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Test and development of a Cherenkov diffusion detector prototype using Airglass aerogel at TJNAF

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Abstract

In this note some operational procedures applied to aerogel tiles are described. These tiles are currently installed in the Cherenkov diffusion box prototype built by INFN groups of ISS-Roma, Bari and Lecce and used to aid the design of a bigger detector to be installed in Hall-A. Particular attention is focused on the baking and cutting procedures of the tiles. Moreover the analysis of data obtained with baked aerogels shows a significant improvement in the average number of detected photoelectrons, when compared with results from unbaked tiles. A factor 4 increase in the number of produced photoelectrons is obtained.

1 Introduction

Since the early 1980's, silica aerogel has been widely used as a radiator for Cherenkov detectors. Its low refraction index and density allows particle identification in experiments where gaseous radiators have been used in the past. Nevertheless, aerogel as Cherenkov radiator has several drawbacks, such as poor light transmission in the UV-visible wavelength region (a region in which most phototubes are sensitive) and extreme fragility. In addition, aerogel tiles produced by Airglass Inc. are strongly hydrofillic: water particles soaked by aerogel and absorbed in its structure tend to degrade its transparency and its optical properties. For this reason it is important to develop 1) a cutting technique which preserves the integrity of cutted pieces of the tiles and their optical properties, 2) a baking procedure which eliminates as much water as possible from aerogel and finally 3) a post-baking procedure which minimizes the air exposure of the tiles until their installation in the detector.

2 The aerogel Cherenkov diffusion box prototype

The aerogel prototype detector [1, 2],depicted in Figs. 1 and 2, consists of six 14-stage 5" BURLE 8854 Quantacon photomultiplier tubes [3], arranged in two rows of three phototubes opposite to each other, collecting the Cherenkov light produced by a $40\times40\times9$ cm^3 aerogel layer, connected to a diffusion zone of $45\times45\times20$ cm^3. All inner surfaces of the detector were covered with Millipore paper as a reflector. A cross-sectional drawing of the detector is shown in Fig. 1 and a schematic view of the experimental set-up is shown in Fig. 2. The present measurements have been taken with aerogel produced by Airglass Inc. with refractive index $n = 1.025$.

The parameters of the detector have been studied using cosmic rays in order to produce Cherenkov light in aerogel. With a rather large aerogel square area the behavior of the parameters of the detector smoothly depends on the position of incoming rays: so there was no need to study details with a pencil beam. Even if the cosmic ray rate is not comparable to that of a particle beam, the large square area allowed the collection of good statistics in a relatively low amount of time ($\sim$24 hours).

As shown in Fig. 2, an upcoming cosmic ray to be detected had to trans-

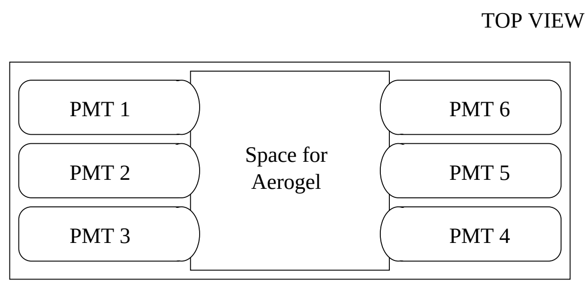

Figure 1: Top view of the aerogel detector prototype. The central chamber contains a $40\times40\times9$ cm^3 Airglass aerogel layer, with refraction index $n = 1.025$.

