The identification capability of the Inner Tracking System for the detection of D-mesons at the NICA/MPD

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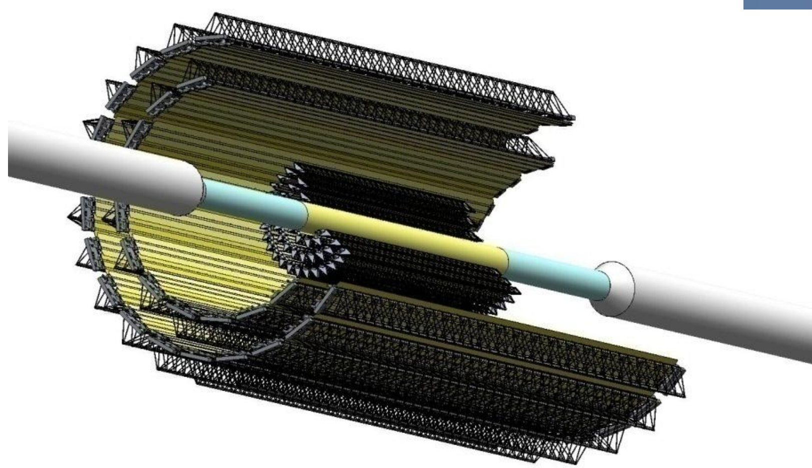

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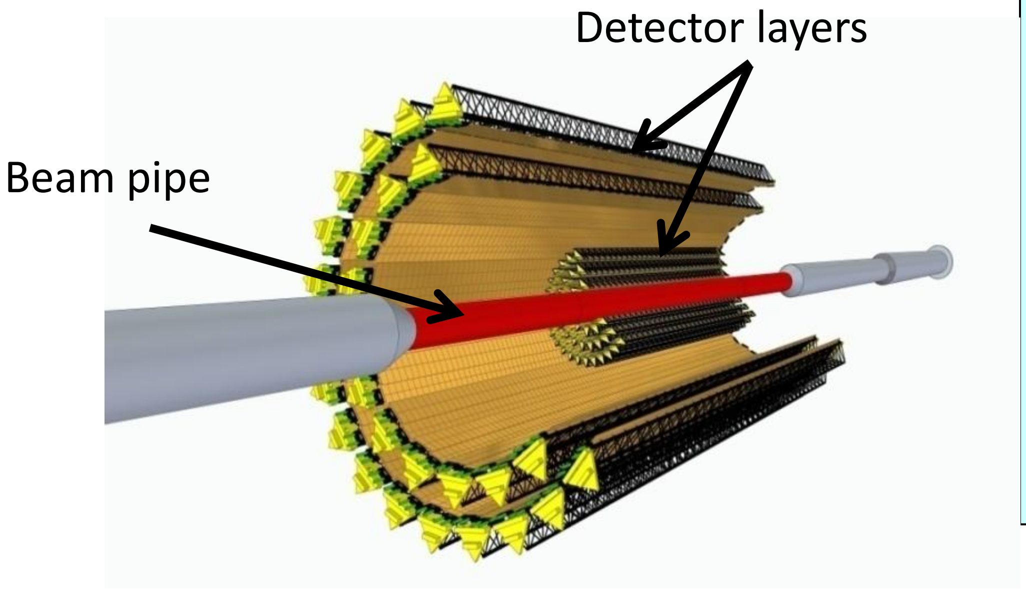
Physical motivation of using ITS

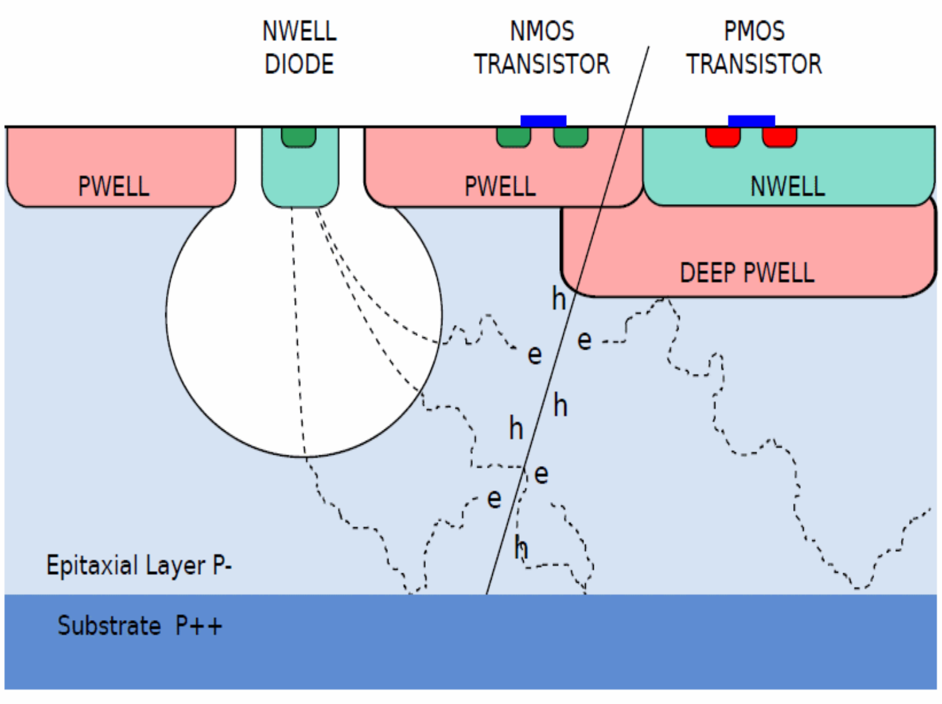
The yields and spectra of charmed particles are the important observables sensitive to critical phenomena in phase transitions of the QCD-matter.
Vertex detectors (Inner Tracking System - ITS) are used in HEP experimental setups for highly efficient detection of such short-lived products of nuclear interactions.



