Cathode pad chambers at NICA/MPD

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My work is focused on simulation studies with Cathode Pad Chambers (CPC).

CPC – tracking detector included in the **MPD** configuration (as shown in the picture below)

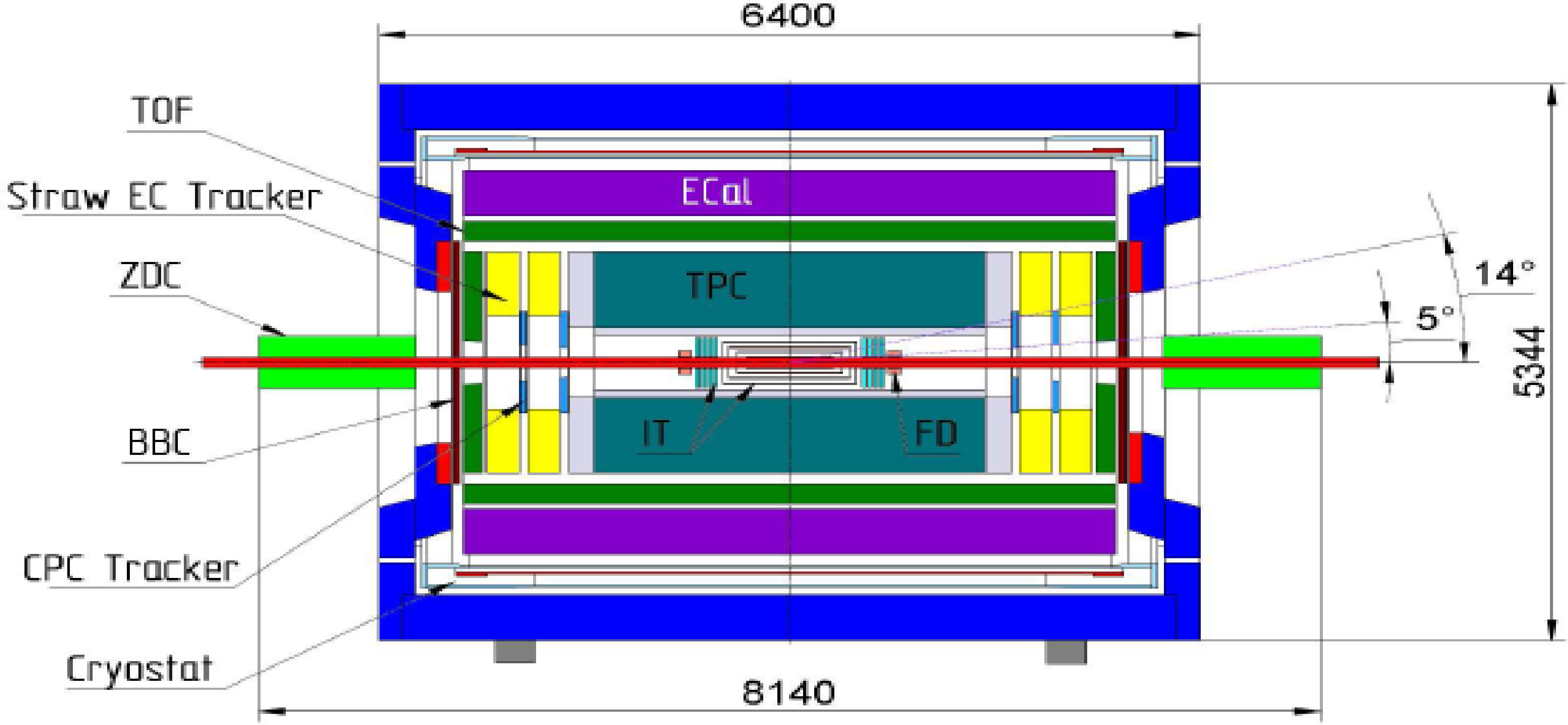


Fig. *Cutaway side view of the central MPD with based dimensions.*

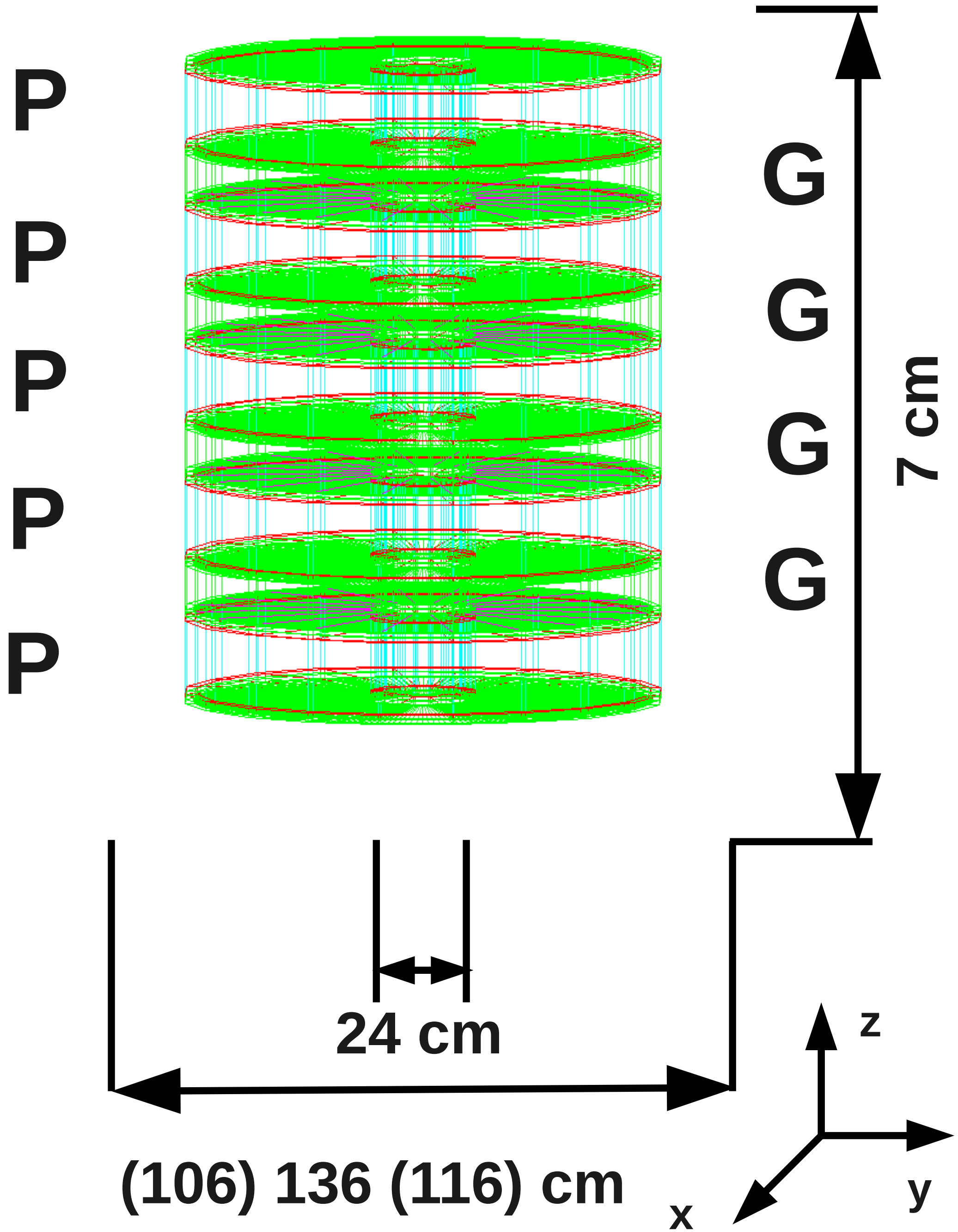
4 CPC's at **z=±172,5 cm** and **±204,5 cm**;
they cover pseudorapidity interval **$2<|\eta|<3$**.

