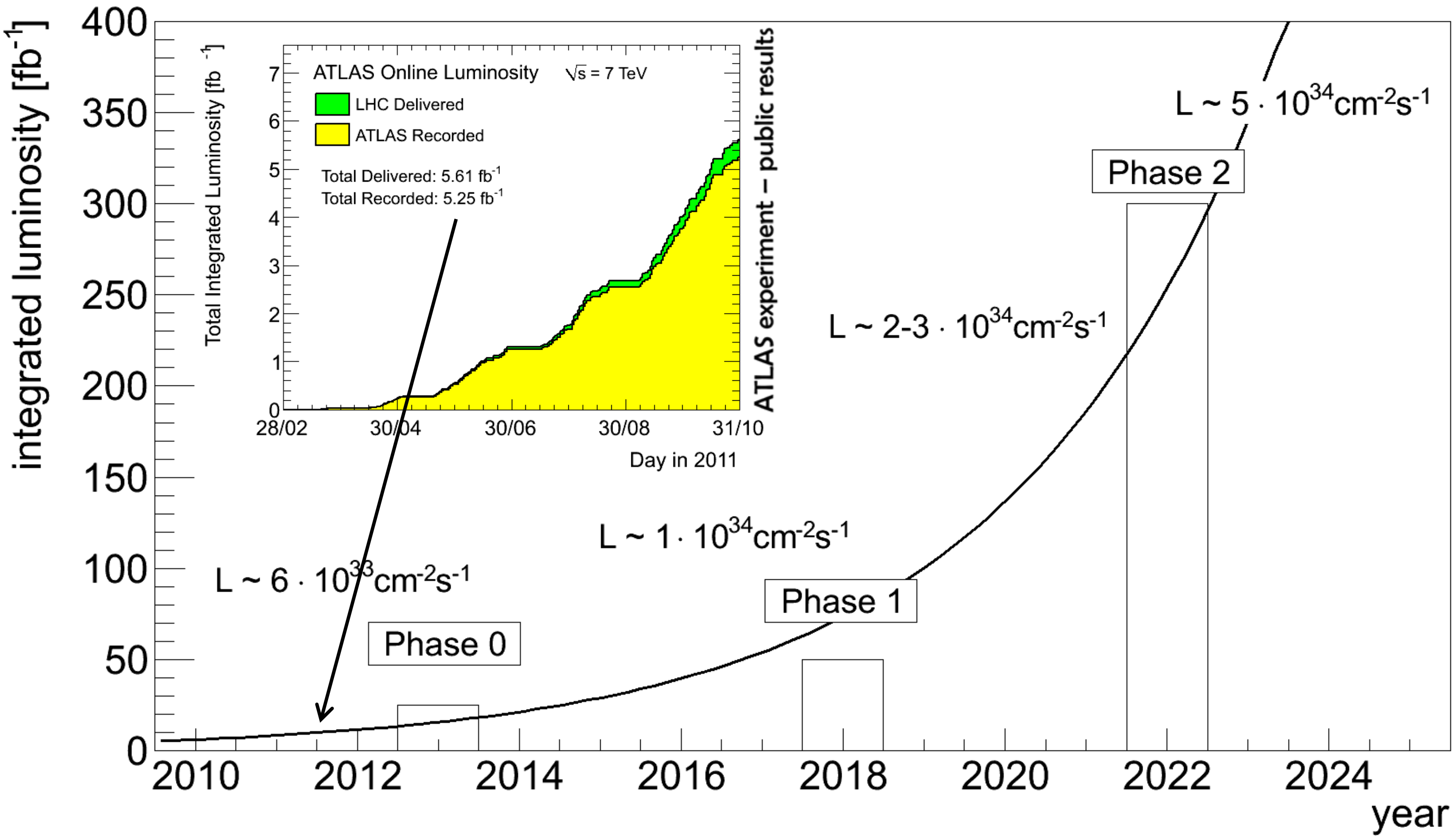
Overview of the ATLAS Insertable B-Layer (IBL) Project

Christian Gallrapp (CERN)

on behalf of the ATLAS collaboration

LHC UPGRADE PROGRAM

LHC upgrade program



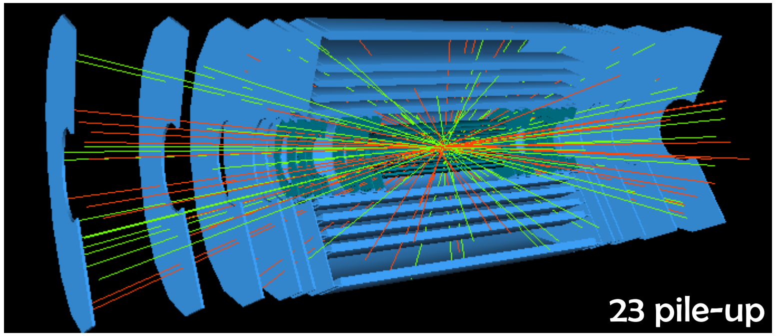
Based on:
Marzio Nessi , Chamonix 2012
8 February 2012

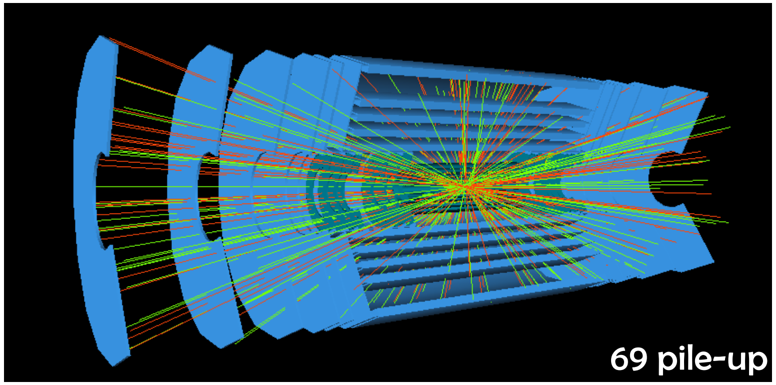
A total integrated luminosity of about 3000fb^{-1} is expected till 2030

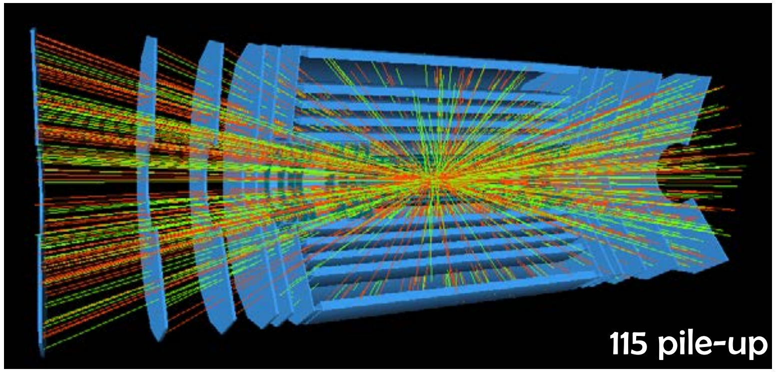
Challenges for the Inner Detector

- Increased luminosity
  - Higher hit-rate capability
  - Higher segmentation
  - Higher radiation hardness
  - Lighter detectors

- Radiation hardness for the innermost layer at 3cm to 4cm
  - Phase 1: $1 \cdot 10^{15}\ n_{eq}cm^{-2}$
  - Phase 2: $5 \cdot 10^{15}\ n_{eq}cm^{-2}$
  - HL-LHC: $2 \cdot 10^{16}\ n_{eq}cm^{-2}$







