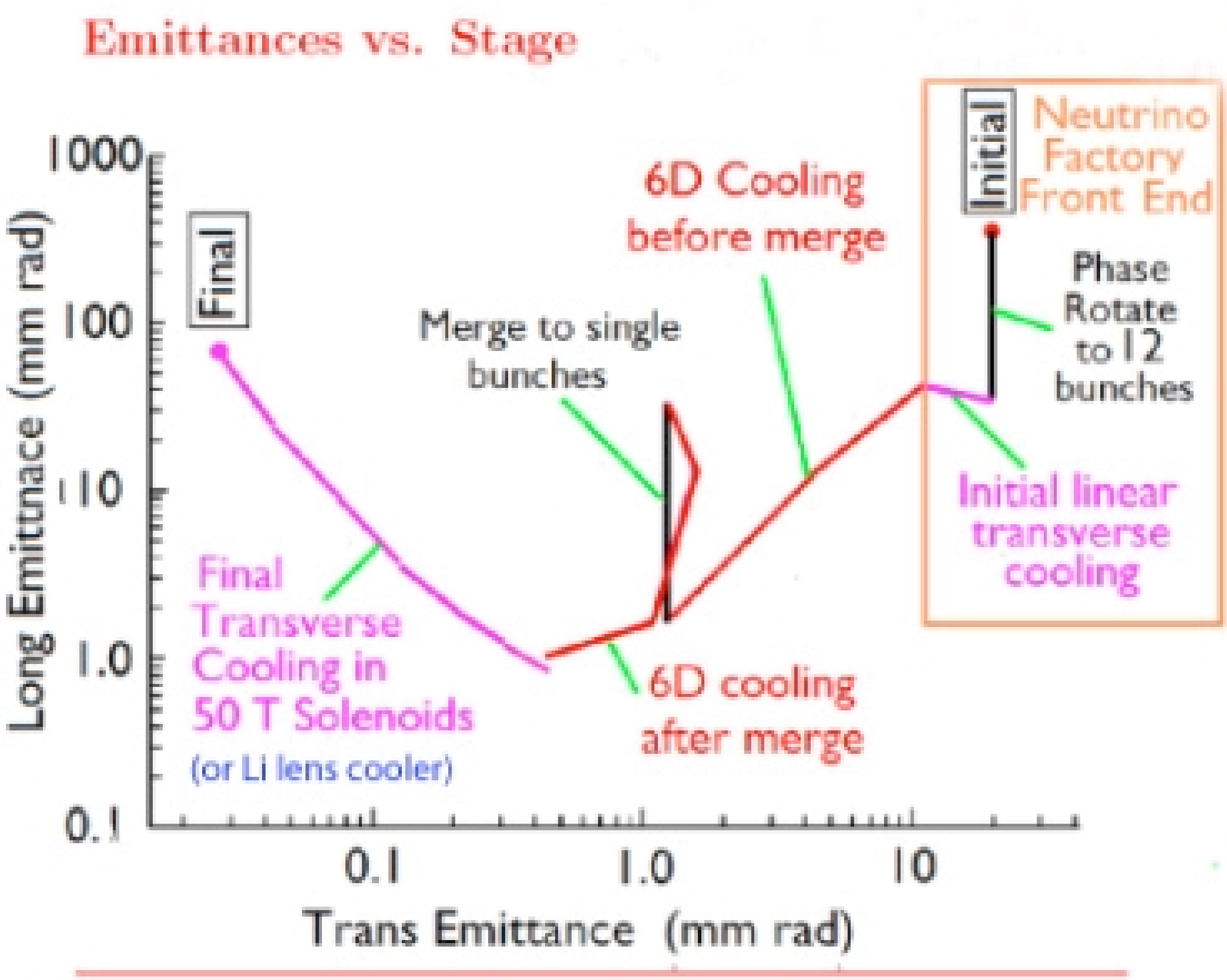
A Lithium Lens Cooling Experiment

UCLA

K. Lee, D. Cline, A. Garren,Y. Fukui

NFMCC June 13, 2008 Workshop

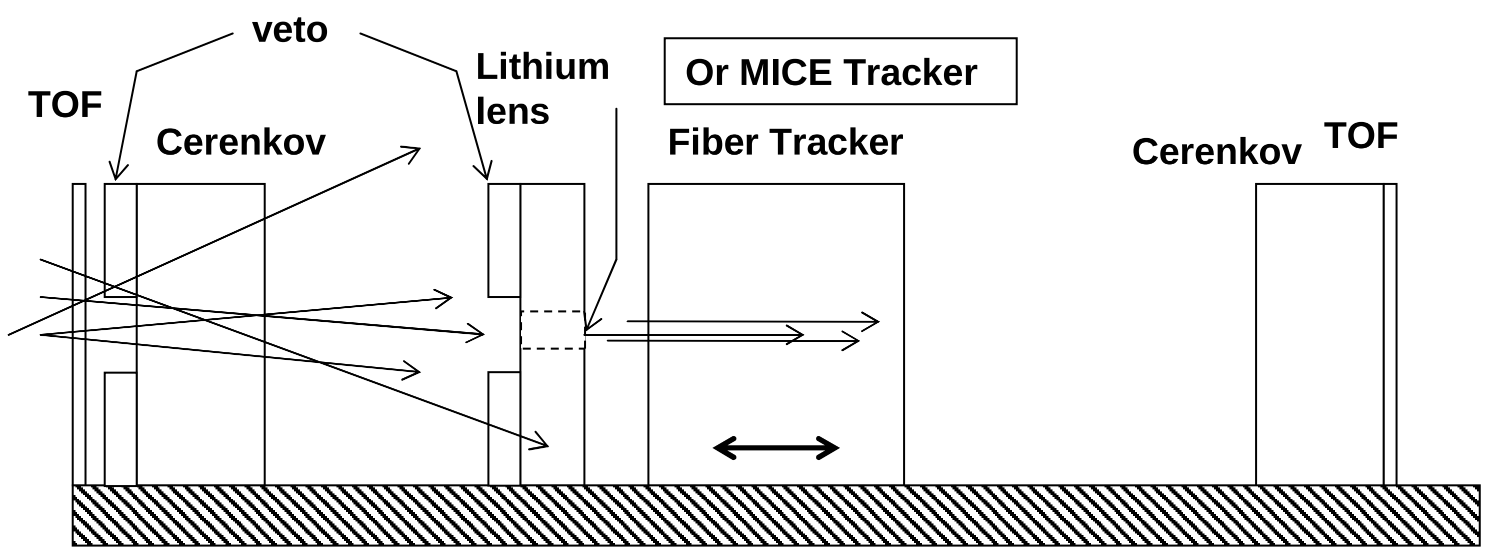
Final Cooling Stages



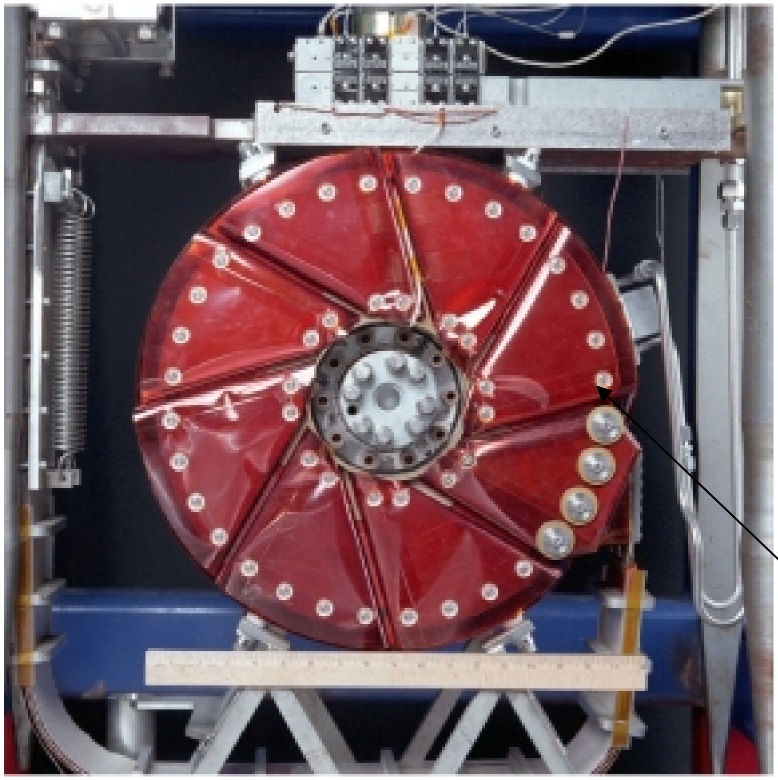
To Show Cooling with Lithium Lens

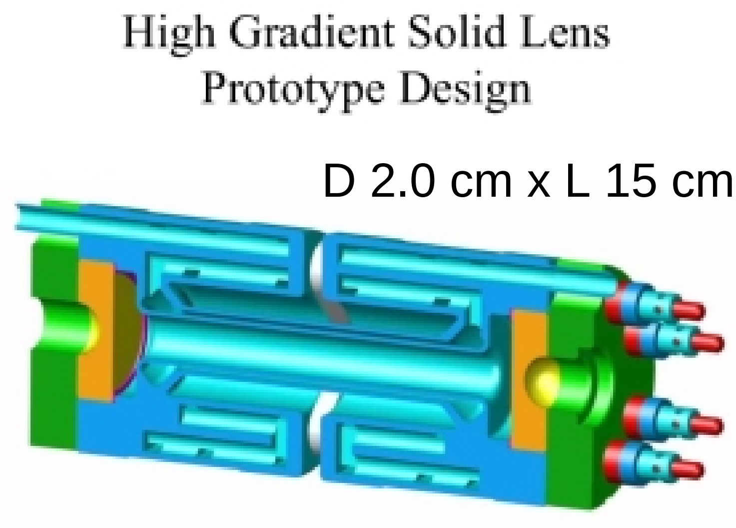
- Use the Lithium lens (Fermilab team and infrastructure) to be available after the Tevatron run in 2010 or 2011
- MICE like fiber tracker or non-magnetic fiber tracker
- For entering beam with low x,y,z-momentum spread, measure the beam spot at entrance and at exit, and measure the momentum direction spread
- Measure for different B field gradient values
