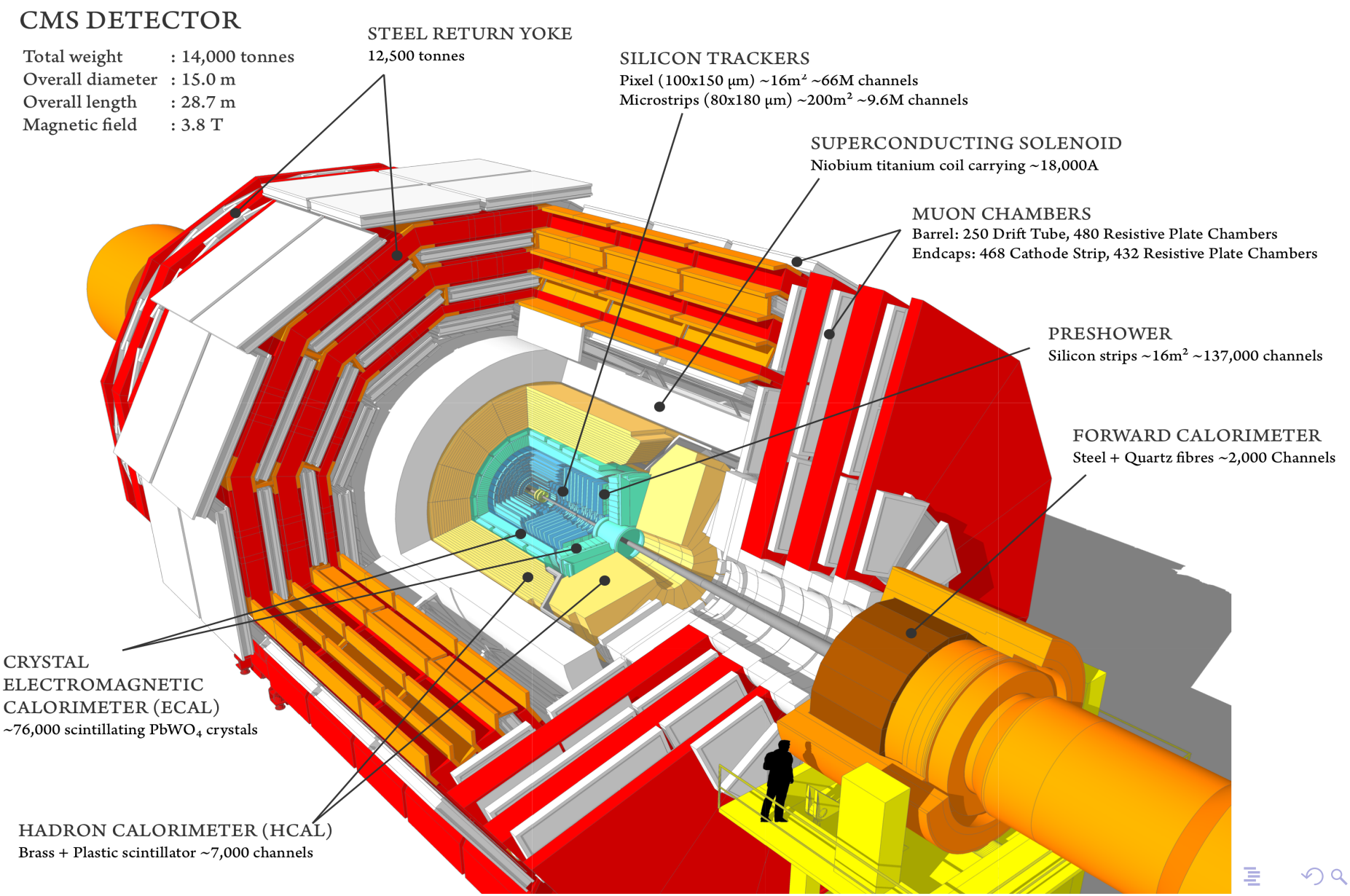
" Assembly, noise and performance tests results of the PS modules for the Phase-2 CMS Outer Tracker "

