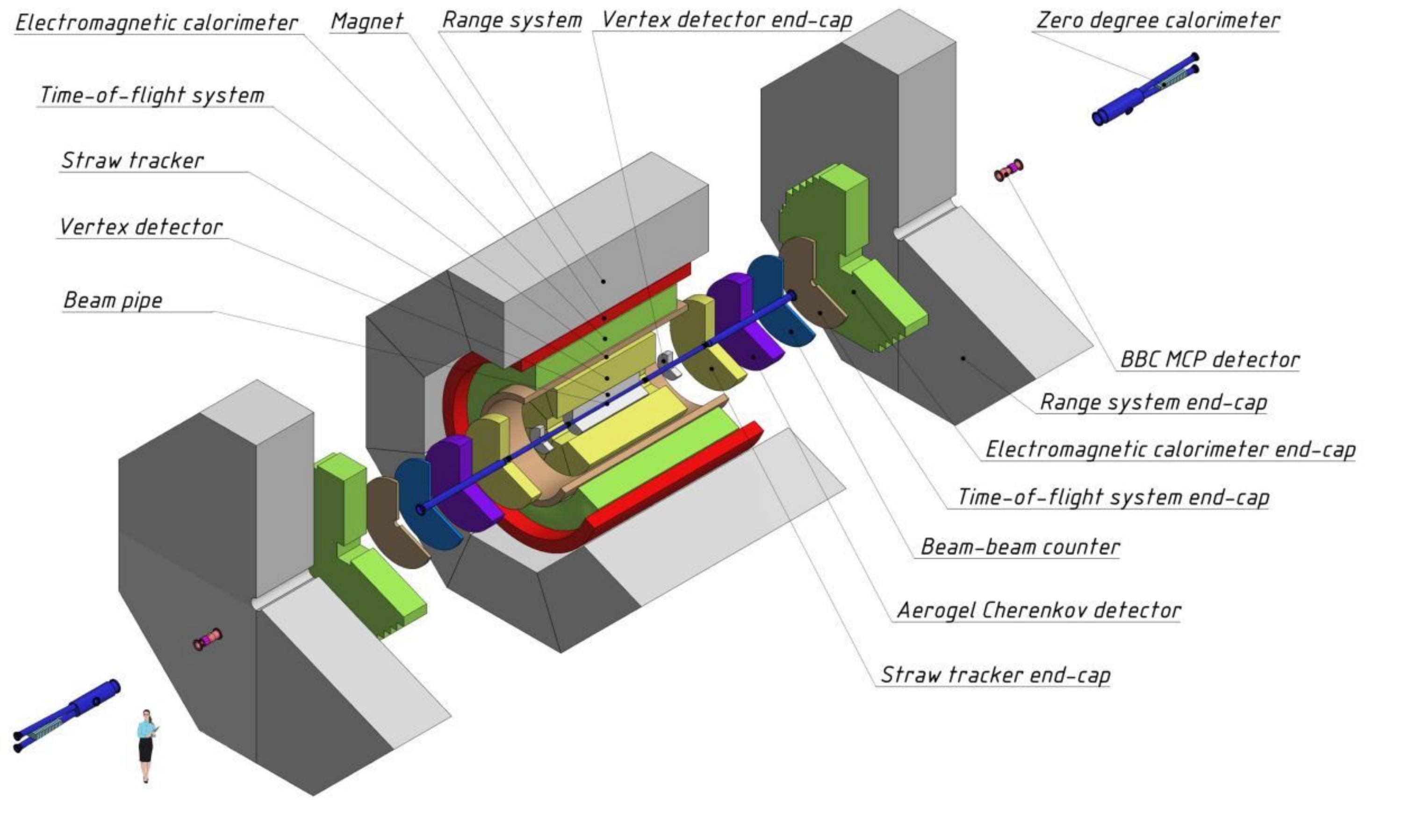
Modelling of SPD EndCup detector

why
what
how
some results

NICA

Spin Physics Detector at NICA (TDR)



General layout of the SPD setup.

SPD straw tubes EndCap detector (TDR)

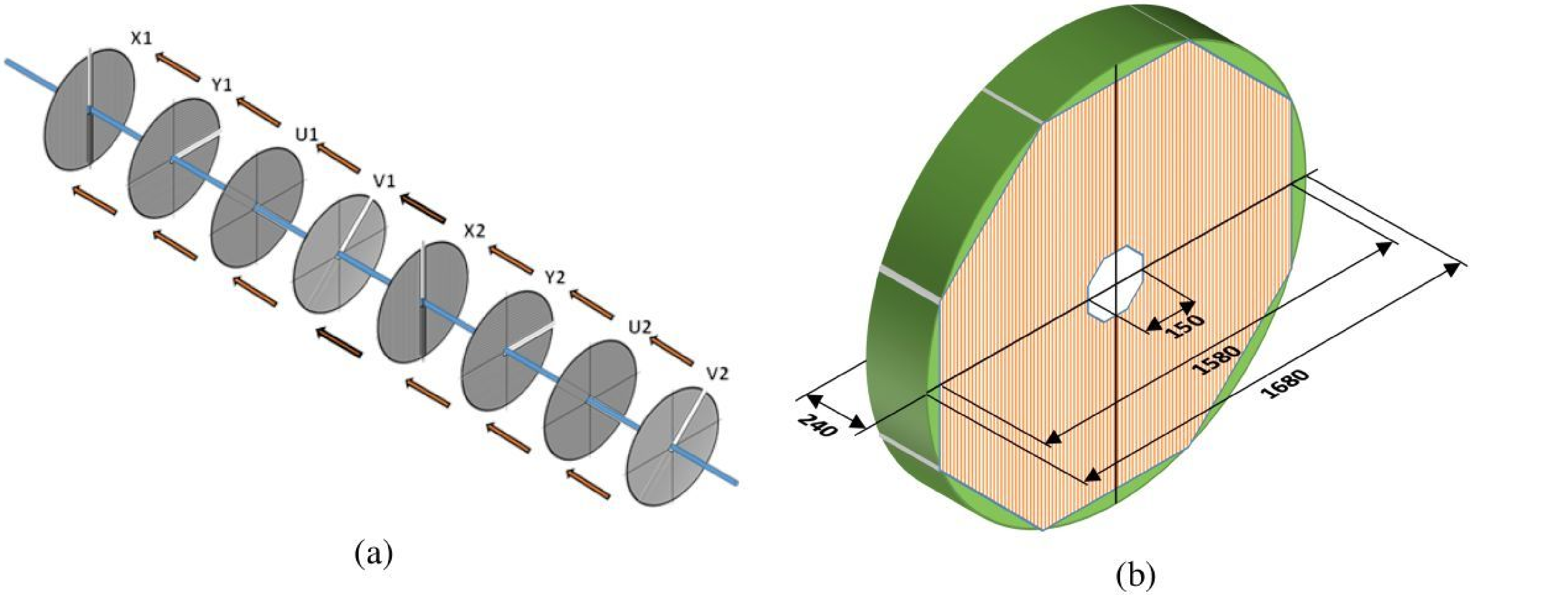


Figure 9.38: (a) ST end-cap consisting of 8 coordinate planes assembled together. (b) Common view and main dimensions.

The coordinate plane consists of 2 same layers rotated 180 degrees relative to each other

