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Very High Intensity Positron Beam Generated by L.E.P.2 Synchrotron Radiation

VERY HIGH INTENSITY POSITRON BEAM GENERATED BY L.E.P.2 SYNCHROTRON RADIATION

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ABSTRACT

This year (1996), the CERN large electron-positron collider (L.E.P.) will produce electron positron collisions from accelerated beams with energies up to 80 GeV per beam, thus providing the highest energy, intense electron beam in the world.

At LEP, a 4-Tesla superconducting wiggler could be used to produce synchrotron radiation.[1] For an electron beam with an intensity of 9 mA, this unique γ-beam would contain photons in the energy range 1 - 100 MeV at an intensity up to 10^{16} γ/sec mrad MeV.

The laminar shape of the synchrotron beam can be used to build a converter that preserves some of the initial (at the production) forward collimation of the positron beam. The converter consists of 200 targets with individual thicknesses of $2 \cdot 10^{-3}\ X_0$, where X_0 is the radiation length, spaced by 10 cm for a total length of 20 m. The 20 m target is contained in a solenoid to focus the positron beam.

The e^+ beam is transported by a solenoid and is energy dispersed by a pair of dipole magnets.

The positron yield in the energy interval 1-2 MeV is $N_{e^+} \sim 10^{13}$ positron/sec MeV at the production level. The flux of positrons that can be obtained at LEP2 is two orders of magnitude larger than that predicted for future projects.[2]

Introduction

This year (1996), the CERN large electron collider (L.E.P.) will produce electron positron collisions from accelerated beams with energies up to 80 GeV per beam, thus providing the highest energy intense electron beam in the world.

The energy spectrum of the γ-beam from the S.R. emitted by the 85 GeV LEP2 electron beam crossing a 4-Tesla wiggler is shown in Fig. 1. Table 1 from Ref. 1 shows the main features of the γ-beam for an electron beam with intensity I_l = 9 mA and energy 85 GeV crossing a wiggler with a 4T field and a radius of cuvature $\rho \equiv 70.8$ m.

This unique gamma beam can provide photons with an energy range of 1-100 MeV at an intensity up to 10^{16} γ/s mrad MeV.
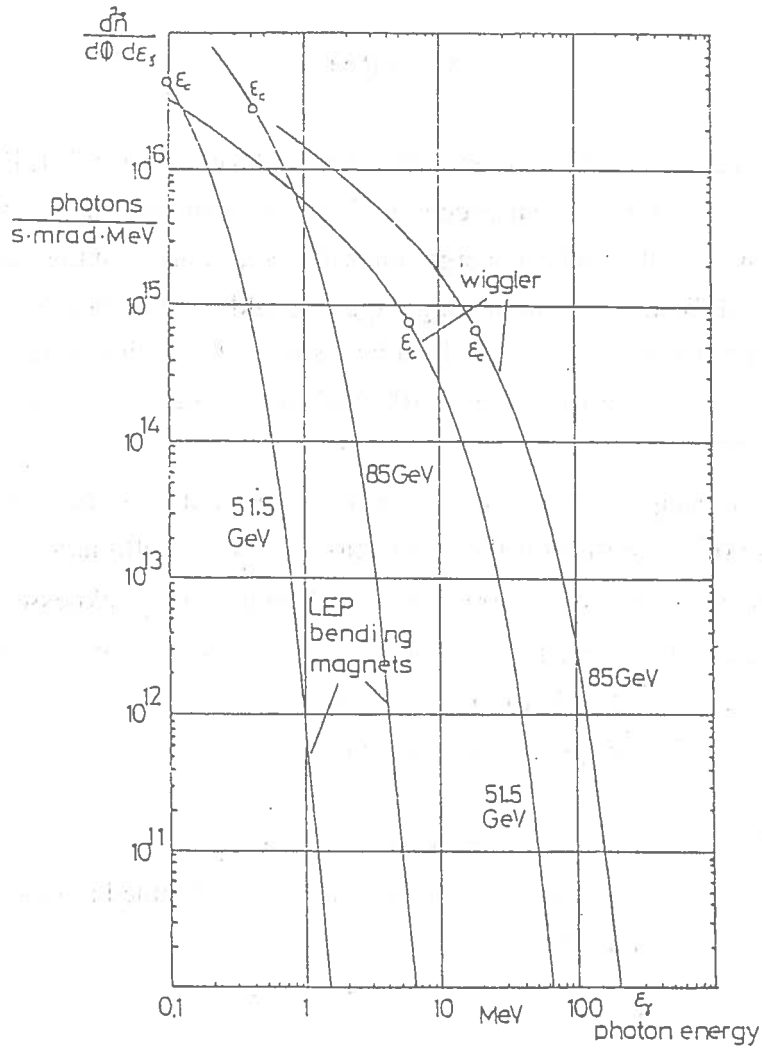

Fig. 1 - Photon spectrum from the LEP2 bending magnets and from the high field wiggler.

