PROCEEDINGS OF SCIENCE

PoS(PSTP2024)072

Polarized Positrons at Ce$^+$BAF

A. Ushakov^{a,*} **for the Ce$^+$BAF working group**

[a] *Thomas Jefferson National Accelerator Facility,*
Newport News, VA 23606, USA

E-mail: ushakov@jlab.org

A baseline concept for a continuous wave (CW) polarized positron injector was developed for the Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab [1]. This concept is based on positron beam generation by a high current polarized electron beam (1 mA, 120 MeV, >85% polarization) irradiating a rotating water-cooled tungsten target or liquid metal target. The update on the development of the Ce$^+$BAF injector concept including the polarized electron source, the development of high power targets, simulations of positron capture, the design of the transport line from the positron injector to the CEBAF North Linac and the planned experiment to measure the upper limits of transverse and longitudinal emittances accepted by the 12 GeV CEBAF optics are presented.

20th International Workshop on Polarized Source, Targets, and Polarimetry
22-27 September 2024
Jefferson Lab, Newport News, Virginia, USA

---

[*] Speaker

ISSN 1824-8039. Published by SISSA Medialab.

1. Introduction

The polarized electron beams of the Continuous Electron Beam Accelerator Facility (CEBAF) [2] have played an important role in advancing our knowledge in hadronic physics for nearly 30 years. Currently, Jefferson Lab (JLab) is exploring a CEBAF upgrade that would provide polarized positron beams to address new physics [3]. Six positron experiments covering a range of physics topics, Generalized Parton Distributions (GPDs), Two Photon Exchange (TPE), and Beyond the Standard Model (BSM), have been conditionally approved by the JLab Program Advisory Committee (PAC) [4]. The approved program includes 210 PAC days of measurements in Hall B and 202 PAC days in Hall C (a PAC day is equal to two calendar days).

A 123 MeV positron injector is proposed to be built at the Low Energy Recirculator Facility (LERF) to take advantage of existing electrical, cryogenic and shielding facilities at LERF. The positrons are transported from the LERF to the front of the North Linac (NL), where they are injected and delivered to the experimental halls with beam energies up to 12 GeV. The scheme of the proposed layout is shown in Fig 1. In this paper, we report ongoing activities for the simulation of positron generation and capture, target and cavity development, beam transport, and an experiment to measure positron beam acceptance.

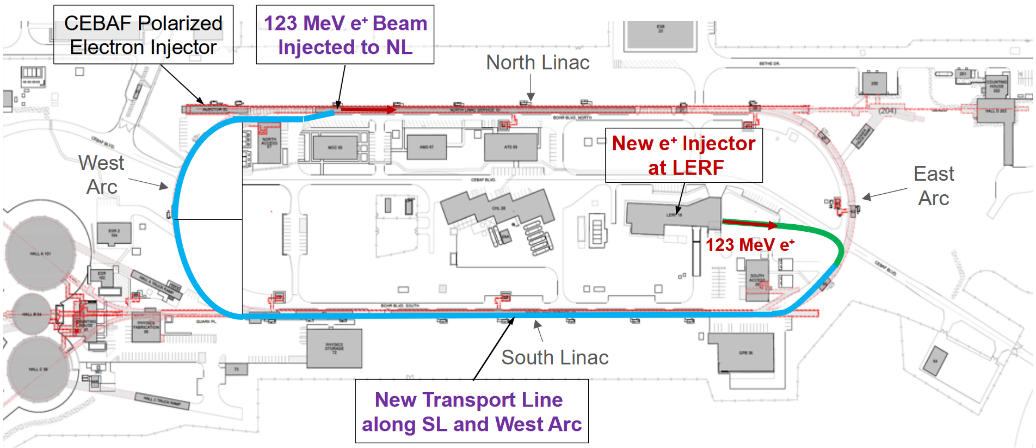

Figure 1: Positron injector at LERF and transport line to north linac.

2. Drive Electron Beam for Generation of Polarized Positron Beam and Conversion Target

The scheme for the positron injector at LERF is shown in Fig. 2. The Polarized Electrons for Polarized Positrons (PEPPo) technique [5] is used for positron production and polarization transfer from a longitudinally polarized electron beam to positrons via bremsstrahlung radiation and e^+e^--pair production in a conversion target. The drive electron beam line consists of a 10 MeV source with polarization greater than 85% and two superconducting accelerator modules (SRF) in which the polarized electron beams are accelerated to 120 MeV.

