

Development of a Vector Finder Toolkit for Track Reconstruction in MPD ITS

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Abstract—A Vector Finder approach for track reconstruction developed for the Inner Tracking System of the MPD experiment is described, including primary and secondary track reconstruction and track matching algorithms. Preliminary results of their application for the tasks of track reconstruction and track matching are presented for Monte Carlo simulated central Au + Au events at $\sqrt{s_{NN}} = 9$ GeV.

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1. INTRODUCTION

With the completion of the civil construction stage of the NICA complex [1] and beginning of the MPD detector assembly work, the MPD experiment [2] moves into the following stage of the preparations to its start-up. As one of the possible MPD upgrade steps, an Inner Tracking System (ITS) based on the next generation of silicon pixel detectors MAPS is planned to be installed between the beam pipe and the Time Projection Chamber (TPC). The new detector is expected to improve the experiment's capability for studying short-lived particles produced in the early stages of nuclear collisions. Its ultimate performance can be achieved only if adequate event reconstruction methods are developed and implemented. In this paper, the current status of the track reconstruction activity for the Inner Tracking System of the MPD project is presented, including description of the track finding approach in the ITS and the ITS-TPC track combination procedure. Preliminary results for high-multiplicity simulated events are shown using an ITS model containing 5 detector layers at radii of ~3.3, 6.6, 9.8, 14.7, and 19.6 cm.

2. VECTOR FINDER APPROACH FOR ITS TRACK RECONSTRUCTION

The Vector Finder approach [3] for track finding in the ITS is based on the combinatorial search for detector hit combinations, which can potentially belong to the same particle track. Here, a hit is a reconstructed point of the particle trajectory crossing a detector layer. Hit combinatorics is reduced by utilizing prior constraints, describing mutual position of hits from the same track on sequential detector layers.

The procedure starts by creating track candidates containing pairs of hits from the outermost detector layers. In order to be accepted, initial track candidates should be compatible with the event topology as observed in Monte Carlo simulated events. This topology defines hit acceptance windows for different geometrical projections. After building the initial set of track candidates the algorithm goes inward, trying to add hits on sequential layers to a current track candidate within some windows defined by a priori constraints depending on detector geometry, current track direction and particle transverse momentum estimates. These windows reduce combinatorics and therefore, processing time. Collected hit combinations are further fitted by the Kalman filter to form tracks and define track parameters. Track quality is determined using χ^2 metrics, so if there are track candidates with shared hits, the ones with higher χ^2 are discarded.

3. PRIMARY TRACK RECONSTRUCTION

Though, in collider experiments, the longitudinal position of beam interaction can vary in a large interval, in heavy-ion collisions with high multiplicity of produced primary particles vertex position can be determined with good accuracy before the track reconstruction process. Therefore, it can be used to define prior constraints for building tracks from primary particles, i.e. tracks passing through the primary vertex. In the reconstruction, one can use azimuthal and polar angular hit positions in the coordinate system typical for collider experiments, i.e. with Z-axis going along the beam line and XY-plane normal to it.

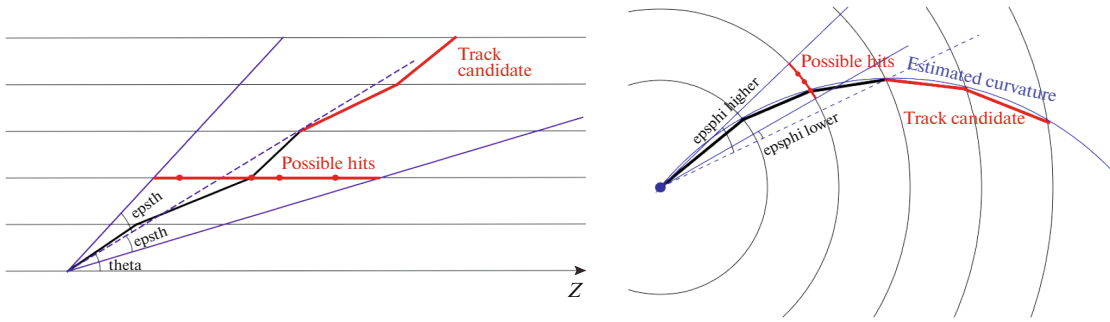


Fig. 1. Left—Primary track scheme in longitudinal projection; Right—Primary track scheme in transverse projection.

