report by V L A D I M I R Z H E R E B C H E V S K Y

NEW VERTEX DETECTOR SYSTEMS FOR PARTICLE REGISTRATION IN HIGH-ENERGY PHYSICS AND POSSIBLE USE THESE TECHNOLOGIES FOR NICA EXPERIMENTS

09 19 23

Grigoriy FEOFILOV Sergey IGOLKIN Nikolai MALTSEV Vitaliy PETROV Vitaliy PETROV Egor ZEMLIN

St. Petersburg State University (project No ID: 94031112)

XXV International Baldin seminar on high energy physics problems
Relativistic nuclear physics & quantum chromodynamics

Outline

1. Silicon Vertex Detectors (VD) in high-energy physics experiments:
    a) Yesterday
    b) Today
    c) Tomorrow and the day after tomorrow

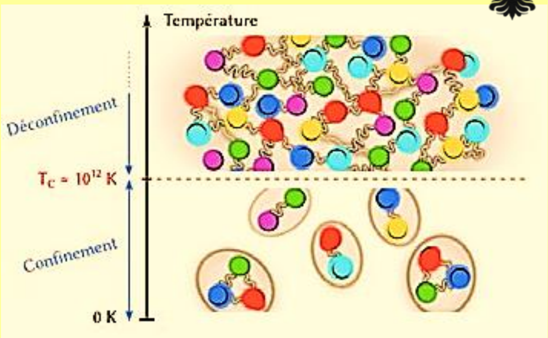
2. ALICE Inner Tracking System (ITS-2): current status

3. ALICE novel VD based on silicon monolithic active pixel sensors (MAPS)
    a) ITS-3
    b) ALICE-3

4. MAPS technologies for NICA: MPD, SPD, ARIADNA experiments

5. Conclusions

Silicon Vertex detectors in high-energy physics experiments

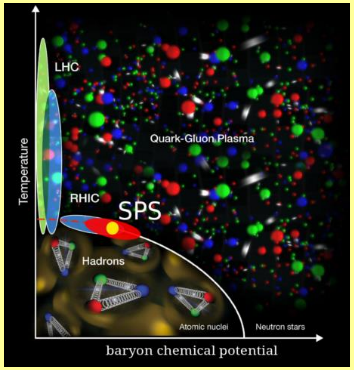


NuPECC Long Range Plan 2017
Perspectives in Nuclear Physics

Leading mega experiments:

ALICE, ATLAS, CMS, LHCb at the Large Hadron Collider

Higgs, Standard Model, Hadron physics,
Properties of Strongly Interacting Matter at extreme conditions of temperature



https://shine.web.cern.ch/node/12

NA61/SHINE at Super Proton Synchrotron

Properties of the onset of deconfinement

Evidence of critical point

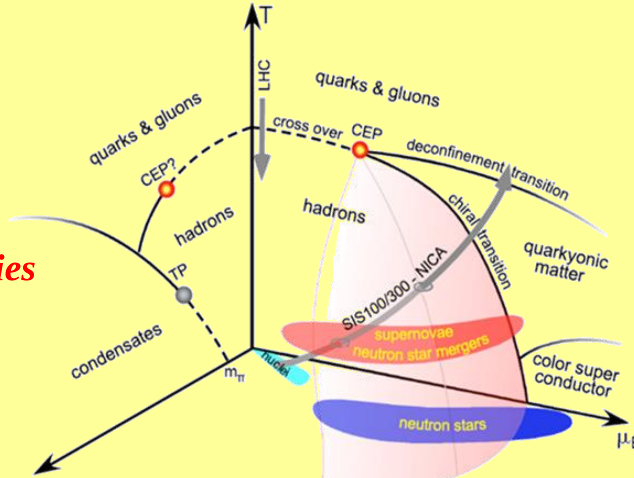
STAR at the Relativistic Heavy Ion Collider (RHIC)

Properties of quark-gluon plasma

CBM at SIS100 in GSI

Investigations of the QCD phase diagram in the region of high baryon densities

MPD, SPD at the NICA Collider



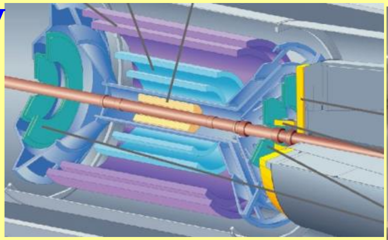
NuPECC Long Range Plan 2017 Perspectives in Nuclear Physics

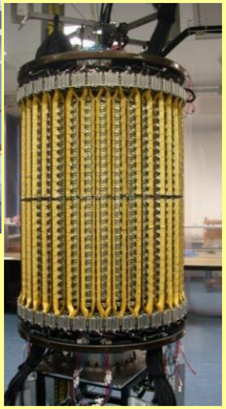
Silicon Vertex detectors in high-energy physics experiments: Yesterday

ALICE Pixel Detector
first two layers : tracking

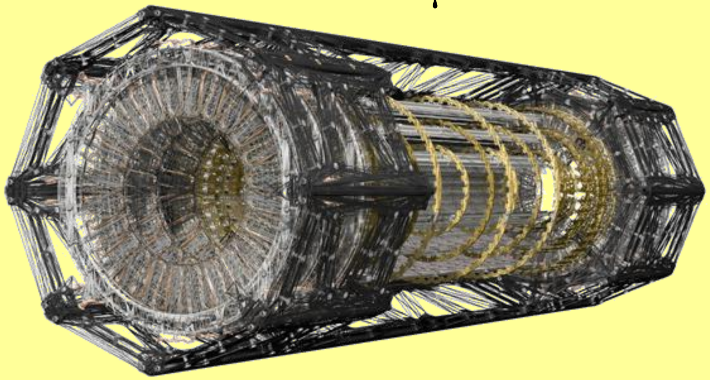
ALICE Drift Detector
two middle layers: tracking+PID

ALICE Strip Detector
two outer layers: tracking+PID

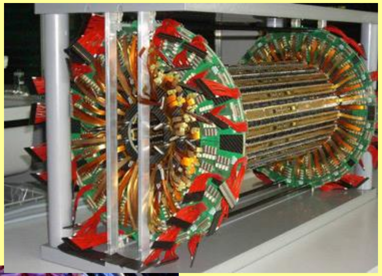




ATLAS Pixel Detector
80 million pixels, Area 1.7m^2
15 kW power consumption
Pixel Size 50 x 400μm^2



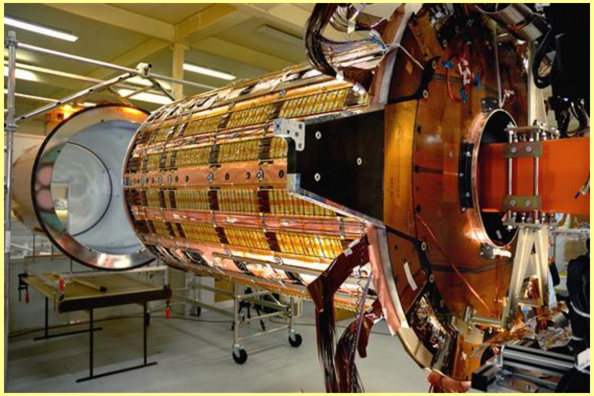
CMS Pixel Detector
65 million pixels. 100×150 um



CMS Strip Tracker IB
First 4 layers (strips)
10 cm x 180 um,
Next 6 layers (strips)
25cm x 180 um
10 million strips

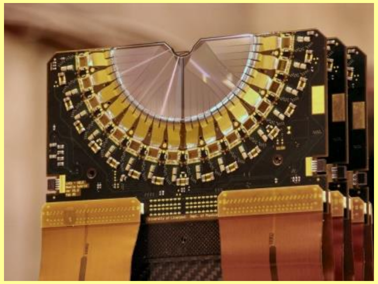
The largest Si detector in the world. More 200 m^2

ATLAS Semiconductor Tracker (SCT)



A silicon microstrip tracker : 4,088 two-sided modules and over 6 million implanted readout strips

LHCb VELO



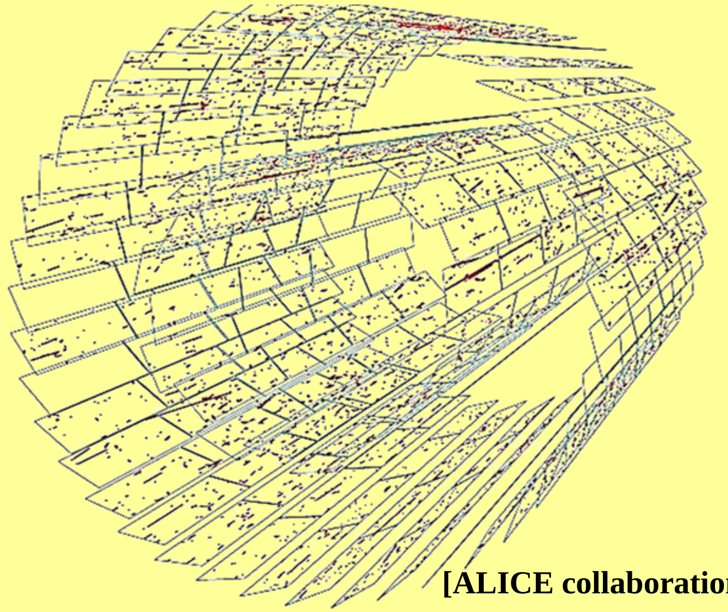
VErtex LOcator

silicon microstrip detector

[materials from www.cernch]

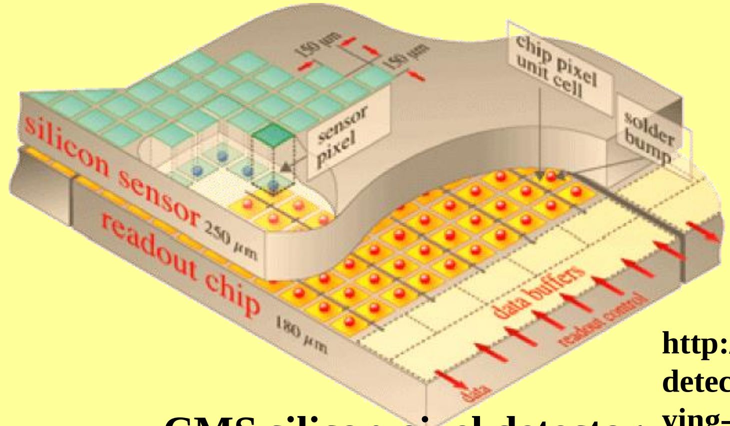
Hybrid Pixel Detectors in LHC

ALICE CMS ATLAS



[ALICE collaboration]

June 2008, ALICE Silicon Pixel detector registered muon tracks produced in the beam dump near Point 2 of the LHC



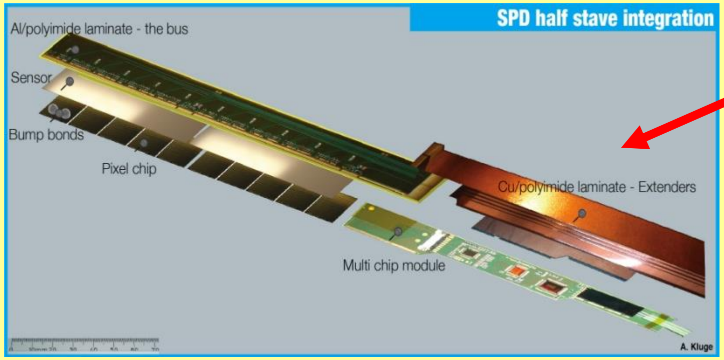
CMS silicon pixel detector

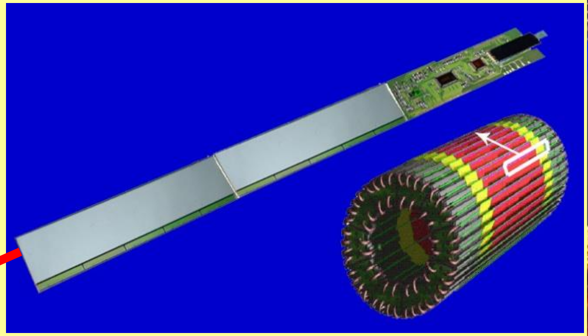
http://cms.cern/detector/identifying-tracks

Good position resolution: Smaller pixels, Higher integration

Small pixels - low capacitance - better S/N - smaller analog power

More pixels – More logic per pixels – high integration work at higher rates and high radiation lavel





ALICE silicon pixel detector

Silicon Vertex detectors in high-energy physics experiments: Today

For HEP experiments. For present and future trackers

Excellent tracking resolution:
Get closer to interaction point
Reduce sensor's size → More channels - Higher integration

Low mass tracking system – Minimum materials (cables, cooling, services) - Low power consumptions

Excellent tracking efficiency and p_T resolution at low p_T :
Increase granularity

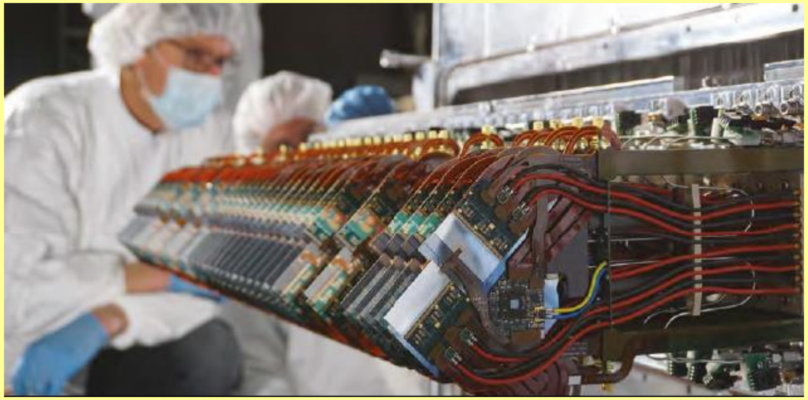
Radiation tolerance – work at high radiation doses

For electronics: acquire more data at higher rate - high speed data processing, low error rates (FPGA based trigger systems, CPU based DAQs)

We will built Large and complicated systems
acceptable cost!

