Technical note for Gas Ring ImaginNg CHerenkov (GRINCH) detector for E12-06-112

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Background Use GRINCH for BigBite in experiment E12-06-112.

Purpose Design GRINCH to extract the electrons from detected particles.

Method Simulate GRINCH in Geant4 and build prototype detector to test it.

Results FIXME.

Conclusions FIXME.

I. INTRODUCTION

The E12-06-112 will measure the $A_n^1$ asymmetry in the DIS region up to $x_{Bj} \approx 0.71$ through the reaction $^3\bar{He}(\vec{e}, e')$ using the Hall A polarized $^3He$ target and BigBite spectrometer with beam energies of $E = 6.6$ and $8.8$ GeV. The BigBite spectrometer will be fixed at a scattering angle of 30°. From previous experiments with 3-6 GeV beam energies, $12-15\mu A$ at the same angle and target, it is found that the background singles rates in the BigBite gas Cherenkov detector were unexpectedly high, particularly on the side of the detector closest to the beamline. Based on the studies done during those runs, the issues are associated with large diameter (5") PMT’s. Those PMT’s require long ADC gate, have large cross sectional area of tube and thick glass PMT face. They are also very sensitive to magnetic fields, which ultimately limited the number of photoelectrons produced per event in the old BigBite Cherenkov detector.

For E12-06-112, the beam current will be increased to $30\mu A$ and a longer target (50cm active length) will be used, resulting in an increase in overall rates at the location of BigBite by a factor of approximately 4 or more. Clearly a new Cherenkov detector is required to handle this large background and overall rates. A new heavy Gas Ring-ImaginNg CHerenkov (GRINCH) detector that uses a single large array of small-diameter PMT’s and timing information to detect Cherenkov radiation in a high rate environment.

The proposed GRINCH detect will use a segmented array of $\sim 553$ 29mm(Diameter) PMT’s located on the large-angle side away from beam pipe. Approximately 4 cylindrical mirrors will be used to transport the Cherenkov light to the PMT array.

1. The detector must fit within a 90 cm keep-out zone between the GEM chambers in the new BigBite(BB) detector frame. For the purpose of assembling GRINCH to BB frame, 2.5 cm gap at front and back side of GRINCH should be conserved. So the length of GRINCH $\leq 85$ cm.

2. It was observed during the d2n experiment that the performance of the Cherenkov detector was significantly compromised by unexpectedly large background rates in the PMT. The multi-wire drift chambers(MWDCs) however, were measuring rates that were consistent with previous BigBite experiments and a Monte Carlo simulation. Through shielding studies, many attempts were made to understand and eliminate the background. However, no significant drop in the background rate was achieved during the d2n run. Later, the simulation showed that the neutron induced background rate in the 5" tubes was three orders of magnitude smaller than the total background rate measured during d2n. And the other simulation have shown that a significant background of low-energy electrons is present due to production from material near the beam line and in the target scattering chamber which was not under vacuum. Bench tests have shown that $\sim 1$ MeV electrons from a $^{106}$Ru source will produce Cherenkov radiation in the PMT glass which produces a single-photelectron hit 30% of the time. Segmented PMT array (29mm tubes); Area=0.05x smaller than 5" tube; 3x thinner face. PMT array located at large angle side away from beam pipe.

3. $C_4F_8O$ heavy gas radiator ($n = 1.00135$ at 1 atm).

4. No ADC (240ns gate) during production runs. Search for timing clusters in 5-10 ns window and clusters of 10 PMT’s with threshold of 20-30% of the single p.e.

