IBL Technical Aspects

H. Pernegger / CERN

Introduction

- IBL detector is physically small ($0.2m^2$ active area) but requires several new technologies

- The specifications for the IBL are driven by expected radiation fluence, hit rate, proximity to beam axis and tight space constraints

- The IBL is also a **technology step to HL-LHC**

  - Radiation hardness (incl. safety factor x2) ~ 5 x 10^{15} n_{eq}/cm^2
  - **Frontend IC4**: go to IBM 130nm process and improve readout architecture to minimize inefficiency at high hit rates and radiation hardness
  - **Radiation hard Sensors:** 3D silicon sensors, new planar sensors and CVD diamond sensors as possible options for radhard detectors
  - **Readout system**: improve data through-put and redundancy.
  - **Cooling system & Mechanics**: more efficient cooling of sensors+chips and significant **reduction in X0** on staves.

IBL Modules

Common sensor baseline for engineering and system purposes

   3D sensors → Single chip modules

   Planar/Diamond sensors → Two chip module

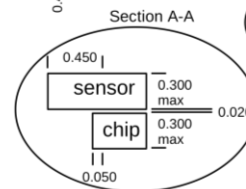## Module engineering parameters

   Sensor bias maximum 1000V

   Power dissipation in Sensor < 200mW/cm^2 normalized at -15C

   Sensor temperature ~ -15C after full irradiation

Sensors/Module prototype for ~10% of the detector in 2010/11

Single chip module:
Edge < 325 um
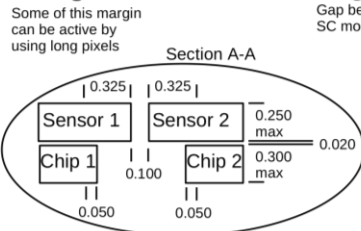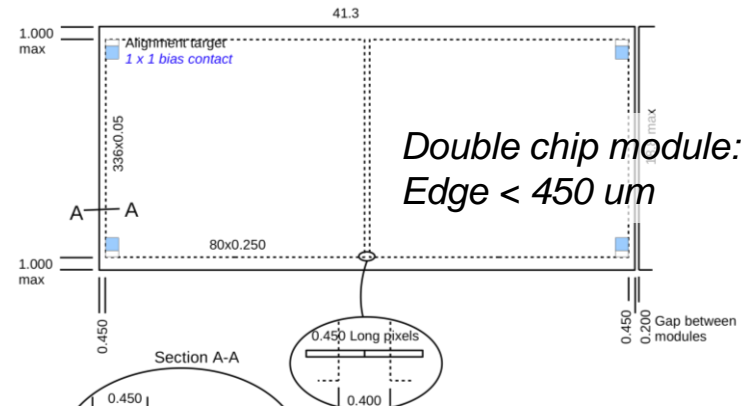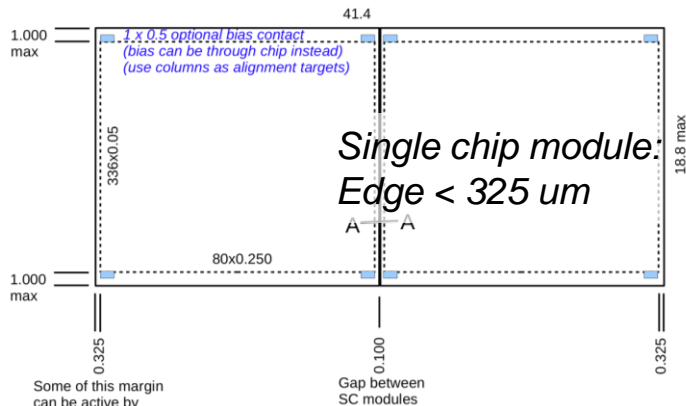
IBL
Envelope for 2 single-chip 3-D modules
Rev. 26.06.2009
(mm)

Double chip module:
Edge < 450 um

IBL
2-chip planar sensor tile
Rev. 26.06.2009
(mm)

IBL Sensor Prototyping

Will produce qualification modules with planar, 3D, diamond sensors this year as soon as we get FEI4's to test chip and sensors to IBL specs

Main sensors in production for all three technologies:

Planar

- N-in-N conservative edge and N-in-N slim edge (CiS) Delivery Sept 25
- Thin n-in-p (HLL, HPK) Delivery End Sept
- 60 single-chip & 30 double chip modules envisaged

3D

- Active edge sensors preferred and in production by Sintef/SLAC, CNM, FBK
- Double sided 3D also in production as backup
- Sensor deliveries from End Oct 2010 to Spring 2011
- 60 single-chip modules envisaged

Diamond

- Polycrystalline CVD diamond sensors available from DDL and II-VI (total ~ 20)
- 6 Delivered and at IZM for UBM, more available
- 20 single-chip modules envisaged

FE-I4 readout chip (IBM 130nm)

