Идентификационная способность вершинного трекового детектора установки NICA-MPD при реконструкции распадов странных и очарованных частиц.

Identification power of the vertex tracking detector of the NICA-MPD setup for decays reconstruction of strange and charmed particles.

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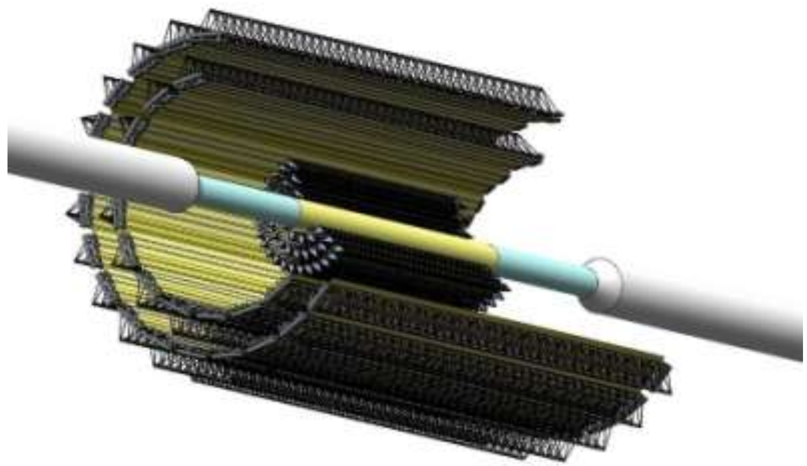


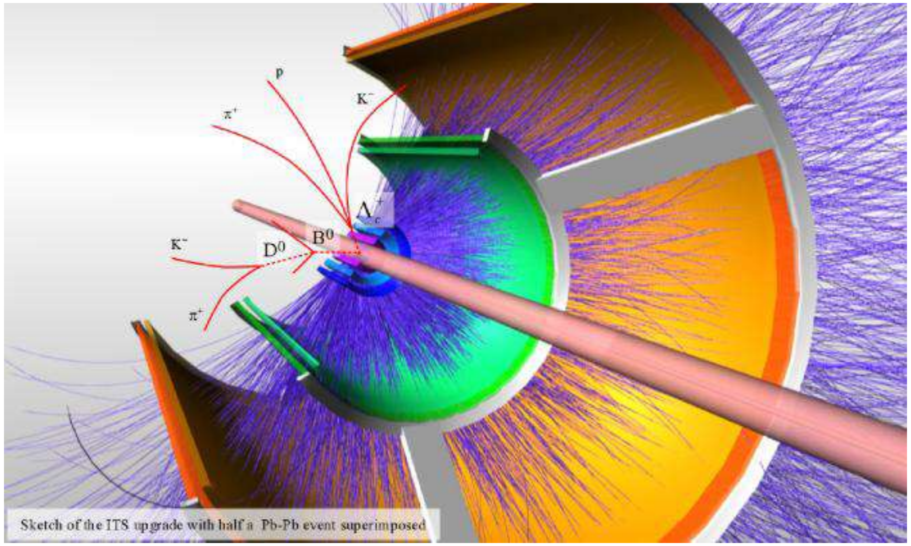
MDP-ITS Coordination Meeting, Dubna, 6 February 2020

Contents

- ❑ Introduction
- • Physical motivation of using vertex detectors
- ❑ Modeling of the Inner Tracker (IT) of the MPD setup
- • Geometric layout
- • Pointing resolution
- • Strange particle reconstruction
- • Charmed particle reconstruction
- ❑ Conclusion

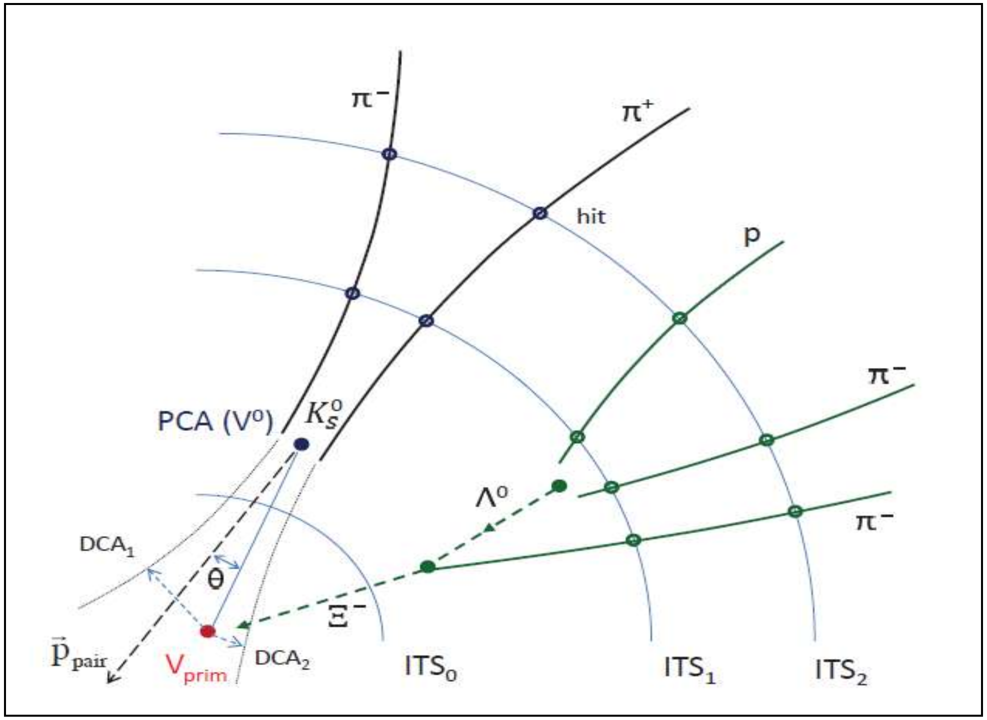
Physical motivation of using IT

MPD is being constructed to study the properties of extremely dense nuclear matter formed in relativistic nucleus-nucleus collisions at NICA energies. The yields and spectra of strange and charmed particles are the important observables sensitive to critical phenomena in phase transitions of the QCD-matter. So, vertex detector (IT) is required for highly efficient registration of such short-lived products of nuclear interactions.



Modern vertex detectors consist of a few layers of silicon position-sensitive sensors.
This kind of detectors are already used in ALICE , ATLAS, CMS and STAR experiments.

Registration of strange and charmed particles by the vertex detector



$\Lambda^0 \rightarrow p + \pi^-$

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

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

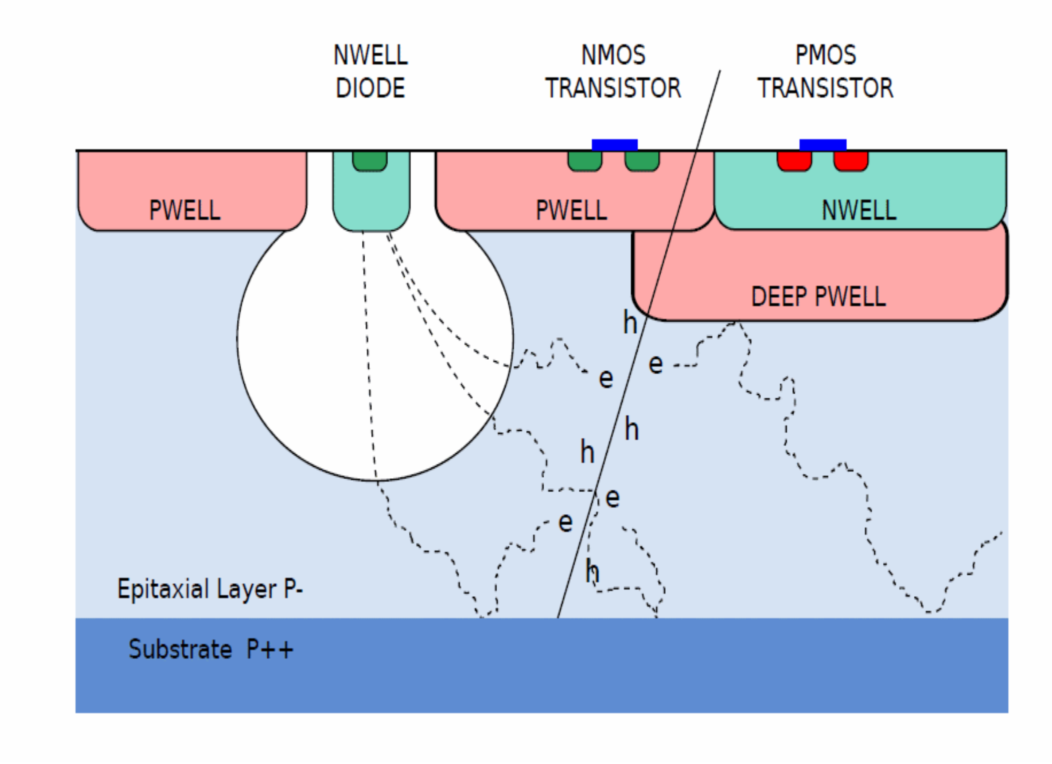
$\Lambda_c \rightarrow p + K^- + \pi^-$
$\tau c = 68\ \mu m$

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

Reliable identification of short-lived particles (multistrange hyperons and charmed mesons) is performed by determining the invariant mass of their decay products. So, for high-efficient reconstruction of decay vertices near the interaction point 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 and their high level of segmentation per pixel allows to install detectors of this type at distances of several centimeters from the interaction point without a threat of frequency overload. Combination of the TPC and the MAPS based vertex detector IT will allow to register short-lived products of A-A interactions with maximum efficiency.



