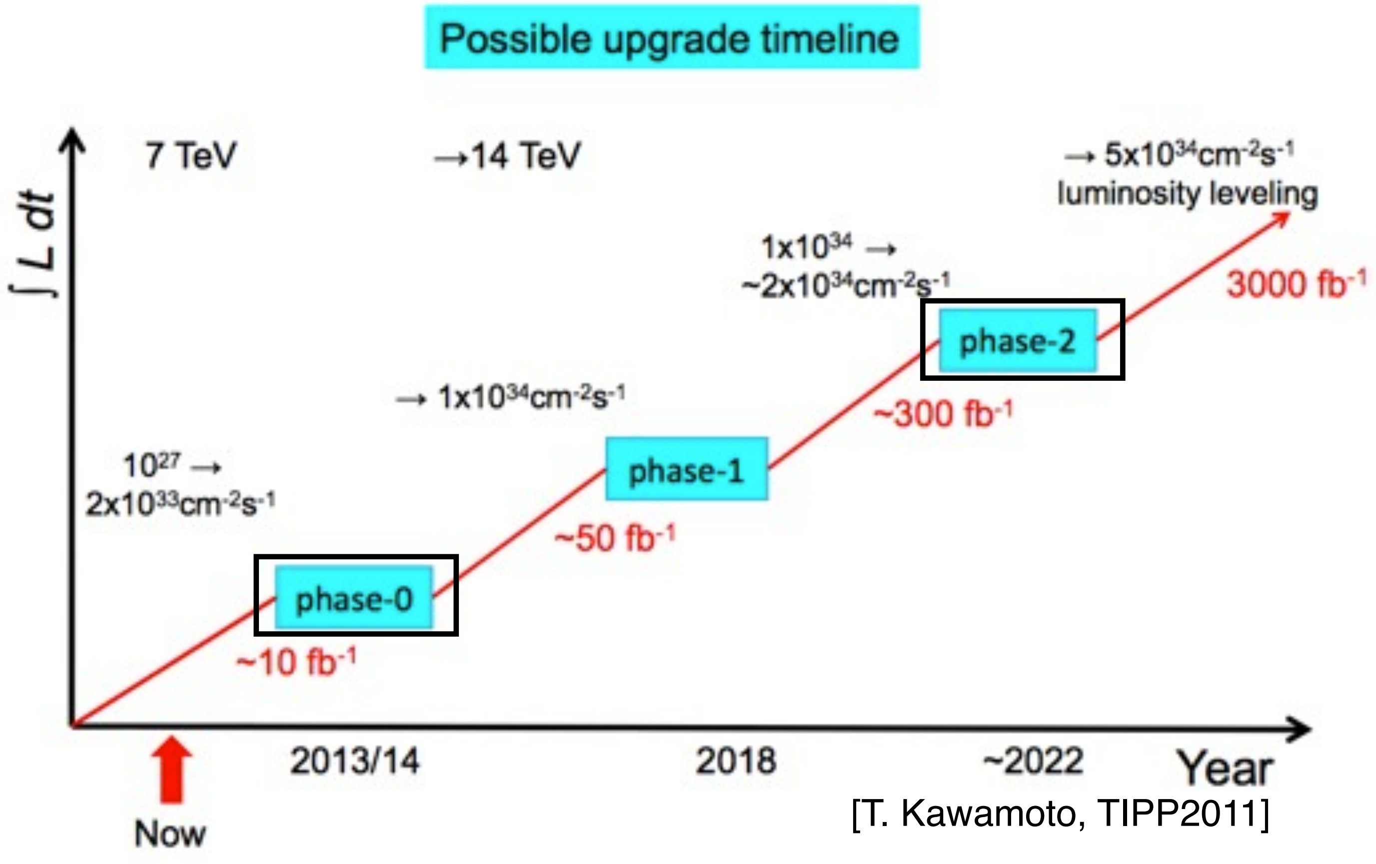
ATLAS-IBL: a challenging first step for ATLAS Upgrade at the sLHC

A. La Rosa / U. Wisconsin and CERN
on behalf of the ATLAS Collaboration

International Europhysics Conference on High Energy Physics.
Grenoble, France July 21-27 2011.

Why Upgrades ?

- LHC/ATLAS physics goals
  - Improve standard model (SM) measurements (W, Z, top)
  - Higgs: understand the electroweak symmetry breaking
  - Beyond the SM: SUSY, extra dimension, even something totally new
- Whatever will be discovery in the next years at LHC, need much data to understand what has been discovered
- Higher luminosity allows extending discovery/ studies to higher masses and processes of lower cross-section
- LHC has plans of upgrade by increasing luminosity to collect ultimately ~ 3000 fb^{-1}



[T. Kawamoto, TIPP2011]

- Consequence:
  - higher data rate
  - higher occupancy
  - more radiation damage
- Detector upgrade are necessary due to:
  - improve TDAQ
  - finer granularity to limit occupancy
  - more rad-hard sensors and electronics

In this talk:

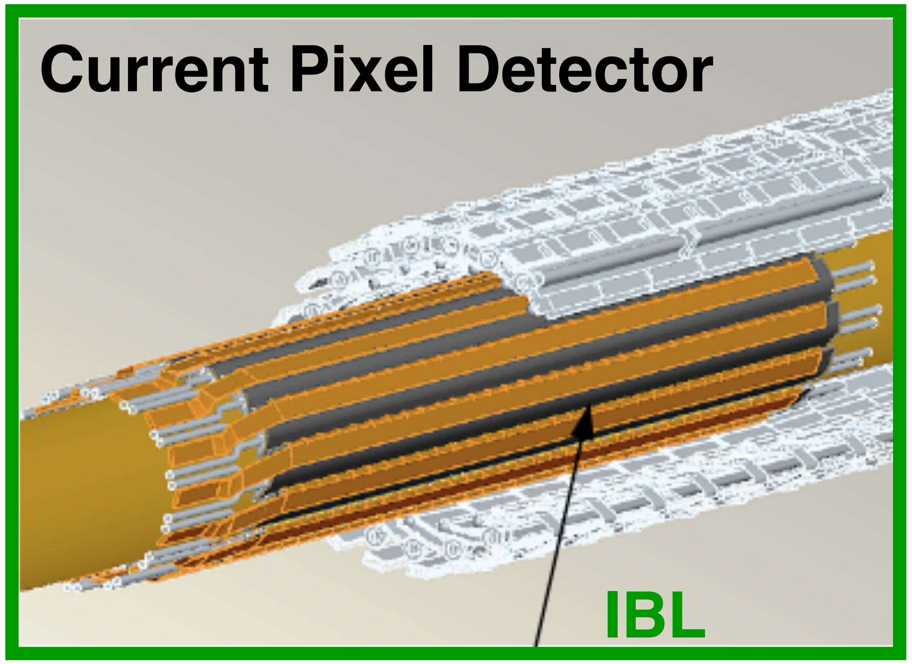
- Phase-0: new Pixel layer (IBL);

- Phase-2: Overview of new Silicon Inner Tracker.

Calorimeter and Muon Systems will be also upgraded (their projects are not treated in this talk).

ATLAS Insertable B-Layer (IBL)

- **Installation of new pixel layer** (the major project for ATLAS/ Phase-0)
  - Excellent vertex detector performance is crucial:
    - improve heavy flavor tagging, primary and secondary vertex reconstruction/ separation
  - Additional innermost layer will boost tracking performance
    - adds additional redundancy of the detector in case of radiation damage
  - Idea: Insertion of new pixel layer inside current Pixel detector: Insertable B-Layer (IBL)
  - Phase-1 was initially in 2016 and now is postponed to 2017 or 2018
    - Advance the project schedule and ***install it in 2013/14***.

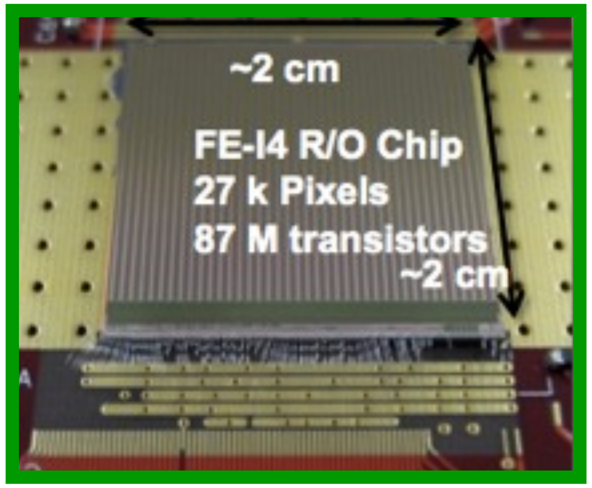


Two competing sensor technologies: Planar and 3D pixel sensors.
Diamond tech was dropped: sensors production not compatible with IBL in 2013

IBL mounted on new beam-pipe
Length: ~64cm
Envelope: R_{IN}=31mm, R_{OUT}=40mm
14 staves, each stave: 32 FE-I4 chips
- for 3D sensors: 1 sensor + 1 chip = 1 module
- for Planar sensors: 1 sensor + 2 chips = 1 module

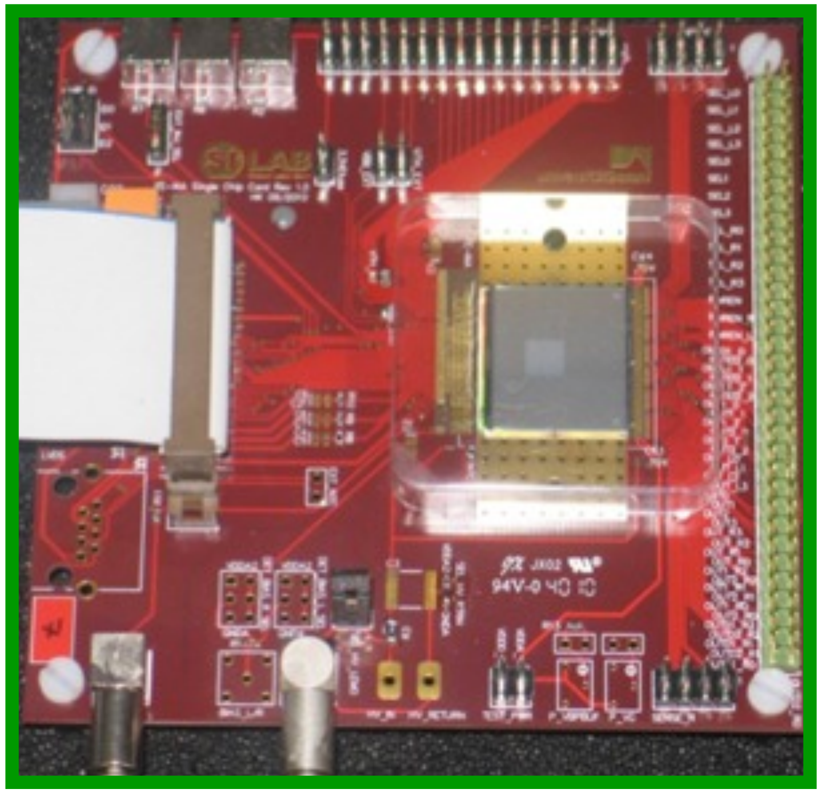
Total: 448 3D modules or 224 planar modules

FE-I4 R/O chip
- IBM 130nm CMOS tech.
- cel size: 50um x 250um
- 80 (col) x 336 (row)= 26880 cels
- 2cm x2cm

