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LITHIUM LENS FOR ILC

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Abstract. Lithium Lens is a key element of FERMILAB proton conversion system in use for many years. We are analyzing the ILC positron source equipped with a scaled version of Lithium lens. Usage of liquid Lithium allows efficient cooling of Lithium container and entrance/exit windows. For the temperature just ~80°C higher, than the temperature of boiling water, the system for circulation of liquid Lithium is a compact and reliable. Overall efficiency of 1.5 secondary positrons per each initial electron passing the undulator is feasible with a compact Lithium lens. Axially symmetric motion of liquid Li does not perturb the field quality required for minimization of emittance of the secondary positrons/electrons polarized longitudinally.

OVERWIEW

International Linear Collider (ILC) supposed to be the next big project in High Energy Physics after LHC. Lepton collisions with theirs pure initial states, including polarization, allow much clear interpretation of results [1]. In ILC polarized electrons will collide with (polarized) positrons at 250 *GeV* (initially). To satisfy demands of physical community, the conversion system with undulator suggested for ILC [2]. Positron could be generated by gamma-quant in a pair with electron through the electromagnetic process involved electric field of nuclei. The gammas in ILC conversion system obtained in a helical undulator in contrast to the beamstrahlung photons of conventional system. Although the thickness of conversion target in a system with undulator can be few times less, than in conventional method, still it requires collection of positrons in a large spherical angle. A special focusing system – an optical matching device (OMD) serves for this purpose. The flux concentrator (FC) [3] which serves as OMD, accepted as the baseline for now. Advantage of FC is obvious: absence of material on the way of beams (gamma beam loses just ~15% of its intensity while passes through the target). One peculiarity of FC is that it focuses equally electrons and positrons, as its focusing properties proportional $\propto 1/e^2\int B^2dz$. So when the particles are focused by the flux concentrator or solenoidal lens, the total charge of beam (mixture of electrons and positrons) appeared in the first accelerator structure is about zero. So while the positrons are accelerated in the first sections of RF structure, the electrons are decelerated there. This requires adequate attention. Another peculiarity- for ILC the pulse duty is ~ 1ms, so the skin-depth phenomenon manifests itself here, forcing to make correction of feeding pulse for compensation of weakening of the focusing field during the pulse.

It is interesting to mention that in E-166 experiment, for collection of ~8 MeV positrons the DC solenoidal lens was used successfully [4]. In principle it will be not a problem to enhance its parameters so the lens will be able to collect 15 MeV particles.

One obstacle here is that the stray fields might interact with the target as it is just a Titanium rid, spinning in a close vicinity of the edge of the lens. The stray fields of the OMD in addition to the perturbation of emittance might add to the friction of the rid spinning in a stray field [5]-[6].

Lithium lens, which is basically a Lithium rod with a current co-propagating with the beam in the axial direction–is another possible candidate for OMD. However, as the beams are going through the body of Lithium, confined in a container with the input and output windows (flanges), the energy deposition in the Lithium material and in the windows is a primary point of concern here. On the other hand, the Lithium lens focuses the only particles with desired sign of charge (positrons), while the particles with other sign of charge became defocused. So the Lithium lens might serve as a preliminary energy separator; the particles with low energy became over-focused and captured in a collimator located after the lens in front of an accelerating structure.

THE LITHIUM LENS CONCEPT

The Lithium lens concept is known for a long time now [7]-[9]. If a steady current *I* runs through the rod having radius *a*, which axis runs along *z*, the azimuthal magnetic field inside the rod could be described as

$$H_{\vartheta}(r) = \frac{0.4\pi I r}{2\pi a^2} \qquad (1)$$

where the magnetic field is measured in *kGs*, *a* –in *cm*, *I* –in *kA*. The current density comes to $j_s = I/\pi a^2$. A particle, when passed through the rod having the length *L*, *cm*, in z-direction will get the transverse kick, which is linearly dependent of transverse offset from the axis of the rod *r*

$$\alpha \cong \frac{\int_0^L H(r,z)\cdot dz}{(HR)} \cong \frac{0.2 I L r}{a^2\cdot(HR)}, \qquad (2)$$

The last estimation is valid for $r \ll L$ i.e. when it is possible to neglect the change of particle offset while it is running through the lens (short lens approximation).

