MPD ITS physical simulation with focus on charmed mesons

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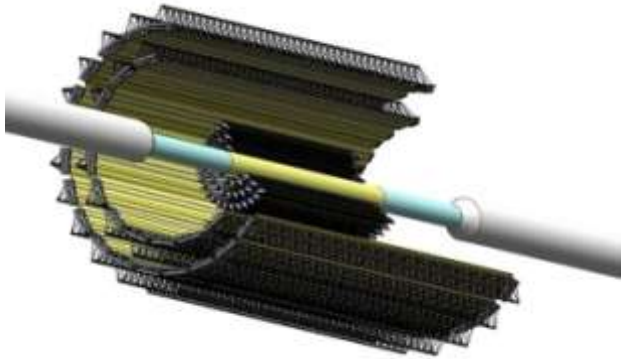

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Outline

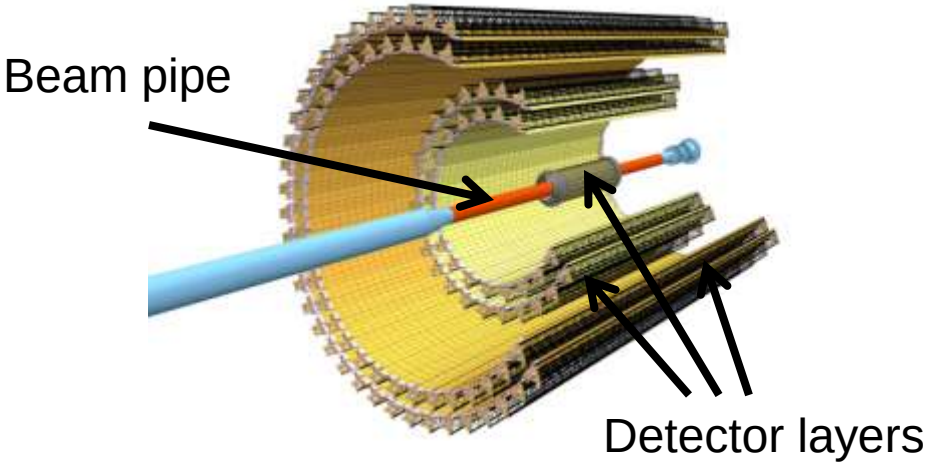
- ❑ Introduction
- • Physical motivation of using vertex detectors
- ❑ Simulation of the Inner Tracker System (ITS) of the MPD setup
- • Geometric models
- • Pointing resolution
- • Charmed particle reconstruction
- ❑ Conclusion

Physical motivation of using ITS

The yields and spectra of charmed particles are the important observables sensitive to critical phenomena in strong interacting nuclear matter

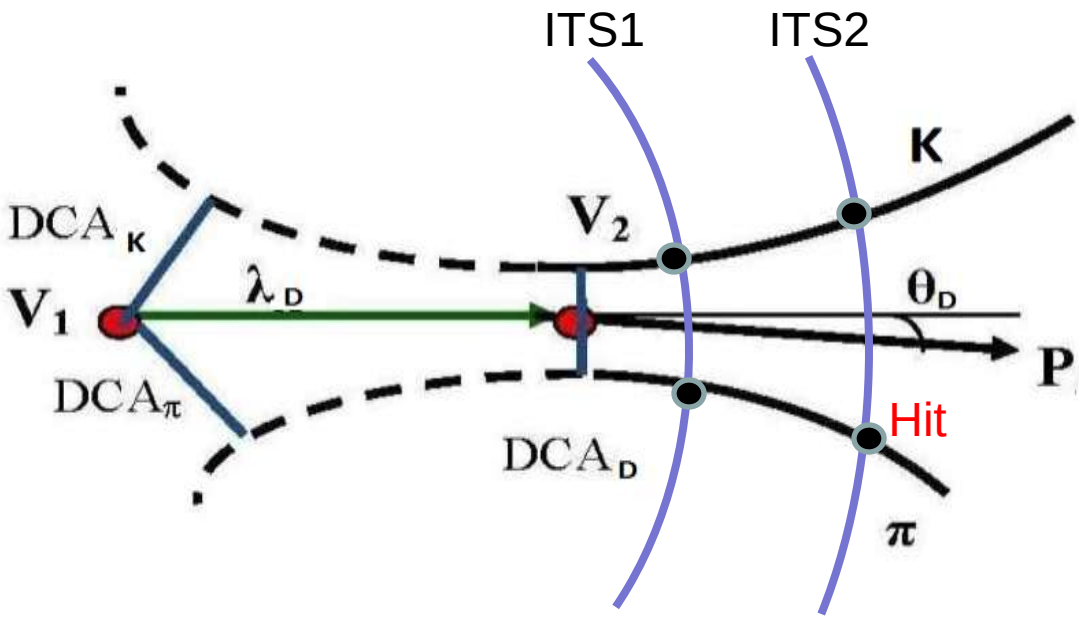
Vertex detector (ITS) is required for efficient detection of such short-lived products of nuclear interactions.

ALICE ITS2



Modern vertex detectors consist 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.

Detection of charmed D mesons by the vertex detector



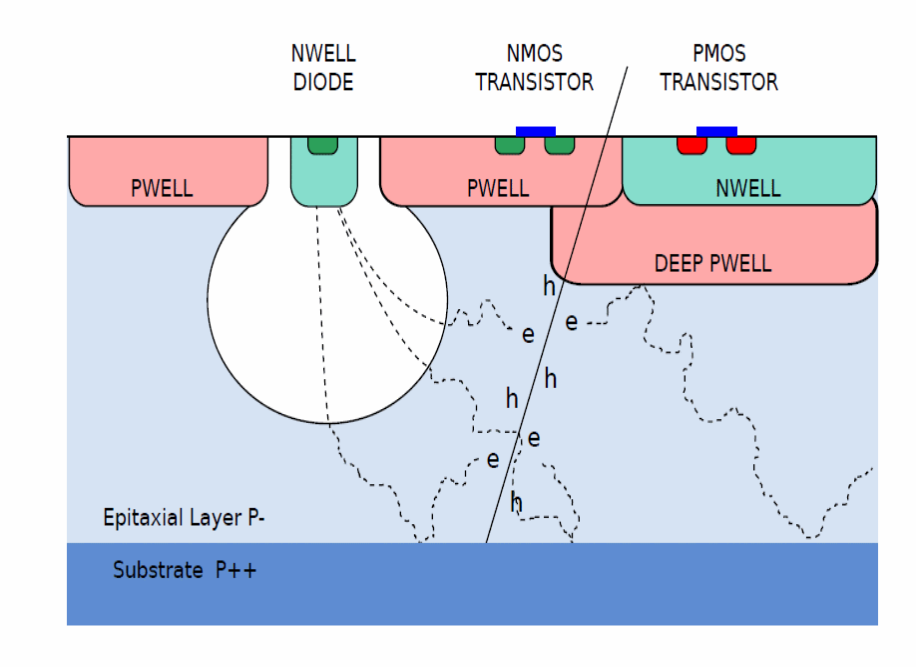
$D^0 \rightarrow K^- + \pi^+$, $\tau c = 123\ \mu m$ $D^+ \rightarrow K^- + \pi^+ + \pi^+$, $\tau c = 312\ \mu m$

Reliable identification of short-lived charmed particles can be performed by determining the invariant mass of their decay products. So, for high-efficient reconstruction of decay vertices V_2 near the interaction point V_1 the vertex detectors with high pointing resolution are needed.