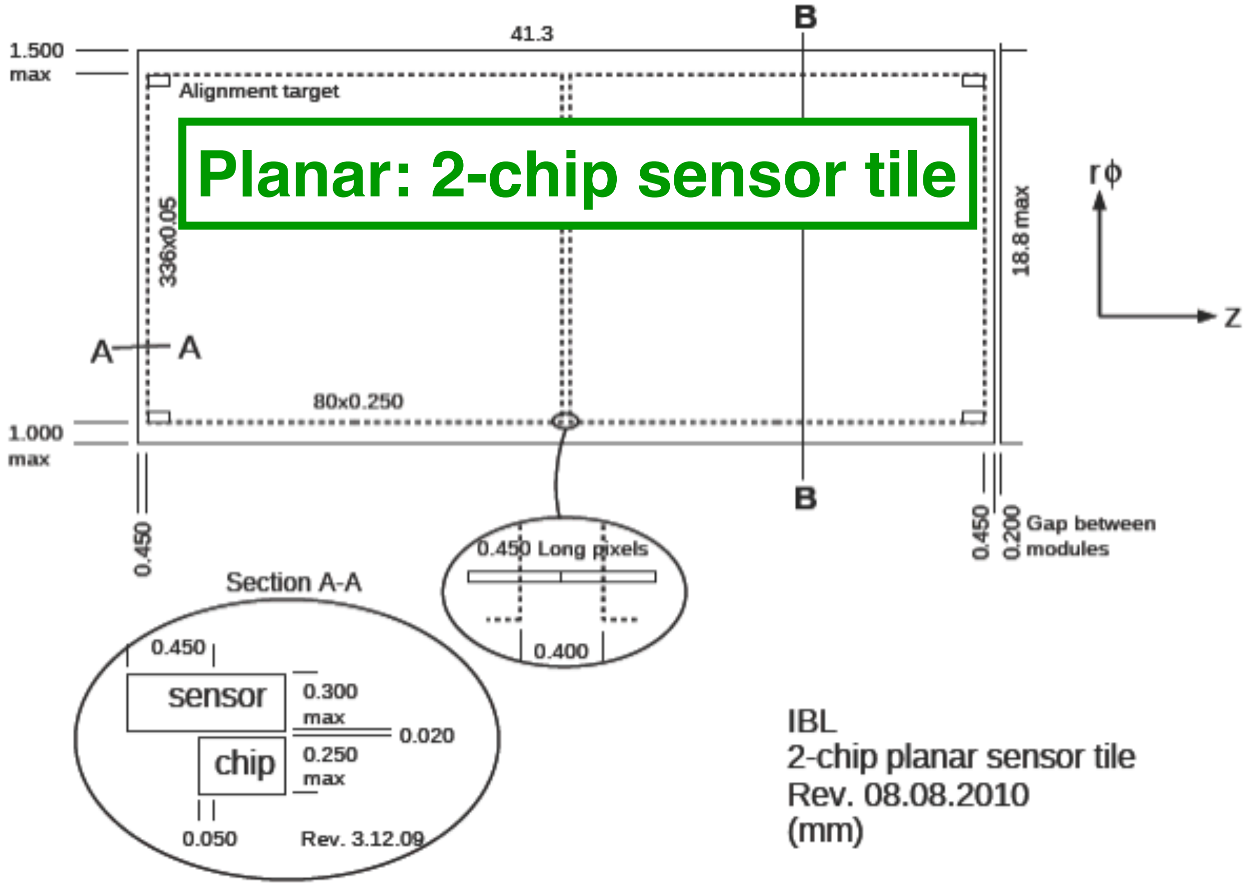


IBL sensor specs and module prototyping

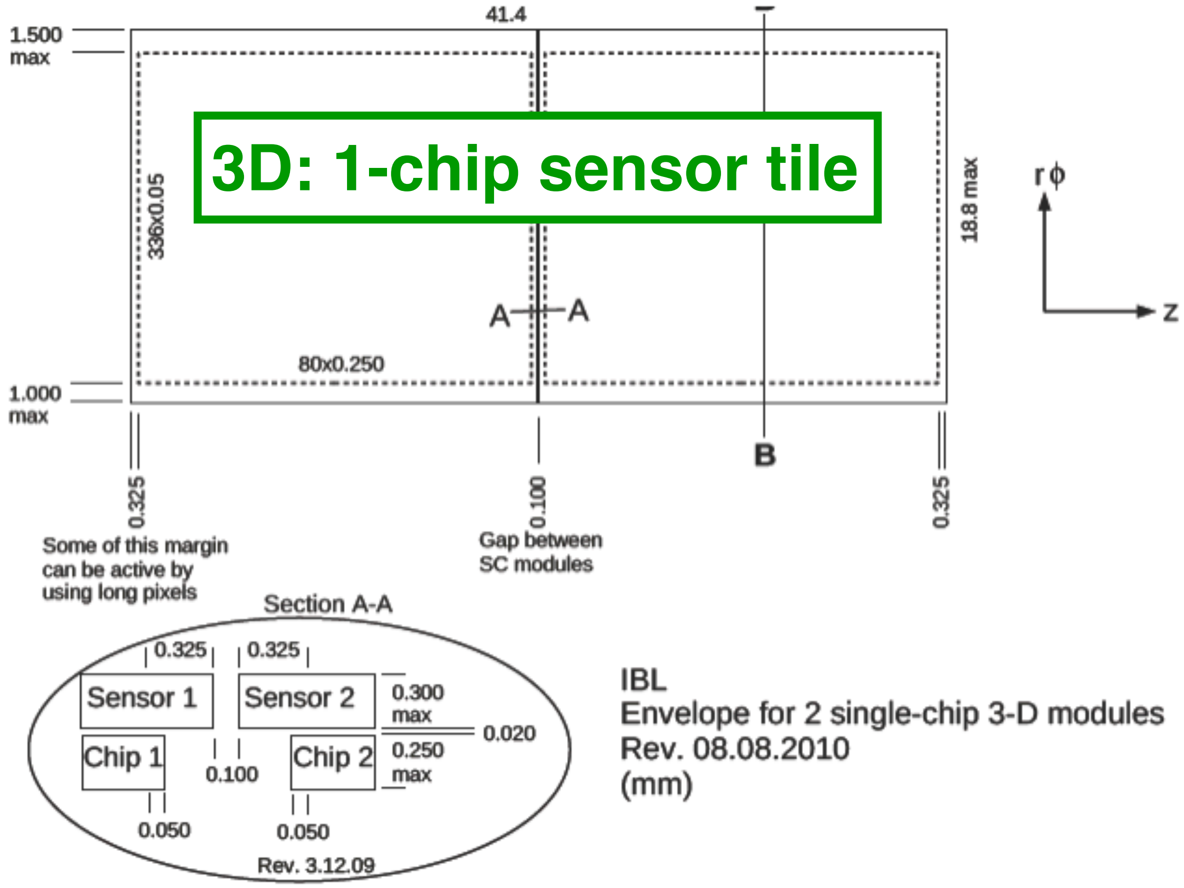
	PLANAR	3D
Active size W x L [mm²]	16.8 x 40.9	16.8 x 20.0
Total size W x L [mm²]	18.54 x 41.27	18.8 x 20.5
Thickness [mm]	0.20	0.23
Typical depletion voltage [V]	< 35	<15
Typical initial operation voltage [V]	60 (V_{dep}+30V)	25
At of at end of lifetime [V]	1000	180



- **Sensor specifications for IBL**:
  - qualify to $5\times10^{15}\ n_{eq}\ cm^{-2}$
  - sensor max. power dissipation: 200 mW/cm² at -15 °C
  - single-hit efficiency > 97%



Planar: 2-chip sensor tile

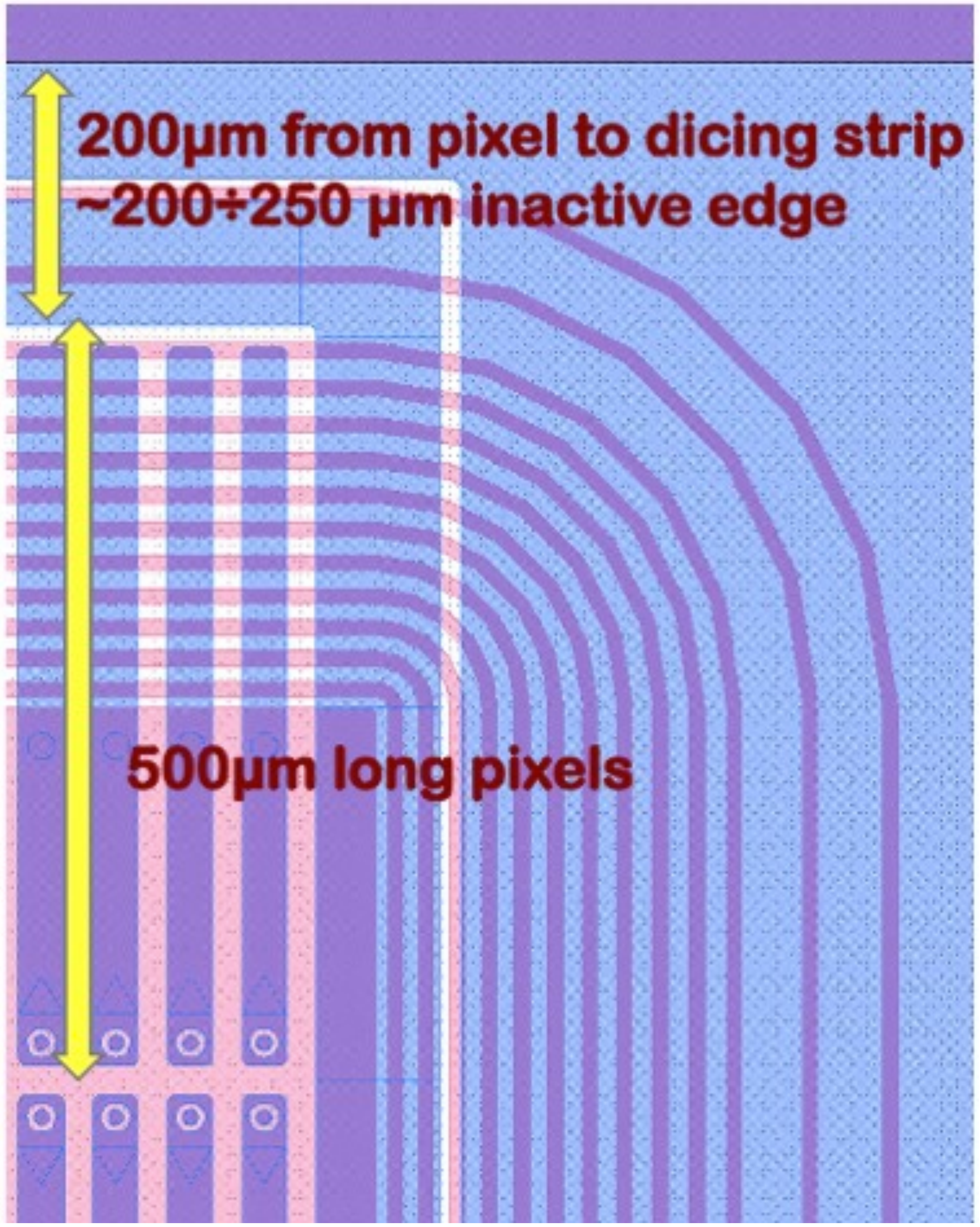


3D: 1-chip sensor tile

IBL sensor types

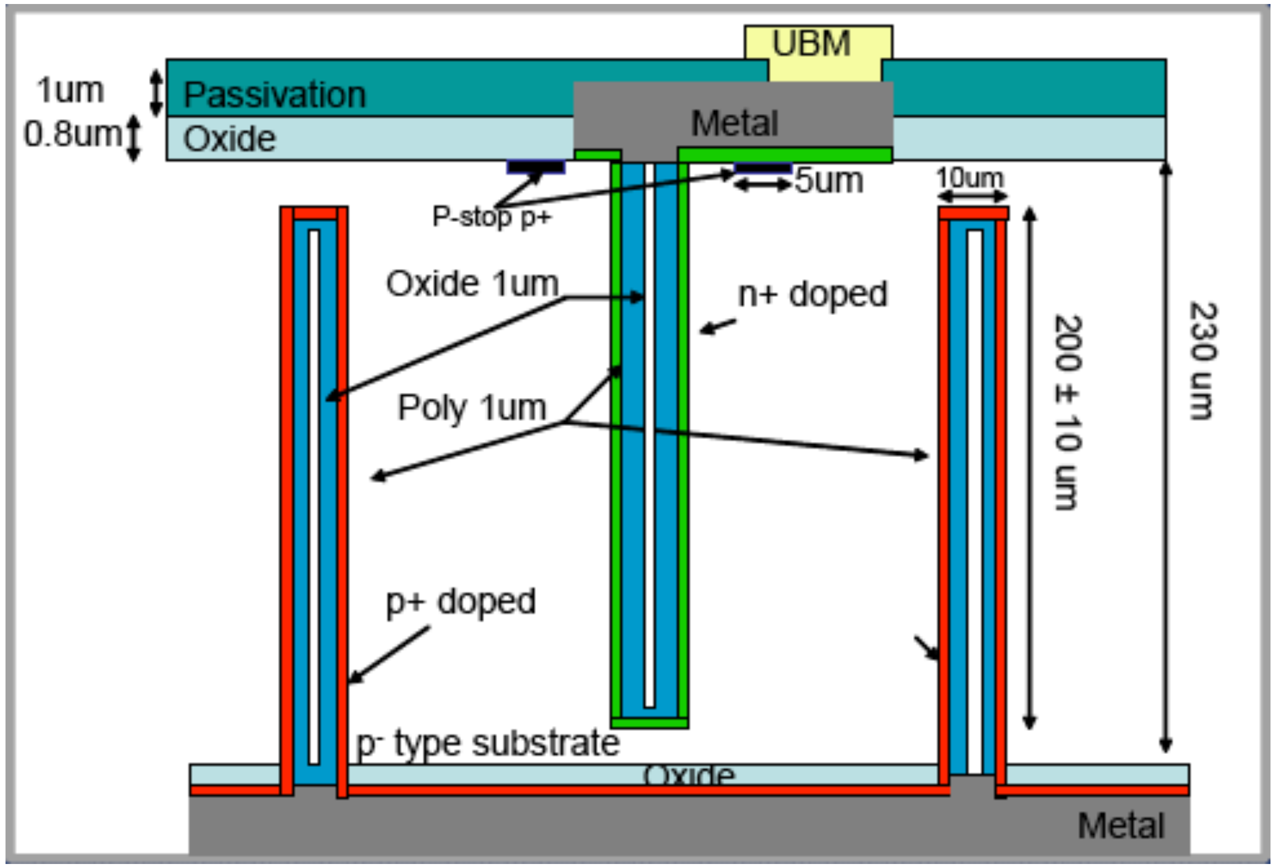
Planar n-in-n Slim Edge Design (CiS)