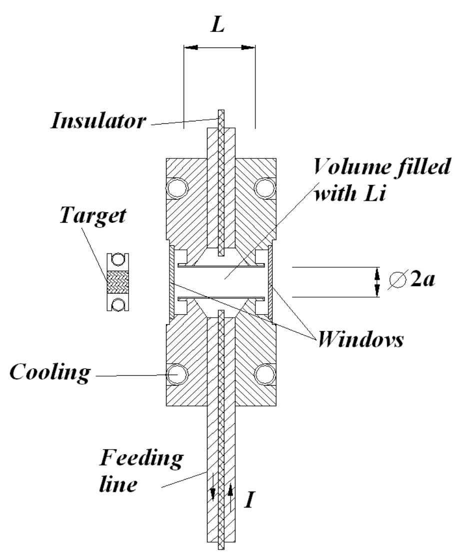


Figure 1. The Lithium Lens concept. The windows made on Be, Ti, BN or BC.

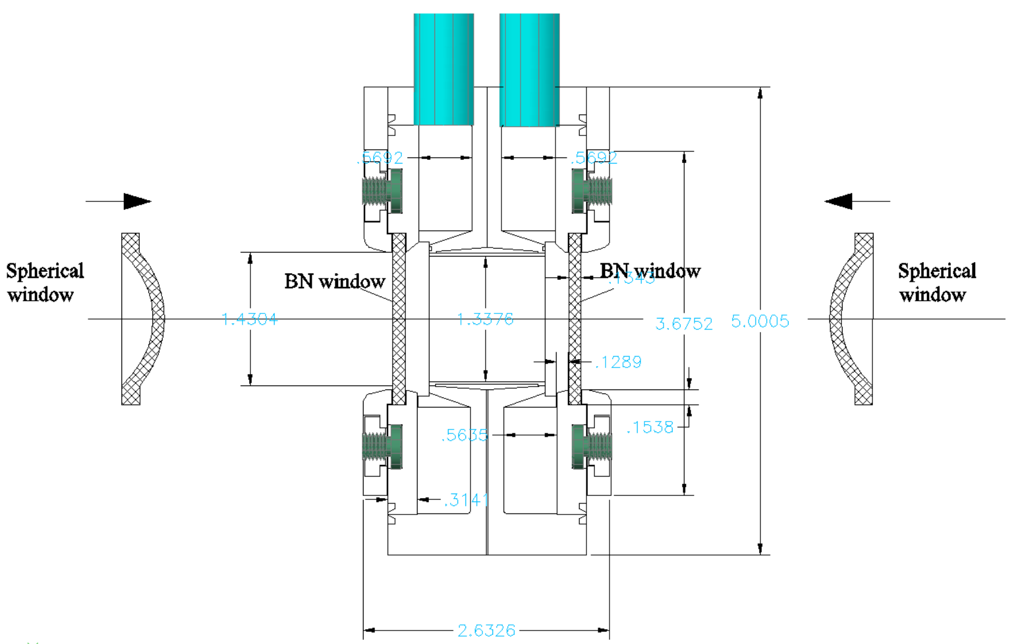
So the focal distance could be defined as the following

