Studying the Proton Radius Puzzle with μp Elastic Scattering

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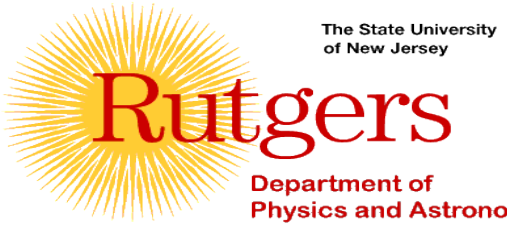

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~50 **MU**on proton **S**cattering **E**xperiment (MUSE) collaborators from:

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FF's and the Proton Radius

Lowest order *ep* scattering cross section:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \frac{1}{\epsilon\,(1+\tau)} \left[\epsilon G_E^2(Q^2) + \tau G_M^2(Q^2)\right]$$

Sach's form factors: G_E and G_M

Proton "radius" determined from slope of G_E in the low Q^2 limit

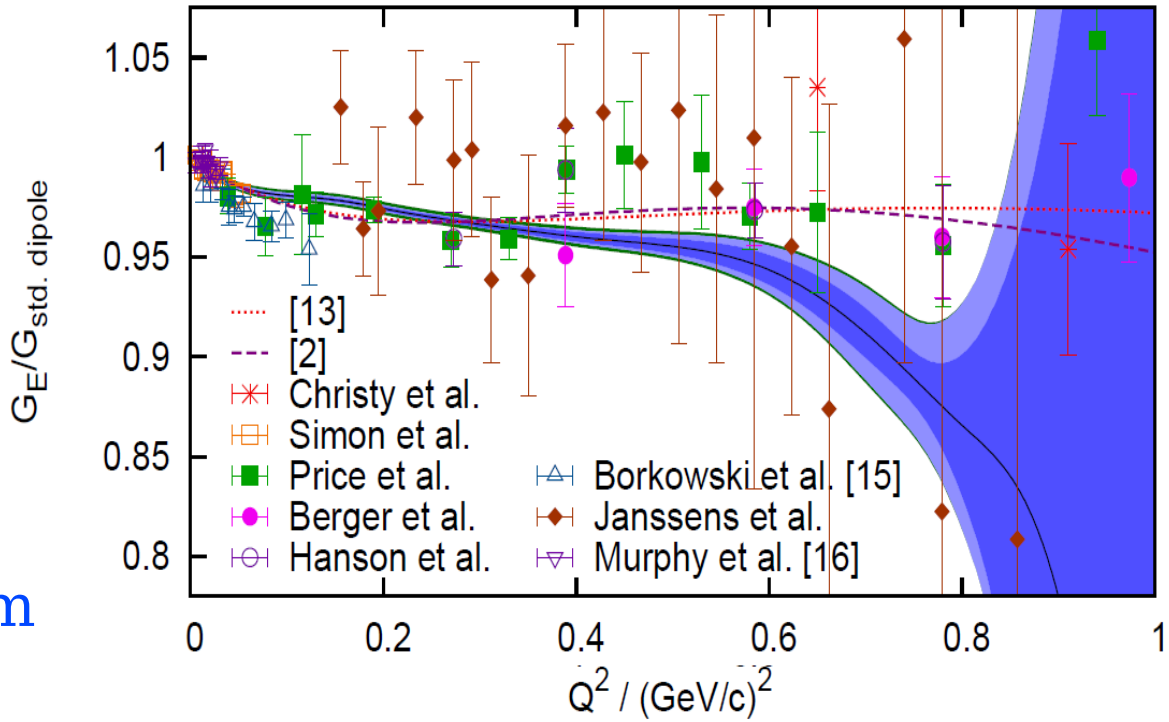
$$\langle r_p^2 \rangle = -6\hbar^2 \frac{G_E(Q^2)}{dQ^2}\bigg|_{Q^2 \to 0}$$

Low Q^2 data example:

Mainz A1 (2010) ~1400 points covering Q^2 ~ 0.01 – 1 GeV^2

Global fit of G_E, G_M with several different models

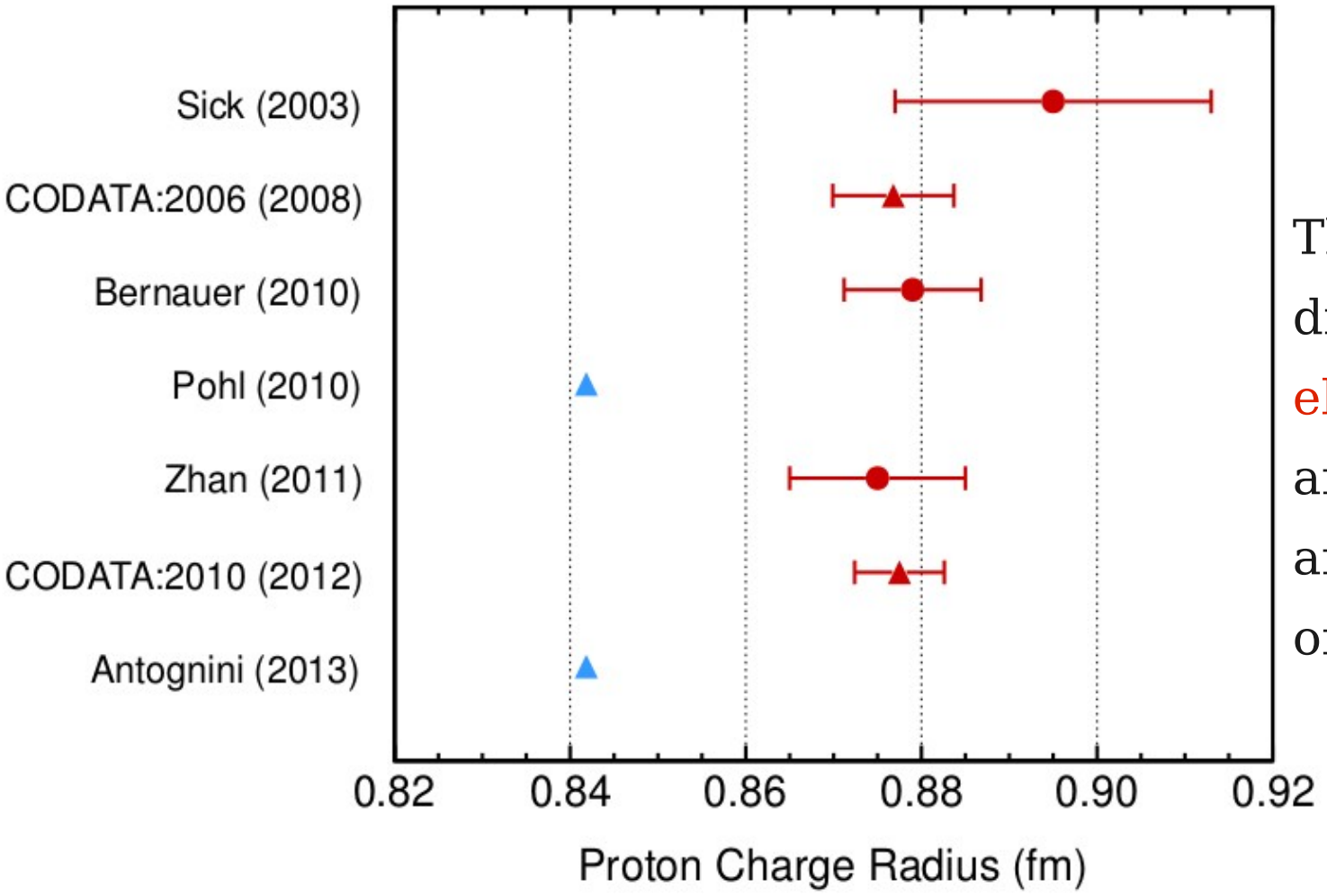
Their result: $r_E^p = 0.879(8)$ fm



J.C. Bernauer et al. PRL 105(24):242001, 2010

The Proton Radius "Puzzle"

Measurements of the proton radius: ● Scattering ▲ Spectroscopy



Puzzle

There exists a 7.9σ discrepancy between electronic (*ep* atomic and *ep* scattering) and muonic extractions of the proton radius.

