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Photon Attenuation in the CLAS Beam Line

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Abstract

Photons from the CLAS tagger are absorbed by materials in the beam line between the physics target and the Total Absorption Counter (TAC). The calculated photon flux determined from the tagger and the TAC must include a correction factor for this photon attenuation. We find that the factor is between 3.6% and 4.4% depending on running conditions.

1 Introduction

For each electron detected by the CLAS photon tagger we need to determine the probability that the accompanying photon actually makes it to the physics target at the center of CLAS. This is called the tagging efficiency. The tagging efficiency is determined using special low intensity runs in which the photon beam is sent into the TAC located 27 meters downstream of the CLAS target. The tagging efficiency is energy dependent, and it is in the neighborhood of 85%. The energy dependence comes from as the photon beam collimation, which scrapes off more low energy photons than high energy photons.

A small correction to the photon tagging efficiency comes from the absorption of photons between the CLAS target and the downstream TAC. The procedure of measuring the tagging efficiency tells us the probability that photons of a given energy reach the TAC, whereas we really want to know the slightly larger fraction of photons that survive to the CLAS target. This correction factor is the topic of this note.

The mechanisms of absorption are mainly pair production and a small amount of Compton scattering. Both processes require the photons to interact with material in the beam line. This material includes the physics target itself (see below), the target endcaps, the helium in the helium bag, some air, and the converter in the pair spectrometer. Thus, we need an accurate accounting of the material in the beam between the CLAS target and the TAC.

There are ways in which a photon interaction can nevertheless give a signal in the TAC. If a Compton scattering event occurs at small enough angles, then the scattered photon will still hit the TAC. Another avenue is that a positron produced by pair production can annihilate again, producing two lower-energy photons which have some chance of hitting the TAC. Crudely speaking, both of these effects result in a less apparent absorption as the photon energy increases.

One final possible effect is what occurs if the current in the Pair Spectrometer is too low to sweep the highest energy electrons out of the way of the TAC. Thus, we must see whether the highest-energy photons, when they pair-produce and make high energy electrons (or positrons) can conceivably hit the TAC.

2 Physics Processes

Pair production in the field of a nucleus creates an e^+e^- pair which travels with a very small opening angle in the forward direction. The average angle between each particle and the photon direction is given by

$$\theta = \frac{mc^2}{E} \tag{1}$$

where E is the photon energy and θ is the angle in radians. At CLAS energies the energy sharing between the two particles is roughly "flat" in the sense that one particle has a uniformly probable distribution of energies, while the other particle picks up the balance. In a closer approximation, the energy-sharing distribution is peaked towards the high/low ends; see Figure 2.31 in Segre's [1] book. The Pair Spectrometer (PS) magnet peels these pairs apart and neither particle hits the TAC. Initially we assume that there is no chance at all for one of the particles to hit the TAC, and thus any pair production in the beam line represents attenuation of the photon beam. Any pair production between the PS and the TAC still results in hits in the TAC because of the tiny opening angle, and therefore does not contribute to attenuation.

In the energy range we are working, between 500 and 5500 MeV, the absorption length for photons in all materials is very nearly constant, as seen in Fig 23.12 of the PDG-2000 book [2], for example. The values range between roughly 10 (high Z) and 100 g/cm^2 (low Z) of material. This constant value, for any given material, is the same as the "conversion length" for photons, which is 9/7 of the "radiation length" of the material. The values can be read off the graph, or they can be accurately computed from formulas given in the PDG book. Thus it appears initially that there is no mechanism for an energy dependence to the photon attenuation at JLab energies.

One way to get a slight energy dependence is to consider that even at these high energies there is some Compton scattering. That is, a small fraction of the photon absorption process proceeds not through pair production but through Compton scattering. The fraction can be determined using Figure 23.13 in the PDG-2000 book. At 500 MeV for hydrogen the effect is largest, and it amounts to about 10%. The angular distribution of Compton scattered photons is very forward peaked at these energies, as given by the Klein-Nishina formula [4]. The differential cross section puts most of the photons well within one degree of the beamline, but some of these photons will hit the TAC and some of them won't. The ones which hit the TAC get counted, and so don't contribute to the overall attenuation, while the wider-angle photons will be lost. At lower energies the Compton angular distribution is wider, so the attenuation at lower energies is slightly greater.

To compute the effective attenuation of photons for any given element of material in the CLAS beam line, we first consider there to be a fixed nominal attenuation coefficient, f.

$$f = e^{-t/\lambda} \tag{2}$$

where t is the thickness of material in gm/cm^2 and λ is the conversion length given by the standard formula given in the PDG book. The fraction of photons lost, ϵ, is then

$$\epsilon = 1 - f \tag{3}$$

Of this fraction, some amount undergoes Compton scattering:

$$\delta = (1 - P)\epsilon \tag{4}$$

where P is the pair production probability given in the PDG book and is energy dependent. Some fraction, η, of this fraction will hit the TAC anyway, where

$$\eta = \frac{2\pi \int_0^{\theta_{TAC}} \sigma_{KN} sin(\theta) d\theta}{\sigma_{KN}^{tot}} \tag{5}$$

where σ_{KN} is the Klein-Nishina cross section, the integral ranges from zero degrees to the edge of the TAC counter, i.e. is taken over the solid angle subtended by the TAC as seen by the material, and σ_{KN}^{tot} is the total cross section for Compton scattering at a given energy.

