APH N.S., Heavy Ion Physics () –

HEAVY ION PHYSICS
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Summer research description, the search for long lost chambers in Mesoamerican pyramids, a guide on how to find 'em.

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Abstract. In Summer 2002 I was employed by a nuclear physics group at UIC. The primary research emphasis of the group are experiments at PHOBOS, a particle detector at RHIC, Brookhaven. However for my 12 week collaboration I worked with Profs Halliwell and Garcia on a seed project to adapt high-energy particle simulation techniques used at RHIC to the search for chambers in Mesoamerican pyramids. The underlying purpose of the project was to provide "sufficient" evidence to a funding committee for further support in the development and execution of the experiment. This required that I quickly come to grips with the rudiments of GEANT 4 [a] (the simulation package) and ROOT [b] (data analysis software) and then a ten week period working on the main project.

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PACS:

[a] http://wwwinfo.cern.ch/asd/geant4/geant4.html
[b] http://root.cern.ch/

1. Motivation

Nobel prize winning physicist Luis Alvarez and his collaborators were the first to adapt cosmic rays to the search for chambers and cavities inside ancient pyramids. In the 1960's they sought to reveal the internal structure of the Second Pyramid of Giza situated a few miles southwest of Cairo. However they found nothing and to this date no further applications of this method can be found in the literature.

Of course today the benefits of modern technology have made the whole process a lot less time consuming and far less tedious. GEANT, a particle simulation package used at most of the world's high, medium and low energy particle detectors is an immensely useful and flexible tool in the simulation of many diverse scenarios

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including cosmic ray interactions. Techniques of data acquisition can be quickly tried, tested, disposed of or adopted at will, thus cutting development times (and costs) by orders of magnitude. GEANT 4 and ROOT provide a powerful double-act on a scale never imagined 30 years ago.

2. Introduction

A simplified sketch (Fig 1) of the site layout is shown below. At the centre of the pyramid superstructure archaeologists believe is a cube-shaped chamber. The aim is to use cosmic rays (muons) passing through the pyramid to deposit energy on a detector placed at the foot of the pyramid. Of course as the muon passes through the limestone of the pyramid it will undergo frequent collisions and lose energy. As a result one would expect to see a higher rate of incidence on the bottom detector for those particles passing through the chamber. Data readings on the bottom detector include angles of incidence, position and momentum. By comparing readings with a Monte Carlo simulation of the data of the particles before they enter the pyramid , one can ascertain a detailed history for each muon trajectory. If a particle were to pass through the chamber, which can essentially be taken as a vacuum compared with the limestone pyramid, it would lose noticeably less energy through more infrequent collisions. Subsequent measurement should yield an energy spectrum on the bottom detector outlining the shape of the chamber according to particle energy losses.

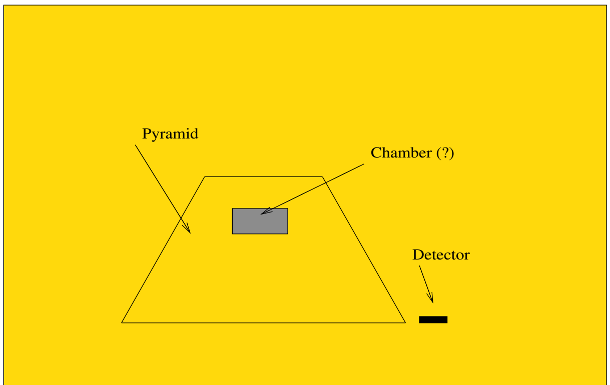

Figure 1: Schematic sketch of site

Fig. 1. Schematic sketch of site

3. Description

Upon my arrival initial trials at simulating such an outcome had been made. In the simulation a basic geometry had been set up. The "pyramid" was approximated with a 10m×10m×18m limestone cuboid, a cubic chamber was placed at the centre of the block and rectangular detectors were located above and beneath the limestone (see Fig 2).

