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DEGRADER BEAMLINE DESIGN AT THE CEBAF INJECTOR FOR MACHINE ACCEPTANCE STUDIES*

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Abstract

A degrader device is being built at the Continuous Electron Beam Accelerator Facility (CEBAF) injector to degrade the electron beam phase space for machine acceptance studies. The electron beam is degraded through multiple scattering in a thin target before further transport in the injector beamline for injection into CEBAF. The degraded electron beam will approximate phase space distributions expected from a bremsstrahlung-based polarized positron source as in the Polarized Electrons for Polarized Positrons (PEPPo) [1] method. The effort is in broader support of the Ce$^+$BAF positron capability [2] that is currently under study. Two options for the degrader device are considered, and simulation results are presented.

INTRODUCTION

The 12 GeV upgrade to the Continuous Electron Beam Accelerator Facility (CEBAF) was completed in 2017 [3]. Measurements of the acceptance of 12 GeV CEBAF have not been made, but can provide valuable information on flexible operation using electron beams with larger transverse and/or longitudinal emittances. Transporting electron beams with degraded transverse and longitudinal emittances will also provide a better understanding of how large positron beams will be transported in CEBAF. This is an important study for assessing CEBAF as a positron machine as it can provide upper limits on positron beam size, and thus positron current, and is in broader support of the Ce$^+$BAF positron capability effort.

Table 1 lists simulated geometric transverse emittances and RMS energy spread of electrons and positrons through CEBAF for 12 GeV operation [4], [5]. In these scenarios, electrons complete all 5.5 passes and are transmitted to Hall D; positrons are extracted after 5 passes. The positron distribution at the end of the injector chicane as listed in Table 1 was estimated by considering the acceptance into the North Linac. Positron beams from a bremsstrahlung-based source are generated with transverse and longitudinal emittances that are much larger than the nominal electron beams available from the CEBAF injector. To best approximate the large positron phase space distributions, a degrader device will be used to perturb the CEBAF electron distributions in a controlled way. The degrader device will be installed in the pre-accelerator of the CEBAF injector beamline, between the quarter cryomodule ("Booster") and the first full cryomodule, to degrade electrons with initial momentum of approximately 7 MeV/c.

DEGRADER CONCEPT

CEBAF electron beams will be degraded through multiple scattering in thin target foils. The initial degrader design explored a bypass chicane for minimal disruption to the existing injector beamline. In this concept, the existing 5D Dipole and three additional dipoles create a 5.5 meter long chicane that bends the electron beam away from the nominal injector beam path, through the degrader target foil and emittance-defining apertures, and returns the degraded beam to the injector beam path for further acceleration. The bypass chicane provides a dispersive region for momentum collimation. A "straight-ahead" degrader section that inserts the degrader target foil and apertures directly into the injector beamline was suggested for ease of implementation at the expense of flexibility, particularly with regard to energy spread definition. We evaluated both designs and present the results in the remainder of these proceedings. Figures 1 and 2 show schematics of the two evaluated designs.

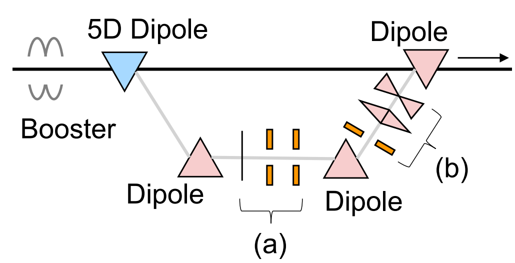

Figure 1: Bypass chicane schematic. (a) Degrader target and transverse emittance-defining apertures. (b) Momentum collimator and quadrupoles. The arrow denotes continuation to the CEBAF injector beamline.

