ATLAS IBL sensor qualification

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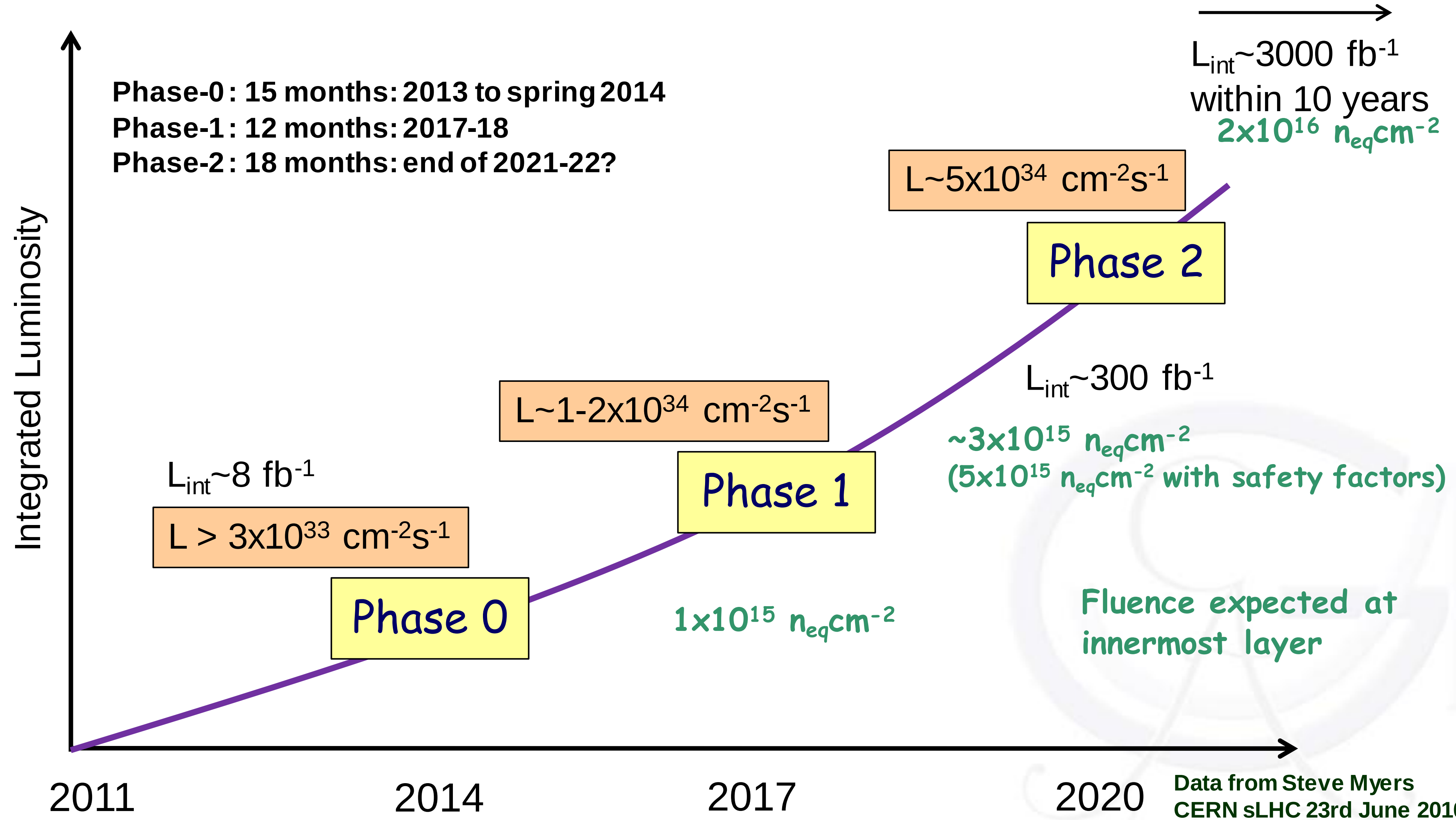
for the ATLAS IBL Collaboration