Main goal of the work:

to estimate optimal geometric characteristics and material composition of the CPC which means to estimate such geometry and other detector properties for which we obtain best track reconstruction results, namely track reconstruction efficiency as well as geometric and kinematic track parameters

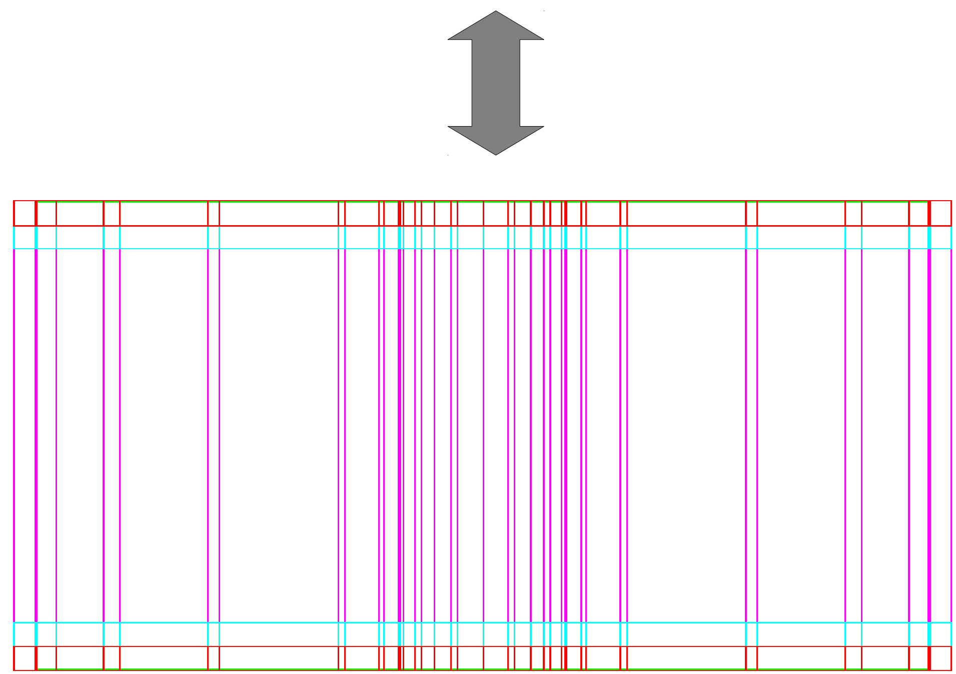
To achieve these goals, standard HEP and NICA/MPD software is used in MC simulations: C++, GEANT3, FAIRSOFT, MPDROOT, UrQMD model + own procedures.

CP chamber schematic outline



G – 80% /20% gas mixture of Ar and CO_2

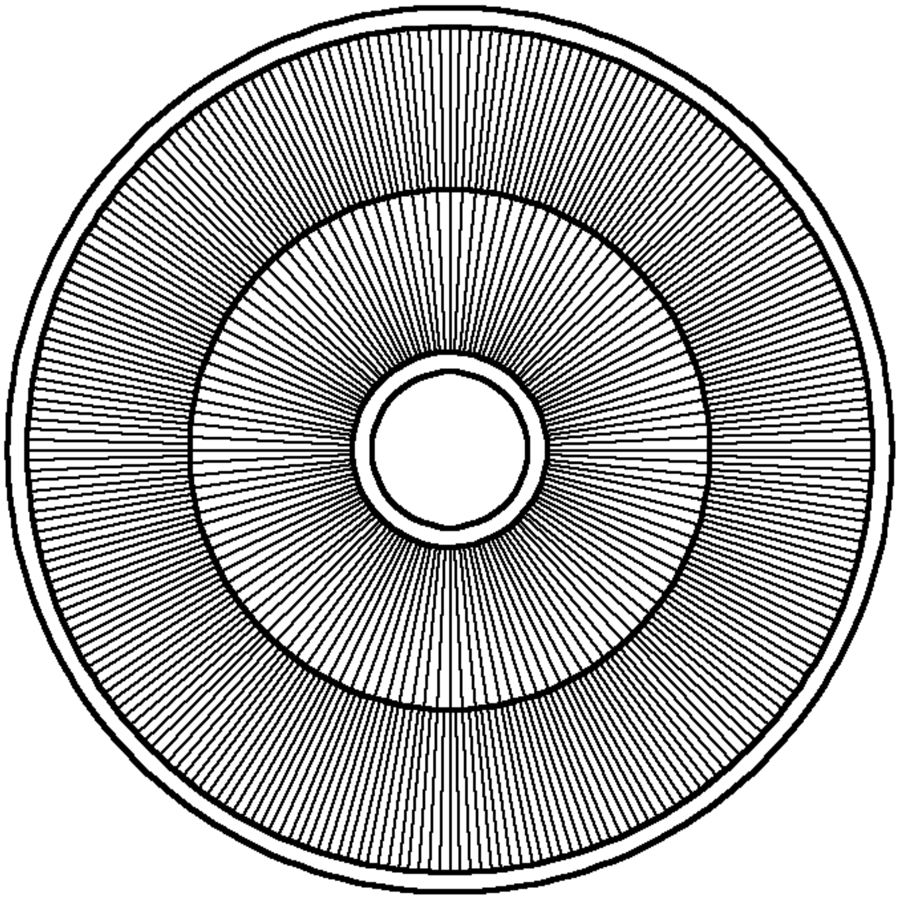
P – module panel consisting of layers of rohacell, carbon fiber comp. (CFC), G10 and copper



