ATLAS Tracker Upgrade: Silicon Strip Detectors and Modules for the SLHC

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Poster summary

This poster shows the R&D programmes that are underway to develop a new ATLAS Tracker for the upgrade of the LHC.
It is mainly focused on three issues:
- The current status of p-type silicon sensor development.
- The current status of module development work for both barrel and endcap.
- The integration of modules into Staves.

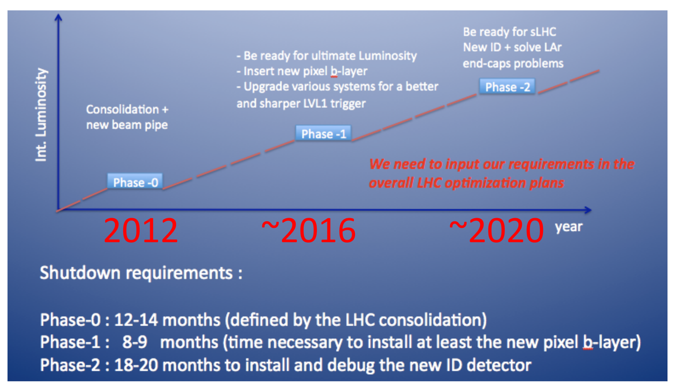
INTRODUCTION

While the CERN Large Hadron Collider (LHC) has been taking data since November 2009, a machine upgrade to achieve a much higher luminosity is being developed:

$$\text{Super-LHC (SLHC)} \rightarrow L_{peak} = 10^{35}\ cm^{-2}\ s^{-1}$$

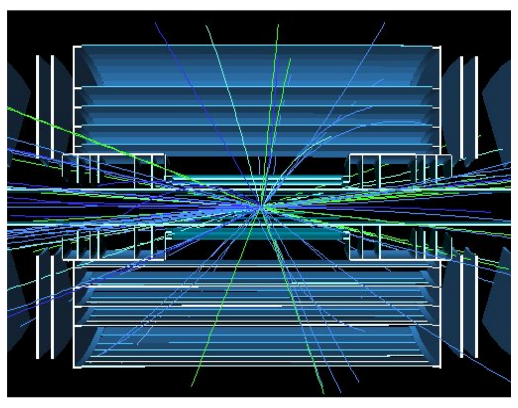
Starting around 2020, we aim to record 300 fb^{-1} of good quality data after the start-up of the SLHC.

The LHC luminosity upgrade is expected to go in two stages:
- Phase 1 (~2015): Upgrade to configuration which can eventually deliver $3x10^{34}\ cm^{-2}\ s^{-1}$.
- Phase 2 (~2020): Upgrade to enable Super-LHC (SLHC) luminosity of $10^{35}\ cm^{-2}\ s^{-1}$.

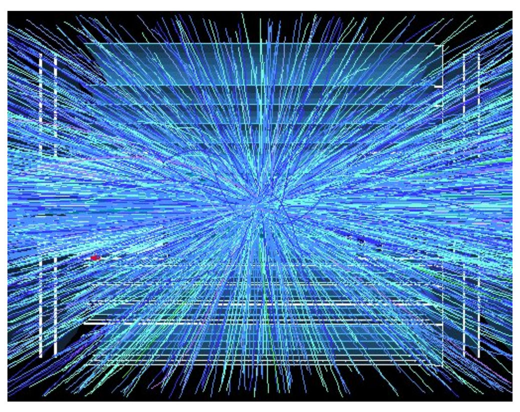


As radiation damage scales with integrated luminosity, the particle physics experiments at the SLHC will need to be equipped with a new generation of radiation hard detectors. This is of particular importance for the semiconductor tracking detectors located close to the interaction region, where the highest radiation dose occurs.

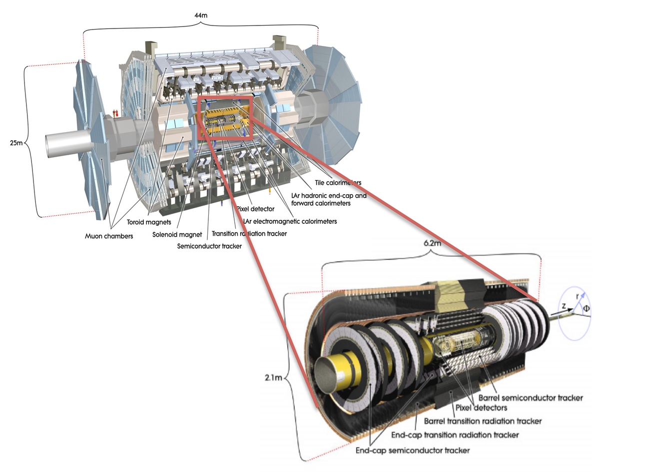
The ATLAS Experiment will require a new particle tracking system for SLHC operation. In order to cope with the increase in pile-up events by about an order of magnitude at the higher luminosity, a silicon detector with enhanced radiation hardness is being developed.



