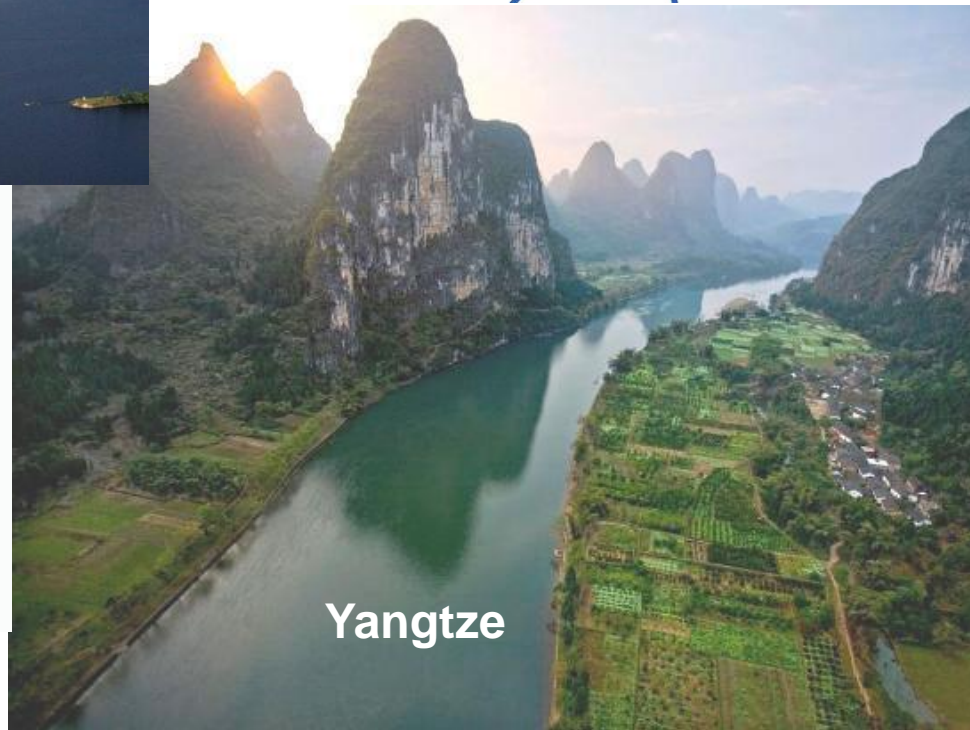
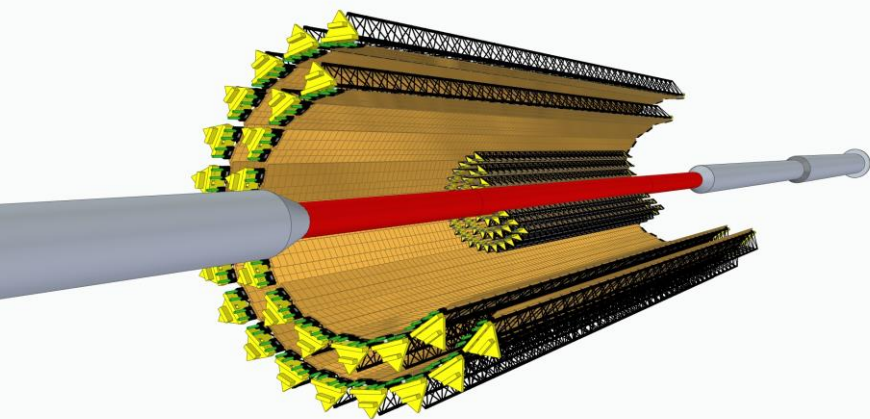
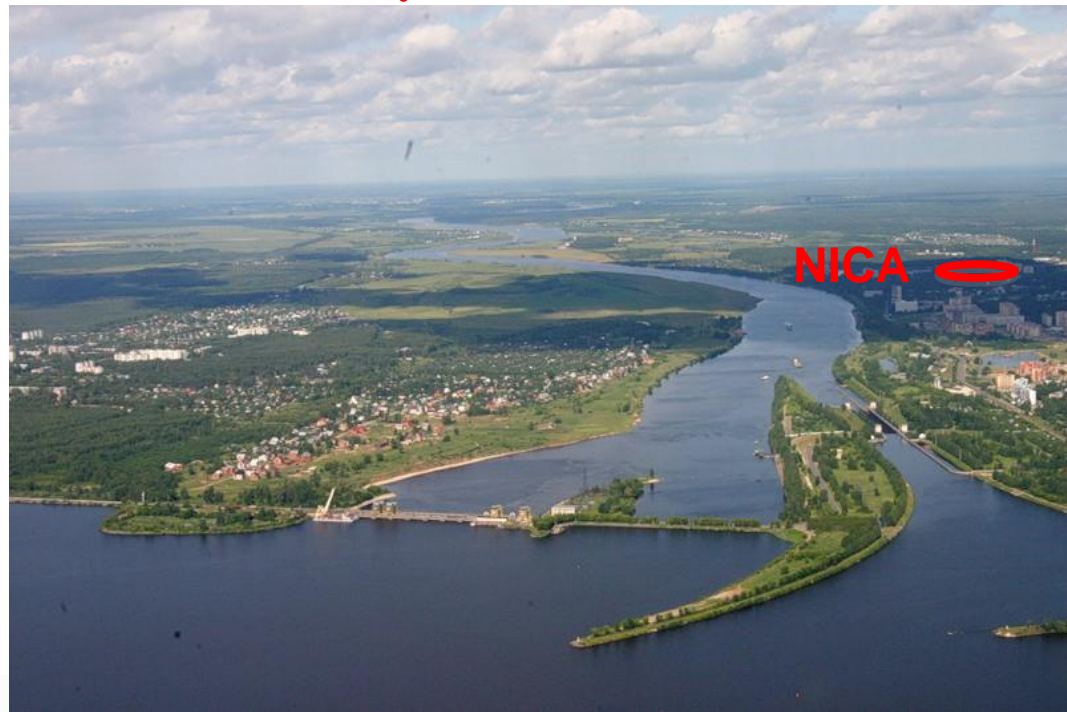


# A MAPS based Inner Tracking System of the Multi-Purpose Detector at the NICA collider

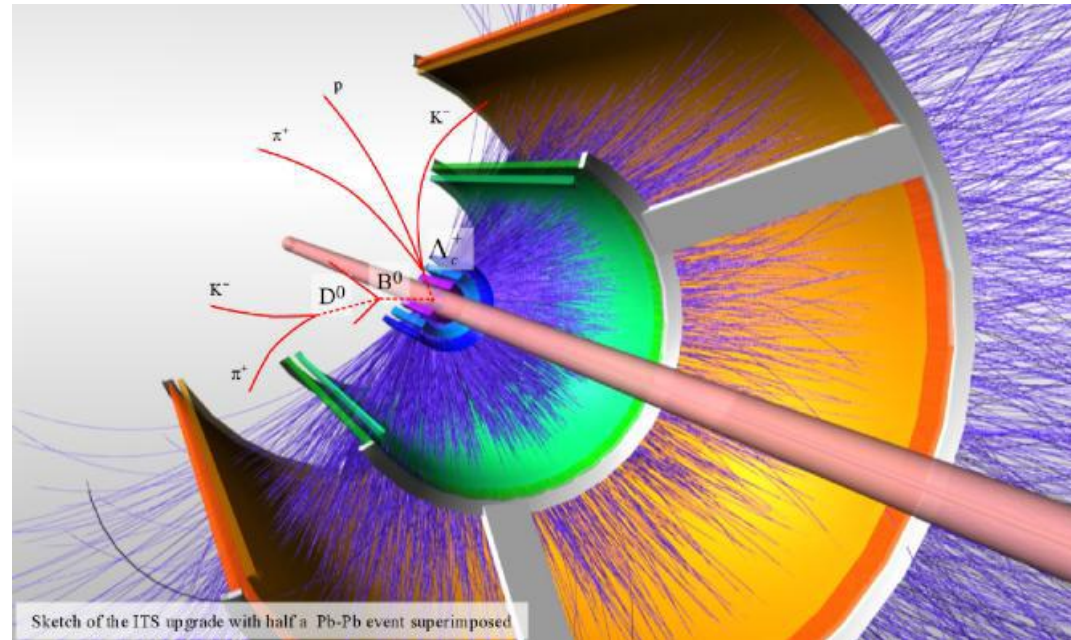
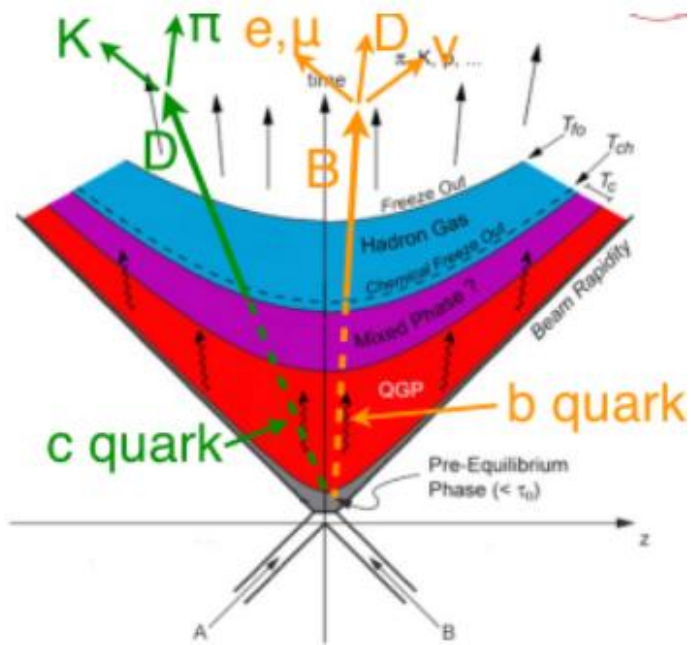


