Status and Recent Highlights
Outline

• The ATLAS detector
• 2016 start-up and detector performance
• Recent physics highlights

For upgrade please see
ATLAS upgrade and potential, A. Henriques, Saturday morning

… and of course the many physics plenary and parallel talks
for more details on the results shown here (and many more)
The ATLAS Detector

- **Inner Detector (ID)**
  
  - Silicon Pixels (4 layers barrel, 3 endcap)
  - Silicon Strips (SCT) (4 layers barrel, 9 endcap)
  - Transition Radiation Tracker (TRT) up to 36 points/track
  - 2T Solenoid Magnet

- **Tracking**

- **Muon Detector**

- **Tile Calorimeter**

- **Liquid Argon calorimeter**

- **Toroidal Magnet**

- **Solenoid Magnet**

- **SCT**

- **Pixel Detector**

- **TRT**
Calorimeter system
EM and Hadronic energy

- Liquid Ar (LAr) EM barrel and end-cap
- LAr Hadronic end-cap
- Tile calorimeter (Fe – scintillator) hadronic barrel
Muon spectrometer
µ tracking
Precision tracking
• MDT (Monit. drift tubes)
• CSC (Cathode Strip Ch.)
Trigger chambers
• RPC (Resist. Plate Ch.)
• TGC (Thin Gap Ch.)
• Toroid Magnet
Trigger system (Run 2)

- L1 – hardware output rate: 100 kHz latency: < 2.5 µs
- HLT – software output rate: 1 kHz proc. time: ~ 550 ms
ATLAS data taking from 2015 to 2016

- **2015 pp data taking @ 13 TeV**
  - A total of 4 fb\(^{-1}\) was delivered
  - ATLAS data-taking efficiency 92.0% (93.5% in 2012)

- **2015 Heavy Ion data**
  - Intense period in Nov-Dec:
    - 5.02 TeV pp reference data (28pb\(^{-1}\), \(\epsilon_{DT}= 96.9\%\))
    - \(\sqrt{s}\) NN = 5.02 TeV Pb-Pb data: 548 \(\mu\)b\(^{-1}\)

- **2016 data taking**
  - Quiet beams Apr 12\(^{th}\) / First stable beams Apr 23\(^{rd}\)
  - Intensity luminosity ramp-up is ongoing
    - Up to 2028 colliding bunches in ATLAS
    - \(L_{peak} \sim 0.88 \times 10^{34}\) cm\(^{-2}\)s\(^{-1}\)
    - Recorded 2.8 fb\(^{-1}\), data taking efficiency 91%

ATLAS has been successfully re-commissioned and is operating smoothly
Detector Status 2016

**Subdetector** | **Number of Channels** | **Approximate Operational Fraction** | **Notes**
--- | --- | --- | ---
Pixels | 92 M | 98.2% | +0.8% changes w.r.t. 2015
SCT Silicon Strips | 6.3 M | 98.7% |
TRT Transition Radiation Tracker | 350 k | 97.2% |
LAr EM Calorimeter | 170 k | 100% |
Tile calorimeter | 5200 | 100% | +13k ch.
Hadronic endcap LAr calorimeter | 5600 | 99.6% | +13k ch.
Forward LAr calorimeter | 3500 | 99.7% |
LVL1 Calo trigger | 7160 | 100% |
LVL1 Muon RPC trigger | 383 k | 99.8% |
LVL1 Muon TGC trigger | 320 k | 100% |
MDT Muon Drift Tubes | 357 k | 99.7% |
CSC Cathode Strip Chambers | 31 k | 98.4% |
RPC Barrel Muon Chambers | 383 k | 96.6% |
TGC Endcap Muon Chambers | 320 k | 99.6% |
ALFA | 10 k | 99.9% |
AFP | 188 k | 98.8% |

**Notes:**
- For the Pixel status: 3-Layers Pixel (80 M channels) - 98%; IBL (12 M channels) - 99.5%
- Now includes the 36 new trigger towers for Sector 12 and 14 on the outer layer.
- For Tilecal we indicate the number of cells (including gap and crack counters) that is more accurate for the status
- Detectors with fewer than 100 channels are not reported

- **Trigger and DAQ**
  - Prepared for luminosities up to $1.2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
  - Most bandwidth still given to *generic* triggers
    - e.g. single isolated e/µ with $p_T > 24$-26 GeV
  - Multi-object and dedicated triggers added

**ATLAS Trigger Operation**
- **L1 Trigger Total Output**, **Single MUON**, **Single EM**, **Multi JET**, **MET**, **TAU**, **Combined**
Muon spectrometer