I. Margjeka, on behalf of the CMS Tracker group

VERTEX 2023

VERTEX 2023 - 32^{nd} International Workshop on Vertex Detectors

The CMS Experiment

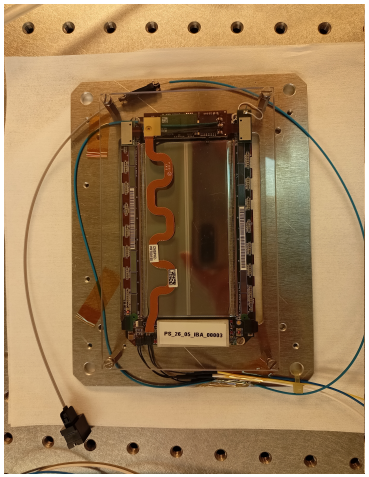


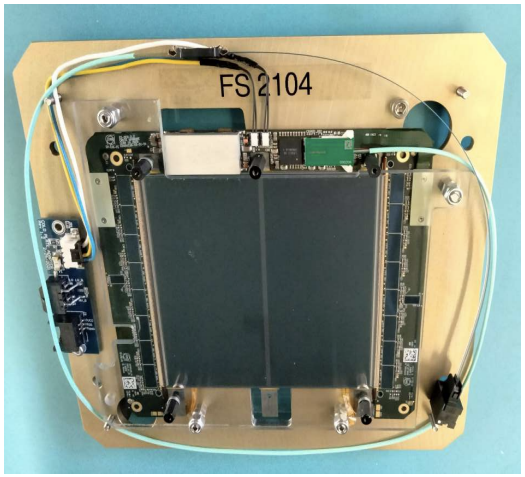
The CMS Phase-2 upgrade

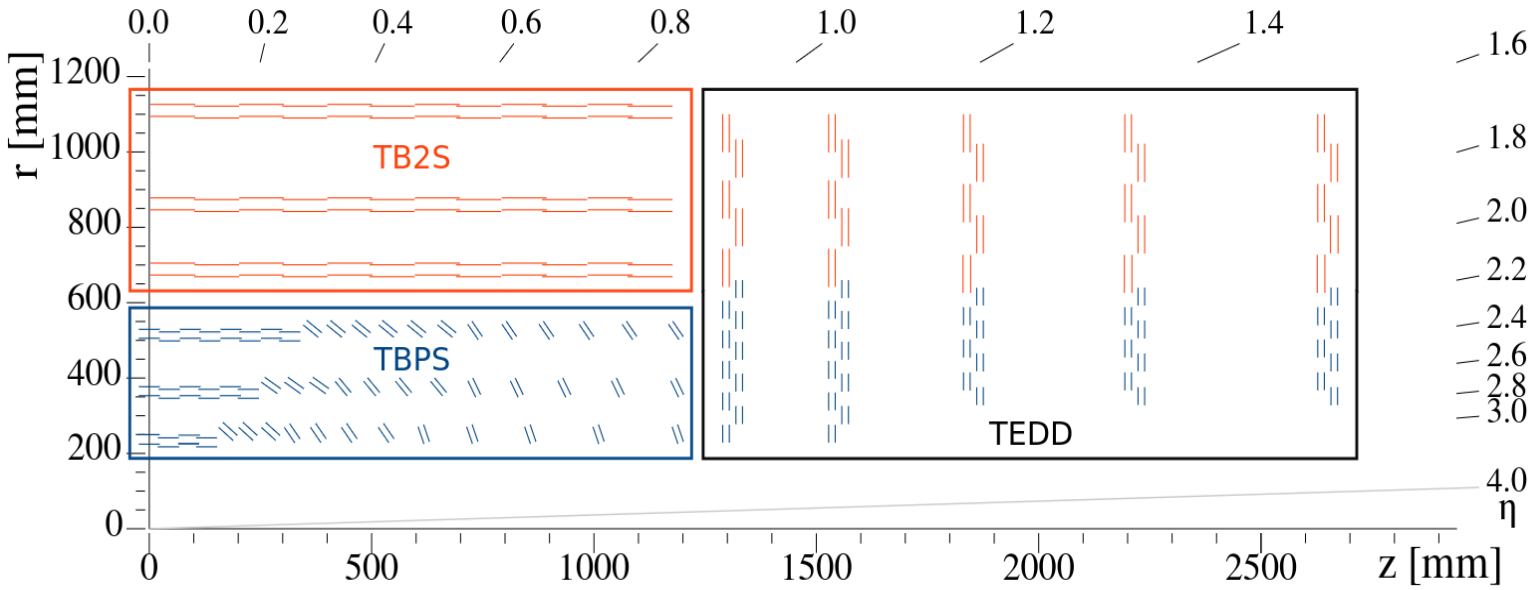
- Radiation tolerance: from $\sim 450 fb^{-1}$ (Run III) to $\sim 4000 fb^{-1}$
- Increased granularity: from ~ 52 (2023) collisions per bunch crossing will between 140 and 200 collisions (pileup)
- Improved two-track separation
- Reduced material in the tracking volume
- Level trigger rate: From 100 kHz to 750 kHz and to increase the latency from the present value of $3.2\mu s \rightarrow 12.5\mu s$.
- Robust pattern recognition: Fast and efficient track finding, notably at the HLT
- Contribution to the level-1 trigger: Solution at hardware level (strip-strip silicon or pixel-strip silicon sandwich)
- Extended tracking acceptance: from $\eta = 2.4$ will be increased to $\eta = 4.0$

The CMS Outer Tracker Phase-2

- 7680 2S-modules (right)
- 5616 PS-modules (left)
- Cross section of the Phase-2 OT (below)



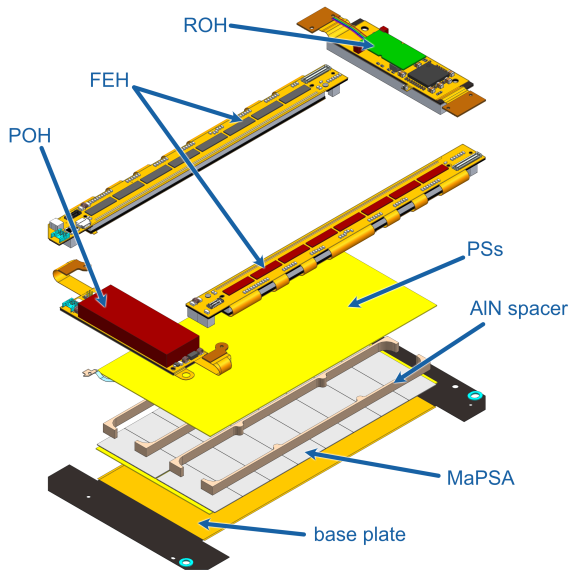


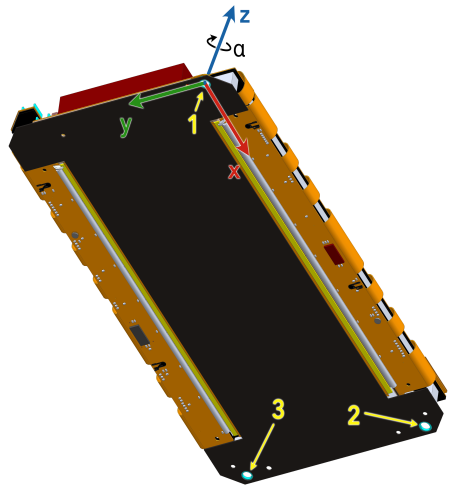


The pixel-strip (PS) modules

- The PS modules will be assembled by **DESY (Germany), INFN Bari and Perugia (Italy), US East (Brown, Princeton and Rutgers University), US Midwest (FNAL)**

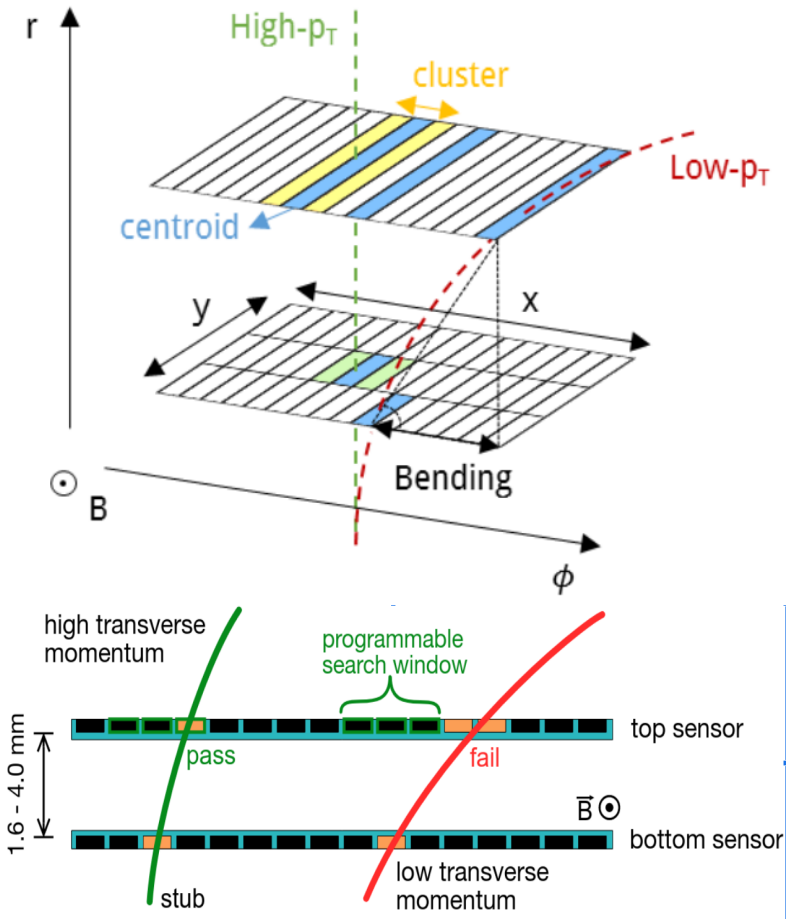
  - View from the back side of the PS module (right), exploded view of the PS module (left)
  - Macro Pixel sensor, connected to 16 Macro Pixel Asic (MPA) chips (16x120 pixels, $\sim 1.5mm \times 100\mu m$)
  - Strip sensor, read-out by 16 silicon Short Strip Asic (SSA) chips (120 strips each, $\sim 2.4cm \times 100\mu m$).
  - PSs and PSp sensors are glued over ceramic spacers, obtaining an active thicknesses of 1.6-2.6-4.0 mm





