



Cornell University  
Laboratory for Elementary-Particle Physics

# **THE STATUS OF POSITRON SOURCE DEVELOPMENT AT CORNELL**

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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  $\frac{1}{4}$ " (7mm magnetic core)

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## **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

## ✓ **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**

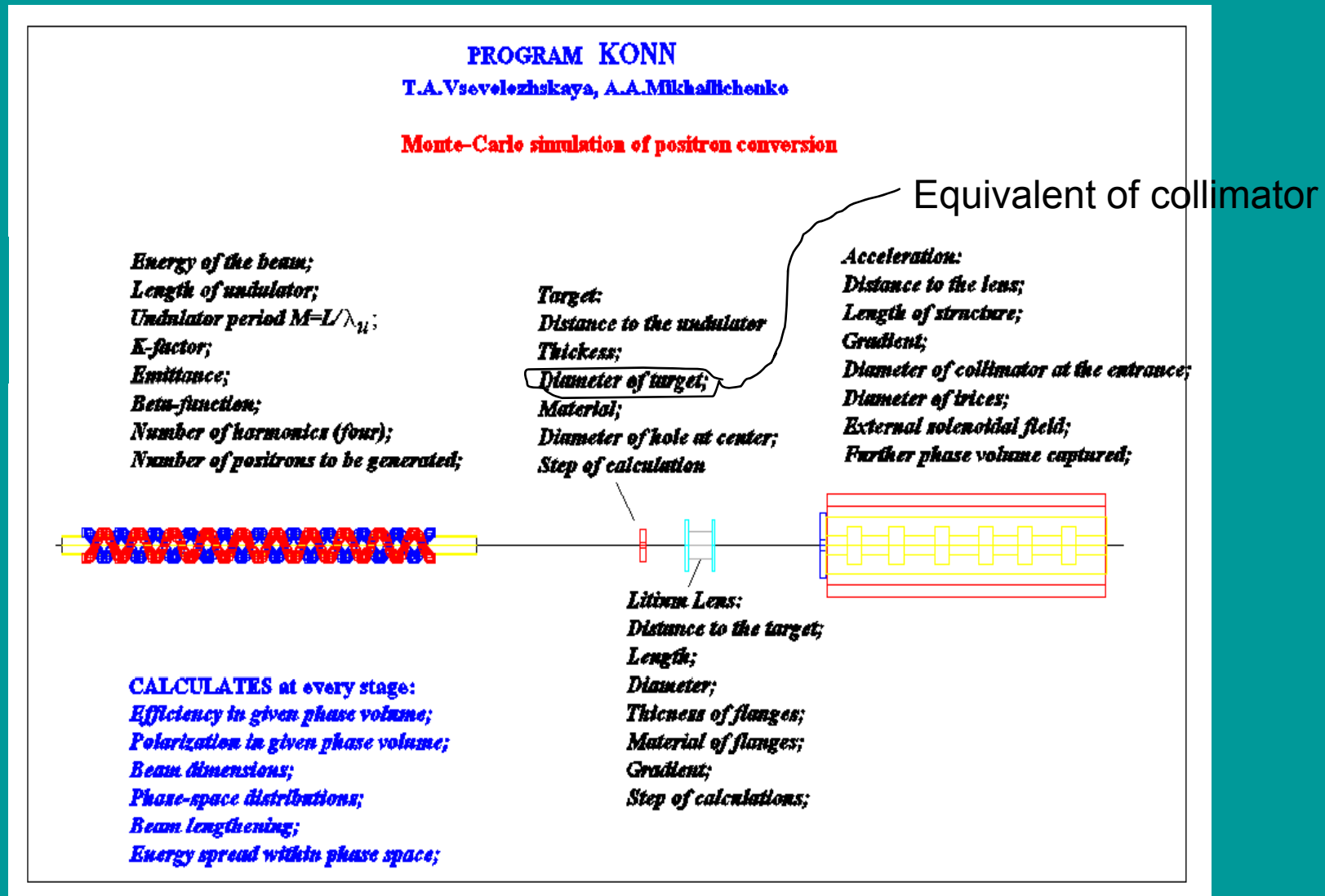
Two-target scheme

} These  
positions not  
closed finally

# 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

```

C:\MSDEV\Projects\POSITRON CONVERSION\Debug\POSITRON CONVERSION.exe

CONVERSION      - C
FOCUSING        - F
ACCELERATION    - A

WHAT TO DO?    -

D0 = .300  AL = .400  DW0 = .100  GG = .070

*** PARAMETERS OF ACCELERATION ***
DISTANCE TO RF STRUCTURE cm = 2.0000  ==
RADIUS OF DIAPHRAGM      cm = 3.0000  ==
LENGTH OF RF STRUCTURE  cm = 100.0000 ==
GRADIENT MeV/cm          = .5000     ==
LONGITUDINAL FIELD MGs   = .0400     ==
INNER RADIUS OF DIPHRAGM cm = 3.0000  ==
FURTHER ACCEPTANCE MeVxcm = 10.0000  ==

POSITRONS PASSED= 4051 POSITRONS ACCEPTED = 4011
WW = 2.065  WWP = .958
P0 = .553  DET0 = .384  DEBT = .119  EFF = 2.065

    PU0    AL0    ALMB    K    EPS    BT    RTG    GG
150000.0  17500.0  1.00    350  .000001  40000.0  .50    .070

RMS = .915  AMS = .040  DEM = 136.344  EM = 58.225  D7 = 18000.00
PTM = 2.383  PZM = 58.176  DPZ = 5.001  PRM = -.017  PUG = 19.071
TM = 100.685  DTM = .620  WW = 2.065  WP = .464  NO = 2400
RF = 3.00    AL/X0 = .40  H0 = .040  EPSF = 10.00 MeVxcm

      EFF<EX,CT>
.0065 .0141 .0286 .0379 .0354 .1444
.0602 .1703 .1959 .1583 .1233 .1462
.0715 .1733 .1486 .1049 .0557 .0126
.0248 .0843 .0700 .0255 .0106 .0007
.0158 .0315 .0211 .0106 .0032 .0006

      EFP<EX,CT>
.0372 -.0222 .0644 .0730 -.0607 .0555
.4200 .4642 .4093 .4150 .3323 .2957
.7056 .6618 .6318 .6424 .6403 .5375
.5951 .6645 .6523 .5436 .5939 .3507
.6141 .6423 .6217 .6786 .6096 .7789

      EFF = 1.610  EFP = 47.420 %
  
```

Period

K-factor

Efficiency and polarization

## Parameters optimized with KONN

### Monte-Carlo simulation of positron conversion example

#### General parameters:

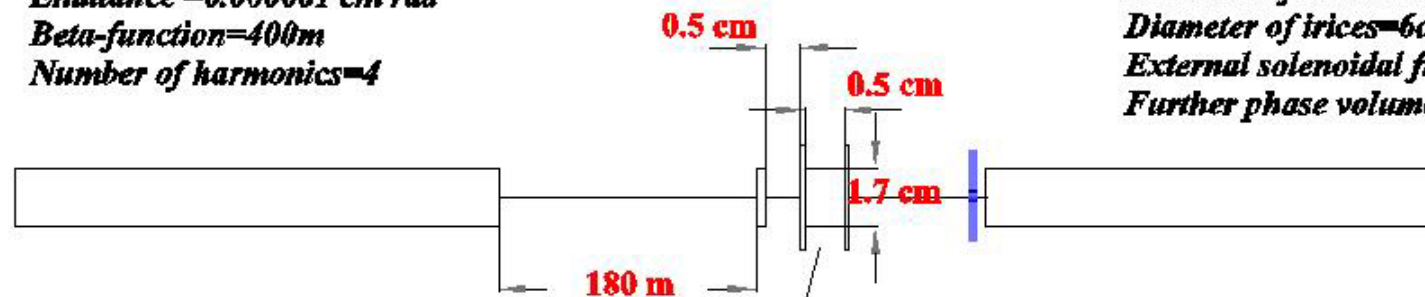
Energy of the beam=150 GeV  
Length of undulator=175m  
Undulator period 10mm  
K-factor=0.35  
Emittance =0.000001 cm rad  
Beta-function=400m  
Number of harmonics=4

#### Target:

Distance to the undulator=180m  
Thickness=0.5mm length=1.75mm  
Diameter of target=0.8cm  
Material=W

#### Acceleration:

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



#### Lithium Lens:

Distance to the target=0.5 cm  
Length=0.5 cm  
Diameter=1.7 cm  
Thickness 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

```
C:\MSDEV\Projects\POSITRON CONVERSION\Debug\POSITRON CONVERSION.exe

WHAT TO DO? -

*** SYSTEM PARAMETERS ***

INITIAL MOMENTA ,MeV      =150000.0  :=49000
LENGTH OF UNDULATOR,cm  = 17500.0  :=100
K FACTOR                  =    .350  :=.17
PERIOD OF ONDULATOR, cm =   1.000  :=.254
DISTANCE TO THE TARGET   = 18000.0  :=3200
RADIUS OF TARGET, cm     =    .500  :=.15
RADIUS OF HOLE            =    .000  :=
EMITTANCE, cmxrad        = 1.000E-06 :=
BETTA-FUNCTION, cm       = 40000.0  :=4000
LENGTH OF TARGET/%o     =    .400  :=.5
STEP OF CALCULATION      =    .100  :=
HARMONICS INDEX          = 0; <5    :=
NUMB.OF PART ON 1 H      = 2400     :=

TOTAL NUMBER OF PHOTONS  =    1.014
MAX ENERGY OF QUANTA   =    8.741  MeV
GAMMA                   =   95890.4

POSITRONS ACCEPTED = 5000    POSITRONS GENERATED = 30820

ENERGY OF QUANTA = 8.741  BETA = 1.274 EFF = .003 PU0 = 49000.0
LENGTH OF UNDUL. = 100.0 PERIOD = .25 PT2 = .03 EPT = .0000010
BT = 4000.0 RTG = .15  F0 = -.091 RMS = 1.138 AMS = .894
XU = .072  NUMBER OF PARTICLES BY FIRST HARMONIC = 2400
PHOTONS/e = 1.014  GAMMA= 95890.4

EFF<EX,CT>

.0000 .0000 .0000 .0001 .0001 .0001
.0001 .0001 .0002 .0002 .0002 .0003
.0000 .0001 .0001 .0002 .0002 .0004
.0000 .0000 .0000 .0000 .0001 .0002
.0000 .0000 .0000 .0000 .0000 .0000

EFP<EX,CT>

-.0336 -.0927 .0143 -.0414 -.0172 -.0734
.4099 .4170 .4039 .3911 .3971 .2796
.7835 .7675 .7085 .7309 .7255 .6872
.8858 .8004 .8221 .8011 .8528 .8420
.6790 .6925 .7001 .6678 .7615 .7450
```

Dependence of  
polarization  
seen in  
experiment



# UNDULATOR DESIGN

Complete design done;

System for magnetic  
measurement designed;

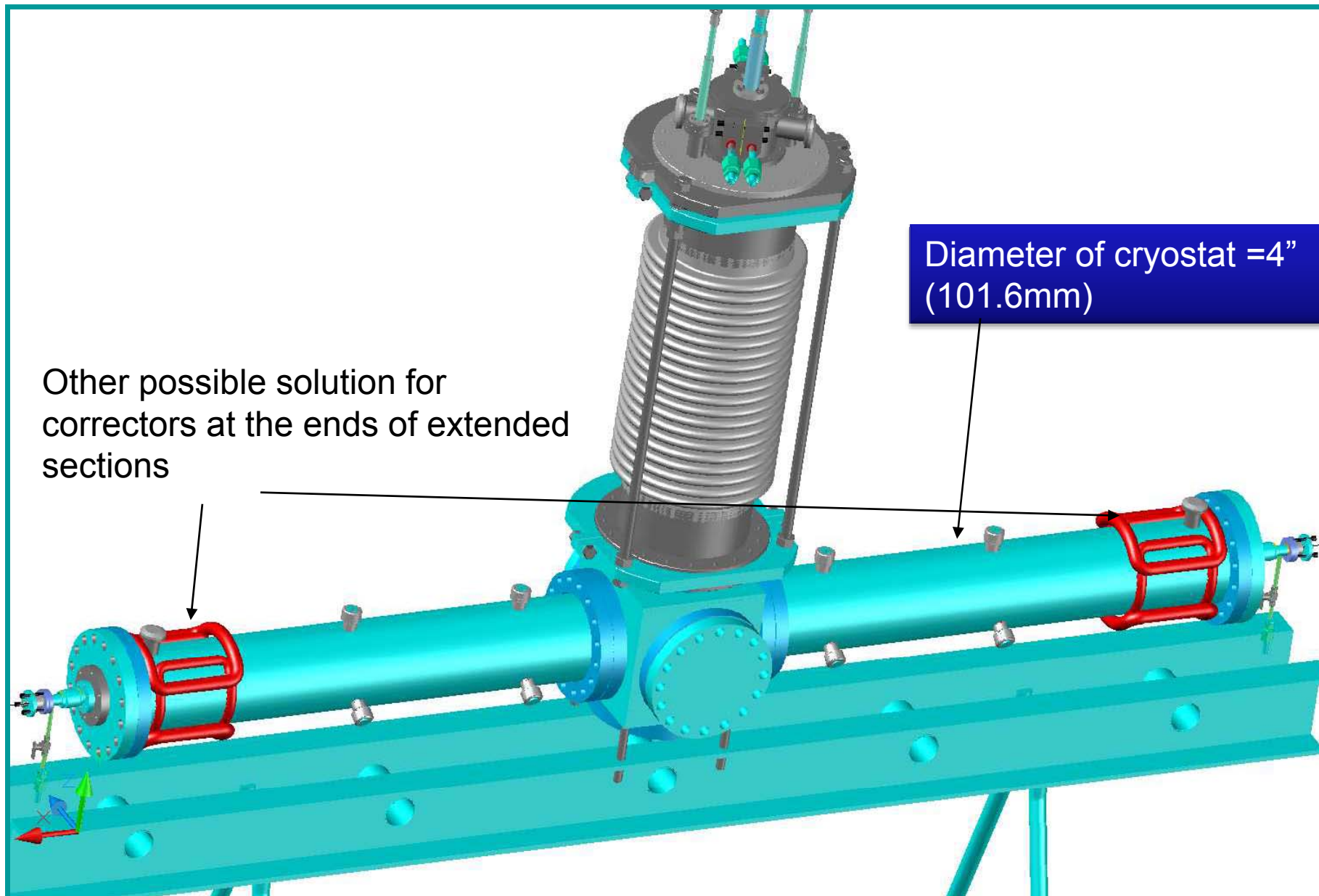
Undulator includes  
correctors and BPMs;

Current input one/few  
modules (ten)

3m possible

Will be extended to 2 m long ~4m total





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

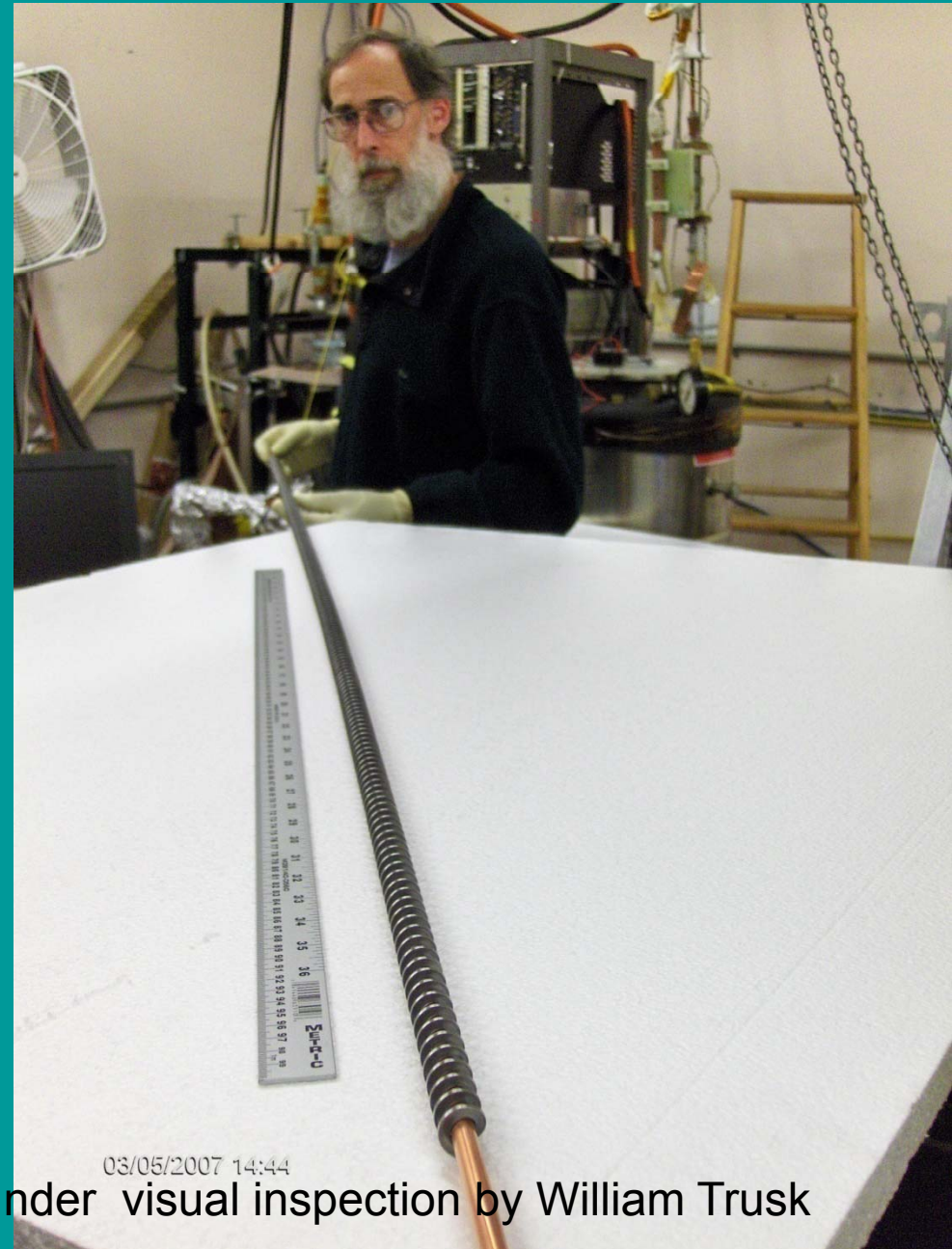


Technology developed for fabrication of continuous yoke of necessary length (2-3m)

