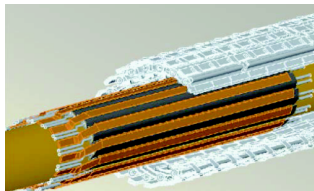


ATLAS Pixel, phase 0 (IBL)

Vertex 2012

Martin Kocian (SLAC) for the IBL collaboration

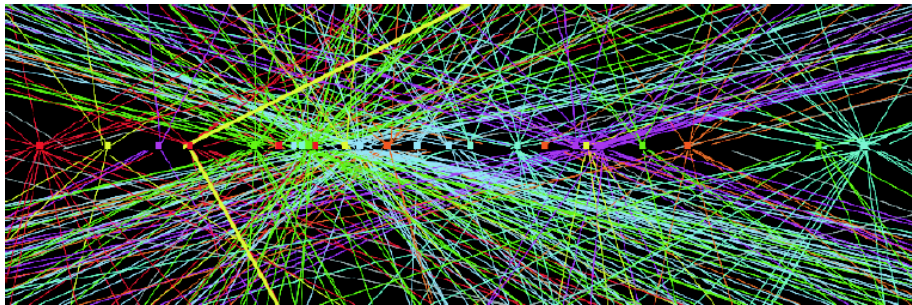


26 September 2012



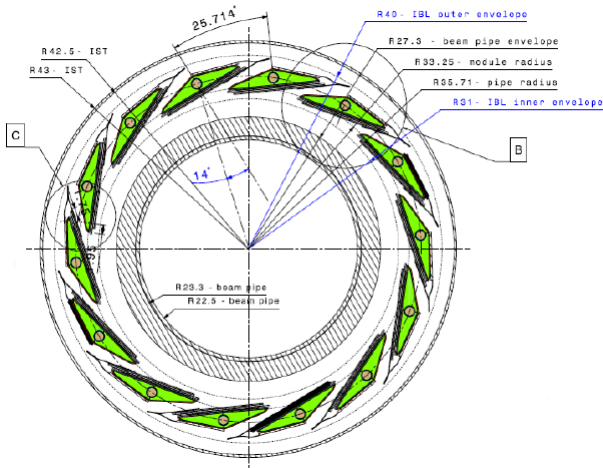
Motivation

- The barrel of the current ATLAS pixel detector consists of three layers.
 - The efficiency in the innermost layer will go down with pile-up. At a luminosity of $\mathcal{L} = 2.2 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ the inefficiency of the innermost will be around 5 %.
 - b-tagging efficiency will be seriously degraded by pile-up.
 - Improved vertexing will therefore be essential to maintain detector performance.
- ⇒ Add a new innermost layer to the pixel detector.



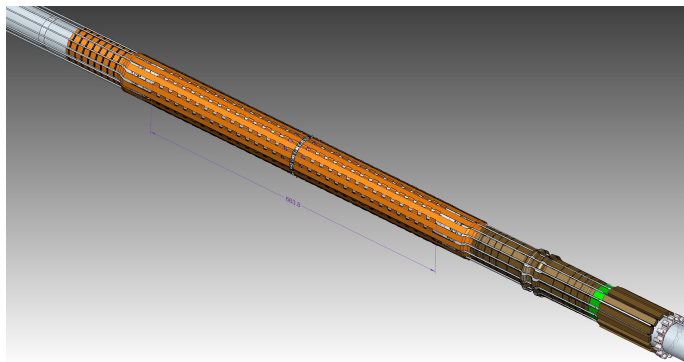
$Z \rightarrow \mu\mu$ event from 15 April 2012, $\mathcal{L} = 4 \cdot 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$, 25 vertices.

- The new layer is called Insertable B-Layer (IBL).
- It will be inserted between beam pipe and the current pixel B-layer.
- A new ATLAS beam pipe ($r=23.5$ mm) will be installed to increase available space.
- 14 staves arranged in a turbine-like fashion.
- 3.2 cm radius.
- Shingling of frontends in φ to achieve full coverage (tilting angle 14°).
- No shingling in z possible because of low clearance.
- IBL material adds up to less than 1.9 % X_0 . Present pixel is 3 % X_0 .

