Final characterization of the ATLAS IBL detector modules with ^{241}Am during the construction phase

B. Mandelli[1,2] on behalf of the ATLAS IBL collaboration
1 CERN
2 University of Oslo

The ATLAS Insertable B-Layer (IBL) project

In 2013 during the long shutdown a fourth layer for the ATLAS Pixel detector will be installed at CERN between a new beam pipe (23.5 mm radius) and the current inner Pixel layer (B-Layer at 55 mm).

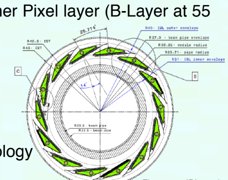


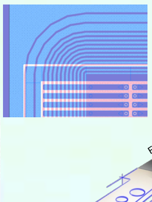
Figure 1: IBL end view section.

Motivations:
- Pattern recognition robustness in view of higher track multiplicity
- Controlling detector occupancy at high luminosity
- Tracking precision for an excellent vertex detector performance
- Large radiation dose will require more radiation hard sensor technology

Main requirements:
- Radiation hard technology for sensors and electronics
- Small space available: no shingling and development of sensor with active or slim edge
- Minimize the material in order to have 1.5% of radiation lenght
- Tight tolerances and clearances

Overall Layout:
- Cylindrical layer formed by 14 staves with a lenght of 72 cm (production of 24 staves)
- Development of new readout chip: FE-I4B (32 FE chips for each stave)
- Each stave will host 12 double chip and 8 single chip modules
  - Double chip module: Slim Edge Planar Silicon n-in-n design Sensor
  - Single chip module: 3D Silicon Sensor
- Total of 12 millions 50 x 250 µm² pixels

Figure 2: Planar edge sensor design for IBL. The IBL planar sensors are based on the proven technology of the current ATLAS Pixel Detector, n-in-n pixels on a diffusion oxygenated float-zone silicon bulk.



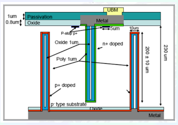


Figure 3: Design of the 3D sensor for IBL. In the IBL 3D sensors the column-like electrodes penetrate the substrate instead of being implanted on wafer surface.

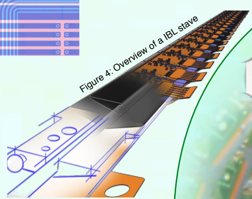


Figure 4: Overview of a IBL stave

IBL Production: final QA

A dedicated set-up has been installed in the SR1 clean room at CERN in order to perform QA tests on the 24 production staves (14 staves to be installed plus 10 spares):
- Thermal insulated aluminium box flushed with dry air
- An innovative CO_2 cooling system named TRACI
- Linear stage for automatic source scans over the two staves
- Set-up for stave test with cosmics
- A custom-built DAQ-system based on ATCA with two CIMs (Cluster Interconnect Module) and three RCEs (Reconfigurable Cluster Element).

The loading and QA activlties will be performed in different institutes where a precise workflow will be followed during the construction phase.

The final production staves QA will be at CERN, where specific tests will be performed:

- Electronic Readout QA
- Functionality tests on electrical components
- Tunings of functional parameters for each stave module
- Data quality
- Source scans
- Bad pixel searching

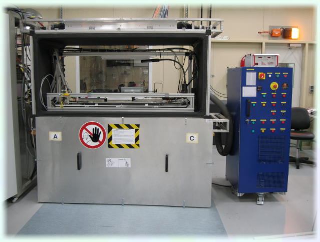
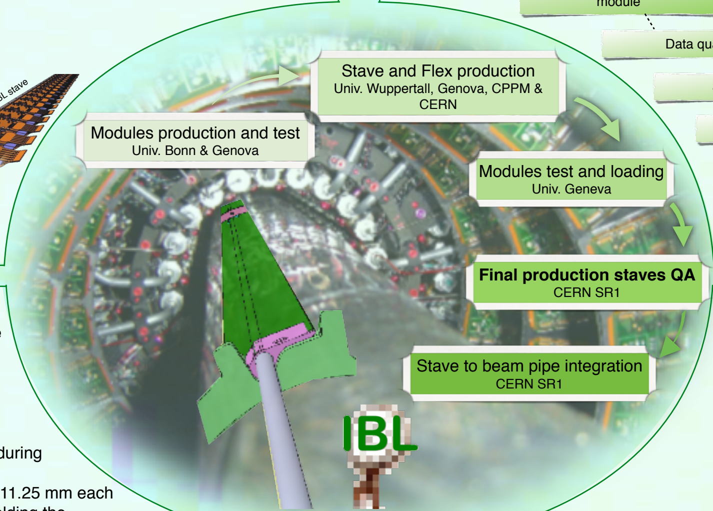


Figure 5: IBL production test set-up installed in SR1 clean room at CERN.



Nowadays a first real prototype stave, named Stave 0a, equipped with the foreseen sensor flavours bump bonded to FE-I4A chips has been fully characterized. In the coming months the final QA will be started and it will end in summer 2013.

^{241}Am Source Scans for QA

One of the QA activities for the 24 staves that will arrive in SR1 is the performance of source scans in order to see the response of the detector to radiation, identify pixels not answering to ionization and provide data for recalibration of the charge calibration.
A dedicated set-up has been implemented in order to perform automated source scans over-all the modules during the production phase:
- Two ^{241}Am sources of 41 MBq with emission along 11.25 mm each
- Linear motor with a special mechanical structure holding the sources over one or two staves moving for the entire stave's length
- c++ software for the linear motor communication and for the automation of the source scans along all the stave

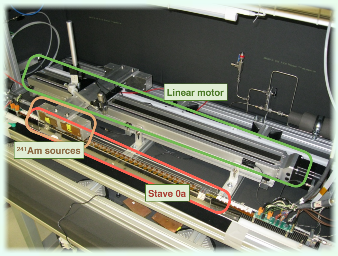


Figure 6: Set-up for automated source scans. The sources, installed on a dedicated structure on the linear motor, move over the stave allowing automated source scan for all the modules on the stave.

