HAPPEX2 detector cosmics test

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1 Introduction

The HAPPEX2 experiment will use 2 detectors installed at the top of the HRS just after the focal plane in the detector hut. The detector is composed of two arms, each one is a stack of brass and quartz plates. The electrons coming from elastic scattering at the target will intercept the detector and will start an electromagnetic shower in the brass. The total thickness of an arm is equivalent to seven radiation lengths and will contain more than ninety percent of the electromagnetic shower produced. All charged particles created with a sufficent β will emit Čerenkov light in the quartz. Five layers of quartz have been chosen to keep the energy resolution below twenty percent ($\approx 18\%$).The detector shape is a 'V' and the angle between the two arms is equal to the Čerenkov cone angle that electrons create in the quartz medium. Therefore, particles going either to one or the second arm will have a part of their Čerenkov cone aligned to the longitudinal axe of the quartz plate. The light produced is collected at one edge of the quartz plates by a PMT via a light guide and the signal is integrated.

High energy muons coming from cosmics rays showers made in the atmosphere could be used to test some of the optical properties of the compounds (quartz and light guide). These first tests with a complete detector, was performed :

- to evaluate the number of photoelectrons by incoming muon and to compare this number with GEANT simulation.
- to measure the sensivity to the incidence angle of the incoming particle.
- to determinate the attenuation of the light along the quartz plates.
- to test and to validate a light guide.
- finally, to look at the crosstalk between the two detector's arm.

Complementary tests with an electron beam will be conducted at Jlab (Moller setup) to measure the resolution of the detector and edges effects degradation.

2 Simulation

Simulations was made in parallel of the tests to reproduce the effects of optical properties of the materials measured [1] and to confirm the results found, in particular, the number of photoelectrons/muon. Ingredients of the simulation are :

▷ an incident particule (electron 3.1 GeV or muon 4 GeV).
▷ electromagnetic cascade in brass.
▷ generation of Čerenkov photons in the quartz.
▷ transmition of light in the quartz.
▷ attenuation in the light guide.

▹ QE response of the PMT for the wavelenght range of [300 ; 550] nm.
▹ simulation of real cosmics muons angle and energy distribution.

Main outputs analyzed are the number of Čerenkov photons collected at the PMT, the number of photoelectrons, the number of bounces made by the Čerenkov photons both in the quartz and in the guide. The associated angular distribution was also simulated to look at the average angle of reflection in the guide.

2.1 Number of photoelectrons

The number of Čerenkov photons created in the quartz plate depends on the type of particle and its energy. Fig. 1 shows a perspective view of the quartz-brass stack corresponding to one arm of the detector. In the first case (picture on the left), it shows thirty muons going through the stack of brass-quartz (in green). Muons are interacting very seldomly in the medium (≈0.5%) but when they do a muon could create a shower comparable to a electron signal. In the other case, with an electron (right picture), a lot of secondary particles are created (electron-positron are in red and gamma in blue). In the simulation, secondary particles tracking threshold is around two hundred keV, below, Čerenkov effect vanished. Čerenkov photons generation was switched off for picture clarity.