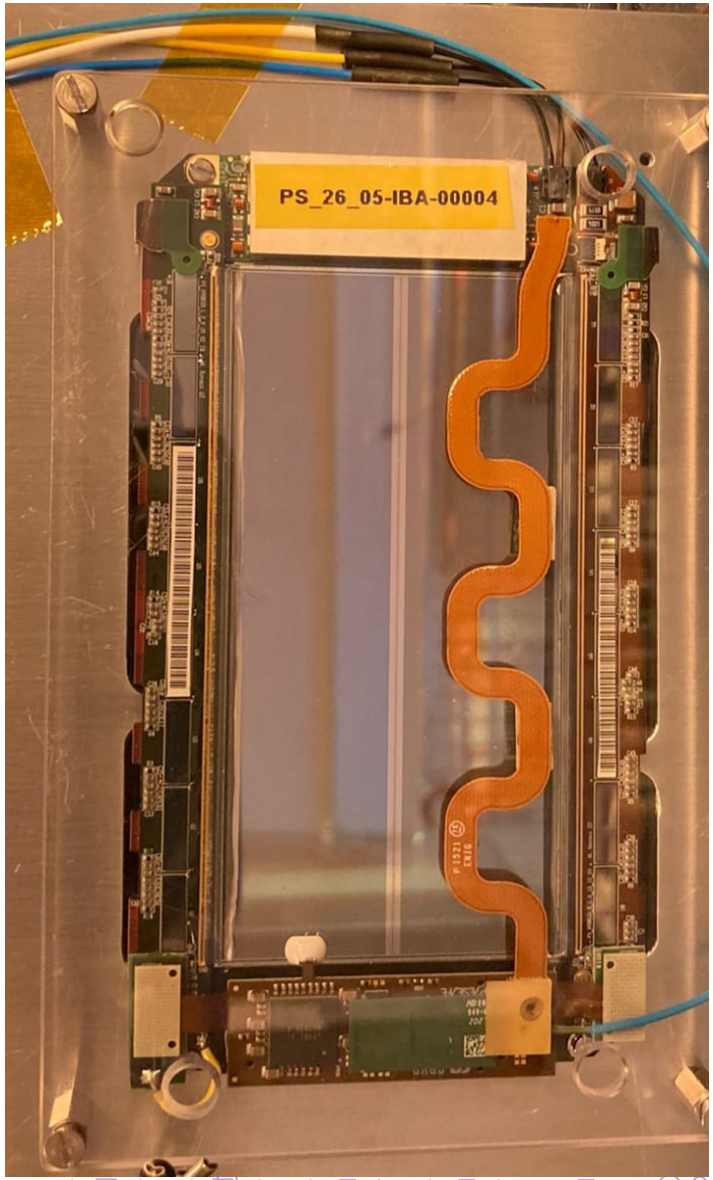
Principle of p_T discrimination in the PS modules

- The Trigger provides the high-p_T information to L1 tracking at 40 MHz
- Stubs: tracks of hits from particles with a p_T threshold of ≥2 GeV, sent to the back-end electronics at 40 MHz to build L1 track primitives
- The position of the stub: Coordinates of the incidence point on the pixel sensor and the momentum with the bending angle in the $r-\phi$ plane of the particle
- The Stub Finding algorithm discriminates the particles based on the bending value
- In output: Encoded position and bending of the stubs



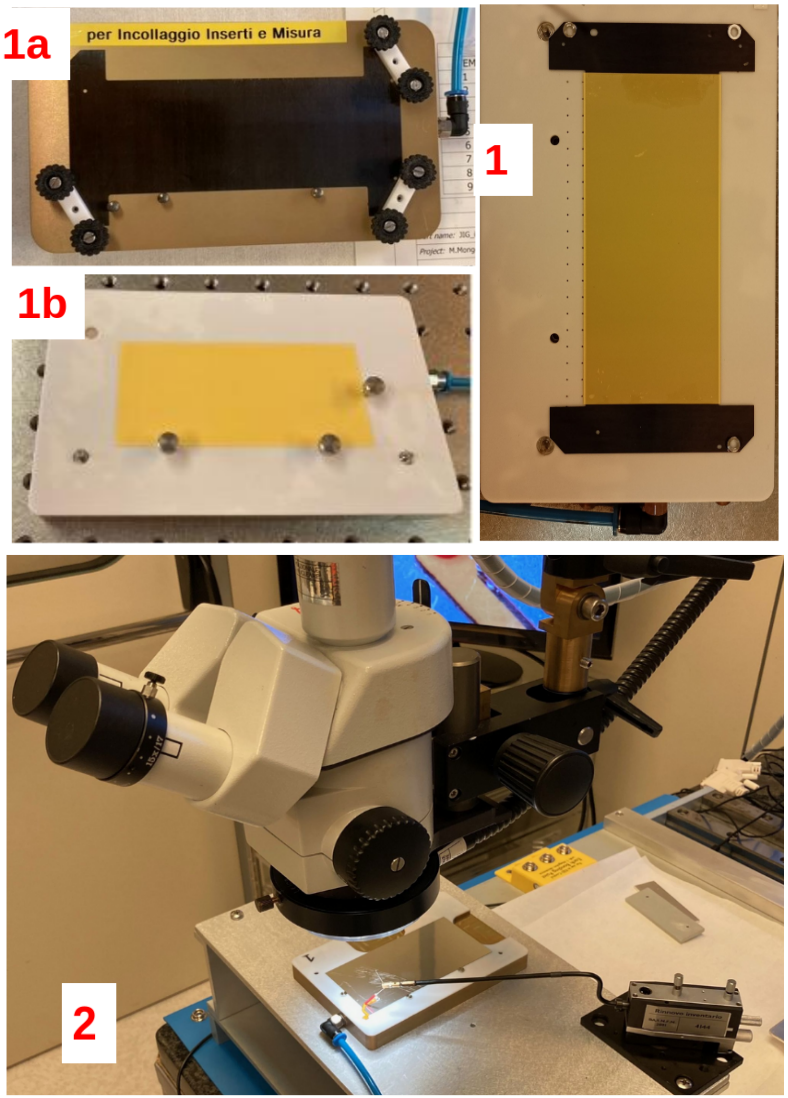
The pixel-strip (PS)

