Vertex Detector of NA61/SHINE experiment for open charm measurements at CERN SPS energies

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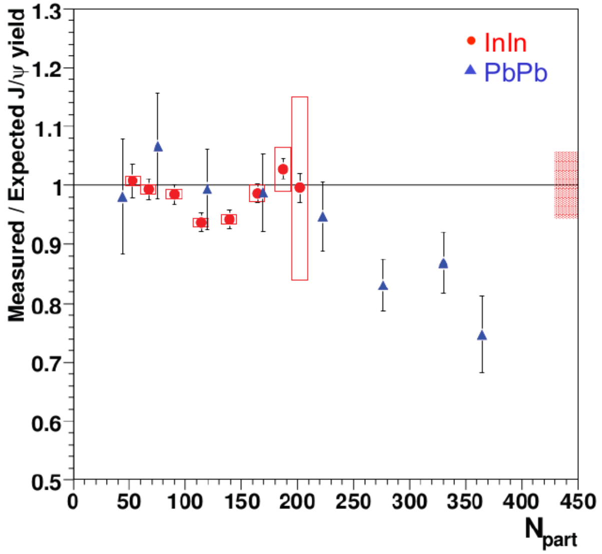
Open charm measurement motivation

- The study of open charm mesons allows for investigation of the properties of the hot and dense matter produced in nuclear-nuclear collisions.
- Predictions of open charm yield from pQCD and Statistical model differ by factor 30 for Pb+Pb at top SPS energy.
- J/Ψ measurements by NA38/NA50 & NA60 consistent with pQCD upto Npart < 200
  - Anomalous J/Ψ suppression;
  - Onset of QGP, or other scenario?
  - Open charm enhancement correlated with J/Ψ suppression?

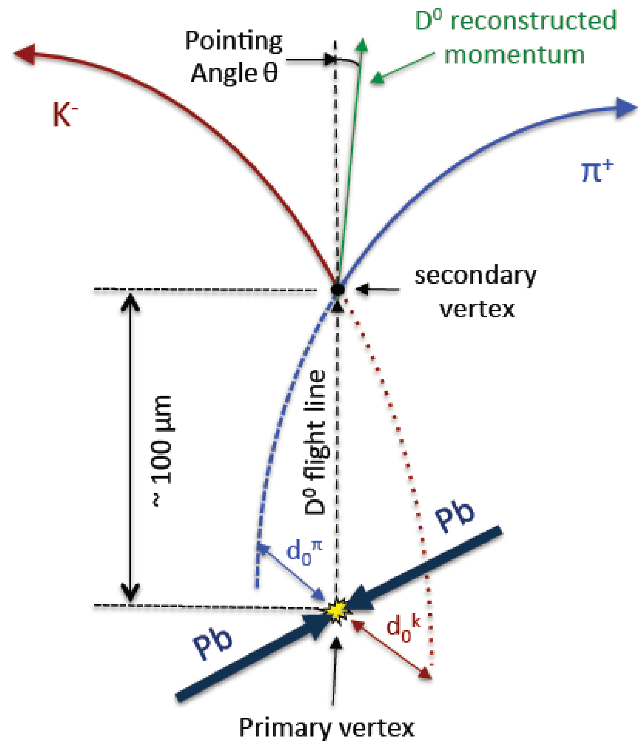


J/Ψ suppression as function of Npart

Ref.