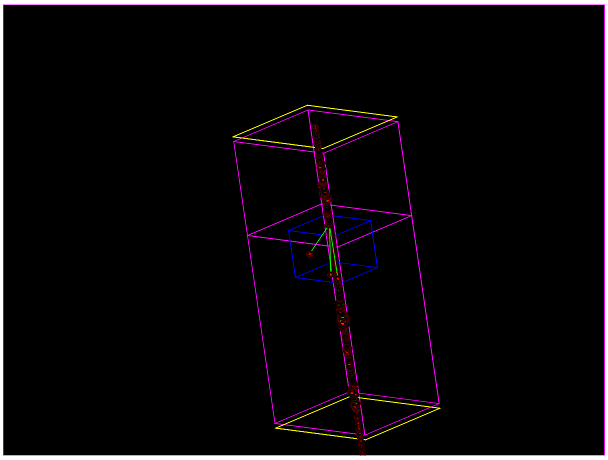

Fig. 2. A simple detector geometry

As a first approximation the muons were set to arrive on an perpendicular trajectory, with a fixed energy distribution, hit the top detector, pass through the chamber and limestone and hit the bottom detector. Results showed that at least on this set-up the principle was sound and further development was justified.

My objective was to generalise the above procedure. Ultimately the goal of the project as a whole is to design the apparatus to be as flexible as possible. It is unlikely that site engineers will be able to place the apparatus directly underneath the chamber and so a method to counter such eventualities must be developed.

Cosmic rays arriving at low and high trajectories can be utilised in any potential solution. A trial was run to re-produce the successes of the above simulation using cosmic rays arriving at all possible azimuthal angles hitting the bottom detector (which was left directly under the chamber to simplify the situation). To do this a new hemispherical top detector was designed, see Fig 3.

Particles were programmed to arrive randomly at a fixed energy and follow a similar procedure to the one delineated above. Working initially without the

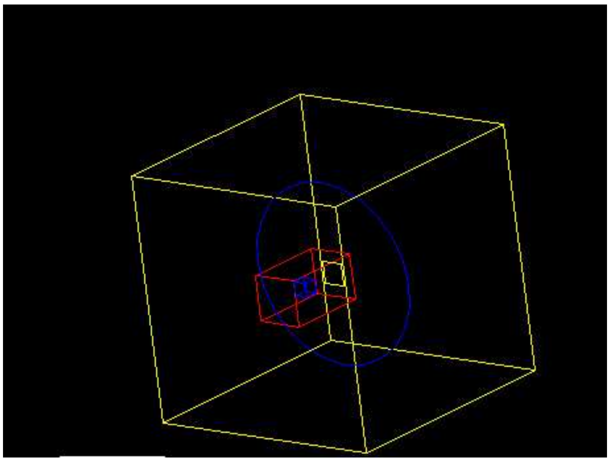

Fig. 3. New detector geometry. For clarity this image as been rotated. Blue rim denotes boundary of hemispherical (top) detector which covers the entire limestone block, small yellow rectangle is bottom detector.

chamber in place we attempted to locate the edges of the limestone block to at least ensure we could see some structure. Muons passing through the limestone at the edges will have more material to cover and should they reach the bottom detector the probability is that there will be less of them, see Fig 4.

Plotting ϕ (x axis) against energy (y axis) and number of particles on the z axis, on the bottom detector, we verified the prescence of the limestone block, Fig 5. ϕ being the azimuthal angle in the x-y plane. At certain angles less energetic particles are expected to hit the detector as they pass through more of the limestone. Four such readings should occur, corresponding to the four edges of the block.

Following the successful identification of the edges of the limestone structure we sought to use a similar method to locate a hypothetical chamber (shown in blue in fig 3).