Yuri Murin, VBLHEP JINR for the MPD ITS team  
murin@jinr.ru

# The outline

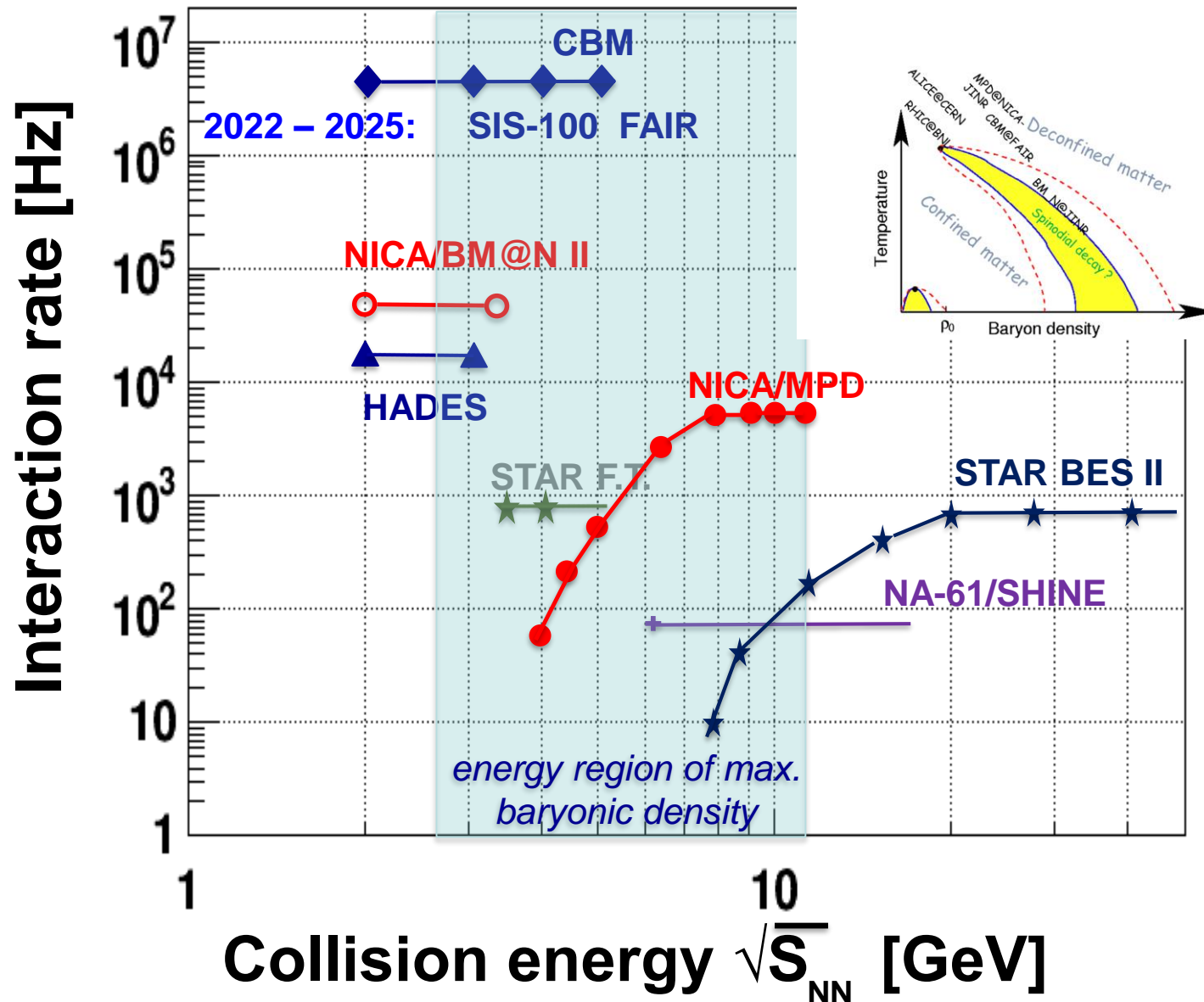
- *The physics case - an attempt to deconfine quarks through density fluctuations of the fireball under critical conditions*
- *A role of the rare probes (heavy hyperons and charmed mesons) in search of hints of critical point*
- *Transition from strips to pixels and the MAPS "invasion"*
- *The new ALICE 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

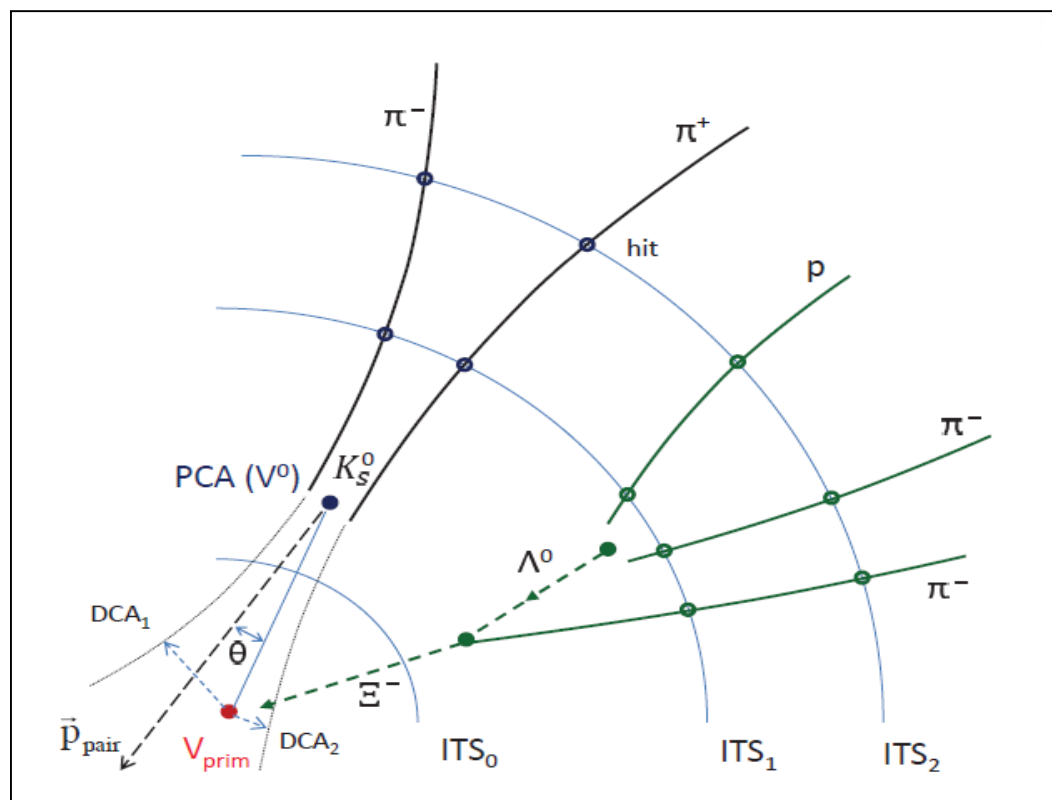


The Inner Tracking System or *Vertex tracker* is a multilayer telescope which measures the position of particle hits positions to restore the track trajectory. It's special task to be located as close as possible to the interaction point and to be as precise as possible to identify specific decays of 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



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

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

$$\quad \quad \quad \downarrow$$

$$\quad \quad \quad p + \pi^-$$

$$\Omega^- \rightarrow \Lambda + K^-$$

$$\quad \quad \quad \downarrow$$

$$\quad \quad \quad p + \pi^-$$

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

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

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

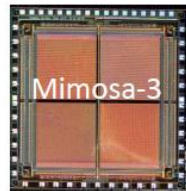
Identification of particles through inspection of Inverse Mass distributions  $M^2 = \sum(E_i)^2 - \sum(P_i)^2$  ( $c=1$ )

# The MAPS "Invasion"

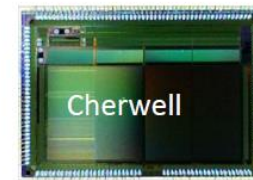
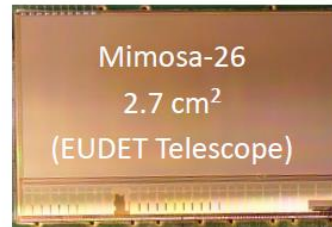
## ALICE LS2 Upgrade



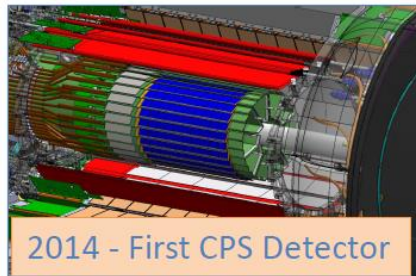
Owing to the industrial development of CMOS imaging sensors and the intensive R&D by HEP community



...



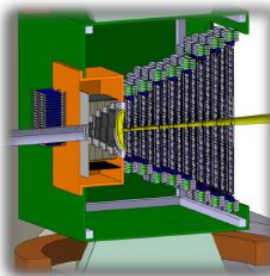
... several HEP experiments have selected CMOS pixel sensors for their inner trackers and intensive R&D for ATLAS



2014 - First CPS Detector

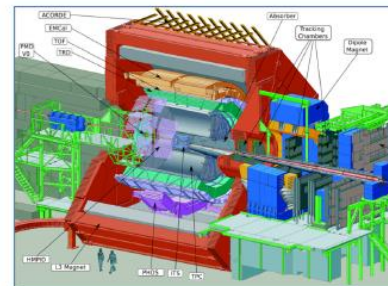
### STAR HFT

0.16 m<sup>2</sup> – 356 M pixels



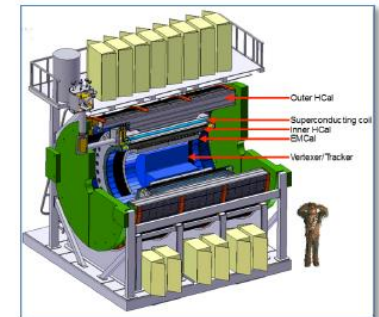
### CBM MVD

0.08 m<sup>2</sup> – 146 M pixel



### ALICE ITS Upgrade (and MFT)

10 m<sup>2</sup> – 12 G pixel



### sPHENIX

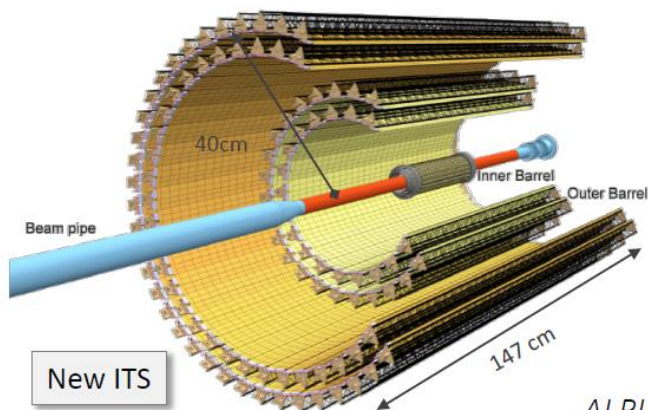
0.2 m<sup>2</sup> – 251 M pixel

ALICE (CERN) - International Workshop on Nuclear Physics - Perugia 3-11 Jan 2010

9

# New ALICE ITS#2: sharing of technology

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



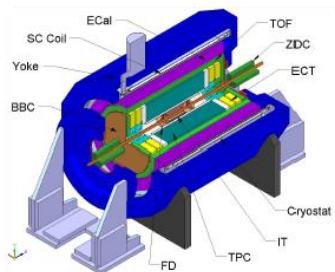
Closer to IP: 39mm ➔ 22mm  
 Thinner:  $\sim 1.14\%$  ➔  $\sim 0.3\%$  (for inner layers)  
 Smaller pixels:  $50\mu\text{m} \times 425\mu\text{m}$  ➔  $27\mu\text{m} \times 29\mu\text{m}$   
 Increase granularity: 20 chan/cm<sup>3</sup> ➔ 2k pixel/cm<sup>3</sup>  
 Faster readout:  $\times 10^2$  Pb-Pb,  $\times 10^3$  pp  
 10 m<sup>2</sup> active silicon area: 12.5 G-pixels,  $\sigma \approx 5\mu\text{m}$

$1.5 \leq \eta \leq 1.5$

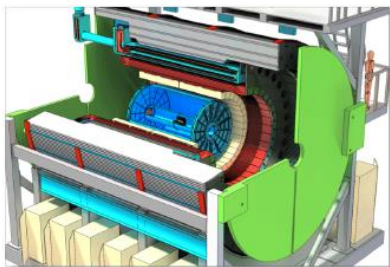
ALPIDE (ALICE Pixel Detector) - Developed for the ALICE upgrade (ITS and MFT)

will be used (or it is proposed) for several other HEP detectors and non HEP applications

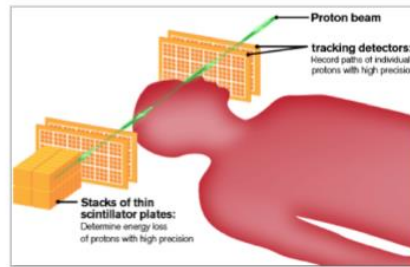
NICA MPD (@JINR)



sPHENIX (BNL)



proton CT (tracking)



CSES – HEPD2



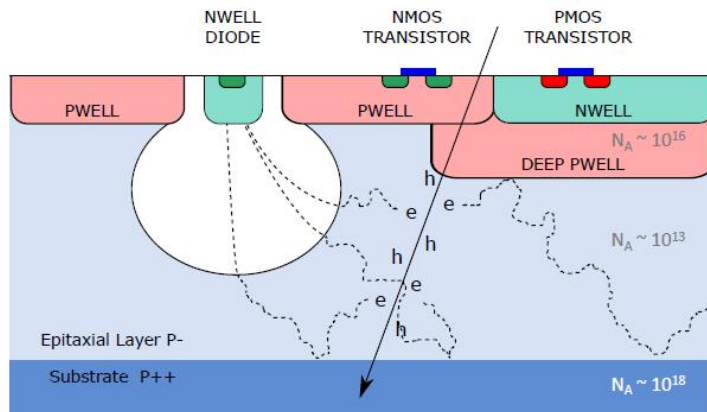
...

