Design and thermal tests of the stave cooling plate of the ITS MPD detector

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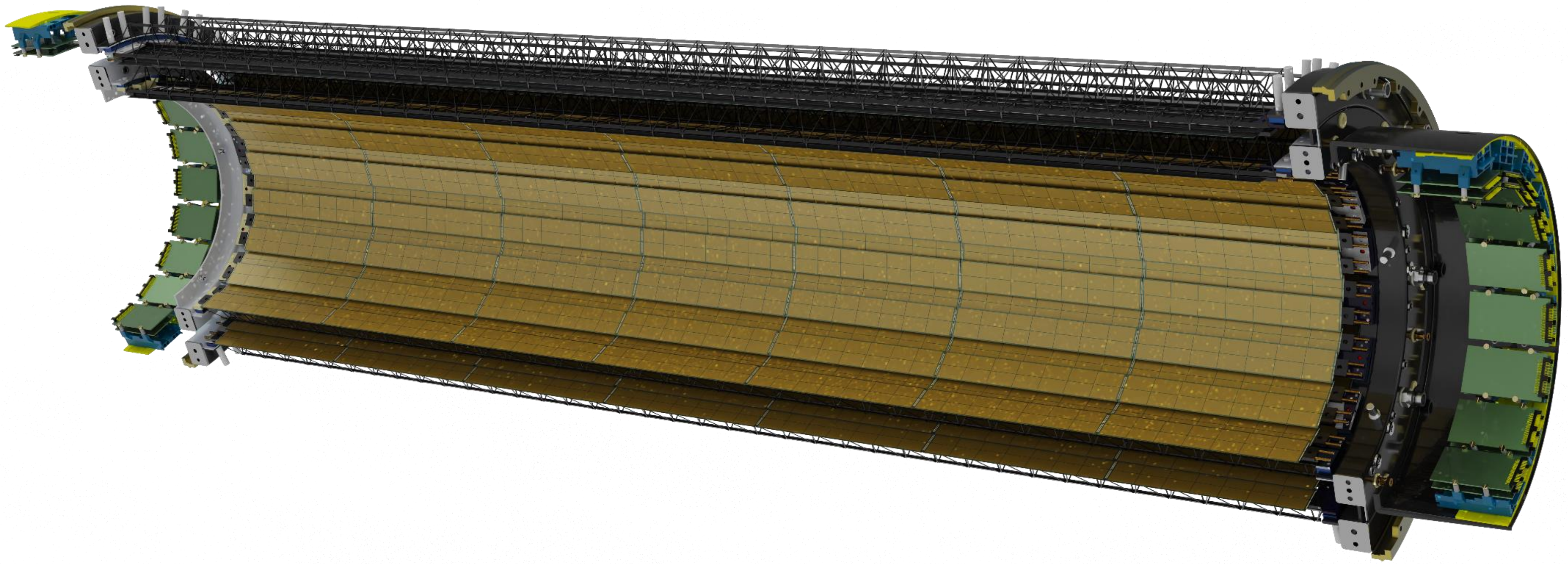


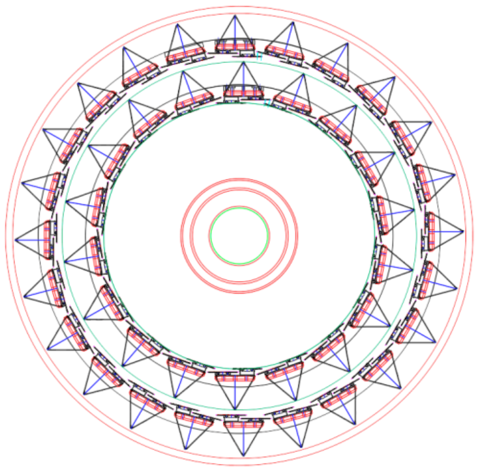
Outline

- Inner Tracking System of MPD detector
- Design of the cooling plate of the ITS stave
- Thermo-hydraulic tests
- Gas cooling tests

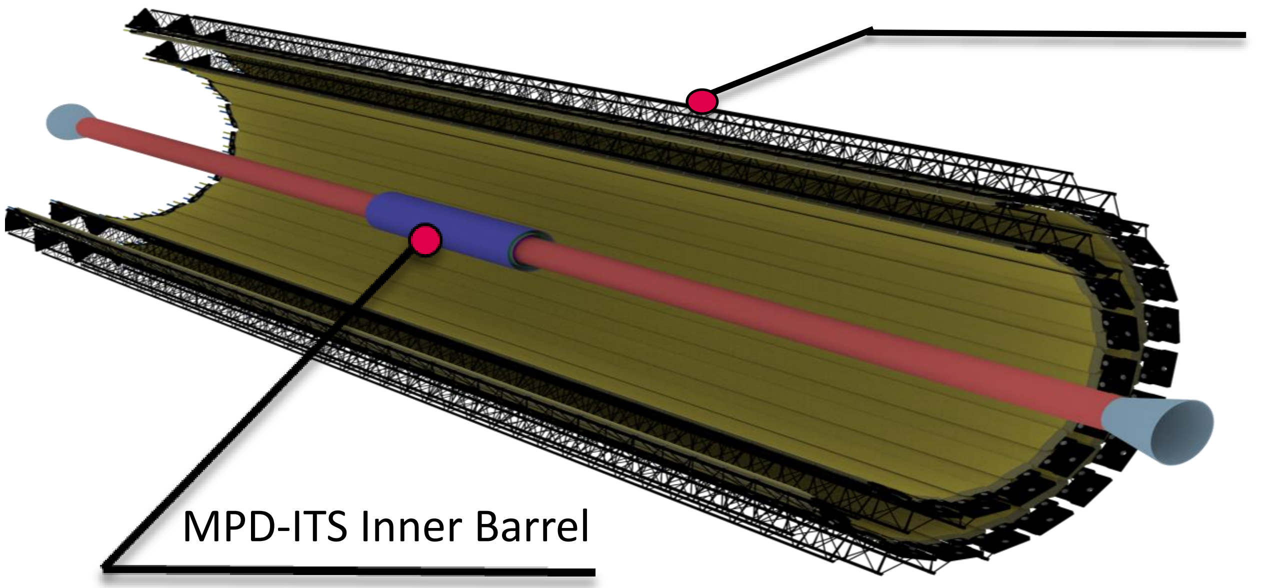
Inner Tracking System of MPD detector

- 5 cylinder layers; 2 barrels (IB, OB);
- Inner Barrel contains 3 layers pixels detectors
- Outer Barrel contains 2 layers pixels detectors:

  Layer 4: 18 STAVEs / Layer 5: 24 STAVEs
- OB - 8232 MAPS-based pixel 3,7 m^2
- The total heat dissipation of the system is 14kW



