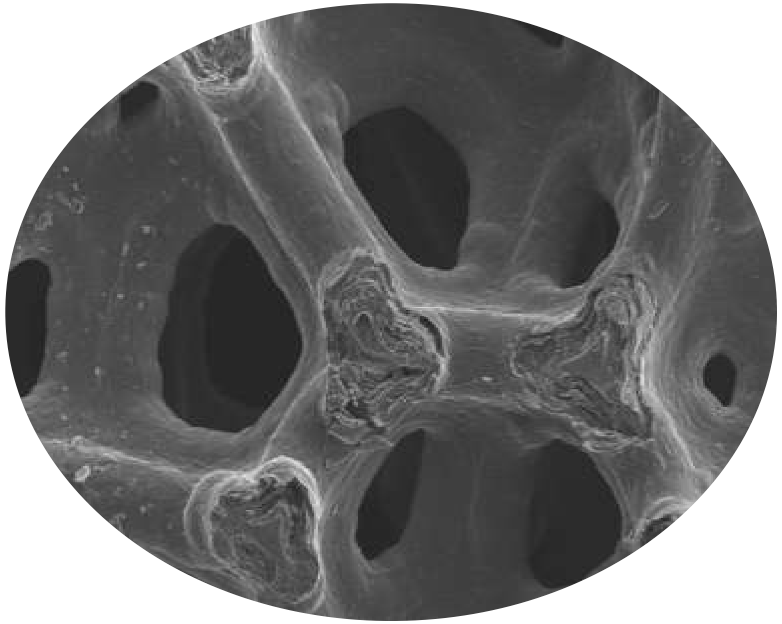


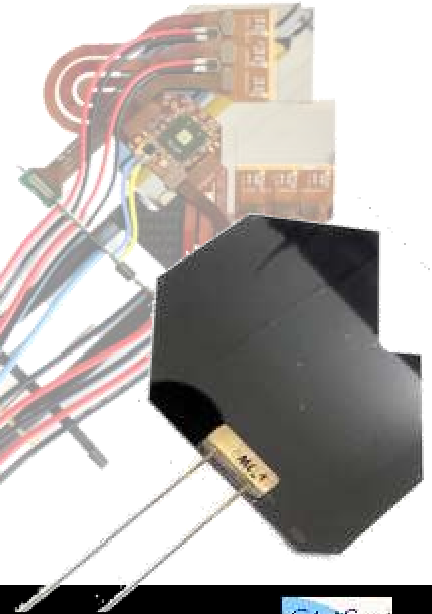
Support Structures for SI detectors

7th FCC PHYSICS Workshop
January 19th – February 2, 2024

Corrado Gargiulo

Vertex detectors (CERN LHC)

LHCB VELO (RUN3)



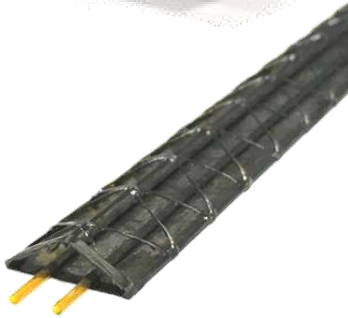
Sensor Pixel size: 55 x 55 µm2
- Power density ~28W/module
- read out by the VeloPix ASIC (bump bonded)
- Radiation hardness

Layout
- 2-retractable halves
- 26 silicon pixel modules each

Nominal Radiation Load
- NIEL: ~8x10^{15} 1MeV neq/cm2 for 50 fb^{-1}

Cooling
- Sensor tip temperature < -20 °C
- Operation under secondary vacuum

ALICE ITS2 (RUN3)



Sensor Pixel size: 29 x 27 µm2
- Power density ~40 mW/cm2
- Radiation hardness limits
- Thickness 50 µm

Layout

3 Inner barrel Layers (IB) based on MAPS **AL**ice**PI**xel**DE**tector

Nominal Radiation Load
- TID: ~270 krad NIEL: ~1.7x10^{12} 1MeV neq/cm2

Cooling
- Sensor Temperature < 30°C
- Operation in dry air

mechanics is inherently linked to cooling

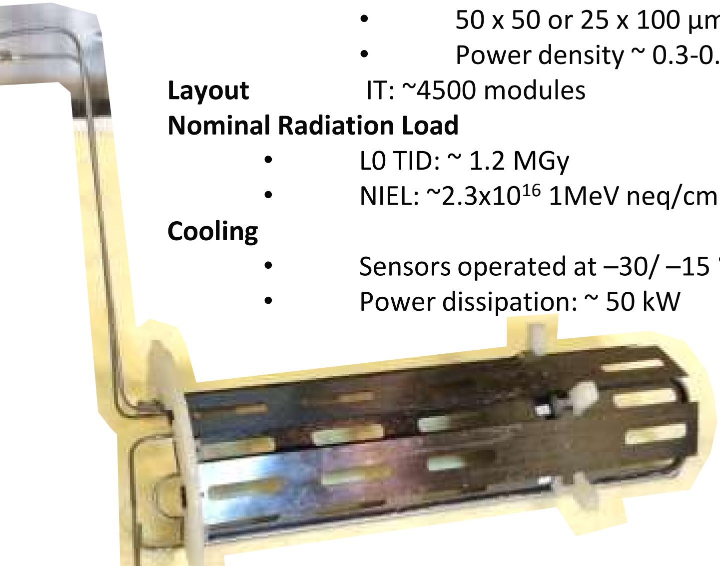
CMS (RUN4)

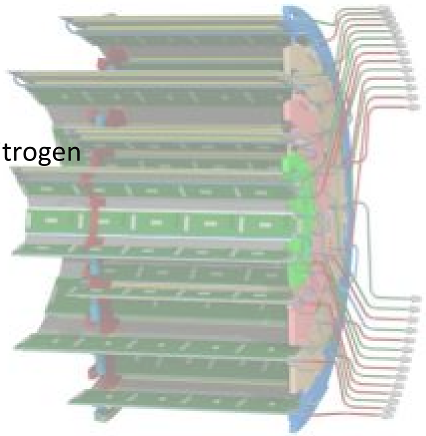
Sensor Inner Tracker (IT) with Pixel sensors
- 50 x 50 or 25 x 100 µm2
- Power density ~ 0.3-0.8 W·cm^{-2}

Layout IT: ~4500 modules

Nominal Radiation Load
- L0 TID: ~ 1.2 MGy
- NIEL: ~2.3x10^{16} 1MeV neq/cm2

Cooling
- Sensors operated at –30/ –15 °C , in Nitrogen
- Power dissipation: ~ 50 kW





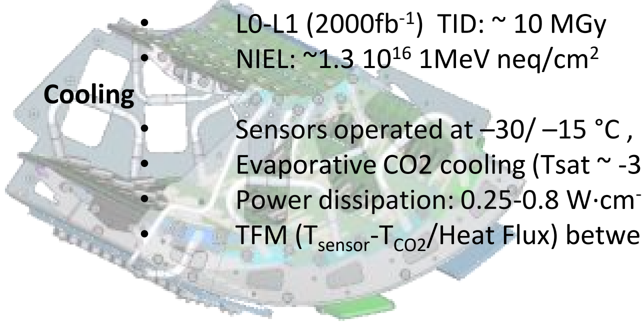
ATLAS (RUN4)

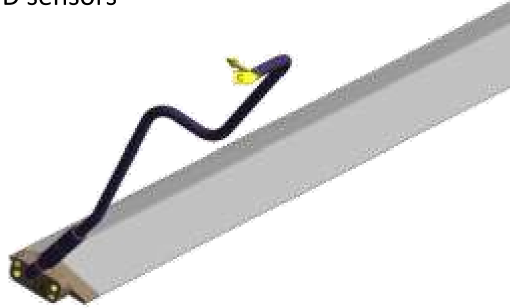
Sensors Pixel Hybrid module (300 µm) with Planar or 3D sensors
- Pixel size 50 x 50 µm^2 or 25 x 100 µm^2
- Power density ~ 0.25-0.8 W·cm^{-2}

Layout Total pixel active area ~ 13 m^2.
- Replaceable Inner System;
- Inclined section in L2, L3 and L4

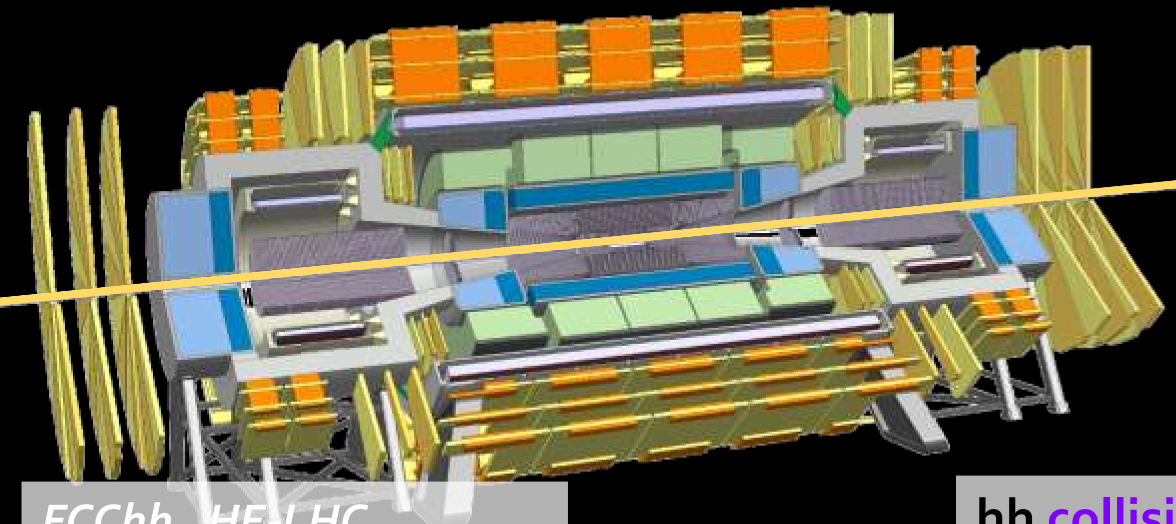
Nominal Radiation Load
- L0-L1 (2000fb^{-1}) TID: ~ 10 MGy
- NIEL: ~1.3 10^{16} 1MeV neq/cm^2

Cooling
- Sensors operated at –30/ –15 °C , in Nitrogen
- Evaporative CO2 cooling (Tsat ~ -30°C),operated in Nitrogen
- Power dissipation: 0.25-0.8 W·cm^{-2}
- TFM (T_{sensor}-T_{CO2}/Heat Flux) between ~ 18 and ~ 30 °C·cm^{-2}·W^{-1}



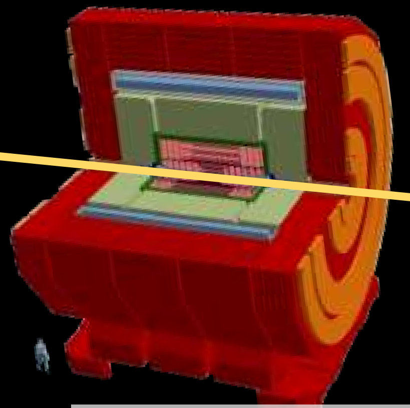


Vertex detectors (Next)



FCChh, HE-LHC, …

hh **collisions** | e^+e^- **collisions**



CLIC, FCCee, ILC, CEPC,…

- Large dimensions (50m)
- **High radiation Level (~ 100 MGy/10years)**
- Magnetic B-field: 4T 10m solenoid, Forward solenoids 4T
- Tracker Radius 1.6m, Length 32m

radiation damage is a concern

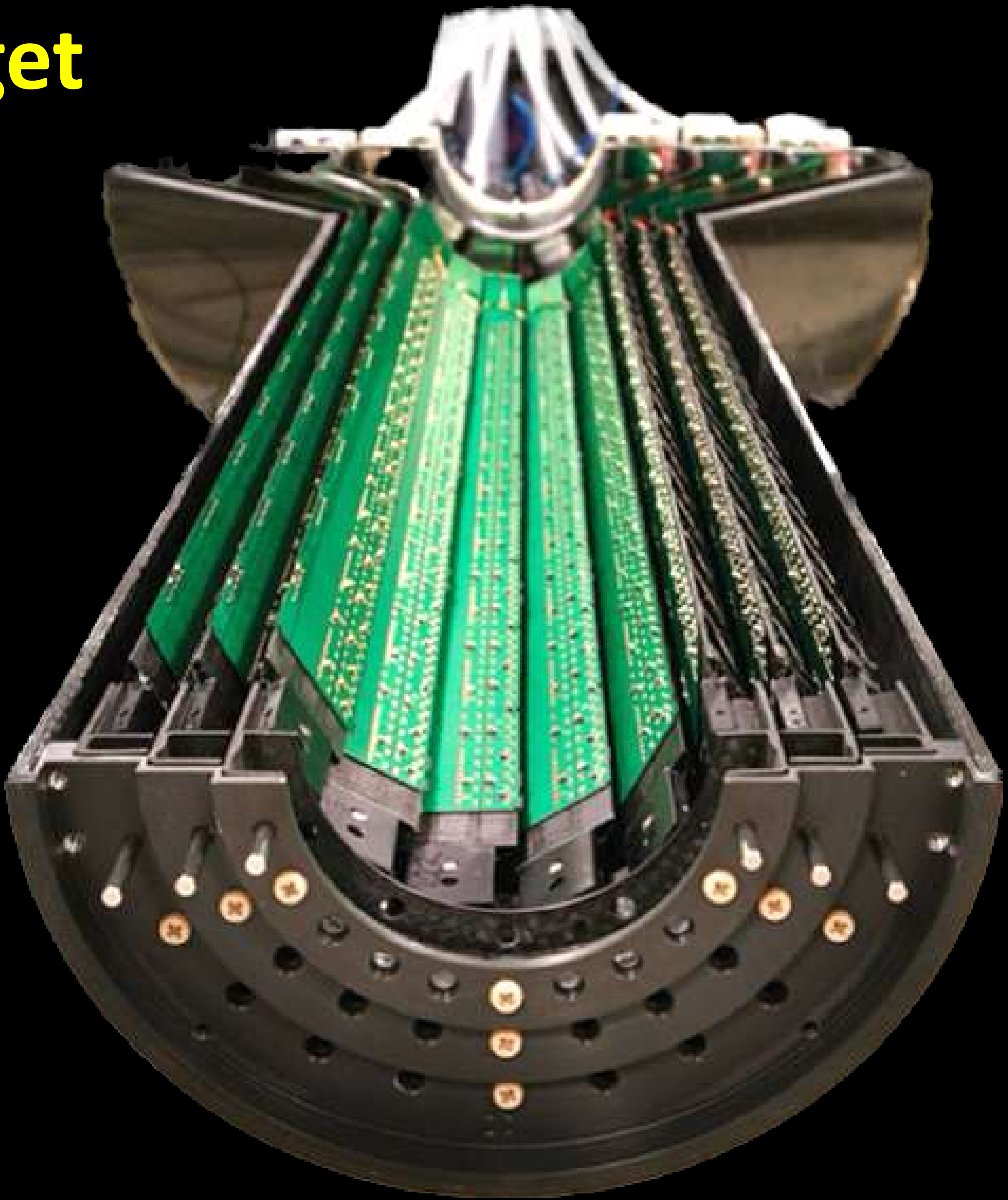
- Standard dimensions
- Low radiation Level: TID (<200 Gy/yr)
- Magnetic B-field: 4T, 2T
- unprecedented spatial resolution (1-5 μm point resol.)
- **very low material budget (0.1X%)**
- Dissipated power (vertex) (<50mW/cm2)
- **Stability**
- **Proximity to IP**

<-40°C very low temperature…….

