Highlights from the ATLAS Experiment

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on behalf of ATLAS Canada

CAP 2021

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ATLAS Canada

UNIVERSITY OF ALBERTA

UNIVERSITY OF TORONTO

Carleton UNIVERSITY

TRIUMF

McGill UNIVERSITY

THE UNIVERSITY OF BRITISH COLUMBIA

Université de Montréal

University of Victoria

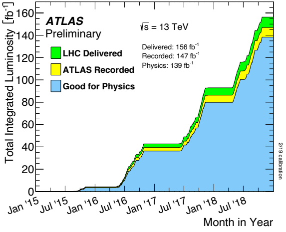
SFU SIMON FRASER UNIVERSITY

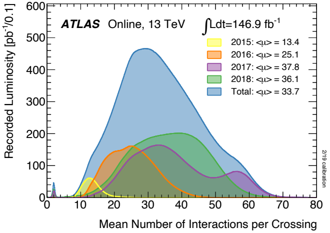
YORK UNIVERSITÉ UNIVERSITY

- Founded in 1992.
- 10 institutions.
- About 40 faculty members, 35 postdocs, and 80 graduate students, along with research and technical staff.

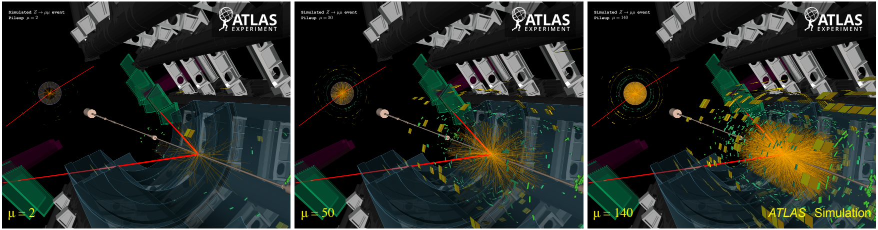
ATLAS Run-2

- **Run-1:** 2011-2012; $\sqrt{s}$ = 7-8 TeV; $\int \mathcal{L}$ = 25 fb^{-1}.
- **Run-2:** 2015-2018; $\sqrt{s}$ = 13 TeV; $\int \mathcal{L}$ = 139 fb^{-1}.
- In 2017, reached and ran at twice the nominal luminosity: $\mathcal{L} = 2 \times 10^{34}$ cm^{-2}s^{-1}.





LuminosityPublicResults

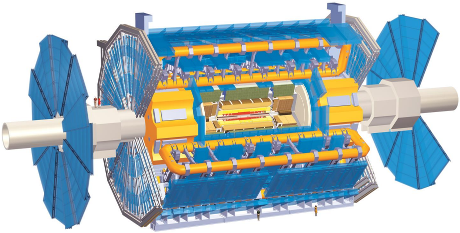


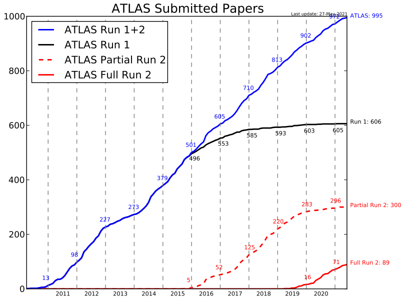
Increasing pileup

Contents

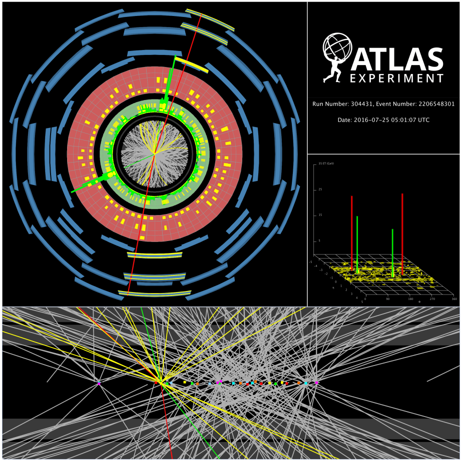
Recently published measurements and searches, and upgrade activities:

- Detector Performance
- Higgs Measurements:
  - Evidence of $H \to \ell\ell\gamma$
- Precision Standard Model Measurements:
  - Test of Lepton Universality
  - Observation of $\gamma\gamma \to WW$
- Beyond the Standard Model:
  - Searches using Monojet Events
- Detector Upgrades