Sensitive area: 15×30 mm^2

Thickness: 50 μm

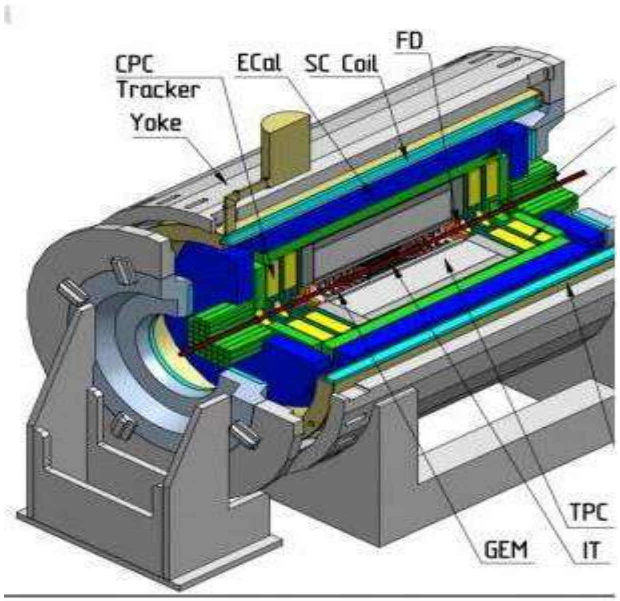
Number of pixels: 512×1024

Pixel size: 28×28 μm^2.

Space resolution:

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

IT design on the base of MAPS

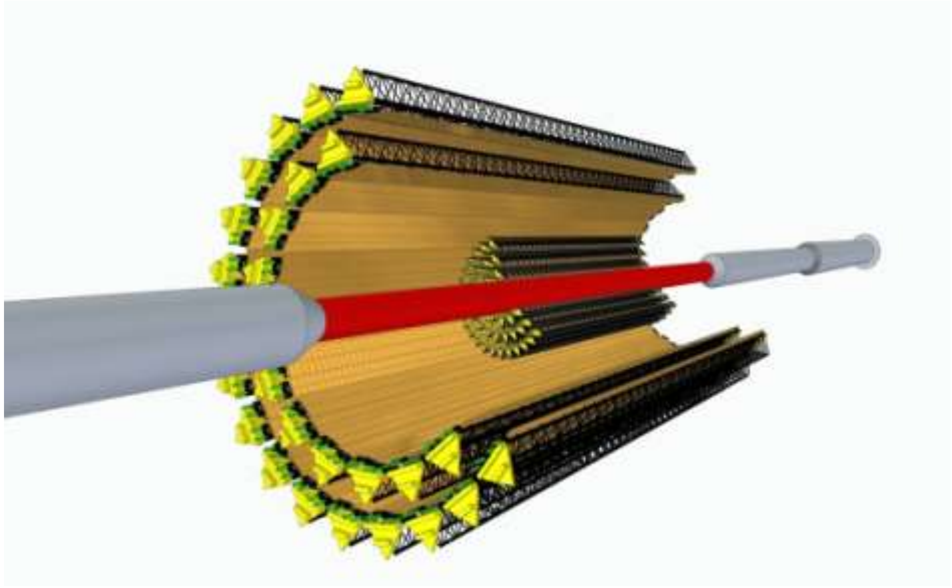


Geometric limitations:

- by the size of the beam pipe, the diameter of which can vary from 40 to 65 mm;
- by the dimensions of the TPC, the inner diameter of which is 500 mm

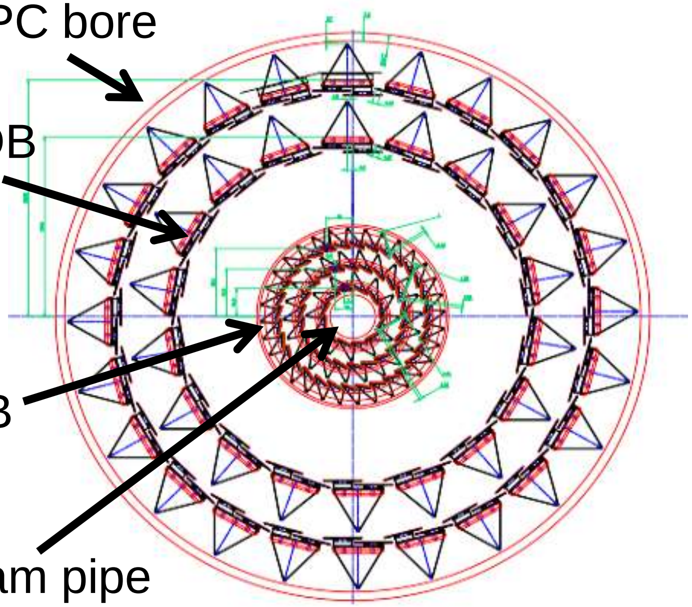
Constructive limitations:

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



These limitations lead to a 5-layer construction of IT with 12 ladders in the innermost layer.

IT geometric model using for simulation



Model IT5-40 (basic project configuration): 5-layer IT 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)

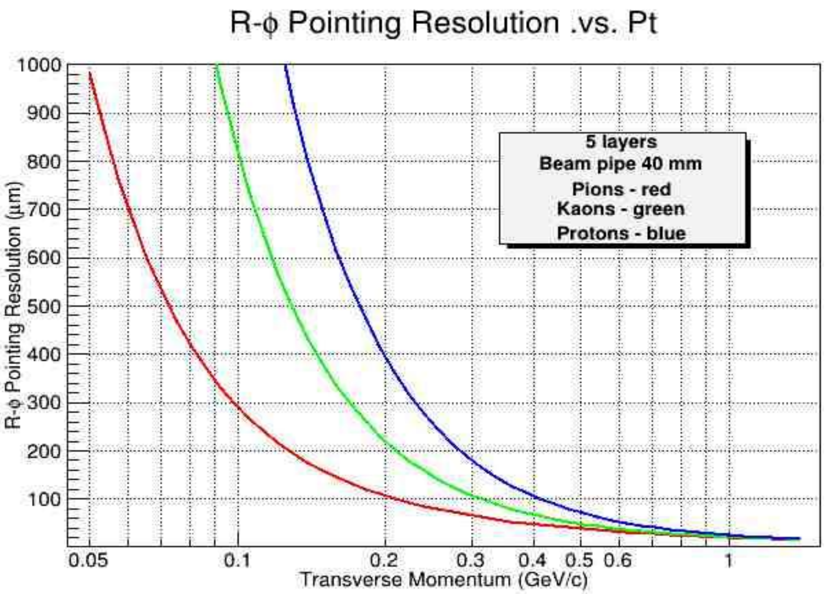
OB: ladders similar to ALICE ITS2
IB: ladders similar to ALICE ITS3

Layer	Number of ladders	Number of MAPS	R_{min}, mm	R_{max}, mm	Ladder length, mm	Effective thickness, μm
1	12	288	22.4	26.7	750	100
2	22	528	40.7	45.9	750	100
3	32	768	59.8	65.1	750	100
4	36	3528	144.5	147.9	1526	700
5	48	4704	194.4	197.6	1526	700

IT pointing resolution for π, K and p

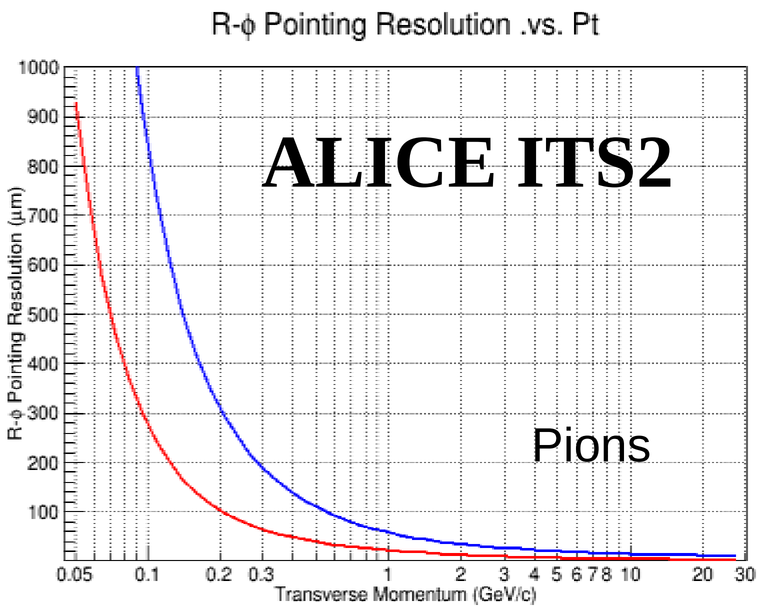
The spatial resolution of the IT5-40 model was evaluated in the framework of the simplified code developed by ALICE collaboration, which performs tracking of charged particles through cylindrical silicon layers with a given radiation thickness.

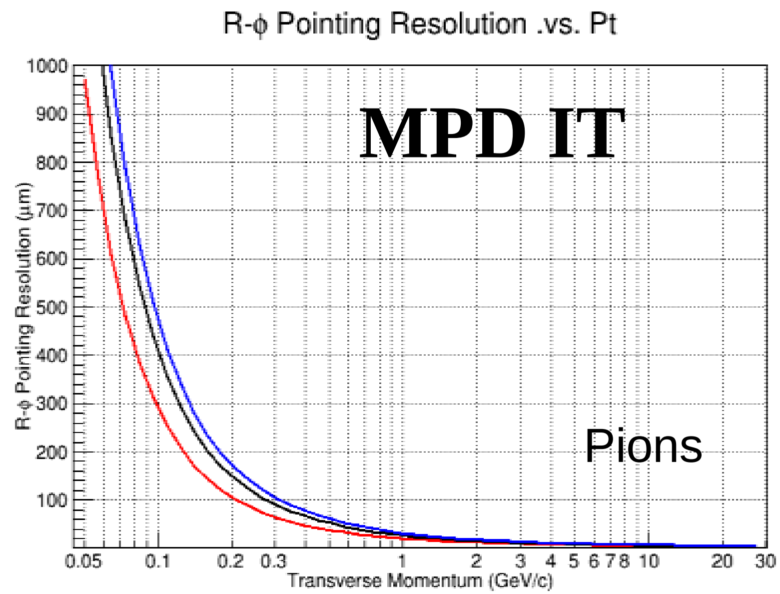
Layer	Mean r, мм	$\sigma(\rho\varphi)$, um	X/X_0, %
Beam pipe	20.0	-	0.22
1	24.6	5.0	0.30
2	43.3	5.0	0.30
3	62.5	5.0	0.30
4	146.2	5.0	0.30
5	196.0	5.0	0.30



Evaluated resolution of IT5-40 provides, for example, the possibility of D^0 decay vertex reconstruction in the channel $D^0 \rightarrow K^- + \pi^+$ (λ = 123 μm) with small p_T up to 300 MeV/c.

