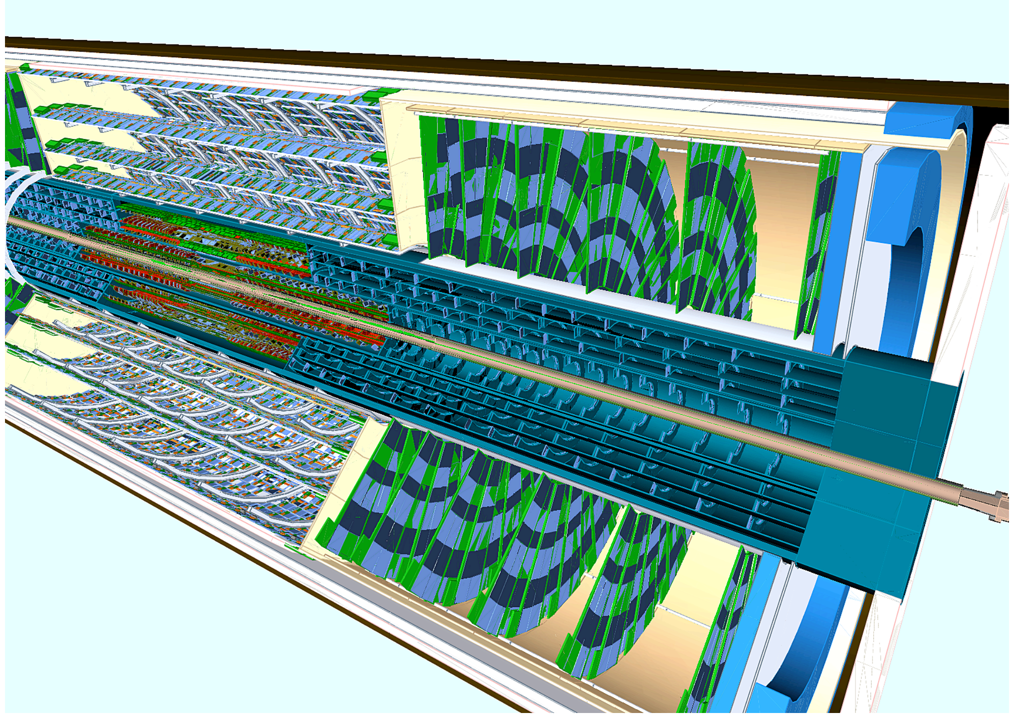
Overview and developments for the Phase-II upgrade of the inner tracker of the ATLAS experiment

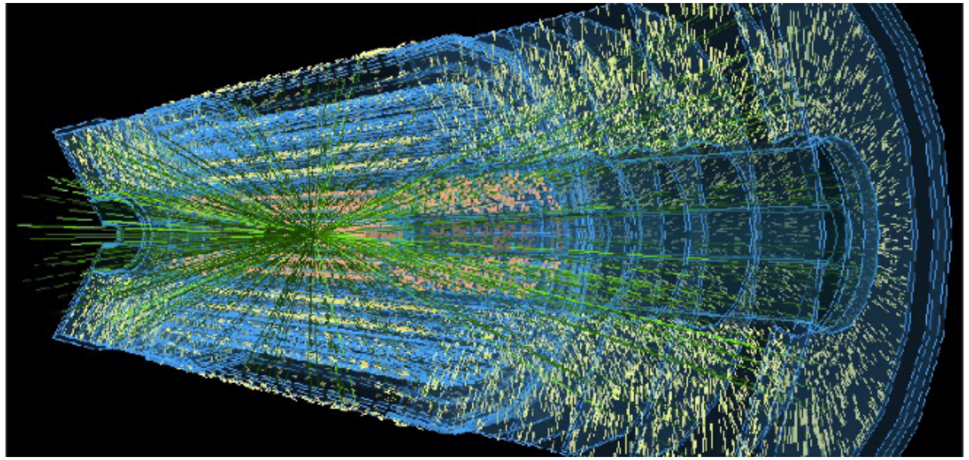


Helen Hayward

On behalf of the ATLAS Collaboration

Why do we need a new tracker?

The Inner detector is performing very well!



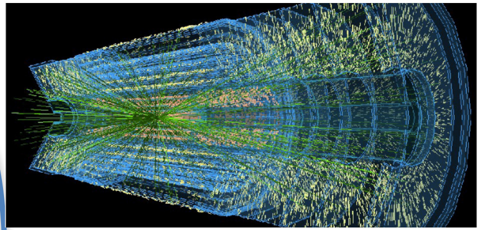
Why do we need to replace?

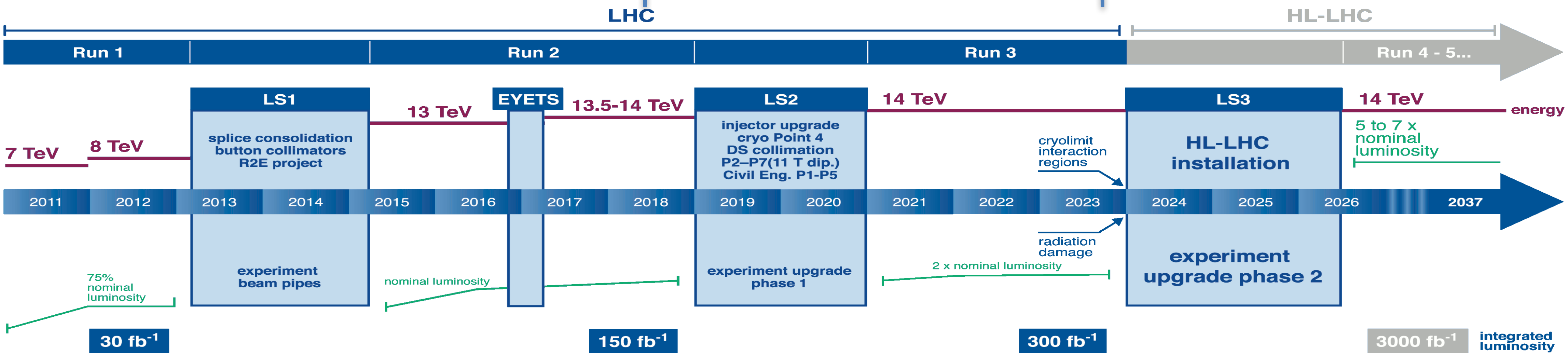
- Up to 4000fb^{-1} integrated luminosity expected for the HL-LHC, corresponding to a fluence of up to 1x10^{16} MeV n$_{eq}$/cm^{2}
  - Radiation Damage
  - Bandwidth Saturation
  - Limitations from Detector Occupancy

	LHC	**HL-LHC**
Time between beam crossings	25 ns	25 ns
Peak instantaneous luminosity	1x10^{34} cm^{-2}s^{-1}	**7.5**x10^{34} cm^{-2}s^{-1}
Number of proton-proton interactions per crossing	23	**200**

Timeline

ONLY 6 years away !