Peter Vankov, ITk Subcommittee meeting
5 October 2011

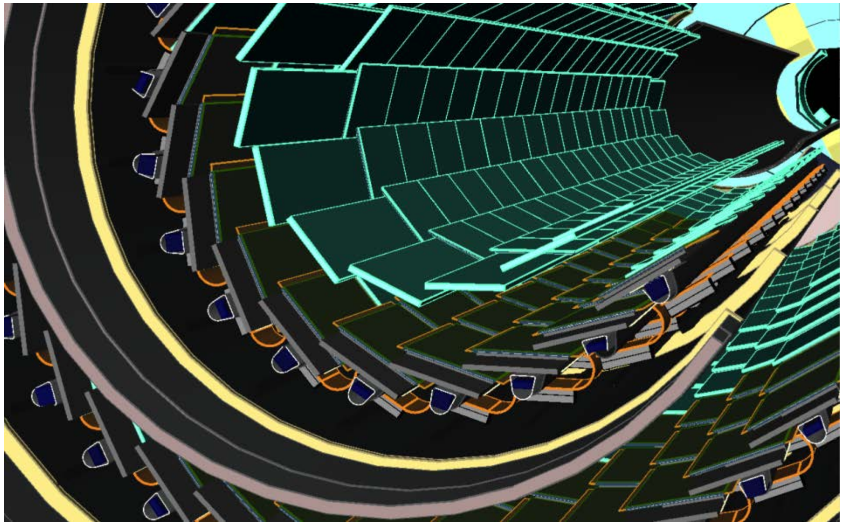
ATLAS Pixel Detector upgrade

- **Phase 0 Upgrade**

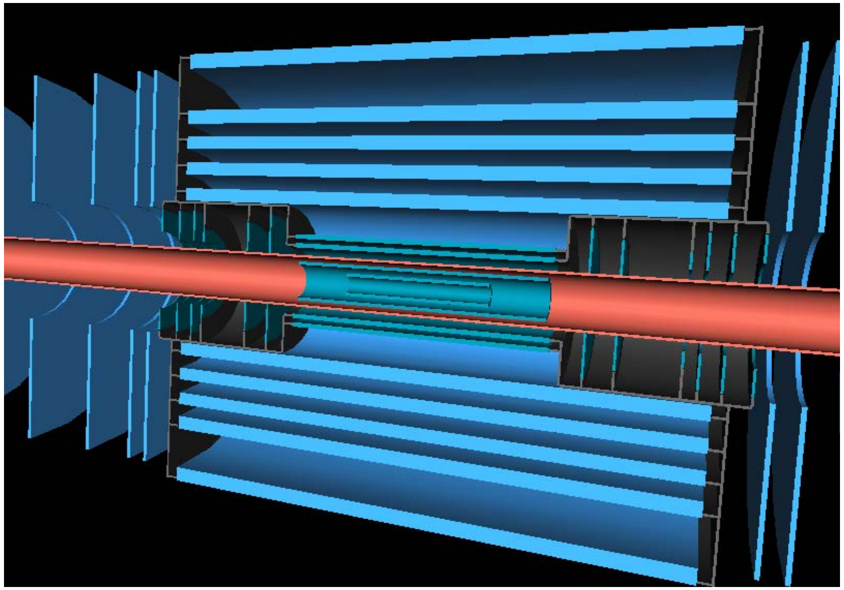
  The new IBL will extend the pixel detector system to a 4-layer system with finer segmentation and at a smaller radius

- **Phase 2 Upgrade**

  Complete new ATLAS tracker for pixels and strip detectors



CERN-LHCC-2010-013

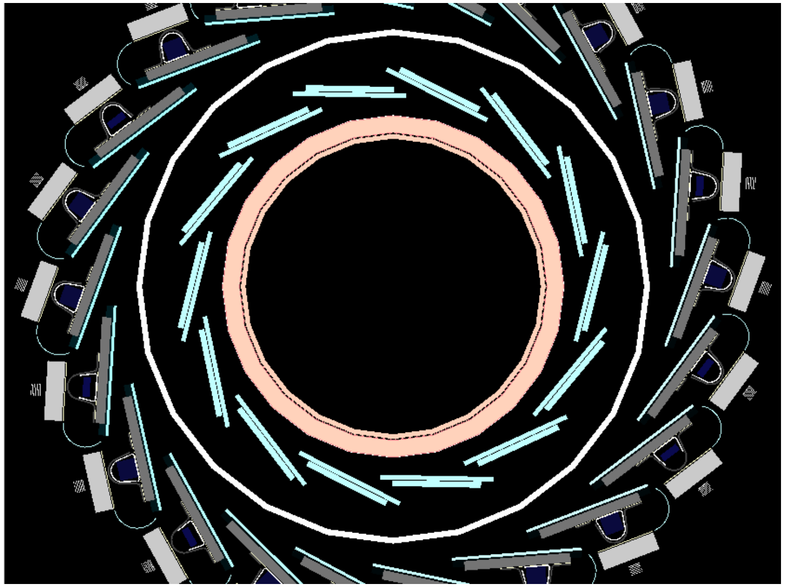


Teddy Todorov, Seminar zur Teilchenphysik
11 November 2011

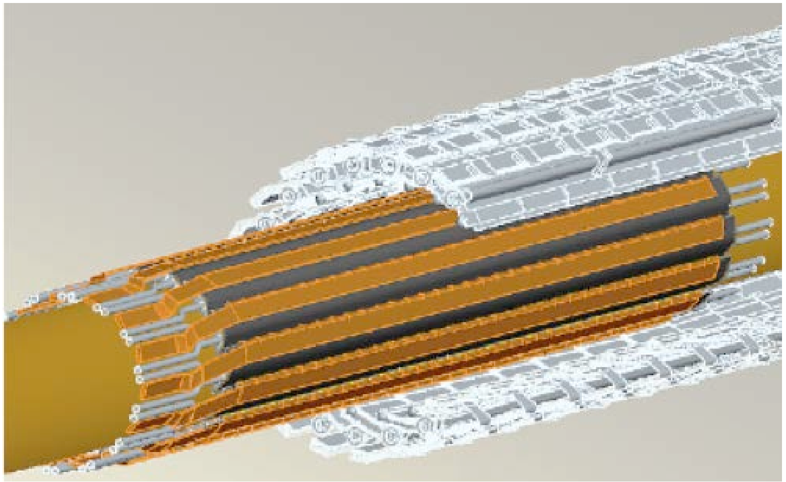
IBL UPGRADE

IBL upgrade

- IBL Properties
  - Smaller beam pipe (R_{min} = 26.5 mm)
  - Smaller z pitch (250µm)
  - Material budget adjusted to 1.5% X0
  - 250 Mrad TID and $5 \cdot 10^{15}$ $n_{eq}cm^{-2}$ NIEL
- Layout is based on performance studies within the ATLAS Simulation framework and the available space
- Fourth pixel layer for tracking in ATLAS
- Maintain and improve physics performance (b-tagging, light jet rejection) until HL-LHC
- IBL layout
  - 14 staves
  - 32 FE-I4 chips per stave
    => 448 FE-I4 chips in total
  - Available Sensor technologies
    - 3D sensors as single chip modules
    - Planar sensors as double chip modules



