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Studies of a Lead Glass Total-Absorption-Counter

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An absolute photon beam intensity monitor has been designed using EGS4. A lead glass block with dimensions of 8.9 cm x 8.9 cm x 33.0 cm was then studied with cosmic rays. Measurements are presented of the effectiveness of surface treatment and filtering to decrease the pulse width for higher count rates.

Study of Lead Glass Total Absorption Counter

The Hall B photon beam will have an intensity of about 10^7 gamma-rays per second. Relative flux measurements will be made by a pair spectrometer which will be calibrated against an absolute flux monitor at reduced rate, $\tilde{}10^5$ events per second. In order to calibrate the pair spectrometer we must apply it to a reduced photon beam while at the same time measuring the beam's absolute intensity. We must thus reduce the number of photons to a point where present electronics are able to count it entirely. The device to measure the reduced beam, the TAC, should count photons at the highest possible rate so that the number of photons might closely resemble in intensity what is to be used in the actual experiment, giving the calibration for the pair spectrometer more accuracy. In order to measure cross sections with 1% accuracy, the TAC should have a detection inefficiency of less than about .1%. Since the incoming photons will range in energy from about 300 MeV to 6 GeV the TAC will need fairly substantial mass and wide energy sensitivity.

We have access to a number of lead glass blocks, 8.9 cm x 8.9 cm x 33.0 cm SF2 lead glass. The characteristic radiation length (X_0) of this material is 2.62 cm, with a Moliere Radius (R_M) of 3.14 cm. In order to determine a proper arrangement of the blocks that would satisfy our boundary conditions as stated above a computer simulation was performed upon various configurations with the EGS4 code. Our initial speculation was a 3 x 3 arrangement of 9 blocks forming a rectangular solid 26.7 cm x 26.7 cm x 33.0 cm. We performed the simulation assuming 1000 photons of 5 GeV energy each incident upon the front middle of the center block. A graph (Fig. 1) produced by the code histograms the energy deposited in the blocks by the 5 GeV gamma-rays. As can be seen from the graph's rather wide peak, the amount of energy absorbed by this configuration is not complete enough for our purposes. Subsequent variations showed that although a 26.7 cm x 26.7 cm (3 block by 3 block) arrangement was wide enough to contain the electromagnetic shower laterally, 33.0 cm would not be an adequate length to contain it longitudinally. In order to increase this dimension of the TAC to 50.8 cm we added 2 layers of blocks (3 in each layer, 6 total) to the front of our array as shown in Fig. 2 (see next page). This in turn gave us the much sharper simulated energy absorption curve of Fig. 3.

Although the blocks provided for us are both free and convenient, it may be determined to have new blocks custom manufactured in more suitable dimensions (ie longer), perhaps with Ce doping for enhanced radiation resistance. Should this be decided upon, a single large block will probably be manufactured approximately 27.0 cm x 27.0 cm x 55.0 cm.

It was then considered whether the design shown in Fig. 2 would give sufficiently low probability (less than .1%) of a photon escaping detection in the TAC. We postulated a 200 MeV energy threshold to be appropriate and assumed an energy resolution given by:

$$\sigma \approx \frac{4\%}{\sqrt{E_{incident}(GeV)}}$$

Again with the EGS4 code we simulated photons of 250 to 310 MeV incident upon the TAC, yielding an energy absorbed in the lead glass which was then scaled by random gaussian deviates to simulate the above average σ energy resolution error. If the measured energy in the blocks was less than 200 MeV, it was considered escaped. Figure 4 shows the percentage of events lost vs. incident energy. It is seen that a suitable 99.9% probability of detection exists near $E_{incident}$ = 300 MeV, and this corresponds to our boundary conditions. Therefore the array of lead glass blocks proposed in Fig. 2 would seem an appropriate design for the TAC.

In order to build a fast-counting TAC, it is desirable to obtain pulses from the photomultiplier tubes that are very sharp, with as little a "tail," or trailoff, in them as possible. We wished to test two design parameters that might aid creation of sharp pulses. One was to blacken the end of the block opposite the phototube to absorb the end-reflected photons that would otherwise arrive late due to a greater path length in the lead glass. The other was to use a blue filter that would screen out any fluorescence induced by the shower, fluorescence that would arrive well after the Cerenkov radiation and serve to lengthen the pulse tail. We also wished to see how adversely these alterations would affect the energy resolution σ.

We then turned to the question of what kind of energy resolution and response time could be expected from the lead glass, as it was important to determine whether or not the above value of σ was overly optimistic. Using one of the glass blocks listed above and borrowed from Rice University, we constructed the apparatus shown in Fig. 5. The entire length of the block was wrapped in aluminized mylar to aid internal reflection.

Two scintillator-lightpipe paddle arrangements were built by cementing a 0.64 cm x 10.0 cm x 10.0 cm block of plastic scintillator material to a lucite lightpipe. Another phototube was placed at one end of the lead glass block, and the paddles were positioned in the middle of its length. Tests were performed with cosmic radiation.

