Cooling systems for the novel pixel detectors

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Section 3. Modern nuclear physics methods and technologies
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Outline

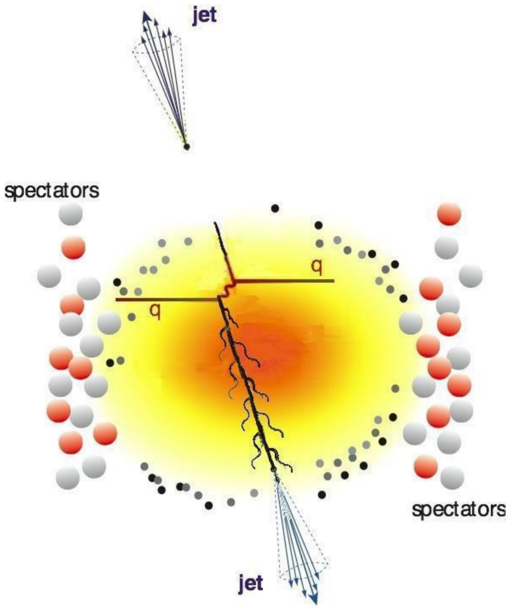
- Vertex detectors in high energy physics experiments
- Mechanic and cooling systems for the vertex detectors: history, today and tomorrow
- Gas cooling systems
- Summary

Vertex detectors in high energy physics experiments

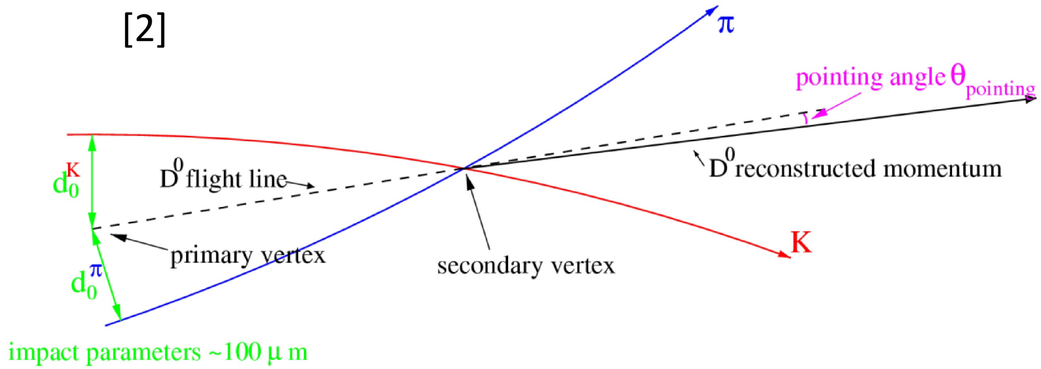
Physics motivations

Hadrons containing heavy quarks are excellent observables since they carry undistorted information about the states of nuclear matter arising during the collision of relativistic nuclei.

[1]



[2]

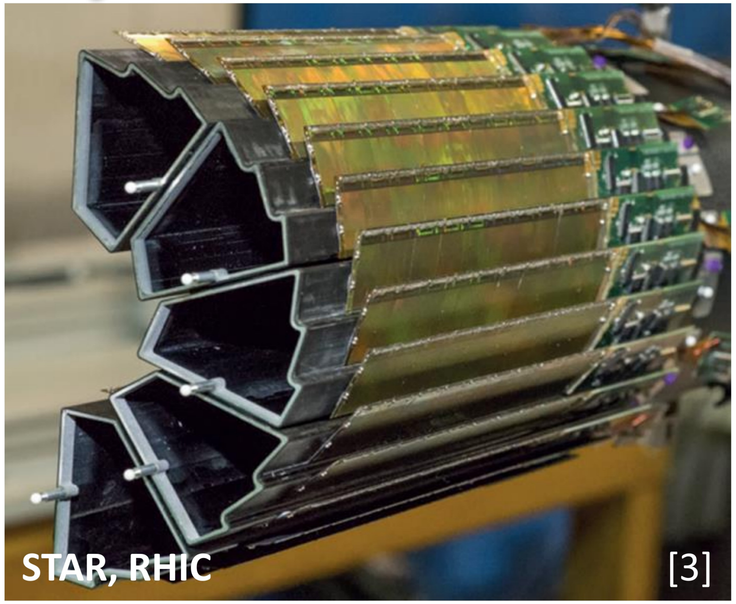


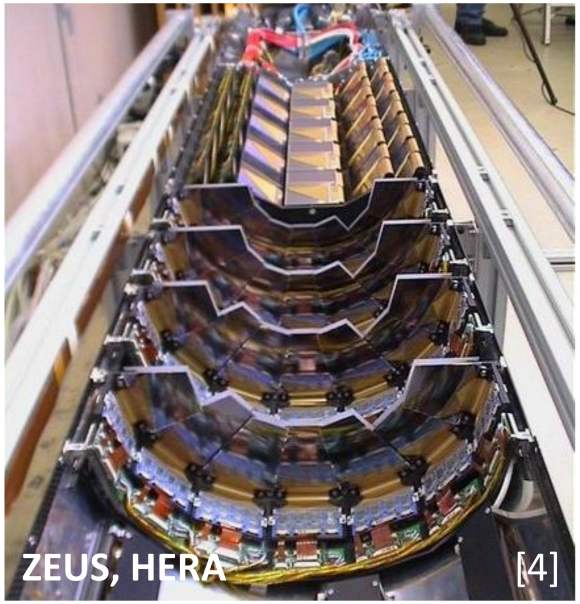
Vertex detector makes it possible to study the processes of heavy flavour production by reconstructing secondary vertices with high precision.

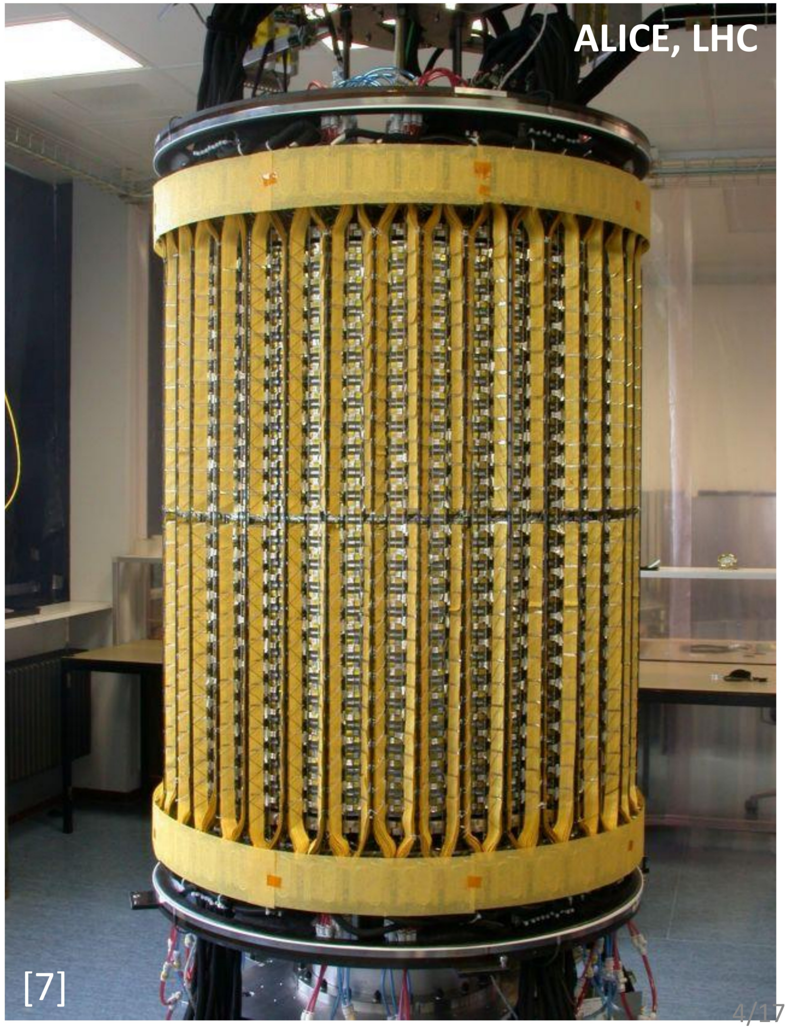
Main requirements for the vertex detectors:

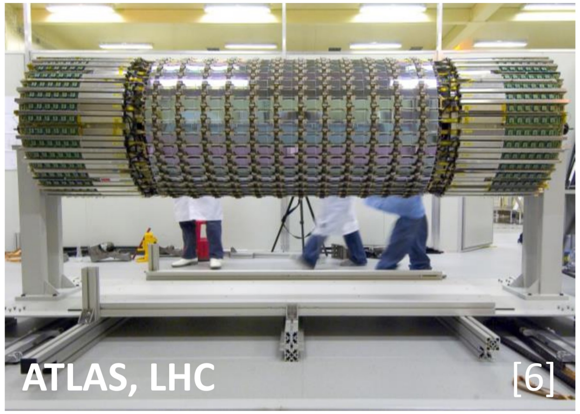
- **Low material budget**
- **High stability of the detectors position**
- **High stability of the detectors temperature and characteristics**
- High granularity
- High counting rate capabilities
- High radiation tolerance of the detectors, electronics and materials

