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

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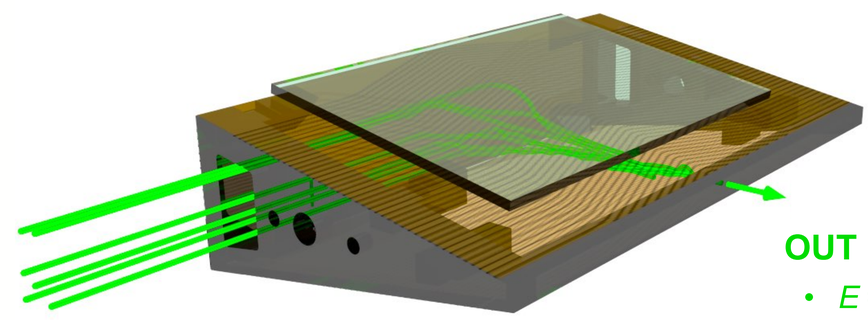
Abstract : At the Paul Scherer Institute we are developing a novel positive muon beam at low energy by compressing the 6-dimensional phase space of an existing 4.1 MeV muon beams. Muons are stopped in a helium gas target with a density gradient at cryogenic temperature and the compression occurs by making use of complex-shaped B- and E-fields.

Introduction

- Device to compress phase space of standard beam by $O(10^{10})$[1]
- For future precision experiments (muon g-2/EDM, Mu 1S-2S spectroscopy, High quality Mu beam from SFHe for gravity experiment[2], μSR)
- Cryogenic He gas stopping target + complex fields
- Fast compression (~6 μs) with efficiency of $O(10^{-3})$

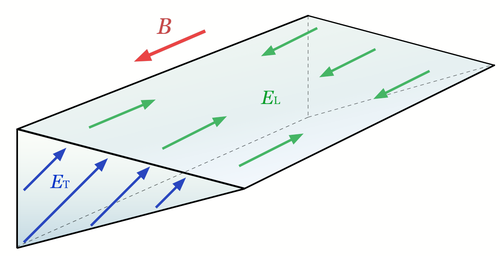


IN
- E = 4.1 MeV
- Δx = 10 mm
- 100% spin polarised

OUT
- E = 1 eV
- Δx = 1 mm
- 100% spin polarised

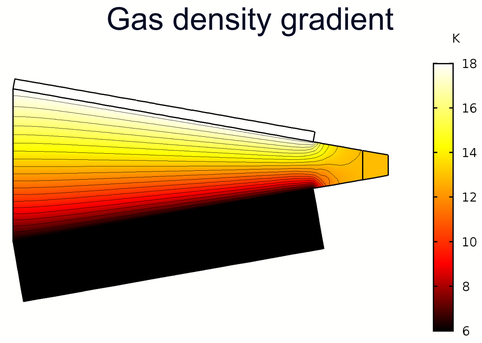
Working principle

Complex fields



+

Gas density gradient

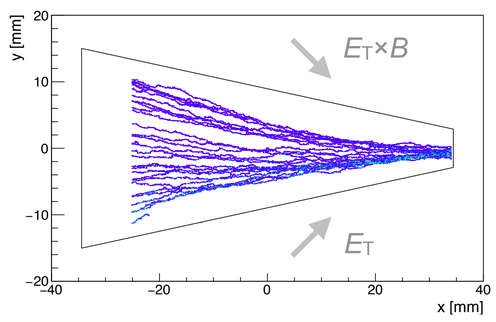


Muon drift velocity vector in He gas

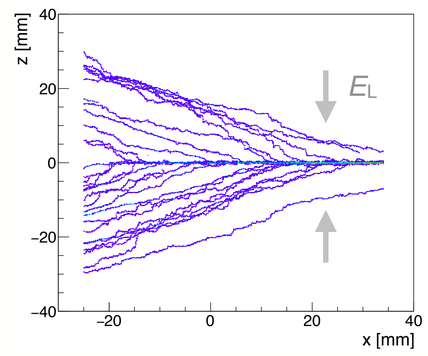
$$\vec{v}_D = \frac{\mu E}{1+\omega^2\tau_c^2}[\hat{E} + \omega\tau_c\hat{E}\times\hat{B} + \omega^2\tau_c^2(\hat{E}\cdot\hat{B})\hat{B}]$$

