The ATLAS Insertable B-layer project

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Outline

Motivation

IBL design

Modules Qualification

IBL production

Status of the current Pixel Detector

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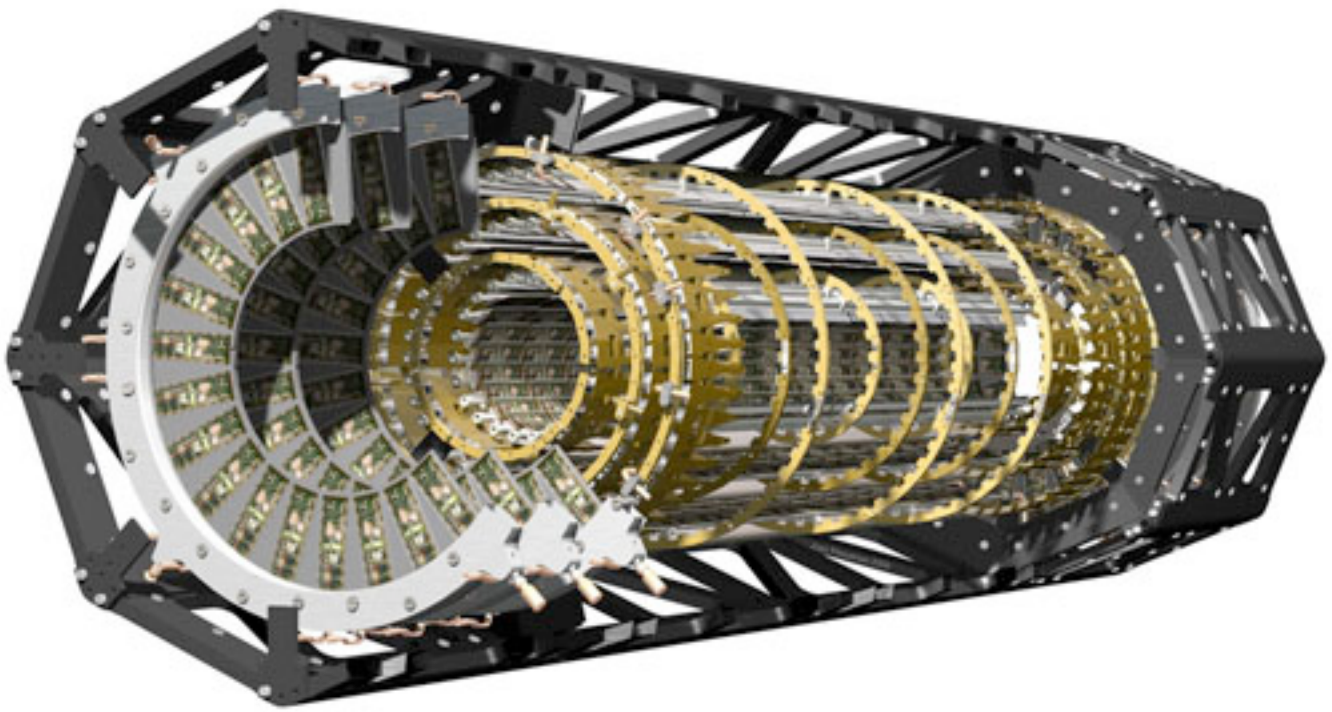
- Due to failures of modules in the Pixel layer:
  - ~2.5% of B-layer is dead
    - Limitation in b-tagging
- Luminosity effects:
  - The current Pixel detector
    - designed for $\mathcal{L} \sim 1\times10^{34}$ $cm^{-2}s^{-1}$
    - $\mathcal{L} \sim 2.2\times10^{34} cm^{-1}s^{-1}$ expected for 2020
    - High $\mathcal{L}$ produces event pileup:
      - redundancy of tracks needed: to control the fake rate
  - High occupancy:
    - readout inefficiencies, in particular B-layer
      - Limitation in b-tagging

Affected System (failure classes)	No of parts in system	No of part fail / % of dead pixels	
		Whole Pixel	B-layer only
Pixel	80 363 520	161 k / 0.20 %	15 k / 0.11 %
Front-end	27 904	42 / 0.15 %	9 / 0.20 %
Module	1 744	40 / 2.29 %	6 / 2.10 %
Opto-board	272	1 / 0.37 %	- / 0.00 %
Cooling loop (high leak)	88	(3) / 0.00 %	(0) / 0.00 %
Total dead pixels		**3.01 %**	**2.41 %**



IBL goals

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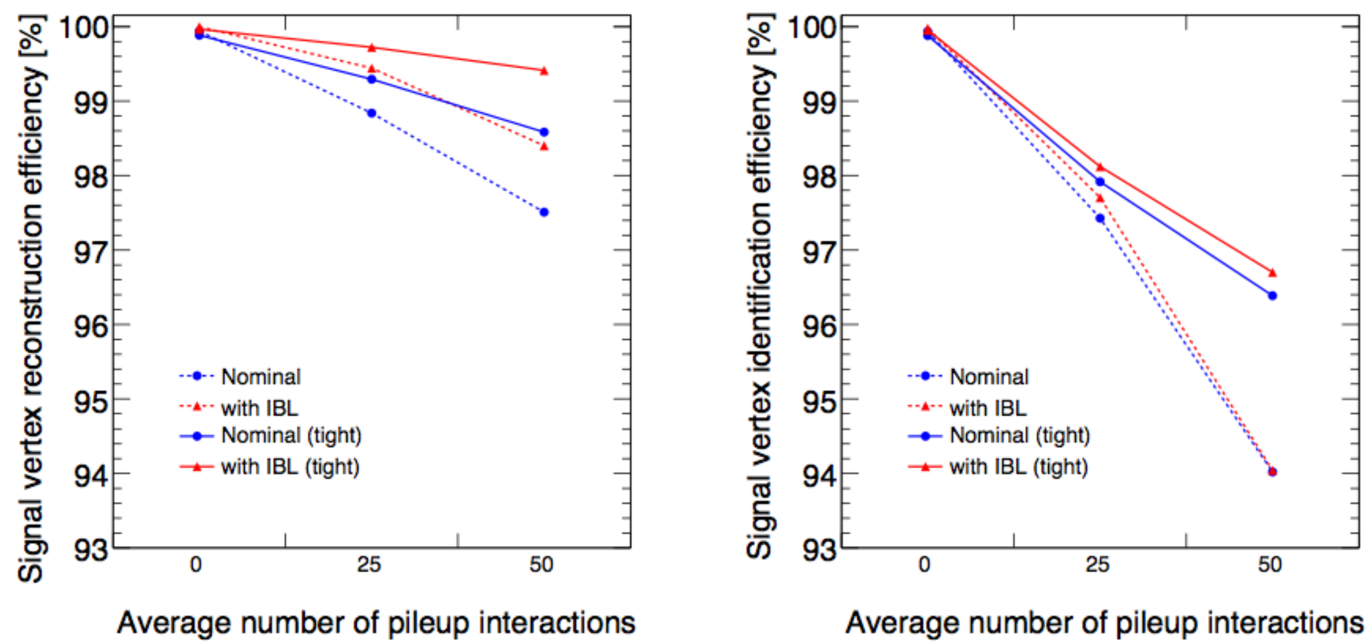
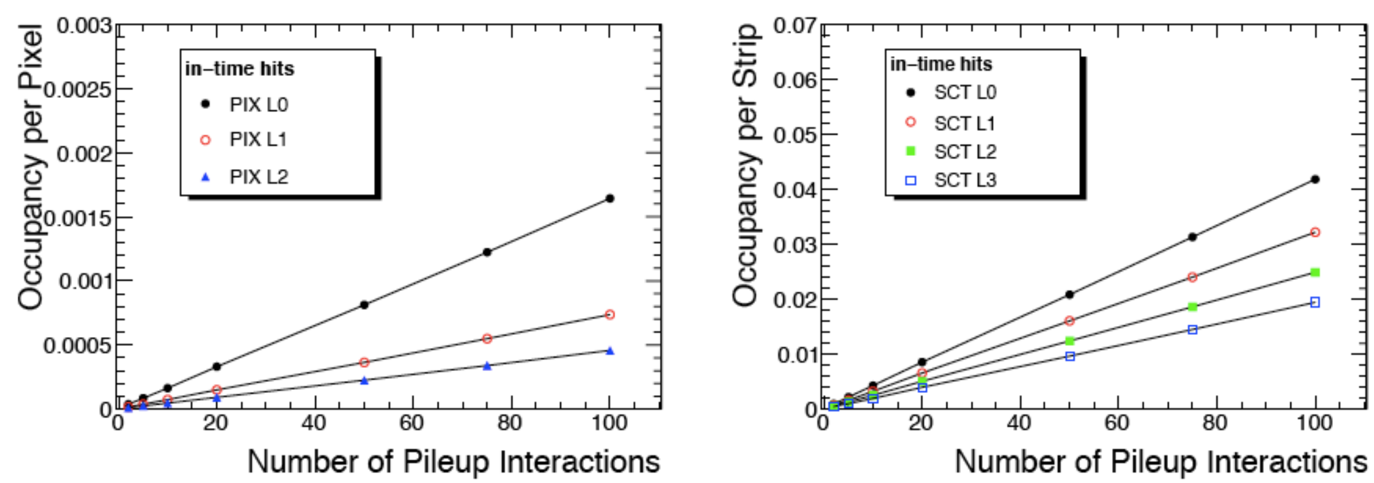
- IBL:
  - low occupancy reduces track fakes,
  - FE-I4 has higher bandwidth than existing readout.
- IBL: Innermost B-layer
  - 4^{th} layer of Pixels
    - redundancy to control the fake rate
    - to preserve tracking performance with respect to luminosity
    - improve b-tagging
  - designed to let ATLAS pixel cope $\mathcal{L} \sim 3\times10^{34}cm^{-2}s^{-1}$

