STATUS AND PERFORMANCE OF THE ATLAS PIXEL DETECTOR AT THE LHC

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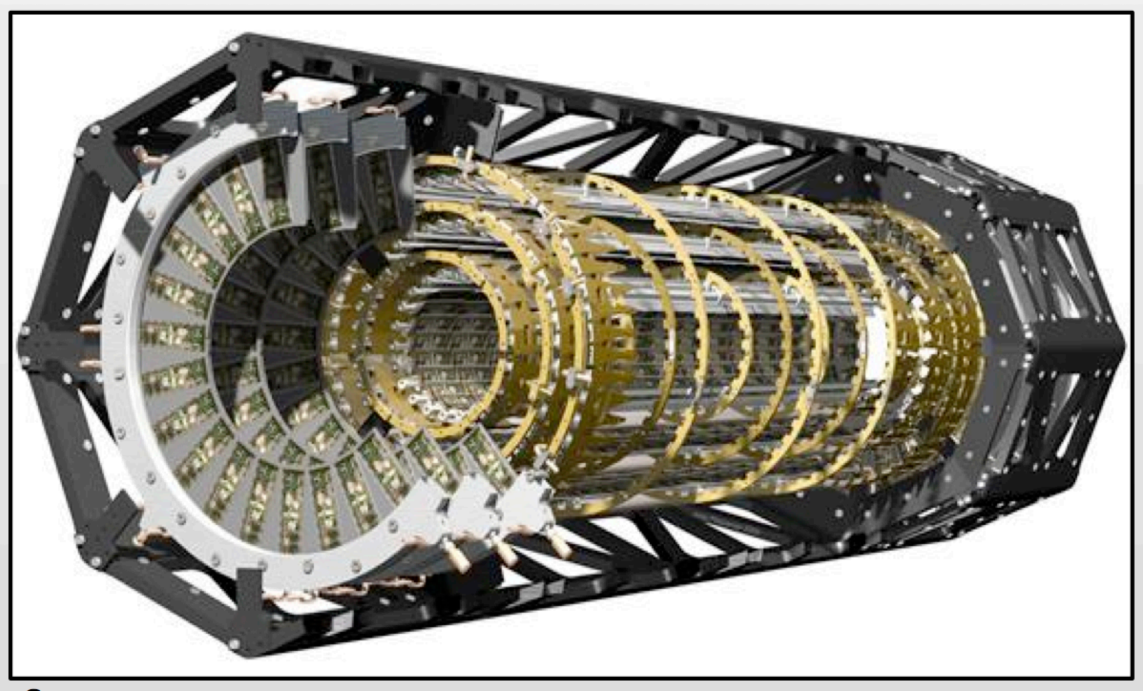
Introduction

The ATLAS Pixel Detector is the innermost detector of the ATLAS experiment at the Large Hadron Collider at CERN, providing high-resolution measurements of charged particle tracks in the high radiation environment close to the collision region. This capability is very important for the identification and measurement of proper decay times of long-lived particles such as b-hadrons, and thus vital for the ATLAS physics program. The detector provides hermetic coverage with three cylindrical layers and three layers of forward and backward pixel detectors. It consists of approximately 80 million pixels that are individually read out via chips bump-bonded to 1744 n-in-n silicon substrates. The detector performance is excellent: ~96 % of the pixels are operational, noise occupancy and hit efficiency exceed the design specification, and a good alignment allows high quality track resolution

The ATLAS Pixel Detector



Three barrel layers

- R=5cm (Layer-0), 9cm (Layer-1), 12cm (Layer-2)
- Modules tilted by 20° in the Rϕ plane to overcompensate the Lorentz angle

Two endcaps

- three disks each
- 48 modules/disk

Three precise measurement points up to |η|<2.5

- Rϕ resolution:10 μm
- η (R or z) resolution: 115 μm
- 1456 barrel modules and 288 forward modules, for a total of 80 million channels and a sensitive area of 1.7 m^2.
- Environmental temperature about -13°C
- 2 T solenoidal magnetic field.