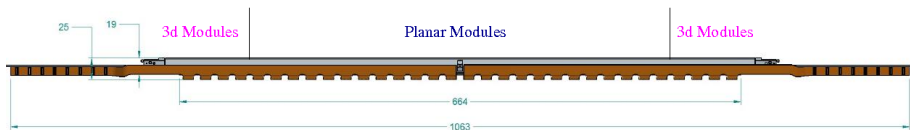


Layout

- Provides coverage in $|\eta| < 2.5$.
- Installation in the 2013-2014 shutdown (LS1).
- Intended to operate until the end of phase 1 (550 fb^{-1}).
- Phase 1 luminosity is targeted at $2 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$.
- Radiation hardness requirement: 250 MRad TID and $5 \cdot 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ NIEL.

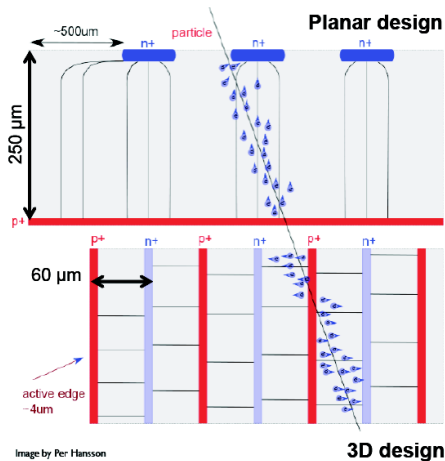


Staves



- 12 double-chip sensors and 8 single-chip sensors per staff.
- 32 frontend ASICs per staff arranged in a single line in z.
- Each frontend is about 2 cm x 2 cm.
- Each module assembly of sensor and frontend chip is mounted on a flex.
- The module flexes are wire bonded to a staff flex that covers half a staff.
- The staff flex is glued onto the mechanical staff.
- Each half staff is serviced separately from the outside of the staff.
- One Titanium cooling pipe per staff.

Sensor Technologies



Use 75 % Planar and 25 % 3d for IBL.

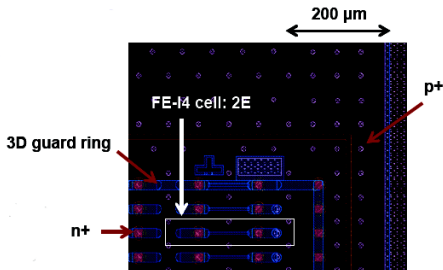
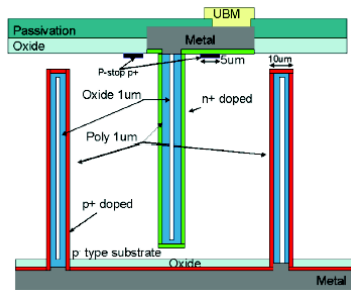
1 Planar

- Electrodes on top and bottom of bulk.
- Proven technology.
- Higher yield and lower cost.

2 3d

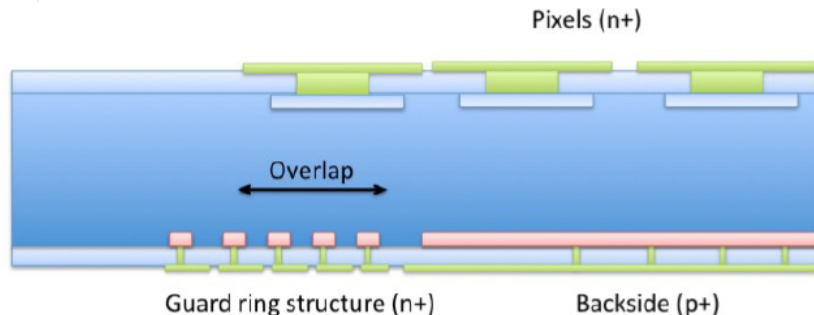
- Electrodes are columns through bulk.
- Fast charge collection due to shorter distance.
- Low depletion voltage.
- Good radiation hardness due to small trapping probability.