- Ultimately, can the Lithium lens be for the final cooling stage?

Schematic Setup of the Experiment



Fermilab Solid Li Lens (Recent Design)





D 2.0 cm x L 15 cm

Induction Coils

J. Morgan

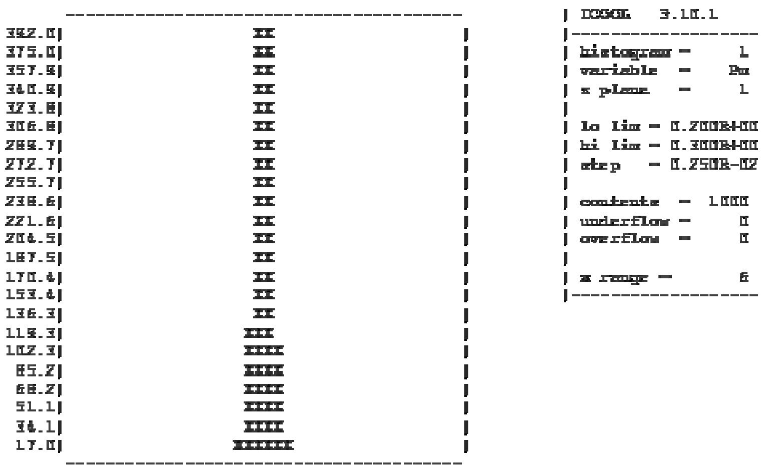
Lens Upgrade Note

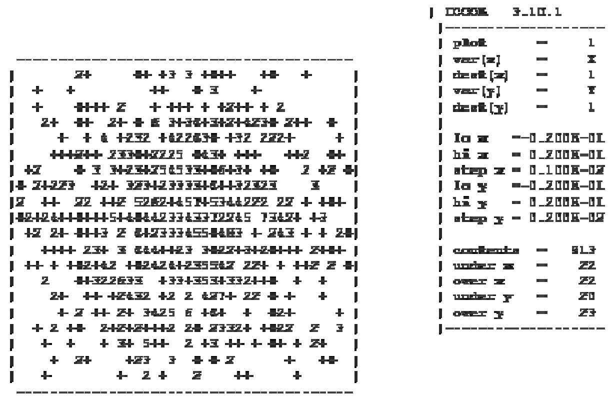
Beam Profiles in 10 T, 2 cm x 15 cm Li Lens

dx, dy, dz = 0.01 m

dpx, dpy = 0.001 GeV/c, dpz = 0.002 GeV/c

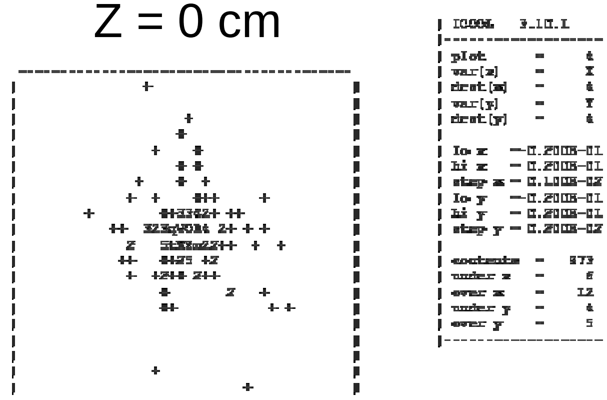
ICOOL v3.05





2 cm

Z = 0 cm



Z = 1 cm

Beam Profiles in 10 T Li Lens

← 2 cm →

Z = 2 cm   3 cm   4 cm   15 cm   RF

delevel = 2; strag level = 4; scat level = 4

Beam size oscillates and the beam exits with a focus.

Need to design the end fields to move the focus to infinity.

