Cornell University
Laboratory for Elementary-Particle Physics

CBN 07-5

LITHIUM LENS FOR EFFECTIVE CAPTURE OF POSITRONS

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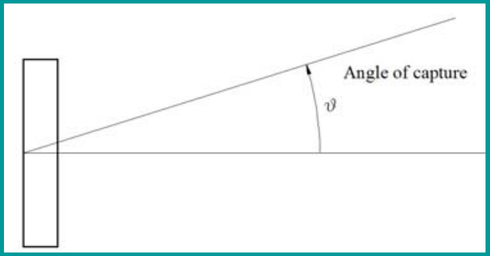
Positron Source Meeting, Jan30-Feb2 2007, Beijing

Efficiency= N_{e+} / N_{gammas}



Angle shown~0.3 rad

Target – Tungsten (W)

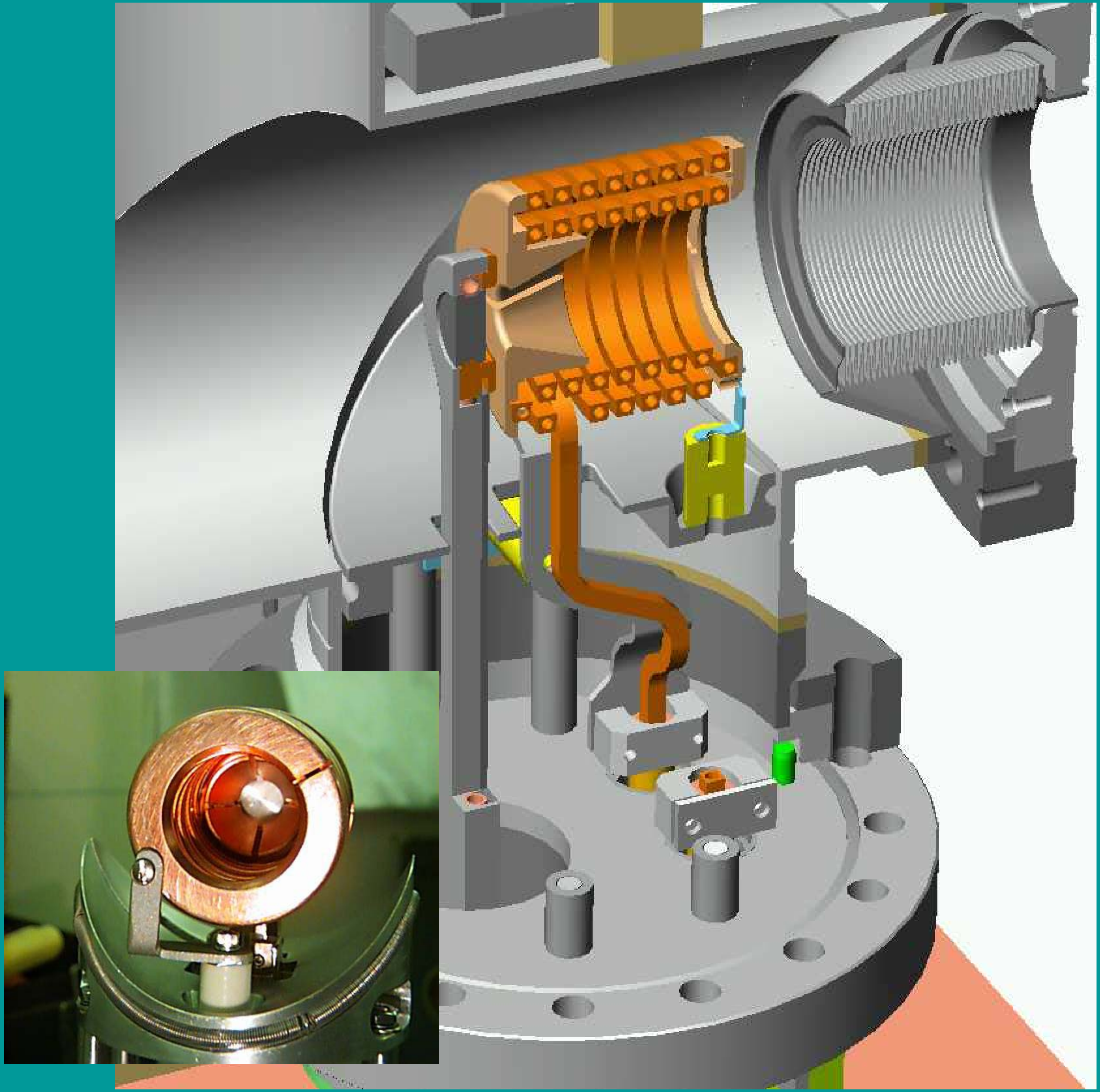
Thickness – 1.5 mm

20 MeV photons

Particles from 10 to 19 MeV only

Efficiency as function of capturing angle; within this angle the particles are captured by collection optics

Many different systems possible here. Shown is Cornell positron capturing system



After the target, e^+ beam accelerated up to 200 MeV in linac and further on it goes to synchrotron. This change in efficiency given for the beam in CESR.

