CBN 07-6

THE STATUS OF POSITRON SOURCE DEVELOPMENT AT CORNELL

Alexander Mikhailichenko

Cornell University, LEPP, Ithaca, NY 14853

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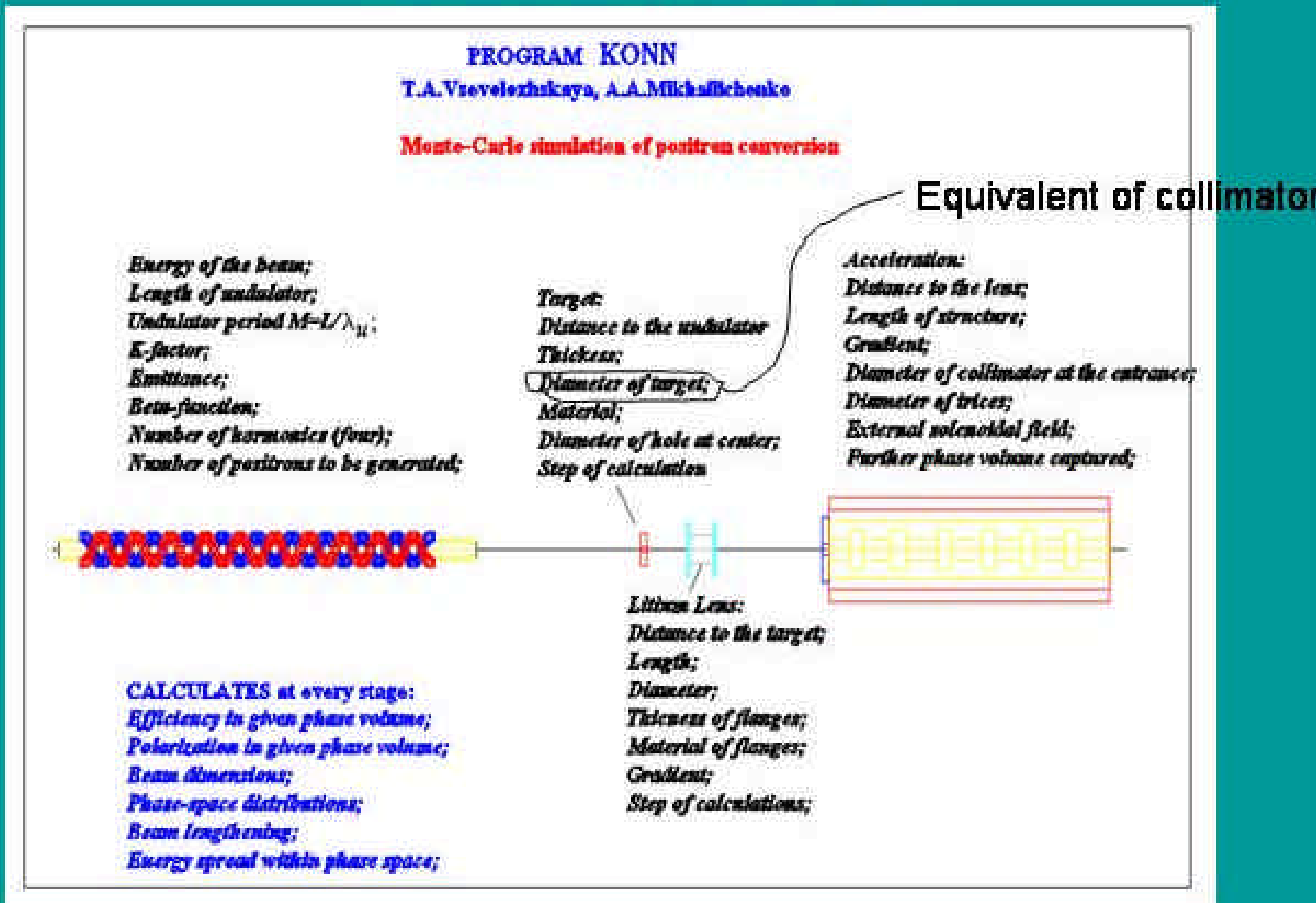
ACTIVITIES
√ CODE FOR POSITRON CONVERSION (UNDULATOR → LINAC → further on)
Choice of undulator parameters → main issue
Choice of target dimensions
Choice of collection optics parameters
√ UNDULATOR DESIGN (main activity)
Undulators with period 10 and 12 mm having 8 mm aperture (tested)
Designed undulators with aperture ¼" (7mm magnetic core)
TARGET DESIGN (in addition to Livermore, SLAC, Daresbury
Rotating Tungsten target (including new sandwich type)
Liquid metal target: Bi-Pb or Hg
COLLECTION OPTICS DESIGN
Lithium lens
Solenoid
These positions not closed finally
√ COLLIMATORS
Collimator for gammas
Collimators for full power beam
√ PERTURBATION OF EMITTANCE AND POLARIZATION
Perturbation of emittance in regular part
Polarization handling
√ UNDULATOR CHICANE
Minimal possible parallel shift
√ COMBINING SCHEME
Two-target scheme

CODE FOR POSITRON CONVERSION

Undulator → target → focusing → post acceleration

Written in 1986-1987, restored in 2007



Interactive code; Solenoidal lens will be added soon

Particles described by 2D array (matrix). One parameter numerates particles, the other one numerates properties associated with each particle: energy, polarization, angles to axes

Code has ~1400 rows;

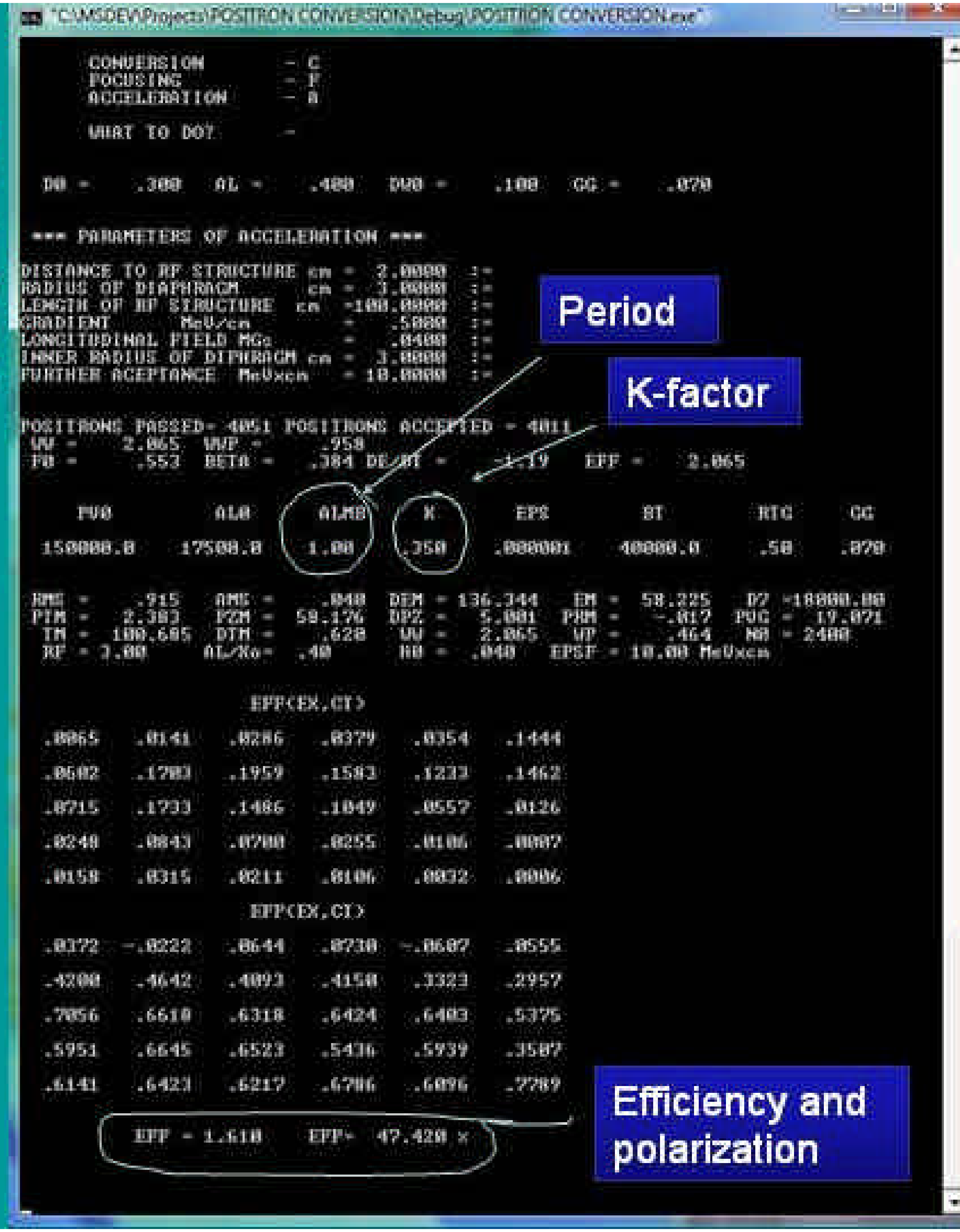
Will be added solenoidal lens;

Will be added more graphics;

Possibility for the file exchange with graphical and statistical Codes (JMP);

Possibility for the file exchange with PARMELA;

Few seconds for any new variant



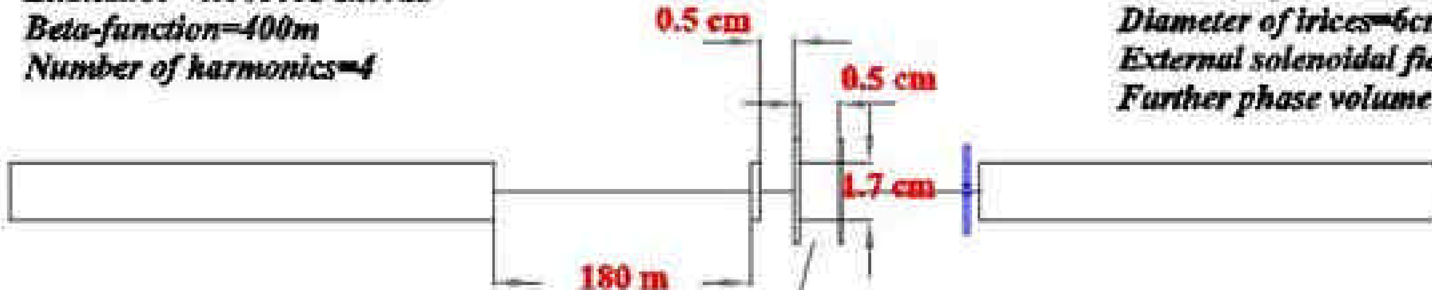
Parameters optimized with KONN

Monte-Carlo simulation of positron conversion example

General parameters:
Energy of the beam=150 GeV
Length of undulator=175m
Undulator period 10mm
K-factor=0.35
Emittance =0.000001 cm rad
Beta-function=400m
Number of harmonics=4

Target:
Distance to the undulator=180m
Thickess=0.5rad length=1.75mm
Diameter of target=0.8cm
Material=W

Acceleration:
Distance between2 lens-structure=2 cm
Gradient in RFstructure=50MeV/m
Length of RF structure =1m
Diameter of collimator at the entrance=4cm
Diameter of irices=6cm
External solenoidal field=40kG
Further phase volume captured=10MeVxcm



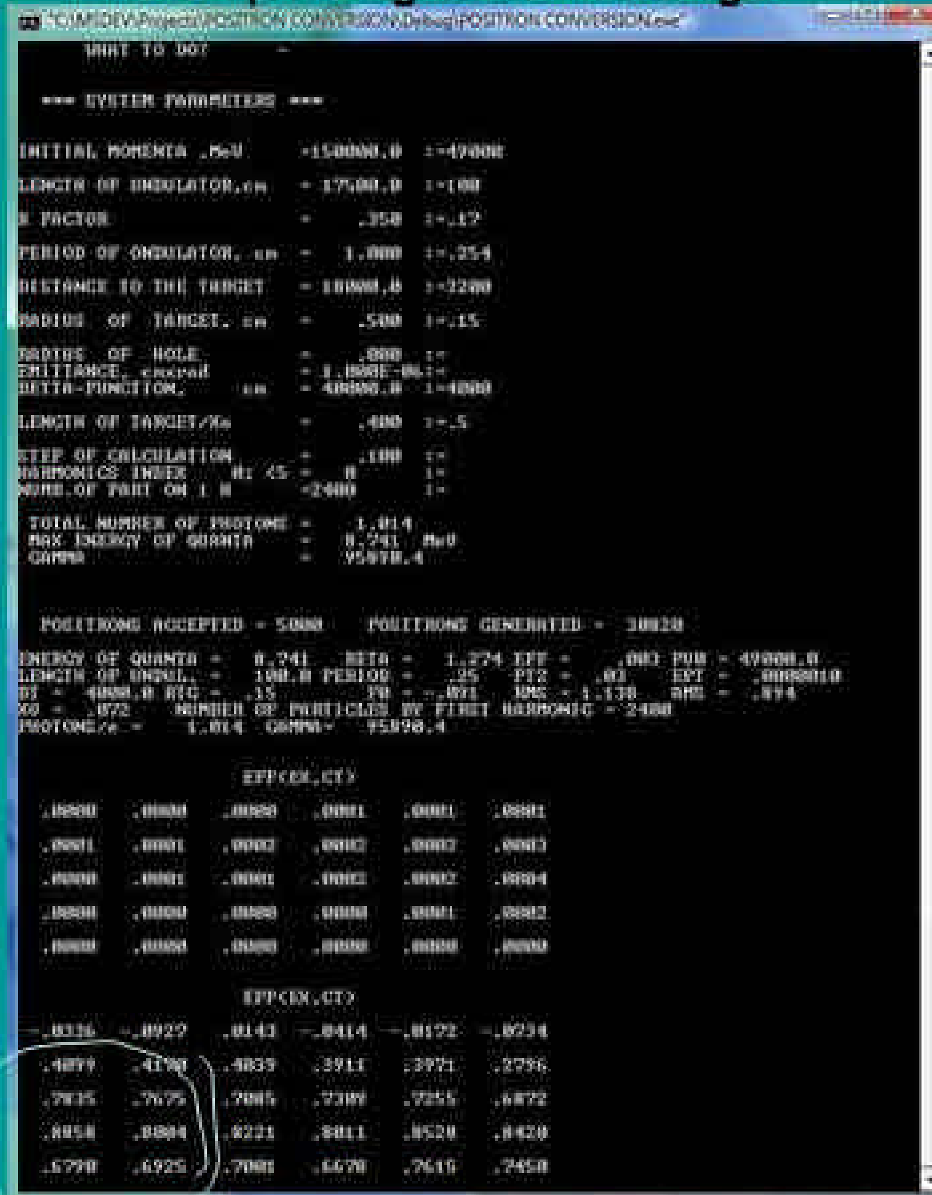
Litium Lens:
Distance to the target=0.5 cm
Length=0.5 cm
Diameter=1.7 cm
Thicness of flanges=0.5mm
Material of flanges=Be
Gradient=70kG/cm

For parameters above : Efficiency =1.54   Polarization =50%

So K-factor can be small, K<0.4, what brings a lot of relief to all elements of system

Modeling of E-166 experiment

Phase space right after the target



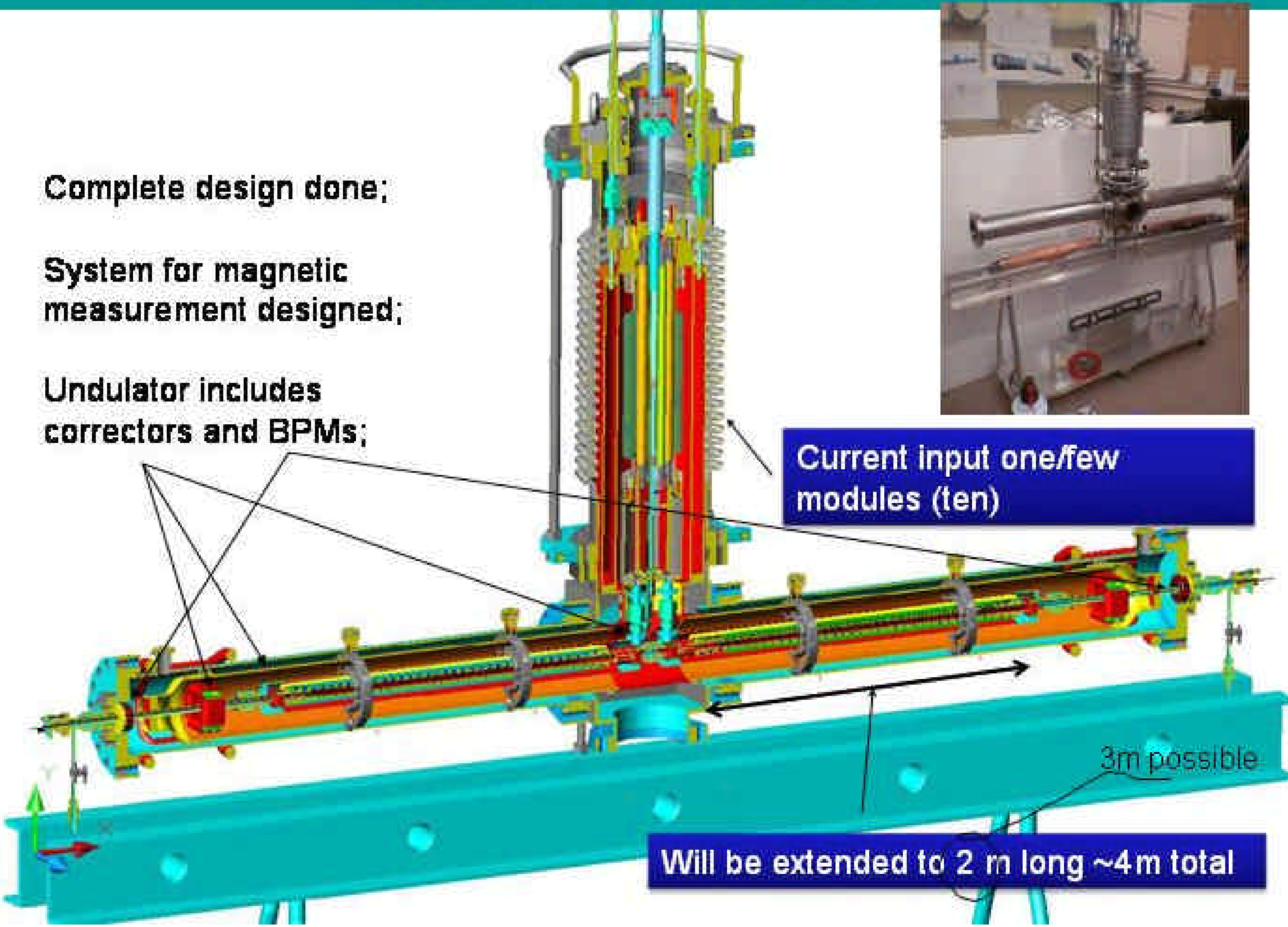
Dependence of polarization seen in experiment

