Neural network based cluster reconstruction in the ATLAS pixel detector

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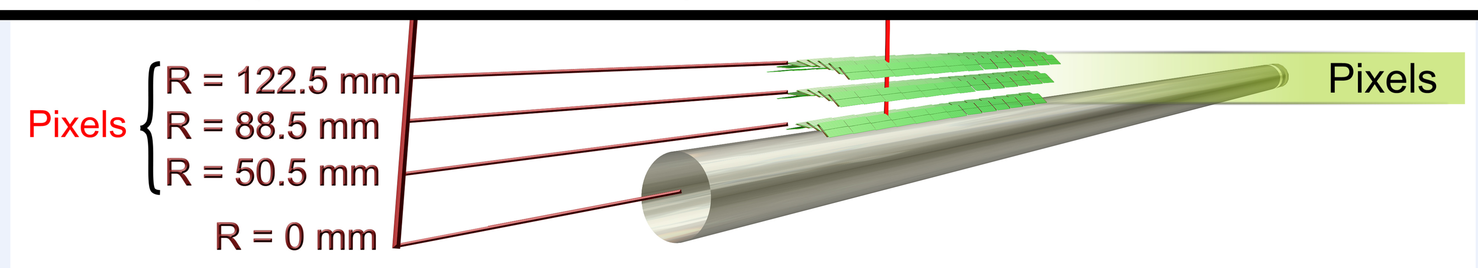
for the ATLAS Collaboration

Introduction

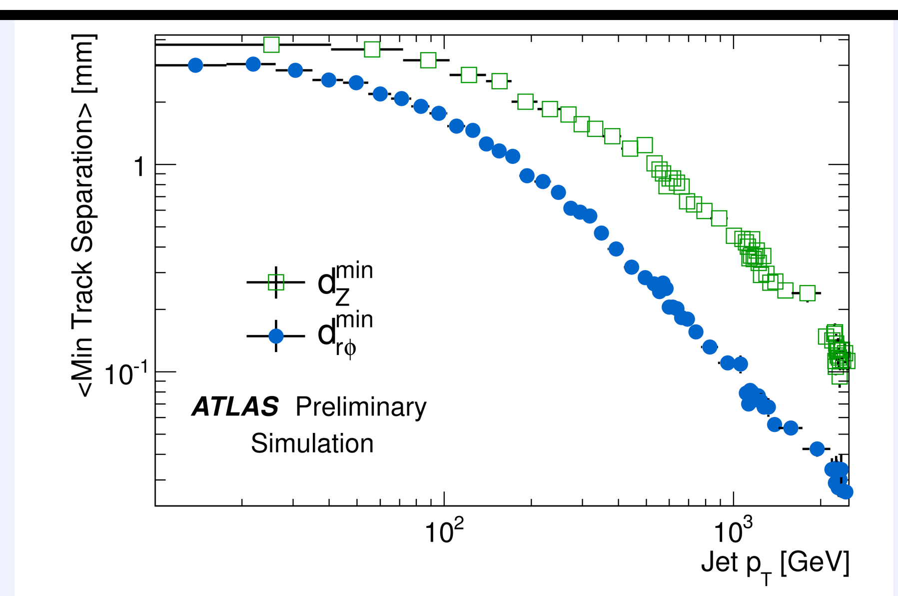
- The ATLAS silicon pixel detector determines the position of passing charged particles
- It consists of three layers with 80.4 million pixels in total of which $\sim 90\,\%$ are $50\,\mu\text{m} \times 400\,\mu\text{m}$



Schematic of the ATLAS Pixel barrel with its three layers being crossed by one high-energy particle

See A.Favareto's poster for further information about the ATLAS Pixel detector

- Pixels with deposited charge are grouped into clusters if they have a common edge or a common corner
- By using the charge deposited in each pixel, measured from the time over threshold (ToT) by the sensors, the resolution of the particle's position can be improved using charge interpolation
- The **standard reconstruction algorithm** uses a **linear interpolation** between the first and last set of pixels in a cluster
- In a densely populated track environment (e.g. a jet) two or more particles might deposit charge in adjacent pixels whereby shared clusters are produced
- As shown in the figure, it is likely that tracks of jets with p_T>1 TeV produce merged clusters



