MULTIPLE SCATTERING EFFECTS ON A SHORT PULSE ELECTRON BEAM TRAVELLING THROUGH THIN BERYLLIUM FOILS

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Abstract

The Argonne Wakefield Accelerator beamlines have stringent vacuum requirements (100 picotorr) necessitated by the Cesium telluride photoinjector. In direct conflict with this, the structures-based wakefield accelerator research program sometimes includes worthy but complex experimental installations with components or structures unable to meet the vacuum standards. A proposed chamber to sequester such experiments safely behind a thin beryllium (Be) window is described and the results of a study of beam-quality issues due to the multiple scattering of the beam through the window are presented and compared to GEANT4 simulations via G4beamline. Three thicknesses of Be foil were used: 30, 75 and 127 micron, probed by electron beams of three different energies: 25, 45, and 65 MeV. Multiple scattering effects were evaluated by comparing the measured transverse rms beam size for the scattered vs. unscattered beam. The experimental results are presented and compared to simulations. Results are discussed along with the implications and suggestions for the future sequestered vacuum chamber design.

MOTIVATION FOR USE OF BE WINDOWS AT AWA

The Argonne Wakefield Accelerator (AWA) beamlines have a demanding vacuum environment to preserve the drive gun Cs_2Te photocathode. Such photocathodes require vacuum pressures on the order 10^{-10} torr. The strict vacuum requirements have a large impact on experimental design, severely limiting material choices to those that are UHV compatible. In addition, the UHV requirement prevents easy access to experimental structures after installation and usually prohibits the possibility of altering experimental setups within the timeframe of an experiment. Thus, the experiment must work "as installed". If it does not, at best, the consequences can include lengthy downtime while the experimental area is vented and equipment is uninstalled, modified, cleaned, and re-installed. Once this occurs, the offending sector of the beamline must be pumped to attain UHV vacuum pressure before the operations and the experiment may resume. This can take several days to more than one week.

Compromise: Separate vacuum regimes

One way of easing the vacuum requirement and 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 (discussed previously in [1]). The vacuum requirement in the "dirty" vacuum chamber can be relaxed to 10^{-8} torr, which can be attained in a matter of hours with much fewer restrictions. Of course, there is a cost: beam quality suffers due to multiple scattering as the beam passes through the Be window. 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. However, it is important to point out that the predictions of scattering theory become increasingly less reliable as the foil thickness is decreased. Hence, it is important to gather some experimental data in order to understand what to expect. The foils used in these studies are very thin: 127, 75 and 30 micron.

The studies described here were designed to develop guidance that can be used in simulations and planning for experiments using such an installation in the near future. It was hoped to use the results of these studies to develop guidance to be used in planning such installations in the future by trying to measure the effects on the beam transverse size and understand how well it is matched to numerical and analytical predictions.

AWA has already had some experience with this limiting effect of the increase in beam transverse size and emittance due to a Be window. Two experiments (one involving an RF choke cavity and another involving a photonic-band-gap (PBG) structure [2]) come to mind. Both devices had an aperture I.D.=6 mm and also 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 scattering through a Be window was indeed a challenge.

TESTING SEVERAL THIN BE FOILS AT AWA

A motorized actuator was equipped with a custom Be foil holder designed to hold foils of three different thicnesses, 127 µm, 75 µm, and 30 µm probed by electron beams of three different energies: 25, 45, and 65 MeV. The laser pulse length was 6 ps FWHM.

Diagnostics: Two YAG(Ce) scintillator screens for beam spot size and an ICT to measure charge. The first YAG captured the initial size of the beam before scattering, and was located at the foil z-position (on the same actuator). The second YAG was located 88 cm downstream. A quadrupole triplet was used to focus the beam to a small spot at the foil position. Thus the two factors that could be studied were foil thickness and beam energy by observing the increase in transverse beam spot size rmsx and rmsy. See Fig. 1 for a schematic of the experimental setup.

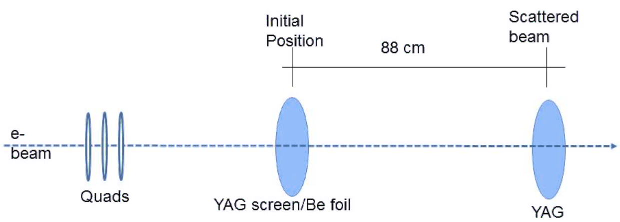

Figure 1: Schematic of the experimental setup. The electron beam propagated from the left, charge measured with an ICT (not pictured) before the foil. The beam was focused by 3 quadrupoles. The image was recorded at the two YAG screens located 88 cm apart, YAG1 at the Be foil position and YAG2 88 cm downstream.

After recording the initial beam image at YAG1, A systematic comparison of beam spot sizes for similar beam conditions on the YAG2 screen with and without the different Be foils in place was performed. The beam energy was varied by turning off RF cavities in the beamline and re-tuning the beam. The beam energy was 65 MeV, 45 MeV and 25 MeV. In each case the mean charge was about 1.5 nC, but the charge varied from less than 1 to more than 2 nC due to laser jitter.

Three quadrupoles located about 1.5 m upstream from the Be foil were used to focus the beam to a small spot on the YAG screen at the position of the foil. Then the beam image was captured using cameras interfaced through a framegrabber, there and at the second YAG with and without the Be foils. The images of the beam spot was analyzed (See Fig. 2). Projections from fits of the intensity distributions were analyzed to calculate the transverse spotsizes rmsx and rmsy. Each table presents the mean results of data taken for one of 3 beam energies, after cut on charge. Charge jitter due to laser intensity fluctuations.was from 0.6 nC to 2.3 nC. Data was cut to include the range from 1.1-2.2 nC.

