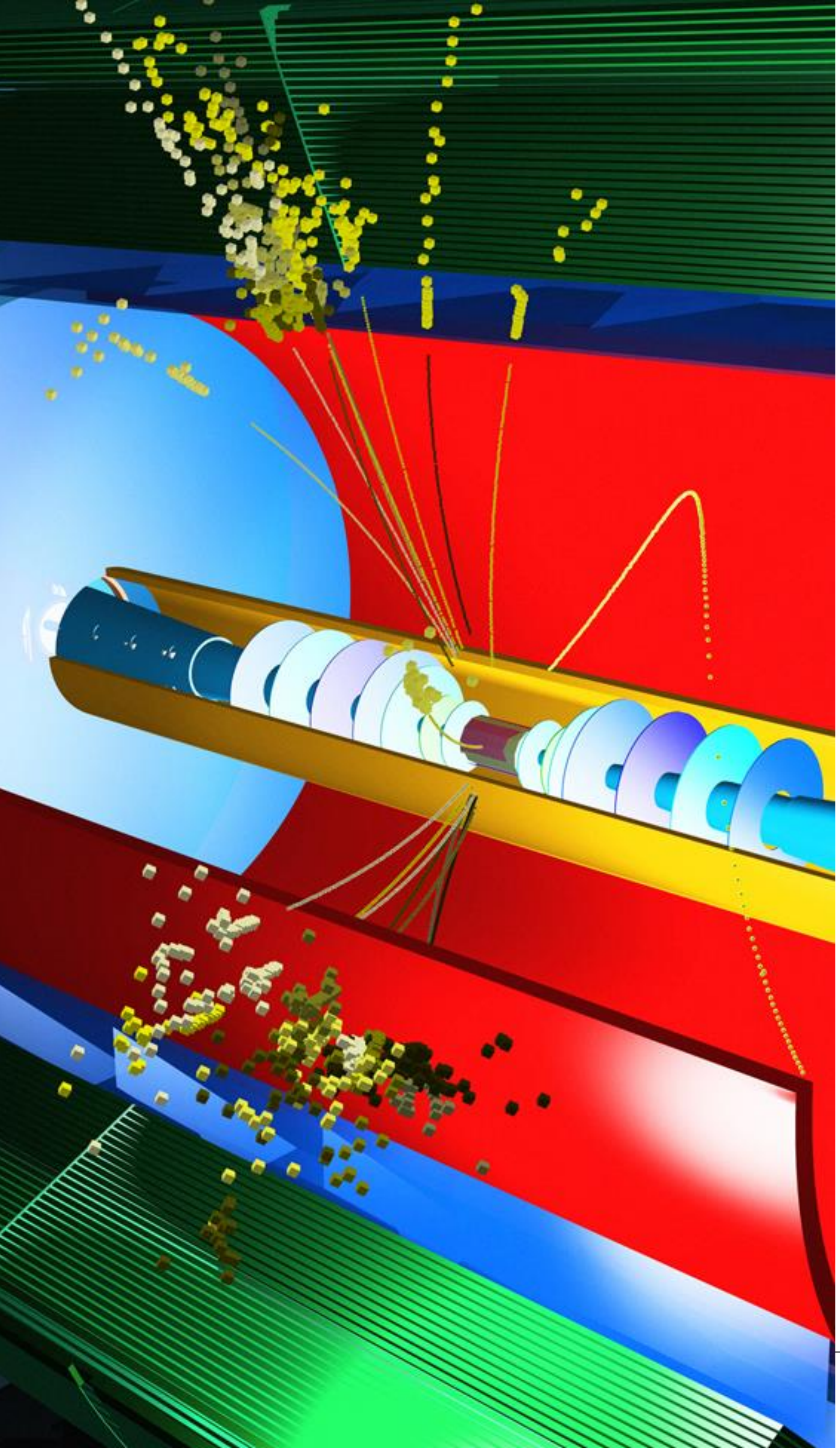


All-Silicon Petals

DEPFET workshop
Ringberg, March 2019

Guillem Vidal, IFIC (UVEG/CSIC) Valencia

Special thanks: Marcel Vos, M.A. Villarejo, Martín Perelló (IFIC)
Laci Andricek (MPG/HLL), Malte Frövel, Maria de la Torre (INTA)
Carlos Marinas (U. Bonn),
David Moyá, Ivan Vila (IFCA)

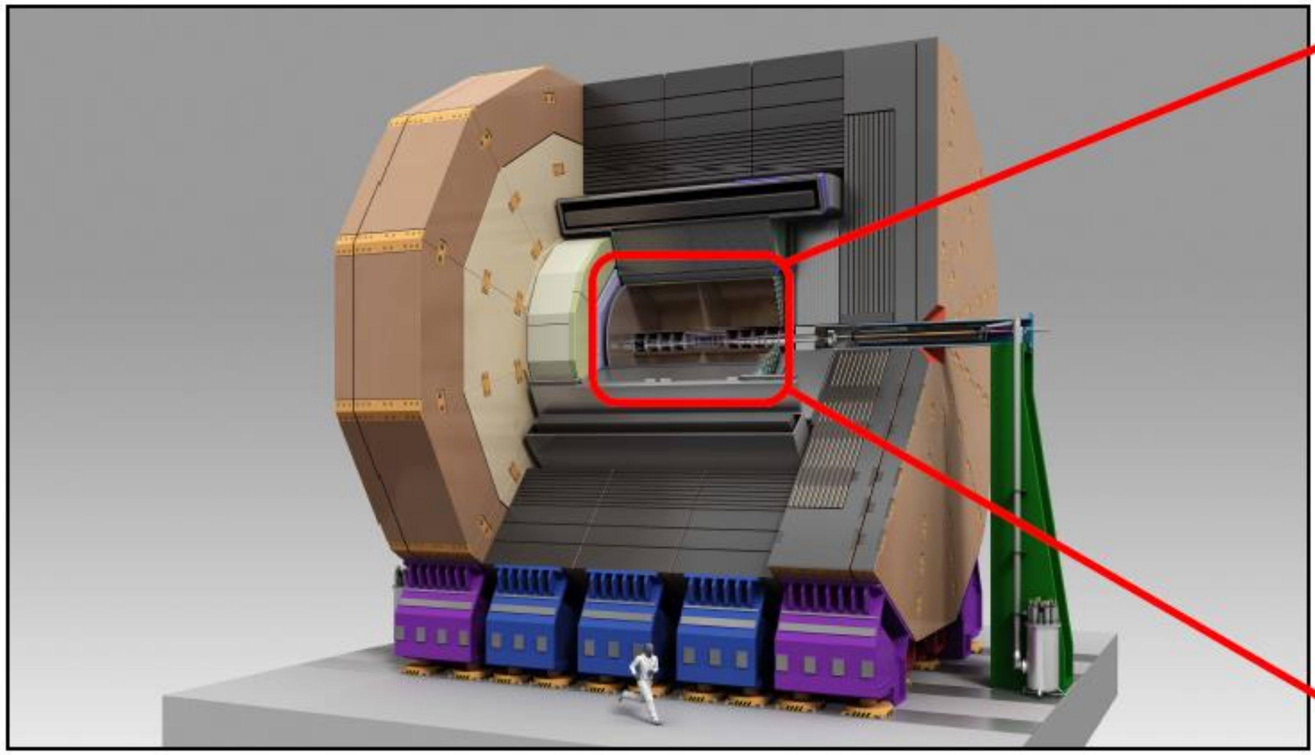
What do we want to achieve

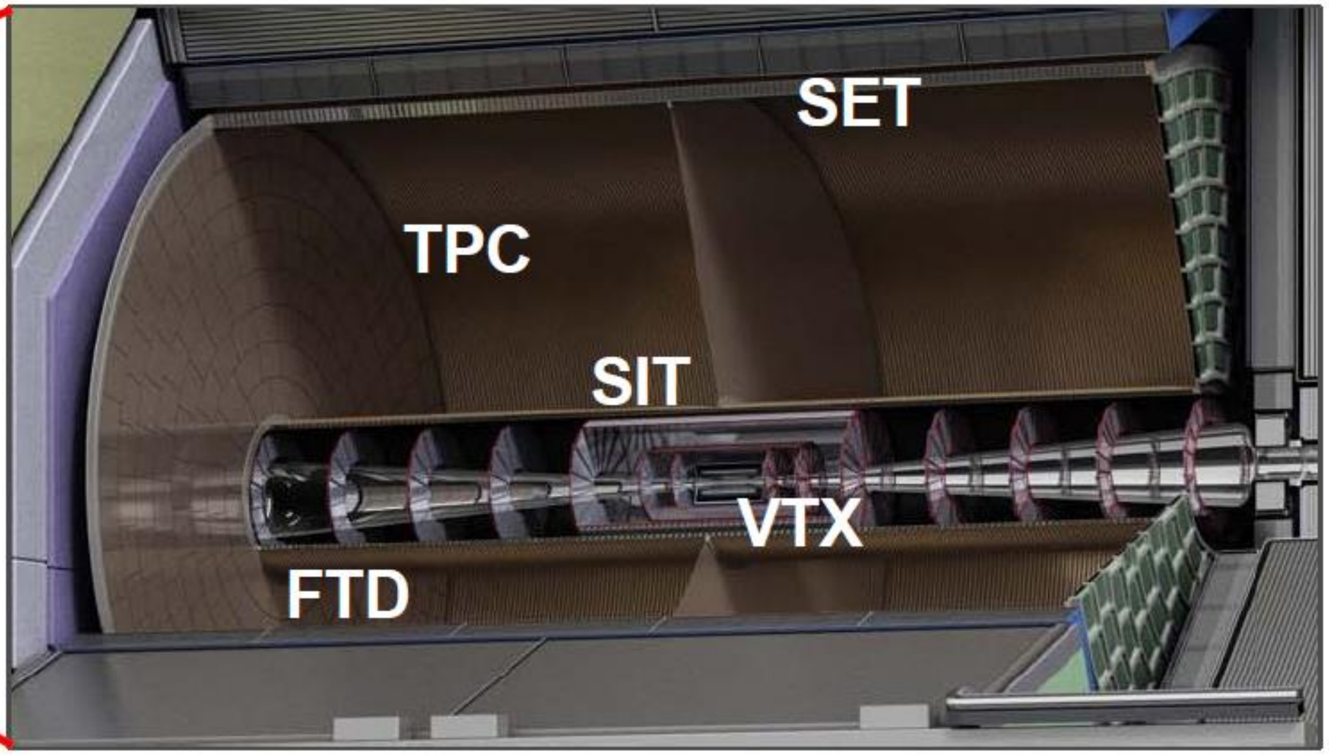
Impact parameter resolution expected at ILC

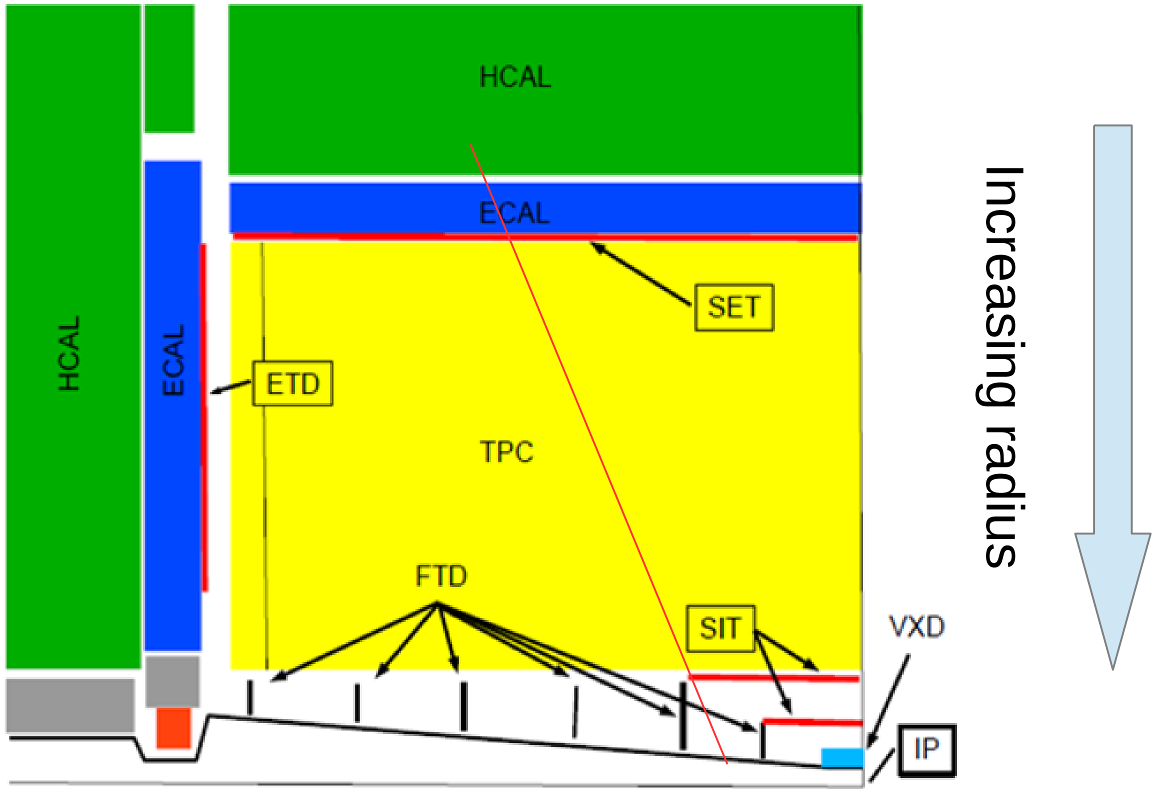
$$\sigma_{ip} = 5\ \mu m \oplus \frac{10}{p\beta \sin\theta^{3/2}}\ \mu m.GeV/c$$

- Spatial resolution of the inner layer close to ≈ 3µm (which corresponds to a pitch 17µm)
- Low material budget to minimize multiple scattering, ≈ 0.15% X_0/layer
- Alignment at the micron level capabilities.