Silicon Vertex detectors in high-energy physics experiments: Today

LHCb new Vertex Locator



silicon-hybrid pixel detectors:
200 μm-thick "p-on-n" pixel sensor bump-bonded to a 200 μm-thick readout chip with binary pixel readout

CERN Courier May/June 2022 p38

CMC Pixel Tracker

Concentric layers and rings of more than 1800 small silicon modules. Each of these modules has about 66000 individual pixels on it, for a total of 120Mpix

Each pixel is only 100x150 μm^2 in size

https://home.web.cern.ch/news/news/experiments/successful-installation-cms-pixel-tracker

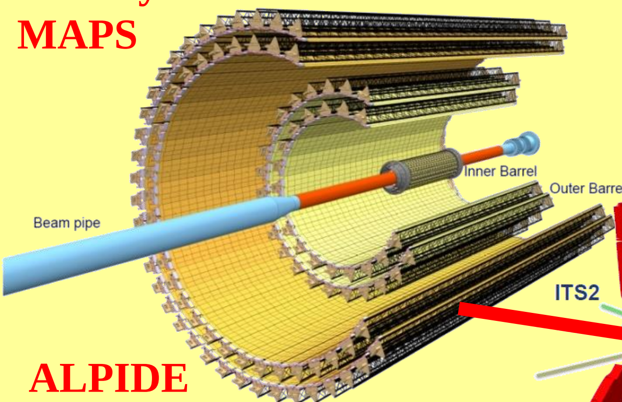
	ALICE upgrade	ATLAS upgrade	CMC upgrade
Innermost point (mm)	22.0	25.7	29.0
X/X_0 first layer	0.35%	1.54%	1.25%

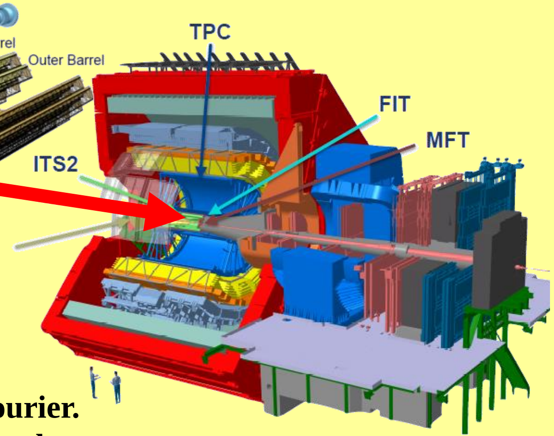
Silicon Vertex detectors in high-energy physics experiments: Today

MAPS trackers

ALICE: ITS-2

all 7 layers with MAPS

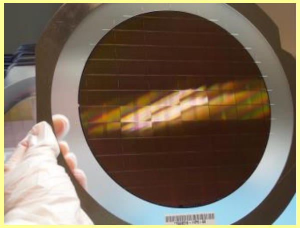




ALPIDE

180 nm CMOS technology

10 m^2 12 G pixel

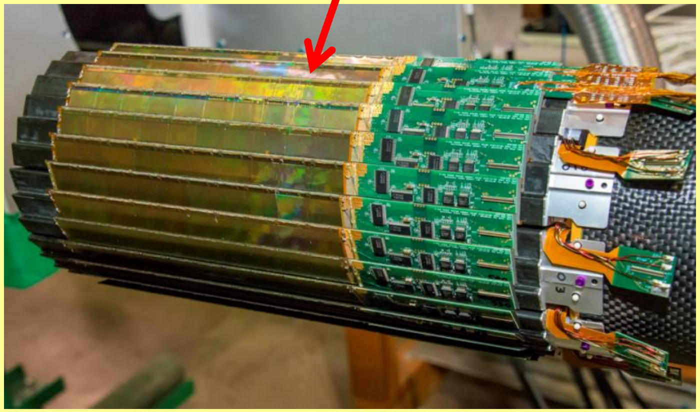


https://cerncourier.com/a/alice-tracks-new-territory/

STAR Heavy Flavour Tracker

1. Silicon Strip Detector (SSD)
2. Intermediate Silicon Tracker (IST)
3. Pixel Detector (PXL)

} Strip



Petra Riedler CERN Detector Seminar, April 28, 2017

PXL is the first operational vertex detector based on MAPS 350 nm CMOS technology

NA61/SHINE Small Acceptance Vertex Detector (SAVD)

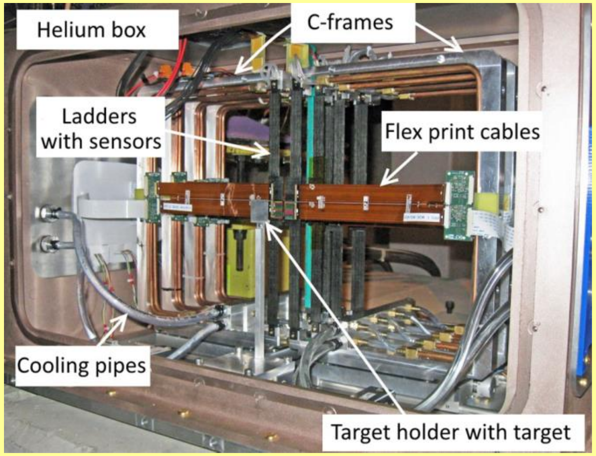
2018-2022

MIMOSA-26AHR

350 nm CMOS technology

NOW

ALPIDE 180 nm CMOS technology

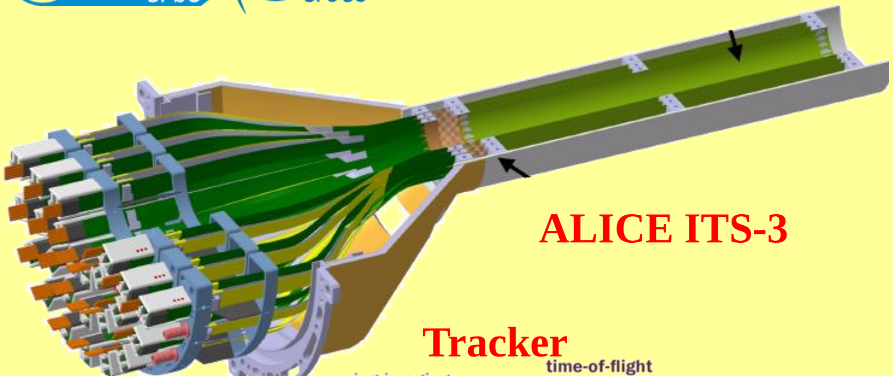


Eur. Phys. J. C (2023) 83:471

0.16 m^2 356 M pixel

https://nsww.org/projects/bnl/star/sub-systems.php

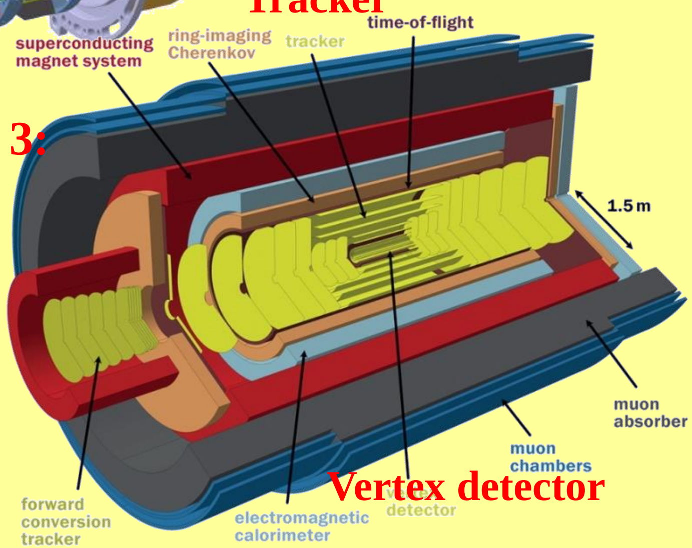
Silicon Vertex detectors in high-energy physics experiments: tomorrow and the day after tomorrow



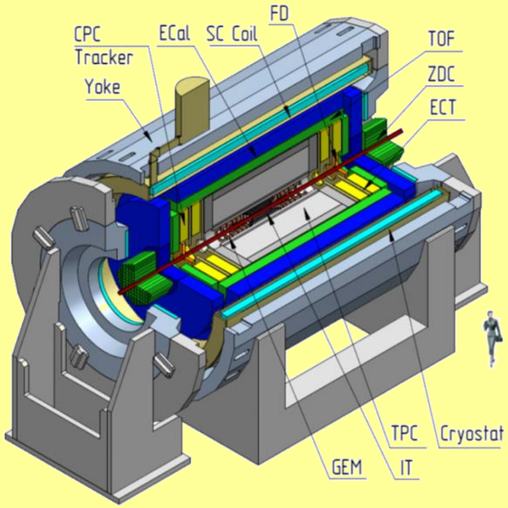
ALICE ITS-3

ALICE 3:

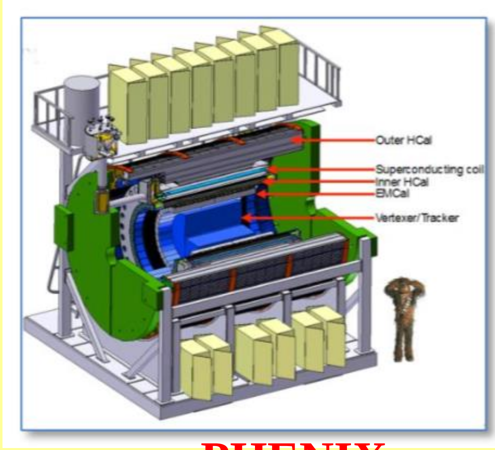
Tracker



Vertex detector



MPD at NICA



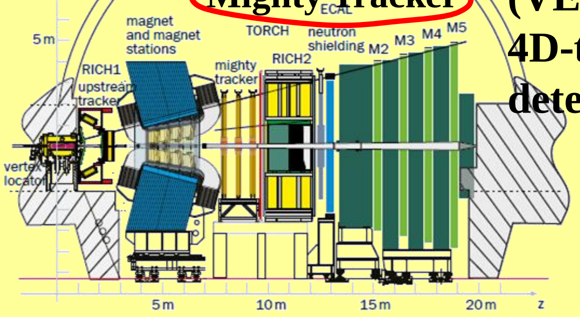
sPHENIX

0.2 m^2 251 M pixel

MAPS

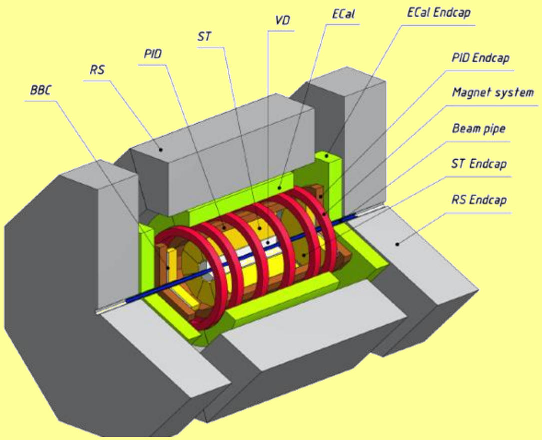
Upstream Tracker

Mighty Tracker

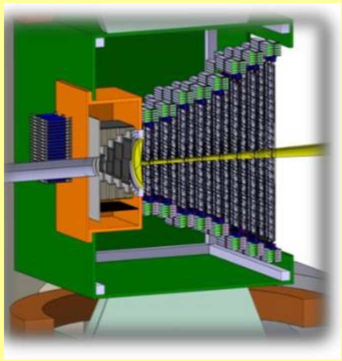


Vertex Locator (VELO) 4D-tracking detector

LHCb Run 3



SPD at NICA

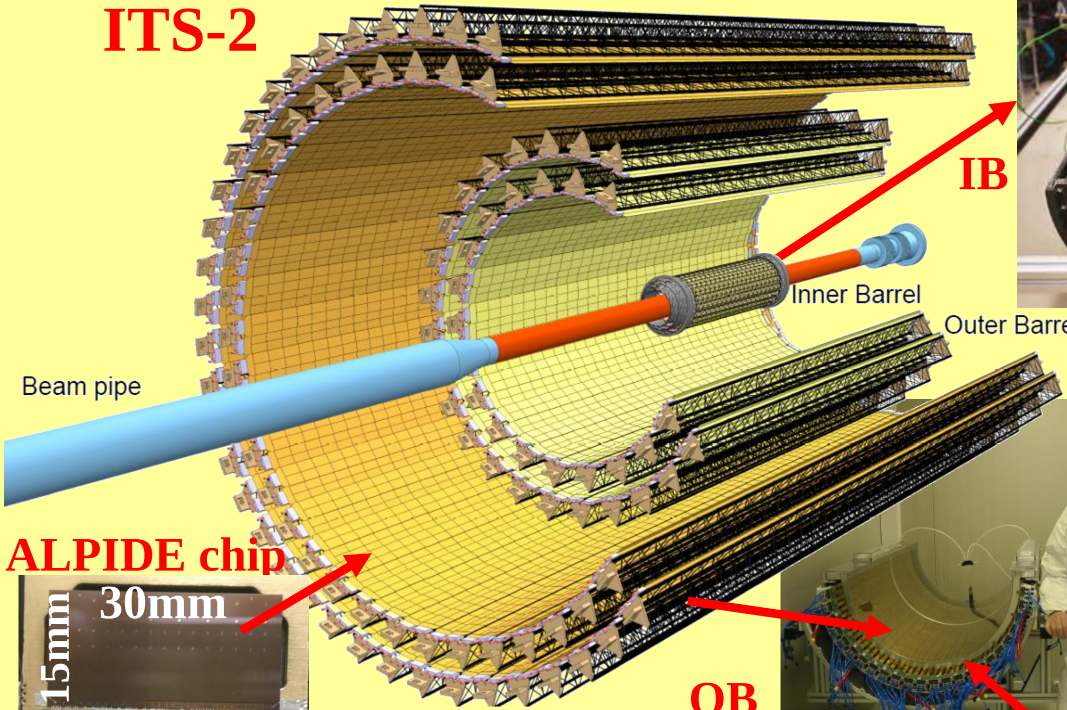


CBM MVD

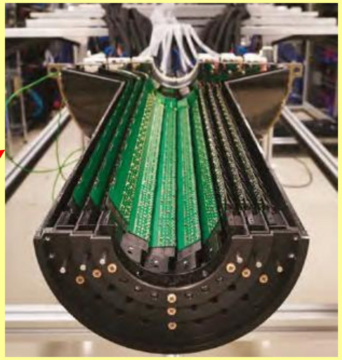
0.08 m^2 146 M pixel

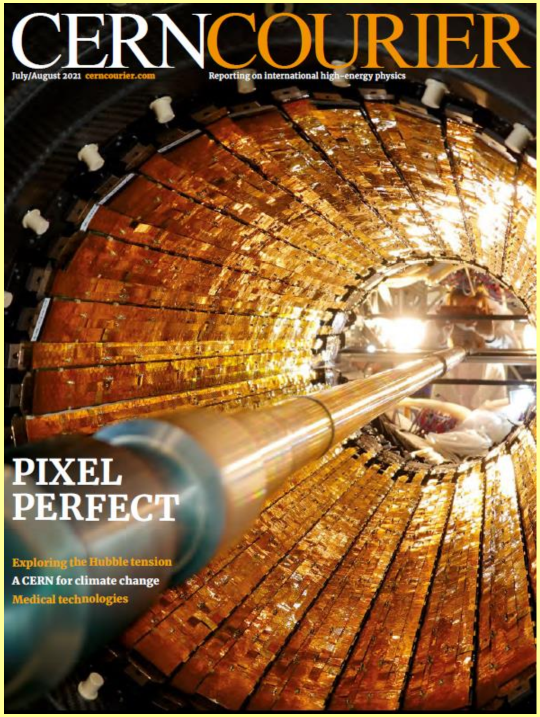
ALICE Inner Tracking System: current status

ITS-2



IB



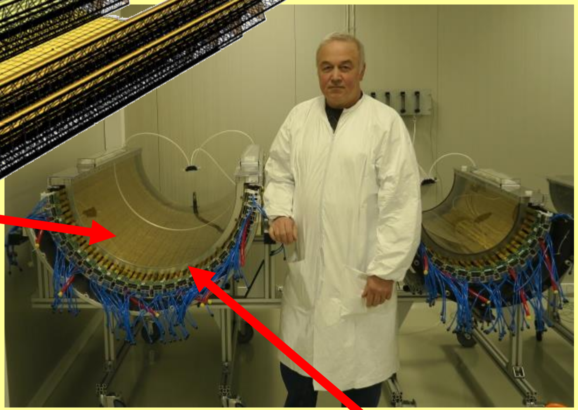


ALPIDE chip

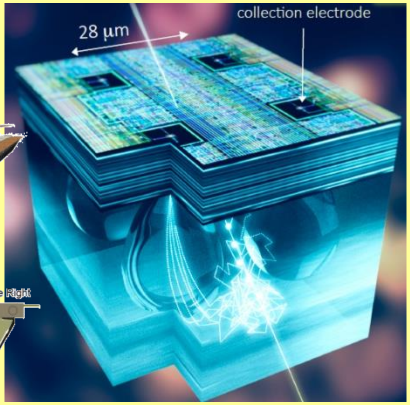
30mm
15mm

512 × 1024 sensitive pixels

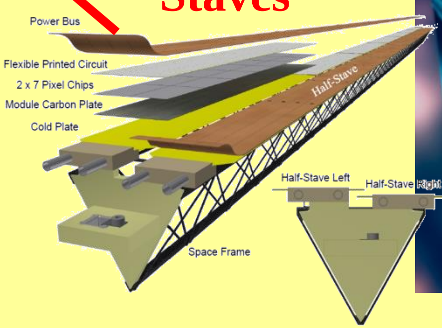
OB



ALPIDE pixel



Staves



ITS-2 ⟶ Barrel: 7 layers of MAPS – 12.5 G pixels
Inner Barrel (IB) : 3 layers
Outer Barrel (OB): 2 middle and 2 outer layers

pixel is 28x28 μm^2
Power density is 40 mW/cm^2

Physics motivation:

rare probes down to very low transverse momentum heavy-flavour program, quarkonium states, real and virtual photons, the study of jet quenching and exotic heavy nuclear states