The effective absorption factor, f', for a given energy and a given material is then

$$f' = f + \eta * \delta \tag{6}$$

We have "added back" the portion of the overall attenuated photon beam which does hit the TAC via small-angle Compton scattering.

Another way to get a slight energy dependence is from annihilation of positrons back into photons which in turn can reach the TAC. The cross section for this to happen is quite small however. The relevant formula is given in books on Quantum Field Theory [3]. The photons are distributed over all space but the cross section is forward peaked, favoring hitting the TAC. Also, the TAC subtends a larger angle in the c.m. frame than in the lab frame. A numerical calculation in the same style as the above Compton calculation was carried out for this study.

3 Results

The material in the beam was inventoried in two ways. Eric Anciant and Claude Marchand wrote a GEANT Monte Carlo description of the beamline which was valid for the g6a run. Positions and thicknesses of materials were extracted from those files. It turned out that many of these numbers were obsolete and not valid for the g2, g1, and g3 runs in October 1999. With the help of Arne Freyberger we found an improved set of numbers based on drawings made specifically for that beam period. These drawings, one for the target area and one for the downstream area, are dated Oct 29, 1999. The difference in the final results between the numbers obtained from the Monte Carlo and the numbers obtained from the drawings was negligibly small, even though the positions of some of the materials was different by on the order of a meter.

Another of Arne's actions was to make a measurement of the actual thickness of the Pair Spectrometer converters. For the fall '99 run period we used the "2%" converter, but it turned out to be only a 1.8% converter. He found that they are made of aluminum and he determined that their thicknesses were

Nominal R.L.	Thickness Measured	Actual R.L.
"1%"	0.035 mil = .889 mm	1.0 %
"2%"	0.063 mil = 1.60 mm	1.8 %

TABLE 1

We assume that all normalization runs were taken with the Pair Spectrometer magnet turned ON, and that in all cases the Pair COUNTER was moved out of the beam. Recall that the Pair Counter was used only as a moving target for measuring the beam profile during the runs. If any normalization runs where taken under other conditions, such as the PS turned off or the PC still moving through the beam, then we would have to modify the calculations given here.

The blocks of the TAC have front faces which are 10 cm square, such that the group of 4 blocks forms a structure which is 20 cm square. A 10 cm transverse radius was used to estimate the amount of small-angle Compton scattering which hit the TAC.

One can wonder whether the physics target itself is a source of photon attenuation for the purposes of this calculation. We are interested in the loss of photons between the target and the TAC, but some photons produce pairs in the physics target itself and therefore cannot produce a physics event. We include this effect by computing the attenuation of photons in one half of the actual target length. That is, assume that any converting photons will on average be removed half way through the target.

We considered what would happen if the PS magnet was not energized enough to sweep all electrons out of the way. Then for high enough photon energy there would be a well-defined fraction of all pairs with enough "stiffness" to hit the TAC. Checking through the on-line database we found the following list of PS currents and their associated beam energies. Scanning over many runs lead us to believe we spotted all the relevant cases, although it is always possible that we missed a setting here or there.

Run Number	Date	Beam (MeV)	PS current I (Amps)	Run Period
11468	05-13-98	2534.3	617	g1a
11887	05-31-98	2486.8	605	g1a
13292	08-04-98	1836.5	440	g1b
12345	06-17-98	4114.15	995	g6a
19141	07-14-99	5498.31	995	g6b
19659	08-04-99	5498.31	1095	g6b
19990	08-18-99	2478.68	598	g2
20187	08-25-99	2478.68	603	g2
20606	09-22-99	3115.09	759	g2
21214	10-20-99	3115.08	759	g1c
21497	11-02-99	2897.40	706	g1c
21912	11-17-99	2445.06	588	g1c
22051	12-01-99	1645.03	399	g3
22372	12-15-99	1645.03	395	g3

TABLE 2

The magnetic field in the PS is given by

$$B(Tesla) = (I(Amps)/6) * 0.0034 - (I(Amps)/6)^2 * 0.0000017 \qquad (7)$$

The formula was quoted by Arne Freyberger, who keeps all such information about the beamline instrumentation; the division by 6 comes from the fact that the PS magnet has six coils feed in parallel. The result is that for all run conditions listed in Table 2, NO electrons should ever have hit the TAC. In short, the PS current was always ample to prevent any confounding hits due to pair-produced electrons.

The complete list of materials and attenuation in each material is given in the Appendix. Here we give the final results in the form of Table 3.

The final results for the runs periods studied are:

Run Period	CLAS Target	Photon Attenuation	Attenuation Slope
g1(abc)/g6b	18cm LH2	3.9%	0.0 %/GeV
g2	10cm LD2	3.6%	0.0 %/GeV
g3	18cm L3He	4.4%	0.0 %/GeV
g3	18cm L4He	4.1%	0.0 %/GeV
g6a	18cm L4He	7.6%	0.0 %/GeV
g6a (hack)	18cm LH2	3.8%	3.2 %/GeV

TABLE 3

The estimated uncertainty on each of these attenuation factors is $\pm 0.2\%$. This uncertainty is based on our confidence of how much material was in the beam line at various locations. We have not verified whether the g1a/b run periods used the thinner or the thicker PS converter. The thicker value used in g1c is assumed here.