Monolithic Active Pixel Sensor (MAPS)

Pixel sensors of the new generation - MAPS - have the best spatial resolution at a high counting rate

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



MAPS parameters used for simulation:

Sensitive area: 15×30 mm^2

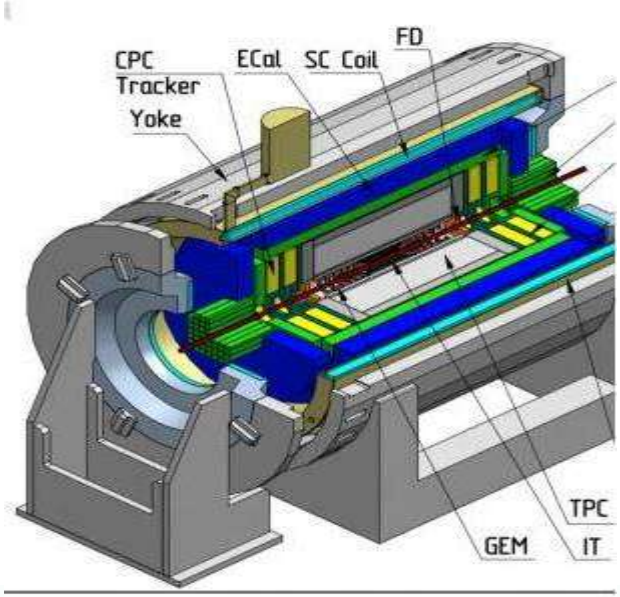
Thickness: 50 μm

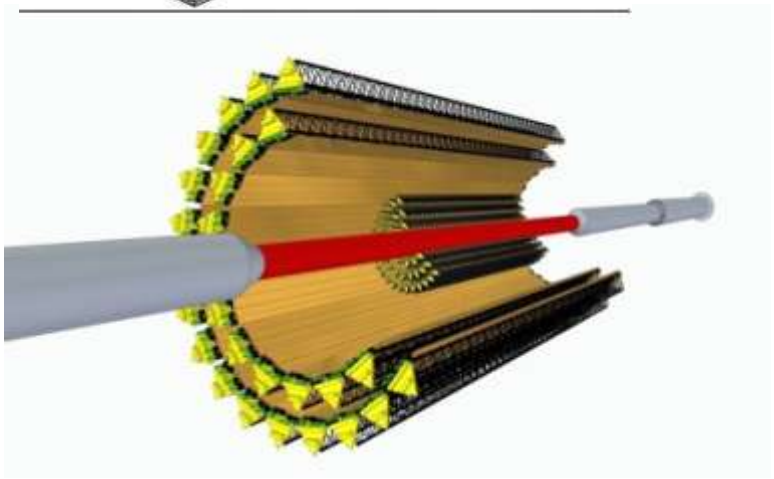
Pixel size: 28×28 $μm^2$.

Space resolution:

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

MAPS based ITS design for MPD





Geometric limitations:

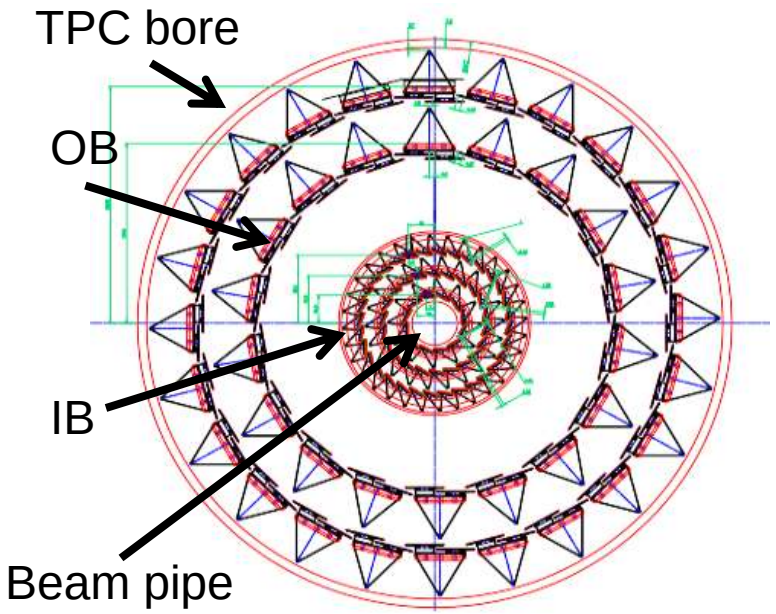
- by the beam pipe diameter (40 - 64 mm);
- by the TPC inner diameter (500 mm).

Constructive limitations:

- by the dimensions of the carbon composite support structures;
- by the transverse dimensions of MAPS.

5-layer model of ITS:
MAPS are combined into ladders located along the surface of 5 coaxial cylinders around the beam pipe.

ITS geometric models used for simulation



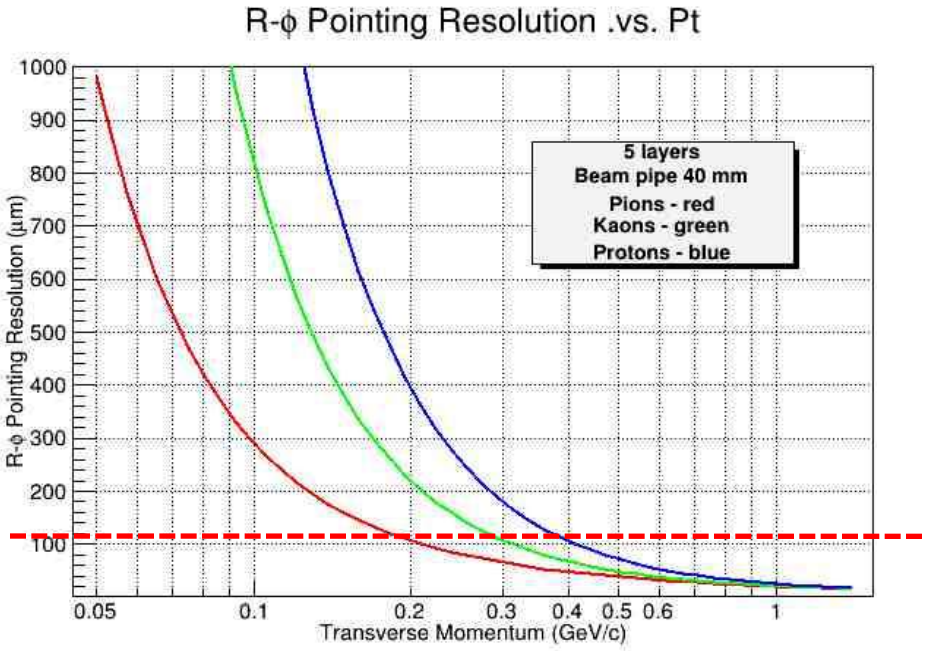
1) Model ITS-5-40:
5-layer ITS for a beam pipe 40 mm
2) Model ITS-5-64:
5-layer ITS for a beam pipe 64 mm