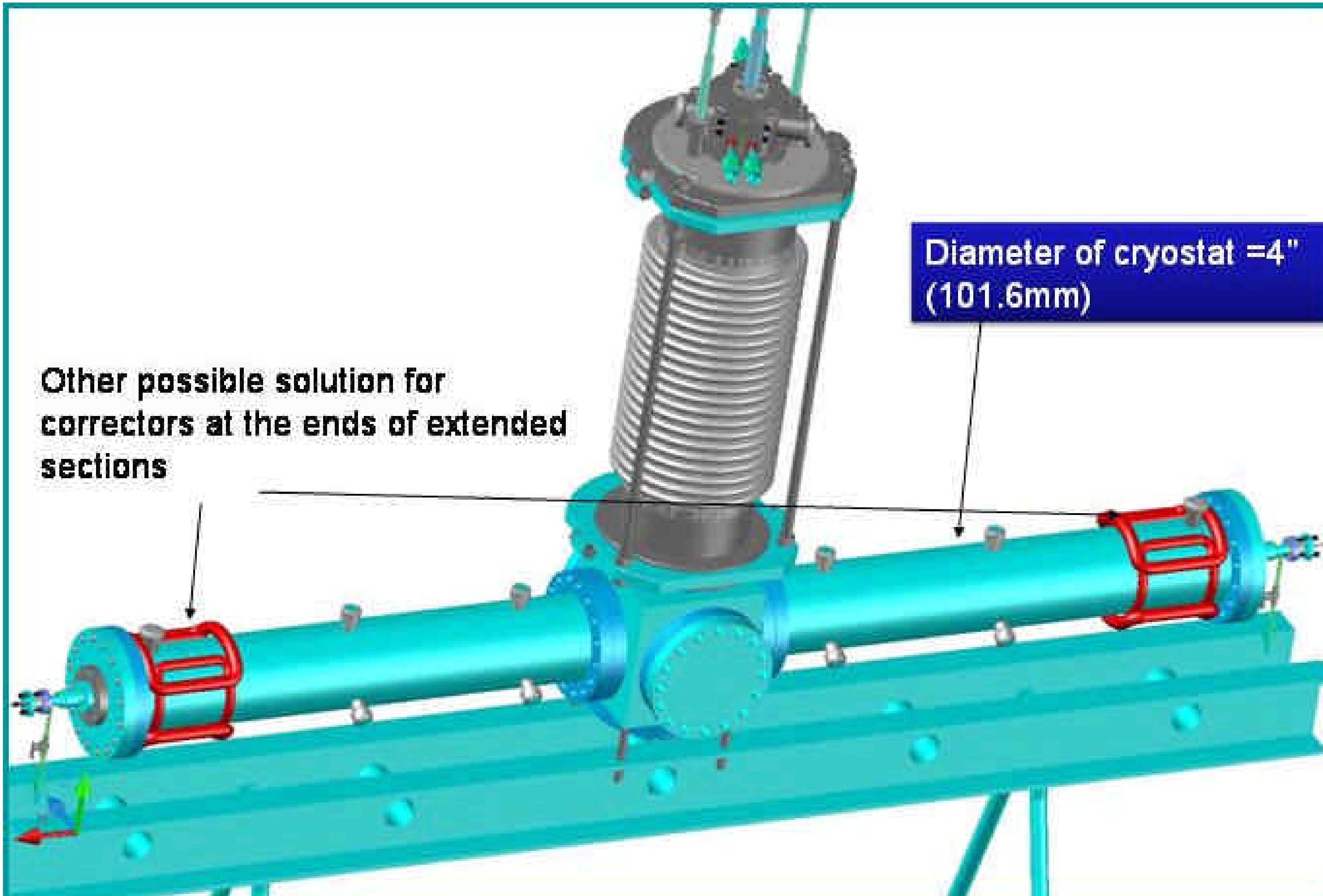
UNDULATOR DESIGN

Complete design done;

System for magnetic measurement designed;

Undulator includes correctors and BPMs;





Cryostat expandable; shown with the terminals for Hall probe insertion;
Field distribution will be measured in this cryostat ; will be tested with beam

Technology developed for fabrication of continuous yoke of necessary length (2-3m)

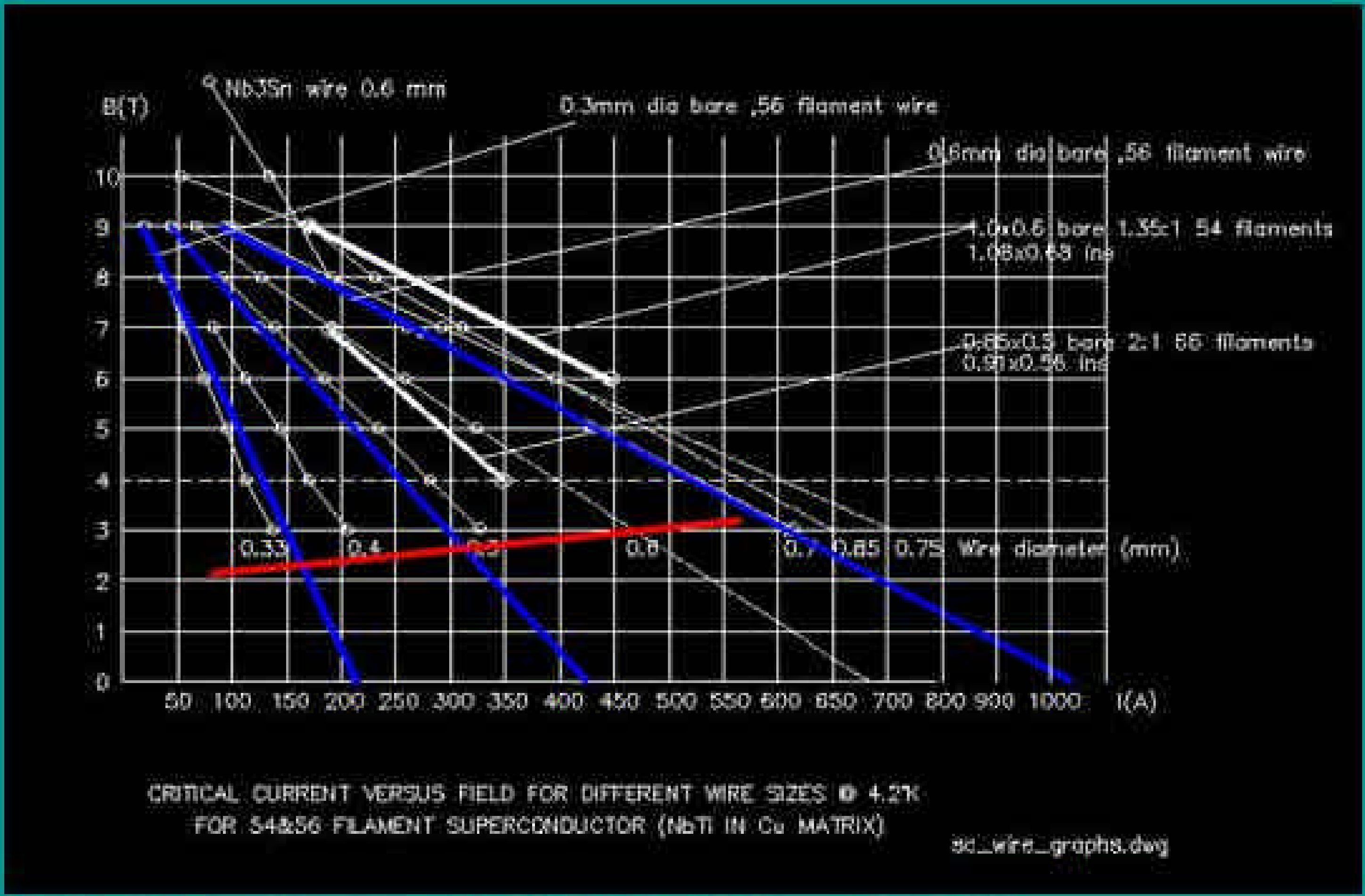
Wire having diameter 0.33mm chosen as a baseline one for now

For 10mm period the coil has 8(z)x11(r) wires; bonded in 4strands

For 12mm period the coil has 12(z)x12(r) wires bonded in 6 strands

Two meter long yoke under visual inspection by William Trusk

Wires for undulator



All new wire is a 56 filaments with SC to Cu ratio 1:0.9

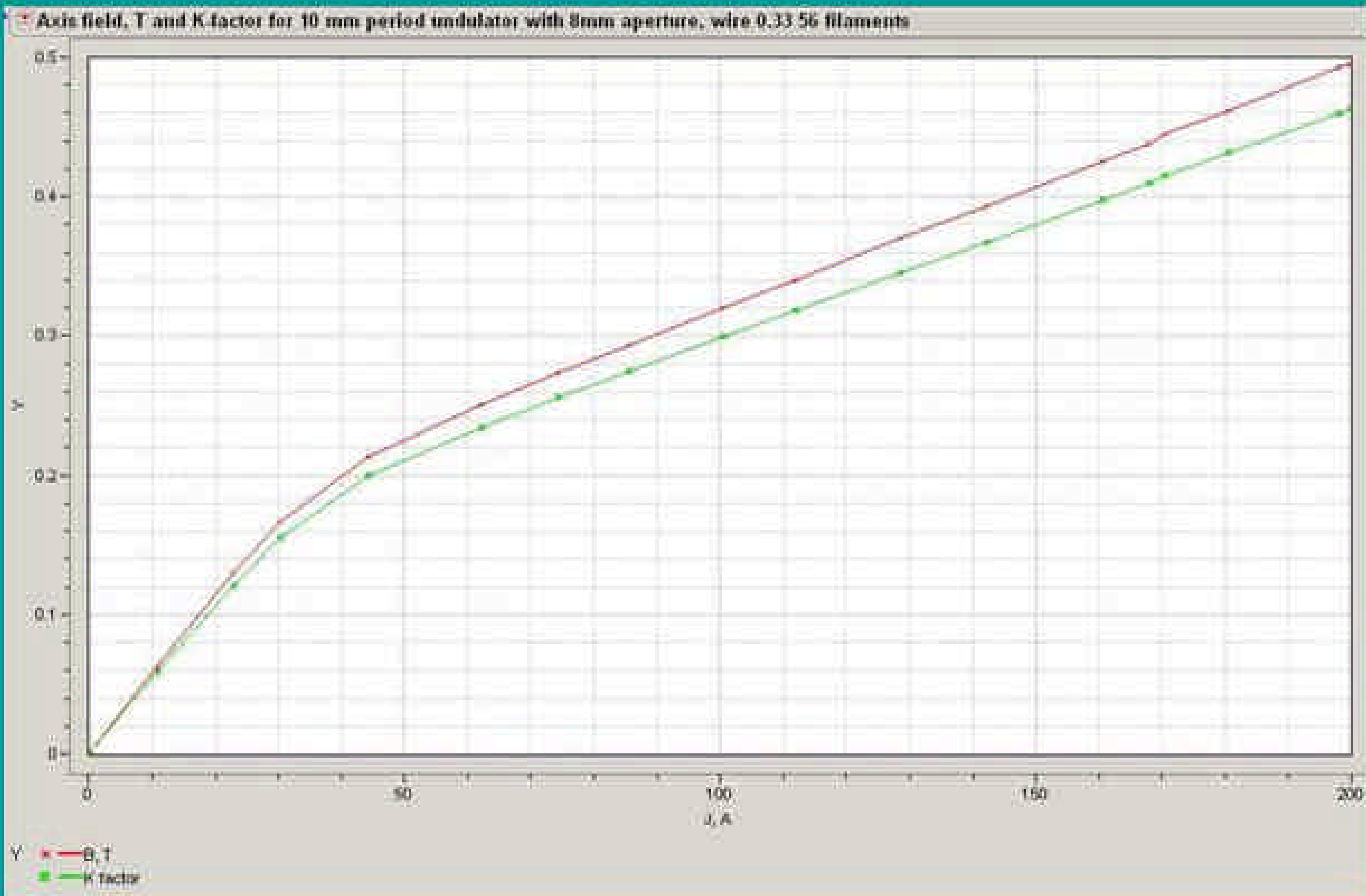
We switched to 0.3 mm bare from 0.6 bare

Wounding with bonded tape of four and six wires in parallel

Operation at lower pressure of He

Dewar sealed and used for low pressure experiments; two oil pumps deliver vacuum down to -24"Hg with Helium level covering the undulator

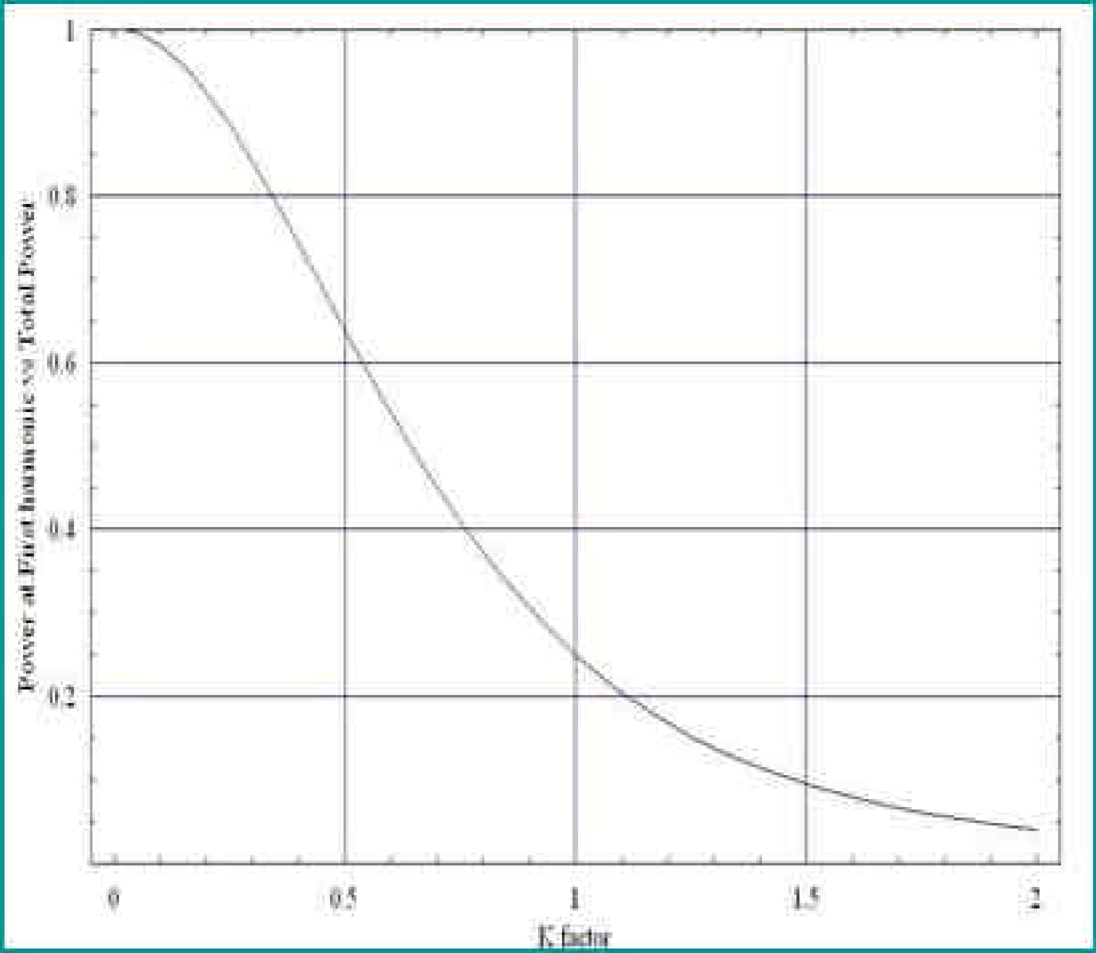
For Dewar pumped down -24"Hg (-609.6mmHg), the temperature ≈ 3 °K



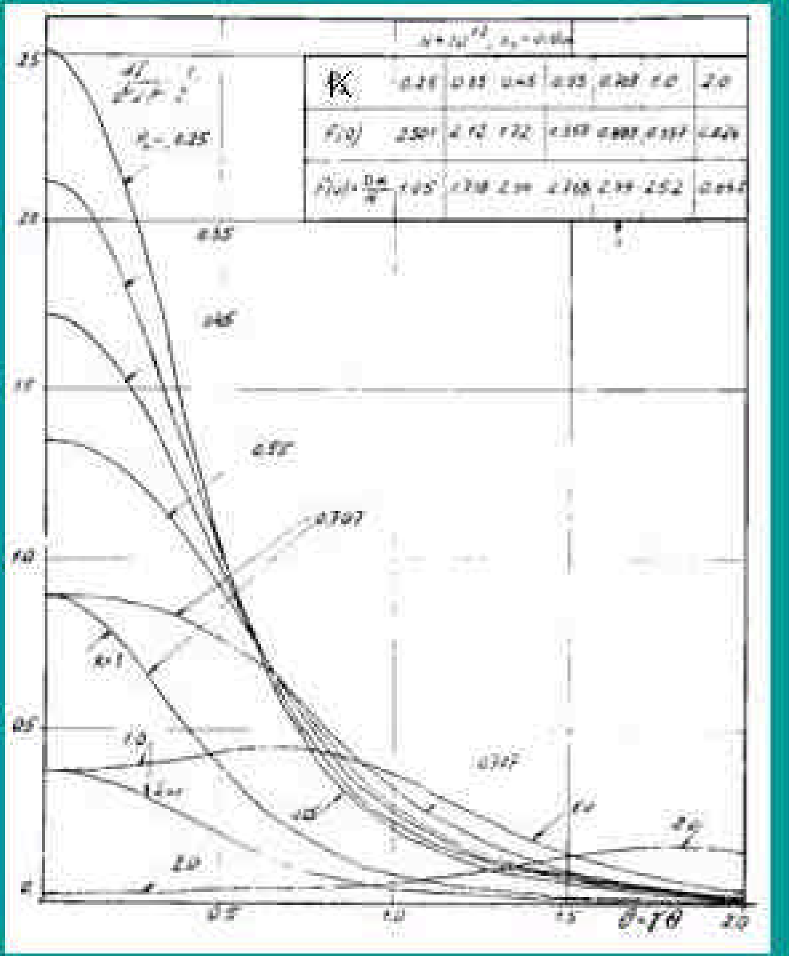
Measured excitation curve for undulator with 8mm aperture, wire-0.33 mm, 56 filaments
Random point; spread of amplitudes~5%

No need for K factor to be high

This is useful for higher polarization



Ratio of Power radiated at first harmonics to the all power in all angles



Angular distribution of intensity of radiation for different K

ILC Beam parameters

$\gamma\varepsilon_x$=8 10^{-6} m rad -high edge
$\gamma\varepsilon_y$=8 10^{-8} m rad –high edge
β_v ~200 m

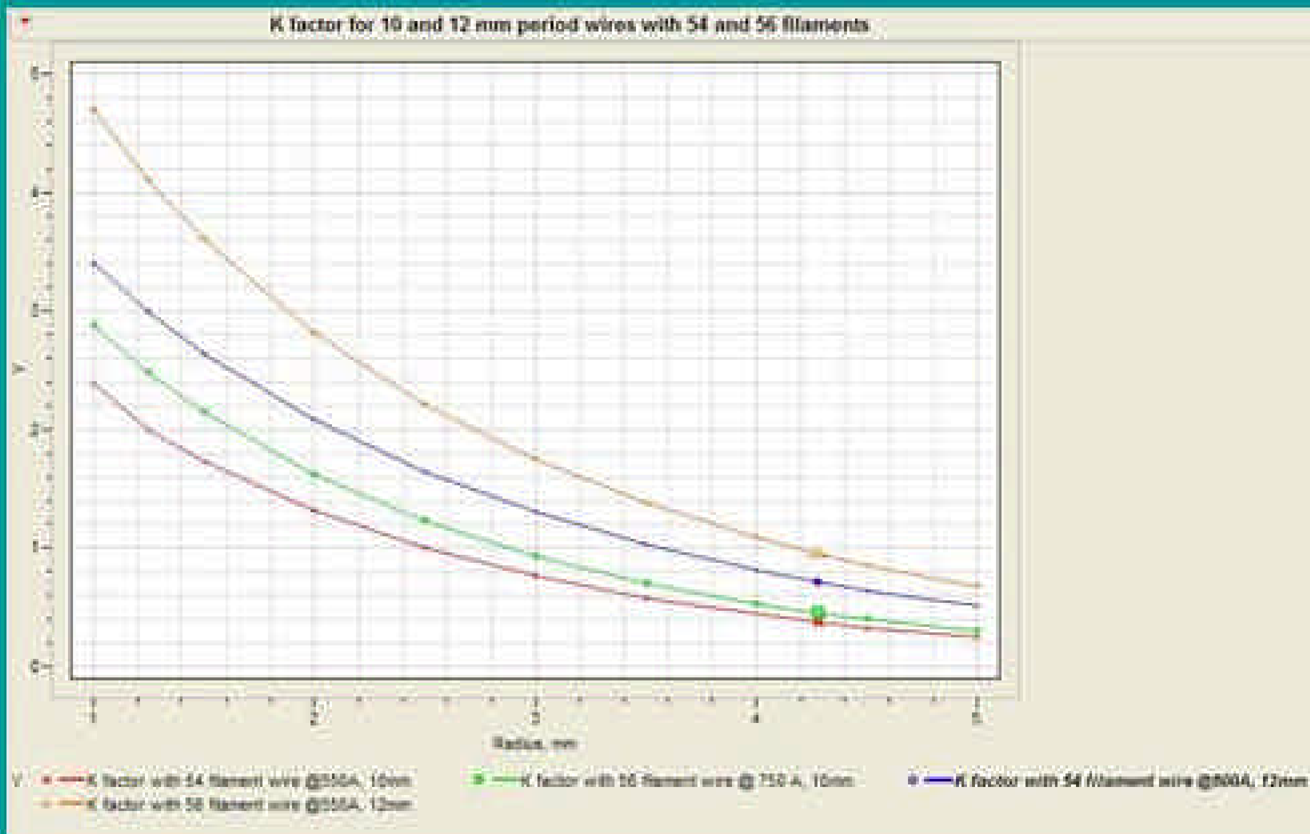
Angular spread in radiation	$\alpha \sim \sqrt{1+K^2}/\gamma$	$3\cdot 10^{-6}$ $(K=1)$
Angular spread in beam, vert.	$y' \cong \pm\sqrt{\gamma\varepsilon_z/\beta\gamma}$	$3.5\cdot 10^{-8}$
Angular spread in beam, rad.	$y' \cong \pm\sqrt{\gamma\varepsilon_z/\beta\gamma}$	$3.5\cdot 10^{-7}$
Radius of helix	$a \cong \lambda\!\!\!^{-}_u K/\gamma$	$5\cdot 10^{-7}\,cm$ $(K=1)$
Beam size, vertical	$\sqrt{\langle y^2\rangle} \cong 2\times\sqrt{\gamma\varepsilon_y\beta/\gamma}$	$1.4\cdot 10^{-3}\,cm$
Beam size, radial	$\sqrt{\langle x^2\rangle} \cong 2\times\sqrt{\gamma\varepsilon_x\beta/\gamma}$	$1.4\cdot 10^{-2}\,cm$

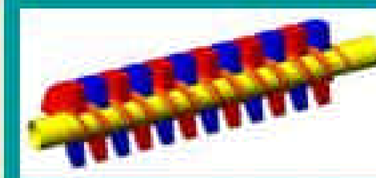
50 sigma ~7 mm ; At the beginning of operation one can expect emittance degradation

That is why we have chosen as big aperture as possible -- Ø8 mm clear.