# The ALPIDE sensor

## ALICE CMOS Pixel Sensor



### CMOS Pixel Sensor using 0.18μm CMOS Imaging Process

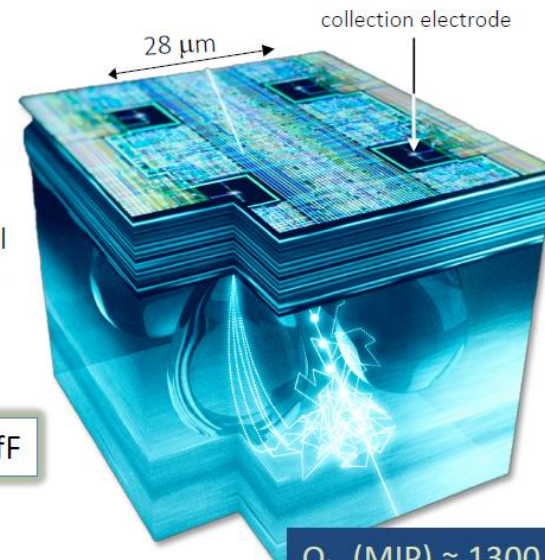


pixel capacitance  $\approx 5 \text{ fF}$  (@  $V_{bb} = -3 \text{ V}$ )

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

2 x 2 pixel  
volume

$C_{in} \approx 5 \text{ fF}$



Artistic view of a  
SEM picture of  
ALPIDE cross section

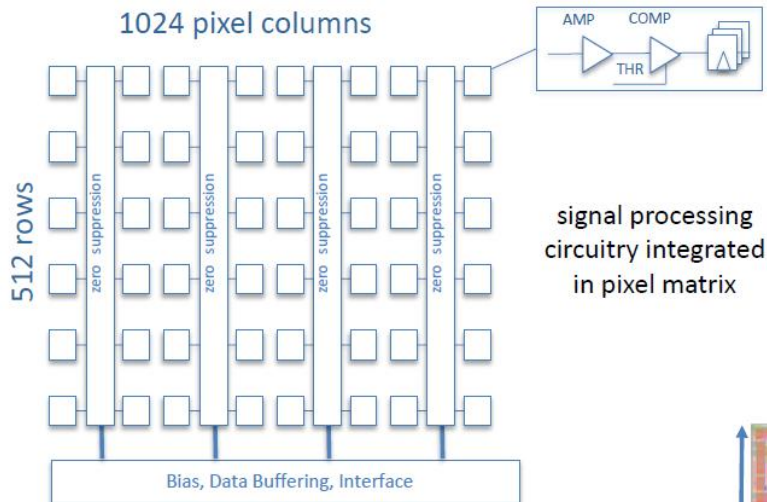
$Q_{in} \text{ (MIP)} \approx 1300 \text{ e} \Rightarrow V \approx 40 \text{ mV}$

➔ full CMOS circuitry within active area

# The ALPIDE Readout

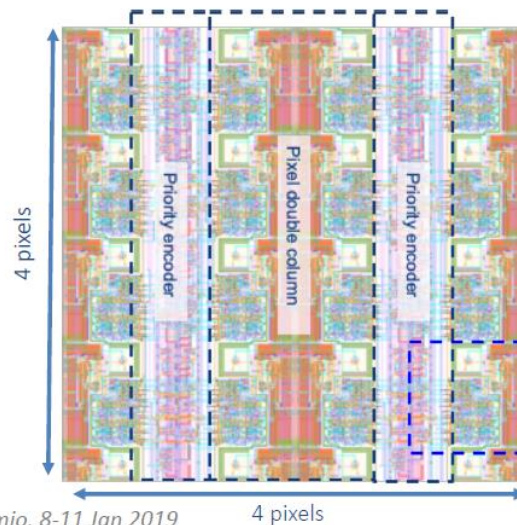


## ALICE Pixel DEtector (ALPIDE)

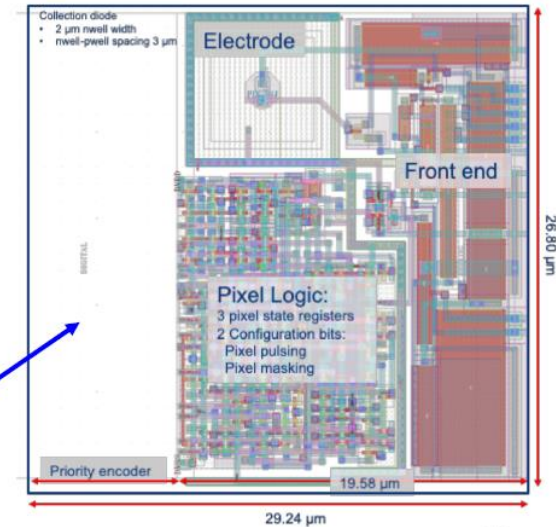


130,000 pixels /  $\text{cm}^2$   $27 \times 29 \times 25 \mu\text{m}^3$   
 charge collection time  $< 30\text{ns}$  ( $V_{bb} = -3\text{V}$ )  
 Max particle rate:  $100 \text{ MHz}/\text{cm}^2$   
 fake-hit rate:  $< 1 \text{ Hz}/\text{cm}^2$   
 power :  $\approx 300 \text{ nW}/\text{pixel}$  ( $< 40 \text{ mW}/\text{cm}^2$ )

Matrix Layout



Pixel Layout



ALPIDE

30mm

50 $\mu\text{m}$  thick

pads over matrix

pixel matrix

15mm

periphery

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

4 pixels

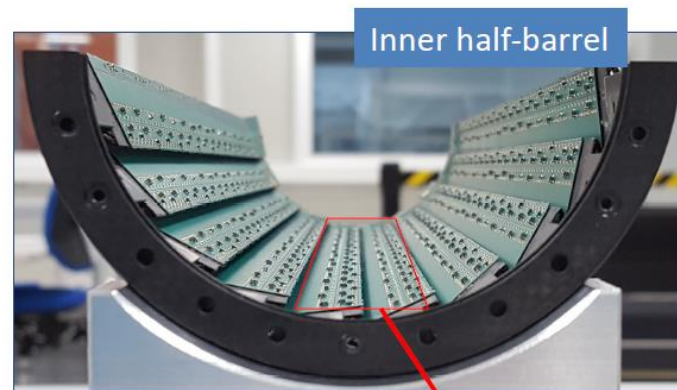
22

# New ALICE ITS#2 beats records on material budget

## ALICE Pixel DEtector (ALPIDE)

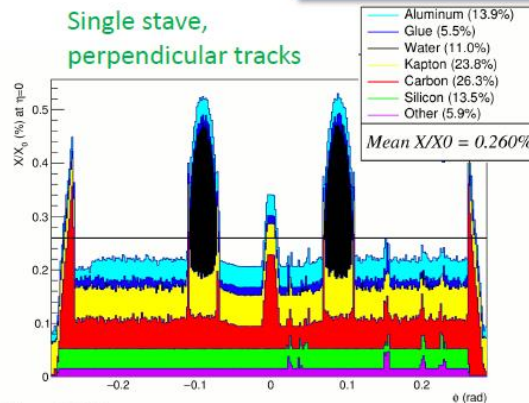


Inner Barrel Production completed and all layers assembled

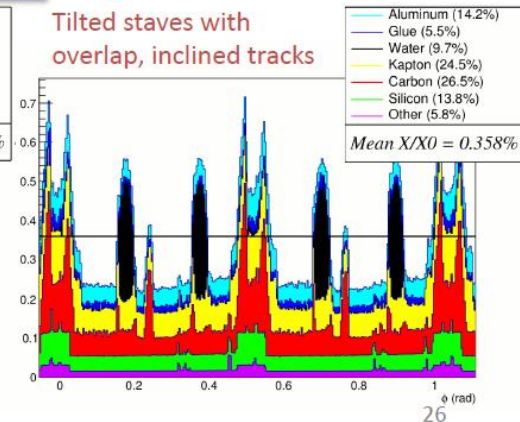


### Material budget

Single stave,  
perpendicular tracks



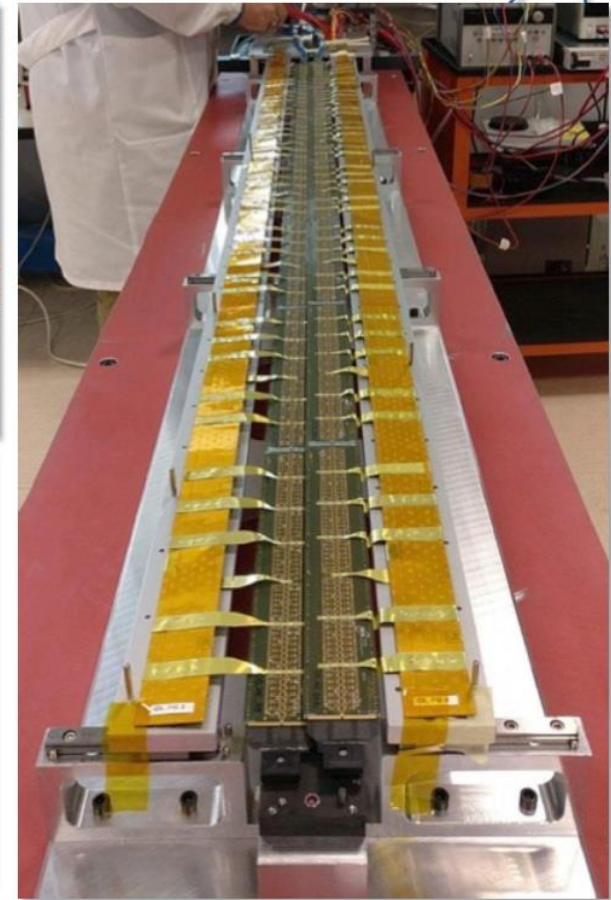
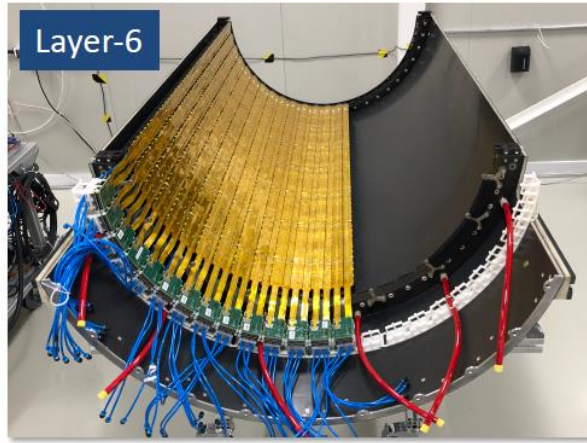
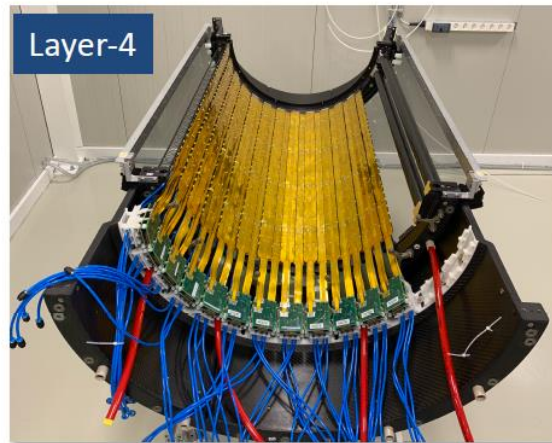
Tilted staves with  
overlap, inclined tracks