- Barrel trigger chambers (RPC)
  - Additional chambers improve acceptance in ‘feet’ region (4% of total)
- Endcap trigger chambers (TGC)
  - Optimisation of coincidences \( \rightarrow \sim 8\% \) rate reduction for L1 MU20
- Precision chambers (MDT/CSC)
  - Working well for precision tracking
  - 2015 alignment applied to 2016 data
Calorimeters

- **LAr calorimeter**
  - Operating smoothly
  - Very good LAr purity stablitily
  - Energy scale in the 2016 data is consistent with 2015

- **Tile calorimeter**
  - Recovered two dead modules and four partially operational drawers → 100% coverage

- **Example of using calorimeter objects in trigger**
  - Three different ETmiss high-level trigger algorithms, using
    - Calibrated cluster
    - Reconstructed jets
    - Cells on EM energy scale
Inner tracking

• Pixel system
  – Readout was upgraded to handle higher pileup w.r.t. the 2015 operation
  – ID alignment is automated, updates before bulk reconstruction

• Semi Conductor Tracker
  – Nearly 99% of the modules are included with good data quality

• Transition Radiation Tracker
  – New gas configuration to reduce loss of xenon
    • Particle-ID re-optimised
      → Negligible impact on physics

TRT geometry and gas component per module

[Diagram showing TRT geometry with Ar and Xe on Side C and Side A]
Forward Detectors

• New Detector AFP: ATLAS Forward Protons (200 m from IP)
  – Roman pots for one arm were installed and integrated in DAQ
  – Hit-pattern plot shows expected “band” of diffractive protons
  – Second arm installation in 2016/2017 shutdown

• The other forward detectors, LUCID, ALFA, and ZDC are also fully operational

ATLAS is well advanced in establishing the 2016 detector performance
Finalising Run-1 analyses

- $B_{d/s} \rightarrow \mu^+ \mu^-$
  - 25 fb$^{-1}$ of the 7/8 TeV data in Run-1
  - Consistent with the SM at 2.0 $\sigma$
  - Also consistent with zero
  
  $$B(B_s^0 \rightarrow \mu^+ \mu^-) = \left(0.9^{+1.1}_{-0.8}\right) \times 10^{-9}$$
  $$B(B^0 \rightarrow \mu^+ \mu^-) < 4.2 \times 10^{-10} \text{ at 95\% CL}$$

  - Top quark mass in the $l+\text{jets}$ and di-lepton channels using 4.6 fb$^{-1}$ @ 7 TeV
    - Di-lepton channel: 1-dim template in average invariant mass of the $l+b$-jet pairs
    - $l+\text{jets}$: 3-dim template determining mass with global jet energy scale factor (JSF) and a relative $b$-to-light-jet energy scale factor ($b$JSF)

... latest news: from 20.2 fb$^{-1}$ @ 8 TeV (di-lepton):

$m_{\text{top}} = 172.99 \pm 0.41 \text{ (stat)} \pm 0.74 \text{ (syst)} \text{ GeV}$
and combined with the 7 TeV data:

$m_{\text{top}} = 172.84 \pm 0.34 \text{ (stat)} \pm 0.61 \text{ (syst)} \text{ GeV}$

$\Rightarrow$ relative precision of 0.4%
Run-2: Top quark cross section

- Measured in the $e\mu$ channel
  - $t\bar{t} \rightarrow e\mu\nu\bar{\nu}b\bar{b}$, $3.2 \text{ fb}^{-1}$ @ 13 TeV
  - Count events with exactly one ($N_1$) and exactly two ($N_2$) b-tagged jets

\[
N_1 = L\sigma_{t\bar{t}}\epsilon_{e\mu}\epsilon_b(1-C_b\epsilon_b) + N_1^{bkg}
\]
\[
N_2 = L\sigma_{t\bar{t}}\epsilon_{e\mu}C_b\epsilon_b^2 + N_2^{bkg}
\]

- Solve for $\sigma_{t\bar{t}}$ and $\epsilon_b$

\[
\epsilon_b = 0.559 \pm 0.004 \pm 0.003
\]
\[
\sigma_{t\bar{t}} = 818 \pm 8 \text{ (stat)} \pm 27 \text{ (syst)} \pm 19 \text{ (lumi)} \pm 12 \text{ (beam)} \text{ pb}
\]
\[
\sigma_{t\bar{t}}^{\text{fid}} = 11.32 \pm 0.10 \text{ (stat)} \pm 0.29 \text{ (syst)} \pm 0.26 \text{ (lumi)} \pm 0.17 \text{ (beam)} \text{ pb}
\]

