COLLECTION OPTICS FOR ILC POSITRON TARGET

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Abstract.

We are considering the implementation of a Lithium lens and SC solenoidal lens for collection of positrons in ILC undulator-based source. Such a lens installed right after the thin target, which is illuminated by gamma quants from helical undulator

INTRODUCTION

Collection optics is an electro-optical system located right after the target, where the primary particles (electrons) or radiation (photons) converted into electron-positron pairs. Main functionality is linked to a short-focused lens, having focal point inside the target, see Fig.1 below.

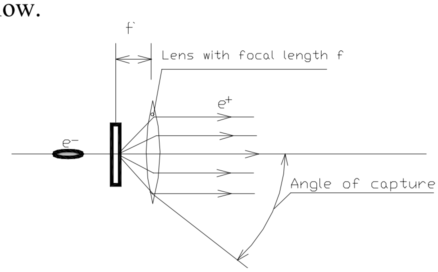

Figure 1: Geometry of capturing. Target located at the distance f -the focal distance of the lens. Shorter the focal distance–smaller the beam size at the exit.

For ILC the baseline for a target is a spinning Ti rim having thickes~14mm [1]. This is done in desire to avoid destruction of target under significant average power deposition in material of target under exposure to the primary gamma beam. Some other possibilities for conversion target include liquid metal target using Pb/Bi or Hg [2]. Another example of target has first layer at the entrance made from Tungsten and the second (outer layer) is made from Titanium-sandwich type. Full target thickness comes to ~3mm total in this case.

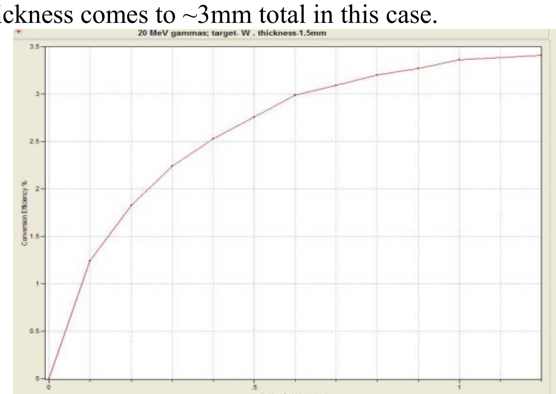

Figure 2: Efficiency of conversion 20 MeV gammas into positrons, %, as a function of capturing angle while irradiating 1.5 mm thick-W target.

In this publication we consider, in brief, two types of short-focusing electro-optical devices such as Lithium lens and solenoidal multi-turn lens for collection of positrons.

Conversion efficiency of positron creation by gamma is a strong function of capturing angle, i.e. the azimuthal angle, within which the positrons are captured, see Figs.1,2 above. Typical capturing efficiency calculated with so-called adiabatic matching device (AMD) is ~30% (see for example [3]), so one can see, that capturing angle, counted from straight –forward direction is something about 0.1 rad only. So finding more effective capturing principles and devices becomes very important business for ILC type machine.

Usage of collection optics has a peculiarity here as the spinning target rim perturbs magnetic field as a result of eddy currents in moving metal [2]. So the collection optics must be field-free in a target region.

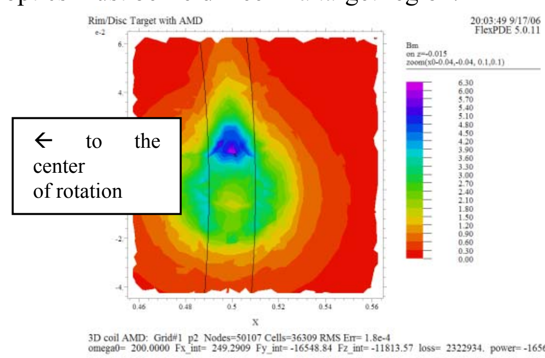

Figure 3: Top view to the rim-target with distribution of magnetic field modulus in material and around. Rim is spinning counterclockwise (direction to the top in this Figure). Drag is seen clearly.

Increase in efficiency of capturing, helps in lowering of maximal temperature of hot spot in a target. It also helps in reduction of field in undulator as a sequence.

First device satisfying these requirements we considering is so called Li lens [4] which has well confined spatial distribution of field. For solenoidal lens the field drops at the distances ~diameter of aperture, so usage of small-aperture solenoid as a lens becomes possible here also.

LITHIUM LENS

Numerical calculations of conversion with start-to-end code [2] shows, that collection by Lithium lens allows at least 1:1.5 conversion of initial electron (positron) beam into the secondary polarized positron beam confined into phase volume

$$\varepsilon_{x,y} \cong p_{\perp} c \cdot \Delta l \cong 2 MeV \cdot cm \,.$$

Polarization of secondary beam comes to ~60% for 175m-lomg undulator. The gradient in Li lens required G~65 kG/cm. Active body of lens has radius r=0.7cm, length L=0.5 cm with Be flanges of l=0.5 mm thick. To reach this gradient the feeding current required ~150kA. For

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modeling of such lens we erected numerical model using time dependent 3D FlexPDE code. Cross section of such lens represented in Fig.4. Flow of Lithium arranged in symmetrical way by gear pump. Flanges have slight spherical shape for better withstand of pressure.