A typical source scan

The ^{241}Am source is positioned at a distance of about 4 cm from the module. Given the distance, the source's activity and the chip size, it is possible to calculate that the gamma rate on the chip is of the order of 1 MHz.

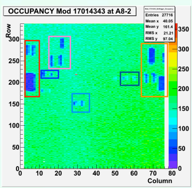


Figure 7: Source scan for a 3D sensor of Stave 0a.

SMD parts loaded to the module flex clearly visible

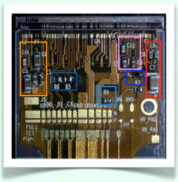
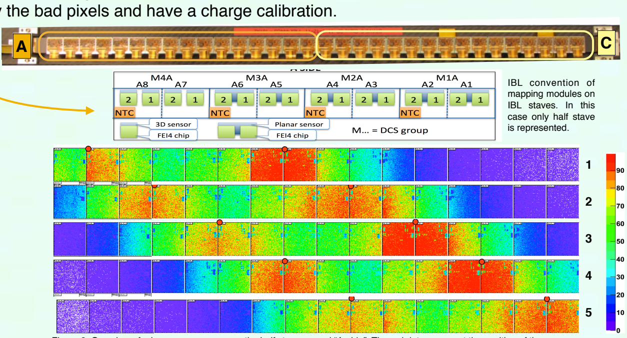


Figure 8: Single chip module loaded to the Stave 0a.

Source scan for half stave

Several ^{241}Am source scans have been performed along all prototype stave with different tuning parameters. The goal is to have an overall view of the detection properties for each module, identify the bad pixels and have a charge calibration.



IBL convention of mapping modules on IBL staves. In this case only half stave is represented.

Figure 9: Overview of a long source scan over the half stave named "A-side". The red dots represent the position of the sources.

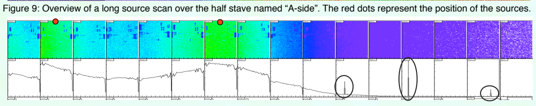


Figure 10: Source scan analysis where the occupancy of each column is plotted. The peaks represent noisy pixels.

A possible charge calibration of all IBL modules

In the Fe-I4A IC no circuitry for direct measurement of the test charge injection capacitances has been implemented. Simulations predict a capacitance of 5.7 fF if both injection capacitors are used.

$$\left.\begin{array}{l} N = N_0 e^{-\sigma_L x} \\ \sigma_L \simeq 2cm^{-1} \quad x = 200\mu m \end{array}\right\} \sim 2\% \text{ of photons will interact in the detector}$$

The absorption of 60 keV photons in Si is dominated by the photoelectric effect even if the Compton scattering is present.
Gamma at 60 keV deposits ~ 16.6 ke⁻ in the sensor
↓
The position of the photoelectric peak of the measured charge distribution can be used to verify the front-end calibration
The FE-I4 ASIC provides individual pixels charge measurements by means of the Time over Threshold (ToT) method, featuring a 4-bit counter for moderate resolution

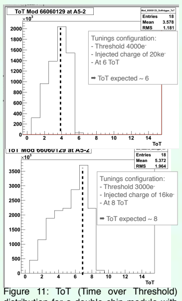


Figure 11: ToT (Time over Threshold) distribution for a double chip module with different tuning configurations.

Source scan for bad pixel searching

The ^{241}Am source scan is useful to identify pixels not answering to ionization because disconnected, merged, defective or badly tuned.
- **Disconnected bump**: bump bond connections can break because of mechanical stress
- **Merged bump**: still form a connection between sensor and FE, but two or more channels are merged to a single connection

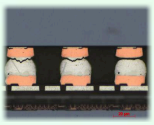
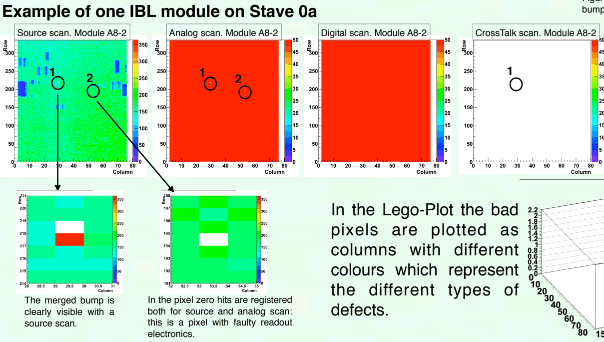


Figure 12: Picture of disconnected bumps in a IBL module.

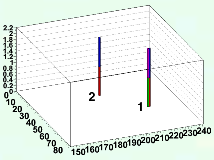
Example of one IBL module on Stave 0a



The merged bump is clearly visible with a source scan.

In the pixel zero hits are registered both for source and analog scan: this is a pixel with faulty readout electronics.

In the Lego-Plot the bad pixels are plotted as columns with different colours which represent the different types of defects.



A module is accepted for IBL if it shows less than 1% defective pixel

Conclusion

The first stave prototype has been fully characterized in the SR1 clean room at CERN. The systematic quality assurance procedure concerning module, stave and flex from the production to the final assembly on the beampipe has been already started.
A dedicated set-up for automated source scans of the IBL production staves has been implemented. The response of the detector to radiation and the FE charge calibration have been verified by means of ^{241}Am source scans. Furthermore a full program for the identification of bad pixel with the help of source scan has been developed.