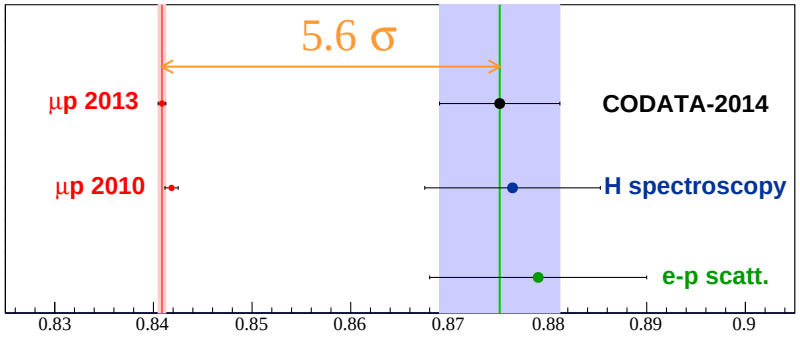
Proton Radius Measurement

$\mu - p$ elastic scattering

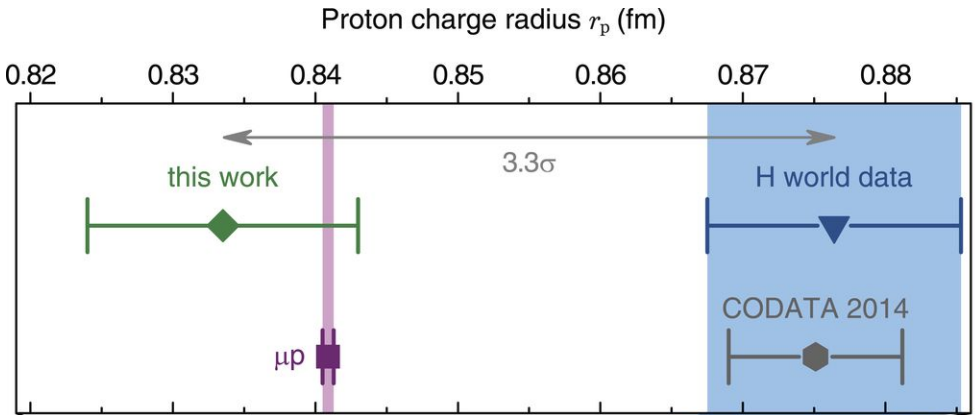
Sebastian Uhl

Physik Department E18
Technische Universität München

LoI Mini-Workshop
20th June, 2018



RP, Gilman, Miller, Pachucki, Annu. Rev. Nucl. Part. Sci. 63, 175 (2013).

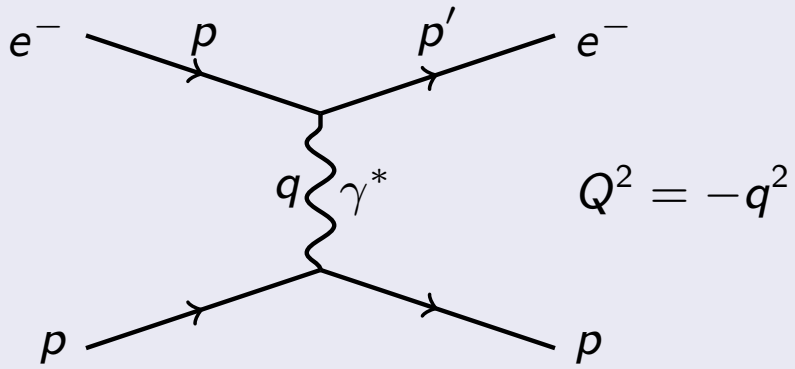


A. Beyer *et al.*, Science 358 (2017) 79

proton radius "puzzle"

- discrepancy between scattering and spectroscopy data
  - measuring the same thing?
  - systematic effects for electron scattering, e.g. radiative corrections?
  - new physics? lepton non-universiality?
  - ...