Vertex detectors in high energy physics experiments





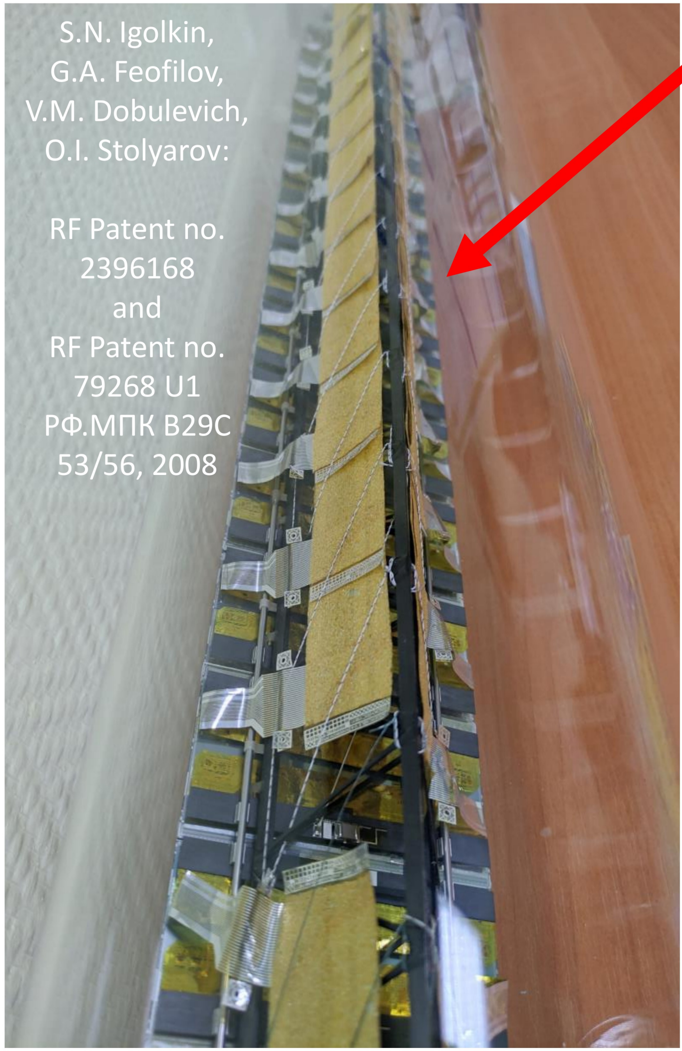


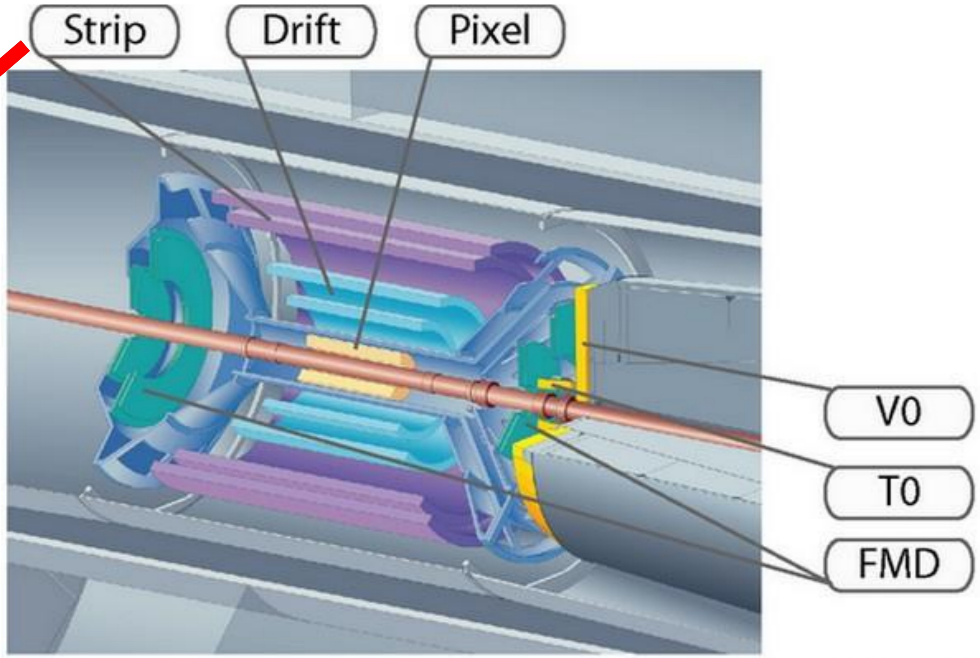


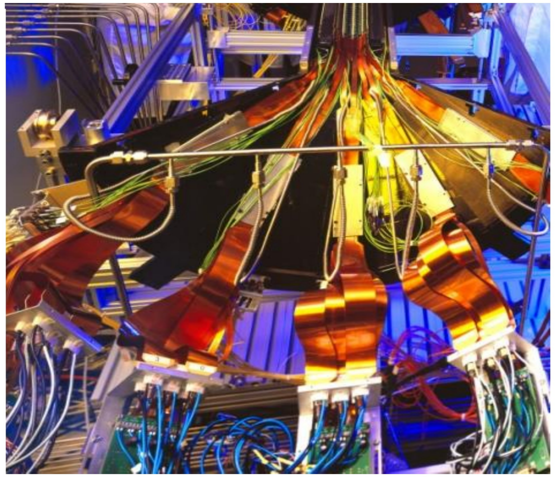
Mechanic and cooling systems: history

Extra lightweight detector support structures for the IT

ELNP SPbU





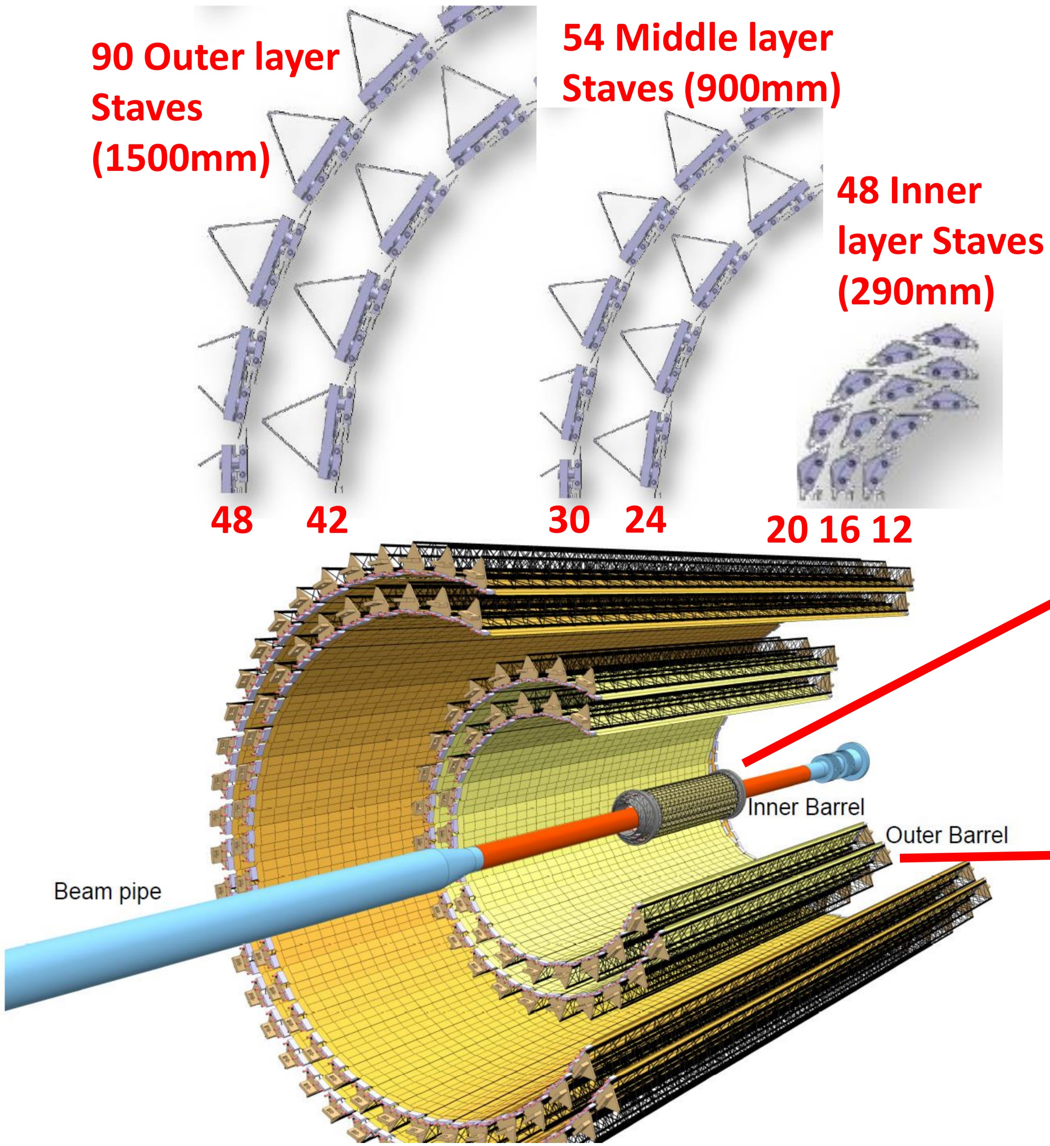


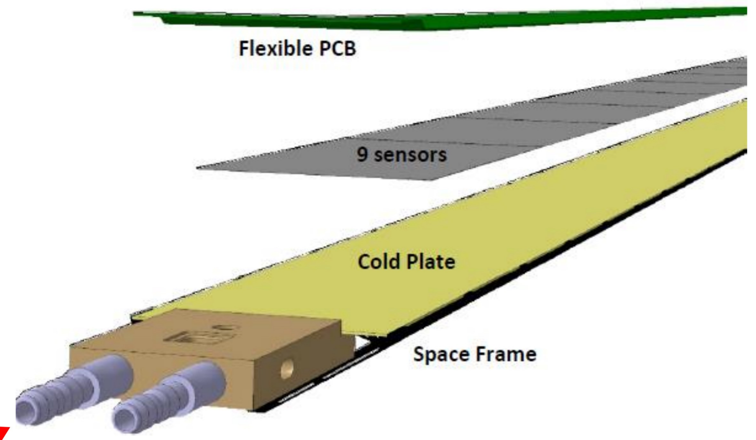
St Petersburg University

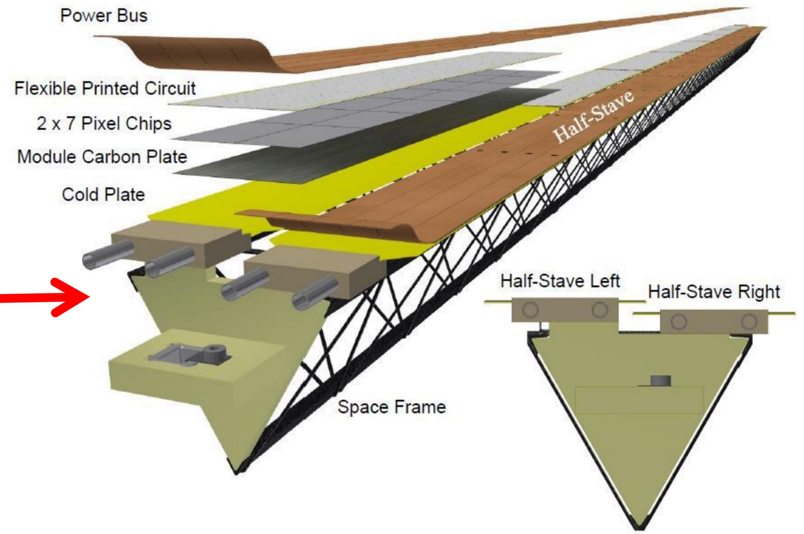
ALICE