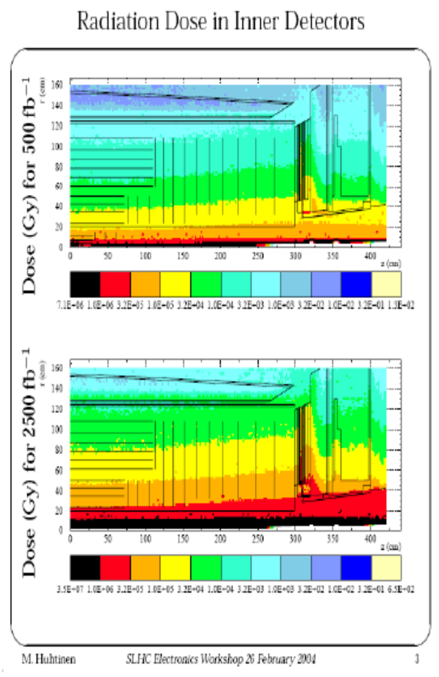
Inner tracker with 5 collisions, corresponding to a luminosity around $0.2 \times 10^{34}\ cm^{-2}\ s^{-1}$



Inner tracker with 400 collisions, corresponding to a luminosity around $10 \times 10^{34}\ cm^{-2}\ s^{-1}$
(plots from Abdel Abdesselam, June 2010)



Tracker Upgrade



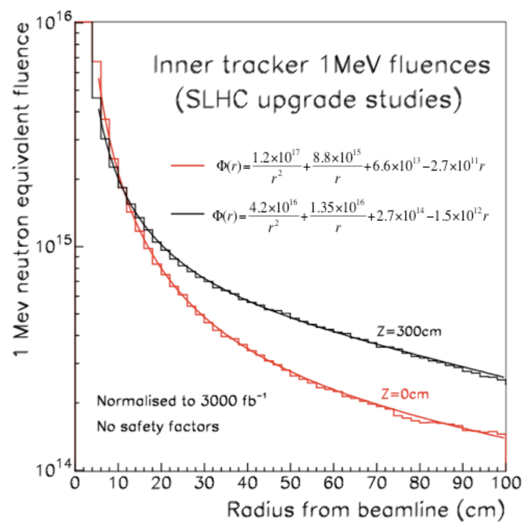
The new silicon strip detector will use significantly shorter strips than the current Semiconductor Tracker (SCT) in order to minimize the occupancy. As the increased luminosity will imply a corresponding increase in radiation dose, the classic concept of p-in-n silicon micro-strip detectors as used in the current ATLAS SCT needs to be abandoned for the sLHC.

These p-in-n detectors (p-strips processed into n-type silicon) are just sufficient for the radiation levels of the present LHC, and would be quickly rendered useless by the large SLHC flux of up to **10^{16} Neutron equivalent per cm^2**.