Efficiency of positron accumulation in CESR with system turned on/off changes 5 times;

This design introduced in 2000; it doubled positron accumulation in CESR, coming to 100 mA/min anytime (R=100m)

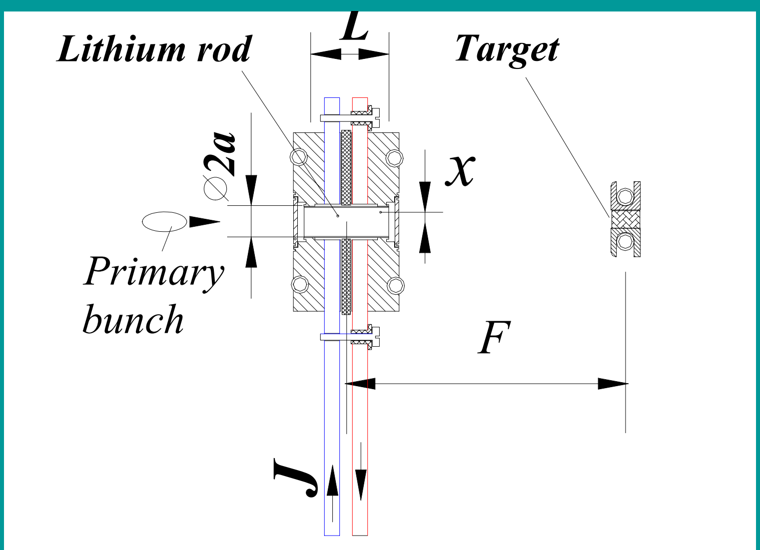
LITHIUM LENS BASICS

If steady current *I* runs through the round conductor having radius *a*, its azimuthal magnetic field inside the rod could be described as

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

where magnetic field is measured in *Gs*, *a* –in *cm*, *I* –in Amperes. Current density comes to $j_s = I/\pi a^2$ The particle, passed through the rod, will get the transverse kick

$$\alpha \cong \frac{H(x)\cdot L}{(HR)} \cong \frac{0.2 I L x}{a^2\cdot(HR)}$$



This picture drawn for the focusing of electron beam to the target

So the focal distance could be defined as the following

$$F \cong \frac{a^2\cdot(HR)}{0.2IL}$$

If the focal distance is given, the current required could be found as $I \cong \frac{a^2 \cdot (HR)}{0.2FL}$

For the primary electron beam of say, 20 *MeV*, $(HR) \cong 66kGcm$, Suggesting F=0.5 cm, L=2cm, a=0.5cm

$$I \cong \frac{0.5^2 \cdot 66}{0.2 \cdot 0.5 \cdot 2} = 83.25kA$$

Scattering of the beam in a Lithium rod target could be estimated as $\sqrt{<\theta^2>} \cong \frac{13.6MeV}{pc}\sqrt{\frac{t_{Xo}}{X_{Li}}}$

where X_{eff} –is an effective radiation length of Lithium, $X_{Li} = 83.3g/cm^2$ (or 156 *cm*),

t_{Xo} –is the thickness of the rod in *g/cm*². $\sqrt{<\theta^2>} \cong \frac{13.6}{20}\sqrt{\frac{2}{156}} \cong 0.077$ rad

Resistance of the 1 *cm* long 1 *cm* in diameter Lithium rod could be estimated as

$$R = \rho L/\pi a^2 \cong 1.44 \cdot 10^{-5} \cdot 2/\pi/0.5^2 \cong 3.7 \cdot 10^{-5}$$ *Ohm*.

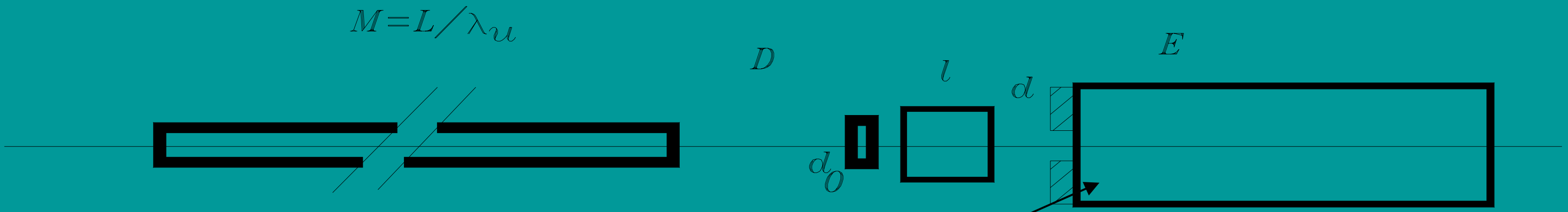
the instant power dissipation in the rod as big as $P = I^2 \cdot R \cong 83.25^2 \cdot 10^6 \cdot 3.7 \cdot 10^{-5} = 2.5 \cdot 10^5$ *W*.

If the pulse lasts for τ seconds with repetition rate *f* , *Hz*, then the average power dissipation will be

