LITHIUM LENS FOR ILC POSITRON SOURCE

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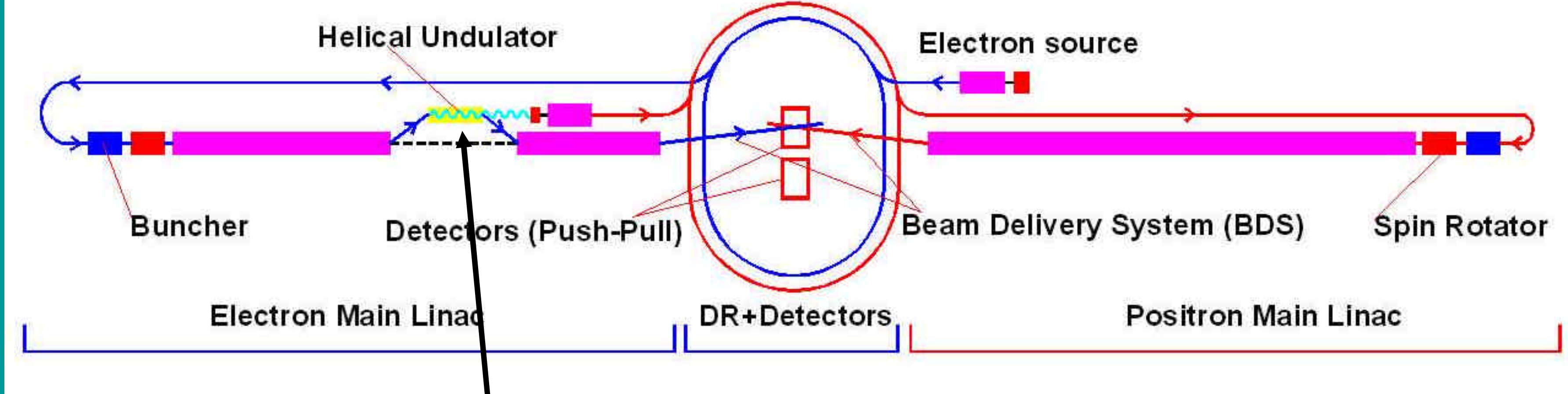
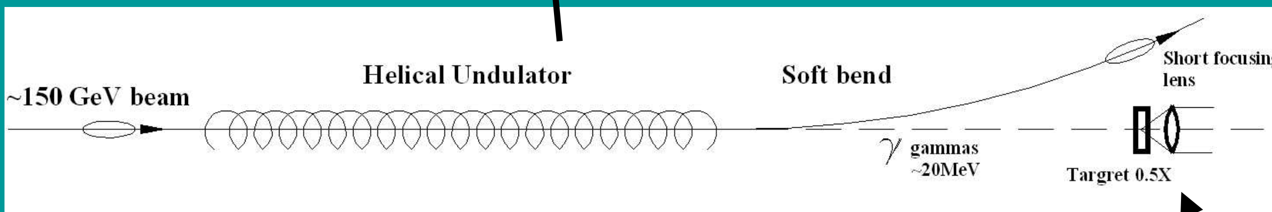
For details see CBN 08-1, LEPP, Cornell, Ithaca, NY

http://www.lns.cornell.edu/public/CBN/2008/CBN08-1/CBN08-1.pdf





Efficiency of photon production defined as

$$h_{photon} = N_{gammas} / N_{primary\ electrons}$$

Conversion efficiency is defined as a ratio of the number of all positrons created (in all angles and full energy interval) to the number of gammas

$$h_{conv} = N_{positrons} / N_{gammas}$$

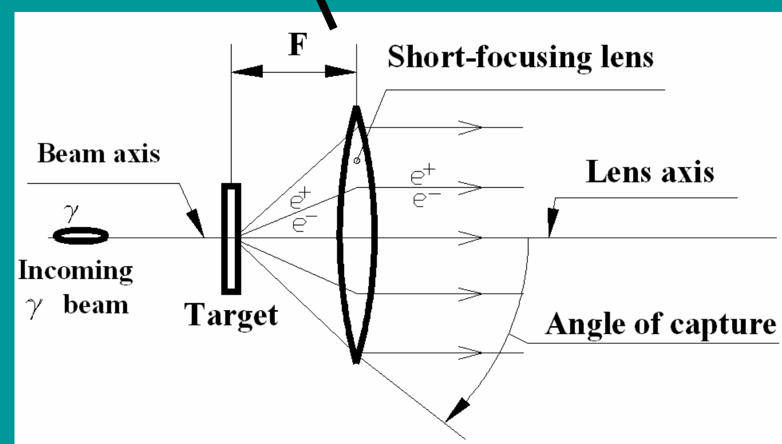
Capturing efficiency (Geometrical capturing efficiency) defined here as the ratio of *captured* positrons to the amount of all positrons

$$h_{capt} = N^{+}_{captured} / N_{positrons}$$

Total efficiency

$$h_{tot} = h_{capt} \times h_{conv} h_{photon} = N^{+}_{captured} / N_{primary\ electrons}$$

−1.5



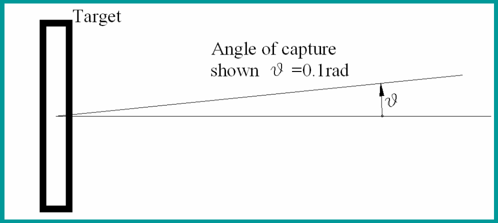
Geometry of capturing. Target located at the distance F – the focal distance of the lens. Shortening the focal distance allows for a smaller beam size at the exit or the enlargement of the angle of capture.

$$h_{tot} = h_{capt} \times h_{conv} h_{photon} = N^{+}_{captured} / N_{primary\ electrons}$$

f efficiency of capture h_{capt} made bigger, then one can redistribute it among the thers; In particular one can reduce h_{photon} $=4/3\, p a\, K^2/(1+K^2)\, L_u/?_u$

L_u is the length of Undulator, $?_u$ its period, a =1/137

Capturing efficiency, %, as a function of capturing angle (within this angle the particles are captured by collection optics) for 20 MeV gammas irradiating 1.5 mm thick-W target. Energy of positrons captured ~15+-5 MeV.



Angle shown is 0.1 rad.

