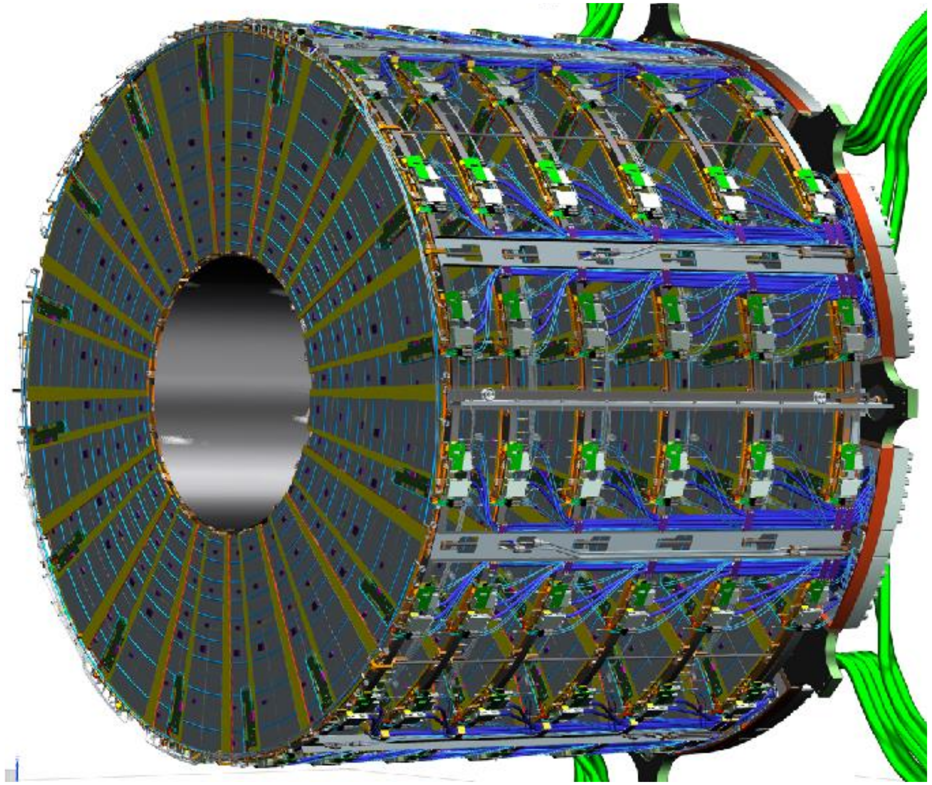
ATLAS ITk strip petals

14th Terascale Detector Workshop 2022



Sergio Díez Cornell
24.02.2022

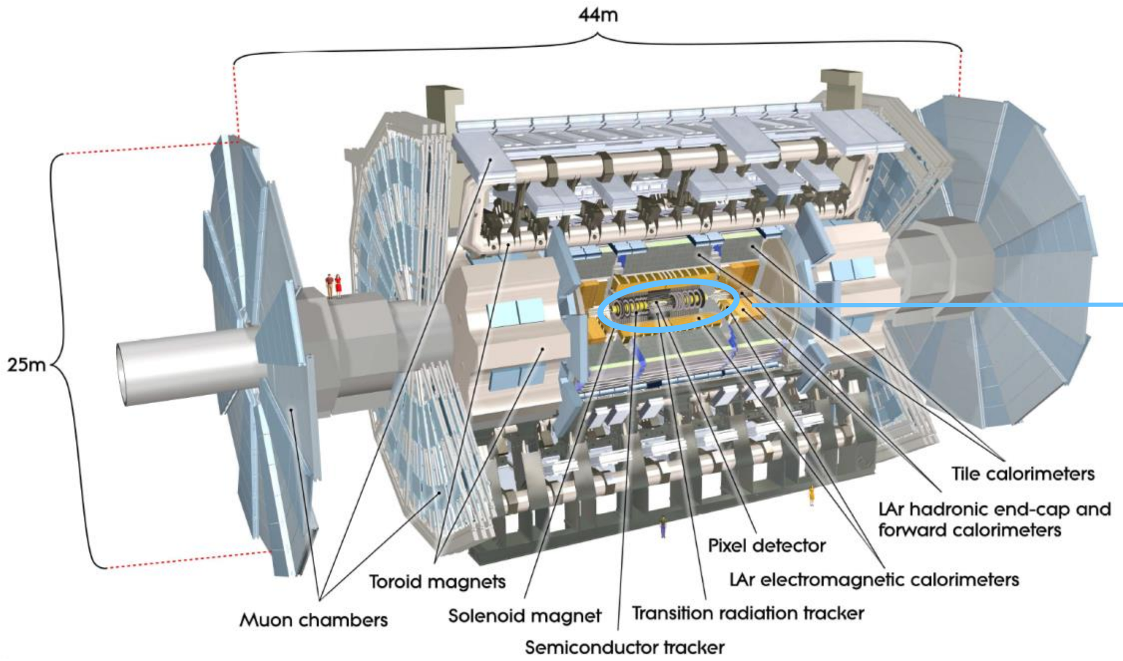
HELMHOLTZ

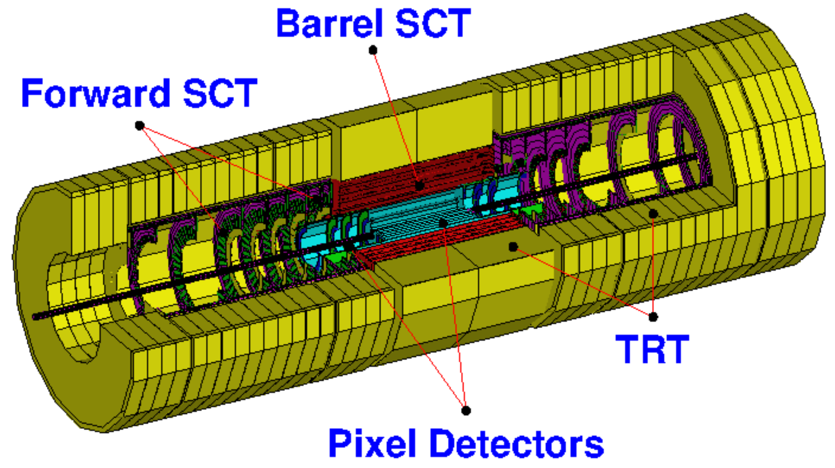
ATLAS ITk

DESY.

The new silicon tracker

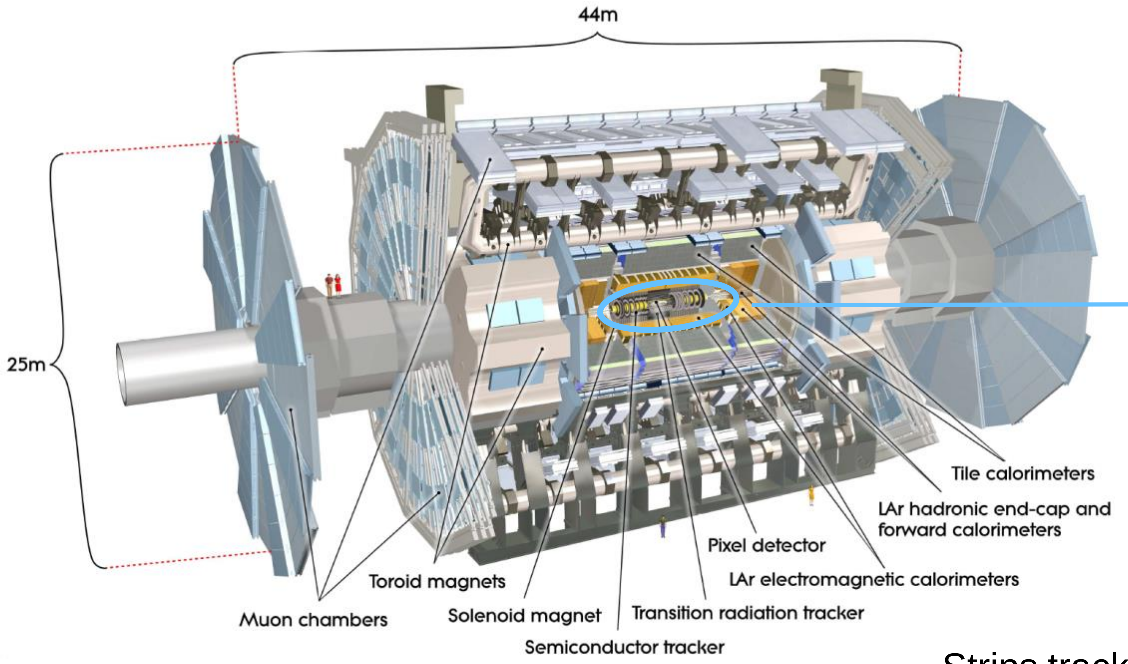
Replacing the old Inner Detector by a new all-silicon Inner Tracker (ITk)

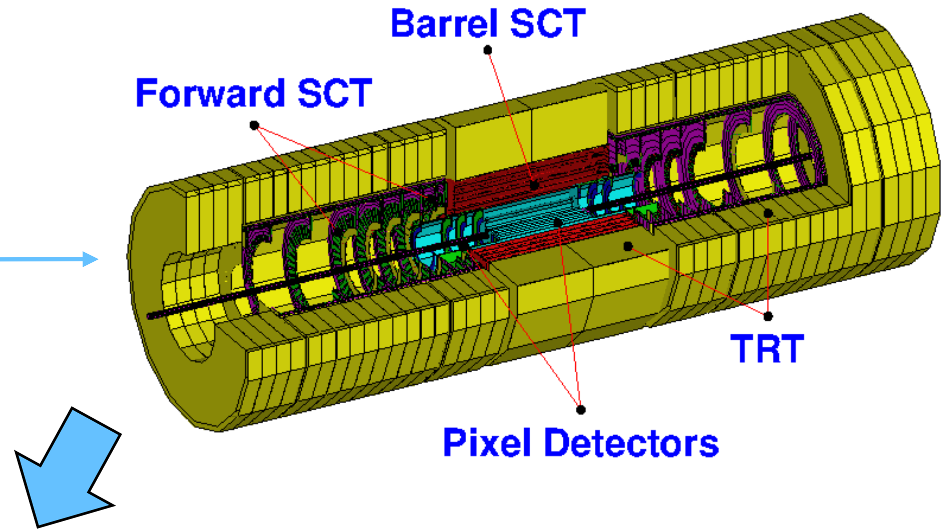


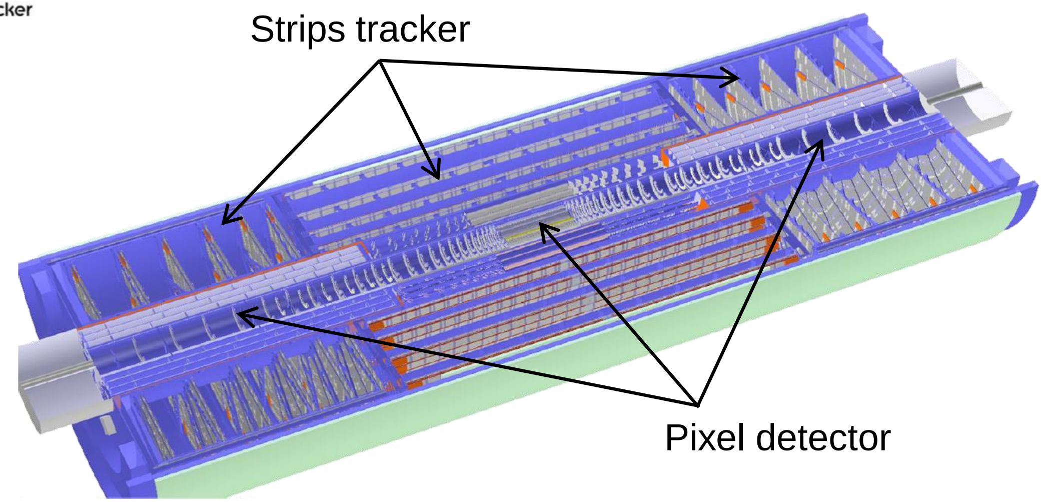


The new silicon tracker

Replacing the old Inner Detector by a new all-silicon Inner Tracker (ITk)







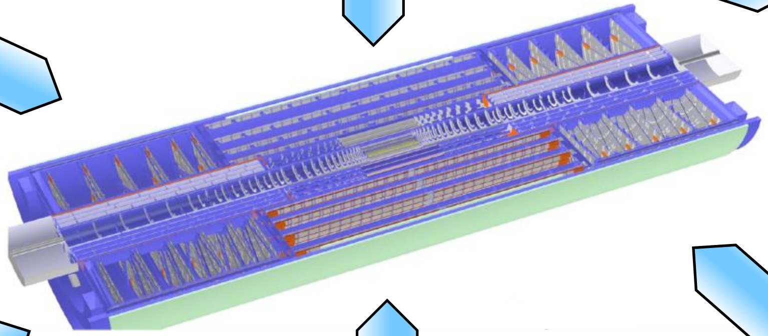
Goals and challenges of the ITk

Layout goal: Maintain or improve resolution and particle identification performance of current ID