4 Discussion

We found that the energy dependence due to Compton scattering is negligibly small. The calculation was checked by varying the effective size of the TAC, and by temporarily hacking the Klein-Nishina cross section to make sure the integrals were behaving correctly. The attenuation slope is probably negligible for our purposes. This means we have an essentially energy independent attenuation correction. The only variation comes from the target material used.

Next we note that the effect of positron annihilation is also small. It ends up having no significant effect on the result, i.e. it does not introduce a slope in the attenuation. For example, for a 2 GeV positron the center-of-mass cross section for annihilation is about 1 $mb/d(cos(\theta))$ at $cos(\theta)$ of 0.5. In a 1 inch block of beryllium this size of cross section results in, after suitable averaging over all photon angles and all positron energies, the annihilation of 0.2% of the positrons. This is just not enough to result in a significant change in the attenuation as a function of initial photon energy.

For the g6a run we find 7.6% attenuation with no energy-dependent slope. This large attenauation is due to the "1 inch" beryllium converter (actually 1.03" = 2.62 cm) for the PS used during that run. These results are not in good agreement with the results obtained by Eric Anciant, shown in Figure 5.11 of his thesis. He obtained an attenuation of 4.0% at 3.5 GeV for the g6a run. There is a puzzle, however, because he also obtained an attenuation slope of 3.5%/GeV. There is no explanation of this effect in the thesis, but it is simply given as the result of the simulation. It is not clear to us how that could be right. As we have shown, the effect of small-angle Compton scattering and of positron annihilation are much too small. There is simply no physical mechanism that will give such a large slope at the energies calculated. It is not a matter of having more or less stuff in the beam.

One possible source of the discrepancy would be an small error in the GEANT simulation presented in Eric's thesis. We find that if the PS current were erroneously set to 350 amps instead of 995 Amps, then our results for g6a would nearly match those quoted by Eric: 3.8% attenuation at 3.5 GeV and a slope of 3.2%/GeV. This is the last line given in Table 3 labeled "g6c (hack)". The slope comes about because the PS magnet is modeled incorrectly, and some of the pairs can hit the TAC. So far we have no way to tell whether he made such an error: the PS code from his simulation is not in CVS, even though all the other parts are there!

5 Conclusions

Photon attenuation for the CLAS beam between the target and the TAC was computed for the Real Photon data sets and given in Table 3. The factors are around 4%, depending on the target, with an estimated uncertainty of $\pm 0.2\%$. We can use these factors to scale up the photon flux in an energy-independent way. The energy-dependent slopes were so small as to be within the overall estimated uncertainty of the correction factors. Since the attenuation factors are small and quite well determined, they are probably completely satisfactory for use in normalizing the CLAS photoproduction measurements.

References

[1] Emilio Segre, "Nuclei and Particles, 2nd Ed", Benjamin/Cummings, 1977.

[2] Particle Data Group, European Journal of Phyics 15, 1 (2000).

[3] M. Peskin and D. Schroeder "Quantum Field Theory", Addison Wesley, 1995.

[4] A. Melissinos, "Experiments in Modern Physics", Academic Press, 1966.

6 Appendix

Sample output of the complete calculations. One set is for the g1c period and one set if for g3 with a helium-4 target. The target materials where slightly different for these two sets of runs. The “zero” of position is taken to be the CLAS target center. The list of materials in the beam line can be read off from top to bottom for each set. Downstream of the PS one sees listed the Air, the PC, the TAC, and the Faraday Cup. These items are on the list for completeness but do not contribute to photon attenuation.

It turned out that there was no attenuation slope, but the outputs still are given for several photon energies (500, 1000, 2000, 3000, 4000, 5000, 5500 MeV). For a fixed PS current, when the given photon is high enough then some photons hit the TAC, as can be seen below. However, in CLAS runs the PS current was always reasonably matched to the maximum photon energy during a run period.

For the g1 periods (g1c in particular) with an 18cm liquid hydrogen target we have:

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                  Photon Attenuation Between the CLAS target and the TAC

Z position   of TAC (cm) = 2660.
Lateral size of TAC (cm) =  10.0
Z position of   PS  (cm) = 2210.
PS Current        (Amps) =  588.
B field in PS    (Tesla) = 0.317
Length of magnet    (cm) =   89.


