FORM-FACTOR FOR A TARGET USED FOR POSITRON GENERATION WITH UNDULATOR RADIATION CONVERSION[1]

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Abstract

It is shown here that the needle type target gives advantages in conversion of gammas from helical undulator into positrons. This is not possible with usual electron to positron production method.

INTRODUCTION

In all operational electron-positron colliders, positrons created by primary electrons in a heavy material target. This primary electron beam with energy E_0, when hits the target, develops a cascade, what is a mixture of electrons, positrons and gammas. Namely these gammas are responsible for positron creation in electric field of nucleus of target material. This cascade develops along the target starting from the points of penetration of initial beam. The cascade propagates inside matter until energy of particles reaches the critical value, $E_c \cong 610/(Z+1.24)$, MeV, Z stands for atomic number. Transverse size of the cascade in maximum is of the order of Molière radius $R_M \cong X_0 E_s / E_c$, where X_0 is a radiation length, $E_s = \sqrt{4\pi\alpha} \cdot mc^2 \cong 21.2 MeV$ –is a scale energy. For W $R_M^W \cong 2.57 X_0$, ($l_M^W = 0.9$cm). For Ti, $R_M^{Ti} \cong 0.7 X_0$, ($l_M^{Ti} = 2.45$cm).

In many laboratories, including BINP Novosibirsk, there were carried investigations on how shape of the target can increase the yield of positrons. Desire was to let positrons, created inside initial parts of volume, escape from the target through the sides without experience of multiple scattering.

Result for W in traditional conversion scheme was negative, however– targets are relatively short and there is no much room for manifestation of angular escape. So, now all operational targets are wider, than the width of a cascade at maximum, $R_t \geq R_M$.

POSITRONS GENERATION WITH UNDULATOR

Method of polarized positron generation was proposed in [1]. In this new method**,** at first stage, circularly polarized gammas obtained from primary high-energy (>100 GeV) electron/positron beam by beamstrahlung in a helical undulator/wiggler. At second stage these circularly polarized gammas converted into positrons/electrons into thin, ~0.5X$_0$, target. Just selecting the positrons or electrons with highest possible energy, one can obtain a beam of *longitudinally polarized* secondary particles. For the wiggling by primary beam it was suggested to use electromagnetic waves, fields of helical crystals and static helical fields [1]. Static helical magnetic fields were found as the only practical ones, however.

Laser radiation as a kind of electromagnetic wave was specially mentioned in 1992 [2] as an example. Formulas and the method are the same, naturally. Later, in 1995, the way with laser radiation was manifested as a direct line for JLC [3,4].

For successful operation, the number of periods in undulator must be around $M \cong 10^4$, what defines the total length of undulator $L = M\lambda_u \geq 100$ m with period $\lambda_u \cong 1$ cm. This covers the losses associated with energy selection of particles. It was found (see [7, 9] for details) that optimal value of undulatority factor $K = eH\lambda_u / 2\pi mc^2$ is K~0.4. Polarization ≥ 65% can be obtained with such long undulator.

So one can see, that any percentage in increase of positron production allows the same percentage in cut of 100 m undulator.

Size of the gamma beam and angular spread can be estimated as

$$\sigma_\gamma \cong \sqrt{\gamma\varepsilon\beta/\gamma} + D\sqrt{<\vartheta^2>} \cong L\sqrt{<\vartheta^2>} \cong 5\cdot 10^{-4} m\,,$$

$$\sigma'_\gamma \cong \sqrt{<\vartheta^2>} \cong 5\cdot 10^{-6} \qquad (1)$$

where the distance from the target to the undulator D estimated as D~L and the size of primary electron/positron beam included too. These numbers used for numerical modeling of conversion.

DESCRIPTION OF PROCEDURE

For calculations the code CONVER [5] operating on PC was used. The code, in its turn, uses results of calculations done by other code- UNIMOD2 [6]. The last one, EGS-like code, calculates the cascade processes in semi-infinite media, keeping the individual history of every particle in cascade since the first appearance. Calculations in CONVER arranged so that the files obtained from UNIMOD2 are transferred to PC and user can easily assemble a target of any shape as a sum of isles, each of them is a body of revolution with polygonal cross section. If trajectory of any particle in cascade meets empty space, its trajectory just continued linearly by CONVER up to the next isle with material. Individual parameters of every particle in cascade at the out of target

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[1] Extended version is available at http://www.lns.cornell.edu/public/CBN/2003/CBN03-2/CBN03_2.pdf . Work supported by NSF.