Efficiency for primary vertex reconstruction in $t\bar{t}$



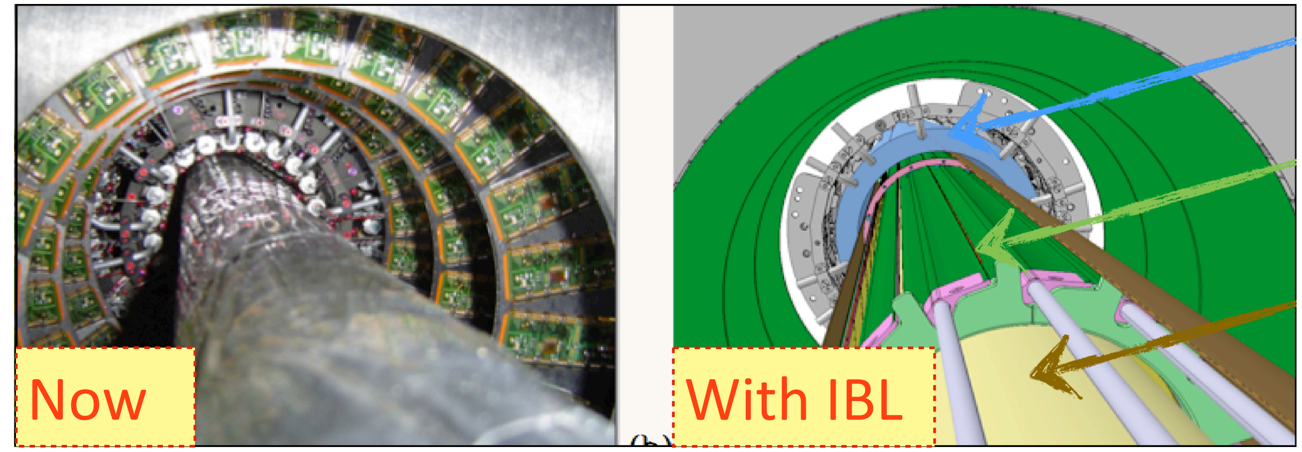
Pile-up vs Occupancy for the Current Inner Detector



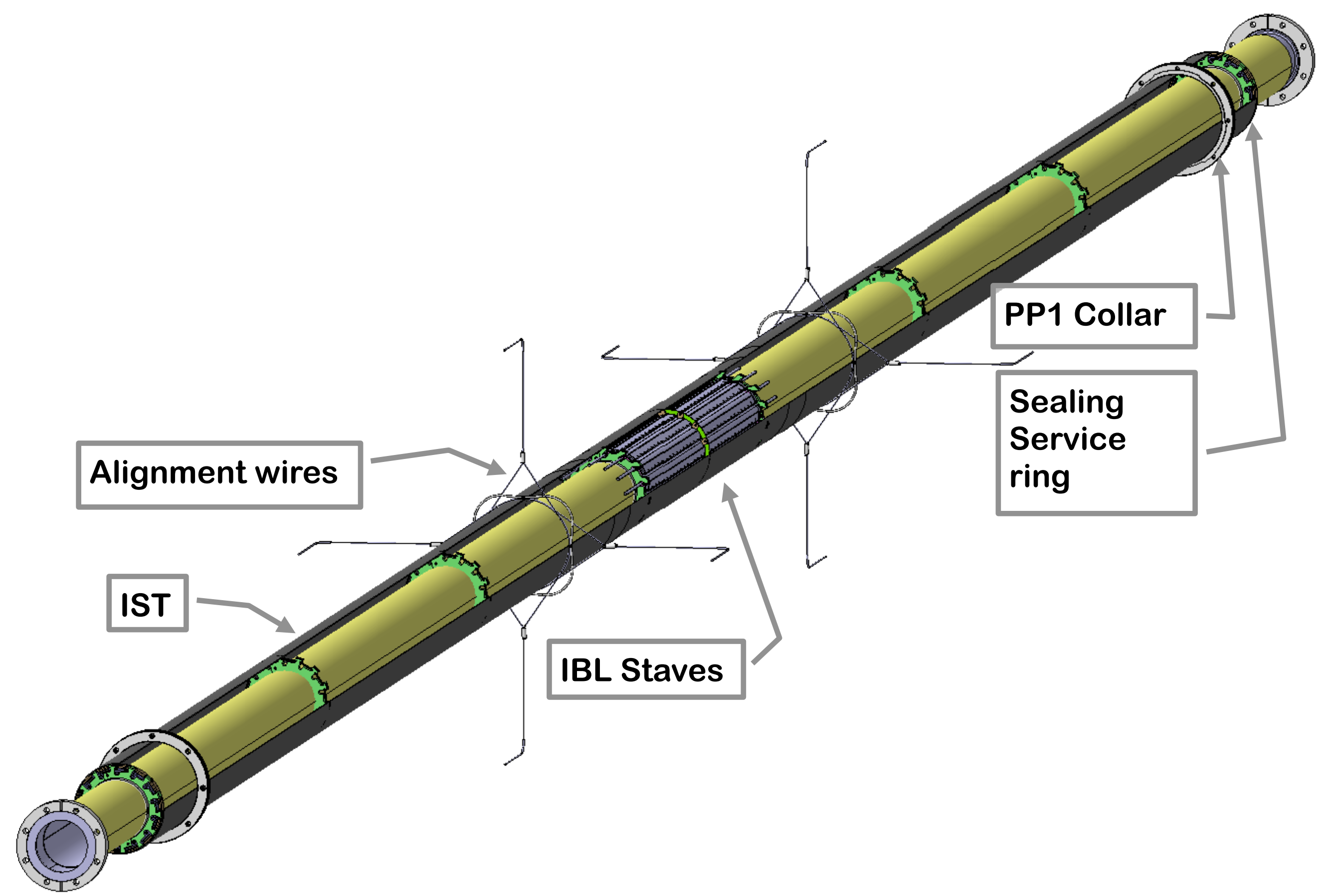
ATLAS EXPERIMENT

IBL detector

- The Insertable B-Layer (IBL)
  - a fourth layer added to the ATLAS Pixel detector between the new beam pipe and the current B-Layer

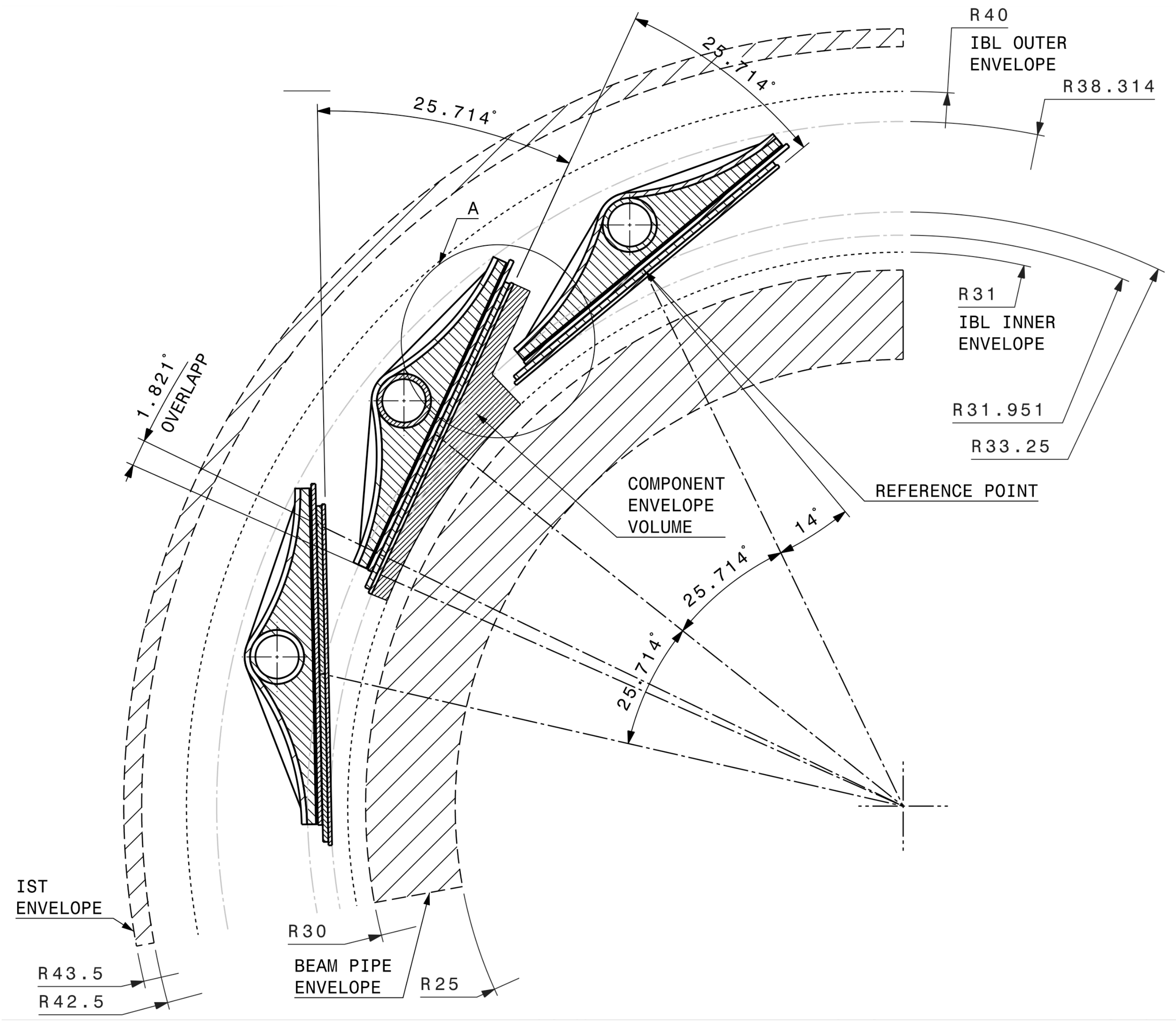


- IBL key Specs / Params
  - Stave structure (14 staves)
    - <R> = 33.25 mm
    - $|\eta|<2.58$ coverage
    - Staves overlap $\Delta\phi = 1.8°$
    - Staves tilted ~14°
  - CO_2 cooling, T < -30ºC @ 0.2 W/cm2
  - X/X_0 = 1.9 % (B-layer is 2.7 %)
  - 50 µm x 250 µm pixels
  - 20 FE-I4 modules per stave
    - Double Chip and Single Chip modules