CERN-LHCC-2010-013

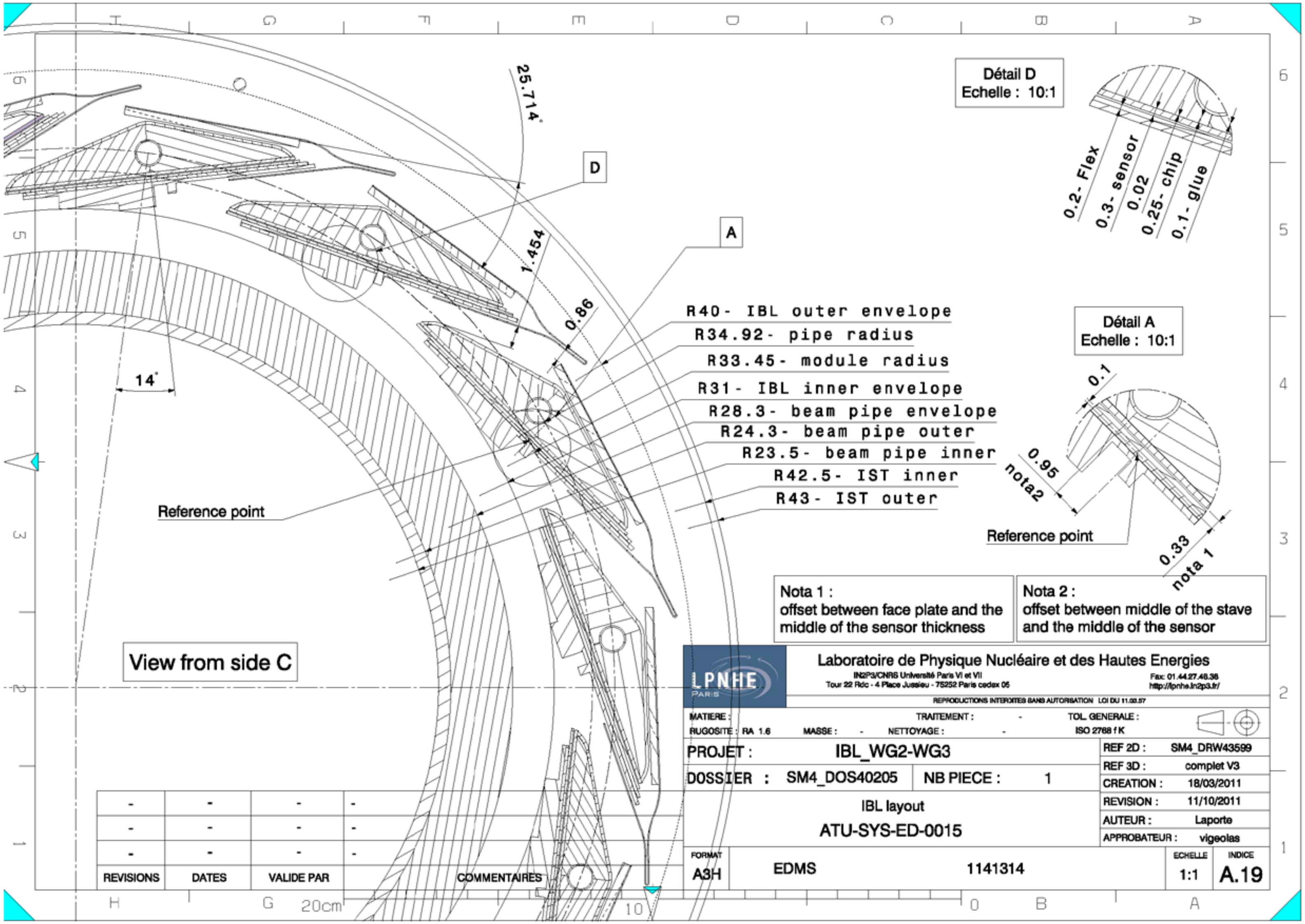


ATL-INDET-SLIDE-2011-251

IBL Requirements and Specifications

- Higher radiation hardness
  - $5 \cdot 10^{15}$ n_{eq}cm^{-2} NIEL (Improve radiation hardness by factor 5)
  - max. power dissipation: 200 mW cm^{-2} at -15°C
  - tracking efficiency > 97%.
- New readout chip with fine segmentation, more active area and improved hit-rate capability
  - New readout architecture and smaller cell size 250·50 μm^2
  - Large single-chip (21·19mm^2)
  - Radiation hardness > 250Mrad TID
- Lighter detector: less radiation length in support and cooling
  - improve radiation length per layer from 2.7% to ~ 1.5% to minimize multiple scattering in closest layer
  - Requires lighter and less material for support and cooling
  - High efficiency CO_2 cooling at -40°C coolant temperature
- New off-detector readout system
  - Matched to FE-I4 pixel chip
  - Increase readout speed by a factor of two

IBL layout



Nota 1 :
offset between face plate and the middle of the sensor thickness

Nota 2 :
offset between middle of the stave and the middle of the sensor

REVISIONS	DATES	VALIDE PAR	COMMENTAIRES
-	-	-	-
-	-	-	-
-	-	-	-

LPNHE PARIS

Laboratoire de Physique Nucléaire et des Hautes Energies
IN2P3/CNRS Université Paris VI et VII
Tour 22 Rdc - 4 Place Jussieu - 75252 Paris cedex 05
Fax: 01.44.27.46.38
http://lpnhe.in2p3.fr/
REPRODUCTIONS INTERDITES SANS AUTORISATION LOI DU 11.03.57

MATIERE :
TRAITEMENT : -
TOL. GENERALE : ISO 2768 f K
RUGOSITE : RA 1.6
MASSE : -
NETTOYAGE : -

PROJET : IBL_WG2-WG3
DOSSIER : SM4_DOS40205
NB PIECE : 1

IBL layout
ATU-SYS-ED-0015

REF 2D : SM4_DRW43599
REF 3D : complet V3
CREATION : 18/03/2011
REVISION : 11/10/2011
AUTEUR : Laporte
APPROBATEUR : vigeolas

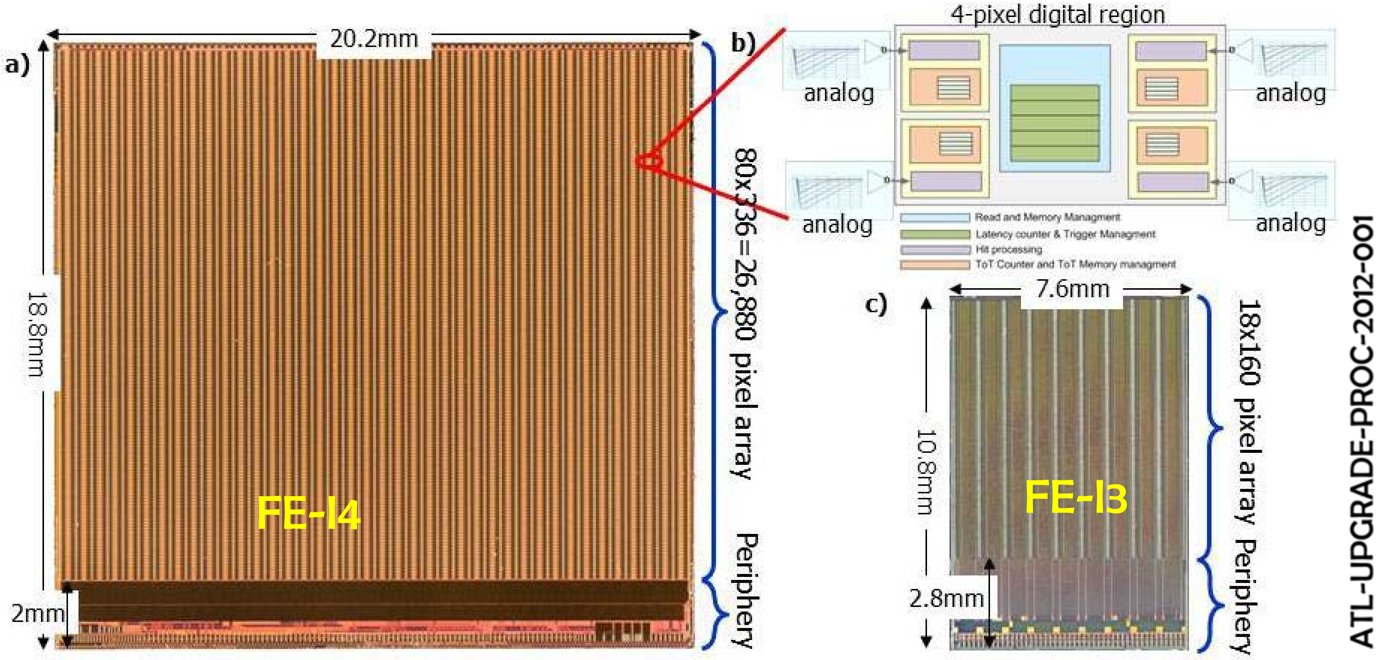
FORMAT A3H
EDMS 1141314
ECHELLE 1:1
INDICE A.19