$$F = \frac{r}{\alpha} \cong \frac{a^2\cdot(HR)}{0.2 I L} \qquad (3)$$

For a particle with energy *E*=20 *MeV*, (*HR*) ≈ 67· *kG·cm*, *I*=100*kA*, *a*=0.7*cm*, *L*=1 *cm* the focal distance comes to a $F \cong 1.7cm$. These numbers demonstrate the possibilities of this type of focusing. Angular scattering in a material of target $\overline{\vartheta} \cong \frac{21 MeV}{E MeV}\sqrt{\frac{L}{lX_0}} \cong \sqrt{\frac{1}{152}} \cong 0.08 rad$ should be compared with the angular spread inside a secondary beam under focusing (collecting) which is ~0.5 *rad*. Here lX_o is the length corresponding radiation length; for Lithium it is ~154 cm, see Table 1. Scattering in the flanges of container with Lithium is $\overline{\vartheta} \cong 0.03 rad$ for the flanges made from Boron Carbide B_4C with thickness 2 *mm*. Of cause, these numbers are given for estimation only. The numerical codes developed for modeling conversion of gammas into positrons take this effect of multiple scattering into account [9]. The last code KONN calculates the energy deposition and temperature gain in Lithium and flanges made from Beryllium.

Table 1: Properties of Lithium[1], Beryllium, Boron Carbide (BC), Boron Nitride (B_4N), and Tungsten

	Units	Li	Be	BN	B_4C	W
Atomic number, ***Z***	-	3	4	5/7	5/6	74
Yong modulus	*GPa*	4.9	287	350-400	450	400
Density, ρ	[g/cm^3]	0.533	1.846	3.487	2.52	19.254
Specific resistance	*Ohm-cm*	1.44 $x10^{-5}$	1.9 $x10^{-5}$	$>10^{14}$	7.14 $x10^{-3}$	5.5 $x10^{-6}$
Length of ***X*0, *l*Xo**	*cm*	152.1	34.739	27.026	19.88	0.35
Boil temperature	^oC	1347	1287	Sublim. at melt	3500	5660
Melt temperature	^oC	180.54	2469	2973	2350	3410
Compressibility	cm^2/kg	8.7 $x10^{-6}$	9.27 $x10^{-7}$	1.2 $x10^{-6}$		2.93 $x10^{-7}$
Grüneisen coeff.	-					2.4
Speed of sound (long)	*m/sec*	6000	12890	16400	14920	5460
Specific heat	J/g^oK	3.6	1.82	1.47	0.95	0.134
Heat conductivity	$W/cm/^oC$	0.848	2	7.4	0.3-0.4	1.67
Thermal expansion	$1/^oC$	$4.6x10^{-6}$	$11x10^{-6}$	$2.7x10^{-6}$	$5x10^{-6}$	$4.3x10^{-6}$



[1] Total mass of Lithium in ~70*kg* human body is ~7*mg*.

Figure 2. Cross section of the lens with liquid Lithium. Optional spherical windows serve for compensation of spherical aberrations. Dimensions in *cm*. Input/ output tubes ducting the liquid Lithium marked by a blue color.

For example, for *K*=0.92, undulator length 35*m* is enough for generation of 1.6 positrons per each initial electron in undulator; the temperature gain in Be entrance window is ~39^{o}C at max, in the Litium ~15^{o}C at max and in the exit window the temperature jump is ~20^{o}C for the beam train with 10^{13} initial electrons passed through the undulator at energy 150 GeV. Period of undulator was taken 1.15 *cm*.

COMPARISON WITH FERMILAB LENSES

Lenses with solid Lithium are in use at FERMILAB for a long time. Total amount of lenses fabricated around 24 [10] . The lenses for positrons and for antiprotons are represented in Fig.3. One can see, that the lens for positrons is much more compact one.