- minimize inactive edge by shifting the guard-rings underneath active pixel region
  ➡ 200 - 250 um inactive edge achievable
- manufactured by CiS like present Pixel



3D Slim Edge Design (FBK and CNM)

- column through ~full bulk with 2 electrodes per pixel (so-called 2E-type)
- depletion horizontally (short depletion width leads to low bias voltage)
- manufacturing yield now being tested with pre-production runs by FBK and CNM



Irradiation

- A total of 77 modules (bump-bonded & assembles) have been produced
  - 40x Silicon 3D
  - 37x Silicon Planar n-in-n
- Several irradiation campaigns have been performed
  - 11x IBL 1-chip modules (3D+Planar) have been irradiated at IBL target fluence ($5 \times 10^{15} n_{eq}/cm^2$)
  - Proton irradiation at KIT (nominal beam energy: 23 MeV)
    - ***Due to the low energies used the ionizing radiation damage to the FE went well beyond the requirements (250 Mrad). Estimated TID: ~750 Mrad (with 23 MeV) and ~1Grad (with ~18 MeV)***
  - Neutron irradiation with n-TRIGA reactor in Ljubljana

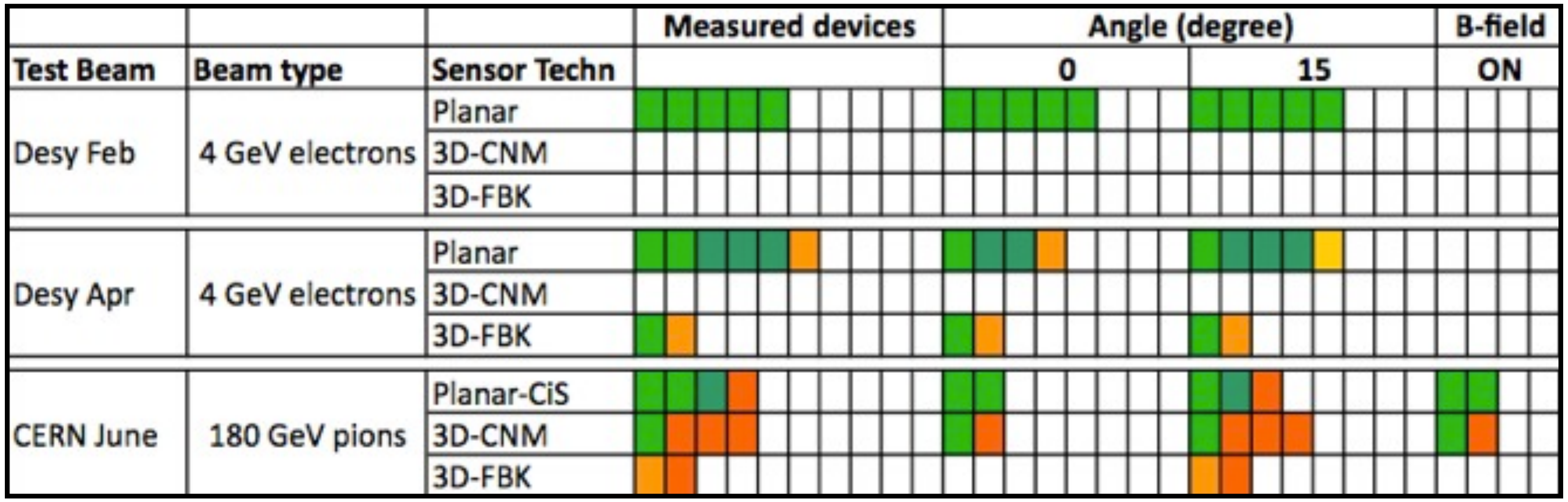
FE-I4 Assemblies for Sensor Review

Foundry	**Technology**	**Batch ID**	**Thickness (µm)**	**Sensor EdgeType**	**Number of Assemblies**			**Target Fluence (neq/cm2)**
					Done	**p-irradiated**	**n-irradiated**	
CiS	Planar n-in-n	<n-in-n 150>	150	slim	2	1		2 x 10e15
				conservative	2			
		<n-in-n 200>	200	slim	12	3	2	5 x 10e15
				conservative	2		1	5 x 10e15
		<n-in-n 250>	250	slim	9	1	2	5 x 10e15
				conservative	10		1	5 x 10e15
CNM	3D, double side	5306	230	slim	16	1		2 x 10e15
						3	2	5 x 10e15
FBK	3D, double side	ATLAS 07	230	slim	8			
	3D, double side	ATLAS 09	230	slim	16	1		2 x 10e15
						1		5 x 10e15
				Total Planar	*37*	*11*		
				Total 3D	*40*	*8*		
				Grand Total	***77***	***19***		

🟩 Green: IBL Design

Test-beams

- Three test-beam periods:
  - February and April in DESY
  - June at CERN
- Most of devices ready/ prepared for CERN test-beam
  - original 24 days, then reduced due to TAX problem and rescheduled. Very short beam time finally delivered ~100 hours (2.5 days) !



			Measured devices	Angle (degree)		B-field
Test Beam	Beam type	Sensor Techn		0	15	ON
Desy Feb	4 GeV electrons	Planar	🟩🟩🟩🟩🟩⬜⬜⬜⬜⬜	🟩🟩🟩🟩🟩⬜⬜⬜	🟩🟩🟩🟩🟩⬜⬜⬜	⬜⬜⬜⬜
		3D-CNM	⬜⬜⬜⬜⬜⬜⬜⬜⬜⬜	⬜⬜⬜⬜⬜⬜⬜⬜	⬜⬜⬜⬜⬜⬜⬜⬜	⬜⬜⬜⬜
		3D-FBK	⬜⬜⬜⬜⬜⬜⬜⬜⬜⬜	⬜⬜⬜⬜⬜⬜⬜⬜	⬜⬜⬜⬜⬜⬜⬜⬜	⬜⬜⬜⬜
Desy Apr	4 GeV electrons	Planar	🟩🟩🟦🟦🟦🟧⬜⬜⬜⬜	🟩🟦🟦🟧⬜⬜⬜⬜	🟩🟦🟦🟦🟨⬜⬜⬜	⬜⬜⬜⬜
		3D-CNM	⬜⬜⬜⬜⬜⬜⬜⬜⬜⬜	⬜⬜⬜⬜⬜⬜⬜⬜	⬜⬜⬜⬜⬜⬜⬜⬜	⬜⬜⬜⬜
		3D-FBK	🟩🟧⬜⬜⬜⬜⬜⬜⬜⬜	🟩🟧⬜⬜⬜⬜⬜⬜	🟩🟧⬜⬜⬜⬜⬜⬜	⬜⬜⬜⬜
CERN June	180 GeV pions	Planar-CiS	🟩🟩🟦🟥⬜⬜⬜⬜⬜⬜	🟩🟩⬜⬜⬜⬜⬜⬜	🟩🟦🟥⬜⬜⬜⬜⬜	🟩🟩⬜⬜
		3D-CNM	🟩🟥🟥🟥⬜⬜⬜⬜⬜⬜	🟩🟥⬜⬜⬜⬜⬜⬜	🟩🟥🟥🟥⬜⬜⬜⬜	🟩🟥⬜⬜
		3D-FBK	🟧🟥⬜⬜⬜⬜⬜⬜⬜⬜	⬜⬜⬜⬜⬜⬜⬜⬜	🟧🟥⬜⬜⬜⬜⬜⬜	⬜⬜⬜⬜

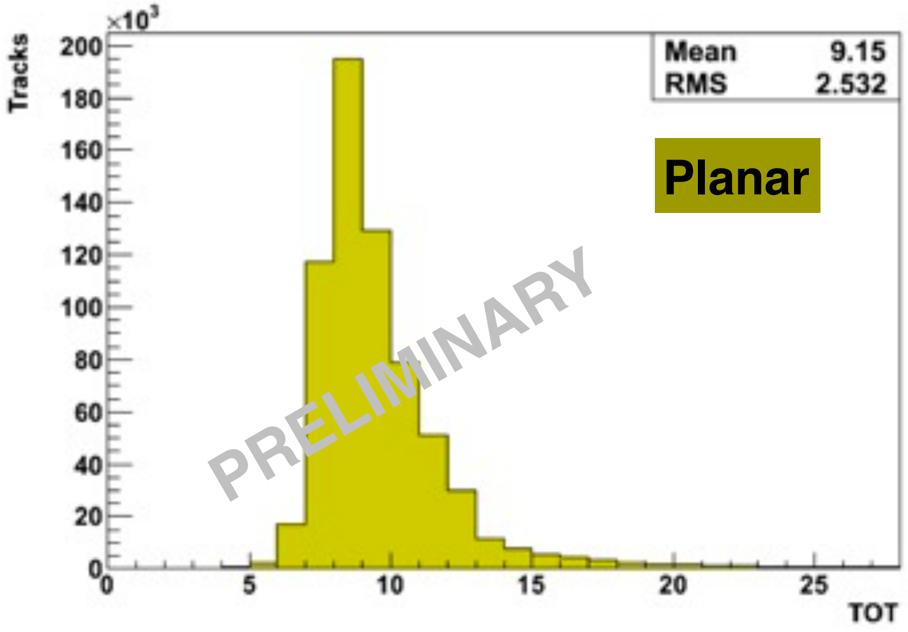
Legend

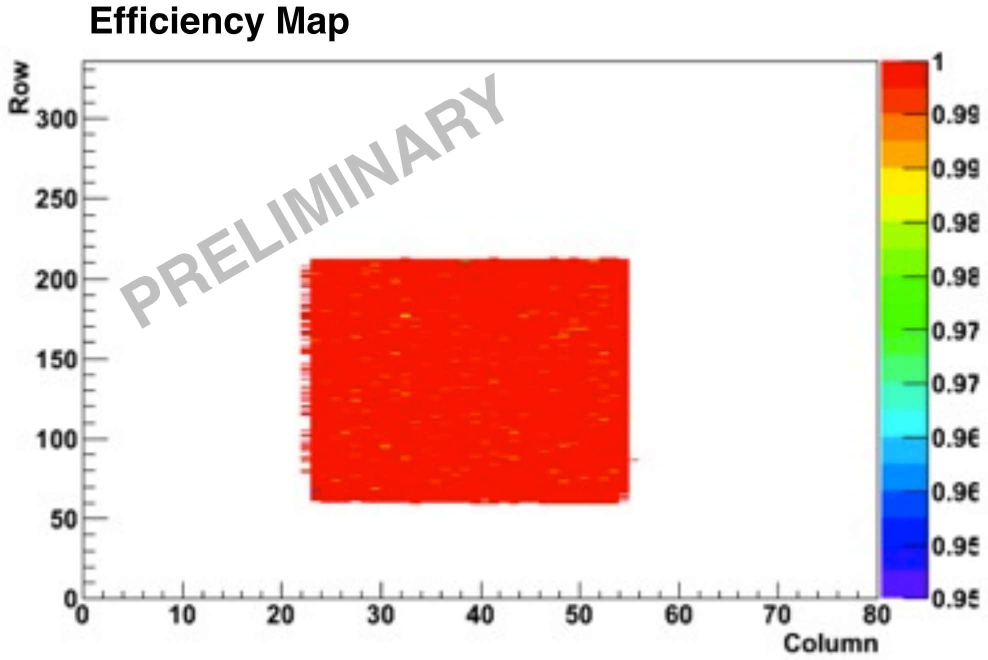
Non-irradiated	🟩
p-irradiated 2e15	🟧
p-irradiated 5e15	🟥
n-irradiated 5e15	🟦

CERN North Area (H8)
EUDET telescope inside Morpurgo magnet (1.6T)

Preliminary: Unirrad sensors + FE-I4 at DESY TB

Charge collected measured in units on 25ns of Time over Threshold (TOT)



