

# A Lithium Lens Cooling Experiment

## UCLA

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## **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)



High Gradient Solid Lens Prototype Design



**Induction Coils** 

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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

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306.Bj	II	i.
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255.Tj	II	i.
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206.5	II	i.
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Z = 1 cm



### Beam Profiles in 10 T Li Lens



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



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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 $\beta$ 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



## Results for Cooling Ring w/ Straight Lens





## **Curved Lithium Lens Cooling Ring**





## Results for Cooling Ring w/ Curved Lens





## Results for Cooling Ring w/ Curved Lens



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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).</li>
- 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* NFMCC June 13, 2008 Workshop



## **Properties of Lithium Metal**

Density [gm/cm<sup>3</sup>]  

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

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

#### Resistivity [10<sup>-6</sup>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 NFMCC June 13, 2008 Workshop



## **Properties of Lithium Metal**



BINP Li Lens Technology

http://www-bdnew.fnal.gov/pbar/Projects/liquidlilens/liquidli.htm NFMCC June 13, 2008 Workshop



## **Properties of Related Elements**

	<u>Melting pt.</u> [C]	<u>Density</u> [ɡ/cc]
Li	180.54	0.54
ΑΙ	660.32	2.7
Ве	1,287	1.85
Ti	1,668	4.51
Steel	1,370	7.874 [Fe]
Li <sub>2</sub> O	1,570	2.01
Li <sub>3</sub> N	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)

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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<sub>DC</sub> = 64.0 kAmps; B<sub>Surface</sub> = 1.00 T; DC Heat Load = <u>1.77 MW</u>; too high

@15 Hz of 10 msec pulses, Heat Load = 70 kW; 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  $c_P@20C \sim 2 \text{ kJ/kg/K}$ : 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.