An Overview of the MUSE Experiment

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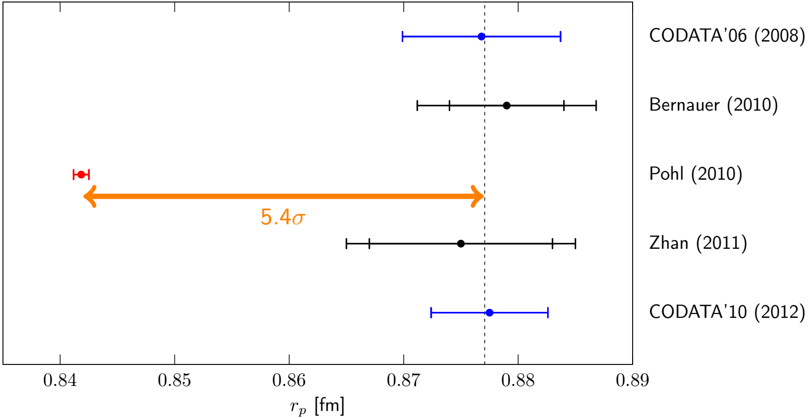
March 18, 2025

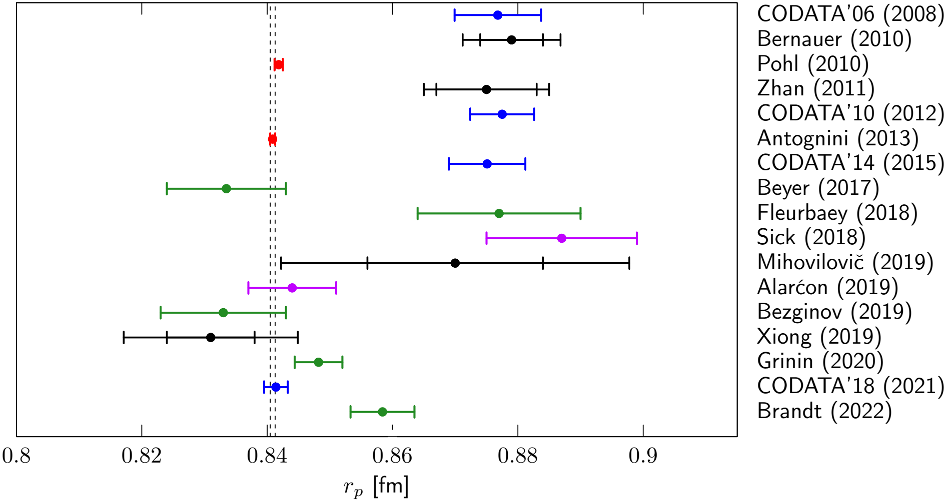
This material is based upon work supported by the National Science Foundation under NSF Grant PHY-2412703. The MUSE experiment is supported by the Department of Energy, National Science Foundation, PSI and the US-Israel Binational Science Foundation.

The Proton Radius Puzzle

- 2010: CREMA collaboration (Pohl et al.) measure Lamb Shift in muonic hydrogen
  - Results: $r_p = 0.8418 \pm 0.0007$ fm
- Average electron scattering measurement: $\sim 0.8770 \pm 0.0127$ fm

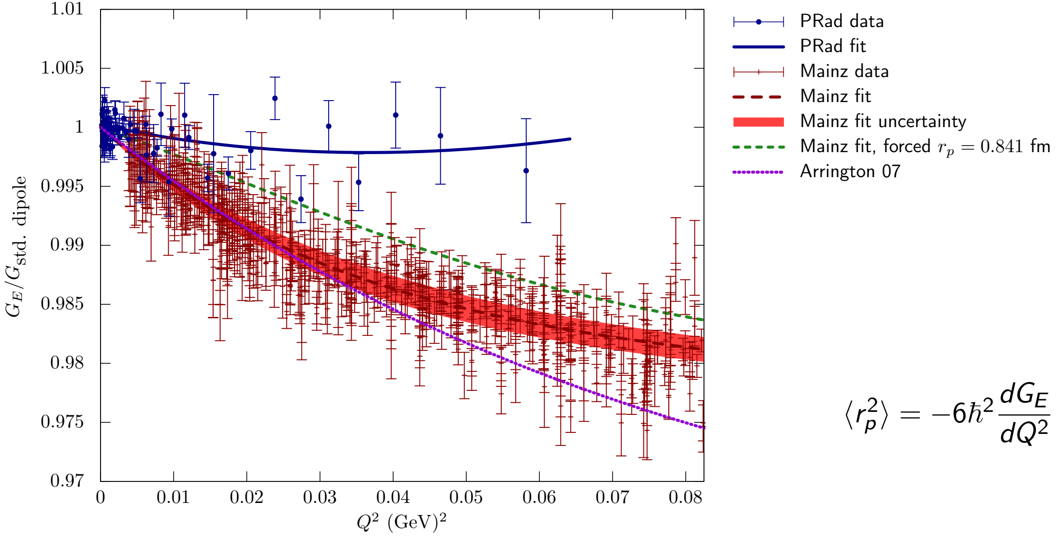


The Proton Radius Puzzle Today



Electron Scattering, Electron Spectroscopy, Muon Spectroscopy, CODATA, Global Refits

