New developments in track reconstruction for the ATLAS experiment for Run-2 of the LHC

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Introduction

- **Improvements** over Long-Shutdown 1 (2012-2014) algorithmic and technical developments
- **Stability** against rapidly changing conditions of detector and LHC
  - data-driven measurements of key observables and comparison with simulation

ATLAS inner tracking results public page:
12 notes and ~20 set of plots on Run-2 data
Run-2 ATLAS Inner Detector

Transition radiation tracker
73 barrel and 160 end-cap planes
<hits> / track ~ 30

• Gas leaks developed ~end of Run-1
• Repair work during LS1
• Using Ar instead of Xe in regions where leaks could not be repaired

• Flexible approach to describe performance under different gas configurations

• Almost no effect on hit resolution
• Particle Identification slightly degraded
Strip detector
4 double-sided barrel layers and 2x9 end-caps
<hits / track> ~ 8

- 3 bunch-crossings read-out
- Veto signal in previous bunch crossing

• Reduced bunch-spacing causes hit inefficiencies after the first bunch in the train
  • tiny effect on track reconstruction efficiency
Run-2 ATLAS Inner Detector

Pixel detector
4 barrel layers, 2x3 end-caps including Insertable B-Layer (IBL) <hits / track> ~ 4

- IBL mechanical instability with temperature

ATLAS Preliminary

in-plane deformation

- Temperature not stable during data-taking due to radiation effects and operational constraints

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• Fit IBL distortion during “calibration loop”
  – detector re-aligned before offline processing after each run with ~1h time granularity

• Excellent alignment accuracy achieved
  – comparable or better to end of Run-1
  – capability of time-dependent re-alignment of full Inner Detector
Track impact parameter resolution

- Improved $d_0$ resolution in Run-2 thanks to IBL

- Measurement of $d_0$ resolution sensitive to
  - Alignment, intrinsic resolution at high $p_T$
  - Material budget at low $p_T$

- Material budget studied using in-situ techniques
Material budget probed using techniques complementary in systematics and coverage

- vertices from hadronic interactions
- photon conversions
- pixel → SCT extension efficiency

Initial under-estimation of IBL material corrected

- cause of over-optimistic $d_0$ resolution in simulation
Primary Vertex reconstruction

- Data-driven measurement of position resolution
  - beamspot transverse size smaller than vertex resolution!

- Algorithmic refinements for 2016 increase efficiency for high vertex densities

\[
\text{Pull}_x = \frac{x_{1, PV} - x_{2, PV}}{\sqrt{\sigma_{x_1, \text{fit}}^2 + \sigma_{x_2, \text{fit}}^2}}
\]

See poster by M. Zhang:
“Performance of the ATLAS primary vertex reconstruction algorithms”
Tracking in Dense Environments (TIDE)

- Resolve close-by particles leading to merged pixel clusters without increasing fakes
  - Local approach (2012) → multivariate technique exploit information on cluster charge and shape
  - Global approach (2015) → correlate information across layers
- Returns # of particles, positions, errors
- Verify robustness of local approach with simulation

ATL-PHYS-PUB-2015-006

ATLAS Preliminary
Simulation, $\tau \to \nu, 3\pi^\pm$
$\leq 2$ Shared SCT Clusters
No Secondaries

ATL-PHYS-PUB-2015-052

Pixel barrel (Nominal = 94.25% ± 0.07%)
IBL (Nominal = 93.12% ± 0.11%)

$\sqrt{s} = 13$ TeV
Number of pixels > 1
TIDE performance

- Performance measured in data with complementary techniques

**Geometrical extrapolation**
- Test local approach in separating single/multiple particle clusters

**Energy loss in Pixels (dE/dx)**
- Measure fraction of particles not reconstructed inside jets
- Statistically disentangle single/multiple particles from dE/dx in innermost layer

See poster by E.M. Duffield:
“Measurement of ATLAS track reconstruction inefficiency in dense jet environments using dE/dx”
“non-standard” tracking

• Dedicated tracking setup for specific needs
  – Minimum-bias → “single-interaction” mode, $p_T$ down from 400MeV to 100MeV
  – Heavy-Ion → “high-occupancy”, but $p_T$ threshold as low as possible (300/500MeV)
  – Large-radius tracking → decay products within the whole Pixel volume (large $d_0$)
  – Short-tracks → pixel-only tracks. Now reconstructed by default ($p_T > 5$GeV)
Conclusions

- Upgraded detector and rapidly changing running conditions pose new challenges to track reconstruction in Run-2

- Performed a comprehensive set of in-situ measurements of key observables

- Developed mechanisms to mitigate new problems and achieve better or similar performance than in Run-1
  - All of this reducing track reconstruction CPU timing by more than a factor of 4!

