MUSE, the MUon proton Scattering Experiment

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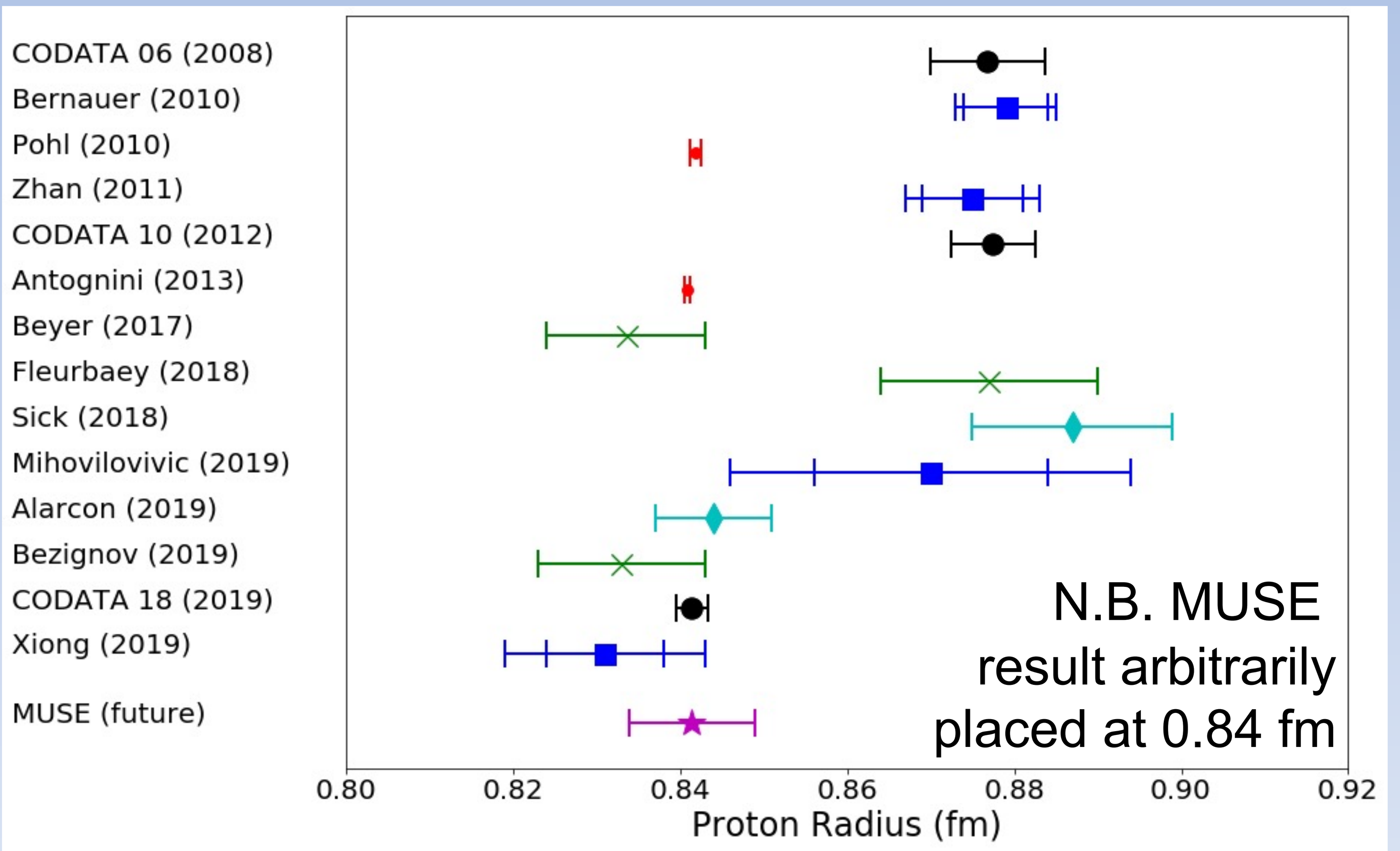
The Proton Radius Puzzle

In 2010 the CREMA collaboration released a measurement of the electric radius of the proton (r_p) using muonic hydrogen, which was an order of magnitude more precise than, but completely inconsistent with, the commonly accepted CODATA radius value. This sparked the Proton Radius Puzzle (PRP).



Experiments addressing the PRP:

- further muonic hydrogen spectroscopy measurements (red circles);
- atomic hydrogen spectroscopy (green crosses),
- electron scattering measurements (blue squares).

