LITHIUM LENSES FOR POSITRONS AND ANTIPROTONS IN COMPARISON

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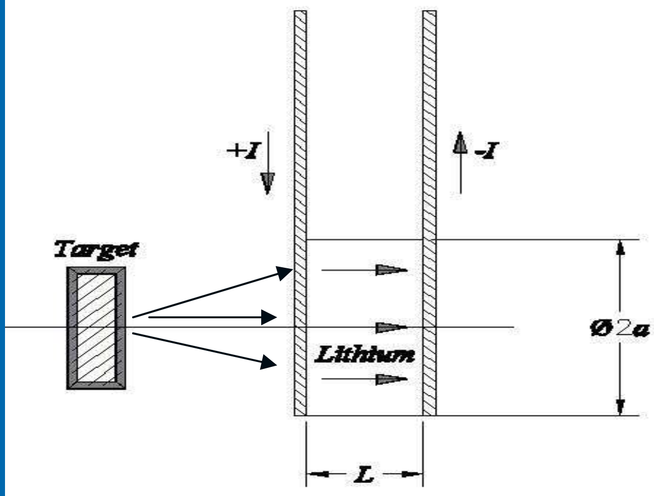
Although usage of lithium lens for focusing of (anti)protons is more or less known, usage of Lithium lens for focusing of positrons remains not known widely; the only operational Lithium lens for these purposes resides in BINP

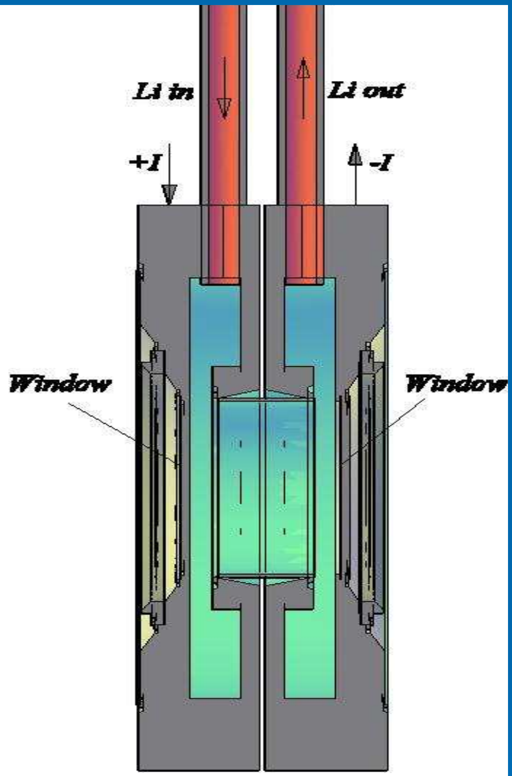
In this contest it is interesting to compare the suggested Lithium lens for ILC and routinely operational lenses for a/protons.

Support for this investigation obtained from ILC GDE Regional Directorship of America.

Li LENS BASICS

Beam and current are moving co-directionally





Li also serves as a coolant for windows

Windows made from BN, BC or Be

W is also under consideration for entrance window

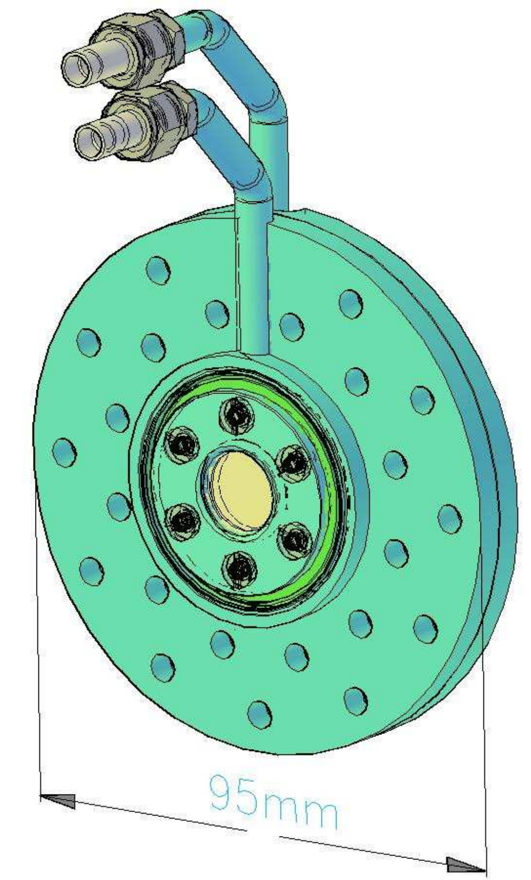
For given focal distance *F*, radius *a*, length *L*, the current required is

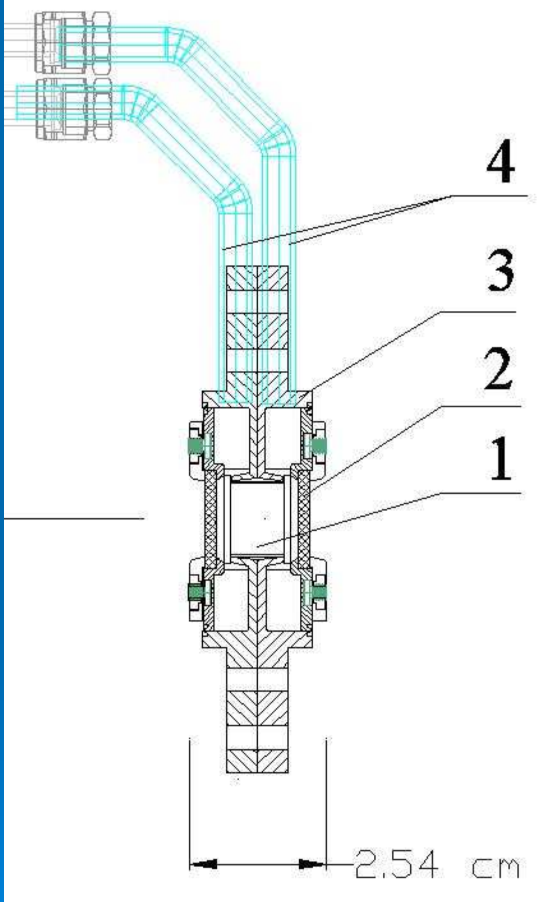
$$I \cong \frac{a^2 \cdot (HR)}{0.2FL}$$

For F~1cm, a~0.5cm, L~0.5cm, E~20MeV → I~166kA

LENS FOR POSITRONS -ILC

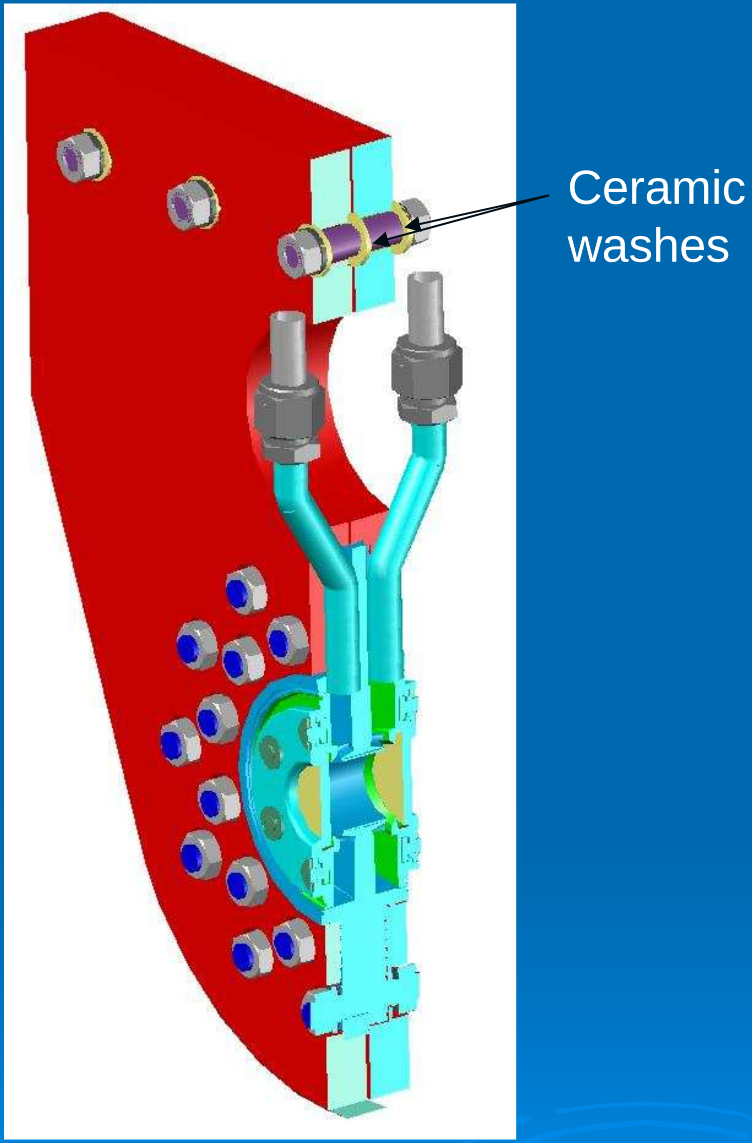
Lens suggested for ILC is represented below. Lithium (92% 7Li and 7.5% 6Li) is located inside a thin wall Titanium-alloy tube having specific resistance much higher, than Lithium.

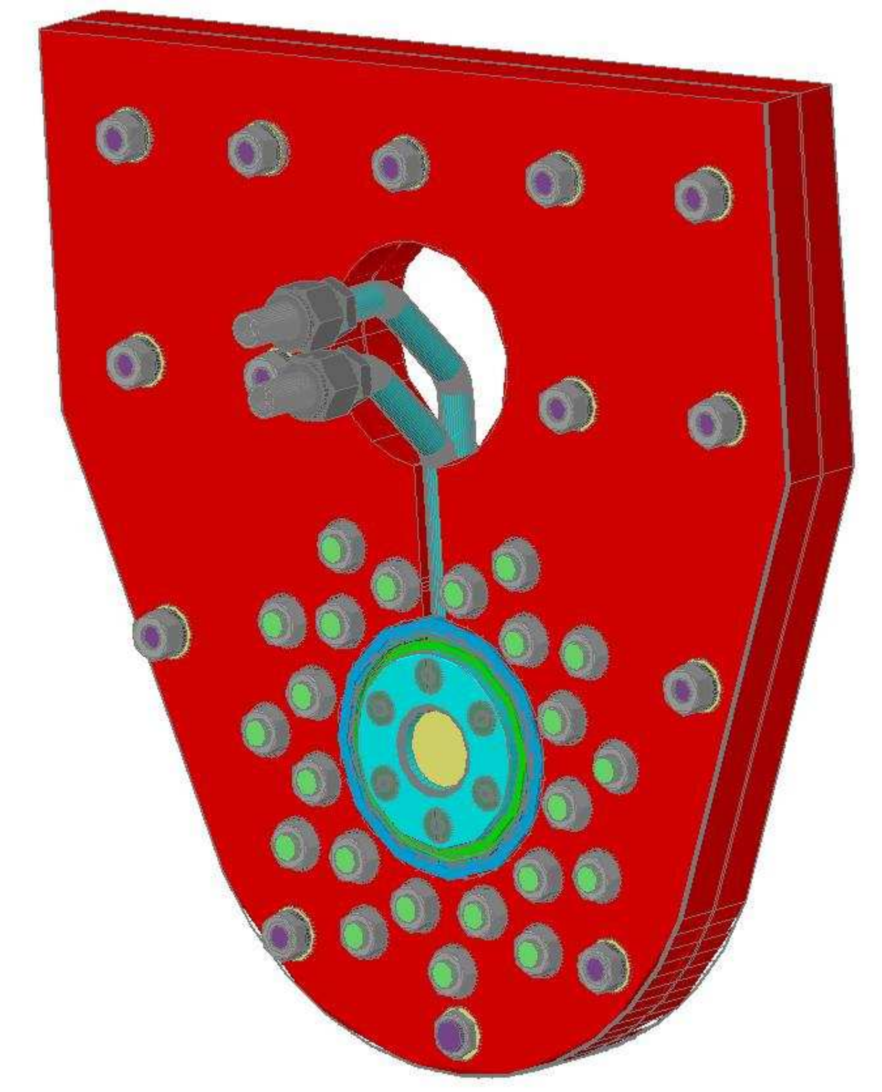




Lens itself is a small insertion at the center; extended flanges serve for electrical contact. 1–volume with Lithium, 2–window (Be/BC/BN), 3–electrical contacts with caverns for Li, 4–tubing for Lithium in/out .