Sensor

- 47232 n-on-n pixels with moderated p-spray insulation
- 250 μm thickness
- 50μm(Rϕ)×400μm(η)
- 328 rows (xlocal) × 144 columns (ylocal)

16 FE chips

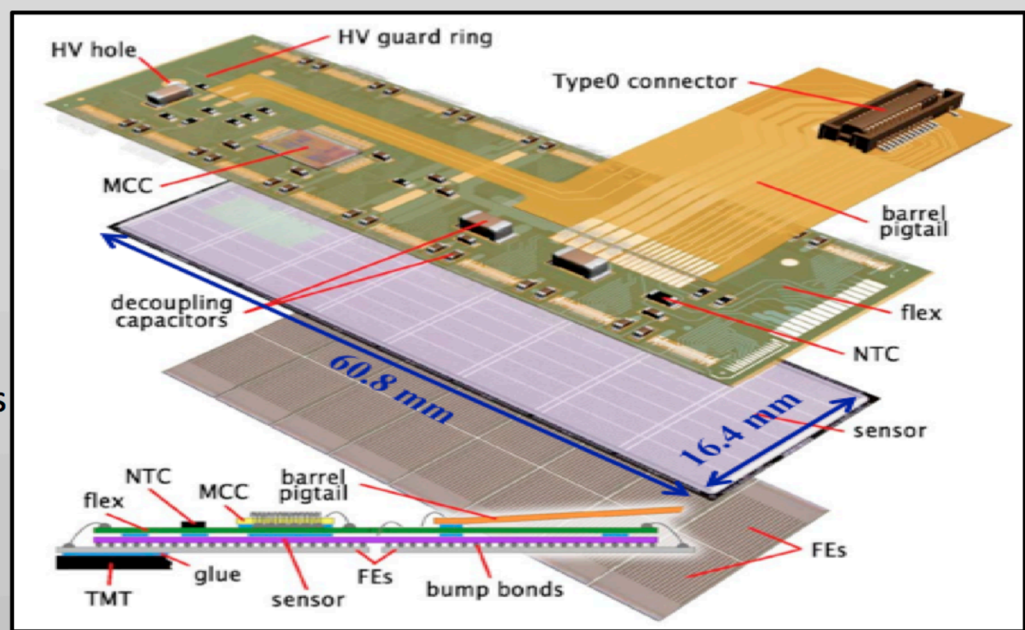
- bump bonded to sensor

Flex Hybrid

- passive components
- Module Controller Chip to perform distribution of commands and event building

Radiation-hard design

- dose 500 Gy
- NIEL 10^{15} neq/cm² fluence



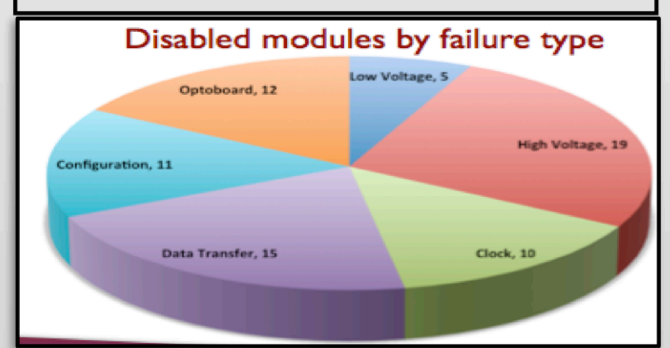
Pixel Detector status

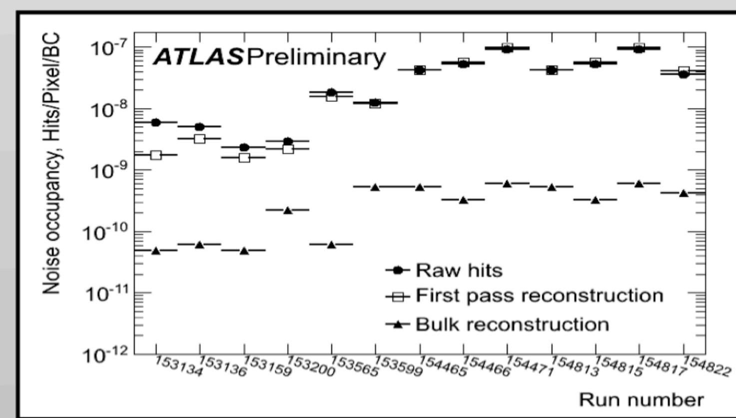
Pixel data taking efficiency was 99.8% during stable beams. 95.9% of the Pixel modules are active in data taking in 2011