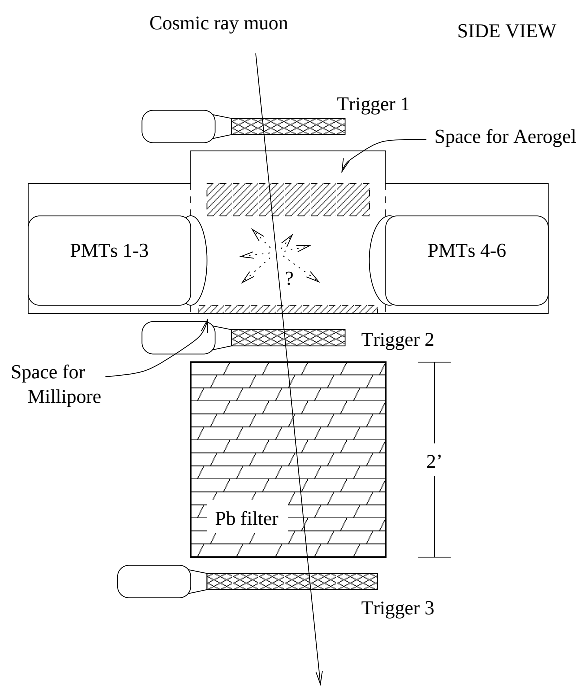

Figure 2: Cross sectional view of the detector with the used cosmic ray setup. The third trigger scintillator fired only for very energetic (>810 Mev) muons.

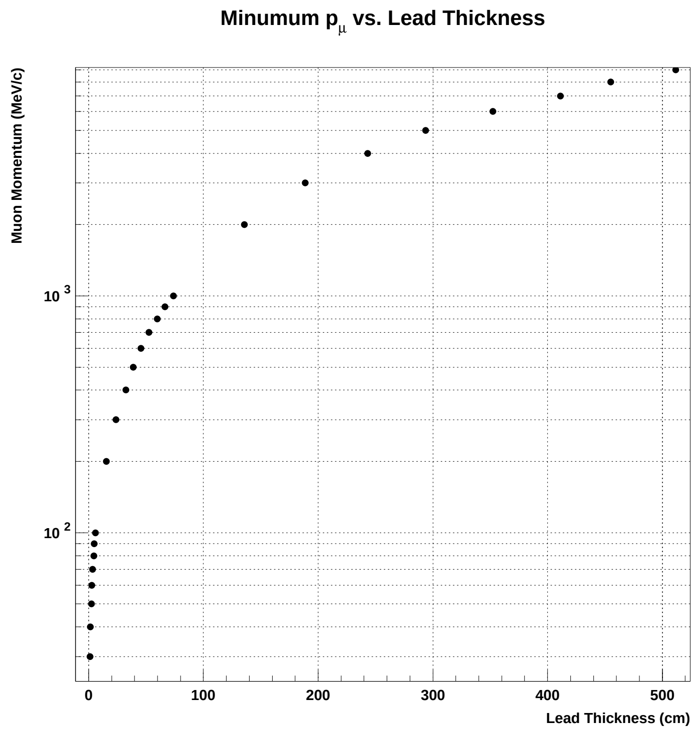

Figure 3: Muon momentum as a function of lead thickness. A choice of ∼60 cm corresponds to ∼800 Mev/c muons.

verse the first trigger scintillator, the detector itself (in which it originated the production of Cherenkov light), the second trigger scintillator, 2' (∼61 cm) thick lead filter, and finally the third trigger scintillator. The electronic chain used in this setup is described in detail in ref. 1. Basically, only the coincidence signal of the first two trigger phototubes, properly timed, provided the gate signal. The third trigger PMT was used to select high energy events, during data analysis, i.e. to select those cosmic rays which passed through the lead filter [1].

Cosmic rays at sea level are composed mostly of muons which have a mean energy at the ground of ∼4 GeV [4]. In order to find the minimum momentum of muons traversing the lead filter, one can refer to the muon energy loss rate (for ionization only) in lead, which depends (rather strongly for very low momenta) to the incoming particle momentum [5]. Then the maximum lead thickness corresponding to a given muon energy (or momentum) can be easily calculated, carrying to the results of Fig. 3. A muon momentum of ∼800 MeV/c (energy ∼810 MeV) corresponds to 2' lead thickness.