Outer Barrel (OB):
2 ladders with MAPS similar to ALICE ITS2
Inner Barrel (IB):
3 ladders with MAPS similar to ALICE ITS3

Layer	Number of ladders		R_{mean}, mm		Ladder length, mm		Effective thickness(Si) , μm
	ITS-5-40	ITS-5-64	ITS-5-40	ITS-5-64	ITS-5-40	ITS-5-64	
1	12	10	24.5	37.5	750	940	50
2	22	16	43.3	64.5	750	940	50
3	32	22	62.5	90.5	750	940	50
4	36	36	146.2	146.2	1526	1526	700
5	48	48	196.0	196.0	1526	1526	700

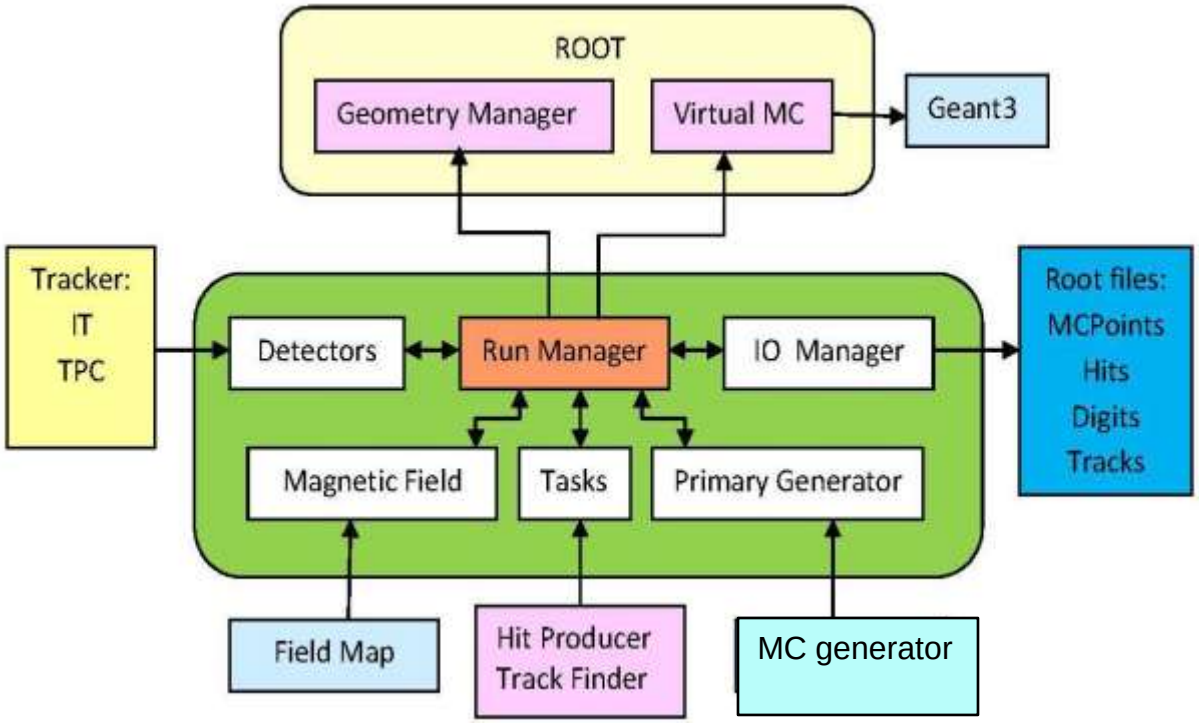
ITS pointing resolution for π, K and p

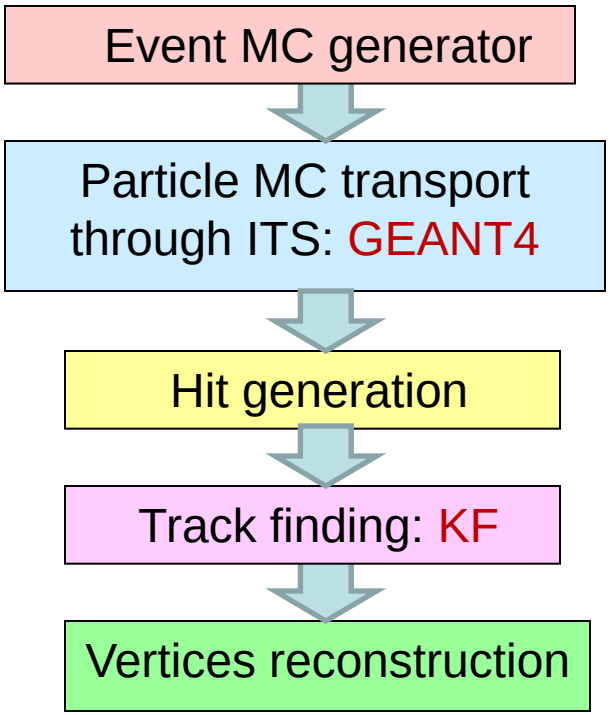
The pointing resolution of ITS-5-40 model was evaluated in the framework of the simplified model, which enables charged particle tracking through cylindrical silicon layers with the specified material budget.



ITS-5-40 pointing resolution of at least 100 mμ makes possible a decay vertex reconstruction of D^0 mesons in the channel $D^0 \rightarrow K^- + \pi^+$ ($\lambda c = 123$ μm) with p_T down to 500 MeV/c.