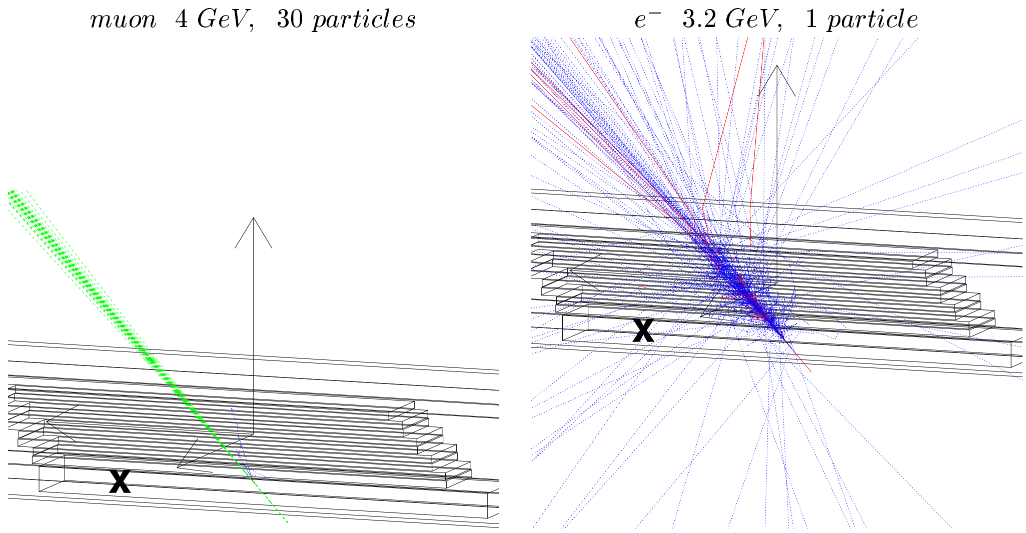

Figure 1: GEANT simulation picture of particles crossing the detector stack. Several muons (left) and one electron (right).

Associated photoelectrons distributions are shown (fig. 2). Muons angular and energy distribution was included in the simulation to render a more realistic signal with edge effects and variation in the angle of incidence. In the second picture, electrons are monoenergetic and generated at the nominal angle. The distribution is fairly gaussian and it shows an energy resolution of $\approx 18\%$.

$muon\ \ 4\ GeV$ $\qquad$ $e^{-}\ \ 3.2\ GeV$

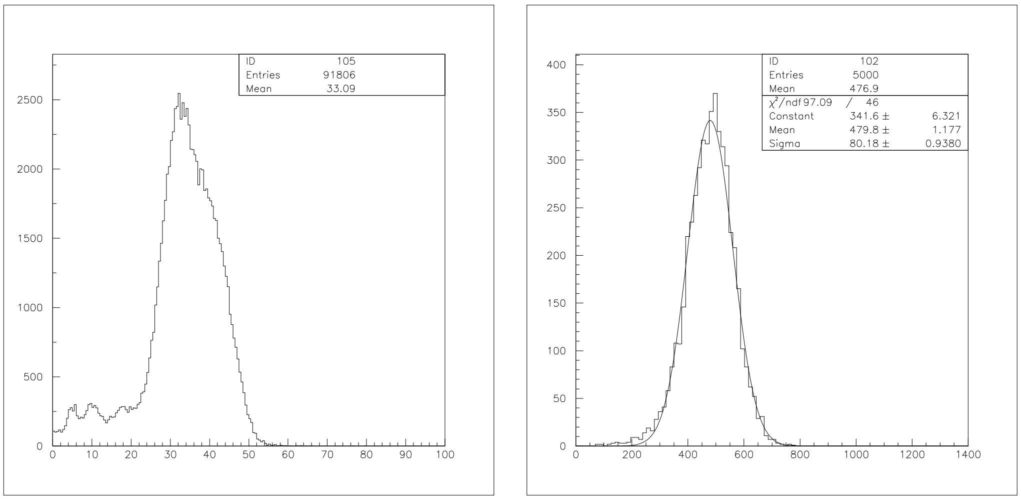

Figure 2: GEANT distributions of photoeletrons collected in detector PMTs. Left figure shows cosmics muons response. Right figure shows distribution for monoenergetic electrons at nominal angle.

Simulations shows that signal coming from a cosmic muon between 1 and 10 GeV could be detected with the detector. A cut on the low energy muons will help decreasing the tail of the distribution for analysis.

2.2 Sensitivity to the angle

The plot fig 3 shows the number of photoelectrons versus a range of angle for the incoming muons.

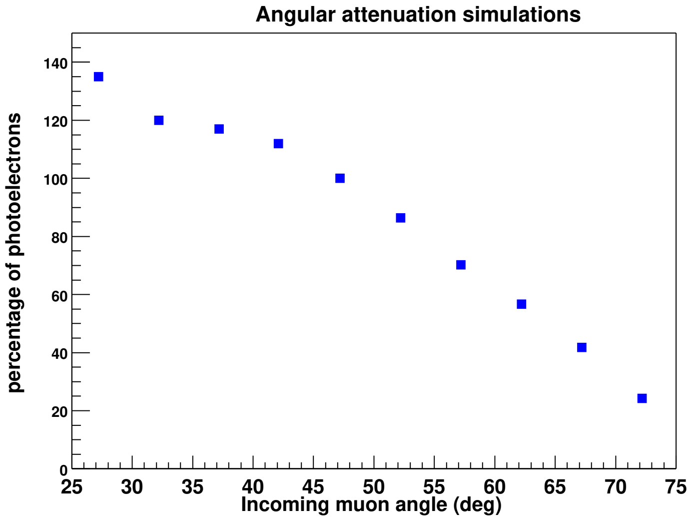

Figure 3: Number of photoelectron versus the angle of the incoming muon.