3d Sensors



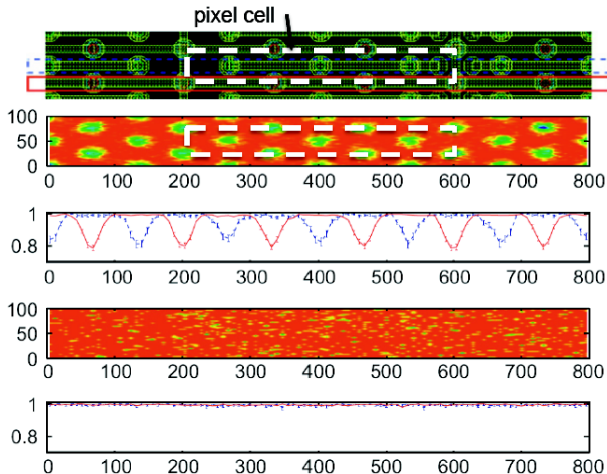
- 2 vendors: CNM and FBK (use a mix of both).
- 200 μm slim edge.
- Wafer thickness: 230 μm.
- 2 electrodes per pixel: optimized for optimal charge collection vs. detector capacitance (noise).
- One sensor tile per frontend chip.
- Depletion voltage: less than 15 V before irradiation, 180 V at end of life.
- Yield on wafers selected for IBL is 62 %. The high yield shows that the technology is mature.

Planar Sensors



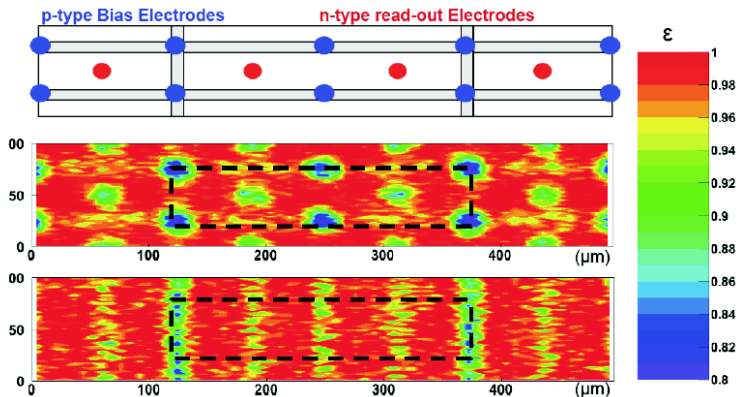
- Made by CiS like the present detector.
- 200 μm slim edge by placing active pixel area under guard rings.
- Wafer thickness: 200 μm .
- Two frontend chips per sensor tile.
- Depletion voltage: less than 35 V before irradiation, 1000 V at end of life.
- Yield on wafers selected for IBL is 90 %.

3d: Tracking Efficiency Before Irradiation (Testbeam)



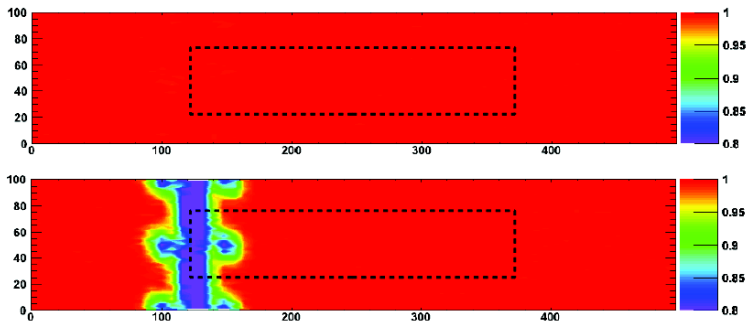
- Upper plots at normal incidence: 97 % efficiency due to electrodes.
- Lower plots at 15° inclination (IBL-like). Efficiency is 99.9 %.

3d: Tracking Efficiency After Irradiation (Testbeam)



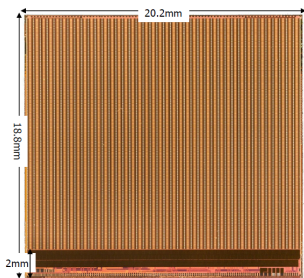
- Neutron irradiated at $5 \cdot 10^{15} n_{eq}/cm^2$.
- Upper plots at normal incidence: 97.5 % efficiency due to electrodes.
- Lower plots at 15° inclination (IBL-like). Efficiency is 97.4 %.
- HV is 140 V.
- See Gian-Franco Dalla Betta's talk on 3D irradiation for details.

