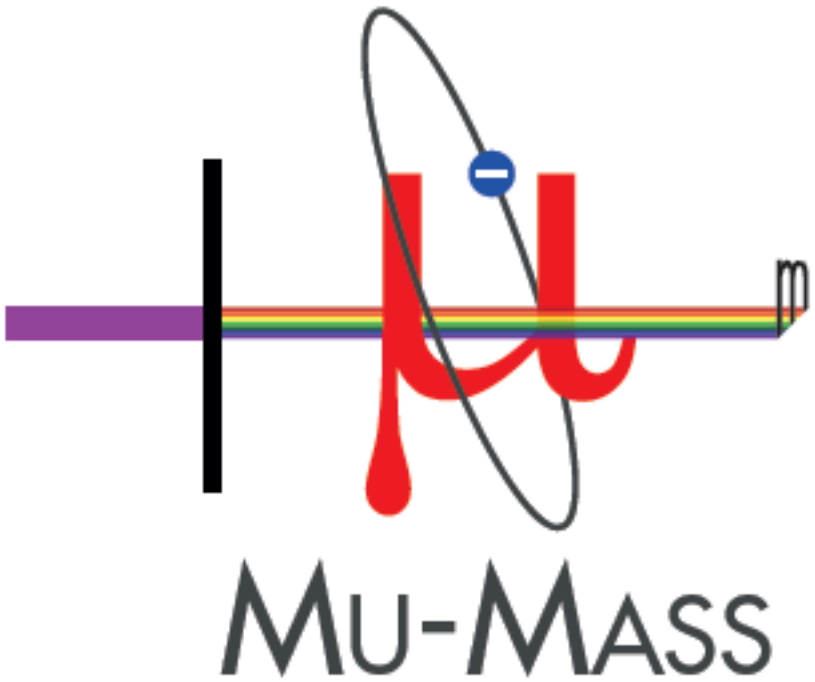

Mu-MASS (MuoniuM lAser SpectroScopy)

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T. Prokscha, Z. Salman, A. Suter, X. Ni
PSI, Laboratory for Muon Spin Spectroscopy (LMU), 5232 Villigen, Switzerland
A. Antognini, K. Kirch, A. Soter
PSI, Laboratory for Particle Physics (LTP), 5232 Villigen, Switzerland and
ETH Zurich, Institute for Particle Physics and Astrophysics (IPA), 8093 Zurich, Switzerland
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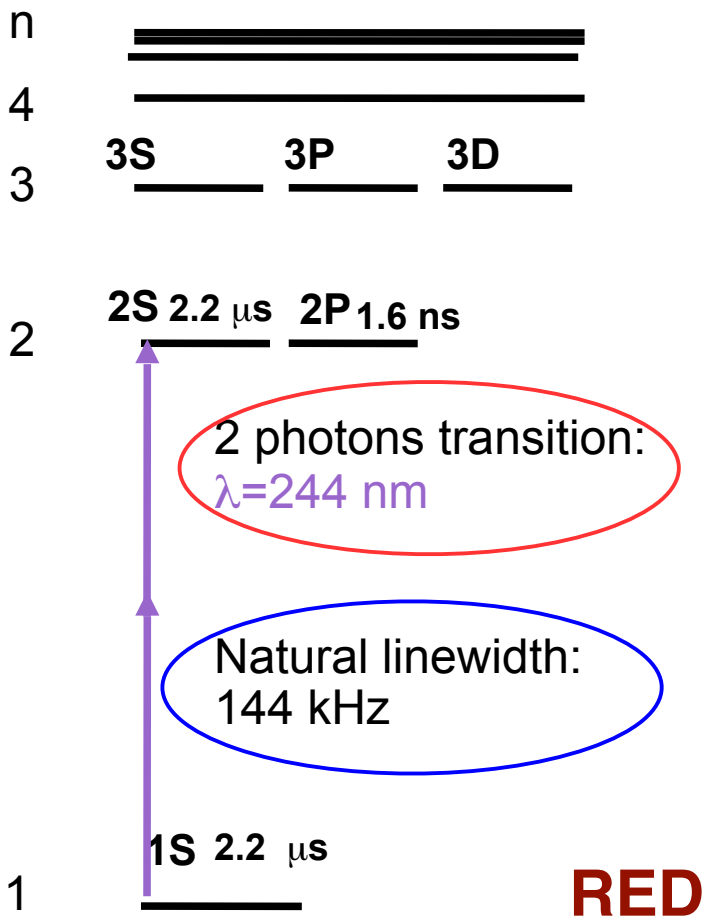
PSI, Laboratory for Particle Physics (LTP), 5232 Villigen, Switzerland
D. Yost
Colorado State University (CSU), Colorado, USA

https://www.psi.ch/en/ltp/mu-mass

R-19-01.1 - Progress report BV52 User meeting - 27th of January 2021

Paolo Crivelli, Institute for Particle Physics and Astrophysics, ETH Zurich

Muonium 1S-2S: current status theory/experiment



$$\Delta\nu_{1S2S}(\text{expt.}) = 2455528941.0(9.8)\,\text{MHz}$$

Meyer et al. PRL84, 1136 (2000)

$$\Delta\nu_{1S2S}(\text{theory}) = 2455528935.4(1.4)\,\text{MHz}$$

Limited by knowledge of muon mass.
QED calculations at 20 kHz *S. G. Karshenboim, Phys. Rep. 422, 1 (2005)*

REDUCED MASS CONTRIBUTION: 1.187 THz (4800 ppm)