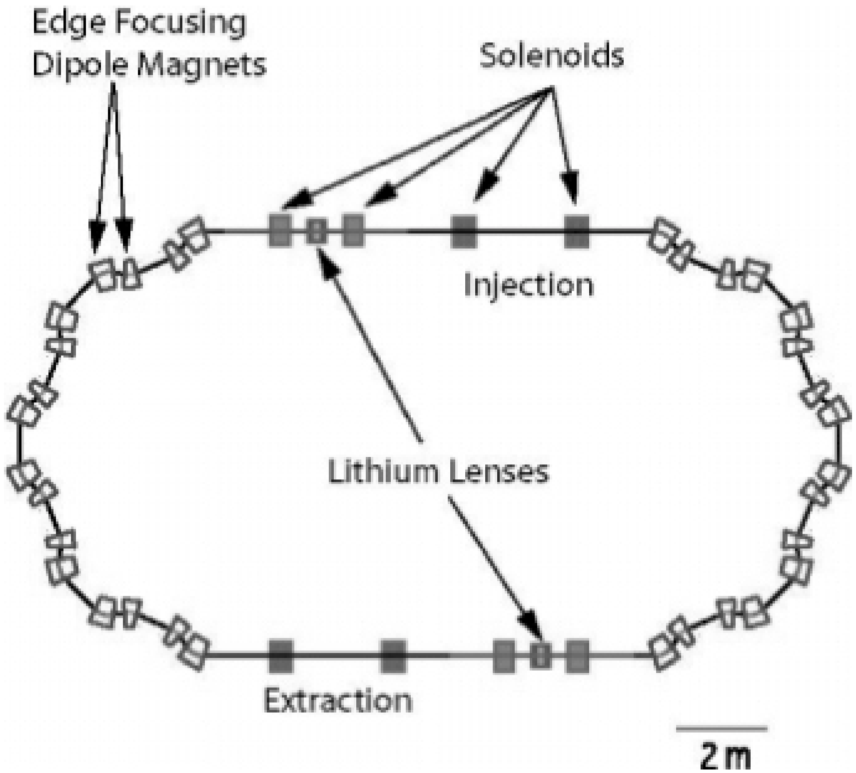
Summary

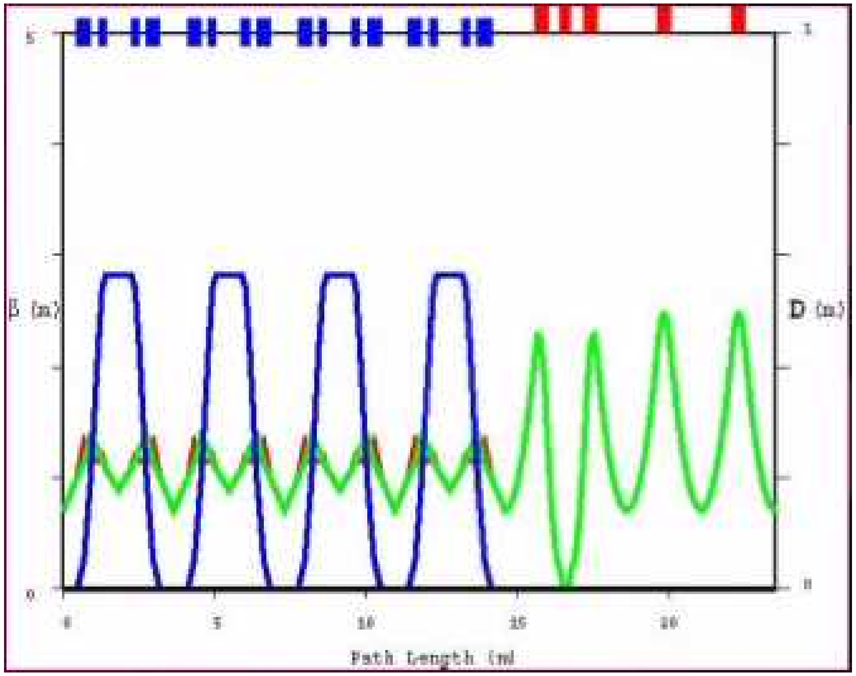
- Started cooling simulation studies w/ ICOOL.
- Continue to find an experiment that will demonstrate the Lithium Lens Cooler can be used in the final cooling stage.

Recent Interest in liquid Li lens

- Curved Li lens (~2004-current) by Y. Fukui
- Cooling Ring studies (~2002-2004) using Li lens by A. Garren and Y. Fukui
- Solid Li lens at the antiproton source for the Tevatron is limited to a few Hz (0.4 Hz) for > 6 mos. operational lifetime.

Li Lens Cooling Ring in ~2004





A. Garren

Parameters of the Li Lens Cooling Ring

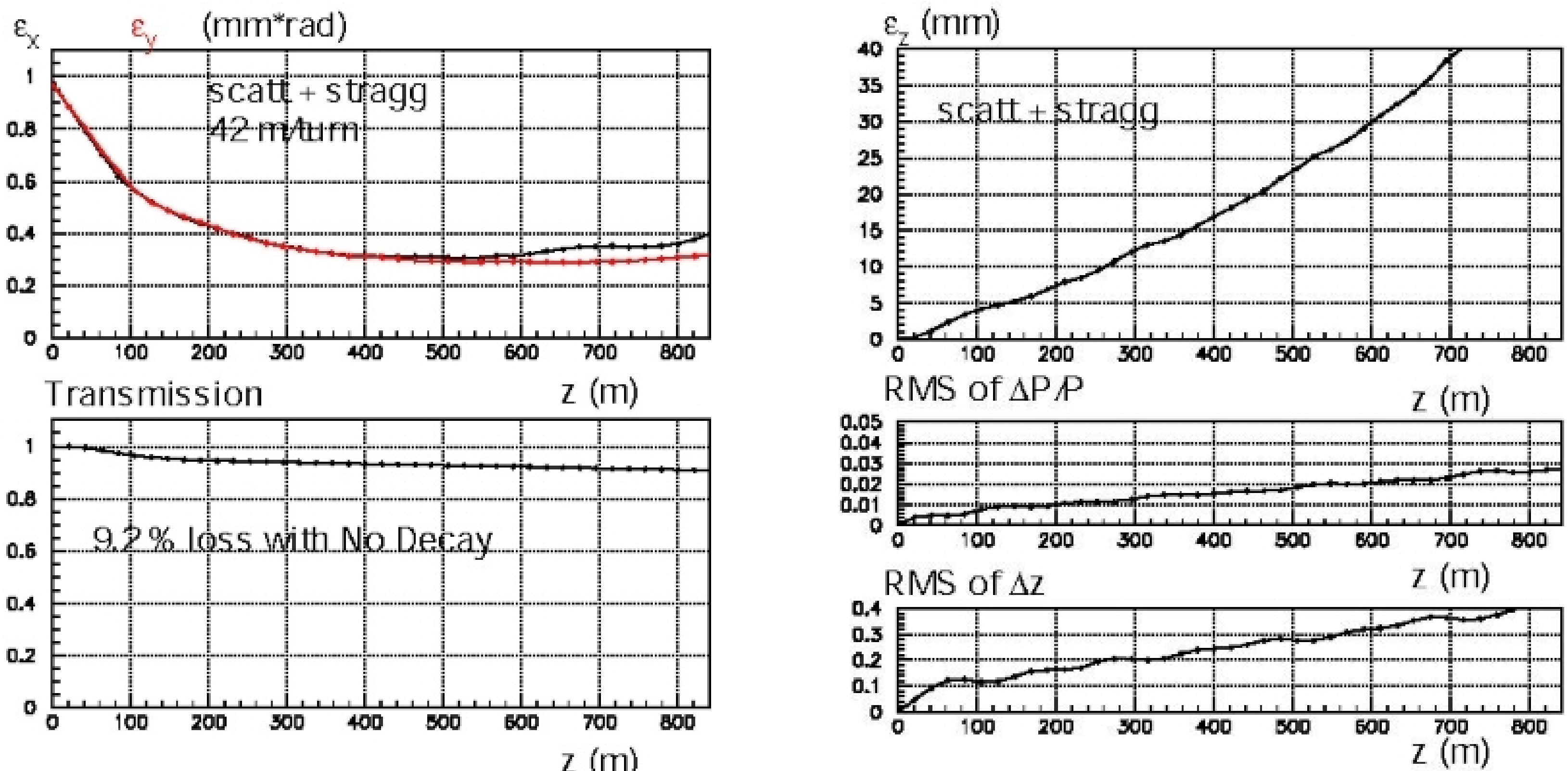
muon momentum	250 MeV/ c
Circumference	42.1 m
straight section length	5.9 m (x 2)
Structure of half cell	2 dipoles with edges
number of bending cells	8
bend cell length	3.6 m
length of Lithium lens	34.5 cm (x 2)
Lowest/ highest β in Li	1.0 cm /16 cm
dE/dx	35 MeV/ turn (x 2)
dipole bend angles	44.2, –21.7 degree
dipole edge angles	30/–3, –11/–11 degree
dipole magnetic field	6.5, -3.2 tesla
Cell tunes bend cell	0.72/ 0.70
Cell tunes straight cell	4.0

