TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
FUNDAMENTAL SCIENCES | NAUKI PODSTAWOWE

1-NP/2016

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THREE-DIMENSIONAL PATTERN RECOGNITION FOR LINEAR SECTIONS OF FORWARD TRACKER IN PANDA EXPERIMENT

ROZPOZNAWANIE ŚLADU W TRZECH WYMIARACH DLA SEKCJI LINIOWYCH TRACKERA W EKSPERYMENCIE PANDA

A b s t r a c t

Straw tube detectors operating as drift detectors are commonly used in nuclear and particle physics experiments. The straw tubes are arranged in layers and placed in areas both with and without magnetic field. In order to resolve the 3D coordinates of a track, the straws are placed in multiple overlapping layers at varying angles of inclination. By measuring the drift time and then converting it to the drift distance, a position resolution per straw can be achieved. Knowing the geometry of the detector, the position of hit straws and the drift distances, it is possible to determine the tracks of the moving particles. In the paper we present the algorithm for the 3D track reconstruction in areas without magnetic field by using vertical and skewed straws. The algorithm has been prepared for the Forward Tracker in the PANDA experiment.

Keywords: straw tube detector, *track recognition*, *analytical method*

S t r e s z c z e n i e

Detektory słomkowe działające jako detektory dryfowe są powszechnie stosowane w eksperymentach fizyki jądrowej i cząstek. Słomki są układane w warstwy i umieszczane zarówno w obszarach z polem magnetycznym jak i bez niego w wielu nakładających się warstwach pod różnymi kątami nachylenia. W celu wyznaczenia współrzędnych toru w trzech wymiarach, dokonuje się pomiaru czasu dryfu, a następnie przekształca się go na odległość punktu interakcji cząstki z materiałem detektora od drutu sygnałowego. Znając geometrię detektora, położenia zapalonych słomek i skojarzone z nimi odległości dryfu, jest możliwe wyznaczenie torów, po których poruszają się cząstki. W pracy przedstawiono algorytm rekonstrukcji torów 3D na obszarach bez pola magnetycznego za pomocą pionowych i ukośnych słomek. Algorytm został przygotowany dla Forward Trackera w eksperymencie PANDA.

Słowa kluczowe: detector słomkowy, *rozpoznawanie śladu*, *metoda analityczna*

DOI: 10.4467/2353737XCT.16.150.5761

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1. Introduction

In experimental and applied particle physics, nuclear physics and nuclear engineering, a particle detector is a device used to detect, track, or identify high-energy particles. It may also deliver information on other attributes such as its momentum or charge.

Drift chambers are used to measure the space coordinates of the charged particle trajectory. This is achieved by measuring the drift time of the ionization electrons to the sensitive electrodes [1]. This technology is applied also in the straw drift tube chambers [2]. The straw type detectors differ in the number of the straws and also their position or orientation. The path is determined by the best fit to coordinates calculated using information coming from hit straws. Additionally, the measured drift time, which is proportional to the distance of the particle's closest approach to that chamber's sense wire, allows the coordinate to be determined with precision better than the straw radius.

The track pattern recognition in detectors has been developed since the first detector was built. A review can be found in [3]. The author after a brief introduction discusses different approaches in global and local methods of track pattern recognition including their strengths and shortcomings. In [4] a novel track finding algorithm, named the Drift Tube Hough Transform (DTHT) algorithm, is presented. The DTHT algorithm uses the possible explanations for a lack of particle hits as additional information, and takes into account all possible scenarios that may occur in the tubes.

It is quite clear that not only the accuracy of the determination of the particle track properties should be taken into account. One should also stress the importance of the analysis time especially in case of on-line processing. For this reason a unique algorithm for each detector is needed.

In this paper the algorithm for the 3D track recognition for a linear forward tracker segment is presented. It is designed for the PANDA experiment [5]. This experiment is one of the key experiments at the Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany. It is foreseen to study the collisions of an anti-proton beam with different fixed targets.

