COLLIMATOR FOR ILC

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Abstract

We considered two types of collimators for usage in undulator conversion system of ILC. In the First is the one with Pyrolytic graphite and it is installed in front of a target, the second one uses InGa alloy in rotating cylinder. The last one installed in front of undulator. Collimators allow absorption single train on bunches in ILC and enhance the photon polarization.

INTRODUCTION

System for generation of positrons for ILC uses a helical undulator, in which primary high energy main beam (E_0~150GeV) generates circularly polarized photons. Further these phonons converted into e^+, e^- in a thin target [1]. Few types of undulators considered in [1], such as electromagnetic wave, crystals with helical dislocation and static magnetic field. Static helical field was found the mostly practical one.

In conversion system with undulator, few types of collimators required. Each of these serves for resolving specific task.

First type is the one for protection of undulator in case of occasional direct hit by the primary beam train. Its role basically the same as the ones placed along linear collider to protect the SC structures and other elements which might be hit by the beam. This collimator must absorb at least one full train of n_b=2820 bunches each with population $N \cong 2\cdot 10^{10}$ caring total energy $E_{tot} \cong en_b N E_0 \cong 1.35 MJ$. As the beam size is extremely small, the density of energy deposition destroys material at once, if not protected properly.

Second type is a collimator for gamma-beam. It serves for two purposes: first, it cuts low energy spectra at first harmonics and, second, it cuts the second harmonic, as the second (and higher) harmonics have zero intensity in forward direction for helical undulator. The second harmonic cut allows having *K* factor higher, than with absence of collimation and to enhance polarization of positron beam in general. This is due to the fact, that the particles (positrons or electrons) of maximal energy must be selected. What is maximal for the first harmonic is the half only for the second one, so the polarization of positrons generated by photons from second harmonic and transferred by selection system, is ~zero. The power which must be absorbed by collimator installed in front of target is of the order of 20-50 kW, depending on regime of operation; more exactly by *K* factor in undulator and its total length.

Sectioned collimator for enhancement of polarization of undulator radiation and for protection of undulator introduced a time ago [2]. Idea of collimation for enhancement of polarization appeared even earlier [3], [4]. There collimator was modeled as a target of finite radius. For high power in can be realized by insertion of small cylinders of W or Ti into Beryllium disk [5]. In sectioned collimator, the first sections made on low Z material (Be); the following sections made from heavy material. The length of such collimator can reach few meters.

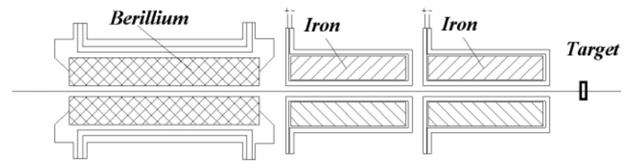

Figure 1: Sectioned collimator [2].

In this example the Iron used as it can be magnetized in azimuthal direction to bend charged secondary particles inside the iron out from forward direction. In this geometry the azimuthtal induction B~15-20 kG can be reached with a small axial current running in cylindrical Copper-made enclosure coaxial with central vacuum chamber (or even through the iron).

TO THE CHOICE OF DIMENTIONS

The primary electron beam with energy E_0, when hits the media, 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,

$$X_0^{-1} \cong 4 r_0^2 \alpha \frac{N_A}{A} Z(Z+1) \ln(\frac{183}{Z^{1/3}}) [cm^2/g], \qquad (1)$$

A –is atomic weight of target substance, $N_A \cong 6.022\cdot 10^{23}$ is the Avohadro number, *Z* is atomic number, $\alpha = e^2/\hbar c \cong 1/137$, r_0 is the classic electron radius. $E_s = \sqrt{4\pi/\alpha}\cdot mc^2 \cong 21.2 MeV$ –is a scale energy. Naturally, the Molière radius, expressed in cm, is bigger for lighter materials, as $R_M \approx 0.035\cdot Z \cdot X_0$ and $X_0 \propto A/Z^2$, so $R_M \propto A/Z$, where *A* is atomic weight. For W with its *Z*=74, $R_M^W \cong 2.57 X_0$ (l_M^W =0.9cm), as geometrical length corresponding to the radiation one is $l_{X_0} \cong 0.35 cm$. For Ti, with its *Z*=22,