Li lens with current duct attached

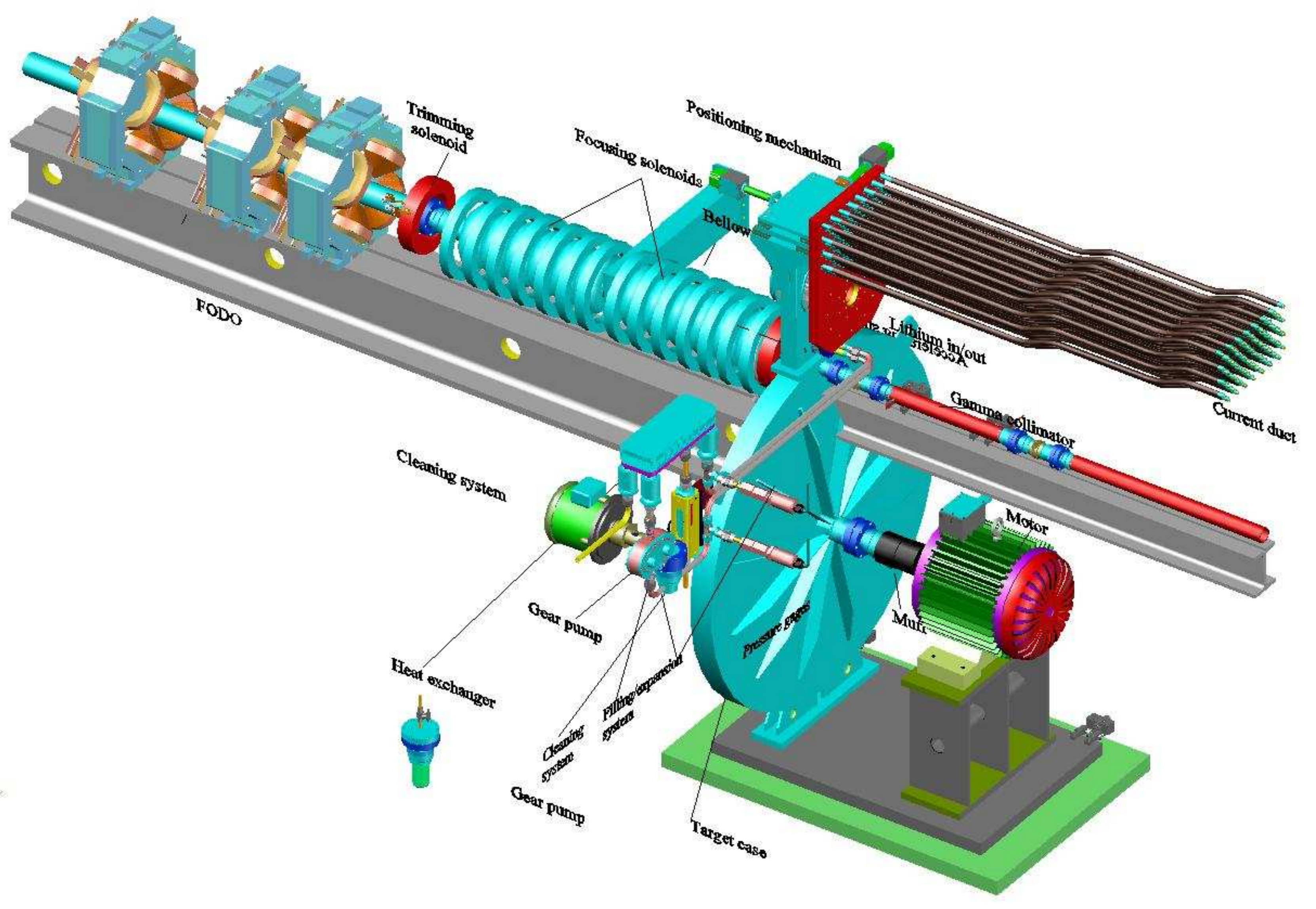




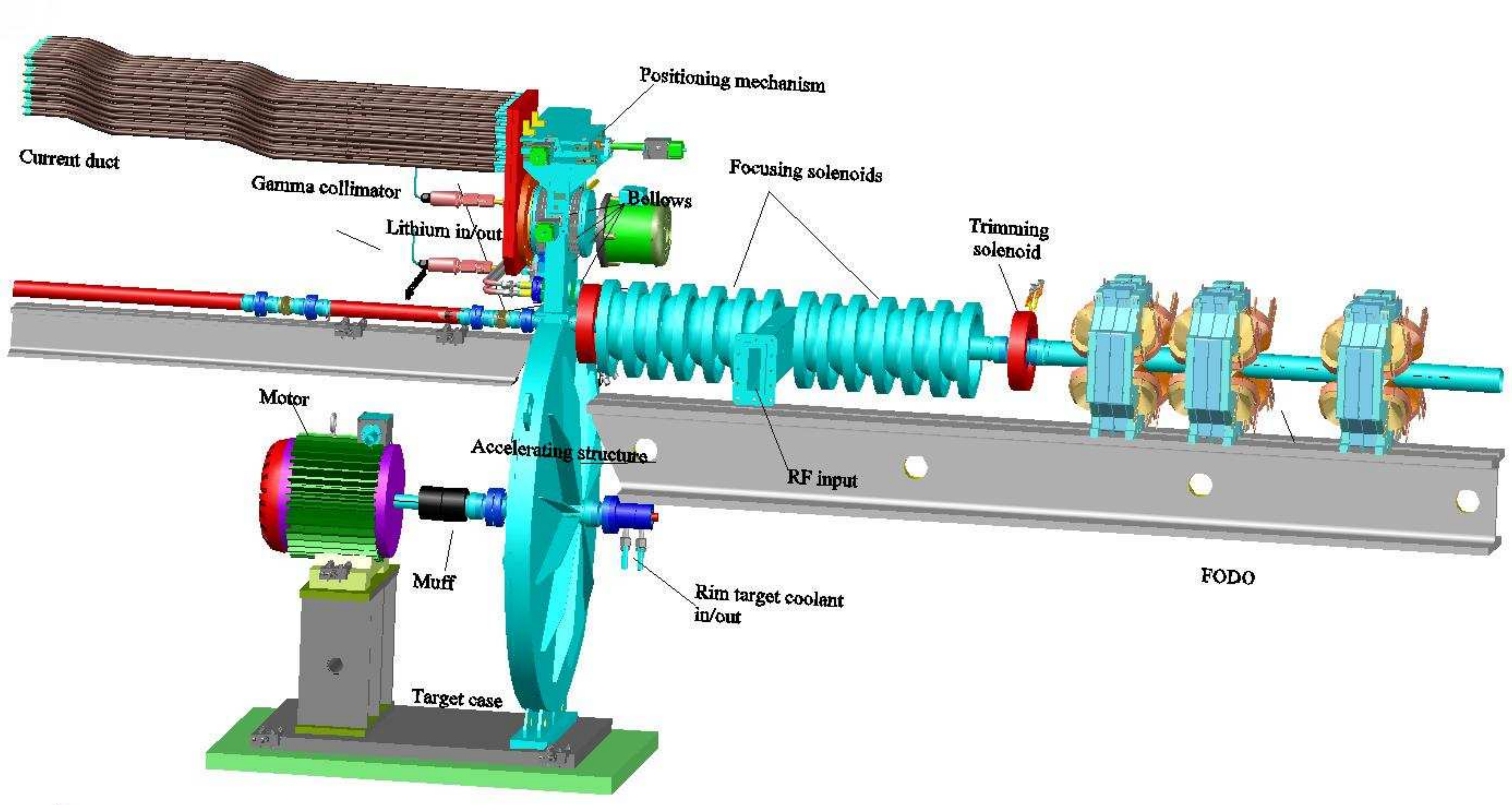
A.Mikhailichenko,” Lithium Lens (I)”, CBN -09-4, Aug 2009, 17pp.

http://www.lepp.cornell.edu/public/CBN/2009/CBN09-4/CBN%2009-04.pdf

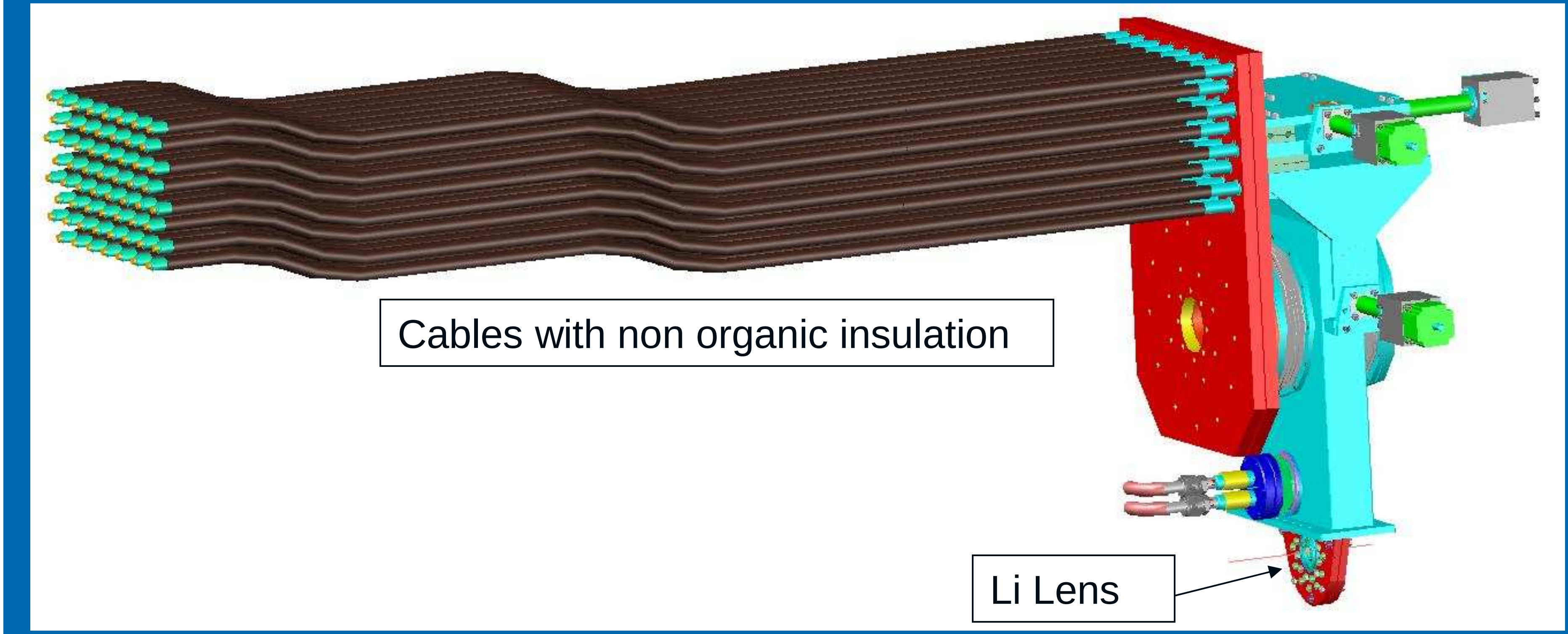
All references are there



View from other side



Lithium lens with current duct

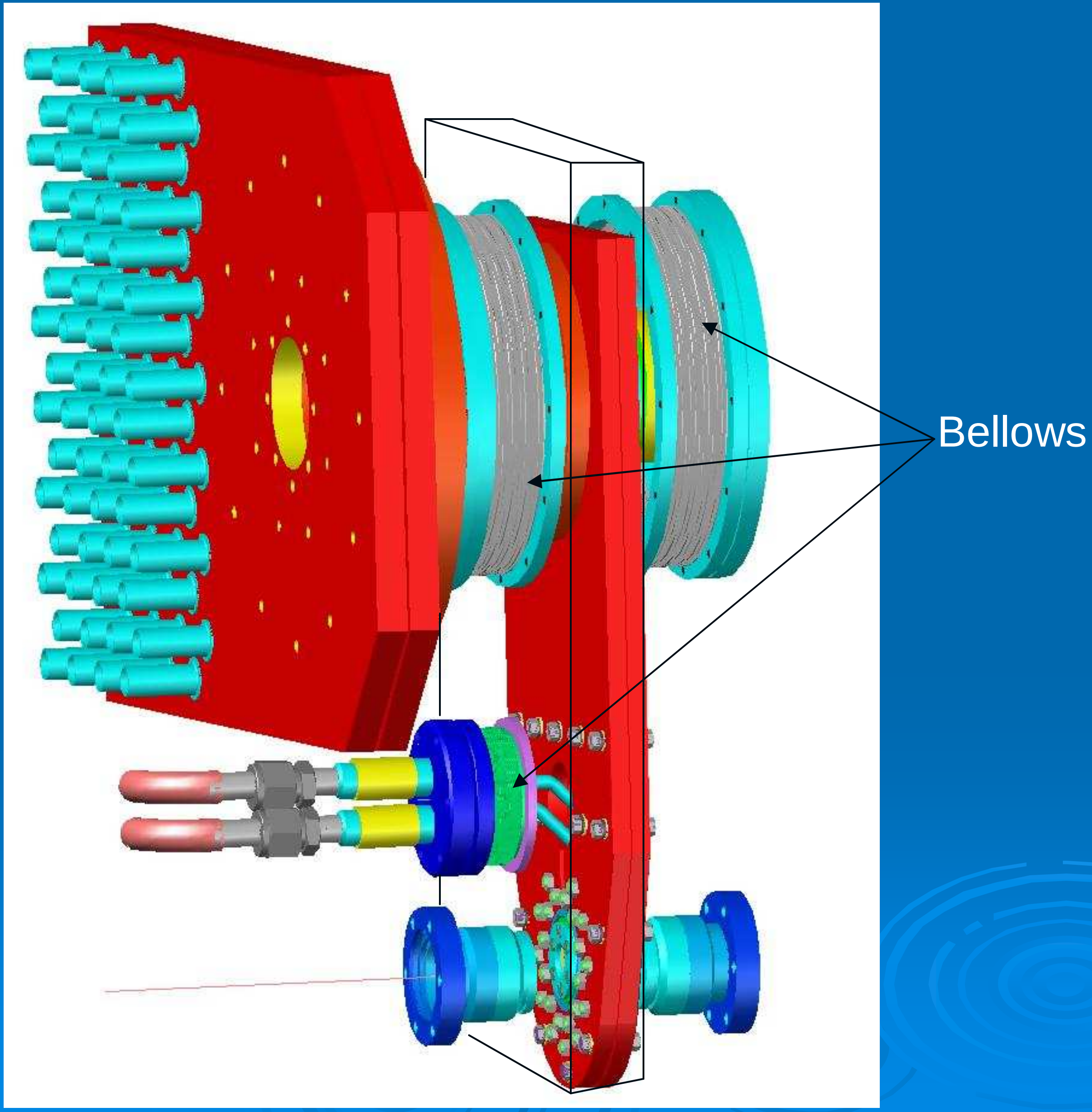


Cables with non organic insulation

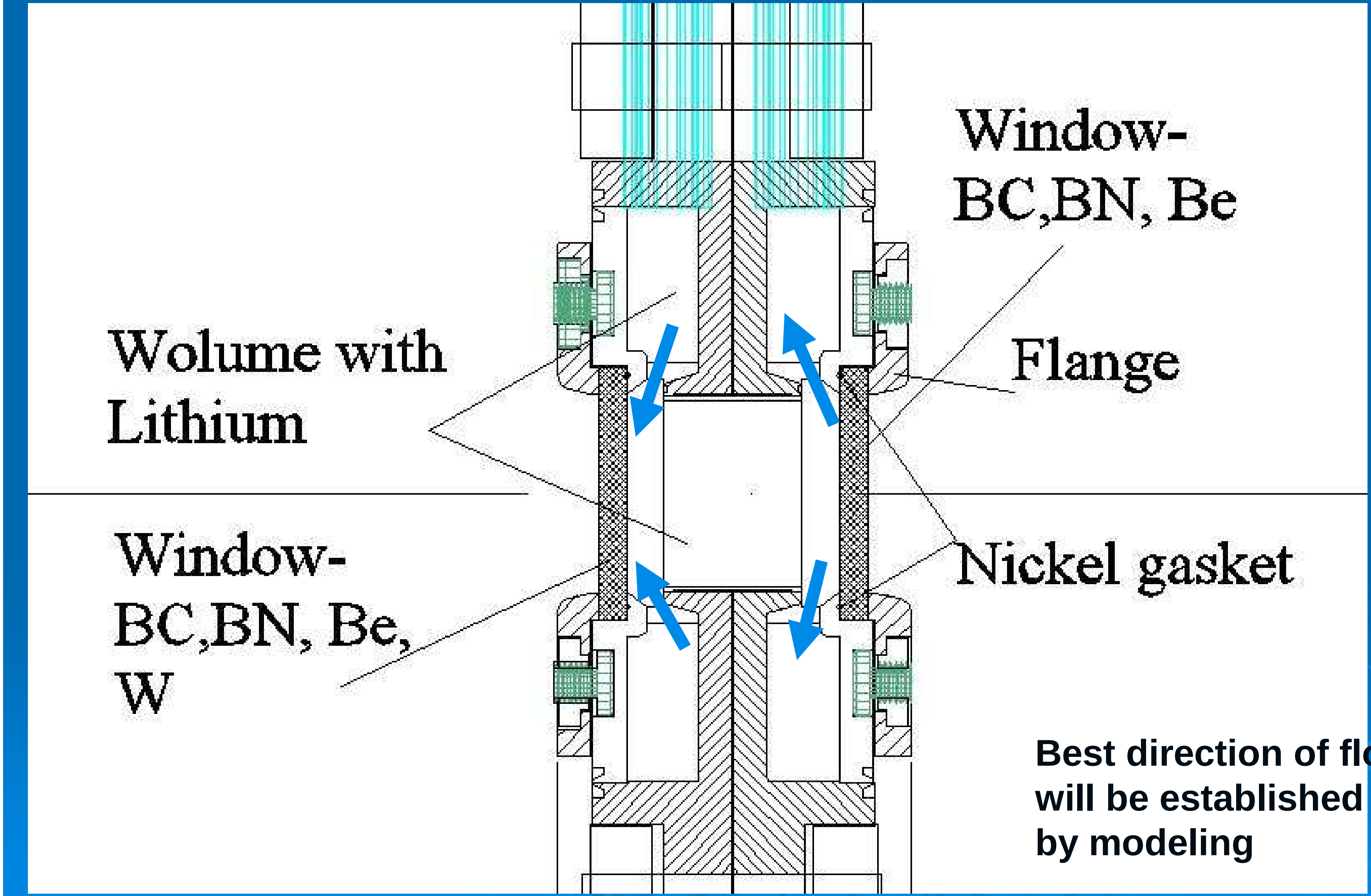
Li Lens

Current duct sould transfer ~ 150 kA in ~4 ms pulse with repetition rate up to 10 Hz

Scaled view on vacuumed feed through and lens; vacuum case not shown



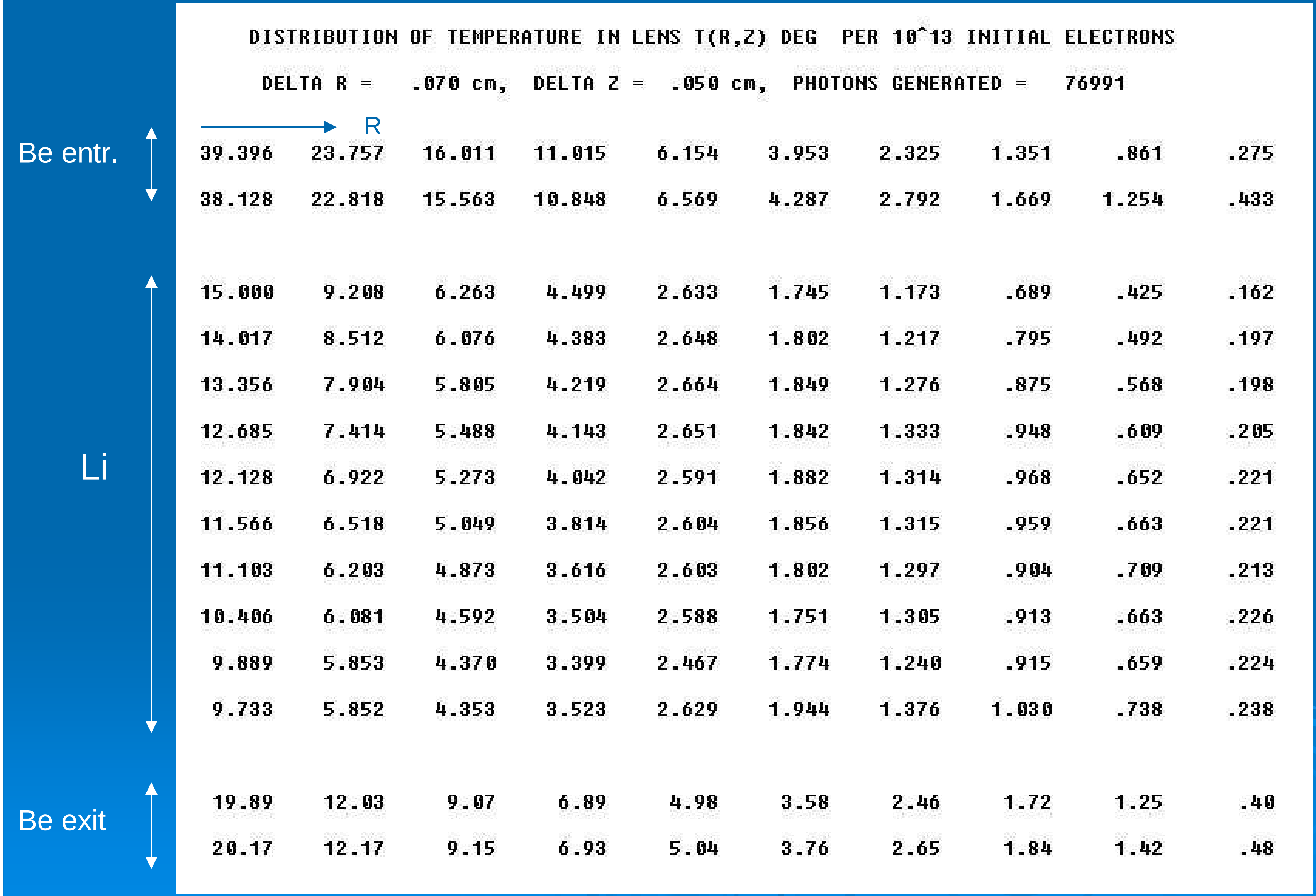
Windows attachment technique



Best direction of flow will be established by modeling

Temperature in lens generated by the beam only

K=0.92; λ=1.15; Eff=1.6; Effp=32%; Undulator length=35m; Distance to target=300m



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    DISTRIBUTION OF TEMPERATURE IN LENS T(R,Z) DEG  PER 10^13 INITIAL ELECTRONS