EDMS: 1141314

ATLAS FE-I4

- Smaller pixels (50·250 μm²)
- Lower noise and threshold operation
- Compatibility for higher data rates
- Column drain architecture with local hit storage
- IBM 130nm process

- Largest chip to date in HEP:
  - maximize active area and reduce bump-bonding costs
- array size: 80 col. x 336 rows
  => 26880 pixels, $8x10^7$ transistors
- average hit rate at 1% inefficiency
  => 400 MHz cm^{-2}; max. trigger rate: 200kHz



ATL-UPGRADE-PROC-2012-001

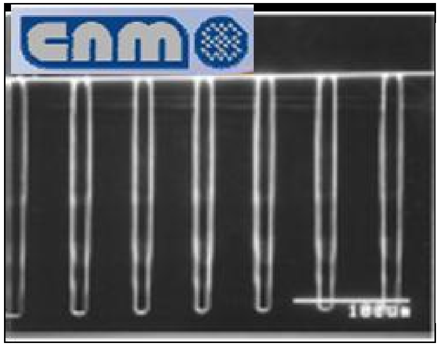
IBL Sensors Technologies

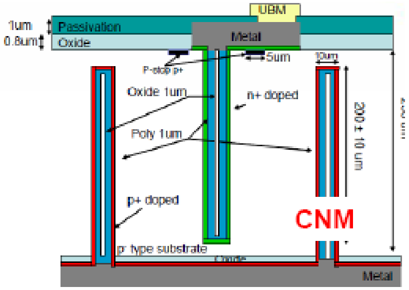
3D slim edge (FBK, CNM)

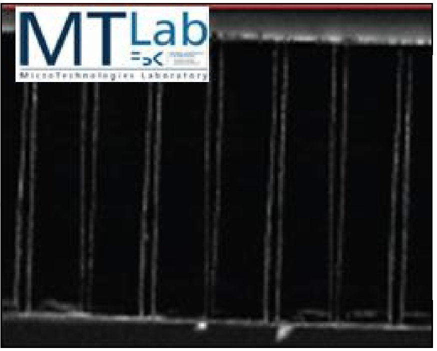
- Horizontal depletion (short depletion width leads to low bias voltage)
- Different processing but common top-layer mask for chip connection
- Manufacturing yield now being tested with pre-production runs by CNM and FBK

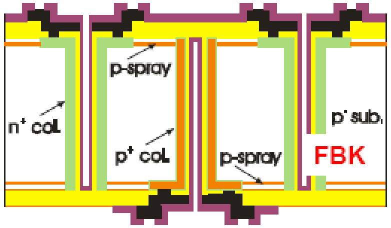
Planar n-in-n slim edge (CiS)

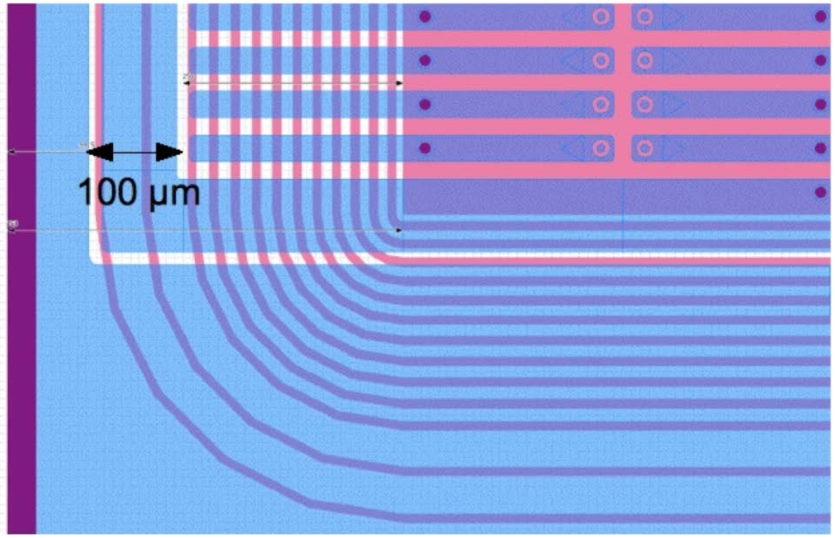
- minimize inactive edge by shifting guard rings underneath active pixel region
- Ongoing efficiency studies after full IBL irradiation
- Manufactured by CiS like present pixel sensors











