Status of the MUon Scattering Experiment (MUSE) at PSI

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Exotic Hadron Spectroscopy Workshop - 2nd July 2024

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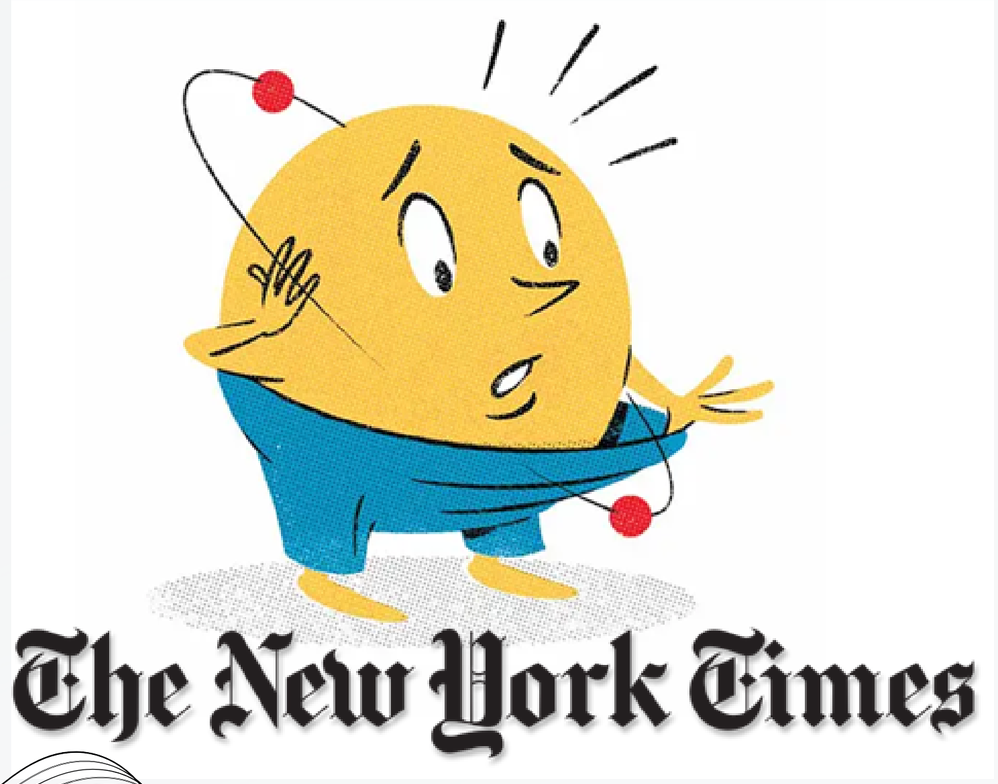
CONTENT

1. Proton Radius Puzzle

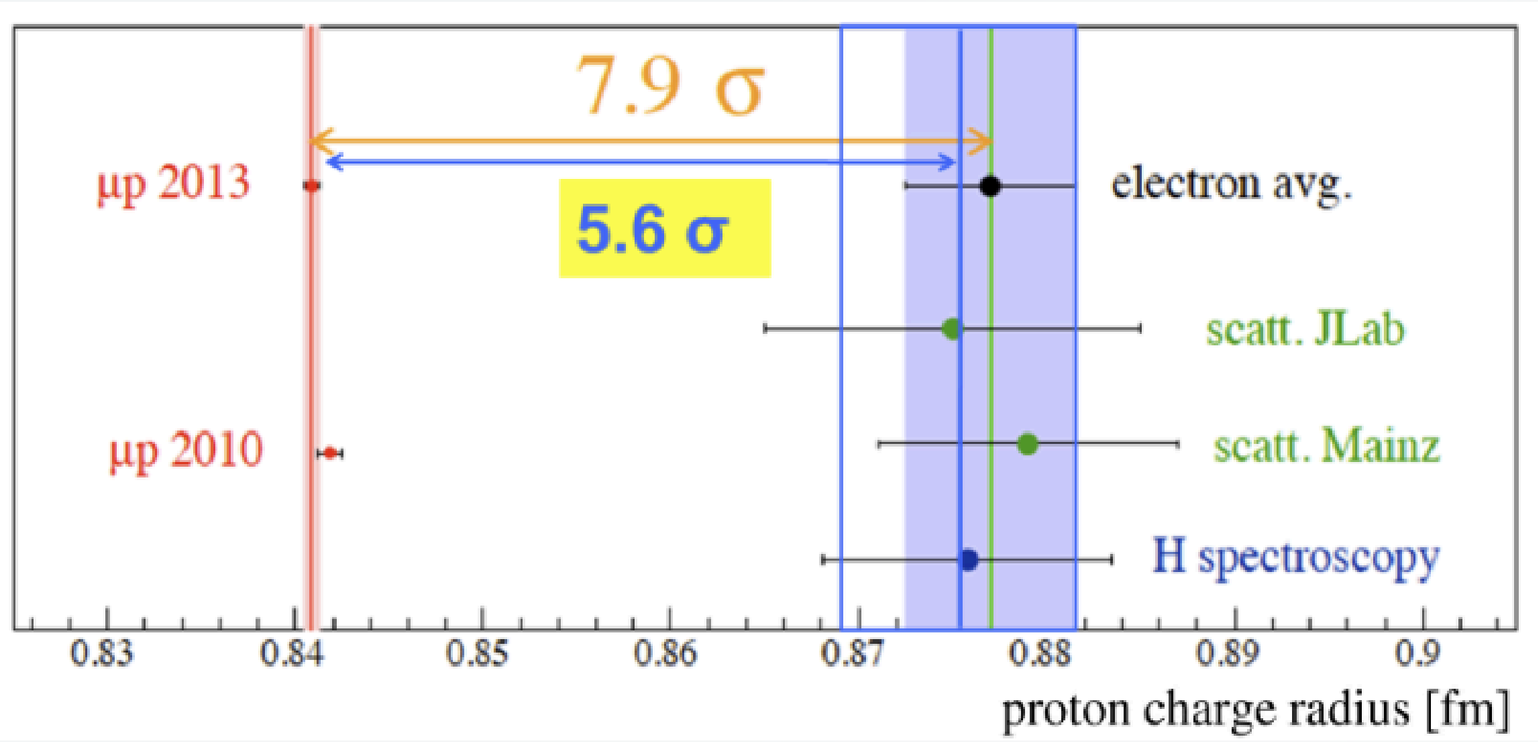
Proton radius puzzle

Discrepancy between radius measured by electrons and muons



Nature 466, 213 (2010)

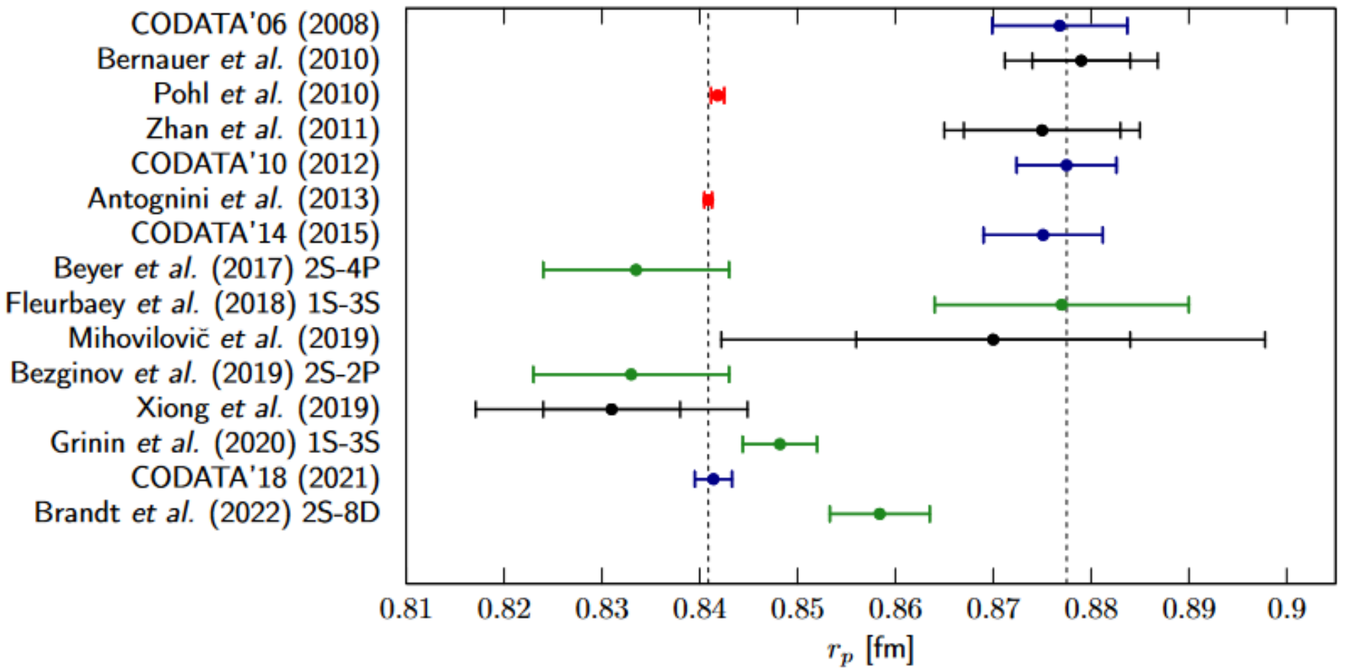
Proton radius puzzle: 2013



- Atomic-hydrogen spectroscopy and electron scattering agree
- First muonic-hydrogen spectroscopy measurement of proton radius published in 2010
- Significant disagreement between muon and electron results
- Muonic-hydrogen confirmation measurement in 2013