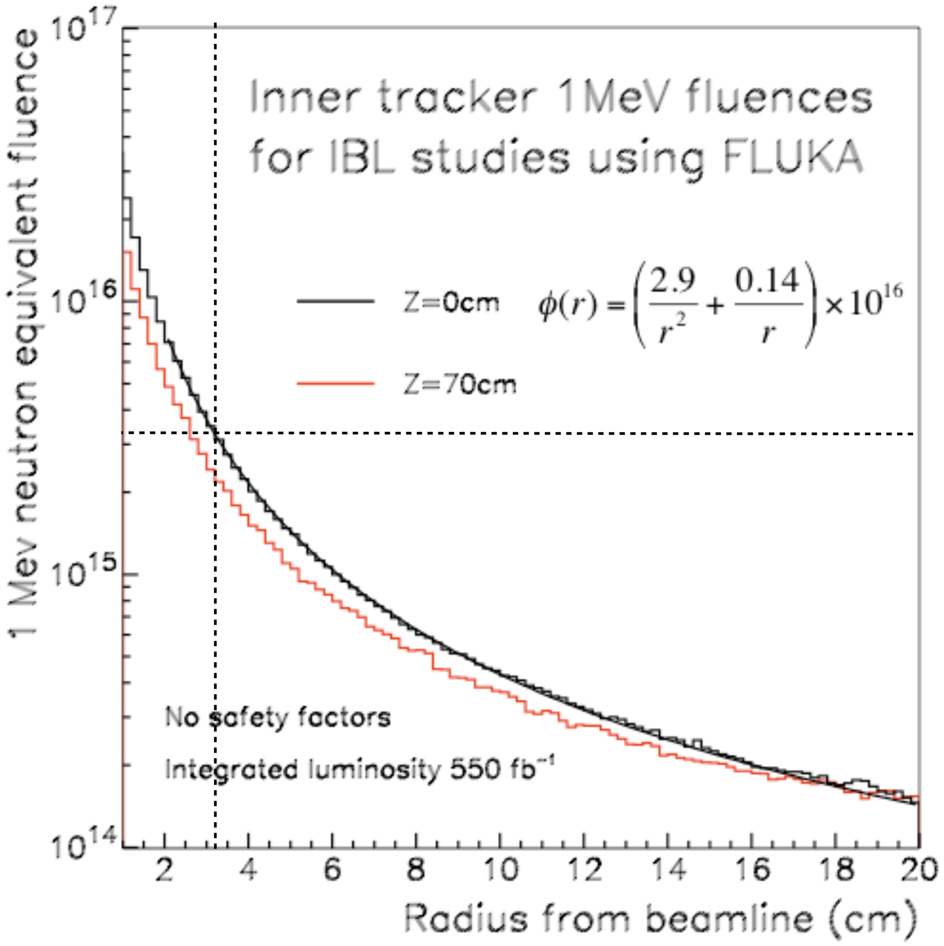
IBL design

- Experience gained from failures in present Pixels leads to improved design for IBL.
  - Titanium pipes: corrosion resistant.
  - Permanent pipe joints inside the detector: avoid leakage at fittings.
  - Move opto-boards to ID endplate: more easily serviceable site.
- Beam-pipe reduction:
  - Inner R: 29 → 25 mm
- Very tight clearance:
  - "Hermetic" to straight tracks in Φ (1.8º overlap)
  - No overlap in Z: minimize gap between sensor active area.
- Material budget:
  - Stave, el.serv. Module: 1.16 % X0
  - IBL Sup.Tube (IST): 0.28 % X0



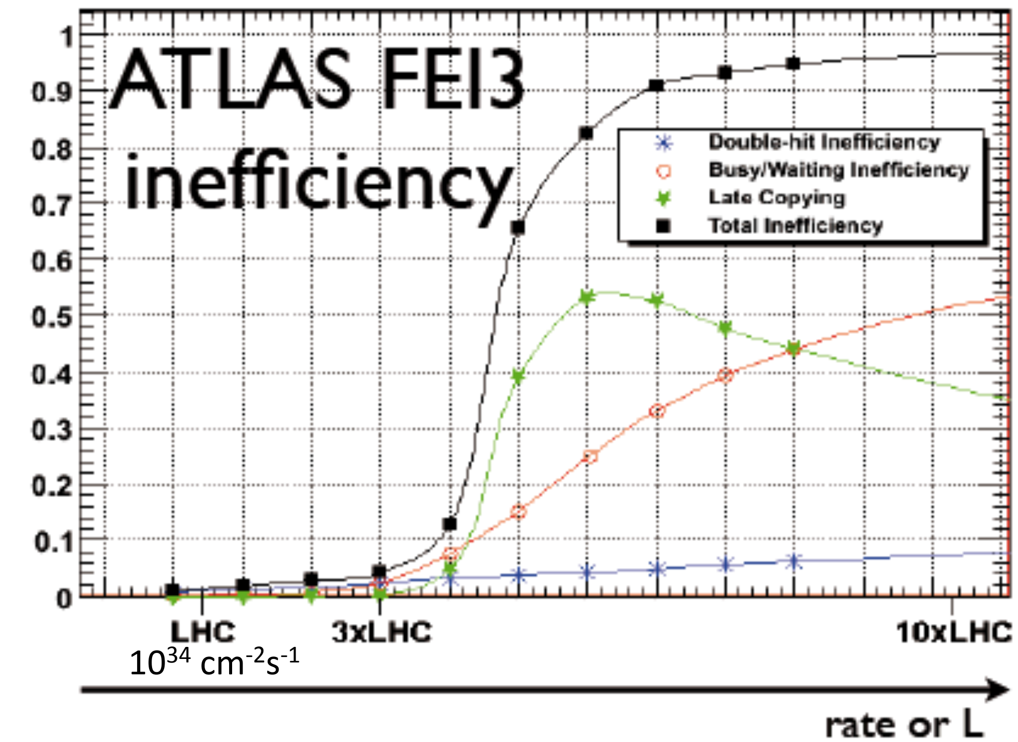
Radiation and Operation of IBL

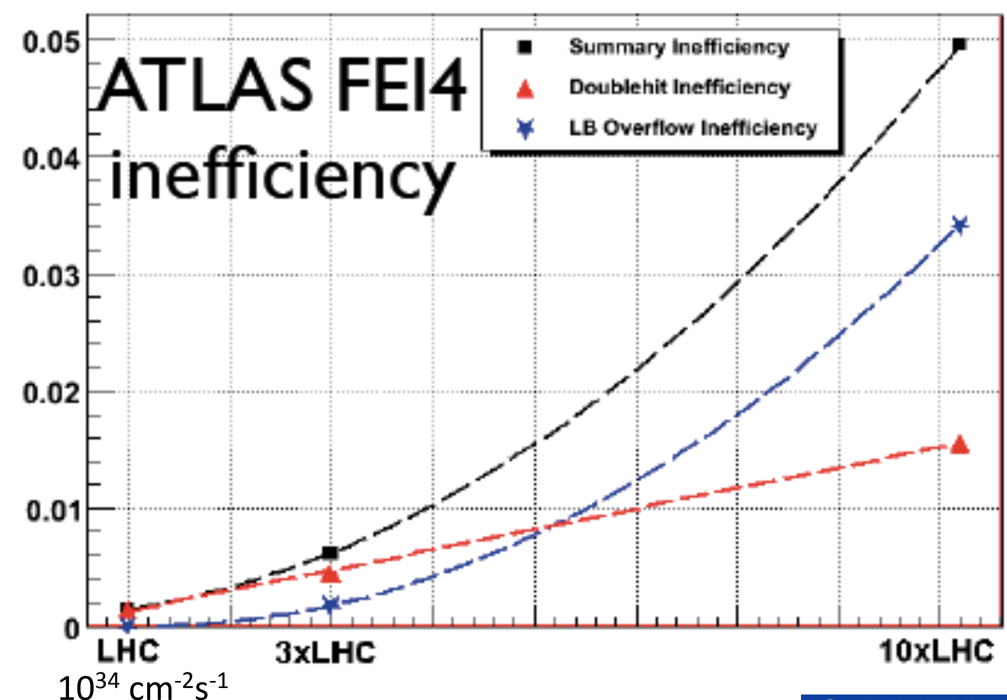
- Large radiation doses
  - 340 fb^{-1} expected in 2020:
    - current Pixel qualified for 730fb^{-1}
- IBL:
  - Simulation w/ FLUKA after 340 fb^{-1}
    - NIEL = 3.3×10^{15} n_{eq}/cm^2
    - TID = 160 MRad
  - IBL life dose requirement for 550 fb^{-1}
    - NIEL = 5×10^{15} n_{eq}/cm^2
    - TID = 250 MRad



FE technology

- ATLAS current pixel technology
  - FEI3: (IBM 250 nm CMOS)
    - inefficiency @ IBL design luminosity would be 5%
- IBL technology
  - FEI4 (IBM 130nm CMOS)
    - more efficient at such luminosity
    - smaller cell size 250x50 μm²
    - large single-chip (21x19 mm²)
    - array size: 80 (col) x 336 (row)
    - Fully qualified up to TID = 250 Mrad
    - Threshold: < 3000 e- | Dispersion: ~100 e- | Noise: < 300 e-
  - Hybryd technology
    - bump-bonded @ IZM (Berlin)



