COMPUTER SIMULATION OF THE IDENTIFICATION CAPABILITY OF A VERTEX DETECTOR FOR THE MPD EXPERIMENT AT THE NICA COLLIDER

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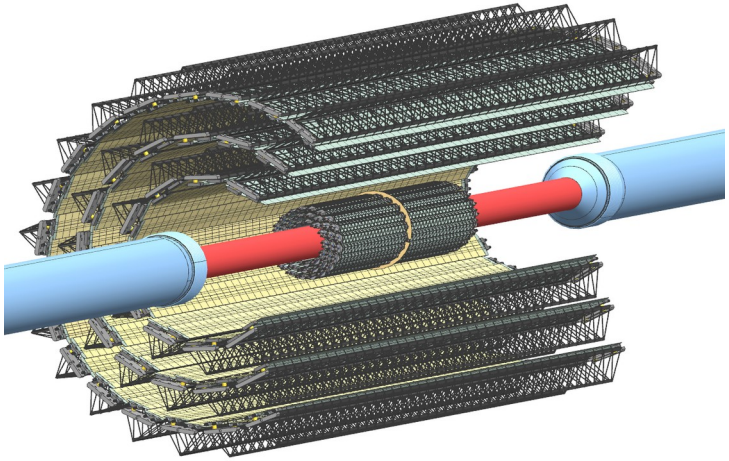

Грант Российского научного фонда № 23-12-00042

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- Physical motivation of using vertex detectors
- Modeling of the ITS of the MPD setup
  - Geometric layout
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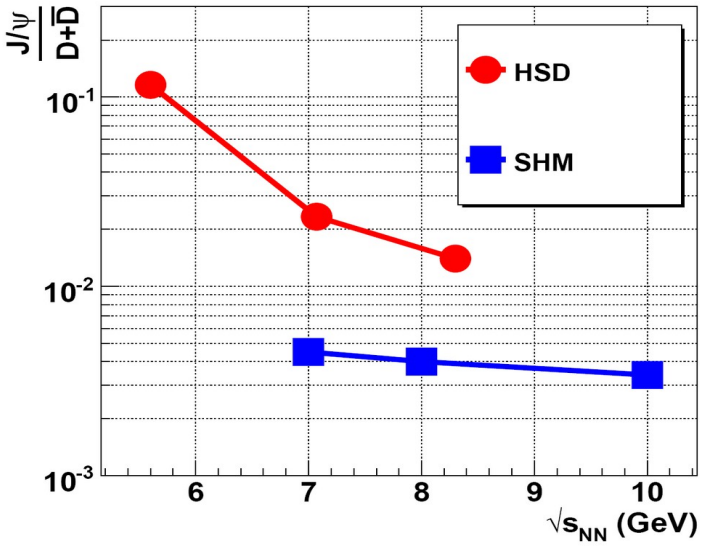
- Conclusion

Physical motivation of using ITS

MPD is being constructed to study the properties of extremely dense nuclear matter formed in nucleus-nucleus collisions at NICA energies. The yields and spectra of charmed particles are the important observables sensitive to critical phenomena in phase transitions of the QCD-matter.



$$R = \frac{Y(J/\Psi)}{Y(D+\bar{D})}$$

Hadron-Strings Dynamics (**HSD**) model

O. Linnyketal., Nucl.Phys.A786 (2007)183

Statistical Hadronization Model (**SHM**)

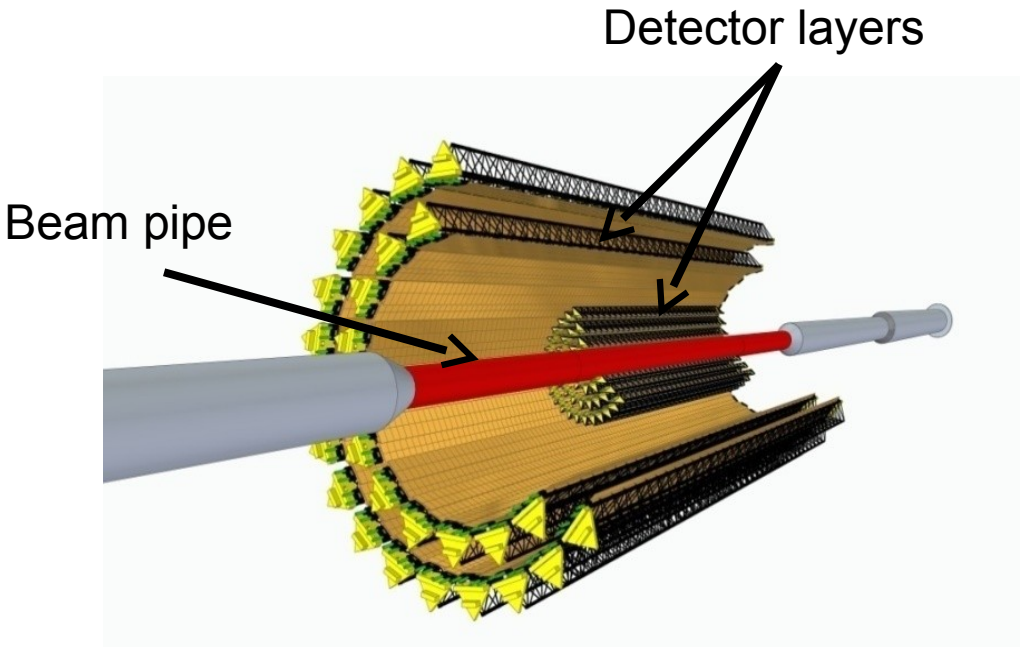
A. Andronicetal, Phys. Lett. B659 (2008) 149

$$R_{QGP} < R_{AG}$$

Vertex detectors (Inner Tracking System - ITS) are used in HEP experimental setups for highly efficient detection of such short-lived products of nuclear interactions.

Vertex detectors in HEP experiments

In modern collider experiments ITS is build of several layers of silicon position-sensitive sensors, surrounding a beam pipe. This kind of detectors are already used in ALICE , ATLAS, CMS and STAR experiments.



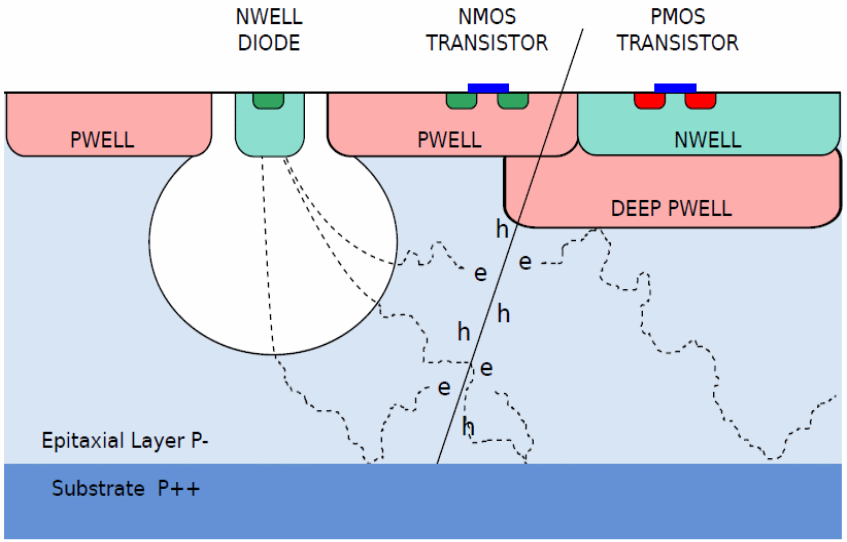
Project ITS of MPD experiment

MPD ITS is planned to be construct of Monolithic Active Pixel Sensors (MAPS)

Advantage:

1) the best spatial resolution
2) high counting rate
3) high level of segmentation per pixel.

Combination of the TPC and the MAPS based ITS makes it possible to detect short-lived products of AA interactions with maximum efficiency.



Standard MAPS parameters for the project MPD ITS:

Sensitive area: 15×30 mm²

Thickness: 50 μm

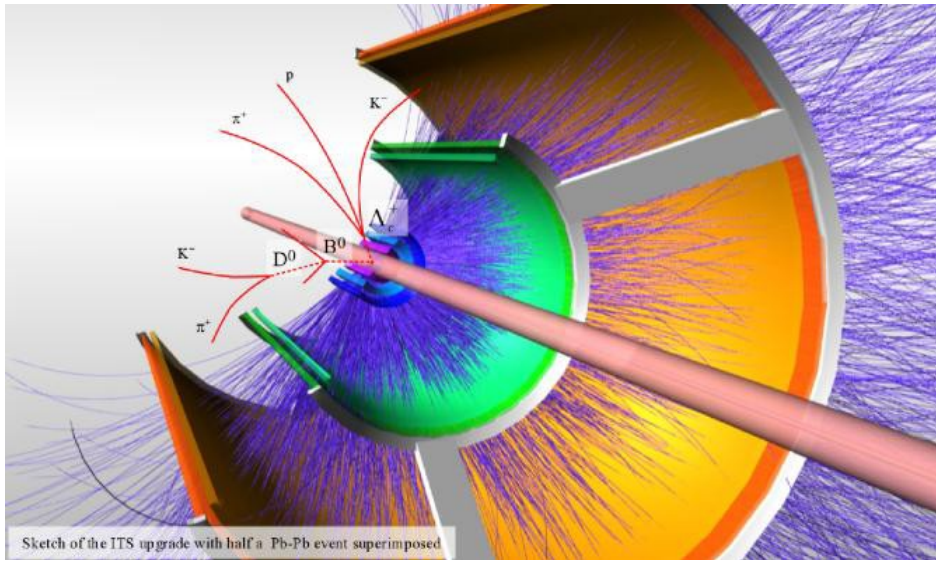
Number of pixels: 512×1024

Pixel size: 28×28 μm².