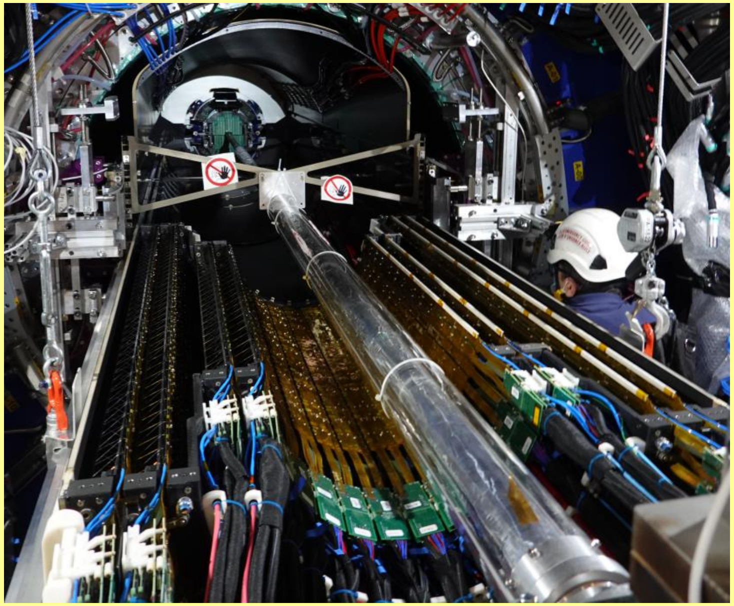
ALICE Inner Tracking System: current status

ITS-2

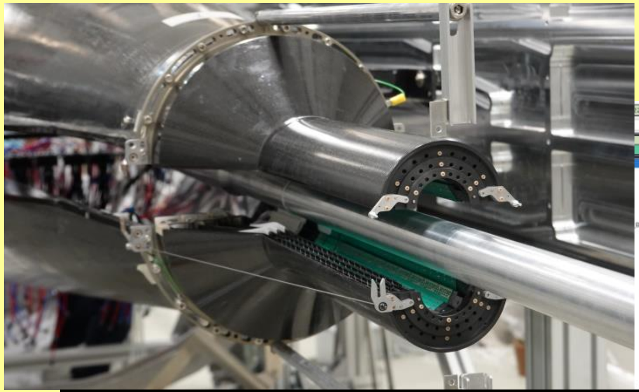
R&D, construction, installation, commissioning and operating since 2022

2012 → 2021

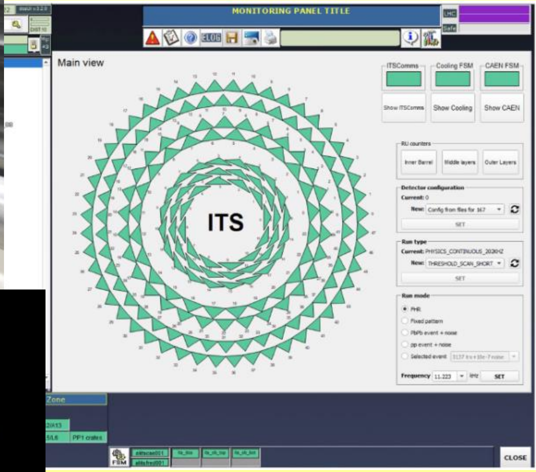
CERN + 35 Institutions

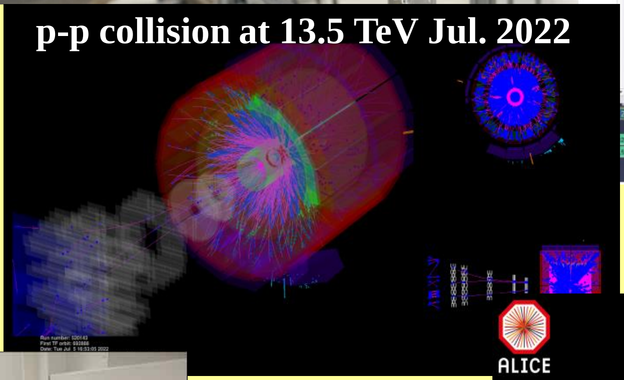


Outer Barrel Bottom installation inside the TPC

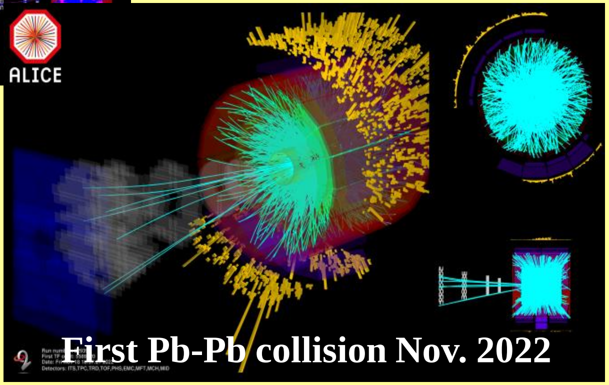


IB insertion





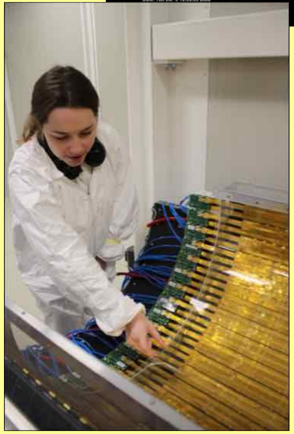
p-p collision at 13.5 TeV Jul. 2022



First Pb-Pb collision Nov. 2022

SPbSU:

- **MAPS characterisation**
- **Mechanics and cooling: extralight weight carbon fiber support structures**
- **Staves commissioning**

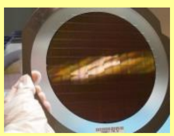


ALICE novel VD based on MAPS: ITS-3 and ALICE-3

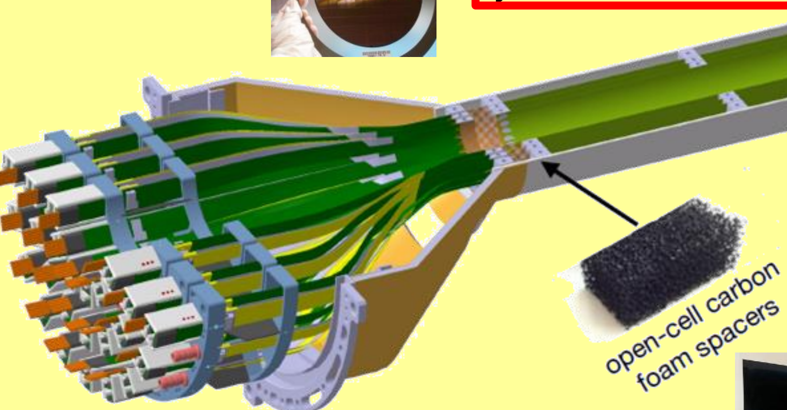
ITS-3

PHYSICS

Low momentum particle reconstruction
Low-mass di-electrons
Heavy flavour with small decay length
(Λc ≈ 60 μm, Ds ≈ 150 μm)
and also: Bs0, Ds+, Λb, Ξc,
"c-deuteron", dΛc
"strangeness tracking"
- Anti-3He production from anti-Λb0



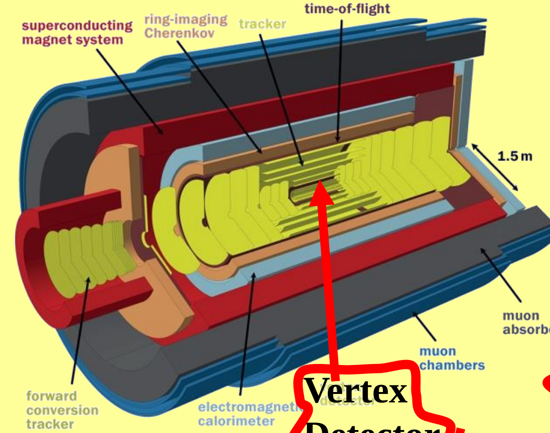
cylindrical detection layers



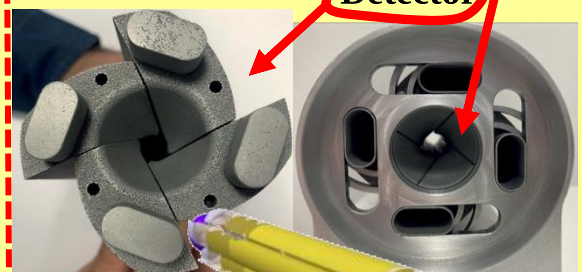
σ_{pos} – 5 μm, X/X0 ≈ 0,1%

300 mm wafer-scale sensors, (using stitching) thinned to 20 - 40 μm are flexible bent to the target radii - mechanically held in place by carbon foam support structures. Max power density is 20 mW/cm²

ALICE-3



Vertex Detector



PHYSICS

Determination of the average temperature of the QGP before the formation of hadrons

precision measurements of di-electrons and multi-charm barions and heavy-flavour hadrons $p_t \to 0$

Retractable Si-pixel tracker:
The four segments can be rotated to bring the tracker sensors closer to the beam pipe. In vacuum!!

IRIS tracker

σ – 2,5 μm, X/X0<0,1%

https://cerncourier.com/a/alice-3-a-heavy-ion-detector-for-the-2030s/

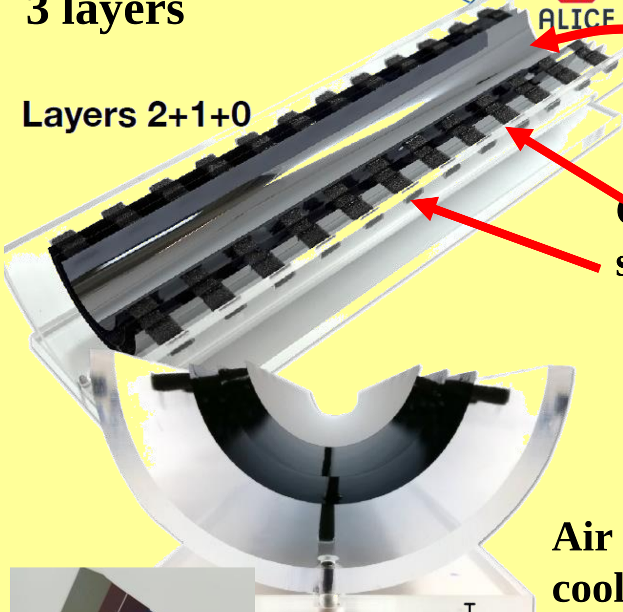
+

ALICE novel VD based on MAPS: ITS-3

ITS-3

Conception from CERN

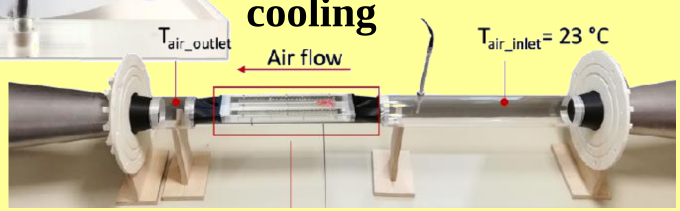
3 layers



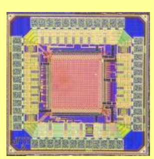
Bended MAPS

Carbon foam ribs as support structures

Air high speed (6-7 m/s) cooling



R&D: sensor development

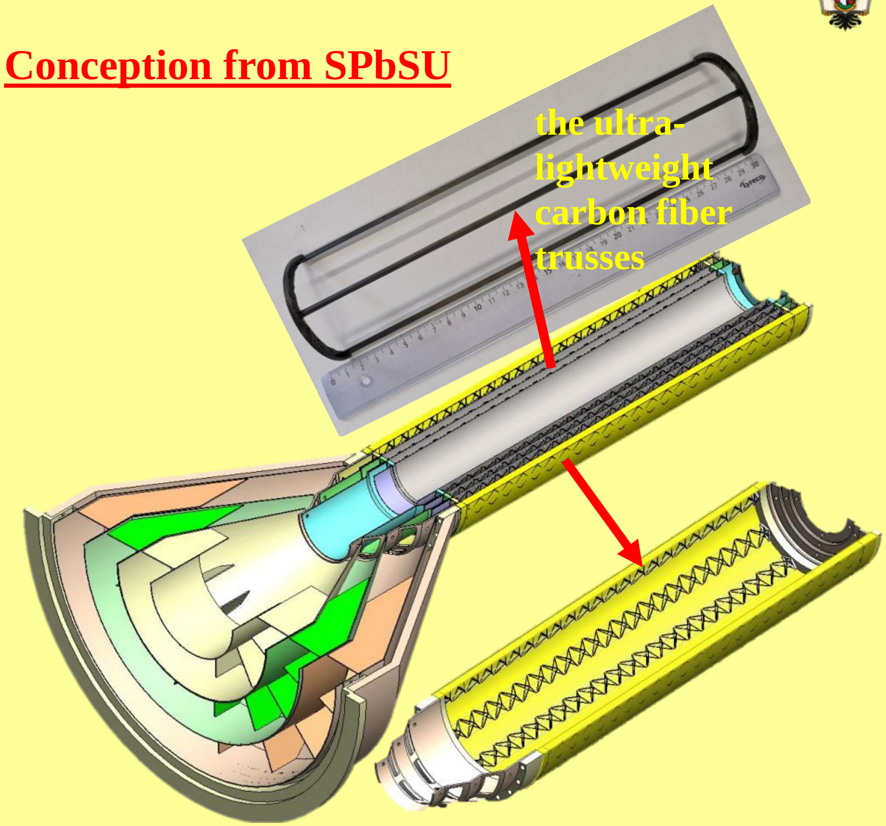


65nm wafers

65 nm prototypes, MLR1

Digital Pixel Test Structure (DPTS) 32 ✕ 32 pixels, 15 μm pitch

Conception from SPbSU



Barrel configuration: 3 layers with carbon fiber trusses + thin curved silicon MAPS inside. Barrel covered by space blanket.

For this construction an effective low speed (< 0.1 m/c) gas cooling system (nitrogen at temperature < 15 ^{o}C) could be used

without condensation and without frost gathering

TDR for ITS-3 in preparation (End of 2023)

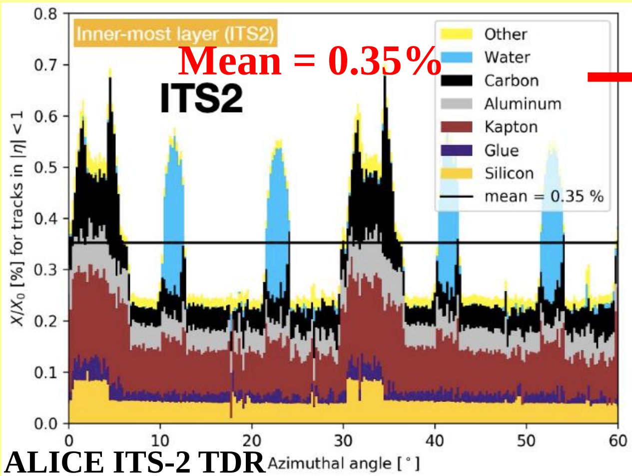
ALICE novel VD based on MAPS: ITS-3

Advantages:

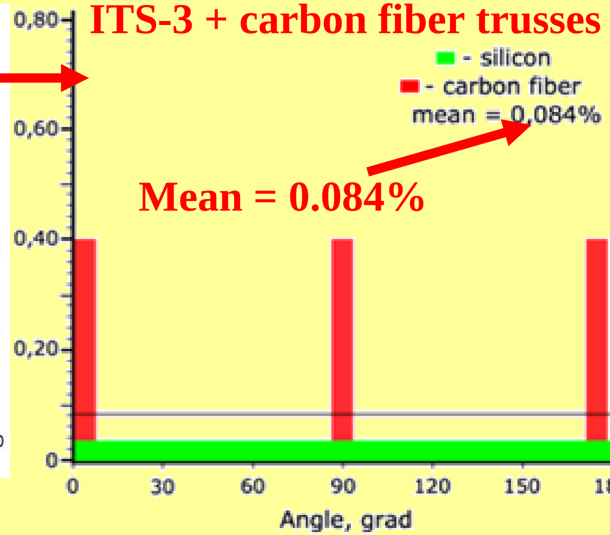
Radiation transparent

Conception from SPbSU

ITS-3

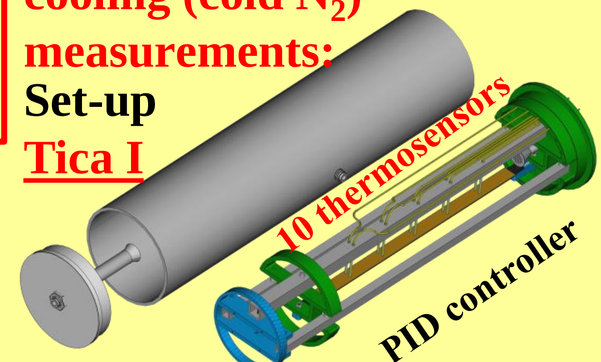


ALICE ITS-2 TDR

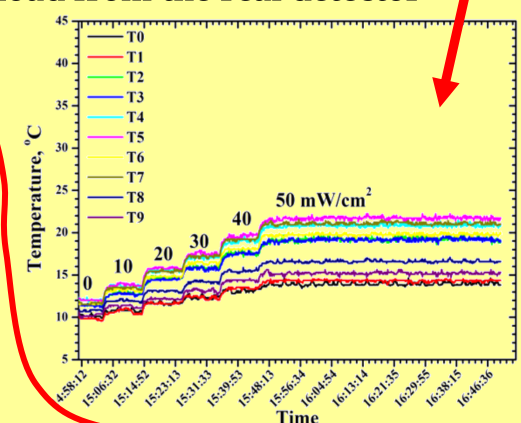


Experimental set-ups for cooling (cold N_2) measurements:

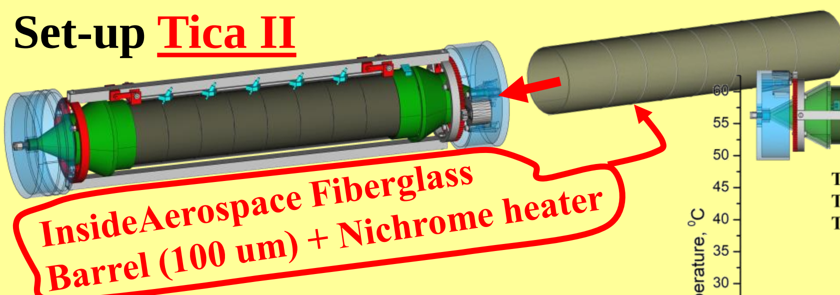
Set-up Tica I

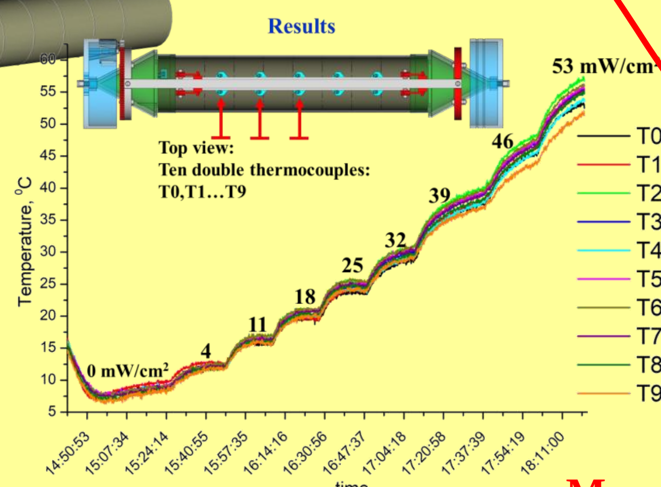


Polyimide heater one can simulate heat load from the real detector



Set-up Tica II





We can cool up to 53 mW/cm²

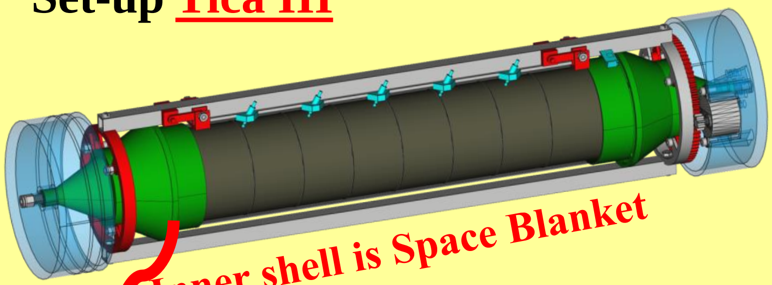
Mean nitrogen velocity is 0.06 m/s!

The temperature at working power 20 mW/cm² was no more 25 °C

ALICE novel VD based on MAPS: ITS-3

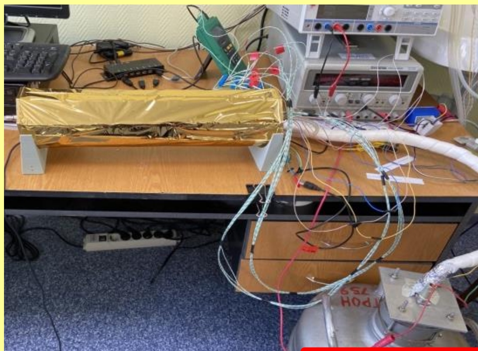
Conception from SPbSU

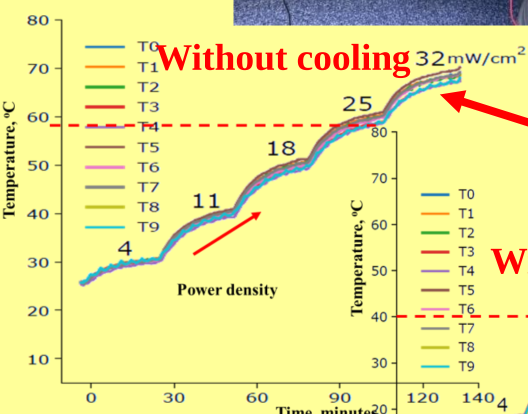
Set-up Tica III



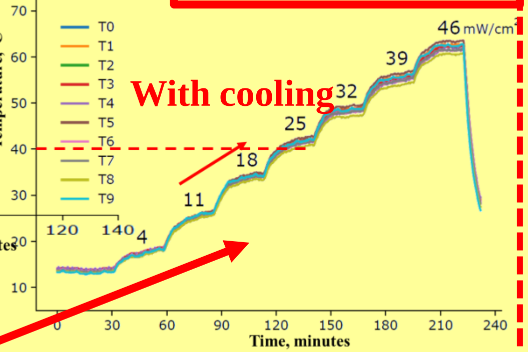
Inner shell is Space Blanket

Metalized Polyethylene terephthalate film - 10 um



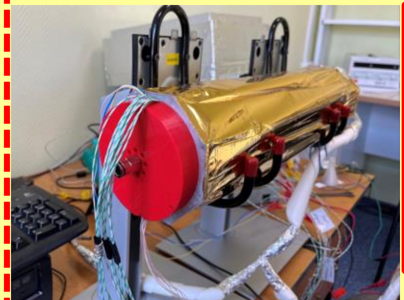


Without cooling only 32 mW/cm² was reached



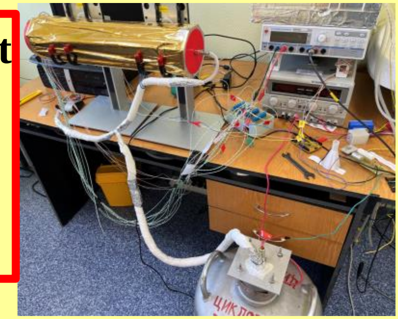
With cooling up to 46 mW/cm² was reached

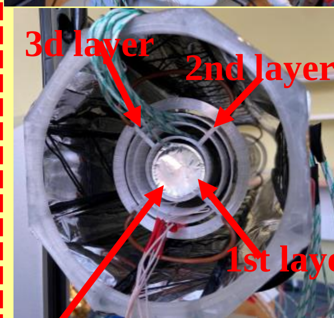
Set-up Tica IV

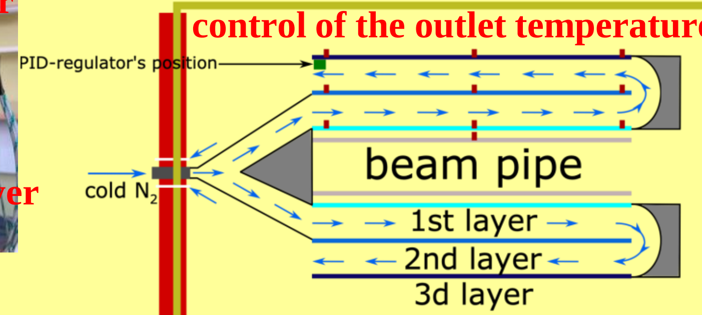


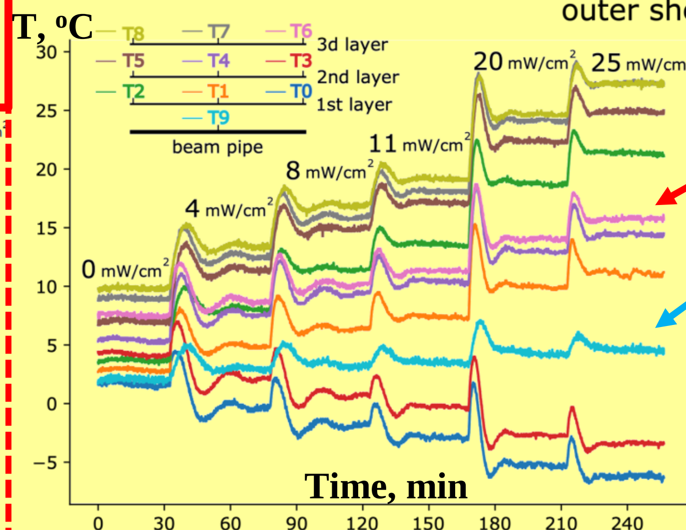
Space blanket + 3 cylinder layers with heaters + beam pipe

Real ITS-3 with imitators









Outlet T is +15 °C

Layers temperature

Beam pipe temperature

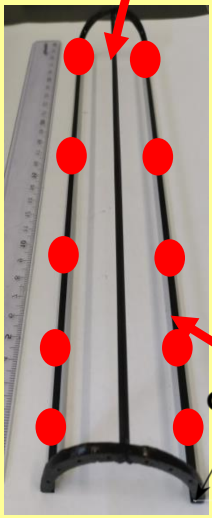
We can cool all layers and the beam pipe up to 25 mW/cm²

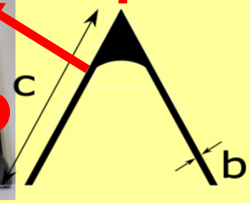
ALICE novel VD based on MAPS: ITS-3

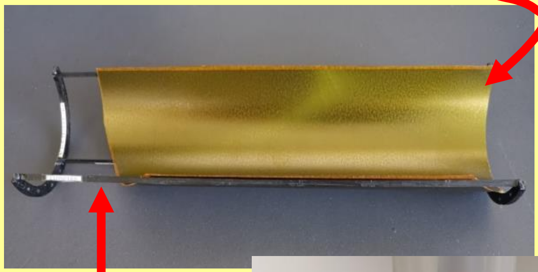
Investigations of the properties of carbon fiber cradle and silicon dummy sheet

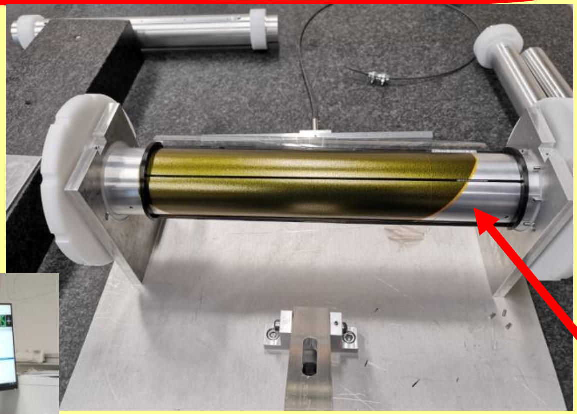
Two sets of the measurements by using Mitutoyo machine without silicon dummy sheet and after the silicon dummy sheet gluing were carried out.

Cradle made of very thin carbon fiber trusses. For these measurements the silicon dummy sheet as emulator of thin curved silicon detectors has been used. This silicon dummy in a kapton shell was bended by especial mandrel and then glued on the cradle.

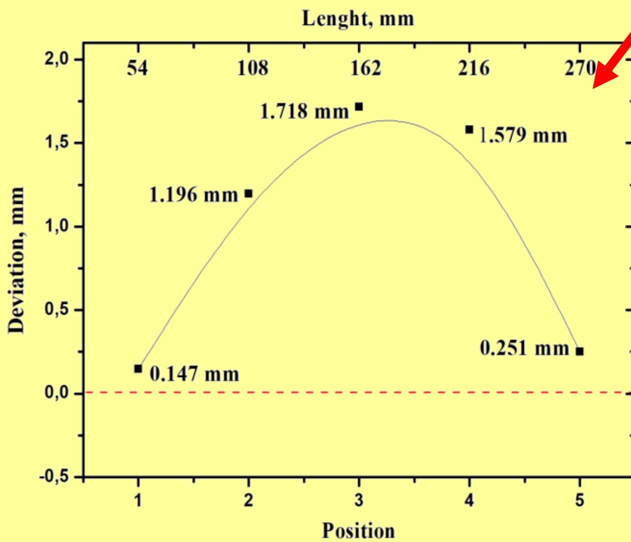








Description	Values
Length, mm	288
Width (c), mm	2,85
Thickness (b), mm	0,40
Weight, g	0,49
Production	SPbSU

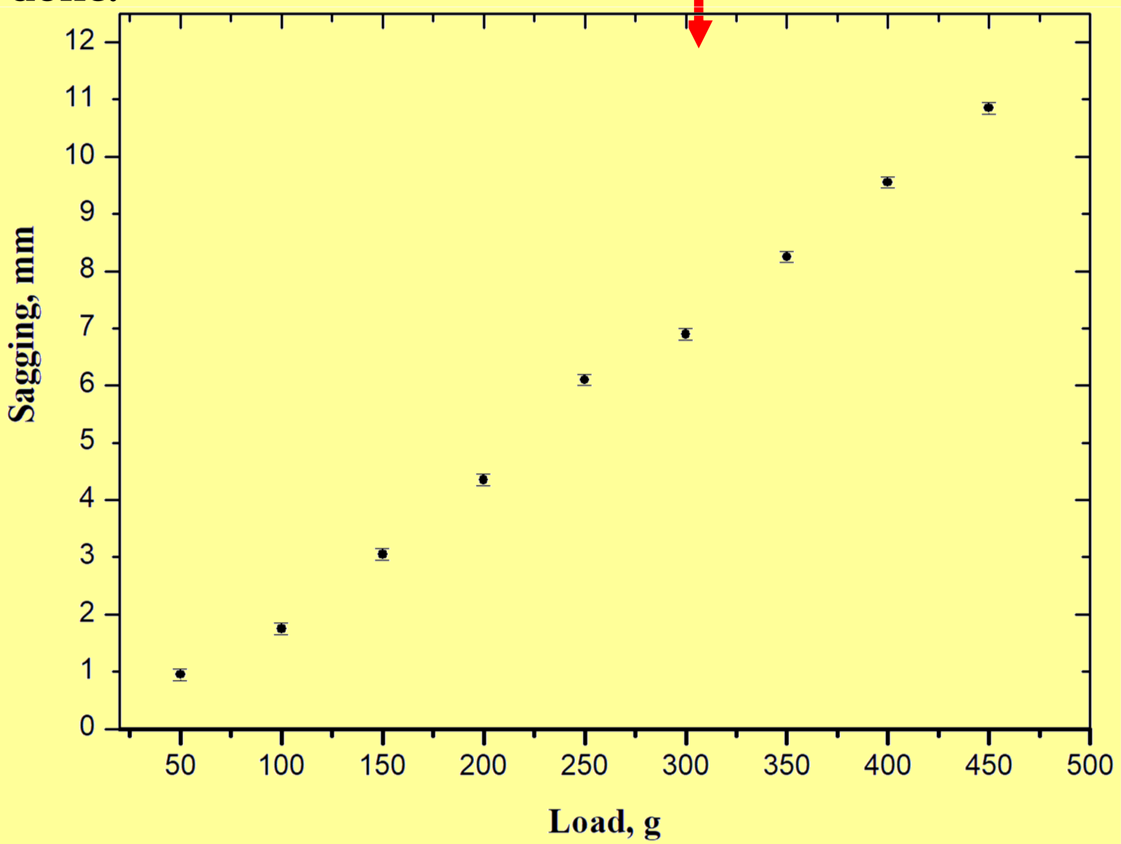


After silicon gluing the distance between cradle trusses was decreased to 150 -250 um in the end of the cradle. But maximum in this spread was about 1718 um (area close to cradle center)

One can need more thick trusses!

ALICE-3

Detector support structure - 3000 mm, weight – 82.0 g.
It was glued from two ALICE OB carbon wound truss structures.
For sagging estimations of 3000 mm support structure the tests with different load (at 50 g intervals) have been done.