scattering experiments

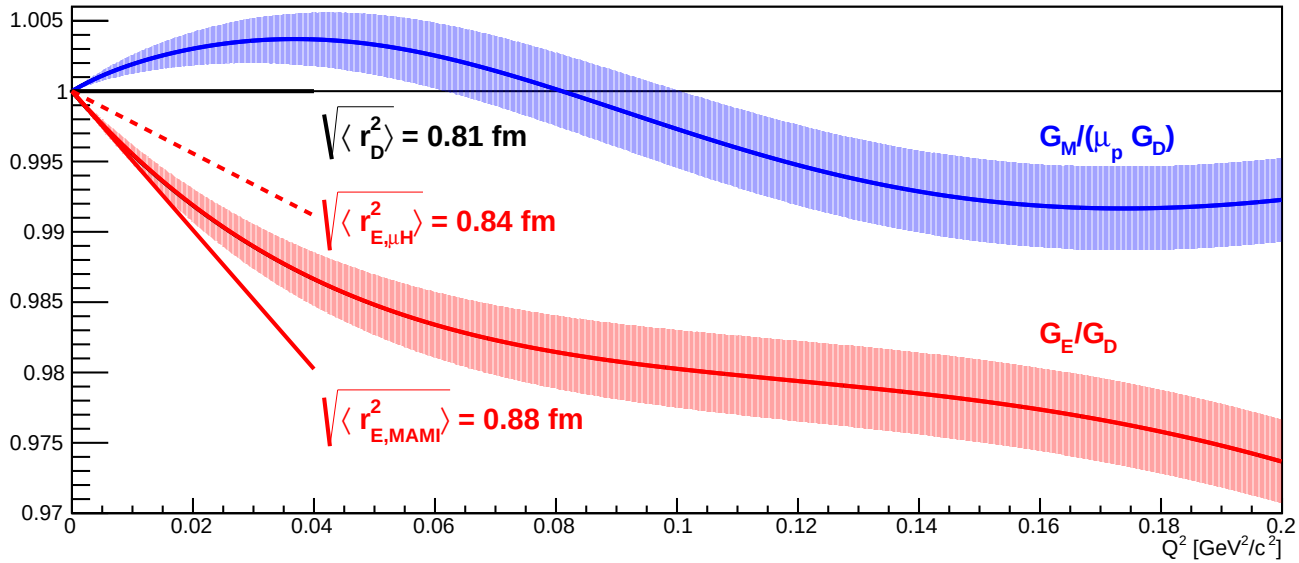


$$\frac{d\sigma}{dQ^2} = \frac{\pi\alpha^2}{Q^4 m_p^2 \vec{p}_e^{\,2}} \left[\left(G_E^2 + \tau G_M^2 \right) \frac{4E_e^2 m_p^2 - Q^2(s - m_\mu^2)}{1+\tau} - G_M^2 \frac{2m_e^2 Q^2 - Q^4}{2} \right]$$

