New MIMOSIS monolithic pixel detector based FOOT Vertex detector status (PRIN HP-DMAPS)

1. HP-DMAPS (High Performance-Depleted Monolithic Active Pixel Sensors) main goal
2. Status of the project
3. Main critical points
4. Project schedule
5. Conclusions

PRIN 2022 «High performance DMAPS (Depleted Monolithic Active Pixel Sensor) for hadrontherapy»

«…….we propose this project with the aim of significantly **improving the capabilities of the pixel tracker**, particularly in terms of the **amount of data that can be collected for the same amount of time and spatial resolution**, which for obvious statistical reasons allows for greater accuracy of the measurements to be made……..»

We propose to improve the detection characteristics of the FOOT experiment's **vertex detector** by **using the MIMOSIS sensor**, developed for the CBM experiment by the In2p3 research group in Strasbourg.

Ultimate integration (M28) time 185,6 µs → MIMOSIS integration time 5,0 µs

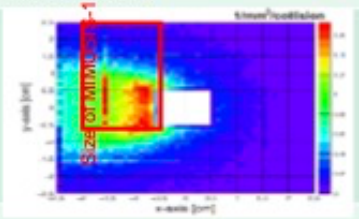
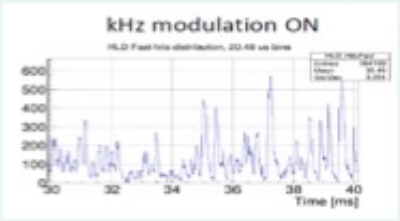
MIMOSIS-1 chip – full scale prototype of one CMOS sensor
✓Matrix dimension: 1024 columns. X 504 rows
✓Pixel dimension: 26.88 µm (height) x 30.24 µm (width)
✓Fabricated with Tower Semiconductor, 180 nm technology

A. Dorokhov (VCI 2022)

✓ Full-scale prototype of the sensor, MIMOSIS-1, extensively tested at lab and in beam, preliminary results for non-irradiated sensors:
- Fake hit rate < 10^{-5}
- Detection efficiency > 99 % at <220 e
- Resolution ~5 µm
- AC pixels show similar to DC pixels performances
- Possible advantages of AC pixels:
  - tune charge collection efficiency within same technology/split
  - more freedom to improve pixels in another technologies
  - applications beyond CBM, Cremlin+, future e+e- colliders

PRIN 2022

MIMOSIS: requirements for the sensor

	Target requirement	comments/complications
Spatial resolution	~5 µm	
Radiation length	~ 0.3 % X_0 (first station) ~ 0.5 % X_0 (other stations)	thickness ~50 µm
Power dissipation	< 200 mW/cm²	operates at vacuum - cooling
Operation temperature	- 40°C to +30°C	temperature gradient 5 K
Heavy Ion tolerance	10 Hz/mm²	
Rate (average/peak)	150/700 kHz/mm²	Fake hit rate < 10^{-5} pix / 5 µs
Time resolution	~5 µs	
Radiation hardness	~ 7x10^{13} n_{eq}/cm² ~ 5 Mrad	radiation gradient 100% over one sensor area
Occupancy gradients in space		 (MVD TDR)
Beam intensity fluctuations in time		 (HADES, GSI)

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Vienna Conference on Instrumentation, 2022 *A. Dorokhov, IPHC, Strasbourg, France*

Key points

Time resolution
- MIMOSIS 5 µs
- Ultimate (M28) 185,6 µs

MIMOSIS – global shutter
Ultimate (M28) – rolling shutter

MIMOSIS active area:
Active area: 30.935×13.520 mm2
Pixel pitch: 26.88 x 30.24 µm2

two sensors per plane:
Active area: about 30×30 mm2
(similar to FIRST vertex arrangement)

Add one station before target.

Second version of MIMOSIS2 arrived in Strasbourg in may 2024

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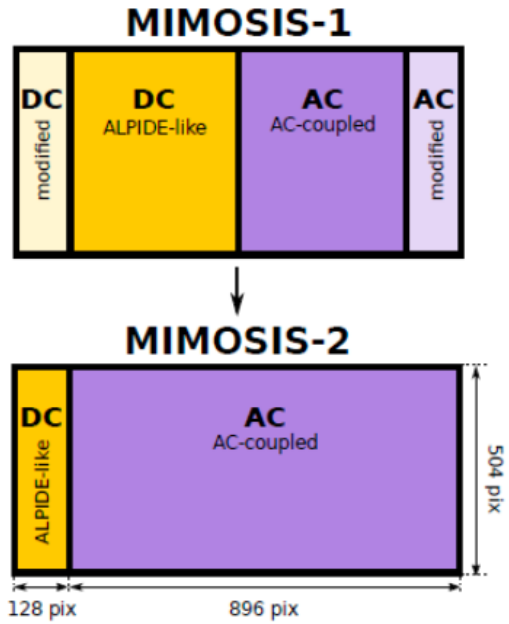
The MIMOSIS sensor: a reminder

Mimosis-2

- Evolution of MIMOSIS-1 with
  - On-chip clustering
  - Triplication added
  - Various improvements
- Goal: validate all blocks/functionnalities before final production sensor (Mimosis-3)
- 25 & 50 μm epitaxial thickness versions
- Back from foundry Q2 2023
  - First tests in June 2023



- 2023 MIMOSIS2 run had some problems mainly in the PLL side.
- Resubmitted: prototypes available in Strasbourg may 2024. Unde test.
- One wafer available for HP-DMAPS
- PRIN2022 MOU INFN-In2p3 under definition
- Clear advantages in using MIMOSIS2 versus MIMOSIS1.
- Production sensors (MIMOSIS3) for CBM too late for PRIN2023 time scale

New MIMOSIS monolithic pixel detector based FOOT Vertex detector status (PRIN HP-DMAPS)

- MOU final version close to definition
- Signature in few months

Memorandum of Understanding between the Laboratori Nazionali di Frascati of the Istituto Nazionale di Fisica Nucleare (INFN-LNF) and the Institut Pluridisciplinaire Hubert Curien (IPHC) regarding the HP-DMAPS project

version 1: 17/12/2023

1. Purpose

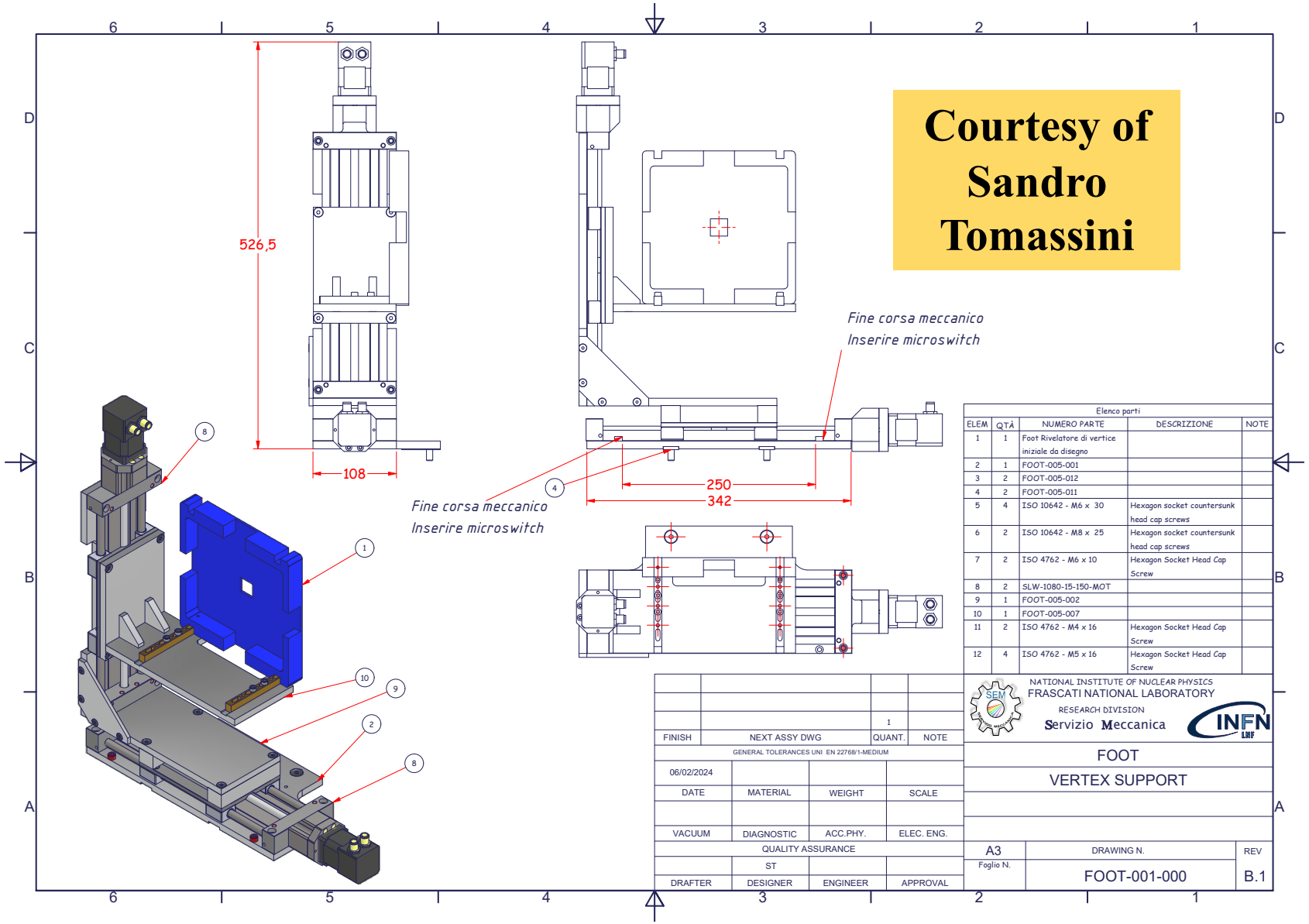
The purpose of this Memorandum is to document the understanding between the Laboratori Nazionali di Frascati (LNF) of the INFN, hereby represented by its Director, Dr. Fabio BOSSI, and the Institut Pluridisciplinaire Hubert Curien of Strasbourg (IPHC), hereby represented by its Director, Dr. Sandrine COURTIN regarding the provision of CMOS pixel sensors for the INFN project High Performance - Depleted Monolithic Active Pixel Sensors (HP-DMAPS) during the period 2023 to 2025.

2. Scientific and technical context

We propose to improve the detection characteristics of the FOOT experimer
vertex detector by using the MIMOSIS sensor, under development for the Micro-Vertex Detector (MVD) at the Compressed Baryonic Matter (CBM) experiment by the In2p3 research group in Strasbourg.

The MIMOSIS sensor family is being designed and characterized by IPHC as state-of-the-art monolithic pixel sensors for charged particles detection. The sensors feature an excellent position resolution of 5 µm combined with a time binning capability of 5 µs. Their high sensitivity guarantees a close to 100% detection efficiency for the ions to be detected in the HP-DMAPS project. Two generations of MIMOSIS sensors exist currently (in 2023), with a further version called MIMOSIS-2.1 under production in the first half of 2024. The main advantage of this solution compared the actual FOOT Vertex detector is the reduction of the integration time from the 185.6 µs to 5 µs.

New MIMOSIS monolithic pixel detector based FOOT Vertex detector status (PRIN HP-DMAPS)

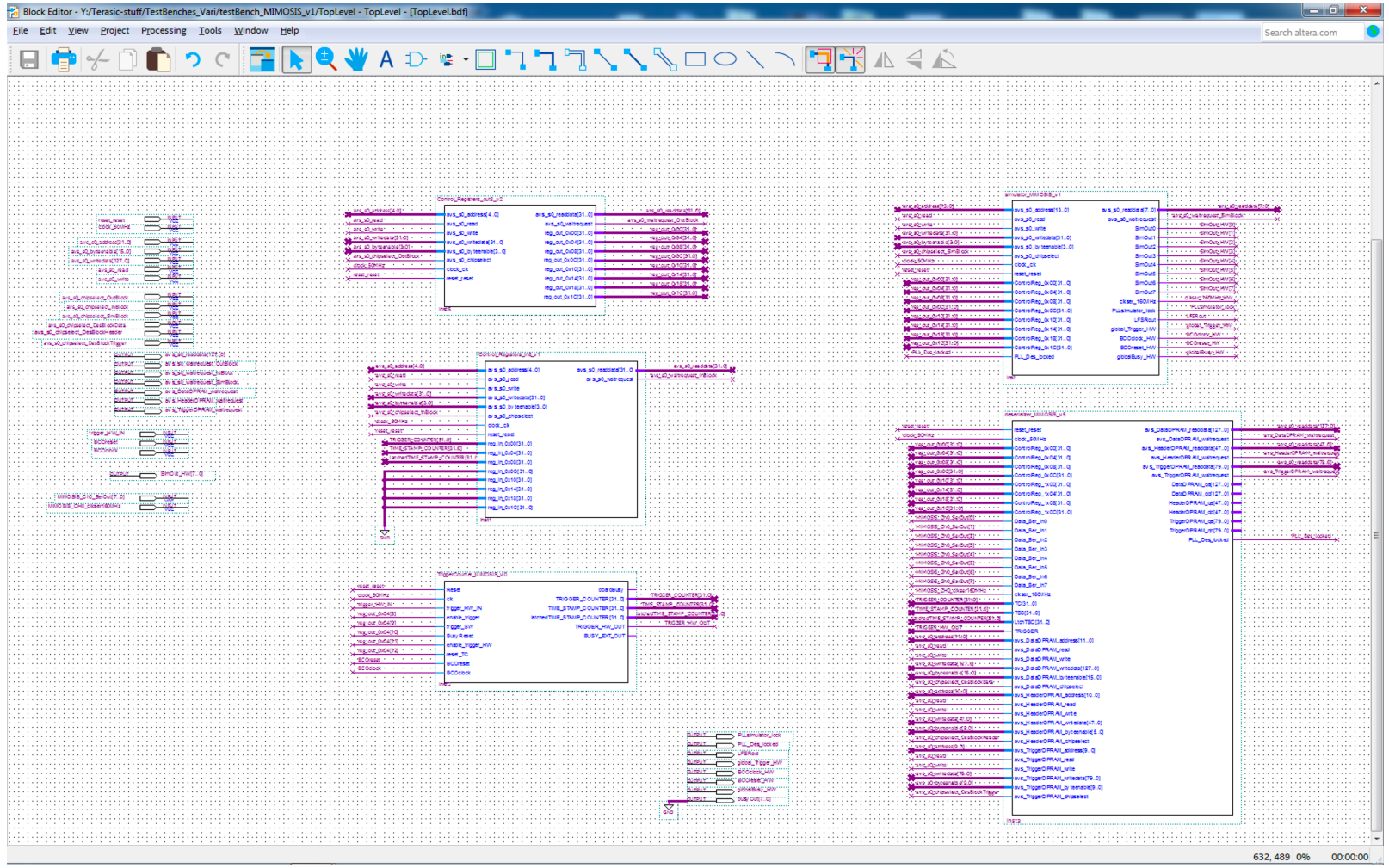


Mecahnical support

- New vertex mechanical support
- Automatic XY vertex movements implemented (to cover the 8x8cm IT area)
- XY actuator available and tested
- Finall mechanics under construction (almost finished)

New MIMOSIS monolithic pixel detector based FOOT Vertex detector status (PRIN HP-DMAPS)

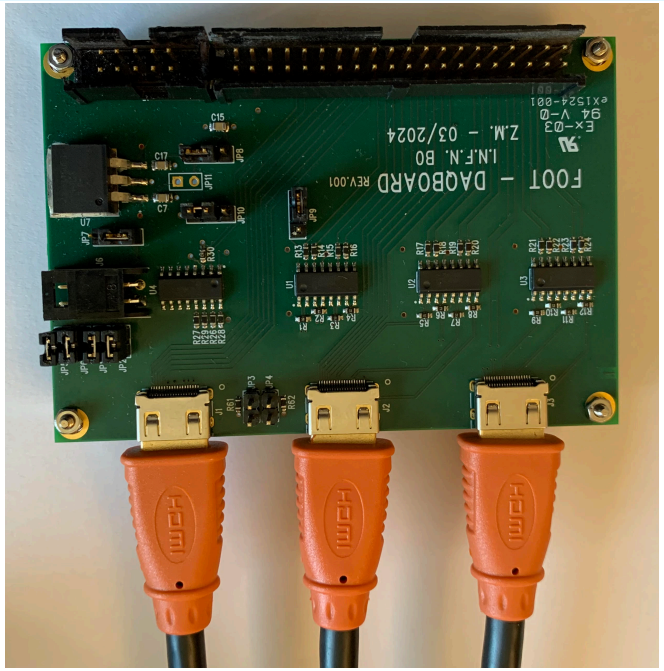
New readout firmware available (simulation seems to work)



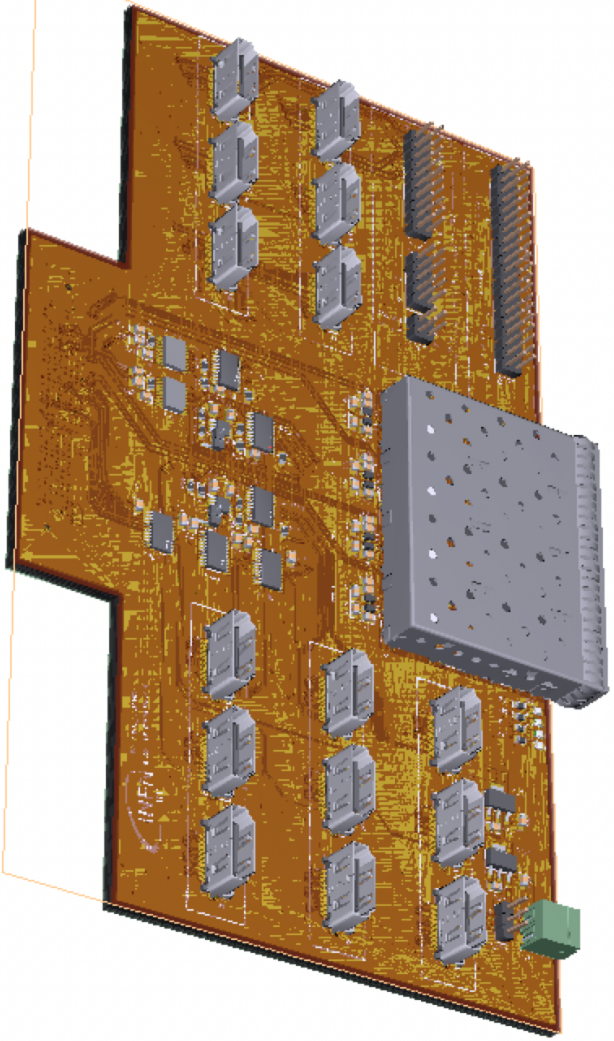
- New MIMOSIS readout firmware available
- Simulation works
- FPGA synthesis under way
- Firmware test start planned in one or two weeks
- One channel adapter board (designed and built in Bologna) available
- Up to five channels adapter boards (designed and ’produced’ in Frascati) under production
- New proximity card to be designed

New MIMOSIS monolithic pixel detector based FOOT Vertex detector status (PRIN HP-DMAPS)

