TRIUMF Experiment E614
Technical Note

Physics Consequences of Target and Chamber Modifications

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Abstract

New target and chamber designs have been proposed to solve certain construction problems. The effect on momentum and angle resolution of these modifications has been studied using a Monte Carlo simulation of monoenergetic positrons. It was found that additional mass in the target region did not significantly degrade resolution, indicating that the new target design could be adopted with little consequence, provided that the target foil can be made flat and the mass of the target holder is minimized. However, the negative effect on resolution of the new chamber designs was significant, indicating that these designs should not be used unless necessary.

1 Introduction

Various modifications of the baseline detector have been proposed to solve problems in detector construction. For the chambers these problems include gas leaks, the bowing of cathode foils due to gravity and differential gas pressures, and the possible lack of ceramic spacers. For the target the main problem is finding a practical design for changing target foils while keeping these foils flat and keeping the mass of the target holder to a minimum.

Each proposed modification has been studied by Monte Carlo simulation in order to determine the effect on momentum and angle resolution. The effect on the positron energy calibration was also estimated based on the Monte Carlo results.

2 New Target Arrangement

A new target design which allows for the changing of target foils [1] calls for a plane of 15μm tungsten wires with 1 mm wire spacing to be placed on both sides of the target foil. These planes would serve as cathodes for the two innermost central proportional chambers since it is unlikely that a bare target foil 75 μm thick can be made large enough and flat enough to serve that purpose. The new planes would be placed 2 or 4 mm from the target foil and a corresponding amount of CF_4-ISO gas would added to the spectrometer. A schematic of the three designs is shown in Fig. 1. Not shown in the figure is a target foil holder made of 5 mm thick G10.

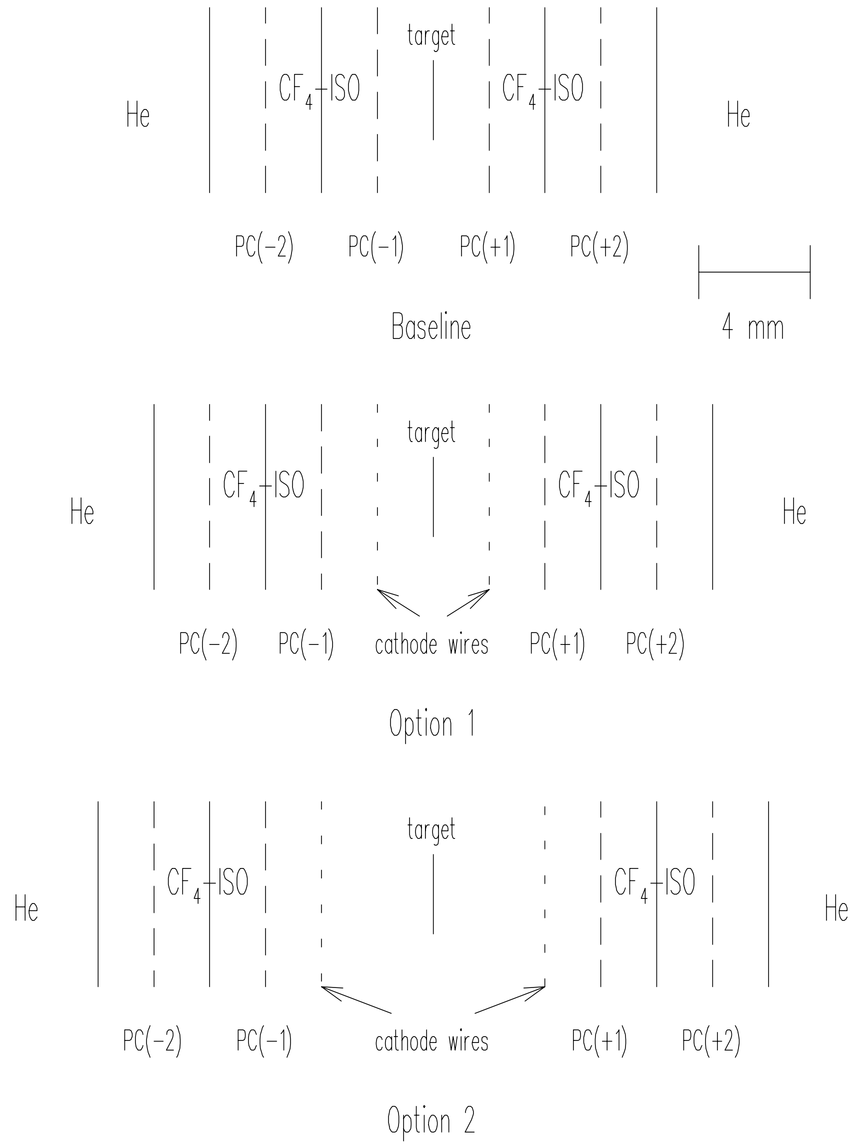

Figure 1: Three target region designs. Top: baseline design with target foil as cathode plane for PC(-1) and PC(+1). Middle: cathode wire planes with 1 mm wire spacing placed 2 mm upstream and downstream of the target foil. Bottom: cathode wire planes placed 4 mm upstream and downstream of the target.