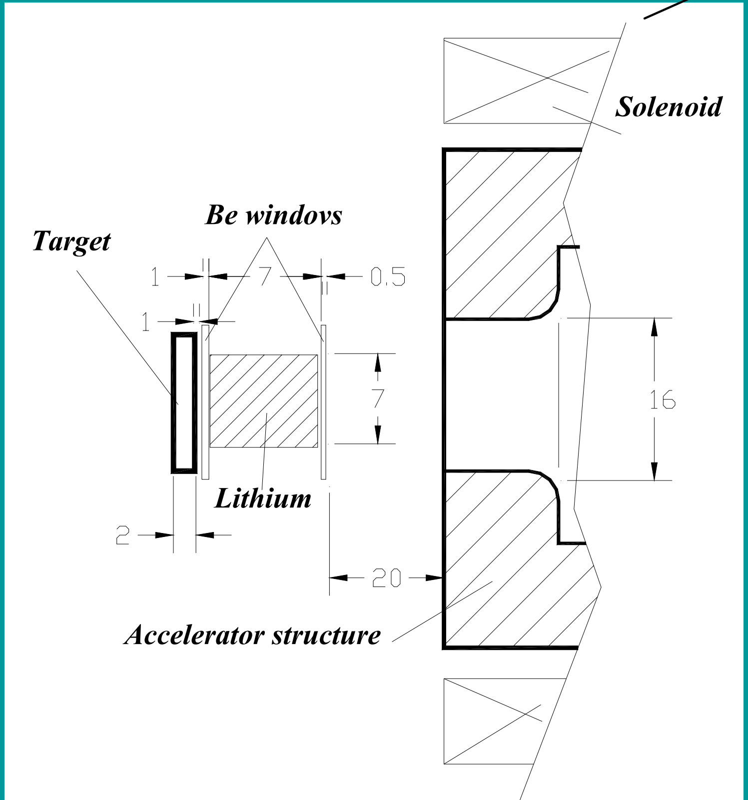
$$<P>= J^2 \cdot R \cdot f\tau$$

. For *f*=5*Hz*, $\tau \cong 2ms$ the last goes to $<P>= 2.5 \cdot 10^5 \cdot 5 \cdot 2 \cdot 10^{-3} \cong$ 2.5 *kW*

MONTE-CARLO START TO END SIMULATION CODE FOR CONVERSION (1986; restored in 2007)



Length of undulator, beta-function, emittance, period, distance to the target, radius of target, parameters of Lithium lens, diameter of diaphragm, accelerating field, magnetic field in solenoid



Beam energy …………….	150 GeV
Length of undulator…….	150 m
Period…………………….	7 mm
K^2 ……………………….	0.1
$\gamma\varepsilon_x$………………………..	$3\ 10^{-5}$ m rad
$\beta_{\text{undulator}}$ …………………..	400 m
Distance to the target…..	180 m
Radius of target ………..	1mm
Positrons/Electron …….	1.5 (3)
Polarization …………….	70% (50% for yield 3)

These numbers can be considered as a base

Some latest improvements allow to relax these conditions~30% (higher K)

Multiple targets allow reduction of the undulator length in half

T.A.Vsevolojskaja,A.A.Mikhailichenko, G.I.Silvestrov, A.D.Cherniakin

“To the Conversion System for Generation of Polarized Beams in VLEPP”, BINP, 1986

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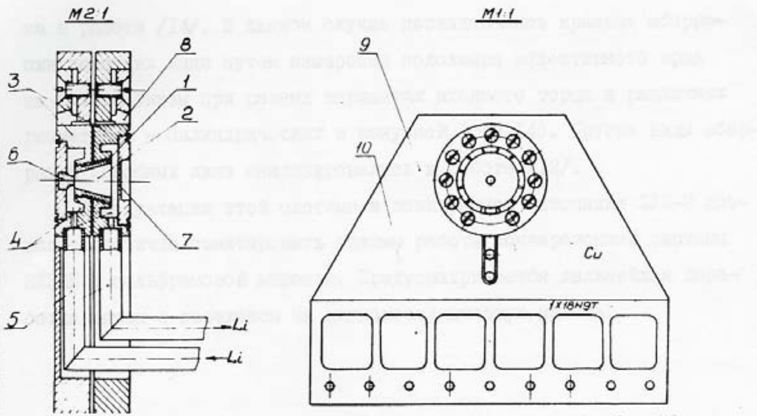
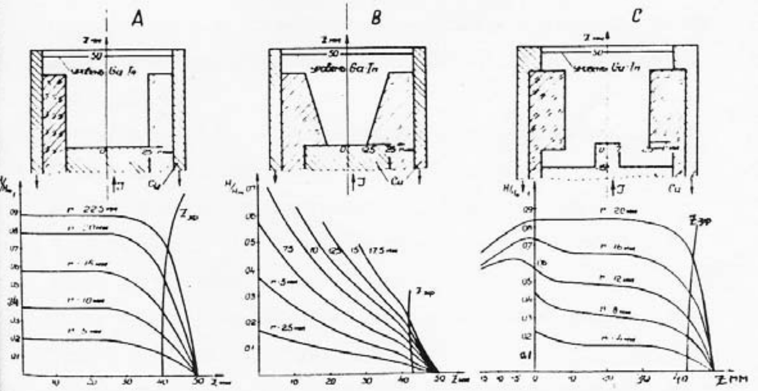
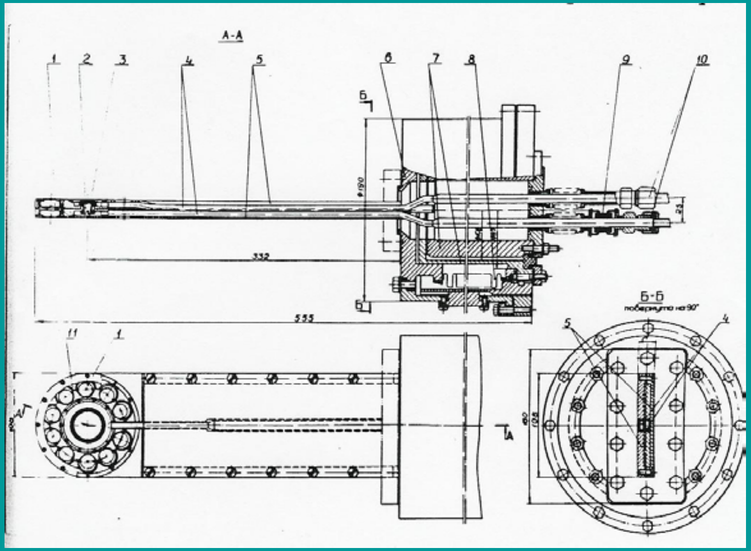


Рис.I3. Модель линзы с жидким литием.