This 8 mm diameter allows K~0.4-0.5

K factor as function of radius of undulator chamber

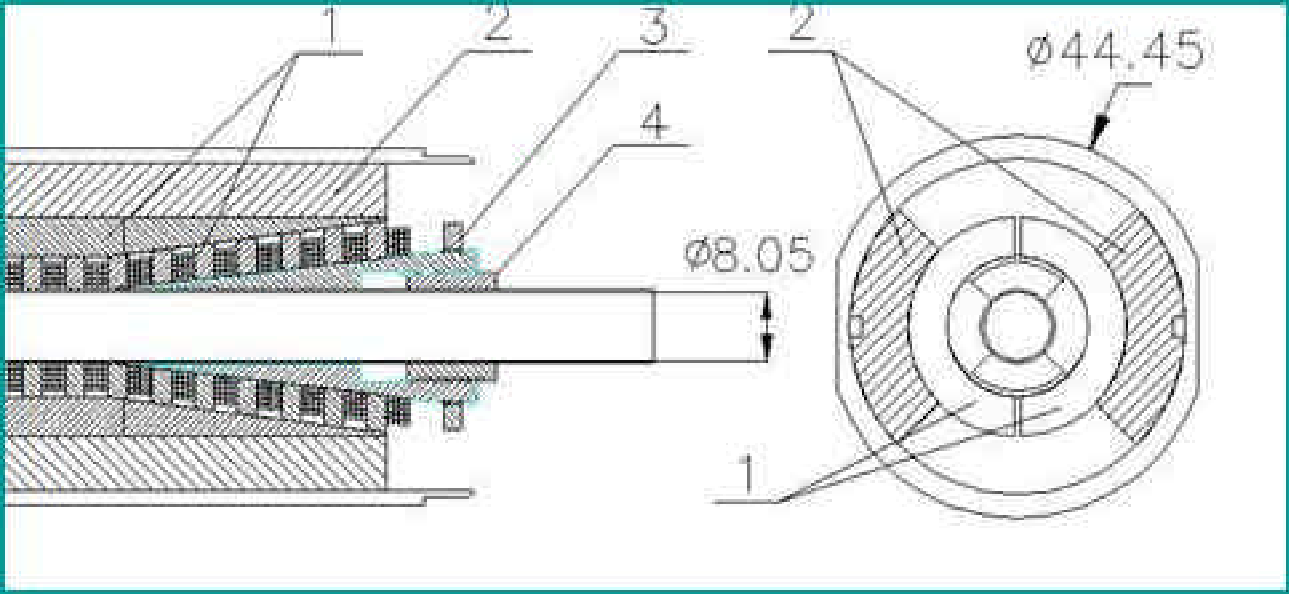




NbTi wire 56 filaments demonstrate best properties

Sectioning coil in radial direction allows further enhancement

End region design

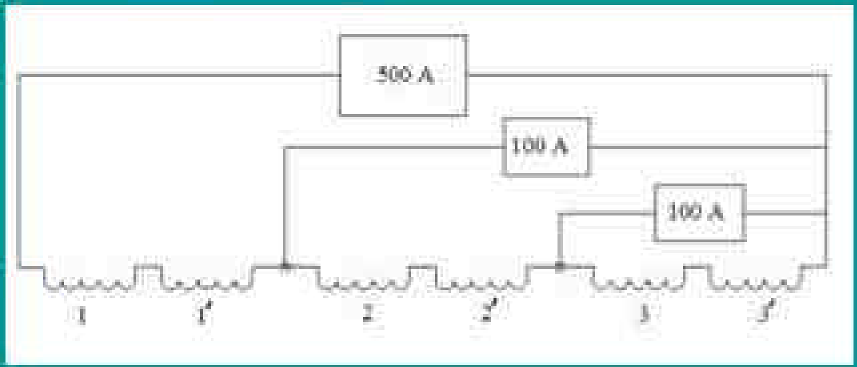


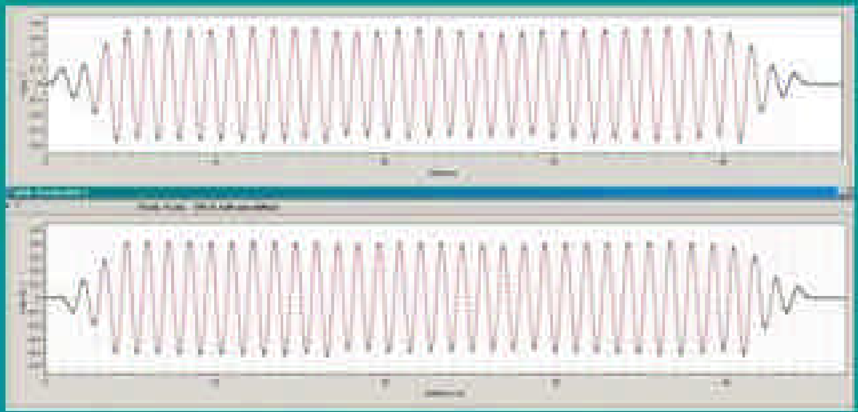
Details of design. 1–Iron yoke, 2–Copper collar, 3, 4–trimming Iron nuts. Inner diameter of Copper vacuum chamber is 8mm clear.

Period kept even

We developed simplified tapering allowing smooth end without diameter expansion

Sectioned coils for undulators





10 mm undulator operated with two PS 500+50 A; 4x6 wires (0.6mm in diam. bare)
Undulator 12 mm feed with one PS;
In a future there will be <3 PS for coils sectioned in radial direction

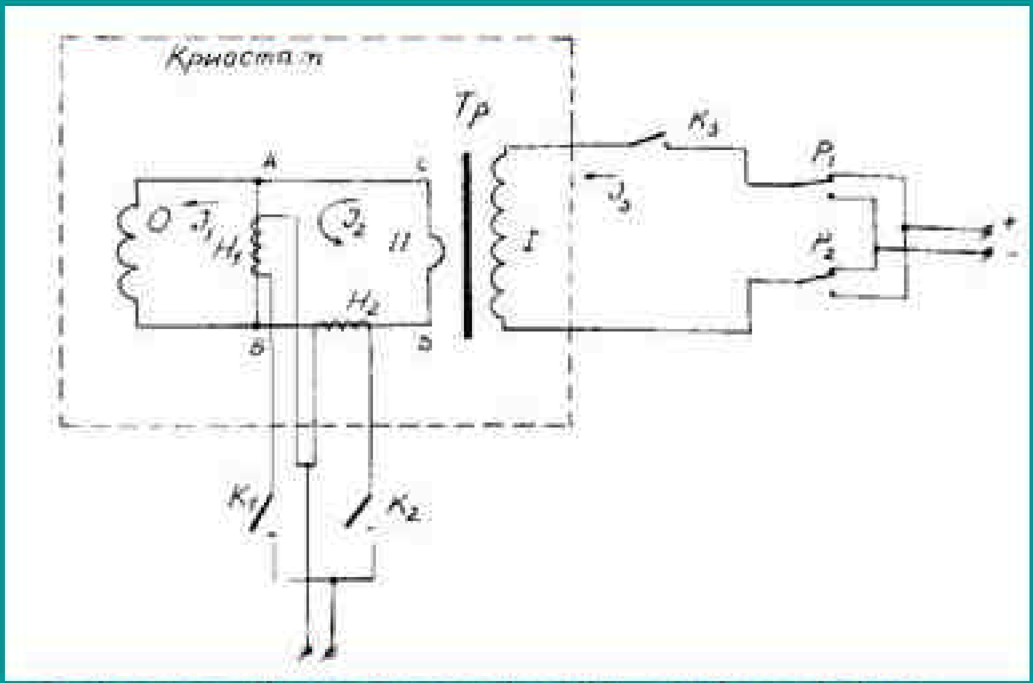
Identification of losses in joints

Tested SC transformer scheme to identify time decay (losses in joints)

For undulator with 36 turns decay time found to be ~400 sec (5joints)

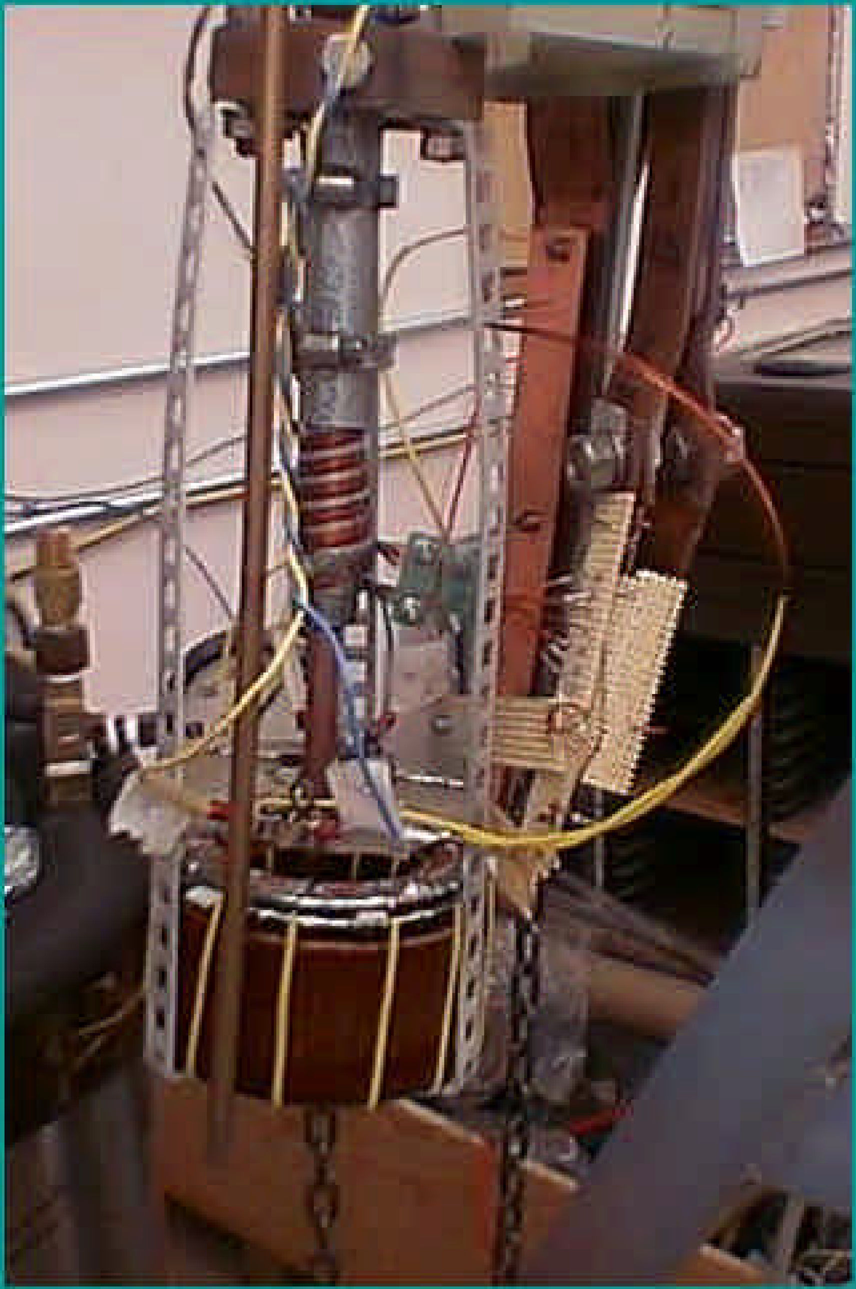
This defines the resistance to be <1E-15Ω

This scheme used in 1986 to feed SC undulator



Scheme allows to work with captured flux

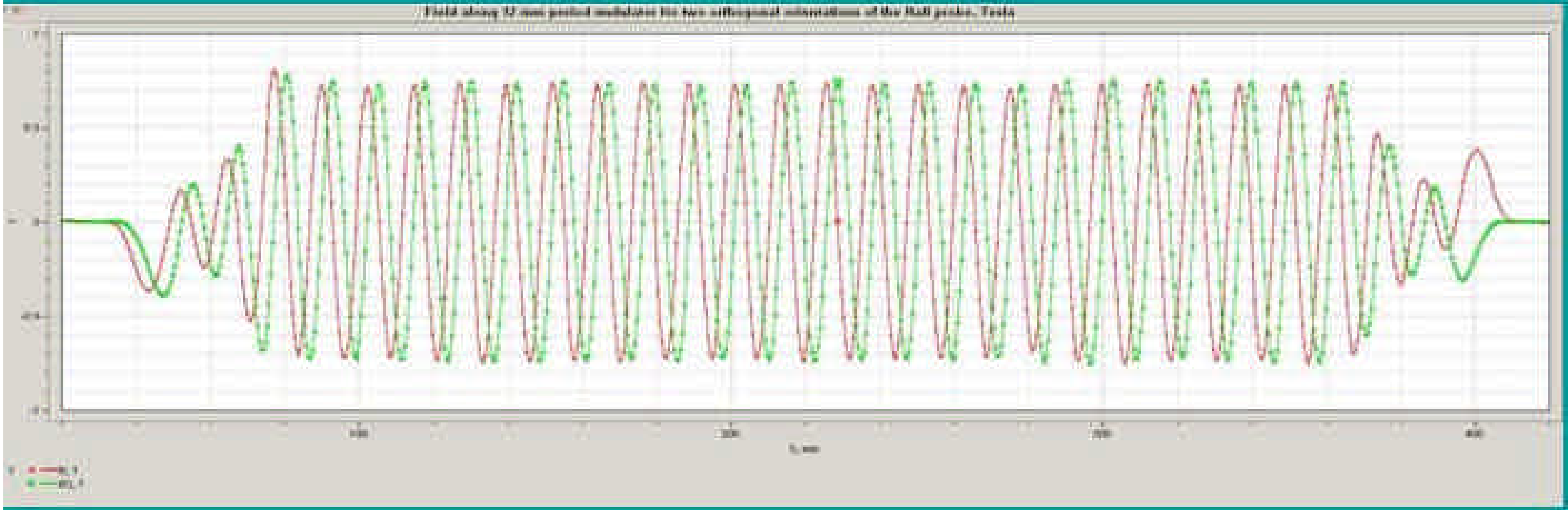
SC transformer with keys

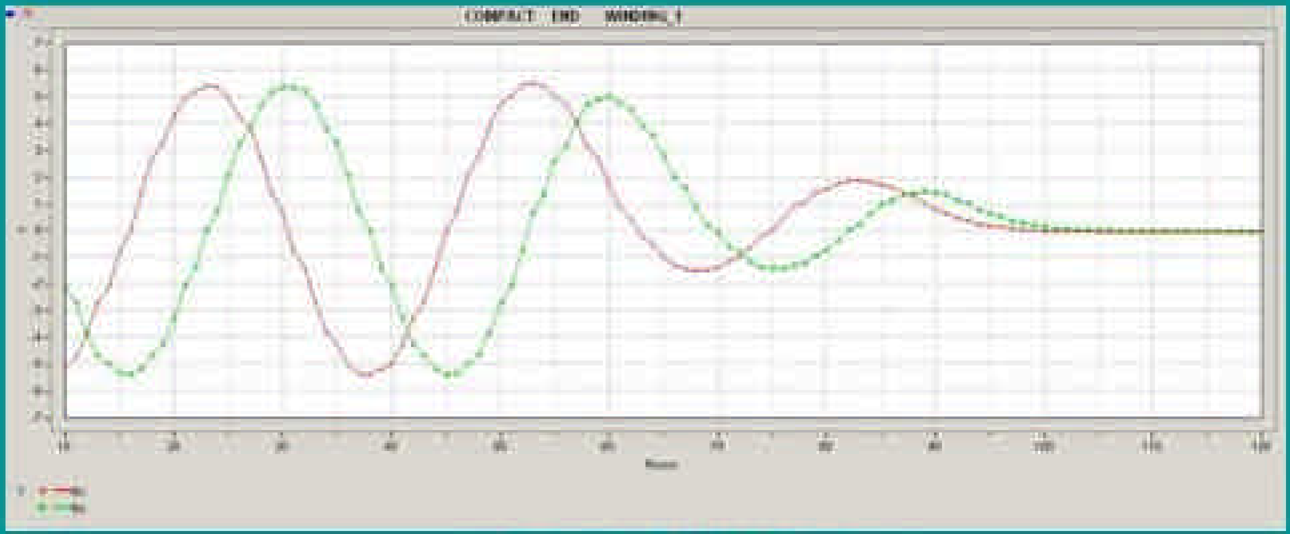


Distribution box for switches

SC transformer installation– at the left

Typical field distribution





Simplified tapering

Undulators tested so far

Aperture available for the beam is 8 mm in Ø clear

OFC vacuum chamber, RF smoothness

SC wire	54 filaments	56 filaments	56 filaments	56 filaments
# layers	5*	6*	11***	9** (12***) +sectioning
λ=10 mm @300 °K	K=0.36 tested	K=0.42 tested	K=0.467 tested	K≈0.5 (calculated)
λ=12 mm@300 °K	K=0.72 tested	K=0.83 tested		K≈1 (calculated)

*) Wire – Ø0.6 mm bare
**) Wire – Ø0.4 mm bare
***) Wire – Ø0.3 mm bare

For aperture diam. ¼" we expect for period 10mm K=0.7; for period 12mm K=1.2

Two sections of 45 cm long each will be measured in cryostat to the end of this year; The plan is to test it with the beam at Cornell ERL test module setup.