There are several consequences of the additional mass in the new target design. Increased energy loss may lead to a loss of positron energy resolution. Similarly, increased multiple scattering will degrade the angular resolution of the positron track. More muons will be ranged out before reaching the target, both increasing stops outside the target and reducing the amount of absorber or monitoring material that can be placed upstream in the muon beam.

Independent of the additional mass is a concern over the distortion of the muon stopping distribution due to warping of the target foil, and the uncertainty in the z location of the target foil.

2.1 Energy Loss

The final, measured positron energy will be taken from the helix parameters at the first drift chamber upstream or downstream of the target and corrected for energy loss in all the materials from the first mylar foil of the drift chamber to the center of the target foil. This correction must be precise enough to achieve the stated energy calibration goal of $\pm$ 5 keV at 52.831 MeV. In order to determine whether or not this value can be attained despite the additional mass around the target, both the baseline and option 2 target designs were simulated using 52.8 MeV/c positrons originating at the center of the target with an initial angle of 60°. The distribution of positron origins was gaussian in x and y with $\sigma = 1$ cm. The distribution of energy lost between the center of the target foil and the first drift chamber foil is shown in Fig. 2 for both cases. The spectra shapes are nearly identical with only small changes in the means and RMS values. Using the baseline target design it has been estimated that a resolution of 4 keV [2] could be achieved. From Fig. 2 the RMS of the energy loss spectrum for the new target design is about 7% larger than the baseline. Assuming that the error in the mean of the energy loss spectrum, and therefore the energy calibration, is proportional to the spectrum's RMS, the energy calibration for the new target arrangement can be known to $1.07 \times 4\text{keV} = 4.3$ keV, still within the stated 5 keV.

The first simulation of the new target design assumed a target foil radius of 3 cm, with the G10 target holder extending inward to that value. At this radius a significant number of positrons passed through enough of the holder material to create a small bump on top of the energy loss spectrum. This undesirable feature would cause uncertainties in correcting for the energy loss in the material before the first drift chamber. Increasing the inner radius of the target holder (and the target radius) to 4 cm removed this problem.

2.2 Multiple Scattering

For 20 MeV/c positrons with an incident angle of 60° the contributions to the mean multiple scattering angle of the materials in the three options are given in Table I. The effect of wires is not included in Table I but treated separately here. In the baseline design the probability that a positron strikes a wire is

$$\frac{0.01178}{cos\theta}. \tag{1}$$

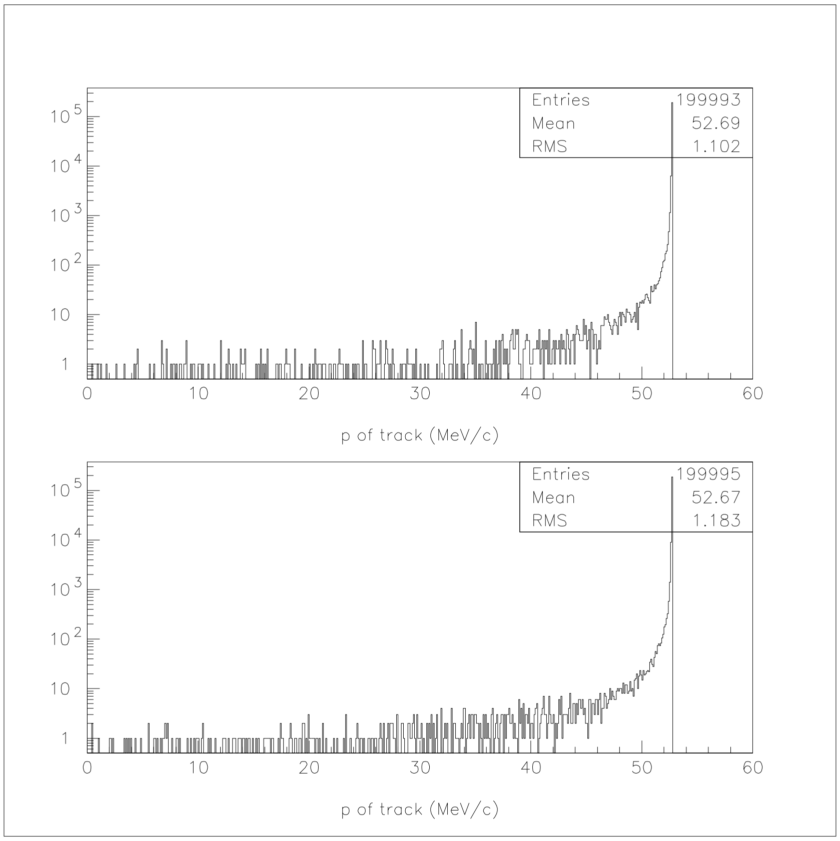

Figure 2: Energy loss of 52.8 MeV/c, 60° positrons through material between target center and first drift chamber foil. Top: baseline target design. Bottom: new target design (option 2).