1. Nucl. Phys A 830 239c (2006)

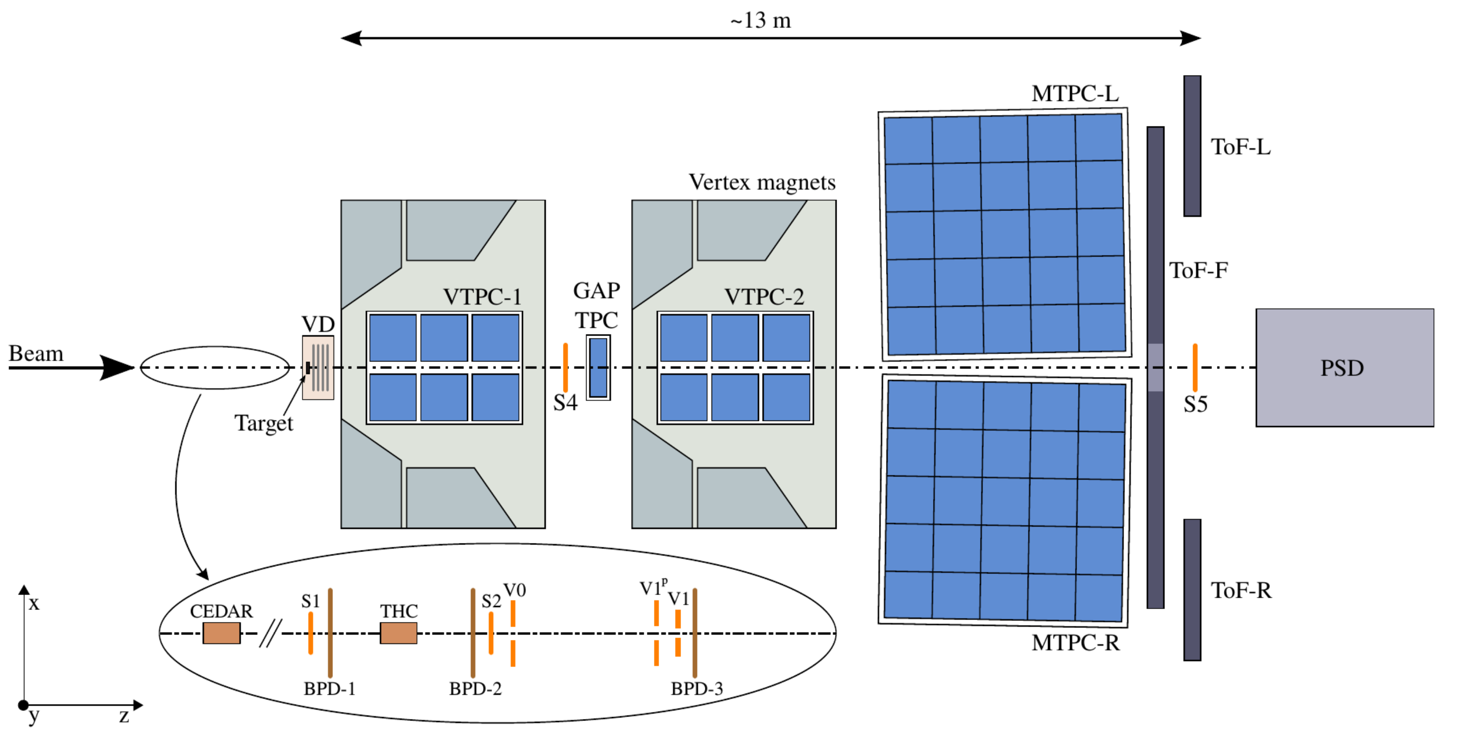
Programme for open charm measurements



- The low yields of charmed particles $\rightarrow$ require high efficiency of track registration and low material budget in the tracking region;
- The short mean life-time of D mesons $\rightarrow$ rather small distance between the decay vertices of D mesons and the primary vertex.

Meson	Decay channel	$c\tau$	Branching ratio
D^0	$D^0 \rightarrow K^- + \pi^+$	122.9 μm	$(3.91\pm0.05)\%$
D^0	$D^0 \rightarrow K^- + \pi^+ + \pi^+ + \pi^-$	122.9 μm	$(8.14\pm0.20)\%$
D^+	$D^+ \rightarrow K^- + \pi^+ + \pi^+$	311.8 μm	$(9.2\pm0.25)\%$
D_s^+	$D_s^+ \rightarrow K^+ + K^- \ \pi^+$	149.9 μm	$(5.50\pm0.28)\%$
D^{*+}	$D^{*+} \rightarrow D^0 + \pi^+$	...	$(61.9\pm2.9)\%$

NA61/SHINE experiment



- The heavy-ion programme of the NA61/SHINE experiment at CERN SPS is expanding to allow precise measurements of exotic particles with short lifetime, such as D-mesons;
- → NA61/SHINE experiment is being upgraded with the new Small Acceptance Vertex Detector (SAVD).

Vertex Detector

- Main purpose of the Vertex Detector is the improvement of track resolution near the interaction point, which allows reconstruction of secondary vertices.

- SAVD is positioned between the primary vertex and the VTPC-1;
- Four planes of coordinate-sensitive detectors are located at 5, 10, 15 and 20 cm distance from the target;

- High position resolution MIMOSA-26 sensors are CMOS Monolithic Active Pixel Sensors and have very low material budget (50 μm thickness)
  →have been chosen as the basic detection element of the Vertex Detector stations.