……..Room Temperature

R&D

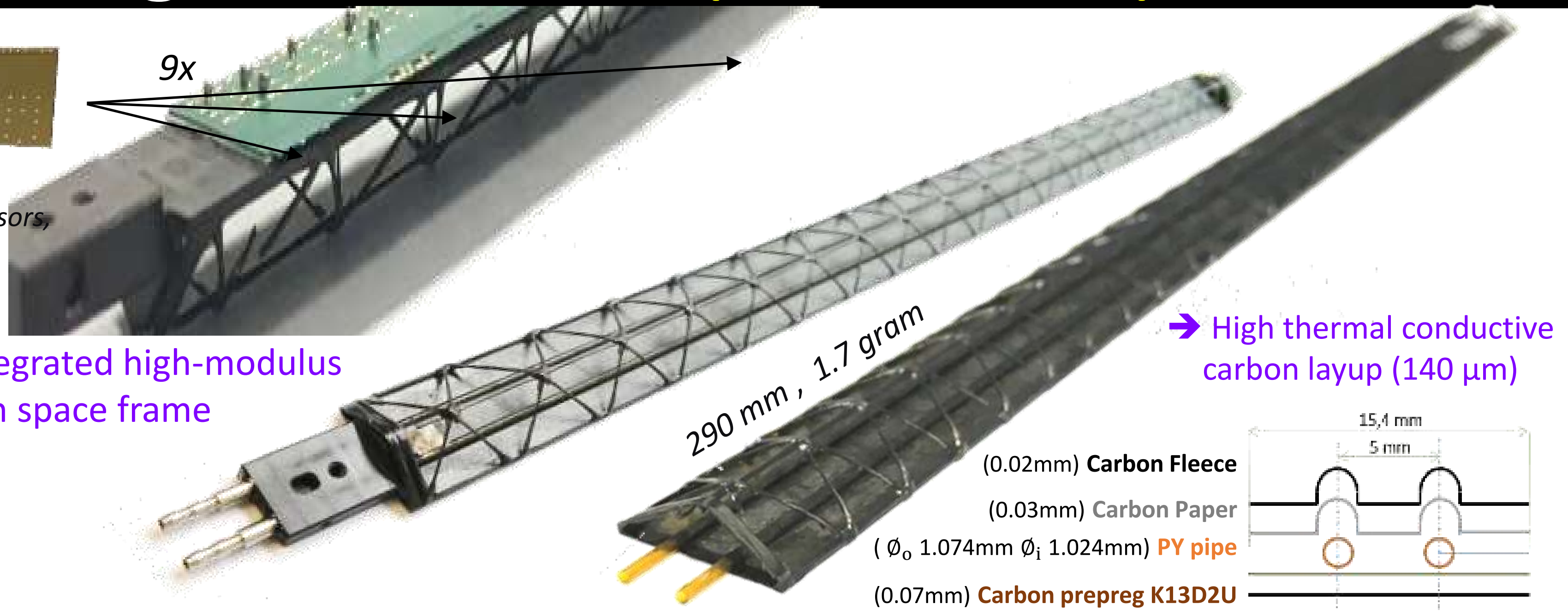
Material budget



Stability

Material budget 0.35 X/X0 (LHC RUN3)

CMOS pixel chip sensors, 50µm

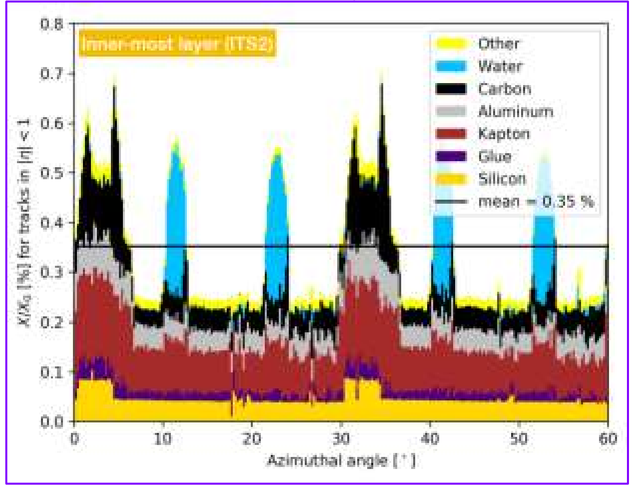


➔ Integrated high-modulus carbon space frame

➔ High thermal conductive carbon layup (140 µm)

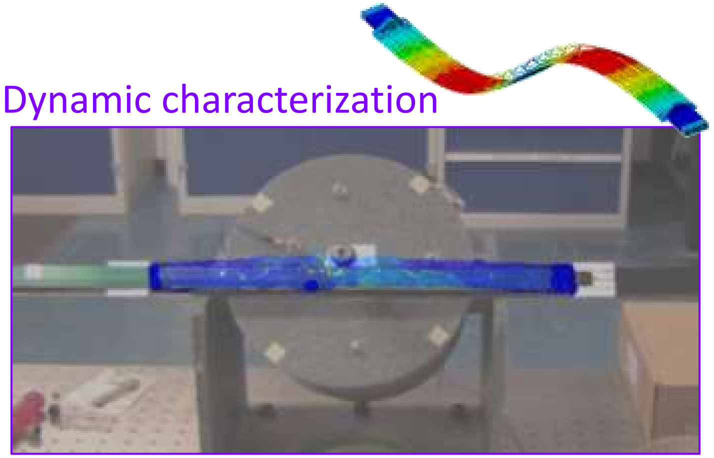
(0.02mm) **Carbon Fleece**
(0.03mm) Carbon Paper
($\varnothing_o$ 1.074mm $\varnothing_i$ 1.024mm) **PY pipe**
(0.07mm) **Carbon prepreg K13D2U**
(0.02mm) **Carbon Fleece**

Material budget



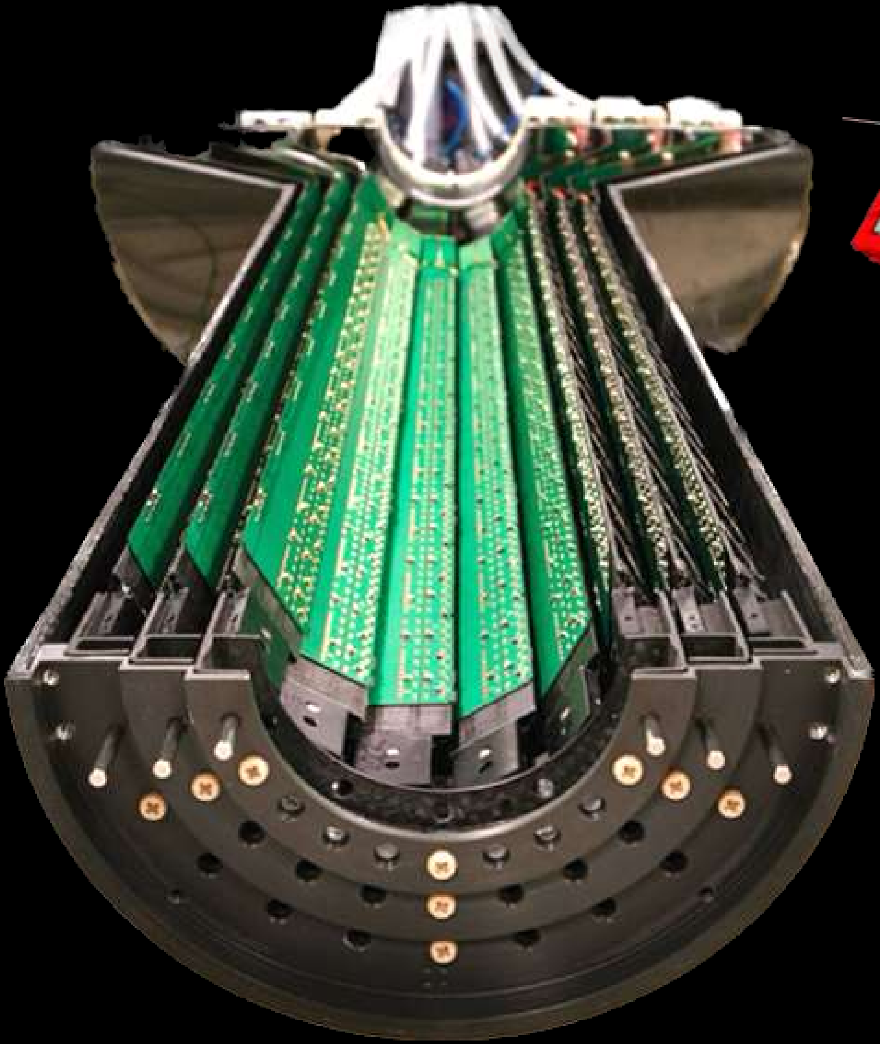
Thermal characterization

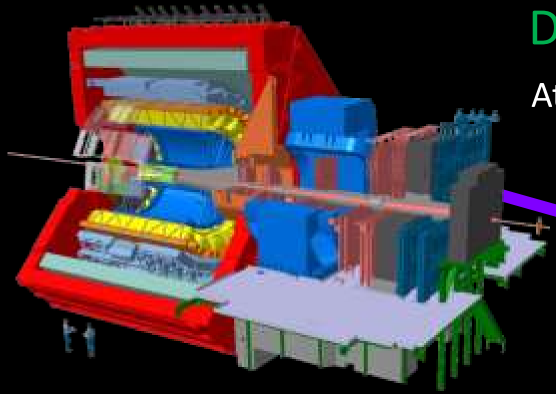
Dynamic characterization



Non-conventional use of Carbon Fibre Reinforced Plastic (CFRP) materials for Vertex Detectors to match the requirements of minimum material budget, high rigidity, thermal management.

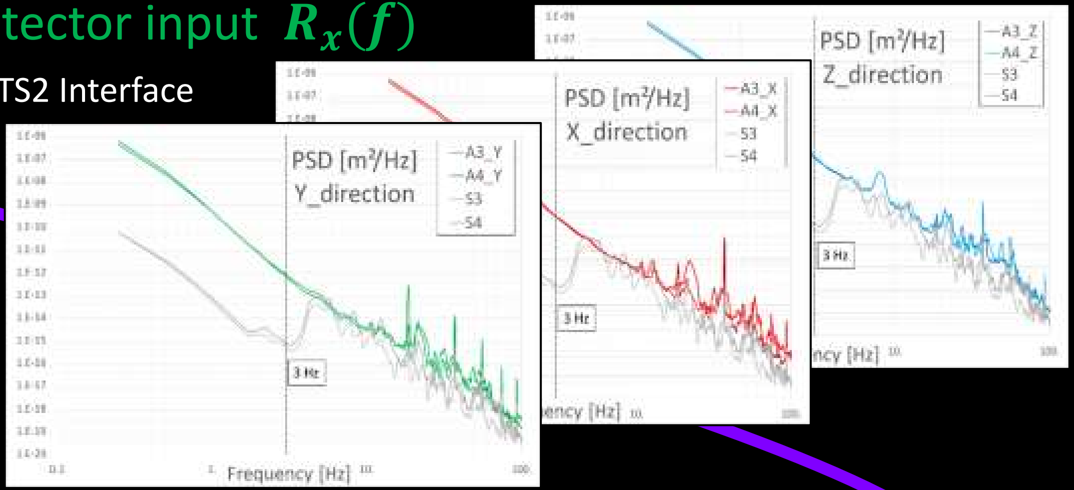
Dynamic stability (HC RUN3)

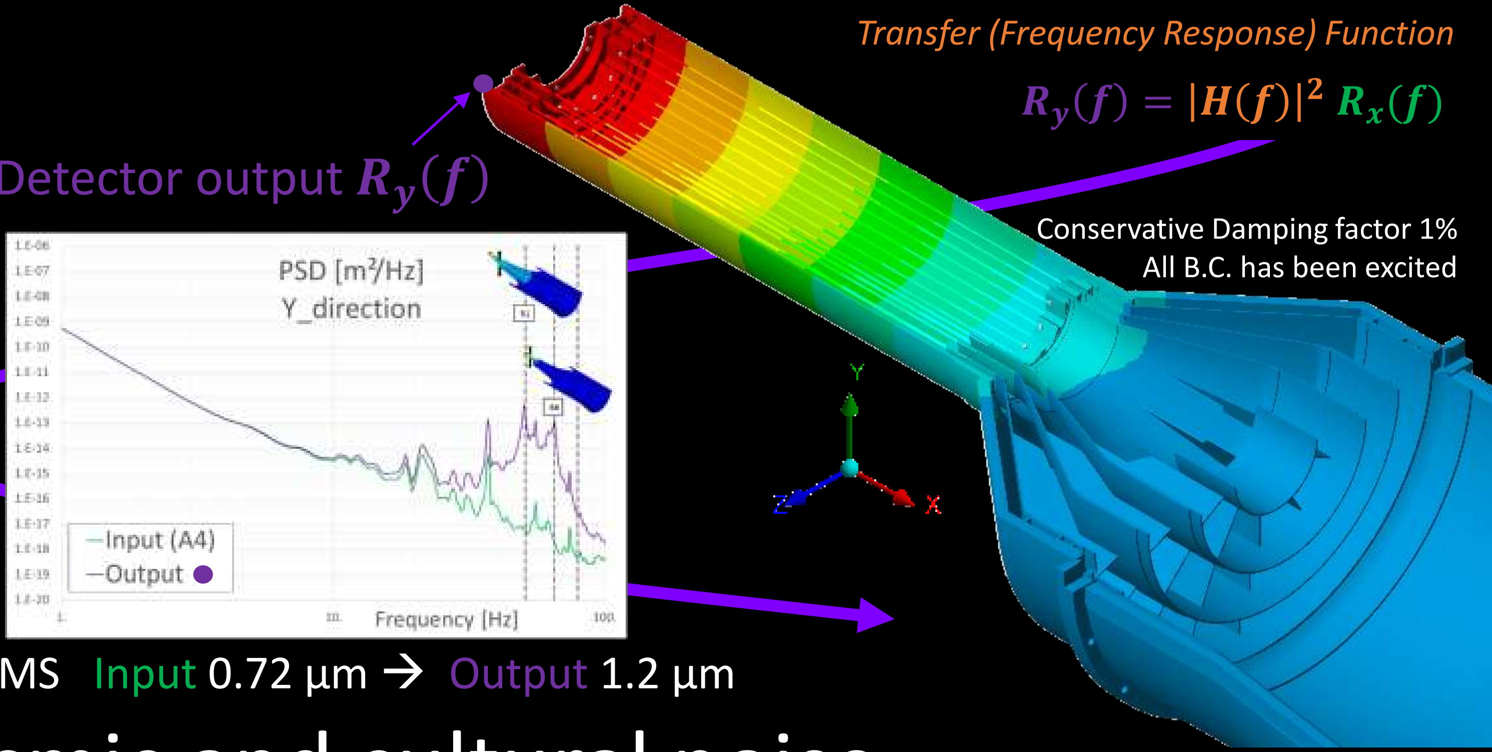




Detector input $R_x(f)$

At ITS2 Interface





Transfer (Frequency Response) Function

$$R_y(f) = |H(f)|^2 R_x(f)$$

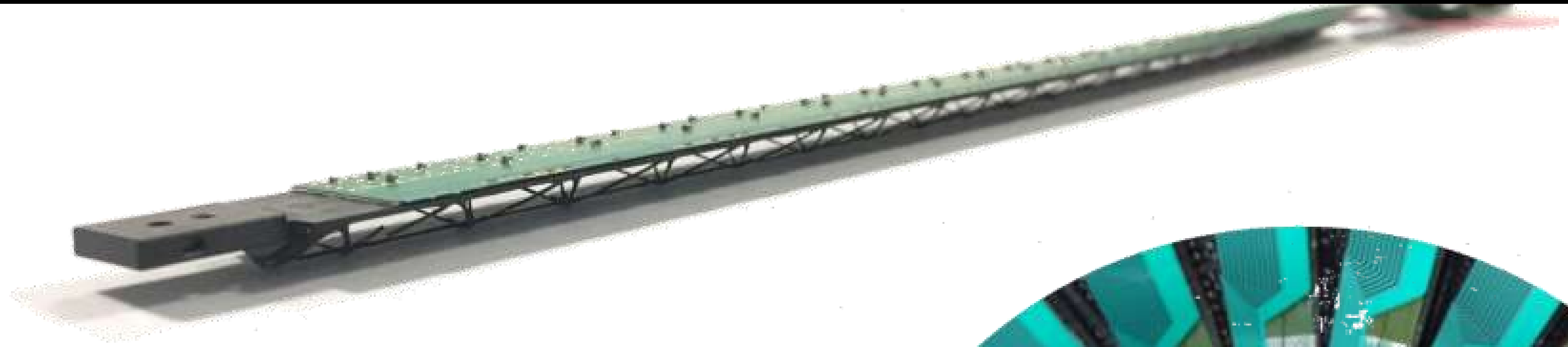
Detector output $R_y(f)$

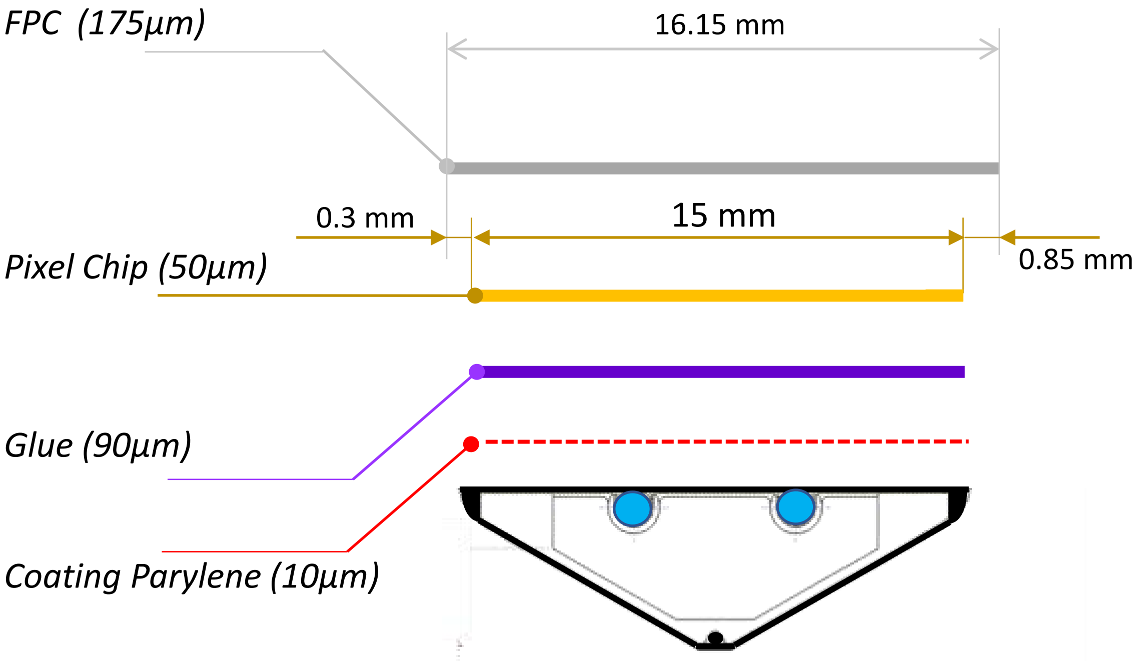
Conservative Damping factor 1%
All B.C. has been excited

Y-RMS Input 0.72 µm → Output 1.2 µm

Stability seismic and cultural noise

Material budget (LHC RUN3)





FPC (175µm)