High speed

Radiation tolerant

High granularity



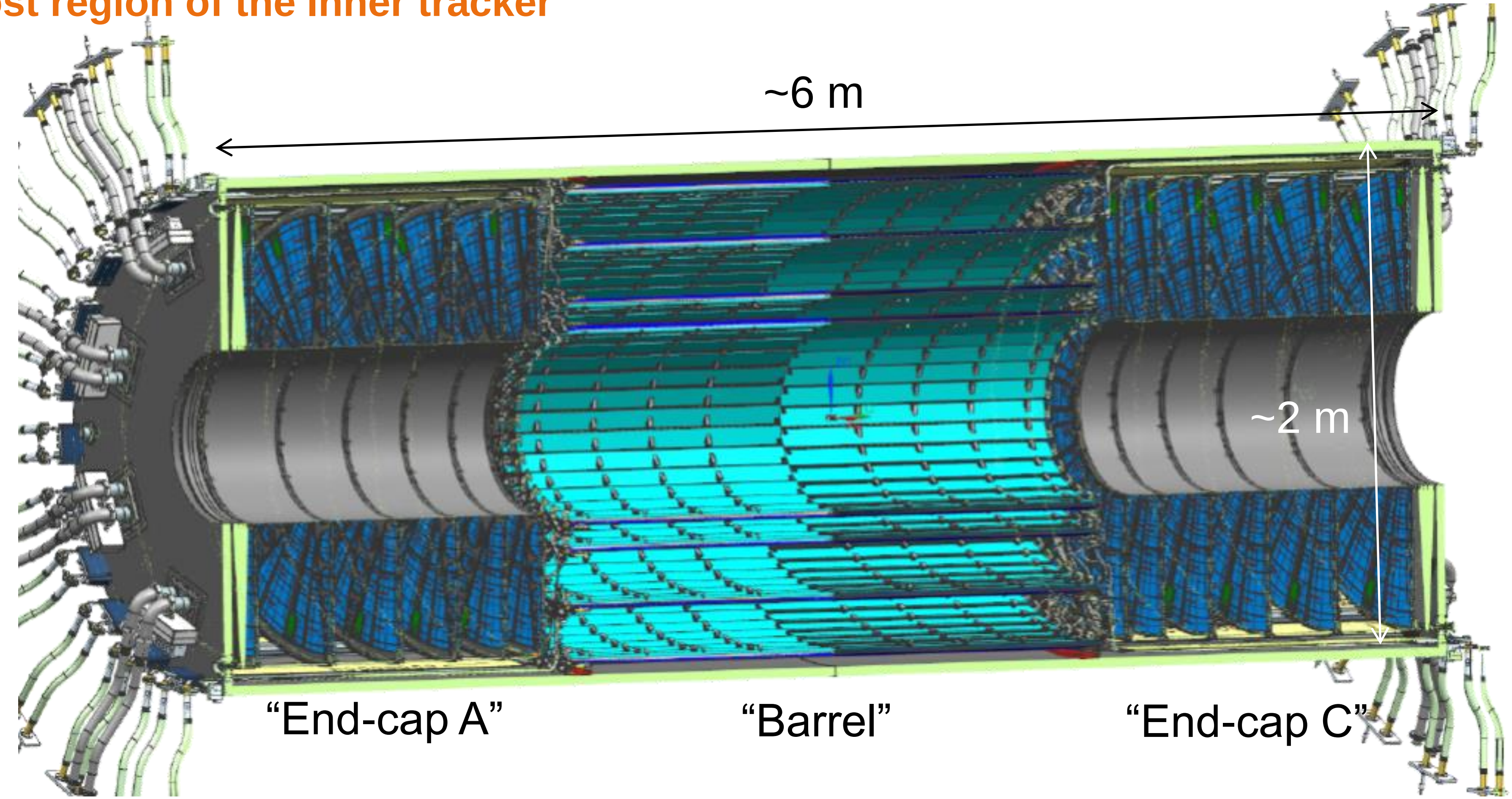
Low mass

Low power

Low cost

The strips tracker

The outermost region of the Inner tracker

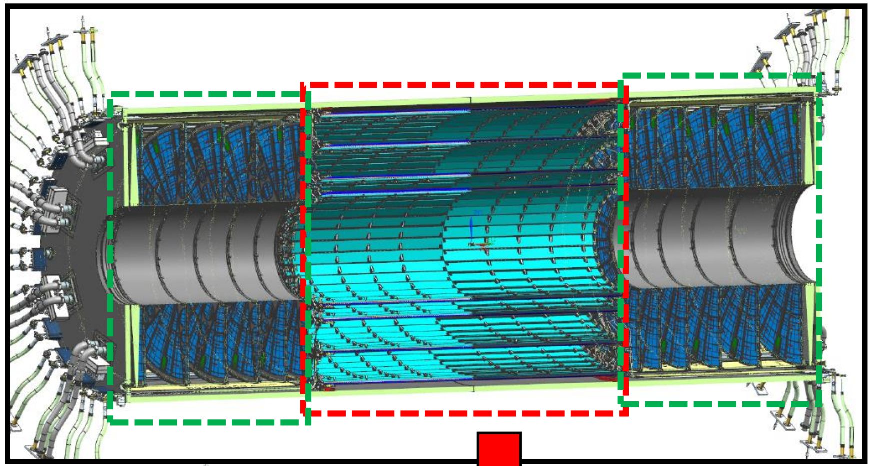


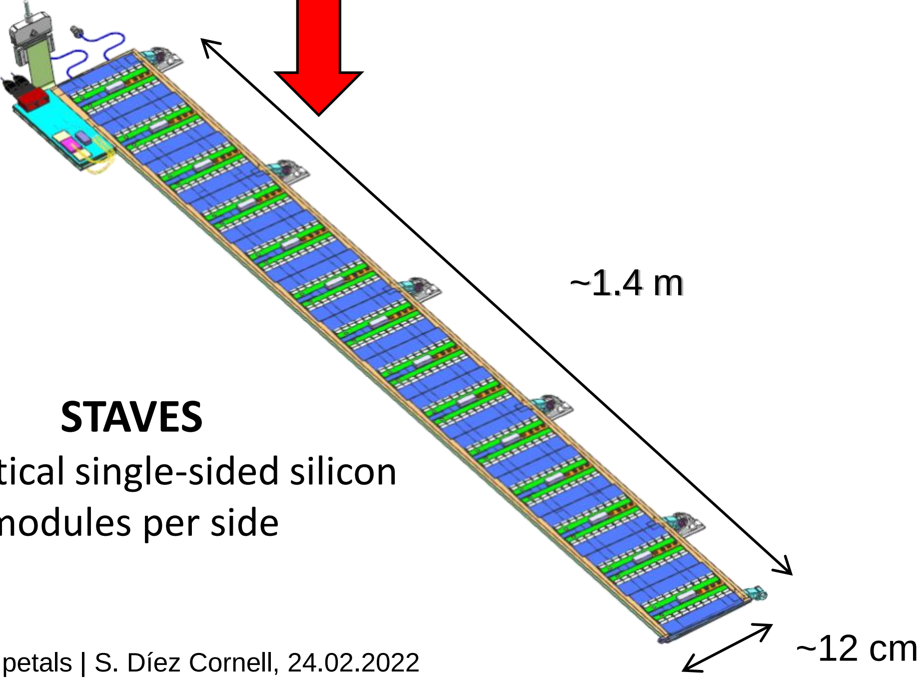
4 barrel cylinders, 6 EC disks per side

160 m^2 of silicon, 50 M channels

The strips tracker

“Stave” and “petal” concept



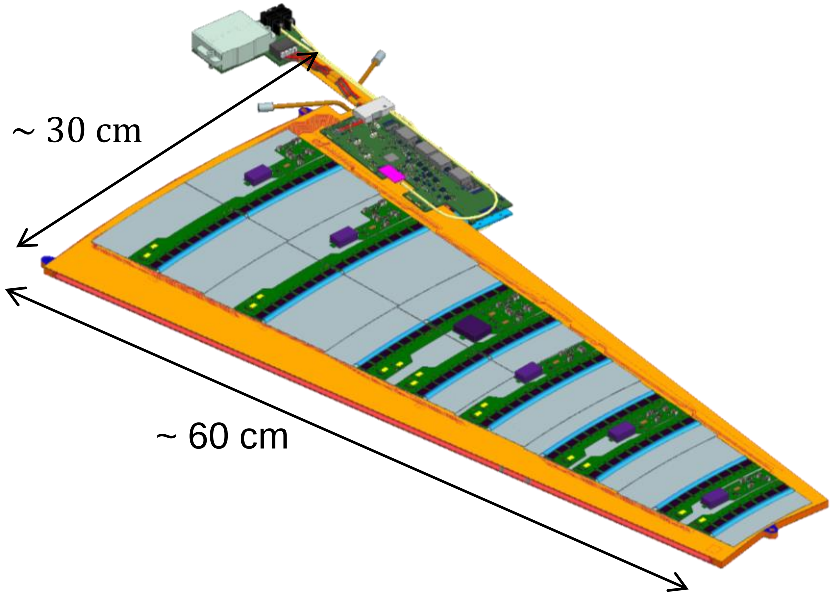


STAVES

14 identical single-sided silicon modules per side

PETALS

6 (9) types of single-sided silicon modules per side



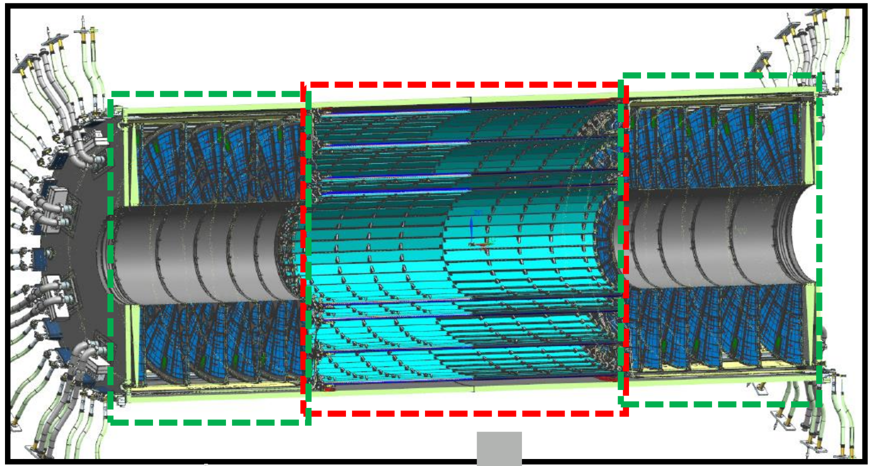
Carbon fiber “sandwich” structures supporting multiple strip silicon modules inside the tracker

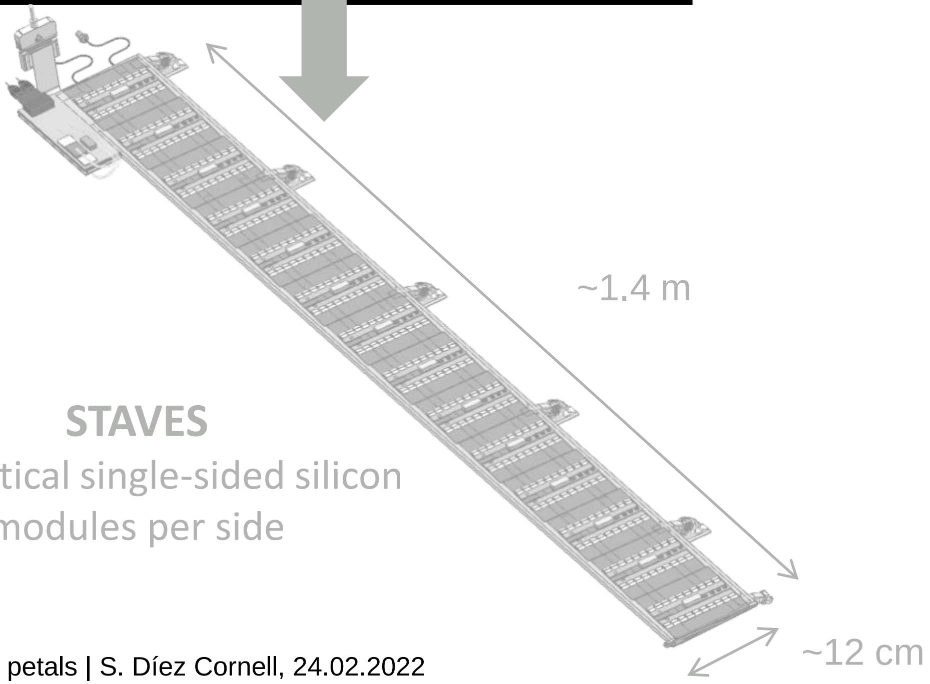
Embedded cooling and electrical connections

Modules are directly glued onto the structures

The strips tracker

“Stave” and “petal” concept





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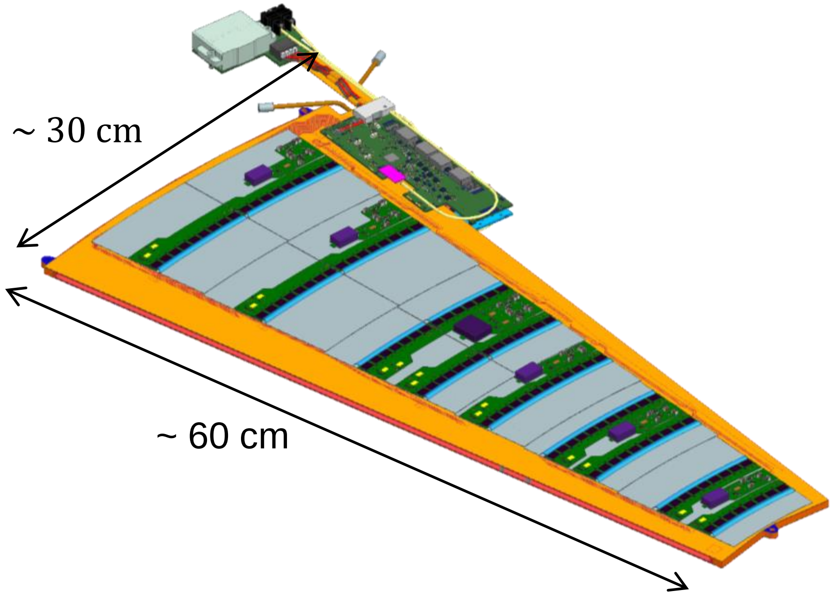

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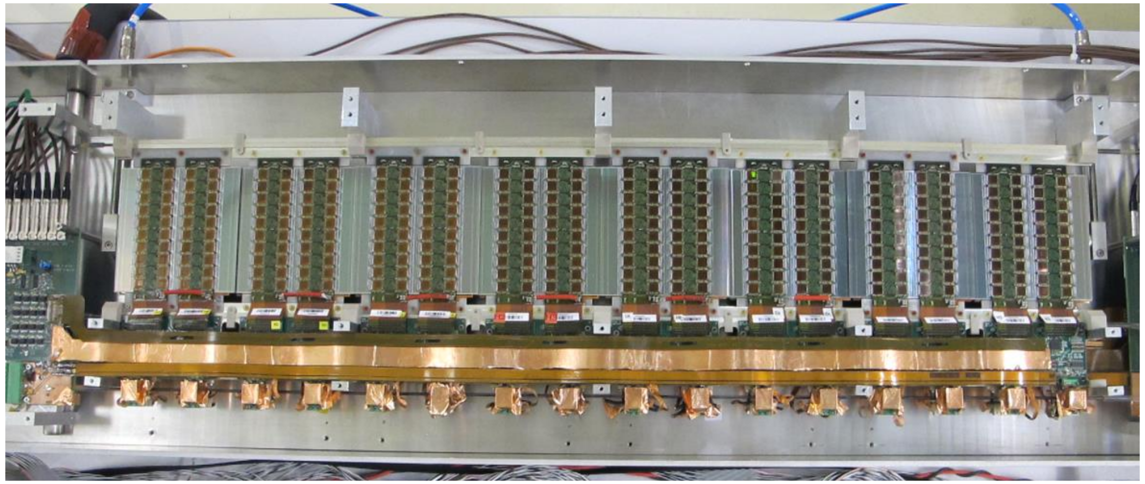
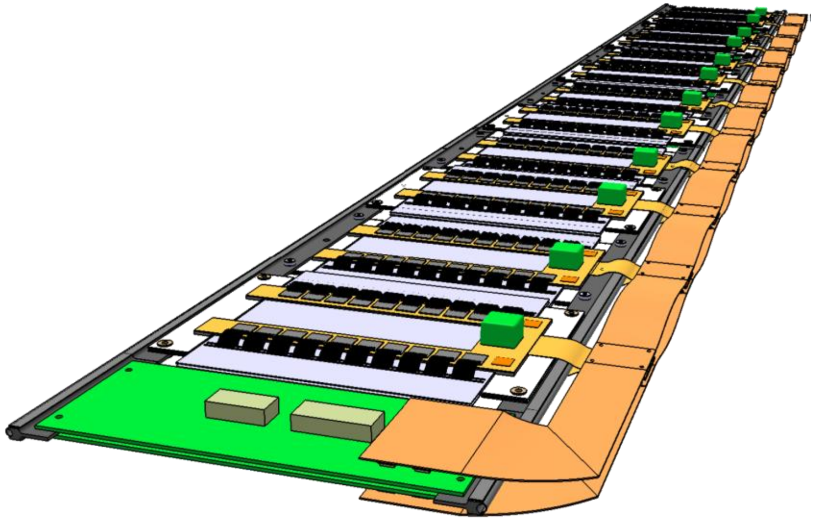
Embedded cooling and electrical connections

Modules are directly glued onto the structures

Double-sided modules approach

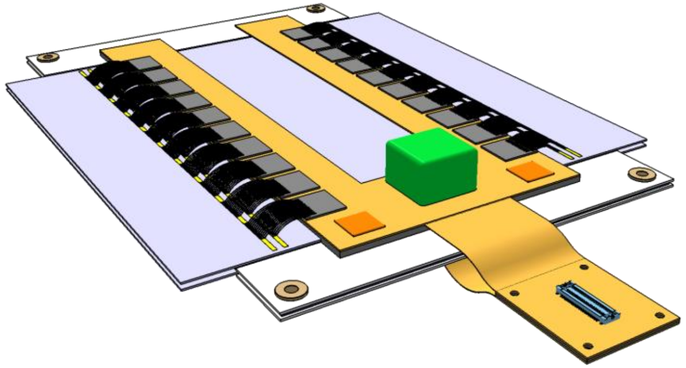
The “super-modules”: an earlier alternative





Double-sided module geometry with the same building blocks (sensors, ASICs, power and DC-DC boards)

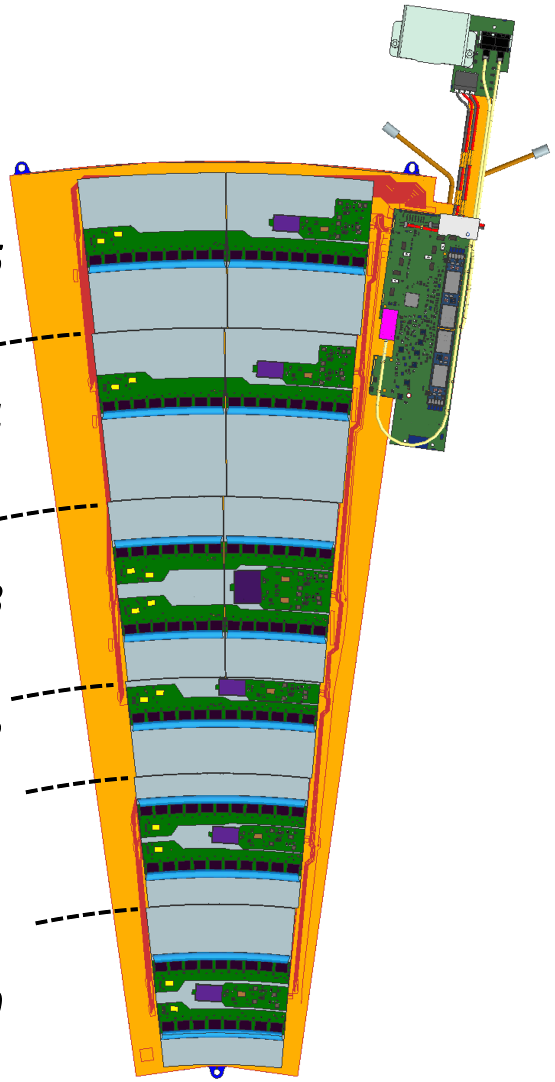
Ultimately, cooling and amount of material concerns, apart from the lack of a viable approach for the endcap regions, led to discarding this option favoring the stave and petal approach



S. González-Sevilla et al., JINST 9, P02003 (2014)

High granularity

The geometry of the endcap petals is dictated by the particle occupancy



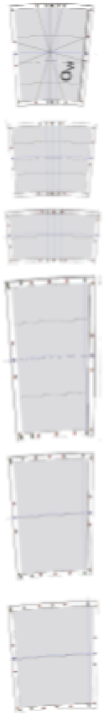
Strip lengths chosen to cope with occupancy

20 mrad stereo angle built into the petal

IP pointing strips for optimal φ resolution

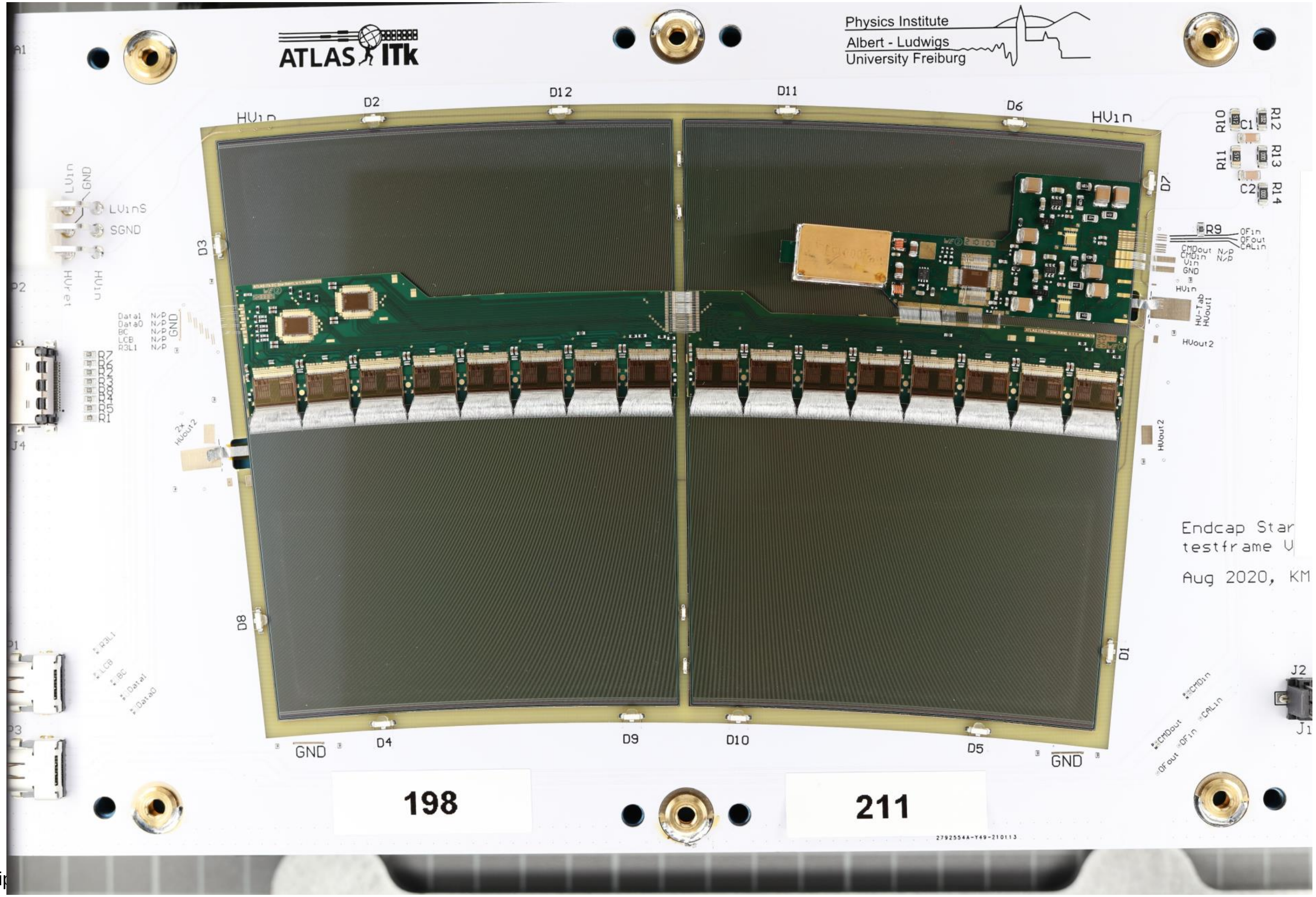
Trapezoidal-like shapes to maintain uniform strip length

Sensor type	Number of sensors	Shape	Number of rows	Channels per sensor	Min/max pitch (μm)
EC Ring 0	768		4	4360	73.5/84
EC Ring 1	768		4	5640	69/81
EC Ring 2	768		2	3076	73.5/84
EC Ring 3	1536		4	3592	70.6/83.5
EC Ring 4	1536		2	2052	73.4/83.9
EC Ring 5	1536		2	2308	74.8/83.6



The strips modules

First Pre-Production R4 module, built at TRIUMF (Canada)



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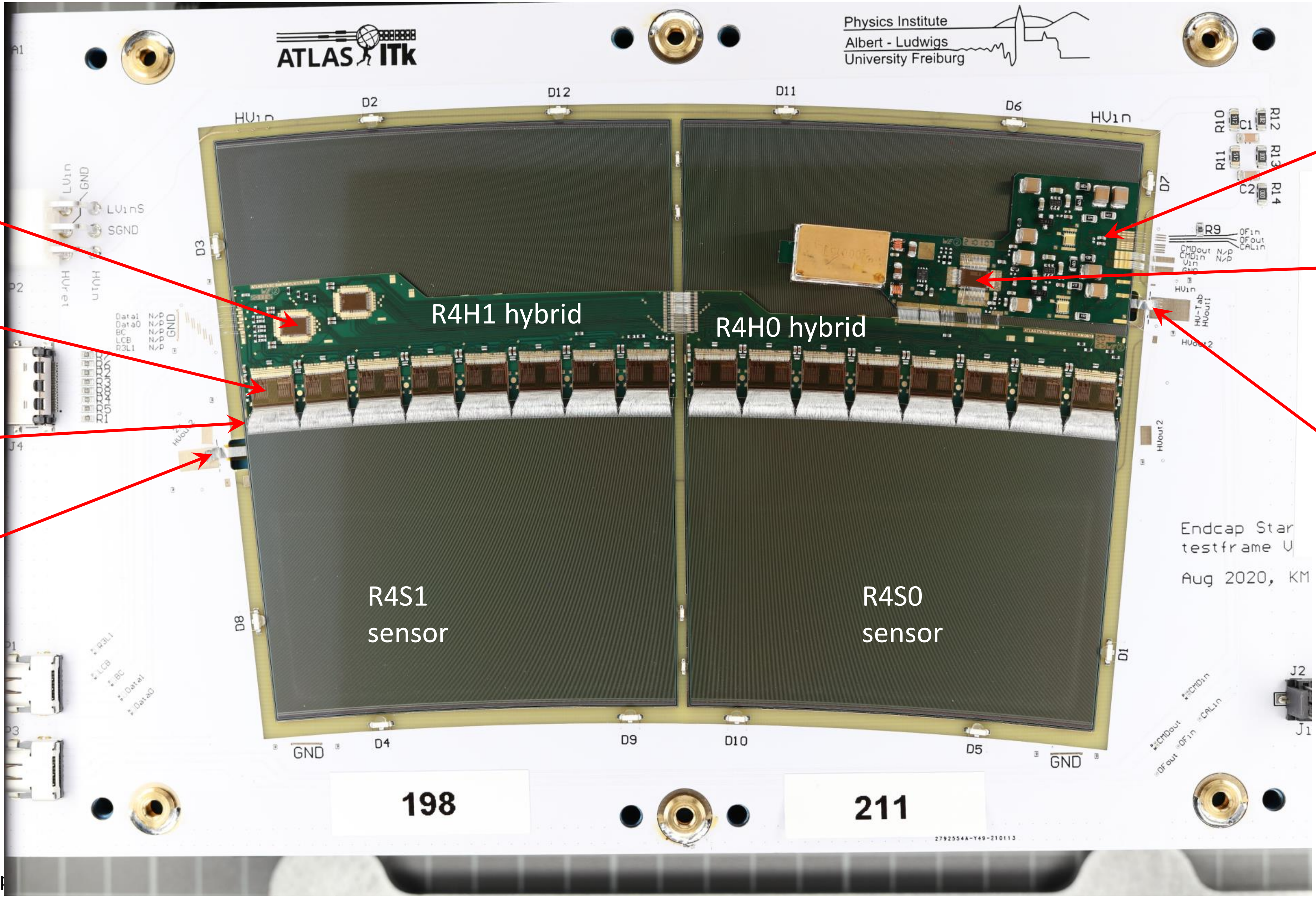