Y. Fukui et. al,
Proceedings of **2005** Particle Accelerator Conference, Knoxville, Tennessee,

IEEE01591401

A. Garren

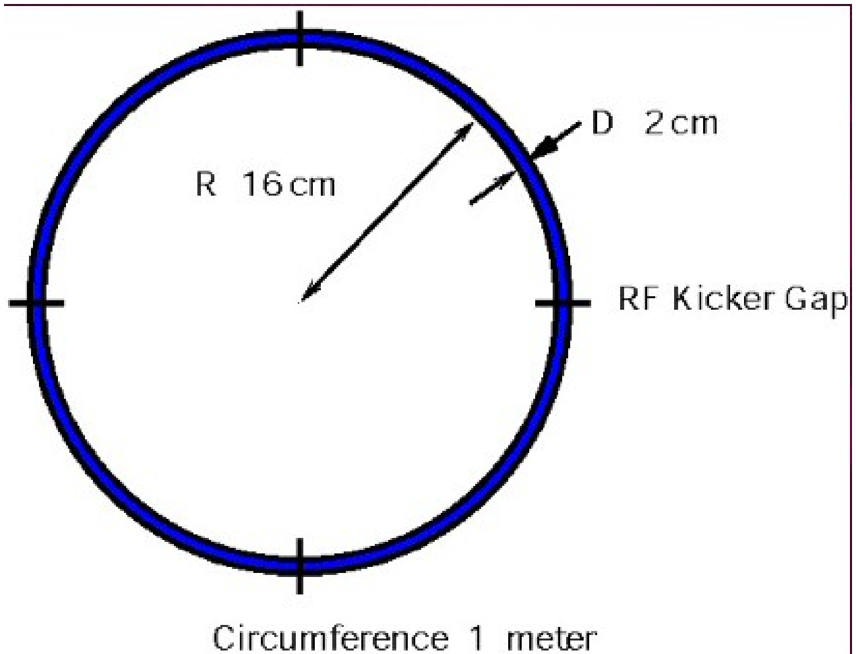
Results for Cooling Ring w/ Straight Lens