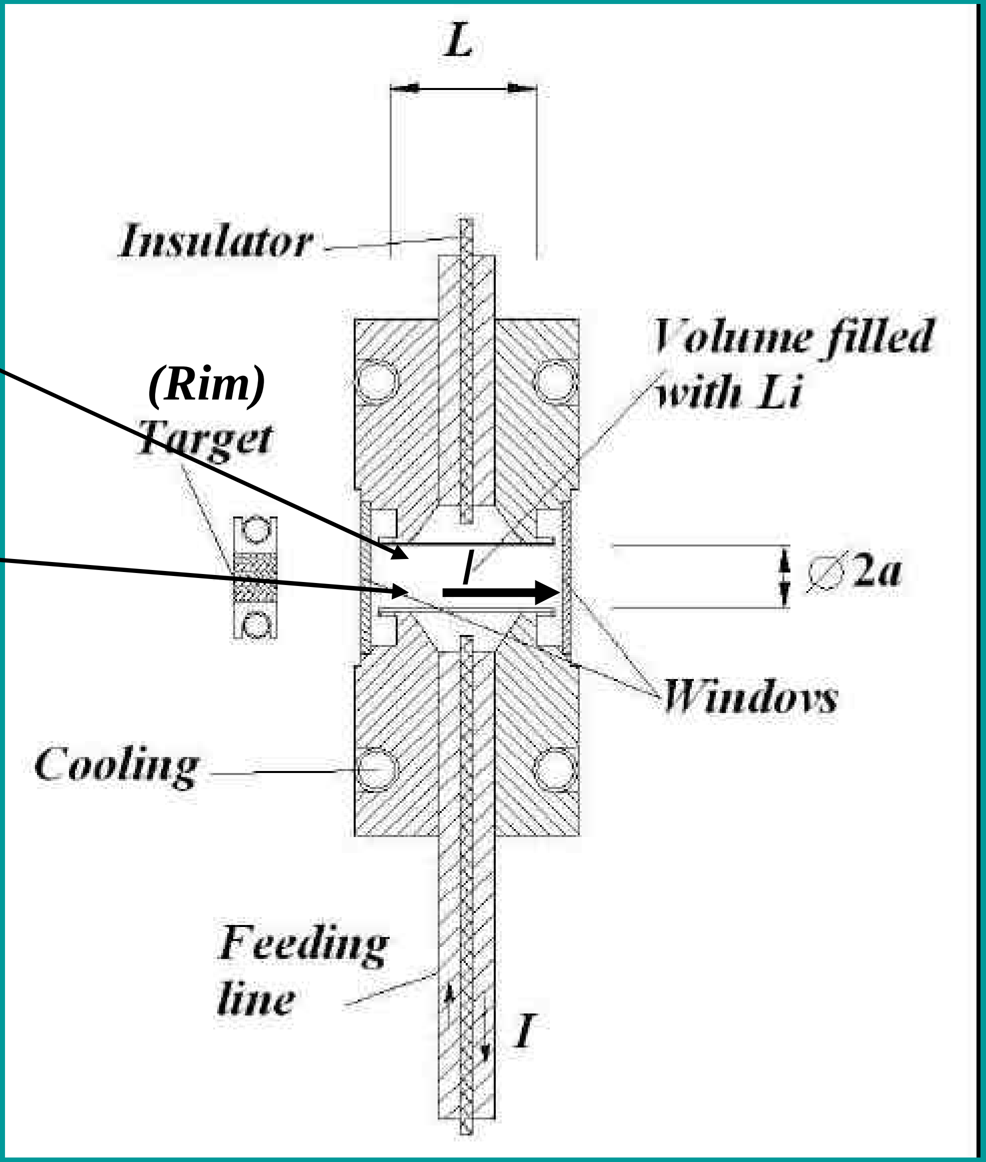
THE LITHIUM LENS CONCEPT

The current *I* runs through the Li rod along the axis

Particles also go through the Li in axial direction

Focal distance

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



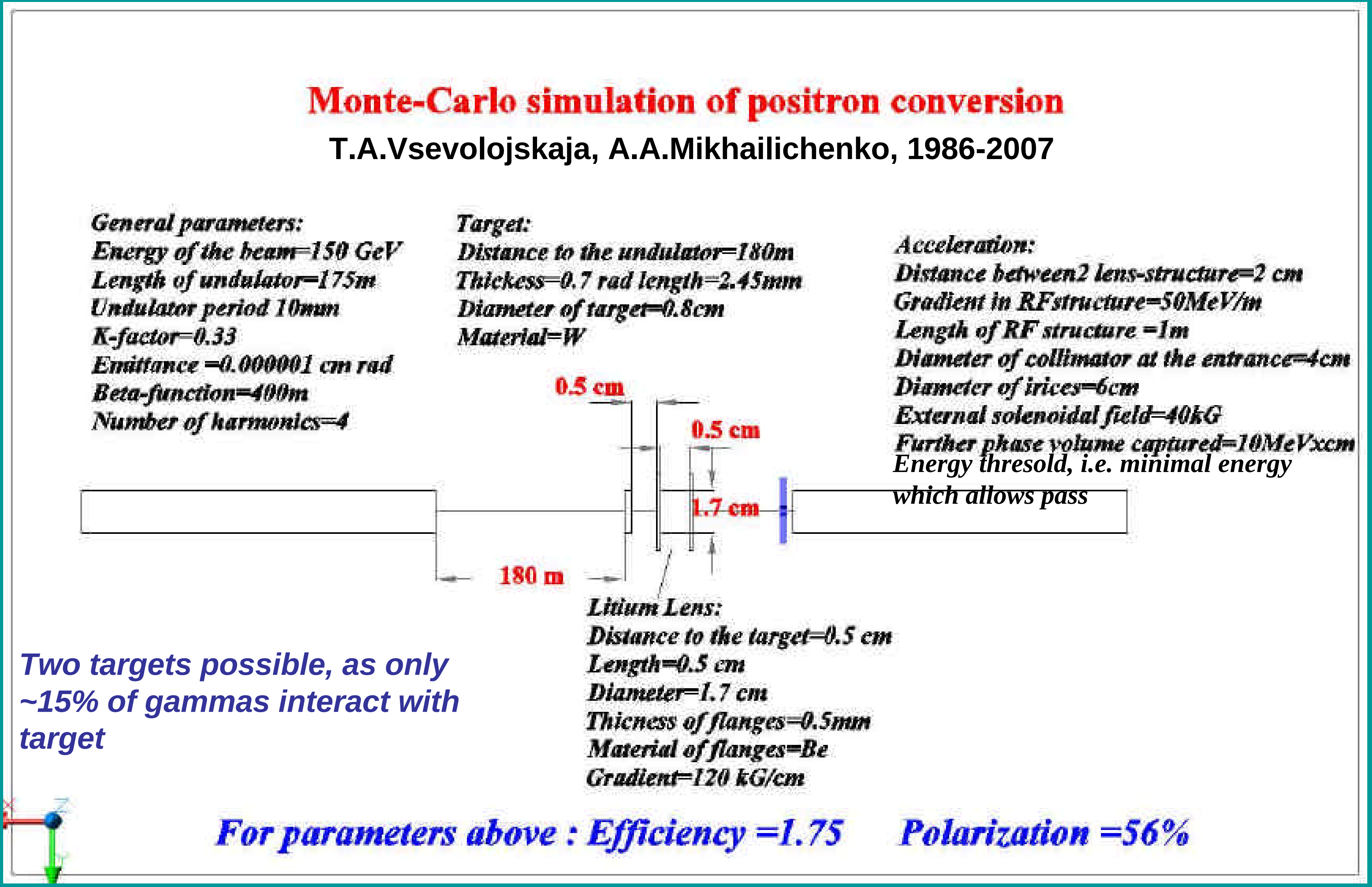
Field is strictly limited by the surface of the lens from the target side.