ITS Monte-Carlo simulation scheme within MpdRoot



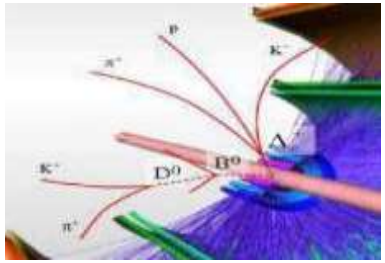


The main simulation tasks include:

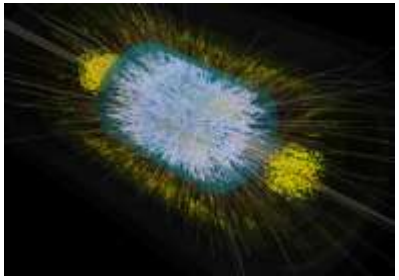
- generation of detector responses (Hit Producer);
- reconstruction of particle tracks using generated hits (Track Finder + Track Fitter) ;
- reconstruction of the primary and secondary interaction vertices (Track Analysis).

Charmed particle reconstruction in central Au+Au at $\sqrt{S_{NN}}$ = 9 GeV

Particle	Mass [MeV/c^2]	Mean path $c\tau$ [mm]	Decay channel	BR
D^+	1869.62±0.20	0.312	$\pi^+ + \pi^+ + K^-$	9.13%
D^0	1864.84±0.17	0.123	$\pi^+ + K^-$	3.89%



Signal simulation: thermal generator
Statistics: 1M charmed meson decays



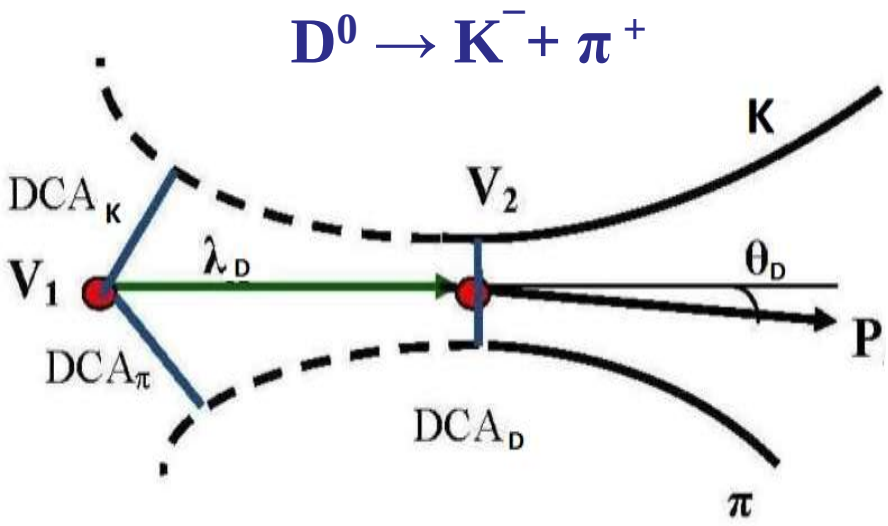
Background simulation: DCMQGSM generator
Statistics: 100K Au+Au central (b<4 fm) collisions

Two methods are used for D mesons selection:
1) Method of topol**o**gical cuts (TC)
2) Method of multivariate data analysis (MVA)

Selection criteria for two particle decay

D^0 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.



Selection criteria:

$DCA_\pi > C_1$ & $DCA_K > C_2$ & $DCA_{\pi K} < C_3$ & $\lambda_D > C_4$ & $\theta_D < C_5$

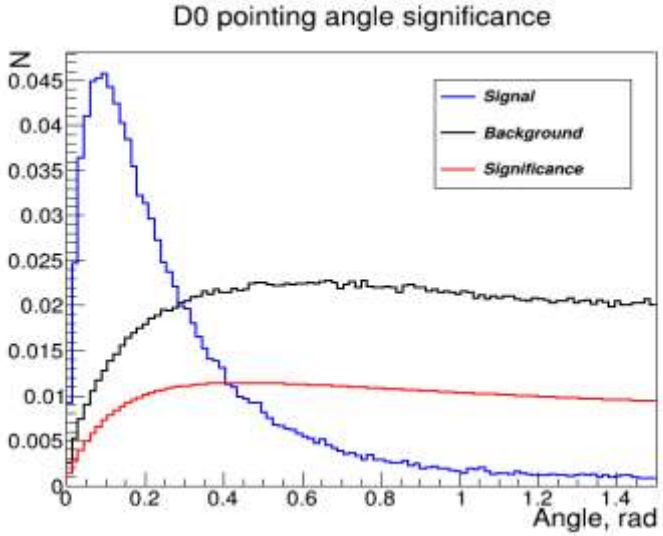
The cut-off level for the specified selection parameters is set based on the maximum value of the significance function $Sg(C_i)$ for each parameter C_i:

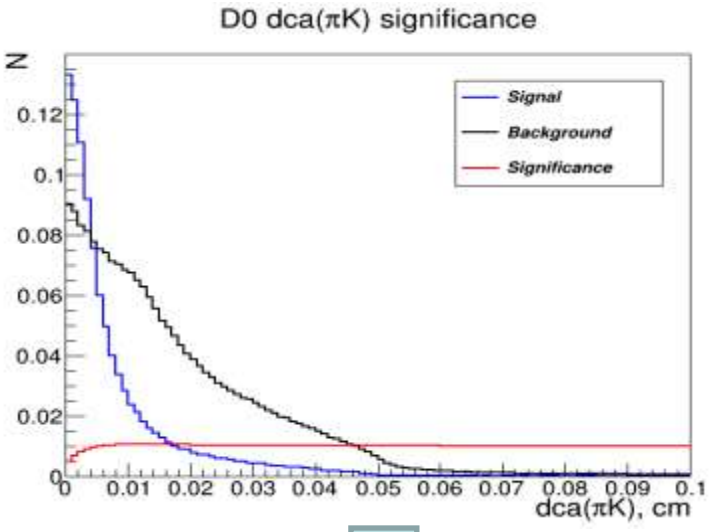
$$Sg(C_i) = \int_0^{C_i} \frac{S}{\sqrt{S+B}} dC_i$$

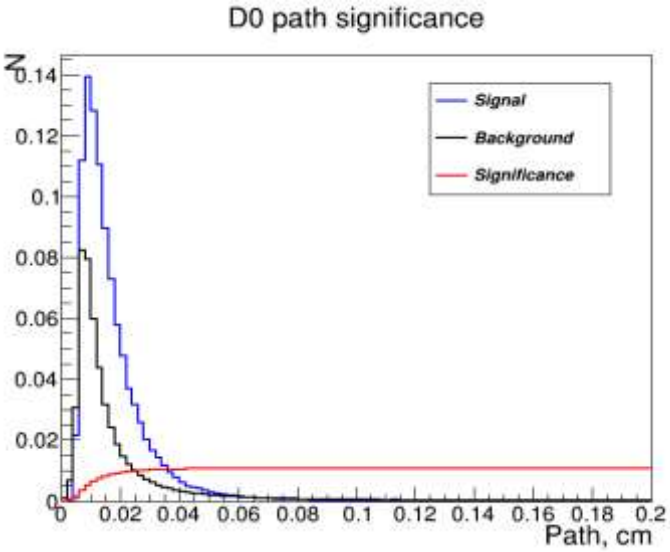
where S and B are the estimated numbers of the signal and background events.