μ : muon mobility
ω : cyclotron frequency
τ_c : mean time between collisions

Transverse compression

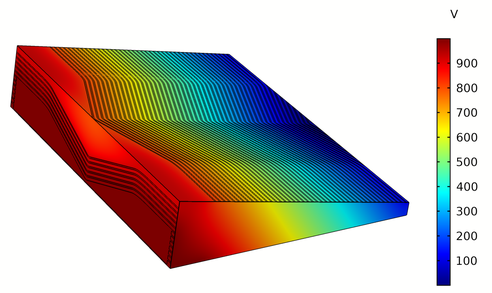


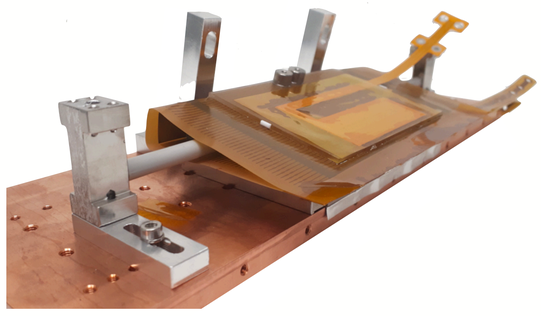
Longitudinal compression



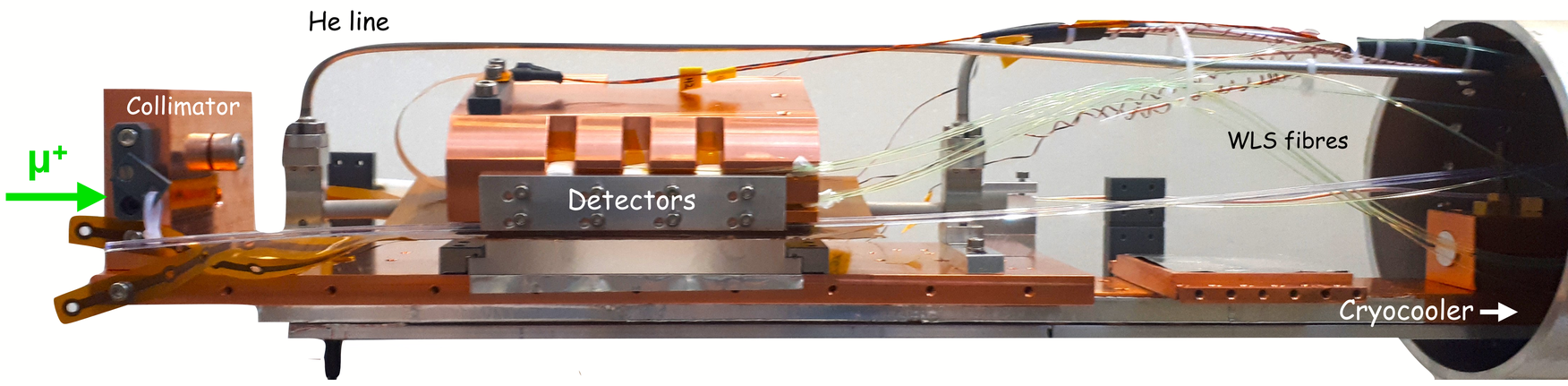
Setup

- Kapton foil with equipotential lines to define E-field
- Sapphire plates to define temperature on top/ bottom





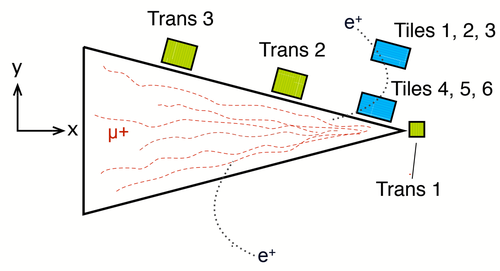
5T solenoid

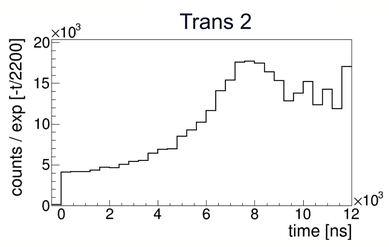


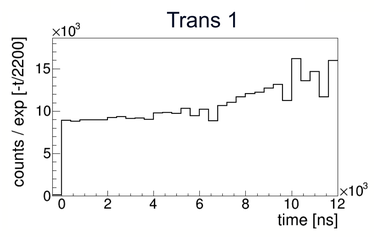
vacuum pipe & thermal shield are not shown

Observed muon compressions

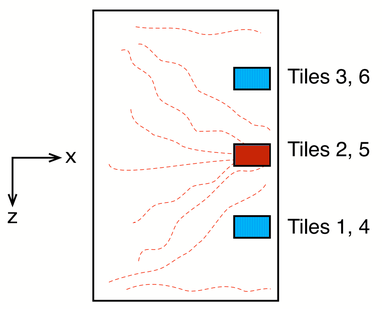
Transverse compression

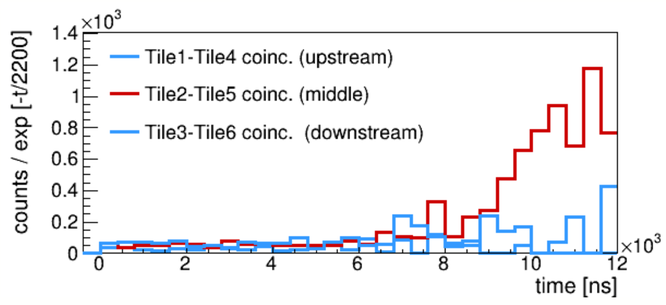






Longitudinal compression



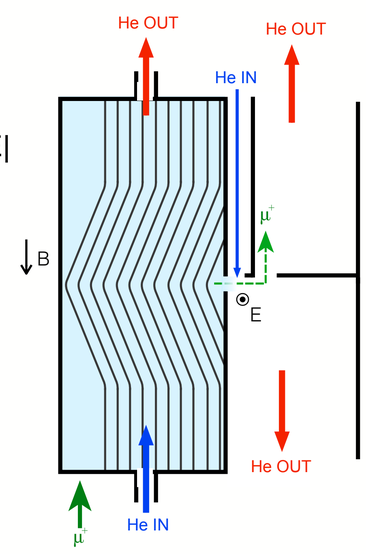


Status

- Transverse and longitudinal compressions were separately demonstrated with different setups[3][4]
- Currently developing a new single-stage setup with both compressions. Muon drifts along both directions were successfully observed

Prospects

- Improving compression by improving |E| (beam test at end of this year)
- Extracting muons into vacuum with differential pumping
- Reaccelerating muons (~keV) and extracting from B-field region



References : [1] D. Taqqu, Phys. Rev. Lett., (2006) 97 194801. [2] MAGE Collaboration (Aldo Antogniniv et al.), Atoms, (2018) 6 17. [3] I. Belosevic et al., Eur. Phys. J. C,79 430 (2019) 224801. [4] I. Belosevic et al., Hyperfine Interact (2019) 240 41.

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