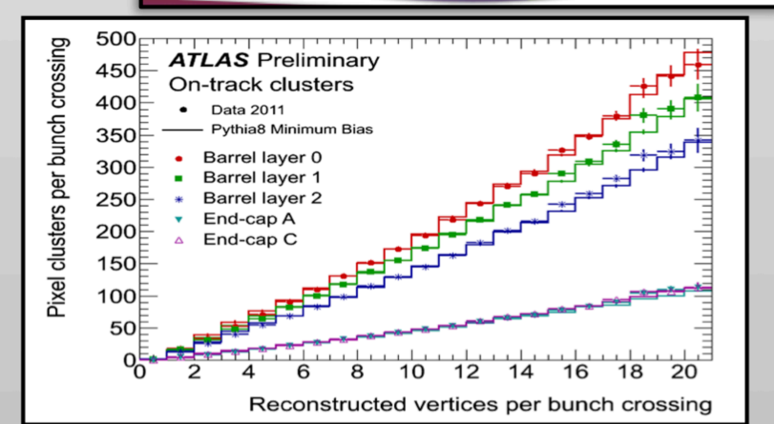
- 72 of 1744 modules are disabled (12 due to failure of two optoboards)
- 47 FE chips disabled (0.17%)
- failures appear correlated with thermal cycles:
  - attempt to mitigate by reduced temperature variations
- disabled module percentage grew from 2.1% to 4.1% in ~4 years of operation

Nearly 500 reconstructed hits/event in the b-layer! Despite the very high pile-up level, the Pixel occupancy is still small

Power connections:
LV and HV – defective links
Data connectivity:
Clock – FE electronics not receiving clock signal
DT – optics reading errors
Configuration – errors in sending configuration files
Optoboard – defective board for electric-optic signal conversions



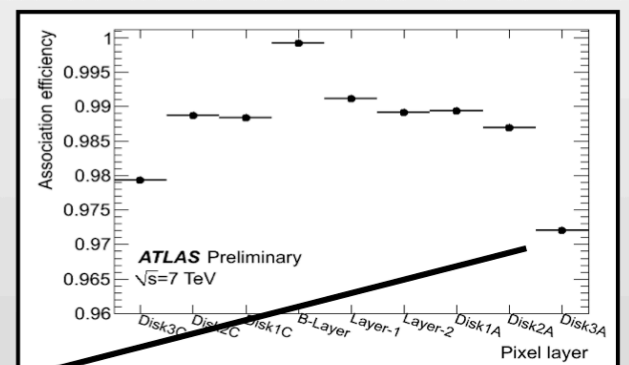


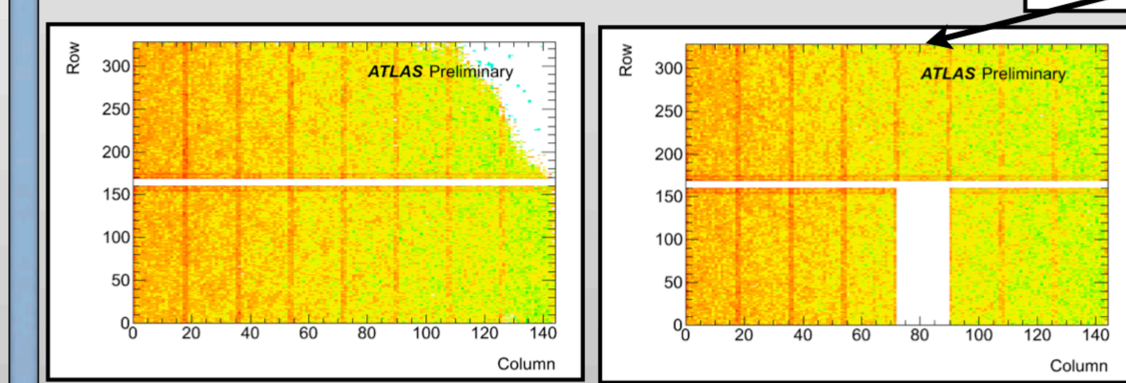


Hit-to-track association efficiency

The hit-to-track association efficiency is near 99% for all of the detector parts

