# Tracking and flavour-tagging performance for HV-CMOS sensors in the context of the ATLAS ITK pixel simulation program

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## HV-CMOS sensors at small radius - Introduction

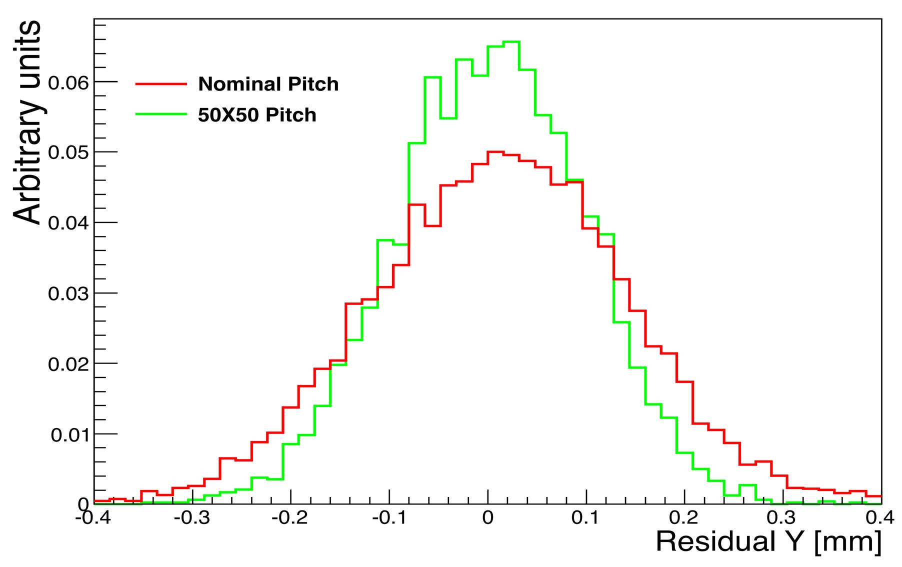
- ✓ HV-CMOS pixel technology has recently risen interest in the ATLAS community in view of its possible usage for the ATLAS Inner Detector Upgrade towards the High-Luminosity LHC phase
- ✓ HV-CMOS sensors can be employed in the pixel outer layers (R>15 cm) where the radiation hardness requirements are less stringent and since they could instrument large areas at a relatively lower cost. However, the largest impact on physics performance, tracking and flavour tagging, could be achieved if exploited in the innermost (IBL), or next-to-innermost (b-layer) layers
  - ✓ fine granularity and small depletion depth (less material, i.e. less multiple scattering) results in improved tracking resolution and better characterization of the cluster size for very inclined tracks
  - ➢ Preliminary studies on physics performance based on tracking and flavour-tagging presented in this poster

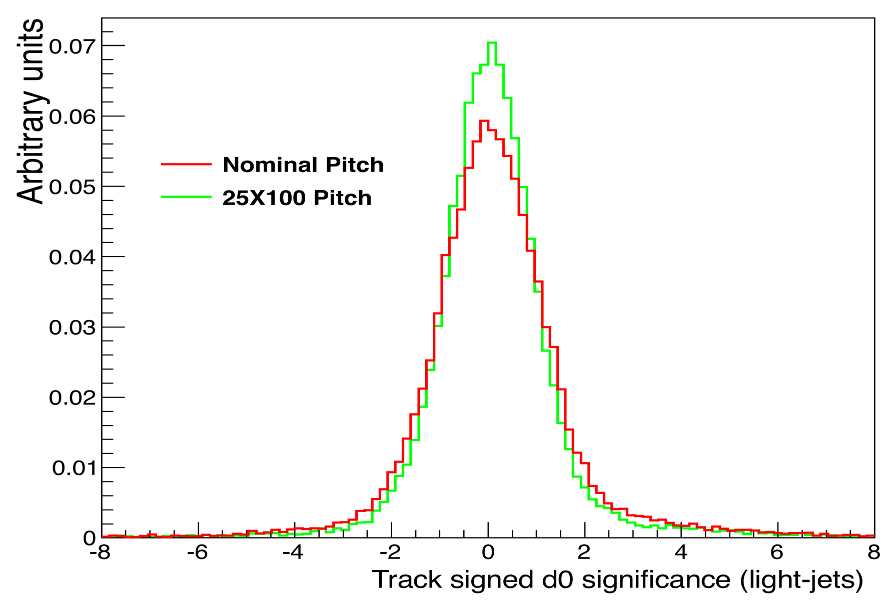
## HV-CMOS sensors at small radius - Simulation