$$\text{with } \tau = Q^2/(4m_p^2)$$

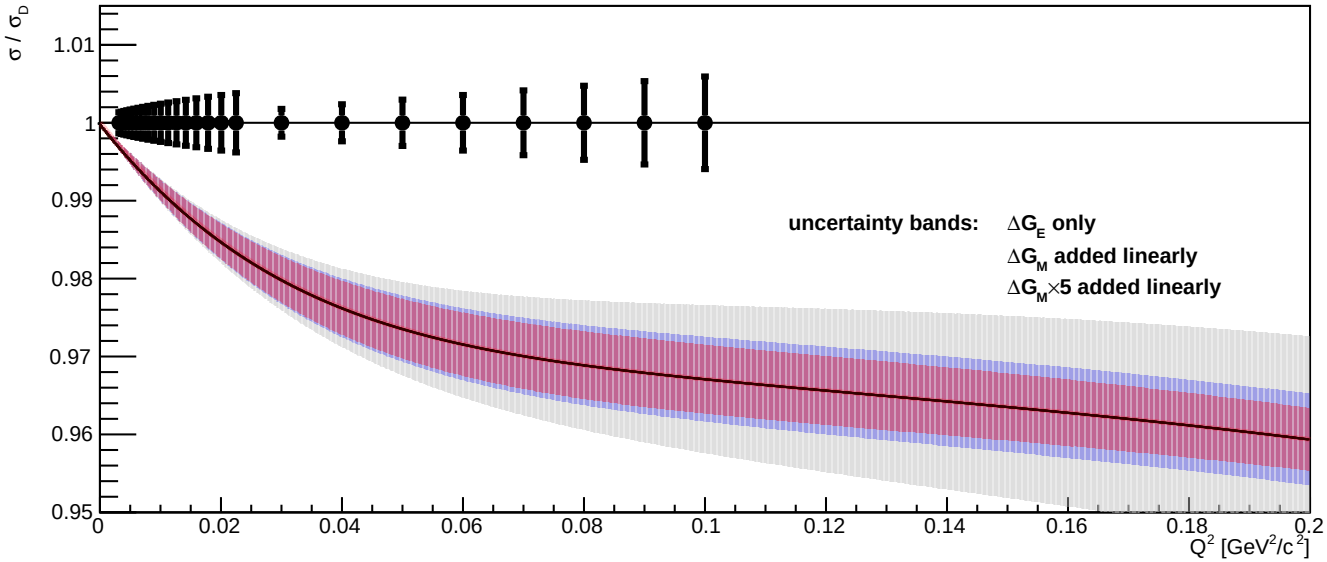
mean squared charge-radius

$$\langle r_E^2 \rangle = -6\hbar^2 \frac{dG_E(Q^2)}{dQ^2}\bigg|_{Q^2 \to 0}$$



opportunity for new generation experiment at M2 beam line

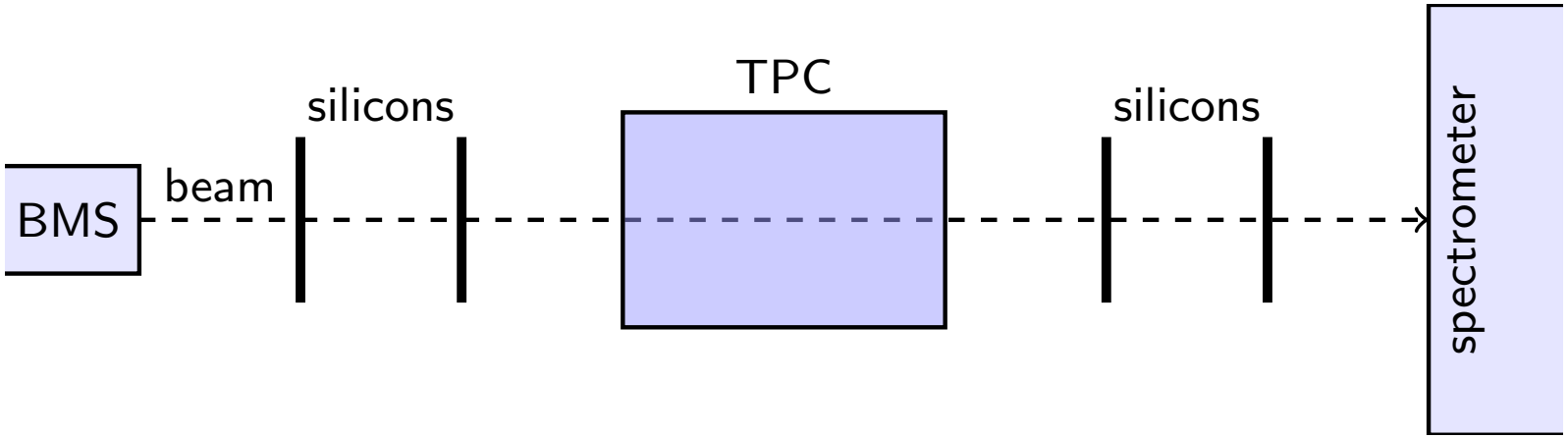
- scatter muon beam off proton target
- measure cross-section dependence on Q^2
- obtain combination of electric and magnetic form factor $G_E^2 + \tau G_M^2$
  - form factors cannot be separated due to high beam energy
- compared to e^- beam: smaller radiative corrections
- compared to μ beam at low energies: much smaller Coulomb corrections



requirements for measurement

assuming one year of data taking

- goal: uncertainty on $\sqrt{\langle r_E^2 \rangle} \approx 0.01\,\text{fm}$
- systematics: $Q^2 \gtrapprox 1 \cdot 10^{-3}\ (\text{GeV}/c)^2$
- uncertainty on G_M: $Q^2 \lessapprox 0.2\ (\text{GeV}/c)^2$