We used 3 Phillips XP 2262 2" phototubes with a standard bialkali photocathode. Tube #1 was connected to the plastic scintillator on top of the block, Tube #3 went to the scintillator on the bottom, and Tube #2 referenced the lead glass block between them. Since the actual TAC would use 3" phototubes for 8.9 x 8.9 cm^2 blocks, we blackened a circle 3 inches in diameter on the glass around Tube #2. A coincidence between pulses from phototubes 1 and 3 was required. ADCs and TDCs were used to measure the integrated charge and arrival time of the pulses, respectively.

To test our two proposed design parameters, we used 4 different configurations of the lead glass block. For two setups the end of the block opposite the phototube was covered with aluminized mylar, then the mylar was removed and the end coated with a matte black paint for the remaining two runs. In two of the configurations a blue filter was placed between the phototube and the glass block, and then removed for the other two experiments. The filter we used was of color Brilliant Blue with a transmission coefficient of 18%. It would block light of wavelength 580 to 660 nm and pass light of 380 to 580 nm. (The quantum efficiency of the phototubes for light with wavelength longer than about 660 nm is very low.) In all four arrangements only a small hole, 1 to 3 cm^2, was allowed for Tube #2; this gave us a single photoelectron peak in the ADC #2 histogram. By almost always allowing only a single photoelectron per cosmic ray interaction to be detected by Tube #2 we measured the arrival time of individual photons. A histogram is shown in Figure 7 on the next page of the ADC spectrum for phototube #2, corresponding to both a reflective end and the blue filter.

All channels below #90 were empty due to a discriminator threshold. Channel #98 is the pedestal, corresponds to a triggering of the measurement electronics as a cosmic ray muon passes through both scintillator paddles, but without a photoelectron being produced in Tube #2. It is the most probable event so that statistical deviations will give rise almost entirely to a single photoelectron peak without also creating two and three photoelectron peaks. If we zoom in on the interesting portion of the histogram (Fig. 8), we can see the single photoelectron peak followed by an exponential trailoff against a steady background of low noise.

TDC #2 has compiled the time structure of the lead glass light pulse. Since the photon can take many different paths inside the block, passing straight to the phototube or bouncing off the sides and ends, the travel time varies. In lead glass light travels about 20 cm/ns. Should the photons travel one or more extra lengths of the block, the arrival time would be delayed by at least 2.5 ns (corresponding to 1 1/2 lengths), a significant figure.

The TDC histogram for Tube #2 is given below in Fig. 9. This was plotted on 2048 channels in bins of 2 channels each (21.3 channels = 1 nanosecond), but only Channels 900 to 1300 are shown. There exists a double peak in the histogram, suggesting that two primary paths can be taken inside the block by the photoelectrons. This corresponds to scintillation photons reaching Tube #2 by either traveling straight from the cosmic ray path to the small exit hole or bouncing off the reflective end before detection and traversing an extra 1 1/2 lengths of the block. The two peaks are separated by 40 channels (1.9 ns).

However, if the end of the block is darkened with a matte black paint and the blue filter left in place, Fig. 10 is obtained. It is much sharper and does not contain the second peak, indicating that the photons can travel only the shortest path to the phototube and can no longer bounce off the far end. Whereas pulses from the reflective-end arrangement averaged about 70 photoelectrons per event, this was reduced to about 25 photoelectrons per event with the blackened-end configuration. Although the light yield is obviously reduced by the block's absorption of many scintillation photons this effect is more than counterbalanced by the sharper time spectra, enabling the TAC to count more quickly.

Turning to the question of the effectiveness of the blue filter, a histogram for TDC #2 (blackened end) without the filter is given in Fig. 11. This is virtually identical with Fig 10 (blackened end w/o filter), above. Should we merge the two graphs and examine Channels 950 - 1000 (where the improvement in trailoff time spectra would be expected) there exists almost no difference between the histograms (Fig. 12). This might be the results of two phenomena: perhaps an insignificant amount of fluorescence is induced in the block by the cosmic ray, or it could be that the filter is set to block the wrong wavelength intervals.

Thus the proposed TAC design for CEBAF, Hall B, is a rectangular volume of lead glass, 26.7 cm x 26.7 cm x 50.8 cm. Computer simulations performed on this configuration gave greater than 99.9% probability of detection for 300 MeV and higher incident gamma rays, assuming both a 200 MeV energy threshold and a $4\% / (E_{incident} (GeV))^{1/2}$ energy resolution. The ends of the blocks opposite the photomultiplier tubes should be blackened to increase the maximum count rate, and this procedure does not drastically reduce the energy resolution. It is unclear at this time whether latent fluorescence could be screened out of the photon pulses with the proper filters, although a blue filter (transmission coefficient 18%) blocking light of wavelength 580 - 660 nm and passing 380 to 580 nm proved ineffective.

The next step in the TAC design is to obtain fast phototubes and fast electronics for measuring the Cerenkov photons. The Total Absorption Counter could then be built and tested on a beam line prior to its installation in Hall B.