- ➢ Results have been produced with Geant4 full simulation – ATLAS reconstruction software run on simulated samples
- ➢ In order to fully exploit the HV-CMOS sub-pixel encoding technology, various choices for the pixel pitch in R-Φ and Z are considered starting from the current one in IBL for planar sensors in the barrel region (50X250 μm)
- ➢ Digital reconstruction algorithm employed→based on the information of the geometrical hit position in the local reference frame (x, y)
  - ◆ Simplified version of the analog clustering algorithm where the (x,y) position of the clustering is calculated by taking into account the position and the charge collected for a given pixel in the R-Φ and Z directions → Digital clustering ensures a very robust response for different detector conditions and simulations
- ➢ Current digitization method exploited in the software is the drift model:
  - ▪ Charge carriers drift in the depleted sensor depth by taking into account the direction of the electric field, the Lorentz angle due to the magnetic field in the Inner Detector and the thermal diffusion
  - ▪ The depletion depth of the sensor in the innermost pixel layer (IBL) is reduced from 200 μm to 20 μm (symmetric in the local Z coordinate) as a first conservative attempt to simulate HV-CMOS-like conditions ➢ dominated by multiple scattering in the inactive region of the sensor thickness → results can be regarded as a lower bound of the typical gain brought by the usage of HV-CMOS at small radius
  - ▪ In order to account for the reduced depletion depth, the relevant signal and noise thresholds for IBL are decreased by assuming a simple linear scaling (in-time IBL threshold reduced from 1500 electrons to 150, and the noise threshold is reduced to 20 electrons being the nominal value 200)
  - ✓ This simplified scaling model has been validated by performing a scan on the tracking parameters when employing higher values of the IBL thresholds → impact of IBL thresholds found to be negligible

## Tracking Performance

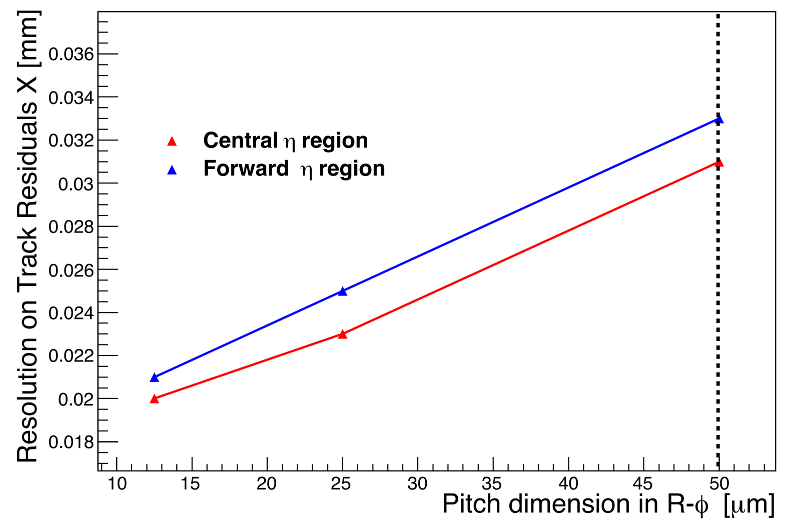
- ✓ Single particle (muons) produced with flat transverse momentum spectrum in the region [1,100] GeV
- ✓ In order to gauge the impact of tracking performance, the distributions of hit residuals (difference between the measured and the reconstructed track position in the local x,y frame) and impact parameters (transverse and longitudinal) are compared with different sensor pitches (robust digital clustering algorithm employed)
- ✓ Performance of hit and track resolution also explored as a function of the transverse momentum of the incident particles