The reconstruction algorithm

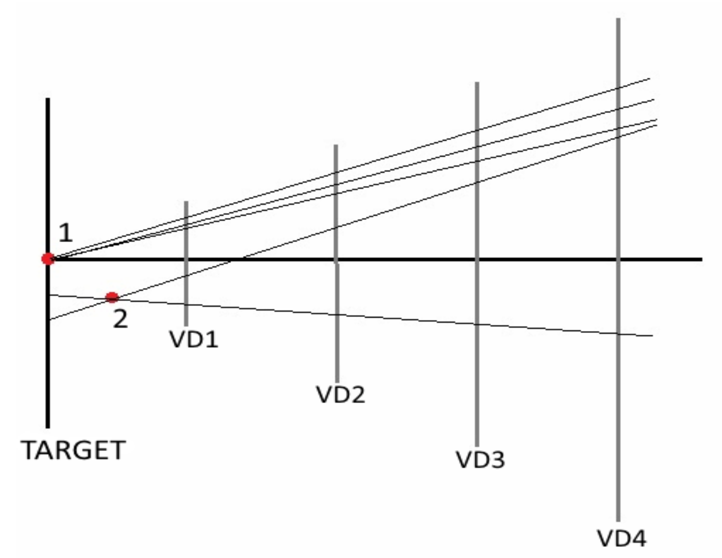
- Track reconstruction is based on the Hough transform.
- It is a global method. It uses a parametric description of a track by a set of parameters. Once the track model and detector measurement model are given, all hits in the detector can be projected into the track parameter space.
- The Hough Transform is based on the voting procedure on best matching value for some parameter describing the feature. This voting procedure is carried out in a parameter space, from which object candidates are obtained as local maxima in a so-called accumulator space.
- Number of parameters should be kept small; size of the Hough space grows as $O(n^l)$ where n is number of hits, l is number of parameters.

- The magnetic field in Vertex detector volume is inhomogeneous (0.13÷0.25T).
- Track model is chosen as parabola in (XZ) and linear in (YZ).

$$x = \frac{Ze}{|p|} B_y \frac{z^2}{2} + a_x z + b_x \qquad y = a_y z + b_y$$

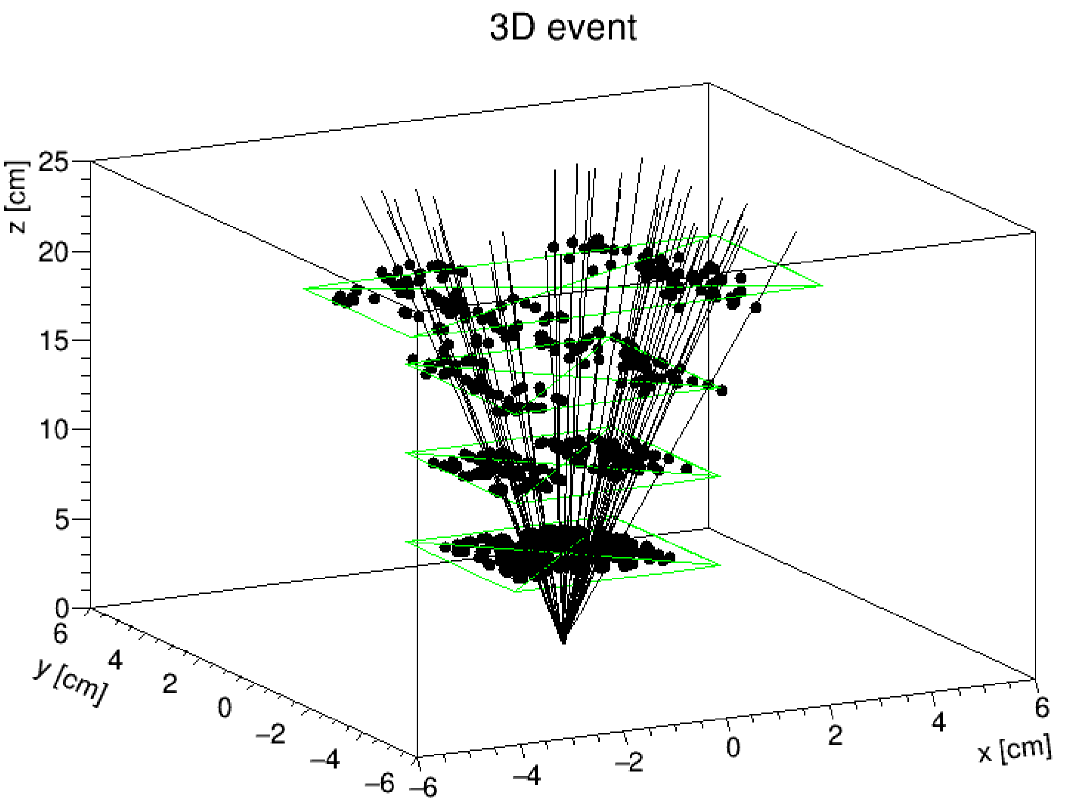
Implementation of the Hough Transform for the Vertex Detector

1. For all hits use the Hough Transform with parameterization without intercepts;
2. Then, extrapolate these tracks to primary vertex, i.e. the coordinate origin. If the point is enough close to coordinate origin, then track is found;
3. If the track parameters can't be found in such parameterization, i.e. extrapolated point is rather far from the coordinate origin then it is secondary track and for these hits should be used parameterization with intercepts.



- For D^0 life time $\tau \sim 410 \cdot 10^{-15}$sec, i.e. $c\tau \sim 123\mu m \rightarrow$ close to primary vertex;
- For Λ-particles life time $\tau \sim 2.6 \cdot 10^{-10}$sec, i.e. $c\tau \sim 7.9cm \rightarrow$ can't be reconstructed in model without intercepts;
- Algorithm with intercepts has 5 dimensions → rather long processing time ($t \sim O(n^l)$).

