

Geometry document of the CLAS12 RICH

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May 5, 2016

Abstract

This document describes the geometry of the RICH detector and its implementation in the simulation and reconstruction softwares.

1 Particle identification in CLAS12

Particle identification (PID) for hadrons in the Forward Detector of CLAS12 is obtained by combining the information of High and Low Threshold Cherenkov Counters (HTCC and LTCC), Forward Time-Of-Flight (FTOF) and calorimeters.

Electrons are identified by combining information from HTCC and calorimeters. The FTOF can discriminate kaons from pions at 4σ level up to momenta between 3.6 and 2.8 GeV/c, depending on the polar angle. The threshold for pions is about 5 GeV/c in the HTCC and Kaons can be separated from pions at 3σ level only above 7.8 GeV. The threshold for pions in the LTCC is 2.7 GeV/c, while kaons are below threshold for momenta up to 9 GeV/c.

To extend the PID capabilities of CLAS12 to efficiently discriminate kaons from pions and protons in the momentum range between 3 and 8 GeV/c, a Ring Imaging Cherenkov (RICH) detector has been designated to replace the LTCC detector. The RICH design incorporates aerogel radiators, visible light photon detectors, and a focusing mirror system which will be used to reduce the detection area instrumented by photon detectors to 1 m². Multi-anode photomultiplier tubes (MAPMTs) Hamamatsu H8500 and H12700 provide the required spatial resolution and match the aerogel Cherenkov light spectrum (visible and near-ultraviolet region).

Due to the relative yield production between kaons and pions, a successfully kaon ID requires a rejection factor from pions around 1:500, i.e. a contamination in the kaon sample of few percent. This corresponds to a 4σ separation.

The concept of this RICH is illustrated in Fig. 1. For forward scattered particles ($\theta < 13^\circ$) with momenta in the range between 3 and 8 GeV/c, the Cherenkov light will be directly detected by the photon detector array (Fig. 1 top). For particles with larger incident angles ($13^\circ < \theta < 35^\circ$), with momenta between 3 and 6 GeV/c, the Cherenkov light will be double-reflected by a spherical and a planar mirror and

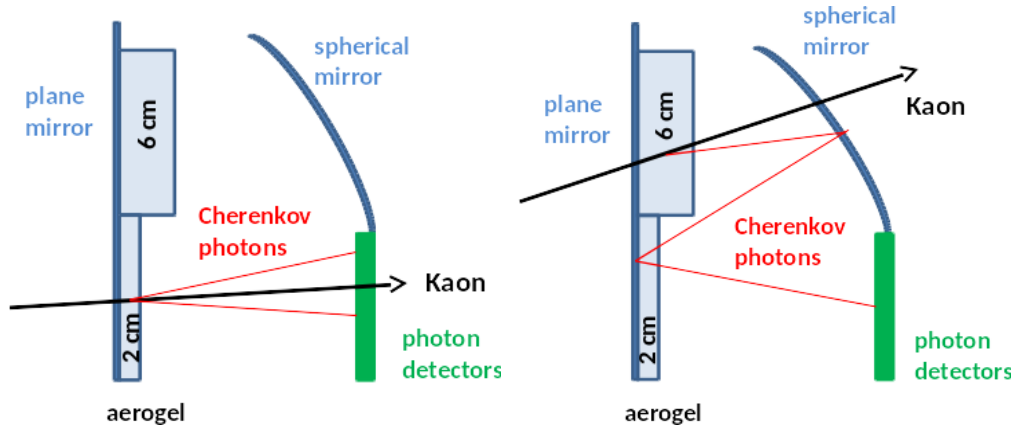


Figure 1: The conceptual design of the RICH detector for forward (top plot) and large angle (bottom plot) particles.

focused onto the photon detector array after two passages through the lower section of the aerogel wall (Fig. 1 bottom). This double pass imposes the use of aerogel with reduced thickness (2 cm) and with relatively high refractive index ($n=1.05$) in the lower section of the detector, to minimize the photon yield loss. The photon yield losses will be compensated by the use of a thicker (6 cm) aerogel in the upper section.