3 Operational procedures

3.1 Cutting silica aerogel

Silica aerogel is extremely fragile: therefore, particular care must be used in handling and, obviously, cutting it. For our purpose, we needed a 40×40×9 cm^3 aerogel tile and we had several tiles each 3 cm thick but with greater square area. So, in order to cut tiles with the desired dimensions, we used the AB Marvel band saw located in the High Bay Area of the EEL Building. Before the cut, each aerogel tile was put on a cardboard sheet to avoid contact with the saw working table. The saw is mostly used to cut aluminium or metal foils, and on its table surface a certain amount of oil, coolant water and metal debris can be present, even after an accurate cleaning. In addition, at the beginning of the operation, each worker should wear appropriate protective clothing, gloves, protective glasses and, optionally, a mask to protect from silica powder, even if silica particles are declared as being non toxic and not harmful to lungs [6]. To minimize contamination, a vacuum cleaner was used while the saw was moving, to capture powder thrown in air by the saw itself. After the cuts, the saw and the environment around it,was to be cleaned.

One might follow the checklist below during the operation:

- Turn cooling off using the switch located on the front panel.
- Close the coolant circuit, operating the switch located near the band itself. This is not to be done while the saw is moving!
- Switch on the saw and let it run for a few minutes, in order for the residual coolant to fall down. After, if possible, switch off and clean the band and the work table with dry towels. Do not use water. The latter operations requires 1/2 hour or so.
- Place the tile to be cut as preferred, and switch on the saw. Set the saw speed to at least 350 ft/min (this increases stability and minimizes

the risk of breaks). Always set speed with moving saw only! Otherwise the saw could be damaged.

3.2 Baking silica aerogel

As emphasized before, aerogel produced by Airglass is extremely hydrofillic. This evidence is shown in the table where the weight variations of the samples after the baking process are reported. In the table m is mass of the aerogel sample before the baking, $\frac{\Delta m}{m}$ is the decrease of the mass after the baking time indicated in the table

sample	m (g)	$\frac{\Delta m}{m}$(%) (8 hrs)	$\frac{\Delta m}{m}$(%) (16 hrs)	$\frac{\Delta m}{m}$(%) (24 hrs)
2	4.331	3.0	3.1	—
3	3.988	2.8	3.0	—
4	5.054	2.9	—	—
5	4.173	2.6	—	—
6	4.694	2.9	—	—
9	4.063	—	3.0	—
10	4.614	—	3.1	—
11	4.566	—	—	3.6
12	3.887	—	—	3.3

The baking process is necessary to eliminate soaked water. This procedure improves the optical properties of the aerogel as shown in Fig. 4 where are reported the transmittance curve by the aerogel before and after the baking (32 h).

In our experiment, an air circulation based oven was used[1] [7].

This oven is programmable by the user, and the following cycle was set:

- 4 hours upward ramp, from ambient temperature to 300 Celsius degrees.
- 32 hours soaking at 300 Celsius degrees.
- 4 hours downward ramp, from 300 Celsius degrees to ambient temperature.

[1]Although the mentioned oven was the only one available at the time of our work, a 500 Celsius oven is planned to be acquired to be acquired for the bigger aerogel detector.

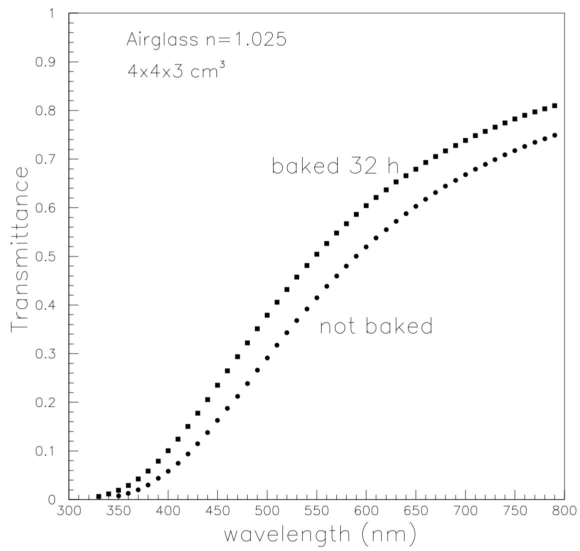

Figure 4: Transmittance spectra measured every 10 nm between 190 and 900 nm for the Airglass aerogel sample before and after a 32 h baking.