MPD IT pointing resolution compared to ALICE ITS





New ITS2

Old ITS1

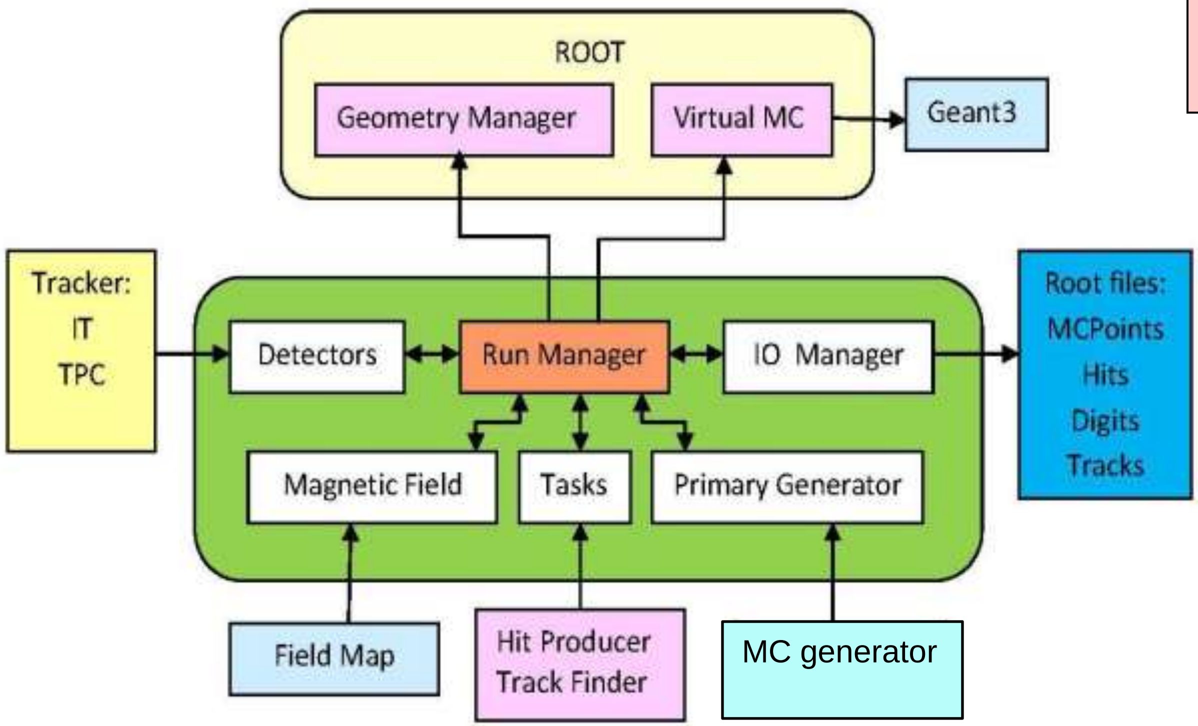
Beam pipe Ø = 40 mm

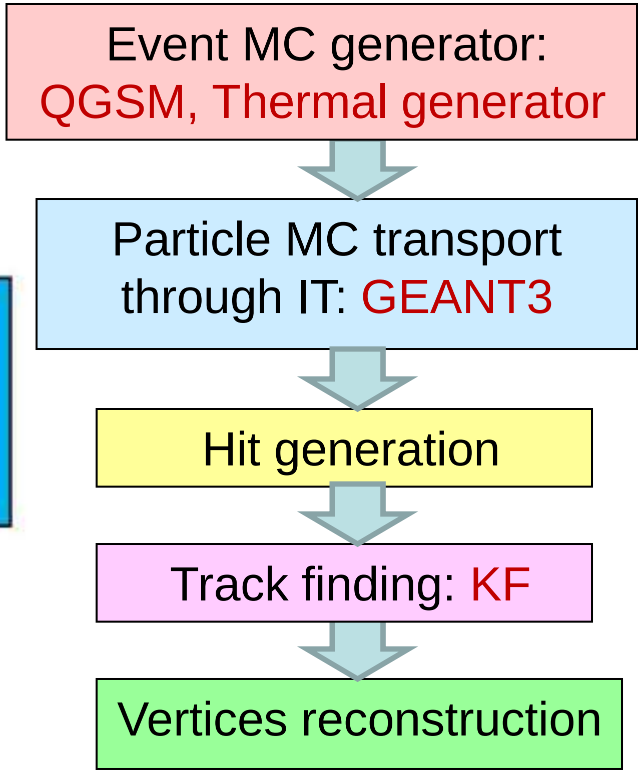
Beam pipe Ø = 50 mm

Beam pipe Ø = 60 mm

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

IT Monte-Carlo simulation scheme within MpdRoot



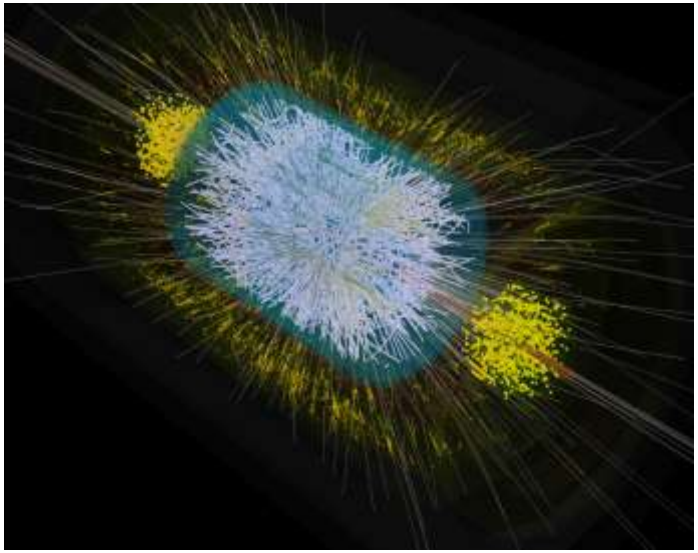


The main simulation tasks include:

- 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).

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

Particle	Mass [MeV/c^2]	Mean path cτ [cm]	Decay channel	BR
Λ	1115.68±0.01	7.89	$\pi^- + p$	63.9%
Ξ^-	1321.71±0.07	4.91	$\pi^- + \Lambda$	99.9%
Ω^-	1672.45±0.29	2.46	$K^- + \Lambda$	67.8%

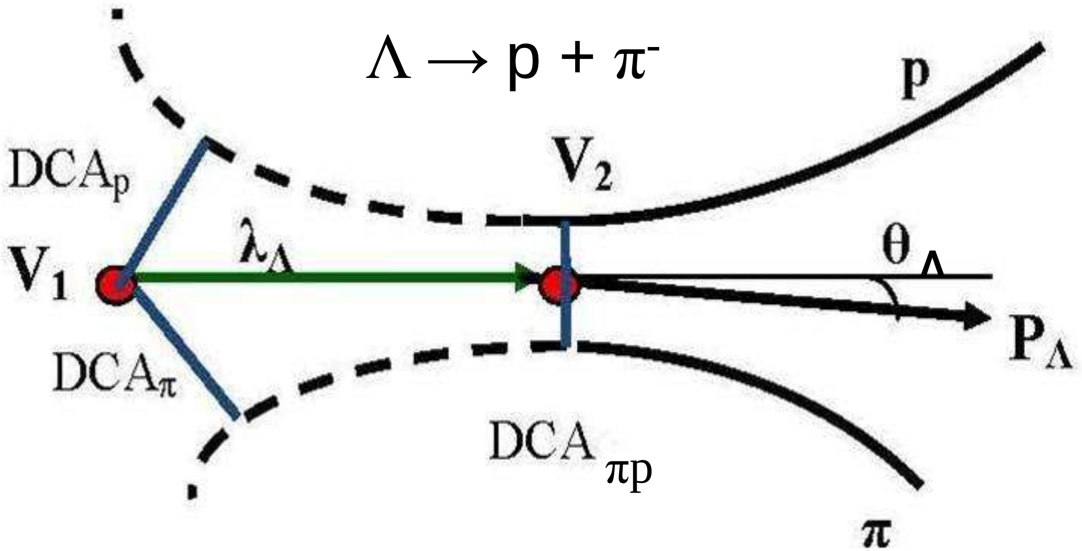


To suppress a large combinatorial background in Au+Au collisions it is necessary to use strict criteria for signal selection corresponding to real particle decays.

Selection criteria for two particle decay

Λ selection parameters are dictated by the decay topology:

- distances of closest approach to the collision vertex $DCA_{\pi,\, p}$,
- two-track separation $DCA_{\pi p}$,
- decay path λ_{Λ},
- pointing angle θ_{Λ}.



