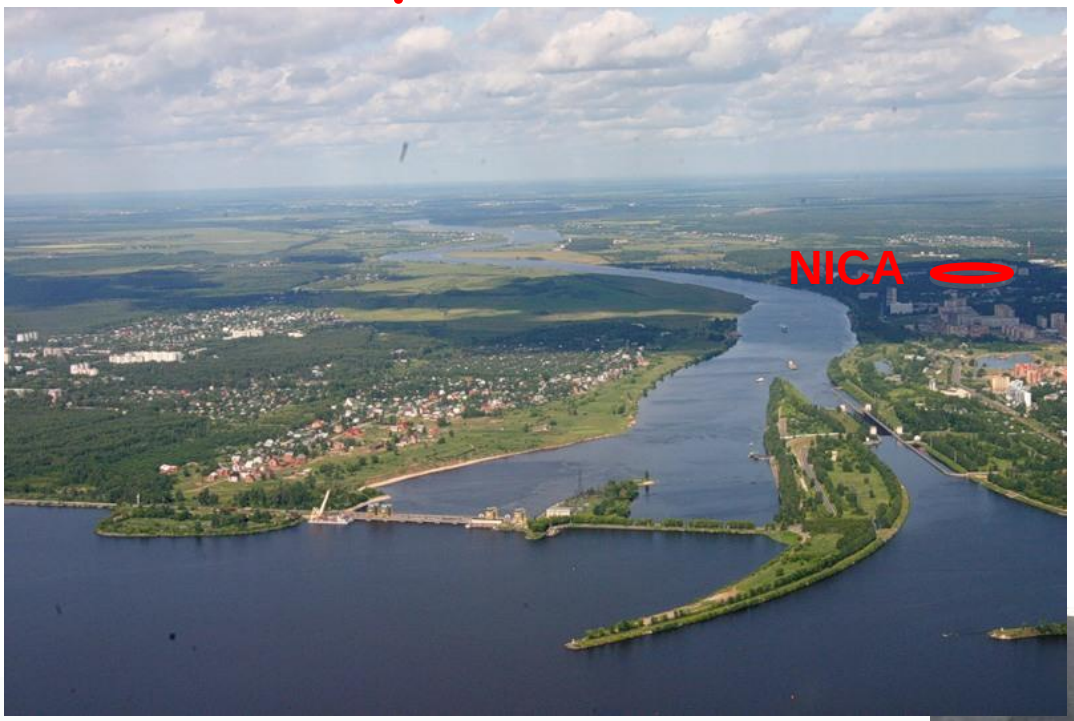
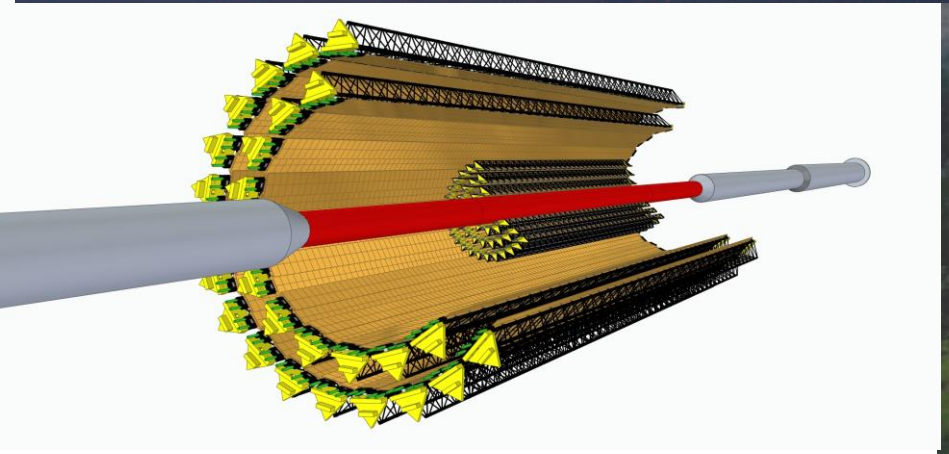
A MAPS based Inner Tracking System of the Multi-Purpose Detector at the NICA collider



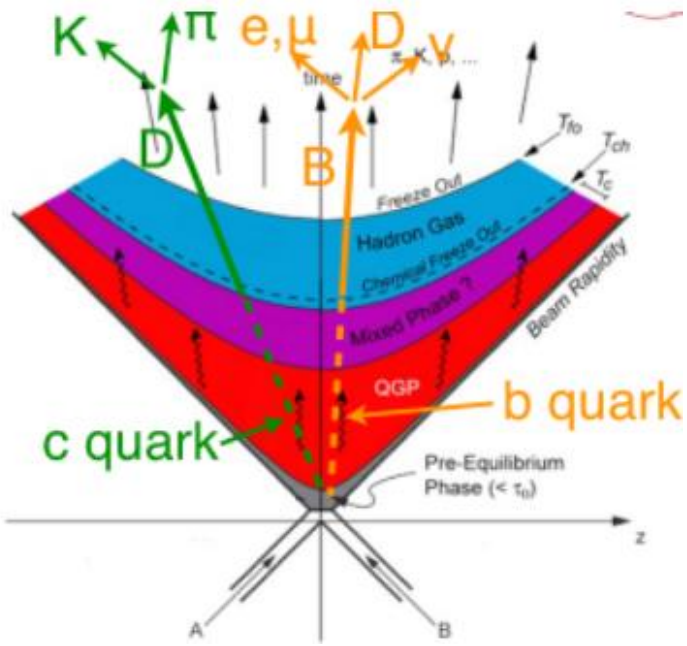


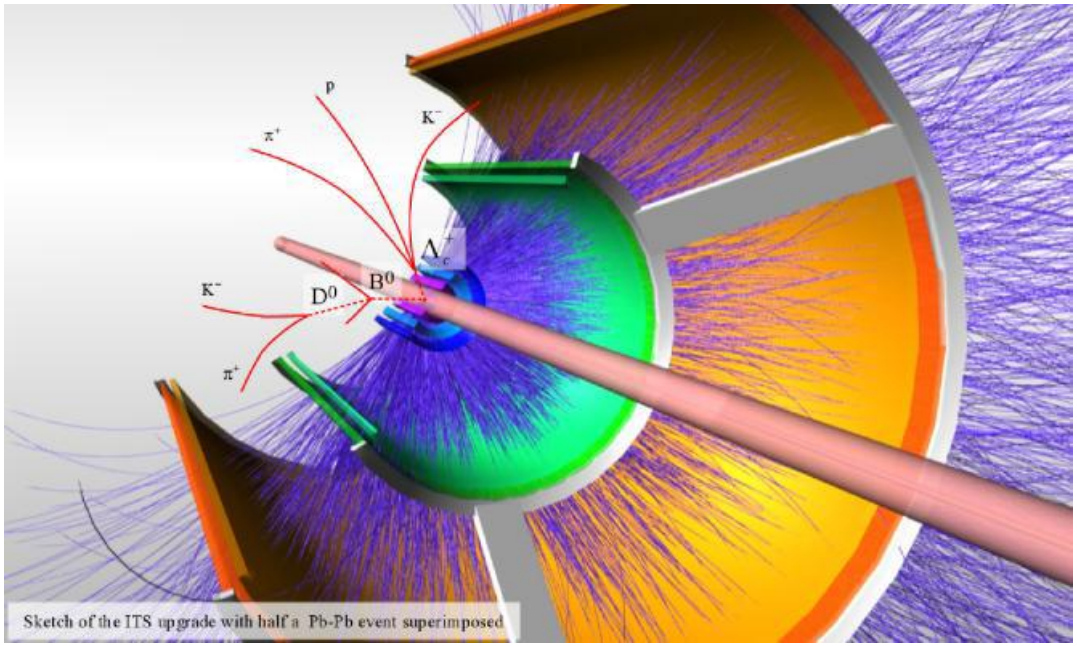
Yuri Murin, VBLHEP JINR for the MPD ITS team
murin@jinr.ru

The outline

- *The physics case – an attempt to deconfine quarks through density fluctuations of the fireball under critical conditions*
- *A role of the rare probes (heavy hyperons and charmed mesons) in search of hints of critical point*
- *Transition from strips to pixels and the MAPS "invasion"*
- *The new ALICE ITS2 saves NICA a generation period*
- *the MPD ITS project and plans for its implimentation*

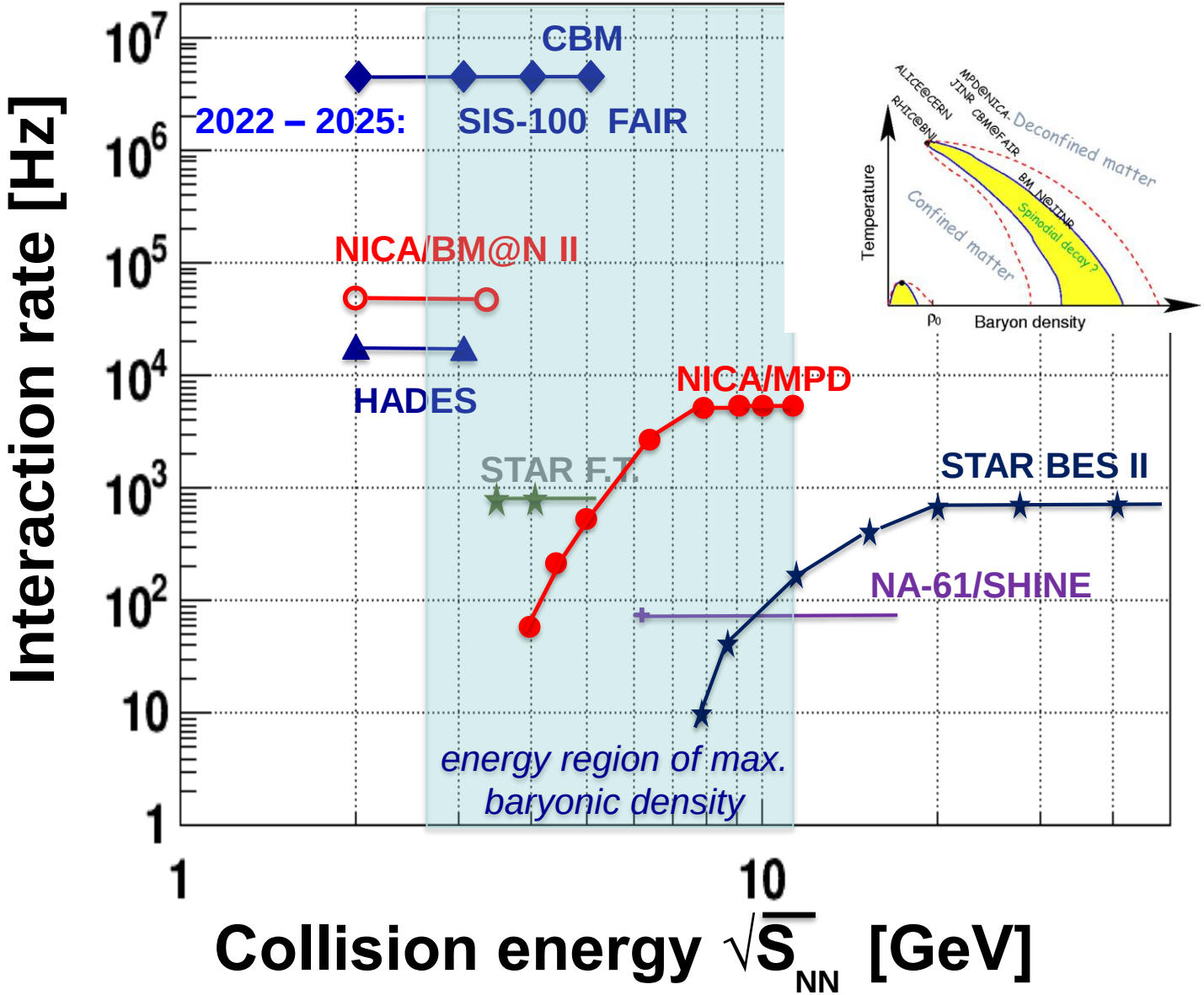
Look for a needle in a "hay" of tracks for rare events