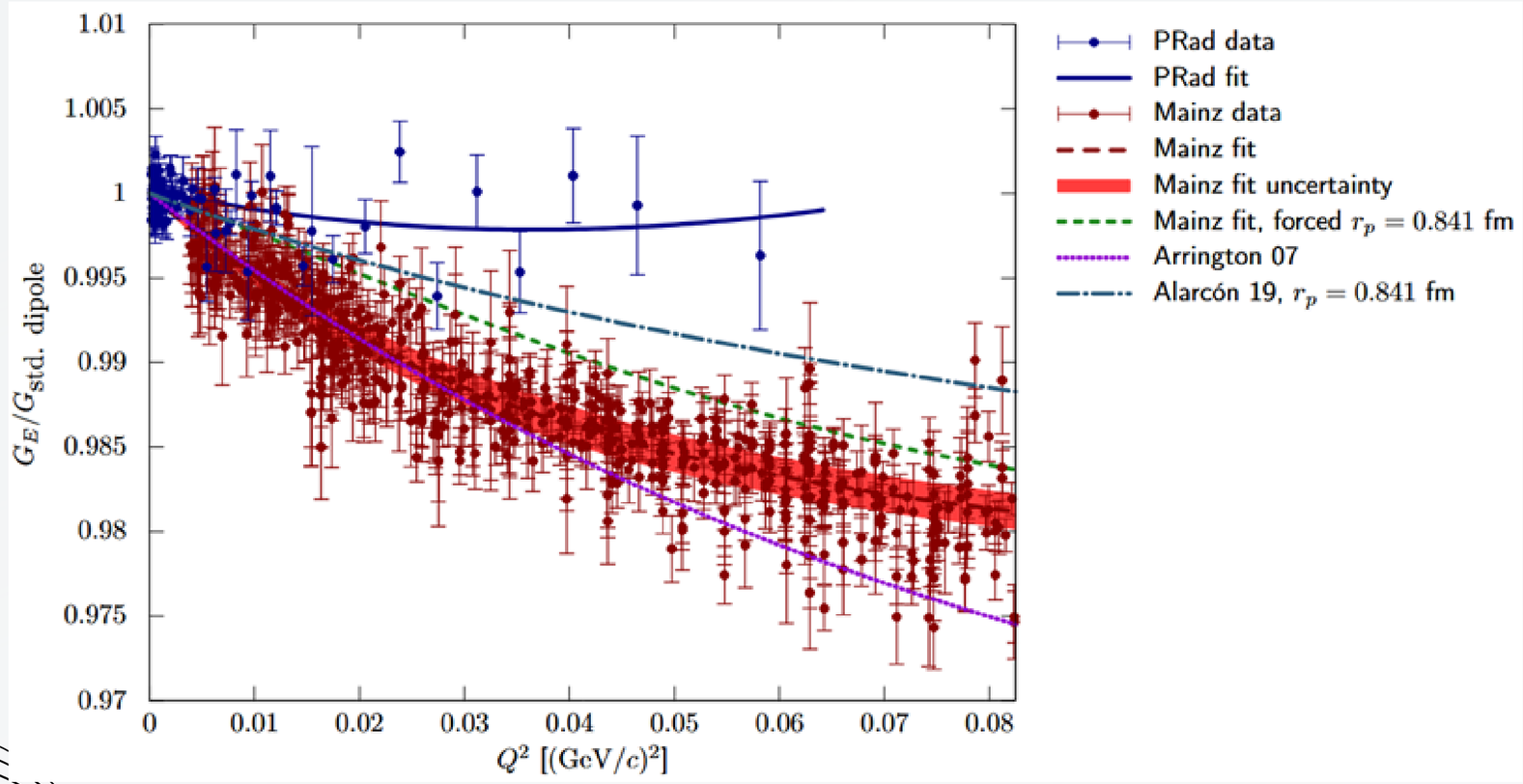
Proton radius puzzle: now

- Inconsistent electron-proton scattering and atomic-hydrogen data
- Muonic-hydrogen value 0.8409 fm
- No adequate muon-proton scattering data



- CODATA
- Electron-proton scattering
- Atomic hydrogen spectroscopy
- Muonic hydrogren spectroscopy

Proton radius puzzle



Two electron-proton scattering experiments.

Why are form factors different?

Which result should be favoured and why?

Independent checks needed:

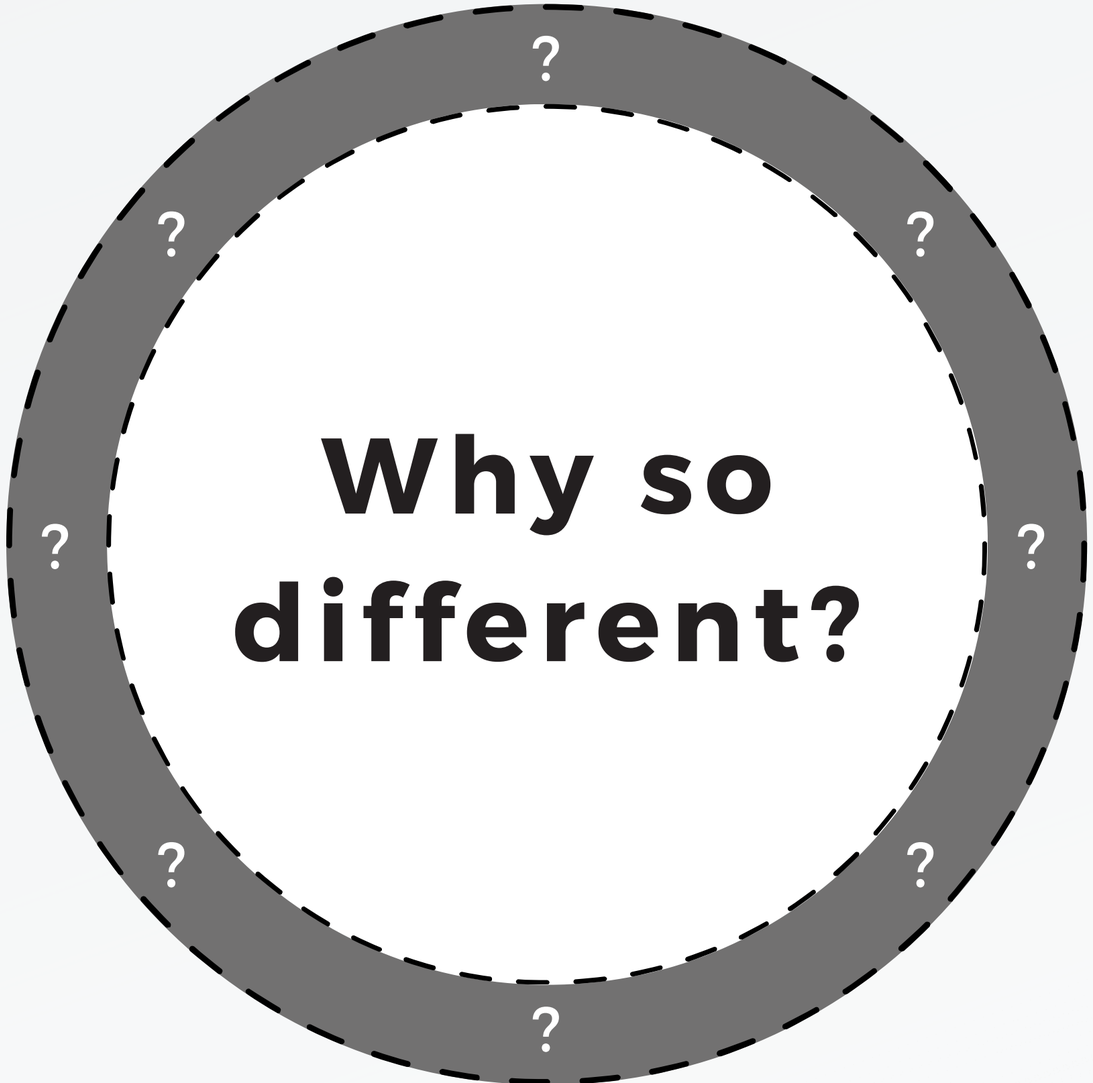
- MUSE
- ISR
- ULQ2

Radiative corrections

Do we know these well enough?

Lepton universality

Are leptons universal or do we go beyond the standard model?



Experiment or analysis

Errors in experiment or analysis?