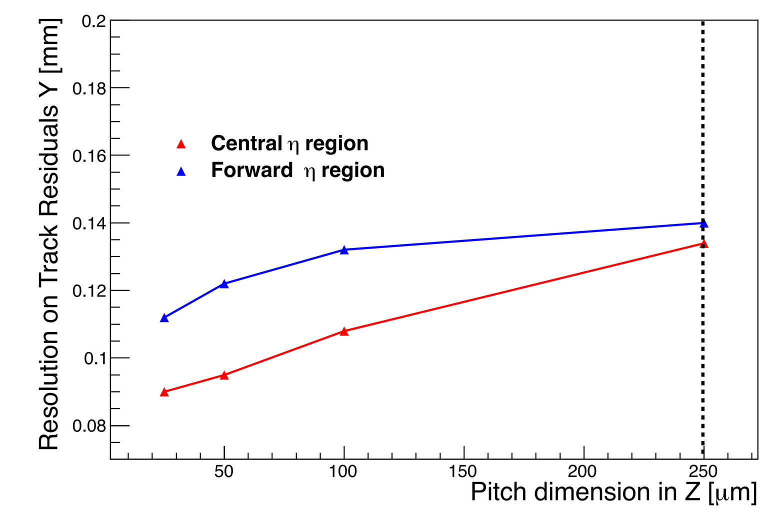



- ➢ Example of the clear improvement in hit residuals resolution and impact parameters when simulating HV-CMOS-like conditions in the innermost layer

- ▪ Resolution of the hit residuals in local x-y:
  - ✓ R-ϕ: [12.5, 25, 50] μm, Z: [25, 50, 100, 250] μm
  - ✓ Tracking performance evaluated in two different pseudorapidity regions (0<|η|<0.5, 1.5<|η|<2)