LHC Upgrade

- improve precision measurements
- increase discovery potential

} by increasing luminosity

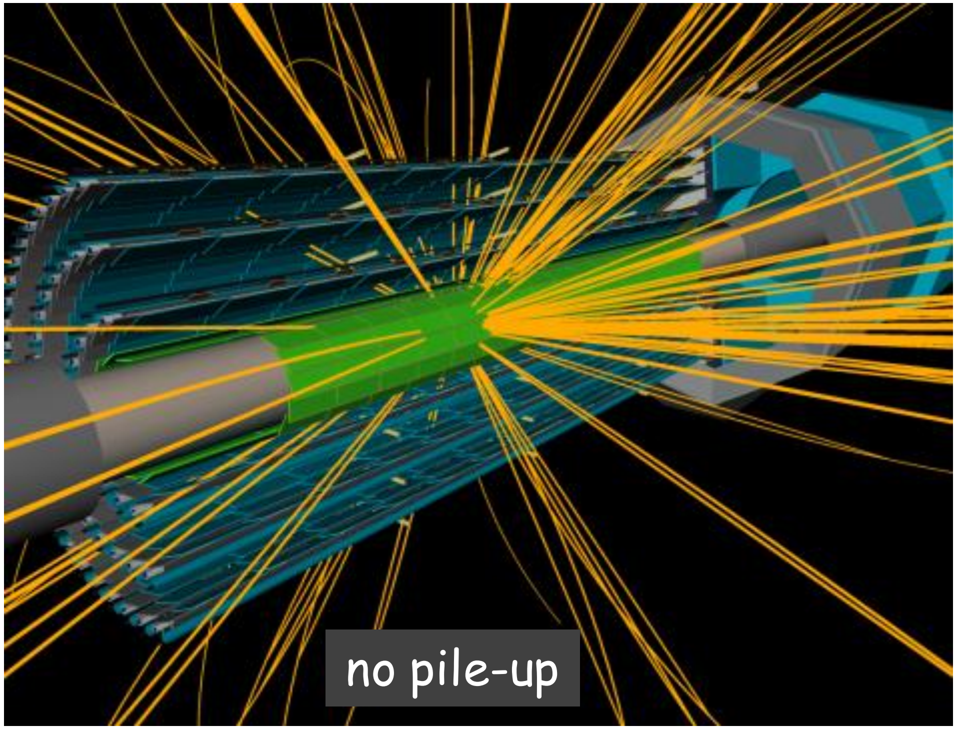


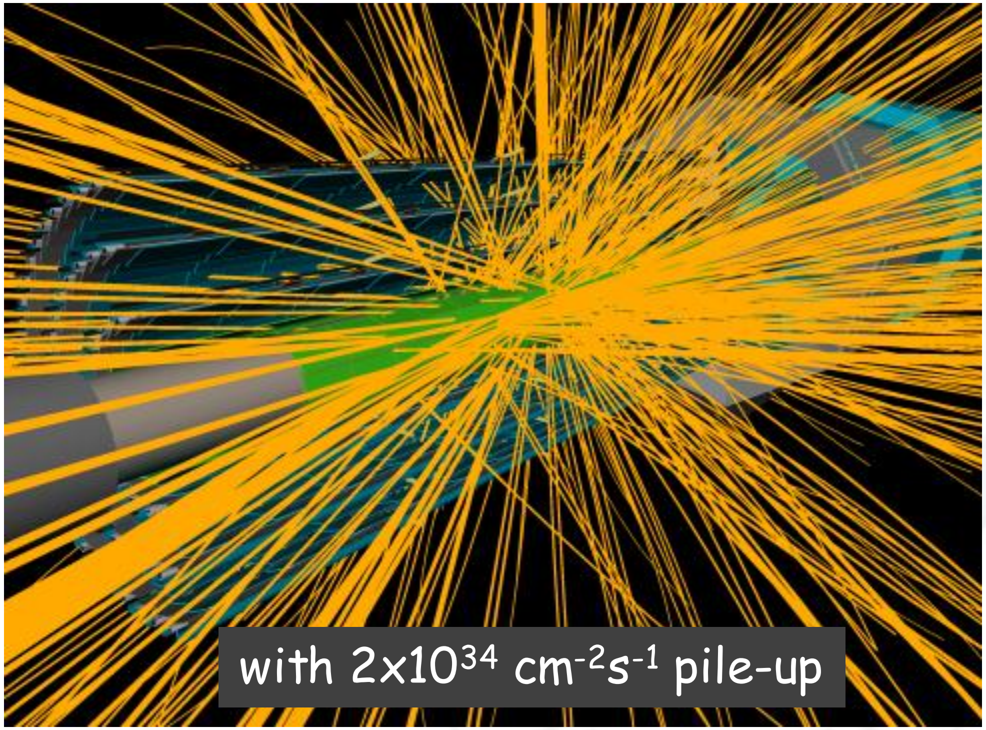
Data from Steve Myers
CERN sLHC 23rd June 2010.

Major detector upgrades are necessary:

→ tracking robustness and vertexing suffer from high occupancy
➔ impact on b/τ tagging, electron ID, etc.

Simulated event containing 2 jets of 500 GeV:
all tracks with pT>0.5 GeV, more than 1 Pixel + IBL cluster

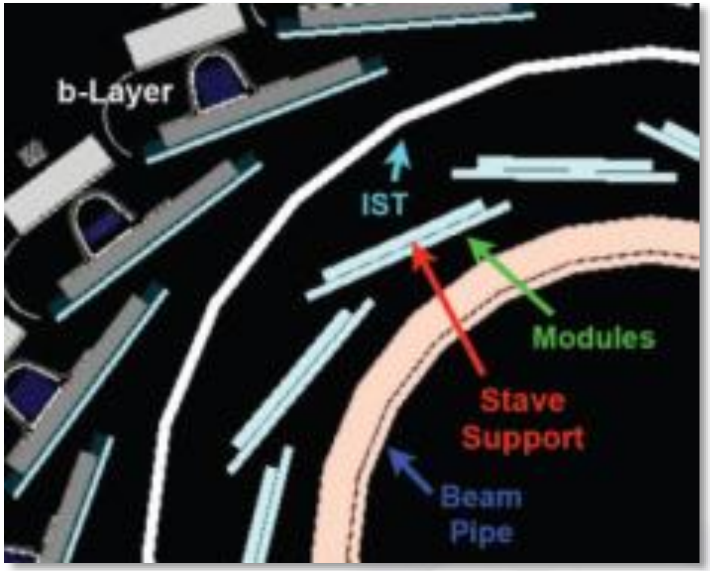




The IBL Detector

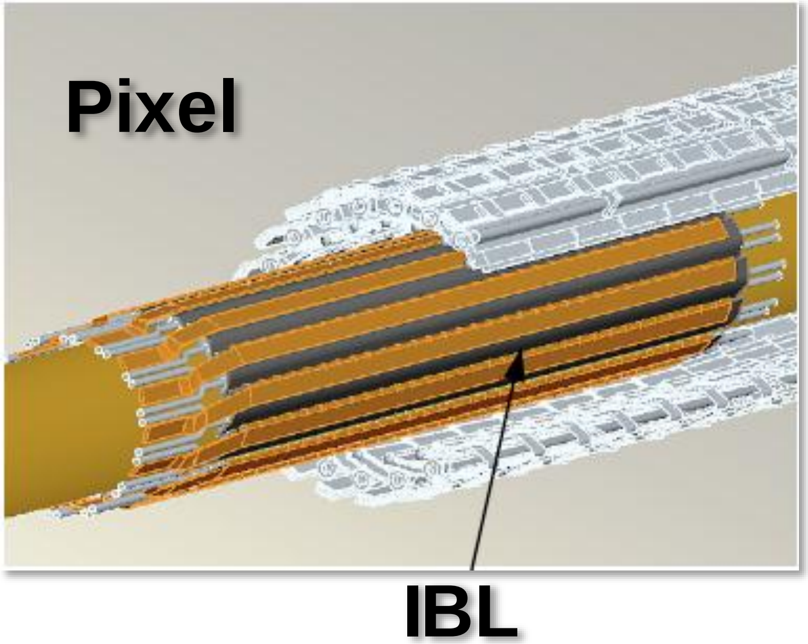
Installation of a 4th pixel layer inside the current pixel detector (major Phase 0 project):

- performance of current pixel detector will degrade before main tracker upgrade (Phase 2)
- maintain physics performance in high occupancy environment (higher granularity, r/o bandwidth)
- increase radiation hardness (IBL fluence ~ 5x B-Layer fluence)



→ Insertable B-Layer

- 250 Mrad TID and 5×10^{15} $n_{eq}cm^{-2}$
- installation originally planned for 2015-2016… advanced (in 2011) to 2013 (Fast-track IBL)