Scattering Experiments

Data taken

Running

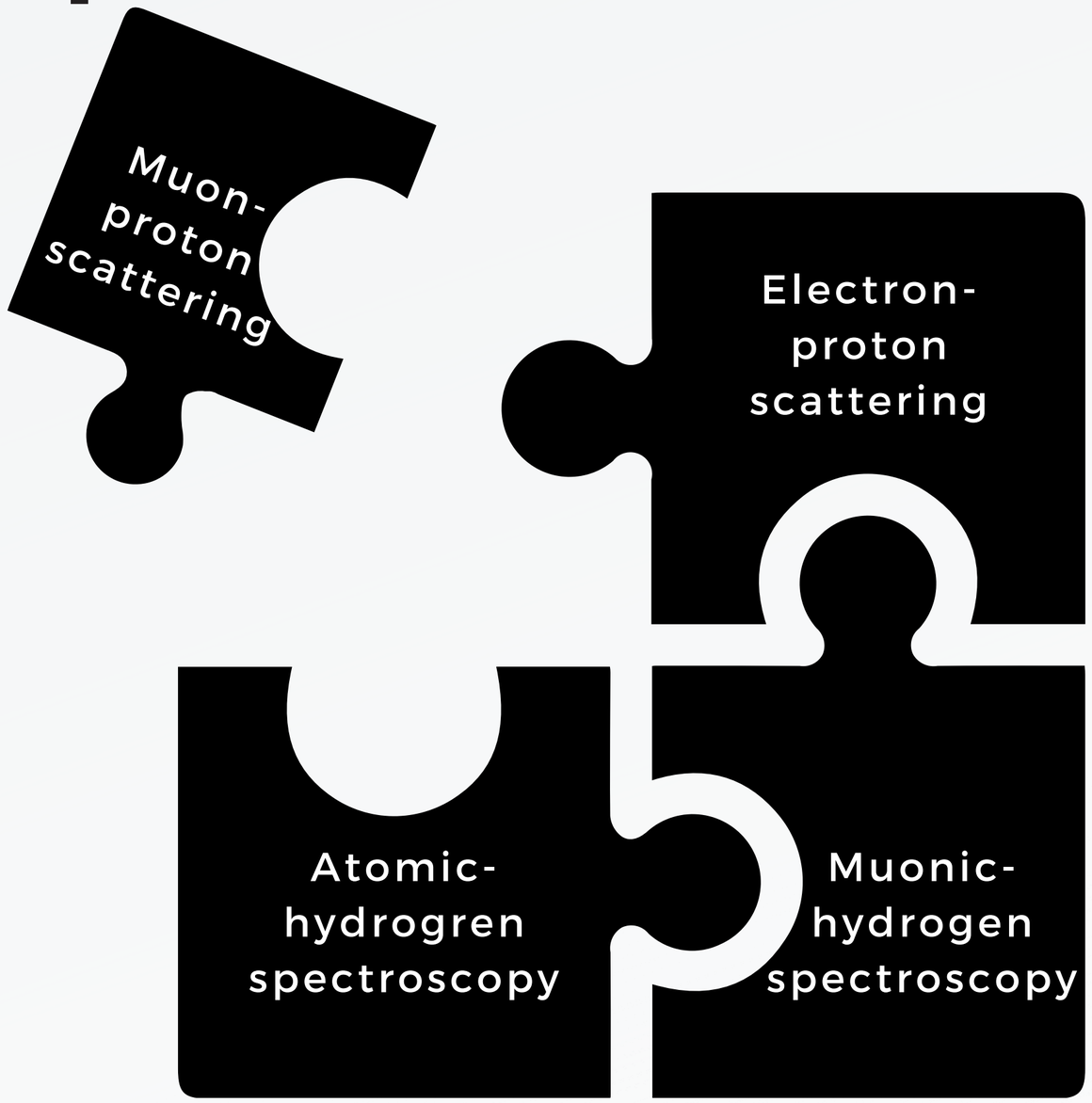
Future

Beam	e^-	e^+	μ^-	μ^+
PRad	✓			
Mainz 2010	✓			
Mainz ISR	✓			
Mainz Jet	✓			
MUSE PSI	✓	✓	✓	✓
ULQ2 ELPH	✓			
AMBER CERN			✓	✓
MAGIX MESA	✓			
PRES MAMI	✓			
PRad-II JLab	✓			

- Many different scattering experiments underway and to come
- MUSE is first muon-scattering experiment
  - AMBER to follow soon
- MUSE is the only simultaneous electron- and muon-scattering experiment

Scattering Experiments

Is muon-proton scattering the missing piece to this puzzle?



2. MUSE Experiment

MUSE Experiment: Possibilities

Simultaneous electron and muon scattering

Lepton universality

Radiative effects much smaller for muons than electrons

Radiative corrections

Both charge polarities gives access to explore

Two-photon exchange

MUSE Experiment: PSI

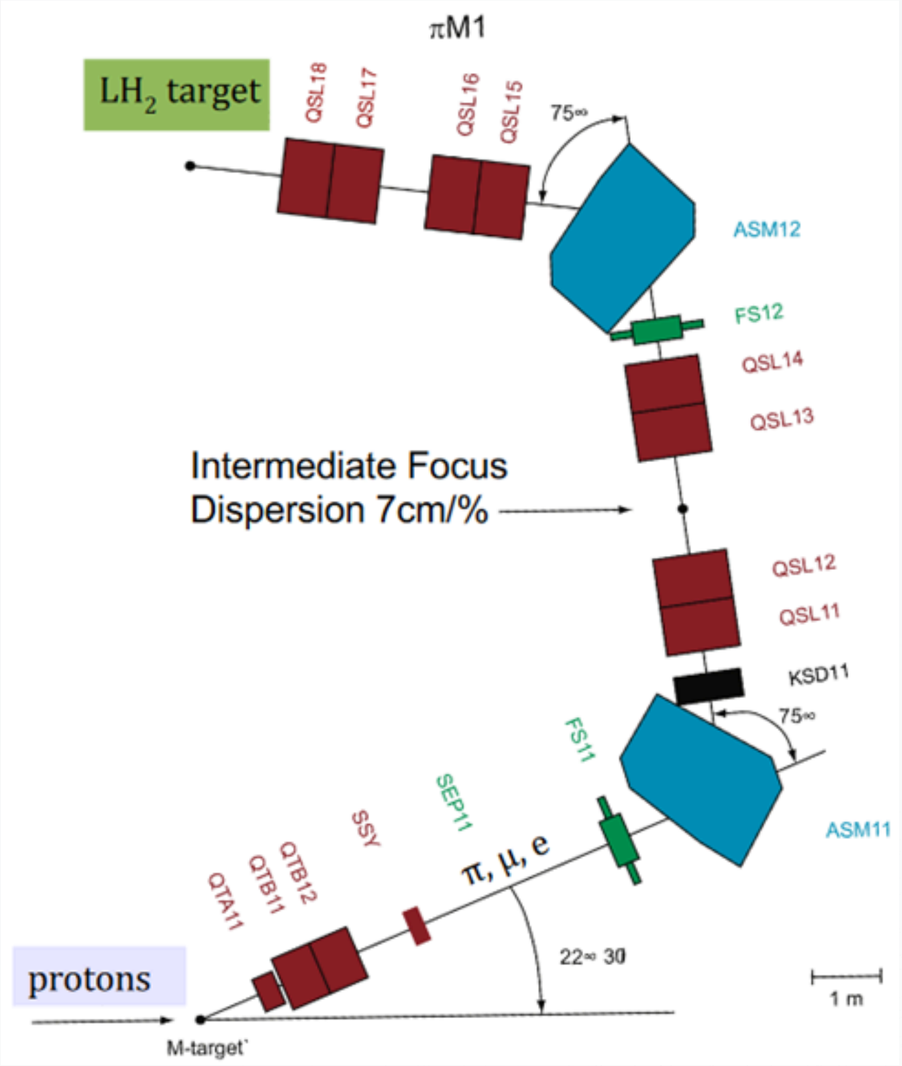
Secondary beams of π,e,μ produced at M-target with 590 MeV protons