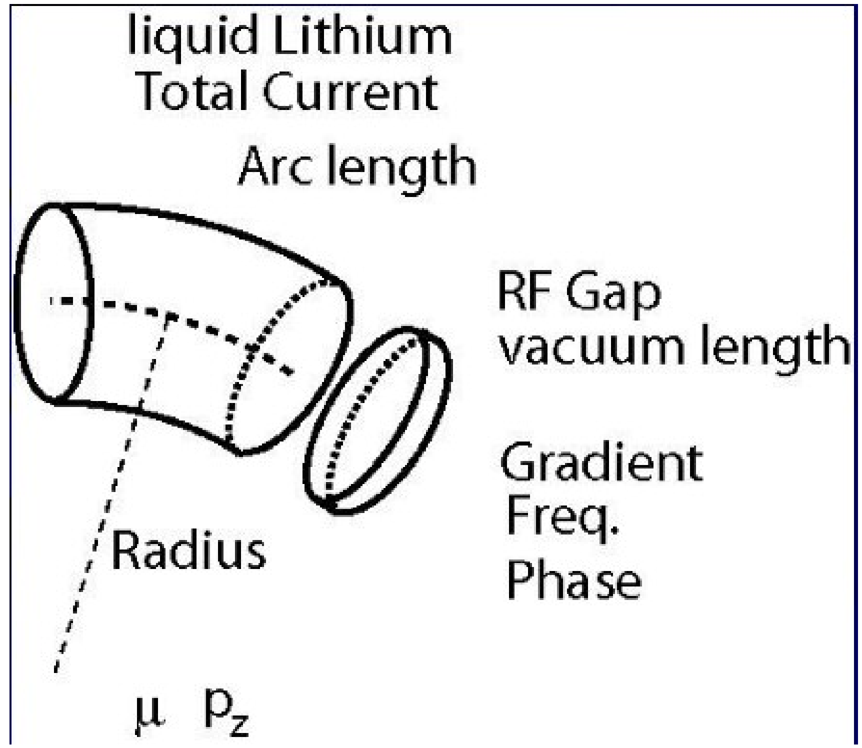


Y. Fukui et. al, Proceedings of **2005** Particle Accelerator Conference, Knoxville, Tennessee,

IEEE01591401

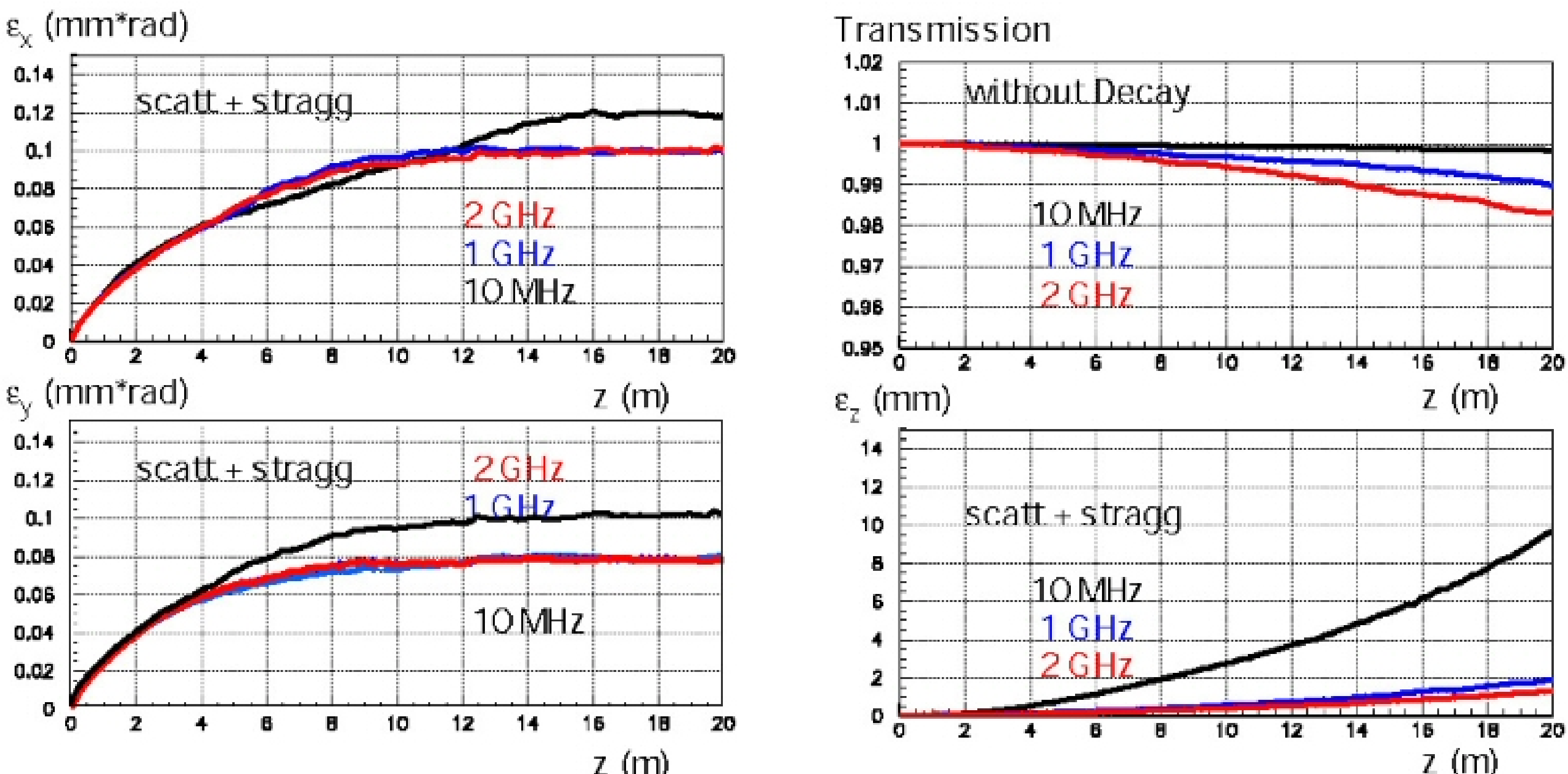
Curved Lithium Lens Cooling Ring





f_0 = 278.3 MHz for 250 MeV/c

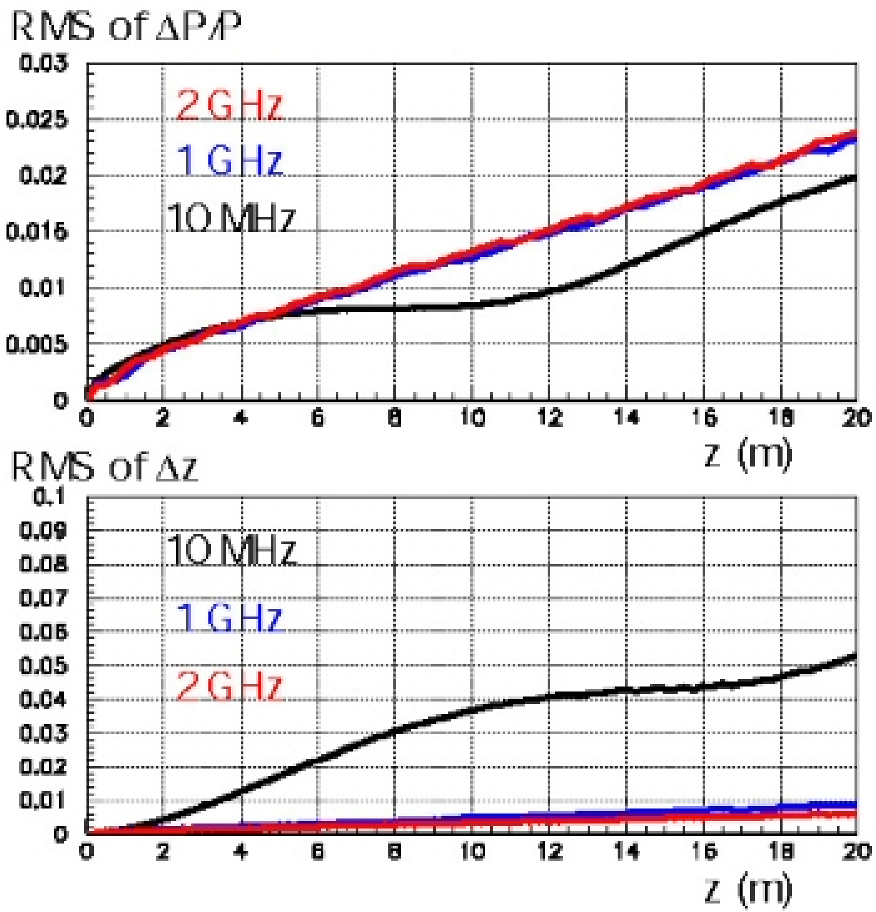
Results for Cooling Ring w/ Curved Lens



Y. Fukui et. al, Proceedings of **2005** Particle Accelerator Conference, Knoxville, Tennessee,

IEEE01591401

Results for Cooling Ring w/ Curved Lens



Y. Fukui et. al, Proceedings of **2005** Particle Accelerator Conference, Knoxville, Tennessee,

IEEE01591401

Liquid Li Lens Development at BINP

- The Li lens work by Dr. Silvestrov et. al at BINP was for use at the Tevatron anti-proton source (accord w/ Fermilab for run II) and at CERN.
- The lens survived < 100k pulses at 7.5 T (design was 10M and 13 T).
- Shock waves in the Li and cracking of the Ti septum.

BINP Li Lens

BINP liquid lithium lens, opened lens lithium vessel and the entire system.

http://www-bdnew.fnal.gov/pbar/Projects/liquidlilens/liquidli.htm

Properties of Lithium Metal

Density [gm/cm³]

$$\rho_{\mathrm{solid}} = 533 \cdot \left(1 - 1.8 \times 10^{-4} \cdot (\mathrm{T} - 273.2)\right)\left[\mathrm{kg/m^3}\right]$$

$$\rho_{\mathrm{liquid}} = 540.43 - 0.02729 \cdot \mathrm{T} - 8.0035 \cdot \mathrm{T}^2 \times 10^{-5} + 3.799 \cdot \mathrm{T}^3 \times 10^{-3} [\mathrm{kg/m^3}]$$

Resistivity [10^{-6} Ω-m]

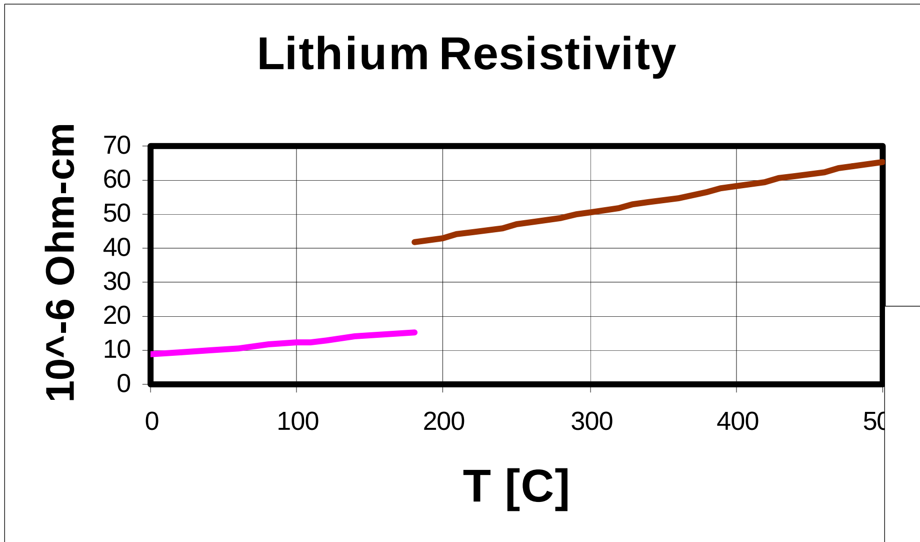
$$\rho_{solid} = 8.55 \times 10^{-2} \cdot \left(1 + 4.46 \times 10^{-3} \cdot (T - 273.2)\right)\left[10^{-6}\,\Omega \cdot m\right]$$