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

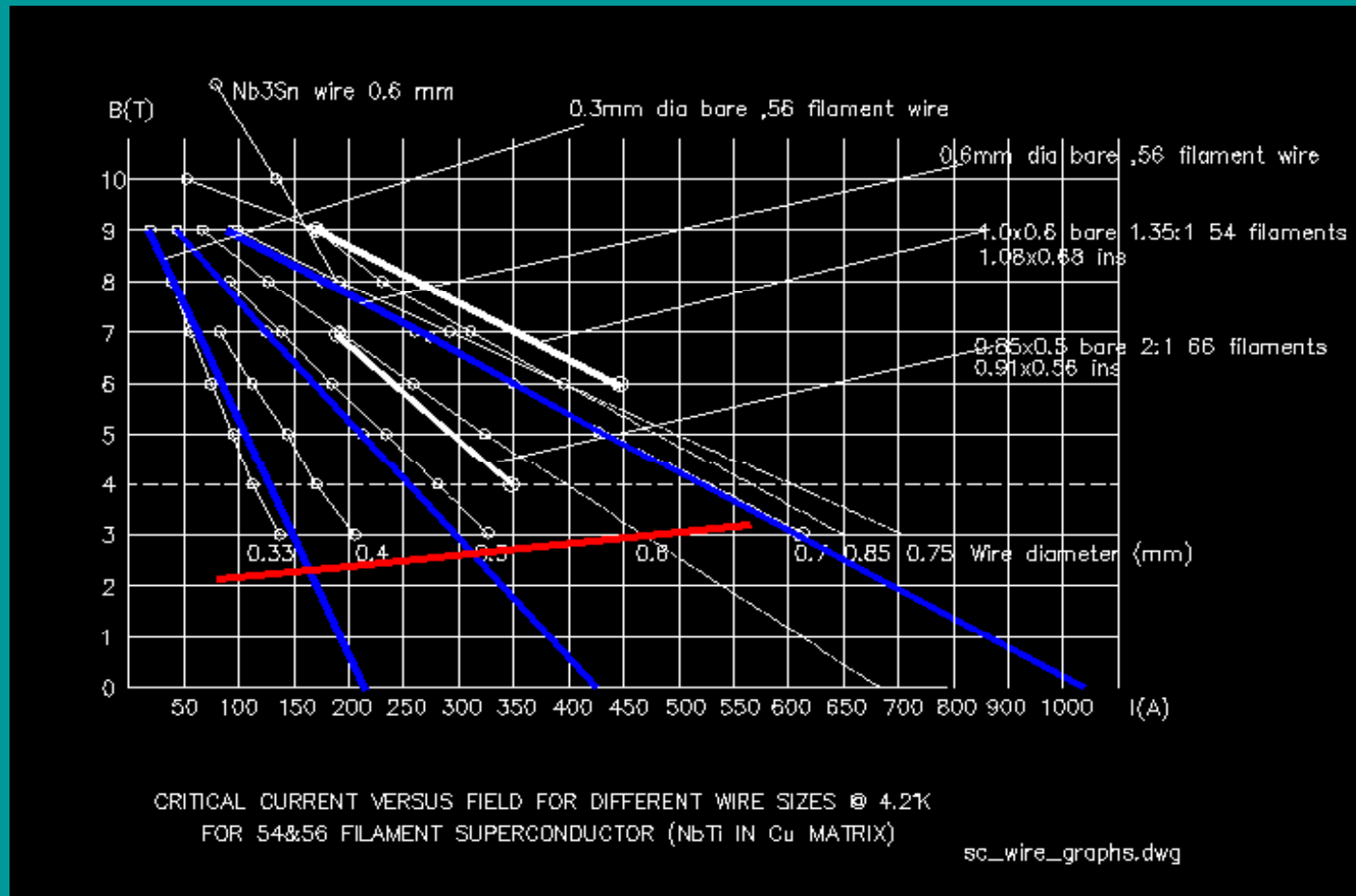
For 12mm period the coil has 12(z)x12(r) wires bonded in 6 strands



03/05/2007 14:44

Two meter long yoke under visual inspection by William Trusk

## Wires for undulator

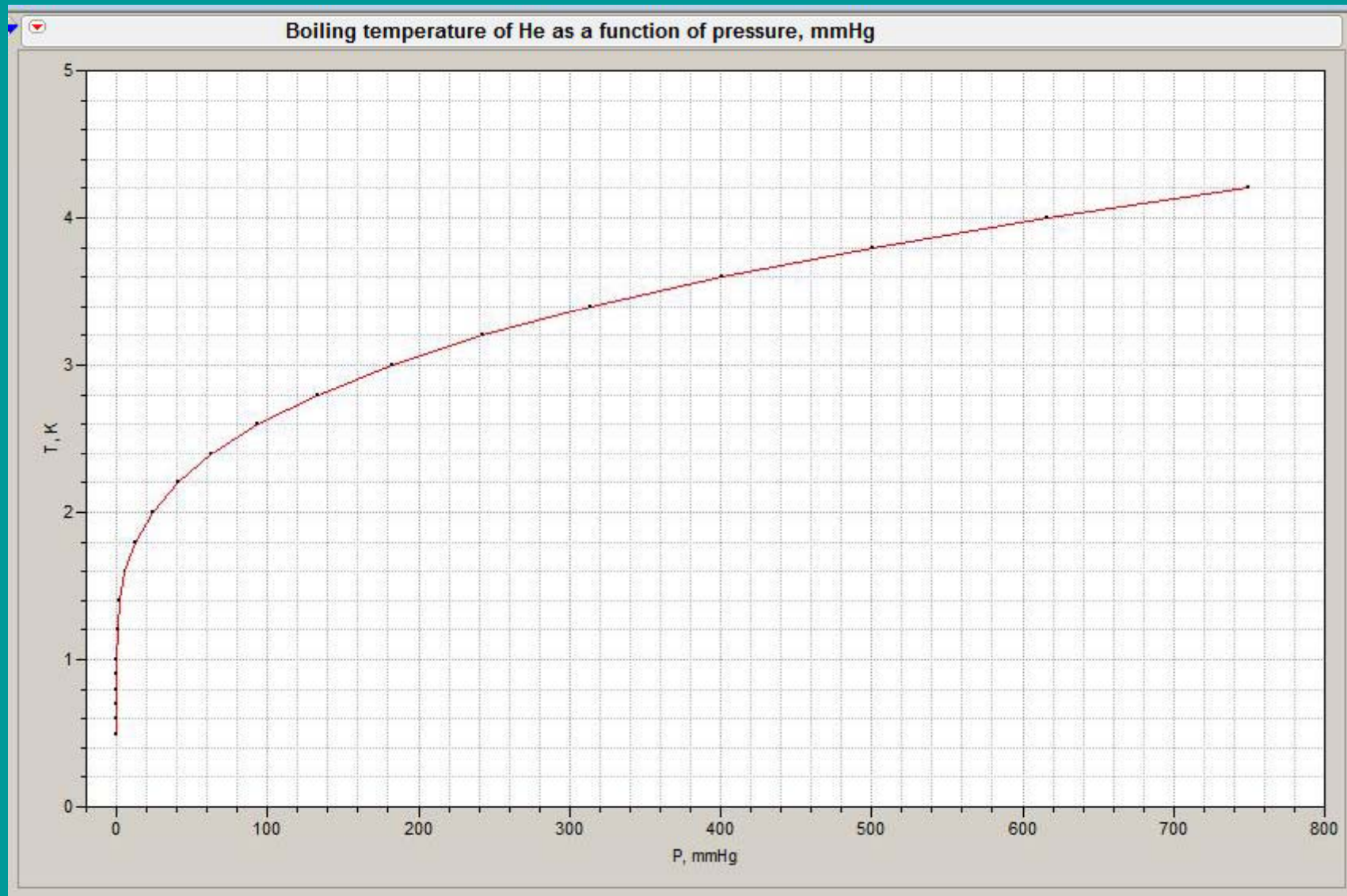


All new wire is a 56 filaments with SC to Cu ratio 1:0.9

We switched to 0.3 mm bare from 0.6 bare

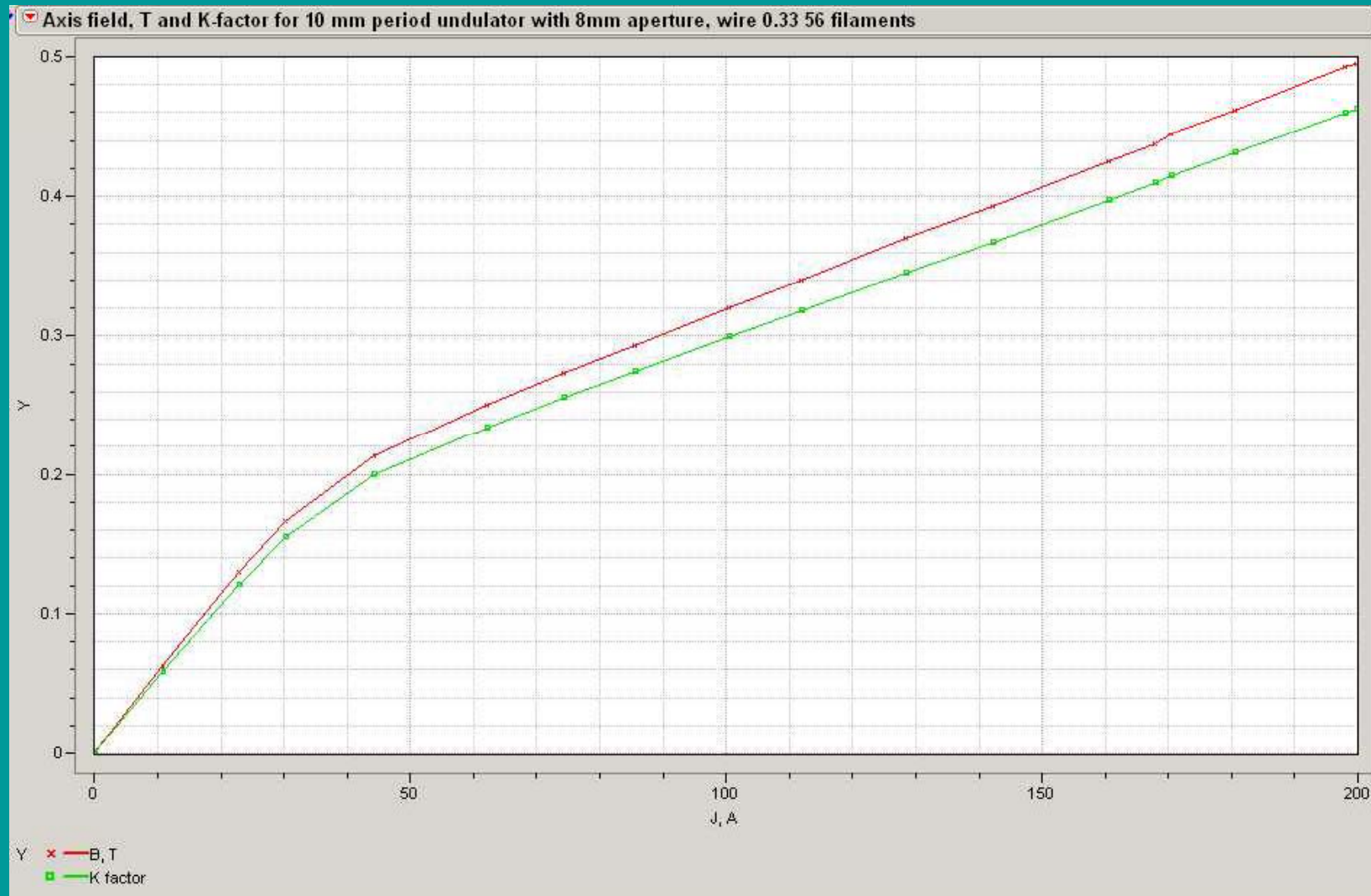
Winding with bonded tape of four and six wires in parallel

## 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

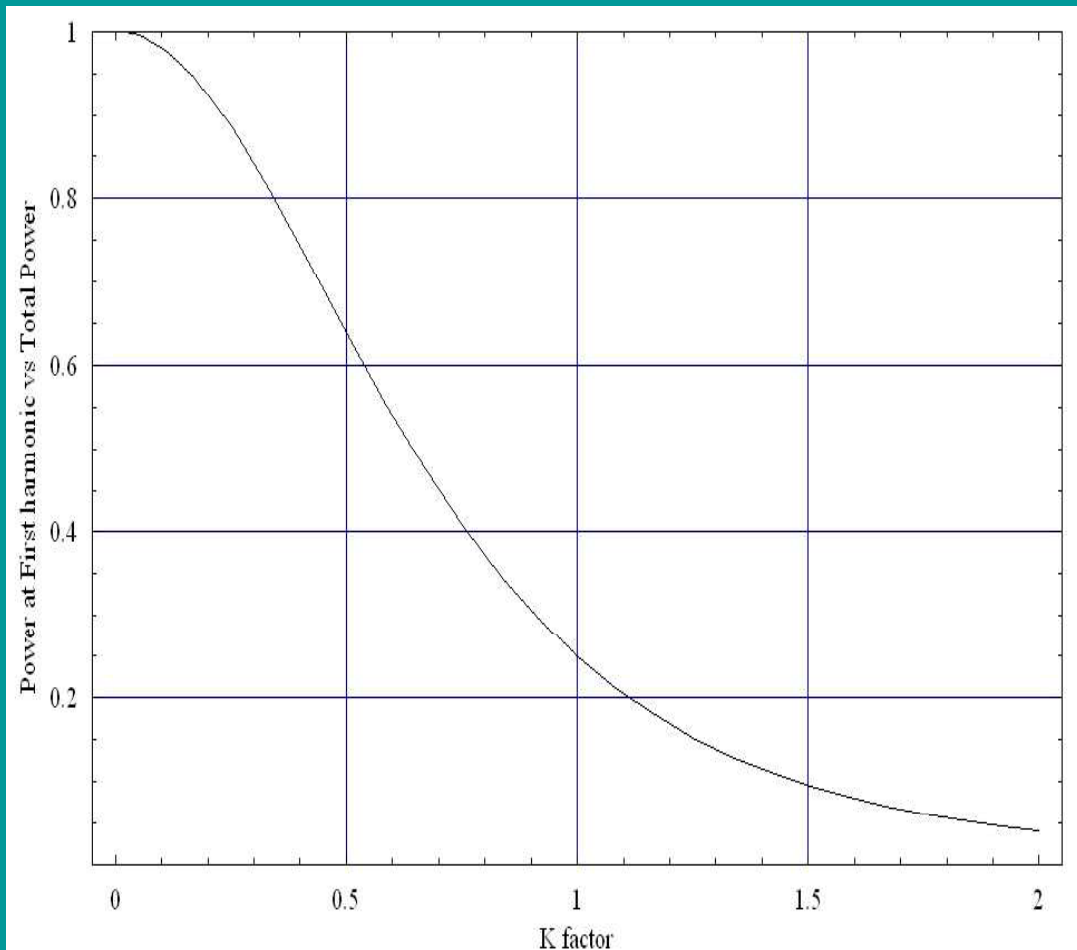
For Dewar pumped down -24"Hg (-609.6mmHg), the temperature  $\approx 3$  °K



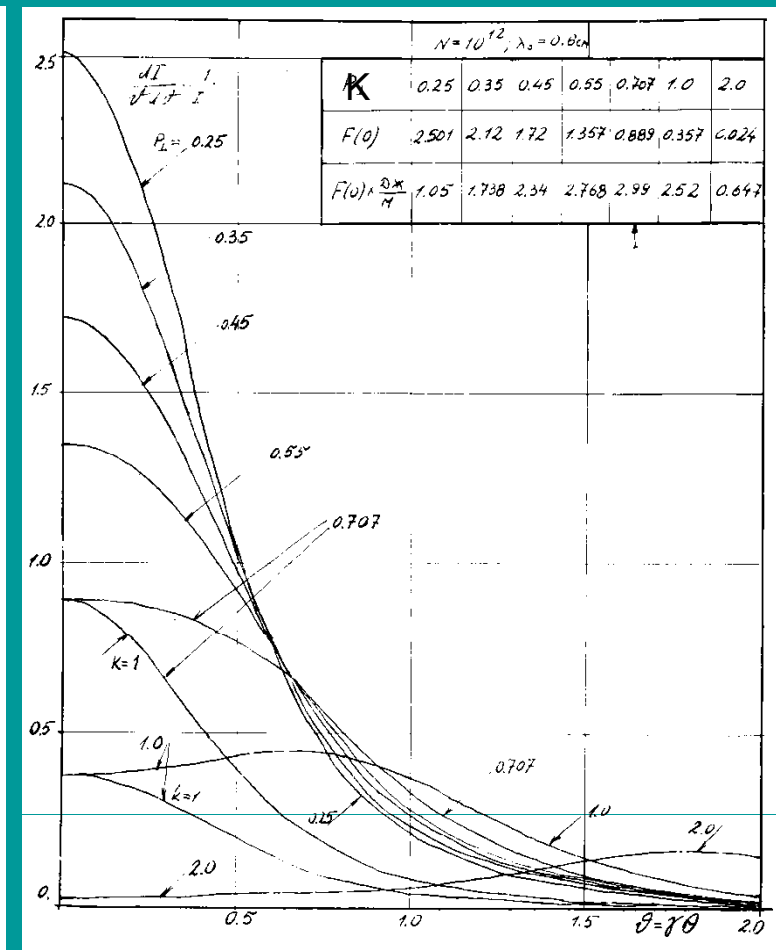
Measured excitation curve for undulator with 8mm aperture, wire-0.33 mm, 56 filaments  
Random point; spread of amplitudes~5%