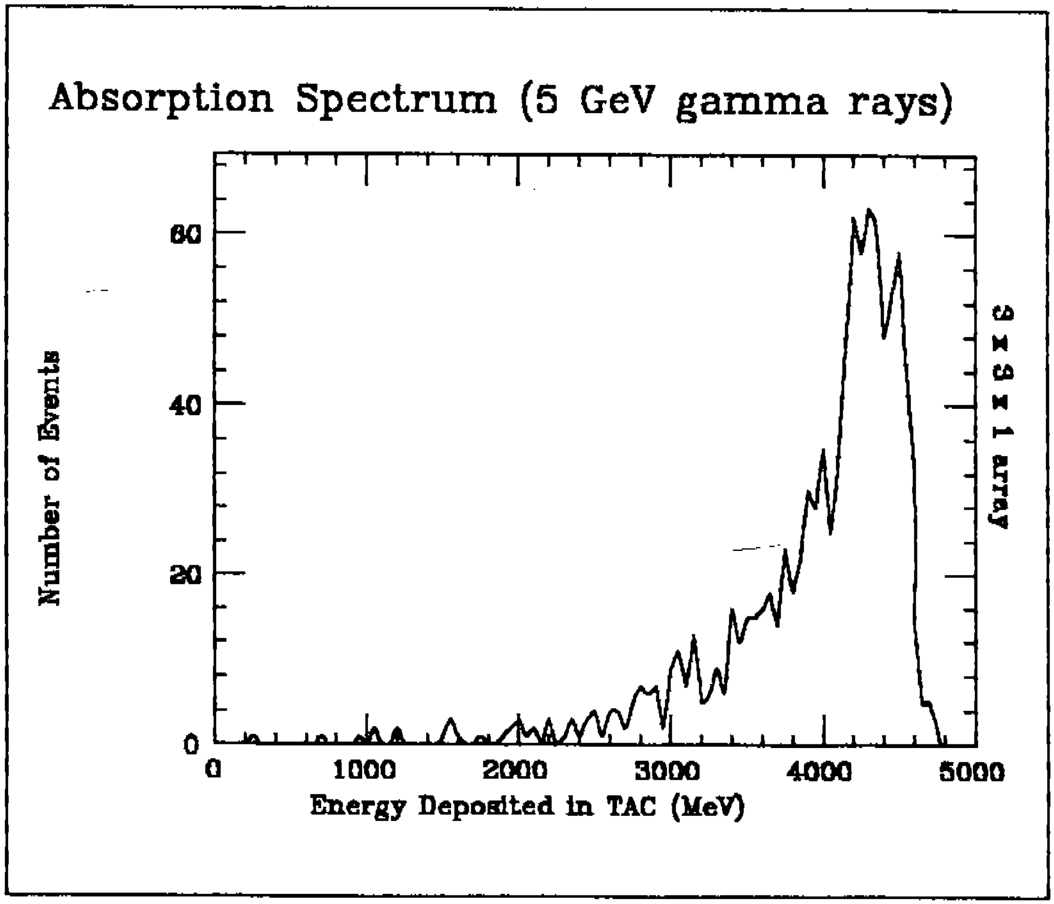

Figure 1: EGS4 simulation of 1000 5 GeV gamma-rays incident upon a 26.7 x 26.7 x 33.0 cm block of SF2 lead glass.