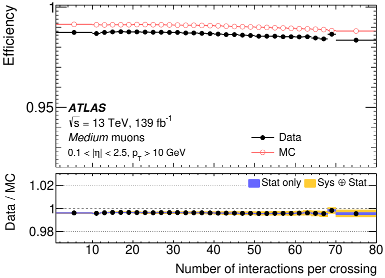


Detector Performance

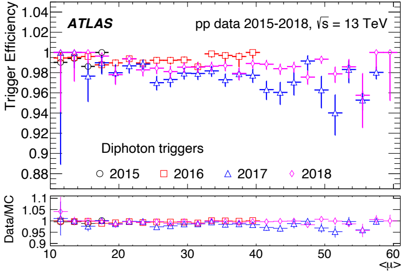


Detector Performance [1, 2, 3]

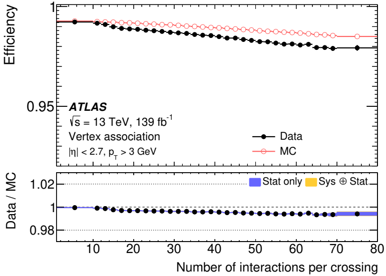
Muon efficiency vs. interactions per bunch crossing:



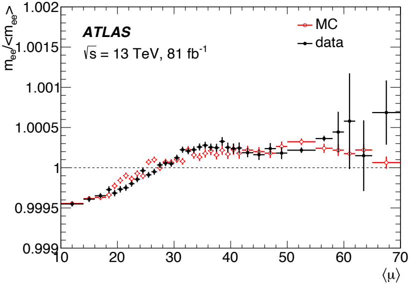
Diphoton trigger efficiency vs. interactions per bunch crossing:



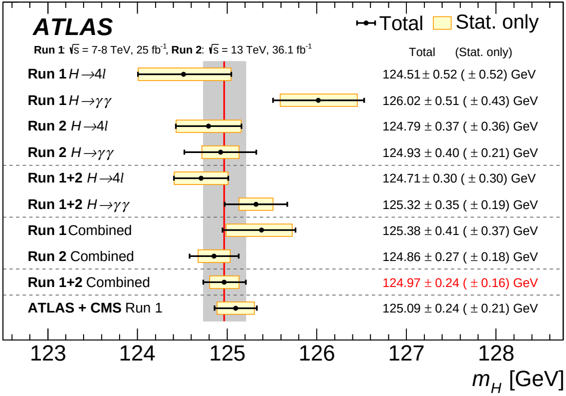
Vertex association efficiency vs. interactions per bunch crossing:



Electron energy scale vs. interactions per bunch crossing:



Higgs Measurements



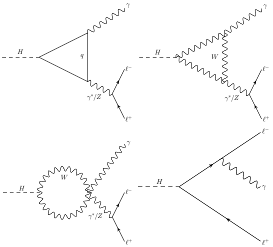
HiggsSummaryPlots

Evidence of $H \to \ell\ell\gamma$ (I) [4]

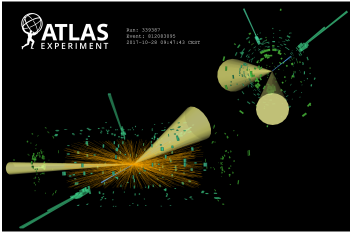
- First evidence for the decay of the Higgs boson into the rare final state of dilepton pair and a photon.
- $\int \mathcal{L} = 139\ \text{fb}^{-1}$, $\sqrt{s} = 13$ TeV.
- Low mass dileptons, $m_{\ell\ell} < 30$ GeV.
- Photon $p_T > 20$ GeV.

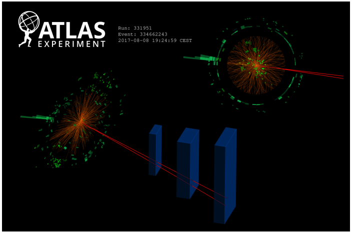
Signal regions:

- **VBF:** Best expected signal-to-background ratio.
- **High-p_{Tt}:** More events.
- **Low-p_{Tt}:** All others events.



