

MULTIPLE SCATTERING EFFECTS OF A THIN BERYLLIUM WINDOW ON A SHORT, 2 nC, 60 MeV BUNCHED ELECTRON BEAM

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Abstract

The Argonne Wakefield Accelerator (AWA) 75 MeV drive beamline at Argonne National Laboratory has as its electron source a Cesium telluride photocathode gun with a vacuum requirement on the order of 10^{-10} torr. In conflict with this, the experimental program at AWA sometimes requires beamline installation of experimental structures which due to materials and/or construction cannot meet the stringent vacuum requirement. One solution is to sequester these types of structures inside a separate vacuum chamber and inject the beam through a thin Beryllium window. The downside is that multiple scattering effects degrade the beam quality to some degree which is not well-known. This study was done in an effort to better understand and predict the multiple scattering effects of the Be thin window, particularly on the beam transverse size. The results of measurements are compared with GEANT4 simulations via G4beamline and analytical calculations via GPT.

MOTIVATION FOR USE OF BE WINDOWS AT AWA

The Argonne Wakefield Accelerator beamlines have a demanding vacuum environment, necessary to preserve the Cs₂Te photocathode in the drive gun. Cs₂Te photocathodes require vacuum pressures on the order of 10^{-10} torr, the upper range of Ultra-high vacuum (UHV). The strict vacuum requirements have a large impact on experimental design, severely limiting material choices to those that are UHV compatible. In addition, for all practical purposes, the UHV requirement completely prevents access to experimental structures after installation. Thus, the experiment must work "as installed". If it does not, at best, the consequences can include lengthy downtime while the device under test (DUT) area is vented and the experimental device is uninstalled, modified, cleaned, and re-installed. After this occurs, the experimental section of the beamline must then be pumped and baked to attain UHV vacuum pressure before the operations and the experiment may resume. This typically takes more than one week.

One way of easing the vacuum requirement and also allowing quick and easy access to make changes to the experimental setup is to place a vacuum chamber sequestered behind a Be window at the end of the beamline. The required vacuum pressure in this "dirty" vacuum chamber can be relaxed to 10^{-8} torr, which can be attained in a matter of hours with much fewer restrictions. The downside is the degradation of beam quality due to multiple scattering at the Be window. It is hoped to develop some guidance to be used in planning such installations in the future by trying to mea-

sure the effect on the beam and compare it to numerical and analytical predictions.

AWA has had some experience with this limiting effect of the increase in beam transverse size and emittance due to a Be window. Two recent experiments (RF choke cavity and a photonic-bandgap structure) come to mind. Both had an aperture I.D.=6 mm and required the beam to be moved within the aperture from an on-axis position to off-axis without significant beam loss inside the structure. In other words, a tightly focused beam was required with a fairly constant transverse size much less than the aperture I.D. Performing these experiments with a beam through a Be window was indeed a challenge.

SIMPLE FORMULA FOR MULTIPLE SCATTERING ANGLE

An electron beam traveling through matter primarily interacts with the nuclei via the Coulomb force. Electrons experience many mostly small deflections as they scatter multiple times within the media. The distribution of scattering events is described by Moliere's theory. The details of the theory are beyond the scope of this paper.

The Review of Particle Physics [1] presents a simplified equation based on a Gaussian approximation to Moliere's theory for the multiple scattering angle. For $\theta_0 = \theta_{rms\ plane} = \frac{1}{\sqrt{2}}\theta_{rms\ space}$. The width is:

$$\theta_0 = \frac{13.6\text{MeV}}{\beta pc} z \sqrt{\frac{x}{X_0}} \times (1 + 0.038) \ln\left(\frac{x}{X_0}\right) \quad (1)$$

for a relativistic electron beam of momentum p , velocity βc , charge number z , and scattering due to a foil of thickness x , made of material with radiation length X_0 . Eq. 1 is accurate to 11% or better for the range $10^{-3} < x/X_0 < 100$ [1].

For the AWA drive beam during these tests, $p = 60\text{ MeV}/c$. And for the thin Be window: $x = \text{foil thickness } (0.007'' = 178\ \mu\text{m} = 0.0178\ \text{cm})$ and $X_0 = 35.28\ \text{cm}$ (beryllium) we finally have $\theta_0 = 0.0036 = 3.6\ \text{mrad}$. This approximation was the basis of one of the simulations, the results of which are presented later in this paper. Note: This foil thickness results in a value of $x/X_0 = 0.0005$, just outside the quoted range of 11% accuracy, and that value will move further from that range as the foil is made thinner.