Hybrid controller chips

Front-End chips

Front-end wirebonds

HV tab

Power board

Monitoring chip

HV tab

Radiation tolerance

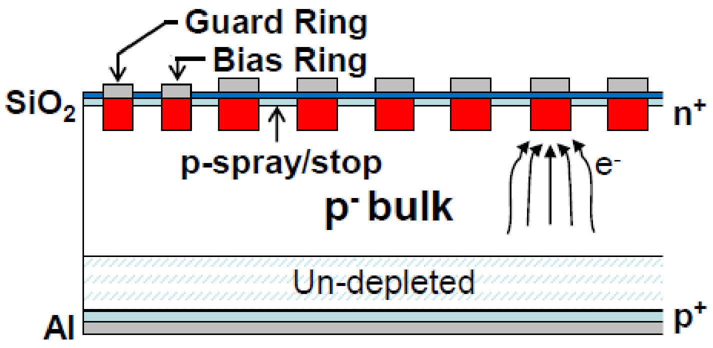
Differentiation factor for microelectronic technologies

Silicon microstrip sensors: n+ strips in p-type FZ substrate (n-in-p)

Faster and more rad-hard than p-in-n

Good signal even under-depleted

Well established technology

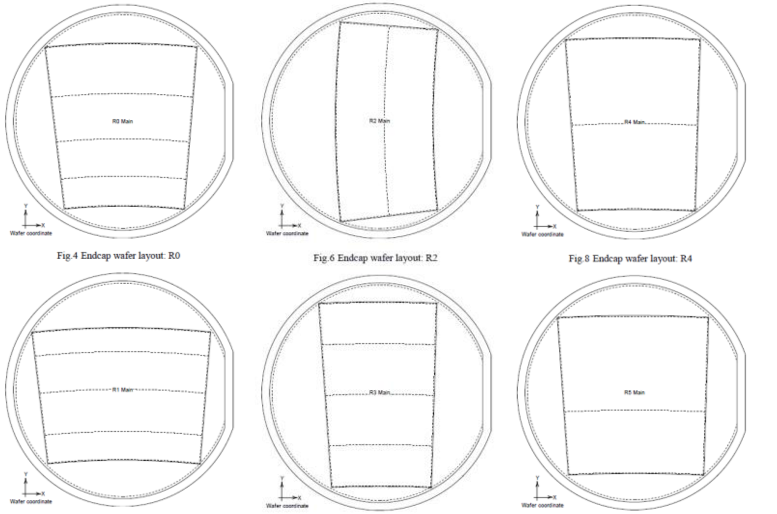


Radiation tolerance

Differentiation factor for microelectronic technologies

Silicon microstrip sensors: n+ strips in p-type FZ substrate (n-in-p)

- 6” wafer technology (~10x10 cm^2)
- Spatial resolution ~ 20 µm
- Time resolution ~ 3 ns



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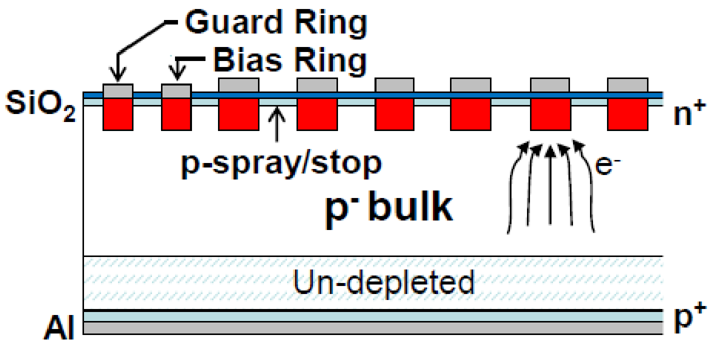

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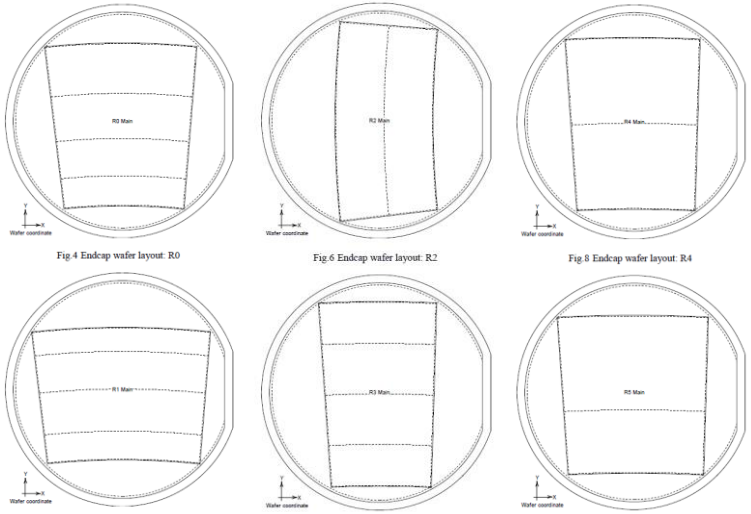

6" wafer technology (~10x10 cm^2)

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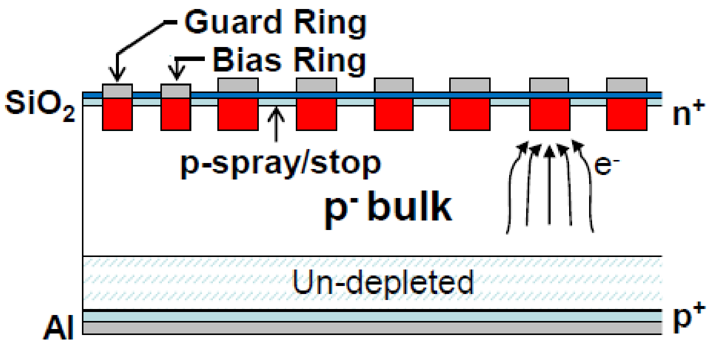
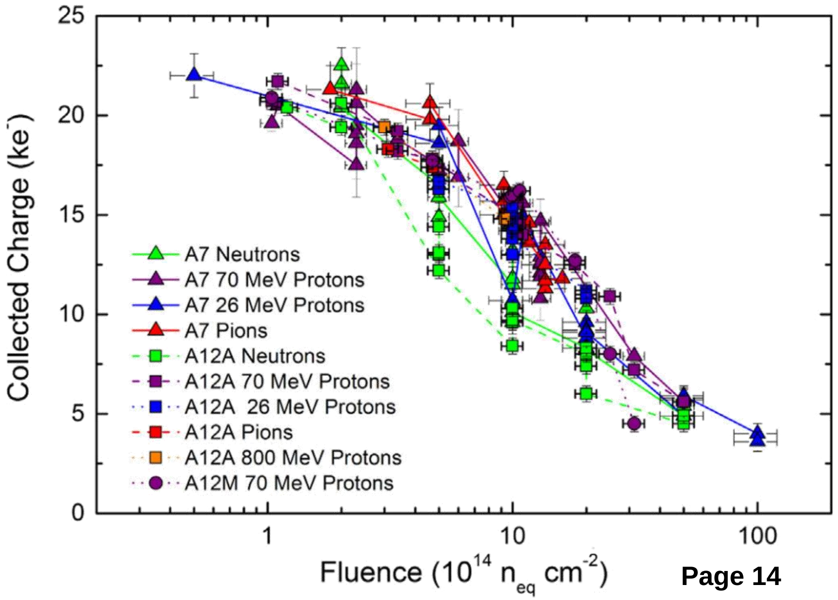


Radiation hardness well understood over the years

Sensors meet specifications after irradiations

RD50



Radiation tolerance

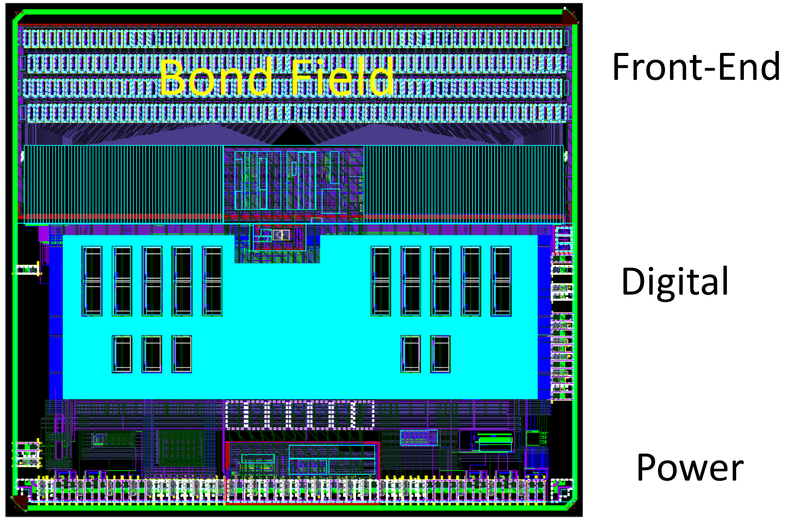
Differentiation factor for microelectronic technologies

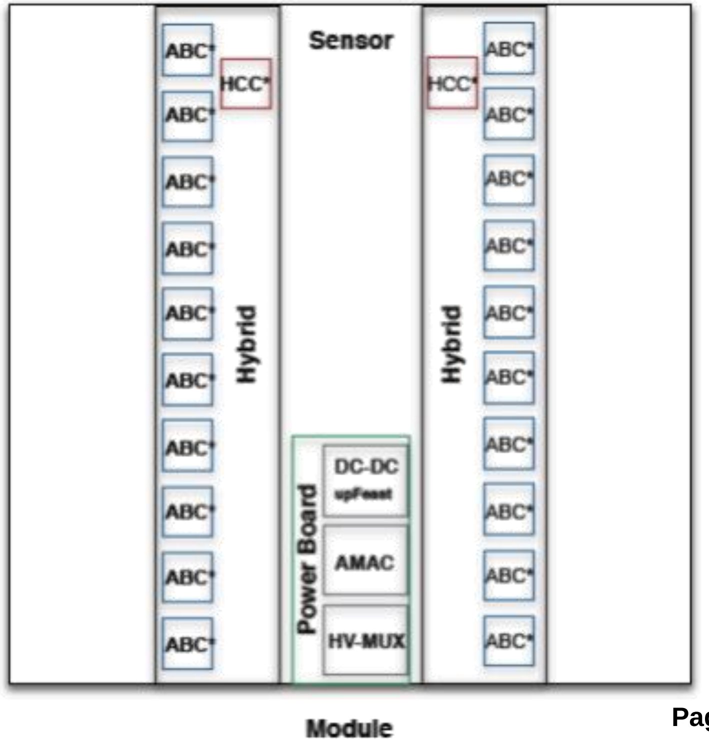
Readout and control electronics: 130 nm CMOS

- Old, but consolidated technology node
- Cost-effective
- Technology continuity guaranteed

ABCStar	HCCStar	AMAC
Front-end chip Binary readout	On-hybrid digital interface chip	On-module monitoring and control chip

ABCStar





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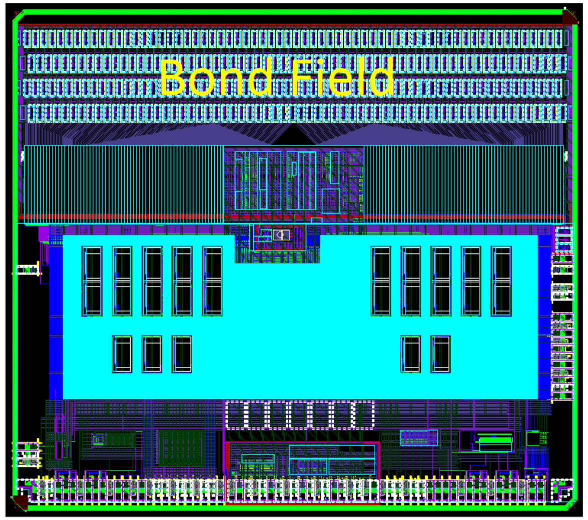
ABCStar	HCCStar	AMAC
Front-end chip Binary readout	On-hybrid digital interface chip	On-module monitoring and control chip

- Radiation-hard by design
- Enclosed layout transistor geometry to mitigate total dose effects
- Triplication logic to mitigate Single Event Upsets (SEUs)
→ "Majority wins"

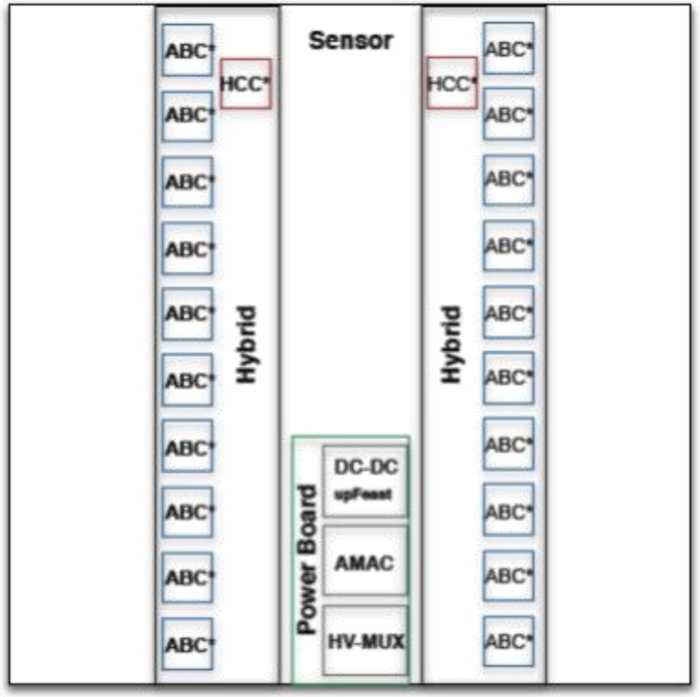
ABCStar



Front-End

Digital

Power



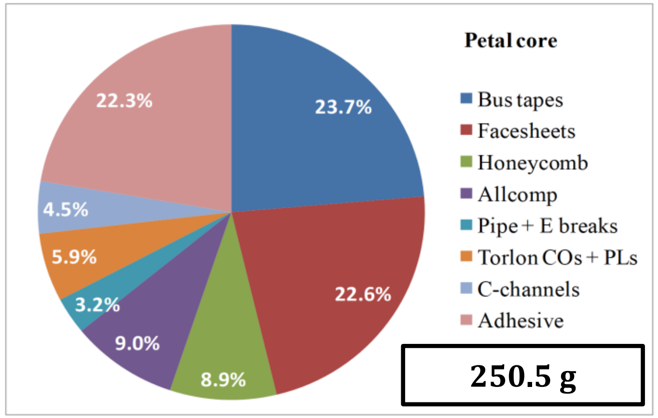
Module

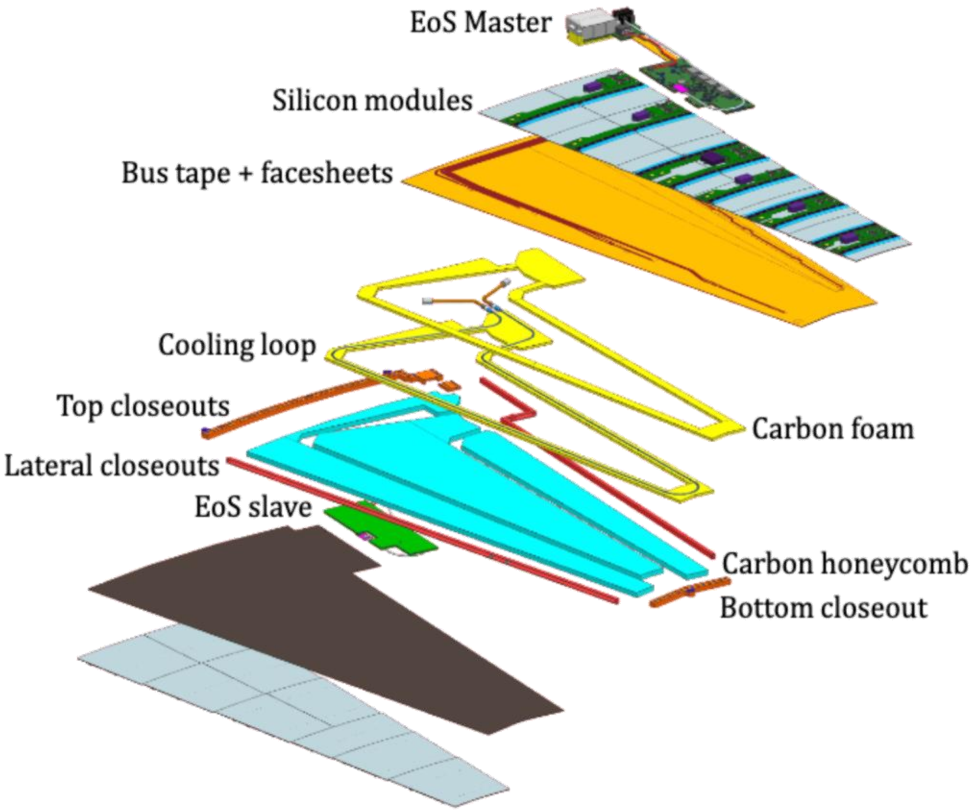
Low mass support structures

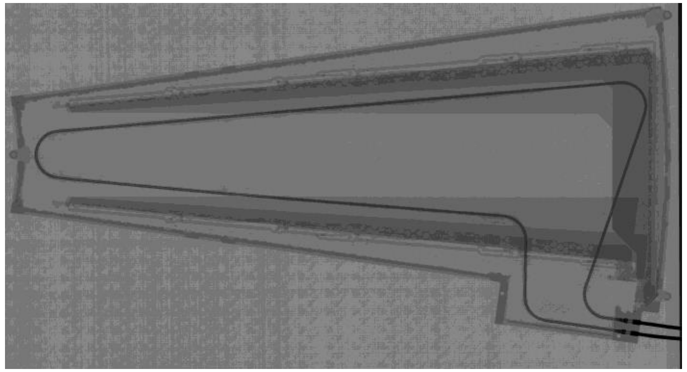
Minimizing the material of support structures

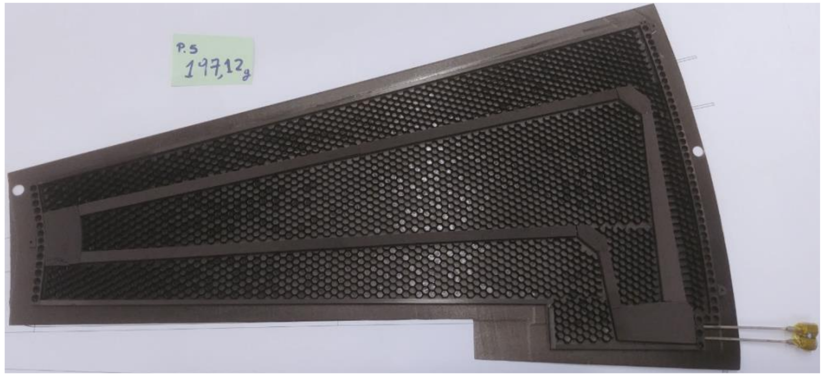
Petal “cores”: carbon fiber-based sandwich structures with embedded cooling

- ✓ Rigidity and stability
- ✓ Mechanical precision
- ✓ Thermo-electrical performance
- ✓ Low mass