ILD tracking







Tracker sub-systems

Beam pipe

Vertex Detector (VXD)

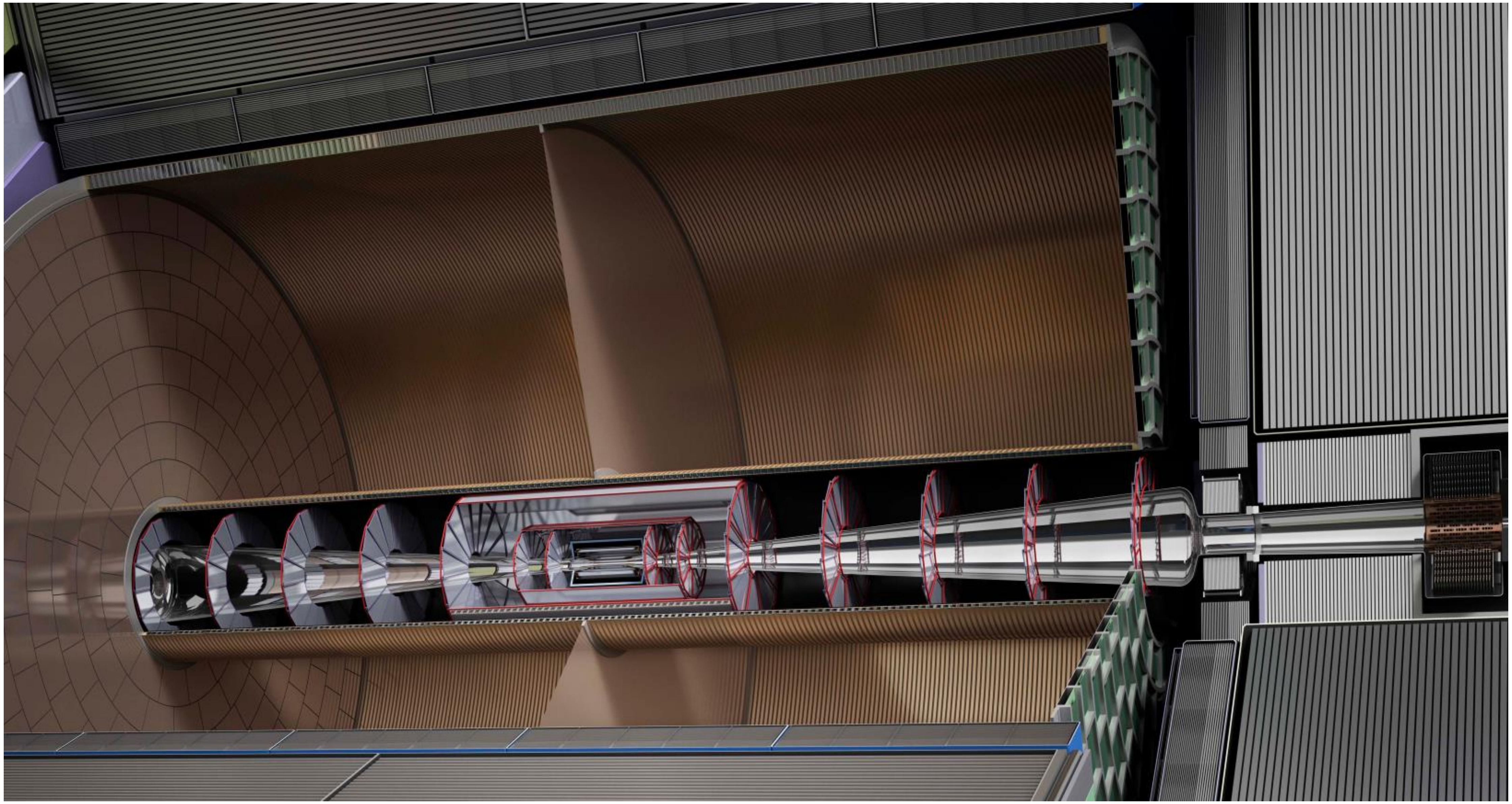
Silicon Intermediate Tracker (SIT)

Time Projection Chamber (TPC)

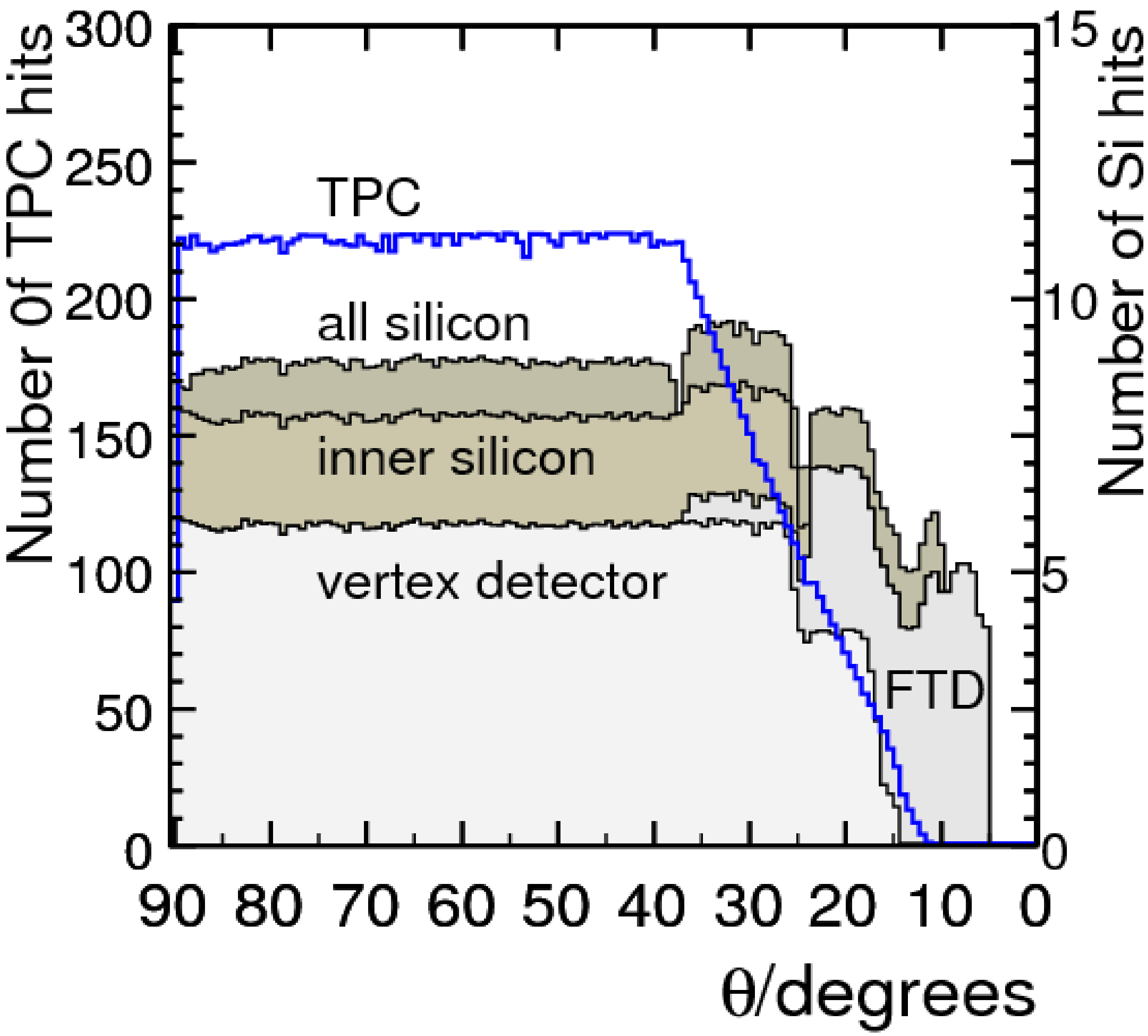
Silicon Envelope Tracker (SET)

The ILD tracker and FTD

- Mixed silicon (vertex, FTD, SIT, SET) and gaseous system (TPC)
- Seven disks cover the forward region between the TPC and the beam pipe.
- Innermost two disks pixelated single layer of silicon sensors
- Five outer disks equipped with a double layer of strip-based silicon sensors



The role of FTD in tracking



Number of hits in different sub-systems vs. polar angle

In the case of ILD

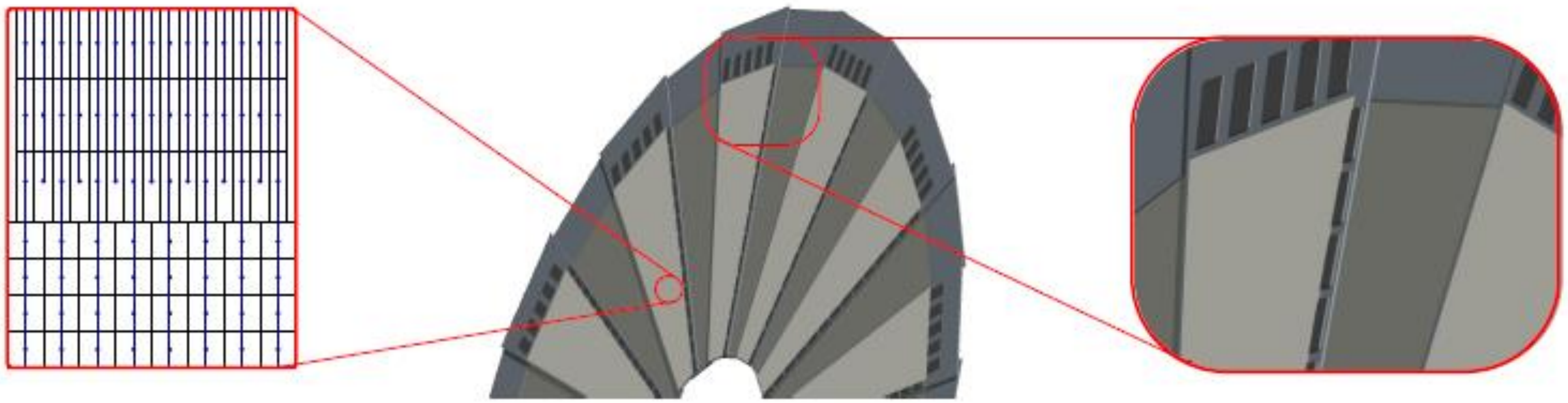
-Barrel covers angles between 90-25 degrees

-The Time Projection Chamber also decreases the number of hits with the angle

-The Forward Tracking Disks cover the angles between 25 and 7 degrees

Pixelated disks

Technologies for pixelated FTD 1 & 2



- All technology options remain open
  - DEPFET
  - CMOS
  - FPCCD
  - 3D-integrated
  - SOI
  - ...
- Conceptual adaption of barrel design to disk geometry for some technologies, but no fully engineered design