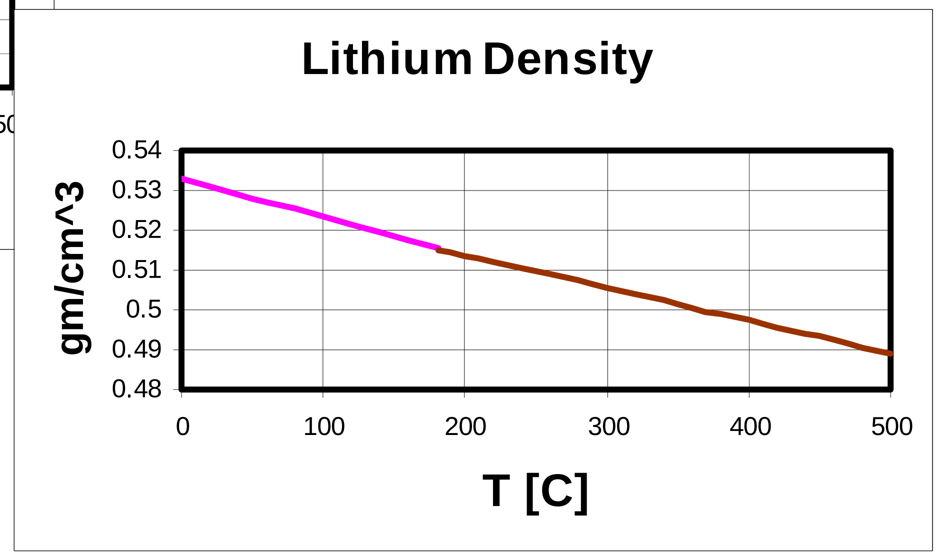
$$\rho_{liquid} = 27.884 \times 10^{-2} \cdot \left(1 + 2.7 \times 10^{-3} (T - 273.2)\right)\left|10^{-6}\,\Omega \cdot m\right|$$

BINP Li Lens Technology

http://www-bdnew.fnal.gov/pbar/Projects/liquidlilens/liquidli.htm

Properties of Lithium Metal





BINP Li Lens Technology

http://www-bdnew.fnal.gov/pbar/Projects/liquidlilens/liquidli.htm

Properties of Related Elements

	Melting pt. [C]	Density [g/cc]
Li	180.54	0.54
Al	660.32	2.7
Be	1,287	1.85
Ti	1,668	4.51
Steel	1,370	7.874 [Fe]
Li_2O	1,570	2.01
Li_3N	813	1.27

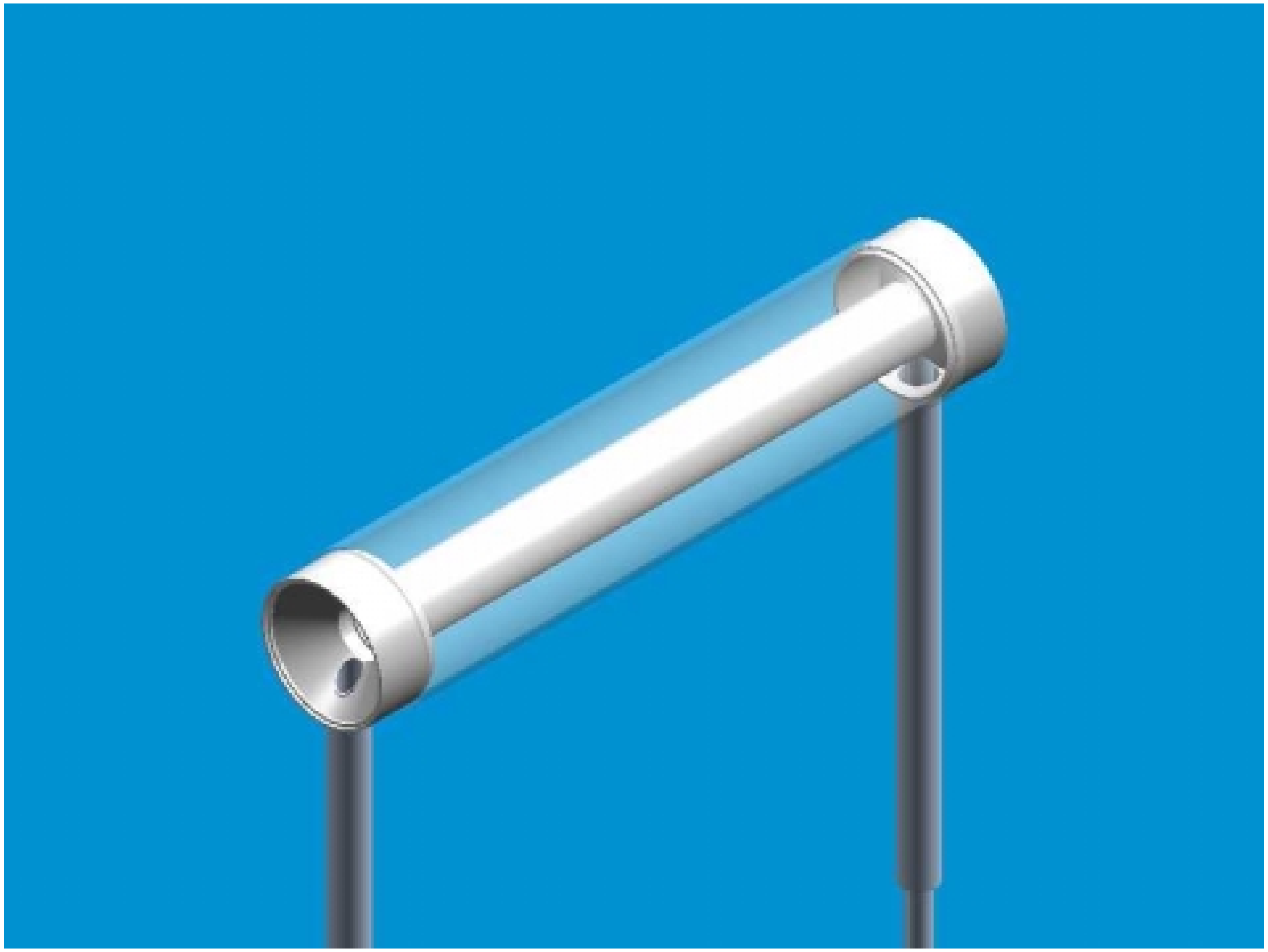
Observed Fermilab Li Lens Lifetime

B grad (T/m)	Avg. Life Time (Pulses)
1,000	<500,000 (1.9 wk)
900	1,000,000 (3.8 wk)
800	3,000,000 (5.7 wk)
740	9,000,000 (17 wk)
700	>10,000,000 (19 wk)