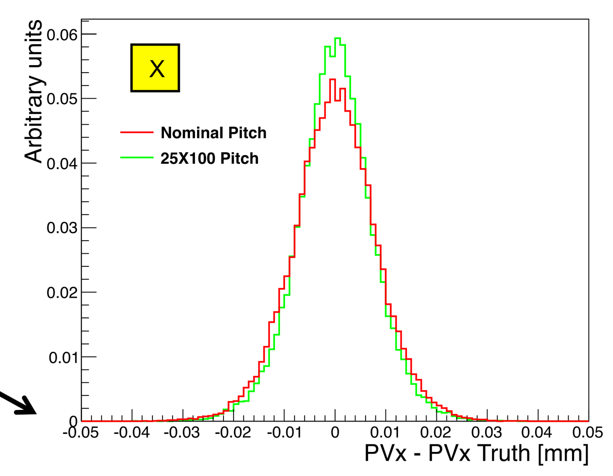


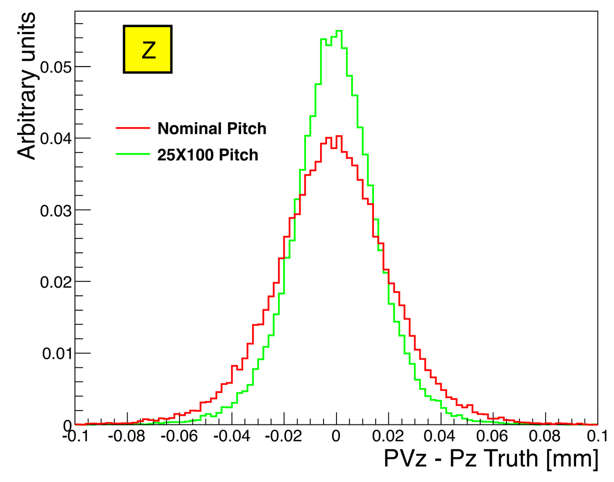



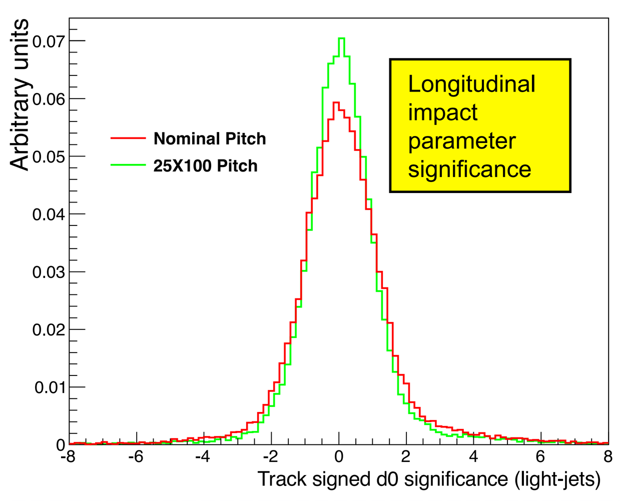

➙ The reduced pixel pitch as well as the other features of the HV-CMOS sensors (small depletion depth) induces a gain in hit resolution of approximately 25-30% in the R-Φ and Z local directions compared to the nominal Run 2 configuration

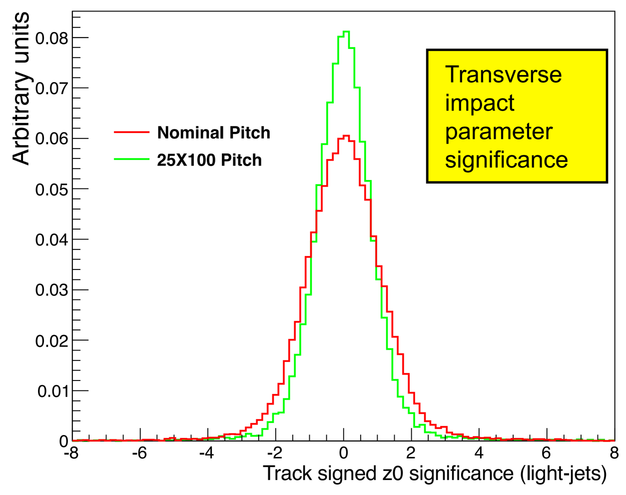
## Flavour-tagging performance

- ✓ Performance brought by the usage of HV-CMOS technology at small radius also assessed in the context of b-tagging
  - ▪ (50X250) μm→(25X100) μm
  - ▪ Analysis carried out on a semi-leptonic tt sample with average pileup (μ) of 20
- ✓ Primary vertex resolution along the x and z axes when comparing nominal pitch in the innermost layer and CMOS technology
  - • Gain in resolution in z is of particular interest (~+25%) →pileup vertex rejection along the beam axis
- ✓ Impact parameter-based taggers make use of the kinematic features of the transverse and longitudinal impact parameters of b- and light-flavour jets to disentangle and tag the b-jet component
  - ❖ Templates for the various flavour hypotheses are extracted in hit-motivated categories in such a way to define a quality criterion of the track matched to the jet
  - ❖ Log-likelihood ratio for b/light-flavour jets computed as the sum of per-track contributions