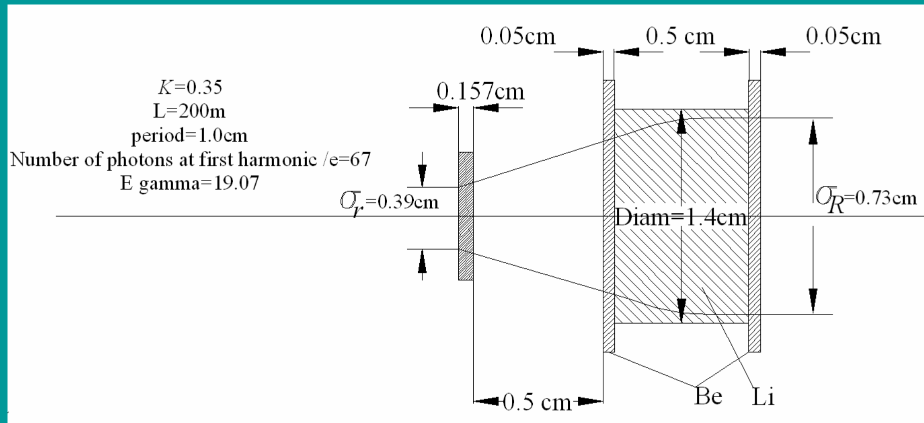
Melting temperature of Li 180°C

Density of Li 0.53 g/cm^3

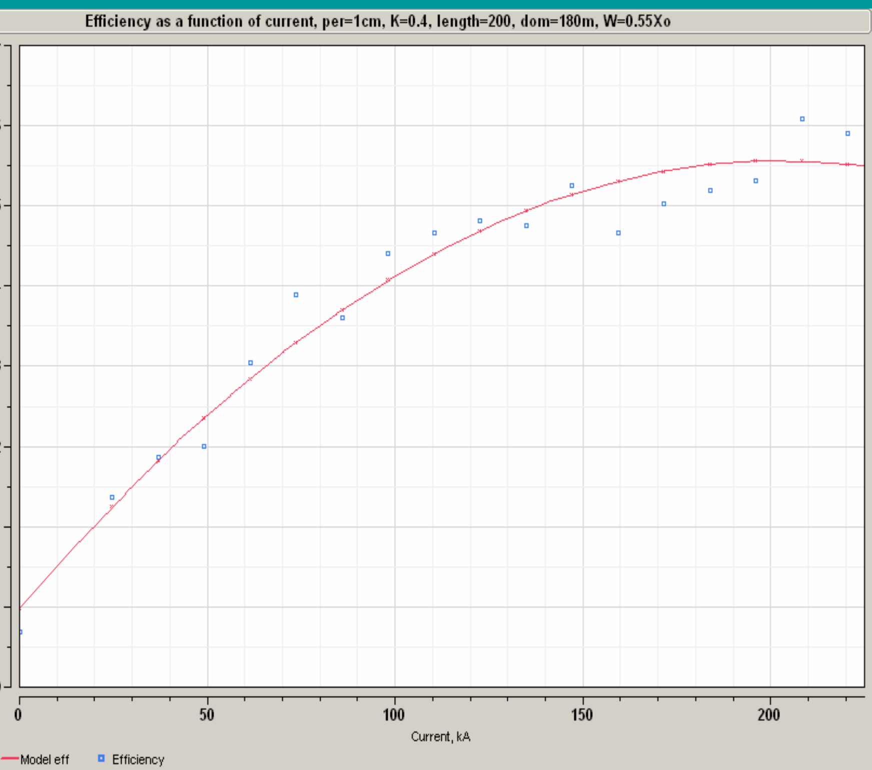
The windows made from Be, Ti or BN.

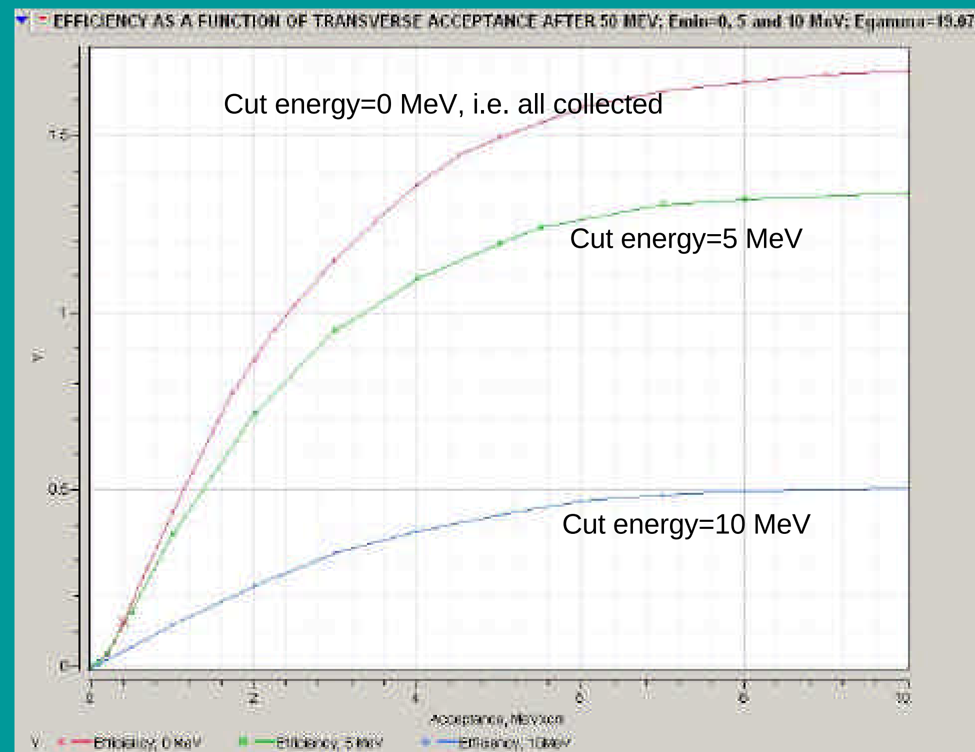
All calculations we carried done with code KONN. It uses Monte-Carlo approach. Starts from undulator-ends at the end of linac; Includes Lithium lens as a short-focusing device (planning to implement short solenoid also).