Planar Efficiency (Testbeam)

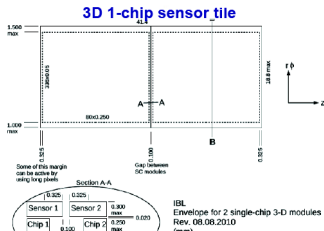
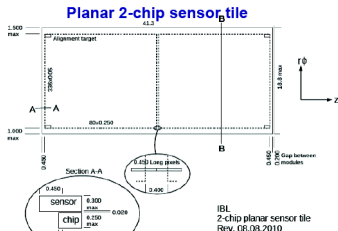


- Upper plot before irradiation: Efficiency is 99.9 %.
- Lower plot after irradiation with neutrons at $5 \cdot 10^{15} \text{ n}_{eq}/\text{cm}^2$. HV = 1000 V. Efficiency is 97.9 %.
- Main losses are in the bias grid. Smears out at higher η .

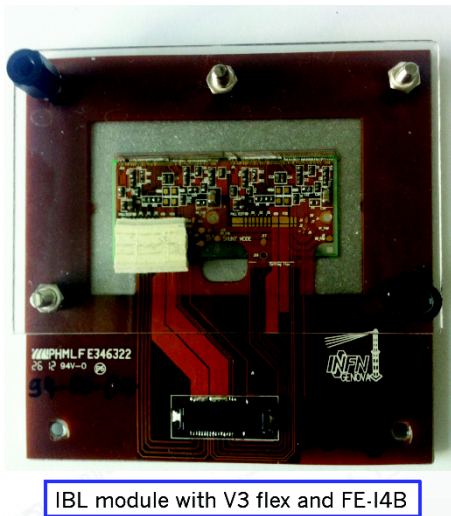
FEI4 Frontend Chip



- 130 nm process with high radiation tolerance.
- Large area of 2 cm x 2 cm.
- Pixel Size is 250 μm x 50 μm . 26880 pixels (80 x 336).
- Data is stored in the pixels and not moved out (or cleared) until LV1. This reduces traffic (bandwidth/power) in the chip.
- 0.6 % inefficiency at a pile-up of 80 ($\mathcal{L} = 3 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$).
- FEI4B production is complete and 2/3 of the wafers have been tested. The yield is well above 50 %.
- Version B of the FE-14 has minor fixes and new features added: Shunt/LDO reference voltages, ADC for readout of temperatures, leakage current measurement, programmable event buffer size limit, extended BCID/L1ID counters.
- See talk by Lea Caminada for details.

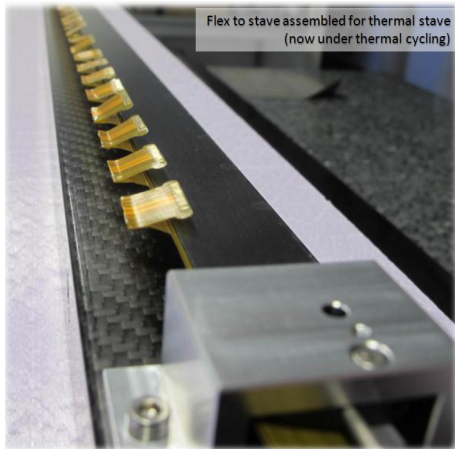


Module Flex



- The chip/sensor assemblies are glued to a flexible PC board.
- The chip is wire bonded to pads on this board.
- There are different flex PCBs for 3d and planar modules.
- The flex has a test connector which is cut off before the assembly is put on the stave.
- The module flex is wire bonded to wings on the stave flex.

