Status of the Silicon Tracker Project

Collaboration between
China, Germany, Italy, UK

CEPC tracker designs: TPC or DCH + Si

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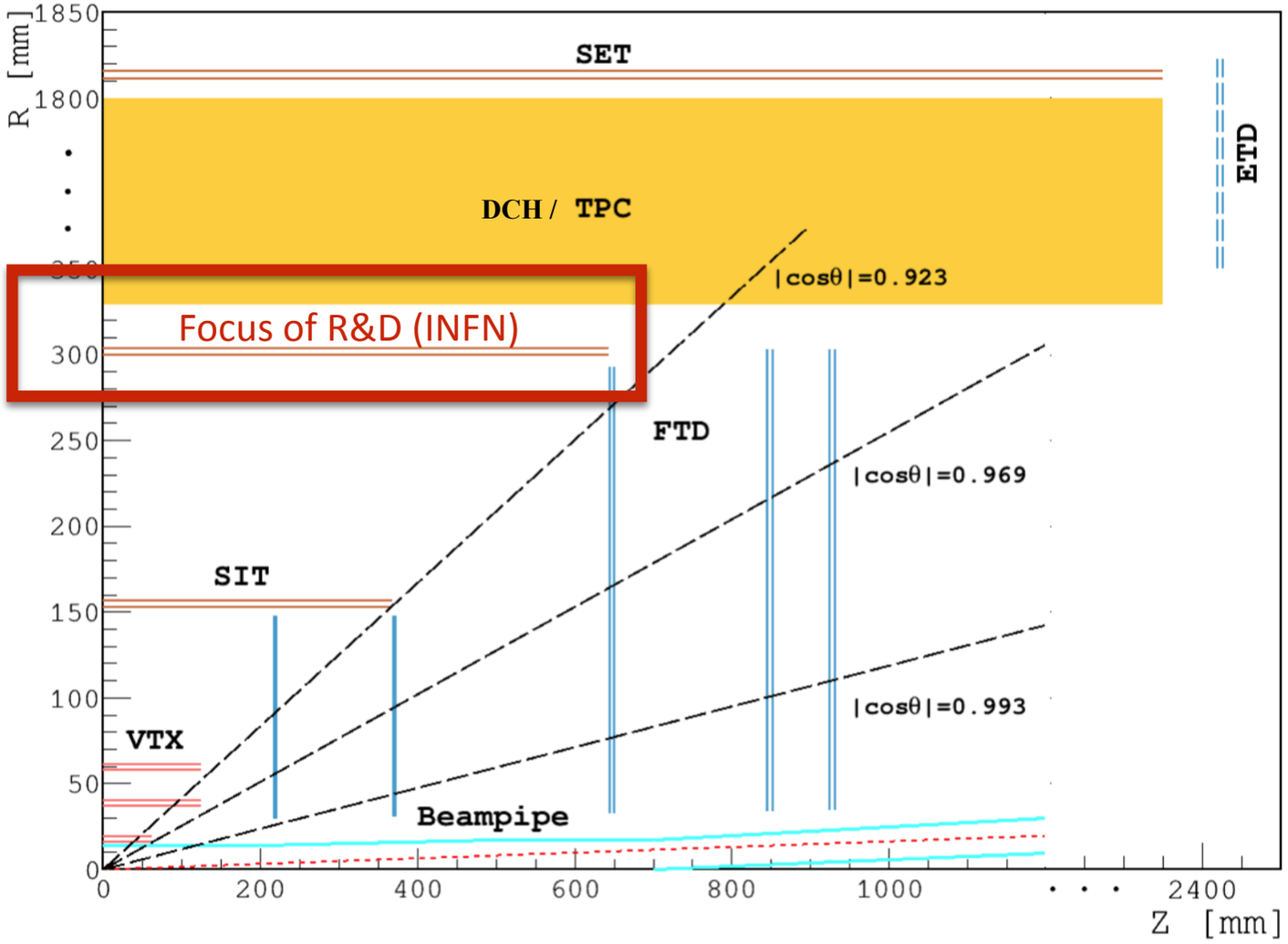
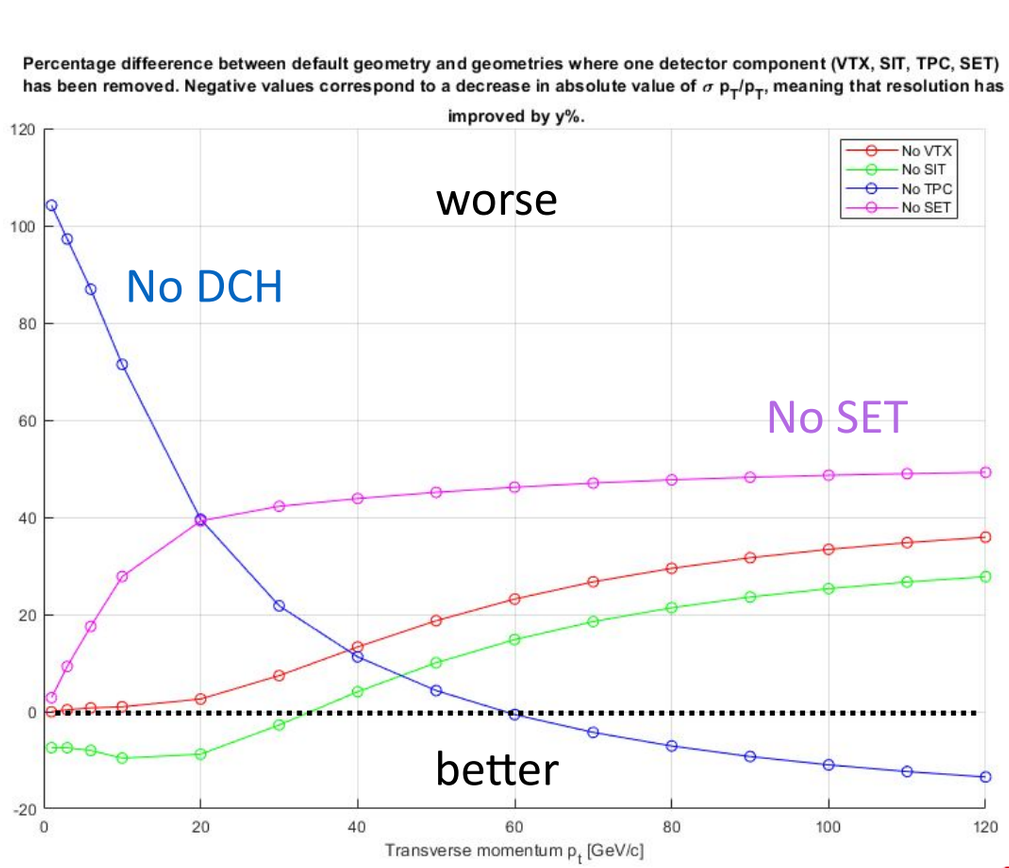
Baseline tracker design: TPC

and 3 layers / 5 disks of silicon sensors,

50 m² (33 w/o ETD) if built in CMOS pixels (strips default)



Detector		Radius R [mm]		$\pm z$ [mm]	Material budget [X_0]
SIT	Layer 1	153		371.3	0.65%
	Layer 2	300		664.9	0.65%
SET	Layer 3	1811		2350	0.65%
		R_{in}	R_{out}		
FTD	Disk 1	39	151.9	220	0.50%
	Disk 2	49.6	151.9	371.3	0.50%
	Disk 3	70.1	298.9	644.9	0.65%
	Disk 4	79.3	309	846	0.65%
	Disk 5	92.7	309	1057.5	0.65%
ETD	Disk	419.3	1822.7	2420	0.65%



Sensor proposal: ATLASPix

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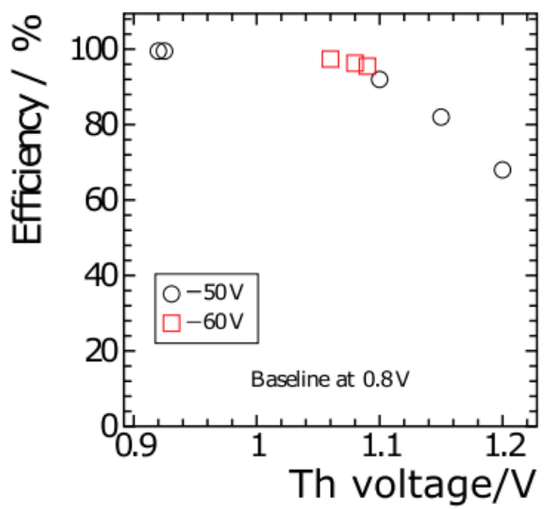
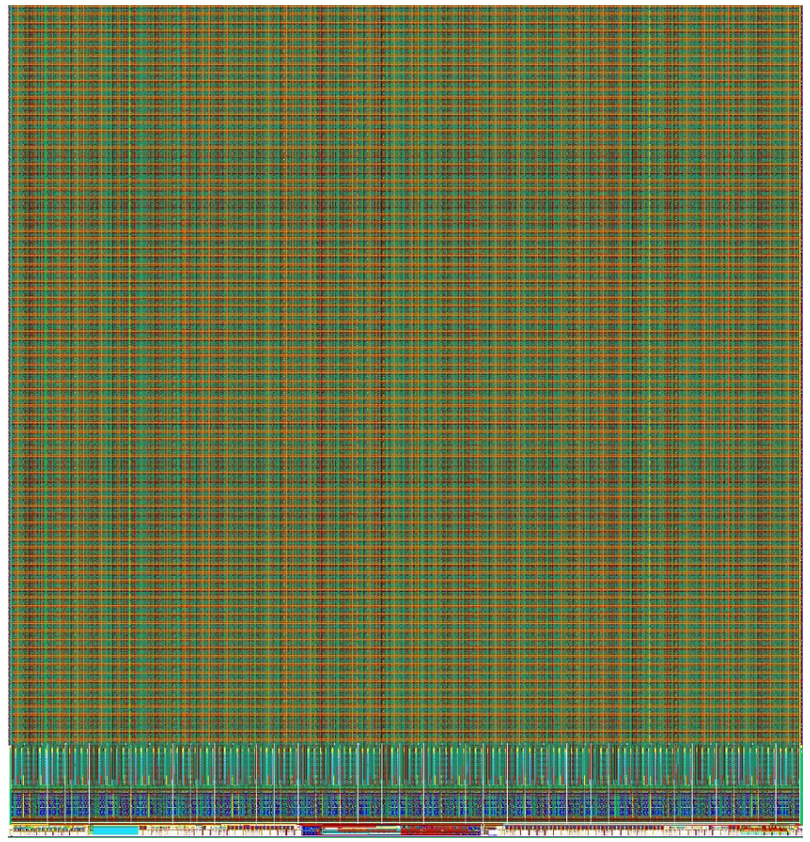
ATLASPix is a CMOS sensor developed to fulfil the requirements for the ATLAS upgrade