PROPOSED TOTAL-ABSORPTION-COUNTER

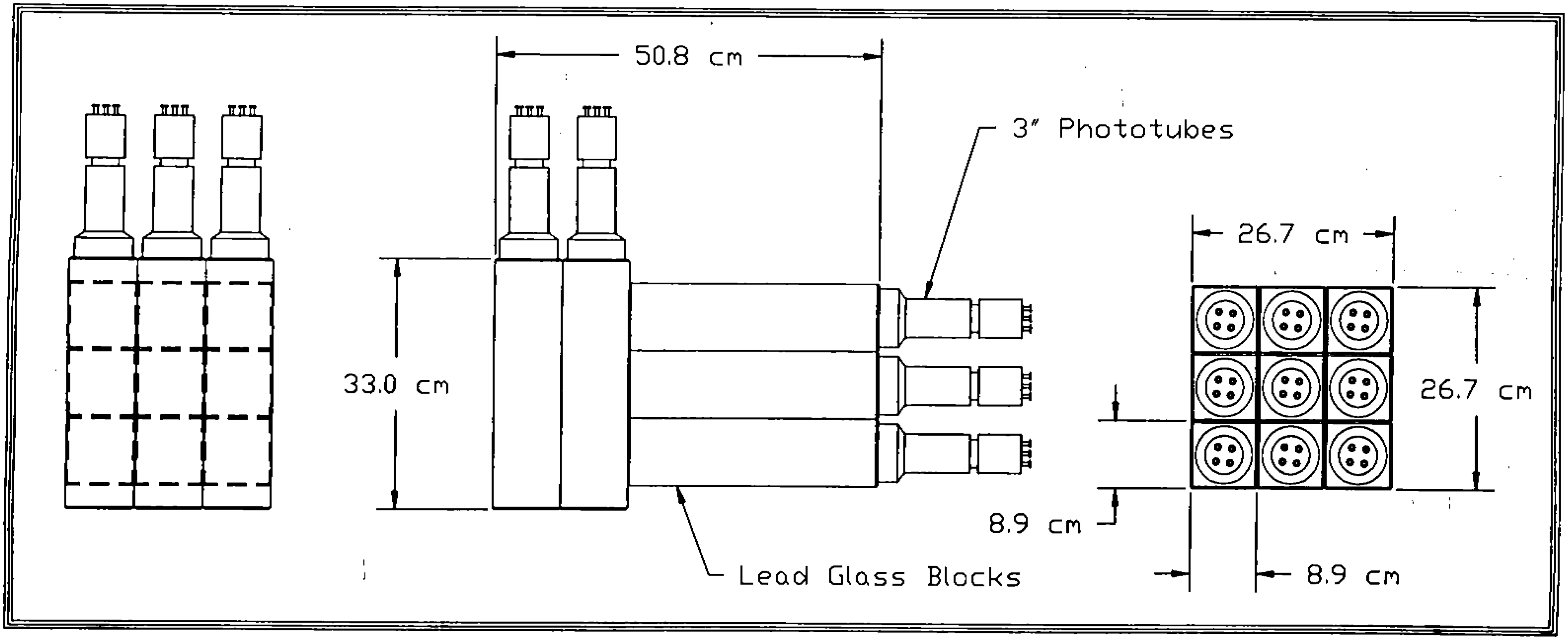

Fig. 2

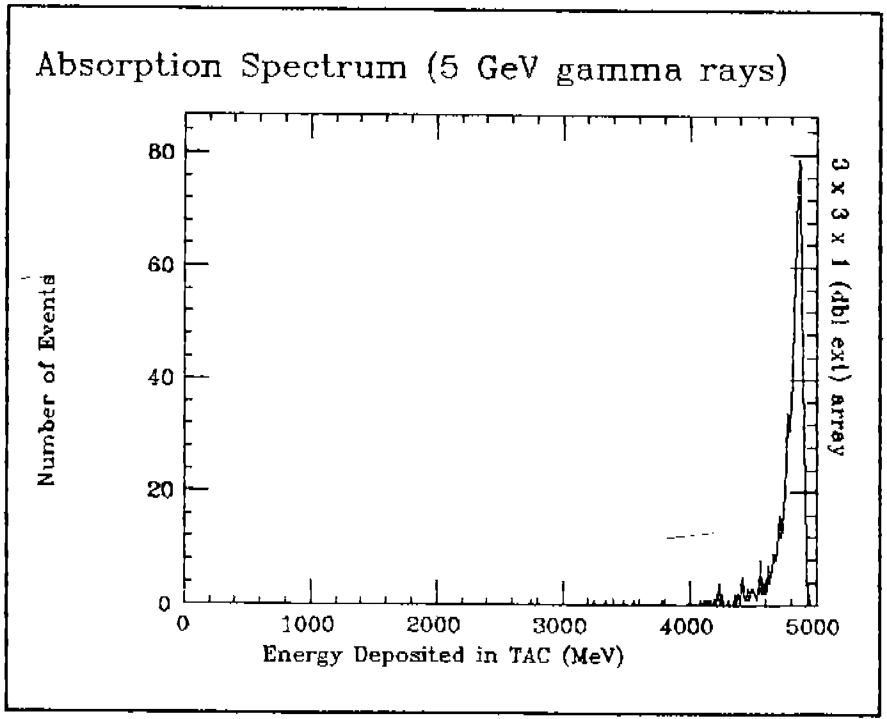

Figure 3: EGS4 simulation of 1000 5 GeV gamma-rays incident upon a 26.7 x 26.7 x 50.8 cm block of SF2 lead glass.