The RMS polar angle induced in an electron beam of energy E passing through a thin target material is given by Eq. (1) [6], where w is the target thickness and X_0 is the material radiation length. The induced energy spread due to multiple scattering is much narrower than the induced angular spread. Low-Z materials will allow for finer control

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Table 1: Simulated Emittances in CEBAF [4], [5]

	Electrons			Positrons		
Area	$\delta p/p[\times 10^{-3}]$	$\varepsilon_x[nm]$	$\varepsilon_y[nm]$	$\delta p/p[\times 10^{-3}]$	$\varepsilon_x[nm]$	$\varepsilon_y[nm]$
Chicane	0.5	4.00	4.00	10	500	500
ARC1	0.05	0.41	0.41	1	50	50
ARC2	0.03	0.26	0.23	0.53	26.8	26.6
ARC3	0.035	0.22	0.21	0.36	19	18.6
ARC4	0.044	0.21	0.24	0.27	14.5	13.8
ARC5	0.060	0.33	0.25	0.22	12	11.2
ARC6	0.090	0.58	0.31	0.19	10	9.5
ARC7	0.104	0.79	0.44	0.17	8.9	8.35
ARC8	0.133	1.21	0.57	0.16	8.36	7.38
ARC9	0.167	2.09	0.64	0.16	8.4	6.8
MYAAT01	–	–	–	0.18	9.13	6.19
ARC10	0.194	2.97	0.95	–	–	–
Hall D	0.18	2.70	1.03	–	–	–

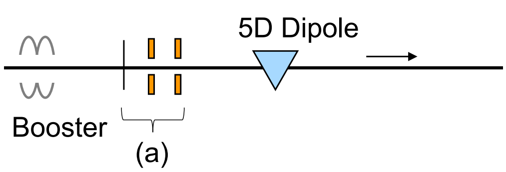

Figure 2: Straight-ahead schematic. (a) Degrader target and transverse emittance-defining apertures. The arrow denotes continuation to the CEBAF injector beamline.

of the transverse characteristics of degraded distributions as well as minimization of beam losses.

$$\theta_{rms} = \frac{13.6}{E[MeV]}\sqrt{\frac{w}{X_0}}(1 + 0.038 \ln \frac{w}{X_0}) \quad (1)$$

Even with thin target foils, the induced angular spread in the beam is much larger than the initial transverse angular spread. Two collimators will be installed as an emittance filter to define the degraded electron phase space distributions for further transport. The maximum transmitted normalized emittance in a three aperture system is determined by the aperture sizes and separation, and is given by Eq. (2) [7], where r_1, r_2, and r_3 are aperture radii and L is the separation between apertures r_1 and r_2, and between apertures r_2 and r_3.

$$\varepsilon^2 = \frac{[\frac{{r_2}^2({r_1}^2+{r_3}^2-2{r_2}^2)}{2} - \frac{({r_1}^2-{r_3}^2)^2}{16}]}{L^2} \quad (2)$$

For a two aperture system, we consider r_1 to be a virtual aperture and take its value to be the RMS beam size at that location, as in [8]. Figure 3 compares the transmitted emittance predicted by Eq. (2) with the transmitted emittance simulated in GEANT4 [9] for varying aperture sizes, fixed beam size r_1=1.68 mm, and fixed aperture separation of L=0.5 m. The simulated emittances agree well with predicted values; the larger simulated values are likely due to electrons scattering in the collimator materials.

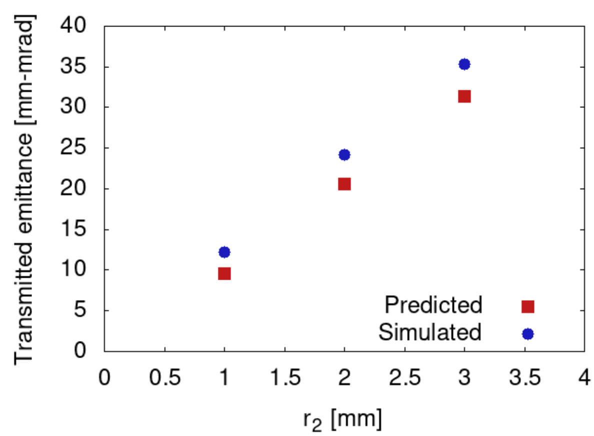

Figure 3: Predicted and simulated emittances transmitted through an emittance filter system consisting of two apertures. The RMS initial beam size is 1.68 mm, aperture separation is 0.5 m, and r_3=2r_2.