- Pixel-strip sandwich is isolated electrically through a capton from the conductive CF-BP base plate.
- PS-POH controls the powering of the hybrids (~10V) and of the sensors with (up to 800 V).
- PSs and PSp sensors are wire-bonded to two FEH (left and right)
- FEH are interconnected with the PS-POH and with an optical Readout Hybrid (ROH)
- Data are carried out from FEH via CIC to lpGBT, via 6 differential lines 320MHz
- L1 data transmission (total BW=320MB/s)
- 5 lines for the trigger data transmission (total BW=1.6GB/s)
- vTRx provides a multi-gigabit optical-physical data transmission layer for the readout (5G/10G)



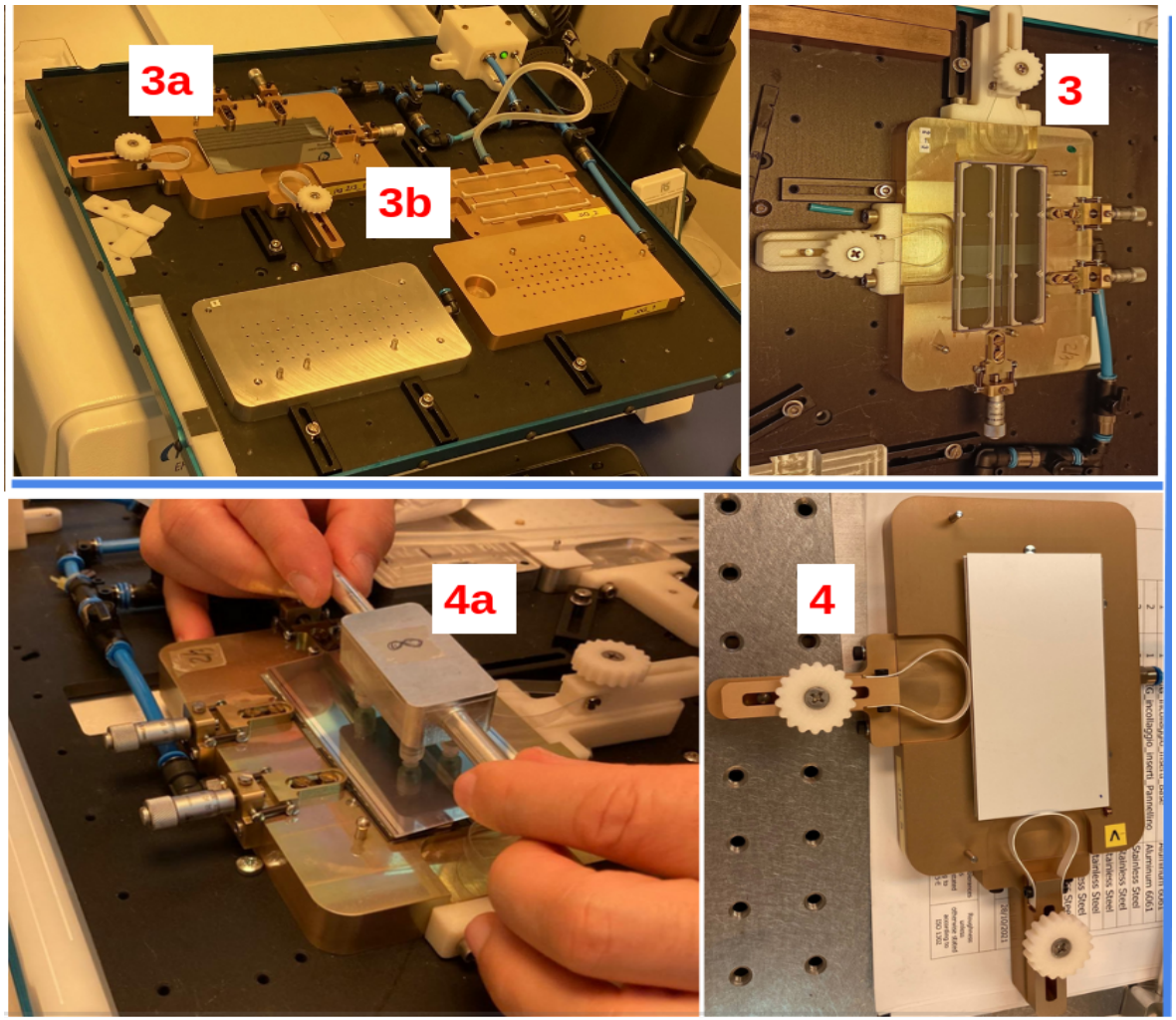
PS module assembling pocedure: part I-II

- Gluing of the inserts **(1a)** and kapton **(1b)** on the baseplate **(1)**
- Gluing and wire-bonding of the HV cable on the back side of the PSs sensor **(2)**



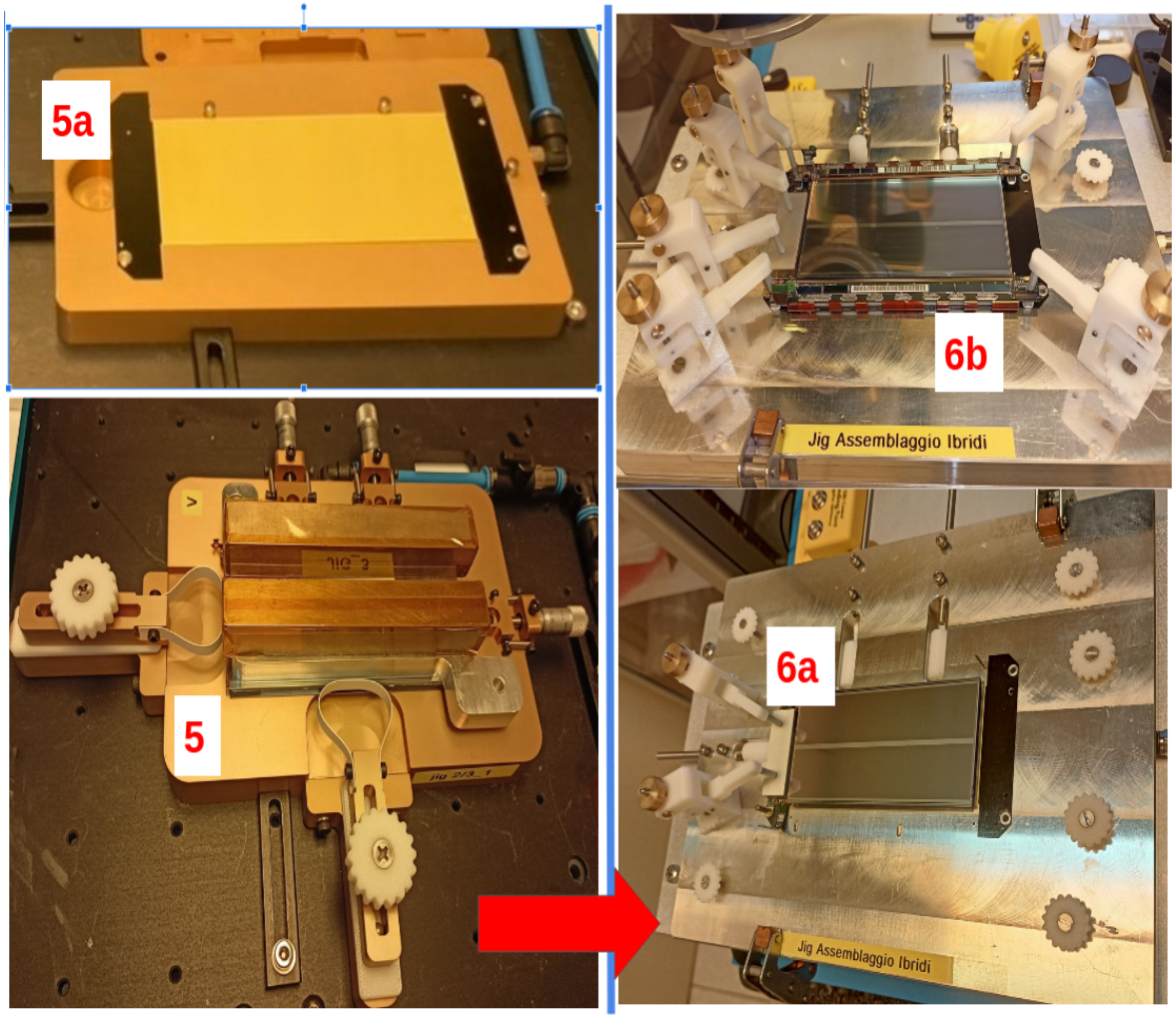
PS module assembling pocedure: part III-IV

