ATLAS status report

Stefania Xella on behalf of the ATLAS Collaboration

LHCC Open Session, February 27, 2019

Di-electron candidate
Mee = 4.06 TeV
Run-2 completed!

ATLAS currently:
- Finalising analysis of the 2015 and 2016 datasets
- Moving ahead to full Run-2 analyses
- Preliminary Run-2 integrated luminosity calibration available: 139 fb$^{-1}$

Luminosity uncertainty 1.7%

Z → μμ candidate event with 65 additional reconstructed primary vertices

Candidate event $\gamma\gamma \rightarrow e^+e^-$ from Pb-Pb collisions
Computing and Software

ATLAS benefited in 2018 from a rock-solid and fully utilised Tier-0 and distributed computing infrastructure and a single consolidated software release for all major data processing tasks.

The ATLAS software was made open-source at the end of the year, to foster collaboration within and outside the HEP community and to allow developers to showcase their work done in ATLAS.
Recent performance and physics results
Performance in Run-2 data for jets, missing $E_T$, muons

$E_{\text{miss}}$ key observable to many ATLAS searches

New techniques improve the jet energy resolution with respect to pile-up effects: particle flow jets

Muon efficiency $Z \rightarrow \mu \mu$ tag&probe

2018 dataset

Full Run-2 dataset

$E_{\text{miss}}$ key observable to many ATLAS searches
Measure three helicity states of W and Z: $f_L$, $f_R$ (transverse) and $f_0$ (longitudinal).

Longitudinal polarisation related to ElectroWeak Symmetry Breaking (non-zero mass of W,Z bosons)

Important test of the Standard Model
WZ cross section, polarisation W & Z

arXiv:1902.05759

Measure three helicity states of W and Z: \( f_L, f_R \) (transverse) and \( f_0 \) (longitudinal).

First LHC measurement of W,Z polarisation in pair-produced events
Combination of ATLAS and CMS (Run-1) on $|f_{LV} V_{tb}|$

**Direct Measurement:**

- Assumes $V_{td}, V_{ts} \ll V_{tb}$
- is independent on number of q generations
- is independent of CKM unitarity

relative uncertainty of 3.7%
New resonance searches: $Z'$ decaying into lepton pairs with 139 fb$^{-1}$

<table>
<thead>
<tr>
<th>Model</th>
<th>Lower limit on $M_{Z'}$ (TeV)</th>
<th>Observed</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z'_{\psi}$</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>$Z'_{\chi}$</td>
<td>4.8</td>
<td>4.7</td>
<td>4.7</td>
</tr>
<tr>
<td>$Z'^{\text{SSM}}$</td>
<td>5.1</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>
New resonance searches: $Z'$ decaying into quark pairs

Results significantly extend the constraints by ATLAS and other experiments at lower centre-of-mass energies on hadronically decaying resonances.

Now extended to masses as low as 225 GeV and up to 1100 GeV.

arXiv:1901.10917

80 fb$^{-1}$
2015-2017 data
Search for long-lived particles

Search for particles that display long lifetime, while still leaving recognisable traces in the ATLAS detector

Multiple search strategies (detector signatures), depending on the lifetime, can be applied to investigate a physics model

Credit: H. Russell
Displaced hadronic jets in the ATLAS calorimeter

Scalar portal

Higgs portal

Stealth susy

Post-EM calorimeter hadronic decay
A long-lived particle hadronically decaying in or after the electromagnetic calorimeters, leaving a jet with a very non-characteristic electromagnetic fraction.

CR (CalRatio)

<table>
<thead>
<tr>
<th>Main Selection</th>
<th>Expected Background</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-ET selection</td>
<td>8.5 +2.3 −2.0</td>
<td>10</td>
</tr>
<tr>
<td>Low-ET selection</td>
<td>5.3 +2.1 −1.6</td>
<td>7</td>
</tr>
</tbody>
</table>

13 fb⁻¹

10 fb⁻¹
Displaced hadronic jets in the ATLAS muon spectrometer

arXiv: 1811.07370

Scalar portal
Higgs portal
Stealth susy

Post-calorimeter hadronic decay
A long-lived particle that decays near the end of the hadronic calorimeters but before the middle of the muon spectrometer, leaving a shower of tracks in the muon spectrometer.