2. Construction of Forward Tracking Stations in PANDA experiment

The Forward Tracker (FT) in the PANDA experiment consists of three pairs of planar tracking stations (Fig. 1). One pair (FT1, FT2) is placed in front of the magnet gap, the second (FT3, FT4) is placed inside the magnet gap (dipole field) and the third pair (FT5, FT6) is placed behind the magnet gap, in order to track the low transverse momentum particles exiting the magnet yoke [6].

Each tracking station consists of four double layers of straw tubes oriented respectively at 0°, +5°, –5°, 0° (Fig. 2) with respect to the vertical direction.

Each double layer contains a different numbers of straws and has the beam pipe openings of different dimensions. The details of the geometry of active areas, positions along the beam direction and the number of straw tubes in individual tracking stations can be found in [7].

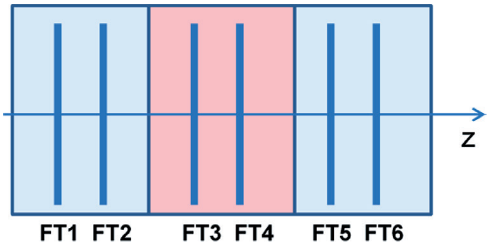

Fig. 1. Forward Tracking Stations in PANDA experiment; FT1, FT2 – in front of the magnet gap, FT3, FT4 – inside the magnet gap, FT5, FT6 – behind the magnet gap

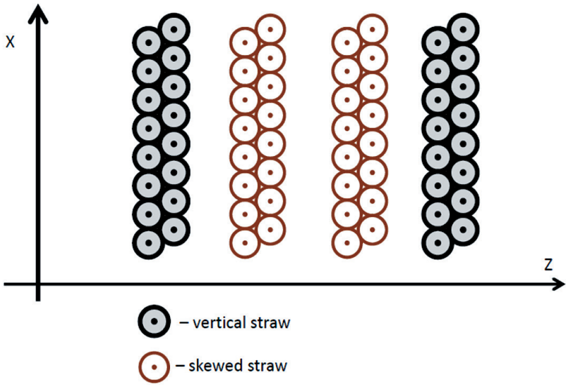

Fig. 2. One Forward Tracking Station

The most important properties of the straws for the track pattern recognition are:
- the straw diameter – 10.1 mm,
- the Mylar straw tube wall thickness – 0.03 mm,
- the tungsten, sense wire diameter – 0.02 mm,
- the gas mixture: 90%Ar + 10% CO at 2 bar.

The positions of individual sense wires in the FT straw tubes are described by straight line equations. The equations are given in a right-handed coordinate system with origin located in the nominal PANDA interaction point, Z-axis is parallel to the beam direction and Y-axis is oriented in the vertical direction.

Each straw has its unique ID number which can be used to access the layer and the tracking station numbers as well as the set of parameters describing the position of the straw sense wire.

Since the outer stations (FT1, FT2 marked as FT12 and FT5, FT6 marked as FT56) are situated outside the magnetic field it can be roughly assumed, neglecting the multiple scattering effects in light material, that in these areas particles will move along a straight line. In contrast, the charged particle trajectory in the central stations (FT3, FT4 marked as FT34) will be close to a helix: circle in X-Z and line in Y-Z projection.

To determine the particle track in three-dimensional space it is enough to calculate the track parameters in two independent two-dimensional spaces:

– horizontal plane ZOX using the vertical straws,
– vertical plane ZOY using the inclined straws.

This paper presents the three-dimensional track recognition using the FT12 and FT56 stations situated outside the magnetic field.

3. Description of the method

It is clear that the same algorithm the particle track finding can be used in the FT12 or FT56 stations since both of them are located in the regions free of the magnetic field.

In the FT12 tracking station there are four double layers of straw tubes. Half of them are vertical and the others are skewed. A straw located above the beam pipe opening matches the direction of the corresponding straw located below the opening i.e. both are described by the same equation.