width of P layer = 1 cm

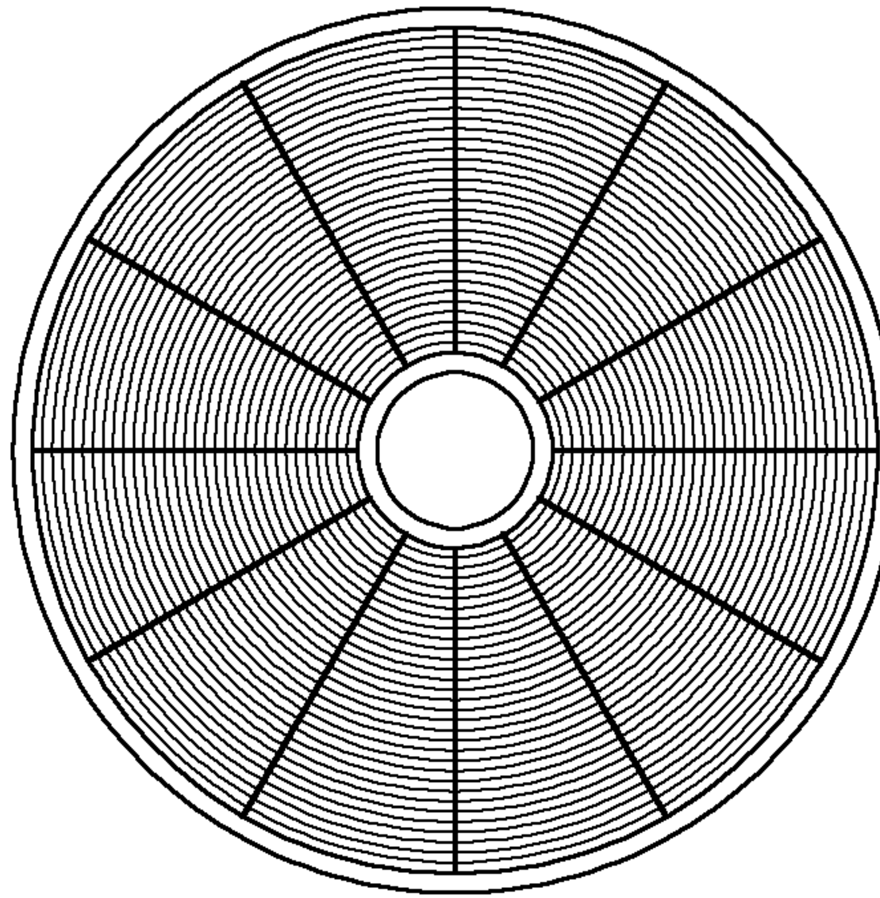
width of G layers = 0.5 cm

Layout of CPC cathode pad structure in φ coordinate.



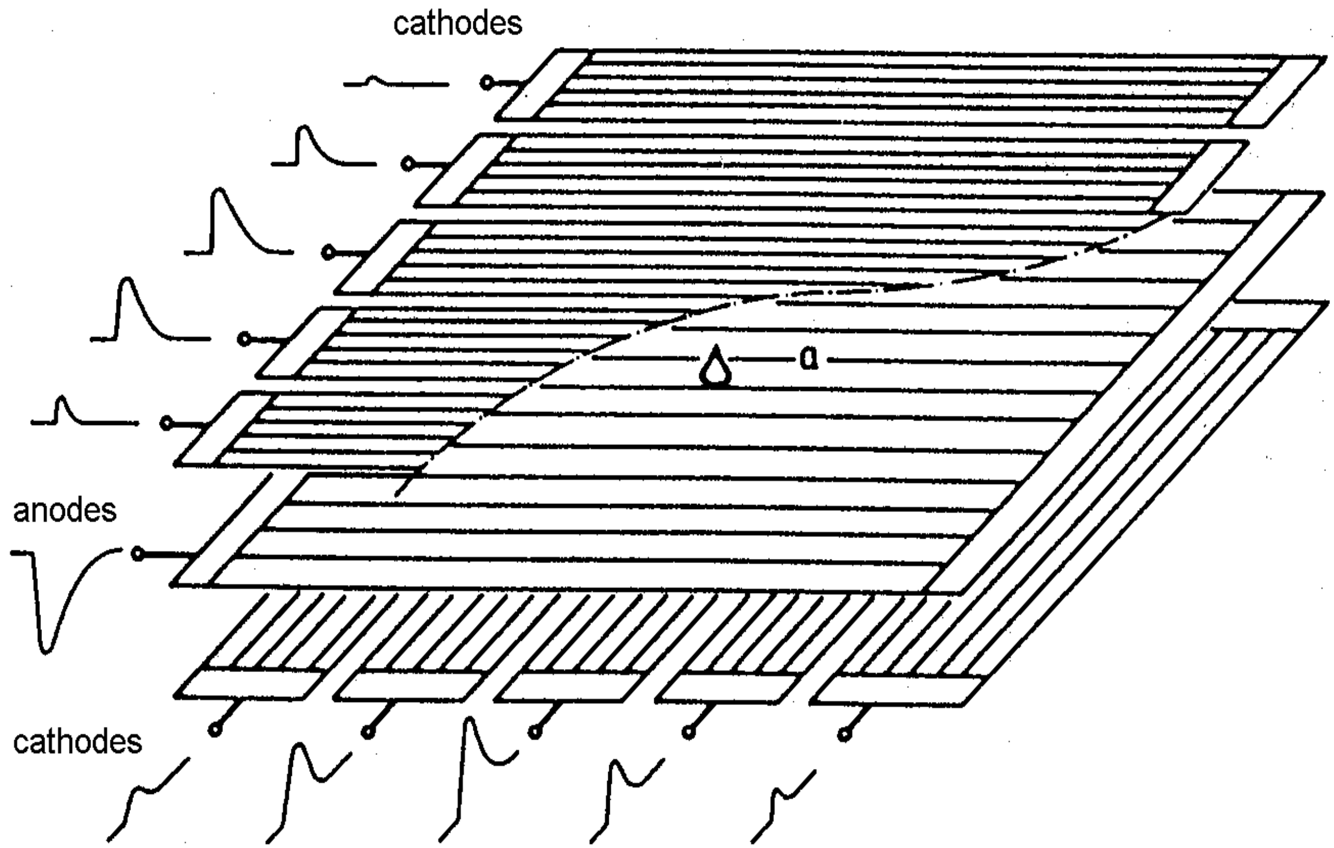
512(384) azimuthal strips in the inner radial sector, 1012(768) strips in the outer one;
Number of channels: 512+512×2= =1536(1152).