[8]

Mechanic and cooling systems: today

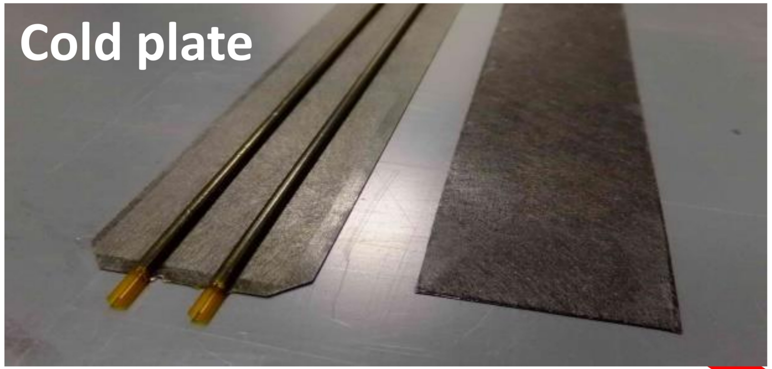


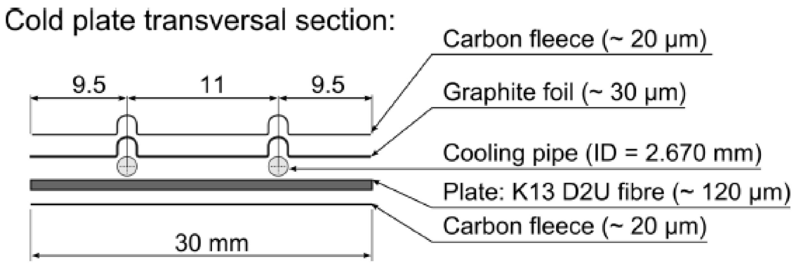


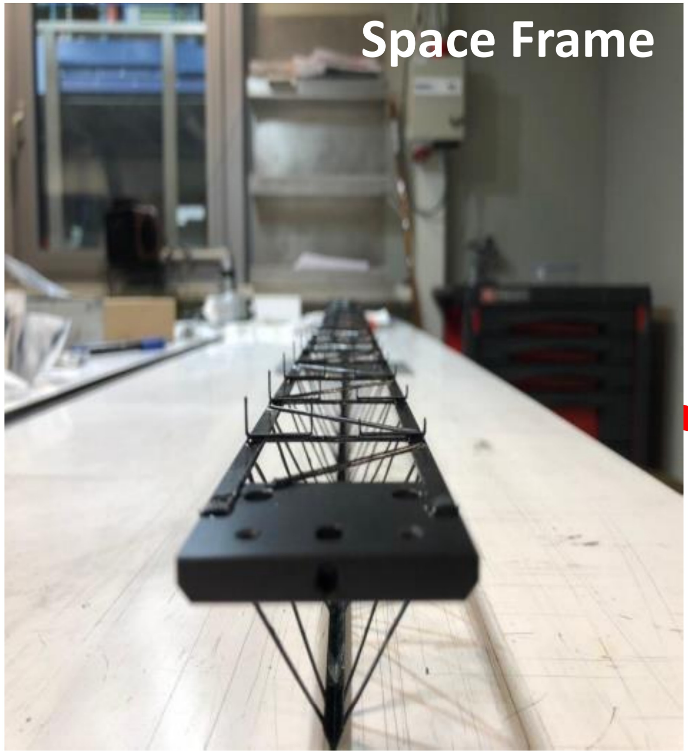


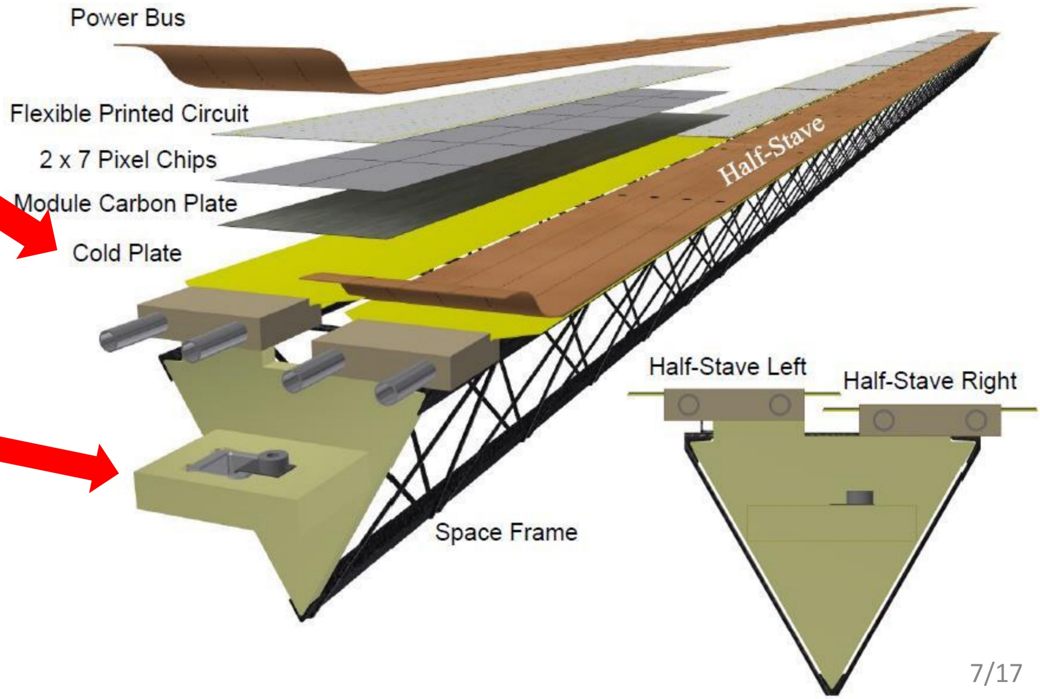
[9]

Mechanic and cooling systems: today



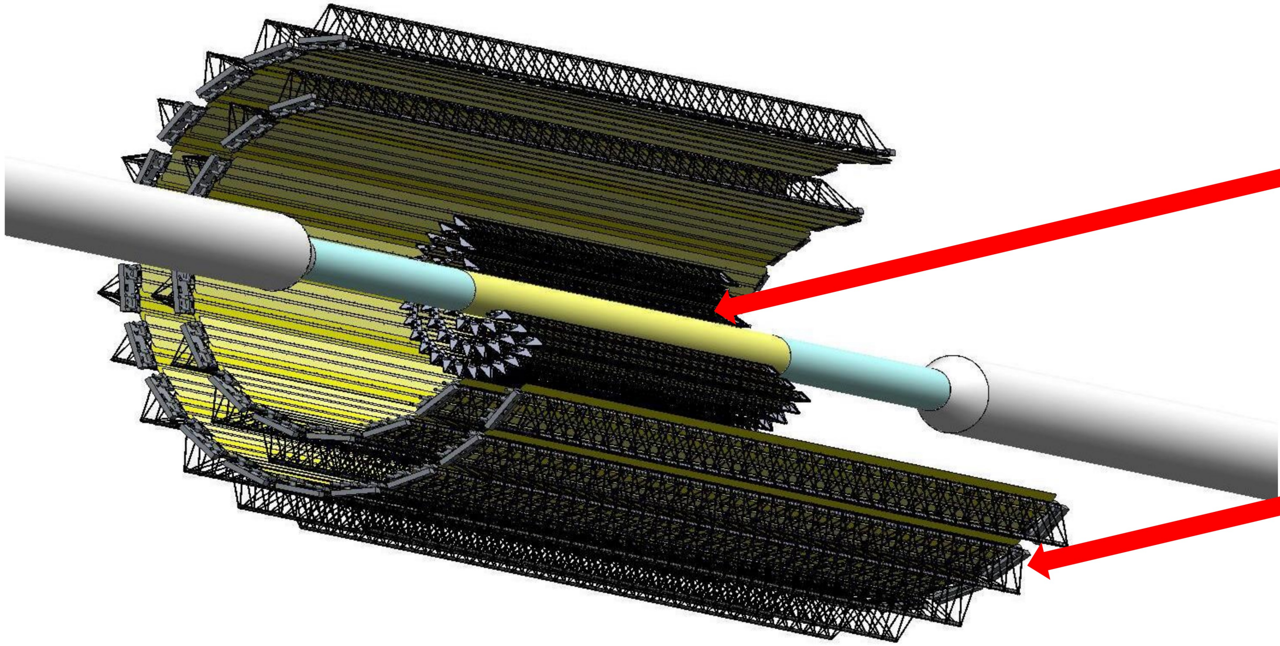






Mechanic and cooling systems: tomorrow

The concept of the Inner Tracking System of the NICA MPD experiment (second stage of the MPD experiment)