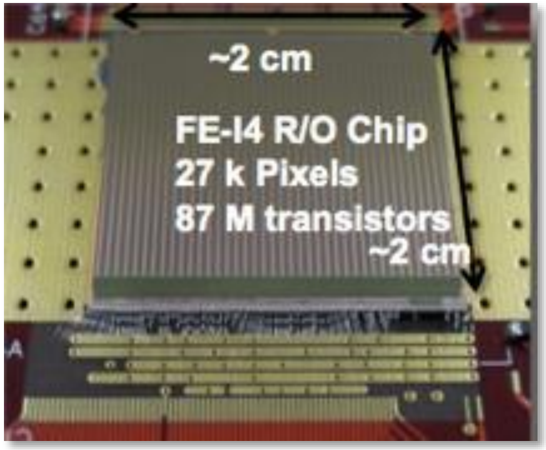


- IBL mounted on new beam pipe
- Length: ~64cm
- Envelope: R_{in} = 31mm, R_{out}=40mm
- 14 staves, 32 pixel sensors / stave.
- Front-end chip:
  - FE-I4 (IBM 130 nm CMOS tech.)
  - 50µm x 250µm
  - 80(col) x 336 (rows) = 26880 cells.
  - 2cm x 2cm!

IBL module design

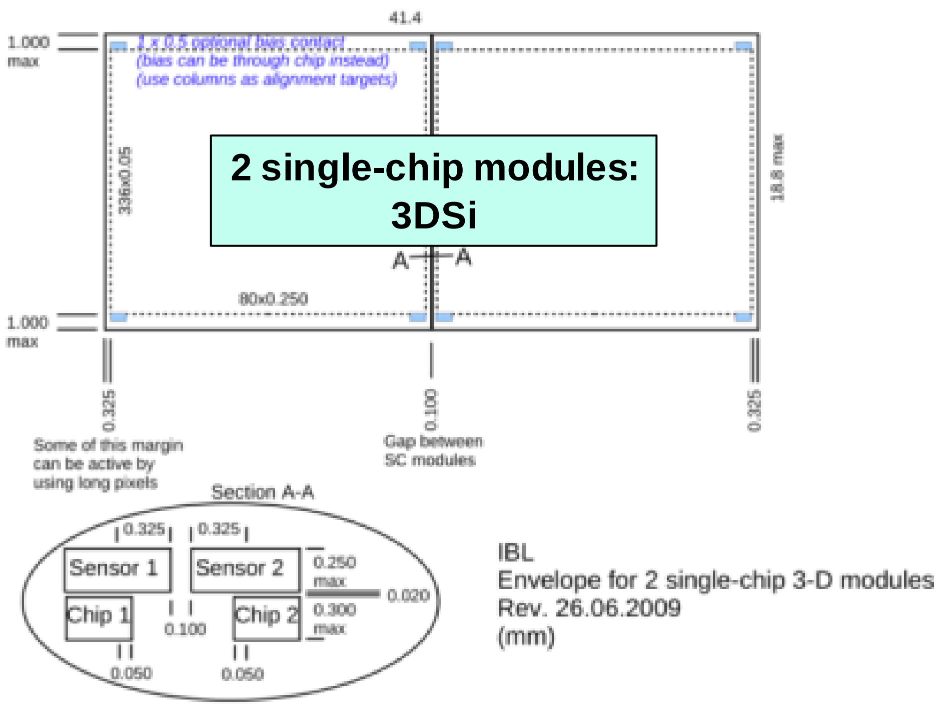
Two competing sensor technologies under development for IBL

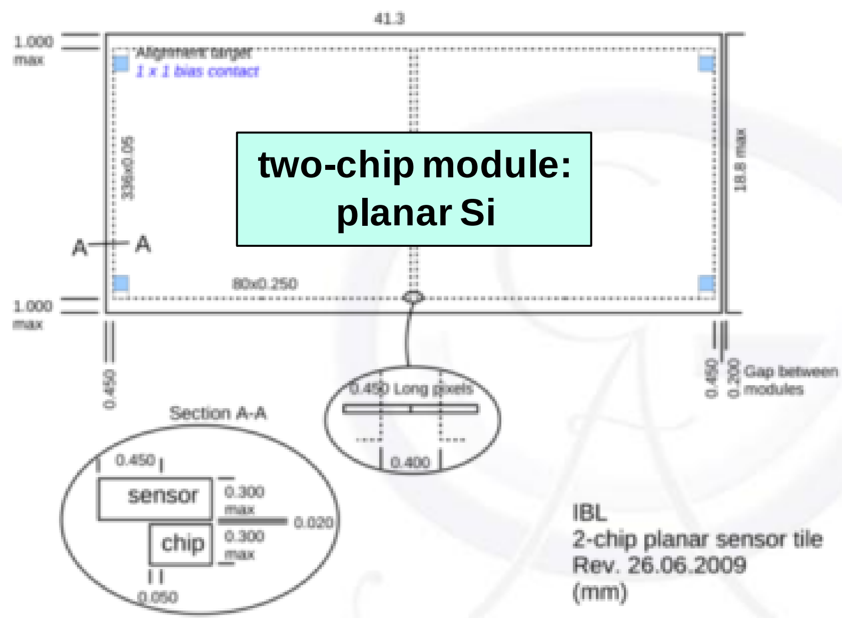
→ 1-chip module for 3DSi sensors
→ 2-chip module for planar Si sensors



Module engineering parameters

- max. sensor bias = 1000 V
- sensor thickness 225 ± 25 μm
- sensor power dissipation < 0.2 W/cm² at -15C
- sensor temperature ~ -15C after full irradiation
- inactive edge < 325 μm (single chip) or < 450 μm (two chip)