TESTING A Be WINDOW AT AWA

A vacuum chamber separate from the beamline vacuum was installed at the end of the drive beamline. The Be window (Materion) is circular with a 2" diameter aperture. The

foil is 0.007" thick (178 μm), the required minimum thickness. Pre- and post-installation tests were performed. Diagnostics were limited to two YAG(Ce) screens for beam spot size and two integrating charge transformers (ICTs) located before and after the window. Thus the two factors that could be studied were charge loss and increase in transverse beam spot size (there was no capability to measure emittance). See Fig. 1.

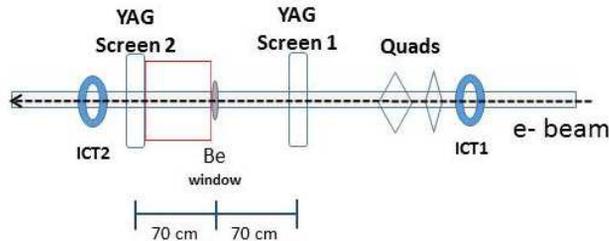


Figure 1: Schematic of the experimental setup. The electron beam propagated from the right, charge measured before and after the window at the ICTs. The beam was focused by two quadrupoles. The image was recorded at the two YAG screens located 70 cm before and after the Be window.

To characterize the multiple scattering effects a systematic comparison of beam spot sizes for similar beam conditions on the same YAG screen with and without the Be window was performed. The AWA drive beam was set to single bunch mode. The beam energy was 65 MeV during the pre-installation run and 60 MeV for the post-installation run. In both cases the charge was about 2 nC. The beam energy difference, while unfortunate, was only about 10%. This was unavoidable due to time constraints, some technical problems related to beamline commissioning and other priorities.

Two quadrupoles located about 2 m upstream from the Be window were used to make as small a spot as possible on the second YAG screen, with and without the Be window. The image of the beam spot was analyzed to extract the transverse spot sizes σ_x and σ_y .

A summary of results from pre- and post- installation runs along with the beam energy and the charge data is shown in Table 1. The pre-installation run showed decreasing transverse spot-sizes (not pictured) which indicated that the beam was collimated and focused. It was obvious during the post-installation run that the focused beam spot-size was badly affected by multiple scattering as it passed through the window.

The image of the 60 MeV/c, 2 nC beam on the YAG screen before and after scattering through the Be window is shown in Fig. 2. In the figure the units are pixels, both YAGs are 50 mm diameter. YAG1 was normal to the beam, YAG2 at 45 degrees.

Table 1: Beam transverse spot sizes (mm) measured 70 cm before and 70 cm after the location of a Be window (thickness= 178 μm).

| Pre-installation | before | after | %change |
|-------------------|--------|-------|---------|
| σ_x | 0.56 | 0.54 | -3% |
| σ_y | 0.67 | 0.54 | -19% |
| Post-installation | before | after | %change |
| σ_x | 1.26 | 4.67 | +370% |
| σ_y | 0.62 | 3.71 | +598% |

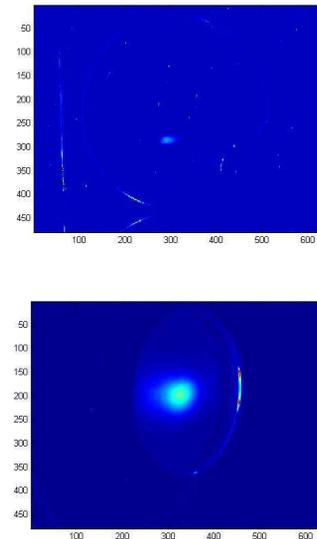


Figure 2: Top: YAG 1 image of the 2 nC beam 70 cm before scattering. Bottom: YAG 2 image, 70 cm after scattering through the window. Units are pixels, YAGs are 50 mm dia. YAG 1 normal to the beam, YAG2 at 45 degrees.

In both cases, the beam spot was focused to be as small as possible at the second position. There was no measurable charge loss. However, the effect of scattering on the beam size was quite large, resulting in transverse sizes that were almost 4-6 times the original size.