Diameter of the ITS caging
Is 495 mm

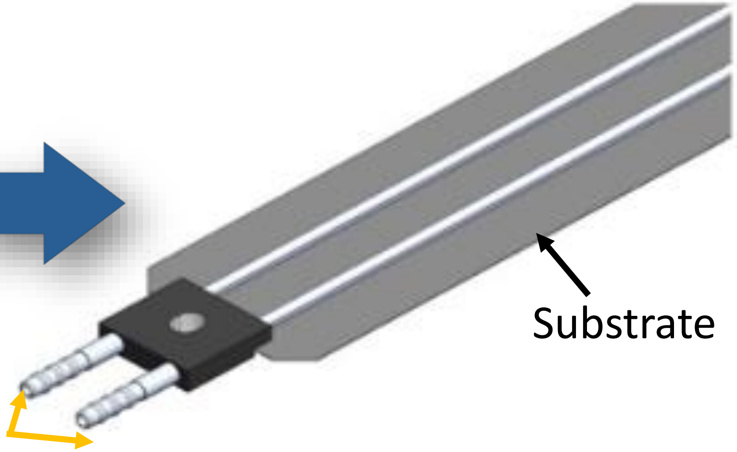


Composition of MPD ITS

ALTAI chips from
Tower Jazz

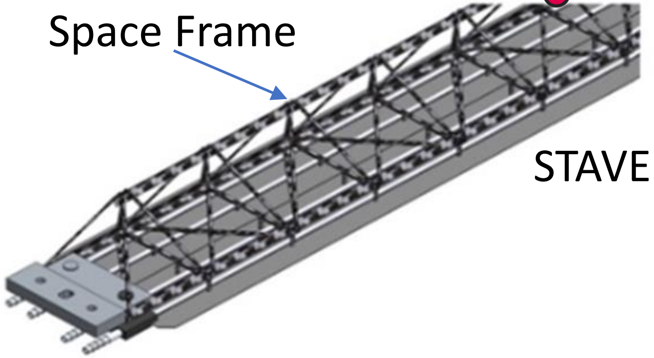
Hybrid Integrated Circuits (HIC)

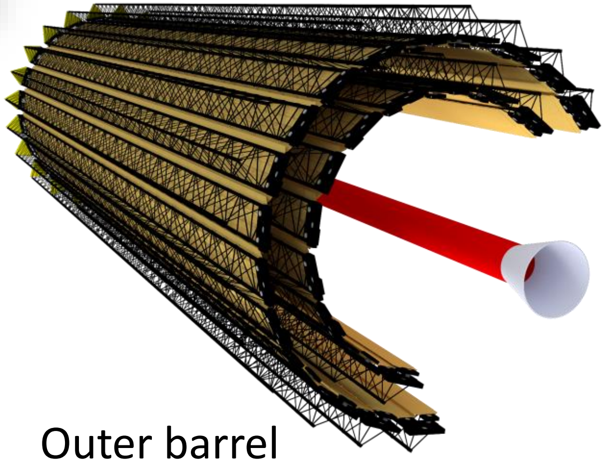
252 HIC’s = Layer 4
336 HIC’s = Layer 5



Cold Plate of the Outer
Barrel Staves of MPD-ITS.

length - 1510mm
width - 34±0,5mm



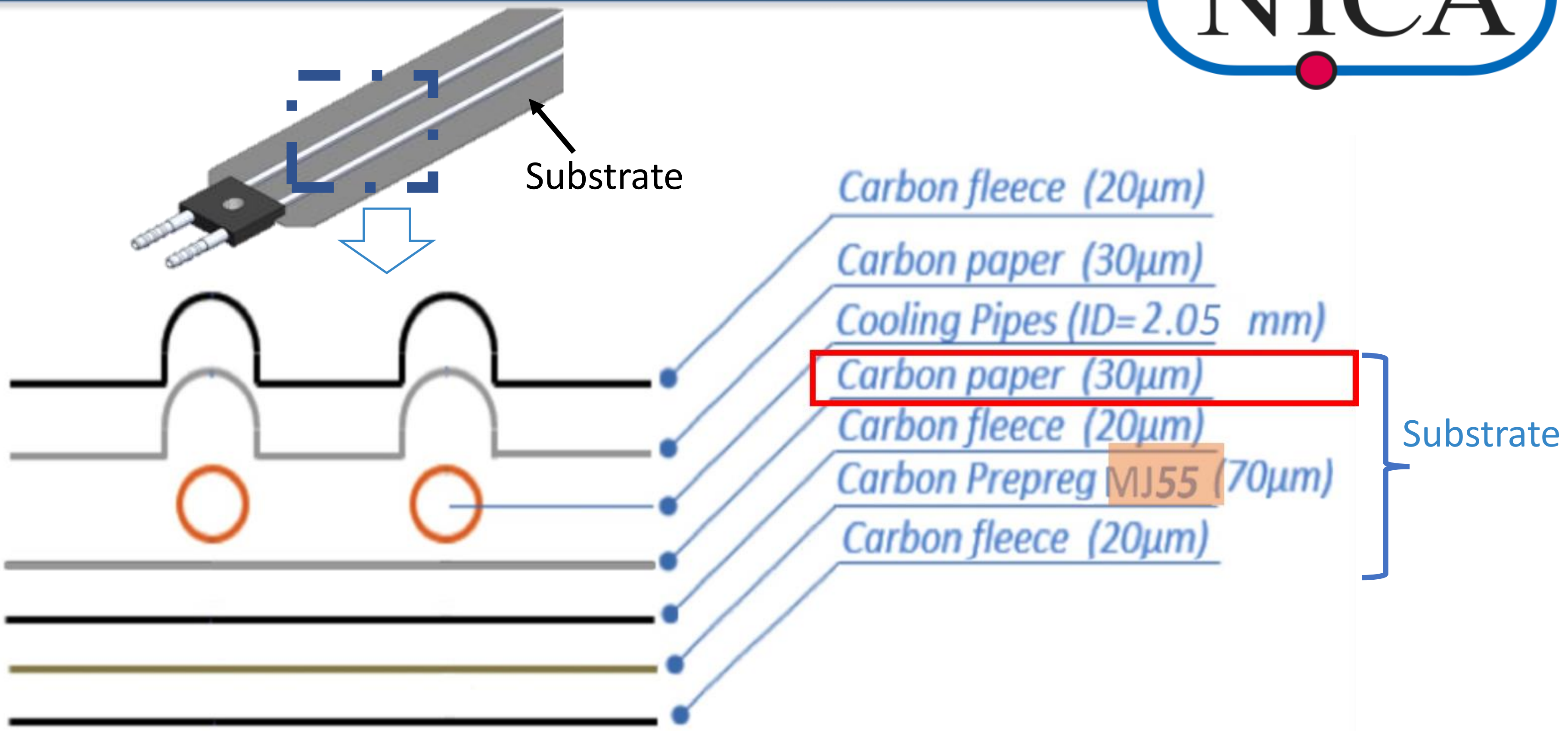


Layer 4 = 18 STAVE’s
Layer 5 = 24 STAVE’s

Design of the cooling plates

The development of ultra-lightweight cooling concepts requires considering:

- The mechanical requirements (stiffness, dimensional constraints),
- The cooling performance (size of the cooling channels, CFRP fiber density, materials)
- Manufacturing feasibility.



Other prepreg + without an additional layer carbon paper single layers JINR cooling plate
Other prepreg + with an additional layer carbon paper double layers JINR cooling plat

Thermo-hydraulic tests

Sensor's heat imitator

The cooling plate will be fix to 5 heat imitator with the thermal interface (glycerin)

Size of the OB HIC heat imitator
width - 3,4 ±0,1 cm
length - 29,3±0,2 cm
thickness – 0,8 ±0,1 mm

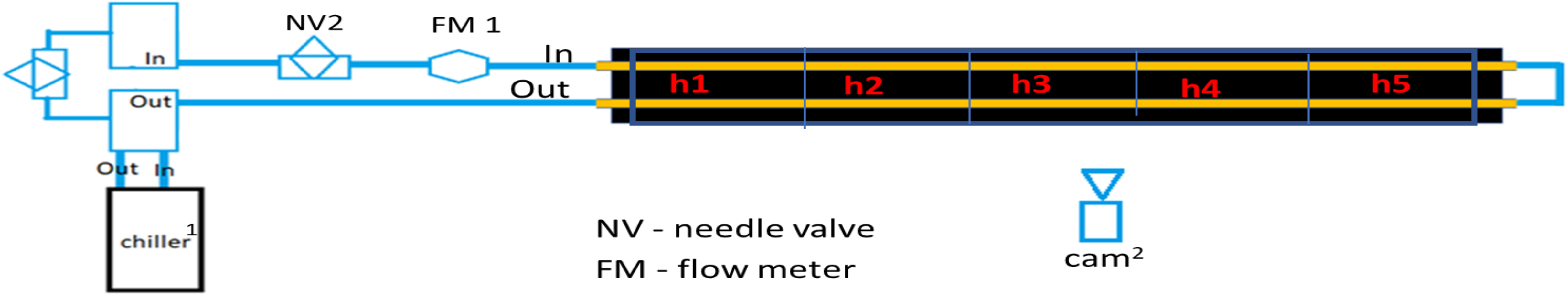
A prototype in which a heating element made from a nichrome wire. It was used as a simulator of sensors:
100 um Si size of 15x30 mm^2
198 pcs
Power = 40 mW/cm^2.