- Not strictly an ATLAS development
- **Monolithic CMOS** allows to produce **large** areas **fast** and **cheap**
- No hybridisation – wirebonds or C4NP bumps possible
- **25ns timing** compliant
- Hit efficiency 99.5% (ATLASPix1)
- Pixel size **150 µm by 50 µm** (or smaller)
- Triggered or triggerless readout possible
- 1.28 GBit/s downlink

I. Peric et. al., NIM A924 (2019) 99-103



ATLASPix3

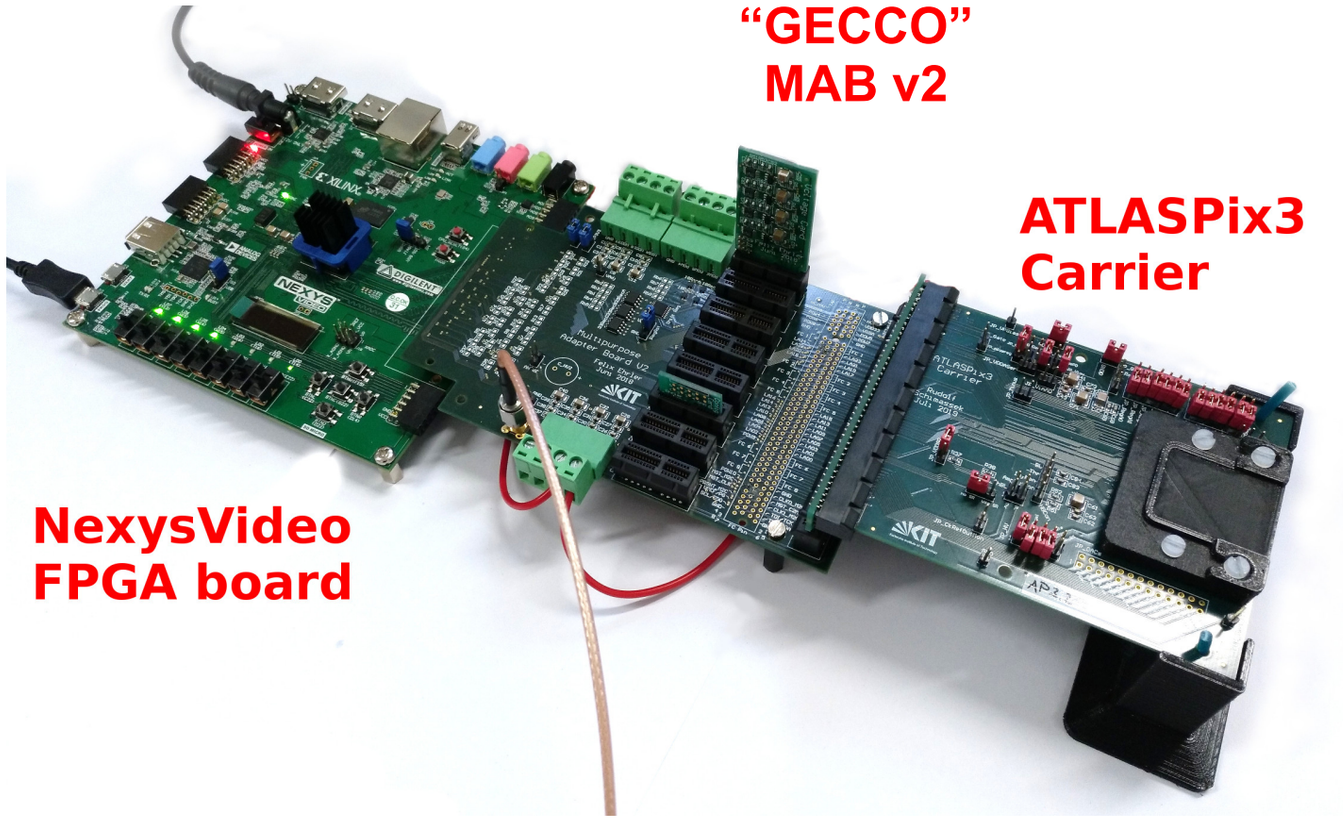


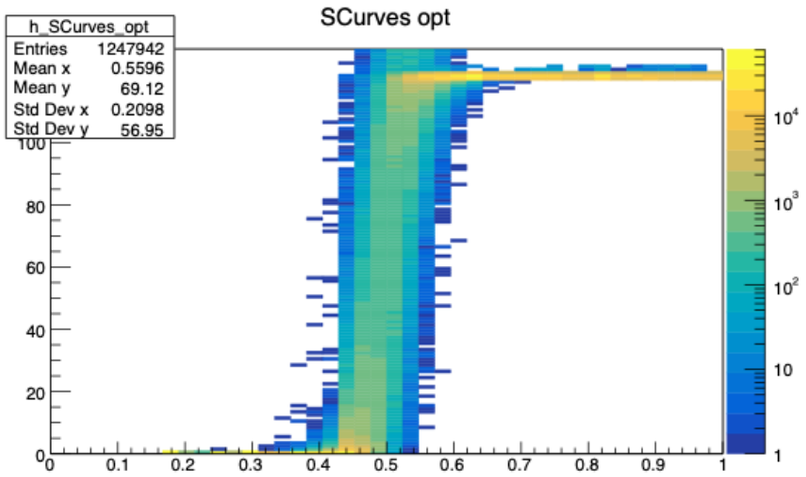
ATLASPix3

- Reticule size: **2.02 cm by 2.1 cm**
- Full-size sensor, ATLASPix3 (TSI, 200Ωcm, 180nm) **available**
- 132 columns with 150µm pixel
- One column contains 372 pixels, a configuration register block, 372 hit buffers, 80 trigger buffers and two **end of column (EoC) blocks**. EoC1 is attached to hit buffers and EoC2 to trigger buffers.

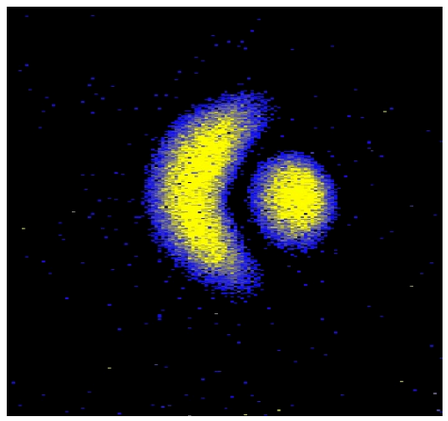
Readout Systems: KIT single chip board

Starting point is the **ATLASPix3 single-chip card** produced by KIT and used for the tests

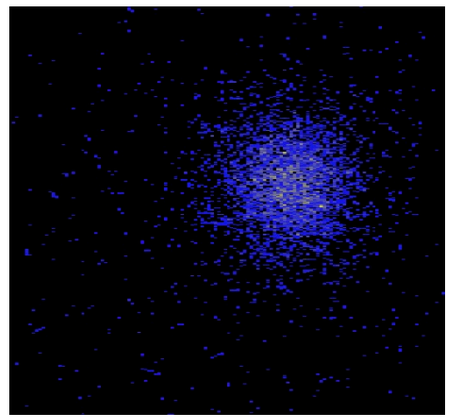




Calibration with S-Curves (injections)



Fe-55 with collimation



Sr-90 with collimation

Telescope and testbeam

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Up to 6 GeV **electron beam at DESY**

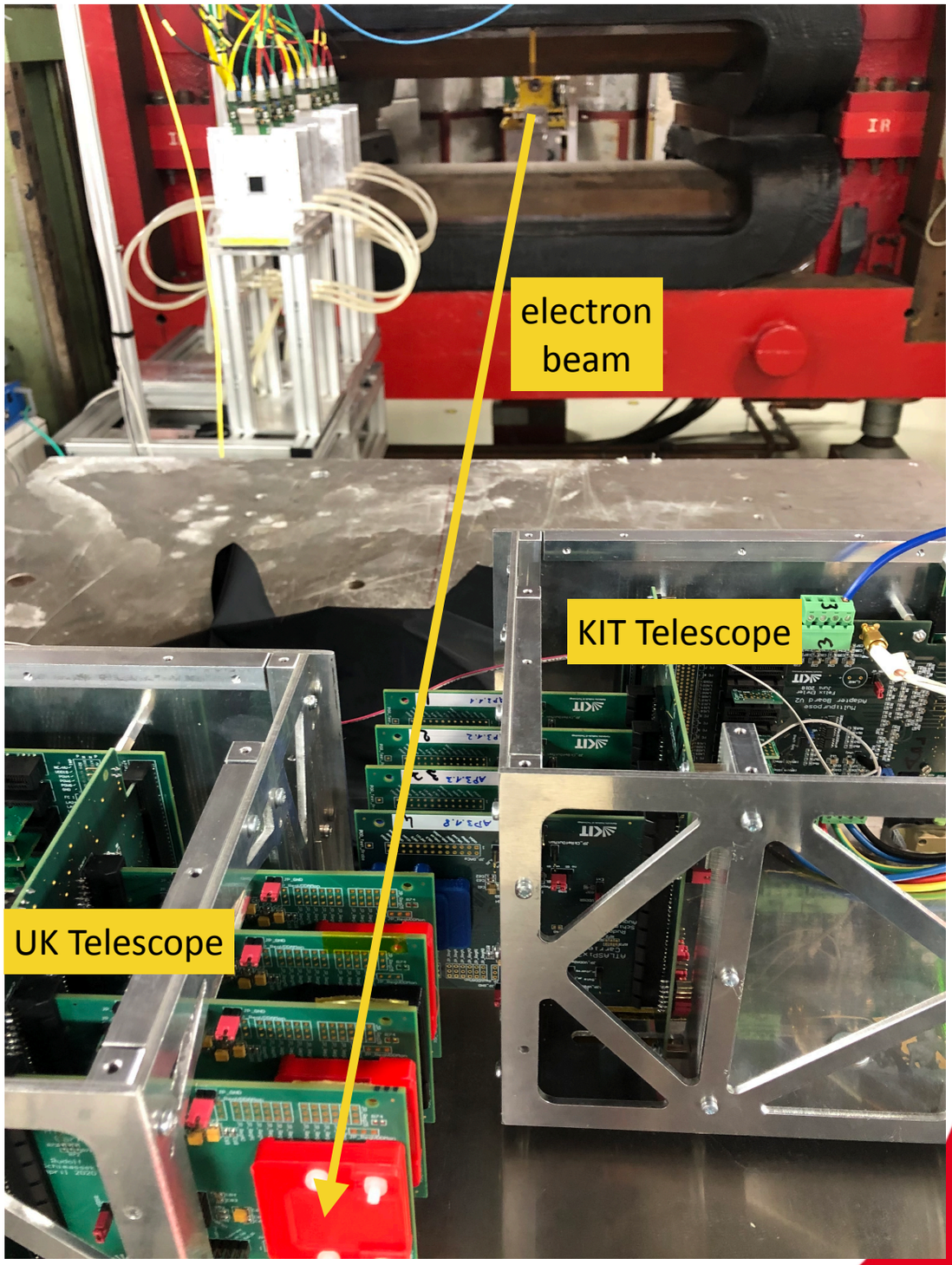
Two **4-layer telescopes** (KIT and UK)

