Mucool Note 84

Effect of Absorber Window Curvature On Cooling Performance

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Abstract

Cooling simulations to date have modeled absorber regions with flat end windows. However, practical absorber cells will almost certainly have rounded windows. We examine the cooling performance of two recent cooling lattices using flat and hemispherical end windows. We find no significant difference in transmission, transverse cooling, or longitudinal heating.

1 Introduction

Liquid hydrogen is the absorber material that gives optimal performance for ionization cooling [1]. Until now all simulations[1] of cooling using liquid hydrogen absorbers have assumed that the hydrogen is contained in a vessel with flat (usually aluminum) end windows. However, practical liquid hydrogen targets typically have curved ends that result in an absorber length that decreases with increasing radius. One could imagine several effects that this curvature could have on the cooling performance. One would expect a decrease in transverse cooling efficiency for large radius particles that have a small divergence, although these particles only occupy a small phase space in the large emittance beam for the neutrino factory. On the other hand one might hope for some improvement in the longitudinal dynamics since the absorbers have the "pill" shape that was conjectured to introduce a desirable p_z-transverse amplitude correlation in the beam [2].

The required thickness of the end window is also an issue [3]. The window must safely hold off a 2 atm pressure differential at 20 K. The stress on the window grows linearly with the window radius. D. Kaplan [4] has shown that hemispherical-shaped end regions

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[1] At least all simulations that I am aware of.

require significantly smaller wall thickness than flat windows or ellipsoidal windows. Taking into account the required safety factors on the allowed stress and the large radius of the beam for the neutrino factory, minimum window thicknesses on the order of 0.5 mm may be required. It has been demonstrated that this leads to significant degradation in cooling performance compared to the 50 μm thickness used in earlier studies [5].

For this study we have written a new hemispherical absorber end region routine for Icool (v2.03) and used it to compare with results using flat windows.

2 Algorithm

The standard region shape in Icool is a cylindrical solid with flat ends.[2] A new region type was defined for the absorber end region, which embedded a hemispherical shell inside a standard Icool region. There are two variants corresponding to the entrance and exit ends of the absorber. In the exit end, for example, the particles see a spherical continuation of the absorber material, e.g. liquid hydrogen, until they reach the curved window boundary. The boundary consists of a segment of a spherical surface. The window consists of another material, e.g. aluminum, with constant radial thickness. Following the window for the remainder of the Icool region is an exterior material, e.g. vacuum.

Once a particle enters this type of region, the subroutine interacts strongly with the standard Icool stepping control routines. The program uses moderately large steps through the absorber until it reaches the window boundary. If the proposed Icool step goes over the boundary, the exact distance to the boundary is computed and Icool is forced to retake a smaller step. Once inside the window material, the program uses a very small step size. The same procedure is repeated at the second window boundary surface. Once the particle reaches the exterior subregion, the stepping can again be taken with moderately large steps.

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[2] Known as a CBLOCK to Icool aficionados.

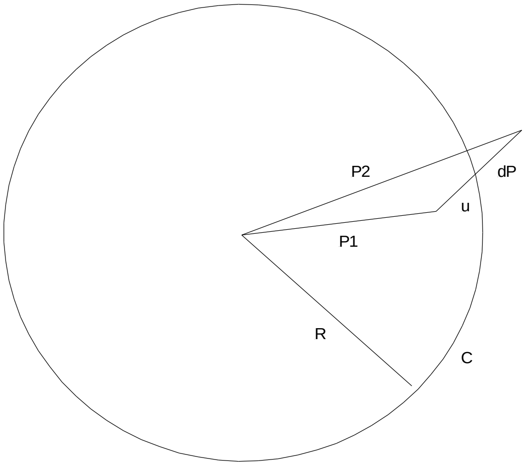

Figure 1. The step dP begins at P_1 and ends at P_2 relative to a coordinate system centered on the boundary surface. The distance *u* is the fraction of dP from P_1 to the boundary surface.

The procedure for recomputing the step size is shown in Fig. 1. Consider a coordinate system whose origin is at the center of the spherical boundary segment C. Let P_1 (P_2) be the radial vector to the start (end) of the current step and $dP = P_2 - P_1$. Define u to be the fraction of the current step that just reaches the boundary surface, so that u satisfies the relation $0 < u < 1$. Then we have the vector constraint $\left| P\bar{1} + u \; d\bar{P} \right| = R$, which leads to a quadratic equation that can be solved for u.