Selection criteria:

$$DCA_{\pi} > C_1 \ \& \ DCA_p > C_2 \ \& \ DCA_{\pi p} < C_3 \ \& \ \lambda_{\Lambda} > C_4 \ \& \ \theta_{\Lambda} < C_5$$

The parameters C_i (cuts) of the corresponding selection are optimized by maximizing the signal significance :

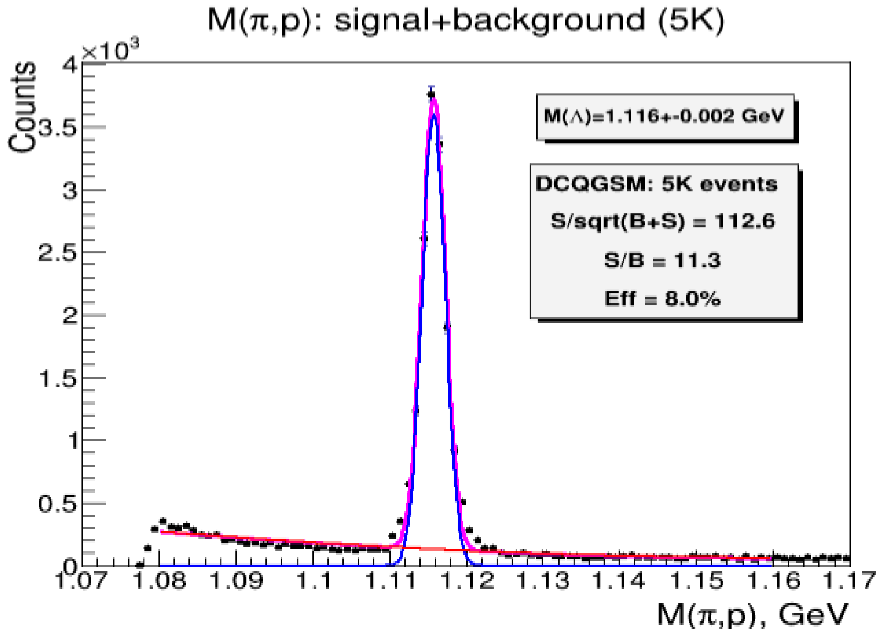
$$Sg(C_i) = \int_0^{C_i} \frac{S}{\sqrt{S+B}} dC_i$$

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

Λ reconstruction ($5 \cdot 10^3$ events):

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

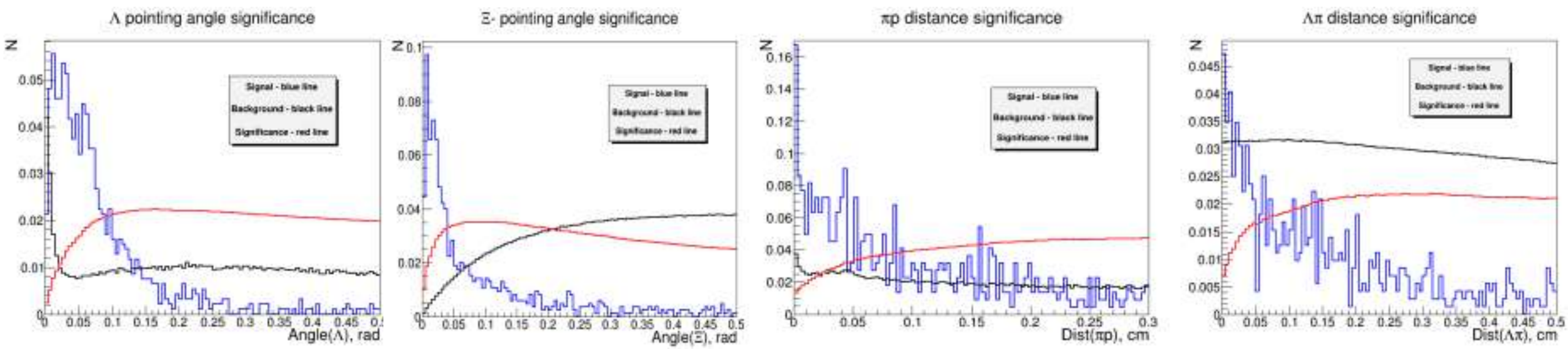
dca(p)>0.3 cm & dca(π)>0.3 cm &
dca(πp)<0.05 cm & $\lambda(\Lambda)$>3.0 cm & $\theta(\Lambda)$ < 0.09 rad



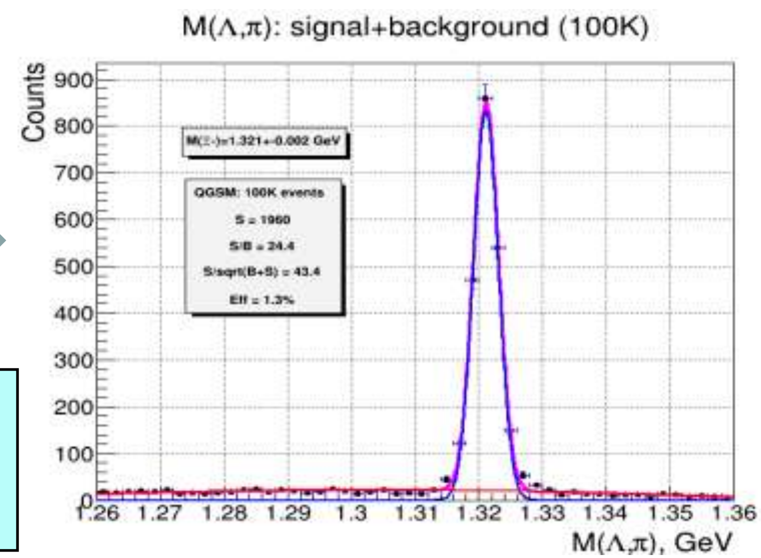
Obtained values of significance level 112.6 and signal-to-noise ratio 11.3 indicate a high quality of charged particle tracking in the MPD tracking system.

Ξ^- reconstruction (10^5 events):

$\Xi^- \rightarrow \Lambda + \pi^-$
$\quad \llcorner\!\!\rightarrow p + \pi^-$



dca(p)>0.3 cm & dca(π)>0.3 cm &
dca(Λ)>0.1 cm &
dca(πp)<0.05cm & dca(Λπ)<0.2 cm &
θ(Λ)>0.02 rad & θ(Ξ)<0.05 rad

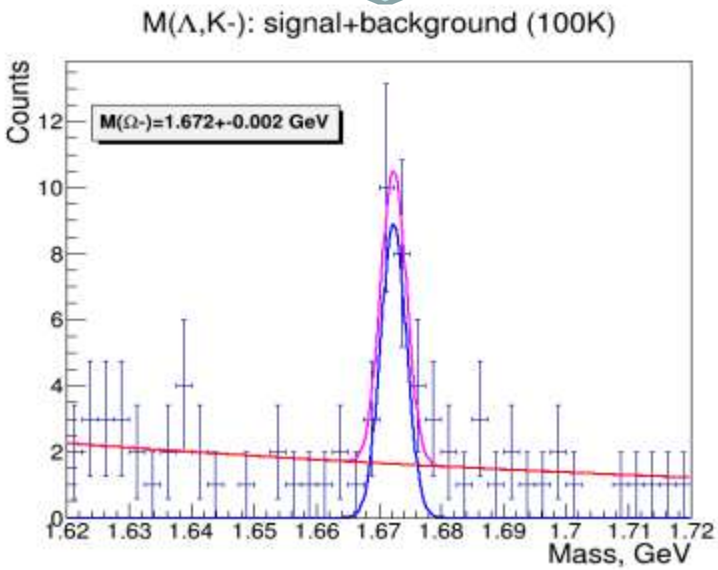


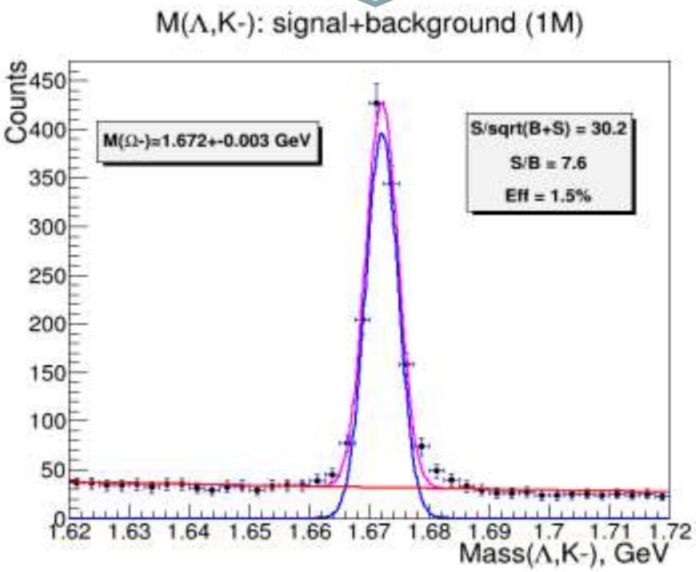
The use of optimized selection criteria allows to reconstruct Ξ^- with an efficiency of 1.3% at sufficiently high level of significance of 43.4

Ω^- reconstruction (10^6 events):

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

dca(π)>0.05 cm & dca(p)>0.05 cm & dca(K)>0.1 cm & dca(Λ) >0.1 cm & dca(πp)<0.3 cm & dca(ΛK)<0.1 cm & θ(Λ)>0.01 rad & θ(Ω)<0.015 rad & λ(Λ)>5 cm & λ(Ω)<8 cm





Signal – QGSM generator
Background – QGSM generator

Signal – thermal generator
Background – QGSM generator

Increasing the statistics to 1M events allows to reconstruct Ω^- with an efficiency of 1.5% at a significance level of 30.2

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

Particle	Mass [MeV/c^2]	Mean path cτ [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%

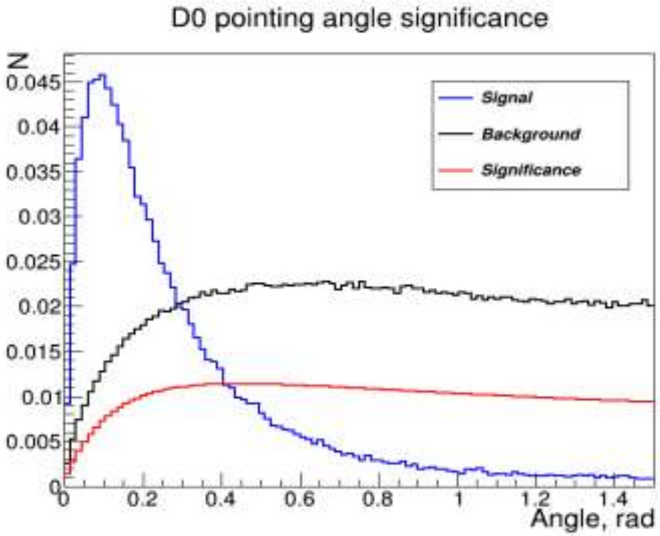
Background simulation - using QGSM generator (100K events)
Signal simulation – using thermal generator (1M events)

