Muonium production for fundamental physics experiments

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Motivation

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

Our approaches:

(a) Develop a novel positive muons beam line

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

(poster no. 375 of A. Eggenberger and no. 376 of G. Wichmann)

(b) Optimize μ^+ to Mu conversion using

- porous silica materials

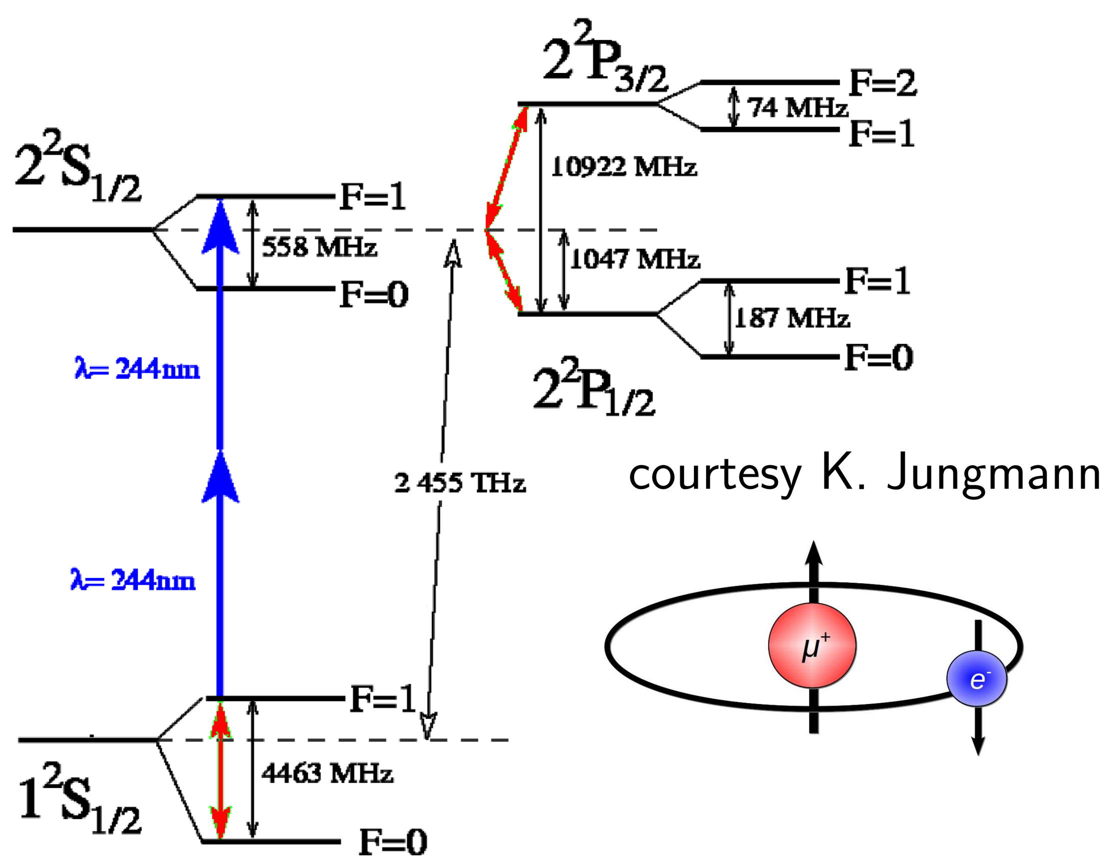
Precision measurements

Next generation experiments with new μ^+ and Mu beams:

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

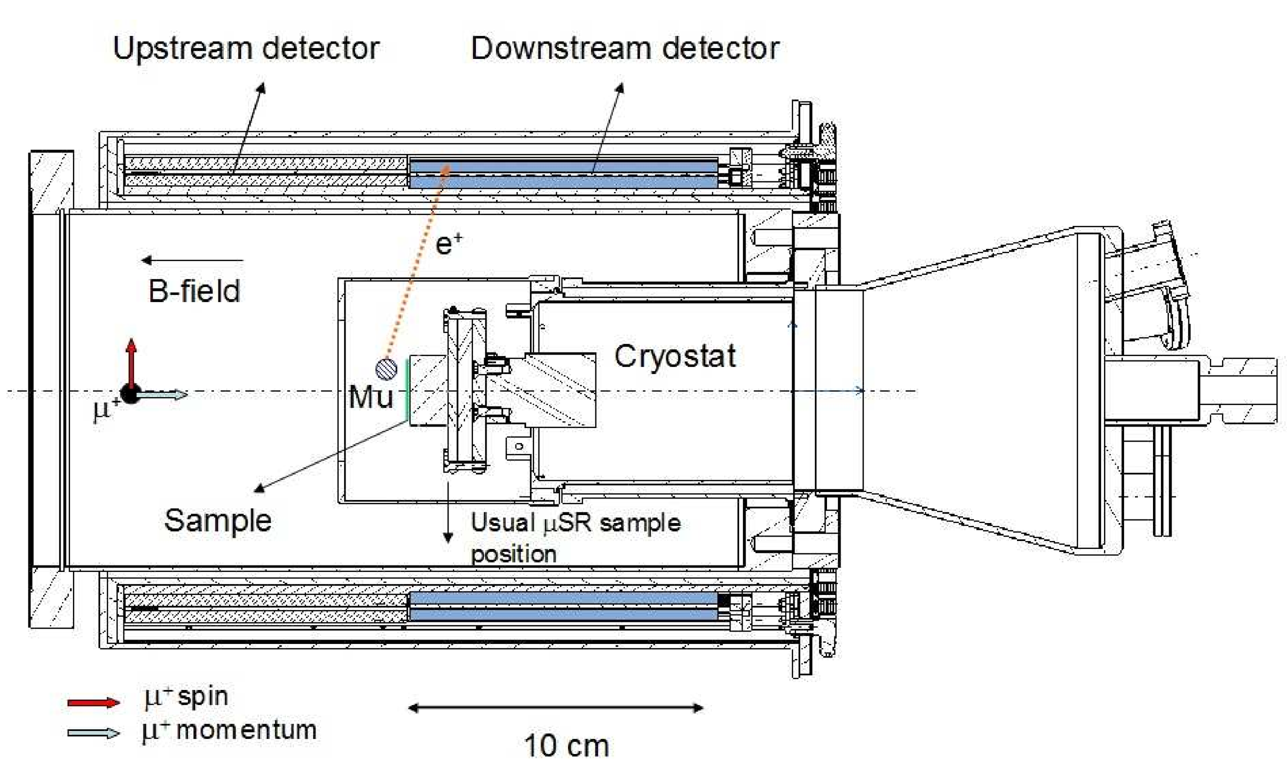
Muonium spectroscopy

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
- antimatter gravity via seasonal changes

Experimental setup



- We have used the **low energy positive muon beam** (LEM) [NIM A 595, 317 (2008)] at PSI. (4000 s^{-1} μ^+ on the sample, 1-30 keV tunable energy)
- Positrons from muon decay are detected by plastic scintillators (upstream and downstream, each of them is segmented into top, bottom, left and right).

Collaborations and funding

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Morenzoni, Prokscha, Salman (LMU, PSI)

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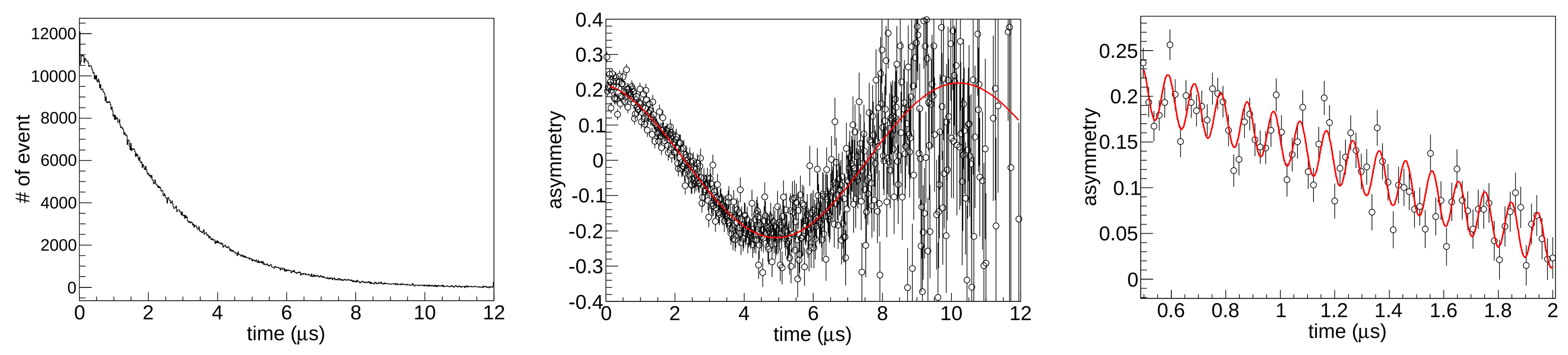
Muon spin rotation (μSR) technique

Muonium formation rate, F_{Mu} can be extracted using this technique.