- $p_{Tt} \equiv |\vec{p}_T^{\,\ell\ell\gamma} \times \hat{t}|$, where $\hat{t} = (\vec{p}_T^{\,\ell\ell} - \vec{p}_T^{\,\gamma})/|\vec{p}_T^{\,\ell\ell} - \vec{p}_T^{\,\gamma}|$, strongly correlated with $\vec{p}_T^{\,\ell\ell\gamma}$ but better experimental resolution.
- Use of both resolved (2 tracks) and merged (single track) *ee* pairs.

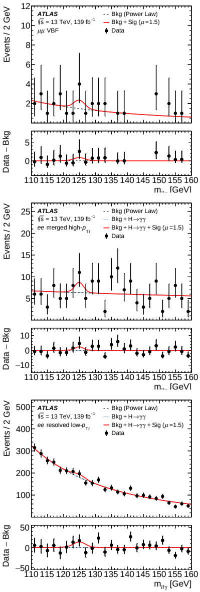


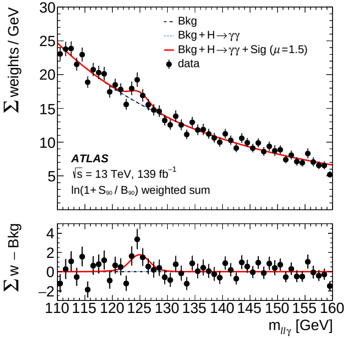


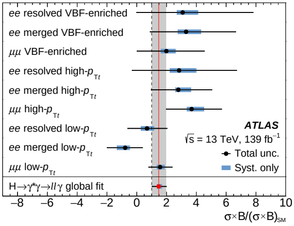
Evidence $H \to \ell\ell\gamma$ (II) [4]

Category	Events
ee resolved VBF-enriched	10
ee merged VBF-enriched	15
$\mu\mu$ VBF-enriched	33
ee resolved high-$p_{\mathrm{T}t}$	86
ee merged high-$p_{\mathrm{T}t}$	162
$\mu\mu$ high-$p_{\mathrm{T}t}$	210
ee resolved low-$p_{\mathrm{T}t}$	3713
ee merged low-$p_{\mathrm{T}t}$	5103
$\mu\mu$ low-$p_{\mathrm{T}t}$	9813

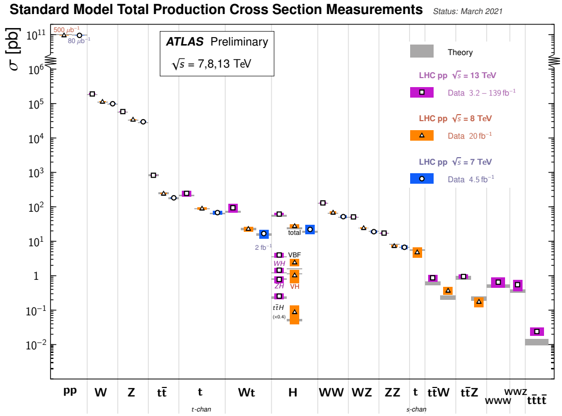
- Significance of 3.2σ over background-only hypothesis, compared to an expected significance of 2.1σ.
- $\sigma \times B = 8.7^{+2.8}_{-2.7}$ fb.
- Signal strength $\mu \equiv \sigma \times B/(\sigma \times B)_{\mathrm{SM}} = 1.5 \pm 0.5$.
- First evidence of $H \to \ell\ell\gamma$, an important step towards probing Higgs couplings in this rare decay channel.





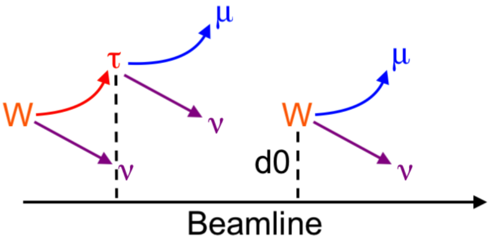


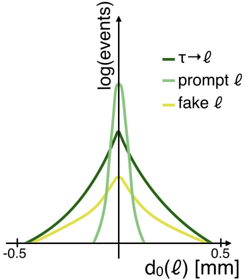
Precision Standard Model Measurements

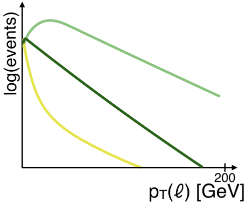


SMSummaryPlots

- Test of lepton universality using measurement of $R(\tau/\mu) = B(W \to \tau\nu_\tau)/B(W \to \mu\nu_\mu)$, which–if true–should be unity.
- $\int \mathcal{L} = 139\ \text{fb}^{-1}$, $\sqrt{s} = 13$ TeV.
- Relies on being able to distinguish prompt $W \to \mu\nu_\mu$ from $W \to \tau\nu_\tau \to \mu\nu_\mu\nu_\tau\nu_\tau$.

