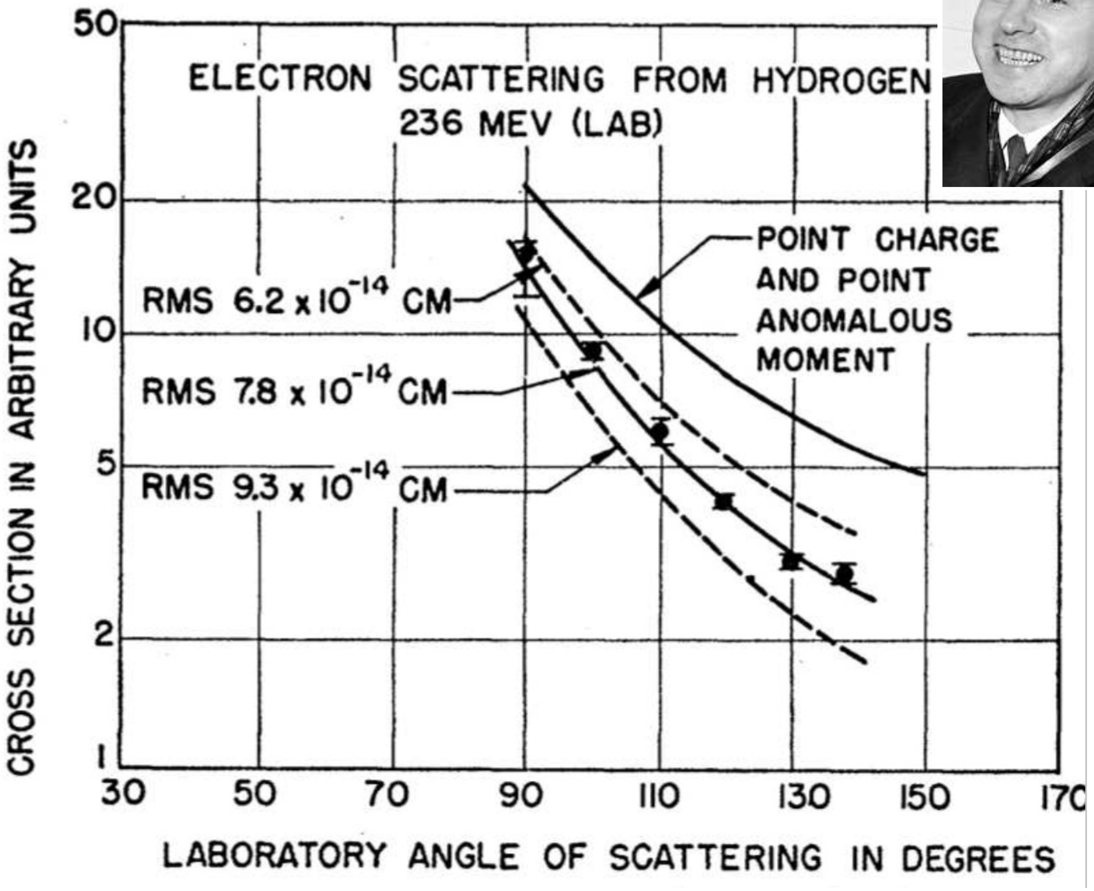
Recent Results of Proton Charge Radius And Experimental Status

- Weizhi Xiong (熊伟志)
- Shandong University

- 12th Workshop on Hadron Physics and Opportunities Worldwide
- Aug. 4th – 9th 2024

Outline

- ➢Introduction: proton charge radius and electromagnetic form factors
- ➢Recent measurements and results
- ➢Future experiments and status
- ➢Summary

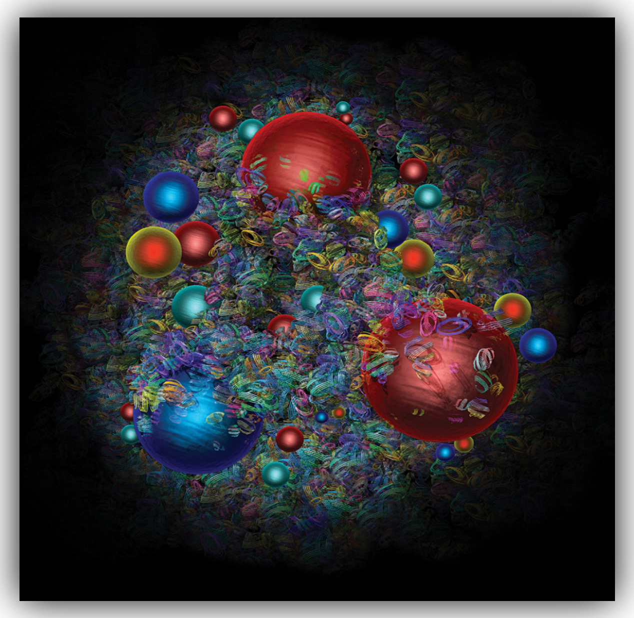


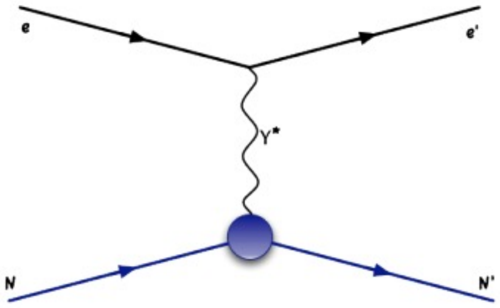
1956 Measurements @ Stanford

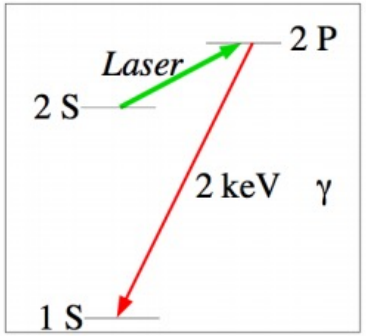
General Info on Proton Charge Radius

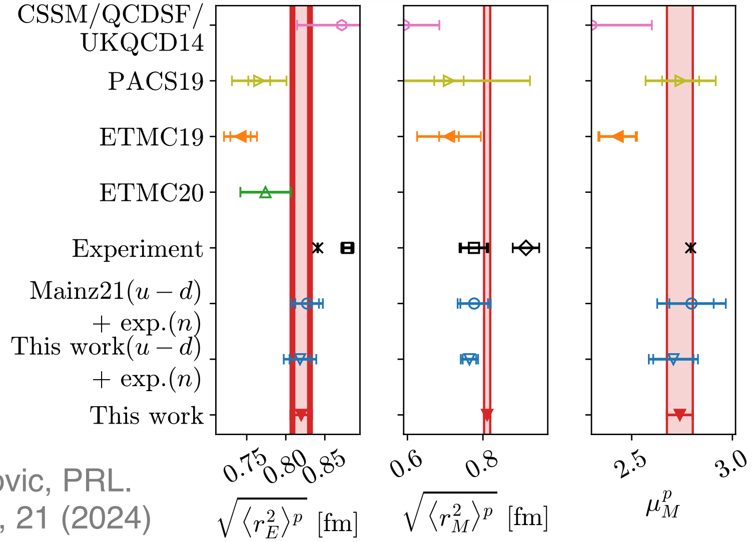
- Proton charge radius (r_p):
  1. Spacial distribution of proton's charge
  2. Important for understanding how QCD works
  3. Input to the bound state QED calculation for atomic hydrogen energy levels
  4. Critical in determining Rydberg constant (R_∞)

- Two well-established experimental methods:
  1. *e-p* elastic scattering (nuclear physics)
  2. Hydrogen spectroscopy (atomic physics)









D. Djukanovic, PRL. 132, no.21, 21 (2024)

Unpolarized Lepton-Proton Elastic Scattering

- Elastic ep scattering, in the limit of Born approximation (neglecting lepton mass):

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{Mott}} \left(\frac{E'}{E}\right) \frac{1}{1+\tau} \left(G_E^{p\,2}(Q^2) + \frac{\tau}{\varepsilon} G_M^{p\,2}(Q^2) \right)$$

$$Q^2 = 4EE' \sin^2\frac{\theta}{2} \qquad \tau = \frac{Q^2}{4M_p^2} \qquad \varepsilon = \left[1 + 2(1+\tau)\tan^2\frac{\theta}{2}\right]^{-1}$$

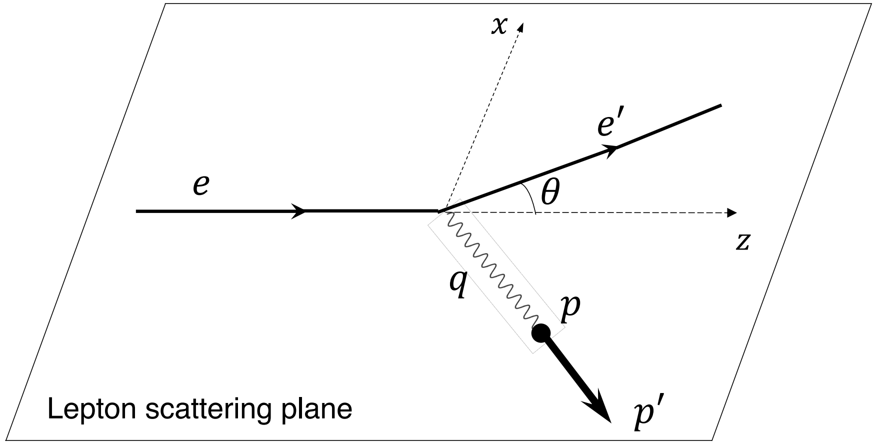
Taylor expansion of G_E at low Q^2

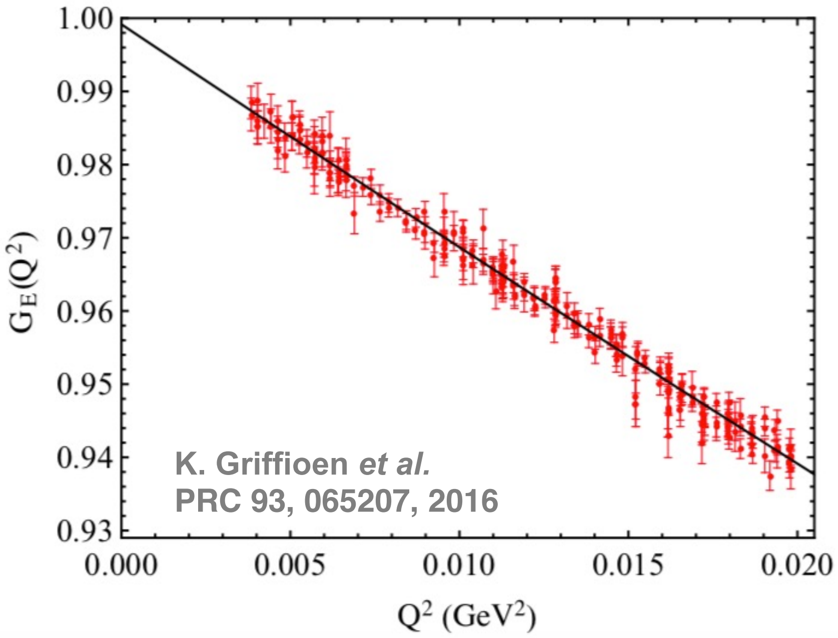
$$G_E^p(Q^2) = 1 - \frac{Q^2}{6}\langle r^2\rangle + \frac{Q^4}{120}\langle r^4\rangle + \ldots$$

Derivative at low Q^2 limit

$$\langle r^2\rangle = -6 \left.\frac{dG_E^p(Q^2)}{dQ^2}\right|_{Q^2=0}$$

- Exploit ε dependency to separate G_E^p and G_M^p





Extracting Form Factors

$$G_D = \frac{1}{(1+\frac{Q^2}{0.71\text{Gev}^2})^2}$$

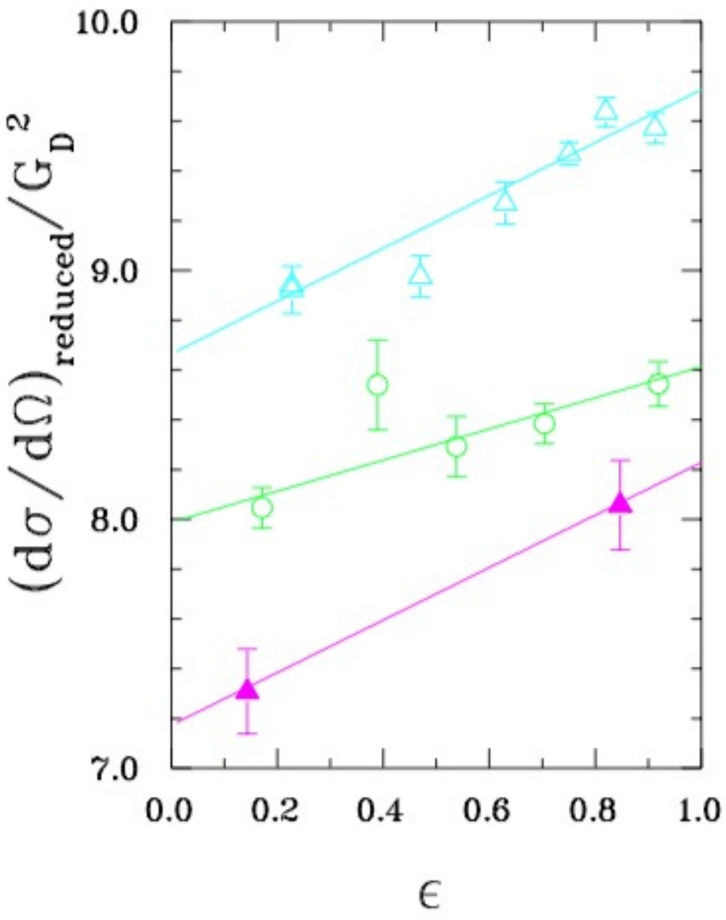
- One of the methods for form factor extraction is the well know Rosenbluth separation:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}} \left(\frac{E'}{E}\right) \frac{1}{1+\tau} \left({G_E^p}^2(Q^2) + \frac{\tau}{\varepsilon}{G_M^p}^2(Q^2)\right)$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{reduced}} = {G_M^p}^2(Q^2) + \frac{\epsilon}{\tau}{G_E^p}^2(Q^2)$$

$$\tau = \frac{Q^2}{4M_p^2} \qquad \varepsilon = \left[1 + 2(1+\tau)\tan^2\frac{\theta}{2}\right]^{-1}$$

- Measure σ_{reduced} at same Q^2 but different values of ϵ
- G_E^p and G_M^p determined as slope and intersection from fits



C. F. Perdrisat, V. Punjabi and M. Vanderhaeghen, Prog. Part. Nucl. Phys. 59, 694 (2007)

Polarized ep Elastic Scattering

- Directly measure G_E^p/G_M^p at a given Q²
- Combined with unpolarized cross section to separate G_E^p and G_M^p
- Ratio measurement, lots of cancellation for systematics
- Overcome several difficulties for unpolarized technique: G_E^p at high Q², radiative correction…

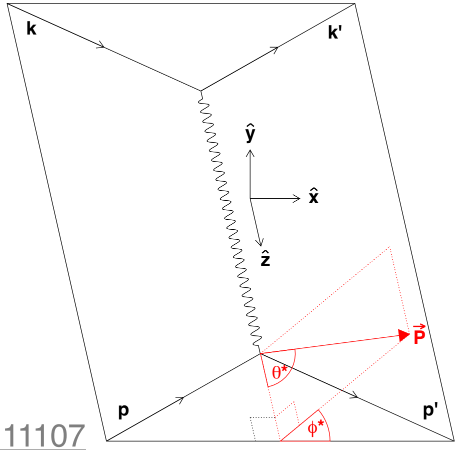
Double polarization, asymmetry measurements

$$A_{eN} \equiv \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$
$$= P_{\text{beam}} P_{\text{targ}} \left[A_t \sin\theta^* \cos\phi^* + A_\ell \cos\theta^*\right]$$

$$A_t = -\sqrt{\frac{2\epsilon(1-\epsilon)}{\tau}} \frac{r}{1+\frac{\epsilon}{\tau}r^2}$$

$$A_\ell = -\frac{\sqrt{1-\epsilon^2}}{1+\frac{\epsilon}{\tau}r^2}$$

$$r \equiv G_E/G_M$$

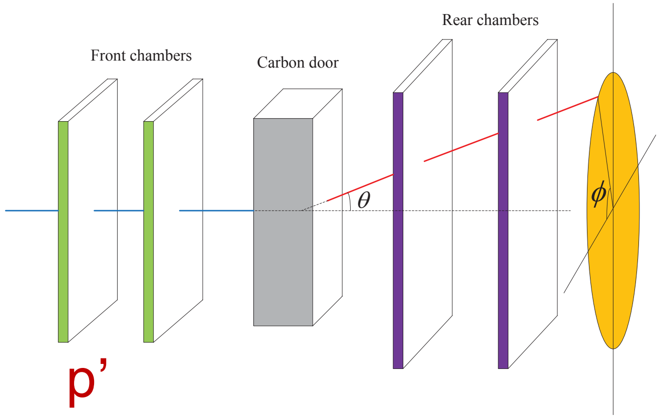


arXiv:2212.11107

Polarization transferred to final state proton

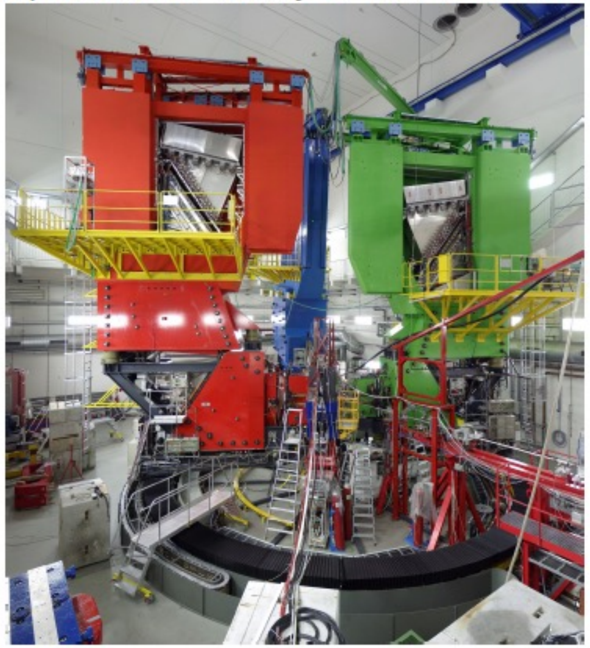
$$P_t = P_{\text{beam}} A_t$$
$$P_\ell = -P_{\text{beam}} A_\ell .$$

$$\frac{G_E}{G_M} = -\frac{P_t}{P_\ell}\sqrt{\frac{\tau(1+\epsilon)}{2\epsilon}} = -\frac{P_t}{P_\ell}\frac{E_e + E_e'}{2M}\tan\left(\frac{\theta_e}{2}\right)$$