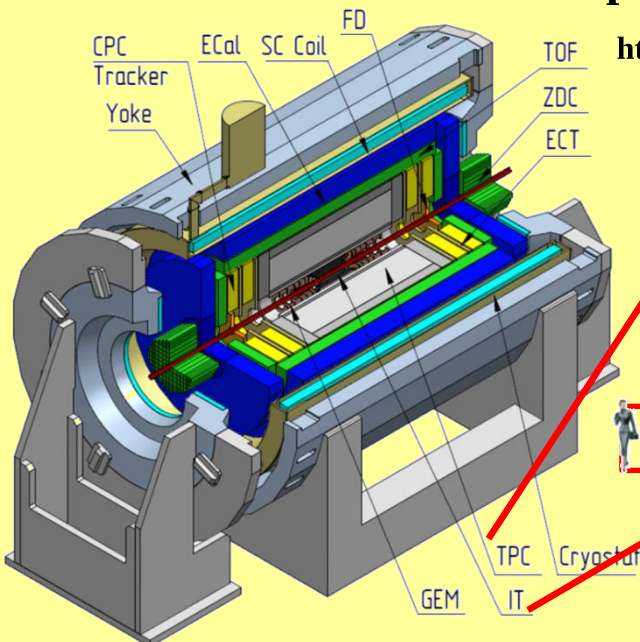
After 500 g load the sagging of support structure increases dramatically!

MAPS technologies for NICA: MPD, SPD, ARIADNA

Three experiments:

1. MPD at NICA – Multi-Purpose Detector

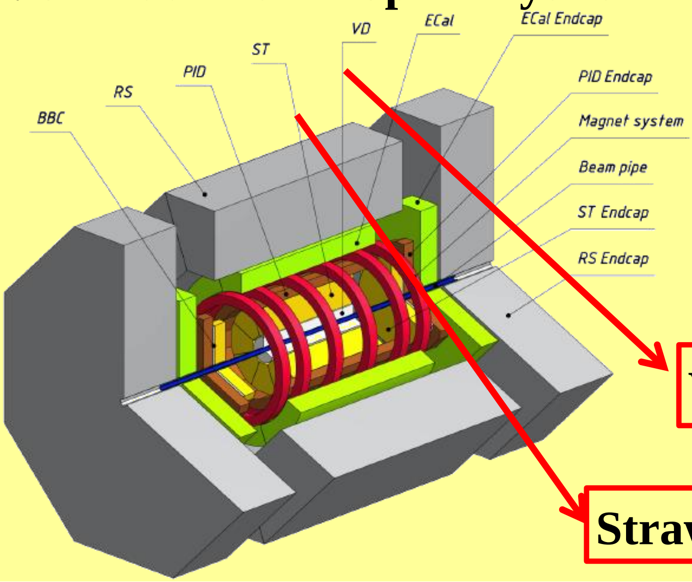
https://nica.jinr.ru/projects/mpd.php



Time Projection Chamber

Inner Tracking System

2. SPD at NICA – Spin Physics Detector



Vertex detector

Straw tracker

3. ARIADNA LS

Proton Tomography

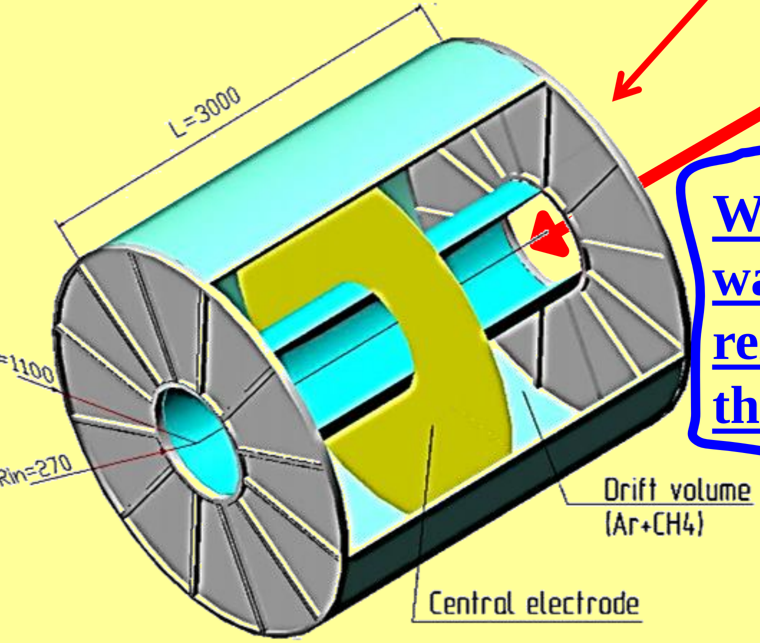
https://www.atomic-energy.ru/news/2018/10/12/89571

MAPS technologies for NICA: MPD, SPD, ARIADNA

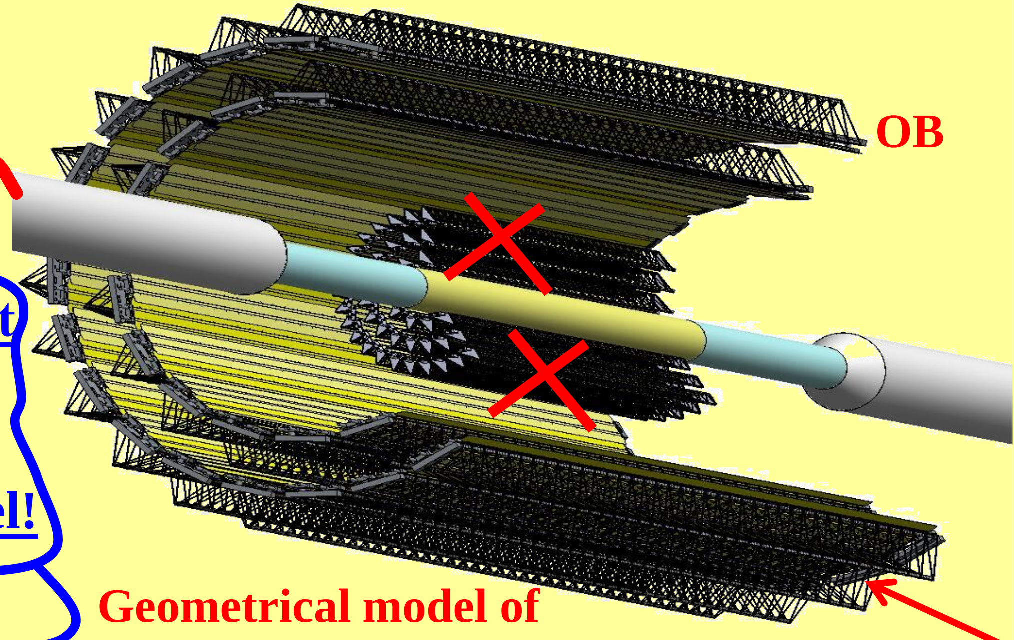
MPD tracking system: TPC + ITS

II stage of the MPD experiment: TPC + ITS

I stage of the MPD experiment: TPC only



We don't want to reinvent the wheel!



Geometrical model of MPD vertex detector

https://nica.jinr.ru/ru/projects/mpd.php

TPC ⟶ accurate reconstruction of particle tracks and their momenta,
+
identification of charged particles by measuring their energy losses

TDR for MPD IT in preparation (End of 2023)

ALICE technologies:
for OB – ALICE Outer layer staves (1526mm)
New technologies for IB – staves 750 mm

STAVES

18
24
} Outer Barrel Only!

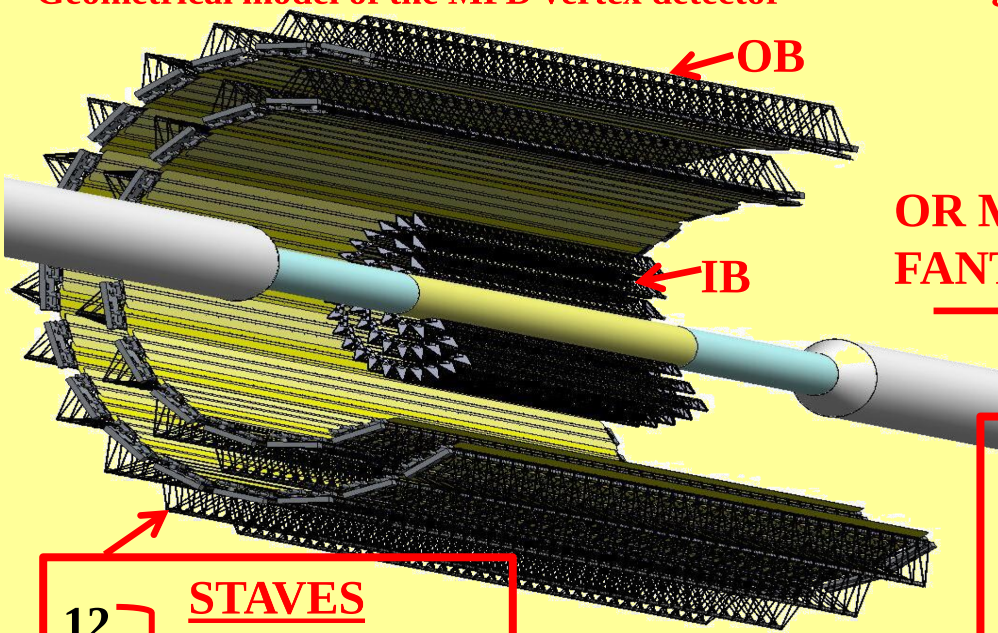
+ possible 1 layer

Pixel Detectors Hybrid Integrated Circuit (HIC) + Cold plate + Space frame

V.I. Zherebchevsky, V.P. Kondratiev, V.V. Vechernin, S.N. Igolkin
Nuclear Inst. and Methods, A 985 (2021), 164668.

MAPS technologies for NICA: MPD, SPD, ARIADNA

Geometrical model of the MPD vertex detector



STAVES

12, 22, 32 – Inner Barrel

18, 24 – Outer Barrel

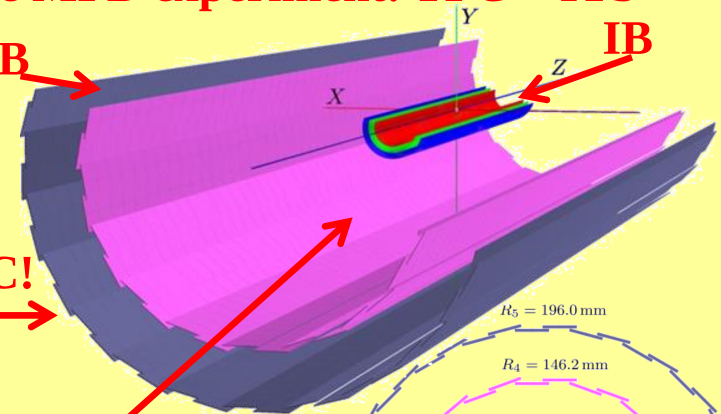
+ possible 1 layer

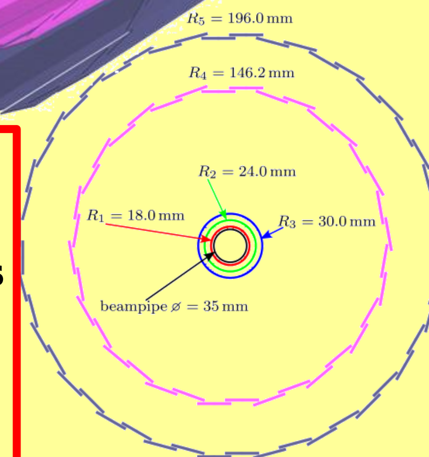
V.I. Zherebchevsky, V.P. Kondratiev, V.V. Vechernin, S.N. Igolkin Nuclear Inst. and Methods, A 985 (2021), 164668

Spatial resolution at the level of 300 μm makes it possible to reconstruct the decay vertex of D^+ mesons ($c\tau$ = 312 μm) in channel $D^+ \rightarrow K^- + \pi^+ + \pi^+$

III stage of the MPD experiment: TPC + ITS

OR More FANTASTIC!

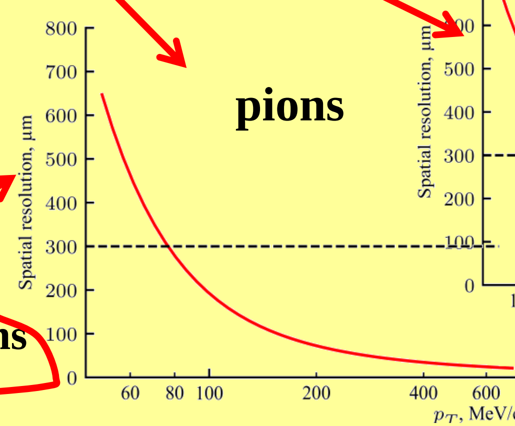


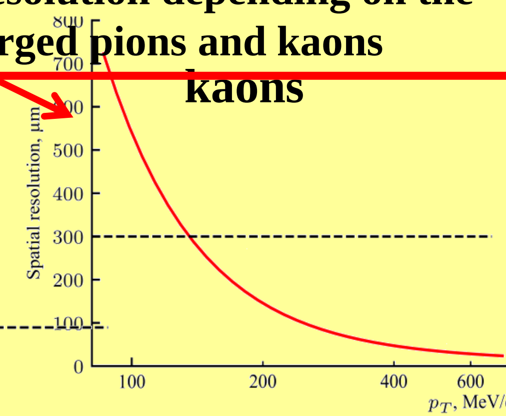


Inner Barrel: 3 inner layers consist of bent large area silicon sensors **Like ALICE ITS-3**

18, 24 – Outer Barrel

D+ reconstructiom. Spatial resolution depending on the transverse momentum of charged pions and kaons



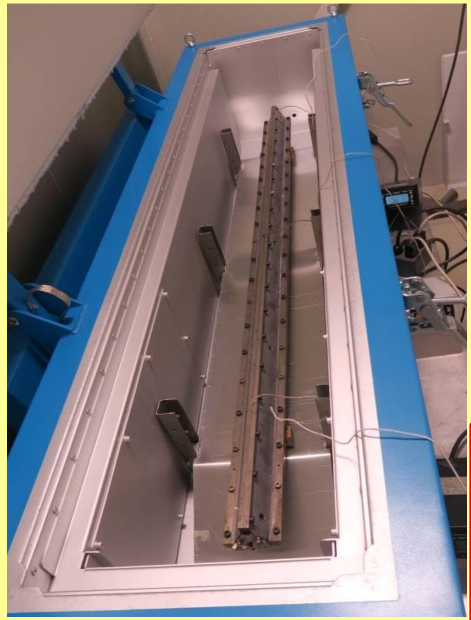


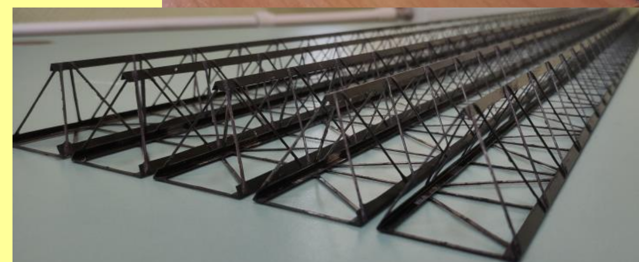
MAPS technologies for NICA: MPD, SPD, ARIADNA

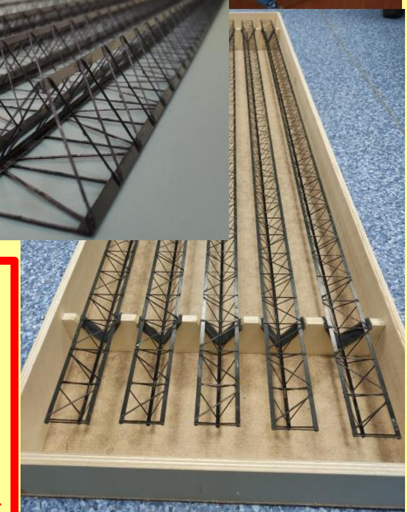
MPD Outer Barrel Stave

1) The technology of production of Extra Lightweight Detector Support Structures was modified for Russian prepreg «НИИКАМ-PC/M55» (Research Institute of Space and Aviation Materials)

2) The studies of mechanical, space, deformation characteristics produced structures were done







