The upgrade of the **ATLAS** Inner Detector

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On behalf of the ATLAS collaboration

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LHC Plans and Upgrade Phases

The future observations at LHC should drive physics investigations at HL-LHC

The Machine and the Detectors are working towards the Upgrade Phases to improve the performances as well as the life time

Insertable B-Layer (IBL)

Features:

- ✓ 4th Pixel layer (instead of b-layer replacement)
- ✓ Closer interaction point ($5.05 \rightarrow 3.27\text{mm}$)
- ✓ Smaller pixels ($50 \times 250 \mu\text{m}^2$)
- ✓ Better sensors, better R/O chip
- ✓ More robust tracking
- ✓ Better performance

Reduce beam pipe diameter (47 mm)
in Beryllium under production

IBL Layout and Features

IBL features:

- 14 staves overlapping in Phi and mounted around the beam pipe on support rings
- Small clearances between beam pipe - IBL - IST : 2.5 to 2.7mm
- Stave to stave gap is only 0.8mm → Integration for the last stave delicate
- Instrumented stave made of **12 planar** and **8 3D** sensor modules along 664mm

Sensor Technologies

Planar sensor – n-in-n

Charges are collected at the strip surface

3D sensor

Charges are collected at the bulk implanted electrodes

Structure	Planar	3D
Thickness (nominal) [μm]	200	230
Depletion voltage [V]	~ 35	10 - 25
Working voltage after LHC fluence (5×10^{15} 1MeV $n_{\text{eq}}/\text{cm}^2$) [V]	~ 1000	~ 160
Module width [μm]	41325	20450
Active size WxL [mm^2]	16.8 x 40.9	16.8 x 20.0

Production status:

- Planar sensors from CiS: **424 good double chip (DC) tiles** (89.1 % yield) - IBL needs 168 tiles (75% planar).
- 3D sensors from CNM & FBK: **306 good tiles** as today (62% yield) – IBL needs 112 tiles (25 %).

1st time 3D sensors will be used on a Si-tracker

Test Beam Results

Efficiency

A number of pixels does not work after proton irradiation (*TID ~ 3x IBL lifetime*)
Same behavior for both sensor types => FE-I4 "feature" (Pixels masked during analysis)
will be addressed with FEI4b

Charge collection

Front-end Electronics – FEI4

FEI4 main features:

- IBM (130 nm)
- 70 Million transistors
- 26880 pixels ($50 \times 250 \mu\text{m}^2$)
- Lower noise than FE-I3 ($\sim 150\text{e}^-$ with sensor)
- Lower threshold operation
- Higher rate compatibility
- Radiation hard to $>250\text{Mrad}$
- In use for pixel R&D and towards Upgrade phase 2

Through the FEI4 progresses:

- First version FEI4a for validation and IBL prototypes (32 FE-I4A wafers received in 2010/11)
- FEI4b features: minor fixes + r/o functionalities + uniform pixel matrix + Power functionality
- First FEI4b delivery in Dec. 2011
- FEI4b now in production (30 wafers) and wafer probing is almost completed (yield $\sim 60\%$)

FEI4b noise before and after irradiation:
114e $\rightarrow$ 124e (both tuned)

Module Production Status

- Production is in progress in two assembly sites
- Started first with FEI4a module production for stave 0
- FEI4b modules has just started – PRR is programmed for beginning of June

Thin module process steps (100 and 150 μ m thick FE): Crack found in the thinnest FE backside
→ IBL will go with 150 μ m thick

- ① FE-I4 wafers thinned
- ② glued on glass support wafer
- ③ bump deposition
- ④ dicing wafer & substrate
- ⑤ flip-chip & reflow
- ⑥ substrate wafer removal by power laser.

