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# UPDATE ON THE FCC-ee POSITRON SOURCE DESIGN STUDIES

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*Abstract*

The studies and R&D on the high-intensity positron source for the FCC-ee have been initiated for a while. The positrons are produced by a 6 GeV electron drive-beam incident on a target-converter at 200 Hz. The drive-beam comes in 2 bunches spaced by 25 ns with a maximum charge of ~5 nC per bunch. Two scenarios using conventional and hybrid targets are being studied for positron production. According to the FCC CDR, the Flux Concentrator is used as the matching device for the capture system, followed by several accelerating structures embedded in the solenoidal field. Then, the positrons are further accelerated to be injected into the damping ring. Recently, the feasibility study on using a SC solenoid for the positron capture has been started, and the design based on the HTS technology is under investigation. In addition, the large-aperture 2 GHz RF structures, which have been specially designed for the FCC-ee positron capture system, are used with the goal of demonstrating accepted positron yield values well beyond the values obtained with state-of-the-art positron sources. The purpose of this paper is to review the current status of the FCC-ee positron source design, highlighting the recent research into the positron production, capture system, primary acceleration, and injection into the damping ring.

## INTRODUCTION

The FCC-ee is a high-luminosity circular collider proposed for a precise study of the Z, W, Higgs bossons and top quarks at energies ranging from 90 to 365 GeV. A special attention is given to the pre-injector complex, which must provide low-emittance beams with high enough intensity to shorten a filling from zero time of the collider and top-up injection [1]. A positron bunch intensity of ~$2.5 \times 10^{10}$ particles (4 nC) is required at the injection into a booster ring on the $Z$ pole operation, allowing for a positron flux of $1 \times 10^{13}$ positrons per second without any safety factor [2]. At the pre-injector level, the main specification for the positron source design is to provide the positron bunch charge of 5.4 nC accepted in the Damping Ring (DR), including the transmission efficiencies from the DR up to the collider ring. Based on the available experience of designing and operating previously or currently operated positron sources, a safety margin of 2.5 is now applied for the whole FCC-ee positron source studies. Thus, a total positron bunch intensity of 13.5 nC should be delivered to the DR.

## POSITRON PRODUCTION AND CAPTURE

Two methods are investigated for positron production for the FCC-ee to obtain the required performances. The first one is based on a conventional positron source using 6 GeV electrons impinging on a 17.5 mm thick tungsten target. A second approach is based on producing a large number of photons in thin crystal targets oriented on their main axes [3]. The investigations led to a concept of a so-called hybrid positron source associating a thin oriented crystal with an amorphous converter [4]. Meanwhile the conventional production scheme is currently assumed for the design studies, optimisation of the hybrid positron source for the FCC-ee is ongoing. The studied schemes provide a positron production rate compared to the conventional target but lower Peak Energy Deposition Density (PEDD) and power deposited in the target [5]. Choosing the final configuration requires detailed positron capture simulations, being in progress now.

The capture section comprises an Adiabatic Matching Device (AMD) followed by the capture linac embedded in a DC solenoid magnetic field to accelerate the beam until about 200 MeV positron beam energy. Two options are currently considered for the AMD: the first involves the use of a Flux Concentrator (FC), which makes use of a pulsed magnet, a technology presently used in the positron source of the SuperKEKB collider [6], while the second involves the use of a SuperConducting solenoid (SC). The latter is based on the High-Temperature Superconducting (HTS) material with which the solenoid coils will be constructed. This technology will also be tested in the SwissFEL at PSI in the framework of the PSI Positron Production ($P^3$) experiment [7].

Several models of the FC have been designed and studied for the FCC-ee in BINP. The FC baseline for the FCC-ee is described in [8]. Given the successful operation of the

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SuperKEKB positron source, we have also started to investigate the SuperKEKB capture system, especially the FC, in application to the FCC-ee. The first simulations were carried out, and the results are very promising [9] (see Table 1). The HTS field map is adopted from the $P^3$ project. The HTS solenoid used as the AMD provides a much higher field value on the target exit surface, a larger aperture and a flexible target position as the target can be placed inside the magnet bore. Furthermore, it is based on the DC operation compared to the FC, where pulsed operation at 200 Hz can be a design challenge. The comparison of the FC and the HTS field profiles used for the current studies is illustrated in Figure 1. The evaluation of the final performance and cost for the FC-based and HTS-based capture systems is ongoing.