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 - which have the best spatial resolution at a high counting rate and their high level of segmentation per pixel allows to install detectors as close as possible to the interaction point without the threat of frequency overload. Combination of the TPC and the MAPS based ITS makes it possible to detect short-lived products of N-N interactions with maximum efficiency.



MAPS parameters for the project MPD ITS:

Sensitive area: 15×30 mm^2

Thickness: 50 μm

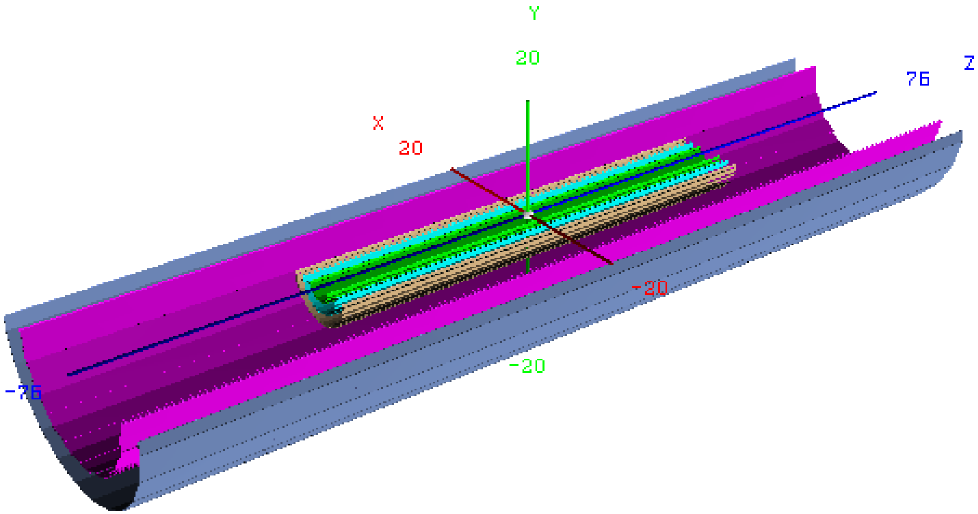
Number of pixels: 512×1024

Pixel size: 28×28 μm^2.

Space resolution:

$\sigma_x = 5$ μm , $\sigma_y = 5$ μm

MPD ITS geometric model

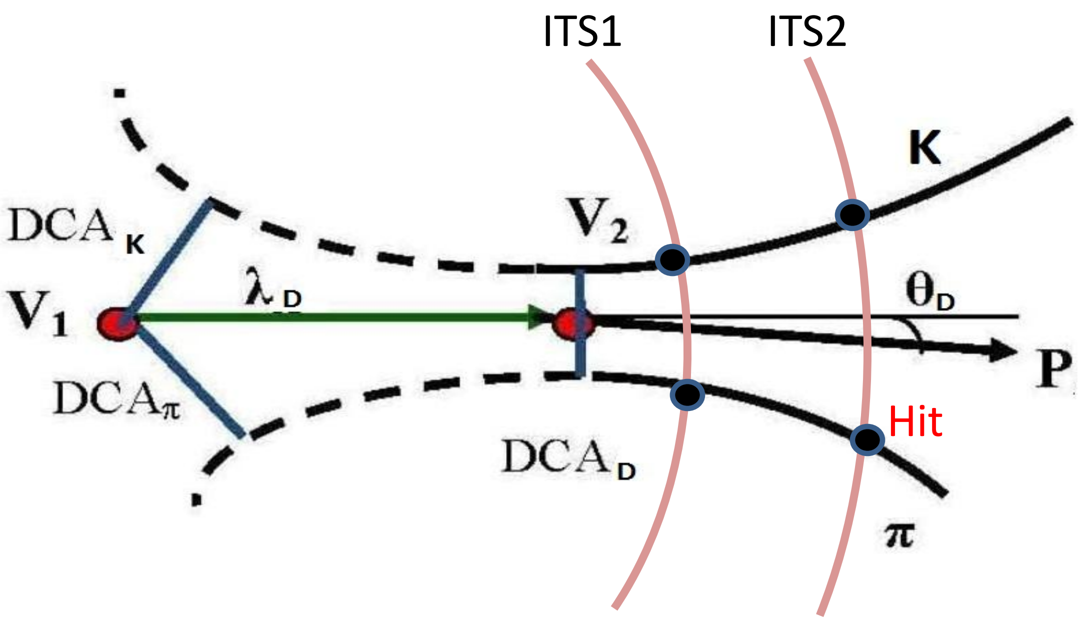


Model ITS-5-40 (project configuration): 5-layer ITS for a beam pipe with the smallest possible diameter of 40 mm
Each layer consists of ladders containing 24 MAPS in Inner Barrel and 98 MAPS in Outer Barrel

