JOINT INSTITUTE FOR NUCLEAR RESEARCH
Laboratory of High Energy Physics

Implementation of a cellular automaton method for track reconstruction in the inner tracking system of MPD at NICA

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XXII International Baldin Seminar on High Energy Physics Problems
«Relativistic Nuclear Physics & Quantum Chromodynamics»
15-20 September 2014, Dubna

The MultiPurpose Detector – MPD

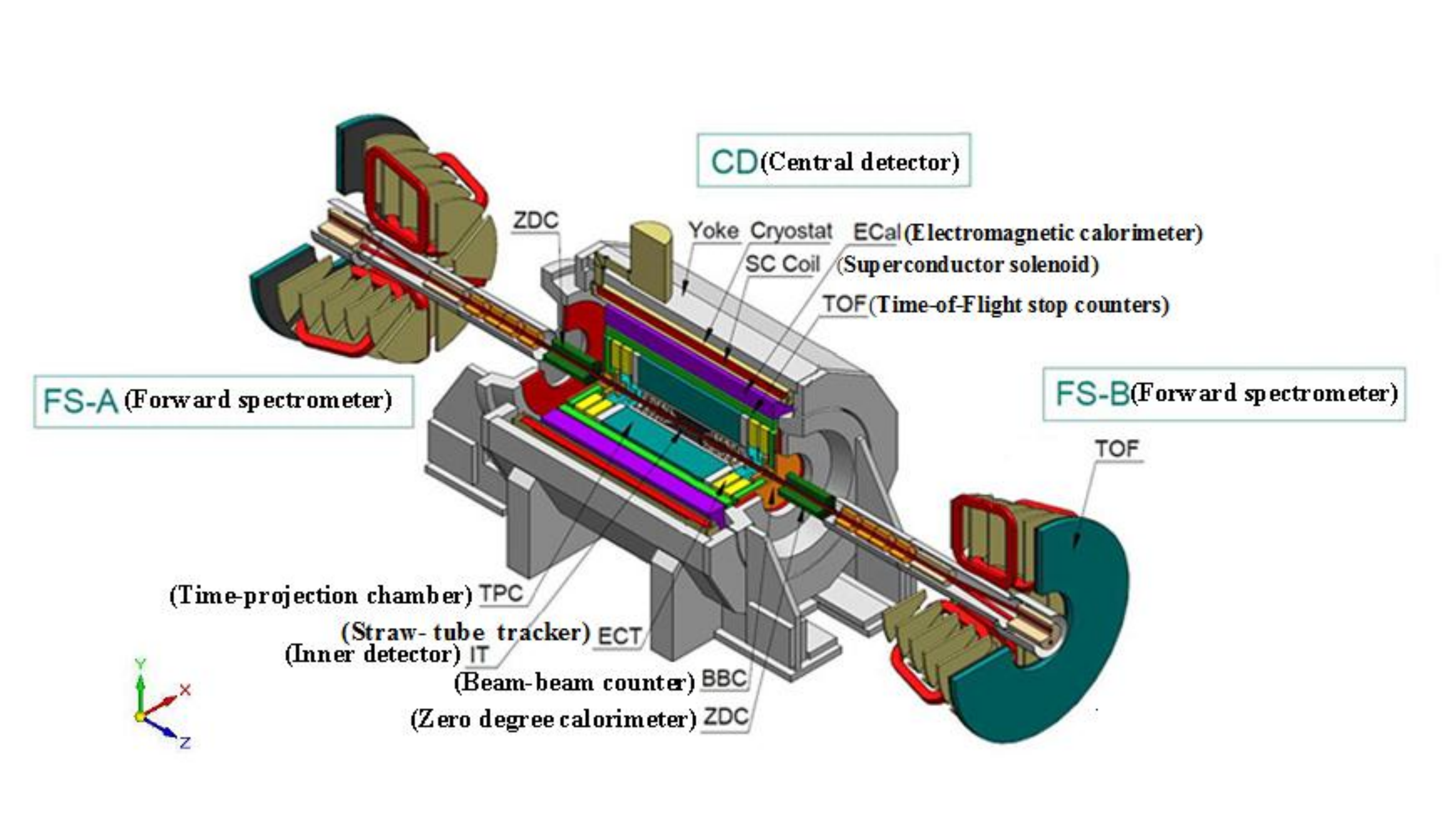

Fig. 1. General view of the detector MPD

Tracking tasks

Reconstruction of events with high multiplicity is a challenge, which physicists had started to be facing relatively recently (within the last 10 years or so - experiments at RHIC and LHC colliders).