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

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

## ALICE Pixel DEtector (ALPIDE)

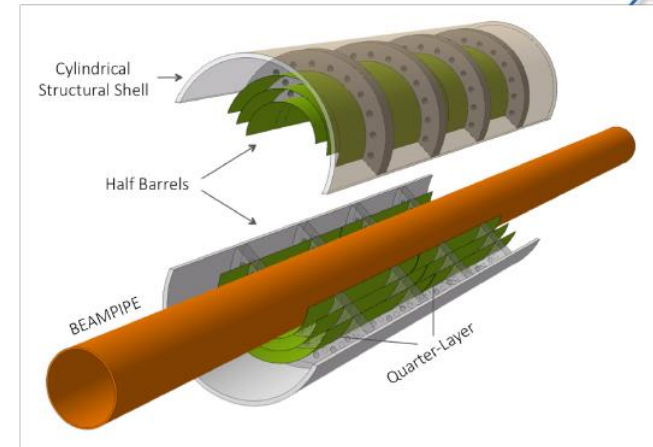
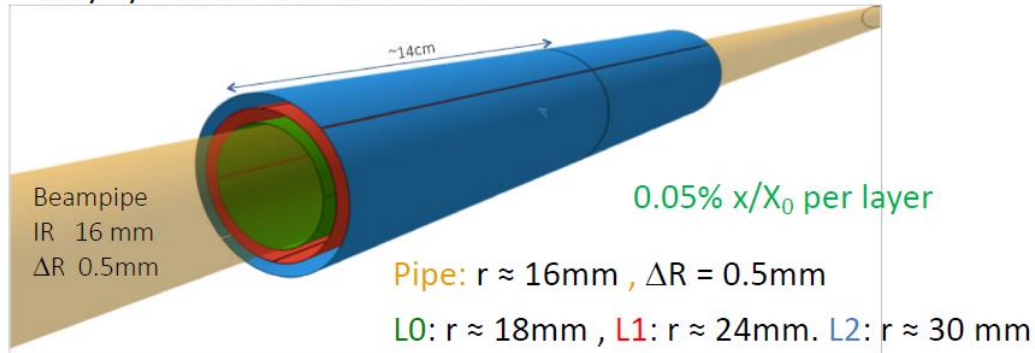


# Plans for ALICE ITS#3: exchange of the IB

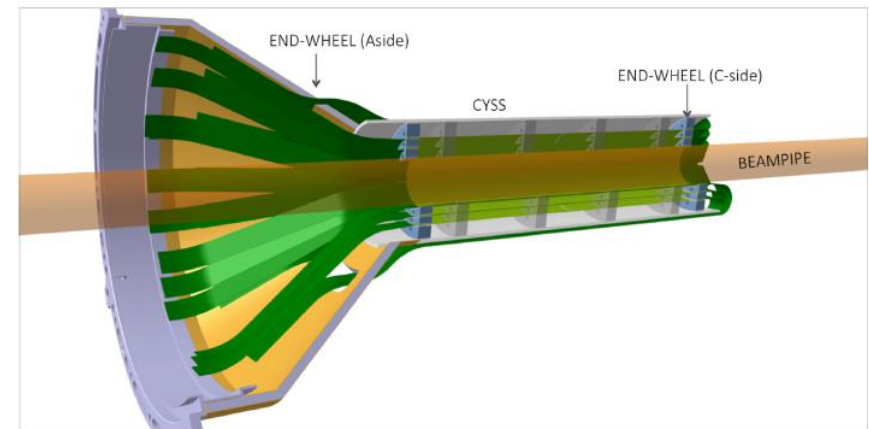
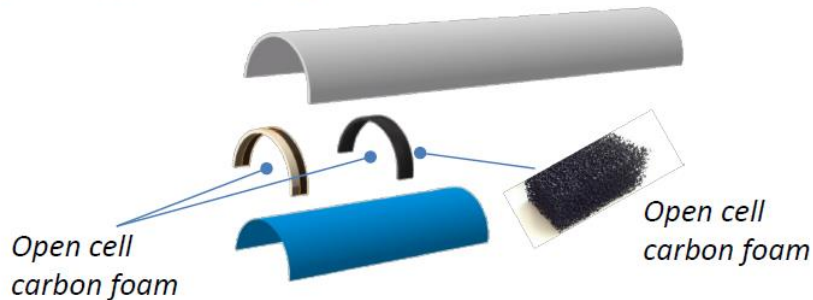
## Vertex Detector (innermost 3 layers)



Truly cylindrical vertex detector



Layers supported by high-thermal conductive carbon foam



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

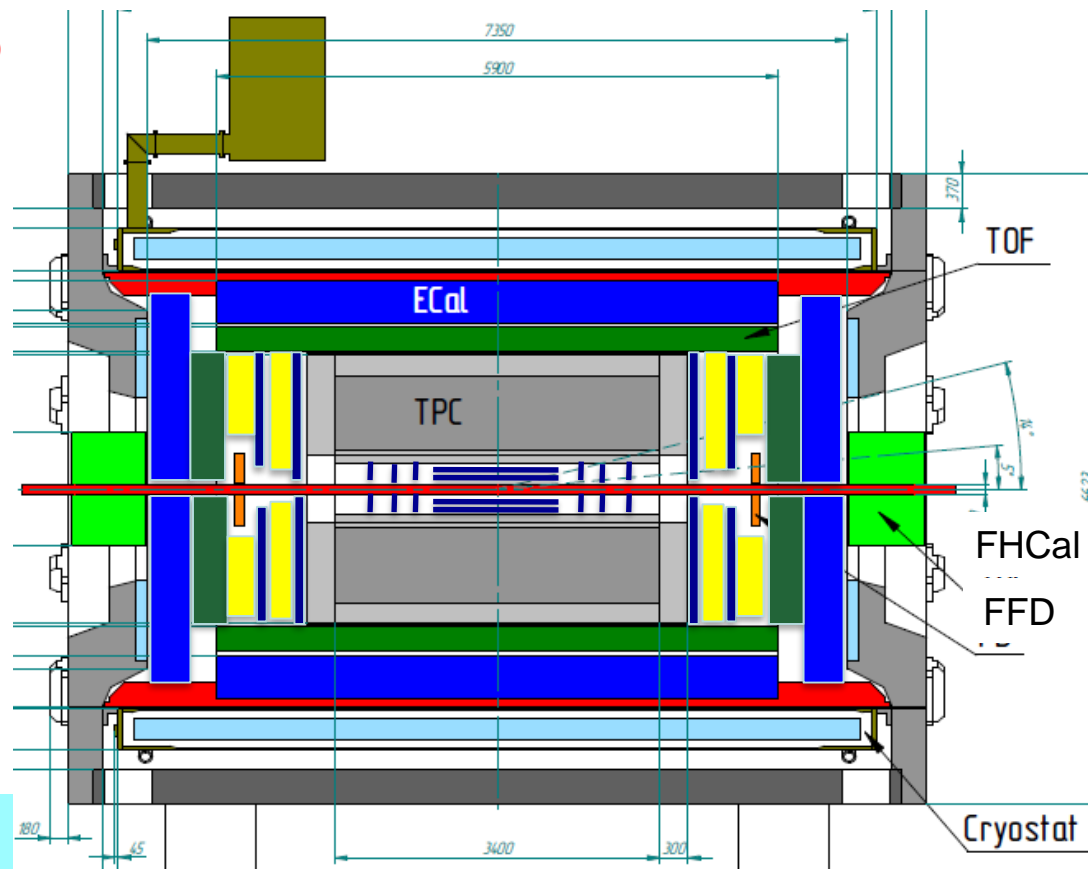
33

# 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



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

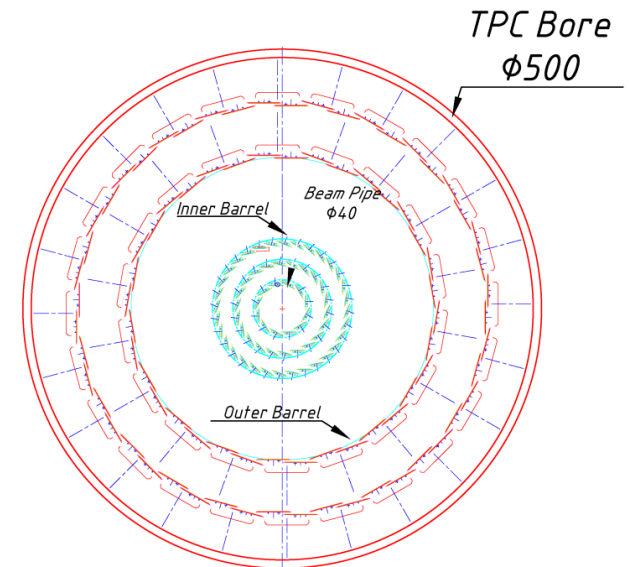
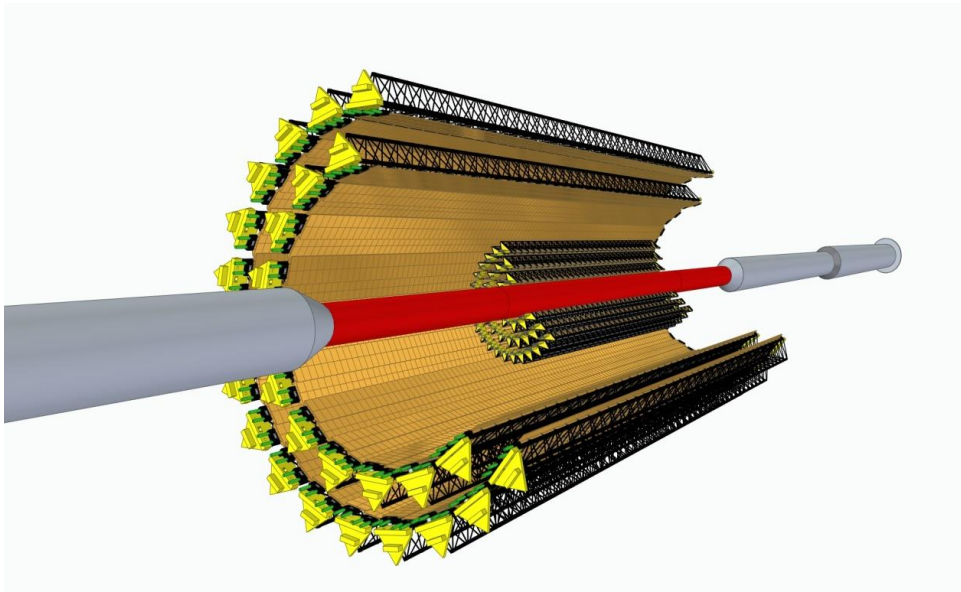