$$m_{\mu+}/m_{e-} = 206.76838(17)$$

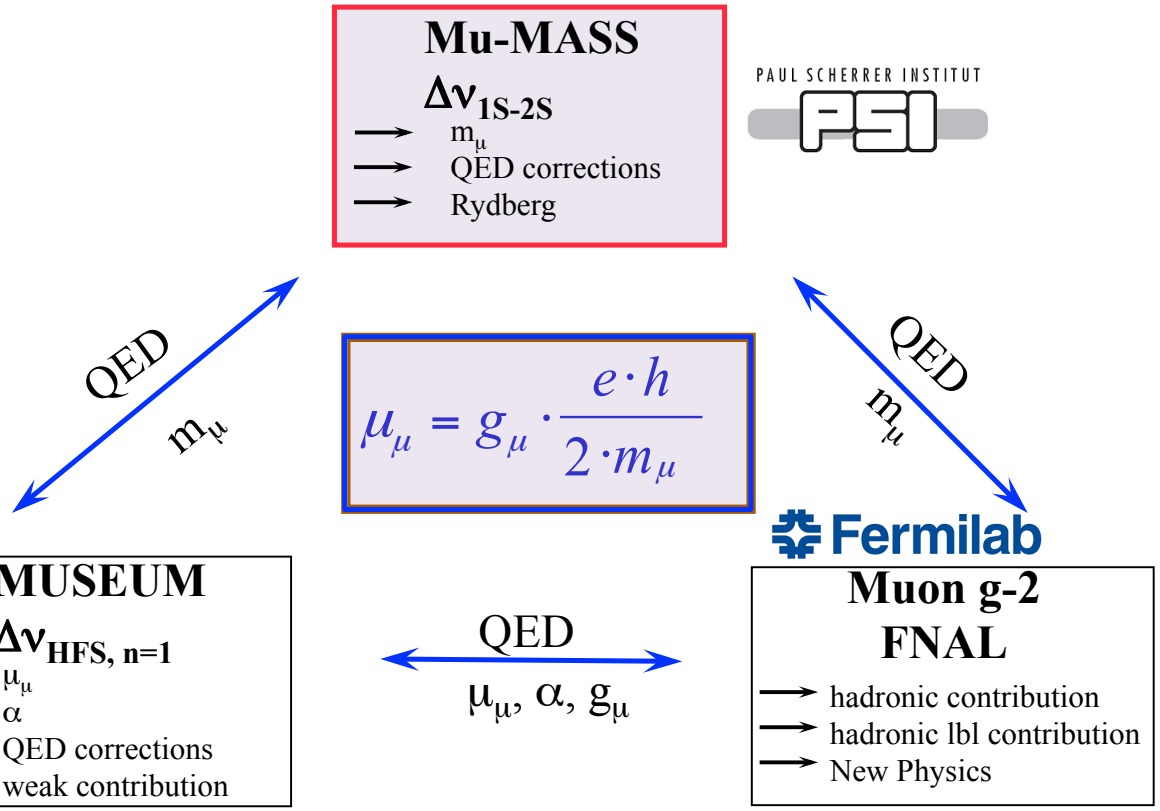
MU-MASS

Mu-Mass: Goal and Output

Mu-MASS: Measure **1S-2S transition** with Doppler free laser spectroscopy
GOAL: improve by 3 orders of magnitude (10 kHz, 4 ppt)

OUTPUT

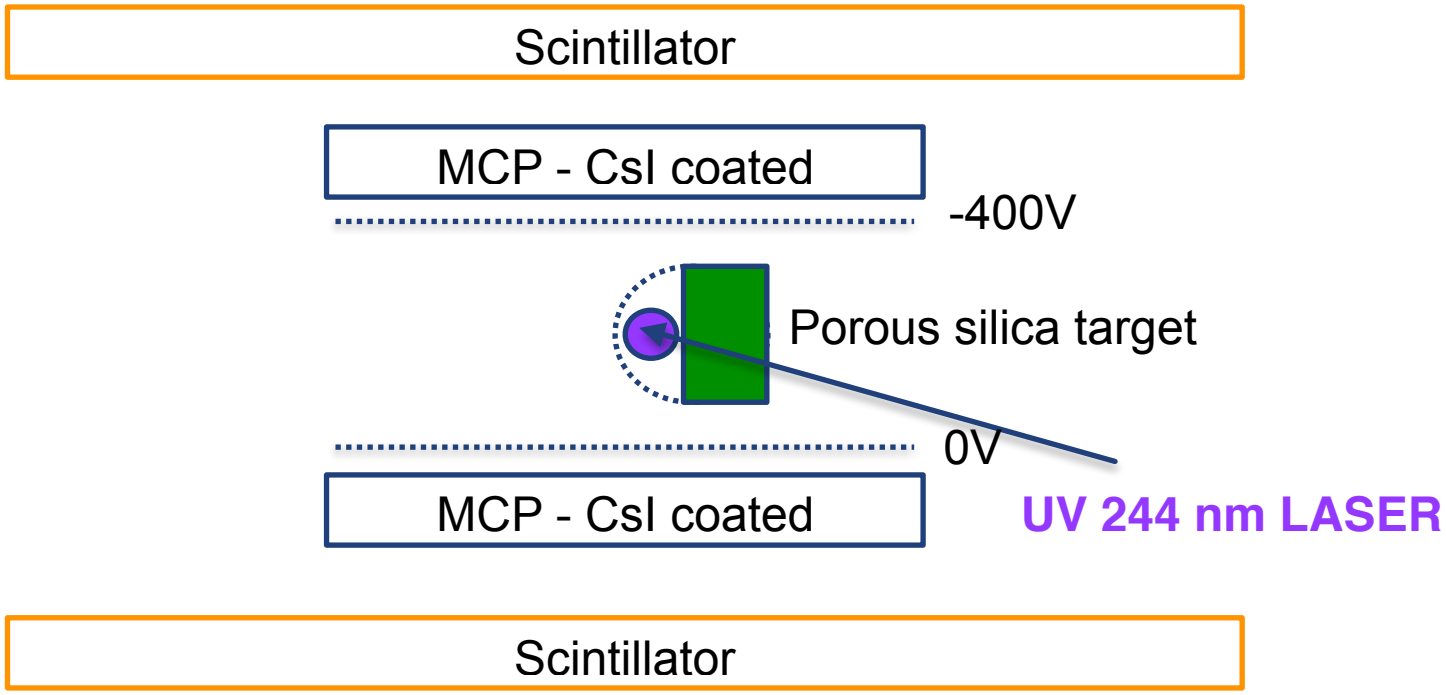
→ **Muon mass @ 1 ppb**
→ Ratio of q_e/q_μ @ 1 ppt
→ Search for New Physics
→ **Test of bound state QED (1×10^{-9})**
→ **Rydberg constant @ ppt level**
→ New determination of α @ 1 ppm
→ Input to muon g-2