Ostensibly we should now have been able to see the chamber. Using a datafile containing 50,000 muon events at a specific energy, ie an energy so that particles **not** passing through (or only passing through a little bit) of the chamber will likely not reach the detector and those particles passing through the chamber **will** hit the detector. It is a known fact that muons passing through limestone lose $\sim$0.5GeV/m. There is 18m of limestone. So particles with an energy of a little less than 9GeV should be completely stopped en route to the detector. If, however they were to pass through the chamber they should lose $\sim$1.5GeV less, (chamber is 3m$\times$3m). An

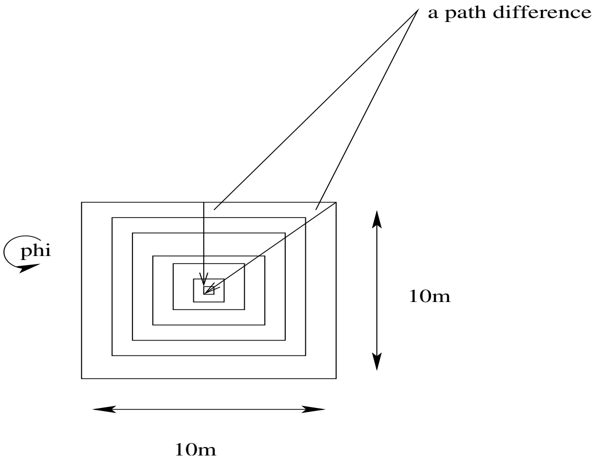

Fig. 4. Looking down from above the limestone block, particles on the diagonal have a longer path-length.

important initial condition on running the simulation is the restriction on θ (angle in x-z plane). If we were to allow θ to run freely from 0-90^{c}irc, it would prove very inefficient as we only seek to view the chamber at acute θ angles. To avoid such a time consuming scenario we allowed only those muons arriving within a cone with an angle spanning $\theta \prec 35°$.

Requiring this condition in ROOT is trivial, the command can be executed in one sentence on the command line.

4. Results

We have been able to detect the prescence of the chamber and discern it's dimensions to a first approximation. [1] Figure 7 below shows three plots, the top two plot the number of particles hitting the bottom detector with and without the chamber and the bottom plots the difference all as a function of $cos\theta$. Firstly we see a large peak at $\sim cos\theta = .998$, this represents the first corner of the chamber where particles pass through the most air and least limestone. Then there is a steep decline in particle number as we move down in the negative z direction along the side of the chamber. Hence the value of $cos\theta$ at the lowest point corresponds approximately to the position of the bottom corner. The function then returns to the familiar

[1] I say "to a first approximation" because the issue of resolution shall become pertinent at this stage, a brief discussion is held later

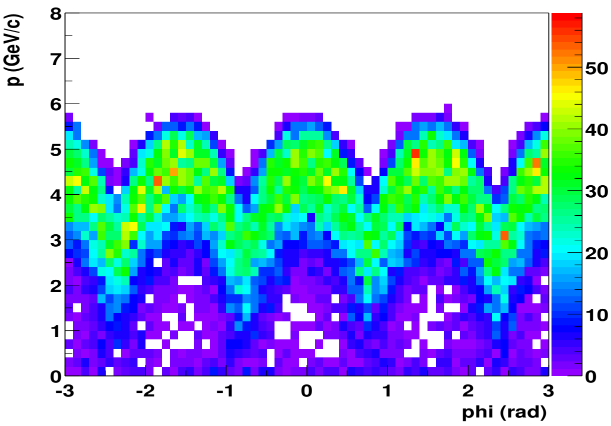

Fig. 5. Plot of Energy-v-ϕ-v-N

distribution that would persist had the chamber not been there, as can be seen in the second plot. The bottom plot takes the difference of the top two and shows a quite spectacular peak verifying conclusively the presence of the chamber.

Figure 8 plots cosθ as a function of ϕ. The second plot , without the chamber shows that at cosθ∼-1 little or no particles get through to the bottom of the detector. The first plot, however, shows an increase in particle number. One can even see the ripply pattern observed for the limestone block above (Fig 5). This is accentuated in the difference plot.

The sheen is taken off the results shown in Figure 7 when one considers we restricted muon targets to a 10cm×10cm square detector, thus eliminating any resolution problems. In reality a 1m×1m detector will be built. Figure 9 shows the results of a simulation where we have expanded our target area to $1m^2$, a **low resolution** scenario relative to our last run. The presence of the chamber is beyond question but defining it's dimensions will be a lot less precise. Figure 10 then shows a series of plots similar to that of Figure 8.