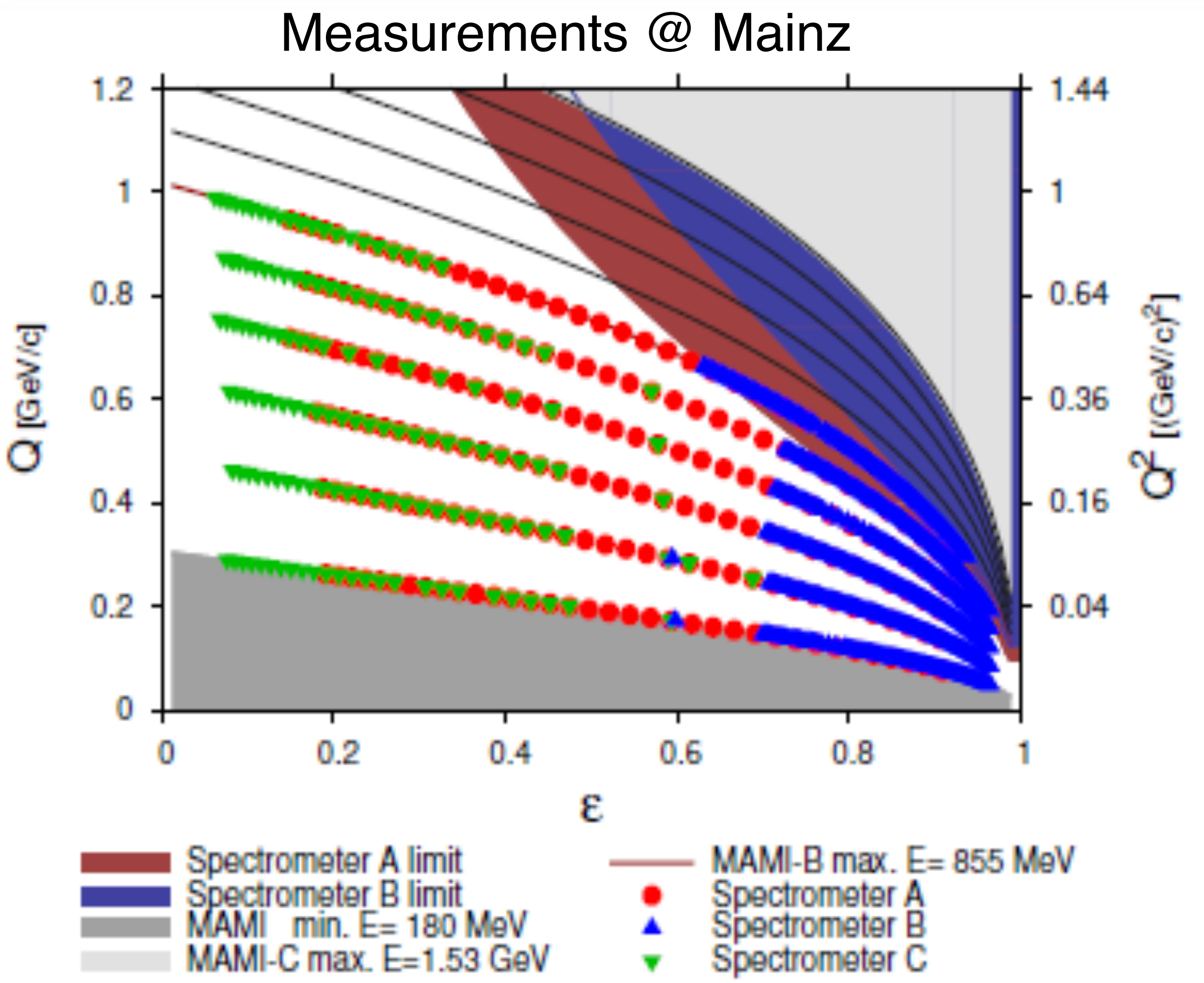


Unpolarized *ep* Elastic Scattering

Three spectrometer facility of the A1 collaboration:

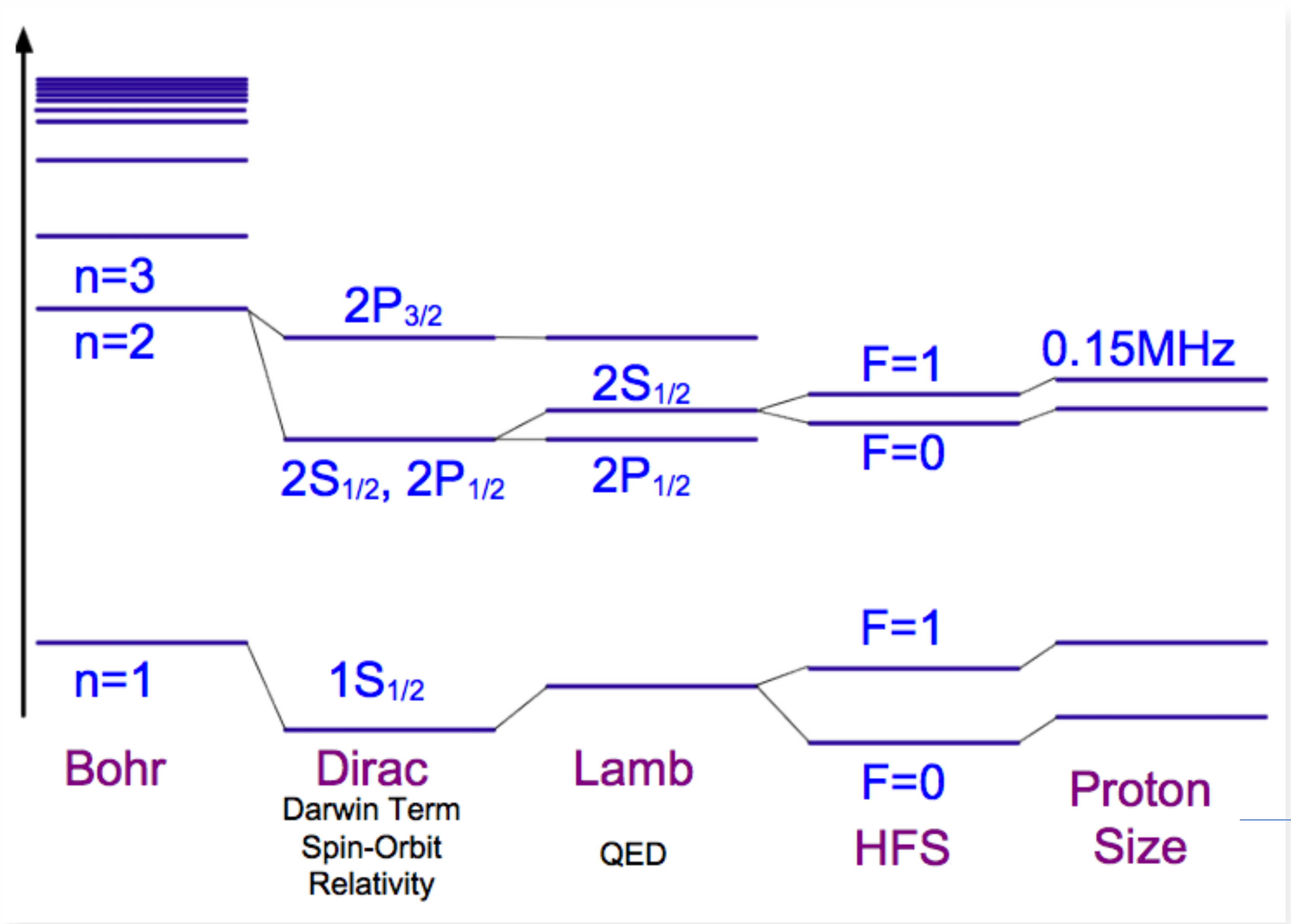


J.C. Bernauer *et al.* PRL. 105 (2010) 242001



- Large amount of overlapping data sets
- Statistical error $\leq 0.2\%$
- Luminosity monitoring with spectrometer
- $Q^2 = 0.004 – 1.0\ (\mathrm{GeV}/c)^2$
- result: $r_p = 0.8791(79)$ fm

Hydrogen Spectroscopy



- Physics origin of the proton finite size effect:
  - S-state wavefunction has overlap with the proton

G. Miller PRC 99 035202 (2019)

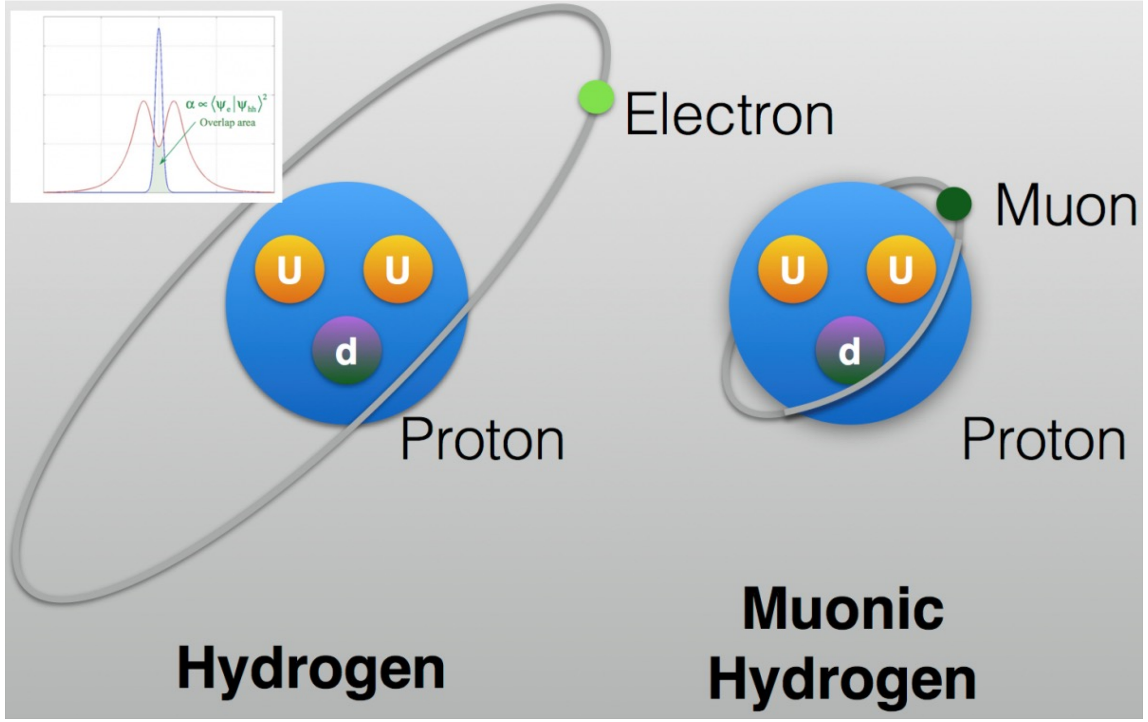
$$\Delta E = -4\pi\alpha G'^{p}_{E}(0)|\psi_{n0}(0)|^2\delta_{l0}$$
$$= 4\pi\alpha\frac{r_p^2}{6}|\psi_{n0}(0)|^2\delta_{l0}.$$

$$\boxed{\langle r^2\rangle = -6\left.\frac{dG_E^p(Q^2)}{dQ^2}\right|_{Q^2=0}}$$

Ordinary Hydrogen v.s. Muonic Hydrogen

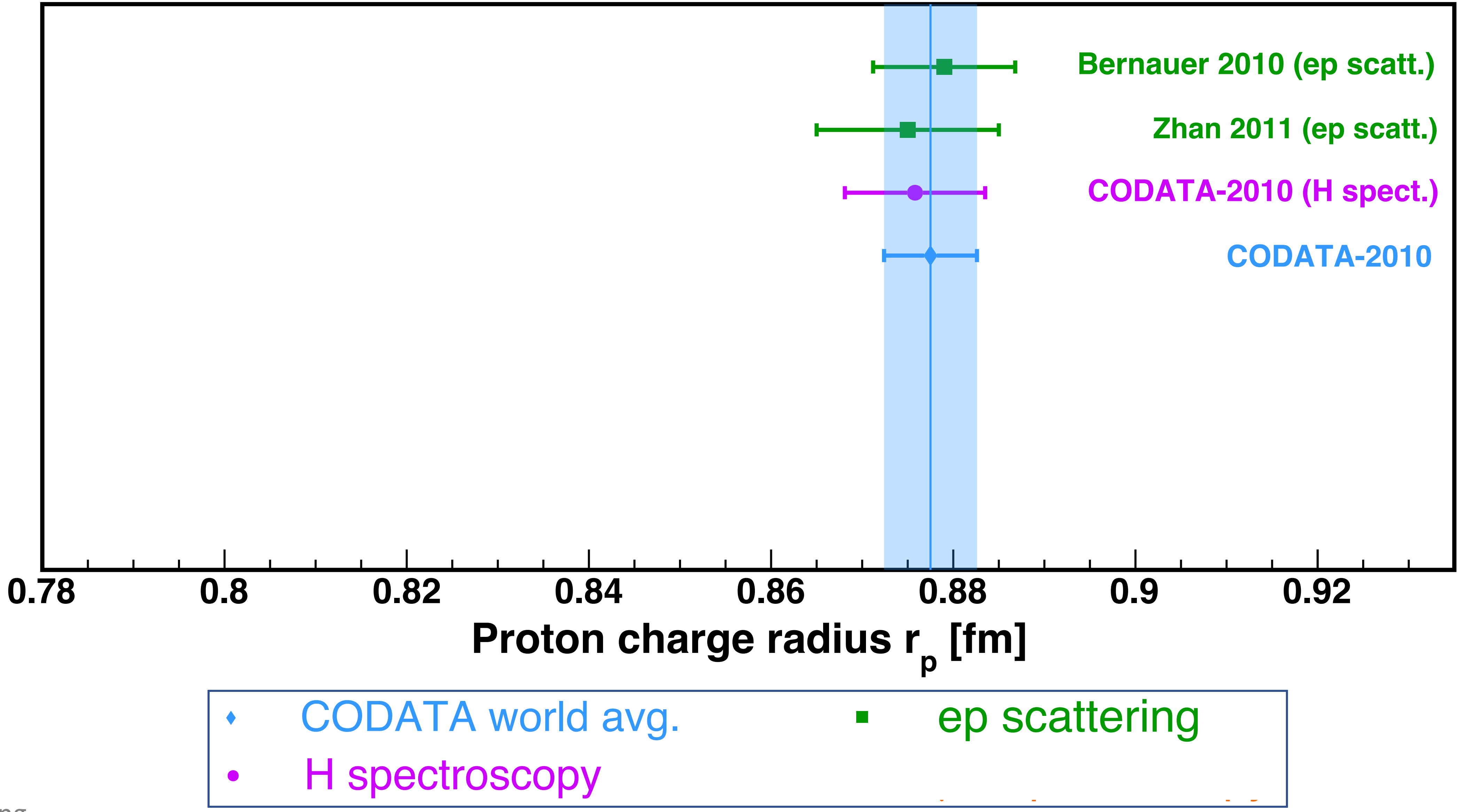
- One can do this with ordinary hydrogen or muonic hydrogen
- Muon is ~200 times heavier than electron
- Orbit much closer to proton, more sensitive to proton size