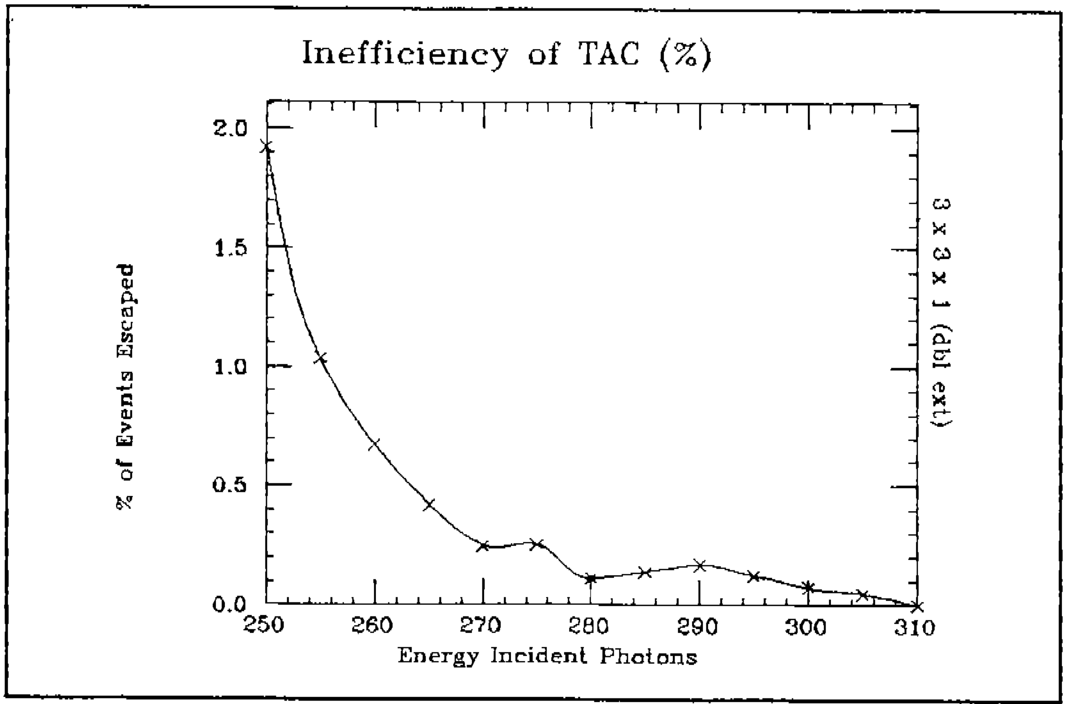

Figure 4: The percentage of events lost ($E_{detected} < E_{threshold}$) is shown vs. $E_{incident}$ of the gamma rays.

