Technical Note
radphi-1998-60

The Bremsstrahlung Beam Shape

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Abstract

During the April 1998 run with 4GeV photons, the Radphi experiment performed diagnostic studies of the photon beam that included scanning the target and a small scintillator simultaneously through the beam in the horizontal direction and recording the rates as a function of position. In this note these data are compared with expectations based upon the ideal bremsstrahlung angular distribution. An excellent agreement is obtained once the geometry and position of the target relative to the beam are properly taken into account. The implications of these data for an absolute normalisation of the photon flux using pairs measured downstream of the Radphi target are explored, and the sensitivity to deviations in beam position on the target is quantified. The proposal that the target be fitted with an aluminum collar to reduce this sensitivity is addressed.

One of the first exercises that were carried out with the Radphi apparatus when photon beams first appeared in Hall B during May 1997 was to measure the intensity profile of the beam. This measurement was performed by remotely translating the Radphi target platform in controlled steps and monitoring two detector scaler rates, which will be labelled scalers 1 and 2 for the purposes of this note.

1) A thin square of scintillator located next to the downstream face of the Radphi target was continuously counting the charged component in the photon beam entering the target. A part of this rate was from conversions inside the scintillator and a part from shower particles generated upstream.

2) Two segments of the recoil proton detector (RPD) subtending lab polar angles from 40^o to 60^o and from 75^o to 105^o (top) and 165^o to 195^o (bottom) in azimuth, respectively. This signal is the `OR` of two $E - \Delta E$ coincidences. It counts the rate of large-angle scattering in the target, what appears above some background coming from the beam halo.

The choice of top+bottom segments of the RPD for scaler #2 was made so that the polar scattering angle was more or less constant during a scan over the width of the target. It was discovered during that run that the RPD rate from the target was overwhelmed by the background, so that scaler #2 showed little variation as the target was scanned across the beam. This was subsequently understood in terms of the expected halo around an unshielded bremsstrahlung photon beam. For a quantitative description, see technical note *radphi-1998-10*. We were able, however to obtain a useful measurement of the photon beam profile in May 1997 from the scan data from scaler #1. Scans carried out both at 1.4GeV and 4.0GeV endpoint showed very good agreement with the expected bremsstrahlung cone profile convoluted with the shape of the target scintillator. These results were presented in technical note *radphi-1997-60*.

1 What is new in 1998?

During the March 1998 technical run, scans were taken again with these two scalers. These data are interesting for a couple of reasons. One is that the 1997 4.0GeV scan did show an extended tail on one side of the beam that was not expected for a symmetrical beam and detector system. This was thought to be a problem with beam stability during the scan. Now that considerable experience concerning beam delivery to Hall B has accumulated, we are hopeful that clean, symmetrical, stable beams will be the norm. If the beam is asymmetrical or wobbling on the time scale of a scan (minutes) then it should show up again as a departure from the expected bremsstrahlung shape. A second reason is to look again at scaler #2 to see to what extent the beam line shielding measures that have been implemented since 1997 have reduced backgrounds in the RPD to the point where the rate is dominantly coming from interactions in the target.

The changes to the beam line in 1998 involved (a) the installation of a 10cm lead wall upstream of the Radphi target, (b) the installation of a helium tube between the CLAS and Radphi targets, and (c) the addition of an anti-coincidence scintillator plane (UPV) just before the Radphi target. The results of a scan with a 4.0GeV endpoint photon beam are shown in Fig. 1.

This plot was prepared by Craig Steffen, who also provided the data. The open circles labelled "target counter rate" are from scaler #1. The crosses labelled "target rate" are from scaler #2 with one important change: the top+bottom RPD signals are vetoed by a UPV hit within a suitable coincidence timing window before being counted by scaler #2. This veto is also present in the Radphi physics trigger for 1998. During this scan it is apparent that the beam was several mm away from the nominal axis, and also that there is some misalignment between the target (as monitored by scaler #2) and the target scintillator. These offsets will be quantified below. The layout of the target and target counter, as described to me by Craig Steffen is shown in Fig. 2.