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

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

Reconstruction of charmed mesons with ITS

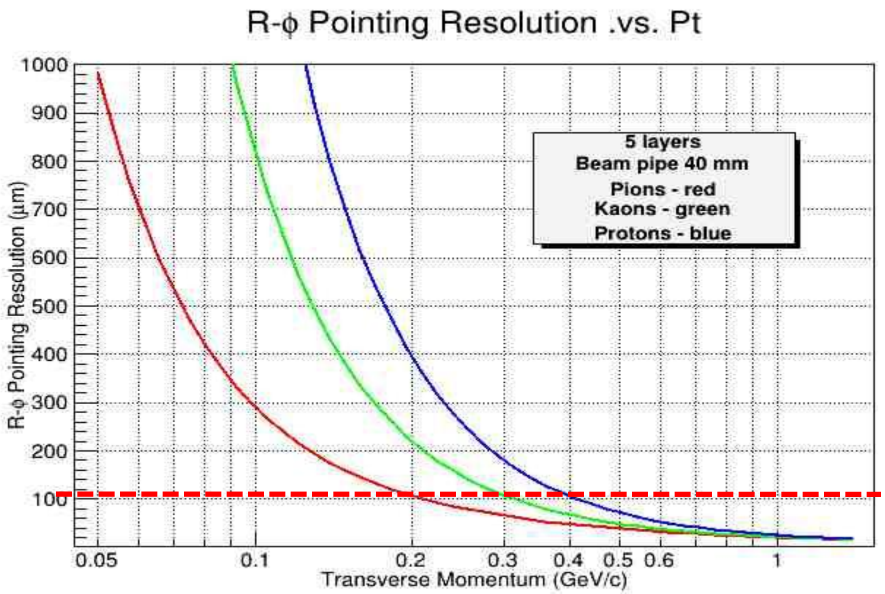


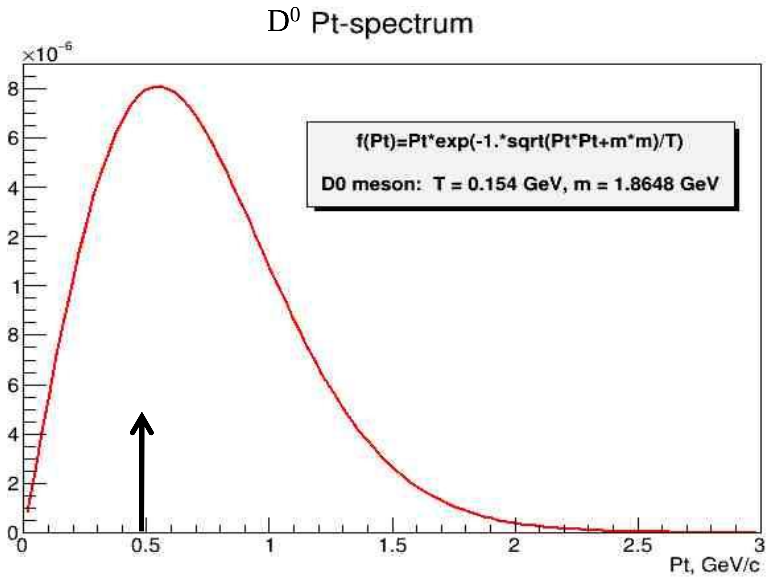
$$D^0 \rightarrow K^- + \pi^+, \tau c = 123\ \mu m$$

Identification of short-lived charmed particles is performed by determining the invariant mass of their decay products. For high-efficient reconstruction of decay vertices V_2 near the interaction point V_1 the ITS pointing resolution should be comparable with the decay length of the particle.

ITS pointing resolution and D p_t-spectra

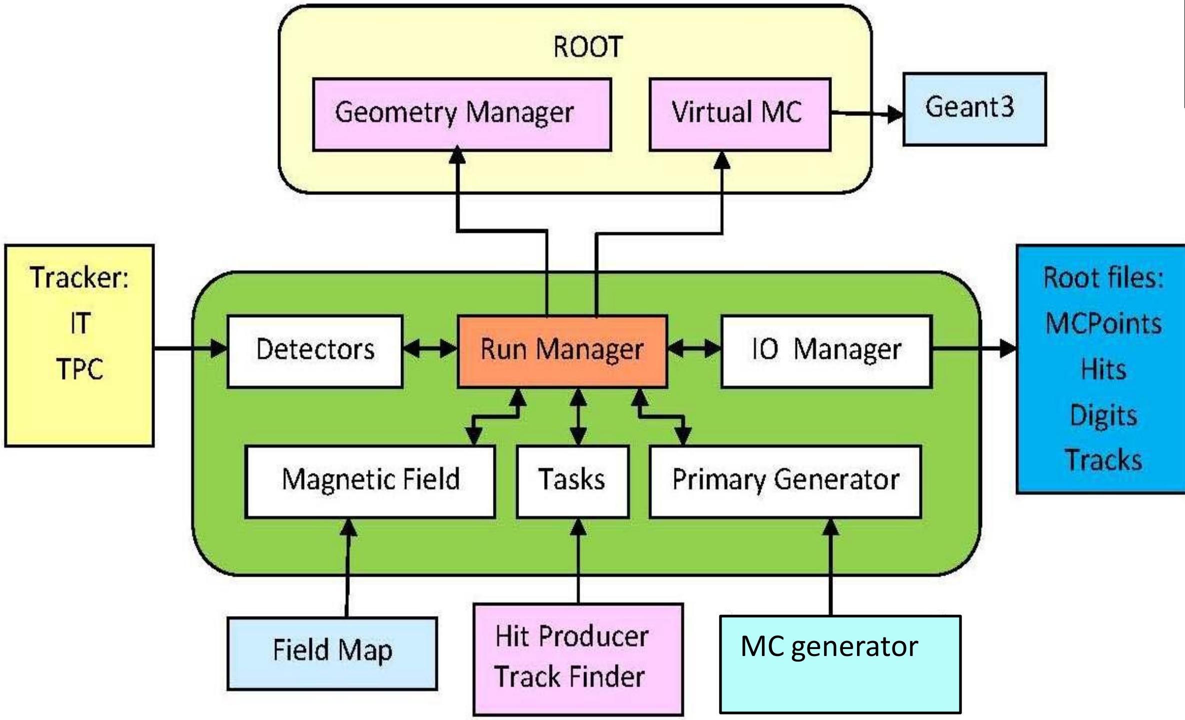
The ITS pointing resolution for ***π*, *K*** and ***p*** tracks was evaluated in the framework of the simplified model which enables charged particle tracking through cylindrical silicon layers with the specified material budget.