The first step of the algorithm is to read in the forward detector geometry data which describe all the straw tubes arranged in 48 layers. In turn, each straw is attributed a set of five numbers, {ID, l, x, y, z}, where ID is the unique straw ordinal number, l is the layer number, x, y, z are the three coordinates which enable the determination of the equation describing a wire in a give area of the detector. The next step is to load input data generated by the PANDAROOT software. The simulator delivers events, containing for example particles of selected energies and selected angles with respect to the beam, which are passed through the detector simulation. During this operation the event number, ID-s of all hit straws (hits) are stored, and the drift radius r for each hit is calculated. Also, real (true) coordinates of the track are stored for each hit. This information is necessary at the later stage of the track pattern recognition to verify the correctness of the obtained results. Input data are loaded into two arrays. One stores information considering the vertical straws, the other one the skewed straws.

3.1. Track recognition in the ZOX plane using the vertical straws

To determine the particle track in the ZOX plane the layers with vertical straws are required. In the case of the tracking stations FT12 the processed layers are: 1, 2, 7, 8, 9, 10, 15 and 16.

At the beginning the track candidates are searched for. Based on the list of vertical hit straws we choose all pairs of the straws ($S1$, $S2$), where the straw $S1(z1, x1)$ with the drift radius $r1$ belongs to the layer 1 or 2, and $S2(z2, x2)$ with the drift radius $r2$ belongs to the layer 15 or 16. Points ($z1$, $x1$) and ($z2$, $x2$) define the place of the intersection wires with the ZOX plane. Next, the straight line L: $x=A*z + B$ passing through these points is constructed. In consequence, the algorithm then looks for all hit vertical straws $S_i(z_i, x_i)$, whose distance from this line is smaller than a predetermined value d (Fig. 3):

$$\frac{\left|A * z_i + B - x_i\right|}{\sqrt{1 + A^2}} < d, \tag{1}$$

with *d* defined as:

$$d = \max(r1, r2) + 0.5\ \text{cm} \tag{2}$$

where *d* is measured in centimetres and the constant 0.5 cm is the inner radius of a straw tube.

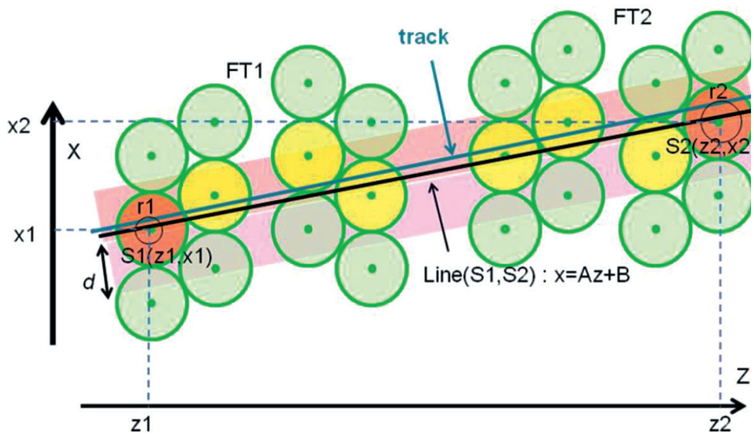

Fig. 3. Candidates to the track on ZOX plane

If the number of selected straws (with *S*1 and *S*2) is greater than 6 the case is accepted and two circles *c*(*S*1, *r*1) and *c*(*S*2, *r*2) are used to construct four tangent lines, see Fig. 4. Later, for each tangent line a new straw search is performed. Again the distance between the selected tangent line and the straw centre is calculated.