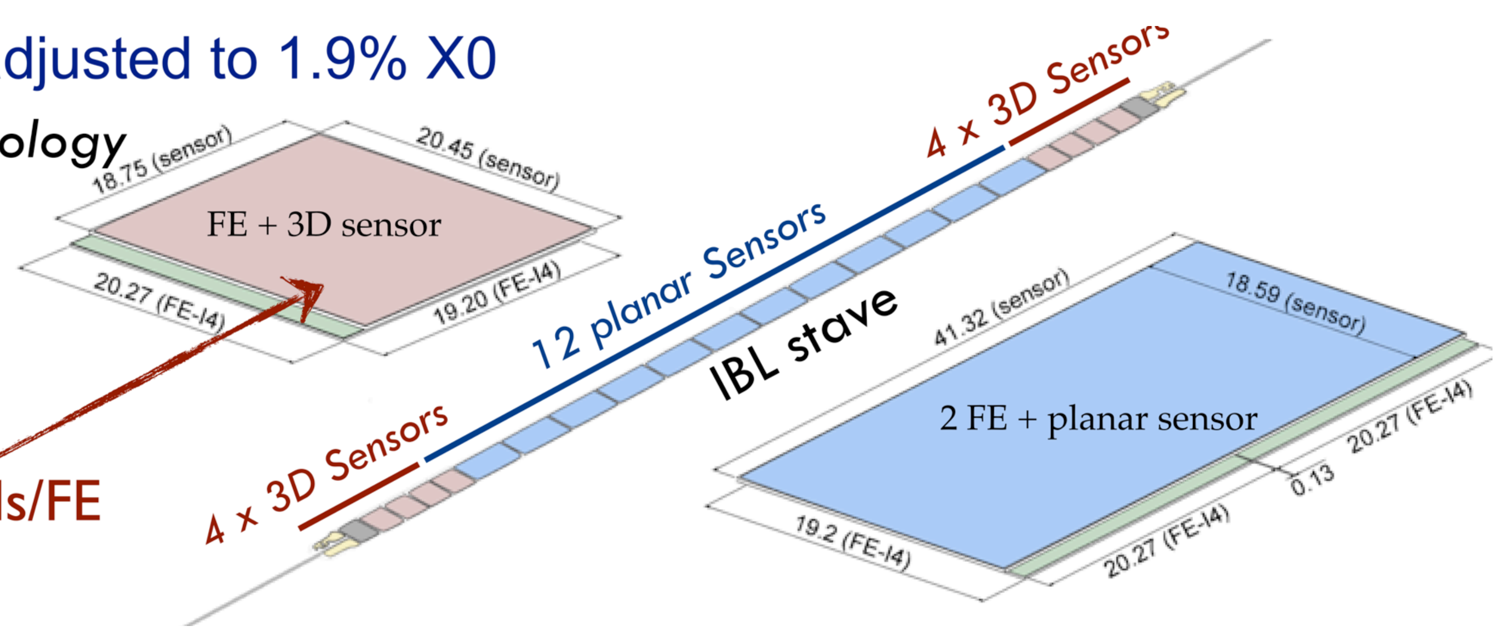


Sensor technologies: 3D

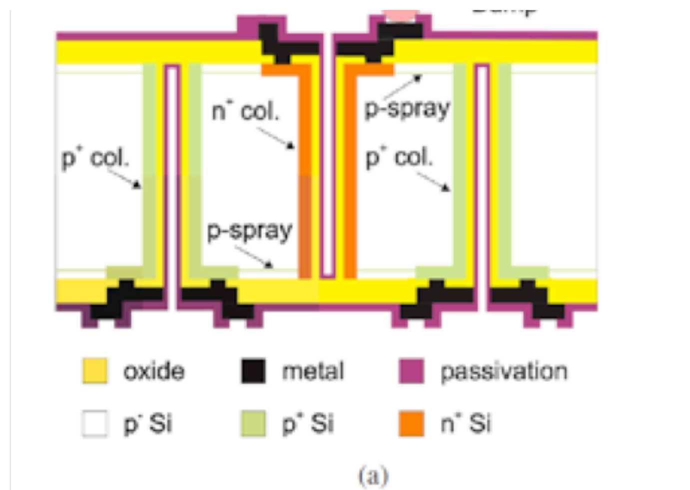
IBL material adjusted to 1.9% X0

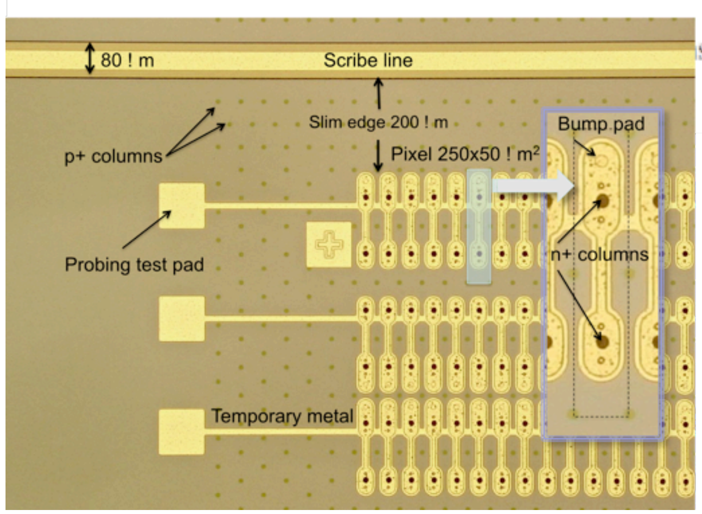
- *2 sensor technology*
- *New FE-I4*

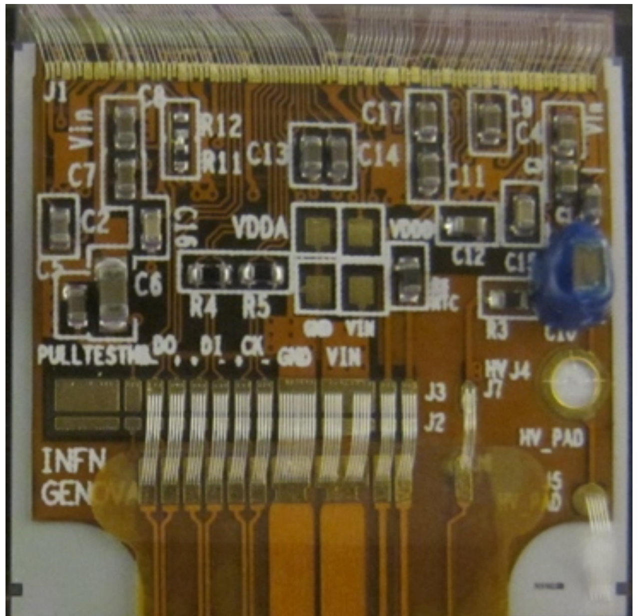
~30 000 pixels/FE



- 2 different Silicon Detectors Technologies
  - 3D: FBK & CNM
    - high |η| region
    - n in p technology
    - 230 µm thick, 2X2cm^2
    - electrodes pass through the bulk
    - operational voltage before irradiation: 20V
    - Single Chip Module
      - 1 sensor -> 1 FE







Single Chip dressed Module

3D after radiation

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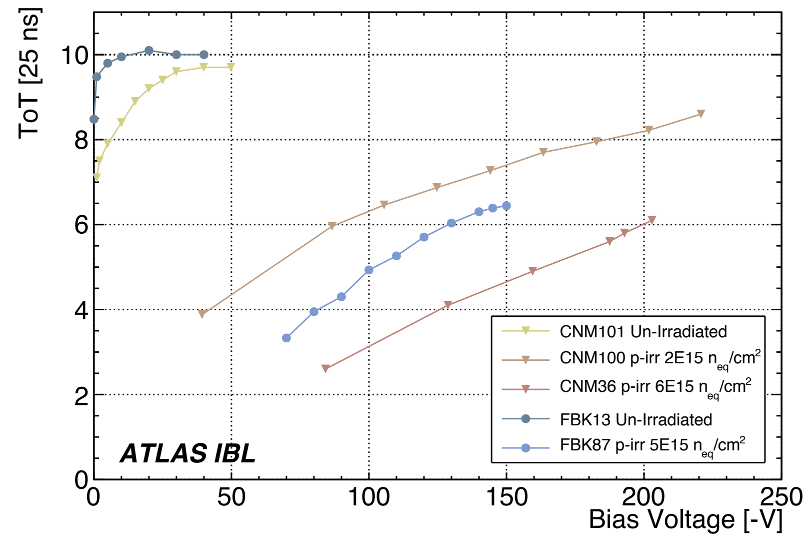
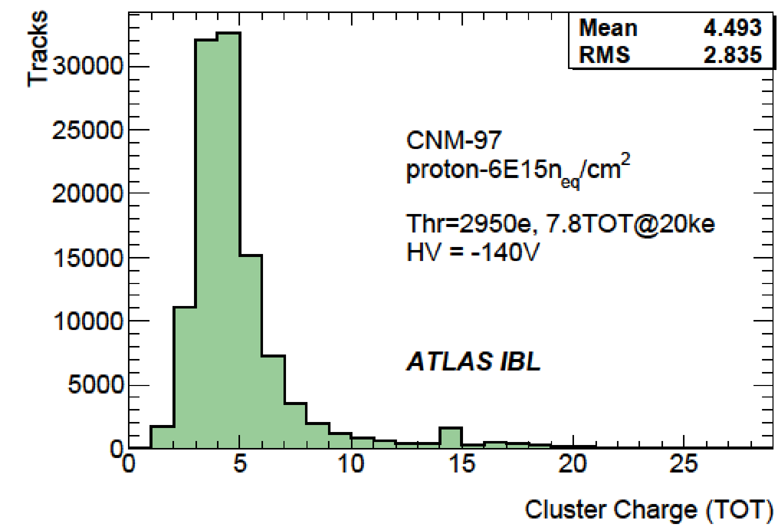
Charge collection

- 90% of ToT after Irr.
- Noise < 250e-
- Irradiation specs:
  - NIEL $5 \times 10^{15}\ n_{eq}/cm^2$

