ATLAS upgrade & 3D development

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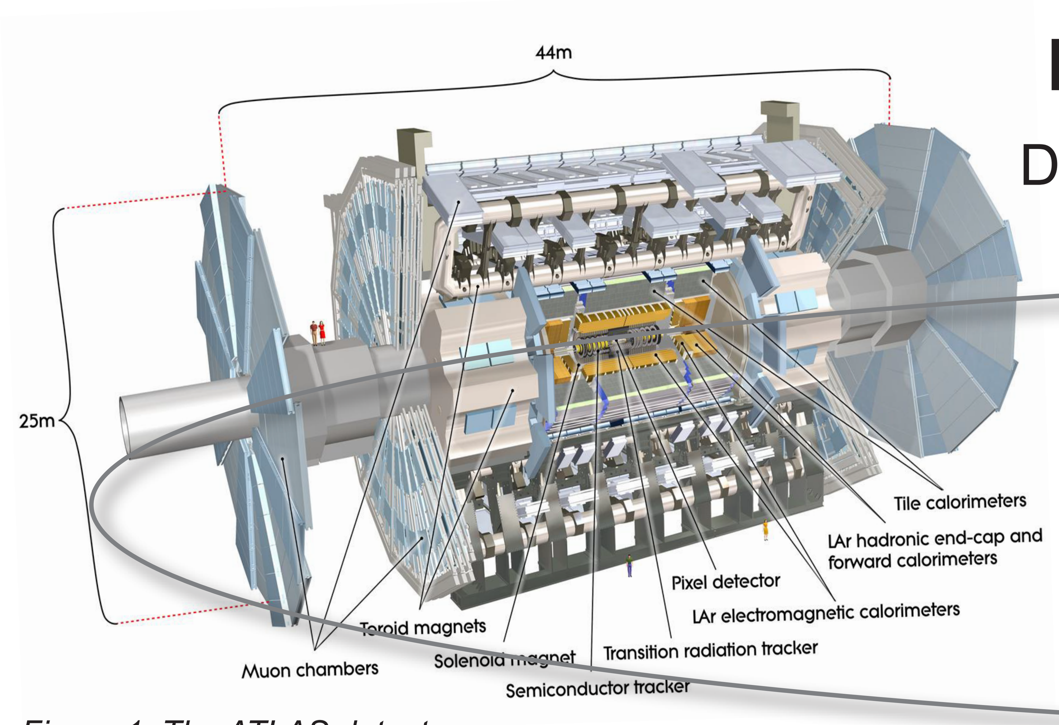
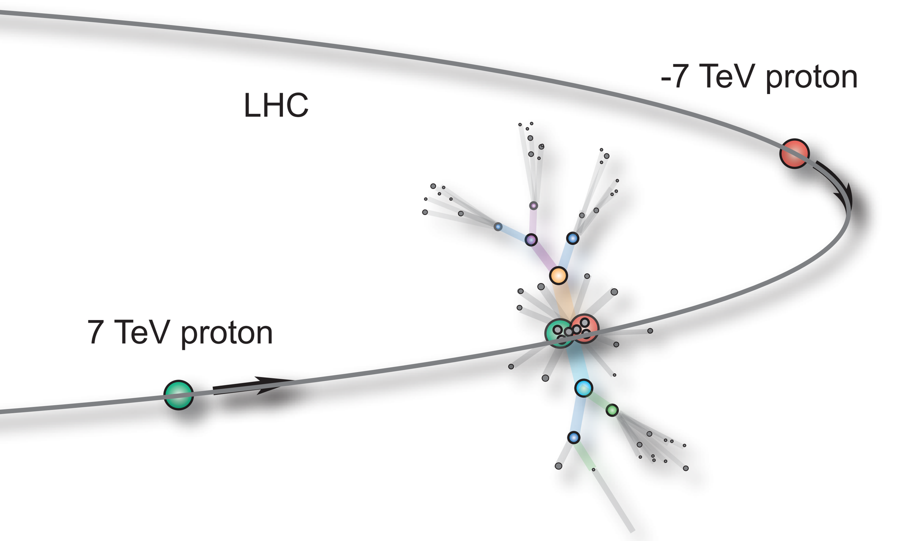


Figure 1: The ATLAS detector



The ATLAS detector

Situated at one of the four interaction points of the Large Hadron Collider (LHC), the ATLAS detector is designed to search for a large range of new physics signals including the Higgs boson, supersymmetrical particles and other signatures of beyond Standard Model.