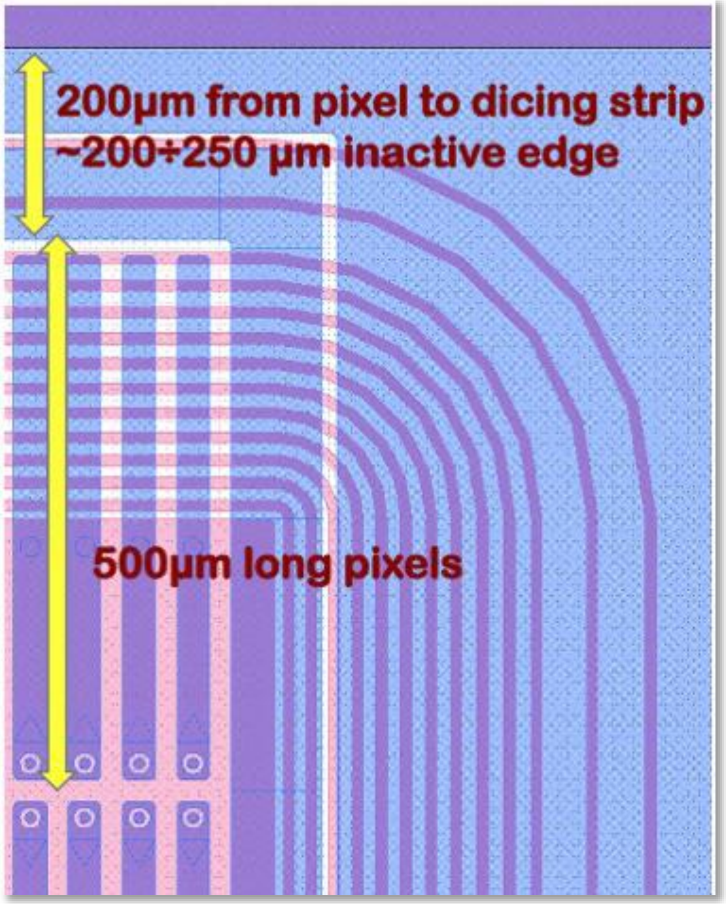




Sensor technology

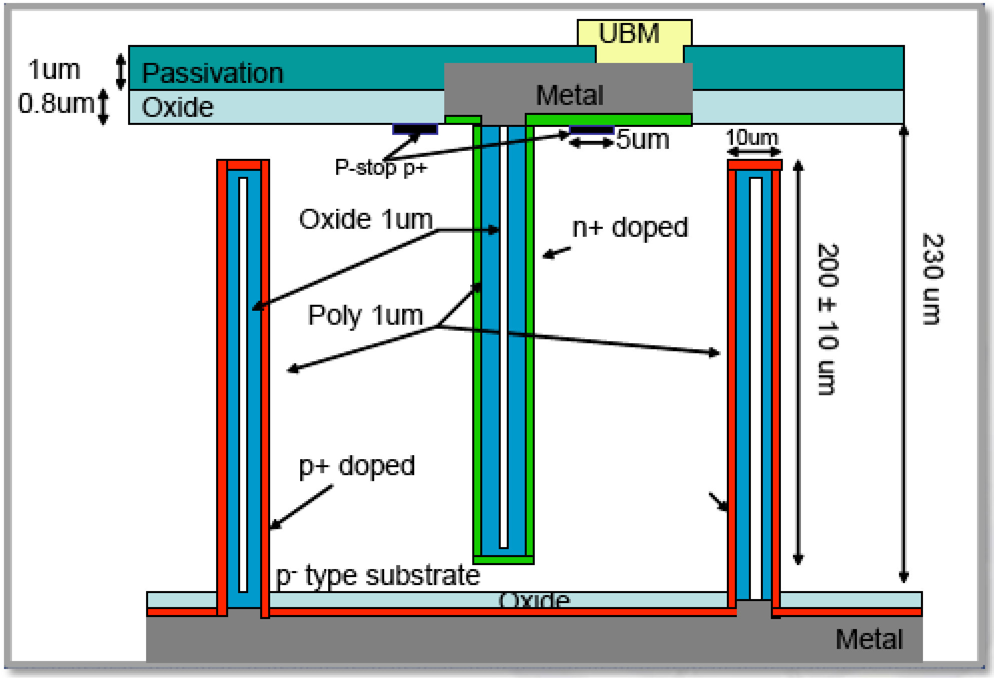
Planar Slim Edge Sensors (CiS)

- oxygenated n-in-n silicon; 200 µm thick
- minimize inactive edge by shifting guard-ring underneath pixels
  ➔ 215 µm inactive edge achieved



3D Slim Edge Sensors (FBK and CNM)

- partial 3D: electrodes etched from both sides
- p-type substrate; 230 µm thick
- no active edge
  ➔ ~200 µm inactive edge achieved



(drawing outdate: columns penetrate full sensor)

Fast Track Sensor Qualification

Task	PLANAR	3D
Ready for installation	July 4, 2013	Aug 1, 2013
Finish loading	Feb 15, 2013	Mar 15, 2013
Start stave loading	Sept 19, 2012	Oct 15, 2012
Sensor production completed	June 11, 2012	Aug 27, 2012
	6 batches x 25 wafers	10 batches x 22 wafers

Sensor production has started following

IBL Fast Track Qualification for sensor choice: review July 4-5.

Heavy program of sensor irradiations and testbeams in 2011:

- 4 proton irradiation campaigns at Karlsruhe (26 MeV protons)
- 3 neutron irradiation campaigns in Ljubljana (reactor neutrons)
- 2 beam tests (Feb. and April) at DESY (4 GeV positrons)
- 1 beam test (June) at CERN (180 GeV pions): Irradiated PPS/3D under IBL operating conditions (temp, B field)

Other critical items:	FE-I4B submission, bump bonding, flex,…

Irradiation

For the preparation of the IBL sensor review, 77 modules had been produced:

- 40x 3D
- 37x Planar

Several irradiation campaigns have been performed

- 11x IBL 1-chip modules (3D and Planar) were irradiated to the IBL target fluence ($5 \times 10^{15}\ n_{eq}cm^{-2}$)
- low energy protons and reactor neutrons
- TID during proton irradiation about 3x IBL lifetime

FE-I4 Assemblies for Sensor Review

Foundry	Technology	Batch ID	Thickness (µm)	Sensor EdgeType	Number of Assemblies: Done	p-irradiated	n-irradiated	Target Fluence (neq/cm2)
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

Testbeams

Three testbeam periods until now:

- February (15d) and April (22d) at DESY → first operation of new FE-I4A chip
- June at CERN SPS

Final IBL-type sensors, irradiated to IBL design fluence available for SPS testbeam