## Items to be shipped from CERN formulated in Addendums to the Protocol

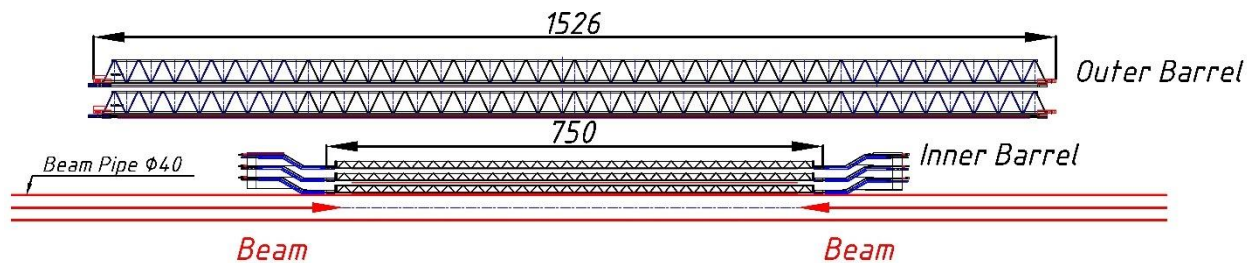
CERN will procure, test and deliver to NICA

- 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.

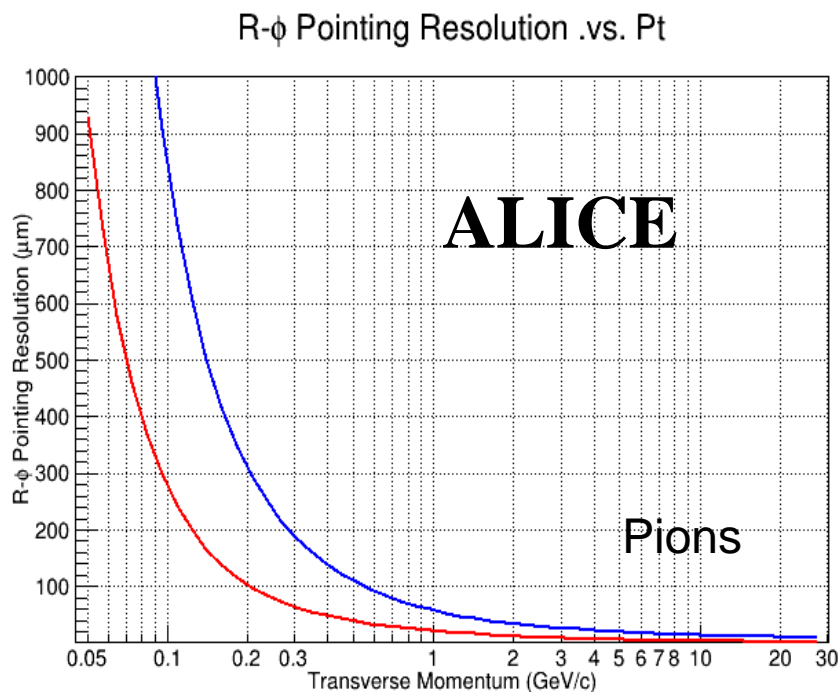
# MPD ITS based on the ALPIDE MAPS CERN technology



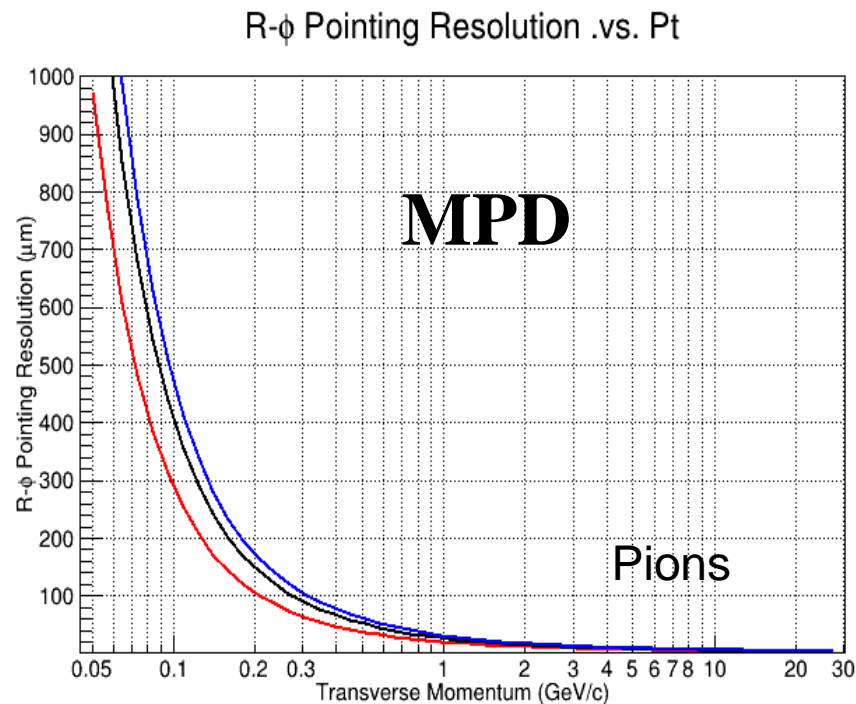
Beam pipe  $\varnothing = 40$  mm



# ITS pointing resolution within STAR-ALICE toy model



— New ITS  
— Old ITS

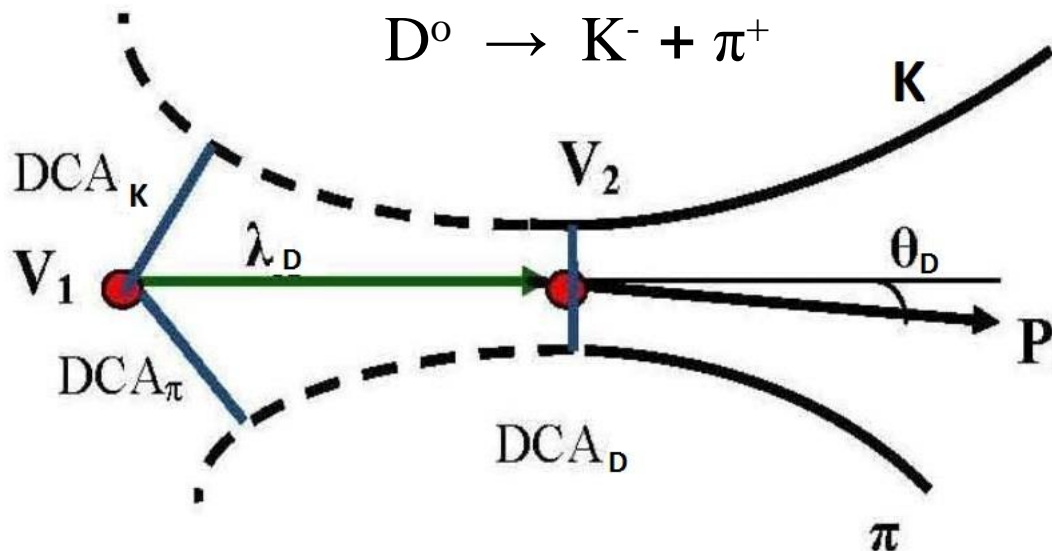


—  $\varnothing = 40$  mm  
—  $\varnothing = 50$  mm  
—  $\varnothing = 60$  mm

# Selection criteria

## $D^0$ selection parameters:

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



## Selection criteria:

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

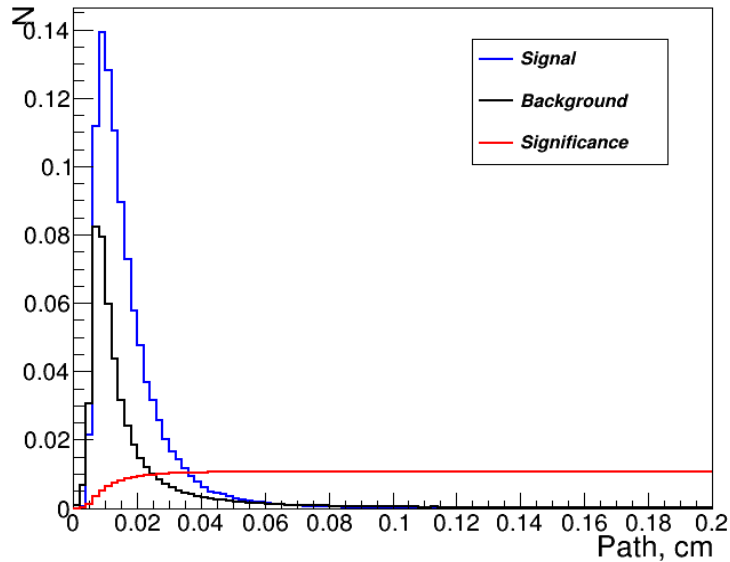
The parameters of the corresponding selections are optimized by maximizing the **signal significance** :

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

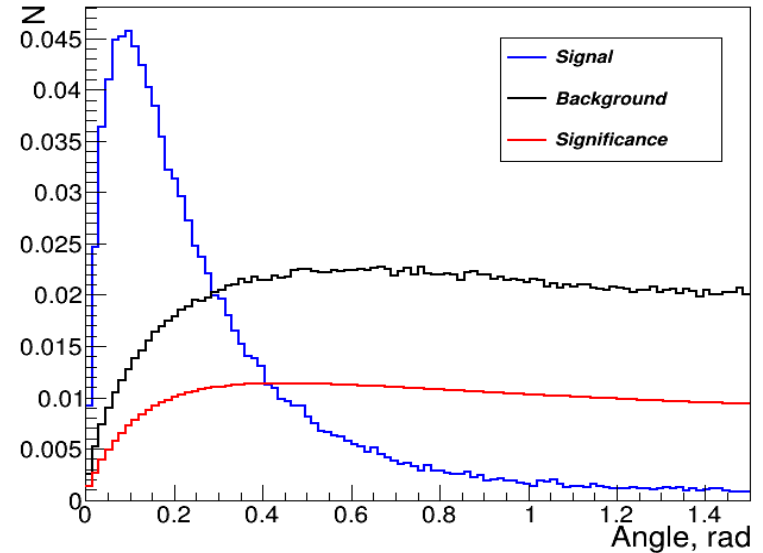
where  $S$  and  $B$  are the estimated numbers of the signal and background events.