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

$ge_x = 8 \cdot 10^{-6}$  m rad -high edge  
 $ge_y = 8 \cdot 10^{-8}$  m rad -high edge  
 $b_v \sim 200$  m

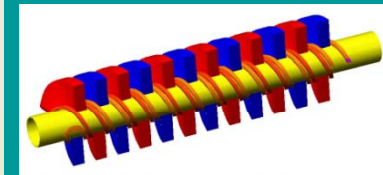
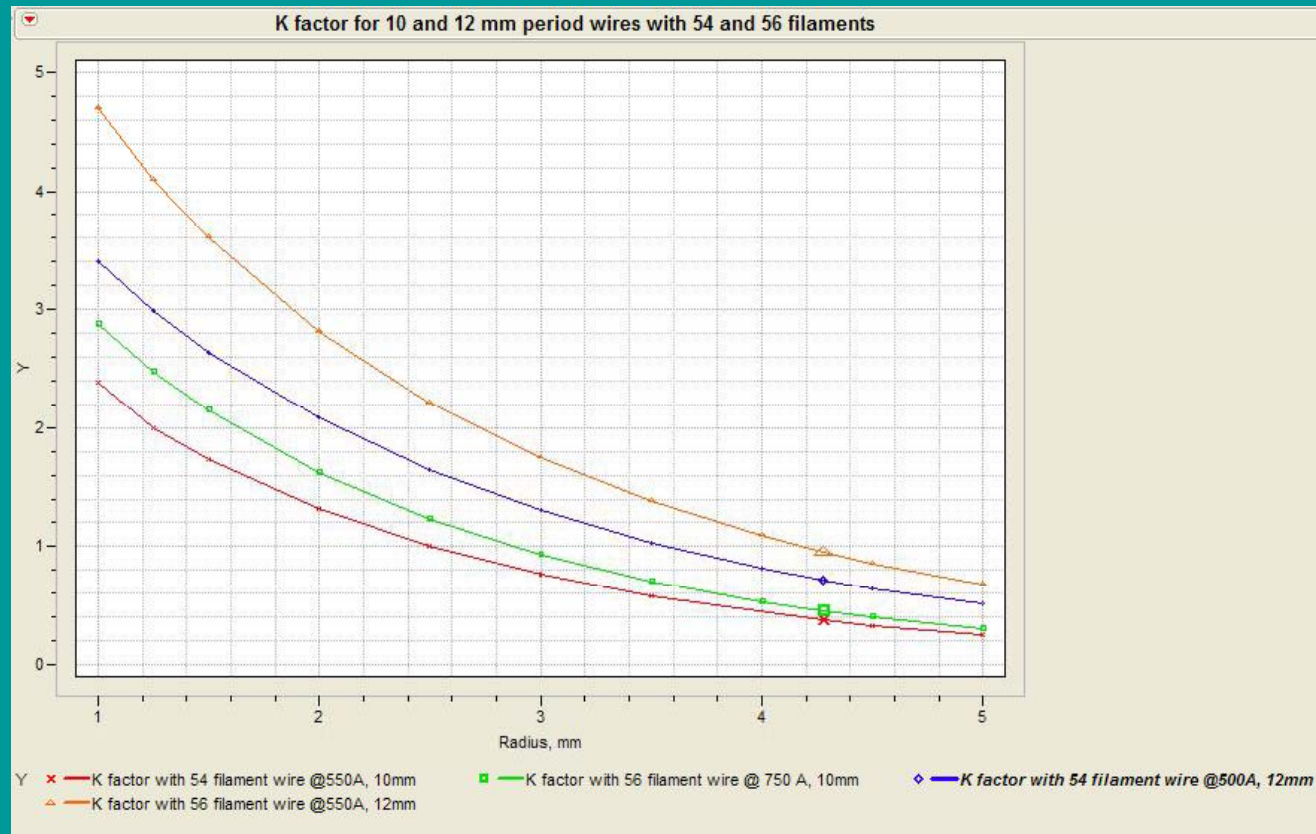
Angular spread in radiation	$\alpha \sim \sqrt{1 + K^2} / \gamma$	$3 \cdot 10^{-6} \text{ (K=1)}$
Angular spread in beam, vert.	$y' \cong \pm \sqrt{\gamma \varepsilon_z / \beta \gamma}$	$3.5 \cdot 10^{-8}$
Angular spread in beam, rad.	$y' \cong \pm \sqrt{\gamma \varepsilon_z / \beta \gamma}$	$3.5 \cdot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

50 sigma  $\sim 7$  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  $K \sim 0.4-0.5$

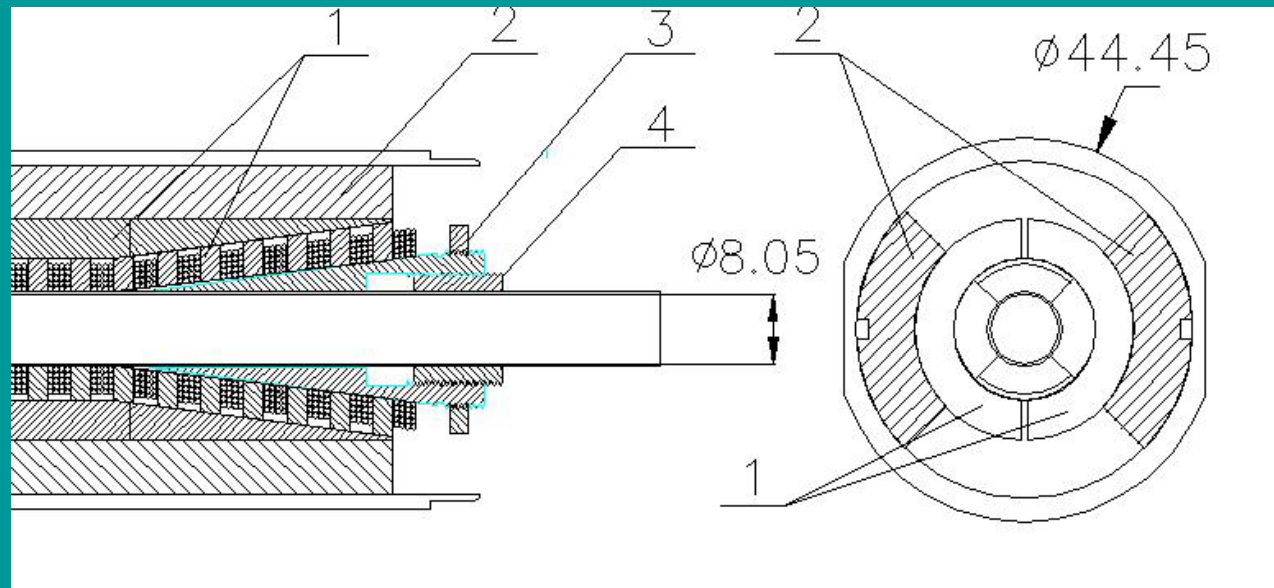
# K factor as function of radius of undulator chamber



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.

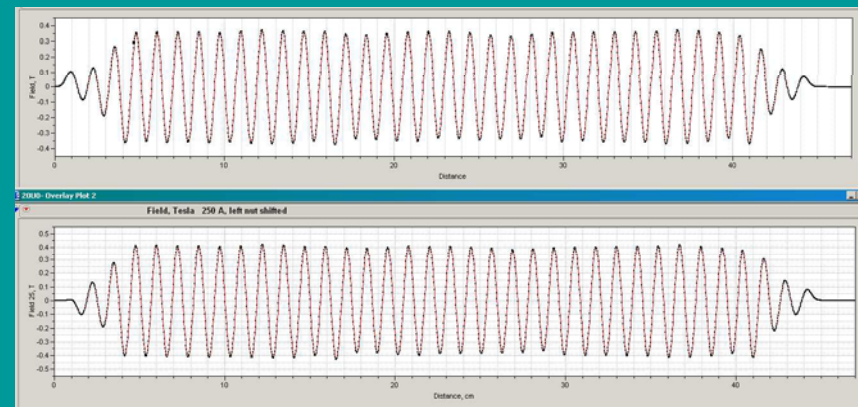
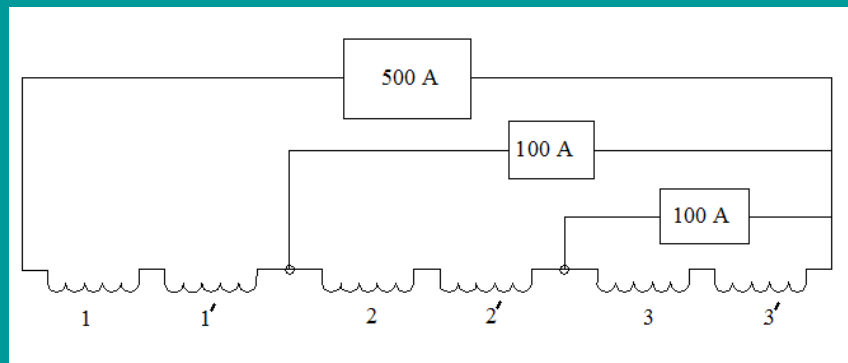


Period kept even



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



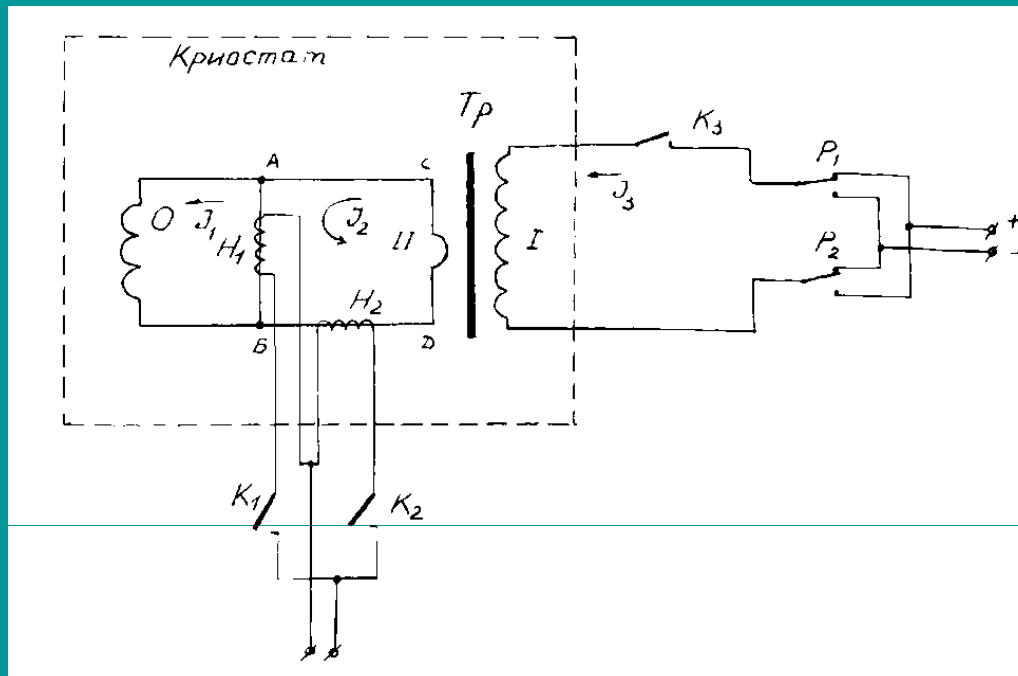
## Identification of losses in joints

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  $<1\text{E-}15\Omega$

This scheme used in 1986 to feed SC undulator

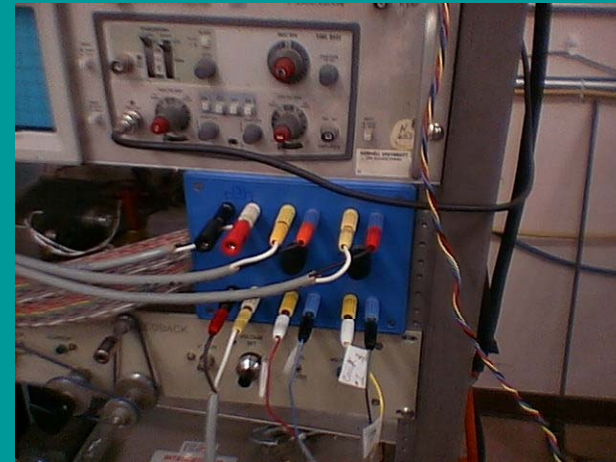
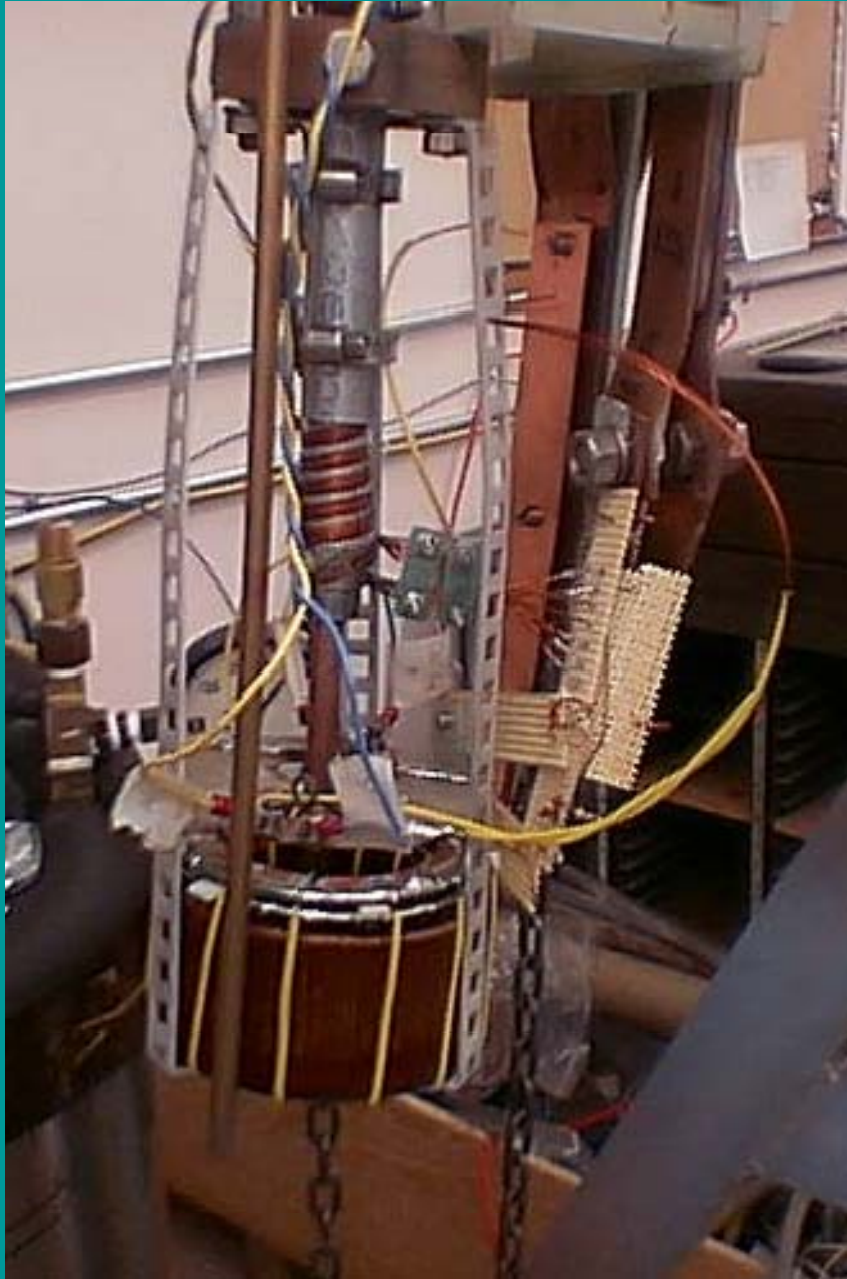