Space resolution:

$\sigma_{r\varphi} = 5$ μm , $\sigma_z = 5$ μm

Registration of charmed particles by the vertex detector



//International Journal of Modern Physics A. 2014

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

$$\tau c = 312\ \mu m$$

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

$$\tau c = 123\ \mu m$$

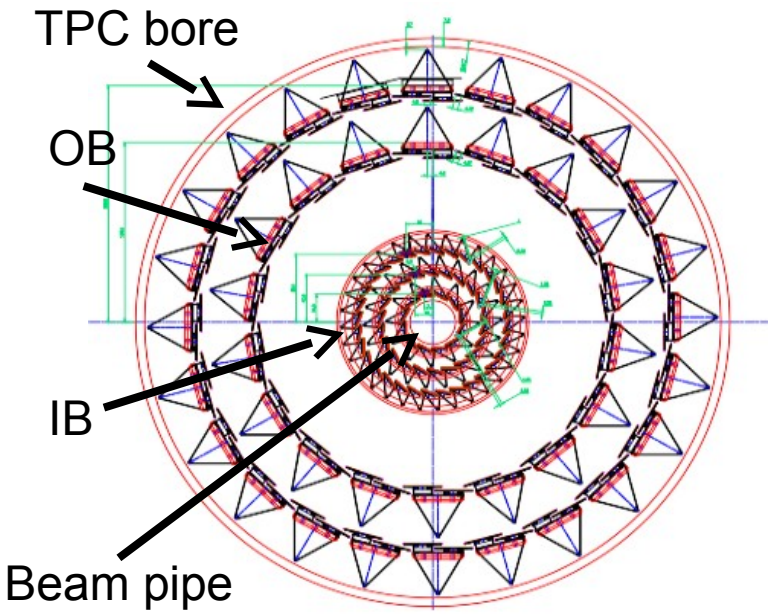
$$D_s^+ \rightarrow K^- + K^+ + \pi^+$$

$$\tau c = 150\ \mu m$$

$$M_{inv} = \sqrt{\left(\sum_a E_a\right)^2 - \left(\sum_a \vec{p}_a\right)^2}$$

Reliable identification of short-lived charmed mesons can be performed by determining the invariant mass of their decay products. So, for high-efficient reconstruction of decay vertices near the interaction point the vertex detectors with high pointing resolution are needed.

First project ITS model



Model ITS-5-40 (basic configuration)
5-layer ITS for a beam pipe with the smallest possible diameter of 40 mm with a staggered arrangement of ladders in Outer Barrel (OB) and a fan-like arrangement of ladders in Inner Barrel (IB)

Each layer consists of ladders containing 24 MAPS in IB and 98 MAPS in OB

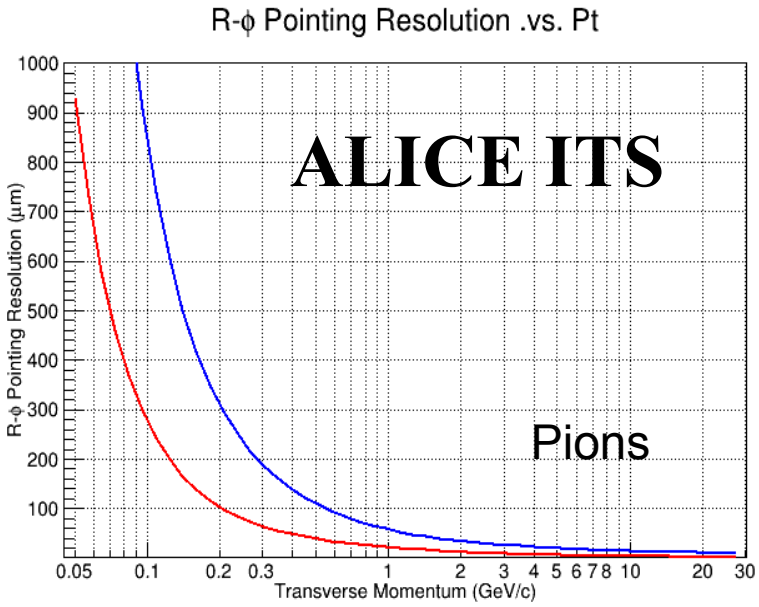
Layer	No of MAPS	R_{min}, mm	R_{max}, mm	Length, mm
1	24 *12	22.4	26.7	750
2	24*22	40.7	45.9	750
3	24*32	59.8	65.1	750
4	98*36	144.5	147.9	1526
5	98*48	194.4	197.6	1526

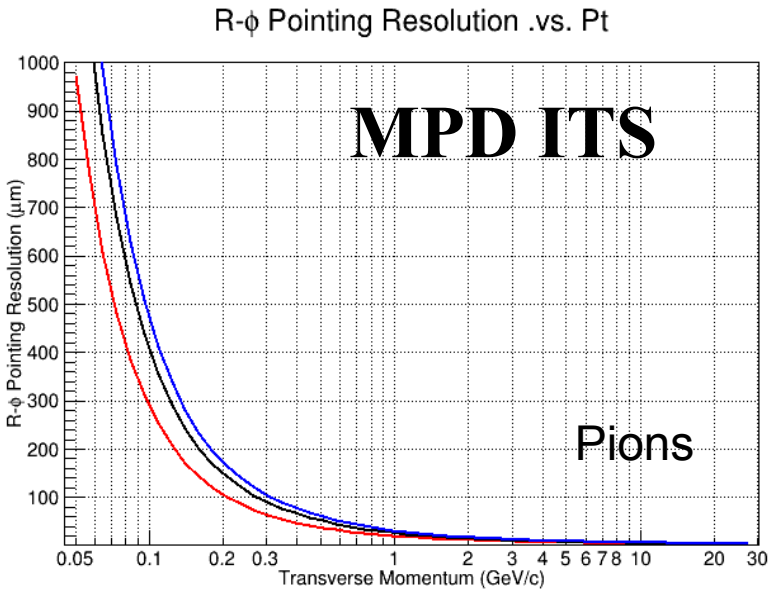
Inner Barrel

Outer Barrel

(**2020**) Murin Yu., Kondratev V. *et al.* Physics of Particles and Nuclei, 17 (6), pp. 856-870.

