Use of superconducting linacs for positron generation: the EPOS system at the Forschungszentrum Dresden-Rossendorf (FZD)

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Abstract. Intense positron sources require the pair production process for the positron generation. In case a pulsed positron source shall be constructed, a superconducting LINAC-based accelerator allows generating the required final time structure for the electron beam. This simplifies the positron beam construction. The first such setup, the EPOS system (ELBE Positron Source) at the Forschungszentrum Dresden-Rossendorf (FZD), is described.

1. Introduction
Pair production for positron sources requires electrons of high energy which can be obtained near the fuel cell of a reactor or using bremsstrahlung of an accelerator. In case of a reactor or conventional LINAC with a repetition time of about 1 ms, the time structure of the positron beam must be obtained later in the positron beamline. An alternative is the use of superconducting (sc) LINACs. Here, the required time structure can be obtained for the whole system, i.e. the electron beam has the required time structure which is retained until the sample. For positron lifetime measurements the maximum time to be measured is the vacuum lifetime of ortho-Positronium (o-Ps), o-Ps = 142 ns. Since the decay is an exponential one, a beam repetition time which is about ten times longer is required. Thus, ideal systems should operate at 1 MHz or 500 kHz provided the bunch charge is large enough to obtain the required intensity. Due to the RF-acceleration in the GHz range, the pulse width of the electron bunch hitting the bremsstrahlung target is only a few ps and is thus short enough.

2. sc-LINACs for positron generation
A sc-LINAC has rather compact dimensions, and 10 MeV beam energy can already be obtained with a 9-cell TESLA cavity of about 1m length. At the ELBE (Electron Linac for beams with high Brilliance and low Emittance) radiation source of the Forschungszentrum Dresden-Rossendorf (FZD) four such 9-cell accelerator cavities are combined to obtain 40 MeV (figure 1). The cavities are made from niobium and operated at 1.8 K to obtain superconductivity. The basic frequency is 26 MHz in cw-mode. Any lower frequency f = 26/2ⁿ MHz (n=1,2,3,...) is also possible. Moreover, a macropulse structure can be provided. A thermionic electron gun is the standard electron source so far. Electrons from a hot cathode are treated by a triode consisting of a pulse grid acting as a beam chopper and the anode system with a DC accelerating high voltage of 250 kV (figure 2). The obtained electron pulse is...
rather long (≈500 ps). It is bunched in two stages with resonant bunchers of 260 and 1300 MHz, respectively. The time focus is located at the entrance point of the first accelerator module. The pulse length there is < 5 ps which is preserved up to the user experiments. The thermionic source has been operated for several years. It is very robust and stable.

![Figure 1](image1.png)

**Figure 1.** Two 9-cell TESLA cavity accelerator stages of the ELBE radiation source at the FZD. Four stages allow a maximum energy of 40 MeV with an average current of 1 mA (40 kW).

However, the bunch charge for an individual bunch is limited to 77 pC. In case a wider time structure of about 1 s is required (see discussion above), the average current drops down to about 80 A (3.2 kW). As a future alternative, the newly developed sc-photo-gun can be used (figure 3).

![Figure 2](image2.png)

**Figure 2.** The thermionic gun at ELBE provides a bunched electron beam of 250 keV. The bunch length is about 500 ps and requires a two-stage bunching system to reach a 5 ps pulse width corresponding to 1 mm length at the entrance of the first sc-accelerator stage [1].

Here, 232-nm laser pulses of about 10 ps length liberate electron bunches from a photo-cathode by the photoelectric effect. This so-called SRF gun (Superconducting Radio Frequency Photoinjector) can be operated with a bunch charge of 77 pC at 13 MHz, but also in a slow mode with 500 kHz and 1 nC corresponding to an average current of 0.5 mA. This beam is then further accelerated with the four cavity accelerators of ELBE to a final energy of about 50 MeV. This would be an ideal electron source for the intense positron source EPOS [2]. However, although the SRF gun at ELBE has shown its
functionality, the final intensity and energy is not obtained so far and the system needs further
development.

Such an SRF gun represents a complete table-top 10 MeV electron accelerator with ideal timing
properties for positron generation. Although the positron yield will clearly be smaller compared to a
40-MeV system (see figure 4), such a system would have the advantage to prevent radioisotope
activation because of the electron energy being under 10 MeV. In this case, no $(\alpha,\alpha')$ processes are to be
expected. Hence, after switching off the electron beam, there will be no radiation anymore. This would
make its operation much easier. Moreover, electron sources of several tens MeV provide average
positron energies of a few MeV, which decreases the moderation efficiency drastically. The average
positron energy for a 9-MeV system is expected to be $<1$ MeV. This effect will at least partly
compensate for the lower positron yield.

3. The EPOS system at the radiation source ELBE
The EPOS system consists now of three parts: the mono-energetic pulsed positron beam (MePS), the
gamma-induced positron spectroscopy (GiPS), and two conventional, isotope-based systems (CoPS).
CoPS does consist of the continuous slow-positron beam SPONSOR [5] and a lifetime/Doppler setup.
The latter system is still operated with analogue electronics which will be replaced in the near future.
by a 4-PMT (PMT=photomultiplier tube) digital system combined with a Ge detector, equipped with an automated He refrigerator system. The GiPS setup, which is in operation for some time now, is unique so far [6]. The bremsstrahlung impinges onto the sample and generates electron-positron pairs via pair production in the whole sample volume. A multi-detector system surrounding the sample detects the annihilation quanta that are emitted by positron annihilation directly inside the sample. Different types of detectors are used for the application of different positron spectroscopies. Fast PMTs equipped with BaF$_2$ scintillators are used for lifetime measurements. The GiPS setup contains four HPGe detectors and two BaF$_2$ detectors. Two HPGe detectors each facing an opposite BaF$_2$ detector act as two independent AMOC (Age-Momentum Correlation) spectrometers. Two further HPGe detectors directly above and under the sample are used as a CDBS (CDBS=coincidence Doppler broadening spectroscopy) spectrometer. The distances between sample and detectors can be adjusted. By using this detector setup, lifetime, (coincidence) Doppler broadening and age-momentum correlation measurements can be realized simultaneously.

The MePS system [2] will make use of moderated, monoenergetic positrons for near-surface studies but is still under construction. First, a 2 keV positron beam is extracted by an electrostatic lens from a Pt moderator which is placed close to the bremsstrahlung target. The positron beam is then fed into a magnetic guidance field which is guiding the beam from the production cave to the laboratory over a distance of about 10 m. The beam properties could already been tested at the entrance of the chopper/buncher system. Due to the positron moderation process in combination with an energy spread during positron acceleration to 2 keV and the magnetic beam guidance process itself, the positron bunch widens in accordance with earlier simulations from originally less than 5 ps FWHM (FWHM=full width at half maximum) to a peak of about 1.9 ns FWHM. However, an adjacent buncher will provide the time focus with a width of < 100 ps at the sample position. An accelerator will give the final positron energy range of 0.05 to 30 keV. A fully digital and remote controlled multi-detector system (8 PMTs and 2 HPGe) will ensure measurements at a high count rate. The whole EPOS system is established as a user-dedicated facility. A web-based application system allows access for interested users [7].

4. References
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