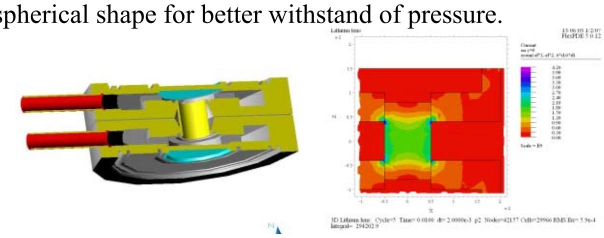

Figure 4: Cross section of lens with liquid Li and distribution of current in it calculated with FlexPDE©.

Cooling is going by circulating liquid Li. Melting temperature 180.54 deg C is low enough for these purposes. One possibility is to use the first flange as a target, if it is made from W alloy.

Energy deposition in flanges can be evaluated by taking into account that the energy deposition in material is going by secondary particles (positrons and electrons) at the level $\delta E \sim 2\ MeVcm^2/g$. One can evaluate that for the secondary beam diameter $d \cong 1$cm area illuminated is going to be $S = \frac{1}{4}\pi d^2 \cong 0.4\ cm^2$. As the volume density of Be is $\rho \cong 1.8\ g/cm^3$, so the energy deposited in a material of flange going to be $\Delta E \cong \delta E \times \rho \times t / 1cm \cong 0.2$ MeV per particle, so the total energy deposited by the train of n_b bunches with population N each, comes to

$$E_{tot} \cong \Delta E \times N \times n_b \times e \quad Joules, \tag{1}$$

where e stands for the charge of electron. The last expression goes to be $E_{tot} \cong 1.8\ J$. This amount must be multiplied by the factor reflecting spare particles, ~1.5-2 , also multiplied by the factor two- reflecting equal amounts of electrons and positrons and, finally, multiplied by factor reflecting efficiency of capturing (~30%). So the final number comes to

$$E_{tot} \rightarrow E_{tot} \cong 1.8 \times 2 \times 2 \times 3 \approx 7.2 \times 3 \approx 21 J.$$

Temperature gain by heat capacity of Be $C_v \cong 1.82$ $J/g/degC$ comes to

$$\Delta T \cong \frac{E_{tot}}{mC_v} \cong \frac{E_{tot}}{\rho S l C_v} \cong 660 \text{ deg.} \tag{3}$$

One needs to add the initial temperature which is above melting point of Lithium, coming to maximal temperature ~850-900 deg. Meanwhile the melting temperature of Be is 1278 deg, so it withstands.

We intentionally kept the component of heating arising from electrons. Although the lens *defocuses* the electrons and spreads those to significantly larger area so they do not give input at the outer flange; this input remains in input flange however. The low energy component of positrons indeed becomes over focused; and might increase the particle density at the center. Most of the heat will be carried out through the contact with Li. For the one millisecond duty of the pulse, the liquid moving with ~1m/sec will pass ~1mm. To the next train which arrives in 1/5 sec i.e. in 200 msec, the Lithium will be refilled the volume of lens few times.

Boron Nitride is other candidate for output window.

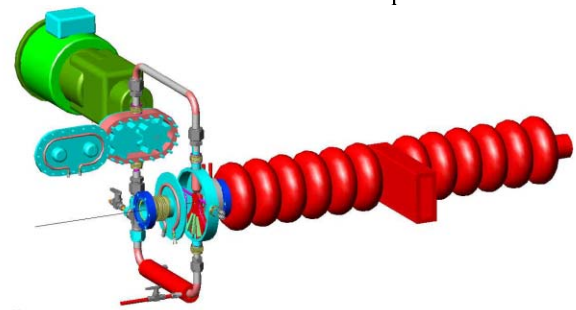

Figure 5: View to the liquid metal target, Lithium lens and accelerating section.

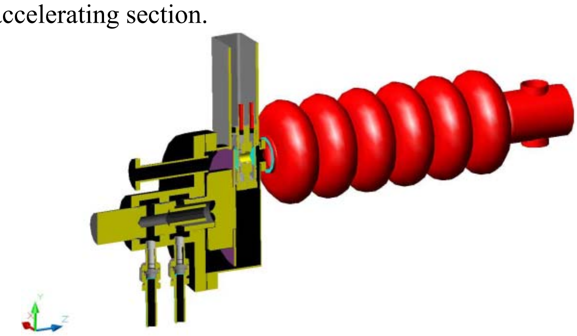

Figure 6: Lithium lens installed right after the spinning target disc [2].