In future experiments (CBM at FAIR and MPD at NICA), this problem will be even more difficult due to the fact that the effective realization of the physics program of searching for new states of nuclear matter will require the reconstruction of particle tracks with very low momenta (of the order of hundreds of MeV/c and even less) and processing of large amounts of experimental data.

TPC and ITS – central tracking detectors of MPD

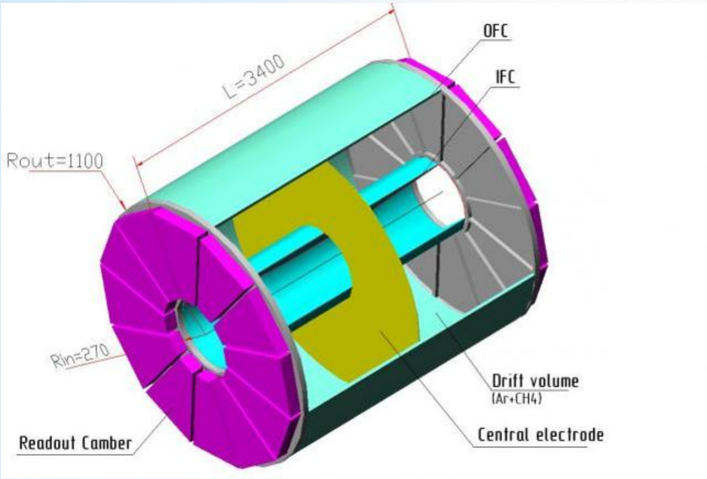

Fig. 2. The layout of TPC detector

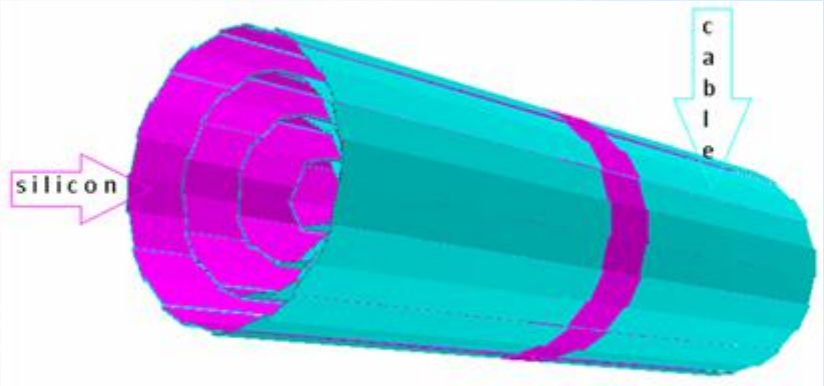

Fig. 3. The layout of ITS detector

The geometry of TPC (Time-Projection Chamber) and ITS (Inner Tracking System) differs in complexity. Contrary to TPC, the track detector ITS has only four layers with multiple sensitive element overlaps.

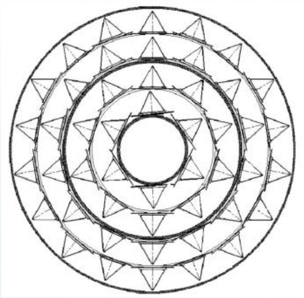

Fig. 4. Transverse view of the cylinder part of the ITS (along the beam direction)

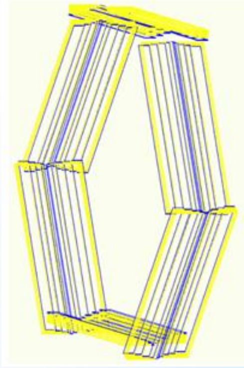

Fig. 5. The layout of the innermost ITS layer

Inner Tracking System

In MPD, ITS is the second phase detector. It is intended to do the following:

- First, it will enhance track reconstruction capabilities of all other tracking subsystems - ITS will be able to improve tracking of particles with momentum less than 150 MeV/c

- Second, the tracker will improve the identification and reconstruction of relatively rare events of hyperon production, in particular, hyperons with strangeness -2 and -3

Kalman filter technique of reconstruction of particle tracks in MPD

The current approach to the problem of track reconstruction is based on the method of Kalman - filter. This method provides means to find tracks and determine their parameters simultaneously. For the central tracking detector TPC with its relatively «simple» geometry, Kalman filter is a natural choice of the reconstruction method.