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region allow to calculate efficiency as well as to prepare the files for further tracking.

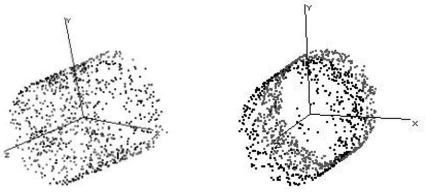
With help of these codes numerous parameters were calculated, such as, for example, polarization, energy deposition and efficiency as function of thickness [7].

TI TARGET

Although utilization of undulator/wiggler conversion decreases average power deposition in target $>10^2$ times, it is still not enough for TESLA. Utilization of Ti for target was suggested in [8]; namely this publication initiated work with Ti in [7]. In addition to bigger volume of cascade developing in this material, it has higher heat capacity. This is a sequence of Dulonge–Petite law.

Now, as the cascade process is no longer involved in conversion with undulator, result of shape optimization might indicate some significant improvements. First results were quite positive. This was mentioned for the first time in [9].

As all the files with Ti from UNIMOD2 were preserved since the [7] done, it was easy to make calculations for the form-factor now. Example of graphical presentation of output coordinates is shown in Fig.1. Here the shape of cylinder is clearly visible. Each point represents coordinates, when particle (positron) leaves the target.



Type#1 Type#2

Figure 1: Different type of arrays of output coordinates. Type#1 for relatively short target. Type #2-for the long target. Lengths of cylinders are not in scale with diameter.

In Fig.2 the efficiency represented as functions of thickness for different target diameter. Energy of photons E_γ=30 MeV, positrons selected in interval 15-30 MeV within capturing polar angle $\Delta\vartheta \le 0.5$ rad. After $R_t > 4\sigma_\gamma$ the graphs began decline as functions of thickness –positrons cannot escape freely though the sides. One can see, that efficiency of positron conversion for infinitely wide target has maximum around 1.25 cm long-target. Accuracy of calculation was $\le 10\%$.

Same data, as in Fig.8, but transposed, are represented in Fig.8. Typically parameters of targets considered for DESY so far located behind the right edge of this Fig.8-wide targets. It is clearly seen from this figure, that optimum target diameter is somewhere between 0.75-1.0 mm. Even for target having length ~1 cm it is better to have its diameter small, something about 1 mm. This is a new result.

So the strategy in obtaining maximum yield is now to increase the length of the target simultaneously decreasing its radius to about $R_t \cong 2\sigma_\gamma$

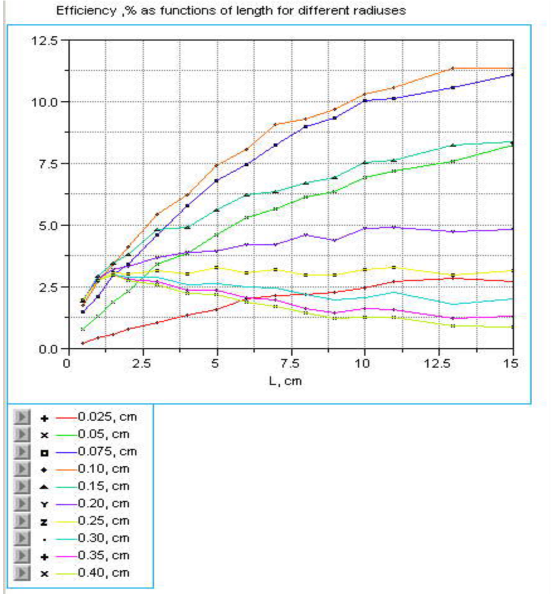


Figure 2: (Color) Efficiency as functions of target length for different values of radius.

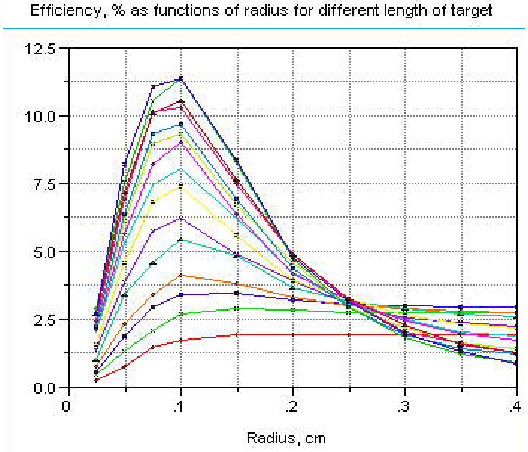


Figure 3: (Color) Efficiency as functions of target radius for fixed length. Curves are running for lengths 0.5, 1.0,1.5, 2.0, 3.0,…11, 13, 15 cm.