- Reason for a new FE design:
  - Increased rad hard
  - New architecture to reduce inefficiencies (L=2x10^{34})
- Biggest chip in HEP to date
- Greater fraction of footprint devoted to pixel array (~90%)
- Lower power/pixel: don't move the hits around unless triggered
- Able to take higher hit rate: store the hits locally in each pixel and distribute the trigger
- *Submitted July 2010; Delivery confirmed for Sept. 23*
- *Final FE-I4B production chip ~ 1 year from now*

	FE-I3	FE-I4
Pixel size [μm^2]	50x400	50x250
Pixel array	18x160	80x336
Chip size [mm^2]	7.6x10.8	*20.2x19.0*
Active fraction	74%	89%
Analog current [μA/pix]	26	*10*
Digital current [μA/pix]	17	*10*
Analog Voltage [V]	1.6	*1.5*
Digital Voltage [V]	2.0	*1.2*
Pseudo-LVDS out [Mb/s]	40	*160*
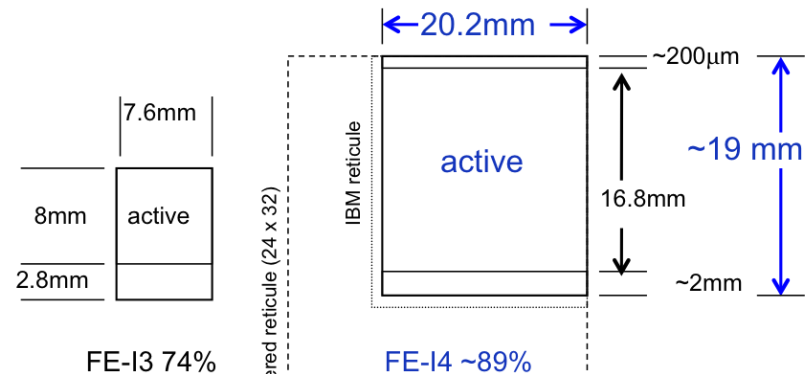
FE-I4 Testing and bump-bonding of prototype modules

1/2 wafer diced for test on single chip test cards (without sensors)

- First wafers to IZM for first batch of prototype modules during October and to single-chip test cards for FE-I4 tests
  - USB based test system for FEI4 chip, module and wafer tests in place

Bump bonding with first 8 FEI4 wafers

- Step 1: demonstrate that FEI4 works with sensors (lab measurements, irradiation, testbeam) (conservative
- Step 2: Advanced module prototypes with thin chips, multi-chip modules, removal of handling wafers

Want to minimize chip thickness to save material: <200µm , target: 100µm

IZM devised special handling-wafer technique to allow solder BB of large but thin chips
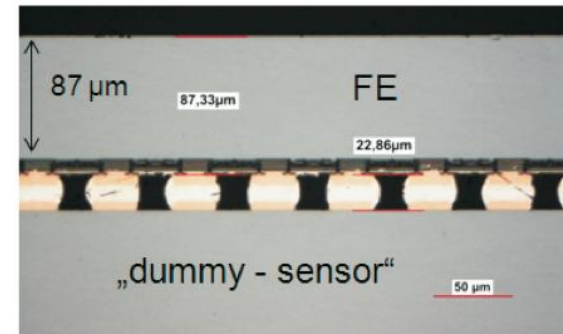
First successful results with 90µm thick chips in ~FE-I4 size chip