3 Simulation Results

The first example that we simulated was a 1.1 m cell, 3.4 T FOFO-like cooling lattice with an initial transverse emittance of 8500 mm mr [6]. This example used 14 cm thick liquid hydrogen absorbers with a radius of 20 cm and with 50 μm thick, flat aluminum end windows. For the curved window case we adjusted the parameters to give the same absorber thickness on-axis as the original flat window geometry. We also used a 50 μm thick aluminum window for the curved case to give a straight comparison of the effect due to curvature. The reference particle sees the same energy loss in both cases and the *rf* tuning did not have to be adjusted. The shape of the curved window is shown in Fig. 2.

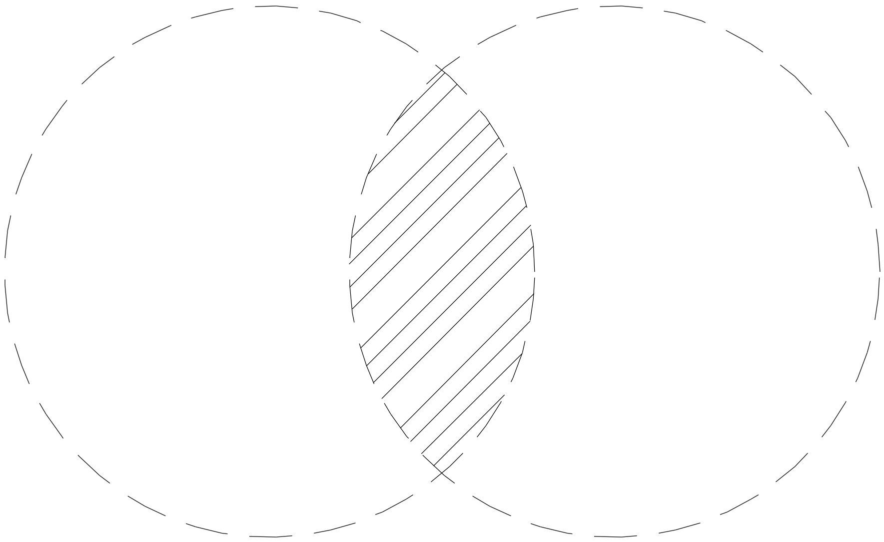

Figure 2. Shape of the 14 cm thick, 20 cm radius hydrogen absorber. There is a 50 μm thick aluminum window surrounding the hydrogen.

The cooling factors for this case are shown in Fig. 3 as a function of distance along the lattice. The quantity **Tr** is the transmission, **fεT** is the fractional change in normalized transverse emittance, and **fεL** is the fractional change in normalized longitudinal emittance. The curved boundary surface makes little difference to the cooling performance.