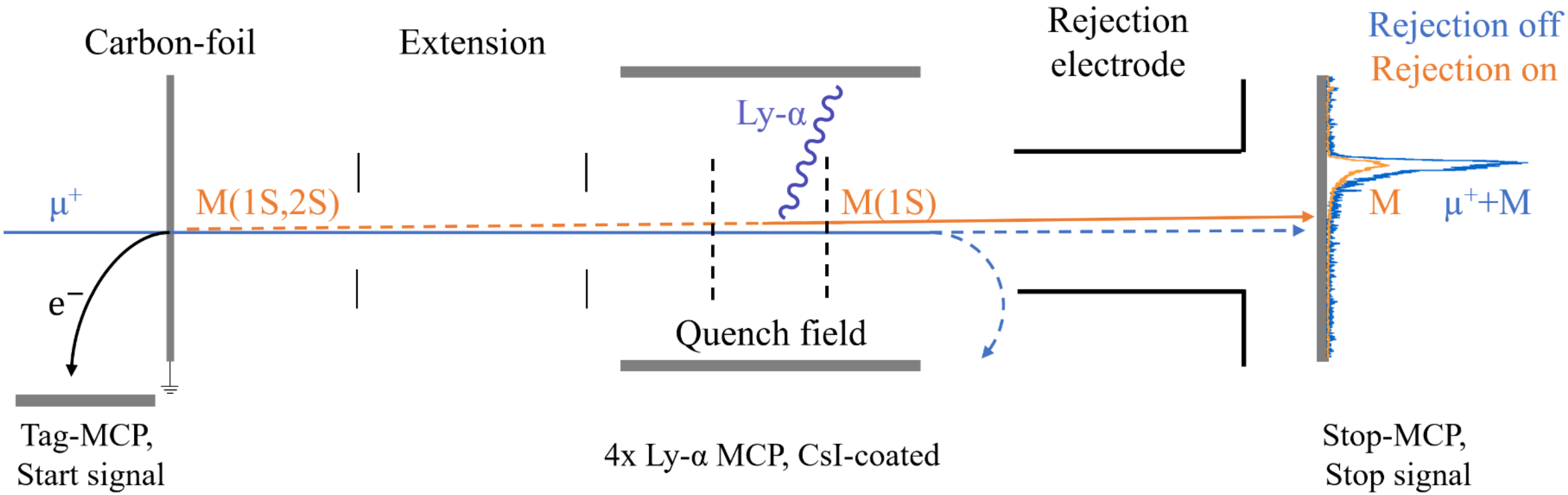
Mu-Mass

Adapted from K. Jungmann, DPG 2017 (Mainz)

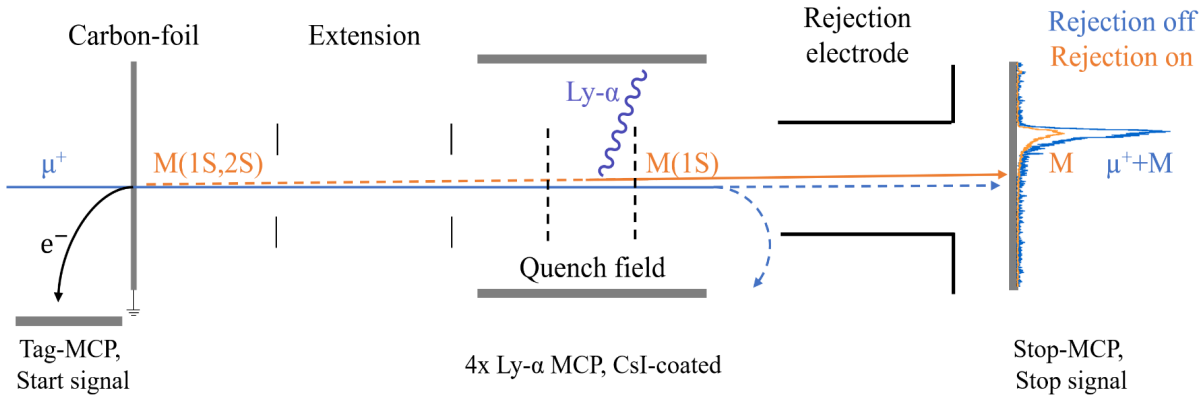
Mu-MASS: Scheme

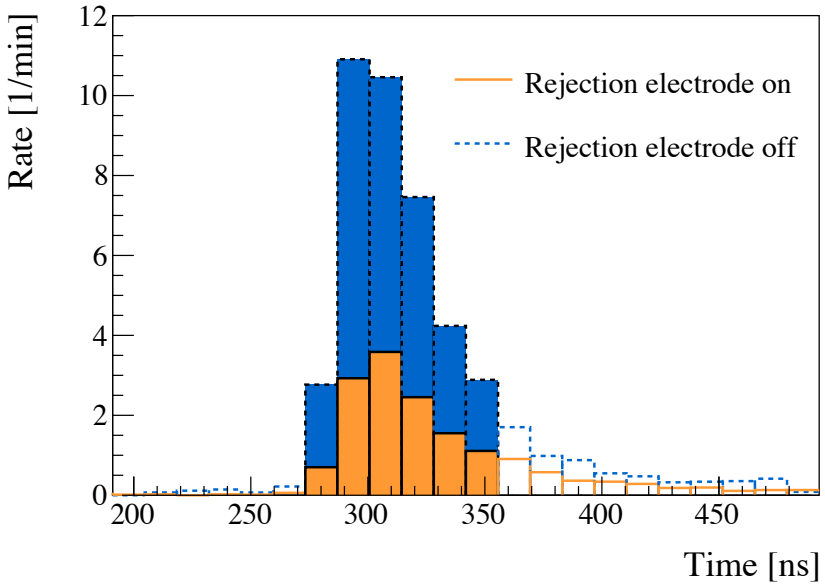


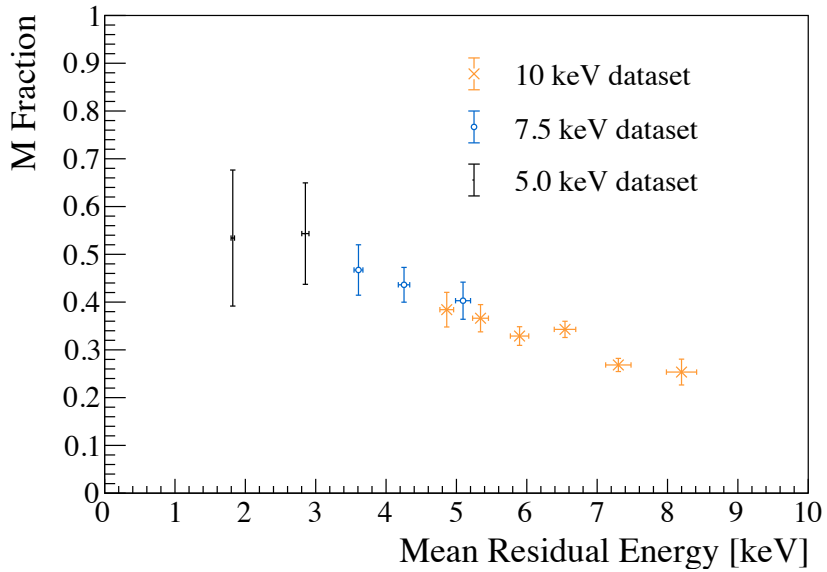
Detection of the 2S states (beamtime at LEM Dec. 2019)



