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Accelerator Based Cold Positron Beams

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Cold positron beams produced using solid state moderators have been used profitably for condensed matter and positronium research.[1] The low emittance and energy spread of these beams makes the technique attractive as a potential positron source for future linear colliders, reducing or eliminating the need for damping rings. However, the intensities attained so far fall short of the requirements of a high energy linear collider. ($\sim 10^{11}$ positrons/pulse at 10 kHz was taken as the positron flux necessary for a linear collider-B$\bar{B}$ factory.) This report briefly reviews the state of the art in accelerator produced cold positron beams and indicate some areas in which yields might be improved. (The discussion here is limited to electroproduced positrons. Beams produced with β+ sources are treated in the articles by Dawson and Ottewitte in these proceedings.)

Solid state moderators exploit the negative positron work function ϕ_+ on suitably prepared metallic surfaces.[2] In particular, tungsten has been widely used for this purpose. Incident positrons slowing to thermal energies sufficiently close to the moderator surface are ejected with energy $e\phi_+ \sim 1$ eV, energy spread $\sim .1$ eV, and angular spread $\sim 20°$. The moderation process is inherently inefficient, due to e+ annihilations within the material.

Facilities at Livermore[3] and Mainz[4] have achieved the best slow e+/e- conversion efficiencies. Positron production geometries are similar, consisting of a tantalum radiator/convertor followed by an array of thin tungsten moderator vanes. Positrons produced in the target strike the moderator vanes at near glancing incidence in order to maximize the probability of thermalization near the radiator surface. The LLNL group has attained overall conversion efficiencies of 2×10^{-6} slow e+/e- and Mainz an efficiency of 9×10^{-6}. The difference results primarily from the higher e- beam energy of the Mainz linac (200 MeV vs 100 MeV at Livermore).

At this point it is clear that given the moderated e+/e- efficiencies attained so far, unreasonably large electron intensities ($\sim 10^{16}$-10^{17} e-/pulse) would be required to produce cold positron useful for linear collider applications. It also does not appear as if moderation efficiencies can be much improved. The alternative is to examine whether modifications to the positron production geometry might be used to increase yields. The EGS4 Monte-Carlo[5] provides a convenient method for computing positron yields for different geometries and media.

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The LLNL beamline uses a radiator/convertor target consisting of 3 radiation lengths of tantalum in front of the tungsten moderator assembly. Using EGS4, the conversion efficiency of this target is found to be 0.15 exiting e+/incident e−. The actual positron production rate in the target, however, is calculated to be ~ 2e+/e−, with the majority of the positrons produced being absorbed inside the target. For a thick target (~ 12 r.l.) which absorbs most of the energy of the beam the raw positron rate is 4.3 e+/e−. This observation suggests that for the same moderation efficiency, a maximum overall increase in the cold positron production rate of < 4.3/0.15 = 29 might be attained if a geometry could be devised to make use of the positrons produced inside the volume of a thick target.

This could be achieved by combining the functions of target and moderator, using a stack of thin tungsten foils as a source (Fig. 1). This scheme, however, suffers from the problem of low brightness--the foils must be sufficiently separated to allow the moderated positrons to be extracted. The overall rate of e+ production is improved at the cost of a large increase in the spatial extent of the source.