The time spectra measured in each individual segment follow the **exponential muon decay distribution**, modulated at the **Larmor frequency** in the external field:

$$N(t) = N_0 e^{-t/\tau}[1 + A_\mu(t) + A_{\mathrm{Mu}}(t)] + B$$
$$A_\mu(t) = A_\mu e^{-\lambda_\mu t} cos(\omega_\mu t - \phi_\mu)$$
$$A_{\mathrm{Mu}}(t) = A_{\mathrm{Mu}} e^{-\lambda_{\mathrm{Mu}} t} cos(\omega_{\mathrm{Mu}} t - \phi_{\mathrm{Mu}})$$

N_0 : normalization, τ : muon lifetime, B : background
$A_\mu(t)$ and $A_{\mathrm{Mu}}(t)$: precession amplitudes at frequencies ω_μ for free μ^+ and ω_{Mu} for Mu
ϕ_μ and ϕ_{Mu} : initial phases, λ_μ and λ_{Mu} : damping coefficients.

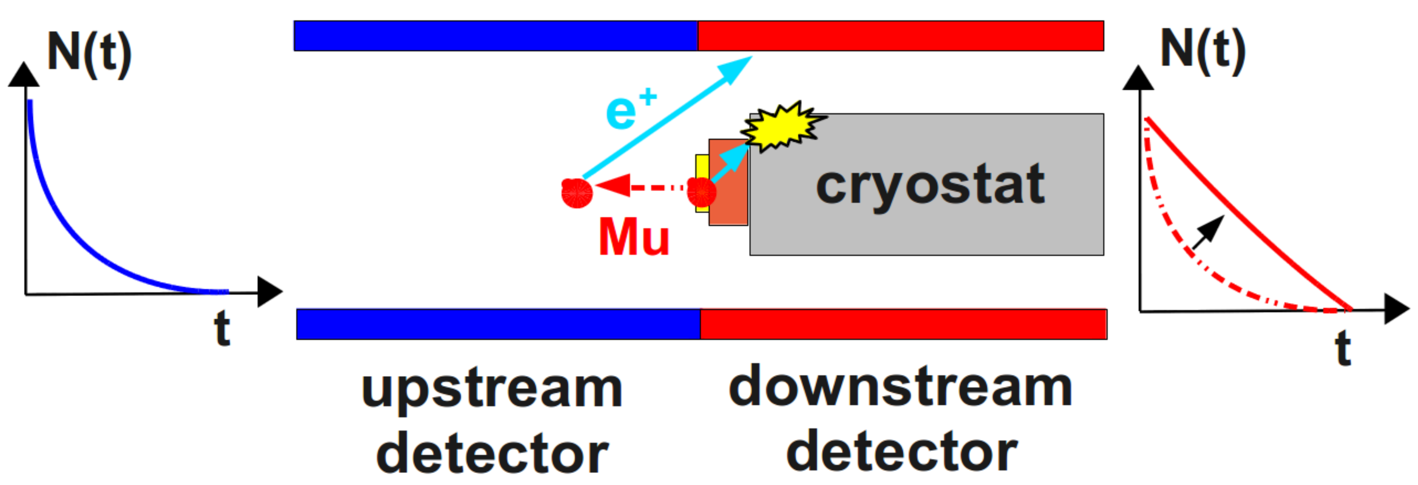


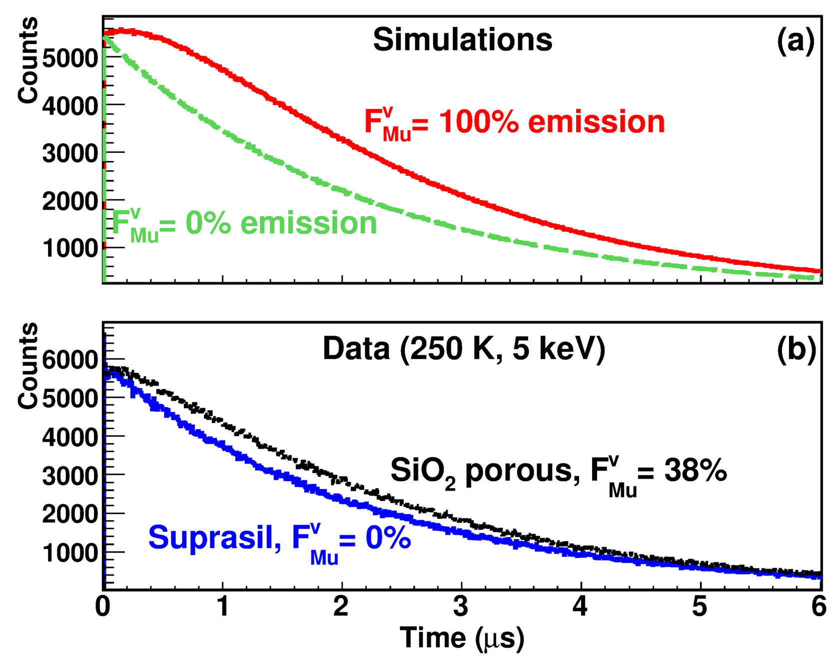
Raw time spectrum — Evolution of μ^+ spin at 6 G — Evolution of Mu spin at 6 G