----------------------------------------------------------------------------------------------------
                         Photon energy  =       500. MeV
                         Fraction of pairs hitting TAC =  0.00
```

Material	Atomic Number	MolecWt (gm/cm3)	Position (cm)	Length (cm)	Density (gm/cm3)	Thickness (gm/cm2)	Rad.Len (gm/cm2)	Conv.Len (gm/cm2)	Percent Lost	Net Loss
g1c/g6b LH2 Tgt	1.	1.00	0.00	9.00E+00	7.08E-02	6.37E-01	62.55	80.42	0.79	0.79
Kapton Tgt Wdw	6.	12.00	9.00	1.27E-02	1.42E+00	1.80E-02	42.66	54.85	0.03	0.82
Superinsulation	6.	12.00	9.20	5.60E-03	1.42E+00	7.95E-03	42.66	54.85	0.01	0.84
Kapton Vac Wdw	6.	12.00	121.70	7.00E-03	1.42E+00	9.94E-03	42.66	54.85	0.02	0.85
Kapton Bag Wdw	6.	12.00	121.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	0.87
Helium	2.	4.00	972.00	1.70E+03	1.79E-04	3.04E-01	94.26	121.19	0.25	1.11
Kapton Bag Wdw	6.	12.00	1821.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	1.13
Air	7.	14.00	2106.00	3.88E+02	1.25E-03	4.85E-01	37.97	48.82	0.98	2.10
PS Alum Conv.	13.	26.98	2210.00	2.08E-01	2.70E+00	5.62E-01	24.01	30.87	1.79	3.86
Air	7.	14.00	2435.00	0.00E+00	0.00E+00	0.00E+00	37.97	48.82	0.00	3.86
PC	6.	12.00	2515.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.86
TAC	6.	12.00	2660.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.86
FC	6.	12.00	2854.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.86

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----------------------------------------------------------------------------------------------------
                         Photon energy  =      1000. MeV
                         Fraction of pairs hitting TAC =  0.00
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Material	Atomic Number	MolecWt (gm/cm3)	Position (cm)	Length (cm)	Density (gm/cm3)	Thickness (gm/cm2)	Rad.Len (gm/cm2)	Conv.Len (gm/cm2)	Percent Lost	Net Loss
g1c/g6b LH2 Tgt	1.	1.00	0.00	9.00E+00	7.08E-02	6.37E-01	62.55	80.42	0.79	0.79
Kapton Tgt Wdw	6.	12.00	9.00	1.27E-02	1.42E+00	1.80E-02	42.66	54.85	0.03	0.82
Superinsulation	6.	12.00	9.20	5.60E-03	1.42E+00	7.95E-03	42.66	54.85	0.01	0.84

Kapton Vac Wdw	6.	12.00	121.70	7.00E-03	1.42E+00	9.94E-03	42.66	54.85	0.02	0.85
Kapton Bag Wdw	6.	12.00	121.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	0.87
Helium	2.	4.00	972.00	1.70E+03	1.79E-04	3.04E-01	94.26	121.19	0.25	1.11
Kapton Bag Wdw	6.	12.00	1821.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	1.13
Air	7.	14.00	2106.00	3.88E+02	1.25E-03	4.85E-01	37.97	48.82	0.99	2.10
PS Alum Conv.	13.	26.98	2210.00	2.08E-01	2.70E+00	5.62E-01	24.01	30.87	1.80	3.86
Air	7.	14.00	2435.00	0.00E+00	0.00E+00	0.00E+00	37.97	48.82	0.00	3.86
PC	6.	12.00	2515.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.86
TAC	6.	12.00	2660.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.86
FC	6.	12.00	2854.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.86

Average photon loss across energies = 3.9 %
Slope of photon loss across energies = 0.0 %/GeV

Photon energy = 2000. MeV
Fraction of pairs hitting TAC = 0.00

Material	Atomic Number	MolecWt (gm/cm3)	Position (cm)	Length (cm)	Density (gm/cm3)	Thickness (gm/cm2)	Rad.Len (gm/cm2)	Conv.Len (gm/cm2)	Percent Lost	Net Loss
g1c/g6b LH2 Tgt	1.	1.00	0.00	9.00E+00	7.08E-02	6.37E-01	62.55	80.42	0.79	0.79
Kapton Tgt Wdw	6.	12.00	9.00	1.27E-02	1.42E+00	1.80E-02	42.66	54.85	0.03	0.82
Superinsulation	6.	12.00	9.20	5.60E-03	1.42E+00	7.95E-03	42.66	54.85	0.01	0.84
Kapton Vac Wdw	6.	12.00	121.70	7.00E-03	1.42E+00	9.94E-03	42.66	54.85	0.02	0.85
Kapton Bag Wdw	6.	12.00	121.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	0.87
Helium	2.	4.00	972.00	1.70E+03	1.79E-04	3.04E-01	94.26	121.19	0.25	1.11
Kapton Bag Wdw	6.	12.00	1821.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	1.13
Air	7.	14.00	2106.00	3.88E+02	1.25E-03	4.85E-01	37.97	48.82	0.99	2.10
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Air	7.	14.00	2435.00	0.00E+00	0.00E+00	0.00E+00	37.97	48.82	0.00	3.86
PC	6.	12.00	2515.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.86
TAC	6.	12.00	2660.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.86
FC	6.	12.00	2854.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.86

Average photon loss across energies = 3.9 %
Slope of photon loss across energies = 0.0 %/GeV

Photon energy = 3000. MeV
Fraction of pairs hitting TAC = 0.00

Material	Atomic Number	MolecWt (gm/cm3)	Position (cm)	Length (cm)	Density (gm/cm3)	Thickness (gm/cm2)	Rad.Len (gm/cm2)	Conv.Len (gm/cm2)	Percent Lost	Net Loss
g1c/g6b LH2 Tgt	1.	1.00	0.00	9.00E+00	7.08E-02	6.37E-01	62.55	80.42	0.79	0.79