Scheme allows to work with captured flux



SC transformer with keys

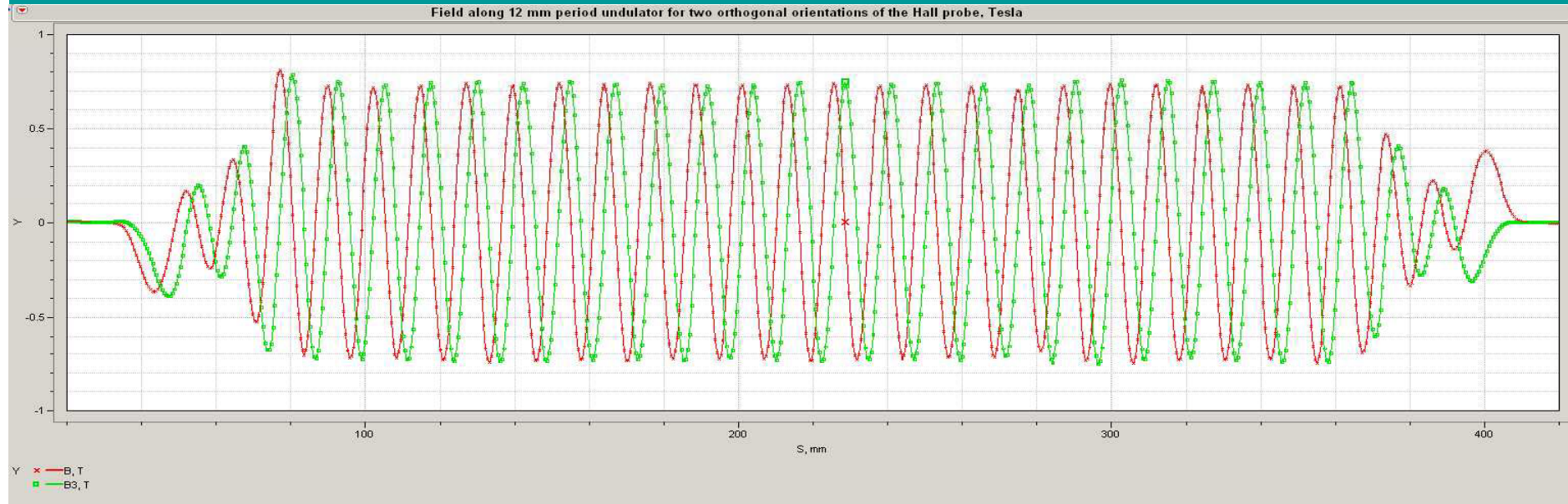




Distribution box for switches

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
$\lambda=10$ mm @300 °K	K=0.36 tested	K=0.42 tested	K=0.467 tested	K≈0.5 (calculated)
$\lambda=12$ 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 guaranteed 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

$$\nabla(k\nabla T) + \dot{Q} = \rho c_V \dot{T}$$

$$\ddot{P} - \nabla(c_0^2 \nabla P) = \frac{\Gamma}{V_0} \dot{Q}$$

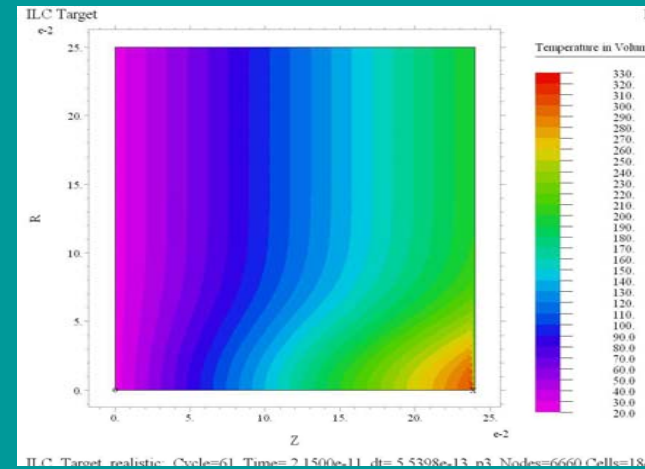
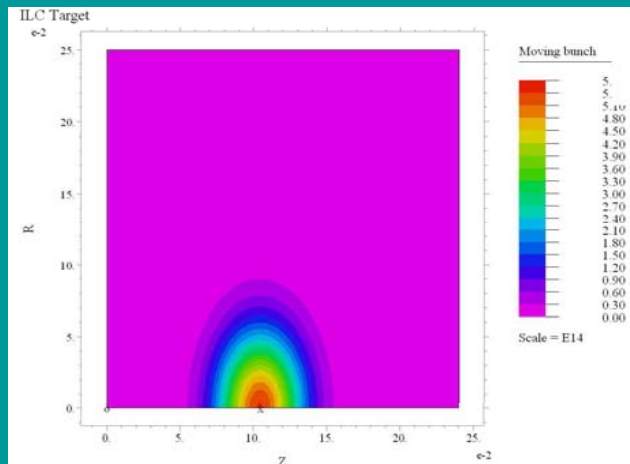
Implemented  
pressure block

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

The thermal pressure  $p_T$  can be expressed

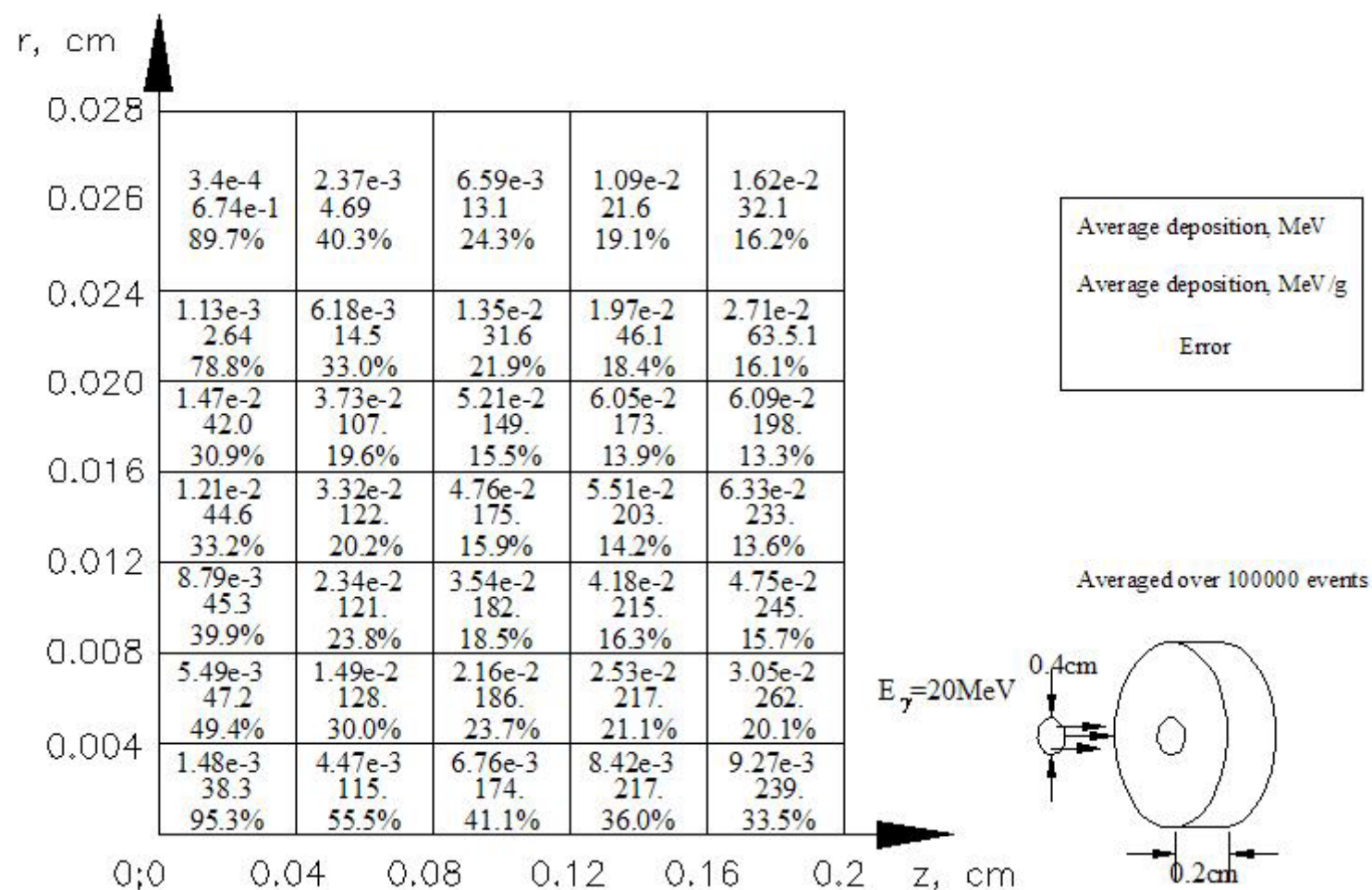
$$p_T = \Gamma(V) \frac{c_V T}{V} = \Gamma(V) \frac{\epsilon_T}{V}$$

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



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

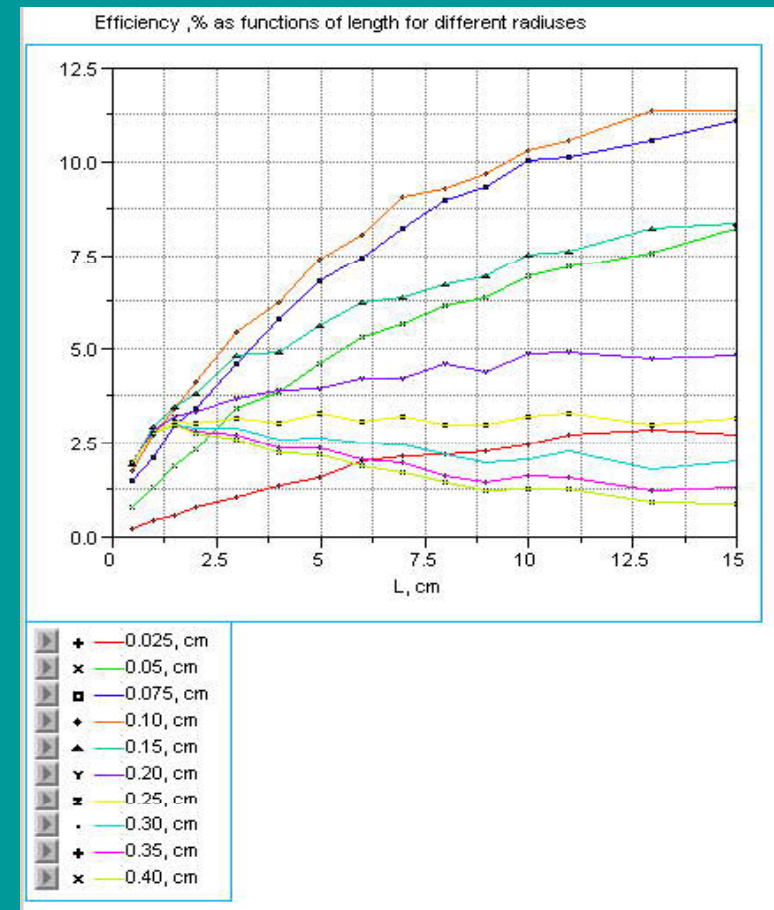
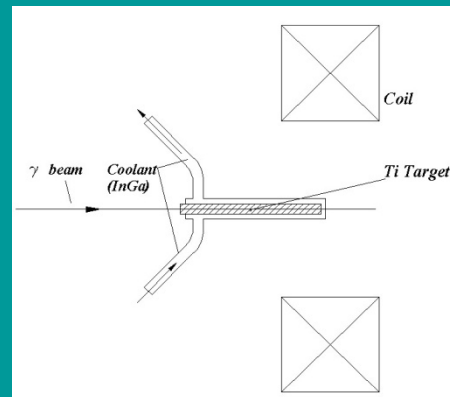
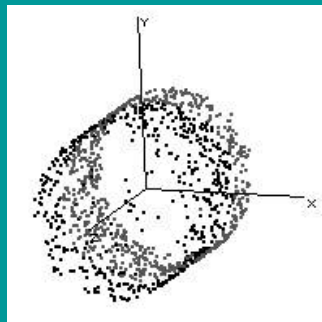
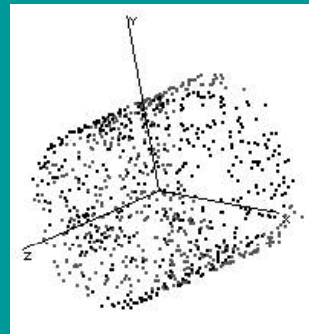
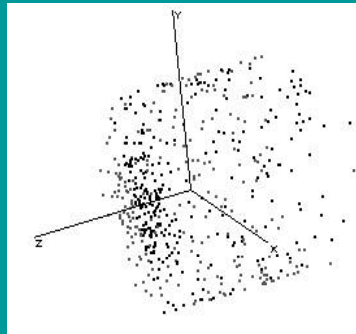




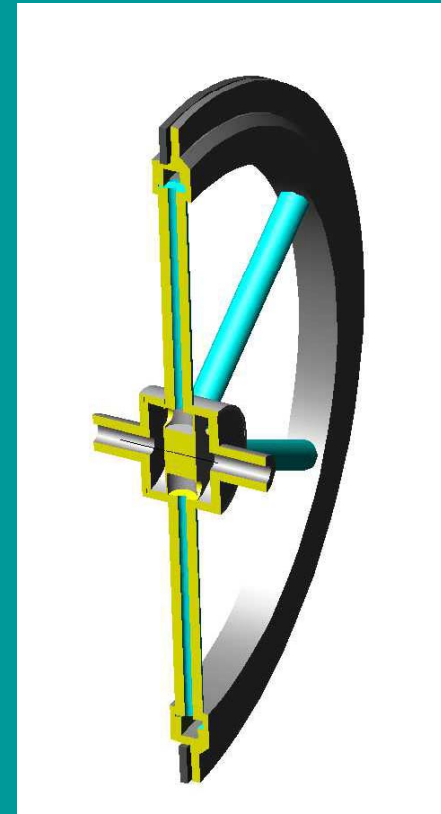
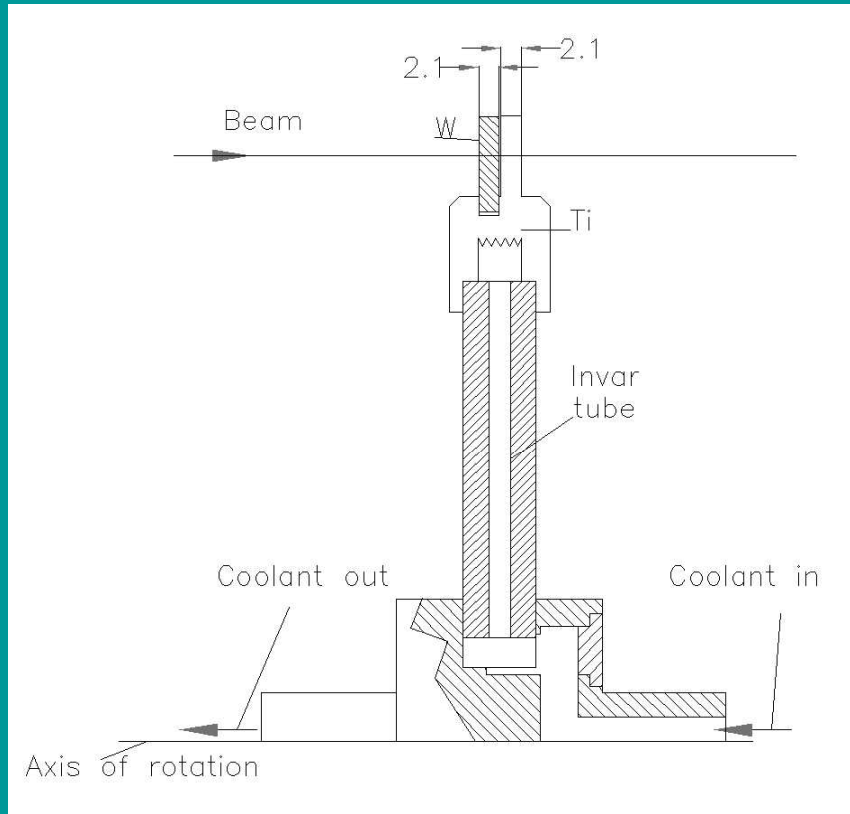
A.D.Bukin, A.A.Mikhailichenko," Optimized Target Strategy for Polarized Electrons and Positrons Production for Linear Collider".  
(IYF) BUDKER INP 92-76, Novosibirsk, 1992.