Possible Resolutions to the Puzzle

Error in the *ep* scattering & atomic extractions:

problem with fits, lack of data, underestimated uncertainties

Proton structure issues in theory (TPE):

enhanced effects differing between e and μ

Novel beyond Standard Model physics:

lepton non-universality, new e/μ differentiating force, parameters constrained by existing data

New data is needed

new low Q^2 *ep* scattering measurement (JLab 12 GeV)

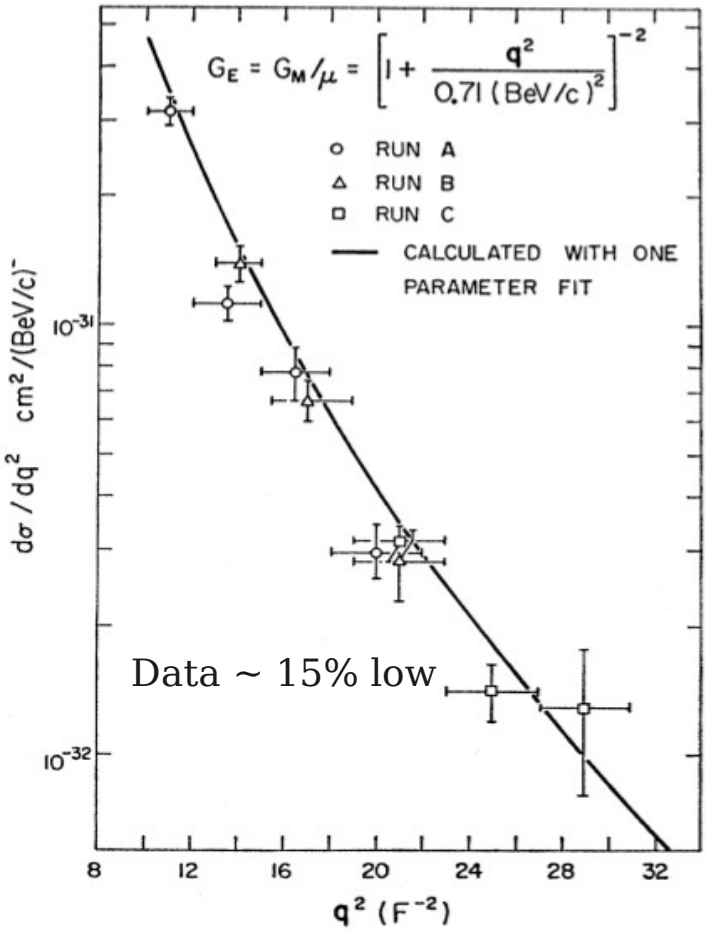
μp scattering measurement (this talk)

e-μ Universality

1970s-1980s: several scattering experiments directly tested e-μ universality to ~10%

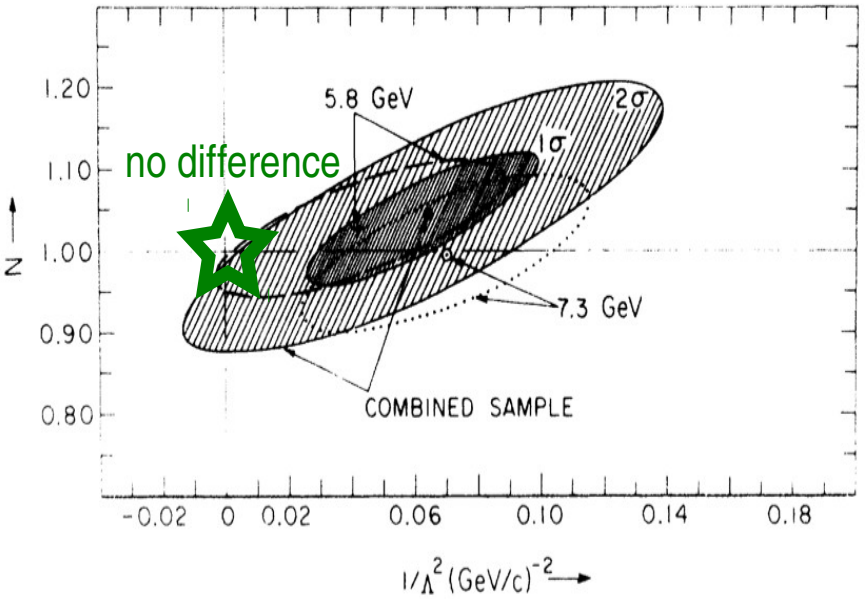
Ellsworth et al, Phys. Rev. 165 (1968):