J. Morgan

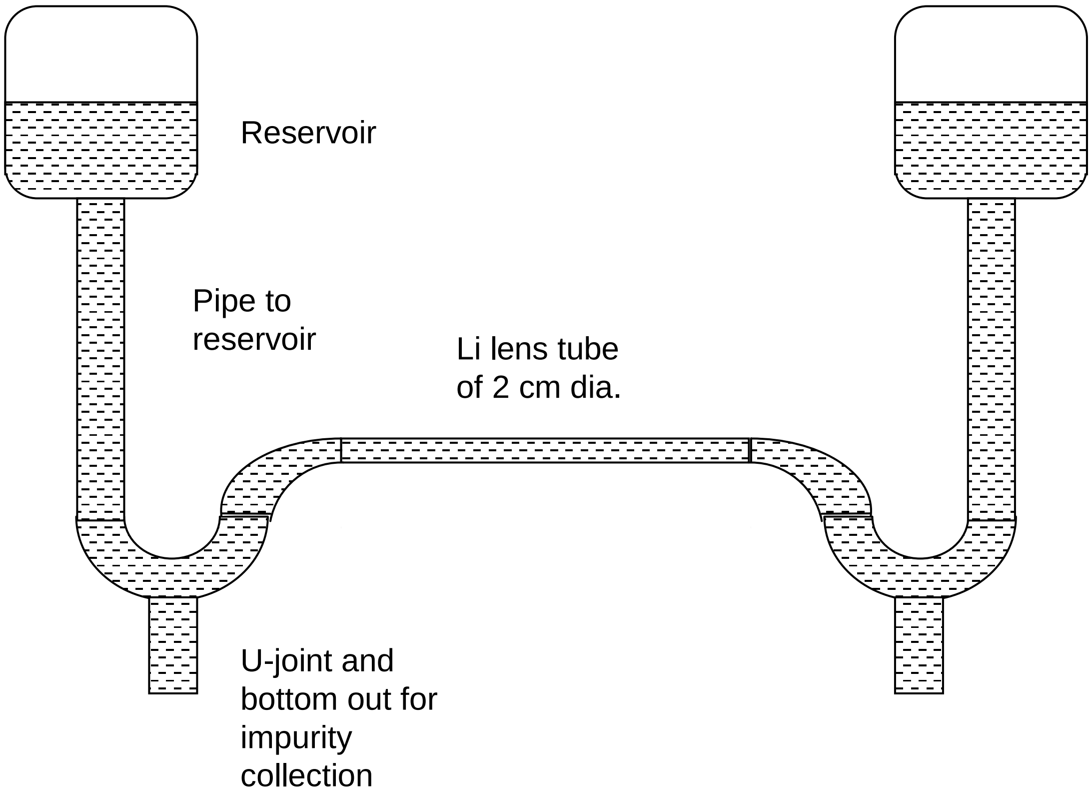
Lens Upgrade Note

Initial Mechanical Design



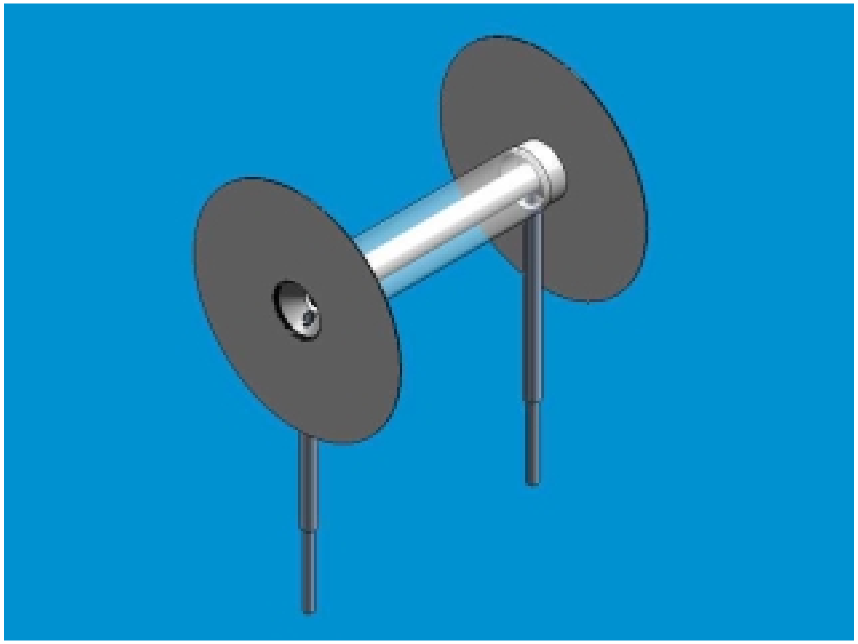
- D 2.54cm $\times$ L 30cm
- Outer tube for heated oil above 200 C
- Double layered tubes for liquid Li and heated oil

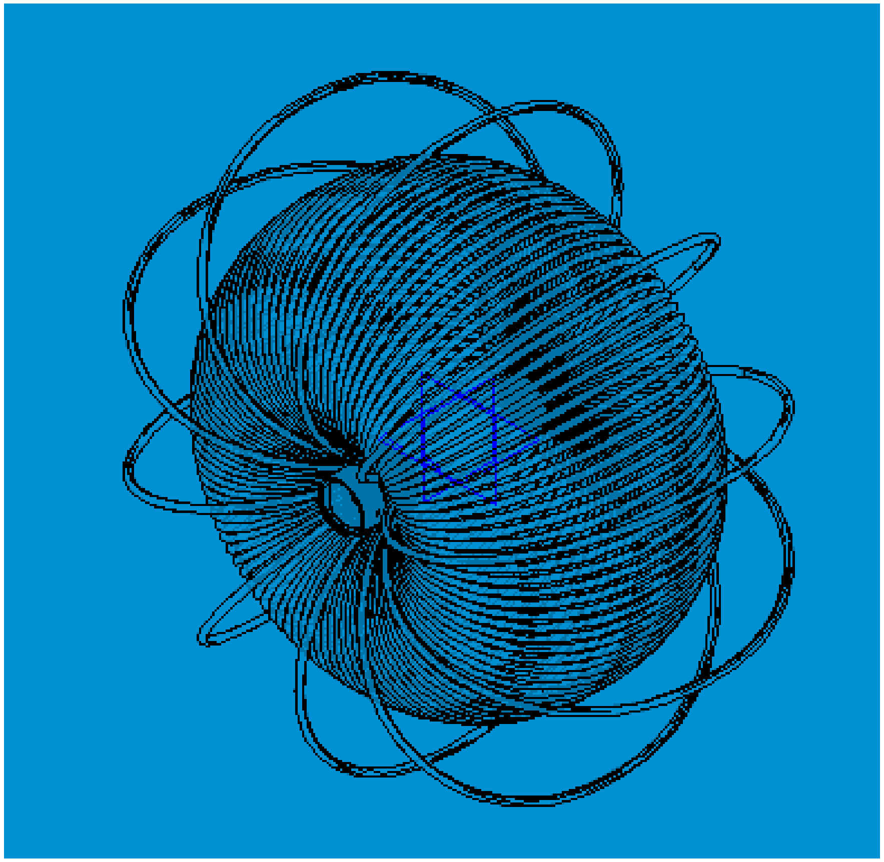
Push-Pull Flow of Liquid Li



Conceptual Design w/ two reservoirs for push-pull thermal cooling action.

Initial Design of Liquid Li Lens





Lens assembly w/ current discs and the primary and secondary coils

Li D = 2.54 cm; L = 30.0 cm

Thermal Cooling w/ static Li in Lens

Li Lens Parameters:
D = 2.54 cm; L = 30.0 cm; Wall Thickness = 1.06 mm (~41mil)

I_{DC} = 64.0 kAmps; $B_{Surface}$ = 1.00 T; DC Heat Load = <u>1.77 MW</u>; too high