     DELTA R =   .070 cm,  DELTA Z =  .050 cm,  PHOTONS GENERATED =   76991

 39.396   23.757   16.011   11.015    6.154    3.953    2.325    1.351     .861     .275

 38.128   22.818   15.563   10.848    6.569    4.287    2.792    1.669    1.254     .433


 15.000    9.208    6.263    4.499    2.633    1.745    1.173     .689     .425     .162

 14.017    8.512    6.076    4.383    2.648    1.802    1.217     .795     .492     .197

 13.356    7.904    5.805    4.219    2.664    1.849    1.276     .875     .568     .198

 12.685    7.414    5.488    4.143    2.651    1.842    1.333     .948     .609     .205

 12.128    6.922    5.273    4.042    2.591    1.882    1.314     .968     .652     .221

 11.566    6.518    5.049    3.814    2.604    1.856    1.315     .959     .663     .221

 11.103    6.203    4.873    3.616    2.603    1.802    1.297     .904     .709     .213

 10.406    6.081    4.592    3.504    2.588    1.751    1.305     .913     .663     .226

  9.889    5.853    4.370    3.399    2.467    1.774    1.240     .915     .659     .224

  9.733    5.852    4.353    3.523    2.629    1.944    1.376    1.030     .738     .238


  19.89    12.03     9.07     6.89     4.98     3.58     2.46     1.72     1.25      .40