# Example : cuts selections for $D^0$

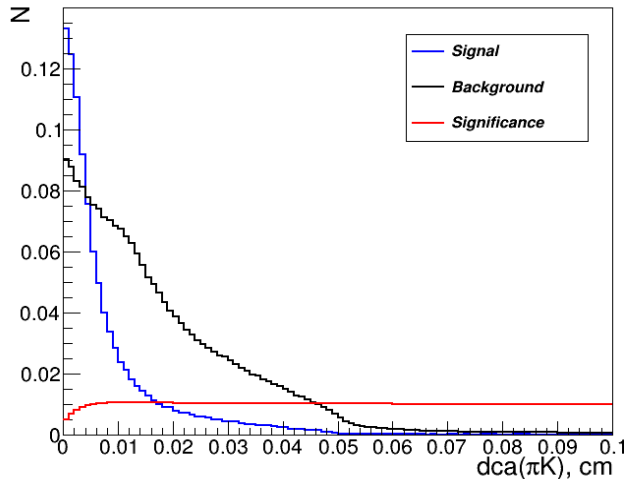
D0 path significance



D0 pointing angle significance



D0 dca( $\pi K$ ) significance

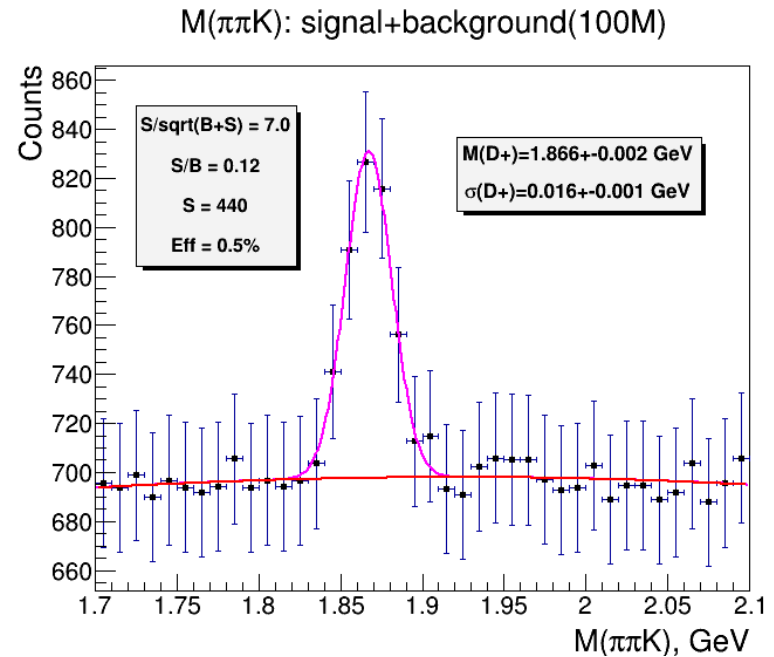
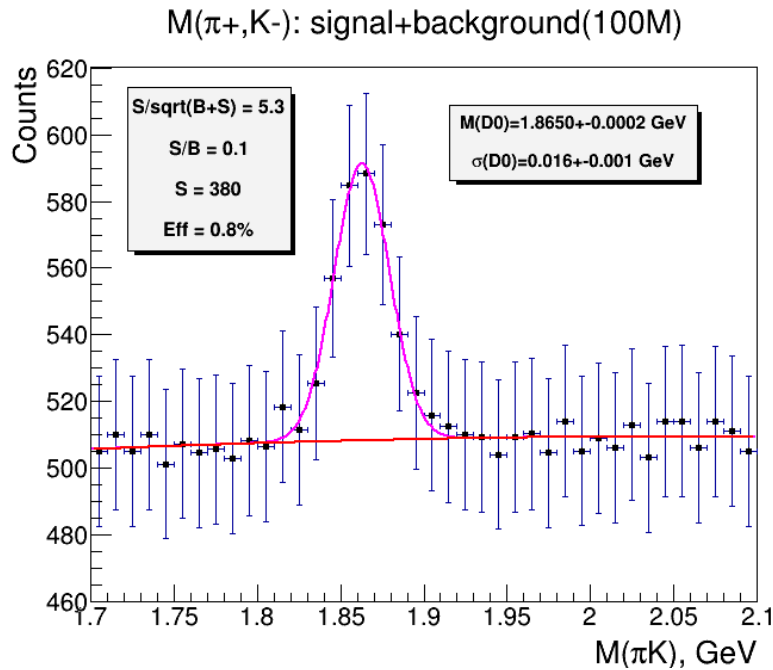


$dcaK > 0.01$  cm &  
 $dcaPi > 0.01$  cm &  $distPiK$   
 $< 0.02$  cm &  $path(D^0) >$   
 $0.025$  cm &  $angle(D^0) <$   
 $0.2$  rad

# $D^+$ and $D^0$ reconstruction

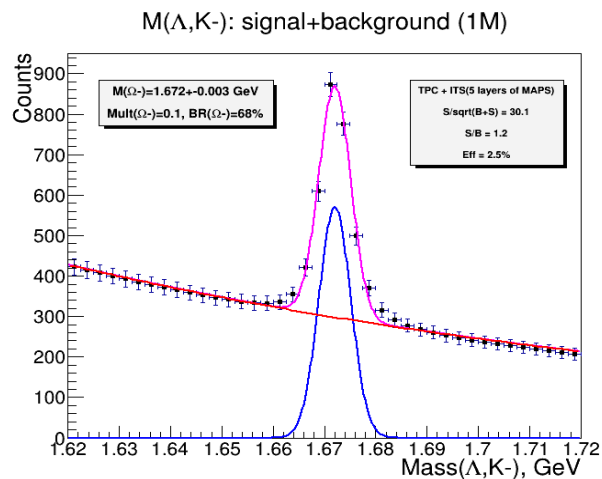
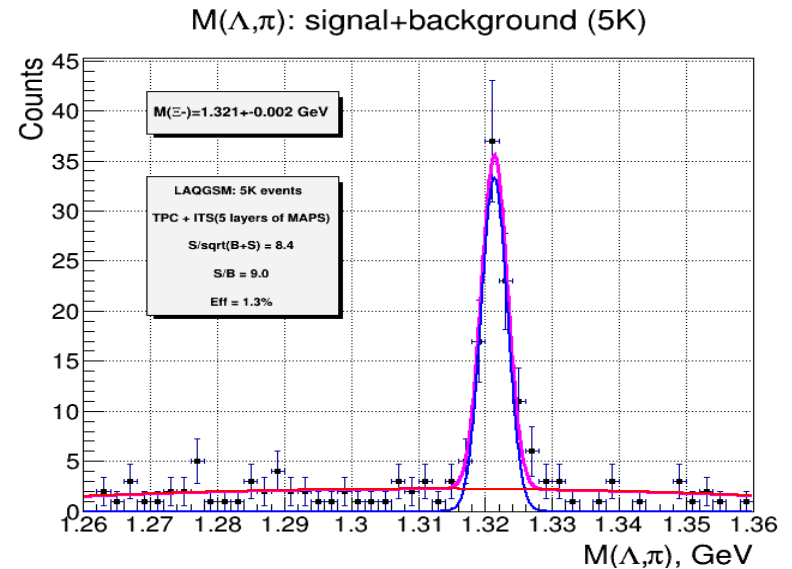
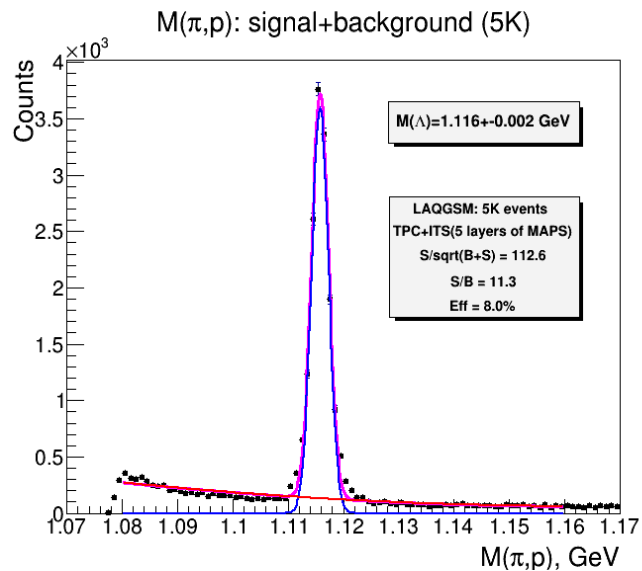
$t_1=t_2=t_3=50\mu$  (IB ITS3)

$t_4=t_5=700\mu$  (OB ITS2)



DCA( $\pi$ , K,  $D^0$ ), path( $D^0$ ), angle( $D^0$ ) cuts

# Strange particle reconstruction results

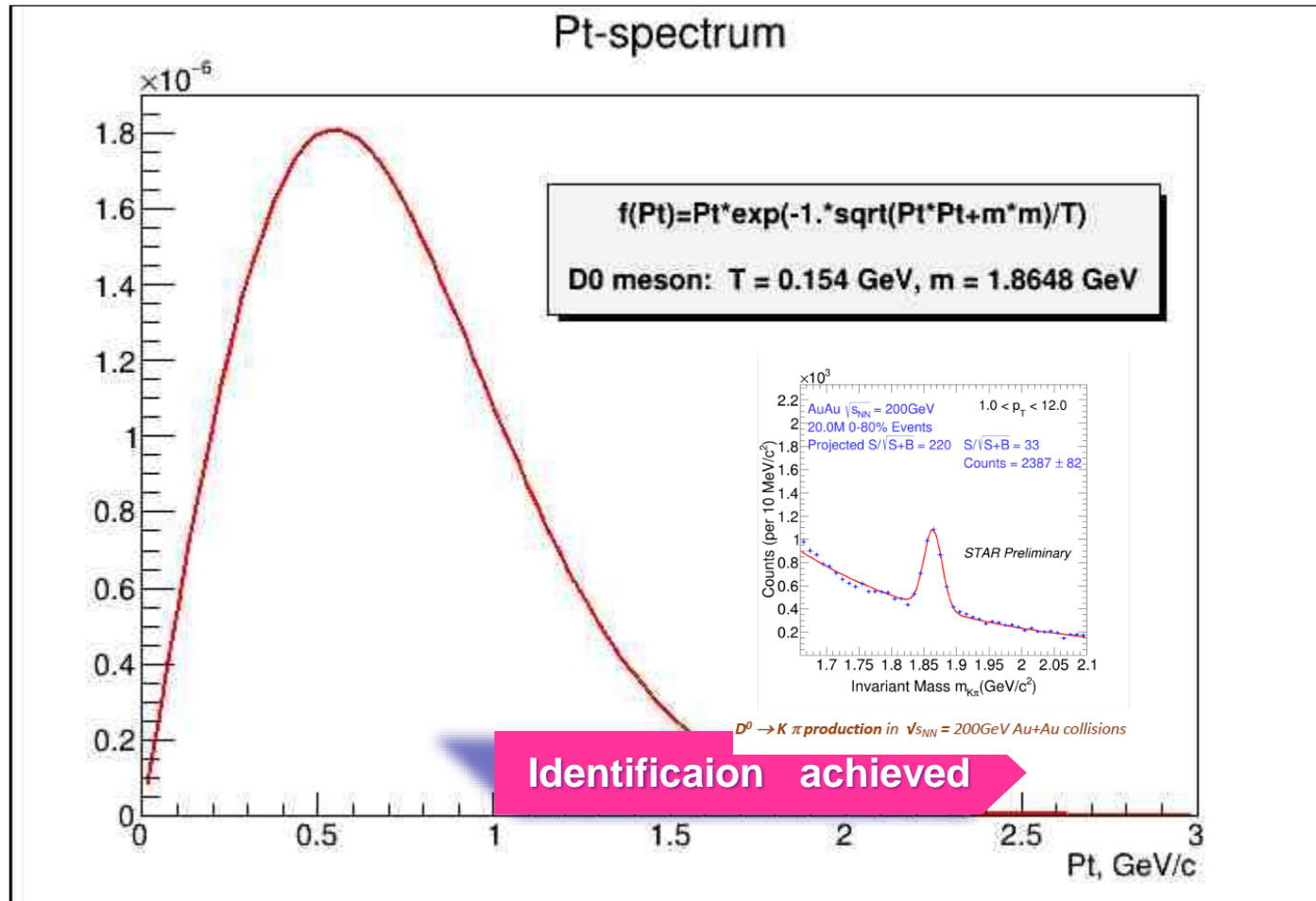


# Impact of Beam pipe diameter on efficiency

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

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(50 $\mu$ )	ITS2(200 $\mu$ )	ITS3(50 $\mu$ )	ITS2(200 $\mu$ )
S/B( $2\sigma$ )	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