3.3 Aerogel installation

Since Airglass aerogel tends to absorb a great amount of water in a relatively low time interval, it is wise to protect the layer to be installed from air exposure (therefore from humidity exposure) as much as possible. For this purpose, as a dry room was not available, an ad hoc technique was developed to protect aerogel consisting in the following steps:

- after the baking process, the aerogel tiles were covered with properly bended stainless steel plates, eventually sealed with duck tape. This was done inside the oven itself, since after the baking the temperature inside is well above the ambient temperature and it takes a sufficiently long time to make a thermal equilibrium between the oven and the environment. A relatively high temperature helps limiting the amount of water soaked by the tiles.
- A little dry chamber was built using flexible and transparent plastics to separate the installation area from the external environment [2].

[2] The latter showed to be a good procedure. However, since the air circulation inside the little chamber is somewhat limited and human bodies exploit oxygen, in similar conditions

- The air inside the chamber was made dry by means of a small automatic dehumidifier. The relative humidity, during the whole installation, was monitored by an hygrometer. It never exceeded 42%, while outside it fluctuated around 50%[3].
- The installation of each needed aerogel tile was performed using gloves and masks, since the human body might emit water particles just for the act of breathing.

4 Data analysis

In order to obtain the average number of photoelectrons, the charge spectrum coming from each phototube was equalized and calibrated, each pedestal was shifted to channel zero and each spectrum was multiplied by a different factor to let the one photoelectron peak to lie on channel 100. From the summed PMT spectra, the average number of photoelectrons can be computed as [1]:

$$\mu = \frac{\text{Mean of Distribution}}{\text{Single Photoelectron Peak}} \left(\frac{A}{A_{eff}} \right) \tag{1}$$

where A/A_{eff} is the ratio of a single photoelectron peak to the mean of a single photoelectron distribution [3] and for our data is equal to 1.12. Of course, we could distinguish between two results: the one obtained by requiring a trigger between the first two scintillators and the second in which also the third scintillator was allowed as a trigger. The same software cuts described in ref. 1 were applied in obtaining μ. From the raw results for high energy events, 0.35 photons must be subtracted as a correction: this term comes from the Cherenkov light produced on air and millipore paper inside the detector [1]. Finally, as described in ref. 1, the results were extrapolated to a $\beta = 1$ particle beam, to consider cosmic rays β distribution. This extrapolation requires a multiplying factor of 1.039, as can be seen in the following table:

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it is wise to arrange things in order not to exceed one hour of total work time inside.

[3]Looking forward at the installation of the bigger detector, a new and more performant dehumidifier has been recently acquired.

n	β_n	$\overline{f}(\beta_{min} = \beta_n)$	$\overline{f}(\beta_{min} = 0.9941)$
1.010	0.990	1.105	1.105
1.015	0.985	1.218	1.068
1.025	**0.976**	**1.186**	**1.039**
1.055	0.948	1.119	1.017

where β_n is the minimum velocity to produce light in the aerogel, $\beta_{min} = 0.9941$ is the minimum β for a muon to traverse the 2' lead filter, and $\overline{f}$ is the correction factor for each β.