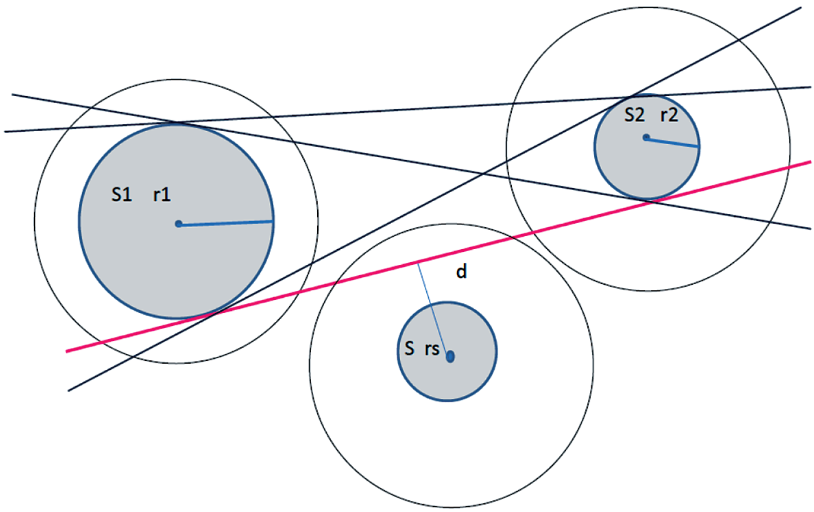

Fig. 4. Selection of the optimal tangent

If this distance diminished by the size of the drift radius *rs* fulfills the condition $|d - rs| < \Delta 1,$ assuming $\Delta 1 = 0.5$ cm (size of the inner radius of a straw tube), then the straw is accepted and added to the straw list associated with a hypothetical track and the sum

$$dd = \min \sum |d(S, \text{tangent}) - rs| \tag{3}$$

is calculated. If more than 6 straws meet this criterion then it is assumed that the tangent is a candidate for the track. From all selected tangent lines the one characterised by the smallest value of dd is accepted as the track candidate.

Initially, the algorithm was initialised only for the pairs of the straws belonging to layers 1 and 16 which prevented the track determination if there was no hit in one of these layers. To improve the algorithm performance it was assumed that the signal due to the particle passage was generated in at least one layer of straws belonging to the double layer structure. Therefore, the initial straw can belong either to layer 1 or 2, and respectively 15 or 16. For this reason, the algorithm considers many more pairs and in cases in which all the layers have a hit some tracks are duplicated. This implies that an elimination procedure has to be carried out. Two track candidates are considered to be an "repetition event" if they contain the same hit straws in at least 7 out of 8 layers or also if out of 7 hit straws no more than 4 straws are not exactly the same but have neighboring numbers. Eventually, out of two such candidates the one with more hits or with smaller value of *dd* is accepted.

The pseudo-code of the algorithm described above is presented in Fig. 5.

```
    for each straw S1 from layer 1 or 2
      for each straw S2 from layer 15 or 16
        line(S1,S2);
        find all straws S for which |d(S,line)-rs| < Δ1;
        if(number of found straws < 6) take next pair;
        else  construct  four  lines  tangent  to  c(S1,r1)  and
  c(S2,r2) and compute
             dd= ∑|d(S,tangent)- rs|;
             select the tangent line having min(dd);
        compare found tracks and eliminate duplicates
```

Fig. 5. Reconstruction of traces in the plane XOZ in FT12

The result of track recognition on ZOX plane is a set of hits belonging to the track and two parameters α and β of $x = \alpha * z + \beta$ forming the track in this plane.

3.2. Track recognition in ZOY plane using the skewed straws

To determine the particle trace in the plane ZOY the layers with skewed straws are used. In tracking stations FT12 the processed layers are: 3, 4, 5, 6, 11, 12, 13 and 14.

For each track found in the ZOX plane the plane Z′OY vertical to ZOX and containing the found track is constructed (see Fig. 6).