Simulations have shown using 1 mA polarized beam with >90% spin polarization, it is possible to design the Ce$^+$BAF injector to deliver either more than 50 nA of positron beam with polarization

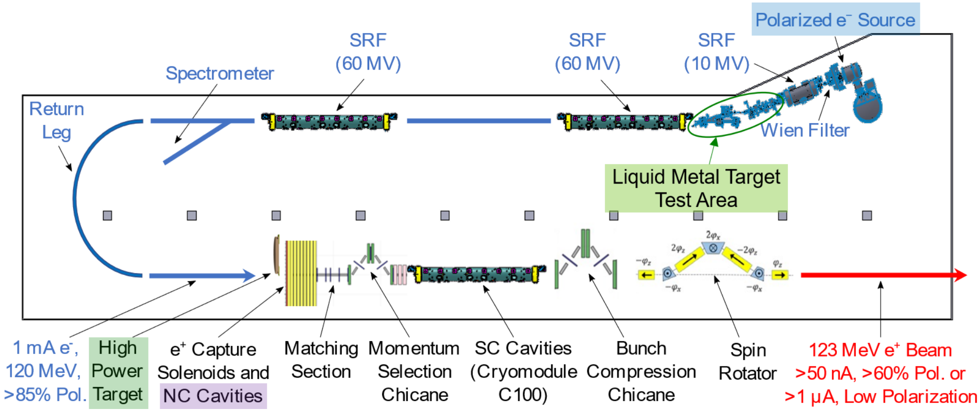

Figure 2: Scheme of positron injector at LERF.

greater than 60%, or more than 1 μA of low-polarization positrons [6]. The requirement for such a high electron current, combined with the unprecedented lifetime of highly polarized photocathodes (>1000 C to operate the source for up to two weeks without intervention), is one of the major technical risks of the Ce$^+$BAF program. The development of a prototype photogun for the Ce$^+$BAF positron source has started [7] and is supported by the JLab LDRD (Laboratory Directed Research and Development) program in fiscal years 2025 and 2026. The program includes: design, fabrication, and testing of the new photogun with improved lifetime; lifetime measurements, Quantum Efficiency (QE) damage mapping, and comparison of measured data with simulations.

Designing a high power conversion target is another challenge associated with high electron beam current and power. Two target designs are under development: a rotated water-cooled tungsten target [8] and a liquid metal target [9].

The positron production in the tungsten target by the 120 MeV positrons has been studied. For a simplified positron capture model, taking into account the assumption of a certain fixed acceptance of the capture system in terms of positron momentum and angle at the target exit, it was found that 4 mm is the optimal thickness of the tungsten target at 120 MeV [10]. Computational Fluid Dynamics (CFD) analysis and thermal assessment of the tungsten target, which must withstand a thermal load of approximately 17 kW [8], is ongoing. The rotating tungsten target with a deposited power of 18.8 kW is being developed for the electron-driven positron source of the International Linear Collider (ILC) [11]. However, the thickness of the ILC target is 16 mm, and the average heating power per unit thickness for the Ce$^+$BAF target is 3.6 times that of the ILC target.

A U.S.-Japan (SLAC/JLab/KEK) collaboration on exchange e$^-$ and e$^+$ source concepts is supported by the US Department of Energy (DOE) High Energy Physics (HEP) program ‘‘Advanced Positron Concepts’’. Ce$^+$BAF target development, CFD thermal analysis, and prototype testing are funded at Jefferson Lab by (DOE) NP-FOA Research and Development for Next Generation Nuclear Physics Accelerator Facilities.

Liquid metal targets are developed by Xelera Research LLC. The liquid targets allow the use of higher drive beam currents compared to solid targets and therefore higher positron currents can be achieved. The prototype of a recirculated free surface liquid jet GaInSn target is being designed and fabricated [9] and is planned to be tested at JLab with a low energy polarized e$^-$ beam (< 10 MeV) in the LERF test area downstream of the 10 MV SRF module, see Fig. 2. Research and testing of the GaInSn target is supported by the DOE Small Business Innovation Research (DOE SBIR) program.

3. Positron Capture Simulations

The concept of positron capture and acceleration is shown schematically in Fig. 2. It includes capture solenoids, normal conducting cavities, matching section, momentum selection chicane, superconducting (SC) accelerator module, bunch compression chicane and spin rotator. The simplified geometry and ideal field distributions of the solenoids and cavities have been used in previous studies of positron beam capture [6]. Now realistic geometries and field maps are used for capture solenoids, NC and SC cavities.

