ATLAS RUN-2: Primi risultati e prospettive

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Legacy from Run-1

- Run-1 data taking completed in Feb. 2013
  - Excellence performance of LHC machine and ATLAS detector
  - Data collected: ~ 5fb$^{-1}$ at 7 TeV, ~ 20fb$^{-1}$ at 8 TeV
  - Data-analysis still on-going

- 465 publications to date
  - Higgs boson observation and main properties measured
  - 198 measurement papers
  - 232 (null) search result papers
  - 26 papers on performance of detector, reconstruction and simulation

- Many ATLAS+CMS combined physics results, e.g.
  - March 2015: Higgs Mass
    - measured with <0.2% precision
  - September 2015: Higgs Couplings
    - sensitivity improved by almost $\sqrt{2}$
LHC Run-2

- **LHC machine**
  - Large increase in cross sections due to $\sqrt{s}$ increase from 8 to 13 TeV
    - Max Luminosity: $1.3 \times 10^{34}$ cm$^{-2}$ s$^{-1}$
    - More than 100 pb$^{-1}$ by end of 2018
  - Priority for 2015 run
    - Establish proton-proton collision at 13 TeV with 25 ns and low $\beta^*$ (from 80 to 60 or 40) to prepare production runs in 2016-2018.

- **ATLAS experiment**
  - Search for new Physics Beyond Standard Model
    - Excellent discovery potential
  - SM Precision measurements at 13 TeV
    - Higgs, top, W/Z, B, ...
  - Study of rare processes
    - $t\bar{t}H$, 4-top, VBS, ...

\[ \sigma^* \propto \sqrt{\beta^*} \]

\[ \hat{S} = x_p \cdot x_{\bar{p}} \cdot s \]

A factor 10 to 50 higher luminosity for $2 < M_x < 3$ TeV
Physics Potential for Run2

Cross section ratio: $\sigma(13 \text{ TeV})/\sigma(8 \text{ TeV})$
- Inelastic pp cross section: 1.2
- Z boson cross sections: 1.7
- ttbar cross section: 3.3
- Gluino pairs ($M=1.5 \text{ TeV}$): 46
- Excited quarks ($4 \text{ TeV}$): 56
- QBH ($6 \text{ TeV}$): 9000

Hugely increased potential for discovery of heavy particles at 13 TeV!
ATLAS Upgrade during LS1

Insertable B-Layer (IBL), 4th silicon pixel detector layer
- 2 cm x 2 cm FE-I4 Pixel Chip, 130 nm CMOS process
- Innermost Pixel detector layer at R=3.3 cm from the beam
- Improves b-tagging performance

Trigger improvements
- New Topological L1 trigger,
- new central trigger processor,
- restructuring of high-level trigger, new Fast TracK Trigger (FTK)

Software
- Many improvements to simulation, reconstruction, analysis software

Overall detector consolidation
- Muon chambers completion (|\eta| = 1.1-1.3) and repairs
- improved readout of various systems, (L1 rate up to 100 kHz)
- repair of pixel modules and calorimeter electronics
- new pixel services, new luminosity detectors, new MBTS detector

22/9/15
### LHC Schedule in 2015

<table>
<thead>
<tr>
<th>Week</th>
<th>April</th>
<th>May</th>
<th>June</th>
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<tbody>
<tr>
<td>Mo</td>
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- **Beam splashes:** April 5th and 7th
- **13 TeV test collisions:** May 20th and 21st
- **First collisions with stable beam:** June 3rd

**July**

- **27th:** Leap second
- **29th:** Intensity ramp-up with 50 ns beam
- **30th:** MD 1
- **31st:** Intensity ramp-up with 25 ns beam
- **32nd:** MD 2