- Gluing (3) of the spacers (3b) over the pixel sensor (3a)
- Gluing of the strip sensor (4a) over the spacers (pixel-strip sandwich 4)

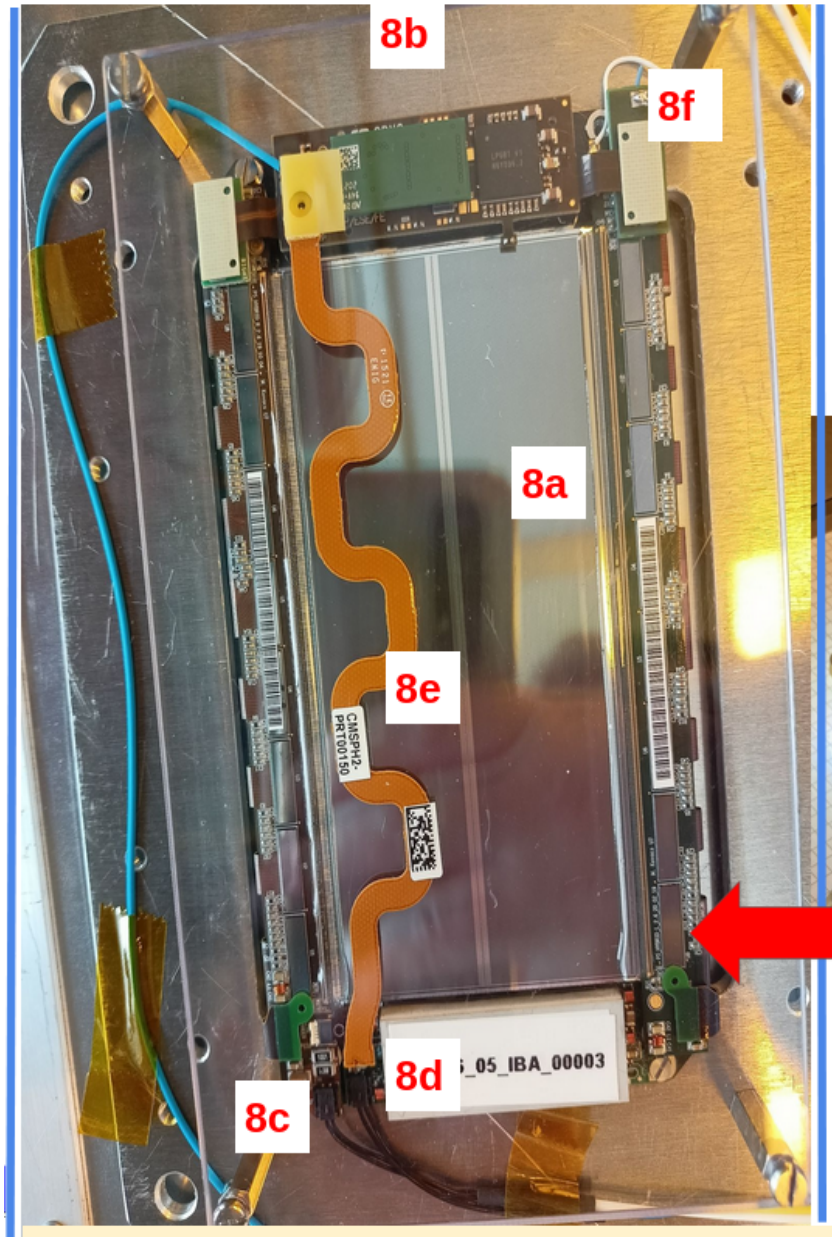


PS module assembling pocedure: part V-VI

- Gluing of the sandwich **(5)** over the baseplate with the kapton **(5a)**
- Gluing of the POH **(6a)**, ROH, FEH-LR **(6b)** on the naked PS sandwich