Modules with FEI4a

Am241 source scan

Layout of the SMD components are clearly visible

3D module

Stave and Flex Features

Stave features:

- Made of light material (K9 carbon foam + CFRP skins for stiffness)
- Ti pipe of 1.5mm ID and 0.1mm wall thickness
- Face plate (module side) is coated with Parylen for safer electrical break to detector HV
- Tight planarity and envelope tolerance: $\pm 0.1\text{mm}$
- Stave fixations on 3 points: 2 end-blocks + central support

Flex features:

- Mix of 4 Cu-layers and 2 Al-layers for the LV lines. Total thickness $\sim 450\mu\text{m}$
- The 2 Al-layers needs to be processed with CVD for Chrome and Copper (vias)
- The wings supply through 1 layer the connectivity for every FE. Wing thickness $70\mu\text{m}$
- Wings are folded and glued for very precise envelope required for the integration

1st AlCu flex ever made for tracker in fabrication for IBL

Stave & flex pre-production started and OK

Module Loading and QA

The module loading and QA consists of 16 working steps

Key features of the loading procedure:

- Modules are mounted with a thermal grease interface + epoxy glue drops
- Thermal grease was qualified for its good thermal performance and for its radiation hardness
- Rework and module replacement is possible but not straight forward
→ Module and flex QA prior to loading is essential
- All staves will be thermal cycled with loaded modules for QA – Electrical tests and metrology survey will be made before and after this operation
- Electrical insulation between HV groups will be done → Thin polyimide layer in module gaps

Stave handling frame

The stave will remain on a **handling frame** for all assembly and QA operations including the pipe extension and the integration around the beam pipe. One per stave with high precision machining.

Loading modules

Stave wire bonding

Stave Integration

*Staves Assembly around the
New Beam pipe with the
MPC (Multi-Purpose Container)*

1. **Stave pipe extension to 7m** - Brazing technique
2. **MPC** as a multi purpose object for: BP container, stave loading, IBL Test bench and, IBL container.
3. **Testing** has been performed on an IBL_MPC 1.6m long prototype (done in January)
4. **IBL_MPC** proto to be used for IBL Integration checks, sealing issue, interfaces with LPSC “tables”

IBL_MPC prototype @ UNIGE
(1.6m long, cut out successfully)

Pipe brazing for extension

Integration & Installation

Two viable options are investigated:

- IBL to Pixel integration in the surface building associated to nSQP installation
- IBL to ATLAS integration in the pit

IBL to Pixel integration in SR I

ITT already in SR I
Integration scenario clearly defined

Pixel Integration & Testing Tool

IBL to ATLAS integration in the pit

CO₂ Cooling

Test bench allowed to evaluate IBL system (branch + stave):

- Coolant at -39°C → Stave -24.4°C (60% of the DeltaT due to the stave T_{FoM})

Joint CERN-PHDT & Nikhef responsibilities

- ✓ Plant construction @ Nikhef (by April 13)
- ✓ Integration of electronics @ CERN (May-June 13)
- ✓ Commissioning of cooling plant (July-Sep. 13)
- ✓ Installation in Cavern: Oct. 13

USA-15

Pixel nSQP – new Service Quarter Panels

nSQP features: (→ *pending decision by mid 2012*)

- No optical transceiver inside the ID region (VCSEL problems on ID triggered the project)
- On-detector optoboards replaced by new accessible optoboards located at ID End-Plate
- Reproduces the Pixel services with design improvements
- Add long-term reliability to the operation of the detector

Installation and Integration (2013-2014) in phase with IBL at the surface building

Pixel running experience 2010 + 2011

- Data taking efficiency in 2011: 99.8%
- 95.9% of Pixel modules are active
 - 2.1% before LHC turn
 - 2.0% lost in 2010 + 2011
 - Problems constantly increase after cooling cycles and ~equally distributed

nSQP is expected to improve Pixel efficiency & reliability

Pixel during integration in SR1

DBM – Diamond Beam Monitor

The goals of DBM:

- ✓ Luminosity
 - Monitor luminosity delivered to ATLAS for individual BCIDs
 - Aim for % level accuracy in lumiblock (1-2 minutes)
- ✓ Beam Spot
 - Unbiased (trigger) beam spot monitoring
 - Aim for ~1cm accuracy per event
- ✓ Background monitoring
 - Topology of BG different than IP interactions
- ✓ Track Trigger test-bed
 - Possible test-bed for ideas (pattern reco., tracking,...)