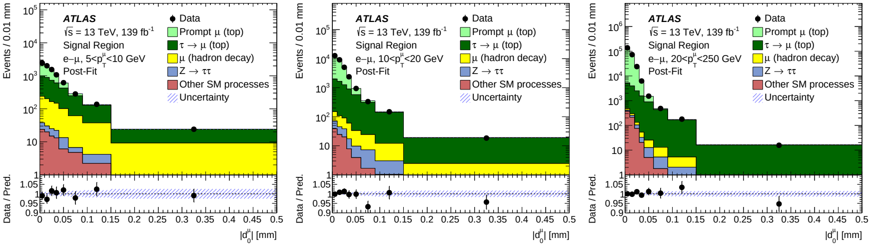




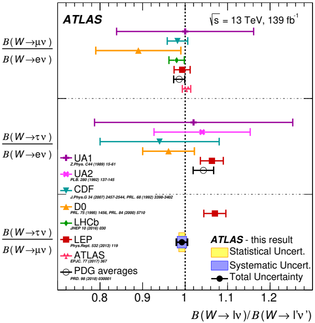


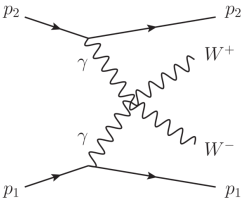
- Uses $t\bar{t}$ semileptonic decays for a sample of W bosons.
- Achievable by utilizing the precise reconstruction of muon tracks obtainable by the ATLAS experiment
- Distinguished using the lifetime of the τ-lepton, through the muon transverse impact parameter, and differences in the muon transverse momentum spectra.

Test of Lepton Universality (II) [5]



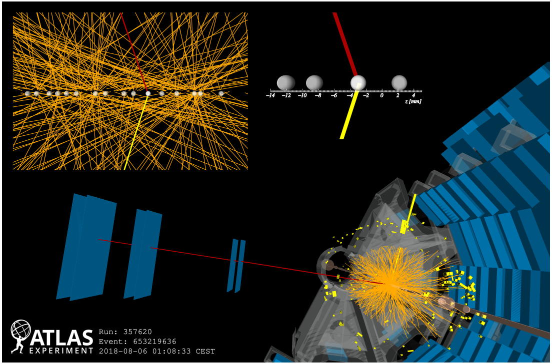
- Data fit to extract $R(\tau/\mu)$.
- $R(\tau/\mu) = 0.992 \pm 0.007(\mathrm{stat.}) \pm 0.011(\mathrm{syst.})$, in agreement with the hypothesis of universal lepton couplings of SM.
- Most precise measurement of $R(\tau/\mu)$ to date.
- Largest uncertainty from prompt μ modelling.
- LEP measurement of $R(\tau/\mu) = 1.070 \pm 0.026$, deviating from SM by 2.7σ.
- Suggests that the previous LEP discrepancy may be due to a fluctuation.

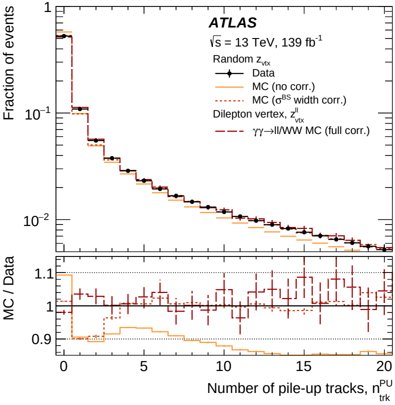


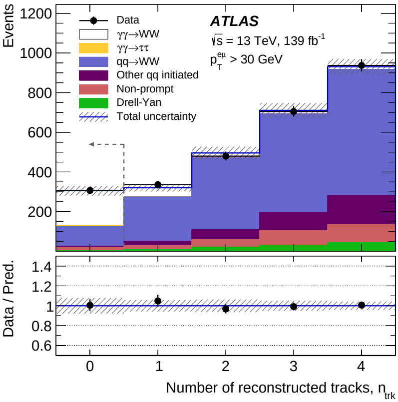


- Hundreds of times less likely than *WW* production from hard scatter.
- Requirement of no additional charged particles from vertex.
- The pileup (20-60 *pp* interactions per bunch crossing) adds to challenge of analysis.
- Simulated beam spot corrected using measured value from LHC.