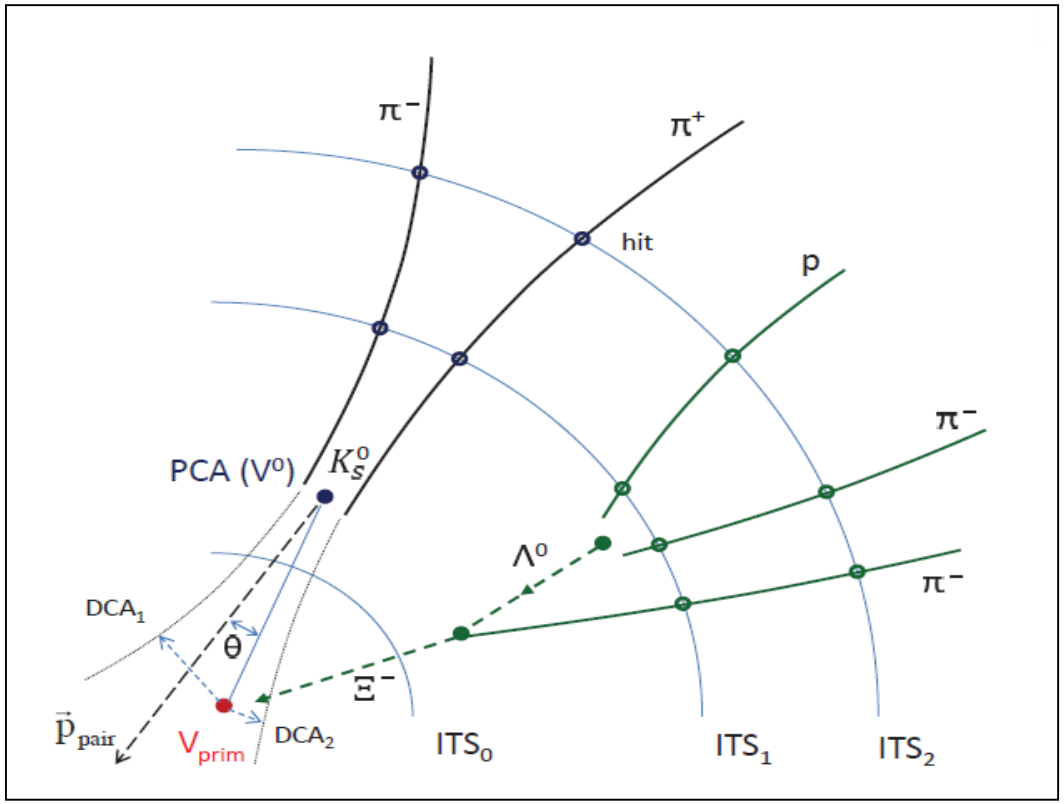


The Inner Tracking System or *Vertex tracker is a* multilayer telescope which measures the position of particle hits positions to restore the track trajectory. It's special task to be located as close as possible to the interaction point and to be as precise as possible to identify specific decays of particles carrying strangeness, charm or beauty i.e. S, C, or B - quarks

To deconfine quarks: to heat or to enhance density fluctuations



The basic task for the Inner Tracking System



$\Lambda \rightarrow p + \pi^-$

$\Xi^- \rightarrow \Lambda + \pi^-$
$\quad\quad\quad\quad \hookrightarrow p + \pi^-$

$\Omega^- \rightarrow \Lambda + K^-$
$\quad\quad\quad\quad \hookrightarrow p + \pi^-$

$D^+ \rightarrow K^- + \pi^+ + \pi^+$

$D^0 \rightarrow K^- + \pi^+$

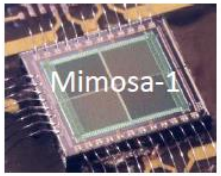
$\Lambda_c \rightarrow p + K^- + \pi^+$

Identification of particles through inspection of Inverse Mass distributions $M^2=sum(E_i)^2-sum(P_i)^2$ $(c=1)$

The MAPS "Invasion"

ALICE LS2 Upgrade

Owing to the industrial development of CMOS imaging sensors and the intensive R&D by HEP community



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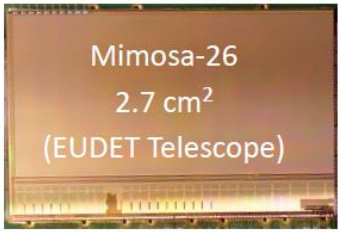
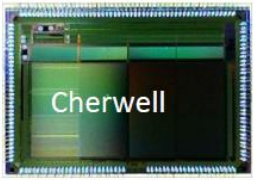
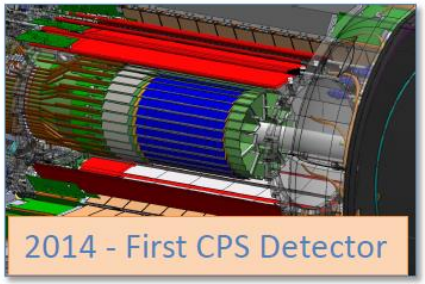
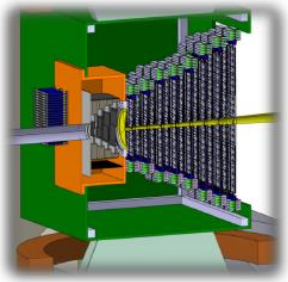




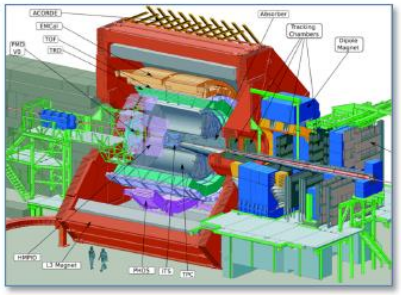
... several HI experiments have selected CMOS pixel sensors for their inner trackers and intensive R&D for ATLAS



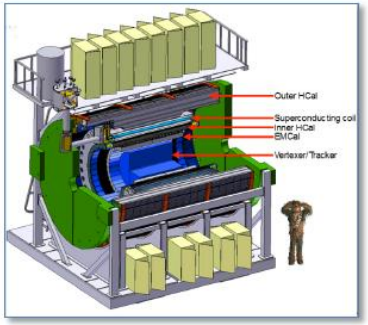
STAR HFT
0.16 m² – 356 M pixels



CBM MVD
0.08 m² – 146 M pixel



ALICE ITS Upgrade (and MFT)
10 m² – 12 G pixel



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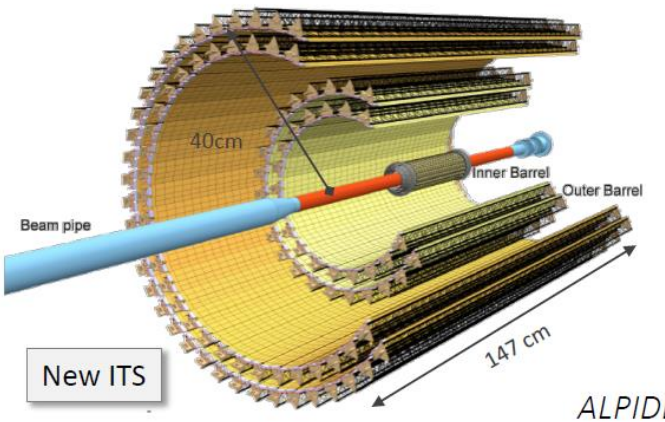
sPHENIX
0.2 m² – 251 M pixel

New ALICE ITS#2: sharing of technology

A new ITS: closer to IP, thinner, higher position resolution



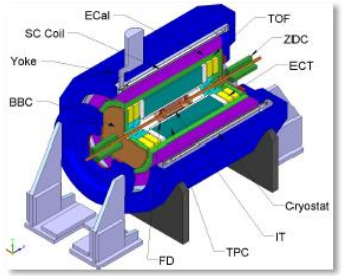
$1.5 \le \eta \le 1.5$

Closer to IP:	39mm ➡ 22mm
Thinner:	~1.14% ➡ ~ 0.3% (for inner layers)
Smaller pixels:	50μm x 425μm ➡ 27μm x 29μm
Increase granularity:	20 chan/cm^3 ➡ 2k pixel/cm^3
Faster readout:	x 10^2 Pb-Pb, x 10^3 pp

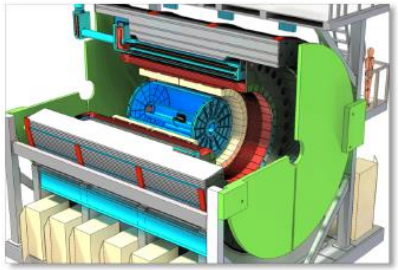
10 m^2 active silicon area: 12.5 G-pixels, $\sigma \approx 5\mu m$

ALPIDE (ALICE Pixel Detector) - Developed for the ALICE upgrade (ITS and MFT) will be used (or it is proposed) for several other HEP detectors and non HEP applications

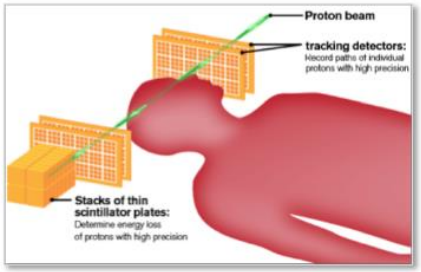
NICA MPD (@JINR)



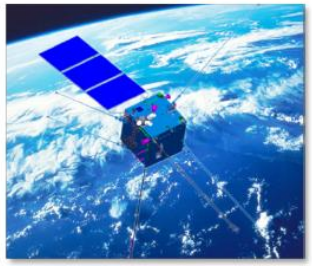
sPHENIX (BNL)



proton CT (tracking)



CSES – HEPD2



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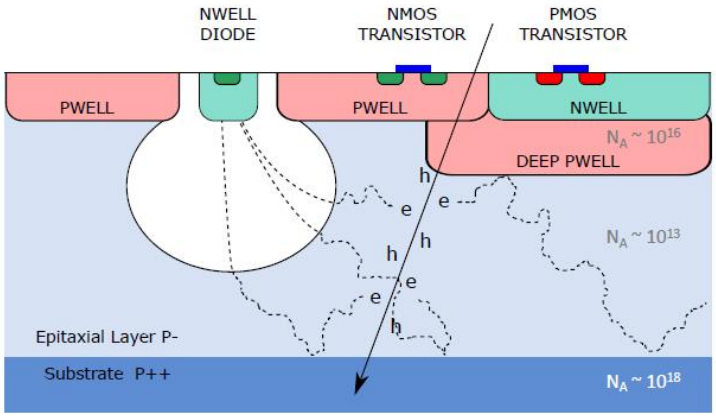
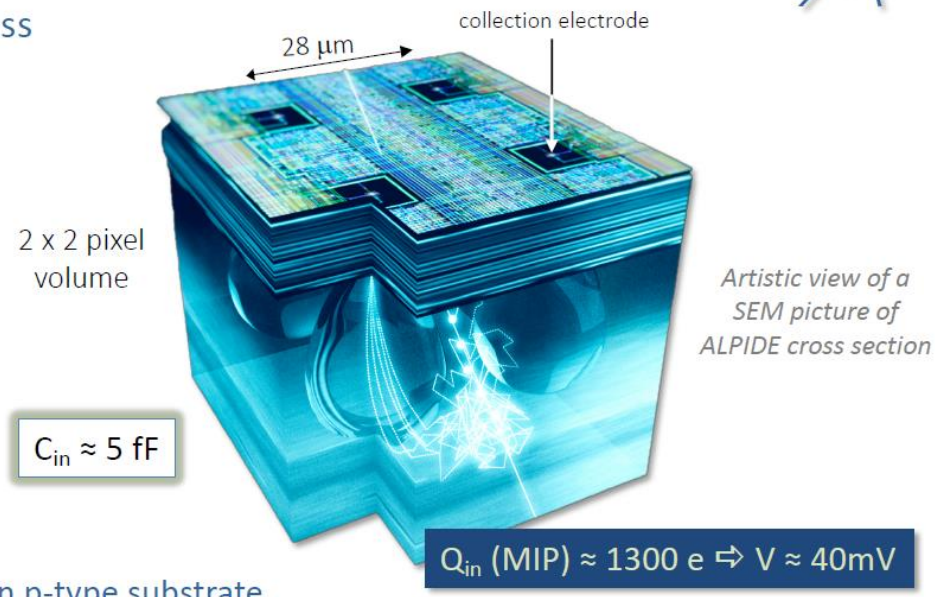
The ALPIDE sensor

ALICE CMOS Pixel Sensor

CMOS Pixel Sensor using 0.18µm CMOS Imaging Process



pixel capacitance ≈5 fF (@ V_{bb} = -3 V)