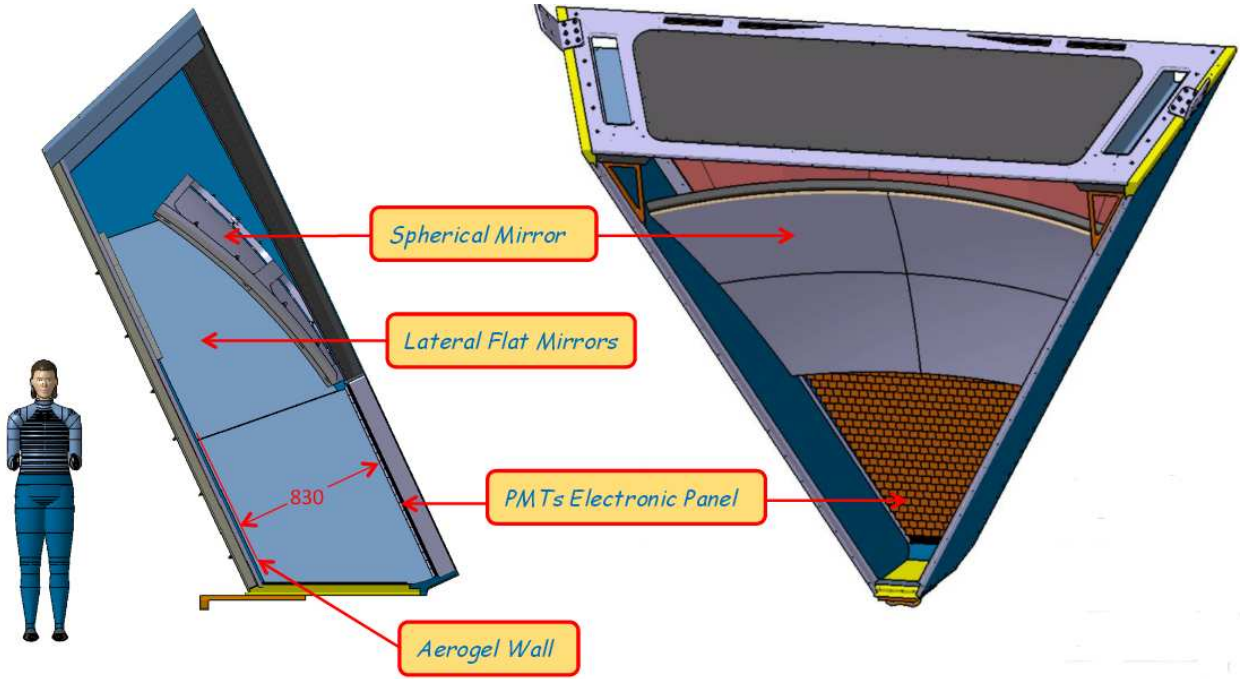


Figure 2: Lateral and frontal drawings of the RICH module.

2 The RICH

A first RICH module will be ready for the beginning of the CLAS12 operation and will replace the LTCC in sector 4. A second RICH module will be constructed for the operation of CLAS12 with transversely polarized targets and will replace the LTCC in sector 1. Even if the first module will be installed in a horizontal position, for simplicity in the following it will be described as if it were placed in vertical position, i.e. with the two bases placed horizontally.

The RICH has a trapezoidal shape, with a smaller base of about 0.3 m, and a greater base of about 4.2 m, a height of about 3.7 m and a depth of about 1.2 m. The planned total weight is approximately 900 Kg. A schematic of the RICH is shown in Fig. 2. It is composed by an external frame in aluminum and carbon fiber on which various elements are assembled. The module is installed in the CLAS12 Forward Carriage (FC) by a steel bottom plate with a collar attached to the beam line and by two steel upper connection stirrups.

The RICH external frame is made by:

- a bottom plate in aluminum;
- two large lateral aluminum panels, made by a sandwich of two skins and a honeycomb core with a stiffening solid frame;
- two upper corner blocks in aluminum;
- a top panel made by a sandwich of two carbon fiber skins with Nomex core and a stiffening frame of solid carbon fiber;
- a stiffening intermediate rib on the backward face in carbon fiber;

All these elements compose the RICH mechanical structure and have a structural meaning.

The bottom plate is parallel to the beam line, while the top panel has an angle of 33.3° with respect to the beam line. By looking from the target point, the two lateral panels form an angle of 60° .

The first RICH inner element the particles will cross is an entrance panel in carbon fiber material, segmented horizontally in two halves. The upper half holds the aerogel tiles of the thick section, made by two layers of 44 aerogel tiles. Each tile is $200 \times 200 \text{ mm}^2$ and 30 mm thick. They are kept on the panel by a frame in carbon fiber that divide each layer in a right and a left section and by a net of wires stretched between two opposite sides of the frame and along the sides of each tile. The lower half of the panel holds the frontal planar mirrors and one layer of 38 aerogel tiles, 20 mm thick. The tiles are kept by the aluminum frame of the mirrors and by a net of wires.

The spherical mirror is attached to RICH in three points, to the intermediate rib and on the two lateral panels. It is made by ten sub-mirrors in a sandwich of carbon fiber skins with a honeycomb core.

The readout electronics is mounted on a box on the back of the RICH, attached to the bottom plate, to the lateral panels and to the intermediate rib. The box is basically composed by two elements made by a sandwich of two carbon fiber skins with a Nomex honeycomb core.

The upper part of the backward face of the RICH is completed by a closing panel, made by 2mm of aluminum.

