# Development of Muon Ring Coolers, Neutrino Factories and Supersymmetric Higgs Factory

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**Abstract.** Over the past few years or so a key new development is the invention of Ring Coolers for muon cooling. In particular these rings demonstrate robust cooling of the longitudinal phase space. We discuss the Quadrupole or UCLA Ring Cooler and the prospects to make this a final cooler to reduce the tranceiver emittance to the value required for a $\mu^+\mu^-$ collider. This will lead to a Higgs Factory for the $A_0$ $/H_0$ in supersymmetry models.

## 1. Introduction

Ever since the recent start of the $\mu^+\mu^-$ collider in December 1992 at a meeting in Napa, the issue of longitudinal phase space cooling has been an issue [1]. In Table 1 we give the formulas for transverse and longitudinal cooling. It now appears that the emphasis on transverse cooling for all of these years may have missed the key point: longitudinal cooling may be easier to achieve as we now see in the Ring Cooler studies.

On the other hand a $\mu^+\mu^-$ collider requires a strong reduction in transverse emittance to the level of 0.3p mm rad. We show here how this may be achieved in a Ring Cooler.

The transverse cooling formula is given in (1).

$$\frac{d\varepsilon_\perp}{ds} = \frac{1}{\beta^2}\frac{dE_\mu}{ds}\frac{\varepsilon_\perp}{E_\mu} + \frac{\beta_\perp^*}{2\beta^2}\frac{(0.014)^2}{E_\mu M_\mu L_R} \tag{1}$$

$$\frac{d(\Delta E_\mu)^2}{ds} = {}^-2d[dE_\mu/ds]/dE_\mu\langle(\Delta E_\mu)^2\rangle \tag{2}$$

We note the need for a very small $\beta_\perp^*$ and large LR, radiation length, to reduce the heating term. The study of the ring cooler now shows that longitudinal or energy cooling may be easier than transverse cooling due to the heating term (equation 2). We believe a new scheme for muon colliders and neutrino factory using ring coolers (as shown in Figure 1) could be constructed in the future [2][3][4].

## 2. Supersymmetric Higgs Factory

In the model of supersymmetry there will likely be one low-mass Higgs ( $h^0$ ) and two high mass (or supersymmetric) Higgs A and H. For the parameter tan $\beta$, larger values lead to a near mass degenerate system of H and A states, most likely in the 300 - 500 GeV mass range. Current evidence on SUSY suggests a large value of tan $\beta$. In this

**Table 1.**

| CoM energy (TeV) | 0.4 |
|---|---|
| P energy (GeV) | 16 |
| P/bunch | $2.5x10^{13}$ |
| Bunches/fill | 4 |
| Rep. rate (Hz) | 15 |
| $1/\tau_\mu$ | 240 |
| $P$ power (MW) | 4 |
| $\mu$/bunch | $2x10^{12}$ |
| $\mu$ power (MW) | 4 |
| Wall power (MW) | 120 |
| Collider cirumference (m) | 1000 |
| $< B > (T)$ | 4.7 |
| $\delta p$ (%) | 0.14 |
| 6-D $\eta_{6,N} (\pi m^3)$ | $1.7x10^{-10}$ |
| Rms $\eta_n$ ($\pi$ mm-mrad) | 50 |
| $\beta$ * (cm) | 2.6 |
| $\sigma_z$ (cm) | 26 |
| $\sigma_r$ spot ($\mu m$) | 1.0 |
| $\sigma_\theta$ IP (mrad) | 0.044 |
| Tune shift | |
| $n_{turns}^{effective}$ | 700 |
| Luminosity ($cm^{-2}s^{-1}$) | $10^{33}$ |
| Higgs/year | |

case the coupling of H and A to $t\bar{t}$ and gauge bosons is sharply reduced, making them difficult to produce and study at the LHC or NLC [5].