Material (Baseline)	θ°_{ms}
37.5 μm Aluminum	0.772
3 $\times$ 6.35 μm mylar foils	0.265
2 $\times$ 4mm CF_4-ISO (80-20)	0.364
2 cm He gas gap	0.048
Quadrature sum	0.895
Added Material (Option 1)	θ°_{ms}
2 mm CF_4-ISO (80-20)	0.161
Quadrature sum	0.909
Added Material (Option 2)	θ°_{ms}
2 mm CF_4-ISO (80-20)	0.161
Quadrature sum	0.923

Table 1: Mean multiple scattering angle for 20 MeV/c positrons at 60° going from the center of the stopping target through the first foil of the first drift chamber.

For a 60° track this is 2.4%. Going from the baseline design to either Option 1 or 2 doubles the number of wires and hence the probability of a wire scattering, from 2.4% to 4.8% . The mean scattering angle for a single wire hit is 1.7°. This represents a significant increase in large-angle scattering events, but since these scatters occur before the tracks reach the first drift chamber, this does not pose a problem for track fitting. Of more concern is the effect of the wires on the overall mean scattering angle. For the baseline design the wires increase the mean angle from 0.895° (Table I) to 0.923°. For options 1 and 2 the extra wires increase the mean to 0.964° and 0.977°, respectively. Between the baseline design and options 1 or 2, the increase in the overall mean scattering angle is negligible.

2.3 Target Position and Flatness

Target holder schemes which do not rely on fixed glass frames will not be able to position the target to a precision of 20μm or better. The degree of uncertainty that can be tolerated is limited by the desired precision of the positron energy calibration, $\pm$ 5 keV. If, for example, the actual target position is slightly upstream of the origin, positrons from the target will pass through less CF_4-ISO going upstream and more going downstream and thus introduce an asymmetry in the energy spectrum. The energy calibration for the baseline design can be measured to $\pm$ 4 keV so any contribution to this error from imprecision in target position should be small by comparison. If the maximum contribution is limited to 10%, the error in positron energy loss cannot be more than 0.4 keV. Hence the error in the thickness of the

CF_4-ISO due to the error in target position is

$$\frac{0.4cos\theta}{13.7}. \tag{2}$$

Here the mean energy loss of 50 MeV/c positrons is 13.7 keV/cm in CF_4-ISO gas. For 60° tracks this uncertainty is about 150 μm. The muon stopping distribution in the target will not be affected by this uncertainty because the muon stopping power of 150 μm of CF_4-ISO is equivalent to that of 0.27 μm of aluminum which is small compared to the precision of the foil thickness (perhaps 1 μm for a 75 μm foil). The overall angle of the foil relative to the plane perpendicular to the z axis will be limited by the flatness of the target holder. Typical deviations from flat will be less than $\pm 75\mu$m at any point on the holder, allowing a maximum overall angle of 150 μm over a 6 cm foil diameter, or about 0.14°. This means that a muon beam profile with $\sigma_x = \sigma_y = 1$ cm will have the width of its stopping distribution increase from 75 μm to at most 125 μm. This will not affect the energy or angle calibration of the positrons.

Another concern is the flatness of the target foil itself. It is difficult to make thick (75 μm) aluminum foils which are flat over large areas. However, for 6 - 8 cm diameter target foils it is unlikely that a warp of more than 100 μm will occur. If, for example, there is a concave warp from the center of the target to the outer radius, the angle that parts of the target would make to the vertical would be $tan^{-1}(0.01/3.0) = 0.19°$. The contribution to the uncertainty in the mean energy loss due to such a warp is therefore negligible.

2.4 Other Concerns

If option 2 is adopted more sense wires in the four central proportional chambers will need to be instrumented. In the baseline design each PC plane has 32 active sense wires, which is enough to cover the width of the incident muon beam and to guarantee that positrons emitted from the target at a radius of 1 cm and with angles up to 70° are recorded by both PCs. In option 2 both PCs are now 4 mm further from the target, so at least 43 sense wires are required to achieve the same positron coverage. Because of TDC packing, 48 instrumented wires on each plane would be more convenient.

For either option 1 or 2 the thickness of the target holder is of concern. A 5 mm thick acrylic target holder has been proposed which extends in to a radius of 3 cm. Positrons leaving the center of the target with angles $> 85.2°$ will intercept the holder, lose energy and scatter. While such positrons are far outside our acceptance some of them may scatter significantly, changing their angle and energy so that they are accepted and therefore distorting the measured Michel spectrum. Some can be rejected if their helix axes do not pass through the target. This problem was alleviated by increasing the target foil radius to 4 cm.

A small-radius target holder may also impede the passage of particles used in upstream-downstream calibration schemes. One of these schemes will use 150 MeV/c pions in a diffused focus beam with the solenoidal field turned off. This will provide straight tracks which can be used to fine-tune wire positions and check their upstream-downstream symmetry. The energy loss of such pions in the target holder is 2.0 MeV. More importantly, the mean multiple scattering angle is about 0.3°. Over the 50 cm half-length of the detector this would cause a 0.26 cm deflection of the track which is too large to be useful for upstream-downstream symmetry checks. Only tracks passing through a 4 cm radius hole or blank in the target holder could serve this purpose. Deflected tracks would still be useful for calibration within each half of the detector.