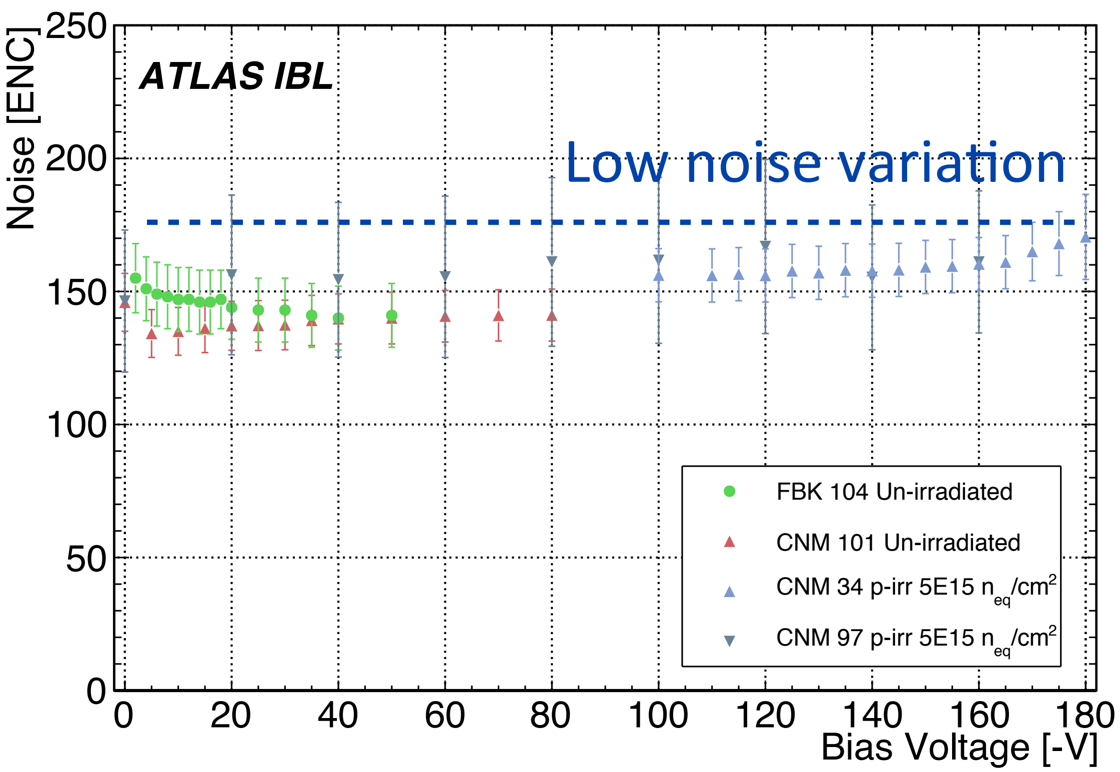
ToT Bf & Aft Ir.



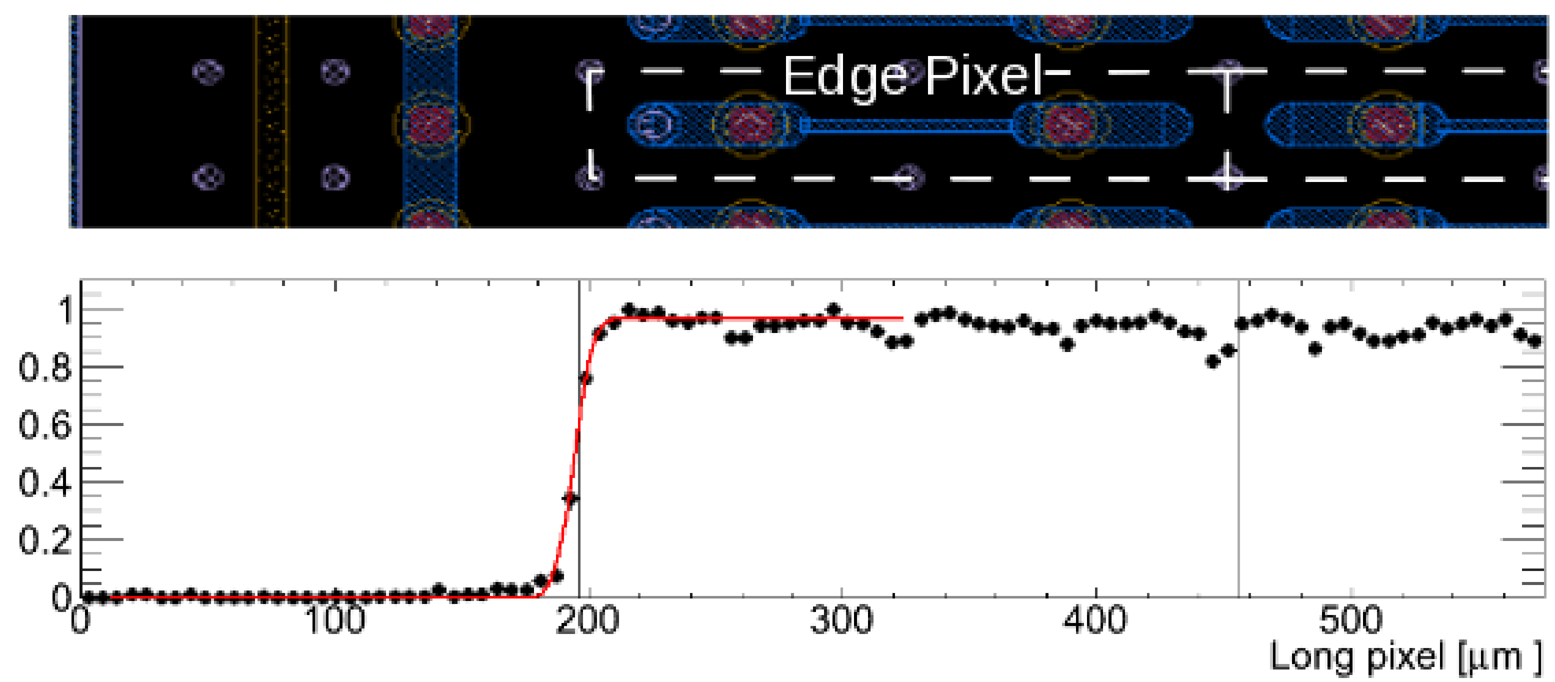
Cluster ToT distribution Aft Ir.



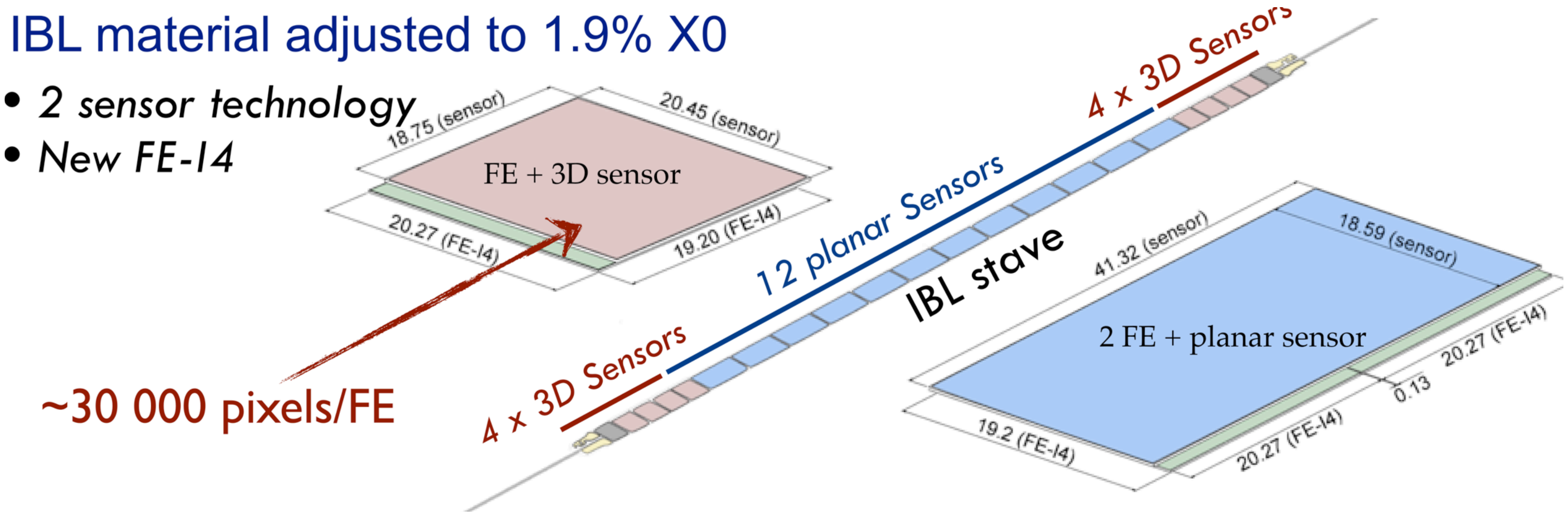
Noise Bf & Aft Ir.



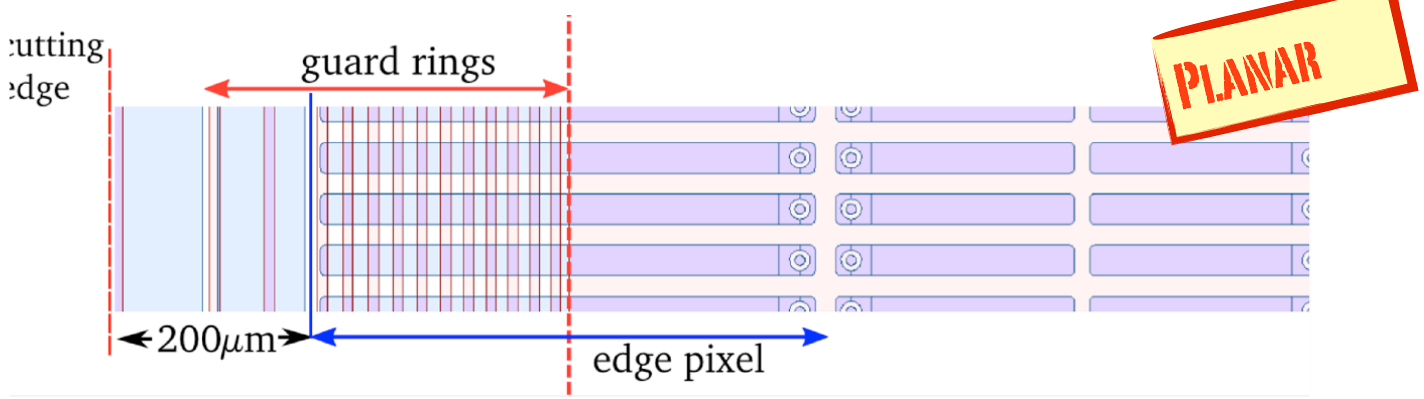
Active Area & Resolution Aft Ir.