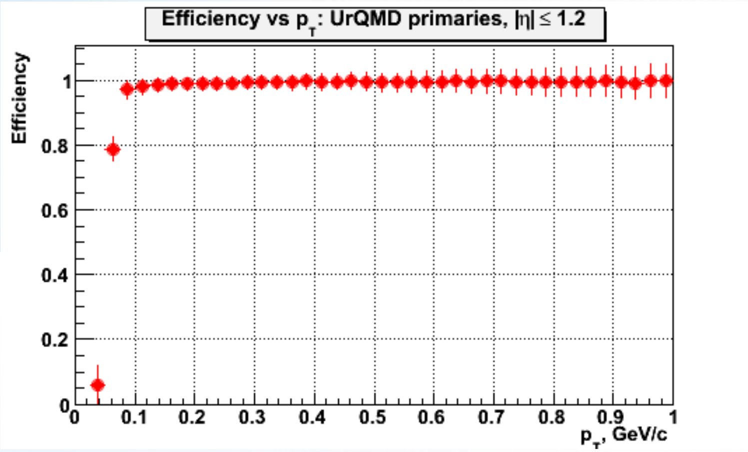

Fig. 6. Efficiency of track finding in the TPC

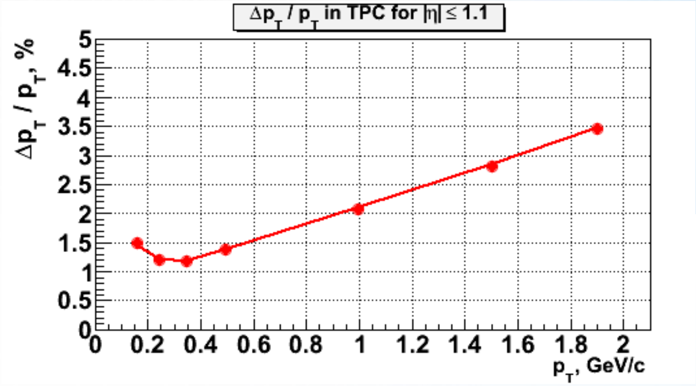

Fig. 7. The relative error of particle transverse momentum estimate in TPC

A large number of ITS hits and a small angular distance between them require a special approach, for instance, as the one proposed in the cellular automaton (CA) method.

CA algorithm

The algorithm of a cellular automaton consists of two consecutive stages::

- formation of tracks – segments
- construction of tracks - candidates

The principle of operation of the machine is based on the "closeness" of adjacent segments. The neighborhood was defined by two angles, allowing two neighbour segments (with close angles) to be combined.

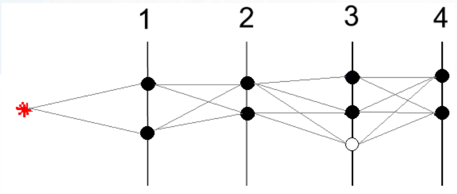

Fig. 9 Initial configuration of CA

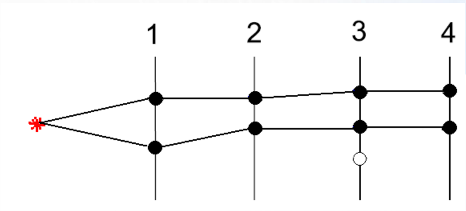

Fig. 10. Result of work of CA

Research objectives for MPD:

1. development of CA algorithm for ITS taking into account its features
2. application of CA results for the initialization of the Kalman filter.

Method of cellular automata in the task of reconstruction of particle tracks in MPD

Particle track reconstruction algorithm in the vertex detector ITS consists of three main steps:

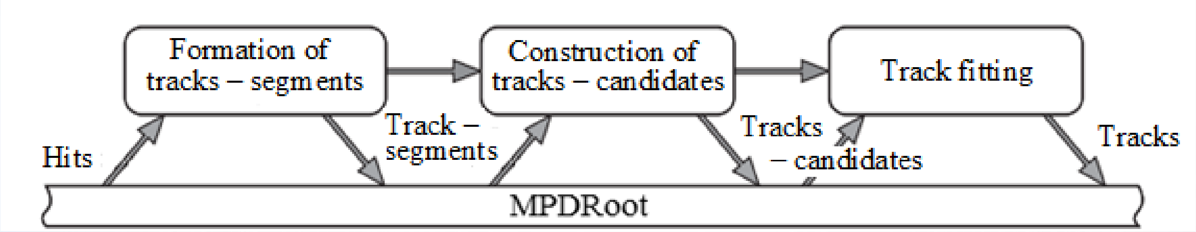

Fig. 8. Track reconstruction steps.

