Development of a novel muon beam line for next generation precision measurements

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

PAUL SCHERRER INSTITUT PSI

Kim Siang Khaw[1], A. Antognini[1], Y. Bao[3], K. Kirch[1,2], *et al.*

[1]Institute for Particle Physics, ETH Zurich, [2]Paul Scherrer Institute, [3]UC Riverside

Motivation

Improve fundamental precision measurements with muon (μ^+) and muonium (Mu), which are mostly limited by statistics and beam quality.

Develop a novel positive muons beam line

- phase space compression of 10^{10}
- sub-eV energies
- sub-mm beam size

Optimize μ^+ to Mu conversion using

- porous silica materials
- superfluid helium below 1 K

Precision measurements

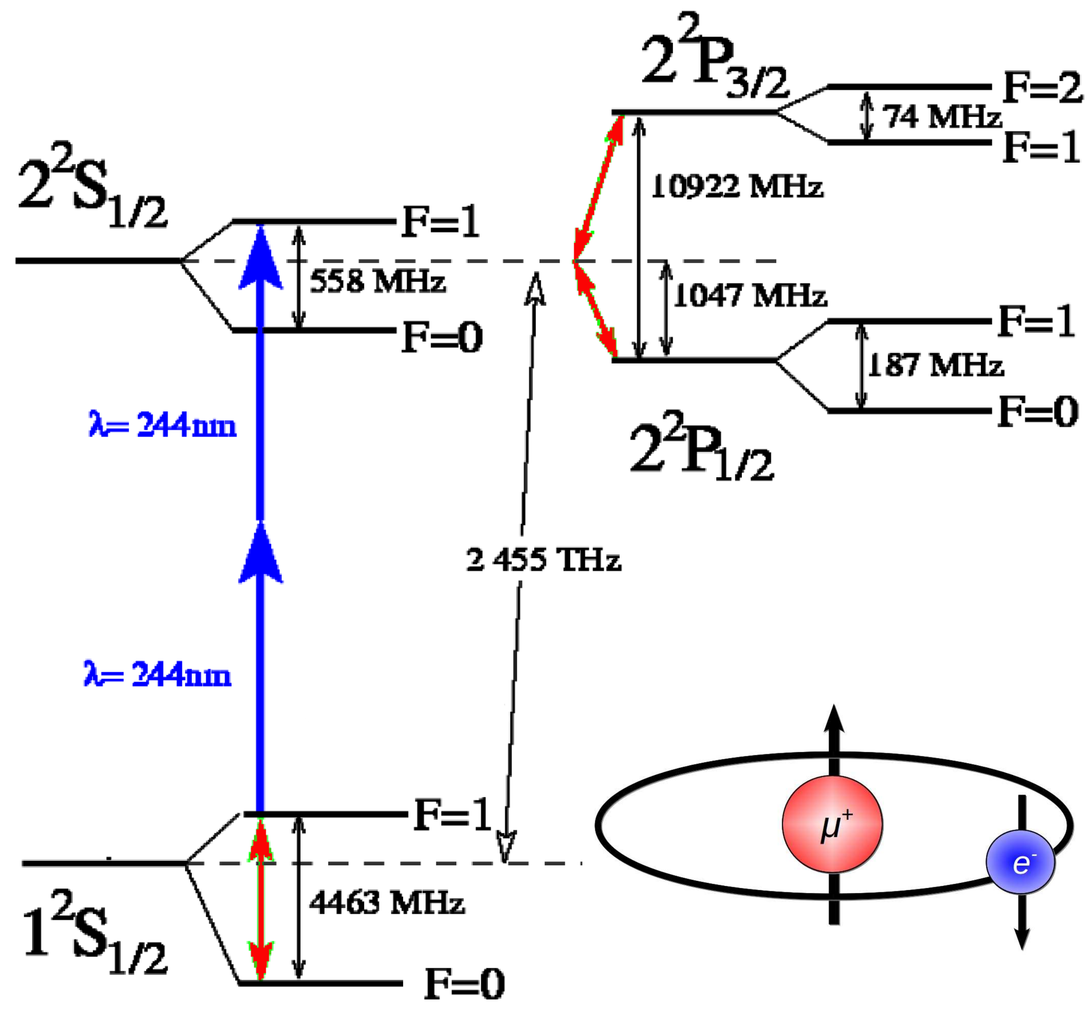
Several next generation experiments can be conceived with new μ^+ and Mu beams:

- Precision Mu spectroscopy
- Search for Mu-$\overline{\mathrm{Mu}}$ oscillations
- Search for muon electric dipole moment
- Precise measurement of $(g\text{-}2)_\mu$
- Mach-Zehnder atom interferometer

Energy scales up to 1000 TeV can be probed. (Complementary to High Energy Physics)

Muonium spectroscopy

Muonium (Mu=μ^+e^-) is a H-like system. Spectroscopy of the **1S-2S transition** and **HFS**:



- test bound-state QED free of hadronic effects
- m_μ and μ_μ determination [essential for $(g\text{-}2)_\mu$]
- test of lepton and charge universality
- anti-matter gravity via seasonal changes

Synergy with positronium (Ps=e^+e^-) spectroscopy.

Solid state applications

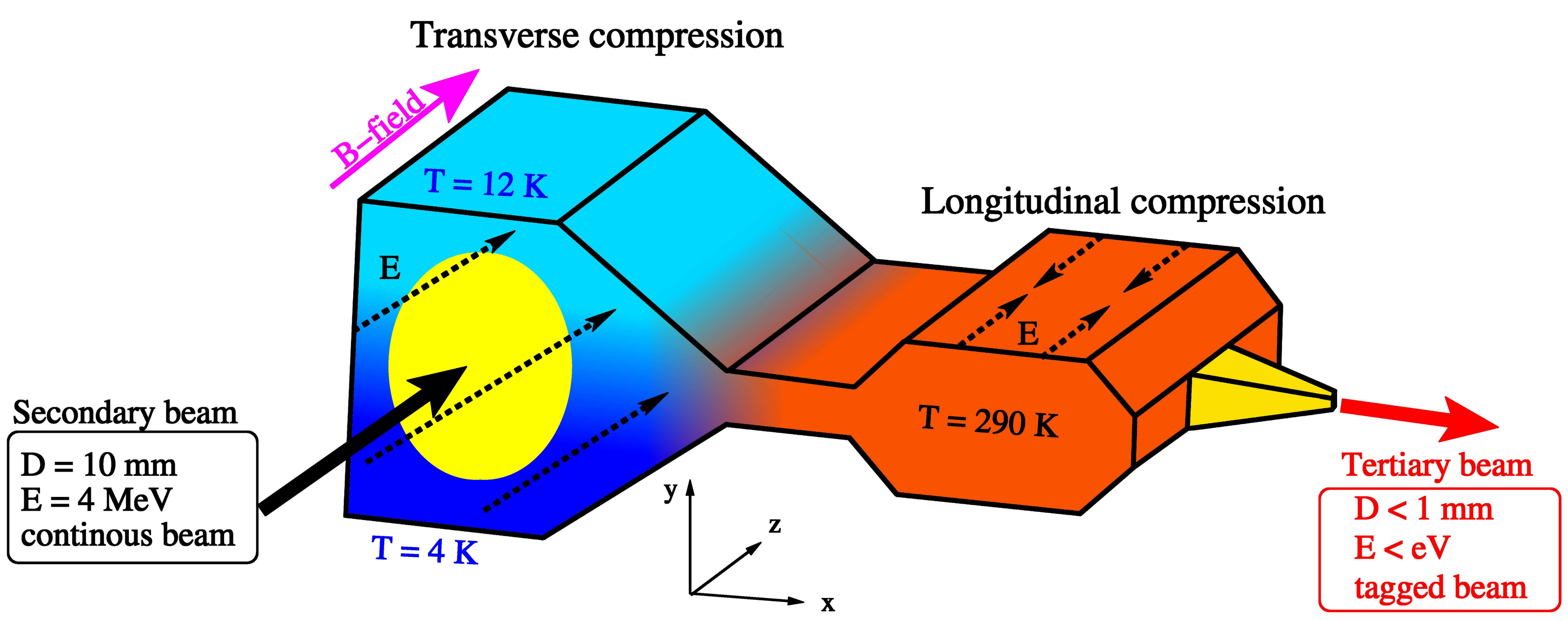
This micro-beam can be used to investigate the physics of thin films, magnetism and superconductivity, using muon spin rotation (μSR) techniques, by varying implantation depth from 1 to 500 nm.