Kapton Tgt Wdw	6.	12.00	9.00	1.27E-02	1.42E+00	1.80E-02	42.66	54.85	0.03	0.82
Superinsulation	6.	12.00	9.20	5.60E-03	1.42E+00	7.95E-03	42.66	54.85	0.01	0.84
Kapton Vac Wdw	6.	12.00	121.70	7.00E-03	1.42E+00	9.94E-03	42.66	54.85	0.02	0.85
Kapton Bag Wdw	6.	12.00	121.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	0.87
Helium	2.	4.00	972.00	1.70E+03	1.79E-04	3.04E-01	94.26	121.19	0.25	1.11
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Air	7.	14.00	2106.00	3.88E+02	1.25E-03	4.85E-01	37.97	48.82	0.99	2.10
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Air	7.	14.00	2435.00	0.00E+00	0.00E+00	0.00E+00	37.97	48.82	0.00	3.86
PC	6.	12.00	2515.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.86
TAC	6.	12.00	2660.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.86
FC	6.	12.00	2854.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.86

Average photon loss across energies = 3.9 %
Slope of photon loss across energies = 0.0 %/GeV

Photon energy = 4000. MeV

Fraction of pairs hitting TAC = 0.00

Material	Atomic Number	MolecWt (gm/cm3)	Position (cm)	Length (cm)	Density (gm/cm3)	Thickness (gm/cm2)	Rad.Len (gm/cm2)	Conv.Len (gm/cm2)	Percent Lost	Net Loss
g1c/g6b LH2 Tgt	1.	1.00	0.00	9.00E+00	7.08E-02	6.37E-01	62.55	80.42	0.79	0.79
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Helium	2.	4.00	972.00	1.70E+03	1.79E-04	3.04E-01	94.26	121.19	0.25	1.11
Kapton Bag Wdw	6.	12.00	1821.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	1.13
Air	7.	14.00	2106.00	3.88E+02	1.25E-03	4.85E-01	37.97	48.82	0.99	2.10
PS Alum Conv.	13.	26.98	2210.00	2.08E-01	2.70E+00	5.62E-01	24.01	30.87	1.80	3.87
Air	7.	14.00	2435.00	0.00E+00	0.00E+00	0.00E+00	37.97	48.82	0.00	3.87
PC	6.	12.00	2515.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.87
TAC	6.	12.00	2660.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.87
FC	6.	12.00	2854.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.87

Average photon loss across energies = 3.9 %
Slope of photon loss across energies = 0.0 %/GeV

Photon energy = 5000. MeV
Fraction of pairs hitting TAC = 0.32

Material	Atomic Number	MolecWt (gm/cm3)	Position (cm)	Length (cm)	Density (gm/cm3)	Thickness (gm/cm2)	Rad.Len (gm/cm2)	Conv.Len (gm/cm2)	Percent Lost	Net Loss
g1c/g6b LH2 Tgt	1.	1.00	0.00	9.00E+00	7.08E-02	6.37E-01	62.55	80.42	0.54	0.54
Kapton Tgt Wdw	6.	12.00	9.00	1.27E-02	1.42E+00	1.80E-02	42.66	54.85	0.02	0.56
Superinsulation	6.	12.00	9.20	5.60E-03	1.42E+00	7.95E-03	42.66	54.85	0.01	0.57
Kapton Vac Wdw	6.	12.00	121.70	7.00E-03	1.42E+00	9.94E-03	42.66	54.85	0.01	0.58
Kapton Bag Wdw	6.	12.00	121.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	0.59
Helium	2.	4.00	972.00	1.70E+03	1.79E-04	3.04E-01	94.26	121.19	0.17	0.76
Kapton Bag Wdw	6.	12.00	1821.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	0.77
Air	7.	14.00	2106.00	3.88E+02	1.25E-03	4.85E-01	37.97	48.82	0.67	1.44
PS Alum Conv.	13.	26.98	2210.00	2.08E-01	2.70E+00	5.62E-01	24.01	30.87	1.23	2.65
Air	7.	14.00	2435.00	0.00E+00	0.00E+00	0.00E+00	37.97	48.82	0.00	2.65
PC	6.	12.00	2515.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	2.65
TAC	6.	12.00	2660.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	2.65
FC	6.	12.00	2854.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	2.65

Average photon loss across energies = 3.3 %
Slope of photon loss across energies = 1.2 %/GeV

Photon energy = 5500. MeV
Fraction of pairs hitting TAC = 0.47

Material	Atomic Number	MolecWt (gm/cm3)	Position (cm)	Length (cm)	Density (gm/cm3)	Thickness (gm/cm2)	Rad.Len (gm/cm2)	Conv.Len (gm/cm2)	Percent Lost	Net Loss
g1c/g6b LH2 Tgt	1.	1.00	0.00	9.00E+00	7.08E-02	6.37E-01	62.55	80.42	0.42	0.42
Kapton Tgt Wdw	6.	12.00	9.00	1.27E-02	1.42E+00	1.80E-02	42.66	54.85	0.02	0.44
Superinsulation	6.	12.00	9.20	5.60E-03	1.42E+00	7.95E-03	42.66	54.85	0.01	0.44
Kapton Vac Wdw	6.	12.00	121.70	7.00E-03	1.42E+00	9.94E-03	42.66	54.85	0.01	0.45
Kapton Bag Wdw	6.	12.00	121.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	0.46
Helium	2.	4.00	972.00	1.70E+03	1.79E-04	3.04E-01	94.26	121.19	0.13	0.59
Kapton Bag Wdw	6.	12.00	1821.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	0.60
Air	7.	14.00	2106.00	3.88E+02	1.25E-03	4.85E-01	37.97	48.82	0.52	1.12
PS Alum Conv.	13.	26.98	2210.00	2.08E-01	2.70E+00	5.62E-01	24.01	30.87	0.95	2.06
Air	7.	14.00	2435.00	0.00E+00	0.00E+00	0.00E+00	37.97	48.82	0.00	2.06
PC	6.	12.00	2515.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	2.06
TAC	6.	12.00	2660.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	2.06
FC	6.	12.00	2854.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	2.06