To predict the expected shape of the target counter scan (scaler #1), I compute the integral of the theoretical bremsstrahlung beam shape over the diamond-shaped region subtended by the scintillator in Fig. 2. I assume a radiator-target distance of 3970cm. The integral is normalised to unity over the entire plane. To compare with the scan, the integration was repeated at a discrete set of offsets from the nominal axis, and the results interpolated to form a smooth curve of integrated rate vs. offset. The results are shown

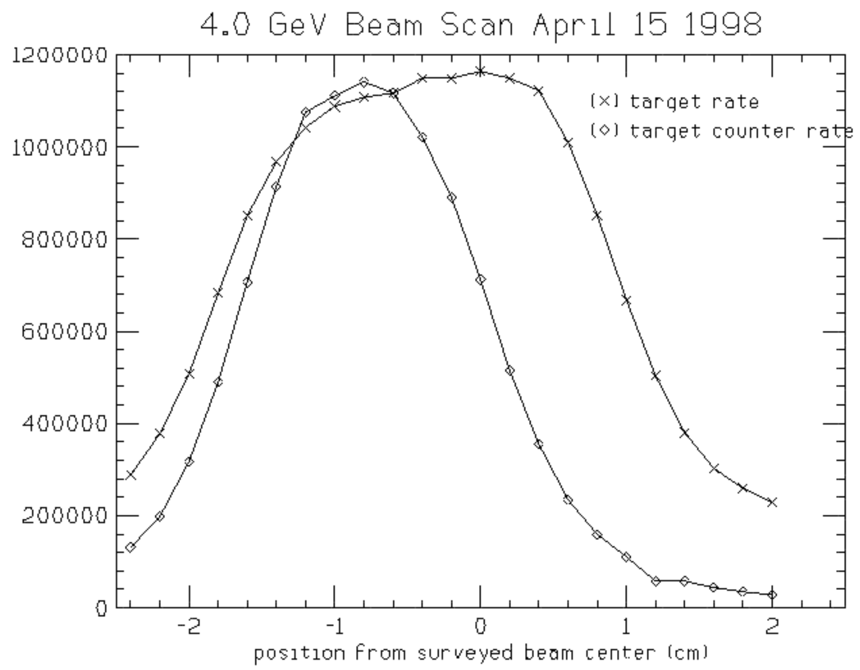

Figure 1: Open circles are the scan data from scaler #1, crosses are from scaler #2. Both data sets were taken during the same scan of the target across the beam. The horizontal origin is the nominal beam axis as defined by the survey crew. The vertical scale is arbitrary.

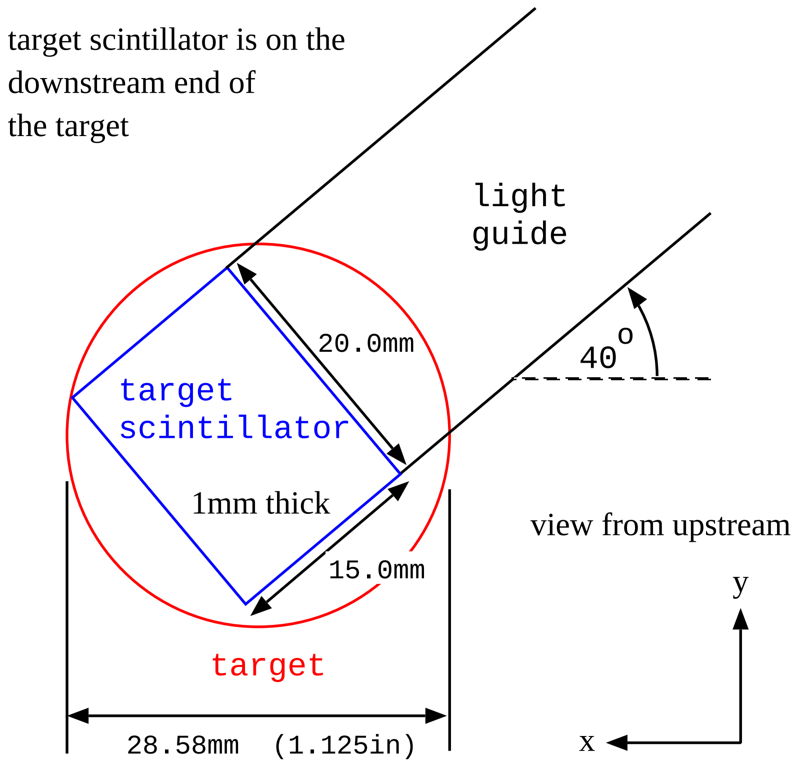

Figure 2: Geometry of the target region as viewed from upstream, including the target disk (red) and the target counter (blue). The target counter is not actually visible from upstream because it is located just downstream of the target.