TECHNICAL REALIZATION OF COLLECTION SYSTEM

First scheme, Fig.4, uses short target with reduced diameter. Here Ti needles pressed is Be wheel. All assembly located in vacuum. Rotation of wheel synchronized with repetition rate of machine.

Total power deposited in the target system is few hundreds Watts only, so the cooling is not a problem here. Other technical solution is shown in Fig.5. Here the target of 2-6 cm long enclosed into a Ti cylinder with a coolant running inside. For coolant it is naturally to use liquid Lithium. For pumping of liquid Lithium a well-developed technique can be used [10].

Some of positrons can hit the target again, but as the target is thin in transverse direction, the scattering is small. Scheme with flux concentrator of this type was successfully implemented into CESR [11].

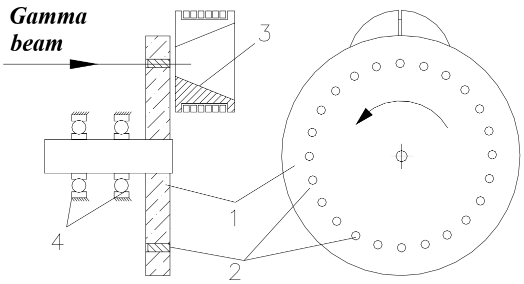


Figure 4: Realization of multi-target assembly. Ti needles pressed into Beryllium wheel. Here 1 is Beryllium wheel, 2 are Ti needles, 3–is a flux concentrator, and 4–bearings.

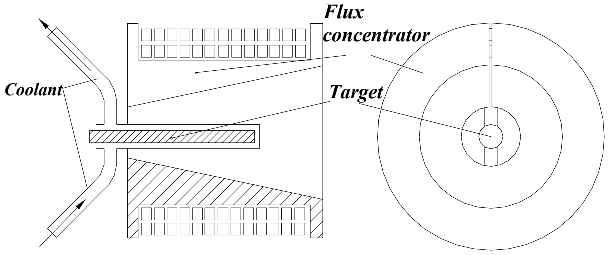


Figure 5: Another technical realization of target assembly. Ti target enclosed in Ti container with Li coolant.

Other way to increase cooling of target is shown in Fig. 6. Coolant flowing between discs effectively working because the distance from coolant edge to the point inside the target defined by thickness of the disc, not a diameter.

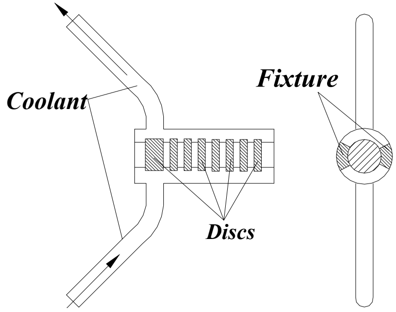


Figure 6: Sandwich-type high power target. W or Ti target discs enclosed in Ti container with coolant.

One other way to increase positron production –utilization of few targets and combining positrons into longitudinal phase–space is among guaranteed ones [1], [7], [9], [12]. This is also some kind of form-factor problem.

CONCLUSION

Increase in positron production allows proportional shortage of ~100-meter undulator and/or a source of additional operational margins for conversion system.

It is shown here for the first time, that needle-like Ti target with radius ~1mm ($R_t \cong 2\sigma_\gamma$) can give yield ~11.4%, which needs to be compared with ~2.7% yield for infinitely wide target and the same capturing angle ~0.5rad and for $E_\gamma = 30MeV$. This is two times bigger than for W target. Of cause final numbers will depend on capturing system, however indication, that form-factor can improve the yield so much, gives the basis for target optimization for real LC conversion unit. Decreasing diameter of the target also helps in cooling, even if the target is short.

Optimistically speaking, one can expect shortage of undulator length at least in half if the optimal target shape is used. If the length kept the same, this optimization will give wider operational margins or higher polarization, as one can select among much more positrons now.

In conclusion Author thanks A.D. Bukin for permission to use his code, which made this job possible.

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