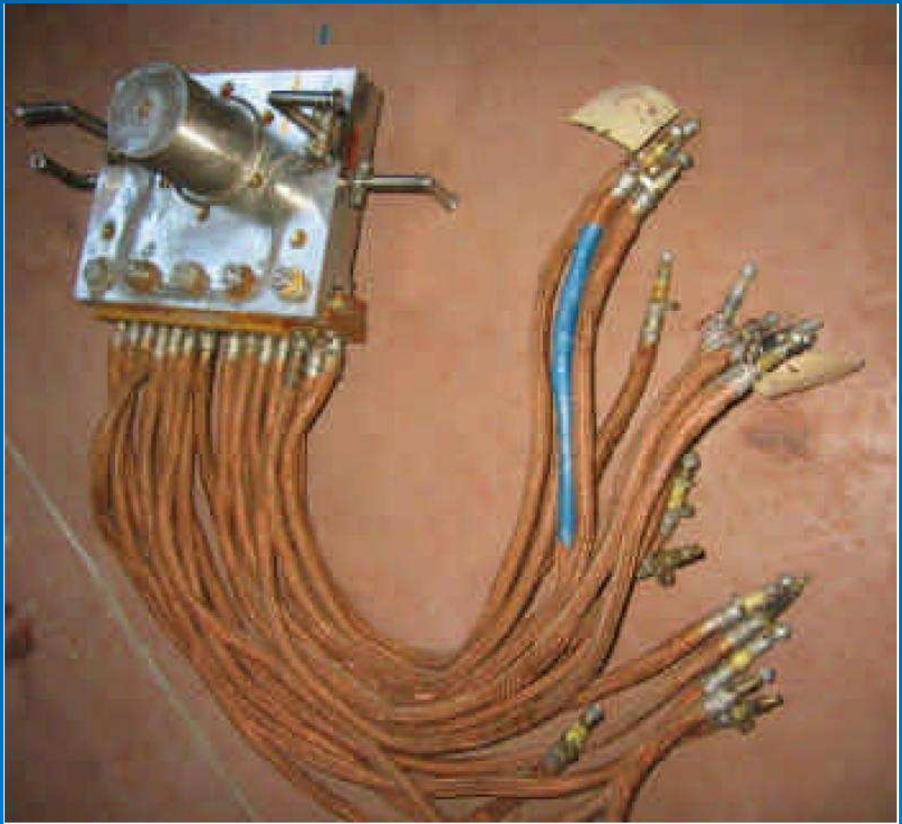
  20.17    12.17     9.15     6.93     5.04     3.76     2.65     1.84     1.42      .48
```

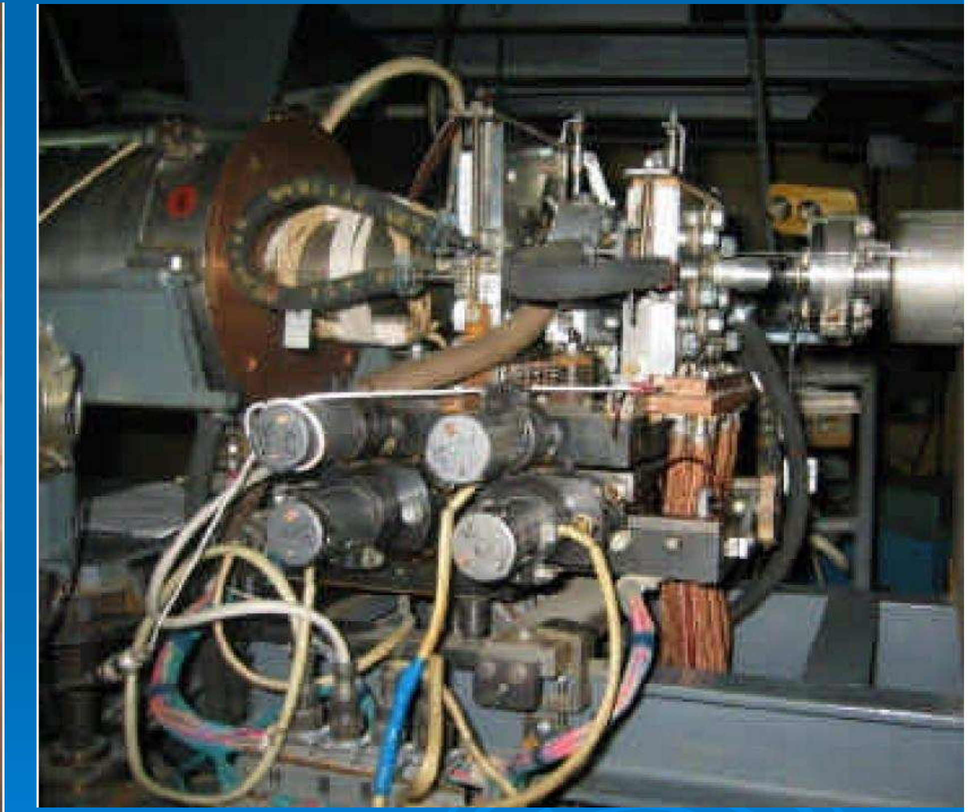
NEW TYPE OF COMMUTATORS FOR HIGH CURRENT

Fig.2. Reverse – switched dinistors for peak current from 200 kA to 500 kA and blocking voltage of 2400 V, encapsullated in hermetic metal – ceramic housing and without housing (RSD sizes of 64, 76, and 100 mm)

S.A. Belyaev, V.G.Bezuglov, V.V.Chibirikin, G.D.CHumakov, I.V.Galakhov, S.G.Garanin, S.V.Grigorovich, M.I.Kinzibaev, A.A.Khapugin, E.A.Kopelovich, F.A.Flar, O.V.Frolov, S.L.Logutenko, V.A.Martynenko, V.M.Murugov, V.A.Osin, I.N.Pegoev, V.I.Zolotovski, "*New Generation of High-Power Semiconductor Closing Switches for Puled Power Applications*", 28 ICPIG, July 15-20, 2007, Prague, Czech Republic, Topic#17, pp.1525-1528.

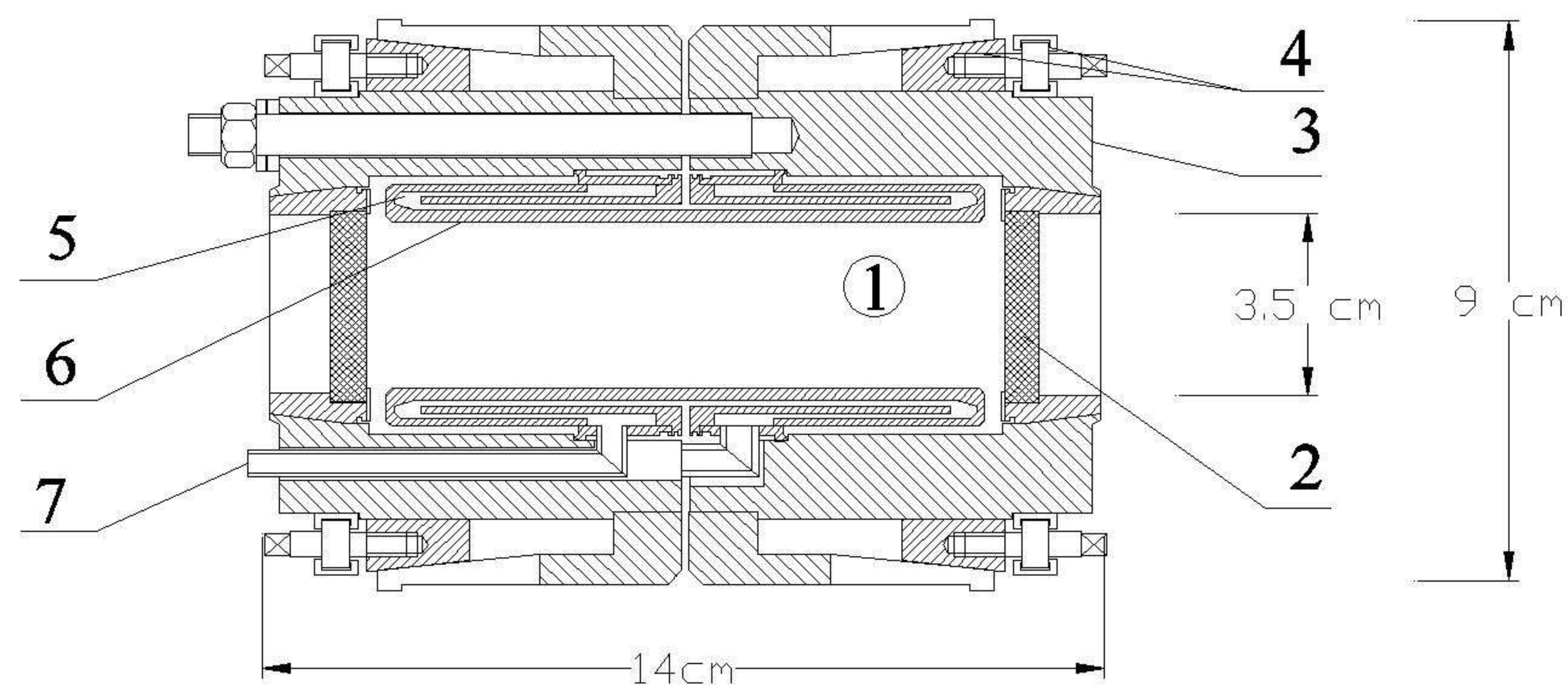
Lenses with solid Lithium operating ~40 years at BINP





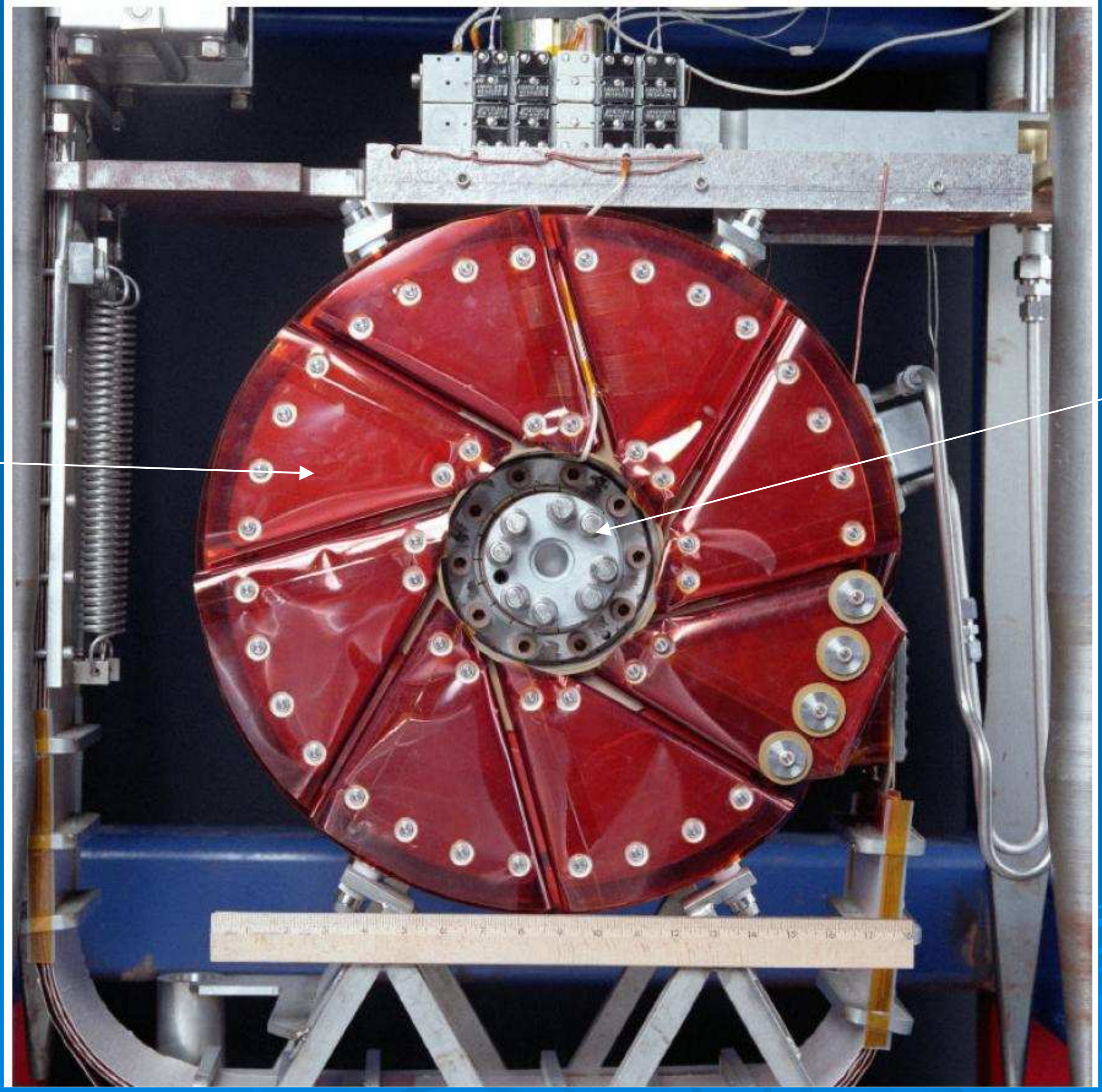
LENSES FOR ANTIPROTONS

Target for antiprotons, typically is made from Nickel of ~7 *cm* long (~half nuclear interaction length) and operates at <1*Hz* repetition rate.



Lithium lens from BINP developed for FNAL. 1–Lithium, 2 –Be window, 3–Case, 4– sphenoid clamps, 5–coolant jacket, 6–Ti cylinder, 7–Coolant in/out.

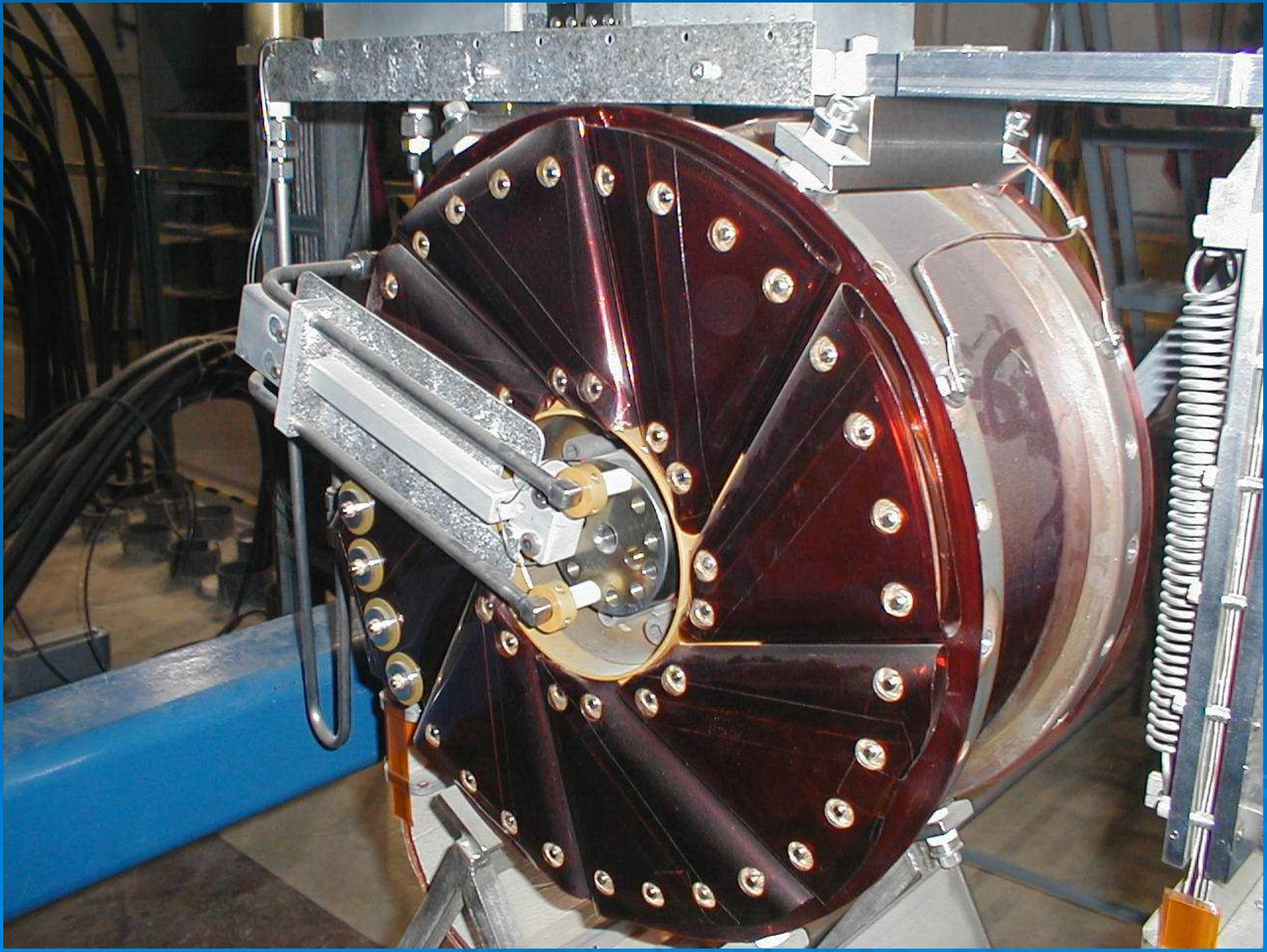
FNAL Lithium lens in transformer. Scale is given by the ruler at the bottom of this photo.


Transformer

Lens

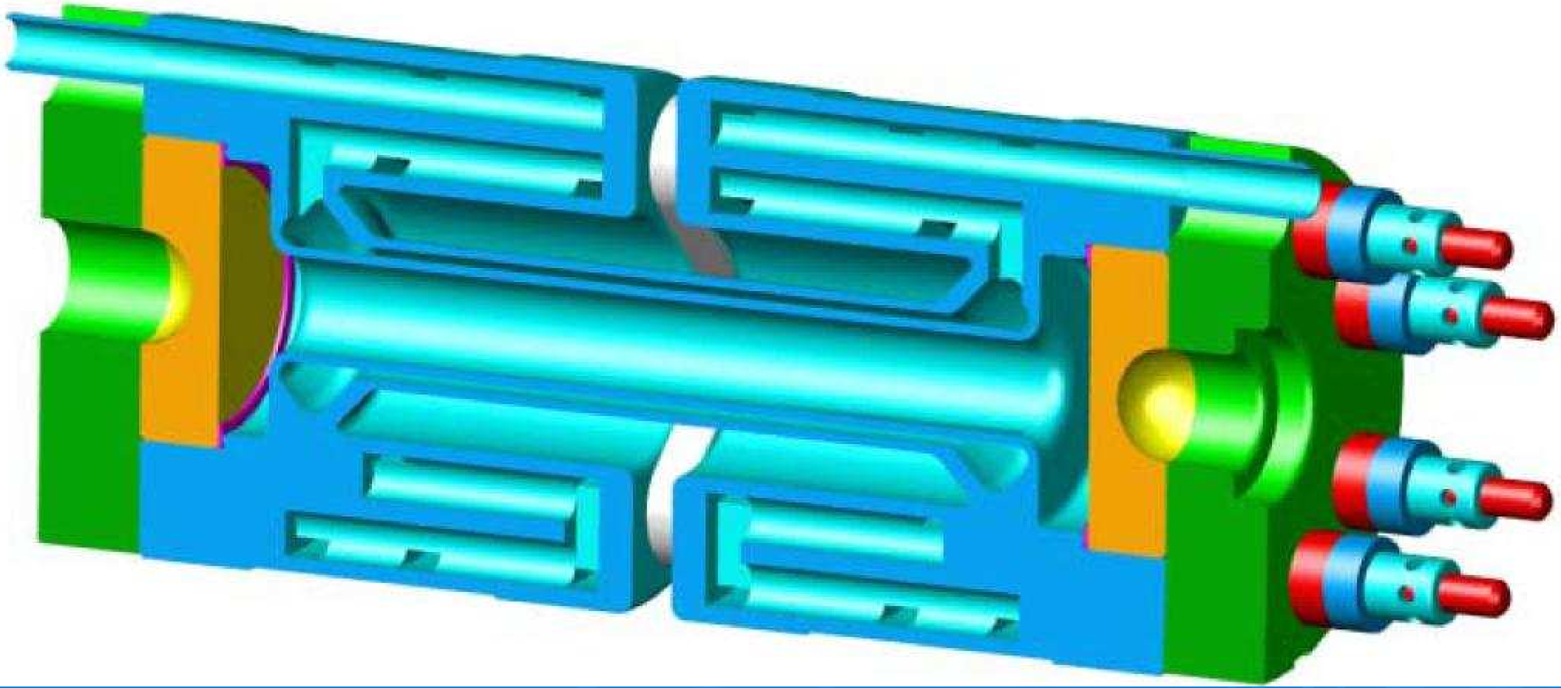
Photo from J.Morgan, “*Lithium Lens Upgrade*”, report FNAL, 2002

The same lens; view from the other side

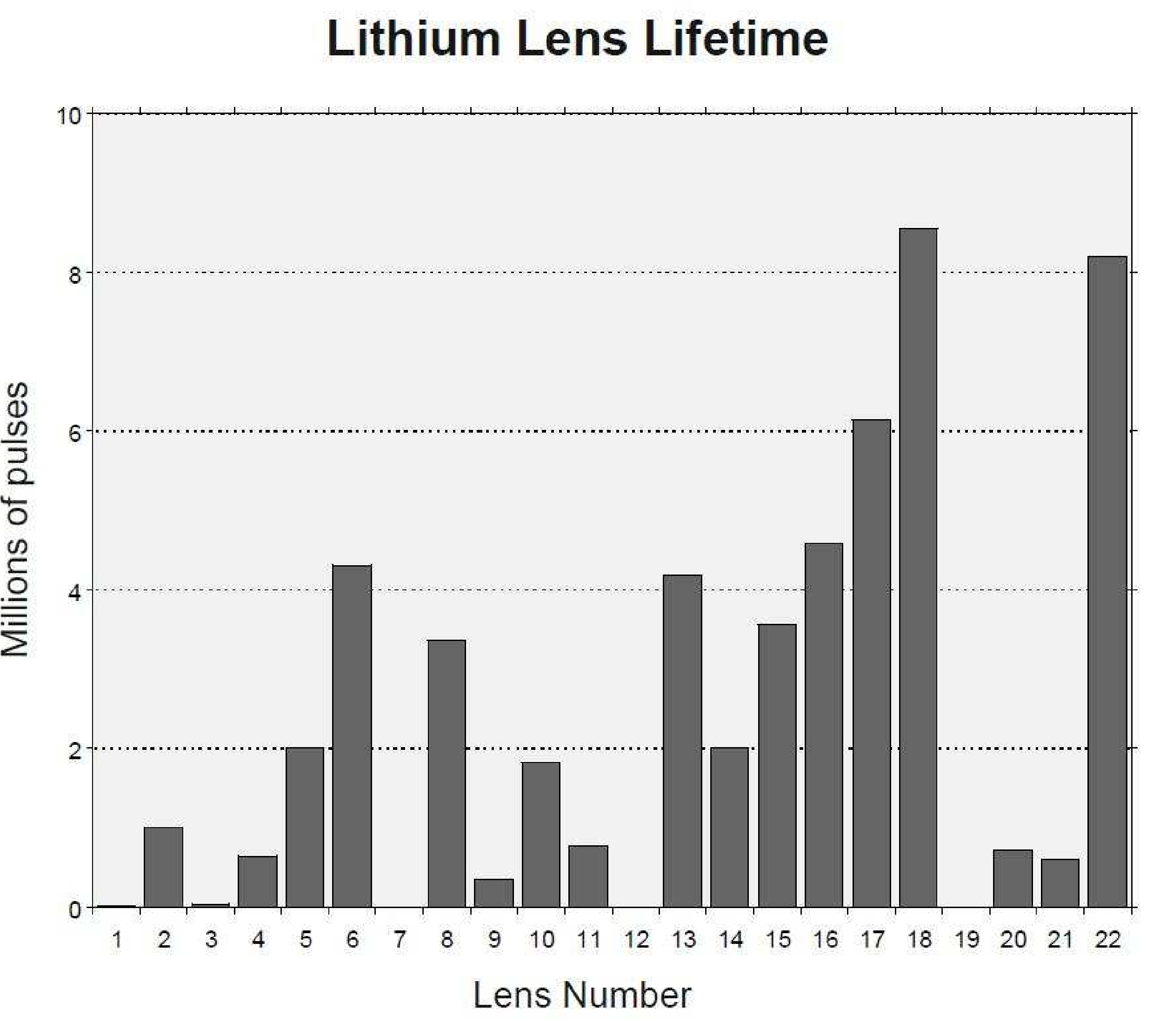


View to the BINP lens from the side with in/out liquid Lithium tubings

High Gradient Solid Lens Prototype Design

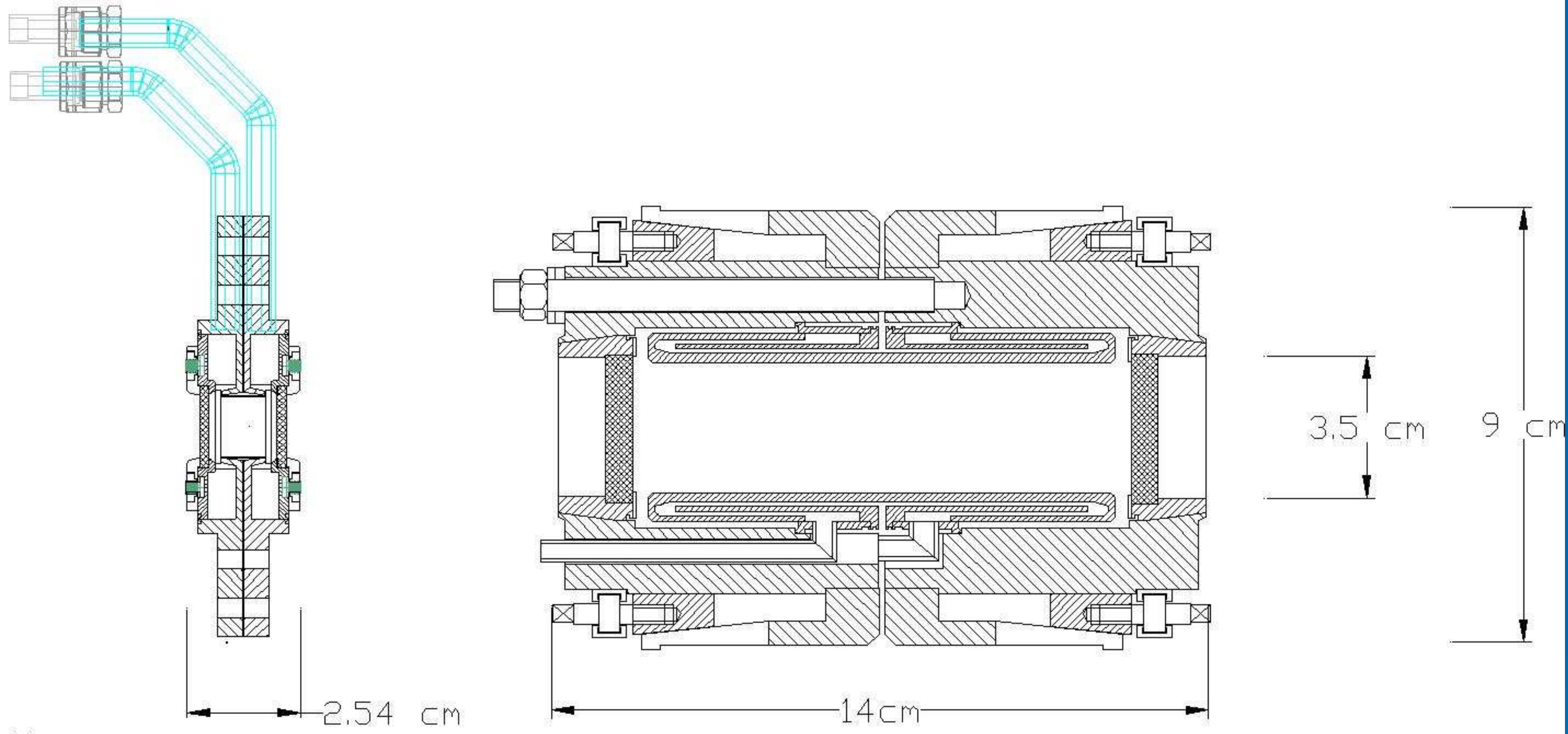


From FNAL antiproton source web site



From J.Morgan, “*Lithium Lens Upgrade*”, report FNAL, 2002

COMPARISON



Lithium lenses for positrons and anti-protons represented in the same scale

It is clearly seen from here that from engineering point of view lens for positrons is a device with much modest parameters. One can expect that the lifetime will be also much longer. No doubts that this lens could be well operational during few months period. New materials for windows, such as BN and BC are forced to help in this intention.

Table 1. Parameters of lenses for positrons, antiprotons and for neutrino-factory

	Positrons	**Antiprotons**	**Neutrino factory**
Diameter, *cm*	1.4	2-3.6	1.8- 6
Length, *cm*	0.5-1	10	15
Current, *kA*	<150-75	~850	500
Pulse duty, *msec*	~4	0.1	~1
Repetition rate, *Hz*	5	0.7	0.7
Resistance *μΩ*	32-64	50	27
Gradient, *kG/cm*	<65	55	45
Surface field, *kG*	43-22	100	80-40
Pulsed Power, *kW*	~720-360	36000	6750
Average Power, *kW*	~15-8	3.6	4.7
Temperature gain/pulse, ^{o}K	170-85	80	80
Pressure at axis, *atm*	75-19	400	256-64

One can see that lens for positrons have highest average power, thanks to repetition rate of 5 Hz. From the other hand it has lowest axial pressure. Usage of liquid Lithium with external cooling allows drastic reduction of thermal load to the lens body and to the windows.

SUMMARY

The lens suggested for ILC positron system is much more compact, than the ones used for collection of antiprotons. All technological challenges could be borrowed from well operated lenses used for collection of antiprotons.

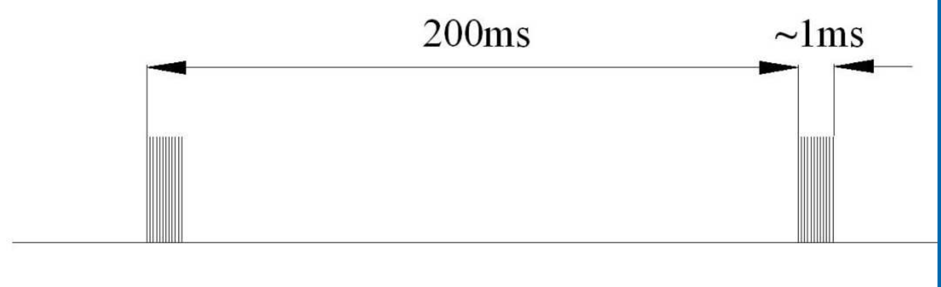
Lens with solid Lithium in operation for about 40 years in BINP gives another example of success of this concept .

Usage of Lithium lens for positron collection looks guarantied after confirmation made by usage of numerical modeling (KONN), that the energy deposition by the beam remains small compared with the direct energy deposition made by the feeding current running through the body of Lithium.

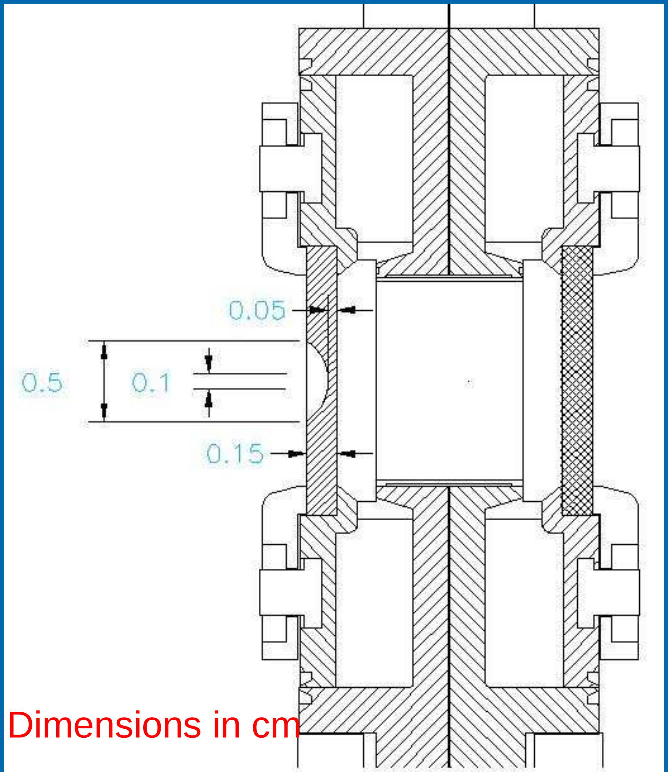
Backup slides

General parameters	
Energy of primary beam	~150 GeV-350GeV
Undulator period λ	10-12 mm
K factor, $K = eH\lambda / 2\pi / mc^2$	0.4-1
Undulator length	≤ 200 m
Efficiency , e^+ / e^-	≥ 1.5
Polarization	≥ 65%
Target W/Ti	1.75 mm/14.8 mm
Energy of quanta	~9-20 MeV
Distance to the target	100-300 m
Lens	
Feeding current, I	<150 kA
Field at surface, H_m	43 kG
Gradient	≤ 62kG/cm
Pulsed power	~200kW
Average power	~4kW
Pulsed duty , τ	<4msec
Lens diameter, $2a$	1 cm
Length, L	0.5-1 cm**
Axial pressure, P_0	74atm (for L=0.5cm)
Temperature gain per train	≤ 170°C at 150kA

Beam pattern



Flange with recession has faster relaxation time



Dimensions in cm

Equation for thermal diffusion

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

defines time of relaxation from its characteristic

For Be: k=2 $W/cm/{}^oK$, ρ=1.84g/cm^3 , c_V =1.82 $J/g/{}^oK$

$$\frac{dx^2}{k}=\frac{dt}{\rho c_V}\rightarrow\quad\delta^2=\frac{k}{\rho c_V}\tau\rightarrow\quad\tau=\frac{\rho c_V}{k}\delta^2$$

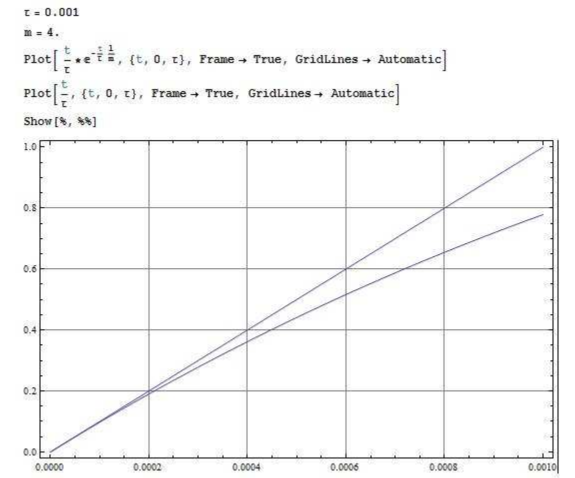
If δ=0.05cm

$$\tau=\frac{1.84\cdot1.82}{2}2.5\cdot10^{-3}\cong4.2ms$$

This gives ~20% temperature drop within train for Be

For Li thermal skin-layer for 1 *msec* time goes to

$$\delta=\sqrt{\frac{k}{\rho c_V}\tau}=\sqrt{\frac{0.848}{0.533\text{x}3.6}0.001}=0.021cm$$

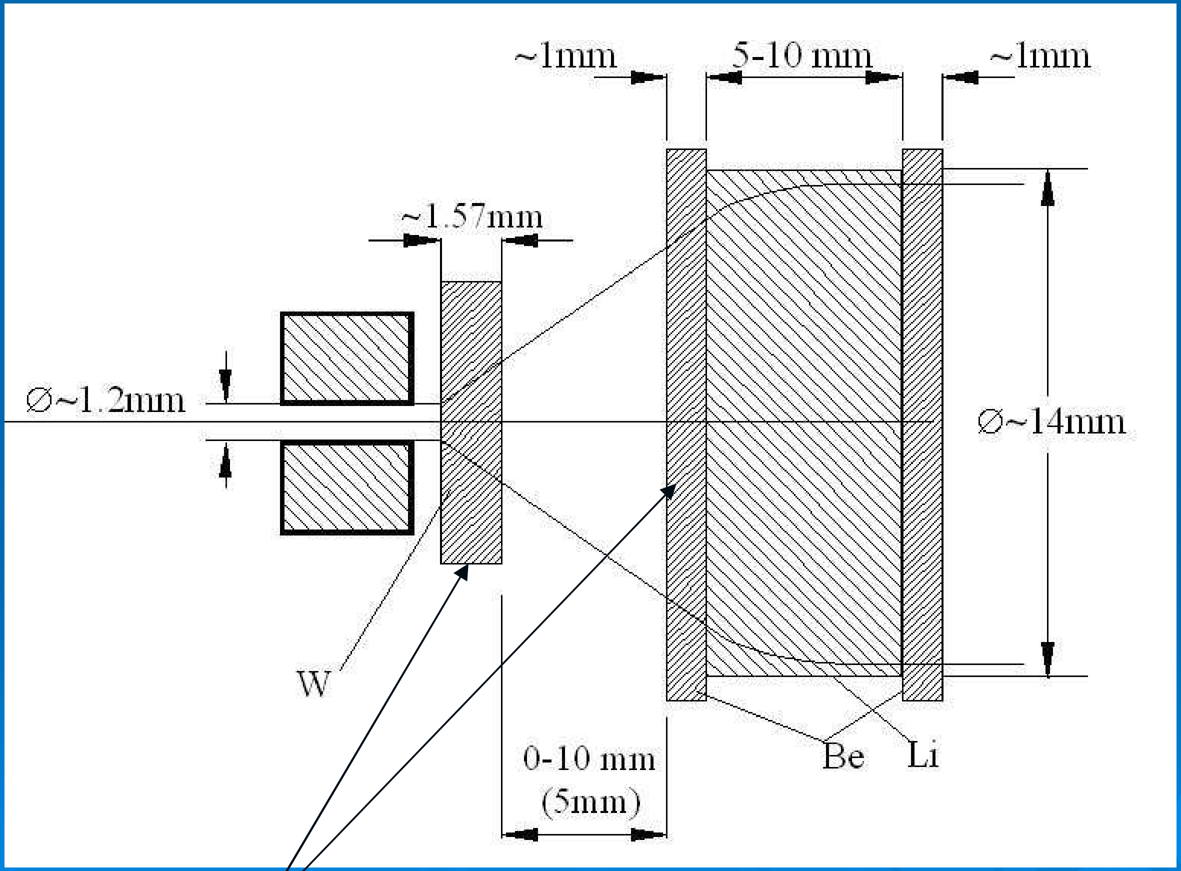