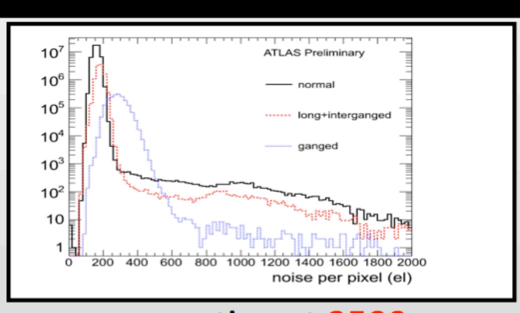
- 100% for b-layer by construction due to track reconstruction algorithm
- disabled modules are excluded, but not dead regions



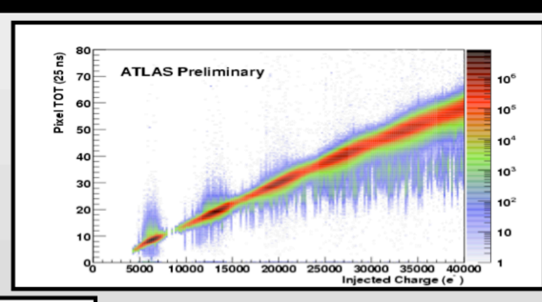


the lower efficiency for the most external disks is mainly due to inefficient regions on some modules

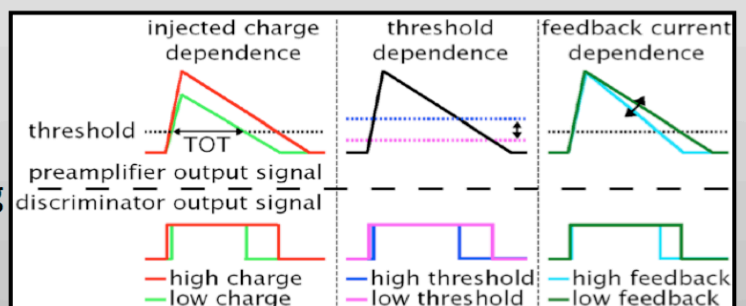
Time-Over-Threshold (TOT)

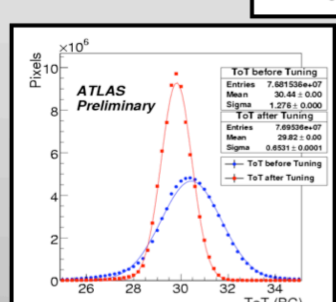


- Time-Over-Threshold (TOT, length of discriminator signal) depends on deposit charge, discriminator threshold, feedback current
- information of the TOT (units of 25 ns) read out together with hit infos (measurement of the deposit charge)



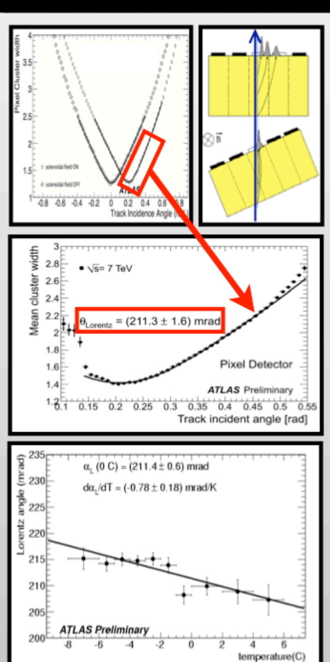
- now operating at 3500 e⁻ threshold with 0.1% of pixels masked
- threshold dispersion after tuning ~40 e⁻
- noise for normal pixels ~170 e⁻



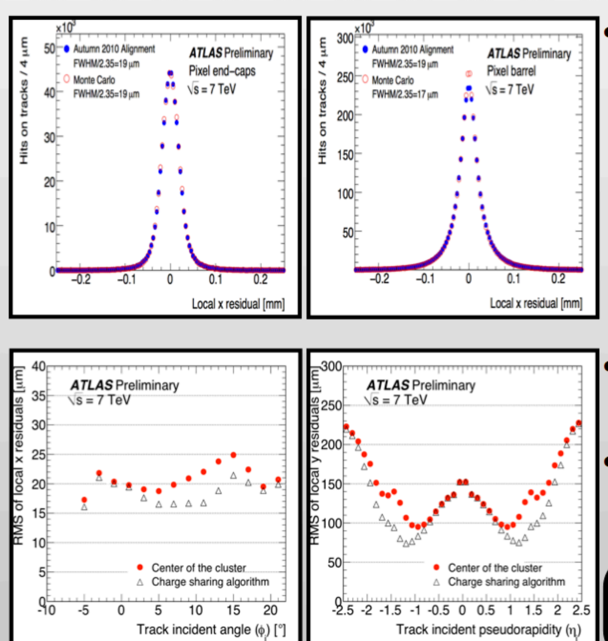


- TOT tuned pixel by pixel to 30 BC @ 20 ke⁻
- calibration by means of test charge injections to reconstruct amount of deposited charge offline