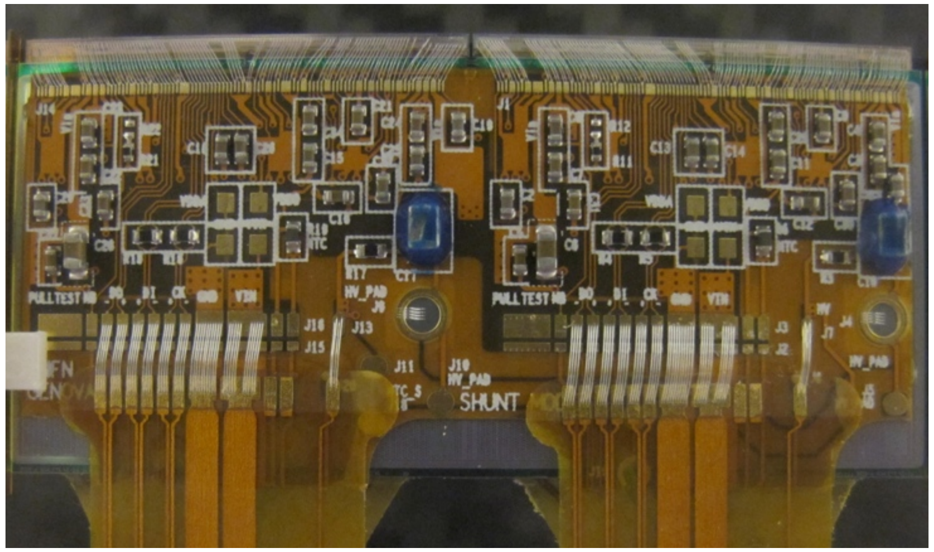


Sensor technologies: Planar



- 2 different Silicon Detectors Technologies
  - Planar: CiS
    - installed in low |η| region
    - 200 µm thick, 2x4cm^2
    - slim edges ->200µm inactive iregion
      - shifted guard rings (13) underneath active pixels
    - n in n technology
    - operational Voltage before irradiation: 80V
    - Double Chip Module:
      - 1 sensor -> 2 FE



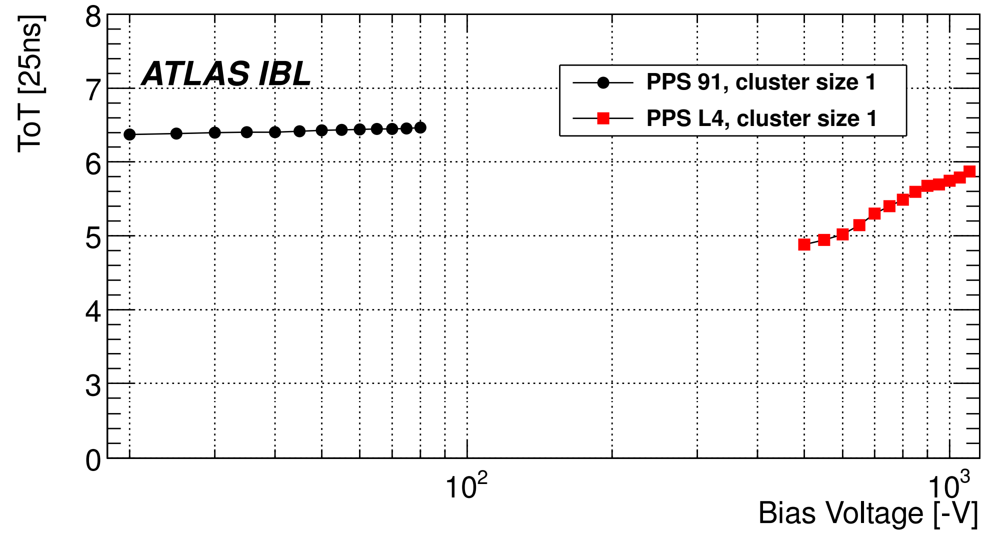


Planar after radiation

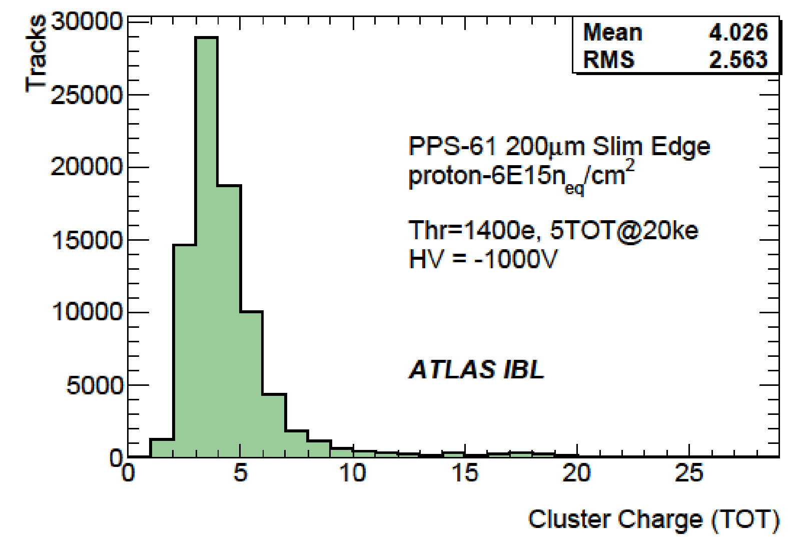
Charge collection

- 90% of ToT after Irr.
- Noise < 250e-
- Irradiation specs:
  - NIEL $5 \times 10^{15}\ n_{eq}/cm^2$

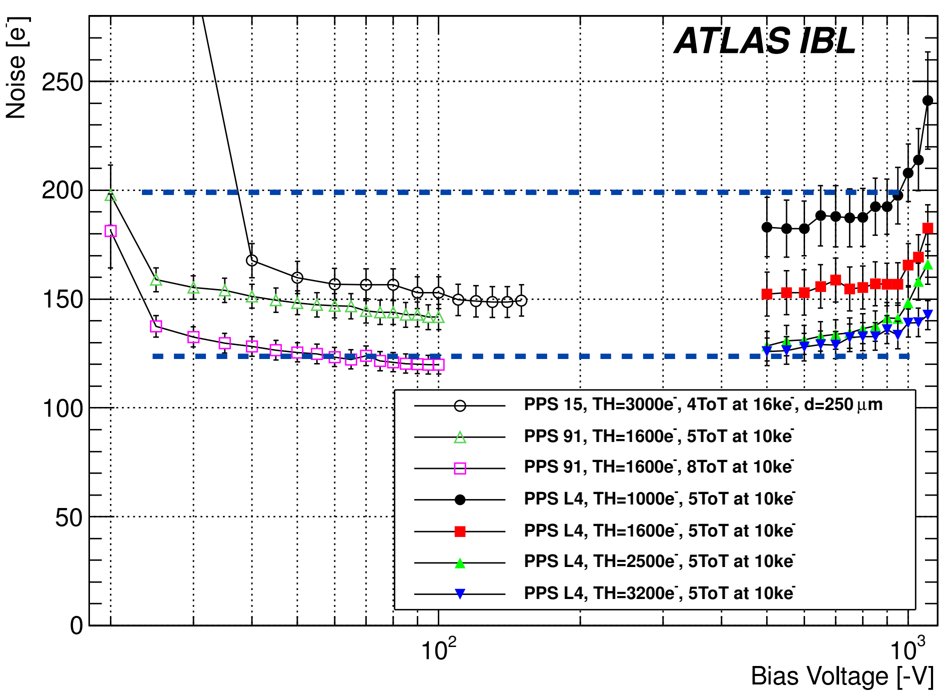
Mean ToT Bf & Aft Ir.



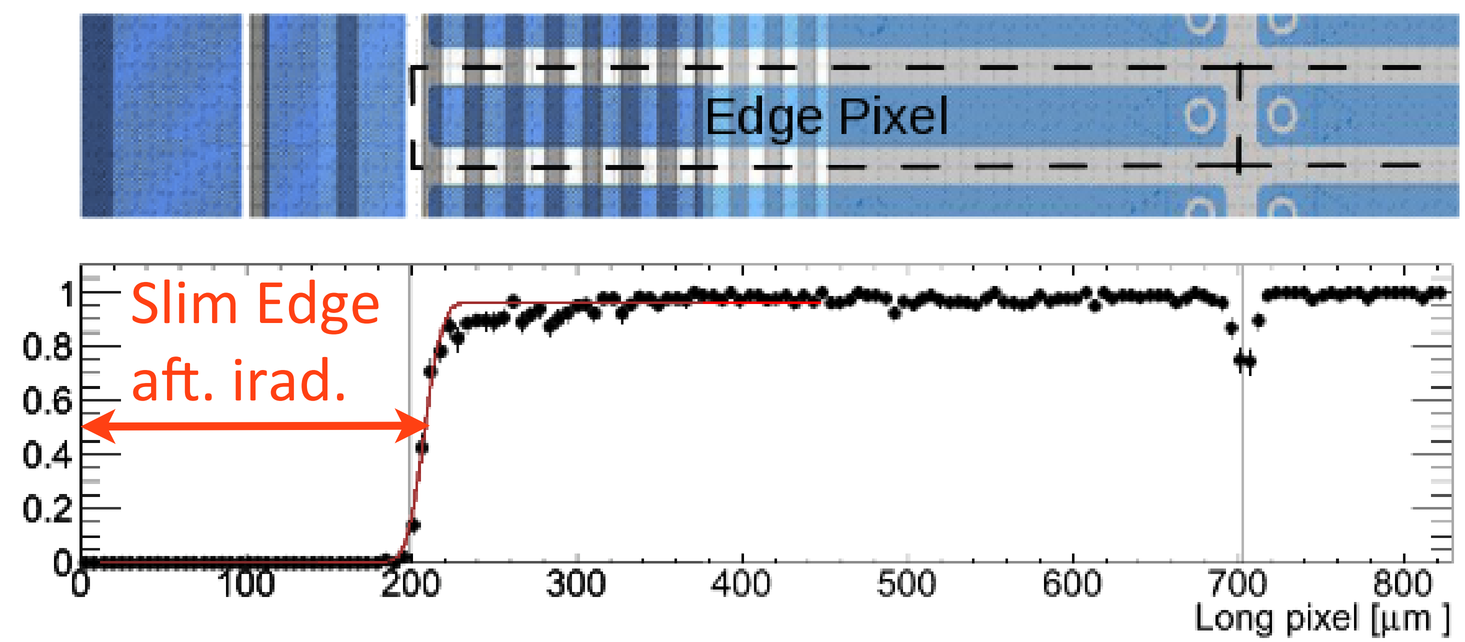
Cluster ToT distribution Aft Irr.