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5. Long active path length to have more photons.
6. $\eta_e \approx 1$ and $\eta_\pi \leq 0.1$
7. Add magnetic shielding for PMT array.
1. Scattering electron energy from 1.6 GeV to 3.3 GeV.
2. $30^\circ$ scattering angle.
3. 70cm active path length.
4. 29mm PMT (9125B) typical spectral response wavelength is from 275nm to 635nm. Positive HV ($\leq 1500$V).
5. $C_4F_8O$ heavy gas radiator ($n = 1.00135$ at 1 atm, $n = 1.002$ at 1.5 atm).
6. Assume 110cm path length for photon, radius of ring on PMT array is 7cm. Approximately 9-10 PMT’s in a cluster with single p.e. hit.
7. PMT array located at large angle side away from beam pipe.
8. Expect 5-10 times increase in luminosity over previous BigBite experiments.
9. No ADC (240ns gate) during production runs.

<table>
<thead>
<tr>
<th>Particle</th>
<th>P threshold (MeV/c)</th>
<th>$\theta (^\circ)$</th>
<th>Number of $\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^-$</td>
<td>8</td>
<td>3.64</td>
<td>36</td>
</tr>
<tr>
<td>$\pi$</td>
<td>2196</td>
<td>3.28</td>
<td>29</td>
</tr>
</tbody>
</table>

**TABLE I:** Cherenkov light table for $e^-$ and $\pi$. Number of photons is calculated with PMT quantum efficiency, mirror reflective efficiency and effective PMT area. The gas path length is 70cm. $\lambda$ ranges from 275nm to 635nm. $n = 1.002$ for $C_4F_8O$ at 1.5 atm.

**II. FEATURES OF GAS CHERENKOV DETECTOR**

Gas Cherenkov detector is used for particle identification in E12-06-112. When a charged particle with speed $v = \beta c$ travels through a transparent material with index of refraction $n$, if $v$ is greater than the speed of light in the material $\frac{c}{n}$ ($c$ is the speed of light in the vacuum), the particle will generate Cherenkov light. This is because the particle along the trajectory in the material at each point radiates, if $v \geq \frac{c}{n}$, the interference of each point will be maximum at an angle $\theta_c$ and disappear at other directions. By detecting if a given particle emits Cherenkov light, one can detect if its velocity is larger than a threshold velocity dependent on the material as shown in equation 1.

The angle $\theta_c$ of Cherenkov light is equation 2.

$$\beta \geq \frac{1}{n}$$

$$p \geq \frac{mc}{\sqrt{n^2 - 1}}$$

$$\cos \theta_c = \frac{1}{\beta n}$$

(1)

(2)

The number of photons emitted along the particle path for a particle with charge $ze$ and per unit energy interval of the photons is

$$\frac{d^2 N}{dE dx} = \frac{\alpha z^2}{h c} \sin^2 \theta_c \approx 370 \sin^2 \theta_c (E)eV^{-1}cm^{-1} (z = 1)$$

$$E = \frac{2 \pi h c}{\lambda} = \frac{1240(eV)}{\lambda (nm)}$$

$$\frac{d^2 N}{d\lambda dx} = \frac{2 \pi \alpha z^2}{\lambda^2} \left(1 - \frac{1}{\beta^2 n^2 (\lambda)}\right)$$

(3)

(4)
III. DESIGN

The coordinate system used here is the following:

- X-axis (Vertical down or height H): Gas Cherenkov center to bottom
- Y-axis (Horizontal left or length L): Gas Cherenkov center to left side
- Z-axis (Beam or thickness or width W): Gas Cherenkov center to back side
- Box
  - Entrance and exit window dimension are 50cm(L) X 200cm(H) X 0.635cm(T)
  - Mirror dimension is 130cm(Radius) X 60cm(L) X 70cm(H) X (0.635cm(T). The distance between the central point of surface and the central point of two edge points is around 4.8cm. The central point of surface is located at (x,0,28.7cm) relative to the central of box. Here x means different vertical offset for each mirror. Once it’s located at the point, all mirrors need to be rotated -17.92° about X-axis with respect to the central point of the surface. Then rotate ±16° about horizontal axis through central point of the surface w.r.t the same point for top and bottom mirrors respectively.