16.15 mm

0.3 mm

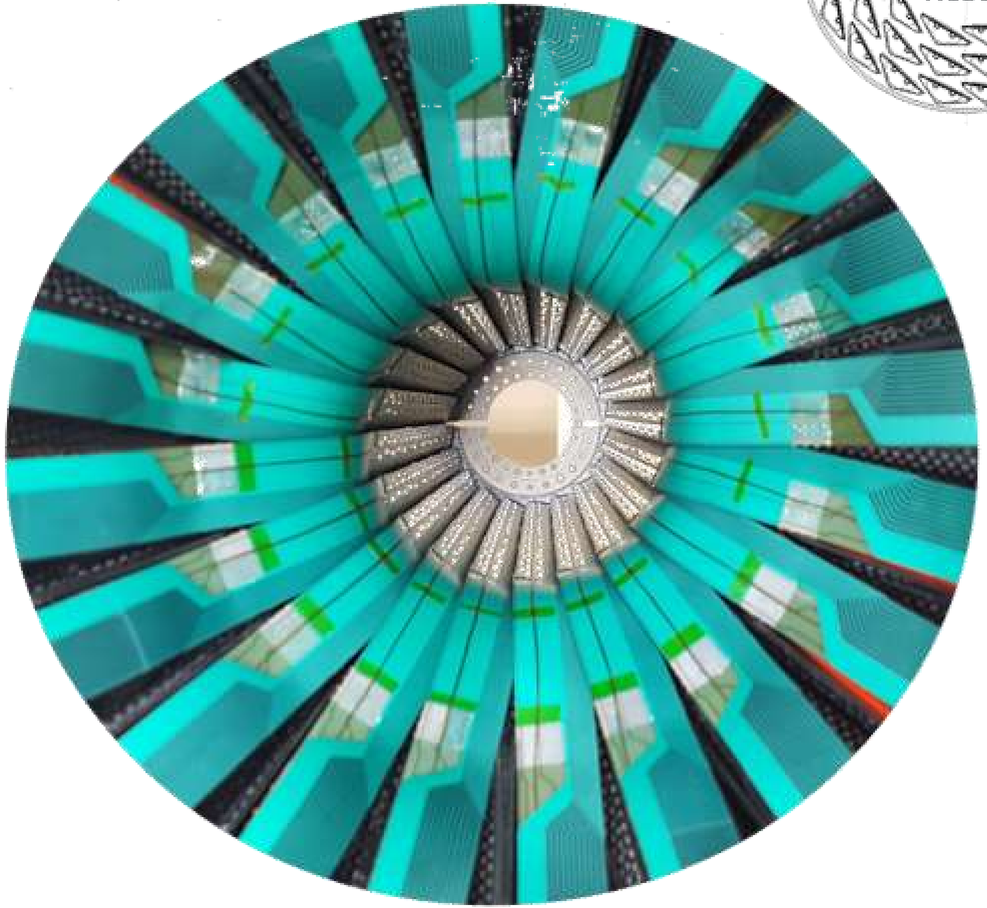
15 mm

0.85 mm

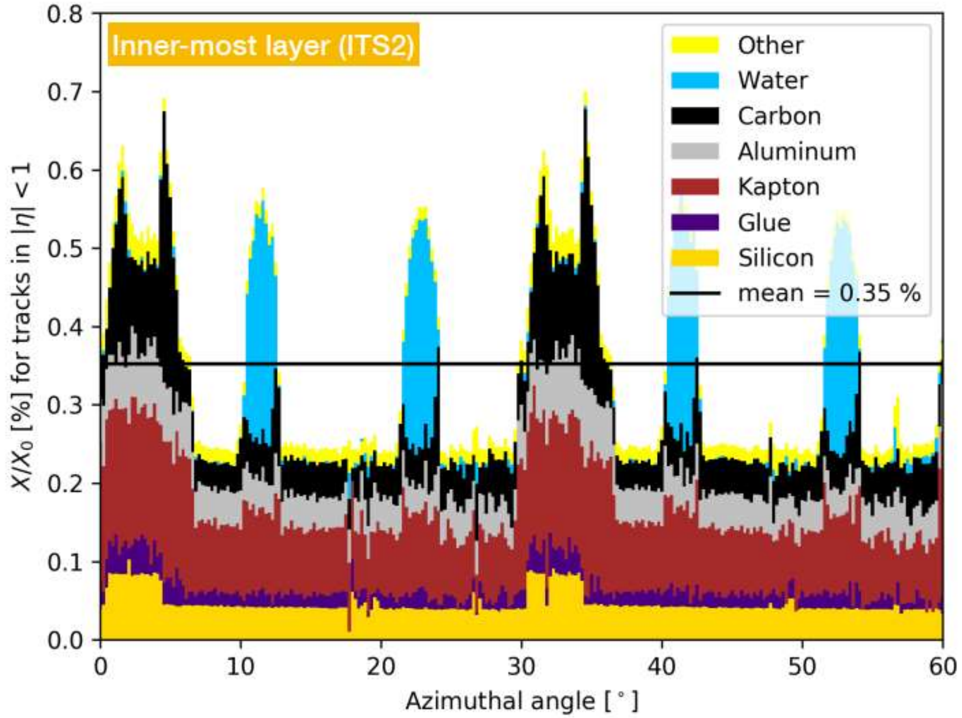
Pixel Chip (50µm)

Glue (90µm)

Coating Parylene (10µm)



Material budget (LHC RUN3)



Si only 1/7 of total material

Non uniformity due to overlaps+ support/cooling

Remove water cooling

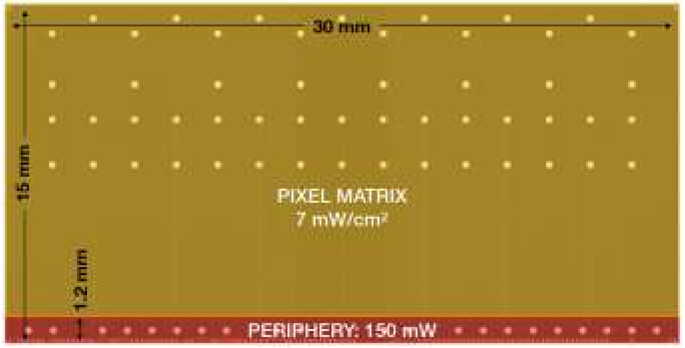
Possible by reducing power consumption in fiducial volume to ~230mW/cm^2

Remove external data lines+ power distribution

Possible to make a single large chip and use that for distribution

Remove mechanical support inside acceptance

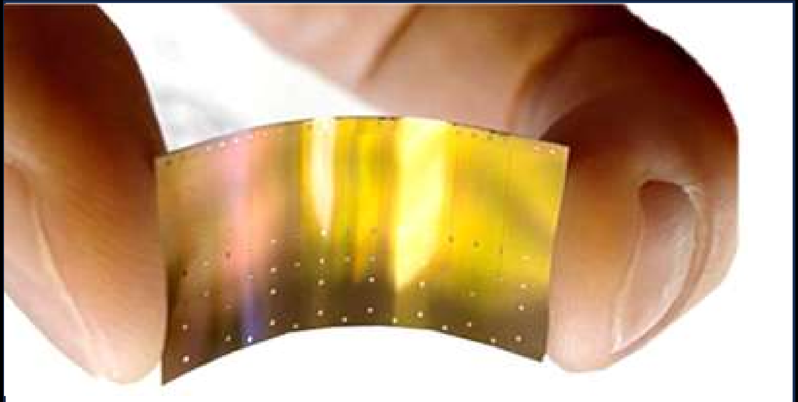
Benefits from increased stiffness by rolling Si wafer



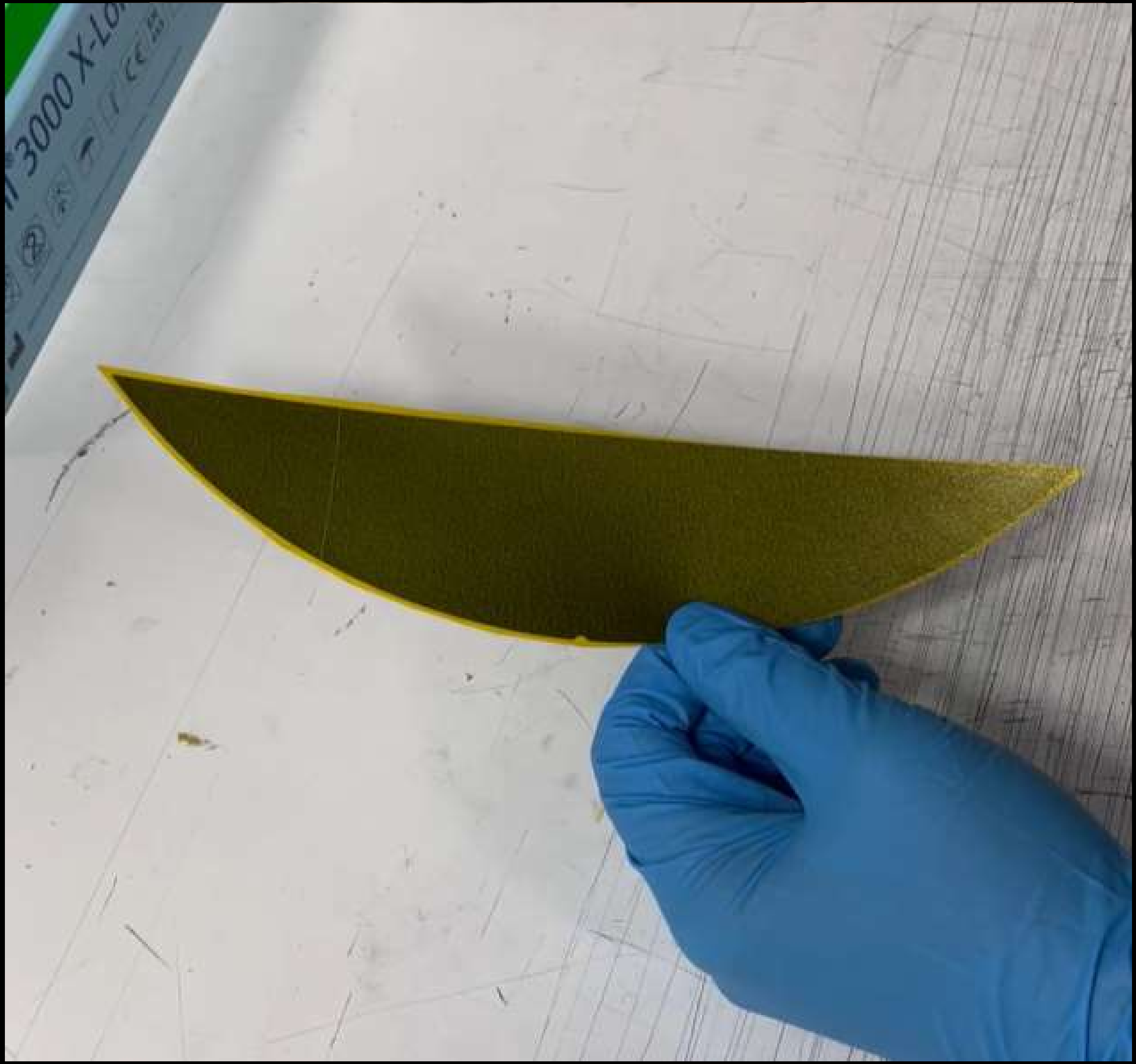
ALPIDE already close: ~40 mW/cm2

Main challenge for the mechanics is to disappear

Material budget (LHC RUN4)



➔ Curved MAPS sensor

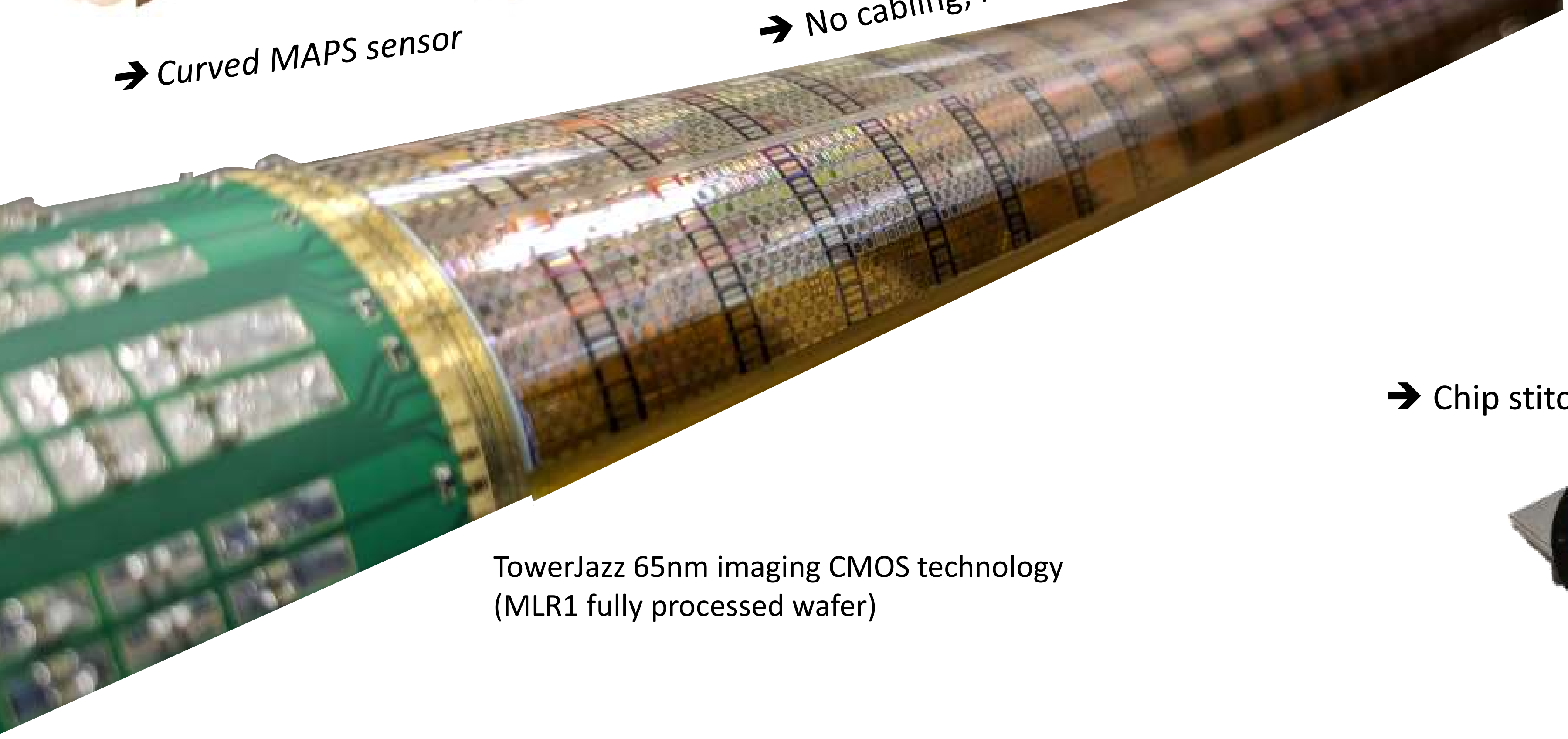


Alpide, MLR1
bent down to 7 mm radius

50 um Silicon bending

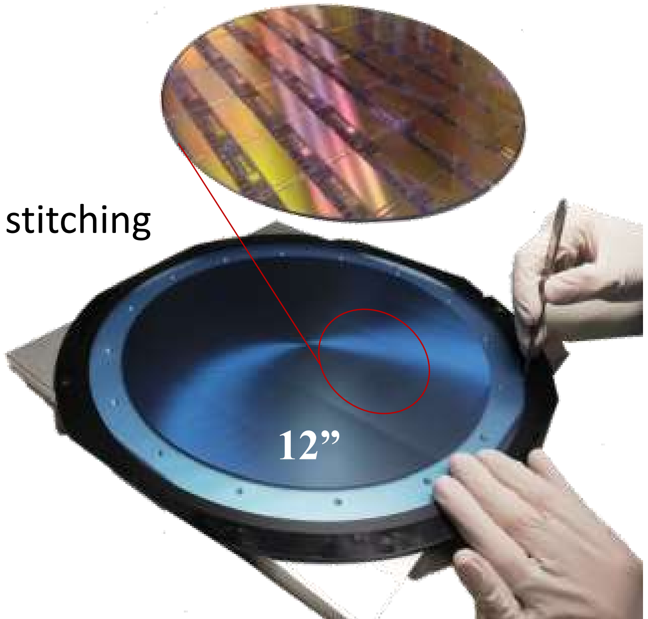
Material budget (LHC RUN4)

→ *Curved MAPS sensor*



→ No cabling, no piping in the active area

TowerJazz 65nm imaging CMOS technology
(MLR1 fully processed wafer)