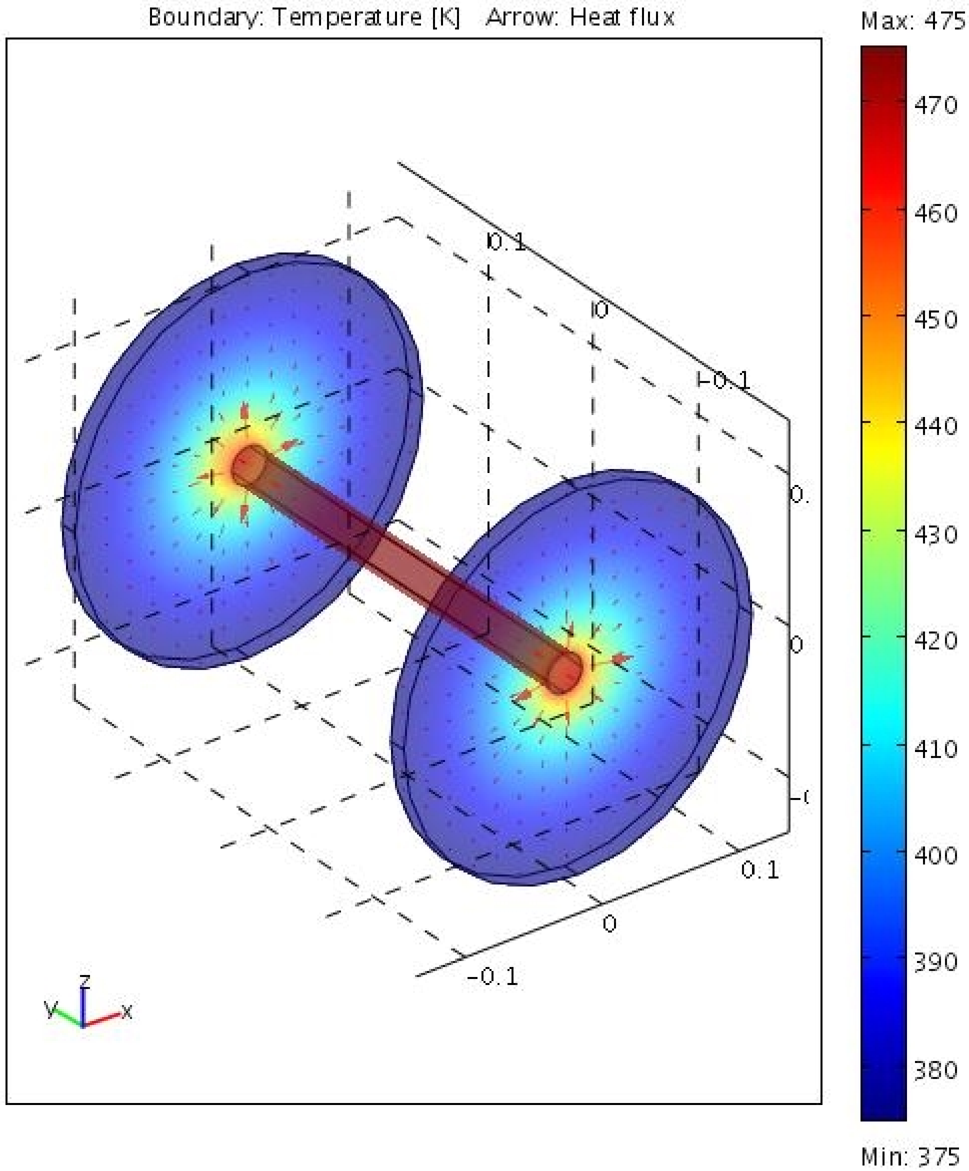
@15 Hz of 10 msec pulses, Heat Load = 70 <u>kW</u>; manageable

Be Tube [k@20C = 190 W/m/K]: Outer T = 200 C; **Inner T = 210 C**

Ti Tube [k@20C = 22 W/m/K]: Outer T = 200 C; **Inner T = 285 C**

Oil Sp. Heat Capacity c_P@20C ~ 2 kJ/kg/K: **Flow ~ 13 L/min**

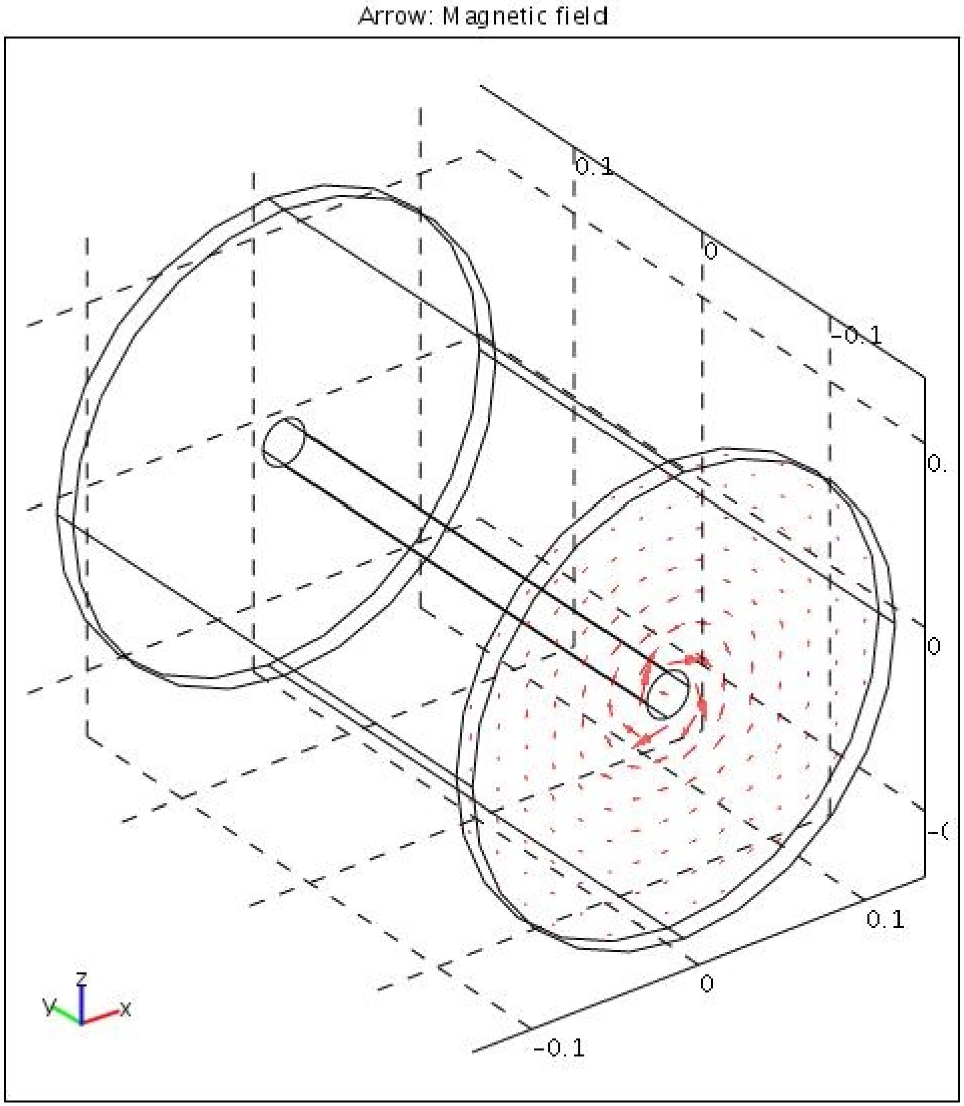
Steady State Heat Transfer



- Current enters in the left disc and exit in the right disc.
- Temperature on tube is maintained at ~200 C.

COMSOL3.4 (trial license)

B Field at the Current Disc



B field map at the disc

COMSOL3.4 (trial license)

Summary

- Cooling simulation studies w/ tracking codes and using field maps in 2008 and 2009.
- Mechanical stress studies on transient heating and field map studies using FEA code in 2008 and 2009.
- Proposal to the Fermilab to get collaboration w/ members at the lab for use of the resources, after the design is matured in 2009.
- Thanks to Tony Leveling and Jim Morgan for the consultation times.