Noise Bf & Aft Ir.

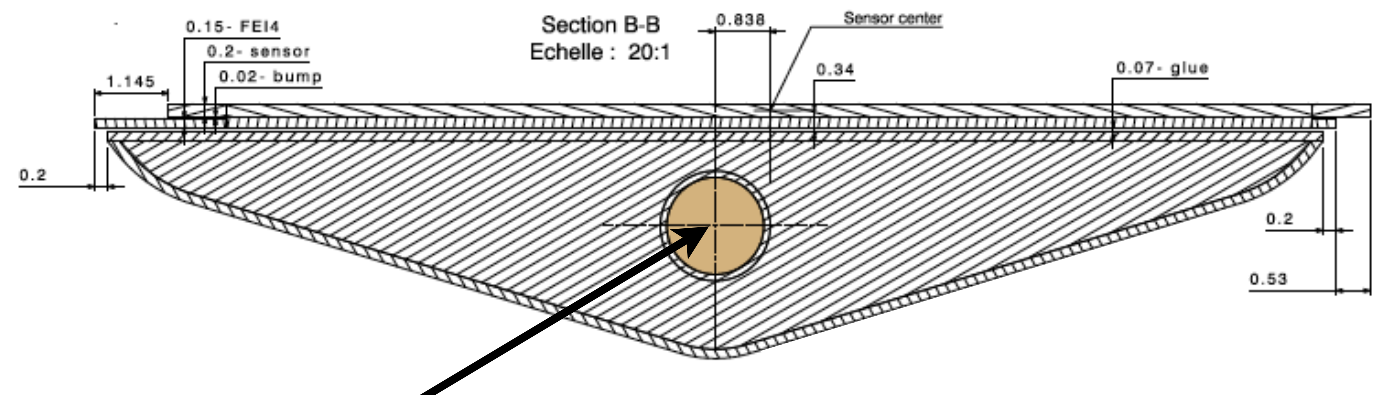


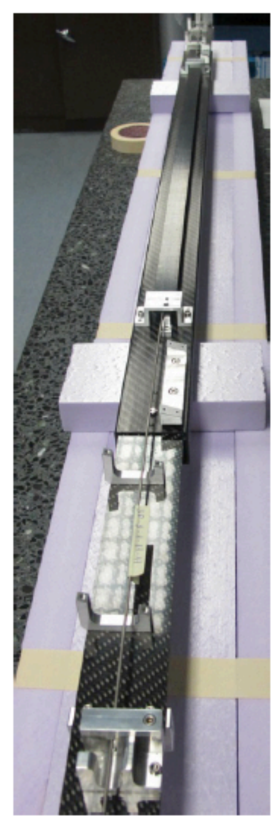
Active Area & Resolution Aft Ir.

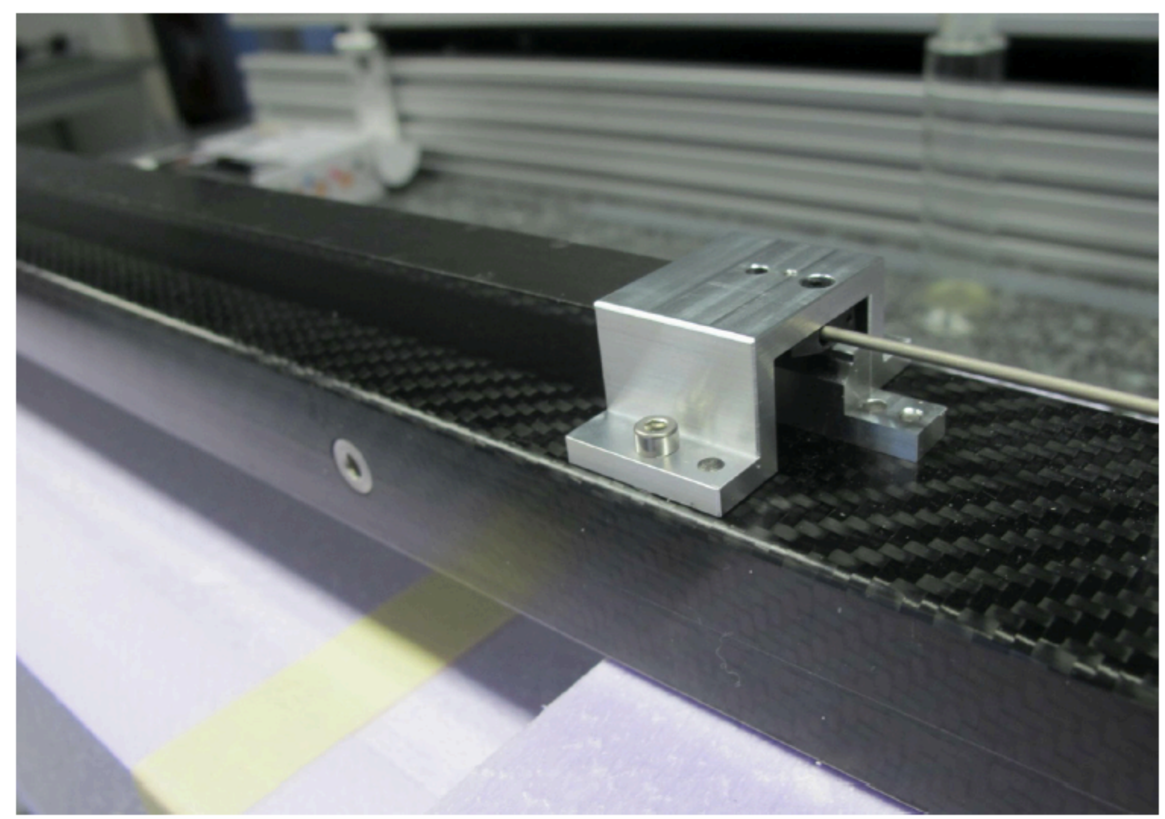


Bare Staves

- Carbon foam
  - heat exchange between the colling pipe and modules
- OMEGA
  - carbon fiber laminate bonded to the foam to provide stiffness to the structure YS-EX1515
- The pipe
  - is hard bonded, thermal contact provided by epoxy-loaded resins.