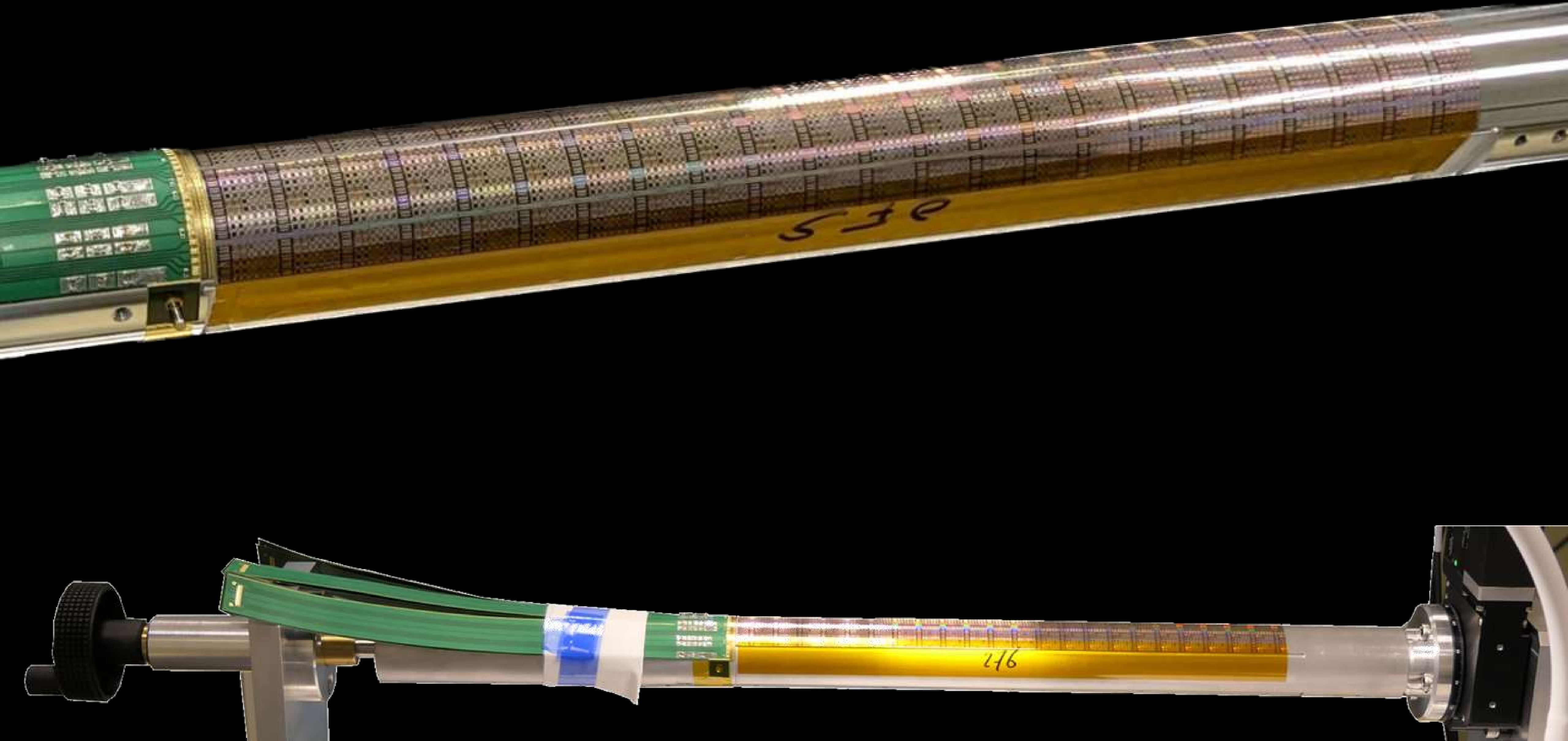
→ Chip stitching

Only the sensor contribution to the active area

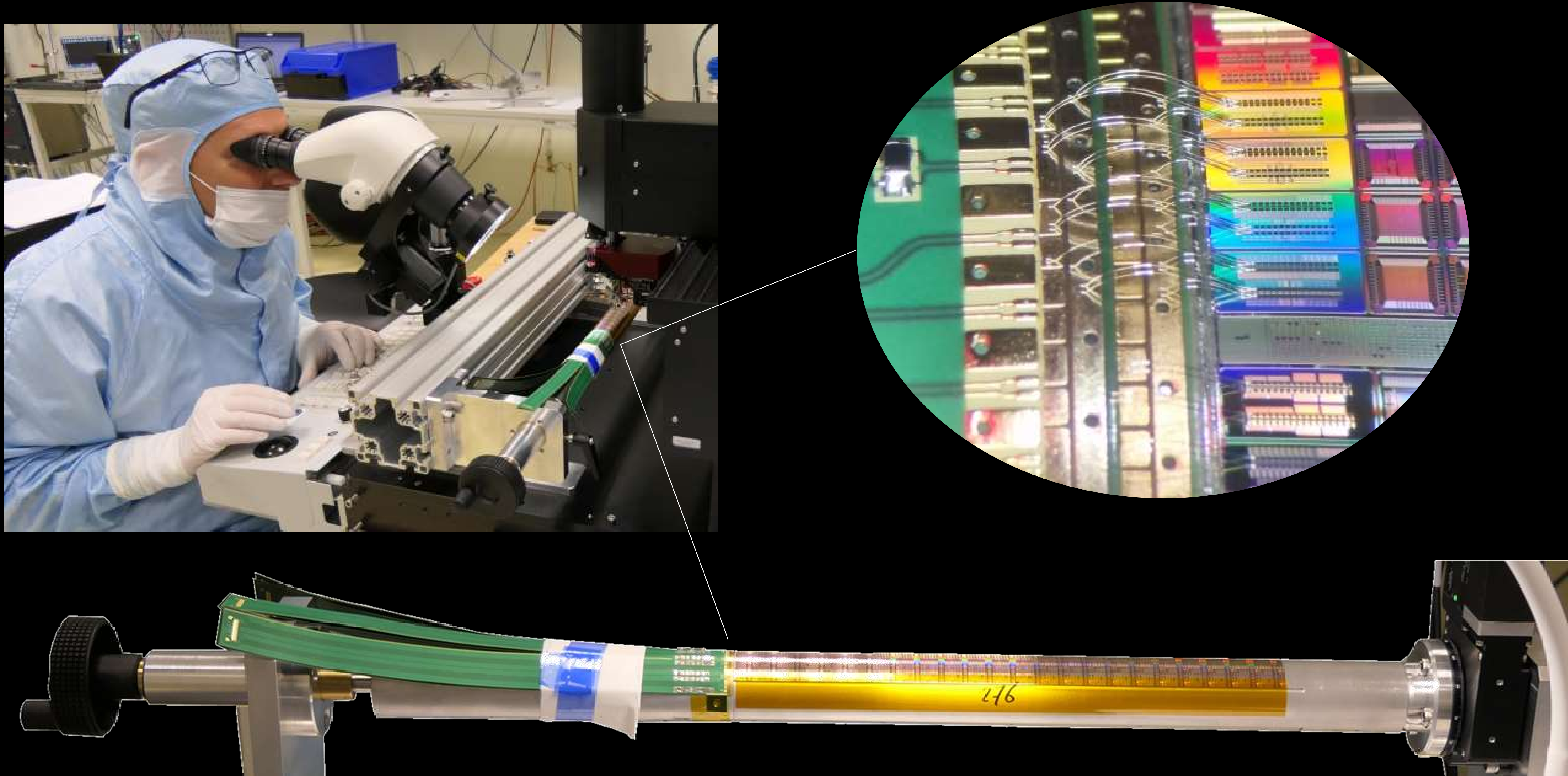
BENDING

TowerJazz 65nm imaging CMOS technology
(MLR1 fully processed wafer)

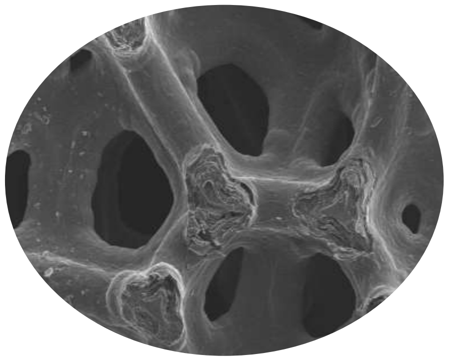
Flex Printed Circuit



WIRE BONDING



CARBON FOAM



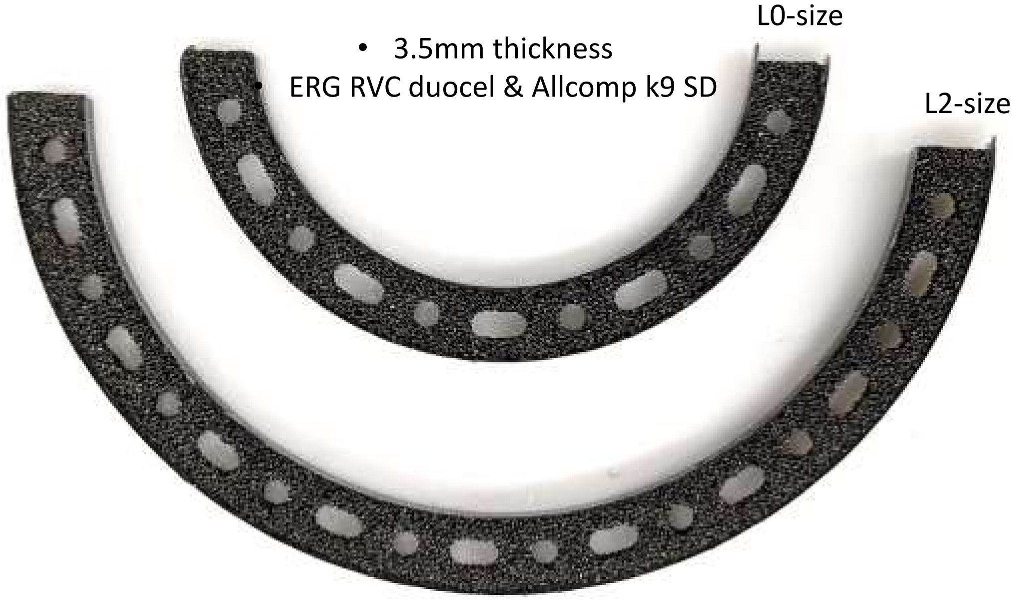
act as mechanical support and air cooling radiator

Longerons

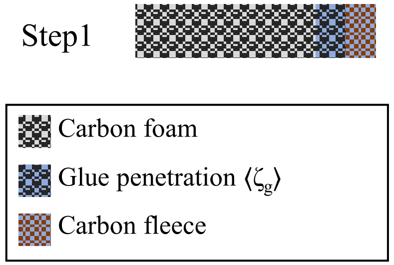
Support: Longerons
ERG Carbon RVC @Duocel
ρ = 0.06 kg/dm^3, k = 0.033 W/m·K,
Radiation length= 854 cm

Half-Rings

Support & **cooling:** Half ring radiators
Allcomp K9 standard density
ρ = 0.2-0.26 kg/dm^3, k = >17 W/m·K
Radiation length= 164 cm

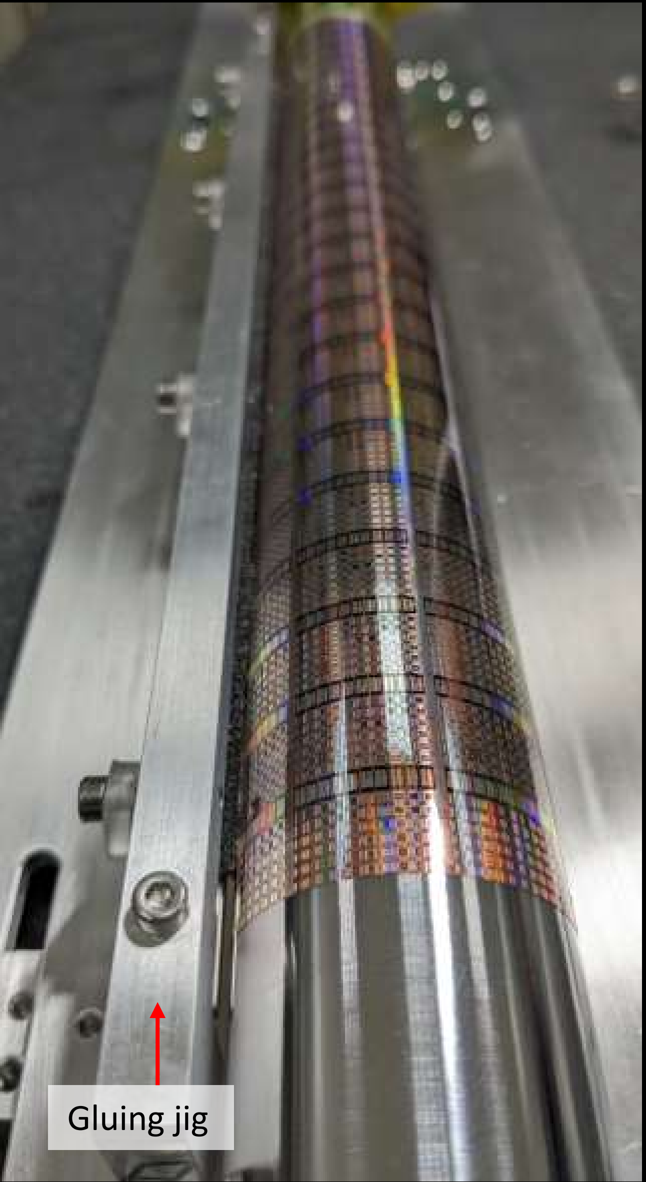


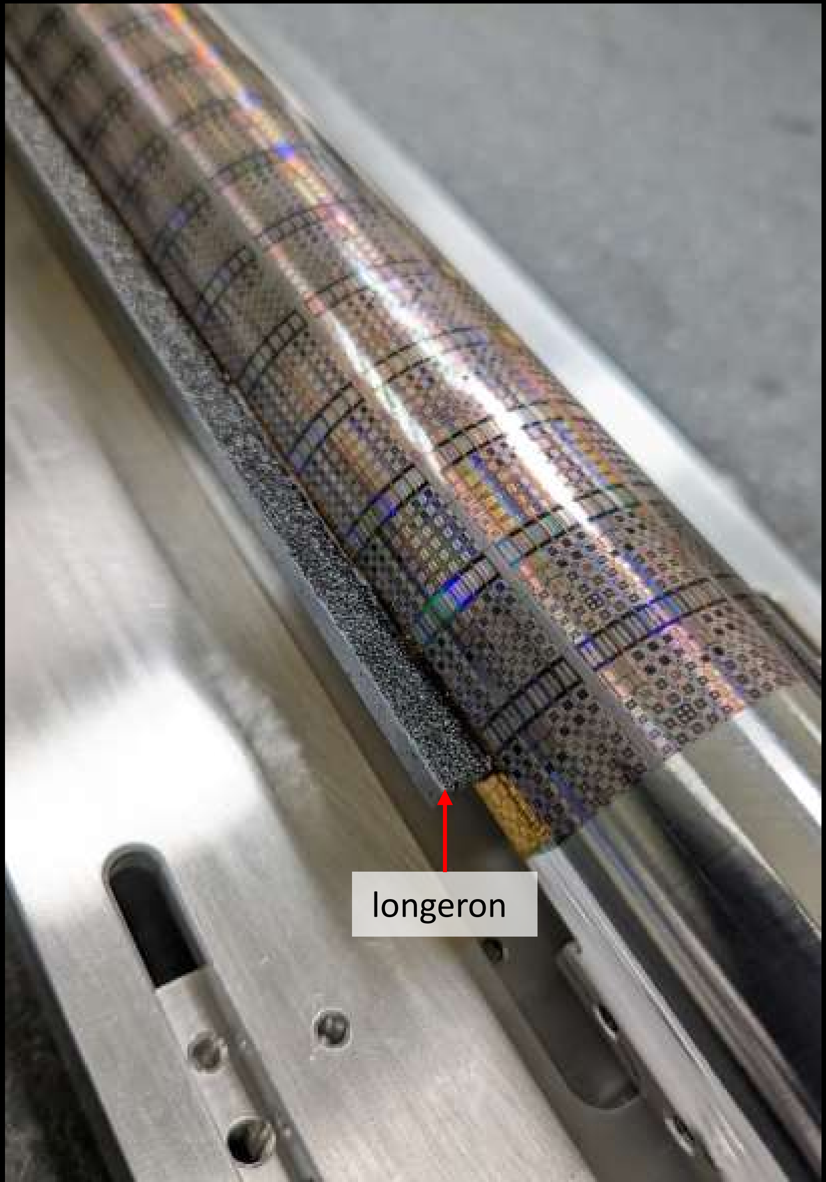
- 3.5mm thickness
- ERG RVC duocel & Allcomp k9 SD