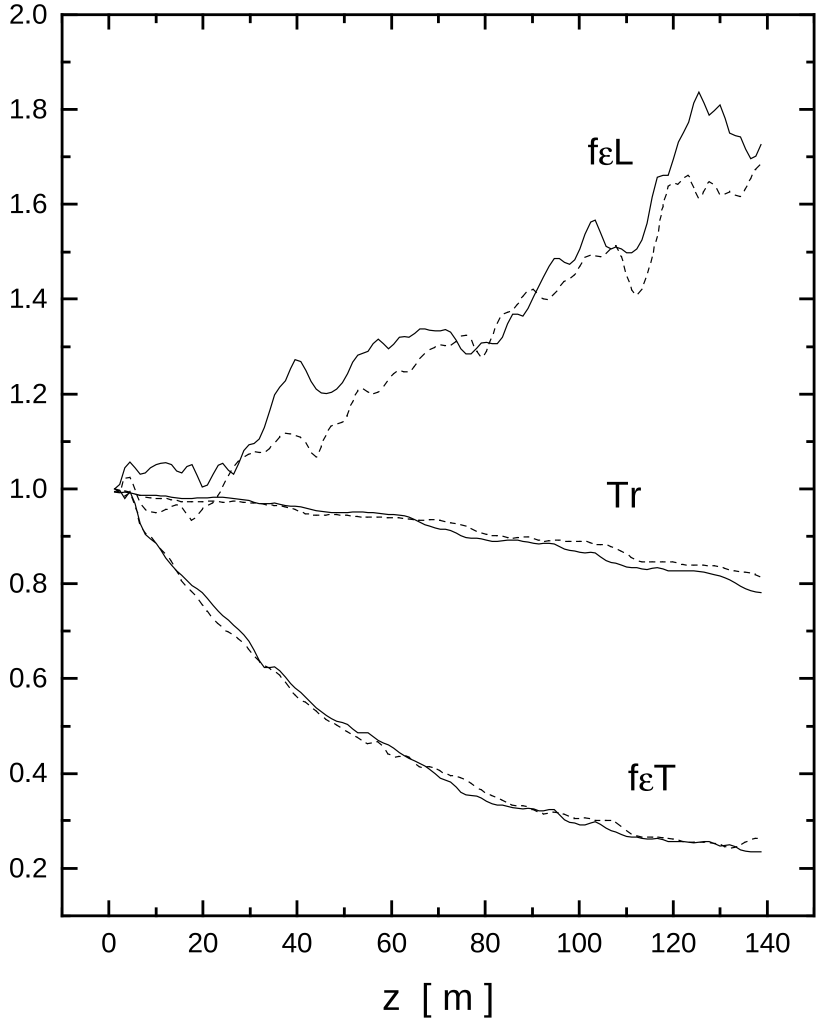

Figure 3. Cooling performance of 1.1 m lattice with flat (dashed) versus curved (solid) aluminum end windows on the liquid hydrogen absorbers.

The second example is a 1.5 m cell, 3.4 T FOFO-like cooling lattice with an initial transverse emittance of 14000 mm mr [7]. The original example used 20 cm thick liquid hydrogen absorbers with a radius of 20 cm and 500 μm thick, flat aluminum end windows. For the curved window case we adjusted the parameters to give the same absorber thickness on-axis as the original flat window geometry. In order to make the comparison as realistic as possible, we used window thicknesses based on our best current engineering knowledge [8]. This called for a 500 μm thickness for the curved case and 1000 μm thickness for the flat case.[3] The shape of the curved window is shown in Fig. 4.

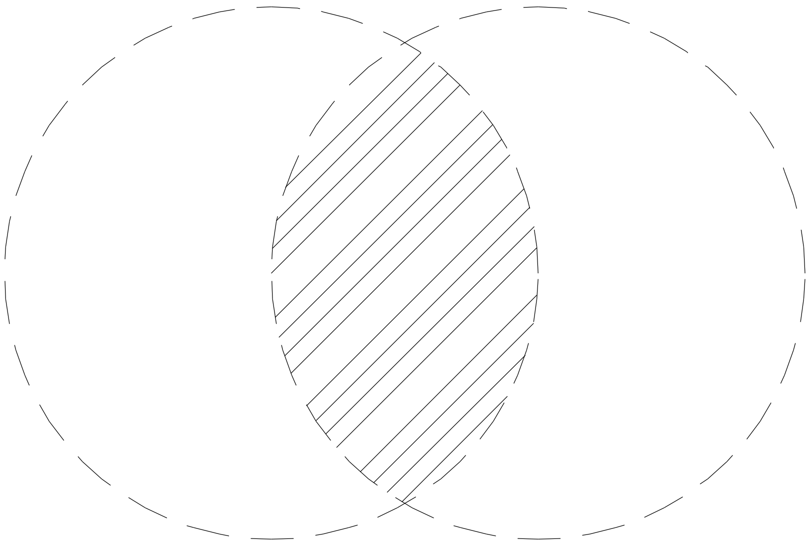

Figure 4. Shape of the 20 cm thick, 20 cm radius hydrogen absorber. There is a 500 μm thick aluminum window surrounding the hydrogen.

The cooling factors for this case are shown in Fig. 5 as a function of distance along the lattice. Again there is little difference between the two cases, although the transmission appears consistently better with the curved ends.

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[3] The Icool parameter GRADREF was adjusted from 6.08 to 6.50 to account for the additional material on-axis.

