishment of the flooded B7L1 station
Run-3 Data Analysis

Run-3 $\mu^+\mu^-$ candidate event

Run-3 $t\bar{t}$ candidate event (di-lepton $e\mu$)
Software and Computing

• Wonderful performance of our computing centers world-wide, including T1s and T2s
• Opportunistic resources (HPCs and HLT farm) continue to provide significant CPU
• Preparing for fresh detector simulation campaigns modeling 2022 and 2023 data conditions
Measurement of $\ttbar/Z$ Cross Section Ratio at 13.6 TeV

- Expect 11% increase of $\ttbar$ cross section driven by gluon fusion, use pure $\ttbar \rightarrow e\mu + b$-jets + MET channel
- Luminosity measurement imprecise before vdM calibration, achieve better precision by normalizing to $Z$ cross section

$$R_{\ttbar/Z} = 0.400 \pm 0.006 \text{ (stat.)} \pm 0.017 \text{ (syst.)} \pm 0.005 \text{ (lumi.)} \quad (4.7\%)$$

$$\sigma_{\ttbar} = 830 \pm 12 \text{ (stat.)}^{+27}_{-25} \text{ (syst.)} \pm 83 \text{ (lumi.)} \text{ pb}$$

$$R_{\ttbar/Z}^{\text{theory}} = 0.4232 \pm 0.0154 \text{ (scale + PDF)}$$

$$\sigma_{\ttbar}^{\text{theory}} = 924^{+32}_{-40} \text{ (scale + PDF) pb}$$
Performance Results with Early Run-3 Data

Electron identification efficiencies in $Z \to e^- e^+$ events from 3.4 fb$^{-1}$ of $\sqrt{s}=13.6$ TeV pp collision data

Relative di-muon mass resolution in $J/\psi$ and $Z \to \mu^- \mu^+$ events from 6.8 fb$^{-1}$ of $\sqrt{s}=13.6$ TeV pp collision data

Invariant mass spectrum of $B_s \to J/\psi \phi$ candidates reconstructed using data in the B-Physics “delayed stream”
Track and Vertex Reconstruction in Early Run-3 Data

- Tracking and vertexing performance have been studied for 13.6 TeV proton-proton collisions recorded in early Run 3 data from a single LHC fill in August 2022.
- Improvements were made to the track reconstruction algorithm chain in preparation for Run 3, the new Adaptive Multi-Vertex Finder (AMVF) ensures that high-activity collisions are reconstructed promptly.
- For the designed value of \( \mu = 60 \), the updated track reconstruction is a factor of 2 faster than the legacy Iterative Vertex Finder (IVF).

**CPU time versus \( \mu \)**

**Number of tracks per reconstructed vertex**
Phase-II Upgrades

HL-LHC $t\bar{t} <\mu>=200$
with 88 reconstructed vertices
ATLAS Phase-II Upgrade Program

- Detailed scope described in 7 TDRs approved by the CERN Research Board in 2017, 2018, 2020

- New Inner Tracking Detector (ITk)
  All silicon up to $|\eta| = 4$

- New Muon Chambers
  Inner barrel region with new RPC and sMDT detectors

- Upgraded Trigger and Data Acquisition system
  - Level-0 Trigger at 1 MHz
  - Improved High-Level Trigger (150 kHz full-scan tracking)

- High Granularity Timing Detector (HGTD)
  - Forward region ($2.4 < |\eta| < 4.0$
  - Low-Gain Avalanche Detectors (LGAD) with 30 ps track resolution

- Electronics Upgrades
  - LAr Calorimeter
  - Tile Calorimeter
  - Muon system

- Additional small upgrades
  - Luminosity detectors (1% precision goal)
  - HL-ZDC
Recent Phase-II Upgrade Progress

- sMDT Chamber Construction
- sMDT Commissioning
- IS Demonstrator
- Tile MiniDrawers to CERN
- HGTGD Hybrids
- GCM v2b
- FLX-182 3D Drawing
- sMDT Chamber Shipment
- End-cap System Test
- Strips End-cap A
- CO2 Building at Point-1
- LAr ADC Test Board
- MDT-TP CM
- Radiation Monitor Prototype
- SR1 Preparations
Recent Phase-II Upgrade Progress

Significant progress in transitioning from design to production, critical final design reviews passed. Also good progress on understanding resource needs for assembly and installation at CERN.
Phase-II Upgrades: Project Contingency

- Graph shows the latest deliverable within each project
- Inner Tracker (ITk): on the critical path; 6 months contingency, so far driven by Pixels
- Consolidation currently underway to gain contingency
Phase-II Tracker Upgrade: Pixels

- Submission of ITkPixV2 postponed to February
  - Despite few critical bugs (data merging, hit registration, isolated hit removal) having been fixed in the past several months
- Newly discovered Single Event Upset (SEU) vulnerability at high trigger rates, data rates, occupancy
- Needs some time to be fixed and verified at the chip level
- Attention on module site qualification, carbon foam availability and data cables qualification and production.
- Heading to sensor and bare local support PRRs, on-detector services and Loaded Local support FDRs
Phase-II Tracker Upgrade: Strips