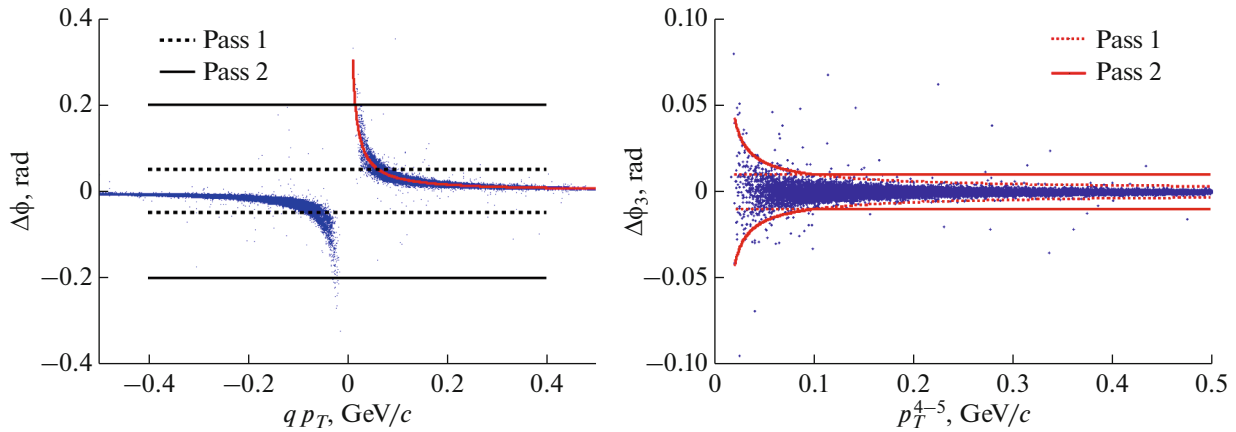


Fig. 2. (Left) Azimuthal angle difference of hits on consecutive layers from the same primary particle as a function of the signed transverse momentum with the sign given by the particle charge. Dotted and solid lines show acceptance windows for passes 1 and 2. (Right) azimuthal angle reconstruction uncertainty on layer 3 $\Delta\phi_3$ from the hit angular position on layer 4 and track transverse momentum estimation from the hits on layers 4 and 5 p_T^{4-5} and the primary vertex. Curved solid line represents the function that approximates the dependence in the form $\sim 1/p_T$.

In the longitudinal projection the magnetic field does not affect the particle trajectory, so tracks can be considered close to straight lines. Therefore, as can be seen from the track scheme in Fig. 1 (left), hits from the same track have quite close polar angles θ . That is why the acceptance window for adding hits to primary track candidates in the longitudinal projection can be defined by the precomputed epsph angles.

In the transverse projection, charged particle trajectories are affected by the magnetic field, so their tracks can be considered close to circle arcs. Therefore, only hits which satisfy track candidate curvature, thus, estimated particle transverse momentum, should be considered as possible track candidate extensions. Thus, the hit acceptance window in the transverse projection can be defined by two angles epsphi lower and epsphi higher shifted from the track candidate's last accepted hit transverse angle ϕ (Fig. 1 (right)).

epsphi lower and epsphi higher should be calculated based on estimated particle transverse momentum and charge.

The window selection criteria are illustrated in Fig. 2. The azimuthal angular position difference of hits from the same track on consecutive detector layers is shown on the left plot. The spread of points defines the acceptance window size for hits on the 4th layer, where the transverse momentum estimate is not available. To speed up the reconstruction procedure it is organized in several passes, with the window size increasing for the later passes which work with a smaller number of hits left after the earlier ones. For the layers starting from the 3rd one, it is possible to evaluate the dependence with the function $\sim 1/p_T$ and use it as a hit angular position prediction (window center) and the window size is defined by the multiple scattering effects at low p_T values (right plot in Fig. 2).