DEPFET active pixel detector technology

DEPFET

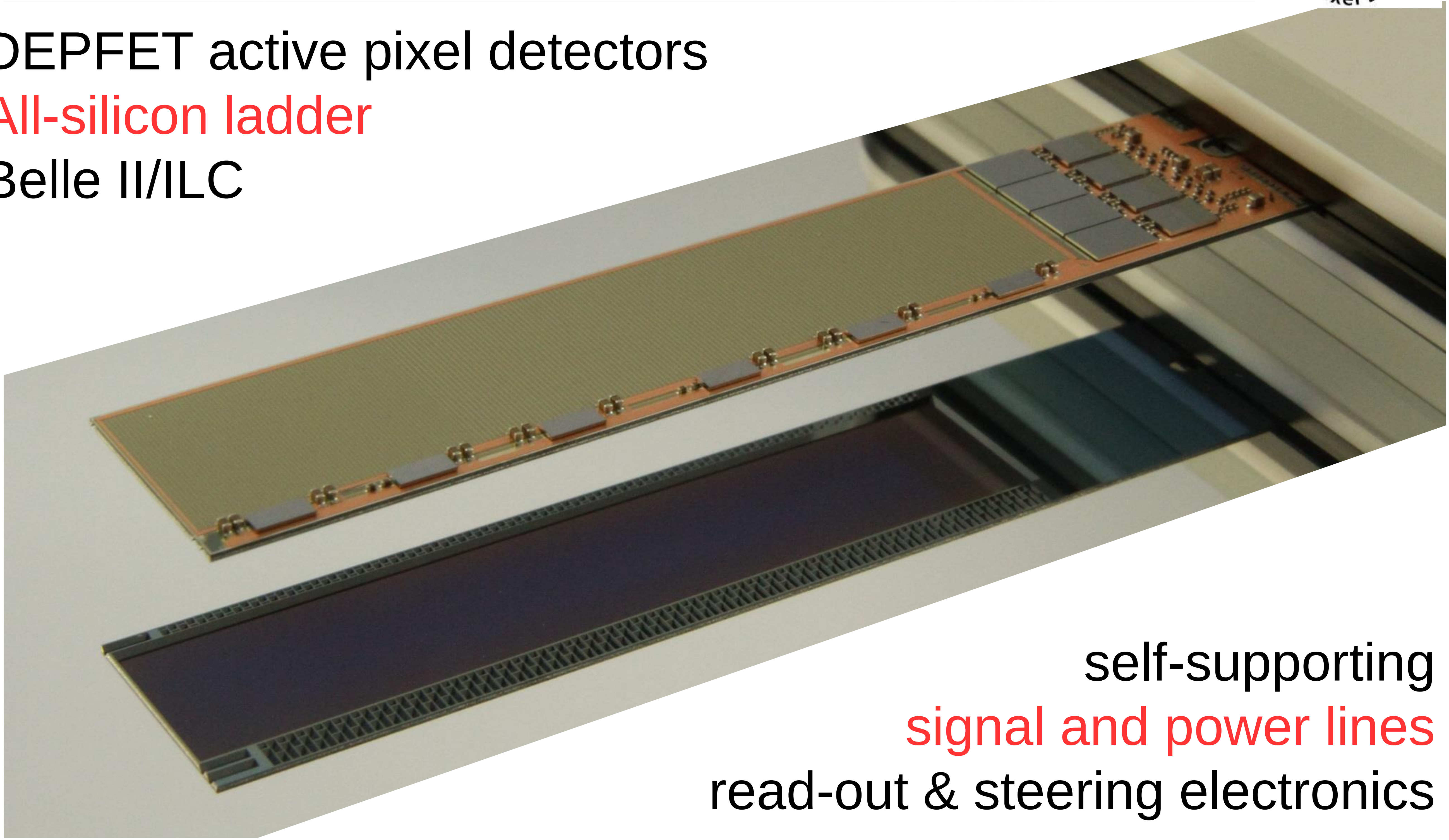
Active Pixel Detector

These DEPFETs meet most ILC requirements

DEPFET active pixel detectors

All-silicon ladder

Belle II/ILC

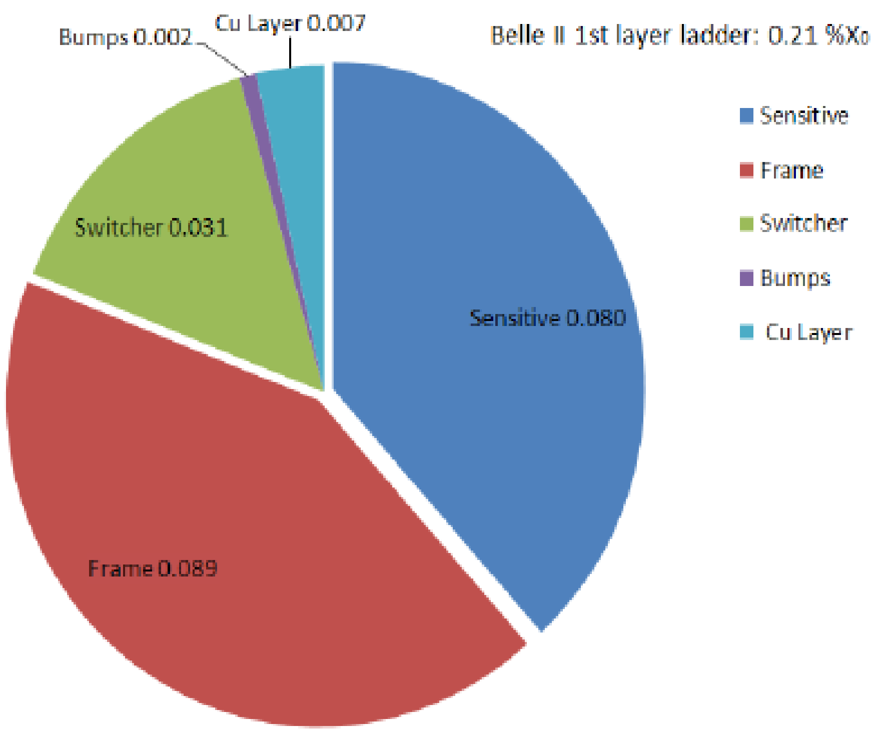


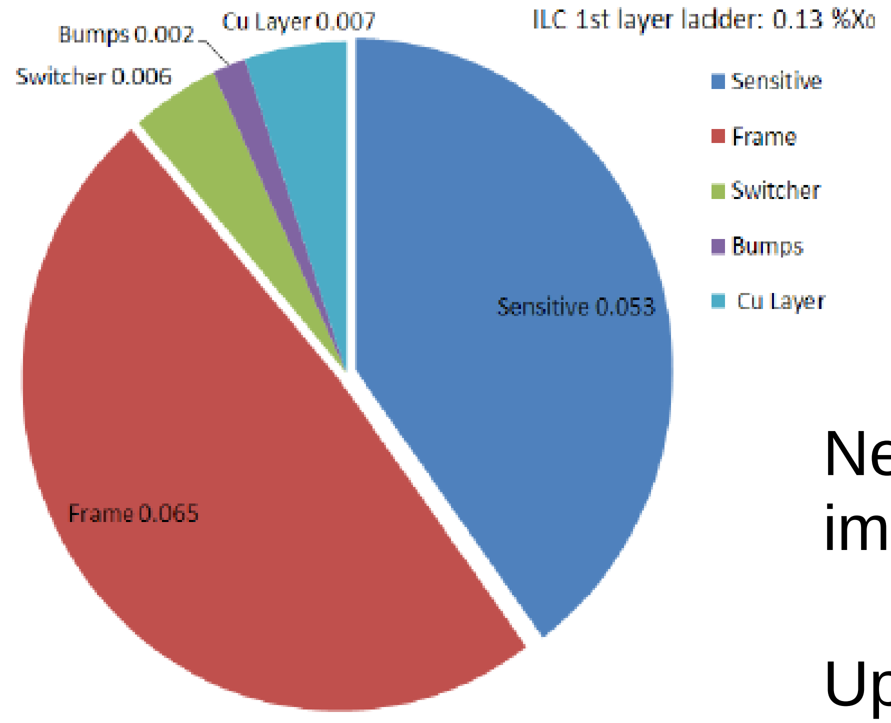
self-supporting

signal and power lines

read-out & steering electronics

DEPFET beyond Belle II





Carlos Mariñas

Laci Andricek

Next 10 years: significant improvement in technology

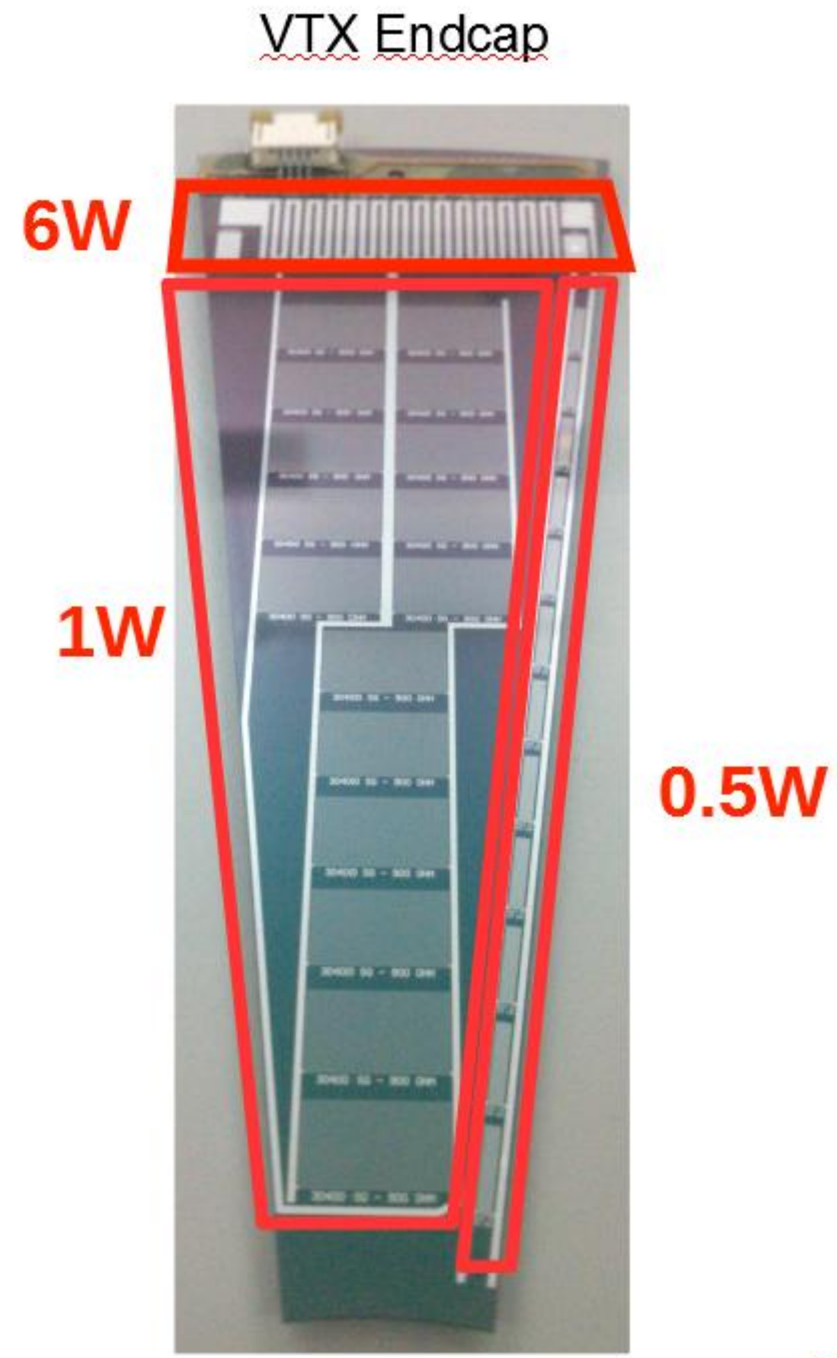
Upgraded lithography offers opportunities for better signal amplification (S/N ratio, resolution, read-out speed)

	Belle II	ILC
Frame thickness	525 µm	400µm
Sensitive layer	75 µm	50µm
Switcher thickness	500µm	75µm
Cu layer	only on periphery	only on periphery
Total	0.21 %X0	0.13 %X0

→ 40% Material Budget reduction

→ less material with small modifications/improvements of module technology within reach