I – конусная оболочка линзы, 2 – рабочий объем лития, 3 – корпус линзы, 4 – объемы для растекания жидкого лития, 5 – трубки подвода лития, 6 – мишень, 7 – выхрдной фланец, 8 – конусные контакты, 9 – плоские токоподводы, I0 – тепловые развязки

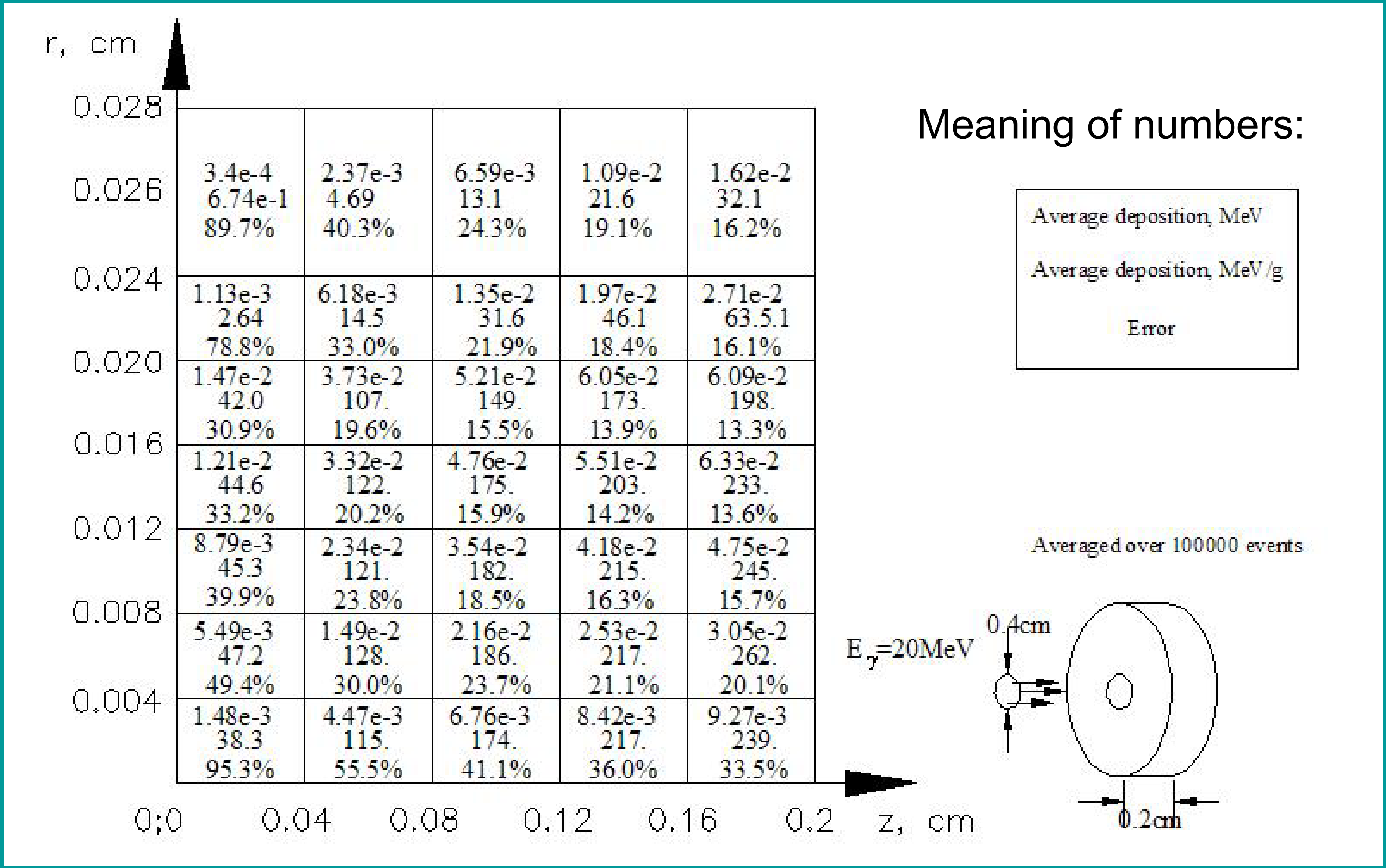




1-ex-centric contact pushers;2-conic lens body; 3-W target; 4-Ti tubing for LI supply; 5-flat current leads; 6-vacuum chamber; 7-coaxial fraction of current leads; 8-bellows; 9-ceramic insulators; 10-conical gasket; 11-set of ex-centric pushers.

Field measured in liquid Gallium model.
A-cylindrical lens with homogenous current leads supply at the end
B- conical lens with the same current feed
C –lens with cylindrical target at the entrance flange

Energy deposition in a volume of W target



3.4e-4 6.74e-1 89.7%	2.37e-3 4.69 40.3%	6.59e-3 13.1 24.3%	1.09e-2 21.6 19.1%	1.62e-2 32.1 16.2%
1.13e-3 2.64 78.8%	6.18e-3 14.5 33.0%	1.35e-2 31.6 21.9%	1.97e-2 46.1 18.4%	2.71e-2 63.5.1 16.1%
1.47e-2 42.0 30.9%	3.73e-2 107. 19.6%	5.21e-2 149. 15.5%	6.05e-2 173. 13.9%	6.09e-2 198. 13.3%
1.21e-2 44.6 33.2%	3.32e-2 122. 20.2%	4.76e-2 175. 15.9%	5.51e-2 203. 14.2%	6.33e-2 233. 13.6%
8.79e-3 45.3 39.9%	2.34e-2 121. 23.8%	3.54e-2 182. 18.5%	4.18e-2 215. 16.3%	4.75e-2 245. 15.7%
5.49e-3 47.2 49.4%	1.49e-2 128. 30.0%	2.16e-2 186. 23.7%	2.53e-2 217. 21.1%	3.05e-2 262. 20.1%
1.48e-3 38.3 95.3%	4.47e-3 115. 55.5%	6.76e-3 174. 41.1%	8.42e-3 217. 36.0%	9.27e-3 239. 33.5%