As an initial information, the ITS hits were used. The hits are the coordinates of particle crossing points with the detector planes.

To initialize the Kalman filter for ITS, it is necessary to determine:

- parameters of the track state vector for the zero iteration
- initial covariance matrix of these parameters.

Realization of CA algorithm

For each layer of the detector, angular acceptance windows ("cuts") on the transverse angle (dangt) and longitudinal angle (dangl) were introduced. Schematic representation of the angles dangl and dangt is shown in Figures 11 and 12. The main difference between these angles is that the particle track in the longitudinal plane of is described by a straight line, and in the transverse plane by a circular arc due to deflection in the magnetic field.

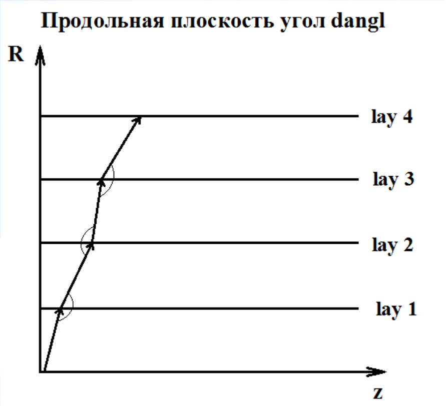

Fig. 11. Schematic representation of the angle dangl in the longitudinal plane

Fig. 12. Schematic representation of the angle dangt in the transverse plane

Realization of CA algorithm

During the first step the angular distributions of dangt and dangl for sets of tracks with fixed transverse momentum p_t were produced to obtain the dependences of their RMS (root mean square) on p_t. These dependences are required to obtain exact values of acceptance cuts for different values of p_t. The spread of angles for fixed p_t is due to the coordinate reconstruction errors and multiple scattering of particles in the detector material.