All of the last 4 figures have been run at 10GeV. If we repeat the above procedures with an energy of 9 GeV the small peak present in the second plot of figures 7 and 9 will disappear and resolution improves somewhat. Figure 11,12 then show the resulting plots.

Finally figure 13 shows a nice three dimensional plot of the $cos\theta$ against ϕ. The inner peaks correspond to the chamber.

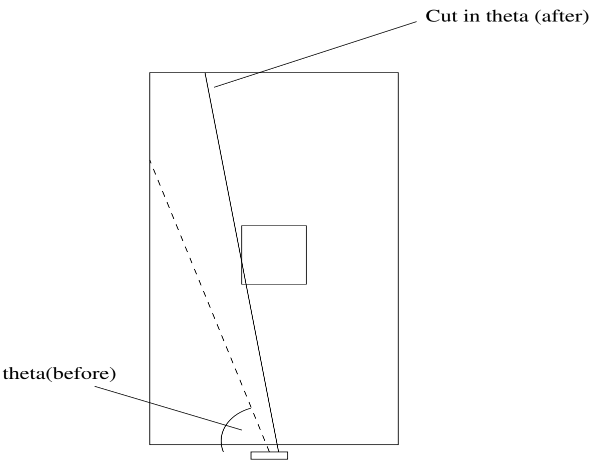

Fig. 6. Cuts in theta

5. References

Seed Project to Search for Tombs in Mesoamerican pyramids, Edmundo Garcia, Russell Betts, Clive Halliwell, David Hofman.

Search for Hidden Chambers in the Pyramids, Luis W. Alvarez et al, Science , 1970.

(see overleaf for figures)

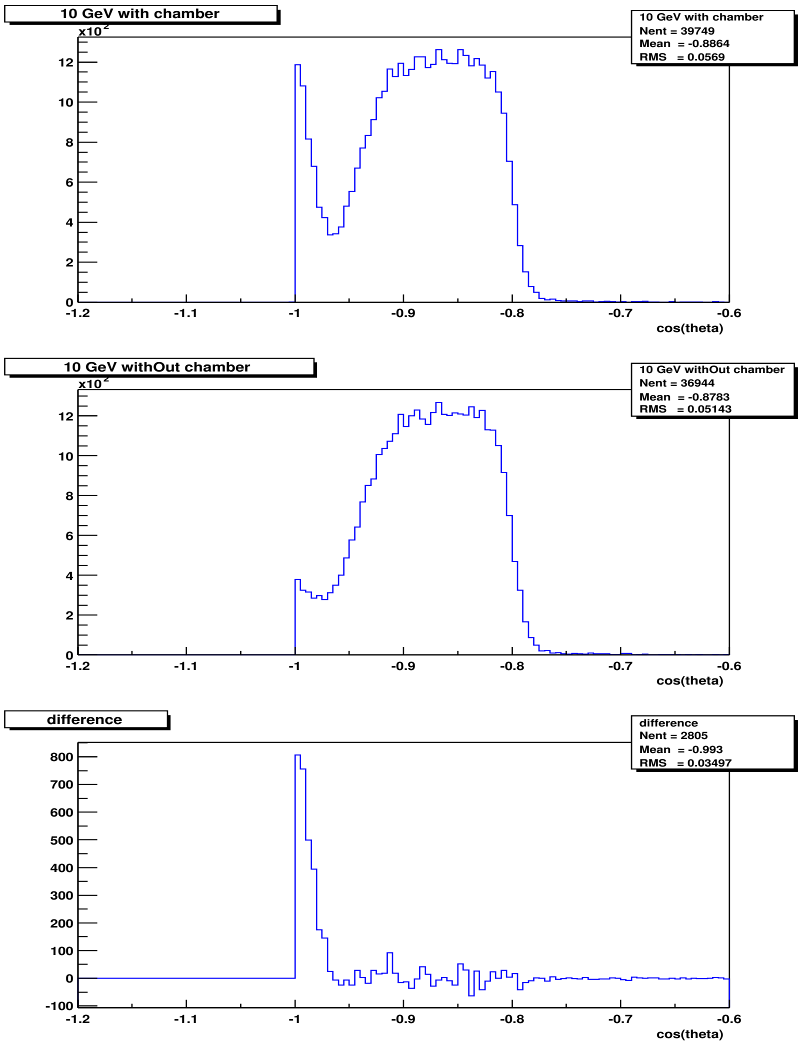

Fig. 7. N-v-Cosθ, high resolution.