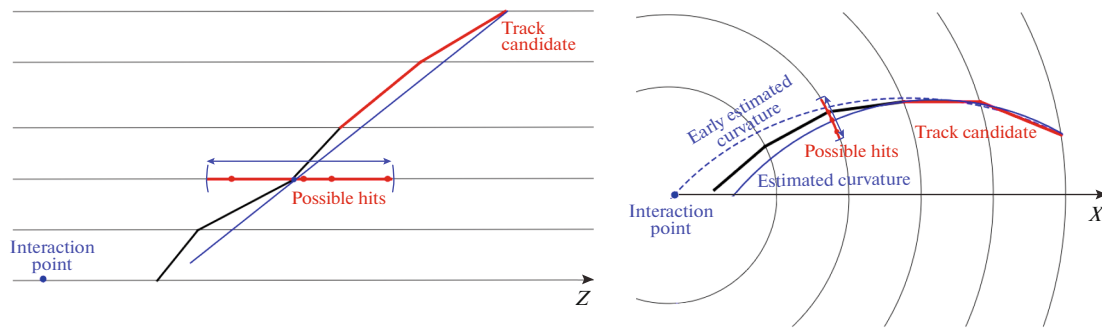


Fig. 3. (Left) Secondary track scheme in longitudinal projection; (Right) Secondary track scheme in transverse projection.

4. SECONDARY TRACK RECONSTRUCTION

Secondary tracks can be produced by decay products of short-lived particles, therefore they do not pass through the primary vertex and, generally speaking, it can not be used to define good constraints. Thus, utilization of longitudinal and transverse angles θ and ϕ is not optimal anymore, and an alternative solution should be used, e.g. based on estimated track parameters during its propagation.

As can be seen from the secondary track schemes in Fig. 3, in the longitudinal projection it is possible to use a linear extrapolation for the track continuation and utilize Z -coordinate for calculating the acceptance window. That is, Z -coordinate for the following detector layer can be calculated using the formula:

$$Z_{\text{next}} = Z_{\text{curr}} + \frac{Z_{\text{prev}} - Z_{\text{curr}}}{r_{\text{prev}} - r_{\text{curr}}} * (r_{\text{next}} - r_{\text{curr}}),$$

where Z_{curr} , Z_{prev} and Z_{next} are Z -positions of the hits on the current, previous and following layers, respec-

tively, and r_{curr} , r_{prev} and r_{next} are the corresponding layer radii.

In the transverse projection a circle arc track model can be used to do the extrapolation to the next detector layer.

Linear extrapolation and circle arc propagation require a certain number of hits on the track candidate—2 for the linear trajectory and 3 for the circle arc estimation. On the first detector layers where there are not enough hits on the current track candidate (layer 5 for the linear extrapolation and layers 4 and 5 for the circle arc propagation), the primary vertex can still be used to define the general track direction. However, the hit acceptance window size for propagating the secondary track candidates using the primary vertex should be rather large.

5. TRACK MATCHING ALGORITHM

Separate track reconstruction procedures in the ITS and TPC require a method to combine tracks from the two detectors to achieve an optimal track reconstruction quality. The following track matching procedure was implemented:

- Propagate TPC and ITS tracks to a cylinder surface with a certain radius from the beam line. The cylinder should lie between the detectors. For the current detector configuration a radius of 27.0 cm was chosen.
- Update track parameters—longitudinal position z and transverse position $r\phi$
- For each ITS track a matching area is defined using the z and $r\phi$ parameters (Fig. 4). Each TPC track propagated to this area should be considered as a possible match.
- Combine TPC and ITS tracks, creating a track containing hits from both detectors, i.e. a hit from the ITS track is added to the combined track if the χ^2 increment does not exceed a certain value (10.0 in the current version).
- If no TPC track was found within the window, ITS standalone track is stored.