TABLE 1

	Ec	P	ϕ	$\dfrac{dP}{d\phi}$	$\dfrac{dN}{d\varepsilon d\phi}_{\varepsilon=\varepsilon_c}$
	(MeV)	(kw)	(mrad)	(kw/mrad)	(N/MeVs mrad)
γ-beam	19	114	1.2	96	$6.6\ 10^{14}$

If the wiggler magnetic field B is vertical the photon beam opening angle in vertical $\Delta\vartheta$ is $\sim \dfrac{1}{\gamma} \sim 5\cdot 10^{-6}$ rad, while the horizontal opening $\Delta\phi$, for the particular considered wiggler, is $\sim 10^{-3}$ rad.

The laminar shape of the synchrotron beam ($\vartheta \sim 5\cdot 10^{-6}$, $\phi \sim 10^{-3}$) can be used to build a γ converter which preserves some of the initial (at the production) forward collimation of the positron beam. The opening angle of the produced electron positron pair is $<\vartheta> \simeq \dfrac{mc^2}{K}$ where m is the positron mass and K the γ energy.

To obtain this result, the converter is divided into many subconverters to reduce multiple scattering in single target ($\vartheta_{sc} = \dfrac{14}{E_{MeV}}\sqrt{t}$); t is the single target thickness measured in unit of radiation length (X_0).

A sketch of this special converter is shown in Fig. 2. The distributed converter consist of 200 targets, each with a thickness of $2\cdot 10^{-3}$ X_0. The spacing between targets is 10 cm, for a total length of 20 m. The target 1 is 300 m downstream of the wiggler. The target position relative to the wiggler is shown in Fig. 3.
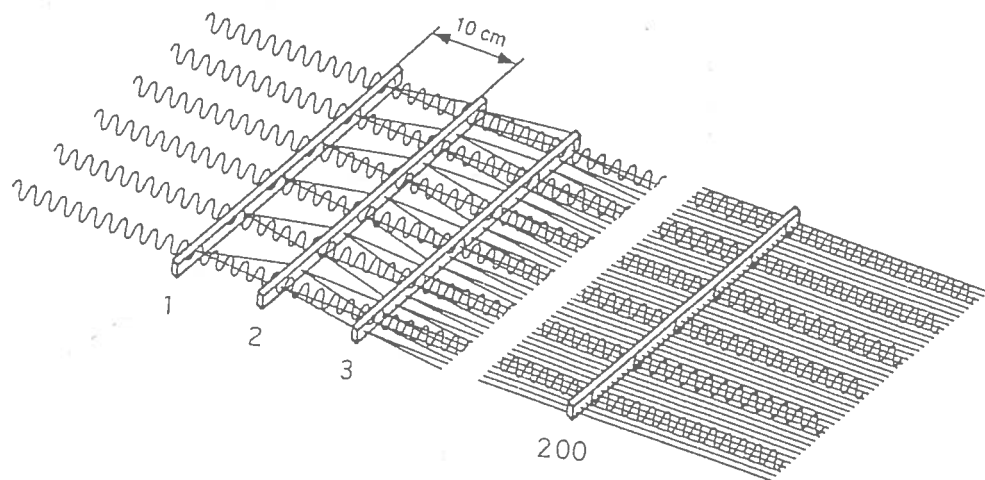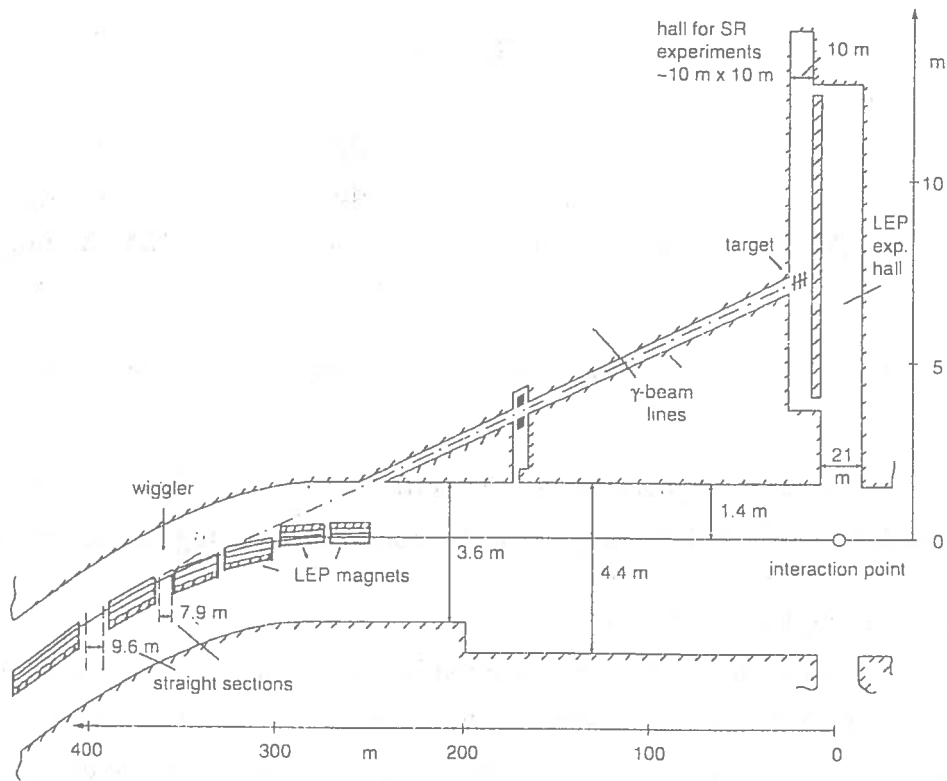