ITS pointing resolution





ITS2

ITS1

Beam pipe Ø = 40 mm

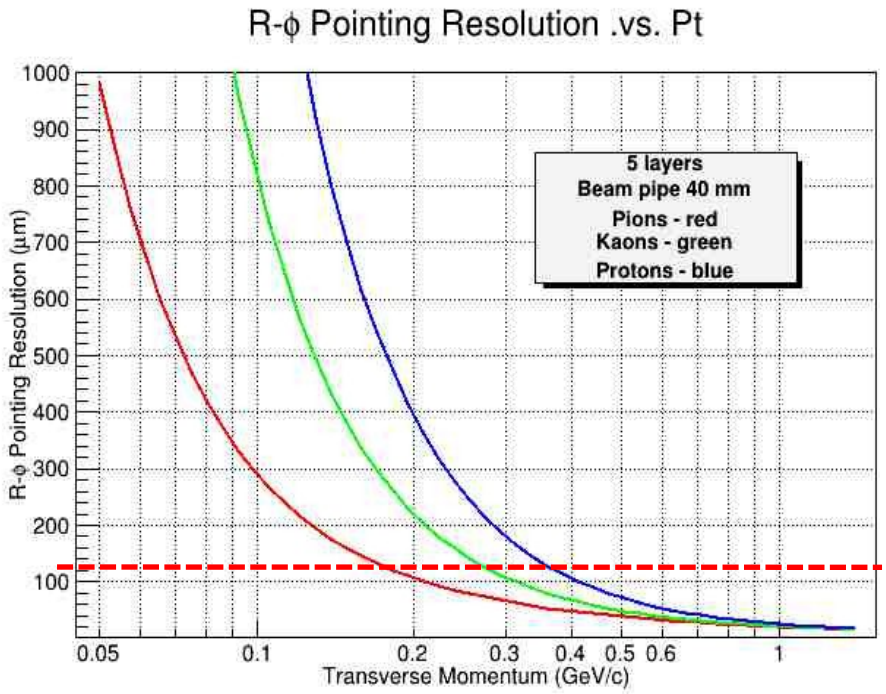
Beam pipe Ø = 50 mm

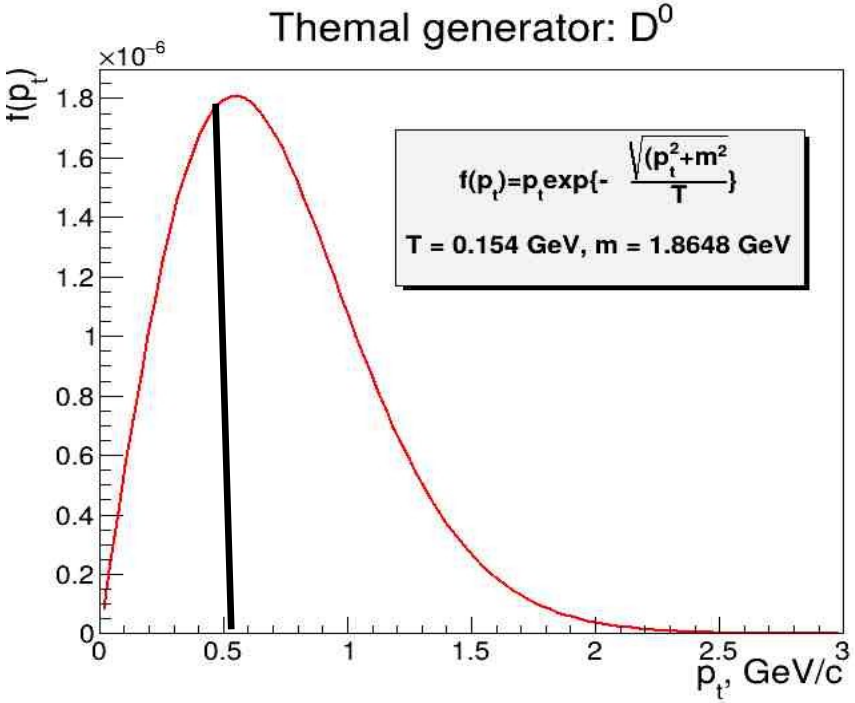
Beam pipe Ø = 60 mm

MPD ITS pointing resolution with beam pipe Ø = 40 mm is comparable with ALICE ITS2.

ITS pointing resolution and D mesons p_t-spectra

The ITS pointing resolution was evaluated for π, K and p tracks as a function of P_t

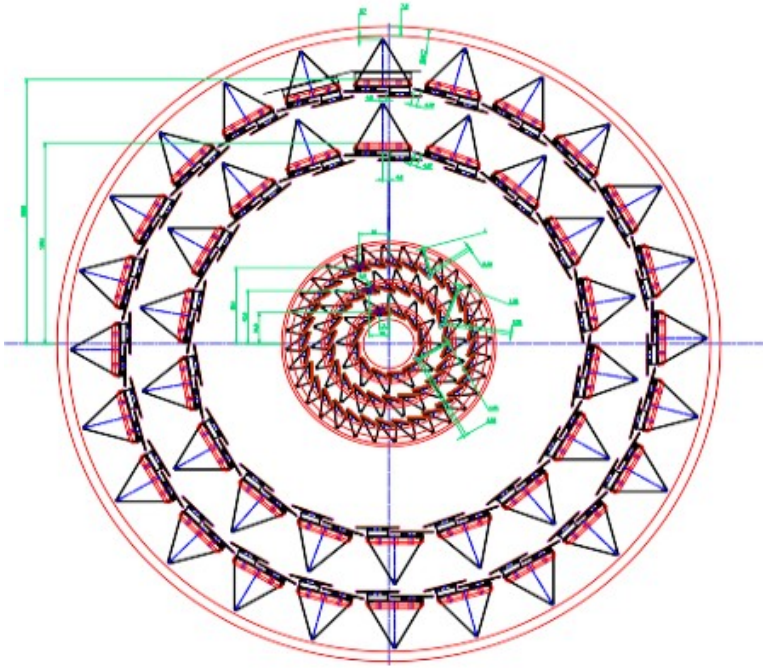




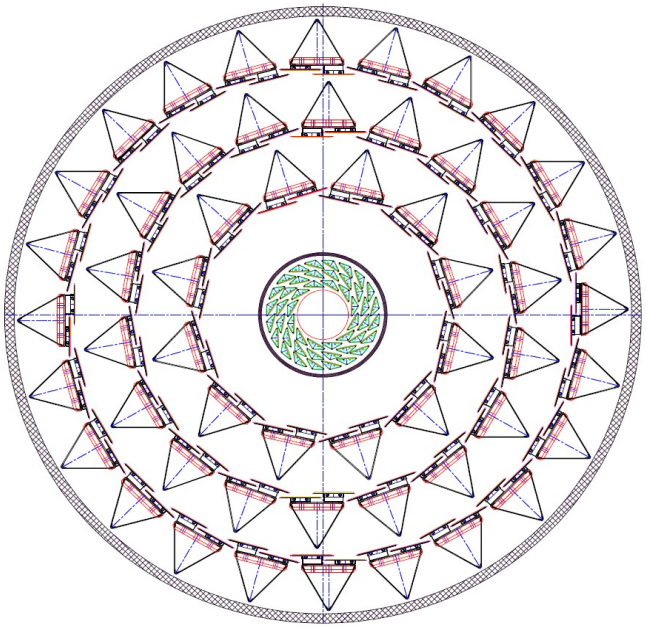
For example, ITS pointing resolution of at least 120 mμ makes it possible a decay vertex reconstruction of D^0 mesons in the channel $D^0 \rightarrow K^- + \pi^+$ ($c\tau$ = 123 μm) with p_T above 500 MeV/c.

New model of the MPD ITS

5 layers



6 layers

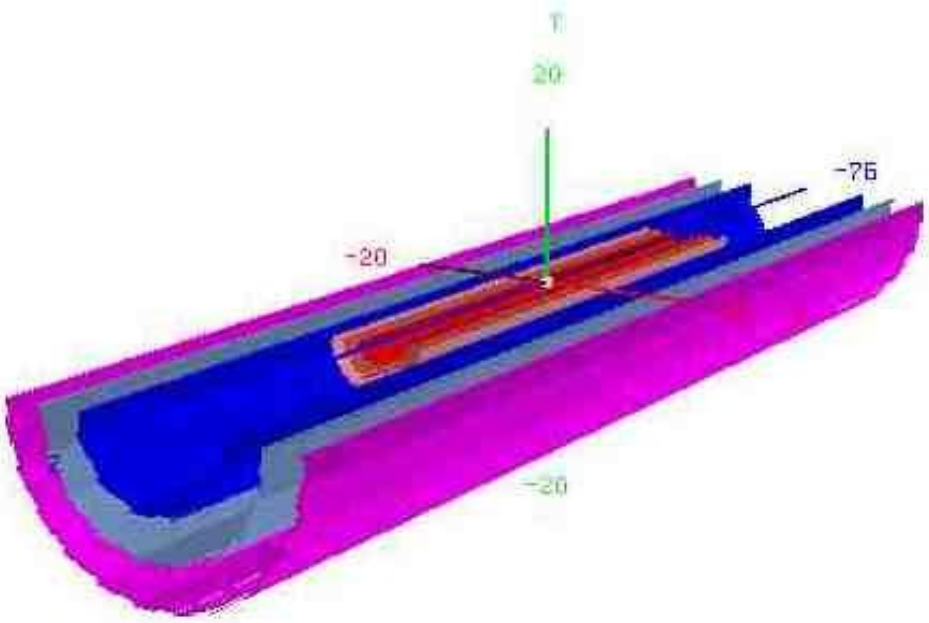


The next step was to add the third outer layer in order to improve the quality of track reconstruction in the whole ITS.

MPD ITS TDR (in preparation)

Geometric model of 6 layer ITS used for simulation

OB - 3 layers of ALPDE-like MAPS (15*30 mm²) with effective thickness of 700 μm
IB - 3 layers of ALPIDE-like MAPS (15*30 mm²) with effective thickness of 50 μm



Layer	R_{min}, mm	R_{max}, mm	Length, mm
1	22.4	26.7	750
2	40.7	45.9	750
3	59.8	65.1	750
4	93.2	96.7	1526
5	144.5	147.9	1526
6	194.4	197.6	1526

Beam pipe diameter – 40 mm

ITS Monte-Carlo simulation scheme within MpdRoot

Event MC generator:
DCMSMM, Thermal generator

Particle MC transport
through ITS: GEANT4

Hit generation

Track finding: KF

Vertices
reconstruction

The main simulation tasks include:

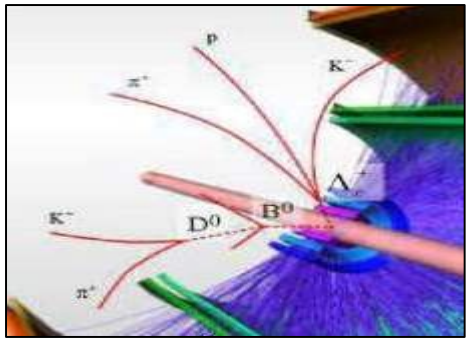
- generation of detector responses (Hit Producer);
- reconstruction of particle tracks using generated hits (Track Finder + Track Fitter) ;
- reconstruction of the primary and secondary interaction vertices (Track Analysis).

