MUCCOOL experiment- Plans

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**Charge from Fermilab**

Sep 13, 2000 letter from John Cooper to me states “I am asking you to lead the work at Fermilab on the following tasks:

1. Design of a muon testbeam that can be used to study the performance of a cooling section.
2. Simulation of the response of a cooling test section to the test beam. Hence determine what properties of the cooling channel can and cannot be tested in a muon beam.

I would like a short report on these items to be given to Mike Shaevitz, Steve Holmes and myself by April 1\textsuperscript{st}, 2001”.

We have had 3 meetings on this topic. I will summarize the ideas generated therein.
1 Targetry and Primary Focusing
(N.Holtkamp, N.Mokhov)

- 8 GeV proton beam (FNAL Booster)
- Active target
- Li lens for primary focusing

Figure 1: Schematic of the target station.

Proton Beam: 8 GeV, $\sigma_x = \sigma_y = 6$ mm, $\sigma_z = 30$ cm, 750,000 protons
Target: Copper, $L = 15$ cm, $R = 1.6$ cm, $G = 4.39$ T/cm,
       $B_{max} = 7.0$ T, $J = 560$ kA
Li Lens:  $L = 40$ cm, $R = 8.5$ cm, $G = 0.158$ T/cm,
       $B_{max} = 1.34$ T, $J = 570$ kA
Muon Test beam-Decay channel

2 Beam Characteristics after Li Lens

Yield: $\pi^-/p = 0.119$, $\mu^-/p = 0.0022$

Figure 2: Energy distribution of $\pi^+\mu^-$ after Li lens
Figure 3: X-Y phase space after Li lens
Circle – acceptance of $Q$-channel

Figure 4: $P_x-P_y$ phase space after Li lens
Circle – acceptance of $Q$-channel
Figure 5: X-$P_x$ phase space after Li lens
Ellipse – acceptance of $Q$-channel
3 Q-Decay Channel: Lattice and $\beta$-functions

- Quads: $L = 36$ cm, $G = 0.059$ T/cm, $R = 13.7$ sm
- Drift 36 cm
- No RF

Figure 6:
Muons test beam – Decay channel

4 Muon Beam Characteristics in Q-Channel

- Radius of aperture 13.7 cm
- E-window 255-355 MeV • T-window ±75 cm

Transmission and emittance in Q-channel (T-window 75 cm, E-window 255–355 MeV)

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>π/p (%)</th>
<th>μ/p (%)</th>
<th>(π+μ)/p (%)</th>
<th>μ emittance (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z (m)</td>
<td>0.0</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Trajectories of muons after π–μ–decay (pions are going along the axis)

Longitudinal phase space after decay channel
μ/p = 0.5% (total), 0.07% (in the window)

R.m.s. emittance of muon beam 5.9 mm

Transverse phase space after decay channel

Figure 7

Figure 8

Figure 9

Figure 10
**Ring Cooler ideas**

- Initial scheme from V. Balbekov

![Diagram of Ring Cooler ideas](image-url)

- Injection
- Extraction
- Period
- 7.5 m
- 316.5 cm
- 32.2 deg
- Period:
  - Solenoid coil
  - LH absorber
  - LiH wedge absorber and field flip
  - Cavity
Ring Cooler – New scheme from Balbekov

5 Ring Cooler

Figure 11: Schematic of ring cooler
## Ring Cooler - Parameters

**Ring cooler: list of parameters**

1. Circumference 32.4 m  
2. Kinetic energy of muons 125-164 MeV  
3. Revolution frequency 8.4 MHz  
4. Bending radius 30 cm  
5. Bending field 2.52 T  
6. Solenoid field ±3.56 T  
7. RF frequency 201.25 MHz  
8. Accelerating gradient 15 MeV/m  
9. RF harmonic number 24  
10. Main absorber LH, 120 cm  
11. Wedge absorber LiH, $dE/dy = 0.8$ MeV/cm  
12. $\beta$-function 42 cm

**Necessary conditions:**

- Field flip  
- $H_0$ dispersion at SS

![Dispersion function in the ring cooler](image)

**Figure 12:**
6 Cooling in the Ring

Injected beam: \( \sigma_X = \sigma_Y = 4.87 \text{ cm} \)
\( \sigma_P = \sigma_P = 26 \text{ MeV/c} \)
\( \sigma_Z = 8.5 \text{ cm}, \sigma_E = 18.8 \text{ MeV} \)
\( \varepsilon_X = \varepsilon_Y = 1.2 \text{ cm}, \varepsilon_Z = 1.5 \text{ cm} \)

After 15 revolutions:
\( \varepsilon_X = 0.32 \text{ cm} \)
\( \varepsilon_Y = 0.37 \text{ cm} \)
\( \varepsilon_Z = 0.68 \text{ cm} \)

Transmission:
68% with decay
49% without decay

Figure 13: Beam emittance and transmission in the ring cooler
7 Phase Space of the Beam

Figure 14: Transverse phase space in the ring cooler (0 rev., normalized r.m.s. emittance 12 mm)

Figure 15: Transverse phase space in the ring cooler (15 rev., normalized r.m.s. emittance 3.2 mm)

Figure 16: Longitudinal phase space in the ring cooler (0 rev., normalized r.m.s. emittance 20 mm)

Figure 17: Longitudinal phase space in the ring cooler (15 rev., normalized r.m.s. emittance 7.2 mm)
8 Bunching in the Ring (Q-Decay channel)

\[ N_p = 6 \cdot 10^{10} \times 6 \cdot 10^{-4} = 3.6 \cdot 10^7 \]

Figure 18:

Transverse phase space in the ring cooler  
Longitudinal phase space in the ring cooler

Figure 19:  
Figure 20:

Q-decay channel is a bottleneck
Solenoidal channel $B = 3.56 \, \text{T}, \ R = 15 \, \text{cm}, \ L = 16 \, \text{m}$ provides 2.5 times more muons at the same window. After the bunching:

$$N_\mu = 6 \cdot 10^{10} \times 1.2 \cdot 10^{-4} = 7.2 \cdot 10^{7}$$
**Injection ideas**

- It is difficult to inject beam of either pions or muons into the ring cooler.
- Try injecting protons (8GeV-1-3ns bunch) and hit one of the wedge targets. Simulation of pion production and capture at 90 degrees is being conducted by N.Mokhov.
- Muon Collider/Neutrino factory fellow – Z.Usubov will help in simulating this setup in Geant4/DPGeant.
- If we can show that it is possible to capture sufficient number of muons this way, then we need to go into an engineering study that will put the design onto a more realistic basis. This can be followed by cost estimates etc.
- The beauty of this scheme (if it works) is that it would demonstrate cooling (6D) on modules that are used by the regular cooling channel. Reusing the modules turn by turn (20 turns foreseen) would reduce the cost of a cooling demonstration channel by that factor.