Fig. 2 - The multitarget

Fig. 3 - Target position relative to the wiggler.

The 20-meter-long target is contained in a solenoid to focus the positron beam.

The projected average angle due to multiple scattering in half of the target for positron with energy of 1.5 MeV is $<\vartheta> \sim 0.29$ rad.

The positron beam from the multitarget still preserves some forward directionality contrary to most conventional sources.

The positron yield in the energy interval 1-2 MeV is $N_{e+} \sim 10^{13}$ positron/sec MeV from the multitarget. For higher positron energies the expected yield is shown in Fig. 4.
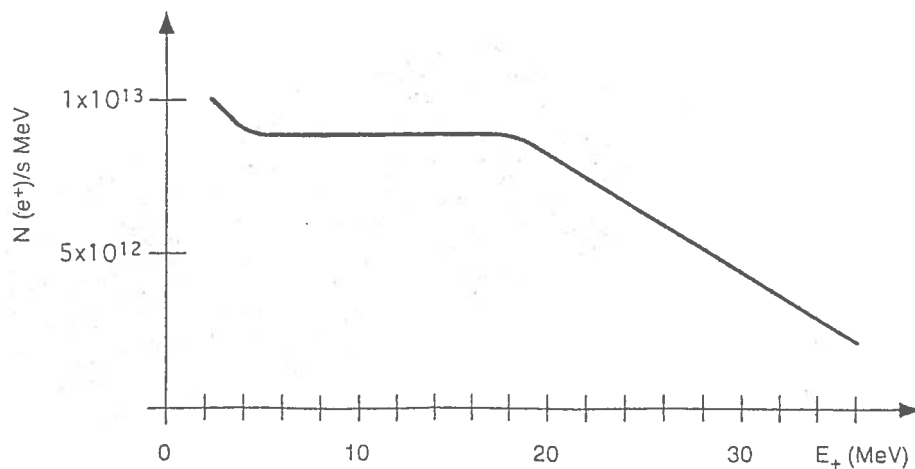

Fig. 4 - Positron yield versus positron energy.

The positron flux that can be obtained at LEP2 is two orders of magnitude larger than that predicted for future projects.[2]

Possible transport system for the positron beam.

The most efficient way to collect the particles produced by the photon beam in the many targets (we suppose each one 100 mm wide and 5 mm high), is to provide a solenoidal magnet producing an axial, longitudinal, uniform field. All the produced particles will move, in the field along helical trajectories, keeping their longitudinal momentum components constant. The radius of curvature of these trajectories projected on a plane perpendicular to the field is: $\rho = \frac{p}{0.3B} \sin\vartheta$ and the maximum angular acceptance of the solenoid will be:

$$\vartheta_a = \arcsin\left(\frac{0.3B}{p} \frac{D}{4}\right)$$

where D is the diameter of the usable volume of the solenoid. The angular acceptance decreases linearly for particles emitted out of the axis. In our specific case (100 mm wide targets), if D = 200 mm, the average acceptance angle $\overline{\vartheta}_a$ will be 75% of the maximum value indicated above.