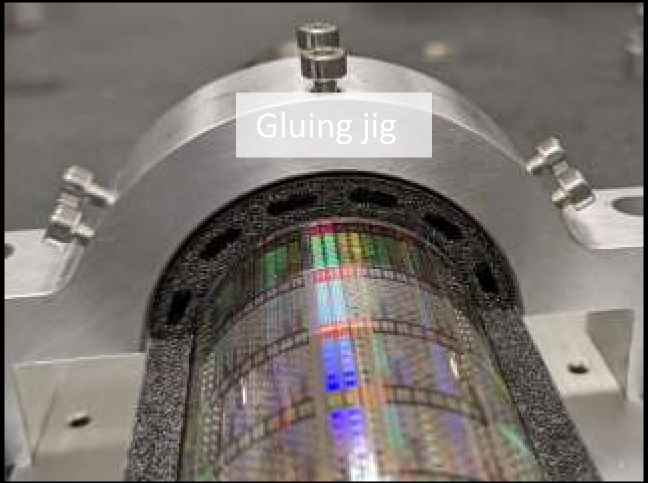
Assembly of a half-layer

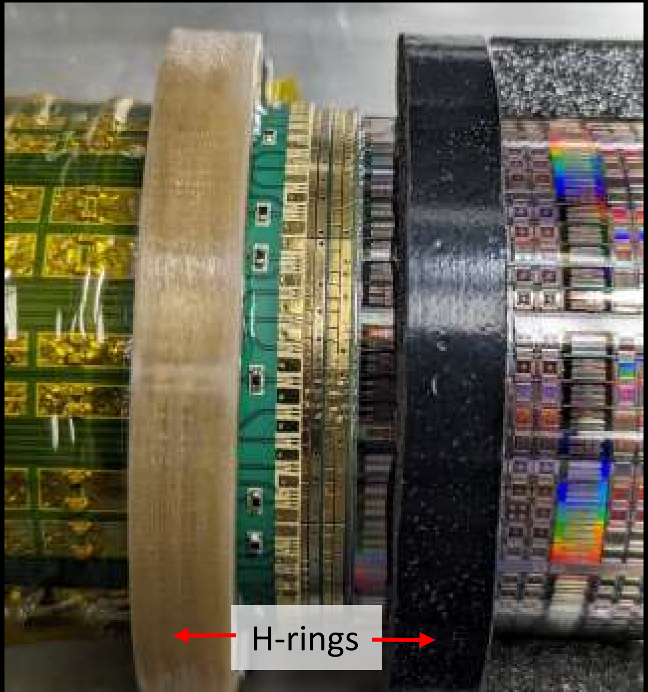
Gluing of the longerons



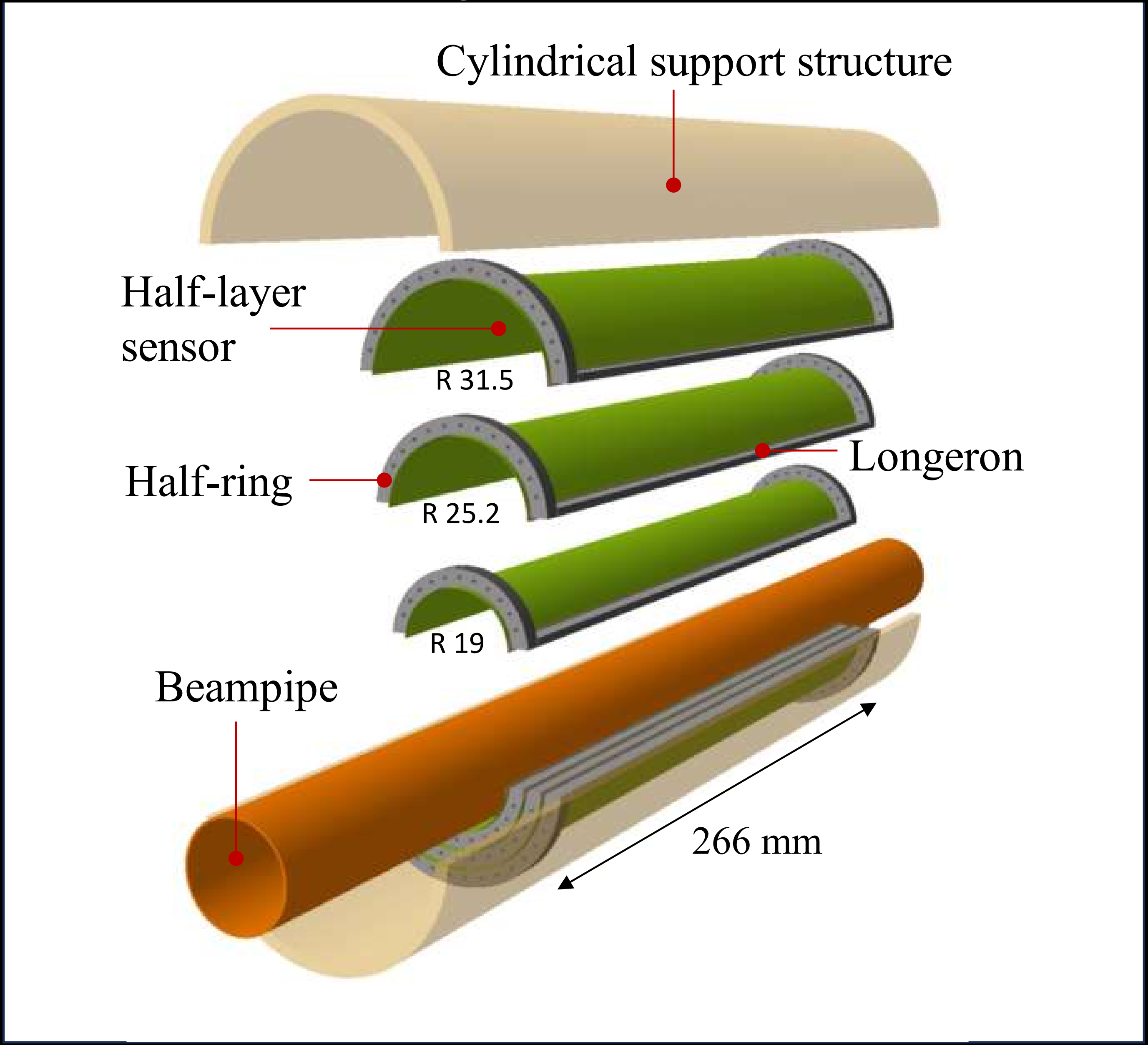


Gluing of the H-rings

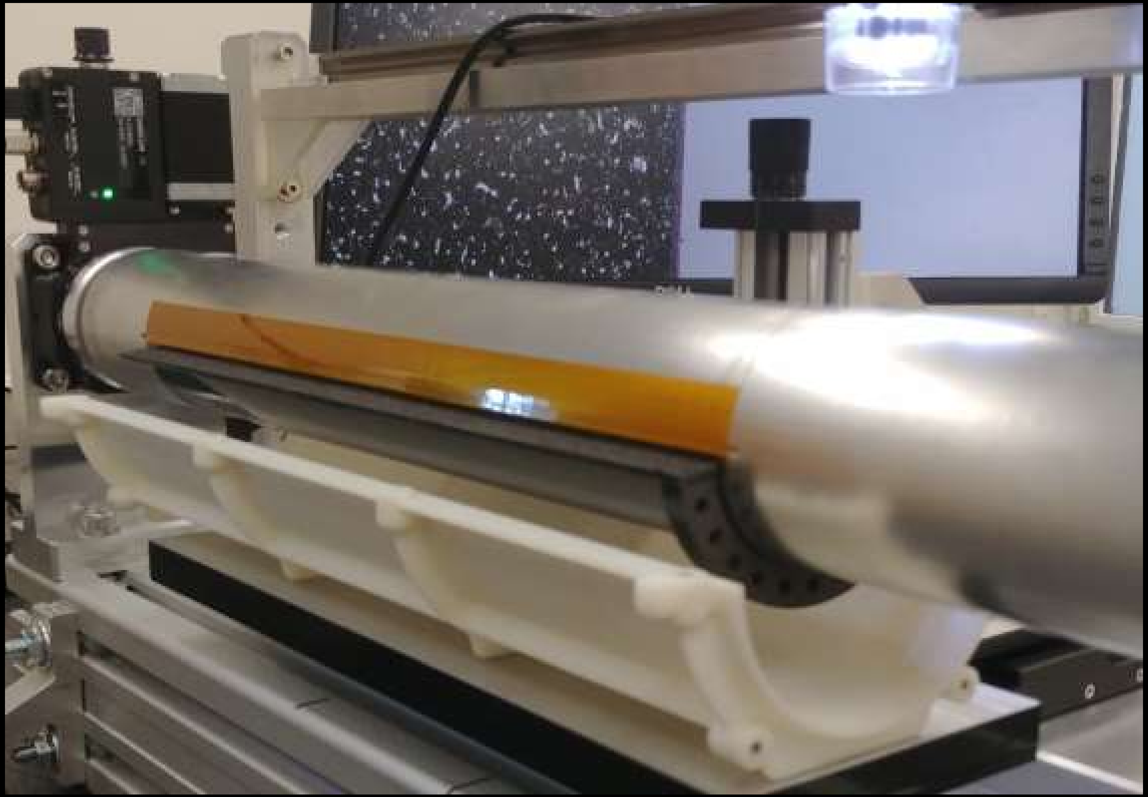




Assembly of a half-barrel

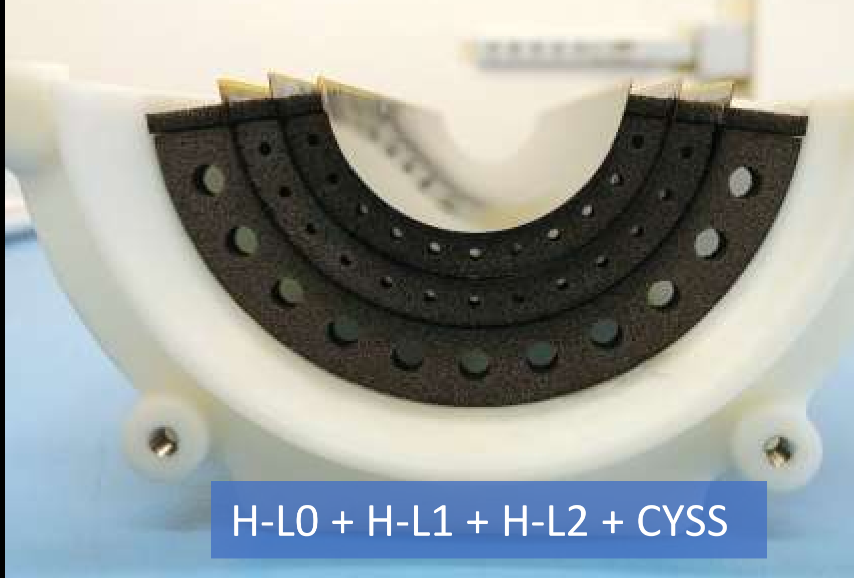


The silicon sensor itself is responsible for 0.07% X0 and the material budget for tracks with $|\eta| < 1$ on average is set at 0.09% X0 for the half-layer 0 reaching 0.13% X0 for $|\eta| = 1$

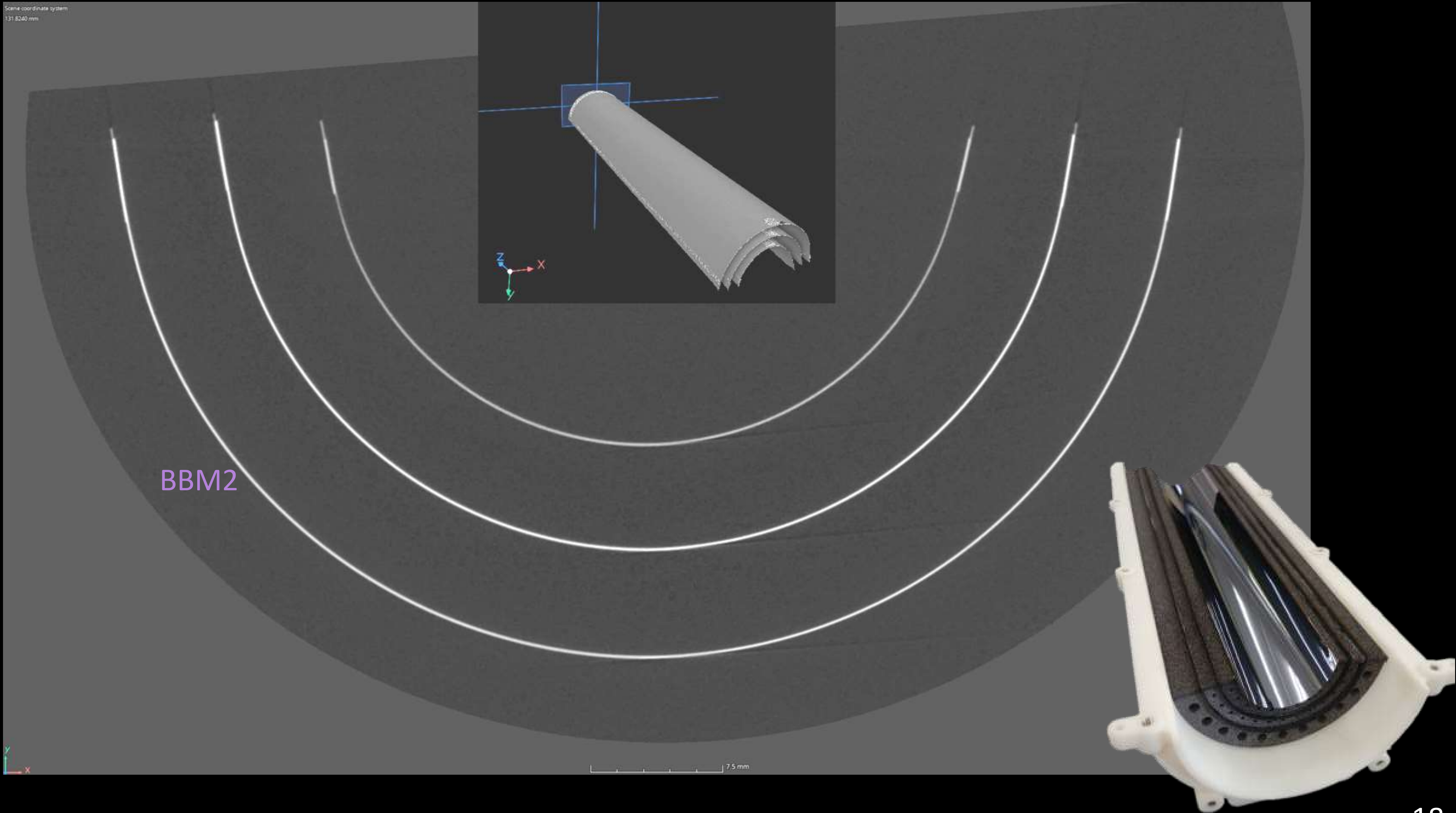


H-L2 + CYSS

H-L1 + H-L2 + CYSS



H-L0 + H-L1 + H-L2 + CYSS

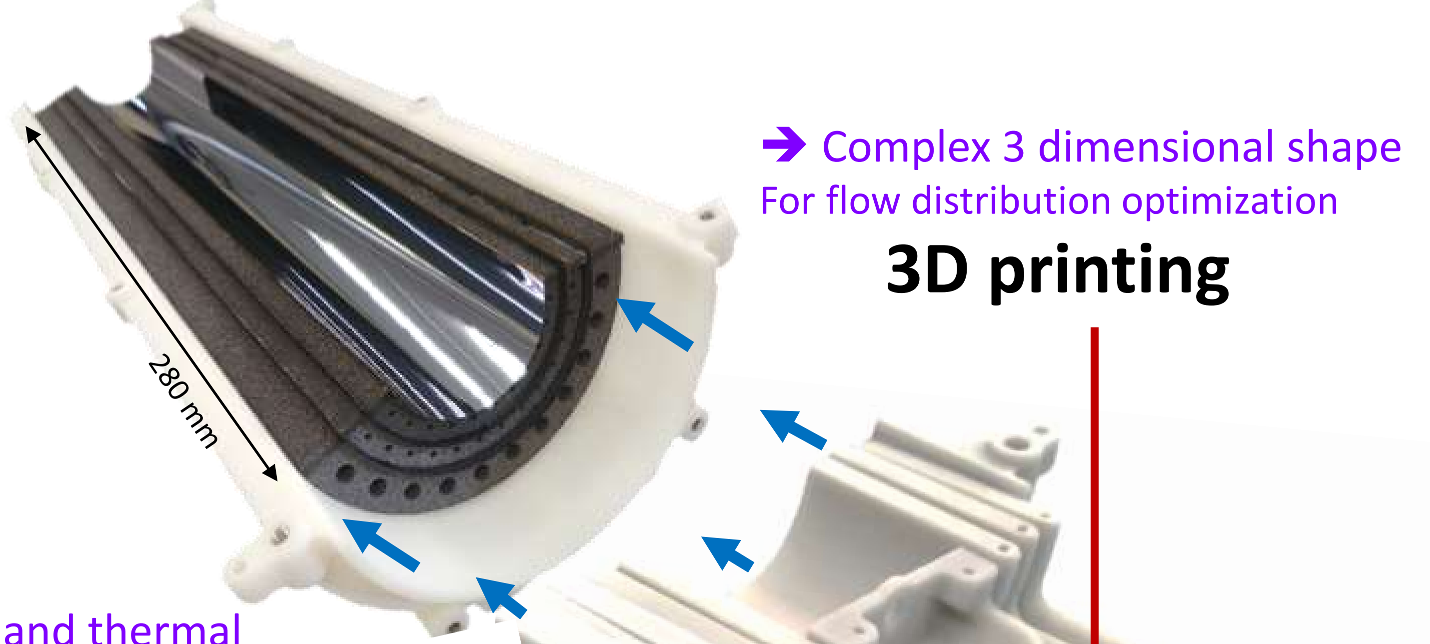


BBM2

Thermal management AIR COOLING (LHC RUN 4)

