PROCEEDINGS OF SCIENCE

The Ce$^+$BAF positron project

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Jefferson Lab is proposing to add positron beams to the 12 GeV Continuous Electron Beam Accelerator Facility (CEBAF). A team of accelerator, physics and engineering staff have been developing the concept for the generation, production and delivery of Continuous (CW) polarized positron beams to the experimental halls, up to the full 12 GeV. A layout of the proposed concept will be shown. We will report on the ongoing efforts in the positron generation and capture, target design, beam transport and expected properties of the e+ beam on the experimental targets at 12 GeV.

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[*] Speaker

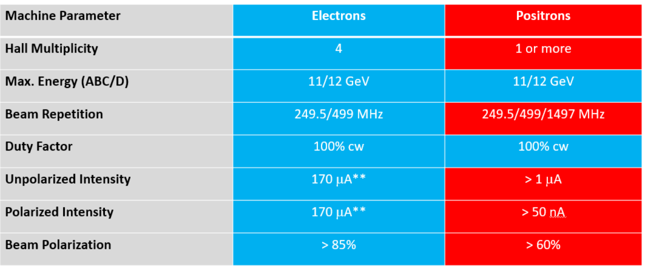
1. Motivation

The Continuous Electron Beam Accelerator Facility (CEBAF) [1] at Jefferson Lab has played an important role in advancing our knowledge in hadronic physics by providing a polarized electron beam with high duty cycle. It enabled investigating the nucleons and nuclei, in both elastic and inelastic processes allowing for the determination of electromagnetic form factors, or more recently generalized parton distributions (GPD). The high polarization of the electrons provides for tests of parity violating processes as well as weak interaction. It was recognized over a decade ago that extending the capabilities of CEBAF with a positron beam would open up a whole range of physics processes that are otherwise inaccessible or difficult to measure due to the competing backgrounds. This led to the creation of a positron working group which culminated in the publication of a white paper [2] laying the grounds for a rich experimental program. Jefferson Lab has already approved several years of experiments covering various physics topics making use of both unpolarized and polarized positron beams.

2. Conceptual design and layout

2.1 Beam specifications

A comparison of the expected beam specifications between the new positron and existing electron beam is given in figure 1.



Machine Parameter	Electrons	Positrons
Hall Multiplicity	4	1 or more
Max. Energy (ABC/D)	11/12 GeV	11/12 GeV
Beam Repetition	249.5/499 MHz	249.5/499/1497 MHz
Duty Factor	100% cw	100% cw
Unpolarized Intensity	170 μA**	> 1 μA
Polarized Intensity	170 μA**	> 50 nA
Beam Polarization	> 85%	> 60%

Figure 1: Beam specifications for the positron beam relative to the e- beam.

A schematic of the proposed layout and its integration with the main CEBAF accelerator is shown in Fig 2. The positrons are generated in the Low Energy Recirculator Facility (LERF), captured and accelerated up to 123 MeV/c, transported to the front of the north linac where they are injected for subsequent acceleration up to 11 or 12 GeV and delivered to the experimental halls.

The intensity of that positron beam ranges from tens of nanoamperes for polarized positrons to several microamperes for unpolarized positrons.

2.2 Beam transport

Beam lines have been designed to accommodate the large energy spread and transverse emittance of the positron beam. A new tunnel will be constructed to bring the beam to the CEBAF machine where it will be further transported via new beam lines attached to the ceiling of the existing tunnel to be injected in front of the north linac.

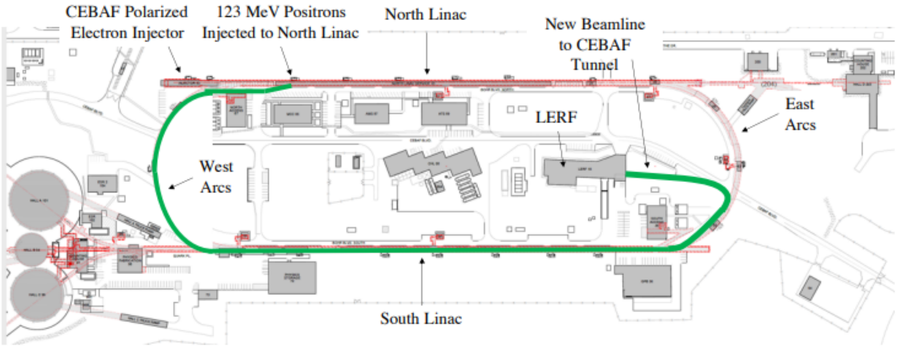


Figure 2: The Positron Beam generated in the LERF is transported to the CEBAF accelerator and injected at 123 MeV.