Layout of CPC cathode pad structure in R coordinate.



12 azimuthal sectors, 128(96) radial strips;
Number of channels: 12×128=1536 (1152).

Working principle

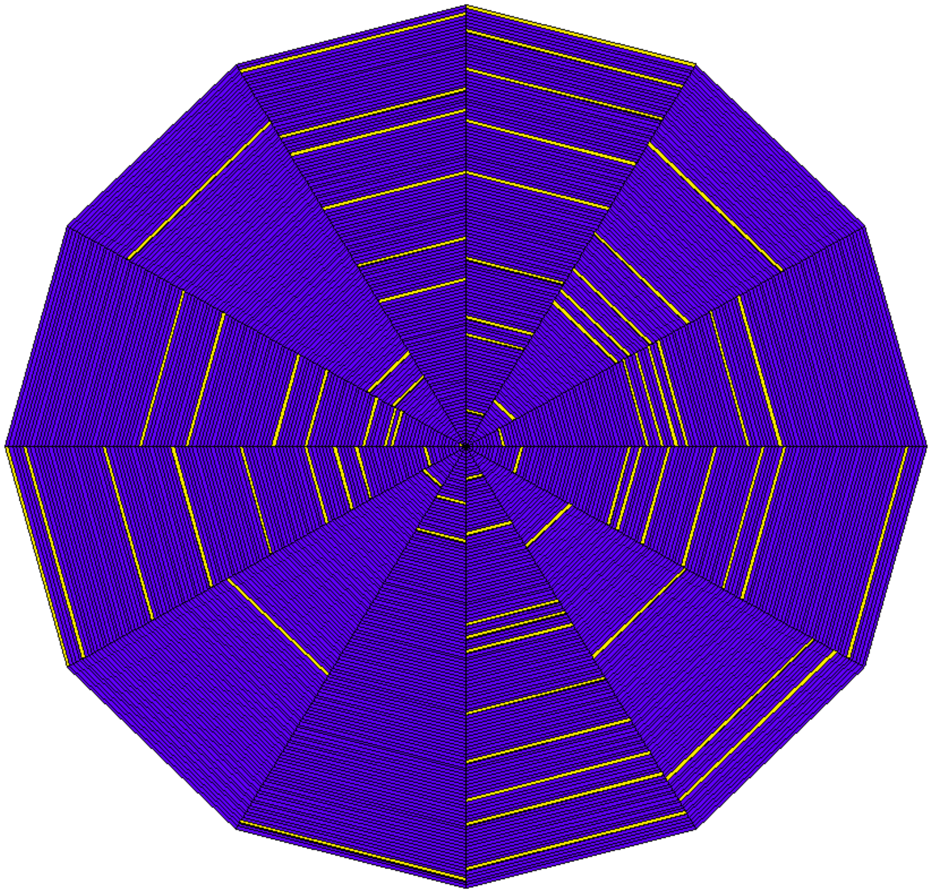


When a charged particle passes through the active gas volume of the detector, it produces ionization (electron-ion pairs) along it trajectory. These primary electrons drift towards the nearest anode wire, where avalanche takes place. The resulting ion cloud induces charge signal on the cathode strips close to the avalanche location by capacitive coupling.

The working principle is shown for chamber measuring Cartesian coordinates but the chambers can be designed to measure polar coordinates as well.

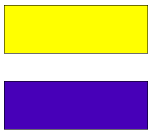
What can we estimate from the MC simulations?