In some ways a Muon Collider is the ideal method to produce (in the S channel) and study these states. Since one will be a scalar and the other pseudoscalar, the use of partially polarized $\mu^+$ beams will be of great usefulness. The mass splitting of the A and H is of order GeV and much easier to observe than the tiny width of the $h^0$.

The physics goals of a supersymmetric Higgs Factory are shown in Figure 2.

- The detector of these states of $e^+e^-$ or pp colliders depends on the coupling to $t\bar{t}$ states. This coupling falls rapidly with tan $\beta$ ; current estimates suggest large values of tan $\beta$ and weak production by these machines. The $\mu^+\mu^-$ coupling will remain large.
- The states could be nearly mass degenerative as shown in Figure 2 for large tan $\beta$. Again this makes the study of the states by associated production at $e^+e^-$ or $pp$ machines very difficult.

The study of the A and H is much less demanding on a collider than for the lower mass Higgs. Table 1 gives the machine parameters. The use of ring coolers could be crucial to the development of such a collider. This will be studied by this group in the next three years.

## 3. THE STUDY OF THE UCLA QUADRUPOLES RING COOLER

In Figure 3 we show the UCLA Ring Cooler worked out with Al Garren, P. He, Y. Fukui (UCLA), H. Kirk (BNL) and the author [2]. Clear evidence for GD cooling has been obtained in our simulators [3][4].

In Figure 4 we show the early evidence for GD cooling. By now the figure of merit is nearly 30 [6] (30 times more GD cooling compared to losses).

## 4. REQUIREMENT FOR THE SUPERSYMMETRIC HIGGS FACTORY

In order to construct a $\mu^+\mu^-$ collider to study the supersymmetric Higgs particles $H^0$ and $A^0$ the 6D cooling must be extremely good. Figure 5 shows the requirement on longitudinal and transverse emittance (from Rich Fernow and D. Neuffer). The UCLA Ring Cooler has reached nearly the required longitudinal emittance reduction but is far from the transverse requirement.

## 5. A LI LENS INSERT INTO THE RING COOLER

Going back to formular (2) we see that a very low $\beta^*$ is needed to reduce the heating term. Such a low $\beta^*$ is possible in a Li Lens (pulsed current of 500 K amp). $\beta^*$ could reach less than 1 cm in this case. We propose to put such a lens as an insert into the UCLA Ring Cooler. Thus the muon beam would make many passes through the lens and the result could be strong transverse cooling in the ring. The insert beam envelope could look like that in Figure 6. Figure 7 shows an example of a red Li Lens at FNAL now that we are using for the study.

## 6. References

[1] Ankenbrandt, C M et al, 1999, "Status of Muon Collider Research and Development and Future Plans", NuMu Collaboration *Phys.Rev. ST Accel.Beams* **2** 081001.

[2] Kirk, H et al, M1 Working Group Paper, Snowmass 2001 Conference, Snowmass, Colorado, 2001, BNL-68735.

[3] Fukui, Y et al, Workshop book, UCLA Ring Cooler Workshop, Tuscon, Arizona, December 2001.

[4] Cline, D B et al, 2002, Mini Workshop at UCLA: The Use of a Ring Cooler for a Neutrino Factory/Muon Collider, UCLA, Los Angeles, California, March 2002.

[5] Fukui, Y et al, Contribution Paper to the Overarching Document of the Snowmass 2001 Conference, Snowmass, Colorado, 2001.