The distribution is normalized to the nominal angle (i.e. the Čerenkov angle of a electron coming across quartz with a $\beta \approx 1$). This angle of 47.2 degree, in term of light collection, is not the optimum. The percentage of photoelectrons continue to increase as we follow smaller angles and below 25 degrees it drops quickly to 0. Most of the high energy muons don't interact in detector arms (as shown in fig 1) thus the number of Čerenkov photons collected is smaller than with an electron.

Besides, a variation in the number of Čerenkov photons is expected for a different angle of incidence. The geometrical conditions of reflection change with the direction of the Čerenkov cone. As it is demonstrated in figure 4, the proportion of the light cone intercepting the quartz plate and the reflection properties in the quartz made better conditions for light collections at a lower angle than the nominal one. for greater angle, however, the proportion drop quickly because a major part of reflection will be impossible.

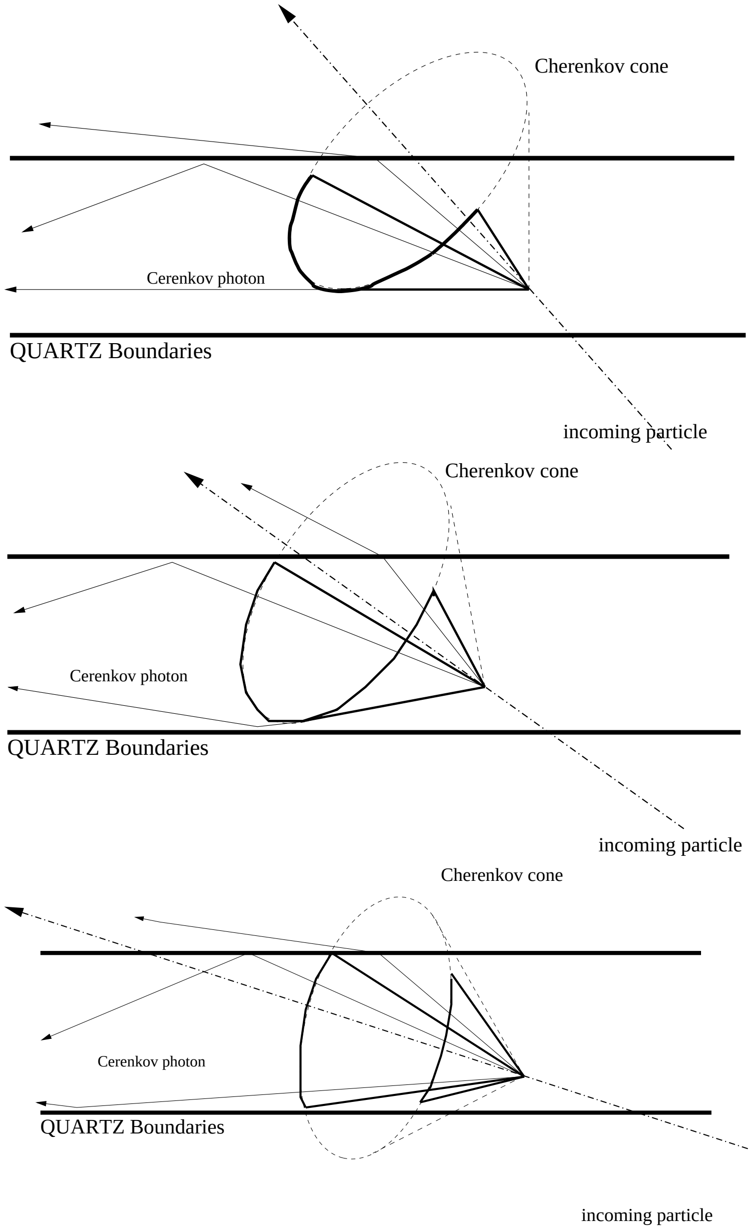

Figure 4: Different cases of the position of the Čerenkov in the quartz. First case depicted on the top, shows the portion of the cone at the nominal angle. The second (in the middle) shows a particle coming with an angle a little less thant the nominal one. Last case at the bottom is for a very small angle of incidence.