simulated data: UrQMD 9 GeV minbiased AuAu events



First approximation: each track produces signal only in one strip

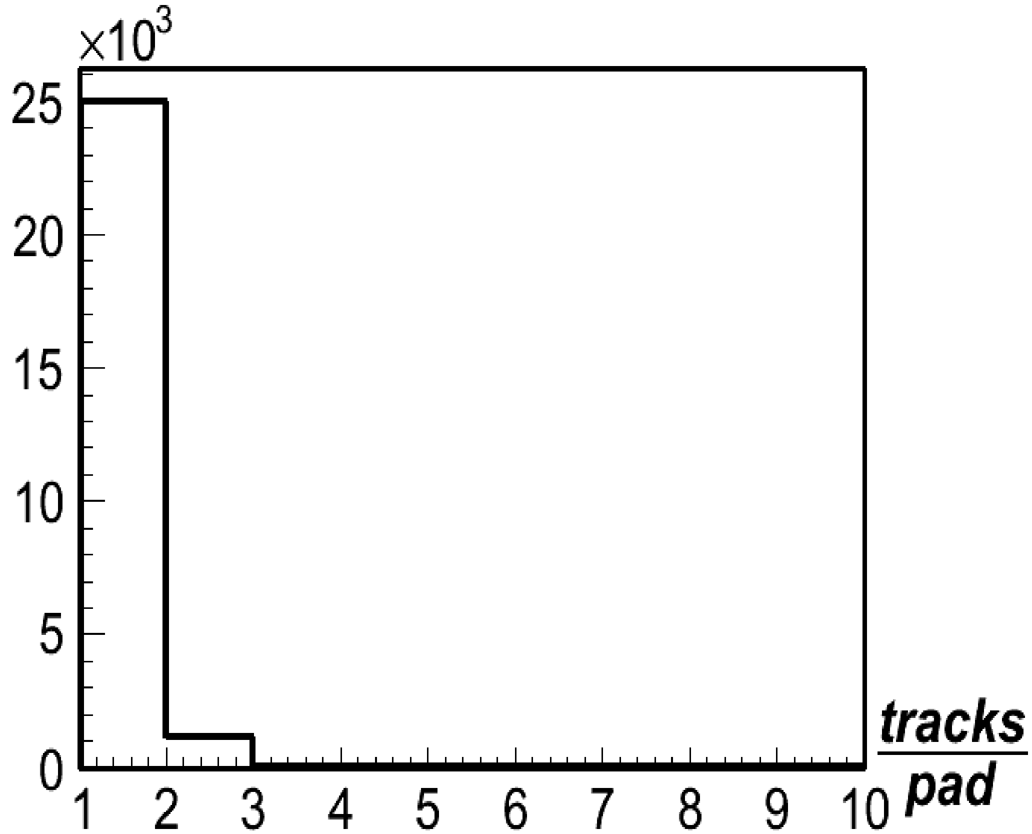
Example: Distribution of track hits in transverse plane presented in polar coordinates at z=170 cm (one event, binning ↔ radial CPC plane).

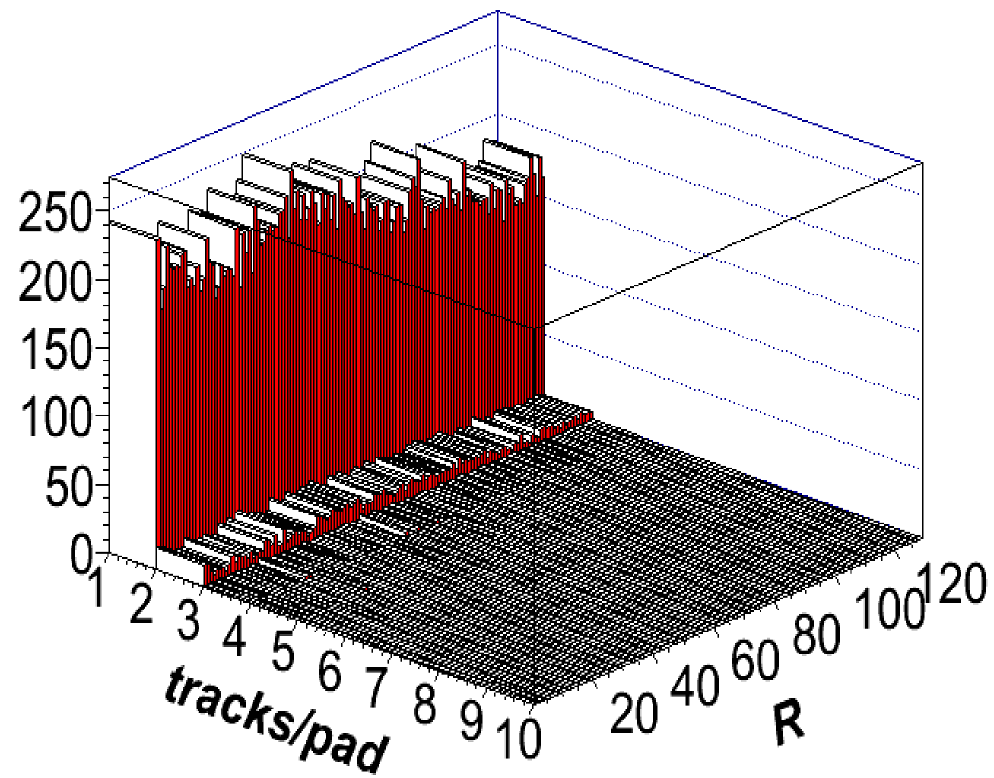


overall mean detector occupancy ≈ (strips with hits)/(all strips) ≈
≈ **3%** *for both R and φ CPC planes, 500 events*

What if 2, 3, ..., hits are found in some strips? ⇒ Strip occupancy must be studied event-by-event.

Event-by-event pad occupancy for the azimuthal (left Fig.) and radial (right Fig.) cathode pad planes. The occupancy in right Fig. shown as function of radius.



