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Open Charm measurements at CERN SPS energies with the new Vertex Detector of the NA61/SHINE experiment

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Open charm measurement motivation

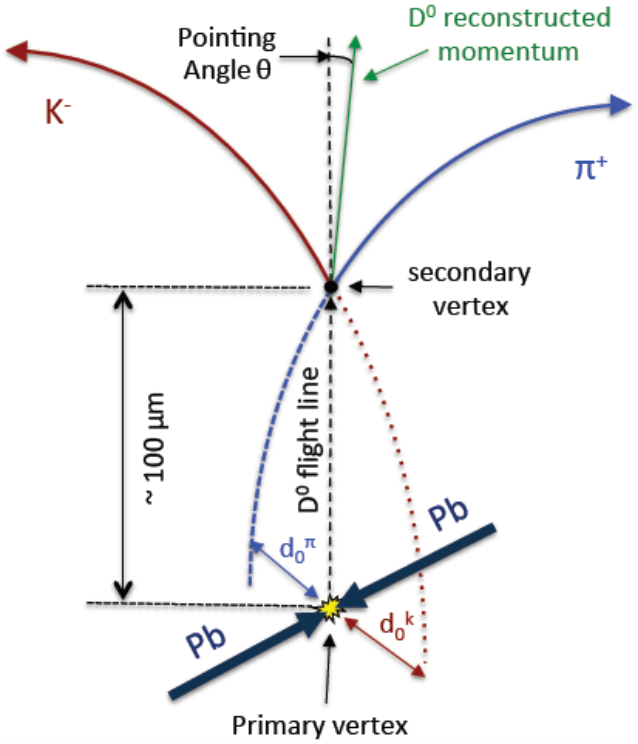
- The measurement of mesons containing heavy flavour is of high importance for better understanding of nucleus–nucleus collisions at relativistic energies;

- Predictions of open charm yield
  - pQCD;
  - Statistical Model;
  - Results differ by factor 30 for Pb+Pb at top SPS energy;

- Up to now, only indirect measurements of open charm production in nucleus-nucleus collisions at the SPS energies exist and they are not reliable enough to distinguish the pQCD and statistical approaches to open charm production
  → One need direct measurements of open charm yields.

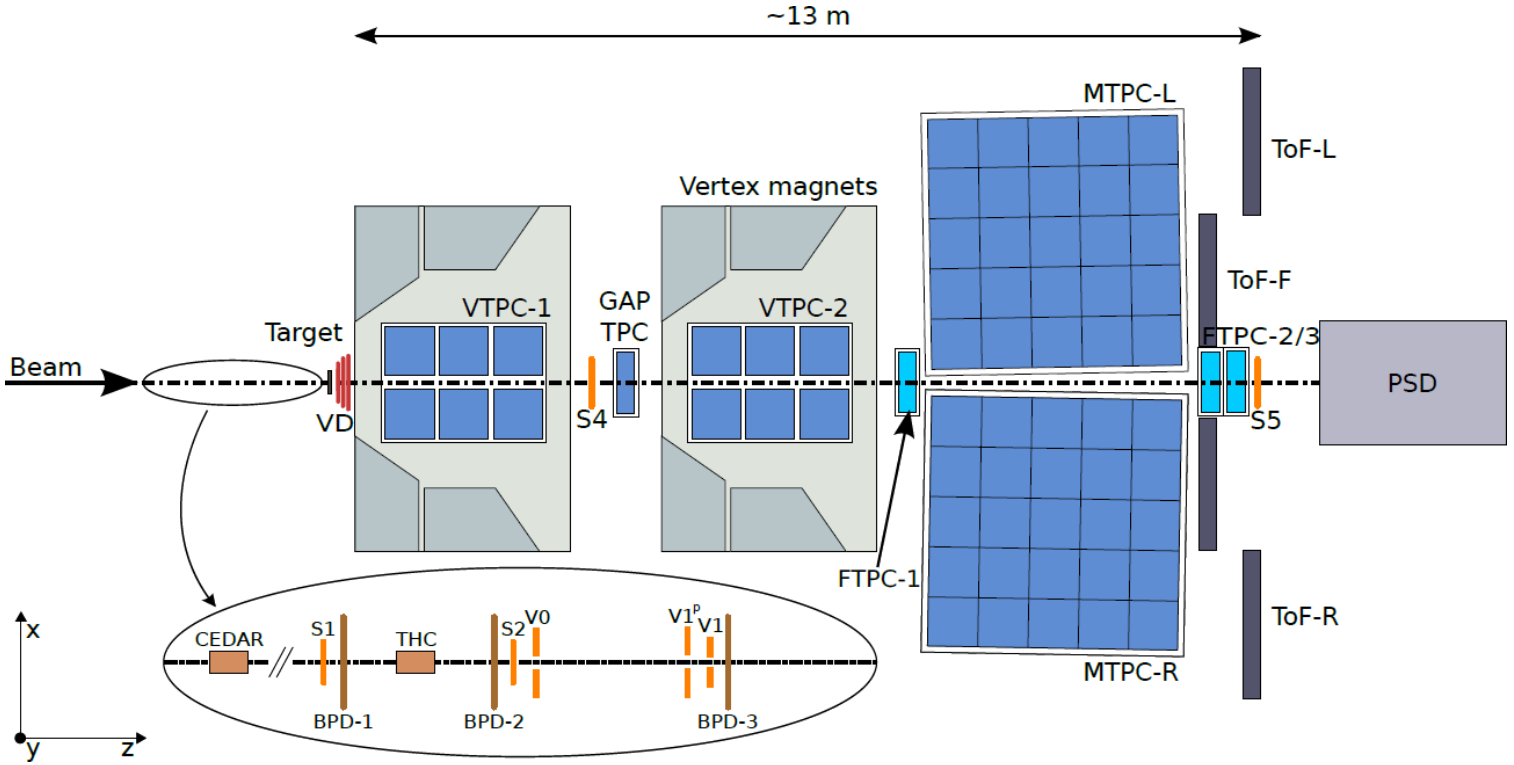
Programme for open charm measurements

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



Meson	Decay channel	$c\tau$	Branching ratio
D^0	$D^0 \to K^- + \pi^+$	122.9 μm	(3.91±0.05)%
D^0	$D^0 \to K^- + \pi^+ + \pi^+ + \pi^-$	122.9 μm	(8.14±0.20)%
D^+	$D^+ \to K^- + \pi^+ + \pi^+$	311.8 μm	(9.2±0.25)%
D_s^+	$D_s^+ \to K^+ + K^- \pi^+$	149.9 μm	(5.50±0.28)%
D^{*+}	$D^{*+} \to D^0 + \pi^+$	...	(61.9±2.9)%