- scheduled for 24 days
- North Area TAX problem
- difficult startup of SPS

➔ ~2.5d of beamtime delivered

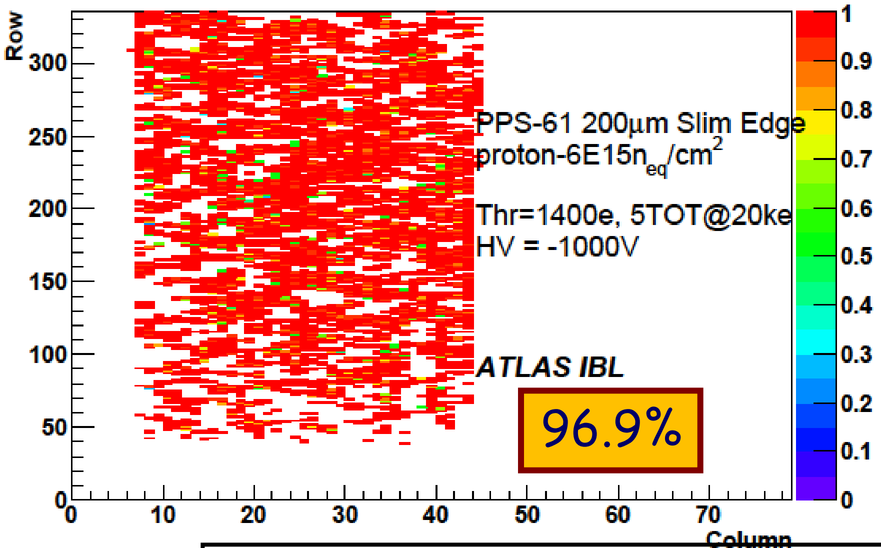
Comments (21-06-11 21:26)
Phone: 77500 or 70475
TROUBLE ON ALL BEAMS
INVESTIGATING...

Legend
Non-irradiated
p-irradiated 2e15
p-irradiated 5e15
n-irradiated 5e15

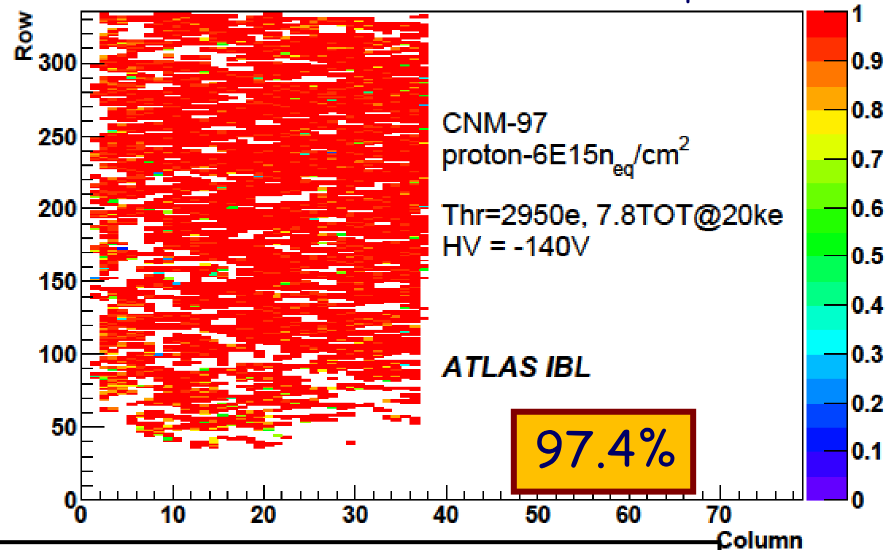
			Measured devices	Angle (degree)		B-field
Test Beam	Beam type	Sensor Techn		0	15	ON
Desy Feb	4 GeV electrons	Planar				
		3D-CNM				
		3D-FBK				
Desy Apr	4 GeV electrons	Planar				
		3D-CNM				
		3D-FBK				
CERN June	180 GeV pions	Planar-CiS				
		3D-CNM				
		3D-FBK				

Hit Efficiency

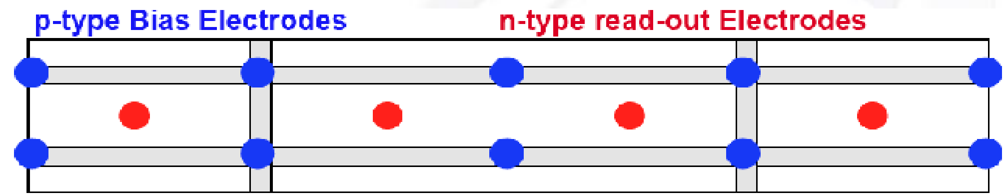
SCC61: Planar $6 \times 10^{15}\ n_{eq}cm^{-2}$

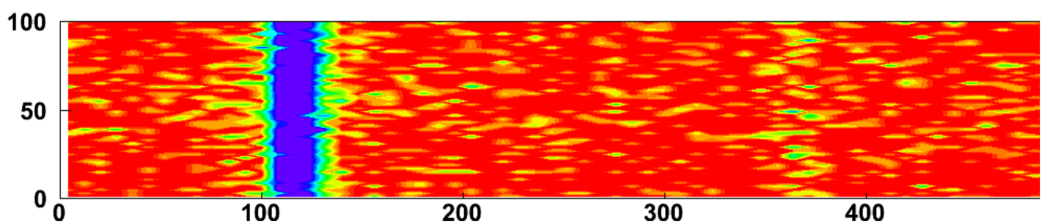


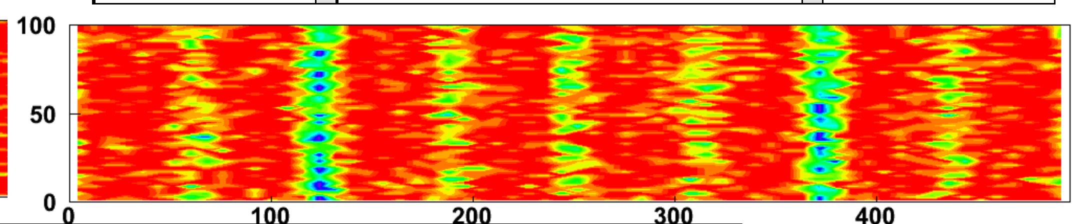
SCC97: 3D CNM $6 \times 10^{15}\ n_{eq}cm^{-2}$



A number of pixels don't work after proton irradiation (TID ~ 3x IBL lifetime)
Same behaviour for both sensor types ➔ FE-I4 "feature"
(Pixels masked during analysis)