Power was regulated by DC power supply

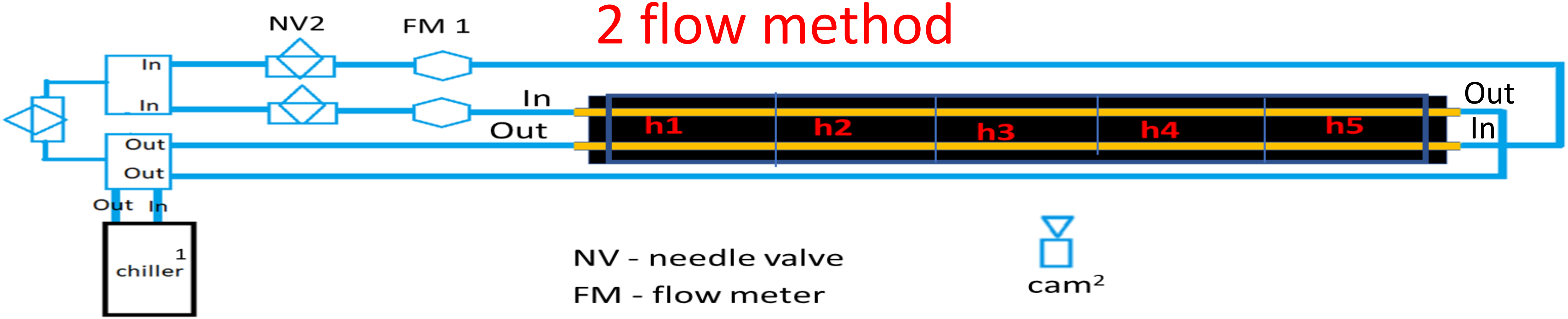
cooling panel

Thermo-hydraulic tests

Loop method



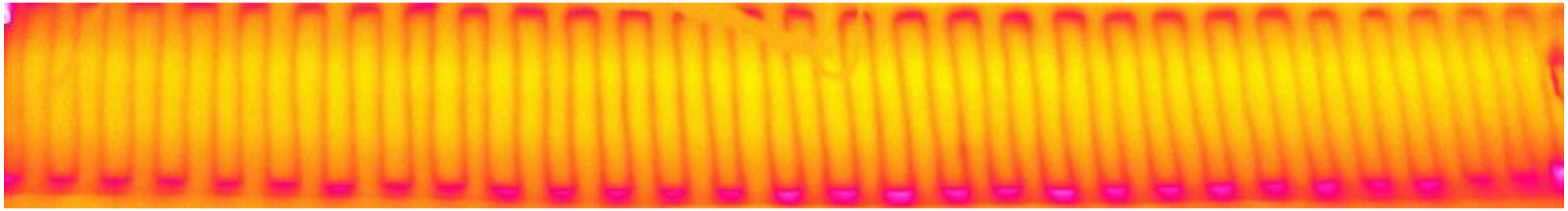
2 flow method



1 – LAUDA ALPHA RA 8
2 – VarioCAM HD headsl

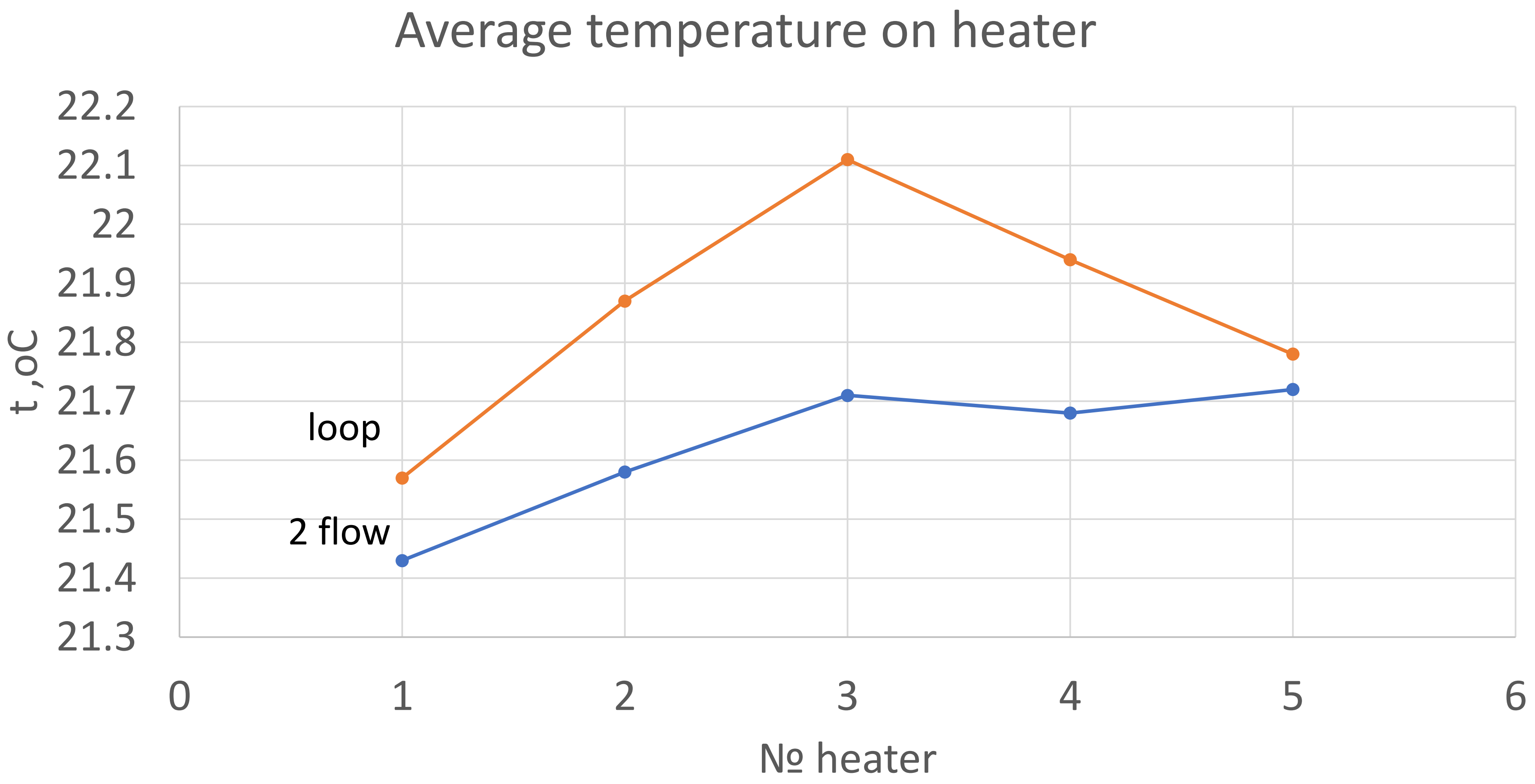
Average test conditions

- Average ambient temperature **21,7±0,5 °C;**
- Water supply temperature(in chiller)**18±0,2 °C**;
- Water flow rate(loop) **5,8 ± 0,5 l/h;**
- Power - **40 mW/cm².**
- **Measurements with a thermal imager**
- **temperature measuring performed using Pt 100**