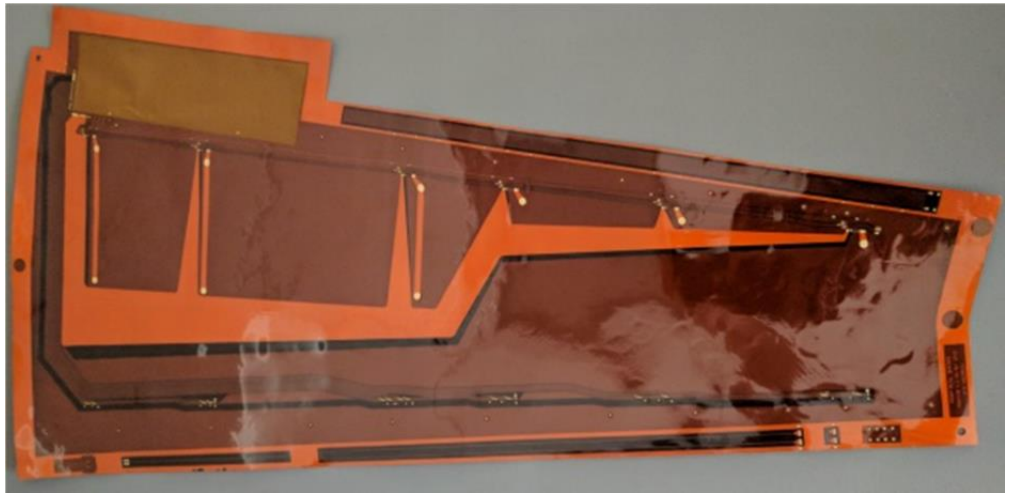




Low mass support structures

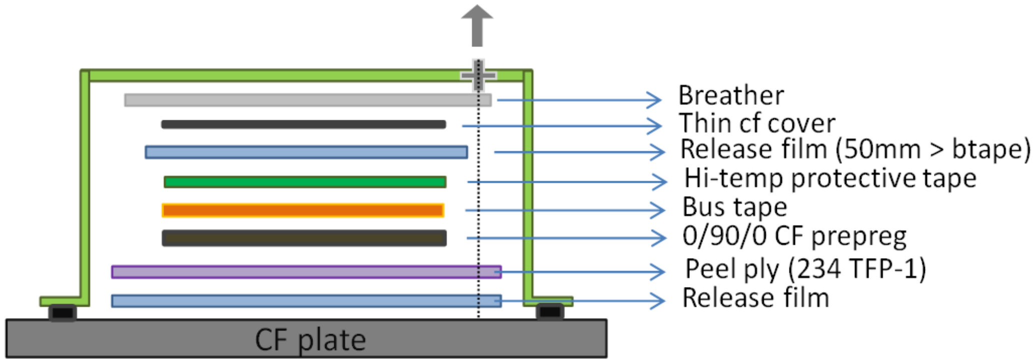
"Facesheets": bus tapes co-cured with CFRP pre-preg

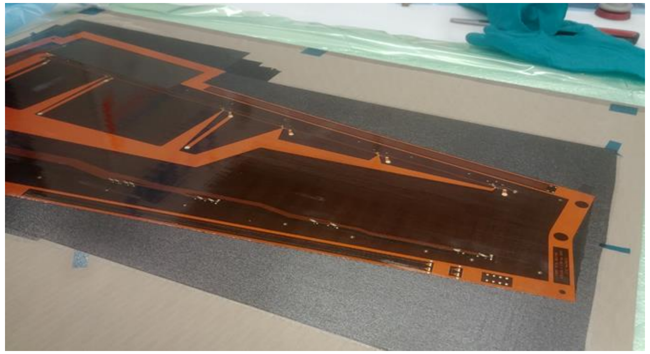
185 µm thick



Optimized for 640 MHz differential signals

Co-cured together in autoclave with lay-up of K13C2U/EX1515 CF pre-preg



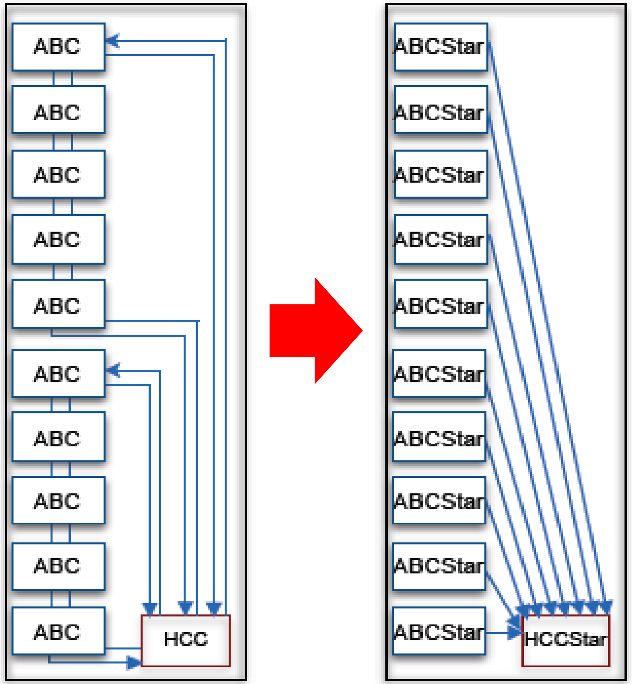


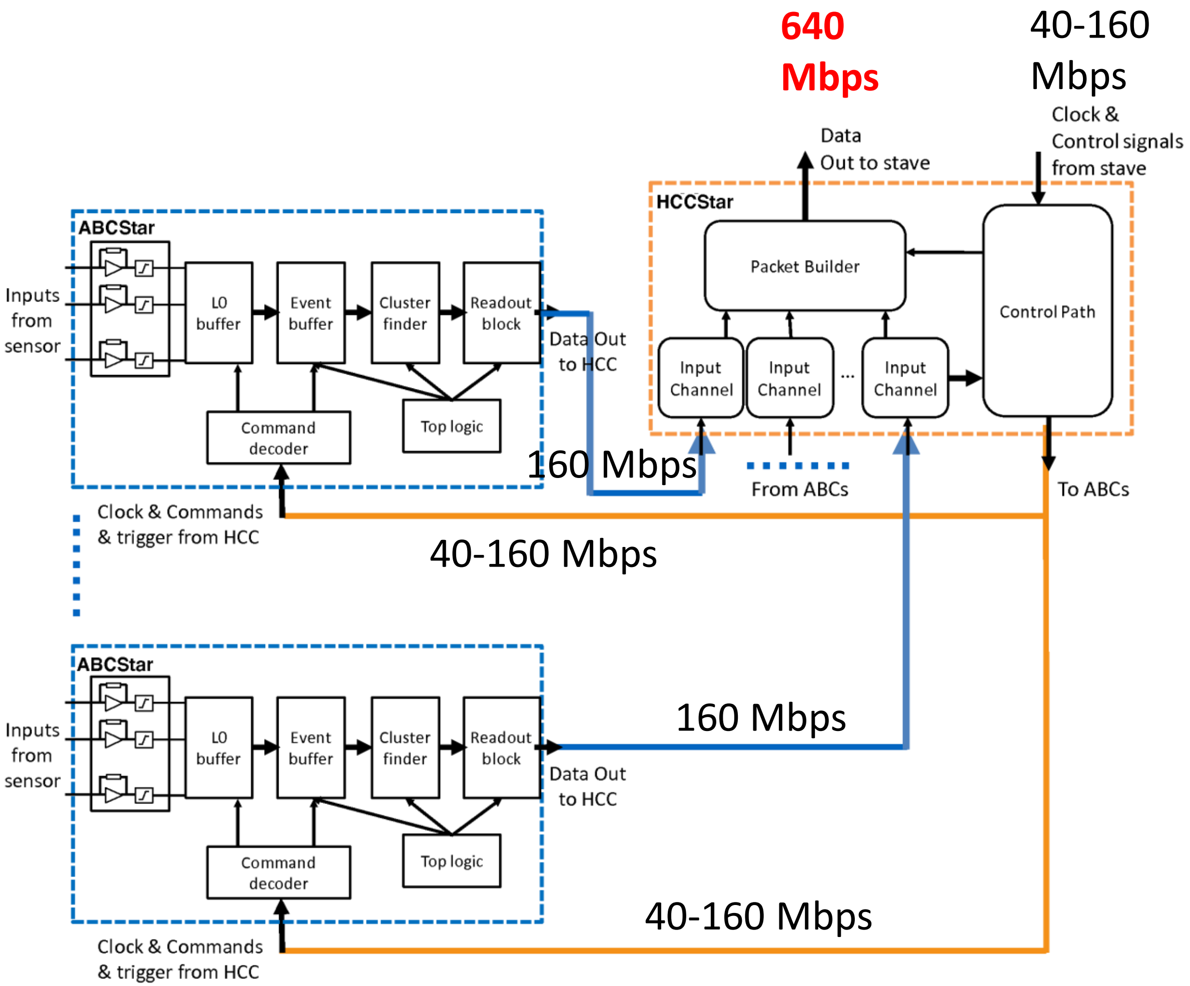
High speed

Coping with 1MHz trigger rates

The STAR architecture

640Mbit/s downlinks from each hybrid controller chip

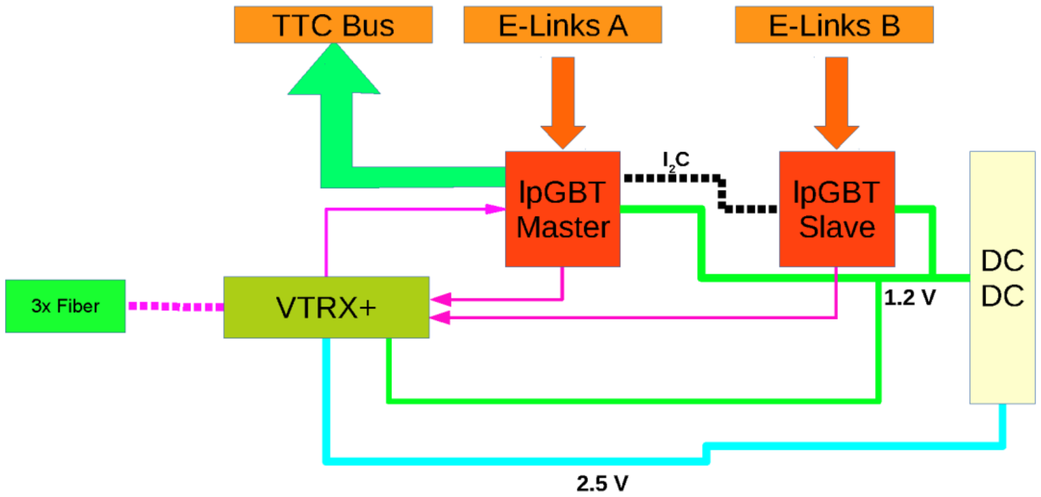




High speed

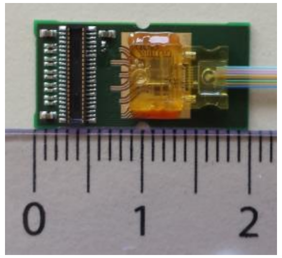
Data concentrator boards to the outside world

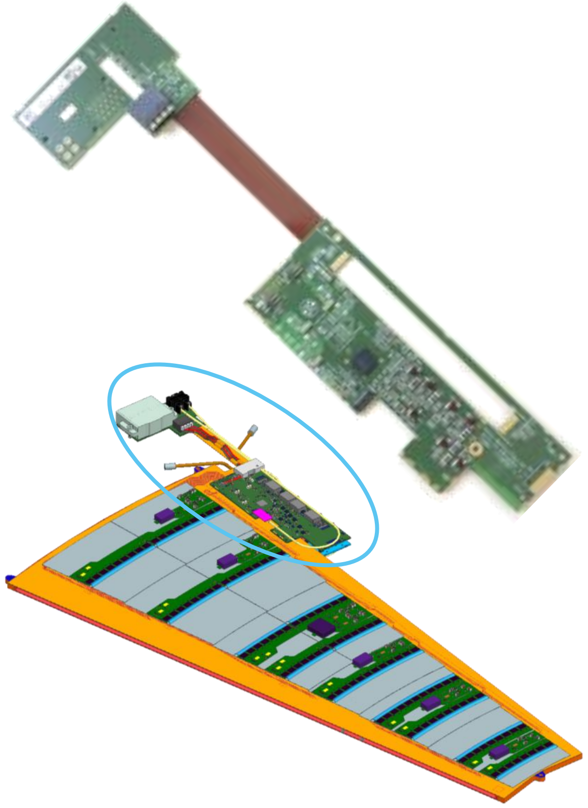
“End of Substructure” board: one per petal side

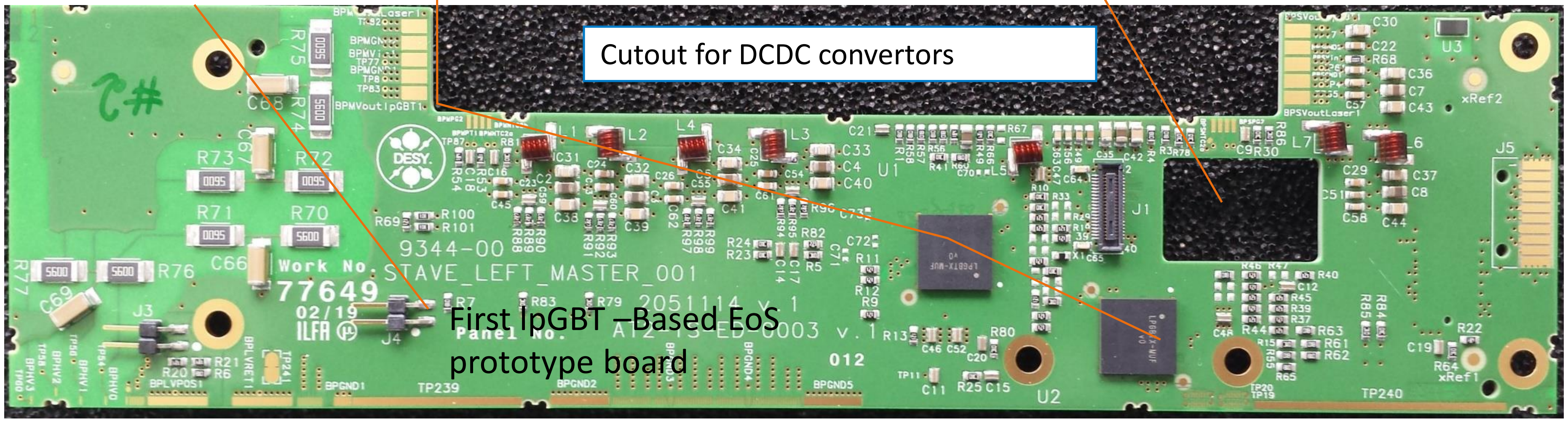


lpGBT: 10GBit/s transceiver, data aggregator

VTRX+: rad-hard optical link + fiber





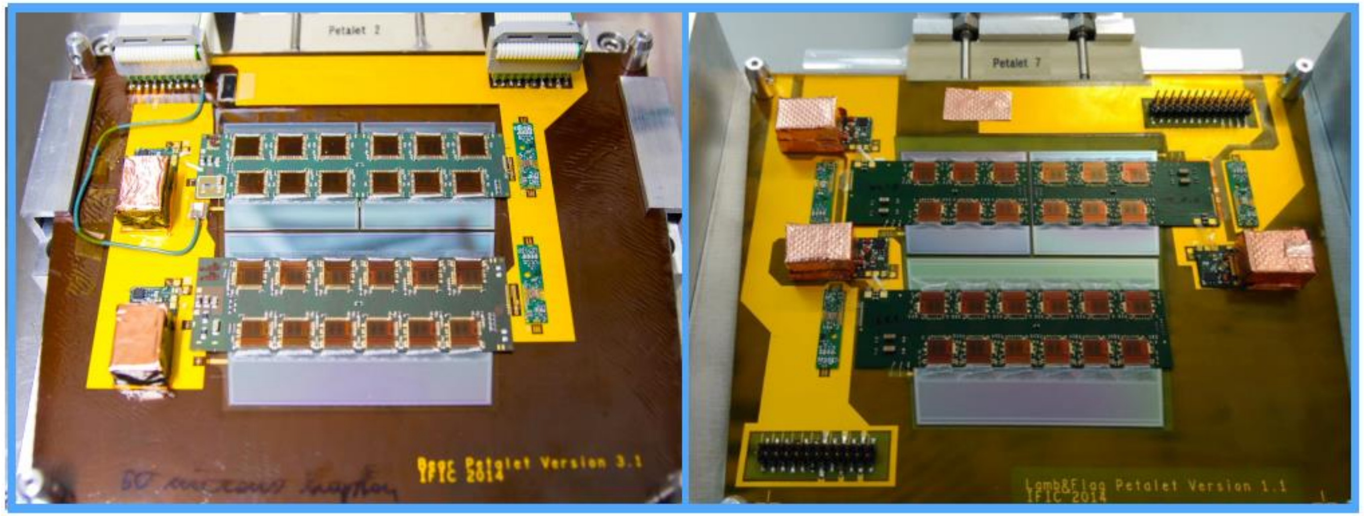


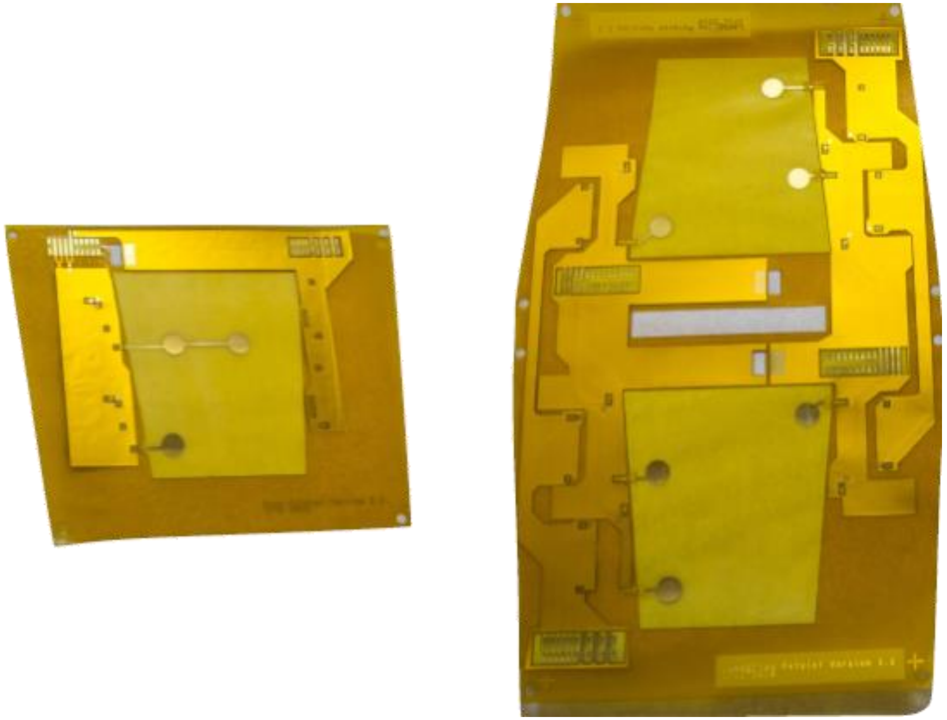
The “petalets”

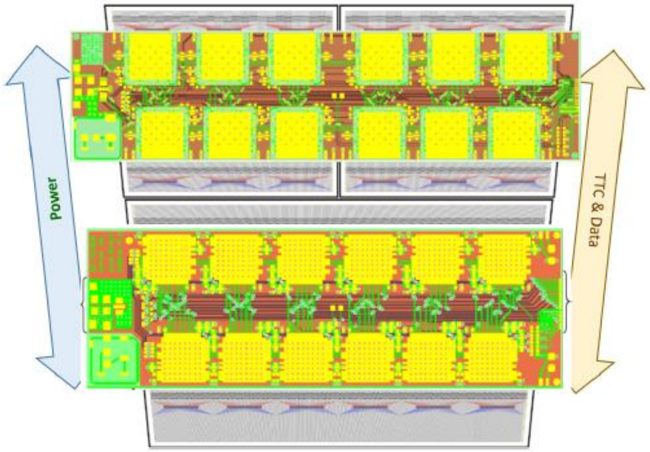
Multiple implementations of downlinks and split modules