3 Inner Barrel (IB) layers:
12, 22 and 32 staves.

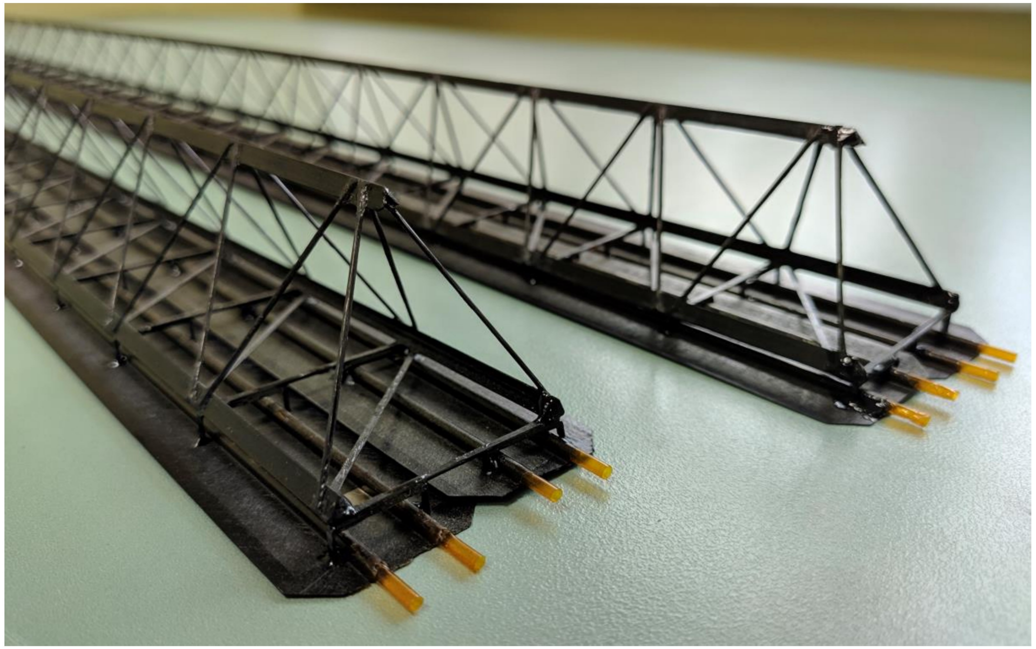
2 Outer Barrel (OB) layers:
36 and 48 staves

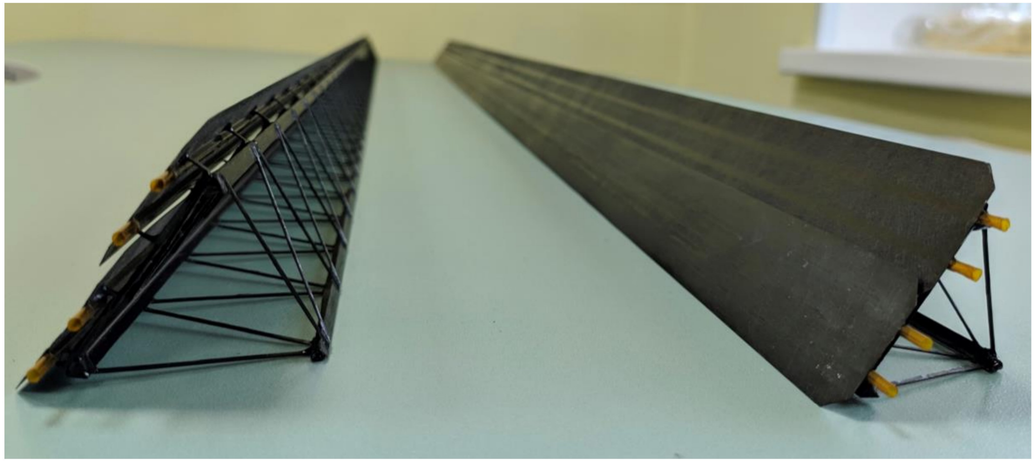
[10]

Total: 5 layers of Monolithic Active Pixel Sensors (MAPS)

ALICE technologies:
for IB – ALICE Middle layer staves (900mm)
for OB – ALICE Outer layer staves (1500mm)

Mechanic and cooling systems: tomorrow



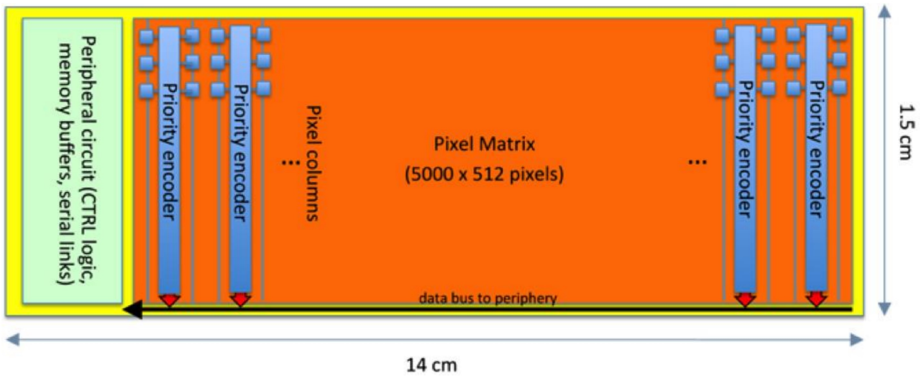


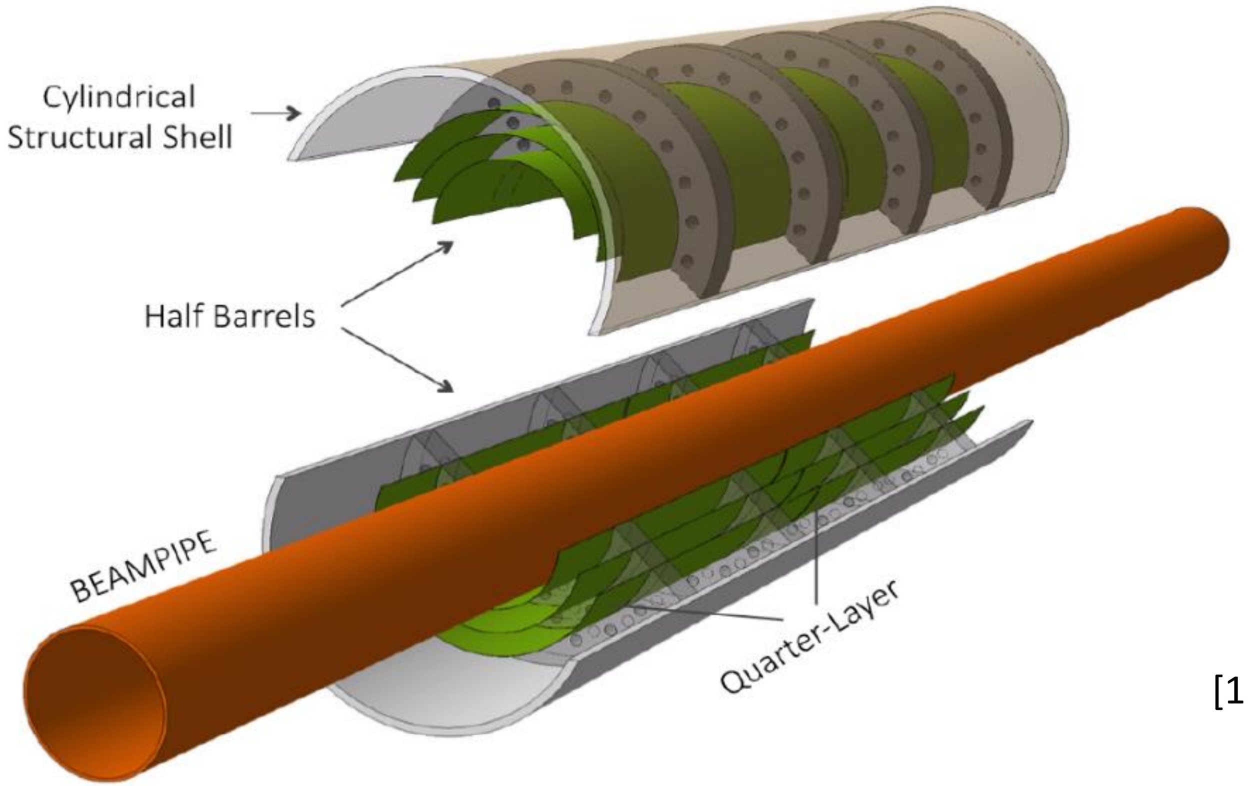
The first samples for the ITS MPD have already been constructed.