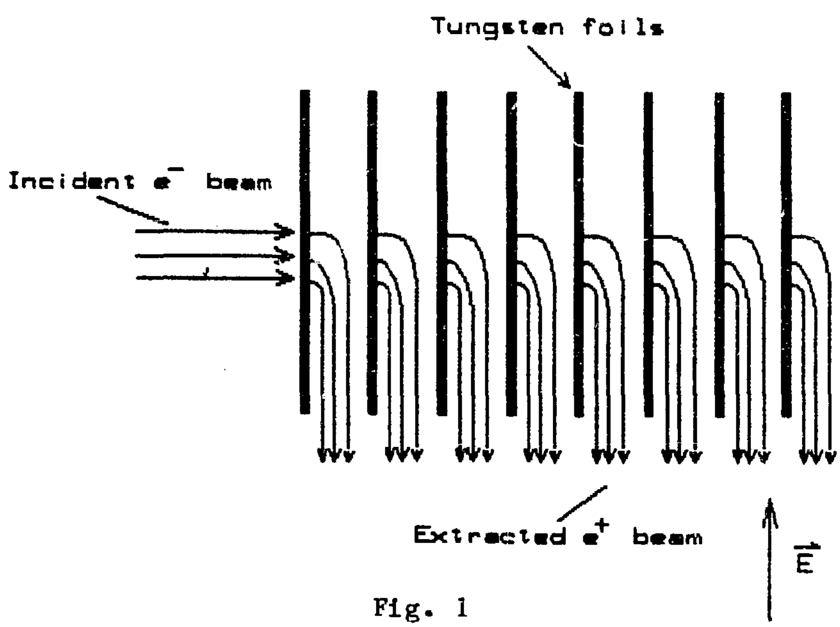

Fig. 1

A brighter source could be produced by magnetically confining the incident electrons and causing them to be passed repeatedly through the same radiator/moderator foils. This geometry is shown in Fig. 2. Electrons are injected into a radial assembly of tungsten vanes, and the moderated positrons extracted by an applied electric field. Here too the difficulties are numerous and probably not worth the modest gain in the e+ rate and brightness.

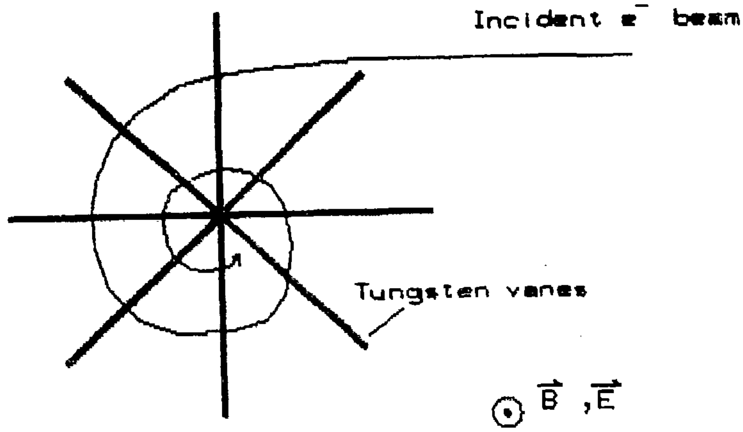

Fig. 2

Although the spatial extent of this source would be smaller than for a linear configuration of moderator foils, the field strength required would strain the limits of present magnet technology. For example, a 10 cm initial radius of circulation for 100 MeV electrons, still not a very bright source, would require a 33 kG field. To produce 10^{11} e+/pulse at 10kHz, the structure would need to dissipate 270 MW, clearly an intolerable heat load! Finally, the positron pulse would be spread out over the hundreds of ns that it would take the electron beam to pass through the equivalent of 4 cm of target.

The preceding discussion examined the the limitations on the intensity of existing slow positron facilities, which use electron beams of few hundred MeV energies. Another means of increasing the raw e+ yield is to use higher energy primary electron beams. A 10 GeV e- beam on the same thickness of tungsten produces >100 raw e+/e-, with even worse thermal load and source brightness difficulties, but only a factor of $\sim$ 25 improvement in e+ intensity.

The low efficiency of the solid state moderation process limits the utility of the electroproduced cold positron technique to applications with less stringent intensity requirements than high energy linear colliders. A more abundant source of positrons can be obtained from radioisotopes, with the attendant difficulties of breeding the isotopes in a fission (or fusion) reactor. A more promising approach may be the use of electromagnetic traps for positron cooling,[6] which do not suffer from the large inefficiencies due to e+ annihilations in matter, and which may yield moderation efficiencies near unity.

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