Meaning of numbers:

Average deposition, MeV

Average deposition, MeV/g

Error

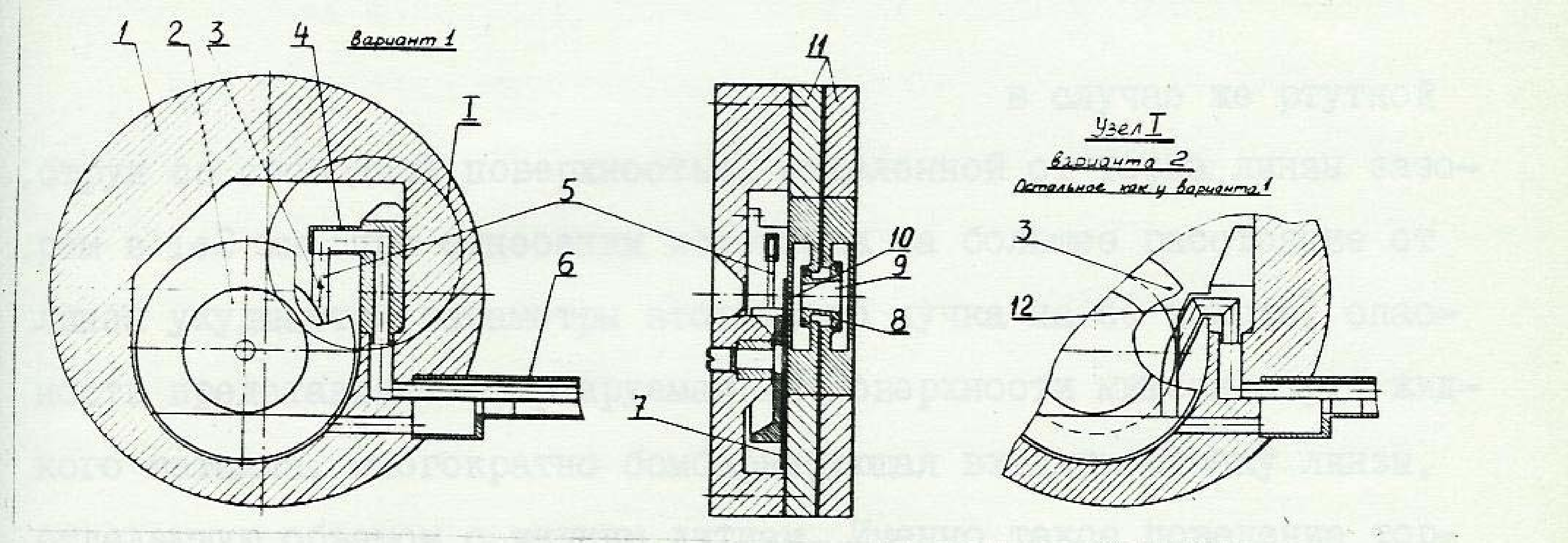
Averaged over 100000 events

A.D.Bukin, A.A.Mikhailichenko," Optimized Target Strategy for Polarized Electrons and Positrons Production for Linear Collider".
(IYF) BUDKER INP 92-76, Novosibirsk, 1992.

The same report

Two possibilities were considered at the time: 1-Mercury jet   2-W disc spin by Gallium

Just reminding, that for VLEPP project the beam with 10^{12} electrons/positrons was used



Variant 1-Mercury jet, Variant 2-spinning W disc, 1-case, 2-disc, 3-beam axis, 4-feeding tube for Hg, 5-Hg jet, 6-tubes, 7-Protective Ti disc, 8-Lithium lens container, 9-Liothium volume, 10- entrance flange of the lens, 11-current leads, 12-Ga jet nozzle.

Energy deposition in Be flanges is going by secondary particles (positrons and electrons) is $\delta E \sim 2\ MeV cm^2/g$, Secondary beam diameter $d \approx 1 cm$.
Area illuminated is going to be $S=1/4\ \pi d^2 \approx 0.4\ cm^2$.
Volume density of Be is $\rho \approx 1.8\ g/cm^3$, for thickness 0.5 *mm*
Energy deposited in a material of flange going to be

$$\Delta E \approx \delta E \cdot \rho \cdot t/1cm \approx 2 \cdot 1.8 \cdot 0.05 \approx 0.2\ MeV \text{ per particle}$$

So the total energy deposited by train of n_b bunches with population N each, comes to

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

where e stands for the charge of electron. The last expression goes to be

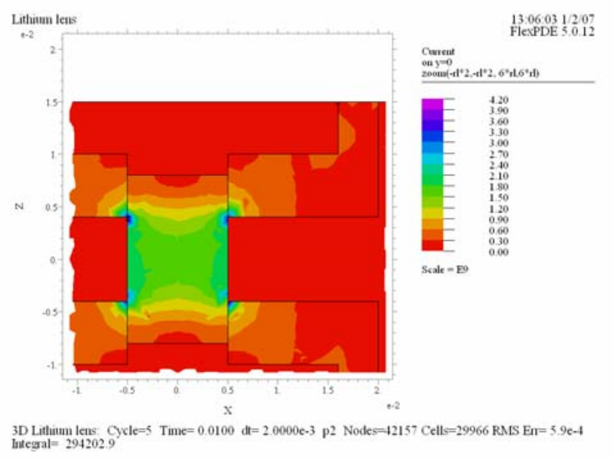
$$E_{tot} \cong \quad 1.8\ J.$$

Factor reflecting spare particles, ~1.5-2 , factor two- reflecting equal amount of electrons and positrons and, finally, factor reflecting efficiency of capturing (~30%).
So the final number comes to→ ≈21*J*.
Temperature gain by heat capacity of Be $C_v \approx 1.82\ J/g/degC$ comes to