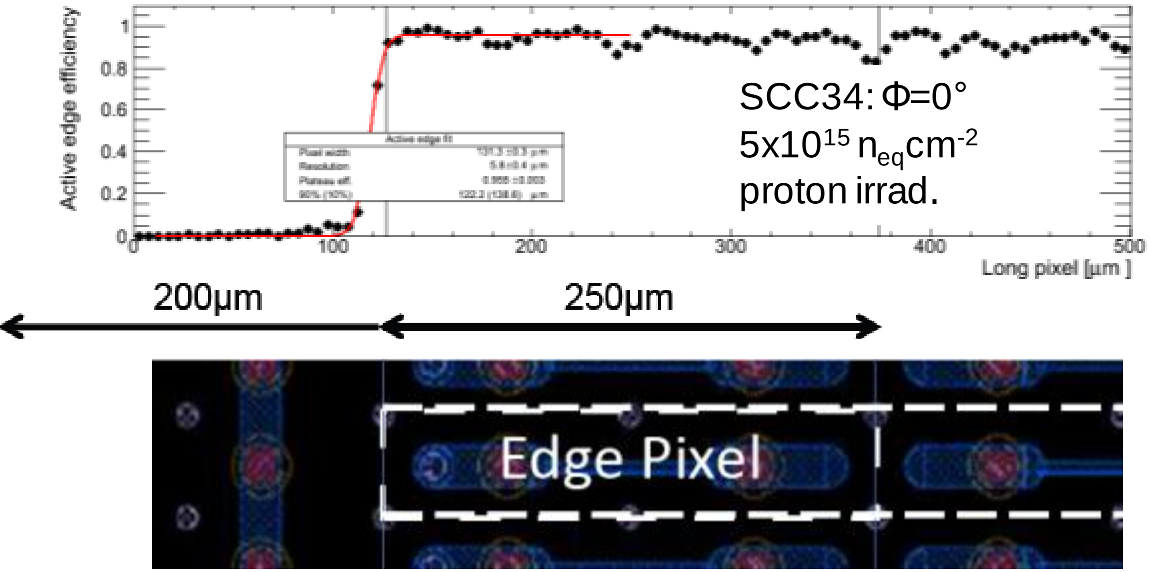


Data taken at Φ =15 ° incidence → smearing of electrode structure

Edge Efficiency

Measure efficiency on edge pixels to estimate inactive area between modules in z

IBL requirement: inactive width <= 450µm



3D

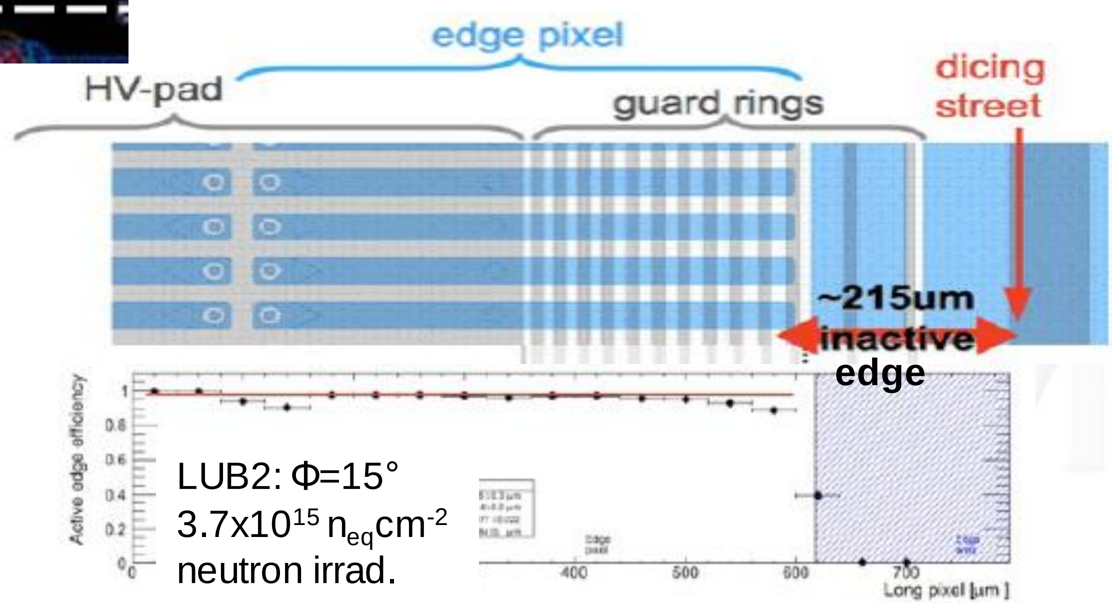
- edge pixel: regular length 250µm
- distance to dicing street: 200µm

➔ effective inactive area: ~170µm

Planar

- edge pixel: extended to 500µm
- guardrings underneath
- distance to dicing street: 200µm

➔ effective inactive area: ~215µm



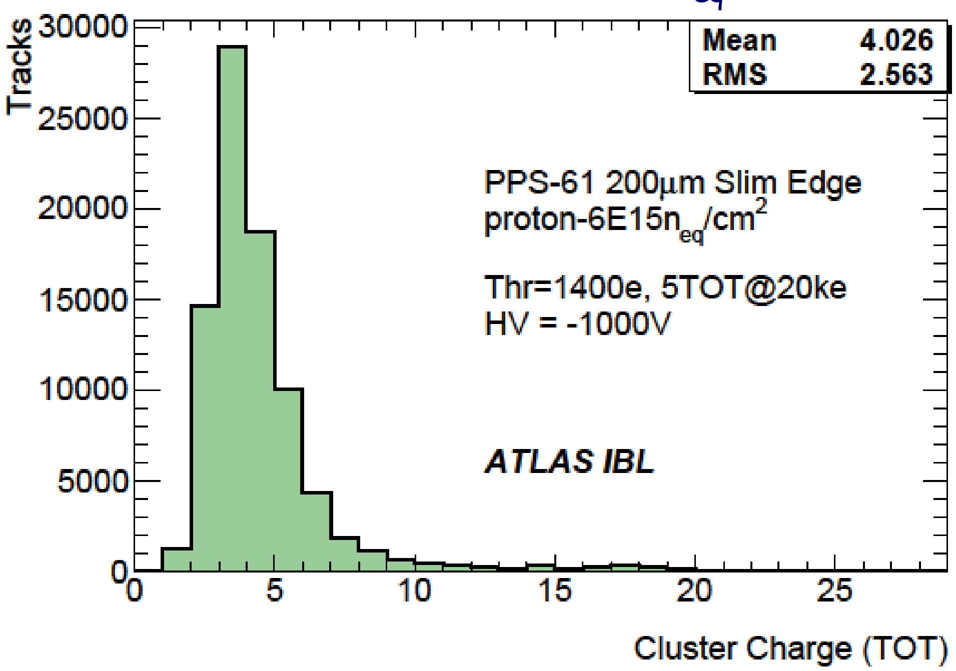
Charge collection

Charge measured as Time-over-Threshold (TOT)