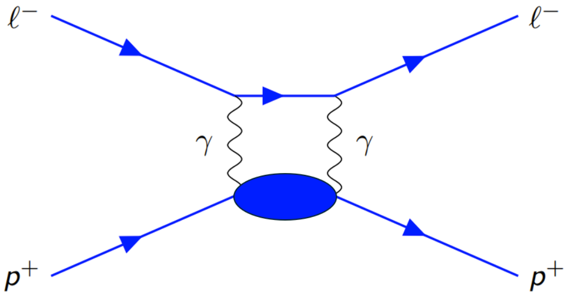
Form Factor Discrepancies



$$\langle r_p^2 \rangle = -6\hbar^2 \left.\frac{dG_E}{dQ^2}\right|_{Q^2=0}$$

Possible Explanations

- Differences between spectroscopy and scattering?
- Lepton Universality?
- Radiative Corrections?
  - NLO contribution of importance: Two Photon Exchange (TPE)
  - Size of contribution: $R = 1 - 2\delta_{2\gamma} = \sigma(\ell^+ p)/\sigma(\ell^- p)$

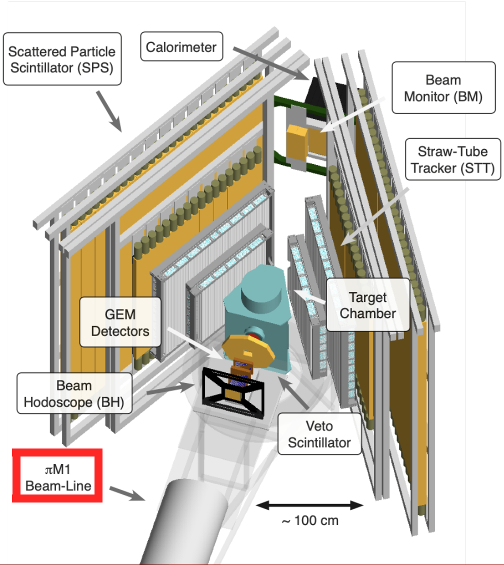


- The MUon Scattering Experiment (MUSE) was directly inspired by the proton radius puzzle
- Goals:
  - Precision measurement of r_p via ep and μp scattering
  - Direct test of lepton universality
  - Precision study of TPE in ep and μp scattering

The Paul Scherrer Institute (PSI)

- Most intense proton cyclotron in the world
- MUSE: πM1 beamline!

- θ acceptance: $20 - 100°$
- $\pi M1$ Beam Line:
    - p $\in 115, 160, 210$ MeV/c
    - Mixed beam of e, μ, π
    - Both charges of particles!
- Q^2 range for
    - e: $0.0016 - 0.0820$ GeV^2
    - μ: $0.0016 - 0.0799$ GeV^2



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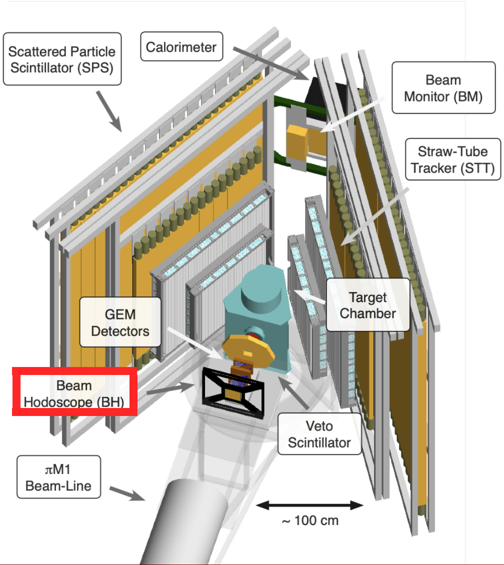