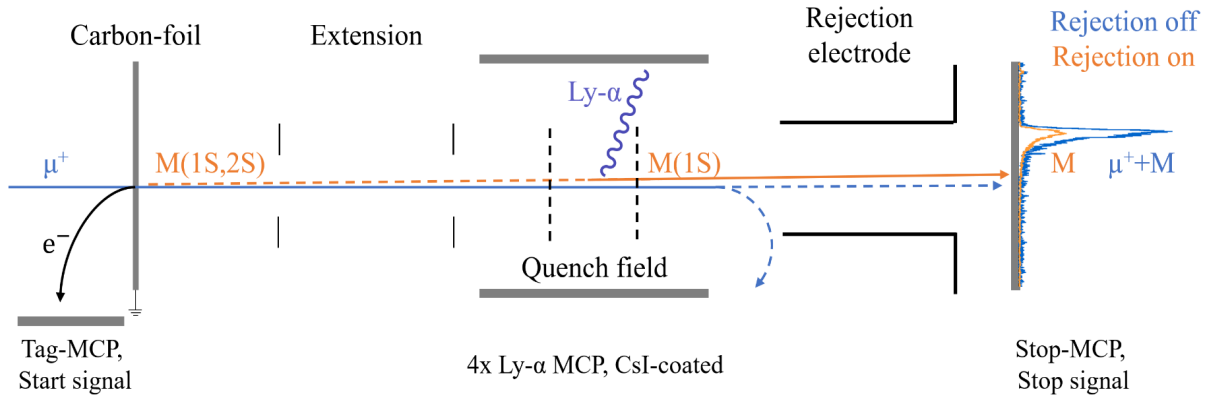
Muonium formation with a C-foil

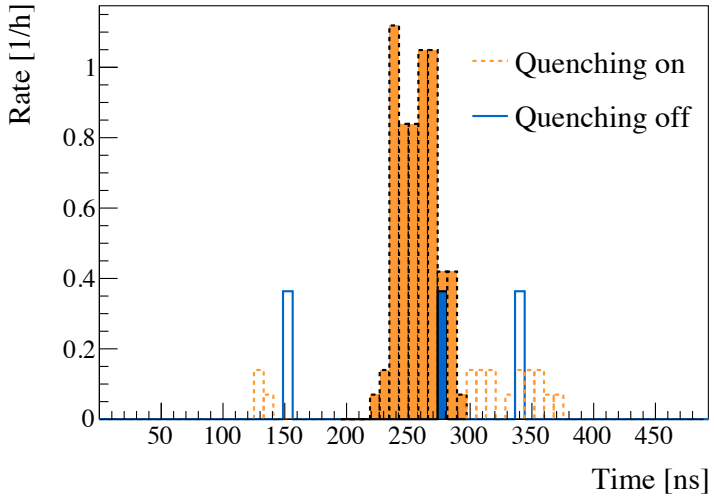






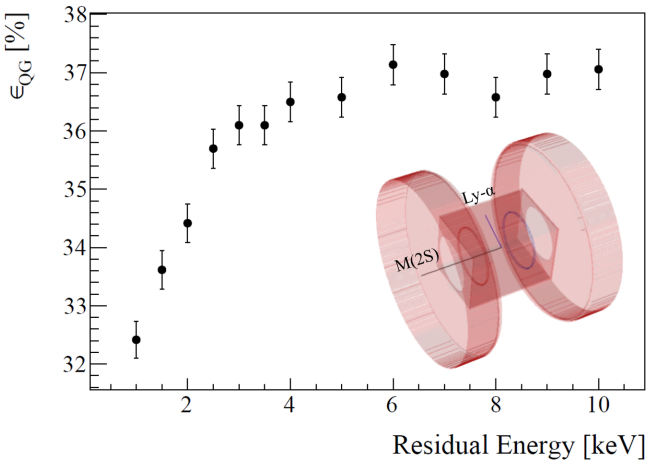
Detection of muonium in 2S state





Quenching efficiency and geometrical acceptance from MC

$$f_{2S/M} = 10 \pm 2\%$$

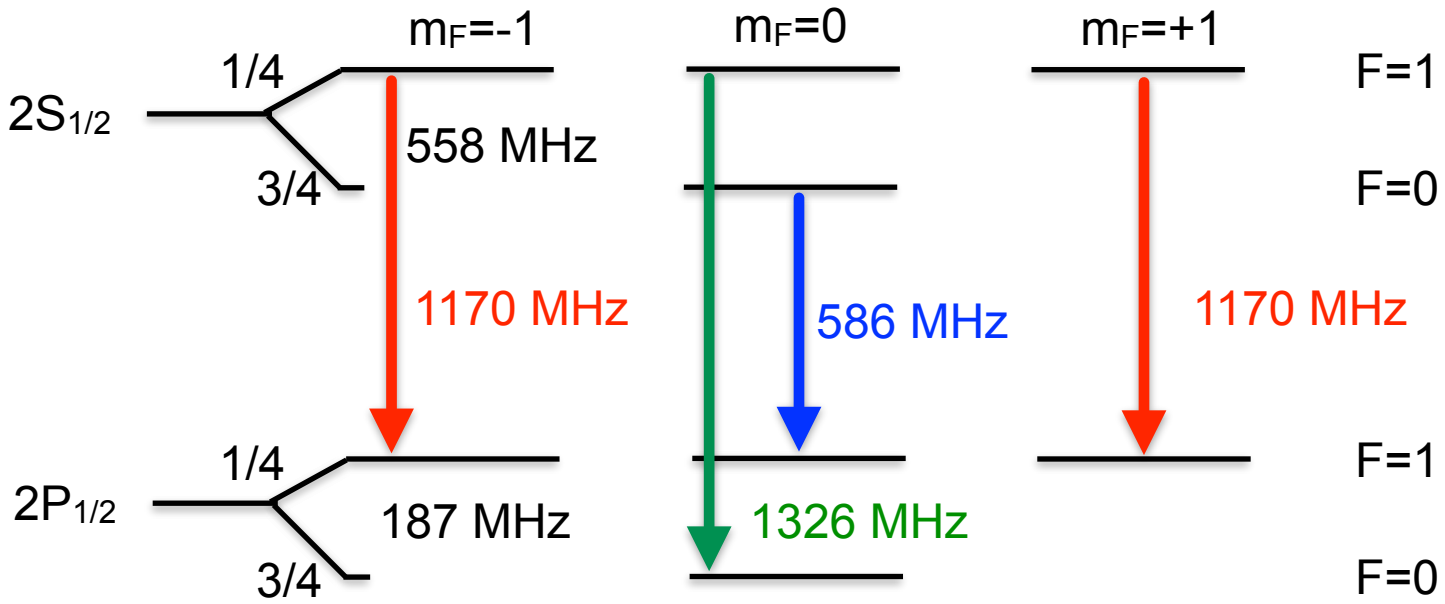


INTENSE 2S M BEAM -> POSSIBILITY TO IMPROVE THE M LAMB SHIFT

G. Janka et al., Eur. Phys. J. C (2020) **80**: 804

MU-MASS

Muonium Lamb shift



THEORY $(E(2S_{1/2}) - E(2P_{1/2}))^{\mathrm{th}}_{\mathrm{Mu}} = 1047.284(2)\ \mathrm{MHz}.$