concentrate on UK telescope for now

Hit driven readout

Reconstruction with **Corryvreckan**

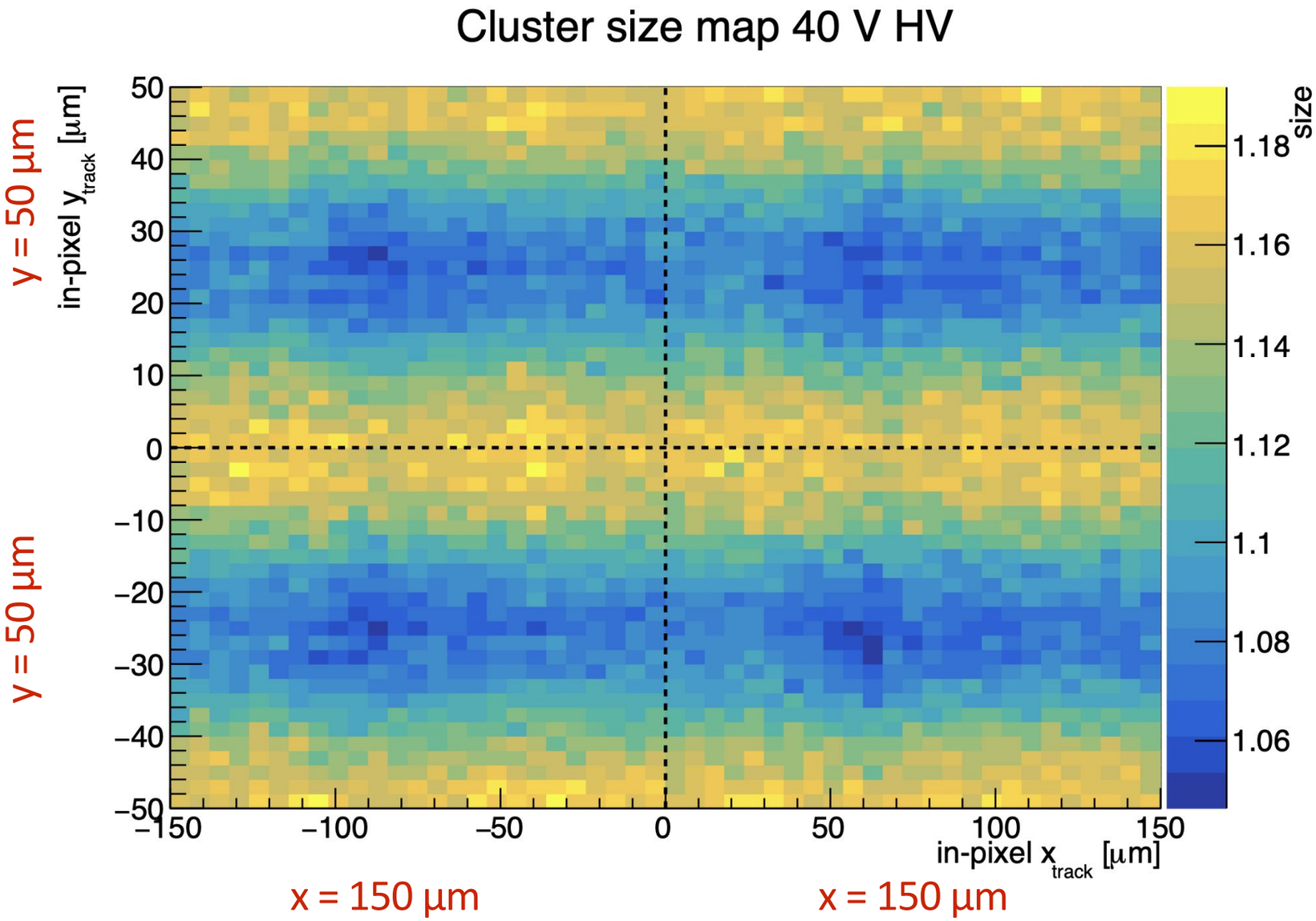
- iterative **alignment** of the layers
- **tracking** through 3 or 4 layers
- an arbitrary layer can function as DUT, here l**ayer 3 is used as DUT**



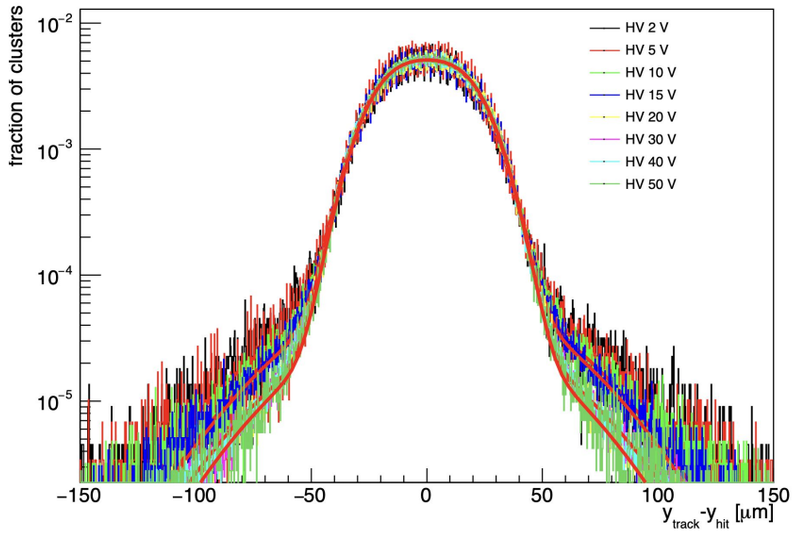
Cluster reconstruction

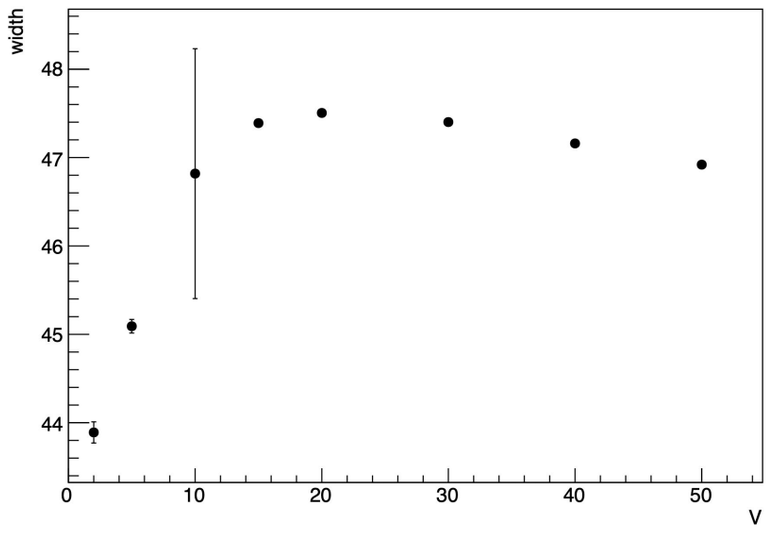
Cluster charge increases linearly with √ HV

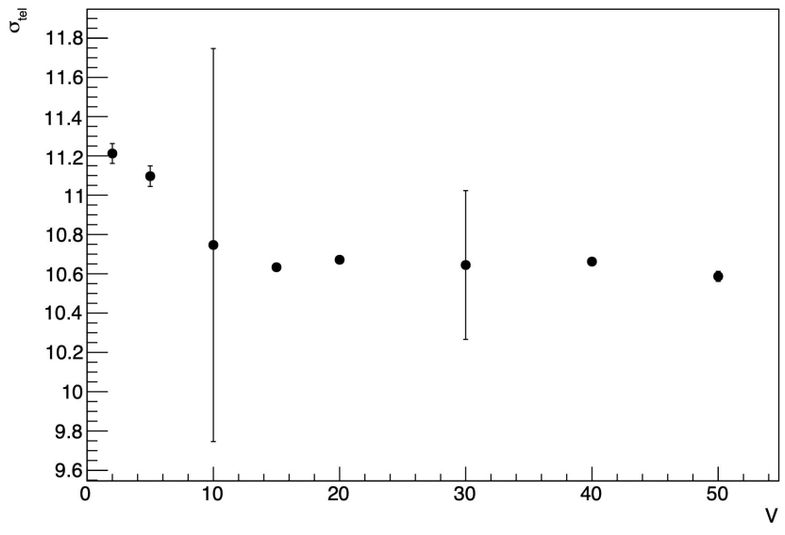
In the y=50µm pixel direction **less than 10%** (HV dependent) of the **clusters are 2-pixel** clusters, mainly at the boundary.