➔ Ultrathin Structural

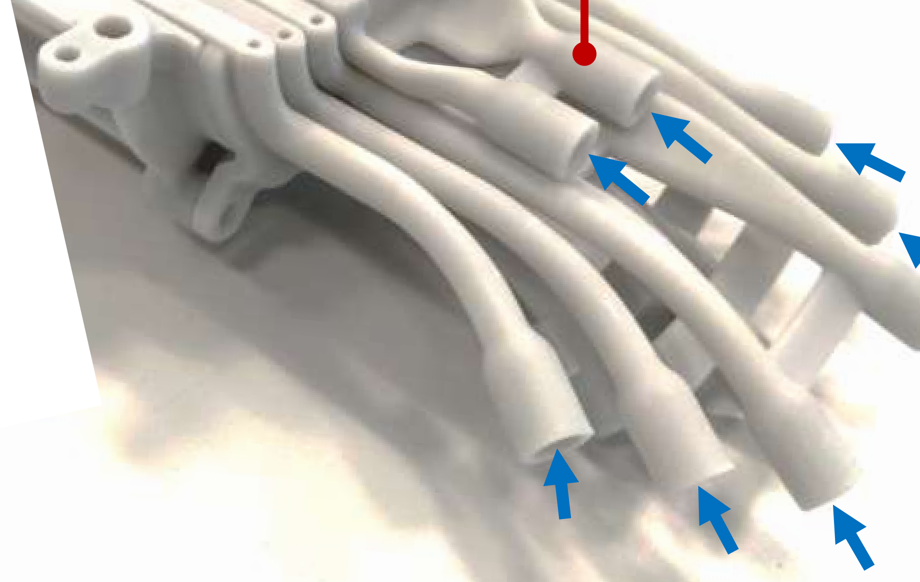
Carbon shell



➔ Complex 3 dimensional shape

For flow distribution optimization

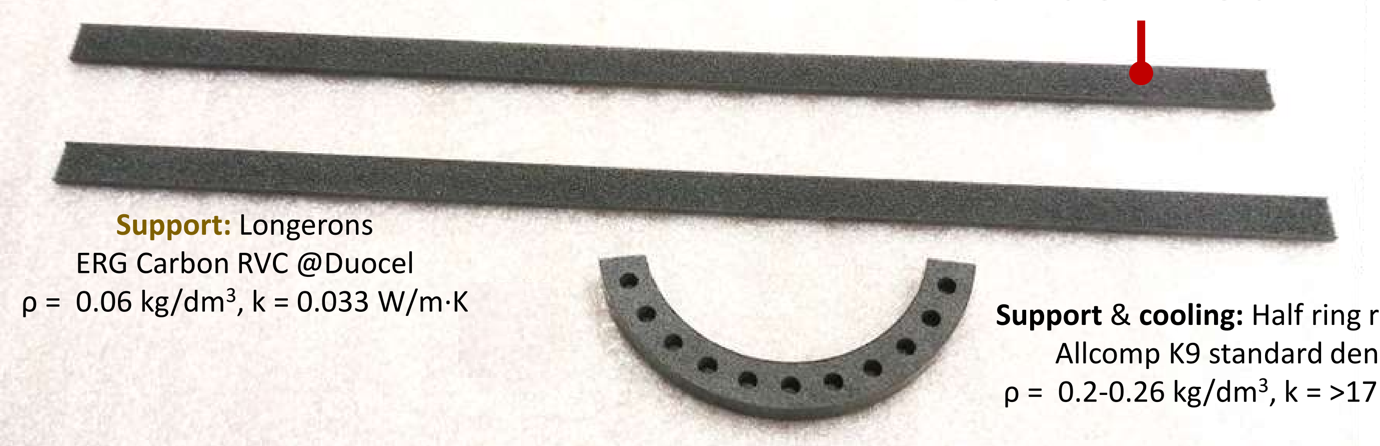
3D printing



➔ Structural and thermal

(acts as radiator for the air cooling)

Carbon foam



Support: Longerons
ERG Carbon RVC @Duocel
ρ = 0.06 kg/dm^3, k = 0.033 W/m·K

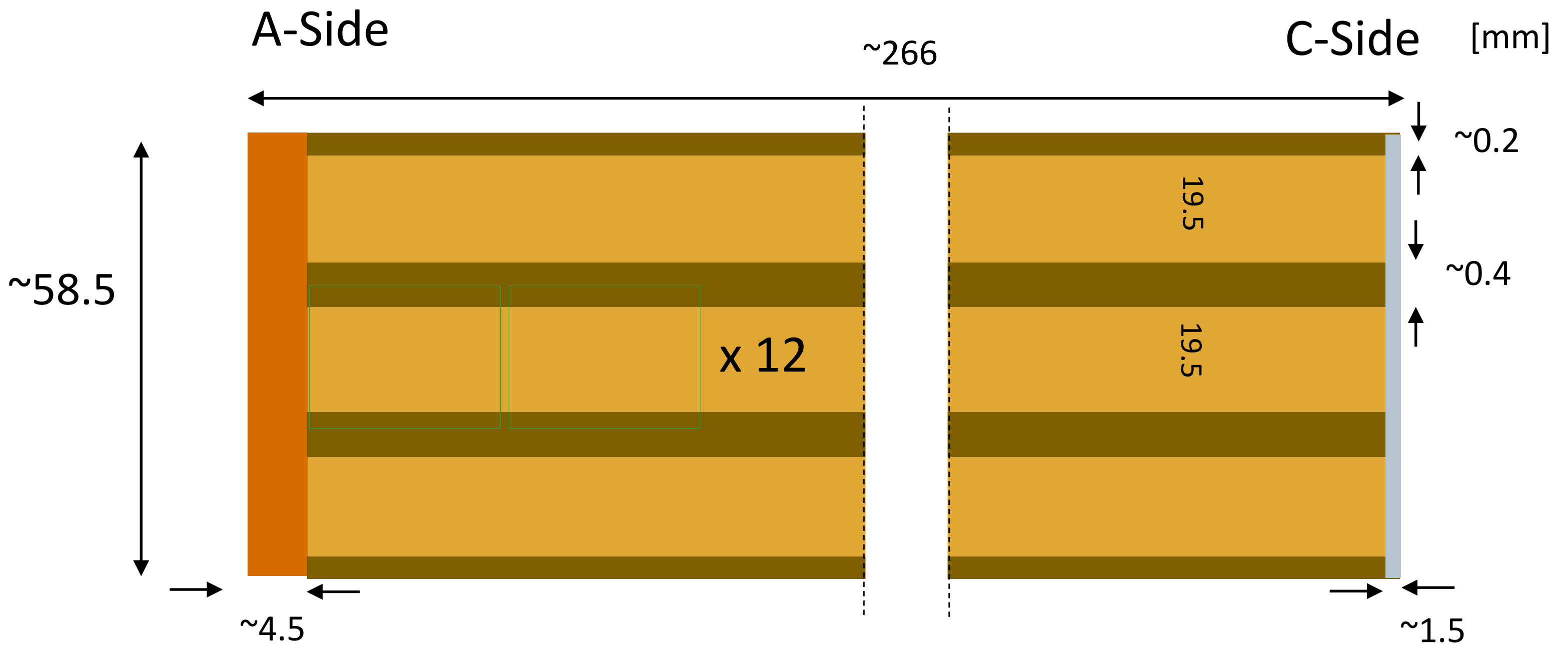
Support & **cooling:** Half ring radiators
Allcomp K9 standard density
ρ = 0.2-0.26 kg/dm^3, k = >17 W/m·K

Carbon foam as heat exchanger and mechanical support…..

Thermal management AIR COOLING (LHC RUN 4)

- Two zones of different power dissipation: endcap and matrix
- Same freestream velocity v_∞ in all layers, v_∞ = 8 m/s
- Temperature of the inlet air $T_\infty \approx 20$ °C

Layer	Half detector Expected Total power comsuption estimate [W]
0	6.4
1	8.5
2	10.6
Totale	25
Totale (2 half)	51



LAYER 0

□ Repeated Sensor Unit (RSU)

Half-layer Power distribution:

- 🟧 Endcap (791 mW/cm^2)
- 🟨 Matrix(15 mW/cm^2)
- 🟫 Periphery (432 mW/cm^2)

Beam pipe Power dissipation:

~10 mW/cm2 → ~ 3 W

Thermal management (LHC RUN 4)

ΔT_Sensor and air <10 °C
ΔT _matrix <5 °C

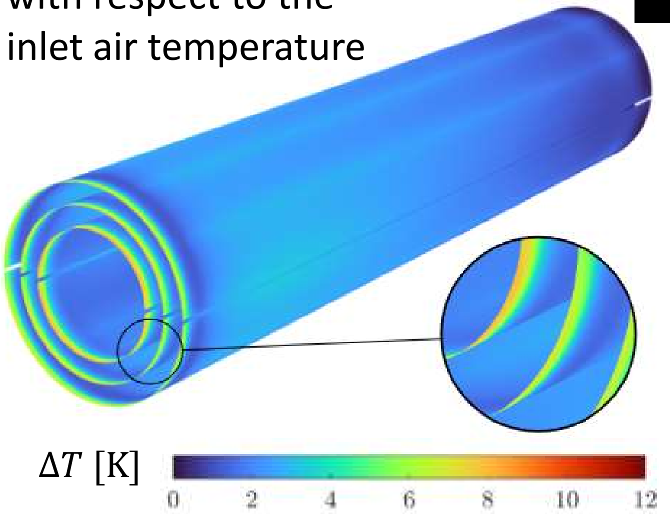
Half layer radius:
L0 18 mm
L1 24 mm
L2 30 mm

Power-map of half-layer 0

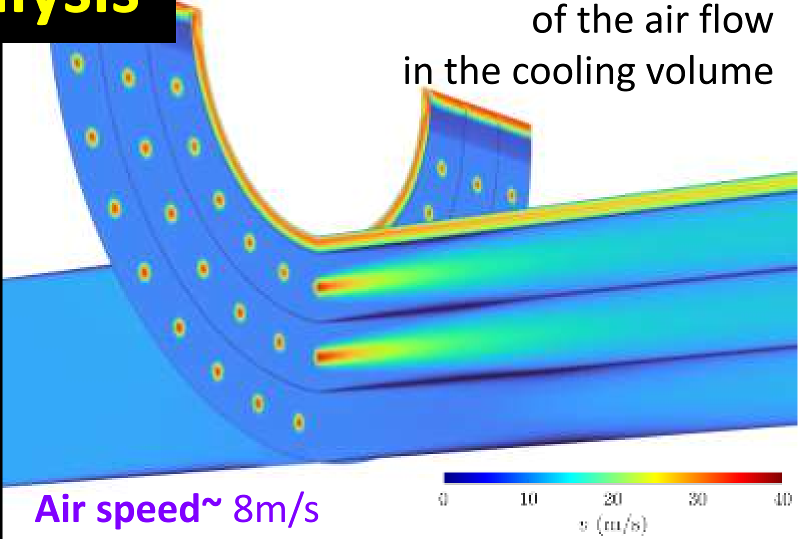
■ Endcap (791 mW/cm^2)
■ Matrix (15 mW/cm^2)
■ Periphery (432 mW/cm^2)

Analysis

Temperature difference with respect to the inlet air temperature



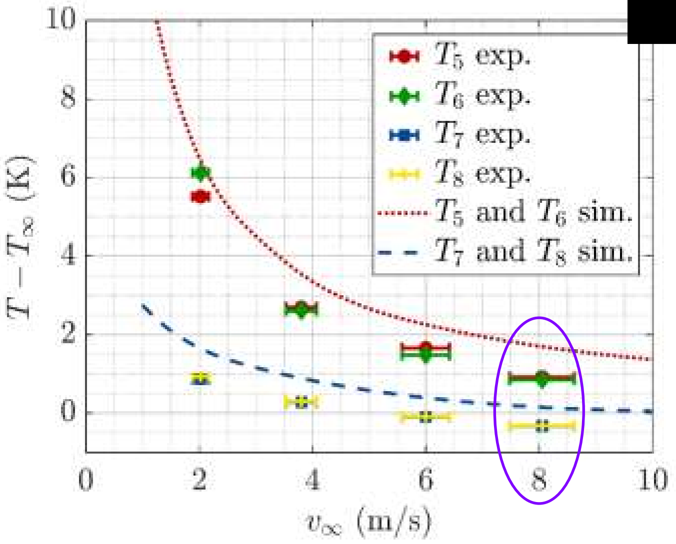
CFD simulation of the air flow in the cooling volume



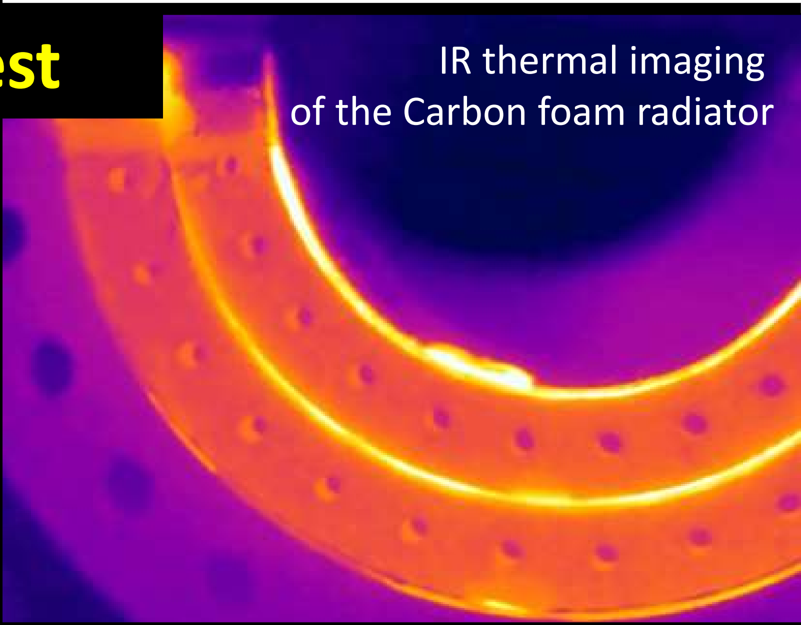
Air speed~ 8m/s

Test

Matrix region of half-layer 0



IR thermal imaging of the Carbon foam radiator

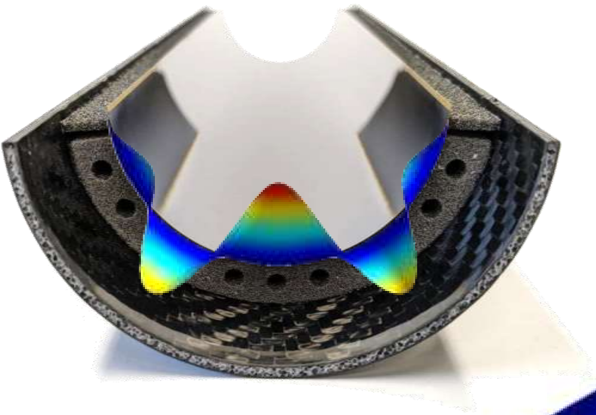


Carbon foam as heat exchanger and mechanical support…..

Aeroelastic stability (LHC RUN4)

➔Simulation strategy

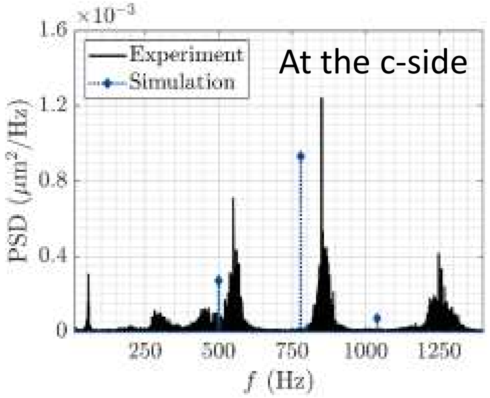
1. CFD simulations (8m/sec)⟶ Aerodynamic forces (pressure fluctuations)
2. Forces ⟶ Transient mechanical simulations ⟶ **L2 displacements**

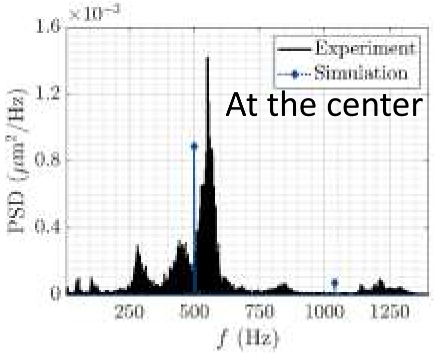


Peak-to-peak dispalcement ~ 1.1 µm

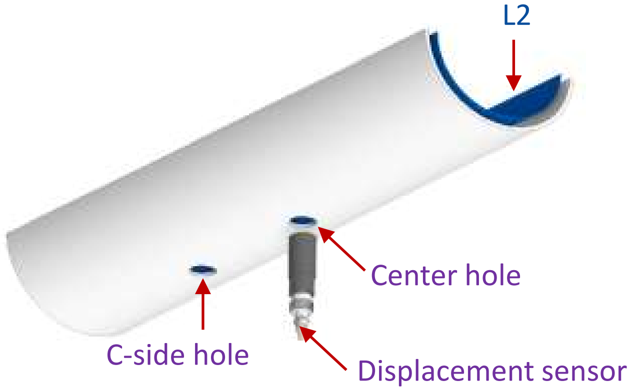
Root Mean Square of the displacement < 0.4 µm

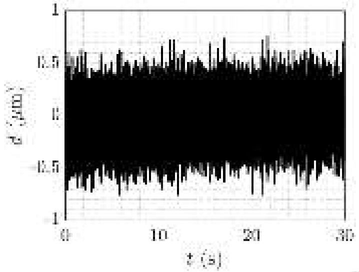
Agreement experimental test and simulation