4m long prototype will be assembled in general to the end of 2007, Field distribution will be measured earlier in 2008

TARGET DESIGN

Ti rotating wheel target is under development at Livermore, SLAC, Daresbury.

We are looking for some other guarantied solutions

Ti needle target

Liquid metal target with Pb/Bi or Hg

Spinning compact W disk

Sandwich type target with W+Ti → New

} Together

FlePDE model calculates temperature and pressure according equations

$$\nabla(k\nabla T)+\dot{Q}=\rho c_V\dot{T} \qquad \ddot{P}-\nabla(c_0^2\nabla P)=\frac{\Gamma}{V_0}\dot{Q}$$

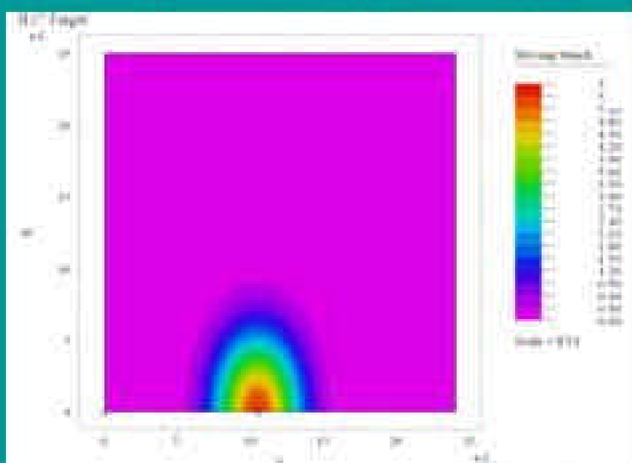
Implemented pressure block

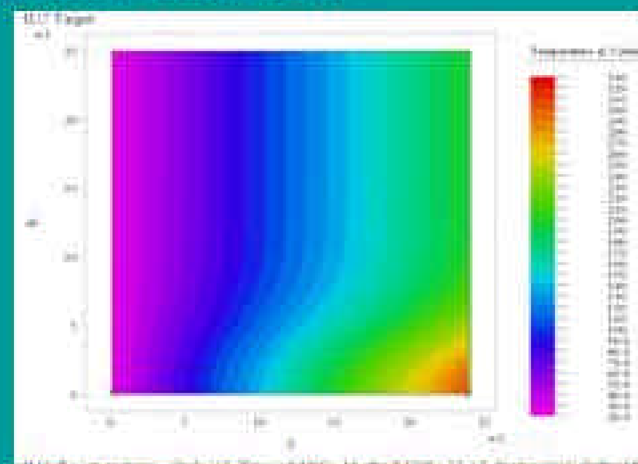
$$\dot{Q}=\sum_i \frac{2cQ_{bunch}}{\pi\sqrt{\pi}\sigma_z\sigma_{1\gamma}^2 l_T}\frac{z}{l_T}\exp\left(-\frac{(z+z_0-c(t-i\cdot t_0))^2}{\sigma_z^2}\right)\cdot\exp\left(-\frac{r^2}{\sigma_{1\gamma}^2}\right)$$

The thermal pressure p_T can be expressed

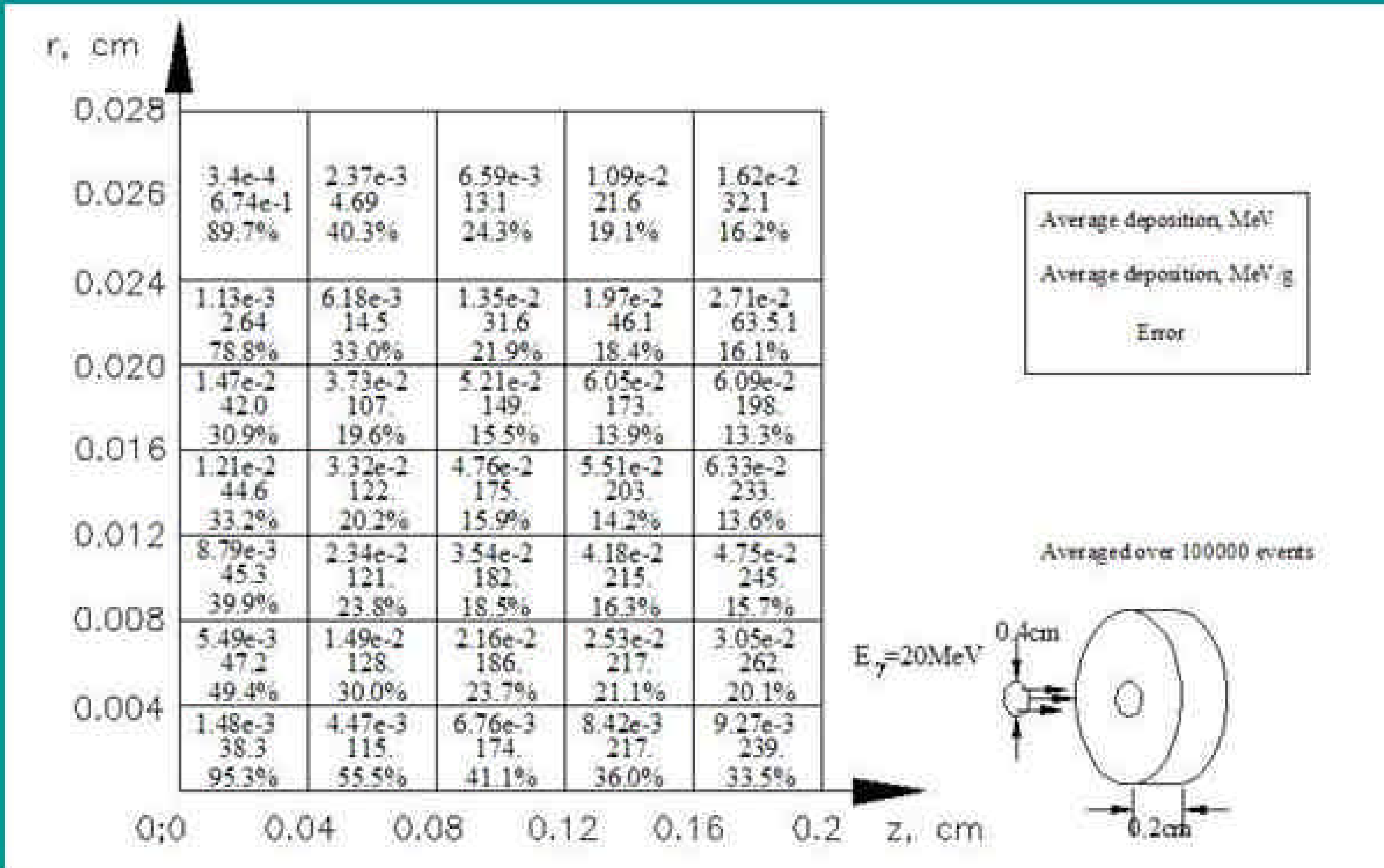
$$p_T=\Gamma(V)\frac{c_V T}{V}=\Gamma(V)\frac{\varepsilon_T}{V}$$

where $\Gamma(V)=V/c_V(\partial P/\partial T_V)$ characterizing the ratio of the thermal pressure to the specific thermal energy ε_T/V called Grüneisen coefficient.





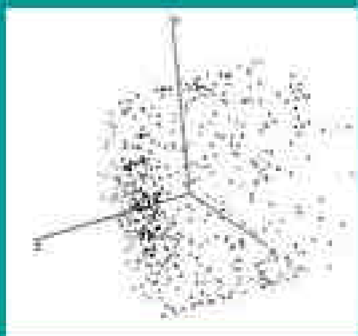
Instant position of the bunch moving in the target, at the left. Isotherms right after the bunch passage, at the right.

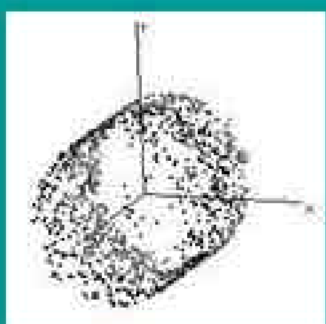


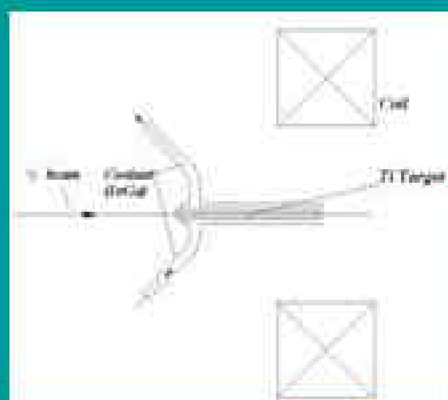
A.D.Bukin, A.A.Mikhailichenko," Optimized Target Strategy for Polarized Electrons and Positrons Production for Linear Collider".
(IYF) BUDKER INP 92-76, Novosibirsk, 1992.

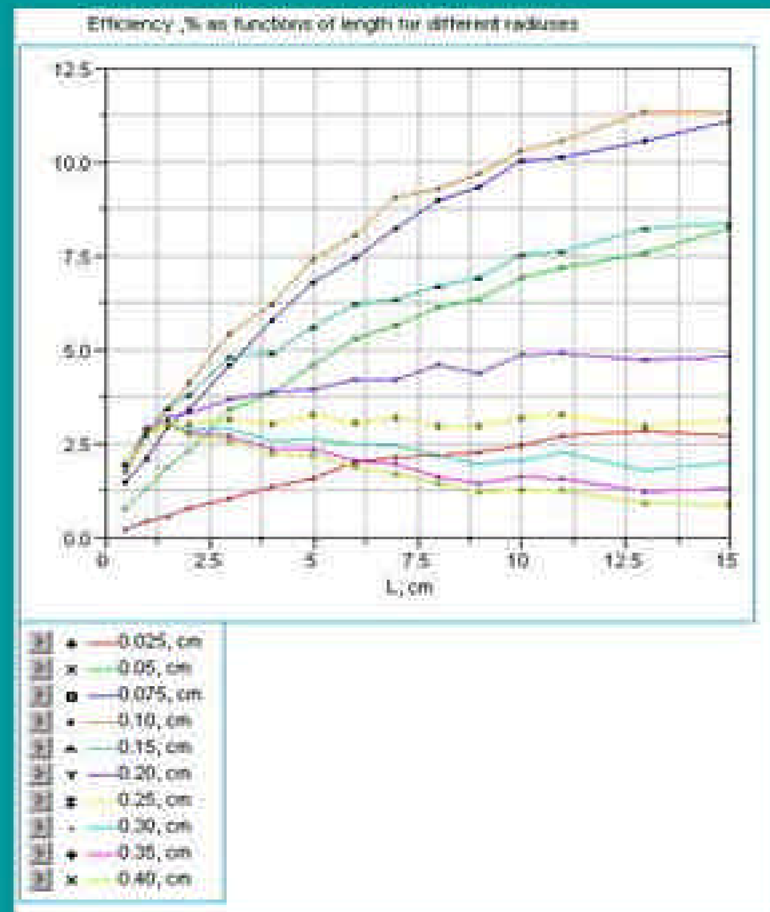
Needle type target made from Ti

We are using numerically available codes to evaluate efficiency. Cylindrical target example

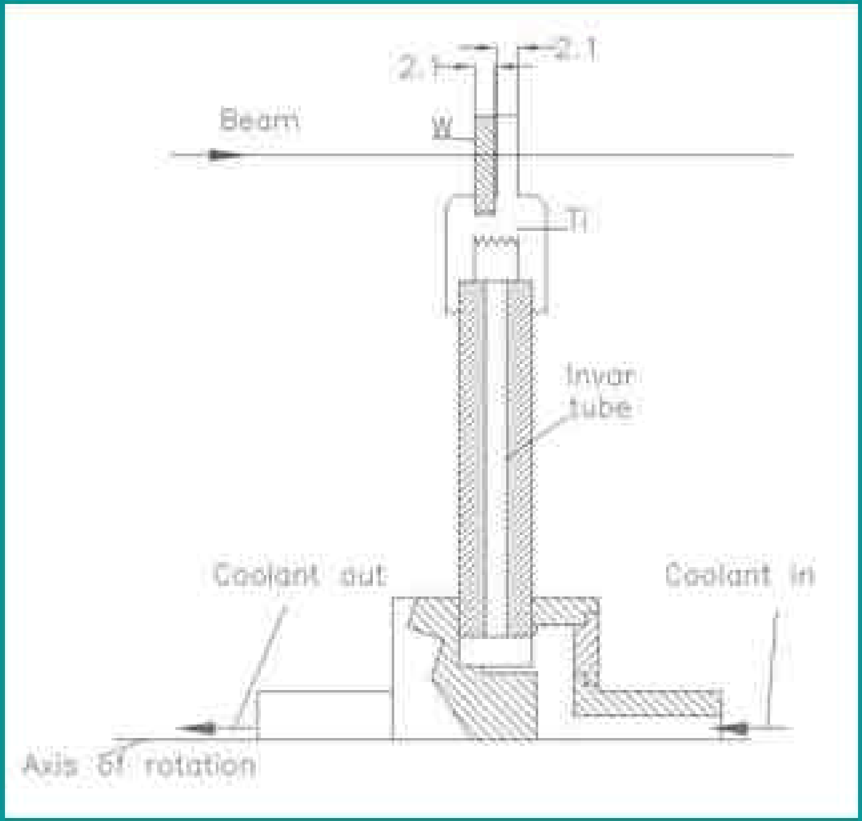


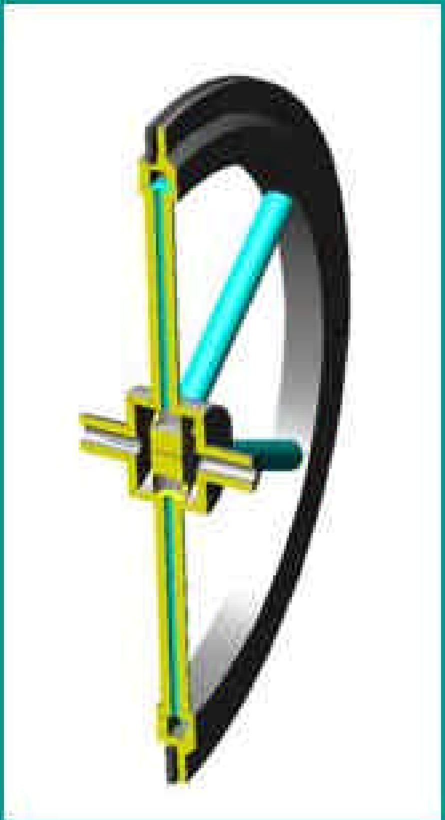






Sandwich type target concept (earlier design)
First layer (at the entrance is W, the last fraction might be Ti



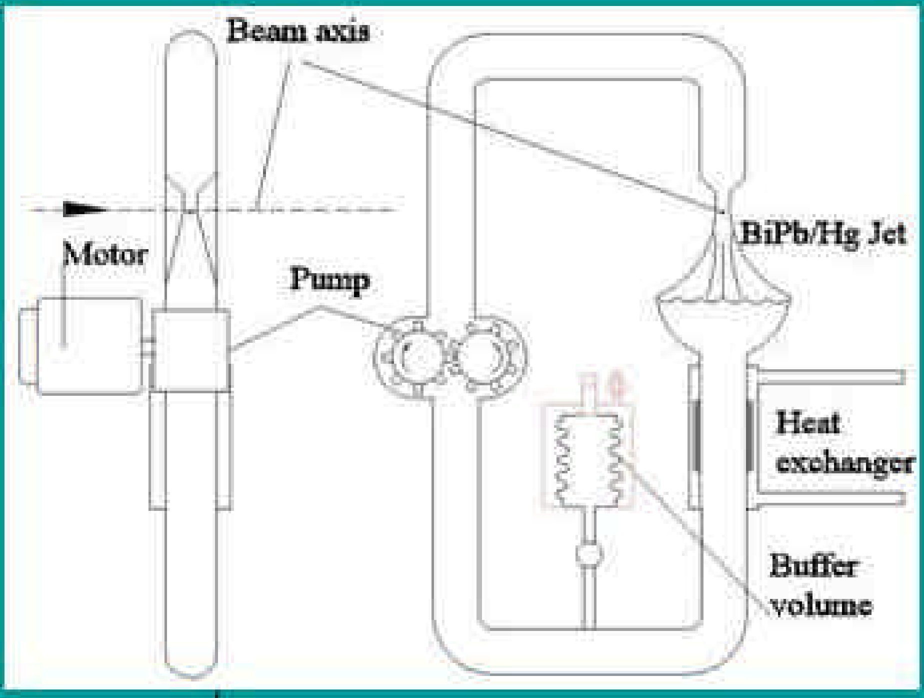


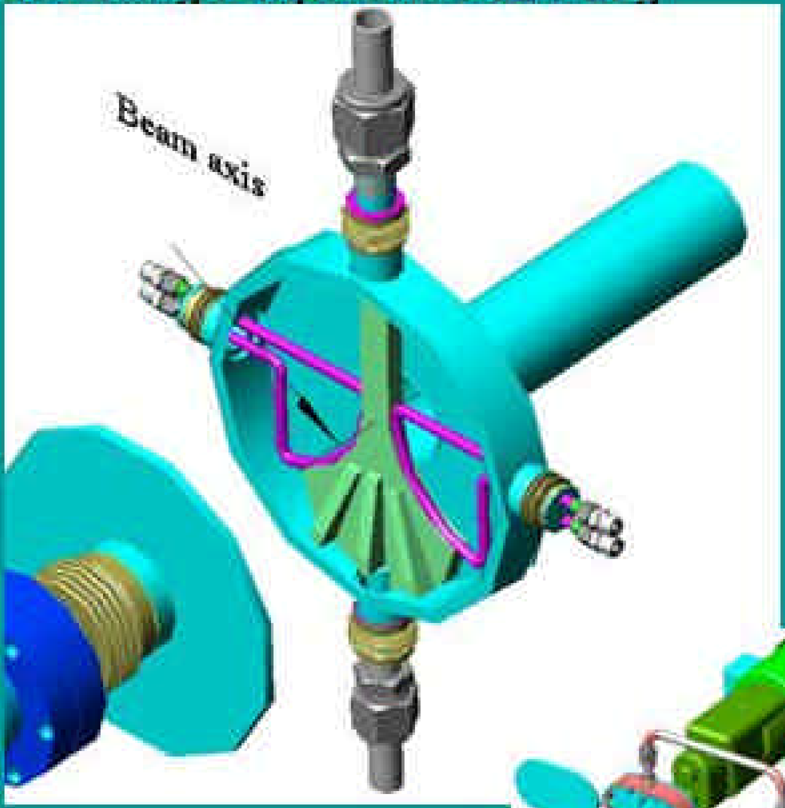
By this one can expect more compact design

Liquid metal target

High Z metals could be used here such as Bi-Pb, Mercury. InGa alloy also can be used here if filled with W powder.

