PROCEEDINGS OF SCIENCE

Improved track reconstruction for prompt and long-lived particles in ATLAS for the LHC Run 3

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In preparation for the LHC Run 3, the ATLAS experiment at the LHC has completed a major effort to improve the track reconstruction performance for prompt and long-lived particles. Resource consumption was halved while expanding the charged-particle reconstruction capacity. Large-radius track reconstruction, targeting long-lived particles, was optimized to run in all events expanding the potential phase-space of these searches. The detector alignment precision was improved to avoid limiting factors for precision measurements of Standard Model processes. Mixture density networks and simulating radiation damage effects improved the position estimate of charged particles overlapping in the ATLAS pixel detector, bolstering downstream algorithms' performance. The Adaptative Multi-Vertex Finder replaced the Iterative Vertex Finder for primary vertex reconstruction, improving the vertex reconstruction efficiency in high pile-up environments like such expected for the LHC Run 3. This contribution highlights the above achievements and reports on the readiness of the ATLAS detector for Run 3 collisions at 13.6 TeV.

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1. Introduction

The reconstruction of charged particles in the ATLAS [1] Inner Detector (ID) at the LHC [2] is a fundamental part of the ATLAS event reconstruction. The high granularity of the ID and its proximity to the interaction point allow to record up to 1500 hits per proton-proton collision. During the LHC Run 2, the number of proton-proton collisions per bunch crossing, pile-up $\langle \mu \rangle$, ranged between 20 and 40, giving rise to a total number of ID hits per bunch crossing between 30000 and 60000. Hits are processed and combined into clusters. With groups of 3 clusters, track seeds are built and, from those, the reconstruction of tracks is attempted via a Kalman Filter algorithm [3]. Since one cluster can correspond to one or more particles traversing that region of the detector, a Machine Learning algorithm predicts the number of particles associated to each cluster, as well as the hit position and uncertainty of each of the particles. With this information, a re-fit of the tracks is performed using a global χ^2 method [4], obtaining the final set of tracks of the event. Finally, the distribution of the impact parameter of the tracks in the beam axis direction, z_0, is used to fit the primary vertices.

The increase of $\langle \mu \rangle$ expected for the LHC Run 3, up to an average value of 50, constitutes a major challenge for the track reconstruction in ATLAS, since the number of charged particles produced per bunch crossing is expected to increase linearly with $\langle \mu \rangle$. The larger number of hits will translate in more complex combinatorics for the track reconstruction, which will demand higher per-event processing time of the tracking software. Moreover, the larger density of tracks will require an improvement in the performance of the tracking algorithms, since tasks like discriminating merged clusters or reconstructing primary vertices will become more challenging.

2. Improved hit position determination: Mixture Density Network

In the Run 2 ATLAS track reconstruction, one neural network (NN) was used to discriminate between three situations: having 1, 2 or ≥ 3 particles in one cluster. Then, nine NNs were used to compute hit position and uncertainty associated to the particles in the cluster. For the LHC Run 3, those nine NNs were substituted by three Mixture Density Networks (MDNs) [6]. Figure 1a shows that the truth hit residuals (difference between truth and predicted hit positions) are more symmetric and the widths are smaller for the Run-3 MDN-based setup.

3. Improved Primary Vertex reconstruction

Primary vertices are the locations of the proton-proton inellastic collisions from where charged particles originate [5]. Accurate and efficient primary vertex determination is crucial for the correct reconstruction of the kinematics of the collisions.

The first step of the primary vertex reconstruction is the *seed finding*, which consists in looking at the distribution of z_0 and locating the point with highest density of tracks, i.e. the primary vertex seed. After the seed is found, tracks whose closest approach to the seed is within $12\sqrt{\sigma^2(d_0) + \sigma^2(z_0)}$ are associated to the vertex[1]. These are used to fit the primary vertex position and, if the fit results pass

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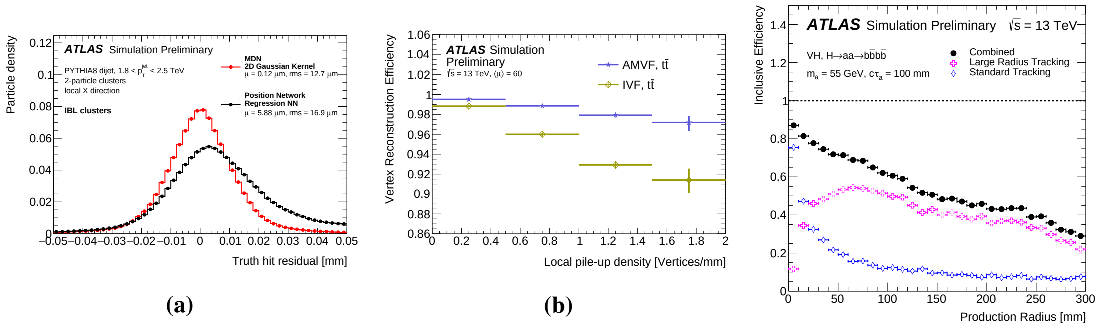
[1] d_0 is the impact parameter of the tracks in the direction transverse to the beam axis, while $\sigma(d_0)$ is the RMS of the d_0 distribution.