3 Extra Foils and Buffer Volumes

In the baseline detector the DME in the drift chambers is separated from the helium between chamber-pairs by a single aluminized mylar foil of thickness 6.35 μm. Recent estimates indicate that the leak rate of helium through the foil into the DME will not be large enough to adversely affect the drift characteristics [3] and that bowing of the foil due to pressure differentials and gravitational sag will be constrained to less than 12 μm. However, should chamber testing indicate that either of these statements is false, a DME buffer region (0.24 cm thick) and accompanying mylar foil will need to be added on either side of each chamber-pair. This will make gas sealing easier and allow for helium-contaminated DME to be flushed out of the system before it reaches the drift chambers. It will also transfer any foil bowing from the cathode foils to the buffer foils. For reference this option will be called "10-extra" because ten extra mylar foils and ten extra DME buffer zones occur in the subset of the detector to be simulated.

Provided that leaks and bowing are not significant, an additional problem may emerge with the baseline design. While there are sufficient ceramic (CITAL) spacers to complete the detector, there may not be enough of them of the correct length in order to build spares for all types of chamber-pair modules. A proposal to yoke two pairs together into a four-chamber module [1] would reduce the number of spacers required, but for gas sealing purposes would require a DME buffer region (0.24 cm thick) and mylar foil on either side of each four-chamber module. This option will be referred to as "4-extra" because it only uses four extra foils and buffers in the same space as the previous option.

In either modification the price paid for the extra mass is of course a loss of resolution, and reduced freedom in the amount of absorber material such as scintillators or absorber gas which can be placed in the muon beam. One way to compare resolutions is to simulate positrons which start from the target with a realistic muon stopping distribution, and track them through the first five drift chamber pairs (which represent one slide in the slide-fitting technique [4]). Another way, which emphasizes the differences in the drift chamber geometries, is to start the positrons just before the first drift chamber and track them through the first five chamber-pairs. For comparison, tracking through only the first four chamber-pairs can also be performed.

In all cases the energy and angle resolution for the baseline, 4-extra and 10-extra designs was estimated using a Monte Carlo simulation of 52.8 MeV/c positrons at incident angles of 10°, 35° and 60°.

3.1 Tracking through Target and Five Chamber-Pairs

In this study target option 2 (see Fig. 1) was used. Positrons were started in the aluminum target at $x = 0$ and $y = 0$ with a gaussian distribution ($\sigma_x = \sigma_y = 1$ cm). The starting z distribution was uniform over the 75 μm target thickness. The tracking points were retrieved and fitted with helices, and the helix parameters were compared to the known initial angles and momenta of the positron. The HWHM of the distributions of the momenta and angle differences are shown in Figs. 3 and 4 for the baseline, 4-extra and 10-extra designs.

As shown in Fig. 3 the largest differences in momentum resolution occur at small angles where the resolution is worst. However, the percentage change in resolution is roughly constant with positron angle. The addition to the baseline design of four extra foils and DME buffers increases the HWHM by an average of 13% over all angles. Ten additional foils and buffers increase the HWHM by an average of 27% over all angles.

The effect of additional mass on the angular resolution is about half as big as that on the momentum resolution. Averaged over all angles, the angular resolutions (HWHM) shown in Fig. 4 increase by 6% when four extra foils and buffers are added, and by 11% when ten extra foils and buffers are added.

3.2 Tracking through Five Chamber-Pairs Only

In order to separate energy loss and multiple scattering effects which come from the target region from those which come from the detector itself, positrons were started just upstream of the first foil of the first downstream drift chamber with a gaussian distribution in x and y of $\sigma = 1$ cm. Tracking and fitting were performed as stated above. The HWHM of the distributions of the momenta and angle differences are shown in Figs. 5 and 6.

In Fig. 5 the momentum resolution averaged over the three angles is 14% worse for the 4-extra design than for the baseline design. The 10-extra design is 29% worse. A comparison of Figs. 3 and 5 shows that there is little difference between tracking the positron through just the chambers and tracking it through both target and chambers. This is because the added spread in energy resolution due to the target is small compared to the spread due to momentum measurement error ($\pm 50 \mu$m) in the five chambers.

With the target removed, the effect of additional foils and buffers on the angular resolution is roughly the same size as that seen in the momentum resolutions. In Fig. 6 the angular resolution averaged over the three angles is 18% worse for the 4-extra design than for the baseline design. The 10-extra design is 33% worse. A comparison of Figs. 4 and 6 shows a large difference ($\sim 40\%$) in angular resolutions when the target is removed. This is due to the dominance of multiple scattering over the angle measurement error in the chambers. These resolutions assumed a positron momentum of 52.8 MeV/c. Hence angular resolutions at lower energies will be worse by as much as a factor of two or more at the low energy end of the E614 detector acceptance (20 MeV).