Barrel and End-Cap straw tubes

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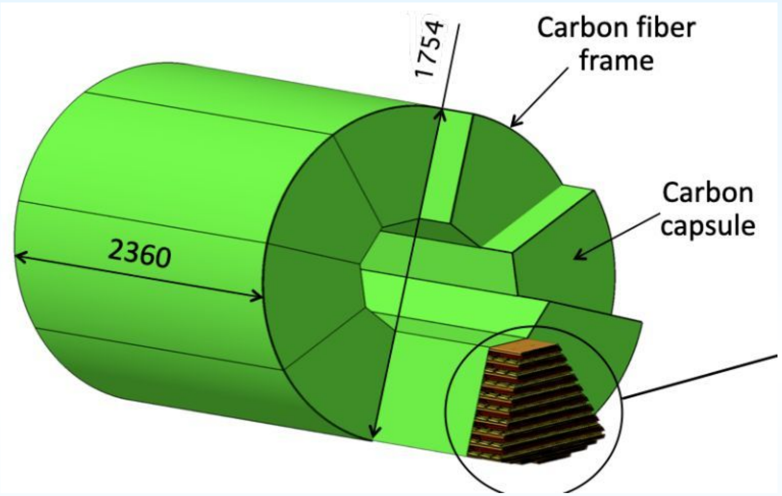
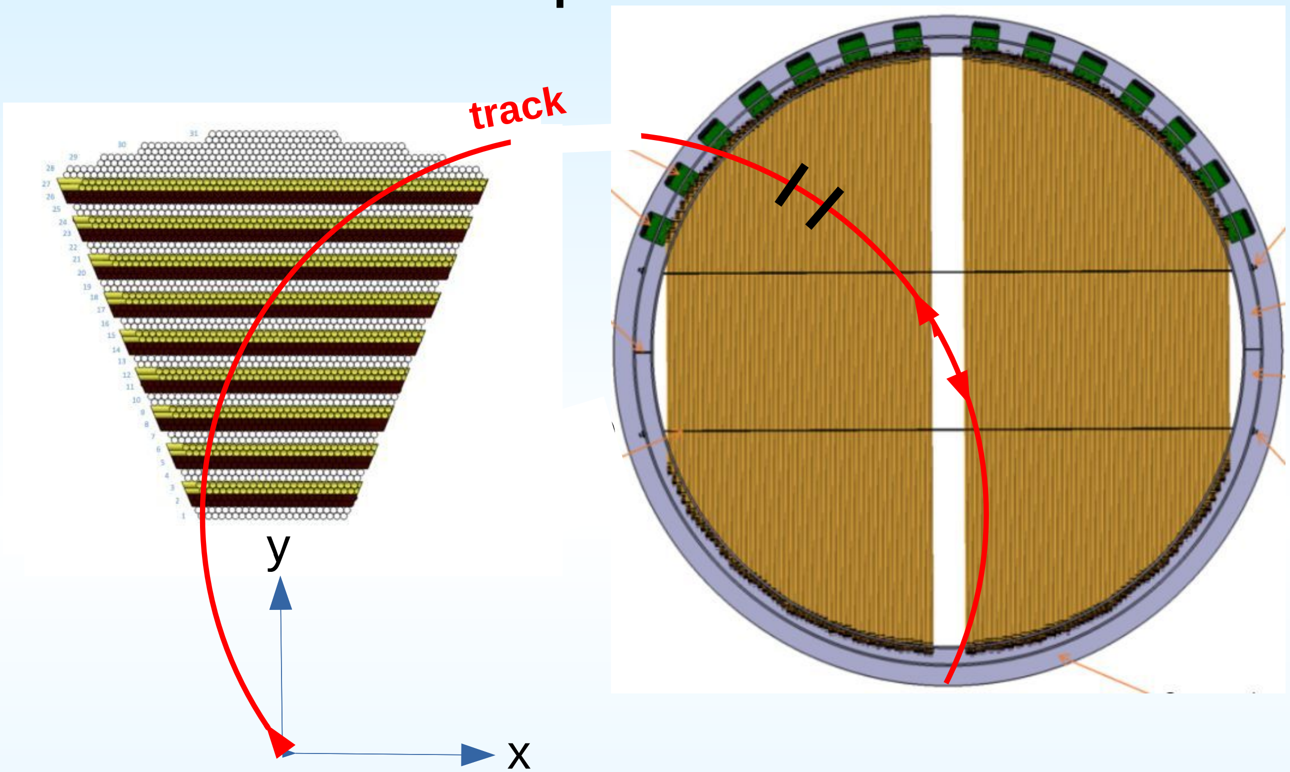


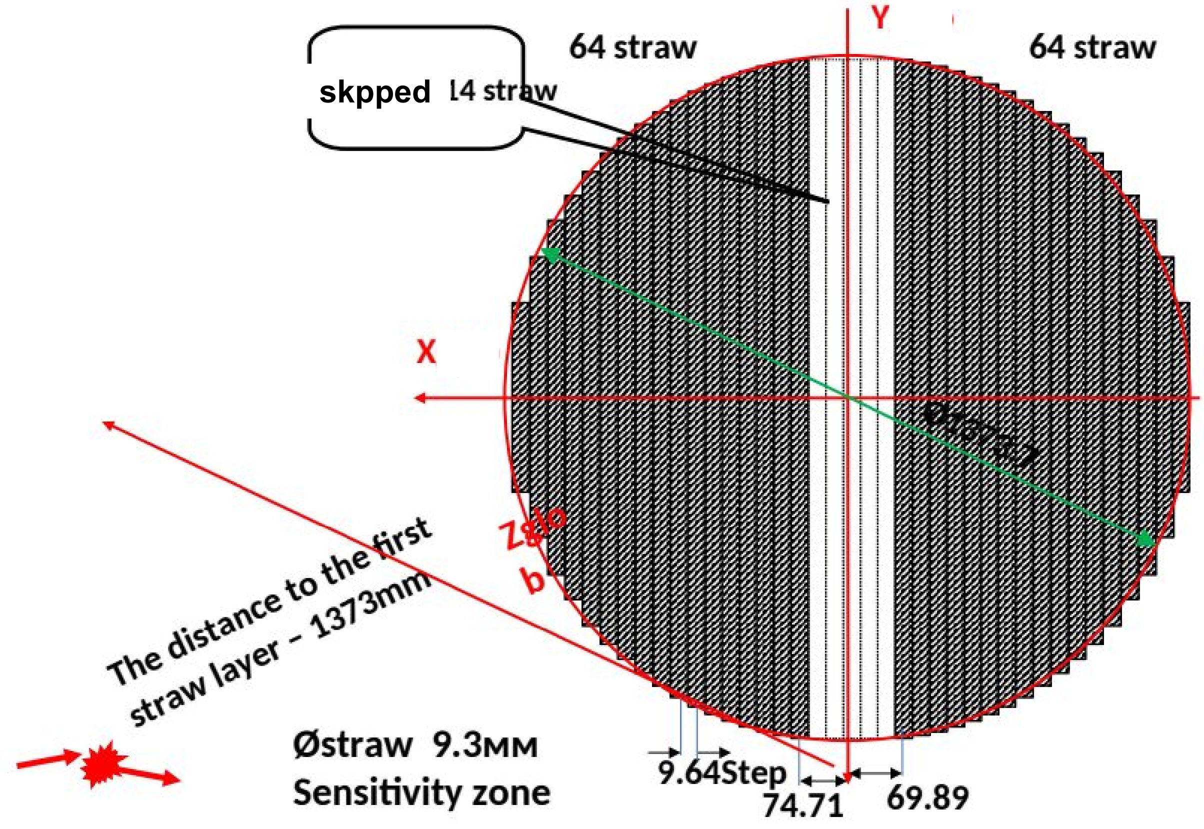
X-Y plane

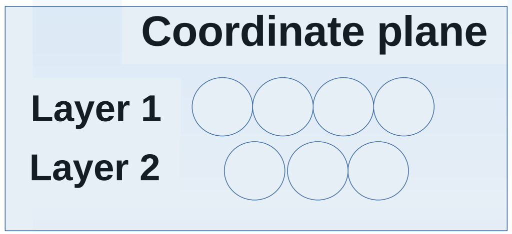


In the barrel detector, coordinates of fired tube centers are track hits.
In the case of the End-Cap detector, there is missing of the layer Y-coordinate.

To find in the EndCap detector the X-Y layer hit, one needs to have adjusted layers with non-parallel straws and as more as possible.

Straw tubes layer geometry

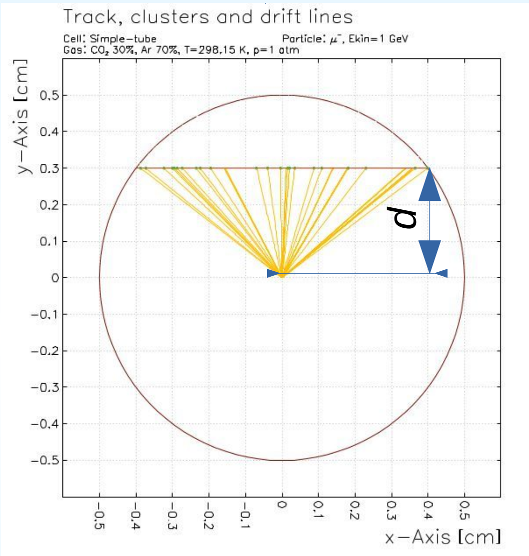




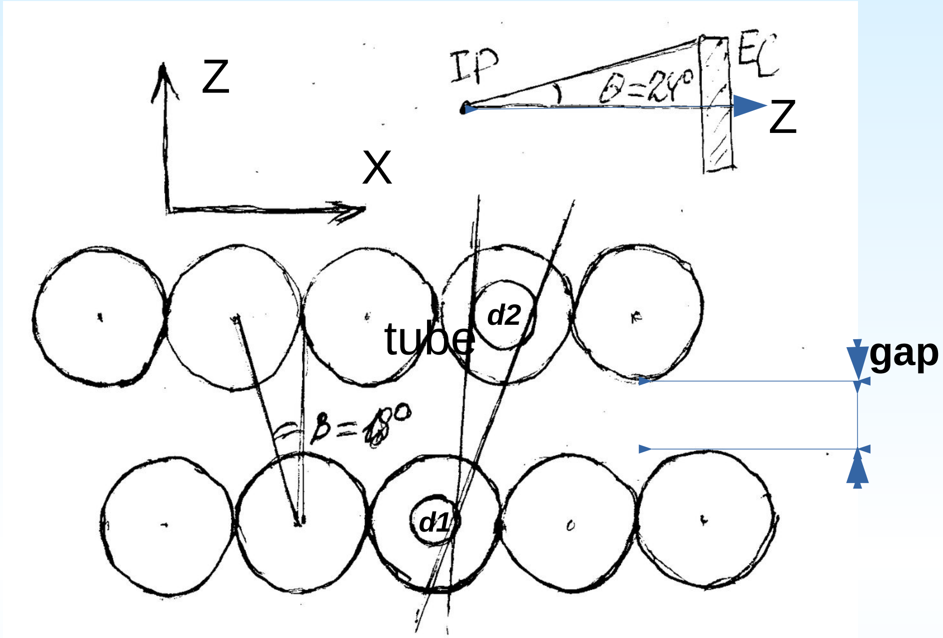
Distance between any adjacent layers Is 18.64mm

A straw is the cylinder of Ø9.64mm the length of which is changing along X-axis.

Coordinate plane with layers shift



The detector's electronics provides the distance ***d+δ*** from the wire to a track.