Reconstructed event

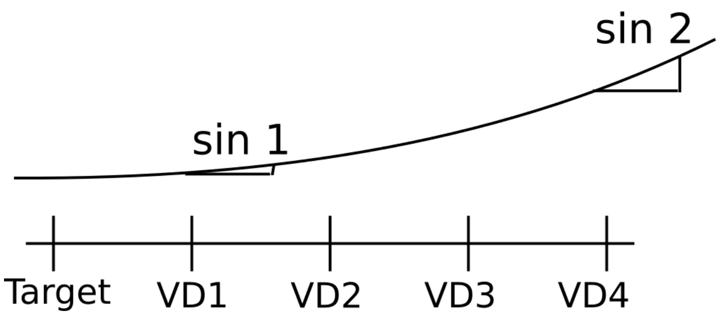


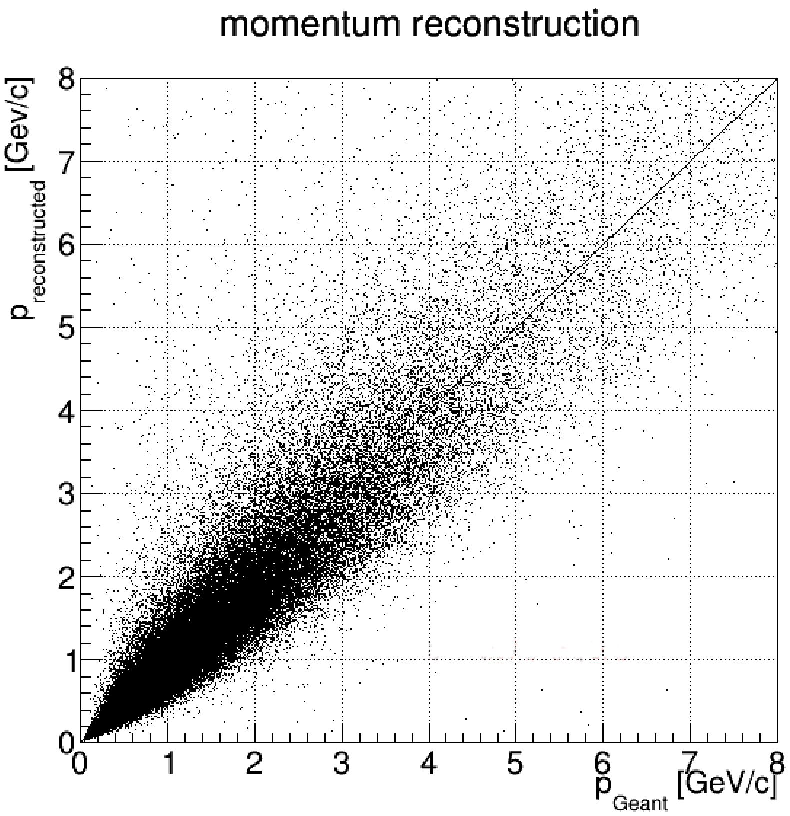
Reconstruction of AMPT simulated Pb+Pb 158A GeV/c central event

Momentum reconstruction

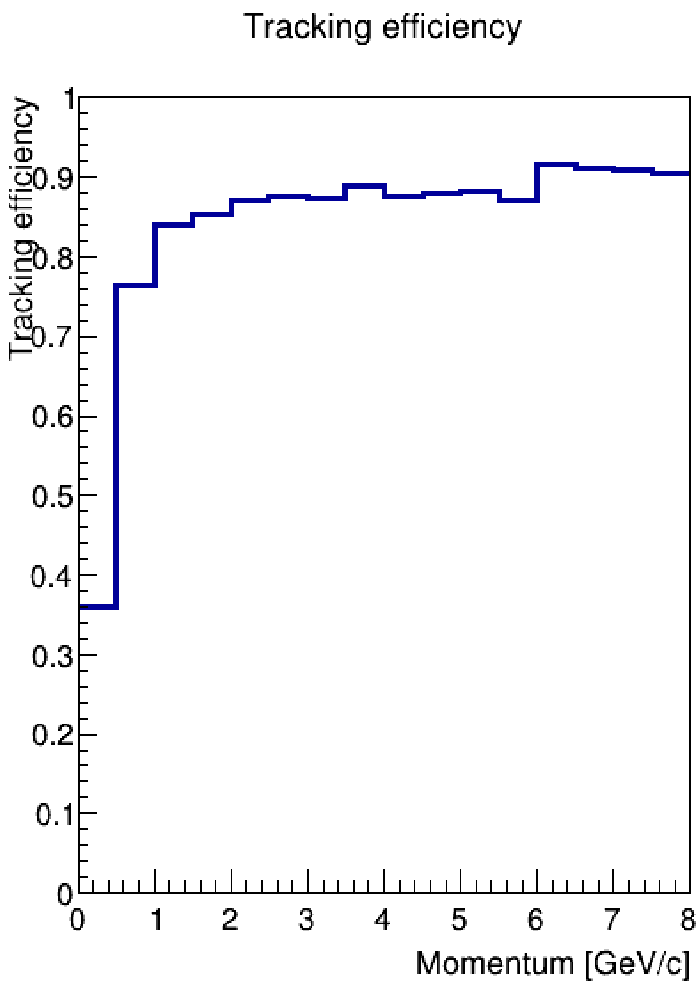
- Inhomogeneous magnetic field (0.13÷0.25T) in Vertex Detector volume
- Track momentum reconstruction method:
  to integrate magnetic field over track length from VD1 to VD4.