$$\langle r^{\mathrm{orbit}} \rangle \simeq \frac{\hbar}{Z\alpha\, m_r c} n^2$$

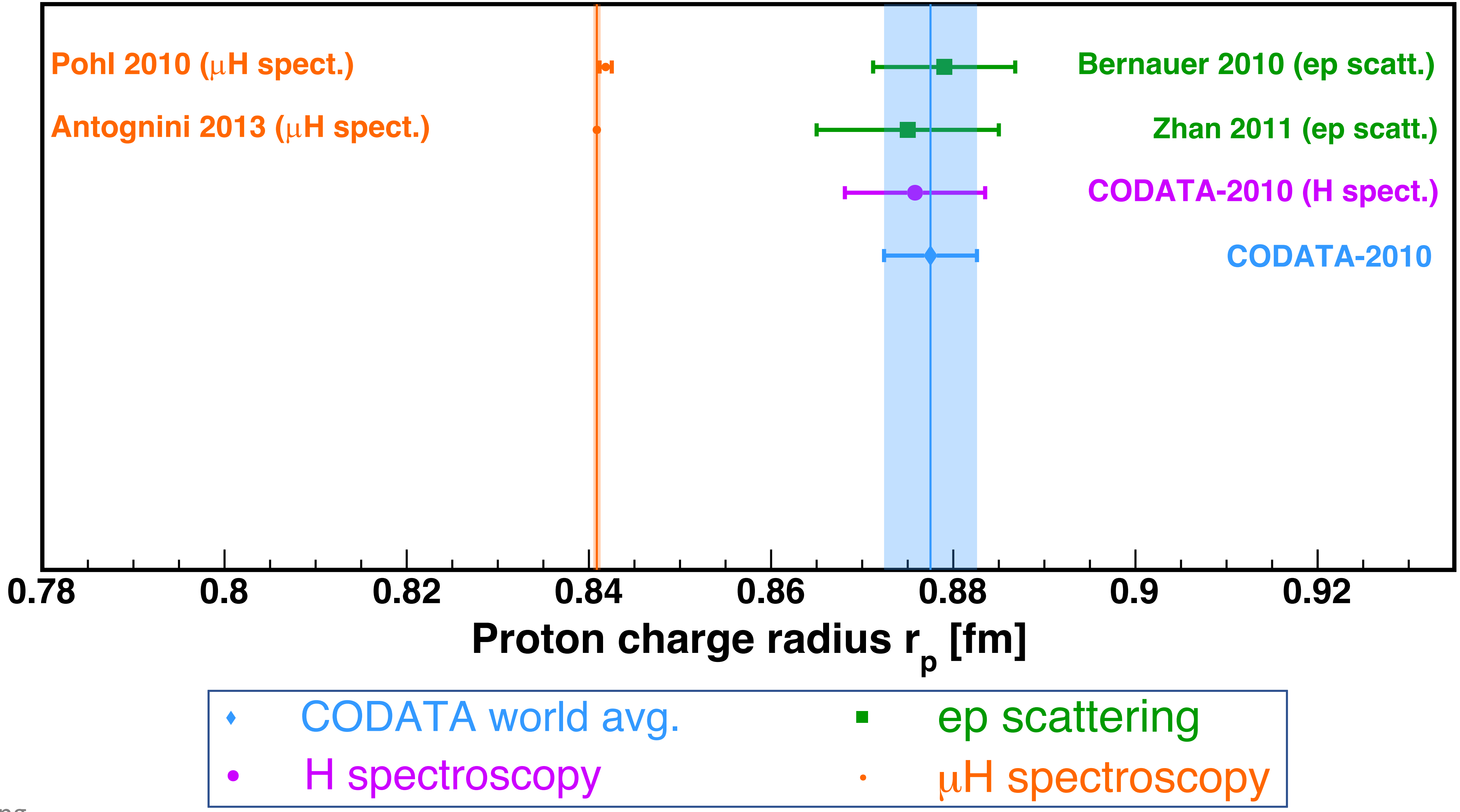


Proton finite size effect in 2S-2P: 2% in μH, 0.015% in H

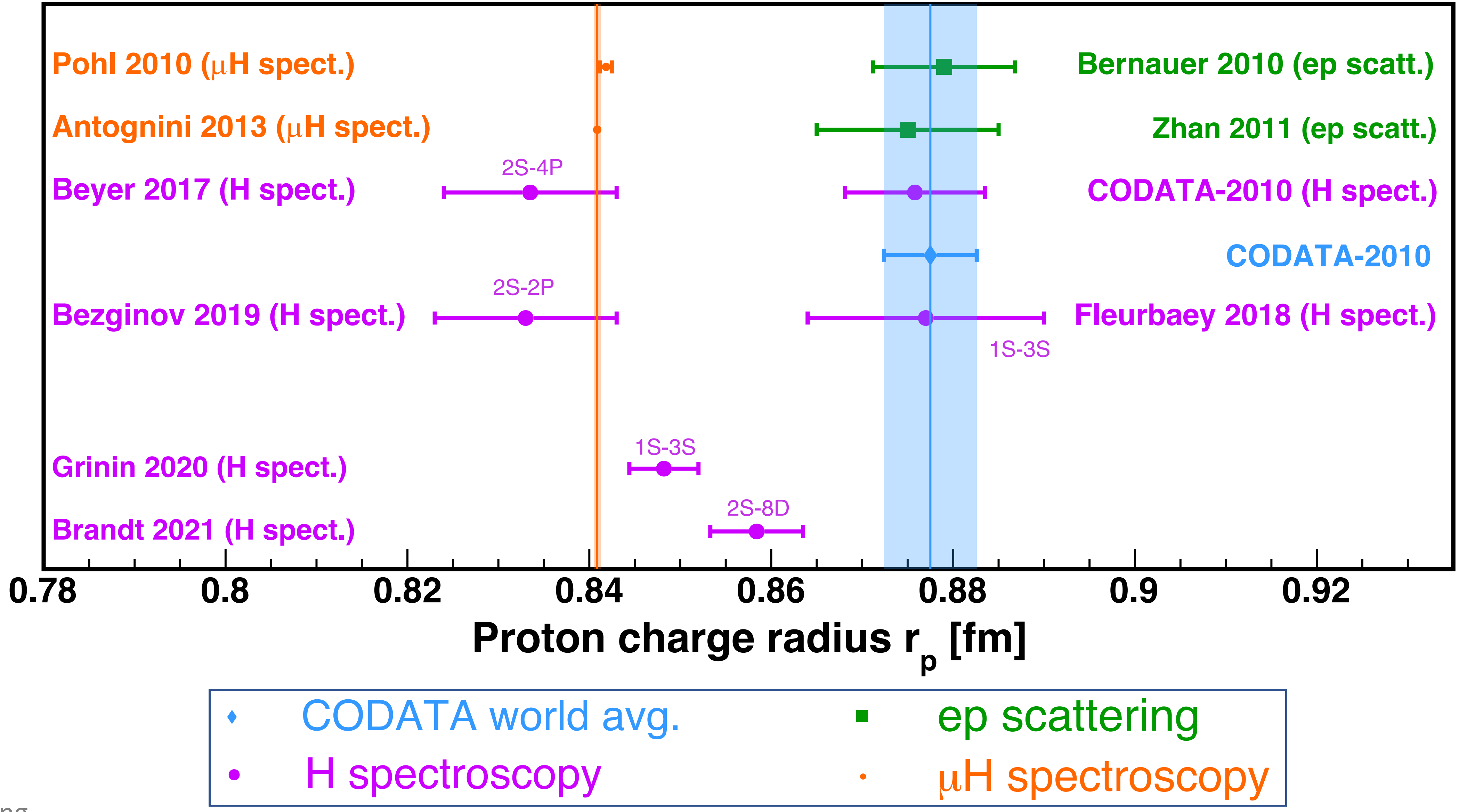
Proton Charge Radius



Proton Charge Radius Puzzle

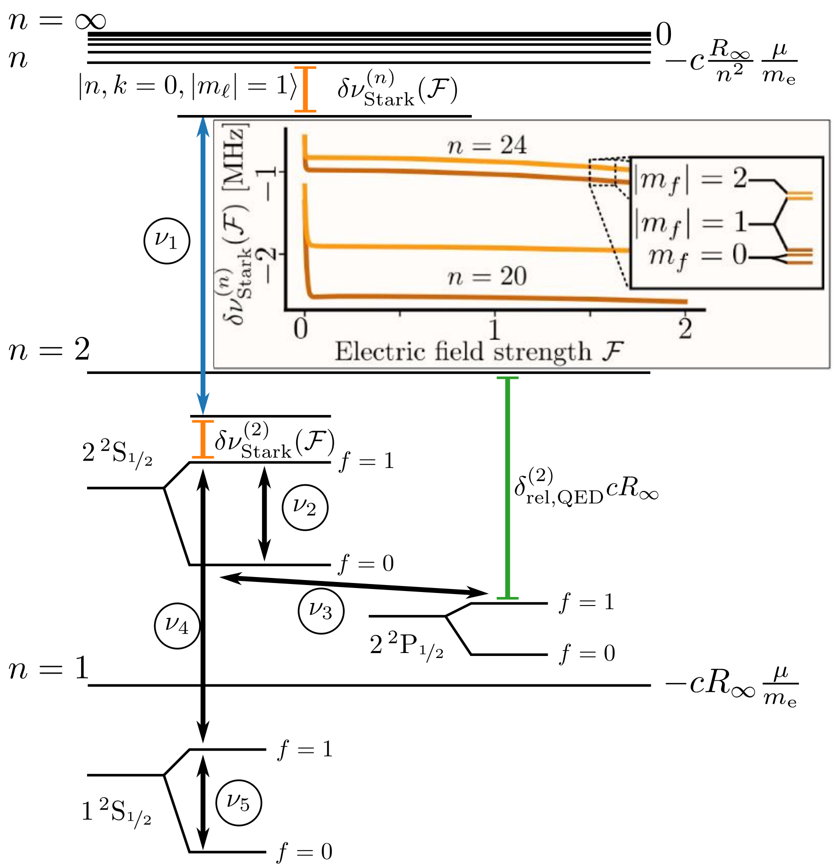


Proton Charge Radius Puzzle

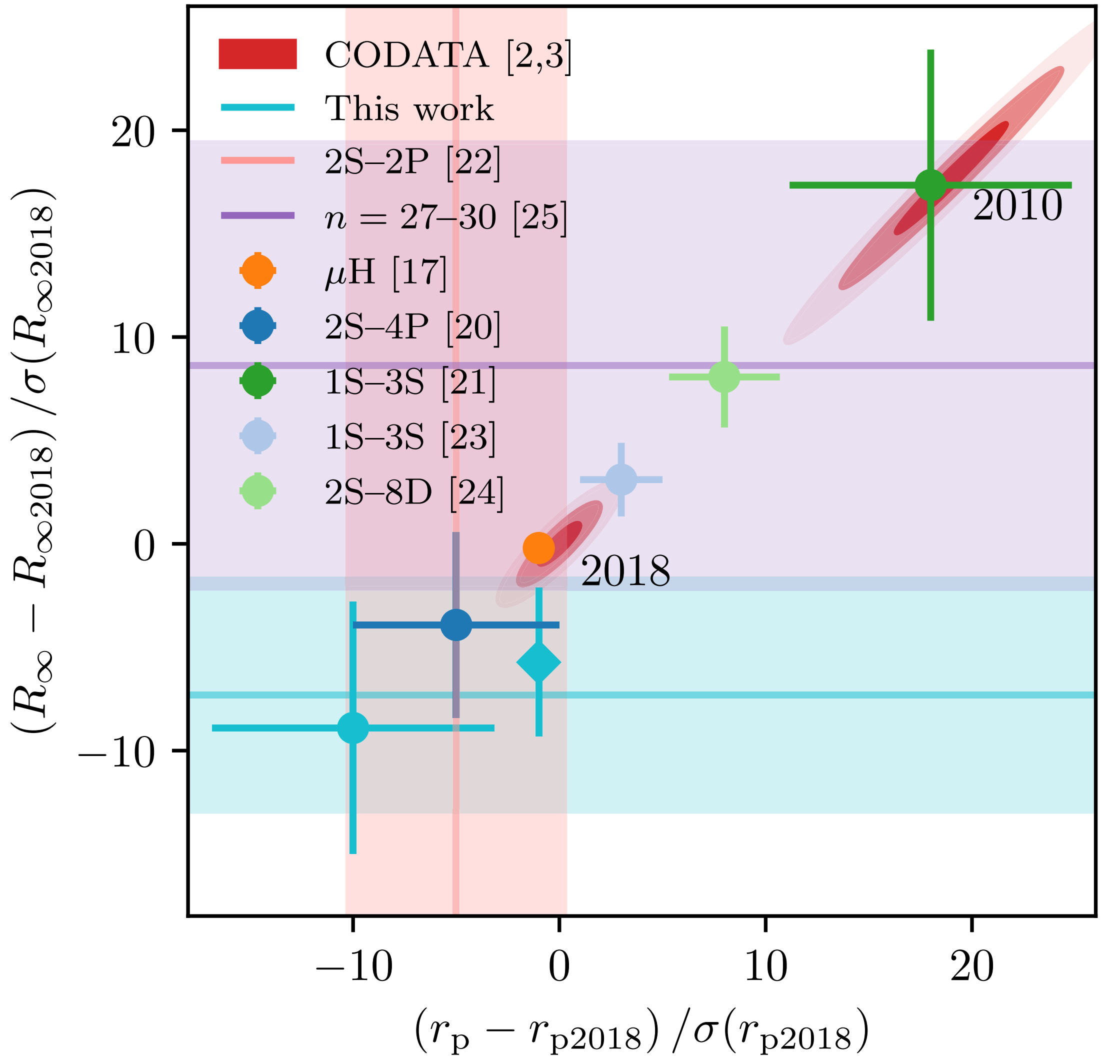


Recent High-n Rydberg State Measurement

$$cR_\infty\left[\left(\frac{1}{4}-\frac{1}{n^2}\right)\frac{\mu}{m_e}+|\delta^{(2)}_{\mathrm{rel,QED}}|\right]$$
$$=\nu_1+\nu_2+\nu_3+|\delta\nu^{(n)}_{\mathrm{Stark}}(\mathcal{F})|+\delta\nu^{(2)}_{\mathrm{Stark}}(\mathcal{F}),$$



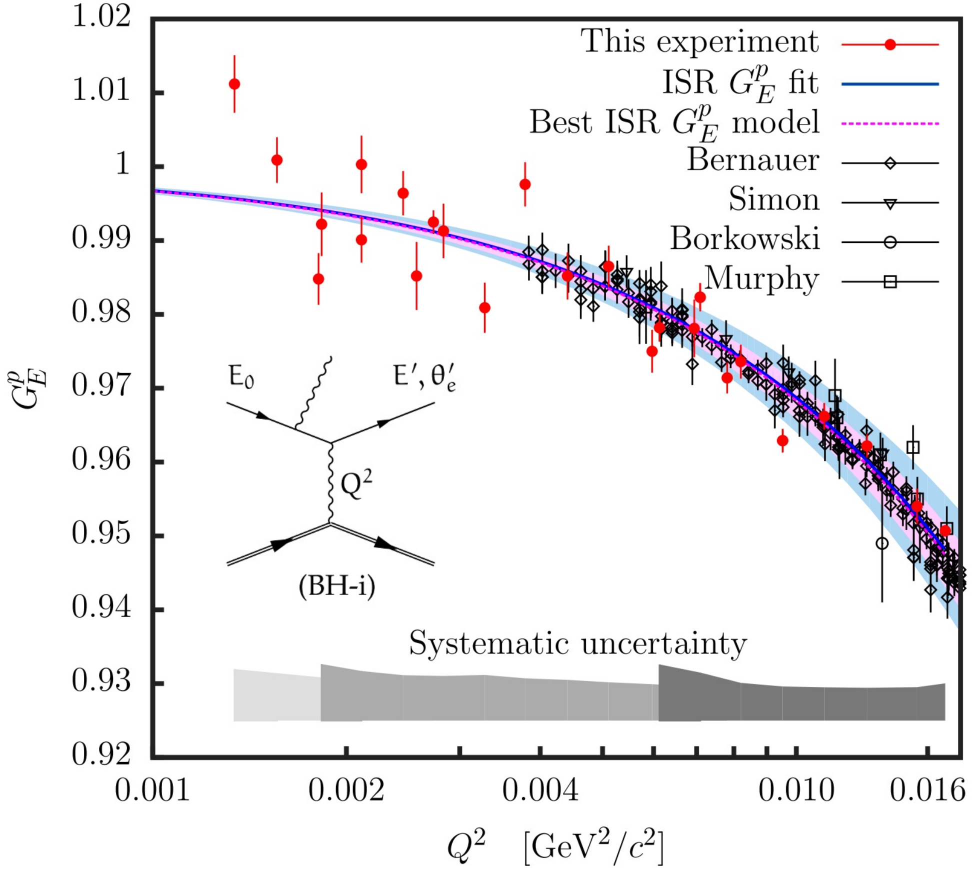
PRL 132, 113001 (2024)



Recent Scattering Experiment at Mainz

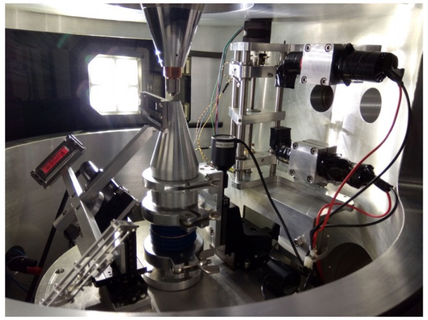
Initial State Radiation Experiment

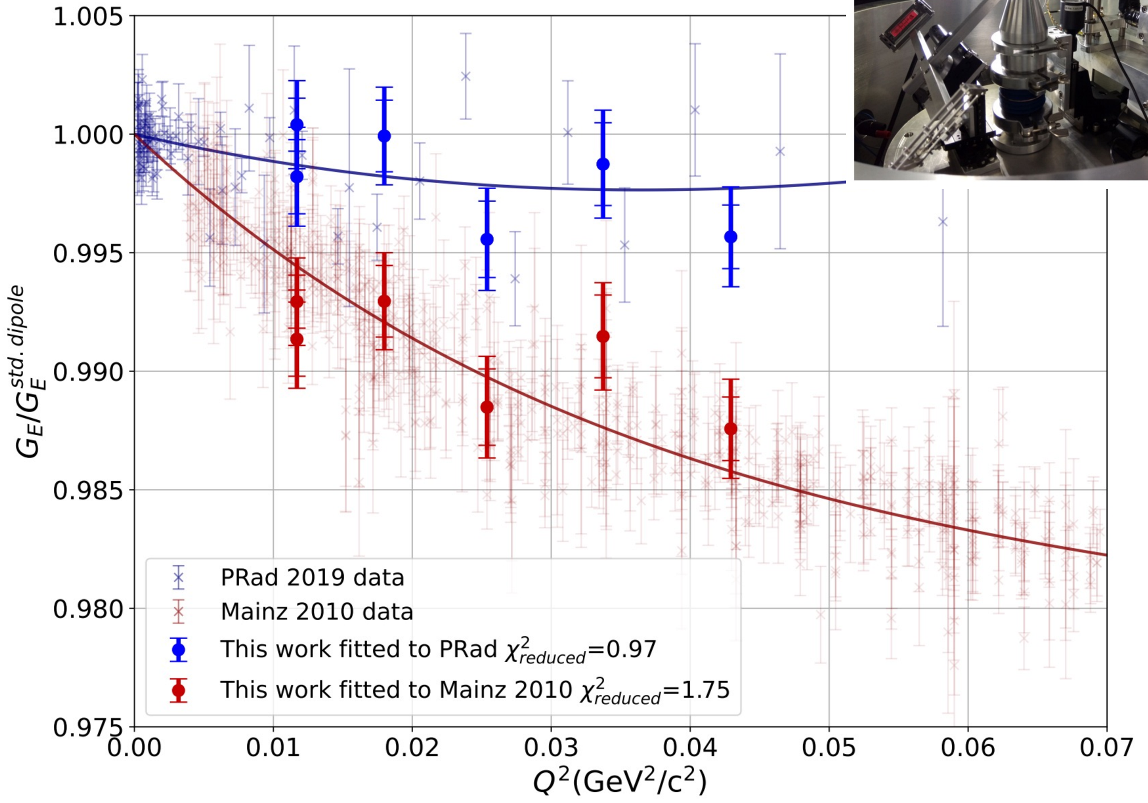
rp = 0.878 +/- $0.011_{stat.}$ +/- $0.031_{syst.}$ +/- $0.002_{mod.}$ fm



M. Mihovilovic *et al.* EPJA (2021) 57:107

Mainz Jet Target Exp.