Another effect of additional mass in the detector is large angle scattering of the positron. Additional foils and DME volumes add more scattering centers and therefore complicate

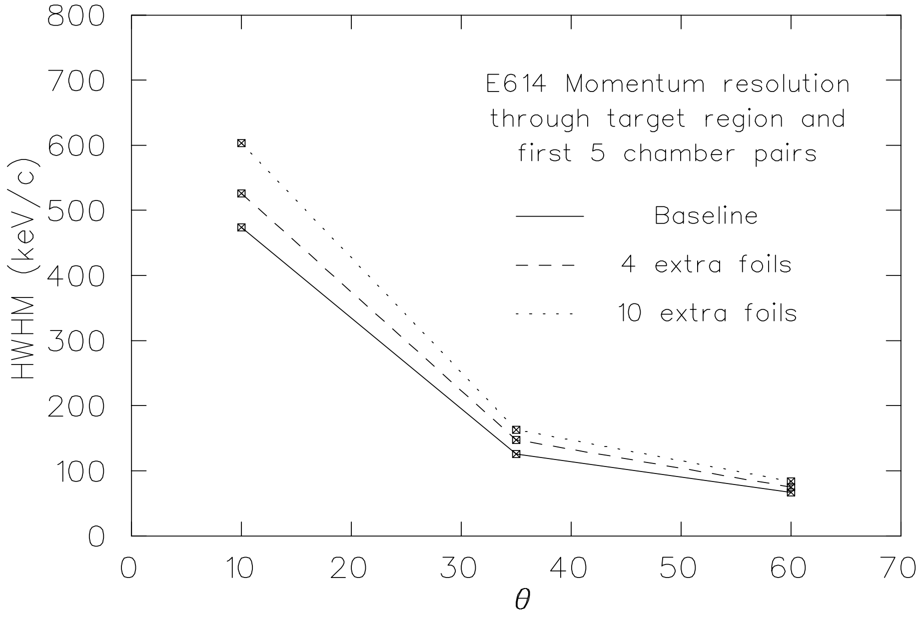

Figure 3: Momentum resolution (HWHM in keV/c) for the baseline design, the design with 4 extra mylar foils and DME buffers and the design with 10 extra foils and DME buffers. Positron is tracked through target and five chamber-pairs.

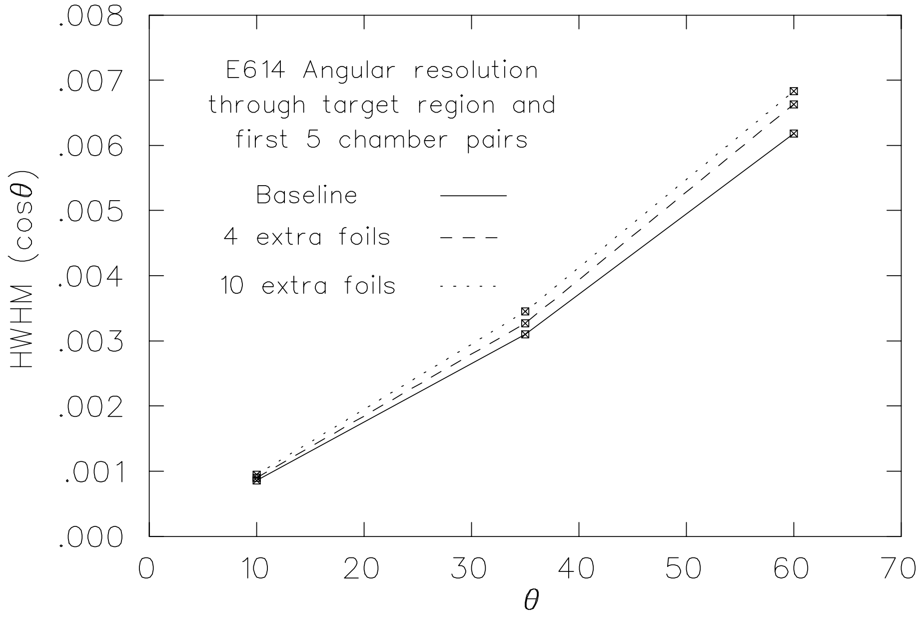

Figure 4: Angle resolution (HWHM in keV/c) for the baseline design, the design with 4 extra mylar foils and DME buffers and the design with 10 extra foils and DME buffers. Positron is tracked through target and five chamber-pairs.