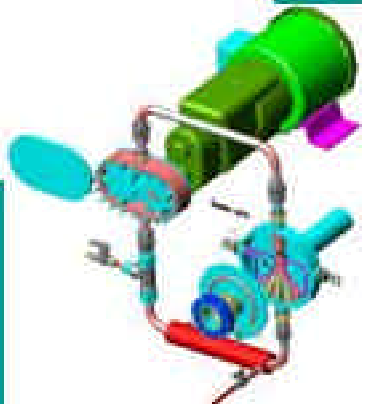
BiPb has melting temperature 154 deg C. Hg has boiling temperature 354 deg



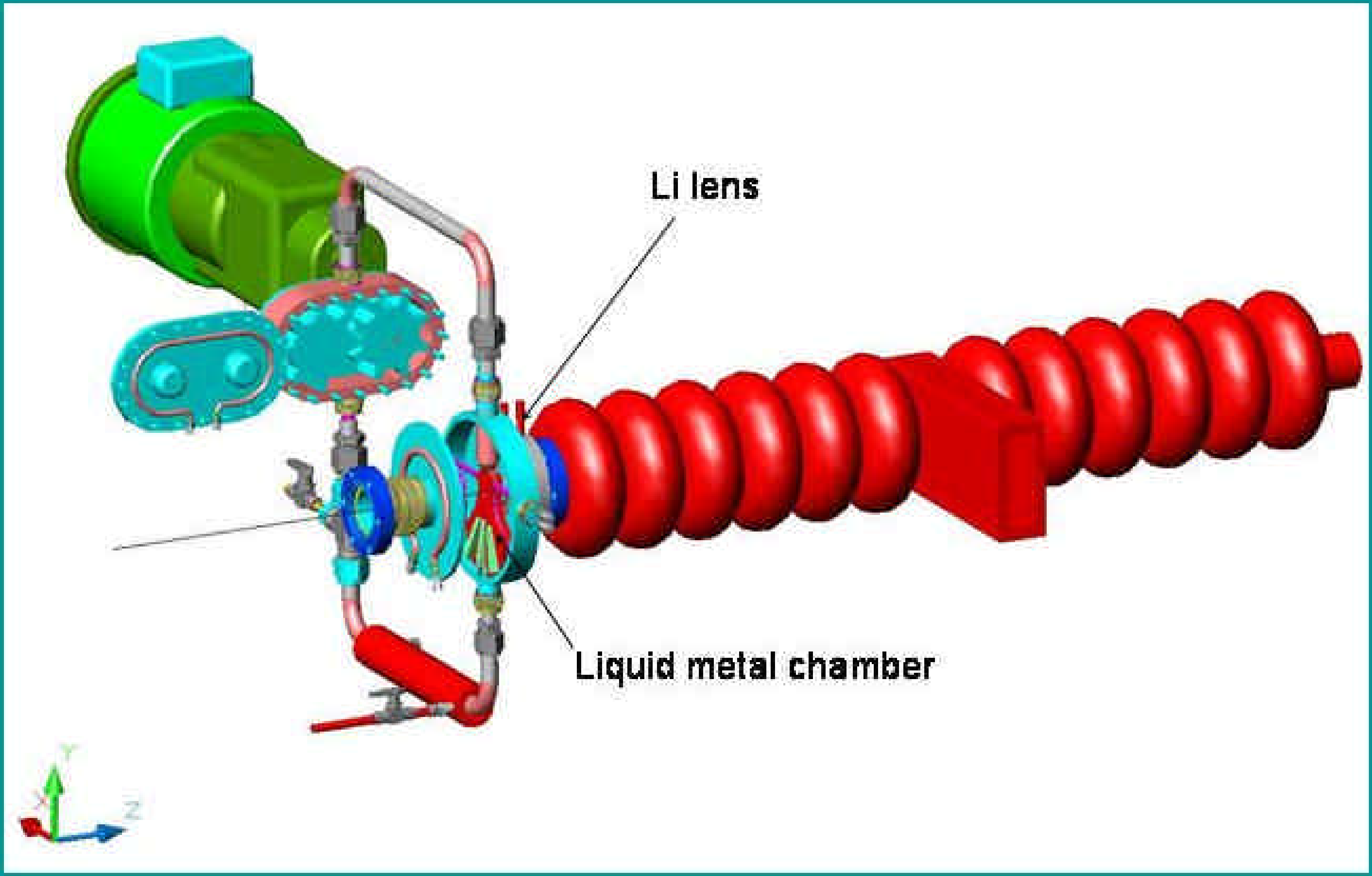


Gear pump. Hg Jet velocity~10m/s

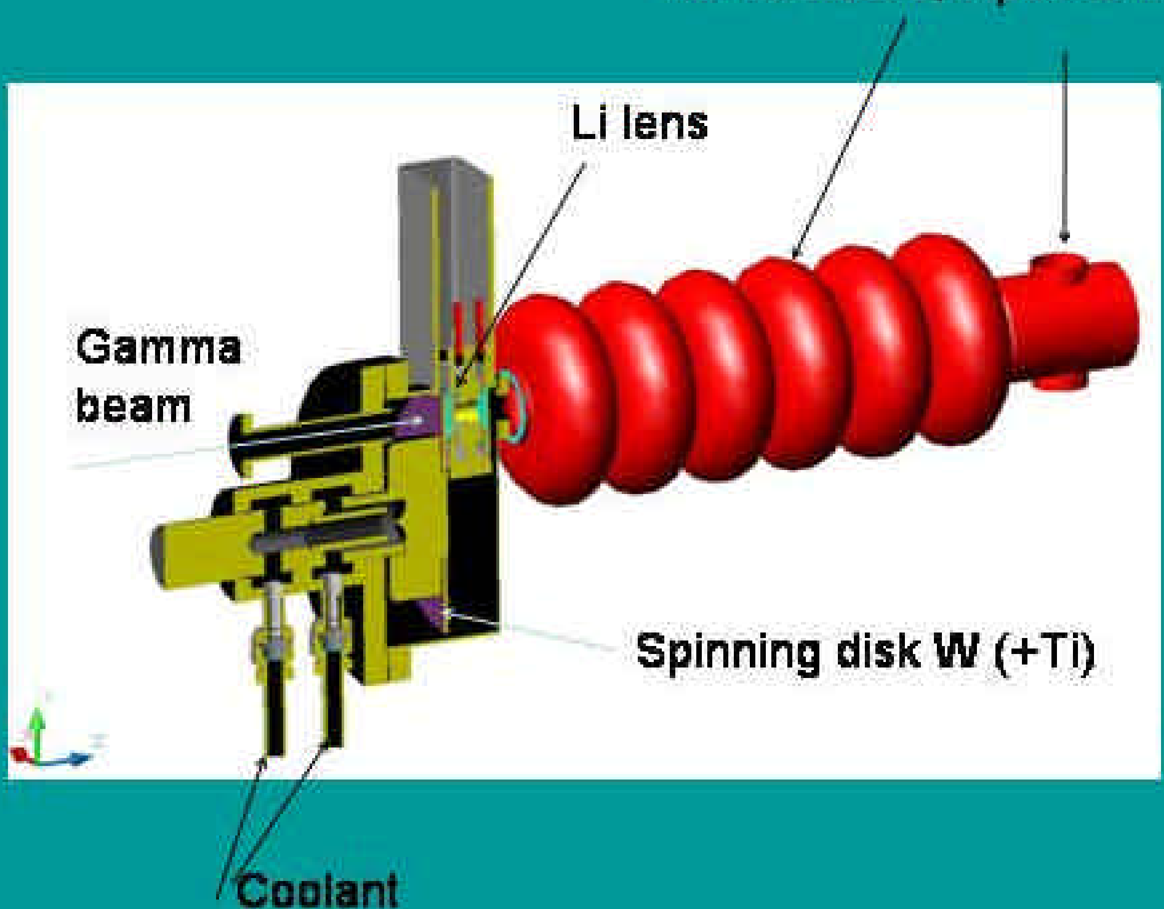
Calculations show absolute feasibility of this approach

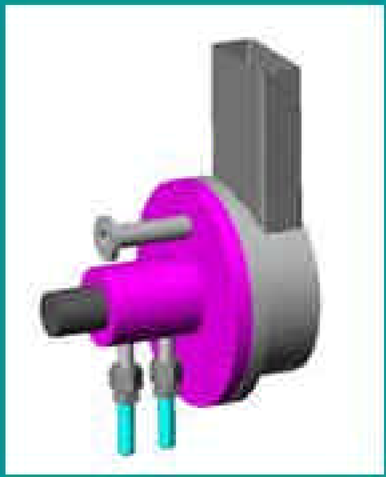


Conversion unit with liquid metal target and Lithium lens (described below)



Conversion unit on a basis of spinning W(+Ti) and Lithium lens

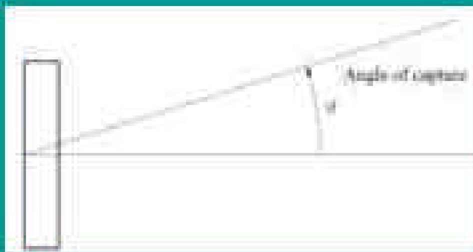




Size ~30cm in diameter

COLLECTION OPTICS DESIGN

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



Angle shown~0.3 rad

Target – Tungsten (W)

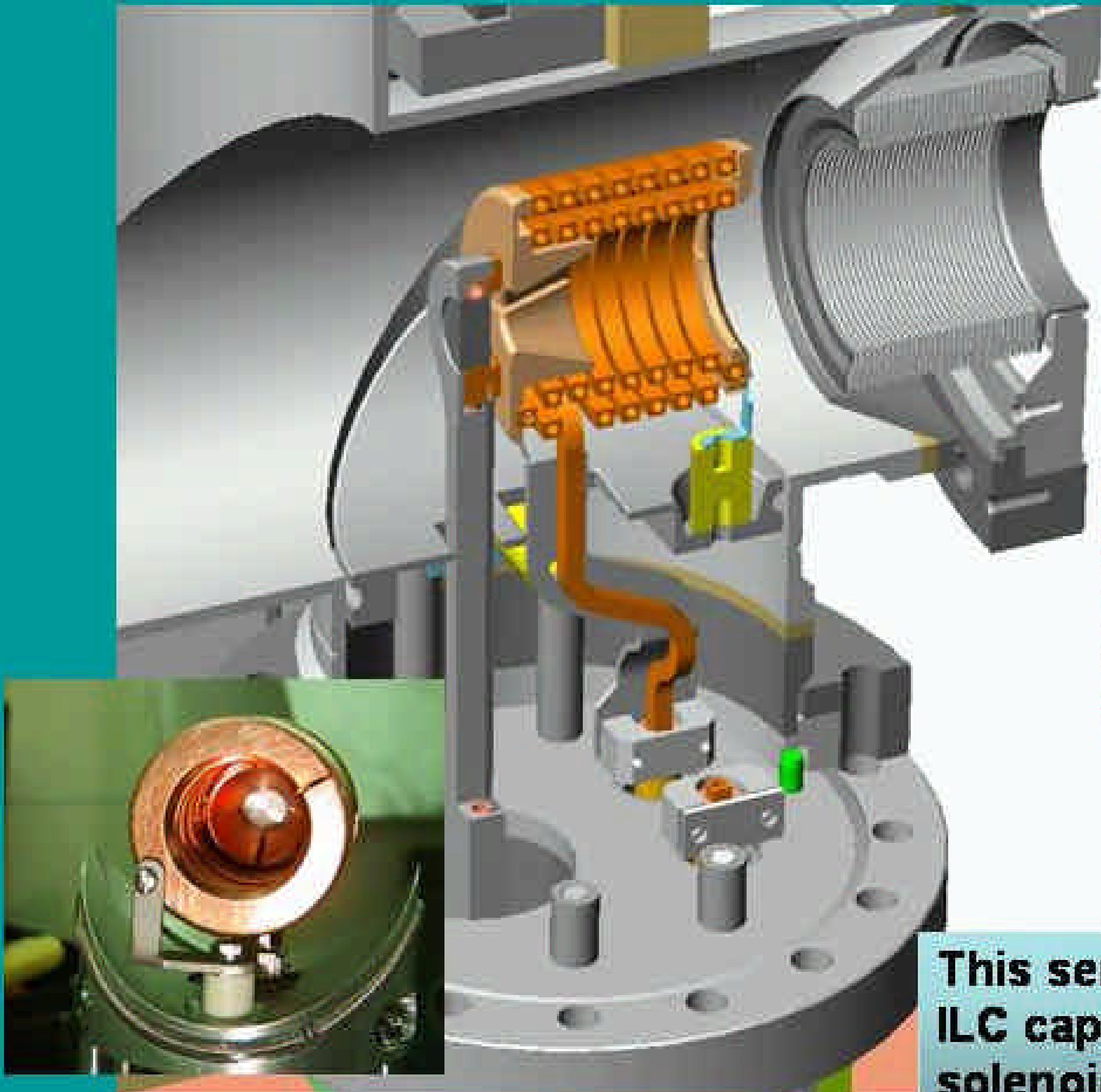
Thickness – 1.5 mm

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



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)

This serves as a prototype for ILC capturing system with solenoid (see below)

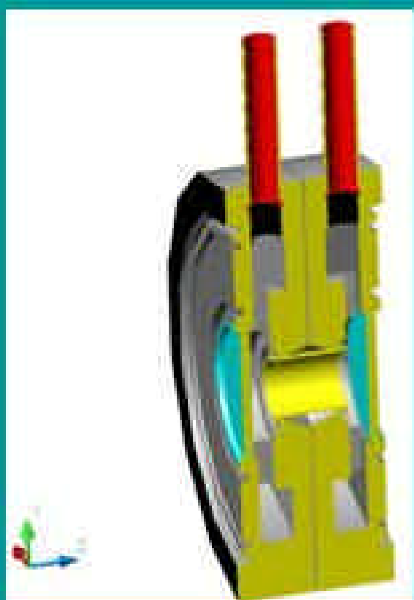
Lithium lens basics

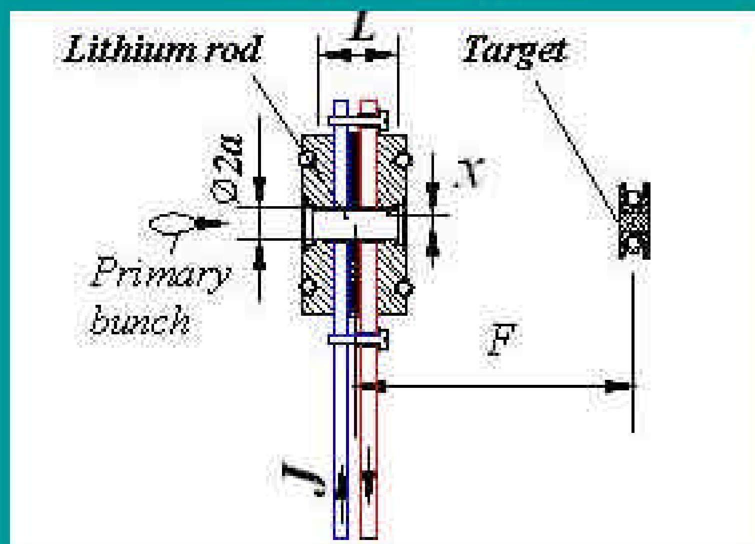
If steady current I runs through the round conductor having radius a, its azimuthal magnetic field inside the rod could be described as

$$H_{\phi}(r)=\frac{0.4\pi Ir}{2\pi a^2}$$

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

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





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

So the focal distance could be defined as the following $F \cong \dfrac{a^2\cdot(HR)}{0.2IL}$

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 $\sqrt{<\theta^2>} \cong \frac{13.6\,MeV}{pc}\sqrt{\frac{t_{X_0}}{X_{Li}}}$

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

t_{X_0} –is the thickness of the rod in *g/cm²*. $\sqrt{<\theta^2>} \cong \frac{13.6}{20}\sqrt{\frac{2}{156}} \cong 0.077$ rad

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

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

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

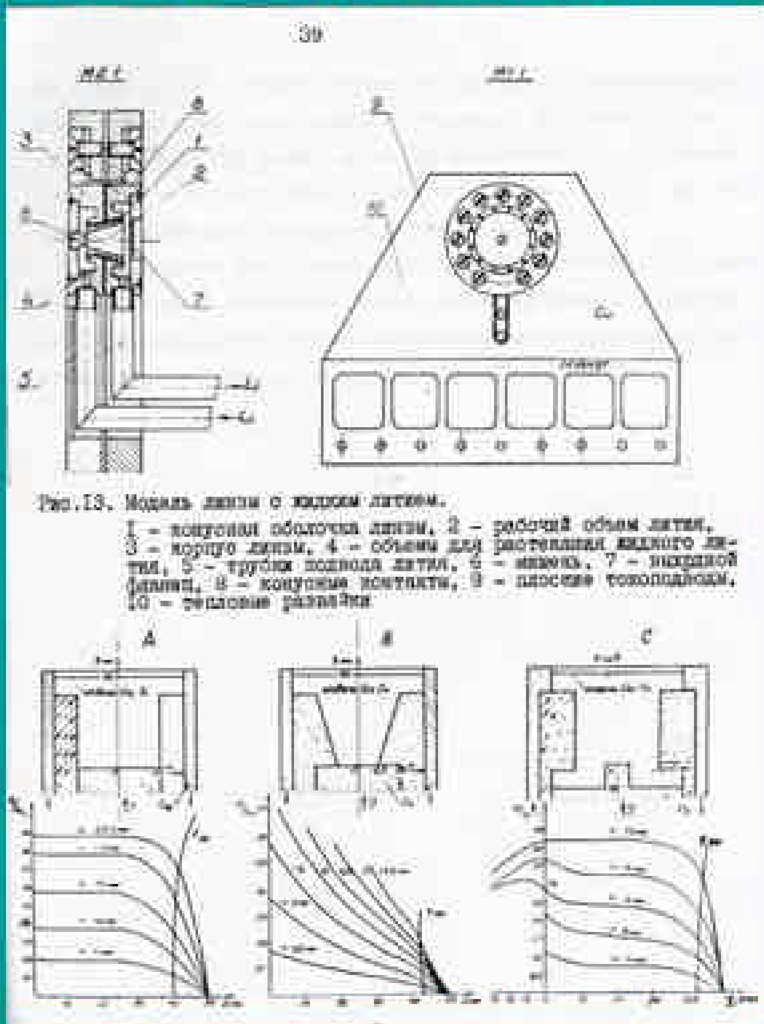
$$<P> = J^2 \cdot R \cdot f\tau$$

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*

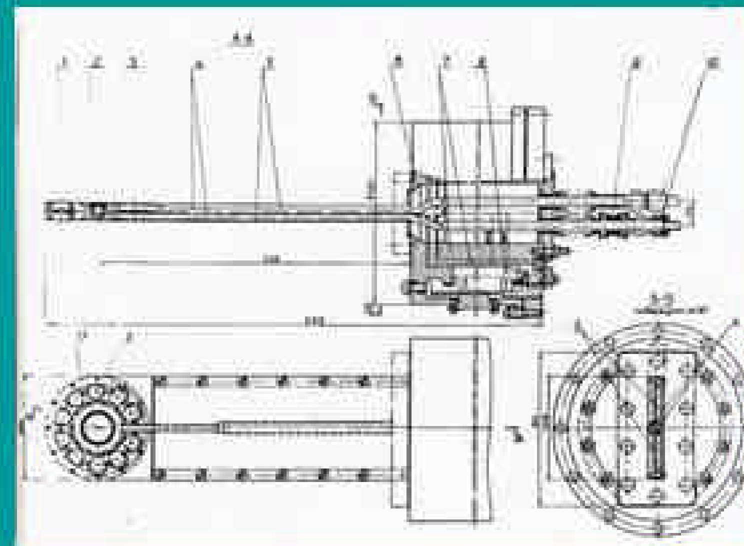
This is much, much easier, than for focusing of (anti) protons.

