Neural network based cluster creation in the ATLAS Pixel Detector

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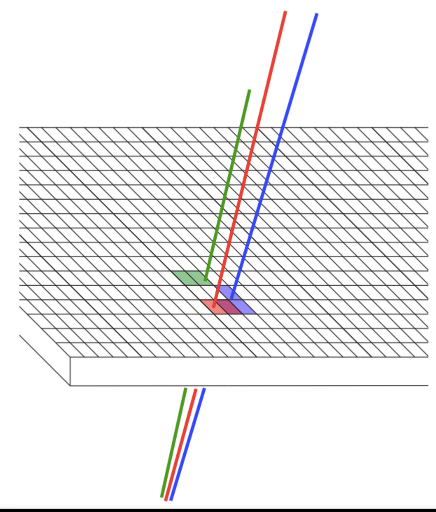
Introduction

- Particles crossing the Pixel Detector often release charge in more than one pixel: position of crossing is computed from the signal heights inside the cluster of pixels.
- A neural network is implemented to make full use of the 2D distribution of the read-out signals.
- This results in significant improvements in position resolution and two-particle separation: especially relevant for particles the very dense core of high energy jets at the LHC.



The standard approach: charge sharing

Cluster reconstruction is usually performed **interpolating the collected charge**.

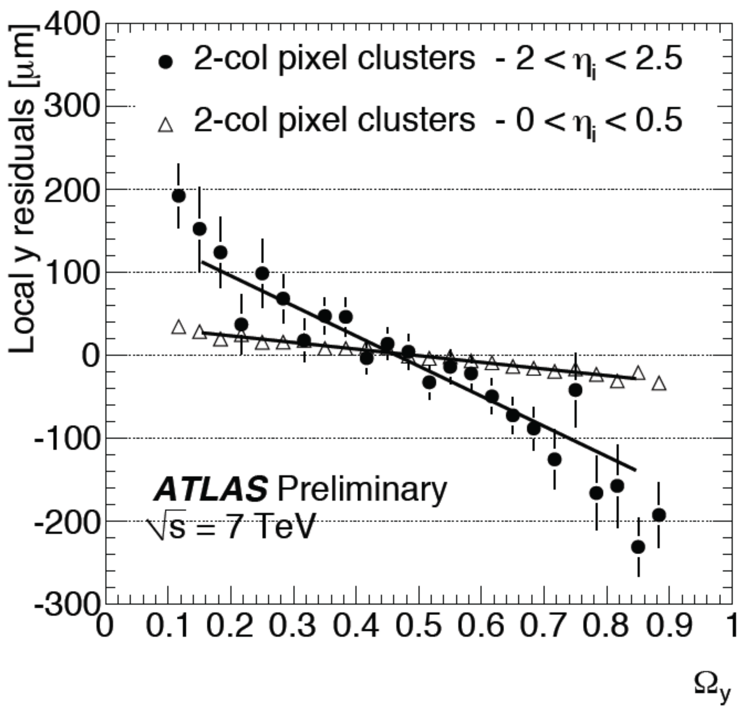
- **Independent projections** on the two pixel coordinates.
- **Charge sharing variables:**

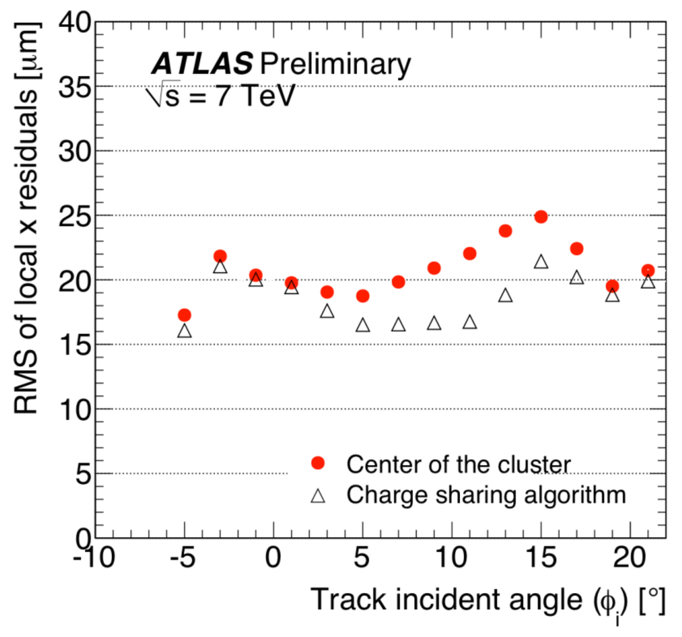
$$\Omega_x = \frac{Q_{\text{last row}}}{Q_{\text{first row}} + Q_{\text{last row}}} \qquad \Omega_y = \frac{Q_{\text{last column}}}{Q_{\text{first column}} + Q_{\text{last column}}}$$