```
τ = 0.001
m = 4.
Plot[t/τ * e^(-t/τ 1/m), {t, 0, τ}, Frame → True, GridLines → Automatic]
Plot[t/τ, {t, 0, τ}, Frame → True, GridLines → Automatic]
Show[%, %%]
```

KONN –Monte-Carlo code for positron production starting from undulator

KONN can calculate now the energy deposition and temperature rise in target and in Li lens at any point.

Distance between target and lens serves for enlargement the spot size on the entrance window

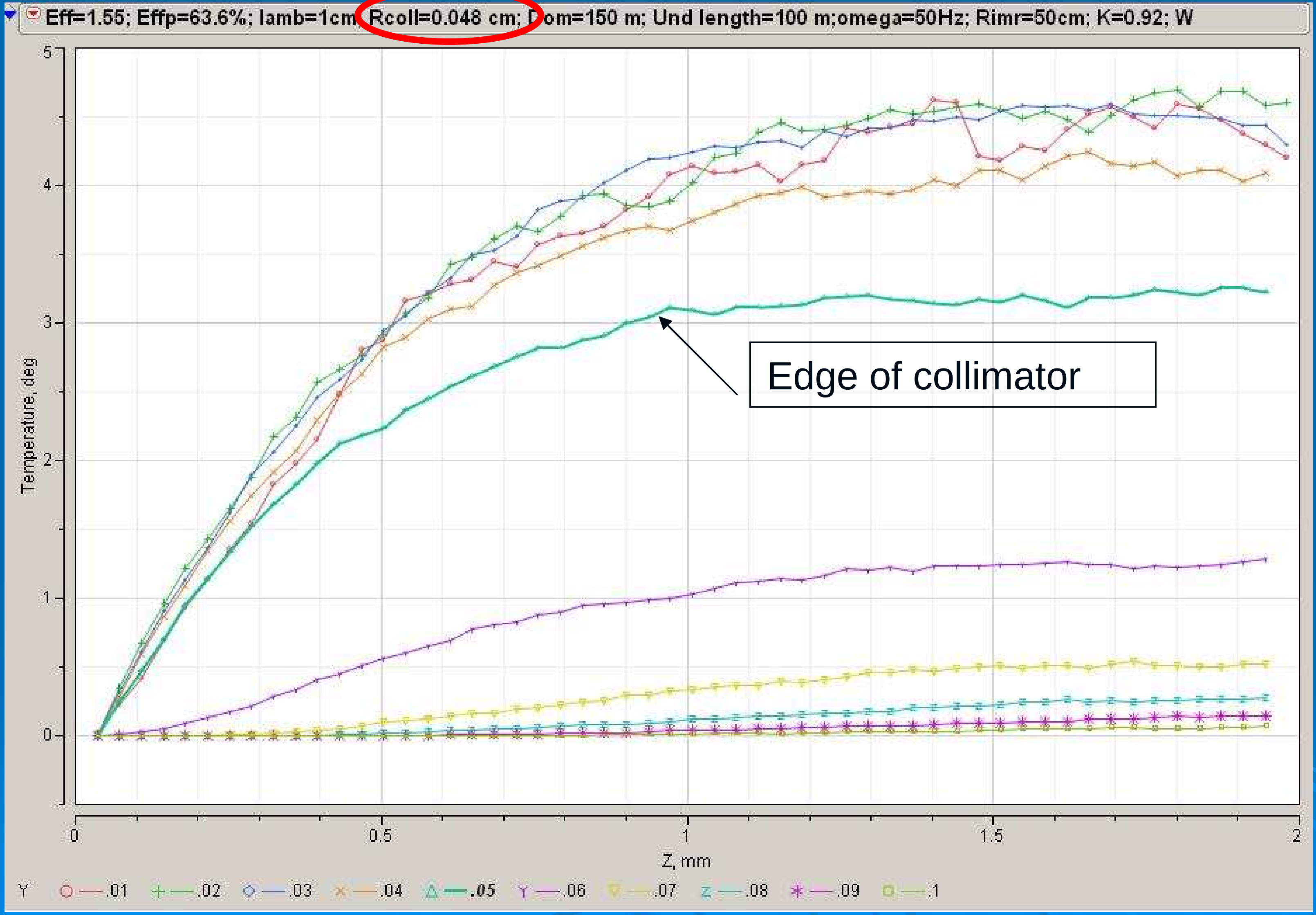


←Typical parameters

Target could be combined with entrance flange

TEMPERATURE ALONG THE **W** TARGET FOR DIFFERENT RADIUSES

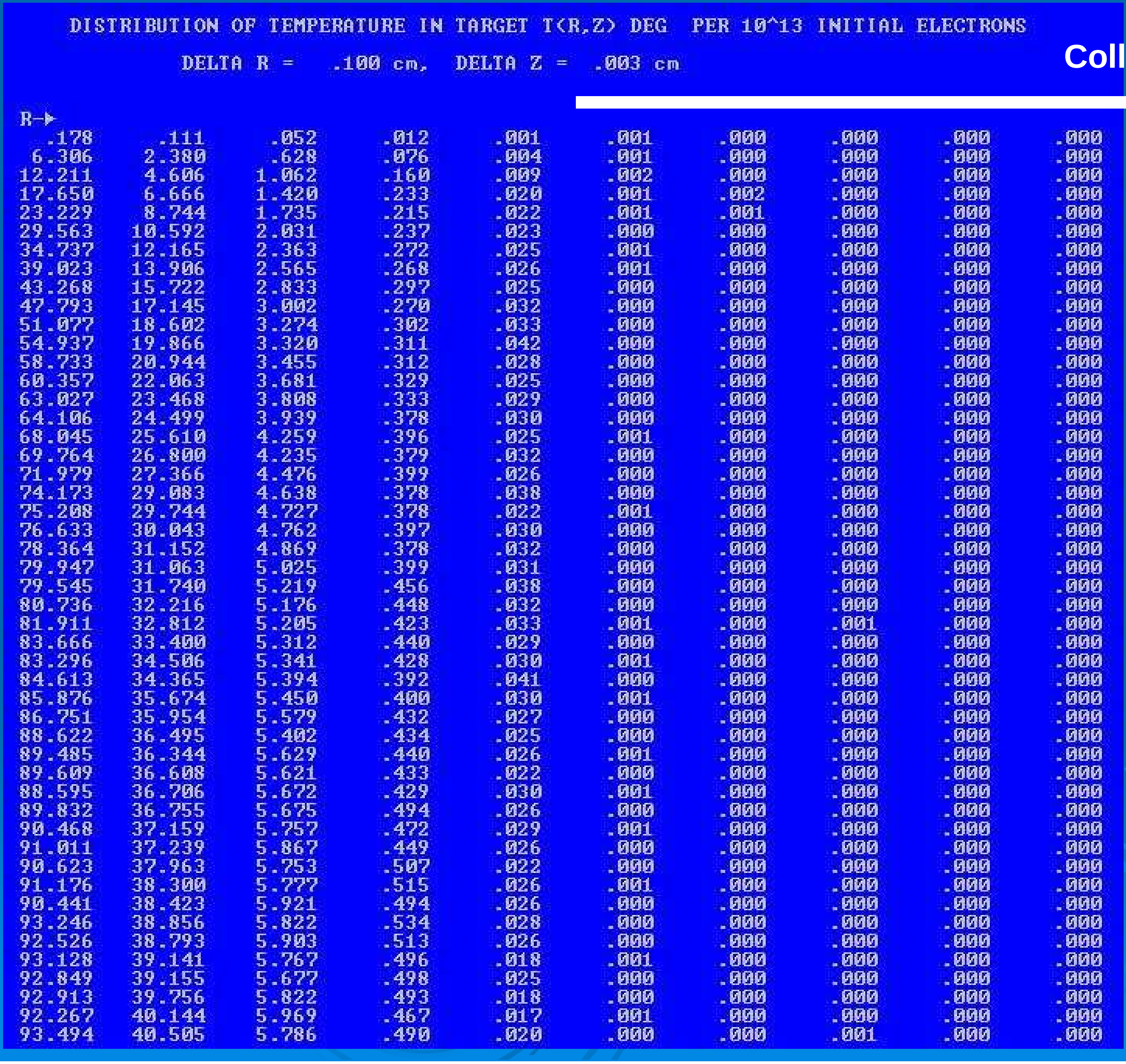
per 10^{13} initial electrons



Edge of collimator

Each particle radiates 2.76 GeV in undulator

Now the target is not spinning



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     DISTRIBUTION OF TEMPERATURE IN TARGET T(R,Z) DEG  PER 10^13 INITIAL ELECTRONS

              DELTA R =   .100 cm,  DELTA Z =  .003 cm


R->
   .178     .111      .052     .012     .001     .001     .000     .000     .000     .000
  6.306    2.380      .628     .076     .004     .001     .000     .000     .000     .000
 12.211    4.606     1.062     .160     .009     .002     .000     .000     .000     .000
 17.650    6.666     1.420     .233     .020     .001     .002     .000     .000     .000
 23.229    8.744     1.735     .215     .022     .001     .001     .000     .000     .000
 29.563   10.592     2.031     .237     .023     .000     .000     .000     .000     .000
 34.737   12.165     2.363     .272     .025     .001     .000     .000     .000     .000
 39.023   13.906     2.565     .268     .026     .001     .000     .000     .000     .000
 43.268   15.722     2.833     .297     .025     .000     .000     .000     .000     .000
 47.793   17.145     3.002     .270     .032     .000     .000     .000     .000     .000
 51.077   18.602     3.274     .302     .033     .000     .000     .000     .000     .000
 54.937   19.866     3.320     .311     .042     .000     .000     .000     .000     .000
 58.733   20.944     3.455     .312     .028     .000     .000     .000     .000     .000
 60.357   22.063     3.681     .329     .025     .000     .000     .000     .000     .000
 63.027   23.468     3.808     .333     .029     .000     .000     .000     .000     .000
 64.106   24.499     3.939     .378     .030     .000     .000     .000     .000     .000
 68.045   25.610     4.259     .396     .025     .001     .000     .000     .000     .000
 69.764   26.800     4.235     .379     .032     .000     .000     .000     .000     .000
 71.979   27.366     4.476     .399     .026     .000     .000     .000     .000     .000
 74.173   29.083     4.638     .378     .038     .000     .000     .000     .000     .000
 75.208   29.744     4.727     .378     .022     .001     .000     .000     .000     .000
 76.633   30.043     4.762     .397     .030     .000     .000     .000     .000     .000
 78.364   31.152     4.869     .378     .032     .000     .000     .000     .000     .000
 79.947   31.063     5.025     .399     .031     .000     .000     .000     .000     .000
 79.545   31.740     5.219     .456     .038     .000     .000     .000     .000     .000
 80.736   32.216     5.176     .448     .032     .000     .000     .000     .000     .000
 81.911   32.812     5.205     .423     .033     .001     .000     .001     .000     .000
 83.666   33.400     5.312     .440     .029     .000     .000     .000     .000     .000
 83.296   34.506     5.341     .428     .030     .001     .000     .000     .000     .000
 84.613   34.365     5.394     .392     .041     .000     .000     .000     .000     .000
 85.876   35.674     5.450     .400     .030     .001     .000     .000     .000     .000
 86.751   35.954     5.579     .432     .027     .000     .000     .000     .000     .000
 88.622   36.495     5.402     .434     .025     .000     .000     .000     .000     .000
 89.485   36.344     5.629     .440     .026     .001     .000     .000     .000     .000
 89.609   36.608     5.621     .433     .022     .000     .000     .000     .000     .000
 88.595   36.706     5.672     .429     .030     .001     .000     .000     .000     .000
 89.832   36.755     5.675     .494     .026     .000     .000     .000     .000     .000
 90.468   37.159     5.757     .472     .029     .001     .000     .000     .000     .000
 91.011   37.239     5.867     .449     .026     .000     .000     .000     .000     .000
 90.623   37.963     5.753     .507     .022     .000     .000     .000     .000     .000
 91.176   38.300     5.777     .515     .026     .001     .000     .000     .000     .000
 90.441   38.423     5.921     .494     .026     .000     .000     .000     .000     .000
 93.246   38.856     5.822     .534     .028     .000     .000     .000     .000     .000
 92.526   38.793     5.903     .513     .026     .000     .000     .000     .000     .000
 93.128   39.141     5.767     .496     .018     .001     .000     .000     .000     .000
 92.849   39.155     5.677     .498     .025     .000     .000     .000     .000     .000
 92.913   39.756     5.822     .493     .018     .000     .000     .000     .000     .000
 92.267   40.144     5.969     .467     .017     .001     .000     .000     .000     .000
 93.494   40.505     5.786     .490     .020     .000     .000     .001     .000     .000
```