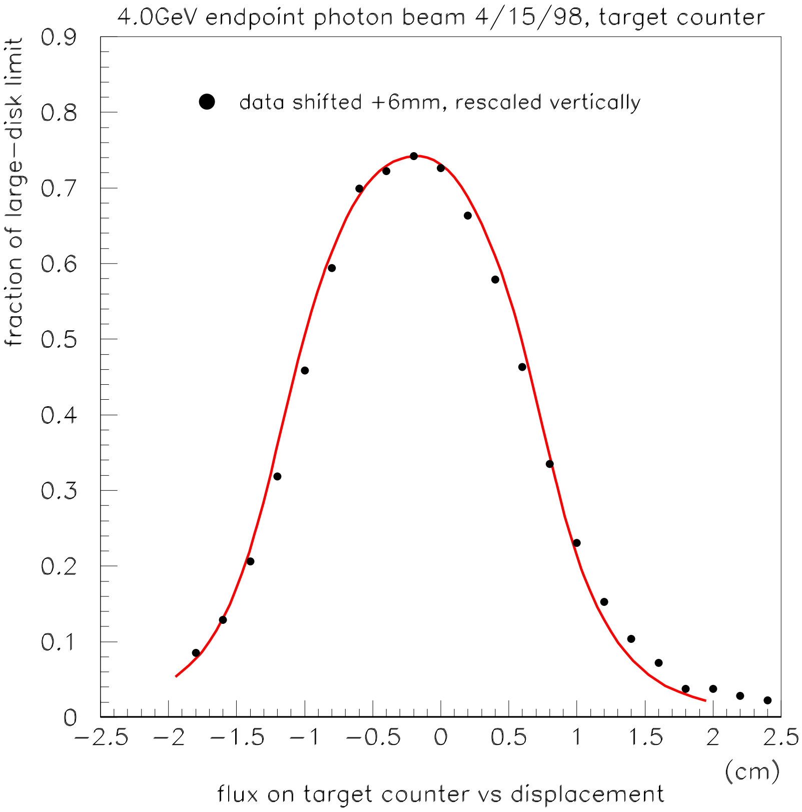

Figure 3: Red curve is the fraction of the total photon beam flux that passes through the active area of the target scintillator for a given displacement of the target from the beam, calculated assuming an ideal bremsstrahlung beam from a zero-emittance 4.0GeV electron beam and 3970cm distance from target to radiator. The points are the open circles from Fig. 1 shifted right by 5mm and rescaled vertically to the maximum of the calculated curve.

in Fig. 3. The data points are the same data as shown by the open circles in Fig. 1, shifted to the right by 5mm and rescaled vertically to the maximum of the calculated curve.

The data peak is somewhat more narrow than the calculation, which suggests that the vertical positioning may not be perfect. If the beam sweeps across the target scintillator above its mid-line it will narrow the profile, as the effective width of the scintillator narrows toward the top. The displacement between the peaks of the scalers #1 & #2 also suggests that beam scans across the target assembly above the mid-line. The best description of the data is obtained by scanning the scintillator with its centre 3mm below the level of the beam. These results are shown in Fig. 4. In this case, the horizontal offset applied to the data is reduced to 5mm. The shift of the calculated peak (red curve) from zero is due to the diagonal orientation of the scintillator and the vertical displacement of the beam. The dark rate of this counter is set to 2% of the peak value in Fig. 4. With these adjustments for vertical alignment and a small background, the agreement between data and expectation is excellent. The calculation assumes a zero-emittance electron beam.