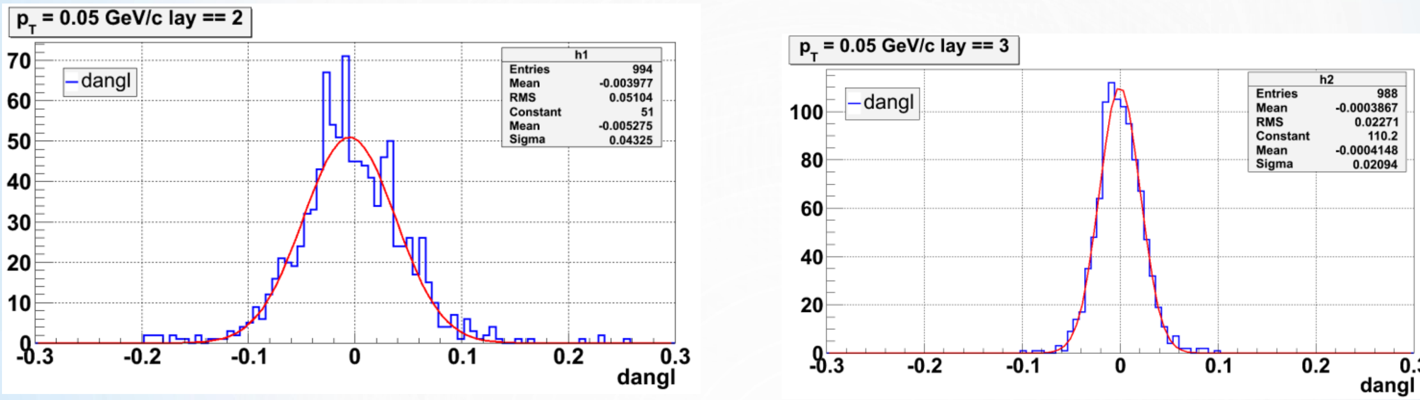

Fig. 13. Histograms dangl for p_t = 0.05 GeV/c

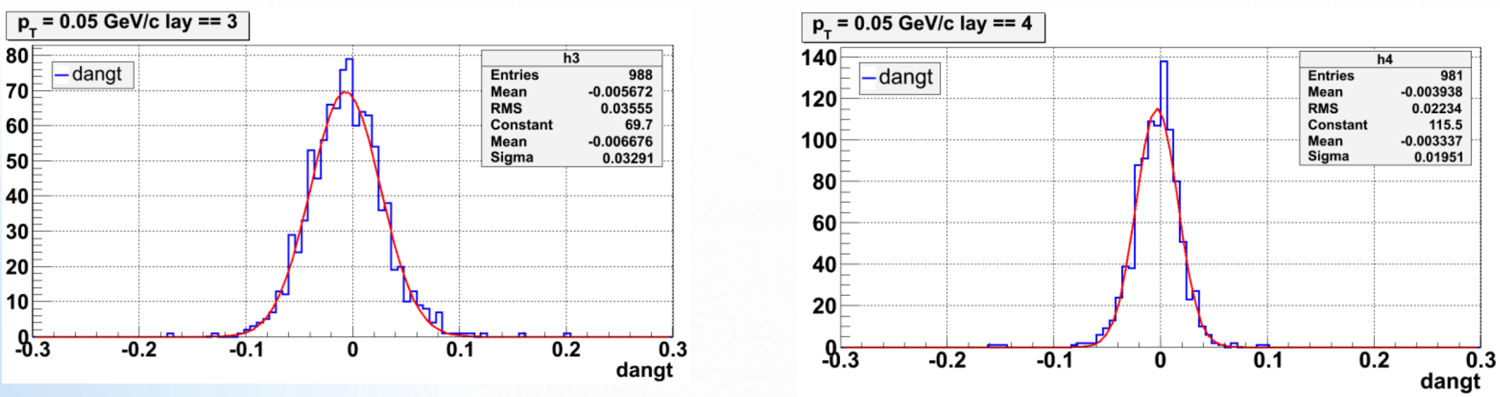

Fig. 14. Histograms dangt for p_t = 0.05 GeV/c

Realization of CA algorithm

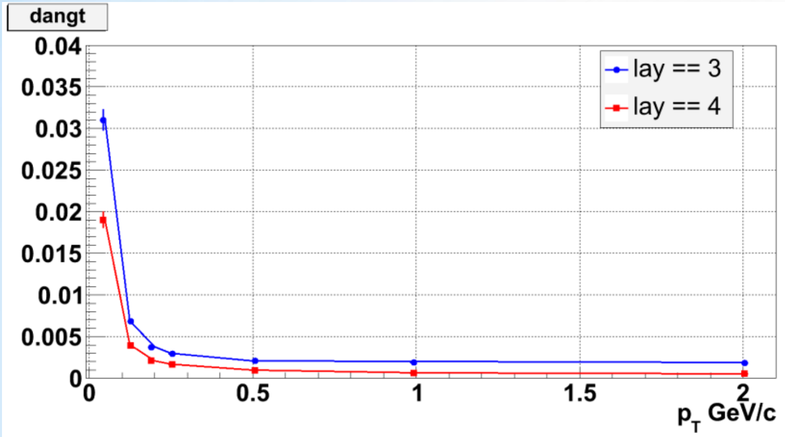

Fig. 15. Dangt sigma dependence on p_t (layers 3,4)

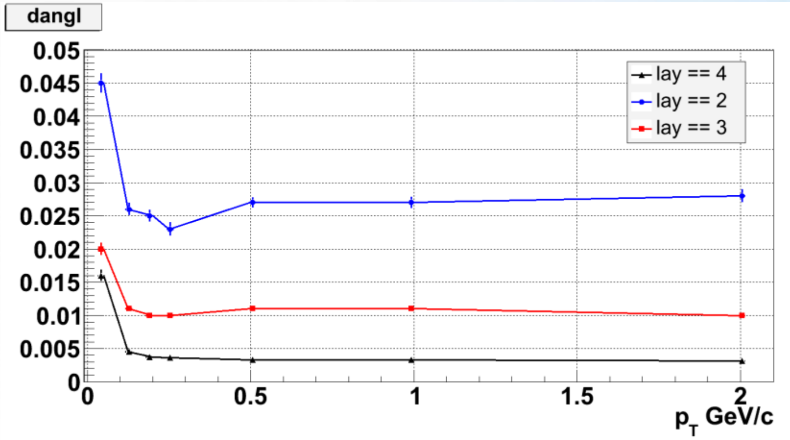

Fig. 16. Dangl sigma dependence on p_t (layers 2 – 4)

During the second step the track segments are combined into the tracks – candidates using the cuts from the first step according to the following scheme:

- two segments, built from hits from the first three layers of the detector give a p_t-estimate from the transverse angle between the segments;
- for the given p_t, it is checked whether the longitudinal angle is within the permissible range;
- the procedure is repeated for the next layer using the information about the angles from previous layers (by averaging).