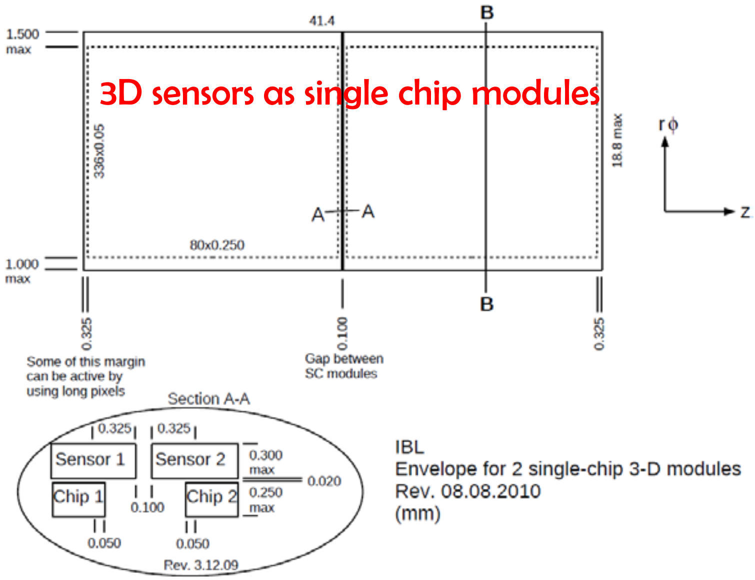
CERN-LHCC-2010-013

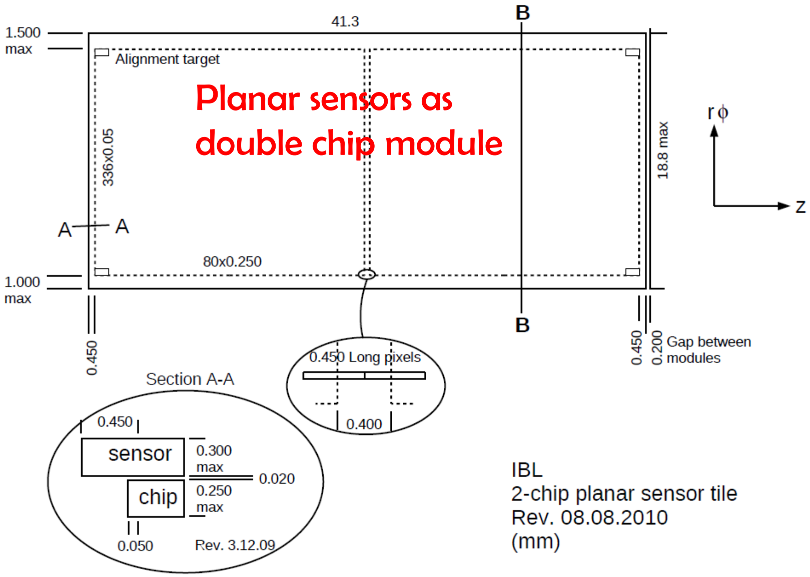
C. Da Via, IBL General Meeting
15 February 2012

MODULES AND STAVE

IBL modules

3D n-in-p sensor	Property	Planar n-in-n sensor
16.8 x 20.0	Active size W x L [mm^2]	16.8 x 40.9
18.8 x 20.5	Total size W x L [mm^2]	18.54 x 41.27
230	Thickness [µm]	200
≤ 15	Typical depletion voltage [V]	≤ 35
25	Typical initial operation voltage [V]	60
180	Operation voltage at the end of lifetime [V]	1000

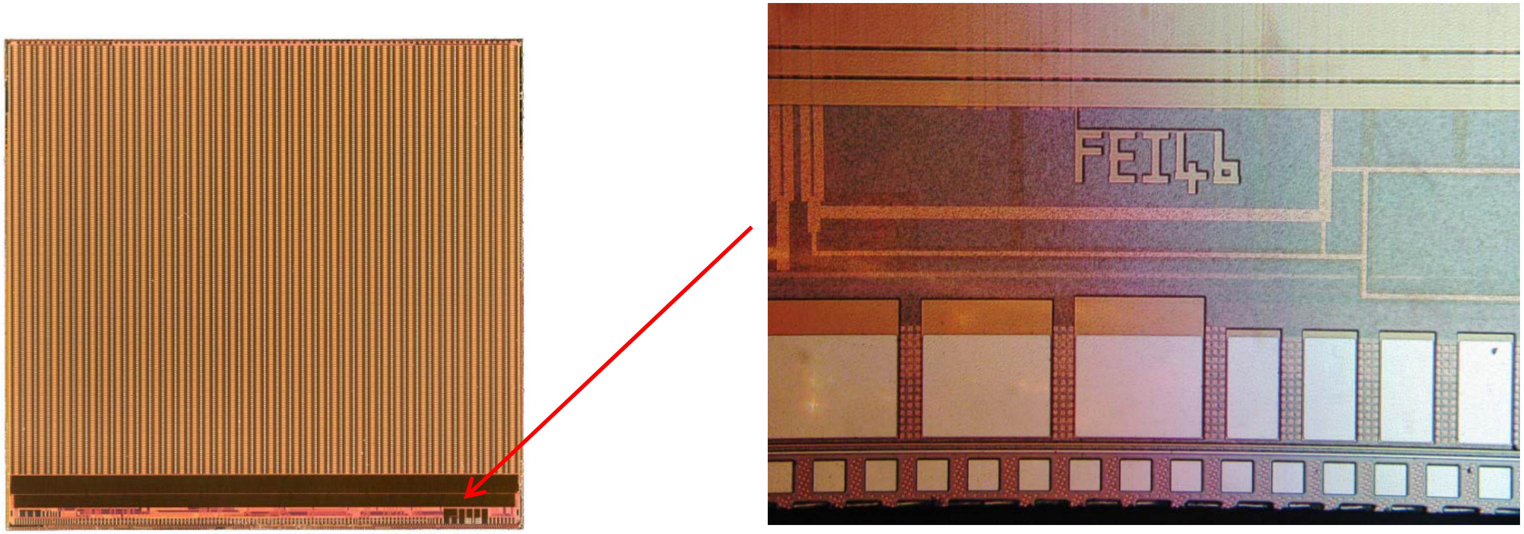

3D sensors as single chip modules


Planar sensors as double chip module

CERN-LHCC-2010-013

IBL module production (I)

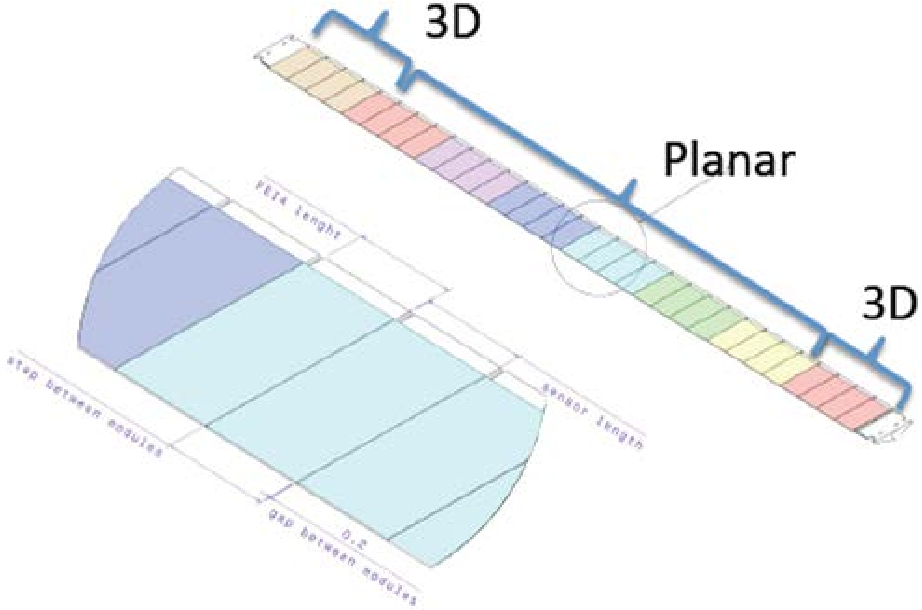
- Decision to install IBL in 2013 came in January 2011
  - Crash program to submit production version of chip in a few months
- Verification of new FE-I4B chip
  - Chip “has to work”
- Submission and tests
  - 16 wafers received in December 2011 and 8 wafer in February 2012
  - One diced wafer at LBNL by December 2011
  - 2 chips tested and in beam at LANL by December 2011



IBL module production (II)

ATLAS Pixel extended Institute Board endorsed the recommendation of the review panel:

- produce enough Planar sensors to build 100% of the IBL
- continue current 3D sensor production to build 25% of the IBL