## 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

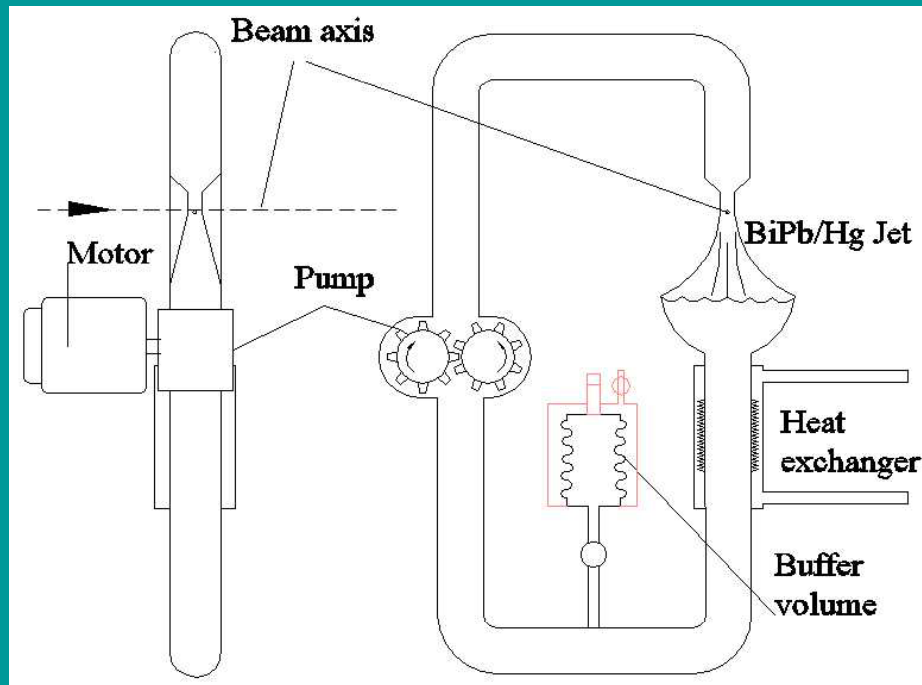


By this one can expect more compact design

# 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.

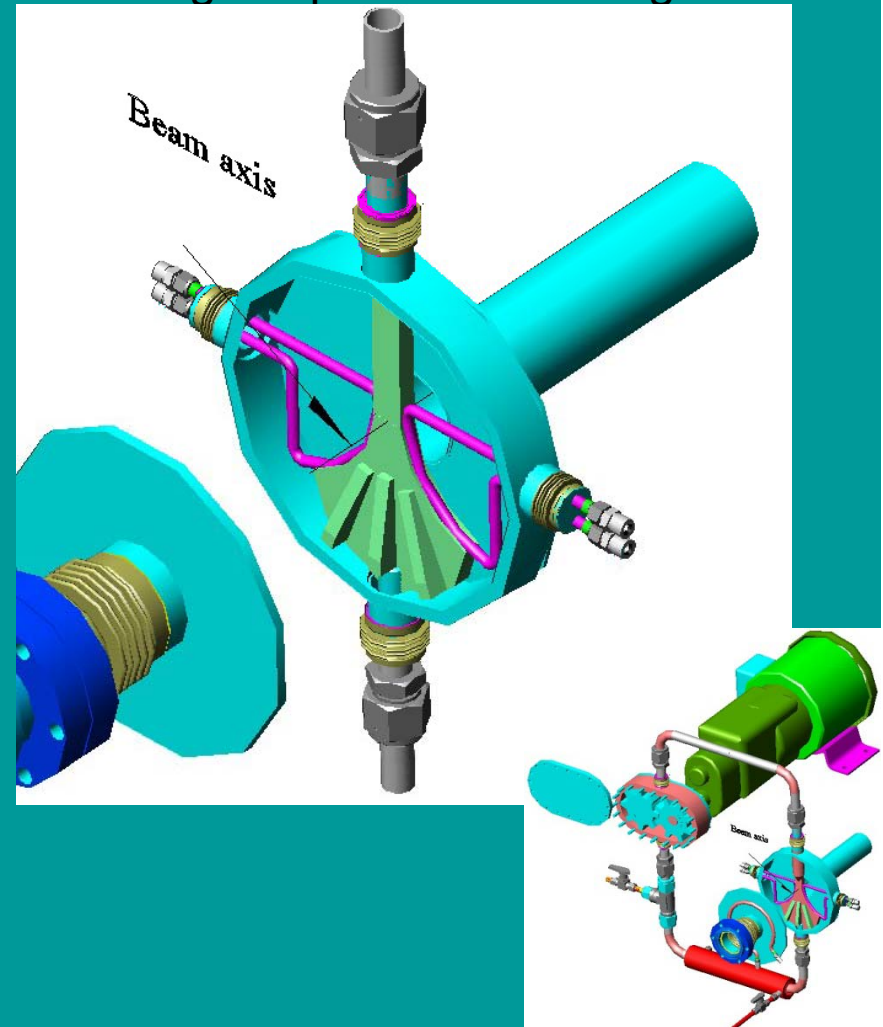
BiPb has melting temperature 154 deg C. Hg has boiling temperature 354 deg



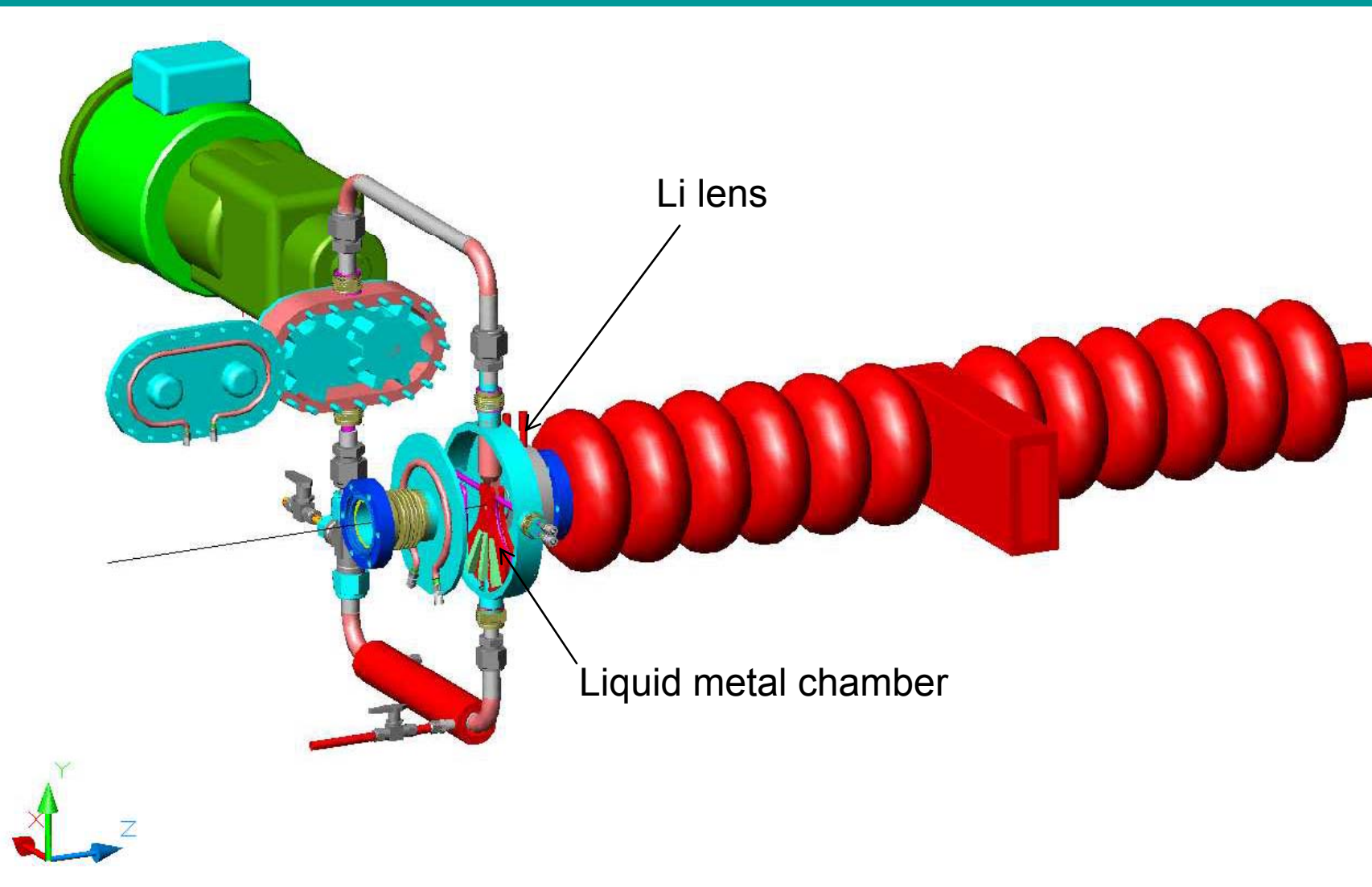
Gear pump.

Hg Jet velocity ~10m/s

Calculations show absolute feasibility of this approach

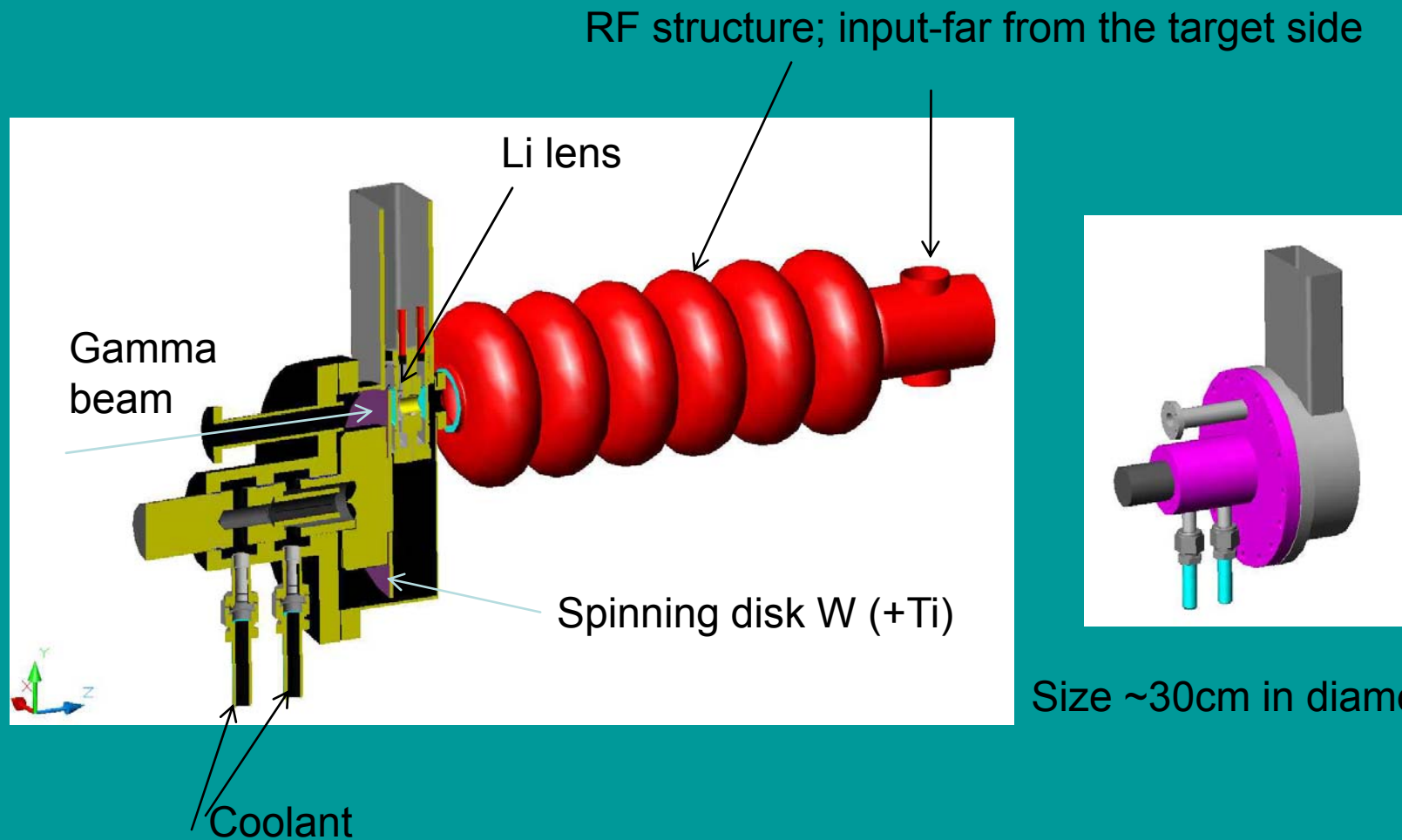


Conversion unit with liquid metal target and Lithium lens (described below)



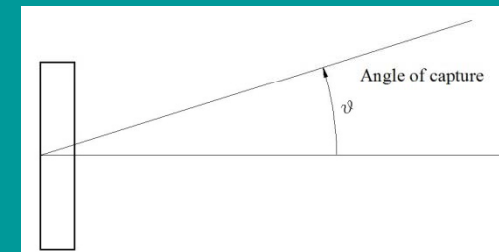
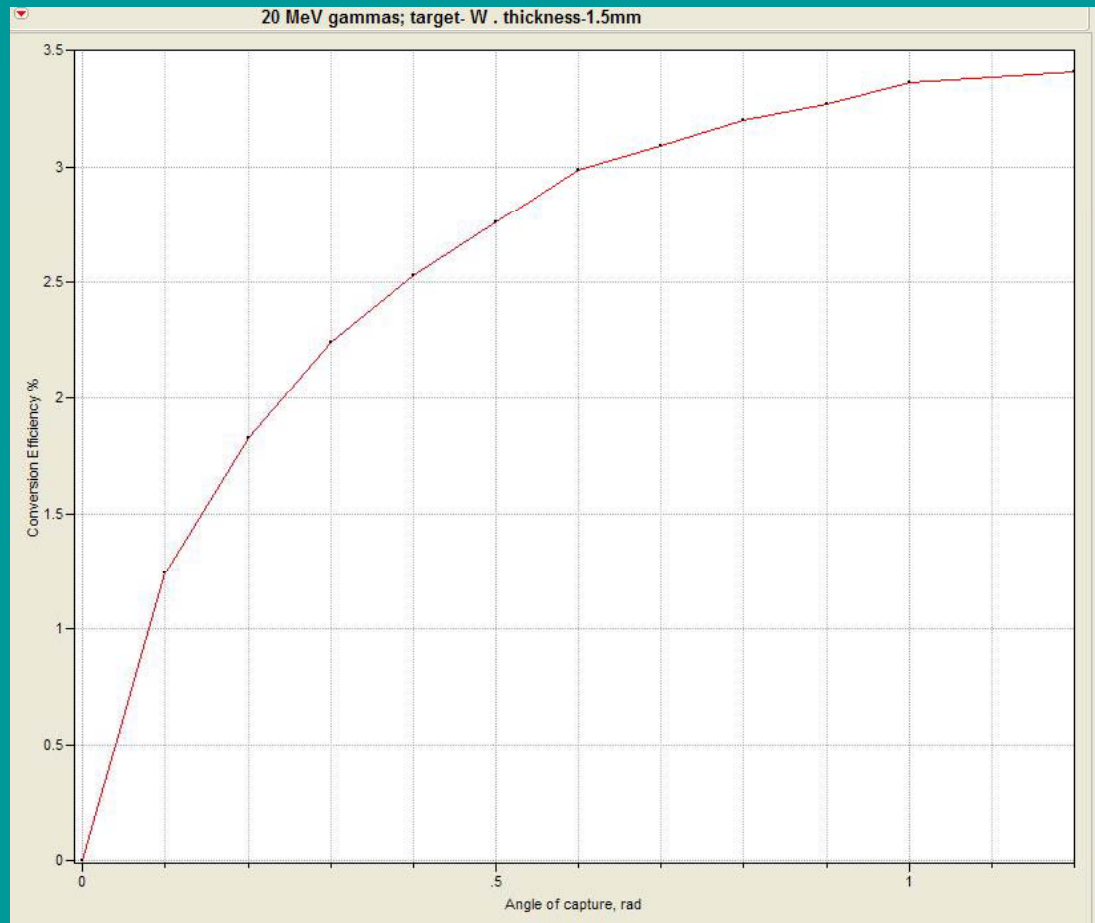


## Conversion unit on a basis of spinning W(+Ti) and Lithium lens



# COLLECTION OPTICS DESIGN

$$\text{Efficiency} = N_{e^+} / N_{\text{gammas}}$$



Angle shown ~0.3 rad

Target – Tungsten (W)

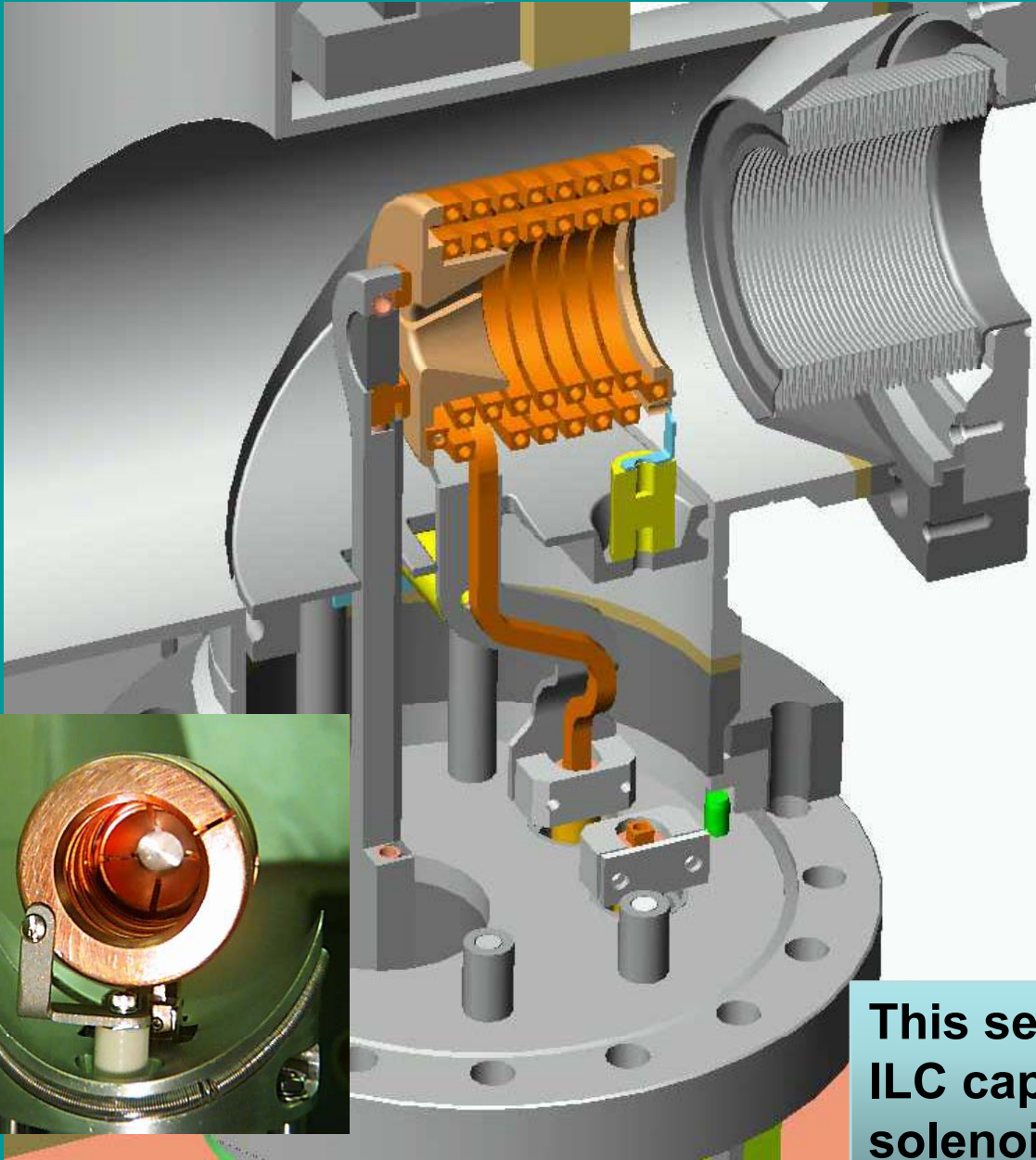
Thickness – 1.5 mm

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 ( $R=100\text{m}$ )