In order to reduce the number of initial track segments for the first layer a limit on the pseudorapidity ($|\eta| < 2$) was set. In addition, it was proposed to use the CA procedure in three passes - the first one to search for tracks with $p_t > 0.4$ GeV/c, the second with $p_t > 0.2$ GeV/c, and the third with $p_t > 0.05$ GeV/c for the remaining hits. After the third step the initial track parameters and error matrix are constructed for the resulting track - candidates. They are stored for the subsequent use in the Kalman - filter.

Results of track extrapolation and parameter evaluation procedures

To check the results of the algorithm the normalized parameter residuals (pulls), demonstrating the correctness of estimates of the track parameter errors were calculated.

$$pull_x = \frac{x_{MC} - x_{rec}}{\sigma_x}$$

x_{MC} - true (Monte – Carlo) value of track parameter

x_{rec} - reconstructed track parameter value

σ_x - computed value of covariance matrix element

Assuming a correct estimate of the covariance matrix, the distribution of the normalized residuals should be described by the normal distribution with a mean of 0 and variance close to 1.

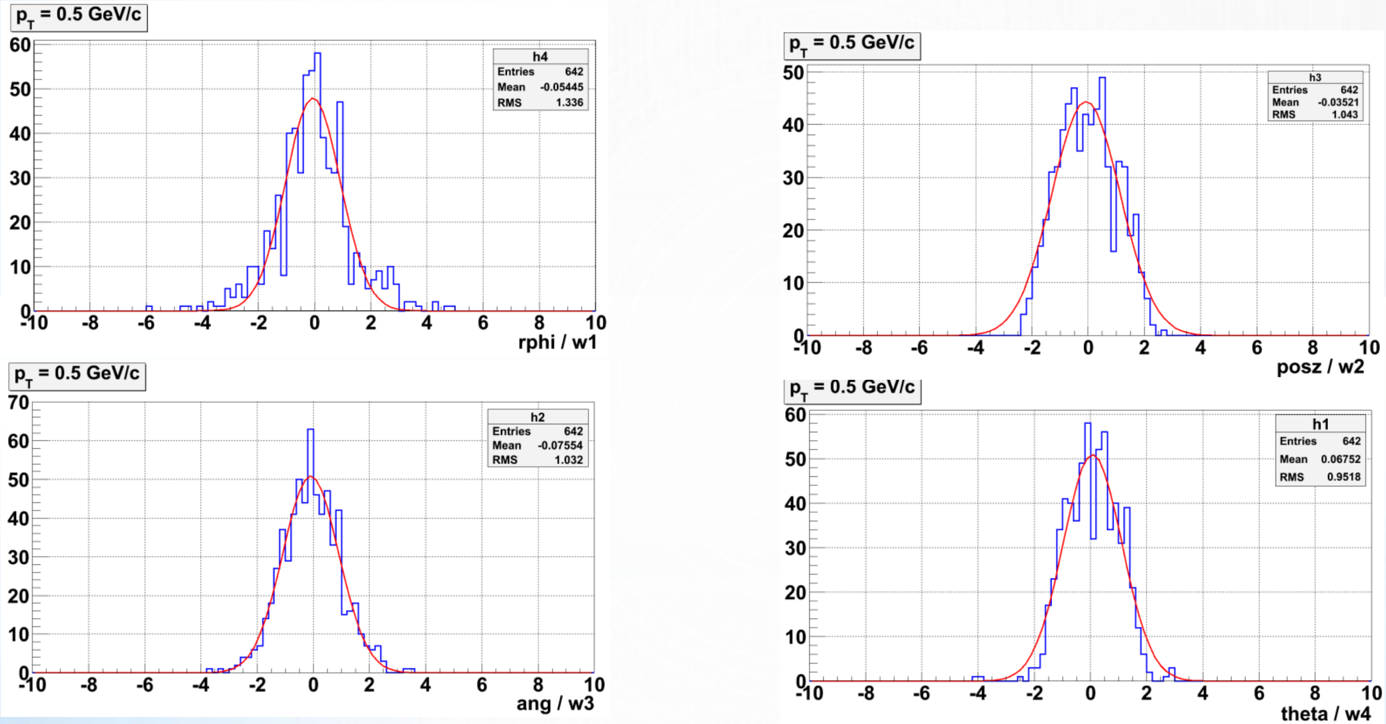

Fig. 16. Distributions of pulls, where(rphi, posz, ang, theta) are the true errors, (w1,w2,w3,w4) are the calculated ones.