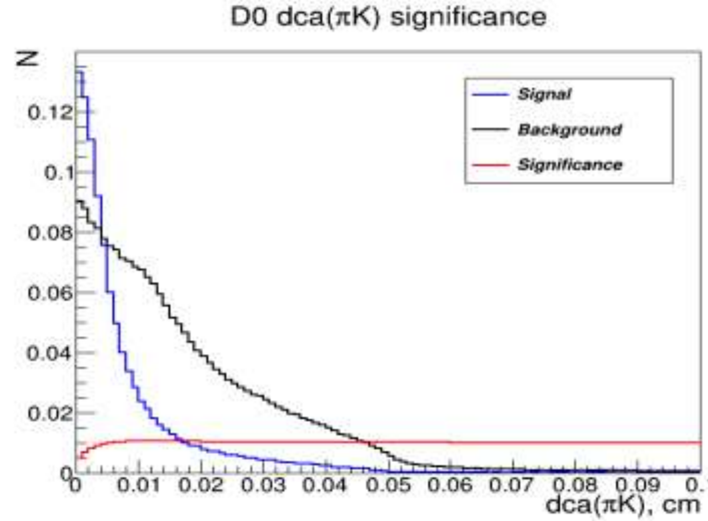
Two methods are used for signal selection:

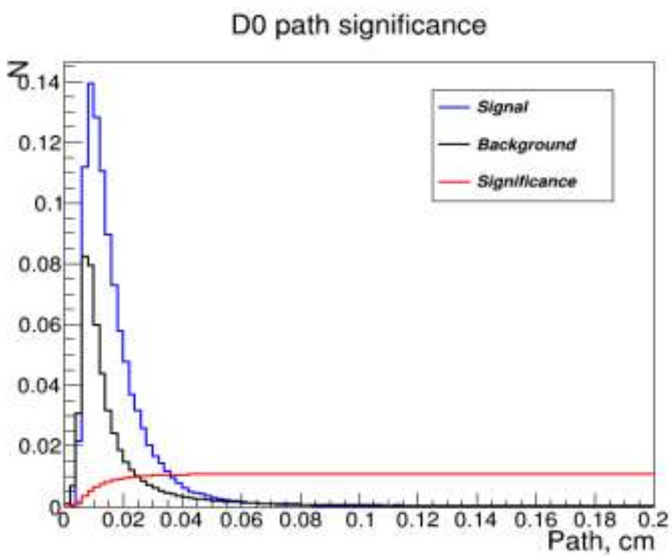
1) Method of topological cuts (TC)
2) Method of multivariate data analysis (MVA)

D^0 reconstruction by TC method: cut selection

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





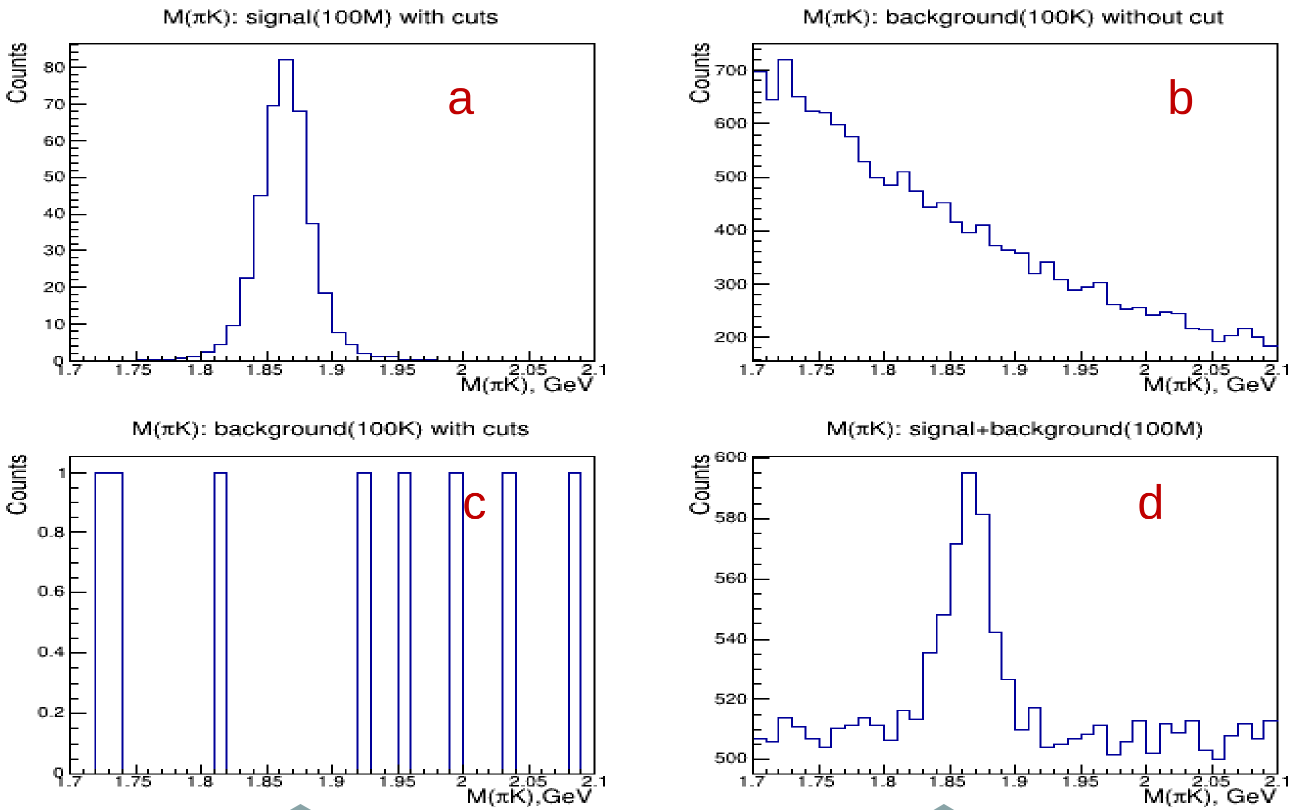


dca(K)>0.012 cm &
dca(π)>0.012 cm &
dca(πK) < 0.019 cm &
$\lambda(D^0)$ > 0.044 cm &
$\theta(D^0)$ < 0.15 rad

D^0 reconstruction (10^8 events): invariant mass spectra

Signal after applying cuts in 10^8 events

Background before applying cuts in 10^5 events

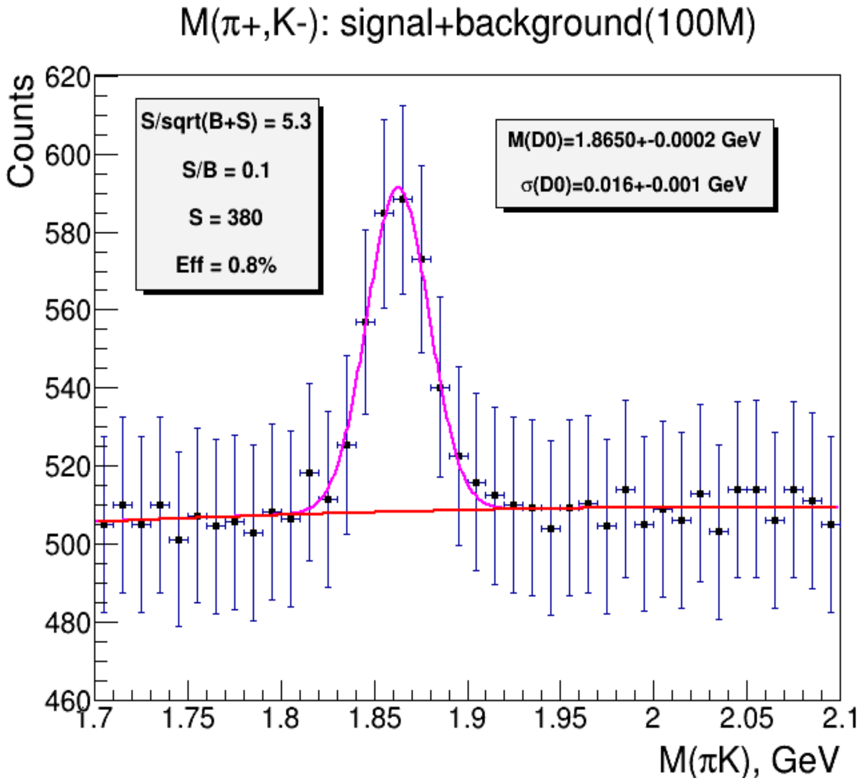


Background after applying cuts in 10^5 events

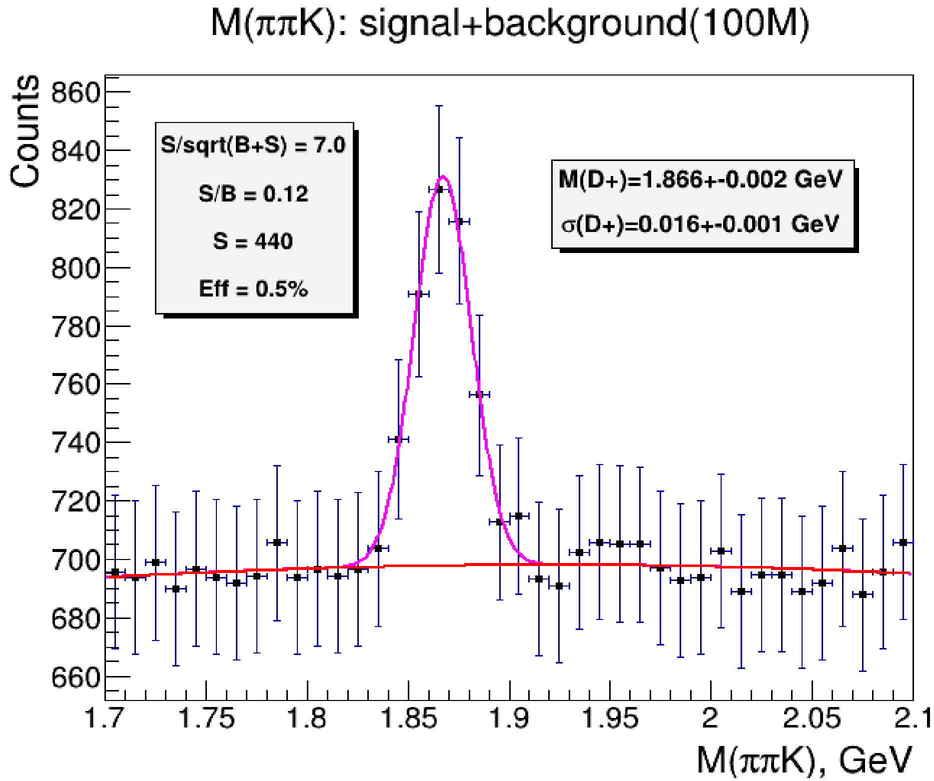
Signal + background after applying cuts in 10^8 events

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^+ with an efficiency of 0.8% and 0.5% respectively.