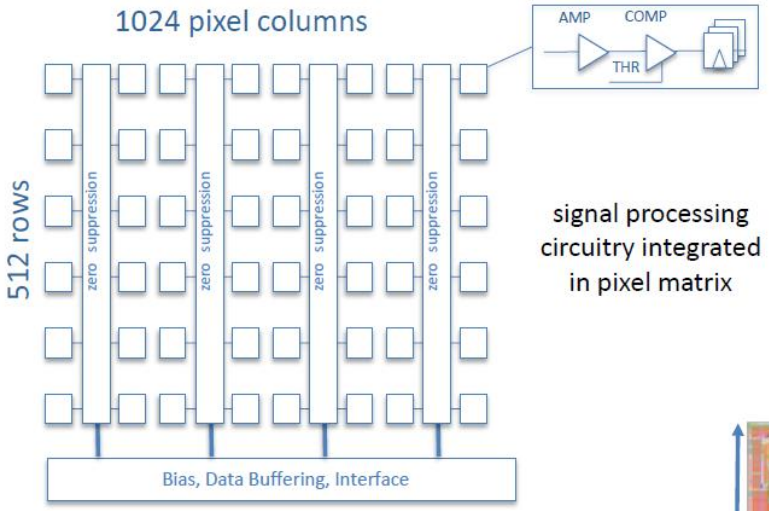
Artistic view of a SEM picture of ALPIDE cross section

- High-resistivity (> 1kΩ cm) p-type epitaxial layer (25µm) on p-type substrate
- Small n-well diode (2 µm diameter), ~100 times smaller than pixel => low capacitance (~fF)
- Reverse bias voltage (-6V < V_{BB} < 0V) to substrate (contact from the top) to increase depletion zone around NWELL collection diode
- Deep PWELL shields NWELL of PMOS transistors

➔ full CMOS circuitry within active area

The ALPIDE Readout

ALICE PIxel DEtector (ALPIDE)



signal processing circuitry integrated in pixel matrix

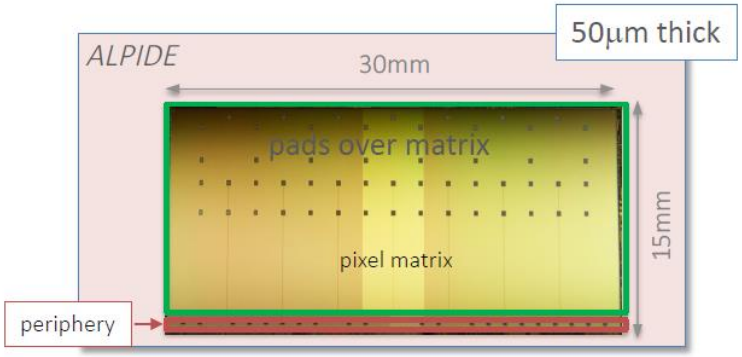
130,000 pixels / cm^2 27x29x25 μm^3

charge collection time <30ns (V_{bb} = -3V)

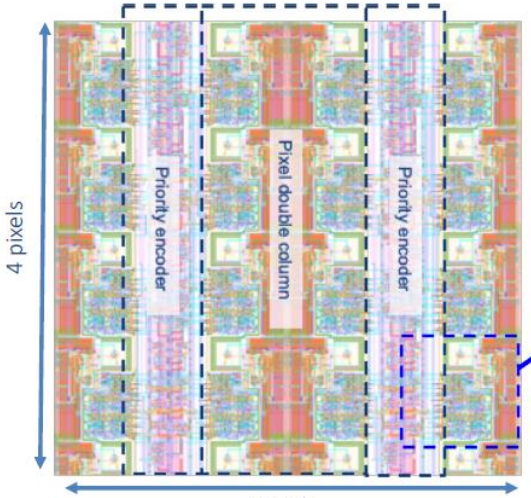
Max particle rate: 100 MHz/cm^2

fake-hit rate: < 1 Hz/ cm^2

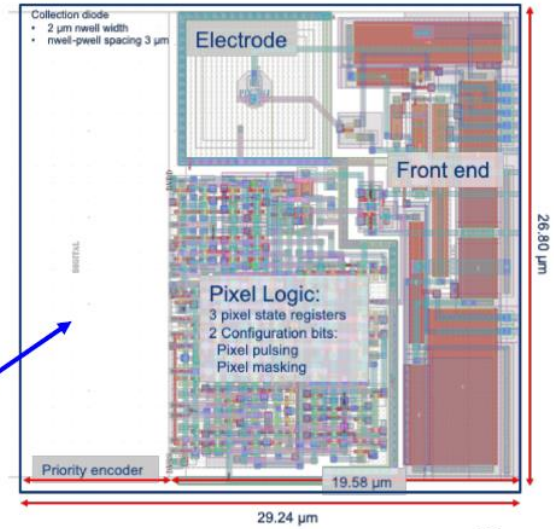
power : ≈300 nW /pixel (<40mW/cm^2)



Matrix Layout



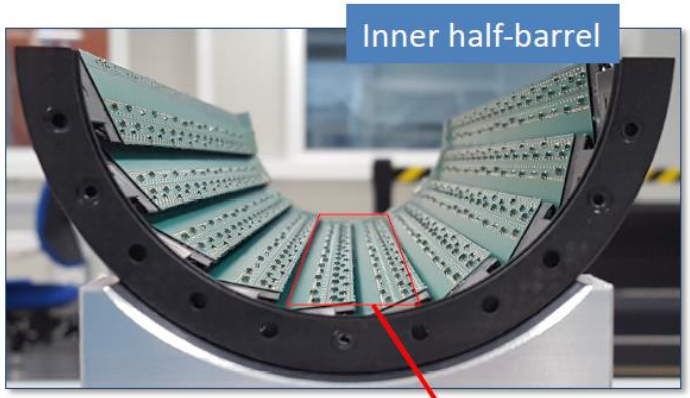
Pixel Layout



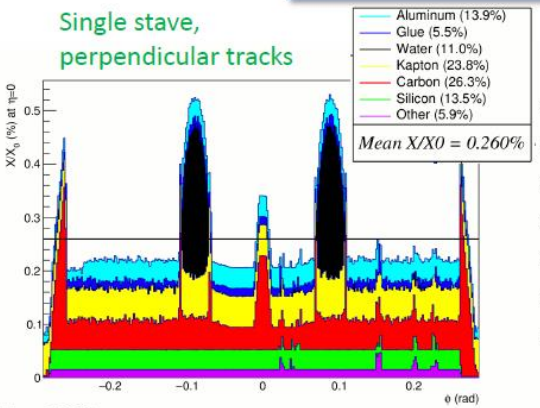
New ALICE ITS#2 beats records on material budget

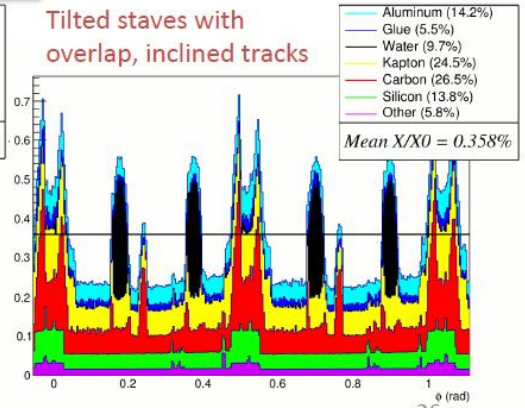
ALICE PIxel DEtector (ALPIDE)

Inner Barrel Production completed and all layers assembled



Material budget





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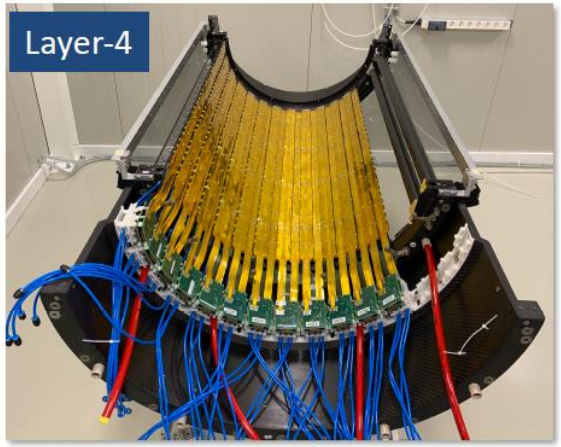
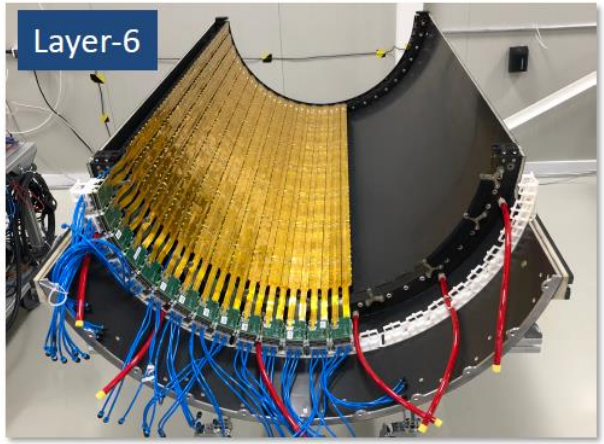
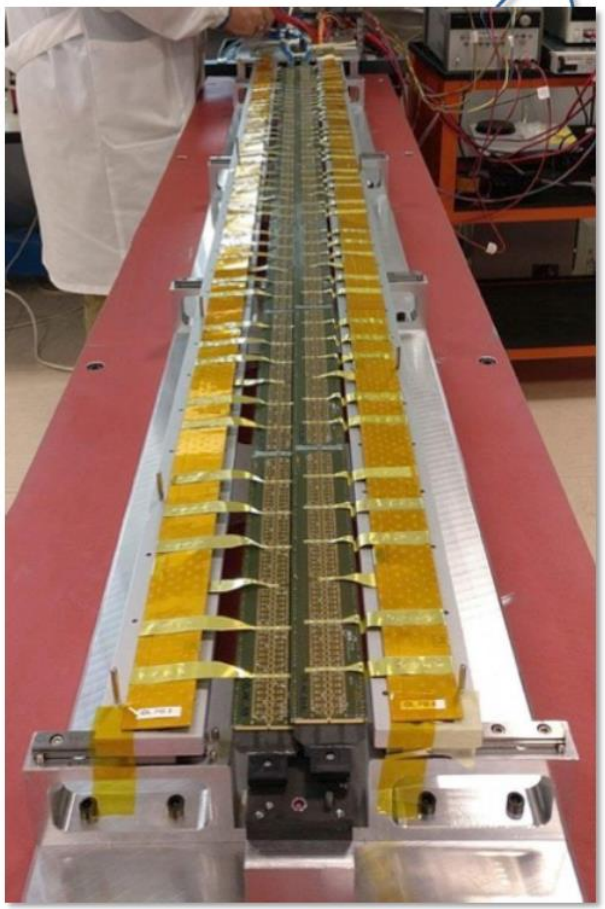
New ALICE ITS#2: …….and number of pixels

ALICE PIxel DEtector (ALPIDE)



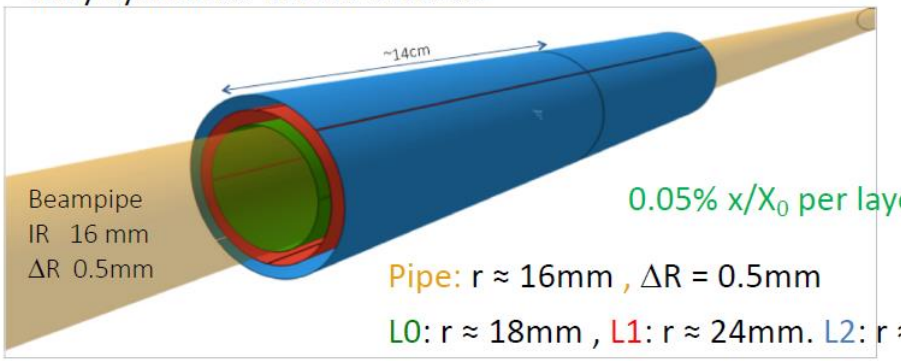




Plans for ALICE ITS#3: exchange of the IB

Vertex Detector (innermost 3 layers)