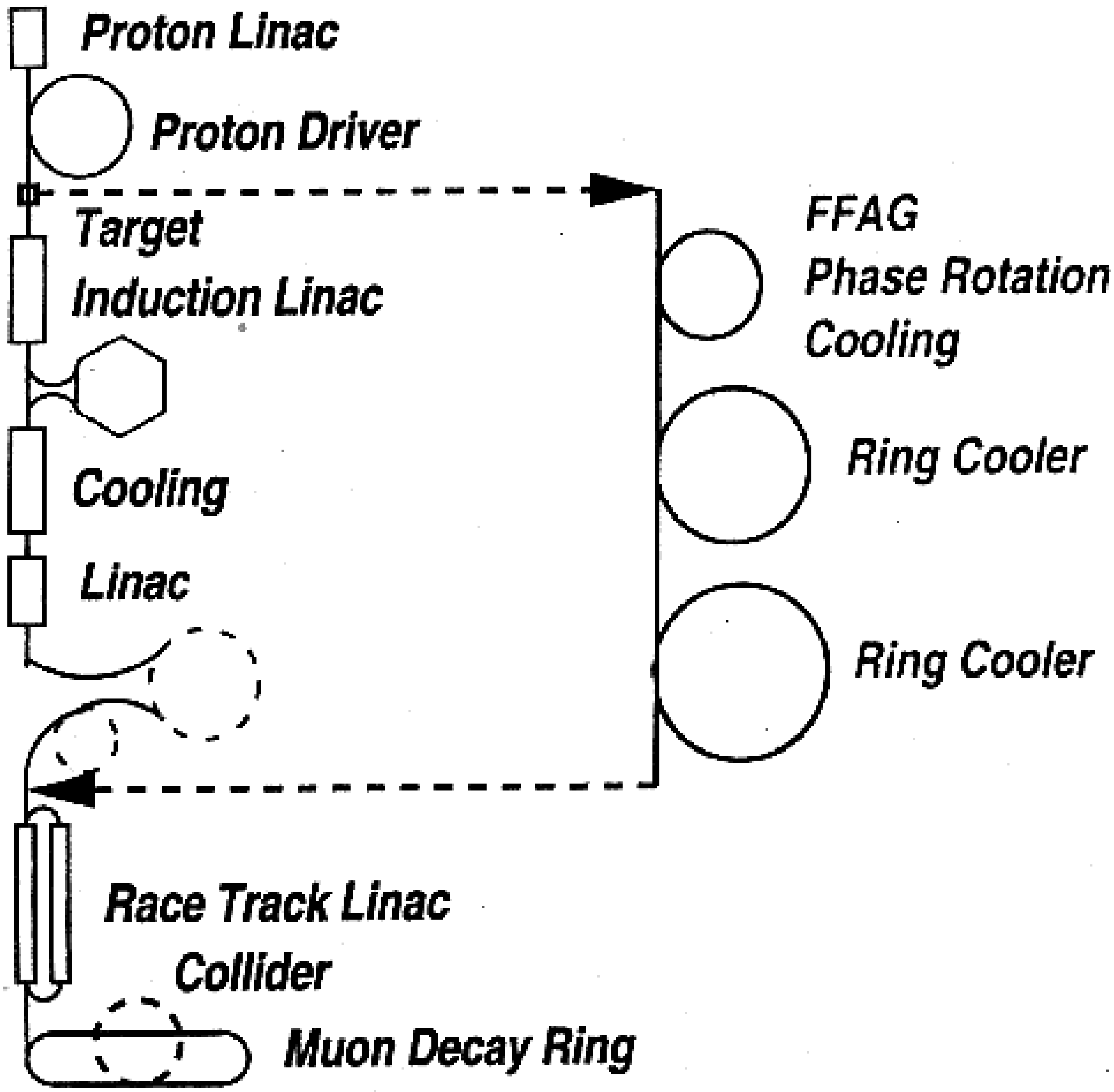


**Figure 1.** Schematic for a new design of the Muon Collider and Neutrino Factory using rings compared to the earlier design.