A simulation with an electron is shown in fig 5 (muon signal is normalized to electron signal) :

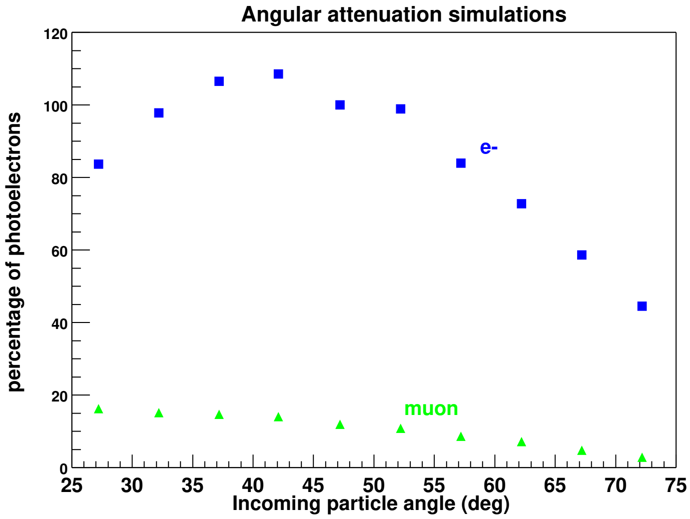

Figure 5: Angular distribution of photoelectron for electron and muon.

First of all, the distribution has a slightly different shape than for muon. The maximum of the distribution, for 3.1 GeV electrons, is around 42 degrees. Main feature is that the amount of light is rather flat around 47.2 degrees. According to this results, the installation of the detector in the Hall will not need a high precision for its orientation in space.

2.3 Bounces in the quartz and in the guide

A 3 GeV electron will create thousands of optical photons in the quartz within the shower process. Something like three or four thousands of them will reach the photocathode of the PMT. Parameters like the polish quality of the quartz surfaces and the reflection ratio of the guide faces could play an important role in this process. We looked (fig 6)at the Čerenkov photons bounces in each medium and the mean angle of reflection in the guide for both electrons and muons

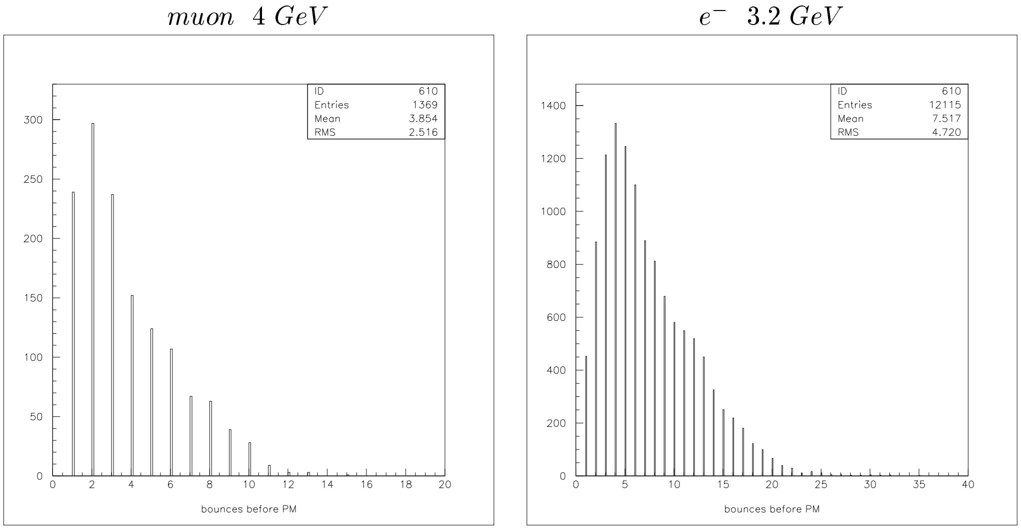

Figure 6: Bounces distributions of photons reaching the photochathode.

A summary of the number of bounces by Čerenkov photons is given below :

	<Number of bounces> before PMT		
Incoming particle	quartz	guide	total
muon	1.88	1.96	3.84
e^-	5.08	2.42	7.5

The number of Bounces is small. It indicates that with a typical optical polishing quality (0.99 of internal reflections) we didn't induce a dramatic drop of Cerenkov photons (<8%). A measurement of the attenuation in the guide at seven degree [1] give 82%. The attenuation in the guide will be estimated in subsection 4.3.