IV. GEANT4 SIMULATION

The coordinate system used here is the following:

- X-axis (Beam or depth L): Bigbite center to gas Cherenkov center
- Y-axis (Vertical up or height H): gas Cherenkov center to top
- Z-axis (Beam right or width W): gas Cherenkov center to right side
Design goals are:

- Mirror array to cover the acceptance of scattered particles.
- PMT array to get as more photon-electrons per PMT as possible but enough number of PMTs to be a ring.
The definitions in the figures:

- Mirror array collection efficiency: \( \frac{N_A \text{ hit on mirror}}{N_A \text{ generated in GRINCH before mirror}} \)

- PMT array collection efficiency: \( \frac{N_A \text{ hit on PMT}}{N_A \text{ reflected from mirror}} \)

The following are some studies of design parameters:

- \( L \) is the distance from Bigbite magnet center to the center of gas Cherenkov detector. The larger the distance is, the smaller the angular acceptance of GRINCH is if the geometry of GRINCH is fixed. But we also want to have a gap between GRINCH and other neighbouring detectors in the package so that we have to keep the distance far enough to fit the GRINCH in.
The distance $L$ in design is $165 \pm 3$ cm. This will make sure there will be around 20 cm gap between gas Cherenkov detector and the front 2nd GEM detector and the back MWDC detector.

- The active length $L_a$ of gas decides how long the electron is passing through the gas. The longer the length is, the more cherenkov light is generated. Then finally more photon-electrons are detected by PMT array.
(a) Mirror array collection efficiency vs $L_a$ (cm).

(b) PMT array collection efficiency vs $L_a$ (cm).

(c) $N_{PMT}$ vs $L_a$ (cm).

(d) $N_p/e N_{PMT}$ vs $L_a$ (cm).

FIG. 6: Study of $L_a$ (cm) active length of gas between GRINCH front surface and mirror surface center.
FIG. 7: $e^-$ detection efficiency / $\pi^-$ rejection vs $L_a$ (cm). The error is statistical error.
The larger the gas pressure is, the more atoms of gas exist, the more Cherenkov light is generated.

(a) Mirror array collection efficiency vs Pressure (atm).
(b) PMT array collection efficiency vs Pressure (atm).
(c) $N_{PMT}$ vs Pressure (atm).
(d) $N_{p.e.}/N_{PMT}$ vs Pressure (atm).

FIG. 8: Study of gas pressure (atm).
(a) $e^-$ detection efficiency for $P = 1.0$ atm

(b) $\pi^-$ efficiency for $P = 1.0$ atm

(c) $e^-$ detect efficiency for $P = 1.0$ atm (Zoom)

(d) $\pi^-$ efficiency for $P = 1.0$ atm (Zoom)

(e) $e^-$ detect efficiency for $P = 1.5$ atm

(f) $\pi^-$ efficiency for $P = 1.5$ atm
• Since the PMTs are sensitive to magnetic field from target and Bigbite magnet, we need to install shielding around PMT array. This will add a gap between the front edge of PMT box and the front surface of PMT array. The larger the gap is, the smaller the effect of magnetic field to the PMTs is. But if it is too large, it will increase the size and the weight of gas Cherenkov detector.

![Graphs showing the relationship between gap size and collection efficiency](image)

(a) Mirror array collection efficiency vs Gap (cm).
(b) PMT array collection efficiency vs Gap (cm).
(c) $N_{PMT}$ vs Gap (cm).
(d) $N_{p.e.}/N_{PMT}$ vs Gap (cm).

**FIG. 10:** Study of Gap (cm) between PMT box front edge and PMT array front surface.

• The rotation angle $\theta$ of PMT box is the angle about Y-axis. If it is too small, the PMT box will block the entrance of GRINCH. If it is too large, the width of GRINCH will be increased if we keep the distance between mirror surface center and PMT surface fixed.
PMT box rotation angle (deg) vs Mirror collection eff

(a) Mirror array collection efficiency vs PMT Box θ (deg).