The positrons at the beginning of the capture system (or at the target exit) have an energy spectrum from zero to almost the energy of the driving electron beam (120 MeV) and a very high divergence angle (the root mean square (rms) angles in the lateral x- and y-directions are 28 degrees [4]). The e$^+$ captured yield and average polarization can be estimated from the positron data at the target exit, assuming a limited energy and angular acceptance of the capture system. The same approach was used in studies by S. Habet [6, 10]. The e$^+$ yield (Y), defined as the number of captured positrons per primary electron, for the tungsten target with a thickness of 4 mm, an energy acceptance of 10‰ and an angular acceptance of 5 deg is shown in Figure 3 on the left plot and the longitudinal polarization (P) on the right plot. The calculations for different thicknesses of tungsten and liquid PbBi targets at 120 MeV and for liquid GaInSn target of 3 mm thickness at several electron beam energies below 10 MeV were presented at this workshop [12].

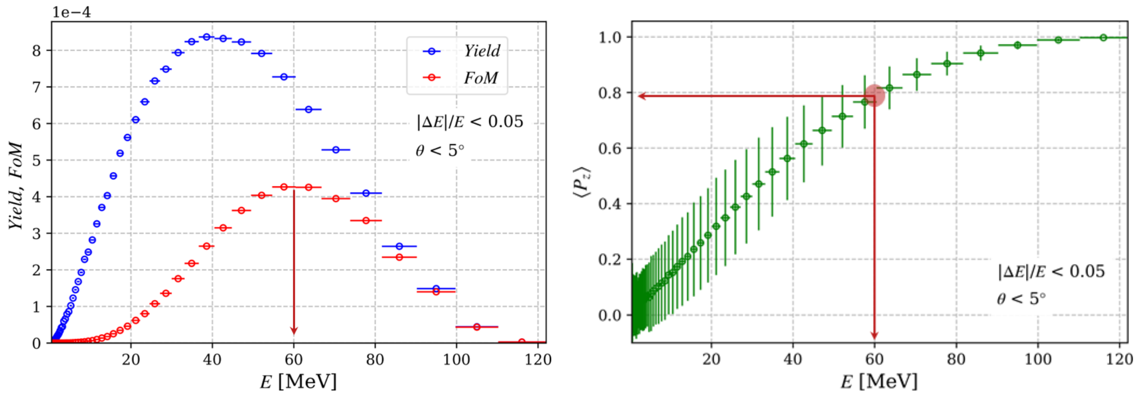

Figure 3: Left plot: Positron yield and Figure-of-Merit (FoM) in units of number of positrons per primary electron and for a variable bin size defined by an energy spread of 10‰ and a maximal angle to the z-axis of 5 deg versus positron energy at the exit of a 4 mm tungsten target. Right plot: Average longitudinal polarization of positrons versus positron energy for the electron beam with $P_{e^-} = 1$.

A positron energy of 40 MeV is the optimal (Y is maximal) for physics experiments that are not concerned by positron polarization or for the unpolarized mode of the positron injector with the 4 mm tungsten target. For the polarization sensitive experiments, the achievable statistical accuracy in a given time is inversely proportional to the Figure-of-Merit (FoM), defined as the product of the yield and the square of the longitudinal polarization. For such experiments, it is better to adjust the positron capture to 60 MeV (half the drive beam energy), where the FoM is maximal

($P_{e^+} \approx 0.78 P_{e^-}$). Such a simple approach to estimate P_{e^+} does not take into account all the complexities of the beam dynamics in the e$^+$ injector, the acceptances of the transverse emittance and the longitudinal bunch length, but nevertheless it is in good agreement with a preliminary calculated polarization of $\simeq 70\%$ at the end of the SRF accelerator module C100 for $P_{e^-} = 0.85$ and for the beam line schematically shown in Fig. 4.