The LHC will operate at an unprecedented energy level and is designed for 14 TeV centre-of-mass p-p collisions at the design luminosity of 10^34 cm^-2s-1 with 25 ns bunch crossing time.

Figure 1 shows the different detector layers in ATLAS. Innermost is the Inner Detector (ID) inside a 2T solenoid field. Outside is the electromagnetic and hadronic calorimeter, surrounded by a large scale muon spectrometer and 3 toroid magnets.

The ID (Figure 2) provides tracking of charged particles and consists of three sub-detectors, the Pixel detector closest to the interaction point followed by the SemiConductor tracker (SCT) and outermost the Transition Radiation Tracker (TRT).

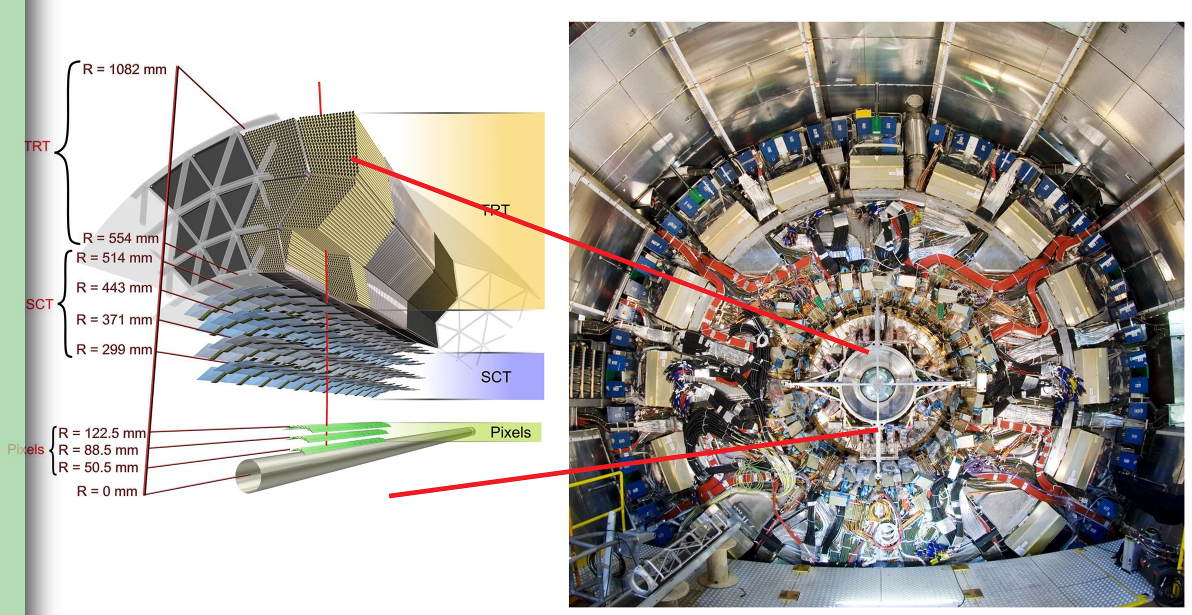


Figure 2: Right, the currently installed ID layout for the central part of the tracker. Left, a picture of the ID as installed underground inside the calorimeters.

ATLAS upgrade activities

The first upgrade of the LHC (phase 1) is expected to take place in 2014-2015 when the new LINAC is being installed. This will increase the LHC luminosity with a factor of 2-3 and the currently installed innermost Pixel layer, the Insertable B-Layer (IBL) will need to be replaced. One of the technologies considered for this is the 3D pixel technology due to its radiation hardness and low amount of dead area.