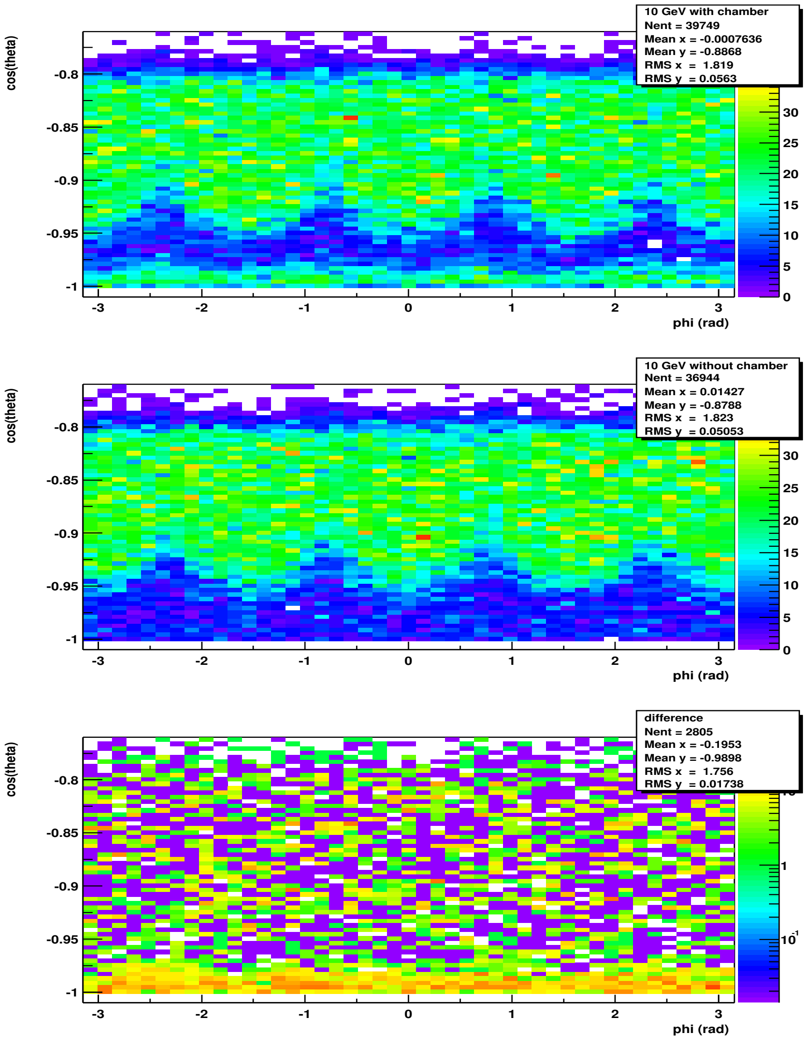

Fig. 8. Cosθ-v-ϕ, high resolution.