Ladder to Petal



Based on DEPFET technology:
-Power distribution
-Material
-Mechanical stiffness

Adapt the ladder design to FTD 1 and 2

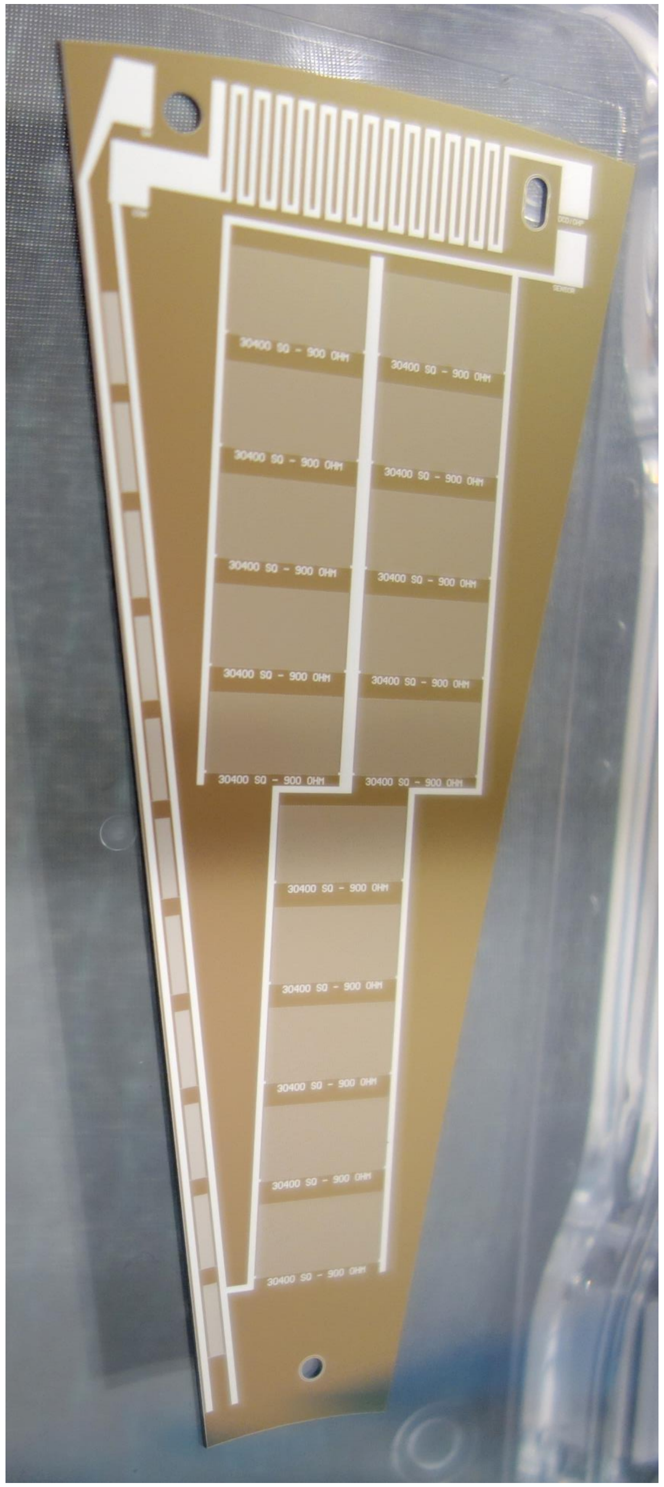
Ladder becomes a petal

Read-out ASICs on outer perimeter

Dimensions reflect ILD design

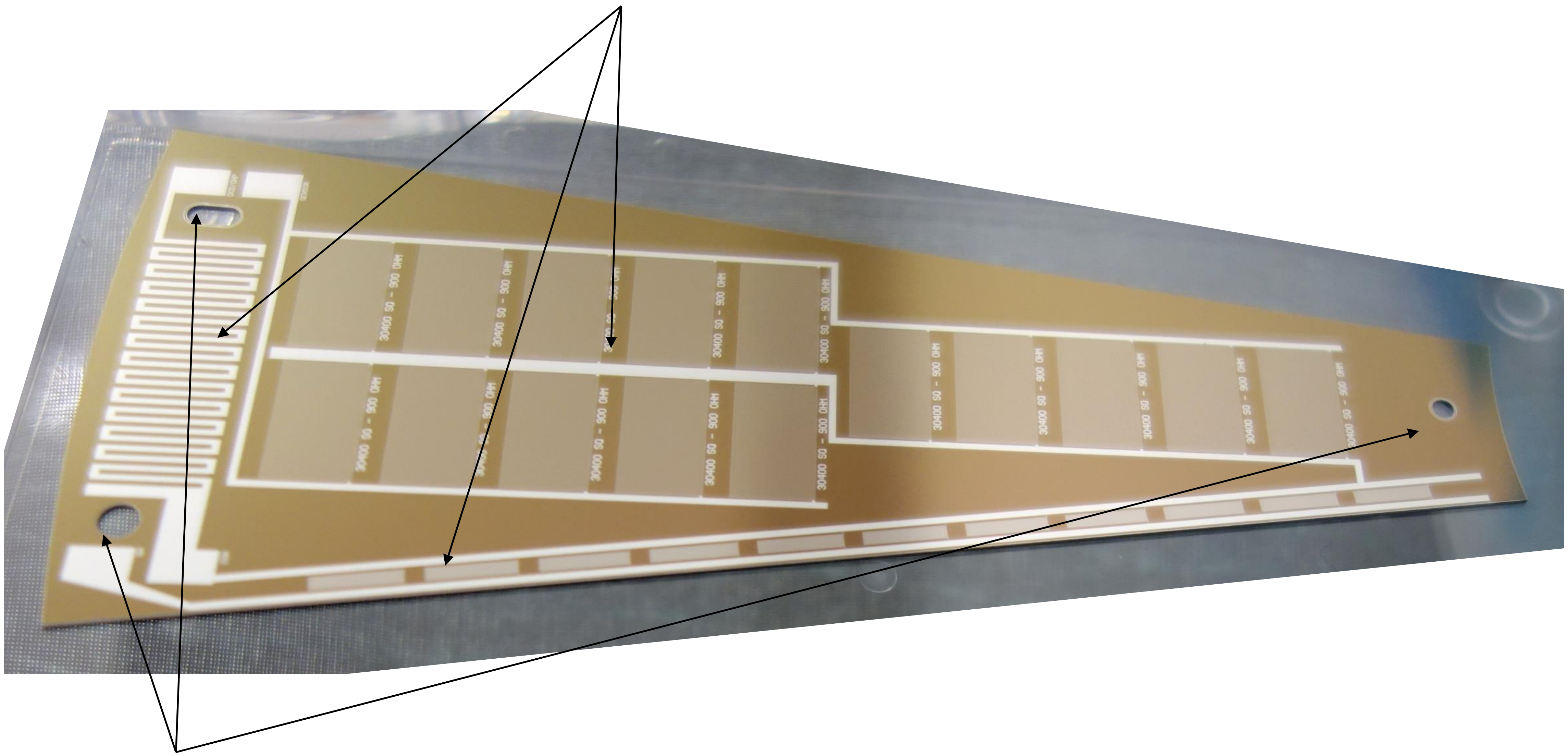
Silicon petal design at IFIC in collaboration with Ladislav Andricek (MPG-HLL)

Material budget:
Thinned sensor area = 50 µm Si = 0.05 % X_0
Thicker rim “frame” = 500 µm Si = 0.5 % X_0



Dummy production

Heater circuits on the sensor (single Al metal layer)

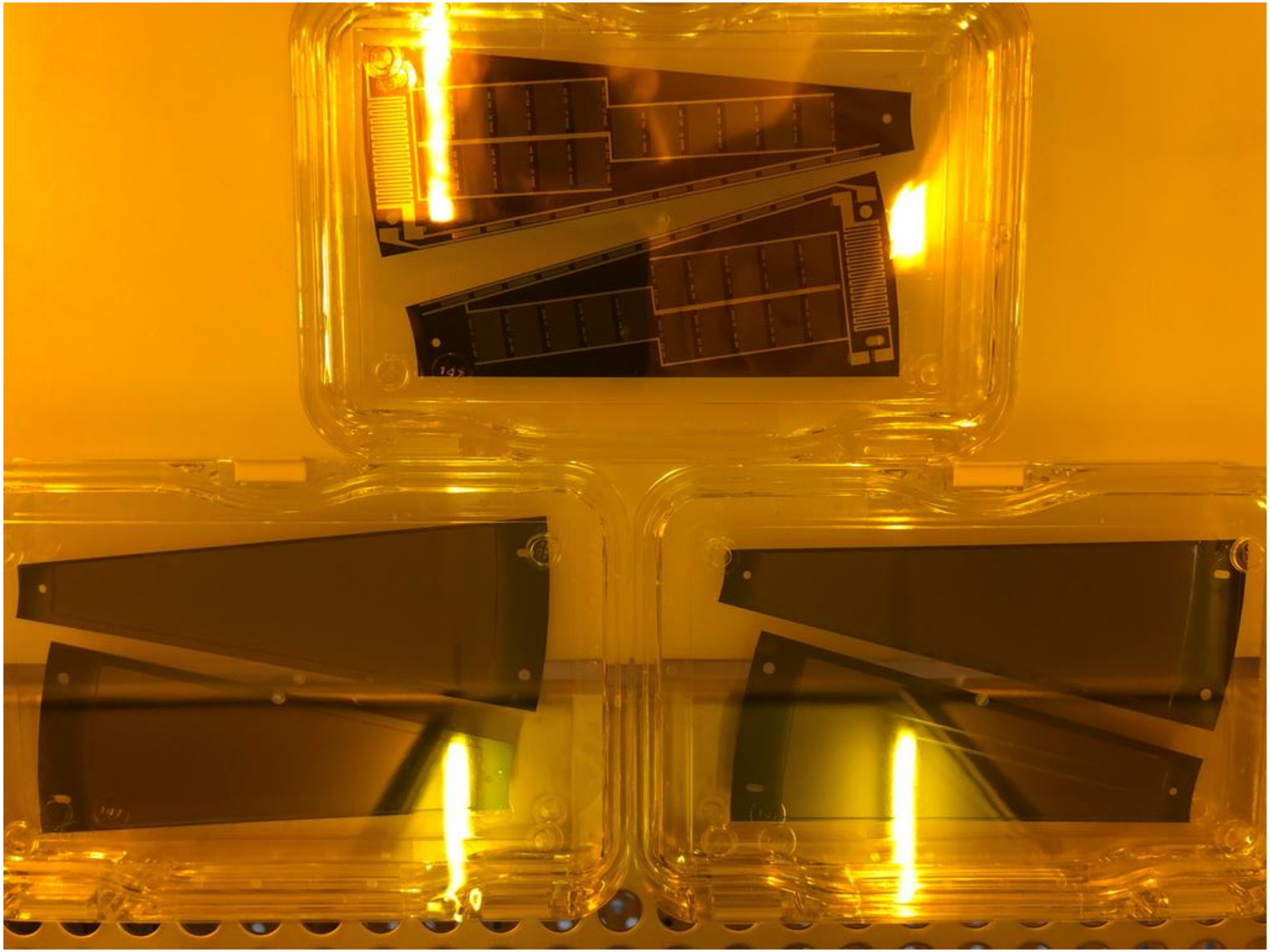


Kinematic mounting slots:
- 3D constraint
- Allows thermal expansion

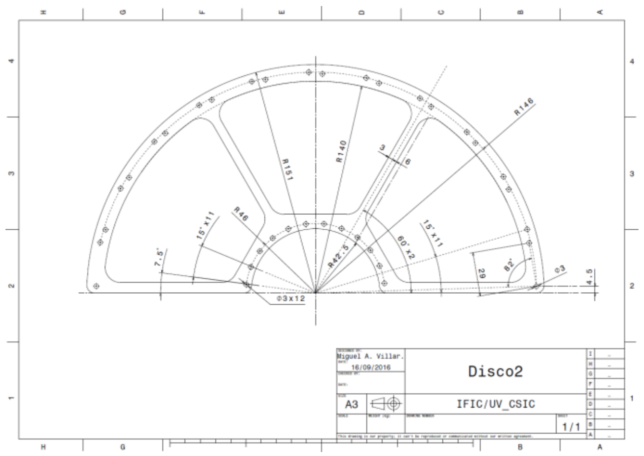
Thermo-mechanical performance

All-silicon petals

Production at silicon lab of the Max Planck society in Munich

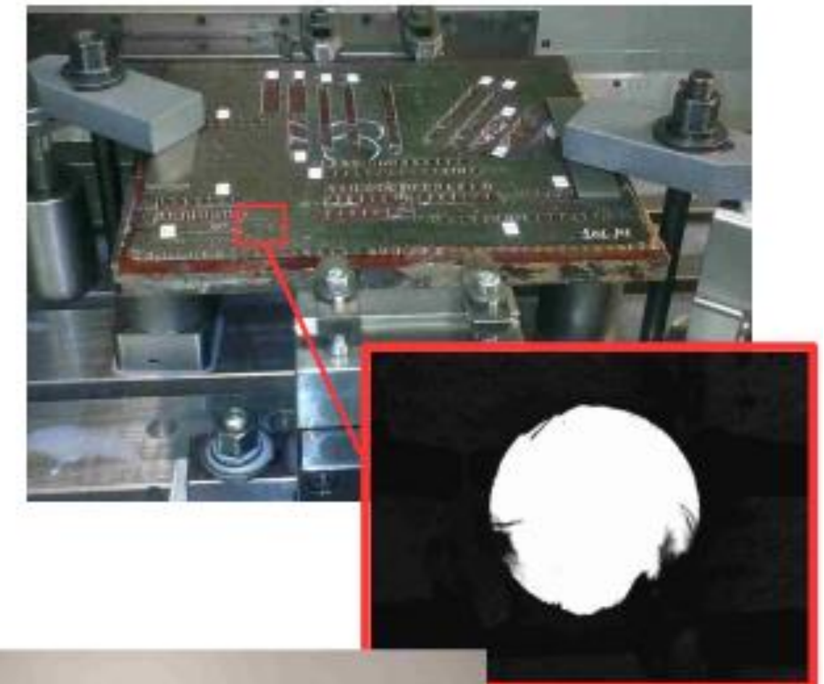


Carbon Fibre disk production



Design by Miguel Angel Villarejo (IFIC)

Machined at Ramem (Madrid)