- Measurement of $\gamma\gamma \to WW \to e\nu_e\mu\nu_\mu$.
- $\int \mathcal{L}$ = 139 fb^{-1}, $\sqrt{s}$ = 13 TeV.
- Test of SU(2)×U(1) gauge structure of SM and sensitive to anomalous gauge-boson interactions.

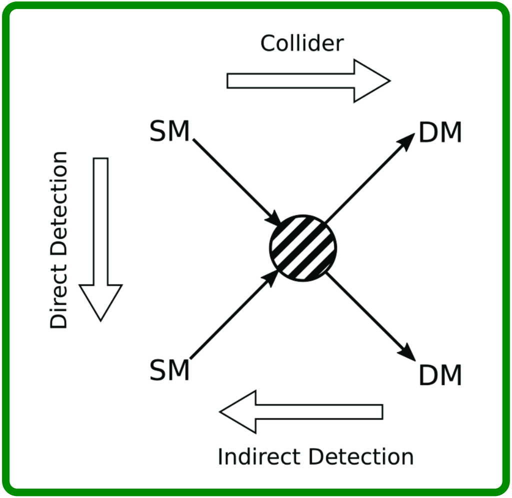






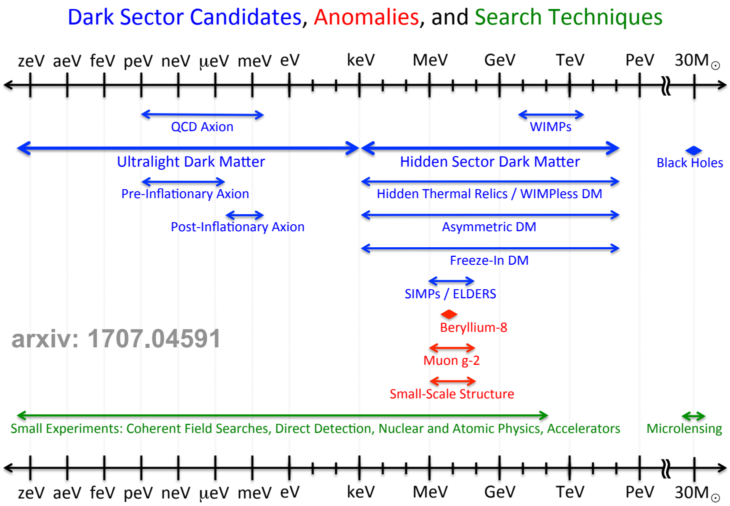
- First observation at LHC, with 8.4σ, well above the 5σ required for discovery.
- $\gamma\gamma \to WW \to e\nu_e\mu\nu_\mu$: $\sigma_{meas} = 3.13 \pm \pm 0.31(\mathrm{stat.}) \pm 0.28(\mathrm{syst.})$ fb.
- One or 2 events in the 30 trillion *pp* interactions in a typical daily run of the LHC in 2018.

Searches for New Physics

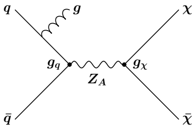


Collider Searches for Dark Matter

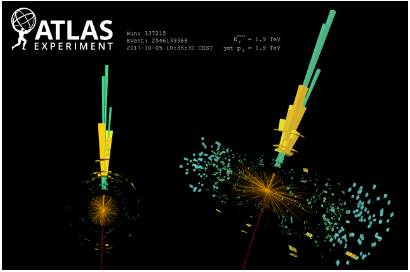
- Searches for dark matter (DM) large focus of Run-2 for ATLAS.
- Collider searches (SM $\rightarrow$ DM) complementary to direct and indirect searches.