**August**

- **30th:** MD 1
- **31st:** Intensity ramp-up with 25 ns beam
- **32nd:** MD 2

**September**

- **24th:** VoM
- **31st:** TS2
- **Jeune G**

**Machine checkout**

- April 6th
- May 20th

**Recommissioning with beam**

- May 19th

**Scrubbing for 25 ns operation**

- June 3rd

**Scrubbing for 50 ns operation**

- June 8th
Run-2 Data taking

- Integrated luminosity recorded: $0.86 \text{ fb}^{-1}$, $L_{\text{max}} = 2.7 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$
- Average Pileup: $\mu \approx 20$ for 50ns, $\mu \approx 17$ for 25ns
  - Special runs taken with low pileup ($\mu << 1$) for soft QCD studies
- Data taking efficiency: $\sim 90\%$
  - 93.3% of recorded data good for physics analyses

ATLAS pp run: June-July 2015

<table>
<thead>
<tr>
<th>Inner Tracker</th>
<th>Calorimeters</th>
<th>Muon Spectrometer</th>
<th>Magnets</th>
</tr>
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<tbody>
<tr>
<td>Pixel</td>
<td>SCT</td>
<td>TRT</td>
<td>LAr</td>
</tr>
<tr>
<td>97.3</td>
<td>99.6</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Tile</td>
<td>MDT</td>
<td>RPC</td>
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<td>CSC</td>
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<td>TGC</td>
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<td>Solenoid</td>
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<td>Toroid</td>
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</tbody>
</table>

All good for physics: 93.3%
Outlook for the rest of 2015 and beyond

Latest news: Intensity ramp up with 25 ns bunch spacing
- 1033 bunches per beam, 144 bunch trains
- Bunch populations $1.0-1.1 \times 10^{11}$
- Now progress in smaller steps

<table>
<thead>
<tr>
<th>Week</th>
<th>Nc</th>
<th>Beta *</th>
<th>ppb</th>
<th>EmitN</th>
<th>Lumi [cm$^{-2}$s$^{-1}$]</th>
<th>Days (approx)</th>
<th>Int lumi [fb$^{-1}$]</th>
<th>Pileup</th>
</tr>
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<tbody>
<tr>
<td>50 ns</td>
<td>476</td>
<td>80</td>
<td>1.1e11</td>
<td>1.8</td>
<td>1.6e33</td>
<td>14</td>
<td>0.1</td>
<td>27</td>
</tr>
<tr>
<td>2015.1</td>
<td>1200</td>
<td>80</td>
<td>1.2e11</td>
<td>3.5</td>
<td>3.6e33</td>
<td>50</td>
<td>~2.3</td>
<td>21</td>
</tr>
<tr>
<td>2015.2</td>
<td>1200</td>
<td>60</td>
<td>1.2e11</td>
<td>2.3</td>
<td>5.6e33</td>
<td>47</td>
<td>~3.4</td>
<td>33</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Peak lumi E34 cm$^{-2}$s$^{-1}$</th>
<th>Days proton physics</th>
<th>Approx. int lumi [fb$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>~0.5</td>
<td>65</td>
<td>3</td>
</tr>
<tr>
<td>2016</td>
<td>1.2</td>
<td>160</td>
<td>30</td>
</tr>
<tr>
<td>2017</td>
<td>1.5</td>
<td>160</td>
<td>36</td>
</tr>
<tr>
<td>2018</td>
<td>1.5</td>
<td>160</td>
<td>36</td>
</tr>
</tbody>
</table>

22/9/15
Run-2 Detector and Object Performance

New pixel layer (IBL)
• IBL fully operational
  – Material mapped using photon conversions and hadronic interactions in situ
• Significant improvement in impact parameter resolution
  – Reduced multiple scattering
  – Reduced size of pixels in longitudinal direction (400 μm => 250 μm)
• Improved b-tagging
  – ~ +10% relative improvement in b-jet efficiency for same light-jet rejection
• Z’s and J/psi’s used to evaluate electron energy scale  
  - Mean and resolution already well understood  
• Electron identification  
  - Based on many variables combined in a likelihood (shower shape, track properties, etc)  
• Electron efficiencies between 75% and 95%  
  - Three different identification criteria defined: loose, medium and tight  
  - Differences between data and MC corrected by in-situ calibration
Muon performance