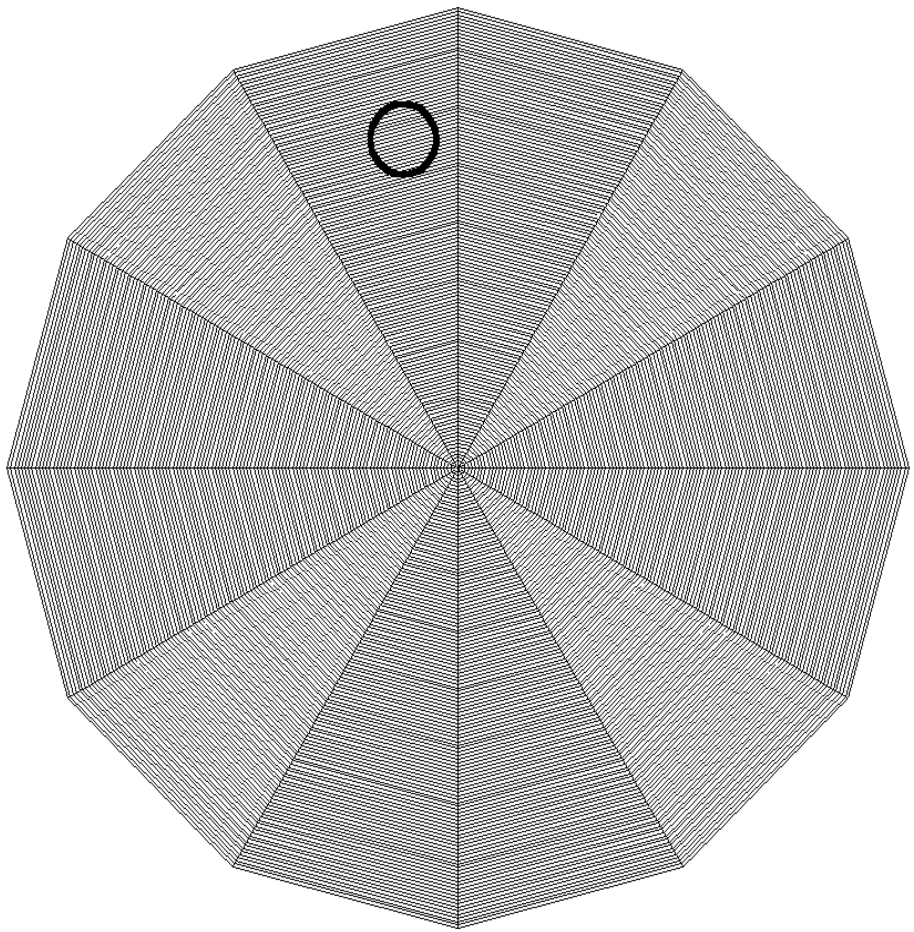


In ideal case, number of hits producing signal in individual strips should not exceed 1. Two or more hits in one strip are experimentally indistinguishable.

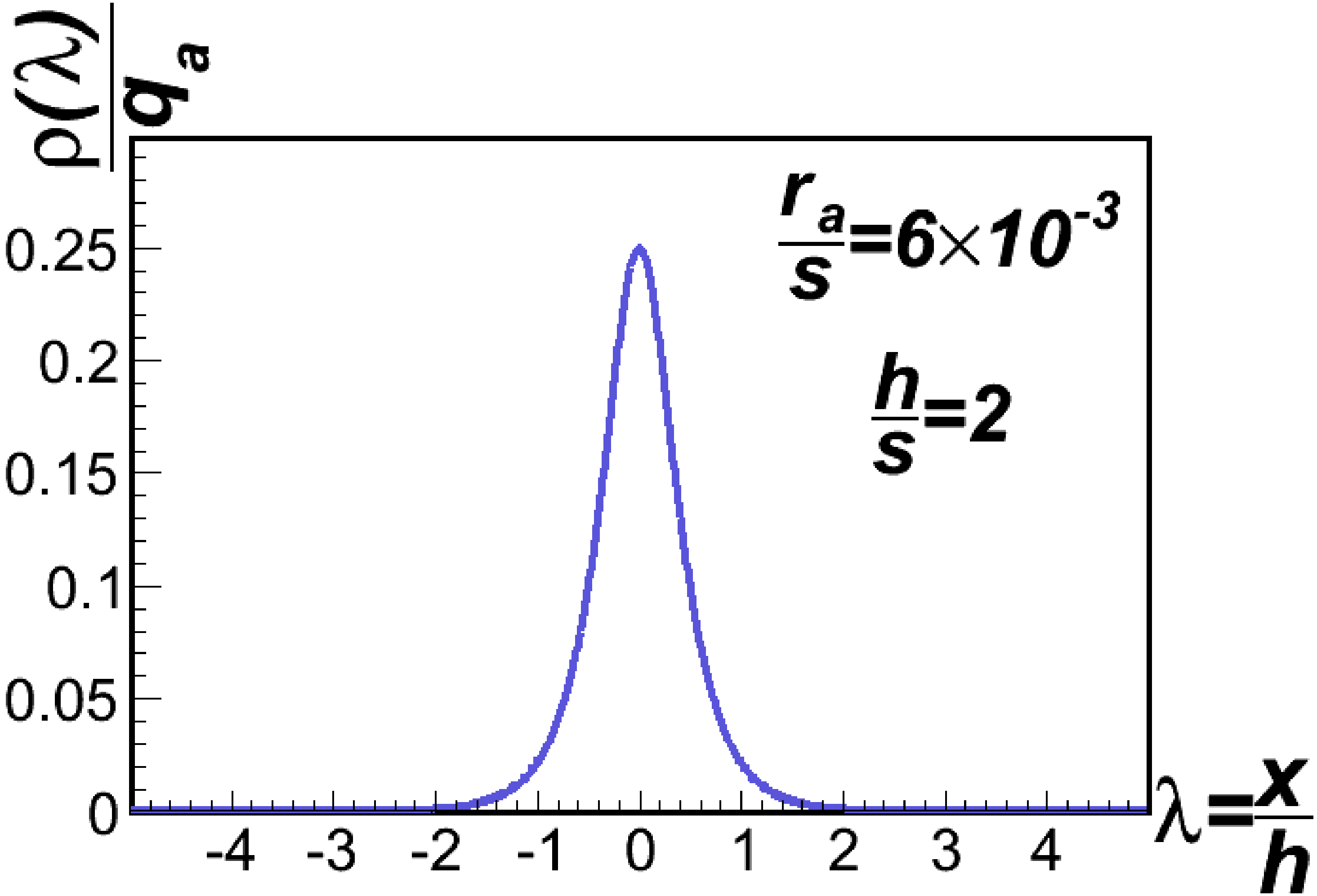
Very close tracks (hits) seen in Figs above are mainly secondary tracks (δ-electrons) produced in inactive parts of the detector.

Track coordinates estimation

requires more precise modeling of measured signals as well as an application of sophisticated methods of signal analysis



In fact, the cathode charge induced by passing particle is observed not only in the nearest strip but in a few neighbouring strips as well. Its distribution in transverse plane is described by 2D Gaussian-like function centered at real hit position. Thus virtually whole charge is collected only from the strips within a circular area as indicated in the Figure. Hit position in CPC *r(φ)*-plane is subsequently estimated by some suitable method that uses as input cathode charges measured in strips with well defined positions.



h – the anode-cathode separation;
s – the anode wire pitch;
r_a – the anode wire radius;
q_a – the net anode charge;

x – the space coordinate (*r* or *rφ*).

Distribution of cathode charge is described by empirical Mathieson formula (1984):

$$\frac{\varrho(\lambda)}{q_a}=K_1\frac{1-\tanh^2(K_2\lambda)}{1+K_3\tanh^2(K_2\lambda)}$$

where $K_2=K_2(K_3)$, $K_1=K_1(K_2,K_3)$ and $K_3=K_3(r_a/s,h/s)$ and h,s,r_a are the geometric parameters of the CPC.

