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Investigations on a hybrid positron source with a granular converter

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ABSTRACT

Promising results obtained with crystal targets for positron production led to the elaboration of a hybrid source made of an axially oriented tungsten crystal, as a radiator, and an amorphous tungsten converter. If the converter is granular, made of small spheres, the heat dissipation is greatly enhanced and the thermal shocks reduced, allowing the consideration of such device for the future linear colliders. A positron source of this kind is investigated. Previous simulations have shown very promising results for the yield as for the energy deposition and the PEDD (Peak Energy Deposition Density). Here, we present detailed simulations made in this granular converter with emphasis on the energy deposition density, which is a critical parameter as learned from the breakdown of the SLC target. A test on the KEKB linac is foreseen; it will allow a determination of the energy deposited and the PEDD in the converter through temperature measurements. Four granular converters, made of *W* spheres of mm radius have been built at LAL-Orsay; they will be installed at KEK and compared to compact converters. A description of the experimental layout at KEK is provided. Applications to future linear colliders as CLIC and ILC are considered.

1. Introduction

There is a strong need on intense positron sources for future colliders. The qualities of such sources are depending on the photon characteristics and on the converter in which these photons are converted into e^+e^- pairs. Since 25 years, a proposal to use crystals as positron sources using the intense channeling radiation in axially oriented crystals [1] brought very promising results as shown in CERN and KEK experiments [2,3]. The main concern for all positron sources is not only the yield but also the energy deposition and the associated PEDD (Peak Energy Deposition Density). Recent investigations led to the concept of a hybrid source where the crystal-radiator and the amorphous converter were separated by some distance allowing the charged particles emitted in the crystal to be swept off [4]. Moreover, the replacement of the compact converter by a granular one, made of small spheres, seems very promising for the deposited power dissipation. We present this idea.

2. Positron source using channeling and with a granular converter

The main interest in the production of photons in channeling conditions is their *soft spectrum* [5], particularly adapted for the positron source as the known matching devices, put downstream of the converter, capture more efficiently soft positrons (typically from some MeV to 20–30 MeV) [6]. Considering a *hybrid scheme* with a crystal-radiator and an amorphous converter separated by some meters distance, where a sweeping magnet eliminates the charged particles exiting from the crystal, it would be possible to choose a *granular converter* made of small spheres instead of a compact converter. As was pointed out for the target of a neutrino Factory [7], such option would present a better heat dissipation associated to the ratio [surface/volume] of the spheres and also a better resistance to the shocks. We present on Fig. 1 such a scheme.

The spheres, made of *W* material, have few mm radius; they are arranged in staggered layers with an even number of spheres at the photon beam entrance and an odd number at the exit; that allows to have a *central sphere* at the converter exit.

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3. The simulations

The simulations are made under the following hypotheses: the electron incident energy on the crystal is taken as 8 or 10 GeV. The transverse rms size of incident beam will be taken as 1 or 2.5 mm. The *W* crystal is oriented on its $\langle 1\ 1\ 1\rangle$ axis and has a thickness of 1 mm. The granular converter has an even number of layers with *W* spheres having radii from 0.1 to 1.1 mm. Sphere radius with 1.1 mm will be most considered. The distance between the crystal-radiator and the granular converter is taken as 3 meters as for the KEK test.

The outputs will concern the γ and e$^+$ yields and spectra, the energy deposited in the converter as well as the energy deposition density from which it would be possible to derive the PEDD (Peak Energy Deposition Density). Some indications on the expected thermal shocks will be given also.

3.1. Energy spectra and yields

As to obtain the photon spectra in the axially oriented crystal, we used the simulations from V.M. Strakhovenko which takes into account the specific character of electromagnetic interactions in axially aligned crystals and based theoretically on the papers [8] and [9]. The energy spectra for the photons and positrons are presented on Fig. 2. The "crystal" curve corresponds to the axis $\langle 1\ 1\ 1\rangle$ orientation, whereas the "amorphous" curve is for the same crystal in random orientation. Underlying the soft character of the photons emitted in channeling conditions, the photon spectrum has been represented with an appropriate vertical scale: EdN/dE, knowing the $1/E$ behavior of the bremsstrahlung spectrum. The positron spectrum presents also a large number of soft positrons. Enhancement in soft photon and positron production can be observed. The enhancement ratio between the axial and random orientation is of 5.4 for the photons coming out from the crystal (with $E_\gamma < 50$ MeV) and of 5.1 for the positrons ($5 < E^+ < 25$ MeV) at the 6-layer converter exit. These positrons are expected to be the most accepted in capture devices like the AMD (Adiabatic Matching Device) [6].