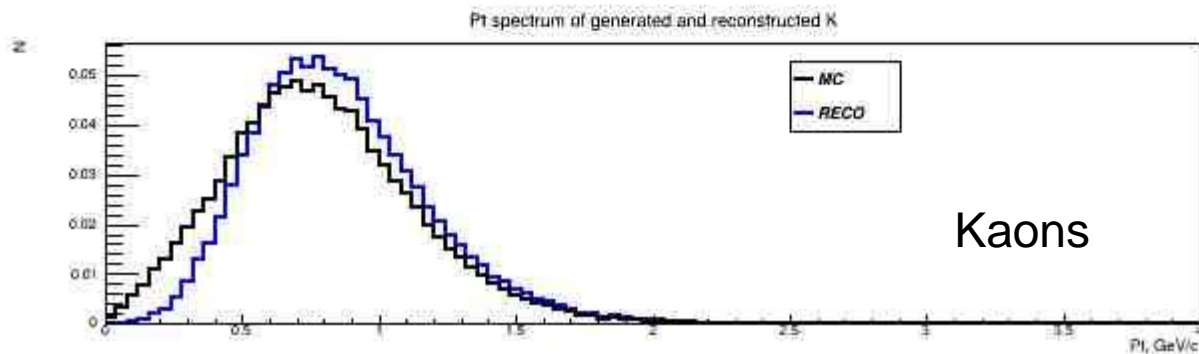
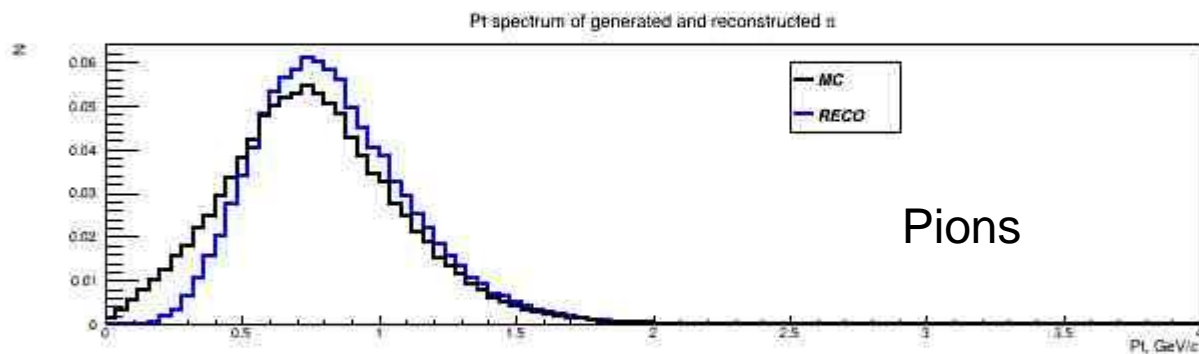
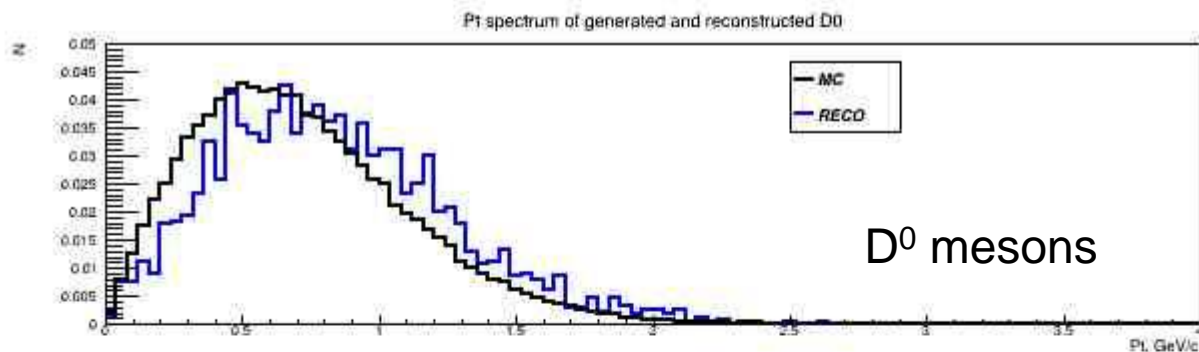


## Thermal generator: D meson's $p_t$ - spectrum

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

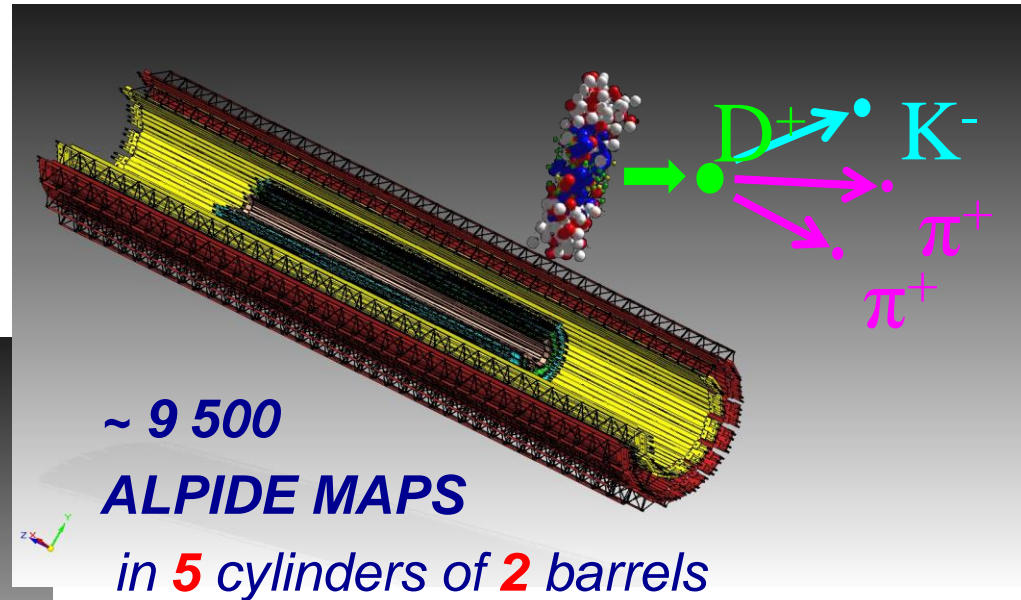
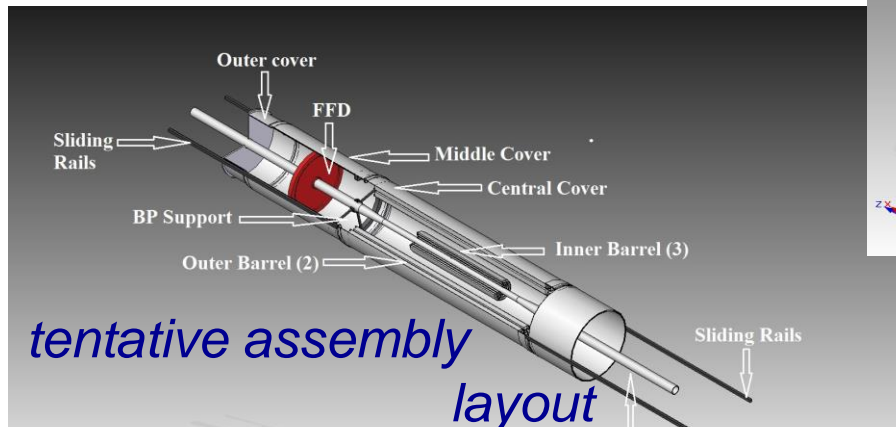
# MC and reconstructed $p_T$ -spectra of $D^0$ -mesons and their decay products



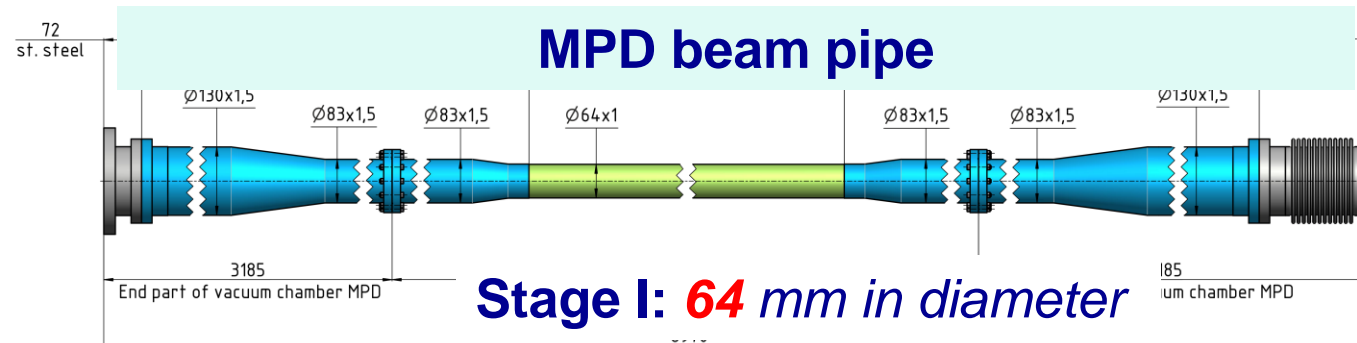
# ITS realization in two Steps (OB first) due to BP sequence