Geometry as it comes from KONN



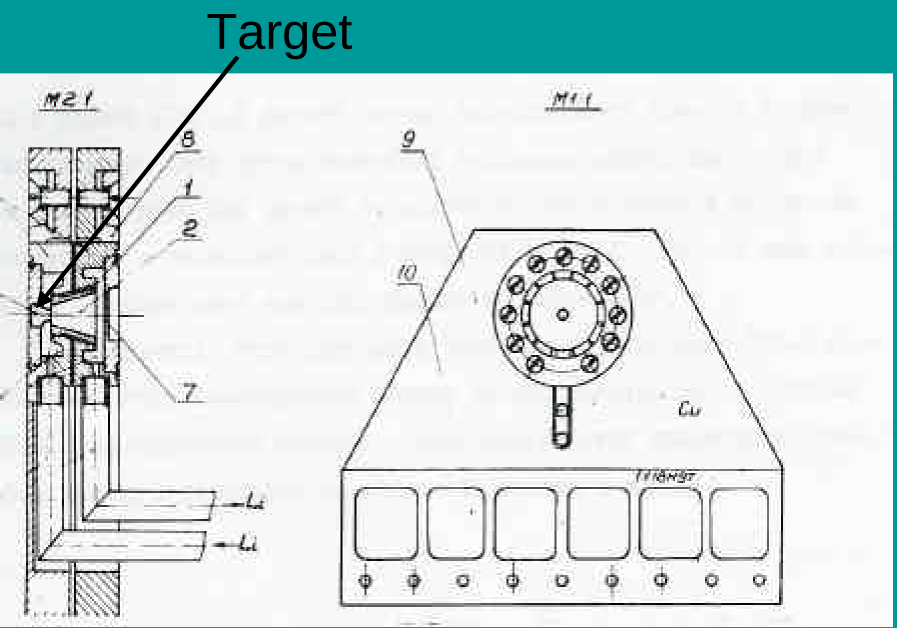


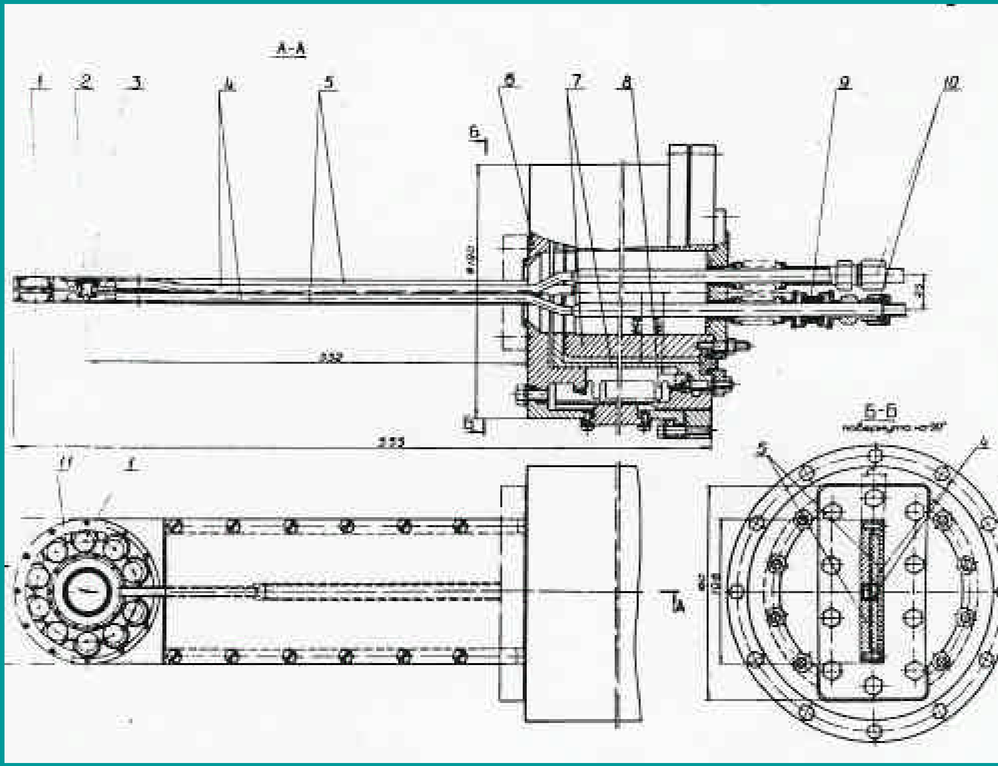
150 kA is around optimum

Transverse acceptance is $\epsilon_{x,y} \cong p_{\perp} c \cdot \Delta x [MeV \cdot cm]$

Emittance ~ 3 MeVxcm is the one delivers 1:1 in DR

LITHIUM LENS ENGINEERING





1-conic lens body; 2- working volume; 3- lens case; 4- buffer volumes; 5- feeding tubes for liquid Li; 6- **target**; 7- exit flange; 8-conic contacts; 9- flat current leads; 10- slots for heat flow reduction.

In this design the W target implemented in entrance flange.

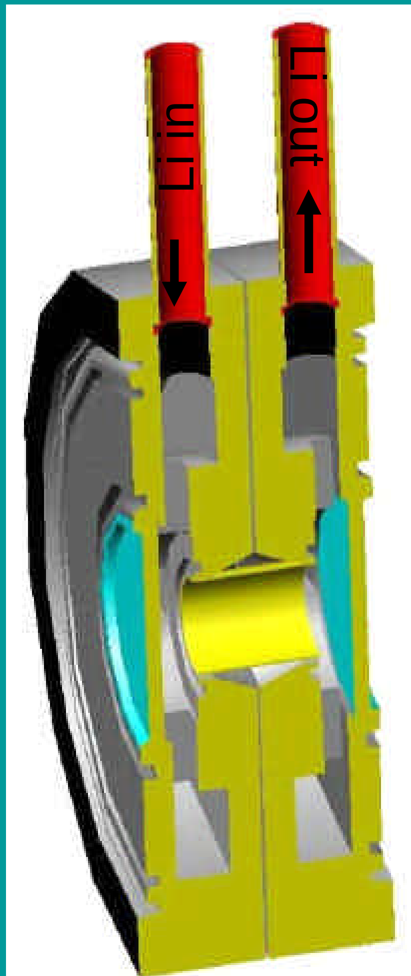
1-ex-centric contact pushers; 2-conic lens body; 3-W target; 4-Ti tubing for LI supply; 5-flat current leads; 6- vacuum chamber; 7-coaxial fraction of current leads; 8- bellows; 9-ceramic insulators; 10-conical gasket; 11-set of ex-centric pushers.