(b) PMT array collection efficiency vs PMT Box θ (deg).

(c) \(N_{PMT}\) vs PMT Box θ (deg).

(d) \(N_{p.e}/N_{PMT}\) vs PMT Box θ (deg).

FIG. 11: Study of PMT Box angle θ (deg) about vertical-axis.

- The focal length of mirror is about half of mirror radius. And here I set the focal length is equal to the distance between mirror surface center and PMT array surface. The smaller the length is, the smaller the size of ring is, then the smaller the number of fired PMTs is.
Many rows of PMT array mean it will cover more reflected photons from mirror but at the same time increase the height and weight of PMT array and box.
• In the simulation, the PMT array is organized as \(N_{\text{min}} + 1, N_{\text{min}}, N_{\text{min}} + 1...\) So to make sure the PMT array cover the reflected photon area and get enough \(N_{\text{PMT}}\), we need enough \(N_{\text{min}}\) but not too many otherwise it will increase the width and weight of PMT array and box.

FIG. 13: Study of \(N_{\text{row}}\) of PMT array.
To converge more photons on the PMTs, we use hexagonal cone which is assumed to have 80% reflectivity in simulation as shown in Figure 15.

There are three important parameters for the cone:

- The maximum tangent radius is defined as the smallest distance between center and edge not edge point at large side or the entrance of the cone. If this radius is too large, it will increase the distance between each PMT and decrease the reflection efficiency so that the size and weight of PMT box and array will be increased and the $N_{p.e}/N_{PMT}$ will be decreased.
FIG. 15: Cone front view

(a) Mirror array collection efficiency vs PMT Cone max inner tangent radius (cm).

(b) PMT array collection efficiency vs PMT Cone max inner tangent radius (cm).

(c) $N_{pMt}$ vs PMT Cone max inner tangent radius (cm).

(d) $N_{p,e}/N_{pMt}$ vs PMT Cone max inner tangent radius (cm).

FIG. 16: Study of PMT Cone max inner tangent radius (cm).
- The minimum tangent radius is defined as the smallest distance between center and edge at small side or the exit of the cone. If this is too small, it will increase the slope of the cone causing the decreasing of reflection efficiency. If too large, not all the photons are hit on the active area of PMT on which the photons are considered to be detected in simulation.

![Graphs showing mirror and PMT collection efficiency vs GC PMT cone min tangent radius](image)

(a) Mirror array collection efficiency vs PMT Cone min inner tangent radius (cm).
(b) PMT array collection efficiency vs PMT Cone min inner tangent radius (cm).
(c) $N_{PMT}$ vs PMT Cone min inner tangent radius (cm).
(d) $N_{p,e}/N_{PMT}$ vs PMT Cone min inner tangent radius (cm).

**FIG. 17: Study of PMT Cone min inner tangent radius (cm).**

- The cone length is defined as the height/length of the cone. If the length is too small, the slope of the cone will be large. If too large, it just wastes the cone.
• The larger the mirror radius is, the more the number of fired PMTs is if we keep the focal length defined as before as the half of the mirror radius.
• In simulation, I set up four mirrors. Two in the middle are only rotated about Y-axis but the top and bottom one are not only rotated about Y-axis first but also rotated by $\pm\alpha$° about new Z-axis which is rotated by Y-axis from the old defined Z-axis.
FIG. 20: Study of Mirror 1&4 rotation angle $\alpha$ (deg) about horizontal plane. Mirror 1 means the top mirror, 4 is the bottom mirror.

- Also I study the PMT response to the Cherenkov photon.

- $e^-$ detection efficiency is defined as how many electrons are detected if known number of electrons $N$ sample is shoot in gas Cherenkov detector. To detect electron on PMT array, we need to set number of PMTs as a cut. And use same cut, we can also calculate pion rejection factor which is defined as one pion is accidently treated as an electron if known number of pions $N_\pi$ is scattered into gas Cherenkov detector. For example, electron detector efficiency 99% means 99% of incoming electrons are detected by gas Cherenkov detector. Pion rejection factor 100 : 1 means one pion in 100 pions is thought as electron in gas Cherenkov detector.
  