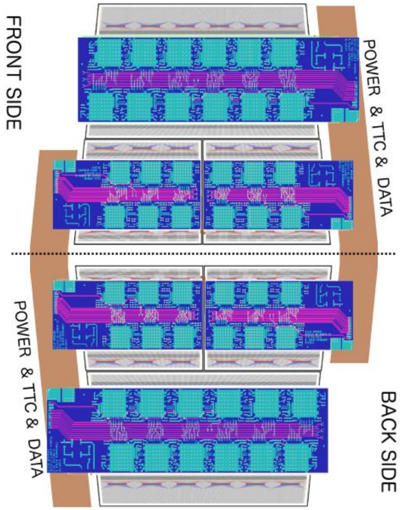
Split readout: the “bear”

Common readout: the “lamb and flag”







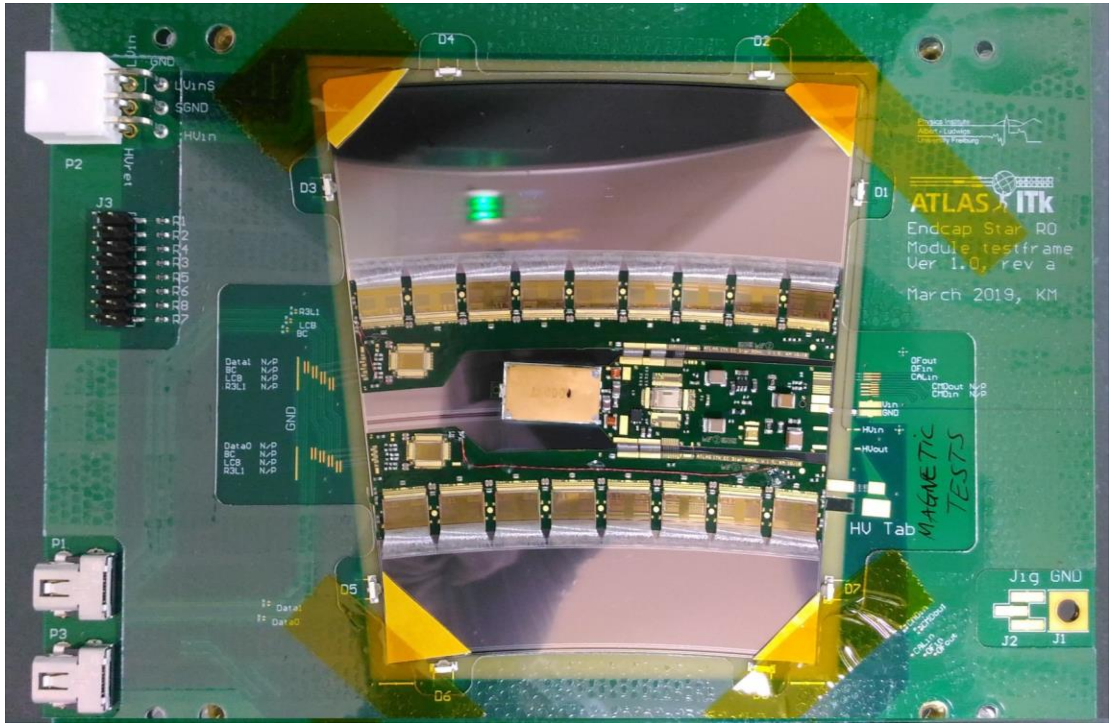


Split readout scheme proved to be less noisy and easier to manufacture mechanically

S. Kuehn et. al, JINST13 (03), pp. T03004 (2018)

Low power

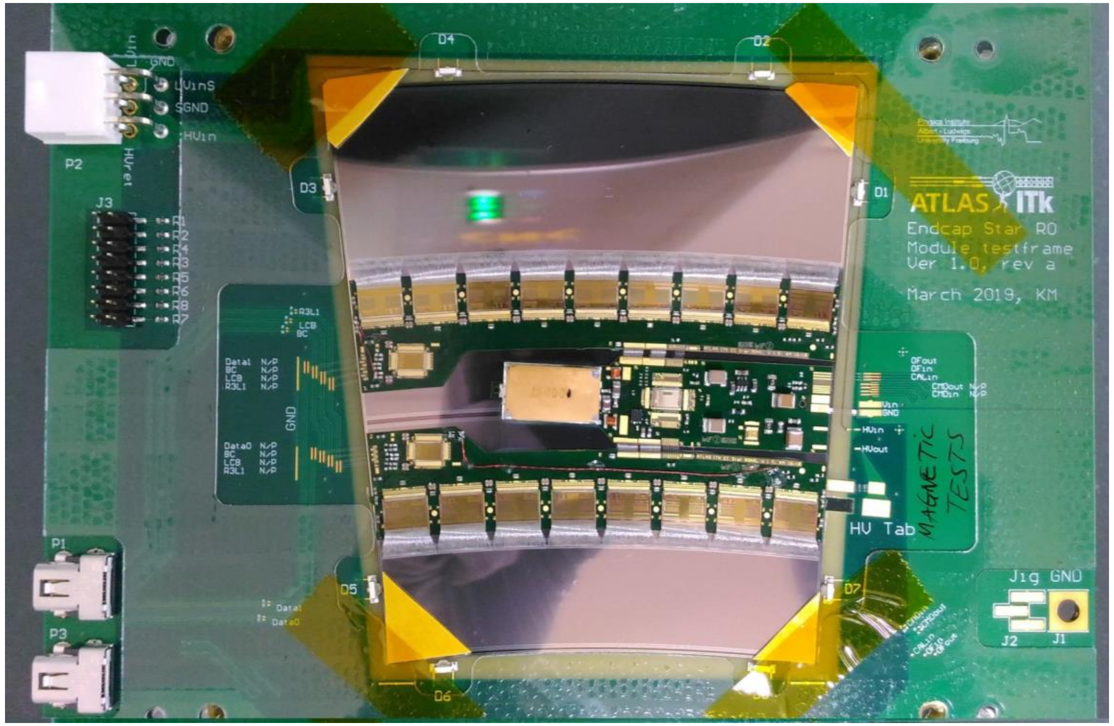
Minimizing power dissipation and cable losses



~65 W per petal
(~57k readout channels)
→ 1.1 mW/ch
…in one cable

Low power

Minimizing power dissipation and cable losses



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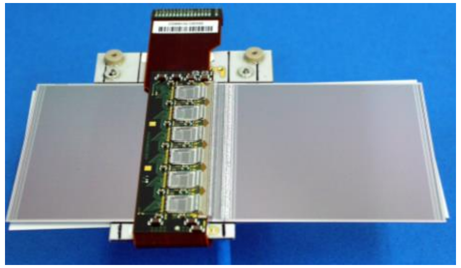
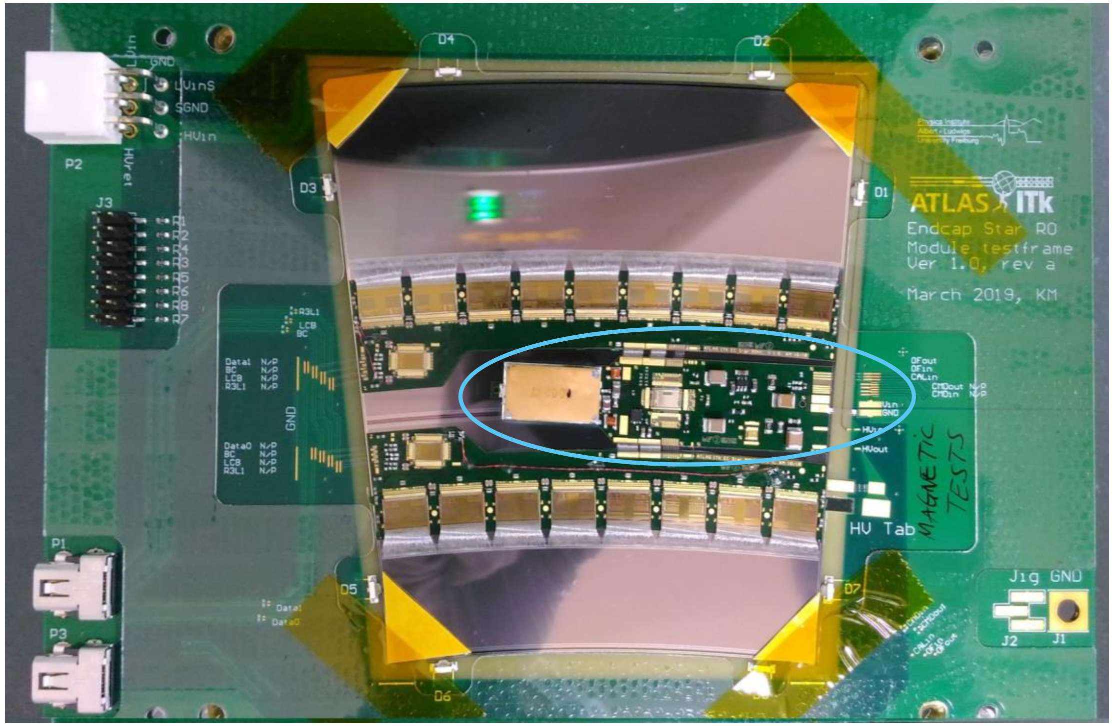
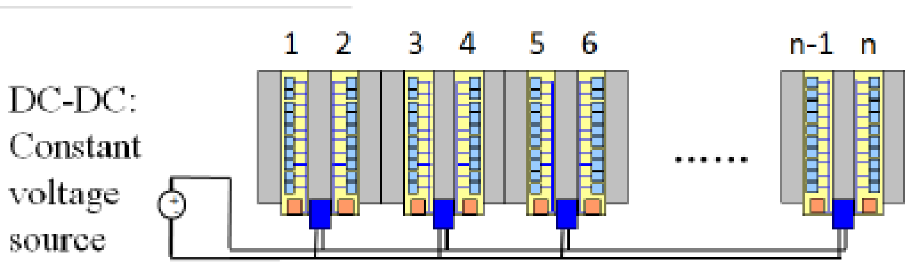


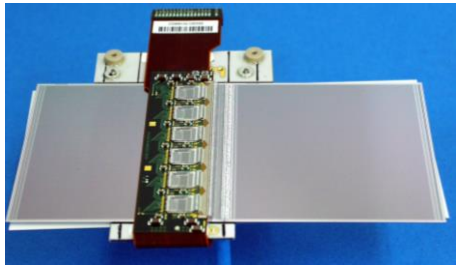
~5.1 W per SCT module
(~ 1.5k readout channels)
→ 3.3 mW/ch
…in one cable

Low power

Minimizing power dissipation and cable losses

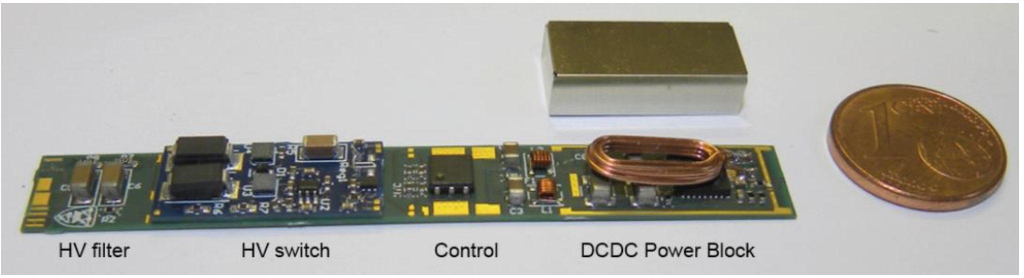






~61 W per petal
(~57k readout channels)
→ 1.1 mW/ch
…in one cable

~5.1 W per SCT module
(~ 1.5k readout channels)
→ 3.3 mW/ch
…in one cable



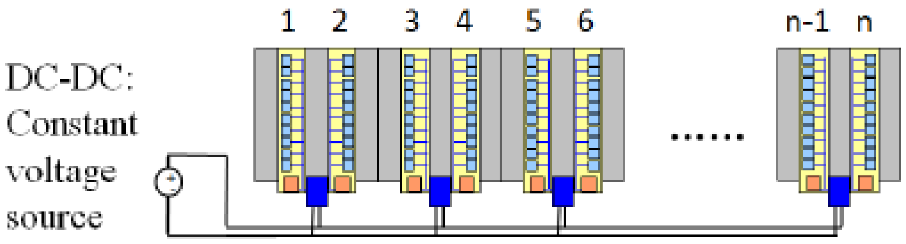
Power board:

Buck DC-DC converter with switch power transistors

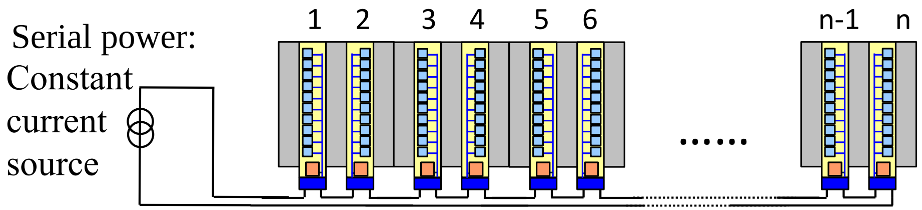
LV and HV control circuitry and monitoring

Powering of ITk strips modules

A years long development…

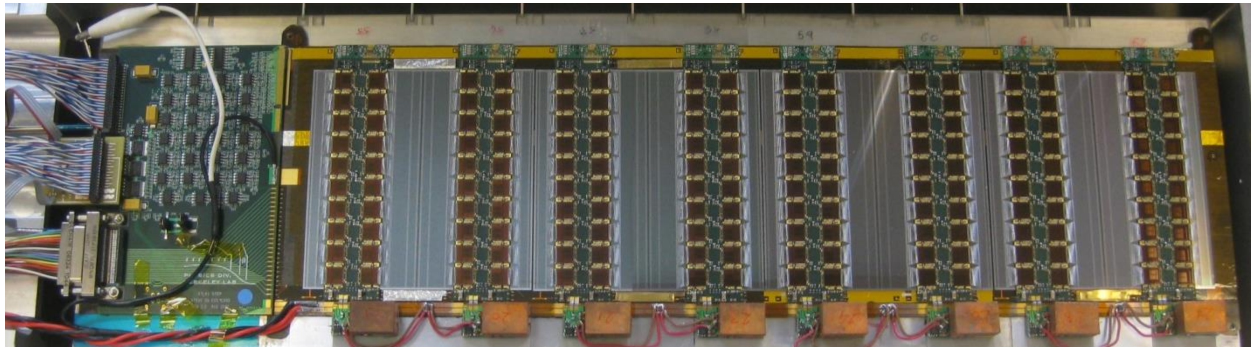


Total current = n x (I/r)
Total voltage = V x r

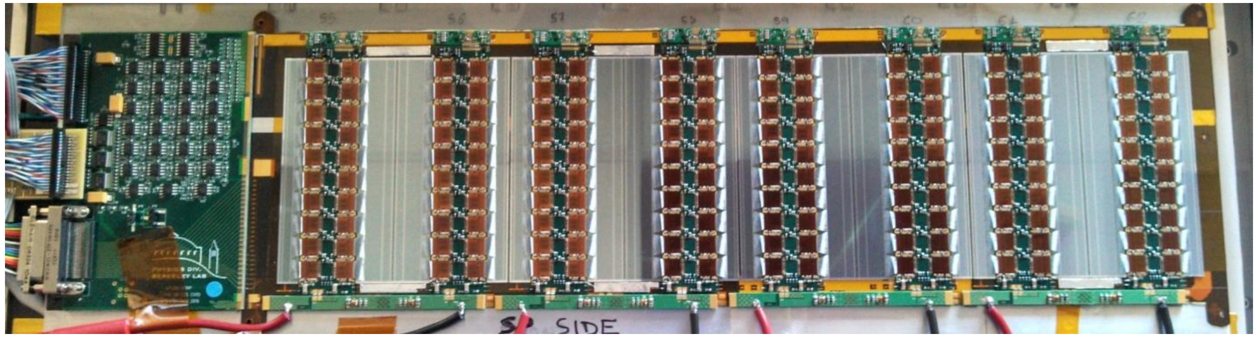


Total current = I
Total voltage = V x n

Shieldless "stavelet"



DC-DC side



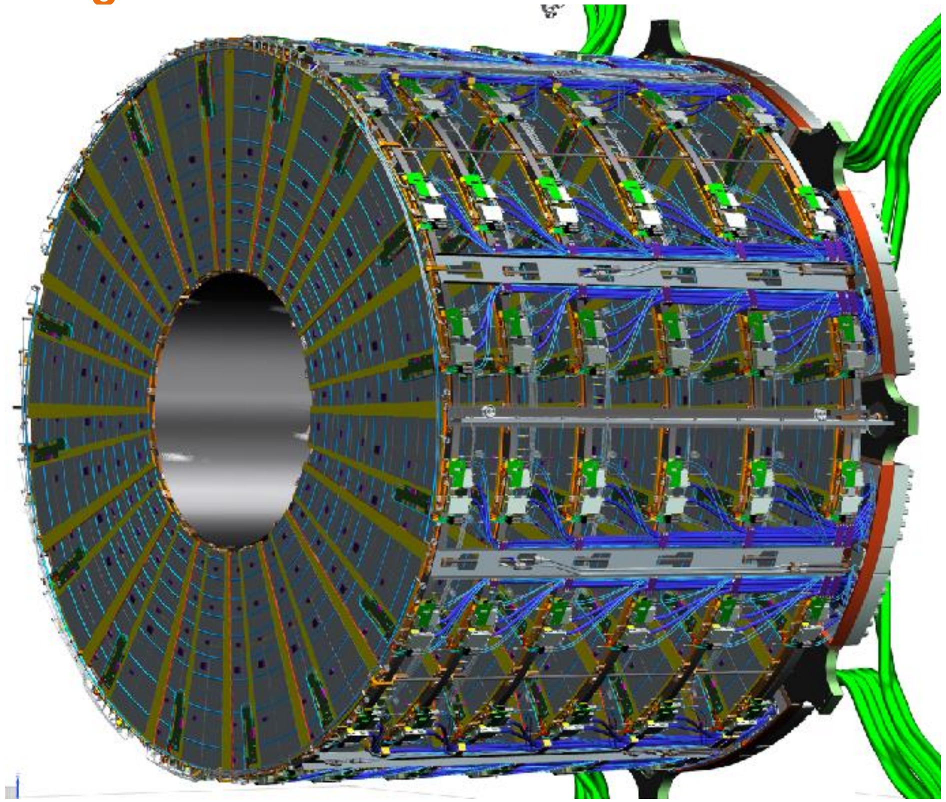
Serial powering side

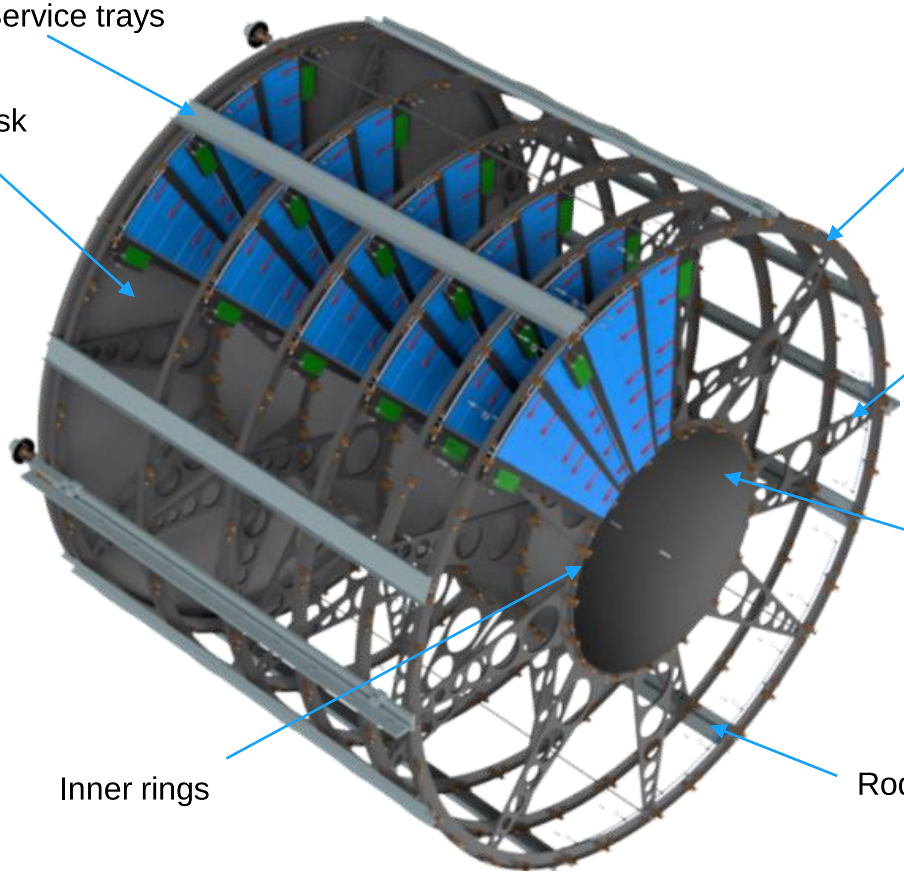
Sensitivity of SP to CM and DT noise and lack of efficient option for EC led to DC-DC power baseline

S. Diez et. al, JINST 9 (03), P03012 (2014)

Where does it all go?