A particular feature of the photon spectrum generated by ultra-relativistic channeled particles is its soft character, as shown in paper [10] by V. A. Dolgikh et al. where planar channeling is considered. This particularity was previously emphasized in the article of X. Artru et al [5] where axial channeling was considered. Comparisons of the photon spectra for different incident electron energies (2 and 20 GeV in [5] and 5 and 1 Gev and below that energy in [10]) is instructive and is leading to choose high enough energies (several GeV).

The positron yield has been calculated on the central sphere of the exit face of the converter and on the whole exit face of the converter (total yield); they are represented on Fig. 3. A narrow incident beam (1 mm rms radius) gives, obviously, a higher yield than a wider (2.5 mm rms radius) on the central sphere, whereas the total yield remains the same. The parameter conditions corresponding to Fig. 3 are: $E^- = 8$ GeV and sphere radius $R = 1.1$ mm.

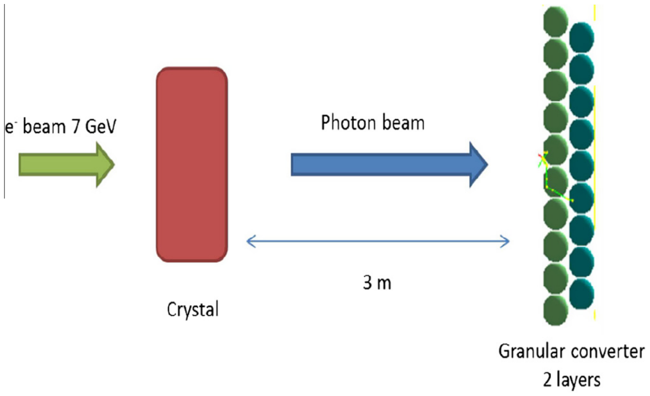

Fig. 1. A hybrid source with a granular converter. The beam parameters correspond to a test foreseen at KEK; incident beam 7 to 8 GeV.

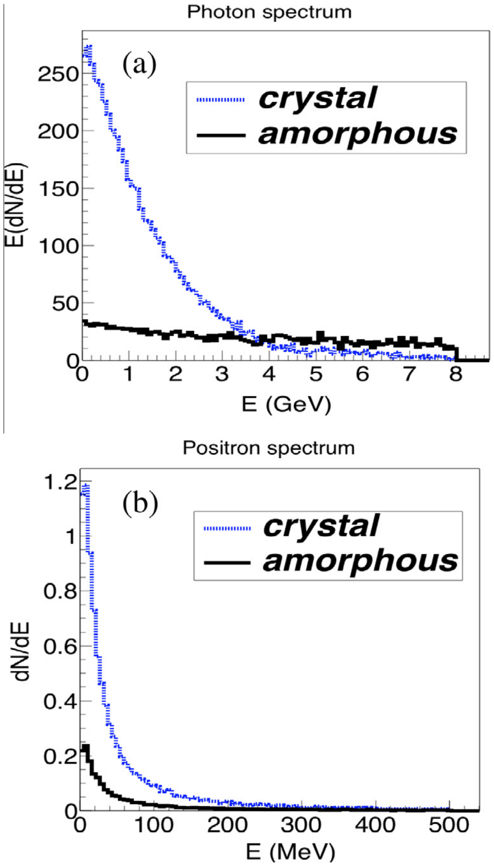

Fig. 2. (a) Energy spectra for the photons, and (b) energy spectra for the positrons.

3.2. Energy deposition in the spheres and the layers

The energy deposited in the converter is calculated in each *W* sphere and its distribution on the transverse exit plane of the converter. These distributions are represented on Fig. 4 with the histograms for the exit faces of the converter. They correspond to successive layers. The vertical scale is in MeV/e$^-$. It is worth noting that the deposited energy is increasing with the rank of the layer and is maximum on or near the central sphere.

It is interesting to calculate the deposited energy in the spheres as the integrated deposited energy in the whole converter made of staggered sphere layers. Such result is represented on Fig. 5 for the case of $E^- = 8$ GeV and a sphere radius of $R = 1.1$ mm. The number of layers is indicated. Two incident electron beam sizes are considered: 1 and 2.5 mm rms. It may be noticed that for 6 layers the deposited energy is slightly larger than 300 MeV/e$^-$.