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

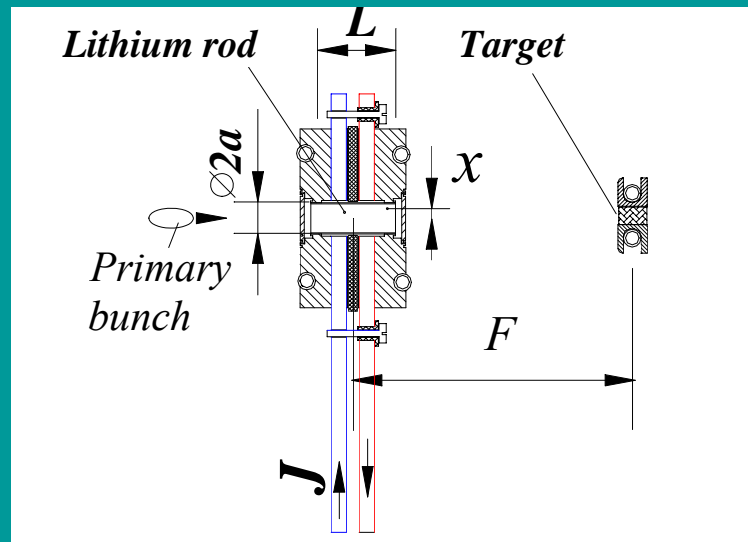
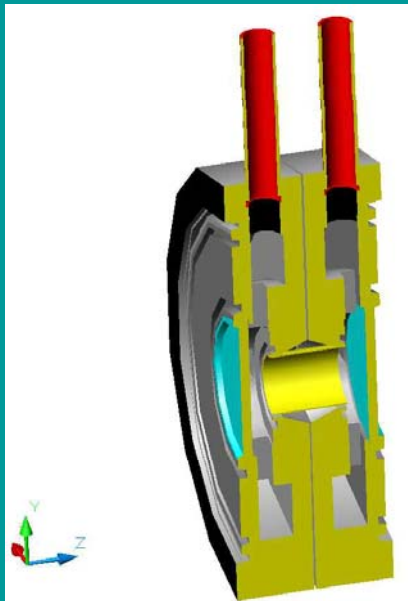
## Lithium lens basics

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

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

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

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



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

So the focal distance could be defined as the following

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

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,  $L=2$ cm,  $a=0.5$ cm

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

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

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  $g/cm^2$ . 
$$\sqrt{\langle \theta^2 \rangle} \cong \frac{13.6}{20} \sqrt{\frac{2}{156}} \cong 0.077 \text{ rad}$$

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

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

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

If the pulse lasts for  $\tau$  seconds with repetition rate  $f$ , Hz, then the average power dissipation will be

$$\langle P \rangle = I^2 \cdot R \cdot f \tau$$

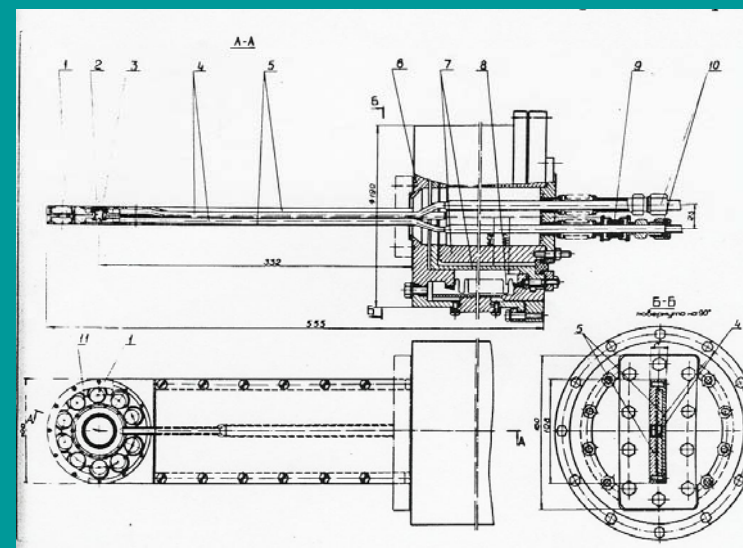
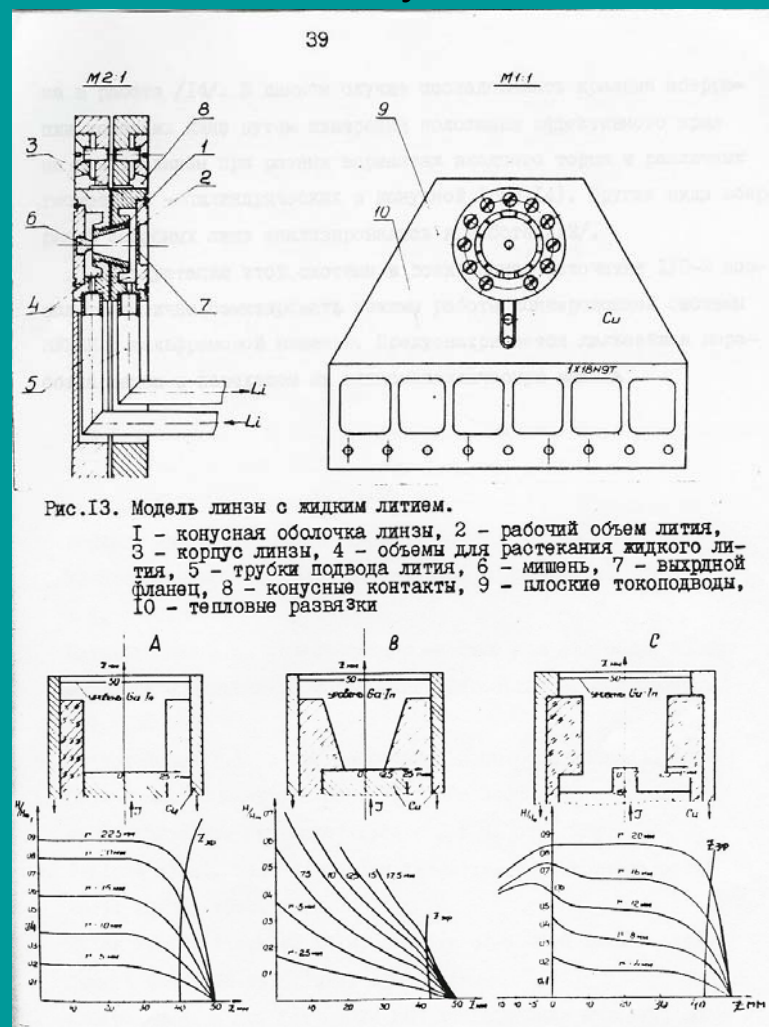
. For  $f=5Hz$ ,  $\tau \cong 2ms$  the last goes to 
$$\langle P \rangle = 2.5 \cdot 10^5 \cdot 5 \cdot 2 \cdot 10^{-3} \cong 2.5 \text{ kW}$$

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



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

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



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.

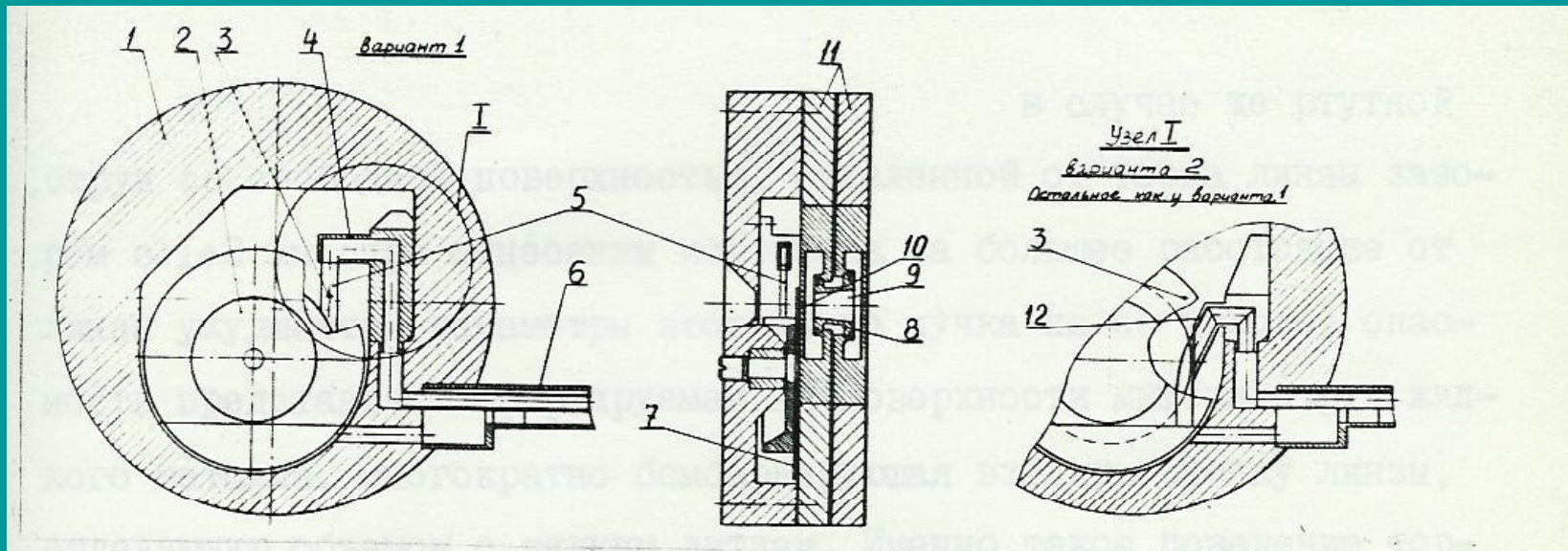
A-cylindrical lens with homogenous current leads supply at the end

B- conical lens with the same current feed

C -lens with cylindrical target at the entrance flange

## 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-Lithium 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  $\delta E \sim 2 \text{ MeV cm}^2/\text{g}$ , Secondary beam diameter  $d \approx 1 \text{ cm}$ .

Area illuminated is going to be  $S = 1/4 \pi d^2 \approx 0.4 \text{ cm}^2$ .

Volume density of Be is  $\rho \approx 1.8 \text{ g/cm}^3$ , for thickness  $0.5 \text{ mm}$

Energy deposited in a material of flange going to be

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

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

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

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

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

Although  $e^-$  defocused

Factor reflecting spare particles,  $\sim 1.5-2$ , factor two- reflecting equal amount of electrons and positrons and, finally, factor reflecting efficiency of capturing ( $\sim 30\%$ ).

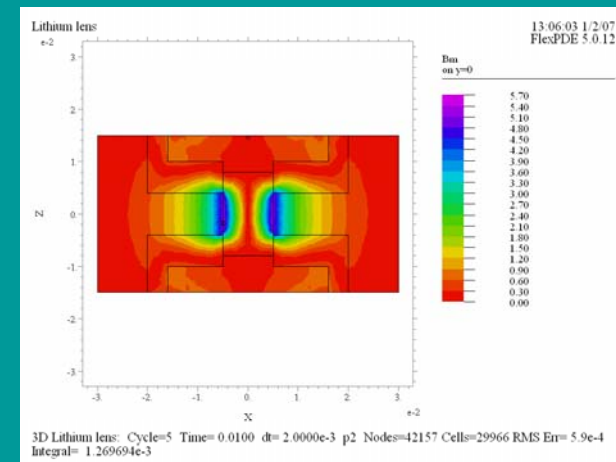
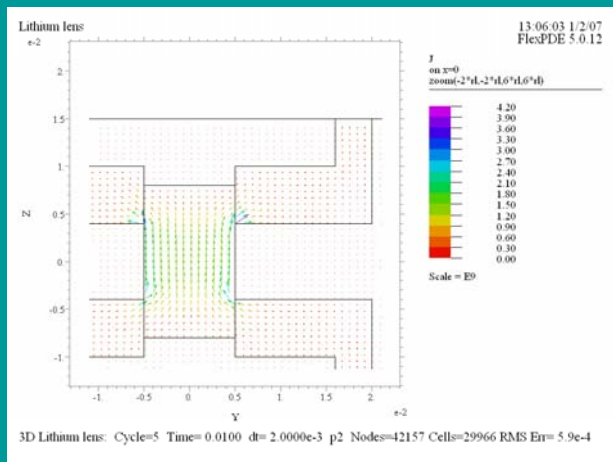
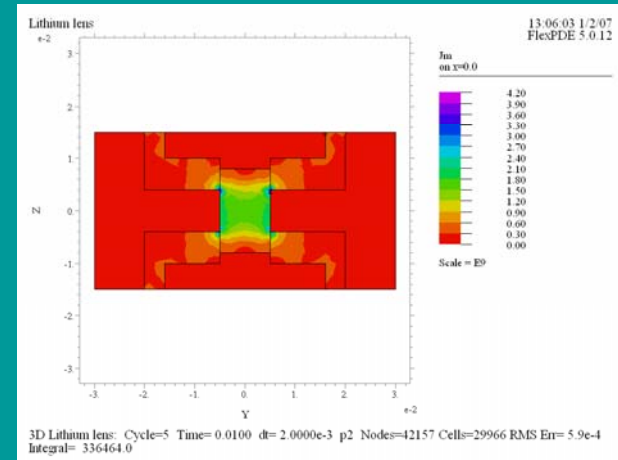
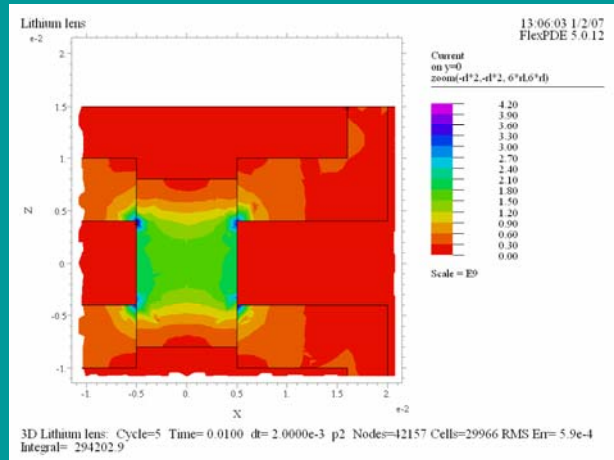
So the final number comes to  $\rightarrow \approx 21 \text{ J}$ .

Temperature gain by heat capacity of Be  $C_v \approx 1.82 \text{ J/g/degC}$  comes to

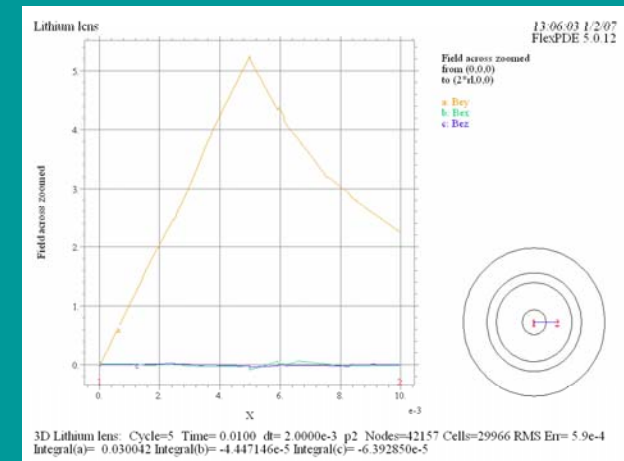
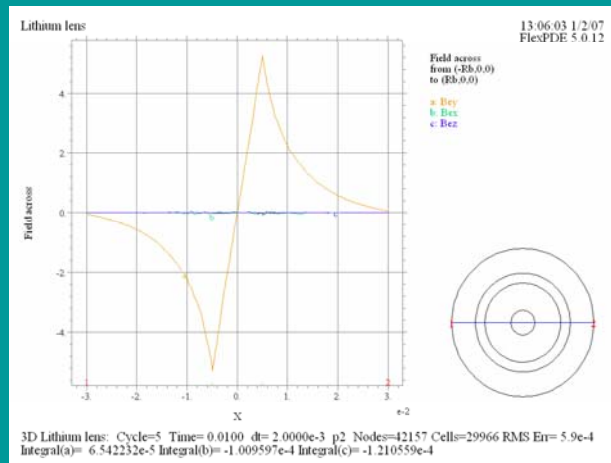
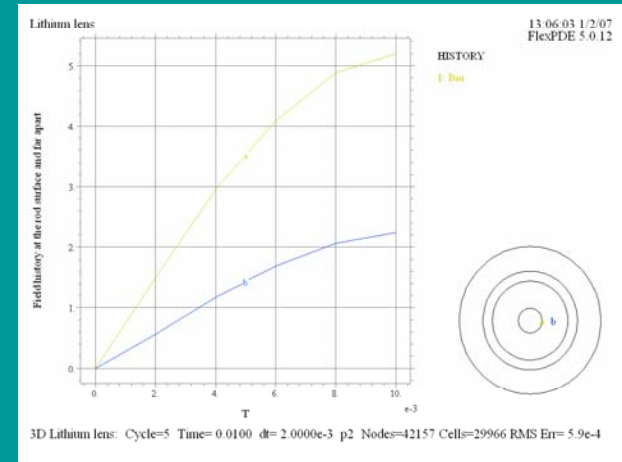
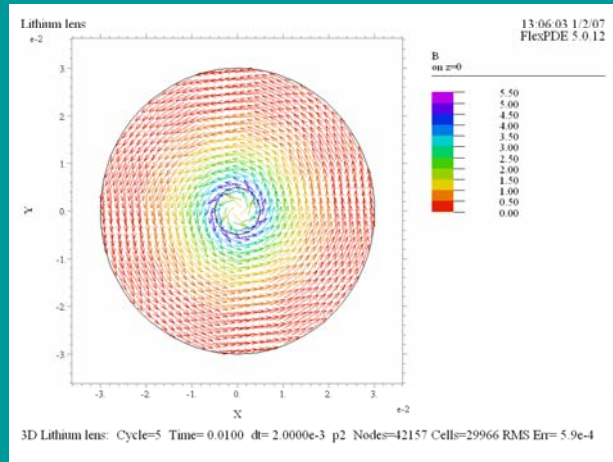
$$\Delta T \cong \frac{E_{tot}}{m C_v} \cong \frac{E_{tot}}{\rho S t C_v} \cong \frac{21}{1.8 \times 1.82 \times 0.05 \times 0.2} \cong 660 \text{ deg.}$$