- **Position correction:**

$$x_{\text{center}} + \Delta_x(\Omega_x - \tfrac{1}{2}),\; y_{\text{center}} + \Delta_y(\Omega_y - \tfrac{1}{2})$$

  - Δ values calibrated on data





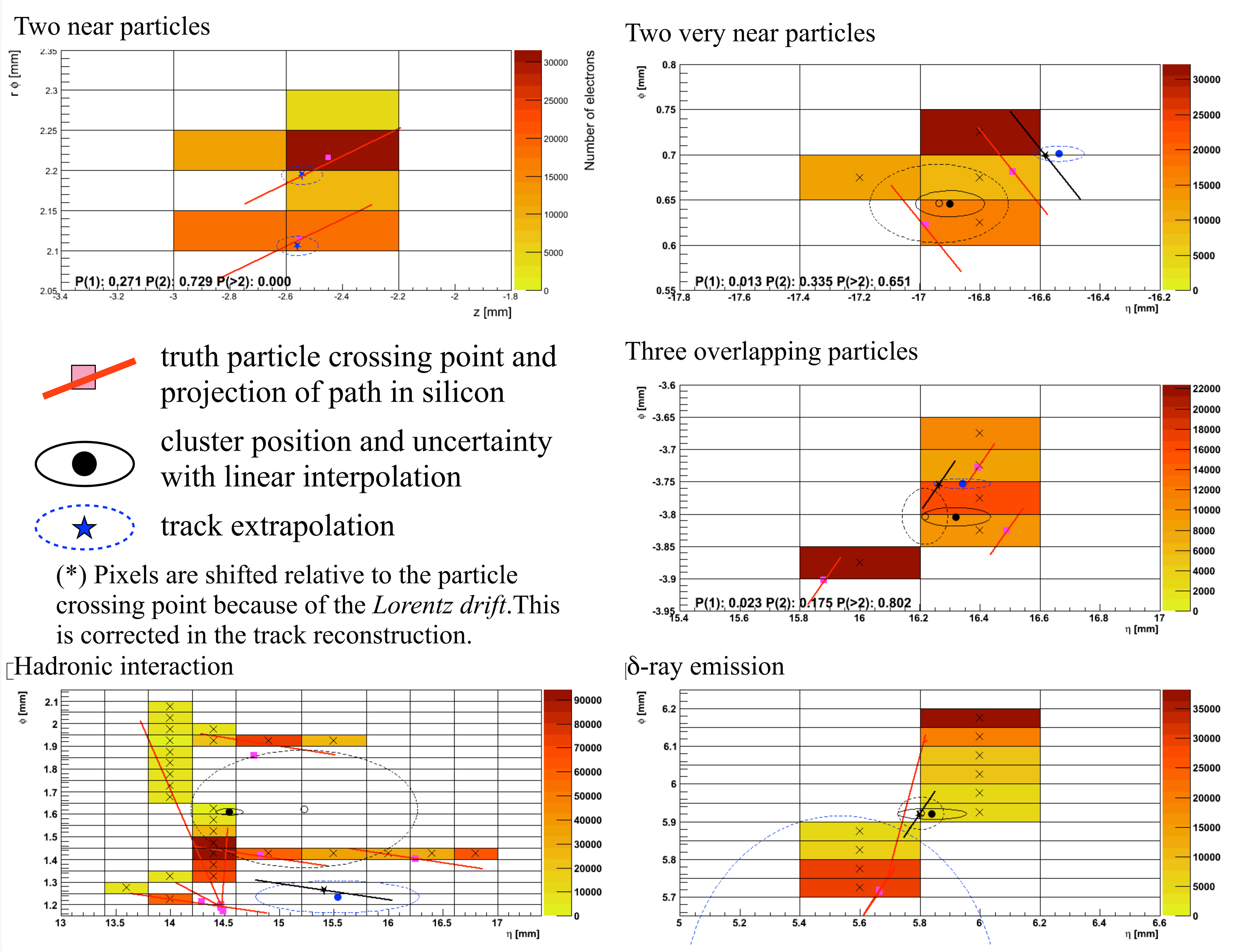
Resolution is excellent for most clusters:

- the algorithm reflects the *approximately uniform charge generation* along the path of the particle in silicon

But the procedure is not always adequate:

- nearby particles giving origin to *merged clusters*
- interaction with the material resulting in *large clusters*

Cluster shapes



The neural network approach

To achieve better performance **all** the detector information needs to be used:

- the **signal** of **each pixel**
- the **detailed cluster shape**

A set of neural networks is trained to compute:

- the **probability a cluster is due multiple** nearby **particles**;
- the **(multiple)** crossing **position** ***during pattern recognition***
- an **improved** crossing **position** ***during track fit***
- estimate the **position uncertainty**

Neural networks inputs:

- a 7×7 pixel matrix, containing the collected charge of each pixel
- the pixels dimensions (y-pitch can be 400 or 600 μm)
- estimated direction of incoming particle:
  - from **module position** during ***pattern recognition***
  - from **track extrapolation** in ***final track fit***

A single hidden layer.

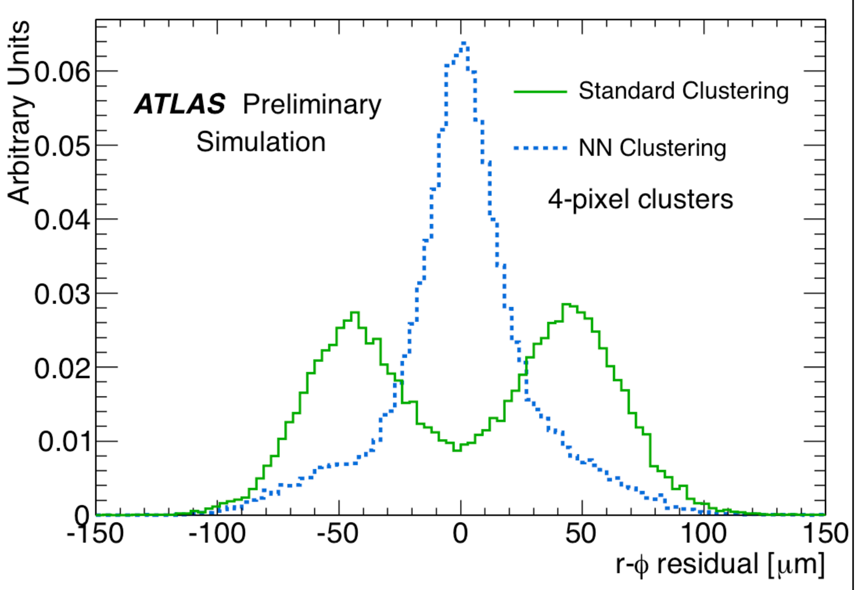
Training on simulated $t\bar{t}$ and high p_T di-jet events (140 < jet p_T < 560 GeV).

Performance

Cluster resolution

A dramatic improvement in resolution is visible on moderately sized clusters.