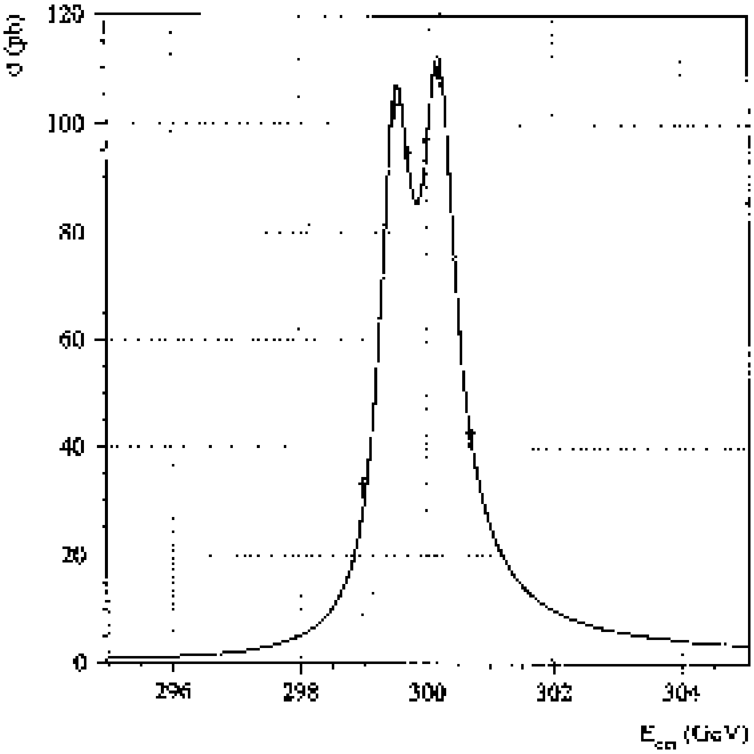


**Figure 2.** Hard A particles with small mass difference.

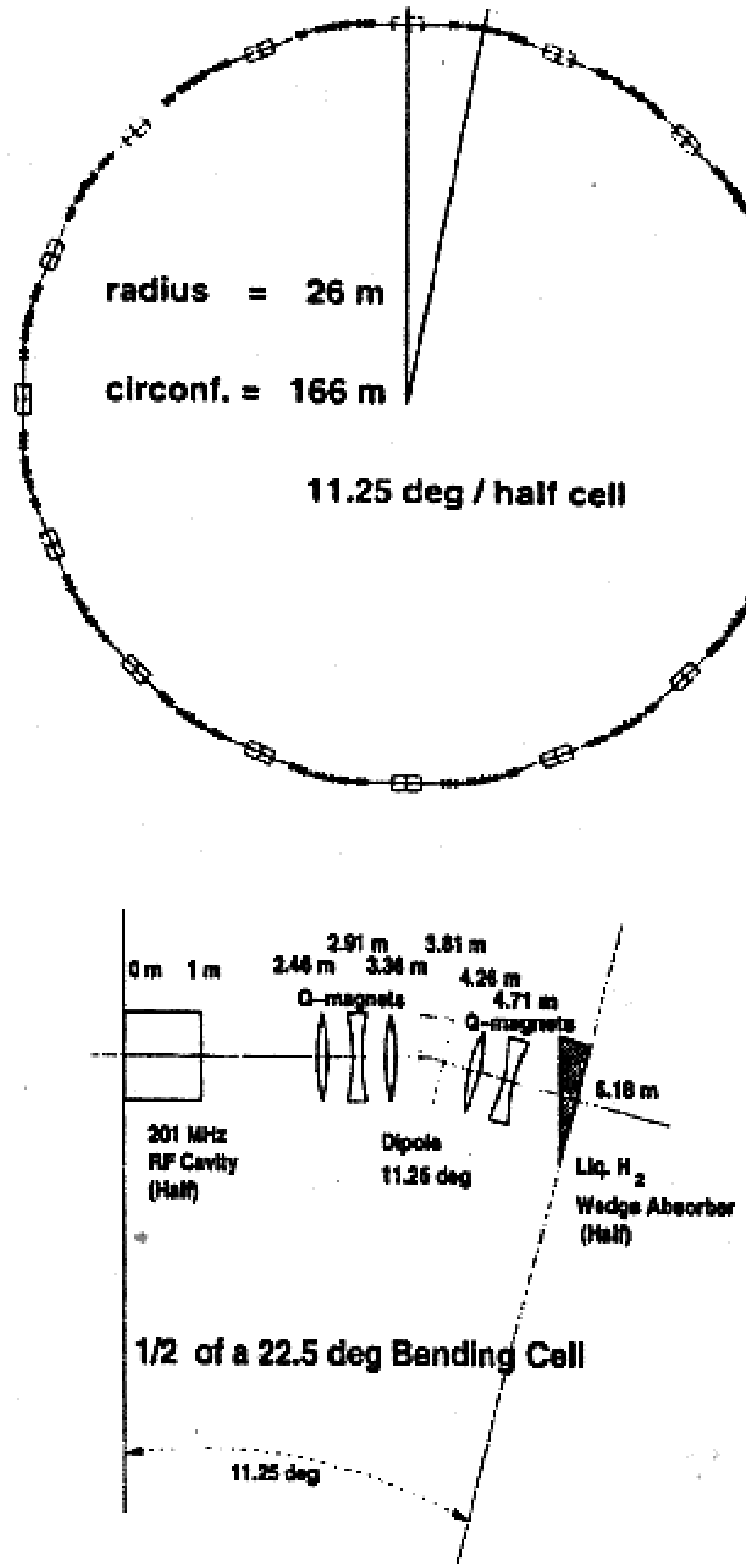