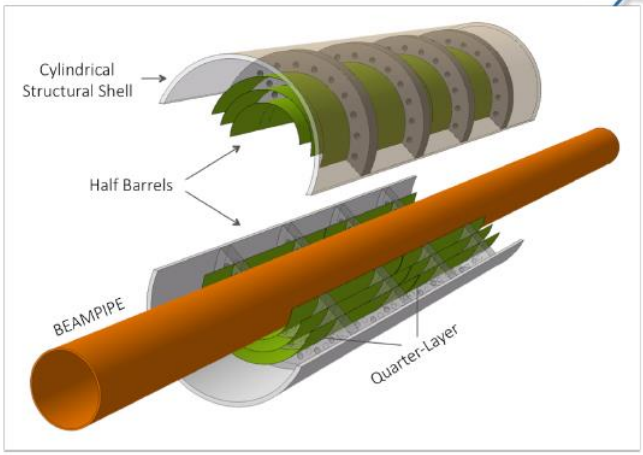
Truly cylindrical vertex detector



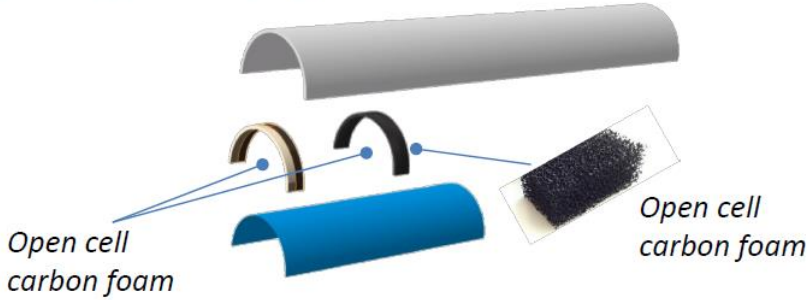
0.05% x/X_0 per layer

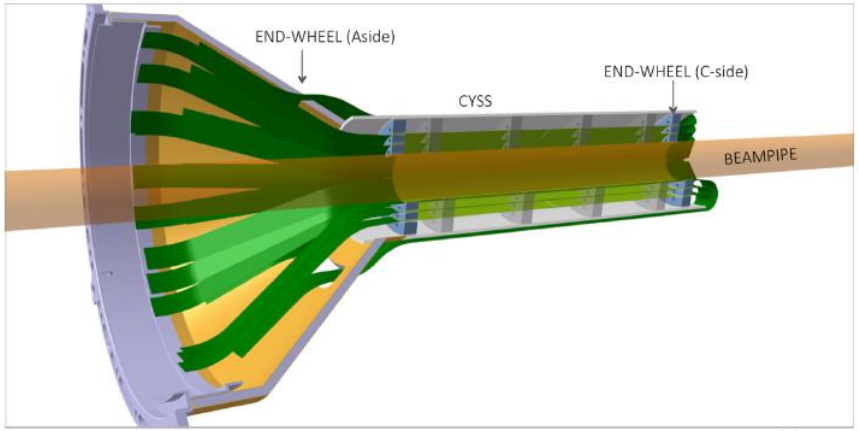
Pipe: r ≈ 16mm , ΔR = 0.5mm

L0: r ≈ 18mm , L1: r ≈ 24mm. L2: r ≈ 30 mm



Layers supported by high-thermal conductive carbon foam





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MPD-ITS (OB) is now recognized at Stage I

Stage I: TPC, TOF, ECAL, ZDC, FFD + ITS(OB)

Stage II : ITS(IB) + EndCap (CPC, Straw, TOF, ECAL)

Transfer of High Tech Instrumentation Know-How from CERN to NICA-MPD

PROTOCOL

to

THE CO-OPERATION AGREEMENT

between

THE JOINT INSTITUTE FOR NUCLEAR RESEARCH (JINR)

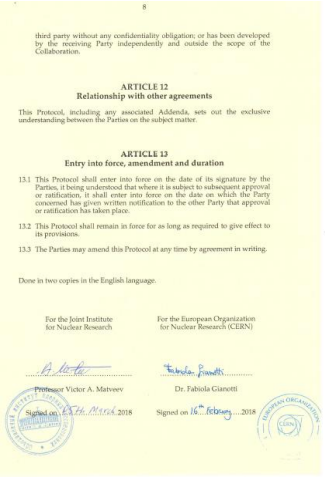
and

THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

concerning

The Development and Provision by CERN of Monolithic Pixel Detectors, TPC Front-end Electronics and other Items for the MPD Experiment at the NICA Facility at JINR

2018



8

third party without any confidentiality obligation; or has been developed by the receiving Party independently and outside the scope of the Collaboration.

ARTICLE 12
Relationship with other agreements

This Protocol, including any associated Addenda, sets out the exclusive understanding between the Parties on the subject matter.

ARTICLE 13
Entry into force, amendment and duration

13.1 This Protocol shall enter into force on the date of its signature by the Parties, it being understood that where it is subject to subsequent approval or ratification, it shall enter into force on the date on which the Party concerned has given written notification to the other Party that approval or ratification has taken place.

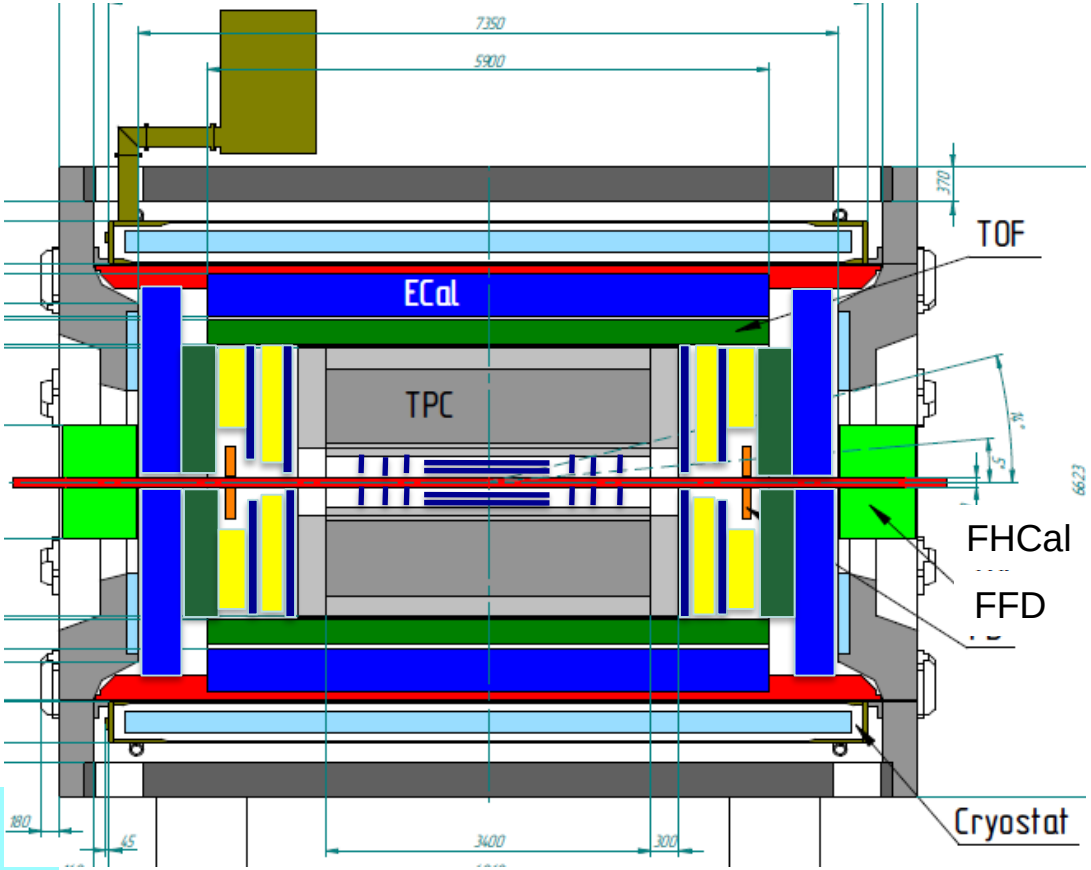
13.2 This Protocol shall remain in force for as long as required to give effect to its provisions.

13.3 The Parties may amend this Protocol at any time by agreement in writing.

Done in two copies in the English language.

For the Joint Institute for Nuclear Research — Professor Victor A. Matveev — Signed on 15 Th. March 2018

For the European Organization for Nuclear Research (CERN) — Dr. Fabiola Gianotti — Signed on 16th February 2018



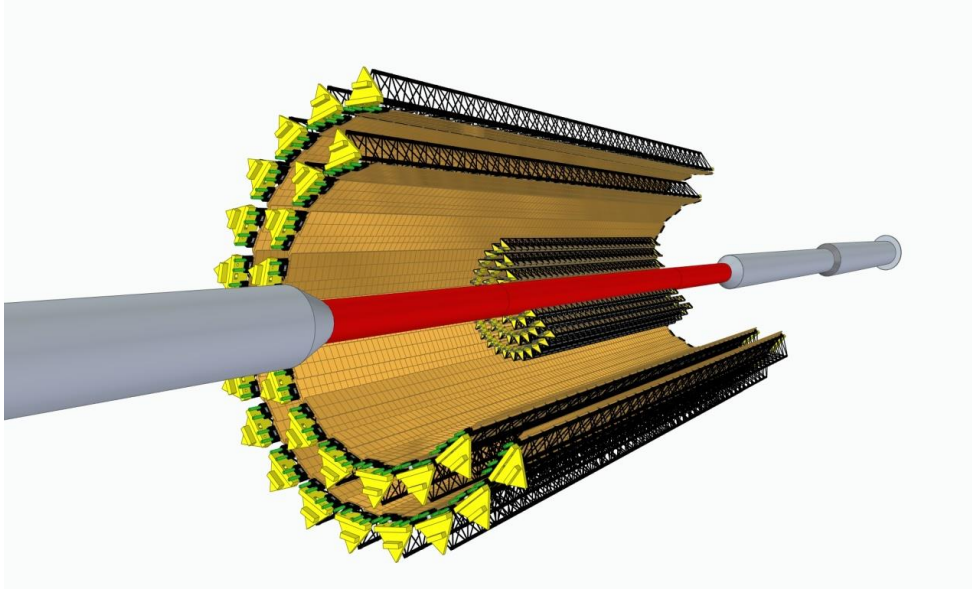
Stage I: *overall commissioning starts in* ***2022 (t.b.c.)***

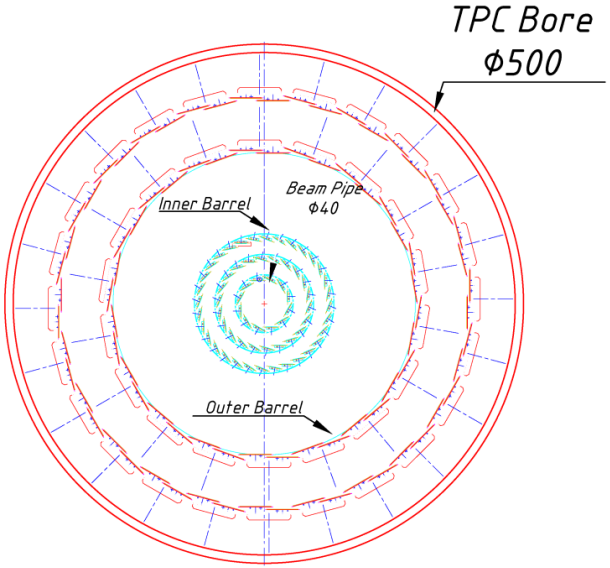
Items to be shipped from CERN formulated in Addendums to the Protocol

CERN will procure, test and deliver to NICA

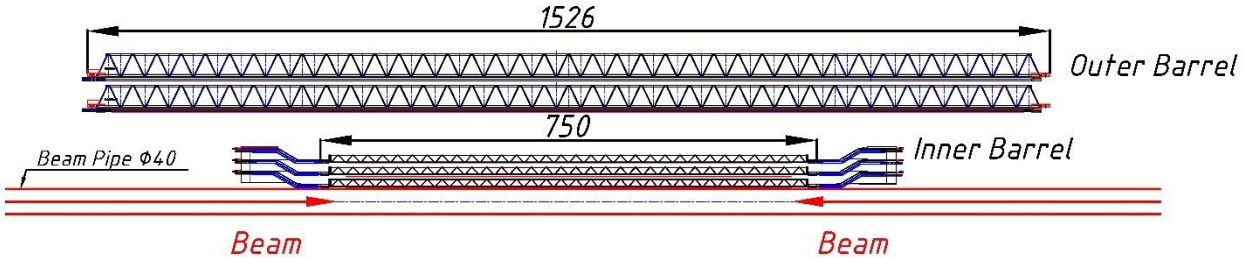
- 19'000 ALPIDE Monolithic Active Pixel Sensors for the MPD ITS
- 4'500 SAMPA electronic circuits for the TPC readout
- 5'000 FEAST DC/DC converters for the ECAL MPD
- Jigs and fixtures for module and supermodule assembly for the MPD ITS
- Training of personal for assembly and QA certification modules and supermodules of the MPD ITS
- Provision of complete technical and commercial information on parts of the new ALICE Inner Tracking System, including drawings, internal technical reports, quotes, etc.