Telescope resolution





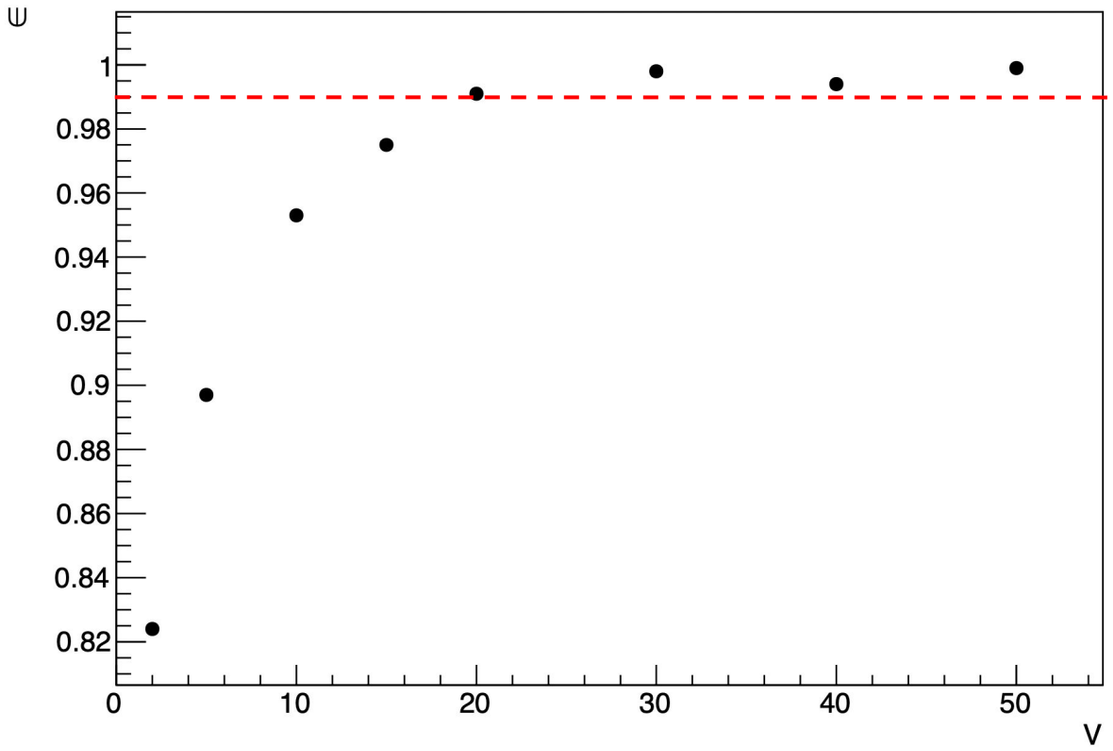


The fit function models the charge collection width as a **step function**, a **Gaussian background** for the tails and a **Gaussian telescope resolution**, here for 1-pixel clusters in the y=50µm direction.

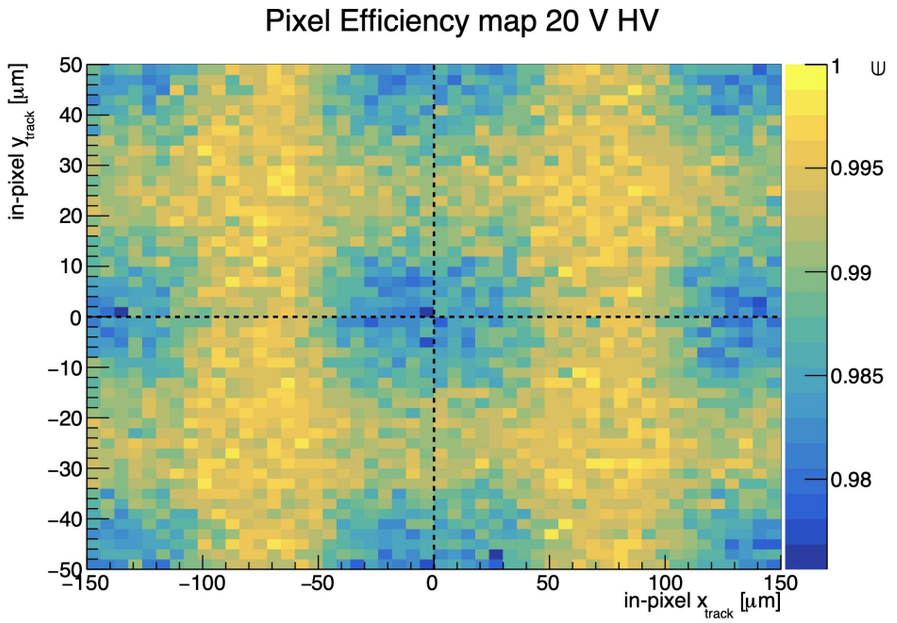
The width of the step function increases from ~44µm at 2V to ~47µm at 50V

The **telescope resolution** σ_{tel} improves with HV from ~11.2 µm to **~10.6 µm**

Efficiency

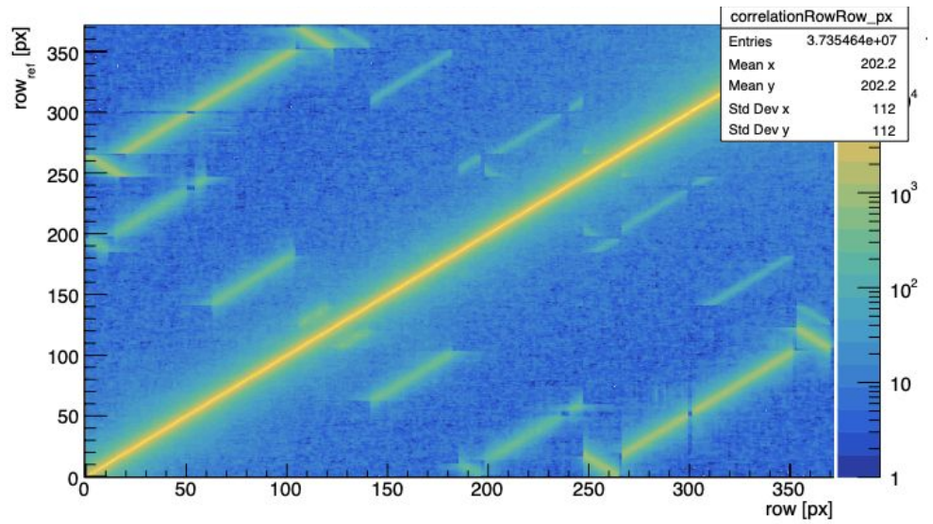


The efficiency is almost constant above HV=20V and reaches 99.8% at HV=50V.



Problems and prospects

Less than 1% of hits appear at the wrong position due to capacitive couplings between the lines.



Work needed to synchronise the two telescopes.

More measurements (e.g. energy scan, incident angles) to be analysed

Serial powering of quad modules

Quad modules consist of an **array of 2 × 2 chips**.

Quads are powered serially, chips on quad are still powered in parallel.

Serial powering limits the amount of current flowing through the stave bus and thus **limits the power consumption**.

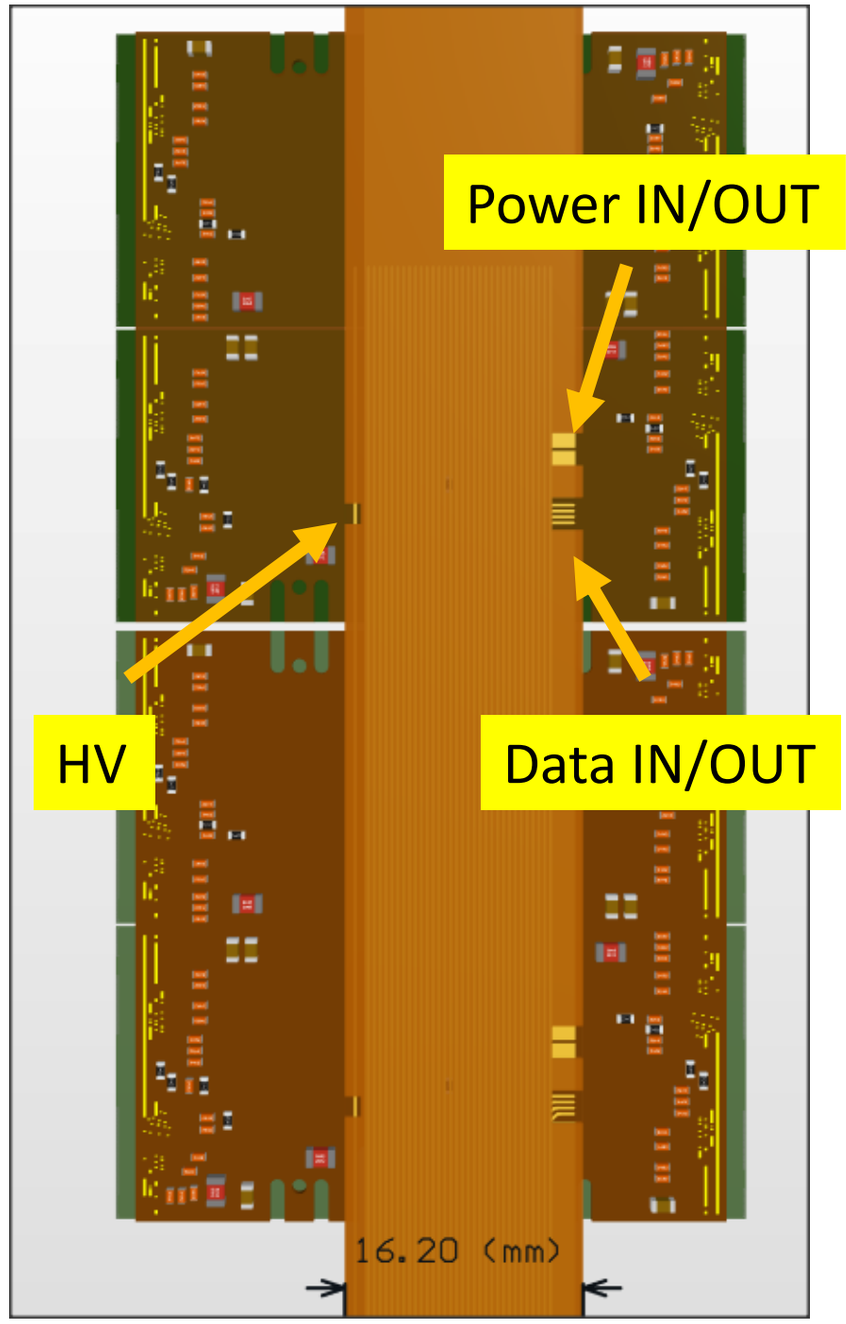
Shunt LDO-regulators on the chip provide the correct voltage to the chip.