**Muon reconstruction efficiency**

- High reconstruction efficiency
  - Well modeled by simulation
- Muon momentum scale
  - Combines Inner Detector and Muon Spectrometer information
  - Resolution and scale extracted in data using Z and J/ψ peak
- Performance
  - Momentum scale already understood with precision of 0.2%
  - Resolution also understood to within 5% in the momentum range of the J/ψ

**Mean value of the J/ψ → μ μ inv mass**

**Resolution using the J/ψ → μ μ peak**
Early results at $\sqrt{s}=13$ TeV
Inelastic pp Cross Section at 13 TeV

- Inelastic cross section measured at 13 TeV
  - using just 63 $\mu$ b$^{-1}$ of data (recorded in low luminosity running period)
- New MBTS detectors installed during shutdown
  - Trigger on one MBTS
  - 2cm thick discs of highly efficient polystyrene scintillators mounted at $z=\pm3.6$ m
  - Pseudorapidity range: $2.07<|\eta|<3.86$

\[ \sigma_{\text{inel}} = 73.1 \pm 0.9 \text{(exp.)} \pm 6.6 \text{(lum.)} \pm 3.8 \text{(extr.)} \text{ mb} \]

\[ \sigma_{\text{fid}} = 65.2 \pm 0.8 \text{ (exp.)} \pm 5.9 \text{ (lum.)} \text{ mb} \]

Syst.error dominated by luminosity measurement
Minimum Bias charged particle differential cross-section

- Event selection:
  - Triggered by MBTS trigger ($\varepsilon > 99\%$)
  - Requirements:
    - $\geq 1$ track with $p_T > 0.5$ GeV and $|\eta| < 2.5$, Vertex ($\geq 2$ tracks with $p_T > 0.1$ GeV)

Measurements compared to variety of MC models
- These MC are used to model pileup pp interaction
- Pythia tunes and EPOS in better agreement with the data
Charged particle multiplicity for $p_T > 0.5$ GeV at $\eta = 0$ versus $\sqrt{s}$

Pythia tunes (used for our pile-up simulation) and EPOS in better agreement with the data
Large-range Correlations

- Dedicated high multiplicity trigger > 60 tracks
- Define correlation function between any two particles a and b

Two particle correlation in $\Delta \eta$ and $\Delta \phi = 0$

$\sqrt{s} = 13$ TeV, $L_{\text{int}} = 14$ nb$^{-1}$

Data 2015

$10 \leq N_{\text{ch}}^{\text{rec}} < 30$

$N_{\text{ch}}^{\text{rec}} \geq 120$

$C(\Delta \eta, \Delta \phi) = \frac{S(\Delta \phi, \Delta \eta)}{B(\Delta \phi, \Delta \eta)}$

- High $N_{\text{ch}}$ events show correlations at large $\Delta \eta$ and $\Delta \phi = 0$
- Observe “ridge” opposite to jet peak
- Effect present strongly in p-A and A-A collisions
  - First observed on p-p collisions by CMS at $\sqrt{s} = 7$ TeV

ATLAS-CONF-2015-027
The Ridge at 13 TeV pp collisions

- Studied integrated yield for for $2<|\Delta \eta|<5$

\[ Y(\Delta \phi) = \left( \frac{\int B(\Delta \phi)d\Delta \phi}{N^a \int d\Delta \phi} \right) C(\Delta \phi) \]

with

\[ C(\Delta \phi) = \frac{\int_2^5 d|\Delta \eta| \cdot S(\Delta \phi, |\Delta \eta|)}{\int_2^5 d|\Delta \eta| \cdot B(\Delta \phi, |\Delta \eta|)} = \frac{S(\Delta \phi)}{B(\Delta \phi)} \]

- Relative strength of “ridge“
  - Same N(trk) dependence as at 7 TeV and 13 TeV
  - consistent with CMS
QCD