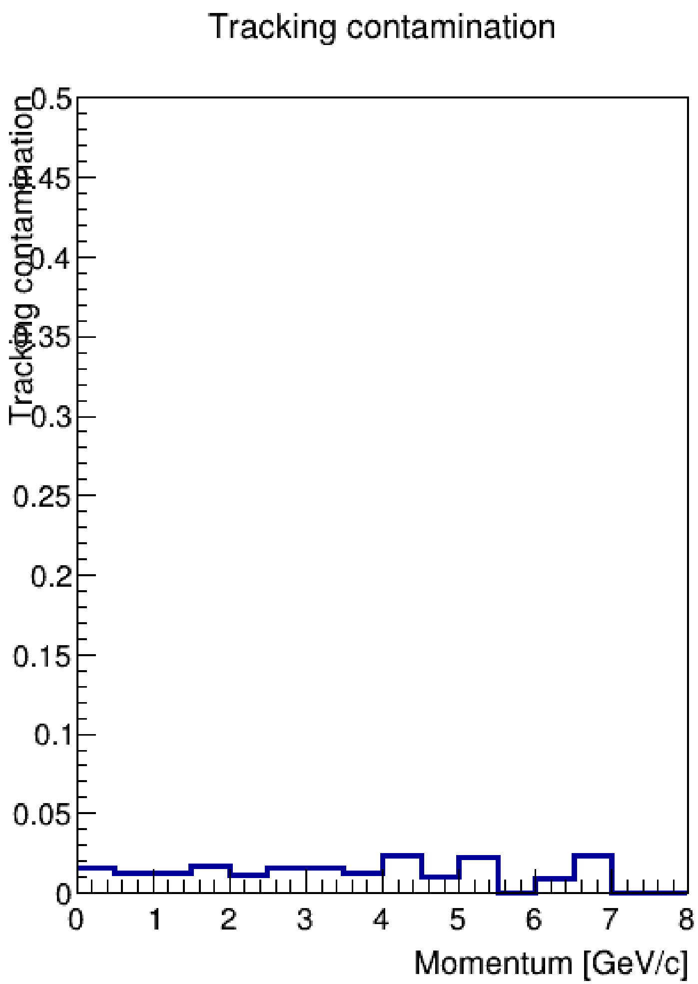
$$p_{xz} = \frac{q\int B_y dl}{\sin 1 - \sin 2}$$





Efficiency of the reconstruction





Open charm simulations

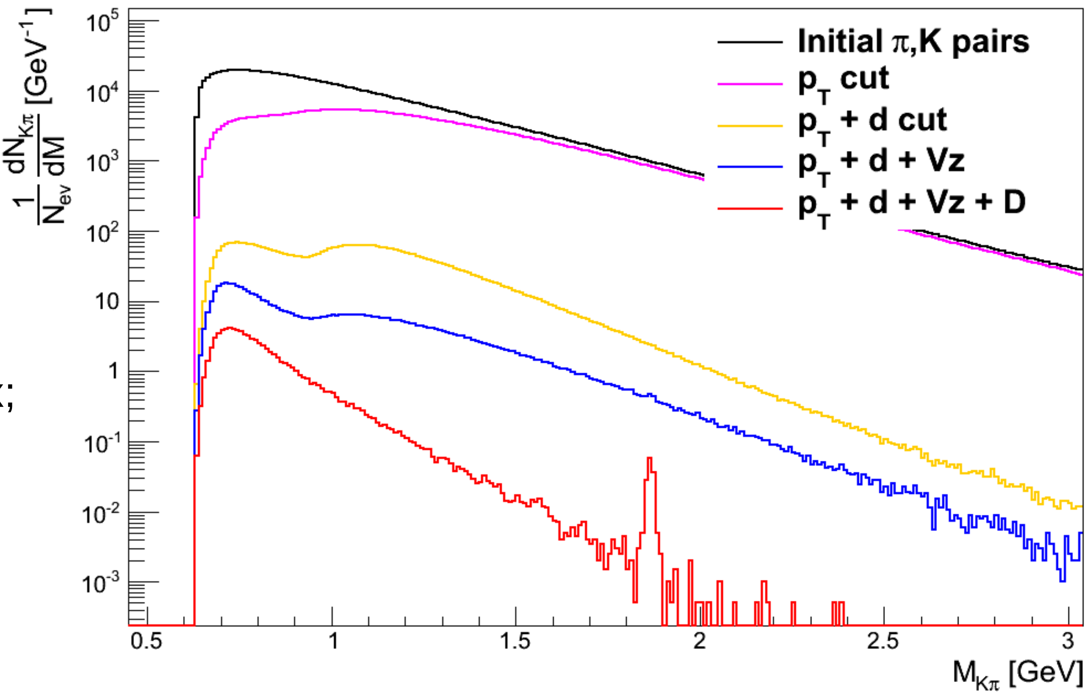
- D^0-meson can be reconstructed by its two body decay channel $D^0 \rightarrow K^- \pi^+$ with the branching ratio of 3.9%.