Signal lines per quad: differential pairs for reset, cmd, clk, trigger per quad, data per chip (=16 lines per quad).

Idea: realise **serial powering** of 3 to 4 quads on a Kapton flex with Aluminium traces.

Requires **new version of the quad flex** and of the **adapter card** to interface with the GECCO readout system.

Serialisation of quads can be done with a power bus or via the new adapter card.



Quad flex 2.0 for serial powering

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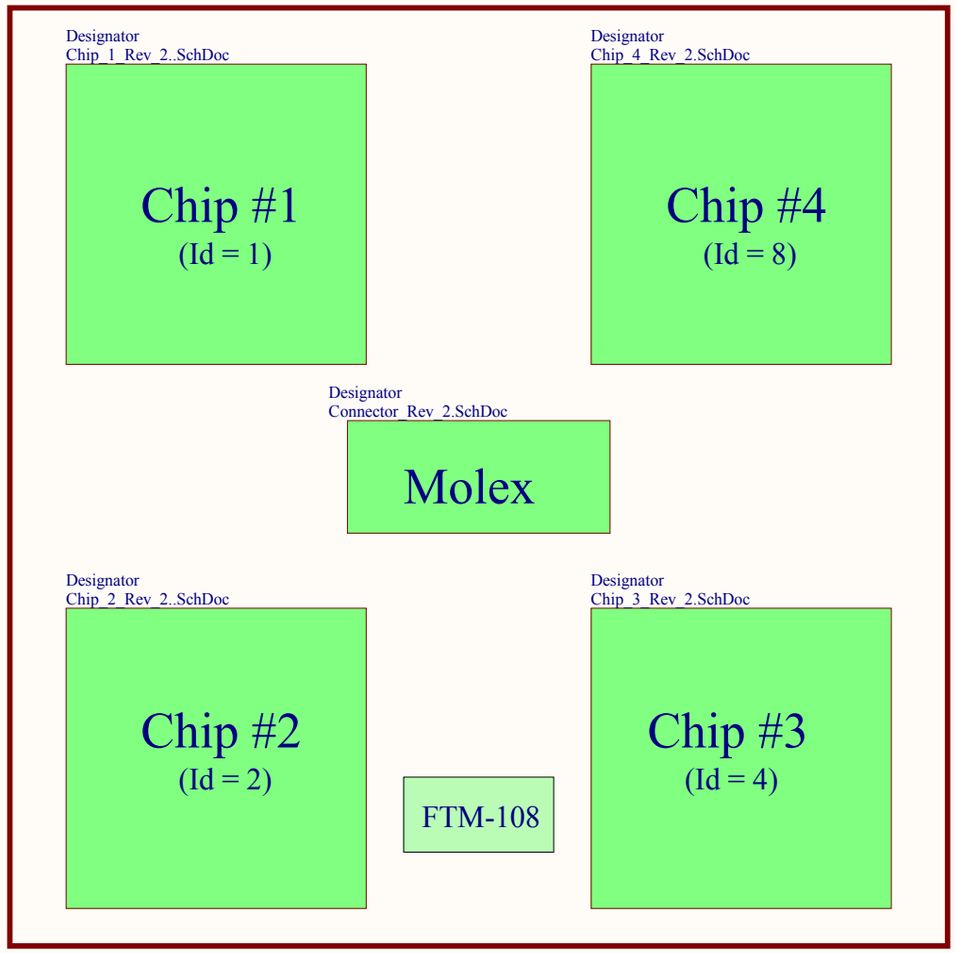
Serial powering via LDO-shunts

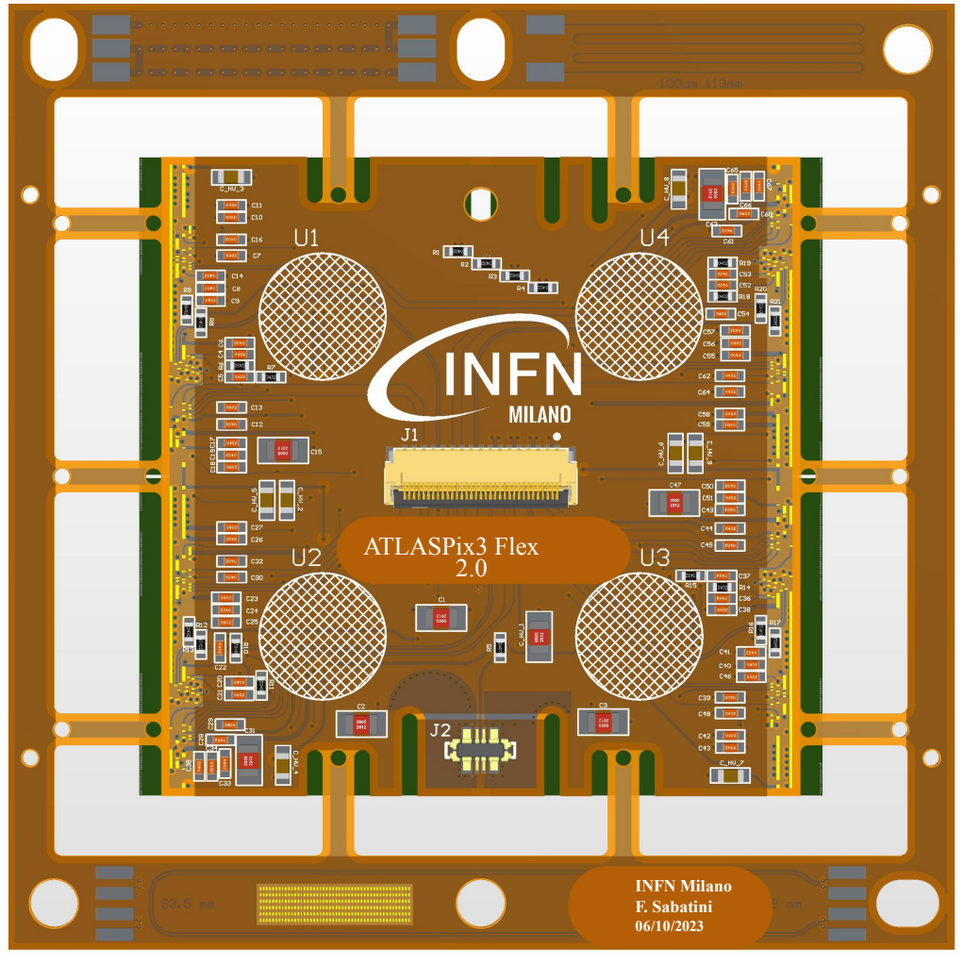
Shared HV, Clk, reset, cmd and trigger lines for the chips; measurement points for voltages / signal

Several jumpered debug lines (enable and select lines)

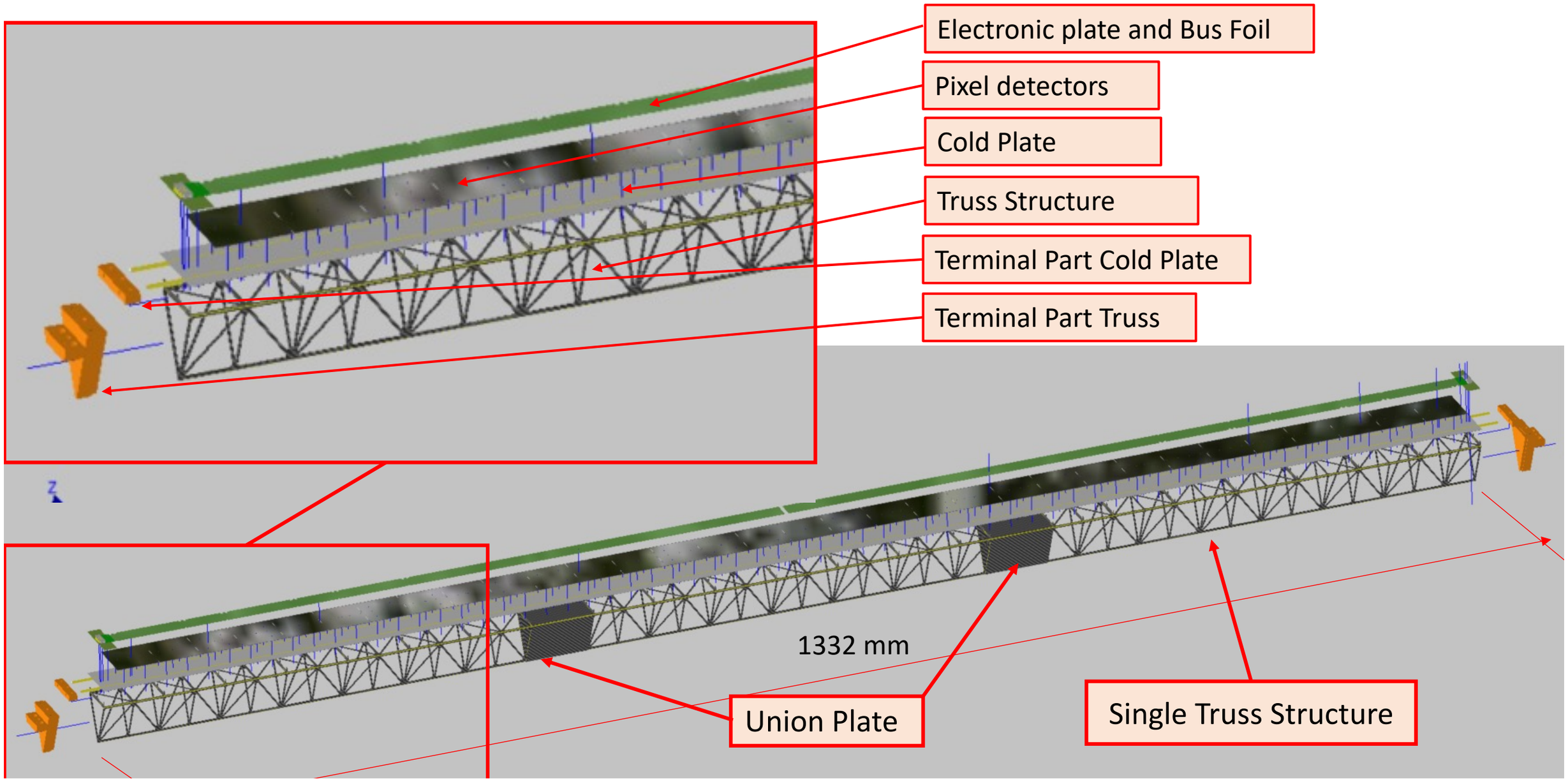
impedance matching and termination done on quad