Coming now to the scan in scaler #2, we can use the alignment information from the target counter scan to fix the calculation of the RPD rate. Putting in the 5mm horizontal and 3mm vertical displacement of the beam and counting simply the fraction of the photon beam intercepted by the target disk, one obtains the curve in Fig. 5. A uniform background of 14% of the peak rate was added to the calculation to obtain the red curve. This ratio peak:background = 7:1 was measured independently during the April run, with the

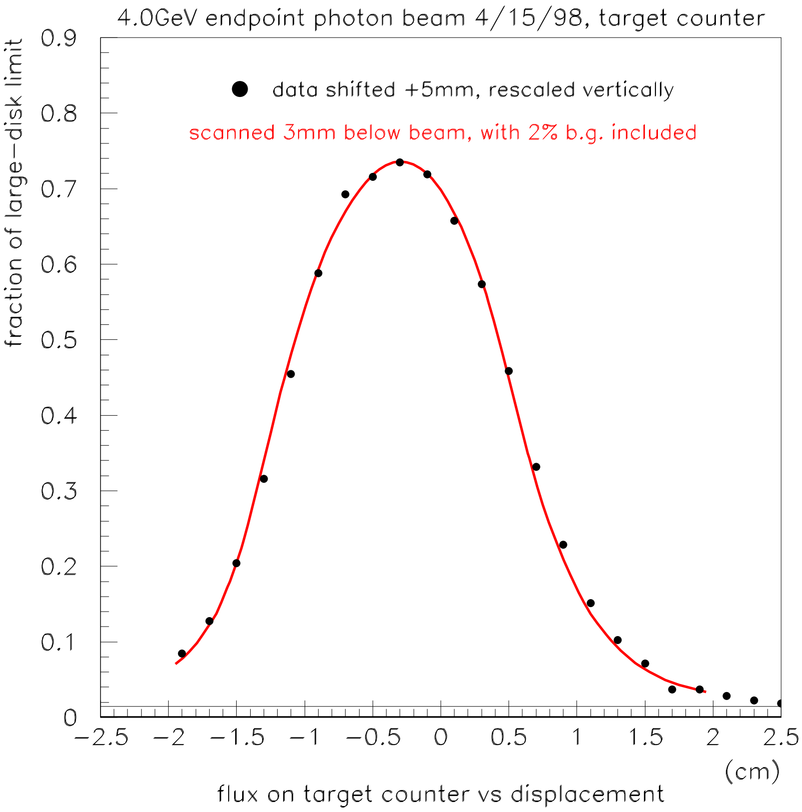

Figure 4: Same as Fig. 3 but with a vertical displacement of the beam with respect to the scan path of the target by 3mm, and the addition of a 2% uniform background shown by the black line.