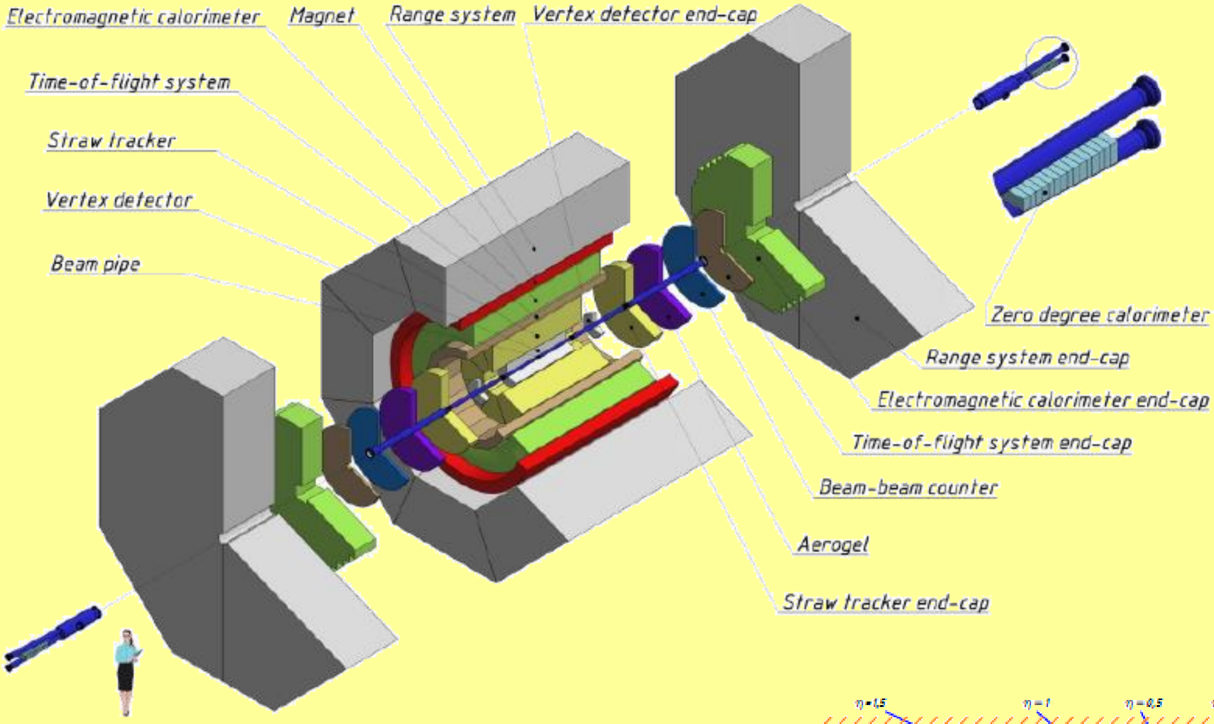
60 Wound-truss structures were produced at SPbSU and shipped to JINR

For the MPD ITS Extra Lightweight Detector Support Structures the new technology for cold plate, wound-truss structures have been developed at SPbSU

→ Wound-truss structures - SPbSU → Final production

→ Cold plate - JINR → Final production

2. SPD at NICA – Multi-Purpose Detector



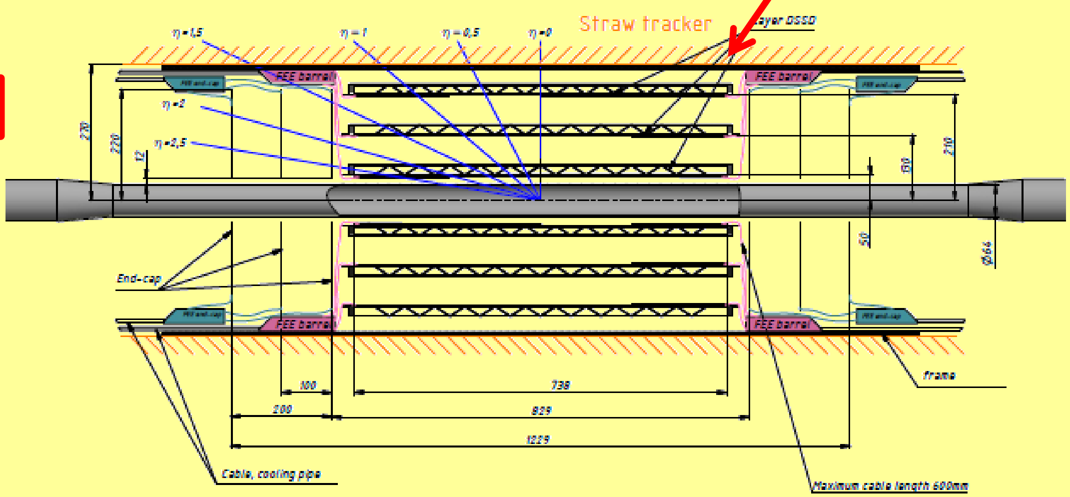
TDR for SPD version 12 February 2023

Silicon Vertex Detector

Two options:

1) MAPS based barrel. 3 layers of pixel detectors

2) Vertex detector, based on the Double-Sided Silicon Detectors (DSSD)

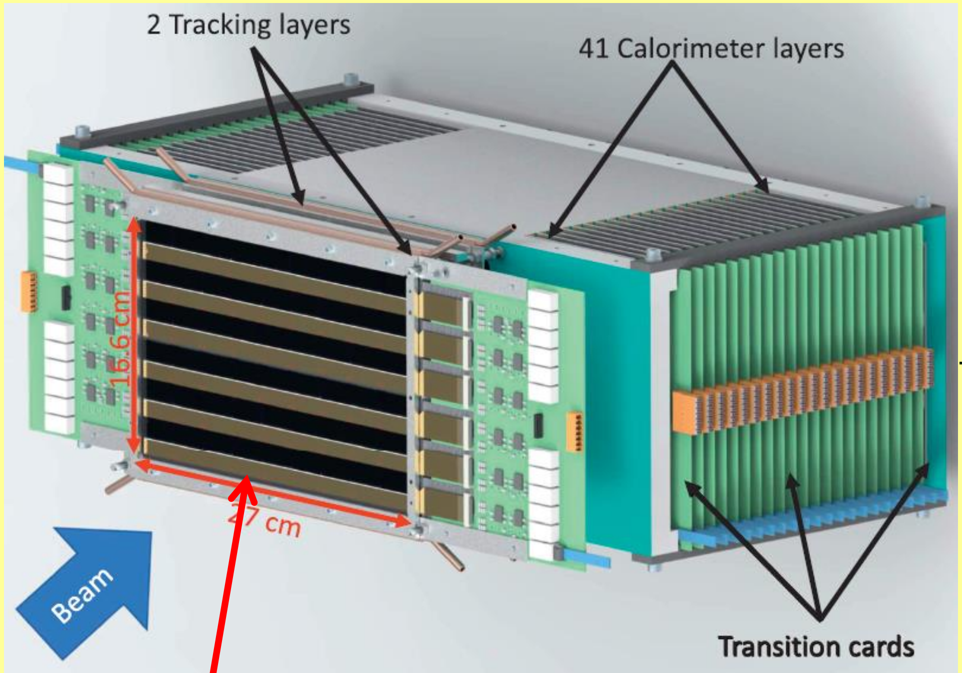


http://spd.jinr.ru/spd-cdr/

Proton thomography

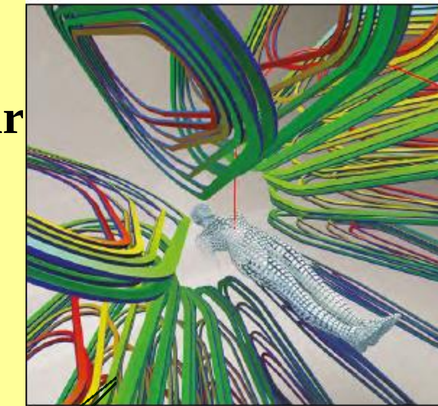
ARIADNA-LS

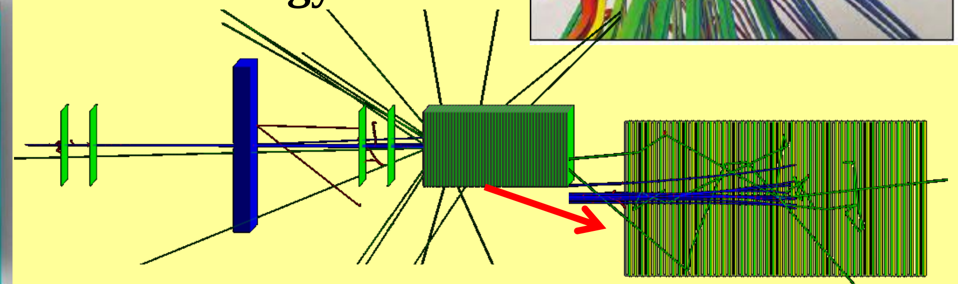
The Bergen proton CT system
2021 SPbSU MoU with University of Bergen

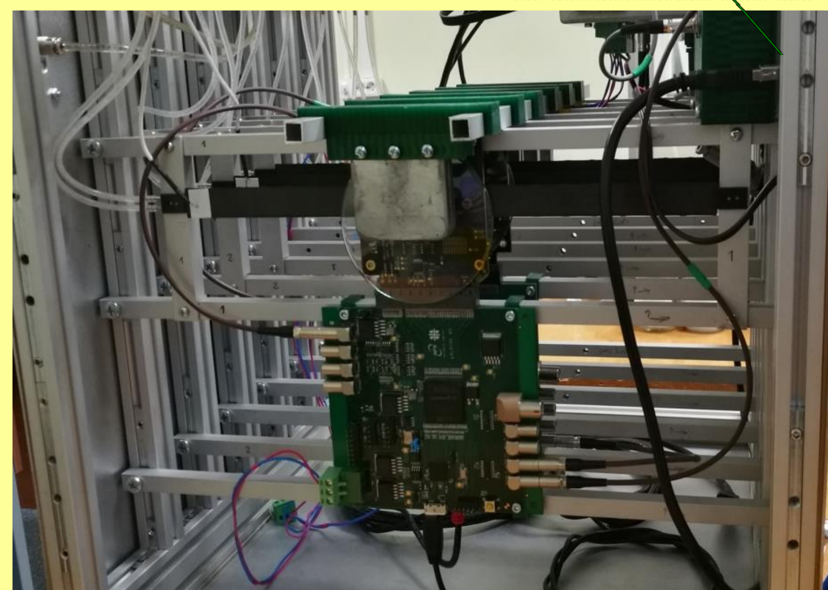


Ultralight cooling panel for support of silicon pixel sensors uses in proton tomography.
Patent SPbSU

Digital calorimeter can be used in nuclear medicine (hadron therapy) for precise measurements of the beam energy







Conclusions

Novel ALICE technologies based on silicon monolithic active pixel detectors could be used for NICA: MPD, SPD, ARIADNA experiments

For ALICE ITS-3 and NICA MPD: the layers with carbon fiber trusses + thin curved silicon MAPS inside was proposed with low speed nitrogen cooling

Next Plans

Mechanics: investigations of carbon fiber support structures + glued thin silicon sheet

Cooling: optimization of cooling system

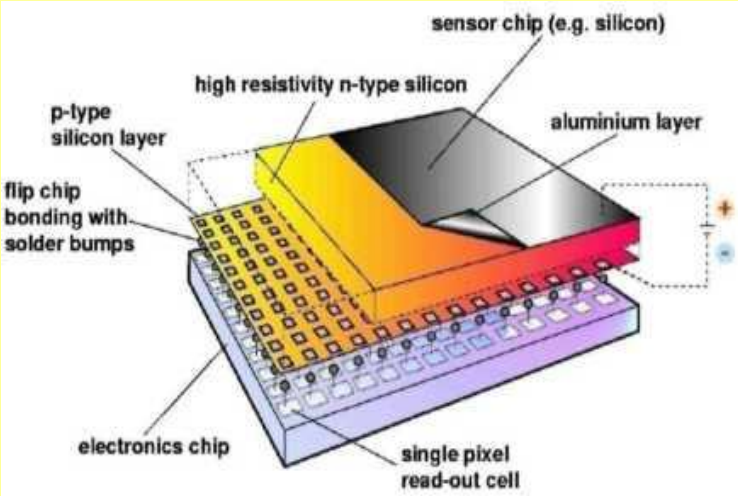
In-beam tests: tracking, calorimetry


Thank you

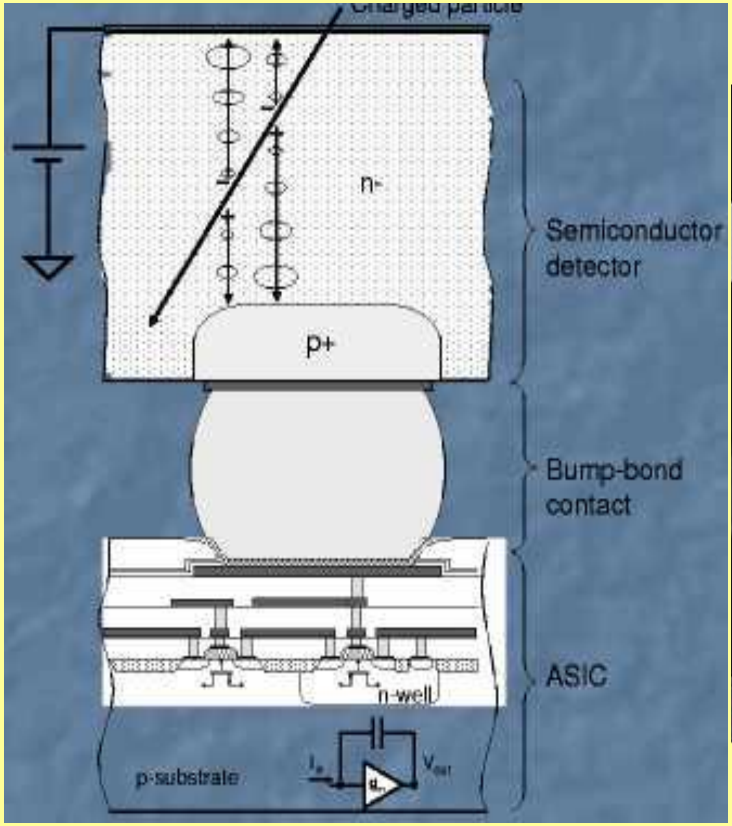
ELNP SPbU LUHEP SPb SU

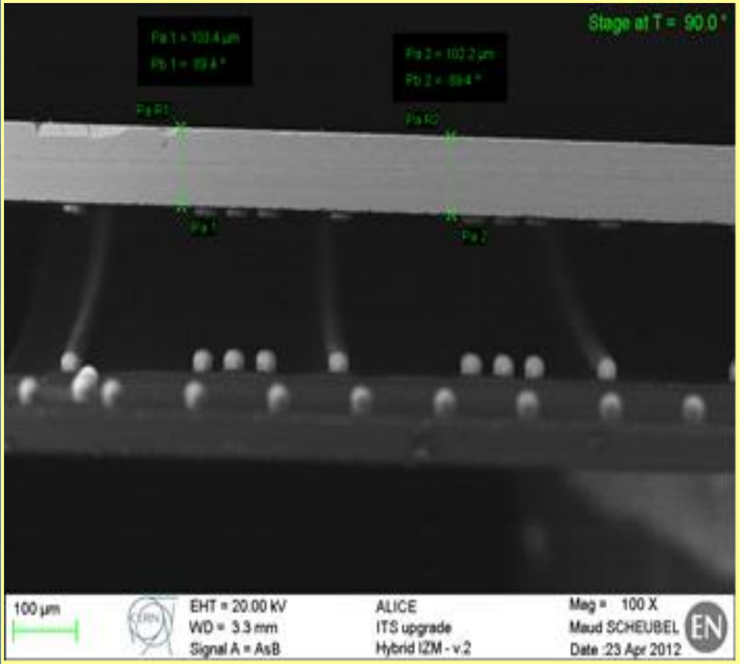
BACK-UP SLIDES

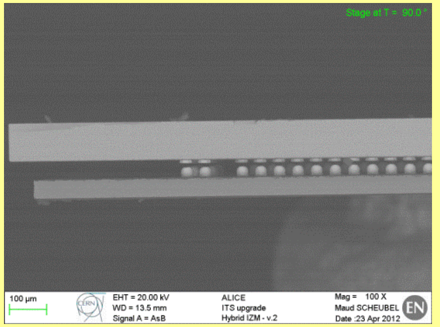
Hybrid Pixel Detectors

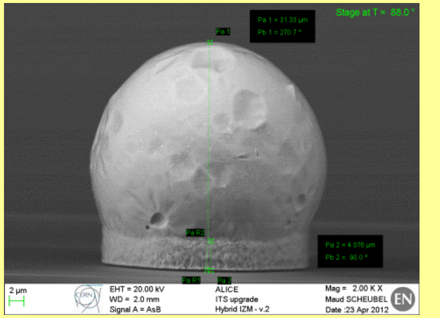


1. Sensor and readout chip (ASIC) are independent modules
2. Interconnection needed to connect each pixel in the sensor to a readout cell in the ASIC - Bump bonding ASIC and detector (very complicated technologies)
3. Thick detector units: radiation length 1 – 3 % X_0
4. Sensor and electronics optimized for very high radiation (hit rate)