The world’s most powerful low-energy, separated π,e,μ beam

MUSE Experiment: πM1 Beamline

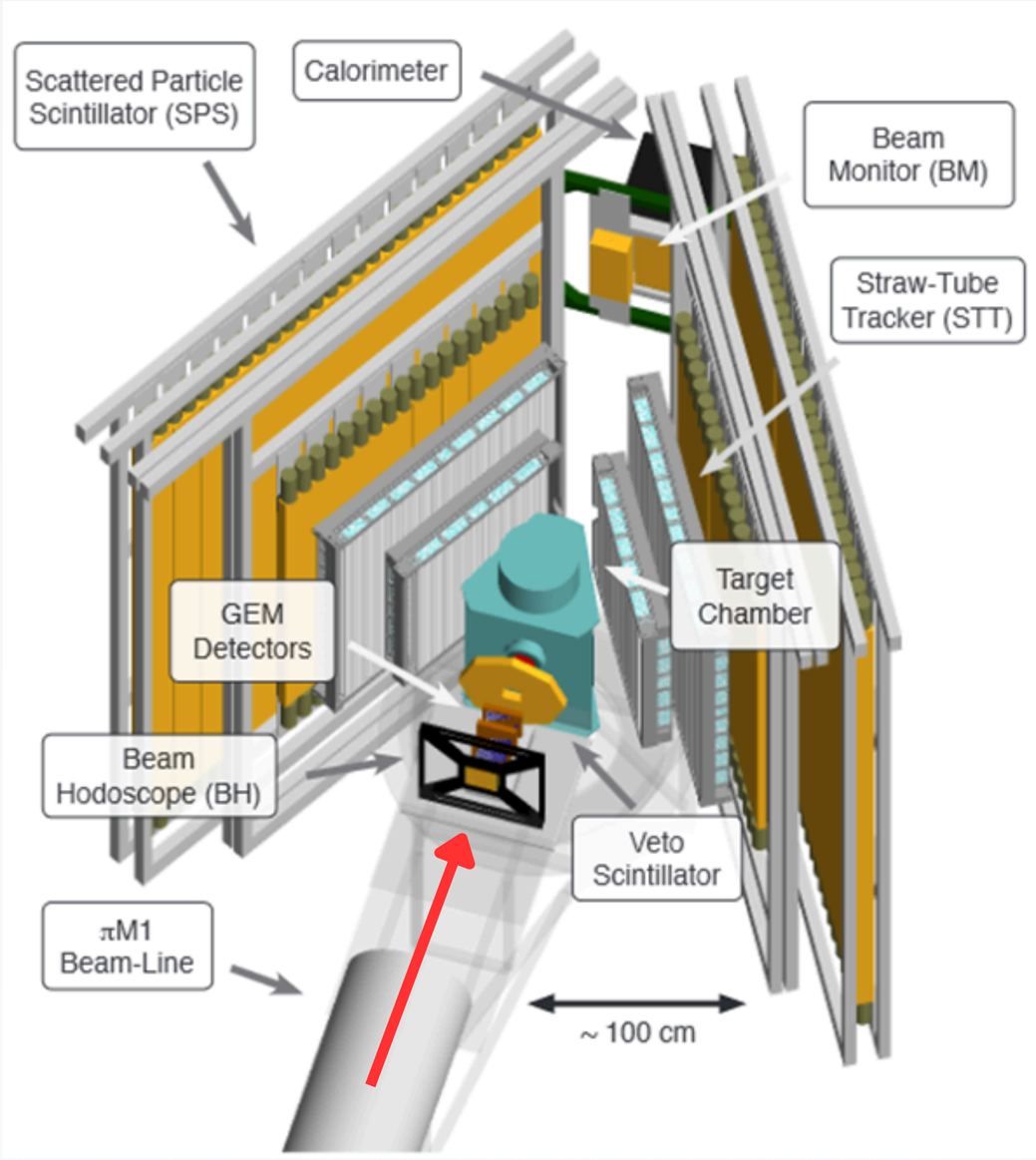
Secondary beam directed to πM1 experimental hall

Beam properties well understood with TRANSPORT, TURTLE, and G4Beamline (E. Cline et al., PRC105, 055201 (2022))



MUSE Experiment: Overview

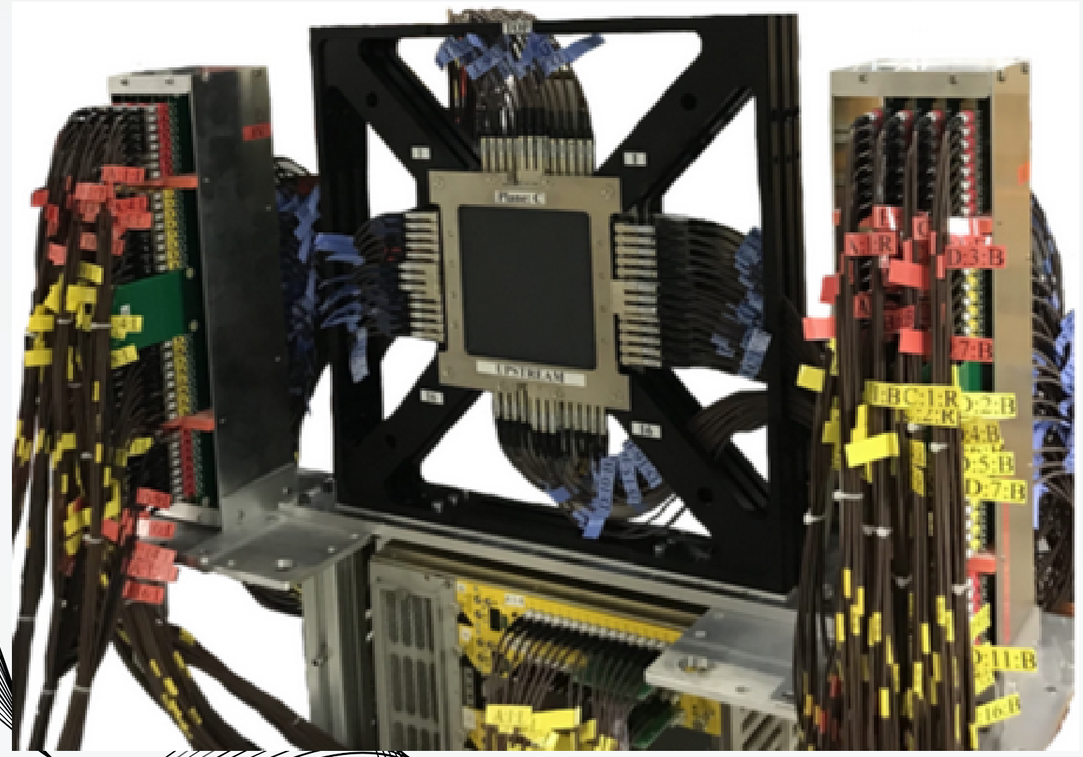
- 3.3 MHz total beam flux
  - ≈ 2-15% μ's
  - ≈ 10-98% e's
  - ≈ 0-80% π's
- p = 115, 160, 210 MeV/c
- $Q^2 \approx 0.002 - 0.07$ GeV²
- θ ≈ 20° - 100°
- 180° coverage in ∅