The second upgrade of LHC (phase 2), installation of new injectors, will be earliest in 2016-2017. After this a new peak luminosity of 10x 1034 cm-2s-1 is expected and up to 10000 tracks/events. For this the whole of the ID will need to be replaced and even smaller pixels considered to achieve the necessary track resolution.

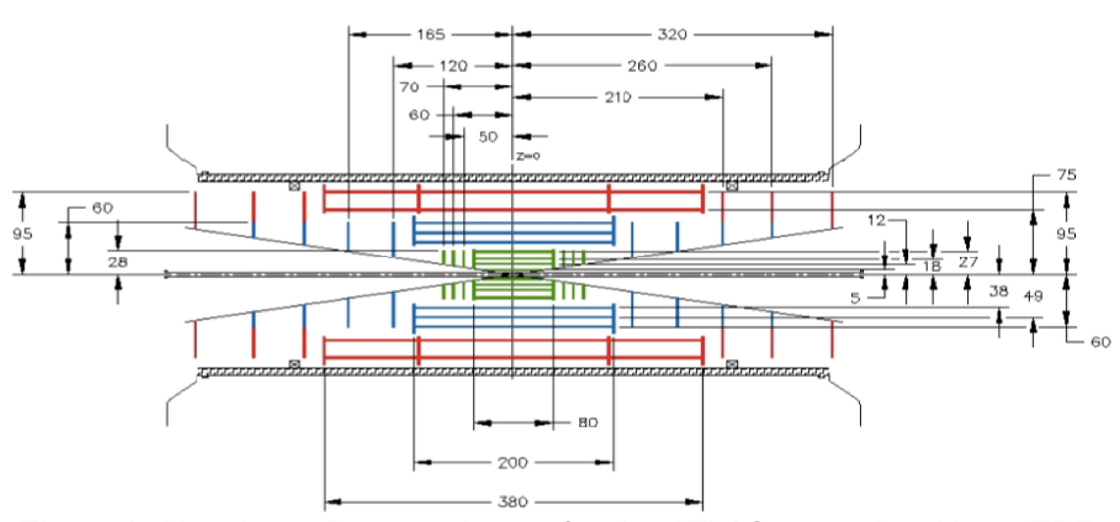


Figure 3: New Inner Detector layout for the ATLAS upgrade with no TRT detector and a total of 9 layers of silicon detectors, 4 pixel layers (~5 m2), 3 layers of short strips (~60 m2) and 2 layers of long strips (~100 m2).

Principle of 3D detection

Figure 4 shows the principle of the 3D detection as proposed by S. Pareker et al. in 1997 [n]. Using Deep Reactive Ion Etching (DRIE) one can etch a matrix of vertical columns into a silicon wafer, which becomes n- and p- type electrodes when doped accordingly.

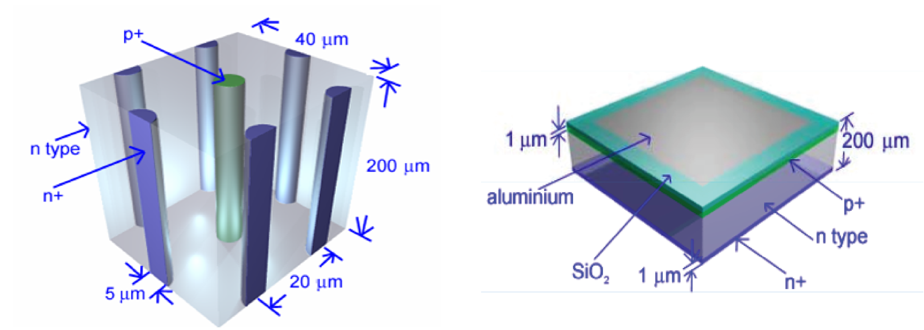


Figure 4: Left, the 3D pixel sensor with vertically doped columns. Right, an eqivalent planar sensor for comparison.