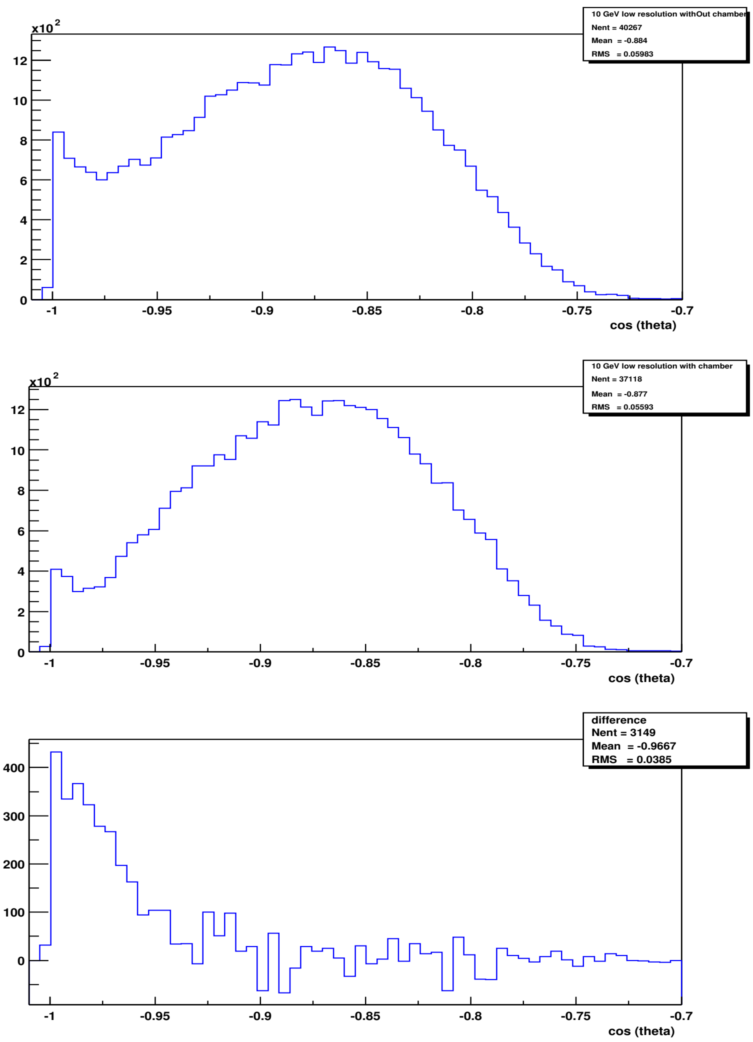

Fig. 9. N-v-Cosθ, low resolution.