New this WS



Long Stave Design



Single short truss structure

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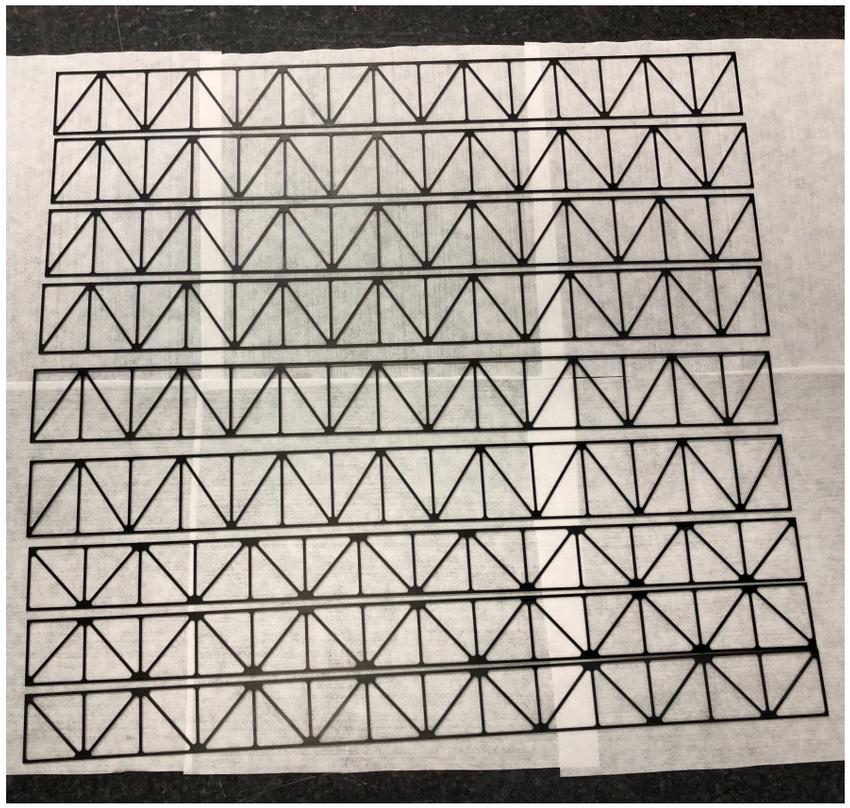
INFN Pisa

Water jet cut carbon fibre. 3 prototypes realised.

LAMINATED FOIL

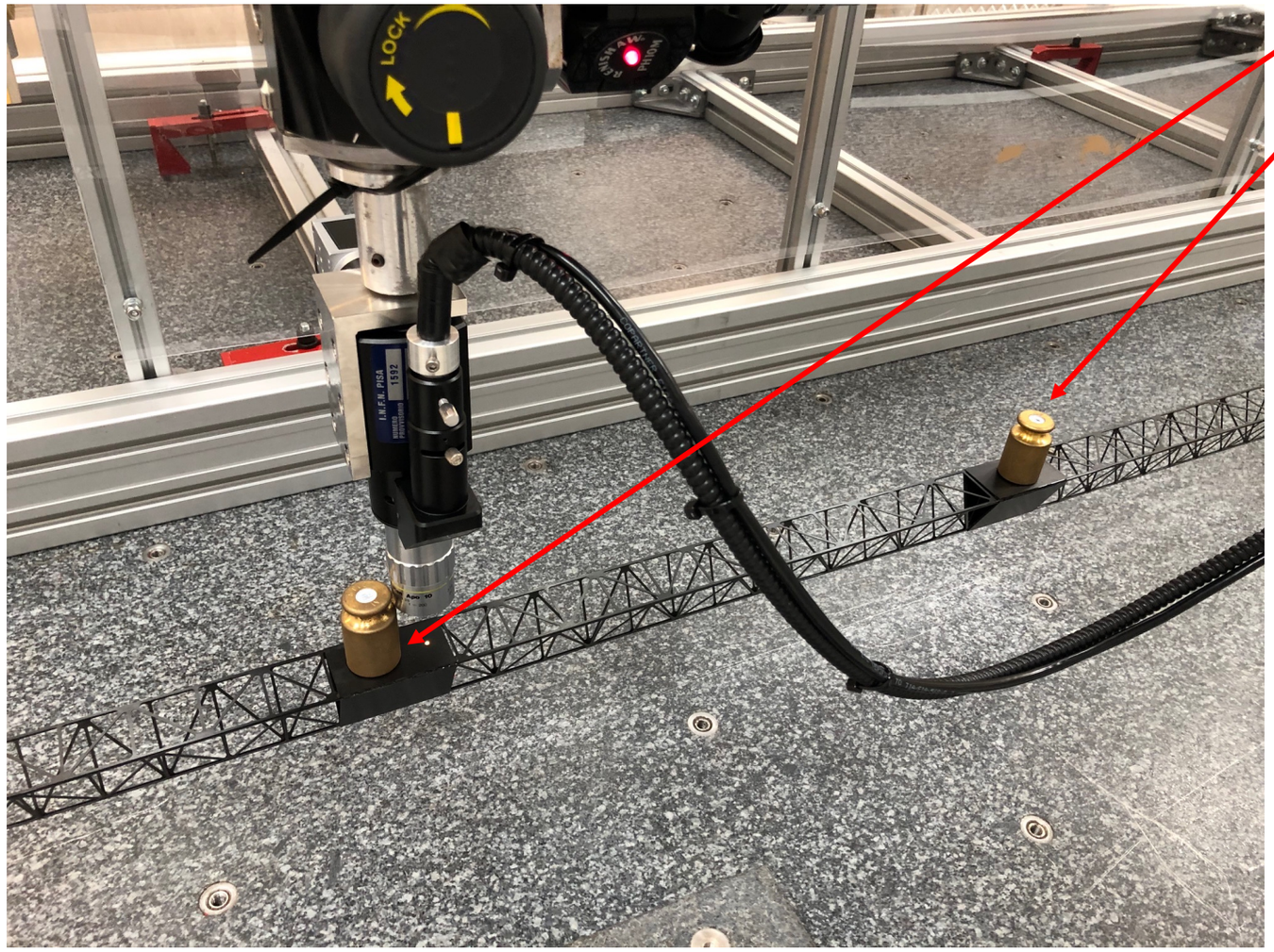
Th=0,5 mm of 550x460 mm2

Carbon Fiber MJ46



By this summerthree short truss structures have been built.

Experimental sagitta measurement



W=200 g

Super weight Test:
Total Weight 400 g

Summary of the sagitta test

Super Weight Test

- Concentrated load 200 g at 450 mm from each edge
- Sagitta at 450 mm from the edge = 800micron
- Sagitta at the center of the structure = 900 micron

(Some difference with the simulation value attributable to no conformal CFRP material: to be optimized)

Real Weight Test

- Uniformily load distribuited of 164,85 g
- Sagitta at 450 mm from the edge =210 micron
- Sagitta at the center of the structure = 280 micron

Simulations (sagitta + vibration)