Mean minimum separation between two particles in a jet for the innermost layer of the ATLAS Pixel barrel ($|\eta|<2.77$ with pixel dimension $50\,\mu m \times 400\,\mu m$) using dijet samples. The mean minimum particle separation in z, d_Z^{min}, requires the separation in $r\phi<50\,\mu m$. The mean minimum particle separation in $r\phi$, $d_{r\phi}^{min}$, requires the separation in $z<400\,\mu m$.

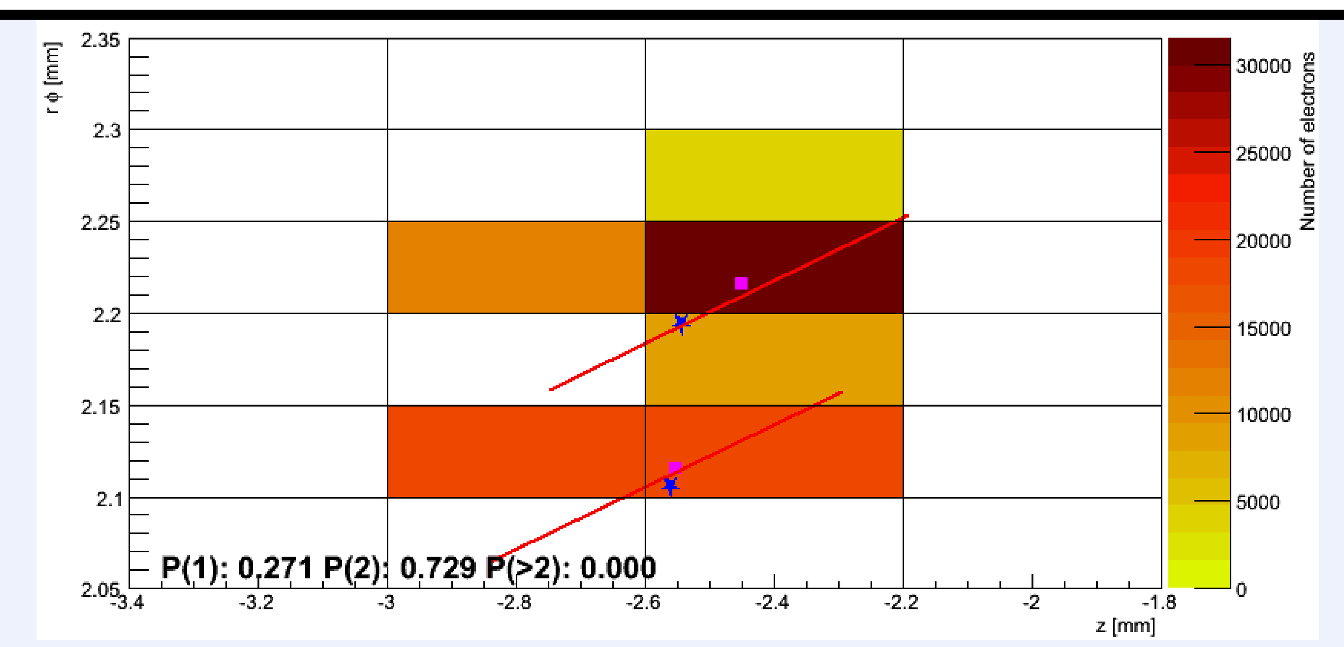
- A **neural network (NN) algorithm** is developed to determine a **more precise cluster position** and improve the **two-particle separation**
- This is achieved by using the detailed information of the cluster shape and identifying merged clusters produced by nearby particles

Method

Neural Network

- *The NN is capable of using variables with non-linear correlations*
- *In hidden layers the different inputs get different weights to finally determine the output*