Results of tracking in ITS

To test the cellular automaton algorithm and study its characteristics, the UrQMD generator of Au - Au interactions with an average multiplicity of about 1000 tracks was used. The relative momentum resolution is defined by:

$$\frac{Pt^{rec} - Pt^{MC}}{Pt^{MC}}$$

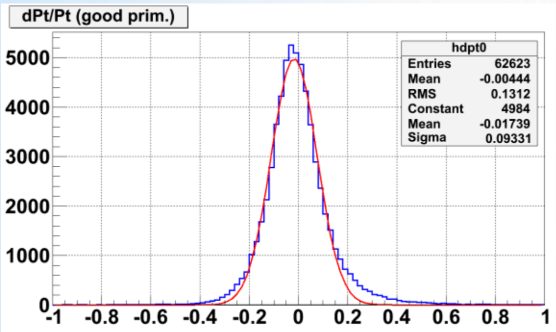

Fig. 17. The relative momentum resolution for the primary tracks.

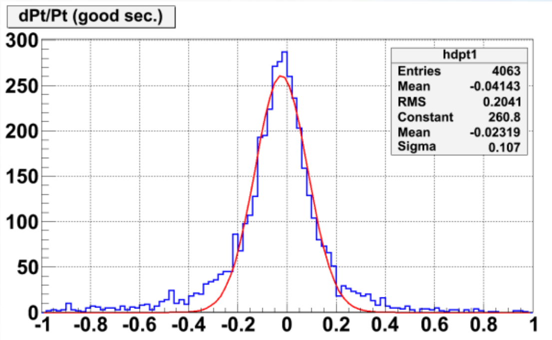

Fig. 18. The relative momentum resolution for the secondary tracks.

Fig. 19 shows the distribution of chi2 / hit. Here CellTrack are the tracks found by the CA algorithm CA and fitted by the Kalman filter. TPC -> ITS - tracks were found in TPC using the Kalman filter and extrapolated to ITS.

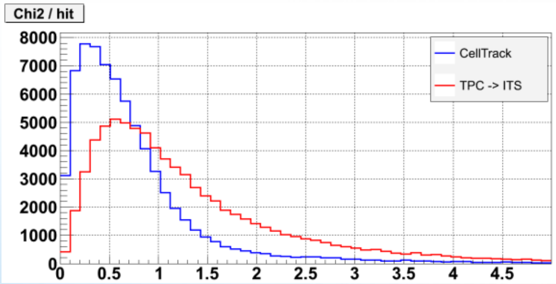

Fig. 19. Distribution chi2/hit

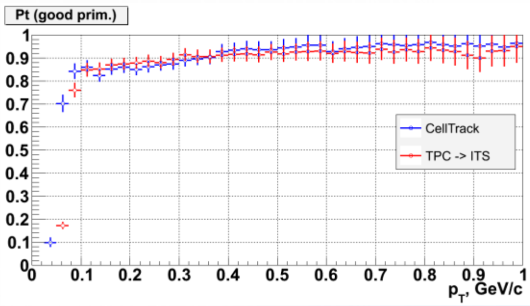

Fig. 20. Efficiency of primary track finding vs p_t

Fig. 20 shows a plot of track reconstruction efficiency for primary tracks as a function of the transverse momentum. For low momenta ITS is more efficient than TPC.

Conclusions

- The cellular automaton algorithm has been developed and implemented for track reconstruction in MPD ITS within the MpdRoot framework
- A hit selection scheme on each layer of the ITS detector has been improved
- The 3-pass track finding procedure has been realized
- The candidate track selection criteria (cuts) have been determined for each layer of the detector
- Several ROOT macros have been written allowing to adjust track parameters, as well as to visualize the results after the reconstruction
- The method of Kalman filter has been adapted for candidate tracks obtained in the cellular automaton
- Some work was done to accelerate the CA procedure
- The algorithm of a cellular automaton at this stage performs its task, but more research and development is required in order to improve its performance.

Thank you for your attention