  - Active length is 70 cm.
  - Active length is 45 cm.

- Space between PMT.
FIG. 21: Event Display
FIG. 22: Efficiency of incoming particles when active length = 70 cm.
FIG. 23: Efficiency of incoming particles when active length= 45 cm.
FIG. 24: Study of PMT Space (cm). $2x$ is the spacing between the center of adjacent PMTs.
The position distribution of photons hit on the PMT from different part of mirror.

FIG. 25: Top left figure is the PMT row number versus PMT column number when photons are scattered from the left edge of mirror. Top right is from the right edge of mirror. Bottom left is from the whole mirror.
FIG. 26: This is the electron detection efficiency ($\eta_{e^-}$) versus $N_{p.e.}$ cut for different part of mirror. Each row of all these eight figures means which mirror starting from top to bottom. Left and right mean which part of the mirror, left part or right part.

For $\pi^-$,
FIG. 27: Top left figure is the PMT row number versus PMT column number when photons are scattered from the left edge of mirror. Top right is from the right edge of mirror. Bottom left is from the whole mirror.
FIG. 28: This is the $\pi$-efficiency ($\eta_{\pi}$) versus $N_{p,e}$ cut for different part of mirror. Each row of all these eight figures means which mirror starting from top to bottom. Left and right mean which part of the mirror, left part or right part.
FIG. 29: This is the $\pi^-$ efficiency ($\eta_{\pi^-}$) versus $P$ (MeV/c) for different $N_{p,e}$ cut for different part of mirror. Each row of all these eight figures means which mirror starting from top to bottom. Left and right mean which part of the mirror, left part or right part.
FIG. 30: This is the π− efficiency ($\eta_{\pi^-}$) versus $N_{p.e.}$ for $P = 3.2$ GeV for different part of mirror. Each row of all these eight figures means which mirror starting from top to bottom. Left and right mean which part of the mirror, left part or right part.

Primary parameters are used in the GEANT4 simulation.

[PrimaryGeneratorAction]
Particle Name: e-
Particle Min Energy: 1600 MeV
Particle Max Energy: 3300 MeV
Particle Distribution: Uniform Distribution