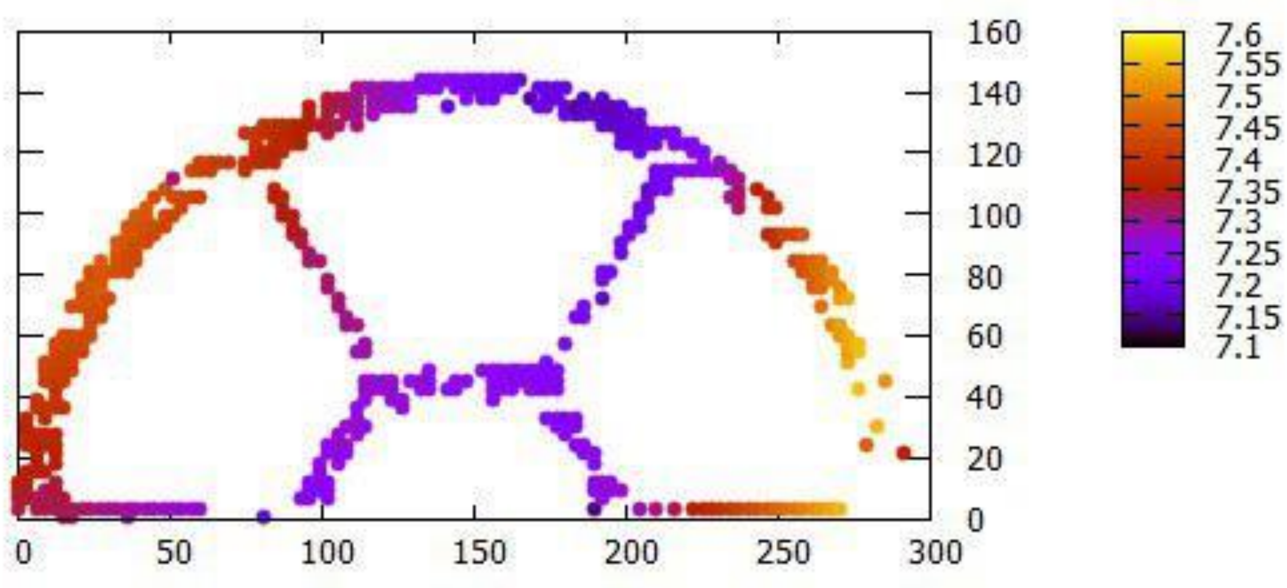


test samples

Goal: gain hands-on experience with Production and operation of an ultra-thin Carbon Fibre + silicon structure

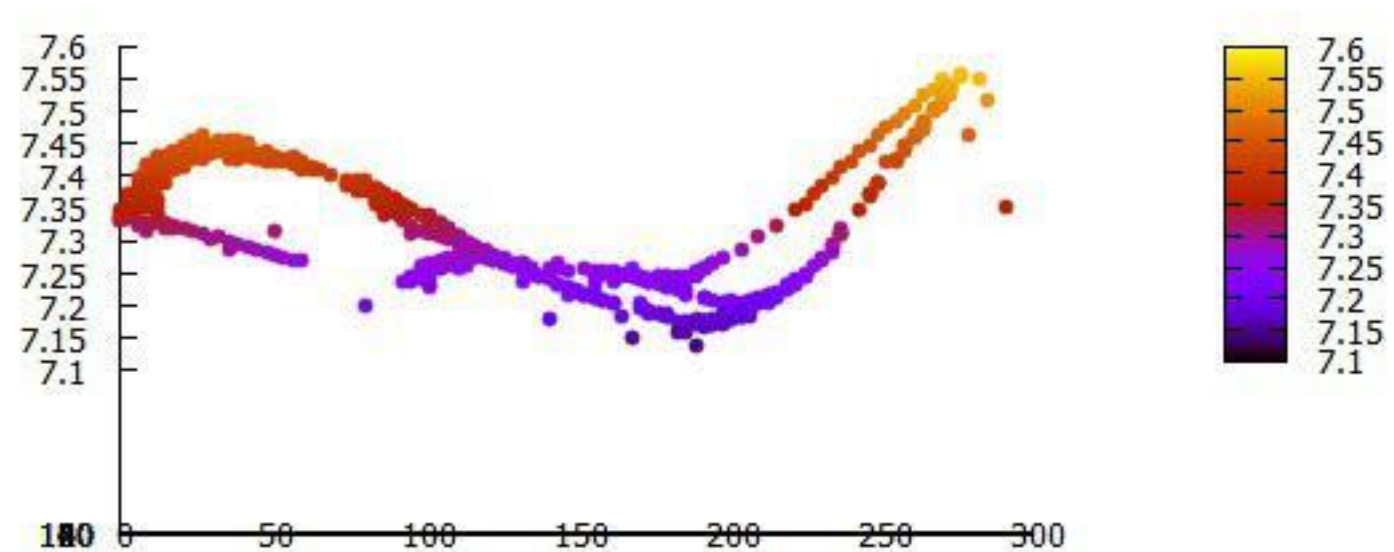
Carbon Fibre produced at INTA in Madrid,
composite material group, Malte Frovel and Maria de la Torre

Planarity



The CF disks have been extensively mesured in a precise metrology system.

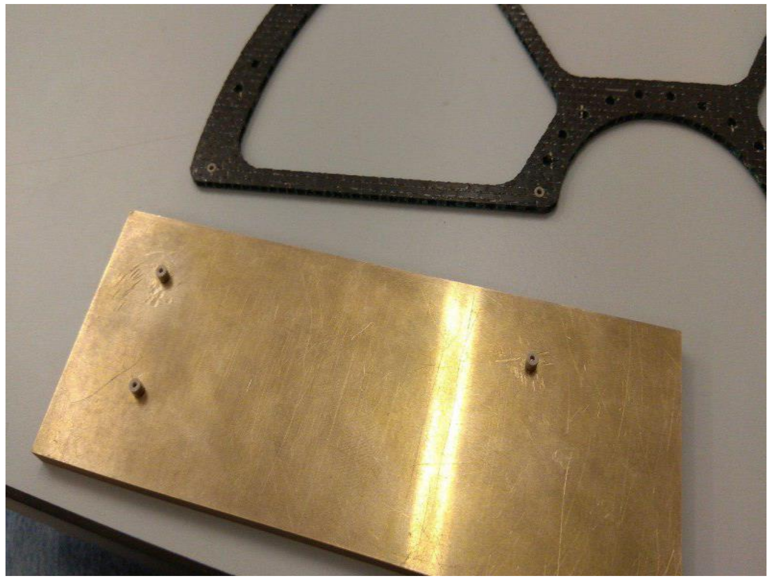
Planarity over 30 cm:
- peak-to-peak ~ 500 µm
- RMS ~ 200 µm

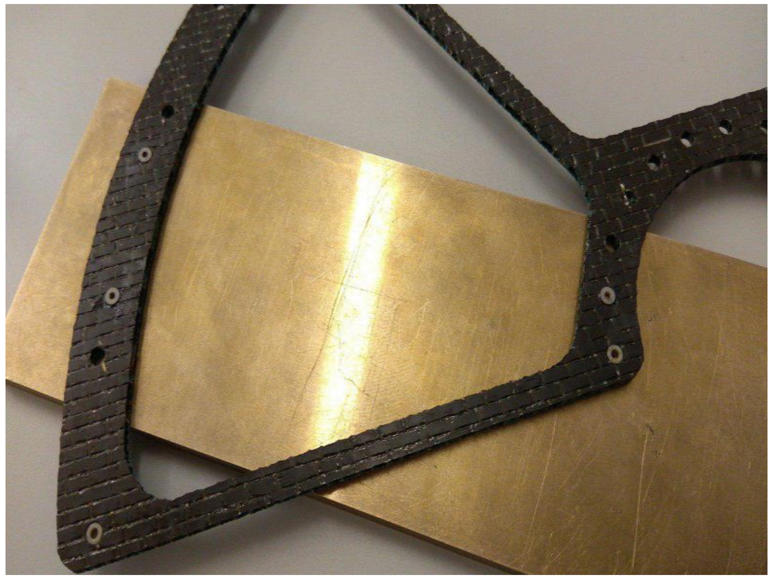


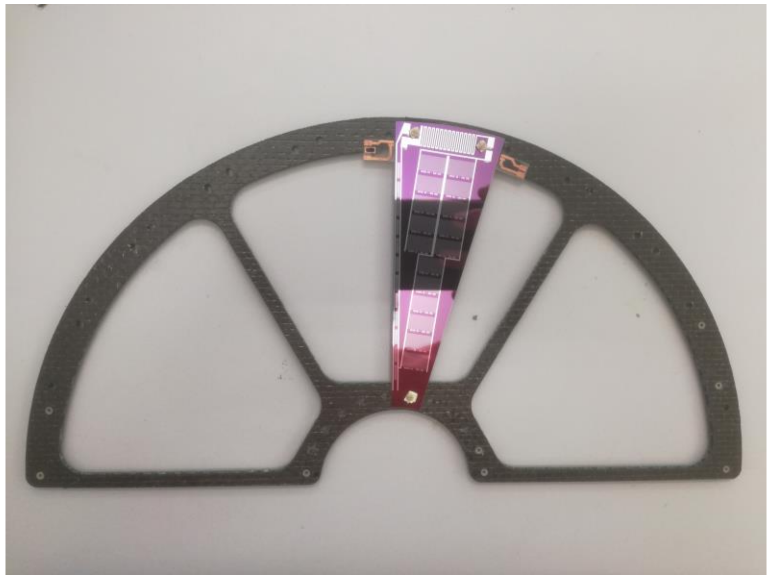
Petals positioning

Holes produced in the carbon fiber with high precision machine, with +-100 µm tolerance

PEEK inserts placed in holes with a precision jig, to achieve better placement precision of the Silicon sensors