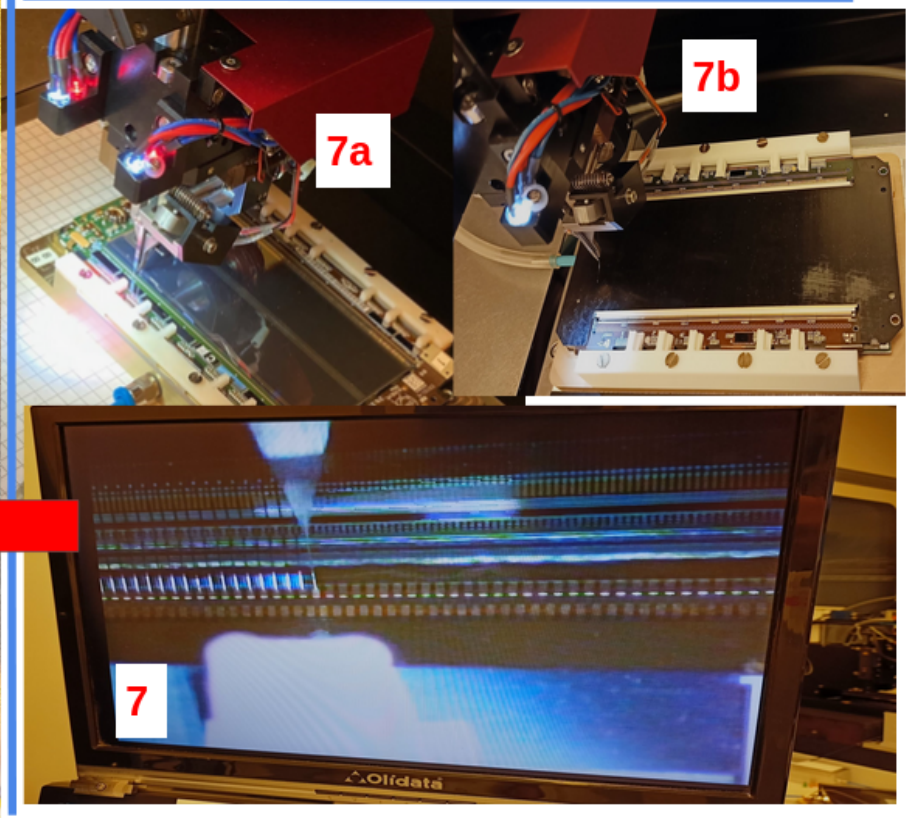


PS module assembling pocedure: part VII-VIII

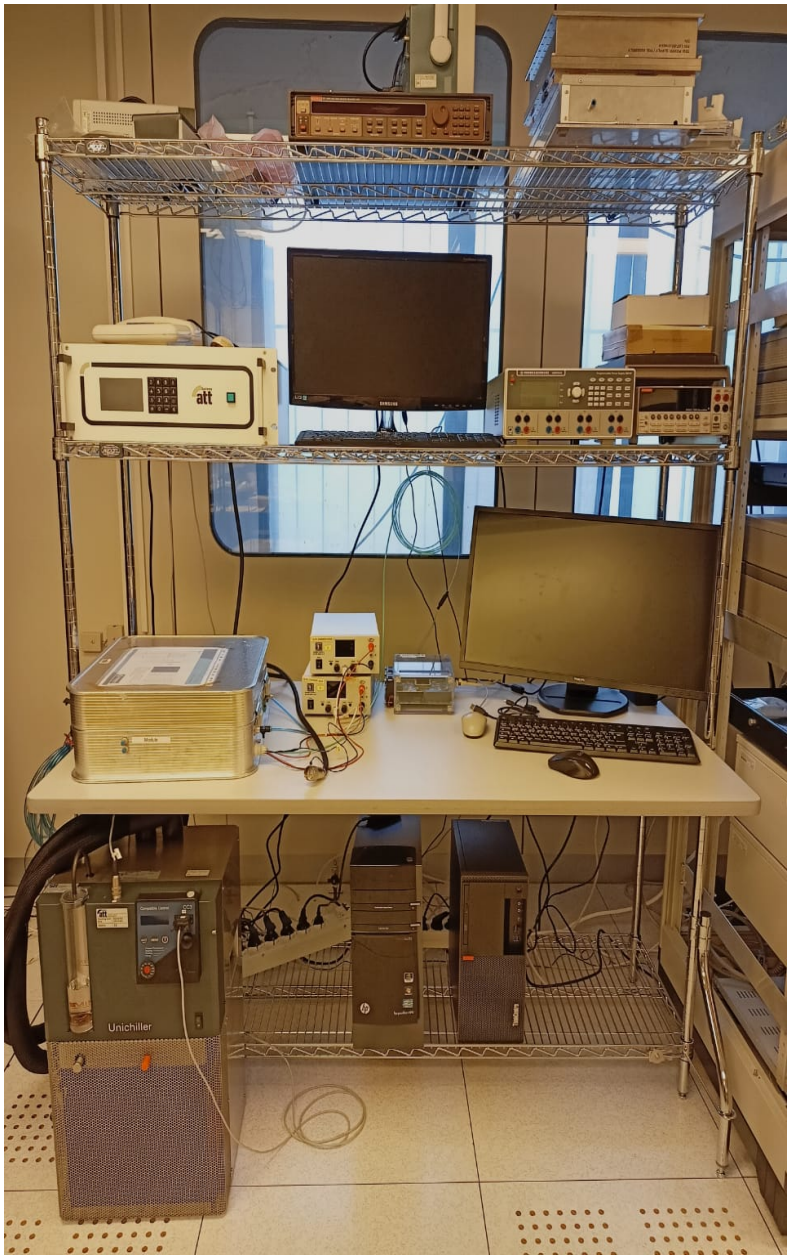


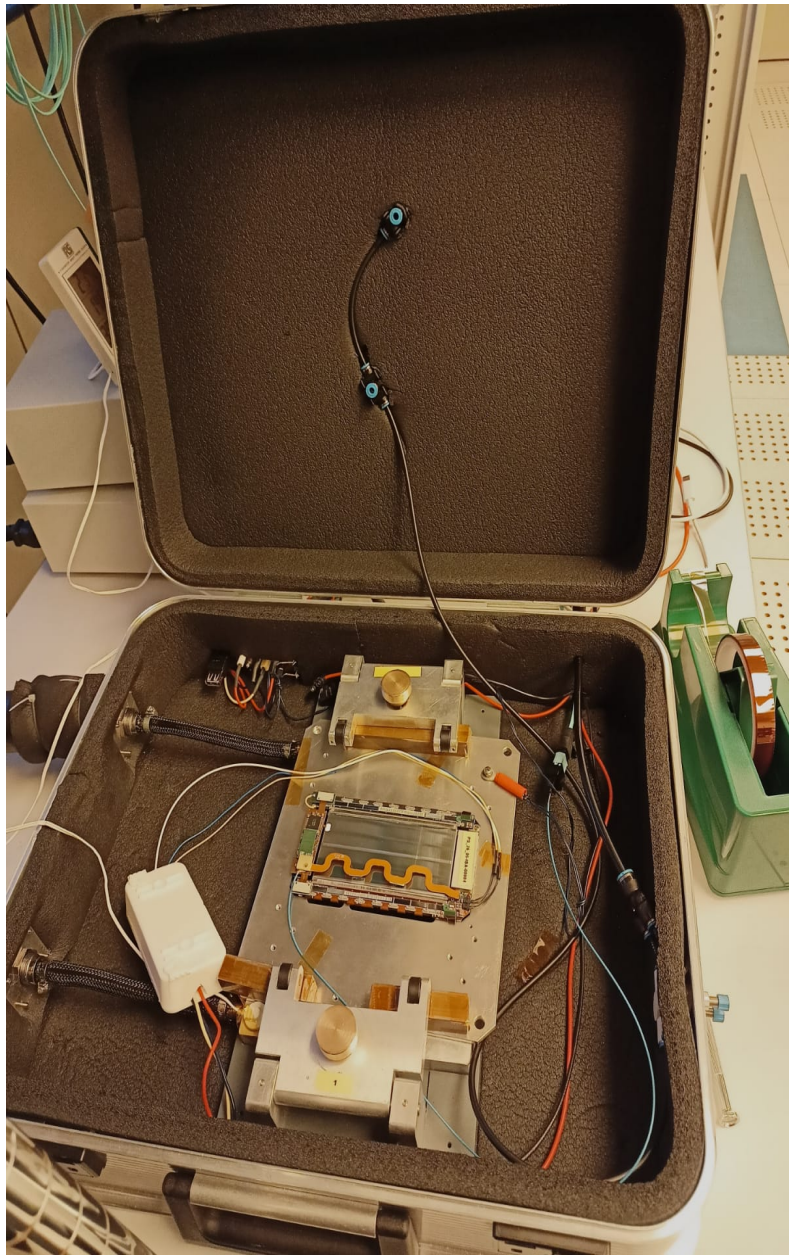
8) Encapsulation (8a) of the wire bondings with Sylgard, vtRX+ connector (8b), HV (8c), LV (8d), power tail (8e), soldering of the 2.5V wire (8f),