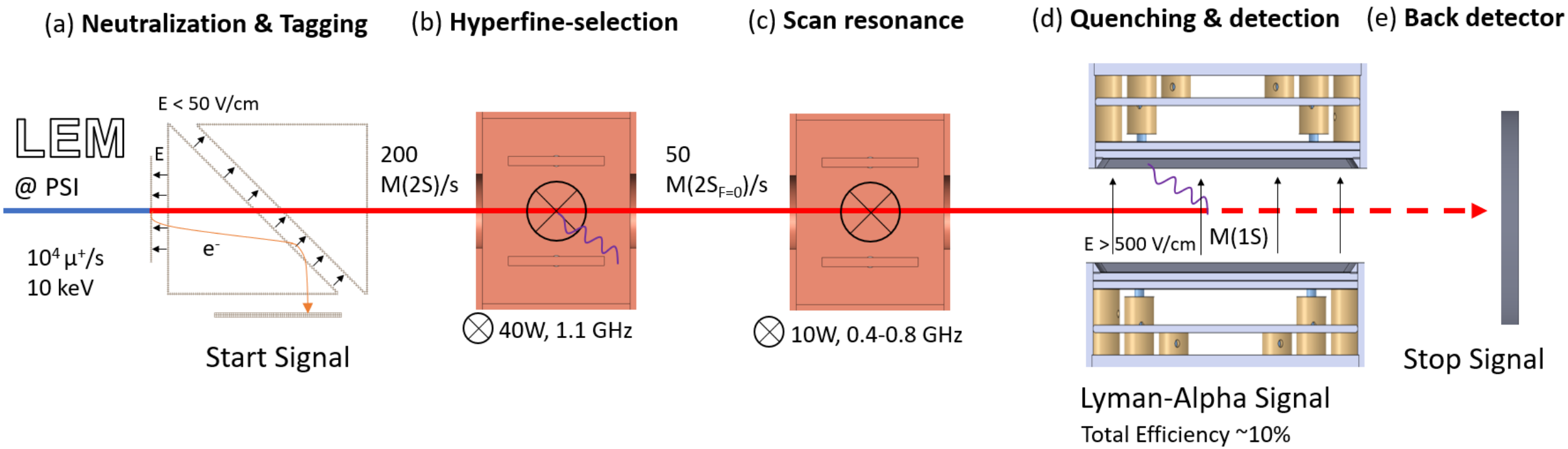
C. Frugiuele, J. Perez-Ríos, C. Peset, Phys. Rev. D 100, 015010 (2019)
M. I. Eides, H. Grotch, and V. A. Shelyuto, Phys. Rep. 342, 63 (2001).
W. Liu, M. Boshier, S. Dhawan et al., Phys. Rev. Lett. 82, 711 (1999).

EXPERIMENT $(E(2S_{1/2}) - E(2P_{1/2}))^{\mathrm{exp}}_{\mathrm{Mu}} = 1042(22)\ \mathrm{MHz}.$

C .J. Oram et al. Phys. Rev. Lett. 52, 910 (1984). DOI 10.1103/PhysRevLett.52.910. @ TRIUMF
K. Woodle, et al., Phys. Rev. A 41, 93 (1990). DOI 10.1103/ PhysRevA.41.93 @ LAMPF

MU-MASS

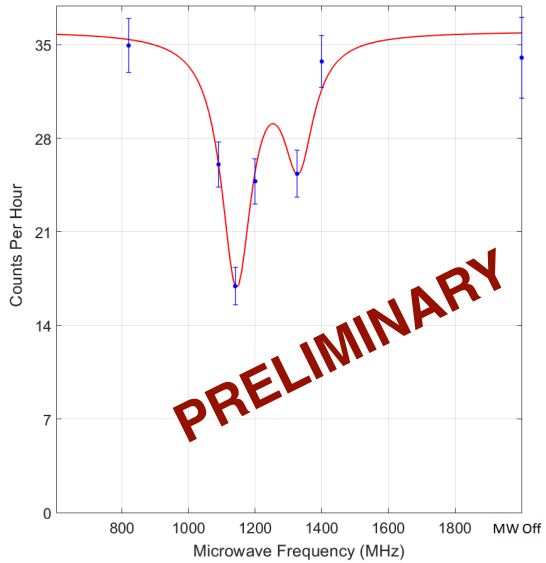
Measurement of the Lamb shift (beamtime Dec. 2020)



MU-MASS

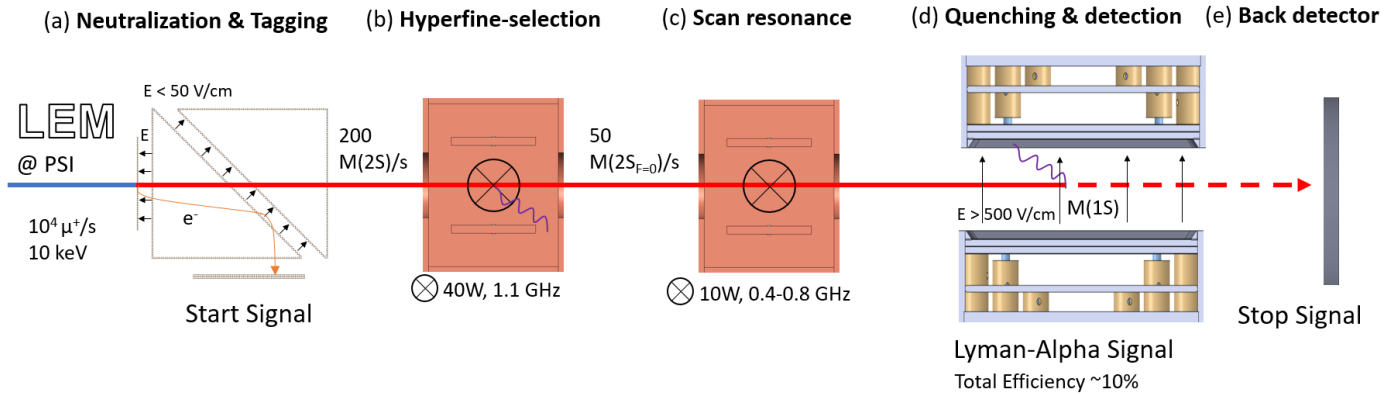
Results of the Lamb shift (beamtime Dec. 2020) & Outlook (2021)