DIAGRAM OF EXPERIMENTAL SETUP

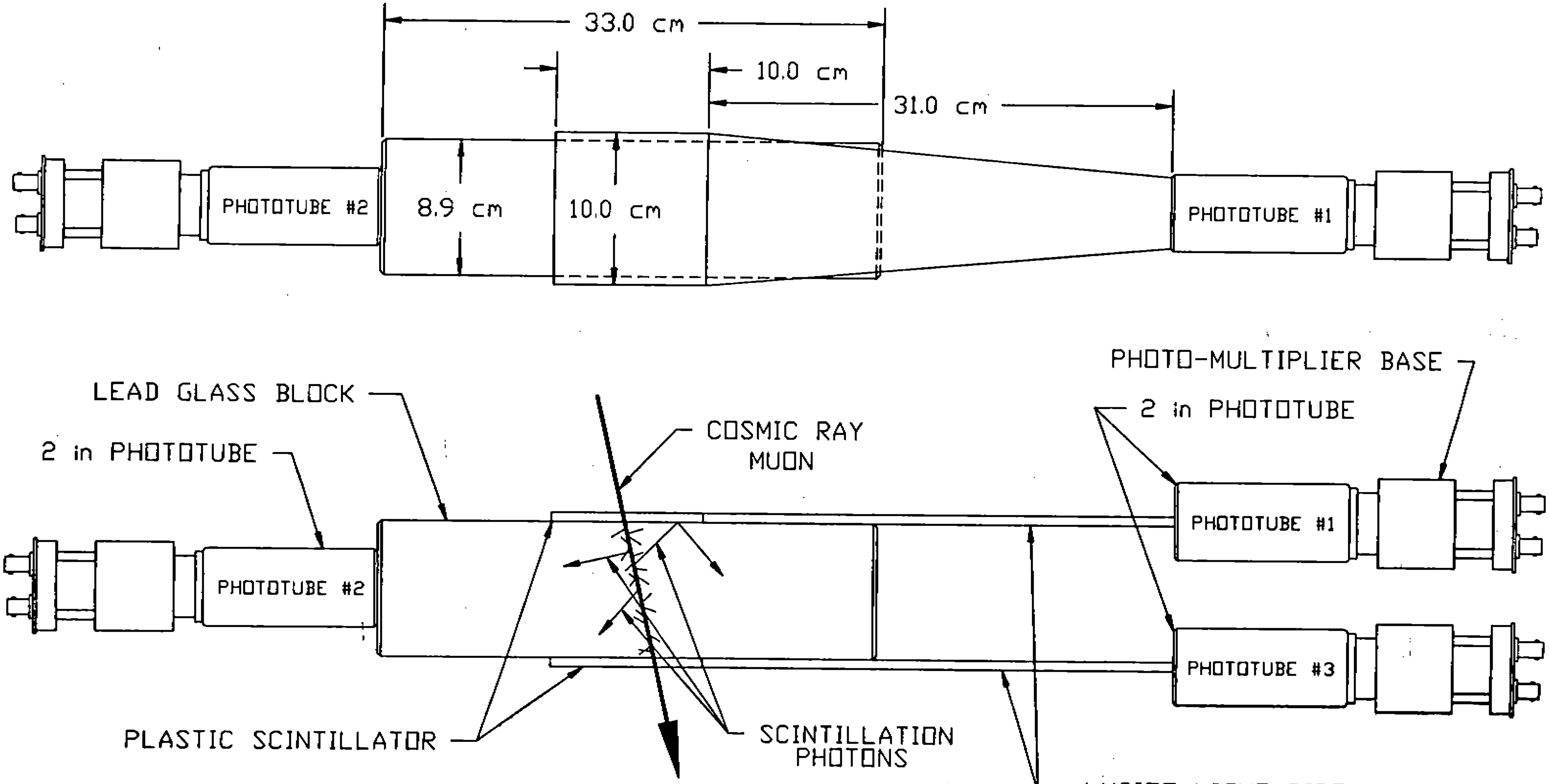

Fig. 5

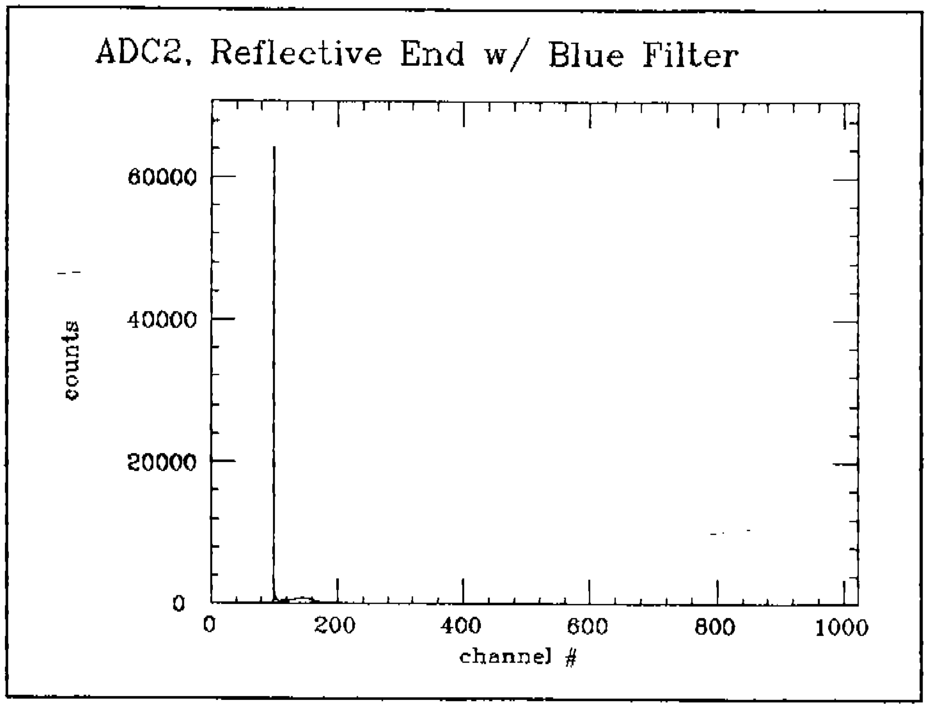

Figure 6: ADC spectrum for Tube #2, reflective end with the blue filter in place.

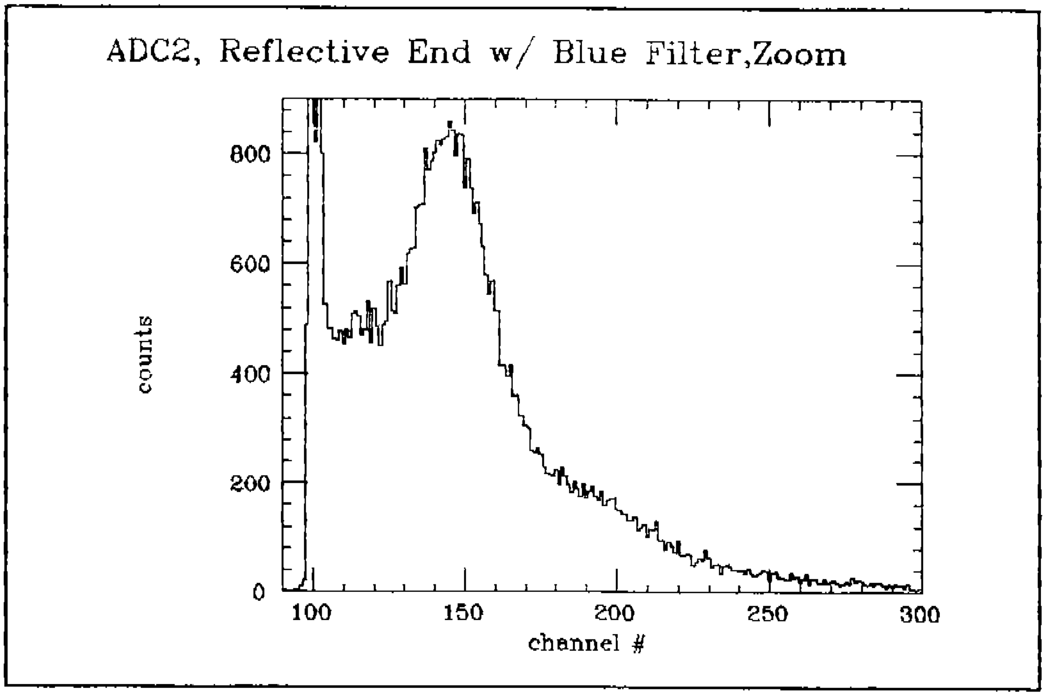

Figure 7: ADC for Tube #2 (same as Fig. 6), with zoom. Note single photoelectron peak.