MUSE Experiment: Beamline Detectors

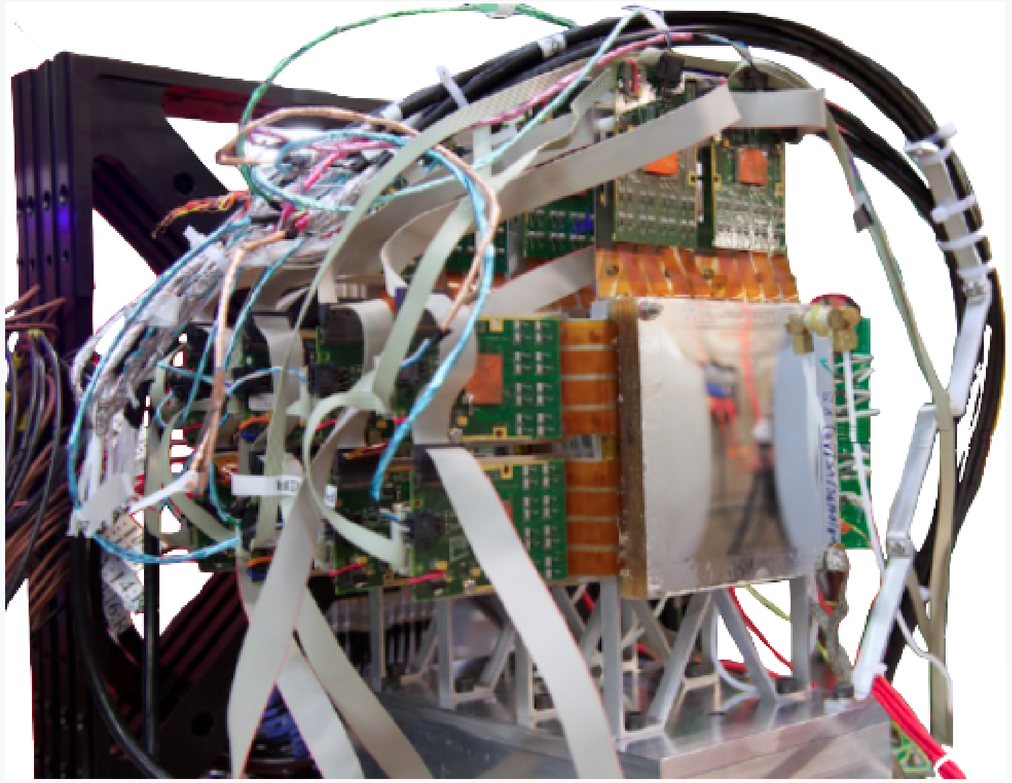
Beam Hodoscope

Timing and particle ID



GEMs

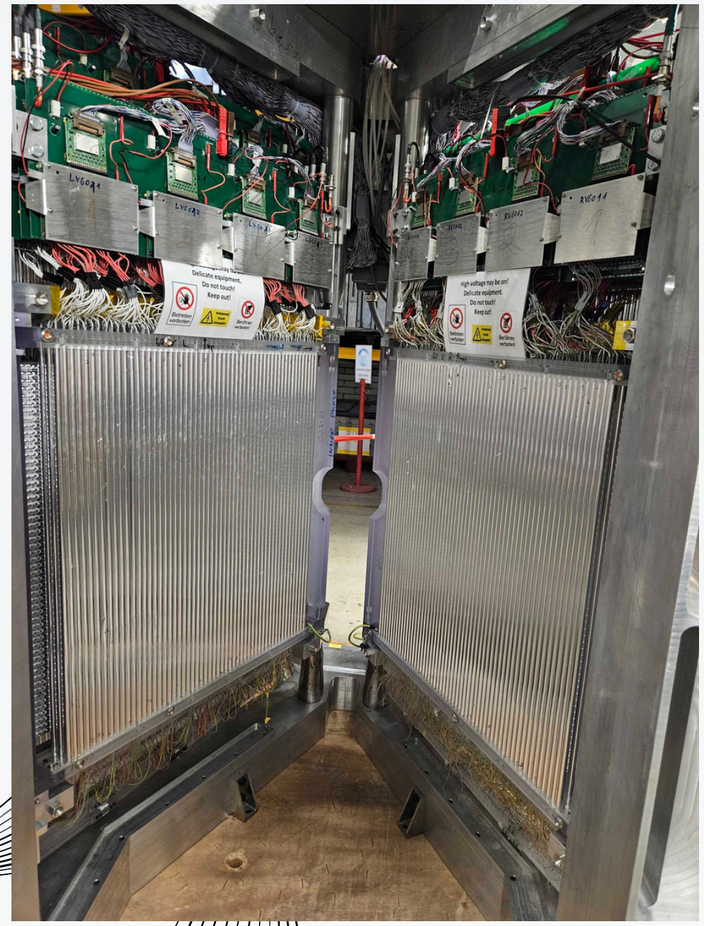
Tracking of incident particle



MUSE Experiment: Scattering Detectors

Straw Tube Tracker

Tracking of scattered particle



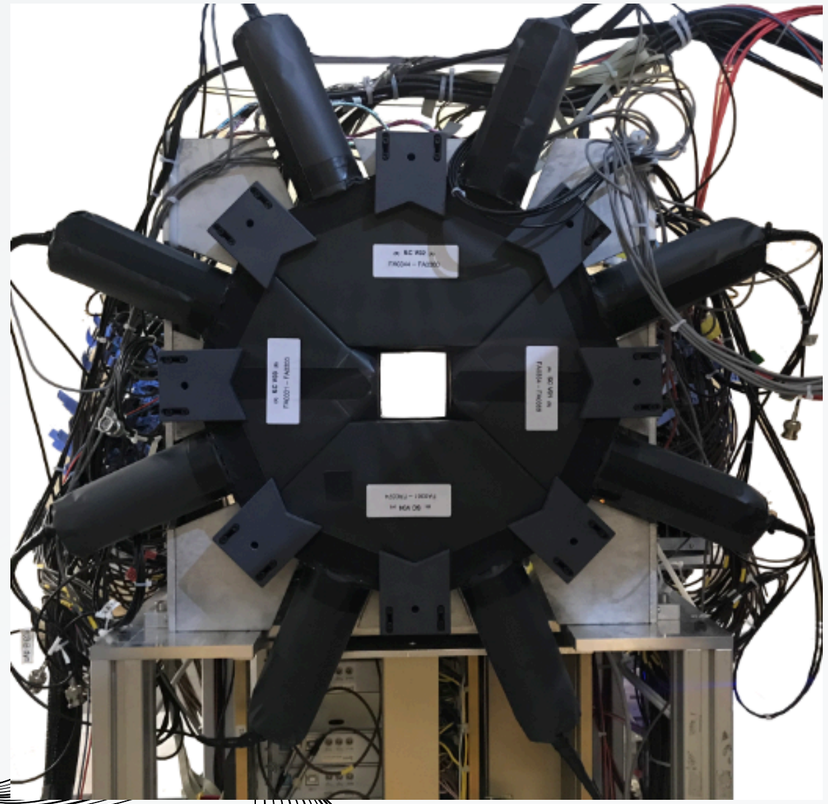
Scattered Particle Scintillator

Scatter trigger and reaction ID

MUSE Experiment: VETO Detectors

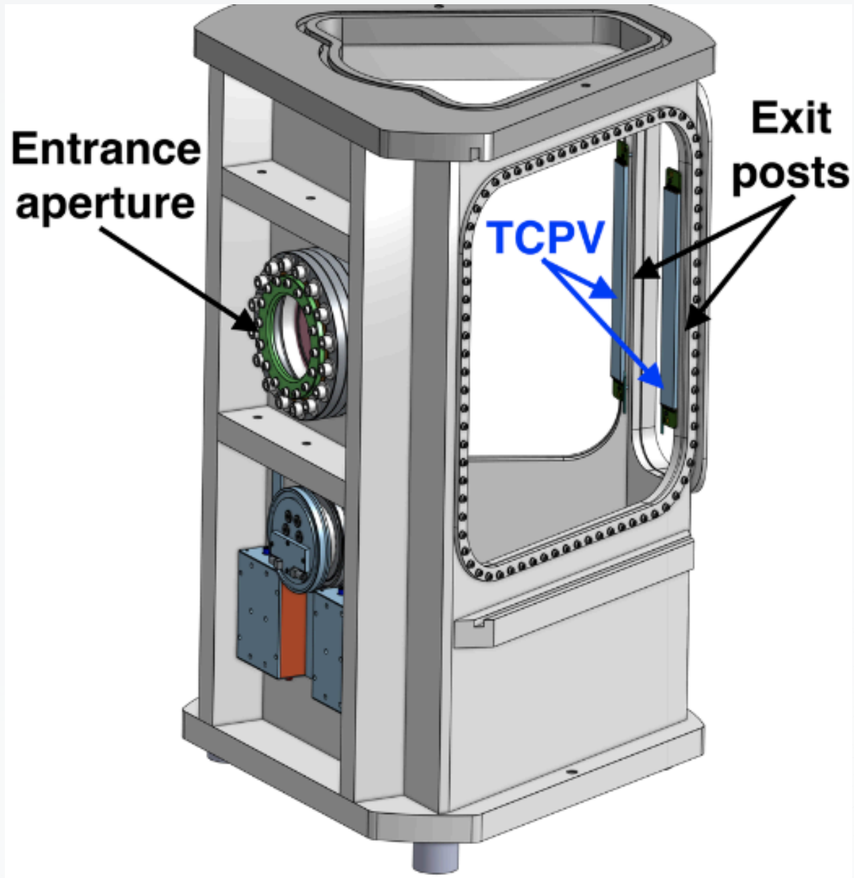
Beamline VETO

Remove decays



Target Chamber Post VETOs

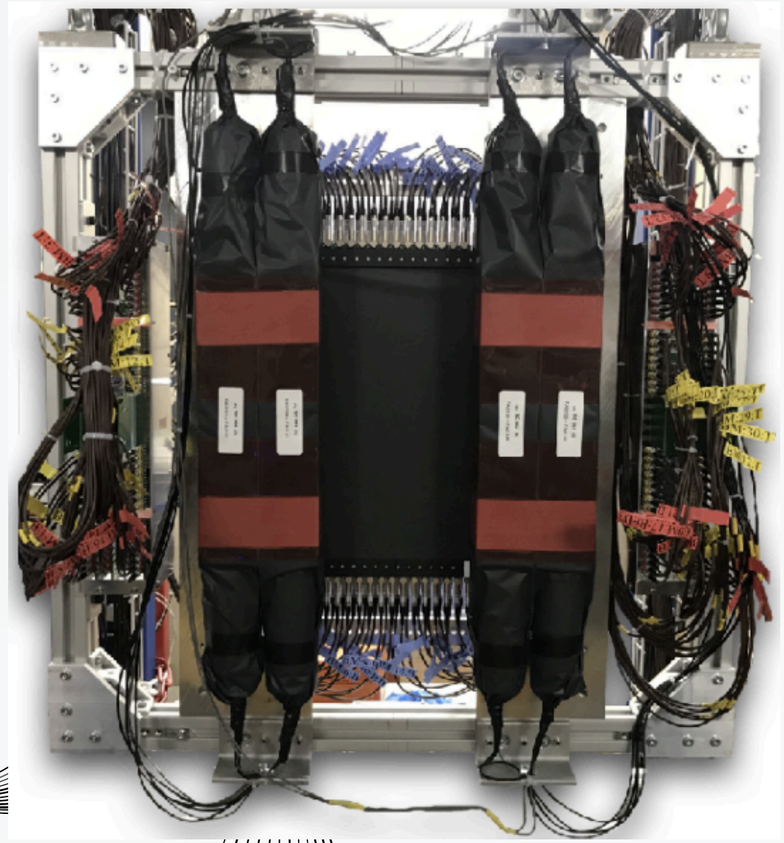
Remove scatters from exit posts



MUSE Experiment: VETO Detectors

Beam Monitor

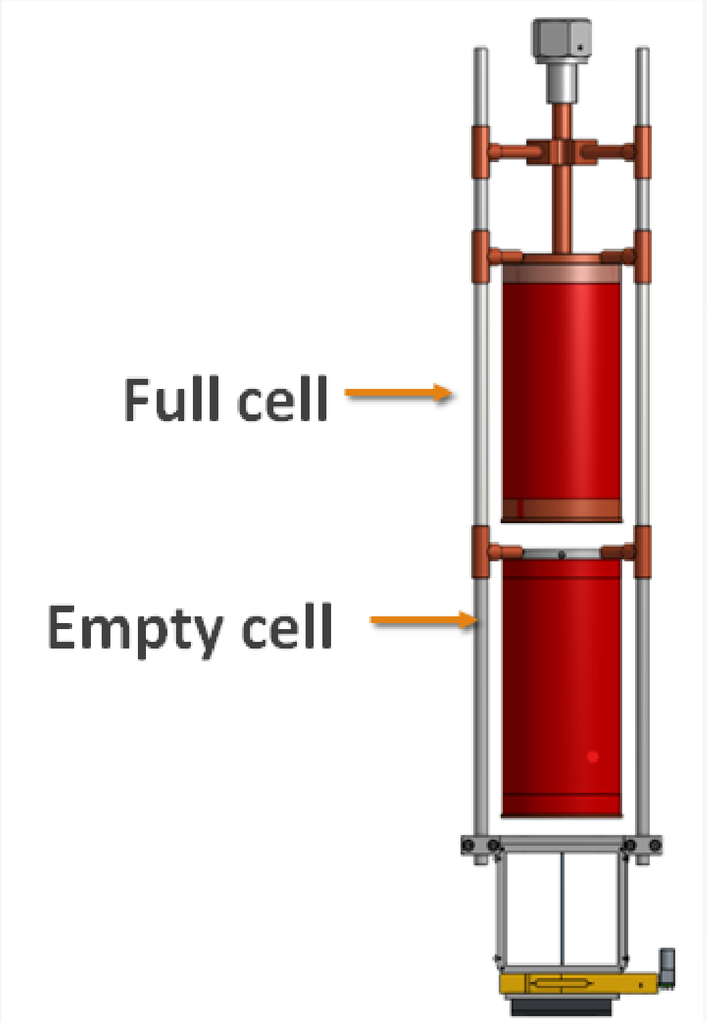
Remove Moller and Bhabha scattering



Calorimeter

Remove hard initial-state radiation events

MUSE Experiment: Target