SIMULATIONS

Simulations were done using two different codes. The goal of the simulations was to see how well the codes could predict the effect of multiple scattering in terms of the experimentally measured transverse spot sizes. The first simulation employed G4beamline [2], a particle tracking code which provides an interface to GEANT4, which does the multiple scattering calculation. According to the GEANT4 reference manual, the multiple scattering algorithm is based on the Lewis theory, which is more complete than Moliere's theory [3]. The second simulation was done using Gen-

eral Particle Tracer (GPT) [4], a code currently being used at AWA to accurately simulate the AWA beamlines. A Be window multiple scattering element based on the simplified multiple scattering angle formula given in Eq. 1 was created and implemented in the GPT simulations.

For both simulations, a gaussian beam was assumed and the experimentally measured parameters beam energy (60 MeV), charge, and initial spot-size at the first YAG screen were the inputs. The simulated particle distributions of the beam at the position of the YAG screens before and after the Be window is shown in Fig. 3 A summary of the results from the simulations is given in Table 2.

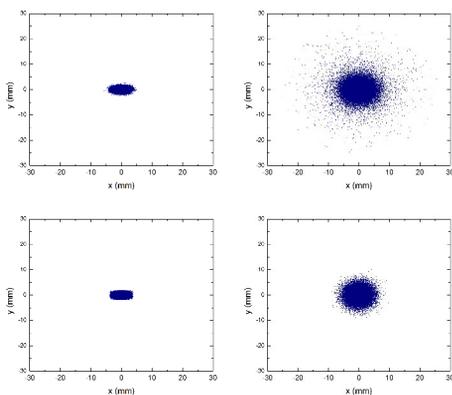


Figure 3: Top: G4beamline transverse particle distribution at initial YAG screen (top left) and final YAG screen (top right). Bottom: GPT transverse particle distribution at initial YAG screen (bottom left) and final YAG screen (bottom right).

Table 2: Simulation of beam transverse spot sizes (mm) measured 70 cm before and 70 cm after a $178 \mu\text{m}$ Be window

| G4beamline (GEANT4) | before | after | %change |
|---------------------|--------|-------|---------|
| σ_x | 1.26 | 3.55 | 281% |
| σ_y | 0.62 | 3.19 | 514% |
| GPT (Eq. 1) | before | after | %change |
| σ_x | 1.26 | 1.790 | 142% |
| σ_y | 0.62 | 1.793 | 289% |

COMPARISON OF SIMULATION RESULTS AND EXPERIMENT RESULTS

The effect of multiple scattering was quite pronounced leading to a large measured increase in transverse spot-size. The G4beamline simulation was reasonably accurate, though it did underestimate the multiple scattering effects, predicting 75-85% of the observed increase in spot-size. The simple model implemented in GPT was considerably

worse, also underestimating the increase, in this case predicting an increase in transverse spot-size only 38-48% of the measured increase.

In order to be more useful for these types of predictions, these simulation methods should be benchmarked using more experimental data with better control of the beam parameters combined with the ability to easily vary the Be window thickness. For example, as mentioned previously, the quadrupole settings that had been tested without the window had to be changed due to a difference in beam energy after the Be window was installed. In the next section, we outline a plan to continue and extend this study.

CONCLUSION

We hope to continue these studies and use the results to develop a useful experimental area with less-restrictive vacuum requirements in order to meet the needs of a broader range of experiments. In the near future, another test is planned that involves mounting several foils of varying thicknesses on an actuator and measuring the beam spot size with and without the foil. In addition to expanding the scope of the investigation to extremely thin foils, this will enable a better comparison using the same beam conditions during the same run. We would also hope to improve upon the simple model of the Be window scattering element used in the GPT simulations so that the Be window chamber can be accurately included in start-to-end simulations of AWA experiments.

AWA is currently investigating the possibility of using a small aperture, very thin foil combined with a collimator in order to reduce scattering and improve the delivered beam quality. The high-charge beam would be directed through the existing Emittance-Exchange (EEX) beamline for bunch compression (see G. Ha, this proceedings). The beam would enter the Be window as a high charge short bunch with a large transverse emittance and exit the collimator as a short, low-charge beam with a small transverse emittance, ideal for experiments with small aperture structures.

The ultimate goal is a simple, cost-effective approach using existing beamlines and capabilities to offer a better alternative for complex experimental setups having trouble meeting the vacuum requirement, require accessibility during the run or both. Perhaps it might best be described as a sort of “have your cake and eat it” experimental chamber. If this proves to be a viable plan, it will certainly enhance the experimental program and possibilities at AWA.

REFERENCES

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