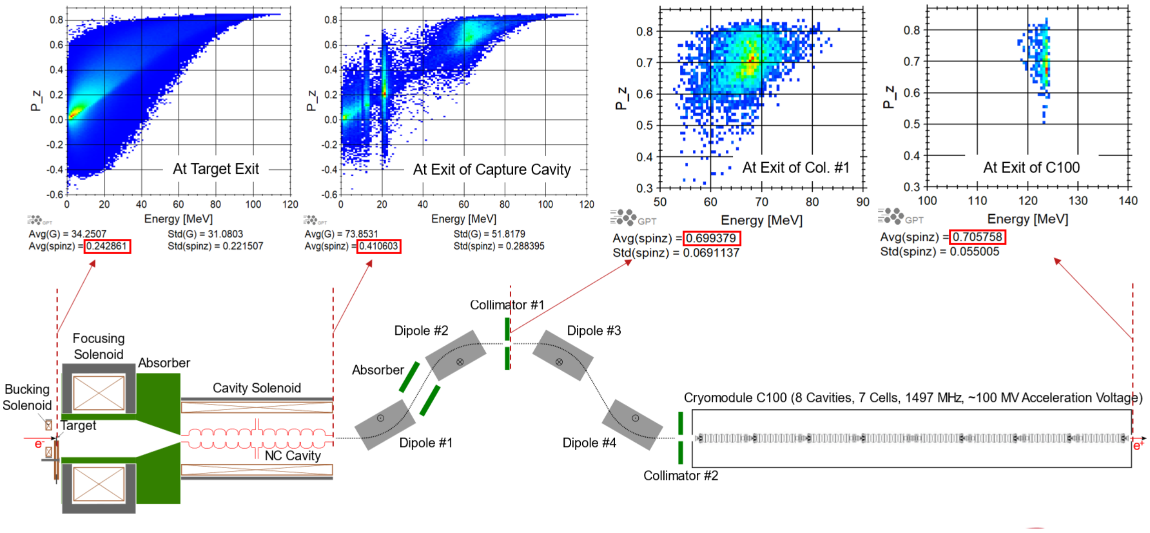

Figure 4: Layout of positron beam line and distributions of polarization versus energy at different locations (target, end of normal conducting capture cavity, middle of energy selection chicane, and end of SRF module C100).

Capture solenoids and the 1497 MHz continuous wave normal conducting capture cavity are under development, and simulations of positron capture and acceleration to 123 MeV are ongoing [13, 14]. The capture system must be flexible for capturing positrons of different energies at the target exit. The development of capture cavity, the e$^+$ injector design and optimal integration of injector components is supported by a JLab LDRD. Calculations of the beam power deposited in the capture system and the design of the required shielding, especially in the target area (target, focusing solenoid and capture cavity), where 115 kW (96%) of the drive beam power is absorbed have begun [13]. The focusing solenoid with a peak field of ~1 Tesla, a coil length of 50 cm and an inner radius of 30 cm and the 11-cell standing wave capture cavity with an iris radius of 4 cm and a peak gradient of 4 MV/m were used in the capture simulations presented at IPAC'24 [13] and in the calculations shown in Fig. 4. Various alternative cavity geometries will be used in further beam dynamics studies, and higher order mode analysis and thermal analysis will be performed in the next phase of this work.

4. Concept of Transfer Line from LERF to CEBAF North Linac

The concept of a low-dispersion e$^+$ transfer line from the LERF to the North Linac, shown in Fig. 5, was developed. The simulations of beam and spin tracking from the end of the positron injector through the Ce$^+$BAF up to the experimental halls with energies up to 12 GeV will be performed soon.

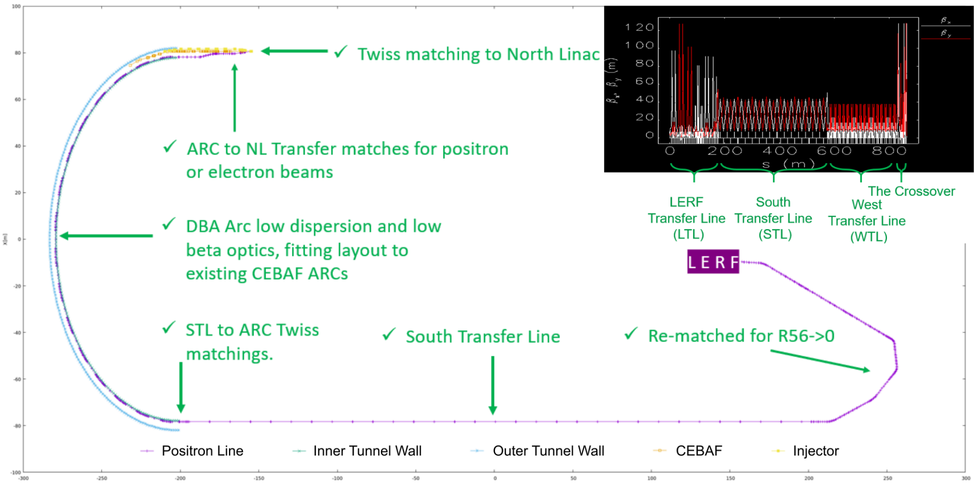

Figure 5: Low-dispersion e$^+$ transfer line from LERF to CEBAF North Linac.