Then for each processed straw (described by equation $y = a*(x - x_0) + y_0$) the point $P(z, y)$ of intersection of the straw with the plane is calculated. Given the drift radius the coordinates of points $P1(z, y1)$ and $P2(z, y2)$ belonging to the track (4) are determined.

$$y1 = y + cc; \quad y2 = y - cc; \quad cc = r\sqrt{1 + a^2} \tag{4}$$

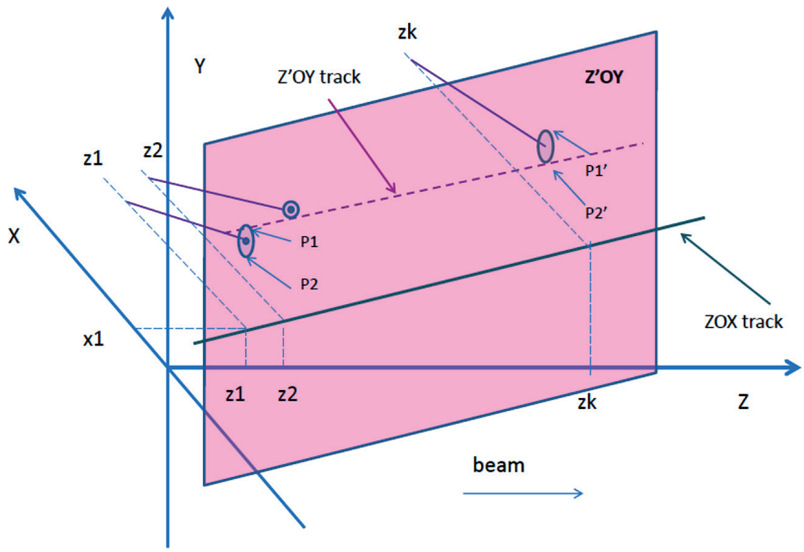

Fig. 6. Points – candidates to the track on Z'OY plane

From the list of all points $P1$ and $P2$ (see Fig. 7) only those pairs of points (P, P') are selected for which point P belongs to the layer 3 or 4, and P' to the layer 13 or 14. Next for each accepted pair a line passing through it points is determined.

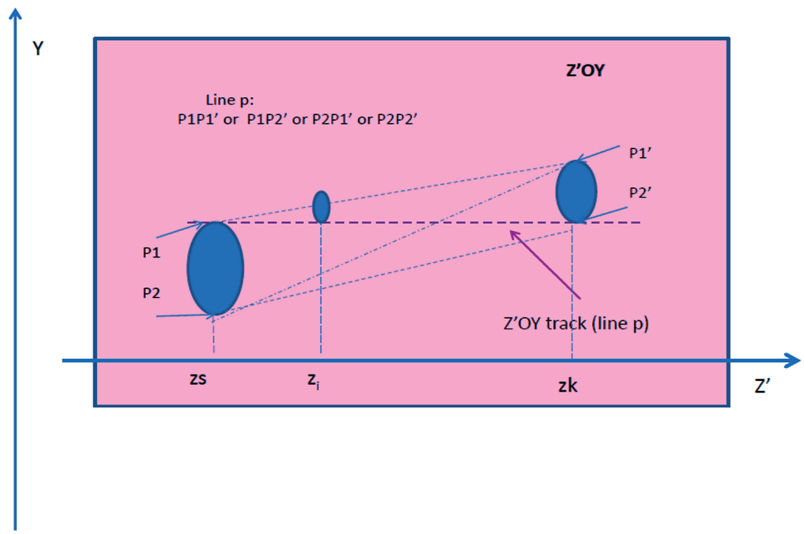

Fig. 7. The track candidates in the Z'OY plane

At the next step, all points, one in each layer, whose distance to this line is the shortest, but no greater than value of $\Delta 2$ ($\Delta 2 = 0.5$ cm; size of the inner radius of a straw tube), are considered and out of all constructed lines the one with the smallest value of the sum:

$$dd = \sum_{\text{layer}} d\min(P, \text{line}) \tag{5}$$

is selected. If there are more than 6 points in the sum then the line is the track candidate in the Z′OY plane. It is quite clear that the transformation of this line from the Z′OY to the ZOY plane is required (Fig. 8). The results of the track recognition in the ZOY plane is a set of hit straws belonging to the track and two parameters α and β defining the track line $x = \alpha * z \quad \beta$ in this plane.