A lot of engineering work for Lithium lens usage in VLEPP Linear Collider was done in BINP, Novosibirsk.

Other well known Laboratories where LL are used for antiproton focusing are FermiLab and CERN.
Lenses used here are much more powerful than is required for positron focusing.

So the dimensions of LL for positron production are typically *ten times smaller*, than ones used in antiproton business.

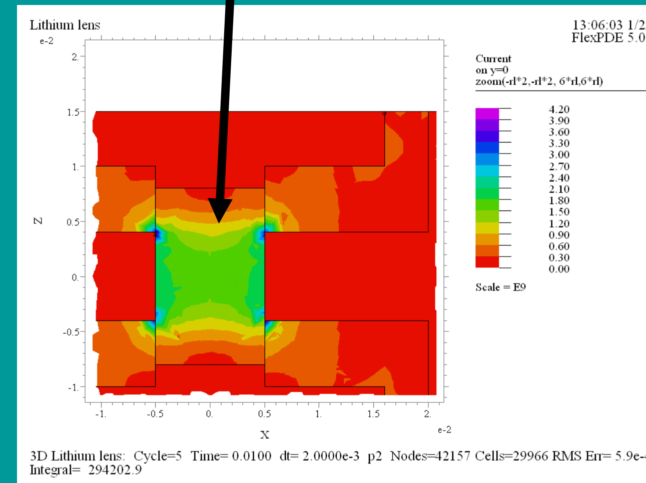
New round of calculations carried with **FlexPDE©.**

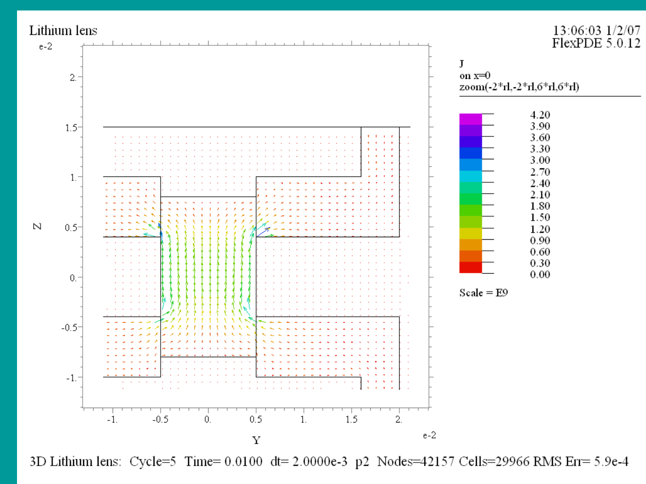


Lithium lens cut-off

Usage of liquid Li allows easy cooling of all system

Temperature of operation >180°C





Distribution of current in the lens

SCATTERING IN LITHIUM

$$\sqrt{<q^2>} \cong \frac{13.6MeV}{pc}\sqrt{\frac{t_{Xo}}{X_{Li}}} \qquad \sqrt{<q^2>} \approx \frac{13.6}{20}\sqrt{\frac{1}{156}} \approx 0.04rad$$

i.e. ~13 times smaller, than angular spread in the beam.

BEAM ENERGY DEPOSITION IN FLANGES

Energy deposition is going by secondary particles (positrons and electrons) with rate *dE*~2 Me*V*x*cm*²*/g*

$$E_{tot} \approx DE \times N \times n_b \times e$$

~1.8 Joules; N=2x10^{10} **,** n_b**=2800, *?E= dEx1.8=0.2MeV/e***

Total energy deposited in flanges comes to ~1.8 x2x2x3~21Joules → temperature gain just by heat capacity goes to be

$$\Delta T \cong \frac{E_{tot}}{mC_v} \cong \frac{E_{tot}}{rSlC_v} \cong \frac{21}{1.8\times 1.54\times 0.05\times 1.82} \cong$$

83°C +170°C=250°C

RESISTIVE HEATING OF Li

As the heat evacuated by the flow of liquid lithium is in a closed loop, there is no problem with overheating during *average* power deposition. For the flow rate v_{Li}**~10m/s, temperature gain comes to (heat capacity of Li** C_v**=3.58*J /g /°K*)**

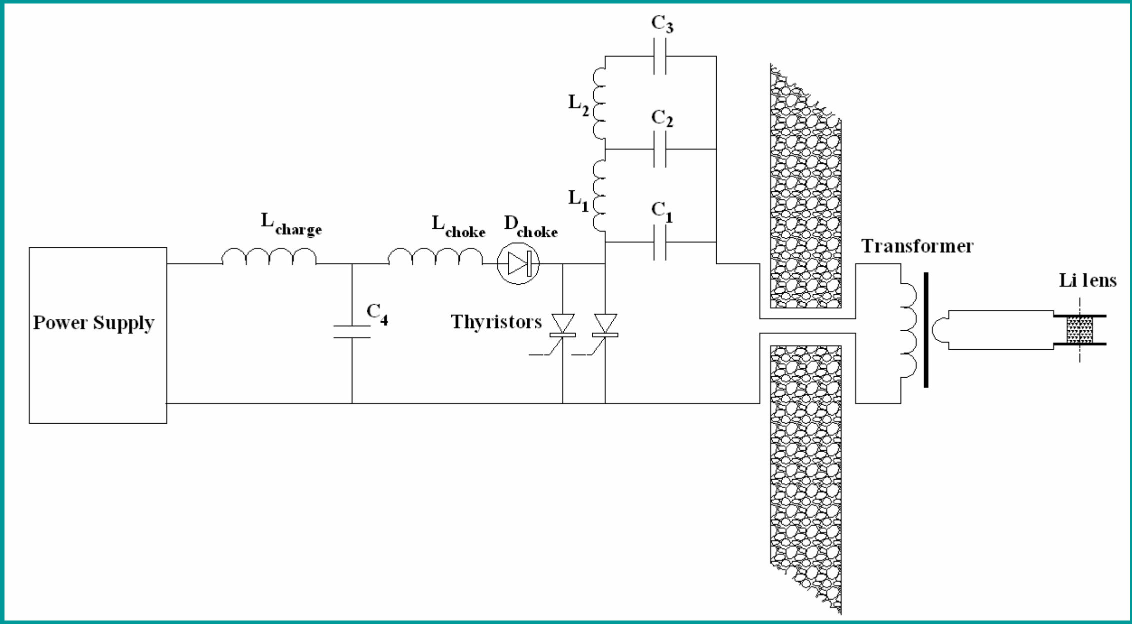
$$DT = \frac{Q}{mC_v} = \frac{Q}{rpa^2 v_{Li} t \times C_v} \approx \frac{10^3}{0.533\times p\times 0.25\times 4\times 3.5} = 170^o K$$