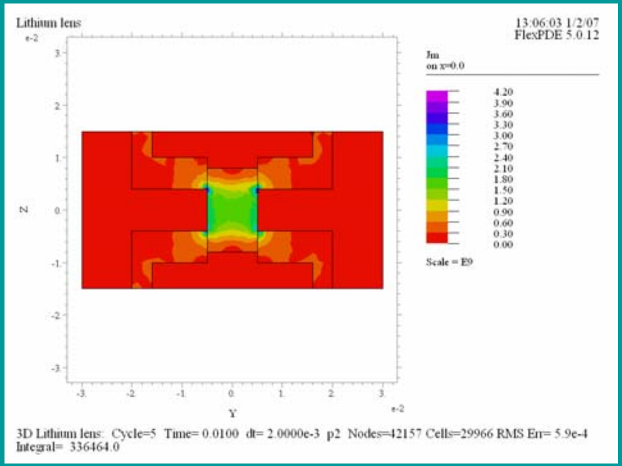
$$\Delta T \cong \frac{E_{tot}}{mC_v} \cong \frac{E_{tot}}{\rho S l C_v} \cong \frac{21}{1.8 \times 1.82 \times 0.05 \times 0.2} \cong \quad 660 \text{ deg.}$$

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.

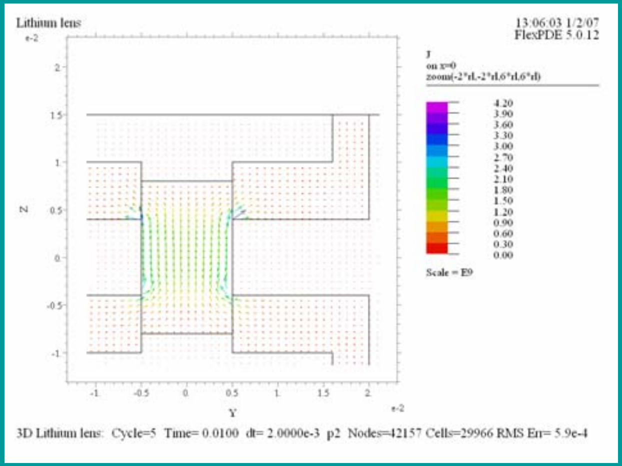
Recent calculation done with FlexPDE© code



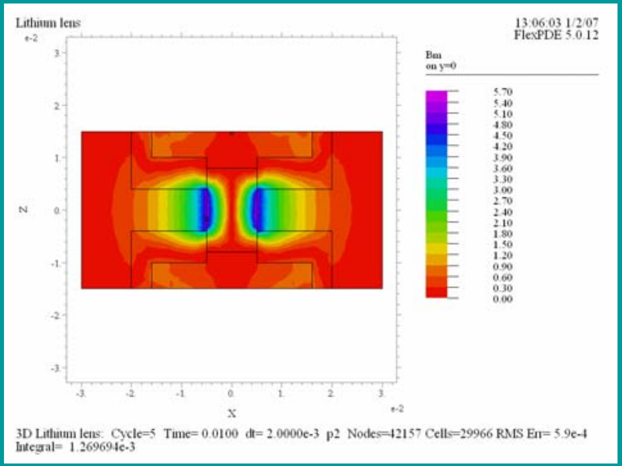
3D Lithium lens: Cycle=5 Time= 0.0100 dt= 2.0000e-3 p2 Nodes=42157 Cells=29966 RMS Err= 5.9e-4
Integral= 294202.9



3D Lithium lens: Cycle=5 Time= 0.0100 dt= 2.0000e-3 p2 Nodes=42157 Cells=29966 RMS Err= 5.9e-4
Integral= 336464.0

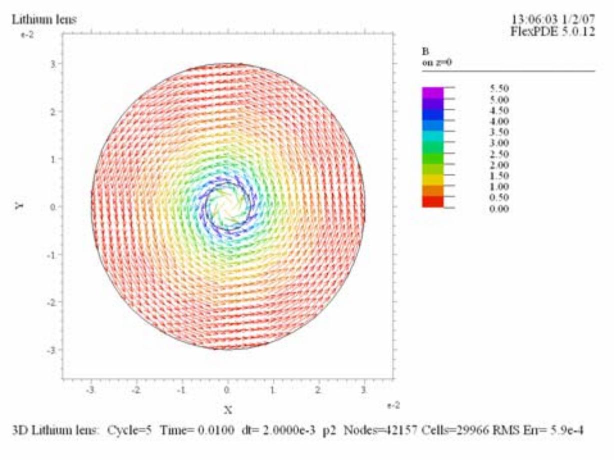


3D Lithium lens: Cycle=5 Time= 0.0100 dt= 2.0000e-3 p2 Nodes=42157 Cells=29966 RMS Err= 5.9e-4



3D Lithium lens: Cycle=5 Time= 0.0100 dt= 2.0000e-3 p2 Nodes=42157 Cells=29966 RMS Err= 5.9e-4
Integral= 1.269694e-3