5. Measurements of Maximal CEBAF Acceptance

In order to measure the upper limits of transverse and longitudinal emittances that can be accepted by the 12 GeV CEBAF accelerator, it is planned to perform experiments using an electron beam with degraded (increased) emittances compared to the typical electron beam at CEBAF. The degrader apparatus consists of the target ladder supporting a viewer and three thin carbon foils of 1 μm, 5 μm and 10 μm thickness followed by two apertures for beam collimation and to limit the emittance of the beam, and a solenoid. The radius of the apertures can be changed: 1 mm or 3 mm for the first aperture and 4 mm or 8 mm for the second one. The details of the degrader design and the projected degraded beam phase space parameters obtained by simulation were presented at IPAC'24 [15, 16]. The degrader was built and installed in the injector beam line after the booster, where the electron beam has an energy of 6.3 MeV. Commissioning and measurements will begin soon (February 2025).

Summary

We are developing a design for the Ce$^+$BAF 12 GeV accelerator with the capability of spin polarized positron beams. Ongoing work includes the optimization of the positron capture system, beam and spin tracking simulations in the injector, the transport line from the LERF to the North Linac and later to the experimental halls. Several critical risk areas were identified, such as the high current (1 mA) polarized electron source, high power targets (solid and liquid) and the capture cavity. Work in these areas and the electron degrader experiment is supported by various US DOE and JLab LDRD projects with the goal of completing the conceptual design of the Ce$^+$BAF injector and writing a white paper.

Acknowledgments

The work presented here was done within the Ce$^+$BAF Working Group and all contributions are gratefully acknowledged. This project is supported by the U.S. Department of Energy, Office of

Science, Office of Nuclear Physics under contract DE-AC05-06OR23177. The research described in this paper was conducted under the Laboratory Directed Research and Development Program at Thomas Jefferson National Accelerator Facility for the U.S. Department of Energy. The development of the solid target is supported by the DOE NP-FOA Research and Development for Next Generation Nuclear Physics Accelerator Facilities. Xelera Research LLC's development of the liquid target is supported by the DOE SBIR program. A U.S.-Japan collaboration is supported by the DOE HEP ''Advanced Positron Concepts'' program. Partial financial support for the Ph.D. student V. Lizárraga-Rubio was received from the National Council of Humanities, Sciences and Technologies (CONAHCYT).

References

[1] J. Grames *et al.*, ''Positron beams at Ce$^+$BAF'', in *Proc. 14th Int. Particle Accelerator Conf. (IPAC'23)*, Venice, Italy, MOPL152, pp. 896–899 (2023). doi:10.18429/JACoW-IPAC2023-MOPL152

[2] P. A. Adderley *et al.*, ''The Continuous Electron Beam Accelerator Facility at 12 GeV``, *Phys. Rev. Accel. Beams* **27**, 084802 (2024). doi:10.1103/PhysRevAccelBeams.27.084802

[3] A. Accardi *et al.*, ''An experimental program with high duty-cycle polarized and unpolarized positron beams at Jefferson Lab``, *Eur. Phys. J. A* **57**, 261 (2021). doi:10.1140/epja/s10050-021-00564-y, arXiv:2007.15081

[4] Y. Roblin for the Ce$^+$BAF collaboration, ''The Ce$^+$BAF positron project'', in *Proc. 31st Int. Workshop on Deep Inelastic Scattering (DIS2024)*, Grenoble, France, 275 (2024). doi:10.22323/1.469.0275

[5] D. Abbott *et al.*, ''Production of highly polarized positrons using polarized electrons at MeV energies'', *Phys. Rev. Lett.* **116**, 214801 (2016). doi:10.1103/PhysRevLett.116.214801

[6] S. Habet, ''Concept of a polarized positron source for CEBAF'', Doctorate Thesis, Paris-Saclay University, France (2023). https://theses.fr/2023UPASP170

[7] M. Bruker *et al.*, ''Toward a long-lifetime polarized photoelectron gun for the Ce$^+$BAF positron source'' in *Proc. 15th Int. Particle Accelerator Conf. (IPAC'24)*, Nashville, TN, USA, MOPC52, pp. 176-179 (2024). doi:10.18429/JACoW-IPAC2024-MOPC52

[8] A. Ushakov *et al.*, ''Evaluation of a high-power target design for positron production at CEBAF'', in *Proc. 14th Int. Particle Accelerator Conf. (IPAC'23)*, Venice, Italy, WEPM120, pp. 3842–899 (2023). doi:10.18429/JACoW-IPAC2023-WEPM120

