CW POSITRON BEAM CAPTURE SCHEME USING SRF CAVITIES[*]

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Abstract

A continuous wave (CW) positron source, as proposed Ce+BAF at Jlab, produces positron beams of variable yield and polarization. Depending on users' preferences, the Ce+BAF positrons from the target needs to be selected and captured before being delivered to CEBAF linac at an energy of 123 MeV. An SRF cavity-solenoid capture scheme is proposed to accelerate and capture the CW positron beam using adiabatic damping and beam profile control to maximize the capture efficiency. Beam particle and power loss throughout the capture section are analysed. The initial beamline design of SRF cavities and solenoids in cryomodules is performed to examine the influence of solenoid's magnetic field. The application of SRF cavities with larger iris radius to the capture section is also studied in efforts to improve the capture efficiency.

INTRODUCTION

A conceptual design for Ce$^+$BAF 12 GeV beginning with a new e^+ injector at the LERF and ending with injection into CEBAF was developed in 2023 [1, 2]. 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 [3], has been adopted to generate positrons. The e^+ injector design includes a conversion target, an energy selection chicane, an SRF linac capture system. Fig. 1 shows a schematic layout of the e^+ injector. The following abbreviations are used for injector components: bucking solenoid (BS), conversion target (T), solenoids (S1, S2), shielding (SH), normal conducting capture cavity (NC RF), matching sections (MS1, MS2), dipoles (D1–D4), beam collimators (C1–C5), CEBAF superconducting module C75 (SRF Module).

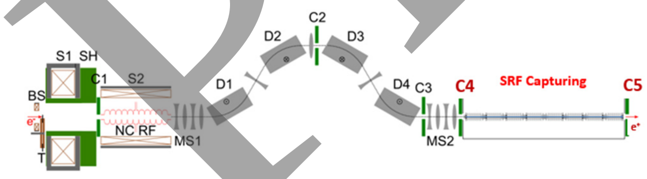

Figure 1: Schematic layout of positron injector

At the end of the 123 MeV e^+ injector, the e^+ beam needs to meet CEBAF's requirements for longitudinal acceptance, with a rms momentum spread <1%, a bunch length <1.2 mm and the transverse acceptance limit of 100 mm·mrad [2].

TRADITIONAL CAPTURE SCHEME

When the positrons exit the target, they have large angles, small lateral dimensions. They must be transformed into small angles, large lateral dimensions, so as to fit with the following accelerator acceptance with a matching capture section. Adiabatic Matching Device (AMD) is a tapered solenoid setting, accepts more energy band; on the other hand, Quarter Wave Transformer (QWT) accepts a larger amount of transverse momentum. QWT is adopted for Ce$^+$BAF's current design. It ensures the positron transverse emittance aligns with the narrow transverse angular acceptance of the capture section and introduce a correlation between the system acceptance and the positron momentum and polarization.

High gradient acceleration is necessary to adiabatically damp the positron bunch as early as possible to preserve as many as possible positrons. For pulsed positron source, the normal conducting capture linac is encapsulated inside a solenoid. The solenoid is employed to focus the positrons and avoid the positron losses, caused by the high divergence of the positron beam. For CW positron sources, the high wall loss caused by the CW operation of the NCRF cavities limit the gradient much lower, to about 1 MV/m [4]. So, we propose to use SRF cavities for the capture linac; and instead of encapsulating the cavities, the solenoids are reconfigured to be in-series embedded in the SRF cavity chain since the solenoid's magnetic field is either being expelled outside of the superconducting cavity wall, or it will destroy the cavity's superconductivity.

SRF-SOLENOID CAPTURE SCHEME

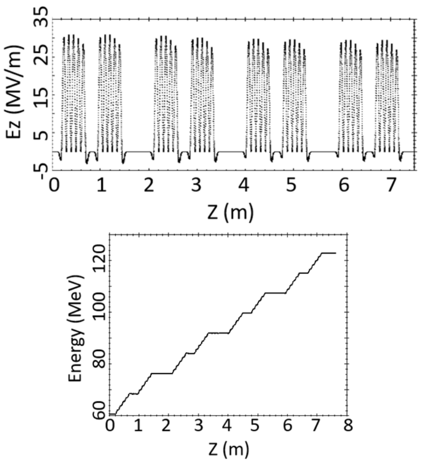

Figure 2: Ez of the SRF cavities and the energy gain

A CEBAF cryomodule is used in simulation to study the SRF-Solenoid capture scheme. The cryomodule has eight C75 SRF cavities. C75 is chosen over C100 because of its

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larger iris radius (35 mm). The Ez profile of the SRF cavities and the energy gain are shown in Fig. 2.