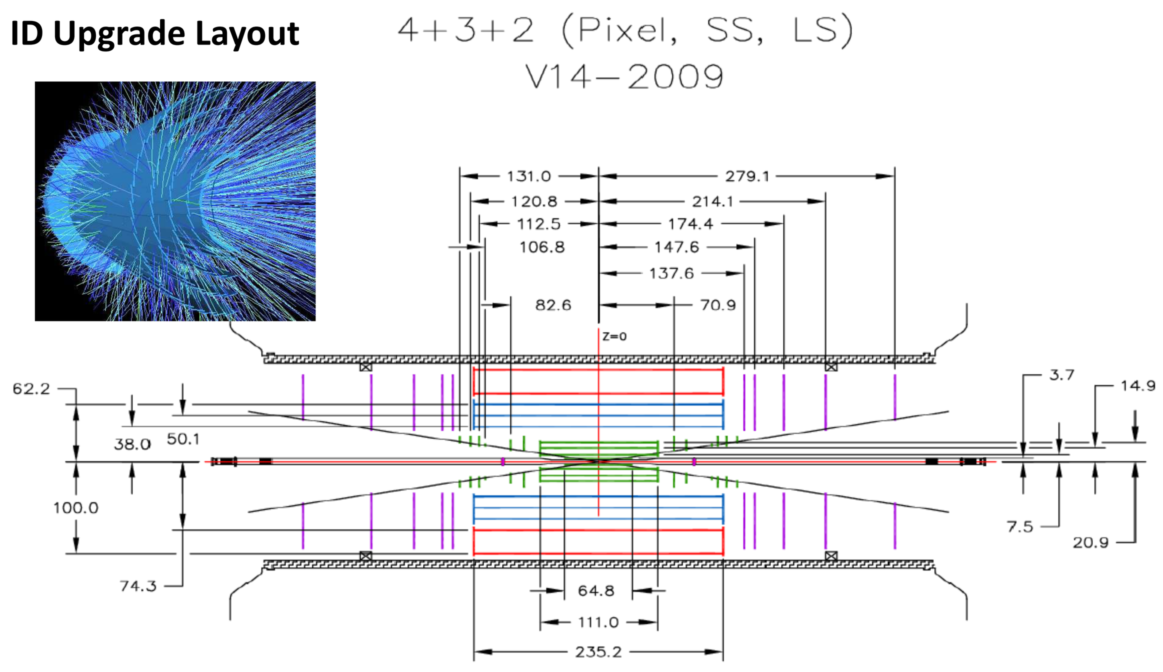
A new generation of extremely radiation hard silicon detectors is required to remain operational up to the **integrated luminosity of 3000fb^{-1}**.

Radiation Hard Silicon Detectors

- New sensor material: p-type silicon
- 3D technology (for the B-layer)
- Alternative module concepts.
- New front-end electronics and read-out concept



ID Upgrade Layout



Location	1 MeV n. eq. (cm^{-2})	Protons	Pions	Neutrons
Strip barrel 1 (SS) (r=38 cm; z=0 cm)	4.9e+14	7.6%	32%	60.4%
(r=38 cm; z=117 cm)	6.0e+14	11.4%	27.4%	61.2%
Strip barrel 4 (LS) (r=74.3 cm; z=0 cm)	2.3e+14	7.6%	20.4%	72%
(r=74.3 cm; z=117 cm)	2.8e+14	9%	17.2%	73.8%
Strip Disc 1 (z=137.1,Rinner=33.6)	7.1e+14	11.2%	30.4%	58.4%
Strip Disc 5 (z=279.1,Rinner=44.4)	6.7e+14	10%	22%	68%

All Silicon ID:

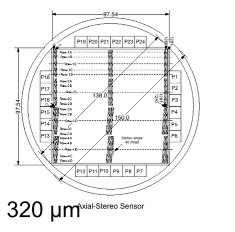
- 4 pixel layers.
- 5 barrel layers @ 38, 49, 60, 75, and 95cm:
  →3 inner layers: Short strips (2.4cm).
  →2 outer layers: Long strips (9.7cm).
- The 3 outer layers + the end-caps (5 discs per end-cap) will replace the TRT.
- The design is expected to keep the occupancy below 1.6% at the innermost radius that it is adequate.
- 40M channels in Si strips (6M in the current detector)
- 160M channels in Si pixel (80M in the current detector)

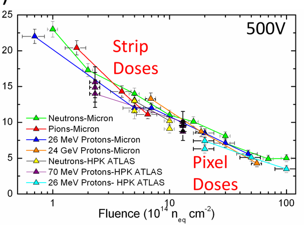
Sensor Radiation Tolerance: ATLAS07 sensors

N-in-p Planar FZ Irradiations

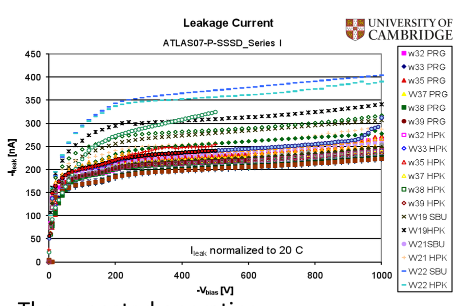
- 6 inch (150 mm) wafers
  - FZ1<100>(~6.7k Ωcm)
  - FZ2<100>(~6.2k Ωcm)
- P-stop and p-stop+p-spray isolation
- pitch 74.5 μm, 1280 strips, thickness 320 μm
- Miniature sensors (1cm x 1cm)
  →For irradiation studies.