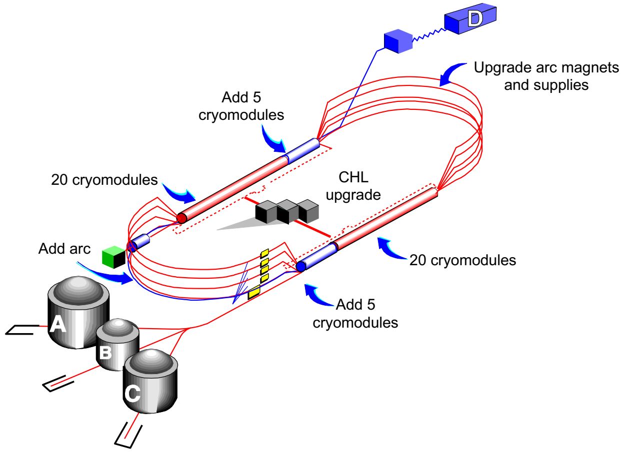


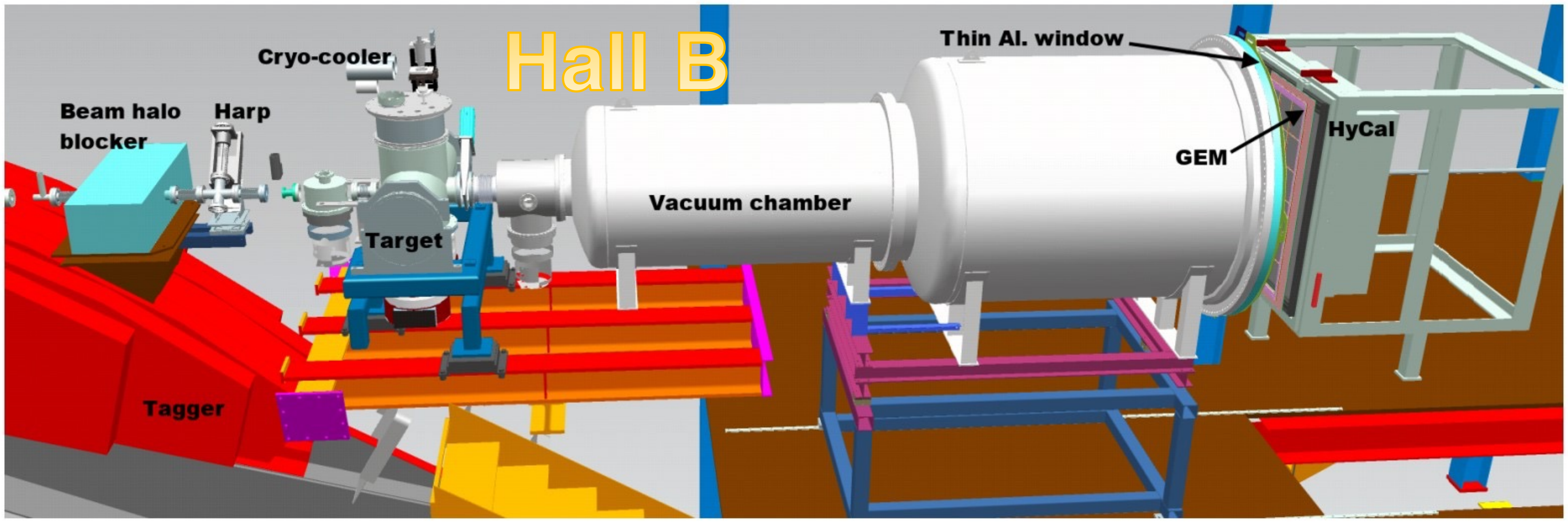


Y. Wang et al. PRC 106 (2022) 4, 044610

PRad Experiment at Jefferson Lab

- Thomas Jefferson National Accelerator Facility (JLab), Newport News, VA
- Data taking May/June 2016, 1.1 GeV and 2.2 GeV e beams



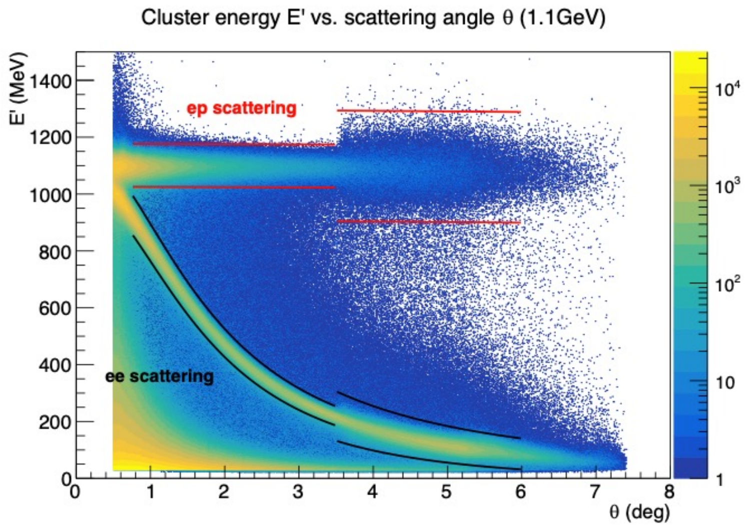


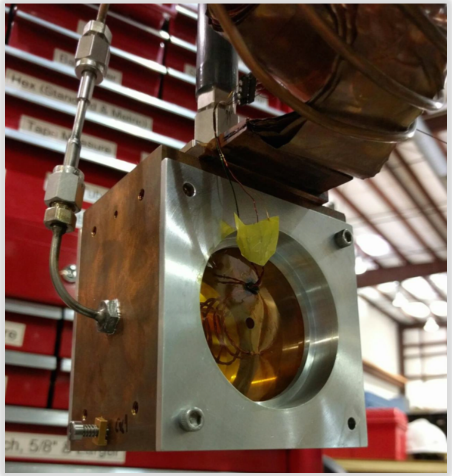
PRad Experiment at Jefferson Lab

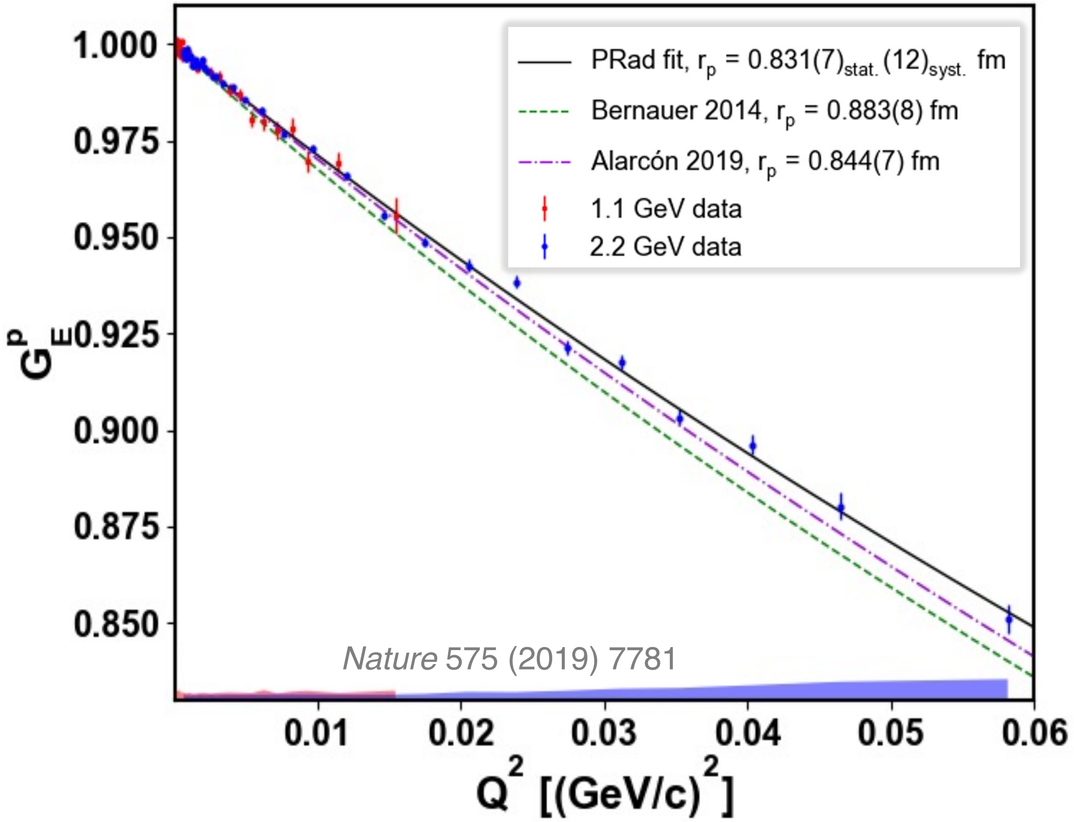
Non-spectrometer apparatus

- Large acceptance:
  - Measure multiple Q^2 data points simultaneously
  - Measure *ep* and *ee* scattering at the same time
- Small scattering angle (0.5^o-7.5^o):
  - Unprecedented low Q^2 (~$2x10^{-4}$ GeV^2)
  - Minimize G_M^p contribution
- Windowless gas-flow target

r_p = 0.831 +/- 0.007 (stat.) +/- 0.012 (syst.) fm

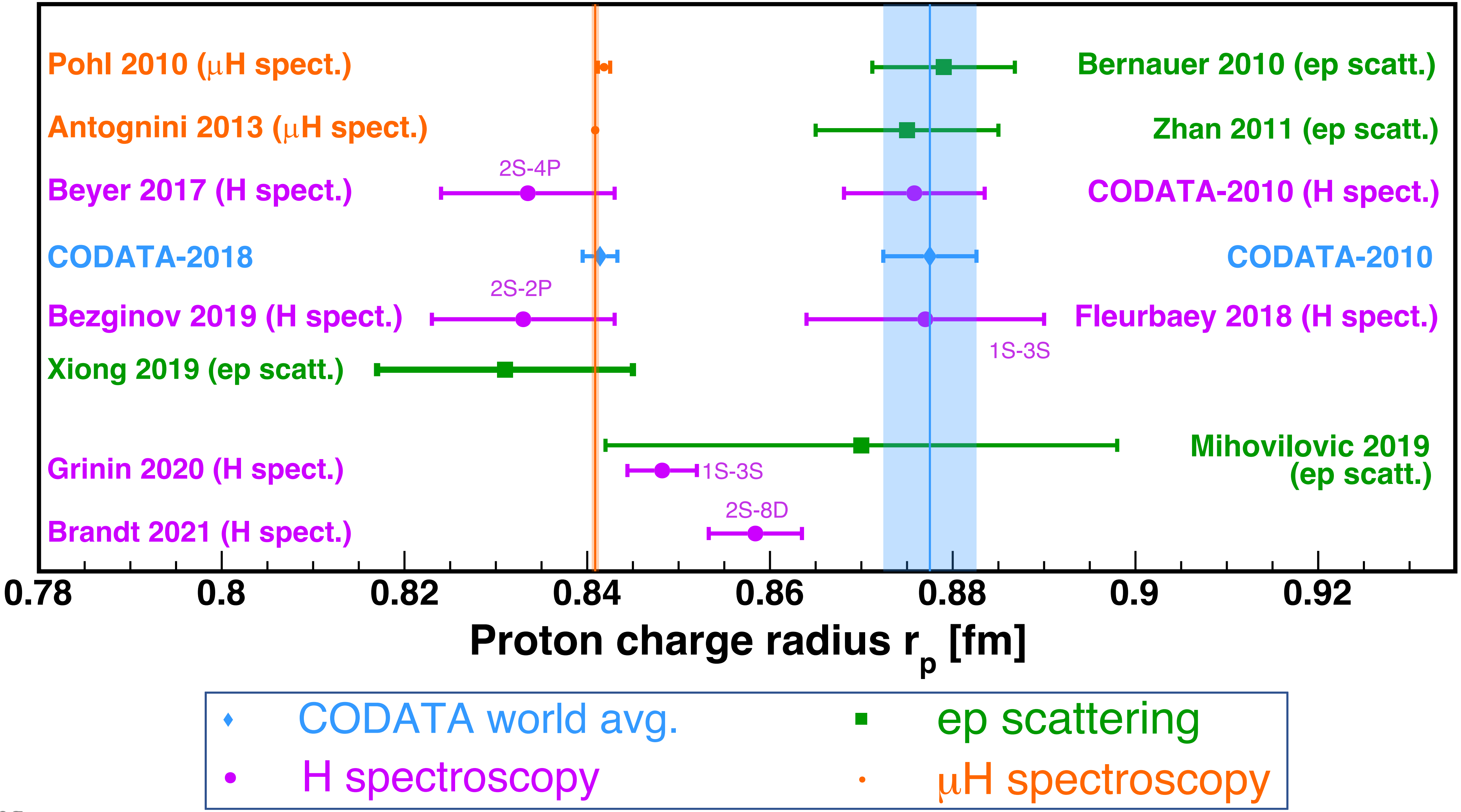






Nature 575 (2019) 7781

Proton Charge Radius Puzzle

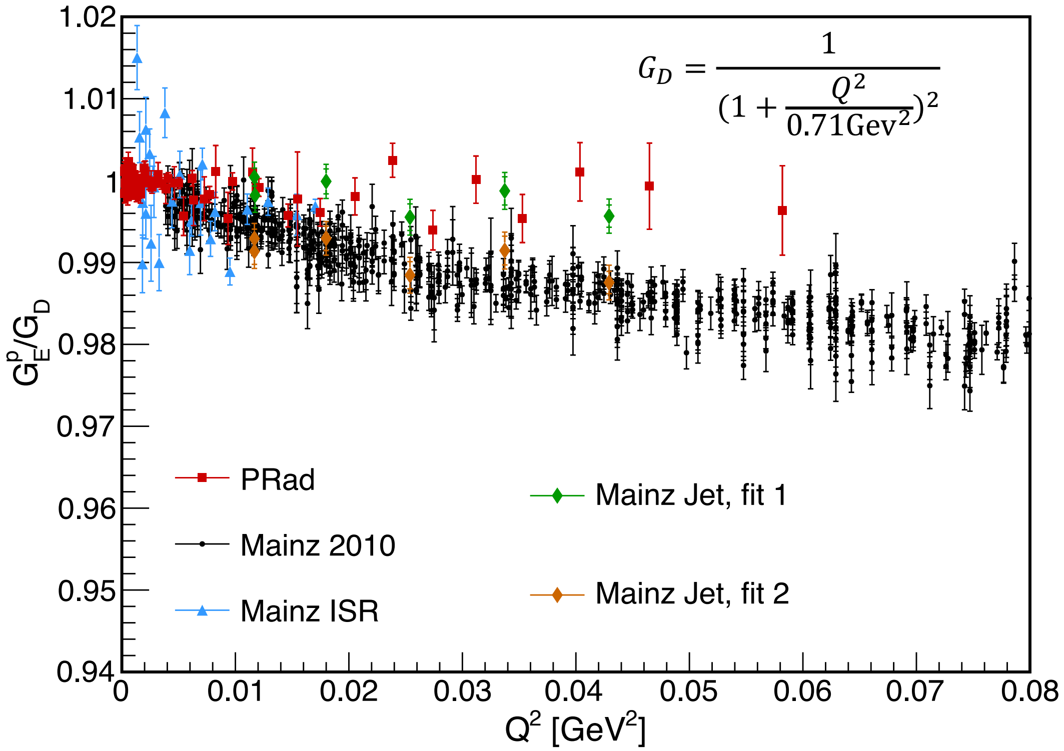


Weizhi Xiong

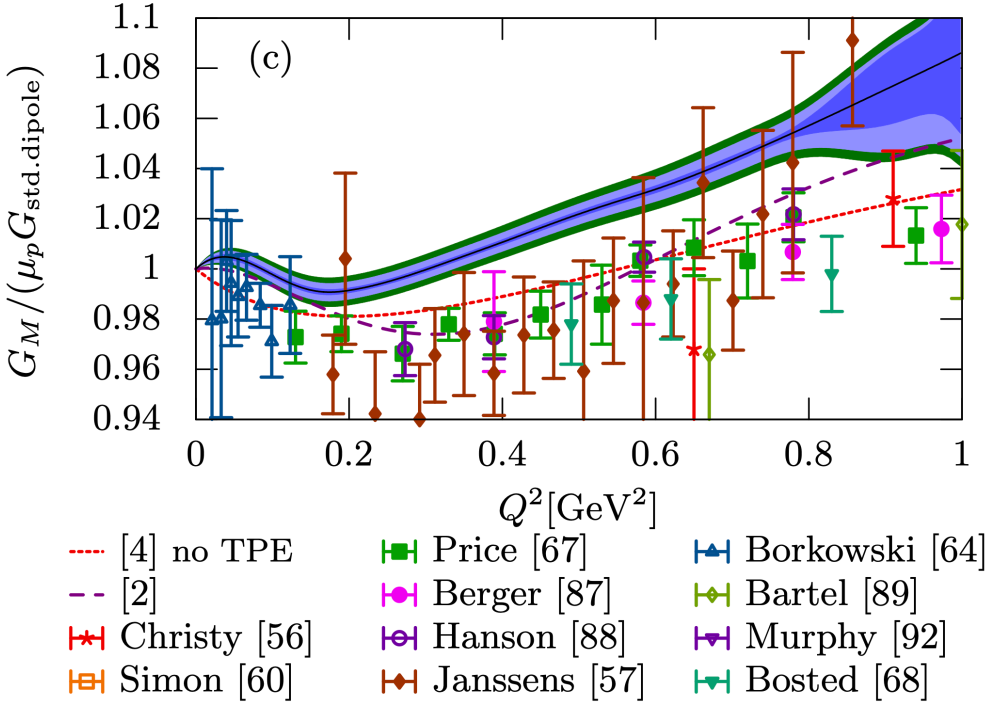
Yet Some Other Form Factor Puzzles

- Over 1% difference for G_E between the PRad data and the Mainz data
  - Possible reasons: radiative correction? Unknown systematics? Fitting procedure?...

- Large discrepancy also exist for for magnetic radius and G_M
  - ➢ 0.776(38) fm for Mainz data , 0.914(35) fm for world data excluding Mainz (G. Lee *et al.* PRD 92 013013)



WX and Chao Peng (彭潮) *Universe* 9 (2023) 4, 182



J. Bernauer et al. *PRC* 90 (2014) 1, 015206

Highlights of Future Lepton Scattering Experiments

Muon scattering

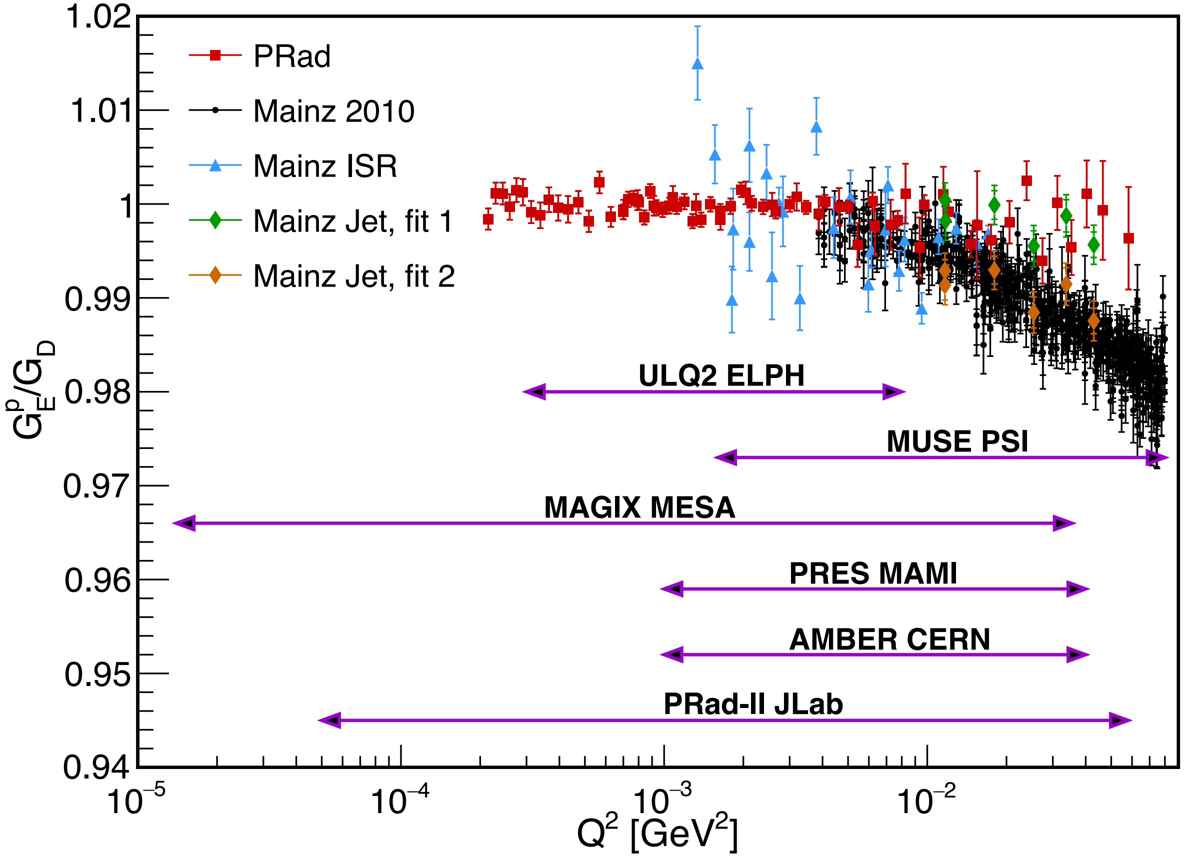
- MUSE exp. at PSI
  - First r_p measurement using muon
  - 4 types of incident leptons: $e^{\pm}$ and $\mu^{\pm}$
- AMBER exp. at CERN
  - 100 GeV muon beam, detecting scattered muon and recoiled proton
  - Ultra-small scattering angle, minimize G_M
  - Smaller RC for muon