IBL Stave and Cooling

- **Stave construction**
  - CF Shell ("Omega") $300\mu m$ for stiffness
  - Ti pipe (ID 2mm wall $100\mu m$): light and high thermal conductivity
  - Carbon foam as filler for module cooling
- **Thermo-mechanical tests with prototype staves with CF and Ti pipes nearly completed**
  - Pipe + heaters -> measure HTC
  - Stave + heater -> measure thermal conductivity of assembly
- **CO_2 cooling of staves with Ti pipes for IBL**
  - Based on LHCb design, total power in IBL ~1.5kW
  - Smaller diameter cooling pipe and lighter coolant to reduce mass
  - Lower coolant temperature (-40C)
  - All inside connections welded (Ti-Ti joint TIG and EB)
  - Each stave = 1 cooling loop
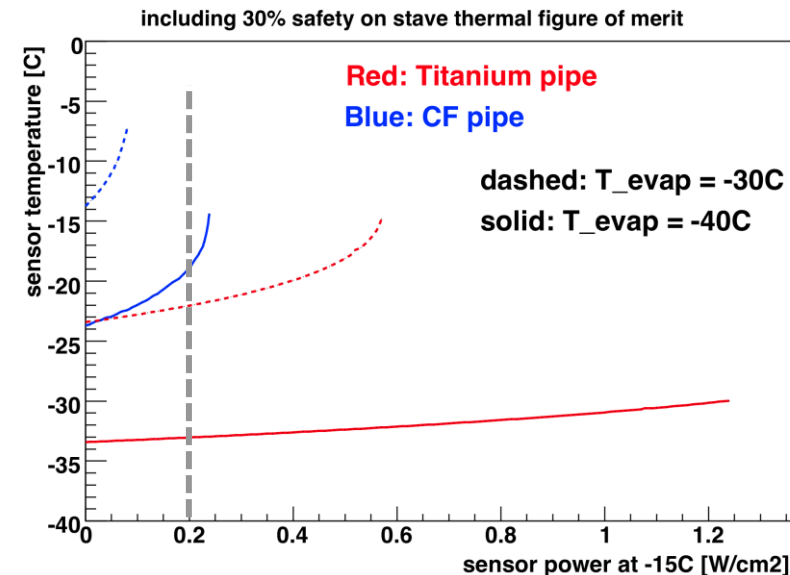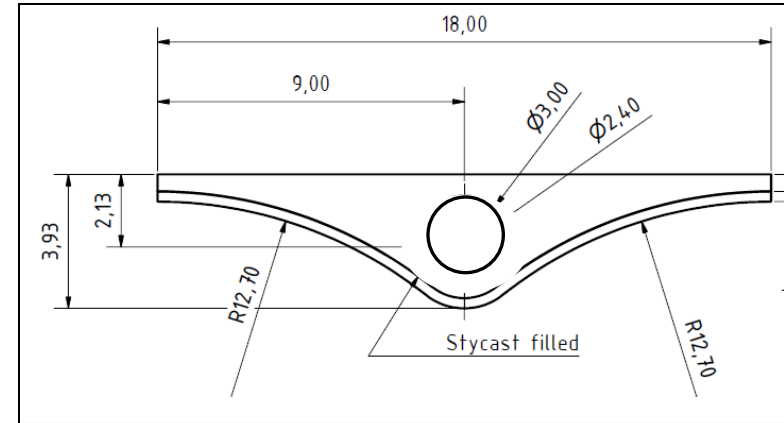
IBL material budget

Radiation length:

- Module and stave with chip target thickness: 1.16%
- IST: CF tube center (0.5mm) : 0.28 % (not incl. shielding foil)

Total currently: 1.44 % using 250 (sensor) +90 (chip) μm silicon
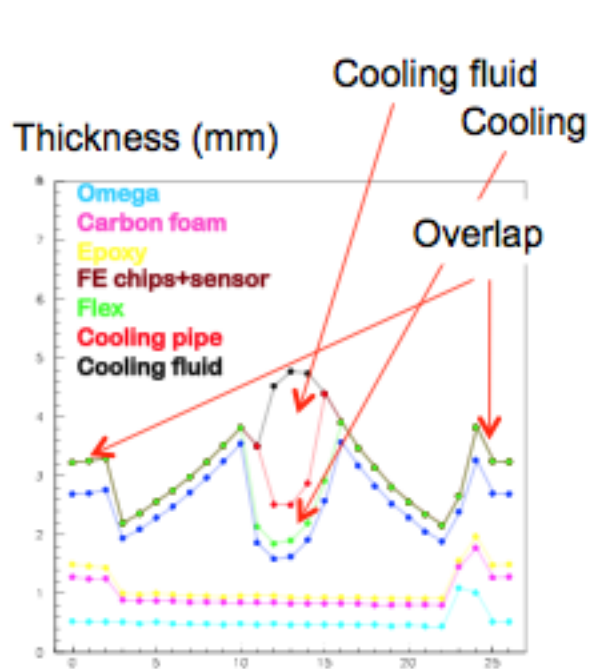
Module parameters
- Sensor thickness = 250 μm
- FE-I4 thickness = 90 μm
- Flex Hybrid (η = 0) = 0.18 % of X_0

STAVE TYPE	Omega Thickness [μm]	Foam Density [g/cm³]	Pipe Material	Pipe Diameters [mm]	Radiation Length X/X_0 [%] Bare Stave	Full Stave Assembly	Thermal Figure of Merit Γ [°C.cm²/W]	Thermal Def. [μm]
Ti pipe Stave	300	0.25	Ti grade II	ID=2 OD=2.2	0.57	1.166	11	41
CF Pipe Stave	150	0.25	CF	ID=2.4 OD=3	0.36	0.956	25	50

Stave Flex: power and readout modules

Proceed with two designs in parallel at the moment:

- Multilayer design.
- Thin Kapton/Al.
- Prototypes exist - main focus is test and simulation of electrical performance