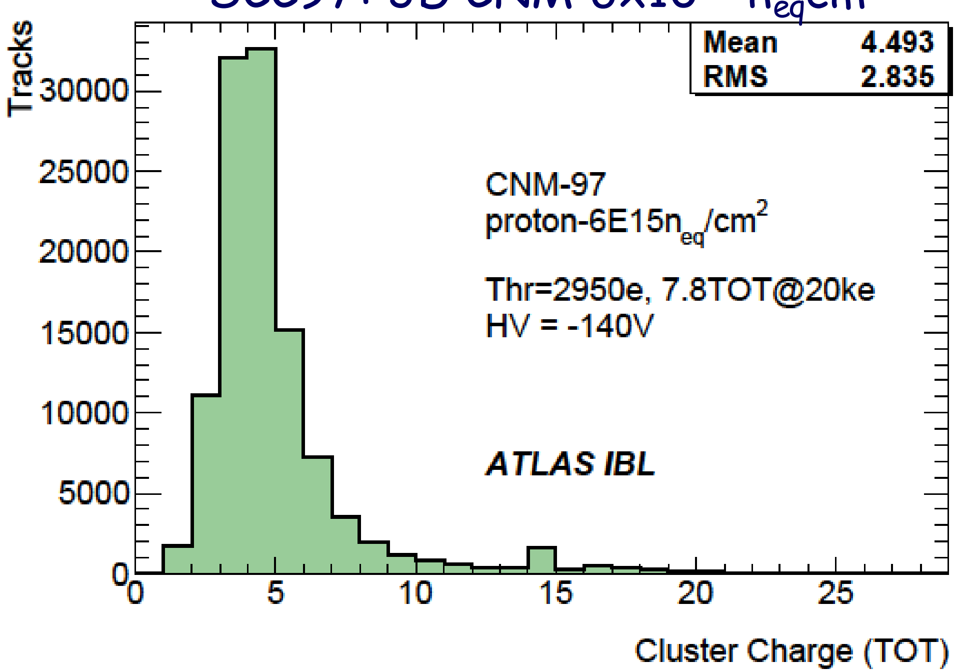
- units of 25ns
- TOT calibration not well-understood
- hard to disentangle FE and sensor effects
- shape looks reasonable

➔ no reliable statement on absolute collected charge possible (yet!)

SCC61: Planar $6\times10^{15}\ n_{eq}cm^{-2}$

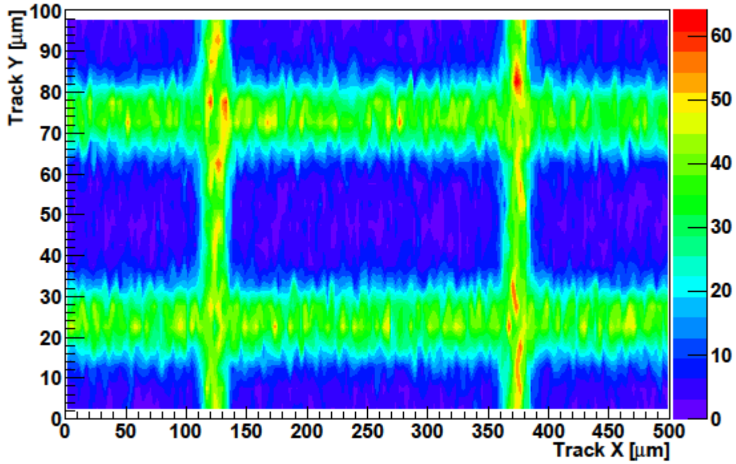


SCC97: 3D CNM $6\times10^{15}\ n_{eq}cm^{-2}$

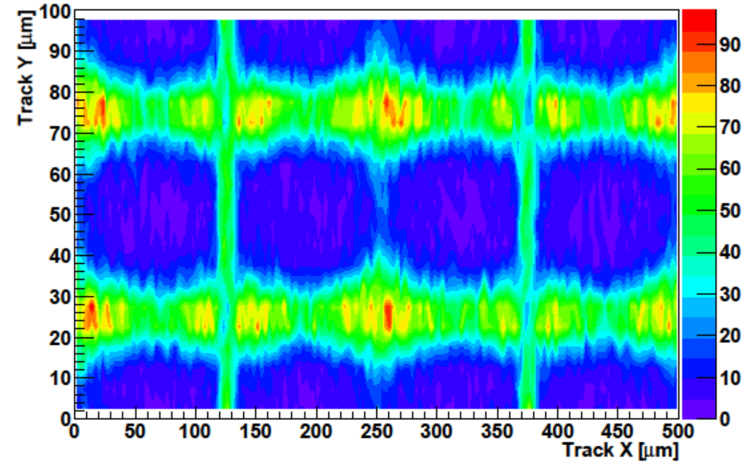


Charge sharing probability

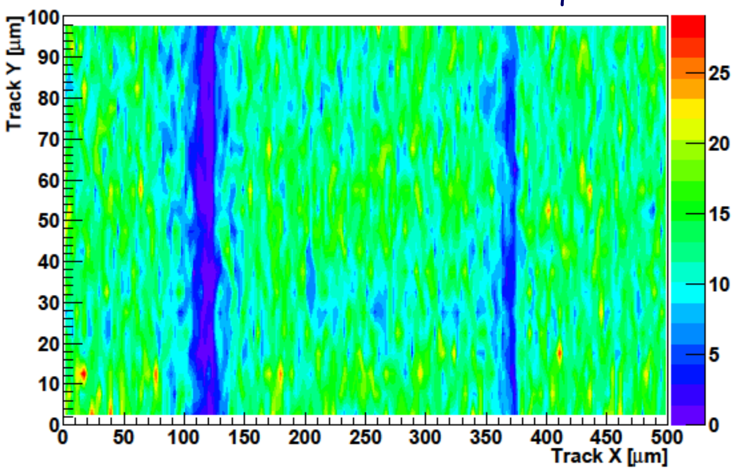
SCC40: Planar unirrad.