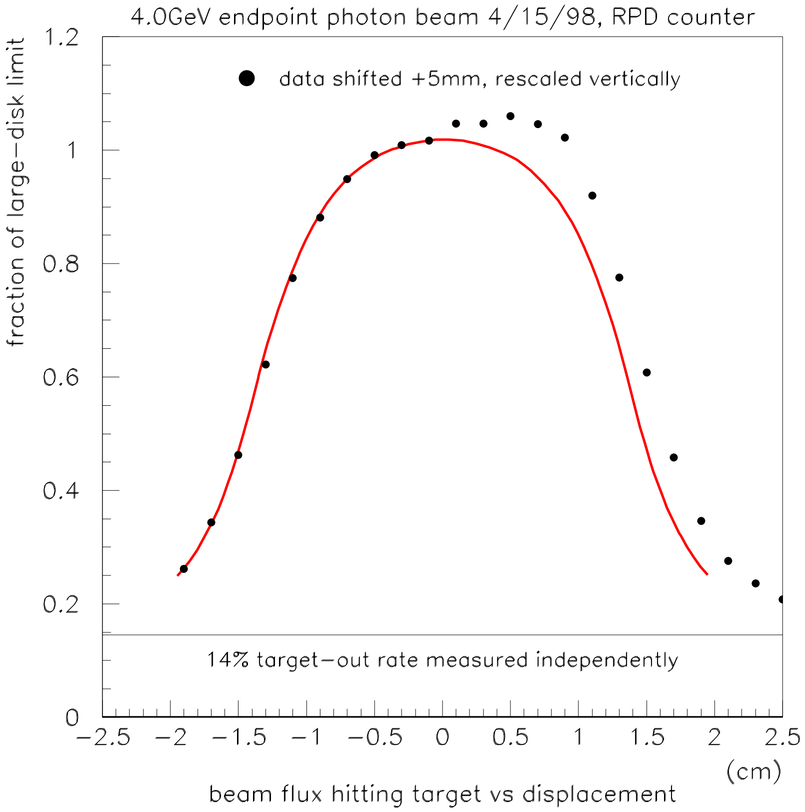

Figure 5: Red curve is the fraction of the total photon flux that falls inside the target disk as a function of displacement of the target from beam-center. The 3mm vertical displacement of the beam from the target scan locus has been included. The points are the crosses from Fig. 1 shifted right by 5mm and rescaled to the maximum of the curve. A uniform background equal to the target-out rate in the scaler #2 has been inserted under the red curve to facilitate direct comparison with the data.

target far out of the beam. The background comes from particles not originating in the target. The only adjustable parameter in this comparison is the vertical scale of the data points. The agreement is excellent on the left side of the peak, but something else is happening on the right side. It appears like an additional 10% or more of target on the +x side.

2 What is this structure in the target?

In principle any scan shape is possible just due to variations in the beam current and/or position during the scan. The scans with scalers #1 & #2 were done at the same time, which means that both should show similar humps if the beam current was changing. Fig. 4 shows that the beam was very stable during this scan. The simplest explanation is that there is some material in the target that has not been taken into account. The target scintillator (TAS) itself does contribute to the RPD rate, but it is only 0.2% radiation lengths (1mm of plastic) and has approximately the same extent as the target, so including it does not appreciably affect the shape of the calculated curve. Credit goes to Craig Steffen for suggesting that the light guide might be responsible. Craig's estimate for the light guide thickness is 2-3mm of plastic. Putting in a light guide 20mm wide connected to the TAS as shown in Fig. 2, I adjusted the thickness and compared

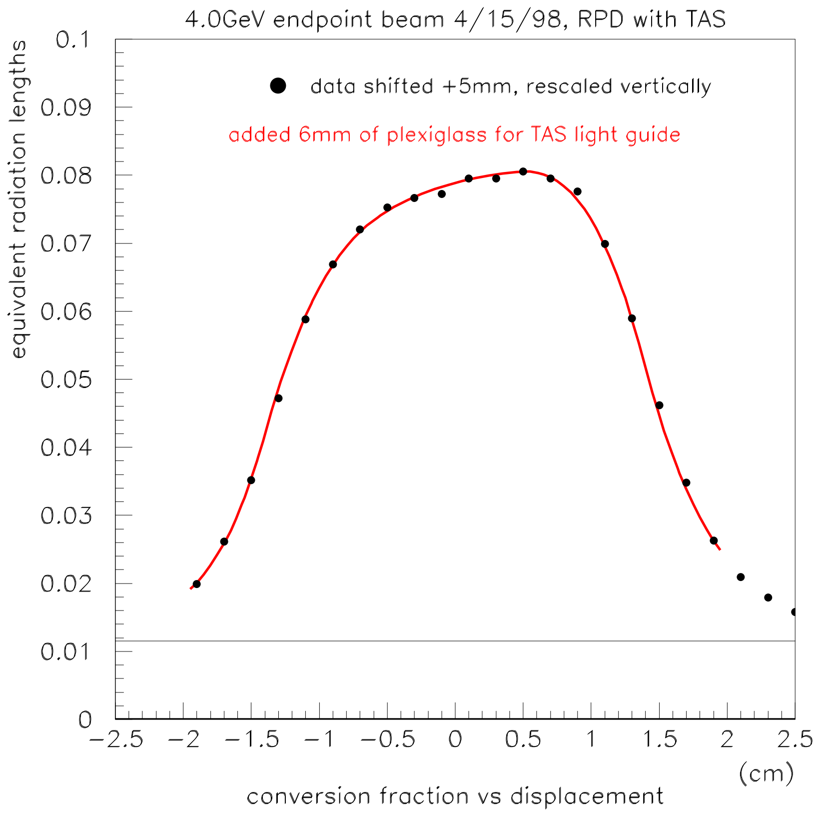

Figure 6: Same as Fig. 5 except that the calculation (red curve) includes the effect of the light guide attached to the target scintillator. The light guide is taken to be 6mm of plastic. The vertical scale now measures radiation lengths seen by the average photon in the beam in order to take into account the differing thicknesses of target and light guide.