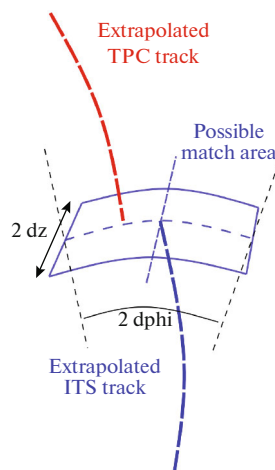


Fig. 4. Track matching scheme.

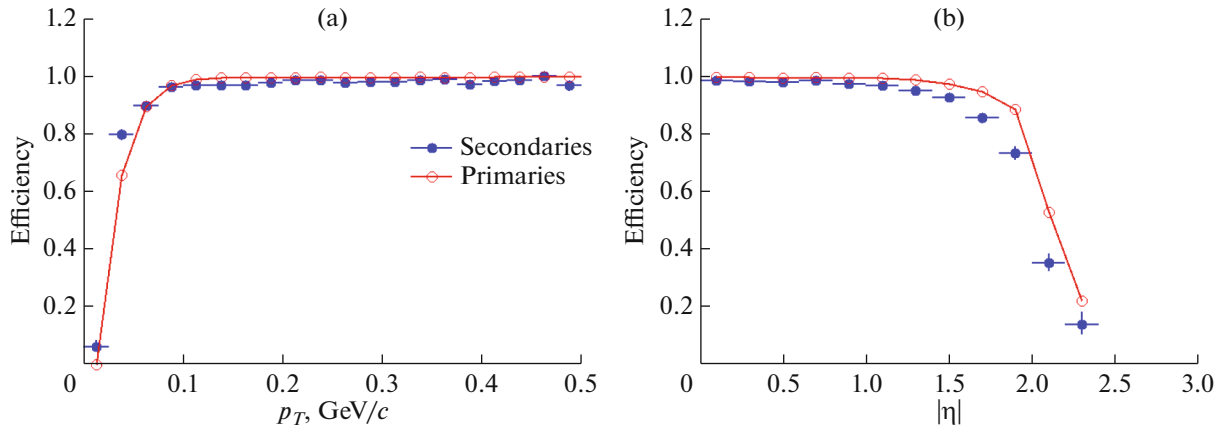


Fig. 5. (a) Reconstruction efficiency vs. transverse momentum for primary and secondary tracks with $|\eta| < 1.2$; (b) reconstruction efficiency vs. $|\eta|$ for primary and secondary tracks with $p_T > 0.1$ GeV/c.

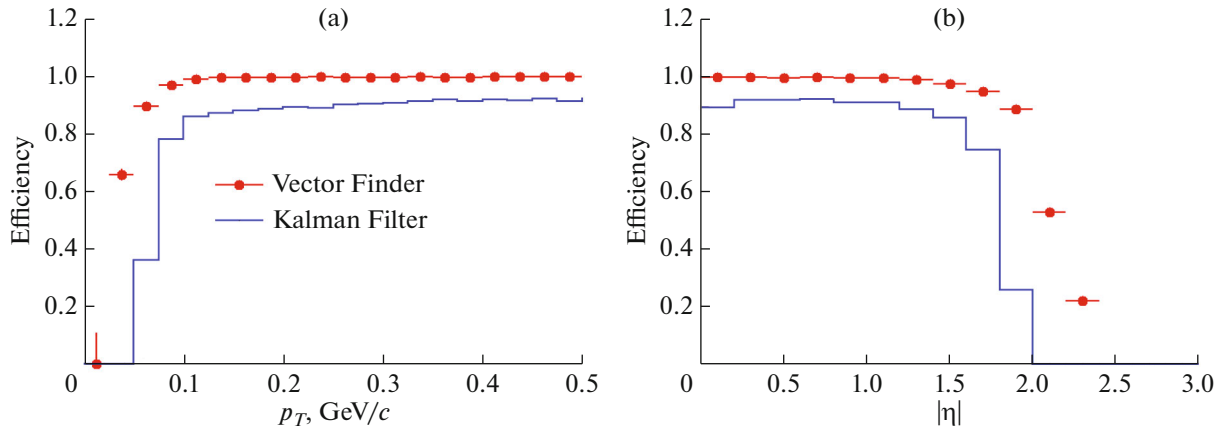


Fig. 6. (a) Reconstruction efficiency vs transverse momentum for primary tracks with $|\eta| < 1.2$ obtained with Vector Finder and Kalman Filter methods; (b) Reconstruction efficiency vs. $|\eta|$ with $p_T > 0.1$ GeV/c.