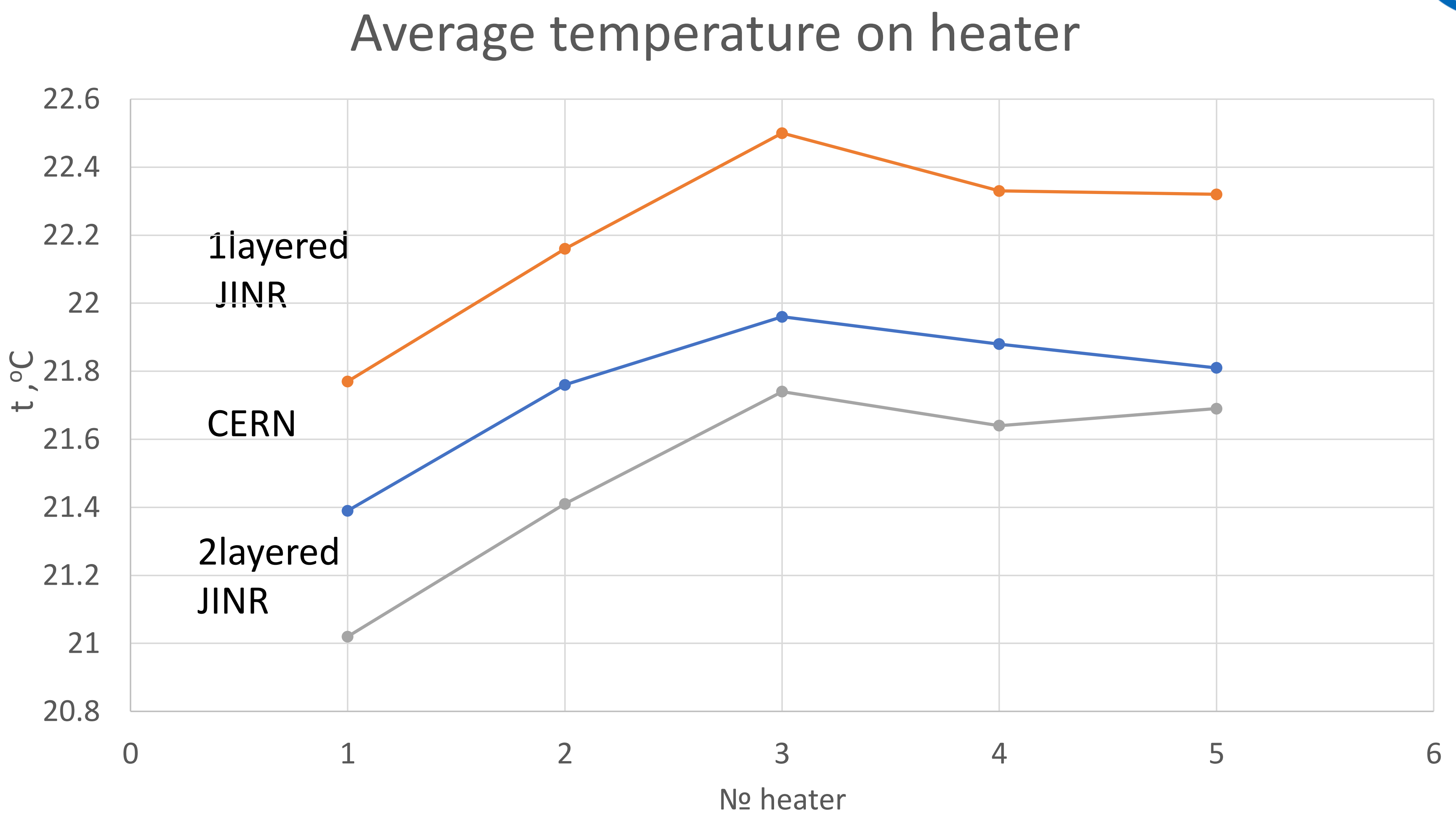
(x5)

Compare 2 method water flow "2 flow " and " loop " water flow for double layered JINR



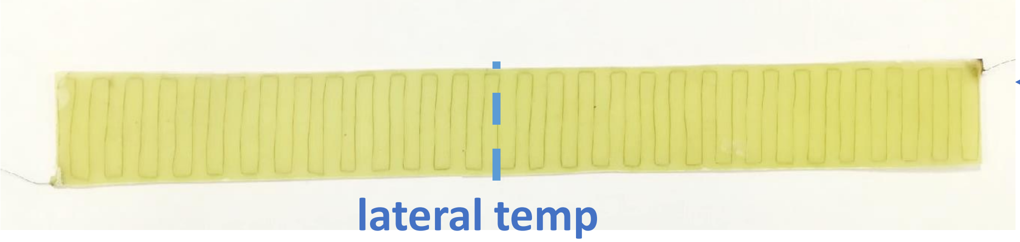
These measurements have shown that the use of the “2flow” method is 1 % more efficient than using the “loop” method,
but the complexity of its implementation and the slight temperature difference do not justify its further use.
In further work, only the "loop" method will be considered.

Compare 3 different design for cooling plate in loop method



The test stand for the air

Experimental setup

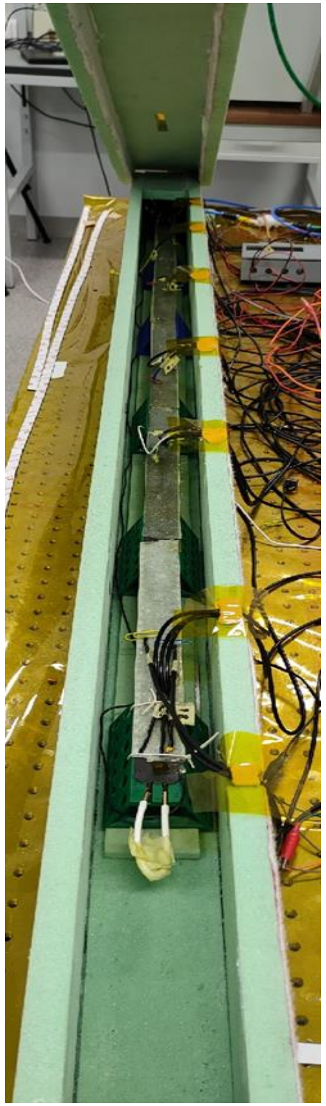


heat imitators

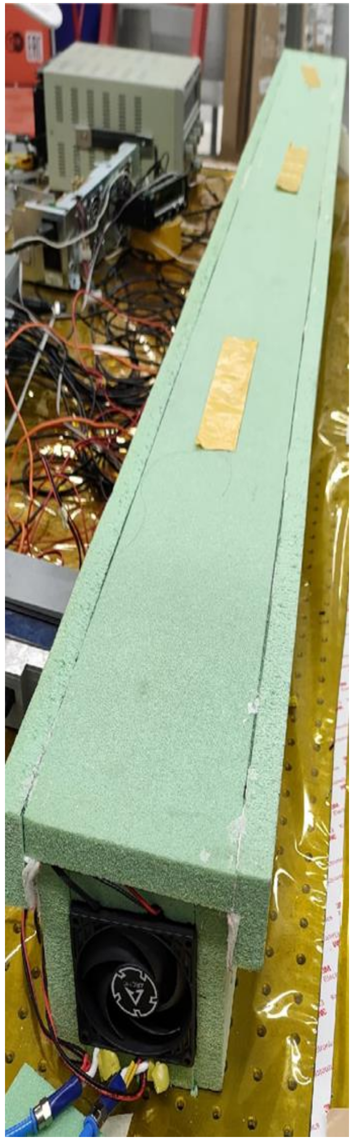
MAPS chip:100 um Si size of 15x30 mm^2
98 pcs
W = 58 mW/cm^2.