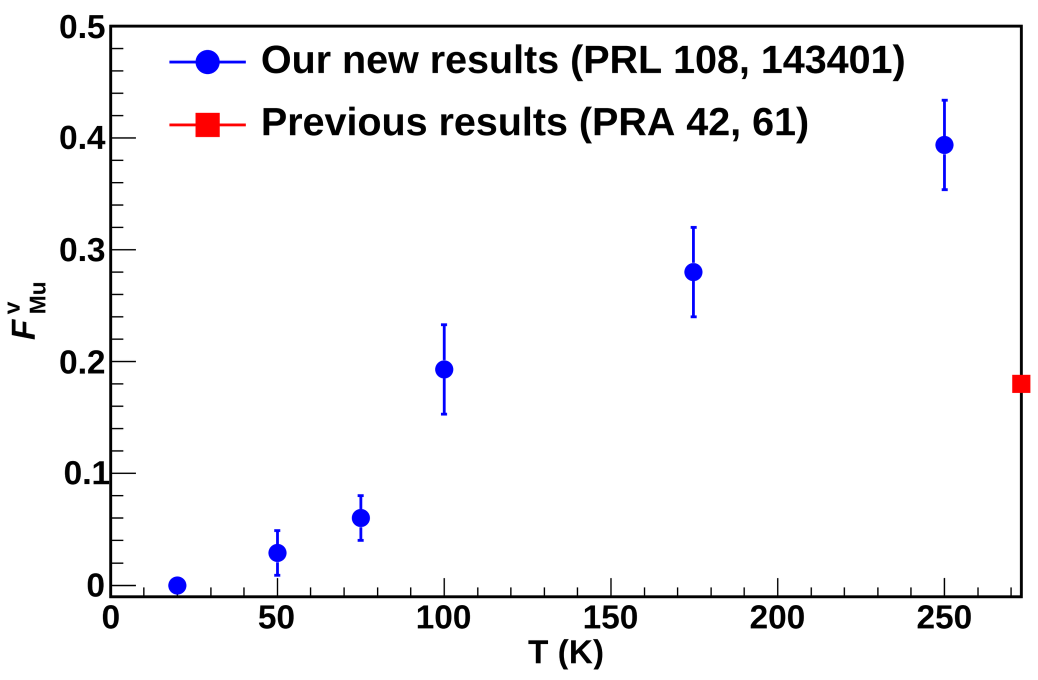
- F_{Mu} is calculated from the **fitted amplitudes** A_μ and A_{Mu}.
- We obtained $F_{\mathrm{Mu}} = (60 \pm 2)\%$ for porous SiO_2 and $(80 \pm 4)\%$ for Suprasil (Reference sample, no Mu emission into vacuum).

Positron shielding technique

We developed a new approach to extract the **fraction of Mu emitted into vacuum**.