Detection of D mesons in central AA collisions with ITS-6-40

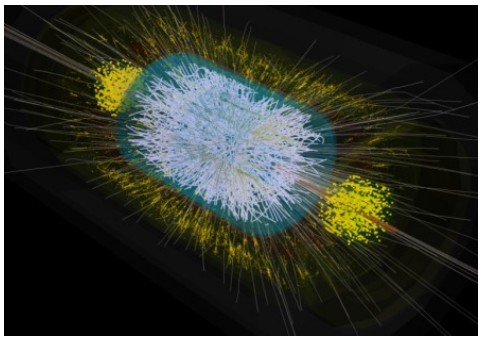
Particle	Mass [MeV/c²]	Mean path cτ [mm]	Decay channel	BR	Multiplicity
D^+	1869.6	0.312	$\pi^+ + \pi^+ + K^-$	9.13%	10^{-2}
D^0	1864.8	0.123	$\pi^+ + K^-$	3.89%	10^{-2}
D^+_s	1968.5	0.150	$\pi^+ + K^+ + K^-$	5.50%	10^{-2}

Simulation methods

Method of mixed events



Signal (D decay)
Generator: TG
Statistics: 1M decays



Background (Bi+Bi)
Generator: DCMSMM
Statistics: 500K mb events

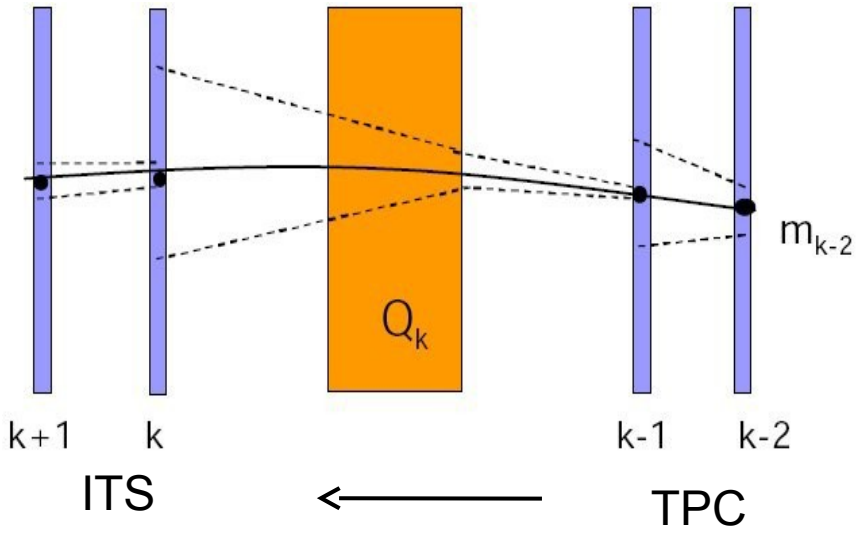
1) Track finder:
   KF
2) Particle identification:
   TOF + dE/dx
3) Track analysis:
   ML (MVA)

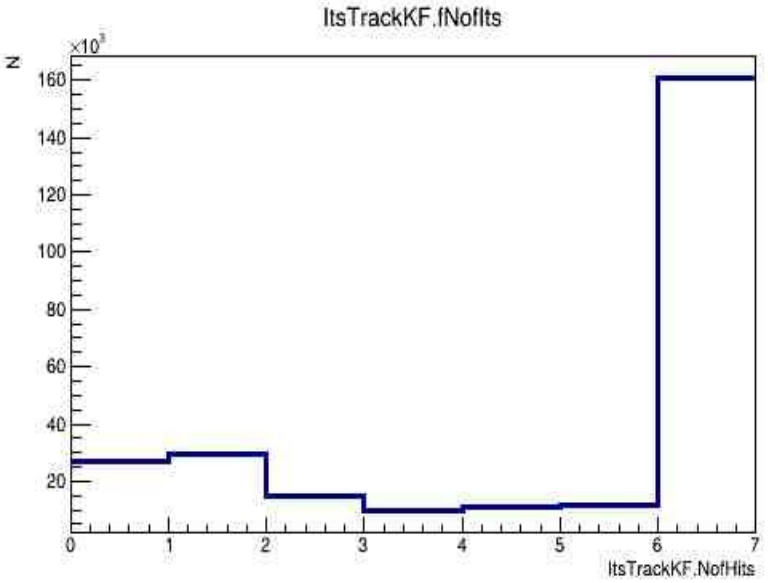
Track reconstruction method

Kalman Filter

Linear recursive method for track parameters estimation according to known hit measurements m_k that describes track candidate by its state vector and error matrix. The arbitrary noise caused by multiple scattering of the particle in the detector material is taken into account by adding a noise covariance matrix Q_k

TPC seed tracks are extrapolated to ITS layer by layer

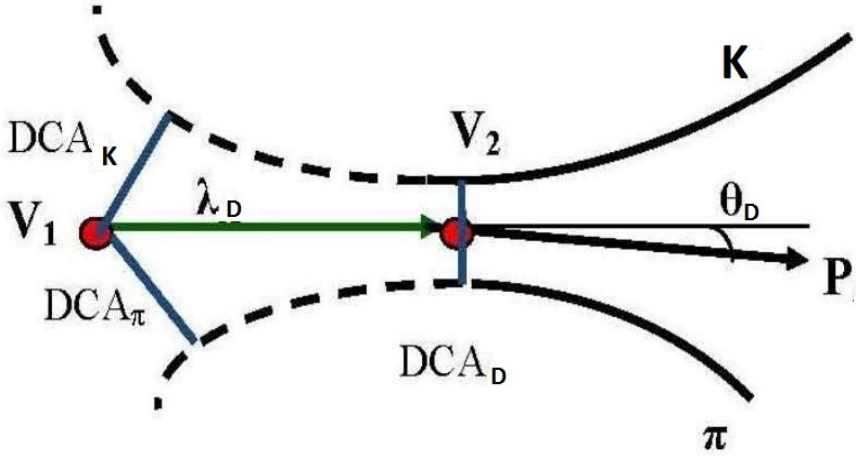




D-meson selection method

Selection parameters are dictated by the decay topology:

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



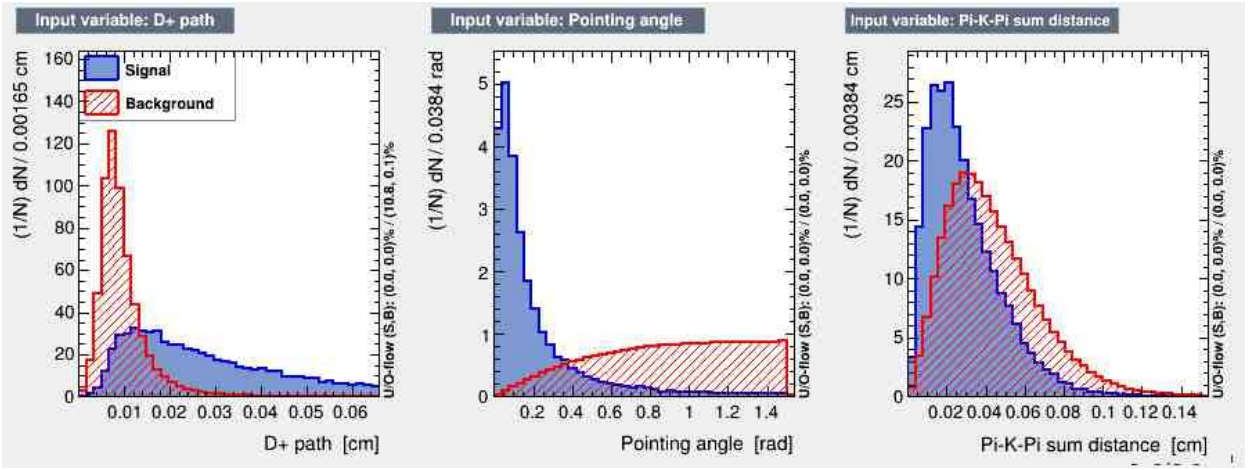
MVA method

The variables from the signal and background samples are trained according the chosen classifier. During the classification the initial **N** input variables **V** are transformed to one dimensional variable **R** : $\mathbf{V^N \rightarrow R}$

The resulting cut of the classifier response **R** is applied to the data to be analyzed.