Run Number: 271298, Event Number: 4036028
Date: 2015-07-11 02:09:14 CEST

pp \rightarrow \text{jet jet +X}
Inclusive jet cross-section

- Jets reconstructed with anti-$k_T$ algorithm, $R=0.4$, $|y|<0.5$
- Cross section measured using only 78 pb$^{-1}$
  - Largest uncertainty: luminosity (+-9%)
  - Good agreement with fixed-order NLO calculation and several PDFs

ATLAS-CONF-2015-034
SIF2015 / A.Di Ciaccio University of Roma Tor Vergata and INFN
$Z \rightarrow \mu\mu$

W and Z bosons physics
W and Z boson measurements

Selection:
- Isolated electron or muon: $p_T > 25$ GeV
- W bosons: $E_T^{\text{miss}} > 25$ GeV, $m_T > 50$ GeV
- Z bosons: Require two opposite-charge leptons $66 \text{ GeV} < m(\ell\ell) < 116$ GeV

• About 1 million W candidates selected and 100k Z candidates
• Measured: fiducial cross section and total cross section
Measurements agree with predictions at NLO EW and NNLO QCD with different PDFs

- Precision limited by luminosity uncertainty of ±9% and lept. efficiency
- Measurement uncertainties (without luminosity) already of the same magnitude as the theoretical uncertainties due to PDFs and higher order corrections

\[
R = \frac{\sigma(W) \times BR(W \rightarrow l\nu)}{\sigma(Z) \times BR(Z \rightarrow ll)}
\]

\[
R = 10.30 \pm 0.04 \text{ (stat.)} \pm 0.33 \text{ (syst.)}
\]
Dependence of $\sigma (W)$ and $\sigma (Z)$ on $\sqrt{s}$

Cross sections increase by factor $\sim 2$ for both W’s and Z’s compared to 7 TeV
Top Quark Production

Run: 267638
Event: 193690558
2015-06-13 23:52:26 CEST
Top cross section: dilepton channel

- Event selection:
  - Isolated $e$ and $\mu$ with $p_T > 25$ GeV
  - One or two $b$-jets
    - $N_1$: 1 $b$-jet
    - $N_2$: 2 $b$-jets
- Solve equations for cross section and fraction of $b$-jets found ($\varepsilon_b$)

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

Data: $\varepsilon_b = 52.7 \pm 2.6$ (stat.) $\pm 0.6$ (syst.)%  
MC: $\varepsilon_b = 54.3\%$

b-tagged jets in preselected $e\mu$ events

<table>
<thead>
<tr>
<th>Event counts</th>
<th>$N_1$</th>
<th>$N_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>319</td>
<td>167</td>
</tr>
<tr>
<td>$Wt$ single top</td>
<td>29.0 ± 3.8</td>
<td>5.6 ± 2.0</td>
</tr>
<tr>
<td>Dibosons</td>
<td>1.1 ± 0.2</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>$Z(\to \tau\tau \to e\mu)$+jets</td>
<td>1.3 ± 0.7</td>
<td>0.1 ± 0.1</td>
</tr>
<tr>
<td>Misidentified leptons</td>
<td>6.0 ± 3.9</td>
<td>2.8 ± 2.9</td>
</tr>
<tr>
<td>Total background</td>
<td>37.3 ± 5.5</td>
<td>8.5 ± 3.5</td>
</tr>
</tbody>
</table>
Top cross section (e μ channel) vs √s

• Large increase of cross section as expected
  – $\sigma (13 \text{ TeV})/\sigma (8 \text{ TeV}) \approx 3.4$ and $\sigma (13 \text{ TeV})/\sigma (7 \text{ TeV}) \approx 4.5$

\[ \sigma_{t\bar{t}} = 825 \pm 49 \text{ (stat)} \pm 60 \text{ (syst)} \pm 83 \text{ (lumi)} \text{ pb} \]
Top cross section: single lepton, dilepton ($e\mu\mu\mu$, $ee$)