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

# Recent calculation of Lithium lens done with FlexPDE<sup>®</sup> code



# Spatial field distribution over time (cinema)



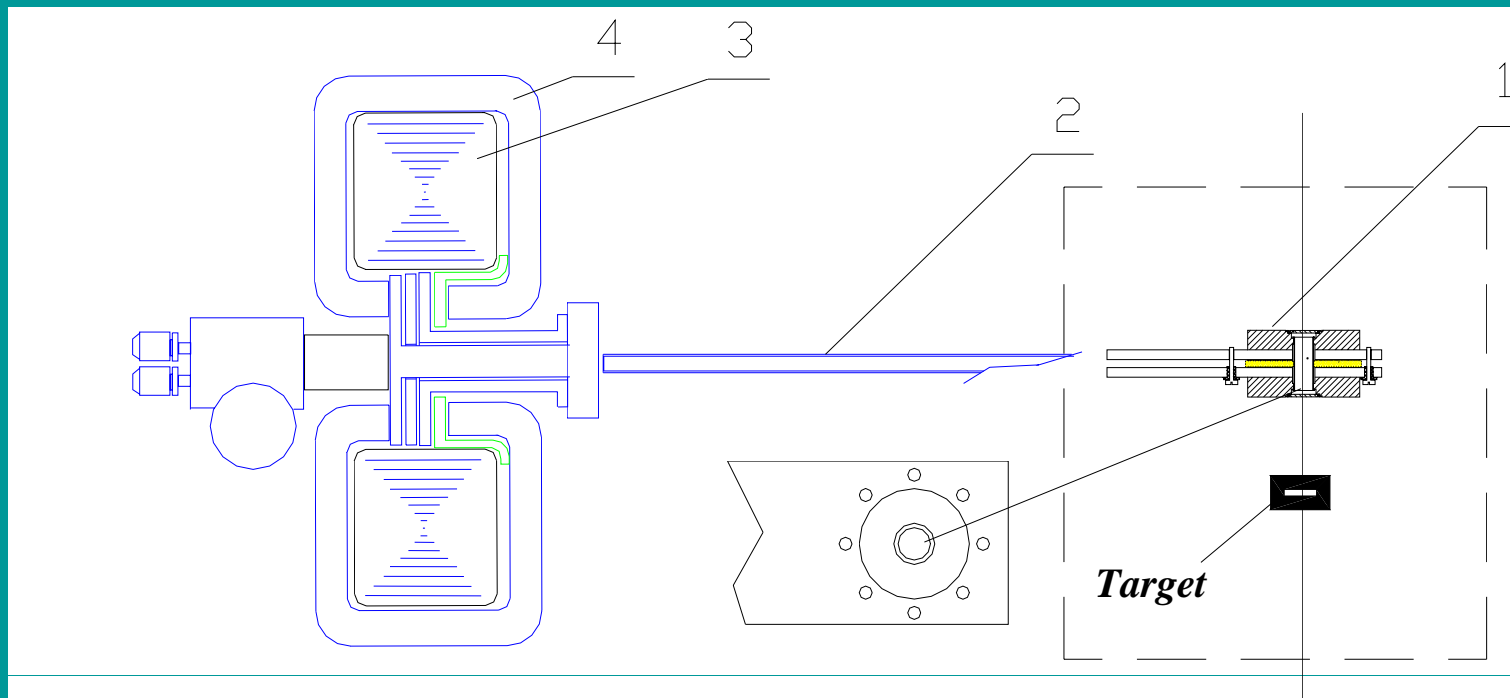


Power dissipated per pulse goes to 0.6 kJ for the current  $\sim 135$  kA and time duration half sin wave with period 40 msec

Energy stored -21.6 J so reactive component is low.

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

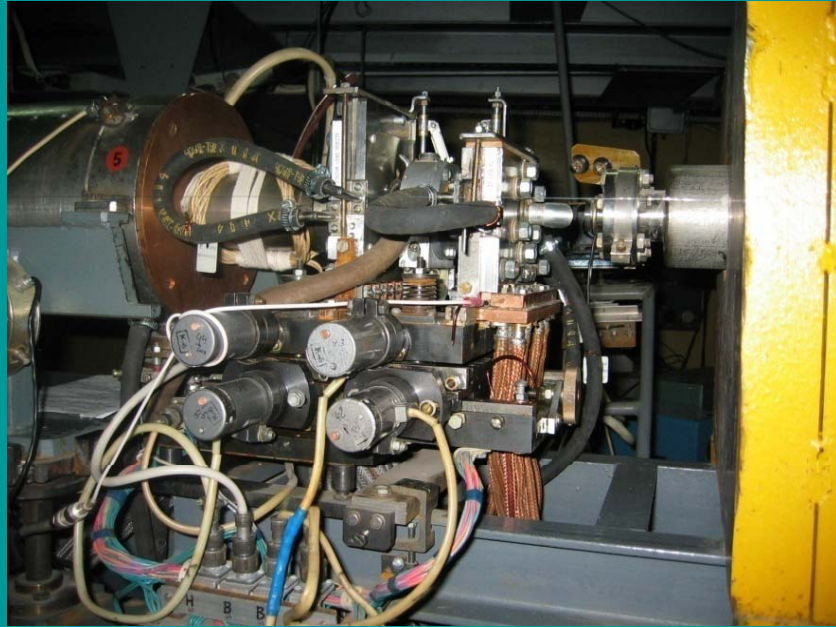
Feeding with 5<sup>th</sup> harmonic allows making current flat.



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  $\sim 150\text{ MeV}$

Number of particles in pulse  $\sim 2 \times 10^{11}$ ;  $\sim 0.7\text{ Hz}$  operation (defined by the beam cooling in Damping Ring)

Lenses shown served  $\sim 30$  Years without serious problem (!)

## Li lens resume

Utilization of Lithium lens allows Tungsten survival under condition required by ILC with  $N_e \sim 2 \times 10^{10}$  with moderate  $K \sim 0.3-0.4$  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

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

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  $L=0.5cm$ . Diameter of solenoidal lens is something about  $5cm$ , then for  $(HR) = 100$  kGcm (for 30 MeV particles), one can obtain

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

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

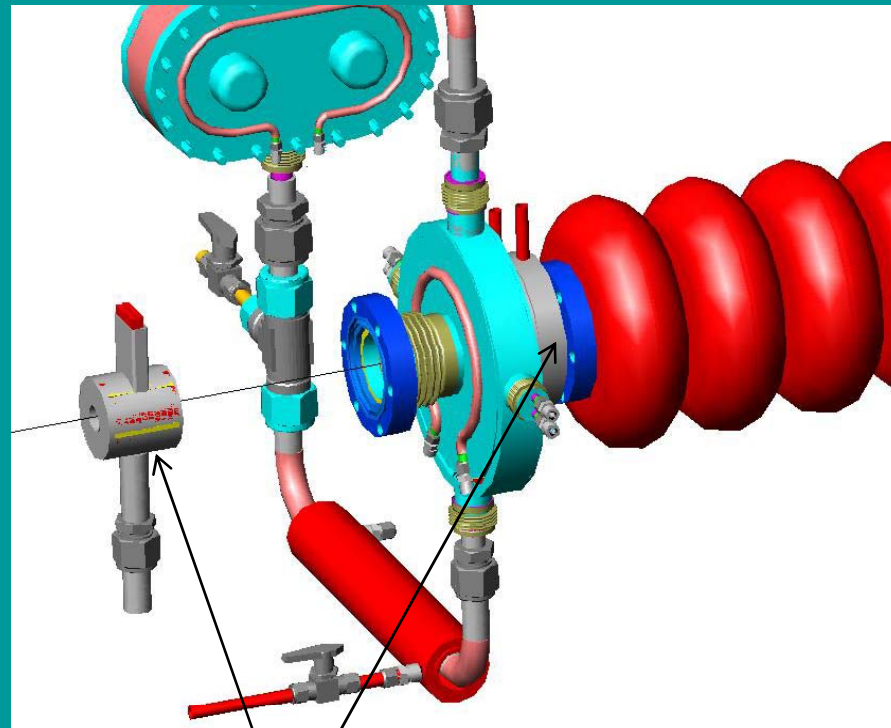
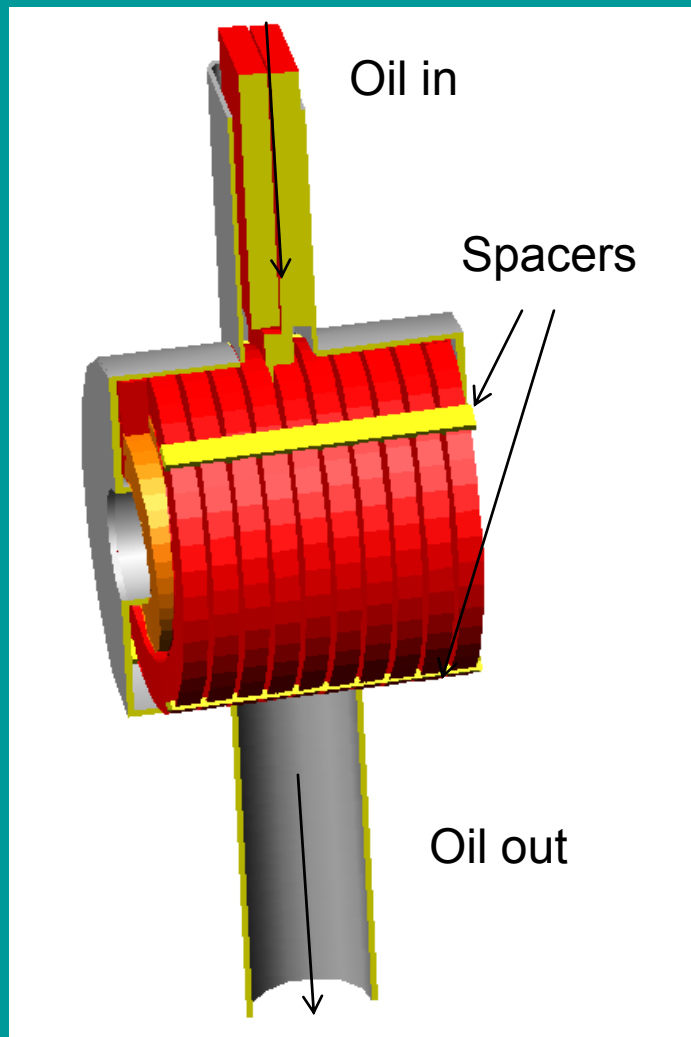
For generation of such field the amount of Ampere-turns required goes to be

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

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  $I_1 \sim 15$  kA during  $\sim 10$  msec duty time;  
Two harmonics for feeding current.  
Conductor cross-section  $\sim 5 \times 10 \text{ mm}^2$ ;  
Coolant-oil

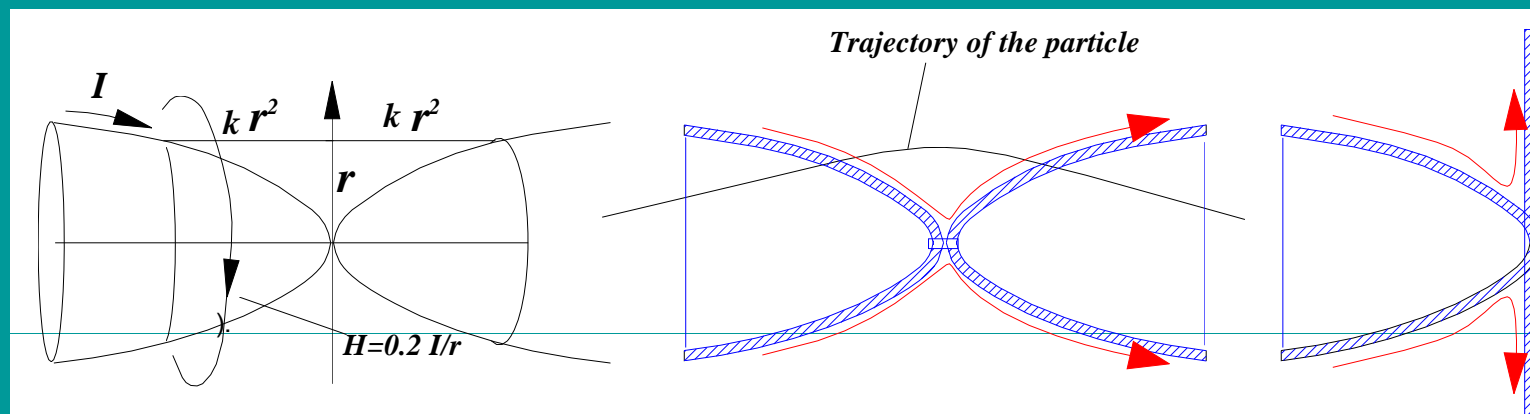


Lenses in comparison; for Li lens current leads are not shown



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

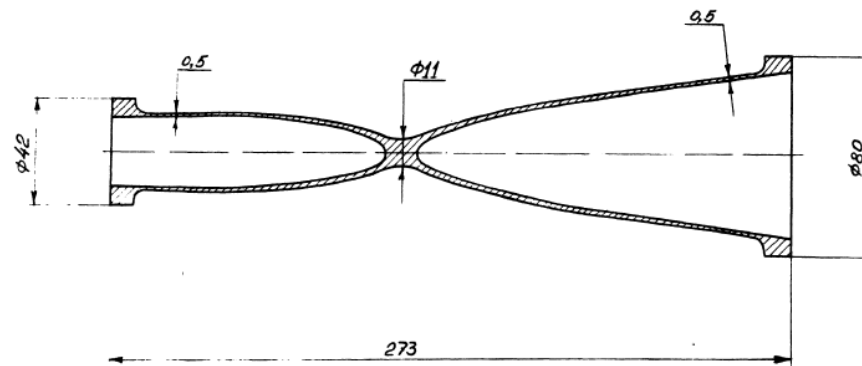


Fig. 2a Special profile of the "linear" lens.

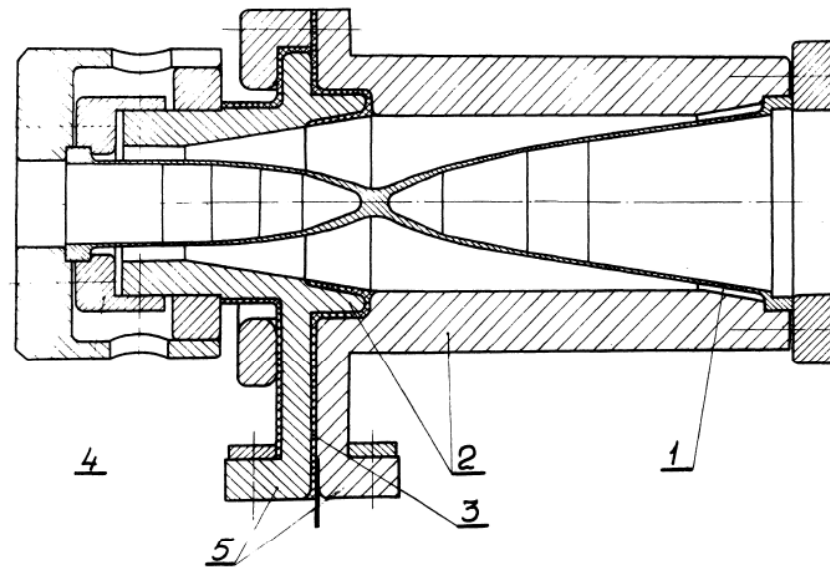


Fig. 2b Sectional view of the "linear" lens

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

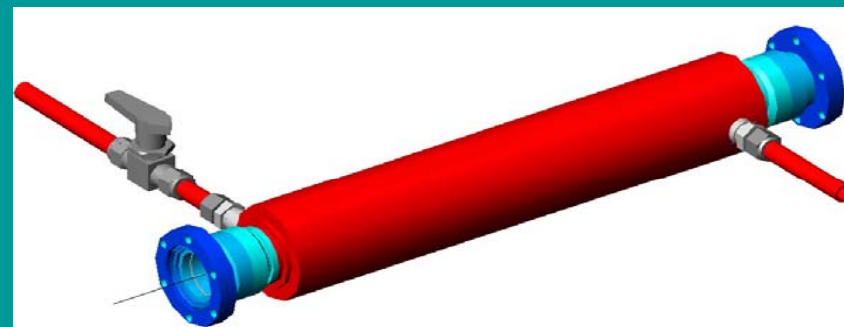
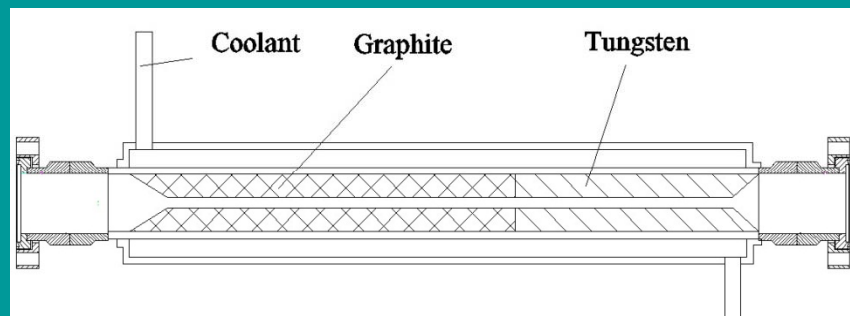
# COLLIMATORS