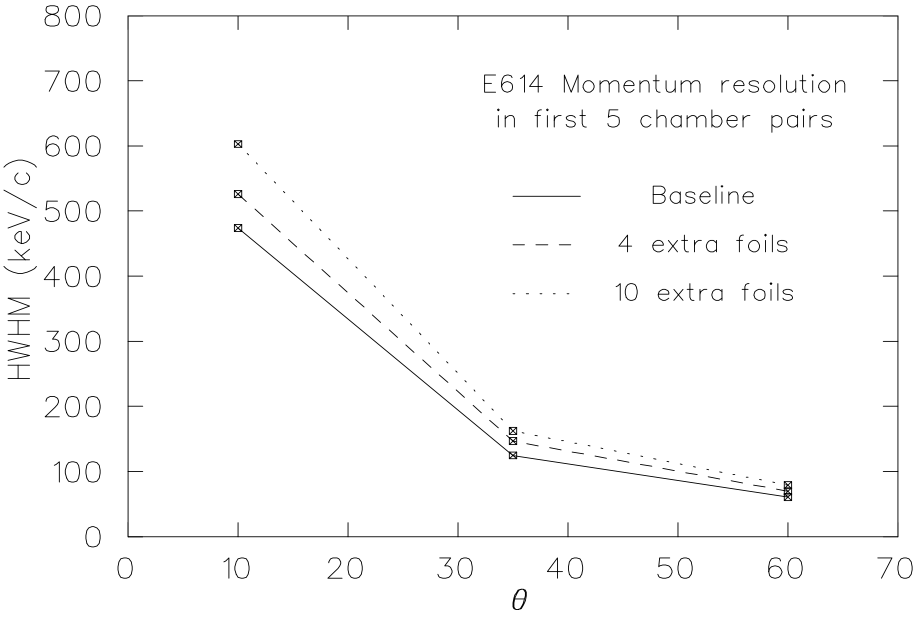

Figure 5: Momentum resolution (HWHM in keV/c) for baseline, 4-extra and 10-extra detectors. Positron is tracked through five chamber-pairs only.

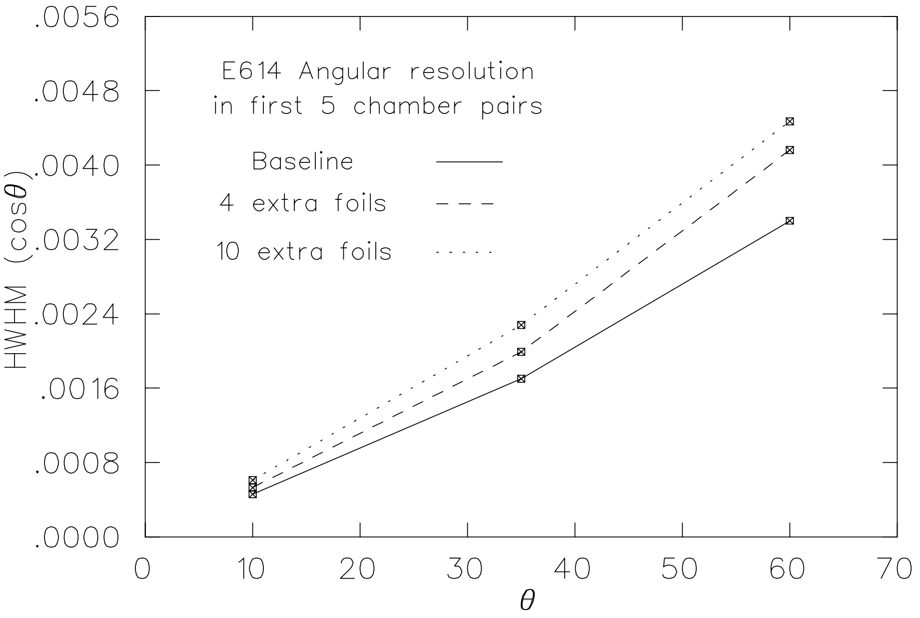

Figure 6: Angle resolution (HWHM in cosθ) for baseline, 4-extra and 10-extra detectors. Positron is tracked through five chamber-pairs only.

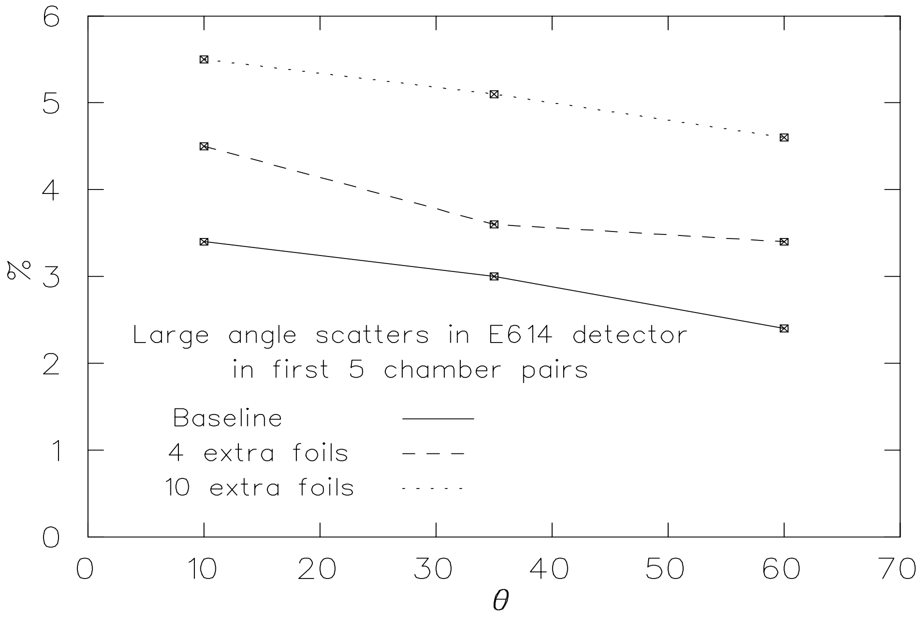

Figure 7: Large angle scattering (%) in five chamber-pairs only.