D^0 reconstruction by TC method: cut selection

All topological cuts are selected according to the maximum of significance functions



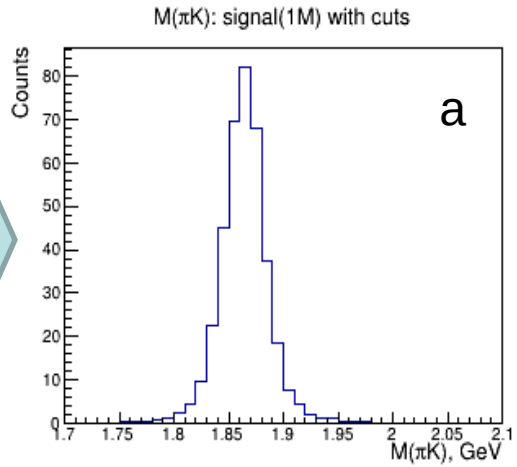


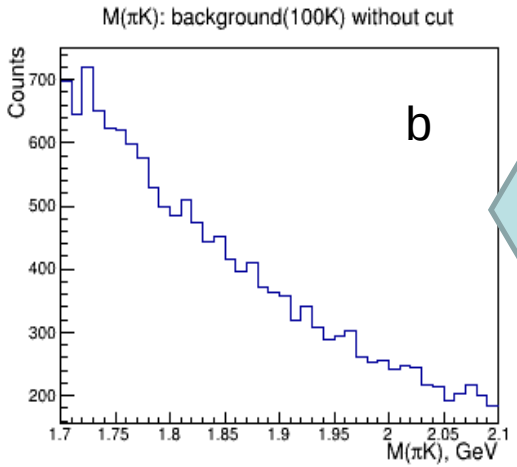


dca(K)>0.012 cm &
dca(π)>0.012 cm &
dca(πK) < 0.019 cm &
$\lambda(D^0)$ > 0.044 cm &
$\theta(D^0)$ < 0.15 rad