MPD ITS based on the ALPIDE MAPS CERN technology

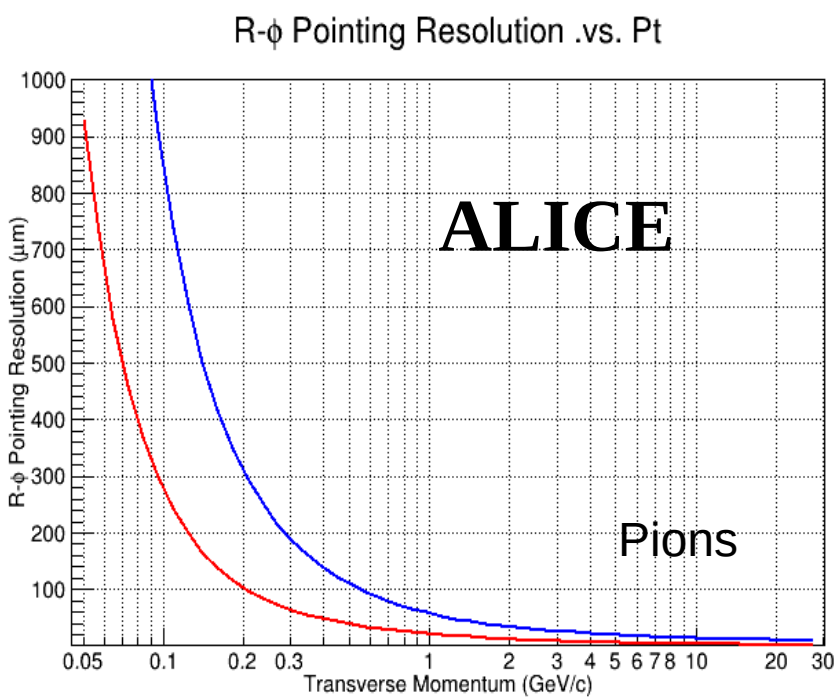


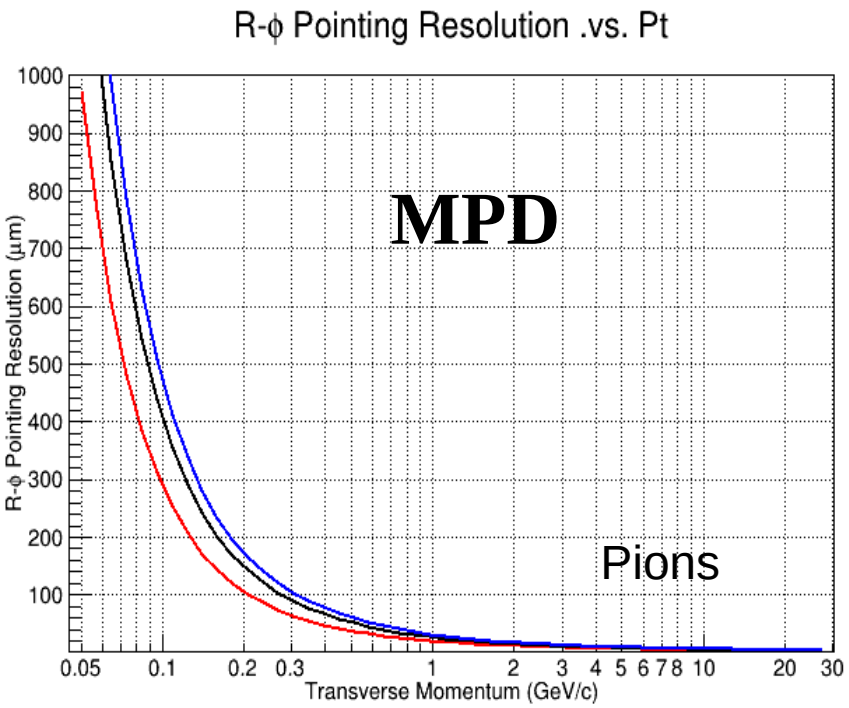


Beam pipe Ø = 40 mm



ITS pointing resolution within STAR-ALICE toy model





New ITS

Old ITS

Ø = 40 mm

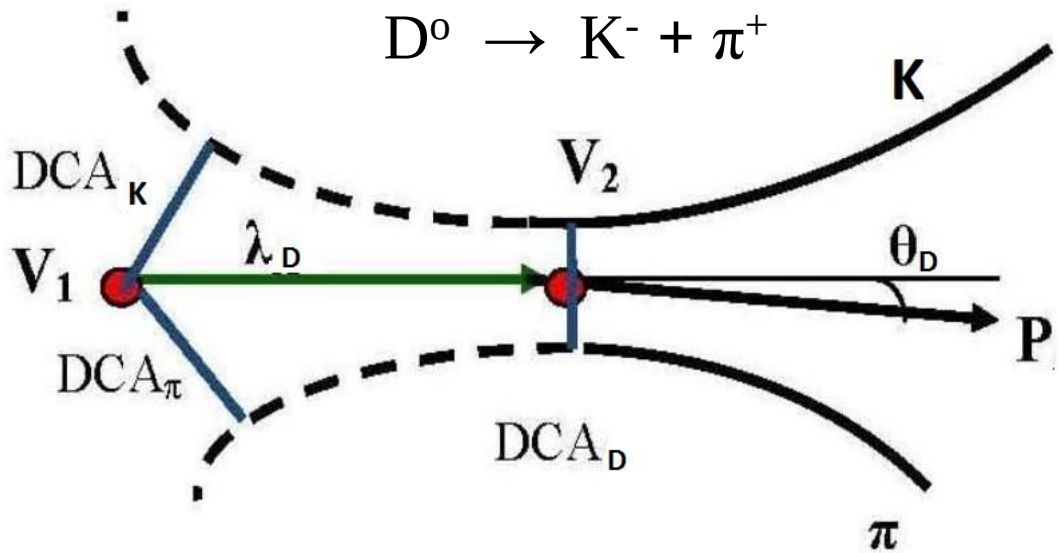
Ø = 50 mm

Ø = 60 mm

Selection criteria

D^0 selection parameters:

- distances of closest approach to the collision vertex $DCA_{\pi,K}$,
- two-track separation DCA_D ,
- decay path λ_D,
- pointing angle θ_D.



Selection criteria:

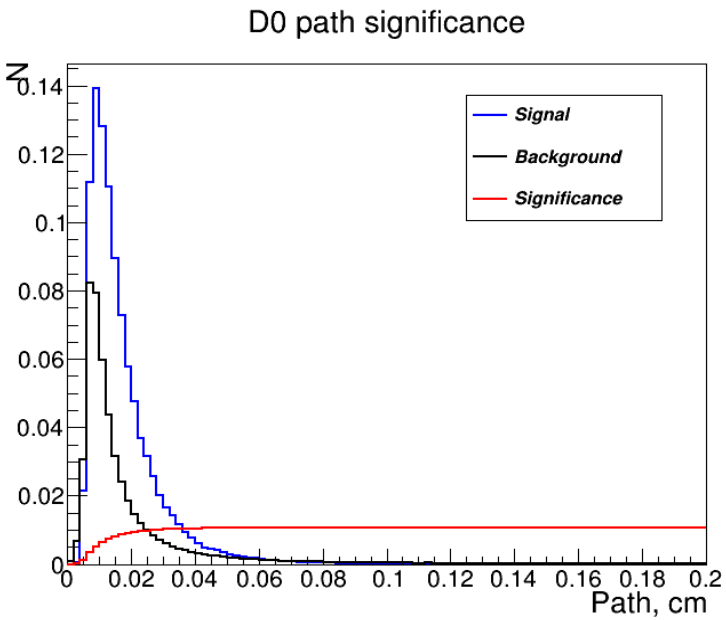
$DCA_\pi > C_1$ && $DCA_K > C_2$ && $DCA_D < C_3$ && $\lambda_D > C_4$ && $\theta_D < C_5$

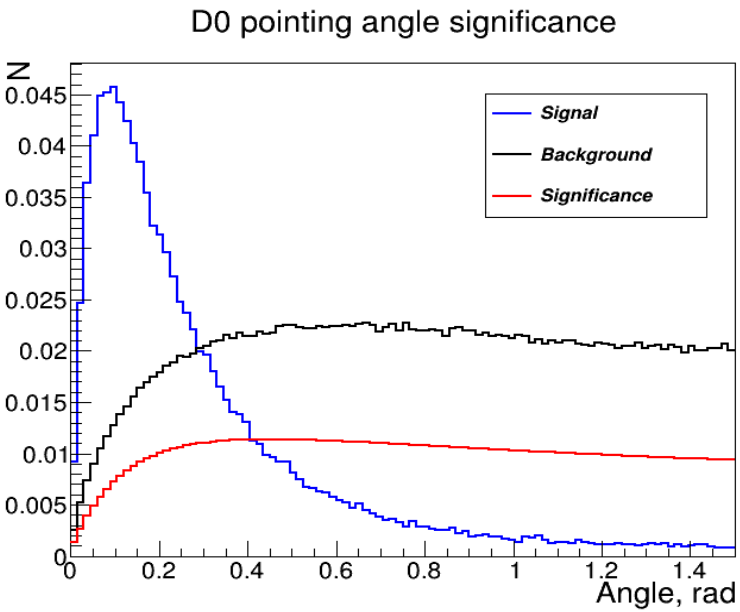
The parameters of the corresponding selections are optimized by maximizing the signal significance :

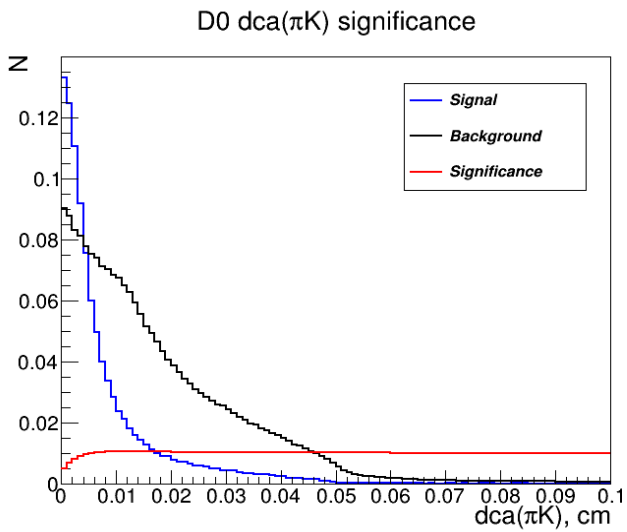
$$Sg(a) = \int_0^a \frac{S}{\sqrt{S+B}} da$$

where S and B are the estimated numbers of the signal and background events.