Chip 50 µm and sensor 100 µm

[6]

ALICE Inner Tracking System upgrade strategy

Physics

Improve primary vertex reconstruction, momentum and impact parameter Resolution

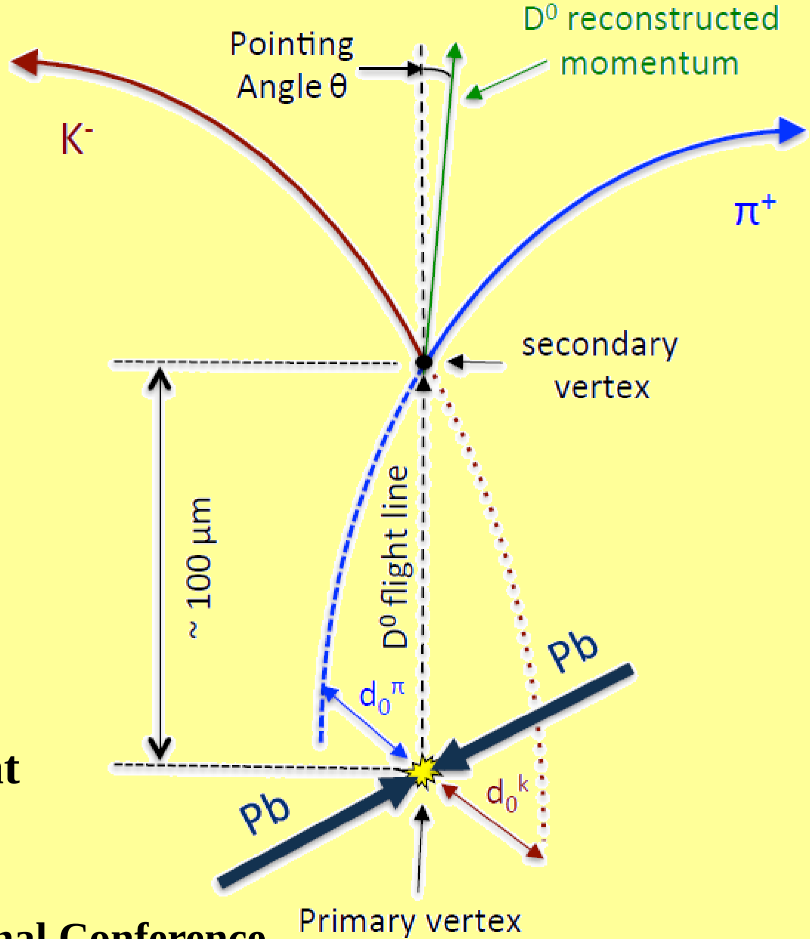
Reconstruction of secondary vertices from c and b decays with high resolution

Particle	**Decay Channel**	**c·τ (μm)**
Λ_c^+	**$pK^-\pi^+$**	**60**

Current ITS Impact Parameter Resolution ~ 70 μm at p_t=1GeV/c

Secondary vertex determination

Example: D^0 meson

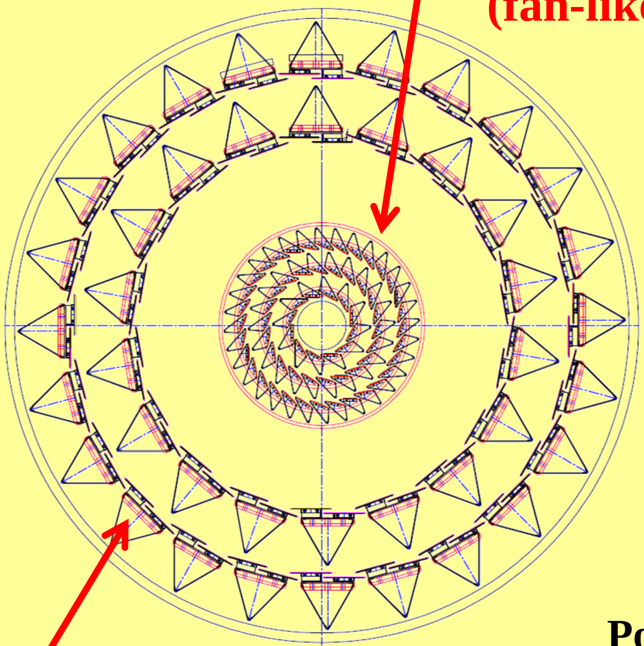


Vertex detectors at the NICA collider experiments

Five detector layers (for beam pipe D=40 mm)

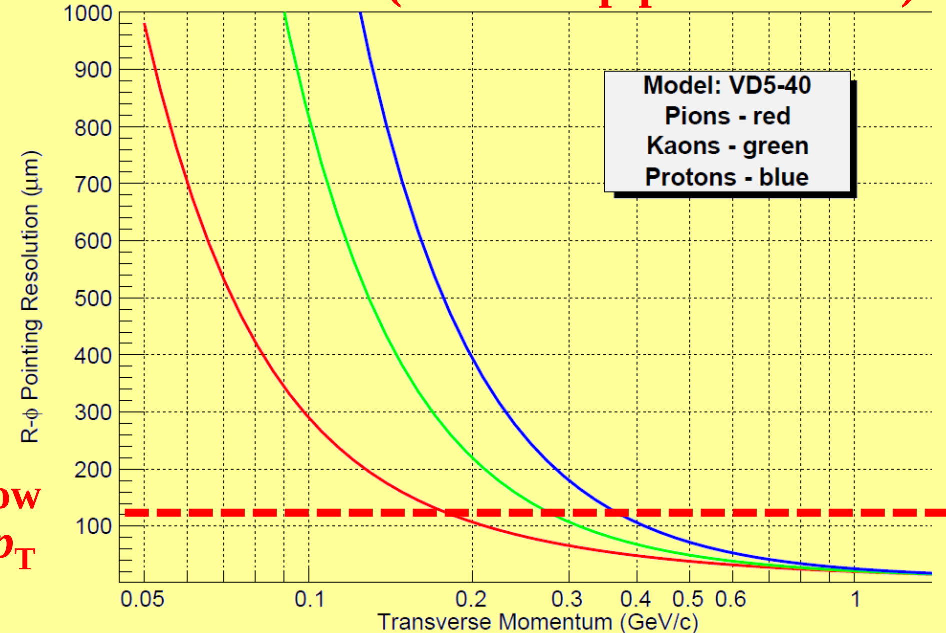
Front view

Inner Barrel (fan-like arrangement)



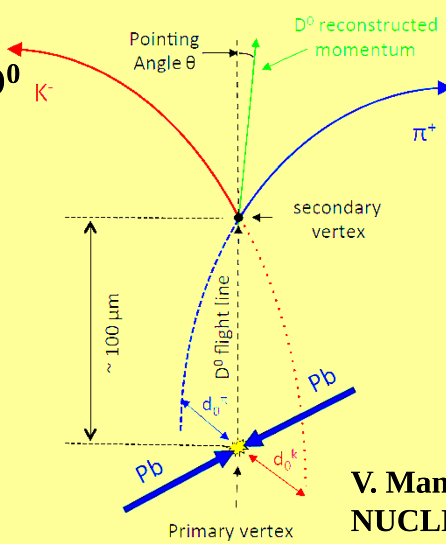
Outer Barrel (staggered arrangement)

Good pointing resolution at low p_T

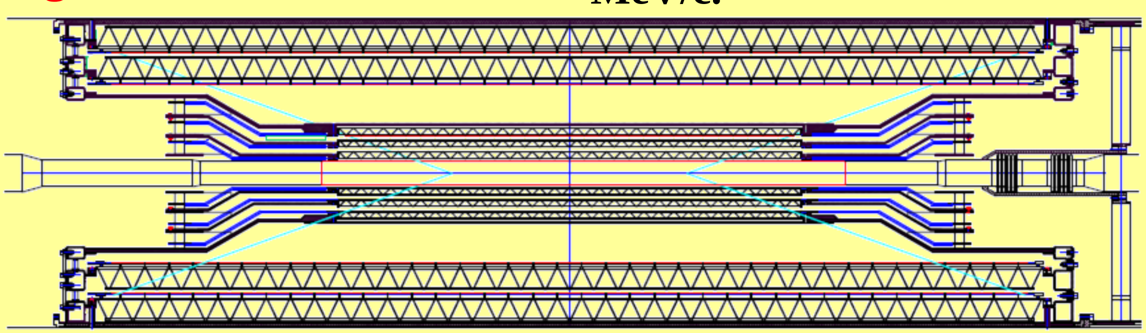


Example: D^0 meson

Pointing resolution of 120 um makes it possible a decay vertex reconstruction of D^0 (123 um) with p_T down to 500 MeV/c.



longitudinal view



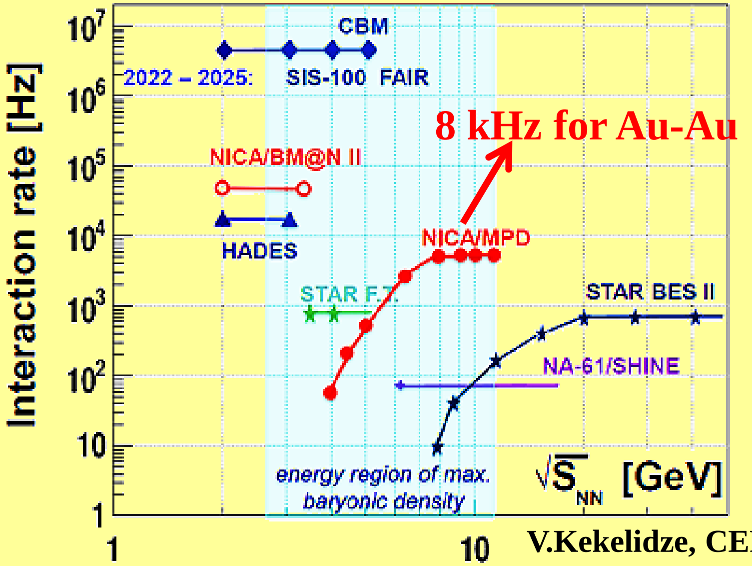
V.I. Zherebchevsky, V.P. Kondratiev, V.V. Vechernin, S.N. Igolkin Nuclear Inst. and Methods, A 985 (2021), 164668.

V. Manzari, NUCLEUS-2015, 29.06-03.07.2015, St.-Petersburg

Vertex detectors at the NICA collider experiments

Estimation of the expected yield of D- mesons in the MPD experiment

V.Kondaratiev
SPbSU



V.Kekelidze, CERN seminar 14.09.2018

For estimations:
5 layers of Pixel Detectors, central collisions, month of collider work, efficiency of D-mesons registration by the MPD tracking system, the multiplicity of D mesons in Au + Au collisions at NICA energies (in the framework of the hadron string dynamic model) = 10^{-2}

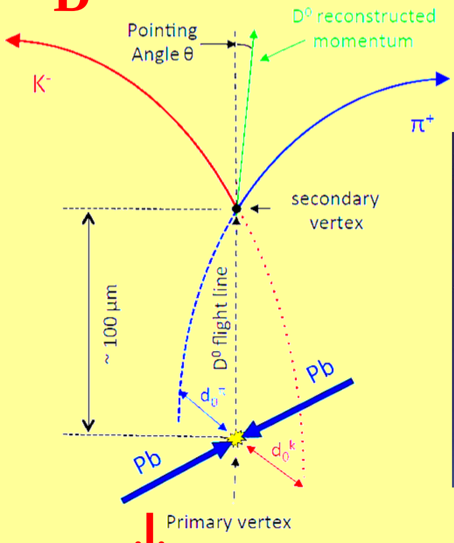
for $D^{+} \rightarrow 2\pi^{+}K^{-}$ (9.2%): ≈ 38 000 mesons

for $D^{0} \rightarrow \pi+K-$ (3.9%): ≈ 16 000 mesons

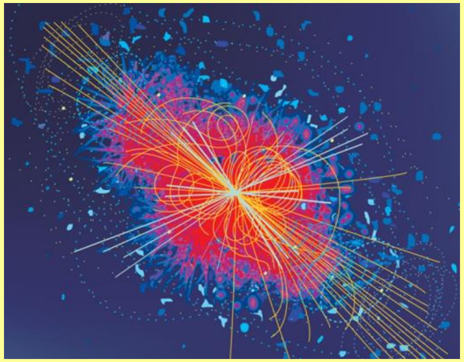
For more read see: V.I. Zherebchevsky, et al., Nuclear Inst. and Methods, A 985 (2021), 164668

Simulation of D-mesons decays

D^0



Mpdroot



Signal events for D-mesons decays
Thermal generator - TG
1) Energy range of NICA
2) Statistics - 1M decays

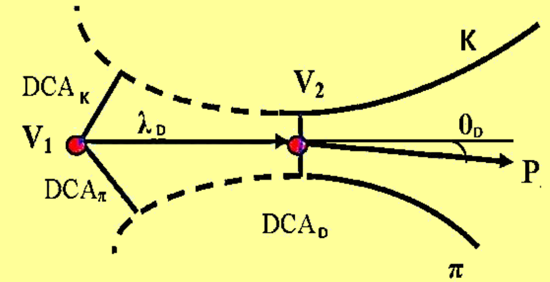
The combinatorial background emulation
Generator of the quark-gluon string model: QGSM
Statistics: 100K events

Signal selection in the invariant mass spectrum

Two methods:
1) The classical method of topological cuts (TC)
2) The method of multivariate data analysis (MVA)

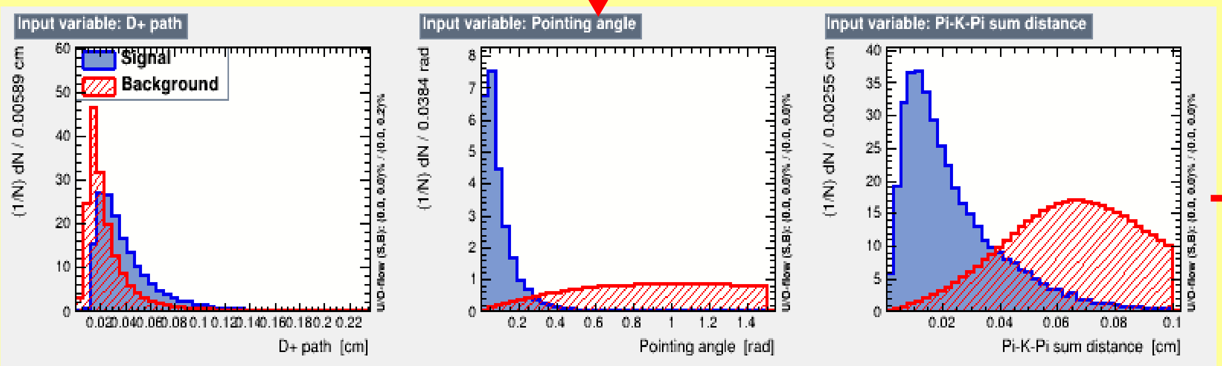
Vertex detectors at the NICA collider experiments