Stave Flex



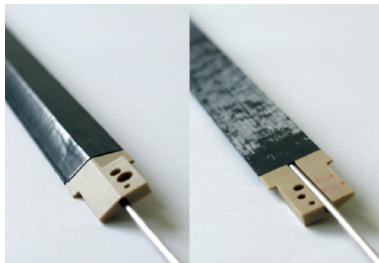
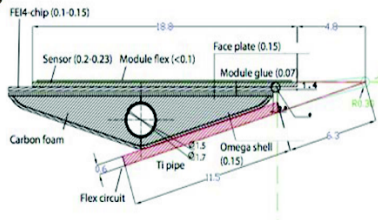
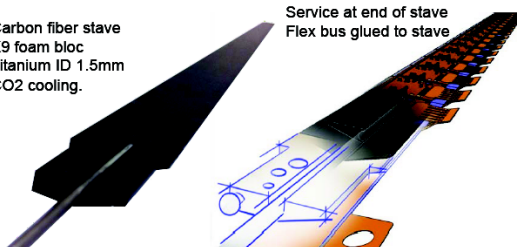
Flex to stave assembled for thermal stave
(now under thermal cycling)

- The stave flex connects HV, LV, signals, and temperature readout between the modules and the end of the stave.
- LV layers done in Aluminum for low material.
- One LV, HV line, and temperature sensor is shared by 4 frontend chips.
- Clock and command are shared between two frontend chips.
- The stave flex is glued to the side of the stave and connects to the module flexes through wings that are wire bonded to the module flexes.

Mechanical Stave

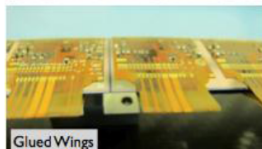
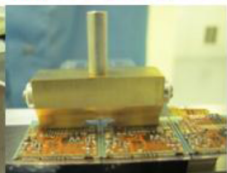
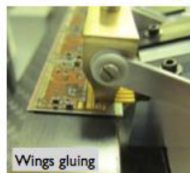
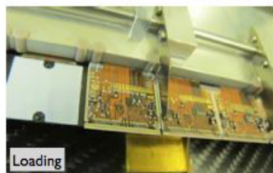
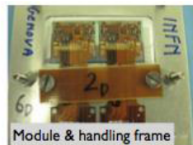
Carbon fiber stave
K9 foam bloc
Titanium ID 1.5mm
CO₂ cooling.

Service at end of stave
Flex bus glued to stave



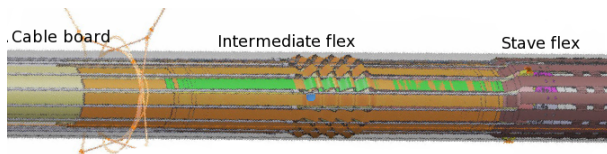
- The mechanical stave consists of a carbon fiber shell filled with thermal foam.
- A 1.5 mm titanium cooling pipe runs through the stave to provide CO₂ cooling.
- Stave flex and modules are glued onto the carbon fiber.
- The average material of the IBL is below 1.9 % X₀.

Stave Loading

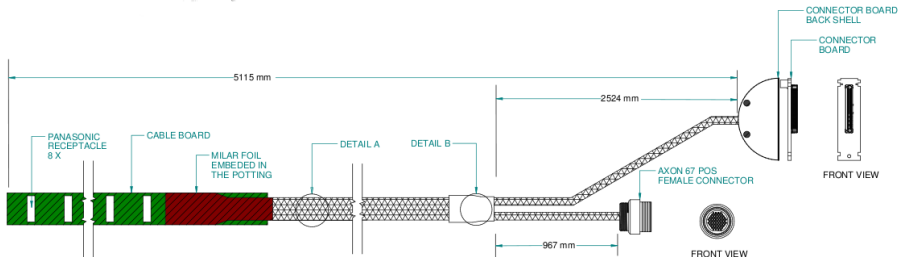


Module loading precision: RMS = 15 μm , maximum error = 50 μm .