- The NN is used due to the non-linear correlations between the cluster properties
- Each of these cluster properties alone (e.g. the charge of a single pixel) is nearly meaningless without putting it in context (e.g. knowing the charges of the adjacent pixels)
- These variables are the following **inputs for the NN**:
  - Matrix with 7×7 pixels containing the **deposited charges** within the original cluster. The cluster is centered in the matrix by using the charge weights determined by ToT
  - Vector containing information of the **longitudinal size of the pixel**. It distinguishes between standard length of $400\,\mu\text{m}$ and long pixels of $600\,\mu\text{m}$
  - Estimated **direction** of the traversing charged particle



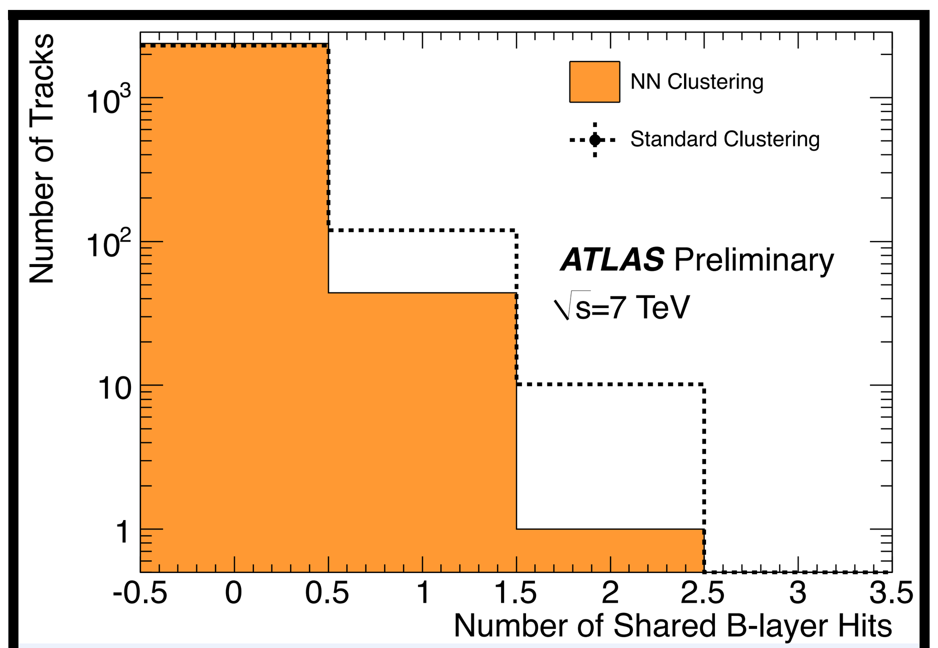
A cluster shown with the particles' true positions (pink marker) and their true directions (red line). Additionally, the NN probabilities for the particle multiplicity (lower left corner) and the estimated positions (blue marker) are displayed.

- The **results of the NN algorithm** consist of:
  - Estimation of the **number of charged particles** passing through the cluster
  - For each of the estimated number of particles, the **position** with its **uncertainty** is determined in two dimensions
- Different sets of NNs are used to determine the particle multiplicity, the particle position and the errors on the particle position
- All of the NNs use the same three inputs specified above
- To train the NNs, mixed samples of $t\bar{t}$ and high p_T dijet events (140<jet p_T<560 GeV) are used