Collimator

Rim W target;

R=50 cm

f=50 Hz

K=0.92

Eff=1.6

Effp=32%

Lund=35m

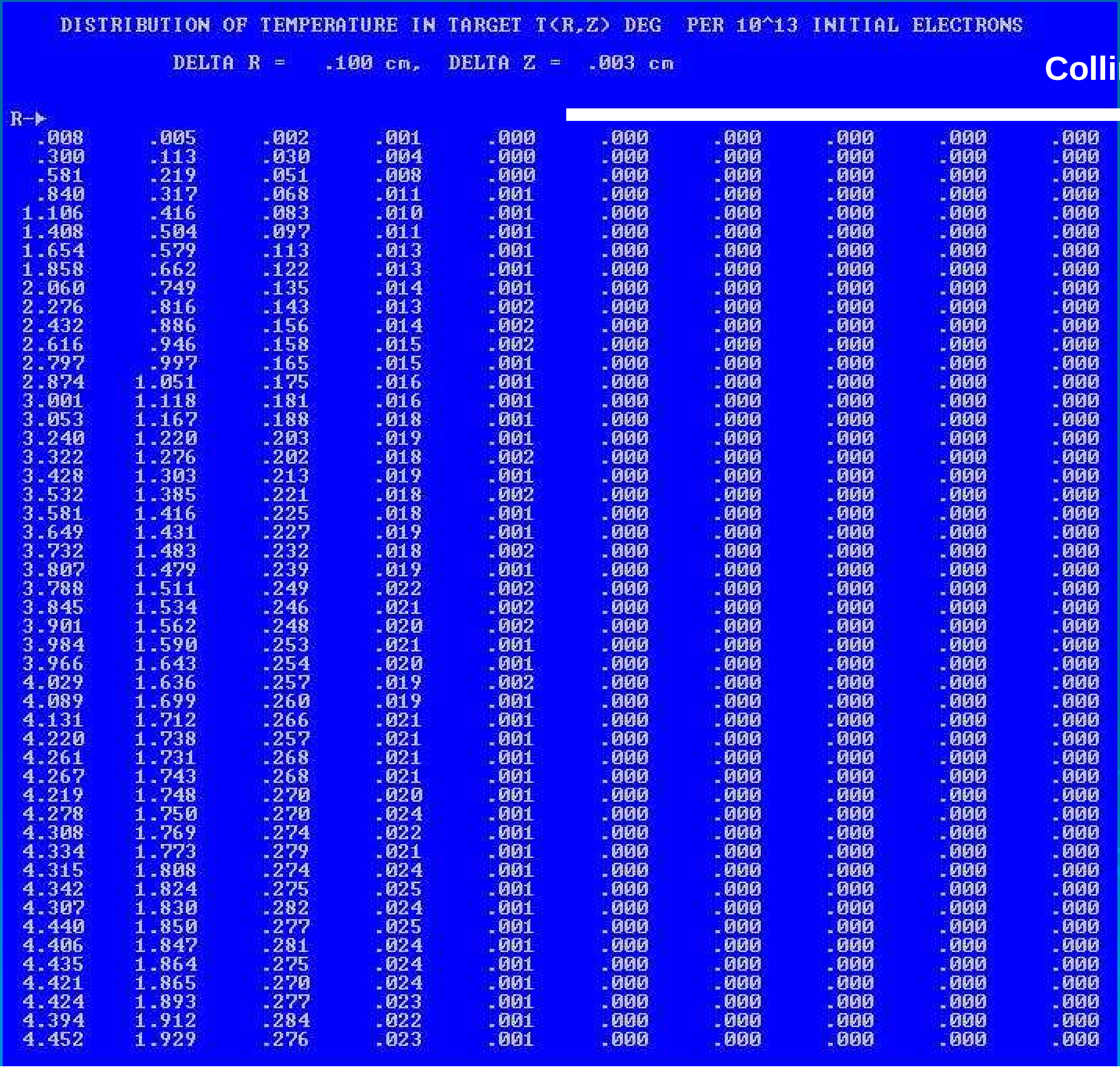
λ_u=1.15cm

Dis=300 m

G=45kG/cm

I=110kA

Rcoll=0.5cm

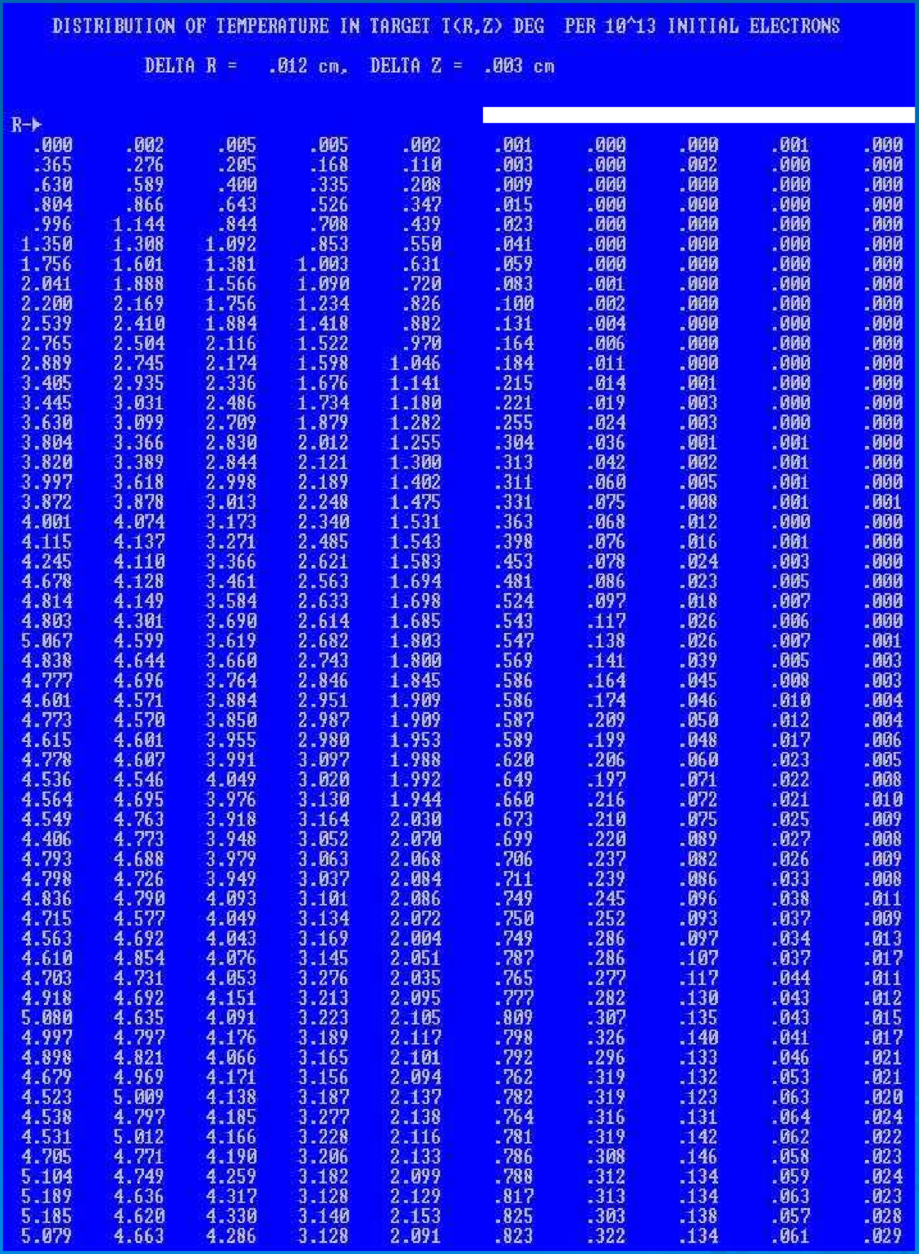


```
     DISTRIBUTION OF TEMPERATURE IN TARGET T(R,Z) DEG  PER 10^13 INITIAL ELECTRONS
               DELTA R =   .100 cm,  DELTA Z =  .003 cm

R->
     .008      .005      .002      .001      .000      .000      .000      .000      .000      .000
     .300      .113      .030      .004      .000      .000      .000      .000      .000      .000
     .581      .219      .051      .008      .000      .000      .000      .000      .000      .000
     .840      .317      .068      .011      .001      .000      .000      .000      .000      .000
    1.106      .416      .083      .010      .001      .000      .000      .000      .000      .000
    1.408      .504      .097      .011      .001      .000      .000      .000      .000      .000
    1.654      .579      .113      .013      .001      .000      .000      .000      .000      .000
    1.858      .662      .122      .013      .001      .000      .000      .000      .000      .000
    2.060      .749      .135      .014      .001      .000      .000      .000      .000      .000
    2.276      .816      .143      .013      .002      .000      .000      .000      .000      .000
    2.432      .886      .156      .014      .002      .000      .000      .000      .000      .000
    2.616      .946      .158      .015      .002      .000      .000      .000      .000      .000
    2.797      .997      .165      .015      .001      .000      .000      .000      .000      .000
    2.874     1.051      .175      .016      .001      .000      .000      .000      .000      .000
    3.001     1.118      .181      .016      .001      .000      .000      .000      .000      .000
    3.053     1.167      .188      .018      .001      .000      .000      .000      .000      .000
    3.240     1.220      .203      .019      .001      .000      .000      .000      .000      .000
    3.322     1.276      .202      .018      .002      .000      .000      .000      .000      .000
    3.428     1.303      .213      .019      .001      .000      .000      .000      .000      .000
    3.532     1.385      .221      .018      .002      .000      .000      .000      .000      .000
    3.581     1.416      .225      .018      .001      .000      .000      .000      .000      .000
    3.649     1.431      .227      .019      .001      .000      .000      .000      .000      .000
    3.732     1.483      .232      .018      .002      .000      .000      .000      .000      .000
    3.807     1.479      .239      .019      .001      .000      .000      .000      .000      .000
    3.788     1.511      .249      .022      .002      .000      .000      .000      .000      .000
    3.845     1.534      .246      .021      .002      .000      .000      .000      .000      .000
    3.901     1.562      .248      .020      .002      .000      .000      .000      .000      .000
    3.984     1.590      .253      .021      .001      .000      .000      .000      .000      .000
    3.966     1.643      .254      .020      .001      .000      .000      .000      .000      .000
    4.029     1.636      .257      .019      .002      .000      .000      .000      .000      .000
    4.089     1.699      .260      .019      .001      .000      .000      .000      .000      .000
    4.131     1.712      .266      .021      .001      .000      .000      .000      .000      .000
    4.220     1.738      .257      .021      .001      .000      .000      .000      .000      .000
    4.261     1.731      .268      .021      .001      .000      .000      .000      .000      .000
    4.267     1.743      .268      .021      .001      .000      .000      .000      .000      .000
    4.219     1.748      .270      .020      .001      .000      .000      .000      .000      .000
    4.278     1.750      .270      .024      .001      .000      .000      .000      .000      .000
    4.308     1.769      .274      .022      .001      .000      .000      .000      .000      .000
    4.334     1.773      .279      .021      .001      .000      .000      .000      .000      .000
    4.315     1.808      .274      .024      .001      .000      .000      .000      .000      .000
    4.342     1.824      .275      .025      .001      .000      .000      .000      .000      .000
    4.307     1.830      .282      .024      .001      .000      .000      .000      .000      .000
    4.440     1.850      .277      .025      .001      .000      .000      .000      .000      .000
    4.406     1.847      .281      .024      .001      .000      .000      .000      .000      .000
    4.435     1.864      .275      .024      .001      .000      .000      .000      .000      .000
    4.421     1.865      .270      .024      .001      .000      .000      .000      .000      .000
    4.424     1.893      .277      .023      .001      .000      .000      .000      .000      .000
    4.394     1.912      .284      .022      .001      .000      .000      .000      .000      .000
    4.452     1.929      .276      .023      .001      .000      .000      .000      .000      .000
```

Collimator

K=0.44; Eff=1.58; Effp=67%; Rcoll=0.06; Lamb=1cm;Lund=170m; 150 GeV
Each particle radiates 1.07 GeV in undulator