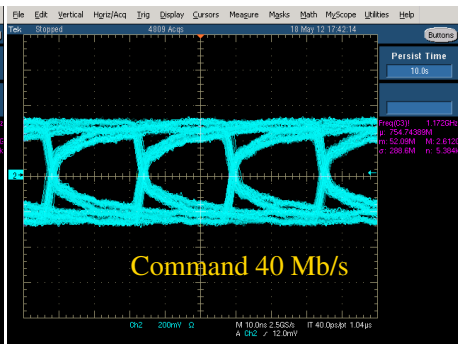
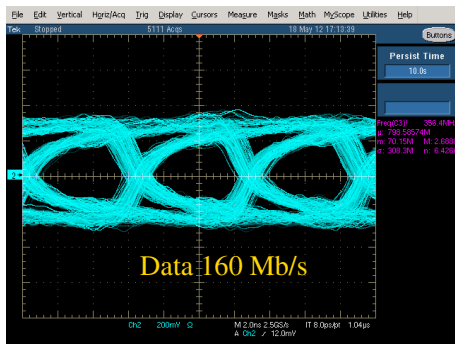
Services



- The stave flex connects to an intermediate, corrugated flex to allow for a 1 cm thermal expansion created by the large differences between normal running (-30°C) and beam pipe bake-out ($+60^{\circ}\text{C}$).
- The intermediate flex connects to a cable board which has the cable soldered to it.
- The service cable consists of a voltage supply part (3.7 m) and a readout part (5.2 m).
- The voltage supply part ends in a custom made connector.
- The readout part plugs into the optical converter.



Data Transmission



- The data transmission chain between the module flaps on the stave flex and the connector with the optoboard has been tested.
- The 5.2 m long cable consists of 36 AWG twisted pair for command/clock and 28 AWG twisted pair for data. The cables are a rad-hard custom design.
- The plots show eye patterns for the transmission of data at 160 Mb/s and commands at 40 Mb/s.
- The transmission quality is satisfactory.

CO₂ Cooling



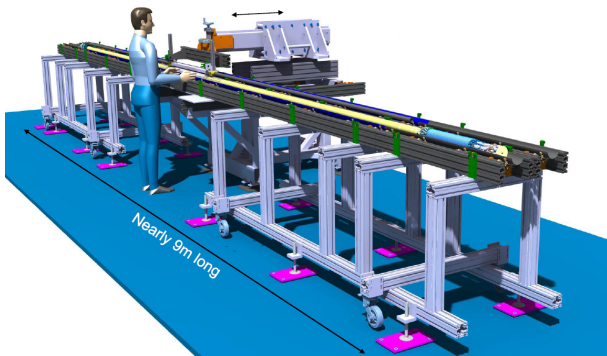
IBL Prototype

Item	Required temperature or range [°C]	Comments
Cold operation nominal T_{evap}	-40 to -30	max power 1.5kW
Warm operation nominal T_{evap}	+15 to +20	max power 1.5kW
Annealing operation nominal T_{evap}	0 to +20	variable power
Standby operation with detector off T_{evap}	-40 to +20	no detector power
Bake-out operation with detector off T_{evap}	-40 to -30	no detector power
Sensors cold running	$\leq -20^{\circ}\text{C}$	avoid thermal run-away
Sensors annealing	$+15^{\circ}\text{C} \leq T \leq +20^{\circ}\text{C}$	annealing scenario to be defined
Sensors bake-out	$\leq +20^{\circ}\text{C}$	
Services in IST	$\leq +30^{\circ}\text{C}$	
Coldest point in IST	Above dew-point	

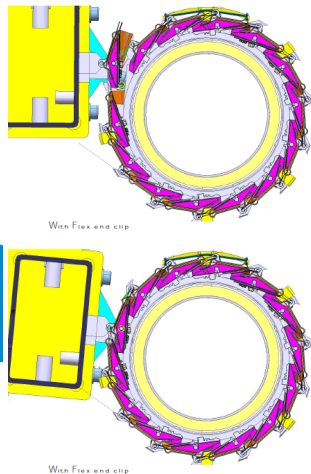
- Evaporative CO₂ Cooling plant.
- 1.5 kW power.
- Operational range of -40°C to +20°C.
- Prototyping is in progress. Smaller units (TRACI) are already fully functional.

Integration

Overview on the Integration stand @ SR1



- Tooling to assemble the IBL is being built.
- New, smaller diameter beampipe in the center.
- Staves are inserted with special handling frames.
- Services have to be connected and routed.