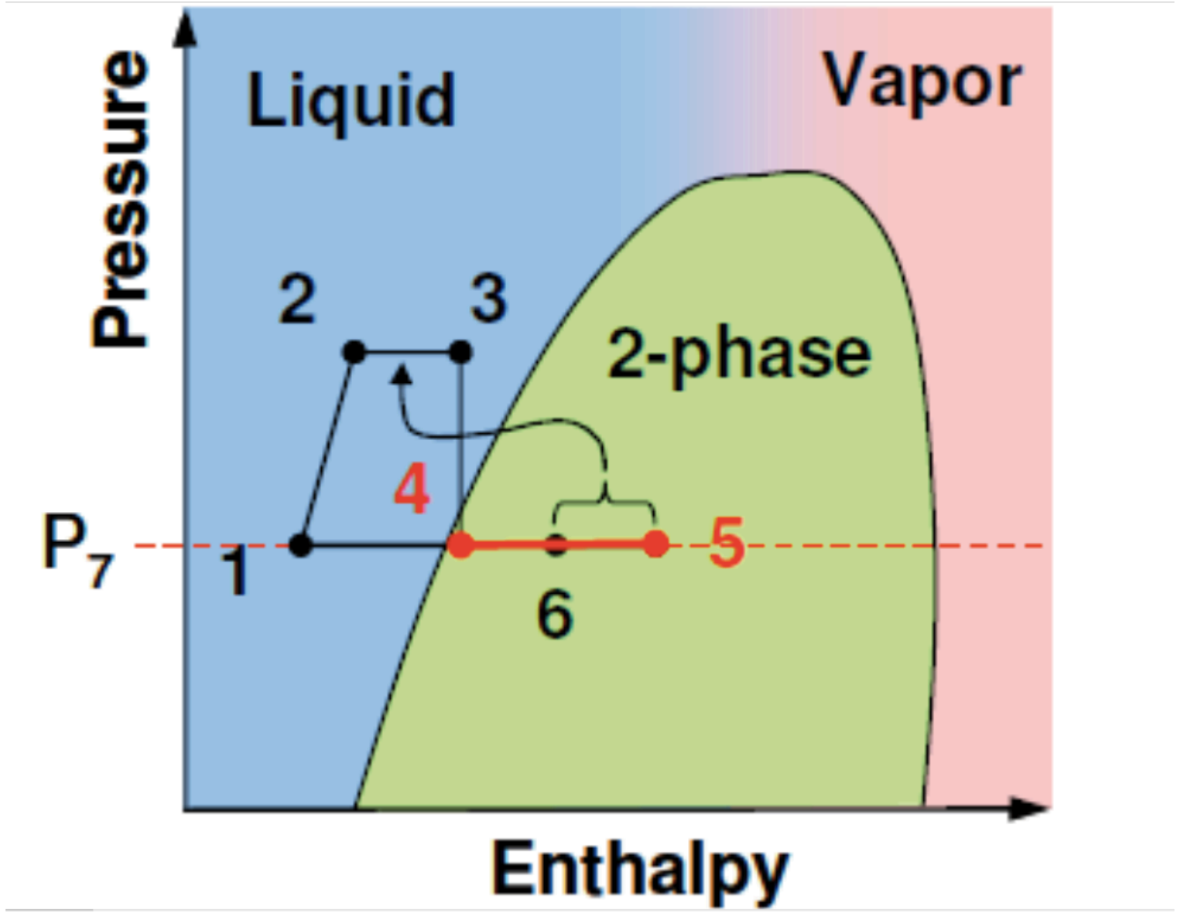




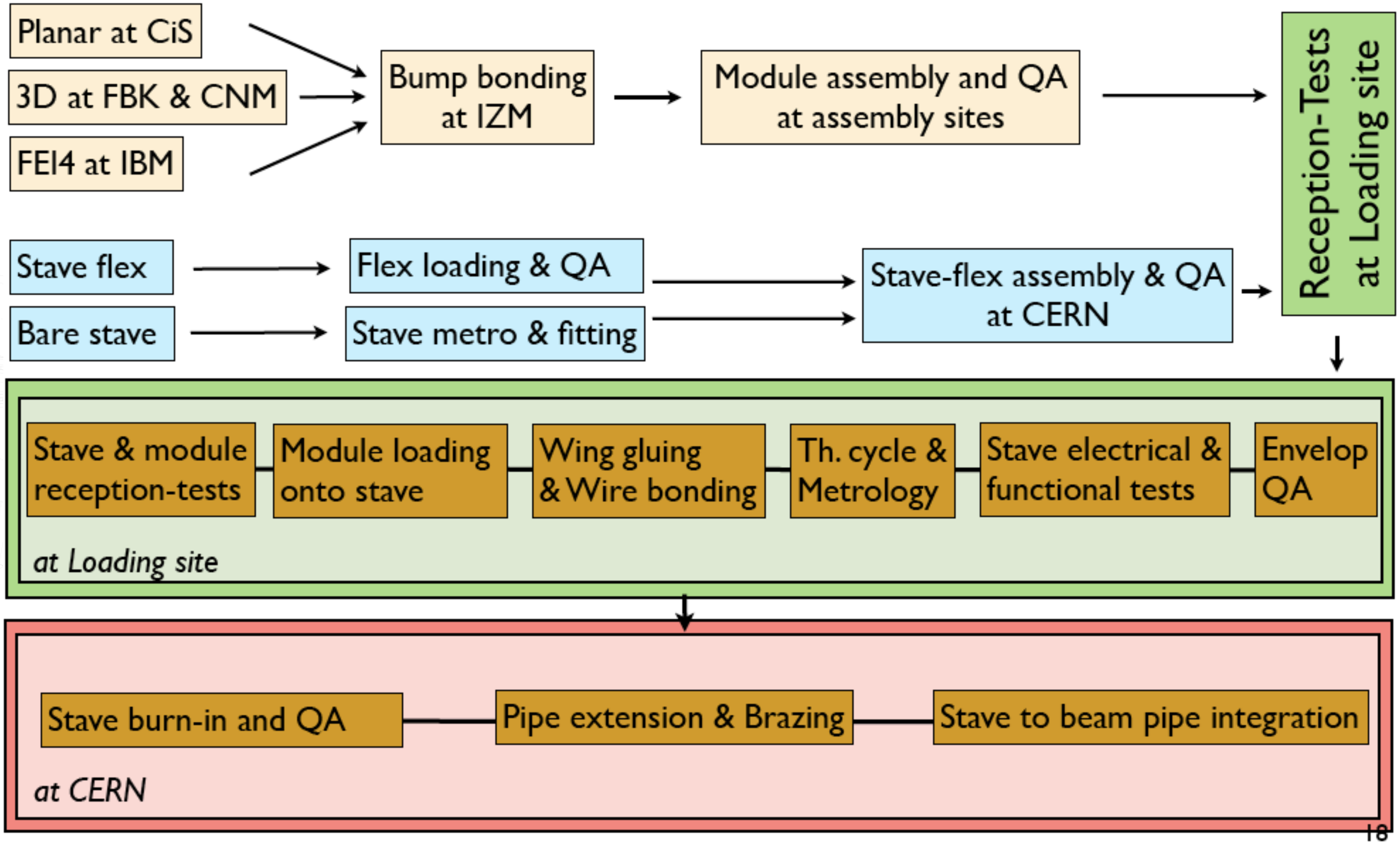
Cooling service

- CO_2 two phase system.
- 14 boiling channels w/ a nominal cooling power of 100W
  - The cooling power of the plant has been set to 2.0 kW
    - safety margin = 40%.
  - Maximum temperature -30°C
- Maximum temperature in the inlet of the channel
  - Thermal gradient alog the pipe
- The Maximum Design Pressure = 100 bar

Number of Loops	14
Evaporation T	-40 °C
MDP	100 bar
Nominal Power/Loop	100 W
Nominal Total Power	1400 W
Plant Design Cooling power	2000 W



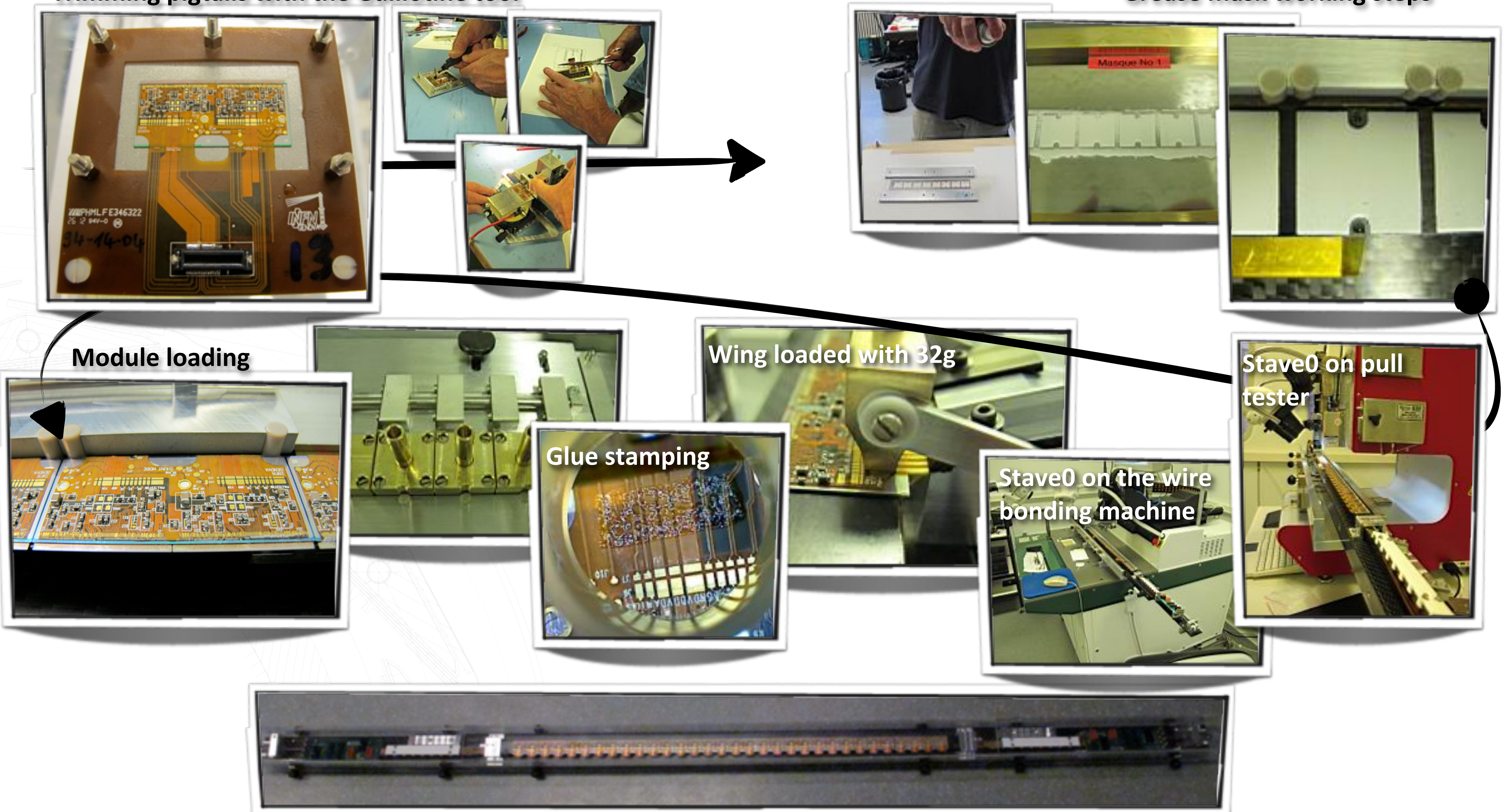
Production chain



IBL staves construction: procedure

Trimming pigtails with the Guillotine tool

Grease mask working steps



Stave QA at CERN

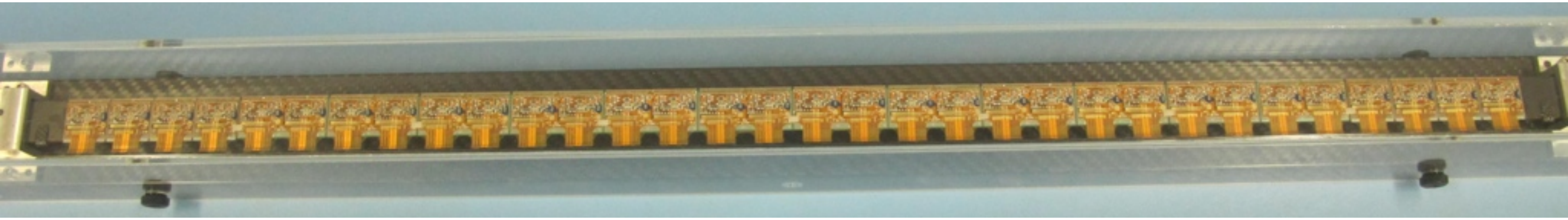
Warm tests @ 10°C

- Arrival of Stave
  - Optical inspection
  - Check powering
  - Check e-readout
  - FE configuration
- Reception Test
  - IV Scan
  - Digital, Analog and Threshold
  - ToT and X-talk scan
  - Noise Scan and short Source Scan

Cold tests @ -15°C

- Tuning
  - 3ke, 2.5ke, 2ke, 1.5 ke | 9 ToT @16ke
  - Noise Occupancy
- Pixel Analysis
  - Digital, Analog and Threshold scan
  - ToT, X-talk and Noise Scan
- Source Scan
  - Am 241 source
  - Sr 90 source
  - Cosmic with external trigger

Production status



- 18 staves planned
  - 14 for the detector
  - 2 as spares
  - 2 for the system test
- 12 production staves already
  - 9 staves under QA at CERN
  - 3 staves in Geneva ready for the delivery
- 6 more staves are coming in next weeks

Conclusions

- Techologies qualified for 550fb^{-1}
- 3D sensor technology for the first time in LHC
- New FE for high peak luminosity
- Stave QA is on-going at CERN
- Production phase is almost over (12/18$_{(14+4)}$ staves)