The classifier **BDT** (Boosted Decision Trees) has been chosen for the analysis phase when reconstructing D mesons

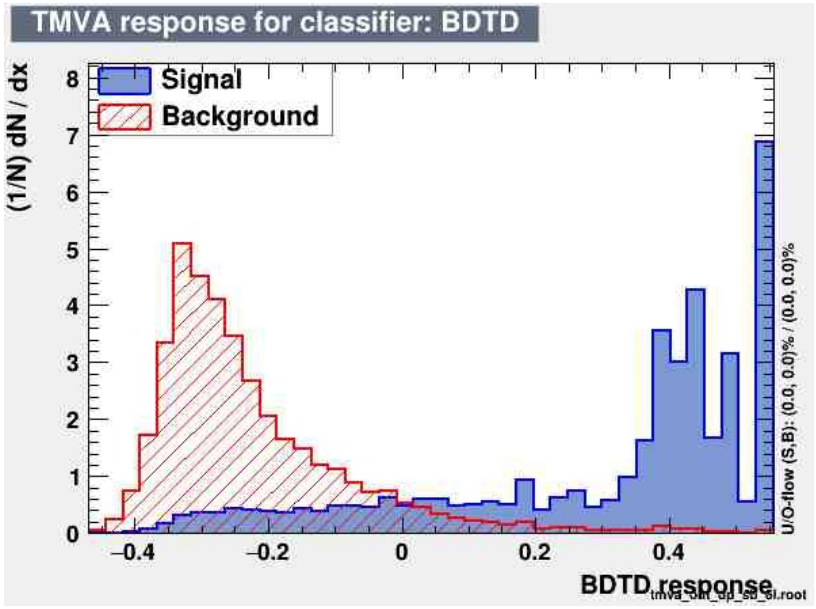
Reconstruction of D^+ with ITS-6-40 model

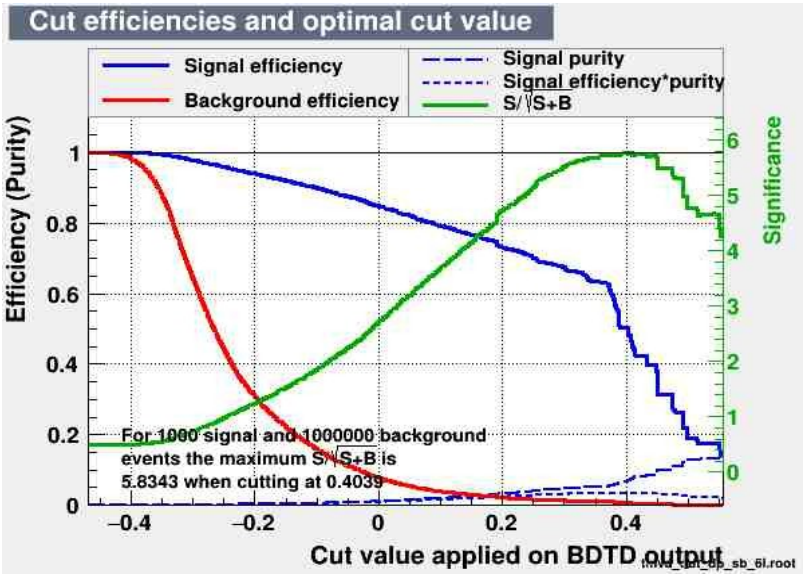


$$D^+ \rightarrow K^- + \pi^+ + \pi^+$$

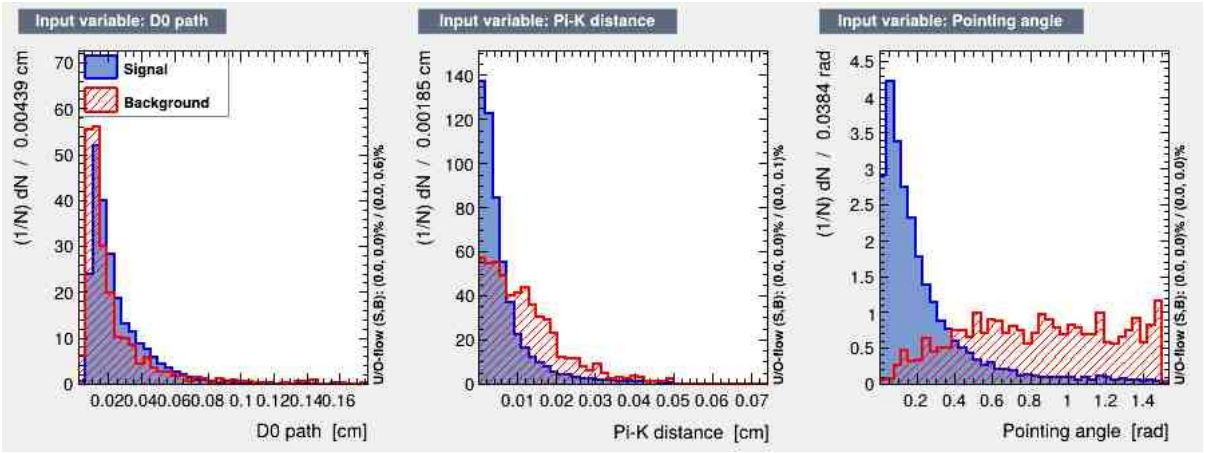
MVA input:
λ_D (D^+ path),
θ_D (pointing angle),
DCA_D (π-K-π sum distance)

MVA cuts:
DCA(π, K) > 0.015 cm,
BDT_response > 0.35





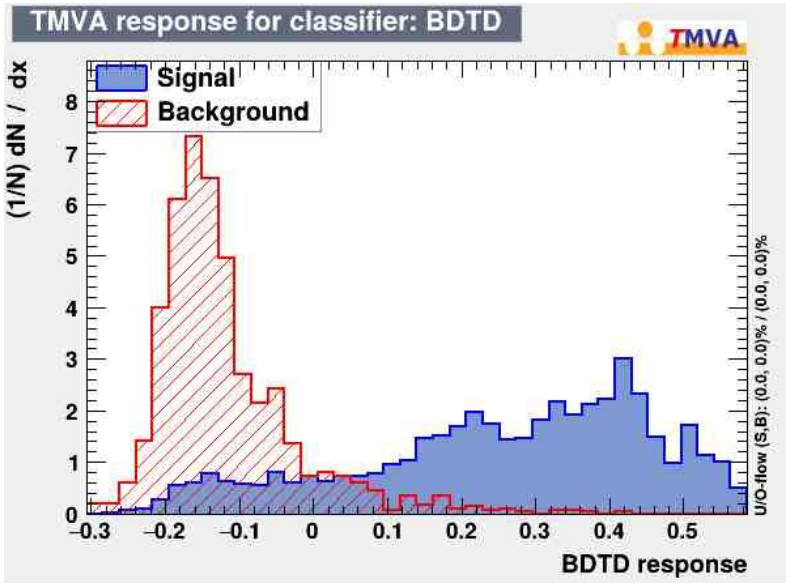
Reconstruction of D^0 with ITS-6-40 model

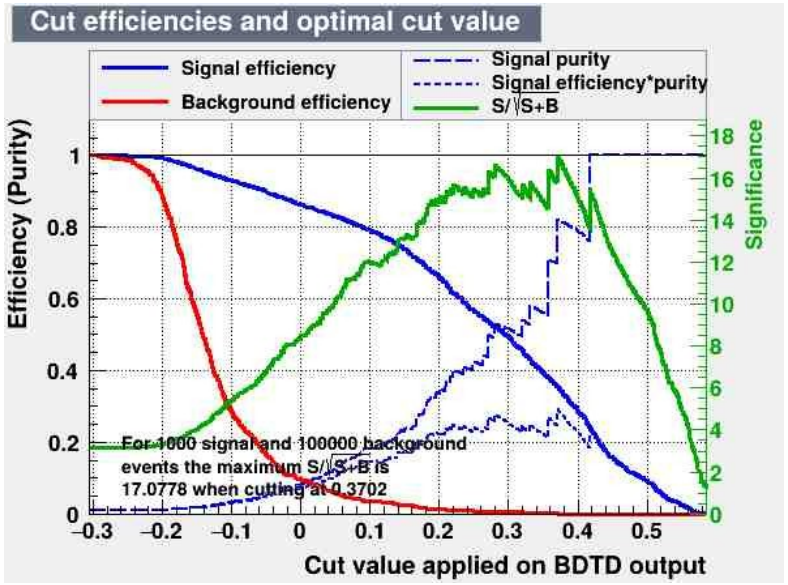


$D^0 \rightarrow K^- + \pi^+$

MVA input:
λ_D (D^0 path),
θ_D (pointing angle),
DCA_D (□-K distance)

MVA cuts:
DCA(π, K) > 0.007 cm,
BDT_response > 0.40





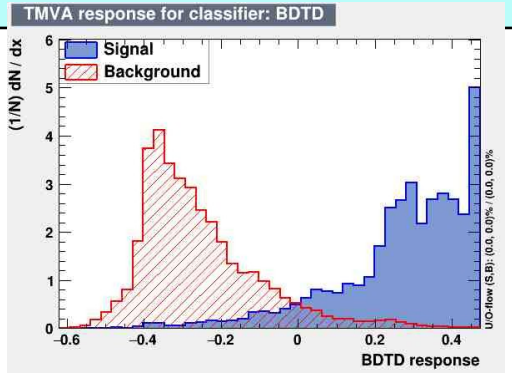
D^+_s reconstruction in central Bi+Bi at NICA energy

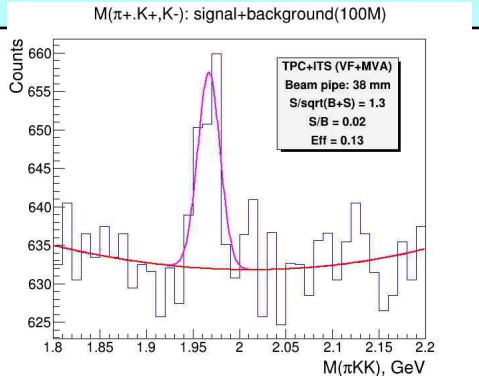
Particle	Mass [MeV/c²]	Mean path cτ [mm]	Decay channel	BR	Multiplicity
D^+	1869.6	0.312	$\pi^+ + \pi^+ + K^-$	9.13%	10^{-2}
D^+_s	1968.5	0.150	$\pi^+ + K^+ + K^-$	5.50%	10^{-2}

Reconstruction of D^+_s is more complicated task compared to D^+ for three reasons:

1) due to the decay length is 2 times shorter,
2) due to the BR is 2 times less,
3) due to the decay channel, since the reconstruction efficiency of K tracks is lower than that of π tracks.