The cooling panels will be fix to the heat imitator with glycerin

cooling panel



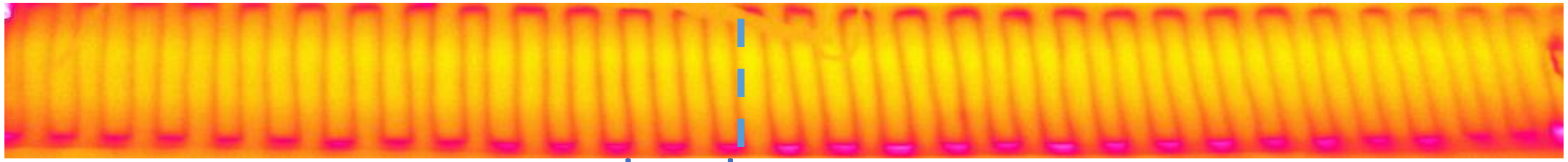
mounted the fans on both sides of the box



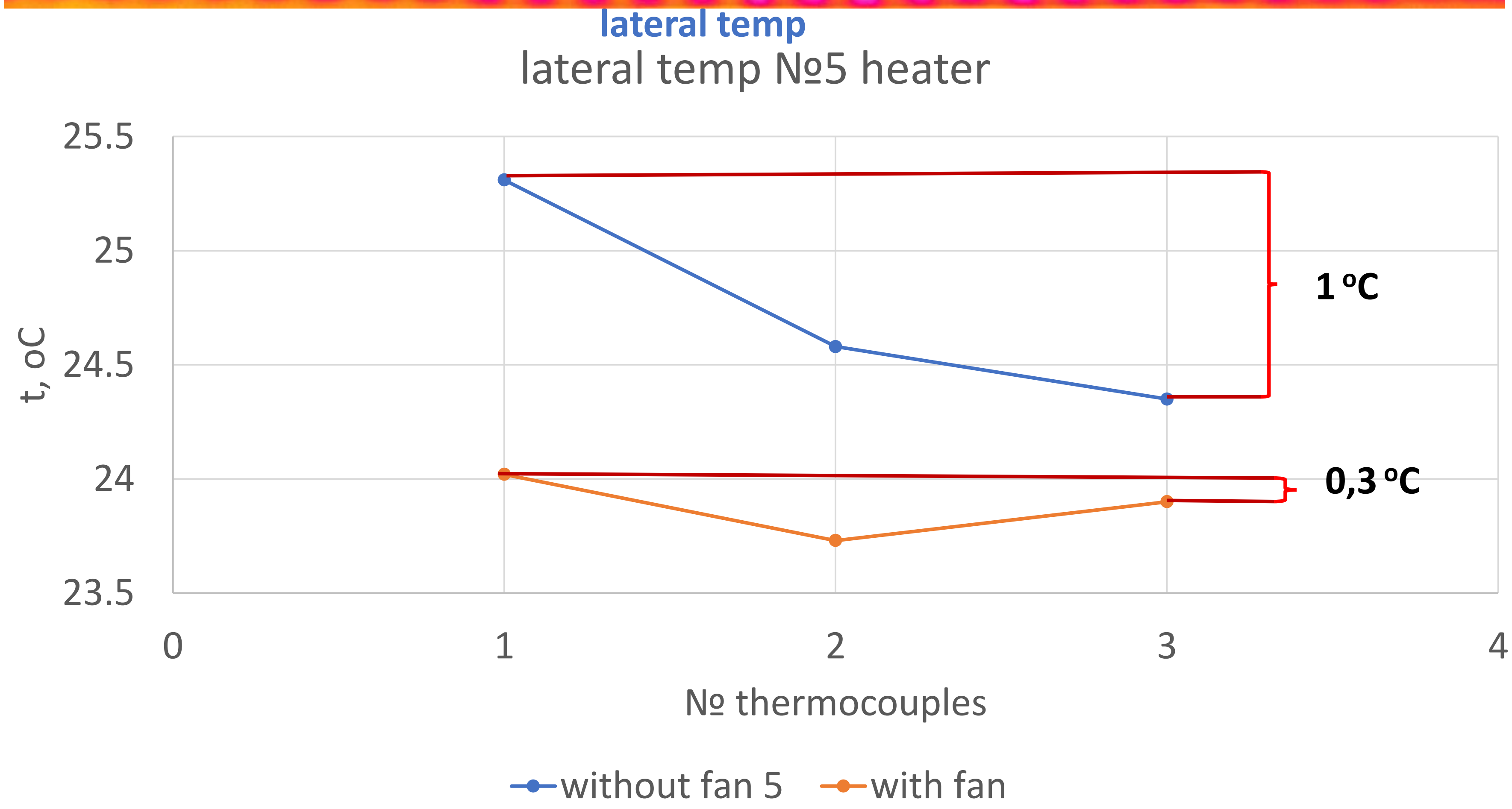
Box from Airex C70.75
length - 2000mm
width - 120mm
Thickness – 20mm

Air flow rate – about 2 m/s

The test stand for the air



(x5)



The ITS gas-flow system reduce the temperature gradient along the vertical axis on 2%

Conclusion

- JINR double layered cooling plate has shown lower temperature and better heat distribution than the single layered panels produced at JINR and CERN.
- Two cooling methods were tested: “2nd flow” and “loop” with different pipe connection schemes
- The measurements have shown that the use of the “2nd flow” method is 1 % more efficient than using the “loop” method, but the complexity of its implementation and the slight temperature difference do not justify its further use.
- The ITS gas-flow system reduced the temperature gradient along the vertical axis about on 2% .

Thank you for the attention

Table 3.2: Detector and service electronics requirements

Requirement		Detector	Sevice electronics
T_{max} Pixel chip working		30 °C	40 °C
ΔT_{max} (uneven)		≤5 °C	
Settings	Magnetic field	500 mT*	400 mT**
	Temperature	T=20 °C RH=35% $T_{Dew\ point}$=4 °C	T_{ux25}=24 °C RH_{ux25}=45% $T_{Dew\ point}$=12 °C
Stability		Temporary (it will not be possible to calibrate) detector positioning ≤5 µm	
Installation/ Removal		Ability to move non-functioning boards (3 months)	Ability to move non-functioning boards (3 months)
System access		Detector installation and maintenance available on both sides	Detector installation and maintenance available on both sides