A very important parameter is the PEDD; in order to calculate it, it is necessary to determine the energy deposition density, given in GeV/cm^3/e$^-$. This energy density has been calculated in the *central sphere* of the exit face of the converter. We have considered the case of a narrow incident e- beam: 1 mm rms radius (for KEK test) and a wider beam: 2.5 mm rms radius. Moreover, we have calculated the deposited energy density for different radii values: 0.1, 0.2, 0.5, 1.1 mm. The results are represented on Fig. 6.

It can be seen on this figure that up to a converter thickness of 1.5 cm, the granular converter does not show significant differences

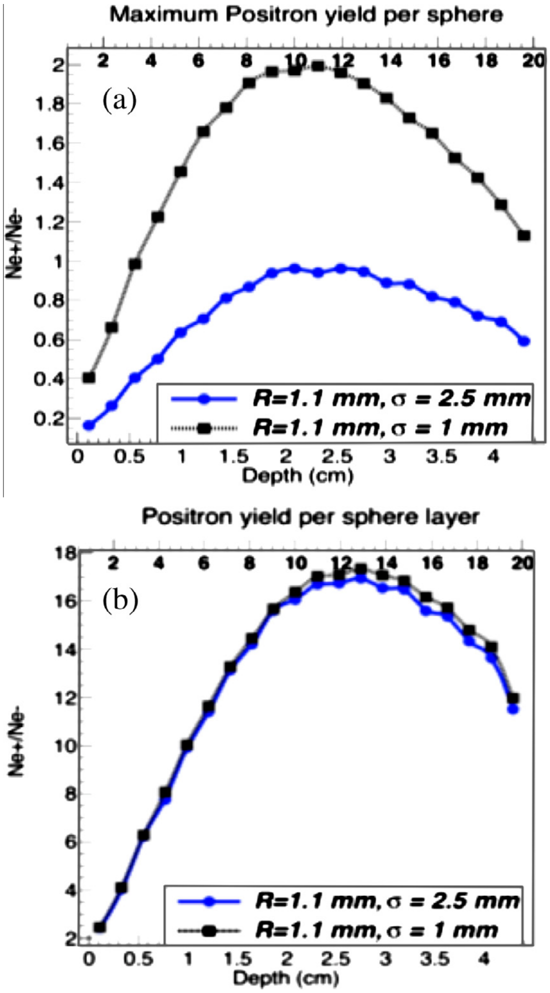

Fig. 3. (a) Positrons yield on the central sphere, and (b) integrated positrons yield on the exit face.

concerning the sphere radius dimension for the same value of the incident beam spot size. That means that, up to that thickness of 1.5 cm, the deposited energy density calculated with spheres of 1.1 m radius represents a rather good approximation for the PEDD. For a 6-layer converter (1.2 cm thick), considered for an application to ILC, this Peak Energy Deposition Density is slightly higher than 1 GeV/cm^3/e$^-$.

3.3. Comparison between granular and compact converters

The energy deposition density is compared for the 2 cases: granular and compact converters. The elementary volumes considered for the calculation of the PEDD have the same values in mm^3; for the compact converter, cylinders with the same radius of the spheres have been taken. At small thicknesses, the energy density is comparable for the 2 cases whereas it becomes lower for the granular converter (Fig. 7). Though the numerical values of the elementary volumes are the same, the difference may be due to the actual relative density of the converter (1 for the compact and about 0.75 for the granular) and to the lateral development of the shower.

Simulations have been operated for 8 and 10 GeV incident energies for both compact and granular targets.

3.4. Lateral distribution of the energy density

The lateral distribution along a transverse central axis has been determined. The density is calculated on adjacent spheres at the exit of the converter. On Fig. 8 we have represented the lateral distribution of the energy density for 2-layer, 4-layer and 6-layer converters. The lateral distribution is determined on the even ranks of layers, which have a central sphere, where the maximum energy density is expected. In an experimental test, thermocouples put on the adjacent spheres should give, through the temperature rise, the energy deposition distribution.

4. Some considerations on the thermal stresses for an application to ILC

Thermal load in the converter material induces stresses and destructive shock waves, as observed on the SLC target. Two ways are used to lower the thermal load: multi-targets system and time structure modification. Considering an application to ILC, the chosen scheme for the modified time structure consists in providing,