Spatial resolution



- **ExB** drift: measurement of Lorentz angle from cluster size vs track angle with and without B field
- measured value very close to expected value (225 mrad)
- expected dependence of the Lorentz angle on the mobility measured on modules with different temperature (-0.78 ± 0.18) mrad/K, expected: -0.74 mrad/K

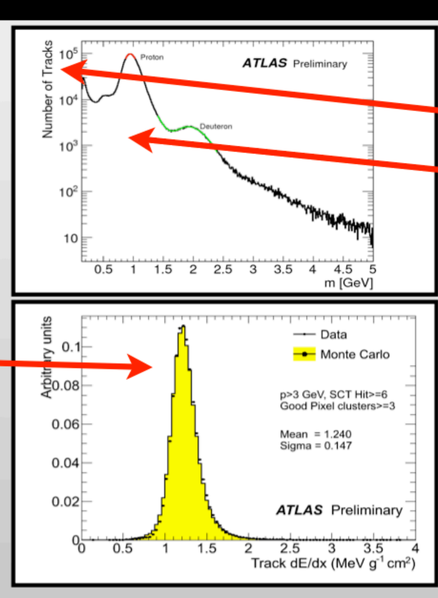


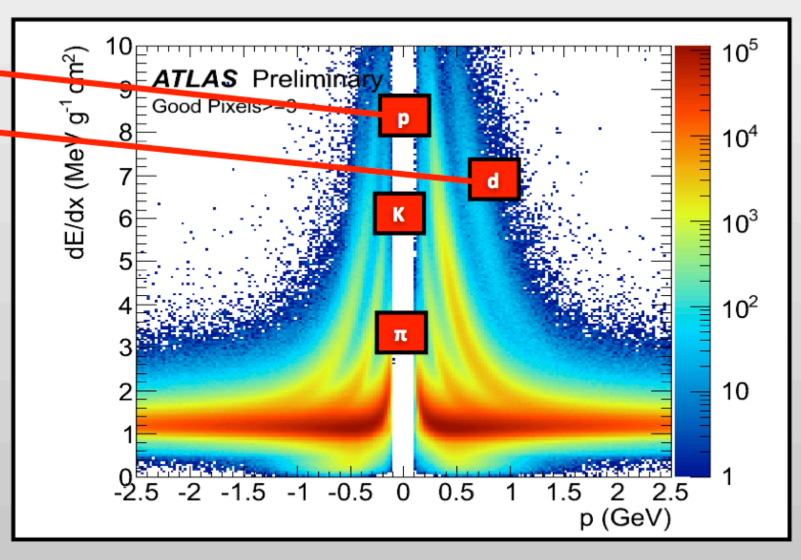
- distribution and RMS of local x and y residuals between cluster position and track extrapolation of the pixel modules with the newest alignment. The local x coordinate of the pixels is along the most precise pixel direction
- width very close to MC for a perfectly aligned detector
- TOT charge interpolation allows better resolution