3D n-in-p sensor

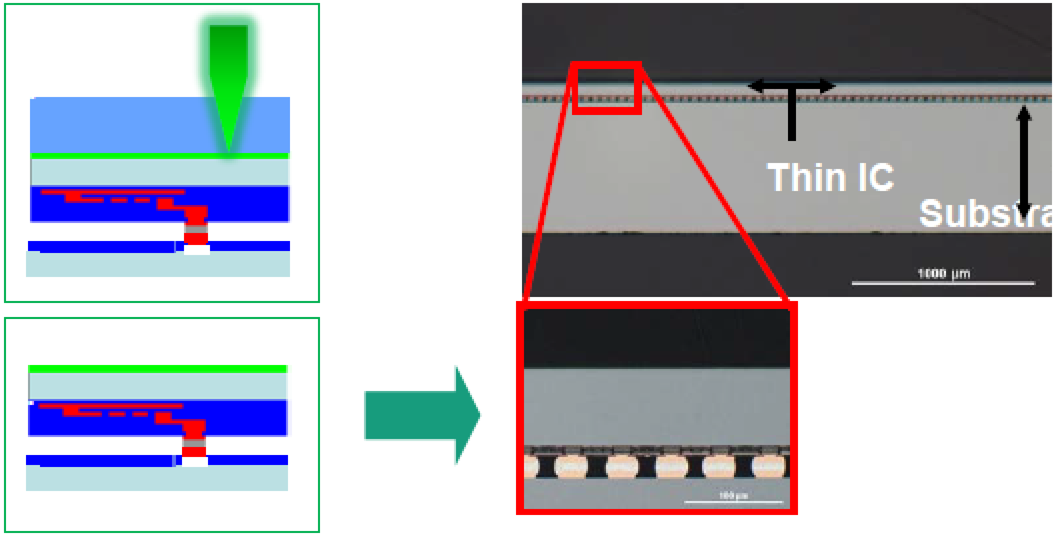
- 6 batches in production: 3 at CNM and 3 at FBK, the first 3 batches will go to IZM for bump-bonding
- 49 out of 50 selected wafer available
- first batch now at IZM for bump-bonding

Planar n-in-n sensor

- 6 batches in production at CIS
- 119 out of 150 accepted wafer received
- 3 batches at IZM for bump-bonding

IBL bump-bonding

- Over 78 single-chip assemblies with planar and 3D sensors have been bump-bonded for the sensor qualification in 2011
- Thin FE-I4 (100µm and 150µm) on planar and 3D sensors have been prepared by IZM to test the feasibility of thin modules (i.e. final IBL modules):
  - first modules single and double chip have been produced successfully with 100µm and 150µm thick FE-I4A
  - 31 planar double chip and 17 3D single chip modules with thin FE-I4 chips done as pre-production to IBL module specifications



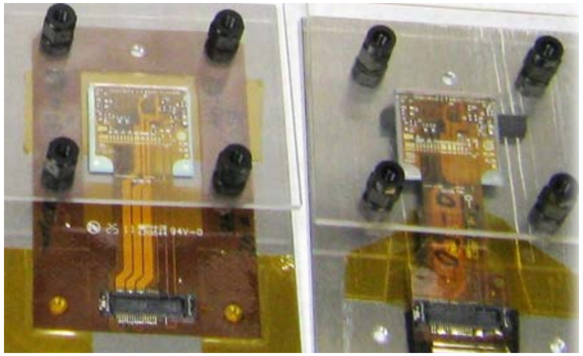
Test results on production chips

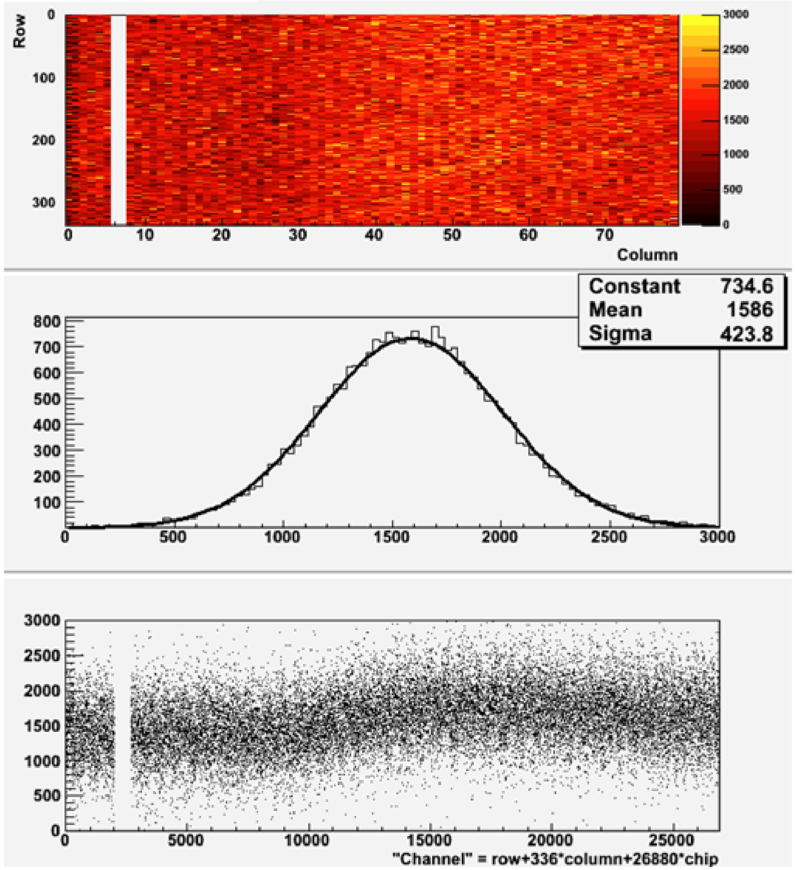
Characterization and tests of FE-I4B:

- 1 single chip tested so far on single-chip cards to test basic functionality and analog part
- New and corrected features with respect to FE-I4A are working fine
- More testing of FE-I4B needed before final conclusion on chip quality
- First chips have been irradiated

Wafer testing:

- Tests on FE-I4A wafers (scan chain etc…). Understanding of test results in progress.
- First batch of FE-I4B wafer tests during February -> All indicators are green so-far