ATLAS measurements at 7, 8 and 13 TeV in agreement with NNLO+NNLL calculations

Czakon, Fiedler, Mitov, PRL 110 (2013) 252004
$m_{\text{top}} = 172.5$ GeV, PDF $\oplus \alpha_s$ uncertainties according to PDF4LHC

ATLASECONF-2015-049
High-mass di-jet searches

Highest-mass dijet event and the highest $H_T$ event at 13TeV

$M_{jj} = 5.2$ TeV $P_{T^{jet1}} = 2.5$ TeV, $P_{T^{jet2}} = 2.4$ TeV
New phenomena in di-jet search

80 pb$^{-1}$

jets: anti-$k_t$, $R = 0.4$

$\geq 2$ jets, $p_T > 410, 50$ GeV

New Resonance search

\[ M_{jj} \text{ mass distribution} \]

**ATLAS Preliminary**

<table>
<thead>
<tr>
<th>$\sqrt{s} = 13$ TeV, $80$ pb$^{-1}$</th>
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<tbody>
<tr>
<td><strong>Data</strong></td>
</tr>
<tr>
<td><strong>Background fit</strong></td>
</tr>
<tr>
<td><strong>BumpHunter interval</strong></td>
</tr>
<tr>
<td>**BlackMax, } m = 4.0$ TeV</td>
</tr>
<tr>
<td>**BlackMax, } m = 5.0$ TeV</td>
</tr>
</tbody>
</table>

\[ \rho \text{-value} = 0.79 \]

Fit Range: 1.1 - 5.3 TeV

$|y^*| < 0.6$

No significant excess found

Deviation in angular variables $\chi$

\[ \chi = e^{2|y^*|} \sim \frac{1 + \cos \theta^*}{1 - \cos \theta^*} \]

$y^* = \frac{1}{2}(y_1 - y_2)$

No significant deviation observed
Interpretation in a model of extra-dimensions and QBH

Assume $n=6$, $M_D = M_{th}$

$M_D =$ Plack scale in extra-dimensions
$M_{th}:$ threshold scale for black hole production

The resonant search excludes:
- $M_{th} < 6.8$ TeV at 95% CL using QBH
- $M_{th} < 6.5$ TeV at 95% CL using BlackMax

The angular search excludes:
- $M_{th} < 6.5$ TeV at 95% CL using QBH
- $M_{th} < 6.4$ TeV at 95% CL using BlackMax
Multi-jet search for thermalizing QBH

- Non resonant search
  - \( N_{\text{jet}} \geq 3, \ P_T > 50 \ \text{GeV} \)
- Look for an excess in \( H_T \) (HT scalar sum of \( p_T \) of all jets of \( p_T > 50 \ \text{GeV} \)), \( H_T > 1 \text{TeV} \)
  - Data-driven background fits in control region (CR)
  - Check in validation (VR)
  - Compared to events in signal region (SR)

No significant deviations observed in any signal region

- Set 95% CL limits on models of low scale gravity (\( n = 6 \)) using \textsc{Charybdis2} Model
- Improvement of 2-2.5 \( \text{TeV} \) on exclusion limit with respect to Run-1 result
Many New Physics Searches on going...

**Z’ search: Dilepton mass spectrum**

**W’ search: Lepton + missing ET**

**G*: Diphoton mass spectrum**

**Control-region for SUSY search**


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Conclusions and Outlook

- ATLAS has successful start data-taking at Run-2 and commissioned all its sub-detectors.
  - Re-establishing understanding of high momentum objects
    - Fundamental keys for the future precision measurements
- First results on several SM processes and searches at 13 TeV with <100 pb$^{-1}$
  - SM precision measurements important to understand background for searches of new physics
- ATLAS is fully ready for possible new discoveries and to perform precision physics at 13 TeV!

 Stay tune, the best has still to come..

- Could find evidence (3$\sigma$) for gluino mass up to ~1.5 GeV already with 5 fb$^{-1}$
Back-up
Resonances decaying to VV

- Major new tool: jet substructure