Electron scattering

- Prad-II exp. at JLab
  - ultra-precise rp measurement (~4 times smaller uncertainty than PRad)
- PRES exp. at Mainz
  - detecting both scattered electron and recoiled proton
- MAGIX exp. at Mainz
  - Using jet target
- ULQ2 exp. at Tohoku University, Japan
  - Normalize to the well-known e-^{12}C cross section

No μ-p scattering result yet

Projected Q^2 coverage



WX and Chao Peng (彭潮) *Universe* 9 (2023) 4, 182

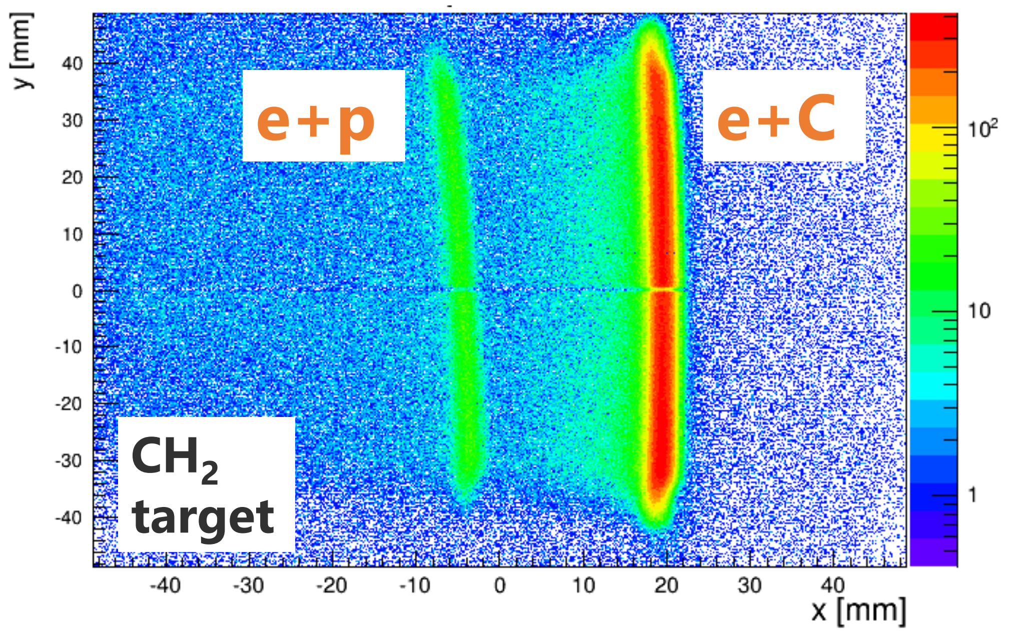
Highlights of Ongoing Lepton Scattering Experiments (ULQ2)

- ULQ2 @Tohoku University, Japan
- 10-65 MeV electron beam
- Using CH2 target, normalize to *e-^{12}C* cross-section
- Projected uncertainty for G_E ~0.1%
- Q^2: 3 x 10^{-4} ~ 8 x 10^{-3} GeV^2

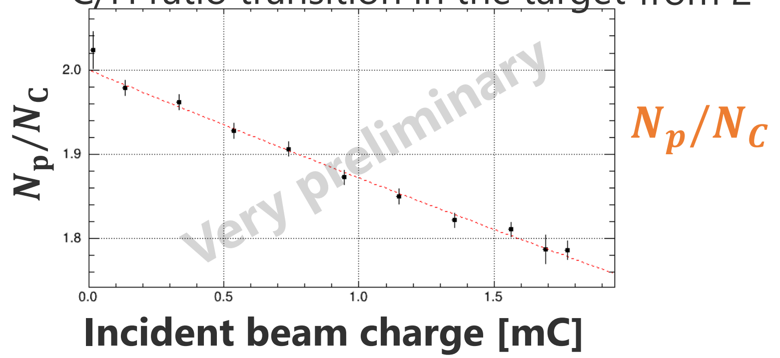
- Data taking almost finished, expect results this year

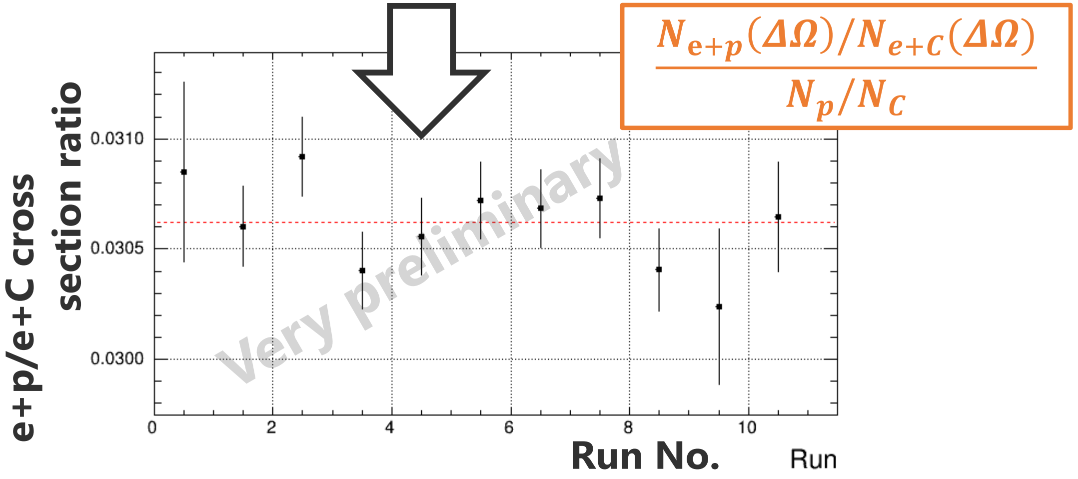
$$\left(\frac{d\sigma}{d\Omega}\right)_{e+p} = \frac{N_{e+p}(\Delta\Omega)/N_{e+C}(\Delta\Omega)}{N_p/N_C}\boxed{\left(\frac{d\sigma}{d\Omega}\right)_{e+C}}$$

Precisely calculatable



C/H ratio transition in the target from 2nd spectrometer

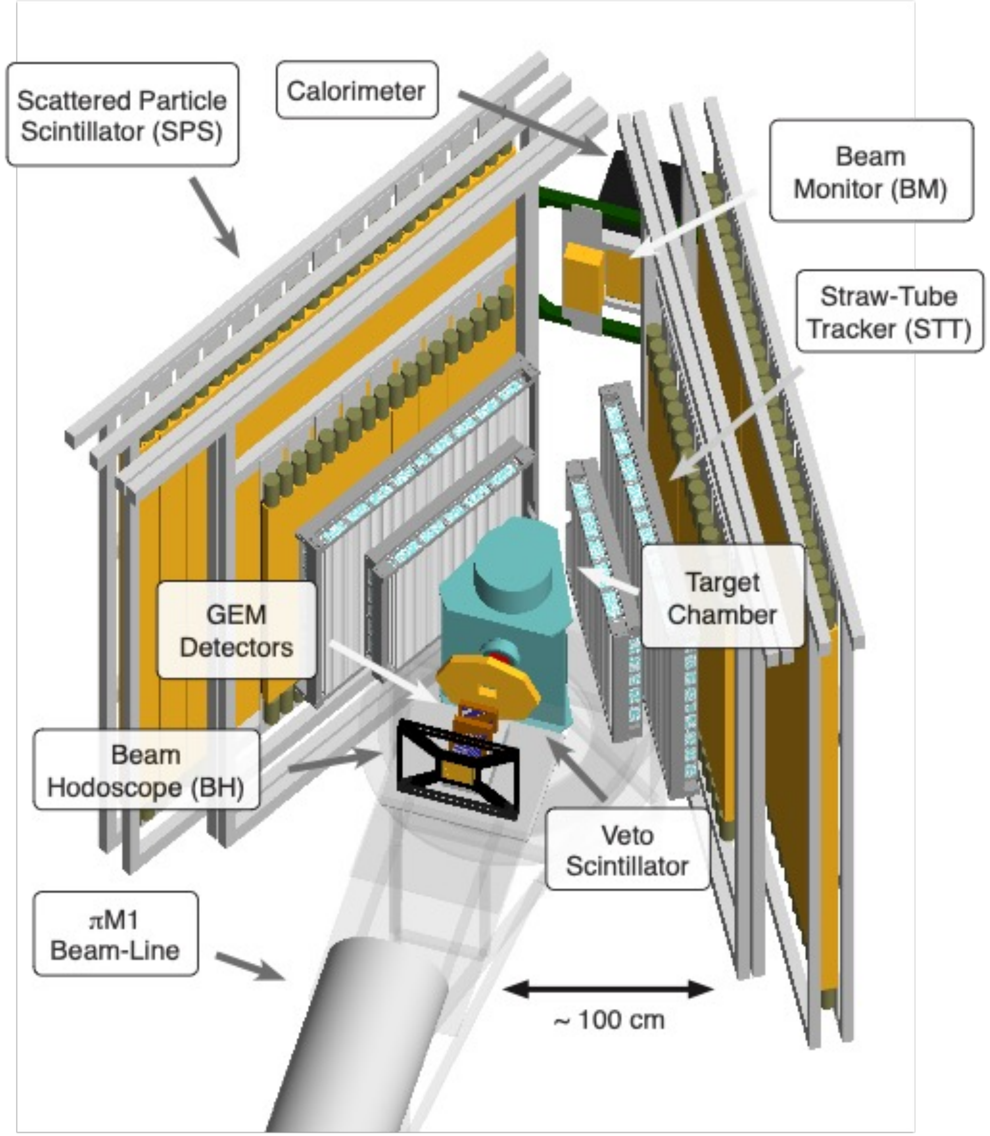




Plots from Yuki Honda (slides @ NREC 2024)

Highlights of Ongoing Lepton Scattering Experiments (MUSE)

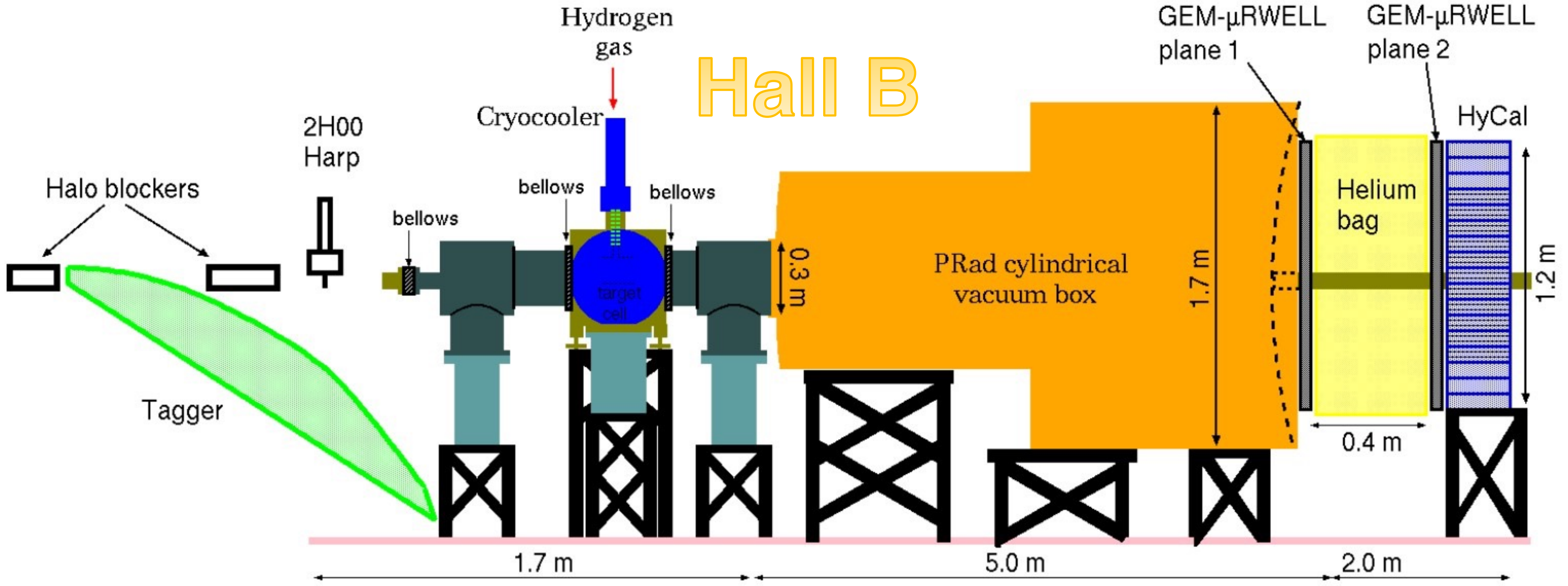
- First r_p measurement using muon
    - 4 types of incident leptons: $e^{\pm}$ and $\mu^{\pm}$
- Direct test for lepton-universality violation
- Different beam polarity can constrain two-photon exchange
- Currently taking data at PSI



Plot by Prof. S. Strauch

PRad-II Experiment

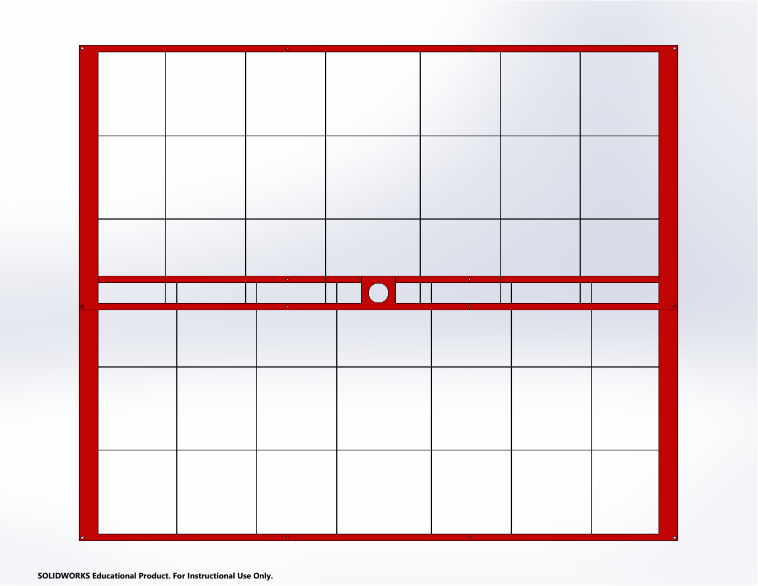
- JLab PAC 48 approved PRad-II (PR12-20-004) with the highest scientific rating “A”
- Goal: reach ultra-high precision (~4 times smaller total uncertainty), resolve tension between modern *e-p* scattering results
  - ➢ Additional new GEM plane
  - ➢ Full DAQ and readout system upgrade
  - ➢ New scintillating detector, help reaching $Q^2 \sim 10^{-5}$ GeV^2

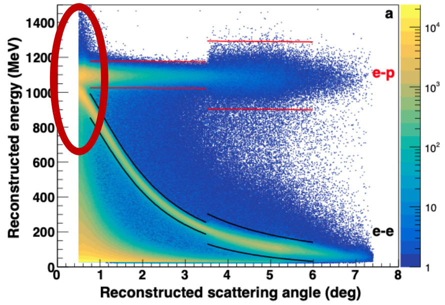


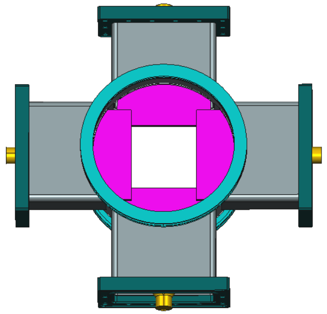
Weizhi Xiong

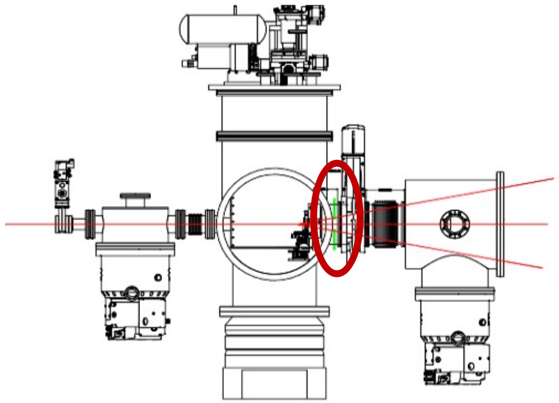
PRad-II Experiment

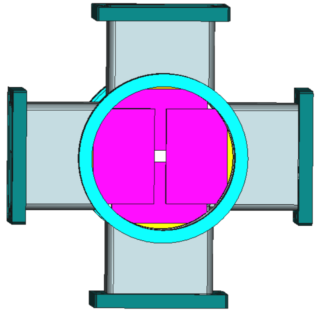
- 4 new GEM chambers to assemble 2 tracking layers.
  - ➢ All GEM parts expected by September/October, expect to complete the detector fabrication by March 2025.
  - ➢ All readout electronics ordered, expected by this November.
  - ➢ Will be ready for installation and testing by mid- spring, 2025.











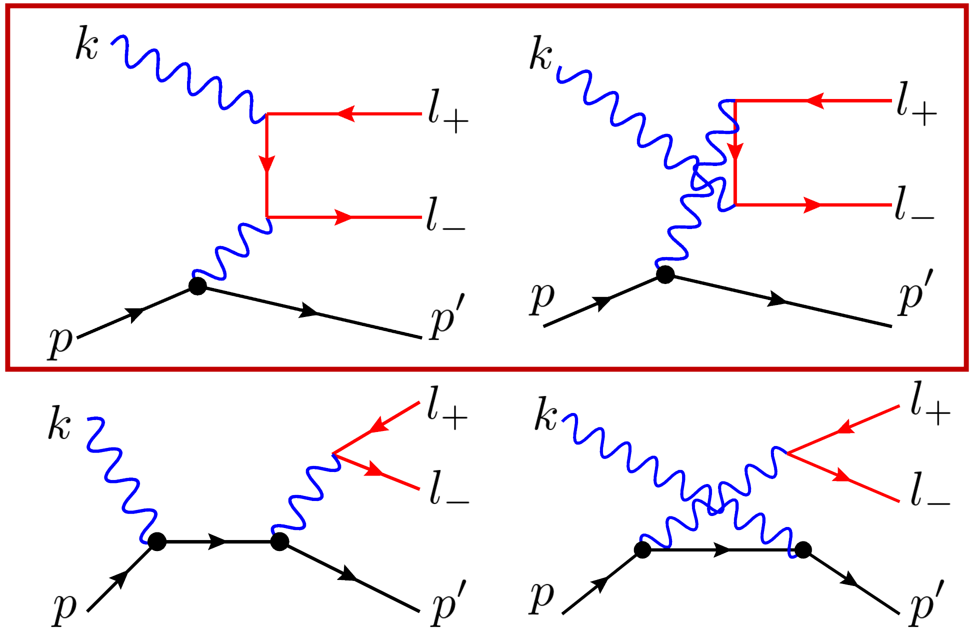
- 4 movable scintillator detectors placed next to the H2 gas flow target chamber.
  - ➢ Conceptual design done, engineering design in progress
  - ➢ Manufacturing: by Spring, 2025
  - ➢ Estimated time for test in beamline: Summer, 2025.