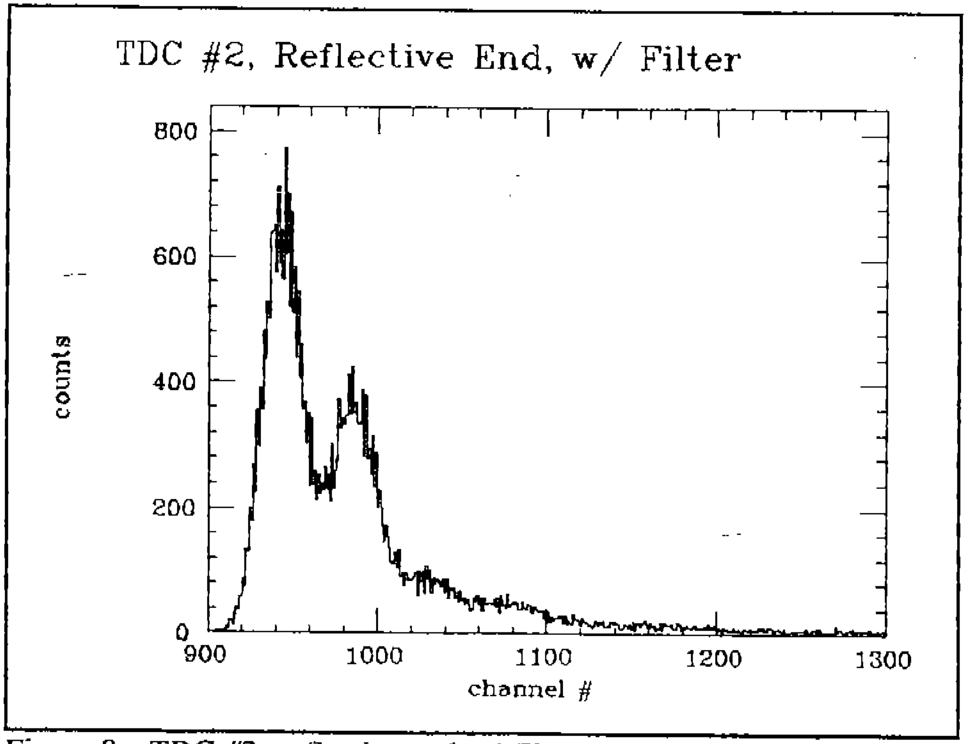

Figure 8: TDC #2, reflective end w/ filter. Note double peak.

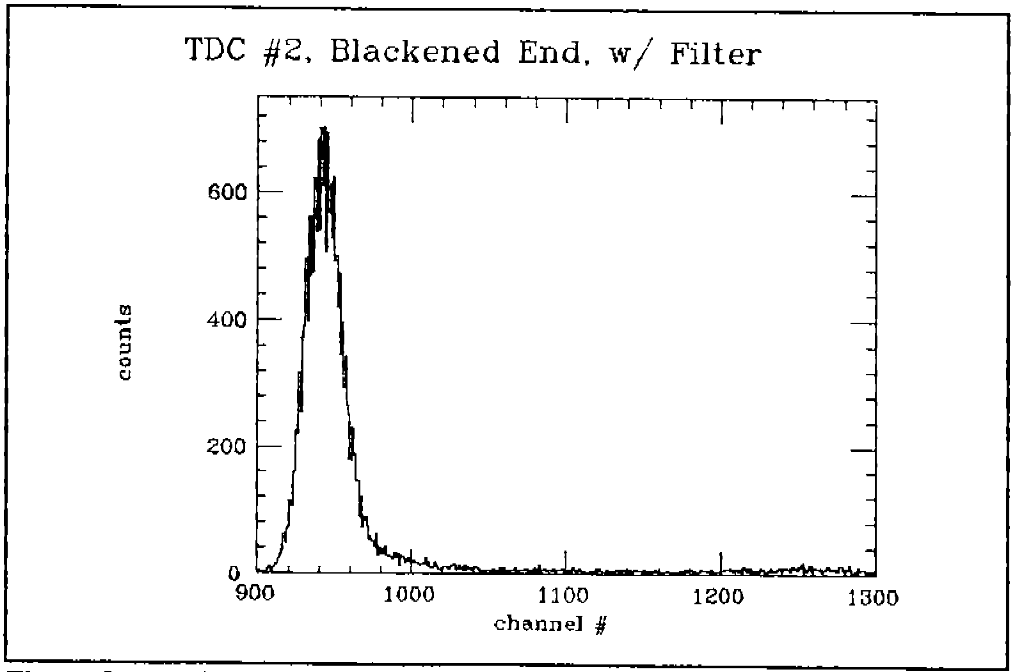

Figure 9: TDC #2 for blackened end w/ filter. Note sharpness of peak compared w/ Fig. 8.