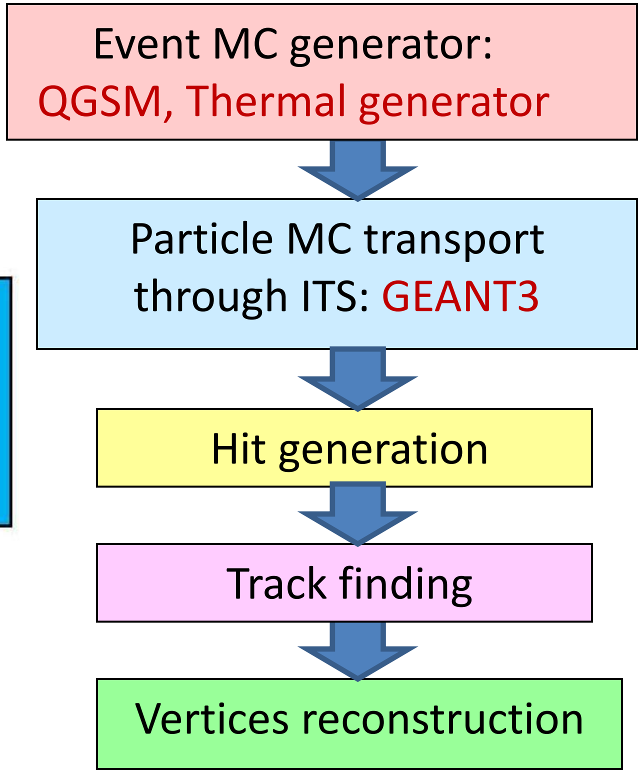




For example, ITS pointing resolution of at least 120 μm makes it possible a decay vertex reconstruction of D^0 mesons in the channel $D^0 \rightarrow K^- + \pi^+$ ($c\tau$ = 123 μm) with p_T above 500 MeV/c.

ITS Monte-Carlo simulation scheme within MpdRoot





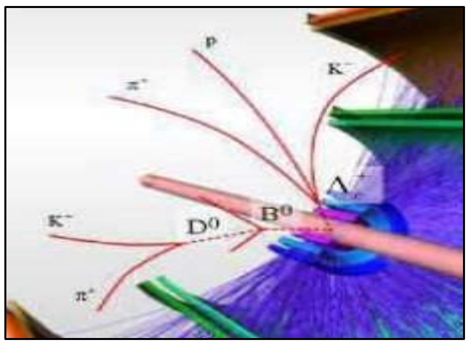
The main simulation tasks include:

- generation of detector responses (hits);
- reconstruction of particle tracks using generated hits;
- reconstruction of the primary and secondary interaction vertices using reconstructed tracks.

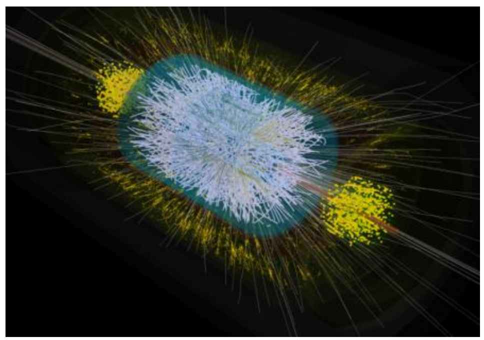
Detection of D mesons in central Au+Au collisions with ITS-5-40

Particle	Mass [MeV/c^2]	Mean path $c\tau$ [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	$\pi^+ + \pi^+ + K^-$	5.50%	10^{-2}

Simulation



Signal
Generator: TG
Statistics: 1M decays



Background
Generator: QGSM
Statistics: 100K events

Two methods are used for track reconstruction:

1) Method of Kalman filter (KF)
2) Method of vector finder (VF)

Two methods are used for D mesons selection:

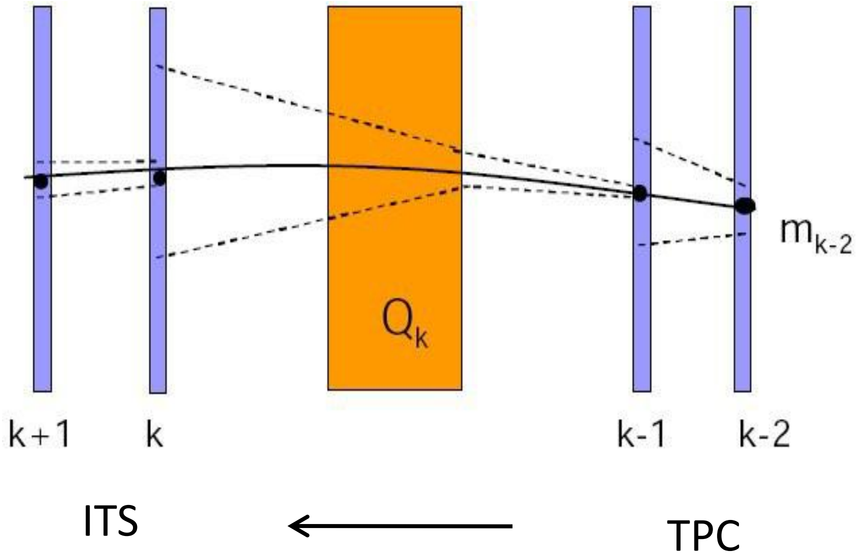
1) Method of topological cuts (TC)
2) Method of multivariate data analysis (MVA)

Track reconstruction methods

Kalman Filter

Linear recursive method for track parameters estimation according to known hit measurements that describes track candidate by its state vector and error matrix