3 Experimental set up

The Detector is hanged up the 'V' pointing to sky in order to make a 47.2 degrees angle between the quartz plates and a vertical cosmic muon (fig 7). PMTs used for the tests are from HAPPEX1 detectors. These PMTs with new base reach a gain of 10^6 at 1950-2100 V.

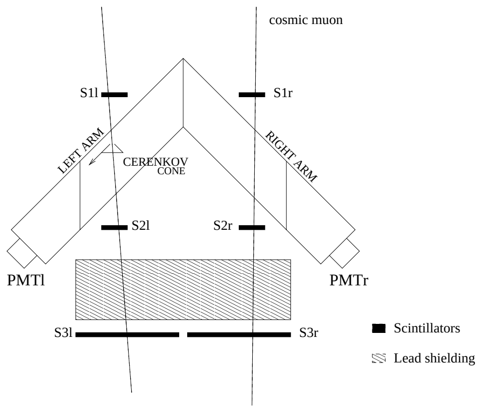

Figure 7: Experimental setup.

Due to the small cosmic muons rate (1 muon $/cm^2$/min), two sets of scintillators were installed to accumulate more statistics in one run. Classical Coincidences on S1 and S2 were used to trigger the aquisition system. A stack of lead gave a cut on the low energy muons (typically below 500 MeV). The signal from detector PMTs was recorded as well as scintillators (S1,S2 and S3). After applying cuts on the data, we gain almost a factor 10 between the top of the distribution and the left bottom. Fig 8 plot shows a typical response of the detector with coincidence S1S2. The one superimposed shows effects of coincidences S1S2 with cut on S3. A typical energy spectrum of cosmics muons at the sea level shows a gaussian like distribution centered at 4 GeV with a tail going to low energy. This distribution mean was used to measure the number of photoelectron created by a muon with a known energy. Fitting this distribution was the method to connect the number of photoelectrons with the the incoming muon energy. A compromise between a sufficent interval for the statistics and the chi square value had to be found. Depending on the statistical sample we had for a typical run of one night, a relative precision on the mean around 5%.

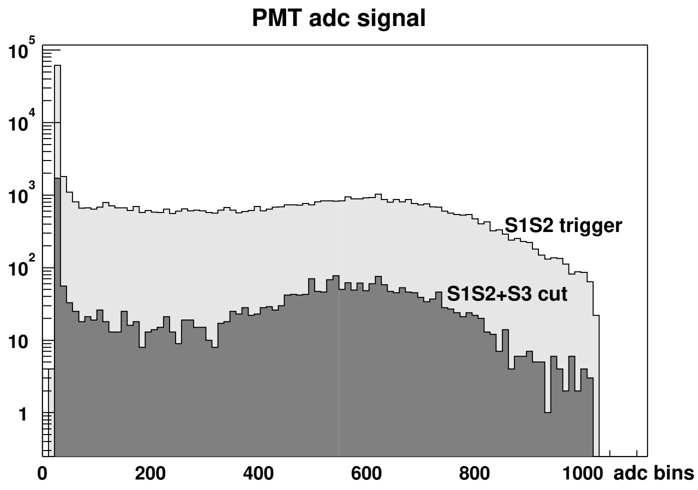

Figure 8: adc energy distribution for a typical cosmic run.

4 Results

4.1 Number of photoelectrons

It was shown in section 2.2 that some optical properties of the quartz and the guide don't make a big difference in the attenuation process of the Čerenkov photons.

However, the number of photons collected will still depend on the whole quality of the different part of the detector. All the quartz plates and the guides have slightly different quality.

During the tests, two kind of light guide were tested :

- First one was a plexiglass box with evaporated aluminium deposition on each inner faces. This light guide was called 'plexi'.
- the second one was aluminium. This aluminium has a high reflective side. This light guide was called 'alzak'.

Measurements revealed a difference of 20% between these two types of guide. The 'plexi' shows better reflectivity properties so it was kept as the detector light guide. A fluctuation of 10% in the number of photons collected was shown between two 'plexi' guide and also between each arm (quartz+brass). Without considering the PMT calibration, a total of 25% fluctuation in the number of photelectrons could be seen between the two PMTS.

incident muon (47.2 deg)	GEANT simul	cosmics test
# of photoelectrons	35	25 - 35

Measurements were done both, on right and left arm. The number of photelectron is compared in the tab below.