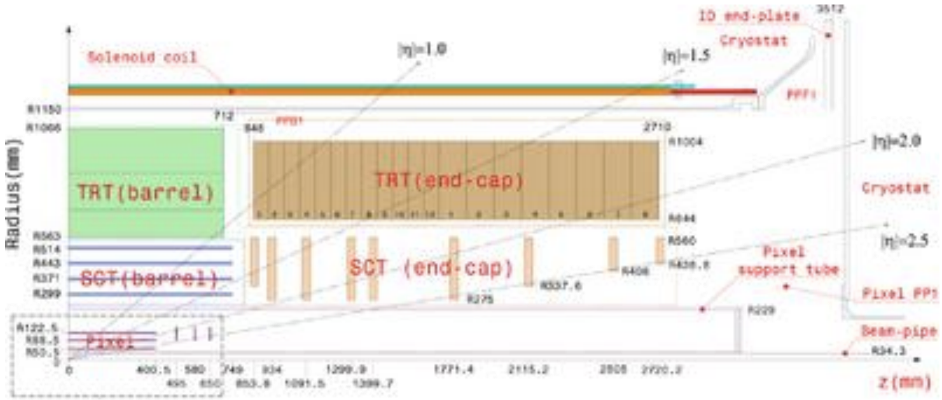


Strip TDR CERN-LHCC-2017-005 ★

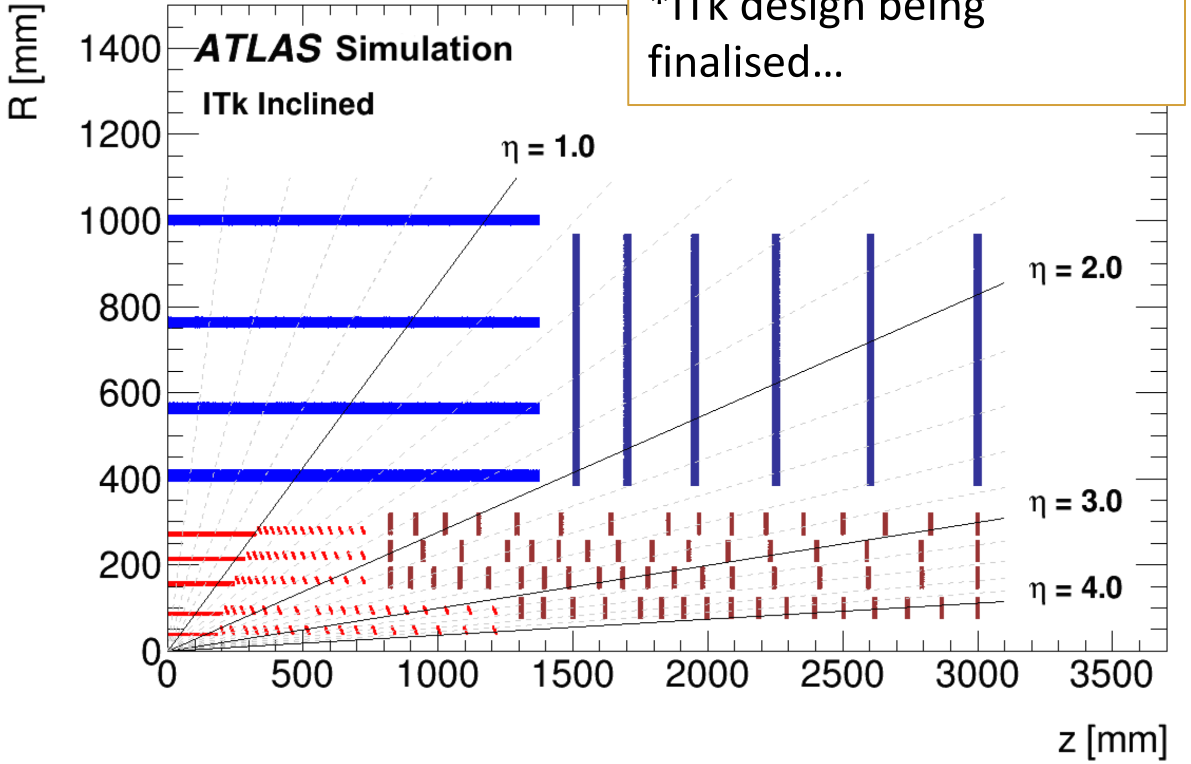
★ Pixel TDR

I will present highlights of the preparation for new Inner Detector TracKer (ITk)

New Design

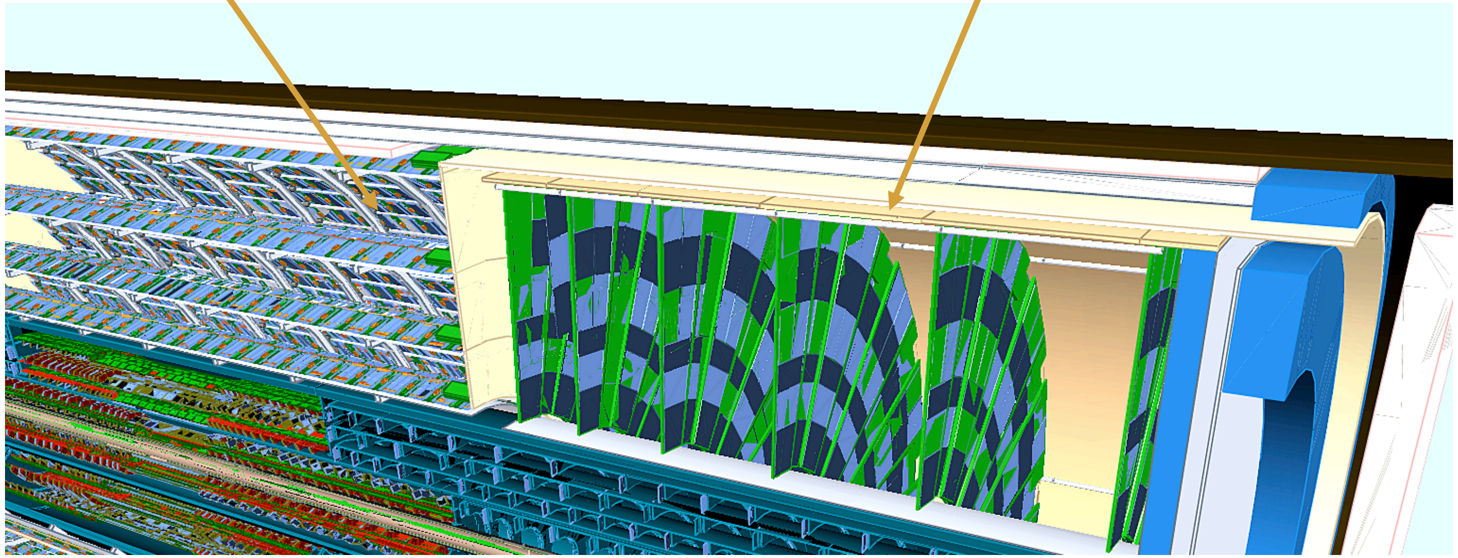


All silicon design,
Eta coverage increased from 2.5 to 4.0



*ITk design being finalised…

The ITk should have the same performance as the current detector, but in the harsher environment of the HL-LHC