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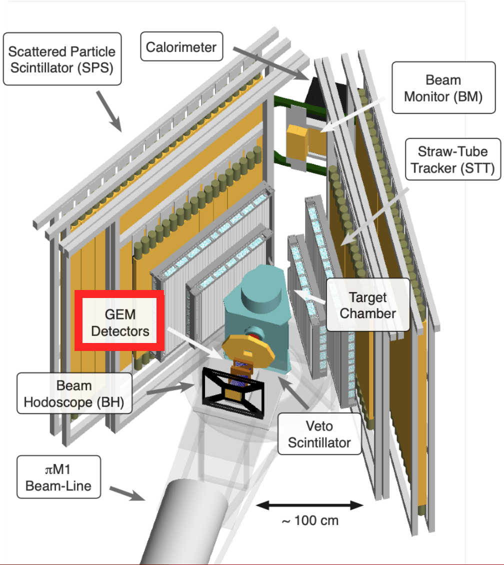

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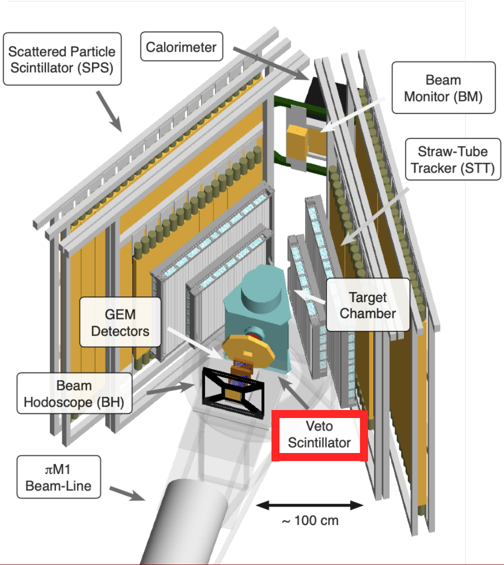

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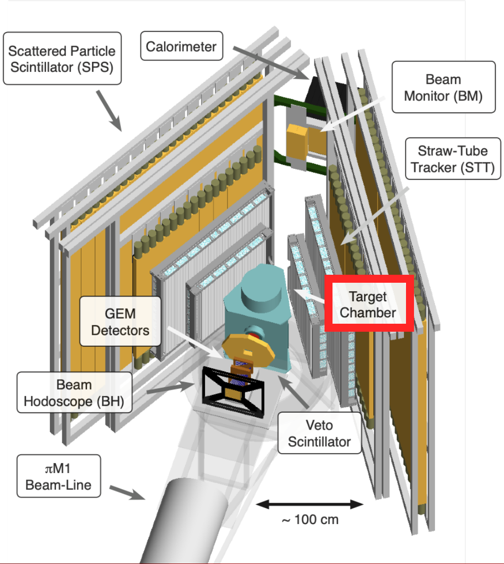

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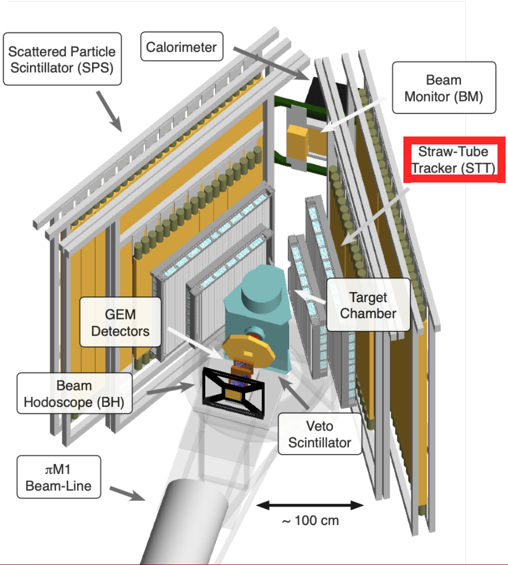

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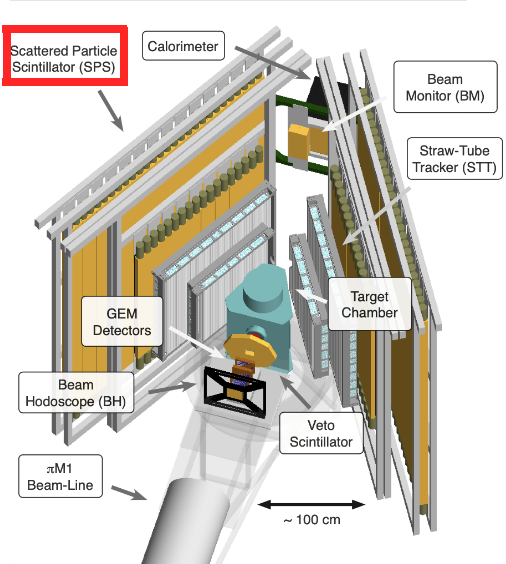