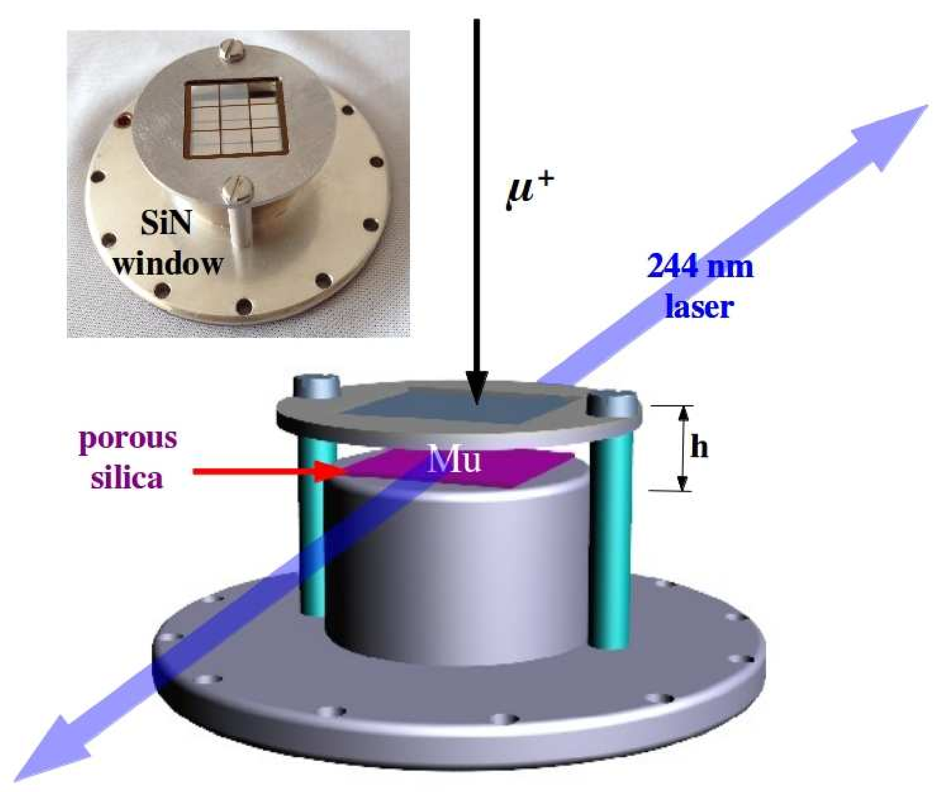




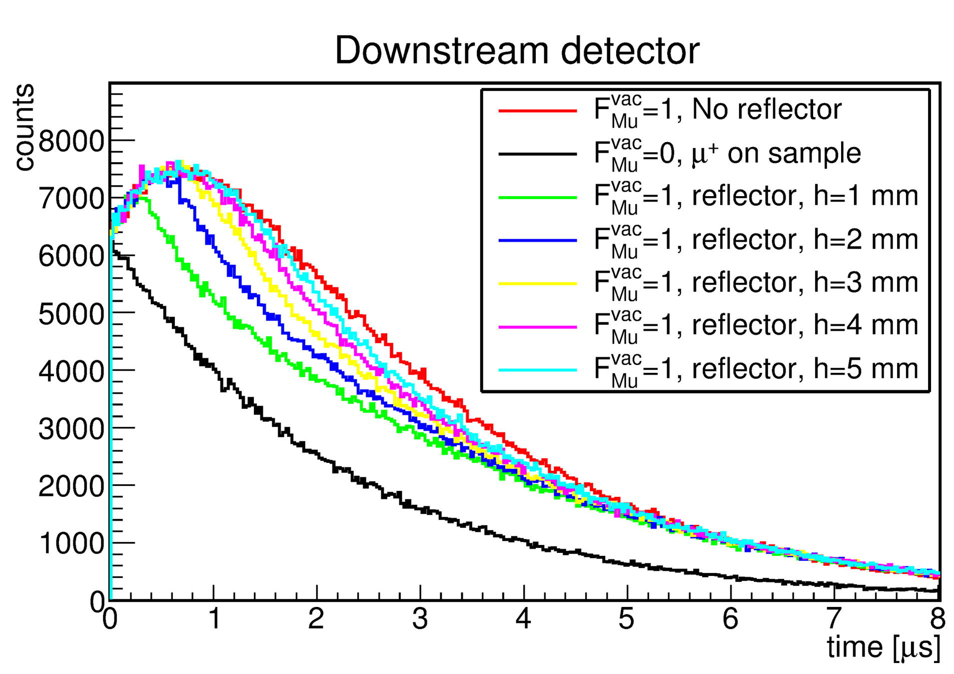


- μ/Mu decays inside the sample $\to$ exponential decay.
- Mu emitted into vacuum $\to$ deviation from exponential decay.
- With **GEANT4 simulation**, we extracted the fraction of Mu emitted into vacuum.

Towards 1S-2S measurement - a muonium trapping cell



Scheme for 1S-2S spectroscopy



Simulated time spectra for different height

- To increase the **laser-Mu interaction time** $\to$ trap Mu atoms!
- Cryogenic tests done at 77 K for the 50 nm thin SiN multi-window.
- Upcoming beam time: summer 2014