Melting temperature for Be~1278°C, for BN~2967°C ;

Contact with Li cools the windows

POWER SUPPLY

Required:
Current ~150kA
Voltage ~1.5V
Duty ~1ms flat top



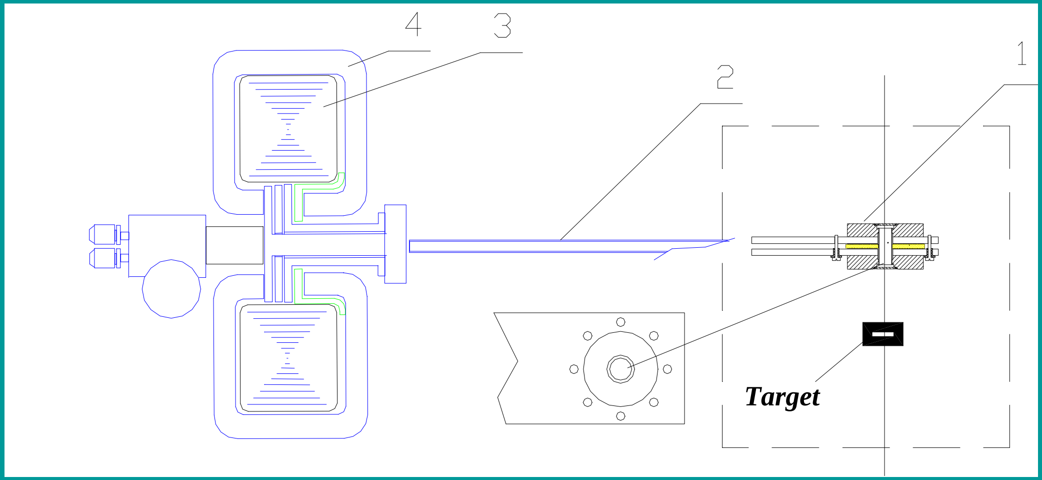
PS with transformer

hese parameters could be delivered by usage f transformer with transforming coefficient =1:20.

o the pulser must deliver about 0.1 *kV* and 325 *kA* in primary windings.

rea of transformer yoke ~100cm^2

ulser located in service tunnel

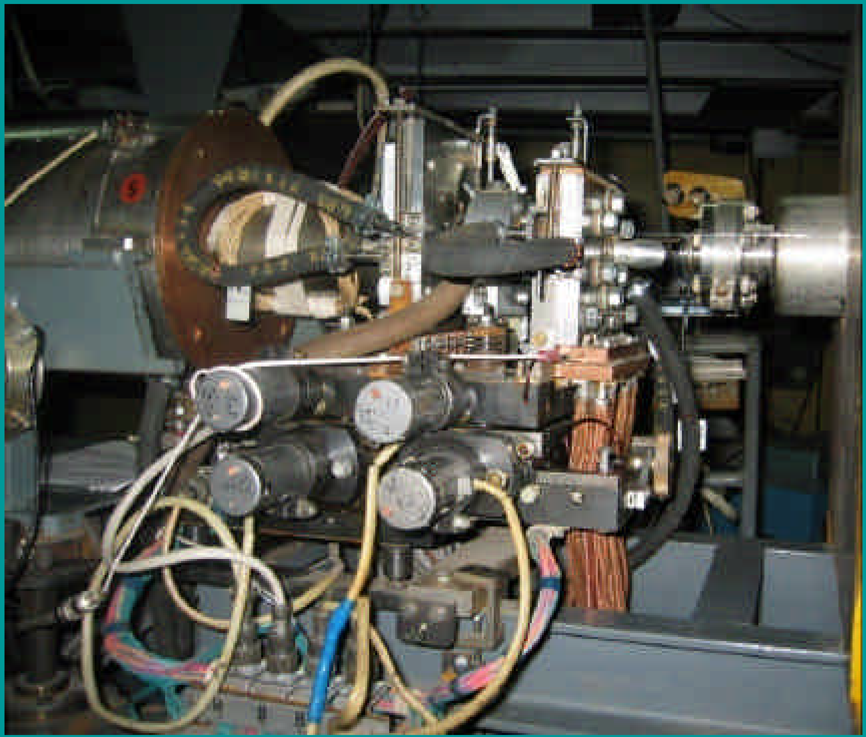


ransformer made as a cable one. This type of ansformer is known as having low stray fields. he art of engineering of low stray transformers well known up to *MA* level of currents.

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

n principle the direct discharge without any transformer is also easible with few 20kA hyristors in parallel

Lithium lens with feeding cables connecting lens with secondary windings of a transformer. (Courtesy of Yu. Shatunov, BINP).

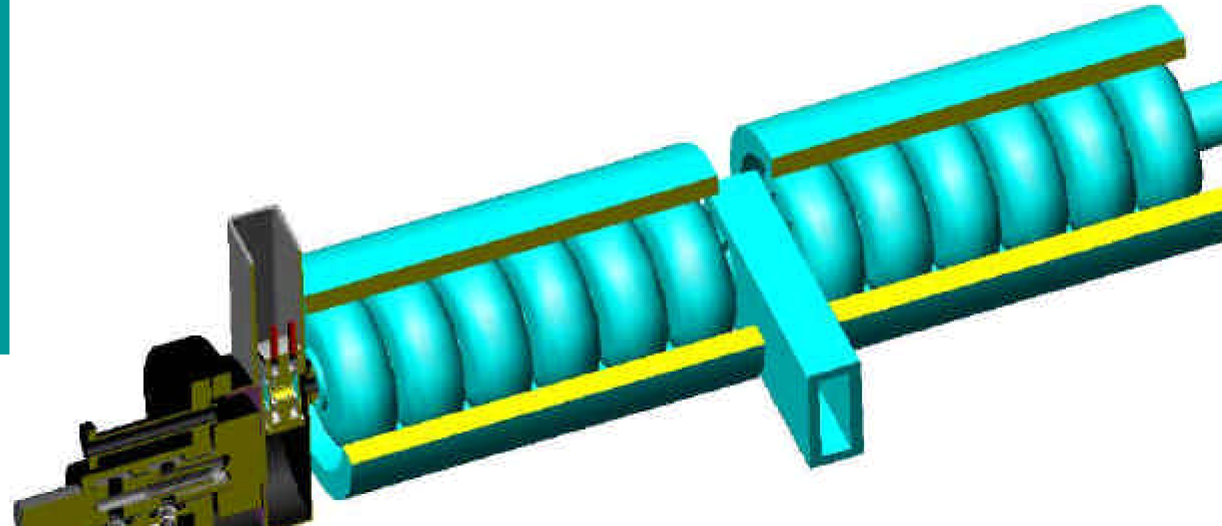


Doublet of Lithium lenses. First lens is used for focusing of primary 250 MeV electron beam onto the W target, Second lens installed after the target and collects positrons at ~150MeV (Courtesy of Yu. Shatunov, BINP)