The next step is the manufacturing of lightweight mechanical carbon fiber wound-truss support structures in Saint-Petersburg University for the whole MPD Inner Tracker.

Mechanic and cooling systems: tomorrow

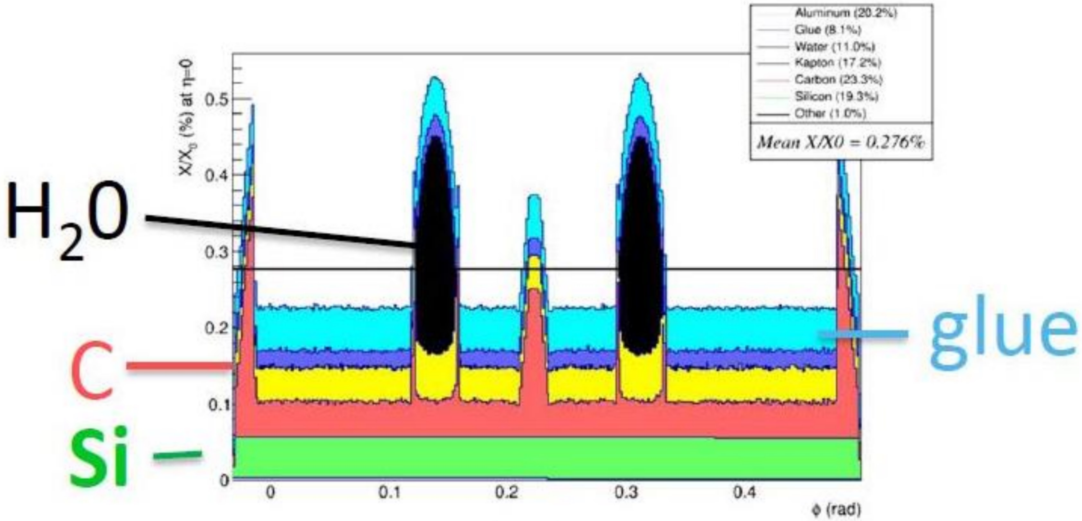
New conception for ITS ALICE upgrade: ITS-3
stitching with the
Tower semiconductor 180 nm
ALPIDE 15 mm X 140 mm,
thickness 20 µm, 0.2% X0

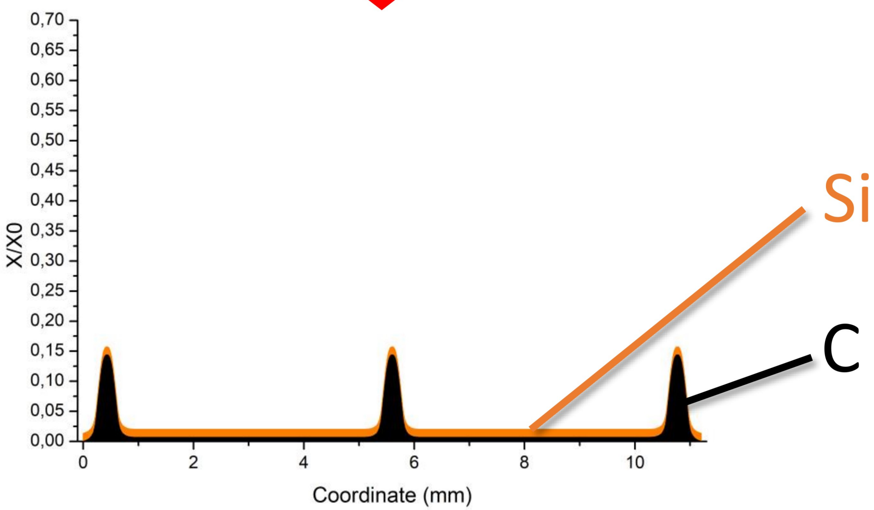




[11]

Cooling with nitrogen vapor





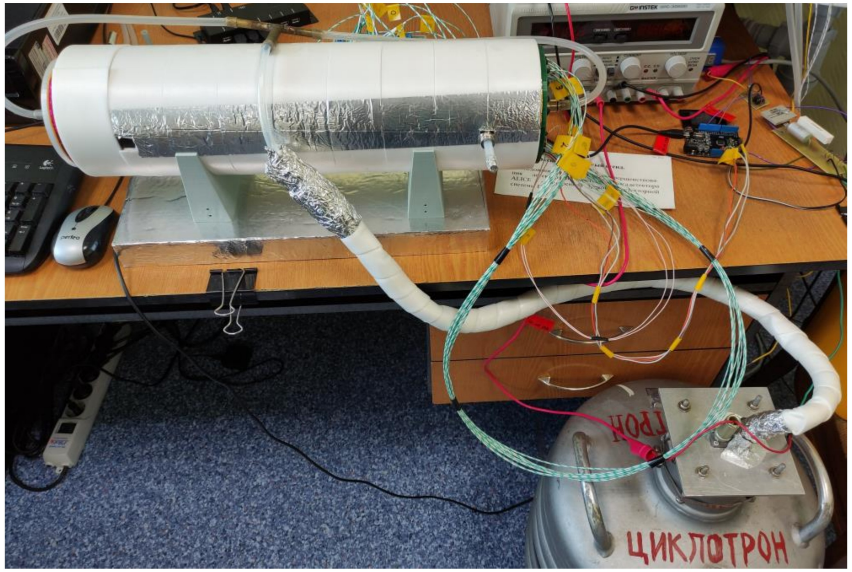
How to reduce the material budget?

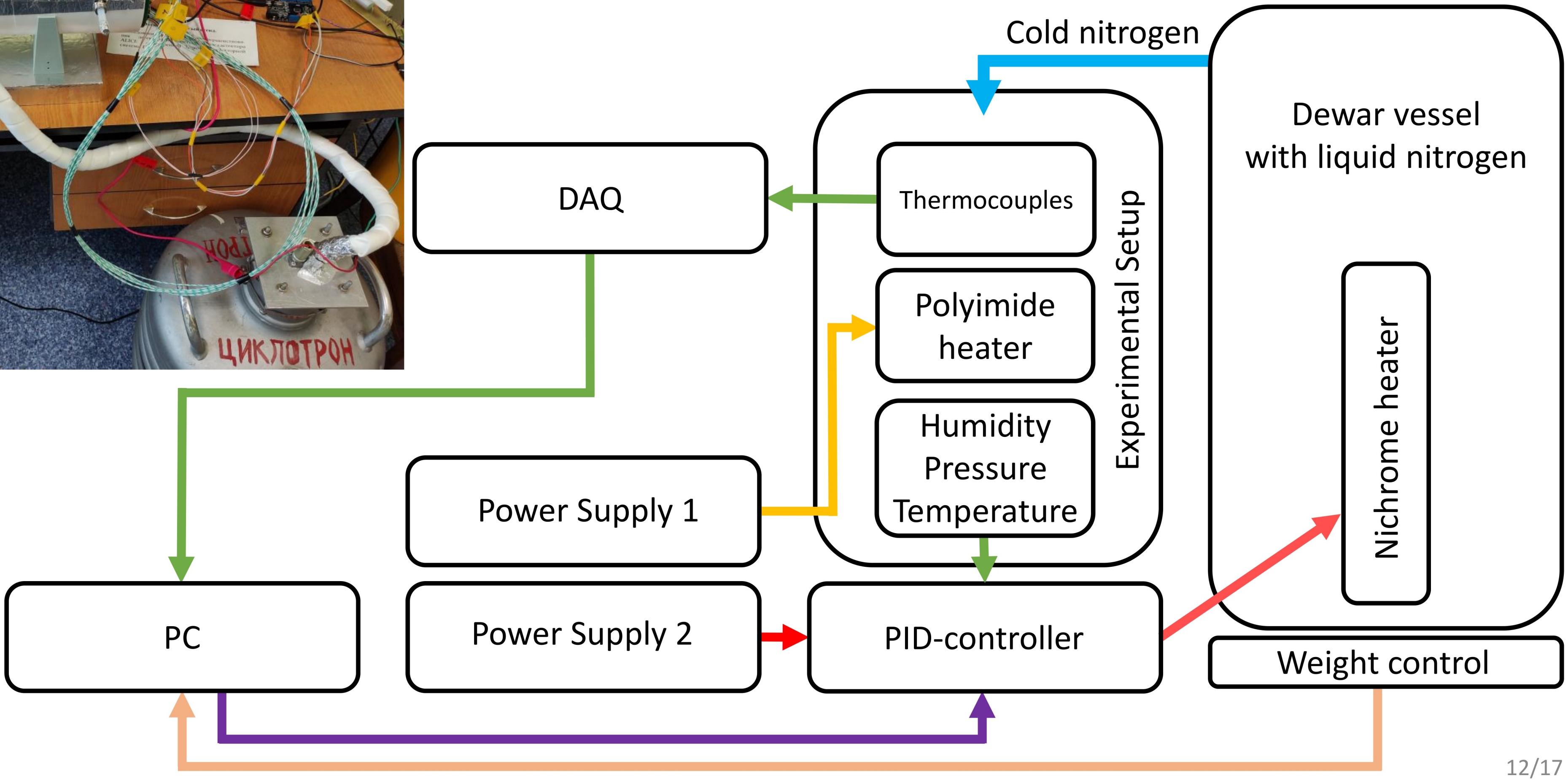
- use ultra-thin detectors
- fix detectors at the edges without any support structures
- all wires at the edge
- **cool with cold gases**

cold nitrogen!