- Sensors: 16 months of sensor receptions (out of ~3.5 years), roughly 1/3 of the production
  - Deficit in delivery rate partially due to unexpected issues in the initial production startup
  - Issues have been resolved but production is still being carefully monitored
- All three ITk Strip ASICs are in production
  - ABCStar probing cuts reviewed and finalized to maintain a high yield
- Regions of high noise appear when modules tested at cold temperatures
  - Variety of tests and special builds to diagnose the issue
  - Origin not understood, but found ways to mitigate it (irradiation campaign starting to validate them).
- Continue all other activities in loading local supports, services, etc., to be ready for integration of End-caps and Barrel in mid-2023
Summary

- We continue to fully exploit the Run-2 dataset, and have seen the first glimpses of what Run-3 has to offer
  - Since the last LHCC Meeting, ATLAS has submitted 27 new papers and released 8 new conference notes
- ATLAS has recorded a total of 38 fb\(^{-1}\) of proton-proton collision data at \(\sqrt{s} = 13.6\) TeV
- First ATLAS Run-3 result features t\(\bar{t}\)/Z cross-section ratio measurement at 13.6 TeV with 4.7% precision
- All Phase-I systems have been integrated in the data-taking; recently with HLT chains seeded by Phase-I items
- ATLAS is now preparing for annual maintenance activities and other interventions to make the most of the YETS
- Phase-II Upgrades are working towards production and the long-term opportunities of the HL-LHC
- And… (next slide please)
Thank You LHC for a Great First Year of Run-3!
Back-up
Journal Papers since the last LHCC

- Measurement of distributions sensitive to the modeling of color reconnection  [arxiv 2209.07874]
- Measurement of the s-channel single top cross-section at 13 TeV  [arxiv 2209.08990]
- DiHiggs HH to bbtautau (resonant search and limits on non-resonant HH cross-section)  [arxiv 2209.10910]
- 2L0j search  [arxiv 2209.13935]
- W-boson polarisation in top quark decays using the cos theta* differential distribution  [arxiv 2209.14903]
- Search for resonances produced in association with or decaying to a Z boson  [arxiv 2209.15345]
- Search for pair-produced scalar and vector LQs decaying to 3rd-gen quarks and 1st/2nd-gen leptons  [arxiv 2210.04517]
- Search for resonant and non-resonant VHH production in a final state with 0,1,2 leptons and 4 b-jets  [arxiv 2210.05415]
- Deep generative models for fast shower simulation in ATLAS  [arxiv 2210.06204]
- VLQ pair search with opposite sign multileptons  [arxiv 2210.15413]
- Search for tH/A→4-top production in multilepton final states  [arxiv 2211.01136]
- Higgs boson self-coupling from double- and single-Higgs production  [arxiv 2211.01216]
- Model independent heavy Higgs bosons decaying to WW in a same-sign di-lepton final state  [arxiv 2211.02617]
- Very-low-mass diphoton resonance search  [arxiv 2211.04172]
- WIMP DM with heavy flavours combination  [arxiv 2211.05426]
- Search for doubly charged Higgs boson production in multi-lepton final states  [arxiv 2211.07505]
- Mono-S to VV in leptonic channel  [arxiv 2211.07175]
- Search for gluinos in multi-b final states  [arxiv 2211.08028]
- Search for resonances in 3-/4-body invariant masses in ≥1-lepton+jets events  [arxiv 2211.08945]
- Polarization in inclusive WZ  [arxiv 2211.09435]
- Jet substructure and suppression  [arxiv 2211.11470]
- Dark matter search in the tW+MET final state  [arxiv 2211.13138]
- Charged-hadron production in pp, p+Pb, Pb+Pb, and Xe+Xe collisions at √s_{NN}=5 TeV with the ATLAS detector at the LHC  [CERN-EP-2022-221]
Conference Notes since the last LHCC

- Search for Dark Photons in ZH Decay [ATLAS-CONF-2022-064]
- Search for heavy resonances in the decay channel \(W^+W^-\rightarrow e\nu\mu\nu\) in pp collisions at \(\sqrt{s}=13\) TeV using 139 fb\(^{-1}\) of data with the ATLAS detector [ATLAS-CONF-2022-066]
- Search for heavy resonances in the decay channel \(W^+W^-\rightarrow e\nu\mu\nu\) in pp Collisions at sqrt(s)=13 TeV using 139 fb\(^{-1}\) of data with the ATLAS detector [ATLAS-CONF-2022-067]
- Study of \(h(125)\) off-shell couplings in 4l and llnunu [ATLAS-CONF-2022-068]
- Mono-H(\tau\tau\tau) [ATLAS-CONF-2022-069]
- Measurement of the \(t\bar{t}b\bar{t}\) cross-section and \(t\bar{t}b/Z\) cross-section ratio using LHC Run 3 pp collision data at a centre-of-mass energy of \(\sqrt{s}=13.6\) TeV [ATLAS-CONF-2022-070]