$R_M^{Ti} \cong 0.7 X_0$ ($l_M^{Ti} = 2.45$cm), as $l_{X_0} \cong 3.55cm$. Cascade reaches its maximum at the depth $t_{max} \cong X_0\, ln(E_0/E_c)/ln\,2$ with the number of the particles there about $N_{max} \cong E_0/E_c$. So one can estimate geometrical volume occupied by cascade as

$$V_c \cong \frac{\pi}{3} l_{t_{max}} l_M^2 \cong \frac{\pi}{3 \cdot ln\,2} l_{X_0}^3 \left(\frac{E_s}{E_c}\right)^2 ln\frac{E_0}{E_c} \propto l_{X_0}^3 \cdot Z^2 \propto A^3/Z^4 \cdot$$

For example the ratio of these volumes for Tungsten and for Graphite becomes

$$V_c^C/V_c^W \propto \left(\frac{l_{X_0}^C}{l_{X_0}^W}\right)^3 \times \left(\frac{Z^C}{Z^W}\right)^2 = \left(\frac{19.2}{0.35}\right)^3 \times \left(\frac{6}{74}\right)^2 \approx 1000,$$

i.e. the volume involved in cascade inside C is about 1000 times the volume inside W for the same initial energy of primary electrons. The number of particles in cascade generated by 20-MeV photons for *W* will be ~10 times bigger than in *C*. Accurate calculations carried numerically with code CONVER [6]. Below in Fig. 2, there the individual trajectories of photons from primary gamma beam inside cylindrical collimator having central hole with diameter 2mm are represented. The gamma beam has $\sigma_\gamma \cong 0.5cm$, which defined by angular spread $\cong \sqrt{1+K^2}/\gamma$ or radiation in undulator and by the distance between undulator and target. Optimal value of distance is~100-150 meters. Influence of natural angular spread of the beam in undulator is small, compared with this one.

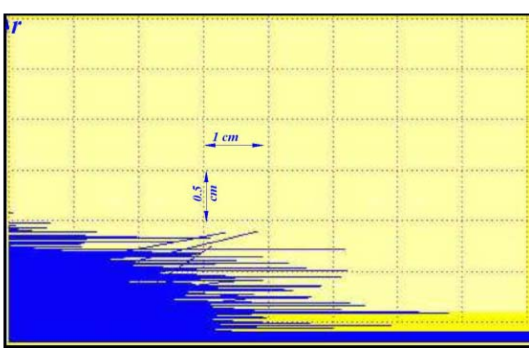

Figure 2: Gamma-beam. $\sigma_\gamma \cong 0.5cm$, diameter of the hole (blue strip at the bottom) *d*=2 mm. Energy of gamma-beam coming from the left is 20 *MeV*.

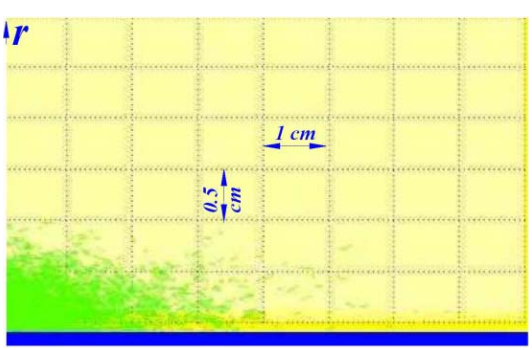

Figure 3: Positron component of cascade from Fig.2.

COLLIMATOR FOR GAMMA BEAM

So depending on the task, the transverse size of collimator can reach couple Molière radiuses. We concentrate at the following collimator, Fig.4, which is similar to one represented in Fig.1. This collimator installed in front of target. Pyrolytic Graphite is used as a low Z material inserted with lapping and brazed into Copper cylinder cooled by liquid. Graphite cylinder has a axial hole of ~3mm in diameter. After this Graphite cylinder, installed a Tungsten cylinder in the same Copper tube. W cylinder has the hole of the same diameter as Graphite one. For making hole in Tungsten cylinder, having the length~8 cm it either can be sectioned in longitudinal direction or split in halves along the beam line.

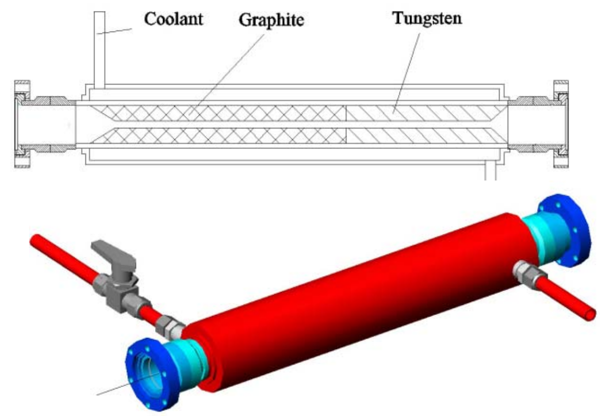

Figure 4: Collimator with Graphite. Flanges are 2 ¾ inch in diameter.