Example : cuts selections for D^0



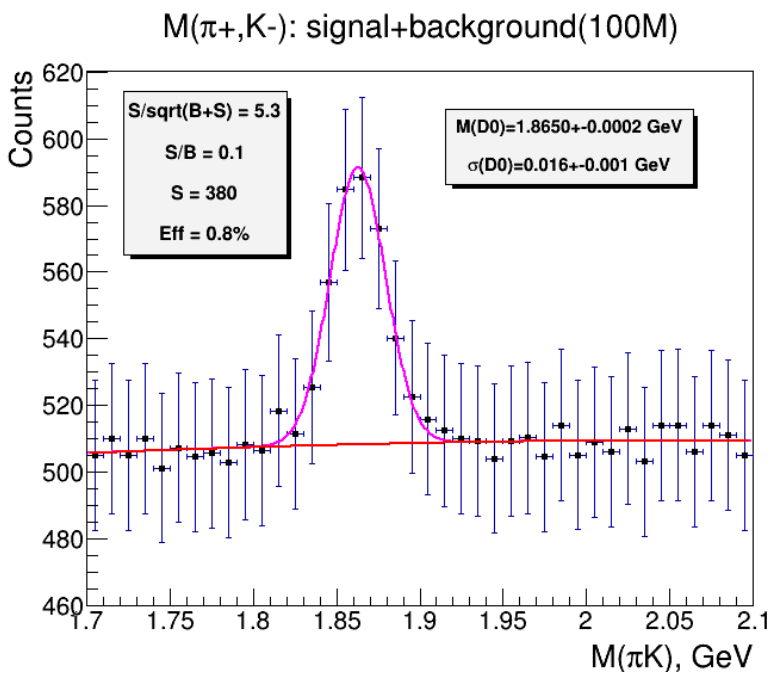


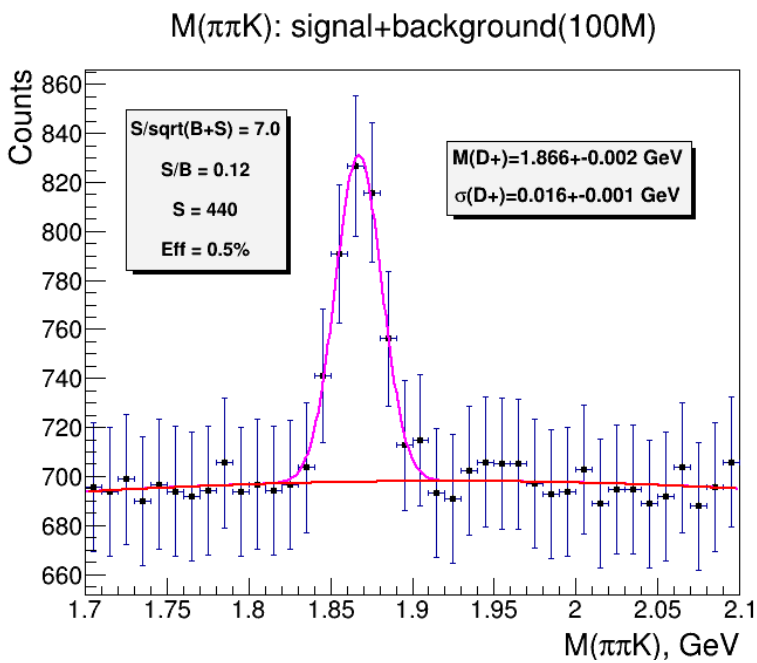


dcaK>0.01 cm & *dcaPi*>0.01 cm & *distPiK* < 0.02 cm & *path*(D^0) > 0.025 cm & *angle*(D^0) < 0.2 rad

D^+ and D^0 reconstruction

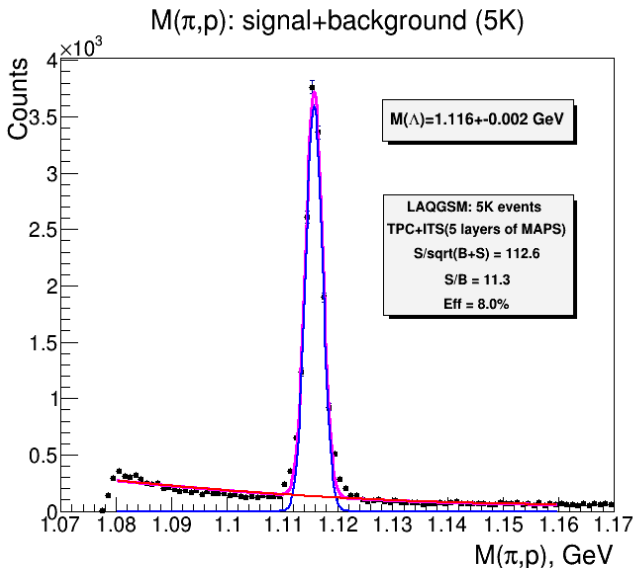
t1=t2=t3=50μ (IB ITS3) t4=t5=700μ (OB ITS2)

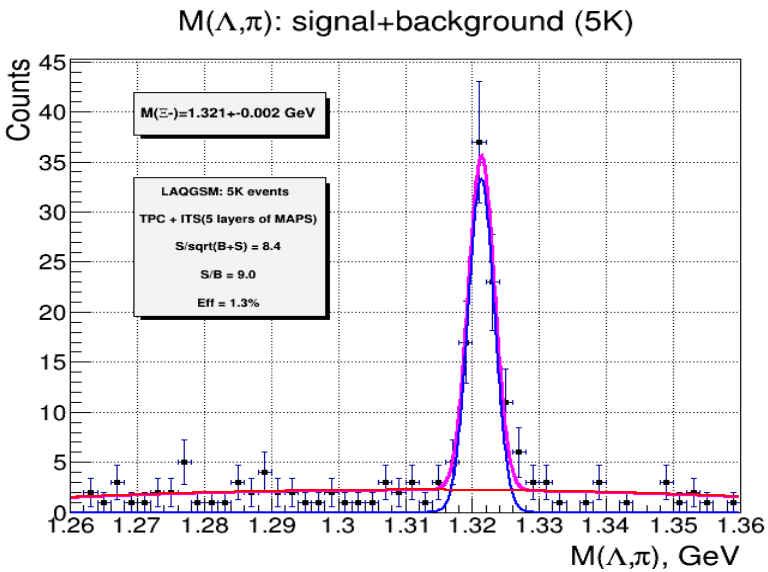


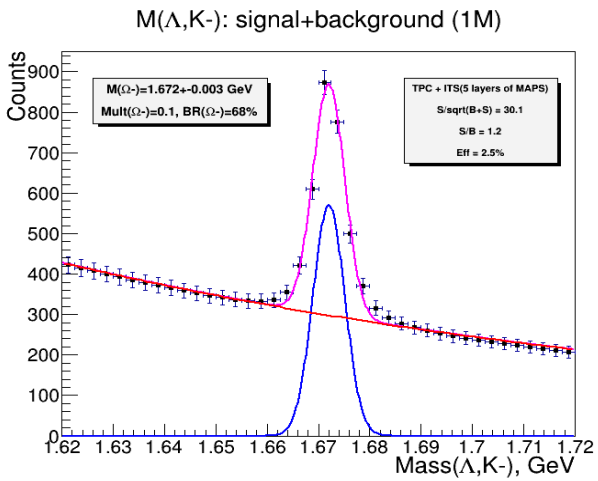


DCA(π, K,D^0), path(D^0), angle(D^0) cuts

Strange particle reconstruction results





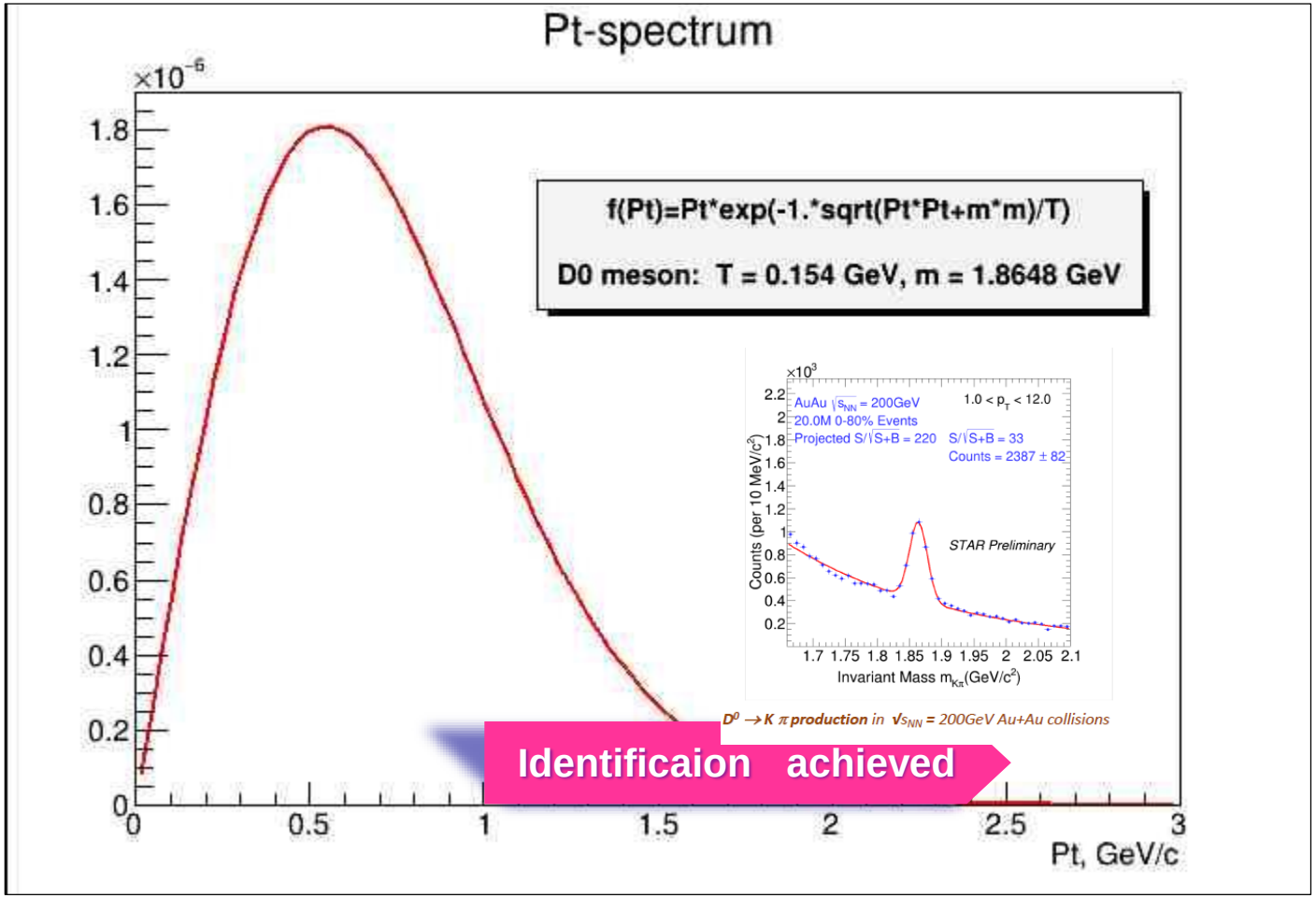


Impact of Beam pipe diameter on efficiency

D-meson parameters in 100M central Au+Au collisions at $\sqrt{s_{NN}} = 9$ ГэВ

Particle	D^0		D^+	
Decay channel	$D^0 \rightarrow K^- + \pi^+$		$D^+ \rightarrow K^- + \pi^+ + \pi^+$	
Multiplicity (HSD	10^{-2}		10^{-2}	
BR,%	3.9		9.1	
IB option	ITS3(50μ)	ITS2(200μ)	ITS3(50μ)	ITS2(200μ)
S/B(2σ)	0.43	0.10	0.65	0.27
Significance	15.1	2.2	28.5	7.6
Efficiency,%	1.9	0.13	2.3	0.3

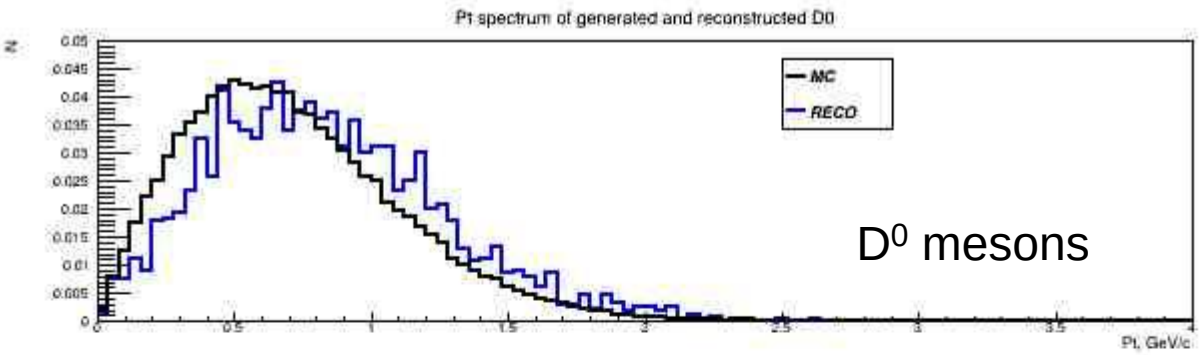
Current limitations of experimental data on D meson