The values of B and D can be chosen in a way to obtain $\overline{\vartheta}_a$ of the order of the scattering angle of the particles at the exit of each target or, taking into account the probability for the particles of traversing during their helical motion more than one target, somewhat larger.

For instance, at 1.5 MeV the scattering in a $2 \cdot 10^{-3}$. X_0 target is:

$$\vartheta_s \cong \frac{21}{1.5} \sqrt{10^{-3}}, = 0.44 \text{ rad} = 25.4^0$$

For D = 200 mm and B = 500 gauss we get:

$$\overline{\vartheta}_a = 22.5^0$$

which fit reasonably with ϑ_s.

Higher momentum particles will be proportionally less scattered in the target but the projected radius of curvature of their trajectories will remain approximately the same and, therefore, the collection efficiency of the solenoid will be constant over the entire particle energy spectrum.

The emittance of the beam (very large anyway) is maximum for low energy particles, and decreases quadratically with the energy since the angular spread decreases in both planes.

The pitch of the helical trajectories is: $P = \frac{2\pi \cdot p}{0.3B} \cdot \cos\vartheta$, approximately proportional to p. In our case the pitch is 0.49 m at 1.5 MeV/0 and 12 m at 30 MeV. The intensity of the low energy particles is consequently more affected by their possible crossing with other targets since a larger fraction of them will be further scattered beyond the

solenoid acceptance.

To separate positrons from electrons in such a beam, and more generally to select particles of the wanted energy interval we have to superimpose on the longitudinal field, a vertical field deflecting the beam horizontally. The longitudinal field shall follow the deflection. The energy spectrum width will be reduced approximately in the inverse proportion of the deflection angle; the unwanted particles will be absorbed in the walls of the solenoid. Generally the deflection angle should be rather large, taking into account the large beam emittance, in particular on the low energy side. Deflection angles shall be chosen in view of the specific application, but angles equal to 45^0 or more are easily obtainable (a dipole 80 cm long with a field of 1000 gauss is sufficient to deflect 30 MeV/c particles by 45^0). A second deflection, opposite to the first one and located after an integer number of pitches, would minimize the emittance of the selected energy band.

The solenoid has to be terminated with a grid made of magnetic material to collect the flux lines and prevent the formation of large transverse field which would otherwise disperse the particles. This particular point has been suggested and discussed extensively in the paper by Shi, Gerola, Waeber and Zimmermann in Applied Surface Science 85 (1995) 143-148.

The solenoid and dipoles here mentioned are relatively inexpensive. More complicated will be the vacuum system, the γ-collimator, the particle absorbers and the cooling systems. A window, possible of berillium, is needed to separate the machine vacuum from the beam vacuum. This window shall be located quite downstream of the photon beam to spread the photons over a large area. Collimators shall be located before the target to limit the photon beam to the target size, and after the target to permit a reduction of the beam emittance, accordingly to the needs. All the targets will be supported by a light frame mounted inside the vacuum pipe which must be vertically adjustable.

The very special time structure of the synchrotron radiation from LEP (sub-nanosecond or ns burst separated by microseconds) can be preserved in the positron beam and used for timing purposes.

Other applications of the High Intensity Synchrotron Radiation.

Photon beams of the intensity provided by LEP2 can be used for nuclear reactions providing for instance very useful quantities of short lived β^+ emitters like ^{15}O, ^{11}C. An important fact of β^+ production by the γn reaction is that there is no need for radiochemical separation and producing $H_2^{15}O$. The product is immediately available for medical applications.[3]

The γ beam from LEP can also be used to produce a neutron beam of $\sim 10^{12}$ n/s cm^2 adequate for some neutron experiments.

Conclusions.

Production of very high intensity positron beams was proposed some time ago.[4]

This year for the first time the world's most energetic electron beam (E = 80 GeV $\gamma \sim E/m \sim 2 \cdot 10^5$) is operating at the LEP storage ring at CERN in Geneva. LEP will operate until the year 2000. If some machine modification and civil engeneering work (Fig. 3) could be done in the LEP shut-down of 1997-98 a very intense positron beam could operate from 1998 to the end of LEP operation 2000-2001 with an effective time of 2-3 years.

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