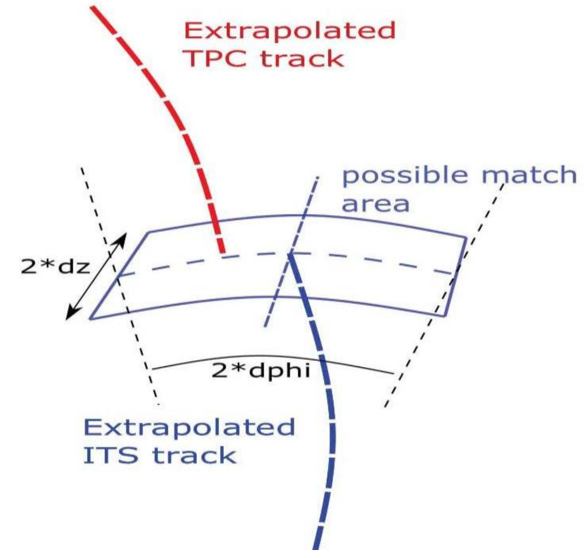
TPC seed tracks are extrapolated to ITS layer by layer



Vector Finder

Combinatorial search method that combines hits with angular positions corresponding to actual particle tracks.

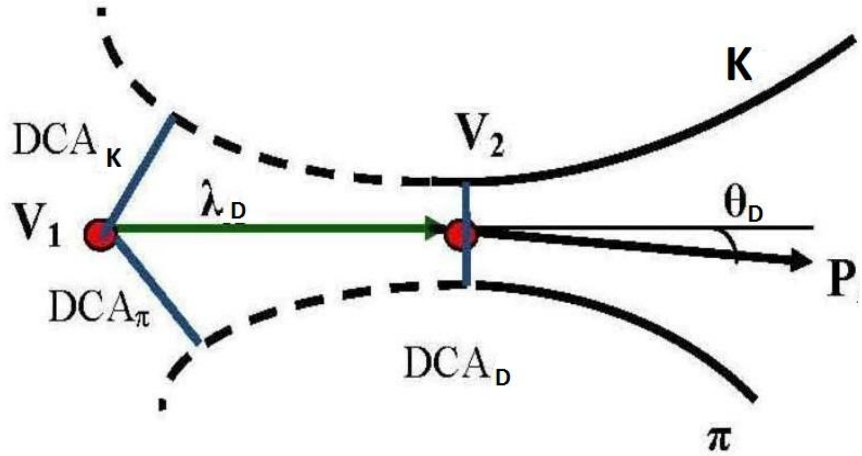
TPC and ITS standalone tracks are matched (implemented by A. Zinchenko)



D-meson selection methods

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



TC method

The cut-off level for the specified selection parameter is set based on the maximum value of the significance function $Sg(C_i)$ for each parameter C_i:

$$Sg(C_i) = \int_0^{C_i} \frac{S}{\sqrt{S+B}} dC_i$$

MVA method

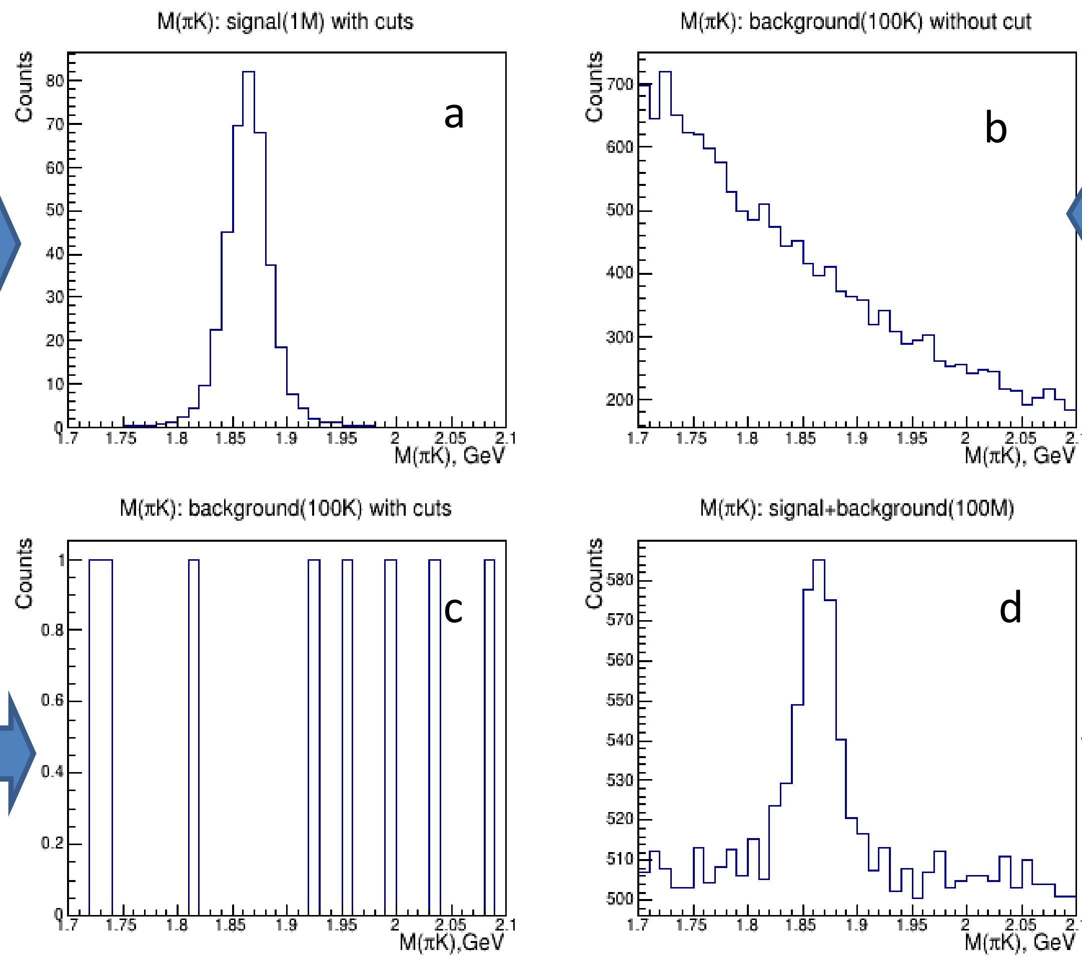
The variables from the signal and background samples are trained according the chosen classifier. During the classification the initial **N** input variables **V** are transformed to one dimensional variable **R** : $V^N \rightarrow R$