Cooling with nitrogen vapor

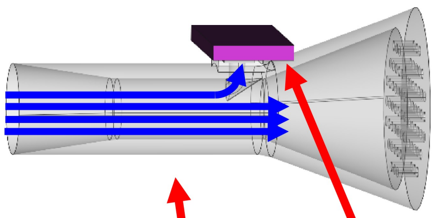
Experimental setup



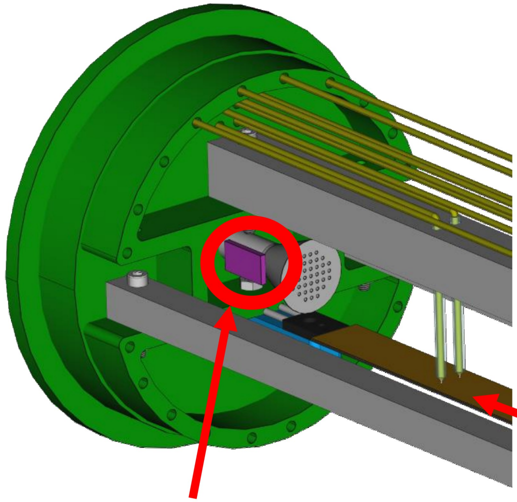


Cooling with nitrogen vapor

Experimental setup

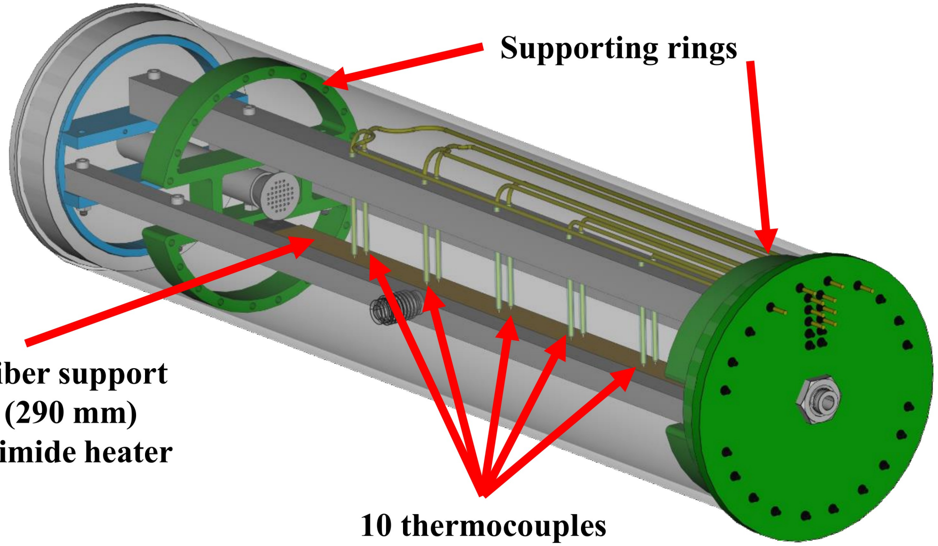


Nitrogen shower, on both sides



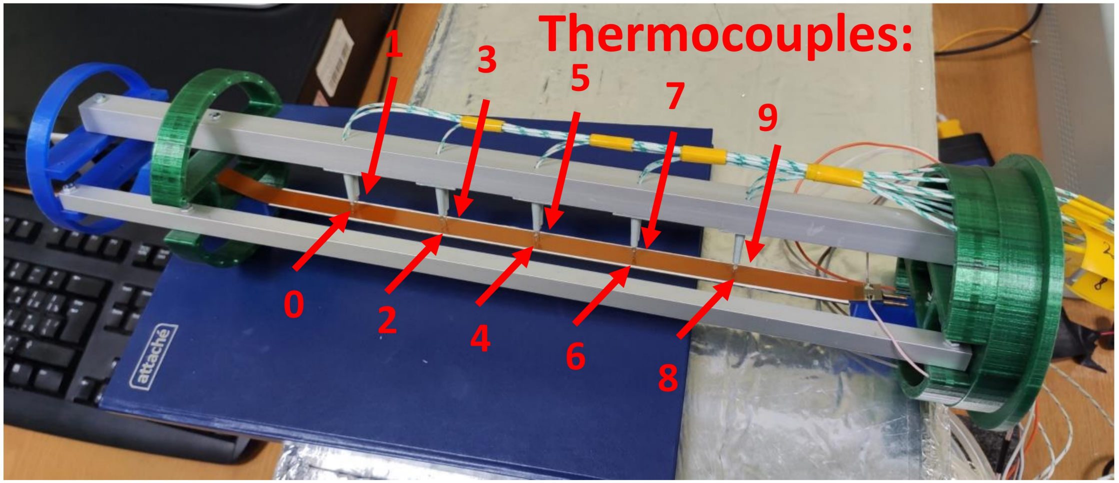
Temperature/humidity/pressure sensor
For PID-regulator

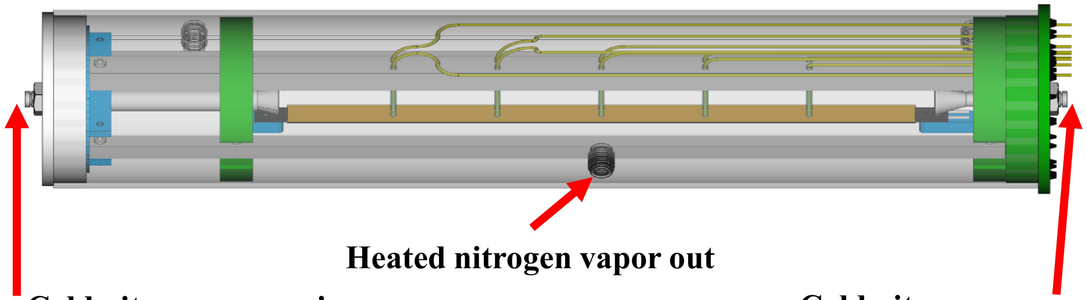
Carbon fiber support structure (290 mm) with polyimide heater