Toolkit for MultiVariate Analysis

TMVA is a ROOT package for training, testing and performances 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. The results of the classification is written into weight files, traducing the initial **N** input variables **V** to one dimensional variable **R** (response) :

$$V^N \rightarrow R$$

- **Application phase**

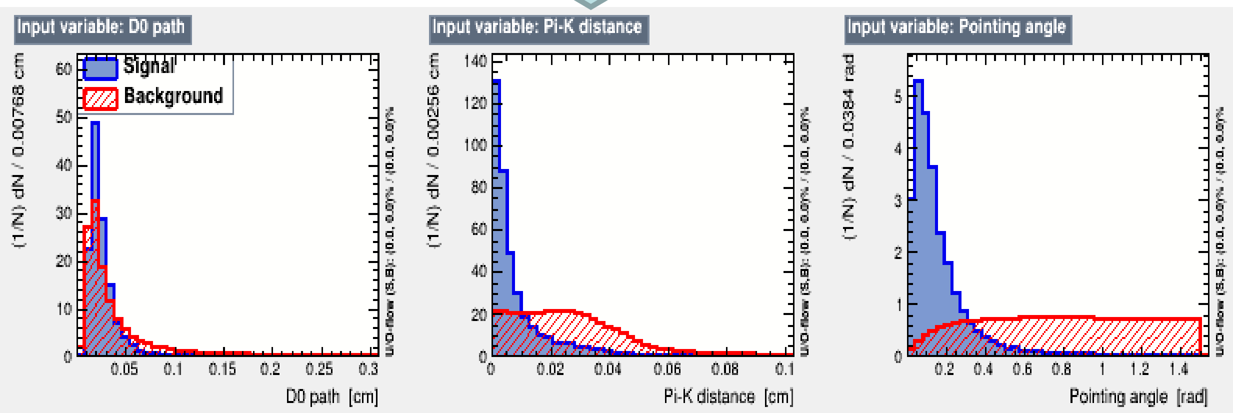
  At this stage the data classification, reading from the weight files, is applied to the data to be analyzed.

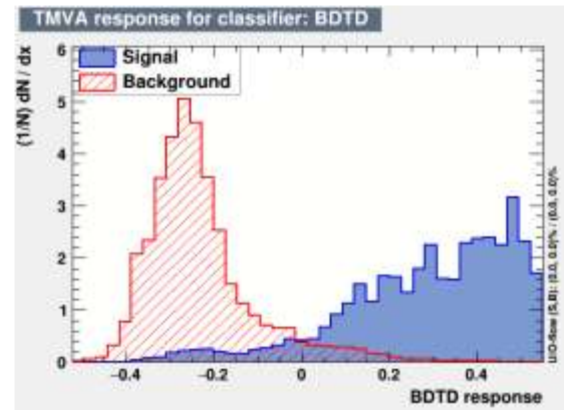
The classifier BDT (Boosted Decision Trees) has been chosen for the analysis phase when reconstructing D mesons

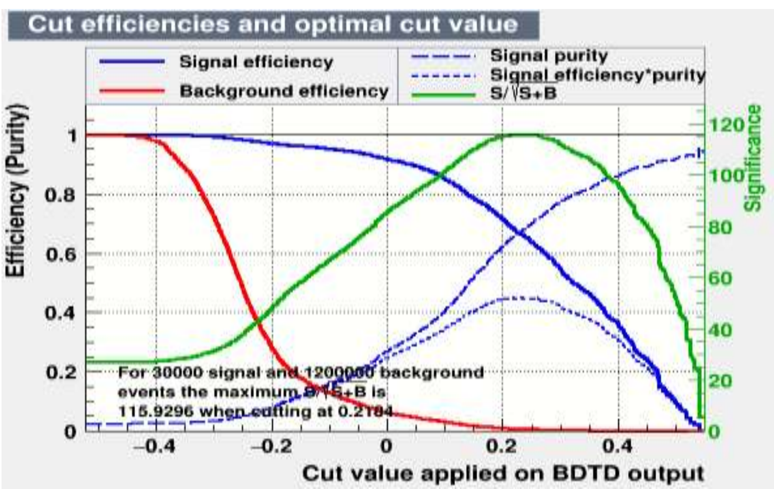
D^0 reconstruction by MVA method: cut selection

dca(π), dca(K), dca(πK), $\lambda(D^0)$, $\theta(D^0)$

BDT cut



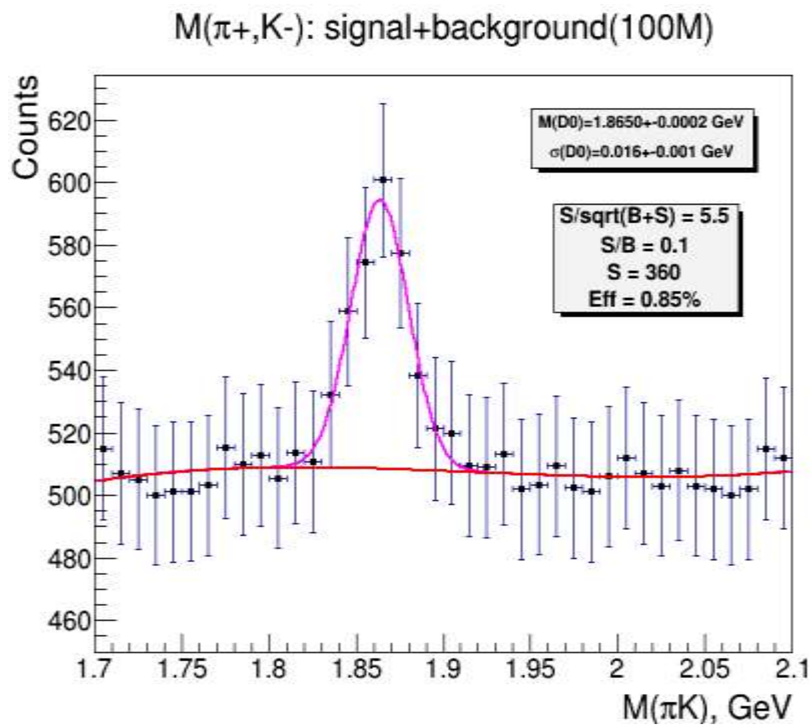




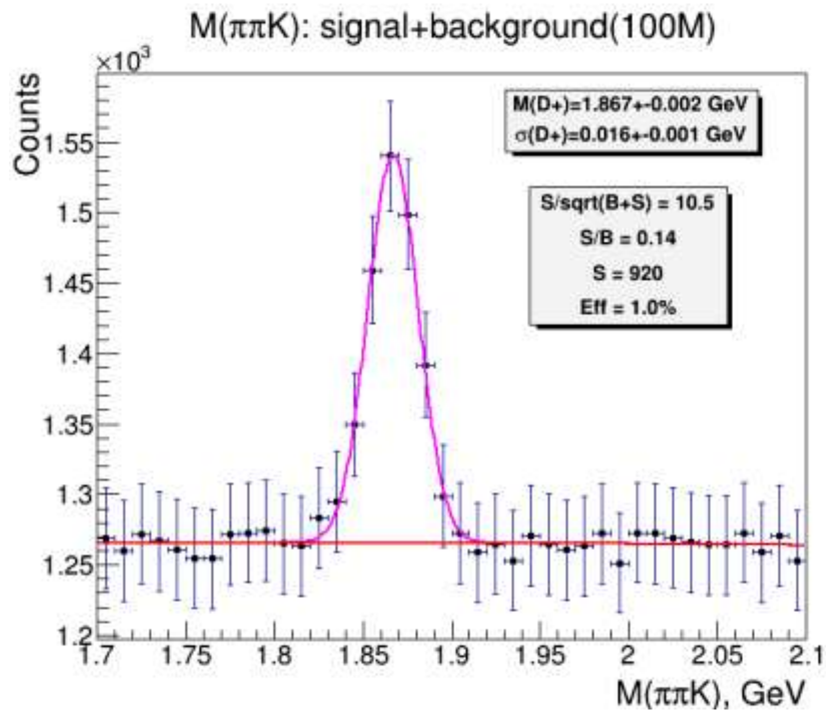
To separate the signal and background the optimal value of the resulting cut of the classifier BDTD_response>0.3 was selected and applied to 1M signal and 100K background events generated using the thermal and QGSM generator

D mesons reconstruction by MVA method: invariant mass spectra

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



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



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 strange and charmed particles in central Au+Au collisions at $\sqrt{S_{NN}} = 9$ ГэВ

Particle	Λ	Ξ^-	Ω^-	D^0		D^+	
Method	TC	TC	TC	TC	MVA	TC	MVA
Multiplicity	20	1.2	10^{-1}	10^{-2}	10^{-2}	10^{-2}	10^{-2}
Number of events	$5 \cdot 10^3$	10^5	10^6	10^8	10^8	10^8	10^8
Efficiency, %	8.0	1.3	1.5	0.80	0.85	0.50	1.0
Significance $S/\sqrt{S+B}$	112.6	43.4	30.2	5.3	5.5	7.0	10.5
S/B(2σ) ratio	11.3	24.4	7.6	0.10	0.10	0.12	0.14
Yield per month	$2 \cdot 10^9$	$3 \cdot 10^7$	$2 \cdot 10^6$	$6 \cdot 10^3$	$7 \cdot 10^3$	$1 \cdot 10^4$	$2 \cdot 10^4$

If D^0 reconstruction efficiencies by MVA and TC are similar, then the use of MVA in the case of D^+ allows doubling the efficiency with a higher level of significance.