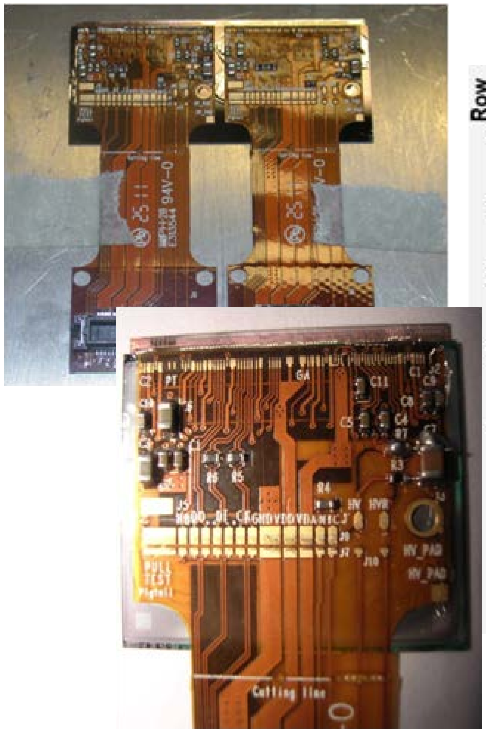


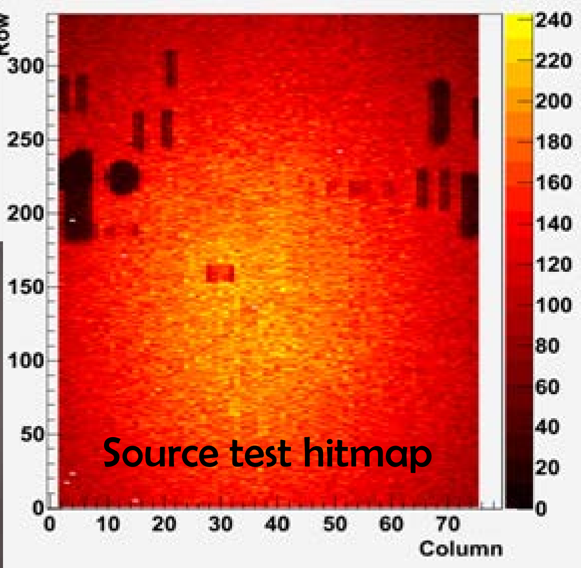


Threshold scan of un-tuned chip shows the expected analog response

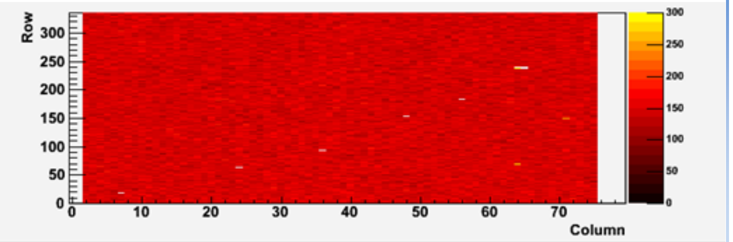
Tests on assembled IBL modules

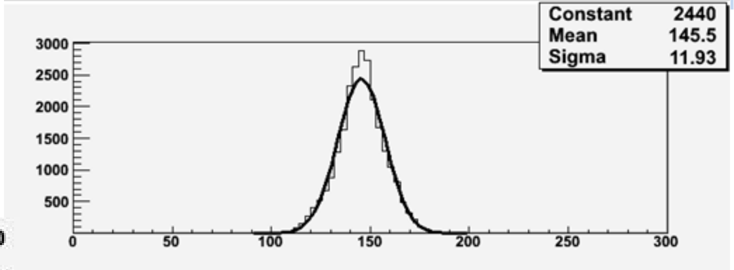
- Finished pre-production with FE-I4 to
  - Test final module design
  - Prepare and test assembly and quality assurance procedure
  - Lab tests with calibration, Am-241 and Sr-90 sources
  - Good performance so far
- Finalizing module flex for final FE-I4B chip

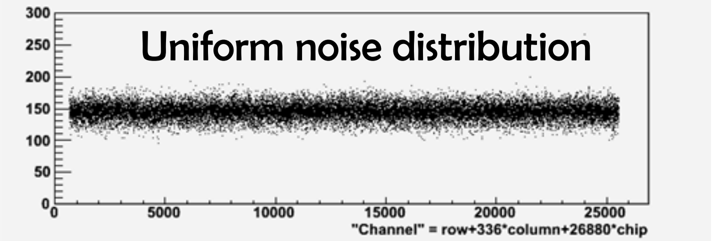




Source test hitmap



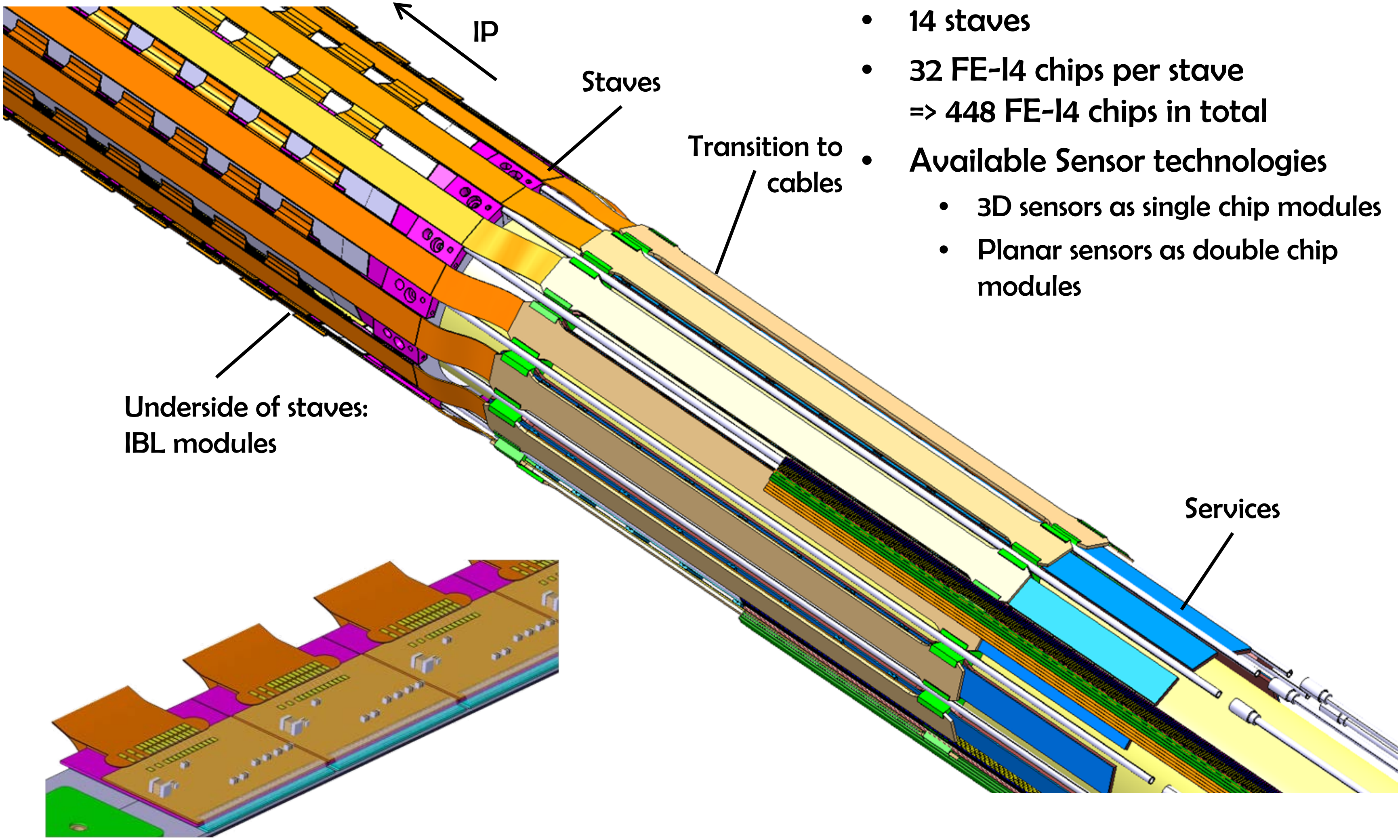




Uniform noise distribution

- Production is running fine
- Expect first FE-I4B production modules end April
- Production will run until ~ end of 2012