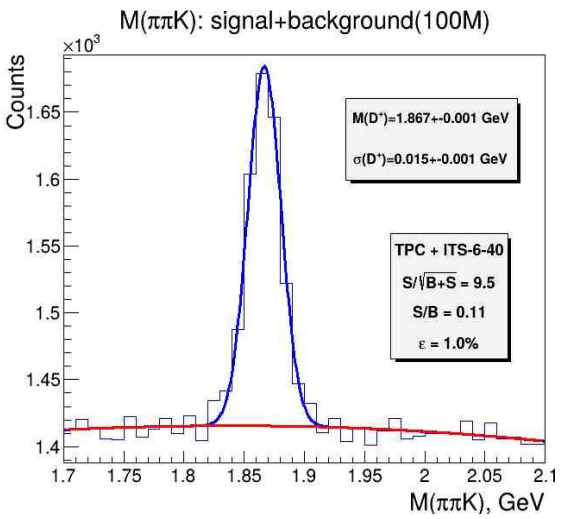
TMVA:
dca(π, K) > 0.02 cm,
BDT_response > 0.25



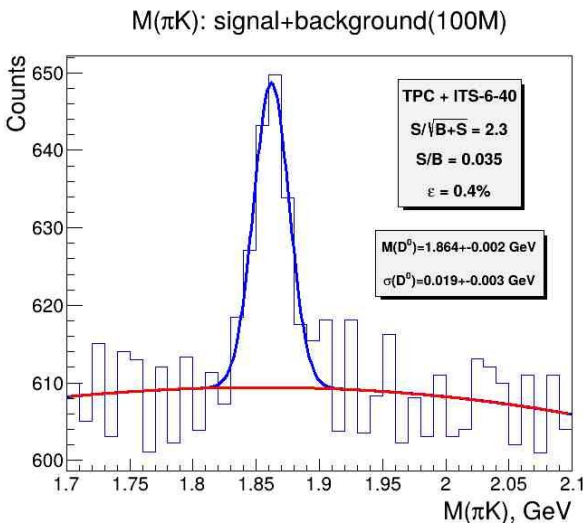


D mesons reconstruction in Bi+Bi at $\sqrt{S_{NN}} = 11$ GeV

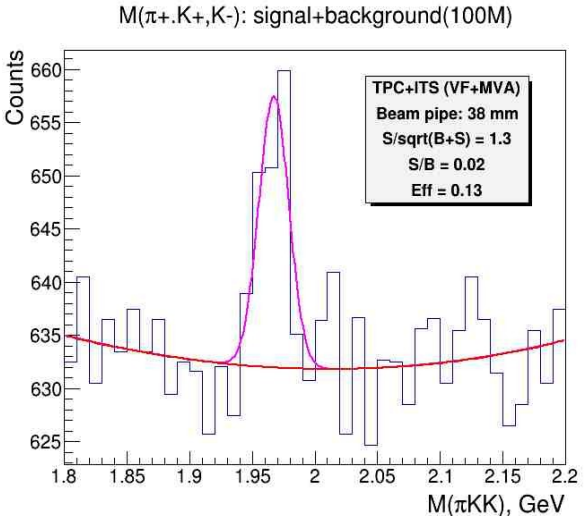
$D^+ \rightarrow K^- + \pi^+ + \pi^+$



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



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



Using the optimal BDT cut allows to reconstruct D^+, D^0 and D^+_s with an efficiency of **1.0%**, **0.4%** **and 0.1%** respectively.

Particle	D^+	D^0	D^+_s
Efficiency, %	1.0	0.4	0.1
Significance	9.5	2.3	1.3
S/B(2σ) ratio	0.11	0.04	0.02

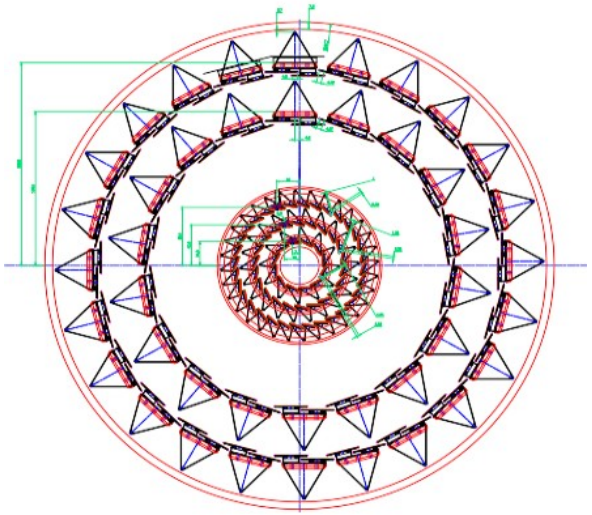
N_D = 19 000 mesons/month for $D^+ \rightarrow \pi^+ \pi^+ K^-$

N_D = 3 200 mesons/month for $D^0 \rightarrow K^- \pi^+$

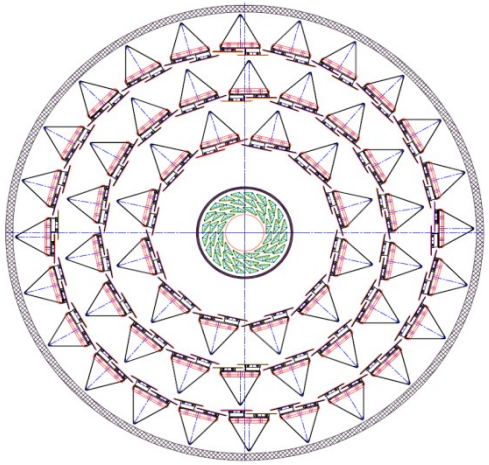
N_D = 1 100 mesons/month for $D^+_s \rightarrow \pi^+ K^+ K^-$

New concept of 6 layers ITS on the base of MAPS with large area

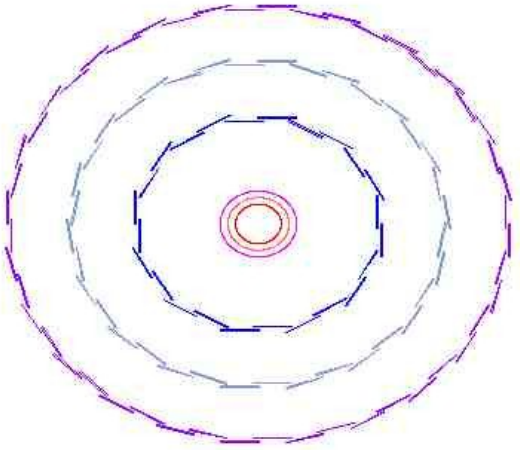
5 layers of standard MAPS



6 layers of standard MAPS



6 layers of MAPS with large area



Beam pipe diameter – 40 mm

Beam pipe diameter – 35 mm

1. V.I. Zherebchevsky, V.P. Kondratiev, N.A. Maltsev, Yu.A. Murin, V.V. Petrov
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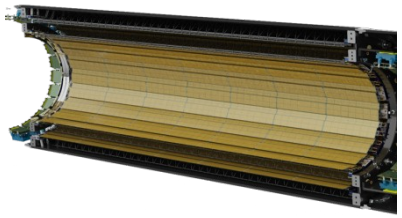
2. Грант Российского научного фонда № 23-12-00042

MPD ITS-6-35 geometric model

ITS-6-35 model with OB consisting of 3 layers of standard MAPS:

Sensitive area: 15×30 mm²
Thickness: 50 μm
Number of pixels: 512×1024
Pixel size: 28×28 μm².