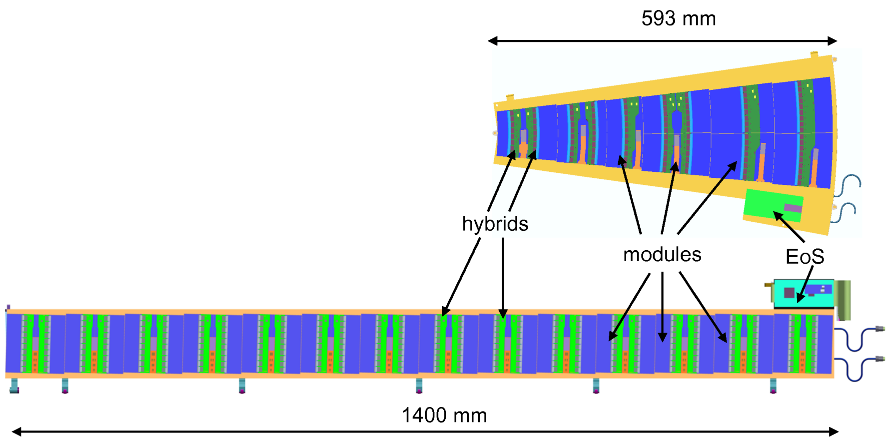


STRIP SYSTEM

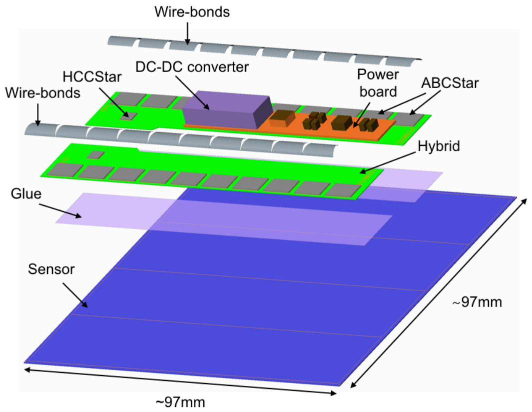
CERN-LHCC-2017-005

Strip Modules

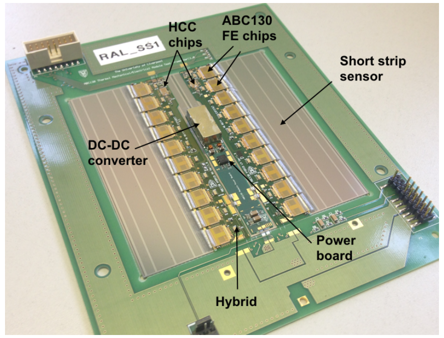
Endcap Petal and barrel stave strip structures



Exploded view of Short Strip Module

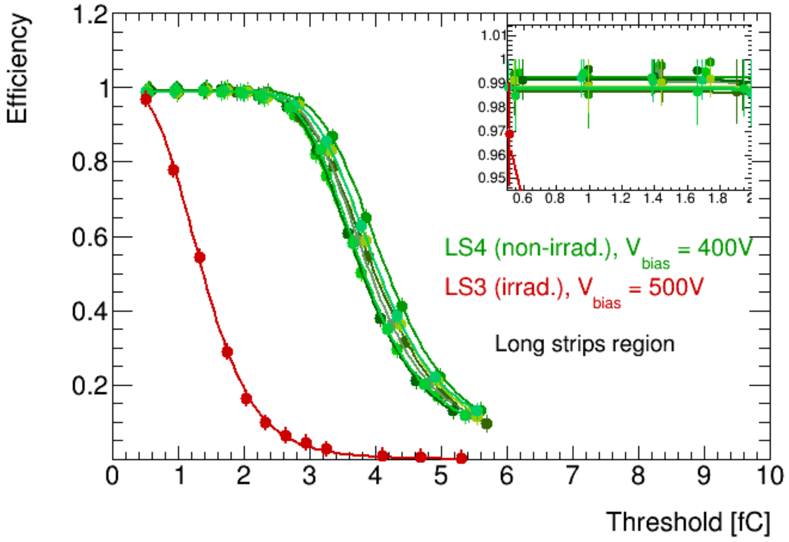


Short Strip Module



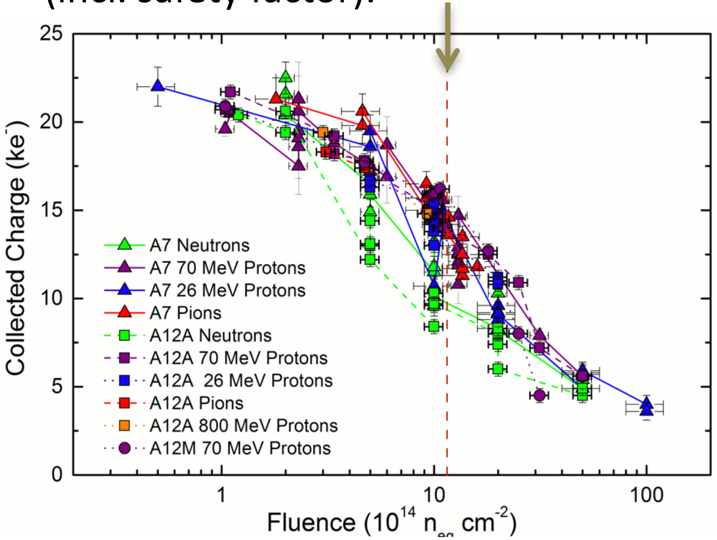
- Each module side consists of one sensor and one or two low-mass PCB’s, called hybrids, hosting the read-out ASICs
- Modules have been designed with mass production and low cost in mind.
- The strips are AC-coupled with n-type implants in a p-type float-zone silicon bulk
  - (n+-in- p FZ).
- n+-in-p technology over the p-in-n used in the current ATLAS SCT is the large difference in the amount of signal after irradiation

Results from Prototype Sensors



Efficiency versus the threshold for four ASICs on a non-irradiated module and one ASIC on an irradiated module (8x10^{14} n$_{eq}$/cm^{2})

Maximal expected fluence within the ITk Strip Detector (incl. safety factor).

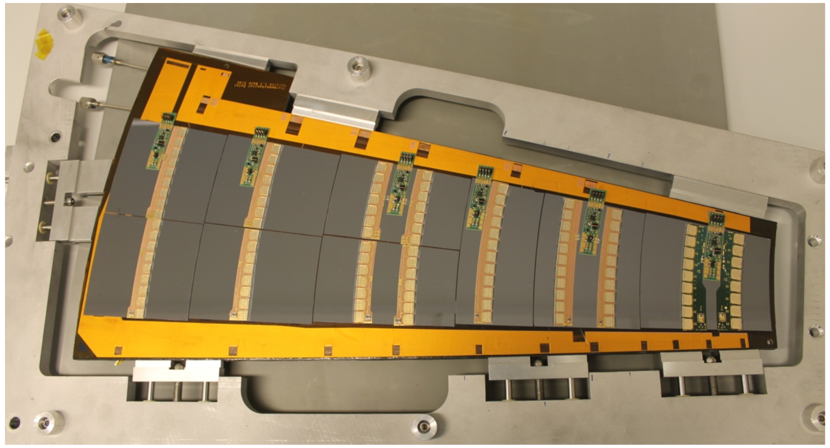


Collected signal charge at 500V bias voltage for minimum ionising particles as function of 1 MeV n$_{eq}$/cm^{2} fluence for different particles.

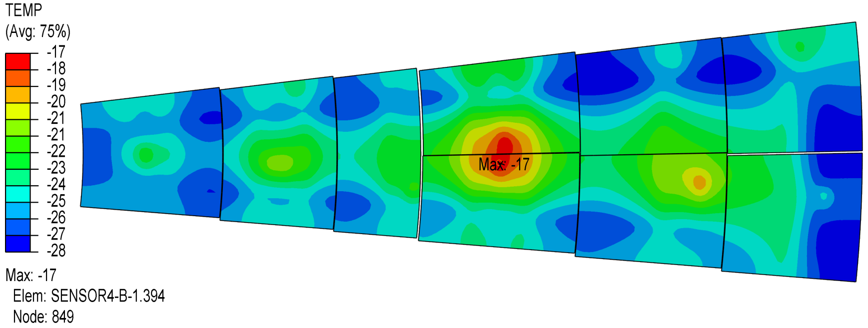
Module Type	Fluence $10^{14}\mathrm{n_{eq}cm^{-2}}$	Charge ke^- 500 V	Charge ke^- 700 V	Noise e^-	S/N 500 V	S/N 700 V
SS	8.1	13.7	16.1	630	21.8	25.6
LS	4.1	17.3	19.5	750	23.1	26.0
R0	12.3	11.5	14.0	650	17.7	21.5
R1	10.1	12.5	15.0	640	19.6	23.4
R2	8.7	13.3	15.7	660	20.3	23.9
R3	8.0	13.8	16.2	640	21.4	25.1
R4	6.8	14.6	17.0	800	18.4	21.3
R5	6.0	15.3	17.6	840	18.3	21.1

Estimated signal-to-noise at the end-of-lifetime for all module types of the ITk Strip Detector.

