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Abstract

The NLC positron production target is optimized with respect to positron yield, target integrity, cooling and shielding.

1 Introduction

The proposed Next Linear Collider (NLC) is a e^+e^- linear collider with the c. m. energy up to 1.5 TeV [1]. One of the essential NLC components is a target used for producing a low energy positron beam to be captured and accelerated. The positron production target design should take into account and properly balance the positron yield per initial electron, target integrity, shielding and thermal problems. A series of Monte Carlo simulations were performed for the various target materials and configurations. The EGS-4 [2], GEANT-3 [3] and MARS [4] Monte Carlo codes were used in the calculations.

2 Design Parameters

The positron yield calculations were performed for the SLAC electron beams with the parameters presented in Table 1 [1].

Table 1: Electron Beam Parameters.

Parameter	NLC 500 GeV	NLC 1.0 or 1.5 TeV
Energy E_{e^-} , GeV	3.11	6.22
Intensity, N_{e^-} /bunch	$1.50 \cdot 10^{10}$	$1.50 \cdot 10^{10}$
Bunch length, psec	5	5
N bunches / pulse	90	75
Intensity, N_{e^-} /pulse	$1.35 \cdot 10^{12}$	$1.13 \cdot 10^{12}$
Rep. rate (Hz)	180	120
Beam Power (kW)	121	134

Positrons generated in the target have to be captured into a flux concentrator with a relatively small spatial acceptance (from 3 to 5 mm) and narrow energy bin of 5 to 25 MeV. The positron bunch accelerated in the linac goes finally to the collider. The design goal is to achieve a yield of approximately 1 positron per electron at the exit from the flux concentrator.

3 Positron Yield

The calculations have been performed for the electron beam parameters given in the last column of Table 1. It is assumed that the initial beam has a Gaussian spatial distribution with $\sigma_x=\sigma_y=0.8$ mm, a Gaussian energy distribution with $\sigma_E=0.001 \times E_{e^-}$ and a Gaussian angular distribution with $\sigma_\theta=5$ mrad. Figure 1 shows the absolute yield (in terms of the number of e^+ per initial electron) for a solid tungsten target, $4L_R$ thick and 100 cm in radius, for several collection radii R_{col} .

FIGURE 1. Absolute positron yield per $\Delta E = 2$ MeV per one initial electron for the solid tungsten target, $E_e = 6.22$ GeV.

Taking into account a flux concentrator collection efficiency equal to 40%, a solid tungsten target gives a yield of about 1.9 positrons per electron, which exceeds the design goal [1]. At the same time, there are severe problems with tungsten as a material for the target. It is fragile and has low specific heat and thermal conductivity, that leads to certain mechanical and cooling problems. Some mitigation is possible with tungsten alloys, but one can try copper instead. Its relatively low Z can result in somewhat decreased positron yield, but copper is far superior from the mechanical and thermal standpoints. A few runs were performed for several copper targets: cylinders and cones of different radii.

FIGURE 2. Ratio of positron yield per $\Delta E=2$ MeV from copper target to that from tungsten. Target thicknesses are $4 L_R$ and radii are 3 mm.

Figures 2 and 3 show that the positron yield from copper is about 60% of that for tungsten in the energy interval 5 to 25 MeV, i. e. about $1.1\text{--}1.2 e^+$ per electron after the same flux concentrator. A yield enhancement can be achieved by using the wire-like cylinder or cone target and collecting positrons in a wider spatial and energy bins. These techniques were proposed in [5] and need additional calculation and design efforts for a nonstandard capture and concentrator system.

FIGURE 3. Ratio of positron yield from cone copper target per $\Delta E=2\text{ MeV}$ to that from tungsten. Target thicknesses are $4L_R$, cone upstream radius is 4 mm and downstream radius is 1 mm.

4 Thermal and Integrity Analyses

Energy deposition density in tungsten and copper targets 6 mm in diameter is shown in Figures 4 and 5, respectively. One can see that the copper target has less energy deposited per unit volume. On the other hand, integral energy depositions are rather close to each other for the same target lengths as shown in Table 2.

FIGURE 4. Energy deposition in a tungsten target.

FIGURE 5. Energy deposition in a copper target.

Table 2: Fraction of the beam energy (%) deposited in tungsten and copper cylindrical targets of different lengths L (in units of the radiation length L_R). Last column shows the peak energy deposition density $\epsilon_{max}(J/g)$.

L	2	4	6	8	ϵ_{max}
W	2.5	15.0	36.1	56.9	174
Cu	4.2	21.7	46.5	67.6	90

The peak energy deposition density in the tungsten targets is very close to the shock wave limit, which is 200 J/g in this material. For this reason the SLAC team suggests special mitigating measures in order to prevent target destruction, namely, a spoiler to increase the initial beam spot size and a target rotation with relatively high speed.

Contrary, in copper the peak energy density is about 20% of the corresponding shock wave limit, that can drastically simplify the target operation. With the current proposal, the tungsten target provides about 40% higher positron yield, with no margin for further increasing of the production rate. At the same time, copper has at least a factor of five margin which allows increasing the positron yield just by using more intense electron beam.

Thermal analysis was performed using the ANSYS code [6]. The effective cooling system with $\Delta T=0$ at the target outer radius was assumed. Figure 6 shows a two-dimensional maximum temperature distribution in the copper target 0.4 sec after the beginning of the irradiation. Figure 7 shows the time dependence of maximum temperature in the copper target with a steady-state regime reached after about 0.3 sec. One can see that with a good cooling system the maximum temperature in the target is $\approx 700^\circ\text{C}$, that allows one, in principle, to stay with a stationary target.

FIGURE 6. Temperature distribution after the pulse.

FIGURE 7. Maximum temperature in the copper target as a function of time.

5 Shielding

A copper target has another advantage, lower neutron yield, which reduces the required shielding. Calculated with the MARS code, hadron ($E > 14$ MeV) and low-energy neutron ($E < 14$ MeV) fluxes around tungsten and copper targets are presented in Table 3. The neutron yield is almost 6 times lower for the copper target, that results in a more compact target zone shielding. Estimated residual dose rate for the copper target is lower compared to the tungsten one.

Table 3: Particle flux around tungsten and copper targets ($4 L_R$ long and 6 mm diameter) irradiated with 6.22 GeV electron beam of 1.13×10^{12} ppp at 120 Hz rate.

Target	Φ_n ($\text{cm}^{-2}\text{s}^{-1}$)	Φ_h ($\text{cm}^{-2}\text{s}^{-1}$)
W	$6.25 \cdot 10^{12}$	$4.72 \cdot 10^{11}$
Cu	$1.04 \cdot 10^{12}$	$4.39 \cdot 10^{11}$

6 Conclusions

Copper is suggested as a material for the positron target with yield of ≥ 1 positron per electron. In contrast to tungsten, copper is farther from the shock-wave limit and has much better thermal properties. A copper target can be designed as a stationary unrotated cylinder with intensive cooling. With a copper target it is possible to increase further positron yield using a more intense e^- beam. Hadron and low-energy neutron yield is lower for the copper target in comparison with the tungsten one, reducing the volume of the required shielding.

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