Pyrolytic Graphite (PG) has unique properties, such as high temperature of operation, low vacuum outgassing and the heat conductivity ~300 W/m-^{o}K which is is comparable with metals. For Graphite $l_{X_0} \cong 19.2$ cm (X_0 =43.3 g/cm^2. is denser, than Be.

HIGHT POWER COLLIMATOR

One of the simplest collimator for high power is represented in Fig.5. Here Beryllium tube separates the vacuum channel and the volume filled with liquid metal. As the diameter of inner tube is relatively small (~5mm in dia) it can withstand significant pressure developed inside the volume of metal.

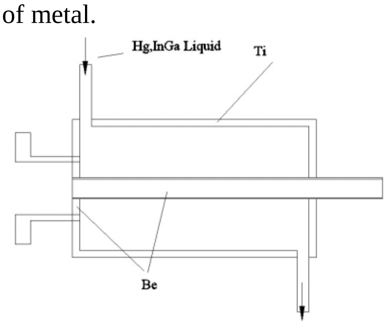

Figure 5: Simplified concept of liquid metal collimator.

Another example is a *collimator with rotating liquid*. It allows excluding the inner tube at all. Represented in Fig. 6 collimator is a contemporary design. Similar device was considered for VLEPP [8]. To fill the inner volume, the cylinder and liquid must have angular speed $\omega \geq \sqrt{g/r}$, where g=9.8m/s^2, and r stands for the inner radius. Let us take for estimations r =2mm=0.002 m, then $\omega \geq \sqrt{9800/2}$ =70 rad/s or 11 turns/s. The last number looks reasonable. In the Figure 4, at the right side, the diameter of the hole in bottom of Be cylinder is smaller, than at the left side.

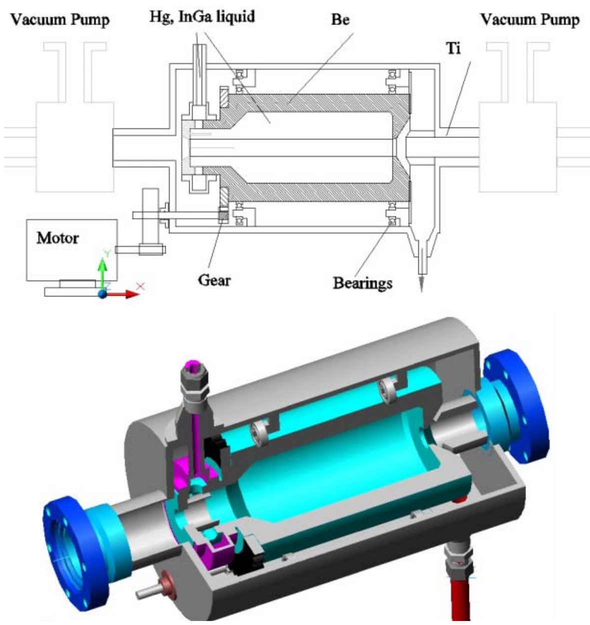

Figure 6: High average power collimator. Beam is coming from the right.

This collimator surrounded by pumping stations from both ends. These stations contain the Cold traps (cooled by Liquid Nitrogen) to avoid metal dispersion to the surrounding vacuum channels.

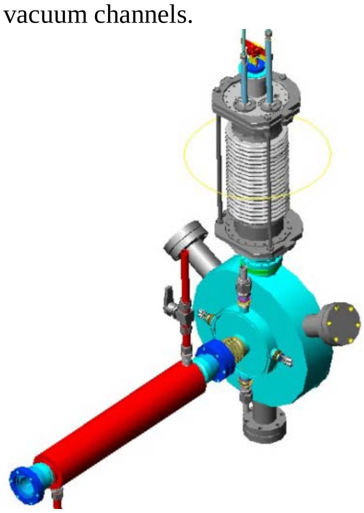

Figure 7: Conversion module with collimator assembled. Flange shown is a 2¾ inch. Elements of transverse motion of these devices for proper spatial positioning not shown here [9].

Sublimation of graphite investigated for usage of graphite as a target for muon production [7]. For temperatures > 2000^{o}K vaporization in vacuum is going from one side of cylindrical hole to another, so formally there is no losses of material.

CONCLUSIONS

Two types of undulators considered satisfy requirements demanding by conversion system for positron production. For enhancement of gamma-beam polarization and fot cut of second and higher harmonics collimator with Pyrolytic Graphite/Tungsten looks adequate. For high power collimator able to absorb single train of bunches we recommend a collimator with rotating metal.

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