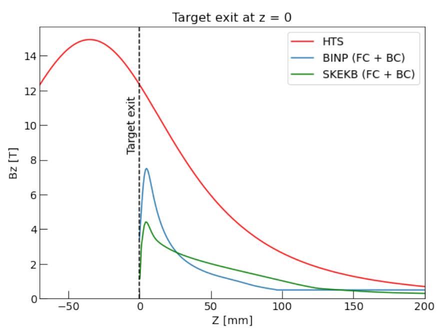


Figure 1: Magnetic field profile of the AMD realized in form of the FC and HTS magnet.

For the capture linac, several types of the RF structures have been considered up to now. Eventually, the 3-meter long, TW 2 GHz ($2a$ = 60 mm) RF structures designed by CERN for the positron linac have been adopted, providing larger iris apertures, which results in the larger transverse acceptance of the positrons.

Based on the obtained results, the capture system, so-called capture system –version 0, has been defined to be used as a starting point for further investigations and optimizations and also as an input for the positron linac and DR studies (see Figure 4). Hence, it is based on the following elements: conventional positron production scheme, HTS solenoid as the AMD and the capture linac made of five 2 GHz 3-m long RF structures embedded in the 0.5 T NC solenoidal field (see Figure 2). Thus, Table 1 summarizes the main current

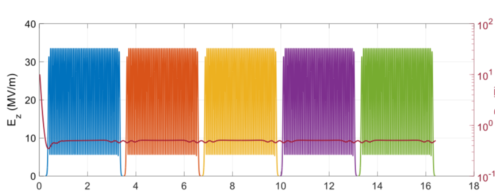


Figure 2: Electric and magnetic field profiles along the whole capture system for the capture system –version 0.

results of the positron production and capture simulations for both FC- and HTS solenoid-based capture systems. At this stage, an energy-longitudinal position cut around the highest density of positrons made within the DR acceptance allows defining the accepted positron yield[1].

Table 1: Latest simulation results for two different options of the AMD. The values, which correspond to the capture system -verison 0 are marked in bold.

| | FC | | SC sol. |
|---|---|---|---|
| **Drive beam** | BINP | SKEKB | HTS |
| Bunch charge, nC | 3.1 | 5 | **1.9** |
| Bunch length (rms), mm | | 1 | |
| Beam size (rms), mm | | 0.5 | |
| Beam power, kW | 7.4 | 12 | **4.6** |
| **Target** | | | |
| Deposited power, kW | 1.8 | 2.9 | **1.1** |
| PEDD, J/g | 11.3 | 18.3 | **7.1** |
| **Capture system** | | | |
| Frequency/aperture | | L-band (2 GHz) / 60 mm | |
| Solenoid strength, T | | 0.5 | |
| AMD peak field, T* | 7.5 (3.5) | 4.4 (1.1) | **15 (12)** |
| **Positron @DR entrance** | | | |
| Bunch charge, nC | | 13.5 | |
| Positron yield, $N_{e^+}^{acc}/N_{e^-}$ | 4.4 | 2.7 | **7** |
| Bunch length (rms), mm | 3.1 | 2.6 | **3.1** |
| Norm. emittance, mm.rad | 11.4 | 11.9 | **12** |
| Energy spread (rms), % | 1.4 | 1.1 | **1.6** |

* The magnetic field at the target exit for each option is shown in between the parentheses.

Capture system studies are in progress to provide the optimized positron bunch 6D phase space matched to the positron linac and DR [10]. Moreover, we started to test the multi-objective optimization with the genetic algorithm GIOTTO [11] to improve the performance of the capture system. The first results are very promising.

## TARGET DESIGN AND RADIATION LOAD STUDIES

In the context of the feasibility and design studies of the positron source, dedicated radiation transport studies to assess the impact of secondary radiation fields were carried out with the FLUKA for the capture system -version 0. The radiation load studies assumed a maximum drive-beam bunch charge of $3.47 \times 10^{10}\ e^-$, which results in a drive beam power of 13.43 kW. With such an electron beam, the target and surrounding shielding absorb around 3.1 kW, with a maximum power density of 80 kW/cm$^3$ at the downstream face (see Fig. 3). This heat load poses a significant challenge for the target design; possible engineering solutions and cooling options are presently under study.

Assuming 200 days of operation per year, the radiation transport simulations show that the displacement damage in the target can reach a peak value of 8 DPA/year for FCC-ee operation at the $Z$ pole. Possible mitigation measures need to

[1] For the results presented in Table 1 the energy window cut of ±3.8% and longitudinal position window of 16.7 mm (or 40 degrees in terms of the phase ) have been used.

