Track reconstruction in the inhomogeneous magnetic field for Vertex Detector of NA61/SHINE experiment at CERN SPS

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Abstract. The heavy-ion programme of the NA61/SHINE experiment at CERN SPS is expanding to allow precise measurements of exotic particles with lifetime few hundred microns. A Vertex Detector for open charm measurements at the SPS is being constructed by the NA61/SHINE Collaboration to meet the challenges of high spatial resolution of secondary vertices and efficiency of track registration. This task is solved by the application of the coordinate sensitive CMOS Monolithic Active Pixel Sensors with extremely low material budget in the new Vertex Detector.

A small-acceptance version of the Vertex Detector is being tested this year, later it will be expanded to a large-acceptance version. Simulation studies will be presented. A method of track reconstruction in the inhomogeneous magnetic field for the Vertex Detector was developed and implemented. Numerical calculations show the possibility of high precision measurements in heavy ion collisions of strange and multi strange particles, as well as heavy flavours, like charmed particles.

1. Open charm measurements for NA61/SHINE

The SPS Heavy Ion and Neutrino Experiment (NA61/SHINE) [1] at CERN was designed for studies of the properties of the onset of deconfinement and search for the critical point of strongly interacting matter. These goals are being pursued by investigating p+p, p+A and A+A collisions at different energies from 13A to 158A GeV. The layout of the experimental setup is shown in figure 1.

Heavy flavour quarks are produced at the early stage of the hadron collision and may serve as sensitive probes for properties of the QGP. For open charm measurements in nucleus-nucleus collisions at SPS energies, the experiment NA61/SHINE is being upgraded with the new Small Acceptance Vertex Detector (SAVD) [2, 3, 4]. The low yields of D mesons and their short lifetime require sufficiently fast detectors located close to the primary vertex that are capable of providing high time resolution, high tracking efficiency and high secondary vertex resolution.

2. Small Acceptance Vertex Detector for NA61/SHINE

The SAVD is positioned between the target and the VTPC-1. Four planes (stations) of coordinate-sensitive detectors located at 5, 10, 15 and 20 cm distance from the target will provide precise track and vertex reconstruction. High coordinate resolution MIMOSA-26 sensors [5]...
whose technology is based on the CMOS Pixel Sensor have been chosen as the basic detection element of the Vertex Detector stations. The sensors have very low material budget (50 \( \mu \)m thickness), the spatial resolution of 5 \( \mu \)m and their readout time is 115.2 \( \mu \)s. The sensors, the integration technology and the DAQ of the SAVD have been derived from the CBM-MVD prototype [6].

3. Track reconstruction

Track reconstruction for the Vertex Detector is based on a global method where all points are processed in the same way. The speed of such a method depends only on the number of hits, making it faster than local methods. As the track recognition method the Hough transform procedure is implemented. It uses a parametric description of a track by a set of parameters. Once the track model is chosen in the coordinate space of the detector, measurements are transformed into the track parameter space. Then, in this so-called accumulation space, using the voting procedure, track candidates are obtained as local maxima: the most popular candidates are assumed to be real tracks.

The magnetic field in the Vertex Detector volume is inhomogeneous (0.13 - 0.25T) because of the TPC magnet, and parabola in (XZ)-plane and linear in (YZ)-plane were chosen as a sufficient track model, i.e.

\[
\begin{align*}
    x &= c^2 z + a_x z + b_x, \\
    y &= a_y z + b_y.
\end{align*}
\]

The number of parameters should be kept small since size of the Hough space grows as \( O(n^l) \), where \( n \) is number of hits, \( l \) is number of parameters. In a first pass all hits are processed by the Hough Transform using the parameterization without intercepts, i.e. \((c_x, a_x, a_y)\). It allows reconstruction of the tracks from primary vertex (the coordinate origin) and secondary vertices that are close to primary, for example \(D_0\)-mesons that have short life-time. Then, in a second pass, tracks that were not found are searched using the 5 dimensional Hough Transform, i.e. with \((c_x, a_x, b_x, a_y, b_y)\).

Figure 2 depicts the reconstruction of a simulated central Pb+Pb event at 158A GeV. On figure 3 the reconstruction efficiency and contamination estimates for the Vertex Detector as stand-alone tracker are shown. The efficiency is defined as the number of true reconstructed tracks divided by the number of reconstructable track. The contamination is the number of fake reconstructed tracks divided by the number of reconstructable tracks. In principle, the values of the efficiency could be increased at the price of more contamination, and the contamination could be reduced by matching Vertex Detector tracks with TPC-tracks.
Figure 2. Reconstruction of simulated Pb+Pb 158A GeV/c event.

Figure 3. Reconstruction efficiency and contamination.

The magnetic field in the Vertex Detector volume allows momentum reconstruction of the SAVD-tracks. Integration along the track momentum is used for momentum reconstruction:

\[ p_{xz} = \frac{Ze \int B_y dl}{\sin \alpha_1 - \sin \alpha_2}, \]

where \( \alpha_1, \alpha_2 \) - angles of the track in the first and last stations. A scatter plot of the reconstructed momentum versus the true momentum (from GEANT) is shown on figure 4. The sigma of this distribution of the difference is about 0.7 GeV/c. Momentum reconstruction is difficult due to the fact that the field is weak and inhomogeneous. Nevertheless, the obtained values will help in matching SAVD-tracks and TPC-tracks.

4. Vertex Detector test run
In July 2016 SAVD was partially installed in the NA61/SHINE experimental area for the test with a beam of protons at 150A GeV/c. During this test only one side of the stations of
Corresponding momenta obtained in Geant and from reconstructed track. The number of sensors was sufficient to provide track reconstruction capability. While exposed to the beam, the sensors were investigated for noisy pixels and for 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. Thus during data analysis these pixels have to be grouped together as a “cluster”. The algorithm for connecting pixels, the so-called “clusteriser”, searches the sensor frame for fired pixels, then scans the neighbours using a recursive algorithm. Then the cluster position in the global detector coordinate system is calculated as the center-of mass of the cluster.

5. Summary
This contribution reports on the software for the Small Acceptance Vertex Detector related to track reconstruction in the inhomogeneous magnetic field and shows its good performance. The efficiency of track reconstruction in the SAVD is about 90% and track contamination is negligible.

Tests of the SAVD 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 on Pb+Pb collisions at 158\( A \) GeV. Looking forward, an upgraded version the so-called Large Acceptance Vertex Detector (LAVD) with more sensors is being planned. The exact design of this detector is currently under investigation.

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References
[1] Abgrall N et al. 2014 J Instrum 9 P06005
[2] NA61/SHINE Collaboration 2015 Addendum (Proposal) CERN-SPSC-2015-038 SPSC-P-330-ADD-8
[3] Ali Y et al. 2013 Acta Phys Pol B 44(10) 2019-34
[4] Ali Y and Staszef P 2014 J. Phys.: Conf. Series 509(1) 012083
[5] Deveaux M et al. 2011 J Instrum 6(02) C02004
[6] Koziel M et al. 2013 NIM A 732 515-8