40 HOURS DATA TAKING (10x statistics compared to TRIUMF)



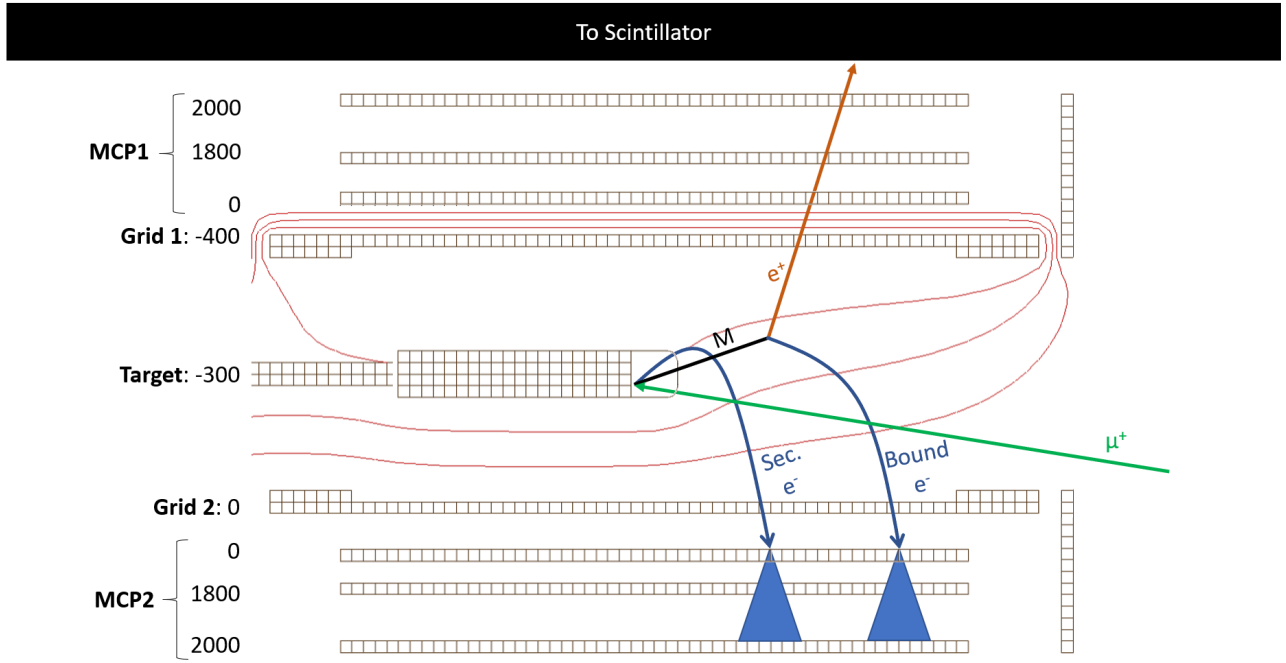
OUTLOOK:

- RUN @LEM in June 2021 (5 days if approved)
- Dedicated tagging system under construction (reduce losses due to scattering in C-foil by factor 10)
- Probe isolated 586 MHz line
- Expected accuracy < 1MHz
- Main systematic: Doppler (change MW direction)

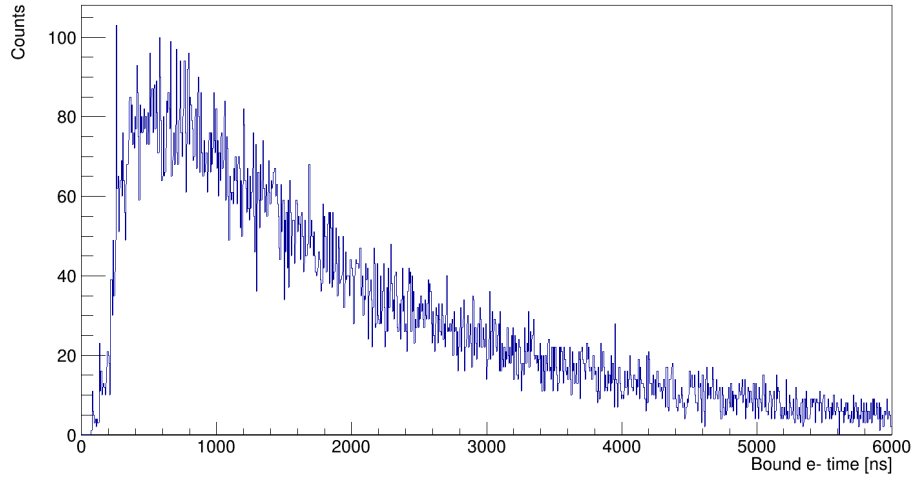


MU-MASS

Test of Mu-MASS detection scheme (beamtime Dec. 2020)

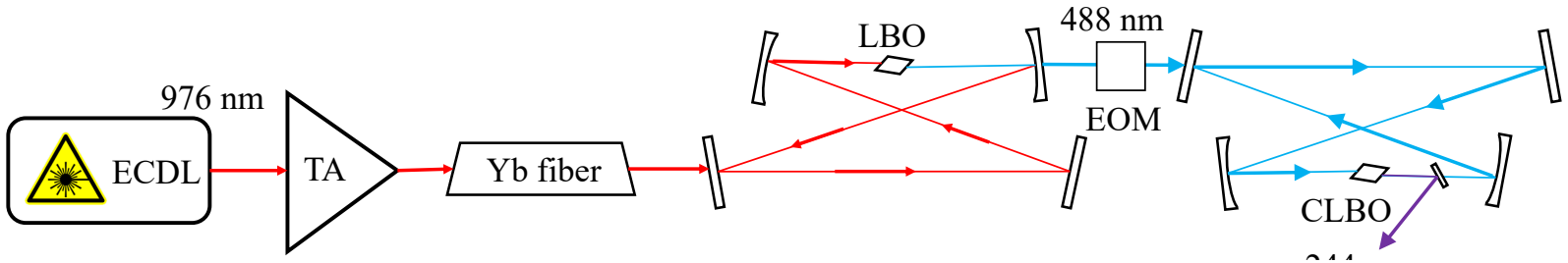


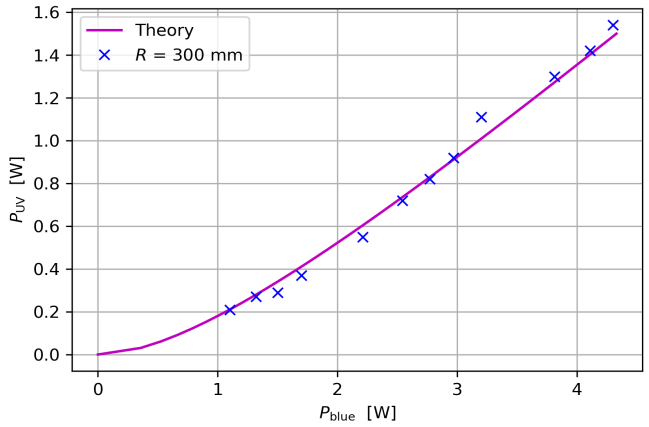
Detection of bound electron in coincidence with the positron in the scintillator