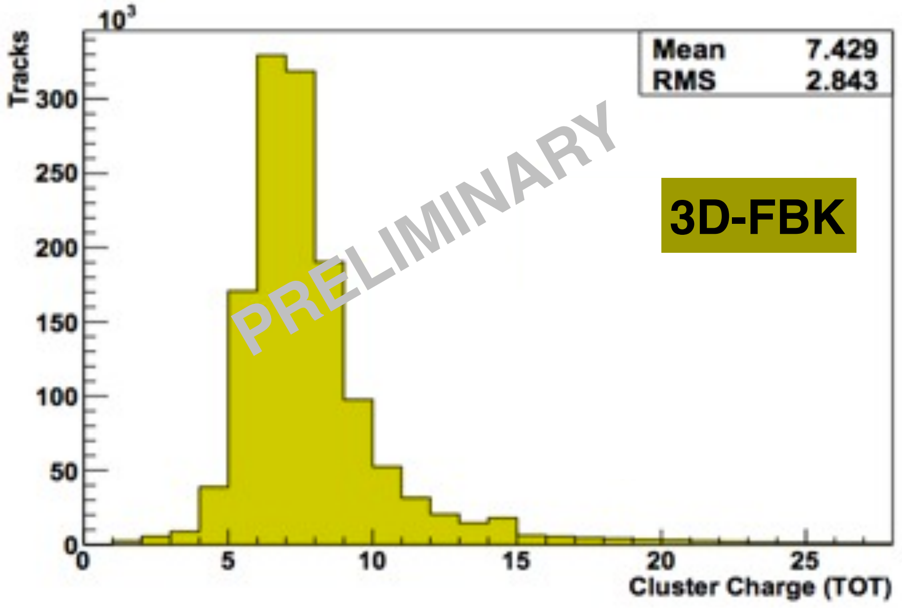


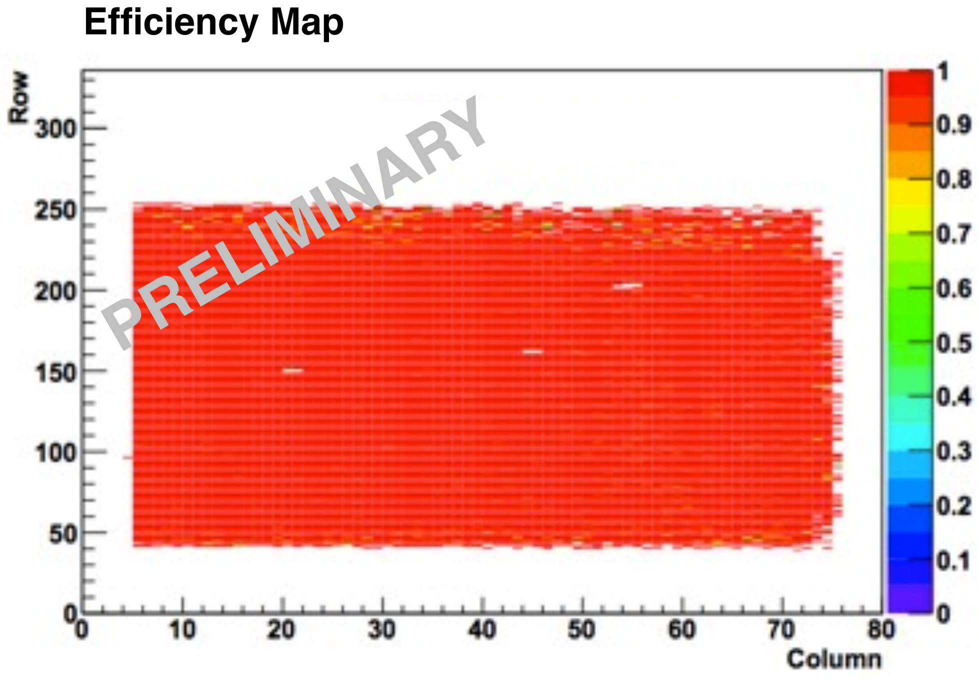
Planar 250um thick

Calibration 10TOT at 30ke larger that expected (under investigation !)

A few noisy/dead pixel

Hit efficiency: 99.95%





3D-FBK 230um thick

TOT distribution as expected !

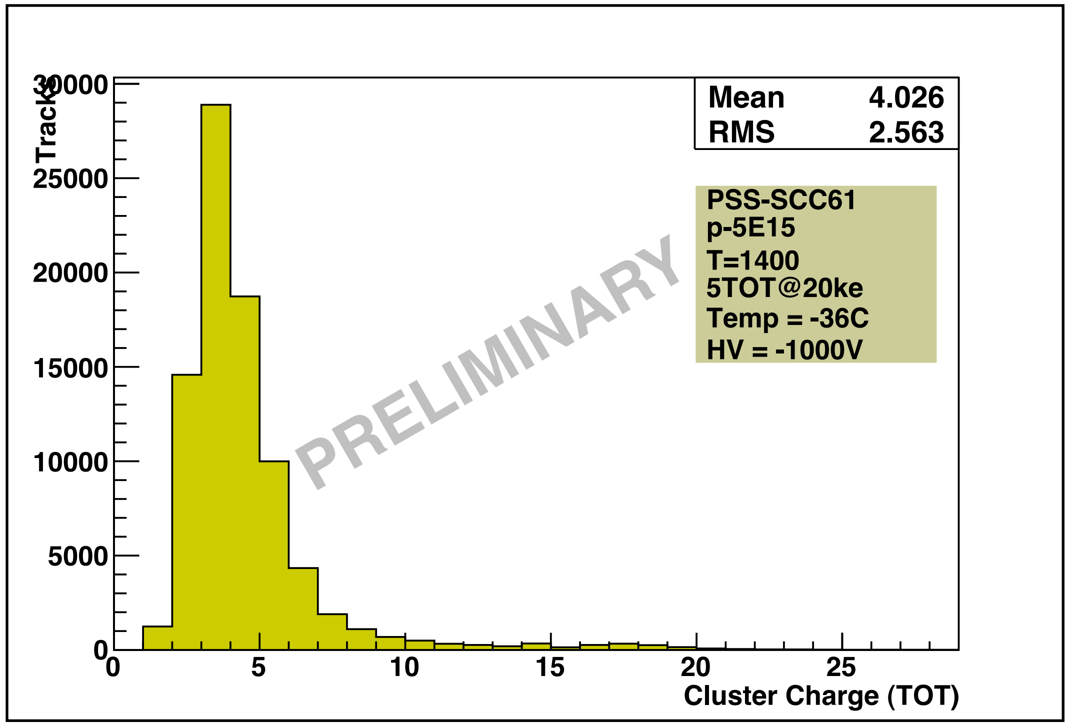
A few noisy/dead pixel

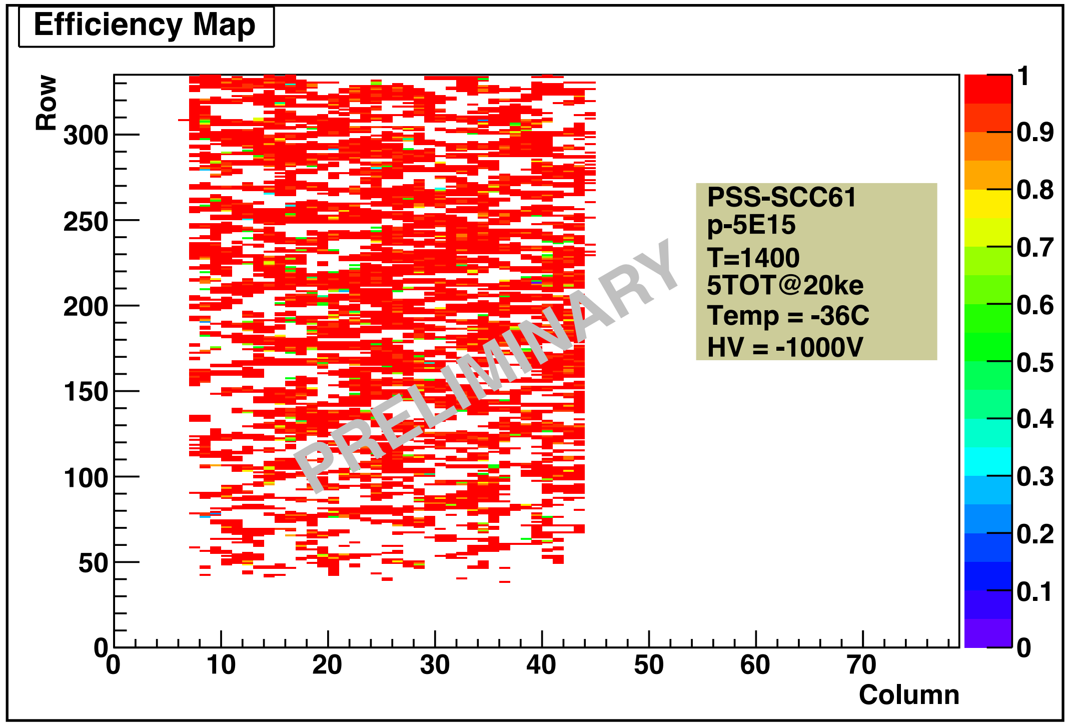
Hit efficiency: 98%, efficiency loss for tracks going through electrodes (electrodes not filled).

H. Pernegger. Vertex 2011

Preliminary: Irrad Planar + FE-I4 at CERN TB

SCC61: Planar 200um thick, p-irrad 6x10^{15} n_{eq} cm^{-2}, HV=-1000V, phi=15^o

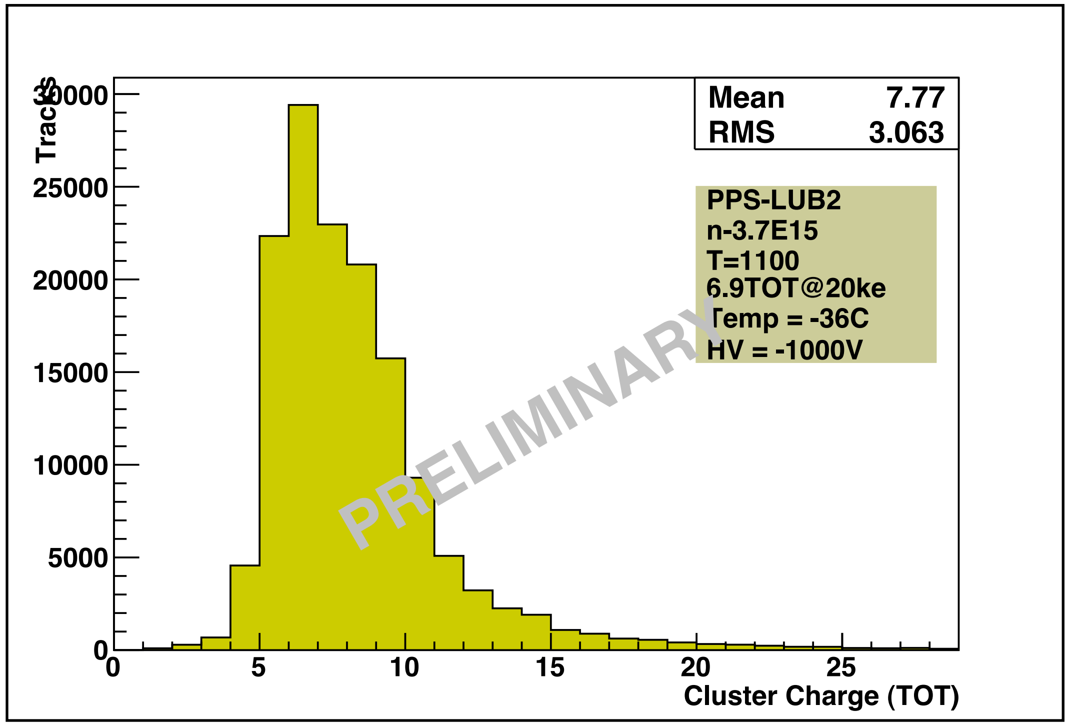


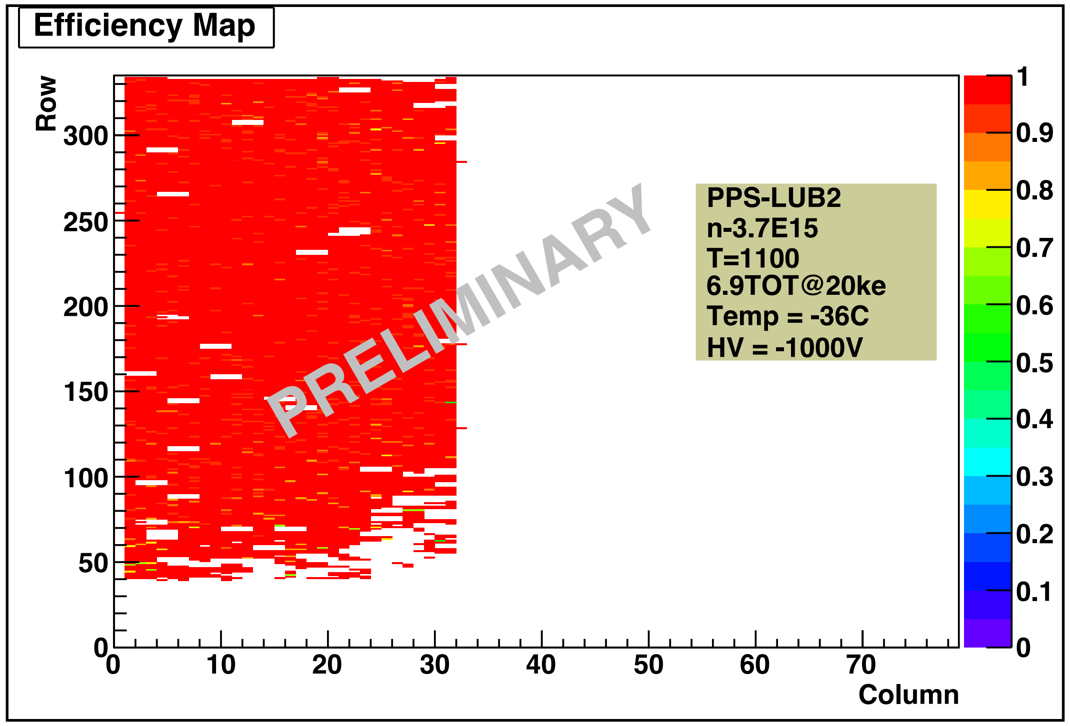


Efficiency Map:
Noise & dead pixel masked out;
Some (most?) are due to FE itself (***Large TID***)