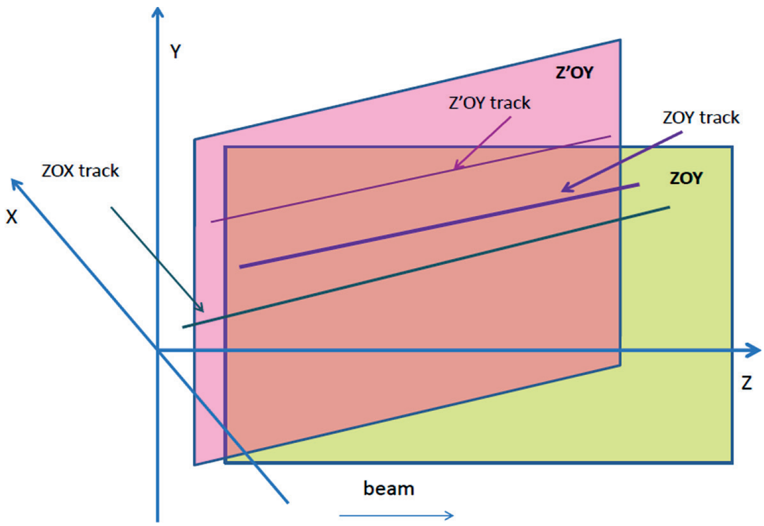

Fig. 8. Transformation of the track from the Z′OY to the ZOY plane

The pseudo-code of the discussed algorithm is presented below in Fig. 9.

```
for each track in ZOX plain
    for each straw Si
        compute points P1(zi,y1) and P2(zi,y2)
    for each point K belonging to layer 3 or 4
     for each point M  belonging to layer 13 or 14
           line(K, M);
           dd= ∑layer dmin(P,line);
```

Fig. 9. Reconstruction of traces in the plane XOY in FT12

4. Results

The algorithm was tested for input data generated by the Pandaroot. The data extracted from the simulations were ordered in the form of rows with a fixed number of columns defining the order:
- the event number,
- the track number,
- whether it is a part of the primary particle (equal –1),
- the layer number,
- the global number of the hit straw,
- the radius,
- *x*, *y*, *z* coordinates.

The last three numbers are the coordinates of the point crossed by the particle allowing to verify the obtained results with the data from the simulator.

Calculations were made for muons with energies of: 0.5 GeV, 2.55 GeV and 5.55 GeV. The angle of incidence of a particle was within the range (2.5°; 5.0°). The generated events contained one, three or five tracks. Only the tracks with at least one hit in each of the double layer were considered in the present analysis.

Fig. 10 shows the distribution of the simulated track position at the first layer for muons of 5.55 GeV energy.

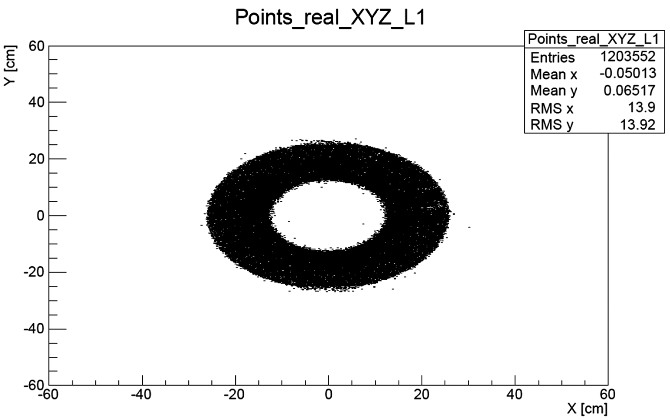

Fig. 10. Distribution of the simulated track position at the first layer for muons of 5.55 GeV

In Fig. 11 and Fig. 12 the difference in X and Y coordinates at each layer of F12 between simulated and reconstructed tracks are presented. The difference in X coordinate was computed using the vertical straws in the ZOX plane, the difference in Y coordinate on skewed straws in the ZOY plane. The difference in X coordinate is about ten times smaller than in Y coordinate.