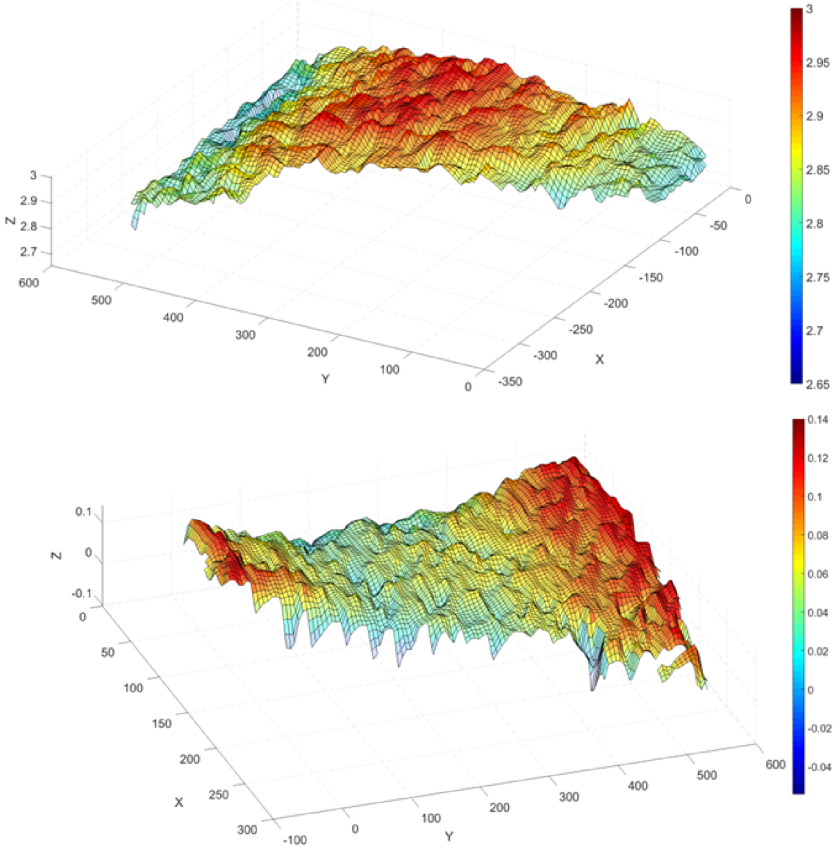
Strip Mechanics+Results



Thermo-mechanical petal

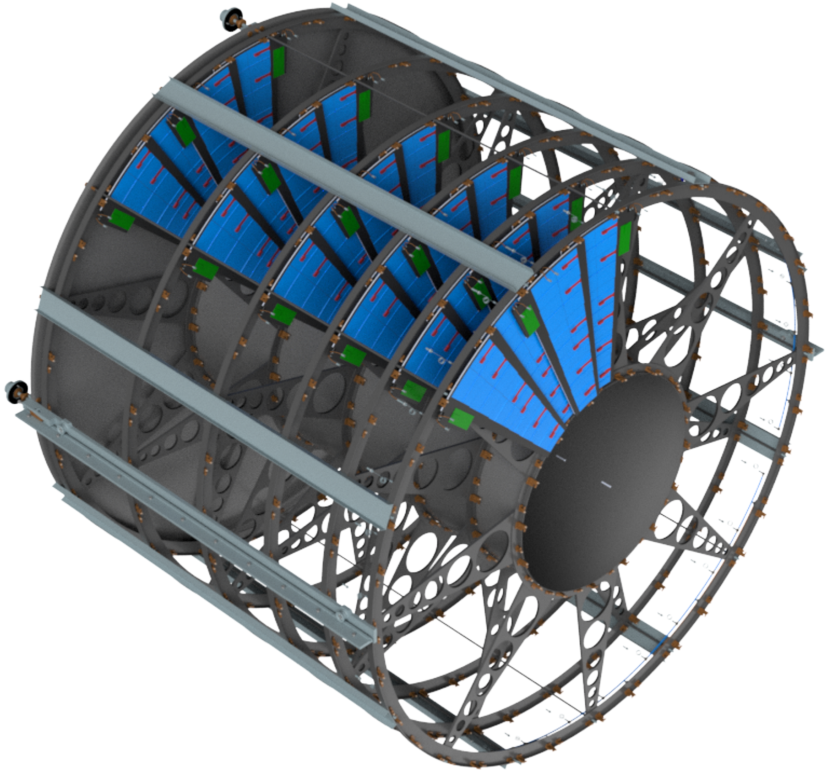


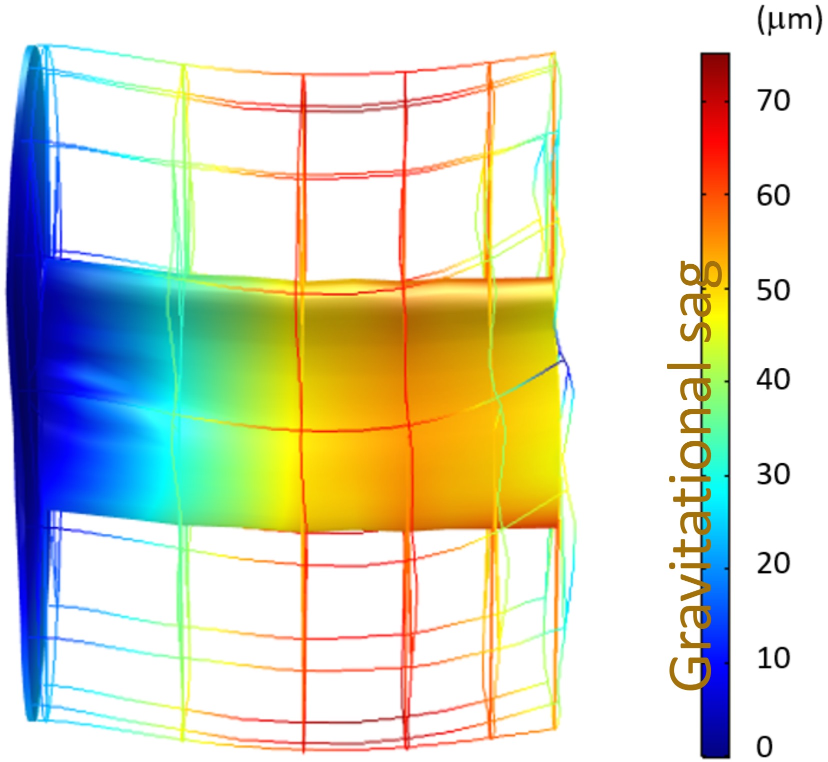
Petal temperature distribution within FEA model, given the estimated power consumption after 3000fb^{-1}