see K. E. Selbach's poster for further info's about Pixel spatial resolution

Energy loss in Pixel: dE/dx

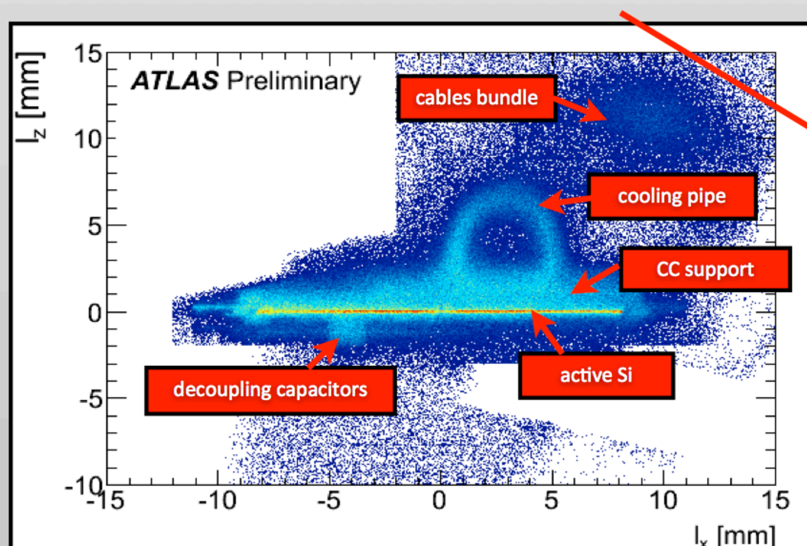
- track dE/dx determined from TOT
- track has typically 3 pixel hits: combined to provide dE/dx measurement
  - remove clusters near module edges or in the ganged region, use truncated mean, discarding cluster with highest energy deposit
- track dE/dx resolution: 12%
- direct application of dE/dx measurements in the search for new particles (high mass, long lived, charged). E.g. R-hadrons: SUSY colourless states composed by stable squarks and gluinos and ordinary particles

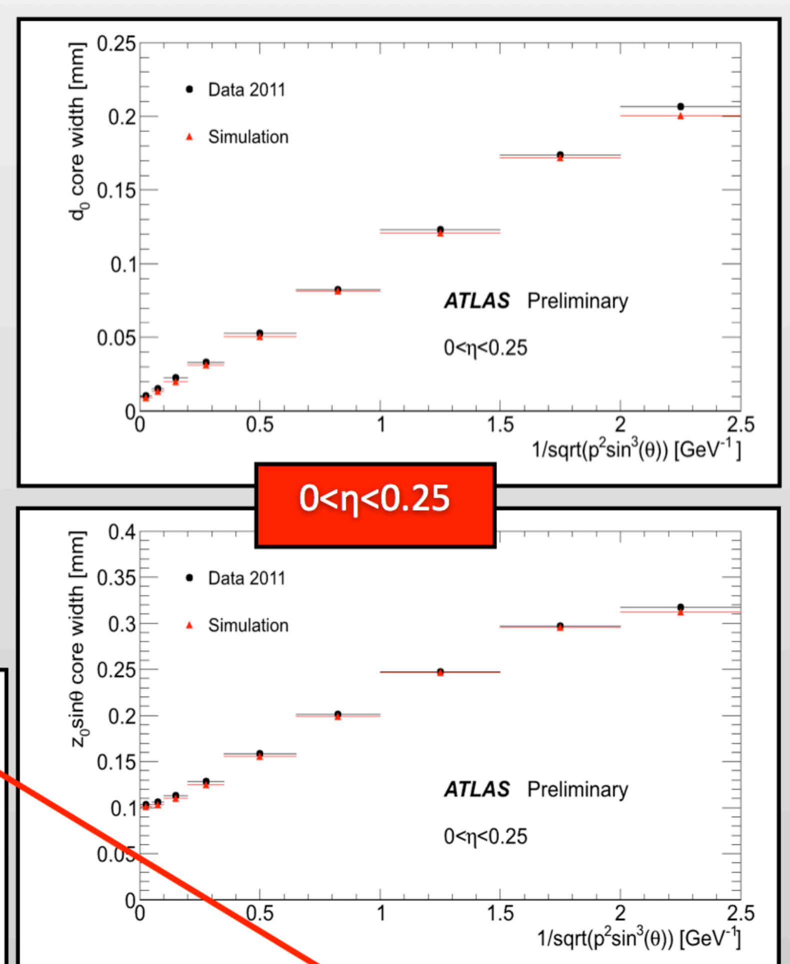




Tracking performance

- very accurate detector material mapping: performed by hadronic interactions. Applications in λ_I measurement, positioning of non-sensitive material (beam pipe, support structures)
- the excellent performance of the Pixel Detector leads to accurate measurements of tracks' parameters, e.g. transverse and longitudinal impact parameters (IP)
  - distance of closest approach to the primary vertex
  - material well described at low p_T





0<η<0.25

$$\sigma_{d_0} = \sqrt{a^2 + \frac{b^2}{p_T^2 sin\theta}}$$

References:
[1] ATLAS-CONF-2011-016 [2] ATLAS-CONF-2010-058 [3] CERN-PH-EP-2011-147
[4] https://twiki.cern.ch/twiki/bin/view/AtlasPublic
[5] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/PixelPublicResults
[6] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsPixel