Status of FOOT pixel tracker detector

1. Last december 5th 2017 Bologna FOOT GM slide
2. Overview of the FOOT tracker mechanical setup
3. Status of the Pixel Vertex detector
   - Venelin Kozhuharov talk at PADME meeting
4. Magnet system
5. Status of the Inner Tracker pixel detector
   - Options and main parameters
6. A proposal to improve the pixel tracker max rate
7. Conclusions

Status of FOOT pixel tracker detectors

Conclusions

Let’s check at the La Biodola shore where we will stand???

05/12/17 E. Spiriti (FOOT GM - Bologna) 20

FOOT tracker mechanical setup

Main characteristics needed

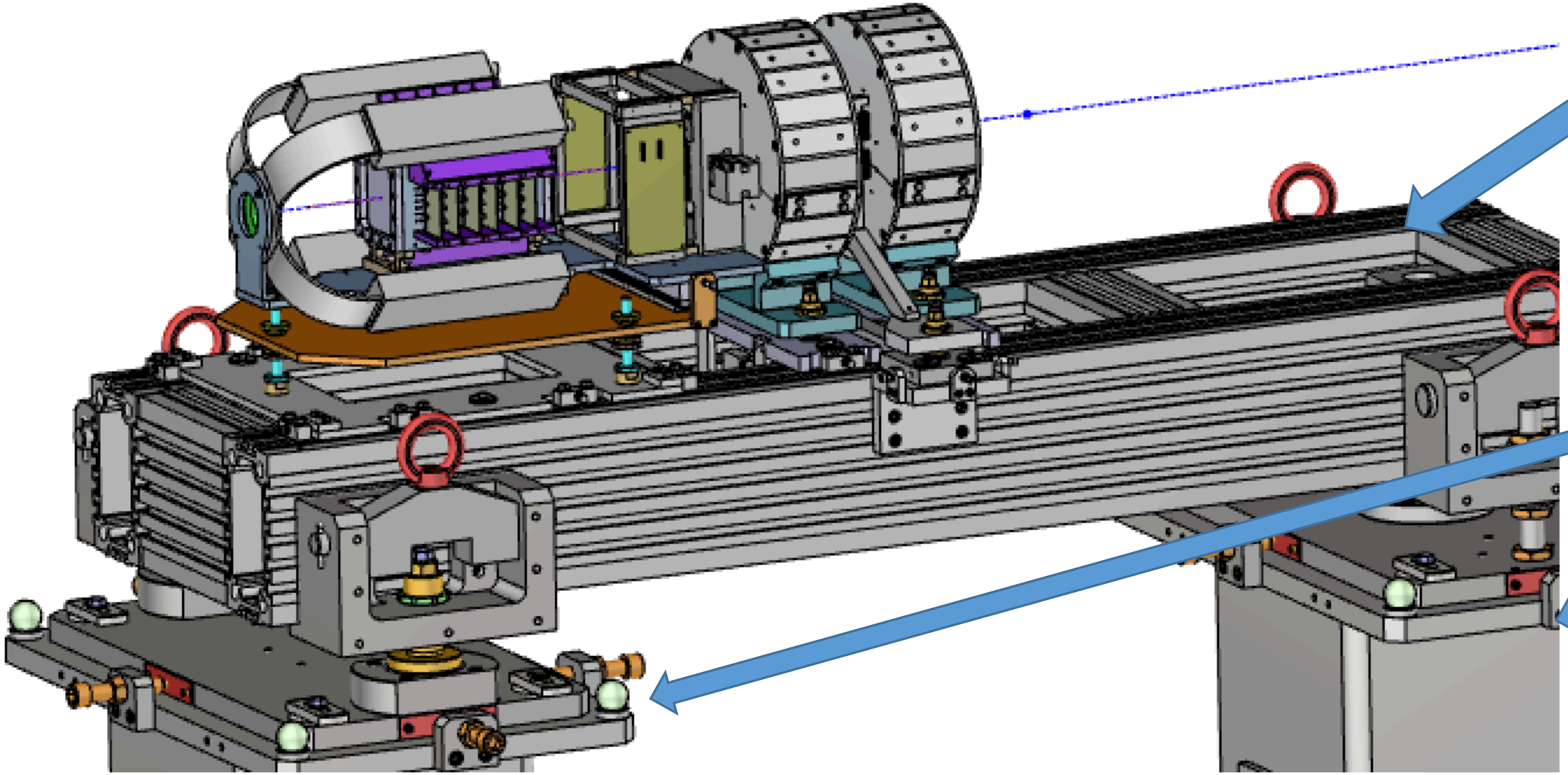
- Relatively small dimensions (table top experiment)
- Portable
- Stable (also during transportation) support for micrometer precision tracker
- Flexible for magnets dismount for alignment of detector
- Reasonable cost

Previous project solution reutilization

ELI-NP support to transport LINAC elements

- Girder structure with new dimensions
- Mechanical suspensions for transportation
- Similar mechanical structure for holding and packing
- Mechanical support with different possible heigths to be designed

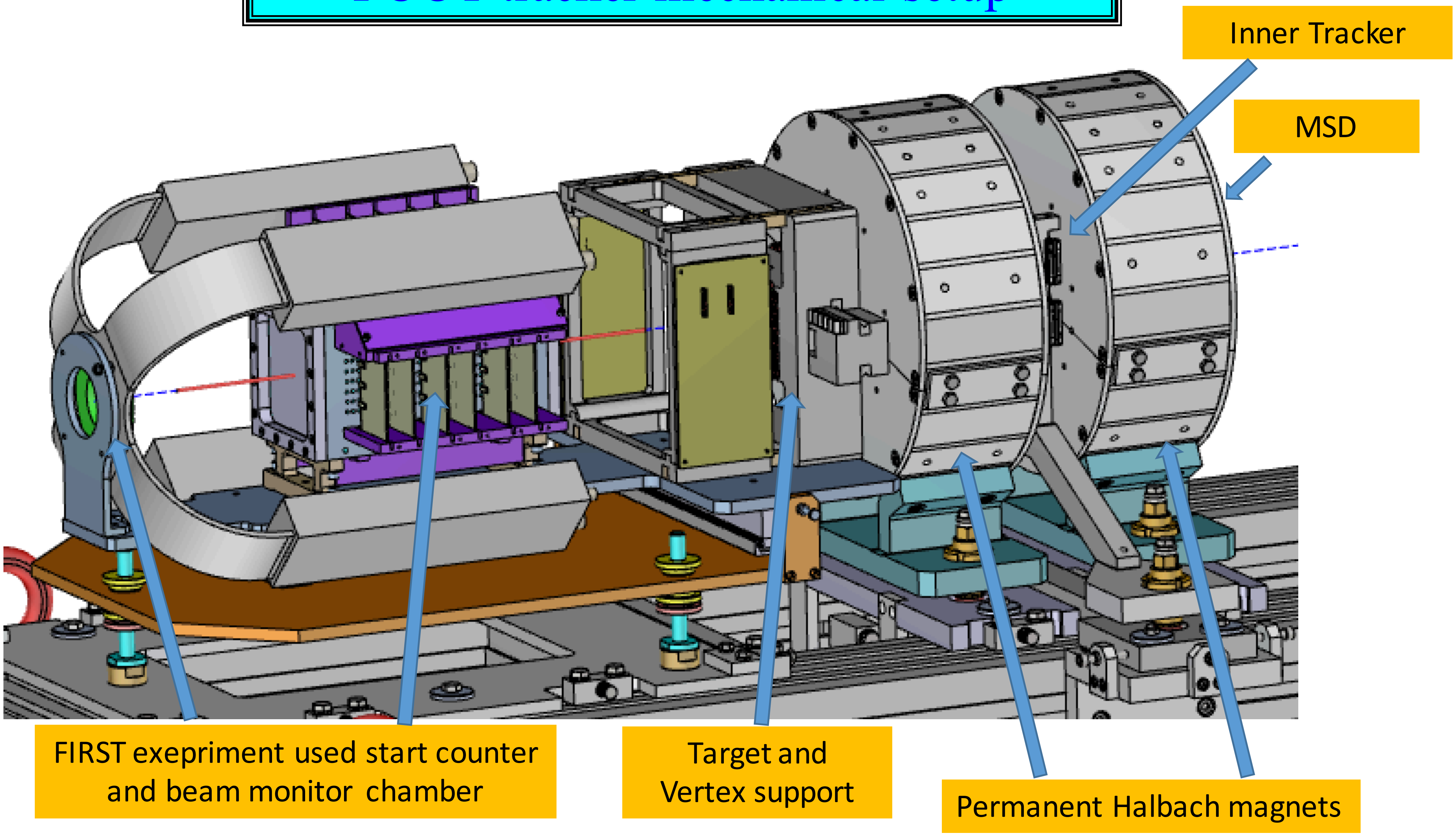
FOOT tracker mechanical setup



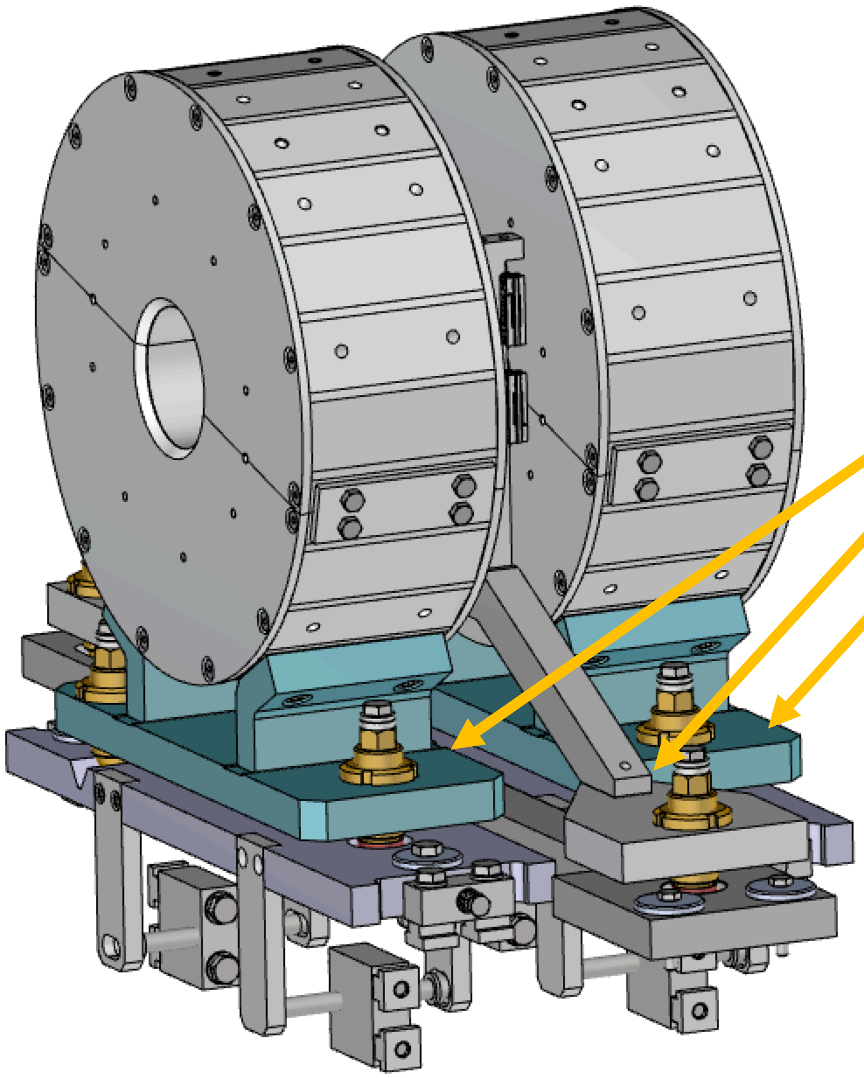
Girder easy to redesign

Support structure (different heigth selectable) under design

FOOT tracker mechanical setup



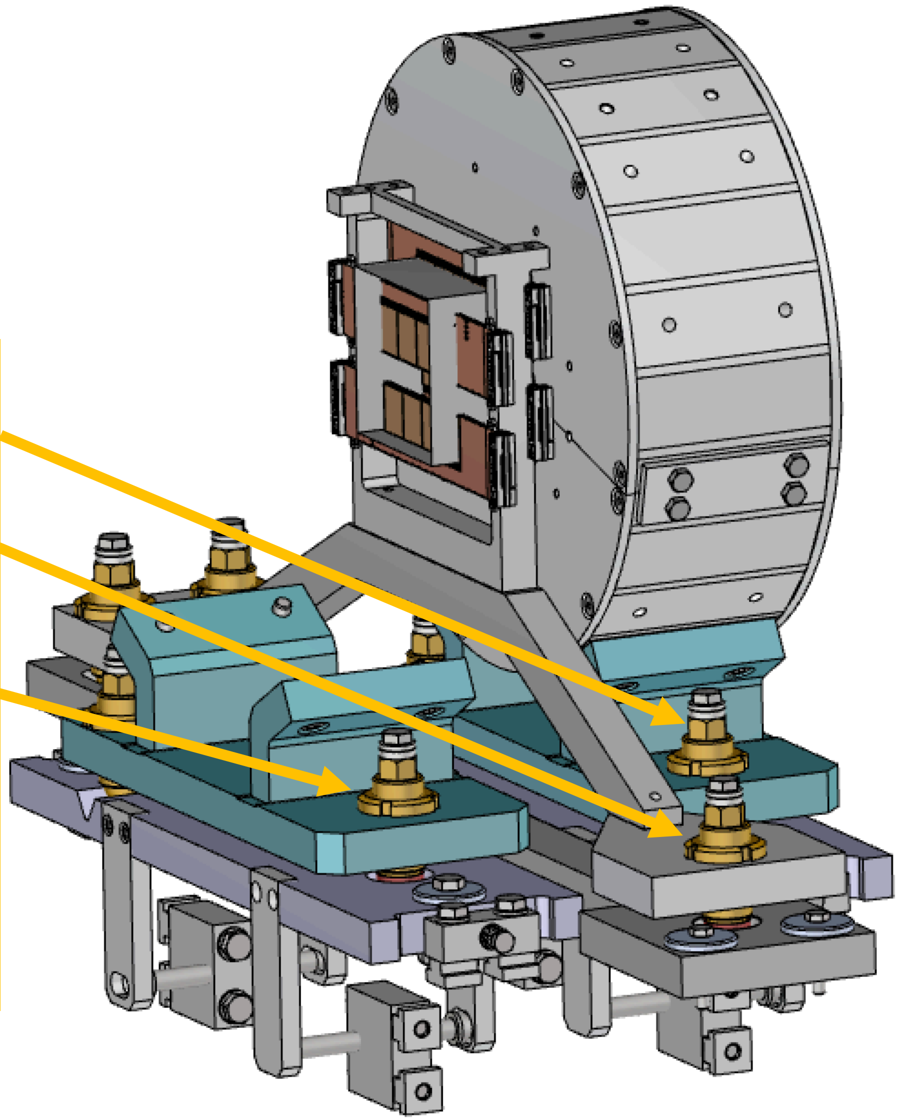
FOOT tracker mechanical setup



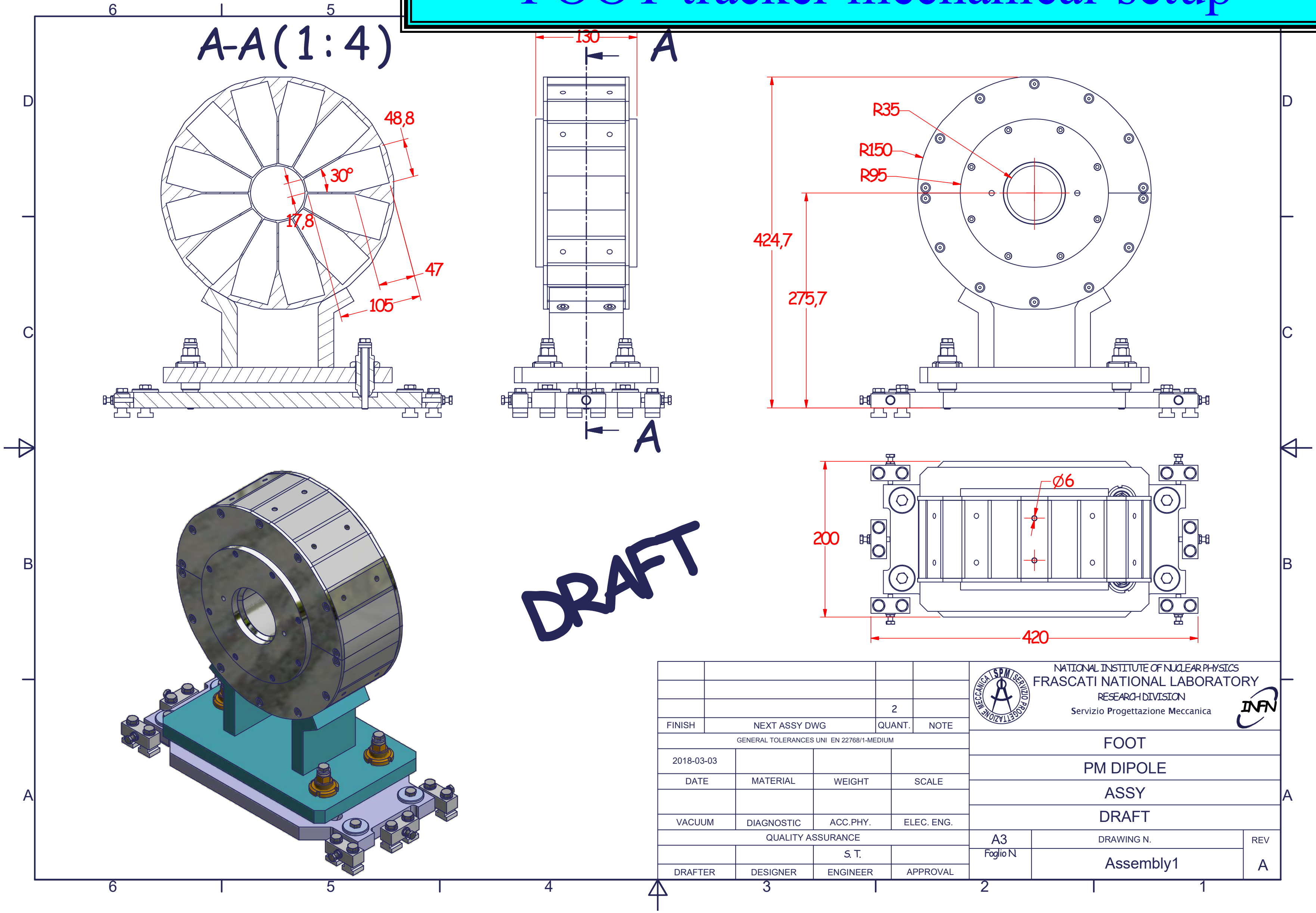
Six degree selectable orientation systems, one per each element:

- first magnet
- Inner Tracker
- second magnet
- MSD

Independently removable

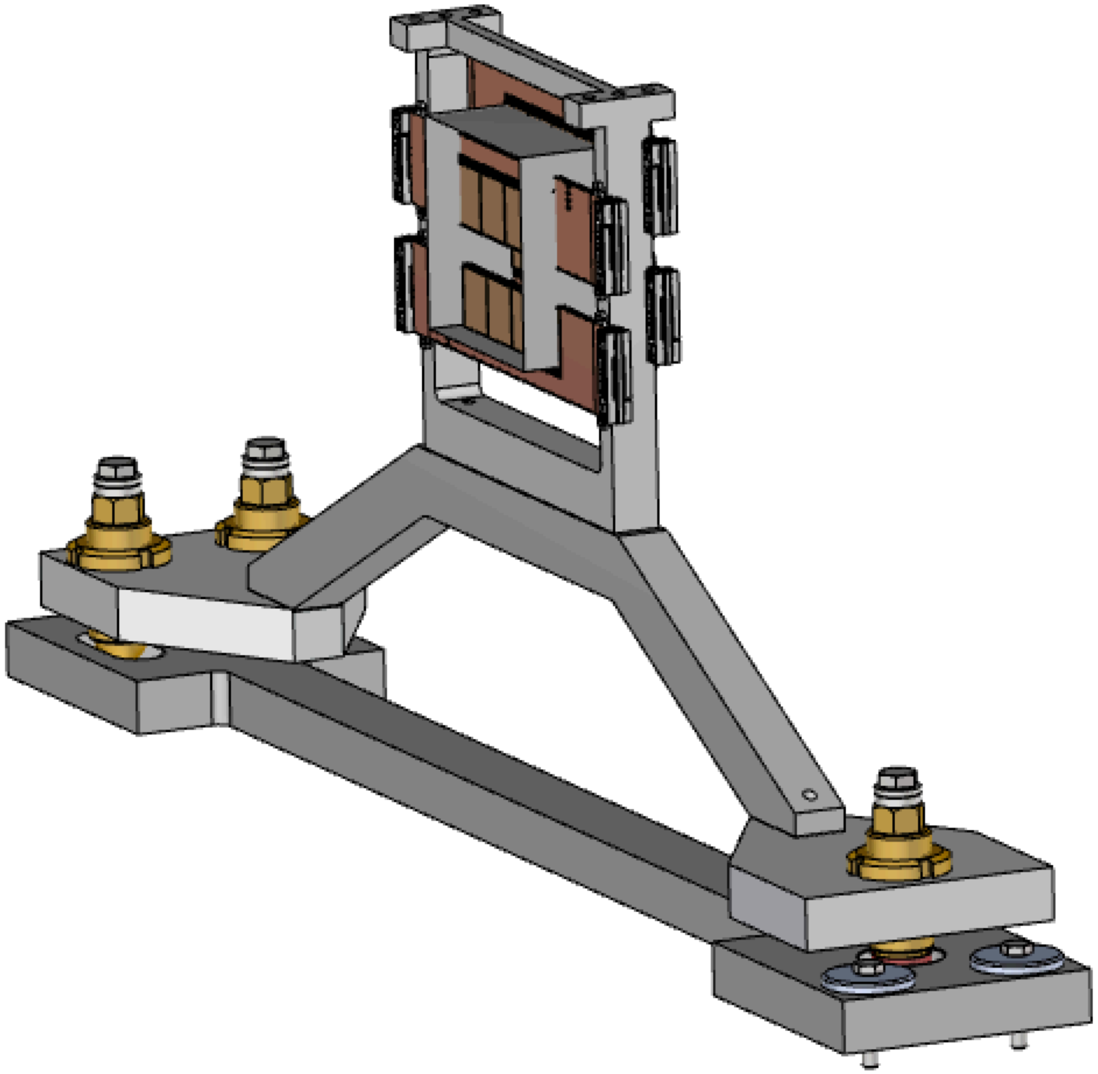


FOOT tracker mechanical setup



Draft of the drawing for the magnets bid.

FOOT tracker mechanical setup



Status of the Pixel Vertex detector

The following slides are a presentation by **Venelin Kozhuharov** at the may 25th PADME meeting

PADME (Dark matter searches at the Frascati BTF - Beam Test Facility) will use a Mimosa28 pixel sensor vertex detector (four planes) thinned to 50 µm to monitor the beam profile and multiplicity.

Only, not trivial, difference with the FOOT vertex is that it will be operated in vacuum!
The main difficulty is the heat (M28 dissipate about 0.7 Watt) removal.
The results of the first test of the M28 (never done before) in vacuum is presented.

PADME

Venelin Kozhuharov
may 25th PADME meeting

Thermal dissipation test of MIMOSA sensor

C. Capoccia, V. Kozhuharov, E. Spiriti

LNF–INFN, University of Rome „La Sapienza, Sofia University*

25.05.2018

СВ. КЛИМЕНТ ОХРИДСКИ

SAPIENZA
UNIVERSITÀ DI ROMA

INFN
LNF
Istituto Nazionale di Fisica Nucleare

ФОНД
НАУЧНИ
ИЗСЛЕДВАНИЯ
МИНИСТЕРСТВО НА ОБРАЗОВАНИЕТО И НАУКАТА

** partially supported by BG NSF, DN08-14/14.12.2016 & LNF-SU 70-06-497/07-10-2014*

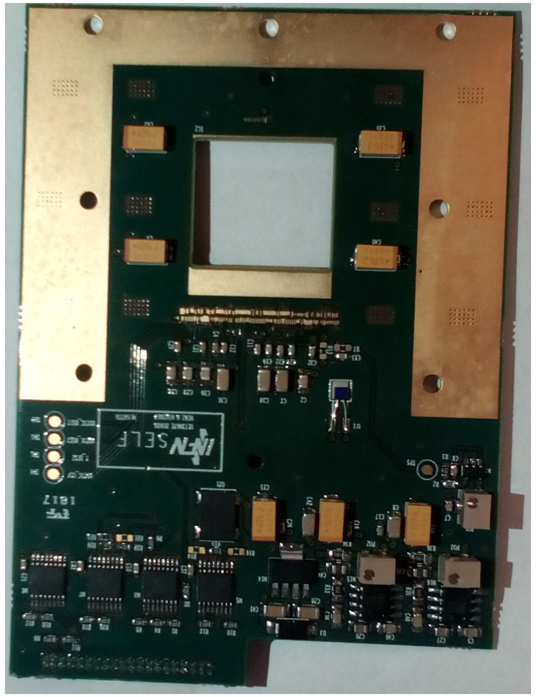
Recall from last week

Venelin Kozhuharov
may 25th PADME meeting

- MIMOSA initial thermal checks in air performed – sensor temperature ~37° C
- Using FLIR 335 IR camera, thanks to Fabio Ferrarotto and LABE, Roma 1
- Attempt to use the on-chip diode to monitor the temperature change - successful
  - Open anode diode realized in the Si substrate
  - However, cathode is connected to the "ground"
  - Measure the voltage, necessary to induce current of 100 μA
  - Dependence V-T observed, but influenced by the operational status of the chip (off, initialized, running)
    - Induced by the shift of the "ground" potential when changing the power state
- A manometer found and attached to the chamber (after some machining) for rough pressure control (~0.05 bar resolution)

Thermal dissipation

Venelin Kozhuharov
may 25th PADME meeting



- MIMOSA chip power consumption – of the order of 0.7 W
- Three paths for thermal dissipation
  - Thermal conductance
  - Dissipation through air
  - Radiation
- Which one is the dominant for the MIMOSA chip?
- Radiation:
  - 2 cm x 2 cm surface (x 2, up and down)
  - Emission: $P = 2*S*\sigma T^4 = 0.4$ W @ 40° C
  - But also absorption from the nearby surroundings, so a better estimator is $\Delta(T^4)$ $\Rightarrow$ 140 – 180 mW, depending on temperature (0 – 10 degrees C)
  - Not bad as a start, but the thermal conductance is clearly necessary and **critical** for the MIMOSA cooling, or the chip will go above 100° C
    - Also because the radiative value would be for the two chips together, since they are looking at each other with one of the surfaces….

Mounting MIMOSA

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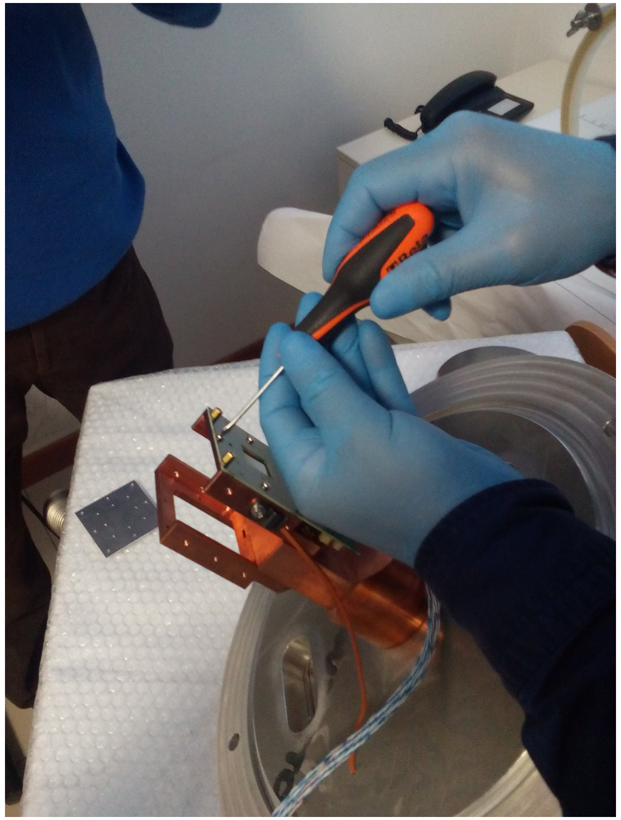
may 25th PADME meeting

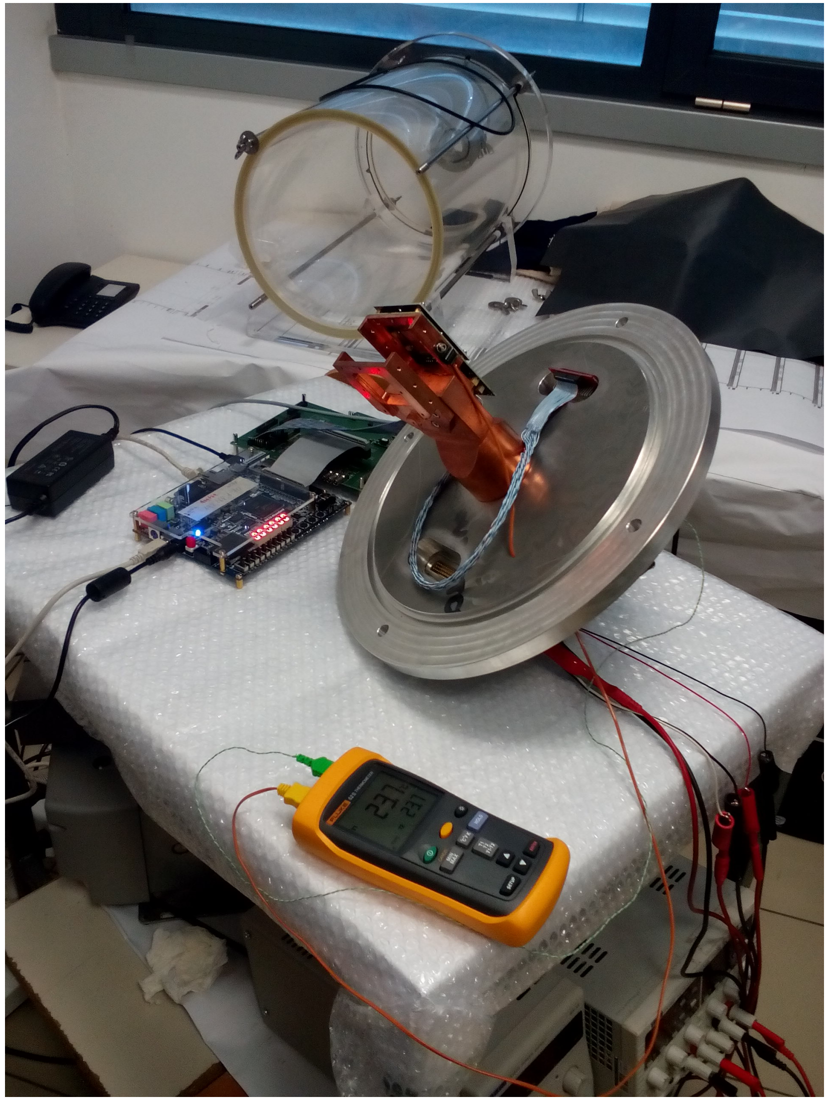


- Carefully attached to the copper support frame
  - Note: chip is only 50 µm thick!
  - The protective metal plate was placed on top
  - Surfaces were cleaned with alcohol

MIMOSA in air

Venelin Kozhuharov
may 25th PADME meeting

- Using the Peltier cooler, attached to the copper arm
- Goal of the test: to see if and how the sensor follows the temperature on the copper arm
- Measuring:
  - Temperature on the inner part of the copper arm - T_{IN}
  - Temperature of the outside part of the arm (close to the Peltier) - T_{OUT}
  - Temperature of the hottest part of the sensor (using the thermocamera) - T_{MIMOSA}
  - The voltage on the on-chip diode (100 μA current generator applied) - **U**



MIMOSA in air

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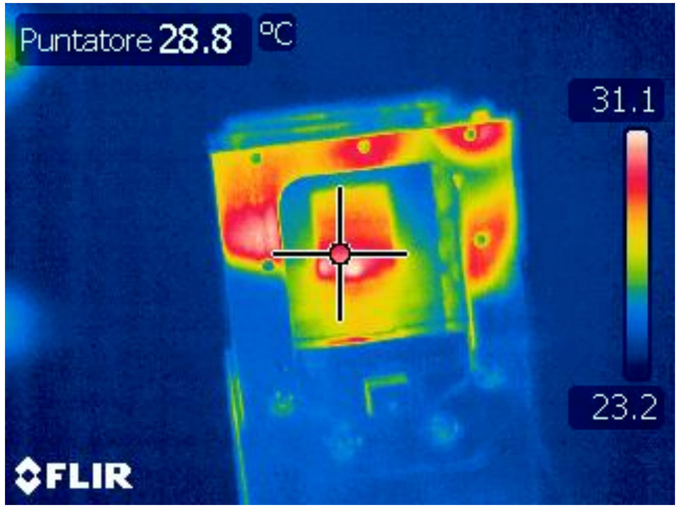
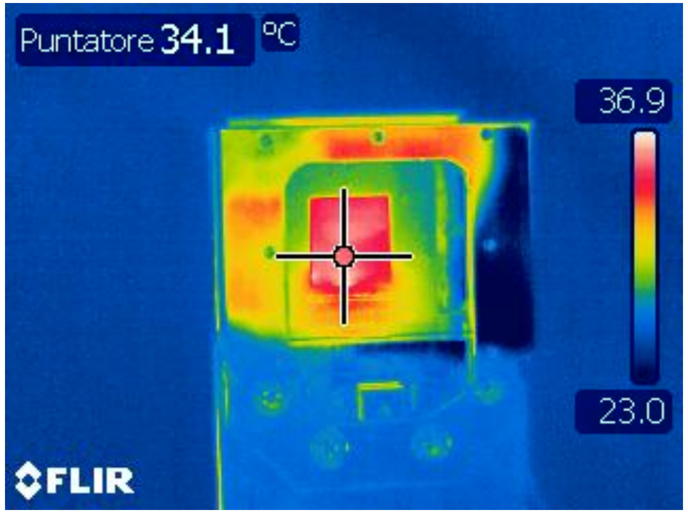
MIMOSA initialized



MIMOSA ON



- Reaching stable running condition (thermal equilibrium) @ 37° C
  - As expected
- Diode voltage: 854 mV
- Temperature in the room (and of the copper bar) ~24° C

Next step: switch on the Peltier

MIMOSA in air

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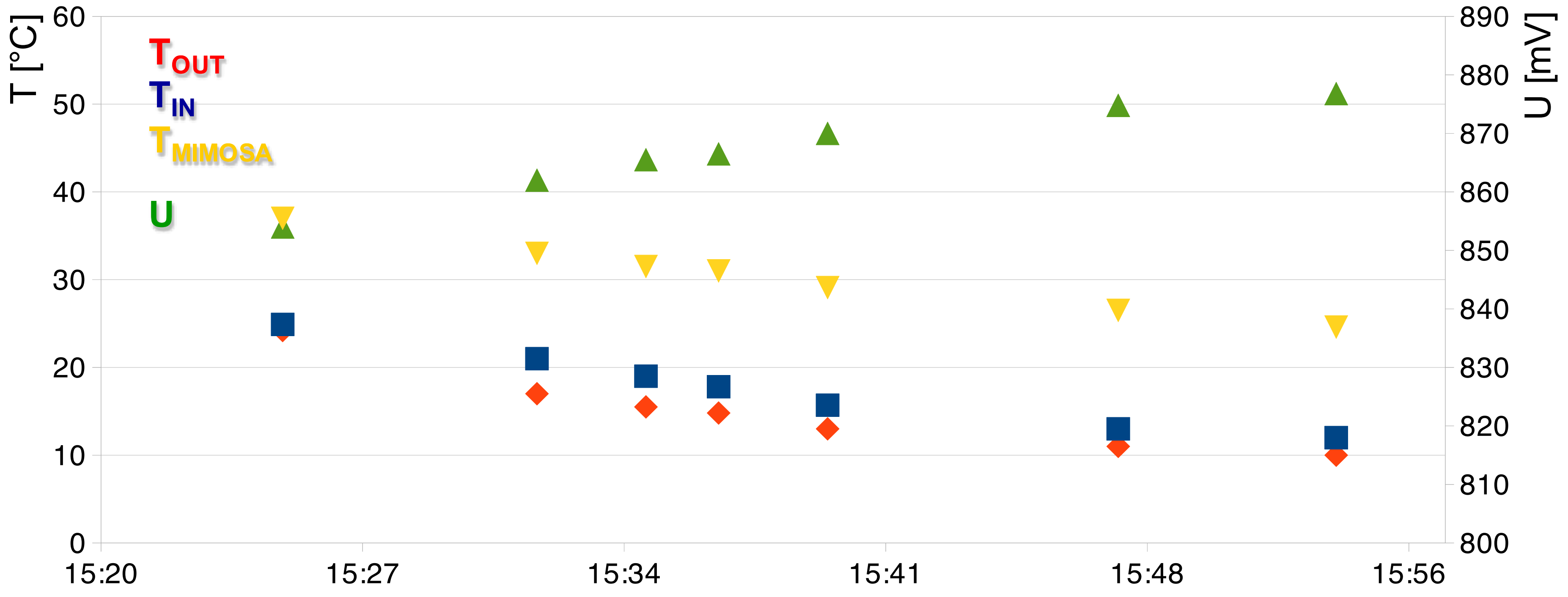
may 25th PADME meeting



- MIMOSA chip temperature followed the temperature on the copper bar!
- The copper bar went into equilibrium at about 12 degrees (and got condense…)
- About 30 min necessary for the system to stabilize
- Temperature of the chip equalized with the ambient air temperature (gas started to warm the chip)

MIMOSA in air

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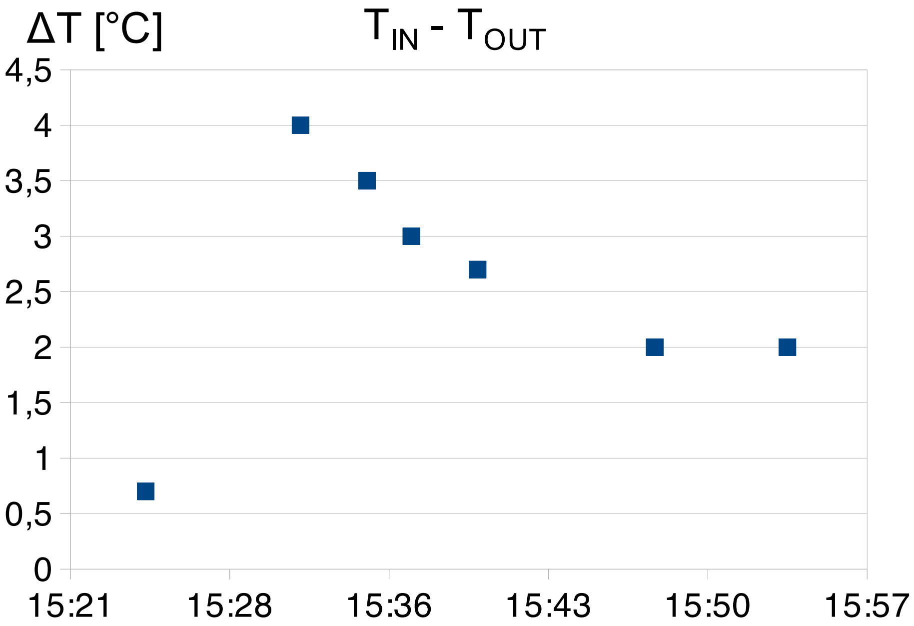
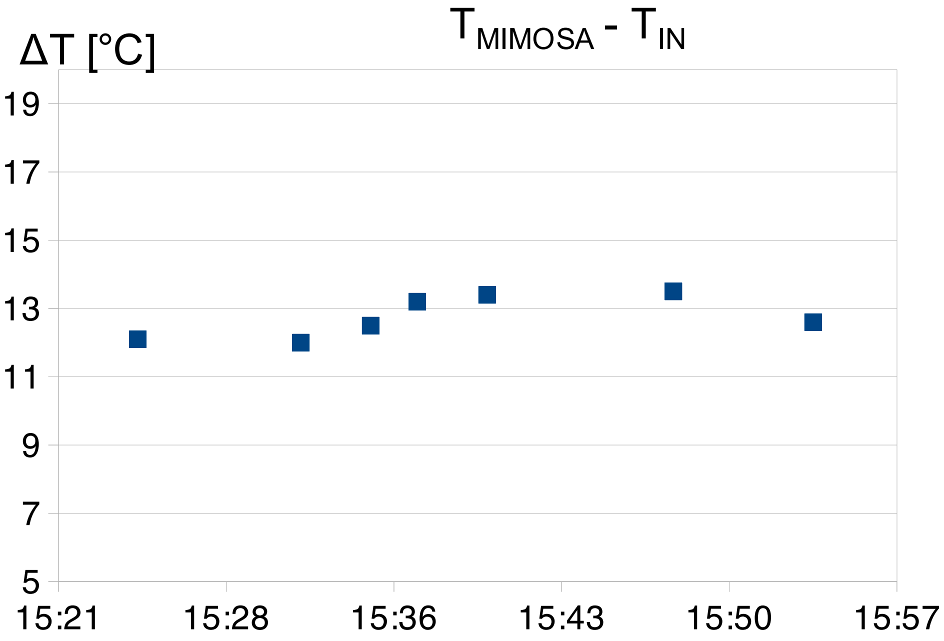
may 25th PADME meeting





- After the initial jump (when switching on the Peltier) the temperature difference stabilized (indication of equilibrium)
- The MIMOSA temperature was within ~12-13 degrees above the copper temperature!

Temperature calibration

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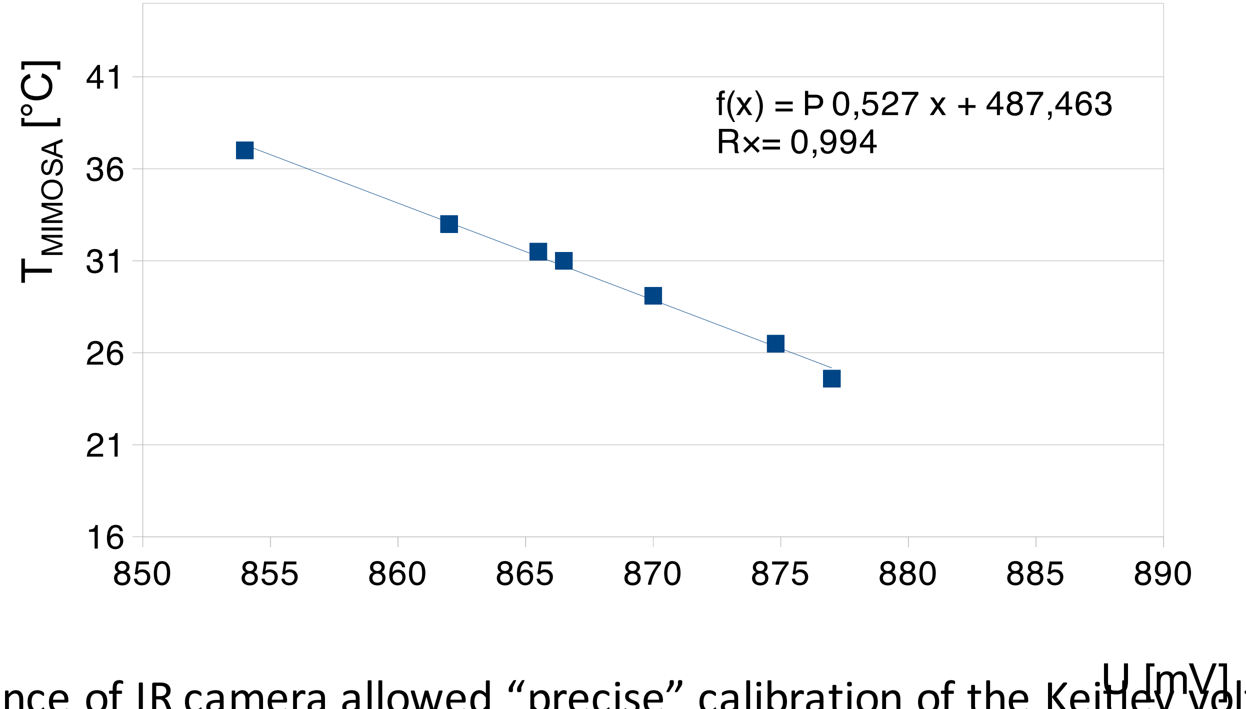
may 25th PADME meeting



- The presence of IR camera allowed "precise" calibration of the Keitley voltage measurement → Chip temperature
- The curve is very much close to linear with slope of 0.53°C per mV
  - Gave optimism that we can actually have a temperature information for the MIMOSA chip in vacuum!
  - NOTE: calibration is unique to the setup, if something changes, the calibration should be repeated!

MIMOSA in vacuum

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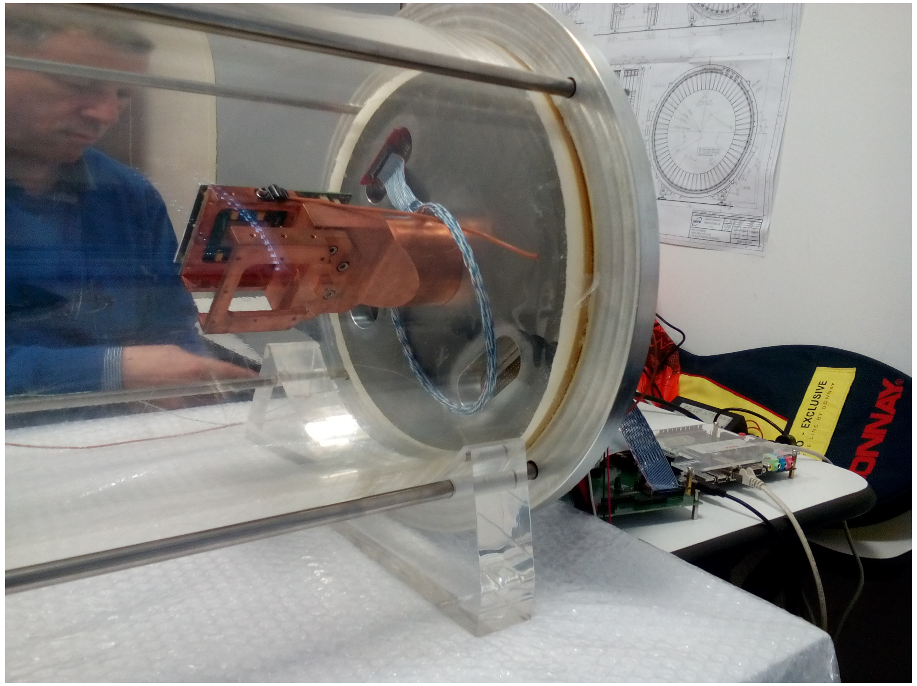
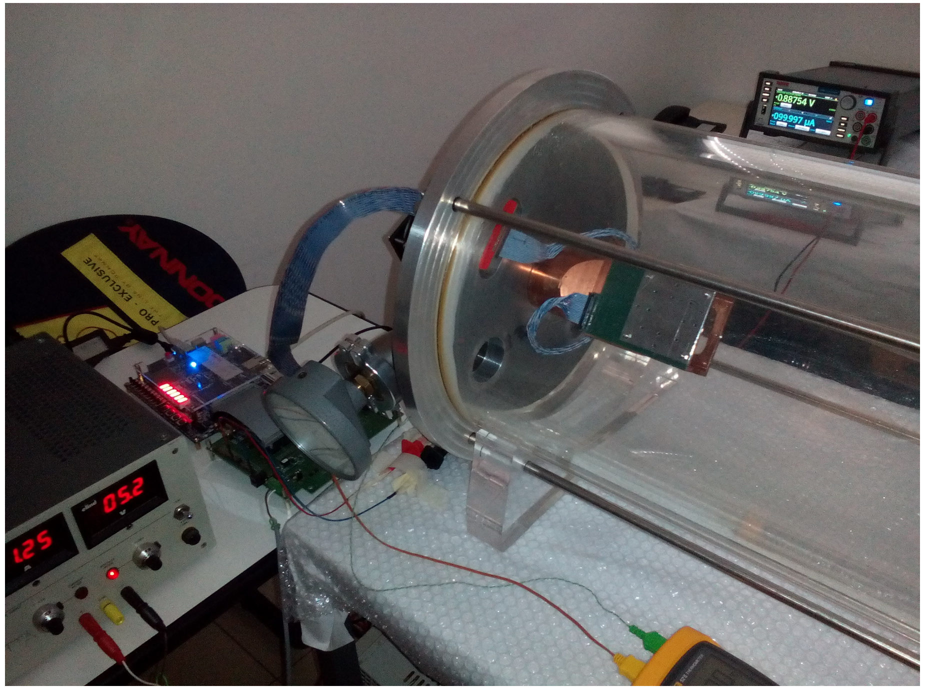
may 25th PADME meeting

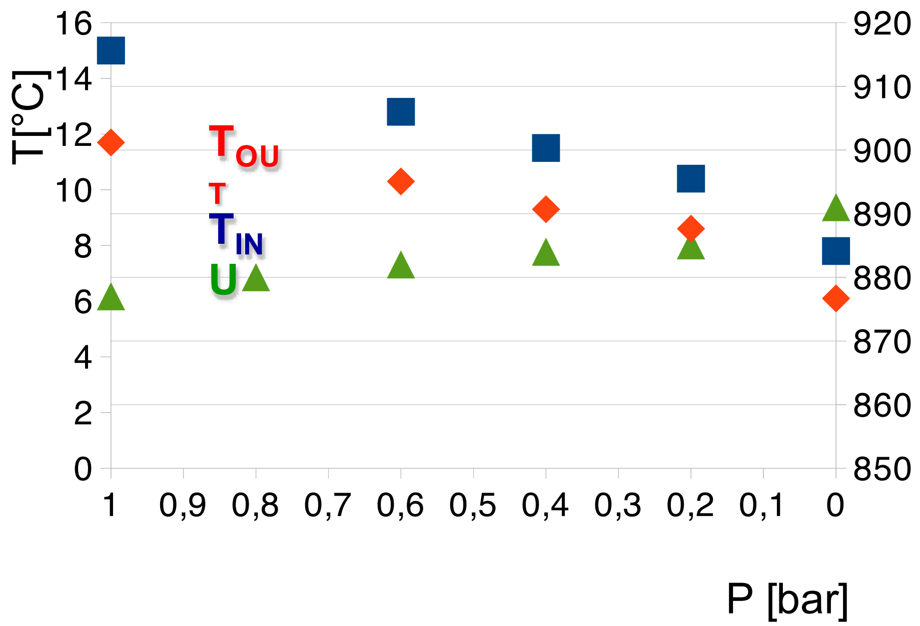




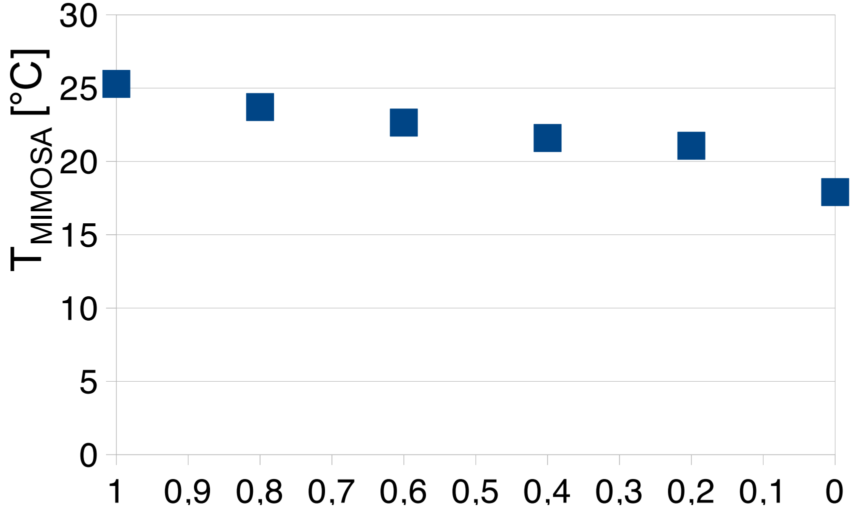
- Two rounds of evacuation of the chamber performed
  - First to remove the condensation from the in-air test
  - Second, step evacuation – the nominal test of MIMOSA
- With a lot of optimism due to the very good results from in-air test

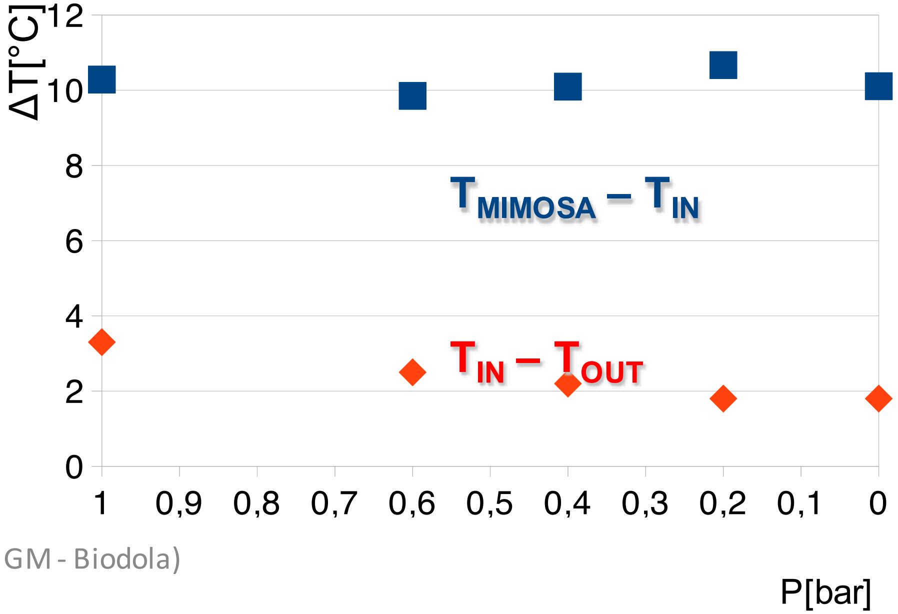
MIMOSA in vacuum

Venelin Kozhuharov
may 25th PADME meeting



- The calibration of the U_{DIOD} allowed to follow the temperature
  - The chip stayed cool during the tests
  - Difference chip – copper ~ 10°C
  - Difference IN – OUT: ~ 2°C (an indication of the thermal flow)





Conclusions

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may 25th PADME meeting

- The test of the MIMOSA thermal dissipation in vacuum performed
  - After the necessary and very important preparatory work
- The internal diode, if properly calibrated, is extremely useful for the knowledge of the operating conditions
- The thermal dissipation through the
  chip → 3 mm wide thermal contact with PCB → PCB metal strips →
  copper bar → Peltier
  is more than adequate solution for MIMOSA
- The work performed on the MIMOSA support and the PCB design and manufacturing is really wonderful
  - Congratulations to the mechanical and electronics services employed in the design of the system

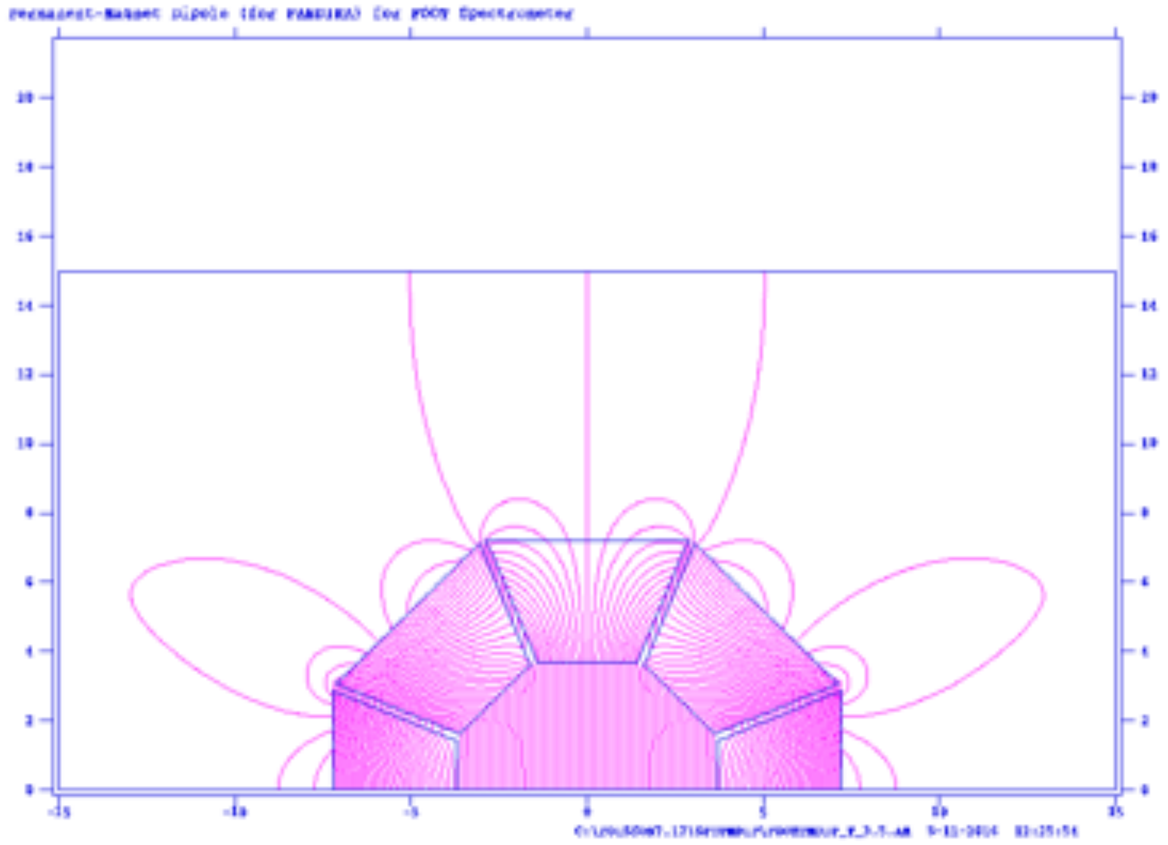
MIMOSA works in vacuum and it works very very well :)

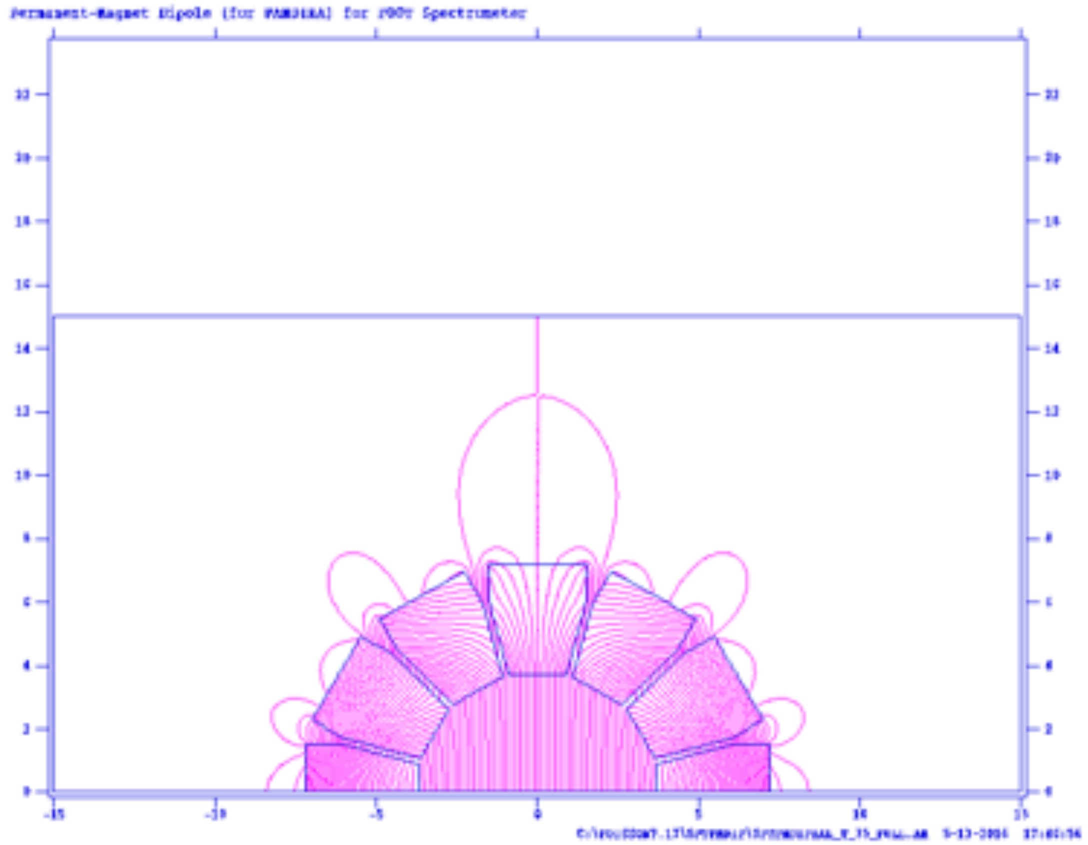
for the first time!

The FOOT tracker magnetic region

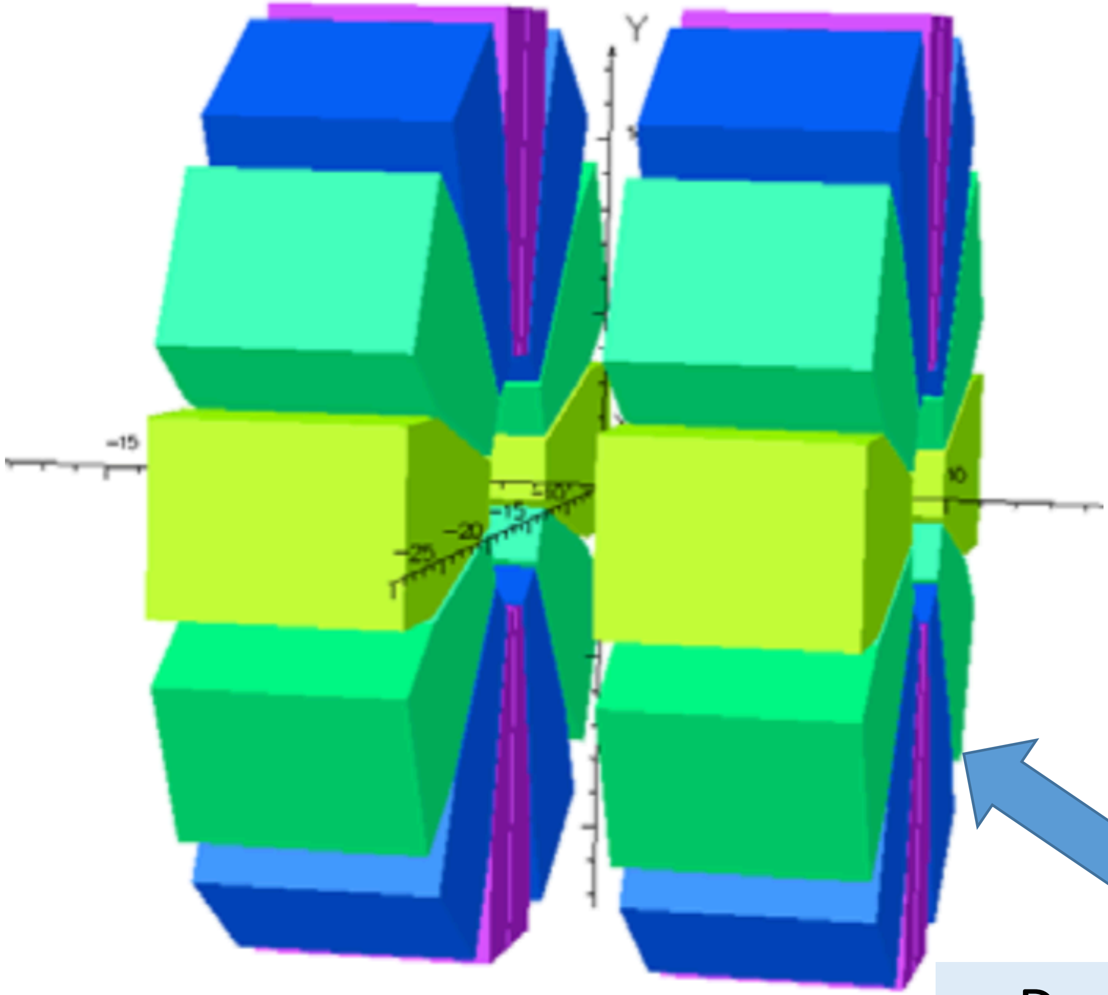
Initial design: C.Sanelli, “Studio di fattibilità dei magneti in configurazione “Halbach” dello spettrometro dell’esperimento FOOT”, **INFN-17-10/LNF**

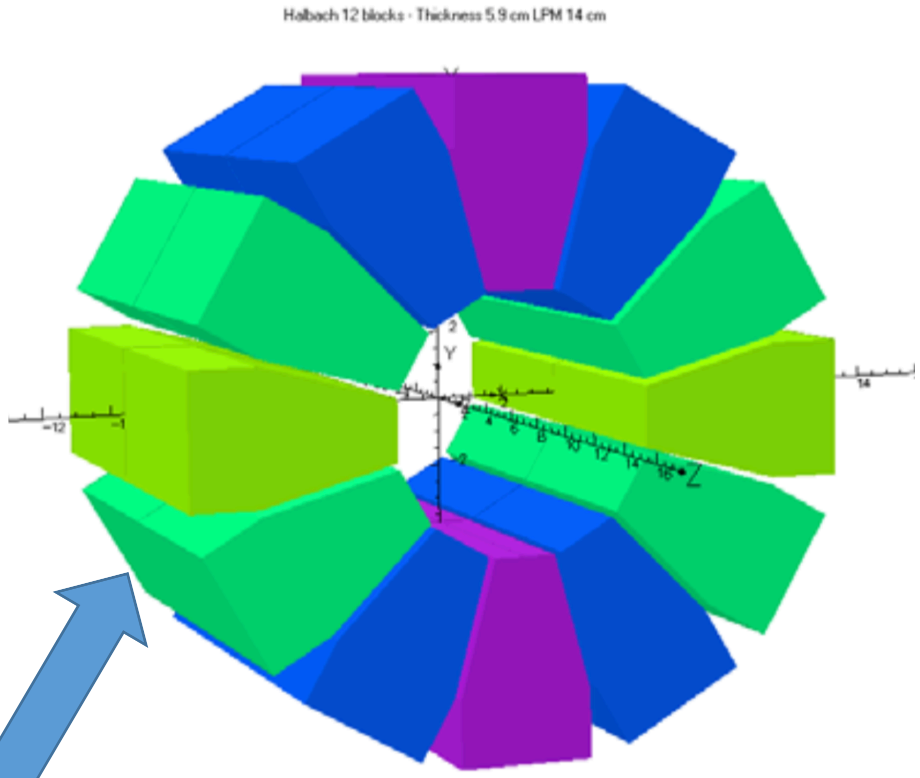
Halbach permanent magnet configurations - Transversal dipole magnetic field in the 8 and 12 single Permanent Magnet Hallbach configurations





The FOOT tracker magnetic region

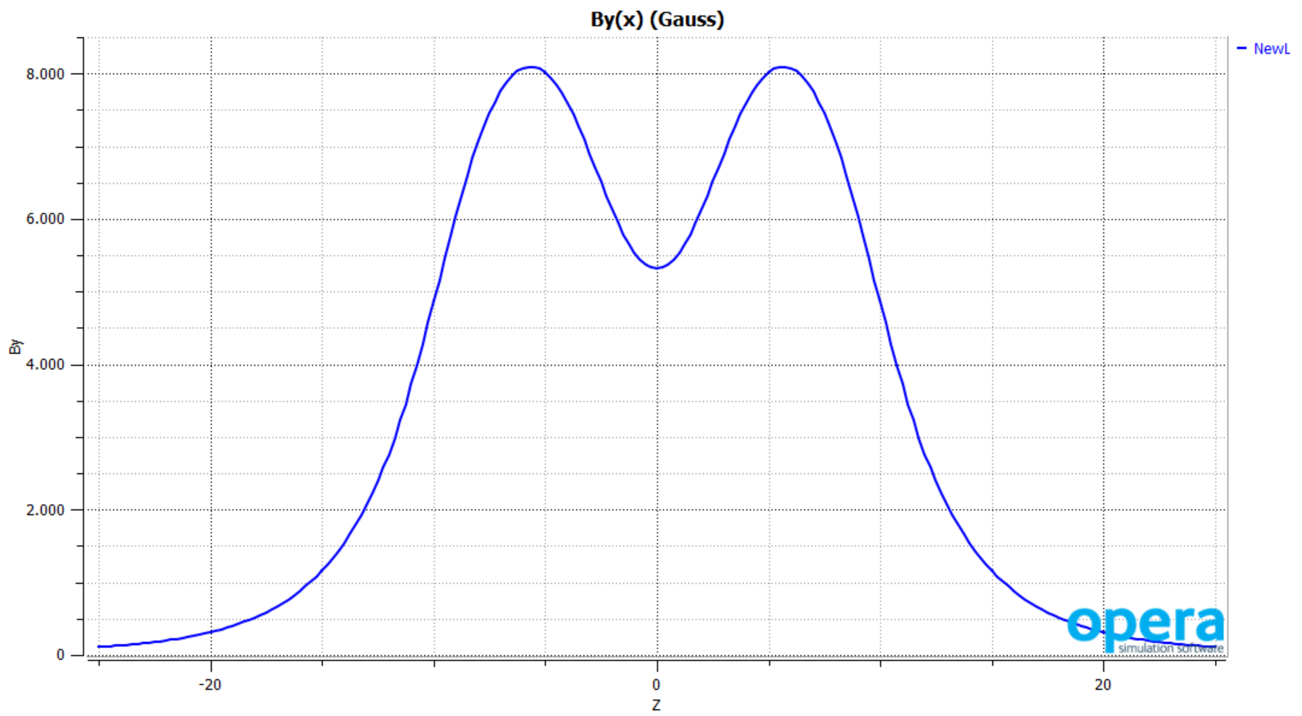




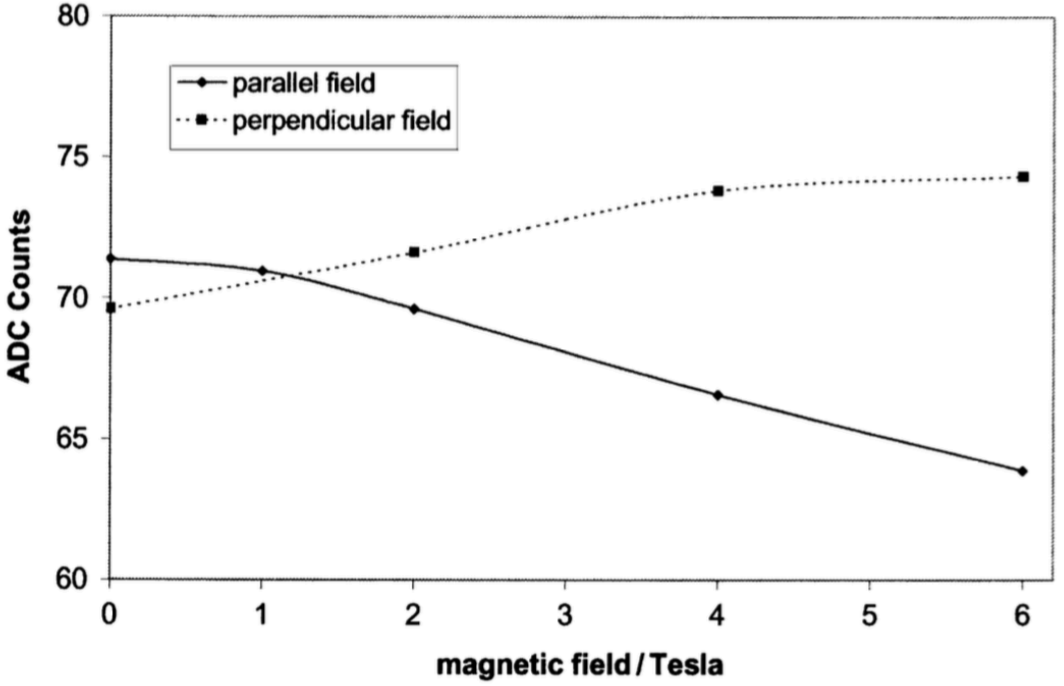
Halbach configuration

Double magnet structure

The FOOT tracker magnetic region

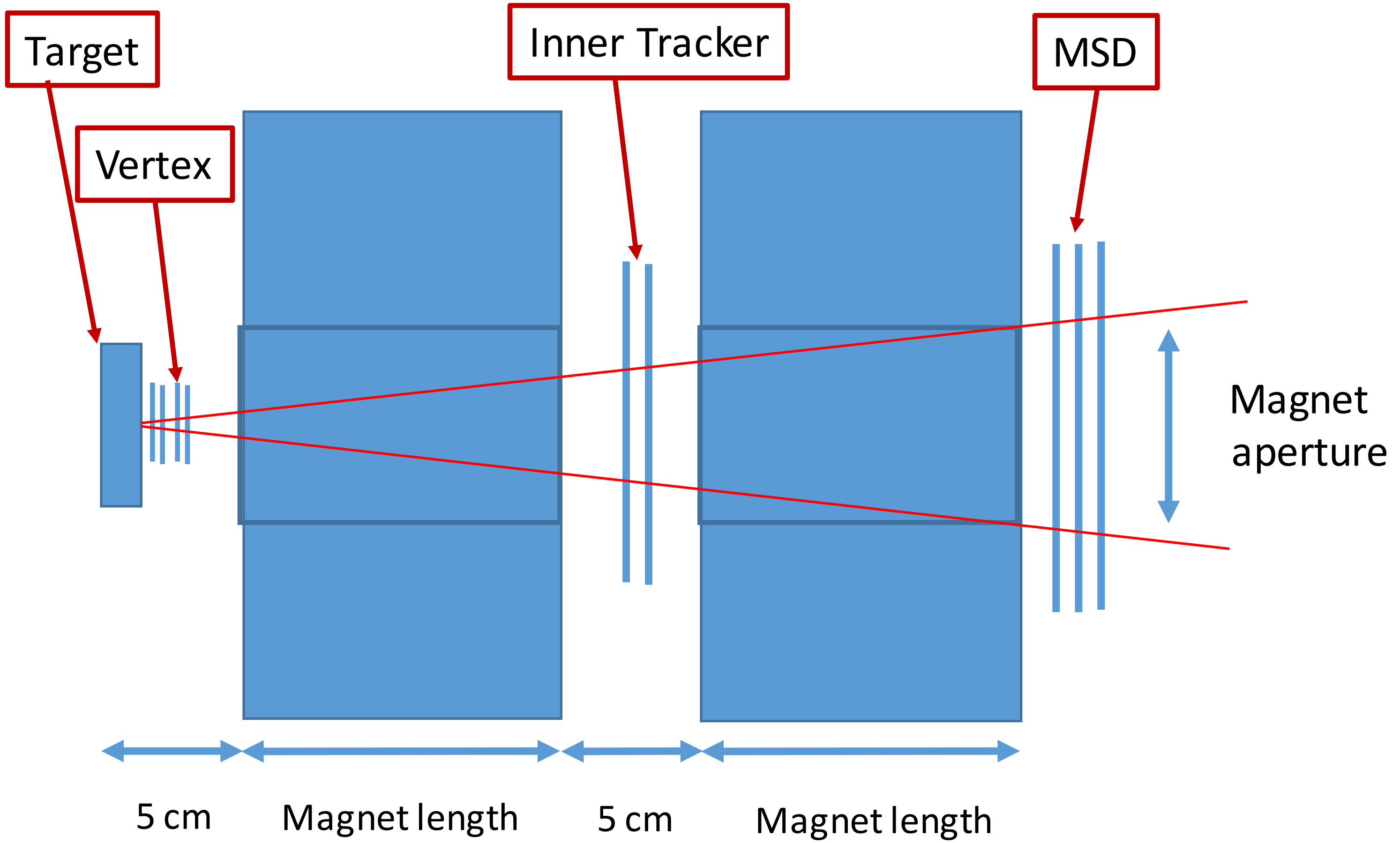


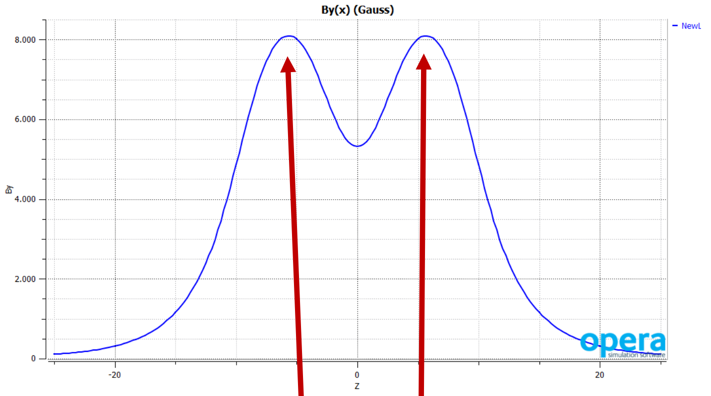
W. de Boer et al. / Nuclear Instruments and Methods in Physics Research A 487 (2002) 163–169



Most probable pulse height of the central pixel as function of the magnetic field parallel and perpendicular to the surface of MIMOSA.

Magnet system





Bmax = 0.8 Tesla

Magnet length = 10 cm

Magnet aperture = 10,6 cm

Original design magnet aperture = 7 cm

Different size magnets (aperture mainly) will reduce the overall cost?

Magnet system

Market survey

- Kyma Undulators (Trieste)
- Danfysik (Denmark)
- ANTEC, S.A., (Vizcaya) SPAIN
- EEC - Electron Energy Corporation (USA)
- RadiaBeam Technologies, LLC (USA)
- SABR Enterprises, LLC (USA)

Cost estimation has been done for 7 cm long magnets, 0.8 T field and 7 cm aperture

↓

Large cost variation (factor 2)

↓

New proposed dimensions (10 cm long and 10,6 cm internal diameter) even if possible could be expensive. The magnetic material could double and so the overall cost.

Final design for bid waiting our decision

Status of the Inner Tracker pixel detector

A long list of questions:

- Material budget???????
  $0.3\%\ x/X_0,\ 0.5\%\ x/X_0,\ 0.8\%\ x/X_0,$ ……..
- Distance of the 2 planes?
- Planarity of the planes?
- Uniformity of material budget distribution?
- ……………………………

Material to be used for the interposer:

- SiC (Plume,…)?
- RVC (many times used)?
- Carbon fiber (STAR, ALICE,….)?
- TPG (CBM,…)?
- Diamonds (CBM,…)?