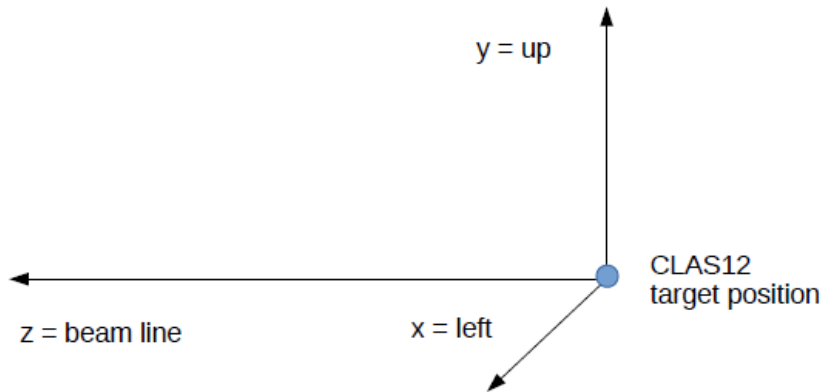


Figure 3: The Forward Carriage reference frame.

3 The RICH description in the software

The RICH will be described by a virtual volume (the RICH box) in which all the inner elements will be placed. Then, the RICH box is positioned within the FC virtual volume, where the whole CLAS12 detector is placed. The FC reference frame, shown in Fig. 3, has the origin at the nominal CLAS12 target position, the z axis along the beam line, the y and x axis pointing up and to the left, respectively. Thus, Sector 4 is on the right side, by looking at the RICH from the target.

Due to the complexity of the detector, only the elements relevant to the performances of the RICH and of the other CLAS12 detectors will be developed in the software. The RICH elements can be classified as:

- active elements that enter in the RICH event reconstruction;
- passive elements within the CLAS12 acceptance that do not enter in the RICH reconstruction;
- passive elements out of the CLAS12 acceptance.

Active elements are the aerogel, the mirrors and the photodetectors. Passive elements in the acceptance are the frontal, backward and top panels. All these elements will be described in the software, with the approximations and simplifications described in the next sections.

Due to the shadows of the torus coils and of the beam line, as shown in Fig. 4 ¹, the bottom aluminum plate, the angular aluminum blocks and the lateral panels are out of the acceptance. Thus, they will not be described in the software.

¹In this figure, the planar mirrors are shown in an out of date configuration, however the total encumbrances are correct.

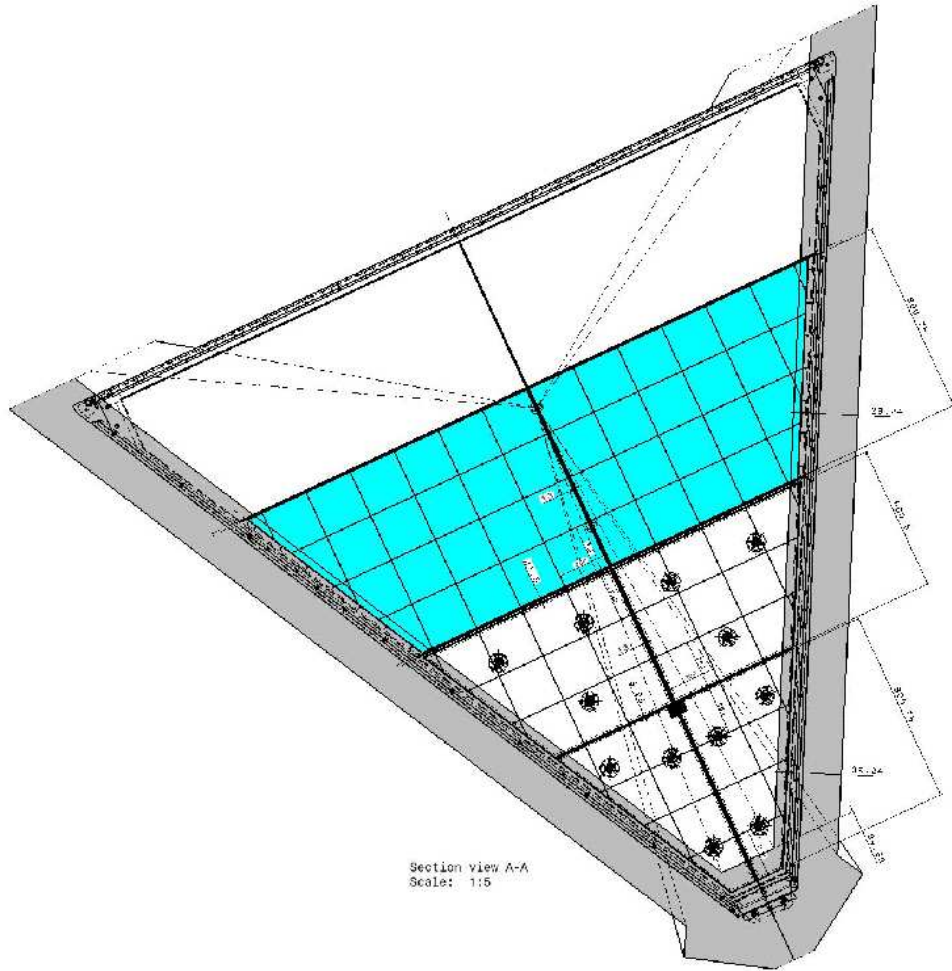


Figure 4: Shadow on the RICH frontal panel produced by the torus coils and by the beam line, indicated by the grey area [1].