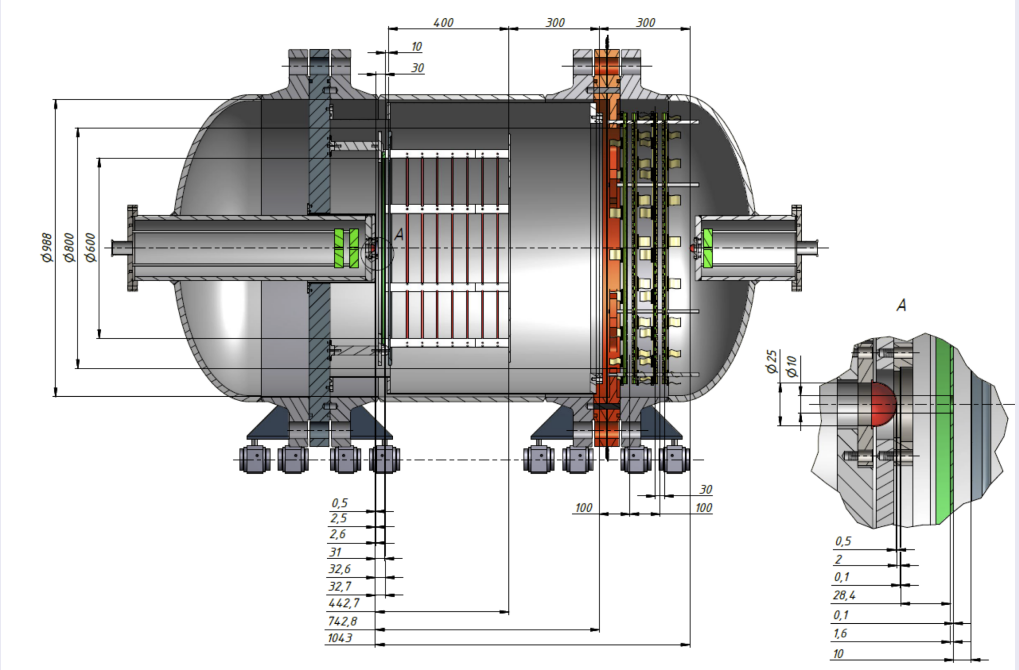


proposed set-up

- hydrogen TPC acting as active target
- silicon telescopes up- and downstream of target

TPC as active target

- high-pressure hydrogen target
- measurement of recoil proton
- wide range of recoil energies: 0.5 MeV to 100 MeV
- required energy resolution: 60 keV



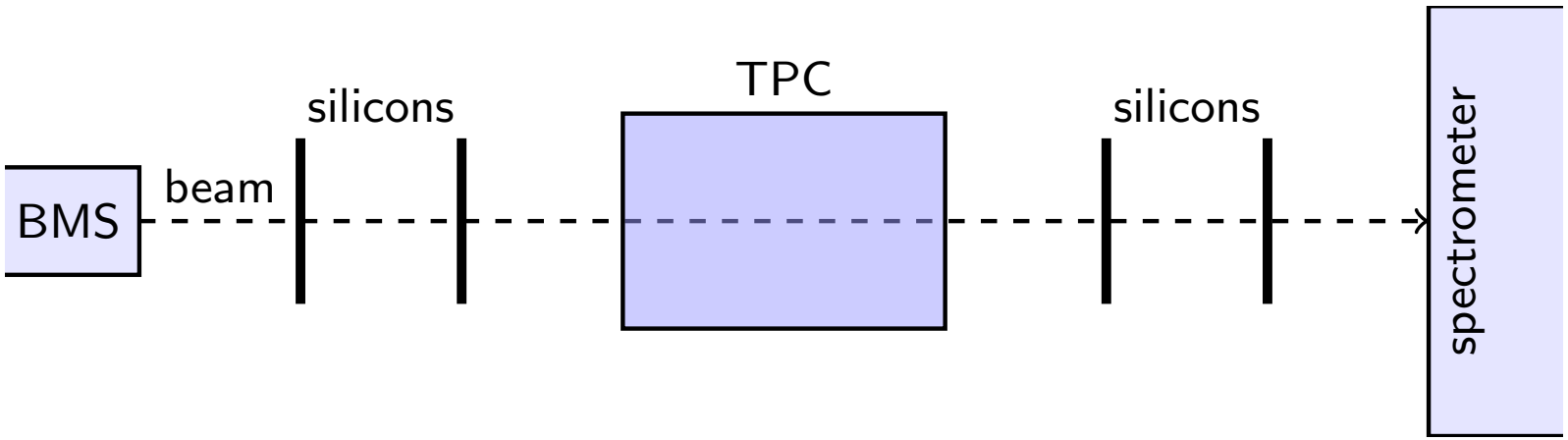
- high luminosity requires long target
  - long drift time might be an issue
- not all protons might be stopped inside TPC