Integration and services





Global structure mostly made out of CFRP or CFRP sandwiches

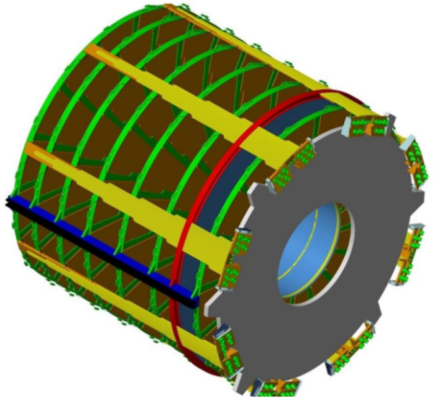
Modular electrical and services

Low mass, low cost, low power

“Blades” or “spokes”?

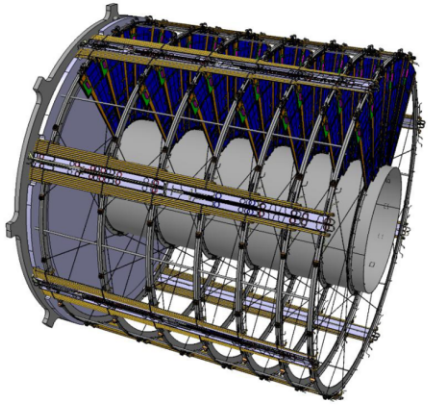
A slide from six years ago…

Endcap integration structures: 2 options



CF blades are single units
CF structure to hold blades
Blades with petals are mounted in structure
Most challenging is to precisely mount blades

The two concepts are not so different
Work on services, etc, shared between the two concepts
Both concepts benefit by comparing the two approaches
Internal review in order to fix the baseline design will occur in May 2016



CF wheels with spokes are single units.
Wheels are put on inner tube.
Petals are mounted on wheels.
Most challenging is the production of the wheels

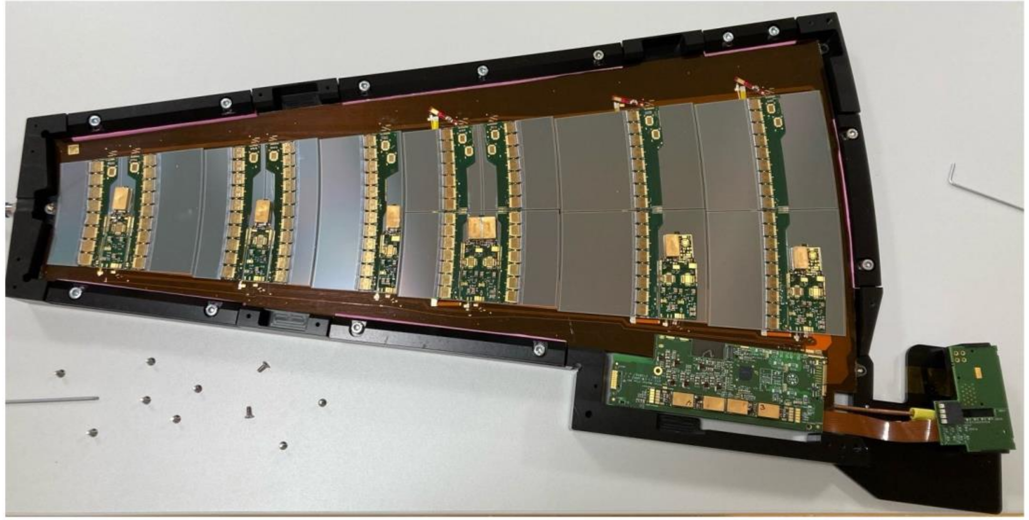
06 Apr 2016 | S. Diez, 9th Terascale detector workshop (Univ. Freiburg) | 27

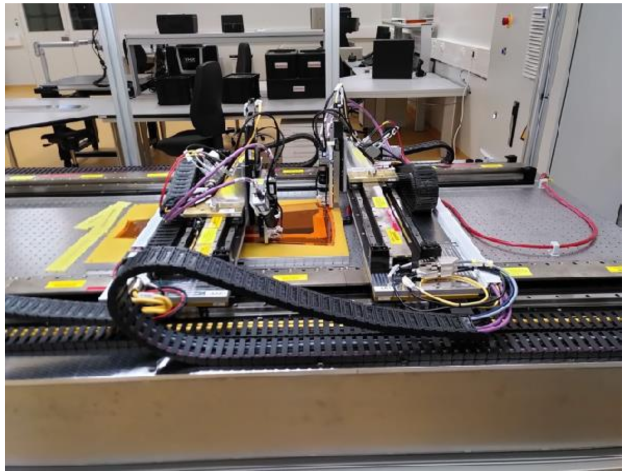
A hybrid solution was adopted

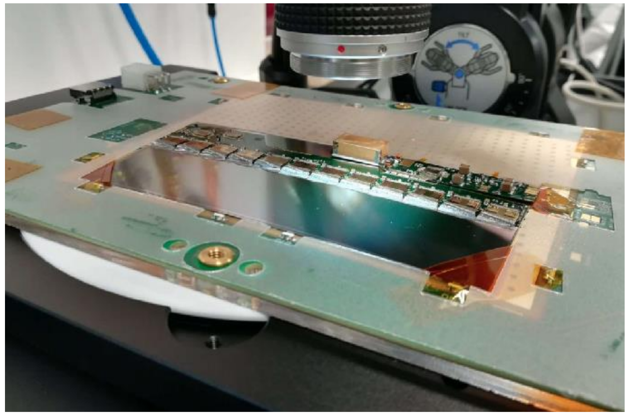
“Blades” on “wheels”, kinematic mount of petals

Where are we?

Pre-production is in full swing







Infrastructures and tooling ready

Production processes under qualification

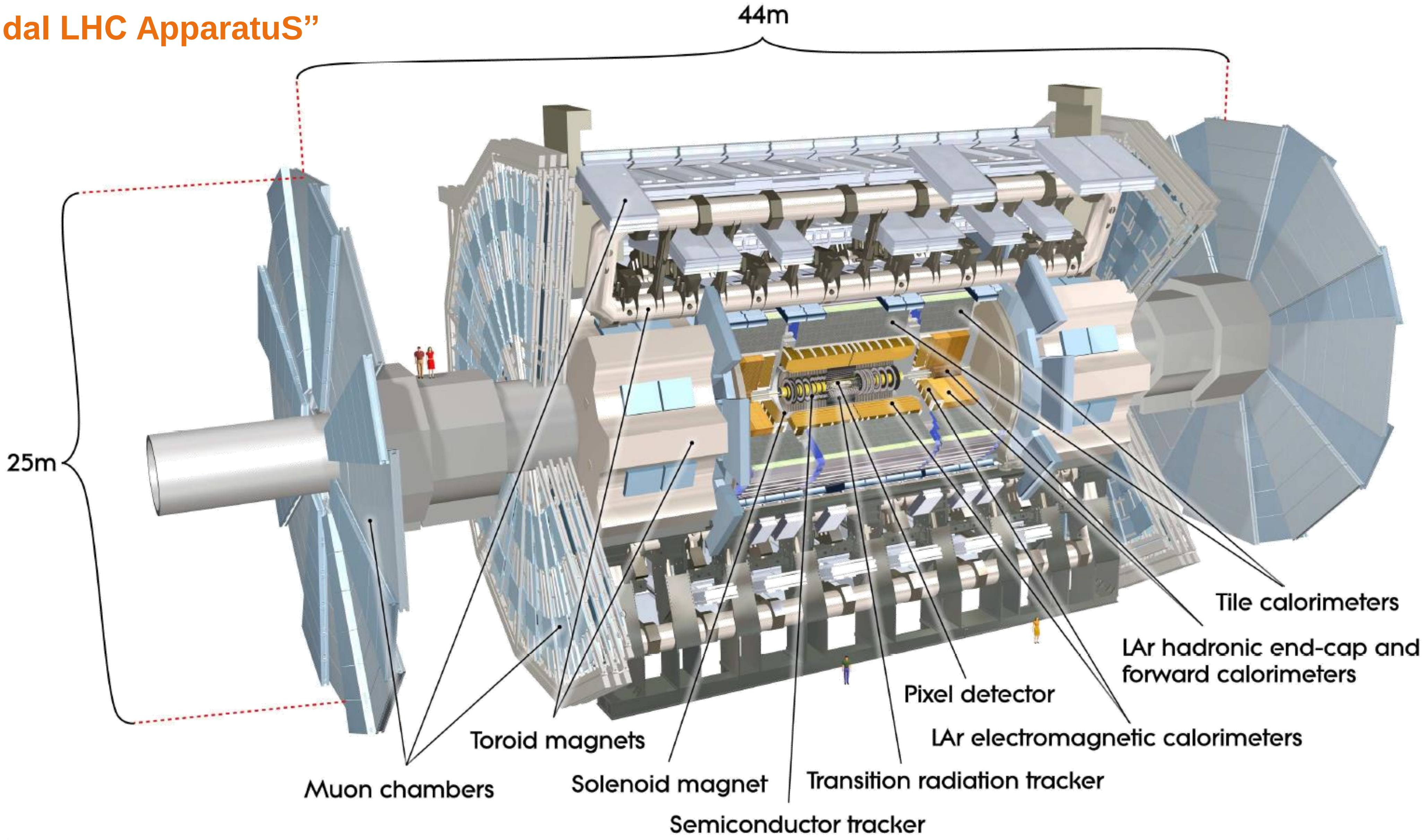
Sensor and global structures already in production

End-cap arrival at CERN ~ end 2025

Thank you

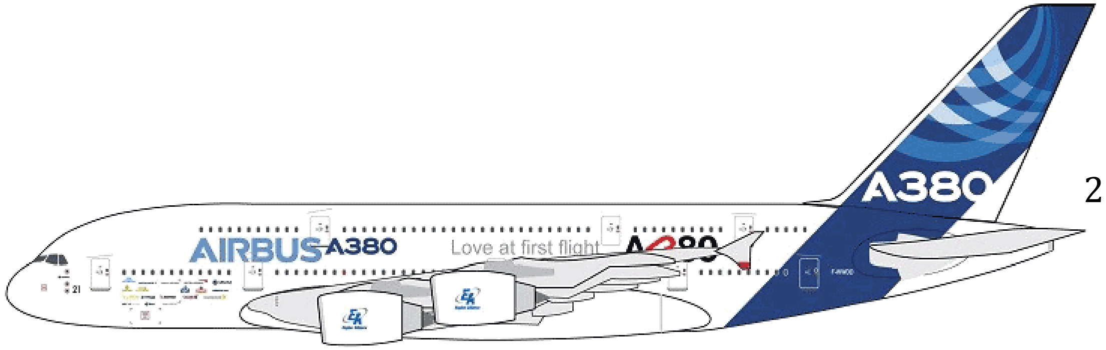
The ATLAS spectrometer

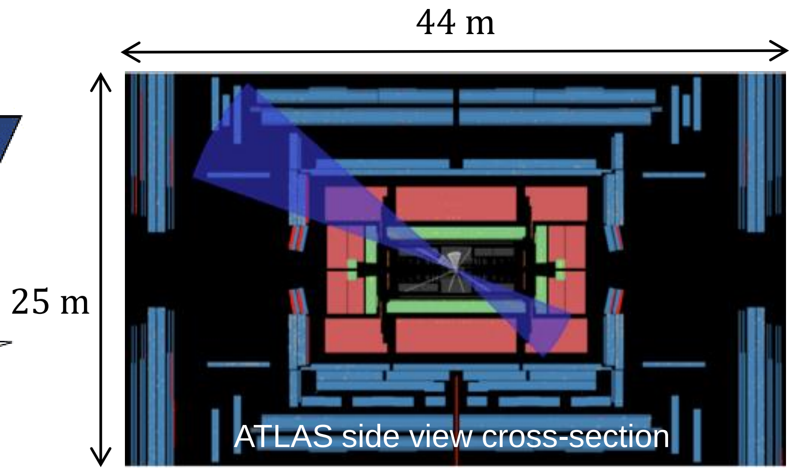
“A Toroidal LHC ApparatuS”

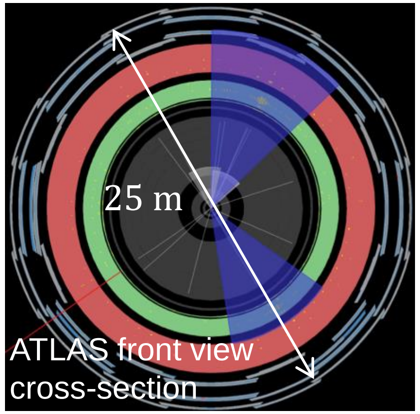


The ATLAS spectrometer

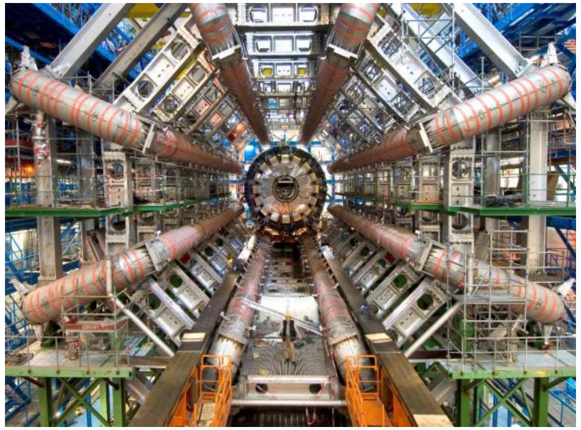
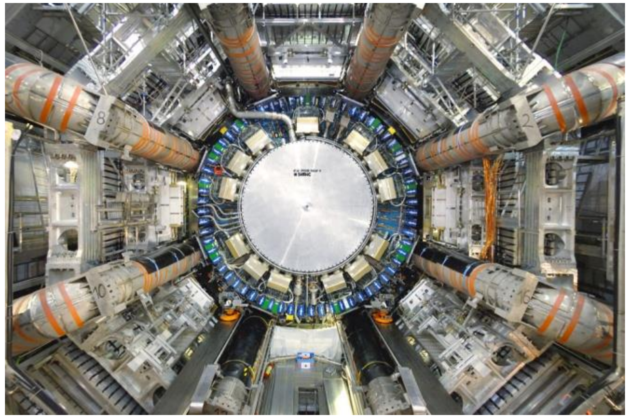
A meaningful size comparison

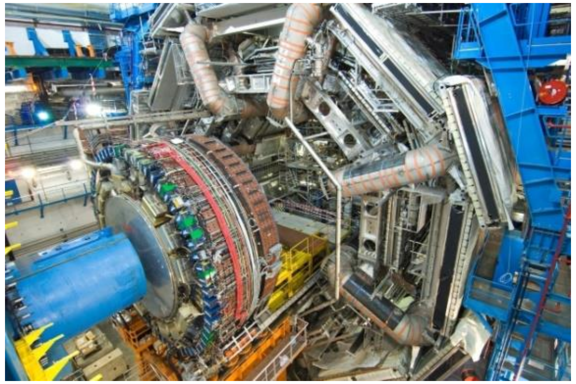
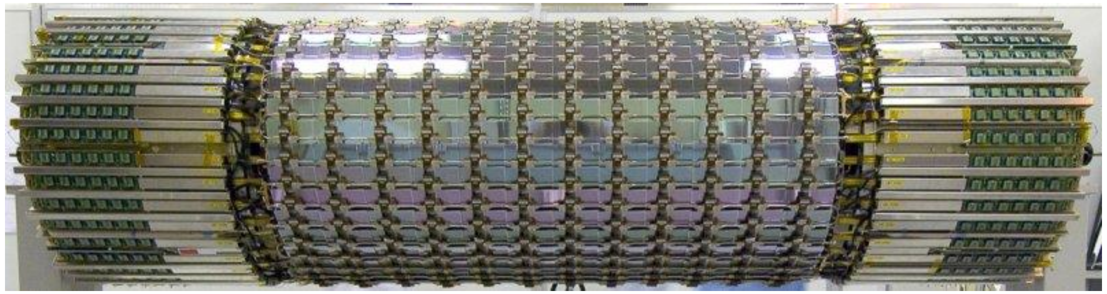
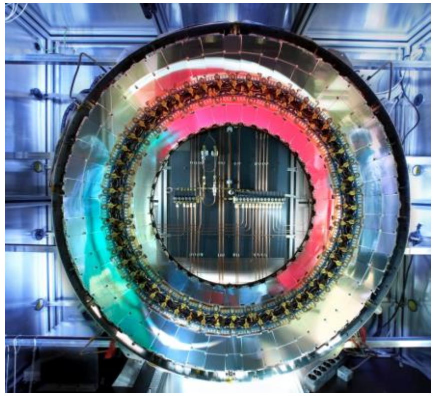
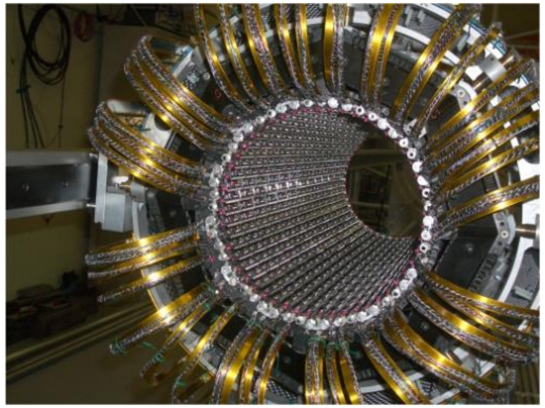