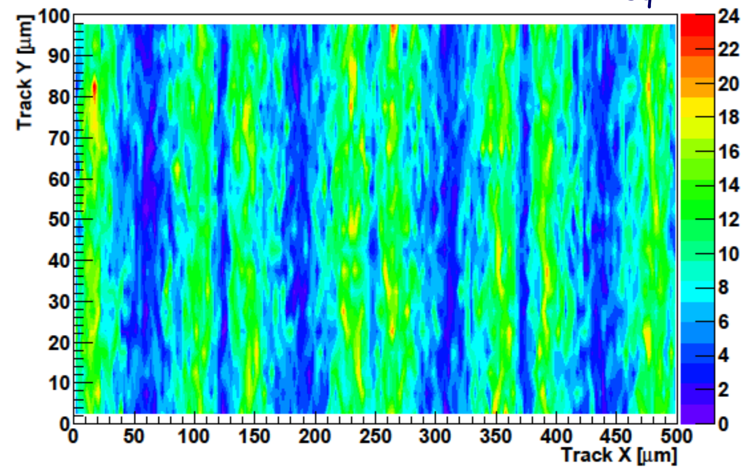
SCC55: 3D CNM unirrad.



SCC61: Planar 6×10^{15} $n_{eq}cm^{-2}$



SCC97: 3D CNM 6×10^{15} $n_{eq}cm^{-2}$



Probability for a hit to be shared with the neighbouring pixel [%]

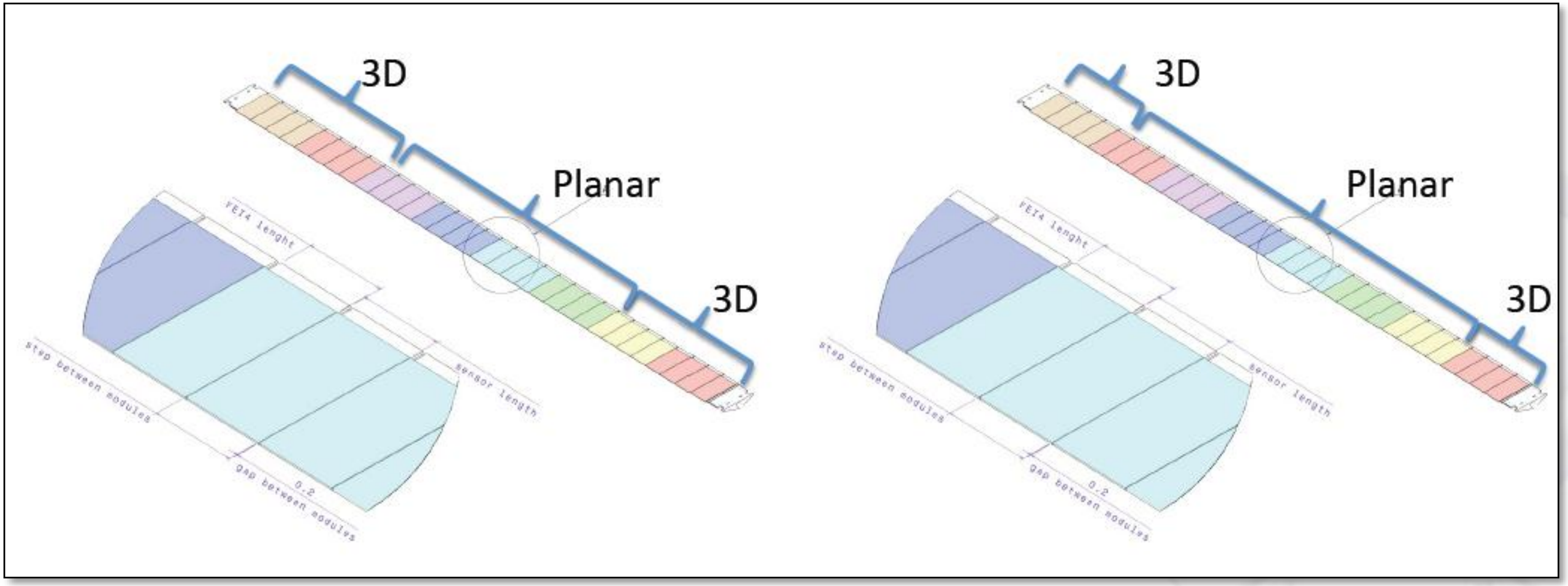
Sensor Review

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 (3 batches each from CNM and FBK)

➔ Baseline: 100% Planar sensors

➔ Option: 25% - 50% 3D sensors



Backup

June TB Summary

Sample	Fluence	ID	Al Board Temp (C)	HV(V)	I(μA)	Thers hold (e)	Tilt Angle	Tracking Efficiency (%)	Charge Sharing (%)
PPS 200μm Slim Edge	n/a	40	-14	-100		2700	0	99.9/99.9	15/73.3
3D-CNM	n/a	55	-14	-20	0.7	1200	0	99.5/99.6	24/37.9
PPS 200μm Slim Edge	p-5E15	60	-14	400/600/800	324/290/555	1300	0	Data unusable (too high rate in Telescope)	
PPS 200μm Slim Edge	p-6E15	61	-36	-1000	160	1400	15	96.9	43.9
		61	-26	-800	260	1400	15	93.7	28.9
		61	-36	-600	57	1400	15	86.7	7.0
PPS 250μm Slim Edge	n-3.8E15	LUB2	-36	-1000	74	1100	15	99.0	43.5
		LUB2	-26	-800	100	1100	15	98.7	9.7
		LUB2	-36	-600	28	1100	15	97.8	14.1
		LUB2	-26	-400	40	1100	15	95.7	12.2
3D-CNM	p-5E15	34	-14	-140	150	1300	0	96.1/97.5	9.4/9.9
3D-CNM	p-6E15	97	~-36	-140	30	2950	15	97.4	22.1
3D-CNM	n-5E15	82	~-36	-160	27	2700	15	89.4	11.3
3D-FBK	p-5E15	87	~-36	-140	35	2450	15	95.3	39.5
3D-FBK	p-2E15	90	~-36	-160	34	3100	15	99.8	59.9