4.2 Attenuation with lenght

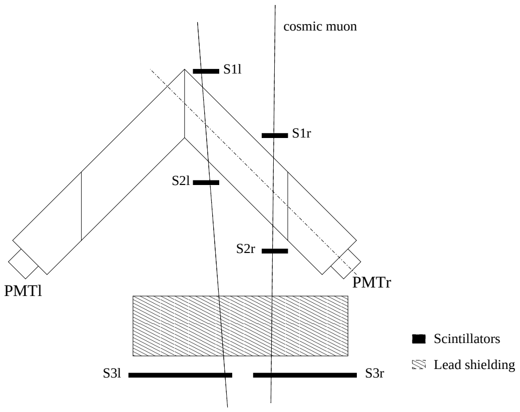

Figure 9: Linear attenuation set up.

Preliminary results with precise optics test, gave for individual quartz plates, an attenuation of 8% over 30 cm [1].

For the test, we placed pairs of scintillators at different positions along the arm axis (dotted line on the schematic fig 9). We compared the value found for the mean value of the cosmic muon distribution and determinated the corresponding number of photoelectron for each distances. Results of measurements are shown in the plot and compared with the optical transmition test (dotted line). We found a very well agreement (fig 10 in the slope between the two type of measurements.

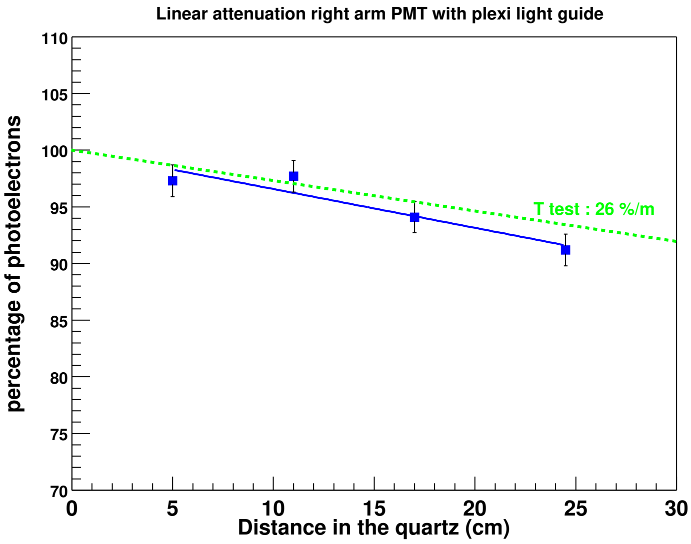

Figure 10: Plot of linear attenuation. GEANT simulation is green dotted line, measurement is shown in blue.

The transmition test for the quartz gave:

$$a. < p >= -26 \quad \%/m$$

The final result of the mean value for the slope is calculated over all the runs :

$$b. < p >= -27.6 \pm 4.7 \quad \%/m$$

4.3 Angular attenuation measurement

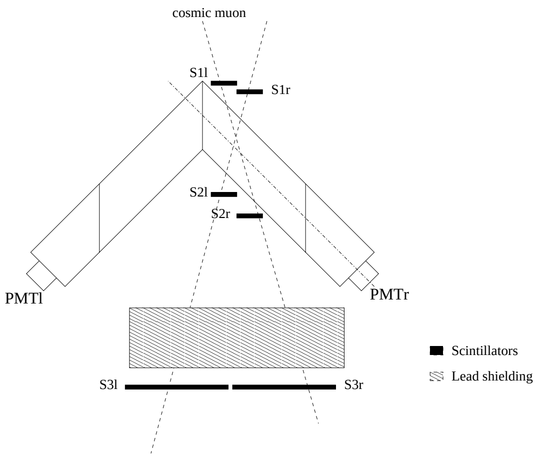

Figure 11: Special set up for angular attenuation survey.

We used diagonal coincidences (fig.11) to measure the effect of the angle in the number of photelectrons. Attenuation in angle was done for 3 angles (47.2 ± 9.5 degrees) and compared to GEANT simulation (3 in section 2.1).