DEGRADER TARGET AND COLLIMATOR SIMULATIONS

Target materials and thicknesses were evaluated using GEANT4. The initial approach assumed high-Z target materials, such as the tungsten targets used in the PEPPo experiment. The induced angular spread using thin, high-Z targets would result in significant beam loss at the collimators; Eq. (1) estimates induced angular spread of 320 mrad for a 0.1 mm thick tungsten target at beam momentum of 6.74 MeV/c, the thinnest target in the PEPPo target ladder. Even thin, low-Z targets can result in substantial beam loss at the collimators, depending on the emittance filter setup. Figure 4 plots the predicted and simulated induced RMS

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angular spread for 6.74 MeV/c electrons incident on carbon targets, as well as the resultant energy spread. These distributions are then transported through copper collimators of varying aperture sizes to define the final emittance for further transport in the injector beamline. In addition to transverse emittance filtering, the collimators also reduce the energy spread in the beam.

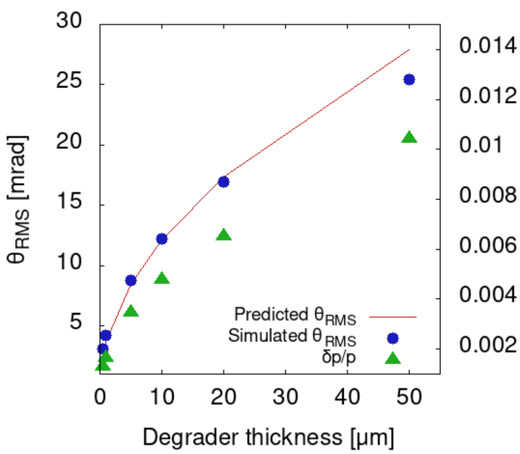

Figure 4: Induced angular and energy spread due to multiple scattering in thin carbon foils.

DEGRADED DISTRIBUTION TRANSPORT

Beam parameters at the projected degrader target location in each beamline option were extracted from initial Elegant [10] simulations and fed into GEANT4 for the degrader target and collimator simulations. The resultant distributions were then imported back into Elegant for tracking simulations through the remainder of the injector beamline. Figure 5 shows the available parameter space for degraded electron distributions from the bypass chicane design for aperture separations of L=0.3 m and 0.5 m. Figure 6 shows the available parameter space from the straight-ahead design for the same aperture separations and same carbon target thicknesses.

We note the similarity in the transverse emittance range covered in the two degrader designs. The flexibility of the bypass chicane option is apparent in the momentum spread range from these initial distributions. Thicker degrader foils and phase offsets in the full accelerating cryomodules of the injector beamline will be explored to reach larger momentum spreads, particularly for the straight-ahead degrader design. We also note that the maximum transverse normalized emittance that can be injected at the front of the CEBAF North Linac is estimated to be 40-120 mm-mrad [2], or 167-500 nm-rad geometric emittance at injection energy of 123 MeV. Thus the anticipated range explored using this degrader device substantially overlaps the projected positron transverse emittance.

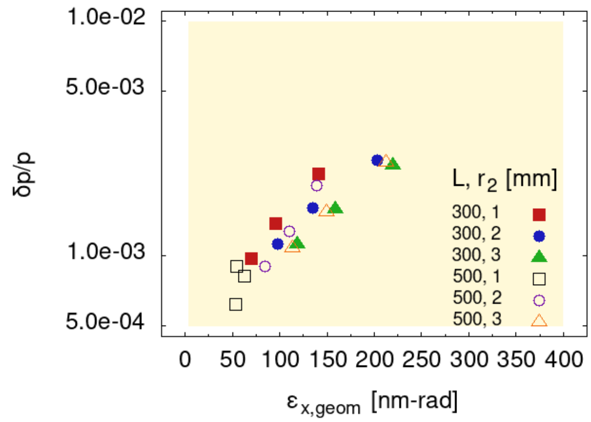

Figure 5: Degraded electron parameter space available from the bypass chicane degrader for carbon targets of thickness 0.5, 1, and 5 μm. The yellow rectangle spans the desired parameter space.