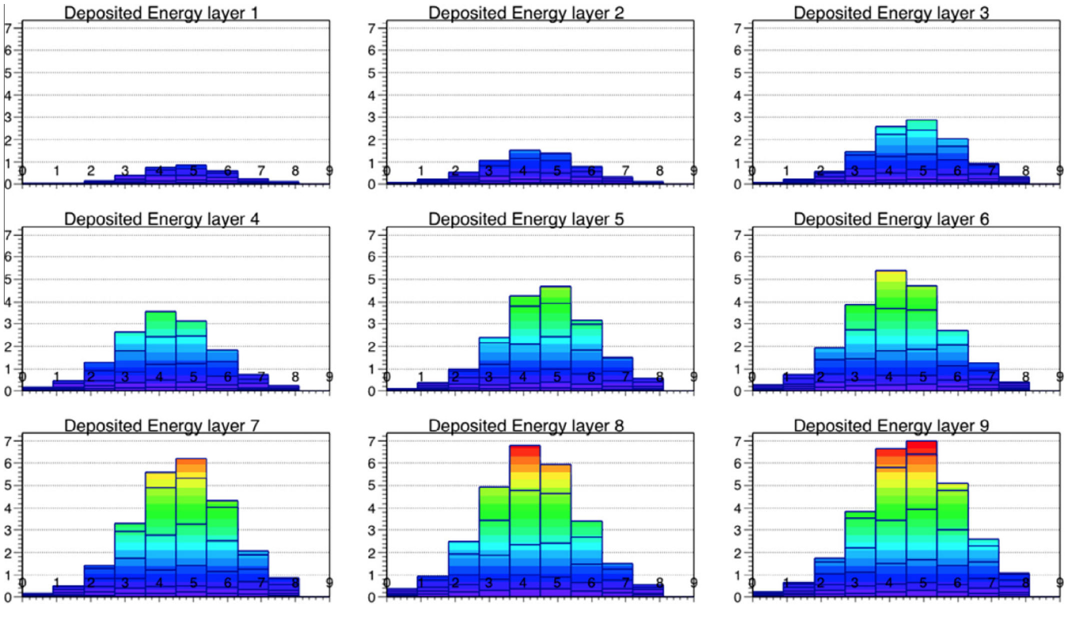

Fig. 4. Transverse distribution of the deposited energy on the successive layers. The vertical scale is the same for all the 9 figures in order to make them more readable.

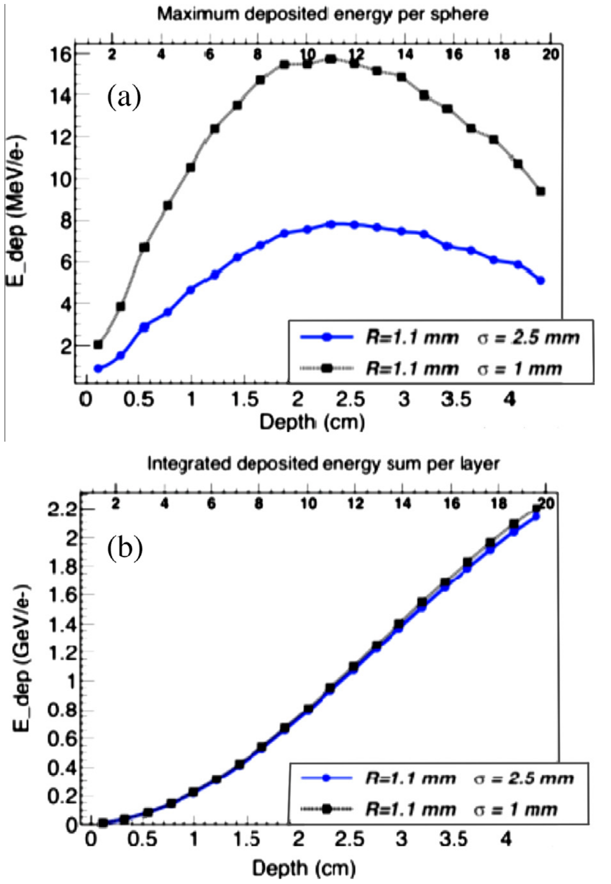

Fig. 5. (a) Deposited energy per central sphere, and (b) integrated deposited energy.

for the incident electron beam, a series of 13 macropulses instead of the long nominal pulse of ILC. These macropulses have a duration lower than 1 µs and a period of 3.3 ms, allowing some relaxation between successive macropulses: a similar scheme was, first, considered by T. Omori et al. [11].

The nominal time structure of ILC is, then, recuperated after the Damping Ring. Considering the small sphere dimensions ($R = 1.1$ mm) there is a stress relaxation during the temperature rise due a shock wave propagation shorter than the heating time (<1 µs). As an example, for the ILC conditions, the radial stress due to a 1 µs pulse is about 10 times lower than for a *Delta function* (see P. Sievers in [12] and the references associated).