For non-unique matches the match with the high-quality is stored. The quality of a combined track is defined as

$$quality = N_{hits} + (100.0 - \min(\chi^2, 100.0))/101.0,$$

where N_{hits} is the number of hits in the combined track and χ^2 is its total χ^2 value. One can see that according to this definition the number of hits has precedence over the χ^2 value.

6. PERFORMANCE RESULTS

To check the performance of the implemented approach a sample of UrQMD [4] generated events of central Au + Au collisions at $\sqrt{s_{NN}} = 9$ GeV was used. The events were passed through the detector setup

within the MpdRoot software framework [5] using the GEANT3 transport package to simulate the effect of the material and magnetic field.

The efficiency of the developed Vector Finder approach for primary and secondary tracks as a function of transverse momentum p_T and pseudorapidity η is shown in Fig. 5. One can see that the method produces quite good results both for primary and secondary tracks. Figure 6 demonstrates that Vector Finder gives some performance improvement as compared with a method based on a Kalman filter extrapolation of TPC tracks.

Preliminary results on the matching efficiency for combining primary tracks from the ITS and TPC detectors are shown in Fig. 7. One can see that some additional tuning for low- p_T tracks is required.

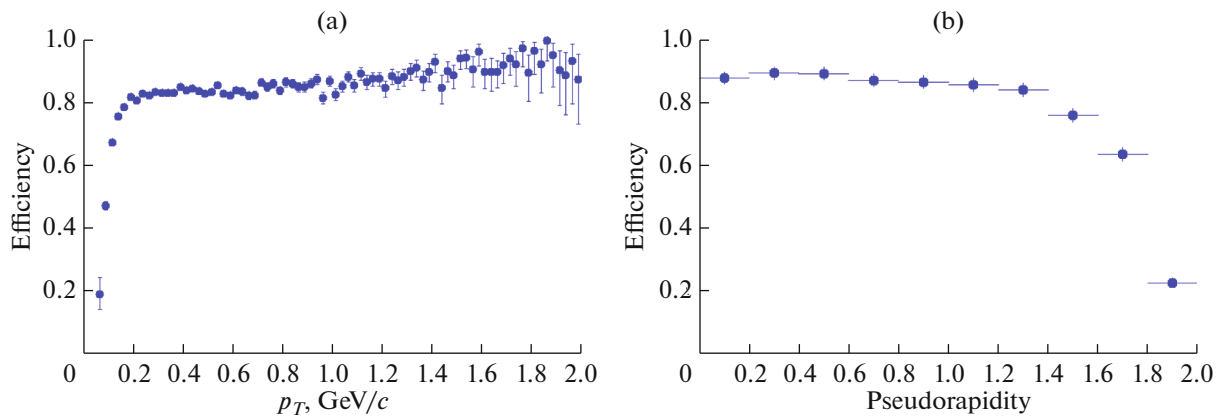


Fig. 7. (a) Track matching efficiency vs transverse momentum for primary tracks with $|\eta| < 1.2$ (b). Track matching efficiency vs $|\eta|$ with $|\eta| > 0.1$ GeV/c.

7. SUMMARY

A Vector Finder approach for primary and secondary track reconstruction in the Inner Tracking System of the MPD experiment and a track matching algorithm for combining TPC and ITS tracks have been developed and described. It has been shown that the methods proposed and implemented demonstrate quite good performance results and can help to fully exploit the ITS potential at the later stage of the MPD experiment.

FUNDING

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