Elastic μp data with ep dipole FF fit



Kostoulas et al, PRL 32 (1974):

Parameterization of μp versus ep



A. Entenberg et al, PRL 32 (1974):

DIS measurement $1/\Lambda^2 = 0.006 \pm 0.016$ GeV^{-2}

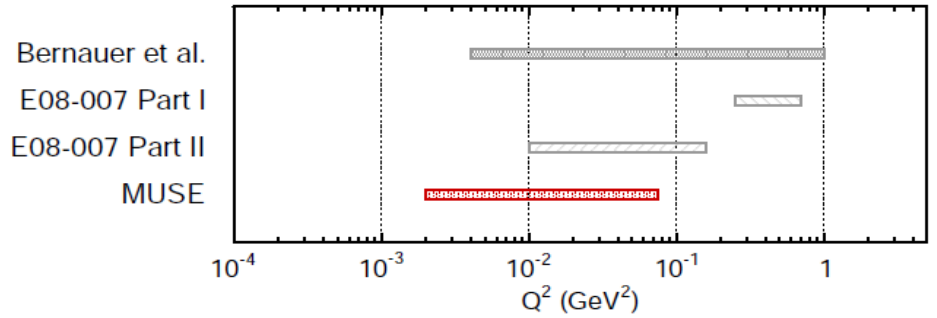
$\sigma_{\mu p}/\sigma_{ep} \approx 1.0 \pm 0.04$ (±8.6% systematics)

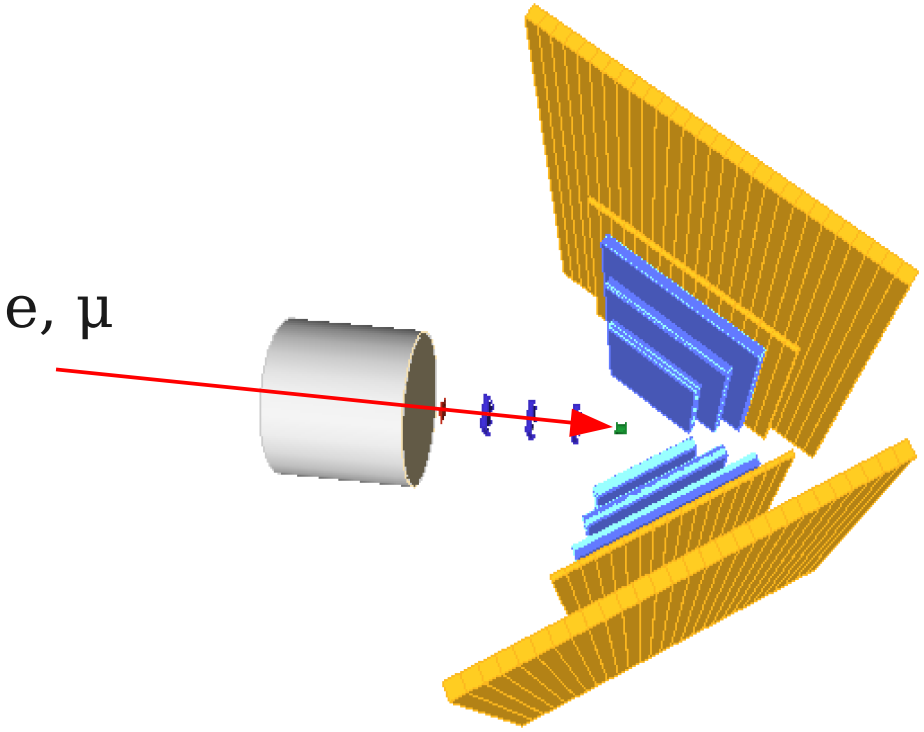
e-C, μ-C scattering are in agreement, but constraints are not very good

The MUSE Experiment

μp scattering at the Paul Scherrer Institut

r_p (fm)	ep	μp
atom	0.877 ± 0.007	0.841 ± 0.001
scattering	0.875 ± 0.006	?