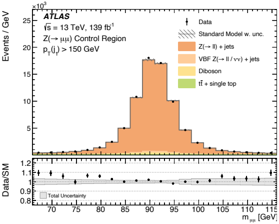
Searches using Monojet Events (I) [7]

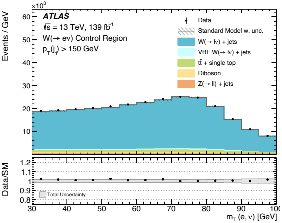


- Premier search channel, looking for a visible jet recoiling off an "invisible" new particle.
- Versatile, can be used to search for WIMPs (DM candidates), SUSY, dark energy, and more.
- Major challenge to accurately and precisely estimate SM background.
  - Dominant background is $Z \rightarrow \nu\nu$ + jets.
  - Backgrounds estimated using simulation.
  - Constrained using data-driven techniques, i.e. simultaneous binned likelihood fits to control regions.

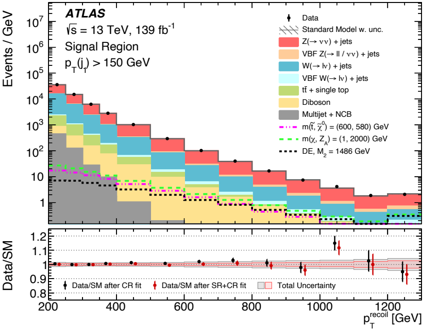


(Highest transverse momentum monojet, p_T = 1.9 TeV, ever recorded by ATLAS.)

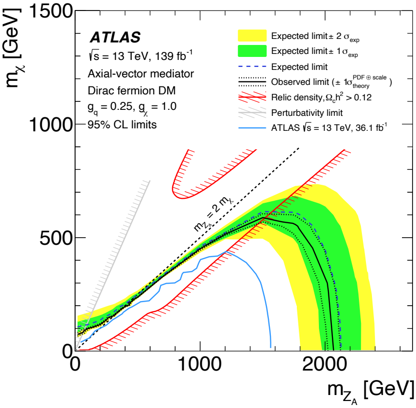




- Total background uncertainty in the signal region ranges from about 1% – 4% in range 200 GeV – 1.2 TeV.
- Leading experimental uncertainties: electron, muon, and jet identification and reconstruction efficiencies.



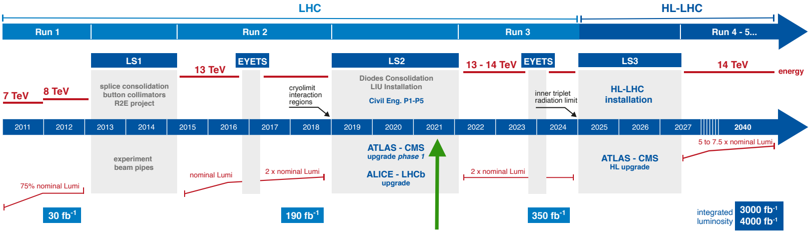
- No significant excess observed in p_T^{recoil} spectrum.



- Exclude (WIMP) dark matter masses up to about 585 GeV and interaction axial-vector mediators up to 2.1 TeV, both at the 95% confidence level.
- Most stringent dark matter limits in a collider experiment to-date.

Detector Upgrades

Detector Upgrades

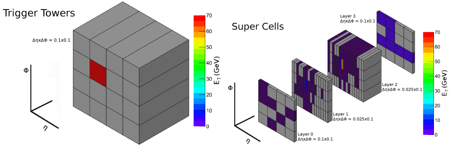


- During **Long Shutdown 2** (2019–early-2022), major upgrades to ATLAS detector being done in preparation for the HL-LHC (**Phase-1** Upgrades).
- Looking ahead, during **Long Shutdown 3** (2025–2027), another set of important upgrades will be made (**Phase-2** Upgrades).

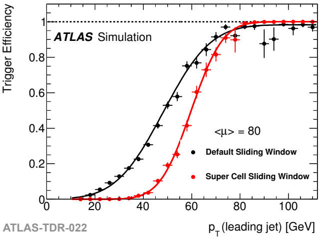
	Phase-1	**Phase-2**
Tracking	–	New all-silicon inner detector 🍁
Timing	–	New high-granularity timing detector
Calorimeter	New L1 LAr electronics 🍁	Continuous readout of LAr and Tile 🍁
Muon	New Small Wheels 🍁	New muon chambers in barrel, continuous readout
TDAQ	New trigger hardware	New trigger hardware

Phase-1 Calorimeter Upgrade [8]

- Upgrade to L1 LAr electronics allows implementation of supercells.

