Design MANX experiment

MANX magnet, Matching, and More

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Aim of the MANX experiment

• MANX is a proof-of-principle experiment.
  – *Six dimensional helical cooling theory* (ref. PRSTAB 8,041002 (2005))
    • Demonstrate 6D cooling, Continuous emittance exchange, Exceptional cooling performance…

• MANX can be a prototype cooling magnet to R&D of cooling performance for muon colliders
  – MANX can be applied for a short length precooler.
  – Synchrotron motion and transverse and longitudinal coupling with the beta function in HCC.
  – Non-linear effects associated with the higher order EM field components and energy loss process.
Combined function magnet (invisible in this picture)
Solenoid + Helical dipole + Helical Quadrupole

Dispersive component makes longer path length for higher momentum particle and shorter path length for lower momentum particle.

\[ \kappa = \frac{2\pi a}{\lambda} = \frac{p_\phi}{p_z} \]

\[ f_{\text{central}} = \frac{e}{m} (b_\phi \cdot p_z - b_z \cdot p_\phi) \]

Both terms have opposite signs.
Overview of MANX channel

- Use Liquid He absorber
- No RF cavity
- Length of cooling channel: 3.2 m
- Length of matching section: 2.4 m
- Helical pitch $\kappa$: 1.0
- Helical orbit radius: 25 cm
- Helical period: 1.6 m
- Transverse cooling: $\sim$150 %
- Longitudinal cooling: $\sim$120 %
- 6D cooling: $\sim$200 %
Design practical helical cooling magnet

- Siberian snake type magnet
- Consists of 4 layers of helix dipole to produce tapered helical dipole fields.
- Maximum field is ~7 T (coil diameter: 1.0 m)

- Use helical solenoid coil
- Consists of 73 single coils (no tilt).
- Maximum field is ~5 T (coil diameter: 0.5 m)
- Flexible field configuration

See Mike Lamm’s talk

Large bore channel (conventional)

Small bore channel (helical solenoid)
Helical field maps in TOSCA

Large bore magnet (conventional)

• Design with $\lambda = 2.0 \text{ m}$ and $\kappa = 0.8$

Small bore magnet (helical solenoid)

• Design with $\lambda = 1.6 \text{ m}$ and $\kappa = 1.0$. 
• Negative field gradient is produced in helical solenoid coils.
• The required helical quadrupole component is changed by $\kappa$ (helical pitch).
• The strength of the quadrupole component can be adjusted by the solenoid coil diameter.

\[ \lambda = 1.0 \text{ m}, \ p = 300 \text{ MeV/c} \]
• Connect the straight beam section to the helical beam section.
  – Need to induce
    • Helical pitch $\kappa (=\phi/pz)$
    • Helical radius $a$
• Use atan to make smooth tapered field.
• Clearly see a smooth tracking.
• This channel is needed 10~15 meters.
Can we make a shorter matching section?

$\begin{align*}
\mathbf{f}_\uparrow &\propto \mathbf{b}_\varphi \cdot \mathbf{p}_z \quad \text{Repulsive central force} \\
\mathbf{f}_\downarrow &\propto -\mathbf{b}_z \cdot \mathbf{p}_\varphi \quad \text{Attractive central force}
\end{align*}$

$$
\mathbf{f}_{\text{central}} = \frac{e}{m} (\mathbf{b}_\varphi \cdot \mathbf{p}_z - \mathbf{b}_z \cdot \mathbf{p}_\varphi)
$$

$$
\frac{\partial \mathbf{p}_\varphi}{\partial a} = \alpha \mathbf{b}_\varphi + \beta \mathbf{b}_{\text{solenoid}} + \delta \frac{\partial \mathbf{b}_\varphi}{\partial a} + \varepsilon \frac{\partial \mathbf{b}_{\text{solenoid}}}{\partial a}
$$

- Transverse $b_\varphi$ field produces transverse $p$ kick.
- Solenoid $b_z$ field stabilizes orbit.
- $\alpha$, $\beta$, $\delta$, and $\varepsilon$ are the coefficients.
Use linear function for first trial

\[ b_{\text{matching}} = \alpha b_0 z \]

- \( b_0 \): Amplitude of initial helical dipole magnet
- \( \alpha \): Ramping rate

Adjust solenoid strength to connect to a proper helical orbit.
Simulation study

Initial beam profile

- Beam size (rms): ± 60 mm
- $\Delta p/p$ (rms): ± 40/300 MeV/c
- $x'$ and $y'$ (rms): ± 0.4
  (Acceptance study has not been done yet.)

- Obtained cooling factor: ~200%
• Good cooling performance is preserved in the helical solenoid coil magnet.
• Longitudinal betatron oscillation makes complicated emittance evolutions.
• Optimize matching magnet
  – Fine tune Twiss parameters
• Optimize MANX magnet
  – Obtain the best cooling performance.
Possible beam line in Fermilab site

• Candidates
  – Linac (0.4 GeV proton) See Andreas Jansson’s talk.
    • Low yield, narrow space
  – Meson Test area (120 GeV proton) Ask B. Abrams.
    • Need energy absorber to reduce momentum.
    • Parasitic design with the ILC detector group
  – pbar accumulator ring (8 GeV)
    • Obtain good quality beam, sufficiently high intensity
    • One of the most preferable place
  – MiniBooNe (8 GeV)
    • Need muon capturing element
Preliminary optics design in MTA

See Andreas Jansson’s talk

Uses BNL D2 quads  “Almost” fits in MTA
• 6D phase space (or emittance exchange) measurements at HCC entrance/exit are the minimum requirement to verify the cooling theory.

• Single particle tracking measurement vs beam measurement
  – Cost, reliability, precision, beam transport, etc...
  – Fermilab AD now consider rastering a pencil beam.

• The hardest part of the spectrometer design is how to determine the longitudinal phase space.
  – Time structure measurement?
  – HCC is a kind of spectrometer itself. Therefore, we can determine the momentum by tracking the particle in HCC.
  – Other interesting parameter is the feature of isochronous. This can be done by measuring ToF between upstream and downstream spectrometers.
  – PID?
Conclusions

- Big inflation in magnet design
- Found the simple solution for matching
- Need fine tuning
- Beam line design in progress
- Spectrometer design in progress
Collaborators list

Muons, Inc.
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And many useful comments & suggestions from Muon Collider Task Force people
Appendix

• Show isochronous feature in HCC
\[ t \text{ vs } P_{\text{total}} \]
MANX $Z=0 \text{ m}$

Fractions from initial

\[ \Delta P_{\text{total}} = 0.937 \text{ /m} \]
\[ \Delta t = 1.001 \text{ /m} \]

\[ t \text{ vs } P_{\text{total}} \]
Z=1 m

\[ \Delta P_{\text{total}} = 0.829 \text{ /2m} \]
\[ \Delta t = 1.002 \text{ /2m} \]

\[ t \text{ vs } P_{\text{total}} \]
Z=2 m

\[ \Delta P_{\text{total}} = 0.829 \text{ /2m} \]
\[ \Delta t = 1.002 \text{ /2m} \]

\[ t \text{ vs } P_{\text{total}} \]
Z=3 m

\[ \Delta P_{\text{total}} = 0.762 \text{ /3m} \]
\[ \Delta t = 1.003 \text{ /3m} \]

\[ t \text{ vs } P_{\text{total}} \]
Z=4 m

\[ \Delta P_{\text{total}} = 0.735 \text{ /4m} \]
\[ \Delta t = 1.005 \text{ /4m} \]

Momentum compaction factor $\eta = 0.34$

$\gamma t^2 = 0.72$