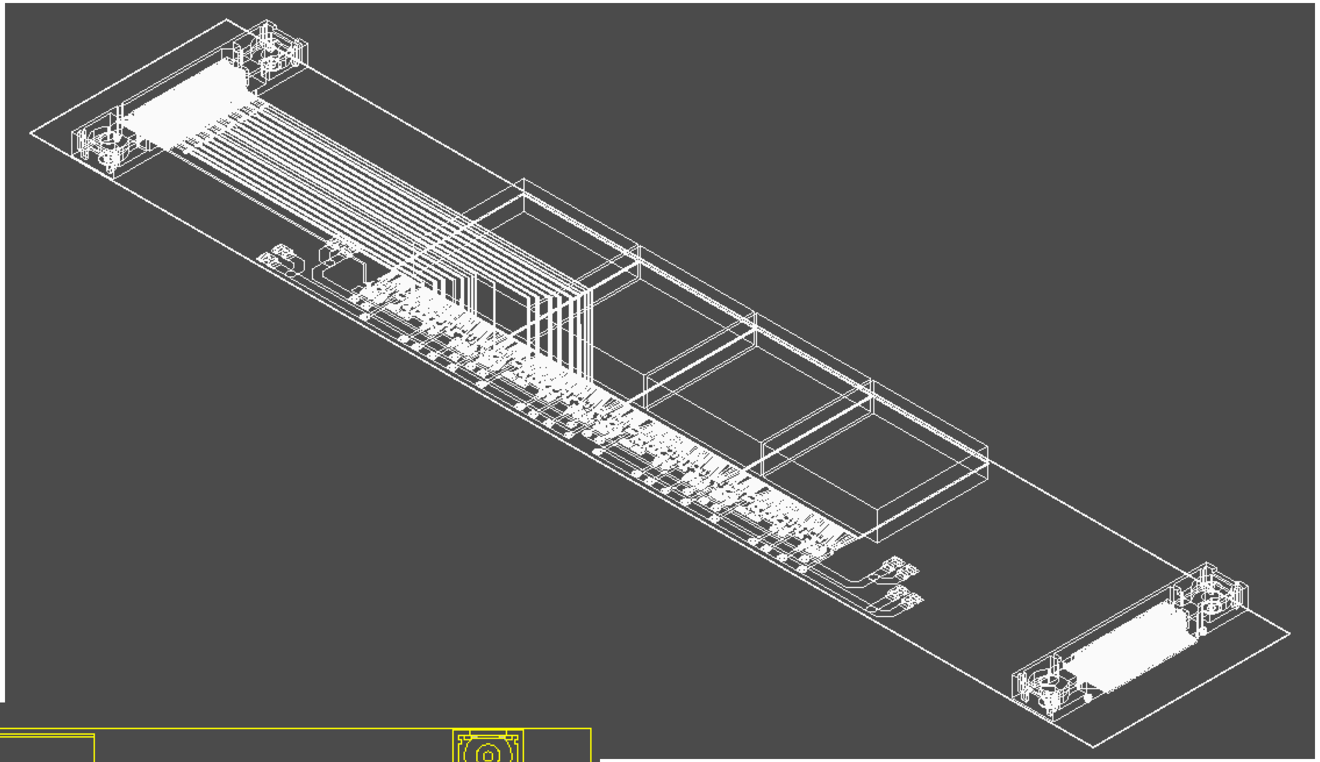
Characteristics of kapton PCBs:

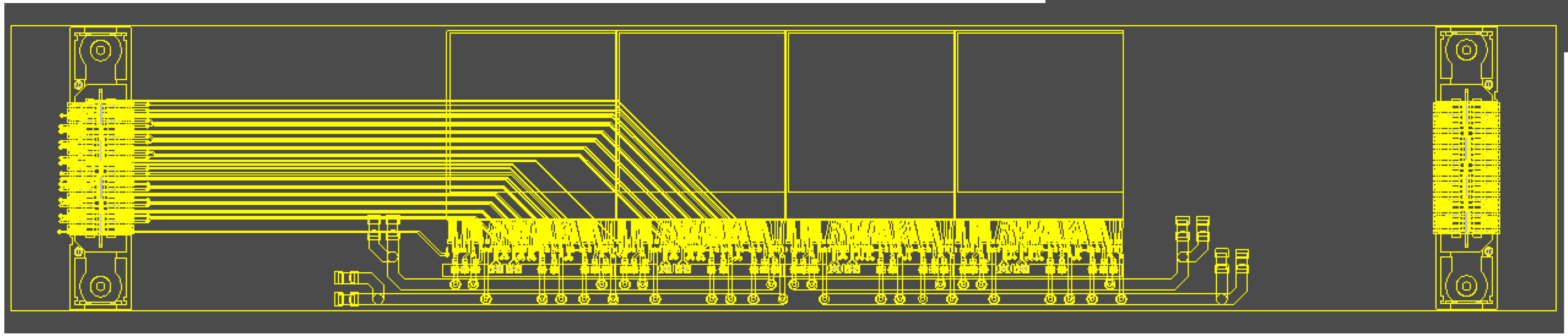
- Low thickness (26 µm coverlayer
  12 µm copper, 25 µm kapton)?
- Should we try Aluminium intead of Copper?
  CERN PCB workshop needed!
- Should we consider even more advanced options?
  Kapton thicknesses of 9 µm……….

Status of the Inner Tracker pixel detector

First **draft** of the **PlumeM28 module**:
- 4 M28 sensors
- 2 connectors (one per side)
- Horizontal sensor position un-centered!

Still many open questions:
- Kapron tickness
- Design for heat removal?
- Mechanical fixed on both side?
- What kind of adapter board?
- Copper or aluminum?



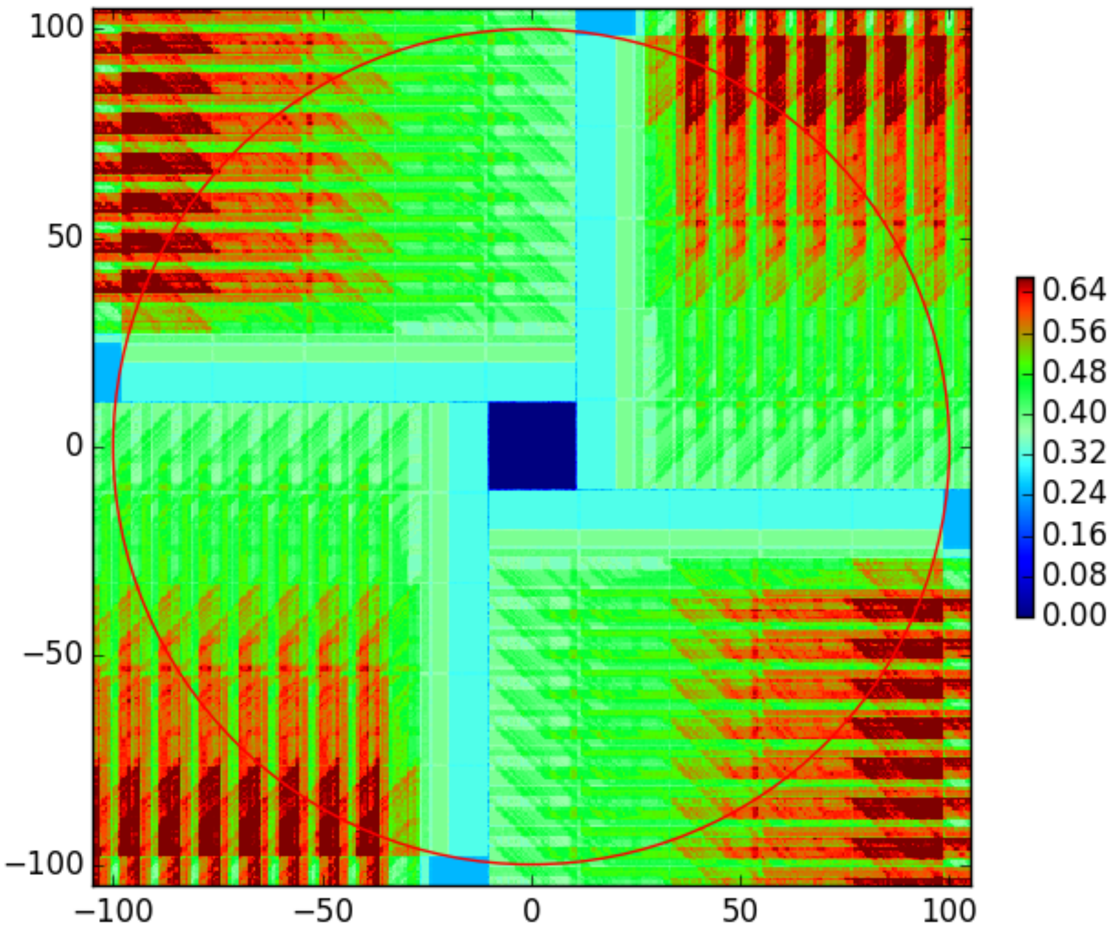


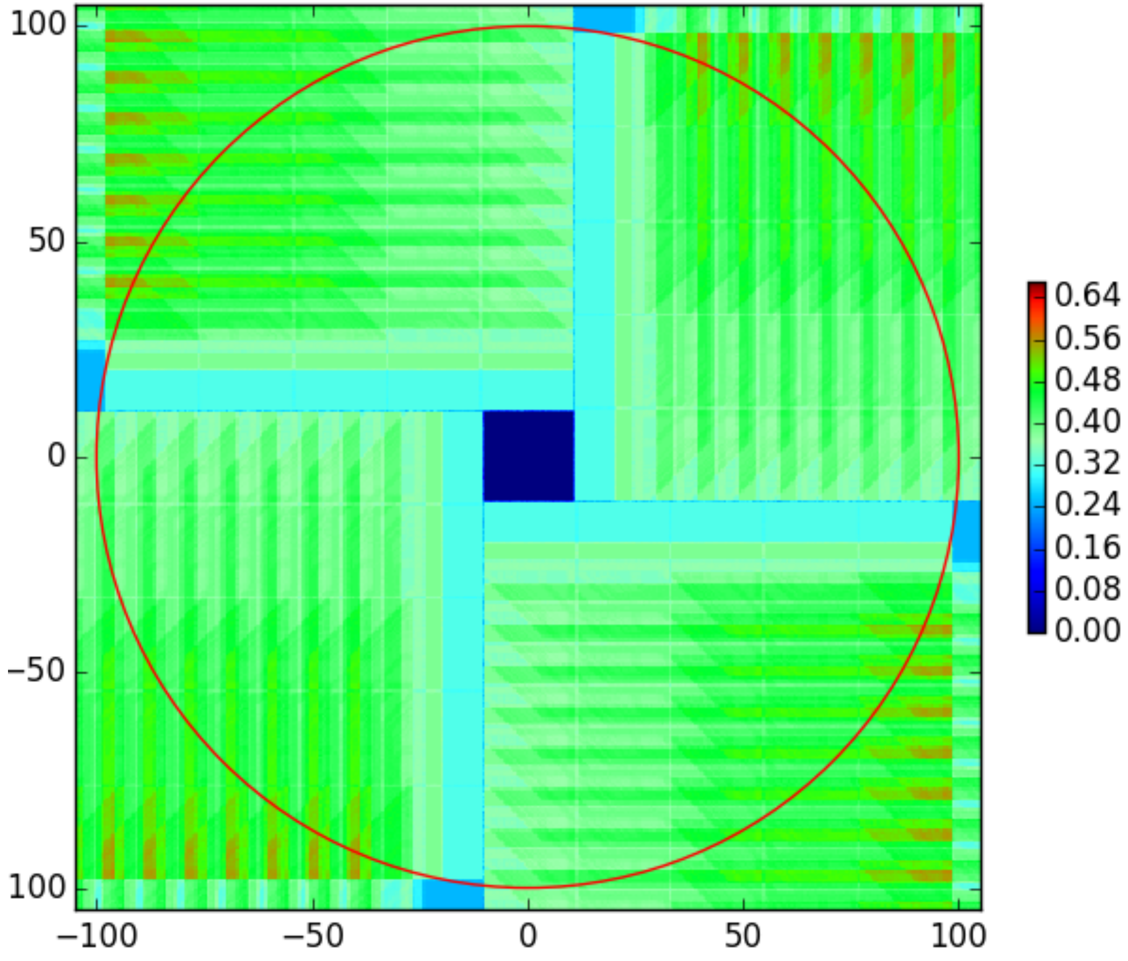
Design by SEA (Servizio Elettronica ed Automazione) LNF

Status of the Inner Tracker pixel detector

"Status of the vertex detector program of the CBM experiment at FAIR",
Philipp Klaus (Goethe University Frankfurt),
2018 14th Pisa meeting

CBM @ FAIR example: Aluminium versus copper PCB solution X_0 values.





Status of the Inner Tracker pixel detector

Examples of material for interposer (support sheet to glue the two modules)

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Duocel® Silicon Carbide

Making a Material Difference Since 1967

Applications limited only by your imagination. How will you use it?

Common Applications Include:
- Gas Diffusers
- Porous Electrodes
- Rocket Nozzles
- Core Structures
- Flame Arresters
- High Temperature Filters
- Optics and Mirrors

Duocel® Materials to Consider for your Application:
- Aluminum
- Carbon
- Copper
- Inconel
- Nickel
- Silicon Carbide
- Silicon Nitride
- Tin
- Zinc

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Characteristics of Silicon Carbide Foam (8% Density)

Compression Strength	200 psi	(1.38 MPa)
Flexural Strength	400 psi	(2.76 MPa)
Shear Strength	100 psi	(.69 MPa)
Young's Modulus	4×10^5 psi	(2.76 GPa)
Knoop Hardness (100gm)	2500	
Poisson's Ratio	0.22	
Thermal Conductivity:		
· 482°F (250°C)	3.05 BTU/ft · hr · °F	(5.28 W/m · °C)
· 1832°F (1000°C)	1.07 BTU/ft · hr · °F	(1.85 W/m · °C)
· 2642°F (1450°C)	.77 BTU/ft · hr · °F	(1.34 W/m · °C)
Thermal Expansion Coefficients:		
· Room Temperature	1.22×10^{-6} in/in · °F	(2.2×10^{-6} m/m · °C)
· 392°F (200°C)	2.06×10^{-6} in/in · °F	(3.7×10^{-6} m/m · °C)
· 932°F (500°C)	2.56×10^{-6} in/in · °F	(4.6×10^{-6} m/m · °C)
· 1292°F (700°C)	2.72×10^{-6} in/in · °F	(4.9×10^{-6} m/m · °C)
Bulk Resistivity at Room Temperature		
· 4×10^5 ohm · in	(1.016×10^5 ohm · cm)	
Sublimation Point	4892°F	(2700°C)
Max Continuous Use (Inert)	3992°F	(2200°C)
Oxidation Resistance	3002°F	(1650°C)
Pore Sizes	5, 10, 20, 30, 45, 60, 80, 100	Pores Per Inch*

*Foam can be compressed to achieve higher densities (up to ~70%) and smaller pore sizes (as high as ~500PPI)

ERG MATERIALS AND AEROSPACE CORPORATION

Duocel® Carbon Foam

Making a Material Difference Since 1967

Applications limited only by your imagination. How will you use it?