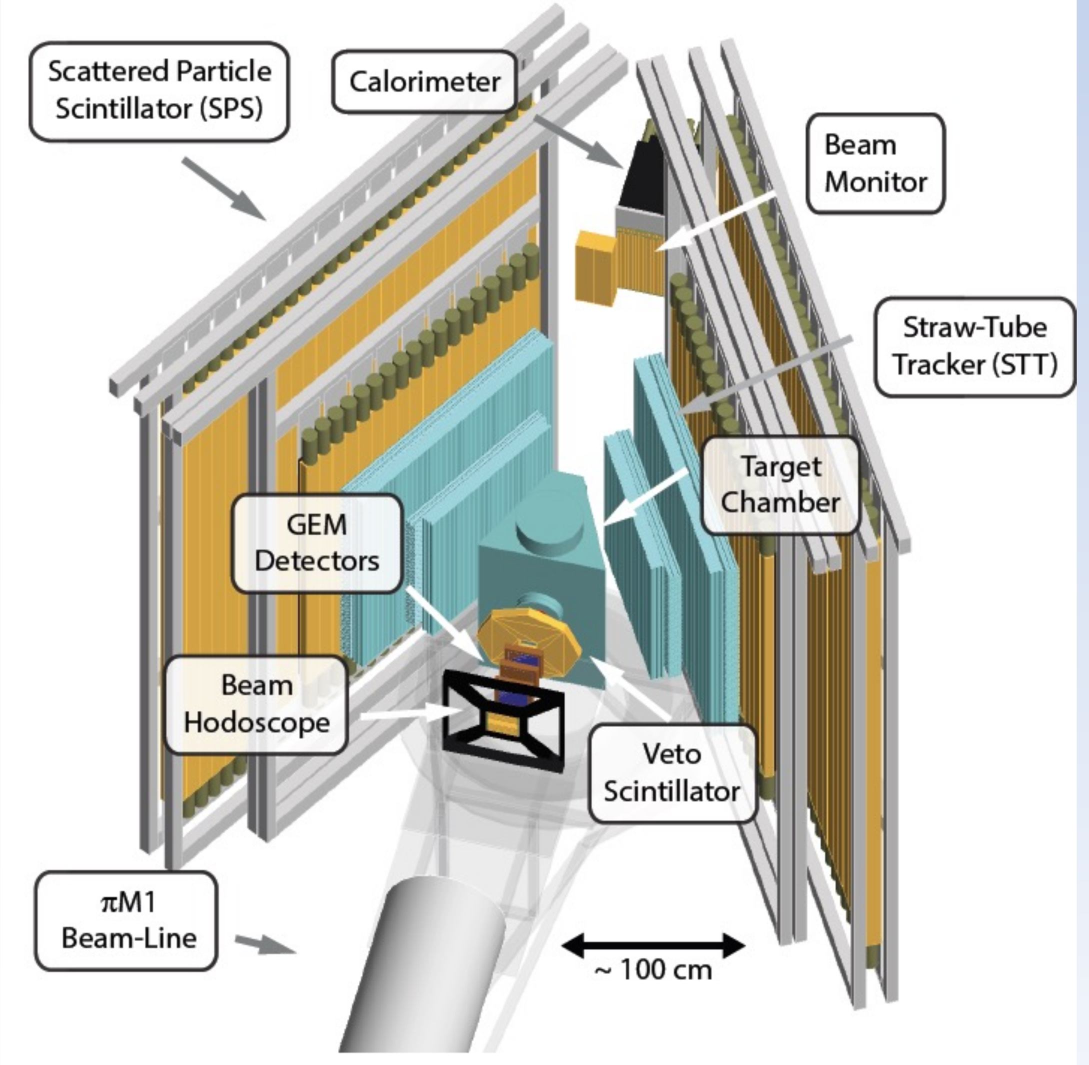
Results mixed, puzzle unresolved.

In 2012, MUSE was proposed as the first measurement of elastic muon scattering on the proton with sufficient precision to address the PRP.

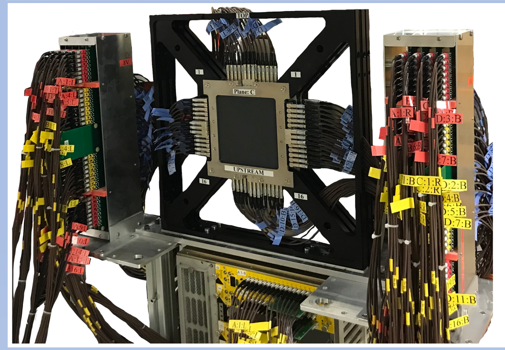
The MUSE Setup

Beam Characteristics:

- Mixed e, μ,π beam in PiM1 area of Paul Scherrer Institute, Switzerland
- P ≈ 115, 160, 210 MeV
- 3.3 MHz total beam flux
  - ≈ 2–15% $\mu^{\pm}$
  - ≈ 10–98% $e^{\pm}$
  - ≈ 0–80% $\pi^{\pm}$
- Particle ID and trajectory determined event by event
- Momentum distribution determined by calibration measurements