The 3D configuration has the following advantages:

- Low depletion voltage
- “Active edge” - DRIE allows for etched and doped trenches around the active area, no need for guard rings an less dead materal (~ few um) and the sensor is efficient to the trenches
- Short charge collection distance (fast signal) due to the vertical columns. The electrode distance is decoupled from the wafer thickness so the distance can be reduce without reducing the active sensor material
- Smaller trapping probablility after irradiation due to the short charge collection path → High radiation hardness

The 3D configuration has the following disadvantages:

- Non uniform response due to electrodes
- Complicated technology
- Higher capacitance with respect to planar

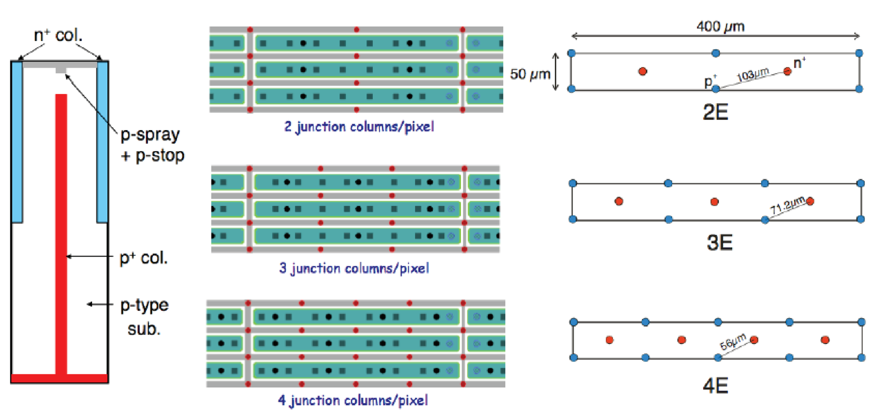


Figure 5: Different 3D sensor configurations.

2008 Testbeam Analysis

The 2008 testbeam took place in June at CERN using a 180 GeV/s pi+/- beam. The 3D detectors tested were produced by Stanford and bump-bonded to the ATLAS FE-I3 readout chip.

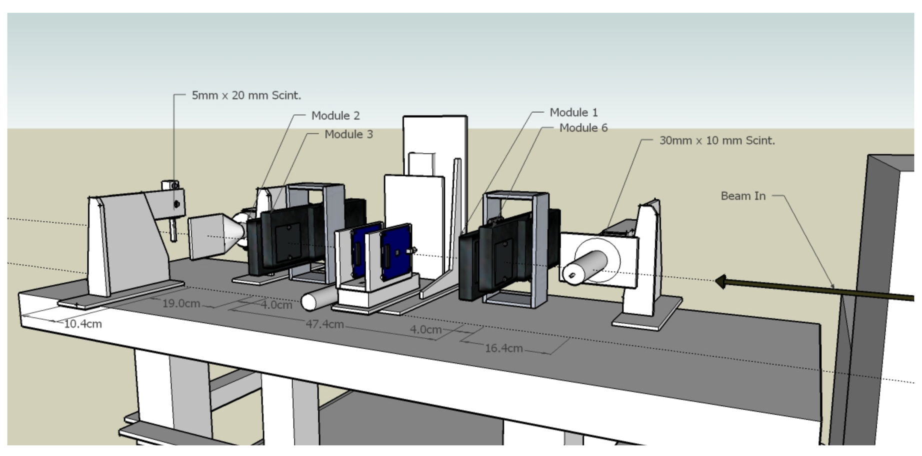


Figure 6: A schetch of the setup in the CERN testbeam area.