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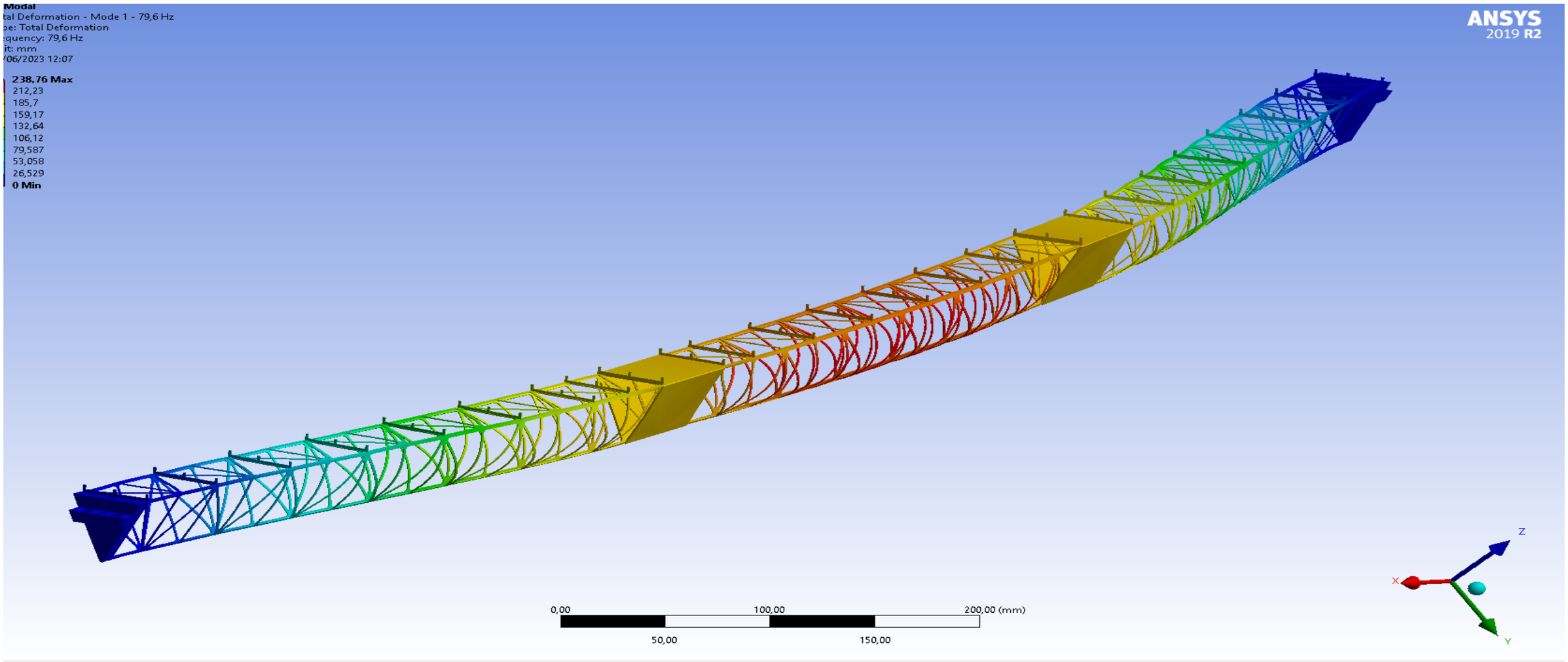
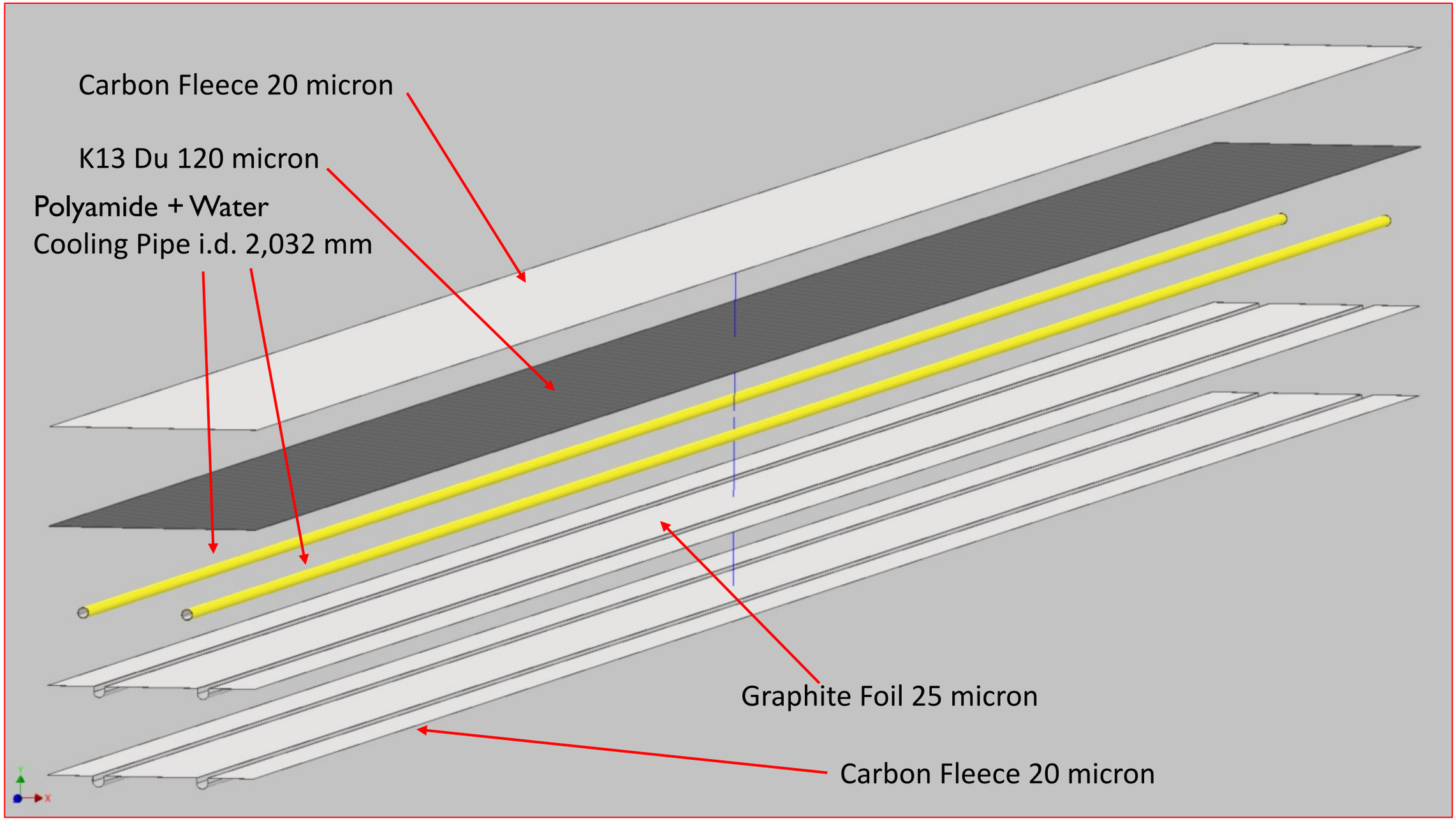
Simulated sagitta is 582 µm for two 200g loads



- First Frequency of resonance = 79,6 Hz
- Second frequency of reasonance = 81,4 Hz
- Third Frequency of resonance = 166,6 Hz

Cold plate for silicon sensors



Radiation length

Truss structure 0,16 % X0

Cold Plate 0,06 % X0

Cooling 0,011 %

Glue 0,011 % X0

Total 0,533 % X0

SUPPORT STRUCTURE L=1332 H=45 mm Th=0.5 mm

MECHANICS	Component	Quantity	Volume (mm3) from CAD	Thickness (mm)	Dimension (mm)	Equivalent Thickness (cm)	Material Radiation Length (cm)	Equivalent radiation Length (%)	
	Supporto a C ribassato struttura	20	33.975x20=679.5	0.5	36x4.6	679.5/42,2x1232/10=0.00120	26	0.00465%X0	0,1628 %X0
	Supporto a C basso struttura 1232	4	23.175x4=92.7	0.5	36x4.6	92.7/42.2x1332/10=0.000165	26	0,000634%X0	
	Staffa intermedia 45	4	2025x4=8100	0.5	60x67.5	8100/42,2x1332/10=0.0144	26	0.0155 %X0	
	Staffa intermedia 36	2	1215x2=2430	0.5	36x67.5	2430/42,2x1332/10=0.00432	26	0.0166 %X0	
	Colla staffa intermedia 36	2	55.903x2=11.806	0.1	36x67.5	11.806/42,2x1332/10=0.000021	26	0.000081 %X0	
	Colla staffa intermedia 45	4	76.719x4=306.88	0.1	60x67.5	306.88/42.2x1332/10=0.000545	33.5	0.00163 %X0	
	Colla supporti a C	24	1.8x24=43.2	0.1	36x0.5	43.2/42.2x1332/10=0.0000768	26	0,000296%X0	
	Colla Araldite struttura 3d - 1332	1	3287.96	/	sx1332	3287.96/42.2x1332/10=0.00585	33.5	0,0175%X0	
	CF Reticular Structure 3D	1	15481.5	0.5	1332	15481.5/42.2x1332/10=0.0275	26	0.1059 %X0	

COLD PLATE

Component	Quantity	Volume (mm3) from CAD	Thickness (mm)	Width (mm)	Length (mm)	Equivalent Thickness (cm)	Material Radiation Length (cm)	Equivalent radiation Length (%)	
Carbon Fleece (lower	1	1306.8	0.020	42.2	1332	1306.8/42.2x1332/10=0.0023	106.8	0.0021%X0	0.0609 %X0
K13D2U	1	6745.2	0.120	42.2	1332	6745.2/42.2x1332/10=0.0119	26.08	0.0456%X0	
Graphite Foil	1	1633.53	0.025	42.2	1332	1633.53/42.2x1332/10=0,0029	26.56	0.0113 %X0	
Carbon Fleece (upper	1	1124.2	0.020	42.2	1332	1124.2/42.2x1332/10=0.002	106.8	0.00187 % X0	

PIPES&COOLANT

Component	Quantity	Inner Diameter	Outer Diameter	Cross Section (mm2)	Length (mm)	Total Volume (mm3)	Width (mm)	Equivalent Thickness (cm)	Material Radiation Length (cm)	Equivalent radiation Length (%)	
Polymide Pipes	2	2.032	2.223	0.638	1332	849.04	36	849.04x2/42.2x1332/10=0.0030	28.41	0.0106 %X0	0.011 %X0
Deminarilized Water	2	2.032	0,0000	3.241	1332	4317.39	36	4317.39x2/42.2x1332/10=0.0153	35.76	0.0427 %X0	

GLUE

Component	Quantity	Thickness (mm)	Volume (mm3)	Length (mm)	Equivalent Wide	Equivalent Thickness (cm)	Material Radiation Length (cm)	Equivalent radiation Length (%)	
Epoxy Glue (Ecobond 45)	2	0.050		1332	42.2	0.0050	44,37	0.0112%X0	0,0112 %X0