MUSE Setup. Target described in NIM-A, 989 (2020) 162874



MUSE Beam Hodoscope, described in:
NIM A, **986** (2021) 164801
https://doi.org/10.1016/j.nima.2020.164801

Key Aspects of MUSE:

Low beam flux

➔ Large angle, non-magnetic detectors
➔ Oversized scattered particle scintillators for triggering
➔ Covers $\theta \approx 20^\circ - 100^\circ$
➔ $Q^2 \approx 0.002 - 0.08\ GeV^2$

Secondary beam

➔ Tracking of beam particles to target
➔ Uses 3-layer GEM stack
➔ Combined with Straw Tube Tracker to give precise scattering angle
➔ ***Can switch beam charge +/-***

Mixed beam

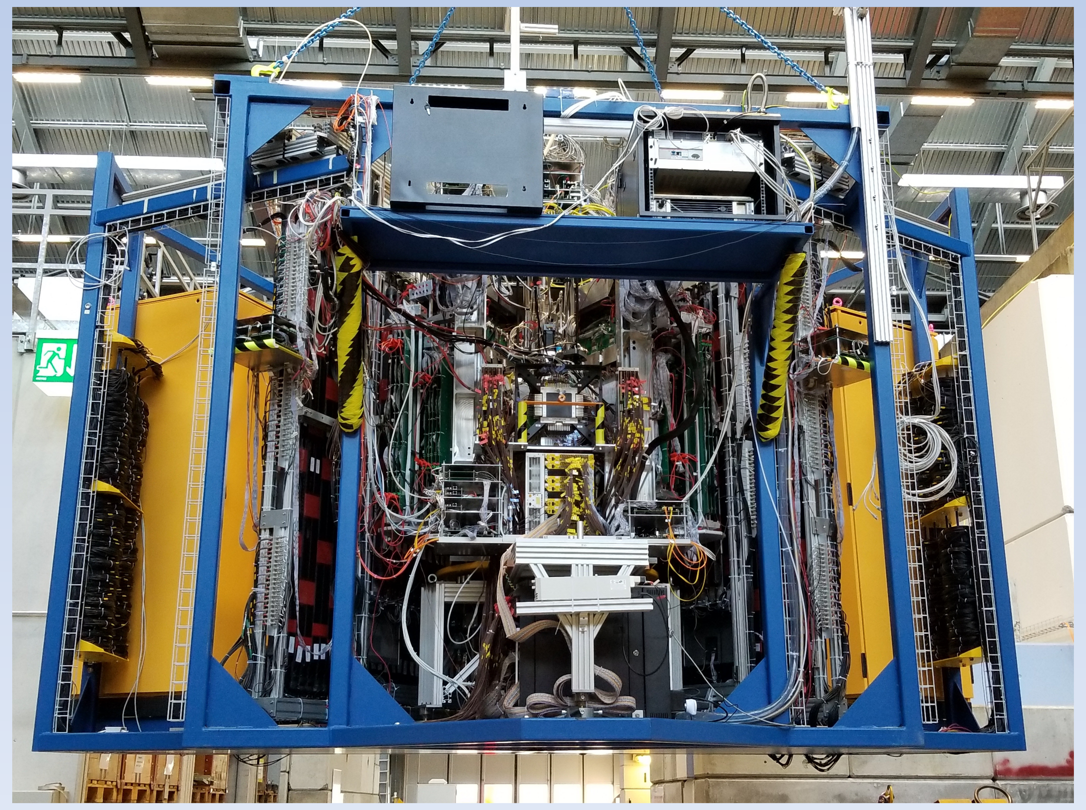
➔ Identification of beam particle in trigger
➔ Uses timing from thin scintillator Beam Hodoscope array, read out by SiPMs
➔ ***Can measure μ and e simultaneously***

MUSE TDR: arXiv:1709.09753 **[physics.ins-det]**

MUSE addresses recent questions about lepton universality in comparing cross sections and form factors measured with μ and e, and will directly measure and compare the two-photon effect in e and μ.

Status of MUSE

- Fully constructed and taking cosmic calibration data
- Move into the PiM1 area on Sept. 27th 2021
- Planned data-taking until December 23rd 2021
- Anticipate two longer beam times in 2022 & 2023 to give 12 months' total beam time
- Direct comparison of e / μ in same experiment
- Direct comparison of both charge states to give two-photon effect measurement in e and μ
- Electromagnetic calorimeter as cross-check of radiative corrections
- Unblinding of radius result 2024/25



Acknowledgements and References

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MUSE TDR: arXiv:1709.09753 [physics.ins-det]
MUSE summary: scipost_202102_00034v2

MUSE SiPM Detector Description: NIM A, **986** (2021) 164801
MUSE Target Description: NIM-A, 989 (2020) 162874