Cooling Channel with Li Lenses

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Li Lens Properties

- Strongly focusing
- Low Z material for ionization cooling

\[ B_{\text{max}} = \frac{\mu_0}{2\pi r_{\text{max}}} I_0 \]

B field ~ 10 T at surface

\[ I_0 = 500 \text{ kA} \]
\[ \Delta t = 500 \text{ m sec} \]
Cooling in an ideal Li Lens

Beam focusing parameter in the azimuthal B field

\[ \hat{\beta} = \sqrt{\frac{p}{eG}} = \sqrt{\frac{pr_{max}}{3B_{max}}} \quad (\text{cm, MeV/c, T}) \]

Equilibrium beam parameters

\[ \varepsilon_{eq} \approx 0.0085\hat{\beta} \approx 0.005\sqrt{\frac{pr_{max}}{B_{max}}} \quad (\text{cm, MeV/c, T}) \]

\[ r_{eq} = \sqrt{\frac{\hat{\beta}\varepsilon_{eq}}{\beta\gamma}} \approx \sqrt{\frac{0.3r_{max}}{B_{max}}} \quad (\text{cm, T}) \]

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V. Balbekov, Aug. 2006
**Idealized multi-lens cooling channel**

In an optimized multi-lens cooling channel, the lens field should increase, and the lens length should decrease by the same factor step by step.

If all the lenses have the same length, a constant increase/decrease factor has to be applied.

Exponential transverse cooling is achieved by this, in spite of scattering. Transverse decrement in the lens is about \( 0.66 / \beta^4 \gamma \) per meter.

Longitudinal increment in the lens is about \( 1.3 / \beta^4 \gamma^3 \) per meter.
Example: 7 x 154 cm Li lens channel

The lens field increases, and the radius decreases by factor 1.6 / cell.

Muon momentum drops from 317 MeV/c to 211 MeV/c in any lens.

Beta function, equilibrium transverse emittance and beam radius are given at 211 MeV/c.

\[
\begin{array}{cccccccc}
  \text{Lense #} & 1 & 2 & 3 & 4 & 5 & 6 & 7 \\
  r_{\text{max}} \text{ (cm)} & 7.50 & 4.69 & 2.93 & 1.83 & 1.14 & .715 & .447 \\
  B_{\text{max}} \text{ (T)} & .881 & 1.41 & 2.26 & 3.61 & 5.78 & 9.24 & 14.8 \\
  \hat{\beta} \text{ (cm)} & 24.5 & 15.3 & 9.55 & 5.97 & 3.73 & 2.33 & 1.46 \\
  \varepsilon_{\text{eq}} \text{ (cm)} & 0.21 & 0.13 & 0.081 & 0.051 & 0.032 & 0.020 & 0.012 \\
  r_{\text{eq}} \text{ (cm)} & 1.60 & 1.00 & 0.60 & 0.39 & 0.24 & 0.15 & 0.095 \\
\end{array}
\]
ICOOL Simulation Parameters

- Li lens 10 cm radii $\times$ 60 cm length
- Beam input parameters
  - $(\sigma_x, \sigma_y, \sigma_z) = (1\ \text{cm}, 1\ \text{cm}, 2\ \text{cm})$
  - $(\sigma_{Px}, \sigma_{Py}, \sigma_{Pz}) = (0.00025, 0.00025, 0.00025\ \text{GeV/c})$
- $B_{\text{max}} = 16$ to $19\ \text{T}$ or $G = 1.6$ to $1.9\ \text{T/cm}$
- Channel
  - O01-Sol25-04Cell{O05-Li60-O05-RF30-}
  - Sol has 0 field at the moment
- Physics interactions
  - dElev=2; straglev=4; scatlev=4
Ionization Cooling with Very Large Beam

• ICOOL simulations show beam cooling in the straight channel Li lens w/o solenoids

• The Li lens channel show trend of cooling out to 6 m for a parallel beam of 10 cm radius.

• strag=on; scatt=on

Li lens channel w/o solenoid

Li lens channel w/ solenoids
ICOOL Simulation Diagnostics

• Channel
  – Li Lens 10 cm $\times$ 20 cm length and RF 10 cm cavities
  – 03Cell-O05-Li20-O05-RF10-
  – strag=on; scatt=on;
  – ($\sigma_x$, $\sigma_y$, $\sigma_z$)=(1 cm, 1 cm, 2 cm); ($\sigma P_x$, $\sigma P_y$, $\sigma P_z$)= (0.00025, 0.00025, 0.00025 GeV/c)

• Almost no particle lost

• Beam momentum restored by RF to 0.25 GeV/c

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ICOOL Simulation Results

- Beam gets a large kick at entrance; avg P_t swings to maximum and down to minimal level.
- avg R is flat or almost flat at exit of each lens
- Beam emitt. almost zero for parallel beam at entrance and increasing. Scattering appears to increase the avg P_t gradually.
**ICOOL on Channel w/ Longer Lens**

emit001b: \((\sigma_{px}, \sigma_{py}, \sigma_{pz}) = (0.00025, 0.00025, 0.00025 \text{ GeV/c})\)

emit004: \((\sigma_{px}, \sigma_{py}, \sigma_{pz}) = (0.025, 0.025, 0.025 \text{ GeV/c})\)

Both: \((\sigma_x, \sigma_y, \sigma_z) = (1 \text{ cm}, 1 \text{ cm}, 2 \text{ cm})\)
Summary

- Found the avg R quantity useful for tuning the B field strength
- Parallel beam easy achieve beam matching and cooling for large size beams
- More scenarios to try but also need a strategy for efficiently finding cooling close to the ideal equilibrium values (V. Balbekov)