Magnitudes of cathode charges follow from energy losses of particles in the detector which are described by Bethe-Bloch formula and their fluctuations are described by Landau (or Vavilov) distribution. The losses are function of particle momenta and particle types.

Spectra d*E*/d*x* vs *p* for the needed particle types are simulated by GEANT.

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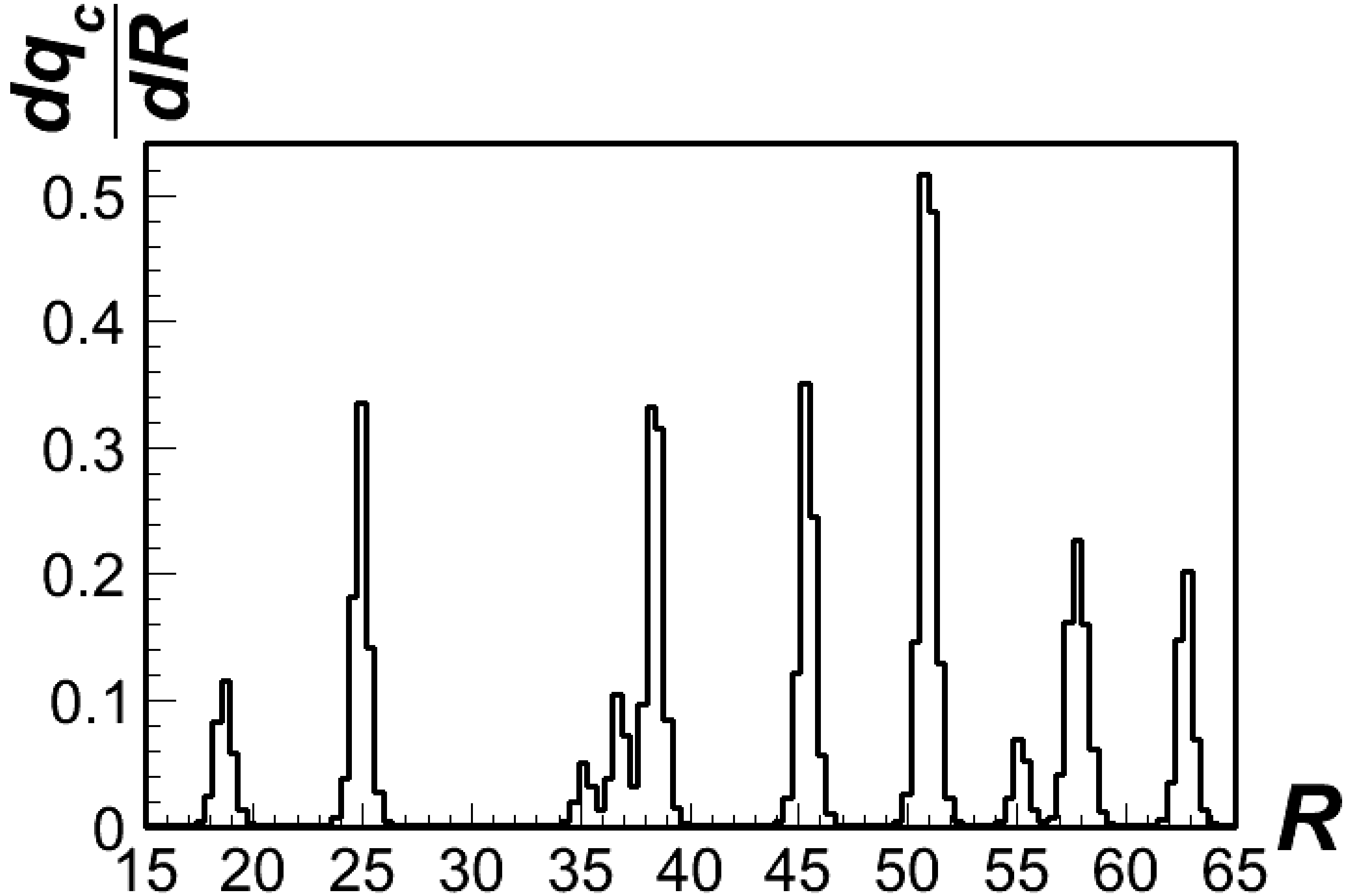
Magnitudes of cathode charges are then generated according to these spectra.



Example: Distribution of cathode charge in the chosen azimuthal sector of radial pad plane. The peaks (clusters) correspond to hits of detected tracks.

We observe that:
1.) Cathode charges amplitudes may differ significantly;
2.) Peaks can mutually overlap which makes their separation difficult or sometime impossible.

Hit coordinates estimation

First, the simple maximum finding algorithm is applied to cathode charge spectra to find and separate peaks (if they overlap).

Area of each peak is regarded as integral of Mathieson function:

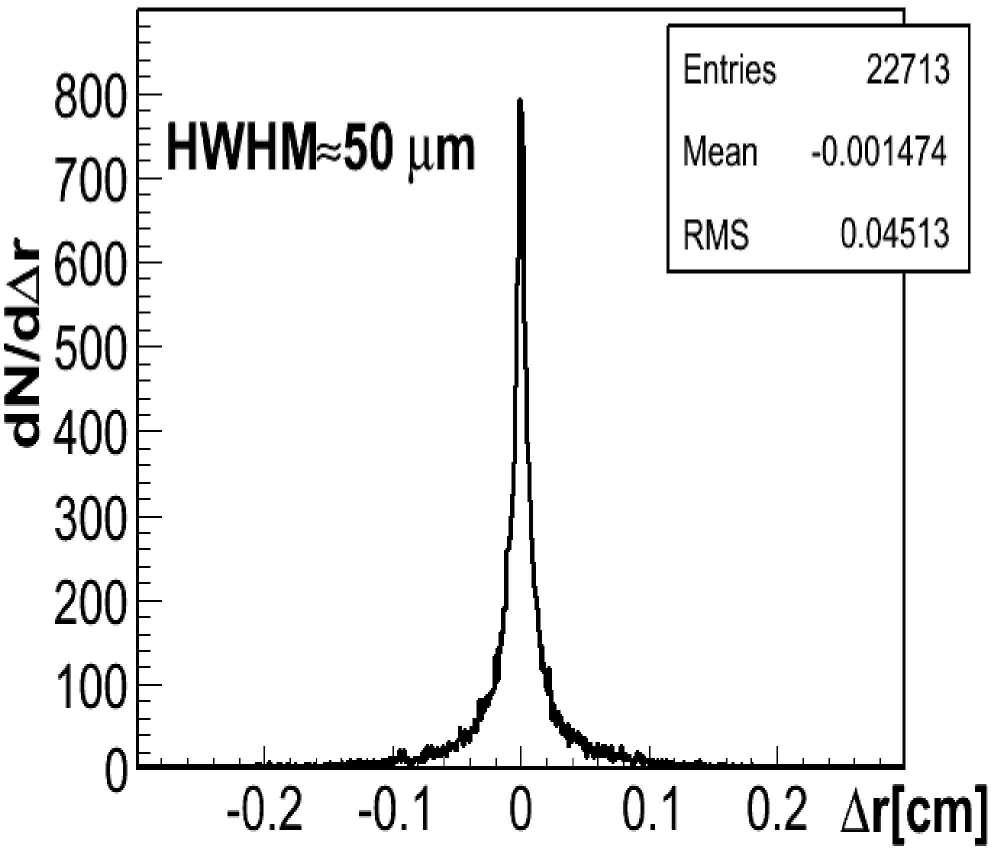
$$\int_a^b \frac{\varrho(\lambda)}{q_a} d\lambda = \arctan\left(\frac{1}{A\exp(x_0)+B\exp(-x_0)+C}\right),$$

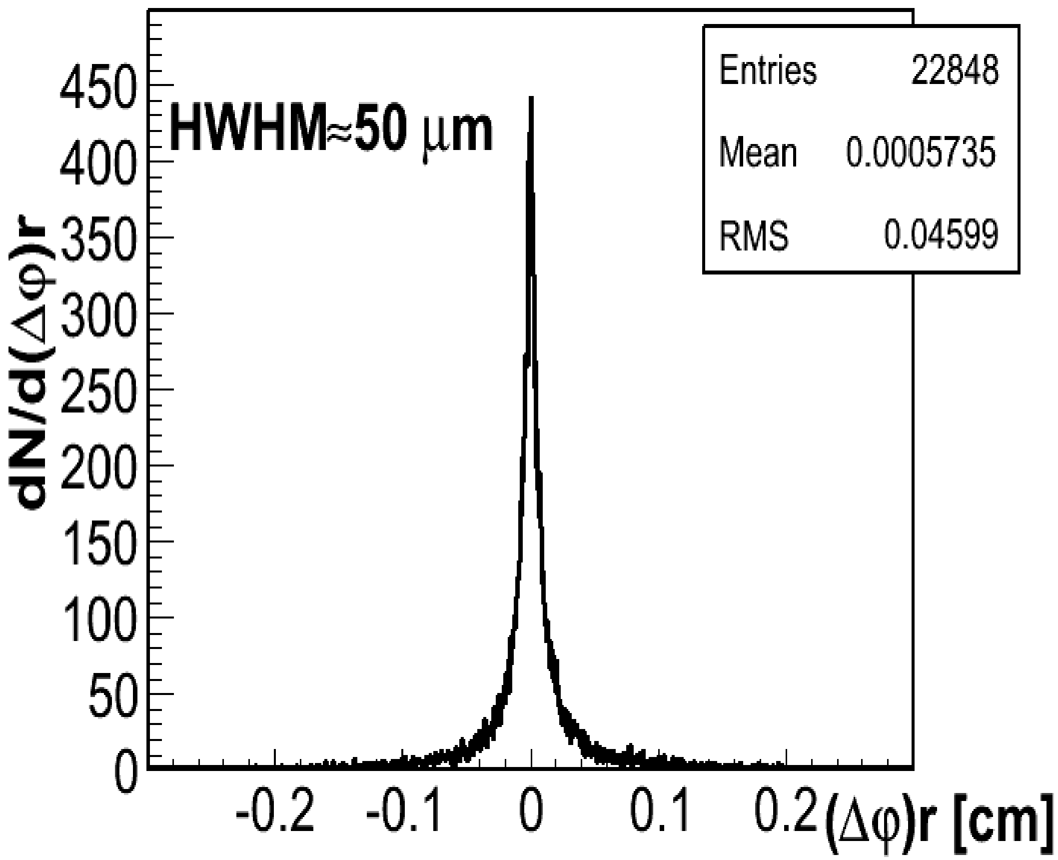
where *a,b* are limits of integration and parameters *A,B,C* are functions of the detector technical constants K_1, K_2, K_3 and of integration limits *a,b*. Symbol x_0 is center of Mathieson distribution.

Solving the above equation for x_0, we get an estimate of hit coordinate.

Difference of real and reconstructed radius (r_{rec} - r_{real}) of CPC hits.

Difference of real and reconstructed azimuth (φ_{rec} - φ_{real})r_{real} of CPC hits.





Sources of errors:

1.) electronic noise from the amplification system. (Gaussian white noise with σ=0.5% of mean total cluster charge added to each strip);
2.) sometime hit overlaps lead to limited track separation;
3.) boundary effects in radial or azimuthal sectors, i.e. incomplete clusters

Another possible sources of resolution degradation (not yet included in the MC simulations): cross talk between neighbouring readout channels, calibration uncertainties (offset and nonlinear gain), ADC digitization error, mechanical tolerances in the chamber construction, inclined tracks, influence of strong magnetic fields (Lorentz angle), delta electrons production

Present stage of work:

coordinates of track hits are estimated,
the corresponding errors as well

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All that is needed for **tracking**.
Currently underway.

Summary:

What has been done for the CPC up to now?

- detector geometry (several layouts tested);
- detector occupancy, occupancy of pads;
- simulation of hits, including electronic noise;
- finding of clusters;
- estimation of hit coordinates and their errors;

What is underway or ahead?

- tracking;
- investigation of other effects that may have impact on track reconstruction;
- testing of alternative methods included in track reconstruction;
- further improvements, tuning