If the values of d1 and d2 in the fired tubes of neighboring layers are known and it is known which tangent of the four possible tracks passed, then the position of track hits in X-Z plane for fire tubes can be determined with an accuracy of *δ*.

1. If the interaction point has z=0 then the angle θ is 24^o, for z=50cm it is 35^o. The angle β is 18^o. Possible uncertainty appears when choosing an option between 4 tangents.
2. The uncertainty to reconstruct e^+e^- pair when its vertex unknown.
3. Less 3D points which we can use to find an initial approach for the circle of the helix in the X-Y plane.

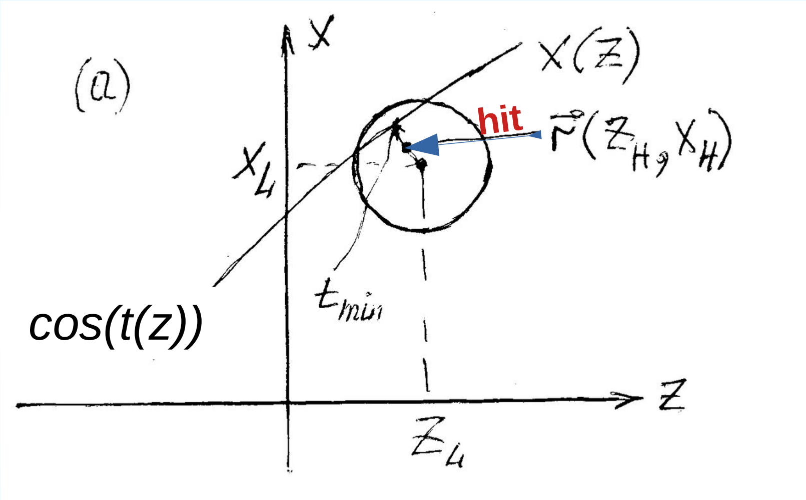
To determine the position of the tangent line to circles in two layers in the coordinate plane, we need an algorithm that takes into account the different positions of the points of interaction!
In this study, we use for coordinate planes "ideal" tangent hits from MC.

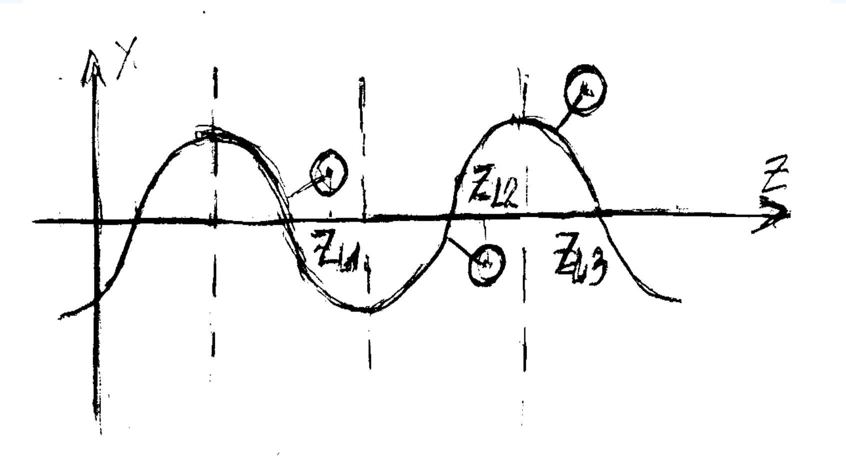
Single layer hits

We offer the method
how to find the *X-Z* track hit without coordinate plane using only one layer

helix

$$\begin{cases} x = x_{cL} + R\cos(\varphi_{0L} - qt) \\ y = y_{cL} + R\sin(\varphi_{0L} - qt) \\ z = z_0 + h_z t \end{cases} \Rightarrow \frac{dx}{dz}(z) = -\frac{qR}{h_z}\sin(\varphi_{0L} - q\frac{z - z_0}{h_z})$$





1. Let's find the initial approximation for the track model.
2. Find the interval of *t* around Z_L where *X(Z)* is monotonous.
3. In this interval we look for the minimum from the tube center and find t_{min} on the track model and the corresponding point (X_{min},Z_{min}).
4. The hit (X_H,Z_H) lies on the vector from the tube center to the point (X_{min},Z_{min}) in the distance *d+δ(d)*.
5. Use the hit to build the track χ2.

Single layer geometry track reconstruction

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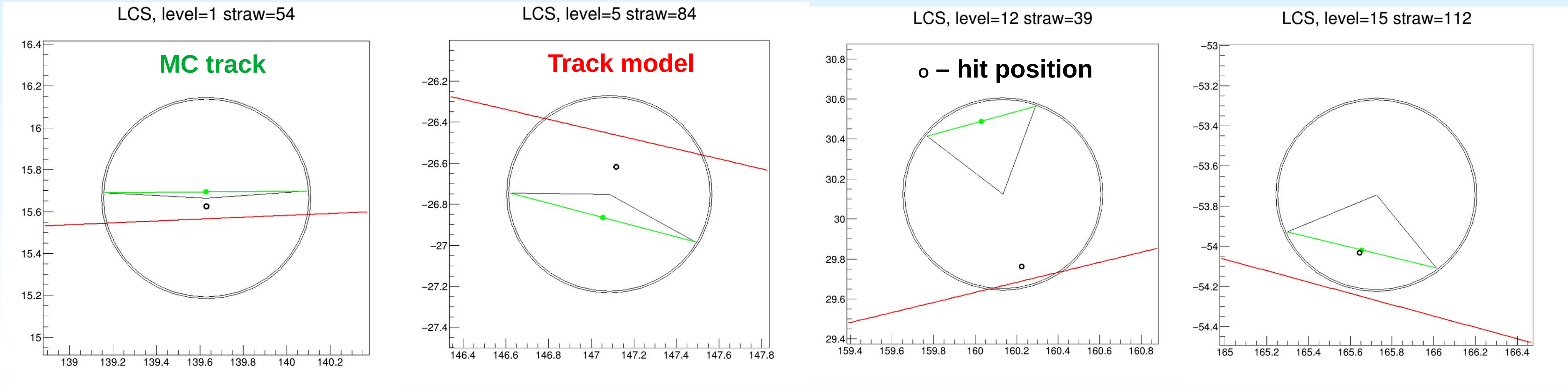
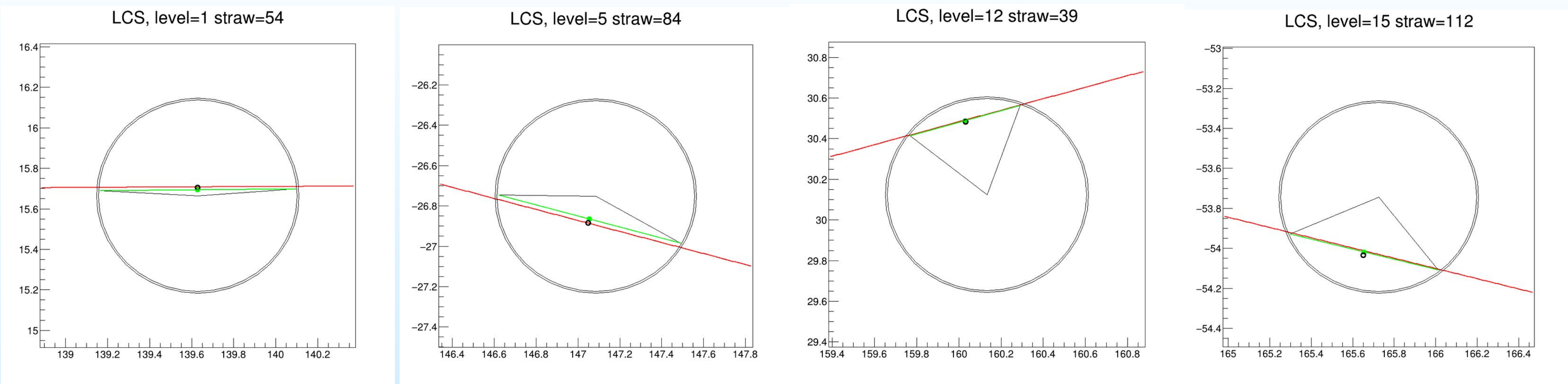
1^{st} approach



After fitting



EndCap detector geometries

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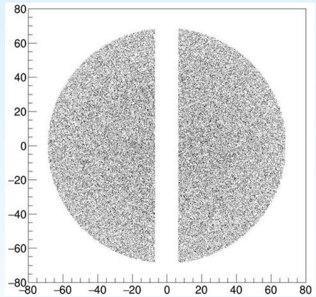
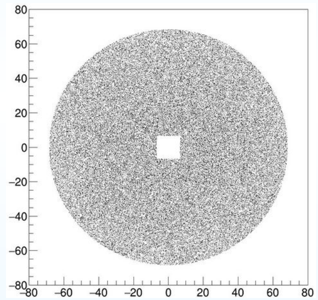
Variants of End-Cap geometrical layouts				
Variant	Beam pipe	Straw shift	Coordinate plane	Layer rotation
G0	strip	yes	yes	TDR
G1	square	yes	yes	TDR
G2	strip	no	no	π/4
G3	square	no	no	π/4
G4	strip	no	no	π/8
G5	square	no	no	π/8

strip



square



The six different detector geometries is the set purpose of the study: the influence of geometry on the geometric acceptance and efficiency of the device.
Two variants of hits were modeled for each geometry:
a) $H(X_h,Z_h)$, b) $C(X_c,Z_c)+R_w$