→ Low Q^2 range (0.002 – 0.07 GeV^2) to have sensitivity to radius

→ Directly test if μ and e are different to a higher precision

→ Simultaneously measure *ep* and *μp* for a direct comparison

→ Measure e+, e- and μ+, μ- to extract TPE effects

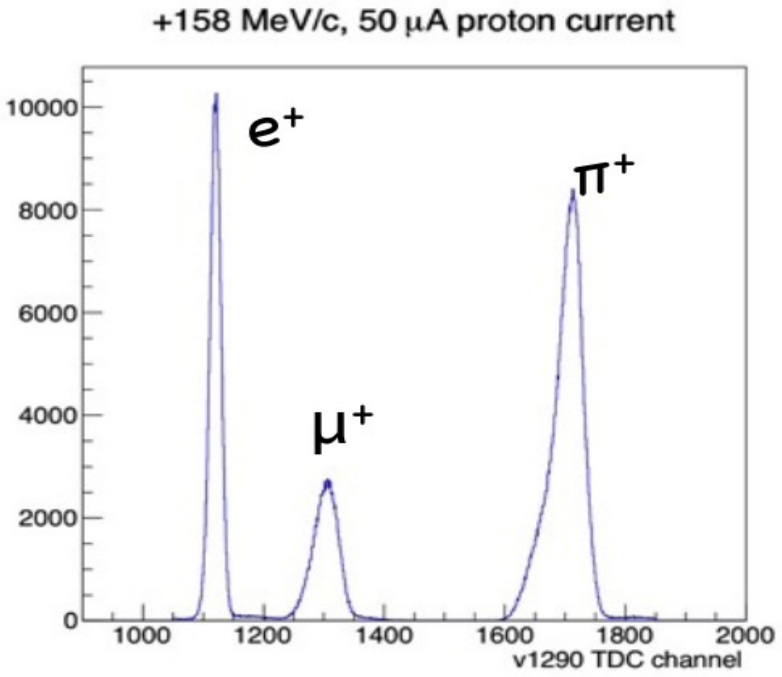
The MUSE Experiment

Experimental Considerations and Components:

Mixed beam of e, μ, and π
→ select beam momenta with good RF separation at target

p = 115, 153, and 210 MeV/c

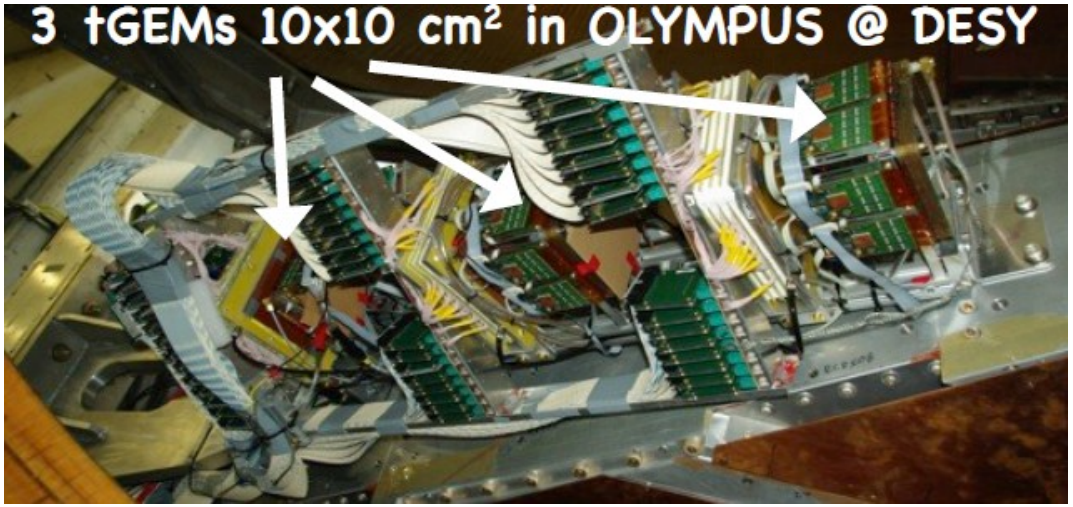
RF time spectrum measured in Fall 2012 Test Run at 158 MeV/c