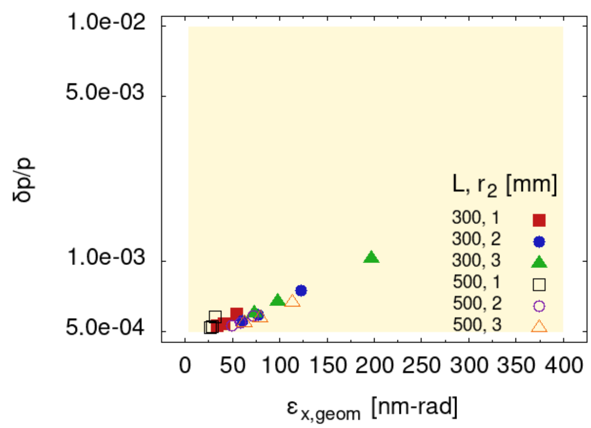

Figure 6: Degraded electron parameter space available from the straight-ahead degrader for carbon targets of thickness 0.5, 1, and 5 μm. The yellow rectangle spans the desired parameter space.

OUTLOOK

The straight-ahead degrader section has been selected for implementation. Final selection of aperture separation and aperture sizes will be completed in order to begin collimator fabrication. Installation is anticipated during the Scheduled Accelerator Down in Spring 2024 and first measurements are anticipated in Summer 2024.

ACKNOWLEDGMENTS

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REFERENCES

[1] D. Abbott *et al.*, "Production of Highly Polarized Positrons Using Polarized Electrons at MeV Energies," *Phys. Rev. Lett.*,

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vol. 116, p. 214 801, 21 2016.
doi:10.1103/PhysRevLett.116.214801

[2] J. Grames *et al.*, "Positron Beams at Ce+BAF," presented at IPAC'23, Venice, Italy, May 2023, paper MOPL152, this conference.

[3] M. Spata, "12 GeV CEBAF Initial Operational Experience and Challenges," in *Proc. IPAC'18*, Vancouver, BC, Canada, Apr.-May 2018, pp. 1771-1775.
doi:10.18429/JACoW-IPAC2018-WEYGBD1

[4] Y. Roblin, "Using CEBAF as a positron machine," Thomas Jefferson National Accelerator Facility (TJNAF), Newport News, VA, USA, JLAB-TN-21-043, Sep. 2017.

[5] T. Satogata, Y. Roblin, M.G. Tiefenback, and D.L. Turner, "12 GeV CEBAF Transverse Emittance Evolution," in *Proc. IPAC'15*, Richmond, VA, USA, May 2015, pp. 640-642.
doi:10.18429/JACoW-IPAC2015-WEBD1

[6] "Electromagnetic and Nuclear Interactions," in *Handbook of Accelerator Physics and Engineering*, A.W. Chao, K.H. Mess, M. Tigner, and F. Zimmermann, Eds. Singapore: World Scientific, 2013, pp. 267.

[7] P. K. Kloeppel, "Emittance measurement with one or three profile monitors: a comparison," Thomas Jefferson National Accelerator Facility (TJNAF), Newport News, VA, USA, CEBAF-TN-89-0191, Dec. 1989.

[8] G. Neil, "Transmission of the CEBAF Injector Apertures," Thomas Jefferson National Accelerator Facility (TJNAF), Newport News, VA, USA, CEBAF-TN-90-261, Sep. 1990.

[9] S. Agostinelli *et al.*, 'GEANT4 - a simulation toolkit", *Nucl. Instrum. Meth. A.*, vol. 506, pp. 250-303, 2003.
doi:10.1016/S0168-9002(03)01368-8

[10] M. Borland, "elegant: a flexible SDDS-Compliant Code for Accelerator Simulations", ANL, Lemont, IL, USA, APS LS-287, Sep. 2000.