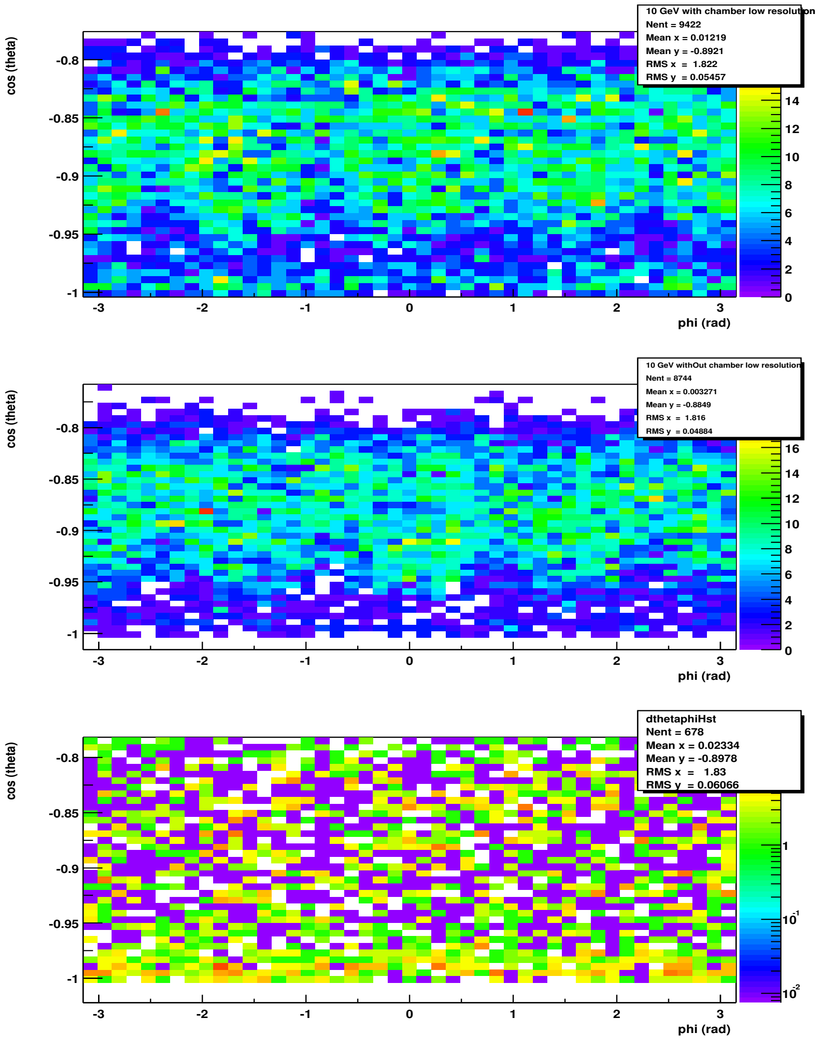

Fig. 10. Cosθ-v-ϕ, low resolution.

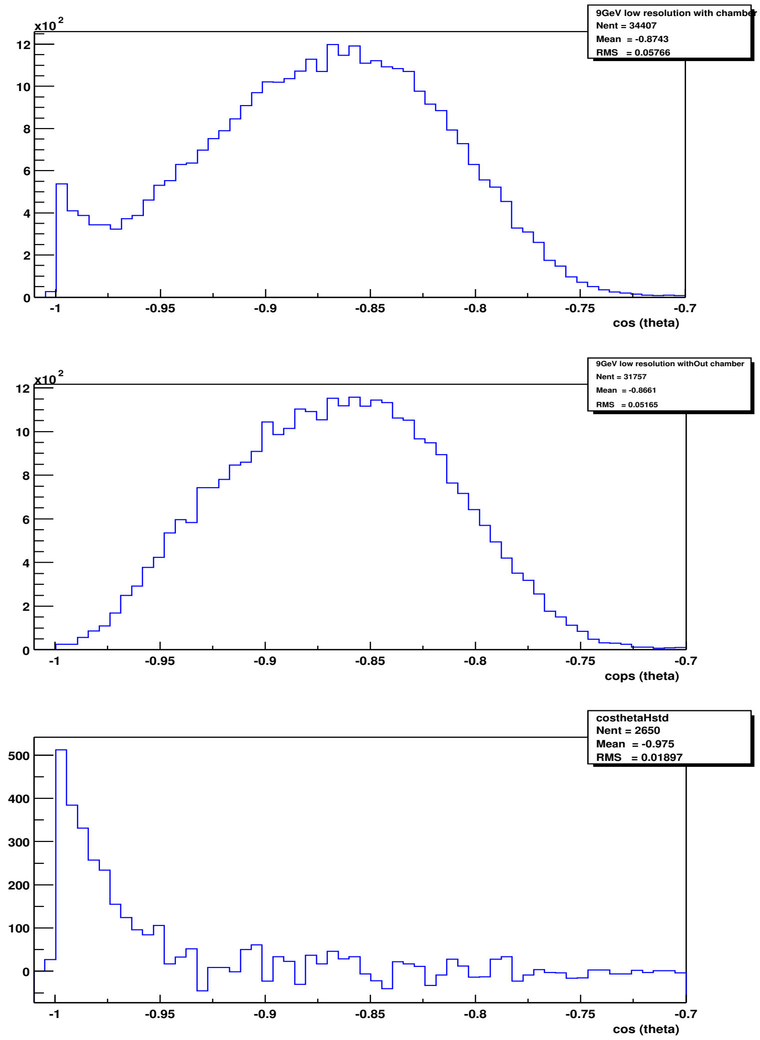

Fig. 11. N-v-Cosθ, low resolution.