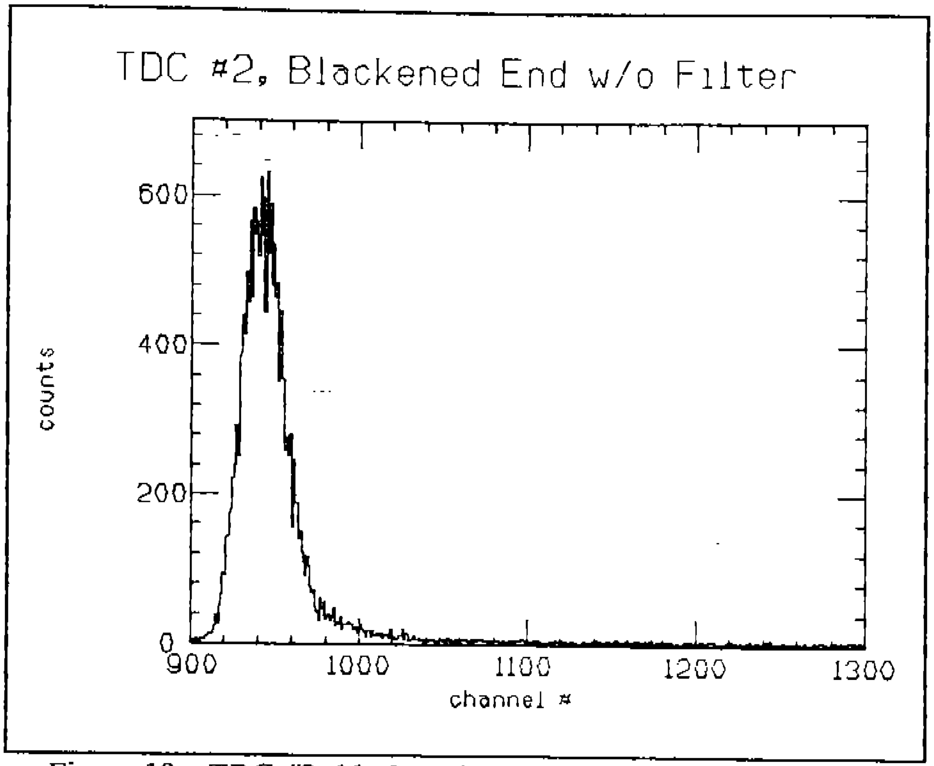

Figure 10: TDC #2, blackened end w/o filter. Note similarity to Fig 10.

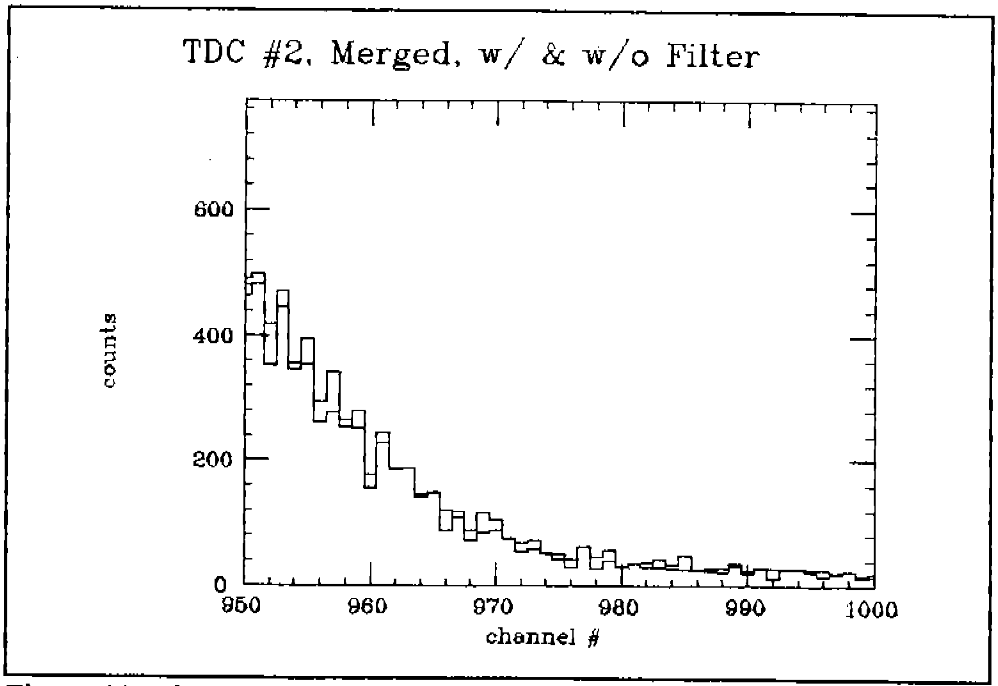

Figure 11: Comparison of TDC #2 for blackened end w/ and w/o filter. Note lack of difference between the two.