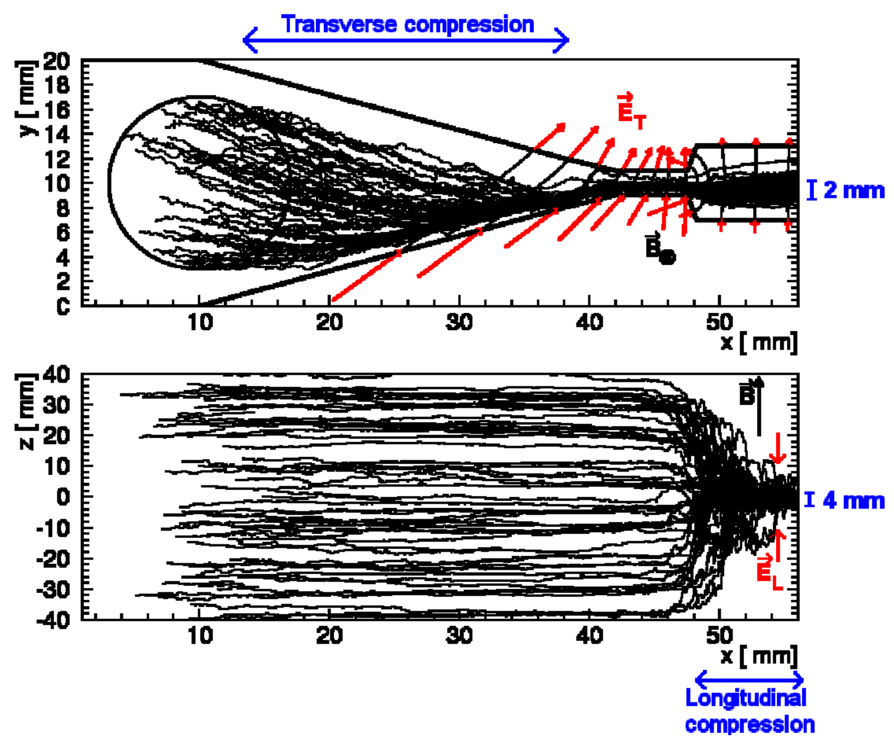
Collaborations and funding

Crivelli (Positronium group, ETH Zurich)
Petitjean, Ritt, Stoykov (LTP, PSI)
Prokscha, Sedlak (LMU, PSI)

This work is supported by the SNF 146902.

Principle of a novel muon beam line





μ^+ trajectories, indicating transverse (y-axis,top) and longitudinal (z-axis, bottom) compression

Muon drift velocity in the gas

$$v_D \propto \frac{E}{1+\omega^2\tau^2}\{\hat{\mathbf{E}} + \omega\tau\hat{\mathbf{E}}\times\hat{\mathbf{B}} + \omega^2\tau^2(\hat{\mathbf{E}}\cdot\hat{\mathbf{B}})\hat{\mathbf{B}}\}$$