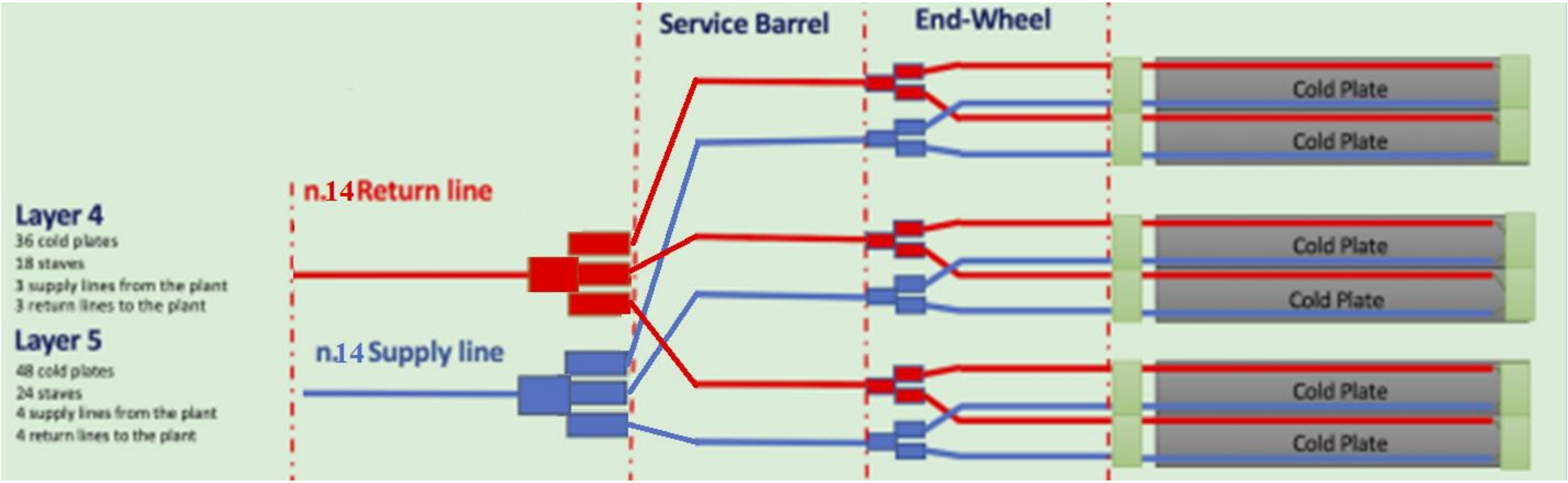
ITS air cooling sysms basic characteristics.

Parameter	**Air circulation**
Air flow	Q=30 m³/h±6 m³/h OB airflow: 20 m³/h Service unit: 7 m³/h
Temperature	T_{in}=20 °C
Humidity	RH_{out}=10 % to 35 % (RH to be set in this range)
Flow direction in the layers*	Layer 5 from A to C Layer 4 from C to A
Flow rate	<2 m/s (Detector housing)

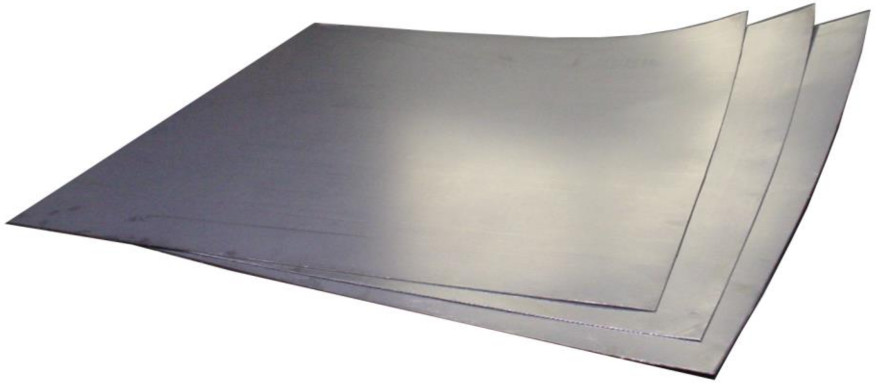
Table 3.3: Technical requirements for Staves and electronics

Technical specifications	**Detector Staves**	**RU Electronics**
Power load	OB: 84 pcs (Half Staves) From the detector 1555 W* Bus 63 W Power Cable 22 W	7.5 kW
Stave pressure difference and water consumption	OB: ΔP=0.2 Kg/cm² Q=6.3 l/h Σ530 l/h	OB: 0.3 Kg/cm² Stave Q=11 l/h
Chip / valid temperature Range	20 °C to 30 °C	20 °C to 40 °C
Chip / working temperature	22 °C±1 °C	30 °C±5 °C

(*)Calculation based on Alpide 4; OB = 28 mW/cm² + 50%.


Service Barrel
End-Wheel
n.14 Return line
n.14 Supply line
Layer 4
36 cold plates
18 staves
3 supply lines from the plant
3 return lines to the plant
Layer 5
48 cold plates
24 staves
4 supply lines from the plant
4 return lines to the plant
Cold Plate
Cold Plate
Cold Plate
Cold Plate
Cold Plate
Cold Plate

Graphite sheets property



FGS-003 graphene paper from AMEC
Thermasol (Chinese paper OLD, 2 layer)

Thickness (µm) ~ 30
Thermal conductivity
X-Y Ax. (W/(m · K)) ~ 1500
Z Ax. (W/(m · K)) ~ 15
Density(g/cm^3) ~ 1,43

Synthetic Graphite Sheet:DSN5032
(Chinese paper NEW, 2 layer)

Thickness (µm) - 32±4
Thermal conductivity:
X-Y Ax. (W/(m · K)) -1300~1500
Z Ax. (W/(m · K)) - 17~20
Density(g/cm^3) - 1.85±0.05

calculations

CERN2 loop

$F := \pi \cdot 2 \cdot \frac{R0}{2} \cdot 1{,}51 = 0{,}0097 \quad м^2$

$\lambda := 0{,}5977$

$a := 14{,}3 \cdot 10^{-8} \quad \frac{m^2}{c}$

$\gamma 0 := 1{,}015 \cdot 10^{-6}$

$\gamma w := 9{,}629 \cdot 10^{-7}$

$\beta := 0{,}00177$

a-коэффициент-температуропроводности, m^2/c

$Re := \frac{\omega \cdot R0}{\gamma 0} = 987{,}5399$

$Pr := \frac{\gamma 0}{a} = 7{,}0979 \qquad Prст := \frac{\gamma w}{a} = 6{,}7336$

$g := 9{,}81$

$Tw := 21{,}76$

$Tf := (18{,}37 + 20{,}8) \cdot 0{,}5 = 19{,}585$

$T0 := 0{,}5 \cdot (Tw + Tf) = 20{,}6725$

$R0 := 2{,}05 \cdot 10^{-3}$

$F0 := \pi \cdot \frac{R0^2}{4} = 3{,}3006 \cdot 10^{-6}$

$V1 := \frac{5{,}8}{3600} = 0{,}0016 \quad \frac{l}{c}$

$\rho := 998{,}3 \quad \frac{kg}{m^3}$

$\omega := \frac{V1}{\rho \cdot F0} = 0{,}489 \quad \frac{m}{c}$

$l := 1{,}51 \quad m$

$\varepsilon зм := 1 + \frac{3{,}54 \cdot 2{,}05 \cdot 10^{-3}}{1{,}5 \cdot 10^{-2}} = 1{,}4838$

критерий Панделя

$Gr := \frac{g \cdot \beta \cdot R0^3 \cdot (Tw - Tf)}{\gamma 0^2} = 315{,}8137$ критерий Граскофа

$Ra := Gr \cdot Pr = 2241{,}6151$ критерий Рэлея

$Ra < 8 \cdot 10^5$ ламинарно вязкостный режим движения

$\frac{l}{Re \cdot R0} = 0{,}7459 \qquad \varepsilon l \geq 0{,}1 \qquad \varepsilon \iota := 1$