NA61/SHINE experiment



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

Requirements for detector

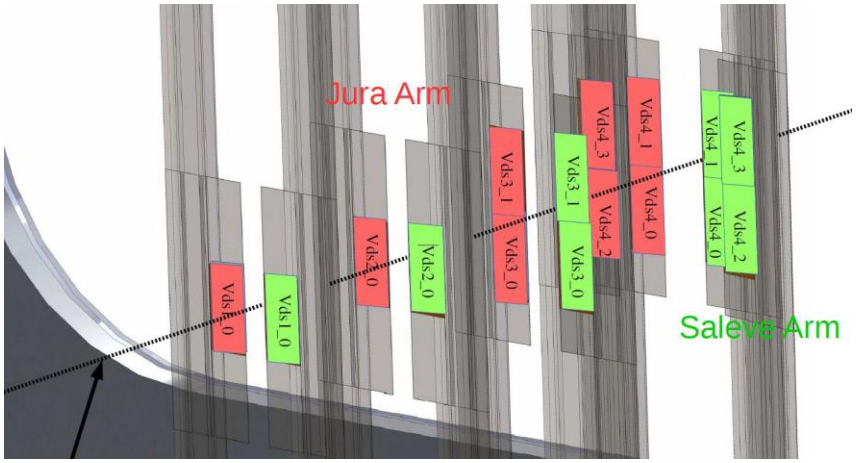
- Rare probes of charm particles;
- Small distance between the decay vertices and the primary vertex.

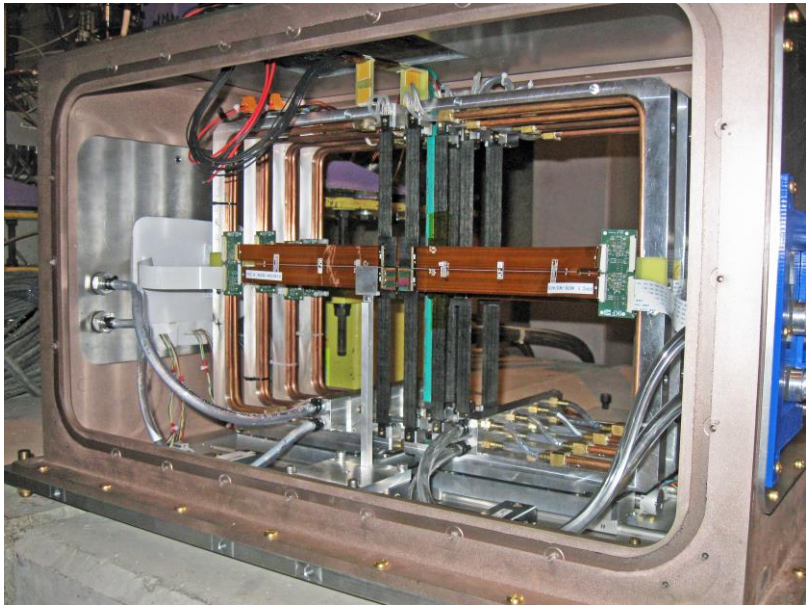
→ general requirements for detector:

- Precise vertexing and tracking accuracy;
- High time resolution detectors;
- The lowest possible material budget in the tracking region in order to increase the efficiency of open charm measurements;
- High granularity of vertex tracking detectors capable to register the multiple tracks in A-A collisions.

→ Vertex Detector project based on CMOS pixel detectors.