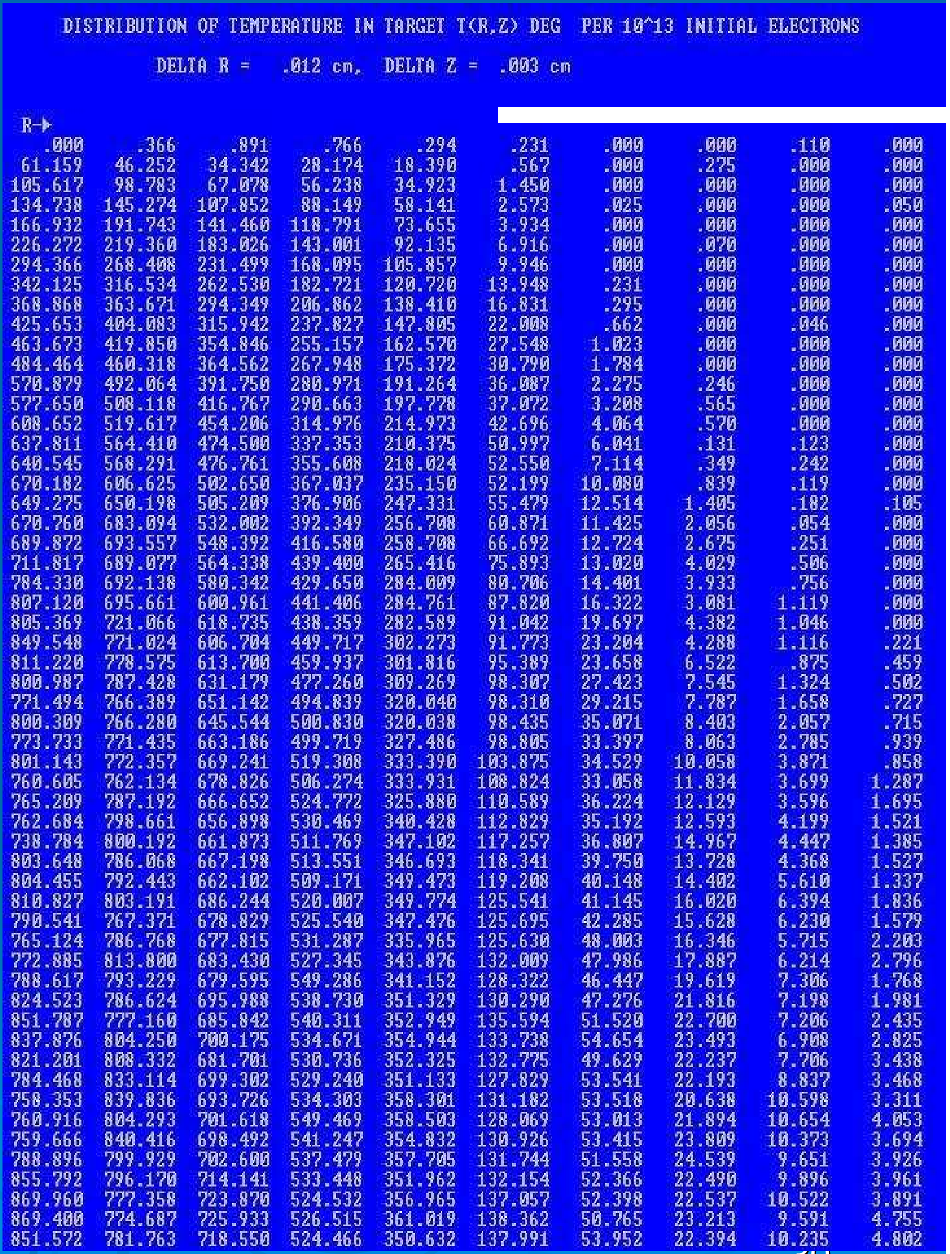


```
      DISTRIBUTION OF TEMPERATURE IN TARGET T(R,Z) DEG   PER 10^13 INITIAL ELECTRONS

                DELTA R =    .012 cm.  DELTA Z =   .003 cm

R->
    .000     .002     .005     .005     .002     .001     .000     .000     .001     .000
    .365     .276     .205     .168     .110     .003     .000     .002     .000     .000
    .630     .589     .400     .335     .208     .009     .000     .000     .000     .000
    .804     .866     .643     .526     .347     .015     .000     .000     .000     .000
    .996    1.144     .844     .708     .439     .023     .000     .000     .000     .000
   1.350    1.308    1.092     .853     .550     .041     .000     .000     .000     .000
   1.756    1.601    1.381    1.003     .631     .059     .000     .000     .000     .000
   2.041    1.888    1.566    1.090     .720     .083     .001     .000     .000     .000
   2.200    2.169    1.756    1.234     .826     .100     .002     .000     .000     .000
   2.539    2.410    1.884    1.418     .882     .131     .004     .000     .000     .000
   2.765    2.504    2.116    1.522     .970     .164     .006     .000     .000     .000
   2.889    2.745    2.174    1.598    1.046     .184     .011     .000     .000     .000
   3.405    2.935    2.336    1.676    1.141     .215     .014     .001     .000     .000
   3.445    3.031    2.486    1.734    1.180     .221     .019     .003     .000     .000
   3.630    3.099    2.709    1.879    1.282     .255     .024     .003     .000     .000
   3.804    3.366    2.830    2.012    1.255     .304     .036     .001     .001     .000
   3.820    3.389    2.844    2.121    1.300     .313     .042     .002     .001     .000
   3.997    3.618    2.998    2.189    1.402     .311     .060     .005     .001     .000
   3.872    3.878    3.013    2.248    1.475     .331     .075     .008     .001     .001
   4.001    4.074    3.173    2.340    1.531     .363     .068     .012     .000     .000
   4.115    4.137    3.271    2.485    1.543     .398     .076     .016     .001     .000
   4.245    4.110    3.366    2.621    1.583     .453     .078     .024     .003     .000
   4.678    4.128    3.461    2.563    1.694     .481     .086     .023     .005     .000
   4.814    4.149    3.584    2.633    1.698     .524     .097     .018     .007     .000
   4.803    4.301    3.690    2.614    1.685     .543     .117     .026     .006     .000
   5.067    4.599    3.619    2.682    1.803     .547     .138     .026     .007     .001
   4.838    4.644    3.660    2.743    1.800     .569     .141     .039     .005     .003
   4.777    4.696    3.764    2.846    1.845     .586     .164     .045     .008     .003
   4.601    4.571    3.884    2.951    1.909     .586     .174     .046     .010     .004
   4.773    4.570    3.850    2.987    1.909     .587     .209     .050     .012     .004
   4.615    4.601    3.955    2.980    1.953     .589     .199     .048     .017     .006
   4.778    4.607    3.991    3.097    1.988     .620     .206     .060     .023     .005
   4.536    4.546    4.049    3.020    1.992     .649     .197     .071     .022     .008
   4.564    4.695    3.976    3.130    1.944     .660     .216     .072     .021     .010
   4.549    4.763    3.918    3.164    2.030     .673     .210     .075     .025     .009
   4.406    4.773    3.948    3.052    2.070     .699     .220     .089     .027     .008
   4.793    4.688    3.979    3.063    2.068     .706     .237     .082     .026     .009
   4.798    4.726    3.949    3.037    2.084     .711     .239     .086     .033     .008
   4.836    4.790    4.093    3.101    2.086     .749     .245     .096     .038     .011
   4.715    4.577    4.049    3.134    2.072     .750     .252     .093     .037     .009
   4.563    4.692    4.043    3.169    2.004     .749     .286     .097     .034     .013
   4.610    4.854    4.076    3.145    2.051     .787     .286     .107     .037     .017
   4.703    4.731    4.053    3.276    2.035     .765     .277     .117     .044     .011
   4.918    4.692    4.151    3.213    2.095     .777     .282     .130     .043     .012
   5.080    4.635    4.091    3.223    2.105     .809     .307     .135     .043     .015
   4.997    4.797    4.176    3.189    2.117     .798     .326     .140     .041     .017
   4.898    4.821    4.066    3.165    2.101     .792     .296     .133     .046     .021
   4.679    4.969    4.171    3.156    2.094     .762     .319     .132     .053     .021
   4.523    5.009    4.138    3.187    2.137     .782     .319     .123     .063     .020
   4.538    4.797    4.185    3.277    2.138     .764     .316     .131     .064     .024
   4.531    5.012    4.166    3.228    2.116     .781     .319     .142     .062     .022
   4.705    4.771    4.190    3.206    2.133     .786     .308     .146     .058     .023
   5.104    4.749    4.259    3.182    2.099     .788     .312     .134     .059     .024
   5.189    4.636    4.317    3.128    2.129     .817     .313     .134     .063     .023
   5.185    4.620    4.330    3.140    2.153     .825     .303     .138     .057     .028
   5.079    4.663    4.286    3.128    2.091     .823     .322     .134     .061     .029
```

Moving target



```
      DISTRIBUTION OF TEMPERATURE IN TARGET T(R,Z) DEG   PER 10^13 INITIAL ELECTRONS

                DELTA R =    .012 cm.  DELTA Z =   .003 cm

R->
    .000     .366     .891     .766     .294     .231     .000     .000     .110     .000
  61.159   46.252   34.342   28.174   18.390     .567     .000     .275     .000     .000
 105.617   98.783   67.078   56.238   34.923    1.450     .000     .000     .000     .000
 134.738  145.274  107.852   88.149   58.141    2.573     .025     .000     .000     .050
 166.932  191.743  141.460  118.791   73.655    3.934     .000     .000     .000     .000
 226.272  219.360  183.026  143.001   92.135    6.916     .000     .070     .000     .000
 294.366  268.408  231.499  168.095  105.857    9.946     .000     .000     .000     .000
 342.125  316.534  262.530  182.721  120.720   13.948     .231     .000     .000     .000
 368.868  363.671  294.349  206.862  138.410   16.831     .295     .000     .000     .000
 425.653  404.083  315.942  237.827  147.805   22.008     .662     .000     .046     .000
 463.673  419.850  354.846  255.157  162.570   27.548    1.023     .000     .000     .000
 484.464  460.318  364.562  267.948  175.372   30.790    1.784     .000     .000     .000
 570.879  492.064  391.750  280.971  191.264   36.087    2.275     .246     .000     .000
 577.650  508.118  416.767  290.663  197.778   37.072    3.208     .565     .000     .000
 608.652  519.617  454.206  314.976  214.973   42.696    4.064     .570     .000     .000
 637.811  564.410  474.500  337.353  210.375   50.997    6.041     .131     .123     .000
 640.545  568.291  476.761  355.608  218.024   52.550    7.114     .349     .242     .000
 670.182  606.625  502.650  367.037  235.150   52.199   10.080     .839     .119     .000
 649.275  650.198  505.209  376.906  247.331   55.479   12.514    1.405     .182     .105
 670.760  683.094  532.002  392.349  256.708   60.871   11.425    2.056     .054     .000
 689.872  693.557  548.392  416.580  258.708   66.692   12.724    2.675     .251     .000
 711.817  689.077  564.338  439.400  265.416   75.893   13.020    4.029     .506     .000
 784.330  692.138  580.342  429.650  284.009   80.706   14.401    3.933     .756     .000
 807.120  695.661  600.961  441.406  284.761   87.820   16.322    3.081    1.119     .000
 805.369  721.066  618.735  438.359  282.589   91.042   19.697    4.382    1.046     .000
 849.548  771.024  606.704  449.717  302.273   91.773   23.204    4.288    1.116     .221
 811.220  778.575  613.700  459.937  301.816   95.389   23.658    6.522     .875     .459
 800.987  787.428  631.179  477.260  309.269   98.307   27.423    7.545    1.324     .502
 771.494  766.389  651.142  494.839  320.040   98.310   29.215    7.787    1.658     .727
 800.309  766.280  645.544  500.830  320.038   98.435   35.071    8.403    2.057     .715
 773.733  771.435  663.186  499.719  327.486   98.805   33.397    8.063    2.785     .939
 801.143  772.357  669.241  519.308  333.390  103.875   34.529   10.058    3.871     .858
 760.605  762.134  678.826  506.274  333.931  108.824   33.058   11.834    3.699    1.287
 765.209  787.192  666.652  524.772  325.880  110.589   36.224   12.129    3.596    1.695
 762.684  798.661  656.898  530.469  340.428  112.829   35.192   12.593    4.199    1.521
 738.784  800.192  661.873  511.769  347.102  117.257   36.807   14.967    4.447    1.385
 803.648  786.068  667.198  513.551  346.693  118.341   39.750   13.728    4.368    1.527
 804.455  792.443  662.102  509.171  349.473  119.208   40.148   14.402    5.610    1.337
 810.827  803.191  686.244  520.007  349.774  125.541   41.145   16.020    6.394    1.836
 790.541  767.371  678.829  525.540  347.476  125.695   42.285   15.628    6.230    1.579
 765.124  786.768  677.815  531.287  335.965  125.630   48.003   16.346    5.715    2.203
 772.885  813.800  683.430  527.345  343.876  132.009   47.986   17.887    6.214    2.796
 788.617  793.229  679.595  549.286  341.152  128.322   46.447   19.619    7.306    1.768
 824.523  786.624  695.988  538.730  351.329  130.290   47.276   21.816    7.198    1.981
 851.787  777.160  685.842  540.311  352.949  135.594   51.520   22.700    7.206    2.435
 837.876  804.250  700.175  534.671  354.944  133.738   54.654   23.493    6.908    2.825
 821.201  808.332  681.701  530.736  352.325  132.775   49.629   22.237    7.706    3.438
 784.468  833.114  699.302  529.240  351.133  127.829   53.541   22.193    8.837    3.468
 758.353  839.836  693.726  534.303  358.301  131.182   53.518   20.638   10.598    3.311
 760.916  804.293  701.618  549.469  358.503  128.069   53.013   21.894   10.654    4.053
 759.666  840.416  698.492  541.247  354.832  130.926   53.415   23.809   10.373    3.694
 788.896  799.929  702.600  537.479  357.705  131.744   51.558   24.539    9.651    3.926
 855.792  796.170  714.141  533.448  351.962  132.154   52.366   22.490    9.896    3.961
 869.960  777.358  723.870  524.532  356.965  137.057   52.398   22.537   10.522    3.891
 869.400  774.687  725.933  526.515  361.019  138.362   50.765   23.213    9.591    4.755
 851.572  781.763  718.550  524.466  350.632  137.991   53.952   22.394   10.235    4.802
```

Stationary target

To the choice of material for windows

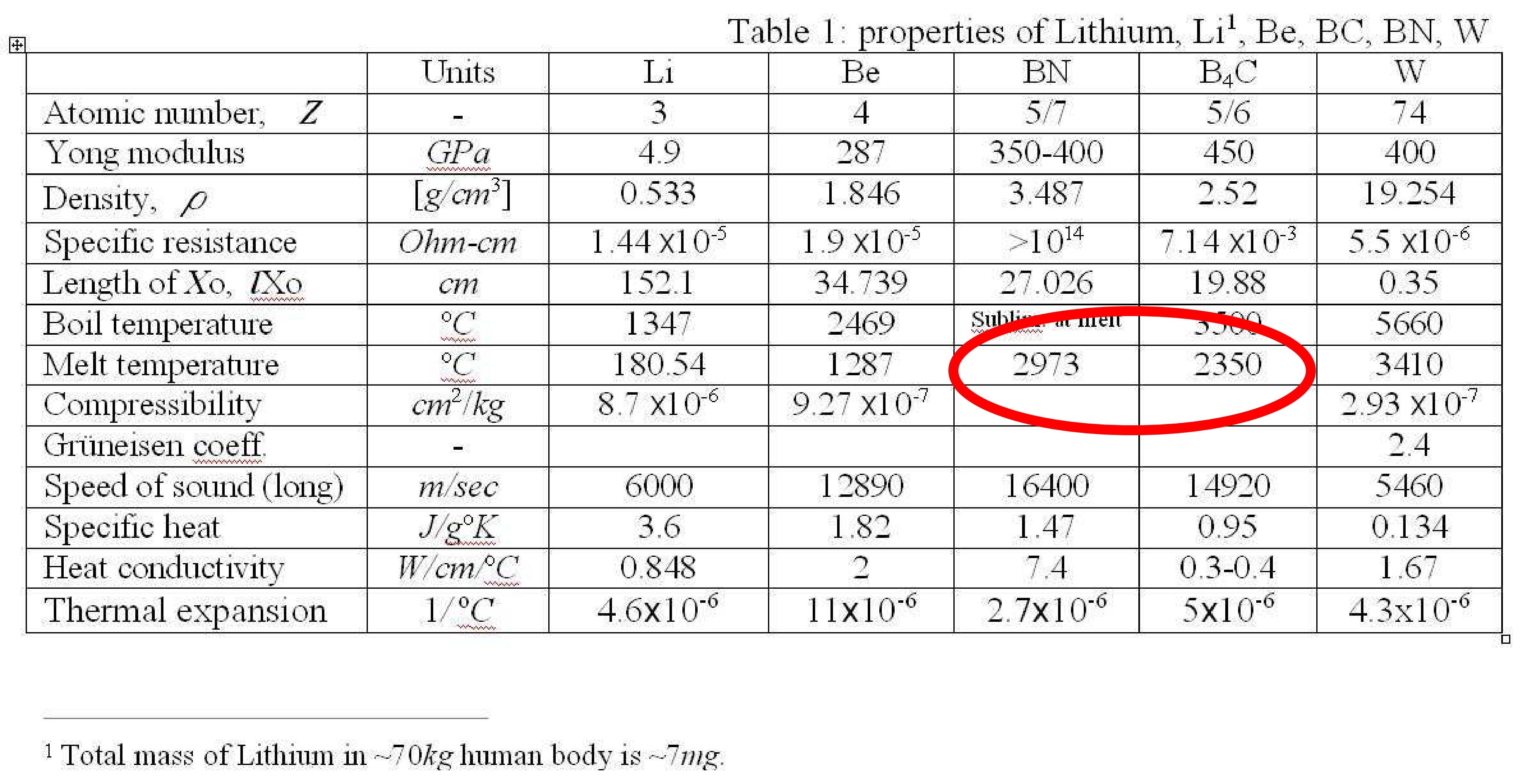


Table 1: properties of Lithium, Li[1], Be, BC, BN, W

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

---

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

Heat capacity, Heat conductivity – functions of temperature; this need to be taken into account

LOSSES FOR DIFFERENT MATERIAL OF TARGET

If energy Q deposited in mass m, then the temperature rise is

$$\Delta T = \frac{Q}{mc_V},$$

where c_V stands for the heat capacity. In its turn, for the $1cm^2$ cross section

$$Q \cong l[cm] \times 1[cm^2] \times 2[MeV/g/cm^2] \times \rho[g/cm^3].$$

For the gamma target, the length l is a fraction of radiation length, $l \cong \frac{1}{2} X_0 / \rho$,

$$Q \cong X_0 \times 1[MeV]$$

From the other hand $m = \rho \times 1[cm^2] \times \frac{X_0}{2\rho} = \frac{1}{2} X_0 \times 1[g]$,

so the temperature gain goes to be

$$\Delta T \cong \frac{2}{c_V[J/g/{}^oK]}[{}^oK] \quad \left(\cong \frac{2A}{25[Mol/g/{}^oK] \cong const:(D-P\ law)} \right)$$

For Ti c_V=0.5 $J/g/°K$; for W c_V=0.134 $J/g/°K$; for Pb c_V=0.13 $J/g/°K$.
So ratio of temperatures comes to

$$\Delta T_{Ti} : \Delta T_W : \Delta T_{Pb} \cong 1 : 3.7 : 3.8; \qquad (A_{Ti} : A_W : A_{Pb} \cong 47 : 183 : 207)$$

The ratio difference in temperature gain is not so drastic; however it is important if the temperature approaching the melting threshold.