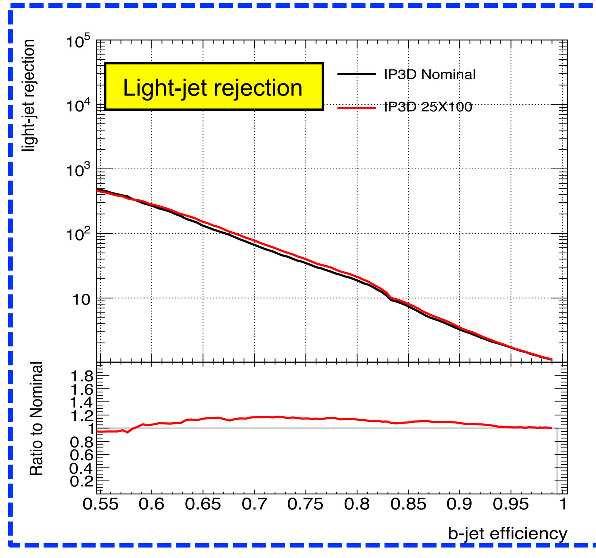


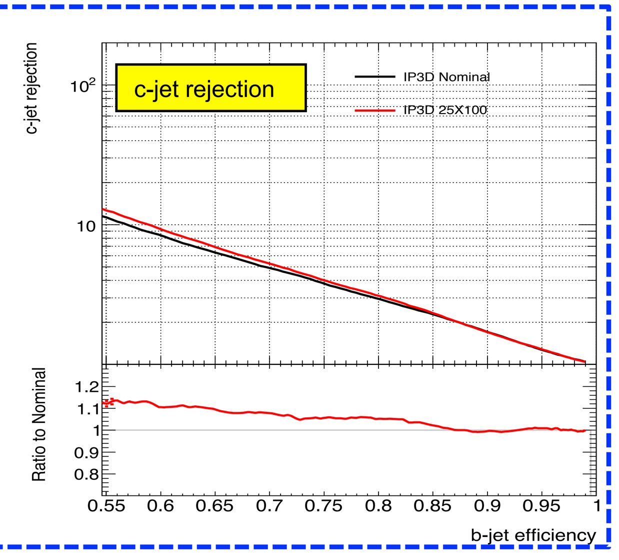



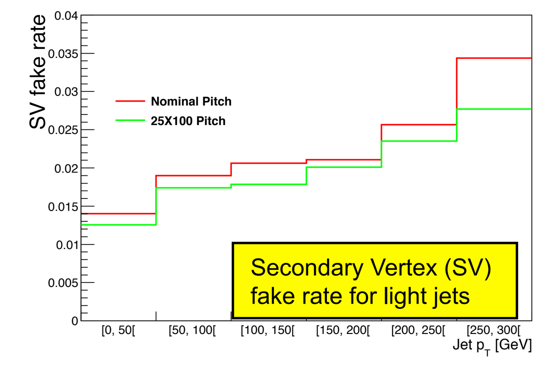



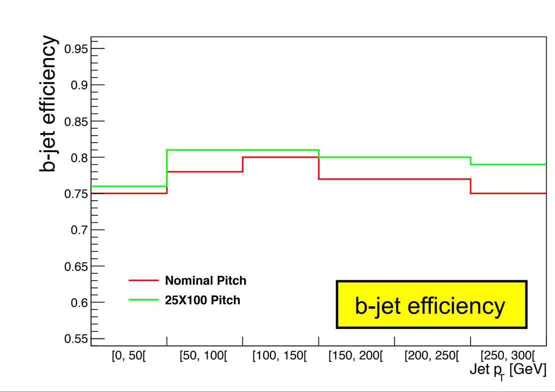




➙ The improved discriminating power induced by the HV-CMOS-like pixel conditions brings an overall gain in light/c-jet rejection of ~ 10/15% throughout the full b-jet efficiency range (large gain also expected for pattern-recognition within the jet)




- ✓ Currently new ATLAS geometry setups available for ITK simulation being tested
  - ▪ will assess the gain in physics performance both for inner and outer pixel layers when applying CMOS conditions

## References


- M. Barbero et al. – Prototype Active Silicon Sensor in 150 nm HV-CMOS technology for ATLAS Inner Detector Upgrade (arXiv: 1601. 00459)
- ATLAS Collaboration – Performance of the ATLAS Inner Detector Track and Vertex Reconstruction (ATLAS-CONF-2012-042)
- ATLAS Collaboration – Flavour-tagging algorithm optimization for the 2016 LHC Run (ATLAS-PUB-2016-012)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