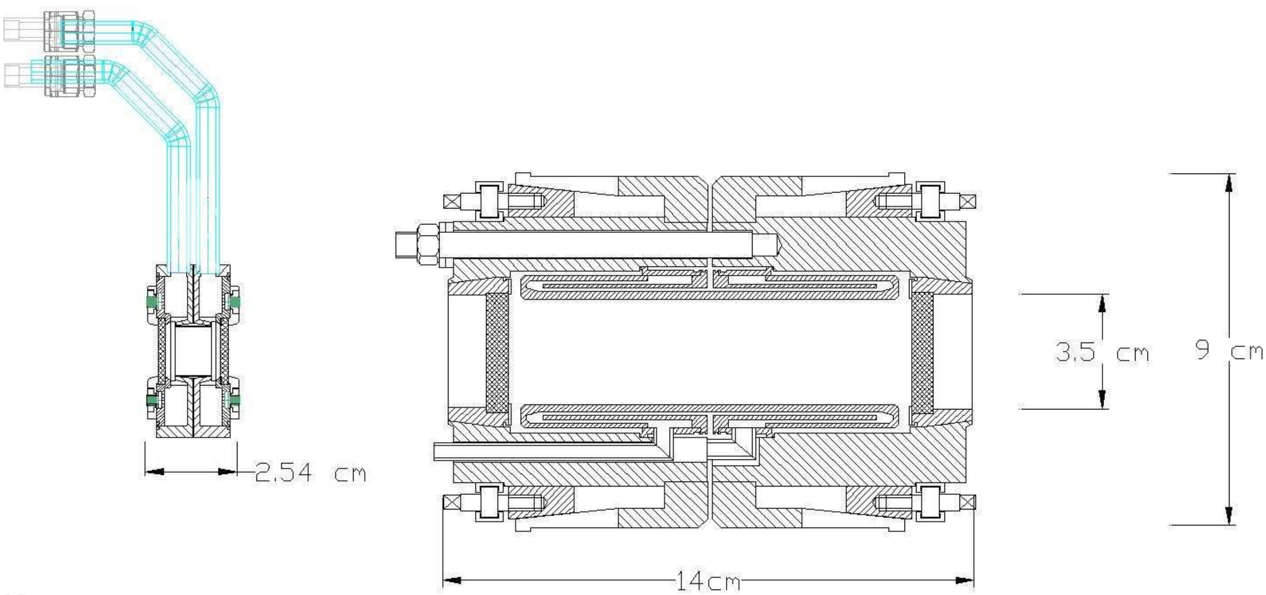


Figure 3. Lens for positrons and for the FERMILAB proton conversion target stations in comparison.

Parameters of lenses are represented in Table 1.

Table 1. Parameters of lenses for positrons, antiprotons anf fpr Neutrino-Factory

	Positrons	**Antiprotons**	**Neutrino Factory**
Diameter, *cm*	1.4	3.6	1.8-6
Length, *cm*	1	10	15
Current, *kA*	<75	850	500
Pulse duty, *msec*	~2	0.1	~1
Repetition rate, Hz	5	0.7	0.7
Resistance $\mu\Omega$	32	50	27
Gradient, *kG/cm*	<35	55	45

Surface field, *kG*	43	100	80-40
Pulsed Power, *kW*	~360	36000	6750
Average Power, *kW*	~3.8	3.6	4.7
Temp. gain/pulse, ^oK	45	80	80
Axial pressure, *atm*	19	400	256-64

SOME TECHNICAL DETAILS

More or less detailed description of lens one can find in Refs [10]-[13]. The latest design of the lens with liquid Lithium is represented in Fig. 4 below. The latest design of the combined heat exchange/pumping device with the gear pump for the liquid Lithium is represented in Fig.5.