5 Results

In the following pictures some example spectra, according to the analysis described in the previous section, are presented. In figure 5, 6 and 7 the contribution due to the single six phototubes is shown. In figure 8, 9 and 10 the sum spectrum belonging to each run, each one presenting different conditions. For the August 14th run an unbaked aerogel layer was installed, while for the August 21st run we used the aerogel baked in the way described before. As one can easily see, although the absolute result in the photoelectron number is not a smash, the improvement is impressive (a factor $\sim$4 in collected p.e.'s) confirming the usefulness of the baking procedure. Before the August 24th run, additional millipore paper strips were added on the tray which contained the aerogel, covering the corners of the layer, a not interesting area since it was excluded by the trigger scintillators position. This increased the total diffusing area. Indeed, the mean number of photoelectrons slightly increased.

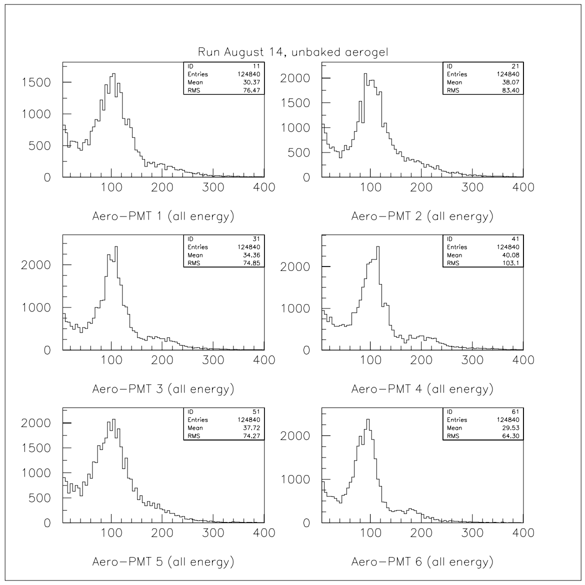

Figure 5: Separate ADC spectra for each PMT, calibrated at channel 100. Unbaked aerogel was installed inside the prototype.

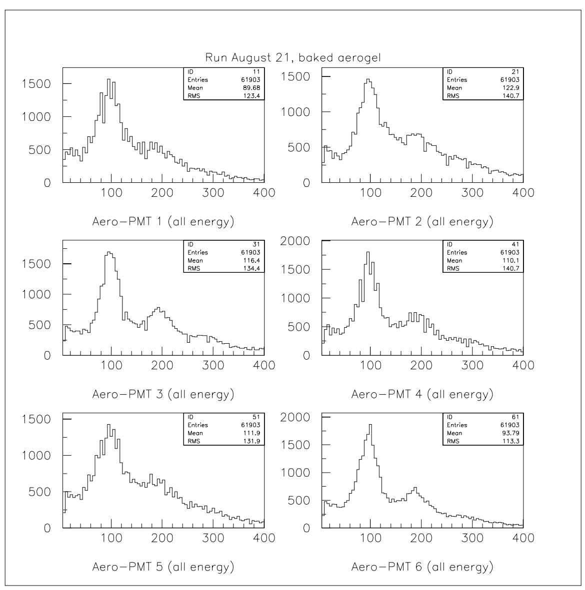

Figure 6: Separate ADC spectra for each PMT. Run with a 32 hours baking process of the aerogel tiles.

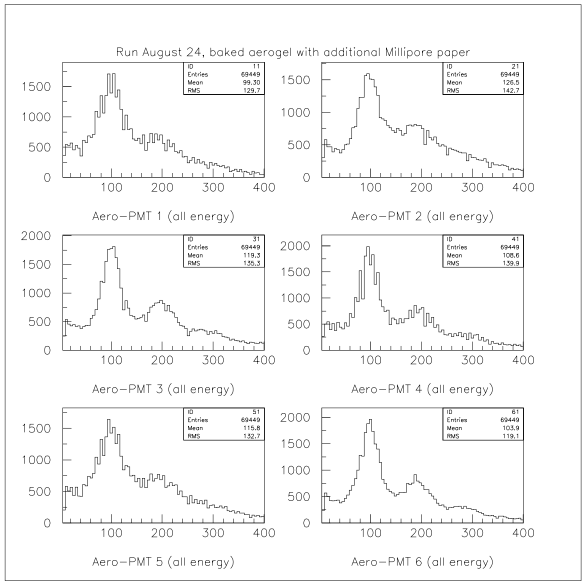

Figure 7: Separate ADC spectra with additional millipore paper.