4 Extracting the RICH dimensions from the 3D model

In the 3D model, the RICH is represented in vertical position, as if it was between sector 2 and 3. The extraction of the dimensions of all the elements composing the RICH is performed in two steps.

In the first step, we take a projection of the RICH on the yz plane and we get the coordinates of the corners of the RICH element. In the second step, we take a frontal projection of the RICH to get the coordinates of the corners of the RICH element along the x axis.

In *gemc*, each element is defined by a geometric description, which uses the dimensions extracted from the 3D model, and it is placed inside its mother volume by knowing the position of its geometric center and three rotation angles.

In *java*, all the elements are defined and placed in the CLAS12 reference frame through the corner coordinates.

5 The RICH box

The RICH box is only a virtual volume, thus, it must be the simplest possible, provided that it is big enough to house all the inner elements and that it doesn't interfere with the other CLAS12 volumes. It is defined as a regular trapezoid. The front and back faces are parallel and with equal shape and area, the top face is parallel to the bottom one and the two lateral faces have symmetric shape and same area. Its dimensions have been set to be equal to the maximum encumbrance of the RICH, by extracting the coordinates of the corners of the volume from the 3D model. The steel plate and collar connecting the RICH to the beam line have not been included in the RICH encumbrance.

The dimensions of the frontal and back faces are given by the total size of the back panel, shown in Fig. 5. The coordinates of the RICH box corners on the yz plane are shown in Fig. 6.

5.1 The RICH box in *gemc*

The RICH box is defined in *gemc* as a *g4trap* volume. The non-vanishing parameters used to define the volume are shown in Fig. 7. By construction, the following relations hold:

- $dx3 = dx1$
- $dx4 = dx2$
- $dy2 = dy1$

Thus, only 5 parameters are independent, 4 half-dimensions and one angle.

The box is then placed in the CLAS12 FC as shown in Fig. 8. One has to determine the coordinate (X_C, Y_C, Z_C) of the geometric center of the box and position it with respect to the FC origin. For this, an offset in the y direction must be considered, to shift the RICH at the right distance from the beam axis. Then, a final clockwise rotation of 60° around the beam axis has to be performed to move the RICH in the