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



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

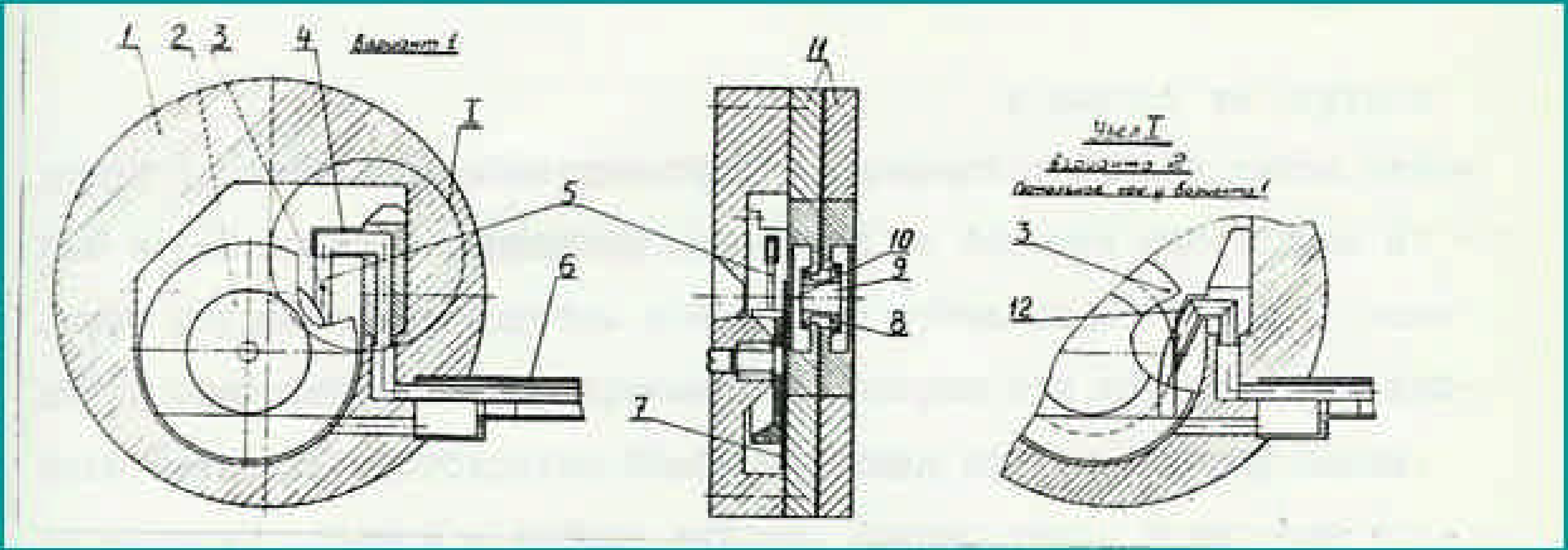


1-ex-centric contact pushers 2-conic lens body, 3-W target, 4-Ti tubing for Li supply, 5-flat current leads; 6-vacuum chamber; 7-coaxial fraction of current leads; 8-bellows; 9-ceramic insulators; 10-conical gasket, 11-set of ex-centric pushers

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 δE~2 $MeVcm^2/g$. Secondary beam diameter $d \approx 1cm$.
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

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

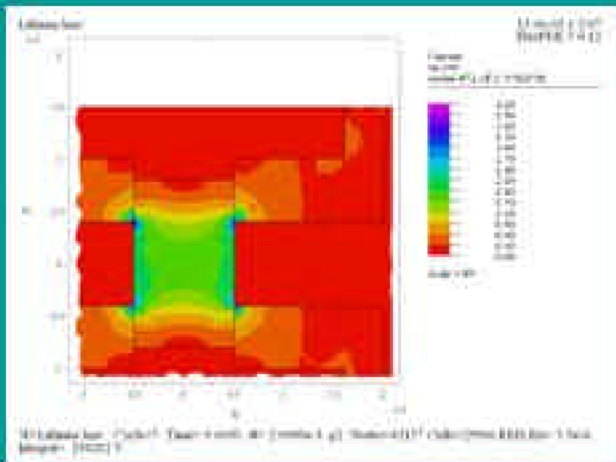
Although e- defocused

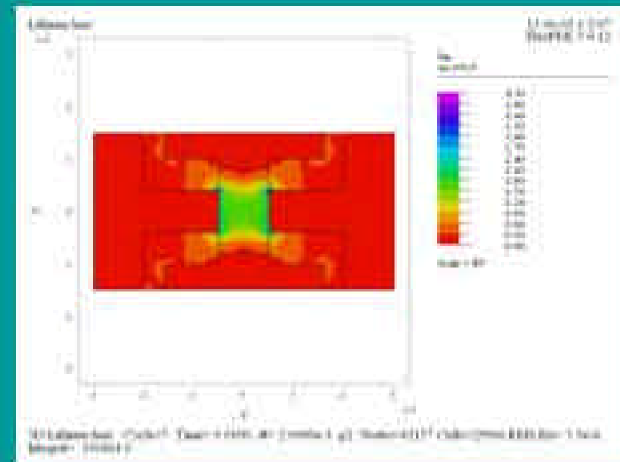
Factor reflecting spare particles, ~1.5-2 , factor two- reflecting equal amount of electrons and positrons and, finally, factor reflecting efficiency of capturing (~30%).
So the final number comes to→ ≈21*J*.
Temperature gain by heat capacity of Be $C_V \approx 1.82\ J/g/degC$ comes to

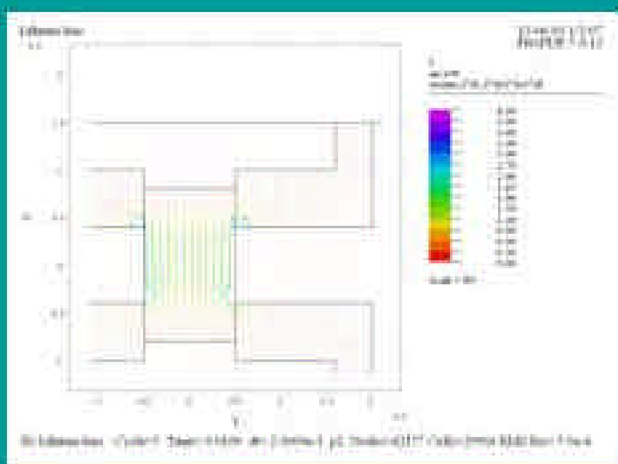
$$\Delta T \cong \frac{E_{tot}}{mC_v} \cong \frac{E_{tot}}{\rho S t C_v} \cong \frac{21}{1.8 \times 1.82 \times 0.05 \times 0.2} \cong \quad 660 \text{ deg.}$$

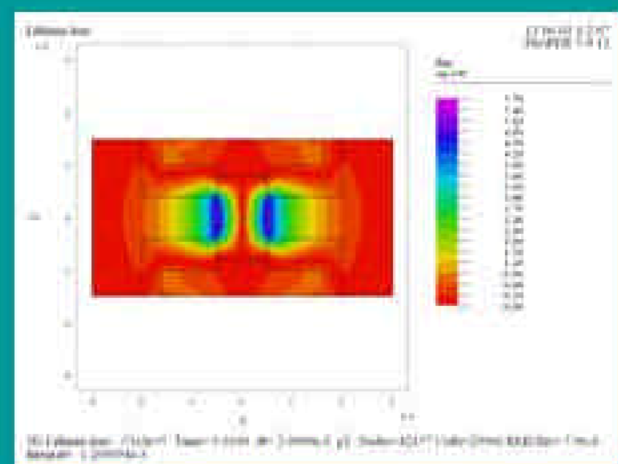
One needs to add the initial temperature which is above melting point of Lithium, coming to maximal temperature ~850-900 deg. Meanwhile the melting temperature of Be is 1278 deg, so it withstands.

Recent calculation of Lithium lens done with FlexPDE© code

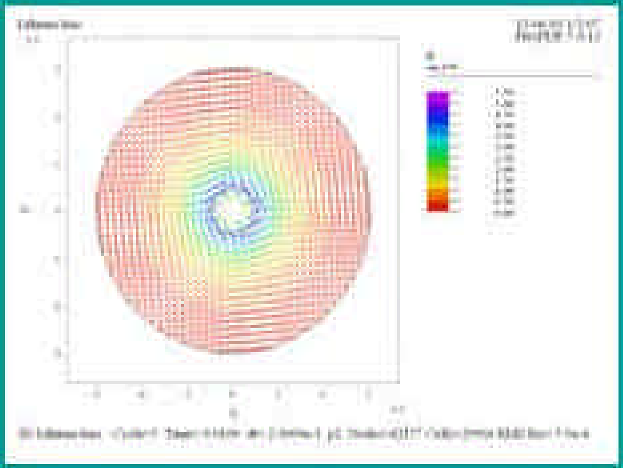


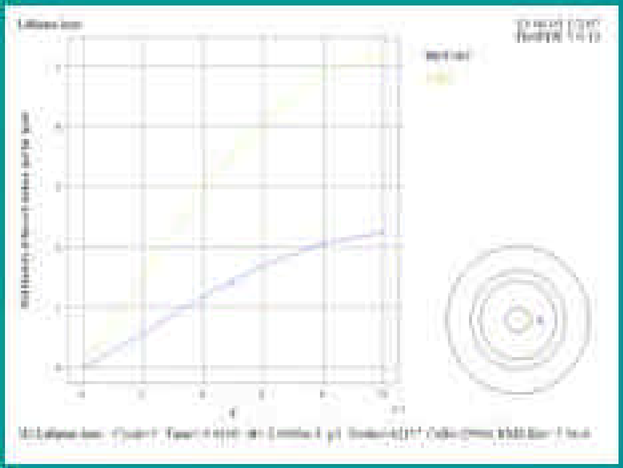


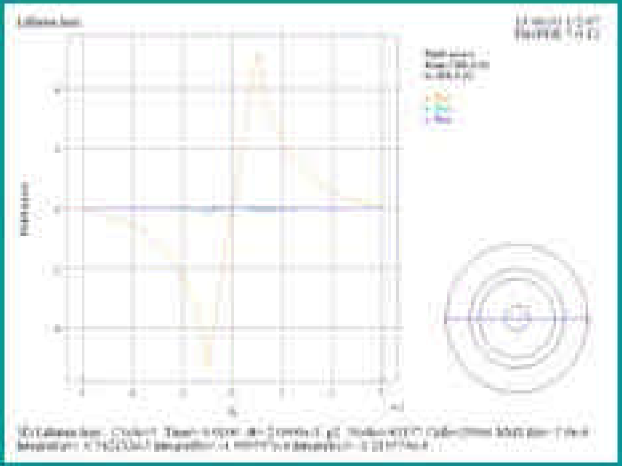


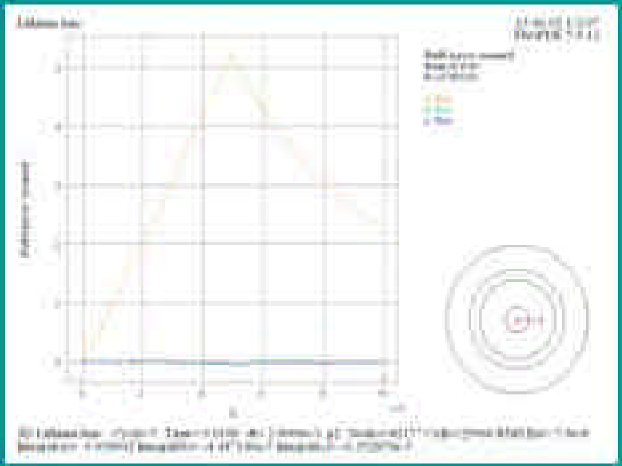


Spatial field distribution over time (cinema)







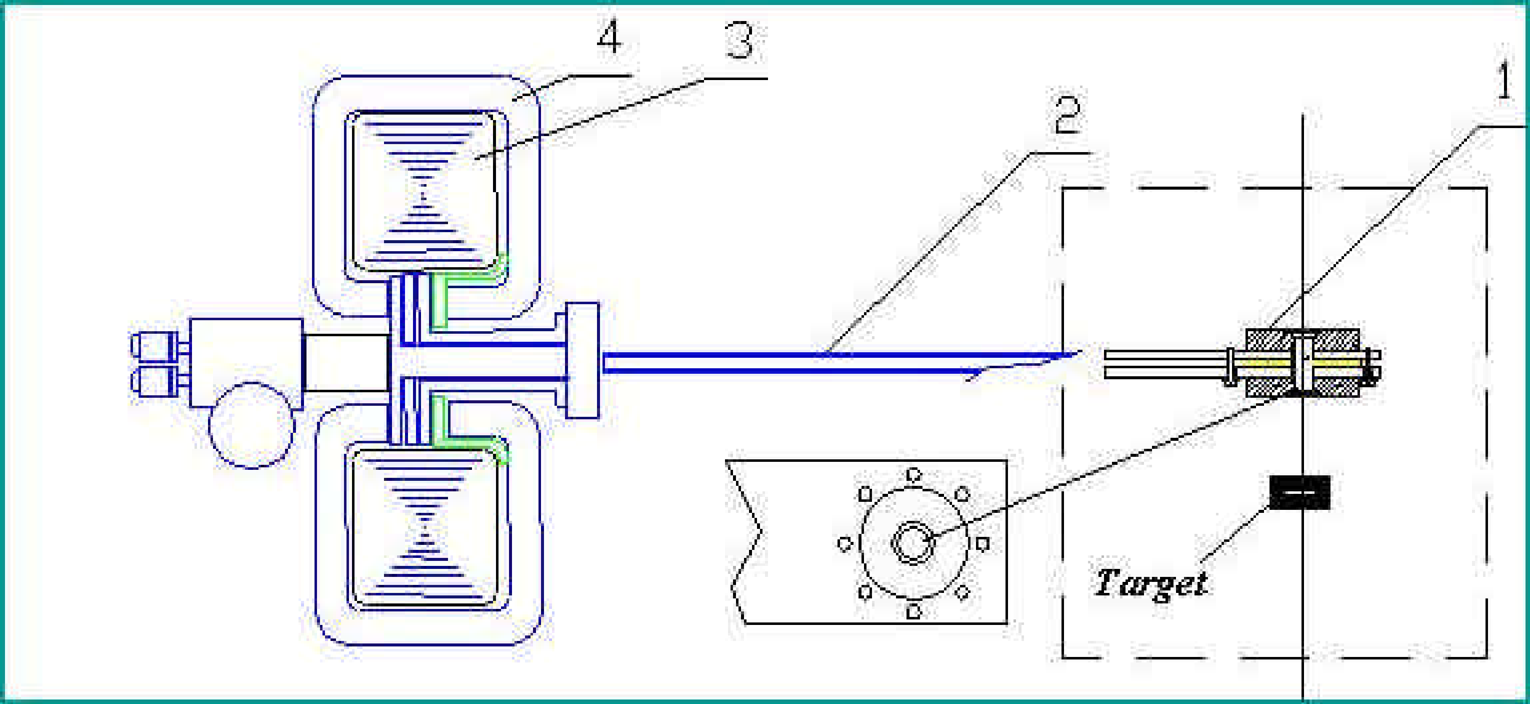


Power dissipated per pulse goes to 0.6 kJ for the current ~135 kA and time duration half sin wave with period 40 msec

Energy stored -21.6 J so reactive component is low.

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

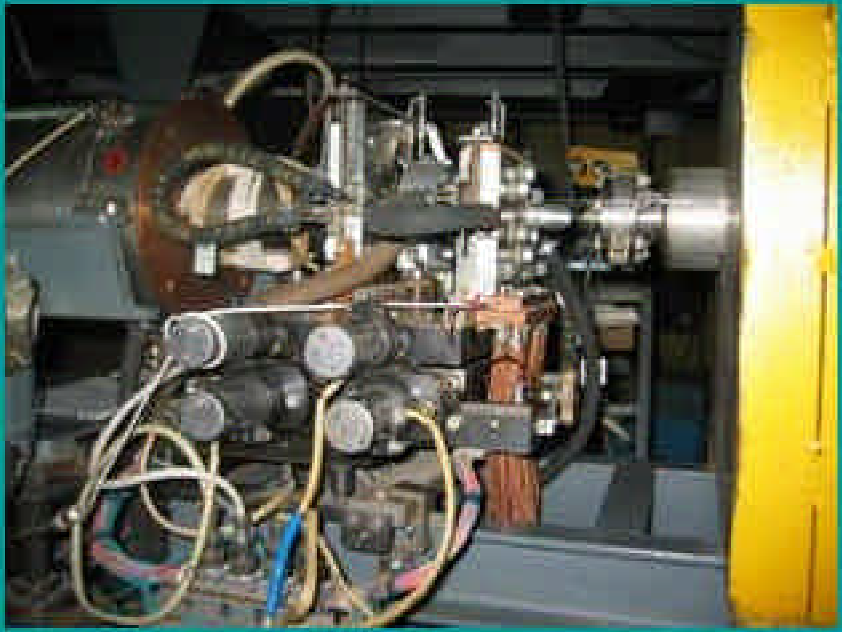
Feeding with 5^{th} harmonic allows making current flat.



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.

Doublet of Lithium lenses in Novosibirsk BINP

Photo- courtesy of Yu Shatunov



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

Number of particles in pulse ~2E+11; ~0.7Hz operation (defined by the beam cooling in Damping Ring)

Lenses shown served ~30 Years without serious problem (!)

Li lens resume

Utilization of Lithium lens allows Tungsten survival under condition required by ILC with $N_e \sim 2x10^{10}$ 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.

Solenoidal lens instead of Li lens

One can equalize the focal length of the Lithium lens and the solenoidal one

$$\frac{1}{f} \cong \frac{GL}{(HR)} = \frac{\int H_{\parallel}^{2}(s)ds}{4(HR)^{2}} \qquad \int H_{\parallel}^{2} ds \cong H_{\parallel \max}^{2} \cdot L \cdot \eta = 4(HR)GL$$

where (HR) =$pc/300$ stands for magnetic rigidity.

Typically longitudinal continuity $L\eta \approx 1.5 \div 2D$, where D stands for diameter of solenoidal lens. The Lithium lens has the length L=0.5*cm* . Diameter of solenoidal lens is something about 5 *cm*, then for *HR*) =100 kGcm (for 30 MeV particles), one can obtain

$$H_{\parallel \max}^{2}(s) = \frac{4 \cdot 150 \cdot 100}{15} = 4000 \quad kG^{2}$$

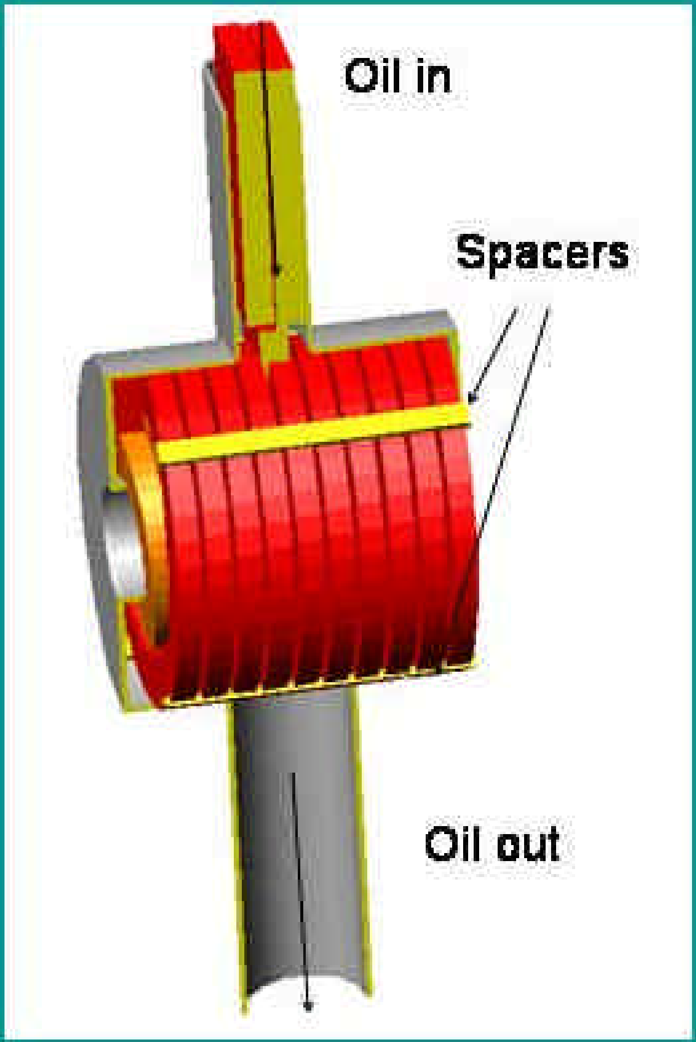
So the maximal field comes to $H_{\parallel \max} \cong$ 63kG (for 30MeV particles)