Such amount of layout variants requires a simplified modeling option.

a) right hits like in an ideal case of a coordinate plane

b) single layer case: circle center plus distance to the wire

End-Cap detector response simulation

Simulation conditions

- **The interaction point is located on the z axis of the Global Coordinate System (GCS) and can be distributed according to the Gauss law around a given axis point.**

- **The charged particle moves from the interaction point in the direction of the detector so that its trajectories uniformly fill the solid angle at which the detector is visible from the interaction point.**

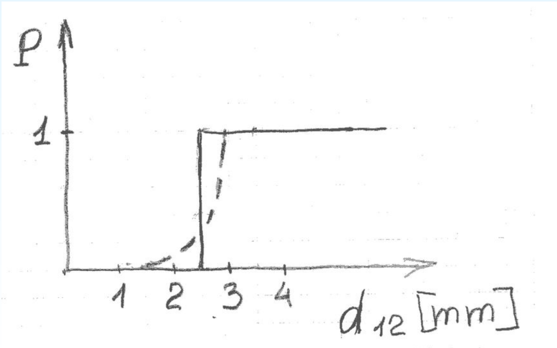
- **Particle trajectory.**
  - **No magnetic field, the trajectory of a particle is a straight line.**
  - **In a magnetic field, the particle flies in a spiral with a radius in a given range of magnitudes, and the longitudinal component of the momentum is selected from the condition of uniform filling of the trajectories of the solid angle at which the detector is visible.**

- **The straw has walls of zero thickness.**

- d_{12} **is the track length of the particle inside a tube.**

Simulation conditions (continuation)

- The probability to fire a straw depends on d_{12}.



2 functions were tested.
The both dependencies were chosen so that the average tube efficiency was equal to experimental value of 96.5%.

The shape of the function P has little effect on the final results of the study, because they are determined by 16 layers and the final distributions, according to the central limit theorem, will poorly remember the distributions of each layer.

- The detector's electronics allow to determine the distance from the track to the electrode wire. We believe that the device determines this distance with an error of δ_R which is smeared by Gaussian with δ_R=200 microns.

Summary of modeling input parameters:

- Geometry (layer layout, layers positions)
- IP position
- Trajectory type (magnetic field or not)
- Probability to fire a straw on the length path inside
- δ_R - electronics error

End-Cap detector response simulation

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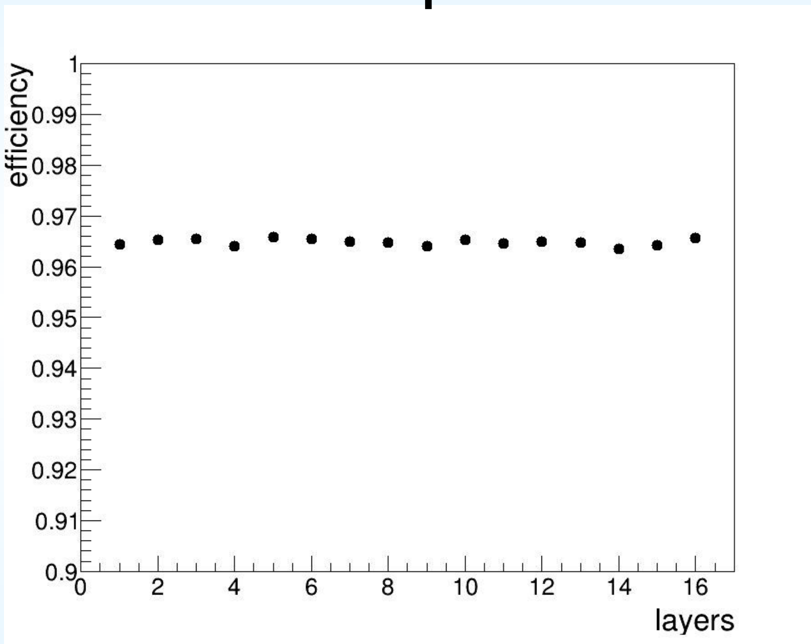
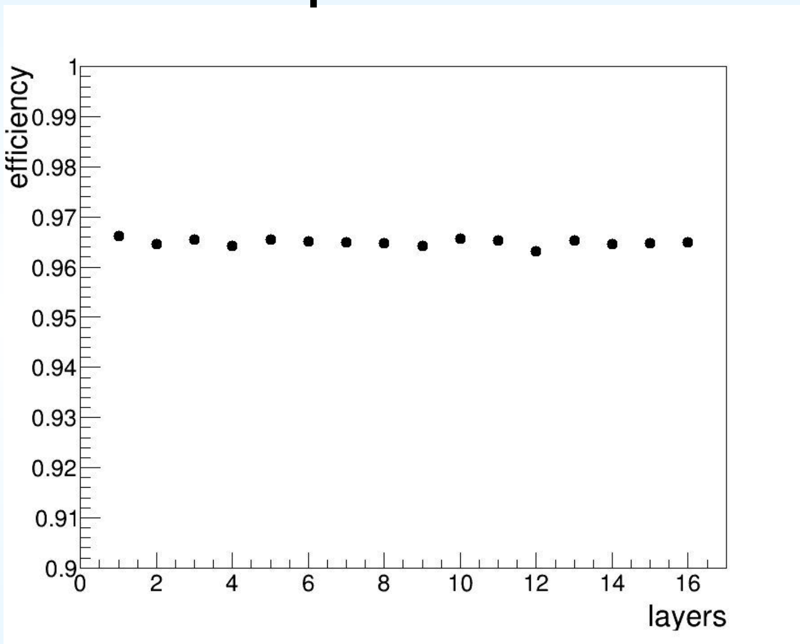
Each sample in the study is based on 100000 simulated events with IP at (0,0,0)

Layers efficiency

strip



square



It is possible to expect a dependence of efficiency on the magnitude of the solid angle at which the layer is visible, but the thickness of the detector along the Z-axis is small, and such a dependence is not observed.

End-Cap detector response simulation

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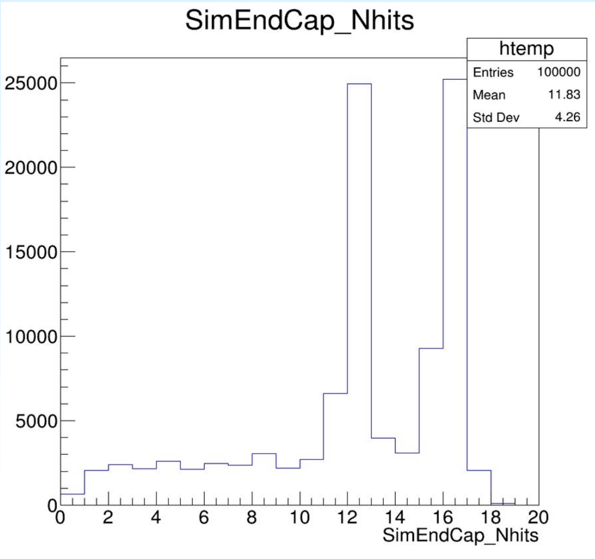
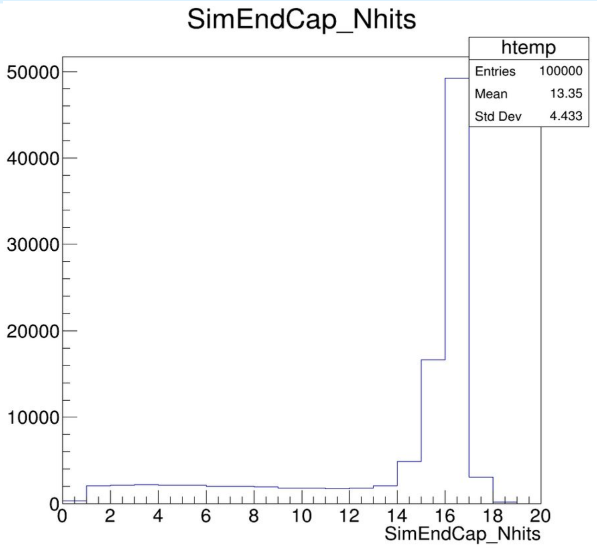
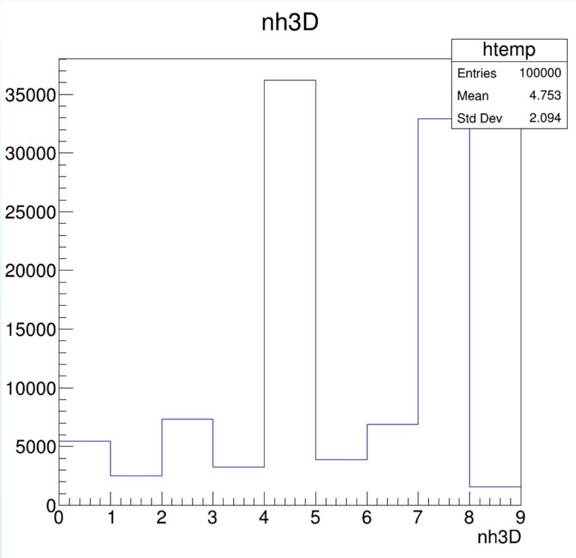
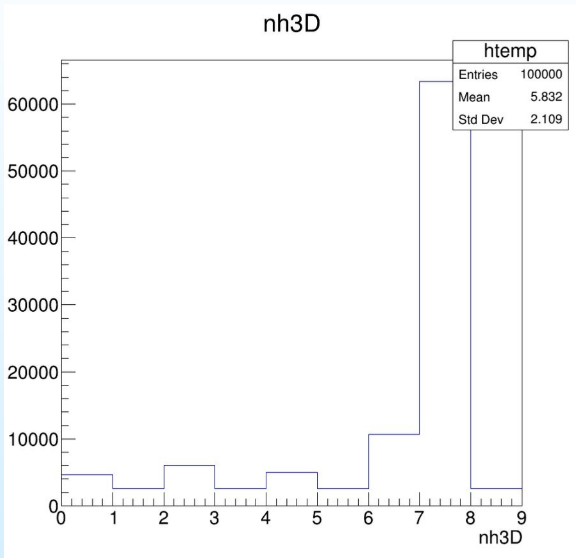
	strip	square
Fired layers		
3D hits		

The number of maximum fired layers and the number of 3D hits in the case of the “strip” geometry 2 times less than in the case of the “square” geometry.