Usage of heavier targets desirable from the point of lowering of focal depth (~10 times) needed to be serviced by capturing optics, however. Also, the positron production efficiency is higher for heavier materials. All together this gives ~50% higher yield for W compared with Ti.

E-166 REJECTED Ti TARGET

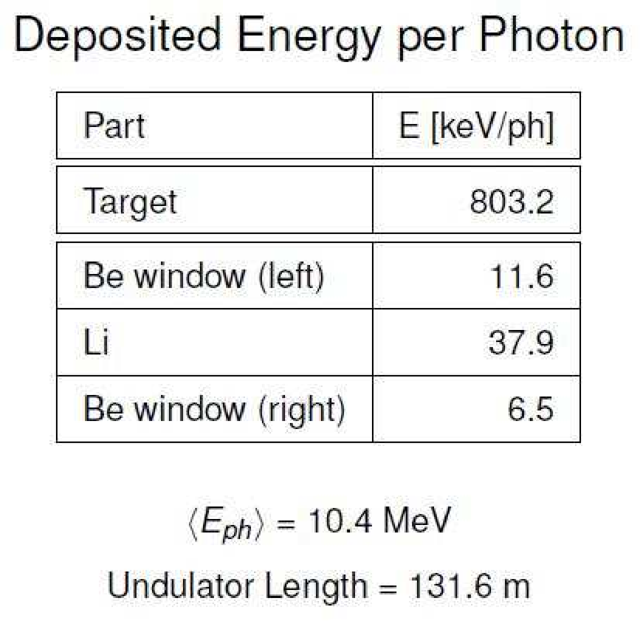
Losses calculated with KONN compared with systematic calculations done with GEANT 3.21 by A.Dubrovin

M.Dubrovin,” Energy Deposition in the Li Lens”, Note on Nov 18, 2007,17pp.

GOOD AGREEMENT

Also with calculations with FLUKA:

S.Riemann, A.Schälicke, A.Ushakov, D.Andrienko, ”Activation and Capture simulation”, ILC Positron Source Collaboration Meeting”, October 29, 2008, 16 pp.



Deposited Energy per Photon

Part	E [keV/ph]
Target	803.2
Be window (left)	11.6
Li	37.9
Be window (right)	6.5

$\langle E_{ph} \rangle = 10.4$ MeV

Undulator Length = 131.6 m

Our numbers: Nγtot =101

1.55 MeV/e (W)

1.44 MeV/e

1.61 MeV/e

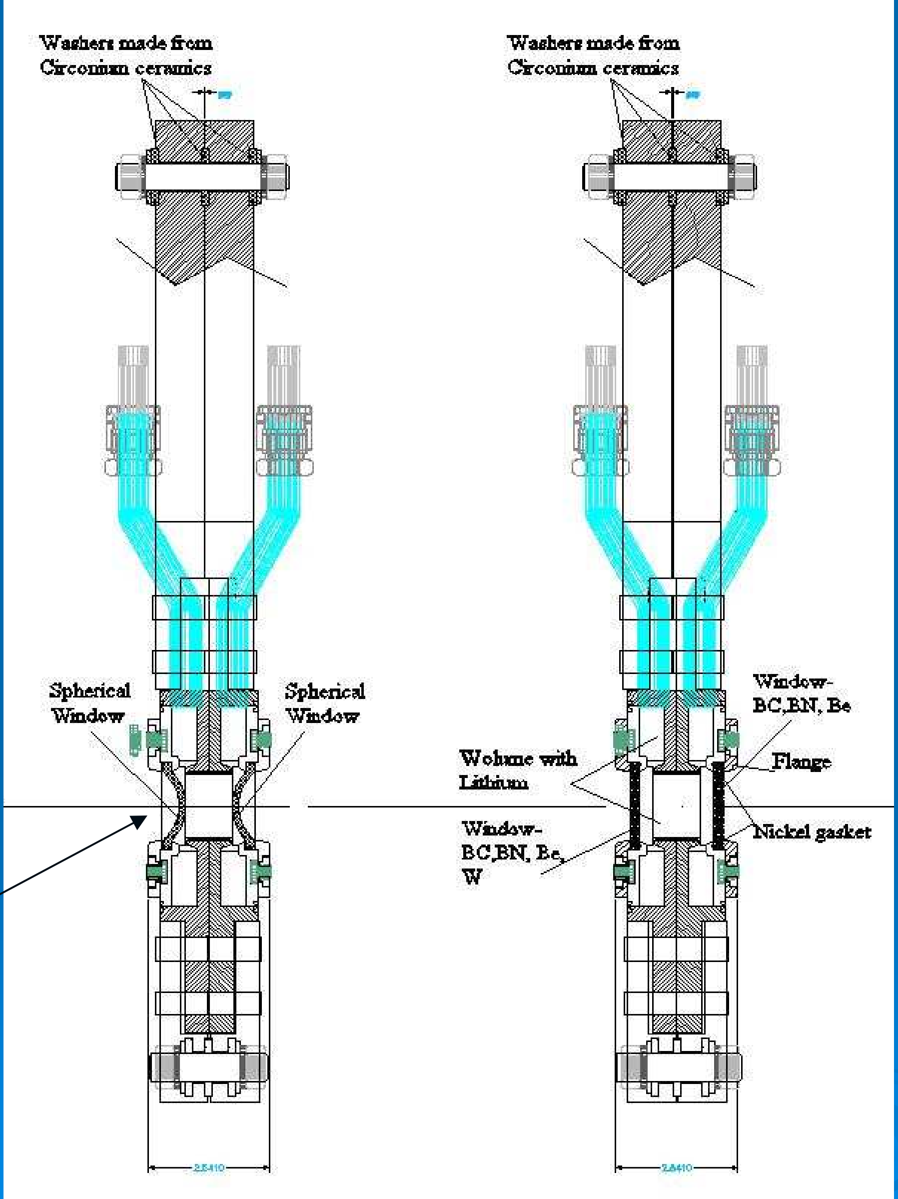
1.05 MeV/e

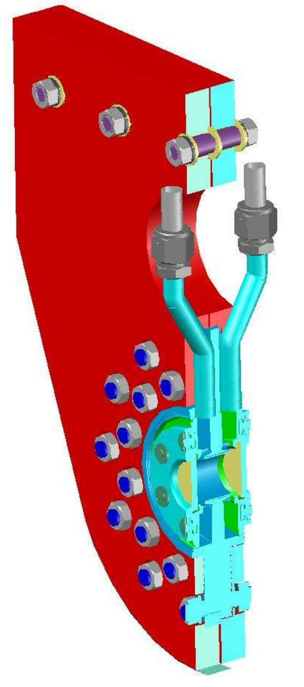
Also considering calculations with GEANT4:

W.Liu, W.Gai ,”Update on Be Window Thermal Issues”, HEP, ANL, May 16,2007

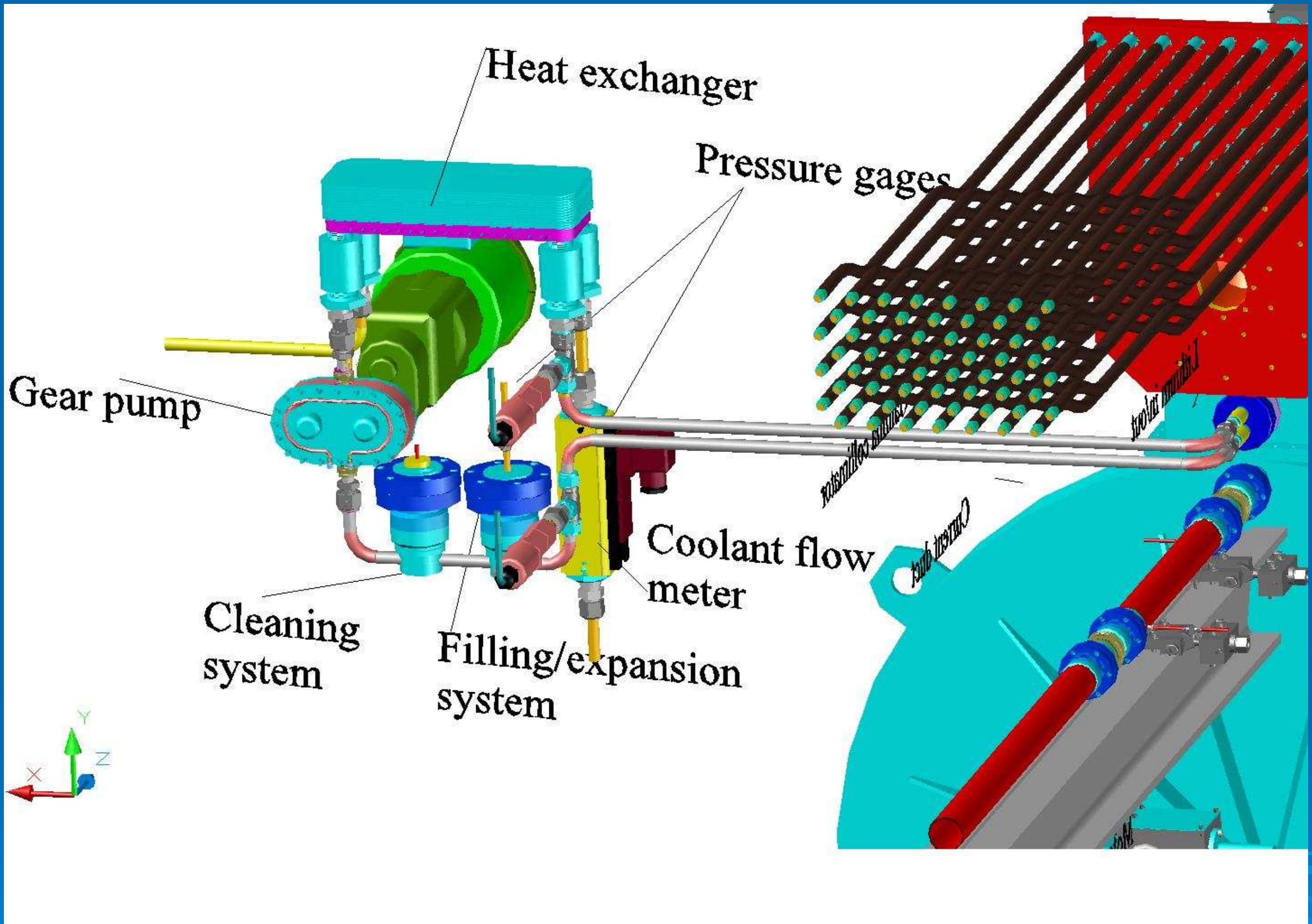
In this publication the gamma beam only was considered; no cooling; Be survives ~20sec

Can be used for compensation of spherical aberrations

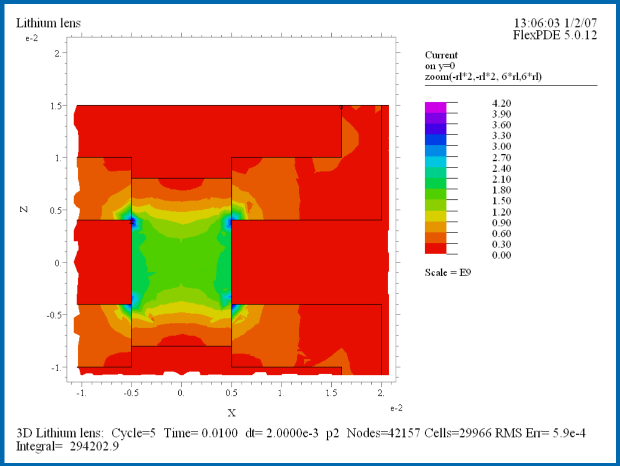




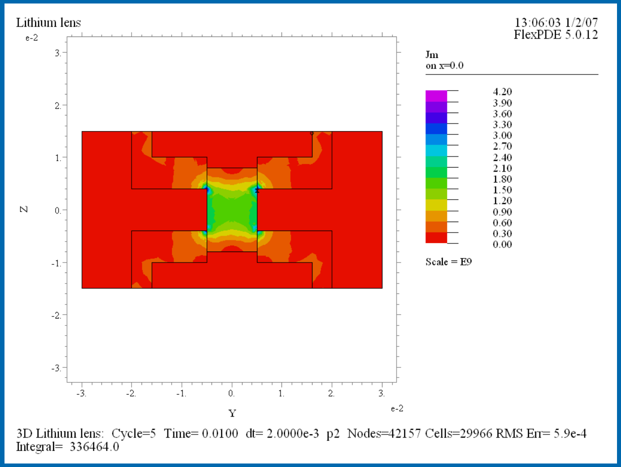
Lithium loop



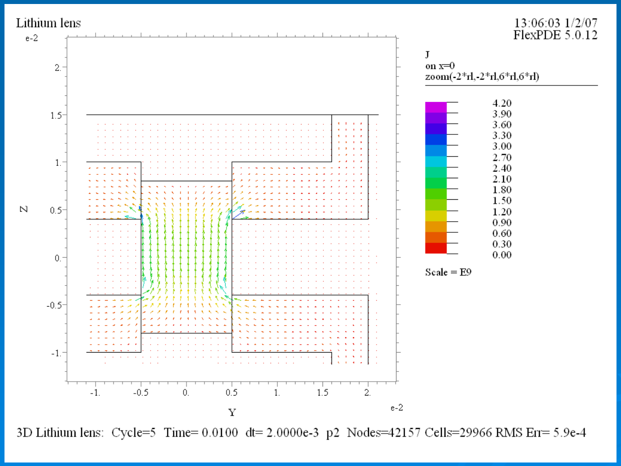
Recent calculation of Lithium lens done with FlexPDE© code at Cornell



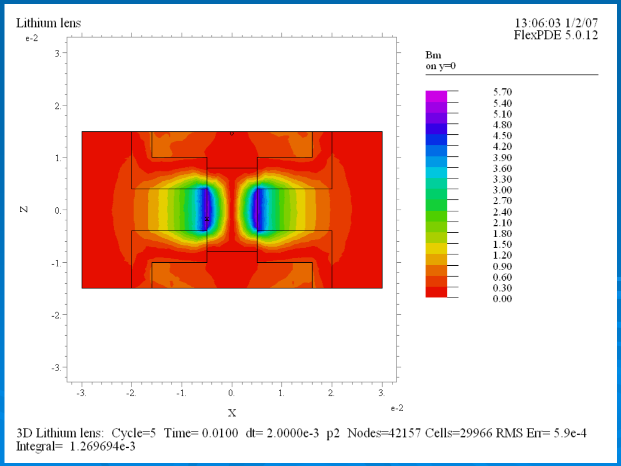
3D Lithium lens: Cycle=5 Time= 0.0100 dt= 2.0000e-3 p2 Nodes=42157 Cells=29966 RMS Err= 5.9e-4
Integral= 294202.9



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



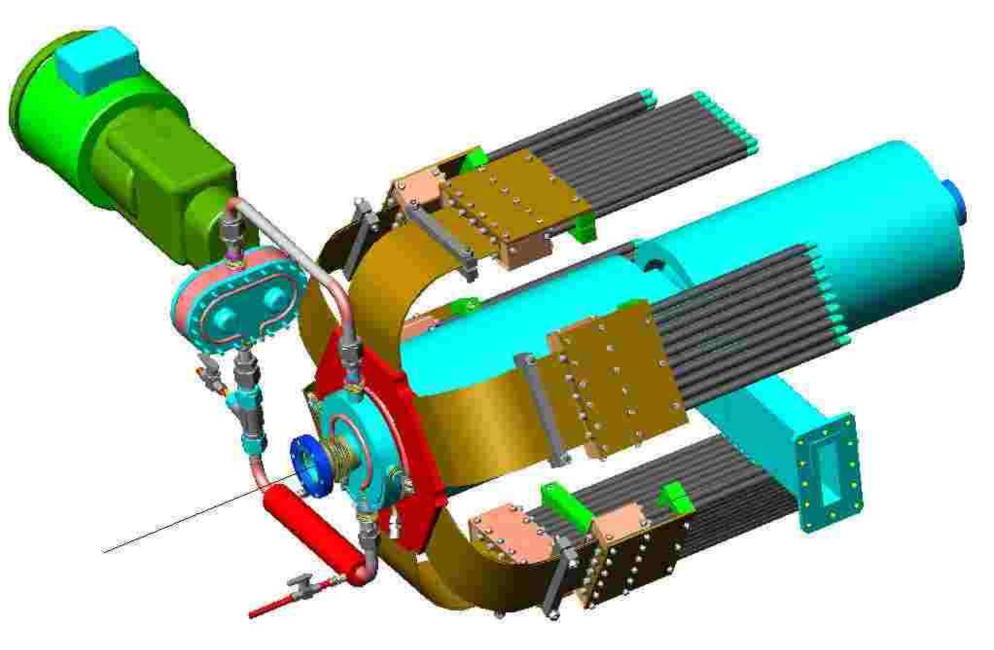
3D Lithium lens: Cycle=5 Time= 0.0100 dt= 2.0000e-3 p2 Nodes=42157 Cells=29966 RMS Err= 5.9e-4



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

Time dependent 3D calculations

Li lens can be used with any target: liquid metal (Pb-Bi, Hg) or Ti rim



Right after the target located Aluminum made accelerating structure immersed in solenoidal magnetic field.

Sectioned solenoid wound with Al conductor. Sections supplied with reversed polarities