[DetectorConstruction]
World Name: World
World Shape: G4Box
World Full Size: (1000 cm, 1000 cm, 1000 cm)
World Material: Vacuum
Target Name: Target
Target Shape: G4Tubs
Target Length: 50 cm
Target Radius: 2 cm
Target Material: Vacuum
Target Color: Black
Bigbite detector package scattering angle: -30 deg
Bigbite detector package bending angle: 10 deg
Distance from Bigbite magnet center to target center: 187.5 cm
Distance from Bigbite magnet center to gem 1 center: 93 cm
Distance from Bigbite magnet center to gem 2 center: 99 cm
Distance from Bigbite magnet center to gas cherenkov center: 165 cm
Distance from Bigbite magnet center to mwdc 1 center: 221 cm
Distance from Bigbite magnet center to mwdc 2 center: 230 cm
Distance from Bigbite magnet center to preshower center: 245 cm
Distance from Bigbite magnet center to shower center: 275 cm
Bigbite magnet gap/width: 25 cm
Bigbite magnet magnetic field: 1.2 tesla
Bigbite magnet corner radius: 28.5 cm
Bigbite magnet corner bending angle: 20 deg
Bigbite magnet thickness: 20 cm
Bigbite magnet top box full size: (45.8601 cm, 28.5 cm, 20 cm)
Bigbite magnet top box material: Carbon_Steel
Bigbite magnet top box color: White
Bigbite magnet bottom box full size: (81.1967 cm, 28.5 cm, 20 cm)
Bigbite magnet bottom box material: Carbon_Steel
Bigbite magnet bottom box color: White
Bigbite magnet entrance box full size: (28.5 cm, 89 cm, 20 cm)
Bigbite magnet entrance box material: Carbon_Steel
Bigbite magnet entrance box color: White
Bigbite magnet exit box full size: (28.5 cm, 111.404 cm, 20 cm)
Bigbite magnet exit box material: Carbon_Steel
Bigbite magnet exit box color: White
Bigbite magnet top-left corner material: Carbon_Steel
Bigbite magnet top-left corner color: White
Bigbite magnet bottom-left corner material: Carbon_Steel
Bigbite magnet bottom-left corner color: White
Bigbite magnet top-right corner material: Carbon_Steel
Bigbite magnet top-right corner color: White
Bigbite magnet bottom-right corner material: Carbon_Steel
Bigbite magnet bottom-right corner color: White
Bigbite magnet electromagnet trapezoid material: Carbon_Steel
Bigbite magnet electromagnet trapezoid color: Blue
Bigbite magnet magnetic field trapezoid material: Vacuum
Bigbite magnet magnetic field trapezoid color: Magenta
GEM 1 frame full size: (4 cm, 150 cm, 12 cm)
GEM 1 frame material: Carbon_Steel
GEM 1 frame color: White
GEM 1 full size: (4 cm, 150 cm, 40 cm)
GEM 1 material: Vacuum
GEM 1 color: Gray
GEM 2 frame full size: (4 cm, 150 cm, 12 cm)
GEM 2 frame material: Carbon_Steel
GEM 2 frame color: White
GEM 2 full size: (4 cm, 150 cm, 40 cm)
GEM 2 material: Vacuum
GEM 2 color: Gray
MWDC 1 frame full size: (4 cm, 200 cm, 12 cm)
MWDC 1 frame material: Carbon_Steel
MWDC 1 frame color: White
MWDC 1 full size: (4 cm, 200 cm, 50 cm)
MWDC 1 material: Vacuum
MWDC 1 color: Gray
MWDC 2 frame full size: (4 cm, 200 cm, 12 cm)
MWDC 2 frame material: Carbon_Steel
MWDC 2 frame color: White
MWDC 2 full size: (4 cm, 200 cm, 50 cm)
MWDC 2 material: Vacuum
MWDC 2 color: Gray