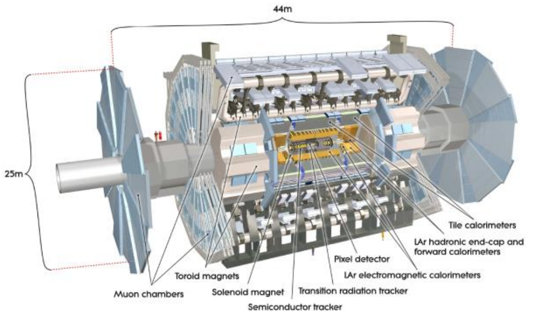




The ATLAS spectrometer

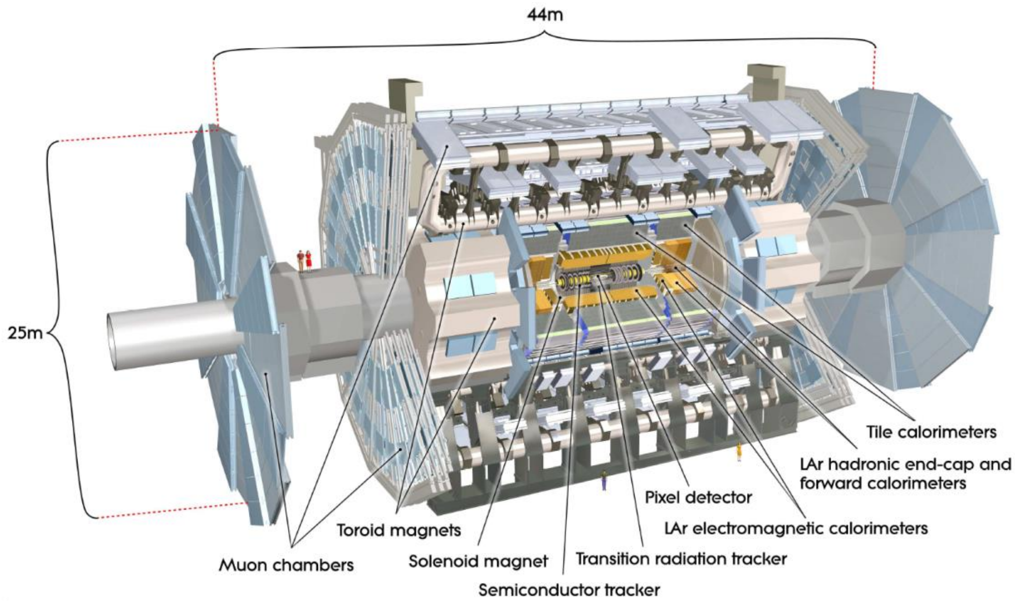



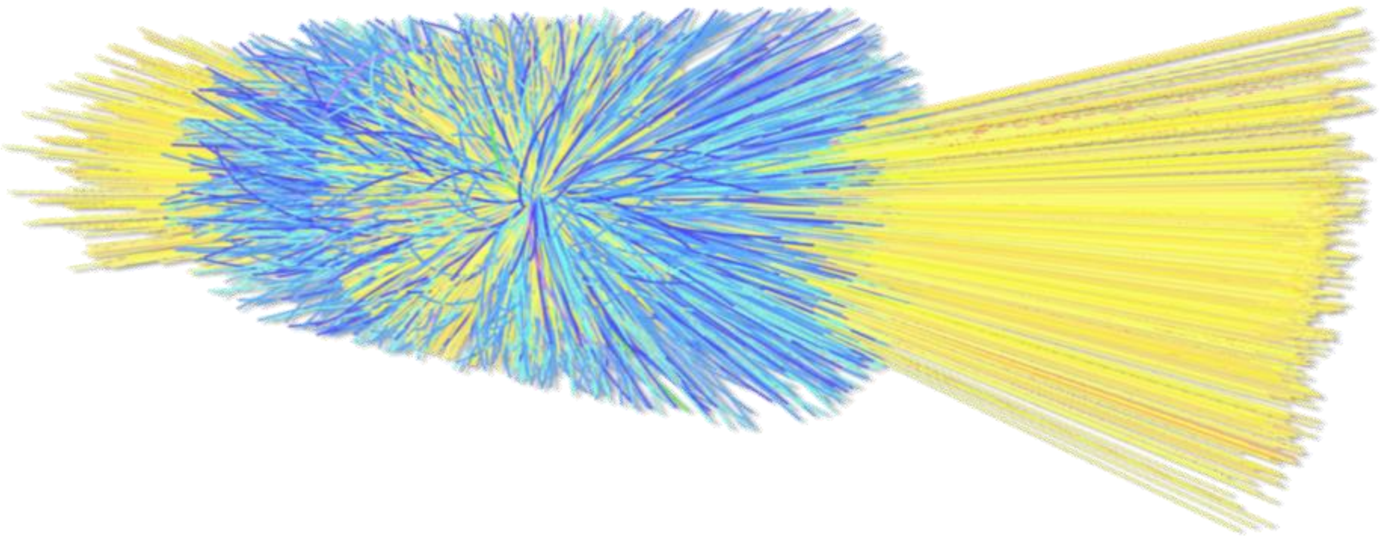







Collisions at the HL-LHC

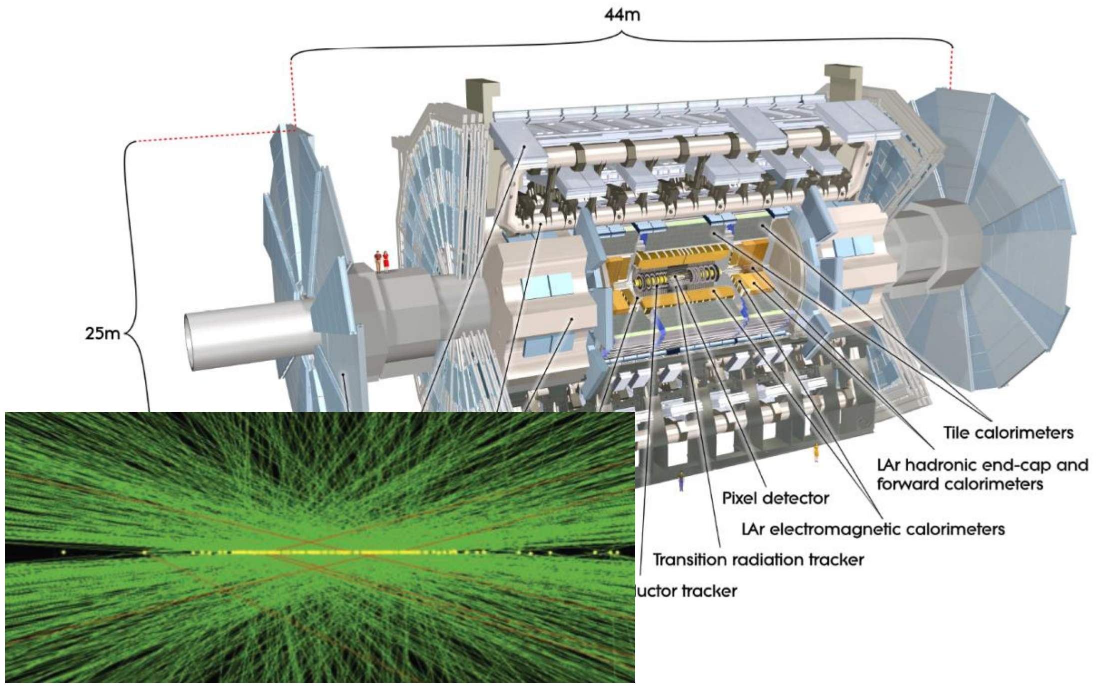
Increasing the luminosity tenfold

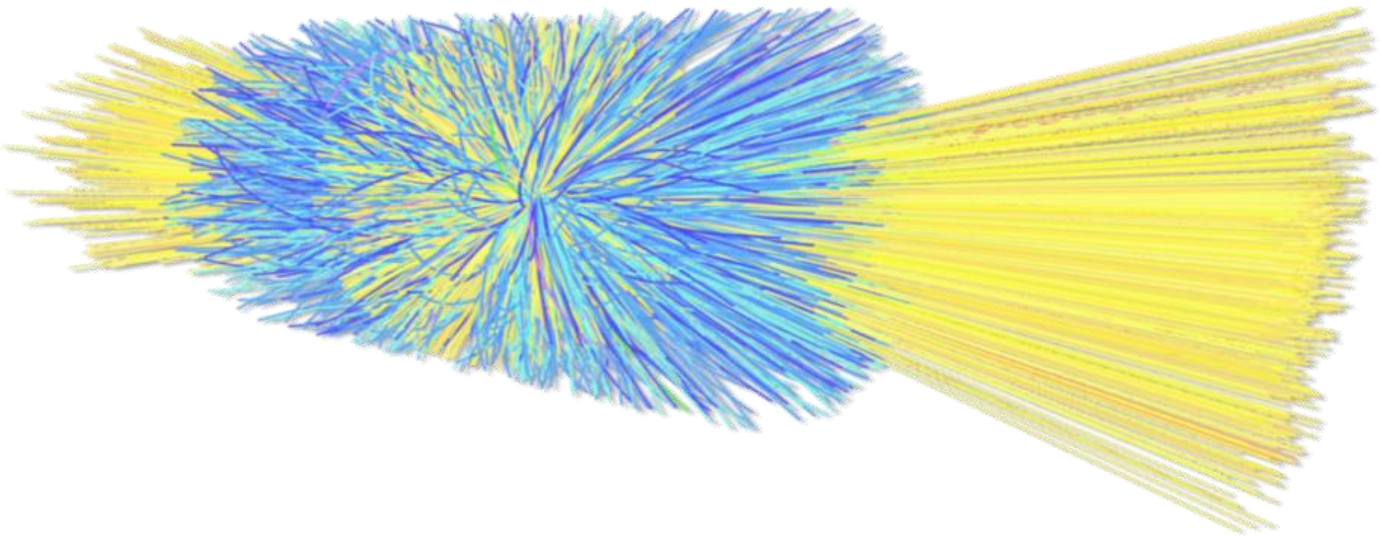




Collisions at the HL-LHC

Increasing the luminosity tenfold



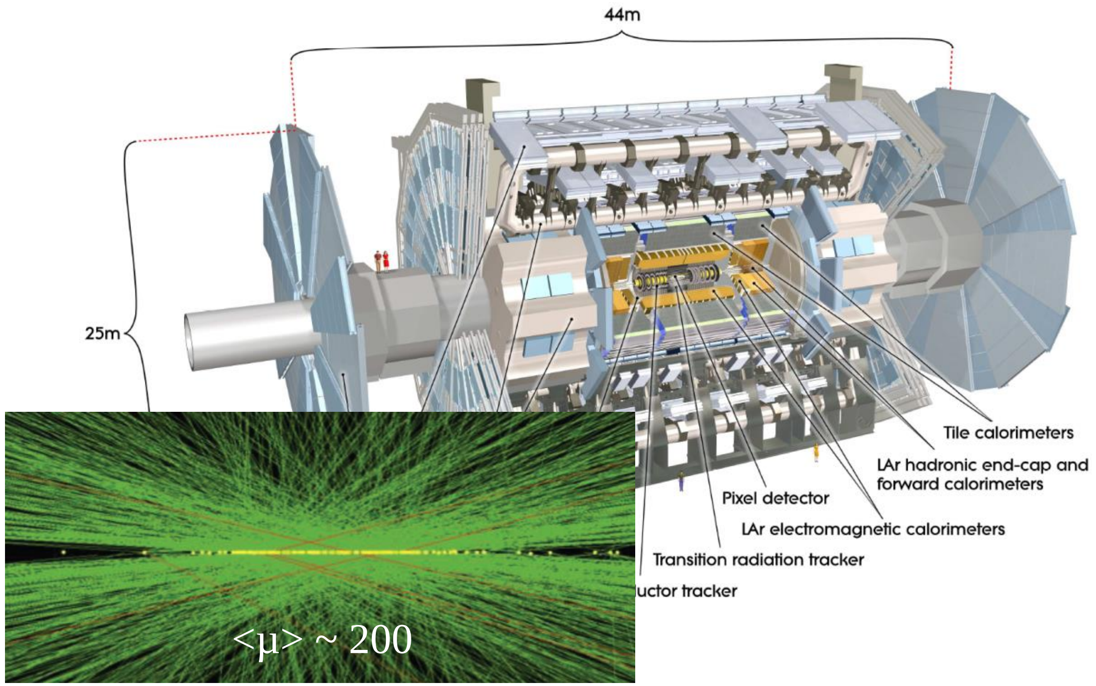


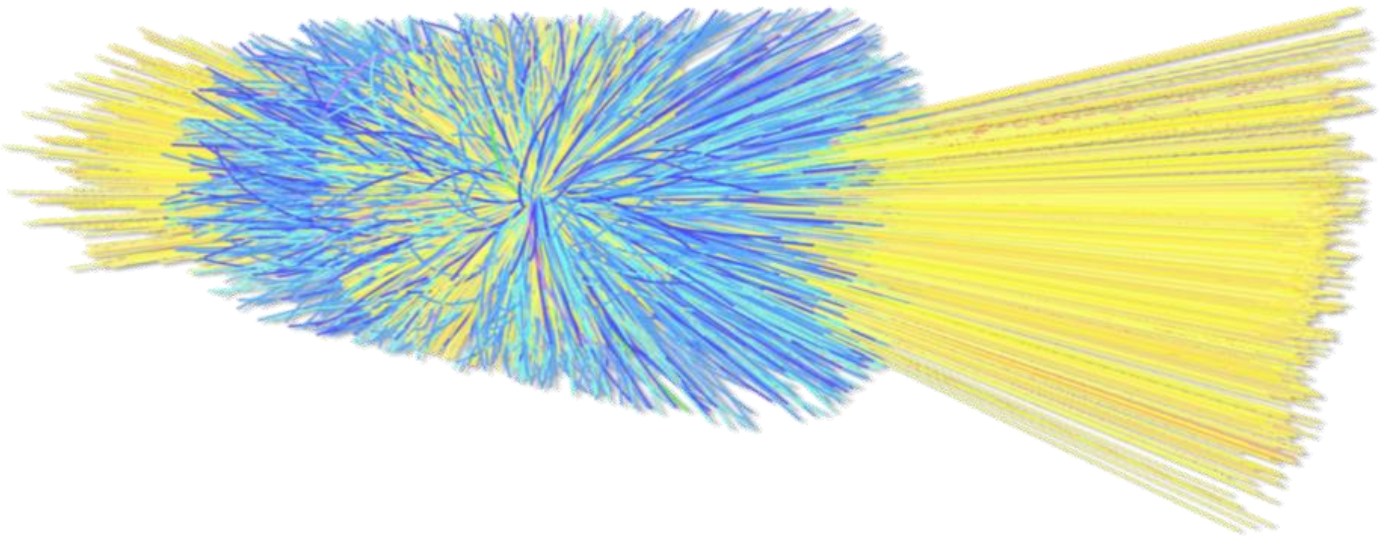
Increased instantaneous luminosity
$10^{34}\ cm^{-2}s^{-1} \rightarrow 5\text{-}7.5x\ 10^{34}\ cm^{-2}s^{-1}$
and pp interaction per bunch crossing
$25 \rightarrow 200$

Increased integrated luminosity
$300\ fb^{-1} \rightarrow 3000\text{-}\ 4000\ fb^{-1}$

Collisions at the HL-LHC

Increasing the luminosity tenfold





Increased instantaneous luminosity
10^{34} $cm^{-2}s^{-1}$ $\rightarrow$ 5-7.5x 10^{34} $cm^{-2}s^{-1}$
and pp interaction per bunch crossing
25 $\rightarrow$ 200

Higher data rate

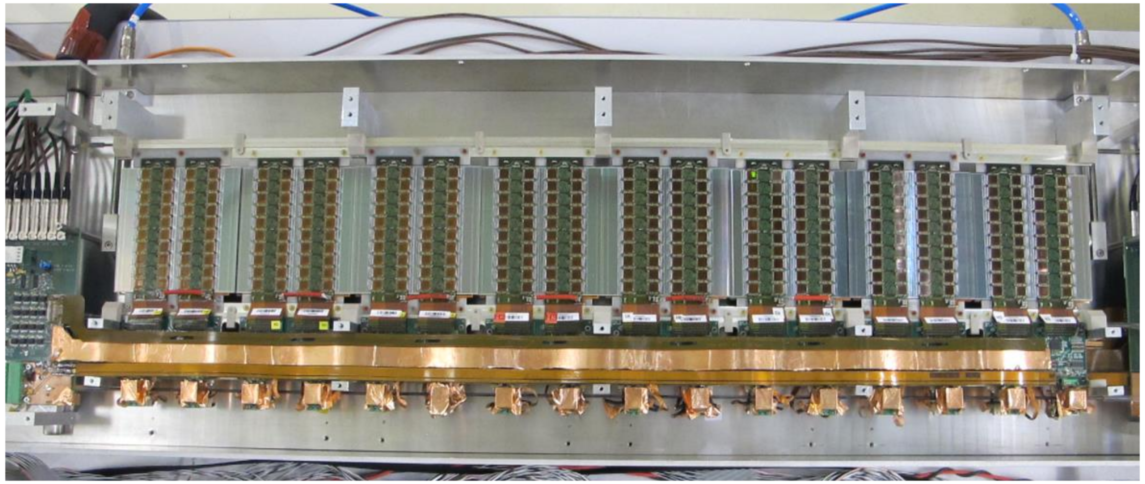
Increased detector occupancy

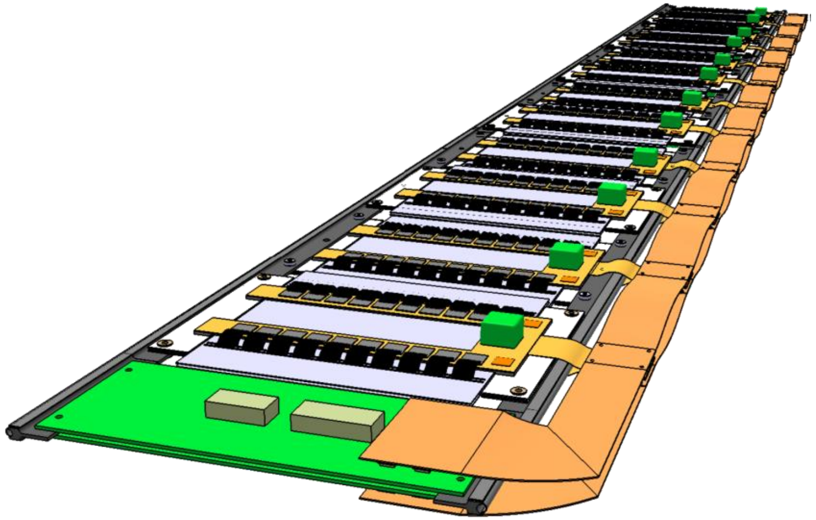
Increased integrated luminosity
300 fb^{-1} $\rightarrow$ 3000- 4000 fb^{-1}

Increased radiation environment

Double-sided modules approach

The "super-modules": an earlier alternative

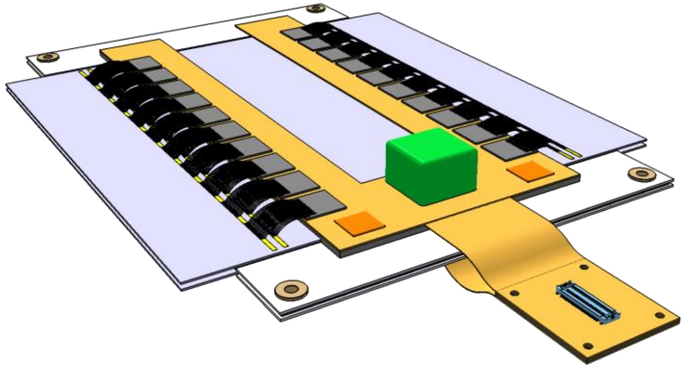




Double-sided module geometry with the same building blocks (sensors, ASICs, power and DC boards)

TPG, AlN, carbon-carbon sheet and precision washers as support

Cooling lines at the modules periphery



S. González-Sevilla et al., JINST 9, P02003 (2014)

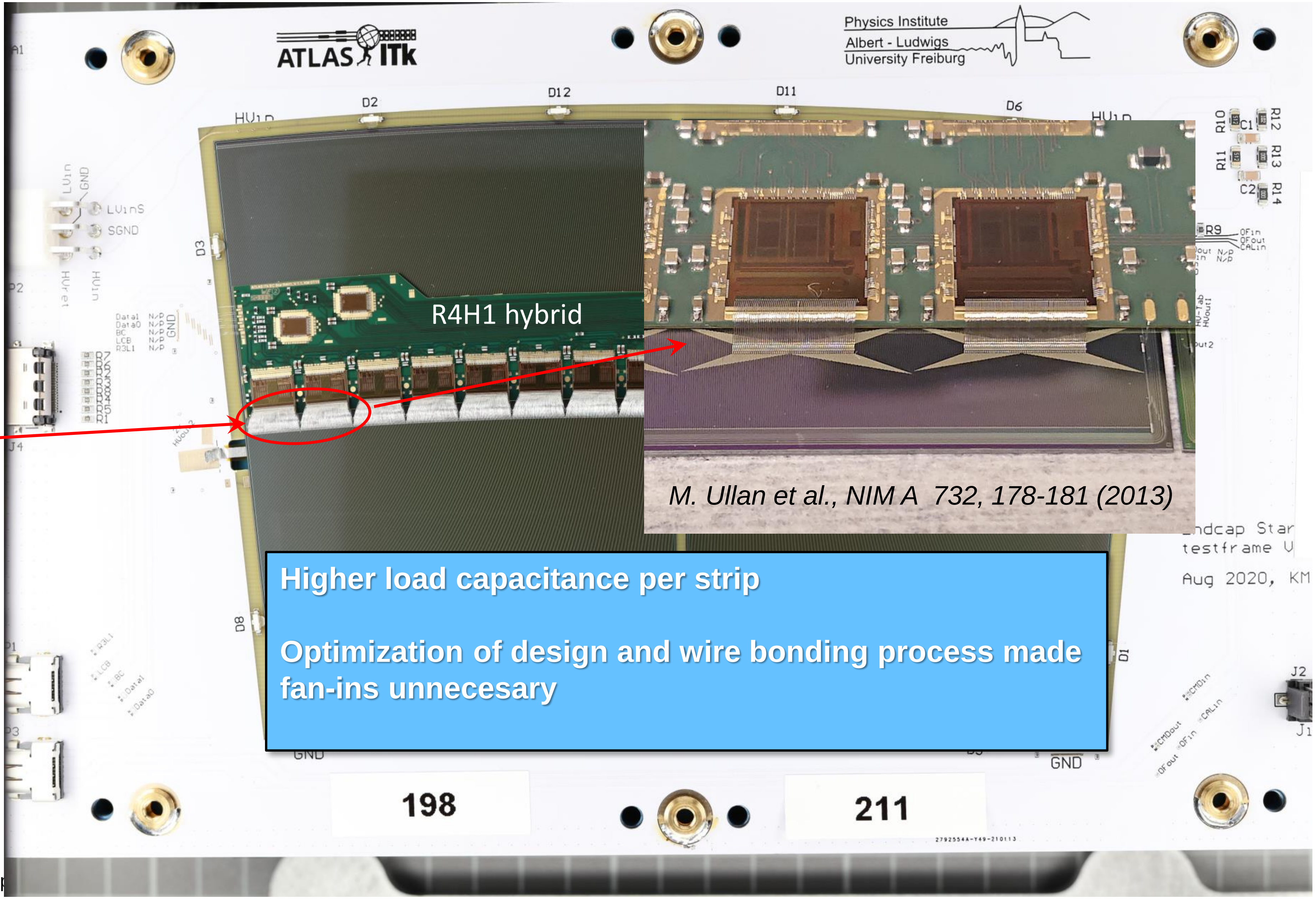
Embedded fan-ins?