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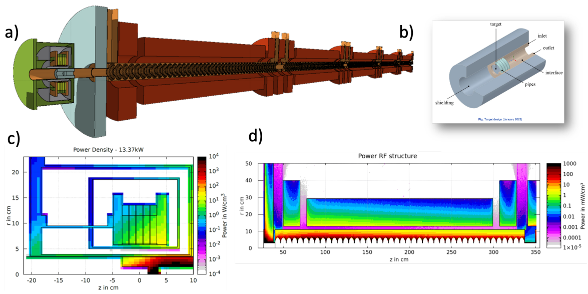


Figure 3: (a) FLUKA model of the capture system -version 0. (b) Positron source target design. Power density on the AMD (c) and the first RF structure (d). The target and the shielding are most impacted, while the HTS coils are well protected.

be elaborated. For the HTS coils, a maximum of 30 mW/cm$^3$ power density is obtained, which is considered acceptable. The cumulative dose in the coils can reach 22 MGy/year for operation at the $Z$ pole. The simulations show that more than half of the power originally carried by the electron drive beam is lost in the capture linac, mainly in the first structure. The tungsten shielding between the AMD and the linac protects the front face of the linac and absorbs almost 10% of the drive beam power. The highest radiation-induced power deposition in a single RF cell is about 190 W, but decreases to about 40 W towards the end of the RF structure (see Fig. 3). With an adequate cooling design, the radiation load in the linac is expected to be manageable. The solenoids around the RF structure are assumed to be normal conducting. The integrated dose in the solenoids is estimated to be about 3 MGy/year for operation at the $Z$ pole, which must be considered in the choice of materials.

Figure 3 shows the current status of the target design with its components and its location inside the AMD. Given the properties of tungsten material: it is brittle at room temperature, has a medium thermal conductivity and is prone to oxidation and further embrittlement at high temperature in direct contact with water; the target is proposed to be embedded in a copper interface, which presents an excellent thermal conductivity, following the adopted solutions in other research facilities as SuperKEKB [12] and ITER [13]. Given the currently assumed drive-beam parameters, heat load and DPA in the target remain a significant concern and, therefore, the reliable target design needs further investigation.

## POSITRON LINAC AND DAMPING RING

In the current positron source design, the positron and electron bunches are separated at the end of the capture system by a chicane at 200 MeV and the solenoid focusing is used until 735 MeV of positron beam energy (see Figure 4). After the matching section at 735 MeV, the positron beam passes to a quadrupole focusing and accelerated up to the DR energy (1.54 GeV). The positron linac comprises large aperture L-band RF structures, identical to those used for the capture linac. Energy Compressor System (ECS) is used before the DR to increase the number of positrons within the DR energy acceptance (±3.8%). The design and beam dynamics studies of the positron linac are well advanced and are currently in progress. The DR is an important part of the positron source design as its dynamic aperture, longitudinal and transverse acceptance parameters define the final performance of the positron source. The baseline design of the DR is described in the CDR of the FCC project [8]. However, a new DR layout is being studies to reduce the number of magnetic elements, increase the number of straight sections and improve the overall performance. Eventually, the positron tracking simulations in the positron linac, followed by the injection and tracking in the DR, will be carried out to have a more realistic estimate of the accepted positron yield.

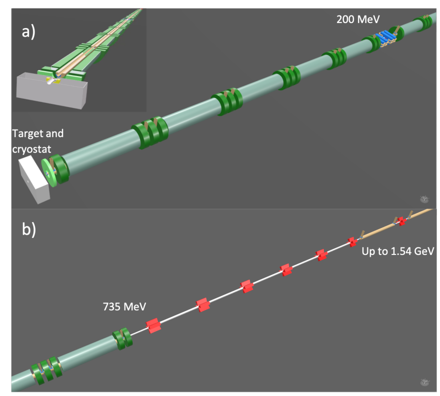


Figure 4: (a) The main view of the capture system –version 0 including the separation chicane, (b) The matching section within the positron linac before quadrupole focusing.

## CONCLUSION

The conceptual design studies of the FCC-ee positron source are ongoing. To ensure the high reliability of the positron source, conventional and hybrid production schemes are currently under investigation. Results of the latest simulations and optimisations have shown that both capture schemes (based on the FC and HTS solenoid) can guarantee the requested positron bunch intensity even with some safety margin. The final choice of the positron target and capture system will be made based on the estimated performances and cost. The assessment of the thermal load and long-term radiation damage was carried out for the HTS solenoid-based layout and ise in progress for all the studied schemes. The design and integration of the production target still need to be investigated and studied in detail.

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