PreShower full size: (10 cm, 210 cm, 74 cm)
PreShower material: Vacuum
PreShower color: Gray
Shower full size: (34 cm, 221 cm, 85 cm)
Shower material: Vacuum
Shower color: Gray
Gas Cherenkov tank Name: GC_Tank
Gas Cherenkov tank Shape: G4Box
Gas Cherenkov tank Full Size: (100 cm, 200 cm, 153.533 cm)
Gas Cherenkov tank active length: 70 cm
Gas Cherenkov tank space after mirror: 2 cm
Gas Cherenkov tank Material: C4F8O
Gas Cherenkov tank Pressure: 1.5 atmosphere
Gas Cherenkov tank Color: Cyan
Gas Cherenkov tank Visibility: true
Gas Cherenkov tank ForceWireframe: true
Gas Cherenkov PMT Box Name: GC_PMT_Box
Gas Cherenkov PMT Box Shape: G4Box
Gas Cherenkov PMT Box Gap Size: (15 cm, 5 cm, 5 cm)
Gas Cherenkov PMT Box Full Size: (28.45 cm, 191.436 cm, 40.516 cm)
Gas Cherenkov PMT Box Thickness: 0.635 cm
Gas Cherenkov PMT Box Angle of rotation about Y-axis: 55 deg
Gas Cherenkov PMT Box Distance between front surface of PMT and mirror center: 65 cm
Gas Cherenkov PMT Box Material: Stainless_Steel
Gas Cherenkov PMT Box Color: Grey
Gas Cherenkov PMT Box Visibility: true
Gas Cherenkov PMT Box ForceWireframe: true
Gas Cherenkov PMT Box Jail Name: GC_PMT_Box_Jail
Gas Cherenkov PMT Box Jail Shape: G4Box
Gas Cherenkov PMT Box Jail Full Size: (0.1 cm, 0.25 cm, 40.516 cm)
Gas Cherenkov PMT Box Jail Space: 2.5 cm
Gas Cherenkov Number of PMT Box Jail Bars: 76
Gas Cherenkov PMT Box Jail Material: Al
Gas Cherenkov PMT Box Jail Color: Black
Gas Cherenkov PMT Box Jail Visibility: true
Gas Cherenkov PMT Box Jail ForceWireframe: true
Gas Cherenkov PMT Name: GC_PMT
Gas Cherenkov PMT Shape: G4Tubs
Gas Cherenkov PMT Cover Radius: 1.751 cm
Gas Cherenkov PMT Active Radius: 1.25 cm
So Gas Cherenkov PMT Active area ratio: 0.509621
Gas Cherenkov PMT Length: 13.45 cm
Gas Cherenkov PMT Number of rows: 60
Gas Cherenkov PMT Min Number of PMTs in a row: 8
Gas Cherenkov PMT Min Wavelength: 275 (nm)
Gas Cherenkov PMT Max Wavelength: 635 (nm)
Gas Cherenkov PMT Quantum Efficiency Fit Parameters:
p0=-74.2442 p1=0.968278 p2=-0.00521893 p3=1.49183e-05 p4=-2.38068e-08 p5=2.00603e-11 p6=-6.96098e-15
Gas Cherenkov Photon-electron threshold (number of p.e): 0.5
Gas Cherenkov PMT Material: Al
Gas Cherenkov PMT Color: Blue
Gas Cherenkov PMT Visibility: true
Gas Cherenkov PMT Cover Color: Grey
Gas Cherenkov PMT Cover Visibility: false
Gas Cherenkov PMT Row 1 Col 1: (0,-89.4682,-14.008) (cm)
Gas Cherenkov PMT Row 2 Col 1: (0,-86.4354,-12.257) (cm)
Horizontal space of PMT: 3.502 cm
Vertical space of PMT: 3.03282 cm
Gas Cherenkov PMT Cone Name: GC_PMT_Cone
Gas Cherenkov PMT Cone Shape: G4Polyhedra
Gas Cherenkov PMT Cone Max Inner Radius: 1.75 cm
Gas Cherenkov PMT Cone Min Inner Radius: 1.25 cm
Gas Cherenkov PMT Cone Length: 1 cm
Gas Cherenkov PMT Cone Thickness: 0.001 cm
Gas Cherenkov PMT Cone Reflectivity: 0.8
Gas Cherenkov PMT Cone Material: Glass
Gas Cherenkov PMT Cone Color: Yellow
Gas Cherenkov PMT Cone Visibility: true
Gas Cherenkov Number of mirrors: 4
Gas Cherenkov Mirror 1 Name: GC_Mirror_1
Gas Cherenkov Mirror 1 Shape: Cylinder
Gas Cherenkov Mirror 1 Radius: 130 cm