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

Example of getting invariant mass spectra of D 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

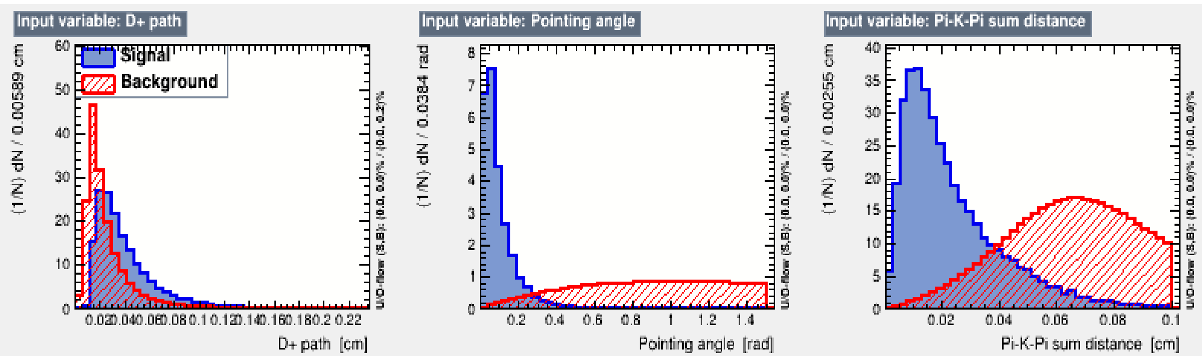
Background simulation - using QGSM generator (100K Au+Au events)
Signal simulation – using thermal generator (1M decay events)
Resulting spectrum is normalizing to statistics of 100M Au+Au events

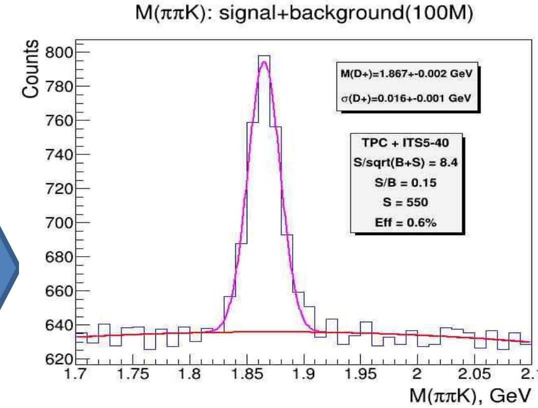
D^+ and D^0 reconstruction using KF

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

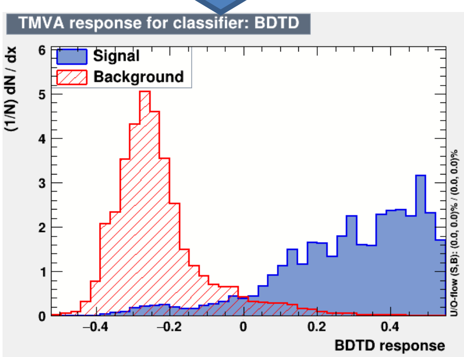
$D^+ \rightarrow K^- + \pi^+ + \pi^+$

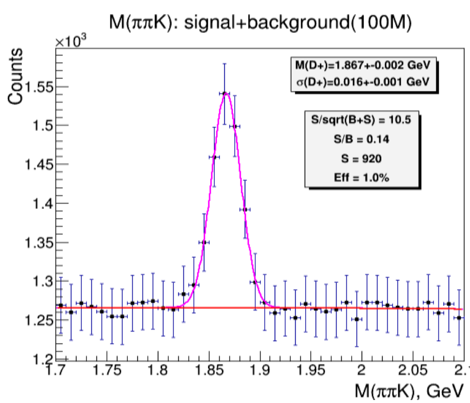
TC: dca(π), dca(K), dca(πK), λ(D), θ(D) cuts





MVA: BDT classifier cut





Particle	D^0		D^+	
Method	TC	MVA	TC	MVA
Efficiency, %	0.80	0.85	0.60	1.0
Significance	5.3	5.5	8.4	10.5
S/B(2σ) ratio	0.10	0.10	0.15	0.14
Yield per month	$6\cdot10^3$	$7\cdot10^3$	$1\cdot10^4$	$2\cdot10^4$

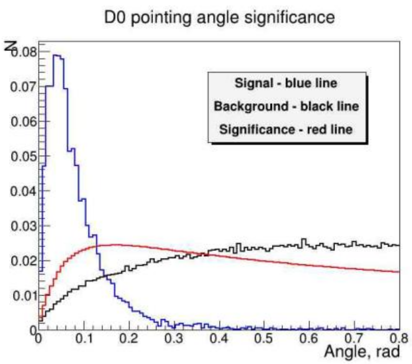
Using the topological cuts allows to reconstruct D^0 and D^+ decays with an efficiency of 0.8% and 0.6% respectively. Using the optimal BDT cut allows to reconstruct D^0 and D^+ with an efficiency of 0.85% and 1.0% respectively.