Num. of noisy pixels (FE/Sensors): 560
Hit efficiency: 96.9%
Overall charge sharing probability: 43.0%

LUB2: Planar 250um thick, n-irrad 4x10^{15} n_{eq} cm^{-2}, HV=-1000V, phi=15^o



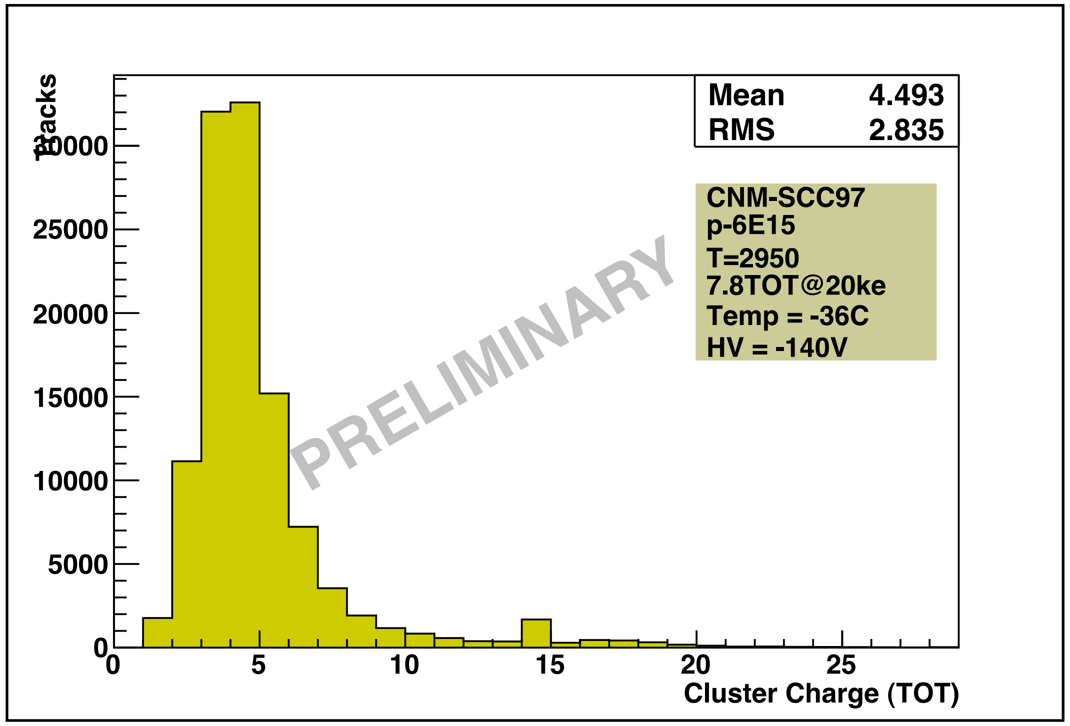


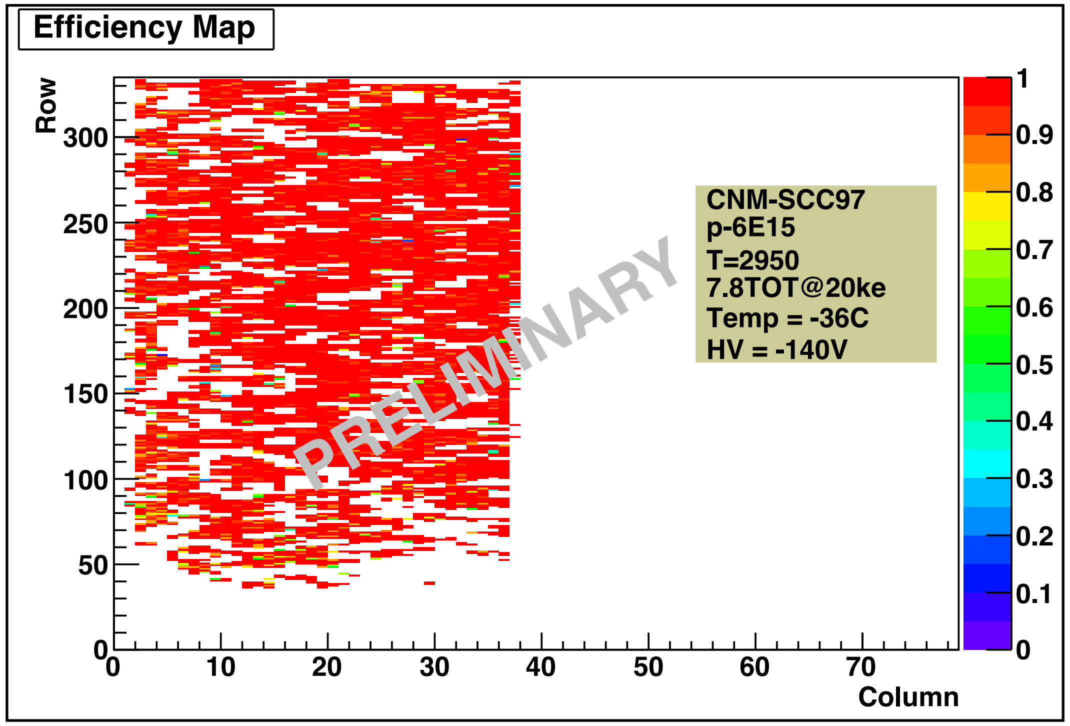
Num. of noisy pixels (FE/Sensor): 80
Hit efficiency: 99%
Overall charge sharing probability: 43.5%

P. Grenier, et al. CERN 4/7/11

Preliminary: Irrad 3D + FE-I4 at CERN TB

SCC97: 3D-CNM 230um thick, p-irrad $6\times10^{15}\ n_{eq}\ cm^{-2}$, HV=-140V, phi=$15^o$

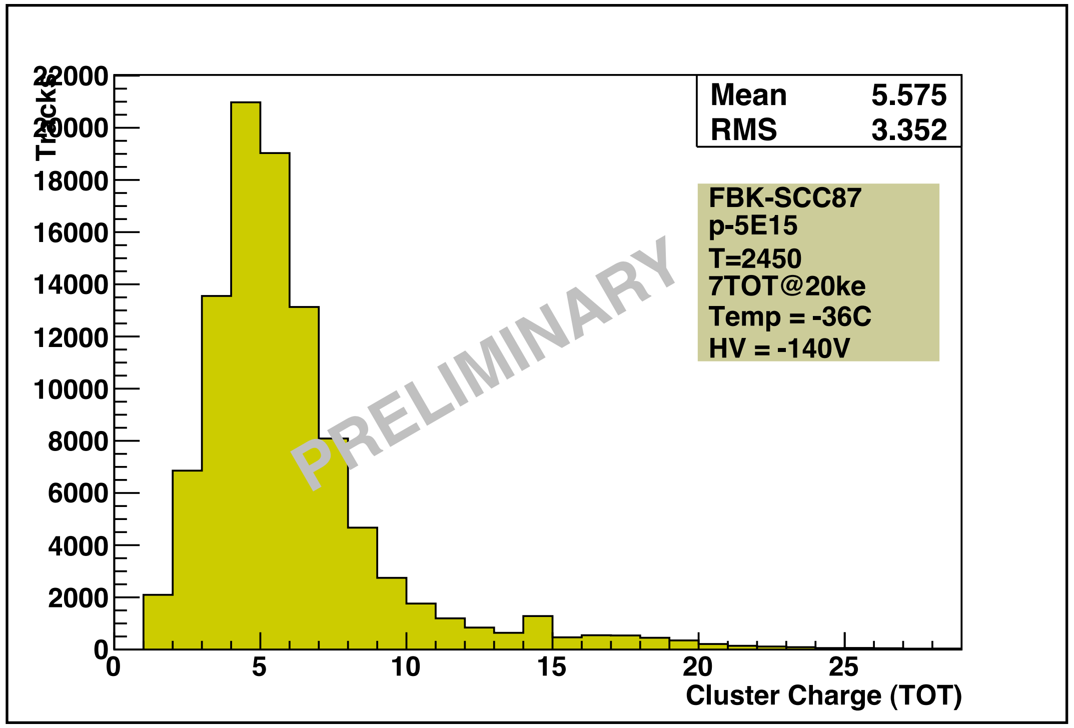


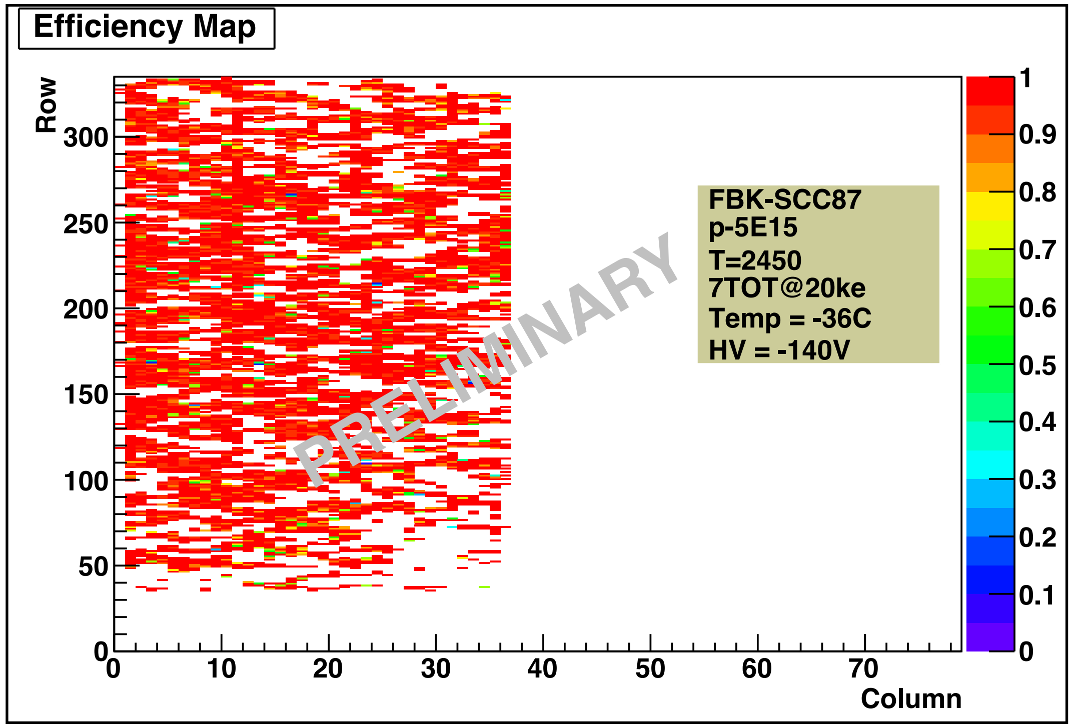


Efficiency Map:
Noise & dead pixel masked out;
Some (most?) are due to FE itself (***Large TID***)

Num. of noisy pixels (FE/Sensors): 244
Hit efficiency: 97.4%
Overall charge sharing probability: 22.1%

SCC87: 3D-FBK 230um thick, p-irrad $5\times10^{15}\ n_{eq}\ cm^{-2}$, HV=-140V, phi=$15^o$





Efficiency Map:
Noise & dead pixel masked out;
Some (most?) are due to FE itself (***Large TID***)

Num. of noisy pixels (FE/Sensor): 290
Hit efficiency: 95.3%
Overall charge sharing probability: 39.5%