7) Micro wire-bonding (7) between the FEH and the sensors for both SSA (left 7a) and MPA (right 7b)



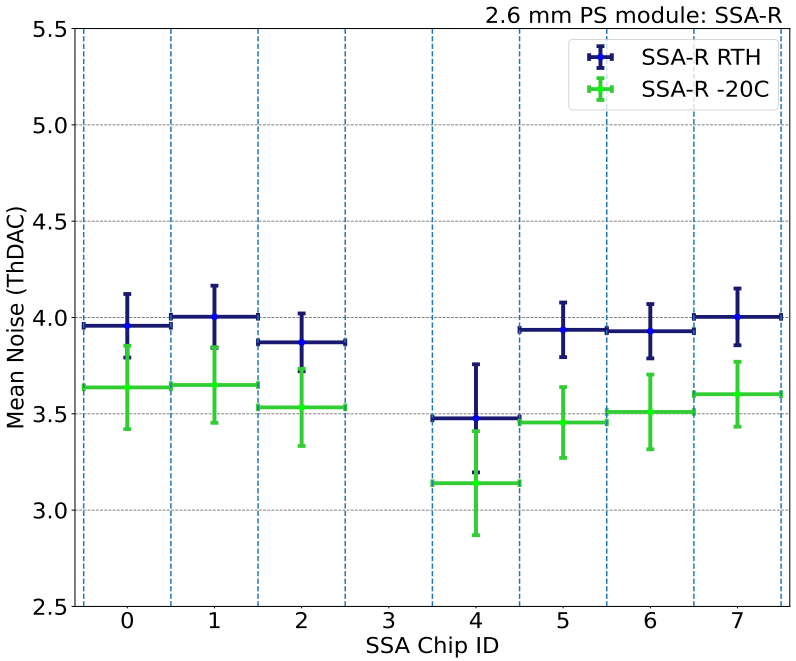
Set-up test at room and low temperatures (up to −25°C)

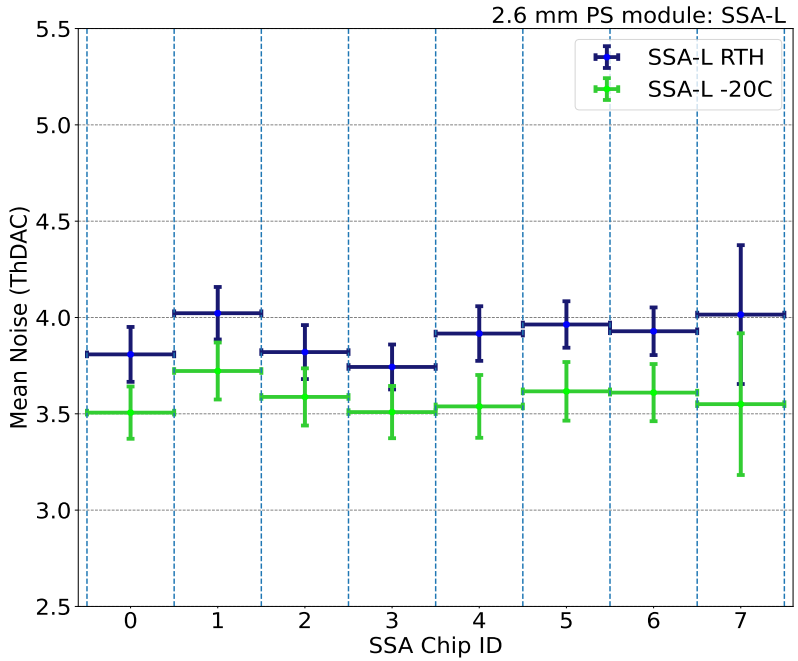




Preliminary noise results at RHT and -20C (HV=400V)

- Preliminary results on the noise regarding the existing prototypes till now
- New results will be updated with the kick-of bench PS modules (60 will be assembled!)





Test (preliminary results)	RTH	-20°C
Mean noise value SSA-R at 400V (1 ThDAC=250 e)	3.88±0.25 Vcth	3.50±0.27 Vcth
Mean noise value SSA-L at 400V (1 ThDAC=250 e)	3.90±0.24 Vcth	3.58±0.26 Vcth
Leakage current I_{leak}	~ 1.85 μ A	~ 1.04 μA
Noise strips ≥ 10 Vcth	None	None
(*SSA-R-3-4 have same address !)		

Preliminary noise results at RHT and -20C (HV=400V)

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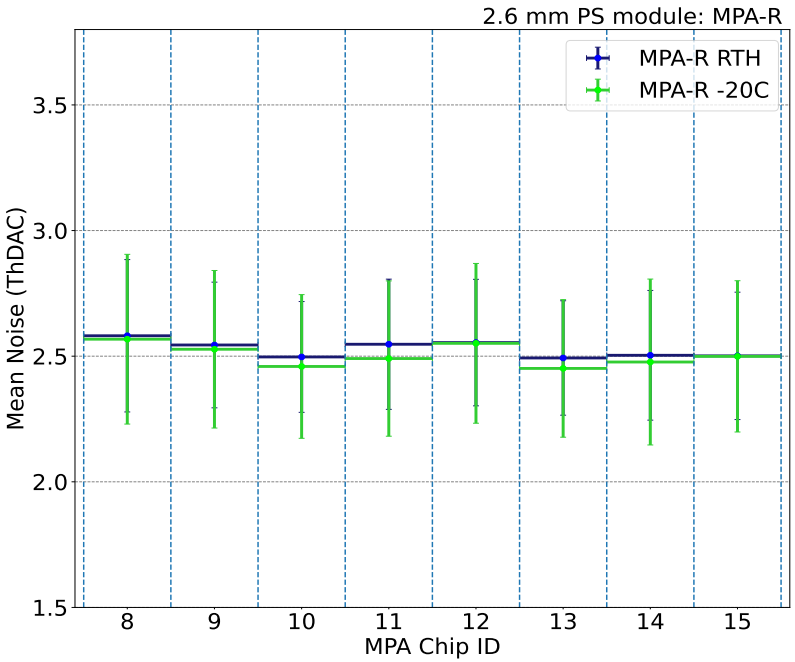
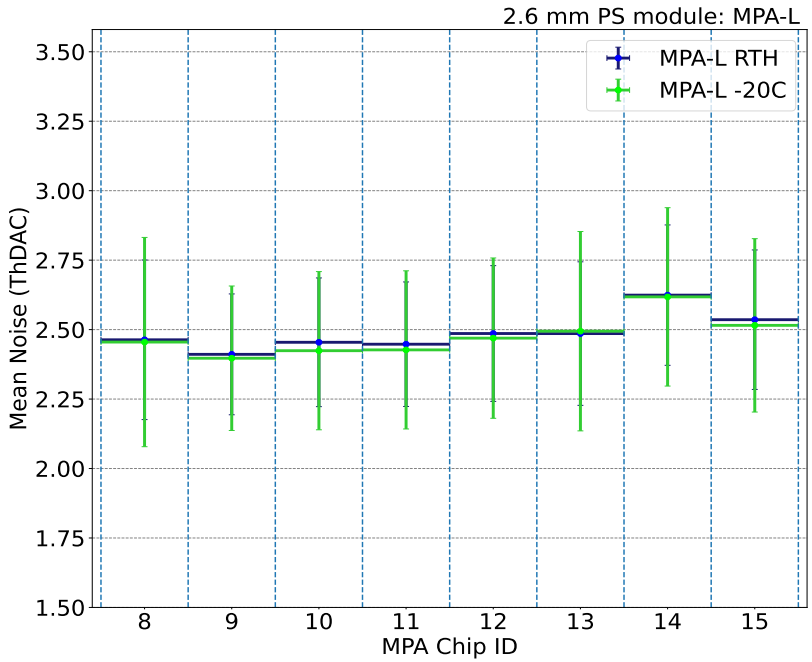