**Figure 3.** Schematics of the UCLA Ring Cooler.

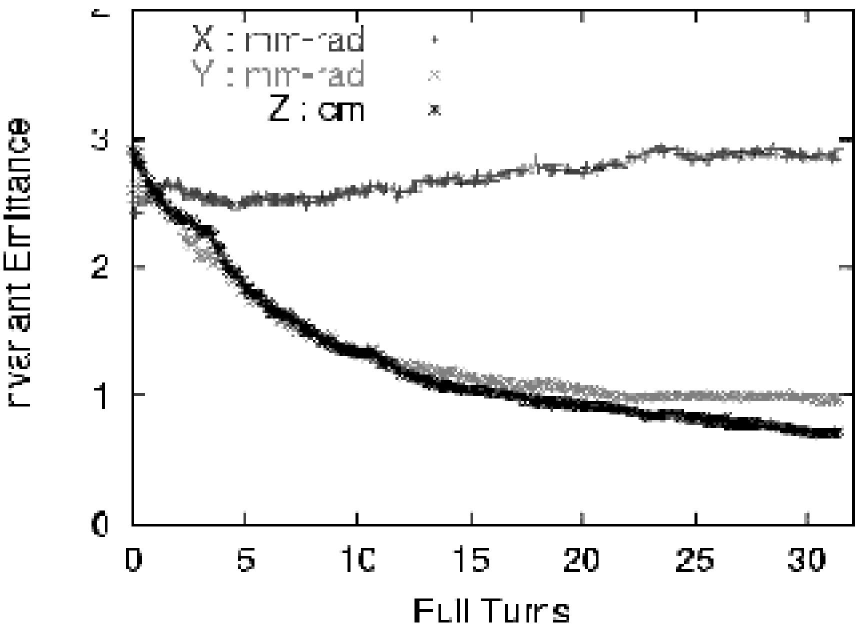


**Figure 4.** The Evolution of x, y, z normalized emittances in 30 full turns.