```
Average  photon loss across energies =    2.4 %
Slope of photon loss across energies =    1.2 %/GeV

Average across ALL photon energies:

Average  photon loss across energies =    3.4 %
Slope of photon loss across energies =    0.4 %/GeV
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For the g3 period with an 18cm liquid 4-Helium target we have:

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                  Photon Attenuation Between the CLAS target and the TAC

Z position   of TAC (cm) = 2660.
Lateral size of TAC (cm) =  10.0
Z position of   PS  (cm) = 2210.
PS Current        (Amps) =  399.
B field in PS    (Tesla) = 0.219
Length of magnet    (cm) =   89.


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                         Photon energy  =       500. MeV
                         Fraction of pairs hitting TAC =  0.00
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Material	Atomic Number	MolecWt (gm/cm3)	Position (cm)	Length (cm)	Density (gm/cm3)	Thickness (gm/cm2)	Rad.Len (gm/cm2)	Conv.Len (gm/cm2)	Percent Lost	Net Loss
g3 L4He Target	2.	4.00	0.00	9.00E+00	1.25E-01	1.12E+00	94.26	121.19	0.92	0.92
Kapton Tgt Wdw	6.	12.00	9.00	2.41E-02	1.42E+00	3.43E-02	42.66	54.85	0.06	0.99
Superinsulation	6.	12.00	9.20	5.60E-03	1.42E+00	7.95E-03	42.66	54.85	0.01	1.00
Heat Shield	6.	12.00	13.40	2.00E-02	1.42E+00	2.84E-02	42.66	54.85	0.05	1.05
Kapton Vac Wdw	6.	12.00	121.70	7.00E-03	1.42E+00	9.94E-03	42.66	54.85	0.02	1.07
Kapton Bag Wdw	6.	12.00	121.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	1.08
Helium	2.	4.00	972.00	1.70E+03	1.79E-04	3.04E-01	94.26	121.19	0.25	1.33
Kapton Bag Wdw	6.	12.00	1821.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	1.34
Air	7.	14.00	2106.00	3.88E+02	1.25E-03	4.85E-01	37.97	48.82	0.98	2.31
PS Alum Conv.	13.	26.98	2210.00	2.08E-01	2.70E+00	5.62E-01	24.01	30.87	1.79	4.07
Air	7.	14.00	2435.00	0.00E+00	0.00E+00	0.00E+00	37.97	48.82	0.00	4.07
PC	6.	12.00	2515.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	4.07
TAC	6.	12.00	2660.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	4.07
FC	6.	12.00	2854.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	4.07

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                         Photon energy  =      1000. MeV
                         Fraction of pairs hitting TAC =  0.00
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Material	Atomic Number	MolecWt (gm/cm3)	Position (cm)	Length (cm)	Density (gm/cm3)	Thickness (gm/cm2)	Rad.Len (gm/cm2)	Conv.Len (gm/cm2)	Percent Lost	Net Loss
g3 L4He Target	2.	4.00	0.00	9.00E+00	1.25E-01	1.12E+00	94.26	121.19	0.92	0.92
Kapton Tgt Wdw	6.	12.00	9.00	2.41E-02	1.42E+00	3.43E-02	42.66	54.85	0.06	0.99
Superinsulation	6.	12.00	9.20	5.60E-03	1.42E+00	7.95E-03	42.66	54.85	0.01	1.00
Heat Shield	6.	12.00	13.40	2.00E-02	1.42E+00	2.84E-02	42.66	54.85	0.05	1.05
Kapton Vac Wdw	6.	12.00	121.70	7.00E-03	1.42E+00	9.94E-03	42.66	54.85	0.02	1.07
Kapton Bag Wdw	6.	12.00	121.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	1.08
Helium	2.	4.00	972.00	1.70E+03	1.79E-04	3.04E-01	94.26	121.19	0.25	1.33
Kapton Bag Wdw	6.	12.00	1821.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	1.34
Air	7.	14.00	2106.00	3.88E+02	1.25E-03	4.85E-01	37.97	48.82	0.99	2.31
PS Alum Conv.	13.	26.98	2210.00	2.08E-01	2.70E+00	5.62E-01	24.01	30.87	1.80	4.07
Air	7.	14.00	2435.00	0.00E+00	0.00E+00	0.00E+00	37.97	48.82	0.00	4.07
PC	6.	12.00	2515.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	4.07
TAC	6.	12.00	2660.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	4.07
FC	6.	12.00	2854.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	4.07