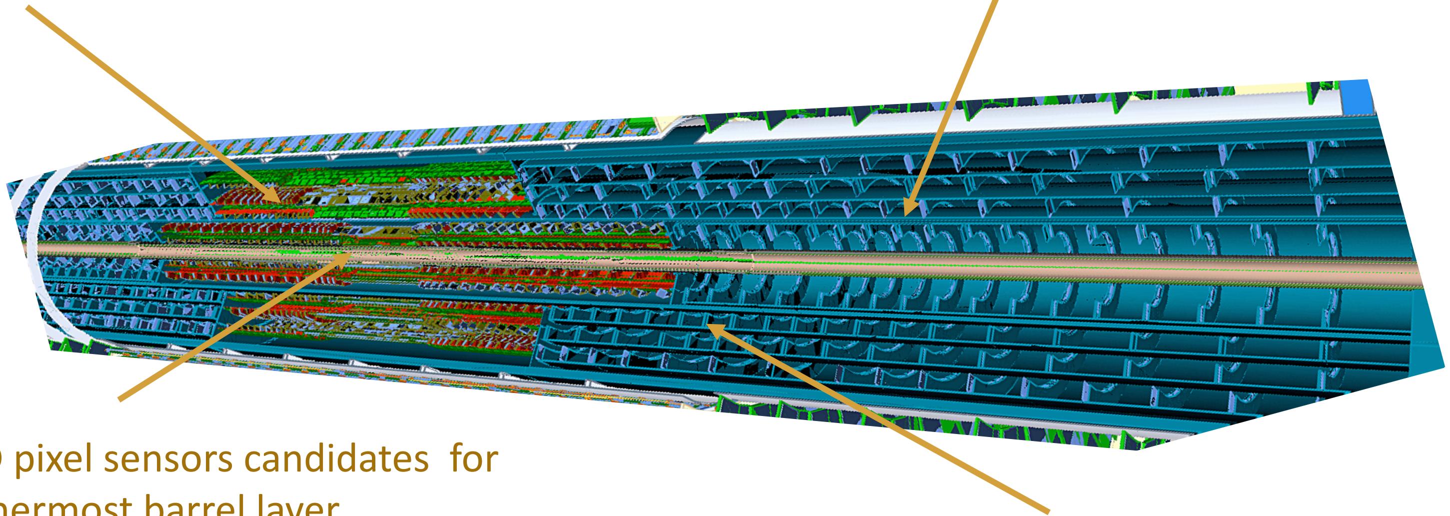
Planarity of strip petal core
Global measured flatness of ~250μm

Strip Mechanics





- Simulation analysis is used to predict any possible Geometric instability resulting from environmental changes:
    - Temperature,
    - Moisture desorption,
    - Radiation damage,
    - Mechanical deformation (gravitational sag, external loads, vibration or material effects).



Pixel Inclined Barrel Sensors

Pixel Endcap Rings

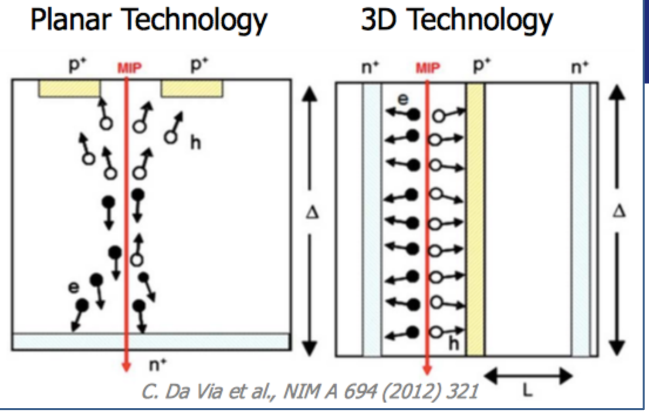
3D pixel sensors candidates for innermost barrel layer

Planar sensors baseline for outer layers
CMOS also candidates

PIXEL SYSTEM

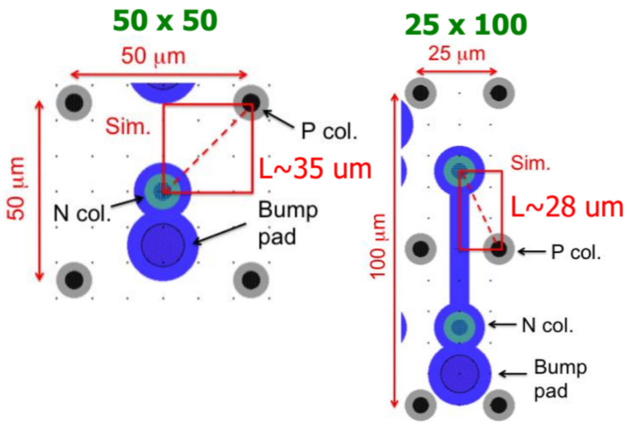
***design being finalised for pixel tdr**

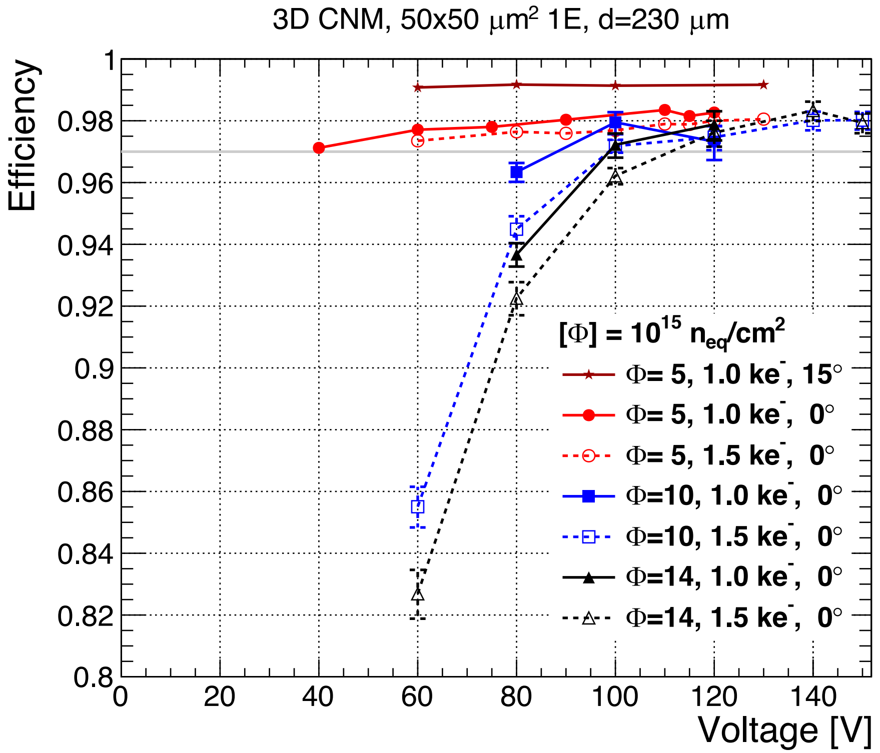
3D Pixel Sensors



C. Da Via et al., NIM A 694 (2012) 321

Design of 3D pixel cells with 50x50 and 25x100μm^2 size





J. Lange et al., TIPP 2017 Proceedings, arXiv:1707.01045

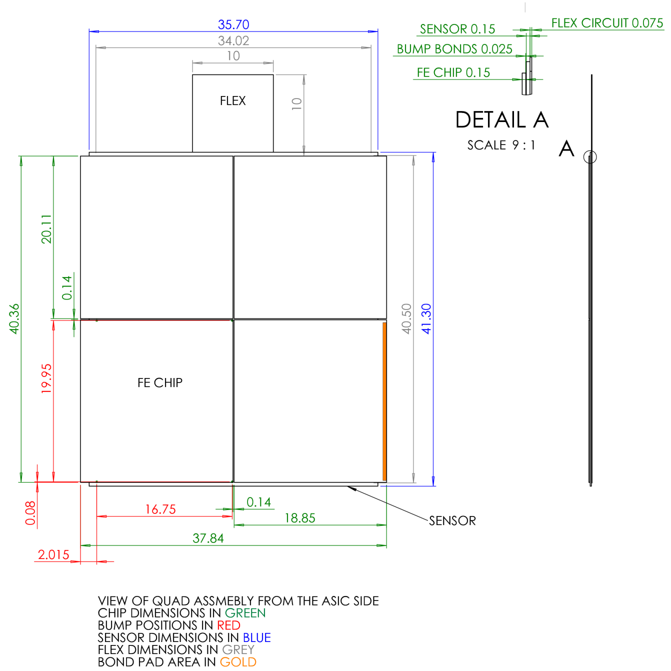
3D pixel detectors are candidates for the innermost layers of the barrel pixel detector

- **Excellent radiation hardness at low operational voltages and moderate temperatures**
- **Low power dissipation**

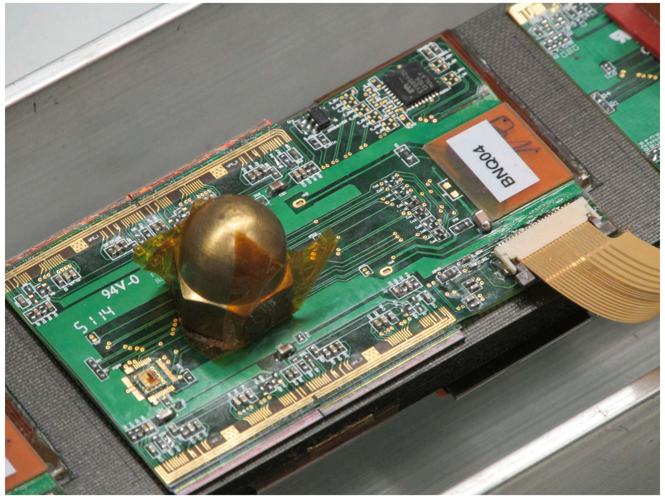
Hit efficiency as a function of bias voltage for different fluence regions on irradiated 3D FE-I4 detector.