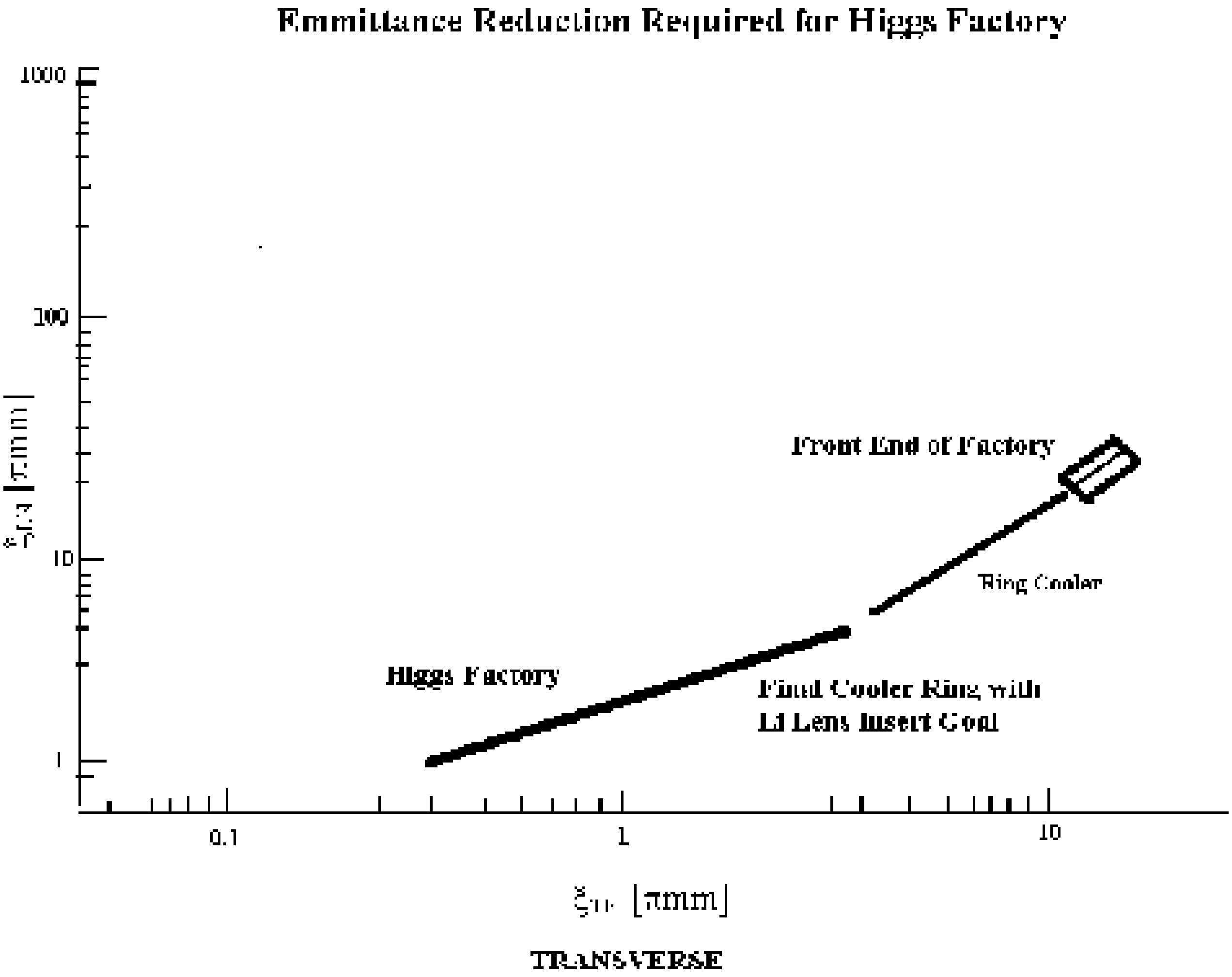


**Figure 5.** The transverse and longitudinal emittance reduction needed for a supersymmetric Higgs Factory.

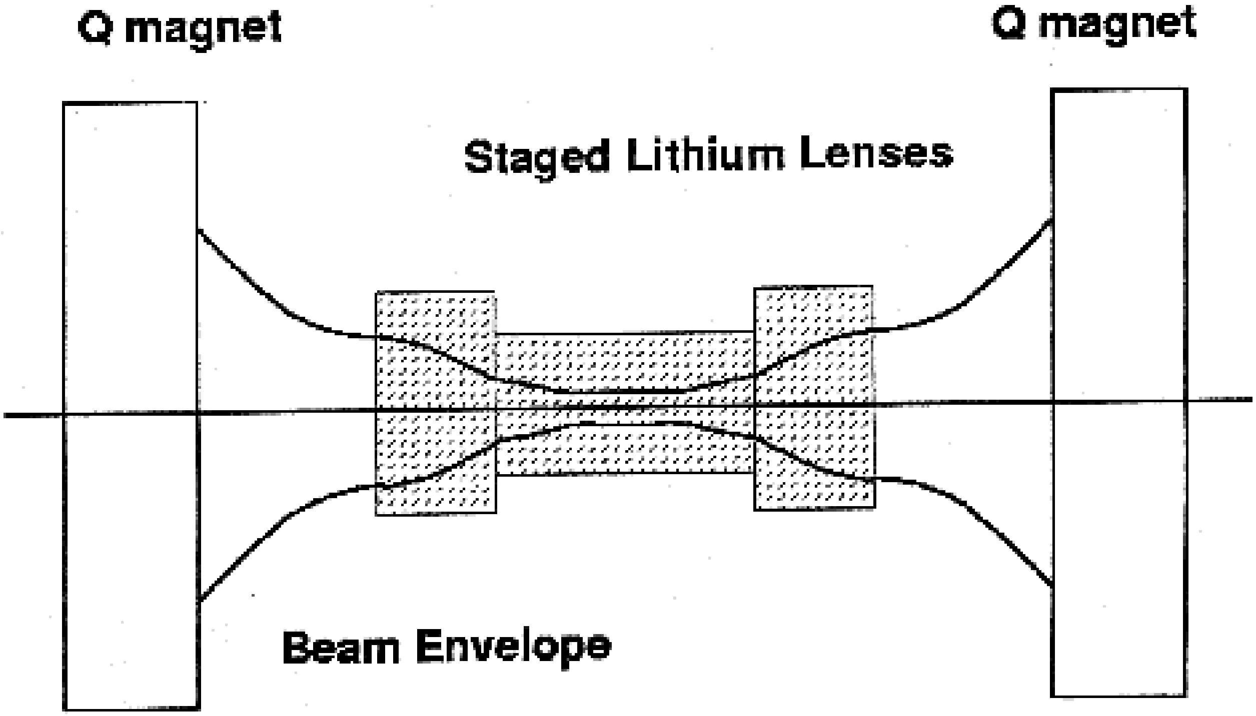