[9] N. Taylor *et al.*, ''A high-power positron converter based on a recirculated liquid metal in-vacuum target'', in *Proc. 15th Int. Particle Accelerator Conf. (IPAC'24)*, Nashville, TN, USA, TUPC83, pp. 1210–1213 (2024). doi:10.18429/JACoW-IPAC2024-TUPC83

[10] S. Habet, A. Ushakov, and E. Voutier, ‘‘Characterization and optimization of polarized and unpolarized positron production’’, Tech. Note PEPPo TN-23-01, JLAB-ACC-23-3794 (2023). doi:10.48550/arXiv.2401.04484

[11] T. Omori *et al.*, ‘‘Development of rotating target with ferrofluid seal for ILC electron-driven positron source’’, arXiv:2407.00587 (2024). doi:10.48550/ARXIV.2407.00587

[12] V. M. Lizárraga-Rubio *et al.*, ‘‘Liquid metal-based polarized positron generation benchmark using the Geant4 toolkit’’, this workshop.

[13] A. Ushakov *et al.*, ‘‘Simulations of positron capture at Ce$^+$BAF’’, in *Proc. 15th Int. Particle Accelerator Conf. (IPAC’24)*, Nashville, TN, USA, MOPC54, pp. 184-187 (2024). doi:10.18429/JACoW-IPAC2024-MOPC54

[14] S. Wang *et al.*, ‘‘Capture cavities for the CW polarized positron source Ce$^+$BAF’’, in *Proc. 15th Int. Particle Accelerator Conf. (IPAC’24)*, Nashville, TN, USA, MOPC51, pp. 173-175 (2024). doi:10.18429/JACoW-IPAC2024-MOPC51

[15] A. Sy *et al.*, ‘‘Towards large phase space beams at the CEBAF injector’’, in *Proc. 15th Int. Particle Accelerator Conf. (IPAC’24)*, Nashville, TN, USA, MOPC53, pp. 180-183 (2024). doi:10.18429/JACoW-IPAC2024-MOPC53

[16] V. Lizárraga-Rubio *et al.*, ‘‘Computational simulations and beamline optimizations for an electron beam degrader at CEBAF’’, in *Proc. 15th Int. Particle Accelerator Conf. (IPAC’24)*, Nashville, TN, USA, MOPC62, pp. 204-207 (2024). doi:10.18429/JACoW-IPAC2024-MOPC62

The Ce$^+$BAF Working Group

J. Benesch[1], M. Bruker[1], L. Cardman[1a], J. Conway[2], S. Covrig Dusa[1], P. Degtiarenko[1], Y. Enomoto[3], S. Gessner[4], P. Ghoshal[1], S. Gopinath[1], J. Grames[1], C. Gulliford[2], S. Habet[5], G. Hays[1], C. Hernández-García[1], A. Hofler[1b], R. Kazimi[1], M. Kostin[1], V. O. Kostroun[2], F. Lin[6], V. Lizárraga-Rubio[7], K. Mahler[8], Y. Morikawa[3], S. Nagaitsev[9], S. Ogur[1], G. Palacios-Serrano[1], N. Raut[1], B. Rimmer[1], Y. Roblin[1], A. Seryi[1], K. Smolenski[2], M. Stutzman[1], R. Suleiman[1], A. Sy[1], N. Taylor[2], D. Turner[1], A. Ushakov[1], C. Valerio-Lizarraga[10], E. Voutier[11], S. Wang[1], Y. Zhang[1]

[1] Thomas Jefferson National Accelerator Facility, Newport News, VA, USA
[2] Xelera Research LLC, Ithaca, NY, USA
[3] KEK, High Energy Accelerator Research Organization, Tsukuba, Ibaraki, Japan
[4] SLAC National Accelerator Laboratory, Menlo Park, CA, USA
[5] Synchrotron SOLEIL, Gif-sur-Yvette, France
[6] Oak Ridge National Laboratory, Oak Ridge, TN, USA
[7] Universidad de Guanajuato, Leon, Guanajuato, Mexico
[8] Old Dominion University, Norfolk, VA, USA
[9] Brookhaven National Laboratory, Upton, NY, USA
[10] Universidad Autonoma de Sinaloa, Culiacan, Sinaloa, Mexico
[11] Université Paris-Saclay, CNRS/IN2P3, IJCLab, Orsay, France

[a] Deceased
[b] Retired