MS (Muon Spectrometer)

<table>
<thead>
<tr>
<th>Main Selection</th>
<th>Expected Background</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1MSVx +jets</td>
<td>Barrel Endcaps</td>
<td>15 ± 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11 ± 9</td>
</tr>
<tr>
<td>1MSVx +MET</td>
<td>Barrel Endcaps</td>
<td>243 ± 48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>497 ± 59</td>
</tr>
<tr>
<td>2MSVx</td>
<td></td>
<td>0.027 ± 0.011</td>
</tr>
</tbody>
</table>

$L_{xy}$: Transverse decay position

$\phi$: Scalar portal
$h$: Higgs portal
$\chi$: Stealth susy

ATLAS Simulation
$m_H = 500$ GeV
$m_H = 1500$ GeV
$\chi \rightarrow cb\bar{c}$, $m_{\chi} = 10$ GeV
$\chi \rightarrow cb\bar{c}$, $m_{\chi} = 100$ GeV

Barrel vertices

Long-lived particle $L_{xy}$ [m]

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

0 1 2 3 4 5 6 7 8
Displaced hadronic jets in ATLAS calorimeter or muon detector

Both analyses improve largely on previous ATLAS Run-1 results

Nice complementarity and improved power from the two displaced jets analyses

Cover a wide range of lifetimes
Long lived heavy multi-charged particles

\[ \frac{dE}{dx} \approx k z^2 Z \frac{1}{\Delta \beta^2} \left[ \frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta \gamma)}{2} \right] \]

Large dE/dx if particle has multiple charge: \( z = 2, 3, \ldots, 7 \) and is heavy, compared to Standard Model particles such as muons (\( z = 1 \)) → good discrimination using Pixel, TRT, MDT:

\[ S(dE/dx) = \frac{dE/dx_{\text{track}} - \langle dE/dx_{\mu} \rangle}{\sigma(dE/dx_{\mu})} \]

\( \sqrt{s} = 13 \text{ TeV}, 36.1 \text{ fb}^{-1} \)

*Pixel only for \( z = 2 \) charge
Long lived very heavy, $z=1$, charged particles

\[ \langle \frac{dE}{dx} \rangle \approx k z^2 Z A \beta^2 \left[ \frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{\text{max}}}{I^2} - \beta^2 - \frac{\delta(\beta \gamma)}{2} \right] \]

At high momentum, very heavy particle is slow and shows large $dE/dx$, which allows to measure $\beta$.

For slow particles, can also use Time of Flight (ToF) to measure $\beta$.

→ good discrimination using mass (calculable given $p$ and $\beta$)
HL-LHC
HL-LHC expectation, HH, ATLAS+CMS combination


Prediction of HL-LHC reach:
Extrapolate 13 TeV result Run-2 or use dedicated MC samples.
Pileup=200. 3000 fb$^{-1}$.
NNLO calculations.

Higgs self-coupling:
Not yet measured, needs high luminosity LHC

SM HH production

<table>
<thead>
<tr>
<th>Process</th>
<th>Significance in standard deviations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Statistical + Systematic ATLAS CMS</td>
</tr>
<tr>
<td>$HH \rightarrow b\bar{b}b\bar{b}$</td>
<td>0.61 0.95</td>
</tr>
<tr>
<td>$HH \rightarrow b\bar{b}\tau\bar{\tau}$</td>
<td>2.1 1.4</td>
</tr>
<tr>
<td>$HH \rightarrow b\bar{b}\gamma\gamma$</td>
<td>2.0 1.8</td>
</tr>
<tr>
<td>$HH \rightarrow b\bar{b}VV(ll\nu)$</td>
<td>- 0.56</td>
</tr>
<tr>
<td>$HH \rightarrow b\bar{b}ZZ(\ell\ell)$</td>
<td>- 0.37</td>
</tr>
<tr>
<td>Combined</td>
<td>3 2.6</td>
</tr>
<tr>
<td>Combined ATLAS+CMS</td>
<td>4.0</td>
</tr>
</tbody>
</table>

ATLAS and CMS

3000 fb$^{-1}$ (14 TeV)
Phase I upgrade - LS2 activities

ATLAS nomenclature in reviewing progress and readiness of new hardware projects

IDR: Initial Design Review
FDR: Final Design Review
  —> pre-production
PRR: Production Readiness Review
  —> production
ATLAS LS2 schedule

LS2 installation scenario in UX15
Baseline V2

We are here

LS2 activities plan
ATLAS LS2 schedule

Small Wheel - side A

LS2 activities in full swing and on track:
- Side A and Side C both open
- Detector refurbishing
- Installation and commissioning of Phase I upgrades

• Side A and Side C both open
• Detector refurbishing
• Installation and commissioning of Phase I upgrades
ATLAS LS2 schedule

Small Wheel - side C  LS2 installation scenario in UX15
Baseline V2

Opening process is finished!