A spin rotator is being designed to orient the polarization vector such that the resulting polarization in the experimental halls is maximized. This is done by a design similar to those being considered for EIC [3] and it will be located in the LERF in the 123 MeV/c region.

3. High power target designs

The positron production and polarization transfer from a CW longitudinally polarized electron beam to positrons via bremsstrahlung radiation and e^+e^--pair production in a high-Z conversion target, referred as the PEPPo (Polarized Electrons for Polarized Positrons) technique [4], has been adopted to generate positrons at Ce$^+$BAF [5]. Only a small fraction of the positrons generated in the tungsten target by the 120 MeV e^- beam are captured. The positron yield, defined as the number of positrons within the CEBAF acceptance per primary electron, is in the range from $5 \cdot 10^{-5}$ to $1 \cdot 10^{-3}$, depending on the energy of positrons selected by the capture system from a wide energy spectrum at the target exit. Therefore, a high current drive e^- beam of 1 mA is required to provide the necessary e^+ currents to the CEBAF experimental halls shown in Figure 1.

A spinning solid 4 mm Tungsten target was designed to allow for the 17 kW of energy deposition to be spread over a larger volume and keep the radiation damage to an acceptable level [6]. Alternative targets are also considered. Xelera Research LLC is developing liquid metal targets [7]. The free-surface liquid-metal jets potentially allow for significantly greater electron beam power densities than are possible with solid targets leading to greater positron production. The GaInSn converter prototype is planned to be constructed and tested at the Jefferson Lab using a low energy polarized e^- beam (< 10 MeV).

4. Positron generation, capture and beam dynamics

For the electron beam with an energy of 120 MeV and a W-target thickness of 4 mm, the positrons at the target exit have a relatively small transverse size ($\sigma_{e^+\,x,y} = 1.2$ mm for $\sigma_{e^-} = 1$ mm), but the e^+ divergence angle and the normalized root mean square (rms) emittance are high ($\sigma_{\dot{x},\dot{y}} = 28$ deg, $\varepsilon_{\mathrm{n\,rms}\,x,y} = 15$ mm·rad). Figure 3 shows the $x\dot{x}$ phase space of positrons at the target exit.

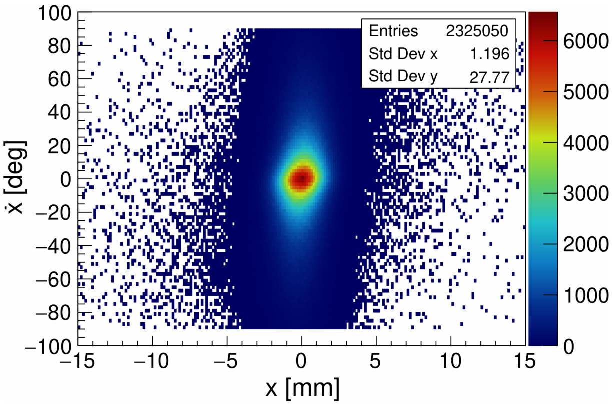


Figure 3: $x\dot{x}$ divergence angle versus position at the target exit

The typical dependence of e$^+$ polarization on e$^+$ energy at the target exit is shown in Fig. 4. The number of low polarized positrons at low energies is high and the yield of high polarized positrons at high energies is low. For polarization sensitive experiments, it is useful to use a figure of merit (FoM), which is defined as the product of the e$^+$ current and the square of the e$^+$ polarization. The maximal value of FoM is at an e$^+$ energy equal to half the drive e$^-$ beam energy [8].

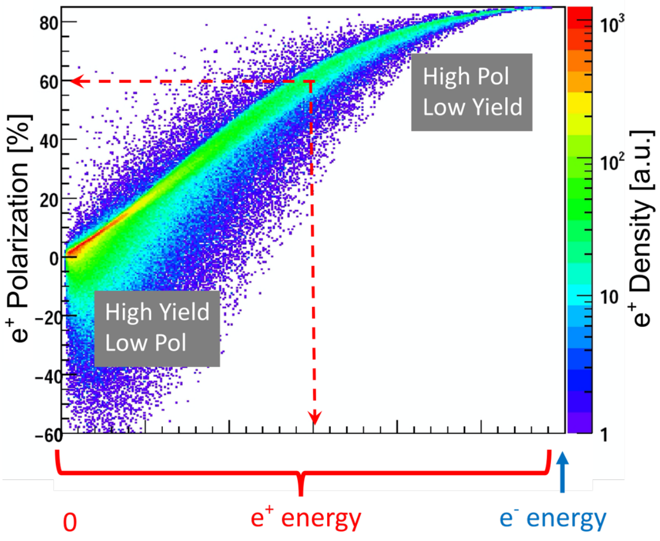


Figure 4: Positron polarization versus incoming e$^-$ momentum

The positrons at the entrance of the e$^+$ capture system must be focused in the capture solenoid to reduce the beam divergence angle and to match the beam to the acceptance of a capture cavity downstream solenoid, and the e$^+$ energy spectrum must be filtered to retain positrons of selected energies: 60 MeV for the polarized mode of the e$^+$ source and 20 MeV or less for the unpolarized/low polarized mode).