- For the physical input we generated 200k 0-10% central Pb+Pb events with AMPT event generator.
- The AMPT model predicts the average production yield of 0.01 for D^0 +anti D^0 per central Pb+Pb event.
  This value seems to be underpredicted with respect to the prediction of the HSD model that gives 0.1 → In simulations the AMPT average yield of D^0 was scaled to the prediction of HDS model.

Open charm simulations

- The combinatorial background is much higher than the D^0 +anti D^0 signal → one needs to introduce cuts to suppress the background:

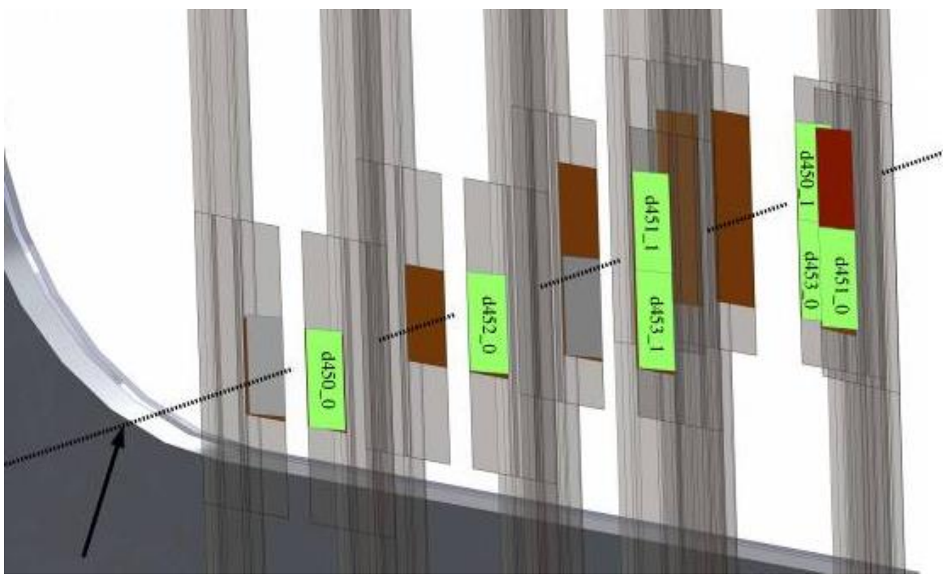
  - Cut on transverse momentum $p_T > 0.4$ GeV/c
  - Cut on the track impact parameter d > 40 μm;
  - Cut on the longitudinal position $V_z > 500$ μm of the track pair vertex relative to primary vertex;
  - Cut on the parent particle impact parameter D < 22 μm.

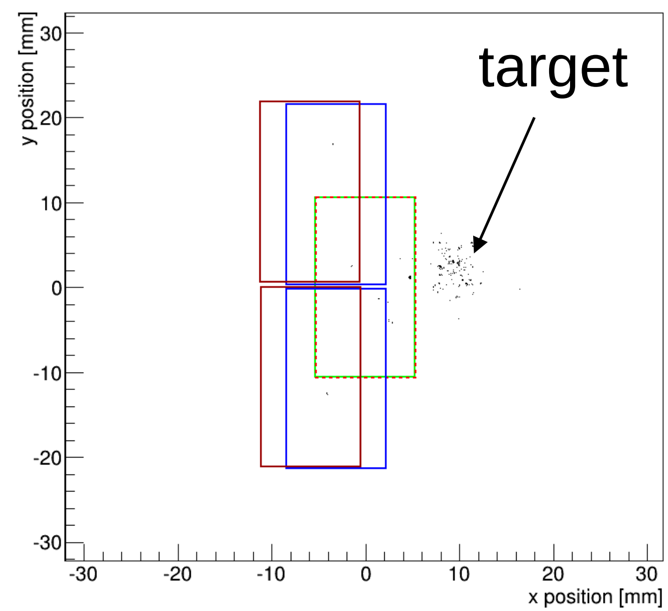


Invariant mass distribution of pion-kaon pair for 200k central events Pb+Pb 158A GeV/c with cuts