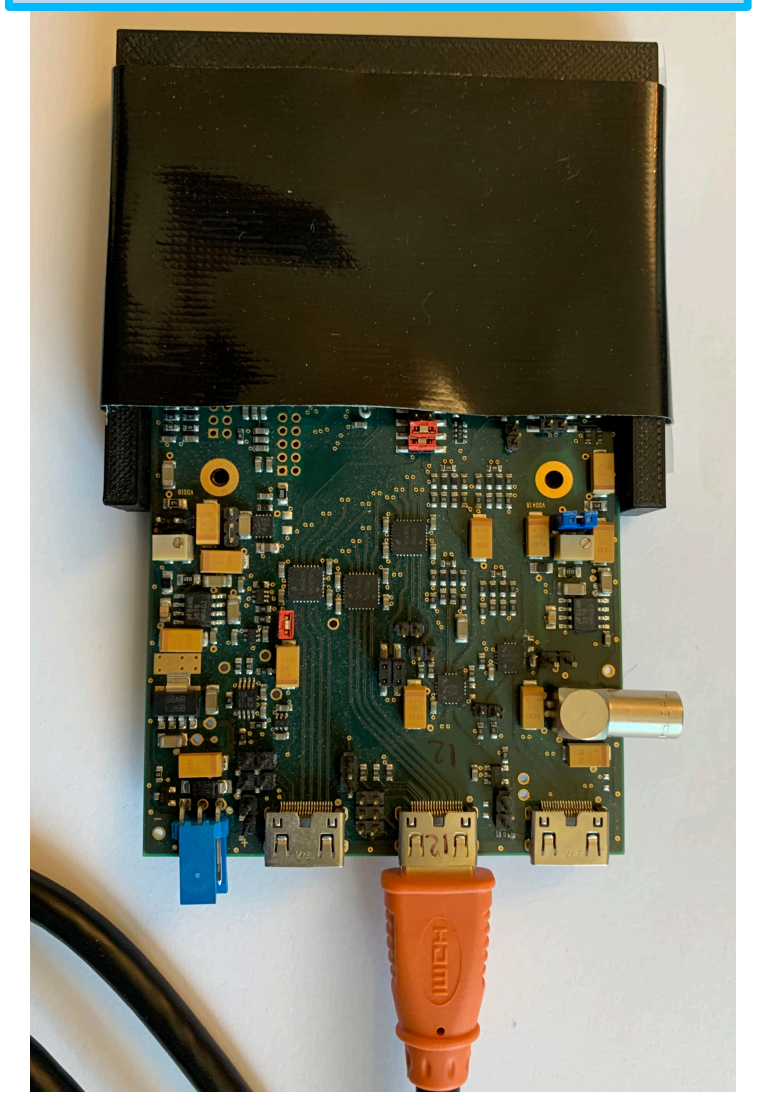
One channel adapter (Bologna)