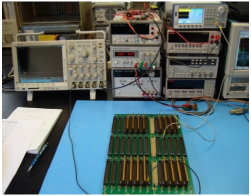


- Improvement of trigger energy resolution and object identification efficiency for electrons, photons, τ leptons, jets, and missing transverse momentum.



Canadian contributions:

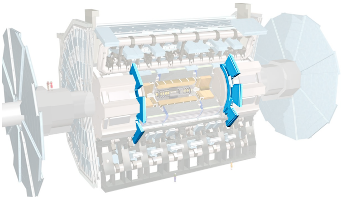
- Designed and built new front-end-crate base-planes (multilayer circuit boards that can accommodate the routing of the new trigger signals).
  - Operations at TRIUMF and UVic.

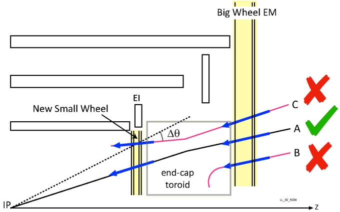


- Also financial contributions to the new trigger digitizer boards.
- Installation of the new electronics started at the beginning of Long Shutdown 2 and is now complete.
- ATLAS-Canada members are playing key roles in the commissioning.

Phase-1 Muon Upgrade [9]

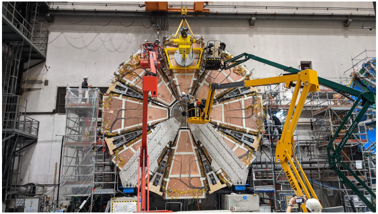
- Replacement of ATLAS small wheels with New Small Wheels (NSW).
- Improve online fakes rejection rate (by $\times 7$) and offline tracking at endcaps.





Canadian contributions:

- Construction of 54 (25%) muon gas chambers of the total 216 needed for the NSW project.
  - Operations at TRIUMF, Carleton, and McGill.
- Major contributions to assembly, integration, and commissioning activities at CERN.
- Leading role in software and performance.



- NSW-A will be ready to be installed in pit in late June, while NSW-C is looking promising.
- More details on the Canadian contribution to be given at upcoming CAP talk.

Conclusions

- Many measurements and searches were conducted with ATLAS detector and the Run-2 LHC dataset.
- Despite the increase in complexity in the collision environment, the performance of the detector has kept pace and remained good.
- Of the nearly 100 published full Run-2 results, 4 were shown in this highlights talk:
  - Evidence of $H \to \ell\ell\gamma$;
  - Test of Lepton Universality;
  - Observation of $\gamma\gamma \to WW$;
  - Searches using Monojet Events.
- Phase-1 upgrades to the ATLAS detector are well underway in preparation for a successful Run-3 and beyond.

References

[1]: “Muon reconstruction and identification efficiency in ATLAS using the full Run 2 *pp* collision data set at $\sqrt{s}$ = 13 TeV”, Accepted by: Eur. Phys. J. C.

[2]: “Performance of electron and photon triggers in ATLAS during LHC Run 2”, Eur. Phys. J. C 80 (2020) 47.

[3]: “Electron and photon performance measurements with the ATLAS detector using the 2015-2017 LHC proton-proton collision data”, JINST 14 (2019) P12006.

[4]: “Evidence for Higgs boson decays to a low-mass dilepton system and a photon in *pp* collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector”, Accepted by: Phys. Lett. B.

[5]: “Test of the universality of τ and μ lepton couplings in W-boson decays from $t\bar{t}$ events with the ATLAS detector”, Accepted by: Nature Physics.

[6]: “Observation of photon-induced W^+W^- production in *pp* collisions at $\sqrt{s}$ = 13 TeV using the ATLAS detector”, Phys. Lett. B. 816 (2021) 136190.

[7]: “Search for new phenomena in events with an energetic jet and missing transverse momentum in *pp* collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector”, Accepted by: Physical Review D.

[8]: “ATLAS Liquid Argon Calorimeter Phase-I Upgrade Technical Design Report”, ATLAS-TDR-022-2013.

[9]: “New Small Wheel Technical Design Report”, ATLAS-TDR-020-2013.