$\tau = \tau(p,T)$: average time between collisions

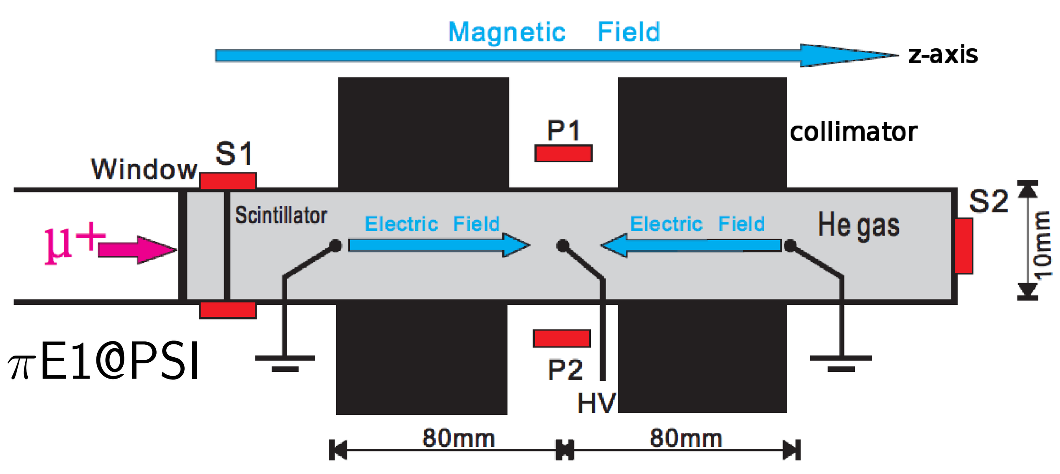
$\omega = \frac{eB}{m_\mu}$: cyclotron frequency