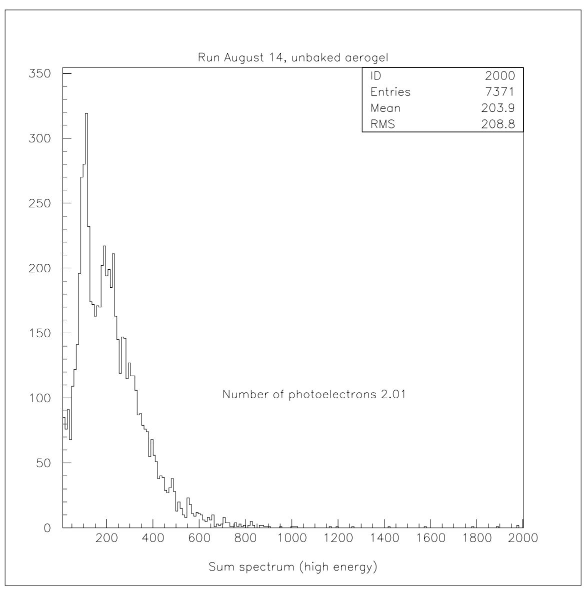

Figure 8: Sum spectrum, for non baked aerogel, of the six calibrated ADC. This refers to high energy muons (trigger 3 included).

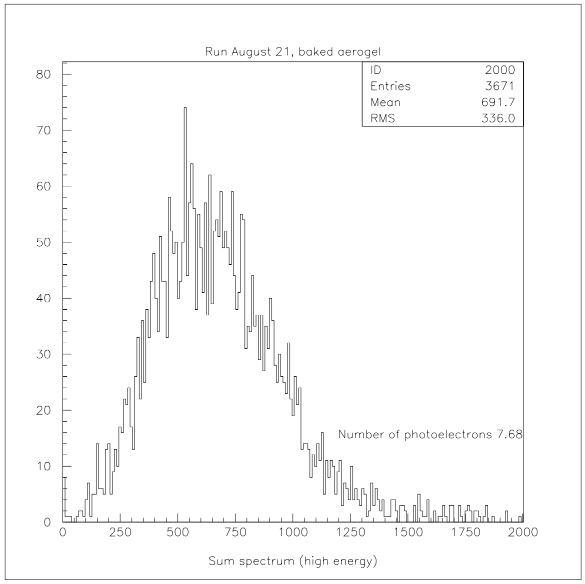

Figure 9: Sum spectrum, for baked aerogel, of the six calibrated ADC. This refers to high energy muons (trigger 3 included). Note the great improvement in collected photoelectrons.

6 Effect of magnetic field on photoelectron number

During the measurements described above, a mu-metal shield was installed on each PM to let the photoelectrons numbers to be not changed by the presence of a magnetic field. The magnetic field around the detector was measured to be 0.5 Gauss at its maximum. With the mu-metal shields removed, as can be seen by fig. 11, 12, the single contribution of each phototube and their sum slightly decreases of an average factor of 6%.