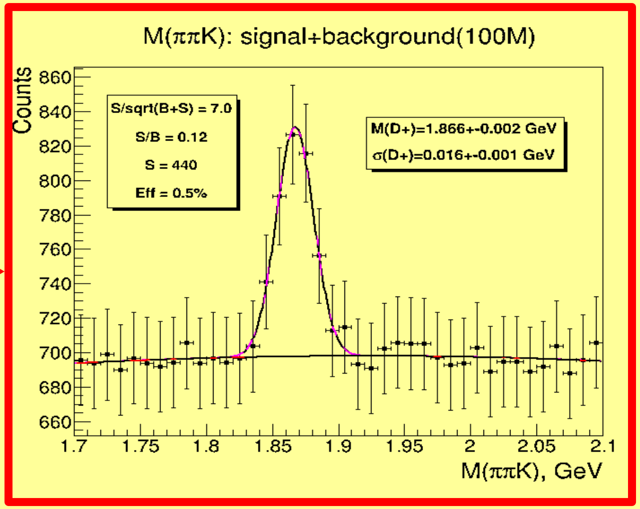
D^+ and D^0 reconstruction with VD-5-40



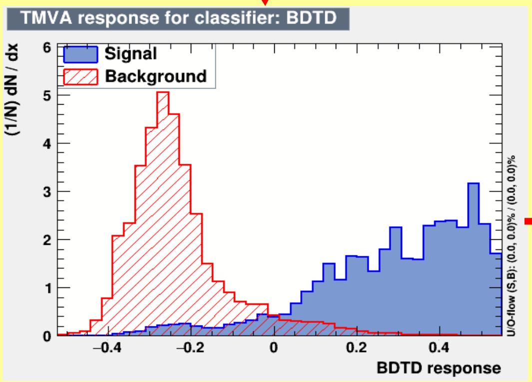
For reconstruction the D meson decays a large combinatorial background has to be to suppressed by using the strict criteria for signal selection:

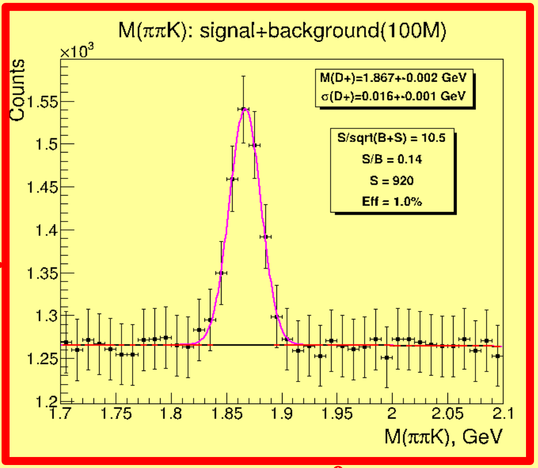
1) TC: dca(π), dca(K), dca(πK), λ(D), θ(D) cuts





2) MVA: Boosted Decision Trees (BDT) classifier cut





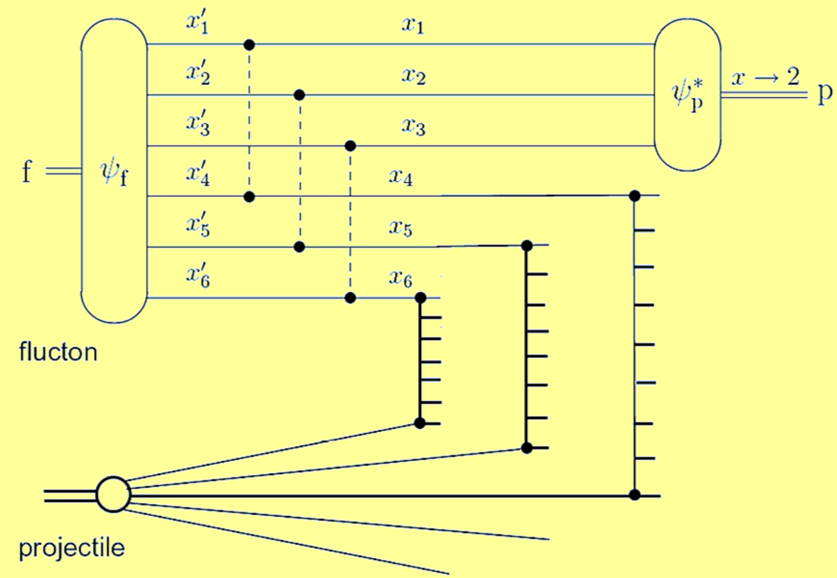
Particle	D^0		D^+	
Method	TC	MVA	TC	MVA
Efficiency, %	0.80	0.85	0.50	1.0
Significance	5.3	5.5	7.0	10.5

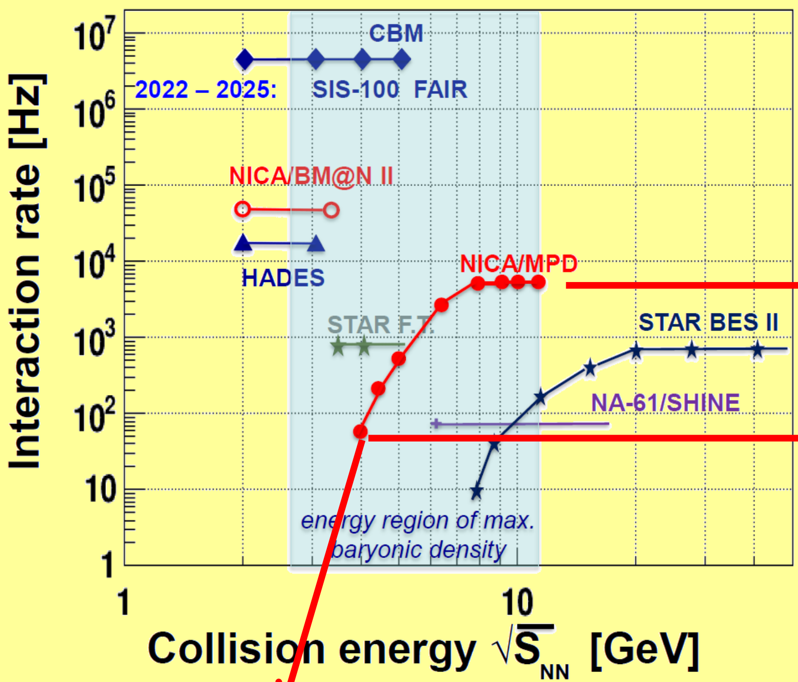
Using the topological cuts one can reconstruct D^0 and D^+ decays with an efficiency of 0.8% and 0.5%

Using the optimal BDT cut one can reconstruct D^0 and D^+ with a higher efficiency of 0.85% and 1.0%

Vertex detectors at the NICA collider experiments

At NICA collider it becomes possible to study clusters of cold and dense quark–gluon matter inside the nuclei





Estimations of the yields of cumulative, pions and protons with large transverse momenta outside the p + p kinematics at central rapidities in Au + Au collisions at NICA collider were done
(estimations by V.Vechernin, SPbSU)

The observation of cumulative particle production with is more favorable at the lowest possible energies of the NICA collider – Sqrt(S_{NN})= 4 GeV.

Cumulative particles yields during <u>one hour</u> of the collider operation

Particle	Yeld at Sqrt(S_{NN})= 4 GeV	Yeld at Sqrt(S_{NN})= 8 GeV
π	50	$2\cdot10^{-3}$
^{1}p	70	$9\cdot10^{-7}$

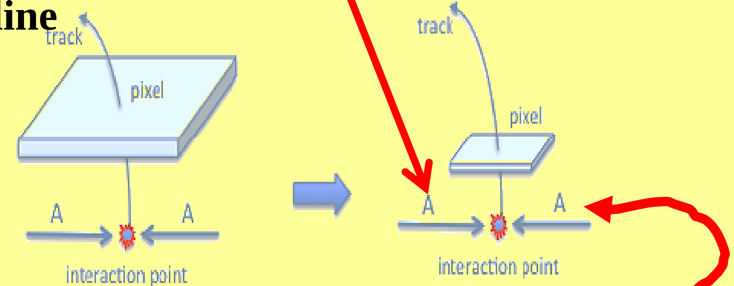
Pixel sensors for the Vertex detectors

Main motivation → **Improve tracking efficiency and p_T resolution at low p_T**

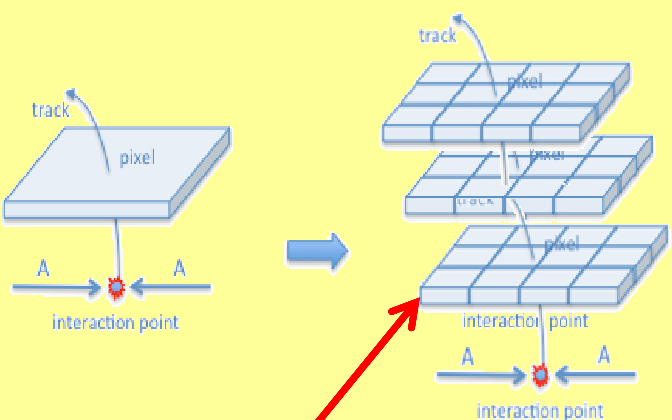
Requirements for the optimal tracking system

1. Good impact parameter resolution

a) First detection layer closer to the beam line



b) Reduction of material budget: min. radiation length per layer



c) Increase in granularity (smaller pixels)

d) more layers

2. Fast readout

readout Au-Au interactions at 8 kHz

(for the NICA luminosity of 10^{27} cm^{-2} c^{-1} in the most central Au + Au collisions at $\sqrt{s_{NN}}$ = 11GeV)

L.Musa, ECFA High Luminosity LHC Experiments Workshop, 3-6.10. 2016 and F. Reidt, PIXEL2016

3) Lower power consumption

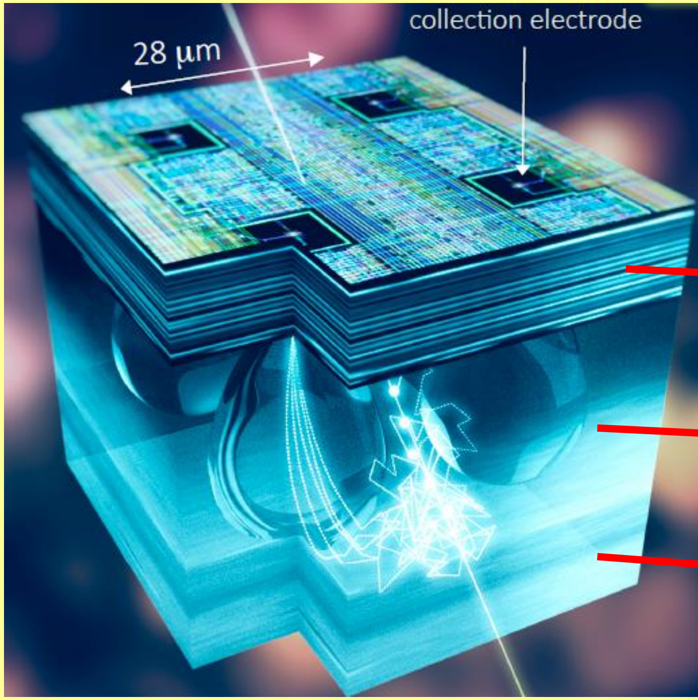
and optimized scheme for the distribution of Power and signals

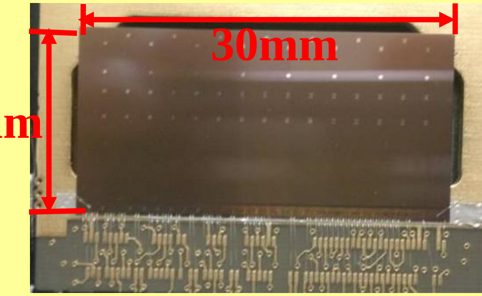
4) Radiation hardness

Pixel sensors for the Vertex detectors

MAPS: TowerJazz 180nm CMOS Imaging Process

How pixel detector works?





30mm

15mm

512 × 1024 sensitive pixels

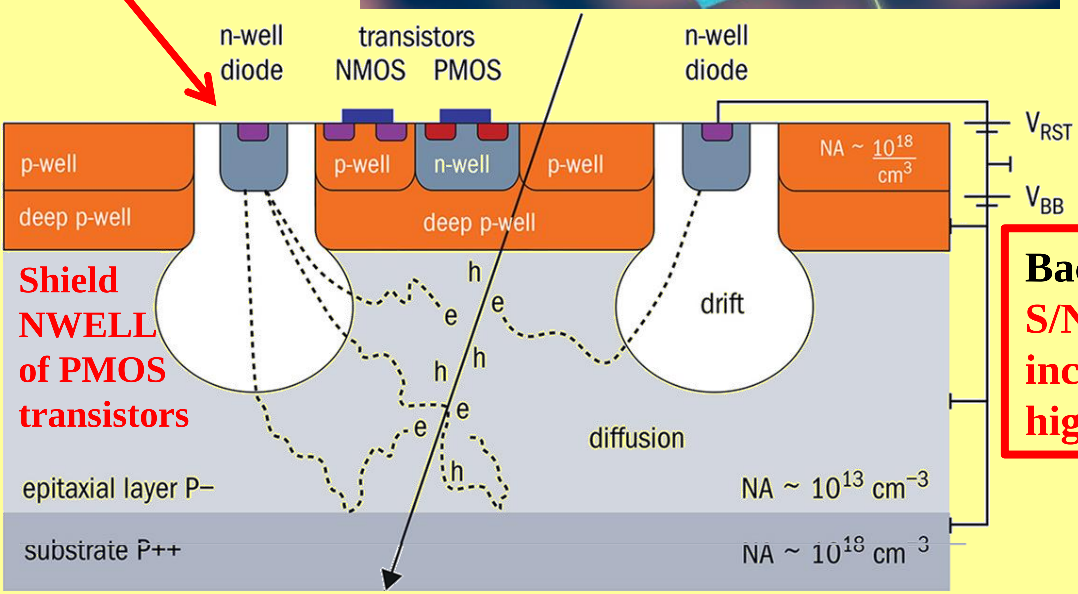
V. Manzari, EICUG2019, Paris

Metal layers (11 µm)

High resistivity(> 1kΩ ·cm) p-type epitaxial layer (25µm)

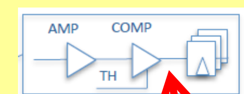
low-resistivity p-type substrate (14 µm)

Small n-well diode (2µm diameter), ~ 100 times smaller than pixel → low capacitance

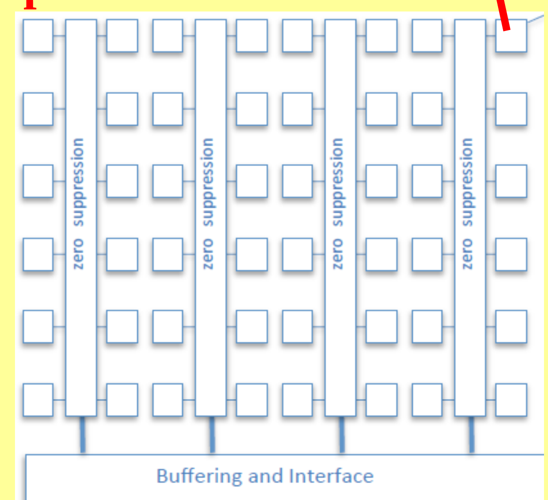


Shield NWELL of PMOS transistors

Back bias S/N ratio increases, higher efficiency



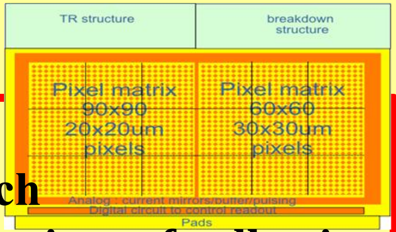
Chip architecture



In-pixel: amplification, discrimination, hit buffer

https://cerncourier.com/a/alice-tracks-new-territory/

ALICE Pixel Detectors (ALPIDE family)

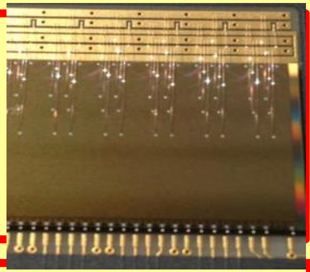


2012 — Explorer → **Two submatrices: 90x90 array of 20 x 20μm pixels and 60x60 array of 30x30μm pixels. Each sub matrices is divided in 9 sectors with one variant of collection electrode(analogue readout). Investigations: pixel geometry, starting material, sensitivity to radiation.**

Explorer-1,2

2013 — pALPIDEss → **Matrix with 64 columns x 512 rows of 22μm x 22μm pixels. (in-pixel discrimination and buffering). Study priority encoder and the front-end electronics**

May-2014 — pALPIDE-1 → **Full-scale prototype to study system effects: 1024 columns x 512 rows of 28μm x 28μm pixels. Four sectors with different pixels.**



May-2015 — pALPIDE-2 → **Four sectors with different pixels. Optimization of several circuit blocks. Allows integration into ITS modules**

Oct-2015 — pALPIDE-3 → **Eight sectors with different pixels. Final interfaces, more features including 1.2 Gbit/s output serial link.**

Jul - 2016 → **ALPIDE – Final Version**