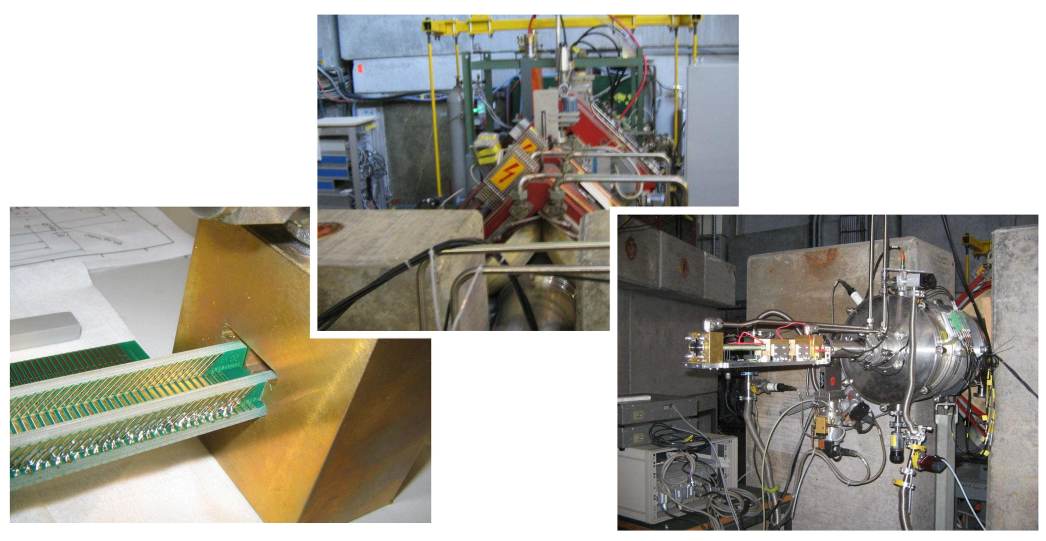
Compress the muon swarm using

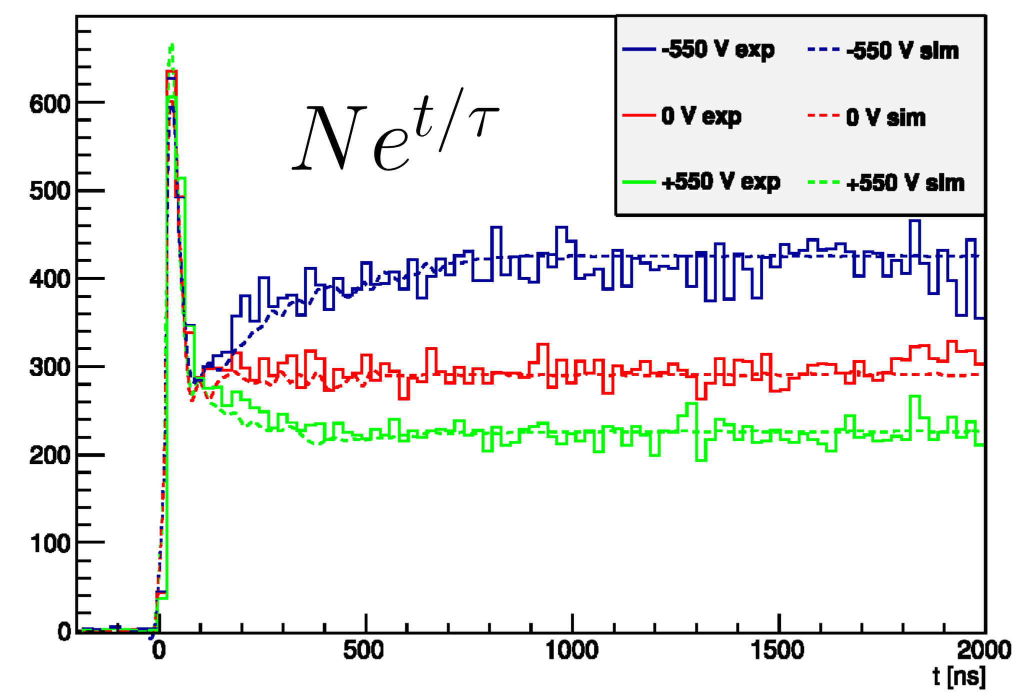
- He gas density gradients at cryogenic temperature
- electric and magnetic fields