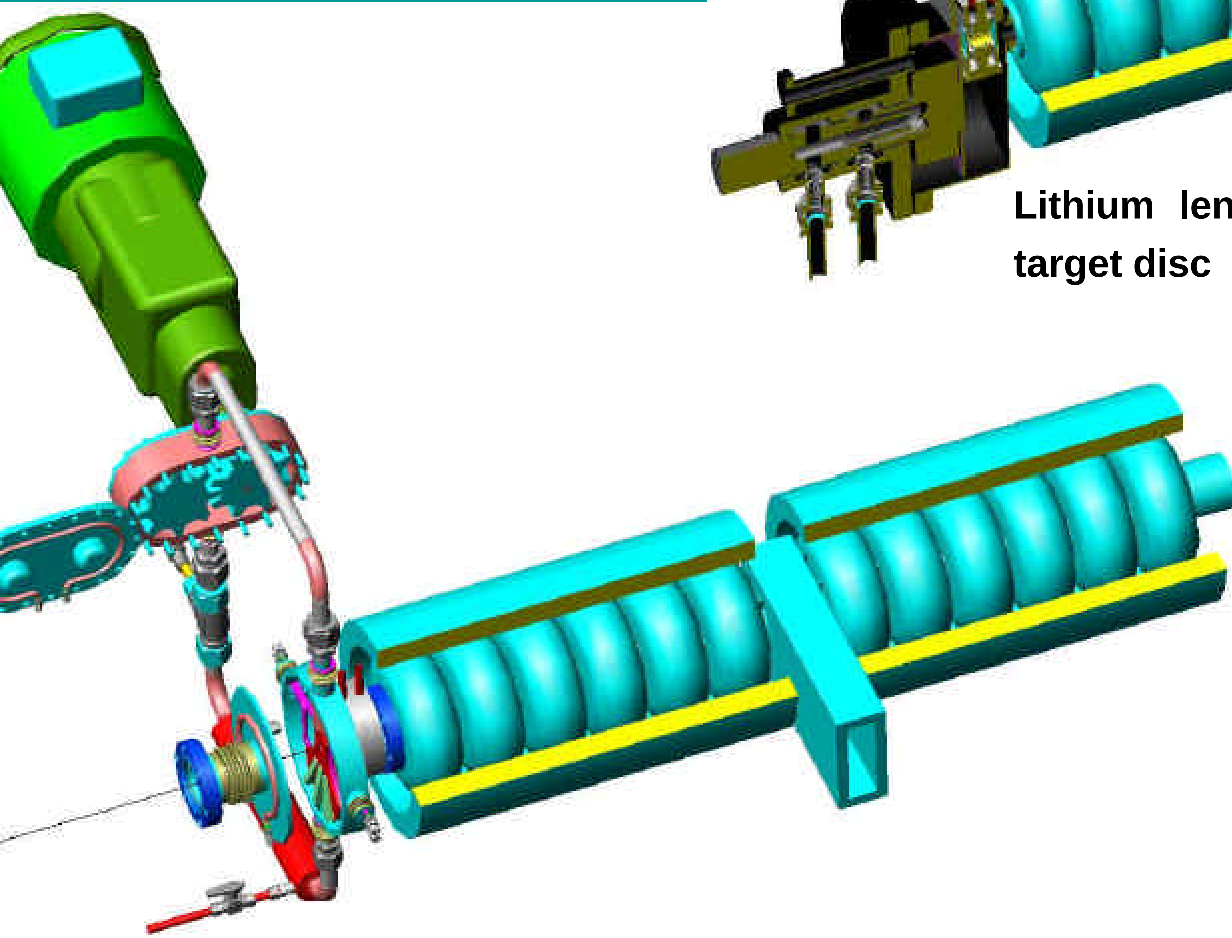
These lenses shown stays in service ~30 years; Number of primary electrons per pulse is up to $\sim 2 \cdot 10^{+11}$; ~0.7Hz operation (defined by the beam size damping rate in a Storage Ring booster- BEP).

LENS INSTALLATION

iew to the liquid metal target, ithium lens and accelerating ection. Pump for liquid Lithium is imilar to the one, used for liquid netal pump shown here.