the calculated curve with the scaler #2 scan data. Fig. 6 shows the result using 6mm of plexiglass for the light guide attached to a polystyrene scintillator 1mm thick. The agreement is excellent.

Note that there were only two adjustable parameters in producing the agreement in Fig. 6, the thickness of the TAS light guide and the vertical scaling of the data points. The vertical and horizontal displacement of the beam from the nominal origin was fixed from the target counter (scaler #1) scan data. The TAS light guide is not the whole story; there is probably extra material at the glue joint, and the wrapping material was not included explicitly. But the dominant effect is clearly due to the light guide, as evidenced by the good agreement in both position and shape shown in Fig. 6.

3 What are the consequences for beam normalisation?

For the purposes of the Radphi experiment, the detailed uniformity of the target is not an important issue. It does have an impact on the program, however, because of the effects it can have on the ability of the CLAS experiment to reliably monitor the absolute normalisation of the photon beam. During normal running, this monitoring involves the counting of pairs in the photon beam downstream of the Radphi target. The 7.2% rad.len. Radphi target provides more than enough pairs rate for this purpose. Their principal requirement is that the fraction of the beam that is converted in the Radphi target be stable at the level required for

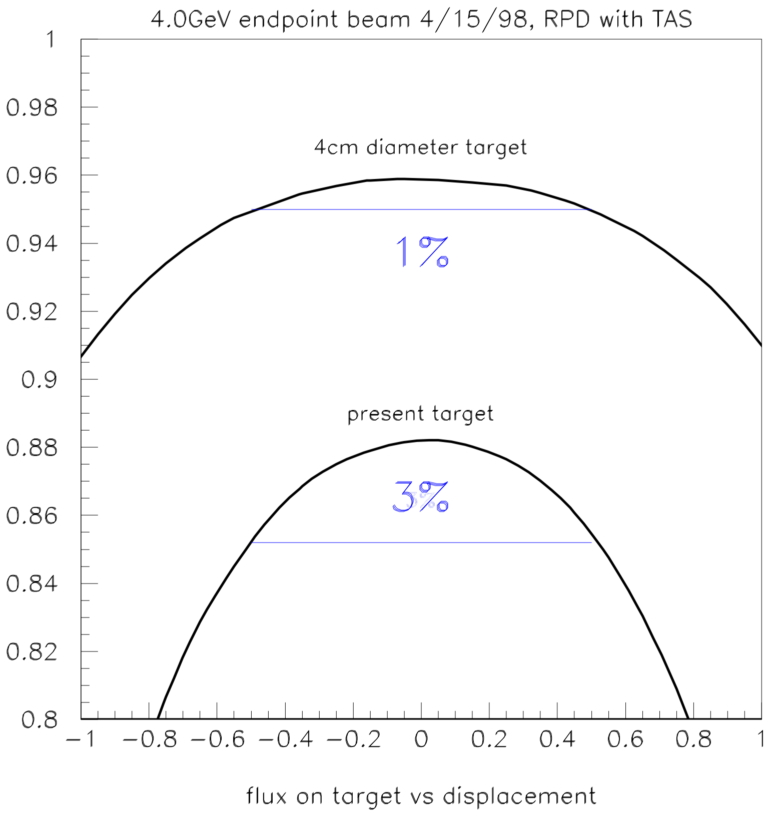

Figure 7: Curves showing the fraction of the total photon flux that passes through the present Radphi target (lower curve) and an extended target of 4cm diameter and same thickness (upper curve). The ±5mm limits for the beam offset in each case indicated by the horizontal lines show the percent variation in the conversion fraction for a a beam that wanders over a 1cm diameter zone at the center of the target.

their absolute normalisation. For the g6 running of 1998 the requirements are likely to be at the level of a few percent. In the future we can expect the tolerances to drop to the level of 1% or less for certain run periods. If we would like to retain the ability to run parasitically with CLAS then this is an issue we must be able to address quantitatively to their satisfaction.