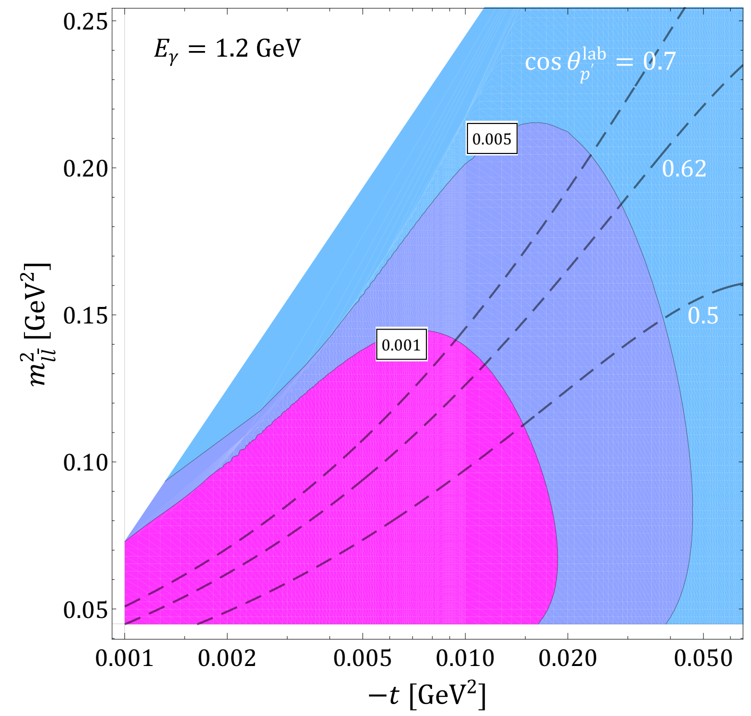
Highlights of Future Lepton Scattering Experiments (PRad-II)

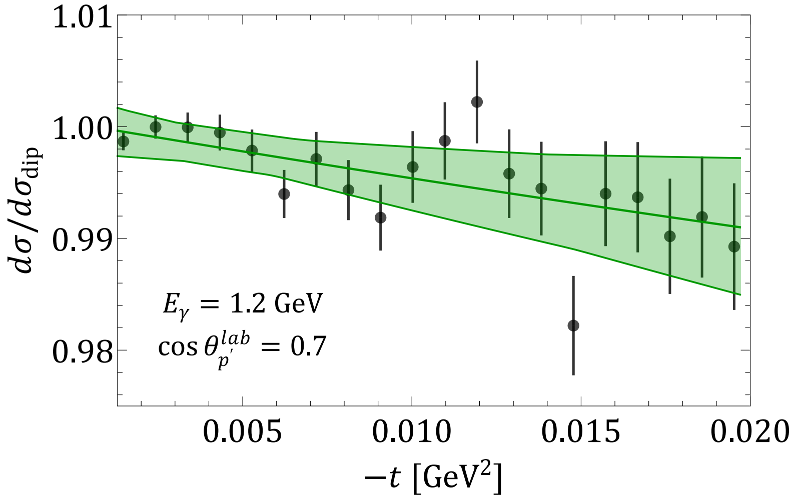
- All FASTBUS crates with power supplies removed
- 5 new VXS crates is planned to install in next few weeks
- HyCal recently re-positioned and ready to start the work
- Planned to finish all tests during this summer/fall period

New Method for r_p Measurement Using Muon

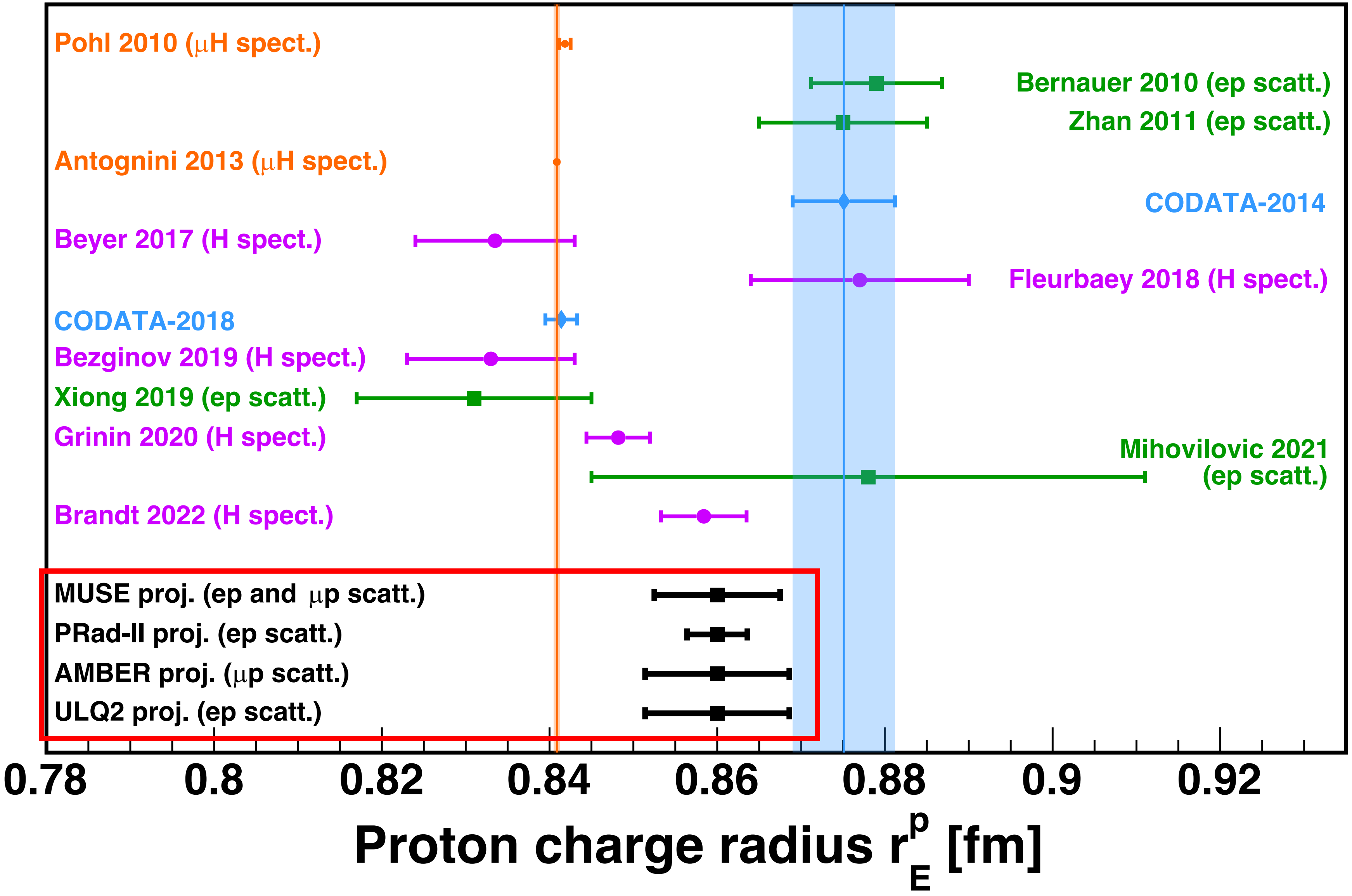
- Proton charge radius measurement using di-muon photoproduction off Proton
  - arXiv:2407.20375, Yong-Hui Lin, Feng-Kun Guo, Ulf-G. Meißner
- BH process contain same hadronic operator as μp elastic scattering, possible for r_p measurement







Projected Results for Future Lepton Scattering Exp.



PRad/PRad-II Collaboration

Duke University, NC A&T State University,
Mississippi State University, Idaho State University,
University of Virginia, Jefferson Lab,
Argonne National Lab,
University of North Carolina at Wilmington,
Kharkov Institute of Physics and Technology,
MIT, Old Dominion University, ITEP,
University of Massachusetts, Amherst
Hampton University, College of William & Mary,
Norfolk State University, Yerevan Physics Institute
Shandong University

PRad-II

Graduate students:
Yining Liu (Duke)
Erik Wrightson (MSU)
Buddhiman Tamang(MSU)
Yuan Li (SDU)

Post-docs:
Tyler Hague (NC A&T/LBNL)
Aruni Nadeeshani(MSU)

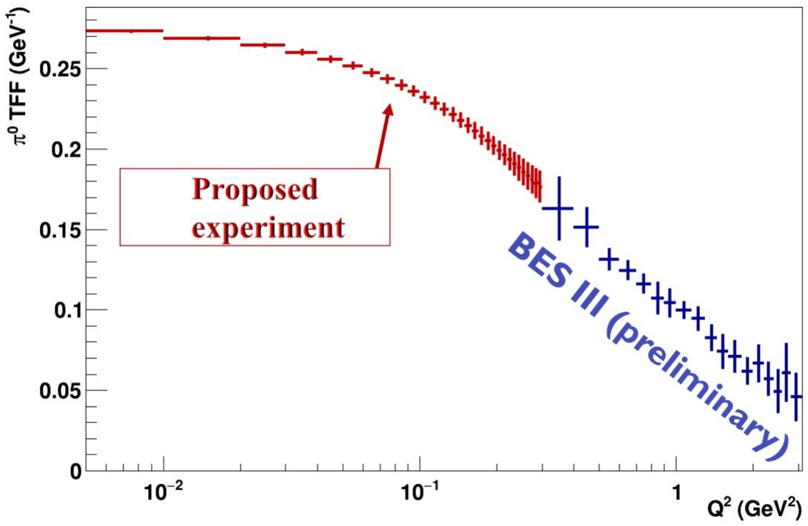
PRad

Graduate students (Thesis students):
Chao Peng (Duke)
Li Ye (MSU)
Weizhi Xiong (Duke)
Xinzhan Bai (UVa)

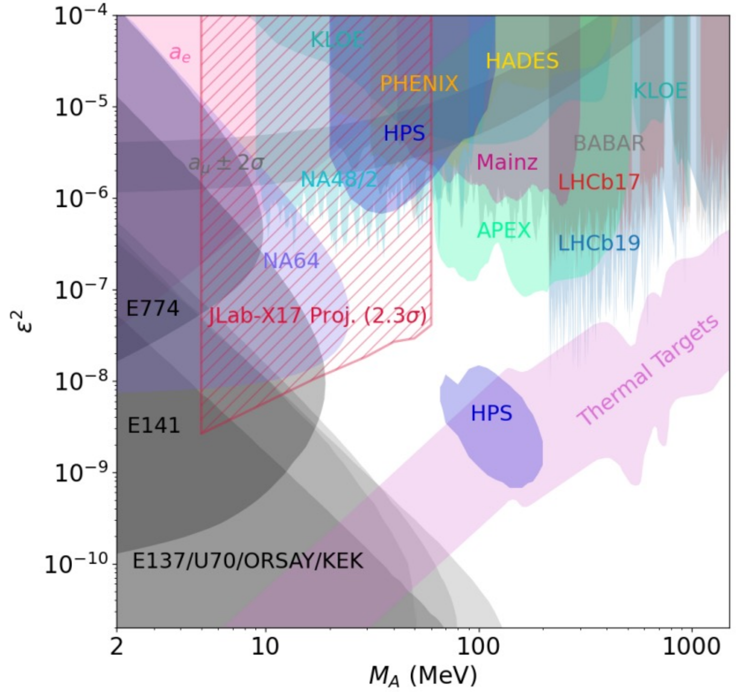
Post-docs:
Chao Gu (Duke)
Xuefei Yan (Duke)
Mehdi Meziane (Duke)
Krishna Adhikari (MSU)
Maxime Lavillain (NC A&T)
Latif-ul Kabir (MSU)

Other Experiments with PrimEx/PRad Setup

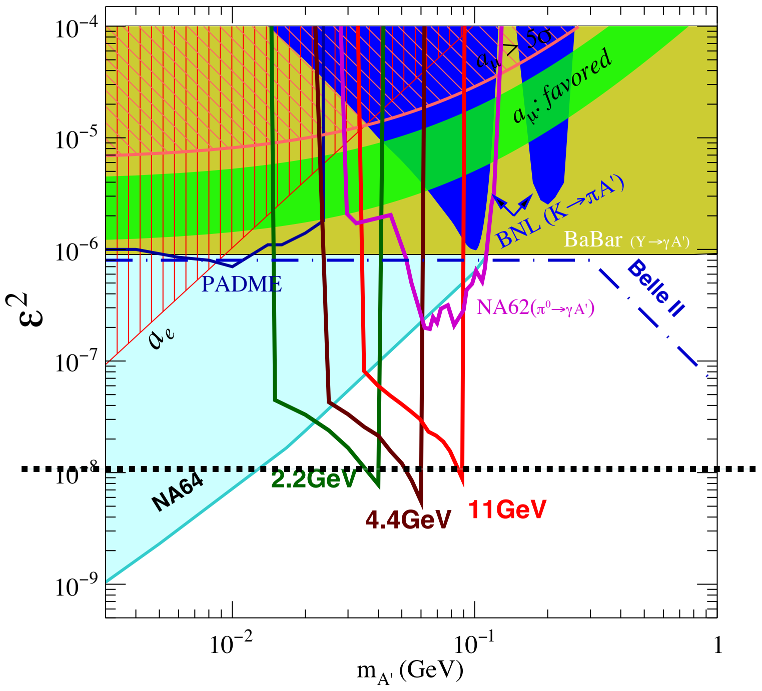
Precision Measurement of the Neutral Pion Transition Form Factor
Rate A-, 67 days



A Direct Detection Search for Hidden Sector New Particles in the 3-60 MeV Mass Range
Rate A, 60 days



A Dark Photon Search with a JLab Positron Beam
Rate A-, 55 days



Summary

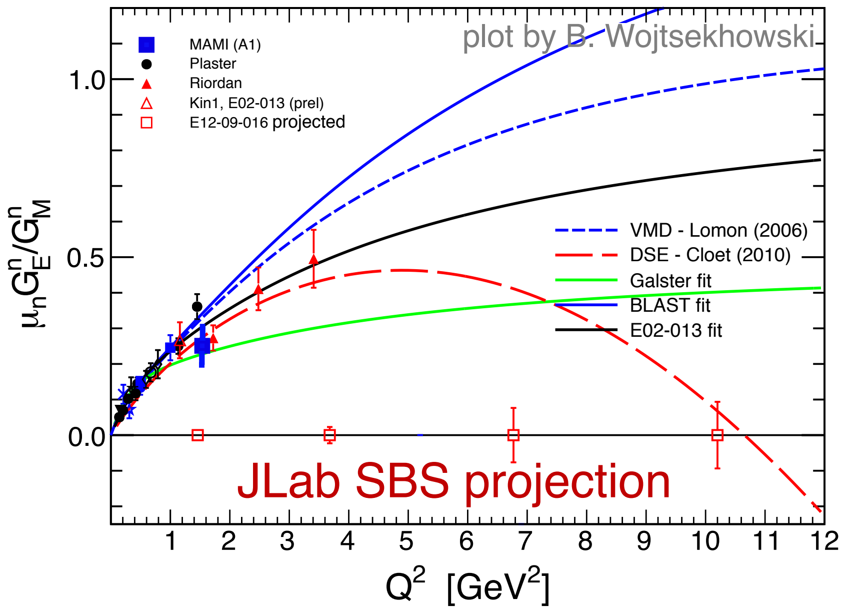
- Puzzle considered partially resolved, but many problems remain
  - ➢ Tensions between some new H spec. results
  - ➢ Form factor difference between PRad and Mainz data
  - ➢ New physics may still be there

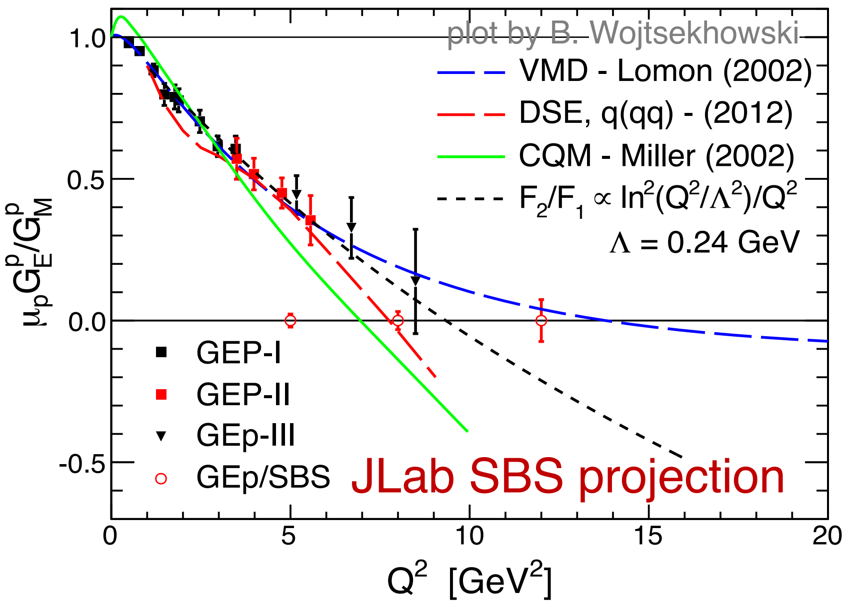
- Many future experiments on proton charge radius and form factors, and push precision frontier
  - New uH measurement for 1S HFS, 2S-2P transition…
  - First r_p measurement using muon scattering: MUSE and AMBER
  - PRad-II experiment with $\delta_r \sim 0.0036$ fm, aim to be most precise scattering result, new search for lepton-universality violation
    - Ready for ERR review in Fall 2024
    - Experiment ready to run from Fall 2025

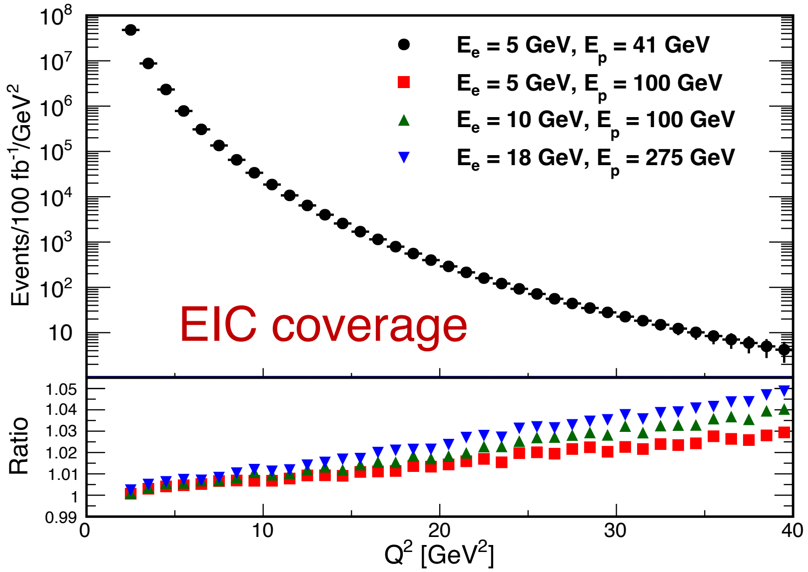
Backup

High-Q2 Form Factor Program at JLab, EIC and EicC

- Lots of high-precision data in the future from JLab (SBS and CLAS12), EIC and EicC
- Test various model predictions:
  - DSE (I. Cloet et al. PRC 86, 015208 (2012))
  - VMD (E. Lomon et al PRC 66, 045501 (2002))
  - GPD-Based (M. Diehl et al. EPJC **39**, 1–39 (2005))
  - pQCD (W. Chen et al. arXiv:2406.19994)
  - …
- For proton charge radius, low Q2 unpol. method is still the way to go (at least for now)

