muCool: Development of ultra-cold high-brightness positive muon beam line

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On behalf of muCool collaboration
Goal

• Build a device to compress phase space of a standard muon beam by 10 order of magnitude

• Add-on to existing surface muon beam lines
  • $E_\mu : 4.1 \text{ MeV} \rightarrow <1 \text{ eV}$
  • Beam size: 10 mm $\rightarrow <1$ mm
  • Conserve initial polarisation
  • Efficiency $\sim 10^{-3}$

• Muons are reaccelerated to keV energy and sent to experiments
Motivation

Particle physics experiments

• Improved injection into magnetic systems
  ➡ muon g–2/EDM

• High quality Mu beam
  ➡ test anti–matter gravity
  ➡ Mu 1S–2S spectroscopy

μSR applications

• Study thin material, small sample
Working principle

Transverse compression

Longitudinal compression

$\vec{B}$

$\vec{E}$

12 K

4 K

293 K

He gas

D. Taqqu, PRL97, 194801 (2006)

Y. Bao et al., PRL 112, 224801 (2014)
Working principle

\[ \vec{v}_D = \frac{\mu E}{1 + \omega^2 \tau_c^2} \left[ \dot{E} + \omega \tau_c \hat{E} \times \hat{B} + \omega^2 \tau_c^2 (\hat{E} \cdot \hat{B}) \hat{B} \right] \]

\( \mu \) : muon mobility
\( \omega \) : cyclotron frequency
\( \tau_c \) : mean time between collisions
Transverse compression

- 5 mbar He gas
- Cryogenic temperature
- Temperature gradient
- Crossed E– and B–field

\[ |\vec{E}| = 3.0 \text{ kV/cm} \]
\[ |\vec{B}| = 5 \text{ T} \]

\[ \vec{v}_D = \frac{\mu E}{1 + \omega^2 \tau_c^2} \left( \hat{E} + \omega \tau_c \hat{E} \times \hat{B} + \omega^2 \tau_c^2 (\hat{E} \cdot \hat{B}) \hat{B} \right) \]
Demonstration of trans. comp.

Detector 1

Detector 2

I. Belosevic, Joint annual meeting of Swiss and Austrian Physical Societies 2017
Longitudinal compression

- 5 mbar He gas
- Room temperature
- Parallel E– and B–field
  \[ |\vec{E}| \sim 60 \text{ V/cm} \]
  \[ |\vec{B}| = 5 \text{ T} \]
- Demonstrated in 2011
  Y. Bao et al., PRL 112, 224801 (2014)

\[ \vec{v}_D = \frac{\mu \vec{E}}{1 + \omega^2 \tau_c^2} \left[ \dot{\vec{E}} + \omega \tau_c \dot{\vec{E}} \times \hat{B} + \omega^2 \tau_c^2 (\hat{E} \cdot \hat{B}) \hat{B} \right] \]
New scheme

- Mixed transverse & longitudinal compression
- Single stage at cryogenic temperature

![Diagram showing mixed transverse and longitudinal compression](image)
Target construction

- Kapton foil + electrodes with SMD resistors
- Sapphire plates to define temperature
Beam test in 2017

- Goal: demonstrate mixed compression
- Setup
• @PiE1 beam line in PSI
Target installation

He gas tube

Heat pad

Detector

scintillator
+ WLS
+ SiPM (outside cryo)

Collimator

$\mu^+$
Time spectra of Michel e+

- Drift in x–y direction

Target condition

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E</td>
</tr>
<tr>
<td></td>
<td>B</td>
</tr>
<tr>
<td>( E_T/E_L )</td>
<td>3.5</td>
</tr>
<tr>
<td>( T_{\text{top}} )</td>
<td>30.8 K</td>
</tr>
<tr>
<td>( T_{\text{bottom}} )</td>
<td>9.2 K</td>
</tr>
</tbody>
</table>

Graphs showing time spectra with and without E-field for detectors Det 1, Det 2, and Det 3.
• Drift in x–z direction

Counts / exp(–t/2200)

w/ E-field
w/o E-field

Det 4

Det 5

Det 6

x

y

x

Coincidence top/bottom
Short term goal

- Improve mixed transverse–longitudinal compression
- E–field strength limited by discharging in He gas
  - eliminate mechanical support inside target
  - improve E–field design, investigation of material, ..
Summary

• A device to compress standard muon beam is under development

• Efficient longitudinal / transverse compressions demonstrated separately

• A new scheme with mixed compression partially worked

• Next step: Improve strength of E-field
  
  Muon extraction from gas into vacuum & acceleration
Backup