SOLENOIDAL LENS

First, let us evaluate the field strength required. Equalizing the focal length of Li lens and solenoidal lens one can obtain

$$\frac{1}{f} \cong \frac{GL}{(HR)} = \frac{\int H_\parallel^2(s)ds}{4(HR)^2}, \tag{4}$$

where $(HR) = pc/300$ stands for magnetic rigidity. Writing this integral as

$$\int H_\parallel^2 ds \equiv H_{\parallel\max}^2 \cdot L \cdot \eta\ , \tag{5}$$

where factor η shows how many times the effective field spatial distribution is longer, that the length of Lithium lens, one can obtain $H_{\parallel\max}^2(s) = 4 \cdot G \cdot (HR)/\eta$. Typically the longitudinal continuity is $L\eta \approx 1.5 \div 2D$, where D stands for diameter of solenoidal lens. The Lithium lens has the length $L = 0.5cm$. Diameter of solenoidal lens is something about 5 cm, then $\eta \cong 15 \div 20$. Thus, substitute here (HR) =100 $kG{\cdot}cm$ (for 30 MeV particles), one can obtain $H_{\parallel\max}^2(s) \cong 4000\, kG^2$, so the maximal field becomes $H_{\parallel\max} \cong 63$ kG. For generation of such field the amount of Ampere-turns required goes to be

$$nJ \cong \frac{H_{\parallel\max}\Lambda}{0.4\pi \cdot n},$$

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where Λ stands for the length of solenoid. So for $\Lambda \cong 5cm$, the last value goes to be $nJ \cong 262$kA-turn. If we choose the number of turns in two layer solenoid as big as ten turns in each layer, 10×2=20, then the current in each turn comes to $I_1 \cong 13$ kA. Let the cross section of conductor be rectangle with area a=5×10 mm^2 so the current density comes to be $j \cong I_1/a \cong 260$A/mm^2 which is allowable for pulsed feeding.

Coil immersed in oil-filled stainless steel container, so the perturbation of field by eddy currents is minimal. Oil circulated by gear pump, similarly to what described in [4].

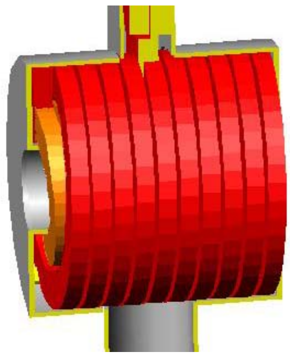

Figure 7: Solenoidal dual layer lens in Stainless steel container cooled by inside oil flow. Conductor cross-section is 5×10 mm^2.

Low oil speed determined by its viscosity, helps in heat exchange. This principle used in pulsed undulator for E-166 experiment. There DC current density tested was 194A/mm^2 and pulsed was 2.3kA/0.6×0.6mm^2=6.4 kA/mm^2 (in 12 μsec pulse) [4]. So the solenoidal dual layer lens can be made with same focal distance as the Lithium lens, f~1cm as the energy of secondary particles are ~15 MeV±5MeV.

Few examples of focusing properties of solenoidal lens are shown in Figs. 8-10 below. Opening angle for trajectory with maximal deviation shown is ~0.3 rad. The beam represented by few rays coming out of target. One ray is associated with straight-forward trajectory.

For feeding such lens usual thyristor switch can be used delivering required current in ~10 ms duty circle. Usage of third harmonic allows further reduction of power dissipated in lens.

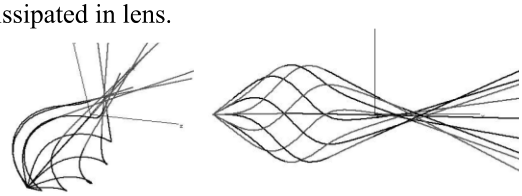

Figure 8: (Over) focused beam. At the left it is shown isometric projection; at the right-side view; nine rays shown.

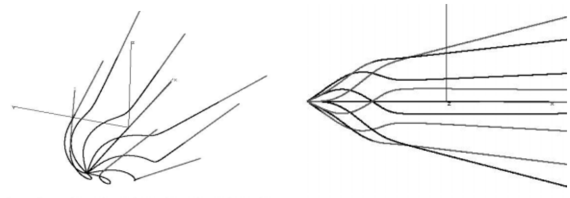

Figure 9: Under focused beam.

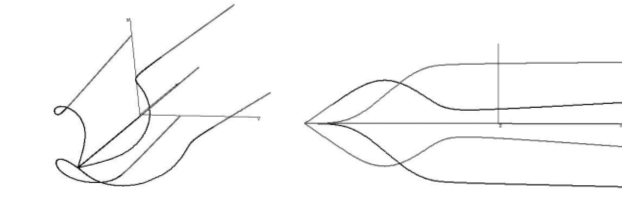

Figure 10: About right focused beam. This corresponds to a quarter wave transformation in Li lens; five rays shown.

CONCLUSIONS

Lithium lens is well developed technique and could be recommended for ILC baseline design. It can work with moving disc-type target as well as with liquid metal target. Solenoidal lens can deliver practically the same focusing parameters. If delivers some fringe field~1kG in region of target.

RF power input in the following accelerating structure must be arranged from far end for better symmetry of RF field in initial sections avoiding RF kick due to symmetry perturbation.

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