Vertex Detector



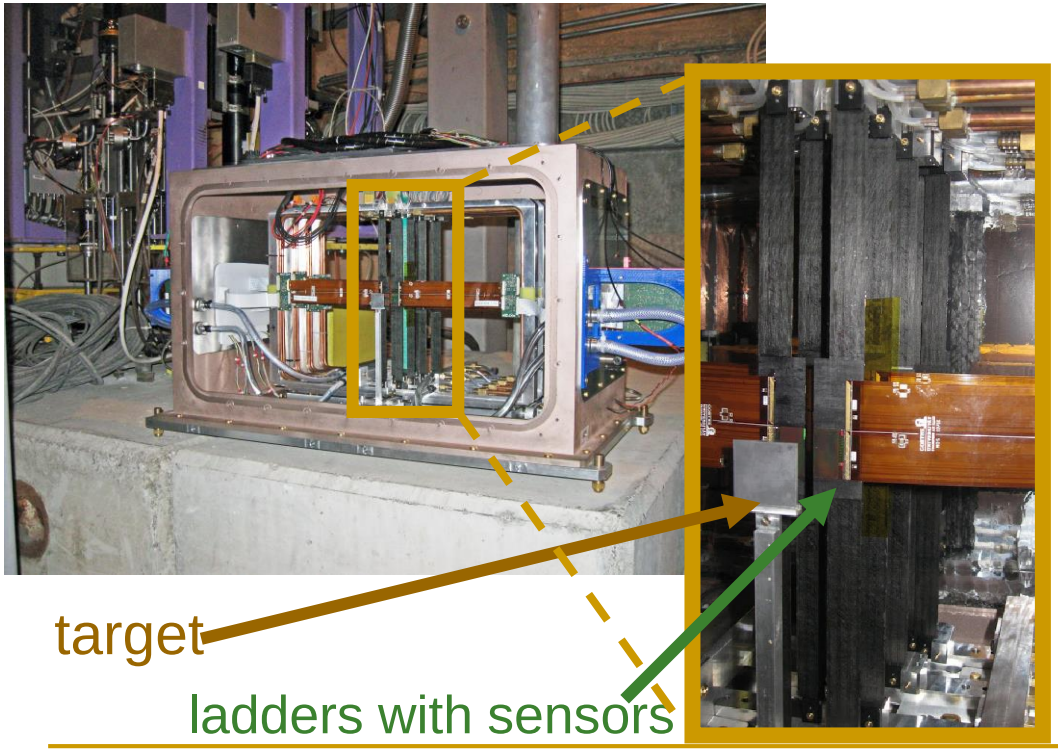


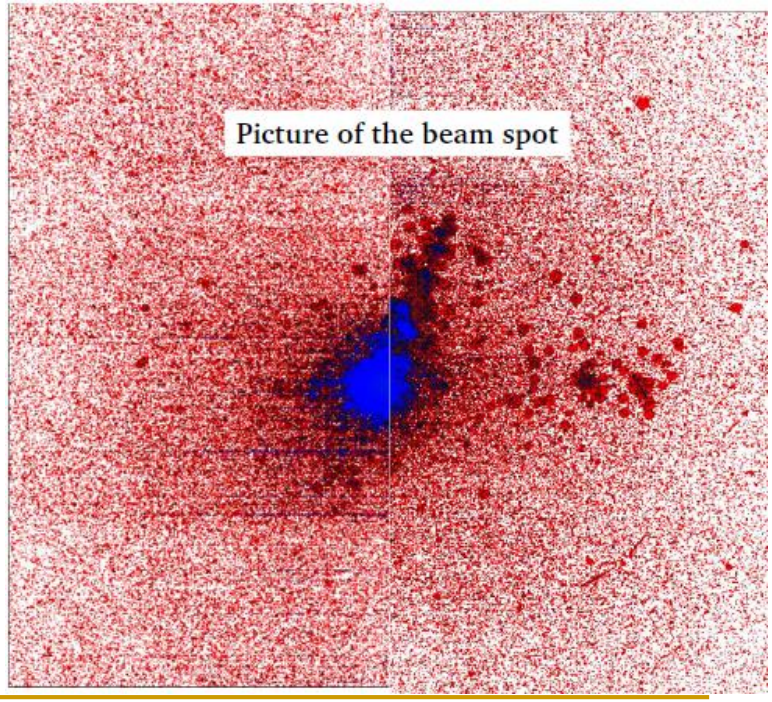
- Main purpose of the Vertex Detector is the improvement of track resolution near the interaction point, which allows reconstruction of secondary vertices;
- SAVD is positioned between the target and the VTPC-1;
- Four planes of coordinate-sensitive detectors are located at 5, 10, 15 and 20 cm distance from the target;
- High position resolution MIMOSA-26 sensors are CMOS Monolithic Active Pixel Sensor (MAPS) and have very low material budget (50 μm thickness)
  → have been chosen as the basic detection element of the Vertex Detector stations.

SAVD data taking

- December 6-11, 2016 Vertex Detector was installed for data taking
  with the beam of Pb at 150A GeV/c
  with 1mm Pb target located 50 mm downstream from the first station;

- Physics runs (with magnetic field) and non-field runs for tuning geometry.





Reconstruction algorithm in SAVD

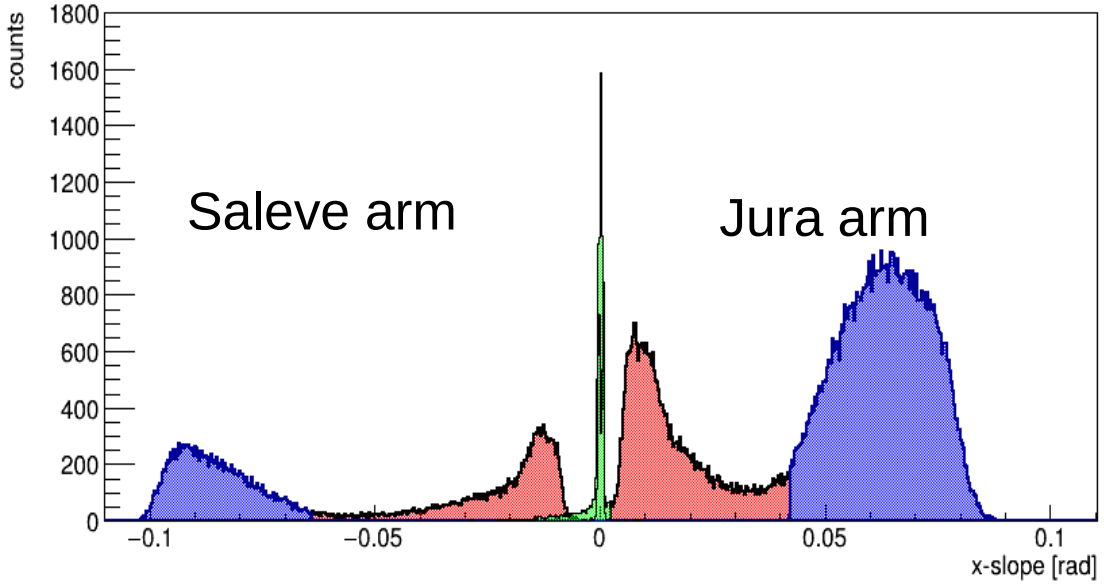
- Vertex Detector consists of two arms: Jura and Saleve, in which reconstruction procedure could be done independently;

- The magnetic field in Vertex Detector volume is inhomogeneous (B_y = 0.13÷0.25T);

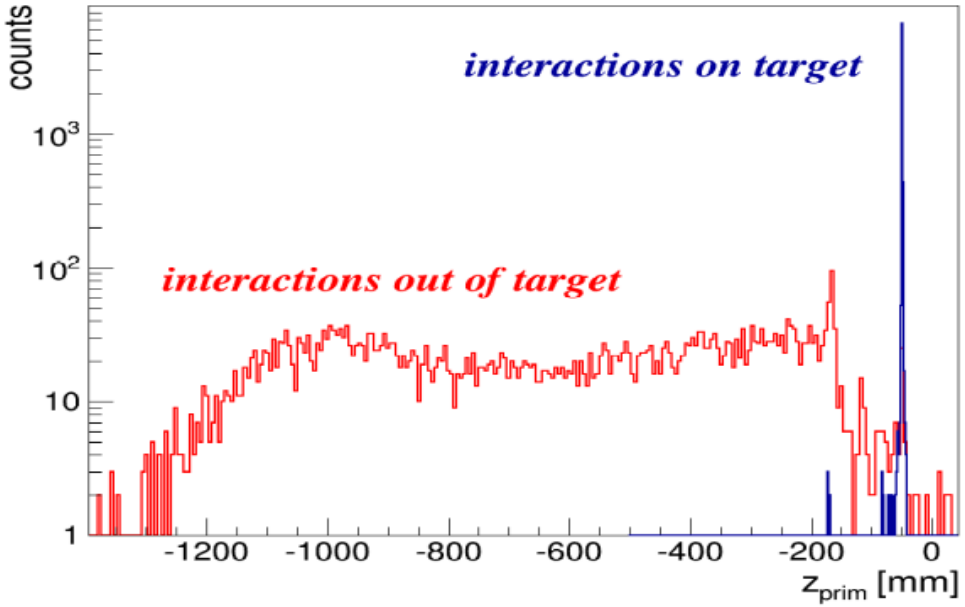
- Track reconstruction is done iteratively:
  1. Finding 4-hit tracks by combinatorial method with strait line track model;
  2. Reconstruction of the primary vertex;
  3. Using information about the primary vertex position one may find 3-hit tracks using the Hough Transform method;
  4. Fitting tracks with parabola in (XZ) plane and linear in (YZ) plane.