Low voltages   CMD+CLK   Data Out   HV   HV Ret   NTC

FE WIREBOND
PIGTAIL WIREBOND
1.501
FLEX
CHIP
SENSOR
WING
PASSIVE COMPONENTS
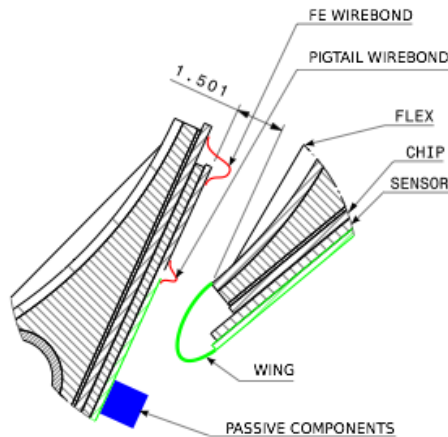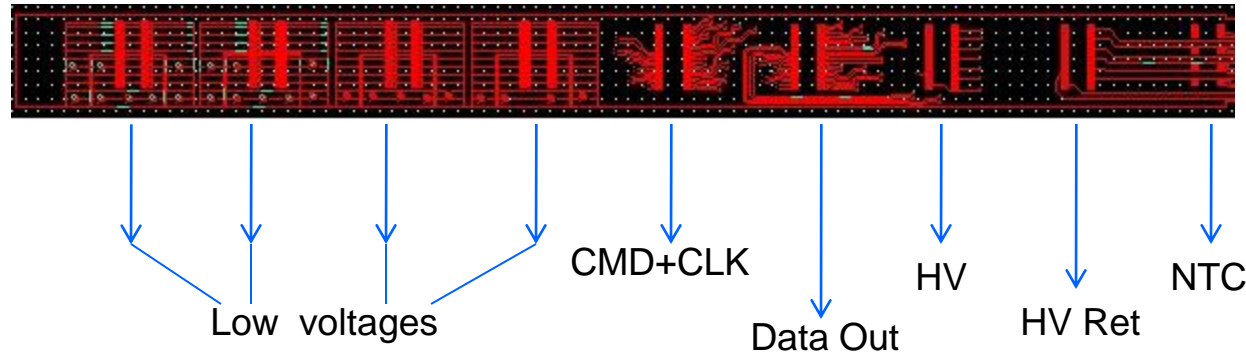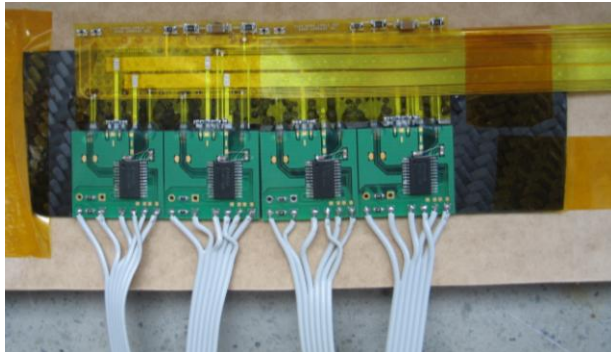
Loading of Modules

- Carry out trial loadings to optimize glue dispersion and module placement
- Flex connects to module through wrap-around "wing"
- Wire-bonded after loading to module flex.

Stave support and integration with Beam pipe

Integrate staves and services around beam pipe on surface (ATLAS SR1)

Staves

Flex dog leg

Type I Patch Panel

4-point support of IBL inside IST similar to present pixel detector

Cooling Pipe Fittings

Ø0.488 x 34

Ø0.217 x 60

WHITHOUT PACKING FACTOR

Ø0.838 x 40

Signal Data
Ø0.488mm x 34

LV
Ø0.838mm x 40

wire + insulation

Overall envelop
when twisted

Ø0.217mm x 60
Clk+cmd
DCS & Env
HV

Beam pipe

IP

Pixel Package

VI   VA   VT

2009 Current configuration

- Center (VI) beam pipe with "split flange"
  - 25 mm IR
  - Reduced flange diameter to fit with present pixel detector and IST
  - VA section planned to be changed in 2012 shutdown
- Extraction of present beam pipe with long guiding tube