DBM installation is linked to IBL and nSQP integration and installation

3 successive modules pointing towards the IP

ID Upgrade Phase 2 - Topics

Topics under investigation for the tracker upgrade:

- **New ID layout:** Only silicon pixel and strip detectors ↔ Simulations
- **Trigger:** Si-track trigger for LI decision is considered using RoI
- **New detector technology:** n-in-p planar for strips and pixel (slim and active edges), 3D-sensors & Diamond (innermost layers), Gossip – Current R&Ds efforts
- **New ASICs technologies:** Deep submicron 250 nm → 130nm
 - Pixel FEI4b in production + R&D in 65nm
 - Strip ABCN130 to be submitted at the end of 2012
- **Cooling with more headroom:** CO₂ plant for coolant down to -35°C or lower
- **New powering scheme:** Serial powering or DC-DC for parallel powering
- **Faster readout:** FE asics (160/320 Mbps) and optical link (5Gb/s)
SCT 1.3 kch/link → Upgrade up to 123 kch/link
- **SCT Module integration** will be grouped on a stave or a super-module structure
- **DCS** is proposed to be partially integrated into the readout architecture
- **Engineering:**
 - Assemble and commission the complete ID in a surface building
 - Service reuse of cables between counting room and detector
- **Installation:** Limited access time inside the cavern → Need clear and well prepared integration plans

- Classical layout – Barrel & Disk
- 2 innermost pixel layers should be replaceable (IST R=11 cm)
- Full pixel package should be replaceable
- Pixel services should be axial

I-beam stave concept for Innermost 2 layers

Pixel Layout

Possible options for outer layers

Goal is to reduce or suppress disc → material budget saving

Conical layout

Bended staves in conical layout

Alpine stave concept

Real prototype for feasibility

Strip Tracker – Stave & Petal

Features:

- Single sided modules mounted on each side of core structure (Carbon foam + CFRP planes)
- Cooling pipe embedding into the core structure
- Stave service bus is laminated with the core structure and modules are glued on top
- Hybrids are directly glued on top of the Si-strips and are serviced at each side of the sensor
- Stave design is compact

Thermo-mechanical stave

Petal layout

Progress so far:

- Successful module production in several institutes with ABCN250
- Stavelets with 4 module evaluated with success on system tests – Noise performance with Serial and DC-DC powering configurations
- Thermo-mechanical measurement of real stave has been studied
- Hybrid and sensor designs in progress for matching the new FE in 130nm technology with 256 ro channels

Stavelet with 4 modules
using DC-DC powering

Strip Tracker - Super-Module

Features:

- Double sided modules allowing for space point reconstruction (back-to-back sensors mounted to few μm)
- Module mounting with Z-overlapping for full hermeticity
- Module symmetry and bridged hybrids allowed for very low thermo-mechanical deformation ($< 2\mu\text{m}$ out of plane)
- 12 modules are precisely mounted with grease joint on a local support with cooling pipe and plates on the sides.
- Modularity allows for modules and items replacement during production or even late after integration

Module noise inside test box and on local support very similar and uniform

Light local support CRFP structure for 12 modules + CC cooling plates

Super-module prototype for 8 modules
5 modules are mounted with DC-DC

Summary

Phase 0 long shutdown will allow :

- The ATLAS ID to insert in 2013/14 a new innermost Pixel layer namely IBL
- **IBL is possible thanks a new reduced beam pipe diameter** now in production (delivery in Fall)
- **IBL layout is a mix of planar and 3D sensor technology** integrated on the stave
- **The FEI4 readout chips is one of the key items** which is working fine and the latest version is in production – Also used for future Upgrade development
- The IBL parts are in production – **Schedule is on a fast track**

Phase 2 long shutdown – R&D:

- Pixel and Strip communities are both working on the layout, the module and the integration concepts
- **Pixel is focusing on sensor R&Ds and working on integration of multi-FE modules**
- **Strips R&Ds have integrated multiple modules into system tests** with DC-DC and serial powering
- Strip **ABCN front-end readout in 130nm technology is under design** and will be submitted by the end of 2012