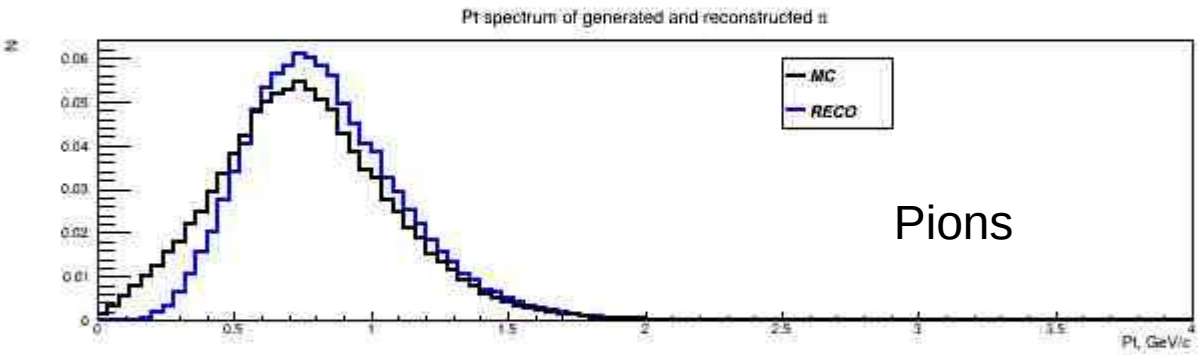


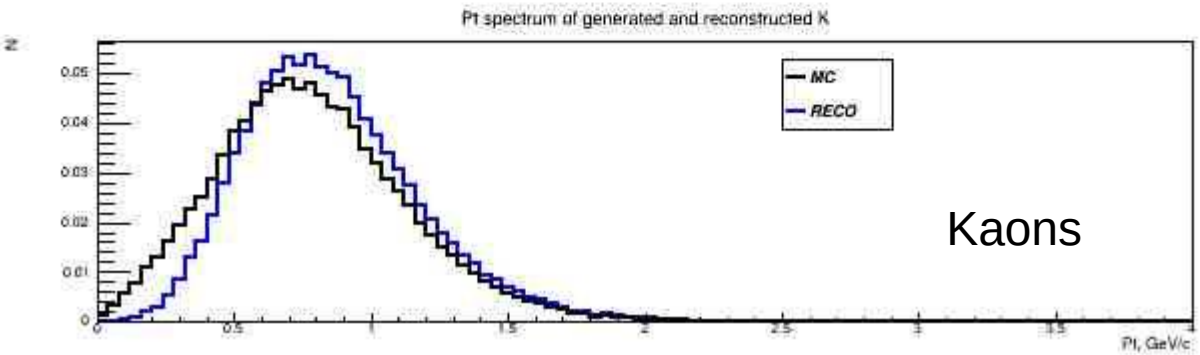
Thermal generator: D meson's p_t - spectrum

Abdel Nasser TAWFIK† and Ehab ABBAS
Thermal Description of Particle Production in Au-Au Collisions at STAR Energies
Physics of Particles and Nuclei Letters. November 2013

MC and reconstructed p_t-spectra of D^0-mesons and their decay products



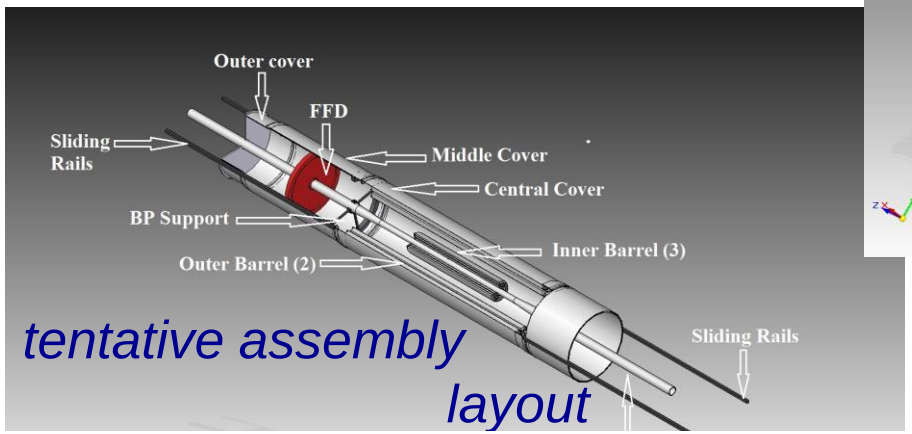




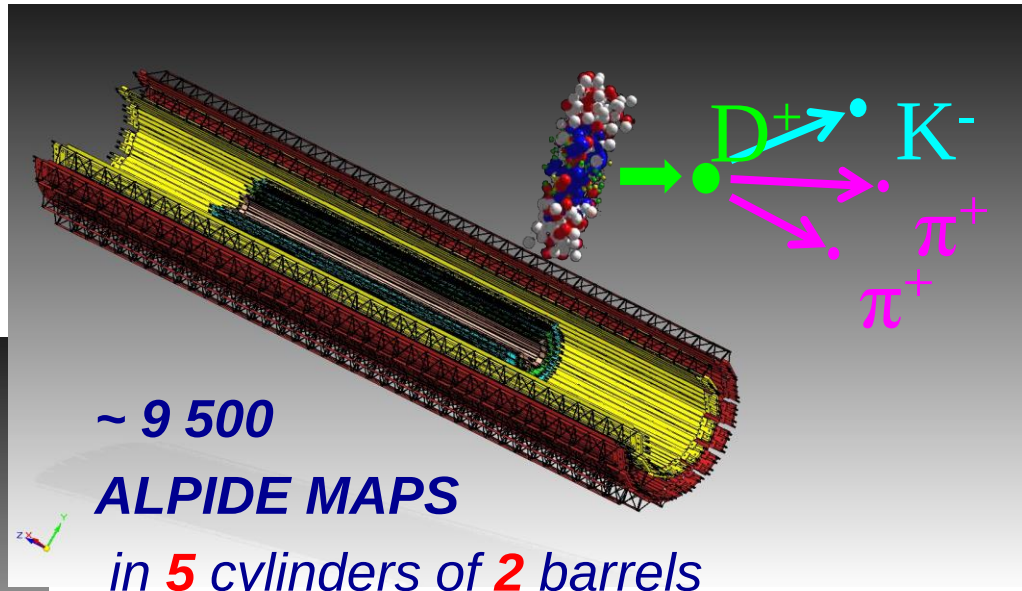
ITS realization in two Steps (OB first) due to BP sequence

Stage I: Installation of OB (2022-23)

Stage II: OB+IB (2022+25) ?



tentative assembly layout



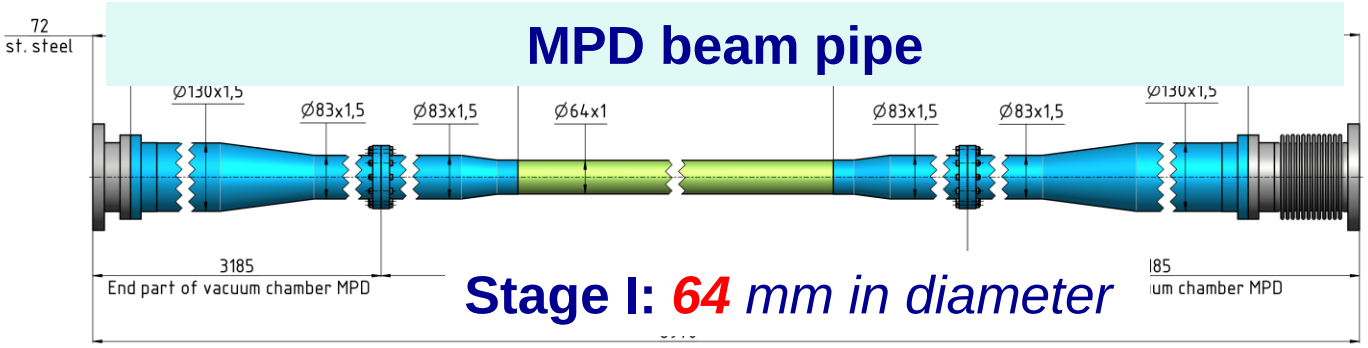
~ 9 500

ALPIDE MAPS

*in **5** cylinders of **2** barrels*

4,9 ·10⁹ *pixels, active area* ***3,9 m²****.*

MPD beam pipe

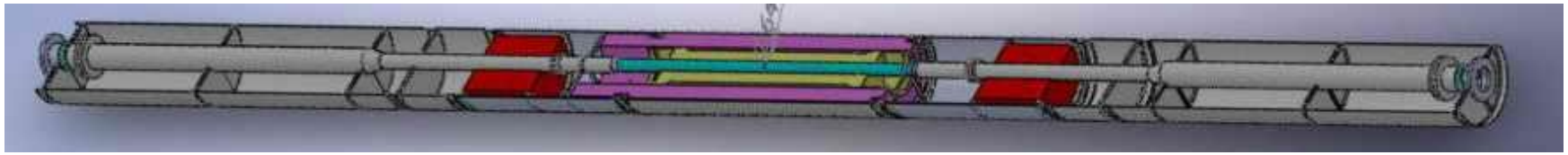


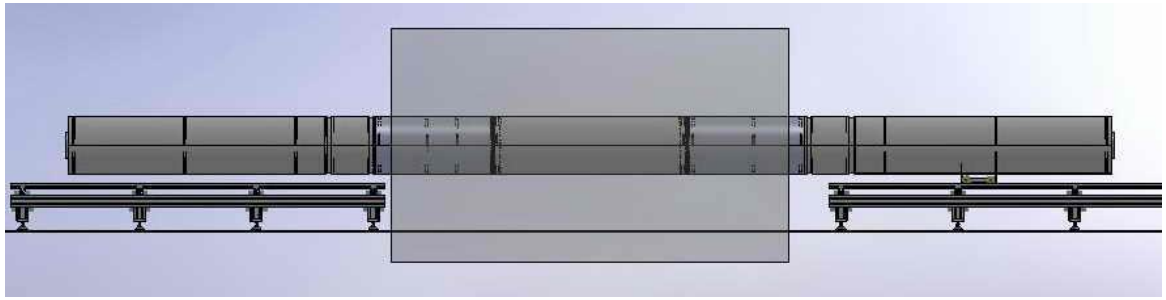
Stage I: ***64*** *mm in diameter*

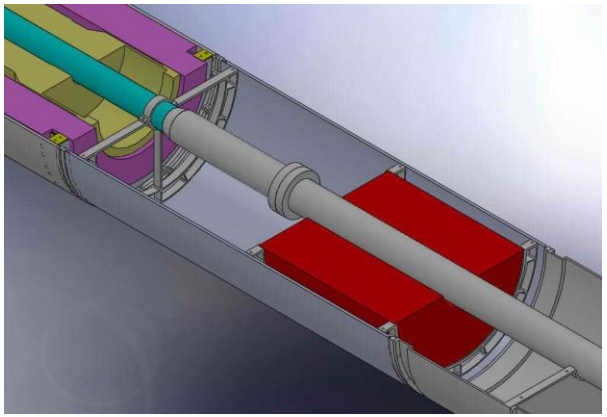
Stage II:
38 *mm in diameter*

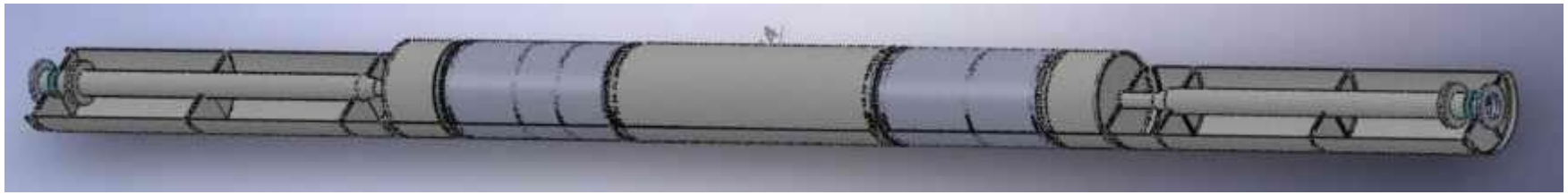
Current Activities

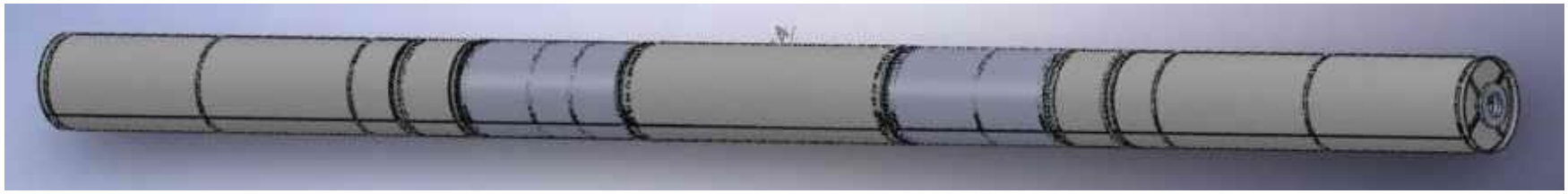
1.Mechanics for integration of ITS with Beam Pipe and TPC - JINR