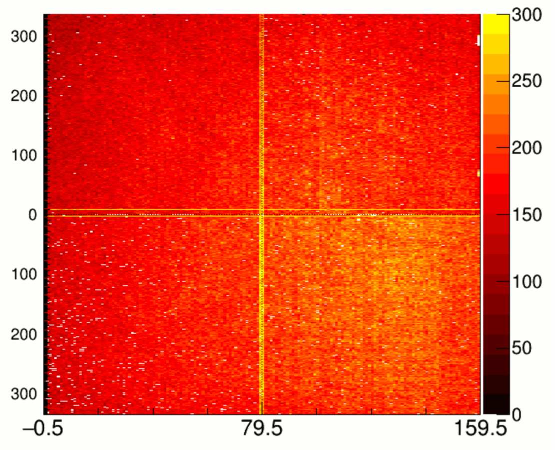
Planar Pixel Sensors

Drawing of a quad-module with four FE-I4 chips



Prototype of the quad-module with four FE-I4 chips.





The response to ^{241}Am gamma radiation.
The plot shows the number of hits recorded per pixel.

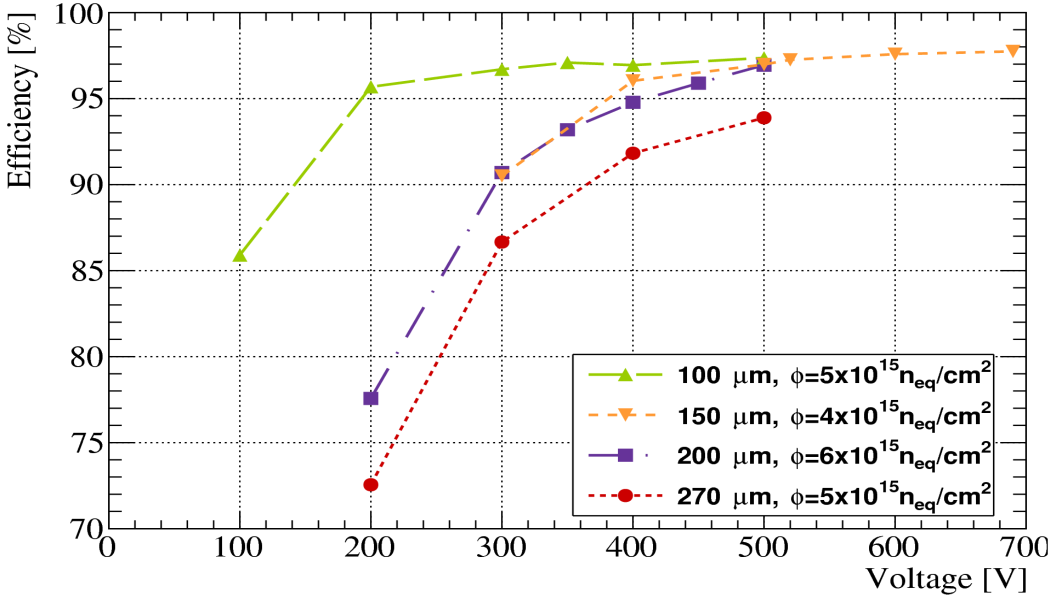
- The high hit pixels are due to their larger size in the inter-chip region.

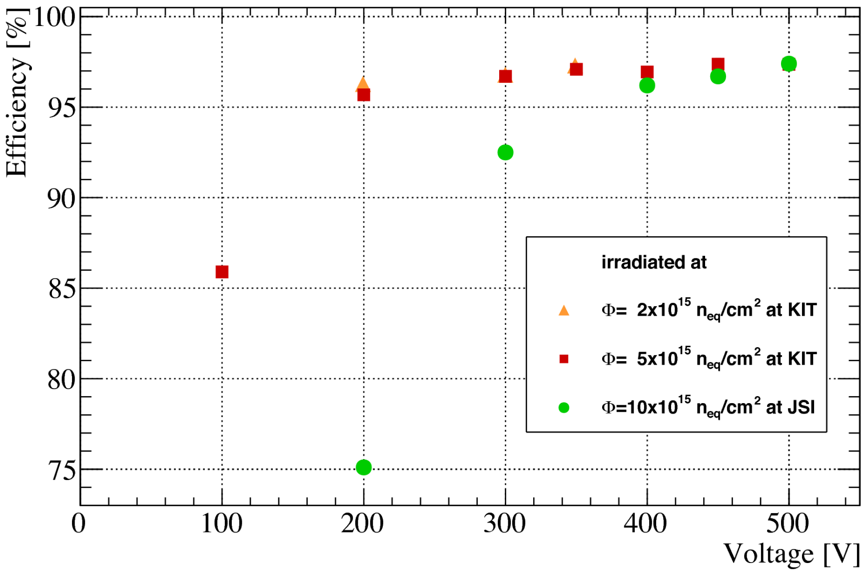
Baseline planar sensor

- quad modules 4x4cm^2 / dual 2x4cm^2
- Readout chip under development within RD53 collaboration
- 50x50µm^2
- N-in-p compared to current n-in-n
- Reduced thickness 100-150µm (currently 200µm)

Planar Pixel Sensors

(Prototype sensors are using FE-I4 chips. The baseline design will use RD53 chips)





- Comparison of hit efficiencies of Different thickness irradiated sensors
  - 100μm sensors can provide same tracking efficiency at lower bias voltages