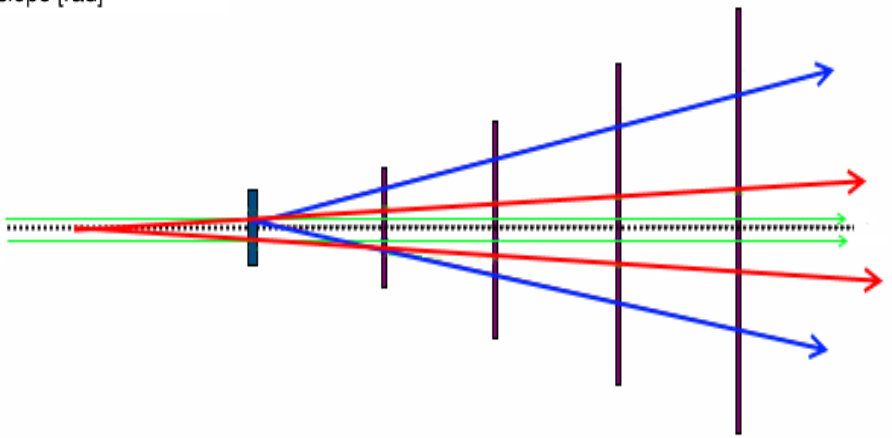
- Spatial sensor resolution obtained by looking at residuals between hits and reconstructed tracks for non-field runs is σ_x = 4.7μm and σ_y = 5.0μm.

Angle distribution

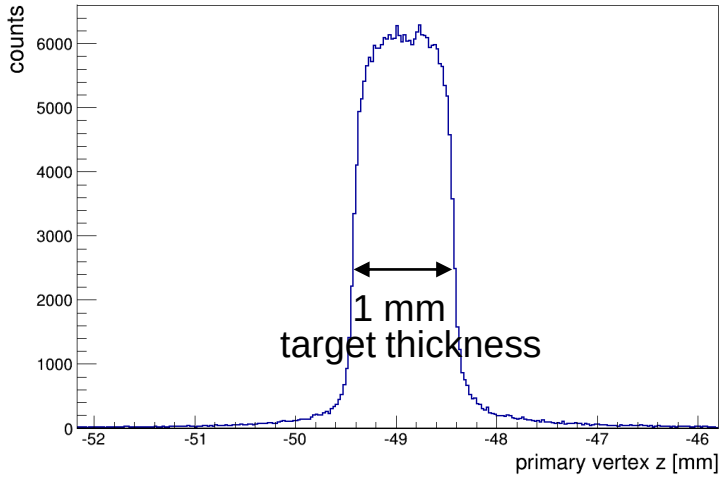


The angular distribution in x directions of the reconstructed tracks for Jura and Saleve arms has clear three peak structure.

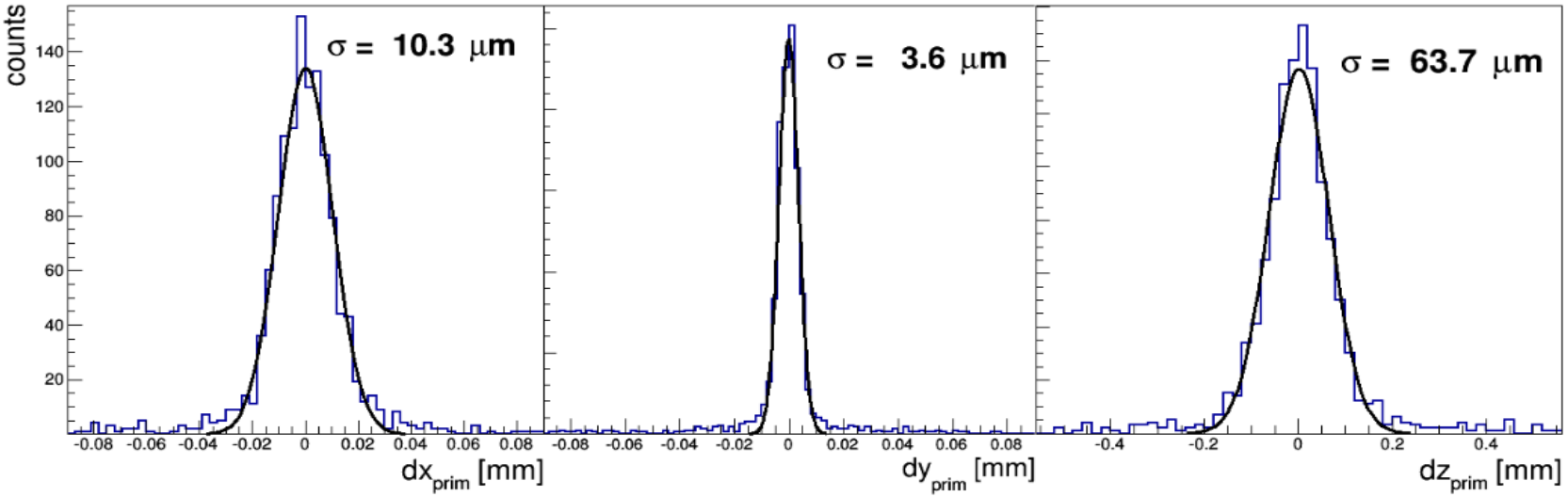




Primary vertex reconstruction



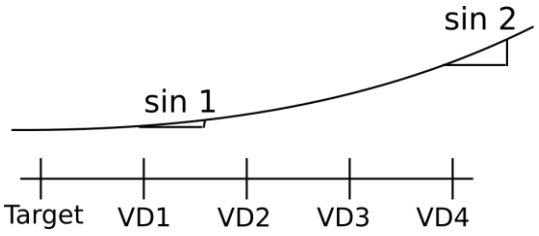
- Spatial resolution of the primary vertex: σ_x = 5 μm, σ_y = 1.5 μm and σ_z = 30 μm.
- The difference between σ_x and σ_y can be attributed to the presence of the vertical component of the magnetic field which deteriorates description of tracks trajectories in the x direction.



Momentum reconstruction

- Presence of the magnetic field in the volume of the Vertex Detector allows momentum measurements;
- Track momentum reconstruction method:
  to integrate magnetic field over track length from VD1 to VD4.