The initial beam size was made very small to ensure that the beam would not be clipped at the window which has an aperture of 1 cm diameter. The YAG size is 50 mm diameter. The smallest rms sizes extracted have a larger error due to the reduction in pixels available for the fit routine (poor resolution). It is hoped to repeat the experiment with a more tightly focused camera to reduce this source of error.

Experimental results are presented in Fig. 3 (25 MeV data), Fig. 4 (45 MeV data) and Fig. 5 (65 MeV data).

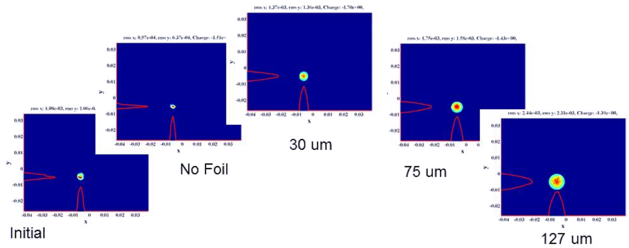

Figure 2: A representative example of the 45 MeV intensity distributions with the projections from fits for the initial spot at YAG1 and the spots at YAG2 for case of each Be foil and no foil.

The effect of scattering on the beam size was quite pronounced, resulting in transverse sizes that were as much as 5 times the un-scattered beam size. However, the case of the 65 MeV beam with 30 micron foil seems promising.

25 MeV	rmsx (mm)	rmsy (mm)	mean Q (nC)
Initial	0.58	0.66	1.46
No foil	1.1	0.97	1.56
30 um	3.9	3.8	1.57
75 um	4.4	3.9	1.48
127 um	5.0	4.5	1.46

Figure 3: 25 MeV results for the 3 Be foils, no foil, and the initial spot at YAG1.

45 MeV	rmsx (mm)	rmsy (mm)	mean Q (nC)
Initial	1.1	0.92	1.46
No foil	0.85	0.60	1.63
30 um	1.4	1.4	1.53
75 um	1.8	1.6	1.58
127 um	2.5	2.3	1.75

Figure 4: 45 MeV results for the 3 Be foils, no foil, and the initial spot at YAG1.

65 MeV	rmsx (mm)	rmsy (mm)	mean Q (nC)
Initial	0.83	0.86	1.82
No foil	0.63	0.71	1.59
30 um	0.95	0.87	1.59
75 um	1.2	1.1	1.51
127 um	1.5	1.4	1.53

Figure 5: 65 MeV results for the 3 Be foils, no foil, and the initial spot at YAG1.

COMPARISON OF SIMULATION RESULTS AND EXPERIMENT RESULTS

The goal of the simulations was to see how well the code could predict the effect of multiple scattering in terms of the experimentally measured transverse spot sizes. The simulations employed G4beamline [3], 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 [4].

The simulations were simplified to the case of a Gaussian beam with the initial energy and transverse size at the screen set to reflect the average from the data. However, not all the beam parameters are well known. For both simulations, a Gaussian beam was assumed and the experimentally measured parameters beam energy (65, 45, and 25 MeV), mean charge (1.5 nC), and initial spot-size at the first YAG screen were the inputs. A comparison of the simulation and data results is shown in Fig. 6 below. Some of the discrepancies are quite large, the closest match being for the 25 MeV, 30 µm foil case. In most other cases the simulation overestimates the scattering effects. The sources of error most likely include the initial beam distribution (the real beam is not a simple Gaussian), energy spread, laser jitter, and other unknown details of the particle distribution, as well as the multiple scattering algorithm in the simulation.In addition, another source of error is the poor resolution in the experimental measurement of the smaller spot sizes.

Foil thickness	30 um		75 um		127 um	
Beam energy	% Increase (on average) in transverse size due to scattering					
	Data	Simulation	Data	Simulation	Data	Simulation
65 MeV	37%	123%	73%	211%	118%	294%
45 MeV	99%	164%	140%	302%	239%	409%
25 MeV	203%	198%	224%	348%	271%	464%

Figure 6: A comparison of the G4beamline simulation and experimental data results of transverse particle distribution measured at initial and final YAG screen

CONCLUSION AND NEXT STEPS

If time permits, it is hoped that a chance will arise to repeat the experiment with better resolution for the spot-size measurements.

AWA is currently planning an experiment with a collaborator involving the use a small aperture (<1 cm diameter), a thin foil (30 micron) and a collimator in order to reduce the effects of scattering on the beam as a follow up to the PBG experiment [2]. In addition, the use of quadrupoles after the window will improve the delivered beam quality. The trade-off is the sacrifice of charge, which in this and many cases, is a luxury that can be afforded, thanks to the high-charge capability of the photo-injector.

In another proposed scenario, a high-charge beam would propagate through the existing Emittance-Exchange (EEX) beamline for bunch compression. The beam would then enter the Be window as a high charge short bunch with a large transverse emittance and exit as a short, low-charge beam with low transverse emittance. If this proves to be a viable plan, it will certainly enhance the experimental program and possibilities at AWA. It is also hoped in the near future to incorporate the multiple scattering through a Be window into future full beamline simulations of sequestered experiments.

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