Conclusion

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

Simulation shows:

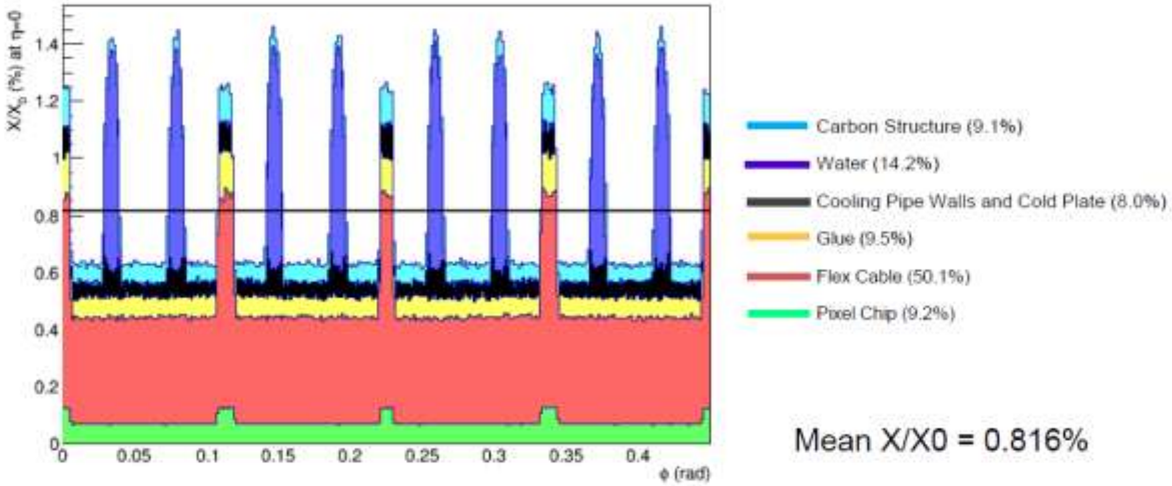
- reliable reconstruction of hyperons Λ, Ξ^-, Ω^-
- possibility of D-mesons reconstruction in central Au + Au collisions at $\sqrt{S_{NN}}$ = 9 GeV, which opens up prospects for studying the heavy flavors physics at the NICA-MPD facility.

Thank you for your attention!