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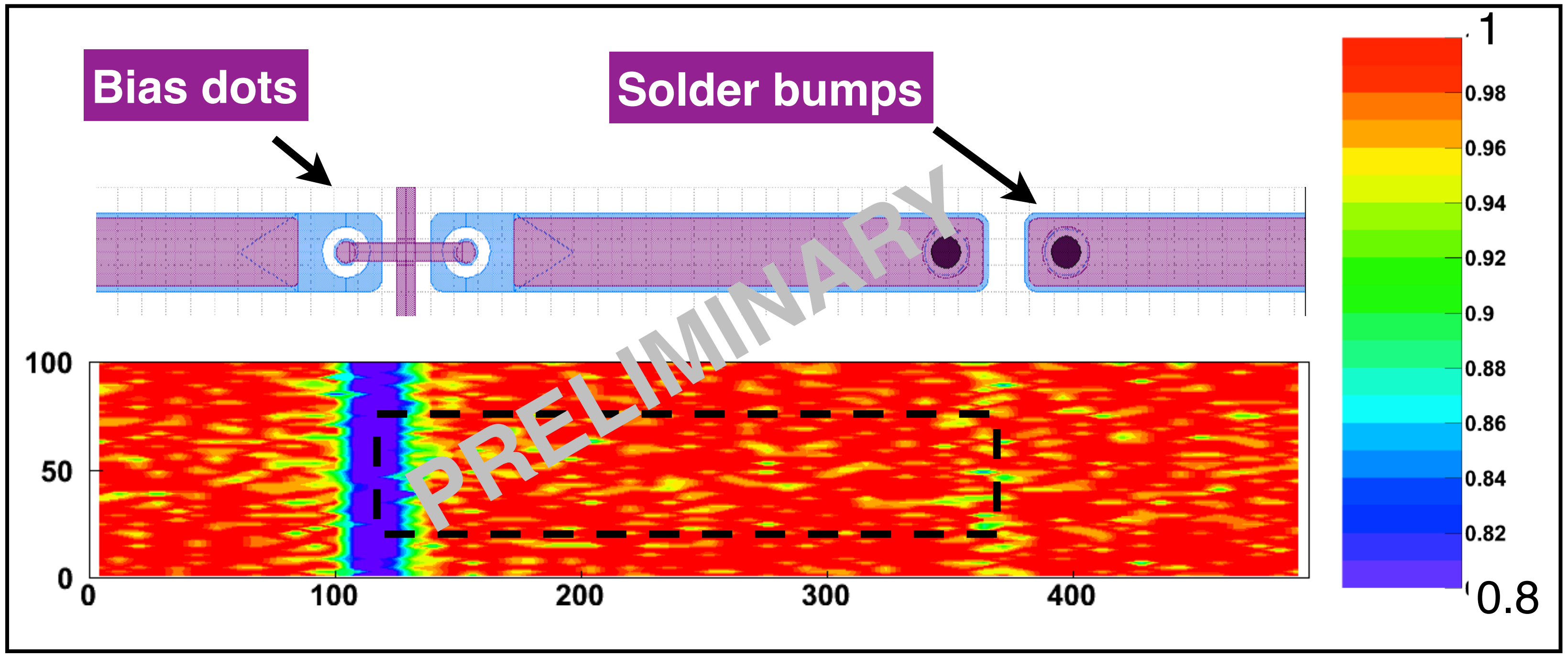
Preliminary: Cell efficiency map

SCC61: Planar 200um thick, p-irrad $6x10^{15}\,n_{eq}\,cm^{-2}$ (Large TID), HV=-1000V, phi=15^{o}

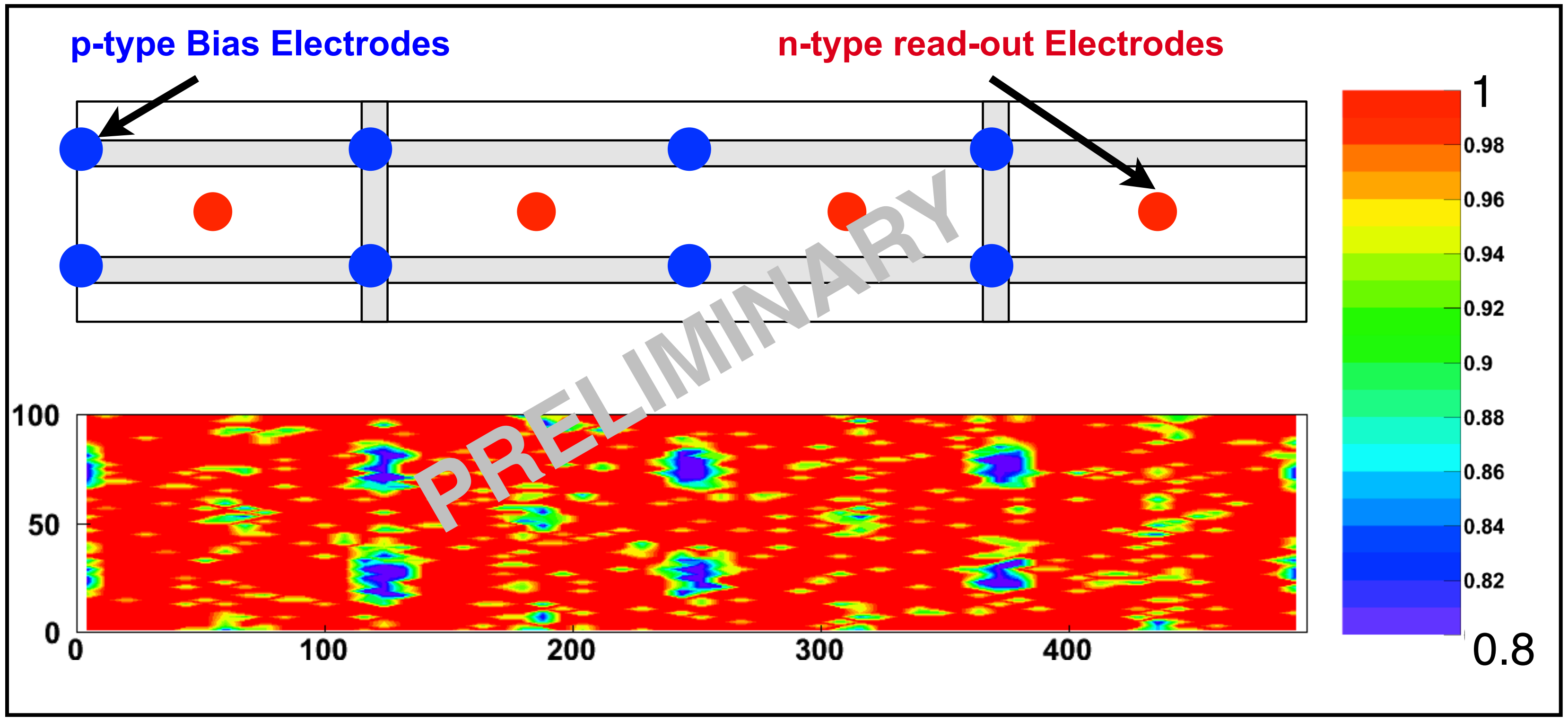


Efficiency distribution within pixel cells.

Efficiency loss at cell borders mainly due to the charge sharing.

More charge loss on bias side: trapping in bias dots and grid

SCC97: 3D-CNM 230um thick, p-irrad $6x10^{15}\,n_{eq}\,cm^{-2}$ (Large TID), HV=-140V, phi=0^{o}



Efficiency loss for tracks going trough (not filled) electrodes: no charge produced

Large effect on bias electrodes as lower field.

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IBL schedule key dates

Activities	Starting	Ending
FE-I4_B	July 11: Submission	Oct to Dec 11 for wafer test
Bump bonding	Aug 11: pre-production	July 12: Completion
Module assembly	Feb 12: 1st modules ready for loading	Oct to Dec 12 depending of sensor
Module loading	Feb12: --> 4 staves to be ready by Apr 12	Jan 13: completion
Stave loading	Sept 12: starting with the 1st available staves	Feb-Mar 13: Completion
Final tests and commissioning	Sept 12	July 13: IBL Installation

[H. Pernegger, VERTEX2011]

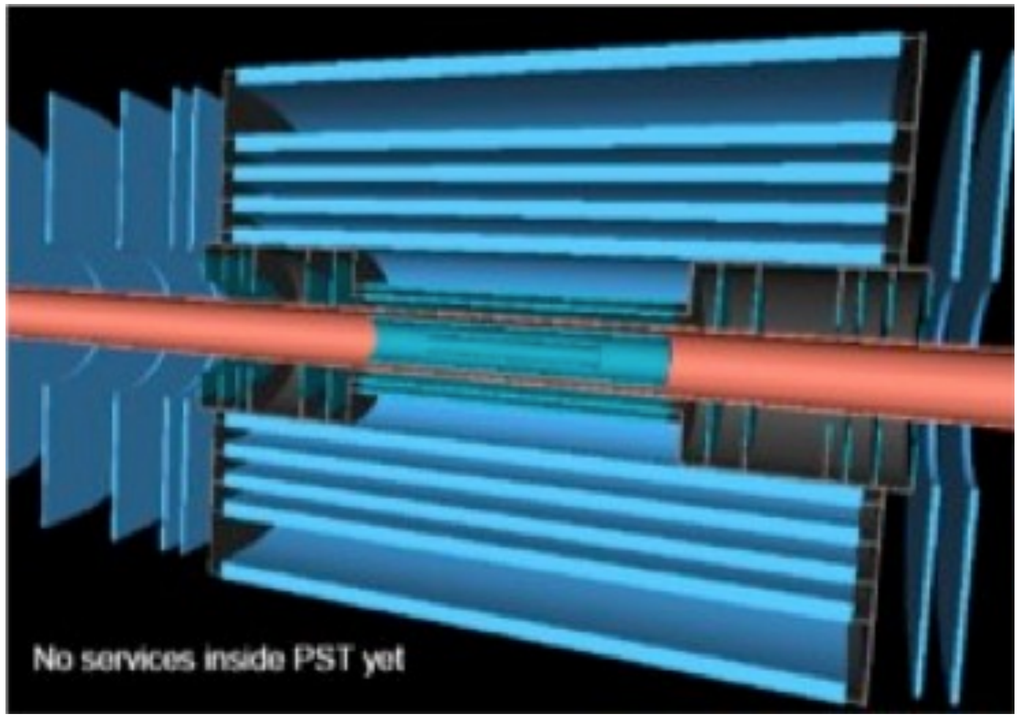
- Tight schedule for installation in 2013, very challenging but possible !

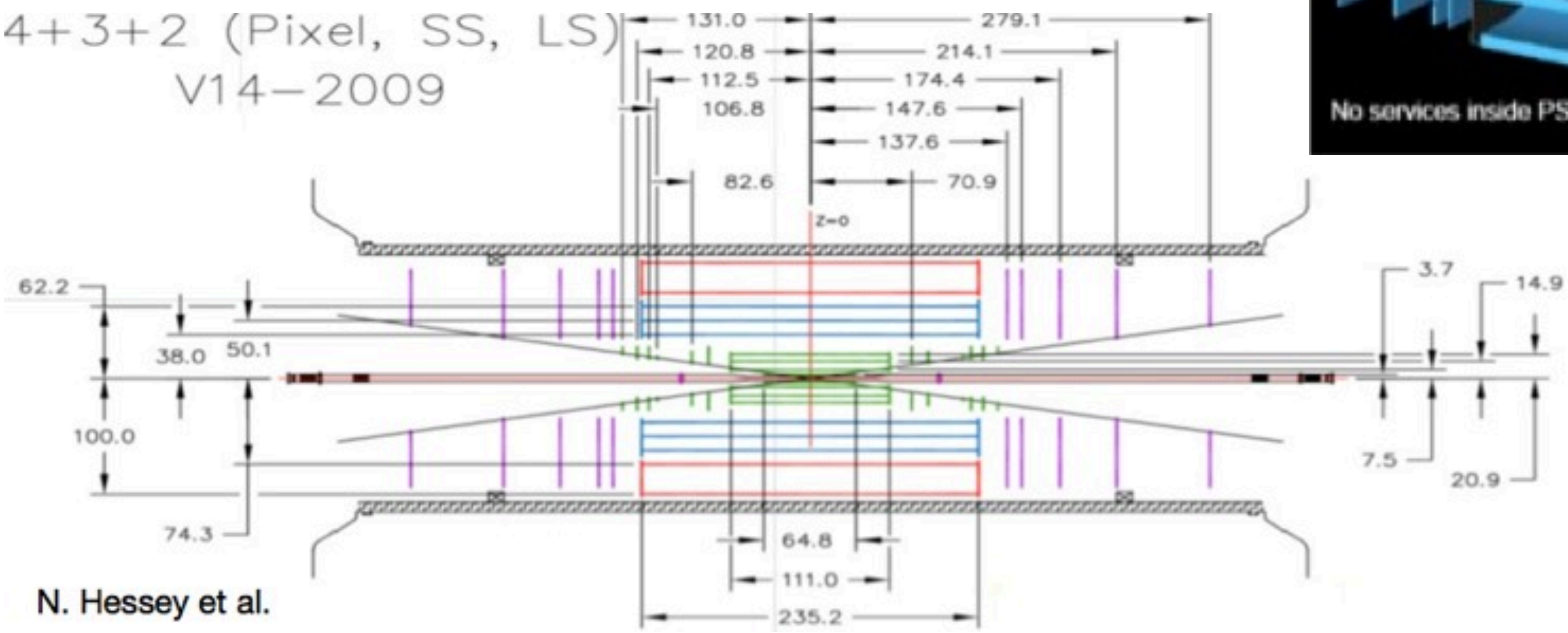
Upgrade for phase-2

- ~2022: to prepare for the following period of ~10 years after having collected some 100 fb^{-1} at sqrt(s)=14 TeV. To run at 5x nominal luminosity: $5x10^{34}$ with luminosity leveling, collecting a total of 3000 fb^{-1} and 200 events per beam crossing