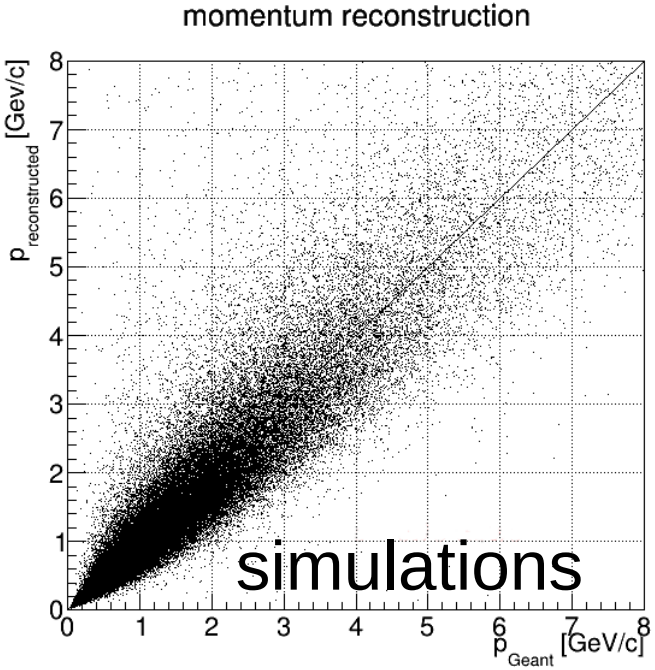
$$p_{xz} = \frac{q\int B_y dl}{\sin 1 - \sin 2}$$



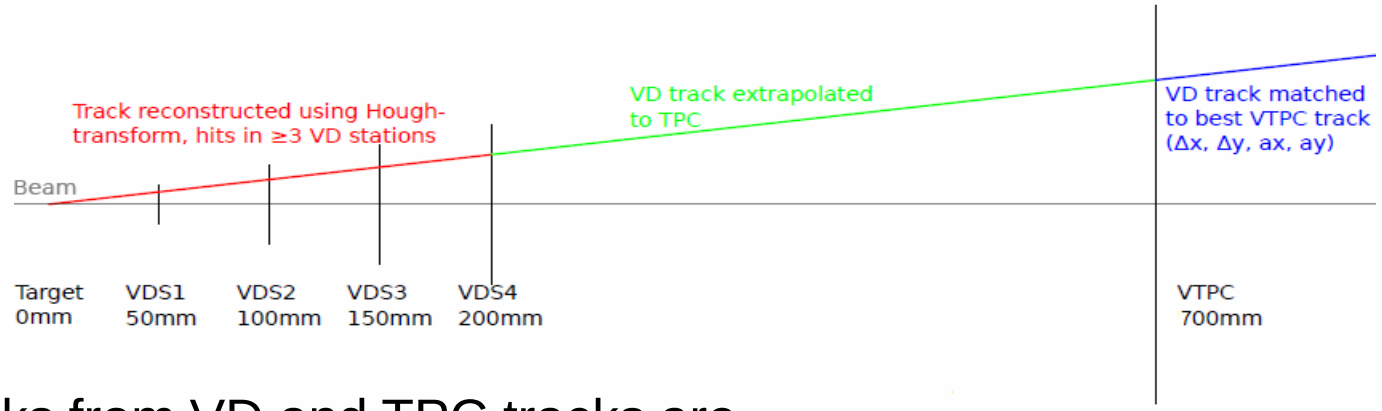
- Momentum resolution in stand-alone SAVD:

$$\frac{dp}{p} \sim 10^{-1}$$

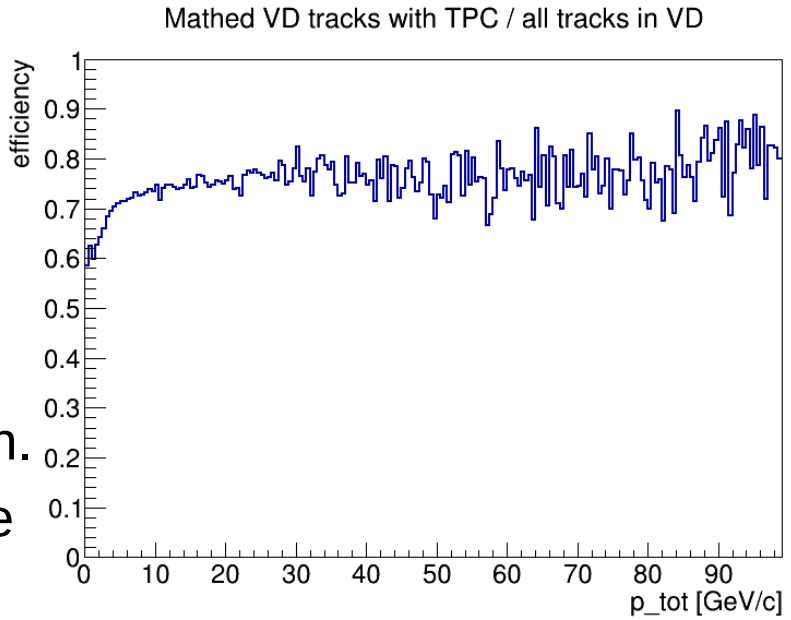
- Momentum of VD tracks is not used directly – this information we use to verify track matching procedure.



Matching algorithm

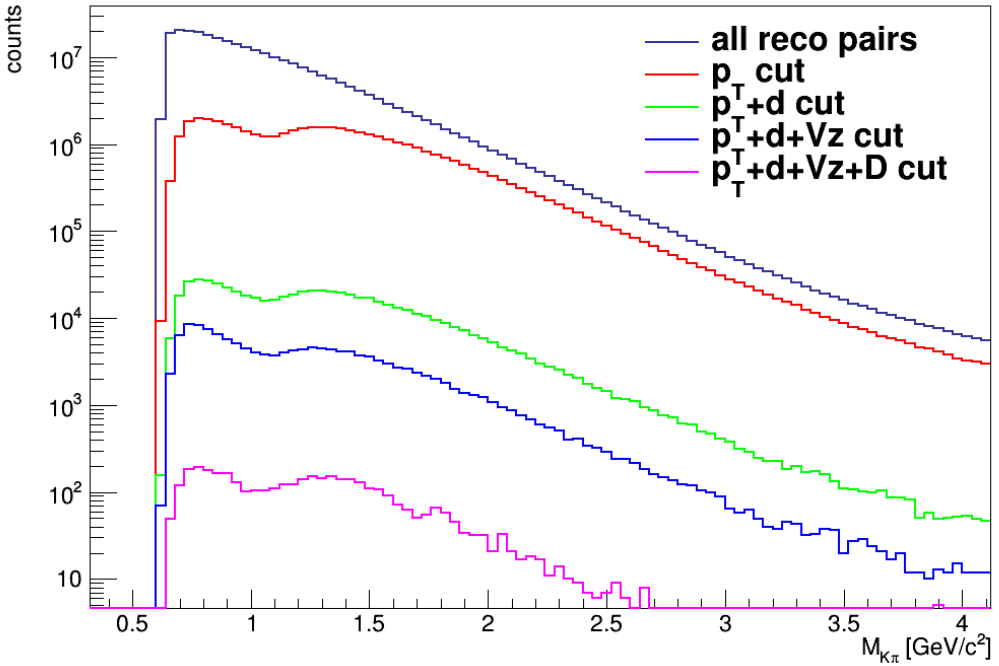


- Tracks from VD and TPC tracks are extrapolated to common plane (VTPC-1 surface);
- Find the best match over all combinations of VD and TPC tracks using basing of difference in the position and direction, and using charge and momentum to verify match.
- The track matching efficiency is on the level of 75%.