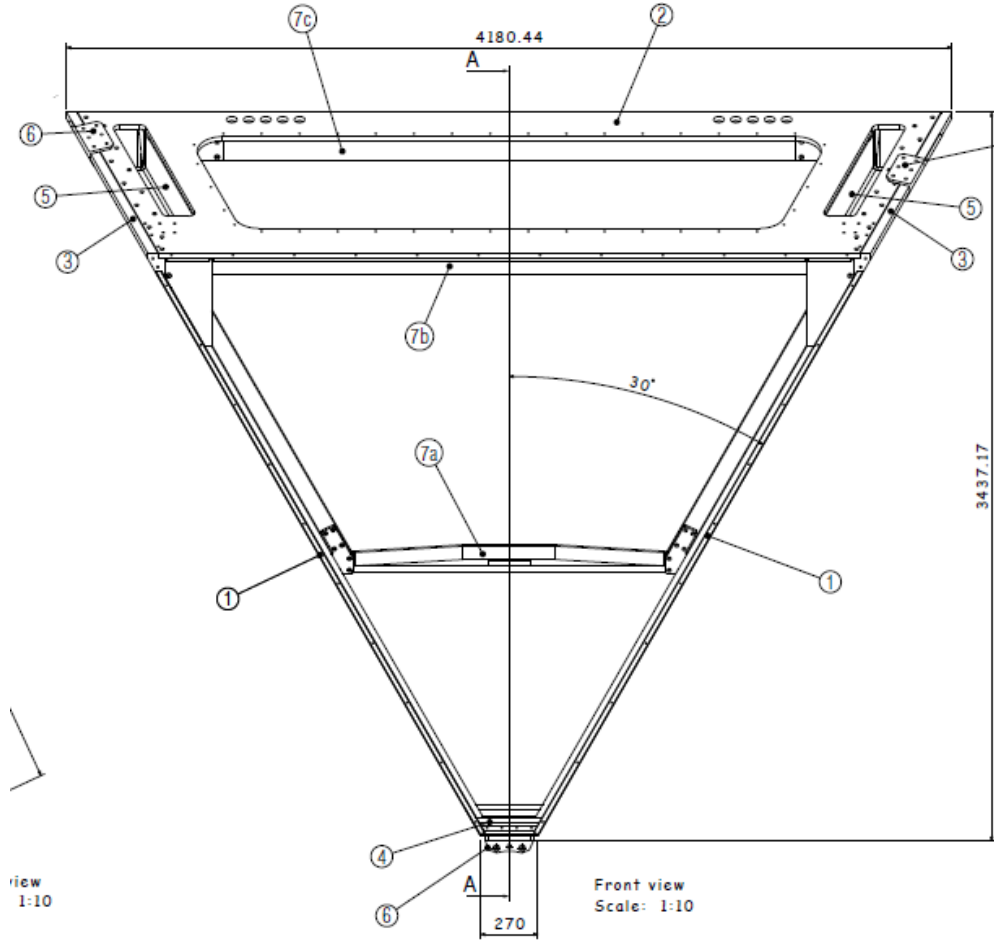


Figure 5: Total frontal encumbrance of the RICH [2].

sector 4. This is done in gemc through three rotation angles with respect to the reference frame axis.

The list of the parameters used in gemc and their values are reported in Tab. 1.

The inner elements of the RICH are positioned inside the RICH box by taking into account the local reference frame shown in Fig. 8. It means that the coordinates extracted from the 3D model must be translated and rotated from the CLAS12 to the RICH box reference frames. This is done by using a simple C script [5].

5.2 The RICH box in java

6 The Electronic Panel

The photodectors and the Front-End electronics are installed on a carbon fiber trapezoidal panel placed on the bottom of the backward face of the RICH [6]. The active elements of the panel are the 391 Hamamatsu H8500/H12700 MAPMTs [8]. A MAPMT is composed by a matrix of 8×8 pixel covering a total surface of $52 \times 52 \text{ mm}^2$ with an active area of $49 \times 49 \text{ mm}^2$.

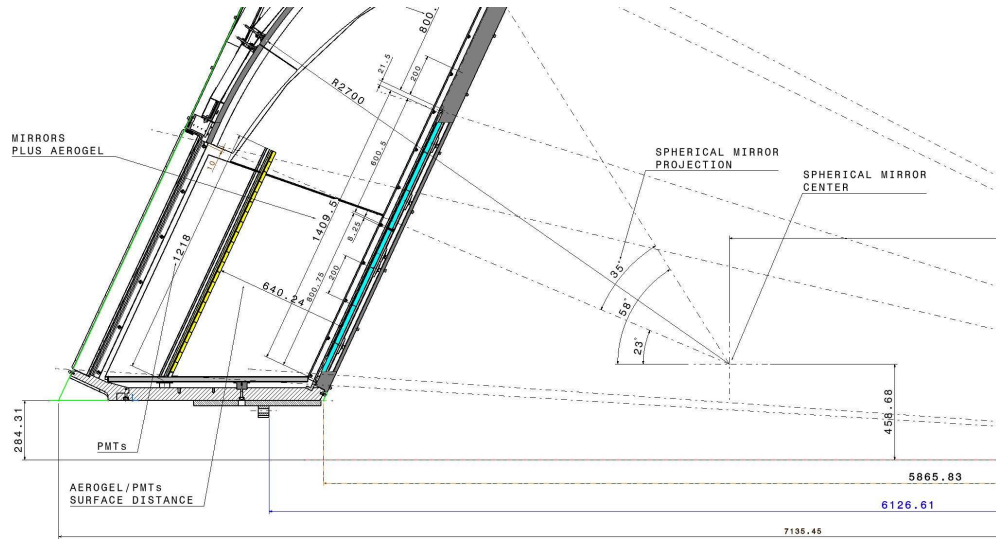
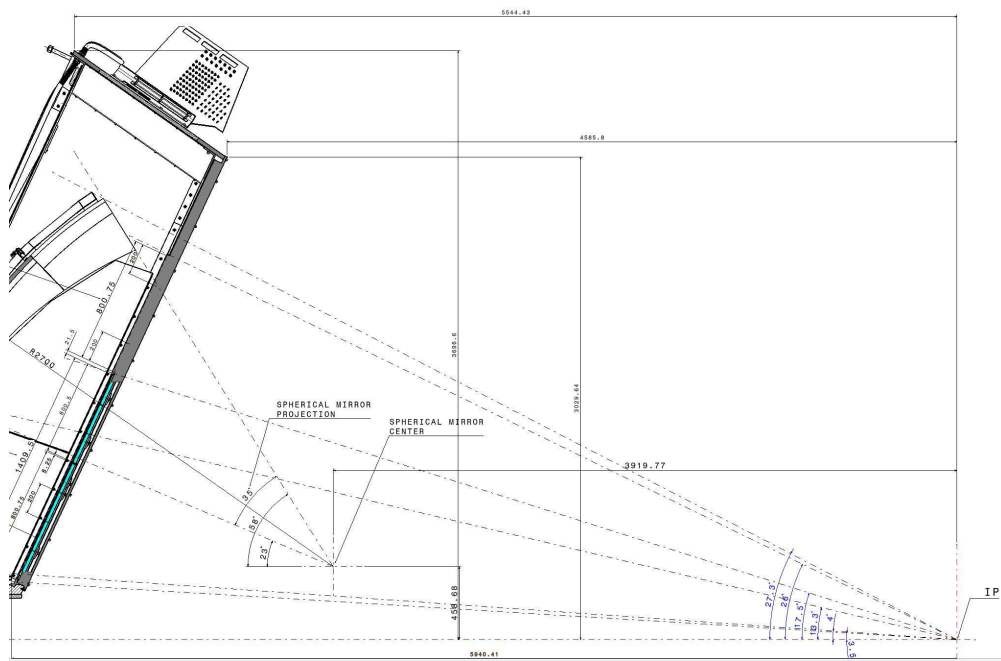