[T. Kawamoto, TIPP2011]

- **All new Inner Tracker**
  - higher granularity to keep occupancy low
  - improved material budget
  - baseline: all silicon strip and pixel





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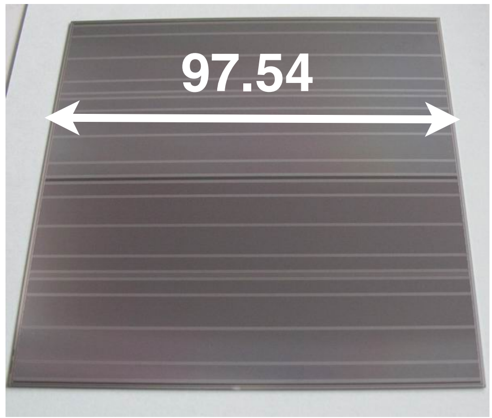
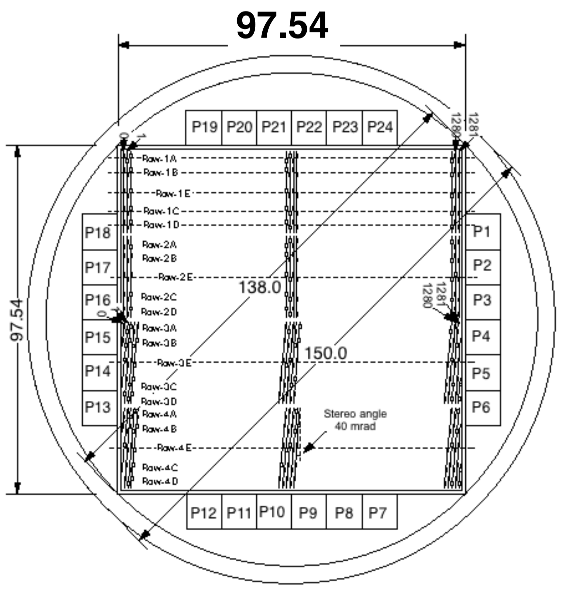
Tracker Layout (under discussion):

- 2 long strip layers
- 2-3 short-strip layers
- 4-5 pixel layers

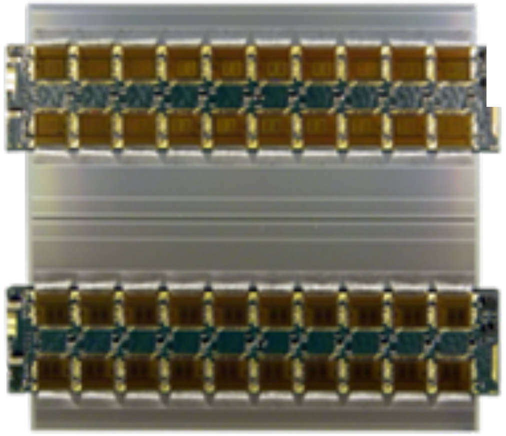
Strip and Pixel prototyping

- STRIP prototyping
  - n-in-p sensors baseline (rad hard verified up to 2x10^{16} n$_{eq}$ cm^{-2} and with irrad modules up to to 2x10^{15} n$_{eq}$ cm^{-2})
  - Successful production (ATLAS07 sensors) at Hamamatsu
  - Extensive stave prototyping program exits (focused on short-strip)
  - New front-end VLSI chip: ABCNext (prototyped in 250um CMOS tech and underway in 130um CMOS tech.)
  - Hybrid with FE chips glued directly to sensor
  - Sensor glued to cold mechanical support (Stave)

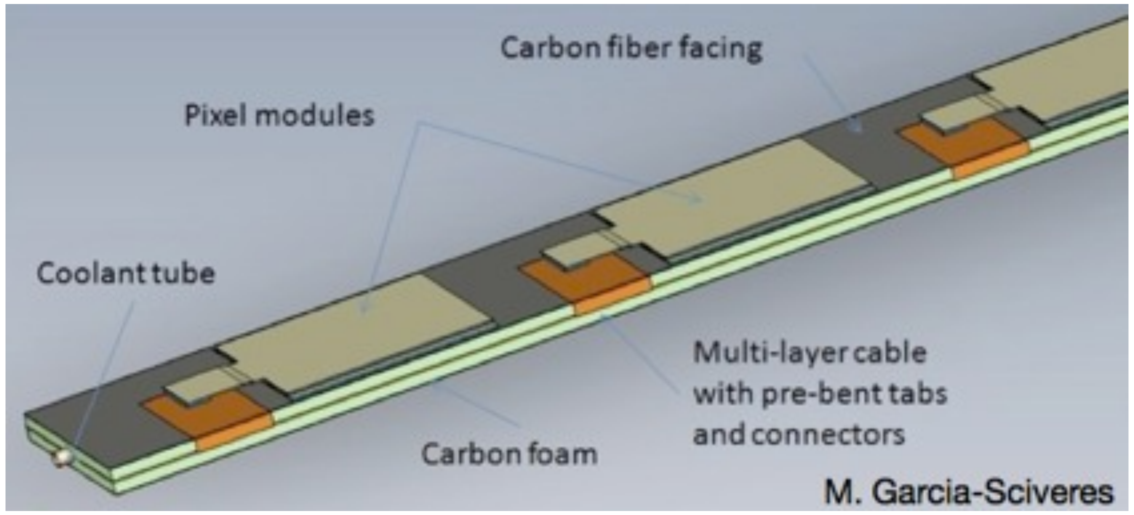




Axial-Stereo Sensor



- PIXEL prototyping
  - Basic concept:
    - double side staves
    - carbon foam
    - flex inside of stave
    - 2x2 MultiChip-Modules

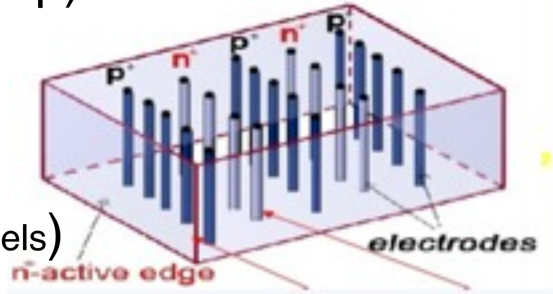


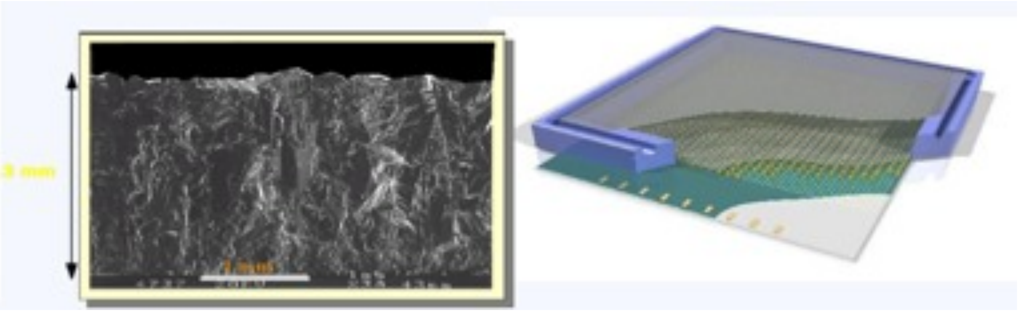
M. Garcia-Sciveres

  - Several sensors under investigation for radiation hardness
    - outer layers: planar (n-in-n and n-in-p)
    - innermost layer:

      Thin Planar, 3D, Diamond

      and GOSSIP (Gas on Slimmed Si-Pixels)



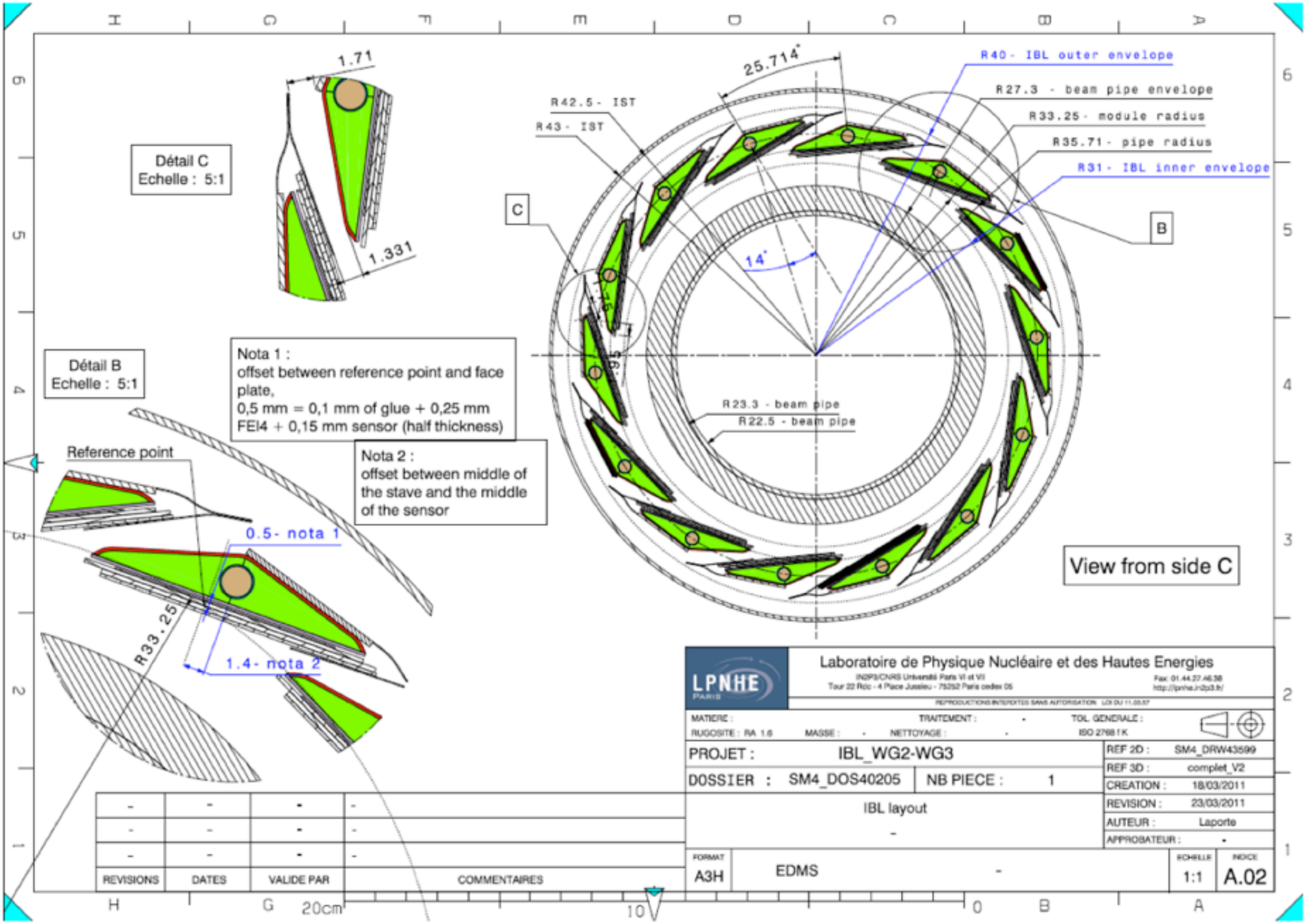


Summary

- ATLAS Tracker plans to upgrade in two (three) phases:
  - Phase-0: Insertion of new pixel inside current Pixel detector - Insertable B-Layer (IBL)
    - First technology step to sLHC (sensors, FE, readout system, cooling, etc...)
    - Installation in 2013: start production of IBL now
  - *Phase-1: Under consideration new Pixel detector based on IBL experience*
  - Phase-2: Full all-Silicon tracker replacement with pixels, short-strips and long-strips
    - Radiation-hardness for
      - innermost pixel layer being investigated
      - outer pixel and strip layer established with planar Silicon
    - Prototype program for outer pixel layers has started
    - Short-strip prototypes already under construction
  - Upgrade also planned for may other subsystems:
    - new front-end electronics and trigger architecture, upgrades to far forward calorimetry, possible implementation of level-1 track trigger, possible further improvements to forward muon stations, ...