Back up slides

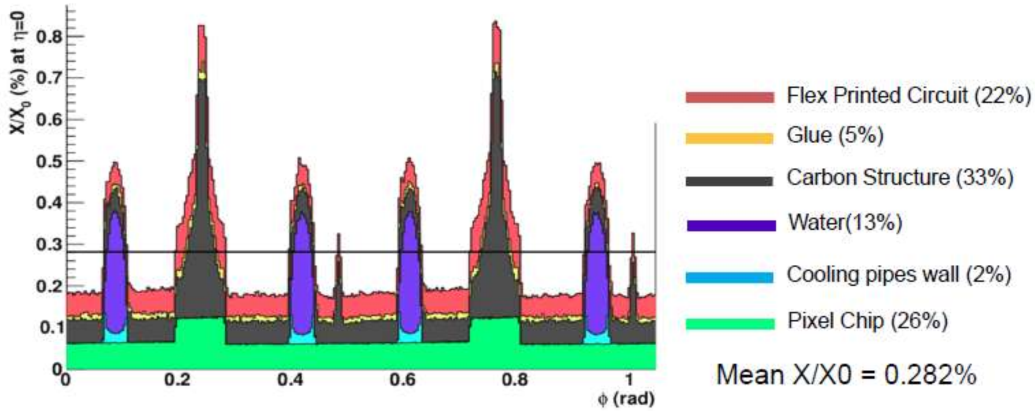
Effective thickness of ITS2 layers

Outer barrel



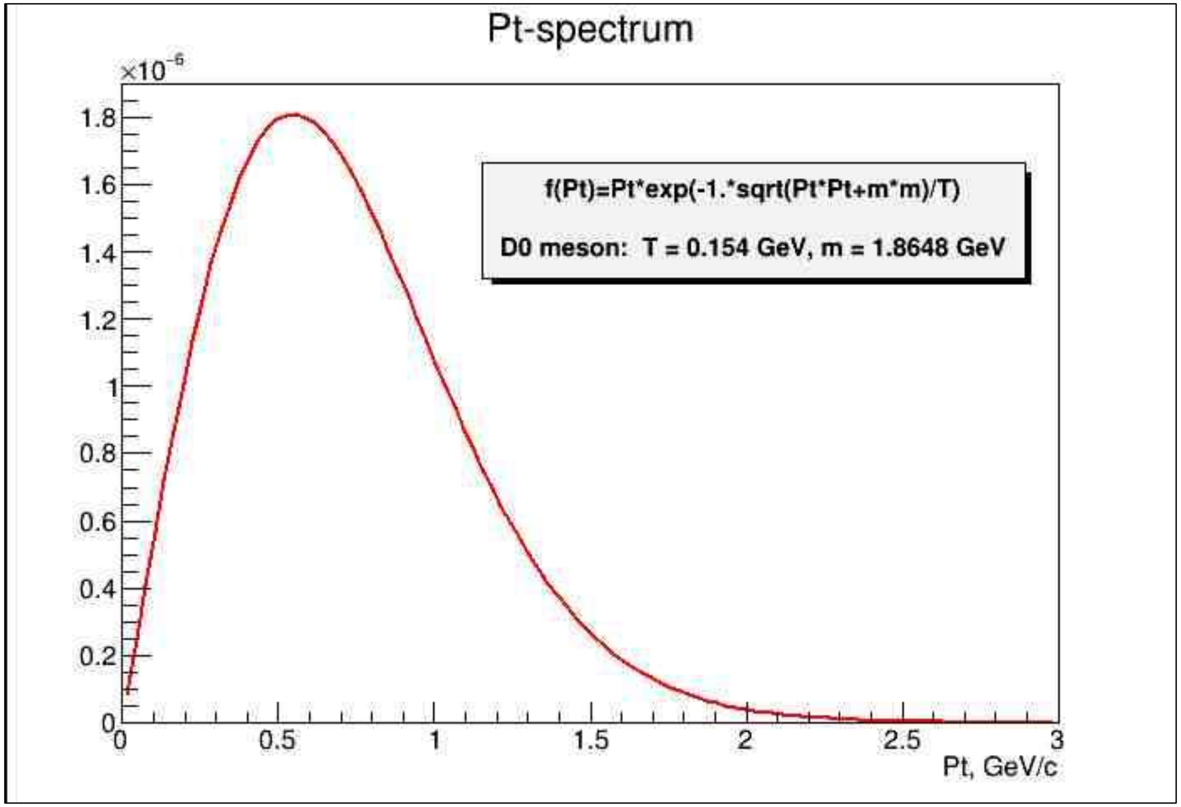
Effective Si thickness t=760 μm

Inner barrel



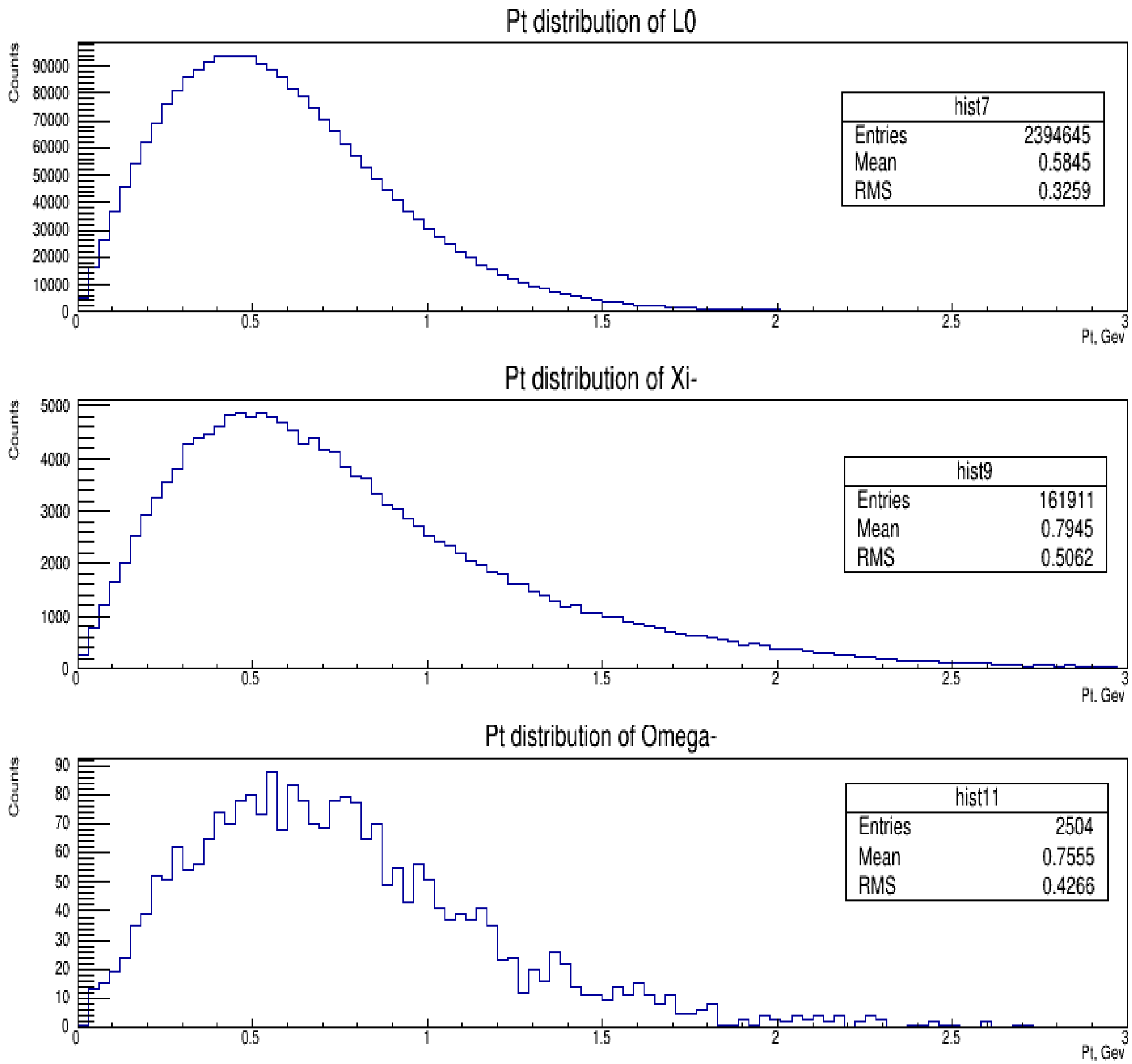
Effective Si thickness t=260 μm

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

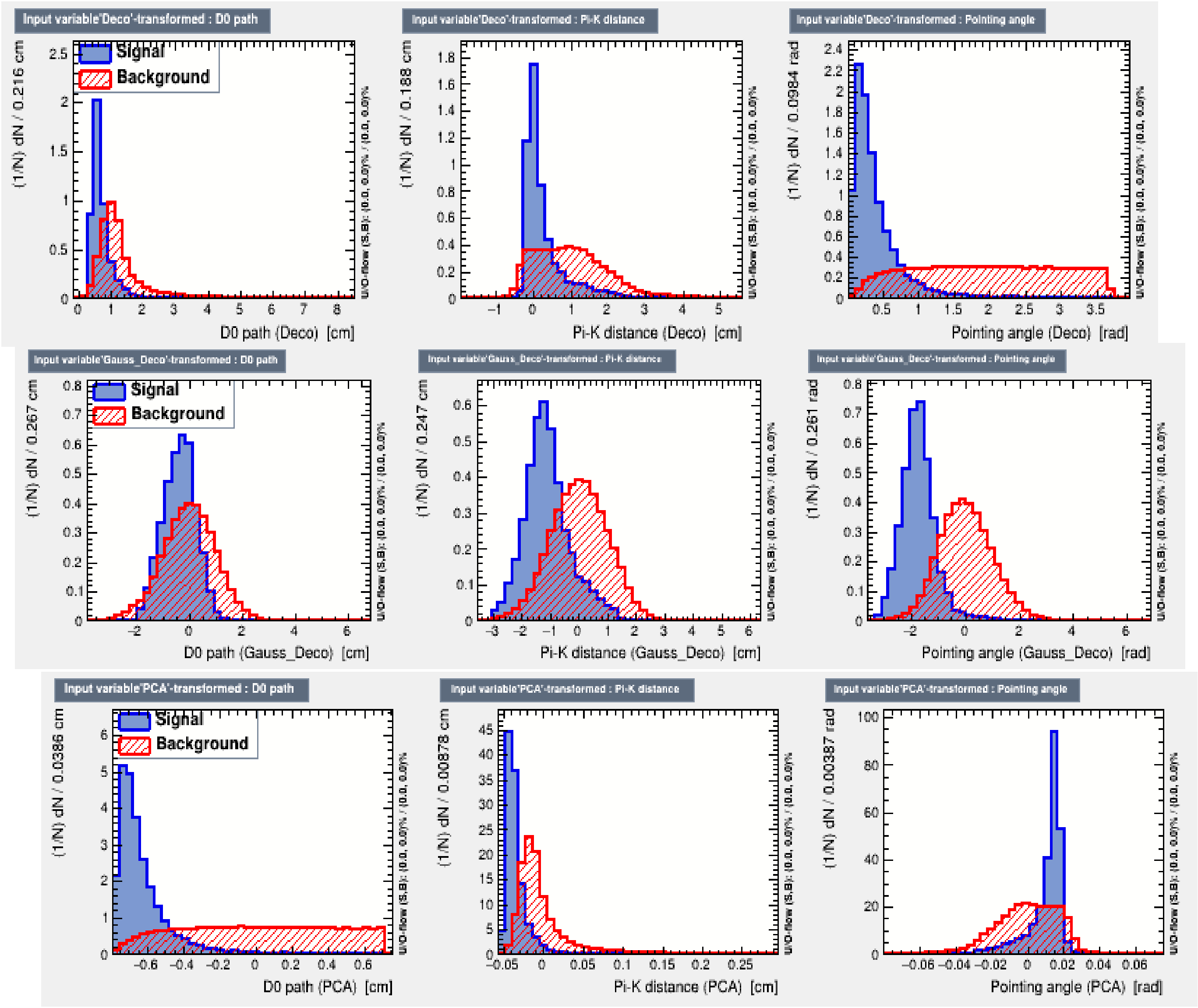


Abdel Nasser TAWFIK† and Ehab ABBAS
Thermal Description of Particle Production in Au-Au Collisions at STAR Energies
Physics of Particles and Nuclei Letters. November 2013

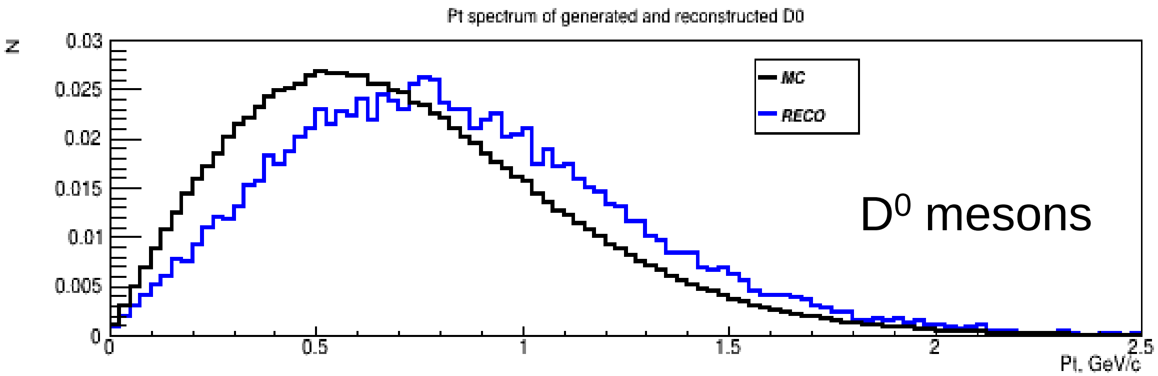
QGSM generator: p_t – spectra of strange particles in 100K central Au+Au collisions at $\sqrt{S_{NN}}$ = 9 GeV

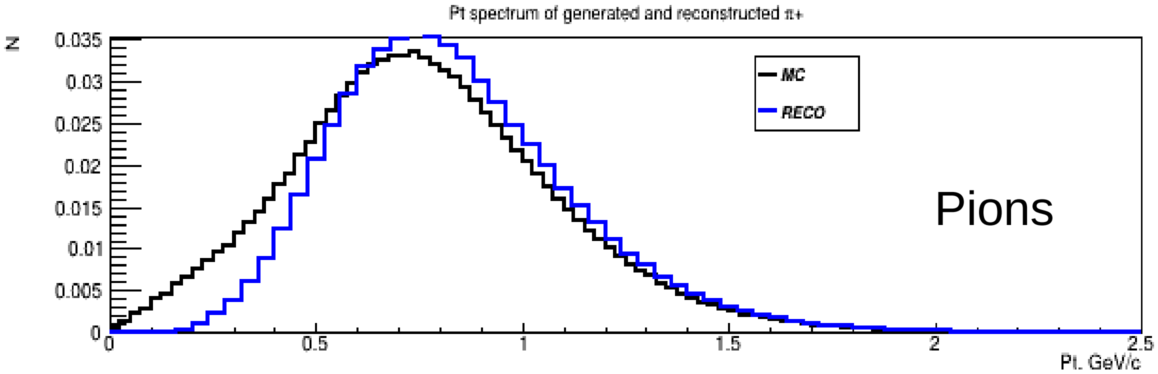


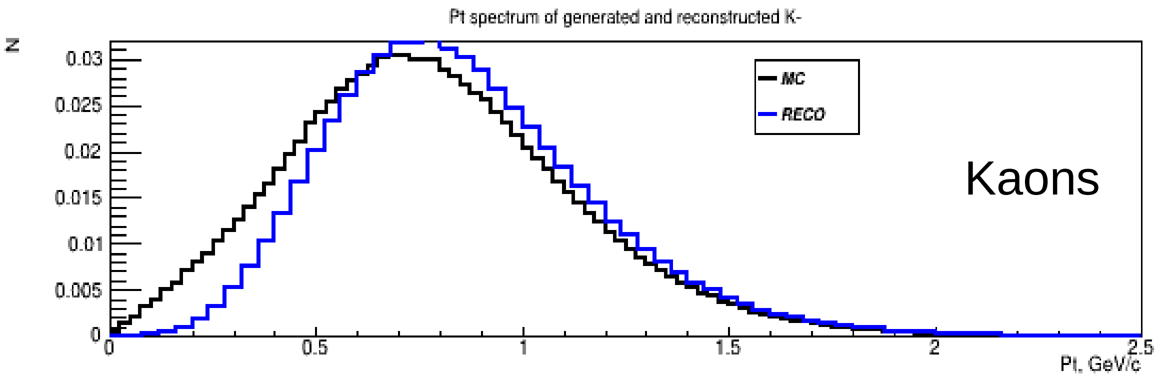
Input variables distributions for signal and background events after the decorrelation , gaussianisation and principal component decomposition



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







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