Full cell
For proton scattering

Empty cell
For background subtraction

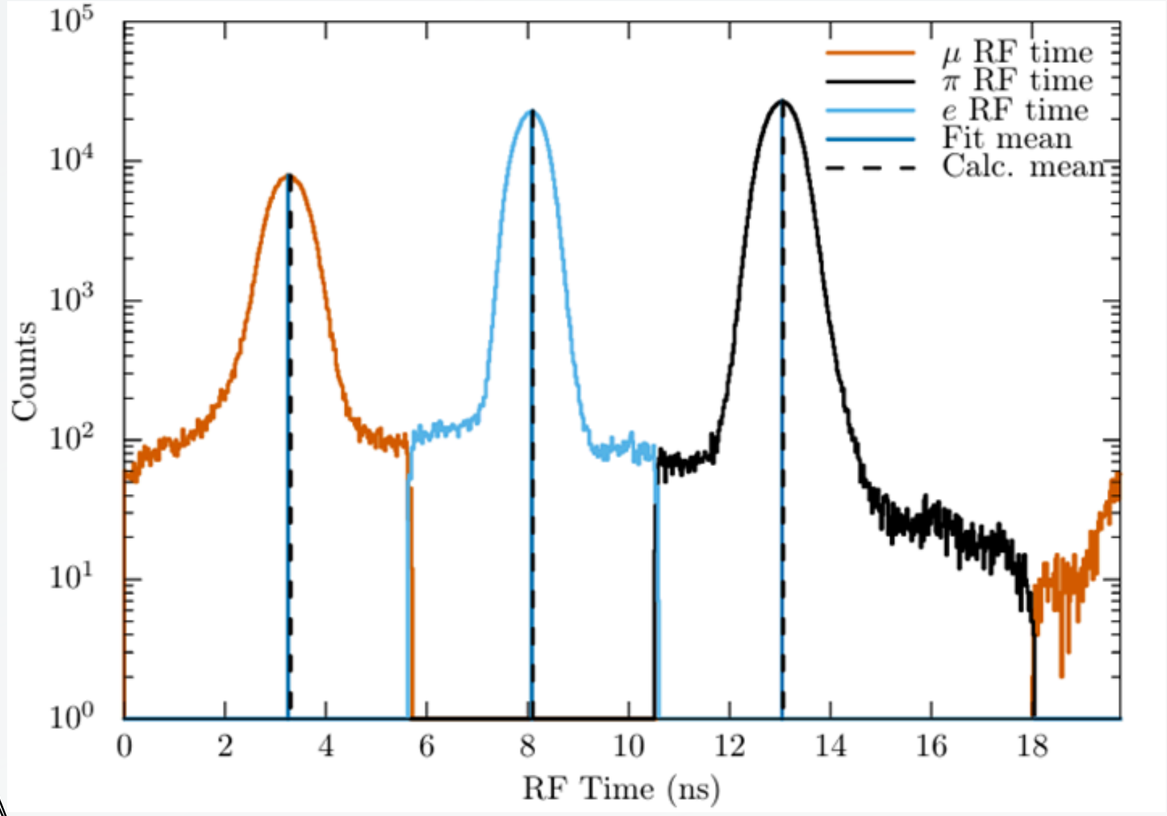
Rod Target
For alignment and resolution

P. Roy et al., A Liquid Hydrogen Target for the MUSE Experiment at PSI, NIM A, 2019, https://doi.org/10.1016/j.nima.2019.162874

3. MUSE Analysis

MUSE Analysis: Beam particle ID

RF of all planes, p = 160 MeV/c

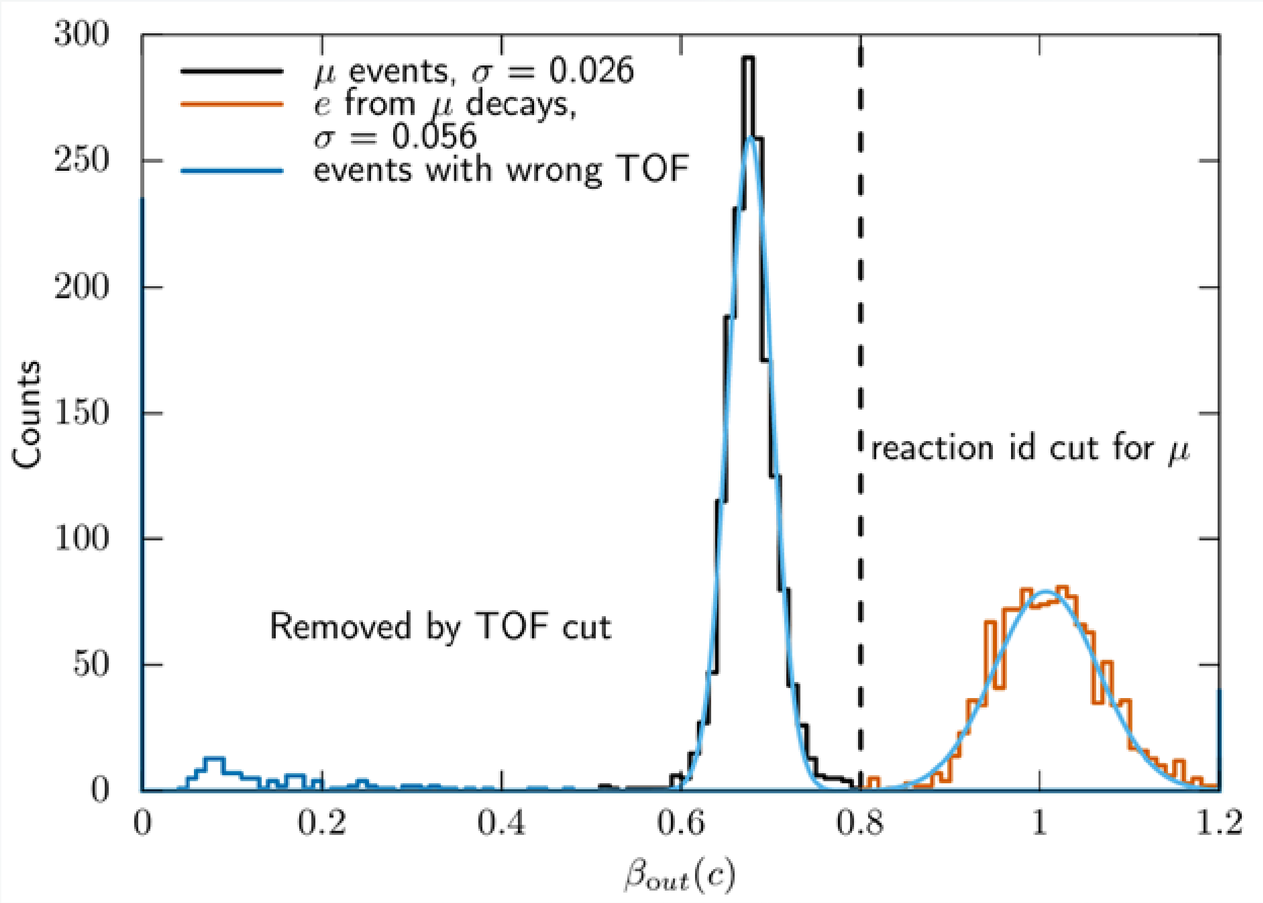


- Proton beam pulses every 19.75 ns
- Time from accelerator and BH used to give RF time
- π,e,μ beam particles separated by RF

MUSE Analysis: Reaction ID

- Muons decay after identification in beamline detectors
- Time of Flight between BH and SPS used for reaction identification

Outgoing beta of particles identified as muons, p = +115 MeV/c



MUSE Analysis: Vertex Reconstruction

Incident tracking (GEMs)