Reconstruction of D^0 signal

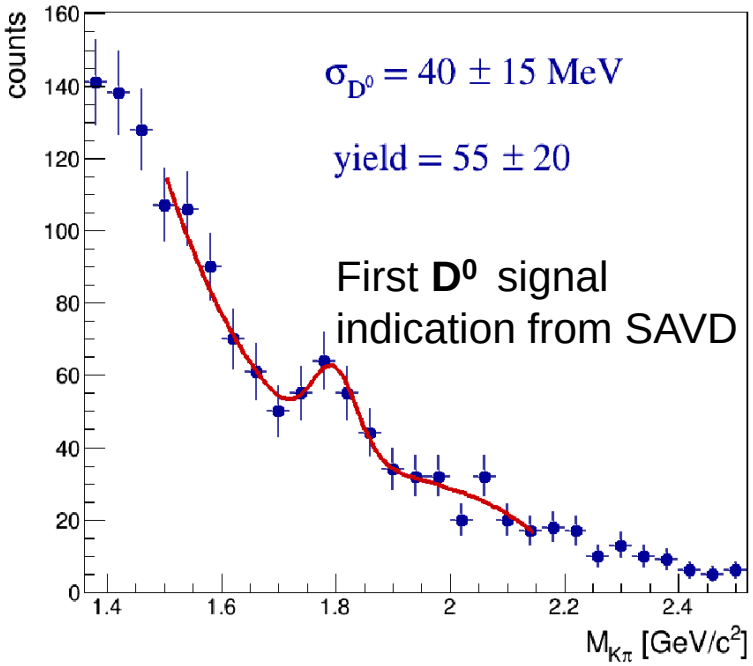
- SAVD tracks matched to TPC tracks are used in the search for the D^0 signal;
- Each SAVD track is paired with another SAVD track and is assumed to be either a kaon or pion;
- To suppress the background one needs to introduce cuts:

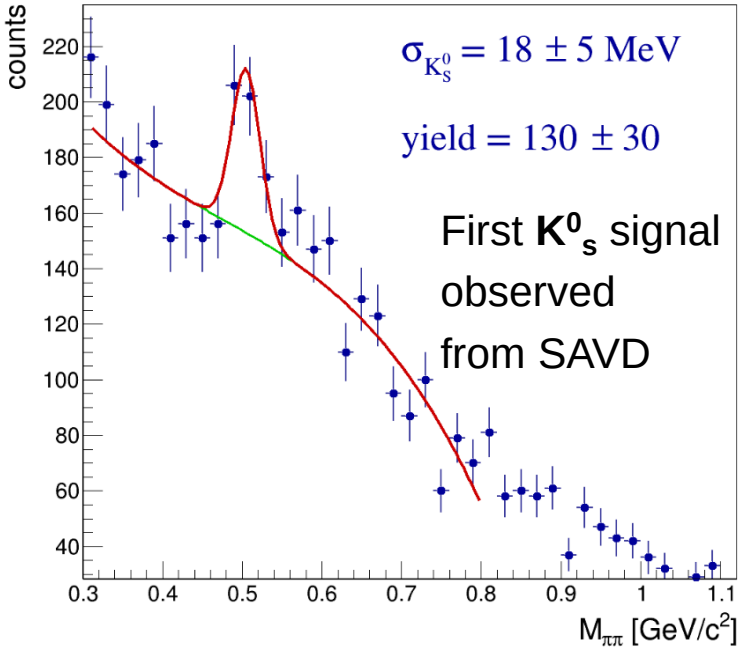


- Cut on transverse momentum $p_T > 0.31$ GeV/c;
- Cut on the track impact parameter $d > 31$ μm;
- Cut on the longitudinal position $V_z > 400$ μm of the track pair vertex relative to primary vertex;
- Cut on the parent particle impact parameter $D < 20$ μm.

First look at D^0 and K^0_s reconstruction (preliminary analysis)

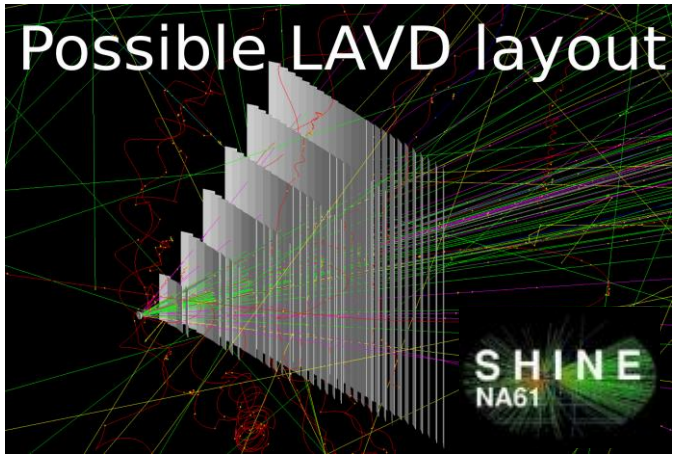
- After reducing the background one may see a small peak emerges at 1.8 GeV/c^2, which could mean an indication of D^0;
- To test the detector capabilities, it was also attempted to reconstruct K^0_s, which is much more abundant.





Summary & plans

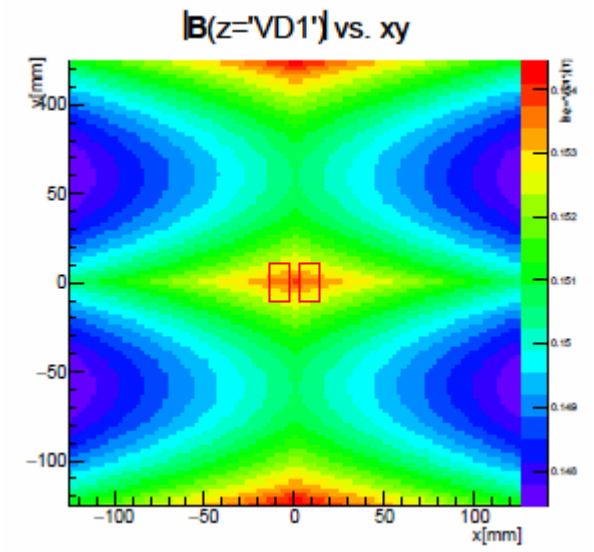
- The full Pb-Pb data set from December 2017 at top SPS energy with new high resolution Vertex Detector has been analyzed;
- At this point there is a weak indication of a D^0 signal;
- The result looks promising. However, the data set in not finally calibrated, and further optimization of track reconstruction, track matching, and analysis algorithms and cuts is still ongoing.
- Also, there will be data taking:
  - 2017: Oct p-Pb run;
  - 2017: Oct – Dec (Xe + La);
  - 2018: Pb+Pb Open Charm production beam time (150*A* GeV/*c*).
- Looking forward, an upgraded version of SAVD so-called Large Acceptance Vertex Detector (LAVD) with more sensors is being planed after upgrade of NA61 to 1kHz trigger rate after 2020. The exact design of this detector is currently under investigation.