Vertex Detector data taking

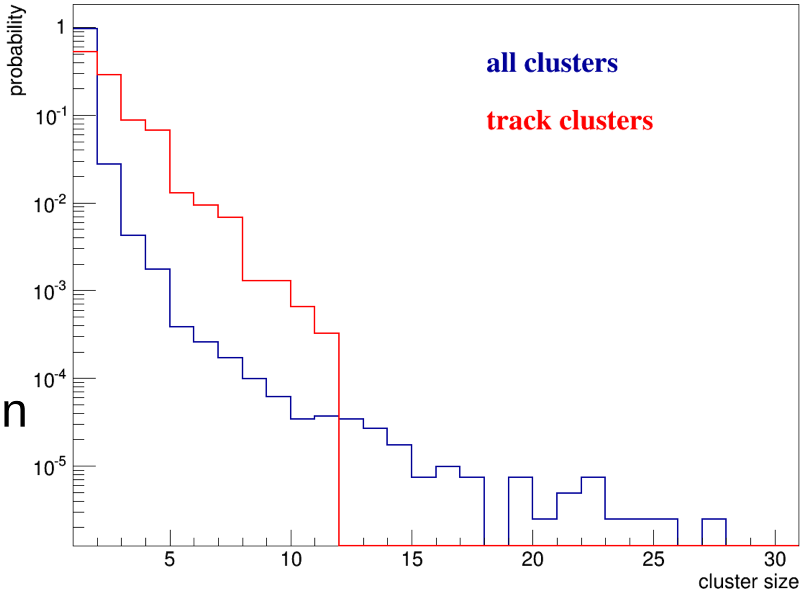
- In July 2016 Vertex Detector was installed for the test with beam of protons at 150A GeV/c with Pb target;
- During this test only one side of the stations of Vertex Detector was used. The number of sensors was sufficient to provide track reconstruction procedure.





Vertex Detector tests

- While exposed to the beam the sensors were investigated for noisy pixel and cluster sizes.
- The pixels in a silicon sensor that give some signal without a particle passing through them are so-called "noisy". Such pixels are identified by determining the fraction of events where the specific pixel fires.
- A particle passing through a sensor may fire more than one pixel, during data analysis these pixels should be grouped together as a "cluster".
  The algorithm for connecting pixels so-called "clusteriser" searches the sensor frame for fired pixels, then scan the neighbours using an recursive algorithm.
  The distribution of the cluster sizes found in multiple events and sensors while the detector was used as a beam telescope during the test run.



Summary

- Simulation showed that open charm measurements in A+A collisions at top SPS energy are possible with NA61/SHINE with new high resolution Vertex Detector;

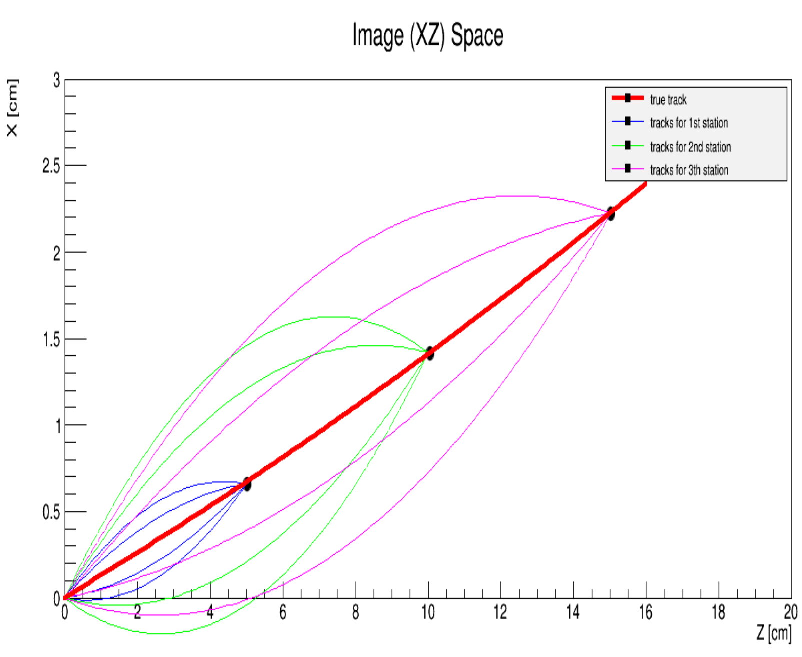
- The tests of Small Acceptance Vertex Detector with beam during this summer run were very successful, and the detector will be finally commissioned at the end of the year with physics data taking;