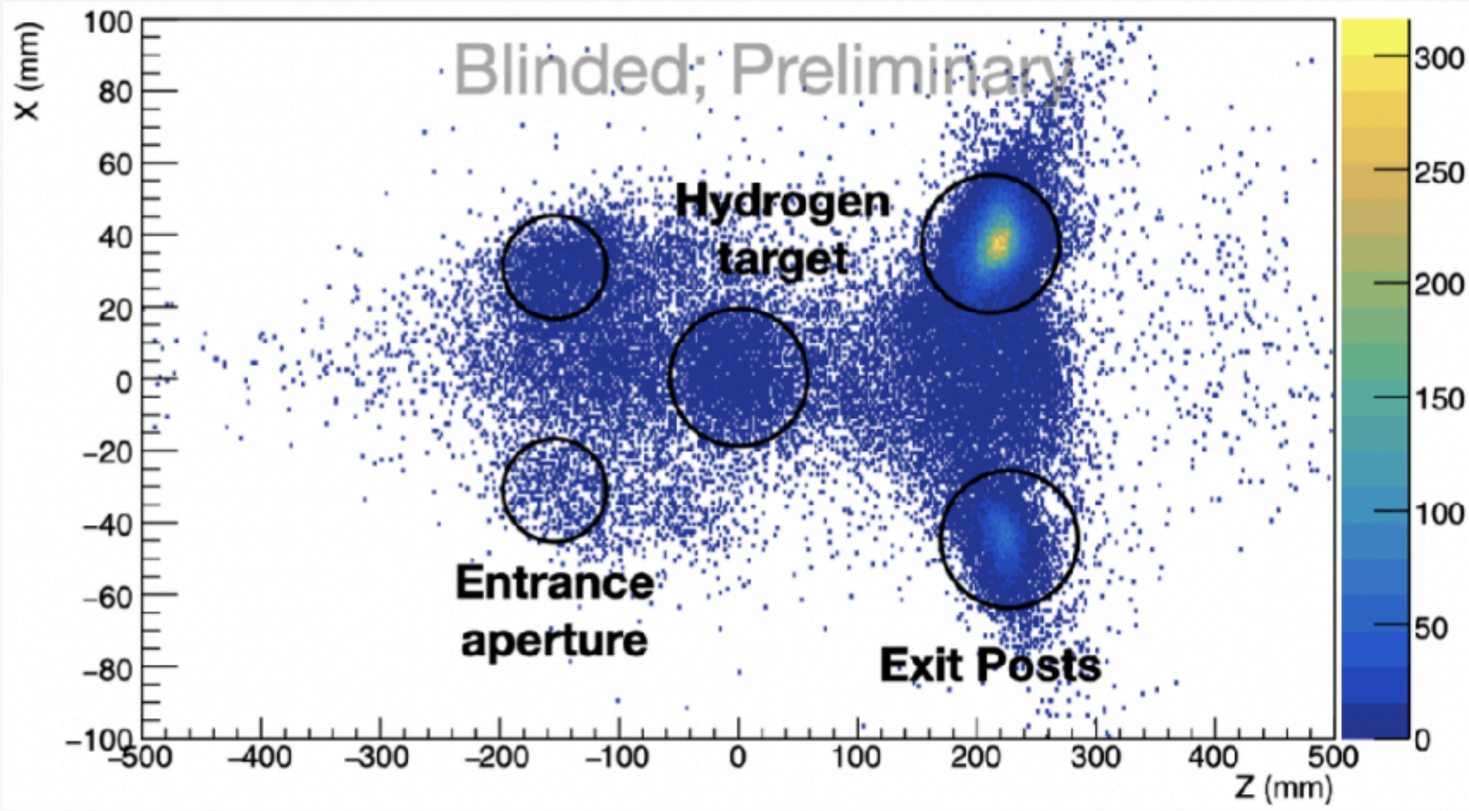
+

scattered particle tracking (STT)

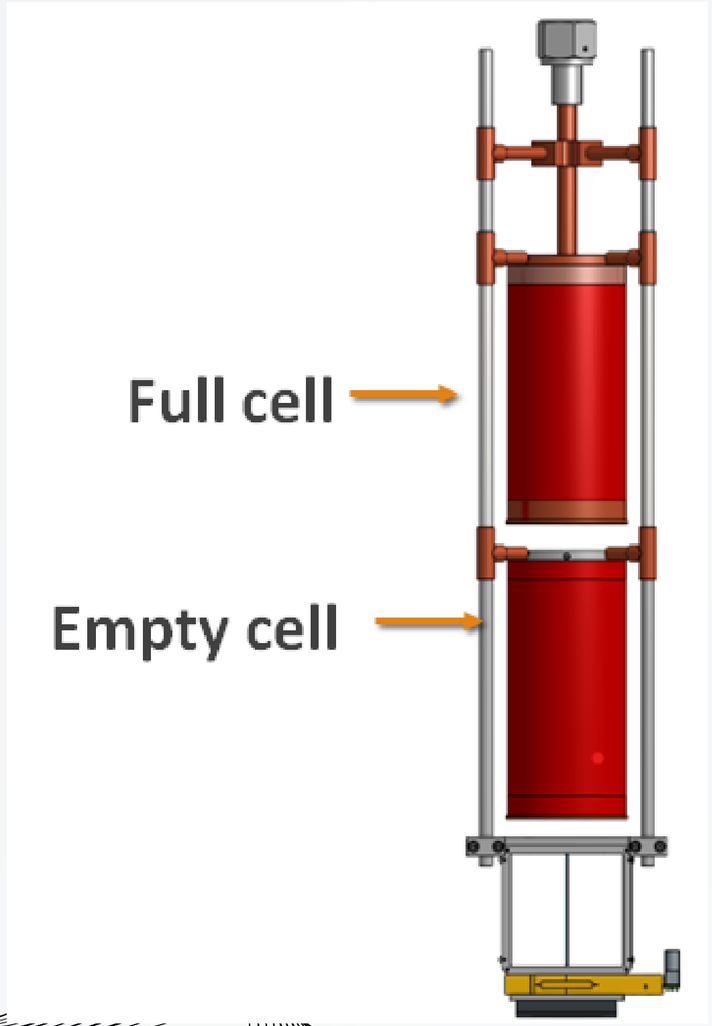
↓

Vertex →

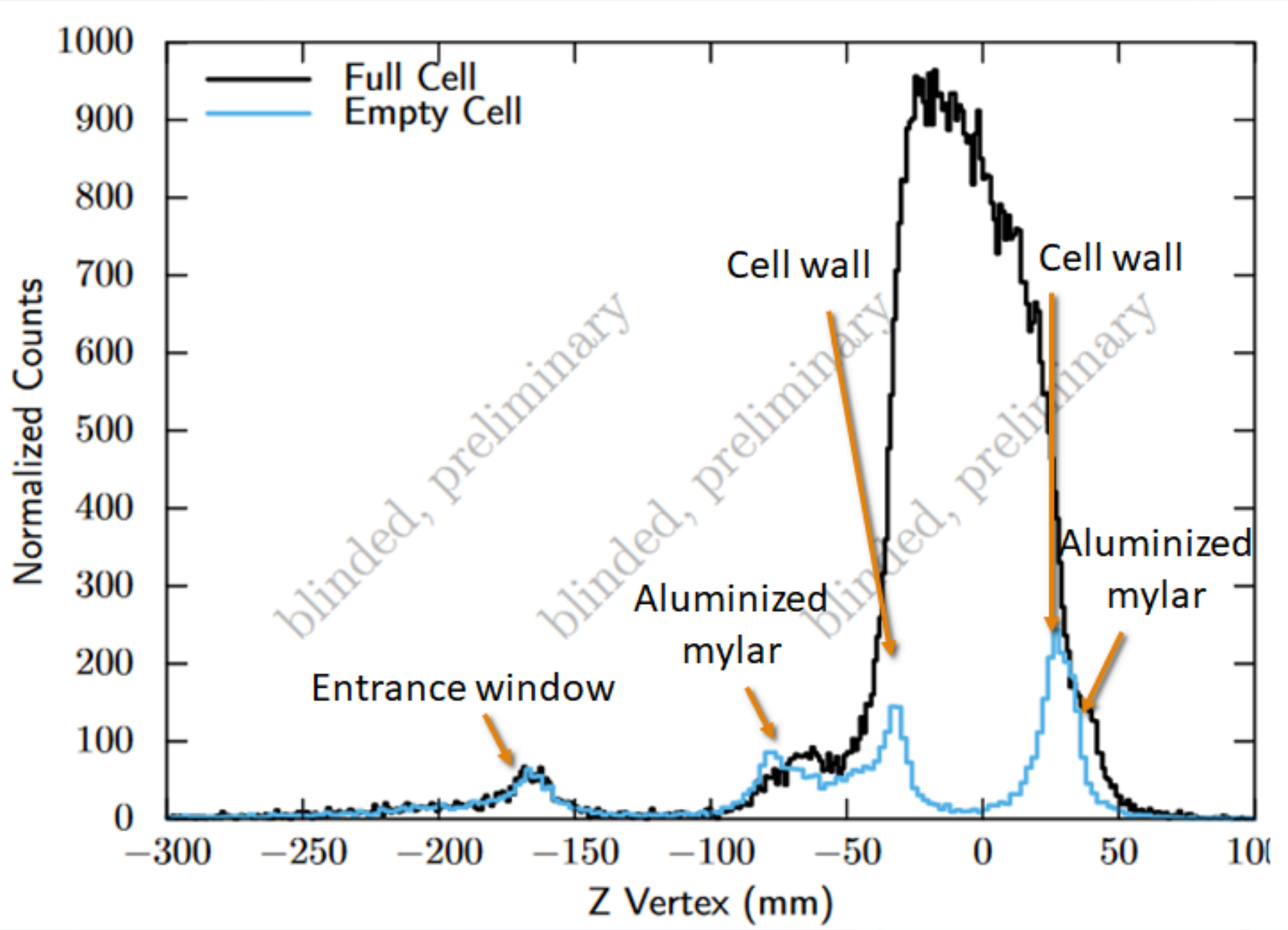
Vertex reconstruction for -115 MeV/c



MUSE Analysis: Vertex Reconstruction



Luminosity-normalised full and empty cells for 210 MeV/c π+ beam



P. Roy et al., A Liquid Hydrogen Target for the MUSE Experiment at PSI, NIM A, 2019, https://doi.org/10.1016/j.nima.2019.162874