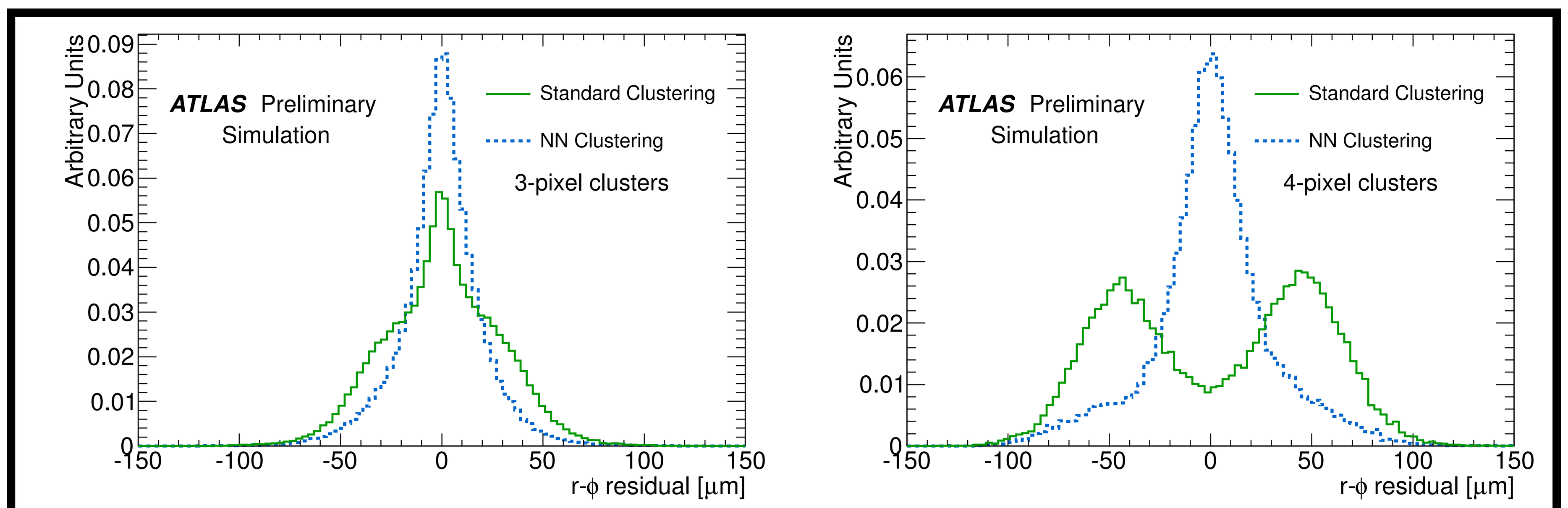
Results

Hit Performance

- The amount of **shared hits on-track** (hits associated to multiple tracks) **decreases** strongly in the innermost layer with NN clustering as shown in the figure below
- In the two figures below, the cluster residual is the difference between the cluster position and the extrapolated track position
- In these two figures, the **significant improvement in resolution** for 3 and 4 pixel clusters in the azimuthal direction is shown:
  - The improvement is especially relevant for 4-pixel clusters where a double-peak shape for standard clustering is observed
  - Clusters of this size are mainly produced by delta rays
  - The residual of clusters effected by delta rays is especially improved by the ability of the NN algorithm to interpolate non-linearly
  - Mainly due to this better treatment of delta rays, the double-peak vanishes when applying the NN algorithm



The number of shared hits on-track in the innermost Pixel layer reconstructed with and without the NN-based clustering for tracks with p_T>100 GeV of a $t\bar{t}$ sample