**Figure 6.** Beam envelope for a Li Lens insert in the UCLA Ring Cooler.

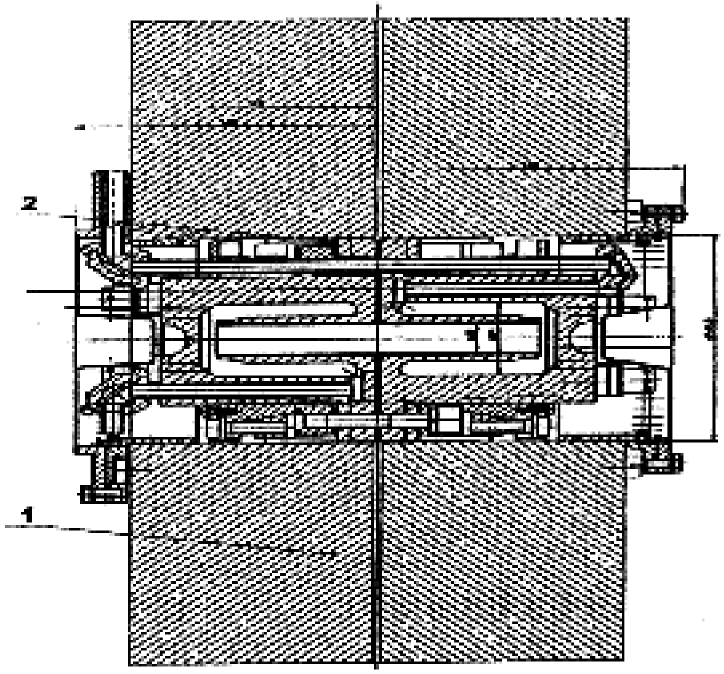


**Figure 7.** Li Lens now at FNAL.