The efficiency of the track recognition algorithm in the forward tracker F12 is illustrated in Fig. 13. It is a function of the number of found tracks in generated events. The found track is a track with minimum 14 hits in 16 layers.

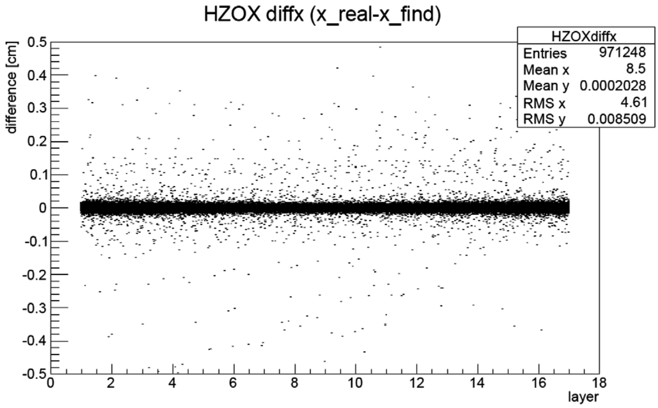

Fig. 11. The difference in X coordinate between the simulated and reconstructed track position for muons of 5.55 GeV

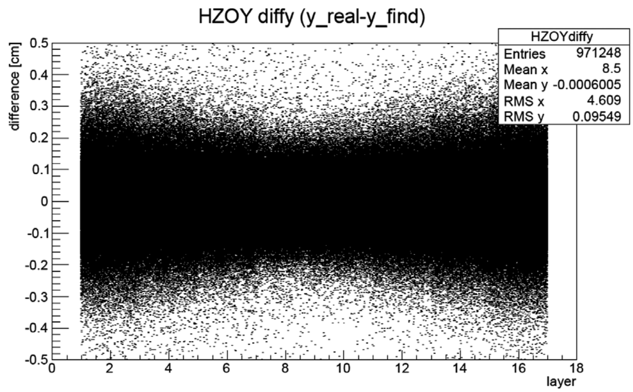

Fig. 12. The difference in Y coordinate between the simulated and reconstructed track position for muons of 5.55 GeV

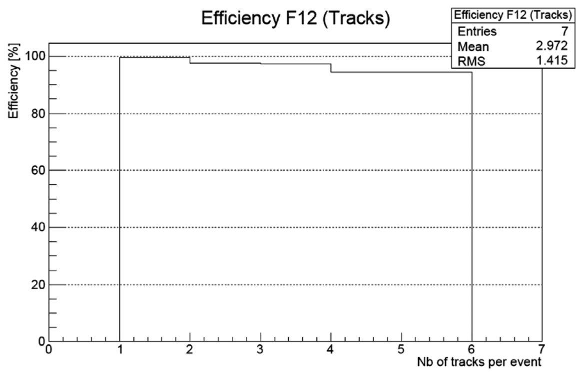

Fig. 13. Efficiency of tracks recognition in FT12 for muons of 5.55 GeV

5. Conclusions

In this paper, the three-dimensional track pattern recognition algorithm outside the magnetic field for PANDA experiment in FAIR was presented. It is based on an analytical solution. The algorithm uses the detector geometry, information about the particle hits and the drift time/radius values.

Results indicate that the obtained accuracy of the particle path determination using the vertical straws is much better than that which can be obtained using the skewed straws. The efficiency of the track finding is still above 95% for events with five tracks.

The algorithm returns a list of straws associated with a track as well as the parameters of the straight line allowing the three-dimensional determination of the particle path before the magnetic field area (in FT12), and after leaving it (in FT56). This information is necessary input for the determination of the particle trajectory of a particle in the magnetic dipole field.

I am indebted to Cracow PANDA Group for stimulating discussions and help and to ACK CYFRONET – Kraków for possibility of using the computing resources.

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