7 Conclusions

This study showed that a baking procedure on hydrofillic aerogel tiles remove a ∼3% of the weight and improves the light output, by a factor 4. In addition, we have seen that technique must be developed since baking to 300 Celsius degrees removes a water fraction equal to ∼ 3% of the tile weight and, after baking, the tiles must be opportunely preserved because they acquire weight

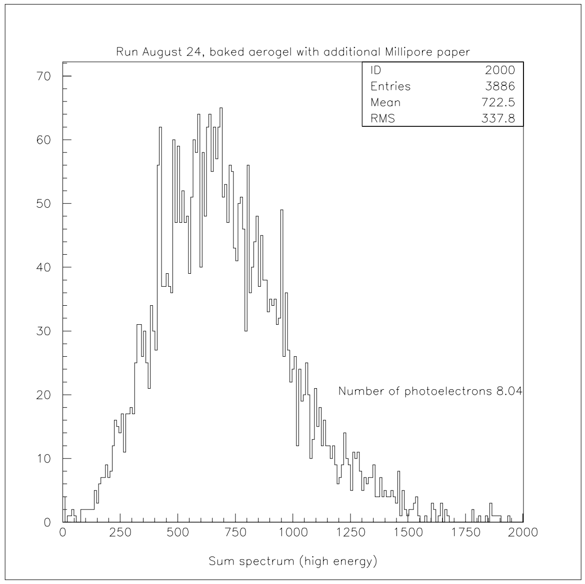

Figure 10: Sum spectrum for baked aerogel with additional millipore paper. The increase in diffusing surface carries out a relative improvement in the number of p.e.'s.

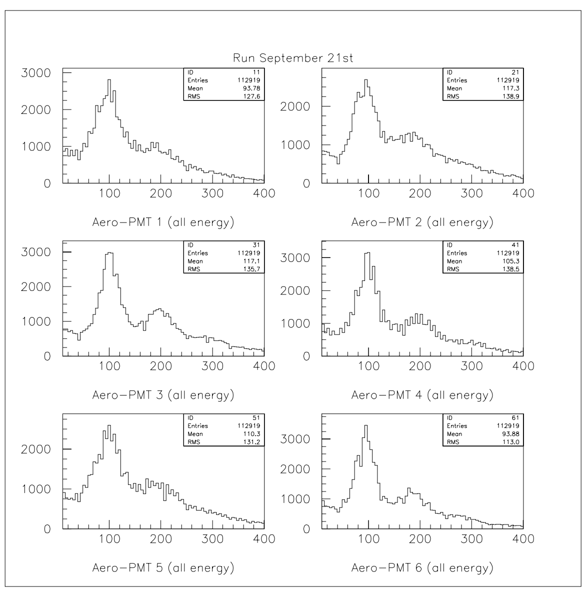

Figure 11: Individual contribution from each phototube having removed the mu-metal shield from the detector.

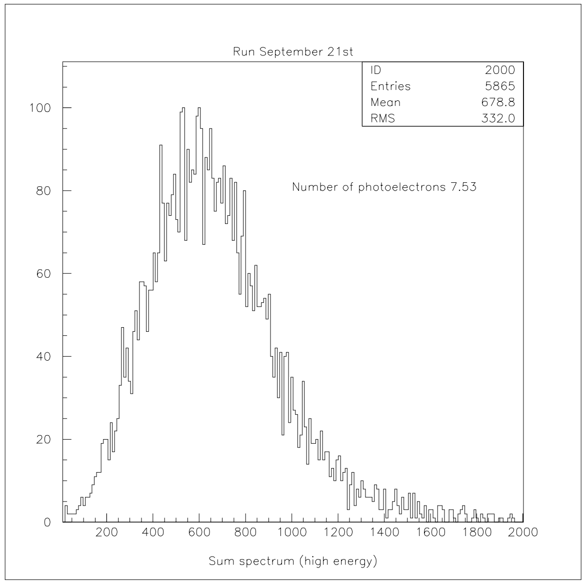

Figure 12: Sum spectrum for baked aerogel, additional millipore paper and removed mu-metal shield. The effect of magnetic field results in a decrease of photoelectron number.

if exposed to the environment.However, more study of baking effects, such as improvement in light transmission, need to be done, together with the use of a dedicated saw for the cutting and a professional dry room for the detector assembly.

8 Acknowledgements

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