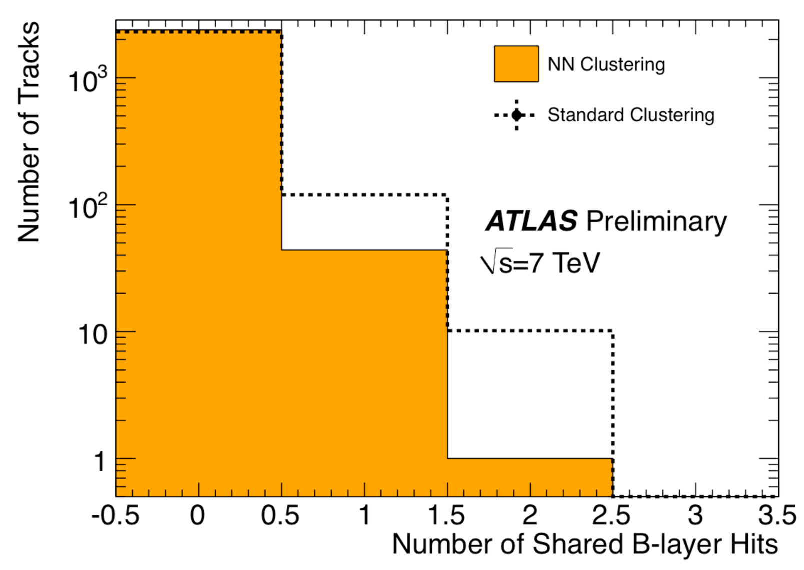
- These clusters are mainly due to δ-ray production.
- The NN recognizes the non uniform distribution of the collected charge.
- Thanks to the non-linear treatment of the charge distribution a **single-peak in track-to-hit residuals is recovered**



Two-particle separation

Reconstructing the position of multiple particles in the same clusters reduces ambiguities in track reconstruction.

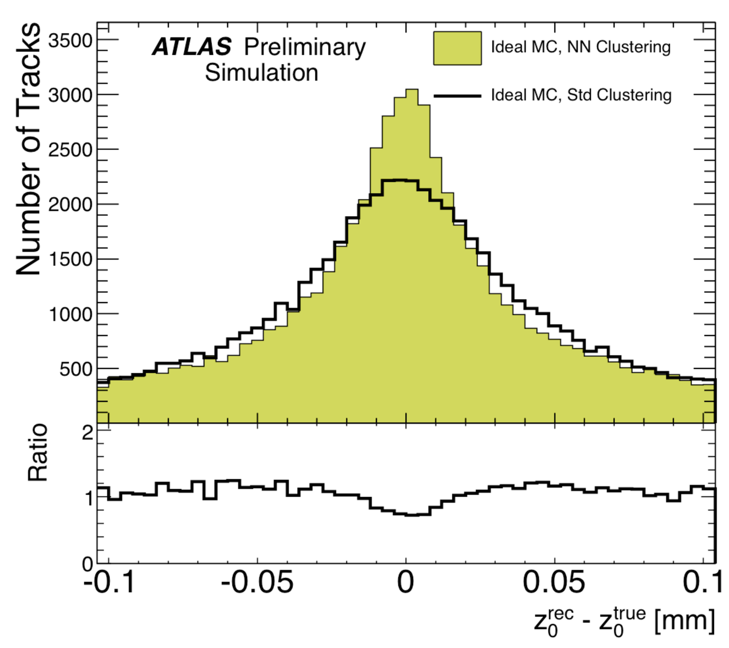
- Clusters that cannot uniquely associate to a track (shared clusters) are frequent in the innermost pixel layer, where the particle density is highest.
- **The NN approach reduces these ambiguities by an order of magnitude.**



Track resolution

Improved cluster reconstruction directly results in an improvement of track parameters.

- Resolution on the **impact parameters** for high-p_T tracks improves by **15%**.
- This is the main ingredient for algorithms used to separare heavy flavours from prompt particles from pp collisions.



Summary and perspectives

- The NN approach makes full use of the ATLAS Pixel Detector potential.
- It **boosts the detector performance beyond the original design** by taking into account all correlations inside a pixel cluster:

2D > 1D + 1D

- The improved two-particle separation will become more and more important with future upgrades where particle density will increase:
  - LHC reaching the design luminosity 10^{34} cm^{-2}s^{-1} and $\sqrt{s}$=14 TeV,
  - the installation of IBL, a new pixel layer at 33 mm from the beam.

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