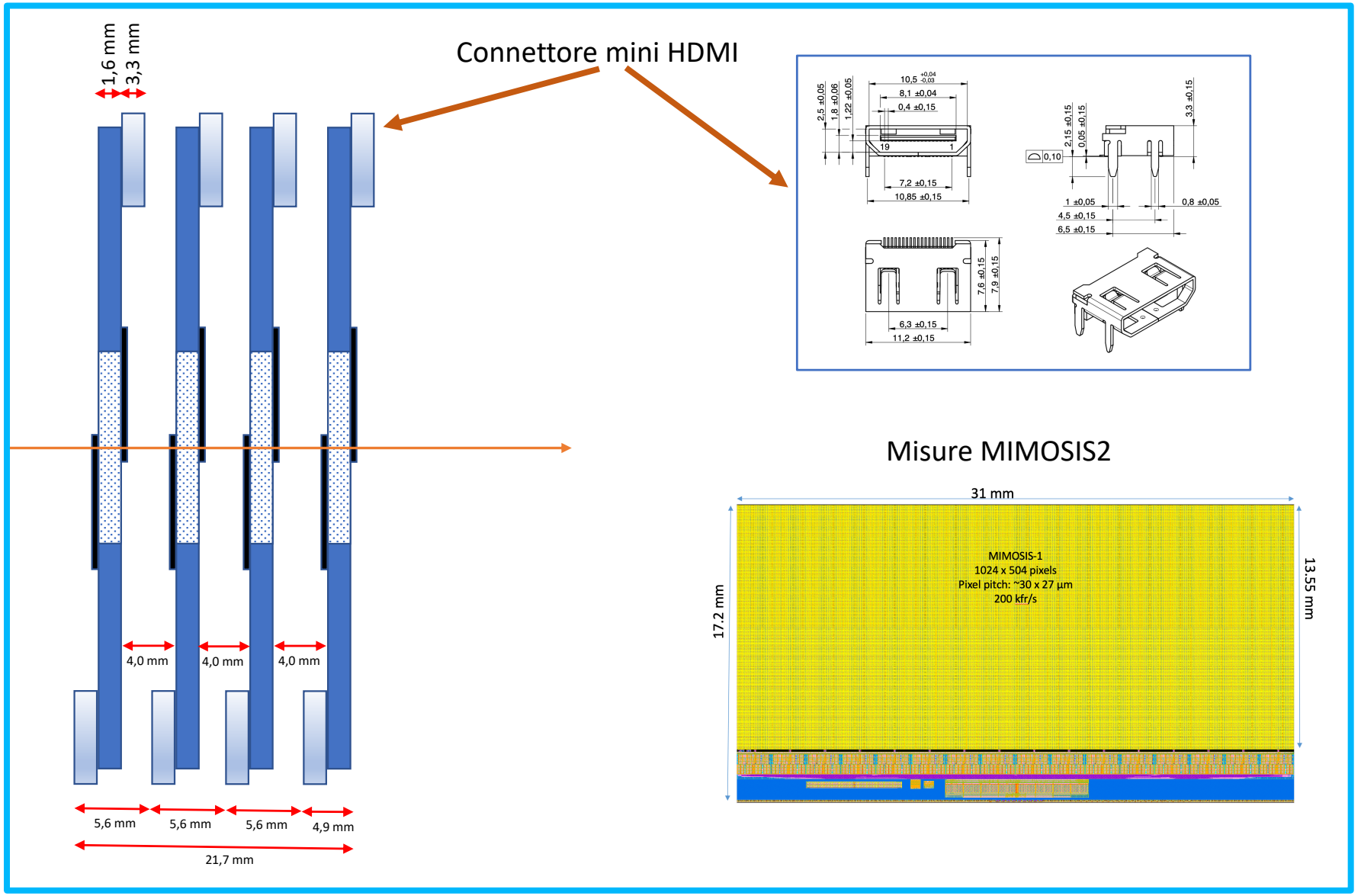
Five channel adapter (LNF)



Proximity MIMOSIS1/2 (@ LNF)