Common Applications Include:
- Porous Electrodes
- High Temperature Insulation
- High Temperature Oven Racking
- Filters
- Demisters
- Storage Batteries
- Scaffolds
- Semiconductor Manufacturing
- Acoustic Control

Duocel® Materials to Consider for your Application:
- Aluminum
- Carbon
- Copper
- Inconel
- Nickel
- Silicon Carbide
- Silicon Nitride
- Tin
- Zinc

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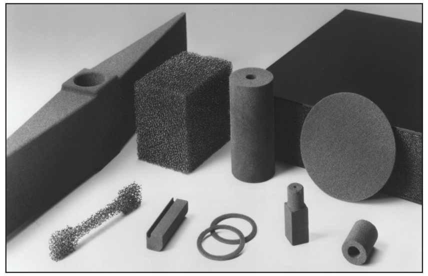
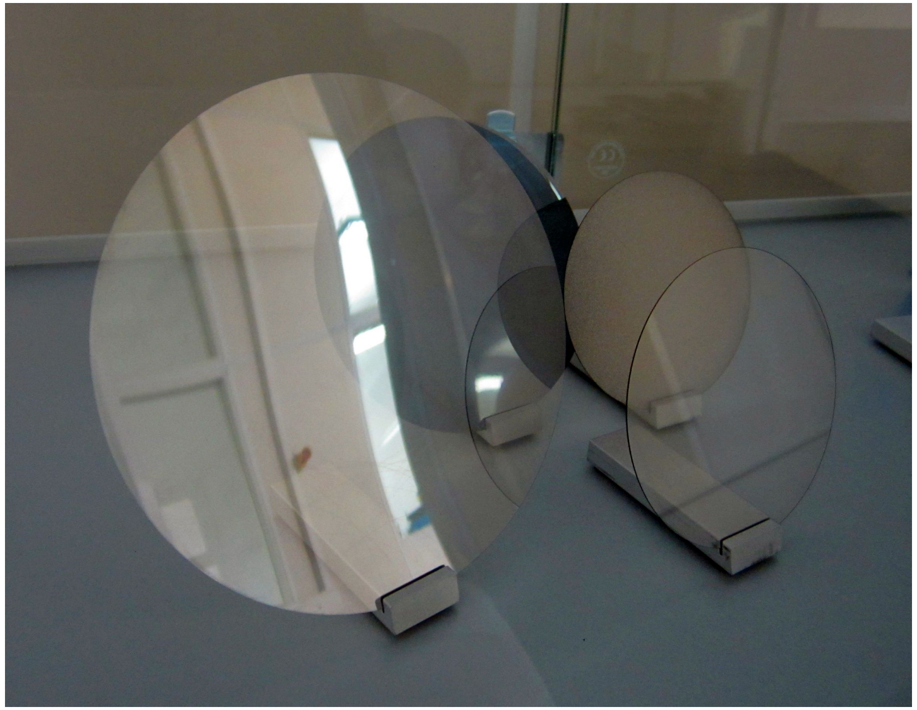


Characteristics of Duocel Carbon Foam (3% Nominal Density)

Compression Strength	15-75 psi	(0.10-0.52 MPa)
Tensile Strength	25-50 psi	(0.17-0.34 MPa)
Shear Strength	4.4×10^3 psi	(30.3 Mpa))
Hardness	6-7 Mohs	
Specific Heat	.3 BTU/lb °F	(1.26 J/g °C)
Shear Modulus	4.4×10^3 psi	(30.3 MPa)
Bulk Thermal Conductivity	0.021-0.29 BTU/ft·hr·°F	(0.033-0.050 W/m °C)
Coefficient of Thermal Expansion	(0-100°C) 1.2×10^{-6} in/in °F (100-1000°C) 1.8×10^{-6} in/in °F	(2.2×10^{-6} m/m °C) (3.2×10^{-6} m/m °C)
Bulk Resistivity	12.7×10^{-2} ohm · in	(32.3×10^{-2} ohm · cm)
Temperature Limitations	In air 600°F Inert environment 6330°F	(315°C) (3499°C)
Pore Sizes	5, 10, 20, 30, 45, 60, 80, 100	Pores Per Inch*

*Foam can be compressed to achieve higher densities (up to ~70%) and smaller pore sizes (as high as ~500PPI)

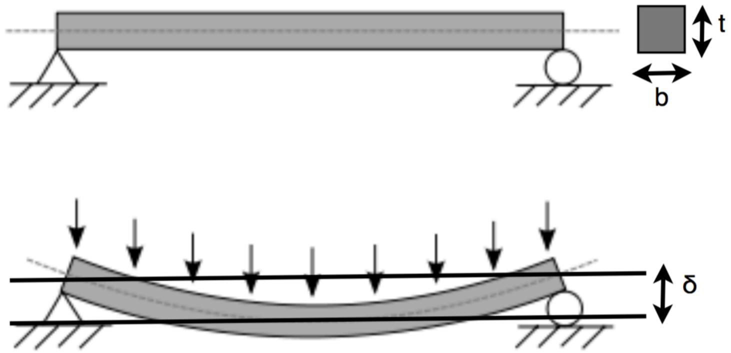


Industrial diamond wafers:
- size 4 inches
- Thickness 100 µm

Status of the Inner Tracker pixel detector

The material is **trade off choice** among different requirements:

- Stiffness of the structure
- Material budget (mass or radiation length)
- CTE (Thermal Expansion Coefficient)
- Availability
- Cost
- ……………………………

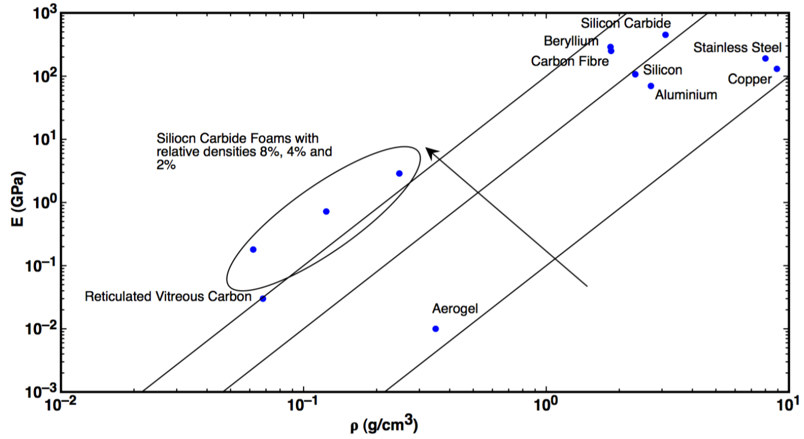


$$m \geq \left(\frac{12S}{C_1}\right)^{\frac{1}{3}} (L^6 b^2)^{\frac{1}{3}} \left(\frac{\rho}{E^{\frac{1}{3}}}\right)$$

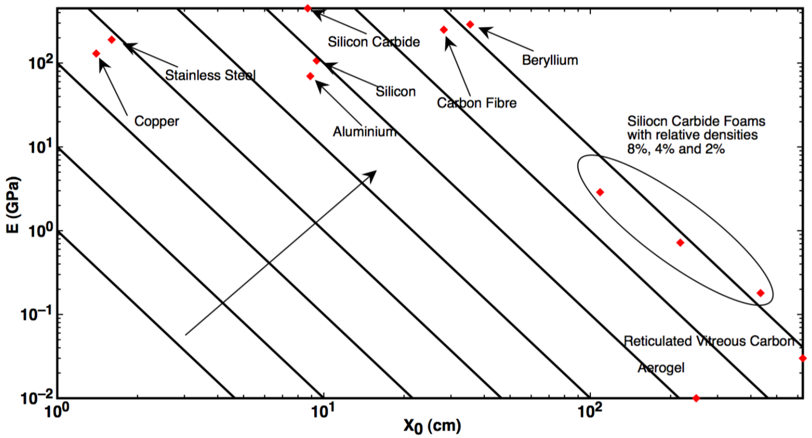
$$S = \frac{F}{\delta} \geq \frac{C_1 E I_{xx}}{L^3}$$

- S = Stiffness
- E = Elastic Module
- I = Second moment
- L = Length

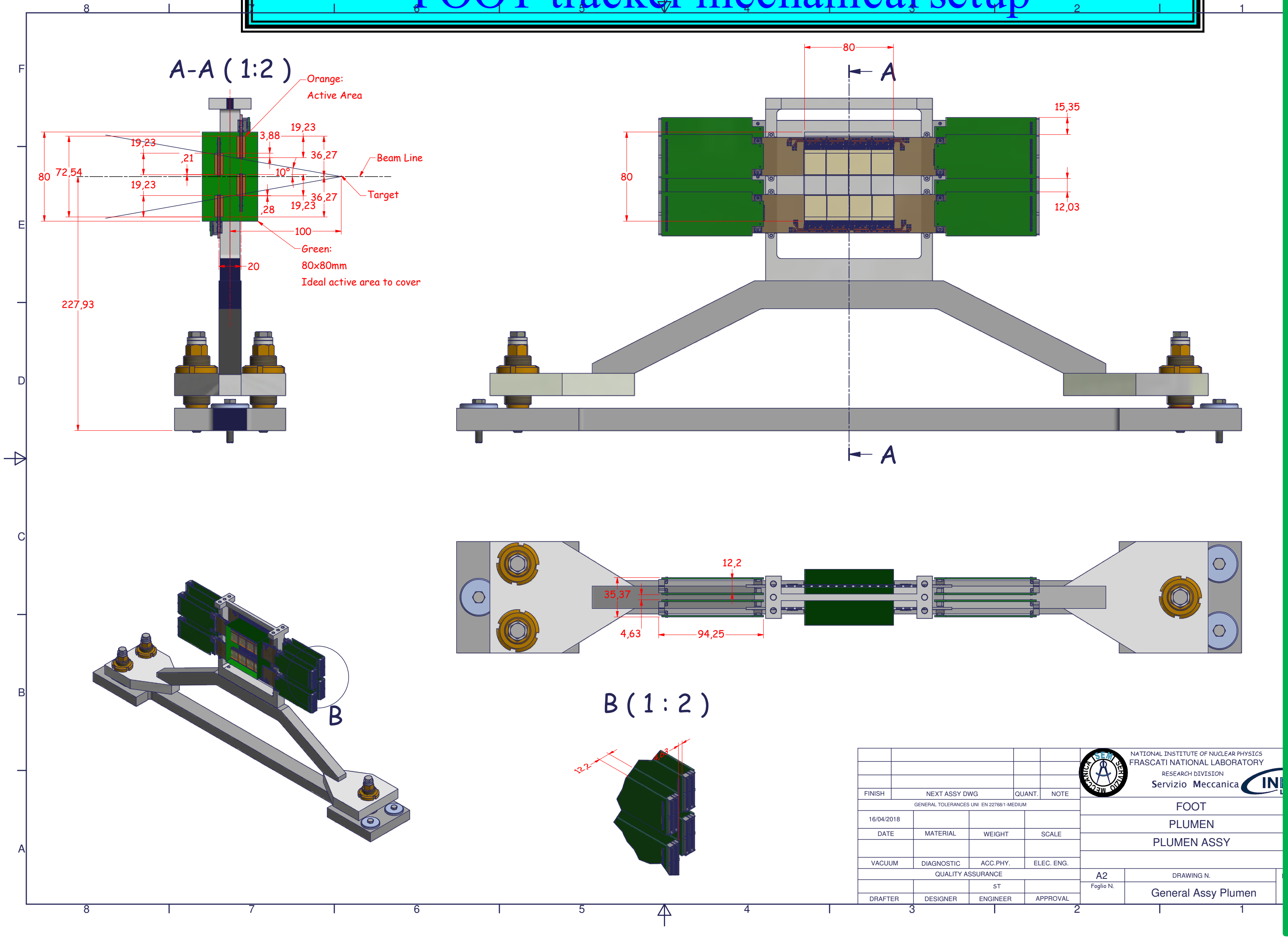
$$M_1 = \frac{E^{\frac{1}{3}}}{\rho}$$



$$M_2 = E X_0^3$$



FOOT tracker mechanical setup



Mechanical draft of the Inner Tracker detector.
A lot of details, mechanical, electrical, assembly procedure and others have to be defined before starting prototypes construction.
G&A company is ready to prepare a quotation as soon as we'll define all the details.

- X_0 max
- Planarity level
- Distance of two planes
- Precision of position of different sensors
- …………………

Simulation is the only way to answer

A possible pixel tracker improvement

M28 pixel architecture limit:

- Rolling shutter full frame readout (～180µs)
- No timing information

NO WAY TO ASSIGN TRACKS FROM DIFFERENT EVENTS OCCURRED IN THE SAME FRAME

Recent result from FBK (Fondazione Bruno Kessler)

- "Large area" LGAD sensor (～ 1 cm2)
- Thickness 50 µm

Possible solution

- **Easily implementable a coarse "pixellated" version with limited number of readout channels (order 10-20).**
- **One additional mask probably sufficient!**
- **One or two plane before or after the target could solve the problem**

Conclusions

FOOT tracker mechanical setup:
- A realistic solution has been envisaged
- Construction foreseen for next year
- Financial request to "commissione III" under definition

Pixel vertex detector:
- The basic block holding PCB constructed and tested
- Test in vacuum successful
- New daq system ready
- Firmware for threshold scan to be debugged

Magnet system:
- Final decision underway (next weeks)
- Needed simulations almost completed
- Market search accomplished
- Funding upgrade "agreed" with Comm. III
- All elements to start the bid prepared

Inner tracker:
- A draft of the module organization defined
- The overall mechanical solution still under definitio
- A lot of simulation work still needed to define the final specs