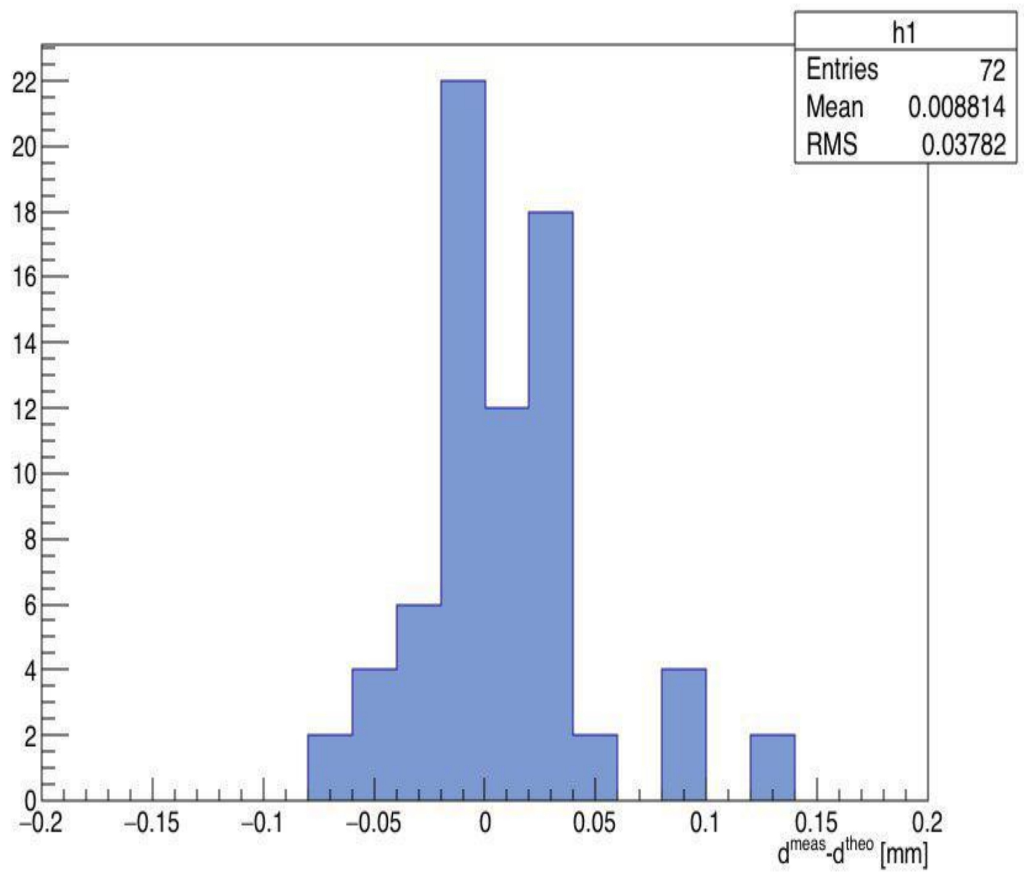




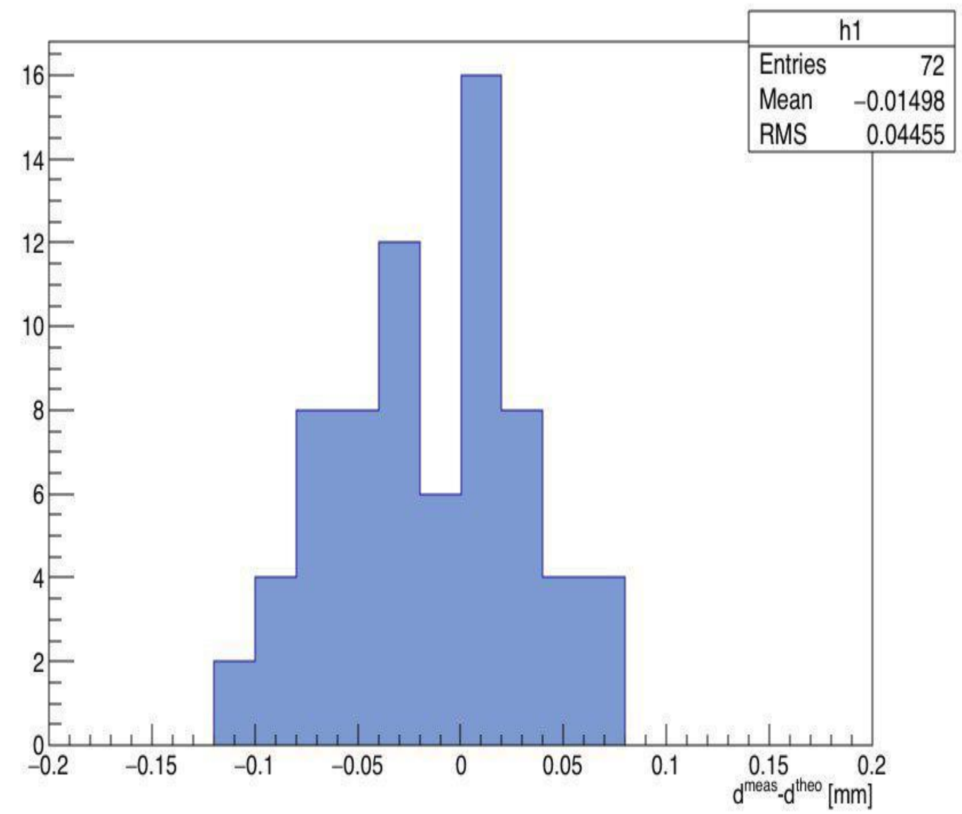
Petals positioning

Relative precision of the PEEK inserts:
± 50µm from nominal position

FTD1



FTD2



Material budget

FTD1	
Carbon f ber + cyano-ester resin	0,0376535
Honeycomb (aramide)	0,0006276
Peek inserts	0,0019486
Peek screews	0,0014073
Inserts glue	0,0006495
Total X/X0 %	0,0422866

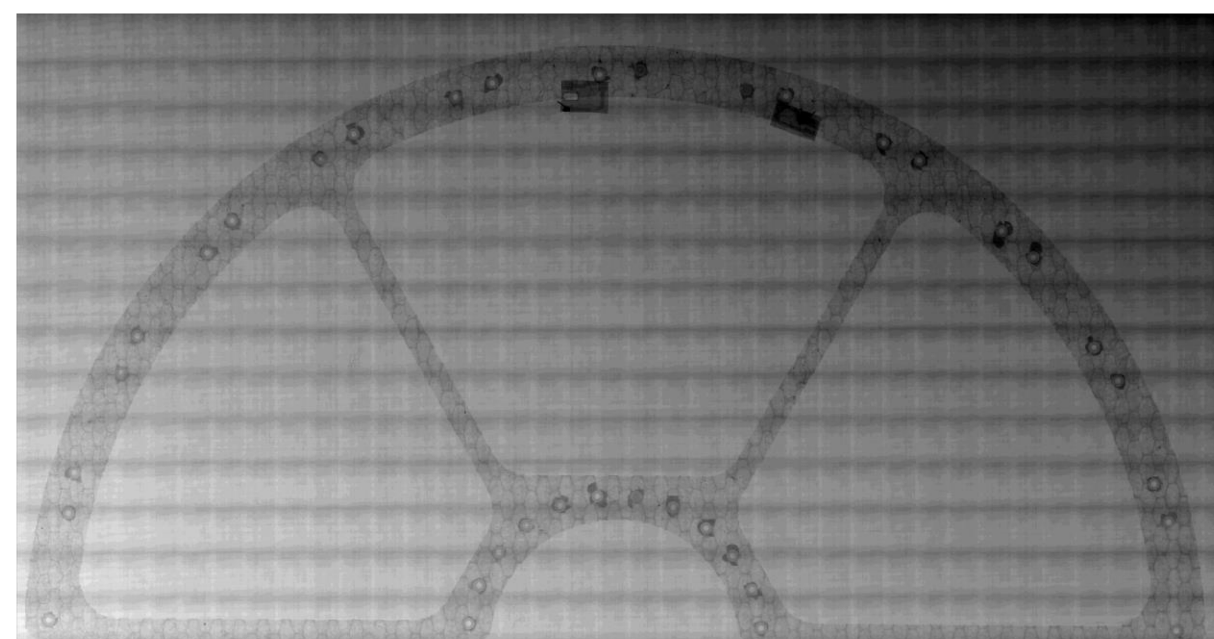
Material in % of X_0, averaged over area

FTD2	
Carbon f ber + cyano-ester resin	0,0383109
Honeycomb (aramide)	0,0006385
Peek inserts	0,0020261
Peek screews	0,0014633
Inserts glue	0,0041013
Total X/X0 %	**0,0465401**

Weight: less than 15 g

Disk contributes less than 0.05% of a radiation length to the material budget

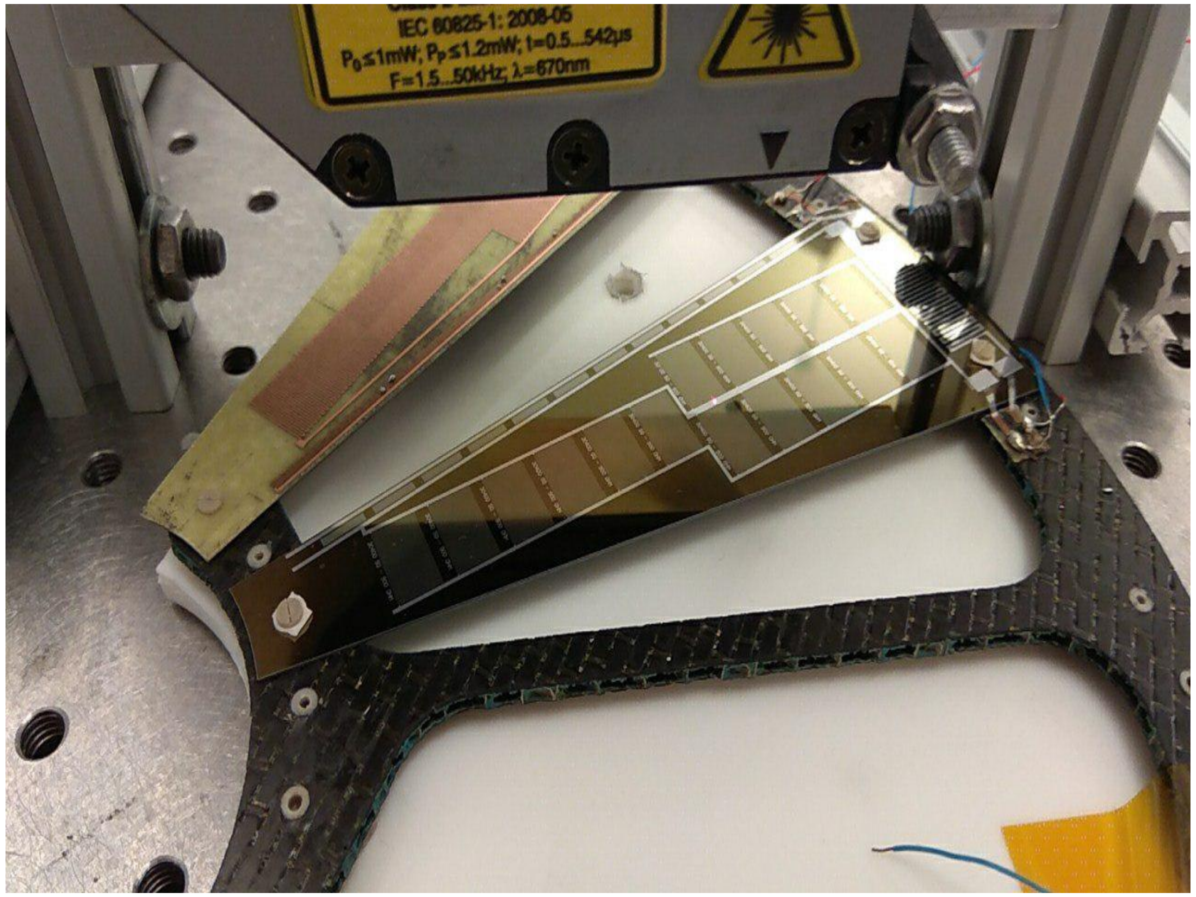
X-ray map of the material in FTD1:



Mounting the Silicon petals

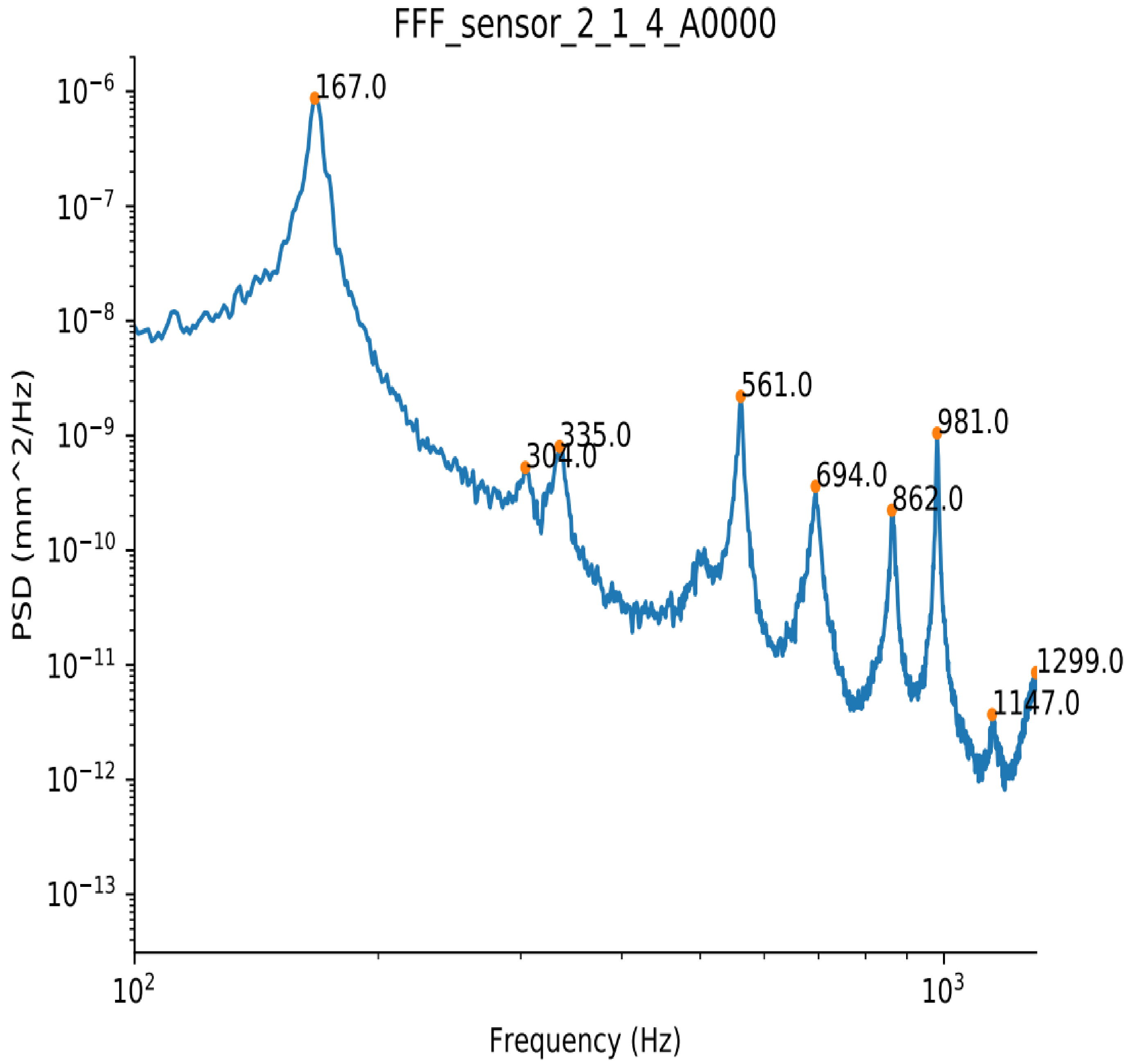
Controlled torque

Deformation and vibration measured with precision



Petals modal analysis

Reference measurements
Free: no torque applied to screws

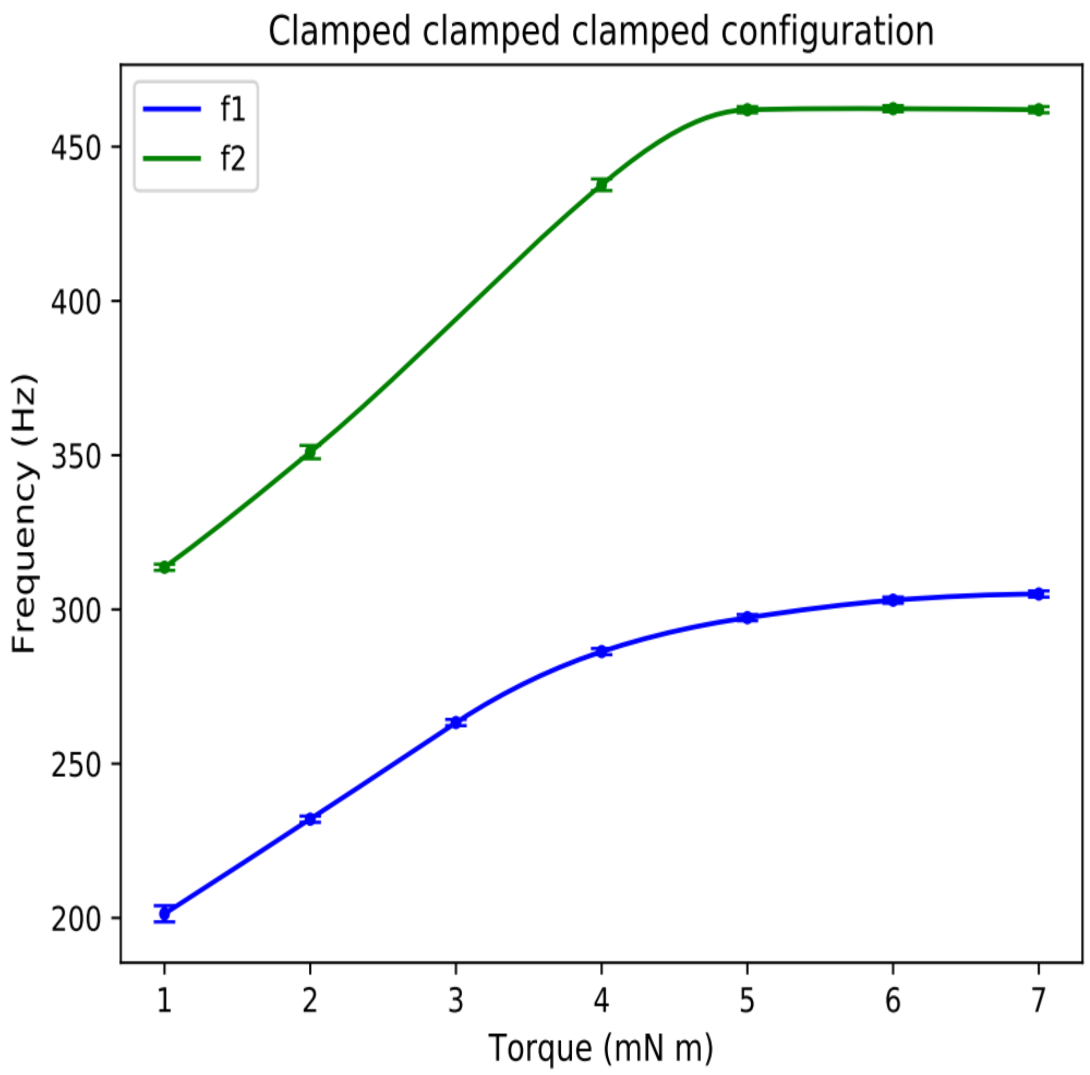


Petals modal analysis

The natural vibration modes (eigenfrequencies) are measured as a function of the torque applied on the screws that fix the Silicon on the three mounting positions

The eigenfrequency increases with the torque applied to the screws
(the joints are elastic; petal degrees of freedom are modified as the torque increases)

The eigenfrequency saturates at about 300 Hz

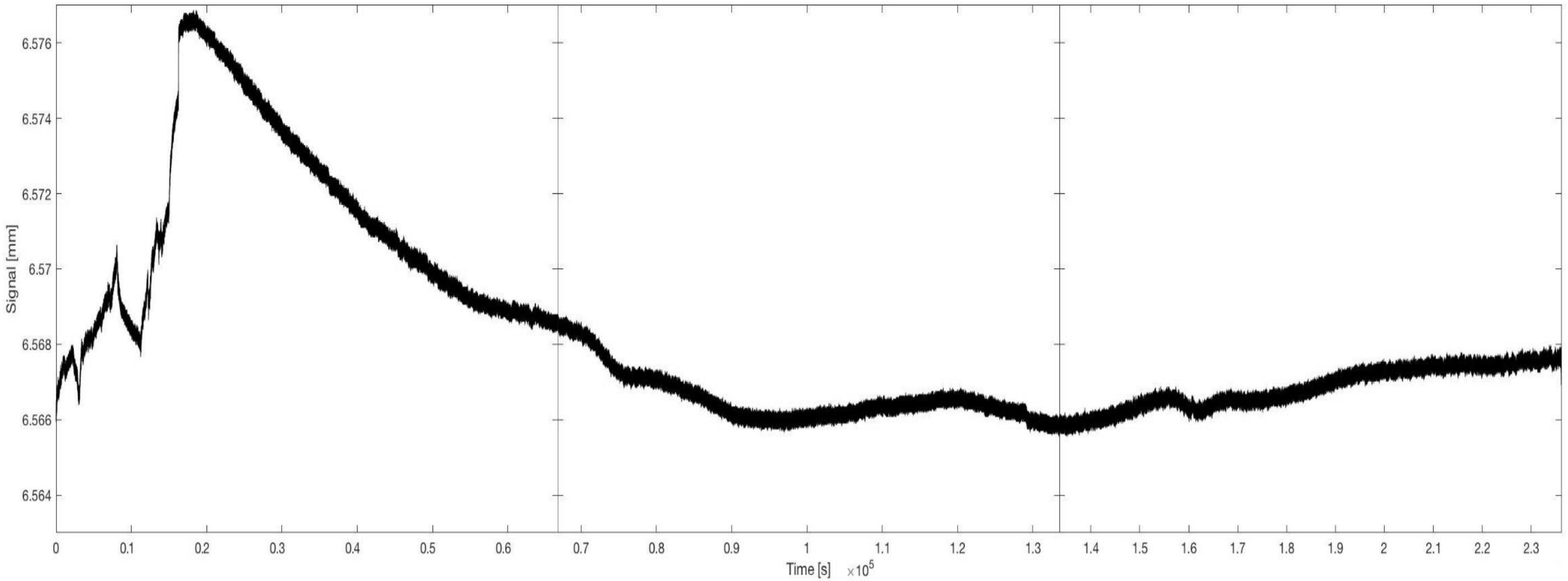


0,3 – 0,5 cN·m for a completely clamped petal

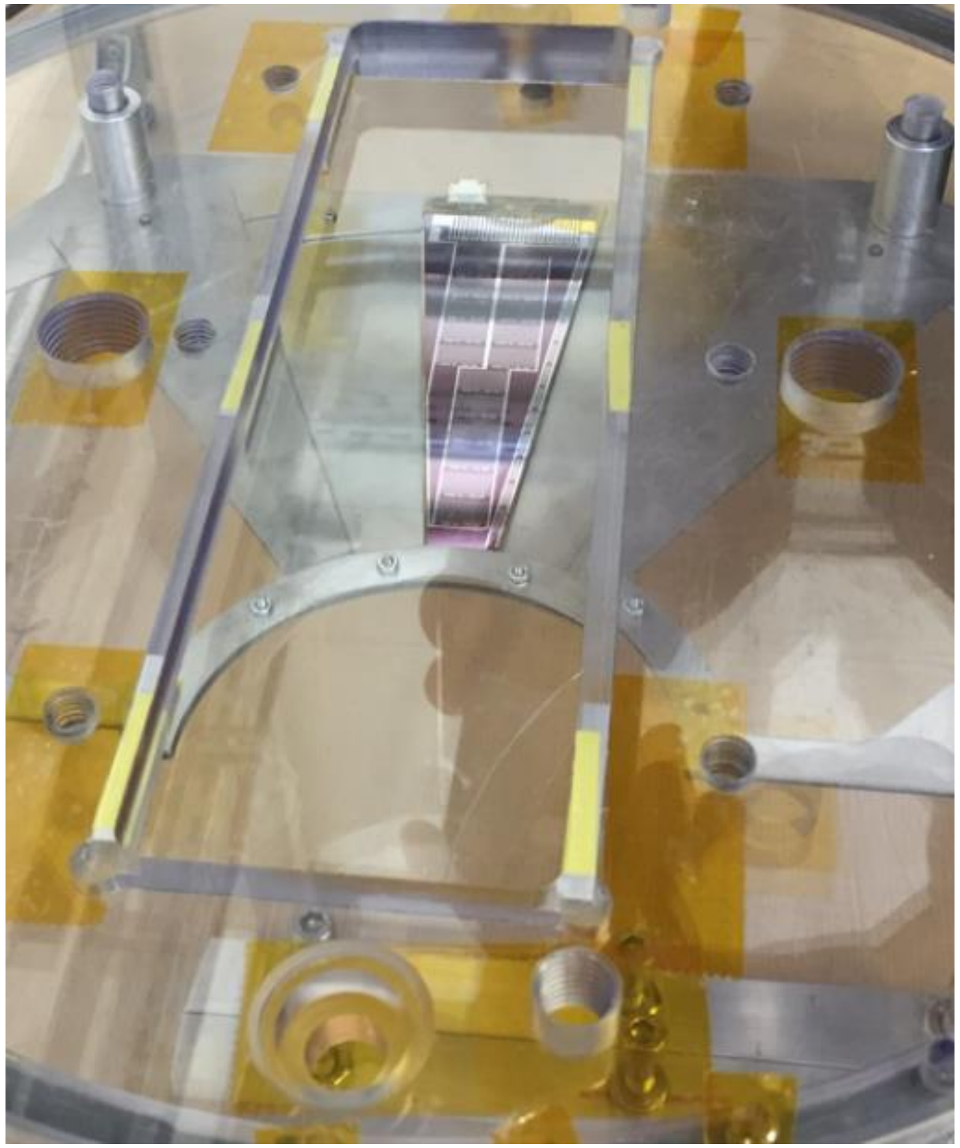
Petals stabilization

Deformations due to background vibrations and temperature variations is stable within 48 hours between +- 1µm in Z