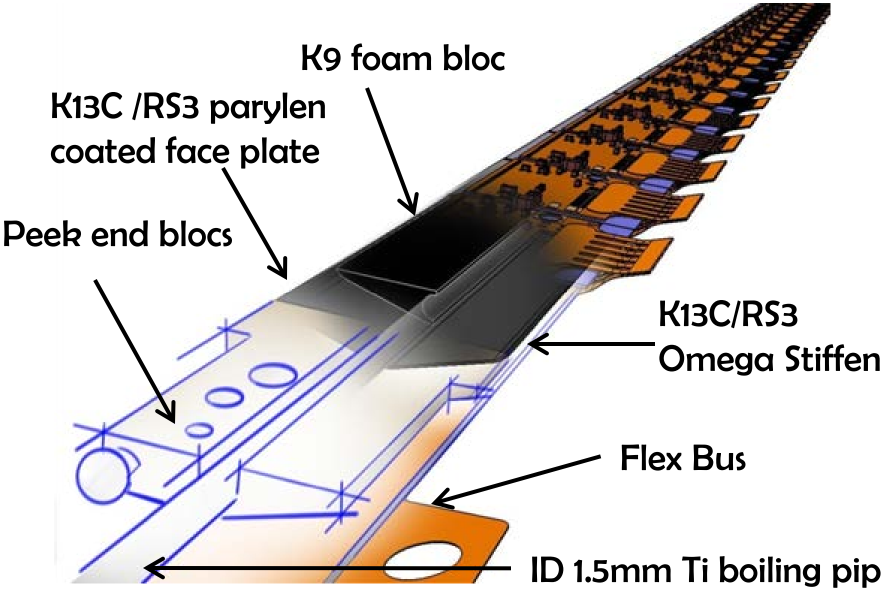
IBL stave



- 14 staves
- 32 FE-I4 chips per stave
  => 448 FE-I4 chips in total
- Available Sensor technologies
  - 3D sensors as single chip modules
  - Planar sensors as double chip modules

IBL carbon-fibre support

- Carbon-fibre support structure with minimal material budget X/X_0~0.5% for support and cooling
- Optimized stiffness and thermal conductivity
- Match thermal expansion
- Material qualification for use in high-radiation environments (300Mrad)
- Detector cooling with a CO_2 system working -40°C to minimize the leakage currents of the sensors



K9 foam bloc

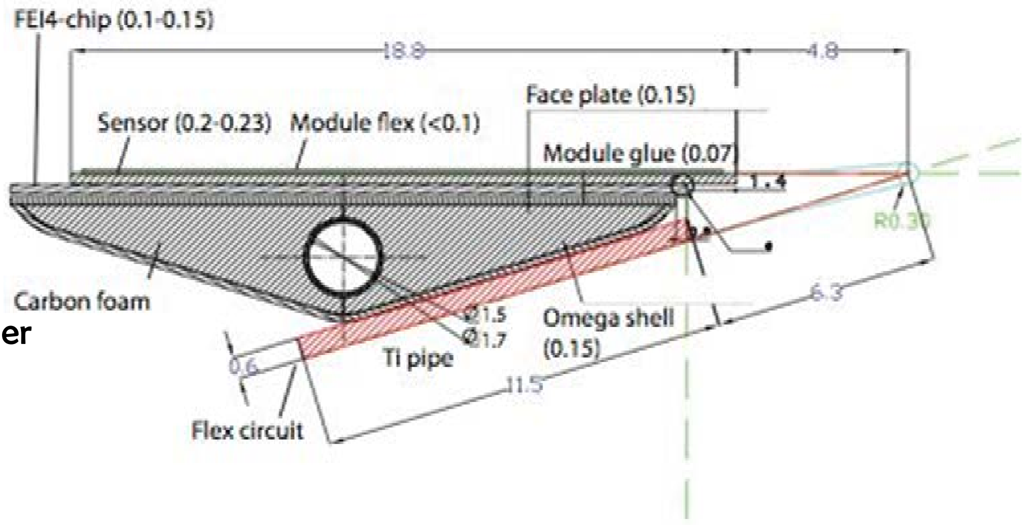
K13C /RS3 parylen coated face plate

Peek end blocs

K13C/RS3 Omega Stiffener

Flex Bus

ID 1.5mm Ti boiling pipe



Stave production

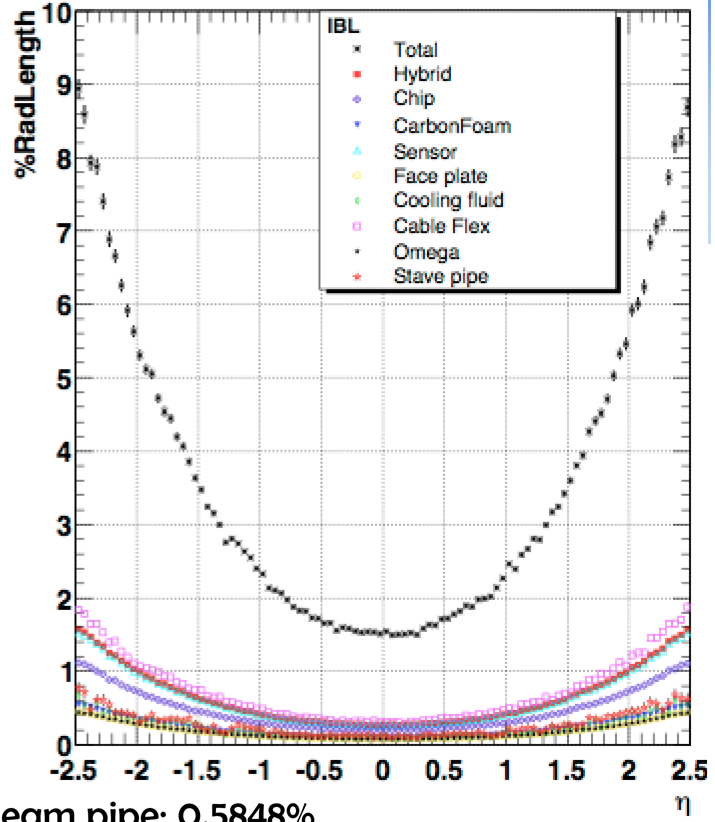
- Bare stave production running -> 6 of 42 received
  - carbon fiber (K13C) Omega glued on the foam to provide mechanical rigidity and to assure the heat transfer to the central cooling pipe
  - Qualified with pressure tests, brazing to external pipes, deformation survey and flatness of staves and thermal conductivity to cooling pipe

Design:

- Titanium cooling pipe
  - Inner diameter: 1.5mm
  - Wall thickness: 0.1mm
- 3 layer (0/90/0) face plate
- EOS and Central Peek support
- Flex fully glued on the Omega
- Short stave for loading (1300mm)

IBL Material Budget

- Status of X_0 in summer 2011 (end of prototyping):
  - perpendicular incident, smeared over active surface, average over stave length $\eta<3$
- Task force in place to monitor actual X_0 during construction
- Increase of X_0 during prototyping from 1.5% (TDR) to 2.0%
- Decrease of X_0 = 1.5% after reduced material budget
- Aim on keeping X_0 within reasonable engineering limits



Beam pipe: 0.5848%
IST: 0.2151%
Stave: 0.6628%
Modules: 1.1395%
Total IBL (IST + staves + modules): 2.0174%
Services: ~1%

OUTLOOK

IBL schedule overview

Activity	**Starting**	**Ending**
FEI4-B	September 2011: Submission	December 2011 chips received, tests of 1st batch completed by the end of February 2012
Bump bonding	August 2011: pre-production	November 2012: Completion (incl. spares)
Module assembly	End May 2012: 1st modules ready for loading	December 2012 (spare and contingency incl.)
Module loading	July 2012: → 4 staves to be ready by September 2012	April 2013: Completion (spare and contingency incl,)
Stave loading	Mar 2012: starting with the 1st available staves	June 2013: Completion
Final tests and commissioning	July 2012	September 2013: IBL Installation

- FEI4B is as scheduled and working fine – Wafer tests to survey
- Next key step: module production with FEI4B to demonstrate the electrical functionality of the stave (flex, module, off-detector readout)
- Loading of first stave with pre-production modules is expected around March/April and first production staves July 2012

THANK YOU FOR YOUR ATTENTION