- Hit efficiency as a function of irradiation for 100μm planar sensors

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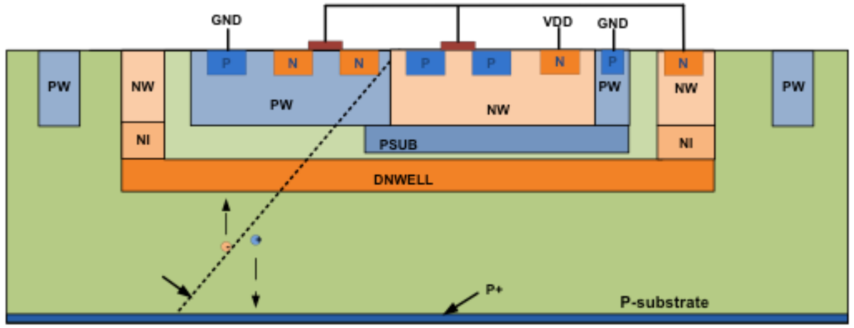
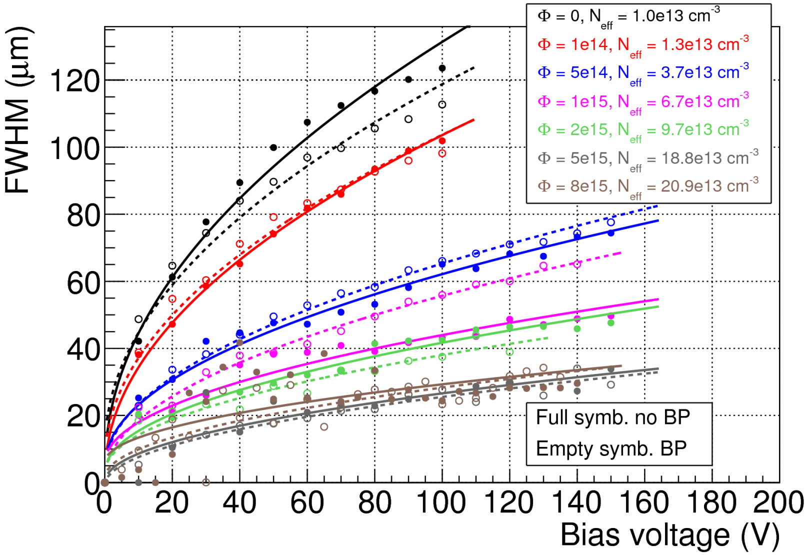
Alternative: CMOS pixel



A typical CMOS sensor pixel cell has a sensor substrate and a CMOS electronics layer embedded in multiple cells



CMOS pixels sensors can with stand radiation fluences > 5 x 10^{15} n_{eq} /cm^2

Promising technology that would reduce costs whilst providing high granularity, radiation hard sensors for outer pixel layers.

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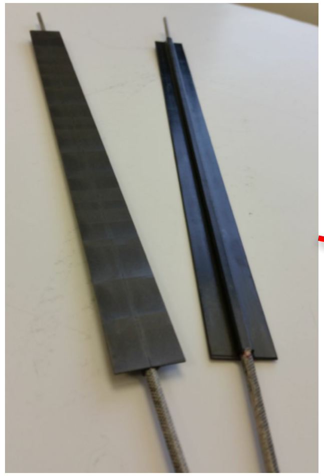
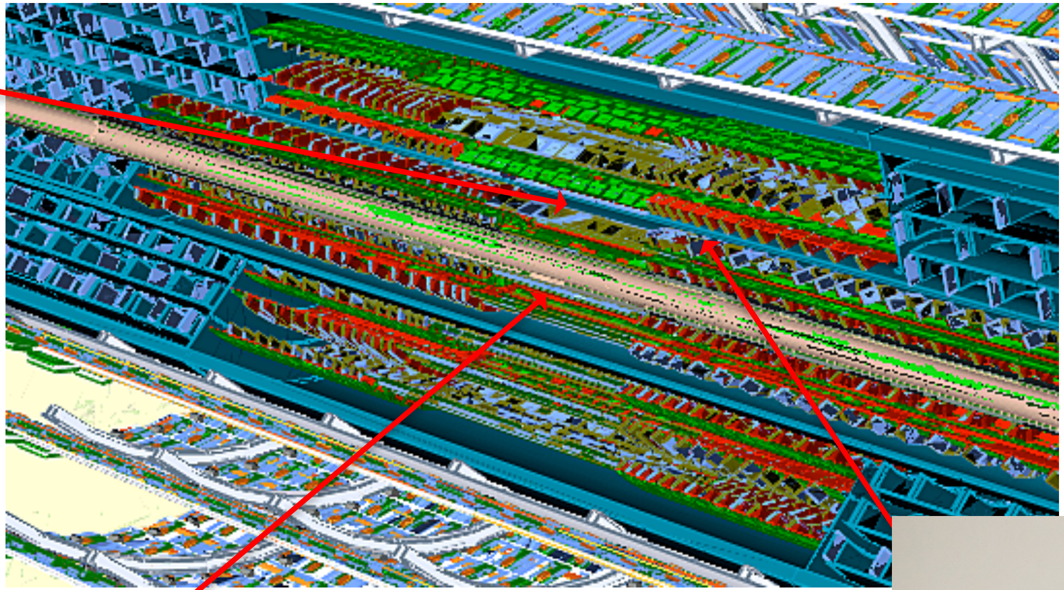
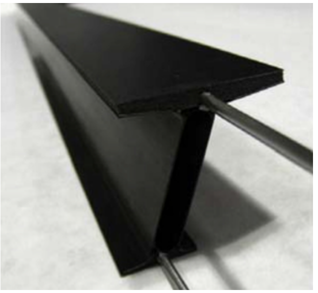
Pixel Barrel – Local Supports

Prototypes have been developed for different possible designs for the local supports.

Carbon stave prototype

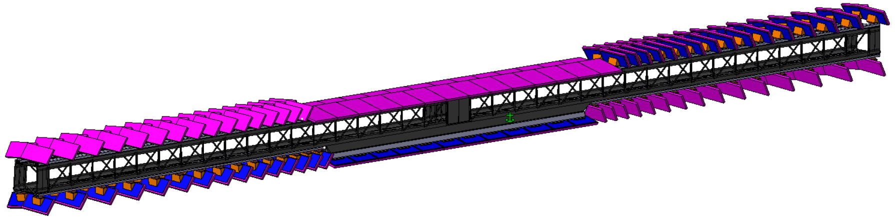




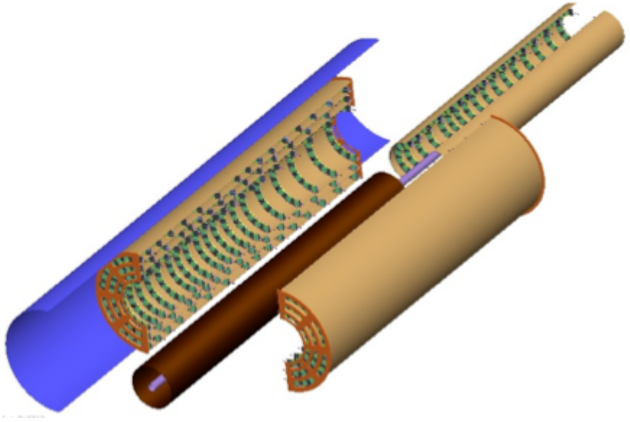


I-Beam stave. Modules loaded on both sides (top and bottom)