A 1 day transitional period of time needed before stabilization

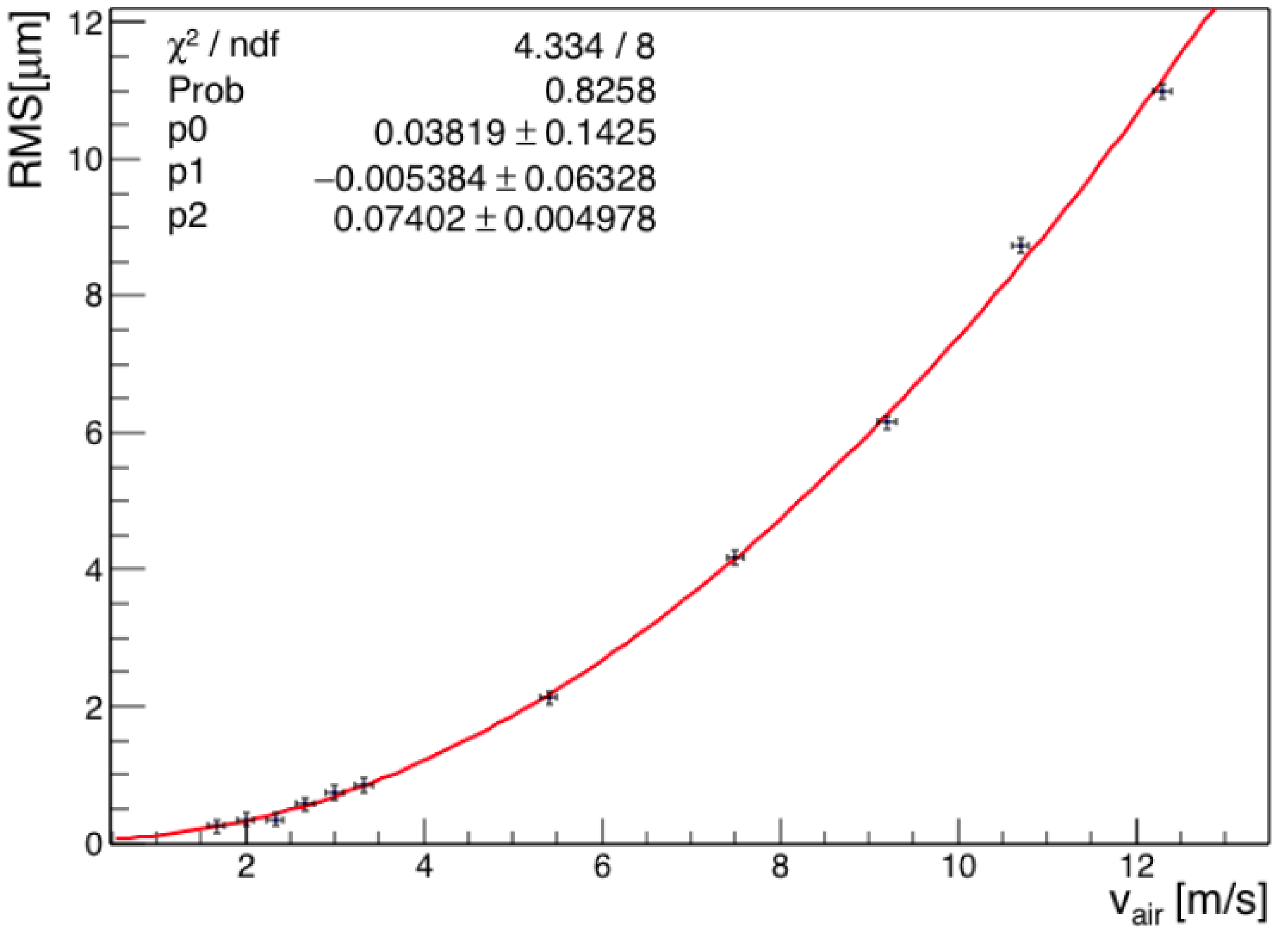


Air cooling & mechanical stability



Dummy petal in CERN wind tunnel

Vibrations remain acceptable for air speed up to several m/s



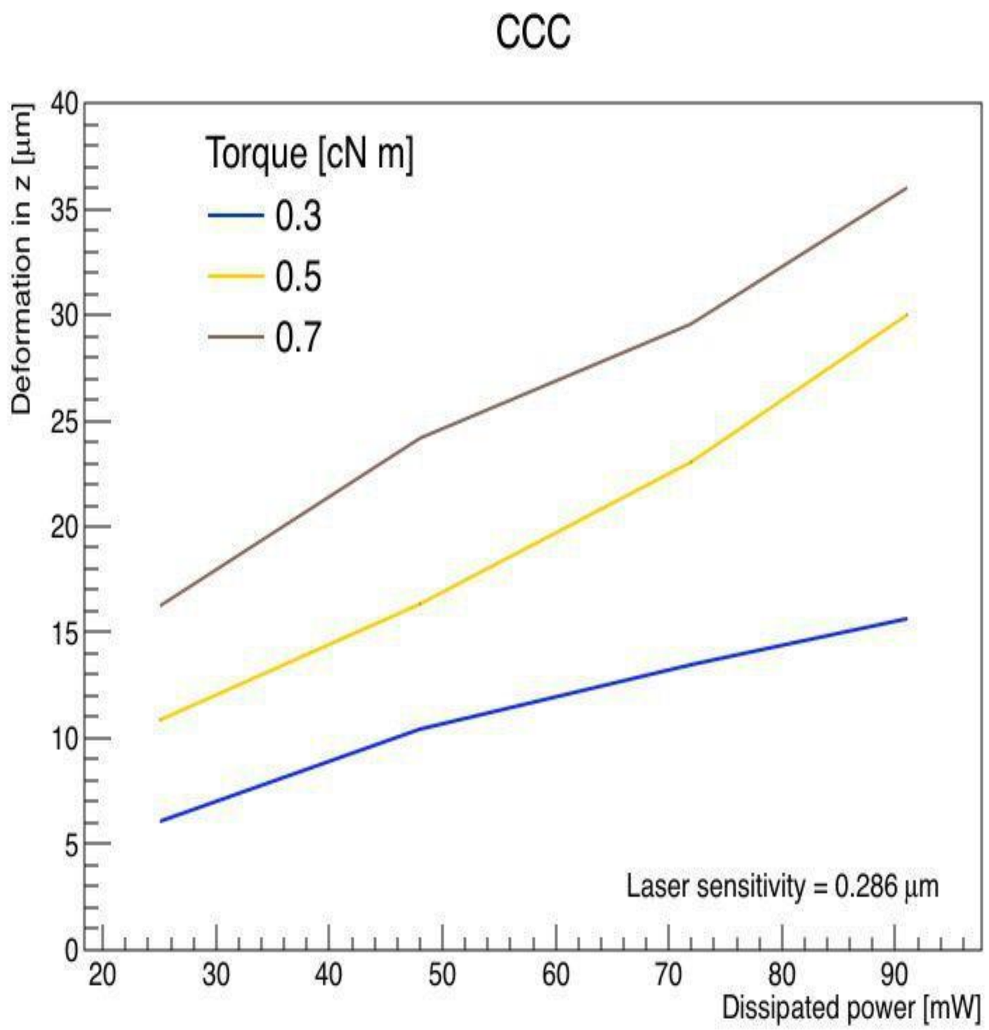
Ph.D. thesis Nacho Garcia,
U. Valencia, 2016

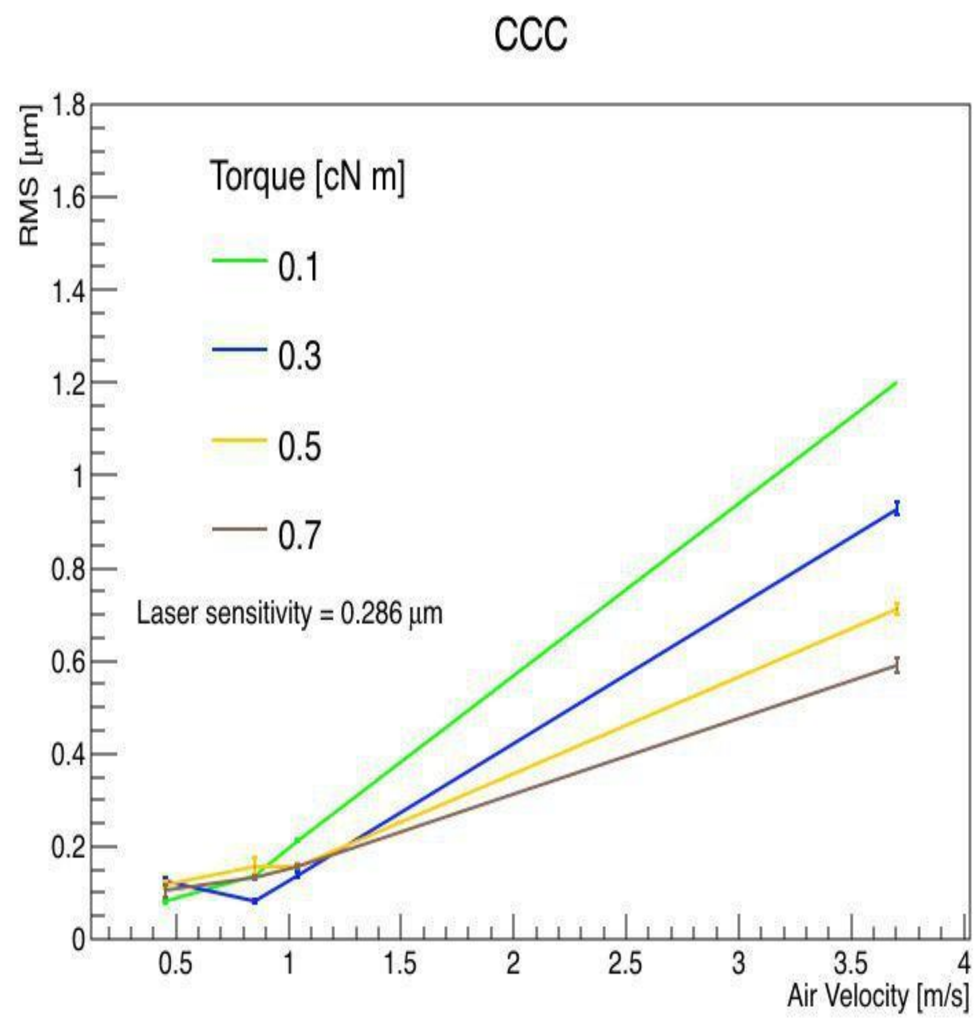
Petal deformations vs. air velocity

Measurements repeated on CF disk, with the petal clamped in a fully controlled way

Deformations due to thermal expansion of the sensor are sizeable: 10 µm when not cooled

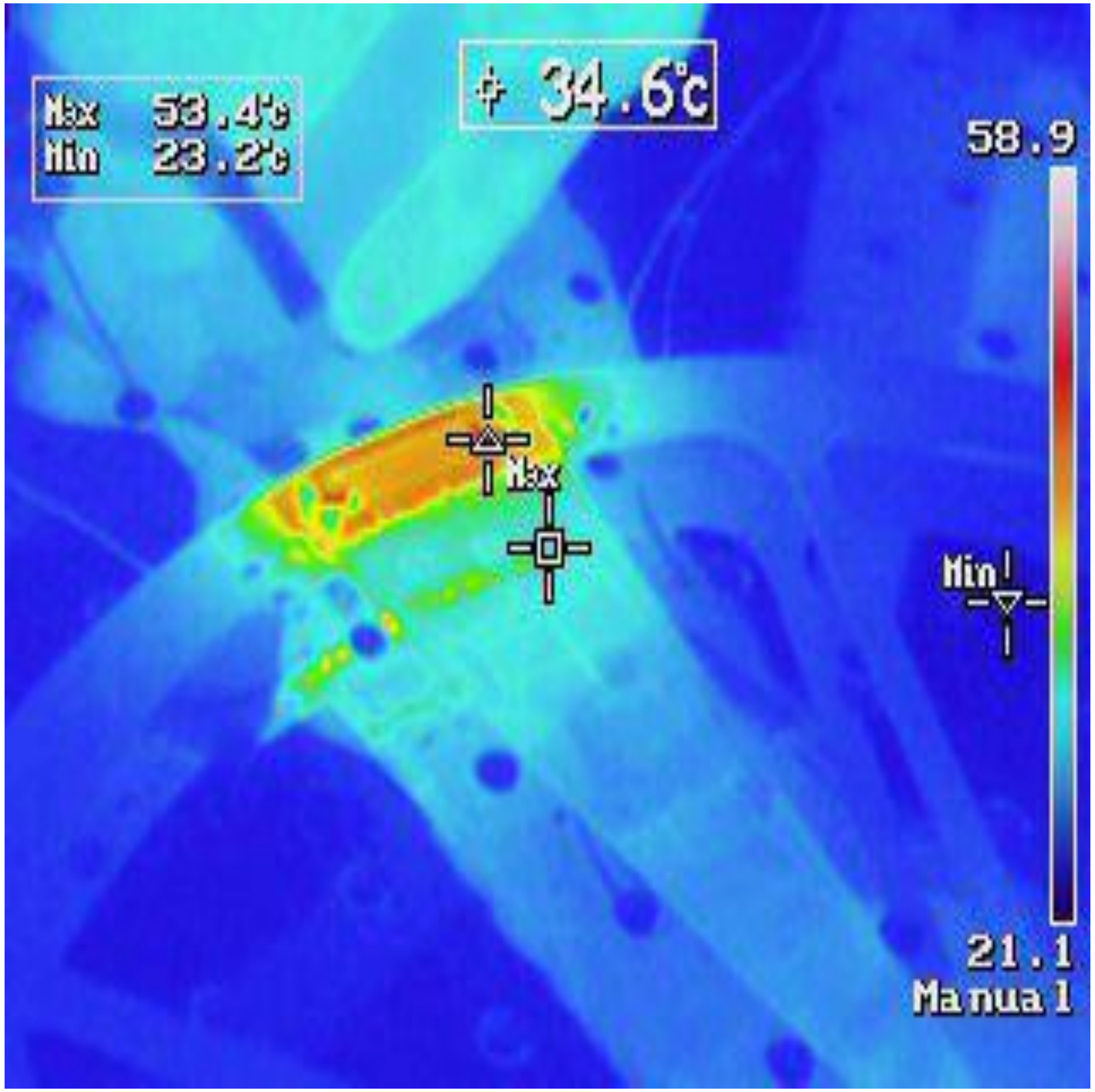
Deformations due to laminar air flow increase with air velocity: less than 1 µm up to 4 m/s





Measurement in realistic conditions

For a maximum temperature gradient over the sensor area of 10K, air cooling at 1m/s is sufficient for nominal power
→ RMS of 0,2 - 0,4 µm.



Summary so far

- Petal mounting precision better than 50 µm
- Petals stability without distortions within +- 1 µm
- Petal distortion under realistic load depends on torque applied to screws

- Carbon fiber structure of 0,045 X/X_0% with first modal frequency of 1 kHz
- First natural frequency of petals in a safe regime, above 200Hz

- Air cooling with ~ 1 m/s air flow yields a ΔT of 10K in the sensitive region
- Vibrations are limited to 0.2-0.4 µm