D^0 reconstruction: invariant mass spectra

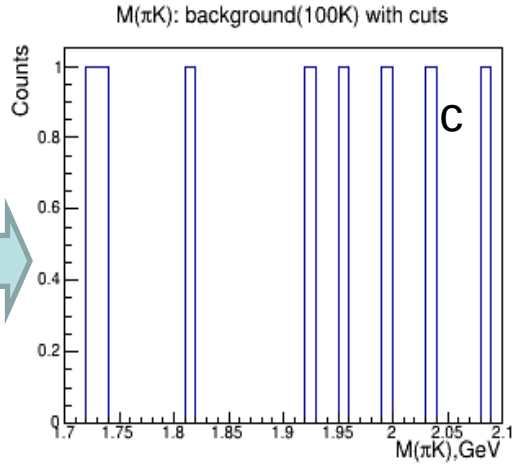
10^6 signal events after applying cuts

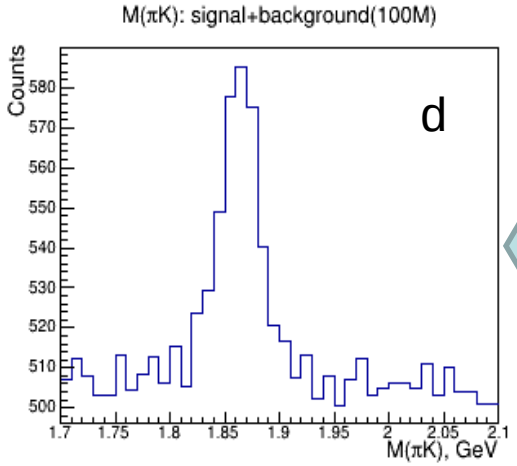




10^5 background events before applying cuts

10^5 background events after applying cuts



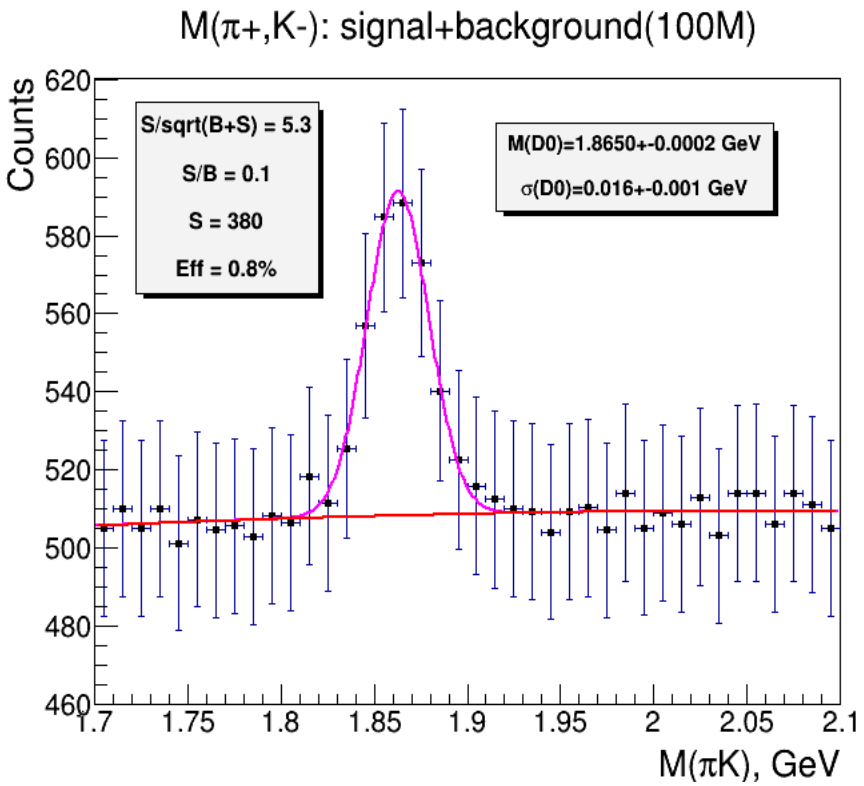


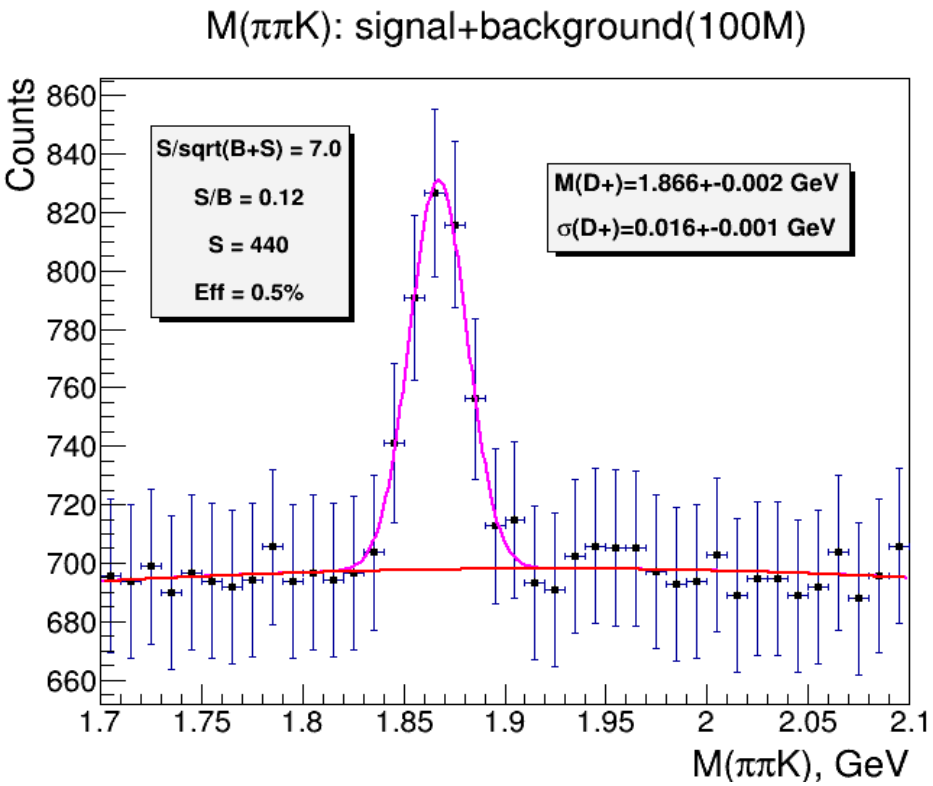
10^8 signal + background events after applying cuts

D mesons reconstruction by TC method: invariant mass spectra

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

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





Using the method of topological cuts allows to reconstruct D^0 and D^+ decays with an efficiency of 0.8% and 0.5% respectively.

D-meson reconstruction by MVA method

TMVA is a ROOT package for training, testing and performance evaluation of multivariate classification techniques.

Analysis is generally organized in 2 steps :

- Training phase

  At this stage the variables from the signal and background samples are trained according the classifier chosen by the user. During the classification the initial **N** input variables **V** are transformed to one dimensional variable **R** :

  $$V^N \rightarrow R$$

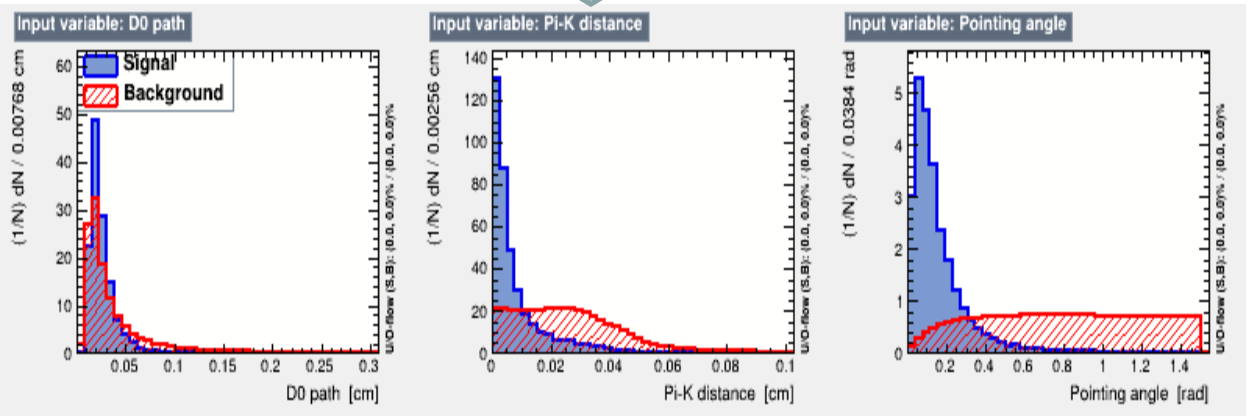
- Application phase

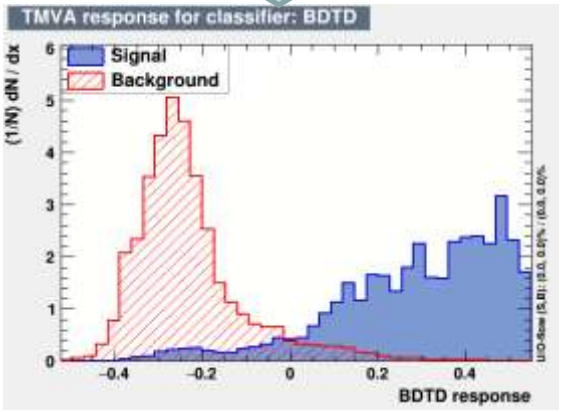
  At this stage the data classification is applied to the data to be analyzed.

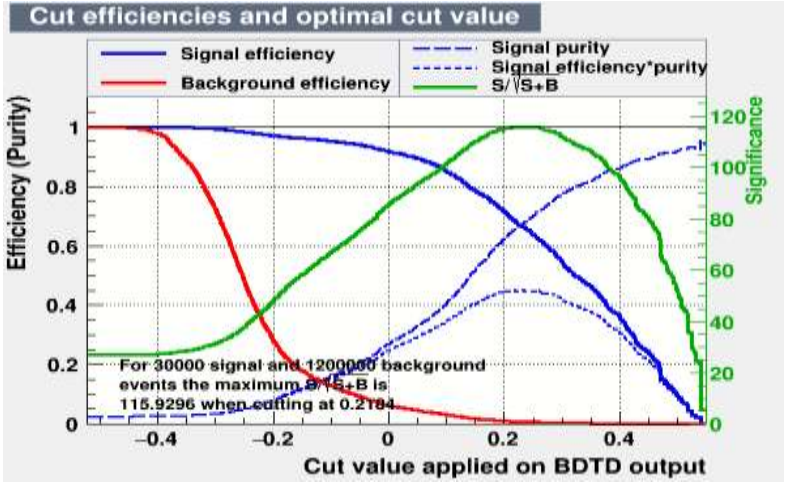
The classifier BDT (Boosted Decision Trees) has been chosen for the analysis phase when reconstructing D mesons