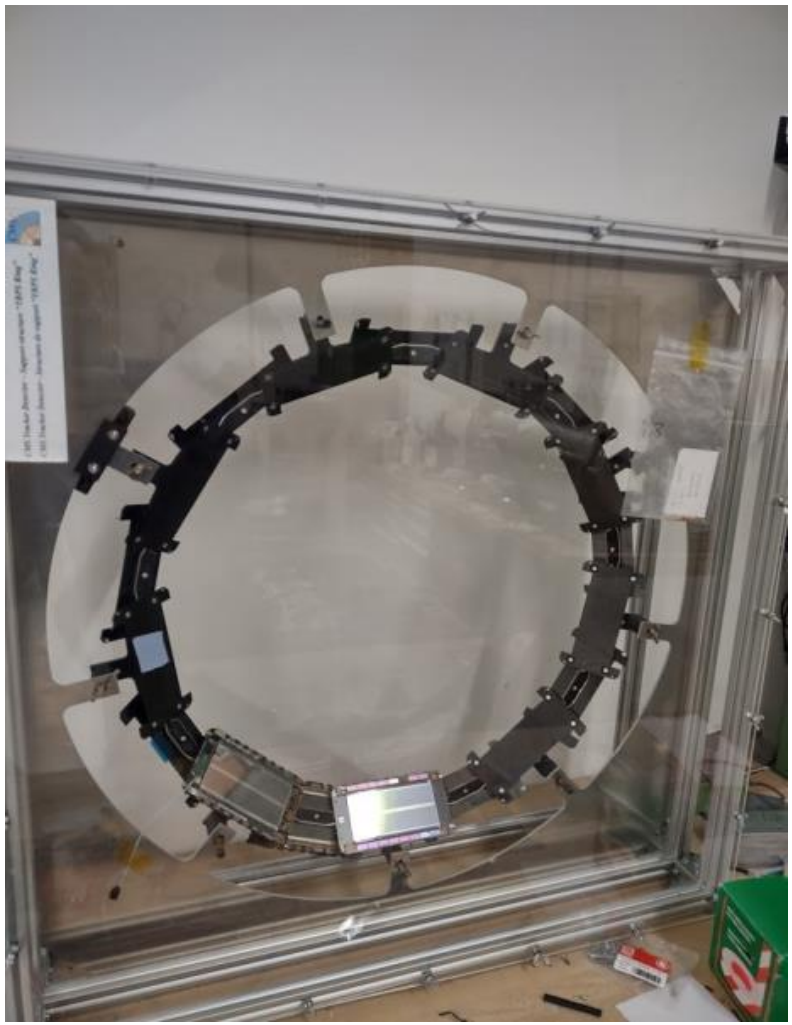
Test (preliminary results)	RTH	-20°C
Mean noise value MPA-R at 400V (1 ThDAC=94 e)	2.53±0.26 Vcth	2.50±0.31 Vcth
Mean noise value MPA-L at 400V (1 ThDAC=94 e)	2.49±0.26 Vcth	2.47±0.31 Vcth
Leakage current I_{leak}	~ 1.85	~ 1.04 μA
Noise strips ≥ 10 Vcth	None	None

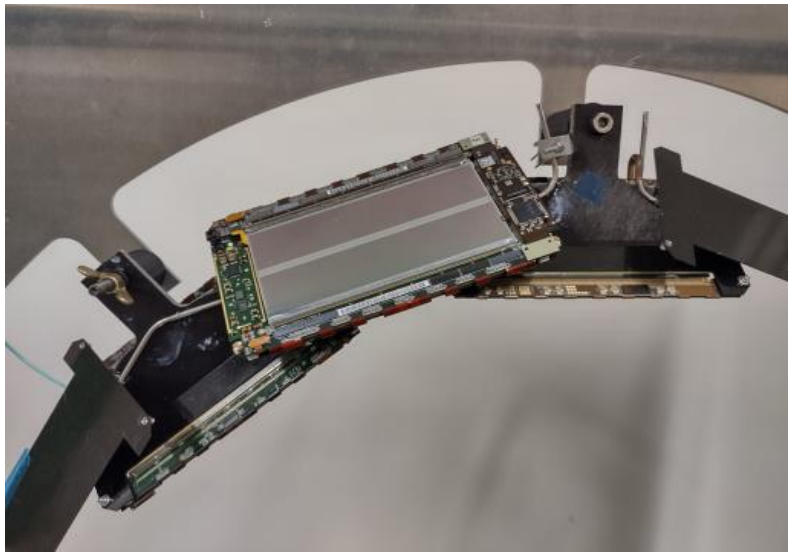
Future developments and Conclusions

- The assembly procedure is well defined.
- Pre-production is planned for 2024.
- A lot of tests with almost the final version of the hybrids have been done (from lab tests up to beam tests at DESY, FNAL and at CERN), in order to access their performance and evaluate the noise values of the pixel and strip sensors.
- Already at room temperature, preliminary results show that we are close to the nominal expected values of the noise ($\sim$ 3.6 VcTH for the strips and $\sim$ 2.5 VcTH for the pixels).
- The general behaviour looks very promising: more tests down to $-35°C$ will be done to simulate the cooling temperature for the modules at the CMS Outer Tracker.
- More accurate investigations will be done on kick-off modules, prensently under assembly

Thank you!

TBPS Integration (PISA): Ring box





TEDD integration tests (DESY)