Photon energy = 2000. MeV
Fraction of pairs hitting TAC = 0.00

Material	Atomic Number	MolecWt (gm/cm3)	Position (cm)	Length (cm)	Density (gm/cm3)	Thickness (gm/cm2)	Rad.Len (gm/cm2)	Conv.Len (gm/cm2)	Percent Lost	Net Loss
g3 L4He Target	2.	4.00	0.00	9.00E+00	1.25E-01	1.12E+00	94.26	121.19	0.92	0.92
Kapton Tgt Wdw	6.	12.00	9.00	2.41E-02	1.42E+00	3.43E-02	42.66	54.85	0.06	0.99
Superinsulation	6.	12.00	9.20	5.60E-03	1.42E+00	7.95E-03	42.66	54.85	0.01	1.00
Heat Shield	6.	12.00	13.40	2.00E-02	1.42E+00	2.84E-02	42.66	54.85	0.05	1.05
Kapton Vac Wdw	6.	12.00	121.70	7.00E-03	1.42E+00	9.94E-03	42.66	54.85	0.02	1.07
Kapton Bag Wdw	6.	12.00	121.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	1.08
Helium	2.	4.00	972.00	1.70E+03	1.79E-04	3.04E-01	94.26	121.19	0.25	1.33
Kapton Bag Wdw	6.	12.00	1821.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	1.34
Air	7.	14.00	2106.00	3.88E+02	1.25E-03	4.85E-01	37.97	48.82	0.99	2.32
PS Alum Conv.	13.	26.98	2210.00	2.08E-01	2.70E+00	5.62E-01	24.01	30.87	1.80	4.07
Air	7.	14.00	2435.00	0.00E+00	0.00E+00	0.00E+00	37.97	48.82	0.00	4.07
PC	6.	12.00	2515.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	4.07
TAC	6.	12.00	2660.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	4.07
FC	6.	12.00	2854.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	4.07

Photon energy = 3000. MeV
Fraction of pairs hitting TAC = 0.06

Material	Atomic Number	MolecWt (gm/cm3)	Position (cm)	Length (cm)	Density (gm/cm3)	Thickness (gm/cm2)	Rad.Len (gm/cm2)	Conv.Len (gm/cm2)	Percent Lost	Net Loss
g3 L4He Target	2.	4.00	0.00	9.00E+00	1.25E-01	1.12E+00	94.26	121.19	0.86	0.86
Kapton Tgt Wdw	6.	12.00	9.00	2.41E-02	1.42E+00	3.43E-02	42.66	54.85	0.06	0.92
Superinsulation	6.	12.00	9.20	5.60E-03	1.42E+00	7.95E-03	42.66	54.85	0.01	0.94
Heat Shield	6.	12.00	13.40	2.00E-02	1.42E+00	2.84E-02	42.66	54.85	0.05	0.98
Kapton Vac Wdw	6.	12.00	121.70	7.00E-03	1.42E+00	9.94E-03	42.66	54.85	0.02	1.00
Kapton Bag Wdw	6.	12.00	121.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	1.01
Helium	2.	4.00	972.00	1.70E+03	1.79E-04	3.04E-01	94.26	121.19	0.23	1.24
Kapton Bag Wdw	6.	12.00	1821.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	1.26
Air	7.	14.00	2106.00	3.88E+02	1.25E-03	4.85E-01	37.97	48.82	0.92	2.17
PS Alum Conv.	13.	26.98	2210.00	2.08E-01	2.70E+00	5.62E-01	24.01	30.87	1.68	3.82
Air	7.	14.00	2435.00	0.00E+00	0.00E+00	0.00E+00	37.97	48.82	0.00	3.82
PC	6.	12.00	2515.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.82
TAC	6.	12.00	2660.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.82
FC	6.	12.00	2854.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	3.82