D^0 reconstruction by MVA method: cut selection

dca(π), dca(K), dca(πK), λ(D^0), θ(D^0) cuts → BDT cut



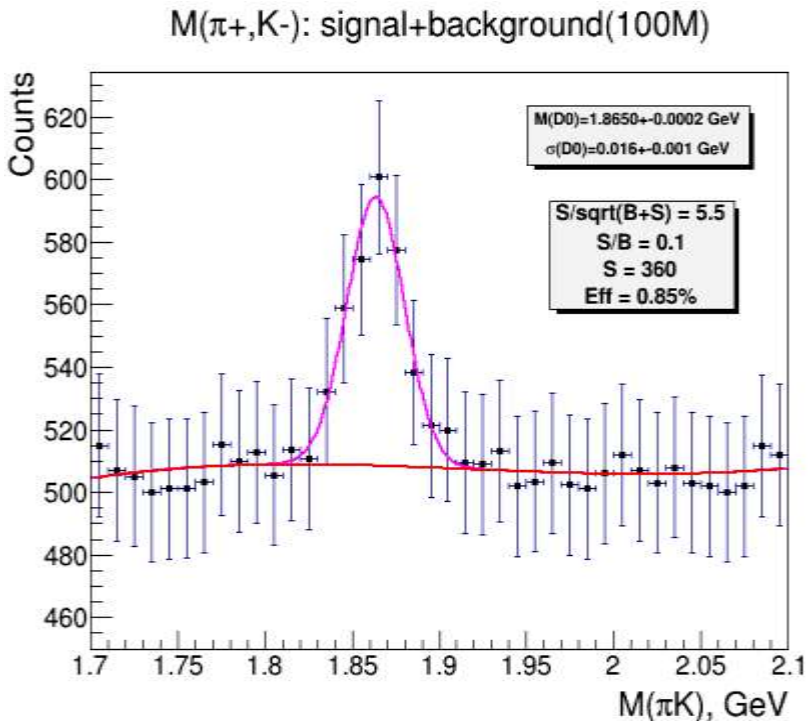




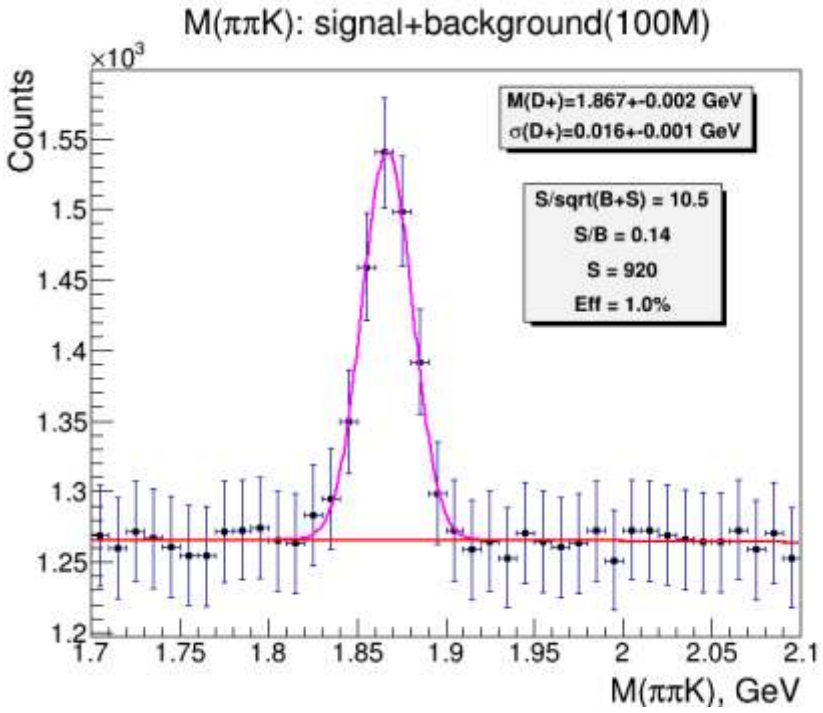
To separate the signal and background the optimal value of the resulting cut of the classifier response>0.25 was selected and applied to 1M signal and 100K background events.

D mesons reconstruction by MVA method: invariant mass spectra

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



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



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

Reconstruction parameters of D mesons in central Au+Au collisions at $\sqrt{s_{NN}}$ = 9 ГэВ with ITS5-40

Particle	D^0		D^+	
Method	TC	MVA	TC	MVA
Multiplicity	10^{-2}	10^{-2}	10^{-2}	10^{-2}
Number of events	10^8	10^8	10^8	10^8
Efficiency, %	0.80	0.85	0.50	1.0
Significance $S/\sqrt{S+B}$	5.3	5.5	7.0	10.5
S/B(2σ) ratio	0.10	0.10	0.12	0.14
Yield per month	$6 \cdot 10^3$	$7 \cdot 10^3$	$1 \cdot 10^4$	$2 \cdot 10^4$

D^0 reconstruction efficiencies by both MVA and TC are similar. Using the MVA in the case of D^+ allows to increase the efficiency by a factor of 2 with a higher level of significance.

D^+ reconstruction with ITS-5-40 and ITS-5-64

D^+ reconstruction efficiency was compared for two 5 layer ITS models:
ITS-5-40 and ITS-5-64 adopted for a beam pipe diameter of 40 and 64 mm respectively

Reconstruction method	TC		MVA	
Number of events	10^8		10^8	
ITS model	ITS-5-40	ITS-5-64	ITS-5-40	ITS-5-64
Efficiency, %	0.5	0.04	1.0	0.06
Significance	7.0	0,9	10.5	0.9

Quality of D^+ reconstruction deteriorates more than one order of magnitude when replacing ITS-5-40 with ITS-5-64.