Spatial field distribution over time



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3D Lithium lens:  Cycle=5  Time= 0.0100  dt= 2.0000e-3  p2  Nodes=42157 Cells=29966 RMS Err= 5.9e-4
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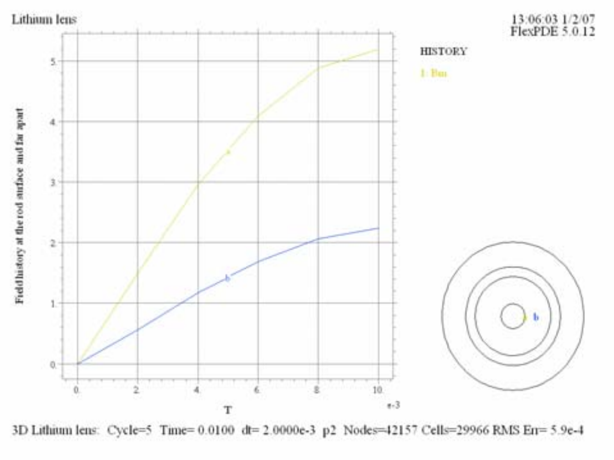

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3D Lithium lens:  Cycle=5  Time= 0.0100  dt= 2.0000e-3  p2  Nodes=42157 Cells=29966 RMS Err= 5.9e-4
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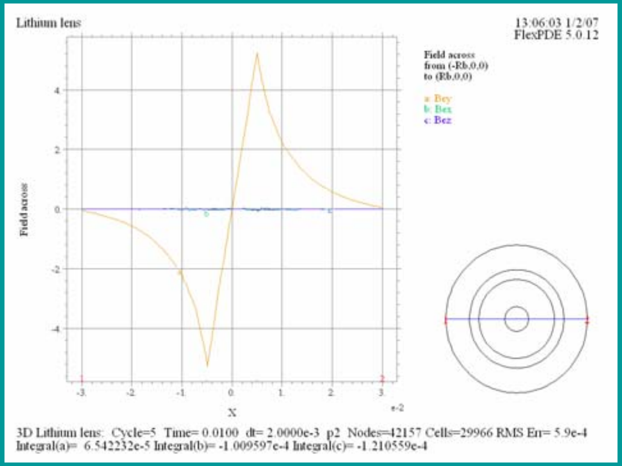
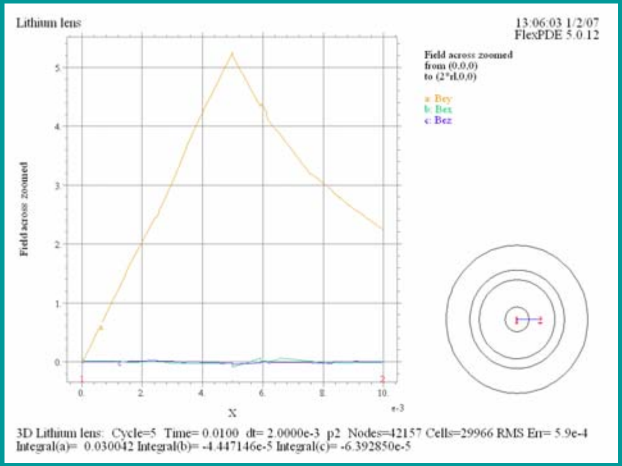


```
3D Lithium lens:  Cycle=5  Time= 0.0100  dt= 2.0000e-3  p2  Nodes=42157 Cells=29966 RMS Err= 5.9e-4
Integral(a)=  6.542232e-5 Integral(b)= -1.009597e-4 Integral(c)= -1.210559e-4
```



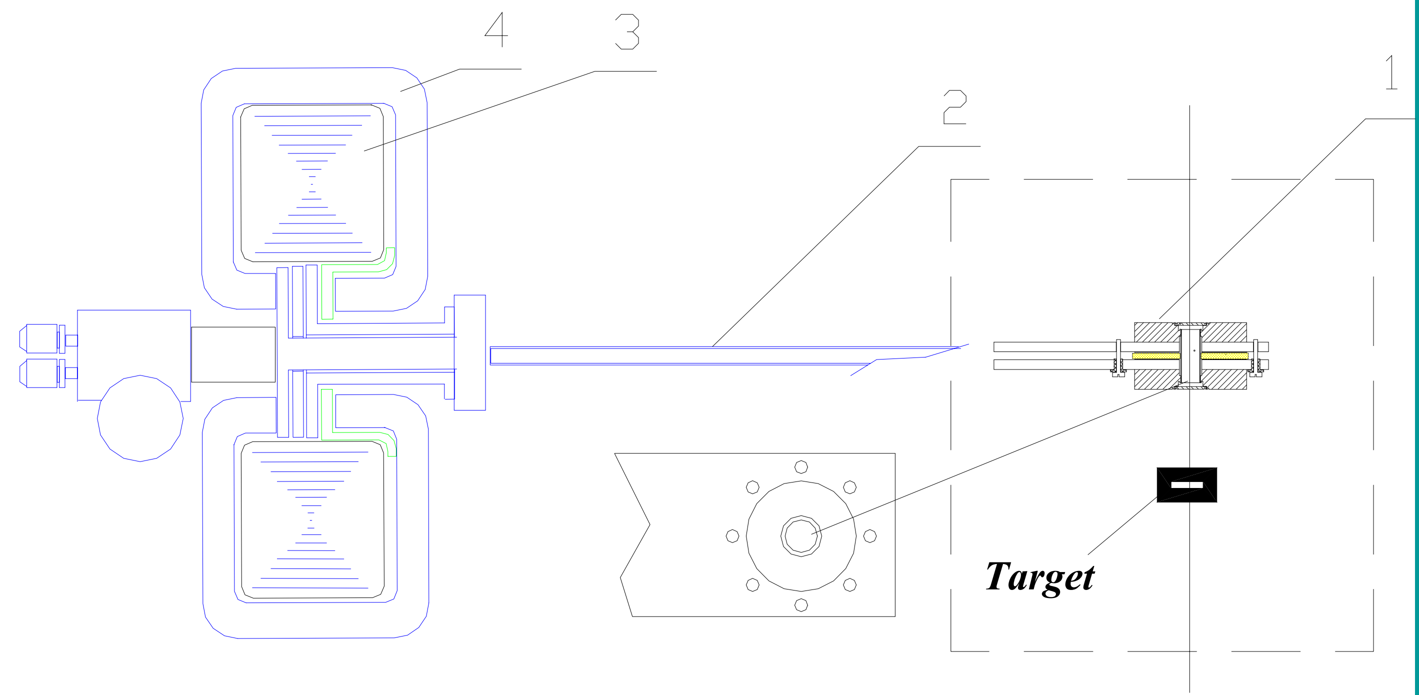
```
3D Lithium lens:  Cycle=5  Time= 0.0100  dt= 2.0000e-3  p2  Nodes=42157 Cells=29966 RMS Err= 5.9e-4
Integral(a)=  0.030042 Integral(b)= -4.447146e-5 Integral(c)= -6.392850e-5
```