Figure 6: Upper left (top plot) [3] and lower (bottom plot) [4] corner coordinates of the RICH box as taken from the RICH 3D model .

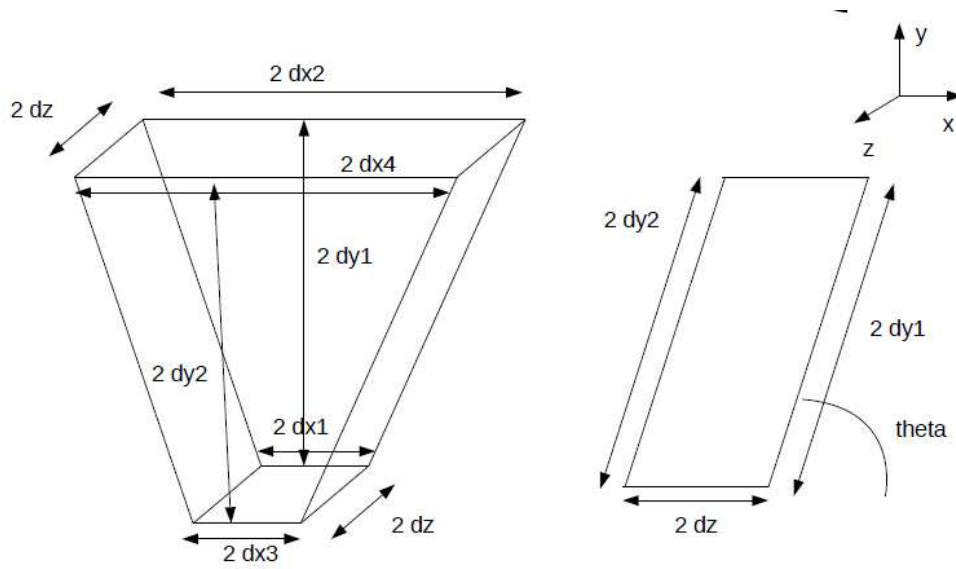


Figure 7: Parameters used to define the RICH box shape in gemc.

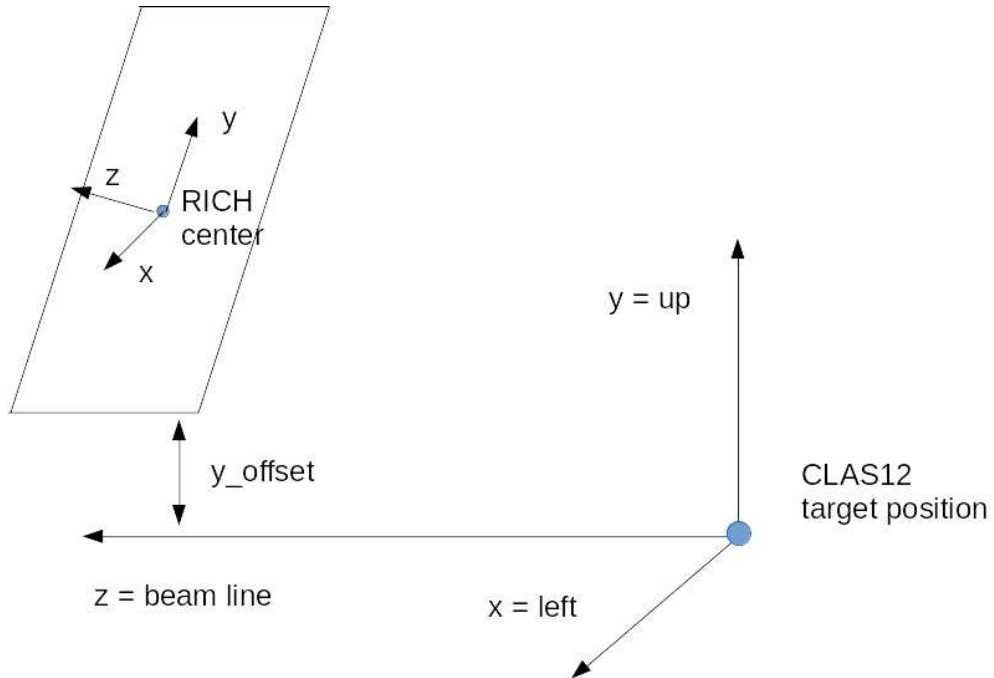


Figure 8: Positioning of the RICH box volume inside the CLAS12 FC reference frame at its reference frame.