the task of track fitting by introducing more kinks. The number of kinks added by the additional material can be estimated by looking at the percentage of events which are far from the mean of the $cos\theta_{actual} - cos\theta_{fitted}$ distribution. For the baseline detector Fig. 7 shows the percentage of events which are more than 3 HWHMs away from the mean. At 10° 3*HWHM = 0.45°, at 35° 3*HWHM = 0.51°, and at 60° 3*HWHM = 0.67°. For the 4-extra and 10-extra designs, new values of 3*HWHM were not calculated. Instead the baseline limits were used in order to make a fair comparison. Averaged over the three angles, the 10-extra design had 73% more large angle scatterings while the 4-extra design had 31% more large angle scatterings.

3.3 Tracking through Four Chamber-Pairs Only

For comparison, the above study was repeated using only the first four chamber-pairs in the stack to simulate a slide. From Fig. 8 it is seen that for each design the momentum resolution for the four-pair case averaged over the three angles is about 15% worse than that in the five-pair case (Fig. 5). Most of this difference is due to the loss of the extra measurement point. The angular resolution, shown in Fig. 9, is actually better for all designs (13%) in the four-pair case than in the five-pair case (Fig. 6) because the reduction in multiple scattering error due to the lower mass outweighs the degradation in the angle measurement error due to the smaller number of measurement points. This suggests that where angle resolution is important it may be better to use a four-pair slide.

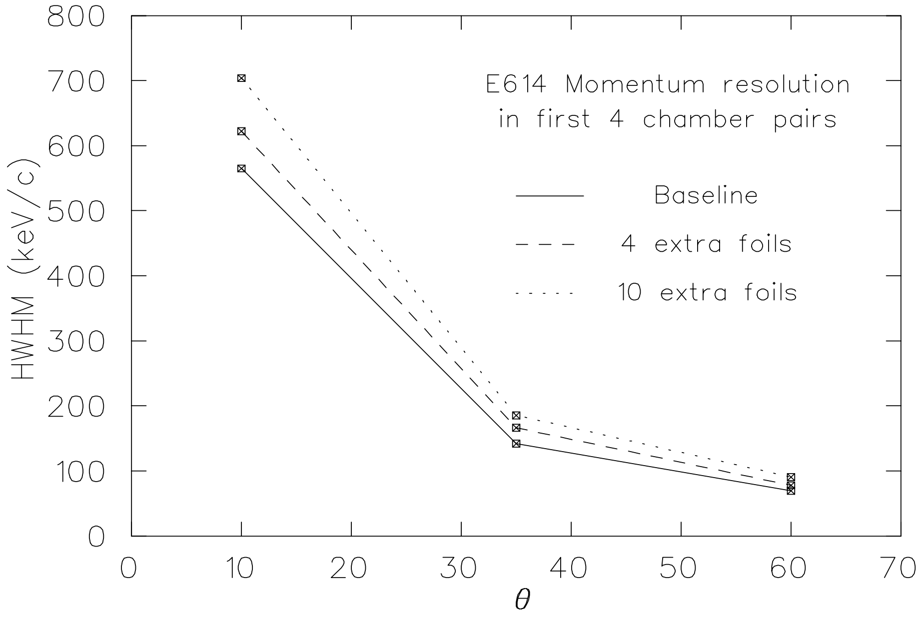

Figure 8: Momentum resolution (HWHM in keV/c) for baseline, 4-extra and 10-extra detectors. The positron was tracked through four chamber-pairs only.