End-Cap detector acceptance simulation

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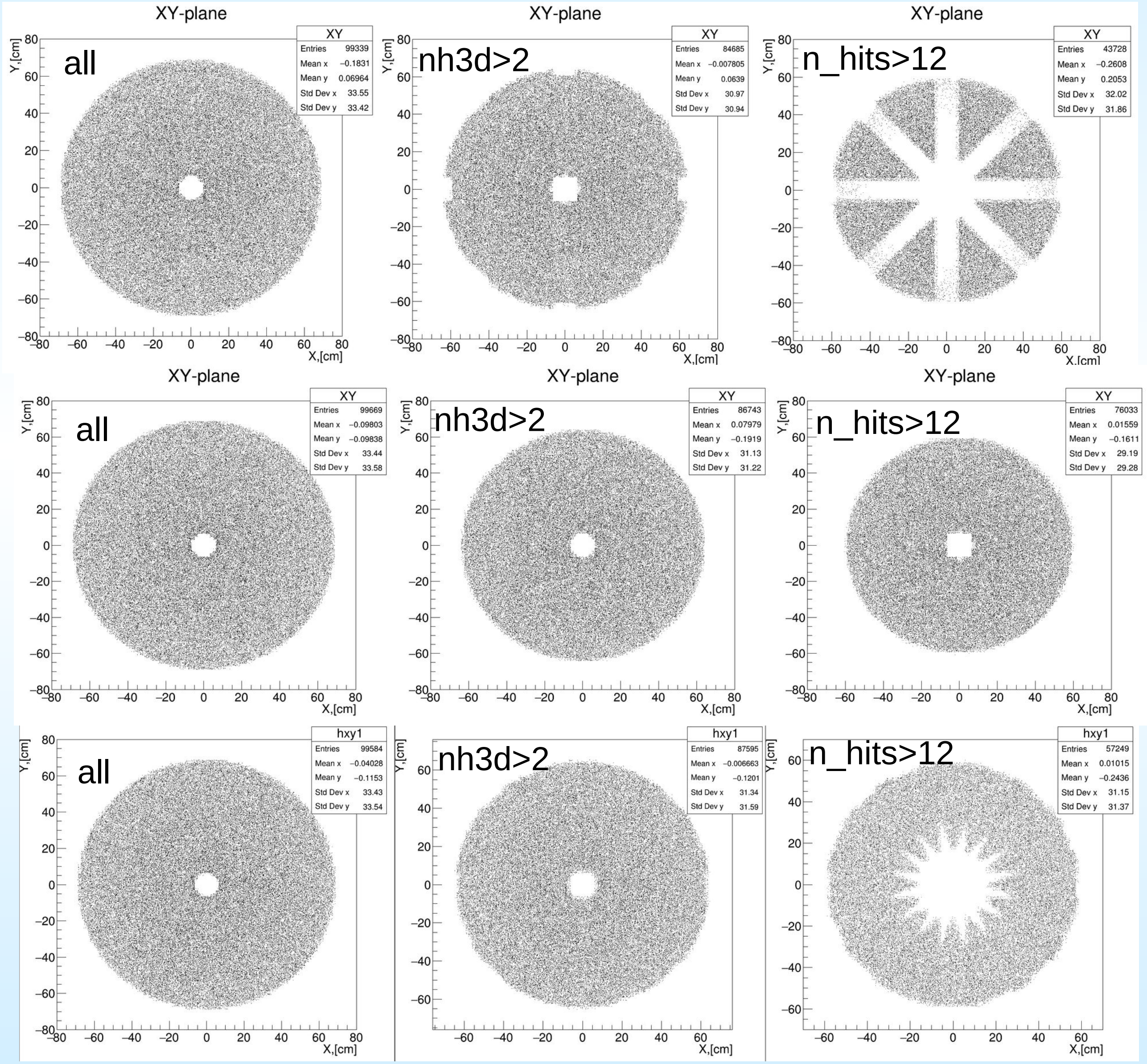
Detector entry points (X-Y plane)

Strip G0

Square G1

Strip G4



End-Cup entry points in the X-Y plane for 3 geometry layouts at different cuts.

The “strip” geometry in the case of coordinate planes has a complex acceptance structure for a half of events.

The “square” geometry has a uniform acceptance.

End-Cap detector track reconstruction

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Track models:

line	helix
$\begin{cases} x = x_1 + a_x t \\ y = y_1 + a_y t \\ z = z_1 + a_z t \end{cases}$	$\begin{cases} x = x_{cL} + R\cos(\varphi_{0L} - qt) \\ y = y_{cL} + R\sin(\varphi_{0L} - qt) \\ z = z_0 + h_z t \end{cases}$

To restore the trajectory of the track, that is, to find the parameters of its model, we have local 2D hits coordinates (H_x,H_z) in each layer with a signal and look for the minimum:

$$\min \sum_{hits} \left(\frac{\boldsymbol{h}_i - \boldsymbol{T}_i}{\sigma_i} \right)^2$$

- **The trajectory of the track is 3D curve when we have only 2D hits.**
- **To find an initial approach to the track model parameters, we need at least two hits for the line and three for the helix.**
- **One 3D hit we can get from two 2D hits of layers with non-parallel local X-axes, better adjacent layers.**
- **As we will see later, the quality of the reconstruction strongly depends on the choice of the initial approximation.**
- **Finding a set of 3D hits is a separate art, the study of which is beyond the scope of this message.**

End-Cap detector track reconstruction

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- Finding the minimum of a function of several variables is not a trivial procedure due to the presence, as a rule, of local minima, one of which can be found by the algorithm.
- In the variant with coordinate planes, the hit is set "rigidly" by tangential point.
- In the case of separated single layers, the hit is not fixed on the circle and its position depends on the initial track approximation that can provide a false minimum.
  It needs a special analysis of the initial approach influence on the minimum value:

$$\min \sum_{hits} \left(\frac{\boldsymbol{h}_i - \boldsymbol{T}_i}{\sigma_i} \right)^2$$

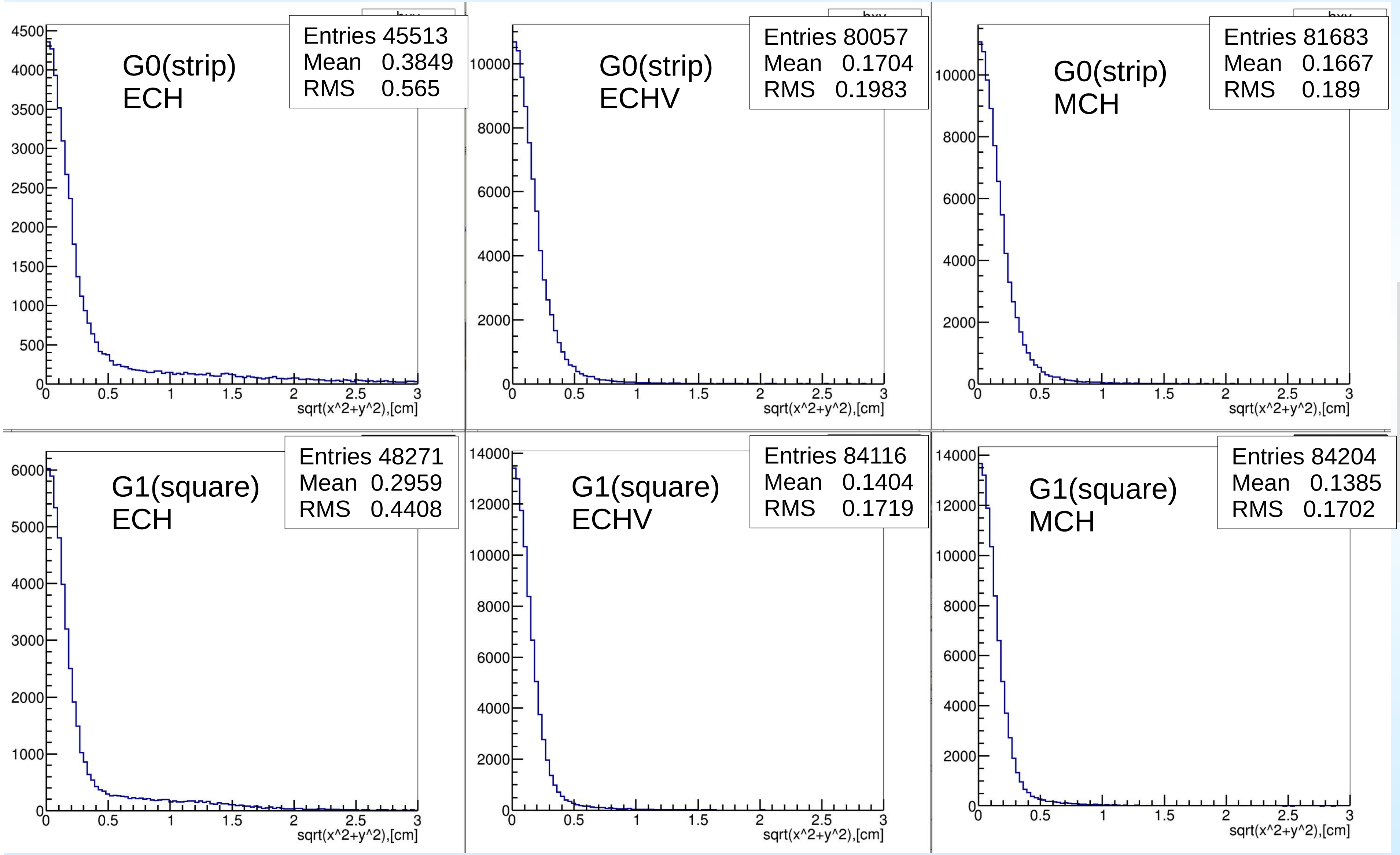
As an initial step of the study we reconstruct each sample using 3 different initial approaches:

a) Track model parameters from reconstructed 3D hits. (“ECH”)
b) Track model parameters from reconstructed 3D hits plus coordinates of IP from the vertex detector. (“ECHV”)
c) “Ideal” or the initial approach is MC track parameters (“MCH”) .

End-Cap detector track reconstruction

No magnetic field

Cuts: nh3D>2 && $\chi^2 < 10$

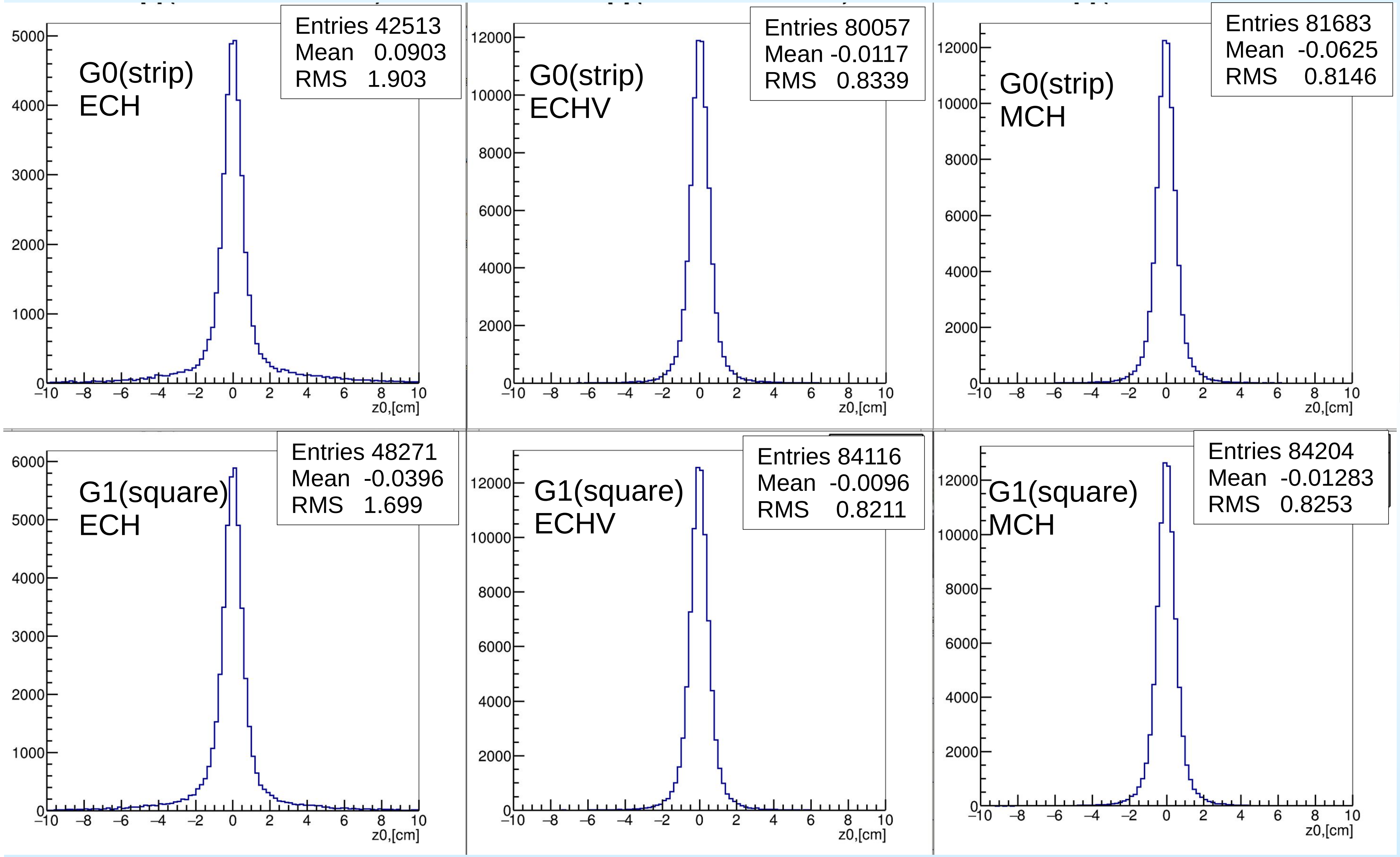


The minimum distance between the restored track and the Z-axis (vertex error in X-Y plane).

End-Cap detector track reconstruction

No magnetic field

Cuts: nh3D>2 && $\chi^2<10$



The Z-coordinate of the track point where the distance between the restored track and the Z-axis is minimal (vertex error in Z direction).

The distributions integrated over the entire acceptance for both detector geometries are similar.
G1 provides ~4% events more.

End-Cap detector track reconstruction

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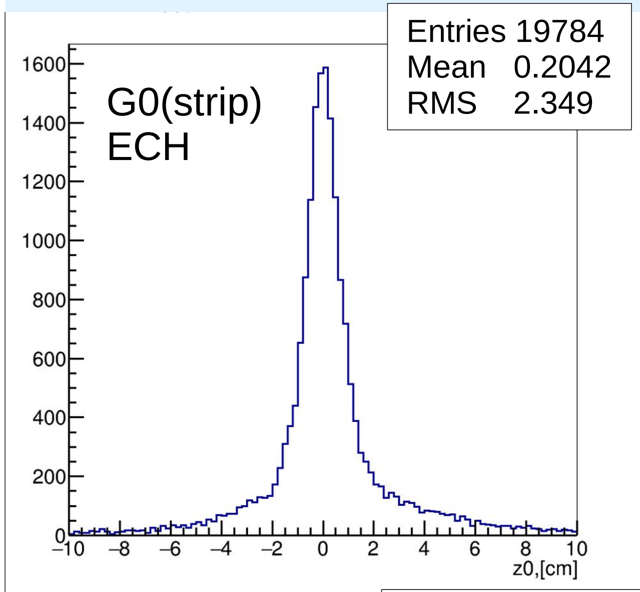
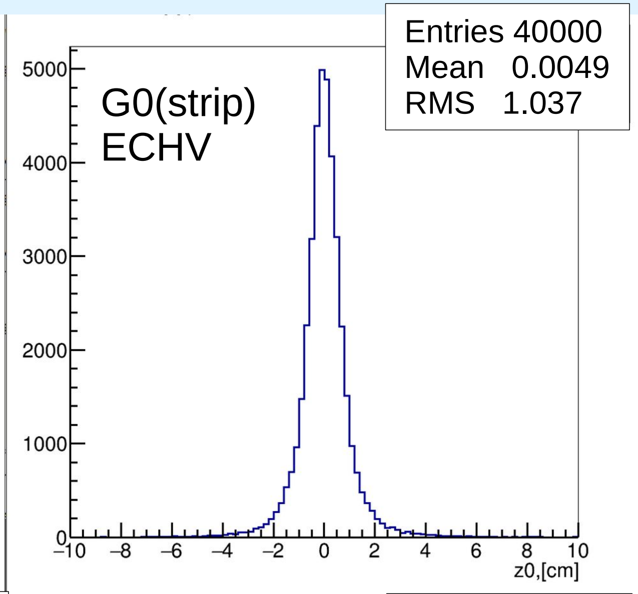
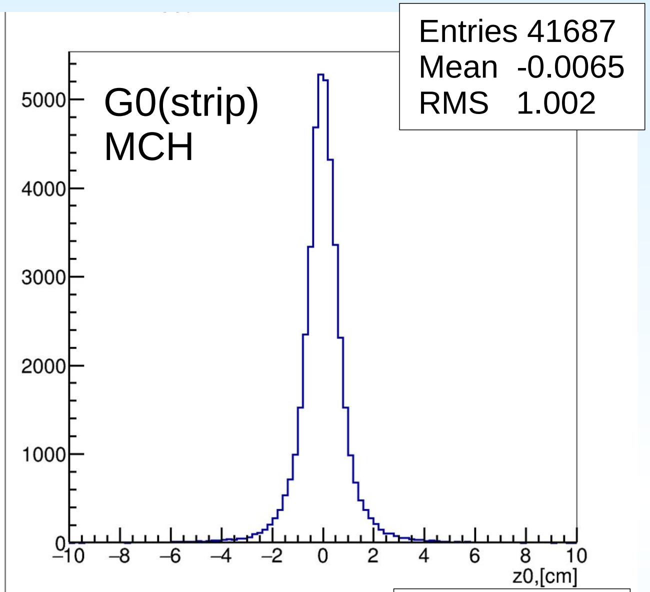
No magnetic field, G0