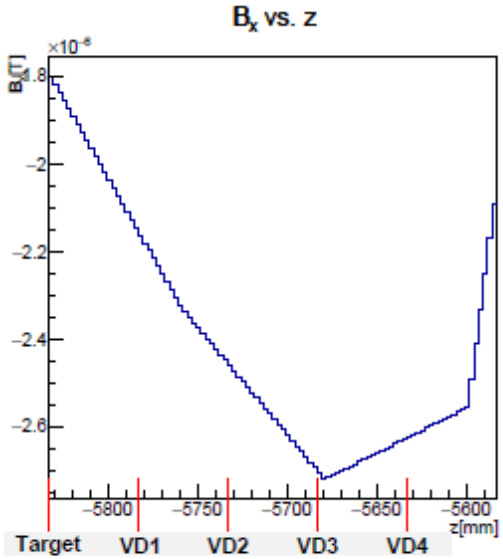


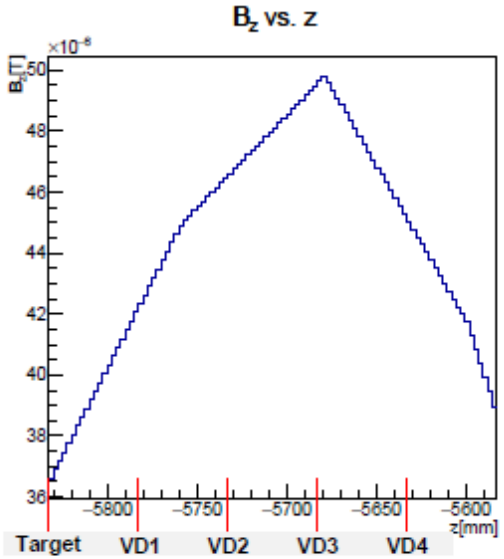
Thank you for your attention!

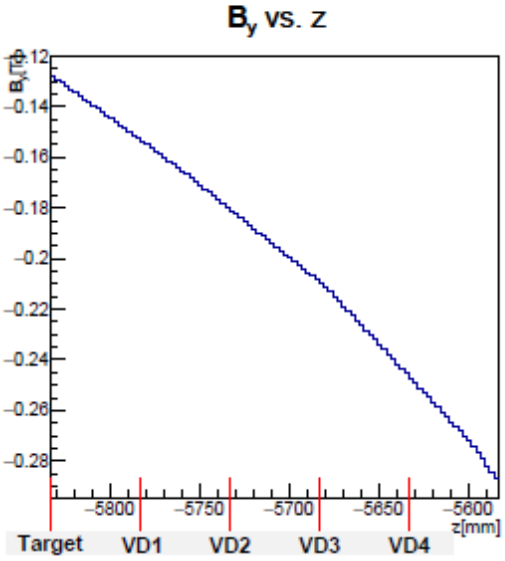
Magnetic field in VD

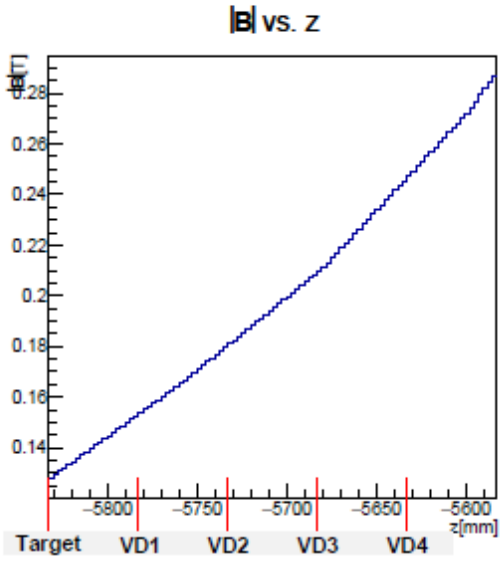
- Inhomogeneous magnetic field (0.13÷0.25T) in Vertex Detector volume.











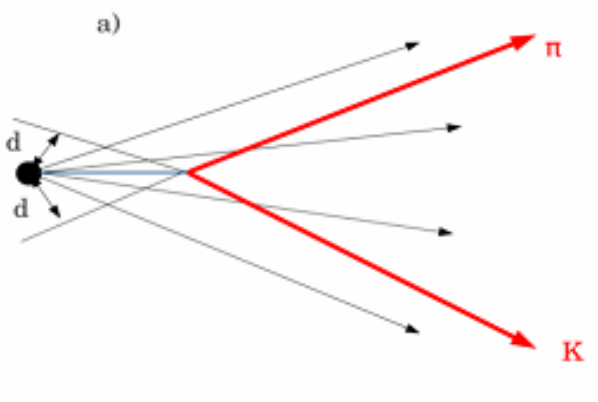
Open charm simulations

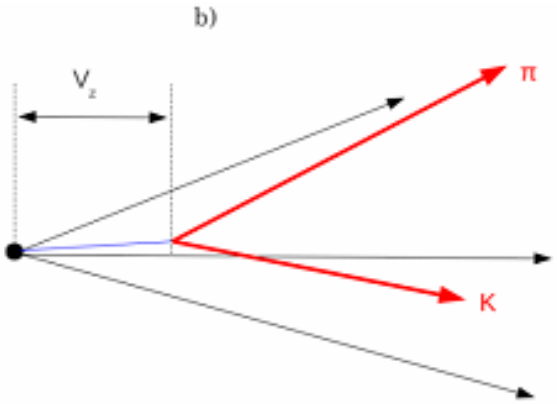
- D^0-meson can be reconstructed by its two body decay channel $D^0 \rightarrow K^- \pi^+$ with the branching ratio of 3.9%.

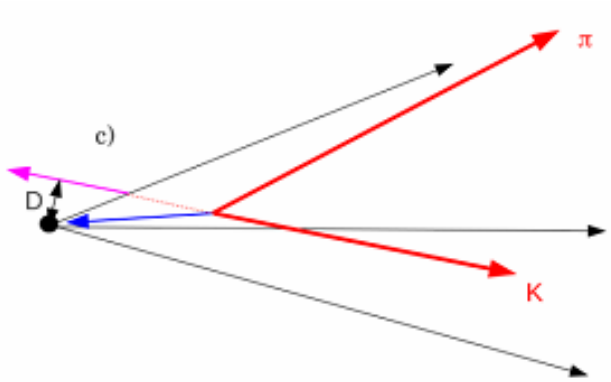
- For the physical input we generated 200k 0-10% central Pb+Pb events with AMPT event generator.
- The AMPT model predicts the average production yield of 0.01 for D^0 +anti D^0 per central Pb+Pb event.
  This value seems to be underpredicted with respect to the prediction of the HSD model that gives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

Open charm cuts

- Cut on transverse momentum $p_T > 0.31$ GeV/c;
- (a) Cut on the track impact parameter d > 31 μm;
- (b) Cut on the longitudinal position $V_z > 400$ μm of the track pair vertex relative to primary vertex;
- (c) Cut on the parent particle impact parameter D < 20 μm.