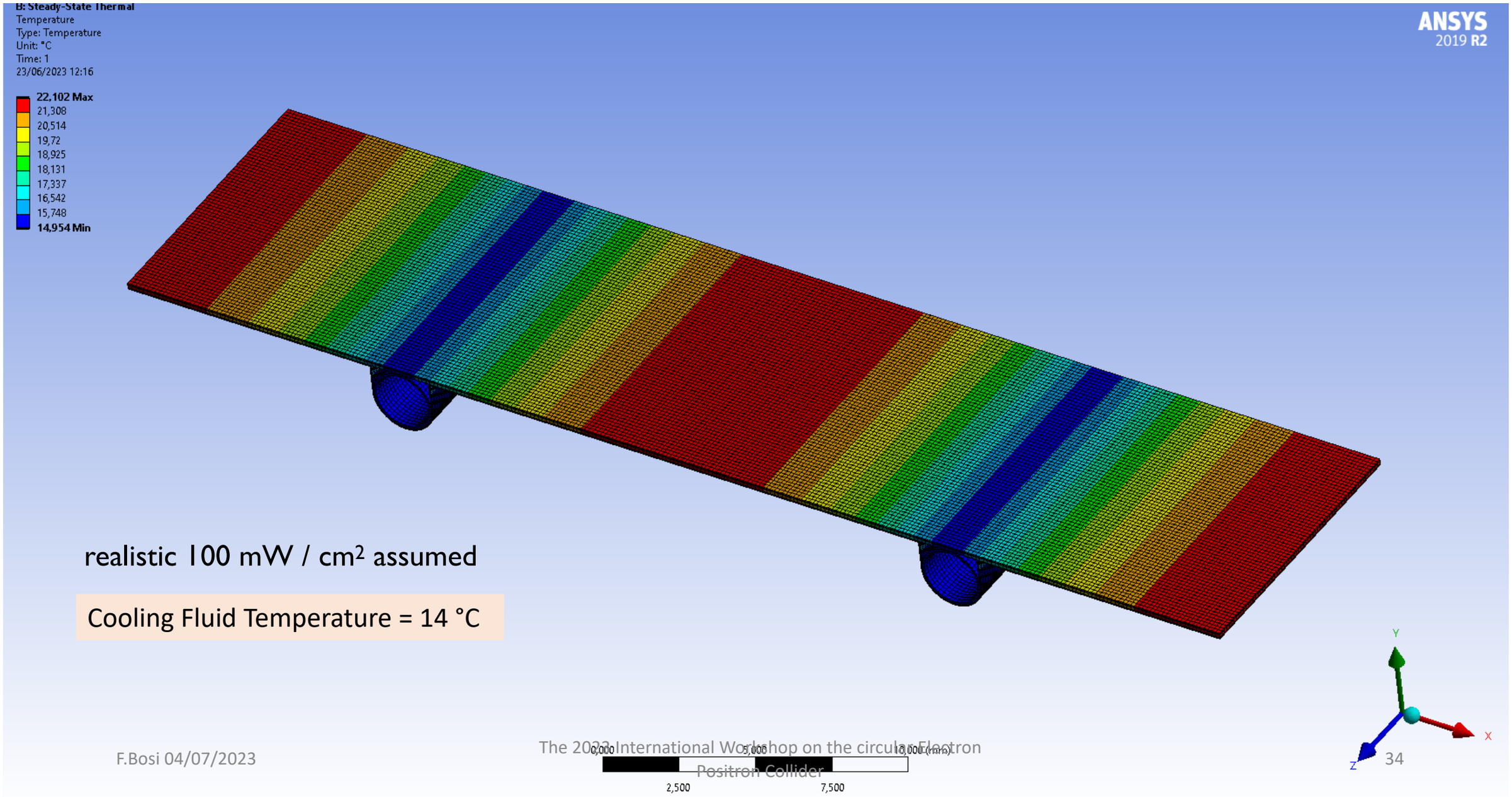
FPC	Component	Material	Thickness (mm)	Equivalent Thickness (cm)	Material Radiation Length (cm)	Equivalent radiation Length (%)	
	FPC Metal Layer	Aluminum	0.050	0.050	8.896	0.056 %	0.114 %
	FPC Insulating Layer	Polymide	0.100	0.100	28.41	0.035 %	0.114 %
	Glue	Ecobond 45	0.100	0.100	44.37	0.023 %	

POWER BUS	Component	Material	Thickness (mm)	Equivalent Thickness (cm)	Material Radiation Length (cm)	Equivalent radiation Length (%)	
	Metal Layer	Aluminium	0.200	0.200	8.896	0.225 %	0,32%
	Insulating Layer	Polymide	0.200	0.200	28.41	0.070 %	0.1705 %
	Glue	Ecobond 45	0.100	0.100	44.37	0.023 %	

DETECTOR	Component	Material	Thickness (mm)	Equivalent Thickness (cm)	Material Radiation Length (cm)	Equivalent radiation Length (%)	
	Pixel Chip	Silicon	0.050	0.0050	9.369	0,0533%	0,0533%X0

Totale 0.533%X0

Thermal simulation



realistic 100 mW / cm^2 assumed

Cooling Fluid Temperature = 14 °C

55nm chip project

First results from October 2022 submission (not HV)

MPW submitted to SMIC in 55nm **HVCMOS process**

1kΩ high resistivity wafer; **August 2023**

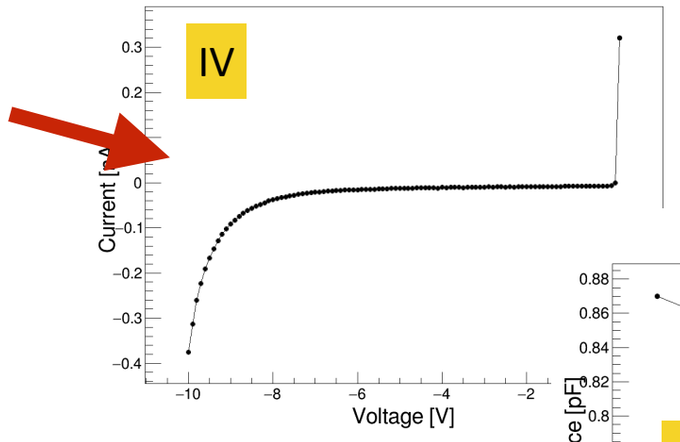
3 sections

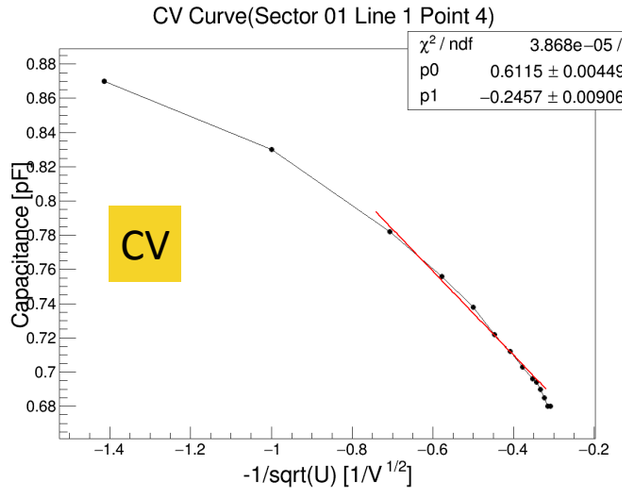
- 1) 32 × 20 pixel matrix with in-pixel **amplifier and discriminator** design for process validation
- 2) sensor **diode array** for IV / CV studies
- 3) 26 × 26 pixel matrix for **new electronics structure study**

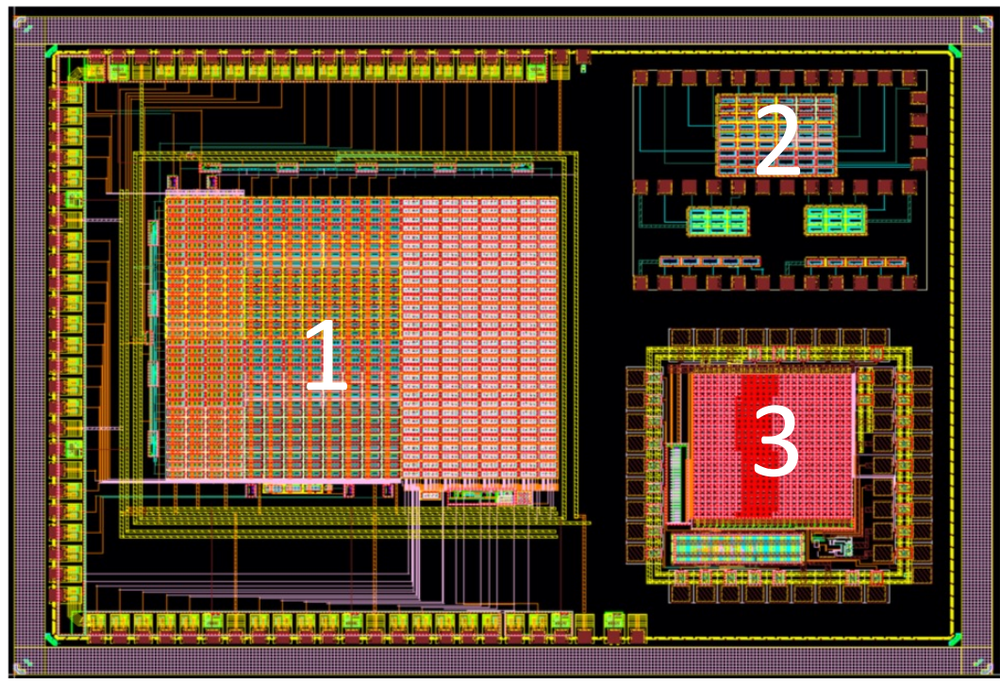
Details in this workshop:

- Zhiyu Xiang's poster https://indico.ihep.ac.cn/event/19316/contributions/143495/
- Hui Zhang's talk https://indico.ihep.ac.cn/event/19316/contributions/142772/
- Ruoshi Dong's poster https://indico.ihep.ac.cn/event/19316/contributions/143499/
- Yang Zhou's poster https://indico.ihep.ac.cn/event/19316/contributions/143507/

See also the **Arcadia** project https://indico.ihep.ac.cn/event/19316/contributions/142771/







Conclusion

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We are making progress on several fronts:

- Understanding the sensor
- The telescope is a good example for a multi-sensor assembly
- First version of quad modules produced and operational in Milano and Edinburgh
- New version of quad modules for serial powering on a stave is being designed

- First prototype of long stave using carbon fibre space frame
  - Sagitta and measurements and simulations
  - Thermal simulation
- SMIC 55nm HV process submitted by IHEP and KIT with test structures and a small fill factor pixel array.

Backup

DAQ: YARR
Yet Another Rapid Readout

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https://iopscience.iop.org/article/10.1088/1742-6596/898/3/032053

YARR is a small **self-contained DAQ system**.

Linux PC with a x4 **PCIe slot for the FPGA card**

FPGA card: e.g. **Trenz TEF1001**, XpressK7,…

FMC cards for FE-I4 and RD53A

Up to **1.6GBit/s possible** with this setup.

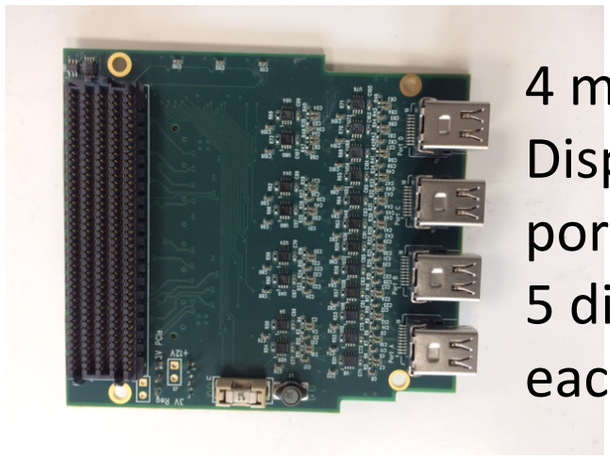
We have used the YARR readout with a digital RD53A module in **Lancaster & Edinburgh**.

Trenz TEF1001

Todo: Adaptation to ATLASPix3 necessary:

- **Software**

Ohio card



4 mini Display ports
5 diff lines each