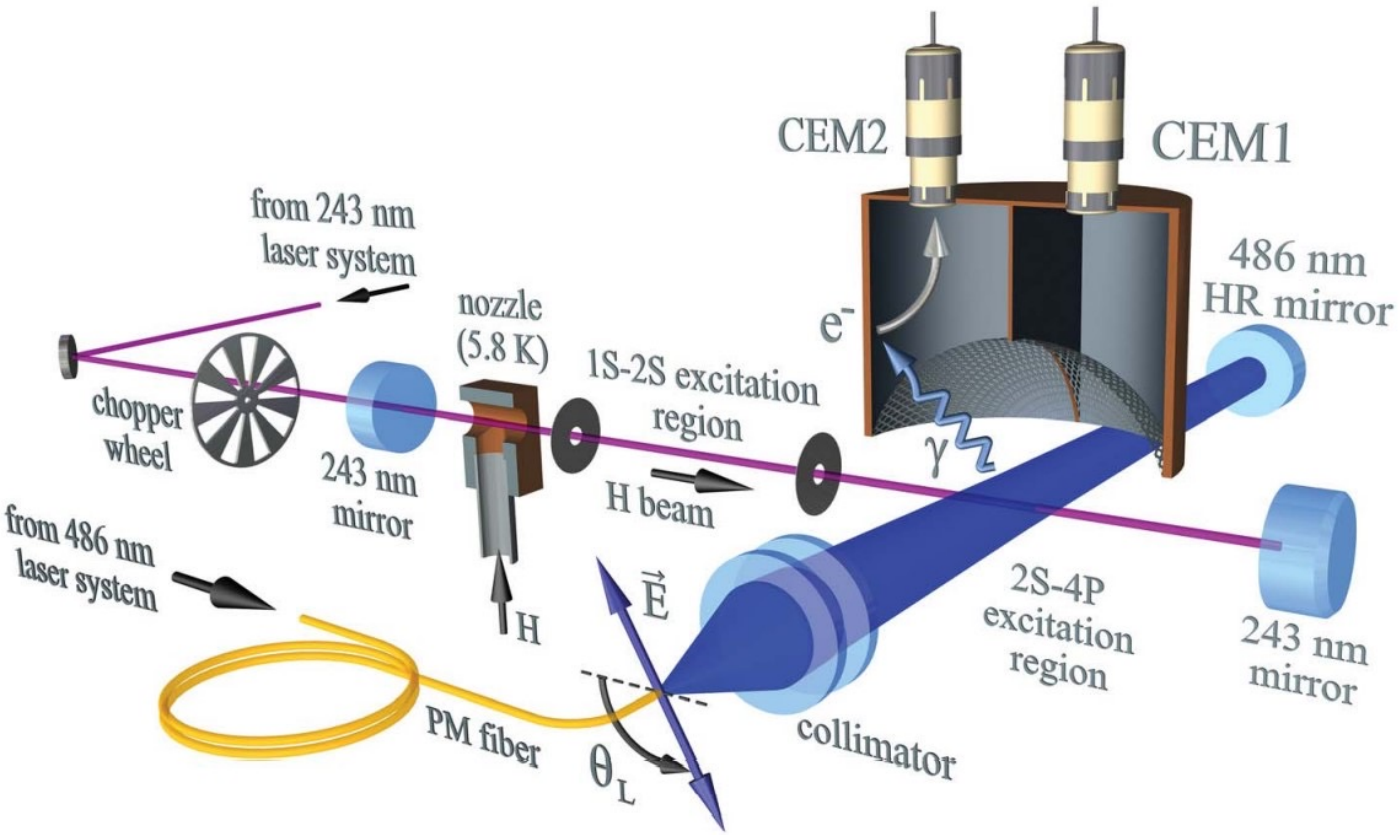


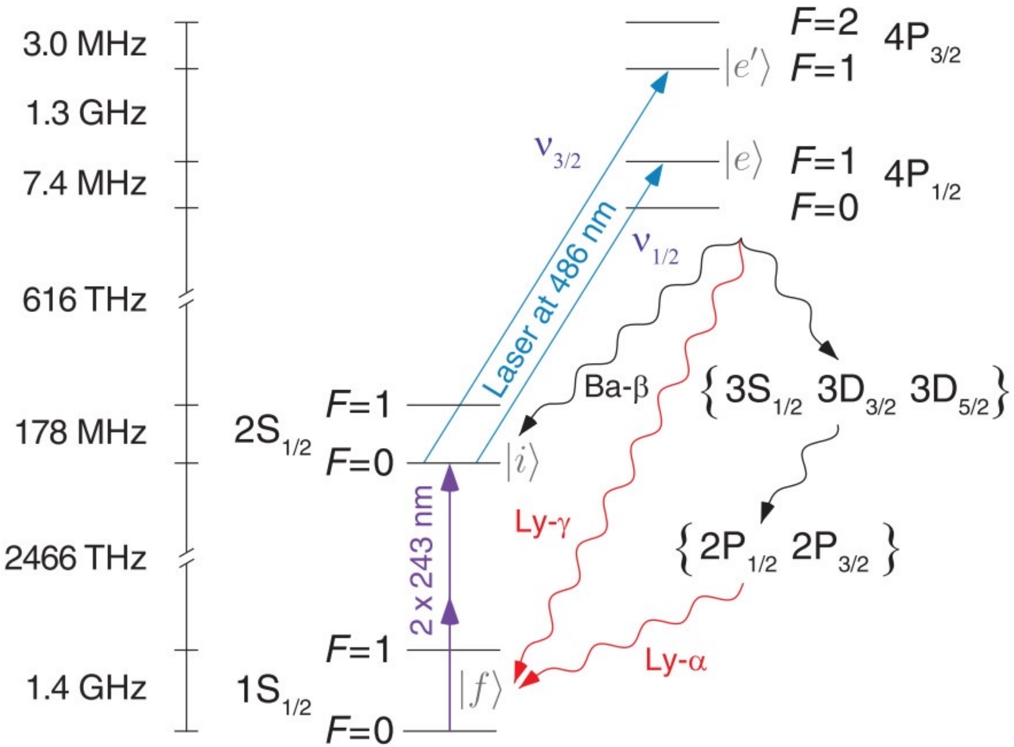




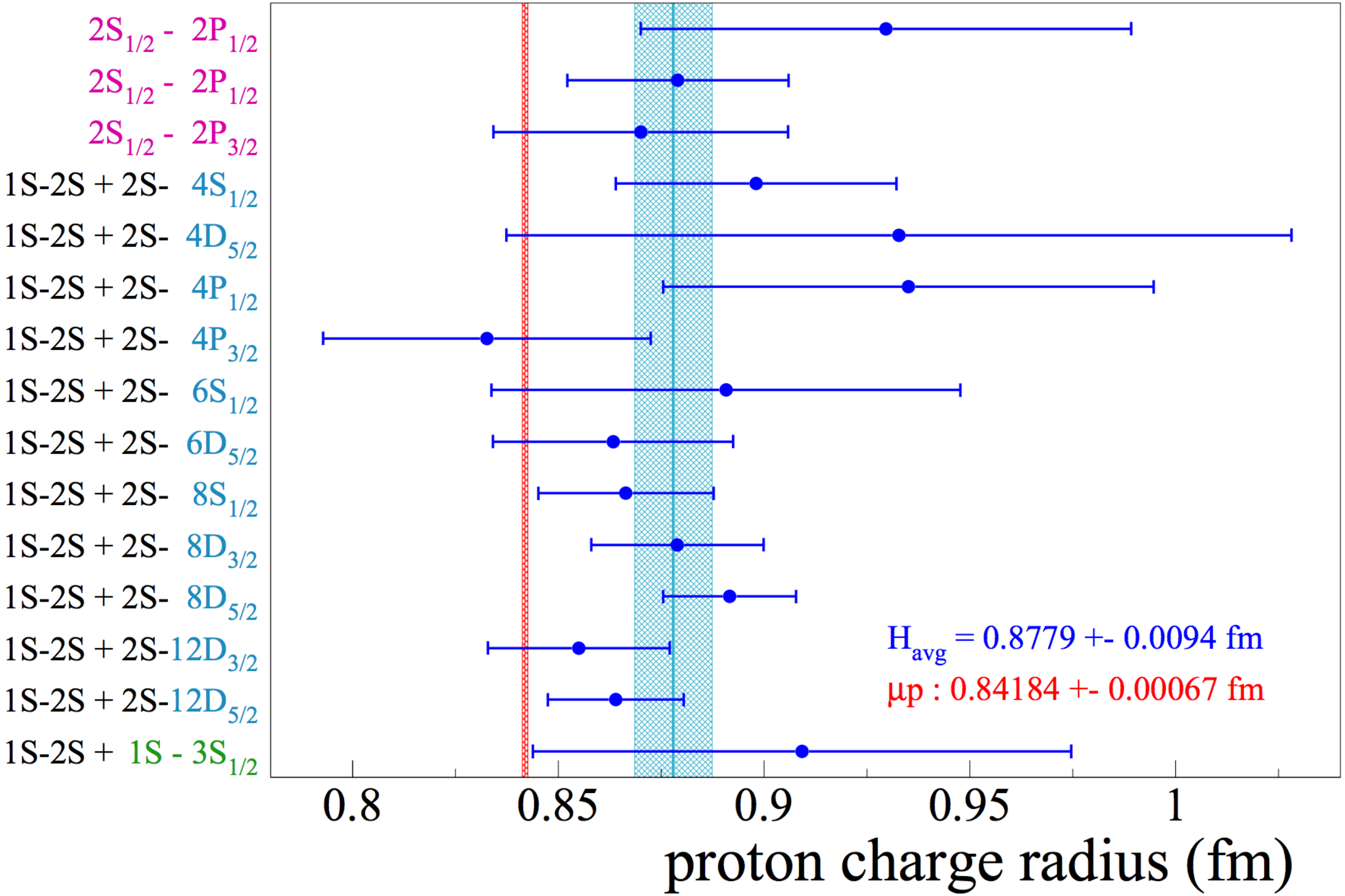
Ordinary Hydrogen Measurement

- Ordinary hydrogen 2S-4P transition measurement (A. Beyer *et al. Science* 358, 79-86 (2017))





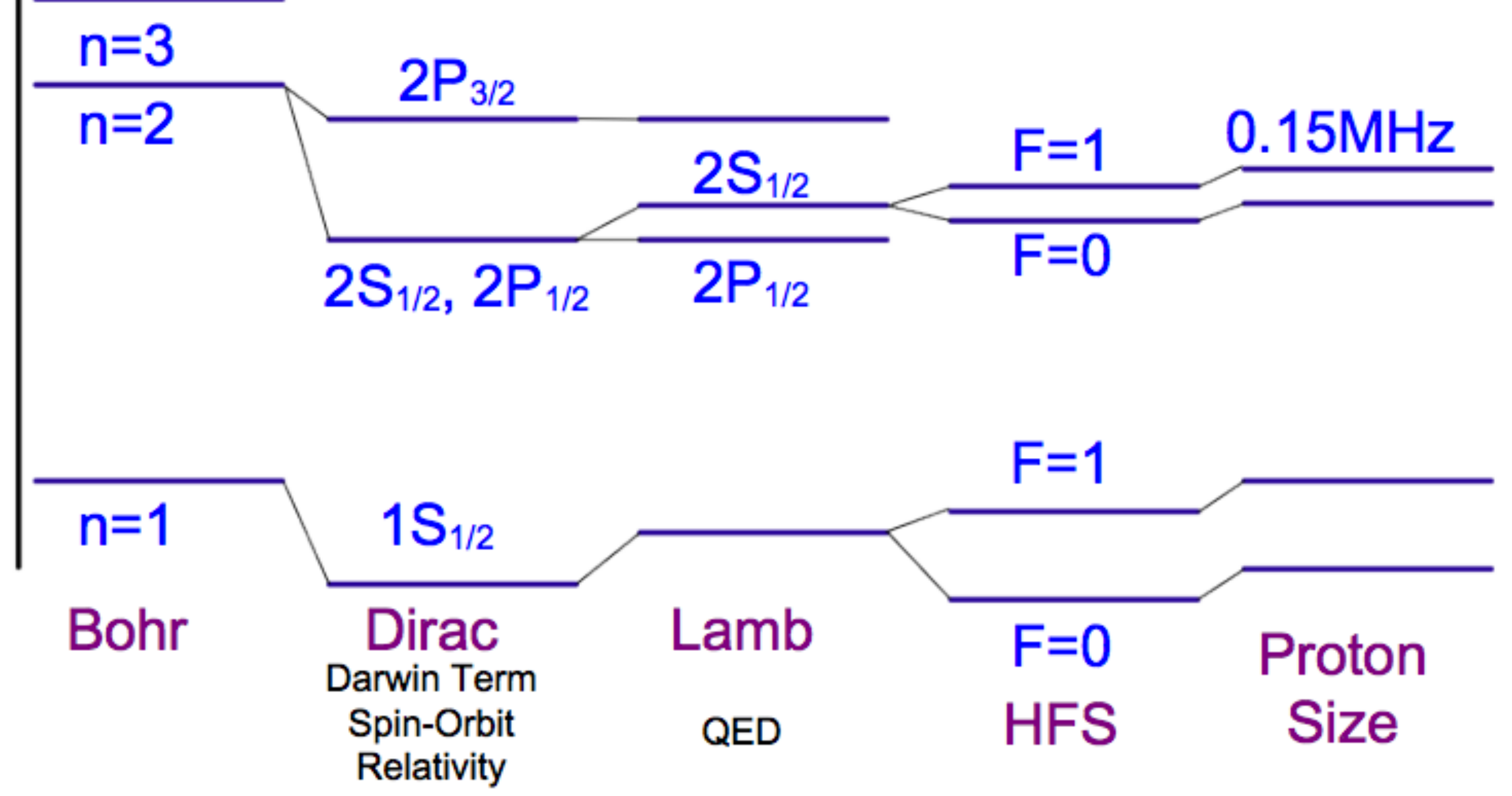
Ordinary Hydrogen v.s. Muonic Hydrogen



Weizhi Xiong

Hydrogen Spectroscopy

$$\Delta E = \underbrace{a \cdot R_\infty}_{\text{QED term}} + \underbrace{b \cdot r_p^2}_{\text{Proton radius term}}$$



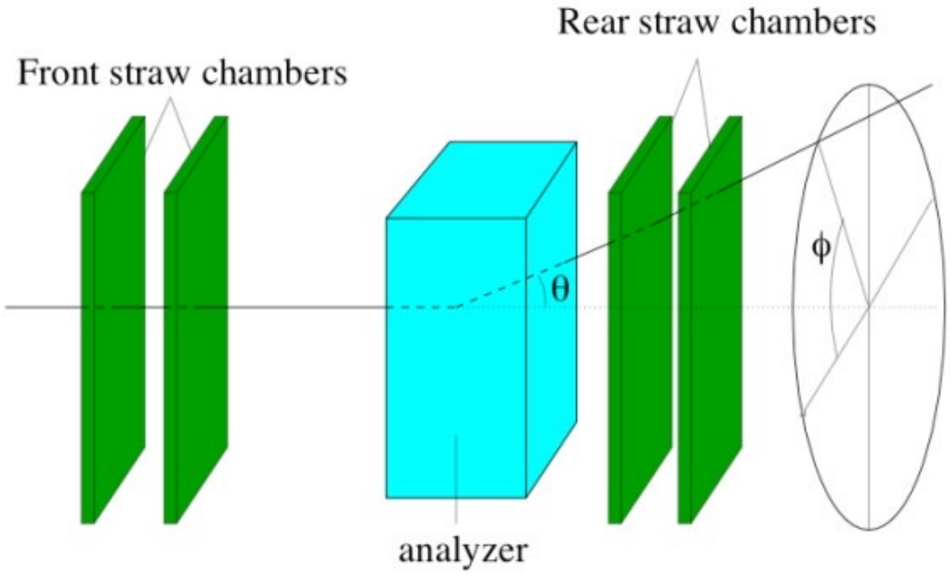
1. Small splitting measurements:
   - ➢ States with the same n
   - ➢ Precise knowledge of R_∞ not required
   - ➢ Independent measurement on r_p
2. Large splitting measurements:
   - ➢ States with different n
   - ➢ Precision on R_∞ not good enough
   - ➢ At least need two different transition
   - ➢ Solve for r_p and R_∞ at the same time

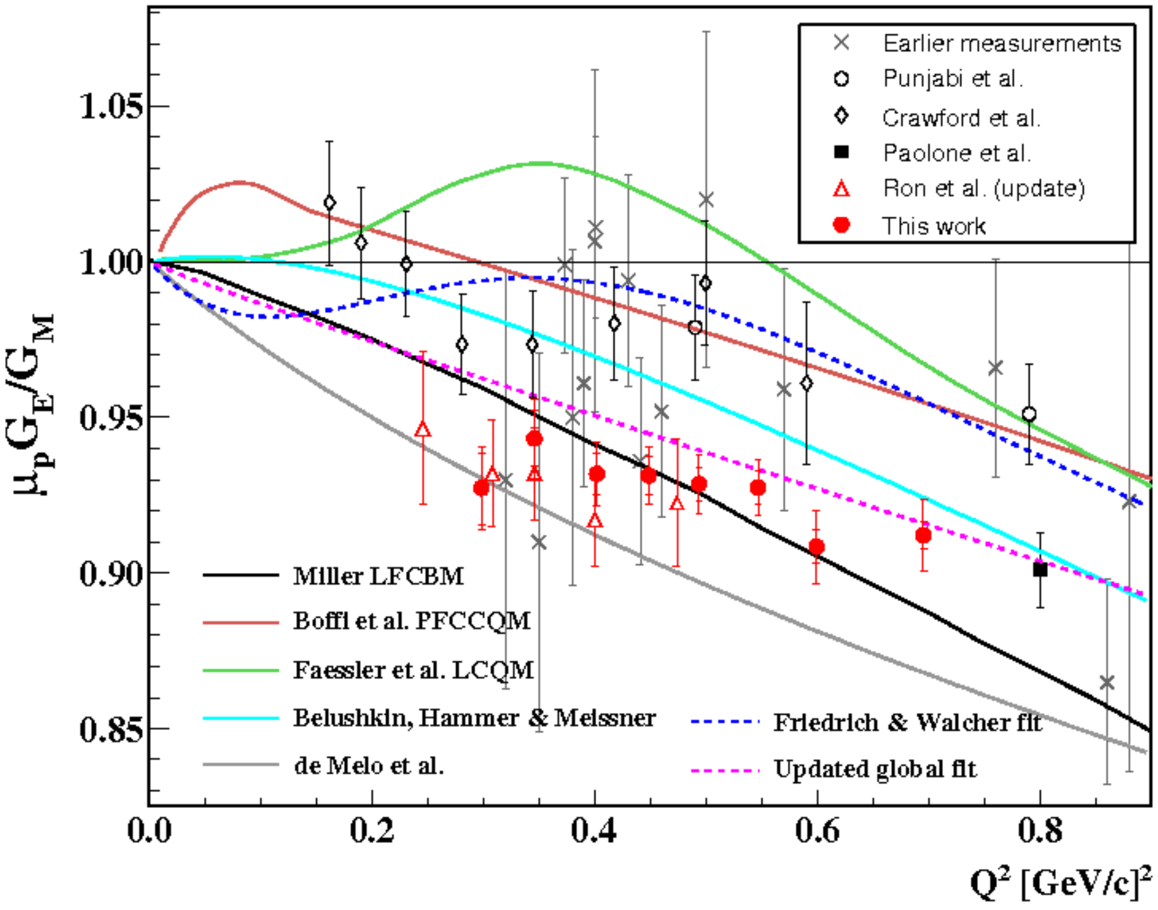
Polarized *ep* Elastic Scattering
(longitudinally polarized electron beam and recoil proton polarization measurement)