ATLAS institutes involved:
- IFIC- Valencia
- JSI- Ljubljana
- Uni. Liverpool
- Uni. Tsukuba/ KEK
- UC- Santa Cruz



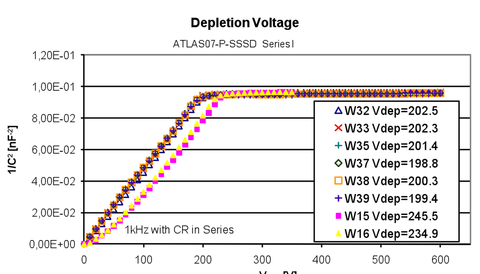


- Full size prototype sensors (9.75 cm x 9.75 cm).



The expected operating depletion voltage at 3000fb^{-1} is 500V

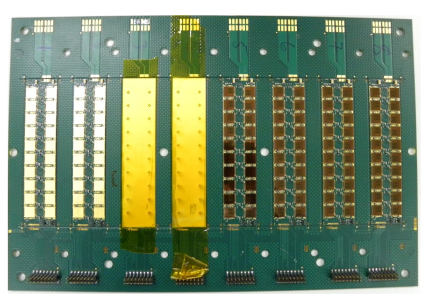
HAMAMATSU Japan

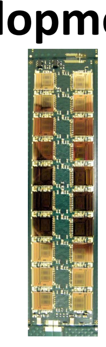


Good performance large area sensors being manufactured by Hamamatsu

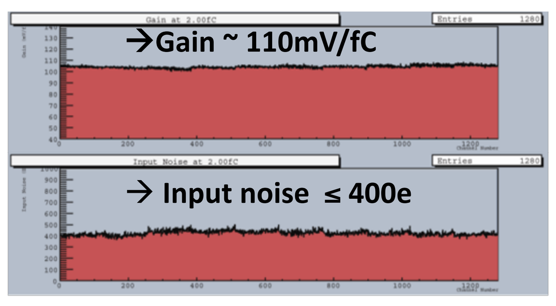
Module R&D

Single-sided module development

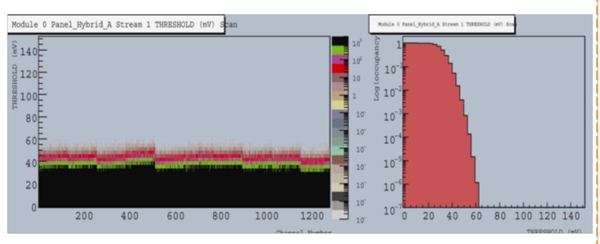




- Panel dimensions: 300mm x 200m
- Hybrid dimensions: 24mm x 107.6mm
- Hybrids + ASICs are electrically tested on panel (20 ASICS per hybrid)



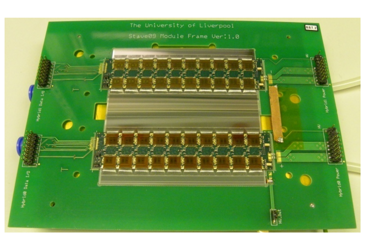
→Noise Occupancy

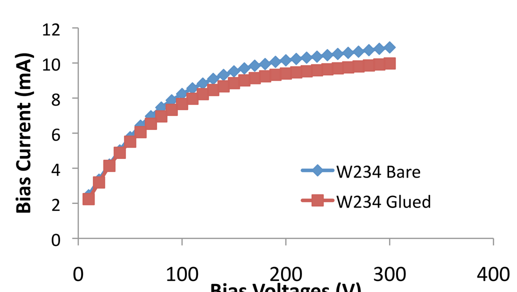


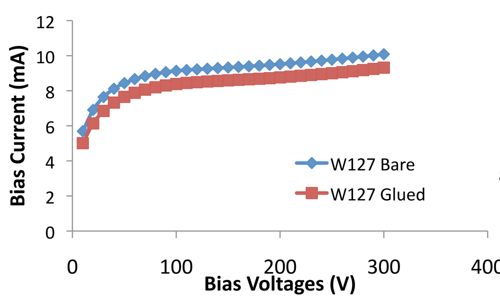
Hybrids work both functionally and electrically

More with hybrids: Develop of mechanical hybrids with sensors and ASICs in order to develop gluing techniques, bonding programes, etc…prior to the availability of new hybrid panels to other sites

Most of the hybrids are in the process of being used to make modules.