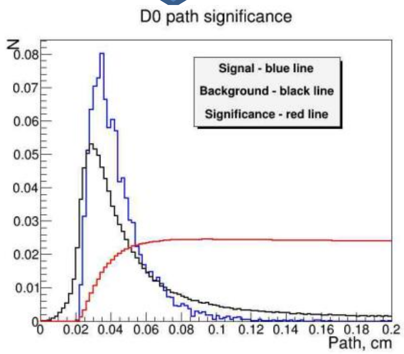
D^+ and D^0 reconstruction using VF

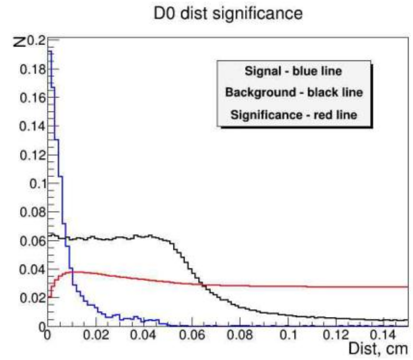
$D^0 \rightarrow K^- + \pi^+$

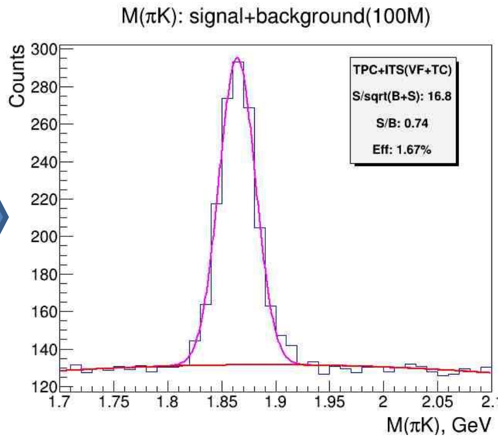
$D^+ \rightarrow K^- + \pi^+ + \pi^+$

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

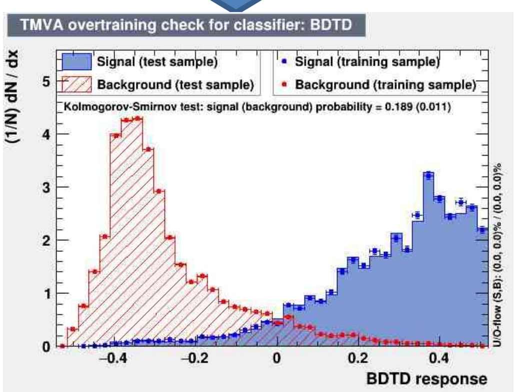


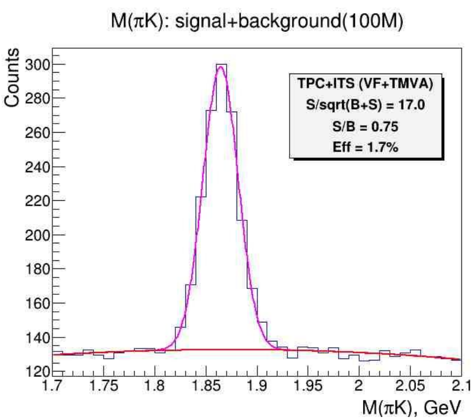






MVA: BDT classifier cut



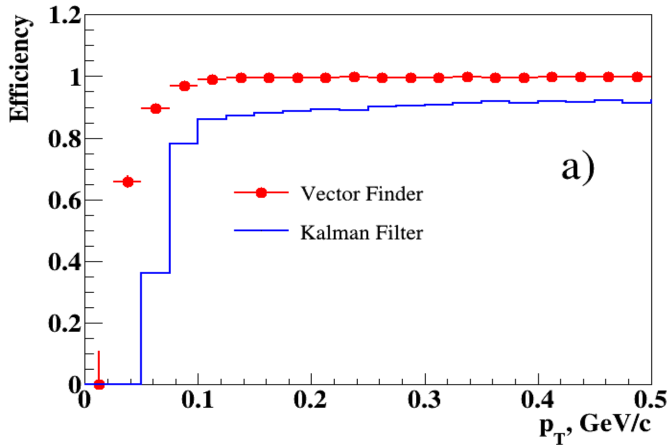


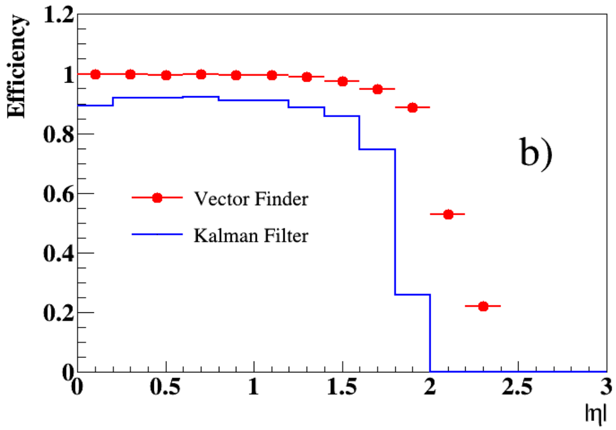
Particle	D^0		D^+	
Method	TC	MVA	TC	MVA
Efficiency, %	1.67	1.70	1.50	2.0
Significance	16.8	17.0	21.2	28.5
S/B(2σ) ratio	0.74	0.75	0.5	0.8

Using VF mechanism allows to reconstruct D^0 with an efficiency of 1.7% by both TC and MVA methods and D^+ with an efficiency of 2.0% by MVA method.