- Ready for the ongoing luminosity ramp-up to make the best use of the large dataset ahead of us
Introduction

**Improvements** over LS1 algorithmic and technical developments

**Stability** against rapidly changing conditions of detector and LHC
- data-driven measurements of key observables and comparison with simulation

**ATLAS inner tracking results** public page:
- 12 notes and 15 set of plots on Run-2 data

### Long-Shutdown (LS1)
- Detector upgrade
- Large software development
- High level Trigger 1kHz

### Luminosity ramp-up (exceeded design $10^{32} \text{cm}^{-2}\text{s}^{-1}$)
- $\sqrt{s} = 13\text{TeV}$
- higher $p_T$ objects
- 50 → 25ns bunch spacing

### Table

<table>
<thead>
<tr>
<th>Year</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
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<tr>
<td>2016</td>
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</tbody>
</table>

### Timeline
- Q1: Long-Shutdown (LS1)
- Q2: Detector upgrade
- Q3: Large software development
- Q4: High level Trigger 1kHz

### Data taking
- 2013
- 2014
- 2015
- 2016
TRT gas operation

**TRT 2015 Gas configuration**
- Xe
- Ar

**TRT 2016 Gas configuration**
- Xe
- Ar

[Diagram showing TRT gas configurations for 2015 and 2016]
IBL distortion

- Impact on track transverse impact parameter
• IBL deformation for various operational temperatures during 2015/2016
Primary vertex

ATLAS Preliminary Simulation $\sqrt{s}=13$ TeV

2015 Reco (R20.1)
2016 Reco (R20.7)

ATLAS Preliminary $\sqrt{s} = 13$ TeV

Data
Monte Carlo
Primary Vertex Resolution

ATLAS Preliminary

$\sqrt{s} = 13$ TeV, 216.9 $\mu$b$^{-1}$

Data 15, low-$\mu$

Monte Carlo

typical beamspot transverse size

2015 2016

 ATLAS Preliminary

$\sqrt{s} = 13$ TeV, 216.9 $\mu$b$^{-1}$

Data 15, low-$\mu$

Monte Carlo

Number of Tracks

Number of Tracks

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ATL-PHYS-PUB-2015-026
**ATLAS Preliminary**

\[ L \, dt = 2.8 \, fb^{-1}, \, \sqrt{s} = 13 \, TeV \]

200 GeV < \( p_T^{\text{jet}} \) < 400 GeV

- Single-Track Template
- Multiple-Track Template

**ATLAS Preliminary**

\[ L \, dt = 2.8 \, fb^{-1}, \, \sqrt{s} = 13 \, TeV \]

1000 GeV < \( p_T^{\text{jet}} \) < 1200 GeV

\( F^{\text{lost}} = 0.033 \pm 0.006 \) (stat)

- Data 2015
- Fit
- Single-Track Contribution
- Multiple-Track Contribution

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0 < \(|\eta|\) < 1.2

Track \( p_T \) > 10 GeV

1 pixel hit per layer

B-layer dE/dx
**Method (a)**

- *ATLAS Preliminary*
- $\sqrt{s} = 13$ TeV
- Measurement using extrapolation
- 2nd pixel layer
- Tracks with single-particle-cluster:
  - Data
  - Di-jet MC
- Tracks with multi-particle-cluster:
  - Data
  - Di-jet MC

**Method (b)**

- *ATLAS Preliminary*
- $\sqrt{s} = 13$ TeV
- Measurement using overlap region
- IBL
- Tracks with single-particle-cluster:
  - Data
  - Di-jet MC
- Tracks with multi-particle-cluster:
  - Data
  - Di-jet MC
TIDE - geometrical