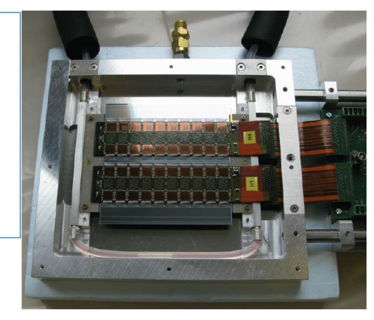


Bias current unaffected during gluing

Double-Sided Module Irradiation Tests (@ Uni. Geneva)

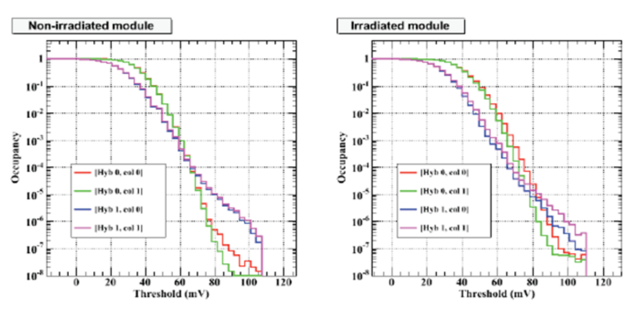
- "Half-module" prototype was irradiated with 24GeV protons in CERN-PS irradiation facility in November 2009.
- The estimation of the fluence received by the module is ~5 x 10^{14} 1MeV n_{eq}.
- After irradiation, the sensor current increased by 5 to 6 orders of magnitude.

Testing conditions during irradiation:
- Sensor biased at -100V
- Chips powered & clocked



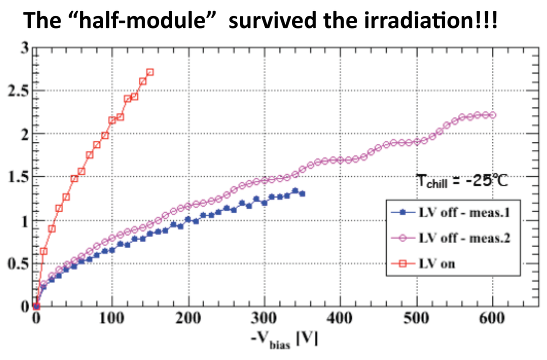
Noise occupancy: No significant degradation

T chiller ~ -25ºC
Minimum temperature overall: ~ -18ºC (LV OFF)

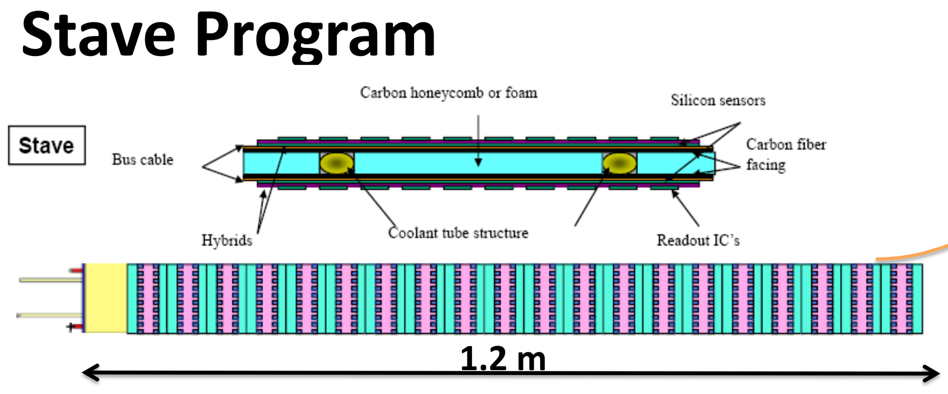


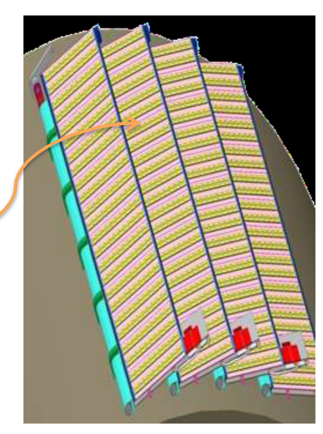
LV-ON	@-100V	
Irradiated Module	T_{hyb} = 5ºC	I_{sl} = 2.4mA
Non-Irrad. Module	T_{hyb} = 25ºC	I_{sl} = 360nA

The "half-module" survived the irradiation!!!