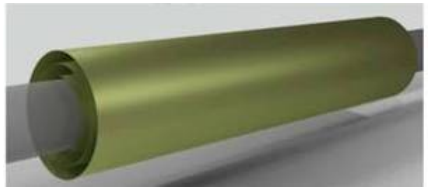
and IB consisting of 3 layers of bended staves of MAPS (15 um pitch) with large area and thickness of 30 μm

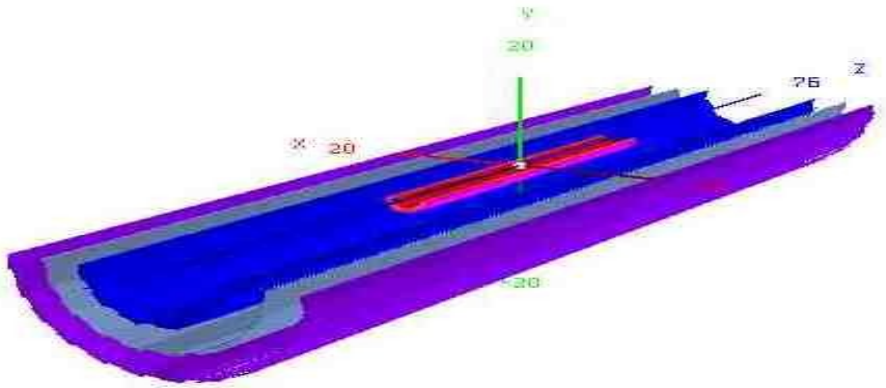
Size of bended MAPS:

1 layer - 280*56.5 mm²

2 layer - 280*75.5 mm²

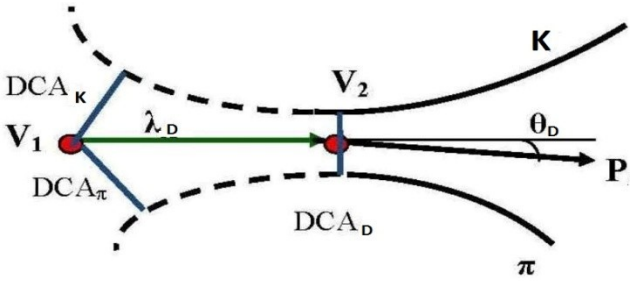
3 layer - 280*94.0 mm²



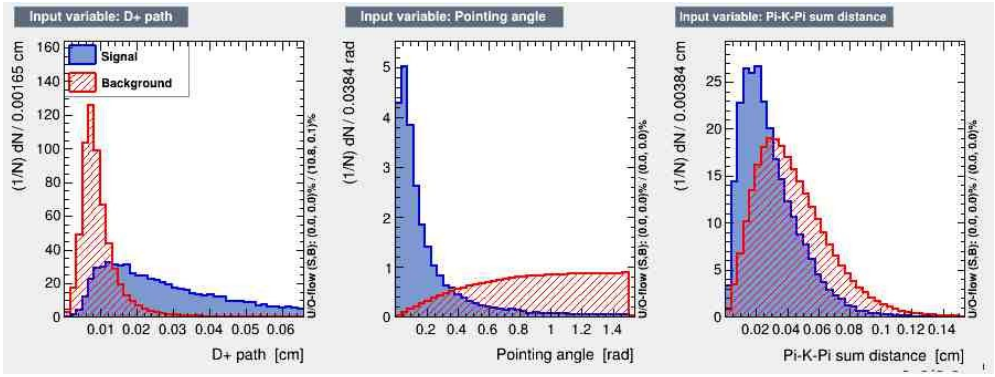


Reconstruction of D^+ and D^0 with ITS-6-35 model in Au+Au central collisions at $\sqrt{S_{NN}}$ = 9 GeV

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

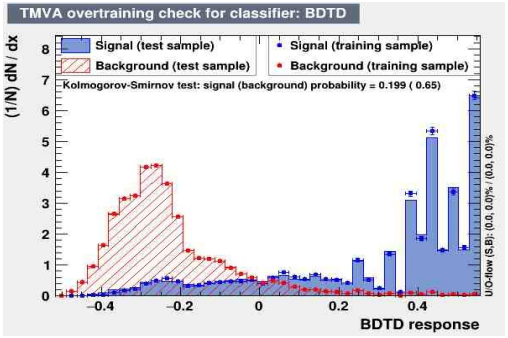


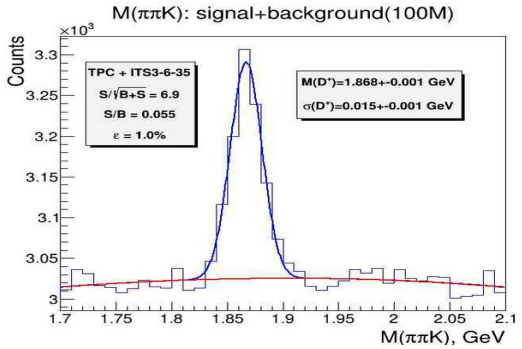
Used methods :
1) Track finder: KF
2) Particle identification: TOF + dE/dx
3) Track analysis: ML (MVA)



MVA input:
λ_D (D path),
θ_D (pointing angle),
DCA_D (□-K-π sum
di

MVA cuts:
DCA(π, K) > 0.012 cm,
BDT_response > 0.35





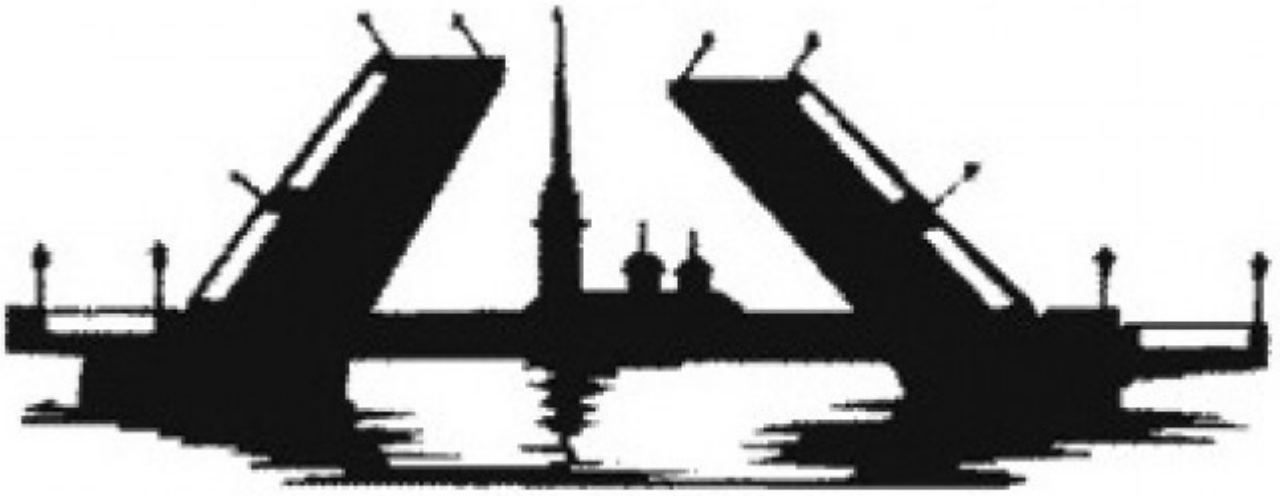
Particle	D^+	D^0
Efficiency, %	1.2	0.5
Significance	6.9	1.7
S/B(2σ) ratio	0.06	0.02

Conclusion

Quality assessment of the MPD tracking system **(TPC + ITS-6-40)** has been investigated when reconstructing charmed particles formed in AA collisions at NICA energies.

Simulation shows:

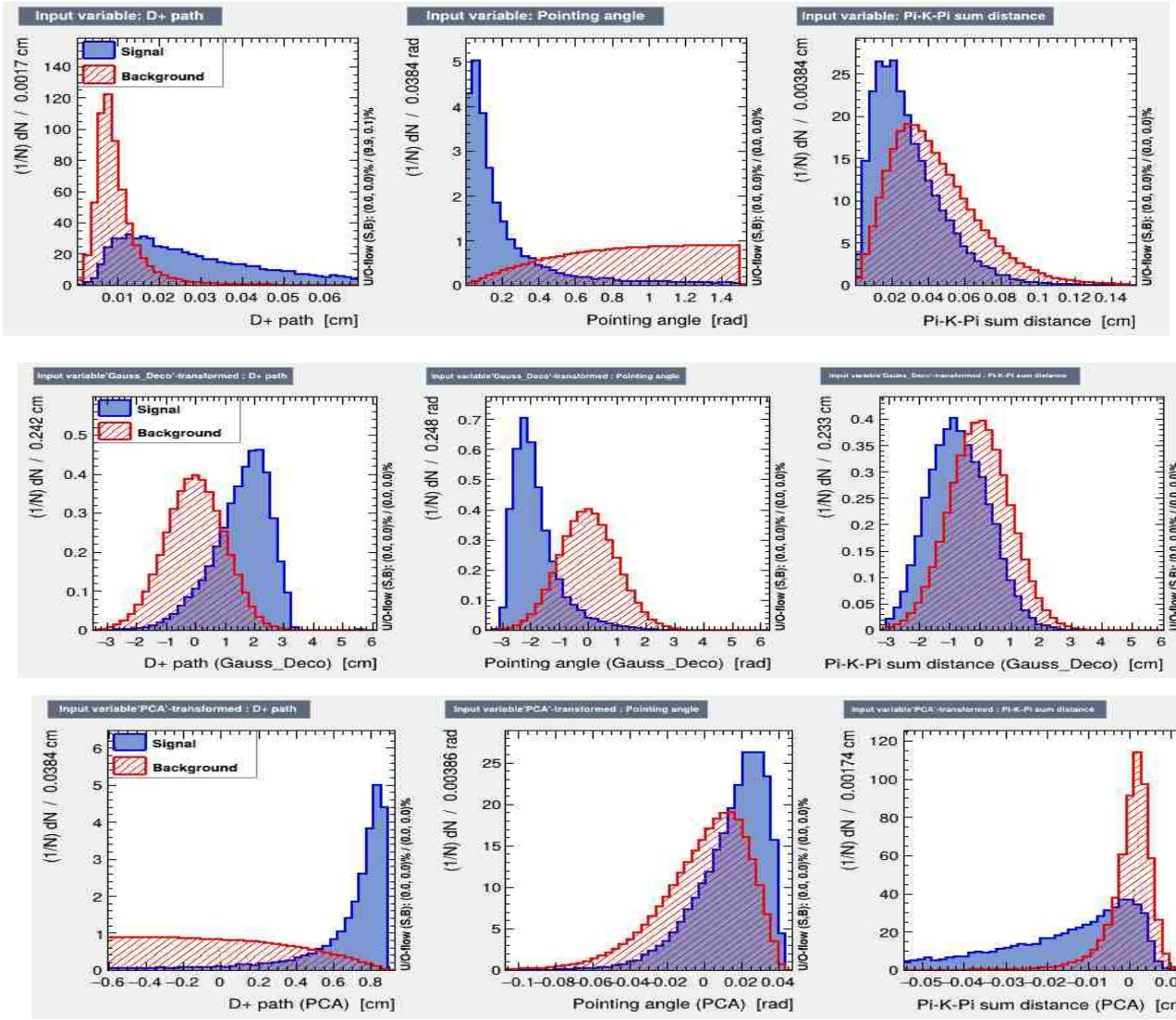
- feasibility of D mesons reconstruction in central Bi+Bi collisions at $\sqrt{S_{NN}}$ = 11 GeV
- estimated meson yields opens up prospects for studying the heavy flavors physics at the NICA-MPD facility.