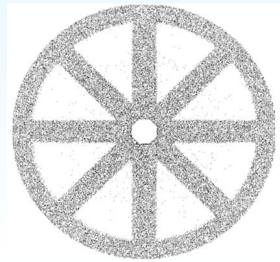
General cuts: nh3D>2 && $\chi^2 < 10$

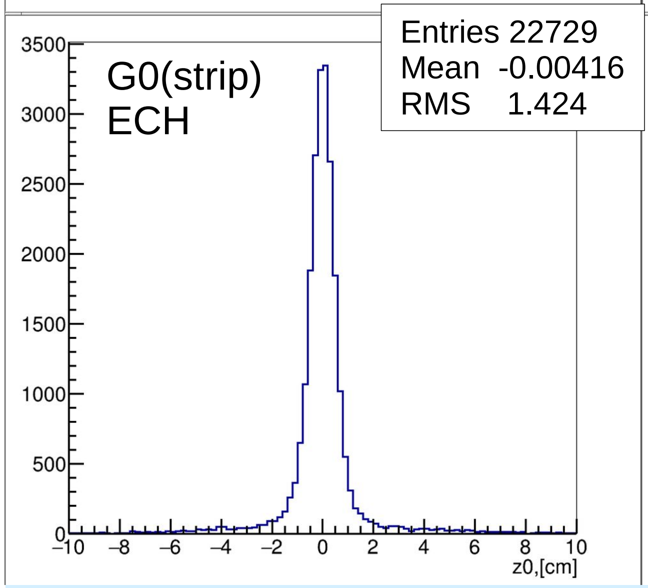


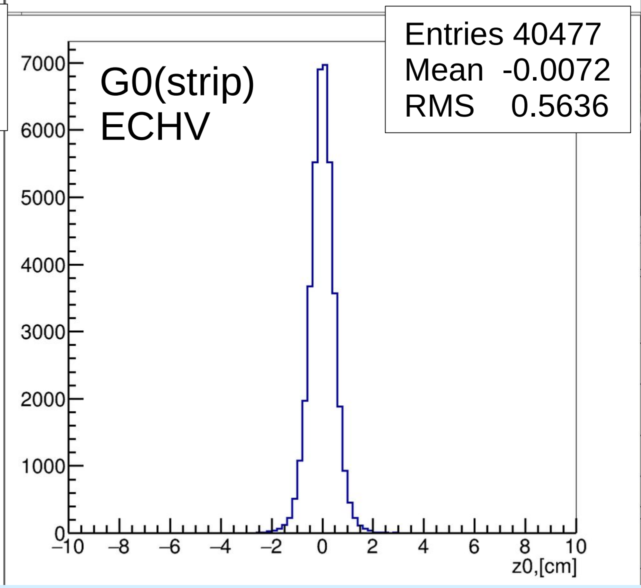


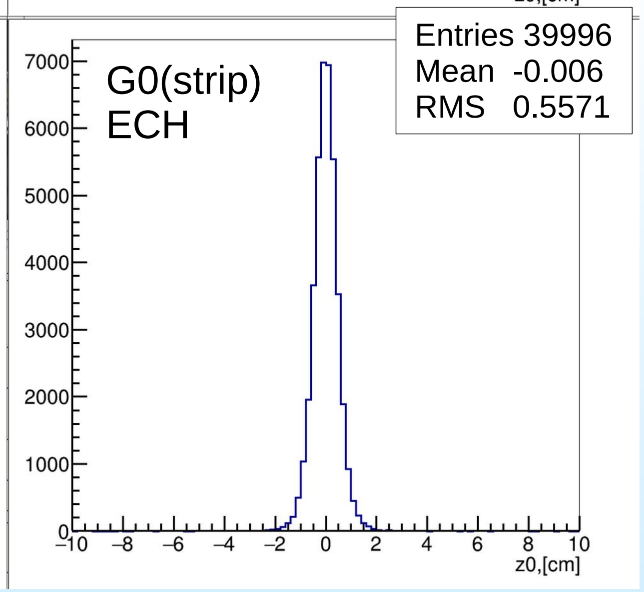


nhits<13

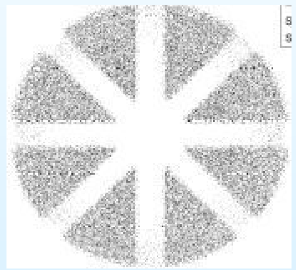






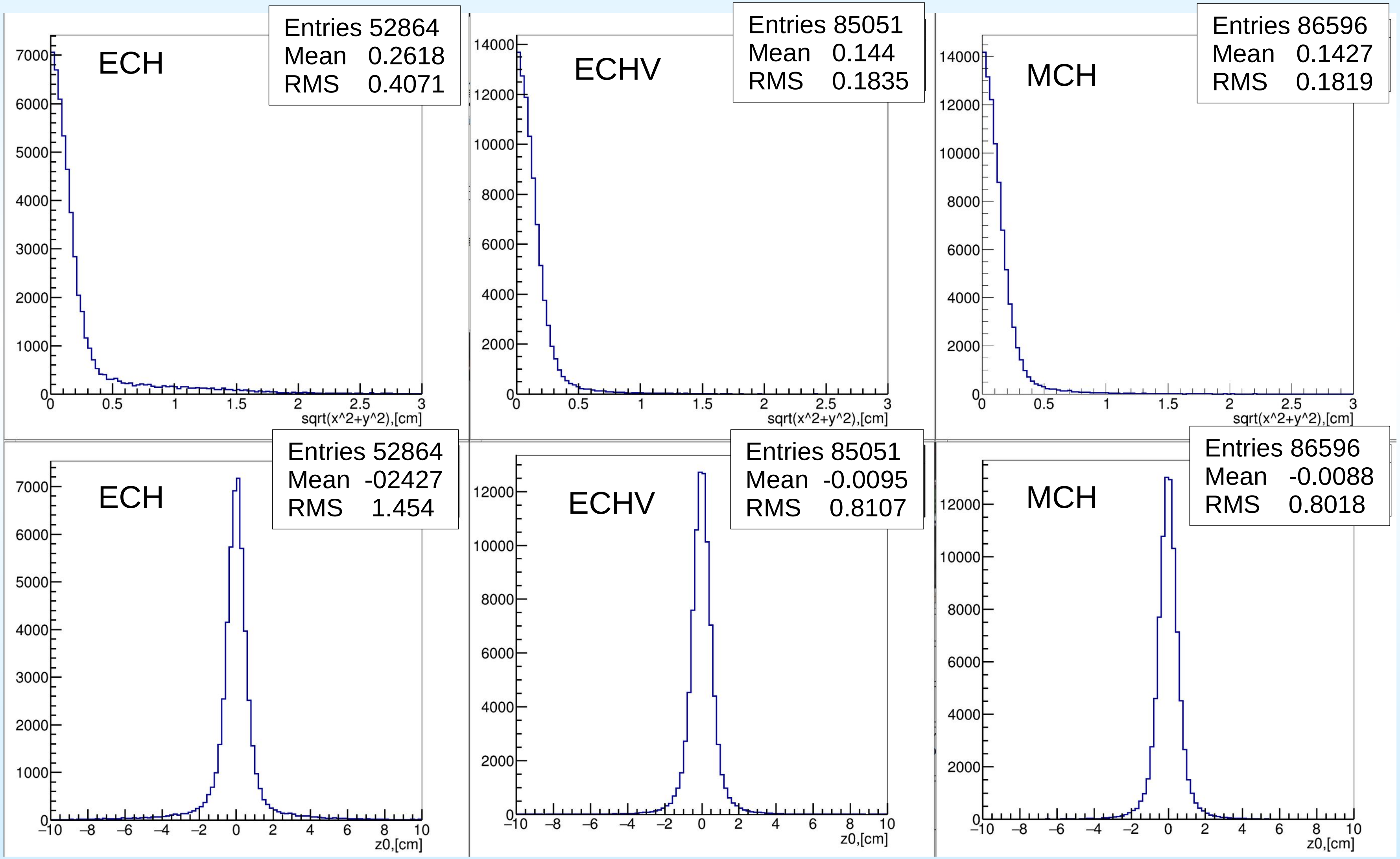


nhits≥13



End-Cap detector track reconstruction

No magnetic field (cuts: nh3D>2 && $\chi^2<10$)
Single layer geometry G3 (“square”)
Vertex reconstruction



Single layer geometry has the same track vertex reconstruction accuracy as ideal detector variant with coordinate planes layout.