silicon tracking detectors

- measurement of muon scattering angles
- 300 μrad at $Q^2 \approx 10^{-3}$ $(\mathrm{GeV}/c)^2$
- required resolution $\sigma \lessapprox 100\,\mu$rad

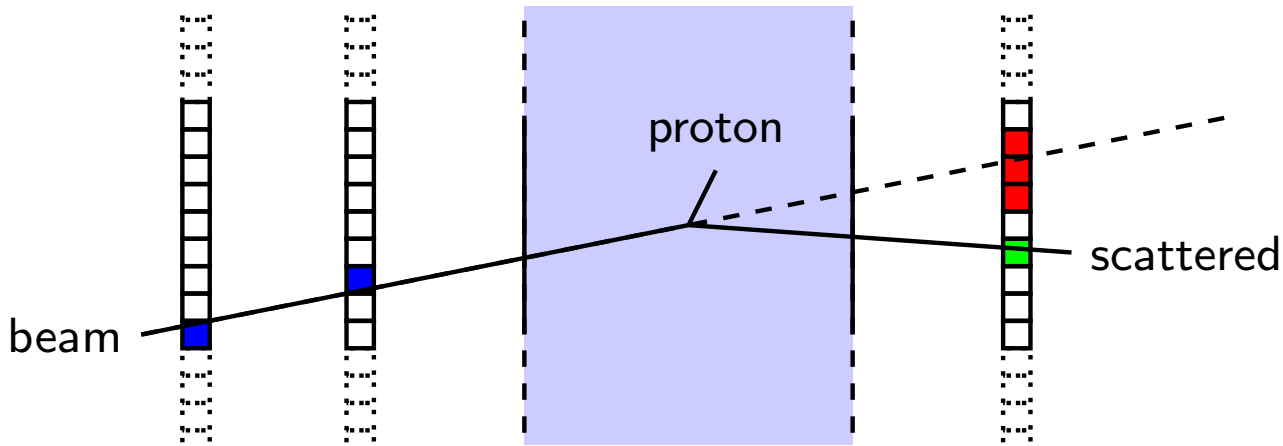
- excellent spatial resolution required
- high intensity
  - fast detectors

- strip detectors
  - required performance has been shown for current silicon detectors



proposed set-up

- trigger on recoil proton signal
  - drift time in TPC $\mathcal{O}(100\,\mu\text{s})$
  - trigger-less readout of all detectors
  - online event reconstruction to correlate proton and muon signals