For generation of such field the amount of Ampere-turns required goes to be

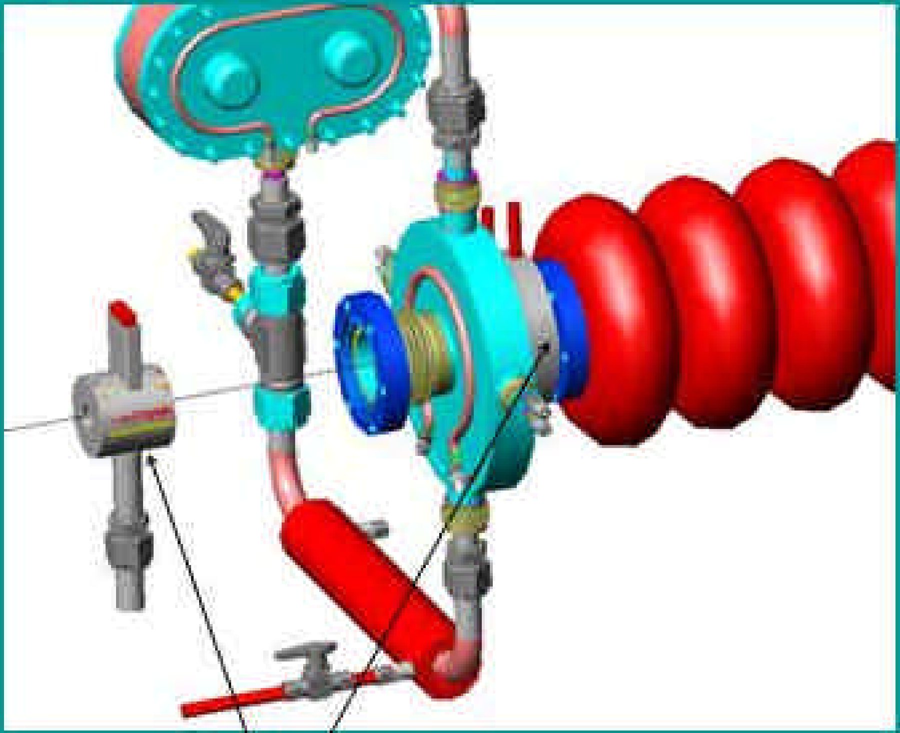
$$nJ \cong \frac{H_{\parallel \max}\Lambda}{0.4\pi \cdot n} \longrightarrow$$ 262 kAxturns (again, for 30 MeV particles)

No flux concentrator possible for 1 msec; skin~3-4mm

Solenoidal lens could be designed with dimensions ~ a bit larger than the Lithium lens



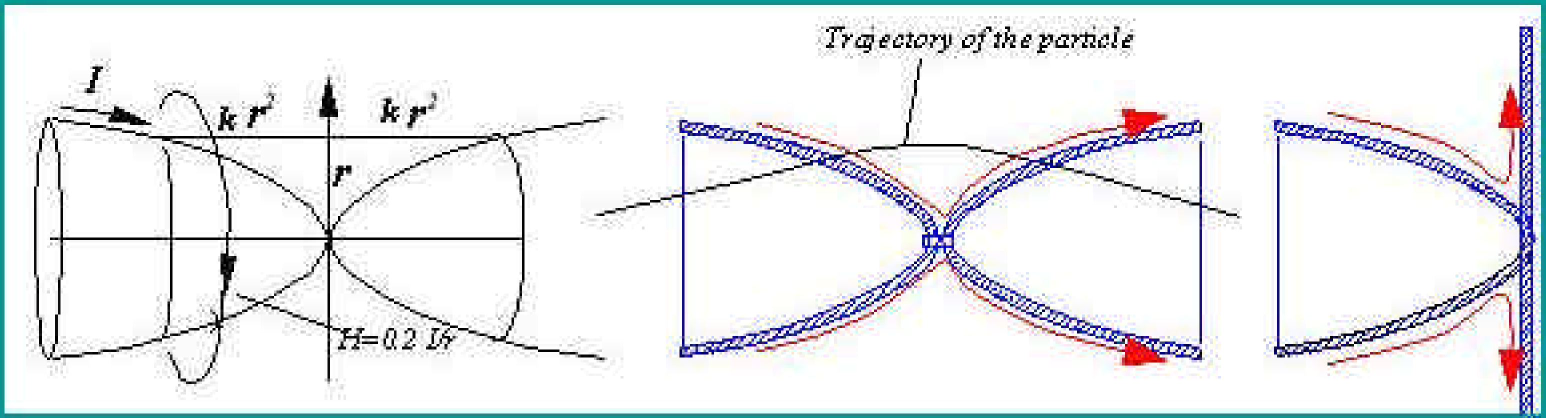
For the number of turns =20, current in one turn goes to I_1~15 kA during~10msec duty time; Two harmonics for feeding current.
Conductor cross-section~ 5x10mm^2;
Coolant-oil



Lenses in comparison; for Li lens current leads are not shown

Other focusing possibilities to be mentioned

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 from Aluminum ($X_{Al} = 24.3 g/cm^2 [\cong 9cm]$) or Beryllium ($X_{Be} \cong 66 g/cm^2 [\cong 35.8cm]$).

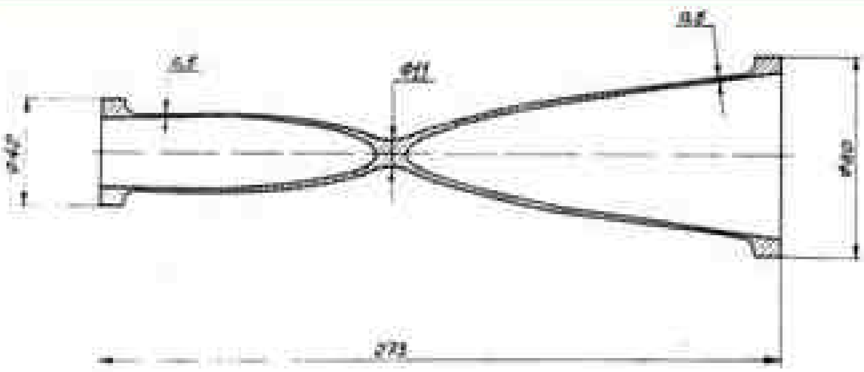


Fig. 2a Special profile of the "linear" lens.

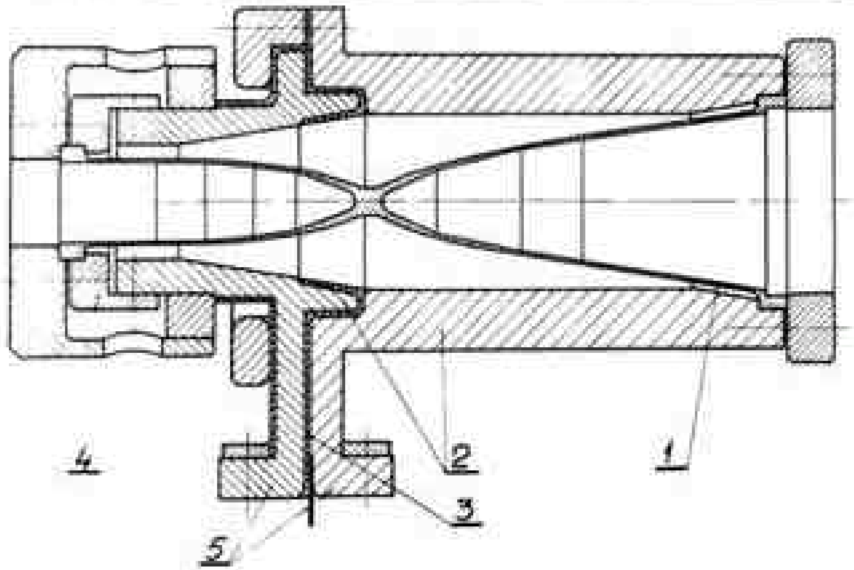


Fig. 2b Sectional view of the "linear" lens

1 - lens body
2 - coaxial conductor
3 - insulation
4 - damping device for demountable contact
5 - flat conductor for connection to the transformer.

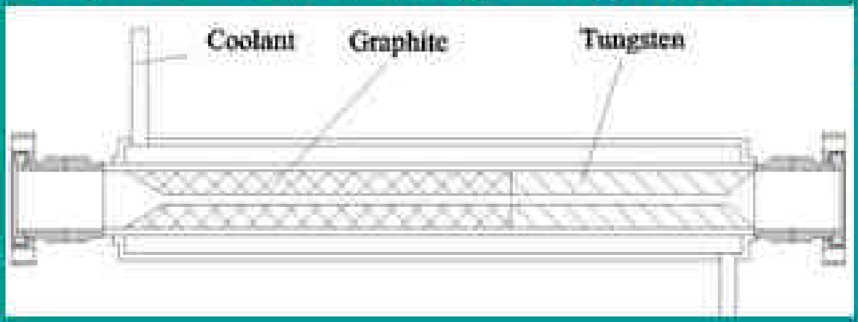
COLLIMATORS

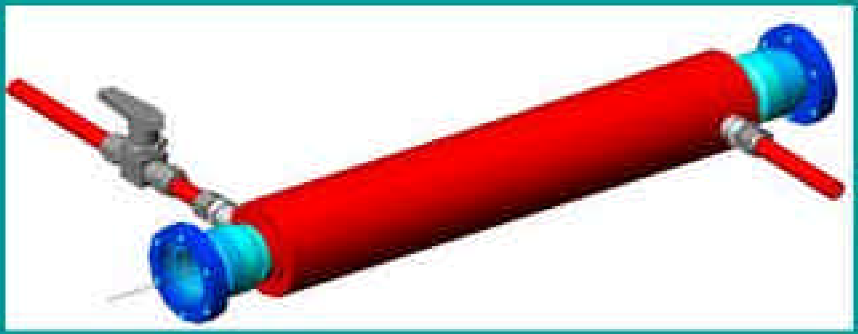
√ **Collimator for gammas**
√ **Collimators for full power primary beam**

- See A.Mikhailichenko, "*Collimators for ILC*", PAC 2006, European Particle Accelerator Conference (EPAC 06), Edinburgh, Scotland, 26-30 Jun 2006. Proceedings, pp.807-809

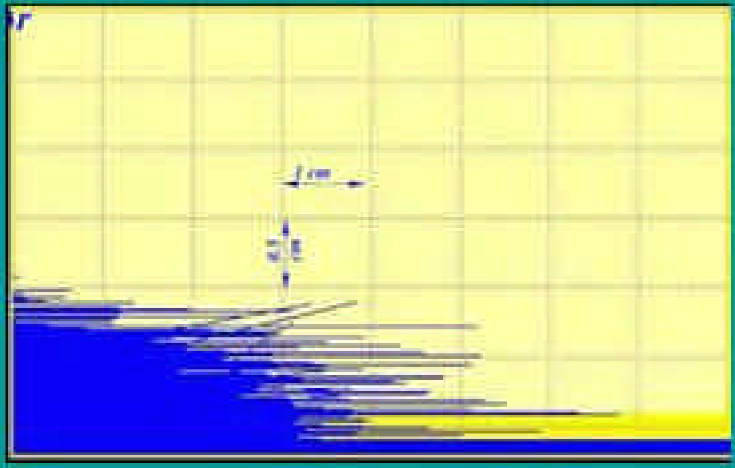
Collimator for gammas

Pyrolytic Graphite (PG) is used here. The purpose of it is to increase the beam diameter, before entering to the W part. Vacuum outgassing is negligible for this material. Heat conductivity ~300 W/m-oK is comparable with meals. ***Beryllium*** is also possible here, depending on task.

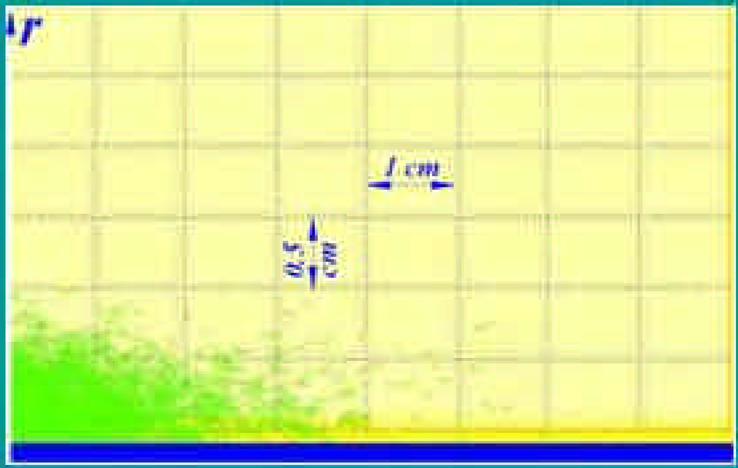




Transverse dimensions defined by Moliere radius



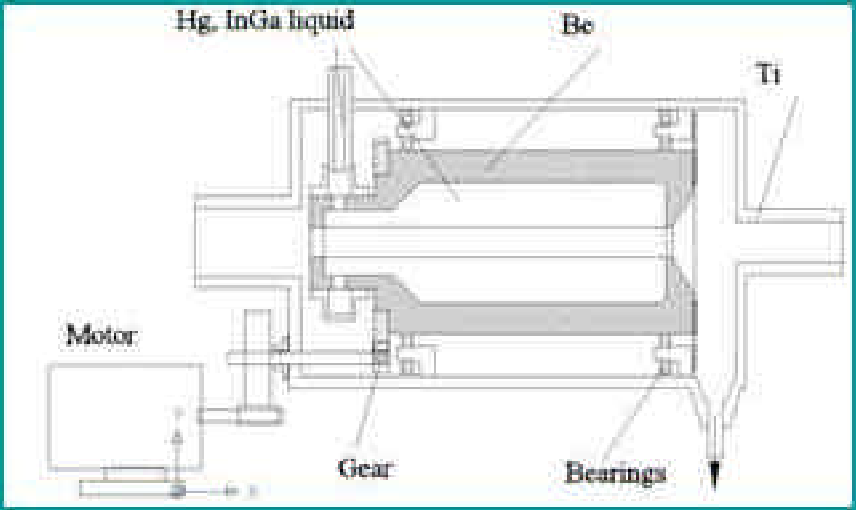
Gamma-beam σ_γ= 0.5cm, diameter of the hole (blue strip at the bottom) *d*=2 mm. Energy of gamma-beam coming from the left is 20 *MeV*.

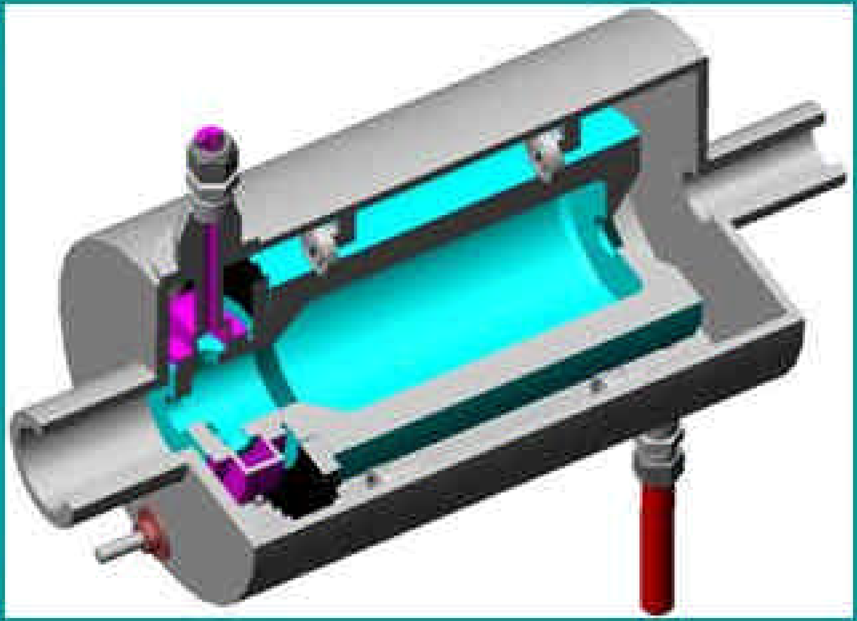


Positron component of cascade

High power collimator

This a liquid metal one. Liquid formed a cylinder as result of rotation and centrifugal force





High average power collimator. Beam is coming from the right.

PERTURBATION OF EMITTANCE AND POLARIZATION

- See A.Mikhailichenko, CBN 06-1, Cornell LEPP, 2006.

Fragment from CBN 06-1

Kinematical perturbations due to multiple scattering in a target

Let us consider the possible effect of *kinematical* depolarization associated with rotation of spin vector while particle experience multiple scattering in media of target before leaving. Typically polarized positron carries out $\sim(0.5\text{-}1)\hbar\omega$ –energy of gamma quanta. As positrons/electrons created have longitudinal polarization, it is good to have assurance that during scattering in material of target polarization is not lost. Each act of scattering is Coulomb scattering in field of nuclei. So BMT equation describing the spin $\vec{\zeta}$ motion in electrical field of nuclei looks like

$$\frac{d\vec{\zeta}}{dt}=\frac{e}{mc^2\gamma}\left\{G\gamma+\frac{\gamma}{\gamma+1}\right\}\cdot\vec{\zeta}\times\left(\vec{E}\times\vec{v}\right), \qquad \text{(A16)}$$

where $\vec{E}=Ze\vec{r}/r^3$ stands for repulsive (for positrons) electrical field of nuclei, factor $G=\frac{g-2}{2}\cong1.1596\times10^{-3}\approx\frac{\alpha}{2\pi}$. Deviation of momentum is simply $d\vec{p}/dt=e\vec{E}$.

So the spin equation becomes

$$\frac{d\vec{\zeta}}{dt}=\frac{1}{mc^2\gamma}\left\{G\gamma+\frac{\gamma}{\gamma+1}\right\}\cdot\vec{\zeta}\times\left(\frac{d\vec{p}}{dt}\times\vec{v}\right) \qquad \text{(A17)}$$

We neglected variation of energy of particle during the act of scattering, so $\frac{d\vec{p}}{dt}\cong m\gamma\frac{d\vec{v}}{dt}$ and vector $\vec{p}$ just changes its direction. Introducing normalized velocity as usual $\vec{\beta}=\vec{v}/c$, equation of spin motion finally comes to the following

$$\frac{d\vec{\zeta}}{dt}=\left\{G\gamma+\frac{\gamma}{\gamma+1}\right\}\cdot\vec{\zeta}\times(\dot{\vec{\beta}}\times\vec{\beta})=\left\{G\gamma+\frac{\gamma}{\gamma+1}\right\}\cdot\vec{\zeta}\times\frac{d\vec{\varphi}}{dt}, \qquad \text{(A18)}$$

where φ stands for the scattering angle and the vector $d\vec{\varphi}/dt$ directed normally to the scattering plane. For intermediate energy of our interest $\gamma\sim40$, so the term in bracket ~1 and, finally

$$\frac{d\vec{\zeta}}{dt}\cong\vec{\zeta}\times\frac{d\vec{\varphi}}{dt}. \qquad \text{(A19)}$$

The last equation means that spin rotates to the same angle as the scattering one, i.e. spin follows the particle trajectory.