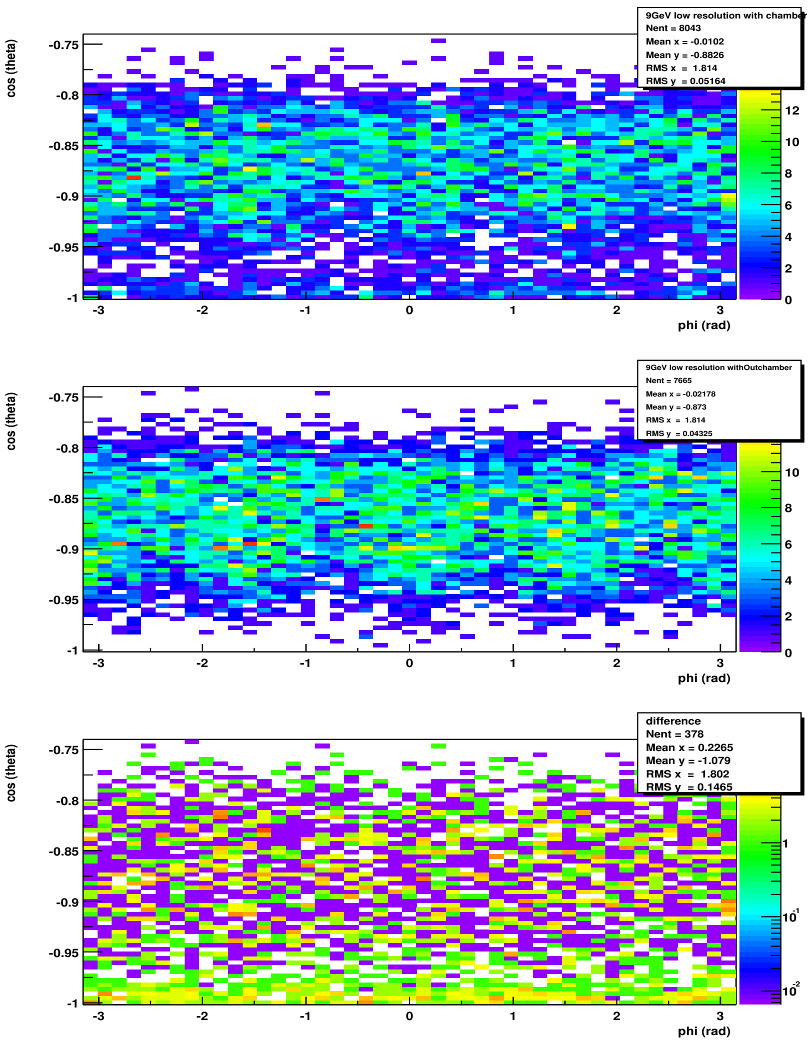

Fig. 12. Cosθ-v-ϕ, low resolution.

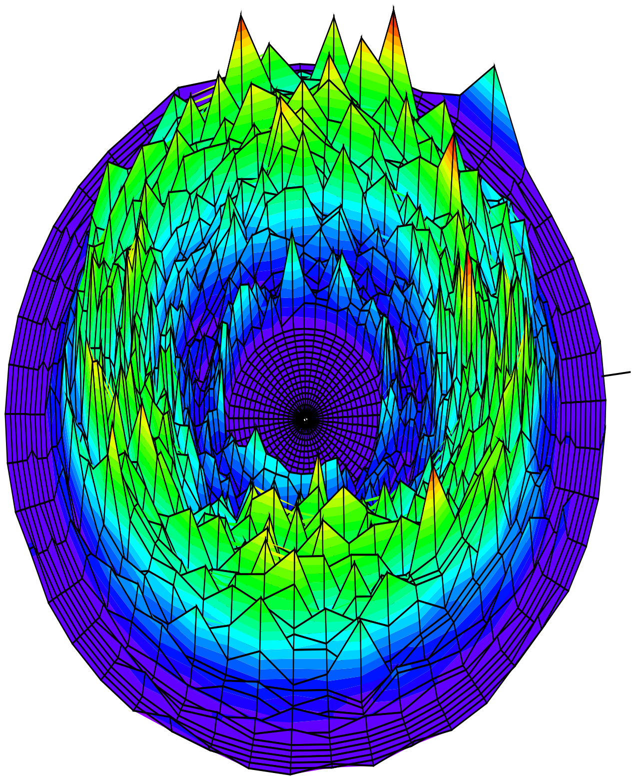

Fig. 13. Cosθ-v-ϕ, low resolution.