Thank you for your attention!

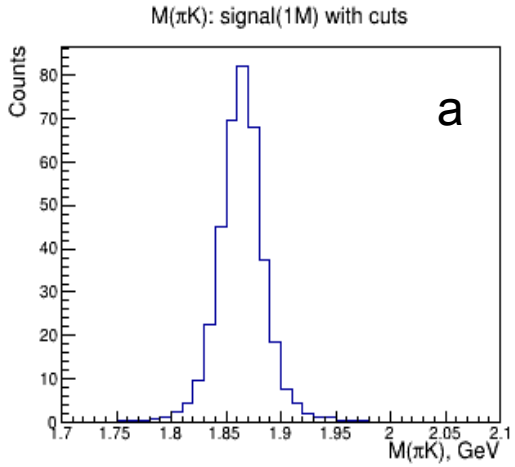
Back up slides

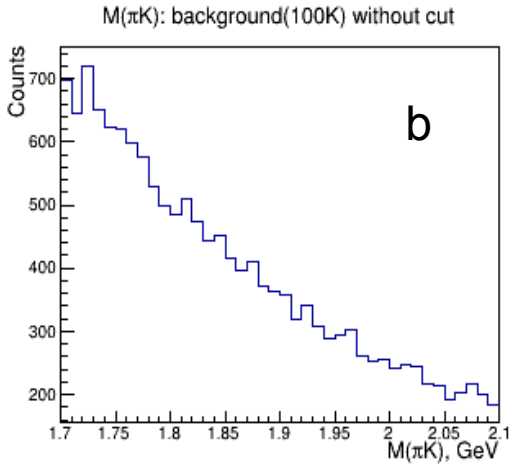
Input variables distributions for signal and background events after the gaussianisation and principal component decomposition (D^+)



Example of getting invariant mass spectra of D^0 mesons

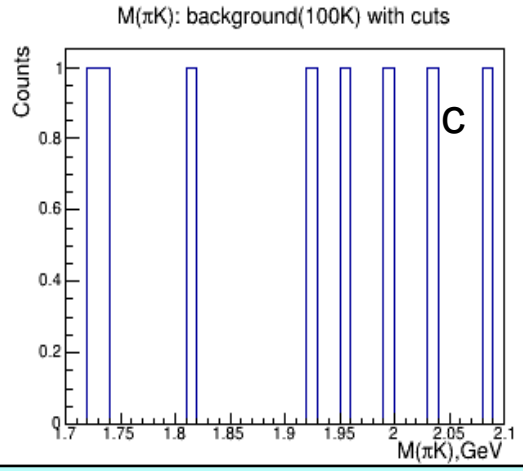
10^6 signal events after applying cuts

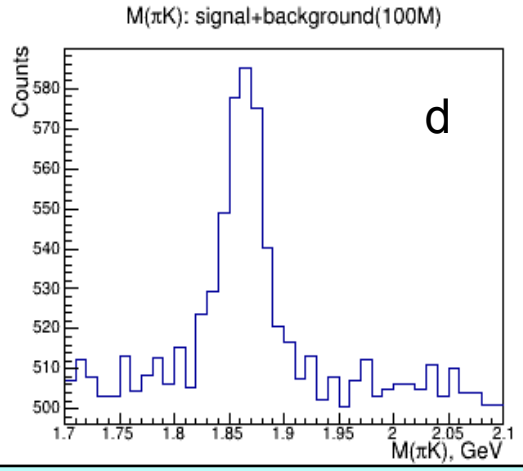




10^5 background events before applying cuts

10^5 background events after applying cuts





10^8 signal + background events after applying cuts

Background simulation - using DCMSMM generator (100K centralBi+Bi events)
Signal simulation – using thermal generator (1M decay events)
Resulting spectrum is normalizing to statistics of 100M central Bi+Bi events

D yields at NICA

1) efficiency: ε = 1% (D^+), ε = 0.4% (D^0)
2) interaction rate: $R=8\cdot10^3$ events/sec
3) central collision fraction: $\delta=0.1$.
4) multiplicity of D in central AA collisions at NICA: $M=10^{-2}$ meson/event.
5) branching ratio of the D meson decay: BR=9.2% (D^+), BR=3.9% (D^0)
6) one month of continuous NICA operation: $T=2.6\cdot10^6$ sec
7) yield: $N_D = R \cdot \delta \cdot M \cdot T \cdot \varepsilon \cdot BR$

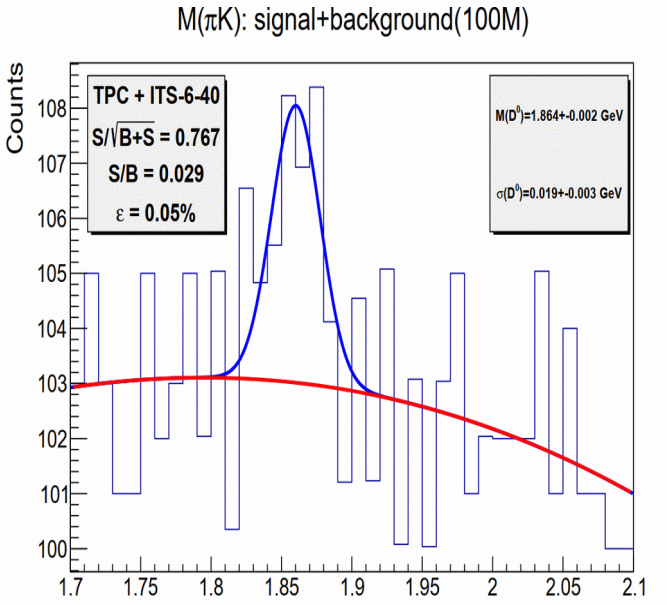
N_D = 19 000 mesons/month for $D^+ \rightarrow \pi^+ \pi^+ K^-$

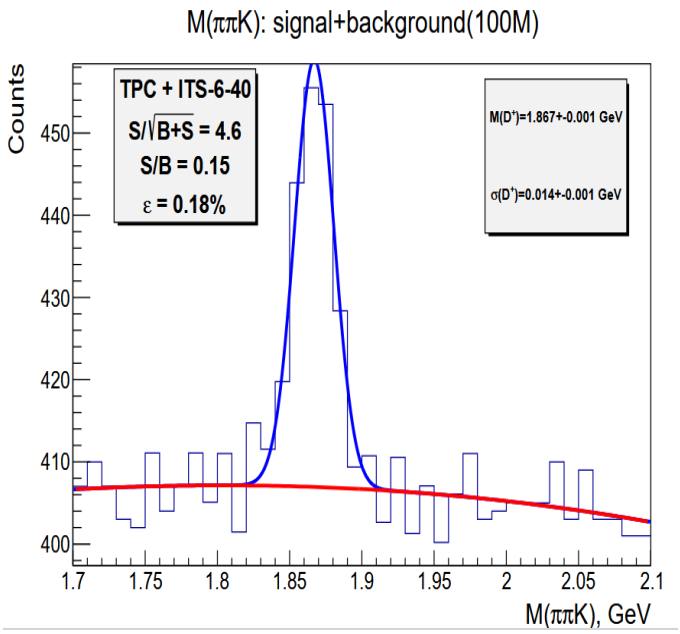
N_D = 3 200 mesons/month for $D^0 \rightarrow \pi^+ K^-$

D mesons reconstruction with new geometry of ITS (gap between the two halves of the inner barrel)

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

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





Preliminary results show that using the optimal BDT cut allows to reconstruct D^+ and D^0 with an efficiency of **0.18%** and **0.05%** respectively.