Taqqu, PRL **97***, 194801 (2006)*

Longitudinal compression successfully tested



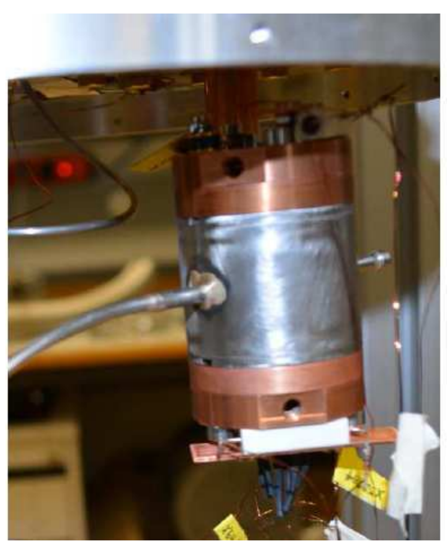


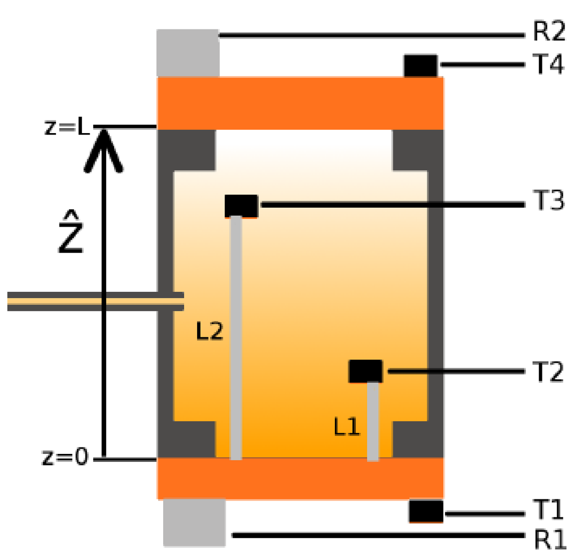


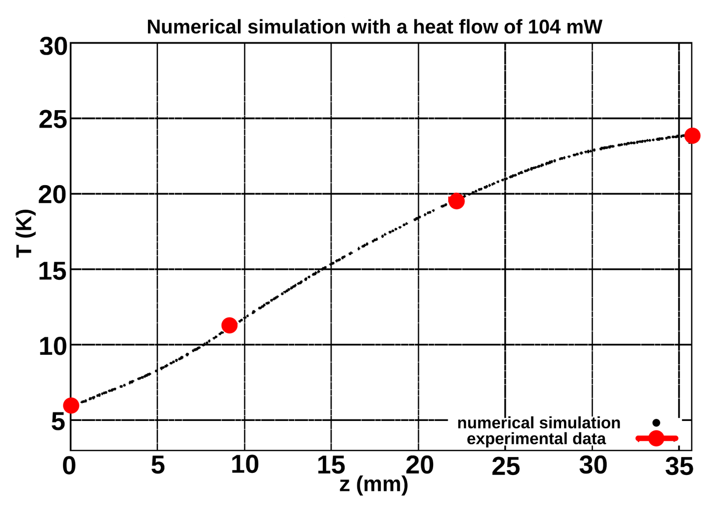
Number of e^+ detected at P1 and P2 versus time

- Implement low energy μ^+-He physics
- Good data-GEANT4 simulation agreement
- Understanding of muon drift in helium gas

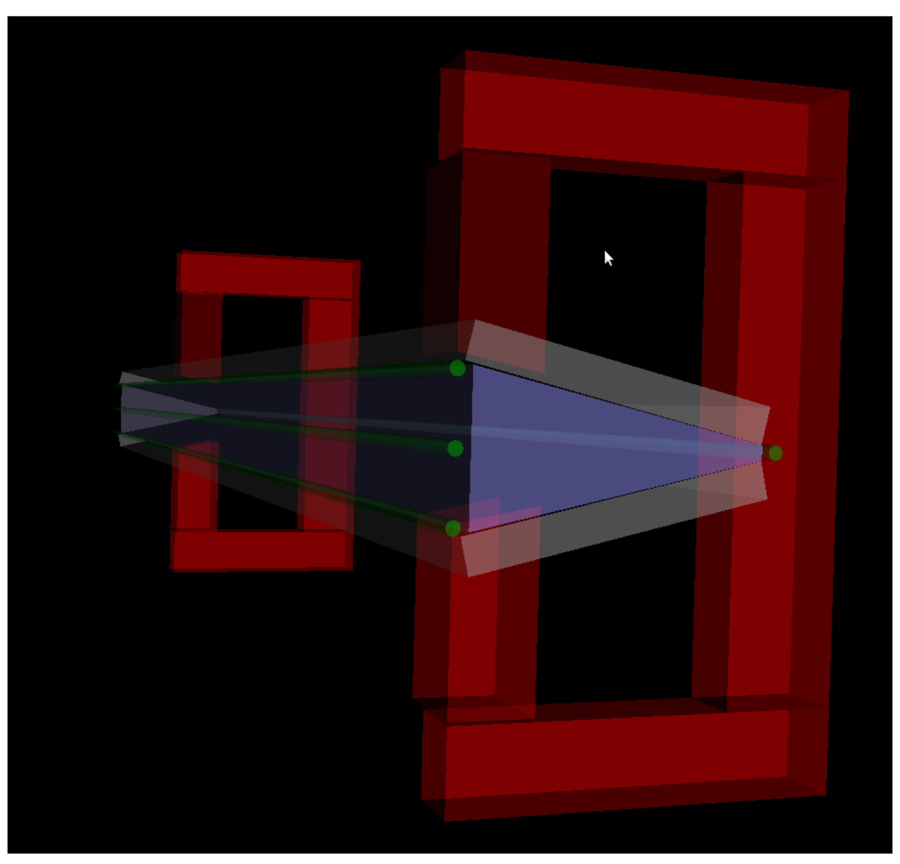
Towards the test experiment for transverse compression







- Helium gas density gradient tested
- Good agreement between data and simulation



Sketch of test experiment for transverse compression

- Searching for appropriate materials for the target (quartz, mylar)
- Designing positron detection scheme (scintillating fiber)
- Implement gas density gradient in GEANT4