Narrative

To fully explore the potential of CEBAF 12 GeV, beams of polarized and unpolarized positrons with quality and modes of operation similar to those of the polarized electron beam are highly desirable. The JLab Positron Working Group, formed in 2018 and now with over 250 members from 75 institutions, continues to build out a case to support this cause, and has explored an experimental program with high duty-cycle positron beams [1, 2].

The creation of positrons with a high degree of spin polarization is however very challenging – limited to beta decay, self-polarization in rings, or via e+/e- pair-production, a process requiring a source of polarized gamma rays. At JLab we have a unique source of polarized gamma rays – the bremsstrahlung radiation produced when the spin polarized electron beams of CEBAF interacts with matter – called Polarized Electrons for Polarized Positrons (or PEPPo). In this new technique, the high electron spin polarization (~90%) like that generated at the CEBAF photo-injector is instead transferred via an electromagnetic shower, initially by polarized bremsstrahlung and then by polarized e+/e- pair creation, within a high-Z "beam dump" target. This technique was successfully demonstrated using an 8.9 MeV/c e- electron beam, resulting in positron polarization up to 82% [3]. Most importantly, this technique is essentially independent of the initial electron beam energy, providing great flexibility in the choice of the electron injector to be used, to establish the positron yield which determines the e+ beam intensity.

Within this framework, a Jefferson Lab LDRD [4] project studied options for implementing a polarized electron driven positron injector and evaluated a rudimentary design for CEBAF. One configuration interacted the CEBAF 123 MeV e- beam with a 4 mm thick tungsten target. High Tesla-level solenoidal magnetic fields and RF cavities define, collect and compress the positron shower into a useful high duty-factor bunch structure, suitable for acceleration to 12 GeV. The study yielded positron beams with collection efficiencies (Ne+/Ne-) ranging from 0.66×10^{-4} (polarized) to 1.90×10^{-4} (unpolarized). Consequently, it appears feasible that a polarized electron beam with intensity >1 mA may generate e+ beams with polarization >60% and intensities >100 nA, and correspondingly higher e+ beam intensities when polarization is not essential. Such a polarized electron source capability, while not routine, has been demonstrated [5] and is assumed.

Given the promise of this approach Jefferson Lab is continuing expanded follow-on studies of a future positron beam source for CEBAF. Additionally, the approach now focuses on utilizing the Low Energy Research Facility (LERF, former FEL) as the site for the new positron beam source. The LERF affords significant existing facilities (cryogenics, LCW, shielding, electronics bays, RF penetrations, control room) and notably a footprint which provide for up to 3 superconducting radio-frequency (SRF) cryomodules to support the e- drive beam and e+ acceleration.

In the present scheme two new injectors (Fig.1) are imagined in LERF. The first will be an electron injector, with polarized beams provided by a GaAs/GaAsP photocathode in a dc-high voltage gun. An electron bunch train with a 1.497 GHz repetition rate and bunch charge >0.67 pC (>1 mA) are then accelerated up to between 75-150 MeV in one or two CEBAF-style SRF cryomodules. The electron beam is extracted to a shielded bunker containing the positron radiator. Inside, a water-cooled tungsten or tungsten alloyed target is considered, composed in the form of a spinning disk to dissipate the expected fraction of beam power deposited within it (~20 kW). Pair-created e+

(or e-) are selected in a quarter-wave solenoid transformer and matched into a normal conducting capture-linac to improve the e+ yield and suppress the large initial emittance. The collection system, tuned for a desired fraction of the e- drive beam momentum, defines the initial e+ yield (and polarization) distribution. The remaining spent beam power and electron drive beam are separated and dissipated in water cooled absorbers. The selected positron bunch train passes a bunch compressor prior to entering a final SRF CM for acceleration to 123 MeV.