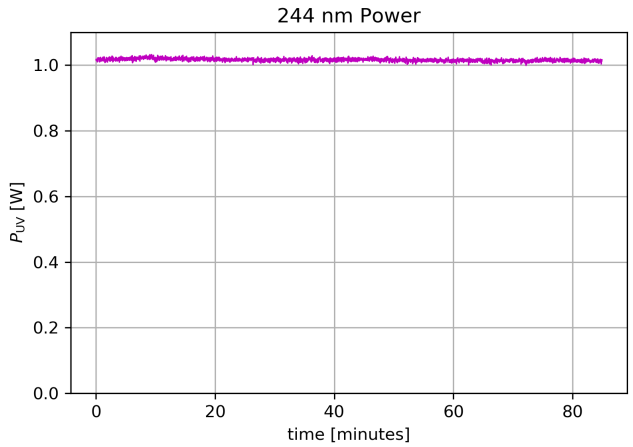


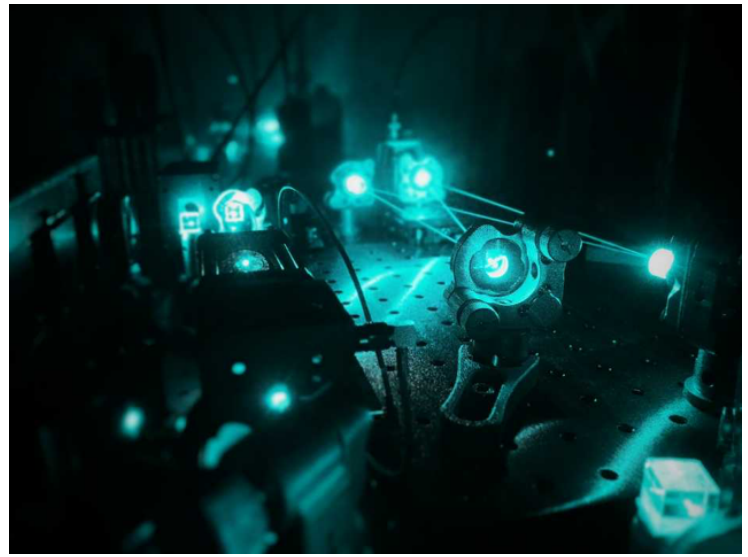
Data analysis ongoing…

Mu-MASS: Laser system









Output at around **600 mW**
stable for more than **1 day**
(new Brewster plate being produced)