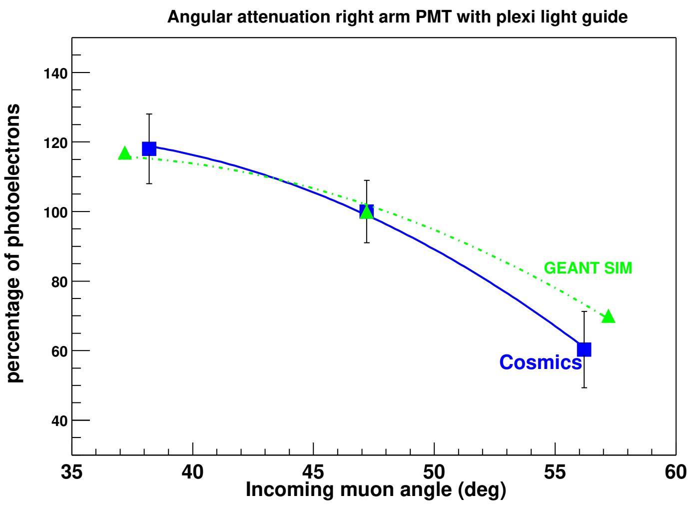

Figure 12: Angle attenuation measurements (blue) results compared to simulation (green).

Values in fig. 12 are normalized to the maximum of the distribution. A good agreement is also found with the simulation.

5 Crosstalk

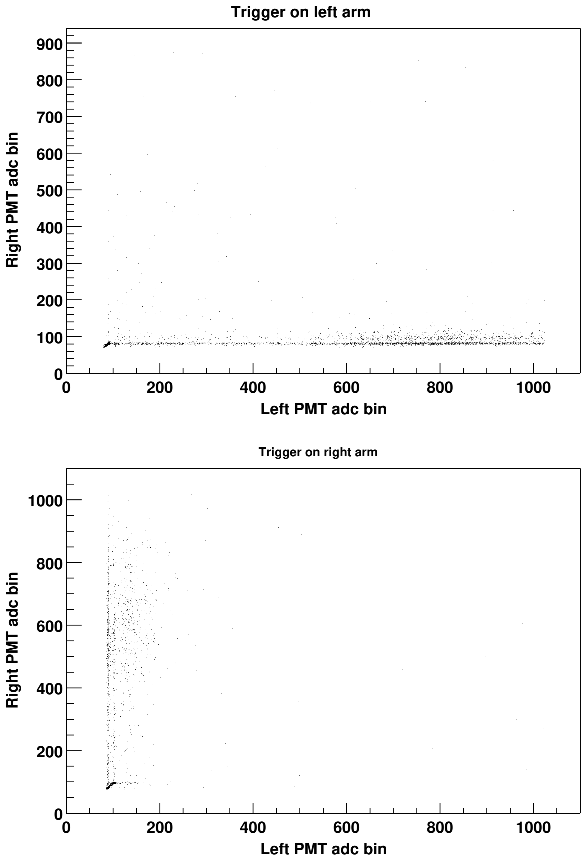

Figure 13: Results of crosstalk survey during typical runs. Top is for right arm, bottom is for left arm.

The trigger was installed on one arm and both PMT signals were recorded. 2d plots shows the correlation between the two PMT signals with S3 cut applied on the data to filter to get vertical muons with high energy. Besides the noise of each PMT (corresponding to 4-5 photoelectrons), there is no evident crosstalk (fig. 13). However, sporadic events (0.6%) occurs with high signal in both PMTS. The fortuitous muons for our geometry and for the time window of the trigger is extremely low (10^{-7} in rate) and it couldn't explain the events found for a signal of the same amplitude in the two PMTs neither a leak of light coming from the other arm. Rate of fortuitous muons is a rate considering single muons. A unexpectable rate is more likely to come from multi-muons signal i.e. muons coming from the same shower.

6 Conclusion

The efficency of the tests made with cosmic muons depended on the energy spectrum and the possibility to isolate with good accuracy the mean value of the distribution centered at 4 GeV. Results for the typical number of photons shows a good agreement with the simulation if we consider the fluctuation in the quality of real materials. A good agreement was also found for the attenuation in angle and in the transmition process along the quartz. Finally no evident crosstalk is observed. The next step is to determinate the resolution of the detector with a real electron beam and to study the edge effects of the electromagnetic showers. This will be conducted at JLAB with one arm detector.

References

[1] G. Tauzin, *quartz etc...*, (2002).

[2] A. Vacheret, *Happex2 Design and simulation report*, (2000).