The principal source of instability in the pair conversion fraction arises from drifts in beam position. Such drifts will occur at some level during any run, and the uniformity of the Radphi target must be sufficient to maintain the conversion fraction within given limits over a certain allowable range in photon beam position on target. The fraction of the photon beam intercepted by the present target disc as a function of beam displacement from target centre can be read off from Fig. 5. The same data is shown in Fig. 7 (lower curve) with the RPD background rate excluded. This shows that for wandering of the beam spot within the zone of diameter 1cm from the centre of the target one can expect a maximum variation of 3% in conversion fraction. Using ±5mm to bracket beam displacements is probably overly pessimistic but so far we have little information about the long-term stability of photon beam position at the back of Hall B. This suggests that if the experiment requires a 5% systematic uncertainty in the absolute beam monitor, nothing is required other than one centring of the photon beam on the Radphi target during setup, and a periodic scan of the photon beam to check for drifts and re-centre if necessary.

If a 3% normalisation systematic error is too large then the Radphi target size will need to be extended. An extension of this type has already been discussed in the form of an aluminum collar. A collar of the same

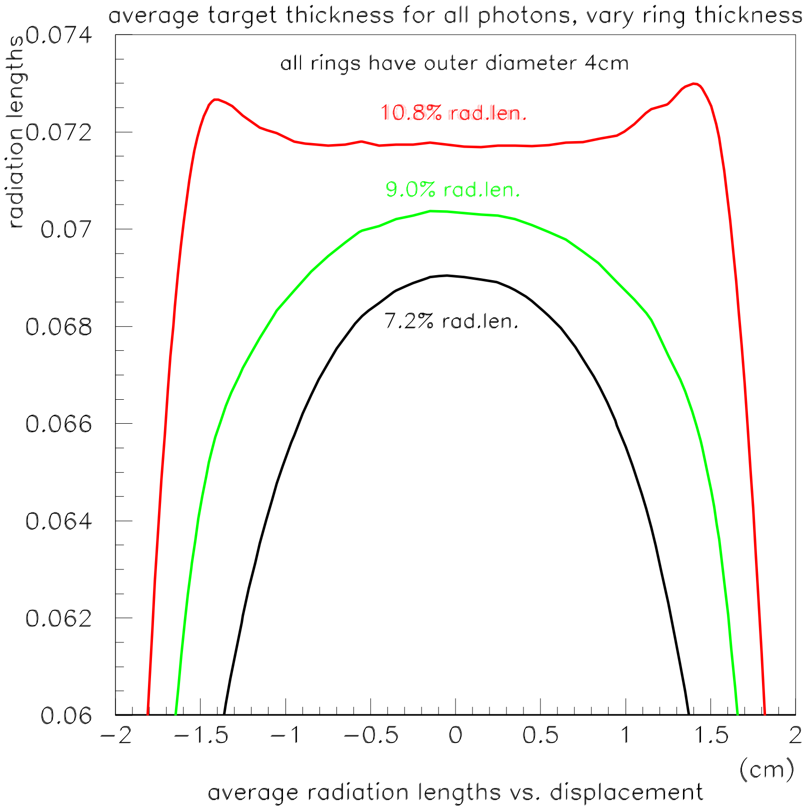

Figure 8: Curves showing the average number of radiation lengths of target intercepted by all of the primary photons in the beam, for varying thicknesses of the collar around the target. All collars extend from the diameter of the beryllium cylinder out to 4cm.

thickness in radiator lengths as the beryllium target would reduce the sensitivity to beam position drifts, as shown by the upper curve in Fig. 7. The same ±5mm discussed above produce ±1% variations in the downstream pairs rate for a collar of 4cm outer diameter. The collar would not intercept the final-state of the Radphi experiment provided that it were fixed to the upstream end of the target. Plans along these lines are under development.