Hybrid controller chips

Front-End chips

Front-end wirebonds

HV tab



Higher load capacitance per strip

Optimization of design and wire bonding process made fan-ins unnecesary

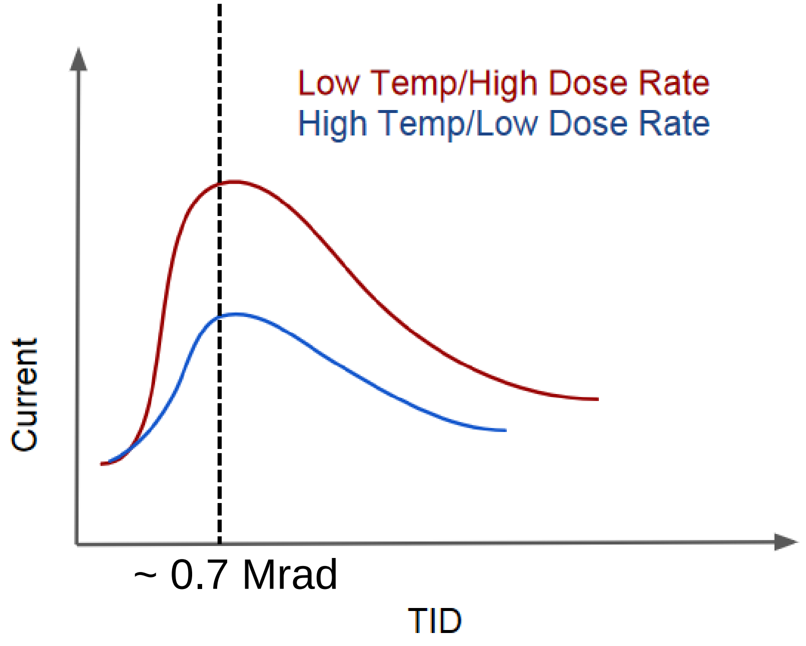
Power board

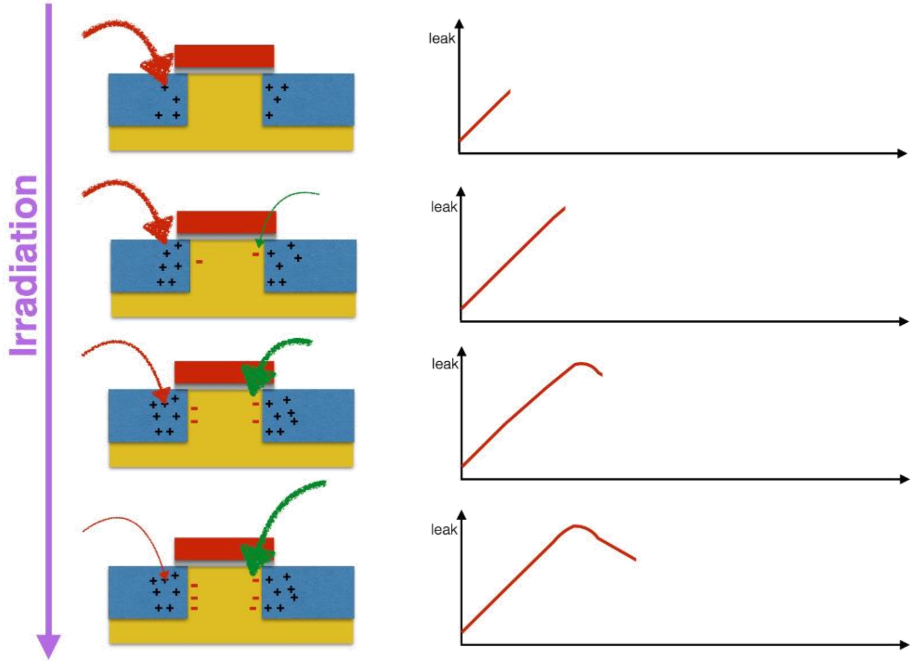
Monitoring chip

HV tab

The TID “bump”

Unexpected effect at low ionizing doses on 130 nm CMOS technologies





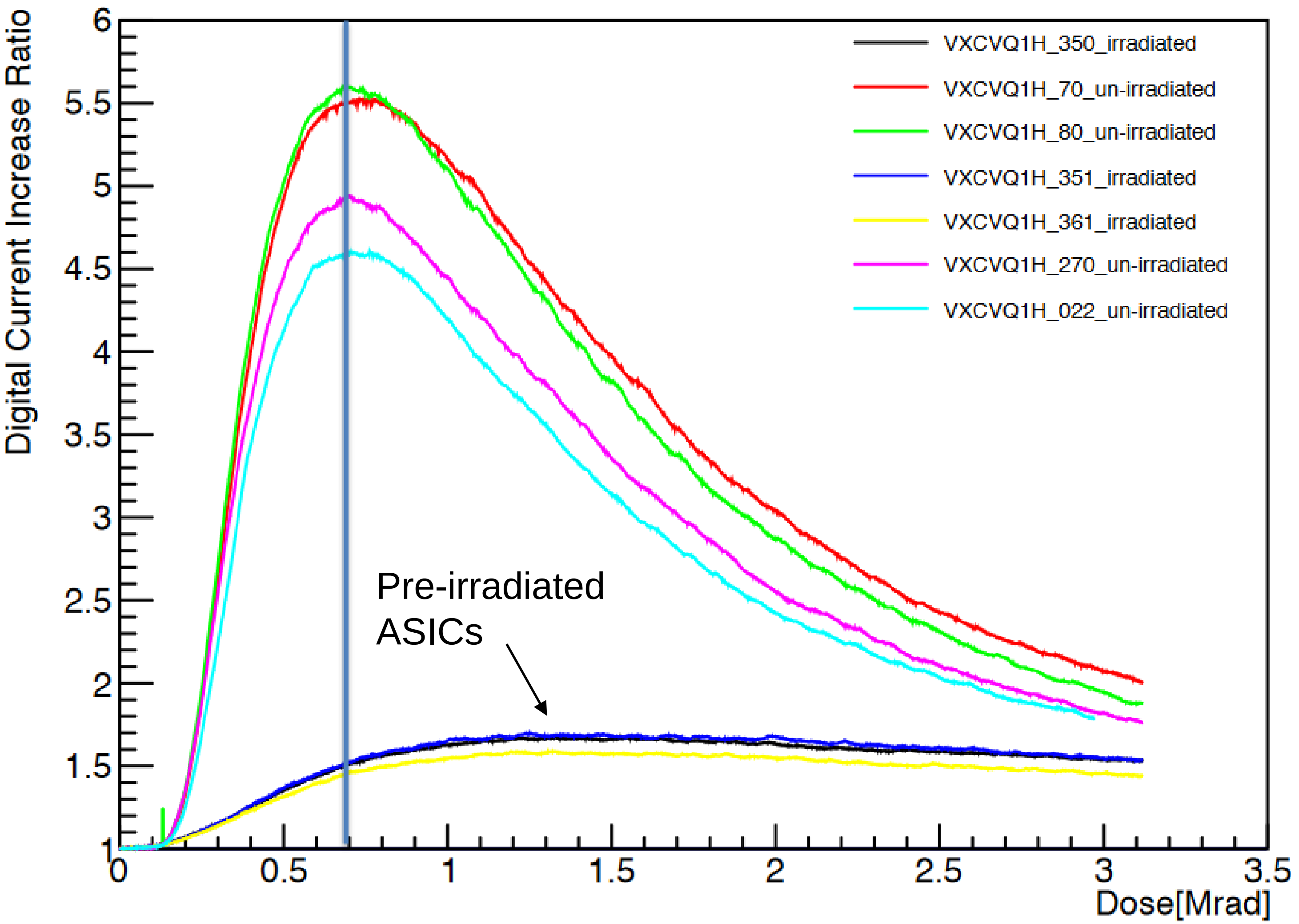
Very significant effect on power consumption at the early stages of the detector

Digital currents recover after a few Mrad

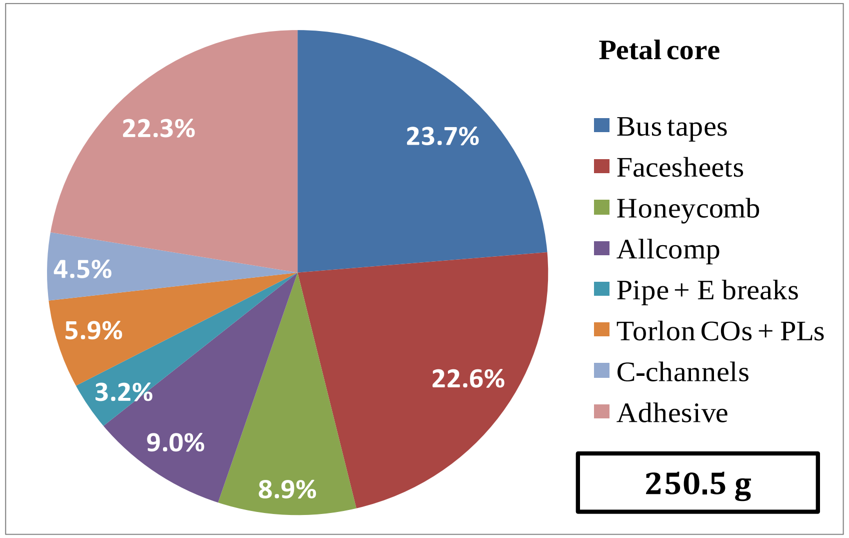
The TID “bump”

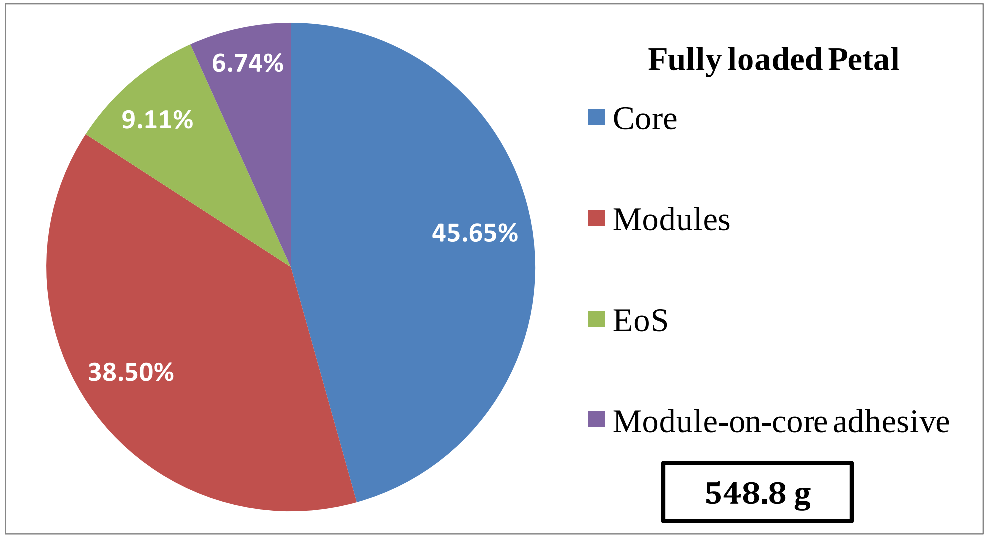
Unexpected solution for an unexpected problem

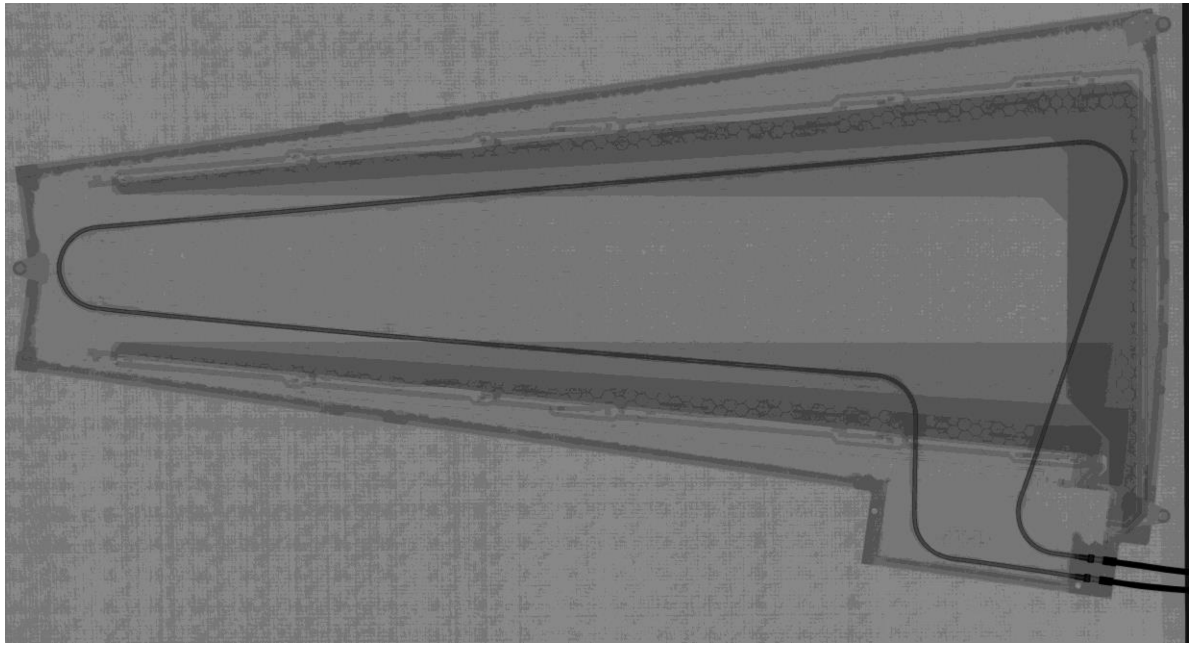
Chipset dies are pre-irradiated up to ~ 5 Mrad even before module construction



Low mass support structures

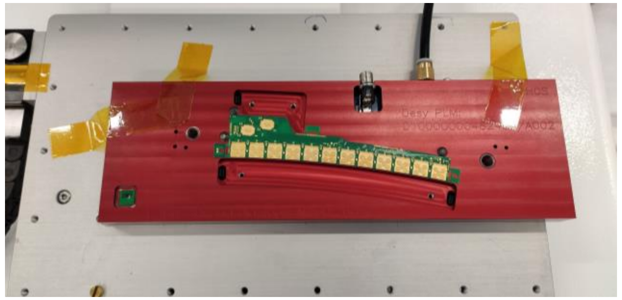


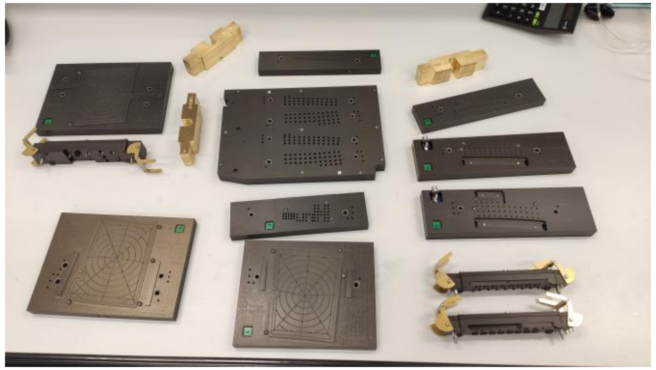


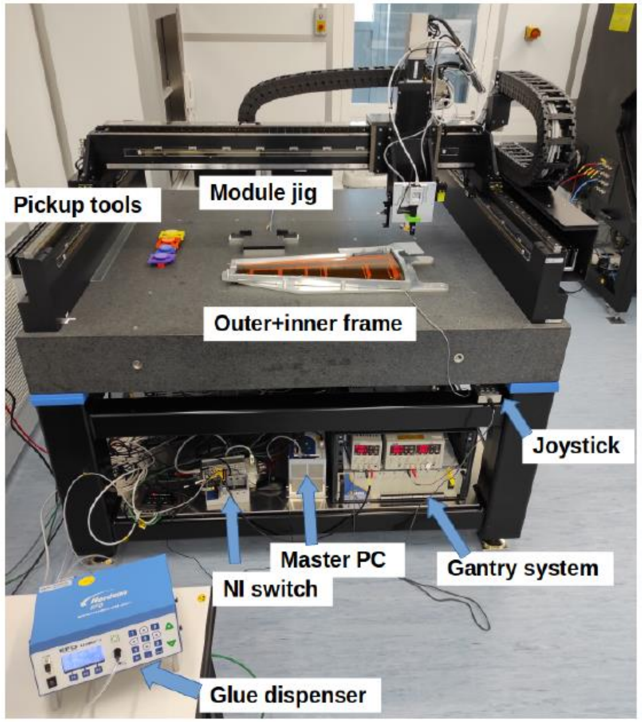


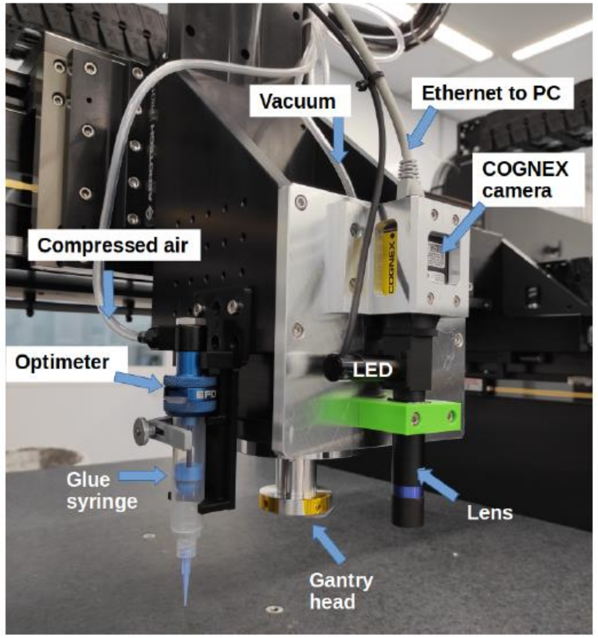
Low cost

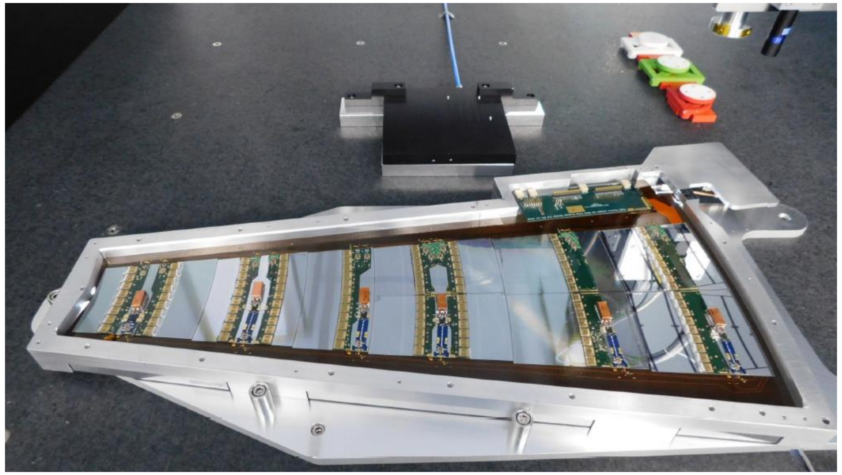
Harmonized tooling and automation











Dedicated effort on tooling and procedures to avoid learning curves for different module types

Automation of glue dispensing and module loading

The ATLAS ITk strips tracker

Where are we?

Production is around the corner