Geometry Parameters	gemc name	value
dz	par_RichBox_dz	634.81 mm
dy1	par_RichBox_dy1	1882.49 mm
dx1	par_RichBox_dx1	135 mm
dx2	par_RichBox_dx2	2090.22 mm
theta	par_RichBox_th	65 deg
Position Parameters	gemc name	value
X_C	par_RichBox_x	0 mm
Y_C	par_RichBox_y = dy1 * sin(theta)+y_offset	1706.45 mm
Z_C	par_RichBox_z	5705.13 mm
theta	par_RichBox_the	25 deg
phi	par_RichBox_phi	180 deg
psi	par_RichBox_psi	90 deg
Other Parameters	gemc name	value
y_offset	par_RichBox_y_offset	284.31 mm

Table 1: Names and values of the parameters used to define the RICH box in gemc.

In the event reconstruction, only the active surface is relevant, thus in java we describe just the pixelization of the MAPMT photocathode. In the simulation, also the total material budget is relevant, thus in gemc a more complex description has been implemented. In both cases, in both the description, one needs to describe only the wall of MAPMT.

The MAPMTs are placed on the panel in 23 rows, see Fig. 9. The clearance between the MAPMTs is 1mm both horizontally and vertically. The lower row has 6 MAPMT. Each next row adds one MAPMT, with the MAPMT shifted horizontally by half MAPMT side length plus half of the clearance. The MAPMTs are numbered from 1 to 391 starting from the bottom left and up to the top right in Fig. 9.

From the 3D model, the position of the MAPMT 1 have been extracted. In Fig. 10, we show the y and z components of the corners of the MAPMT mother volume. The x component can be easily derived from the symmetry of the panel.

6.1 The Electronic Panel in gemc

For simplicity, the total material budget of the panel [7], including the Front-End electronic, is attributed to the MAPMT in an effective way. The electronic boards and the supporting panel are not explicitly described.

Each MAPMT is made by a virtual containing *box* volume, with total size of $52 \times 52 \times 27 \text{ mm}^3$. This volume contains:

- the MAPMT case, made by a 1 mm thick aluminum layer on the lateral faces;
- the entrance window, made by a $50 \times 50 \times 1.5 \text{ mm}^3$ borosilicate box;
- the photocathode, made by a $49 \times 49 \times 0.1 \text{ mm}^3$ bialkaly box;
- a MAPMT socket, made by a $50 \times 50 \times 2.7 \text{ mm}^3$ copper box.

The thickness of the socket has been set to take into account the material budget due to the elements not explicitly considered, for a total of $0.30 X_0$ [7]. The entrance