- ✓ Collimator for gammas
- ✓ Collimators for full power primary beam

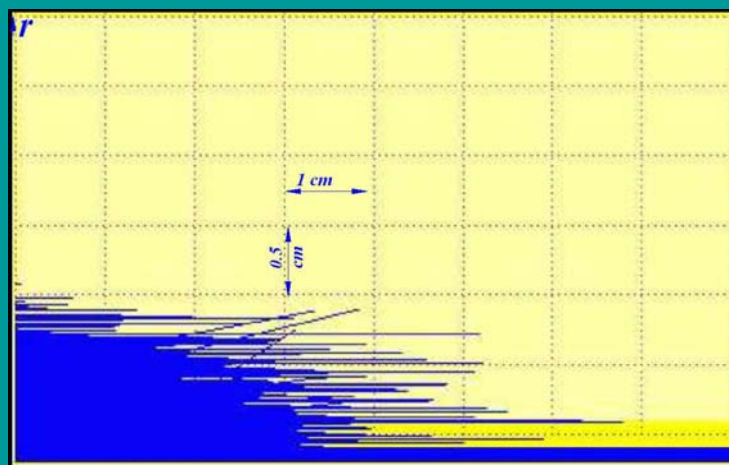
- See A.Mikhailichenko, "*Collimators for ILC*", PAC 2006, European Particle Accelerator Conference (EPAC 06), Edinburgh, Scotland, 26-30 Jun 2006. Proceedings, pp.807-809

## Collimator for gammas

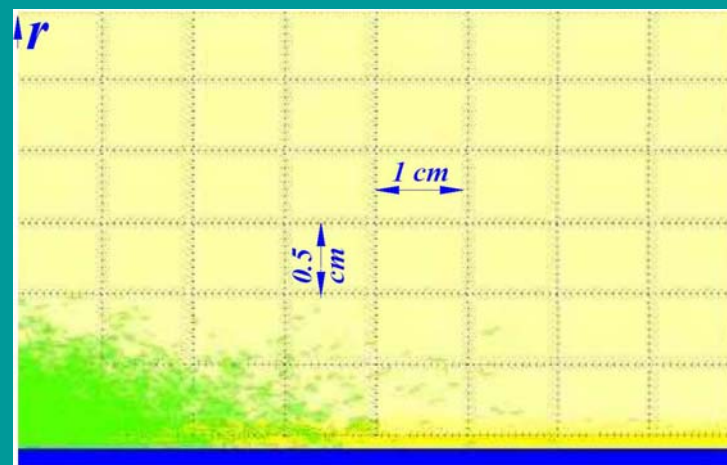
Pyrolytic Graphite (PG) is used here. The purpose of it is to increase the beam diameter, before entering to the W part. Vacuum outgassing is negligible for this material. Heat conductivity  $\sim 300 \text{ W/m}\cdot\text{oK}$  is comparable with meals. *Beryllium* is also possible here, depending on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



Transverse dimensions defined by Moliere radius



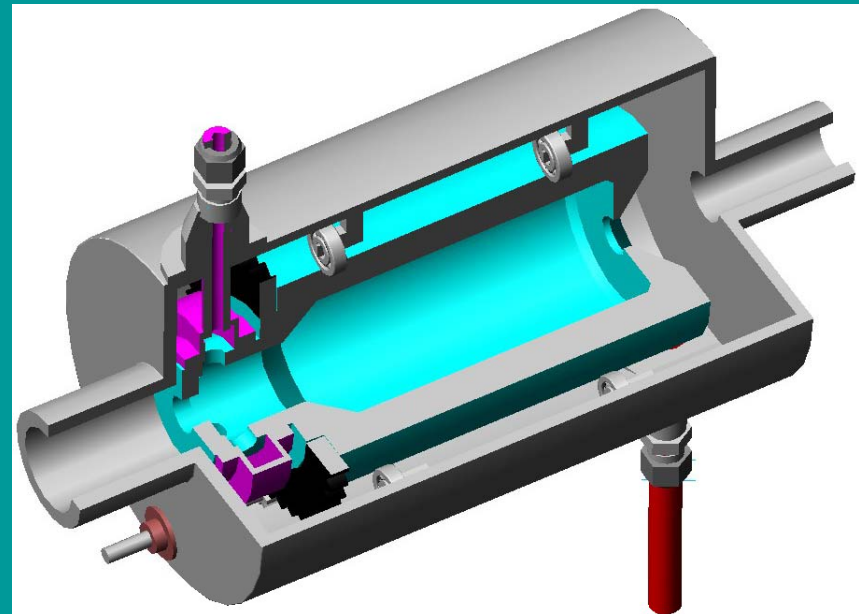
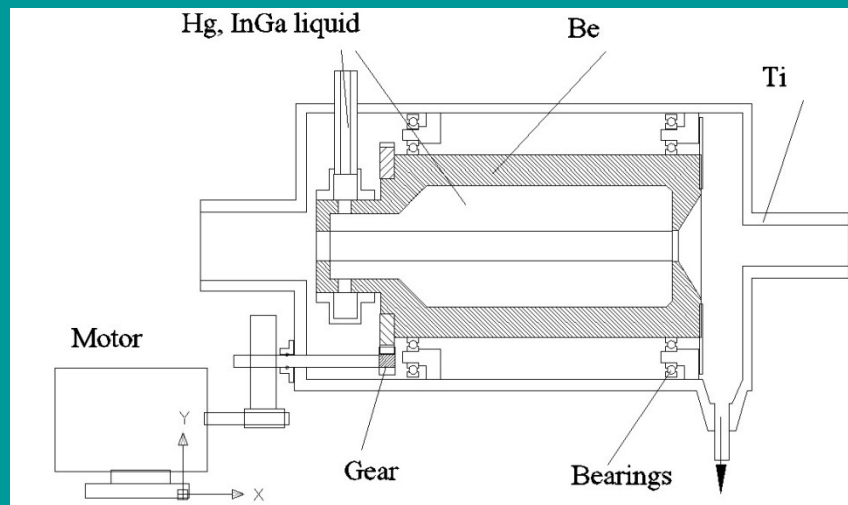
Gamma-beam.  $s_g = 0.5 \text{ cm}$ , diameter of the hole (blue strip at the bottom)  $d = 2 \text{ mm}$ . Energy of gamma-beam coming from the left is  $20 \text{ MeV}$ .



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  $\sim(0.5-1)\hbar\omega$  –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

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

where  $\vec{E} \sim Ze\vec{r}/r^3$  stands for repulsive (for positrons) electrical field of nuclei, factor  $G = \frac{g-2}{2} \cong 1.1596 \times 10^{-3} \approx \frac{\alpha}{2\pi}$ . Deviation of momentum is simply  $d\vec{p}/dt = e\vec{E}$ .

So the spin equation becomes

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

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

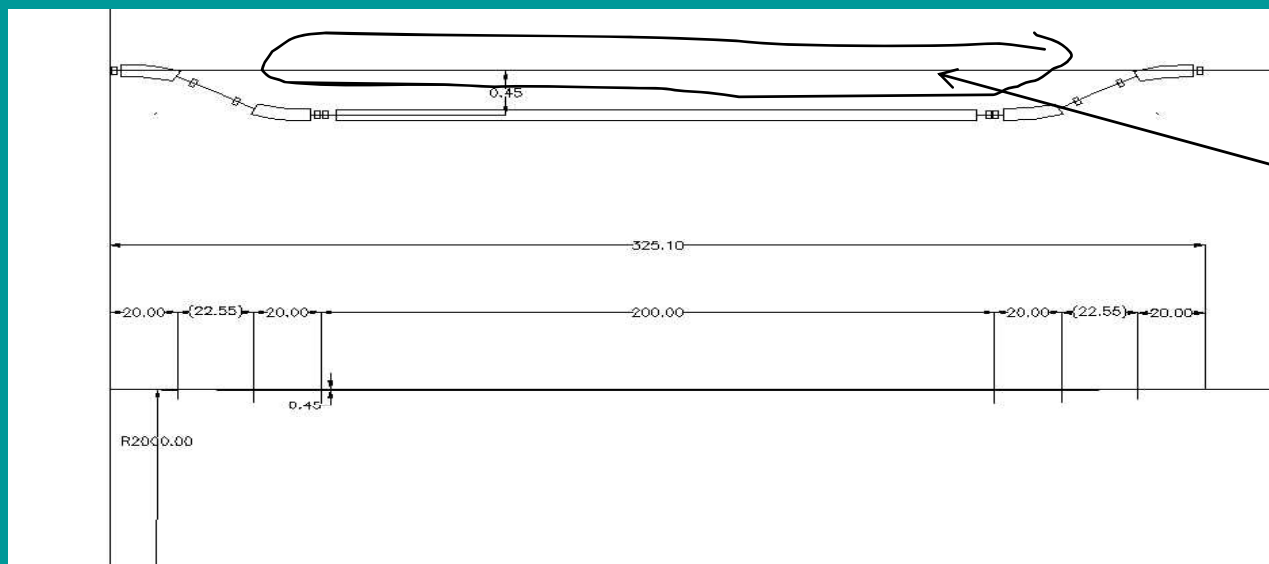
$$\frac{d\vec{\zeta}}{dt} = \left\{ G\gamma + \frac{\gamma}{\gamma+1} \right\} \cdot \vec{\zeta} \times (\dot{\vec{\beta}} \times \vec{\beta}) = \left\{ G\gamma + \frac{\gamma}{\gamma+1} \right\} \cdot \vec{\zeta} \times \frac{d\vec{\varphi}}{dt}, \quad (A18)$$

where  $\varphi$  stands for the scattering angle and the vector  $d\vec{\varphi}/dt$  directed normally to the scattering plane. For intermediate energy of our interest  $\gamma \sim 40$ , so the term in bracket  $\sim 1$  and, finally

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

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

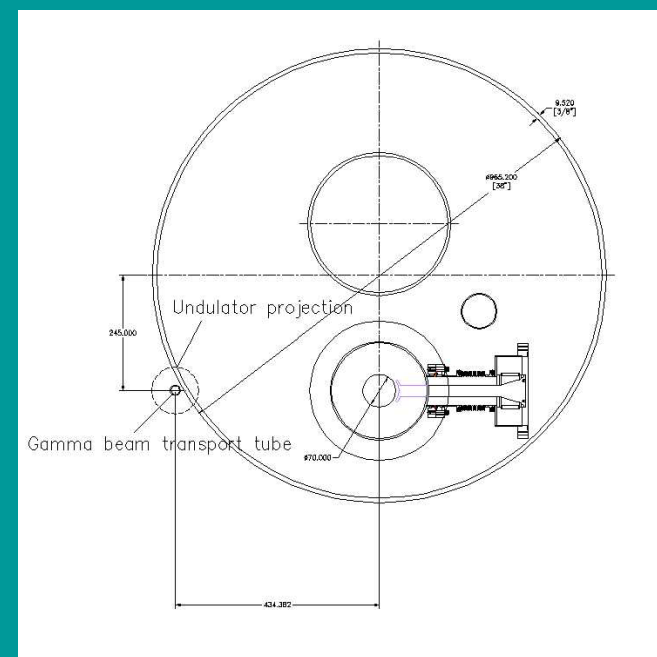
# UNDULATOR CHICANE



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.Vsevolozskaya, 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.



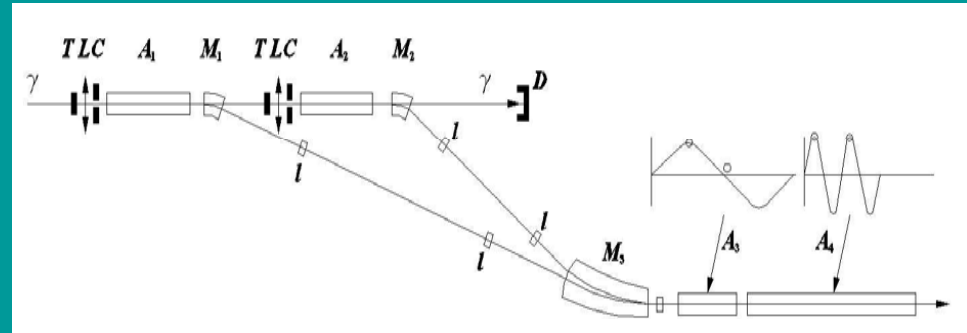
# COMBINING SCHEME

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.

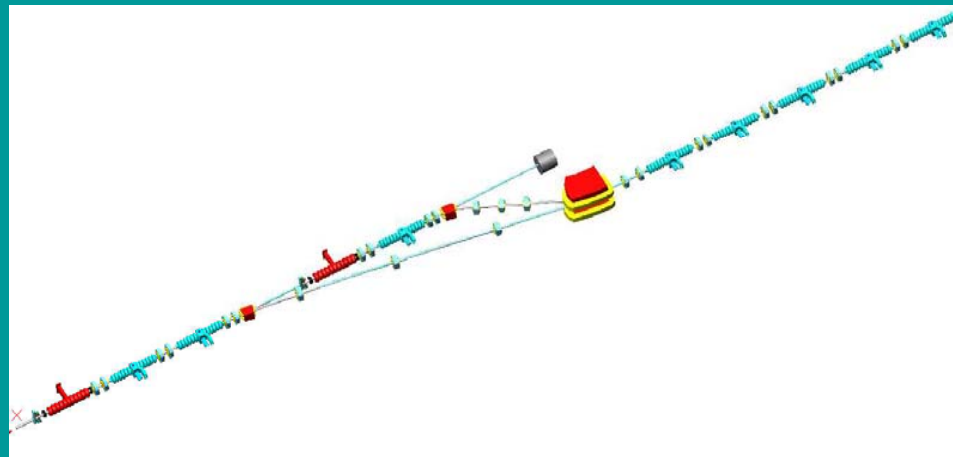
Combining in longitudinal phase space could be arranged easily in the same RF separatrix in damping ring.

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  $A_1$  and  $A_2$  are slightly different,  $A_1 > A_2$ .



**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;

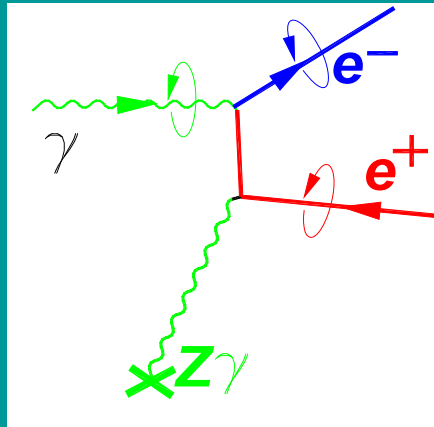
Helical iron yokes of 3 m long obtained from industry;

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

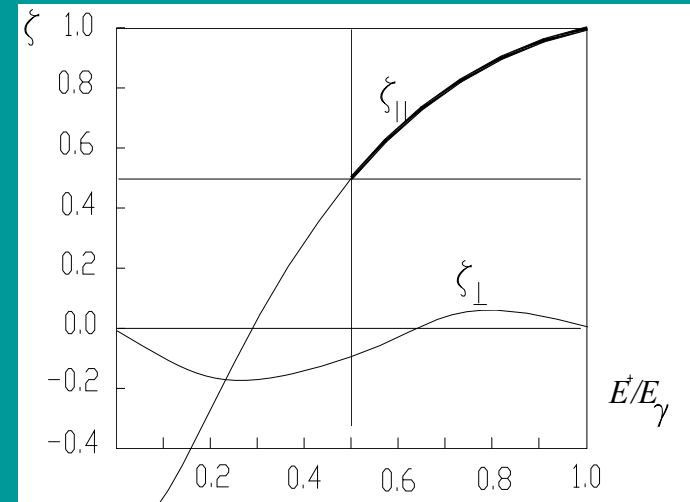
Designed undulator with 6.35mm aperture,  $K \sim 0.7$  for 10mm; and  $K \sim 1.2$  for 12mm

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

# Polarized $e^\pm$ 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

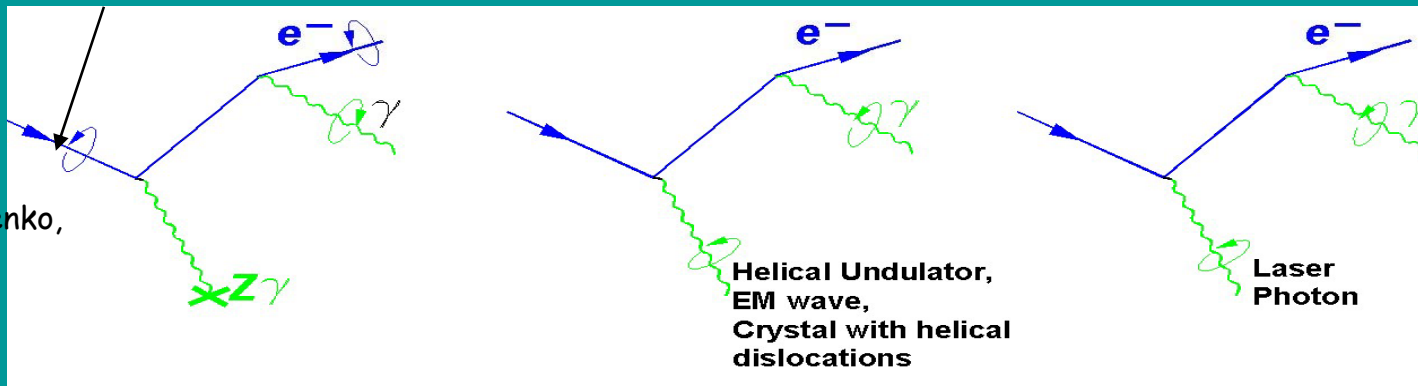


## The way to create circularly polarized photon

Polarized electron

V.Balakin, A. Mikhailichenko, 1979

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