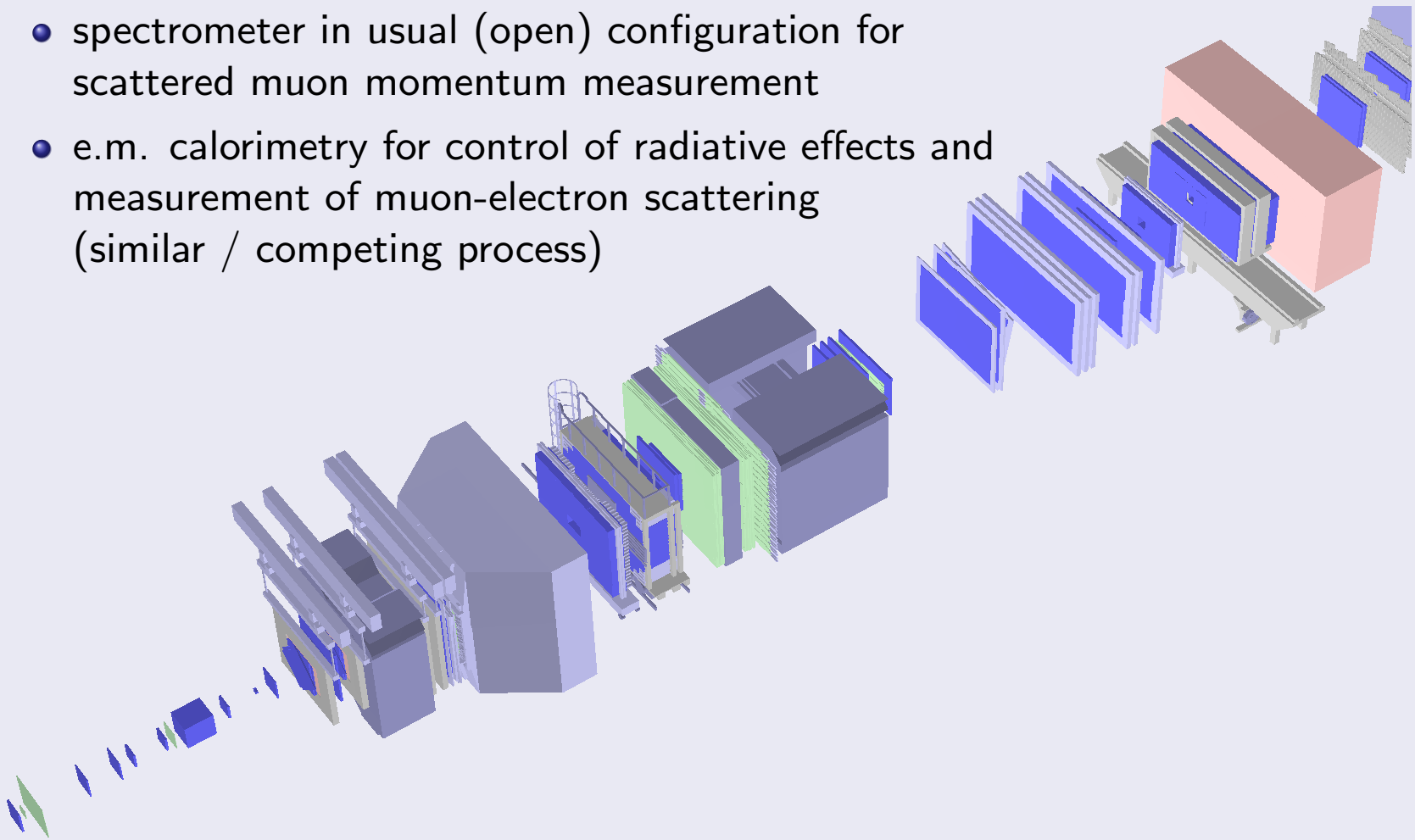


proposed set-up

- trigger on recoil proton signal
  - drift time in TPC $\mathcal{O}(100\,\mu\text{s})$
  - trigger-less readout of all detectors
  - online event reconstruction to correlate proton and muon signals
- trigger on small kink in muon track

Measurement in a COMPASS-like set-up

- TPC and silicon telescopes in the nominal COMPASS target region
- trigger: two scenarios under investigation
  - SciFi with high segmentation for a "kink trigger"
  - high-rate triggerless readout
    (requires new readout scheme for the silicon detectors)
- spectrometer in usual (open) configuration for scattered muon momentum measurement
- e.m. calorimetry for control of radiative effects and measurement of muon-electron scattering
  (similar / competing process)



Competitors and Time Scales

- on-going efforts (at least)
  - at MAMI ($e^- - p$)
  - PSI ($\mu - p$ at low energies)
  - spectroscopy of further muonic atoms
- the potential to contribute to the field is there now
  - result might not be relevant anymore if measurement shifted beyond LS3

New Collaborators

- interest of groups to join for development of TPC
- decision and agreements must be taken now without further delay for realizing the measurement in 2022