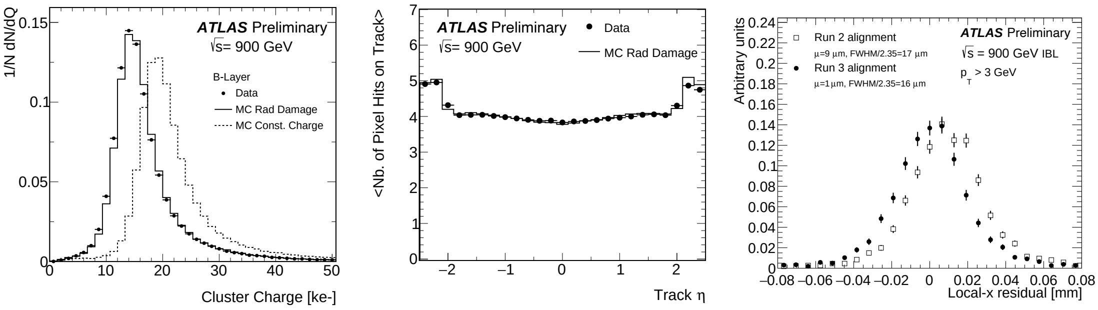
(a) **(b)** **(c)**

Figure 1: **(a)** Truth hit residual (difference between truth and predicted hit positions) for the Run-3 MDN-based setup and the Run-2 NN-based setup on clusters from the innermost pixel layer associated to two particles in dijet events. Figure extracted from Ref. [6]. **(b)** Vertex reconstruction efficiency for AMVF and IVF as a function of local pile-up density for $t\bar{t}$ events. Figure extracted from Ref. [7]. **(c)** Track reconstruction efficiency for displaced charged particles produced by the decay of long-lived scalar particles a as a function of their production radius. The a boson exclusively decays into a pair of b quarks and is produced in pairs through the decay of the higgs boson. The a boson mass is 55 GeV and the proper lifetime $c\tau$ is 100 mm. Figure extracted from Ref. [8]

some quality criteria, the fitted vertex is accepted as a reconstructed primary vertex. In the LHC Run 2, the Iterative Vertex Finder (IVF) algorithm removed the tracks associated to an accepted vertex and repeated the process to find the next primary vertex location. This approach works for low pile-up environments. However, for high $\langle\mu\rangle$, like that expected for the LHC Run 3, it is very likely that one track is very close to several seeds, which suggests that tracks should not be removed from the pool after being assigned to one accepted primary vertex. For this reason, the Adaptative Multi-Vertex Finder (AMVF) was developed for the LHC Run 3 [7]. Its main difference with respect to IVF is that tracks that belong to an accepted primary vertex are not removed from the pool of tracks for the next primary vertex assignment. Figure 1b shows that, for low pile-up conditions, IVF and AMVF present roughly the same vertex reconstruction efficiency. However, AMVF performance is considerably better when increasing the local pile-up density.

4. Improved large-radius track reconstruction

The standard track reconstruction in ATLAS is optimized for particles that point back to the interaction point (IP). Since this is not efficient for reconstructing particles that decay more than 5 mm away from the IP (see Figure 1c), a dedicated large-radius tracking (LRT) is used to reconstruct long-lived particles. During the LHC Run 2, the LRT was optimised for high signal efficiency, resulting in the reconstruction of a high number of fake tracks during real data-taking. Due to this, the LRT processing time per event was twice that of the standard track reconstruction. Consequently, LRT was only applied to ∼ 10% of the events recorded by the ATLAS detector. For the LHC Run 3, the LRT was updated, reducing the number of reconstructed fake tracks and the time consumption [8]. This allowed to include the LRT in the standard ATLAS track reconstruction, what will significantly increase the statistics of long-lived particles analyses with respect to Run 2.



(a) **(b)** **(c)**

Figure 2: **(a)** Cluster charge for the B-Layer planar sensors in data (points), MC simulation considering radiation damage (continuous line) and MC simulation without considering radiation damage (discontinuous line). **(b)** Average number of pixel hits associated to selected particle tracks as a function of the track pseudorapidity η. **(c)** Track-hit residuals in the IBL in the sensor local X direction (transverse to the beam pipe). Figures extracted from Ref. [10].

5. First LHC Run 3 pp collisions at $\sqrt{s}$ = 900 GeV

Thanks to the improvements, the per-event processing time of the ATLAS track reconstruction chain was reduced by a factor 2 for the LHC Run 3 ($\langle\mu\rangle \sim 50$) [9]. Moreover, radiation damage of the pixel sensors was included in the Run 3 ATLAS Monte Carlo, providing a more realistic description of the detector response [10]. These improvements in the track reconstruction chain were already tested on the Run 3 data for collisions at a center of mass energy $\sqrt{s}$ = 900 GeV. Figures 2a and 2b show the nice agreement between Run 3 Monte Carlo simulation and data. Moreover, routine jobs such as ID alignment are already being performed to great precision, as shown in Figure 2c.

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