Power dissipated per pulse goes to 0.6 kJ for the current ~135 kA and time duration half sin wave with period 40 msec

Energy stored -21.6 J so reactive component is low.

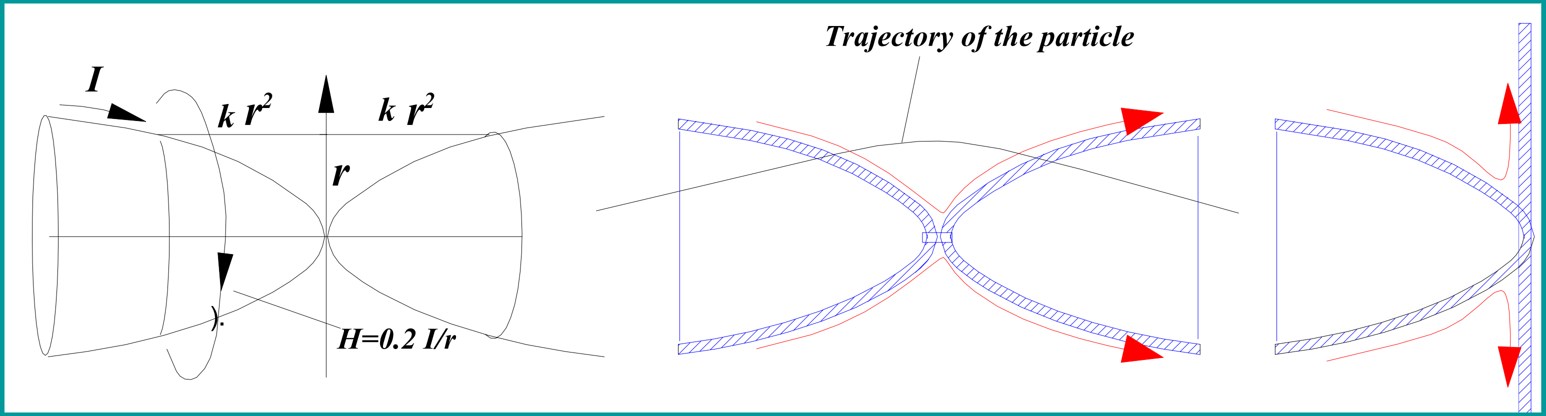
(Dissipation for time from zero to 10 msec is 0.3 kJ)

Feeding with 5th harmonic allows making current flat.



The transformer with Lithium Lens (example). 1-fixture, 2-flat coaxial line, 3-transformer yoke, 4-cable windings. Lens with a current duct could be removable from the beam path.

Other short –focusing elements-such as horn, can be used here as well. Design also was done, horn lens, so called x-lens was at service for positron capture for may years at BINP (G.Budker, G.Silvestrov)



So the device has ideal dependence for linear focusing. The focal distance of this lens goes to $F \cong \frac{(HR)}{0.4Ik}$.

As the particles here going through material of the horn, it manufactured usually on Aluminum ($X_{Al} = 24.3g/cm^2[\cong 9cm]$) or Beryllium ($X_{Be} \cong 66g/cm^2[\cong 35.8cm]$).

CONCLUSIONS

AMD as element of collecting positron optics is so ineffective, that it forces to compensate bad collection ability by increasing the flux of primary particles (photons).

Under these conditions one forced to use Ti material, what in its turn reduces efficiency even more.

Was shown earlier that eddy fields in mowing target immersed in magnetic field might sweep the positron beam.

Utilization of Lithium lens allows Tungsten survival under condition required by ILC with N_e~$2x10^{10}$ with moderate K~0.3-0.4 and do not require big-size spinning rim (or disc). Thin W target allows better functioning of collection optics (less depth of focusing).

Liquid targets as Pb/Bi or even Hg allows further increase of positron yield.

Lithium lens (and x-lens) is well developed technique.

Usage of Li lens allows drastic increase in accumulation rate, low K-factor.

Field is strictly limited by the surface of the lens from the target side.

Plan is to repeat optimization of the cone angle in Li rod.