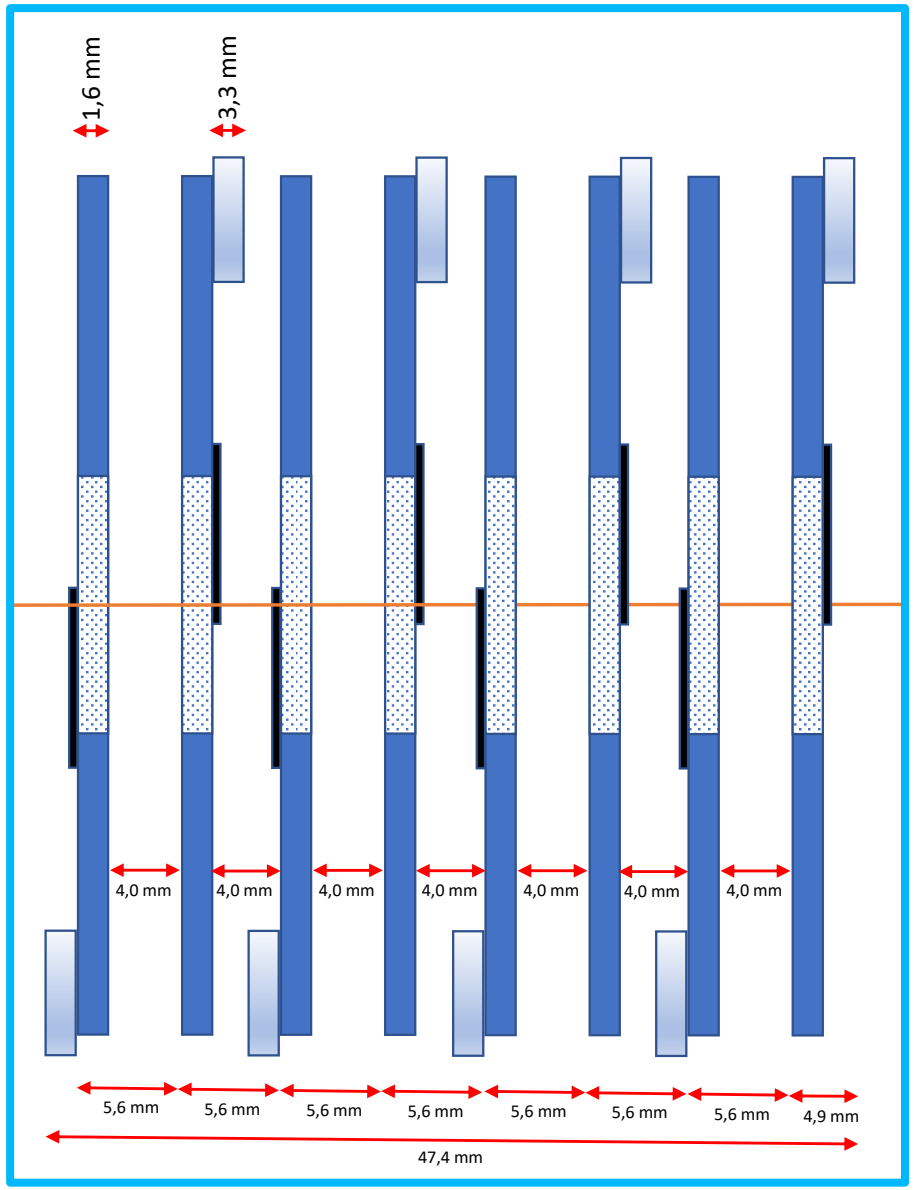


New MIMOSIS monolithic pixel detector based FOOT Vertex detector status (PRIN HP-DMAPS)



- Layout new MIMOSIS based Vertex (Version A - a la FIRST)
- Four proximity boards housing two sensors each
- Possible daisy configuration to accomodate 8 mm thick HDMI connectors
- Overall geometrical acceptance larger than Ultimate Vertex version

New MIMOSIS monolithic pixel detector based FOOT Vertex detector status (PRIN HP-DMAPS)



- Layout new MIMOSIS based Vertex (version B)
- Eigth proximity boards housing one sensors each
- No daisy configuration needed to accomodate 8 mm thick HDMI connectors
- Overall geometrical acceptance compatible with the Ultimate Vertex version

Version A length = 18,4 mm

Version B length = 40,8 mm

Comparison of the two solutions:

- Spatial resolution analytical mathematical calculation by **Marco Toppi** under way
- GEANT/Fluka models (ready to be used) by **Christian Finck**.

New MIMOSIS monolithic pixel detector based FOOT Vertex detector status (PRIN HP-DMAPS)

Conclusions

- HP-DMAPS (2 years project) **started october 2023**
- Funds available end 2023
- Order adapter five channel under preparation
- MIMOSIS2 proximity board for FOOT Vertex will start as soon as CAD will be again available at INFN
- Firmware under development (on track)
- Slow control firmware software (I2C) under development in Bologna
- Strasbourg group ready to assemble new FOOT Vertex proximity boards (sensor bonding)
- MOU ready to be signed ('small' difficulties with NDA)
- New proximity development (not difficult) stil has to start (**possible bottleneck**)
- DAQ software architecture to be copied by the existing one (should not be a problem)
- END of PRIN autumn 2025 (schedule coherent with this time scale)