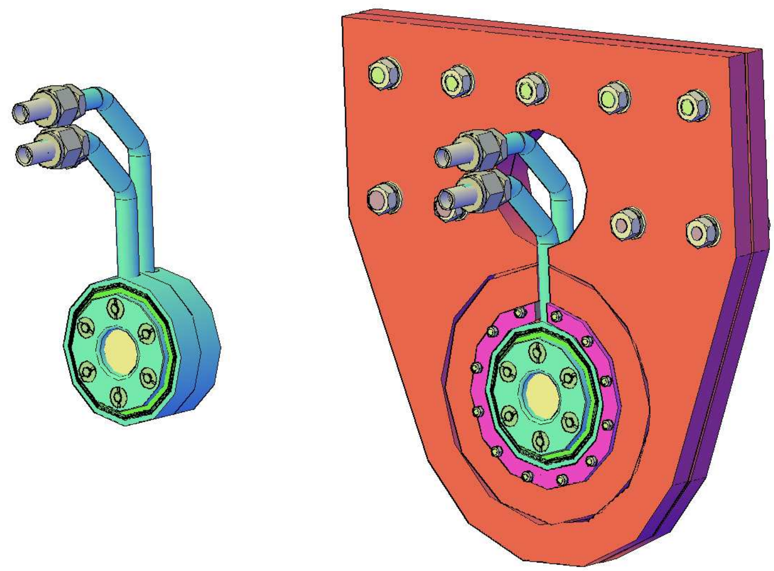


Figure4: At the left: The lens with liquid Lithium. Diameter of lens ~2*in*, thickness~1*in*. The tubing serves for the Lithium in/out. The cross section is represented in Fig.2. At the right: The lens installed into the current duct.

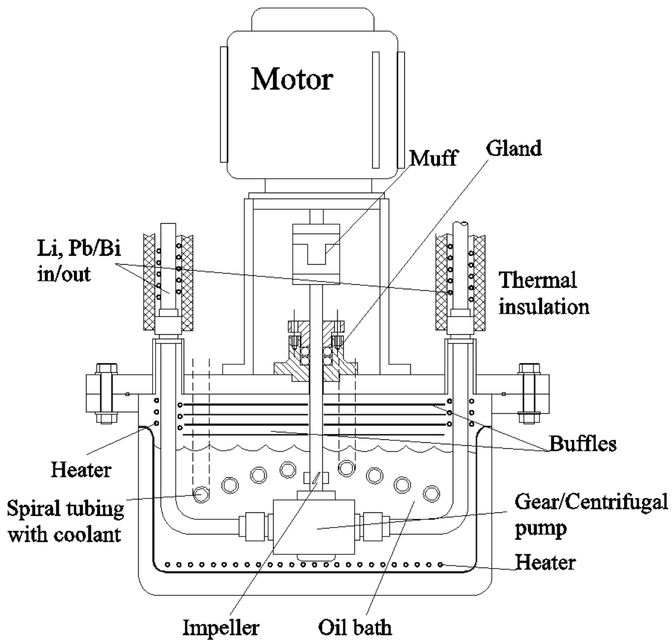


Figure 5. Pumping and cooling system.

High flash point of oil[2] ~300°C allows normal operation of this system. In Fig. 6 two possible options for the current duct are represented in comparison. The whole conversion unit is represented in Fig. 7.

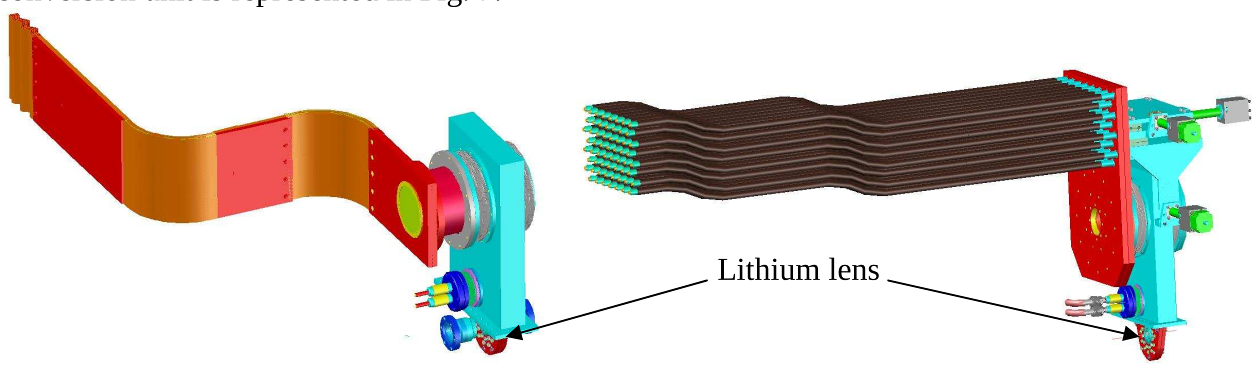


Figure 6. Two variants of the feeding duct: the stripline-at the left, with coaxial cables- at the right. Just a tip of the Lithium lens is visible in these pictures (see Fig.3).