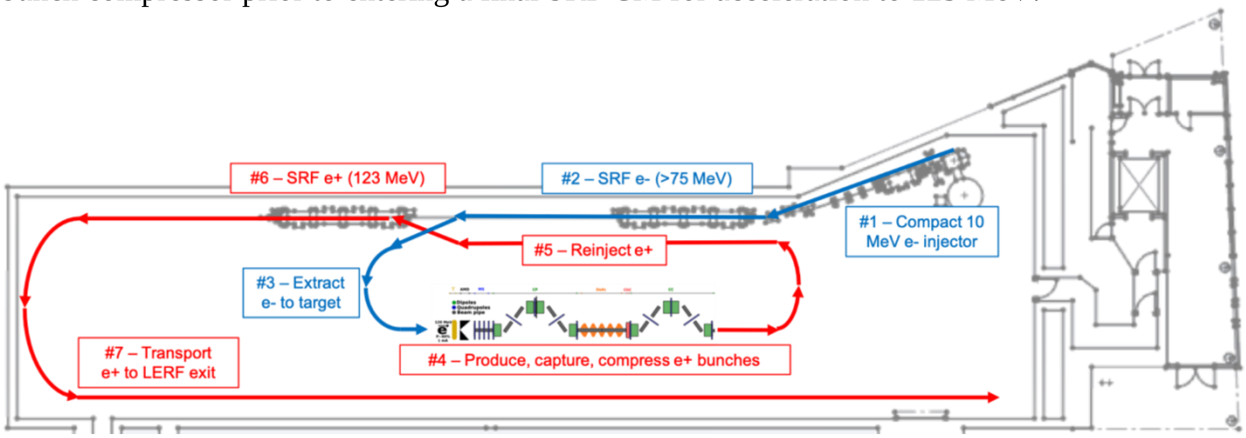

Figure 1. Sequence of a new polarized SRF electron injector (blue) followed by the positron target, collection and SRF e+ CM acceleration and transport lines within LERF (red) are shown.

Once the 123 MeV e+ beam is created, it is then a matter of transporting it to CEBAF for acceleration to 12 GeV. Leaving the LERF, the e+ beam is passed through a new connector tunnel to the lower elevation of the CEBAF enclosure. The new transport line enters into the East Arc, where a long FODO lattice manages the positron beam envelope within the CEBAF tunnel along the ceiling East Arc, South Linac, and West Arc. The 123 MeV e+ beam is injected at the usual point in front of the NL for multi-pass acceleration and beam extraction to any of the four Halls at any of the passes. Additionally, the intention is for all of the CEBAF electro-magnets to have a capability for polarity reversal on the scale of a day, for experiments which required both e+ and e- pair-created beams from the LERF source.

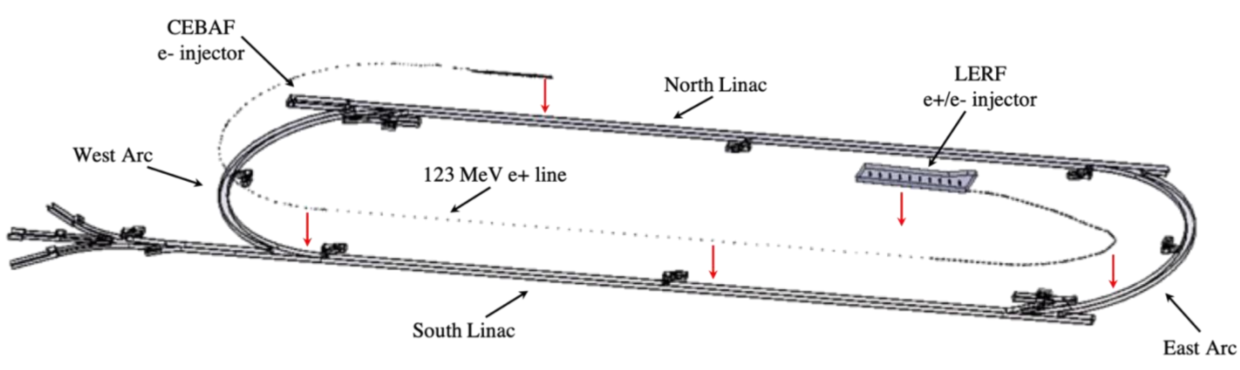

Figure 2. A new tunnel and beam line (shown raised) connects the LERF to CEBAF and transports the 123 MeV e+ beam for injection and acceleration into CEBAF 12 GeV.

Finally, it is anticipated the original CEBAF polarized electron injector will remain intact and functional during the era of positron beams. This provides Jefferson Lab a possibility to shift programs (e.g. during a Scheduled Accelerator Down) back to the original CEBAF 12 GeV e- injector as needed. Later, to support the energy upgrade, the LERF and new transport lines would be re-utilized to create and inject 650 MeV e- beams for the CEBAF 22 GeV upgrade. At this time, the original CEBAF polarized e- injector and LERF e+/e- source would likely be decommissioned and repurposed.

References

[1] J. Arrington, et al., "Physics with CEBAF at 12 GeV and Future Opportunities" (2021) https://arxiv.org/abs/2112.00060.

[2] A. Accardi, et al., "An experimental program with high duty-cycle polarized and unpolarized positron beams at Jefferson Lab" (2020) https://arxiv.org/abs/2007.15081

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

[4] J. Grames (on behalf of the LDRD Positron Team), "Positrons for Our Future", LDRD Final Project Report, Project ID 2021-LDRD-L2104 (2021).

[5] J. Grames, et al., Proceedings, 17th International Workshop on Polarized Sources, Targets, and Polarimetry (PSTP2017): Kaist, South Korea, October 16-20, 2017 (2018).