Design and simulation of 6D ionization cooling lattices for Muon Accelerators

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Outline

• Introduction to the tapering concept
• Present a promising 6D cooling lattice
  • A tapered Guggenheim Lattice
• Evolution to a straight (snake-type) Guggenheim
  • I will show that you can transform the Guggenheim to a straight lattice with no parameter changes! Yes, it works!
• Lattice Details
  • Identify the required rf, voltage, B-field, radius, absorber length
• Evaluate Performance
  • Track particles: Carry out a full “front-to-end” simulation
• Review magnet & engineering feasibility
Cooling Requirement

- Ionization cooling is the only feasible option
- Longitudinal cooling through emittance exchange
- Simultaneous transverse & longitudinal cooling
RFOFO Cooling Concept

- Tilt coils to generate dispersion
- Emittance exchange on a wedge absorber
- Ring evolved to a helix to avoid injection/extraction issues

Palmer et al., PRST-AB 8, 021021 (2005); Snopok & Hanson, IJMPA 8, 021021
Tapering

- Lattice parameters such as rf freq., cell length, focusing strength, absorber length, change with distance
- Keep emittance above equilibrium
- Tapering pros:
  - More dispersion, faster cooling
  - Impressive constant cooling efficiency
  - Shorter than untapered channels
  - Method is not restricted to a Guggenheim
- We can transform it to a straight lattice with no changes (R_FOFO)
Stages of the Guggenheim

- 17 tapered stages are enough
- Each stage consists of a series of identical cells
- Only four different frequencies are necessary
- Highest B is \(~18\, \text{T}\), conservative grad. \(~23\, \text{MV/m} \text{ for } 805\, \text{MHz}\)
Example: Stage 11
• Cools to MC baseline parameters. We start with a real distribution from the post-merger (100,000 particles)
• Notice that Q is flat all the way (importance of tapering)
• Transmission \( \sim 45\% \) with decays, windows, stochastics.
Cooling Limitations due Space-Charge

- 20% particle loss after $z > 200$ m due space-charge
- Thus, we avoid cooling longitudinally below 2 mm

D. Stratakis, R. Palmer and D. Grote, Proc. of IPAC 2013, p. 759
Critical B-Field limits

- All simulations use realistic fields calculated from coils.
- Our lattice fields are below or close to the critical limits of existing magnet technology.
• Preliminary studies with COMSOL
Von-Mises Stress (H. Witte)

Stage 16

Mandrel

Steel 4340

max: 3.57736E8

min: 1.37513E7

1.0×10^9

3.5

3.0

2.5

2.0

1.5

1.0

0.5

3.5771×10^8

3.5751×10^7
Convert to a straight Guggenheim

• Conversion from Guggenheim to Rectilinear_FOFO
  • Good news: Only minor variations of the Guggenheim lattice parameters are needed
Design a late stage with R_FOFO

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell period</td>
<td>0.588 m</td>
</tr>
<tr>
<td>RF Frequency/ RF number</td>
<td>805.0 MHz / 4</td>
</tr>
<tr>
<td>RF voltage</td>
<td>23.6 MV/m</td>
</tr>
<tr>
<td>Synchronous phase</td>
<td>32 deg.</td>
</tr>
<tr>
<td>Absorber</td>
<td>LH2</td>
</tr>
<tr>
<td>Minimal beta function</td>
<td>3.2 cm</td>
</tr>
<tr>
<td>Max Field on Coil</td>
<td>18.6 T</td>
</tr>
<tr>
<td>Max Field on Axis</td>
<td>17.0 T</td>
</tr>
</tbody>
</table>

This is the worst case!
Last Stage with a R_FOFO

- Cools towards the baseline requirements for a MC with a >40% transmission!
- Initial distribution is the output of Stage12 of Guggenheim
Summary

Some additional things to remember:

- A Guggenheim can become \textit{straight} with the \textit{same} parameters!
- This is a front-to-end complete simulation. We include rf and absorber windows, muon decays and stochastics.
- We reach close to the baseline MC requirements with $T > 45\%$
- We use realistic fields calculated from coils
- \textit{“Low” < 19 T} fields (worse case is 18.6 T on coil and 17 T on axis)
- Current densities within limits including a \textit{moderate} safety factor
- Only 4 rf: 201, 402, 603, 805 MHz. Conservative 23 MV/m 805 MHz
- Notable \textit{flat & high} cooling efficiency. 6D drop by a 1/1000 factor.
- Encouraging results look encouraging from preliminary studies!
- This work is submitted to Phys. Rev. ST-AB