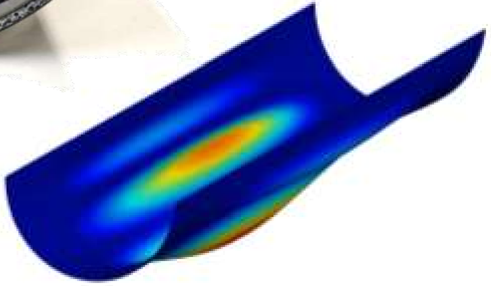




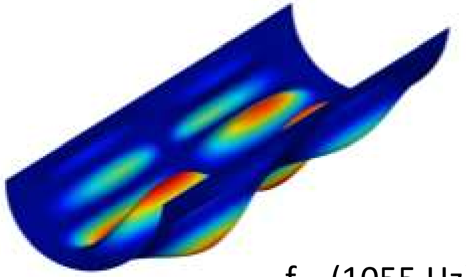
Test ⬅



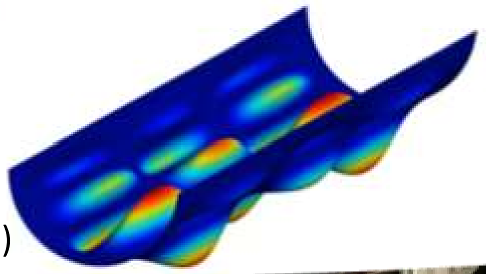




f_1 (492 Hz)
1st Natural freq

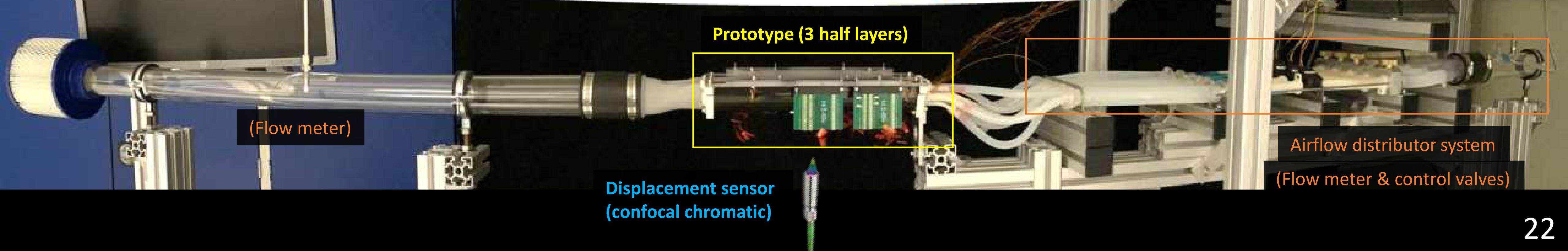


f_5 (775 Hz)



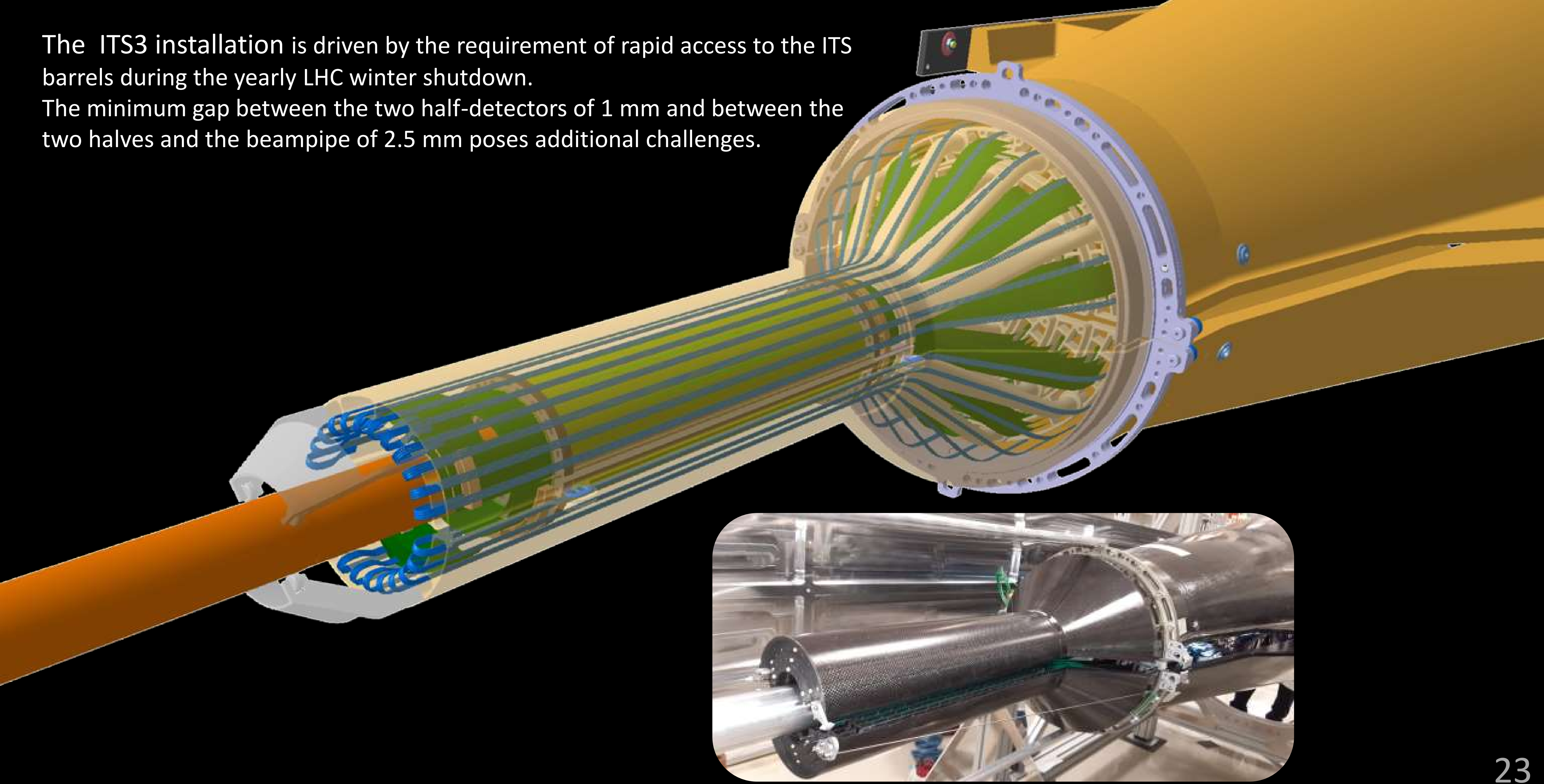
f_{11} (1055 Hz)

Test set-up



Installation

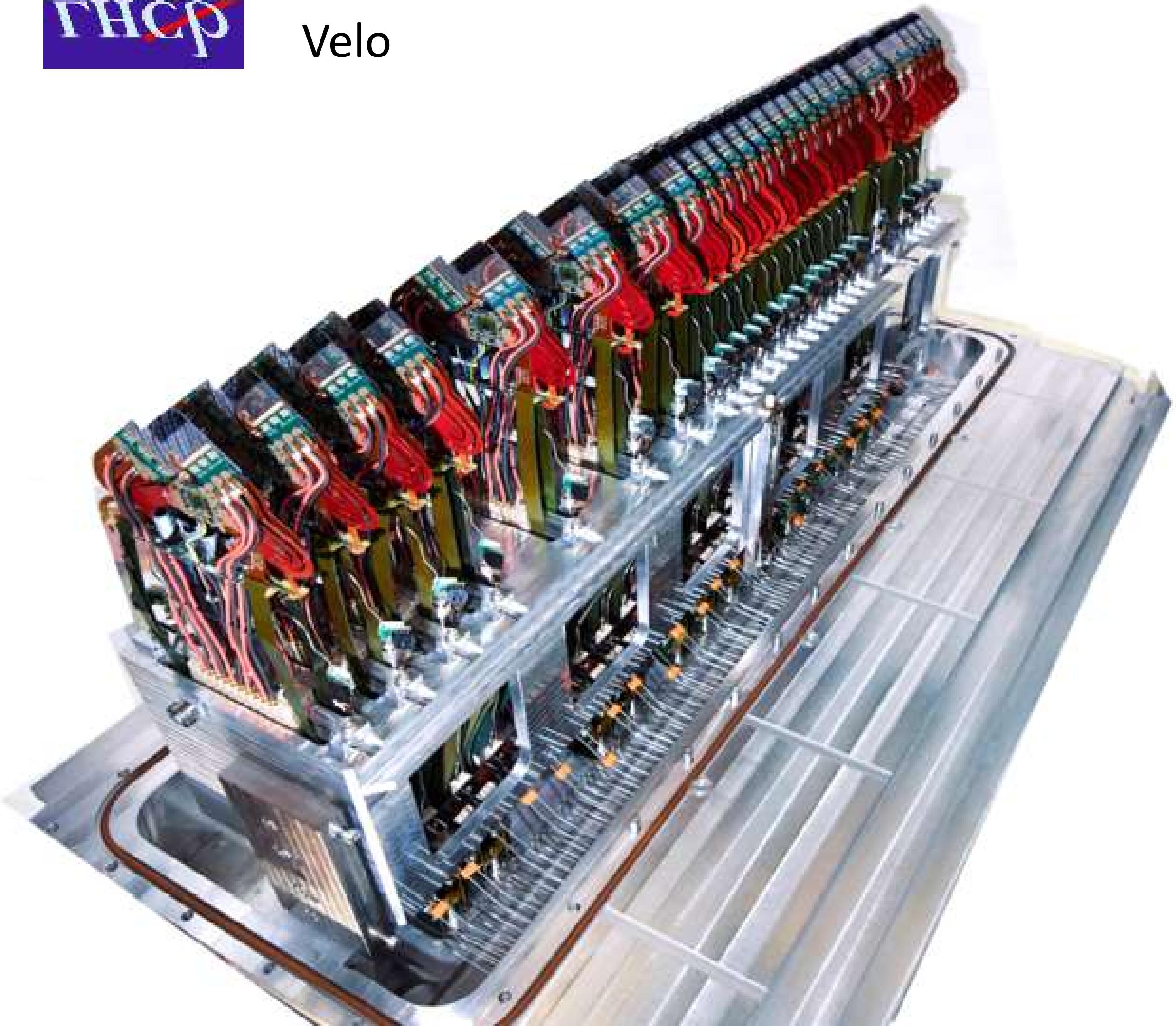
The ITS3 installation is driven by the requirement of rapid access to the ITS barrels during the yearly LHC winter shutdown.
The minimum gap between the two half-detectors of 1 mm and between the two halves and the beampipe of 2.5 mm poses additional challenges.

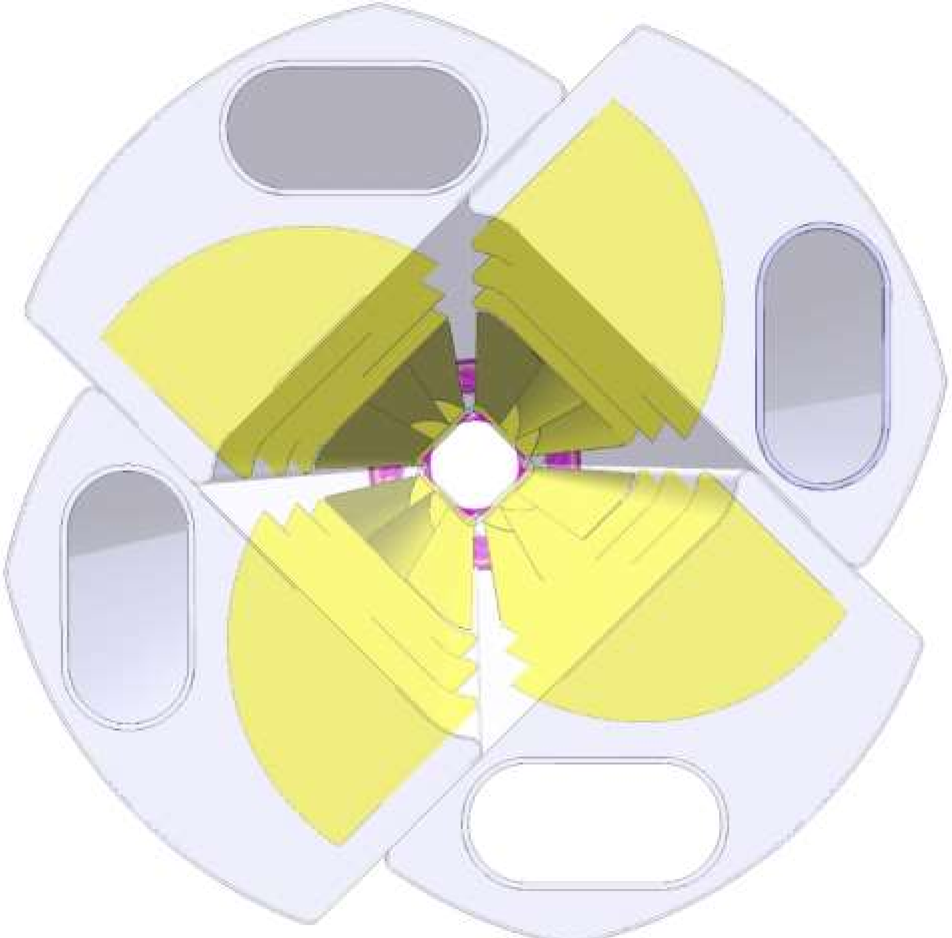


More challenges

Closer to IP

LHCb Velo





ALICE IRIS RUN4

CERN EP R&D

Beampipe at LHC

	Inner radius/ thickness			*[mm]*
	RUN1	RUN2	RUN3	Run 4
ALICE	29.2/ 0.8	29.2/ 0.8	18.2/ 0.8	16/ 0.5
CMS	29.2/ 0.8	21.7/ 0.8	21.7/ 0.8	
ATLAS	29.2/ 0.8	23.5/ 0.8	23.5/ 0.8	
LHCB	5/ 0.3	5/ 0.3	3.5/0.15	

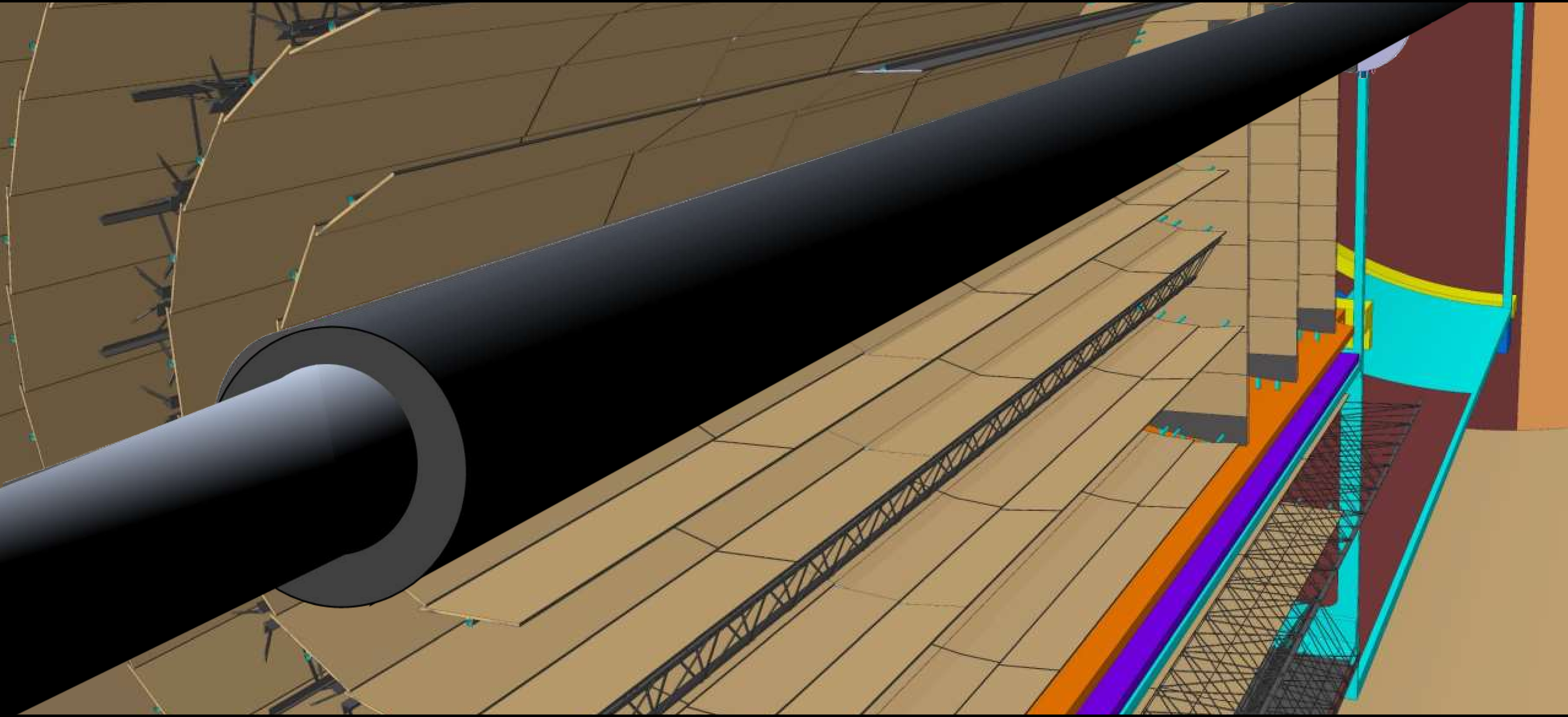
At LHC Apertures, impedance, vacuum stability for the vacuum chambers at the interaction points inside the LHC experiments are key parameters both to the safe operation of the LHC machine and to obtaining the best physics performance from the experiments.

Going closer to the beam with the Tracker layers, has a direct impact on these parameters

New designs for retractable trackers is being investigating, starting from Velo like concept and going to completely new concept like the Iris Tracker.