$Pe := \frac{\omega \cdot R0}{a} = 7009{,}4613$ критерий Пекле

$\mu w := 0{,}0009609 \quad Па \cdot c$

$\mu f := 0{,}0009865 \quad Па \cdot c$

$Nu := 1{,}55 \cdot \left(\frac{Pe \cdot R0}{l}\right)^{\frac{1}{3}} \cdot \left(\frac{\mu f}{\mu w}\right)^{0{,}14} \cdot \varepsilon \iota = 3{,}2967$

μ – динамический кооэфициент вязкости

$\alpha := \frac{Nu \cdot \lambda}{R0} = 961{,}1996$

$P := \alpha \cdot F \cdot (Tw - T0) = 10{,}1654$

1 layer

$Tw := 22{,}05$

$V1 := \frac{5{,}8}{3600} = 0{,}0016 \quad \frac{l}{c}$

$Tf := (18{,}61 + 21{,}28) \cdot 0{,}5 = 19{,}945$

$\rho := 998{,}2$

$T0 := 0{,}5 \cdot (Tw + Tf) = 20{,}9975$

$\omega := \frac{V1}{\rho \cdot F0} = 0{,}489 \quad \frac{m}{c}$

$\lambda := 0{,}598$

$\beta := 0{,}00177$

$\varepsilon \iota := 1 \qquad a := 14{,}3 \cdot 10^{-8} \quad \frac{m^2}{c} \qquad V := 0{,}001611 \quad \frac{l}{c}$

а-кцэффициент-температуропроводности, m^2/c

$Pe := \frac{\omega \cdot R0}{a} = 7010{,}1635$ критерий Пекле

$\mu w := 0{,}0009542 \quad Па \cdot c$

$\mu f := 0{,}0009787 \quad Па \cdot c$

$Nu := 1{,}55 \cdot \left(\frac{Pe \cdot R0}{l}\right)^{\frac{1}{3}} \cdot \left(\frac{\mu f}{\mu w}\right)^{0{,}14} \cdot \varepsilon \iota = 3{,}2964$

$\alpha := \frac{Nu \cdot \lambda}{R0} = 961{,}5875$

$P := \alpha \cdot F \cdot (Tw - T0) = 9{,}8422$

calculations

2 layer

$Tw := 21,9$

$Tf := (18,44 + 21,14) \cdot 0,5 = 19,79$

$T0 := 0,5 \cdot (Tw + Tf) = 20,845$

$V1 := \frac{5,7}{3600} = 0,0016 \ \frac{l}{c}$

$\lambda := 0,598$

$\omega := \frac{V1}{\rho \cdot F0} = 0,4806 \ \frac{m}{c}$

$\rho := 998,2$

$a := 14,3 \cdot 10^{-8} \ \frac{m^2}{c}$

$\beta := 0,00177$

а-кцэффициент-температуропроводности, m^2/c

$Pe := \frac{\omega \cdot R0}{a} = 6889,2986$ критерий Пекле

$\mu w := 0,0009576$ Па·с

$\mu f := 0,0009824$ Па·с

$$Nu := 1,55 \cdot \left(\frac{Pe \cdot R0}{l}\right)^{\frac{1}{3}} \cdot \left(\frac{\mu f}{\mu w}\right)^{0,14} \cdot \varepsilon_l = 3,2775$$

$\alpha := \frac{Nu \cdot \lambda}{R0} = 956,058$

$P := \alpha \cdot F \cdot (Tw - T0) = 9,8088$

china paper2 NEW

$R0 := 2,05 \cdot 10^{-3}$

$F0 := \pi \cdot \frac{R0^2}{4} = 3,3006 \cdot 10^{-6}$

$\rho := 998,1 \ \frac{kg}{m^3}$

$\varepsilon_l := 1$ $\lambda := 0,599$

$Tw := 21,5$

$Tf := (18,13 + 20,53) \cdot 0,5 = 19,33$

$T0 := 0,5 \cdot (Tw + Tf) = 20,415$

$\mu w := 0,0009669$ Па·с

$\mu f := 0,0009926$ Па·с

$F := \pi \cdot 2 \cdot \frac{R0}{2} \cdot 1,51 = 0,0097 \ м^2$

$V1 := \frac{5,57}{3600} = 0,0015 \ \frac{l}{c}$

$l := 1,51 \ m$

$\omega := \frac{V1}{\rho \cdot F0} = 0,4697 \ \frac{m}{c}$

$F0 := \pi \cdot \frac{R0^2}{4} = 3,3006 \cdot 10^{-6}$

$a := 14,3 \cdot 10^{-8} \ \frac{m^2}{c}$

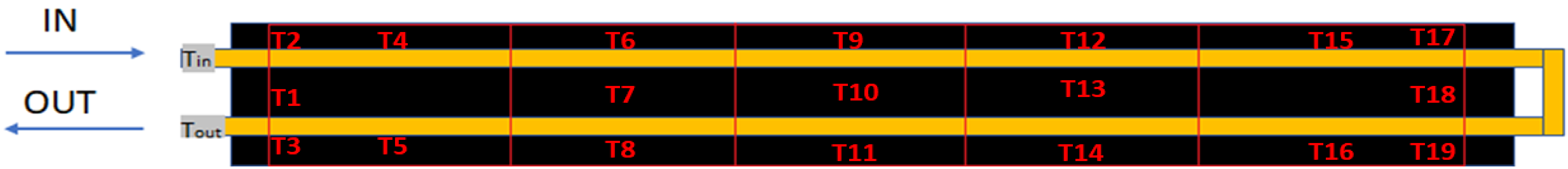
а-коэффициент-температуропроводности, m^2/c

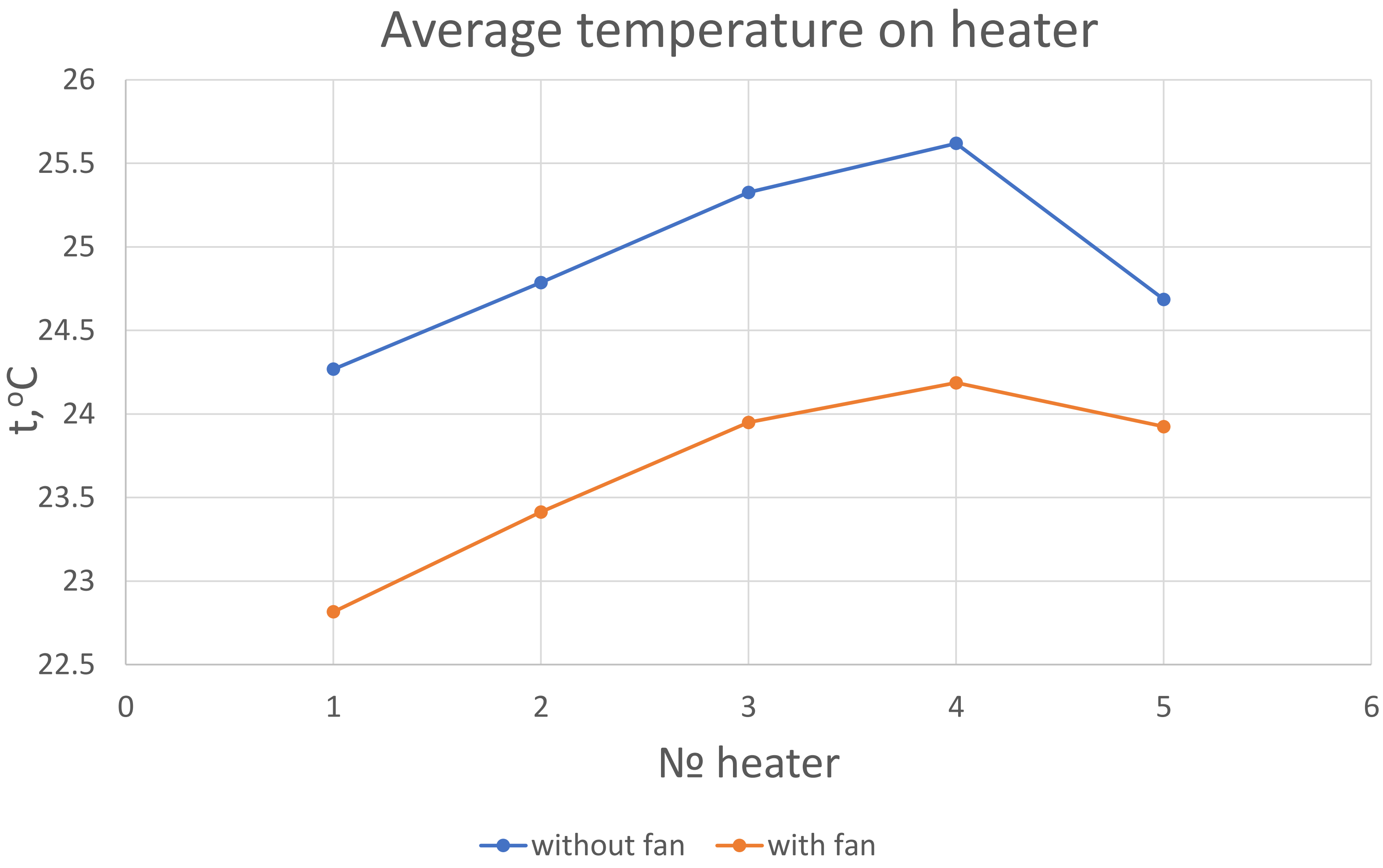
$Pe := \frac{\omega \cdot R0}{a} = 6732,8488$ критерий Пекле