Lithium lens installed right after the spinning target disc

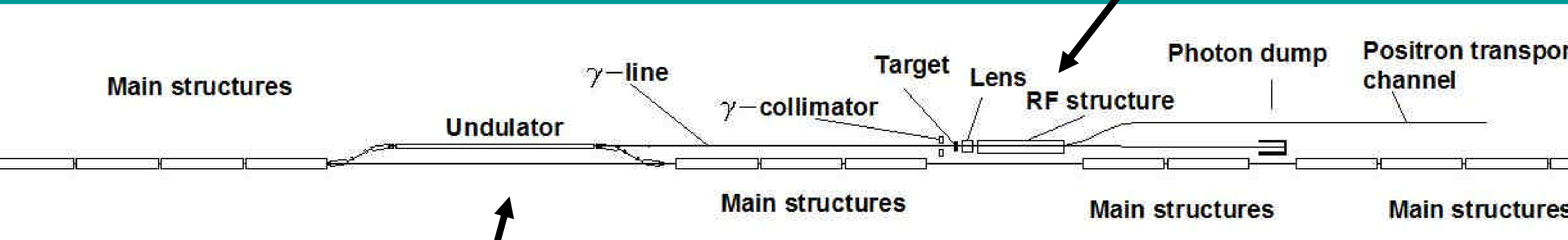


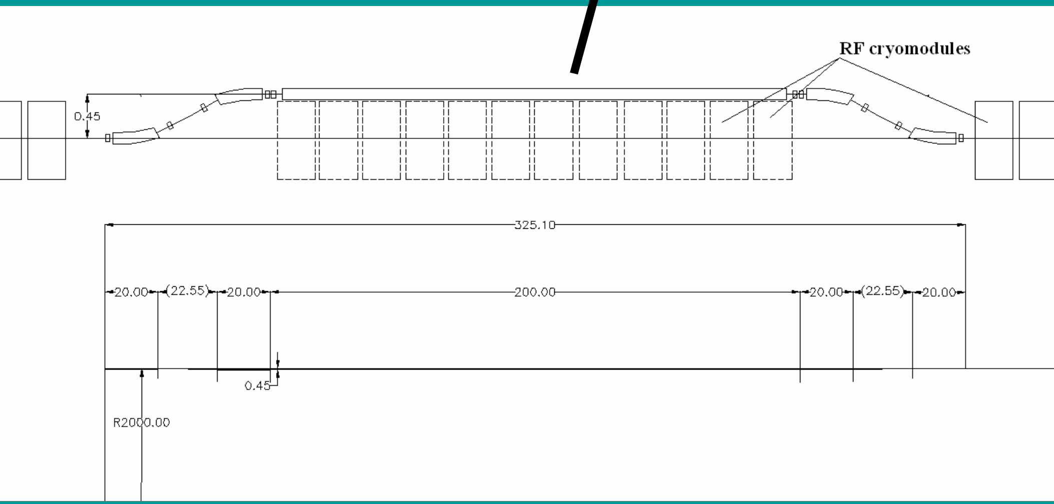
Focusing solenoid made with Al conductor.

It is good to have first section of RF structure made from Al too.

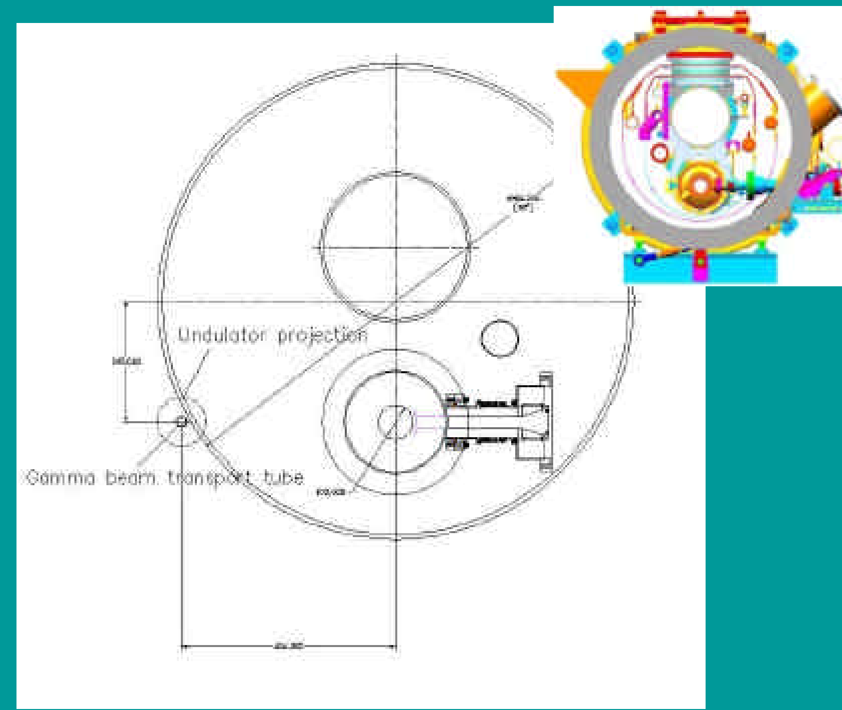
CIVIL CONSTRUCTION

In tunnel near the target two main accelerating structures removed allowing allocation target, collection optics and first sections of positron accelerator.





hicane schematics. At the top-the general concept is epresented (transverse dimension is enlarged). In principle, F cryomodules could remain not removed at the line arallel to undulator. In the sketch the dimensions are epresented in meters.



To the choice of minimal shift between axes Diameter of undulator cryostat is 4in (~10 mm).

SUMMARY OF PARAMETRS

Parameter	Value
General parameters	
Energy of primary beam	~150 GeV
Undulator *K* factor	£ 0.4
Undulator period	10-12 mm
Undulator length	£ 200 m
Efficiency	1.5 e^{+}/e^{-}
Polarization	³ 60%
Target	Tungsten 1.75 mm (+Ti)
Energy of quanta	~18 MeV
Distance to the target*	180 m
Lens	
Feeding current	£ 160 kA
Field at surface	65 kG
Gradient	£ 130kG/cm
Pulsed power	250kW
Average power	5kW
Pulsed duty	4msec
Lens diameter	1-1.7 cm
Length	0.5-1 cm
Axial pressure	~163atm
Temperature gain per pulse	£ 170^{o}C at 160kA

* Calculated from the

Calculations with KONN show, that with *K*~1, having period 1 cm the length of undulator is going to be ~30 *m* only. Average level of polarization becomes ~36%. Conversion efficiency remains 1:1.5 ,i.e. for each primary electron 1.5 positrons created in average after post-acceleration to 50 MeV.

Two targets are feasible here allowing further reduction of gamma flux

CONCLUSIONS

Low efficiency of positron collection optics forces to compensate this by increasing the flux of primary photons. Under these circumstances one is forced to use spinning Ti rim, which reduces efficiency even further. In its turn, excessive photon flux and scattered positrons/electrons lost during collection, generates severe radiation activity in a target, nearby accelerating structure and elements of collection optics itself.

Utilization of Lithium lens allows improvements not only with Ti target, but Tungsten survival under conditions required by ILC with N_e~$2x10^{10}$ with moderate *K*~0.3-0.4 and do not require a large size spinning rim (or disc). Thin W target allows better functionality of collection optics (less focusing depth as a result of thinner target; Liquid targets as Pb/Bi alloy or even Hg allows further increase of positron yield).

Meanwhile Lithium lens (and x-lens) is a well developed technique. Usage of Li lens allows for a drastic increase in accumulation rate and lowering *K*-factor as a sequence. As the *K* factor could be made lower by at least 2.5-3 times, the photon flux goes down ~6-10 times. In turn this will reduce the energy spread in primary beam accordingly.

Calculations are under way for further optimization (conical shape; FlexPDE)

For K~1 the length of undulator for 1 to 1.5 conversion is 30 m; polarization~36%

Lithium lens is well known techniques; broadly in use for antiproton collection (FNAL, CERN)

- **As a result of usage of Li lens, we get significant cost savings and reduction of activation**

Usage of Li lens in other than ILC beam format, say the CLIC one, allows for further simplifications for the lens as the feeding current pulse becomes shorter. This allows for more relaxed conditions for the power supply.