Concepts for 6D MANX
Cooling Demonstration Experiment

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Simultaneous 6D cooling/acceleration in a long HCC
(review of our preferred Helical Cooling Channel technique)

6D cooling without RF
(using a shorter HCC segment where fields are adiabatically reduced as the beam loses energy)

Sequential cooling scenario
(RF sections alternate with HCC segments)

Expectations from MANX experiment

MC Collaboration Meeting
February 14 – 17, 2005
LBNL
Berkeley, California

Simultaneous cooling/acceleration in HCC

(theory review)

Helical system: solenoid B + screw magnet $b(\rho,\varphi - kz)$ (dipole + quad +…) /one period $2\pi / k$ /

Features:

- Combines the advantages of a line and ring (homogeneous synchrotron) muon coolers
- Continuous dispersion along helical orbits $\rightarrow$effective emittance exchange
- Conservative focusing (in helical frame…) $\rightarrow$ large acceptance
- Compatible with either homogeneous or wedge absorber (yet to be simulated with wedges)
- HCC allows one to develop a comprehensive analytical dynamic and cooling theory (first linear, then non-linear) in order to provide a guidance for simulation and design
- Simple and effective for simulation
- High flexibility (possibility to easily manipulate field parameters for optimization)
- HCC efficiently compatible with continuous high voltage RF (pressurized hydrogen cavities)

Periodic helical orbits, dispersion and cooling decrements

The periodic orbit is described by

$$p(a) = \frac{\sqrt{1+\kappa^2}}{k}[B - \frac{1+\kappa^2}{\kappa} b(\kappa)] \rightarrow a(p)$$

Where, a is the radius, p total momentum, $\kappa = ka = p_\perp / p_z$ is the arctan of the helix pitch angle, and $b_\rho = 0$ at the periodic orbit.

Dispersion factor:

$$\hat{D} = \frac{pda}{adp}$$

Longitudinal decrement:

$$\Lambda_\gamma = [-\frac{2}{\gamma^2} + \hat{D}(\frac{\kappa^2}{1+\kappa^2} + \frac{a\partial n}{n\partial a})]\frac{|\gamma'_{abs}|}{\gamma\beta^2}$$

Sum of three decrements: $\Lambda_\gamma + \Lambda_+ + \Lambda_- = \Lambda \equiv 2|\gamma'_{abs}|/\gamma$

<u>Equalizing three decrements</u> is compatible with dynamical stability (even in a homogeneous absorber)

Analytical cooling theory has been developed
Equilibrium has been calculated for a homogeneous absorber

6D cooling without RF

Longitudinal cooling without RF can be undertaken to *reduce the beam momentum spread* before bunching. With dispersion such that $\Lambda_\gamma = \Lambda$, the momentum spread decreases as γ^2, thus $(\Delta p / p) \approx (\gamma / \beta)$.
More generally, for $\Lambda_\gamma = (1+\alpha)\Lambda$:

$$\Delta p \approx \gamma^{2(1+\alpha)}, \quad \text{then } \varepsilon_{tr} \approx 1/\gamma^{\alpha}$$

/some increase of transverse emittance when $\alpha > 0$ might be acceptable, so that significant additional reduction of the momentum spread is possible/

Comments on two ideas under investigation:

- No RF-cooling may be more effective using wedge absorbers (the condition of both transverse decrements equal to zero is easier to satisfy)
- The cooling efficiency may be improved by manipulating the orientation of quadrupole field (relative to the dipole) together with direction of the wedge absorber. With this extension, the cooling decrements can be manipulated over a large interval of momentum spread of the initial muon beam

Continuously changing helical magnets

A challenge: in order to maintain the optical matching for a muon beam under deceleration, one needs to (adiabatically) reduce the magnetic field parameters.
There are possible approaches to resolve this issue:

1. Vary (decrease) the helix period, while maintaining the fields and orbit radius/period ratio. This way, in principle, is the most elegant, however, its efficiency can be limited by the beam size due to the transverse emittance

2. Decrease the field strength while maintaining the period and orbit. Decreasing the solenoid field seems not difficult, but varying the helix strength may require a non-ordinary superconducting magnet design

3. Compromise solution: vary both the period and field strength, while maintaining radius/period ratio constant

Continuously changing helical magnets (cont.)
Applications:

- No-RF pre-cooling (MANX experiment)
- Transition sections (filled with RF) between helices of the continuous 6D cooling channel
- Cooling section (followed by RF) as an alternative to the original HCC with HPRF

Sequential cooling-acceleration concept

(alternative to continuous cooling /acceleration HCC)

In this scenario, 6D cooling and energy compensation sections are separated, alternating along the beam path

Concept constituents (preliminary view):

- **Solenoid (continuous, variable)**
- **6D cooling sections: designed as helices including dipole and quadrupole field and absorber (homogeneous or wedge)**
- **Balanced cooling decrements**
- **Isochronous (yet achromatic) optics along cooling sections (the helix may include a sextupole component), in order to prevent beam debunching**
- **Acceleration in each RF section to a reasonable energy**
- **Magnets, RF may be easier to build**

/Under investigation/

6DMANX experiment

This experiment can demonstrate:

- 6D cooling in a helical cooling channel

- Longitudinal cooling in a homogeneous absorber

- A Prototype device for 6D cooling using a HCC with variable field strength
  - as a precooler or as an
  - alternative to the original scheme with HPRF

- Technical feasibility of the HCC
  - With high-field solenoid, helical dipole and quad magnets,
  - Perhaps cooled with LH2 using HTS