Conclusion

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

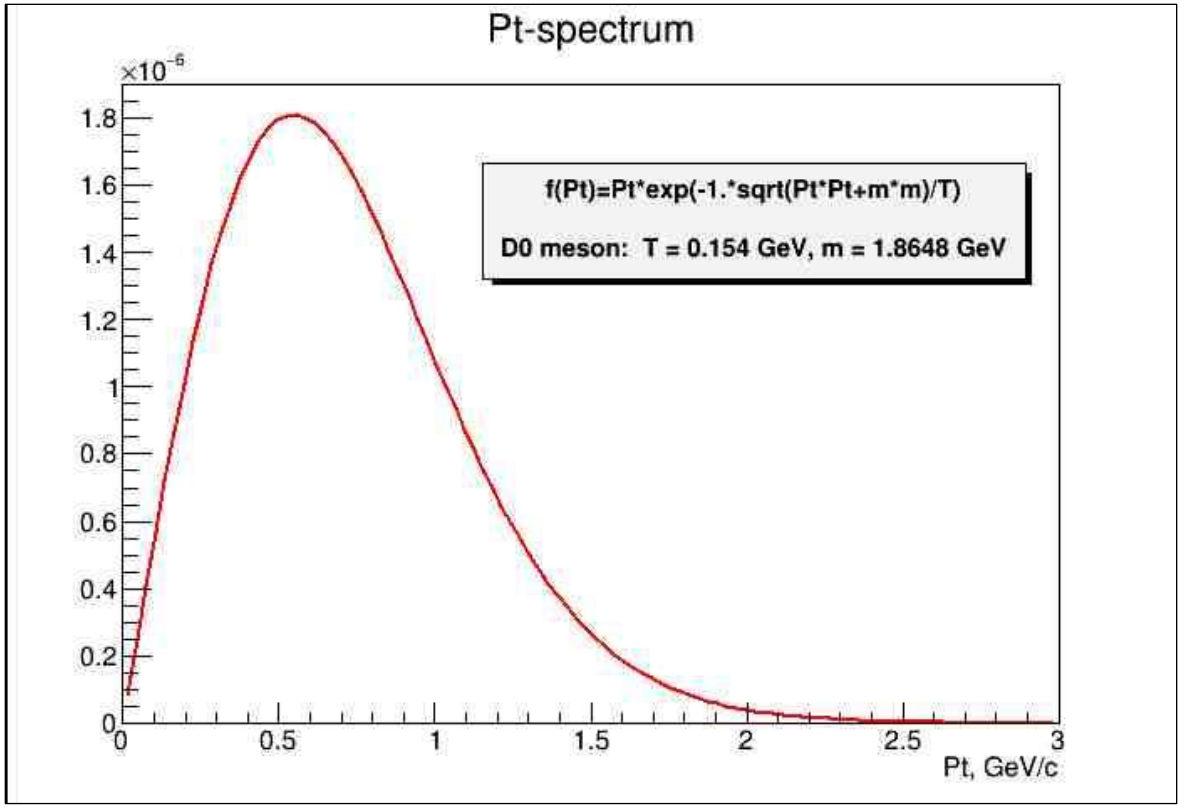
- Simulation shows the feasibility of identifying particles with open charm provided the diameter of the beam pipe will be reduced to an optimum value of 40 mm after the NICA collider first stage of tuning will be completed.

The reported study was supported by RFBR, research project No. 18-02-40119

Thank you for your attention!

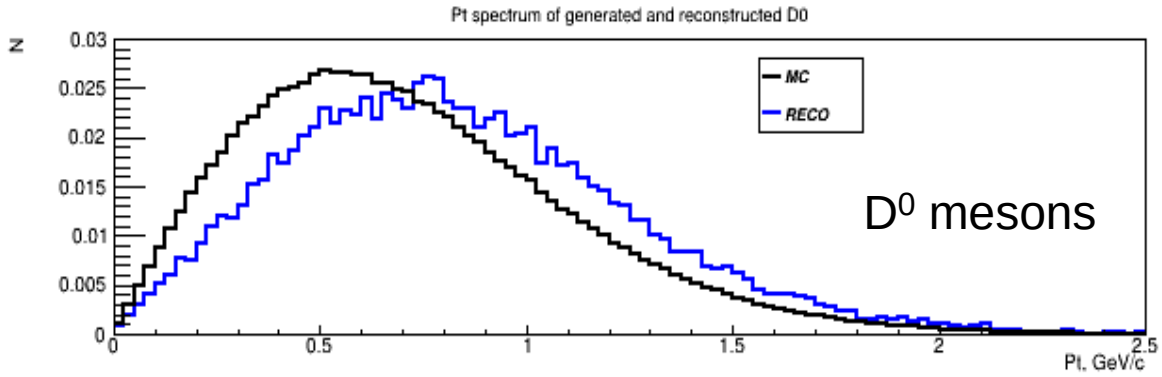
Back up slides

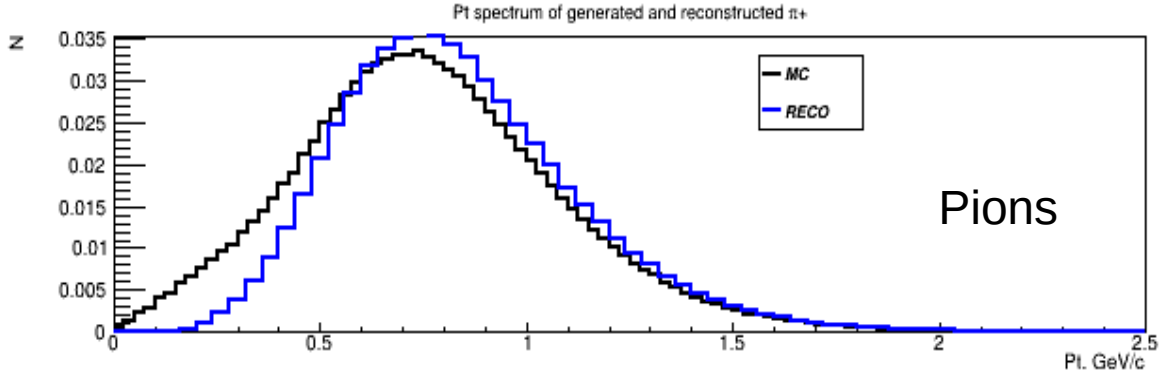
Thermal generator: p_t – spectrum of D^0 in Au+Au collisions at NICA energies

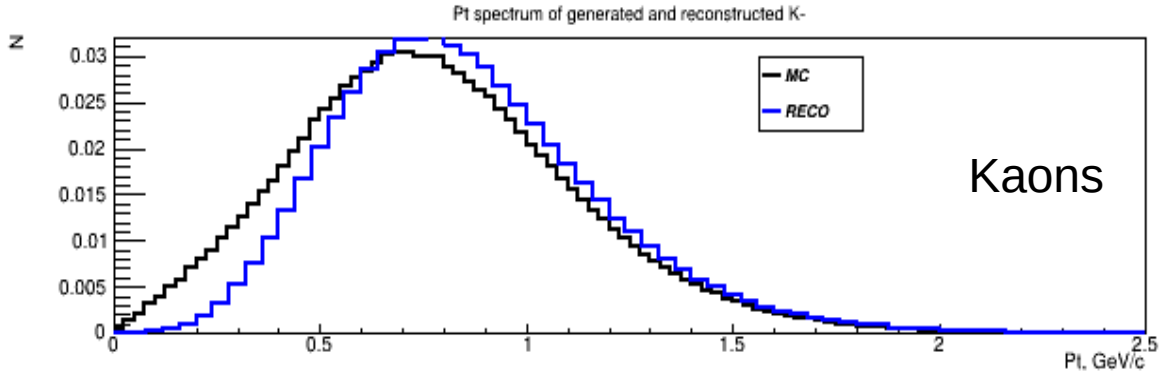


A. N. Tawfik and E. Abbas, “Thermal description ofparticle production in Au-Au collisions at RHIC Energies(STAR),” Phys. Part. Nucl. Lett. **12**, 521 (2015).

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







Input variables distributions for signal and background events after the decorrelation , gaussianisation and principal component decomposition