Minimum aperture at injection (n>7) i.e. 16mm radius aperture

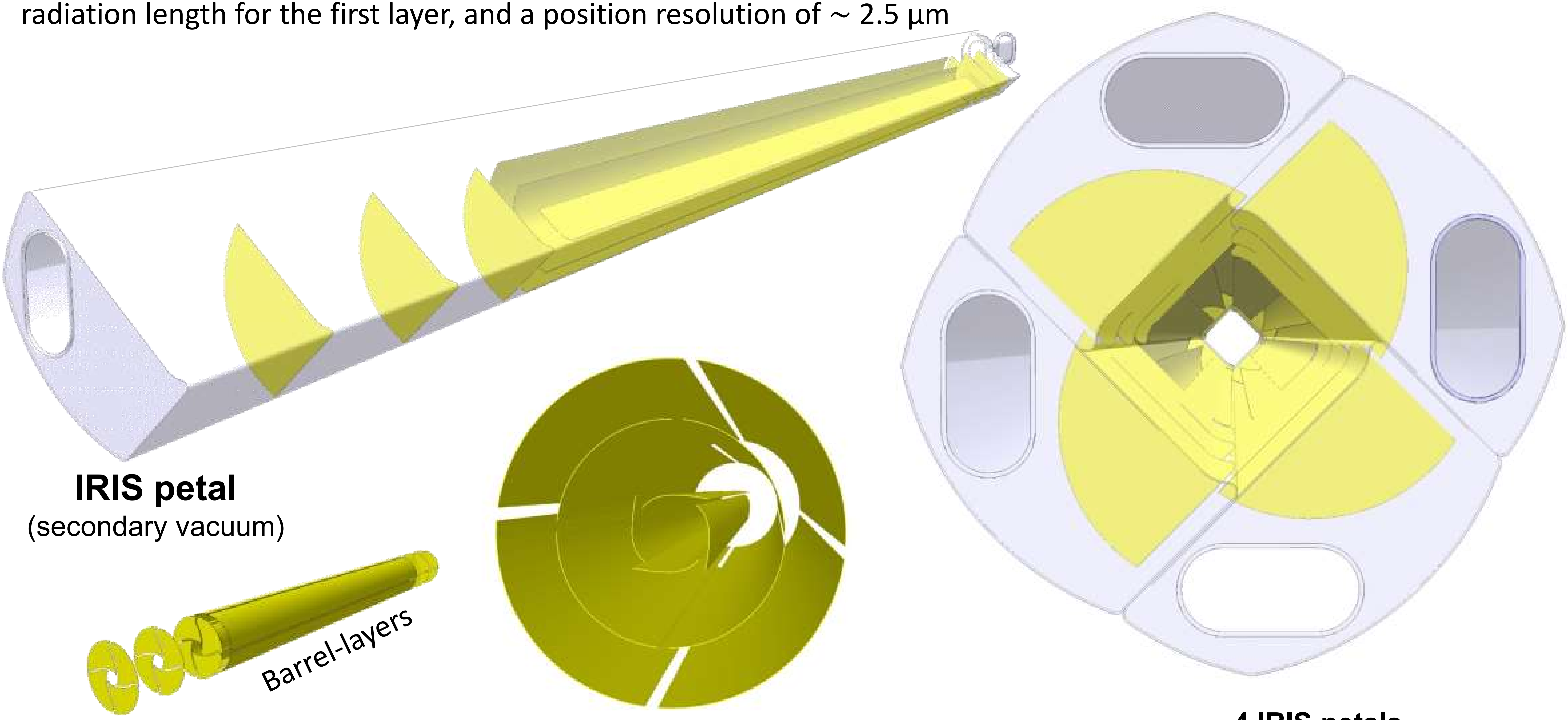
Closer to IB (ALICE IRIS RUN4)



A retractable vertex detector inserted inside the beampipe

Closer to IB (ALICE IRIS RUN4)

The requirements on the pointing resolution are met by a vertex detector with an inner radius of 5 mm, about 0.1 % X0 of a radiation length for the first layer, and a position resolution of ~ 2.5 µm



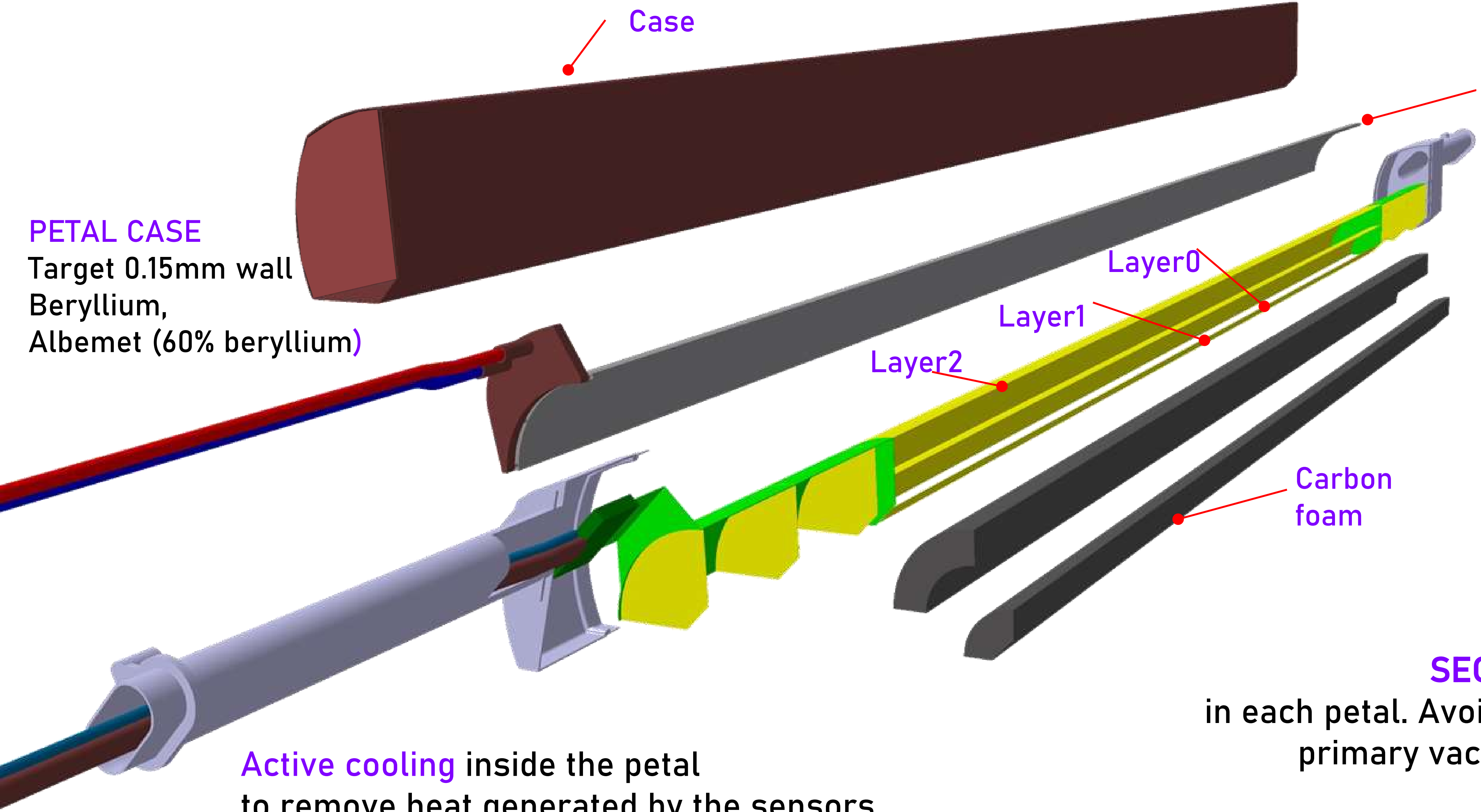
IRIS petal
(secondary vacuum)

Disks

Barrel-layers

4 IRIS petals
aperture from 5mm (operational)
to 16mm (beam injection)

Closer to IB (ALICE IRIS RUN4)



PETAL CASE
Target 0.15mm wall
Beryllium,
Albemet (60% beryllium)

Active cooling inside the petal
to remove heat generated by the sensors.
A coldplate is in thermal contact through
Carbon paper/ foam to the sensors

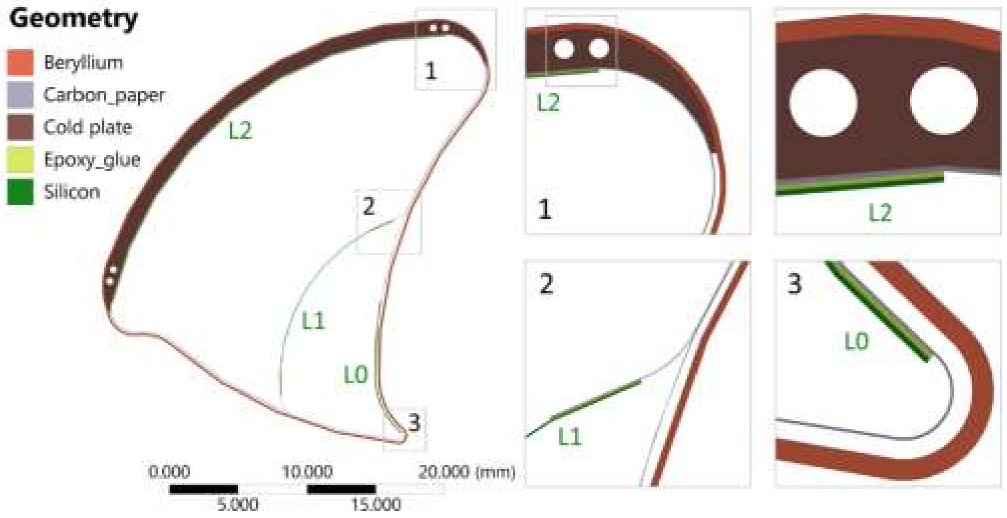
SECONDARY VACUUM
in each petal. Avoid contamination of
primary vacuum from detector
outgassing

THANK YOU

BACK-UP

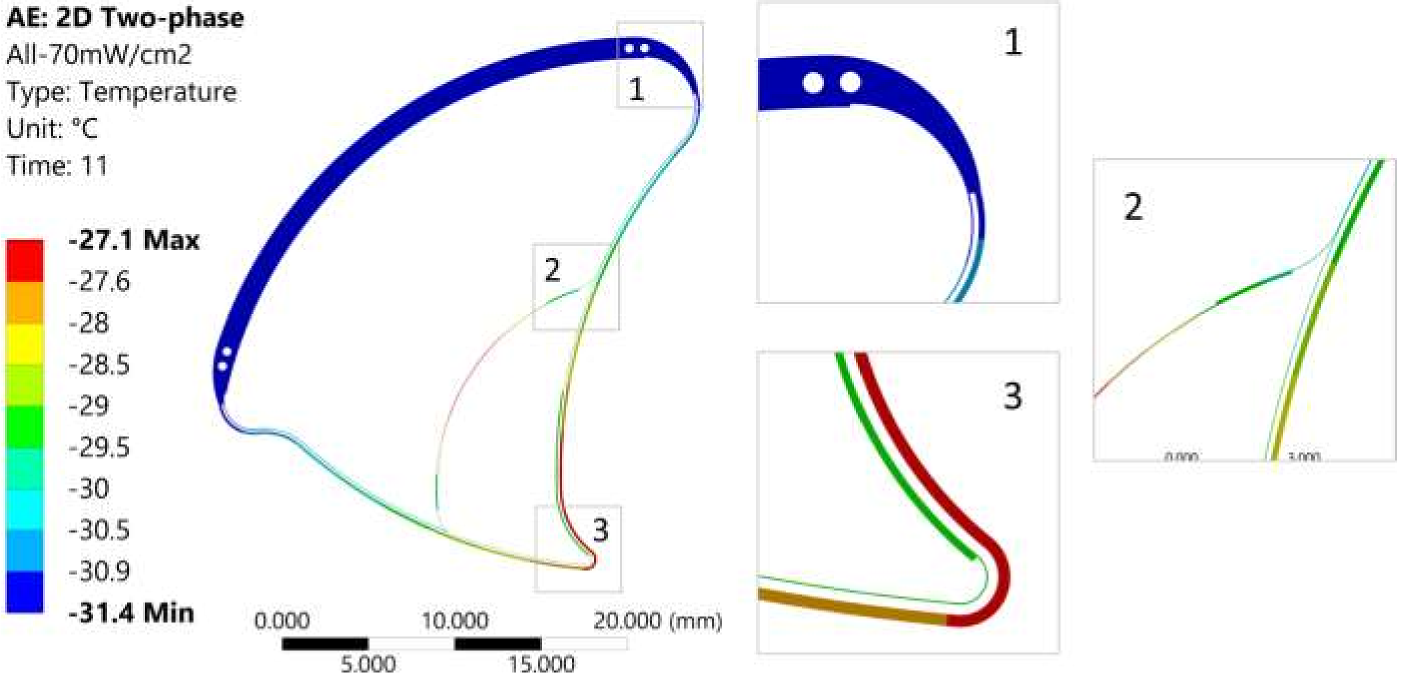
Iris tracker: Petals Cooling @~-25°C

Expected 1x10^16 1 MeV n_eq of NIEL in 50 months of operation and 6 Mrad TID. Cooling will mitigate leakage current damages that will also depend on the process and the pixel geometry, not yet defined, in addition to the NIEL radiation level. The NIEL radiation load is about the same as for ATLAS and CMS.



Design assumption for preliminary assessment

1. Two-phase evaporative CO2
   (alternatives fluid will be considered)
2. Applied heat flux
   70mW/cm2 sensors heat flux
   100mW/cm2 beam pipe current flow (impedance)



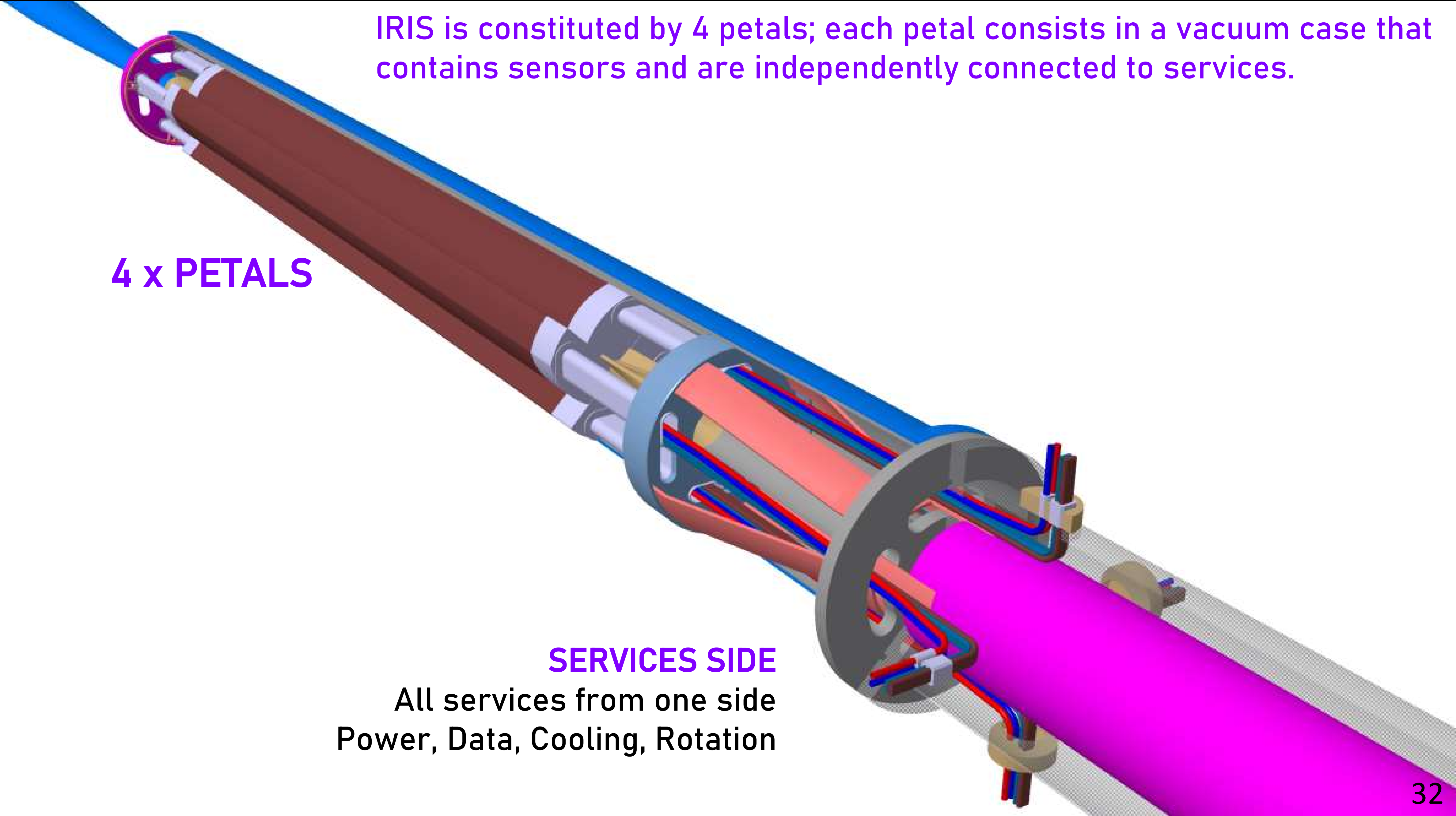
Temperature profile

Preliminary results show that the sensors can be cooled at ~ -29C with an inlet CO2 at -35C.

Same analysis also shows a deltaT of 1-2 degrees within the single sensor and 5 degrees between the coldest (outermost) and hottest sensor (innermost).

Closer to IB (ALICE IRIS RUN4)

IRIS is constituted by 4 petals; each petal consists in a vacuum case that contains sensors and are independently connected to services.



4 x PETALS

SERVICES SIDE

All services from one side

Power, Data, Cooling, Rotation