Stave Program





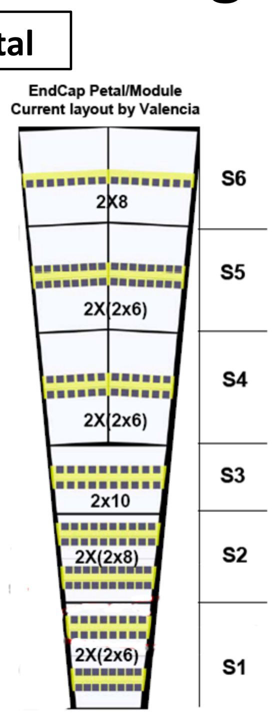
Module integration into Staves:
End-Insertion (developed by KEK/Uni. Geneva, LBL/ BNL, UK)
Barrel structures can be assembled before the Staves are integrated.

Hybrids glued to sensors, glued to Bus tape, glued to cooling substrate.
- Embedded bus cable
- Independent cooling pipe
- Stave mechanical core
- End of stave card

End-insertion gives flexibility for assembly & rework

Petal Program

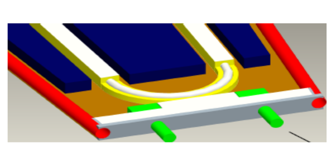
Petal

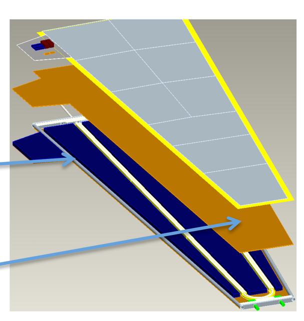


Sensor area: 830 cm^2
650mm length
- 6 different detector types mounted on petals :
  →Max. 18 Si sensors/petal
  → Min. 12 Si sensors/petal

132 chips/side

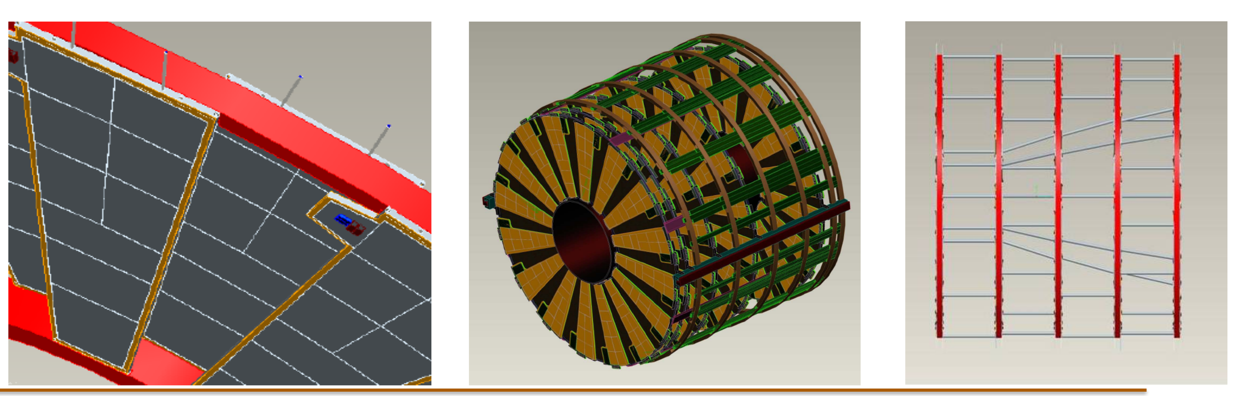
- CO_2 cooling pipe





- 2 carbon facings + Honeycomb sandwich core.
- Independent e-services + Bus cable