Supporting rings

10 thermocouples



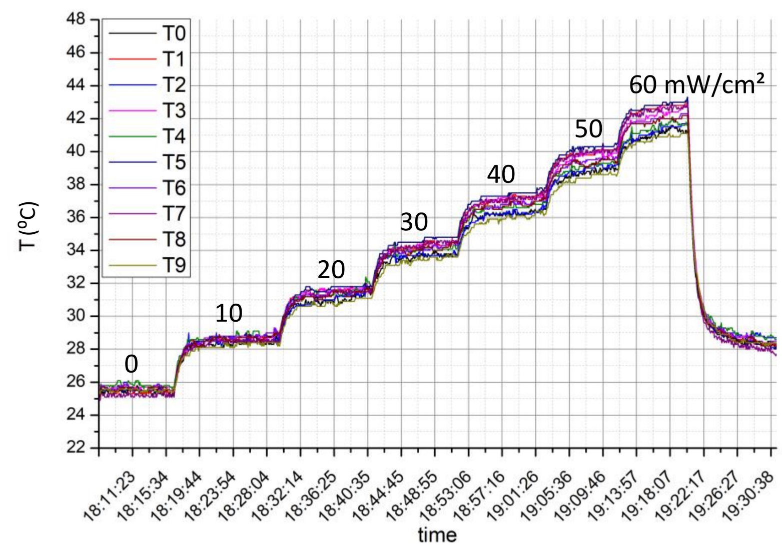


Heated nitrogen vapor out

Cold nitrogen vapor in

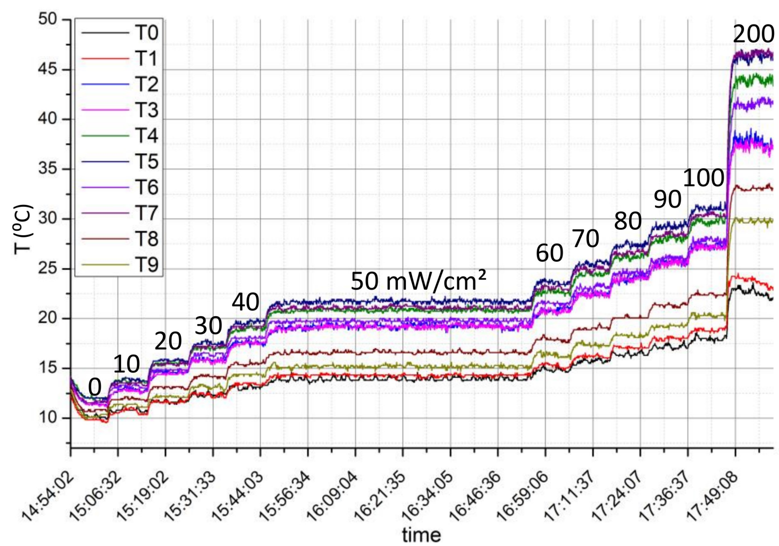
Cold nitrogen vapor in

Cooling with nitrogen vapor



Temperature field on the polyimide heater

Without cooling

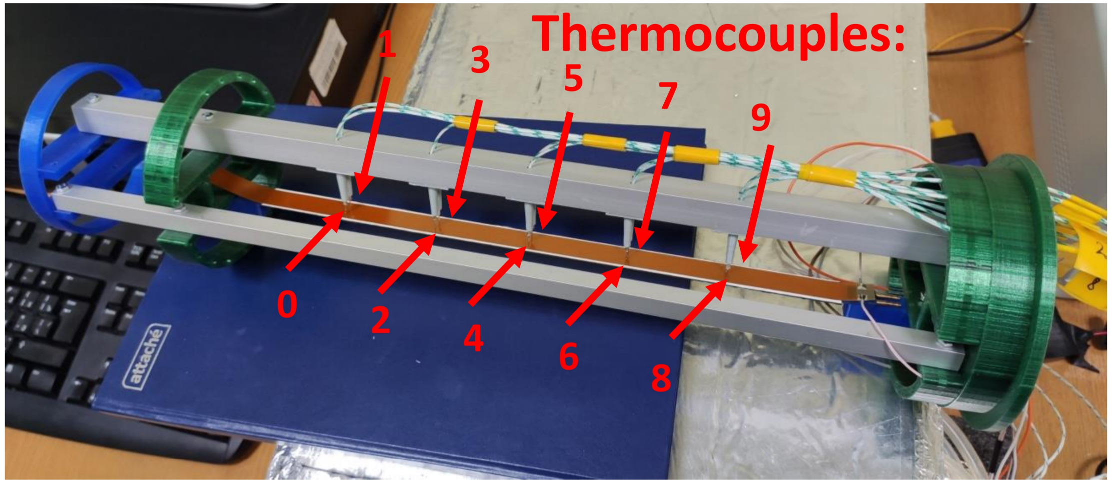


Temperature field on the polyimide heater

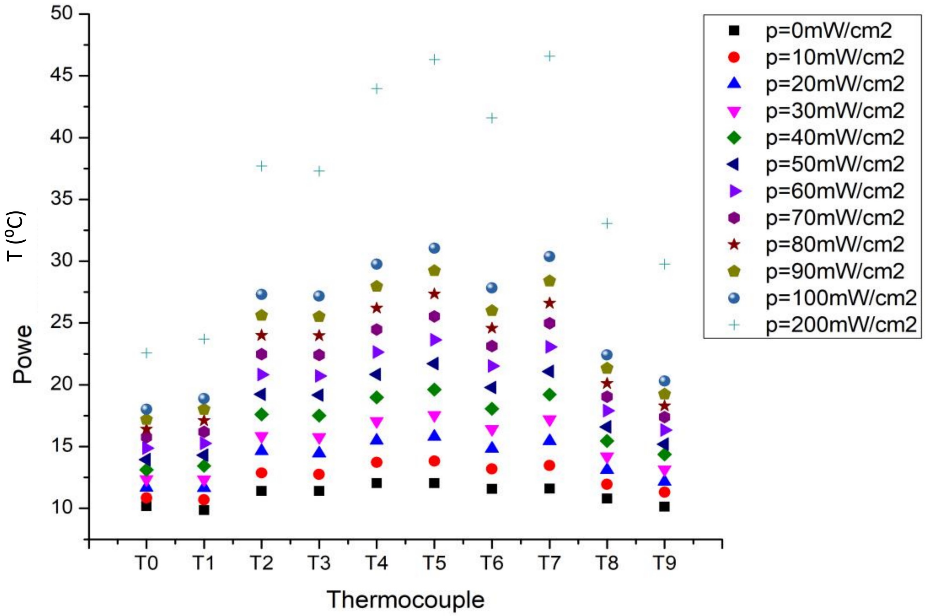
With cooling

With very low speed of cold nitrogen it is possible to keep the detector temperature (in case of 10^{o}C nitrogen input):

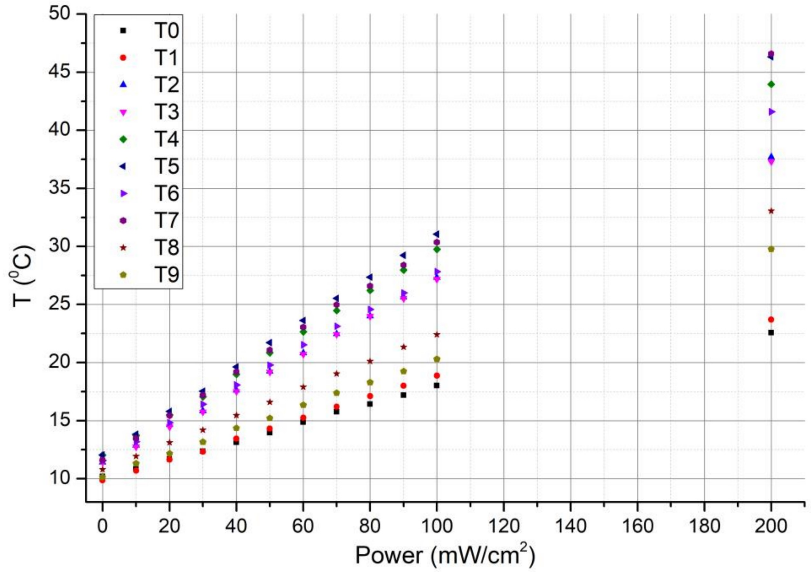
14^{o}C for detectors with power density 10 mW/cm²
17^{o}C for detectors with power density 30 mW/cm²
21^{o}C for detectors with power density 50 mW/cm²
30^{o}C for detectors with power density 100 mW/cm²



Cooling with nitrogen vapor



Average temperature at the corresponding point on polyimide heater vs power



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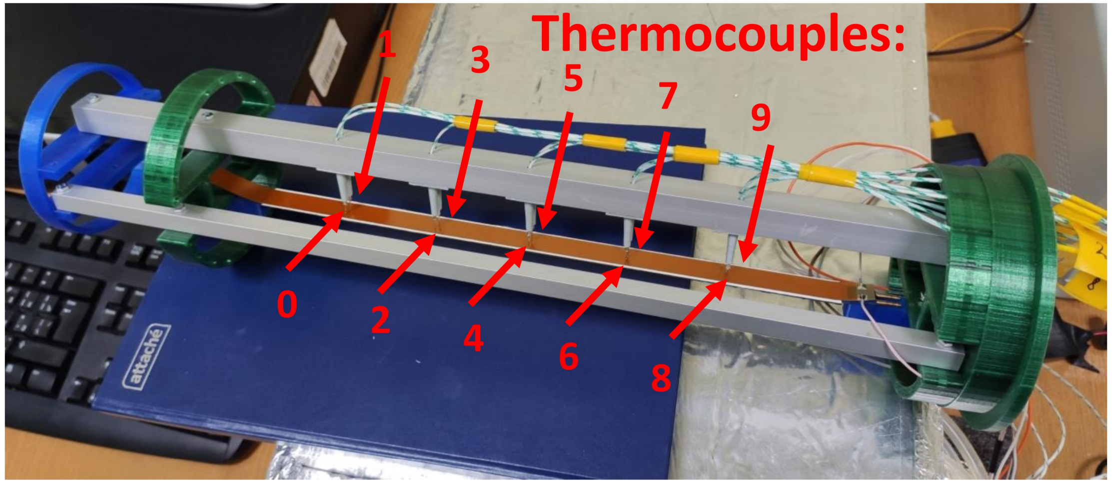


Summary

- New extremely lightweight mechanical carbon fiber support structures with an integrated liquid cooling system for monolithic silicon pixel detectors have been proposed for the Inner Tracking System of the NICA MPD experiment. These structures are:
  1. Guarantees high stability of the detectors position
  2. Provides high stability of the detector temperature and characteristics
  3. Makes a minimum contribution to the material budget of a vertex detector
- It is possible to reduce the material budget by using new way of cooling with the cold nitrogen
- With very low speed of cold nitrogen, it is possible to keep the detectors at a stable temperature and also, in this case, one can avoid any vibration of the detectors.

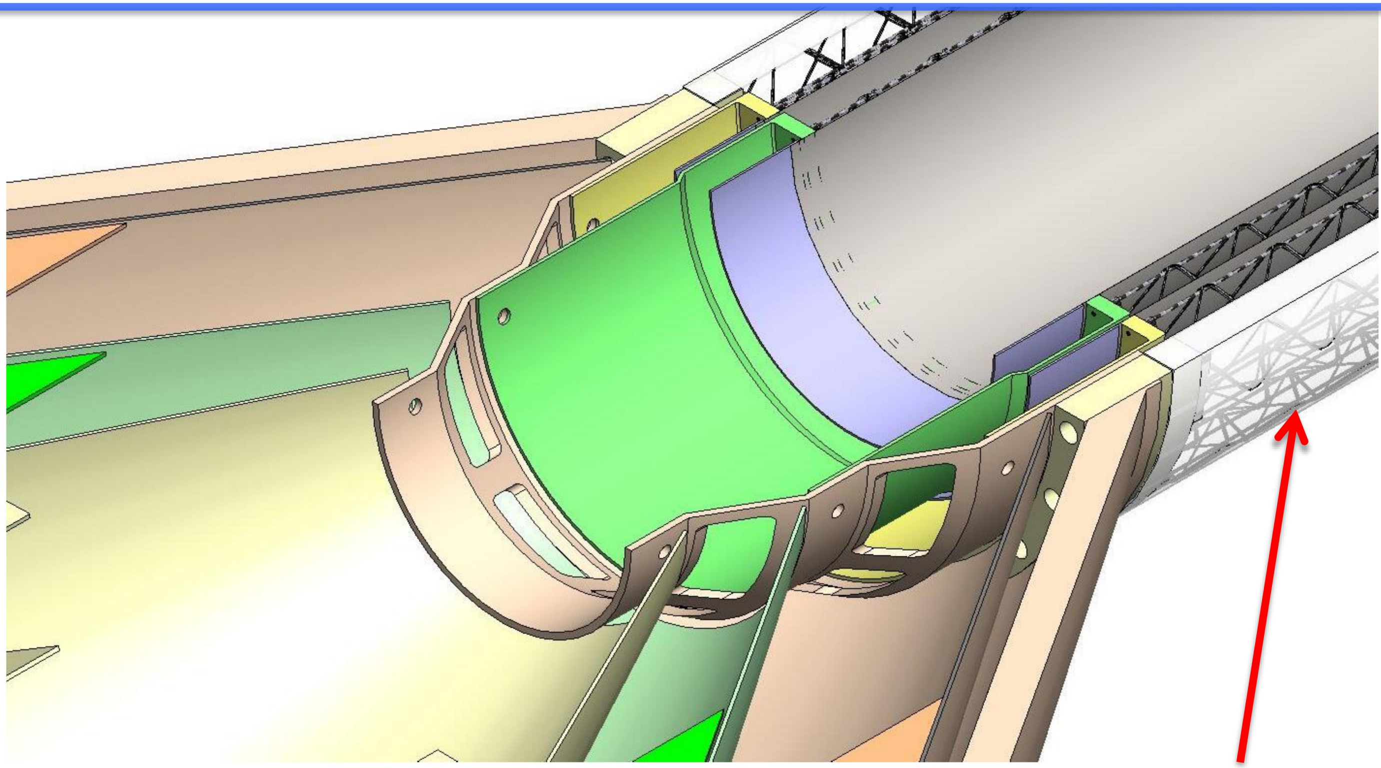
Thank you for your attention!