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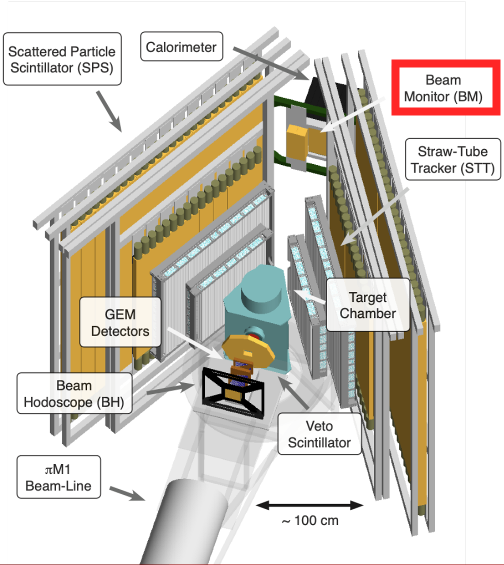

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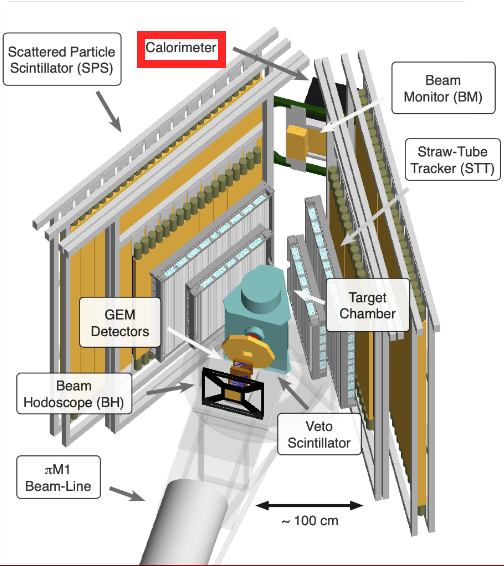
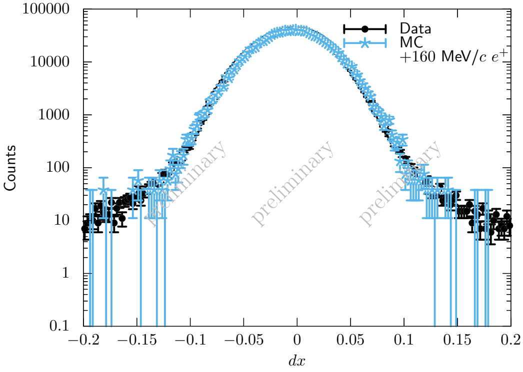
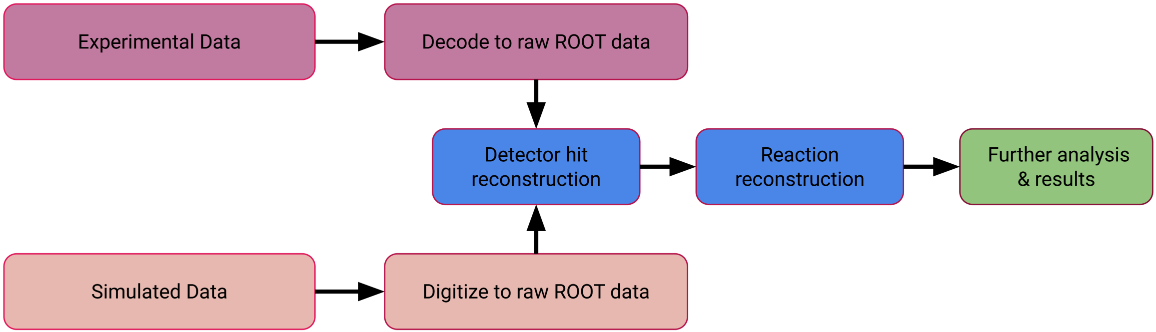


- MUSE uses a detailed Monte Carlo simulation in Geant4
- Recent updates:
    - Including radiative effects
    - Rare event simulation
    - Realistic beam (mixed secondary beam: nontrivial)