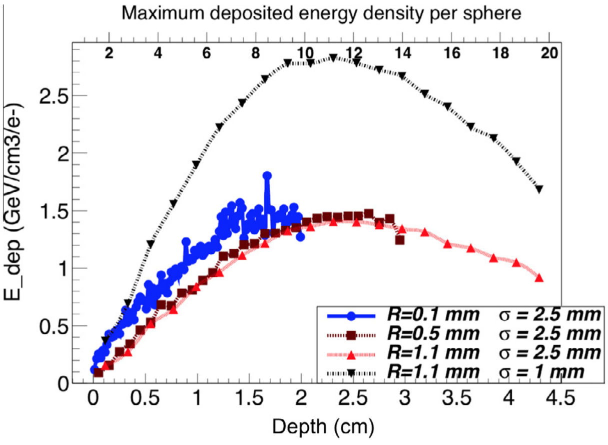

Fig. 6. Deposited energy density on the central sphere.

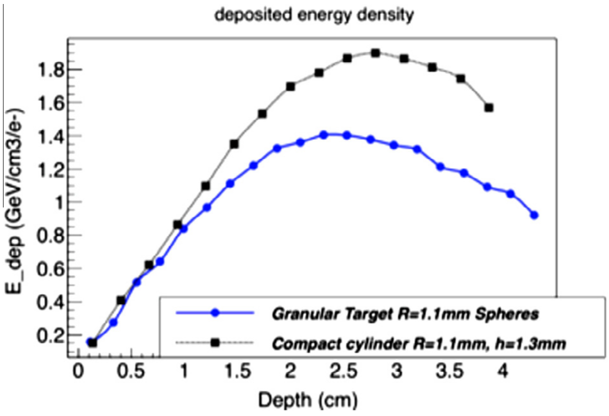

Fig. 7. Deposited energy density in compact and granular converter. The depth represents the converter thickness.

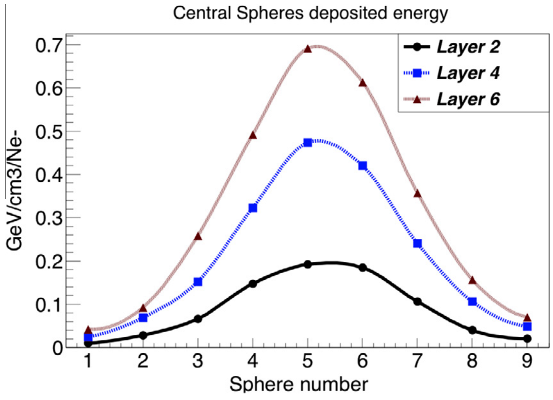

Fig. 8. Lateral distribution of the energy density at the converter exit.

5. Test foreseen for the granular target

It would be interesting to determine the energy deposition density in the converter and, henceforth, to know the PEDD which is one of the main parameters conditioning the target reliability. With the granular structure of the target it is possible, using thermocouples, to measure the temperature rise of the *W* spheres in many locations. We can, then, determine the energy deposited and also its density on the exit face of the converter. This test is foreseen at KEK with the KEKB linac beam. For that purpose 4 granular targets have been built at LAL-Orsay with *W* spheres of 1.1 mm radius. These spheres are put in Al containers, which have grids of 1.8 mm diameter to allow the positioning of the thermocouples on the spheres.

Up to 20 thermocouples will be put on the exit faces of the converter to get information on the temperature rise. In a future stage infrared cameras would be considered to give complementary information. The experimental layout is represented in [13] and it has been already used for a test on a hybrid positron source with a compact converter.

6. Summary and preliminary conclusions

Investigations related to a hybrid positron source using the intense channeling radiation of a tungsten crystal and the interesting features for the heat dissipation presented by a granular converter have been carried out. The hybrid source was already selected by CLIC for the positron source baseline [14]. An application to the collider ILC has been considered and the simulations have shown that a total yield about 12 e^+/e^- and a deposited energy about 400 MeV/e^- could be obtained with a 6-layer granular target at 10 GeV incident energy. The use of a thin crystal radiator associated to a granular converter provides significant enhancements in photon production as in positron generation. For the application considered for ILC, that represents interesting values for the accepted yield. The PEDD remains lower than 2 GeV/cm^3/e^-; that gives a PEDD lower than 32 J/g for the duration of the macropulse, which is below the critical value of 35 J/g.

Simulations were performed also for the experimental test of the hybrid source with the granular converter at KEK. Moreover, four granular converters made of 2, 4, 6 and 8 layers have been provided for this test. The experimental results will be compared with the previsions shown here.

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