Actually it is possible to further reduce the sensitivity of the conversion fraction to beam displacements about the nominal center without increasing the diameter of the target. This can be accomplished by making the collar thicker in radiation lengths than the beryllium target. For a suitable choice of collar thickness, as the beam shifts from target center the losses from the tails that miss the target are compensated by the increased fraction of the beam that intercepts the thickened region (the collar). A comparison is shown in Fig. 8 of several different choices for collar thickness with the diameter kept fixed at 4cm. The 10.8a very uniform response over a large area.

4 What are the consequences for Radphi?

Photoproduction in the aluminum collar would contribute 3-5% to the total Radphi hadronic rate for a beam centred within the 1cm diameter strike zone of the target. These events would have a degraded mass resolution (from longitudinal displacement of the collar from the centre of the target) and degraded t-resolution (from the transverse displacement of the vertex) but they are a small fraction of the total for a well-centred beam. This is not a major concern.

There is an irony with regard to the TAS. The target counter must be removed in order to obtain a reliable absolute normalisation using downstream pairs. With the target counter in place, the data in Fig. 6 indicate drifts on the order of 10% over the $\pm$5mm strike zone we are discussing. The TAS can easily be removed, and its function to provide the accelerator crew a means of centring the photon beam on the Radphi target can be replicated with the RPD signal (scaler #2). But once the collar is installed, this rate will be insensitive to displacements of the beam about the origin. The present method of centring the beam works by making small deflections of the electron beam just before the bremsstrahlung radiator and watching the variation in the rate coming from the target counter. So the attempt to make the apparatus insensitive to displacements of the beam makes it more difficult to tell where the beam is! In the limit of a flat response it does not matter. But given that the response is never perfectly flat, there is no obvious gain in decreasing the sensitivity to displacements if it comes along with diminshed means to monitor and control the displacements.

For any size of target, one could always locate the edges of the disk and interpolate in between to centre the beam. But with the 4cm collar in place this would require steering the photon beam dangerously close to the the inner blocks of the lead-glass calorimeter in order to reach the steep part of the edge (see Fig. 6). The alternative is to leave the beam fixed and move the target assembly instead, but the times involved are much longer, particularly for the vertical displacements. Ironically it may turn out that the most stable normalisation can be performed with the naked Radphi target, where the situation is such that we are able to quickly and accurately position and centre the beam without risking damage to the calorimeter. From Fig. 7, reducing the margin of error on the target strike zone to $\pm$3mm gives the same 1the collared target with $\pm$5mm margins. My conclusion is that the most important thing for controlling systematics in the absolute normalisation is having an easy and reproducible method for centring the beam and watching for drifts. If the procedure can be done in 1 min, it would be done often; if it takes 20 min - 1hr, as even a simple series of horizontal and vertical scans of the target assembly would require, it would be done less frequently and with fewer checks. In this case, even maintaining the $\pm$5mm limits would be difficult to ensure. For the future, it would be a good idea to look into a scanning scintillator arrangement that can quickly step through the beam horizontally and vertically and then be parked off to the side for regular running.

5 Conclusions

I conclude that the requirement of a stable absolute normalisation of the photon beam using the pairs rate downstream of the Radphi target places significant constraints on the allowable wander of the beam from the center of the target. With the present target there is a 3% walk in the conversion fraction associated with a 5mm displacement from the target center. This would be reduced to 1% by the addition of an aluminum collar around the target that extends the outer diameter to 4cm. With a suitable placement of the collar, its impact on the Radphi experiment could be minimised. The target scintillator that presently sits directly in the beam downstream of the target would have to be removed to provide the required level of uniformity in the target region. With the TAS removed, the only remaining way to measure the position of the beam on the target would be to monitor the rate of some process in the target. However the resolving power of this method would be reduced in the case of the collared target. Scanning out to the edge of the 4cm target by deflecting the beam would be problematic due to radiation damage to the lead glass. Under these circumstances, it might be better to make use of a fast and frequent beam-deflection scanning procedure with the small target rather than run with an extended target and with less control over the beam position. I recommend that the aluminum collar be prepared in time for the June run as planned, but that the decision of whether or not to install it or not be postponed until a procedure for centering and monitoring the position of the beam on the Radphi target can be established that will meet the requirements of all of the interested parties.