LS2 activities in full swing and on track:
- Side A and Side C both open
- Detector refurbishing
- Installation and commissioning of Phase I upgrades
Phase I upgrades

New Liquid Argon (LAr) Calorimeter trigger electronics:
- provide digitised, more granular information to Level 1 calorimeter trigger

→ Higher rejection, better efficiency

New Small Wheel (NSW) detector:
- Replaces current small wheel
- Preserves resolution and efficiency at high luminosity
- Provides better rejection of fake muons already at Level 1 muon trigger

Trigger & DAQ:
- New L1 Muon Trigger Sector Logic and L1 calorimeter/topological trigger hardware, utilising the upgrades in LAr and NSW.
- Fast TracKer (FTK) system.
LAr trigger electronics

All HW is under production or produced

Tested at various sites

Installation has started
New Small Wheel

Provides tracking up to $|\eta| < 2.7$ and triggering up to $|\eta| < 2.4$
New Small Wheel

**Mechanics & Engineering:**
Both support structures (NJD disks) are complete.
All small sector spokes in place.
Services installation on the NJDs is nearing its completion. Ready to receive detector sectors!

**sTGC chamber construction:**
Production steady at all sites.
Side A: Quadruplets for small sectors all assembled,
for large sectors all assembled by Q4 2019.

**sTGC wedge integration (at CERN):**
Wedge integration is in progress and production mode.
Two Wedges completed.
Most wedges will be assembled by end of 2019.

**MicroMegas chamber construction:**
Panel production progressing very well in all sites, since Q3 2018.
Reduced HV goals, operating point ~ 560-570 V, ε~90-92%
Acceptable, due to large redundancy in system.
Full production speed needs to be reached at all sites

**Micromegas wedge integration (at CERN):**
Work on production double wedge #1 has started
PRR Wedge assembly scheduled Q1 2019.
New Small Wheel - Electronics, Installation

all four ASICs (ART, TDS, ROC and VMM) are in production.
all on-detector electronics cards underwent their FDR. (sFEB/pFEB noise in system context still being followed up). PRR possibly in Q2 2019.

Generally, all cards in pre-production or production.

Trigger processor mezzanine design final, carrier v2 prototype under fabrication.

Next major milestone is installation and full commissioning/slice test of the first sector. Planned for early summer 2019.
Trigger & DAQ

New tall racks for new L1 Calo hardware

Old and new L1 calo hardware
Both running at start of Run-3

USA15

Old cables
L1 Muon SL-MuCTPI cut in December 2018

USA15

Old SL gone in Feb 2019
New SL in Spring 2019

USA15

Replacement of switches and routers (SDX1 and USA15)
Installation of FELIX readout (USA15)
ROS rack refurbishment to host also SWROD/FELIX (USA15)
Prototype boards exist for all FEXs. No problems found. Being tested in Surface Test Facility (STF) @ CERN for FEX-Hub-ROD-FELIX data path.

Baseline algorithms established for all FEXs. Results from latency tests are within envelopes.

System Testing integration of modules in STF at CERN from now until October 2019. Installation from Q4 2019 onwards.
Goals:
- Hemisphere: commissioning data sharing among DF boards
- Tower 22: commissioning 8L tracks
- Tower 40: commissioning 12L tracks

Large delays compared to the initial schedule of the project.

Run-2 results in Tower 22 and 40:
- Able to fit 8-layer tracks for a full ATLAS run
- Able to fit 12-layer tracks for hours during ATLAS run
- Tracks written to dedicated stream at ~3Hz

Hardware-based tracking system to provide tracks to Higher-Level Trigger at L1 rate

Detector

LS2 activities:
- All hardware available, except for SSB and half of AMB boards.
- SSB boards modified being tested.
- Large commissioning effort in LS2.
- Demonstrate a working multi-DF system, achieve running stability (use test data) and scale up the system.
Phase II Upgrade
Phase II

- Six TDRs approved (ITK pixel, ITK strips, LAr, Tile, Muon, TDAQ)
- MoU prepared for 5 out of 6 TDR, will be released for signature at the beginning of March.

- $\sigma_{/\text{track}} \sim 30-50 \text{ ps up to end HL-LHC}$
- $2.4 < |\eta| < 4.0$; $Z \sim +3.5$ m from IP
- $< 10\%$ occupancy
- $1.3 \times 1.3 \text{ mm}^2$ LGAD pixels (6.4 m2)
- 3.59 M channels
- Luminosity (hit counting) detector
- $< 5.1 \times 10^{15} \text{ neq/cm}^2$

HGTD: A new powerful way to mitigate the effects of pileup is to use high-precision timing information (30ps per track) to distinguish between collisions occurring very close in space but well-separated in time.

Most important in forward region, to reduce pileup effects.
Summary

• Run-2 is complete - providing extraordinary datasets for analysis.

• Our focus is now on the analysis of the full Run-2 pp and PbPb datasets for which very first performance and physics results were presented today.

• The collaboration’s other focus is on the refurbishing of the detector and on the finalisation, installation and commissioning of the Phase I upgrade projects.

• In parallel, many activities on the Phase-II upgrade are ongoing.