Polarization effects implemented in KONN

```
!   POLARIZATION CURVE APPROXIMATION
!
      EP4=EP-0.4
      EP6=EP-0.6
      PP=0.305+2.15*EP4
      IF(EP.LT.0.4)PP=PP-0.05*EP4-2.5*EP4**3
      IF(EP.GT.0.6)PP=PP-0.55*EP6-2.65*EP6**2+0.7*EP6**3   ! PP=PP-0.55*EP6-2.6*EP6**2
      IF(PP.GT.1.)PP=1.
!
```

EP=POSITRON ENERGY/ Egamma-2mc^2

Sentinel

Depolarization occurs due to spin flip in act of radiation of quanta having energy $0 < \hbar\omega_\gamma \le E_1$ where E_1 stands for initial energy of positron. Depolarization after one single act

$$D = 1 - \left| \frac{d\sigma_{\gamma e}(\zeta_1, \zeta_1) - d\sigma_{\gamma e}(\zeta_1, -\zeta_1)}{d\sigma_{\gamma e}} \right|$$

Where $d\sigma_\gamma(\zeta_1, \zeta_1)$ stands for bremstrahlung cross section without spin flip, $d\sigma_{\gamma e}(\zeta_1, -\zeta_1)$ –the cross section with spin flip and $d\sigma_{\gamma e}$ is total cross section.

$$D = \frac{\hbar^2 \omega_\gamma^2 \cdot [1 - \frac{1}{3}\zeta_{1\|}^2]}{E_1^2 + E_2^2 - \frac{2}{3}E_1 E_2}$$

Energy after radiation

$$L_{dep} \cong \frac{1}{n \int D(\vec{p}_1, \zeta_1) d\sigma} \longrightarrow L_{dep} \cong \frac{2X_0}{1 - \frac{1}{3}\zeta_\|^2} \cong 2X_0$$

Rad. length

Depolarization ~5%

Spin flip in undulator

Positron or electron may flip its spin direction while radiating in magnetic field. Probability:

$$\frac{1}{\tau}[\sec^{-1}] = w_{flip} = \frac{5\sqrt{3}}{16}\frac{r_0^2}{\alpha}\frac{\omega_0^3}{c^2}\gamma^5\left(1 - \frac{2}{9}\zeta_{\parallel}^2 - \frac{8\sqrt{3}}{15}\frac{e}{|e|}\zeta_{\perp}\right)$$

Probability of radiation:

$$w_{rad} \equiv \frac{I}{\hbar\omega_0 2\gamma^2} = \frac{2}{3}\frac{e^4 H^2 \gamma^2}{m^2 c^3}\frac{1}{\hbar\omega_0 2\gamma^2} = \frac{1}{3}\alpha\gamma^2\omega_0$$

$$\lambda_e = r_0/\alpha = e^2/mc^2/\alpha \cong 3.8616\cdot 10^{-11}$$

The ratio

$$\frac{w_{flip}}{w_{rad}} = \frac{15\sqrt{3}}{16}\frac{\lambda_c^2}{\lambda_u^2}\gamma^3\left(1 - \frac{2}{9}\zeta_{\parallel}^2 - \frac{8\sqrt{3}}{15}\frac{e}{|e|}\zeta_{\perp}\right)$$

(K~1)

Effect of spin flip still small (i.e. radiation is dominating).

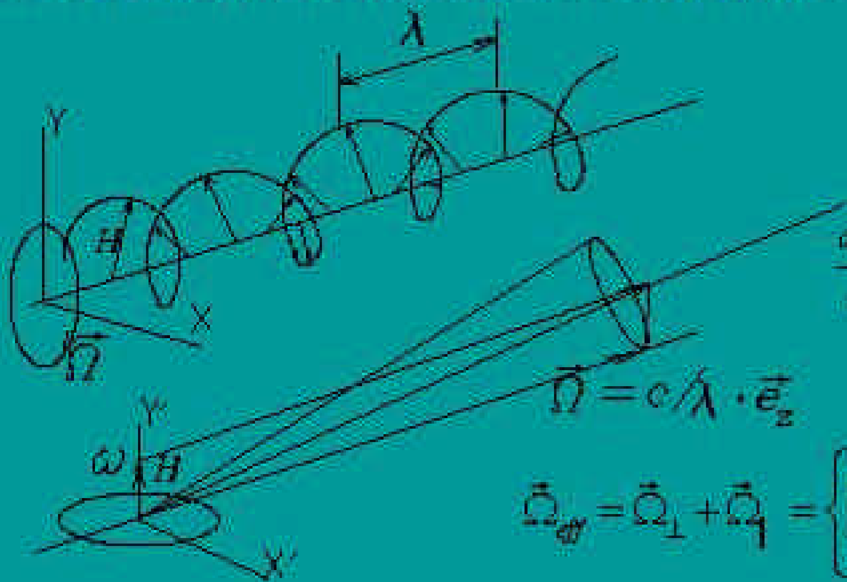
Depolarization at IP

- Depolarization arises as the spin changes its direction in coherent magnetic field of incoming beam. Again, here the deviation does not depend on energy, however it depends on location of particle in the bunch: central particles are not perturbed at all. Absolute value of angular rotation has opposite sign for particles symmetrically located around collision axes.
- This topic was investigated immediately after the scheme for polarized positron production was invented. This effect is not associated with polarized positron production exclusively because this effect tolerates to the polarization of electrons at IP as well. Later many authors also considered this topic in detail. General conclusion here is that depolarization remains at the level ~5%

E.A. Kushnirenko, A. A. Likhoded, M.V. Shevlyagin, "*Depolarization Effects for Collisions of Polarized beams*", IHEP 93-131, SW 9430, Protvino 1993.

Kinematic depolarization in undulator

Process can be considered in a system of reference rotating with frequency $\vec{\Omega} = \frac{c}{\lambda_u}$



$$\frac{d\vec{\zeta}}{dt} = \vec{\zeta} \times (\vec{\Omega}_s - \vec{\Omega}) \equiv \vec{\zeta} \times \vec{\Omega}_{eff}$$ where

$$\vec{\Omega}_{eff} = \vec{\Omega}_\perp + \vec{\Omega}_\parallel = \left\{[1+\gamma G]\cdot\frac{eH_\perp \lambda_u}{mc\cdot\gamma}\cdot\frac{c}{\lambda_u}; 0; \frac{c}{\lambda_u}\right\} \cong \left\{[1+\gamma G]\frac{K}{\gamma}\cdot\frac{c}{\lambda_u}\vec{e}_\perp; 0; \frac{c}{\lambda_u}\vec{e}_\parallel\right\}$$

$G=(g-2)/2$ can be represented as $G = 1/\gamma_0$ where γ_0 corresponds to 440.65 MeV

so $$\vec{\Omega}_{eff} = \vec{\Omega}_\perp + \vec{\Omega}_\parallel = \left\{\left[1+\frac{\gamma}{\gamma_0}\right]\frac{eH_\perp \lambda_u}{mc\,\gamma}\cdot\frac{c}{\lambda_u}, 0, \frac{c}{\lambda_u}\right\} \cong \left\{\frac{K}{\gamma_0}\cdot\frac{c}{\lambda_u}\vec{e}_\perp, 0, \frac{c}{\lambda_u}\vec{e}_\parallel\right\}$$

Does not depend on Energy→
depolarization $\approx (K/\gamma_0)^2$

During passage through undulator spin rotates around ***y'*** $\varphi = \Omega_\perp t = \frac{K}{\gamma_0}\cdot\frac{c}{\lambda_u}\cdot\frac{L}{c} = \frac{KL}{\gamma_0 \lambda_u} \cong 50$ rad

This needs to be taken into account while preparing polarization at IP

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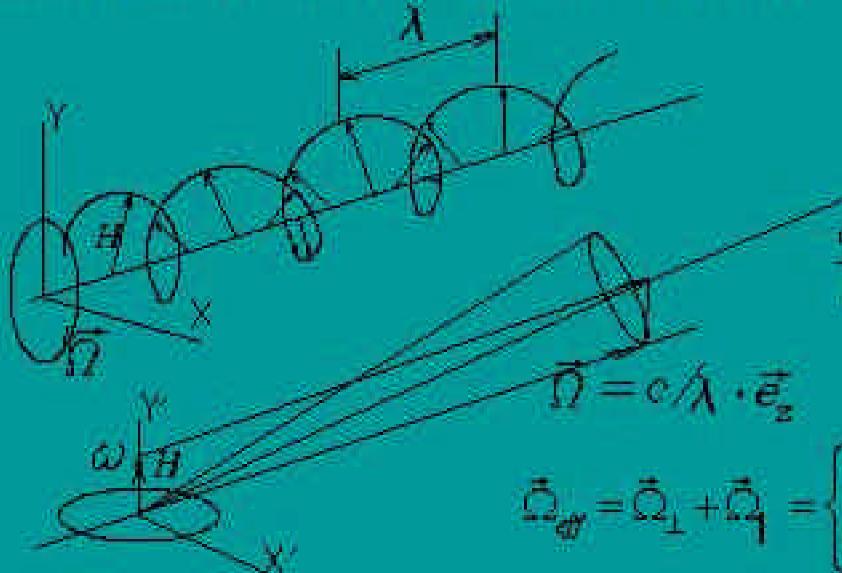

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$G=(g-2)/2$ can be represented as $G = 1/\gamma_0$ where γ_0 corresponds to 440.65 MeV

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Does not depend on Energy→ depolarization $\approx (K/\gamma_0)^2$

During passage through undulator spin rotates around *y'* $\varphi = \Omega_{\perp} t = \dfrac{K}{\gamma_0} \cdot \dfrac{c}{\lambda_u} \cdot \dfrac{L}{c} = \dfrac{KL}{\gamma_0 \lambda_u} \cong$ 50 rad

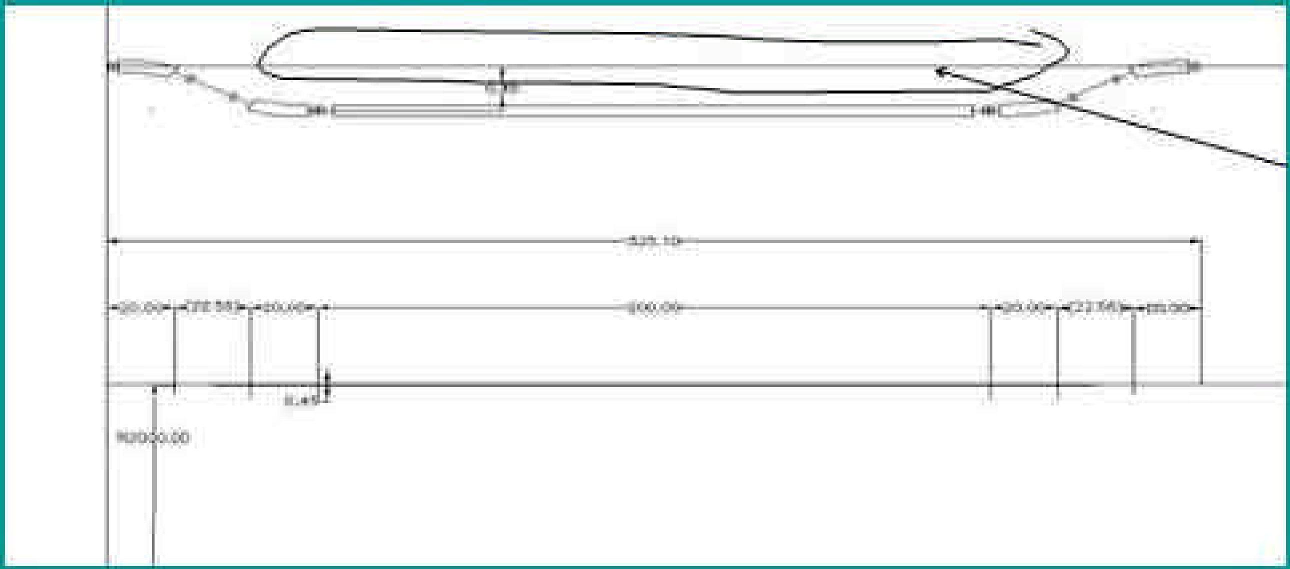
This needs to be taken into account while preparing polarization at IP

CONCLUSIONS ABOUT POLARIZATION

Perturbation of spin is within 10% total (from creation).

This number could be reduced by increasing the length of undulator, making target thinner (two targets) and beams more flat at IP.

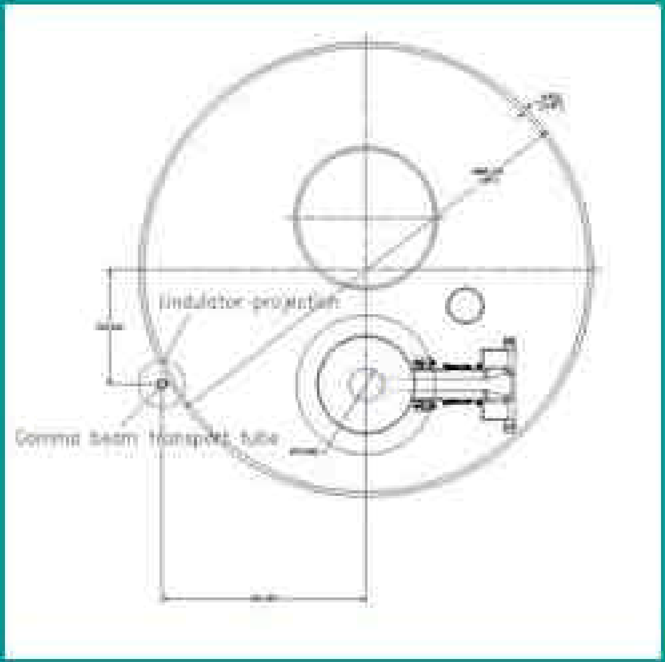
UNDULATOR CHICANE



This space can be used for accelerator - "keep alive" source

[1] V.V. Vladimirsky, D.G. Koshkarev, "*The Achromatic Bending Magnet System*", Instr. Exp. Tech., (USSR), (English Translation) N6, 770(1958).

[2] T.A.Vsevolojskaya, A.A.Mikhailichenko, G.I Silvestrov, A.N. Cherniakin, "*To the Project of Conversion System for Obtaining Polarized Beams at VLEPP Complex*", unpublished internal report BINP, Novosibirsk, 1986.



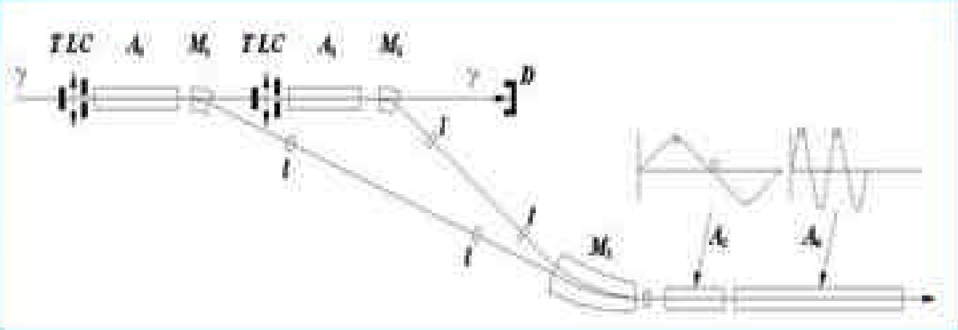
COMBINING SCHEME

After the first target only 13% of photons are lost. So it is possible to install second target and collect positrons from this second target.

Combining in longitudinal phase space could be arranged easily in the same RF separatrix in damping ring.

Additional feed back system will be required for fast dump of coherent motion.

This combining can help in reduction of power deposition in target if each target made thinner, than optimal.



Energy provided by acceleration structures A1 and A2 are slightly different, A1>A2.

Combining scheme allows –double positron yield and cut in half the length of undulator

CONCLUSIONS

Restored start to end code for Monte-Carlo simulation of conversion; Confirmed low K factor possible here; K<0.4 with period 10 mm

For 500 GeV, a conversion system requires more efforts; one solution is to move the system as a whole to a new 150 GeV point.

Tested 10 and 12 mm period undulators, aperture 8 mm, ~40 cm each; Reached K=0.467 for 10 mm period with for 56 filament wire diameter 0.33mm; Longitudinal field profile measured; Reached K=0.83 for 12 mm period undulator wire 0.63mm;

Pumping of Helium was tested, gain >10%;

Radial sectioning will be implemented in the following models

Our calculations show that these parameters satisfy ILC

4-m long Undulator module fabrication and its test is a priority job→ end 2007;

Helical iron yokes of 3 m long obtained from industry;

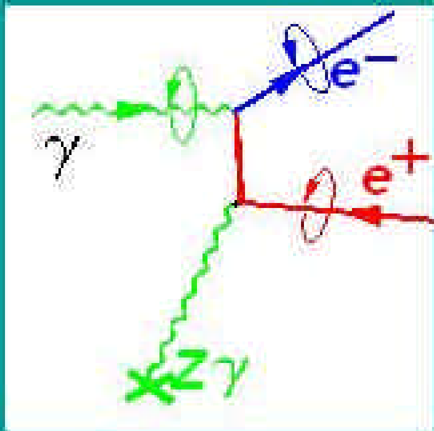
Wire 0.33 used for latest model; strands x4(used) and by x6 (obtained).

Designed undulator with 6.35mm aperture, K~0.7 for 10mm; and K~1.2 for 12mm

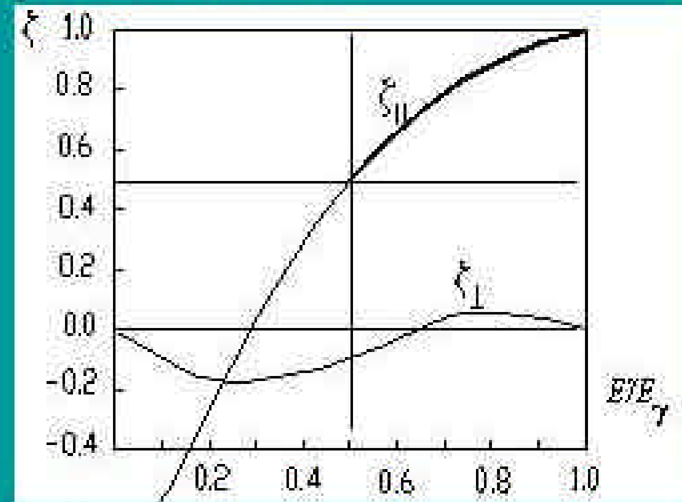
Target, collection optics and spin handling are in scope of our interest.

Back-up slides

Polarized e± production



The way to create circularly polarized positron, left. Cross-diagram is not shown. At the right-the graph of - longitudinal polarization - as function of particle's fractional energy

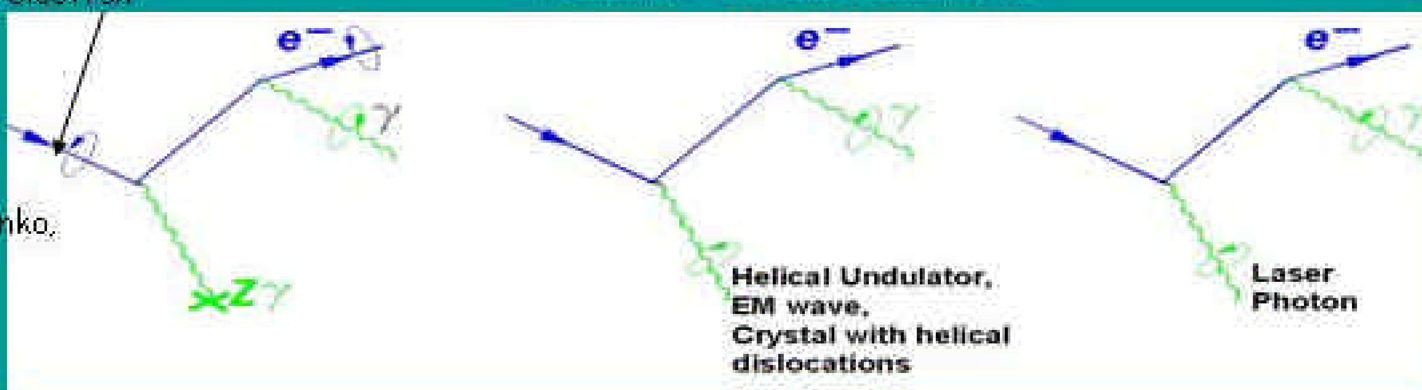


The way to create circularly polarized photon

V.Balakin, A. Mikhailichenko, 1979

Polarized electron

E.Bessonov, A.Mikhailichenko, 1996



E.Bessonov 1992

Polarization of positrons is a result of positron selection by energy

$$\vec{\zeta} = \xi_2 \cdot \left[f(E_+, E_-) \cdot \vec{n}_\parallel + g(E_+, E_-) \cdot \vec{n}_\perp \right] = \vec{\zeta}_\parallel + \vec{\zeta}_\perp$$

Two-year Budget, in then-year K$

Item	9/07-8/08	9/08-8/09	Total
Other Professionals	31.0	32.55	63.55
Graduate Students	21.8	23.762	45.562
Undergraduate Students	5.0	5.250	10.25
Total salaries and Wages	57.8	61.562	119.362
Fringe Benefits	10.23	10.742	20.972
Total Salaries, Wages and Fringe Benefits	68.03	72.304	140.334
Equipment	25	49	74
Travel and transportation	7.5	7.5	15
Materials and Supplies	30	45	75
Other direct costs	19.528	21.286	40.814
Subcontract	0	0	0
Total direct costs	153.33	195.089	345.147
Indirect costs	62.263	73.634	135.897
Total direct and indirect costs	212.321	268.723	481.044