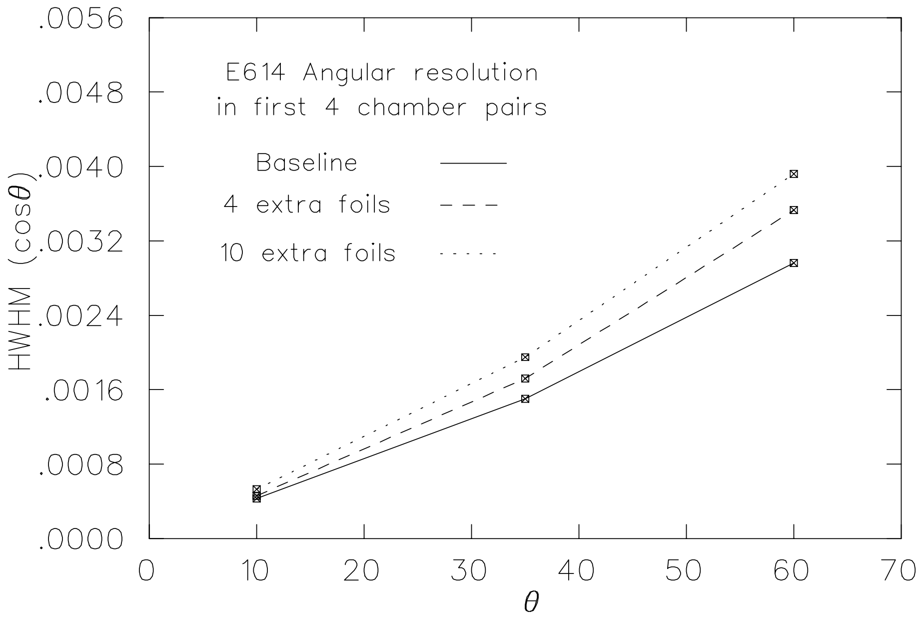

Figure 9: Angle resolution (HWHM in $\cos\theta$) for baseline, 4-extra and 10-extra detectors. The positron was tracked through four chamber-pairs only.

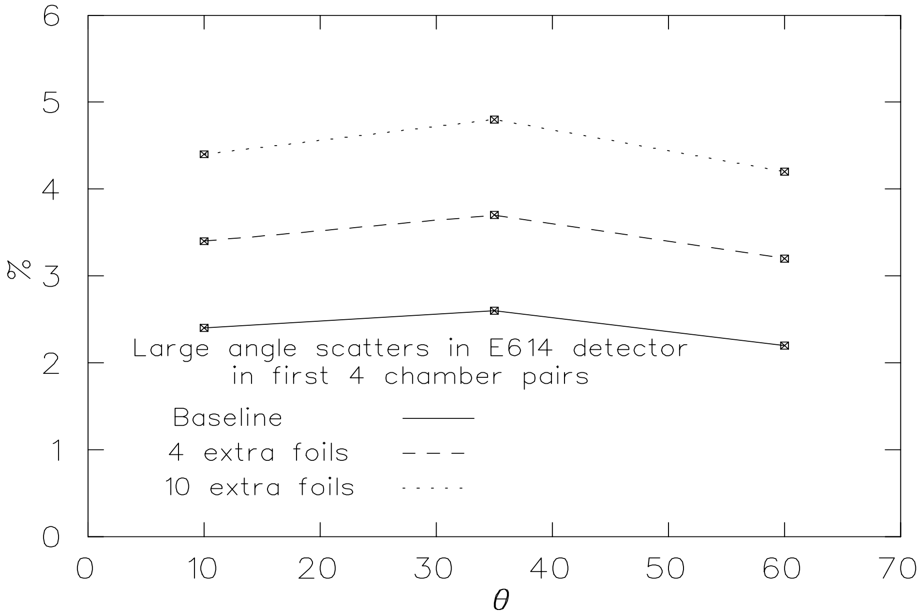

Figure 10: Large angle scattering (%) in four chamber-pairs only.

Design Option	% increase in Δp	% increase in $\Delta\cos\theta$
4 extra foils + target	13	6
10 extra foils + target	27	11
4 extra foils	14	18
10 extra foils	29	33

Table 2: % increase above baseline detector design of Δp and $\Delta\cos\theta$ for detector designs with four extra foils and DME volumes and ten extra foils and DME volumes. Values quoted represent an average over incident positron angles of 10°, 35° and 60°. Positrons were tracked through the target and the first five chamber-pairs and through the first five chamber-pairs alone.

4 Conclusions

The original design for the target region does not allow for the easy changing of muon stopping targets. Design options 1 and 2 make this possible but require more mass between the target and the first drift chamber. However, neither option causes a significant degradation in energy calibration or multiple scattering and so both are acceptable. Option 2 is preferred because of ease of construction. In either option the target foil must be positioned to better than 150 μm to guarantee good energy calibration. Warps in the foil of less than 100 μm and overall foil angles of less than 150 μm over 6 cm will not cause significant distortions in the muon stopping distribution. If option 2 is chosen, at least 43 sense wires per PC plane will be required to provide the same positron coverage as the baseline design.

The addition of extra mylar foils and DME buffer zones was found to degrade the momentum and angle resolution of positrons coming from the target. These results are summarized in Table II. Also, large angle scatterings were found to increase by 31% for the 4-extra design and 73% for the 10-extra design. Because the resolution is substantially degraded in the new design options, they should not be used unless it is found that gas leaks or foil bowing makes them necessary. For the angular resolution alone, some of the loss can be recouped by using a four chamber-pair slide instead of a five-pair slide.

The increased mass of the new designs reduces the amount of plastic scintillator or absorber gas that can be placed in the beamline. If target option 2 and the 10-extra detector design are chosen, only 160 μm of plastic scintillator would be allowed for a particle ID trigger.

References

[1] R. Henderson, presentation to E614 meeting, January 1999.

[2] E614 Proposal 1996.

[3] R. Openshaw, presentation to E614 meeting, February 1999.

[4] A.A. Khrutchinsky, Yu.Yu. Lachin and V.I. Selivanov, Nucl. Instr. & Meth. A 396, 135 (1997).