Problem: BP sags much more than clearance to B-layer once wires are removed

Use pre-tensioned Brandeis Long Guide Tube – minimize sagging of BP

Exercise and qualify all steps on existing mockup in Bat 180
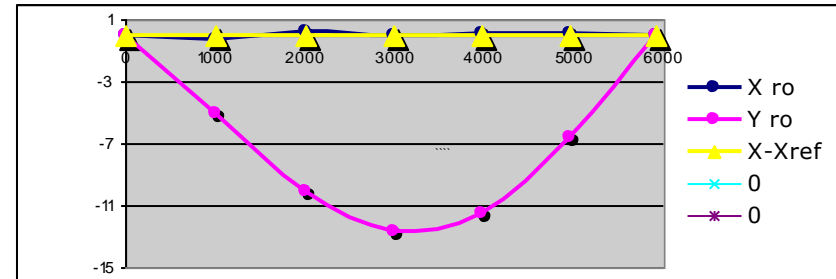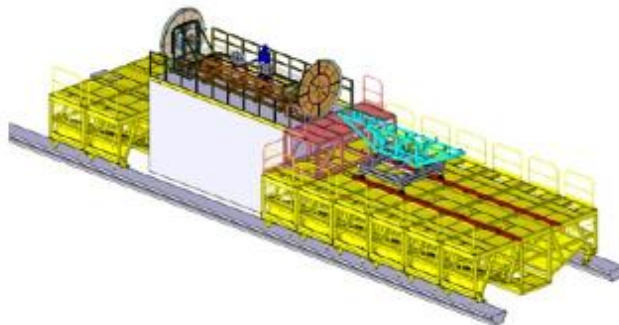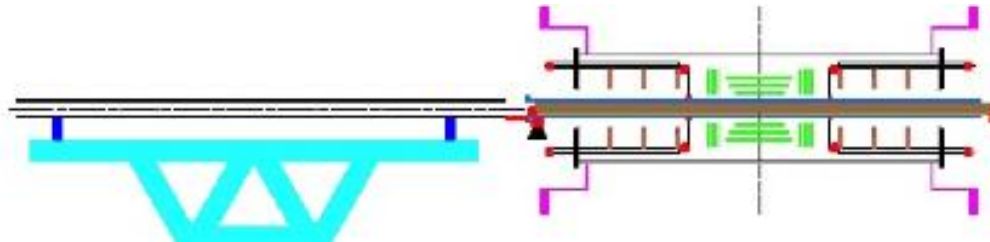
6 meters Al (!) prototype 55 OD 50 ID with tension rod inside has been built

No tension: |y| ~15mm With tension: |y| ~ 2mm
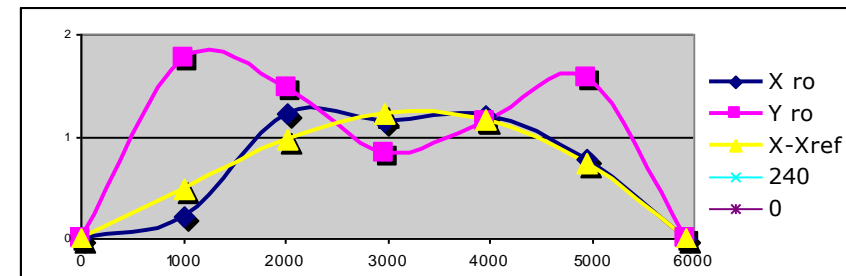
Off-detector: readout

VME readout cards are under development

- ROD card having a Virtex5 controller and Spartan6 data handling chips
- BOC card having a Virtex5 for all functions

Firmware work in progress: developed and define consistent ROD+BOC FW concept

- PPC in FPGA modeling started
- ROD FPGA code : explore function and size of code
- Adoption of existing firmware to IBL usage started
- BOC detector interface firmware under development (TX and RX)

Hardware developments

- Design of ROD first prototype board has started
- BOC test board for interfaces is ready

Bologna-Genova-Wuppertal-Gottingen-Mannheim ROD proposal

Milestones
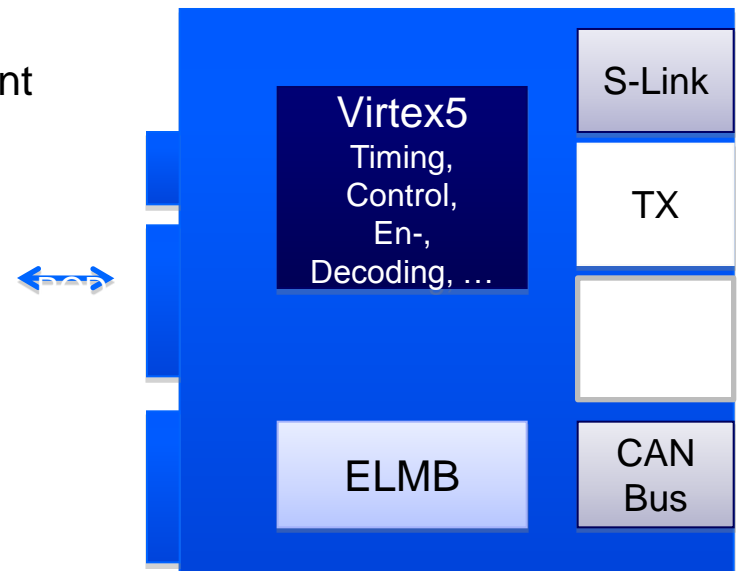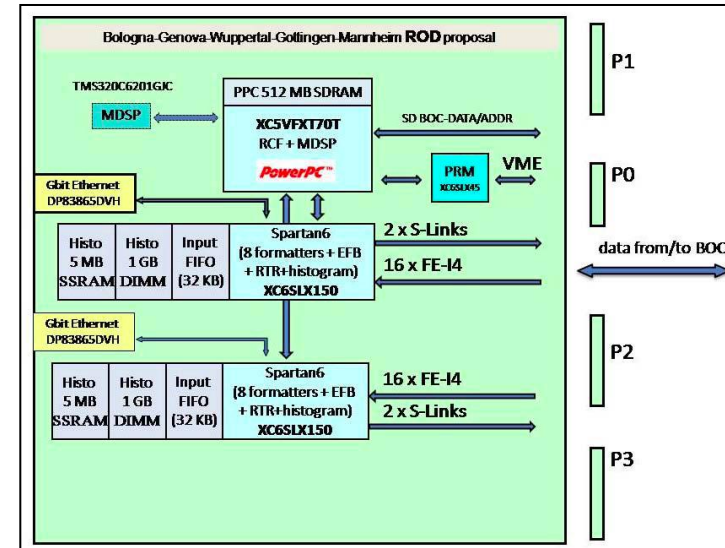
Detailed Schedule available at sharepoint:

https://espace.cern.ch/atlas-ibl/Shared%20Documents/IBL-Schedule-DraftV3-4-14-06-2010.pdf

Main dates

- FEI4 submission : July 2010
- sensor choice June 2011
- FEI4 Version 2 eng. submission Sep 2011
- first prod module Nov 2012
- last prod module Sep 2013
- Stave loading completed (incl. contingency) June 2014
- IBL installation on or after May 2015

Schedule: Chips, Sensors, Modules

Task Name	2010				2011				2012				2013				2014				2015			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
TDR																								
Modules																								
Qualification Modules...																								
Review and Choice...																								
Module Production																								
IBL FEI 4 Version 2 Eng....																								
FEI 4 Version 2 Prod...																								
Sensor Production																								
Contract placement																								
Planar...																								
3D...																								
Diamond																								
Bump bonding...																								
Flex for module...																								
Last module ready for loading (earliest)...																								
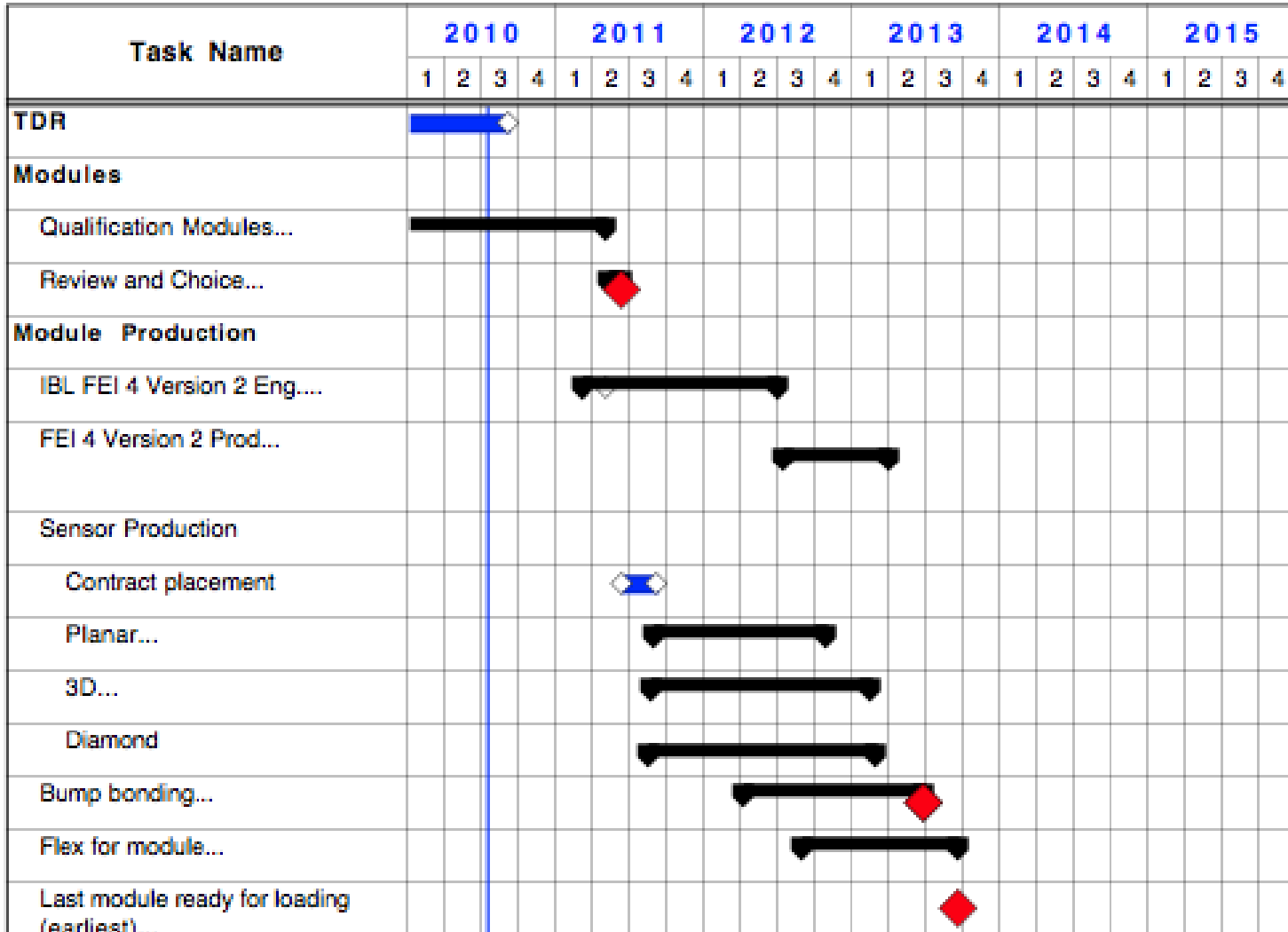
Schedule: Staves, Integration, Installation