Results: Edge response of 3E and 4E electrodes measured to be sigma = 11-12 um (probably dominated by tracking resolution and residual misalignment). Efficiency

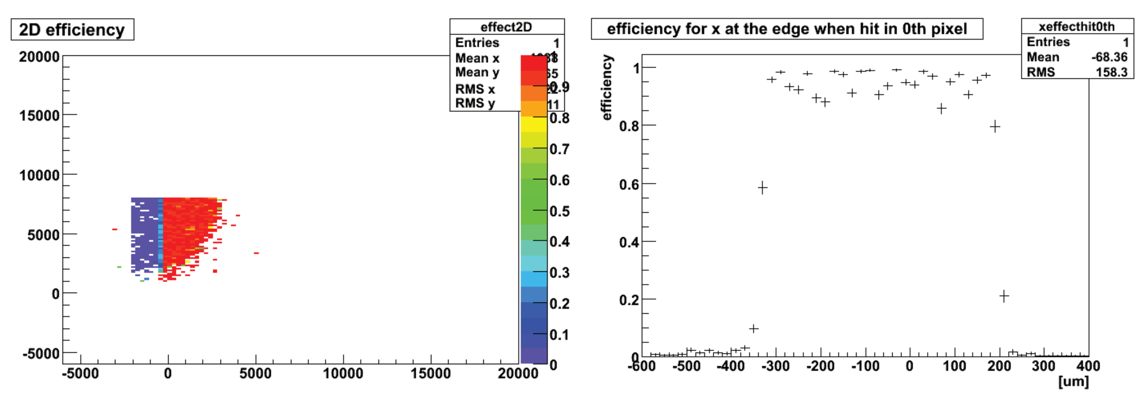


Figure 7: Preliminary study of the “active edge” properties of the Stanford 3E sensor at 40 V. Left, track efficiency when test beam is directed towards a corner of the detector. Right, the corresponding efficiency in the 0th pixel (-200 to 200 um) showing high efficiency also when the tracks are outside of the sensor area.

May 2009 Testbeam Analysis

The main goal of this testbeam (180 GeV/c pi+/-) was to make the first characterisation of ATLAS 3D Si pixels in a magnetic field (Figure 8) and to study the 3D pixel devices under conditions similar to the ID (mounting angle of 16 deg.)

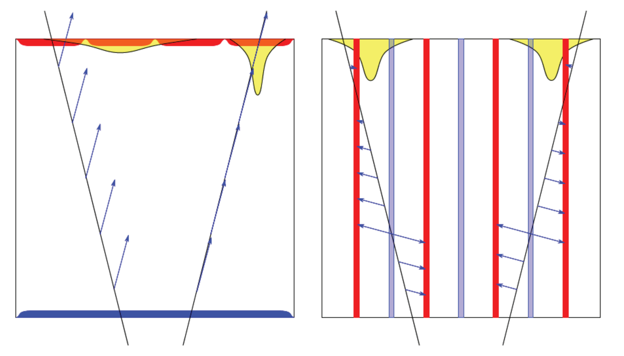


Figure 8: Left, the charge collection under a magnetic field is focussing or defocussing. Right, the effect for 3D devices is expected to be very small

The signal response, hit efficiency, probability of charge sharing and hit resolution have been successfully measured and compared to a planar device. The magnetic field has been shown to have a small effect. More detailed studies are planned for the autumn 2009.