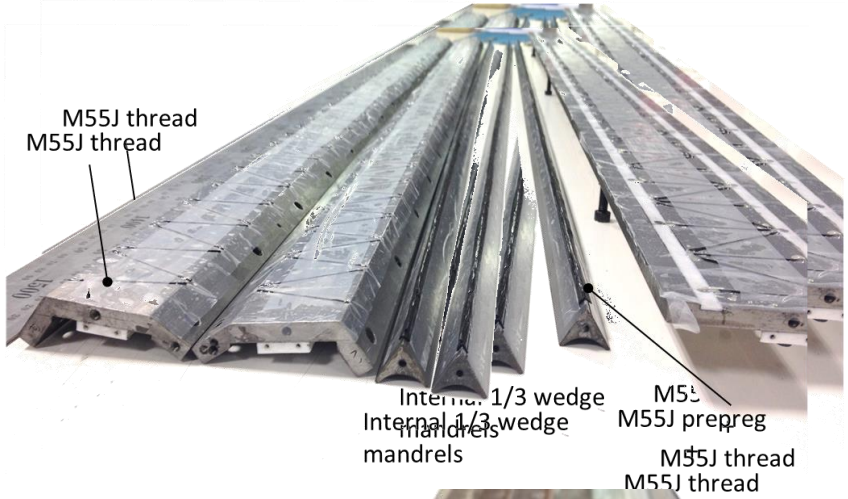


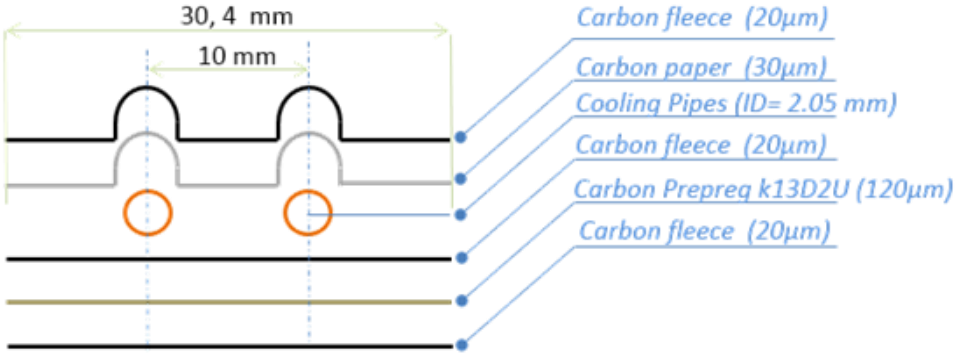




Current Activities

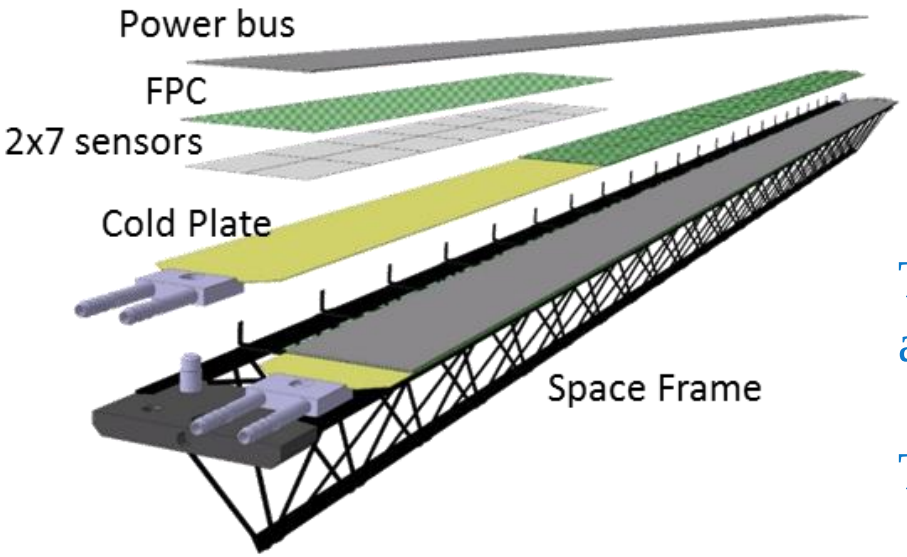
2. Start production of ultralight CF mechanics in SPbSU and VBLHEP





Current Activities

3. Start Assembly of HICs in Dubna and China (2020 Q1) and Staves(2021 Q1)



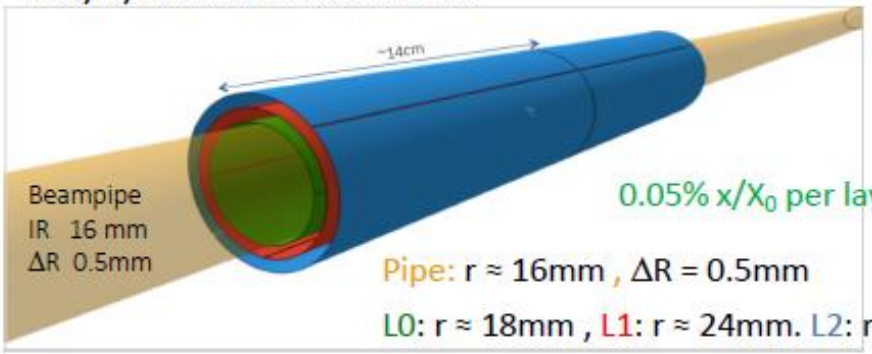
Truss length is 1540 mm. Modules (HICs) are are located on two cooling plates .
OB stave carriers 196 sensors.
The MPD ITS need is 42 OB staves.

Planned Activities

4. Development of ITS3 together with ALICE ITS3 team

Vertex Detector (innermost 3 layers)

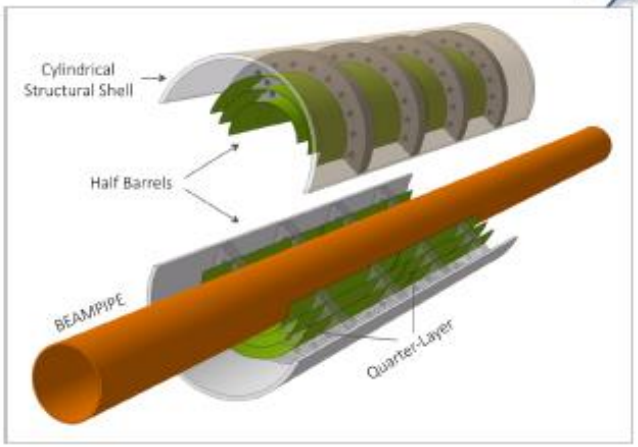
Truly cylindrical vertex detector



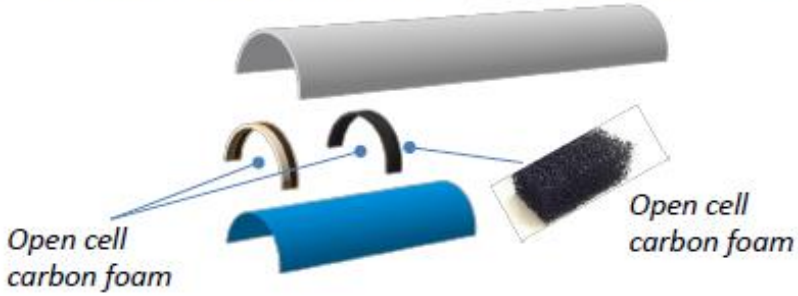
0.05% x/X_0 per layer

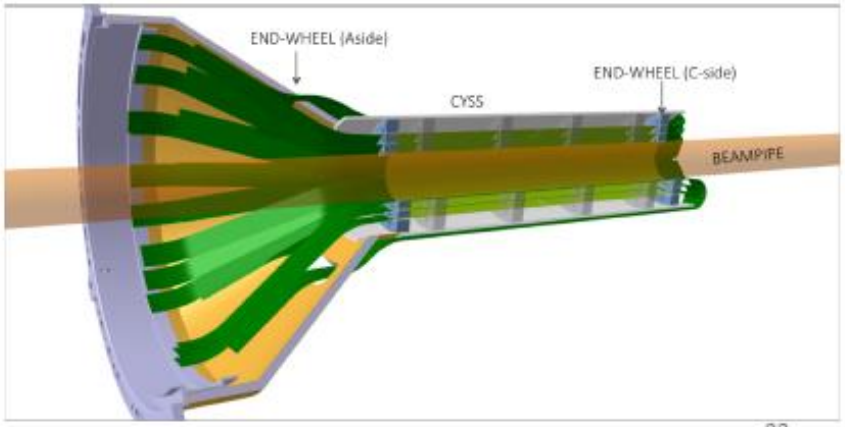
Pipe: r ≈ 16mm , ΔR = 0.5mm

L0: r ≈ 18mm , L1: r ≈ 24mm. L2: r ≈ 30 mm



Layers supported by high-thermal conductive carbon foam





L. Musa (CERN) – International Winter Meeting on Nuclear Physics, Bormio, 8-11 Jan 2019

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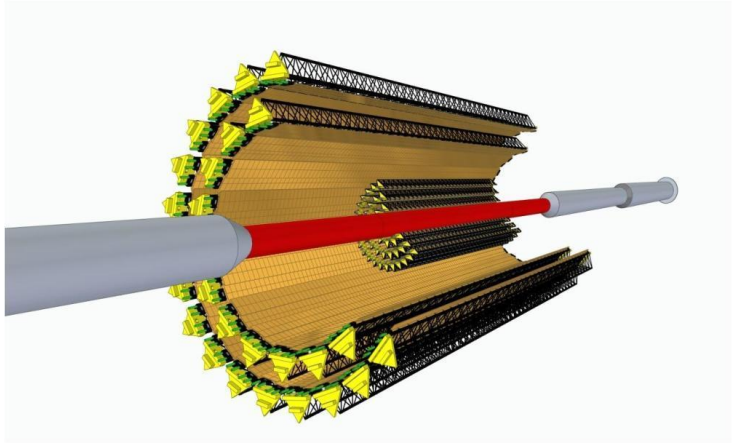
Planned Activities

5. Preparing the Technical Design Report and Organization of the MPD ITS Consortium

Technical Design Report

The Inner Tracking System

of the MPD experiment



Dec. 2019

Conclusions and summary

major milestones of the MPD ITS project (tentavily!)

- ***2018 –2019*** *– simulations and start of delivery of parts from CERN*
- ***2019*** *– organization of the Russian-Chinese Consortium*
- ***2019*** *– Writing TDR (Draft)*
- ***2019-2020*** *– Production of first HICs at VBLHEP and CCNU*
- ***2020 –2021*** *– Mechanics including parts for integration*
- ***2020 –2021*** *– updating the readout chain (with China and ?)*
- ***2020 –2023*** *– R@D effort on IB together with ALICE*
- ***2021 –2023*** *– Production HICs, assembly of OB staves (with China)*
- ***2023 (?)*** *– **ITS-OB** assembly, bench testing, commissioning*
- ***2025(?)*** *– **ITS-OB+IB** commissioning (**Stage II**)*

summary

- The MPD-ITS project is both scientific- and time-wise well justified
- The project has a solid reason to be accomplished in two stages
- The MPD-ITS(OB) (stage 1) one is now recognized and approved for financing at JINR
- The MPD-ITS(IB) (stage 2) contains R@D proposed to be performed under the supervision of ALICE Collaboration (ITS-3)
- The project effort due to its technical complexity cannot be undertaken by JINR alone and calls for organization of a Consortium of Institutes from Russia and China (and elsewhere!) functioning at least till 2025

Thank you for attention and RFBR for GRANT # 18-02-401119!