Task Name	2010				2011				2012				2013				2014				2015			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Stave																								
Studies on welding, joints, cracks, termal conductivity																								
Stave 0 prototyping and tests...																								
Stave Flex...																								
Internal services ...																								
Bare Stave production																								
Stave loading...																								
Integration and Installation																								
Installation 2012...																								
Integration...																								
Off detector...																								
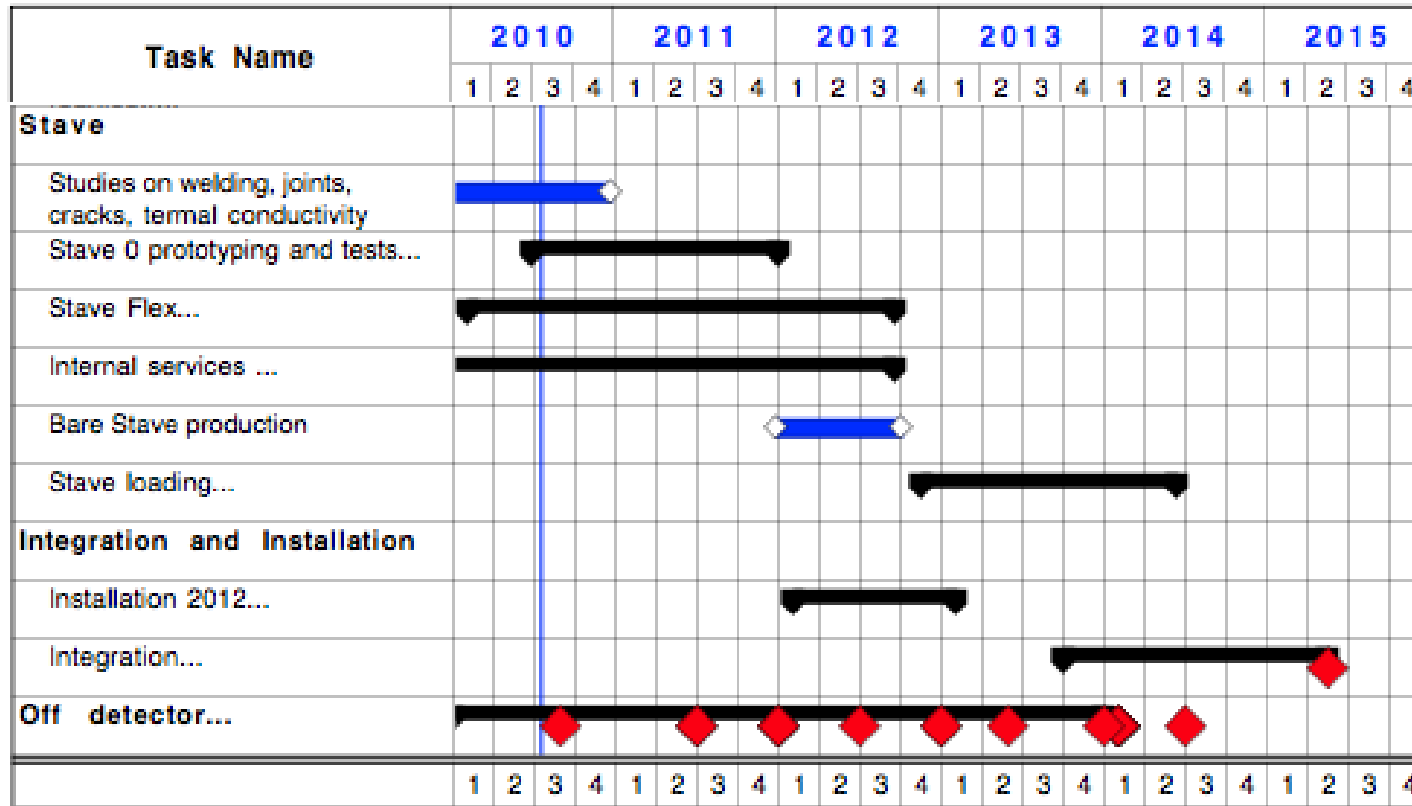
Service installation (USA15 to detector)
Plan to install services up to detector during opening in 2012 shutdown