Using latest luminosity uncertainty: 2.1%
W, Z measurements @ 13 TeV

• Recent additions include
  – W and Z cross sections & ratios @ 13 TeV
    • E.g. ratio of W\(^+\) to W\(^-\) fiducial cross sections
    • Measured to a precision of 0.8%
    • 1-2\(\sigma\) lower than the various predictions based on different PDFs
  – W\(^\pm\)Z cross sections
    • Further important test of the SM EW sector
      – Measured in 3.2 fb\(^{-1}\) @ 13 TeV
      – Fiducial cross sections in e and \(\mu\) decay modes extrapolated to total phase space
      – Ratios of 8 and 13 TeV and \(W^+Z/W^-Z\)

\[ \sigma(W^\pm Z) \text{ vs } N_{jets} \]

Test of QCD for diboson production processes

Using latest luminosity uncertainty: 2.1%
Search for di-photon resonance: $m_{\gamma\gamma}$ spectrum

- Search for excess in di-photon invariant mass spectrum

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Spin-0</th>
<th>Spin-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>Extended Higgs sector</td>
<td>KK-graviton</td>
</tr>
<tr>
<td>Selection</td>
<td>2 isolated-(\gamma)'s: $E_T/m_{\gamma\gamma} &gt; 0.3, 0.4$</td>
<td>2 isolated-(\gamma)'s: $E_T(\gamma_1,2)&gt;55, 55$ GeV</td>
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Using 3.2 fb\(^{-1}\) of $\sqrt{s} = 13$ TeV data collected in 2015
Search for di-photon resonance: significance

• Significances intriguing but not compelling at this point

→ One analysis we are watching carefully in 2016
- Searches for light (< 1 TeV) di-jet resonances motivated e.g. by Leptophobic Z’ models
  - Sub-TeV searches limited by available trigger bandwidth
  - Avoid limitation using partially built events with only the information needed for the search (5% of full event size) \(\rightarrow\) additional 2kHz event rate
Trigger Level Analysis

- TLA selection fills the gap at low $m_{jj}$
- SM backgrounds estimated by fitting binned $m_{jj}$ distribution to empirical function
  - Significance of any localized excess evaluated with BumpHunter algorithm

Limits are set on $\sigma \times A \times BR$ of a leptophobic $Z'$ simplified model and on generic Gaussian resonances.
A large number of other results ....

- Many other results are available and coming out
  - Stay tuned for many more interesting talks this week
Conclusions

• ATLAS is up and running taking 2016 data
  – Much of the detector performance for this year has been (re-)established → ongoing activity

• Computing and software is operating well

• Steady output of physics results
  – Still Run-1 analyses being finalised, Run-2 results increasingly taking over

ATLAS is very much looking forward to this year of high luminosity production and any surprise the data might have for us

ATLAS/CMS Higgs combination paper submitted to JHEP last week
Additional material
Looking for $H(125)$ @ 13 TeV

- Using 3.2 fb$^{-1}$ @ 13 TeV
- Diphoton channel:
  - Observe 1.5σ significance, expect 1.9σ
- Four-lepton channel:
  - Observe 0.7σ significance, expect 2.8σ
- Combined compatibility with SM
  - … is around 1.3σ
W, Z measurements @ 13 TeV

- A wide range of cross section measurements has been performed
\[(Z) \rightarrow \ell\ell + \text{jets} + \text{missing } E_T\]

- **SUSY targeted search**
  - Modest excess at Run-1 \[\rightarrow 3\sigma \text{ when } m_{\ell\ell} \sim m_Z\]
- **Modest excess in 2015**
  - 2.2 \(\sigma\) on and off \(m_Z\)
  - With intermediate \(E_T\)

To be watched in 2016
Heavy Ion: Pb+Pb data in 2015

- Recorded 550 $\mu$b$^{-1}$ of Pb+Pb data at $\sqrt{s_{NN}} = 5.02$ TeV
  - Big increase in hard-probe statistics
  - Jet events with $p_T$ from 100-1000 GeV
  - Analyses ongoing with first results now available on:

- High-mass di-muon pairs in ultra-peripheral Pb-Pb collisions
  - Studying the strong EM field surrounding nucleus
    - induces interactions at large impact parameters where strong interaction is not active
  - Well-described by STARLIGHT calculations of $\text{Pb} + \text{Pb} \rightarrow \mu^+ + \mu^- + \text{Pb}^{(*)} + \text{Pb}^{(*)}$
Search for di-photon resonance: significance, spin-2

Figure 15: Compatibility with the background-only hypothesis as a function of the assumed RS graviton mass for different values of $k/\bar{M}_{Pl}$ for the analysis optimized for a spin-2 resonance search.
Search for di-photon resonance: significance, spin-0

Figure 16: Compatibility with the background-only hypothesis as a function of the assumed signal mass $m_X$ for different values of the relative width $\Gamma_X/m_X$ for the analysis optimized for a spin-0 resonance search.