Photon energy = 4000. MeV
Fraction of pairs hitting TAC = 0.55

Material	Atomic Number	MolecWt (gm/cm3)	Position (cm)	Length (cm)	Density (gm/cm3)	Thickness (gm/cm2)	Rad.Len (gm/cm2)	Conv.Len (gm/cm2)	Percent Lost	Net Loss
g3 L4He Target	2.	4.00	0.00	9.00E+00	1.25E-01	1.12E+00	94.26	121.19	0.42	0.42
Kapton Tgt Wdw	6.	12.00	9.00	2.41E-02	1.42E+00	3.43E-02	42.66	54.85	0.03	0.44
Superinsulation	6.	12.00	9.20	5.60E-03	1.42E+00	7.95E-03	42.66	54.85	0.01	0.45
Heat Shield	6.	12.00	13.40	2.00E-02	1.42E+00	2.84E-02	42.66	54.85	0.02	0.47
Kapton Vac Wdw	6.	12.00	121.70	7.00E-03	1.42E+00	9.94E-03	42.66	54.85	0.01	0.48
Kapton Bag Wdw	6.	12.00	121.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	0.49
Helium	2.	4.00	972.00	1.70E+03	1.79E-04	3.04E-01	94.26	121.19	0.11	0.60
Kapton Bag Wdw	6.	12.00	1821.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.01	0.61
Air	7.	14.00	2106.00	3.88E+02	1.25E-03	4.85E-01	37.97	48.82	0.45	1.05
PS Alum Conv.	13.	26.98	2210.00	2.08E-01	2.70E+00	5.62E-01	24.01	30.87	0.81	1.85
Air	7.	14.00	2435.00	0.00E+00	0.00E+00	0.00E+00	37.97	48.82	0.00	1.85
PC	6.	12.00	2515.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	1.85
TAC	6.	12.00	2660.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	1.85
FC	6.	12.00	2854.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	1.85

Photon energy = 5000. MeV
Fraction of pairs hitting TAC = 0.84

Material	Atomic Number	MolecWt (gm/cm3)	Position (cm)	Length (cm)	Density (gm/cm3)	Thickness (gm/cm2)	Rad.Len (gm/cm2)	Conv.Len (gm/cm2)	Percent Lost	Net Loss
g3 L4He Target	2.	4.00	0.00	9.00E+00	1.25E-01	1.12E+00	94.26	121.19	0.15	0.15
Kapton Tgt Wdw	6.	12.00	9.00	2.41E-02	1.42E+00	3.43E-02	42.66	54.85	0.01	0.16
Superinsulation	6.	12.00	9.20	5.60E-03	1.42E+00	7.95E-03	42.66	54.85	0.00	0.16
Heat Shield	6.	12.00	13.40	2.00E-02	1.42E+00	2.84E-02	42.66	54.85	0.01	0.17
Kapton Vac Wdw	6.	12.00	121.70	7.00E-03	1.42E+00	9.94E-03	42.66	54.85	0.00	0.17
Kapton Bag Wdw	6.	12.00	121.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.00	0.17
Helium	2.	4.00	972.00	1.70E+03	1.79E-04	3.04E-01	94.26	121.19	0.04	0.21
Kapton Bag Wdw	6.	12.00	1821.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.00	0.22
Air	7.	14.00	2106.00	3.88E+02	1.25E-03	4.85E-01	37.97	48.82	0.16	0.37
PS Alum Conv.	13.	26.98	2210.00	2.08E-01	2.70E+00	5.62E-01	24.01	30.87	0.29	0.66
Air	7.	14.00	2435.00	0.00E+00	0.00E+00	0.00E+00	37.97	48.82	0.00	0.66
PC	6.	12.00	2515.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	0.66
TAC	6.	12.00	2660.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	0.66
FC	6.	12.00	2854.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	0.66

Photon energy = 5500. MeV
Fraction of pairs hitting TAC = 0.94

Material	Atomic Number	MolecWt (gm/cm3)	Position (cm)	Length (cm)	Density (gm/cm3)	Thickness (gm/cm2)	Rad.Len (gm/cm2)	Conv.Len (gm/cm2)	Percent Lost	Net Loss
g3 L4He Target	2.	4.00	0.00	9.00E+00	1.25E-01	1.12E+00	94.26	121.19	0.05	0.05
Kapton Tgt Wdw	6.	12.00	9.00	2.41E-02	1.42E+00	3.43E-02	42.66	54.85	0.00	0.05
Superinsulation	6.	12.00	9.20	5.60E-03	1.42E+00	7.95E-03	42.66	54.85	0.00	0.06
Heat Shield	6.	12.00	13.40	2.00E-02	1.42E+00	2.84E-02	42.66	54.85	0.00	0.06
Kapton Vac Wdw	6.	12.00	121.70	7.00E-03	1.42E+00	9.94E-03	42.66	54.85	0.00	0.06
Kapton Bag Wdw	6.	12.00	121.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.00	0.06
Helium	2.	4.00	972.00	1.70E+03	1.79E-04	3.04E-01	94.26	121.19	0.01	0.07
Kapton Bag Wdw	6.	12.00	1821.70	5.10E-03	1.42E+00	7.24E-03	42.66	54.85	0.00	0.07
Air	7.	14.00	2106.00	3.88E+02	1.25E-03	4.85E-01	37.97	48.82	0.05	0.13
PS Alum Conv.	13.	26.98	2210.00	2.08E-01	2.70E+00	5.62E-01	24.01	30.87	0.10	0.22
Air	7.	14.00	2435.00	0.00E+00	0.00E+00	0.00E+00	37.97	48.82	0.00	0.22
PC	6.	12.00	2515.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	0.22
TAC	6.	12.00	2660.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	0.22
FC	6.	12.00	2854.00	0.00E+00	0.00E+00	0.00E+00	42.66	54.85	0.00	0.22

Average across ALL photon energies:

Average photon loss across energies = 2.7 %
Slope of photon loss across energies = 0.8 %/GeV