RF timing determined by scintillating fiber arrays in the target region:
→ 1 ns resolution
→ reject pion events

Limit total channel flux to 5 MHz

GEM chambers:
→ Determine incident angle to 0.5 mr
→ project track to target
→ Existing chambers from OLYMPUS



The MUSE Experiment

Target:

→ 4 cm LH2, thickness constrained by effects of multiple scattering

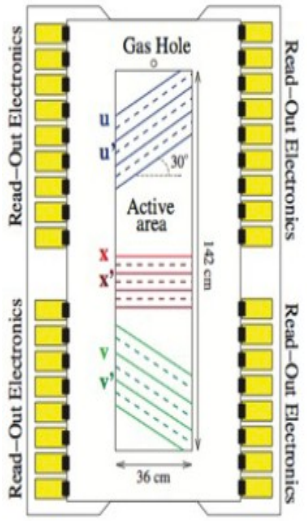
Quartz Cerenkov in target region

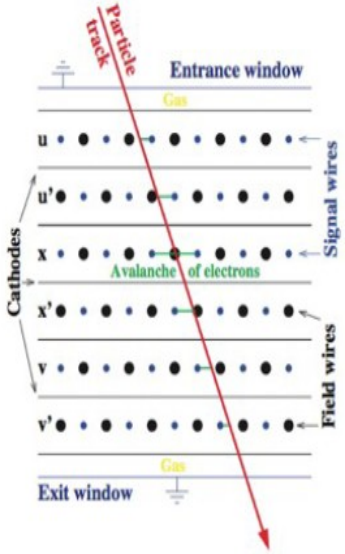
→ 50 ps resolution
→ better RF time at analysis level for PID
→ muon decay rejection

Scattering measured for θ = 20-100 degrees

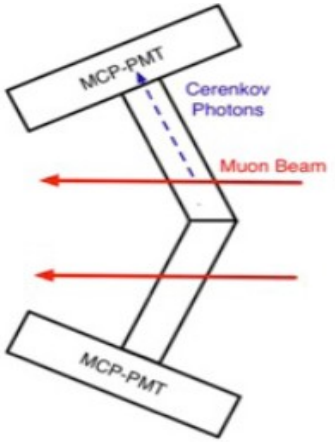
Wire Chambers

→ 3 UU'VV'XX'
→ mimic Hall A BigBite design
→ 98% plane efficiency
→ 100 μm resol.