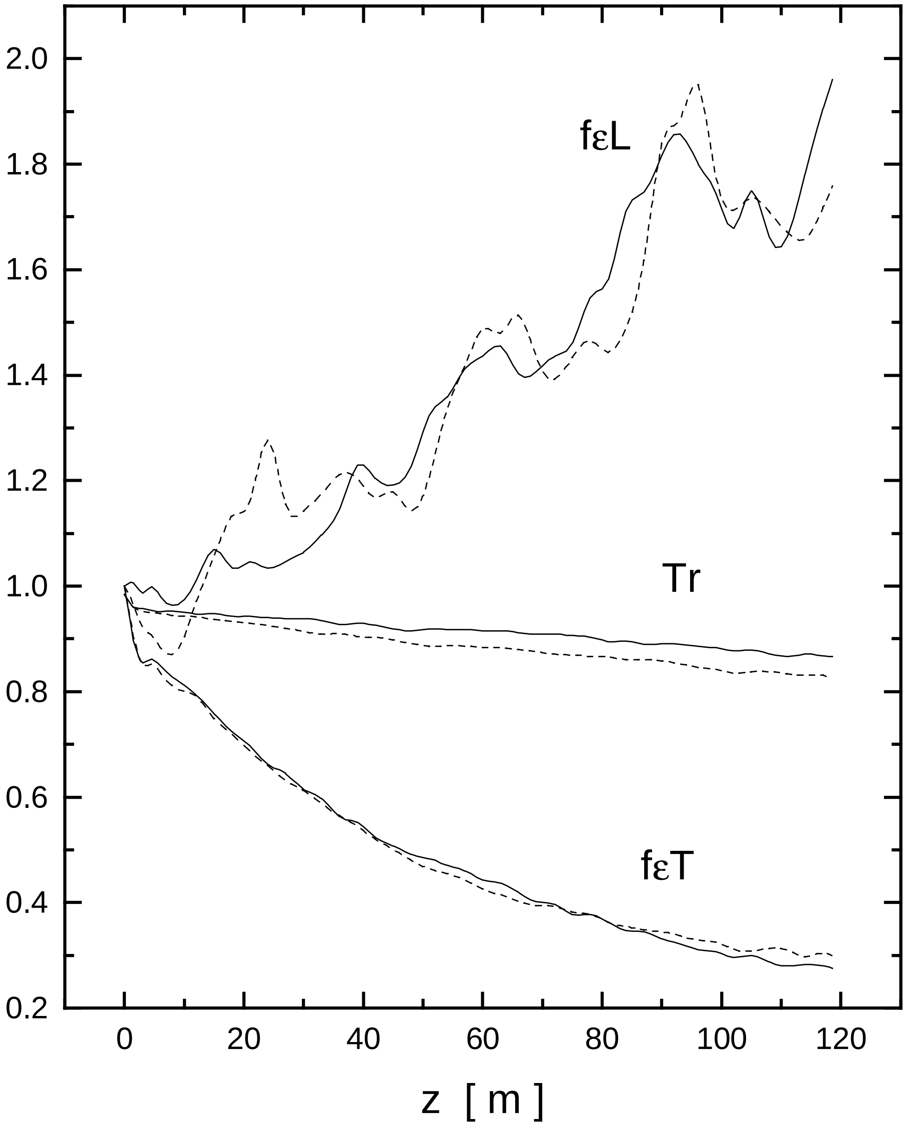

Figure 5. Cooling performance of 1.5 m lattice with 1 mm flat (dashed) versus 0.5 mm curved (solid) aluminum end windows on the liquid hydrogen absorbers.

The numerical values of the cooling parameters at the end of the two lattices are given in Table 1.

Table 1 Cooling performance at end of lattices

		Flat			**Curved**		
Cell [m]	**Z [m]**	**Tr**	**fεT**	**fεL**	**Tr**	**fεT**	**fεL**
1.1	**138**	**0.814**	**0.265**	**1.686**	**0.781**	**0.235**	**1.726**
1.5	**118**	**0.826**	**0.300**	**1.759**	**0.866**	**0.276**	**1.960**

Acknowledgements

I would like to thank Eun-San Kim and Dan Kaplan for their help on this study.

Notes and References

[1] C.M. Ankenbrandt et al, Status of muon collider research and development and future plans, Phys. Rev. ST-AB 2:081001-1, 1999.

[2] P. Lebrun, Development of a correlator matching section for the alternate solenoid cooling channel…, Mucool note #33, 1999.

[3] D.M. Kaplan et al, Alternating solenoid design studies, Mucool note #56, 1999.

[4] D. Kaplan, LH2 absorber design status, Muon collider collaboration meeting, LBNL, December 1999.

[5] P. Lebrun et al, Comparison of the performance of 3.4 T FOFO and 6.6 T SFOFO cooling channels simulated in ICOOL and DPGeant, Mucool note #68, 1999. Changing the window thickness from 50 to 500 μm increased the transverse emittance at the end of the 130 m long channel from 1500 to ~3000 mm mr.

[6] Input files for this example did exist at the URL, www-hifar.lbl.gov/~eskim/, but they seem to have sublimated away into cyberspace after this study was started. The properties of the channel are described in reference 5, above.

[7] E. Kim, DFOFO cooling channels for a neutrino factory, Mucool note #79, 2000.

[8] M. Zisman, private communications.