$$Nu := 1,55 \cdot \left(\frac{Pe \cdot R0}{l}\right)^{\frac{1}{3}} \cdot \left(\frac{\mu f}{\mu w}\right)^{0,14} \cdot \varepsilon_l = 3,2528$$

$\alpha := \frac{Nu \cdot \lambda}{R0} = 950,4404$

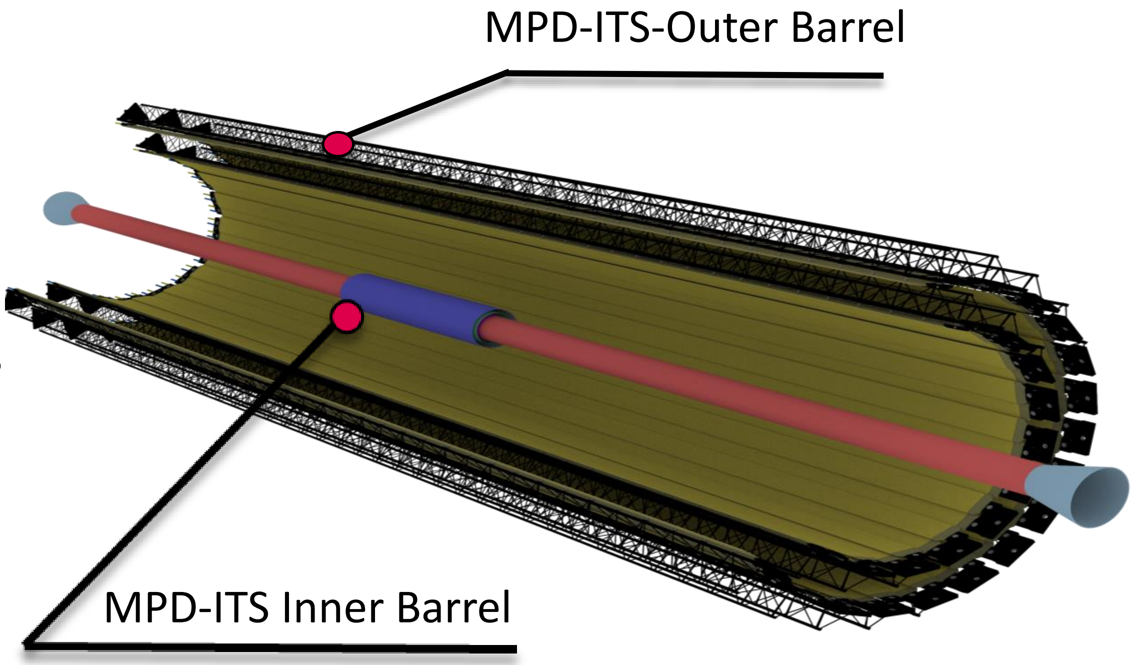
$Q := \alpha \cdot F \cdot (Tw - T0) = 10,0285$


IN
OUT
Tin
Tout
T2
T4
T6
T9
T12
T15
T17
T1
T7
T10
T13
T18
T3
T5
T8
T11
T14
T16
T19


Average temperature on heater
t, °C
26
25.5
25
24.5
24
23.5
23
22.5
0
1
2
3
4
5
6
№ heater
without fan
with fan

Inner Tracking System of MPD detector

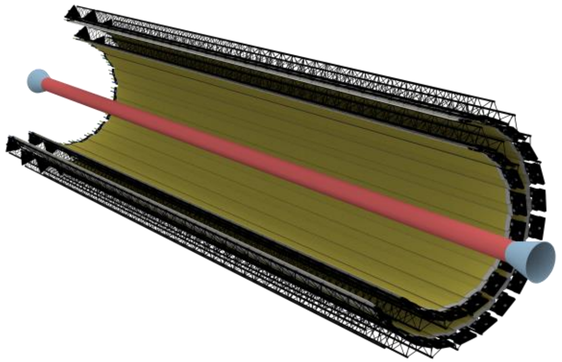
- The MPD installation must meet is to solve the very challenging task of the high precision registration of strange, multi-strange and charmed particles formed in the relativistic heavy-ion collisions at the energies of NICA collider
- The application of fast and high granularity pixel sensors is required (the total heat dissipation of the system is 14kW)
- A considerable reduction of the material budget components working in a sensitive region is a must to be considered



Inner Tracking System of MPD detector

The MAPS-based IT detector will enable charm-hadron measurements and detection of collision vertexes for the MPD experiment:

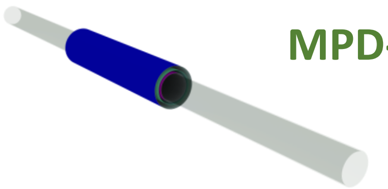
- Charm production in heavy ion collisions at the NICA energies
- Clean measurement of (multi-)strange hadron productions



MPD-ITS-Outer Barrel

Stage 1: ALPIDE-based OB layers (Design of ALICE ITS2)

Stage 2: Stiching-based large-area MAPS IB layers



MPD-ITS Inner Barrel

	Inner Barrel			Outer Barrel	
	Layer 0	Layer 1	Layer 2	Layer 3	Layer 4
R_{min} (mm)	18	24	30	145.8	194.4
R_{max} (mm)	18	24	30	147.9	197.6
Length (mm)	270	270	270	1468	1468
$P_{seudo\text{-}rapidity}$	±2.5	±2.3	±2.0	±2.0	±2.0
Number of chips per layer	4	4	4	3528	4704
Pixel chip dimensions (mm^2)	140 × 56.5	140 × 75.5	140 × 94	15×30	
Active area (cm^2) (2mm dead area in r-phi)	305	408	508	13 759	18 346

MAPS-based pixel

5 cylinder layers;

2 barrels (IB, OB);

4.5 x 109 pixels;

3.3 m^2 active area;

$|\eta| \leq 2.0$;