Literature

1) Talk «Two-particle angular correlations», Małgorzata Janik, Faculty of Physics Warsaw University of Technology, Oslo Winter School, 2-7.01.2018;
2) Talk «Open Heavy Flavour production», Andrea Rossi, Padua University & INFN, Quark Matter 2018;
3) https://cerncourier.com/a/star-tracker-snares-heavy-flavours/
4) Presentation Experience from ZEUS Microvertex detector is running for more than five years without access! E.N Koffeman NIKHEF & University of Amsterdam.
5) https://www.nikhef.nl/~i93/Experiments.html
6) The ALICE ITS (Inner Tracking System) Upgrade – Monolithic Pixel Detectors for LHC, Petra Riedler, CERN EP-DT, Seminar, February 22, 2018
7) http://cds.cern.ch/journal/CERNBulletin/2005/39/News%20Articles/883916?ln=en
8) Talk "ITS upgrade", Grigory Feofilov, ALICE-Russia meeting, September 14-15, 2016, Moscow, Kurchatov Institute
9) The ALICE Collaboration: "TDR", J. Phys. G41 (2014)
10) V.I. Zherebchevsky, V.P. Kondratiev, V.V. Vechernin, S.N. Igolkin, The concept of the MPD vertex detector for the detection of rare events in Au+Au collisions at the NICA collider, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 985, 2021, 164668, ISSN 0168-9002, https://doi.org/10.1016/j.nima.2020.164668
11) THE ALICE UPGRADE: FUTURE PROSPECTS, Kristjan Gulbrandsen Niels Bohr Institute, Copenhagen, Denmark, ICNFP - 26/08/2019

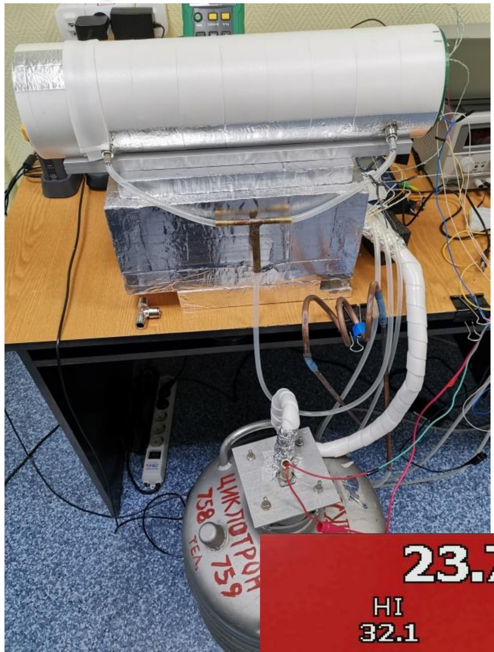
BACK-UP SLIDES

Thermal enclosure



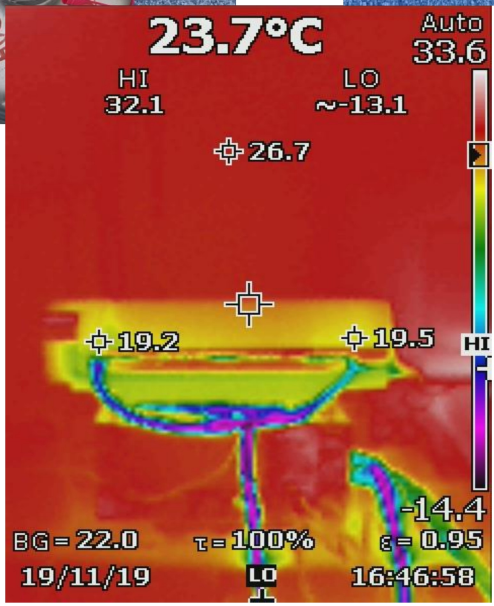
Thermal enclosure—1 layer of 30μ metalised mylar

Experimental setup



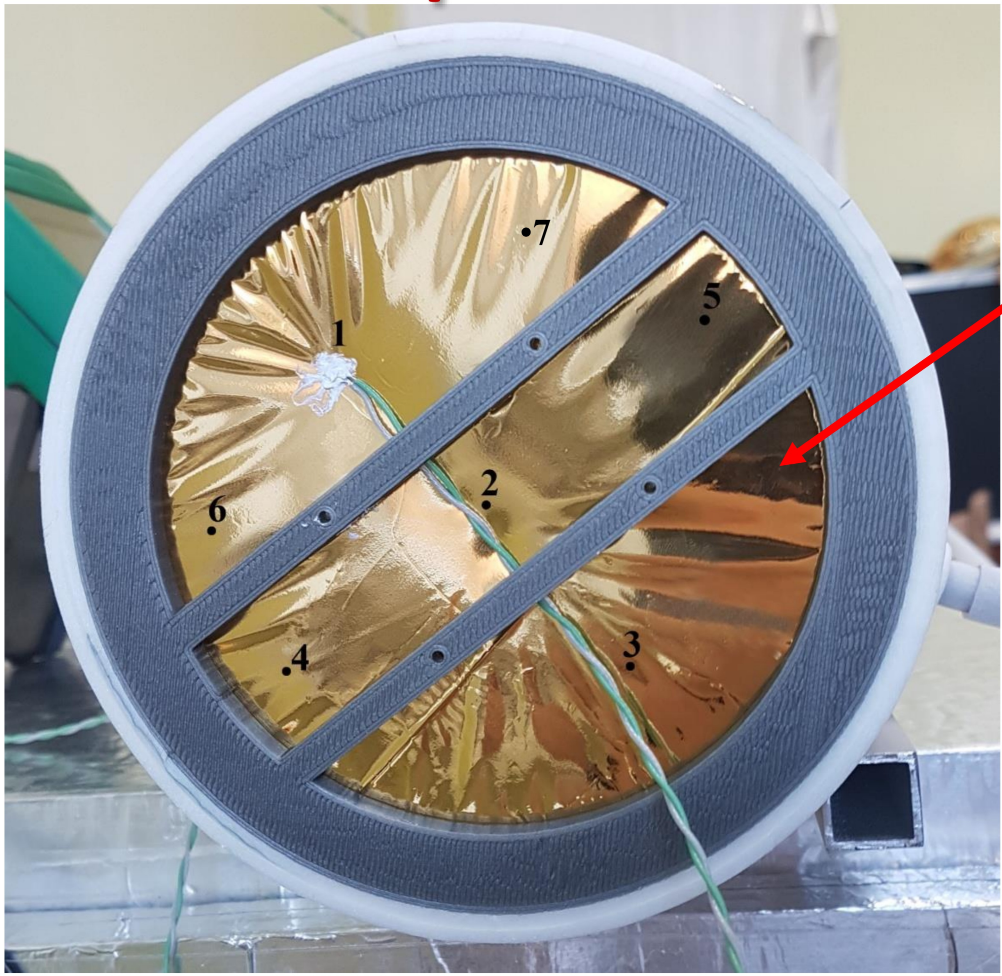
Cold Nitrogen
inside the set-up

Space Blanket



Set-up Thermo-image

Experimental setup



Thermocouple location numbers

Measurements:

1. Outside. Locations of the thermocouples are shown in fig.

2. Inside:

T_{in} (center) – thermocouple was mounted inside the set-up volume (in the middle)

T_{in} (edge) – thermocouple was mounted inside the set-up volume (close to the edge with space blanket)

T_{out} – thermocouple was mounted outside (on top of the space blanket)

Experimental setup

One blanket layer

Room temperature 24,5 ºC

Temperature inside the set-up = 5-6 ºC

Temperature outside

Thermocouple location numbers	T_{out} ºC	T_{in} (edge) ºC	T_{in} (center) ºC	T_{out} - T_{in} (edge)
1	16,2	5,5	5,16	10,7
2	17,3	6,4	5,03	10,9
3	17,1	6,3	5,03	10,8
4	17,1	6,1	5,28	11,0
5	18,4	6,1	5,22	12,3
6	16,1	5,8	5,22	10,3
7	16,0	5,9	5,22	10,1

Mean = 16.9 ºC

Mean = 10.9 ºC