[2] 561® Transformer Fluid, for example. Fire poit for this liquid >340°C.

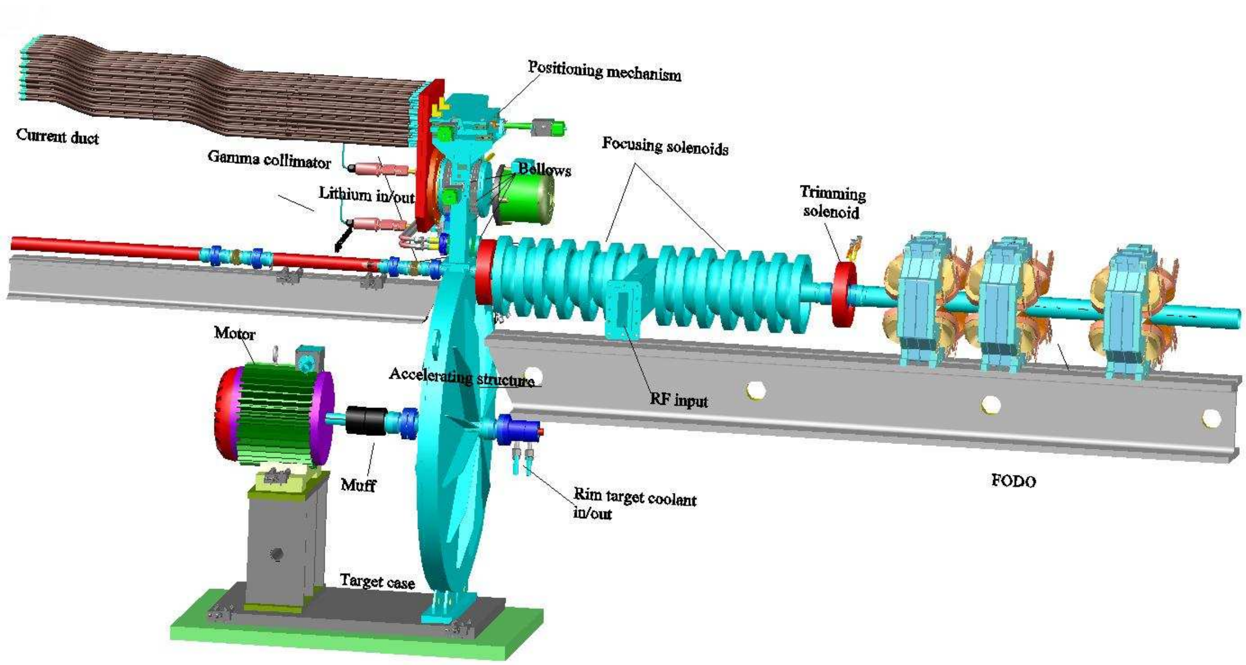


Figure 7. Positron conversion system assembled. This is a variant with a spinning target rim.

SUMMARY

Collection of positrons with Lithium lens rises evident question about possibility its components (windows mostly) against severe exposure by secondary beams of positrons and electrons. Calculations show however that the temperature gain is tolerable. The heat removal with liquid Lithium flow is adequate. Some magneto-effect of interaction of Lithium flow with magnetic field [12] helps in mixture of Lithium having different temperatures. The general temperature gain in Lithium arises from the feeding current flow. Indeed the maximum input into heating in windows arises from the secondary beams. Anyway the temperature regime is tolerable. Successful experience of Lithium lens exploitations at FERMILAB brings assurance that the lens with Lithium is a feasible device. In a case of positron production usage of *liquid* Lithium is much more beneficiary. Although functioning of the lens with liquid Lithium is not tested experimentally yet, all parameters of this system remain within guaranteed by the physical properties of all materials and components involved.

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