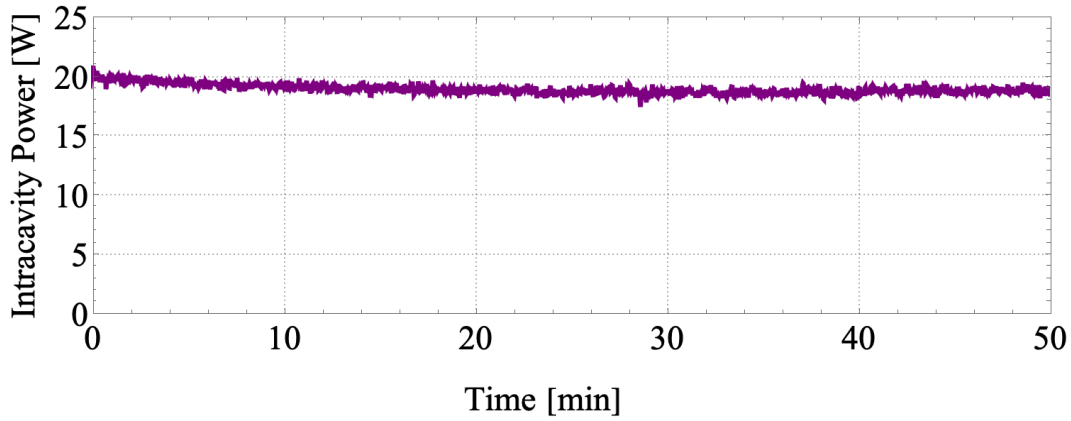
Mu-MASS: Laser system

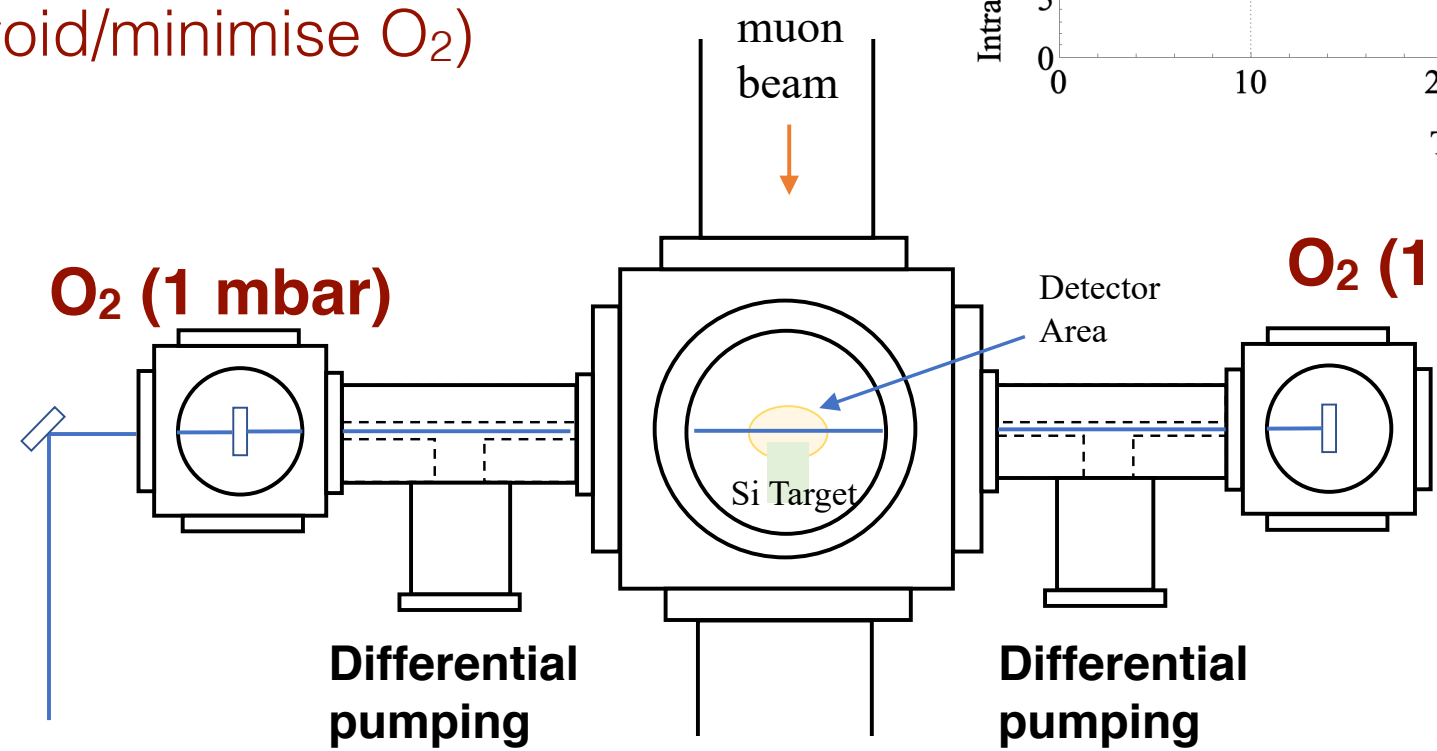
About 500 mW input

20 W in enhancement cavity

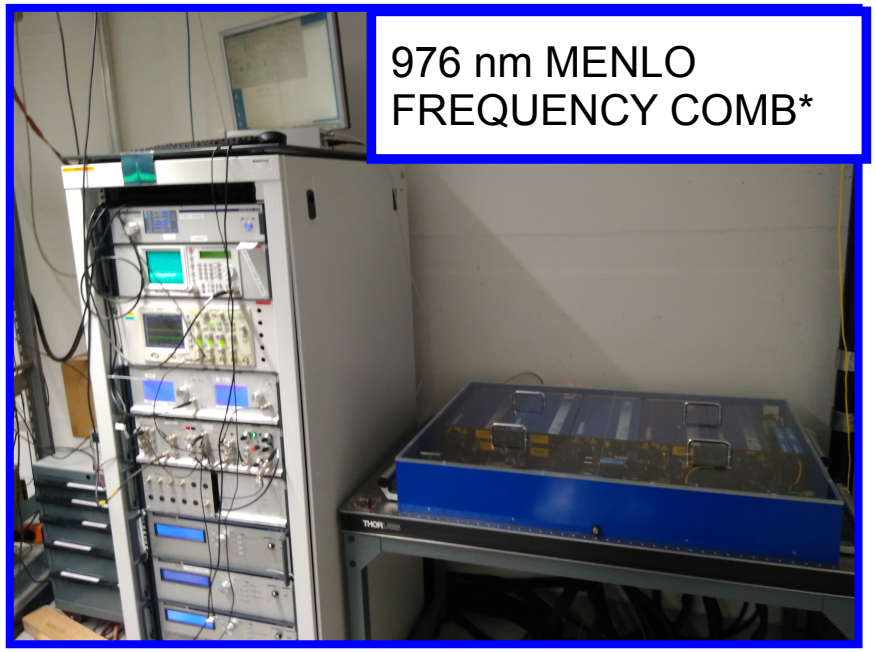
with new CaF_2 and fluoride coatings

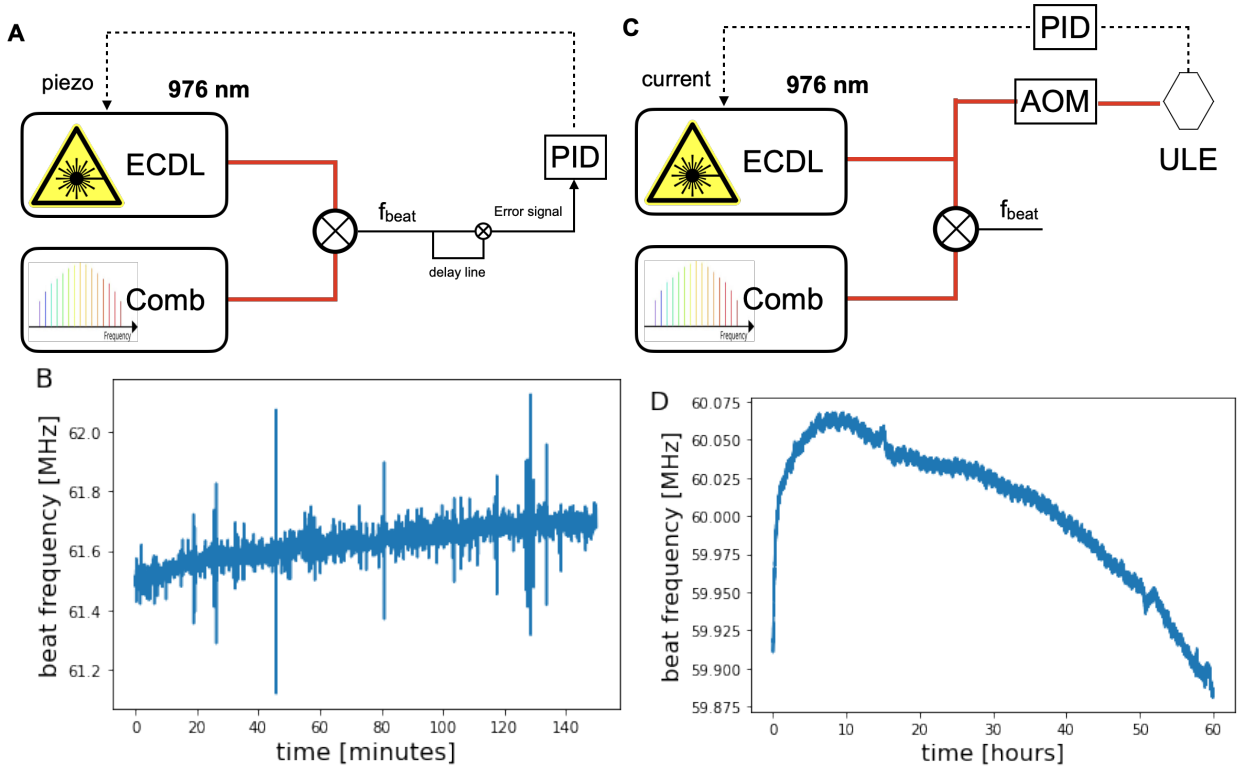
(goal avoid/minimise O_2)





Frequency reference





*a big thank you to Prof. T. Esslinger to allow us to use it old comb which we upgraded with a fibre oscillator and an output at 976 nm

Summary and outlook for Mu-MASS

CURRENT STATUS:

- Detection of 2S states was demonstrated.
- Detection of bound electron from M in coincidence with the positron.
- Laser system, 20W circulating power achieved, improvement in stability ongoing.
- Frequency reference for the experiment is ready.

GOALS 2021:

- Perform an a LS measurement at <1MHz in June 2021 Beamtime at LEM
- combine laser system + experiment at LEM in December 2021, attempt detection of 1S-2S transition

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Mu-Mass

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