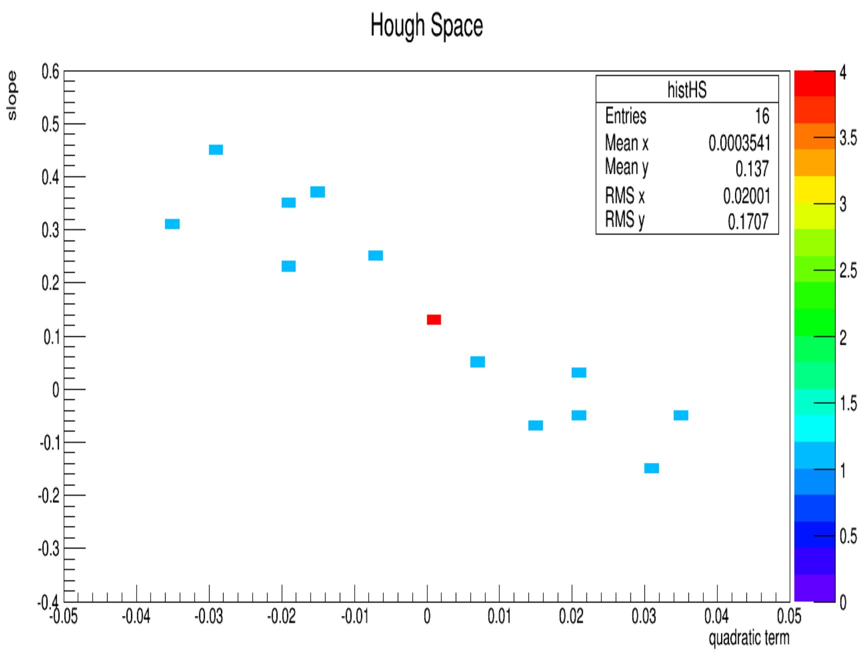
- Looking forward, an upgraded version of SAVD so-called Large Acceptance Vertex Detector (LAVD) with more sensors is being planed. The exact design of this detector is currently under investigation.

Thank you for your attention!

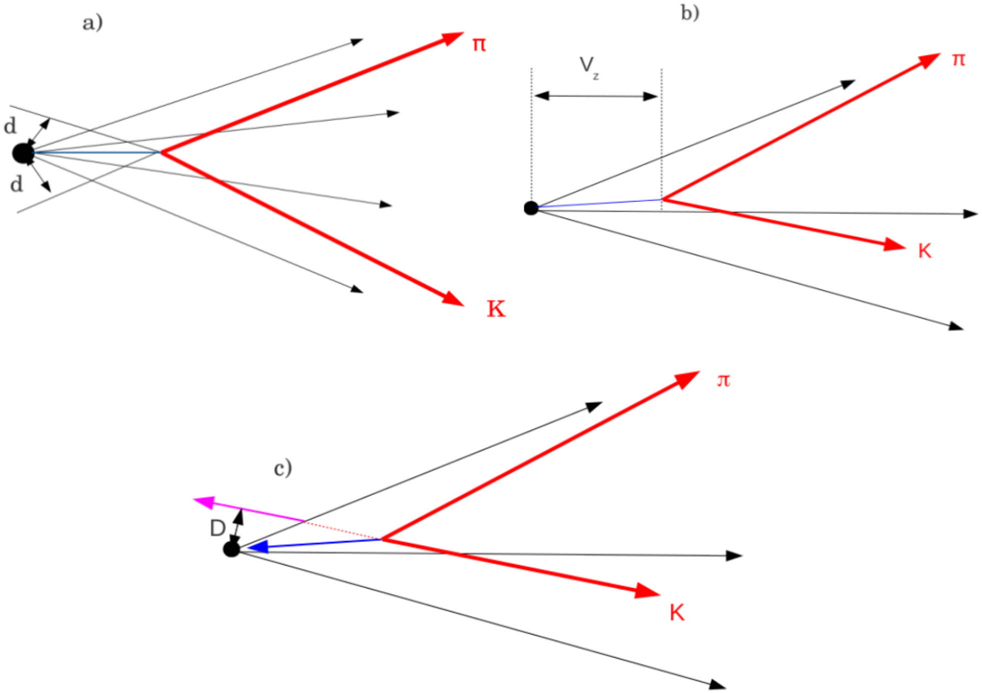
The algorithm

- Choosing parameterization for track;
- Converting the coordinates of the detector hits of particle tracks into the Hough space (space of track parameters);
- Accumulating sets of bins in histogram for each of the measurements in segment;
- Measurements that are lying along one track show up as peak in histogram. The voting procedure: object candidates are obtained as local maxima, so peaks assumed to correspond “real” tracks.





Cuts for open charm



Sketch of the $D^0 \rightarrow K^- \pi^+$ decay topology with definitions of
(a) track impact parameter d,
(b) longitudinal position Vz of the track pair vertex relative to primary interaction point and
(c) impact parameter of the parent particle D (the distance of closest approach between the primary interaction vertex and the reconstructed trajectory of the D0-meson).