**Stage I: Installation of OB (2022-23)**

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



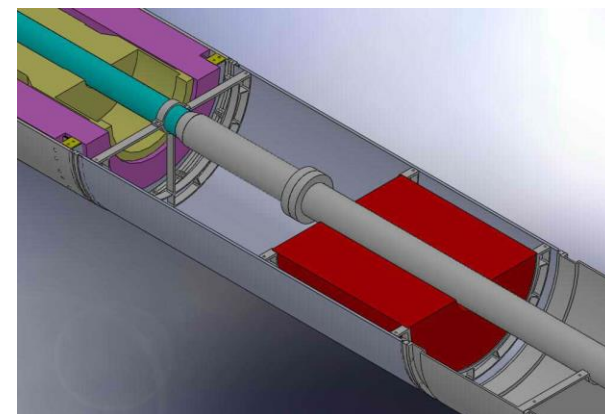
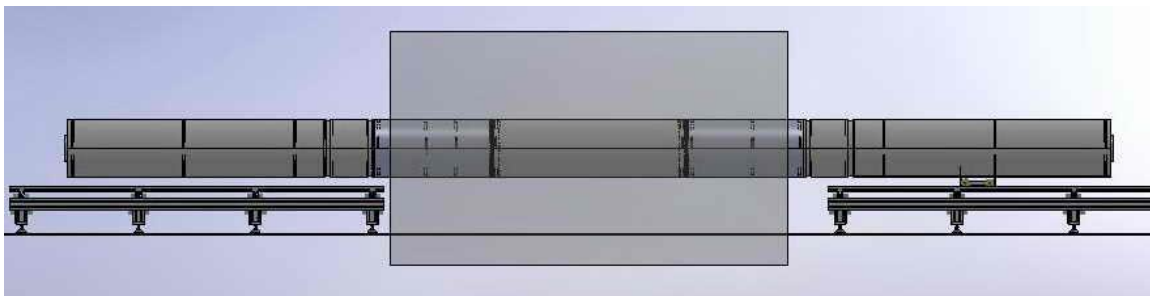
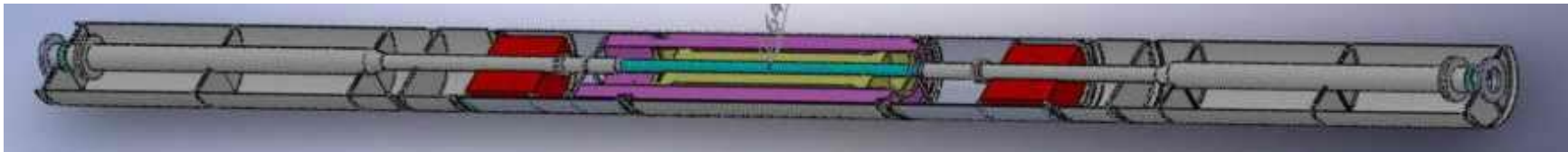
**$4,9 \cdot 10^9$  pixels, active area  $3,9 \text{ m}^2$ .**



**Stage II:**  
 **$38 \text{ mm}$  in diameter**

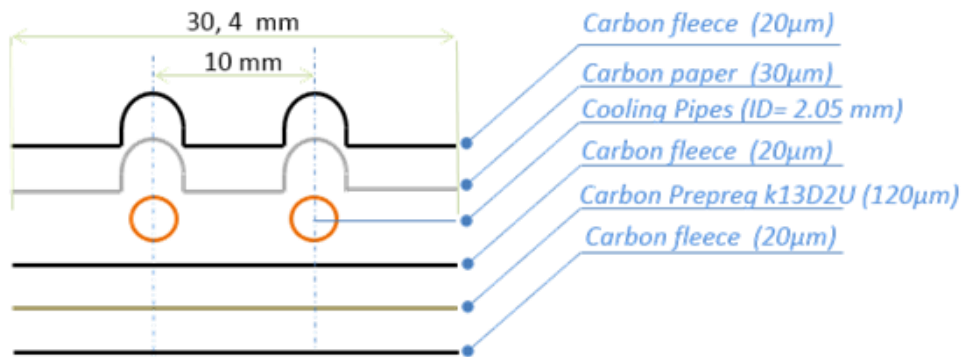
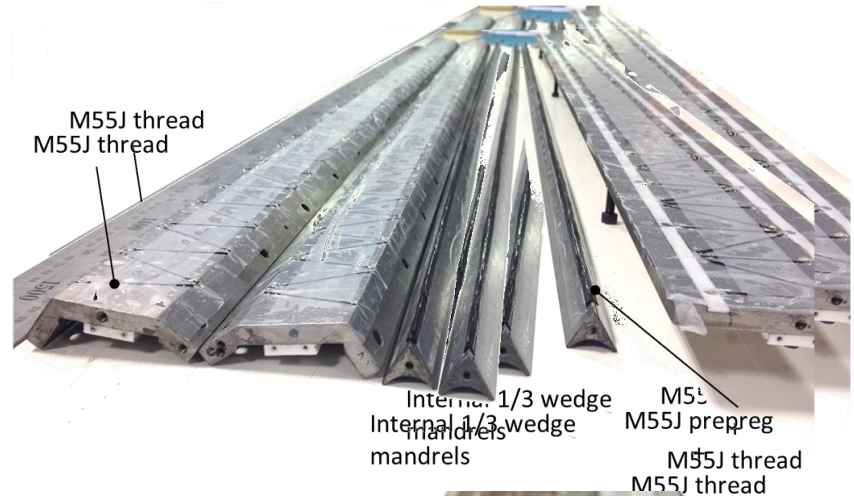
## Current Activities

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



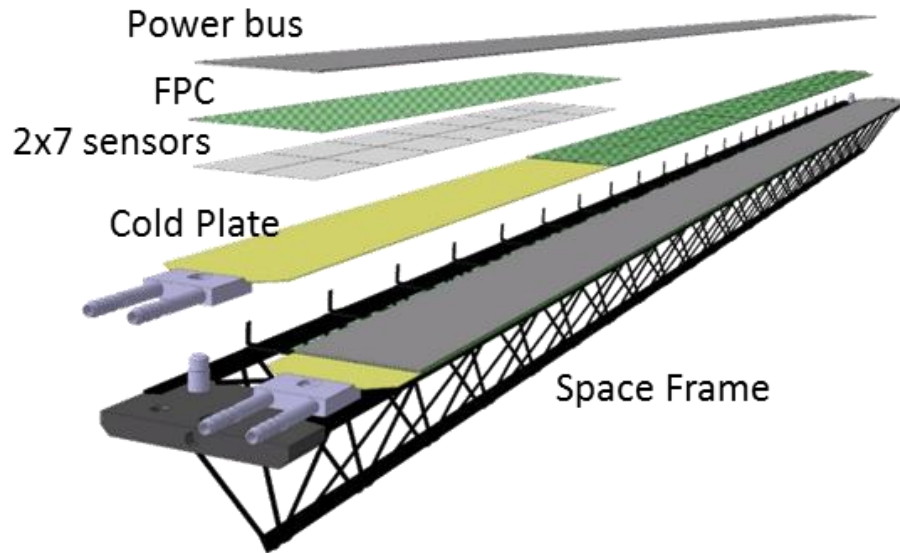
## Current Activities

### 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)



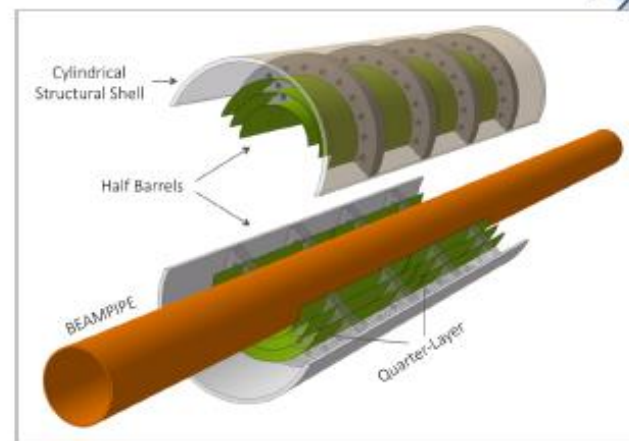
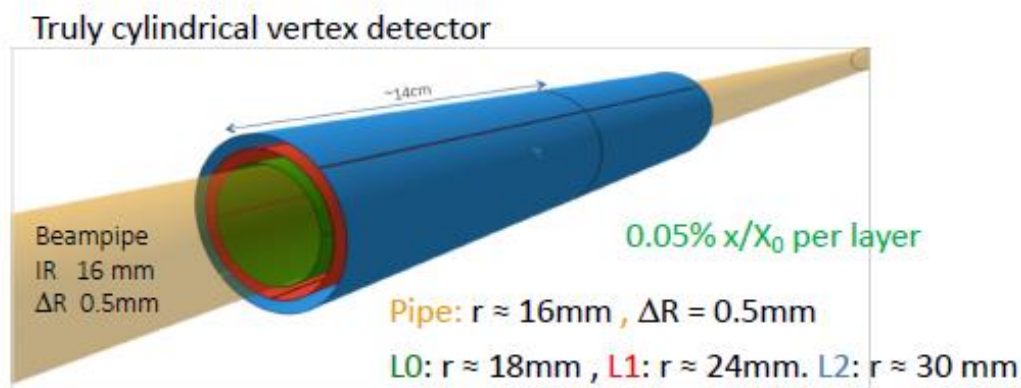
Truss length is 1540 mm. Modules (HICs) are located on two cooling plates .  
OB stave carriers 196 sensors.  
The MPD ITS need is 42 OB staves.



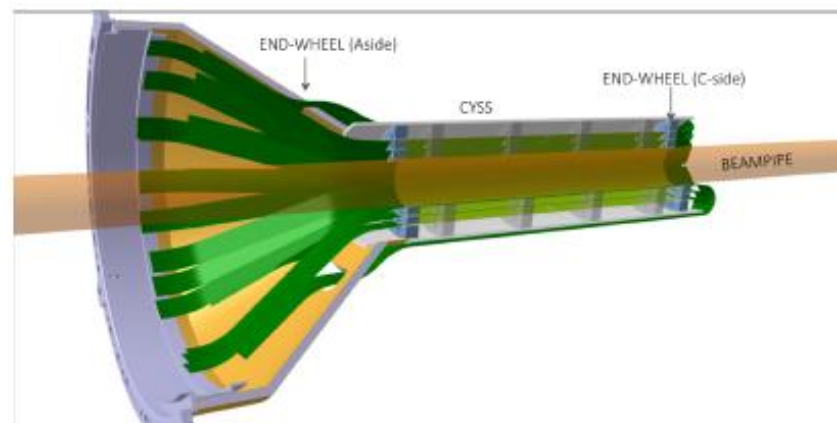
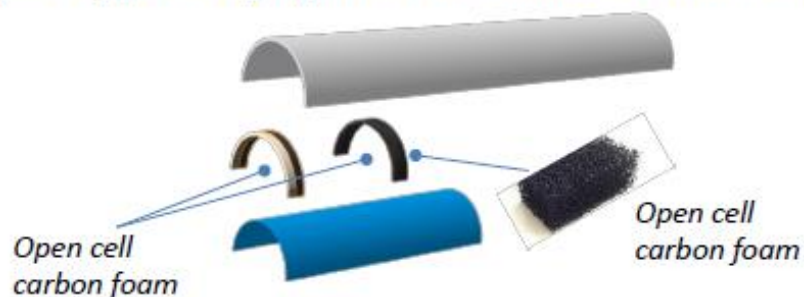
# Planned Activities

## 4. Development of ITS3 together with ALICE ITS3 team

### Vertex Detector (innermost 3 layers)



### Layers supported by high-thermal conductive carbon foam



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

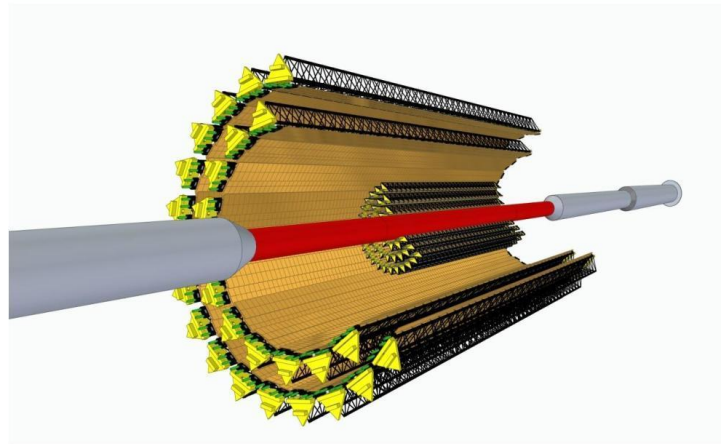
33

# 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!