Truss prototype for Longeron design for outer barrel

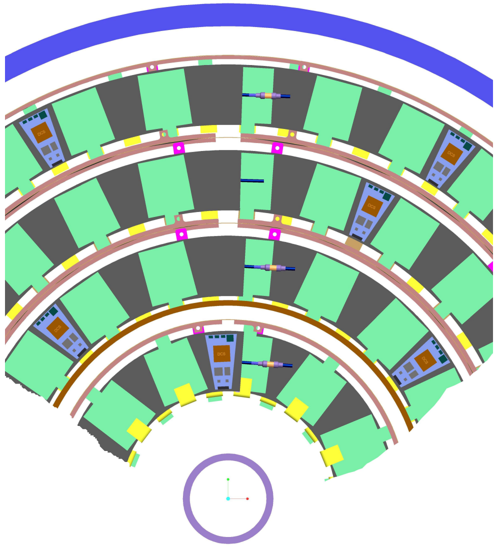


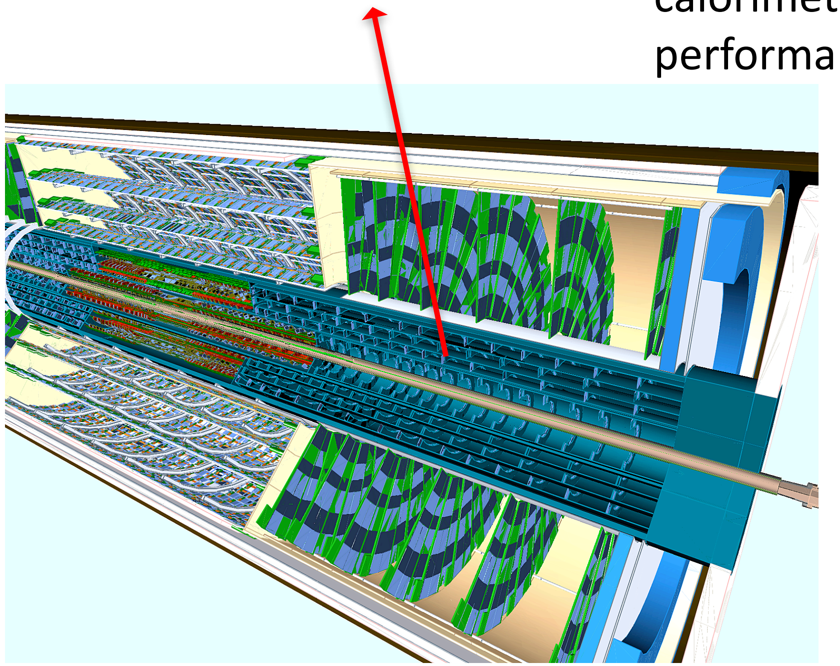
Pixel Endcap

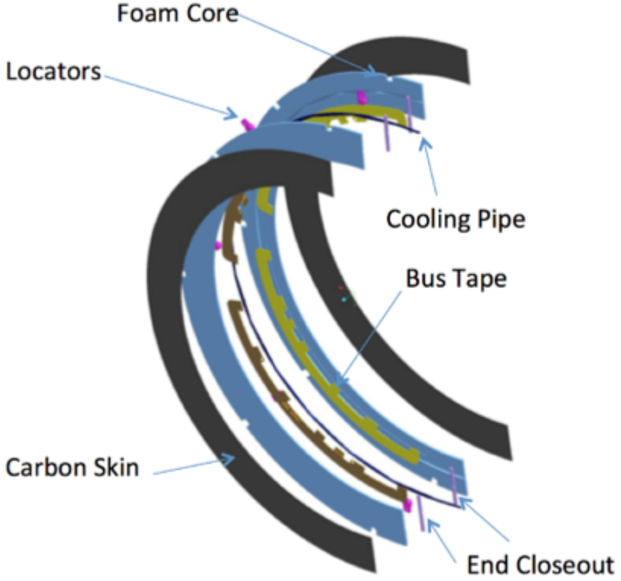


Pixel Endcap: half cylindrical shells supporting quad modules

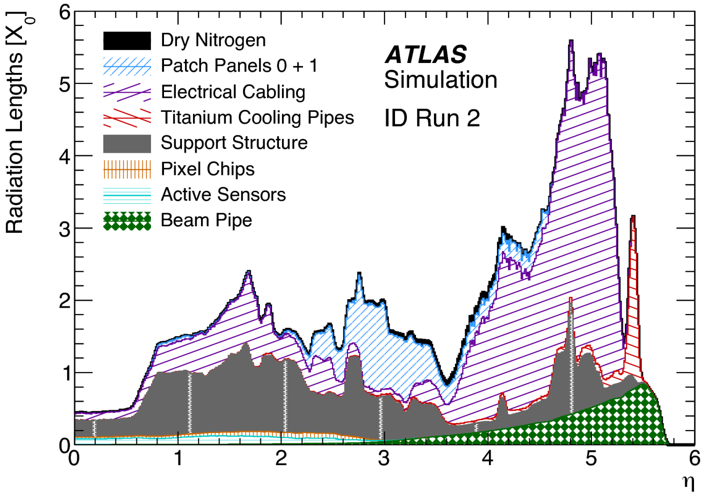
Designed to minimise mass of ring system in order to reduce the particle background reaching forward calorimeter and to improve tracking performance at high-eta





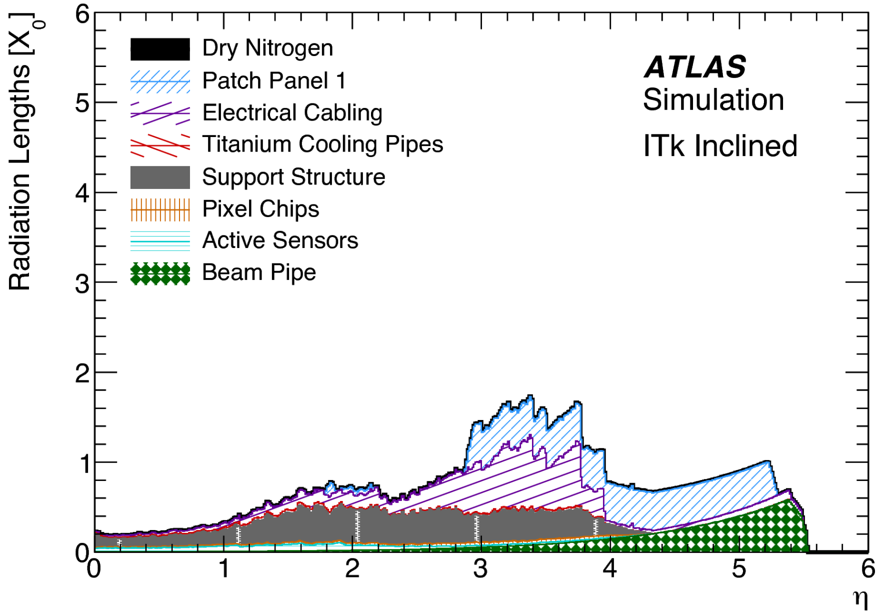


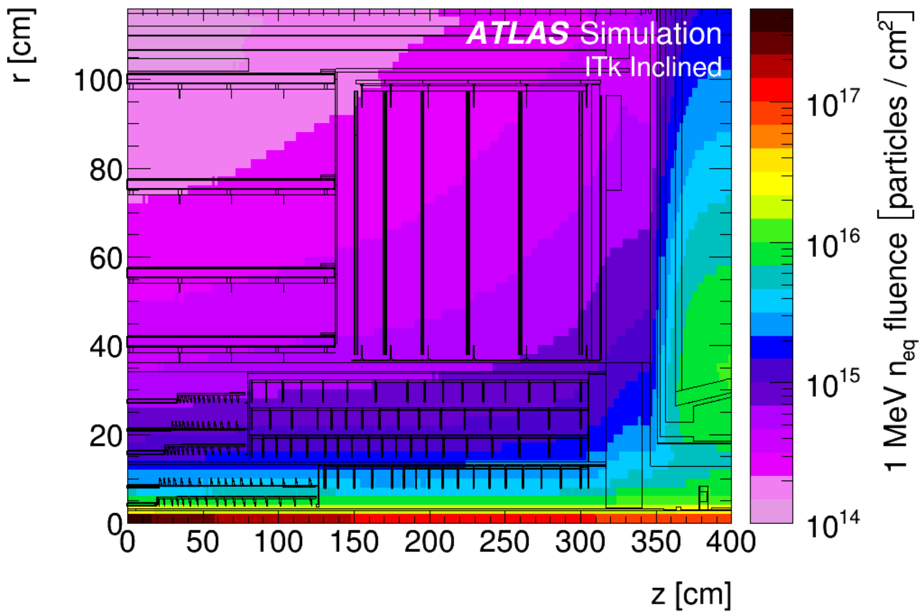
Material and Fluence



The ITk material budget is around 30% lower in the region $|\eta| < 4.0$, compared to the Run 2 detector.

Reducing material is crucial for good tracking and reducing the fluence





Summary

- A new tracker detector is needed for ATLAS to extract good physics measurements out of the HL-LHC
  - Extended eta coverage
  - Low mass
- A lot of work has been done into the design of the ITk
  - Progress achieved by simulations and prototypes.
- We are gearing up to installation in ~2024