The concept of a e$^+$ capture system based on a 1 T solenoid and a CW normal conducting standing wave cavity was proposed [9]. The development of the capture cavity was started [10]. Since 17 kW of the 120 kW beam power is deposited in the target area (target, main solenoid and first cavity) [9], the cooling systems of the beam line components and the radiation shielding, including the neutron shielding, must be calculated and designed.

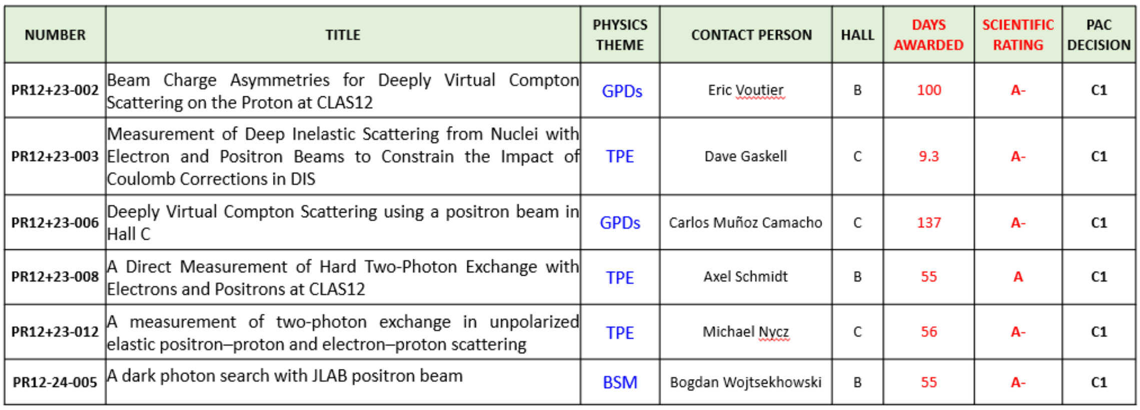
Work on the design of the energy selection and bunch length compression chicanes and beam dynamics studies in the positron beam line is in progress.

5. Long term schedule

We are pursuing a number of initiatives in parallel with the goal of writing a pre-CDR document by FY2025. A new photogun capable of delivering 1 mA with a 1000 Coulombs of lifetime in order to operate for up to two weeks without intervention is being designed and is scheduled to be tested. Other initiatives funded at the lab level via LDRD include designing and installing a degrader to study and optimize the transport of large emittance beams, refining the layout of the beamlines and performing start to end simulation.

This work has consequences beyond the Ce$^+$BAF project and as such, we are collaborating with SLAC and KEK[11] as well as other laboratories on advanced e- source concepts.

6. Currently Approved Experiments



NUMBER	TITLE	PHYSICS THEME	CONTACT PERSON	HALL	DAYS AWARDED	SCIENTIFIC RATING	PAC DECISION
PR12+23-002	Beam Charge Asymmetries for Deeply Virtual Compton Scattering on the Proton at CLAS12	GPDs	Eric Voutier	B	100	A-	C1
PR12+23-003	Measurement of Deep Inelastic Scattering from Nuclei with Electron and Positron Beams to Constrain the Impact of Coulomb Corrections in DIS	TPE	Dave Gaskell	C	9.3	A-	C1
PR12+23-006	Deeply Virtual Compton Scattering using a positron beam in Hall C	GPDs	Carlos Muñoz Camacho	C	137	A-	C1
PR12+23-008	A Direct Measurement of Hard Two-Photon Exchange with Electrons and Positrons at CLAS12	TPE	Axel Schmidt	B	55	A	C1
PR12+23-012	A measurement of two-photon exchange in unpolarized elastic positron–proton and electron–proton scattering	TPE	Michael Nycz	C	56	A-	C1
PR12-24-005	A dark photon search with JLAB positron beam	BSM	Bogdan Wojtsekhowski	B	55	A-	C1

Figure 5: Currently Approved e$^+$ experiments

This table summarizes the list of currently approved positron experiments spanning a range of physics topics, GPDs, Two Photon Exchange (TPE) and beyond the standard model (BSM). A decision of C1 means approved pending construction and commissioning of the positron beamlines.

Acknowledgements

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