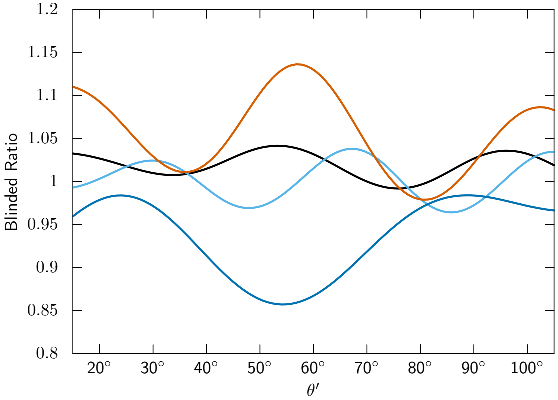


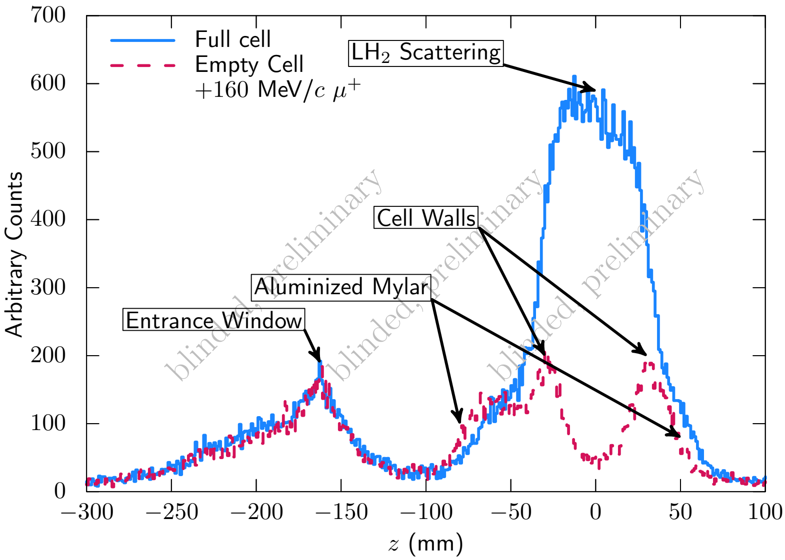
Analysis Chain: Cooker



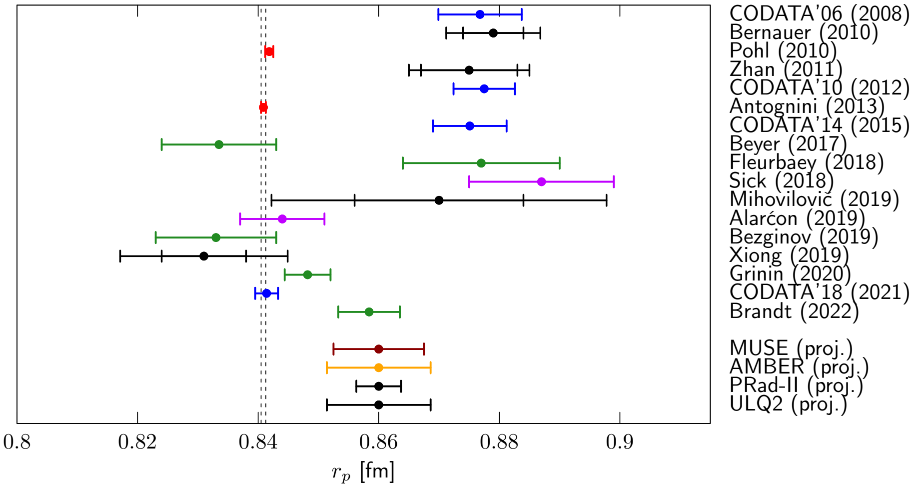
Blinding

- Reduce bias: cryptographically blind at tracking stage
- Stochastic suppression of events
  - $p_{\text{sup}} = \frac{0.2}{3}\left(A_i + 0.3\cos\left(B_i\theta'\right)\right)\left(3 - \theta'\right),\ A_i \in [0.25, 1],\ B_i \in [3, 10]$
- Publication: arXiv:2310.11469, responding to PRC referee comments



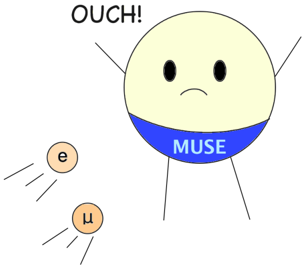

Full cell
Empty Cell
+160 MeV/c μ^+
LH$_2$ Scattering
Cell Walls
Aluminized Mylar
Entrance Window
blinded, preliminary
Arbitrary Counts
z (mm)
0
100
200
300
400
500
600
700
−300
−250
−200
−150
−100
−50
0
50
100

Proton Radius Puzzle Outlook



Summary/What's Next?

- Analysis of MUSE is progressing nicely
- Awarded 5 months of beamtime starting June 2025
- MUSE will end data taking in 2025!



Blinding: More Detail

- Maximum blinding: 20°, minimum: 100°
- Blind based on PID, momentum, polarity, data/sim: 36 blinding parameters!