Two contingency periods included in schedule
Stave completion: 3 months in 2014
End of surface integration: 3 months in 2015

Summary

FE-I4 design completed and submitted to IBM. Will receive chips this week – this is a major milestone for IBL project

Sensors

three sensor technology IBL prototype sensors are in production (planar, 3D, diamond). We will decide sensor technology summer 2011 based on test results with prototype modules and sensor+module production experience

Prototype module

plan to build significant number (>100) of modules to test bump bonding of thin modules , module performance, module on staves loading and operation of staves

Stave

we have constructed >10 prototype staves (CF pipes, Ti pipes) and tested thermal performance -> will use staves with Ti pipes and CO_2 cooling

Material budget: X/X_0 = 1.16% of loaded staves, X/X_0 ~ 1.5 of IBL with full support

Integration and Installation

Will integrate IBL around new beam pipe (IR 25mm) on surface

Installation of IBL + all beam pipe operations to be exercised on mockup in Bat 18

Target installation for 2016 shutdown

Scheduled completion mid 2015 including contingency

- Backup slides

Sensor technologies for IBL

- Present ATLAS n-in-n sensors were designed to ~$1 \times 10^{15} n_{eq}/cm^2$ and we have good production and operation experience with them
  - Their design was modified to become suitable for IBL specs
  - Reduction of dead edges to maximize sensitive area
  - Operation at higher voltages
- New sensor technologies, which are being developed for HL-LHC, promise significant advantages: Thin n-in-p, 3D silicon, CVD diamonds
  - Active edges or slim edges
  - Lower depletion voltages
  - Less cooling requirements
- The IBL can benefit from those advantages if we can show that
  - The sensors work well with the FEI4 chip up to highest fluences
  - The modules can be operated reliably
  - The manufacturing of high quality sensors and modules with reasonable yield is possible
- We therefore decided to prototype a significant number modules with different technologies until the sensor technology needs to be decided for pre-production (~June 2011)
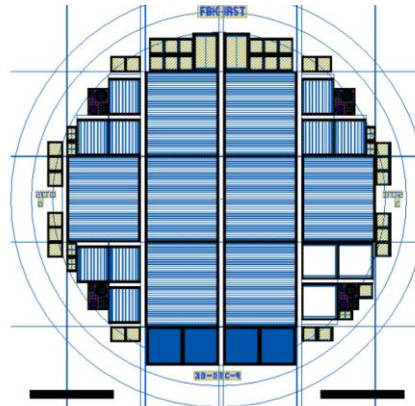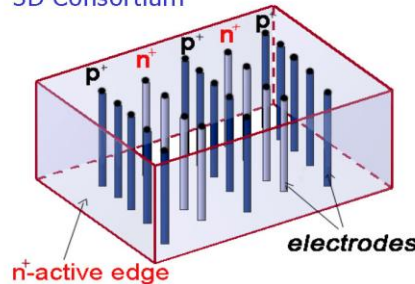
Sensor technologies for IBL

Planar silicon

- Slim edge n-in-n
- Thin n-in-p
- Prototyping with CiS, HLL, HPK

N-in-n slim edge

100um

Thin n-in-p

450um
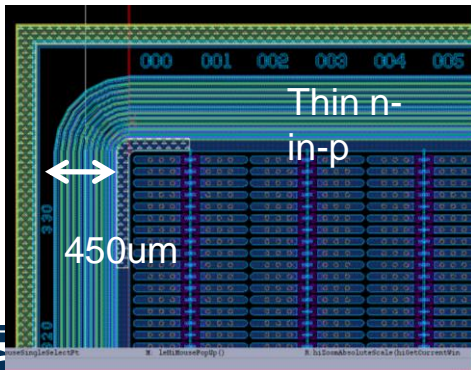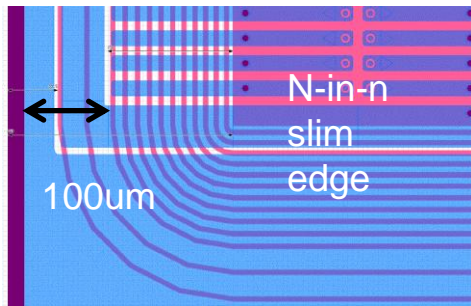
3D silicon

- Active edge single sided and double sided
- Prototyping with CNM, Sintef/SLAC, FBK

Full 3D Active edge
3D Consortium

p⁺   n⁺   p⁺   n⁺   p

n⁺-active edge   electrodes

Diamonds

- Polycrystalline CVD diamonds
- Prototyping with DDL and II-VI

Growth side

Substrate side

ATLAS Pixel FE-I3 diamond module