The beam accepted by the SRF capture section is transported with upstream optics such that the beam is converging and near the beam waist in both transverse planes when entering the SRF capture section. We expect such distribution can make the capture section accommodate more particles and improve the capture efficiency. The beta functions in the upstream beamline and the particle distribution at the entrance of the SRF capture section is shown in Fig. 3. Note that the beam is not symmetric in transverse plane.

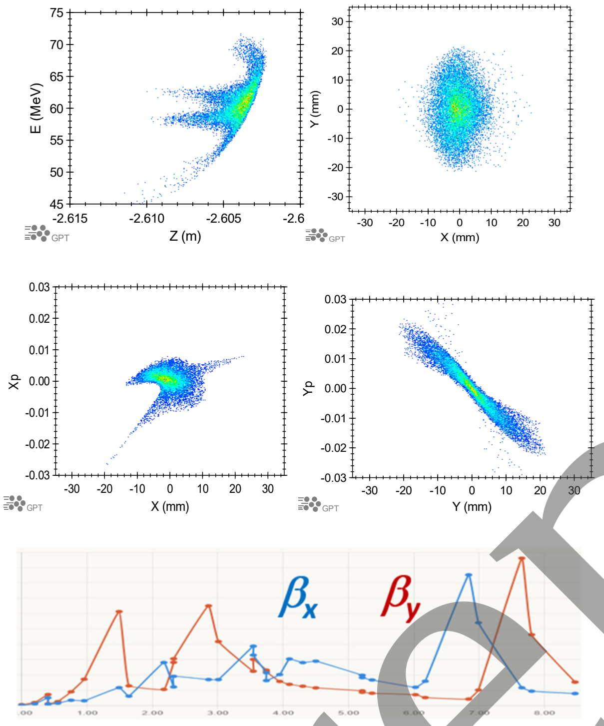
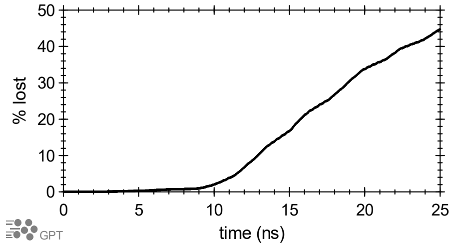


Figure 3: the particle distribution at the entrance of the SRF capture section

In this SRF cavity only capture section, although the particles are effectively accelerated from about 60 Mev to 123 MeV, about 45% particles are lost along the traveling through the cryomodule. The initial distribution of the lost particles compared with all particles is shown in Fig. 4, a clean boundary can be seen in (x', y') plane. This indicates that the initial transverse motion angle distribution control can help improve the capture efficiency. It can also be seen that the fast particle loss starting at about 10 ns is caused by the Y size growing up after over focusing.



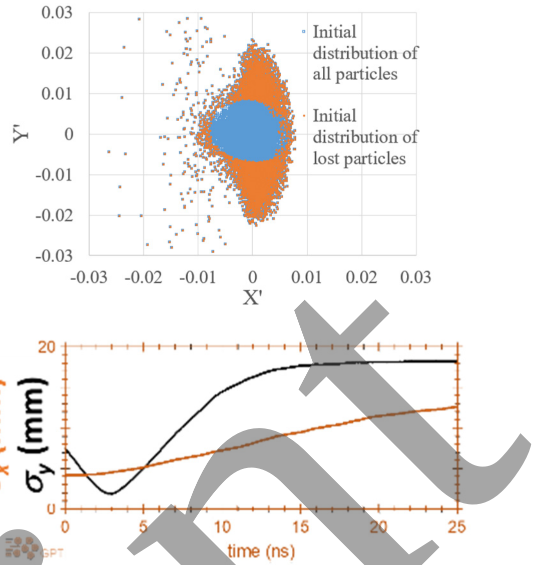


Figure 4: particle loss with SRF cavity only capture section and the lost particles' initial distribution.

SRF cavity – solenoid in-series configuration

Two solenoids are placed in the cryomodule to replace two sets of two cavities. A simple Gaussian-like shaped Bz profile is used to verify SRF-solenoid capture scheme concept. A more detailed solenoid design and hard-edged Bz profile should be adopted for more realistic study. Obviously, two such cryomodules are needed to provide same energy gain.

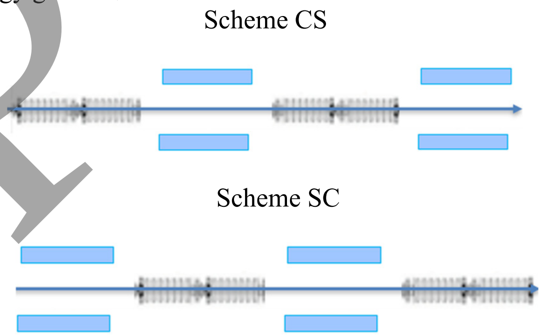


Figure 5: Two SRF-solenoid schemes

Two SRF-solenoid schemes are studied, as shown in Fig. 5, Fig. 6, Fig. 7. The difference of these two schemes is only the location of the solenoids. Then the amplitudes of the solenoids are tuned to minimize the particle loss.