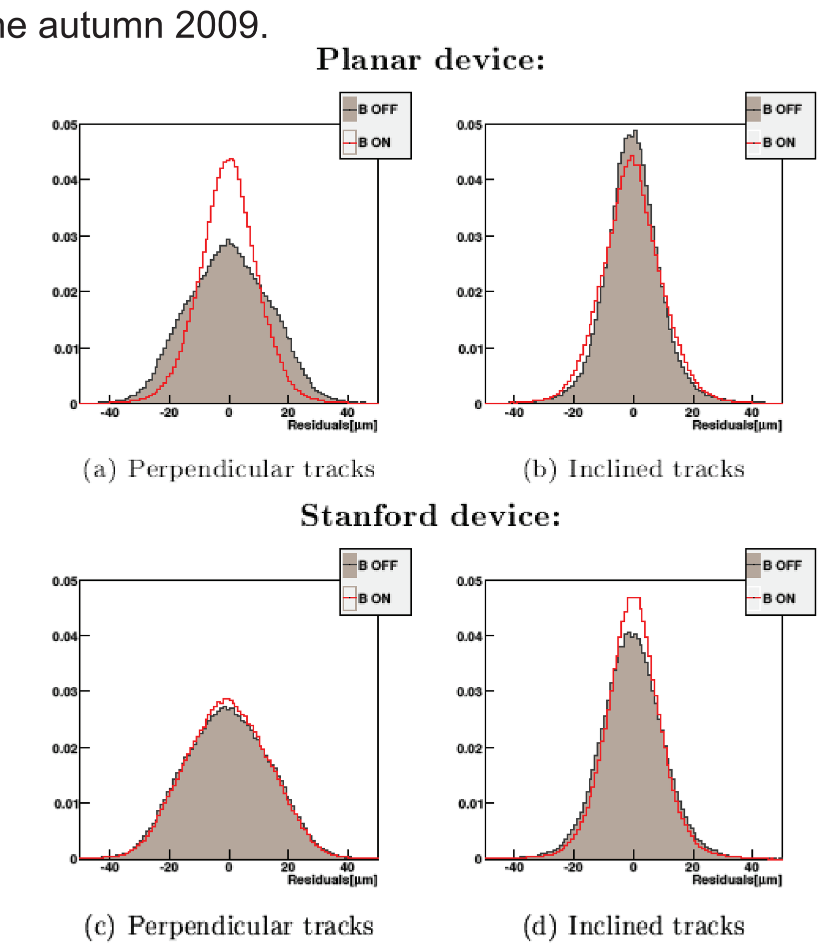


Figure 9: Residuals for both planar and 3D devices, with field on and off.

3D testsetup in Bergen

Preparation and training for 3D sensor tests have started at UiB. A first measurement system has been setup and commissioned.

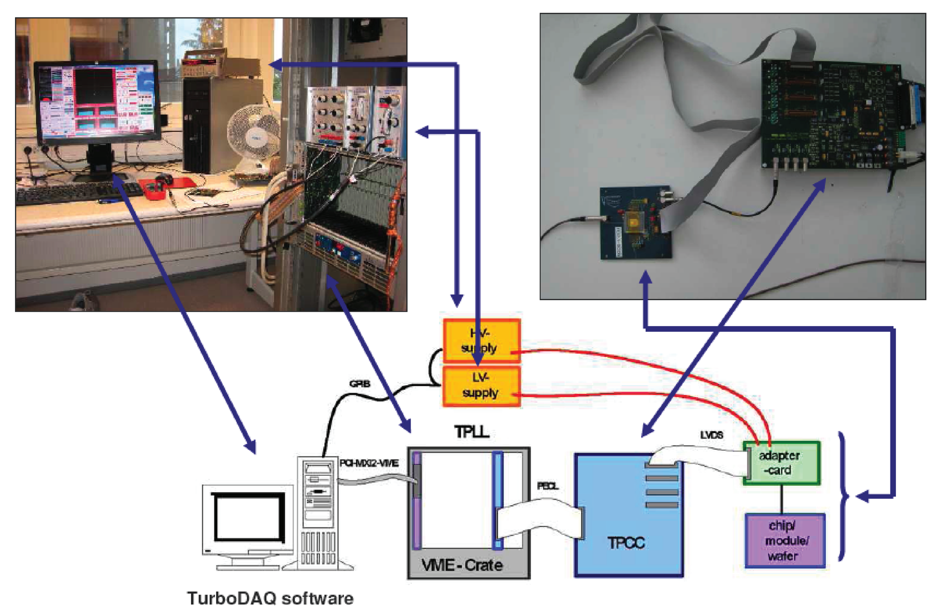


Figure 10: 3D sensor test setup in Bergen.

References

[1] A New architecture for solid state radiation detectors, S. I. Parker, C. J. Kenney, J. Segal, 3-D, Nucl. Instrum. Meth. A395, 1997

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[3] Edge Characterization of 3D Silicon Sensors after Bump-Bonding with the ATLAS Pixel Readout Chip, Ole Myren Røhne, IEEE 2008

[4] Test Beam Characterization of 3-D Silicon Pixel Detectors, M. Mathe et al., IEEE, VOL. 55, NO. 6, 2008

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