Gas Cherenkov Mirror 1 Horizontal Full Size: 70 cm
Gas Cherenkov Mirror 1 Vertical Full Size: 40 cm
Gas Cherenkov Mirror 1 Thickness: 0.635 cm
Gas Cherenkov Mirror 1 Angle of rotation about Y-axis: 27.5 deg
Gas Cherenkov Mirror 1 Angle of rotation about new-axis(0.461749,0,0.887011): 14.1 deg
Gas Cherenkov Mirror 1 Offset relative to center of tank: (20 cm, 80 cm, 0 cm)
Gas Cherenkov Mirror 1 Offset along new x-axis(0.887011,0,-0.461749): -4.8723 cm
Gas Cherenkov Mirror 1 new Offset relative to center of tank: (15.6782 cm, 80 cm, 2.24978 cm)
Gas Cherenkov Mirror 1 Reflectivity: 0.8
Gas Cherenkov Mirror 1 Material: Glass
Gas Cherenkov Mirror 1 Color: Blue
Gas Cherenkov Mirror 1 Visibility: true
Gas Cherenkov Mirror 2 Name: GC_Mirror_2
Gas Cherenkov Mirror 2 Shape: Cylinder
Gas Cherenkov Mirror 2 Radius: 130 cm
Gas Cherenkov Mirror 2 Horizontal Full Size: 70 cm
Gas Cherenkov Mirror 2 Vertical Full Size: 60 cm
Gas Cherenkov Mirror 2 Thickness: 0.635 cm
Gas Cherenkov Mirror 2 Angle of rotation about Y-axis: 27.5 deg
Gas Cherenkov Mirror 2 Angle of rotation about new-axis(0.461749,0,0.887011): 0 deg
Gas Cherenkov Mirror 2 Offset relative to center of tank: (20 cm, 30 cm, 0 cm)
Gas Cherenkov Mirror 2 no Offset along new x-axis: 0
Gas Cherenkov Mirror 2 Reflectivity: 0.8
Gas Cherenkov Mirror 2 Material: Glass
Gas Cherenkov Mirror 2 Color: Red
Gas Cherenkov Mirror 2 Visibility: true
Gas Cherenkov Mirror 3 Name: GC_Mirror_3
Gas Cherenkov Mirror 3 Shape: Cylinder
Gas Cherenkov Mirror 3 Radius: 130 cm
Gas Cherenkov Mirror 3 Horizontal Full Size: 70 cm
Gas Cherenkov Mirror 3 Vertical Full Size: 60 cm
Gas Cherenkov Mirror 3 Thickness: 0.635 cm
Gas Cherenkov Mirror 3 Angle of rotation about Y-axis: 27.5 deg
Gas Cherenkov Mirror 3 Angle of rotation about new-axis(0.461749,0,0.887011): 0 deg
Gas Cherenkov Mirror 3 Offset relative to center of tank: (20 cm, -30 cm, 0 cm)
Gas Cherenkov Mirror 3 no Offset along new x-axis: 0
Gas Cherenkov Mirror 3 Reflectivity: 0.8
Gas Cherenkov Mirror 3 Material: Glass
Gas Cherenkov Mirror 3 Color: Red
Gas Cherenkov Mirror 3 Visibility: true
Gas Cherenkov Mirror 4 Name: GC_Mirror_4
Gas Cherenkov Mirror 4 Shape: Cylinder
Gas Cherenkov Mirror 4 Radius: 130 cm
Gas Cherenkov Mirror 4 Horizontal Full Size: 70 cm
Gas Cherenkov Mirror 4 Vertical Full Size: 40 cm
Gas Cherenkov Mirror 4 Thickness: 0.635 cm
Gas Cherenkov Mirror 4 Angle of rotation about Y-axis: 27.5 deg
Gas Cherenkov Mirror 4 Angle of rotation about new-axis(0.461749,0,0.887011): -14.1 deg
Gas Cherenkov Mirror 4 Offset relative to center of tank: (20 cm, -80 cm, 0 cm)
Gas Cherenkov Mirror 4 Offset along new x-axis(0.887011,0,-0.461749): -4.8723 cm
Gas Cherenkov Mirror 4 new Offset relative to center of tank: (15.6782 cm, -80 cm, 2.24978 cm)
Gas Cherenkov Mirror 4 Reflectivity: 0.8
Gas Cherenkov Mirror 4 Material: Glass
Gas Cherenkov Mirror 4 Color: Blue
Gas Cherenkov Mirror 4 Visibility: true

1. V. Nelyubin. A GEANT Simulation of Background Rate in Quartz Window of PMT XP4508 in Cherenkov Detector. 2011.