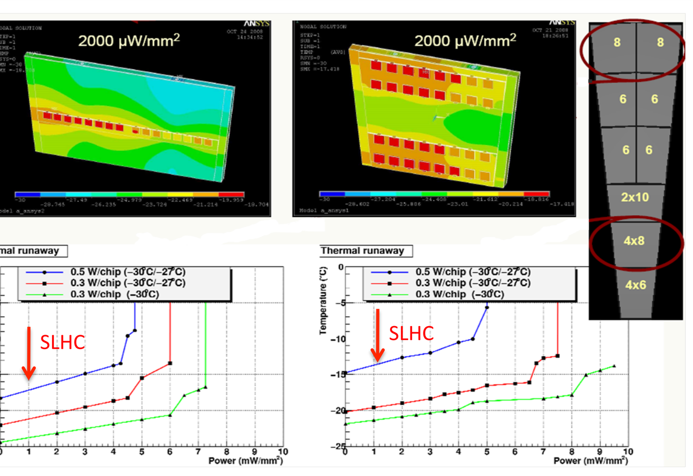
Strip End-cap : Simulation layout (@ IFIC-Valencia)
- 5 discs on each side: D0, D1, D2, D3, D4
- 32 petals/disc (All discs)
- 4 different petal shapes (38<R<95cm)
- Overlap in Φ with upper/lower petals
- Development of services routing and disc support schemes



Thermal Simulations (@ IFIC-Valencia)

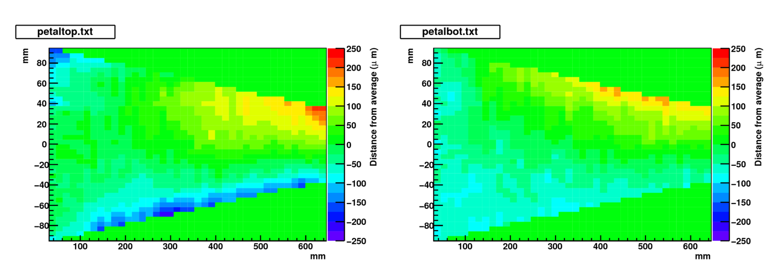
Thermal simulations to explore behaviour at critical points:
✓ Assumed -30ºC coolant temperature (-27ºC on the return pipe)
✓ Assumed 0.3W/chip on pictures right

The curves show the highest temperature on sensor as a function of the power.
They are within safety range (to be confirmed with prototypes)



First Measurements of prototype (@ LBL)
- Deviations along the side are due to
  →Glue
  →Honeycomb

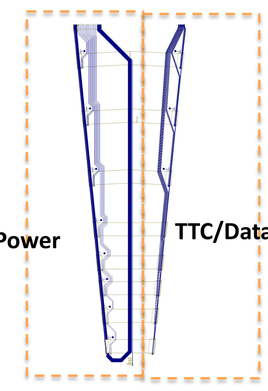
Metrology:
- Plots show deviation from average value



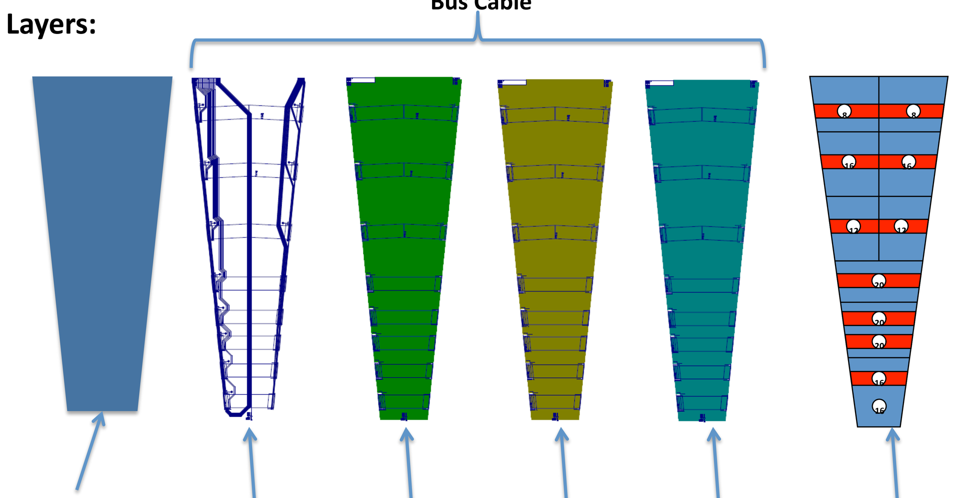
Progress on Bus Cable

(@ IFIC- Valencia)

- Mainly to equip mechanical petals
- Based on Barrel Stave: Under detectors
- Access to hybrids on edges of the petals
  - Power
  - TTC/Data
- 11 different hybrids in one petal!
  - Access to paired hybrid only one side
  →Power side or TTC/Data side
- Serial powering



Layers:



Conclusion after facing problems:
- DC-DC (parallel powering) is much easier and efficient for endcap
- Alternative is two bus cables (power and TTC/Data) on each side