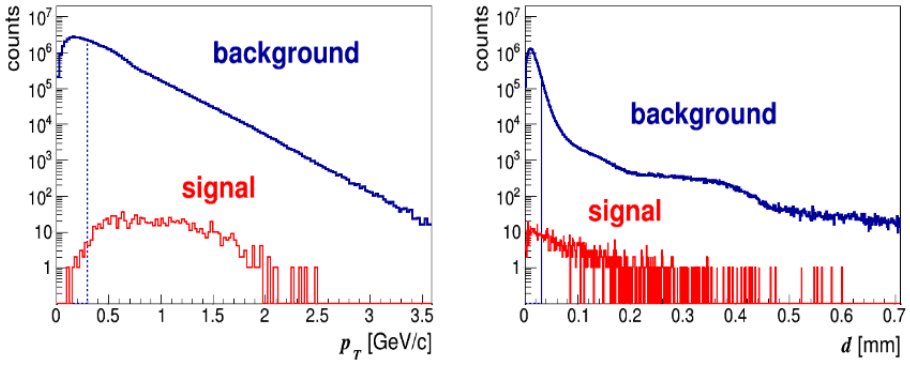


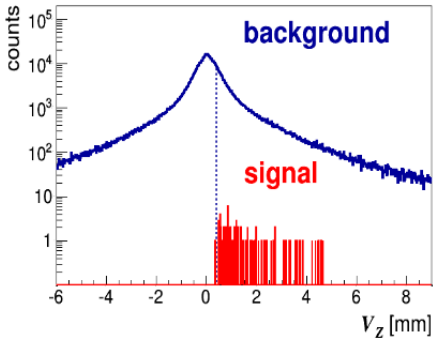


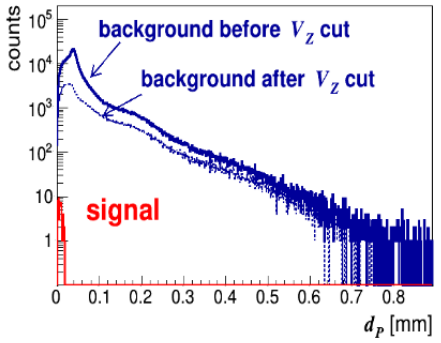


Open charm cuts

simulation







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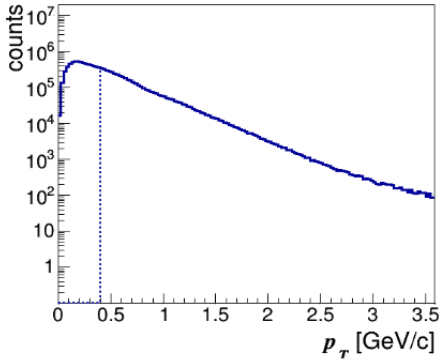
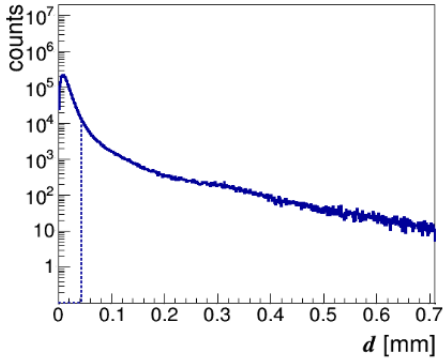
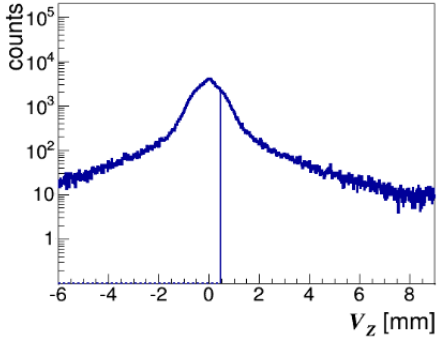
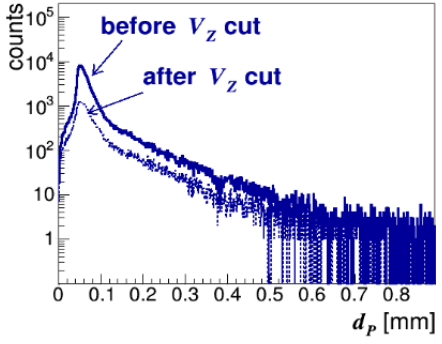


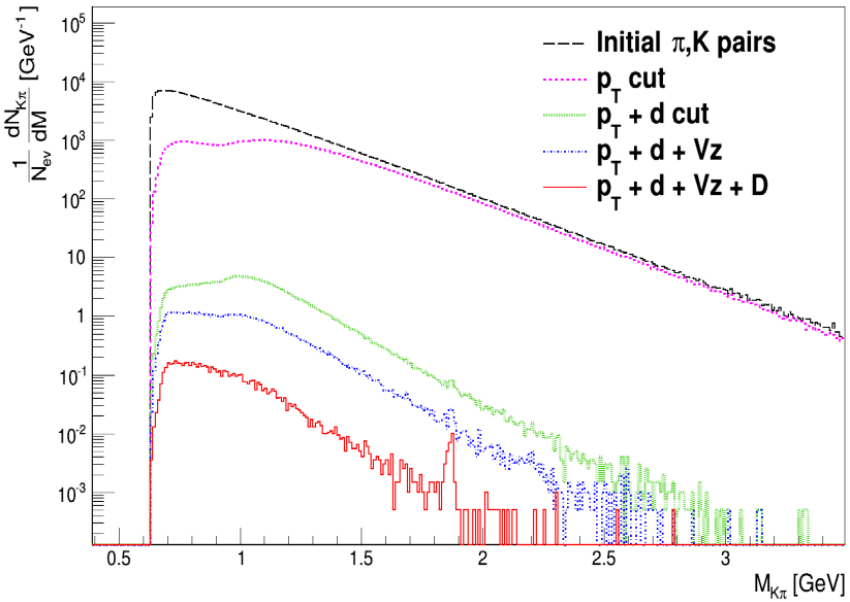






Open charm simulations

simulation



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