D mesons reconstruction using KF and VF methods: comparison

Vector Finder (VF) vs Kalman Filter (KF) tracking efficiency comparison (by A. Zinchenko)





Particle	D^0				D^+			
Reconstruction method	KF		VF		KF		VF	
Selection method	TC	MVA	TC	MVA	TC	MVA	TC	MVA
S/B ratio	0.10	0.11	0.74	0.75	0.12	0.14	0.50	0.80
Significance	5.3	5.5	16.8	17.0	7.0	10.5	21.2	28.5
Efficiency, %	0.80	0.85	1.67	1.70	0.5	1.0	1.5	2.0

Using VF mechanism allows to reconstruct D^0 and D^+ with an efficiency 2 times higher and with higher level (~20) of significance compared to KF technique

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

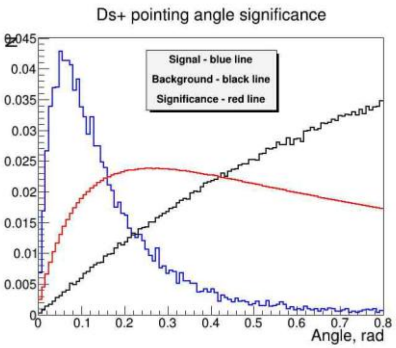
Particle	Mass [MeV/c^2]	Mean path cτ [mm]	Decay channel	BR	Multiplicity
D^+	1869.6	0.312	$\pi^+ + \pi^+ + K^-$	9.13%	10^{-2}
D^+_s	1968.5	0.150	$\pi^+ + K^+ + K^-$	5.50%	10^{-2}

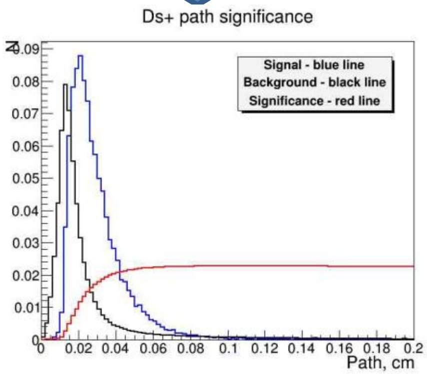
Reconstruction of D^+_s is more complicated task compared to D^+ for three reasons:
1) due to the decay length is 2 times shorter,
2) due to the BR is 2 times less,
3) due to the decay channel, since the reconstruction efficiency of K tracks is lower than that of π tracks.

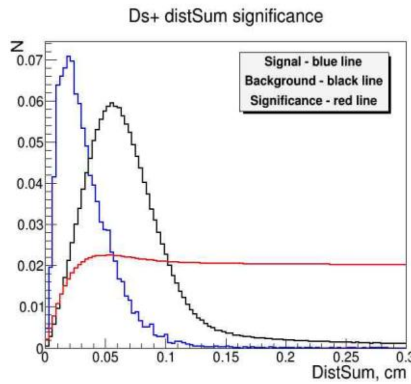
D^+_s reconstruction using VF

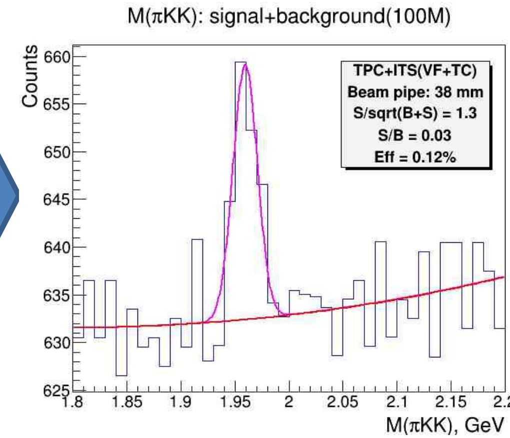
TC: *dca*(π, K) > 0.018 cm, *angle*(D^+_s) < 0.22 rad & *dist*(πK) < 0.04 cm & *path*(D^+_s) < 0.05 cm

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

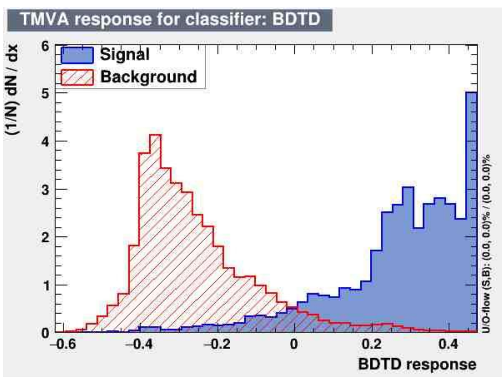


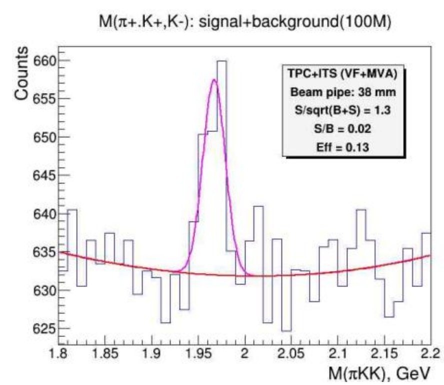






MVA: *dca*(π, K) > 0.02 cm, BDT_response>0.25





Particle	D^+_s	
Method	TC	MVA
Efficiency, %	0.12	0.13
Significance	1.3	1.3
S/B(2σ) ratio	0.03	0.02

VF mechanism opens up the feasibility of reconstruction D^+_s with an efficiency of 0.12 % by both TC and MVA methods at the same level of significance (1.3) with project ITS

Conclusions

Quality assessment of the MPD tracking system, which includes TPC and MAPS based ITS has been studied when reconstructing charmed mesons formed in AA collisions at NICA energies.

Simulation shows the feasibility of identification of D^0 , D^+ and D^+_s with project ITS model.

The reconstruction efficiency of D mesons increases by a factor of 2 when using Vector Finder tracking mechanism instead of Kalman Filter method.

Thank you for your attention!