4. MUSE Outlook

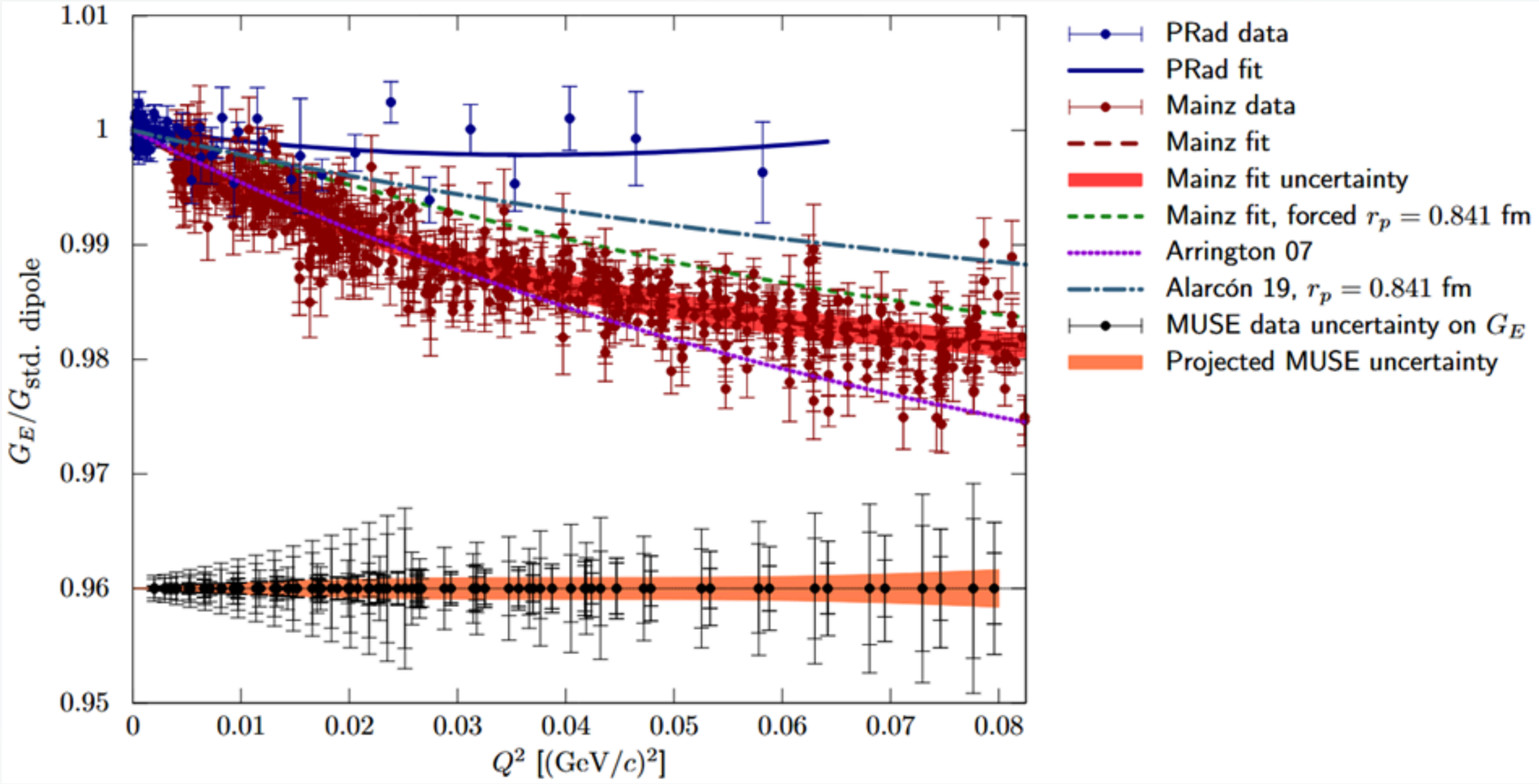
MUSE Outlook: Anticipated Results

MUSE could help understand the discrepancies between Mainz and the PRad data

Sub-percent uncertainties

PRad-II will provide an improvement on PRad by a factor of 4

Anticipated form factor uncertainty



E. Cline, et al., SciPost Phys. Proc. 5, 023(2021)

MUSE Outlook: Current Status

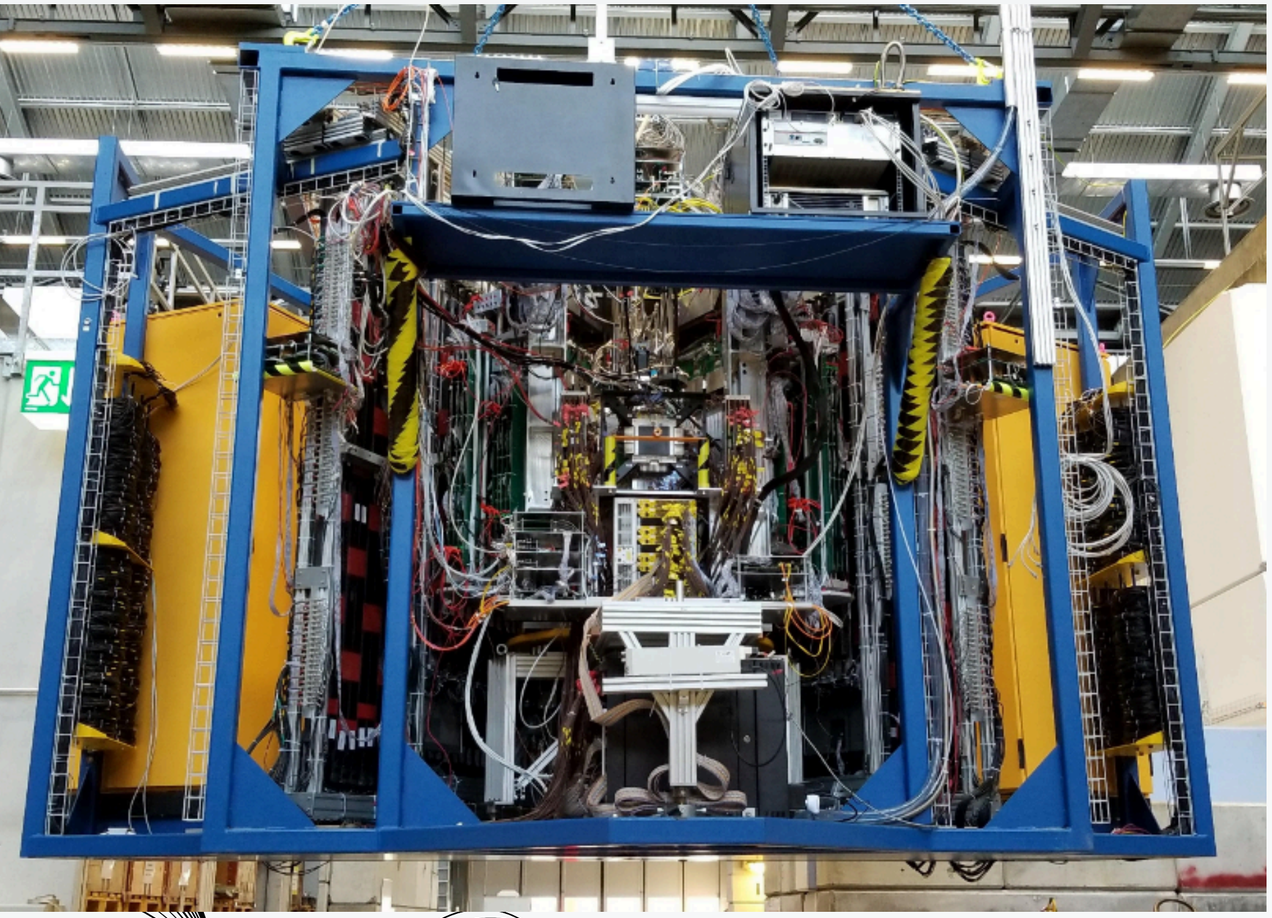
MUSE taking ~5 months data this year
Anticipate similar in 2025

Preliminary, blinded cross-sections are being extracted

Discussions about path to unblinding underway

5. Summary

Summary



MUSE will be the first ever muon-proton scattering measurement looking to address the proton radius puzzle

Anticipated results with sub-percent uncertainties

Data taking on track to achieve statistical goals