End-Cap acceptance in magnetic field

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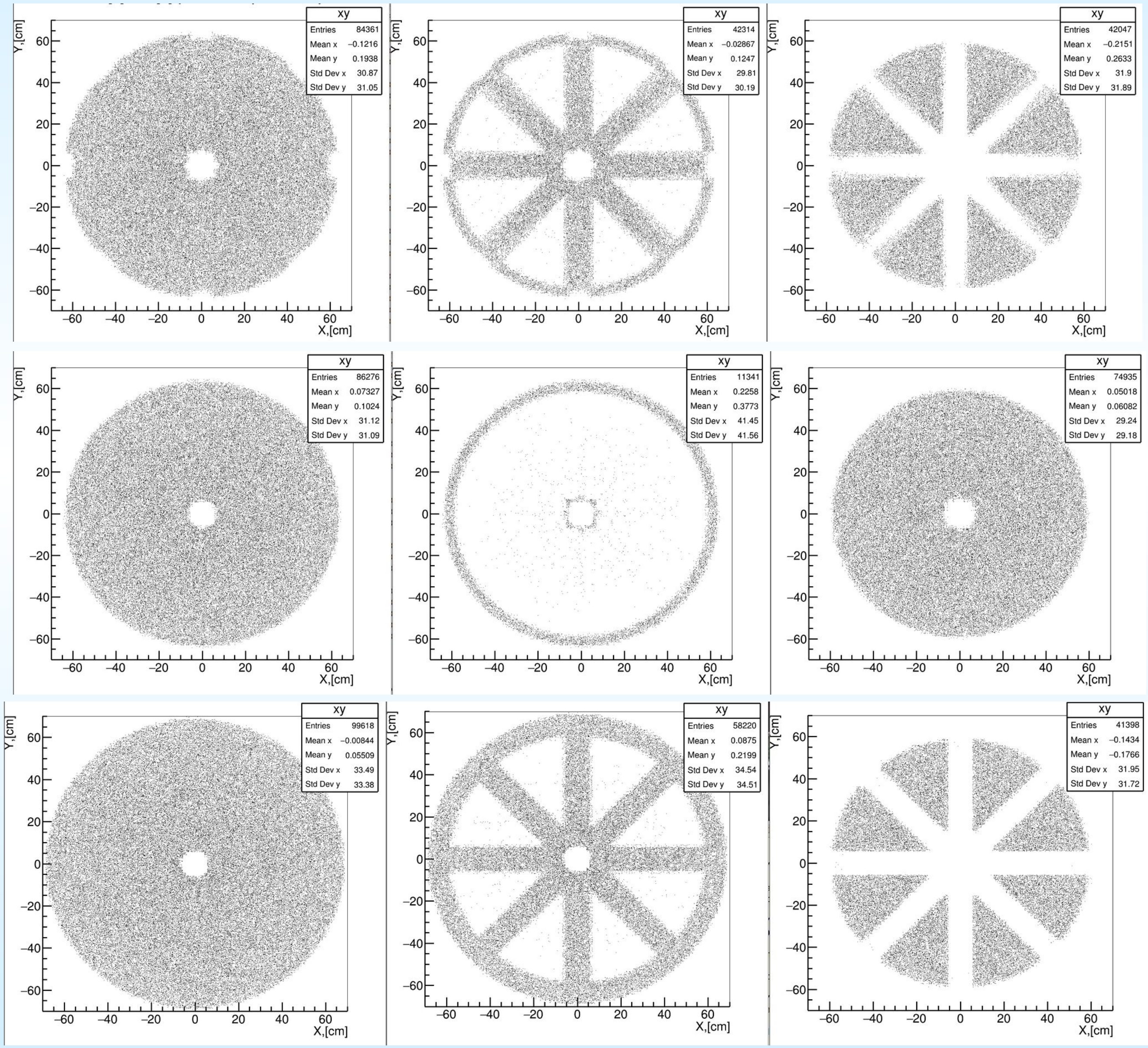
all | nhits<13 | nhits≥13

G0 (strip) Magnetic field

G1 (square) Magnetic field

G0 (strip) No magnetic field



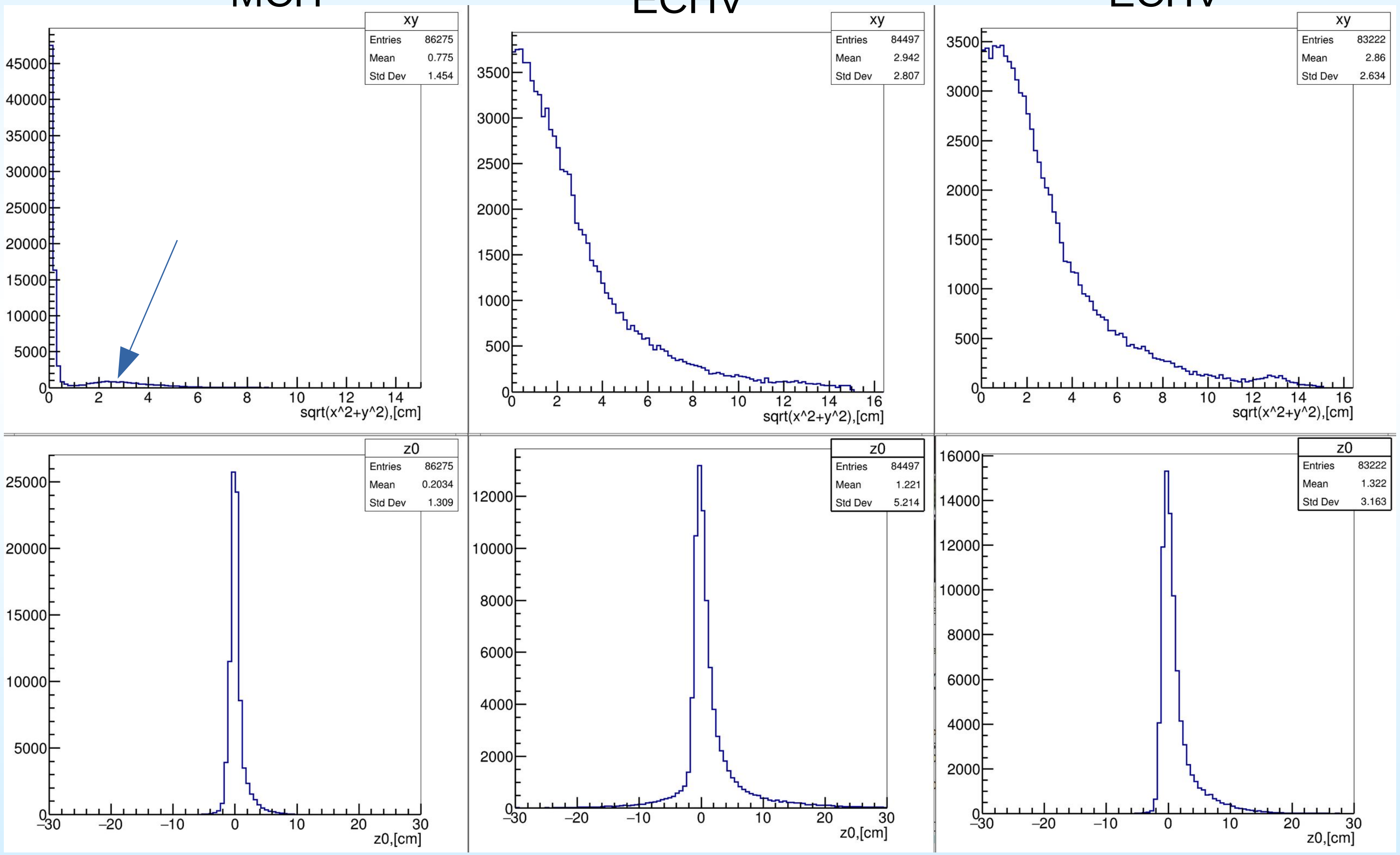
End-Cup acceptance for tracks with the curvature radius of 100cm (At the field of 1Tesla, it corresponds to Pt of 150MeV).

The accuracy of track reconstruction depends on the knowledge of the hit position. The presence of a magnetic field determines the accuracy δ(200μ), which is used for both straight tracks and curved tracks. Therefore, the results for different End-Cap layouts obtained for straight tracks should be qualitatively valid even in the presence of a magnetic field in the detector, but the numerical values may vary for different transverse pulses, which is the subject of a separate study.

End-Cap & SPD magnetic field

Curvature radius of 100cm

G1(square) MCH | G3(square) ECHV | G1(square) ECHV



On left plots the initial approach is MC track parameters. The events under the arrow are reconstructed incorrectly. Due to the accuracy δ of hits, there is a stronger minimum for the track parameters than the real ones.

The problem with the EC detector is its small thickness and, as a result, the small track length in the X-Y plane, which is less than 10 cm long. This, plus the lack of hits in the X-Y plane, leads to poor-quality initial approximations for track parameters. This explains the lower accuracy of the vertex reconstruction in the right figures.

The accuracy of the EC track reconstruction in a magnetic field is a topic of separate study.

Conclusion & Outlooks

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- Mathematical and programming software have been developed to simulate the responses of different geometrical layouts of the end-cap detector and to evaluate the accuracy of reconstructed tracks by the detector.
- The detector variant with the absence of sensors in the entire band leads to a non-uniform complex structure of the device's acceptance in the X-Y plane for tracks. The accuracy of track reconstruction in the acceptance region differs almost 2 times.
- Offered single layer geometry method has the same level track reconstruction accuracy as ideal detector variant with coordinate planes layout.
- There is very strong dependence of the accuracy of track parameters reconstruction on the quality of the initial approximation.
- Using the coordinates of the interaction point for the initial approximation significantly improves the quality of reconstruction.

- A lot of job needs to be done:
  - To simulate a real End-Cap response in the case of the coordinate planes layout: one needs to create an algorithm for finding tangents.
  - To analyze the possibilities of improving the initial approximation by an interactive way.
  - To test different models of 3D hits finding.
  - To investigate the condition of successful electron-positron pair reconstruction which are born inside the SPD.

Students are welcome to join the study!

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The end

Thank you!