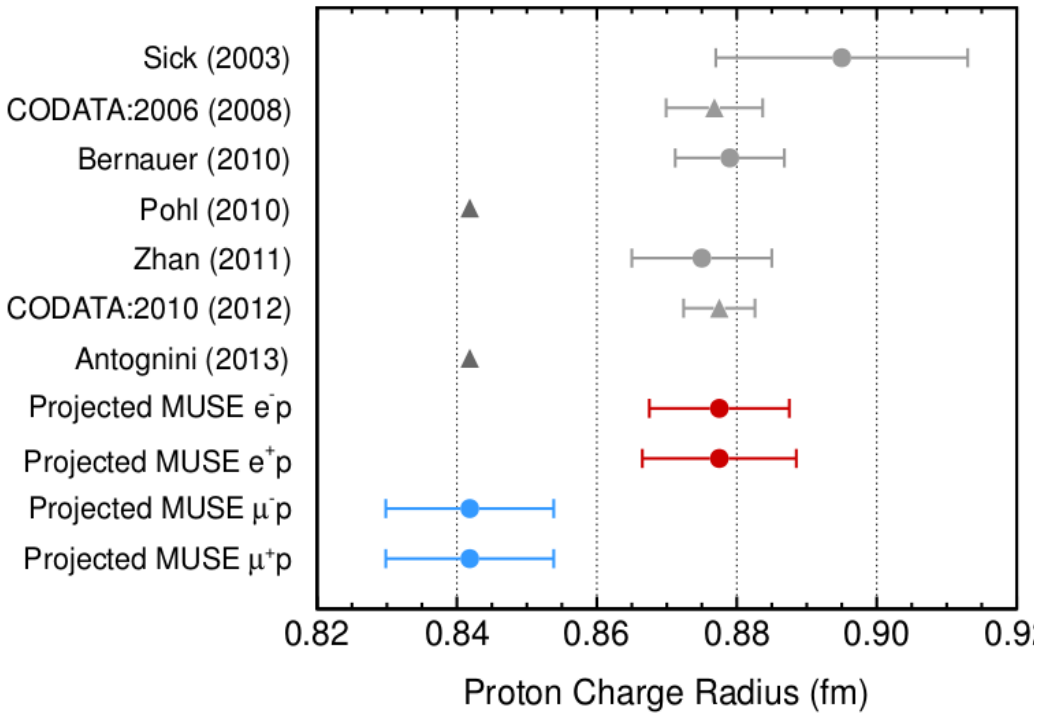
Scintillators



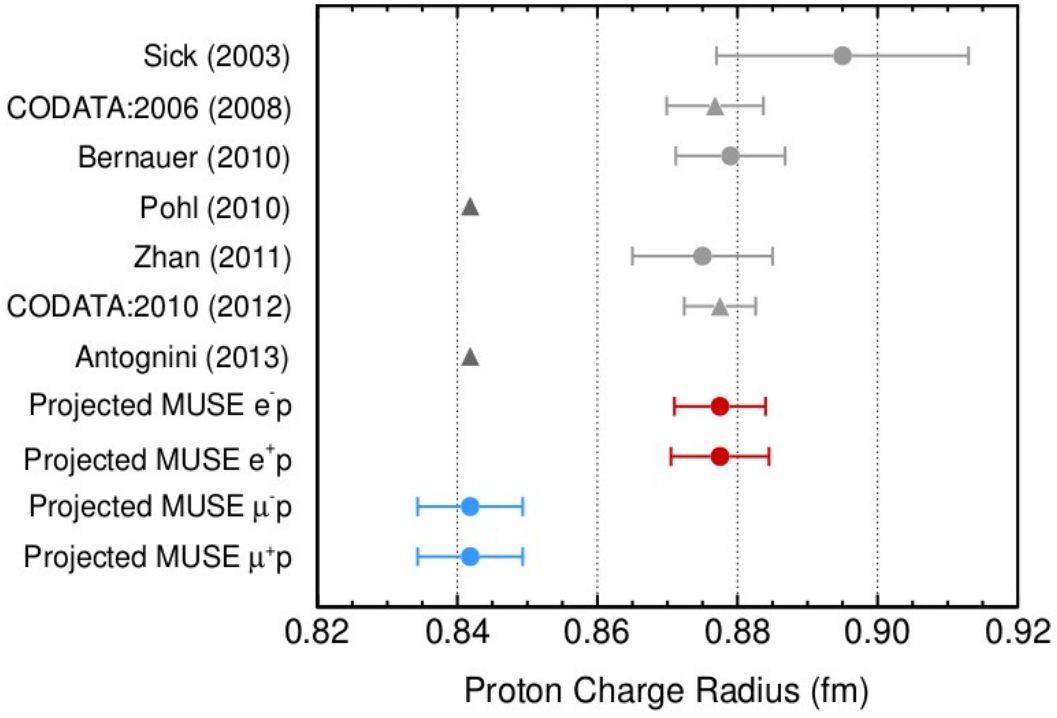
Albrow et al (FNAL)

→ 2 planes with <= 50 ps resol.
→ PID and muon decay rejection
→ Adopt South Carolina design for CLAS12

Projected Impact



Absolute Uncertainties



Relative Uncertainties

Point-to-point systematics: 0.7%, dominated by radiative corrections

Uncertainty in radius extractions: Independent measurements: 0.01 fm
Relative comparison: 0.006 fm
Current discrepancy: 0.035 fm

Summary

→ Proton Radius “Puzzle” challenging and unresolved

- 7σ discrepancy between muonic and electronic measurements

→ MUSE will do a direct comparison of ep and μp scattering to:

- Compare proton charge radius, extract form factors
- Test beyond SM physics: difference between e's and μ's
- Measure two-photon exchange effects

→ Timeline for MUSE:

- Experiment approved by PSI PAC January 2013
- Successful beam test run Fall 2012
- Another test run planned June 2013
- Plan few month “dry run” in late 2015
- Two 6 month production runs 2016-2017

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Thank You!