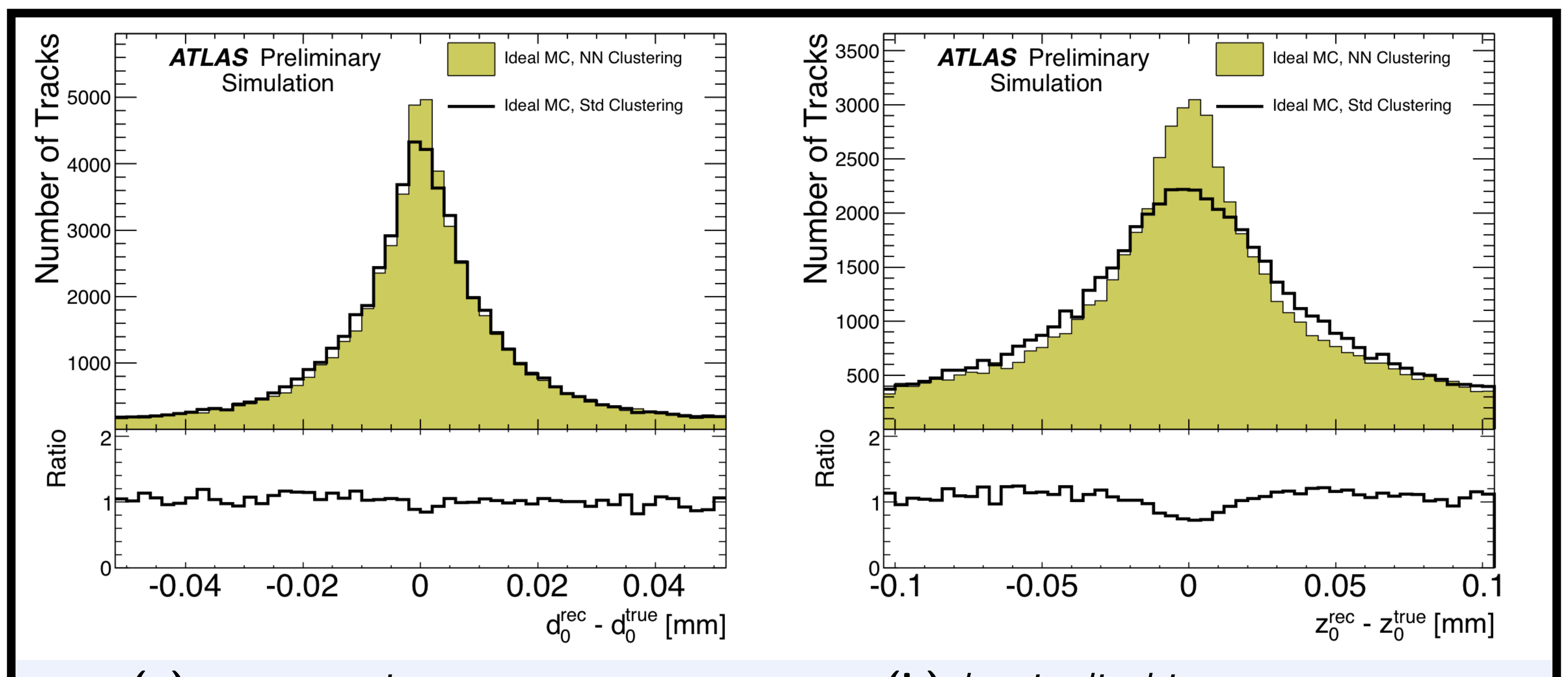


(a) *for 3-pixel clusters* **(b)** *for 4-pixel clusters*

The cluster residual in the $r\phi$-direction reconstructed with the standard algorithm and the NN clustering algorithm of a $t\bar{t}$ sample

Tracking Performance

- The NN algorithm can develop its potential best in the innermost Pixel layer, where the two-particle separation is very small
- The innermost cluster position determines most considerably the impact parameter resolution
- The improvement of the cluster position resolution has a direct impact on primary and secondary vertex reconstruction especially relevant for heavy flavor tagging
- The **impact parameters** shown in the figure below are **improved by $\sim$ 15 %** for high p_T tracks for which the improvements by the NN position reconstruction are particularly striking



(a) *transverse impact parameter* **(b)** *longitudinal impact parameter*

Simulated impact parameter resolution with and without NN-based clustering for tracks with p_T>100 GeV of a $t\bar{t}$ sample

Conclusions

- The NN algorithm **significantly improves tracking performance** for physics analysis
- The improvements coming from the NN reconstruction will boost performance even more when reaching the design luminosity of the LHC, and in future upgrades, because of the higher particle density and statistics of high p_T jets
- During the 2013 shutdown, the ATLAS pixel detector will be upgraded with the insertion of a new layer even closer to the interaction point (R=33.25 mm)
- In this extremely dense environment, the improved two particle separation power of the NN algorithm will **boost the detector capability** extending the physics potential of ATLAS