Installation Options

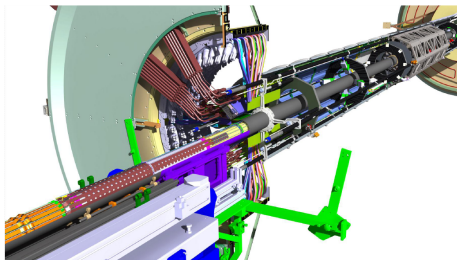
1. In situ:

- No removal of the pixel detector needed:
No risk to damage an aged detector and no extended work in a high radiation environment.
- Insertion of the entire 9 m long IBL including services and new beam pipe into the detector. Very challenging.

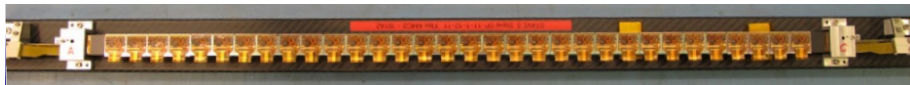
2. On the surface:

- Extract pixel detector.
- Insert IBL and beam pipe on the surface. Much easier since the area outside $z = \pm 1$ m is accessible.
- Reinstall the entire package.

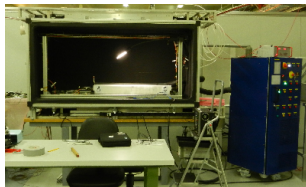
If new service quarter panels are installed to move the optoboards out of the detector then the pixel detector will come out \Rightarrow IBL Option 2. The diamond beam monitor (DBM) will be installed in the pixel volume (optimal position) if option 2 is chosen; an alternative position is being determined for option 1. A decision on an option is expected in December.



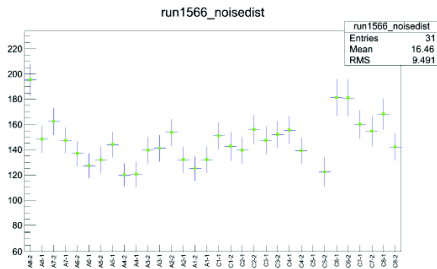
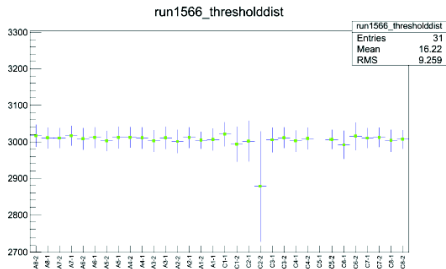
Prototype Stave



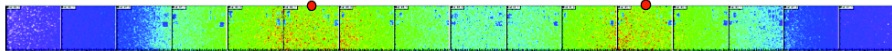
- A first stave has been assembled to gain experience with operating the IBL:
- One fully populated stave:
 - 32 frontend chips (FEI4A).
 - 8 single-chip 3d sensors and 12 double-chip planar sensors.
- Set up in a temperature controlled box.
- Prototype detector control and LV/HV supply.
- CO₂ cooling unit.
- Linear motor for source scans.
- Scintillator panels for cosmic data taking.
- A second prototype stave which will have FEI4B chips and on-chip voltage regulation will be installed this month.



Prototype Stave Measurements



- The frontends have been tuned for threshold (3000 e⁻) and signal response uniformity (time over threshold).
- Noise performance for the pixels is between 120 and 200 electrons.
- The results on the stave are comparable to single frontend measurements.
- Long term tests (source scans, cosmic data taking) are being done to look for more subtle problems.



Two Americium sources on stave (red dots).

IBL Features:

- The IBL is a new, innermost pixel layer for the ATLAS pixel detector.
- It has high bandwidth and good radiation hardness for high luminosity running.
- It contains the new FEI4 readout chip with 26880 $50\ \mu\text{m} \times 250\ \mu\text{m}$ pixels.
- The sensors are 75 % planar and 25 % 3d. This is the first time that 3d sensors are used in an experiment.

Schedule:

- All sensors and readout chips have been produced.
- Module assembly has started. Completion by February 2013.
- Loading module on staves: August 2012 - May 2013.
- The first prototype stave has been produced and is being tested now.
- Loading of staves onto the beampipe: March 2013 - July 2013.
- The fully assembled IBL will be installed in the ATLAS detector at the end of 2013 - beginning of 2014.