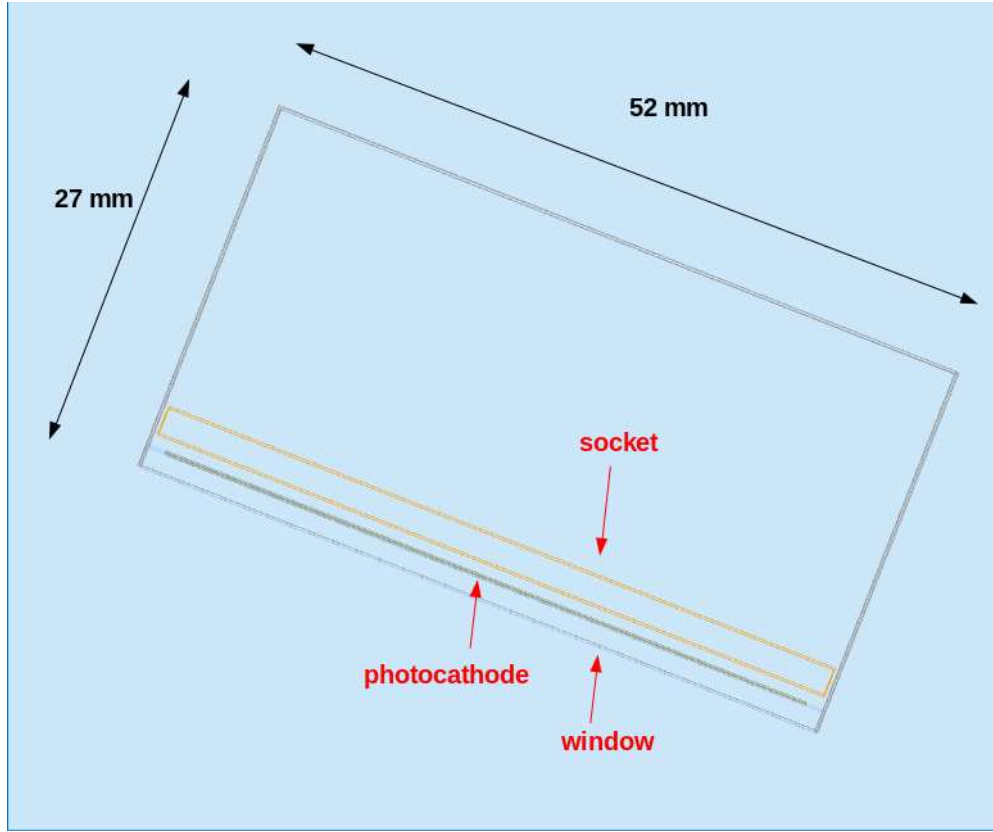


Figure 11: Description of one MAPMT in gemc, with the containig volume and the inner elements.

window is placed at the frontal edge of the MAPMT containing volume, followed by the photocathode. The socket is placed on the back edge of the MAPMT volume. In Fig. 11, we show a lateral view of one MAPMT.

The bialkaly and borosilicate materials have been defined by taking into account their composition. In addition, the borosilicate has been attributed with optical properties, in order to allow the Cherenkov photon propagation.

The photocathode area is segmented in a 8×8 matrix of pixels. According to the Hamamatsu datasheets, the central pixels have a dimension of $6.08 \times 6.08 \text{ mm}^2$, the corner ones of $6.26 \times 6.26 \text{ mm}^2$ and the other border ones of $6.26 \times 6.08 \text{ mm}^2$. To take into account the efficiency loss on the border of the pixels, a dead space of 0.28 mm is inserted between the pixels.

The list of parameters used in gemc to define the shape of one MAPMT and to place it inside the RICH box are shown in Tab. 2. The algorithm starts by positioning the MAPMT 1 in the bottom left corner of the panel, then proceeds adding all the MAPMTs of the first row. Once the first row is completed, the number of MAPMTs of the next row is computed and they are placed starting from the leftmost one. The procedure is repeated for all the 23 rows.

Geometry Parameters	gemc name	value (mm)
half x-size of the case	par_PMTCase_dx	26
half y-size of the case	par_PMTCase_dy	26
half z-size of the case	par_PMTCase_dz	13.5
thickness of the case	par_PMTCase_width	1.0
half z-size of the window	par_PMTWindow_dz	0.75
half x-size of the photocathode	par_PMTPhotocathode_dx	24.5
half y-size of the photocathode	par_PMTPhotocathode_dy	24.5
half z-size of the photocathode	par_PMTPhotocathode_dz	0.05
half z-size of the socket	par_PMTSocket_dz	1.35
PMT Position Parameters	gemc name	value (mm)
y center of MAPMT 1	par_PMTFirstRaw_y	-1931.23
z center of MAPMT 1	par_PMTFirstRaw_z	474.10
Inner Position Parameters	gemc name	value (mm)
z position of the window	PMTWindow_z = -PMTCase_dz+PMTWindow_dz	-12.75
z position of the photocathode	PMTPhotocathode_z = -PMTCase_dz+2*PMTWindow_dz +PMTPhotocathode_dz	-11.95
z position of the socket	PMTSocket_z = PMTCase_dz-PMTSocket_dz	12.15

Table 2: Names and values of the parameters used to put the MAPMTs in the RICH box in gemc. Note that the position parameters are referred to the reference froma of the mother volume in which the element is placed.

6.2 The Electronic Panel in java

7 The Frontal mirrors and the thin aerogel layer

The bottom half of the frontal panel holds the two frontal planar mirrors and the thin layer of aerogel. Each mirror with its aerogel forms an integrated system, which may be moved by acting on the three attaching point on the frontal panel. For this reason, mirrors and aerogel tiles are implemented together in a common containing volume. There is one volume for the lower frontal mirror and the first four aerogel rows and another volume for the upper frontal mirror and the last three rows of aerogel.

References

- [1] https://clasweb.jlab.org/wiki/images/e/ee/RICH_Shadow_-_Aerogel_Cheking_Section.PDF
- [2] https://clasweb.jlab.org/wiki/images/c/c0/RICH_Main_Views.PDF
- [3] <https://clasweb.jlab.org/wiki/images/2/2d/RichBox1.JPG>
- [4] <https://clasweb.jlab.org/wiki/images/4/42/RichBox2.JPG>
- [5] <https://clasweb.jlab.org/wiki/images/a/ad/GetPosition.cpp>

- [6] https://clasweb.jlab.org/wiki/index.php/RICH_Technical_Notes, Technical Note no. 15.
- [7] https://clasweb.jlab.org/wiki/index.php/RICH_Technical_Notes, Technical Note no. 9.
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