Snowmass'21 (Letter of Interest)

Physics and technology challenges in generating high intensity positron beams

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Positron sources are essential to the future e^+e^- / $\mu^+\mu^-$ collider projects (ILC, CLIC, SuperKEKB, FCC-ee, LEMMA, etc.) with challenging critical requirements of high-beam intensity and low emittance necessary to achieve high luminosity.

In a conventional positron source, positrons are produced by high energy electrons passing through a target, then the low-momentum population exiting the target is captured and accelerated in a capture section to the required energy needed. This scheme has been used for all circular e^+e^- colliders (ADA, ACO, DCI, SPEAR, ADONE, VEPP, LEP, KEKB, SuperKEKB, PEP-II) and also for the first linear collider SLC [1]. In the conventional positron-generation system, a possible scheme to increase the positron intensity is to increase the incident electron beam power (intensity and/or energy). However, the allowable heat load as well as the thermo-mechanical stresses in the target severely limit the allowable beam power of the incident electrons.

Within this framework, recent investigations led to a hybrid scheme based upon a relatively new kind of positron source, one that uses an intense photon production by high energy (some GeV) electrons channelled along a crystal axis (i.e. channelling radiation). Thus, electrons propagating in the crystal at glancing angles to the axis can be channelled or quasi-channelled with consequent emission of a large number of soft photons due to the collective action of a large number of nuclei along the axes [2,3]. Several experiments at CERN and KEK, including a proof-of-principle experiment in Orsay, have been performed to investigate such a possibility [4-6]. They have shown very promising results for the enhancement of the positron yield. Further studies demonstrated a possibility of reducing significantly the energy deposition in the target, if compared to the conventional one. This led to a concept of the hybrid scheme [7,8]. In this context, the hybrid scheme has been adopted by CLIC as a baseline for the unpolarized positron source.

The necessity of using both polarized electron and positron beam at the future colliders is well established and has been comprehensively analyzed in [9]. There are three methods to generate circularly polarized high-energy (>10's MeV) photons which can be converted to the longitudinally polarized positrons. Radiation from helical undulator and Compton scattering sources are intended for high energy colliders, and bremsstrahlung from polarized electrons is also considered at lower energies typical for Hadron Physics (MAMI, MESA, JLab), and also for the much smaller energy range of Atomic Physics and Material Science [10]. In these domains, a conventional positron source design using initially polarized electrons and capturing high-energy positrons has been demonstrated to be particularly efficient [11].

Almost all the positron sources ever built (past or currently in operation) were integrated to the injector complex of a circular lepton collider. Thus, the required bunch population from these sources has been a few 1×10^{10} e^+/bunch corresponding to average currents less than 1 µA except the PEP-II/SLC case ~1 µA [12]. At present, the positron production rate obtained at the SLC (~ 8×10^{12} e^+/second) is considered as a world record for the existing accelerators. However, the intensities required from the positron sources at the future colliders CLIC, ILC or LHeC are a few orders of magnitude higher than that delivered by ever existed facilities. In the case of the FCC-ee, the requirements are more relaxed given the possibility of stacking and top-up injection, yet will still require a low-emittance positron beam with intensity high enough to shorten the injection time. A positron bunch intensity of 2.1×10^{10} e^+/bunch is required at the injection into a pre-booster ring [13]. This value is comparable with the positron yield foreseen at the SuperKEKB 0.6 Ne+/Ne- (a positron flux comparable the one obtained at the SLC). The positron source of SuperKEKB is the world's highest intensity positron source currently in operation. Much efforts for R&D and optimization studies for the positron source are ongoing at KEK to mitigate limitations to reach the required positron beam intensity.

Intense positron sources may play also an important role for even higher-luminosity colliders and, in particular, for positron-based muon production (cf. LEMMA proposal) [14]. In this context, profound studies of the positron source capable to deliver an exceptional flux of about $\sim 10^{16}$ e^+/second are needed to narrow down the possible design choices and define the R&D directions to mitigate the critical issues. Creating low-emittance energetic muon beams would open the door to a new generation of lepton colliders.

These anticipated beam intensities and emittances impose technological challenges for the positron source design (target design, cooling systems, capture optics, power dissipated on the structures, and remote handling/target removal engineering design). The complete optimization of the positron production requires not only maximizing the total polarized or unpolarized positron yield, but also innovative studies of target thermodynamics which limit the performance of the positron source. Therefore, investigations/studies of the heat dissipation and thermo-mechanical stresses in the targets and closest beamline components, technological R&D and experimental testing are all mandatory for more robust and reliable positron source designs to meet future needs.

The positron source community should consolidate the effort and explore different methods of positron production, both classical techniques and especially novel/exotic ones, primarily for future high-energy physics applications requiring orders of magnitude higher intensity than what was demonstrated up to now, and for considering future hadronic applications (including the EIC) requiring both polarization and intensity. These studies should be focused on different source types, target designs, capture/acceleration approaches including the existing limitations and potential for polarized positron production identifying the main axes for future R&D.

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