Additional Slides

IBL Layout: 14 staves around beam-pipe



Nota 1 :
offset between reference point and face plate,
0,5 mm = 0,1 mm of glue + 0,25 mm FEI4 + 0,15 mm sensor (half thickness)

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

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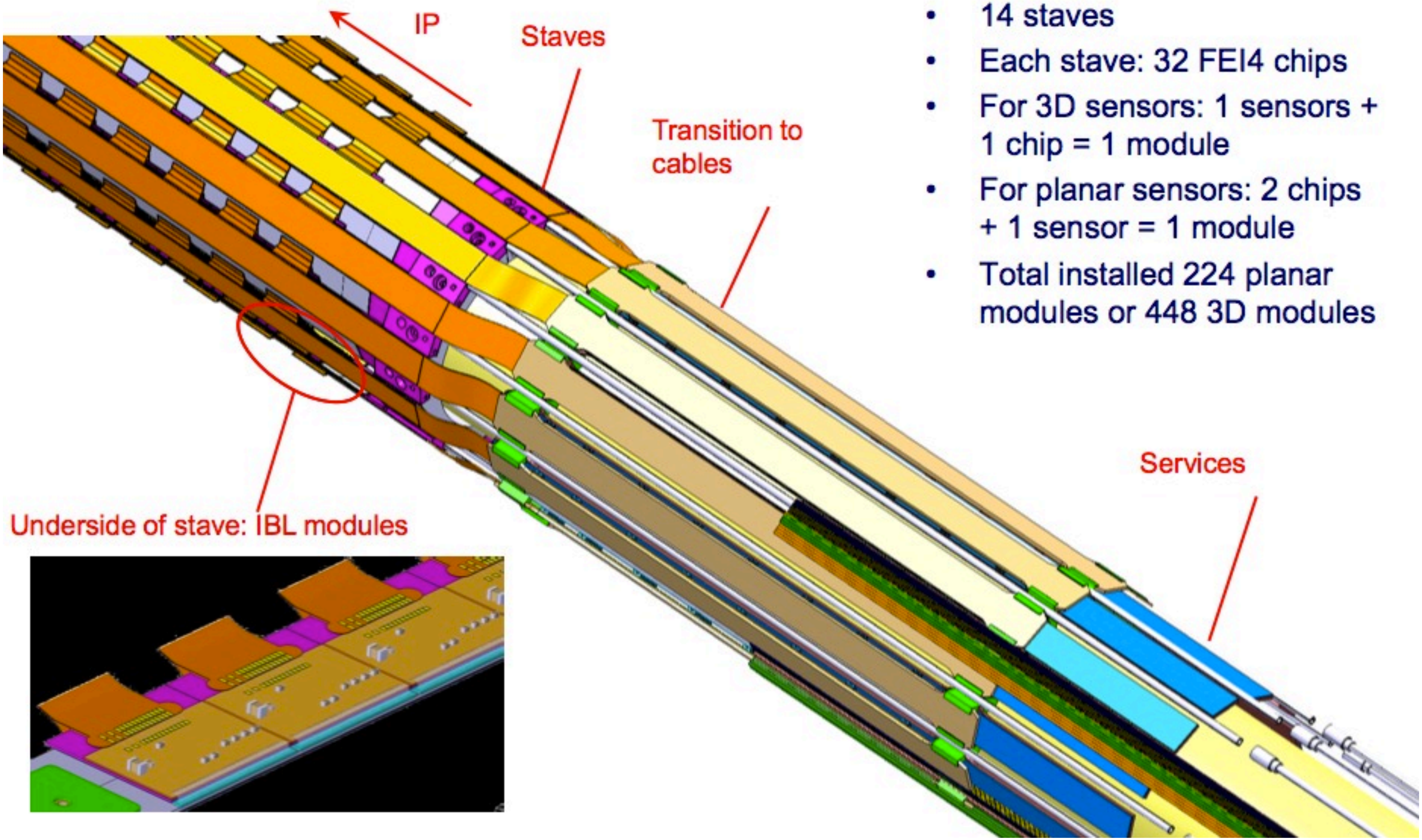
http://lpnhe.in2p3.fr/
REPRODUCTIONS INTERDITES SANS AUTORISATION LOI DU 11.03.57

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

PROJET : IBL_WG2-WG3
DOSSIER : SM4_DOS40205
NB PIECE : 1
IBL layout
-
REF 2D : SM4_DRW43599
REF 3D : complet_V2
CREATION : 18/03/2011
REVISION : 23/03/2011
AUTEUR : Laporte
APPROBATEUR : -
FORMAT A3H
EDMS -
ECHELLE 1:1
INDICE A.02

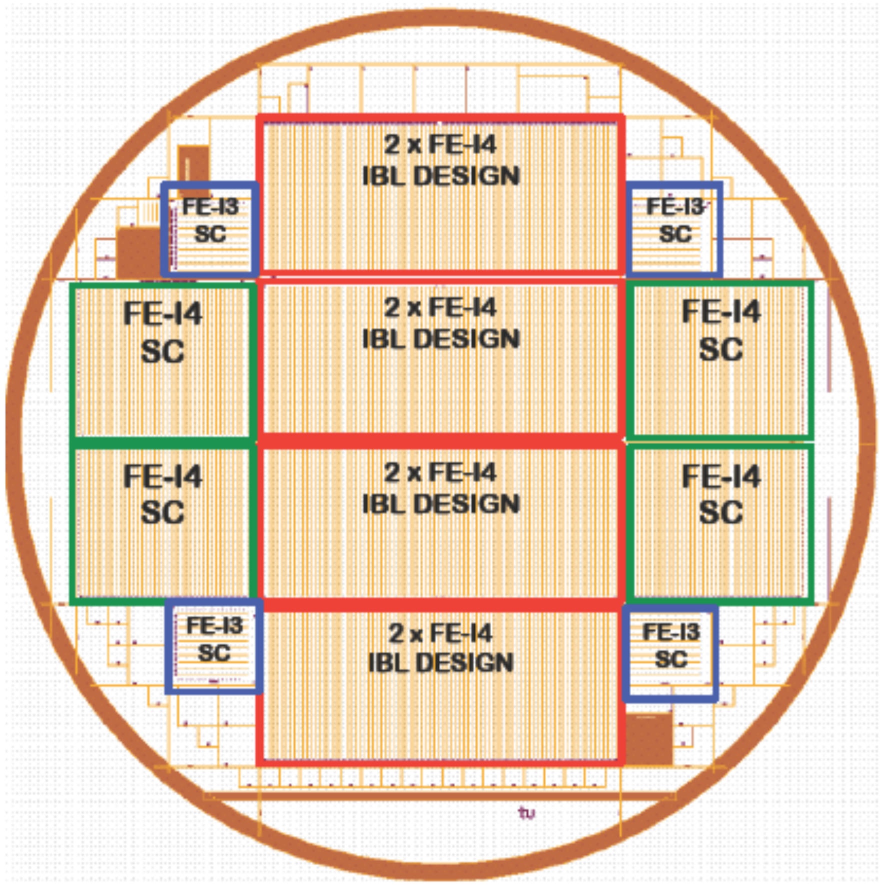
IBL Staves and module arrangement



- 14 staves
- Each stave: 32 FEI4 chips
- For 3D sensors: 1 sensors + 1 chip = 1 module
- For planar sensors: 2 chips + 1 sensor = 1 module
- Total installed 224 planar modules or 448 3D modules

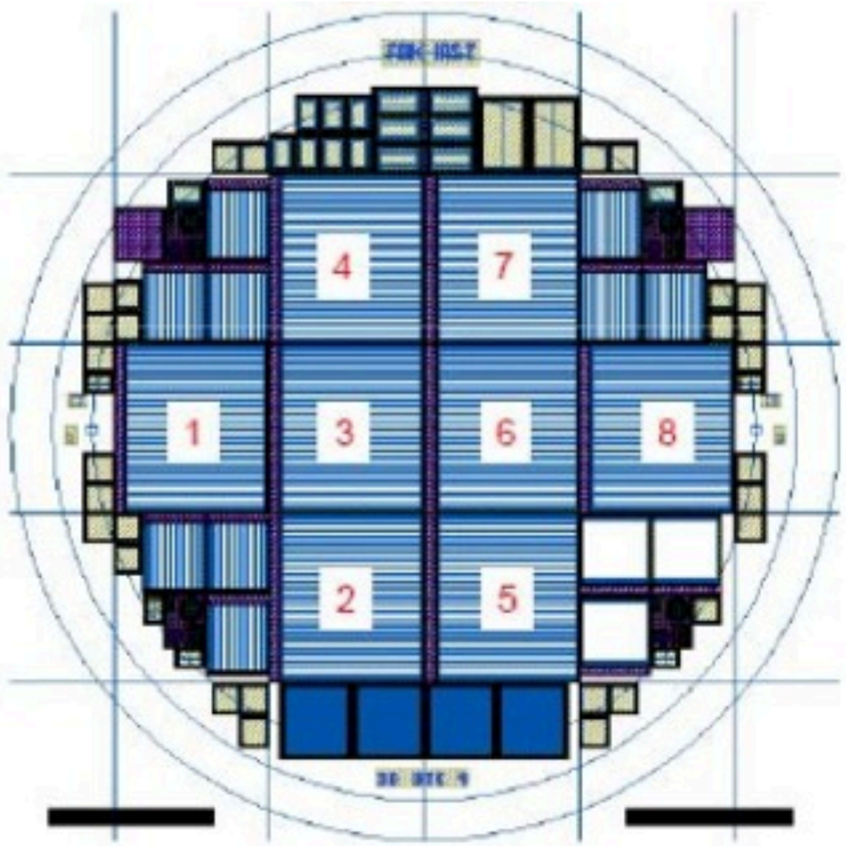
IBL sensor floor-plan

Planar at
CiS, Germany

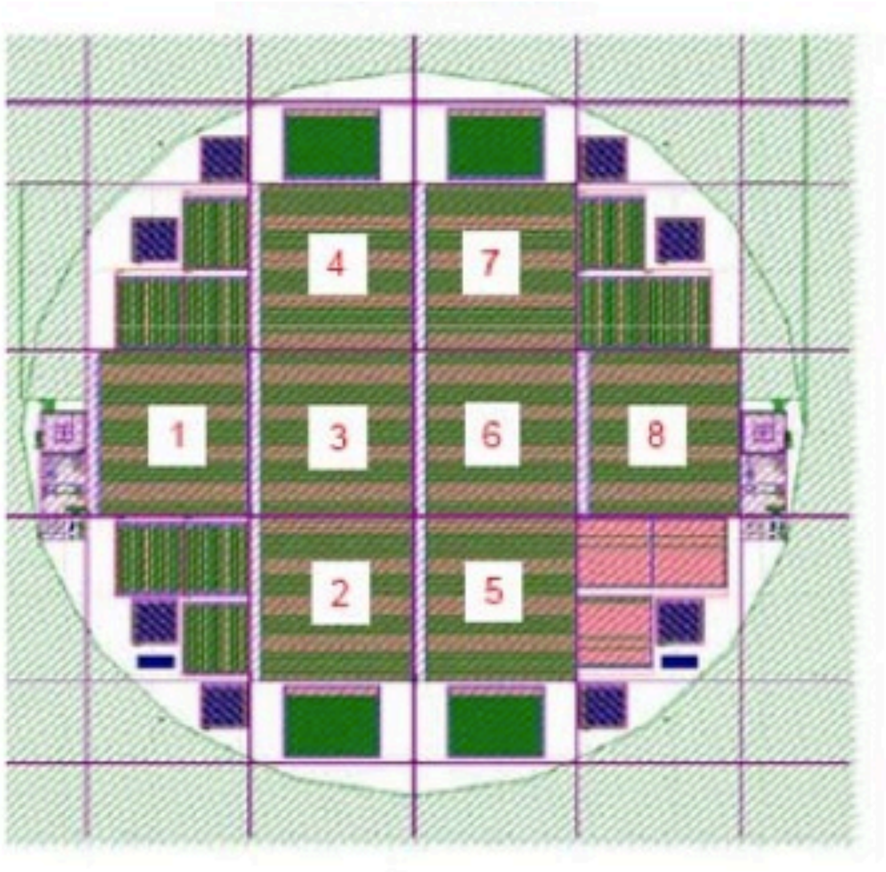


- Planar n-in-n sensor type
- 4x IBL (2-chip sensor) tiles
- 4x 1-chip sensor tiles
- test structures

3D at
FBK-irst, Italy



CNM, Spain



- 3D n-in-p sensor type
- 8x IBL (1-chip sensor) tiles / for both producers
- test structures

FE-I4: low threshold operation

- Studied on Planar and 3D assemblies (irradiated with proton to $5\times10^{15} n_{eq}/cm^2$)
  - Noise occupancy increase when threshold below 1500e$^-$
  - At 1100e$^-$, occupancy is ~10^{-7} bits/BC/pixel

- Low threshold operation with irradiated assemblies demonstrated