The over-focused initial distribution in Y plane makes it prefer the first solenoid being put after the waist and more effectively suppress the maximum transverse size of the beam. As we can see on the left column of Fig. 5, once beam is under control by the first solenoid, the following downstream beam profile control will be easier and almost no more particles are lost downstream. The integrated beam loss is only ~1% and can be improved with further fine tuning of the beam line design. . While in the scheme SC, the location of the first solenoid makes it hard to control the maximum beam size in both transverse planes simultaneously, the beam transverse sizes are not well controlled even at the exit of this first cryomodule. Beside the location of the solenoids, we also should notice that the solenoid is a symmetric element, it will be easier to control the beam profiles if we have a symmetric beam at the entrance of the capture section, both transverse beam size symmetry (i.e. round beam) and transverse angle symmetry (as indicated in the lost particle initial distribution in Fig. 4).

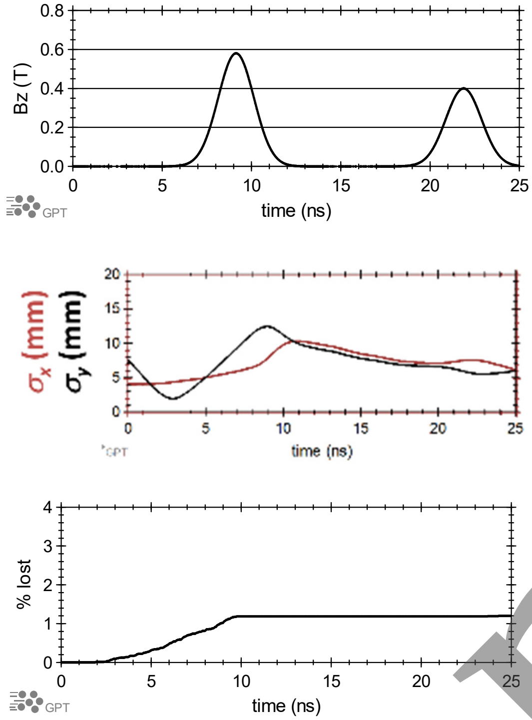


Figure 6: Scheme CS and the resulted beam profiles and particle loss.

Non-homogeneous SRF cavity chain

Obviously, cavities with larger iris radius can contain more particles and higher capture efficiency. But there is a trad-off between the cavity iris radius and the achievable gradient. We can also see that the first set of cavities and solenoid have extra importance in controlling the particles loss. It can be imaged that if the first set of cavities have extra larger iris radius, more particles will be accepted and captured with minimum energy gain loss.

CONCLUSION

In this paper, authors proposed an SRF cavity – solenoid scheme to efficiently capture large angle CW positron beams. Simulations show the feasibility of the approach. The matching between the incoming beam and the capture section and fine tuning of the capture section design needs more detailed study to fully manifest the benefit of the method.

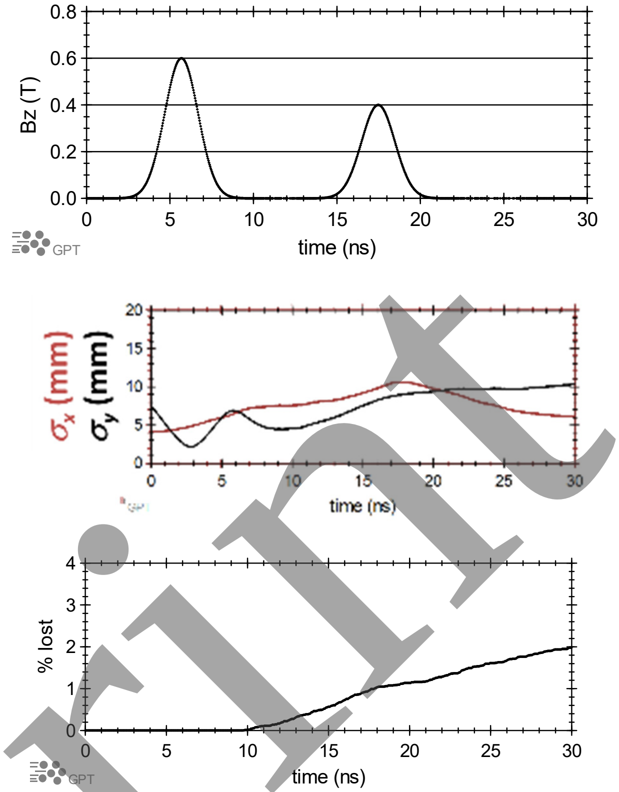


Figure 7: Scheme SC and the resulted beam profiles and particle loss.

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