- Extract form factor ratio by measuring polarization of recoil proton:

$$\boxed{\frac{G_E}{G_M} = -\frac{P_y}{P_z}\frac{E+E'}{2m}\tan\frac{\theta_e}{2}.}$$

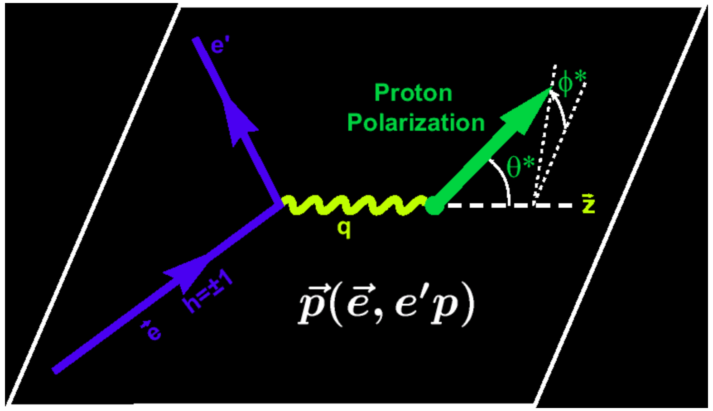
- Couple with cross section measurement to separate form factors
- Reduce many typical systematics for RS

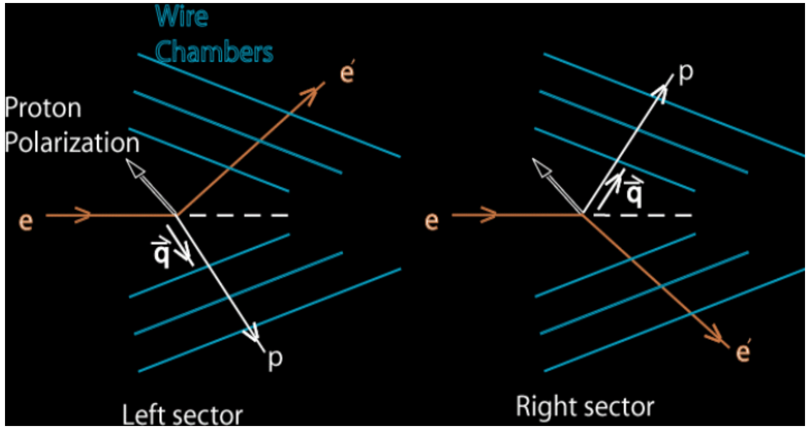




X. Zhan et al. Phys. Lett. B 705 (2011) 59-64

Polarized *ep* Elastic Scattering
(Polarized electron – polarized proton measurement)



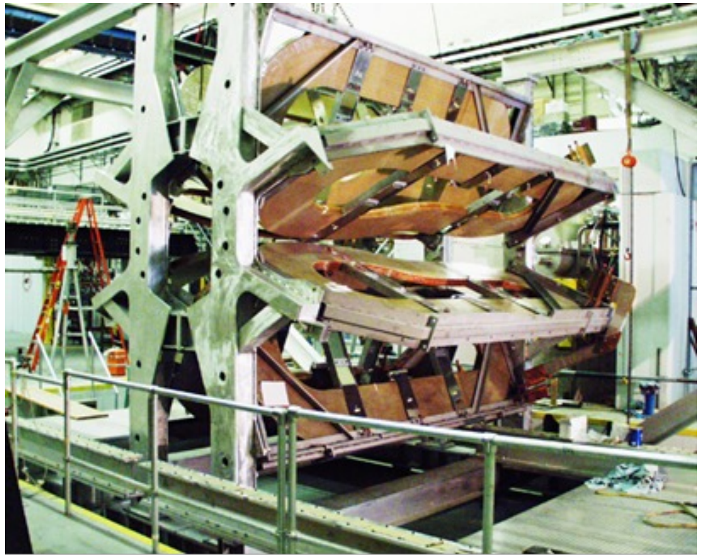


- Elastic scattering asymmetry (longitudinally polarized beam, polarized target):

$$A_{phys} = \frac{v_z \cos\theta^* G_M^{p\,2} + v_x \sin\theta^* \cos\phi^* G_M^p G_E^p}{(\tau G_M^{p\,2} + \epsilon G_E^{p\,2}) \;/\; [\epsilon(1+\tau)]},$$

$$A_{exp} = P_b P_t \, A_{phys}$$

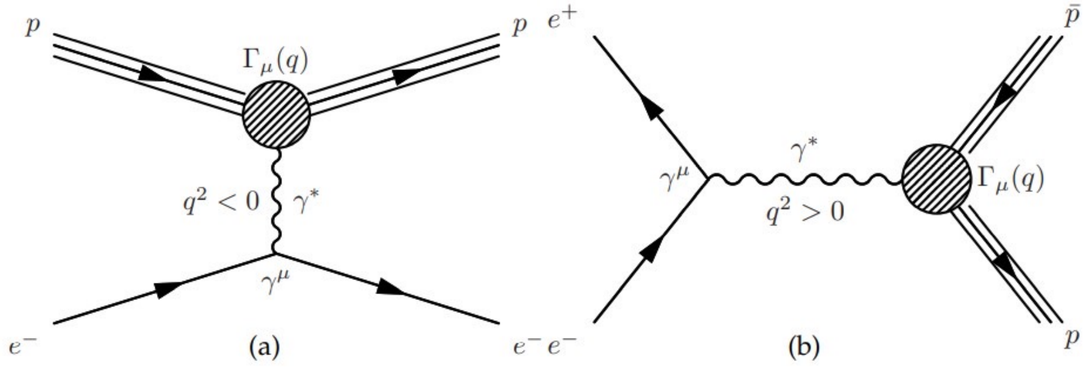
- Form factor ratio can be obtained from two experimental asymmetries (A_l and A_r), at same Q^2 but with different target spin orientations



BLAST pioneered the technique, later also used in Jlab Hall A experiment

Timelike Form Factor

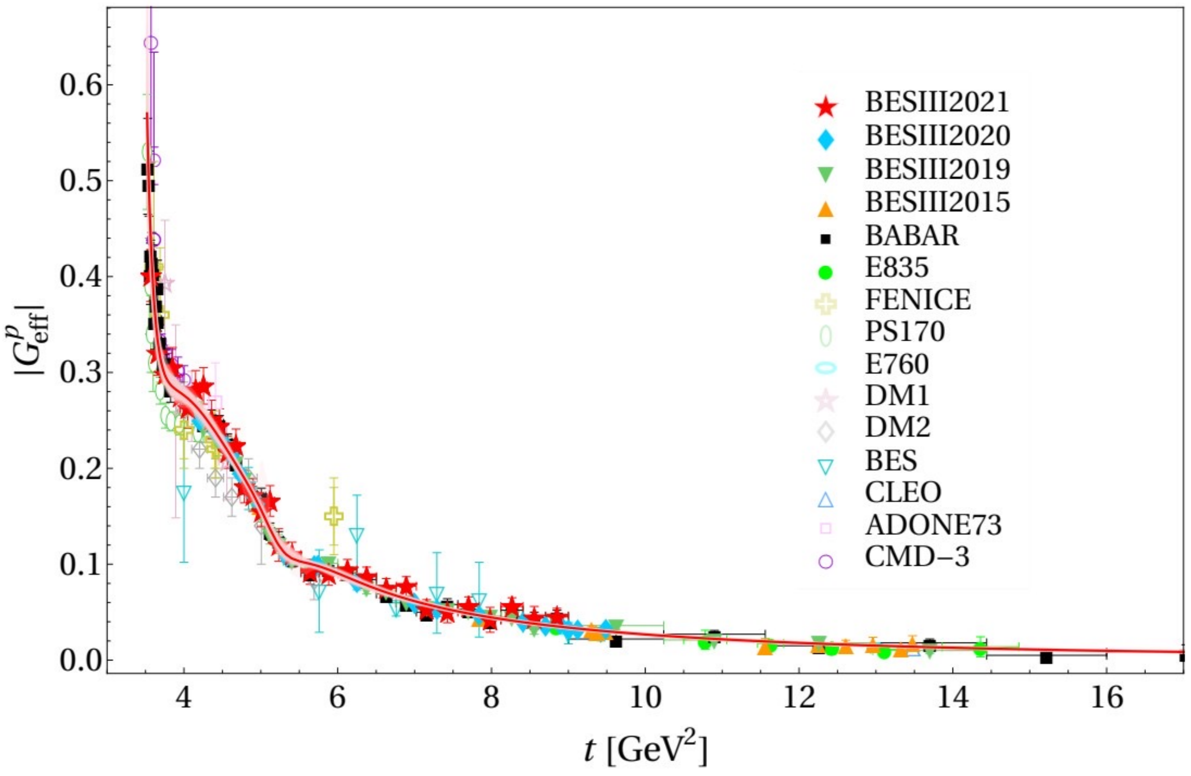
- EM form factor can also be measured in e+e- annihilation:



$$\sigma_{e^+e^-\to p\bar{p}}(t) = \frac{4\pi\alpha^2\beta}{3t}C(t)\left[|G_M(t)|^2 + \frac{2m_p^2}{t}|G_E(t)|^2\right]$$

$$\equiv \frac{4\pi\alpha^2\beta}{3t}C(q^2)\left(1+\frac{2m_p^2}{t}\right)|G_{\text{eff}}^p(t)|^2.$$

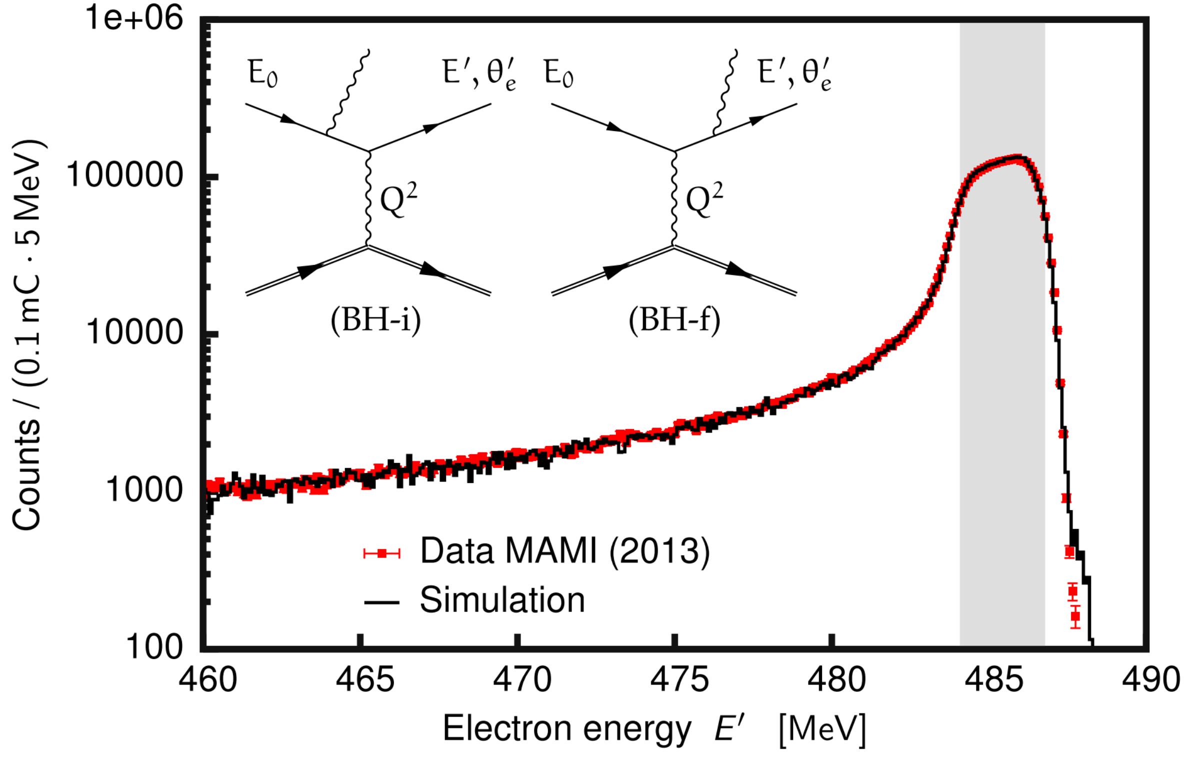
arXiv.2211.05419



$$|G_{\text{eff}}| \equiv \sqrt{\frac{|G_E|^2 + \xi|G_M|^2}{1+\xi}}$$

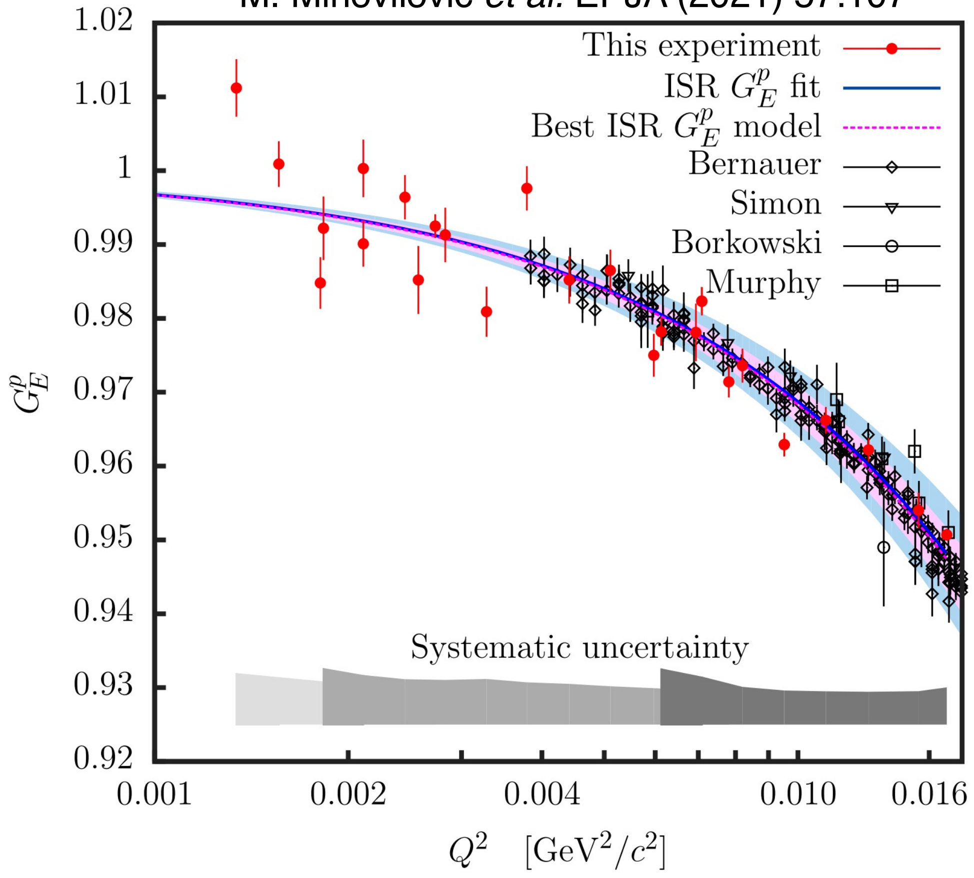
Mainz Initial State Radiation (ISR) Experiment

- Using ISR technique to reach lower Q^2: 0.001 to 0.016 GeV^2
- Final result: $r_p = 0.878 \pm 0.011_{stat.} \pm 0.031_{syst.} \pm 0.002_{mod.}$ fm



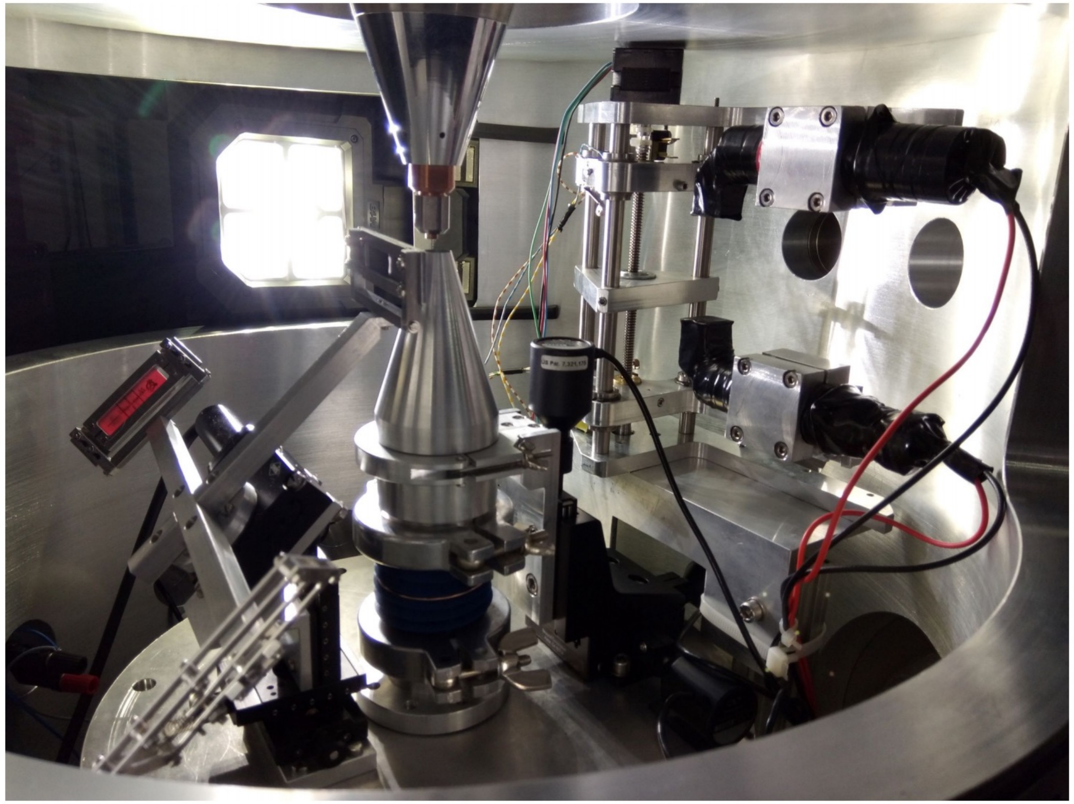
M. Mihovilovic *et al.* arXiv.1905.11182

M. Mihovilovic *et al.* EPJA (2021) 57:107

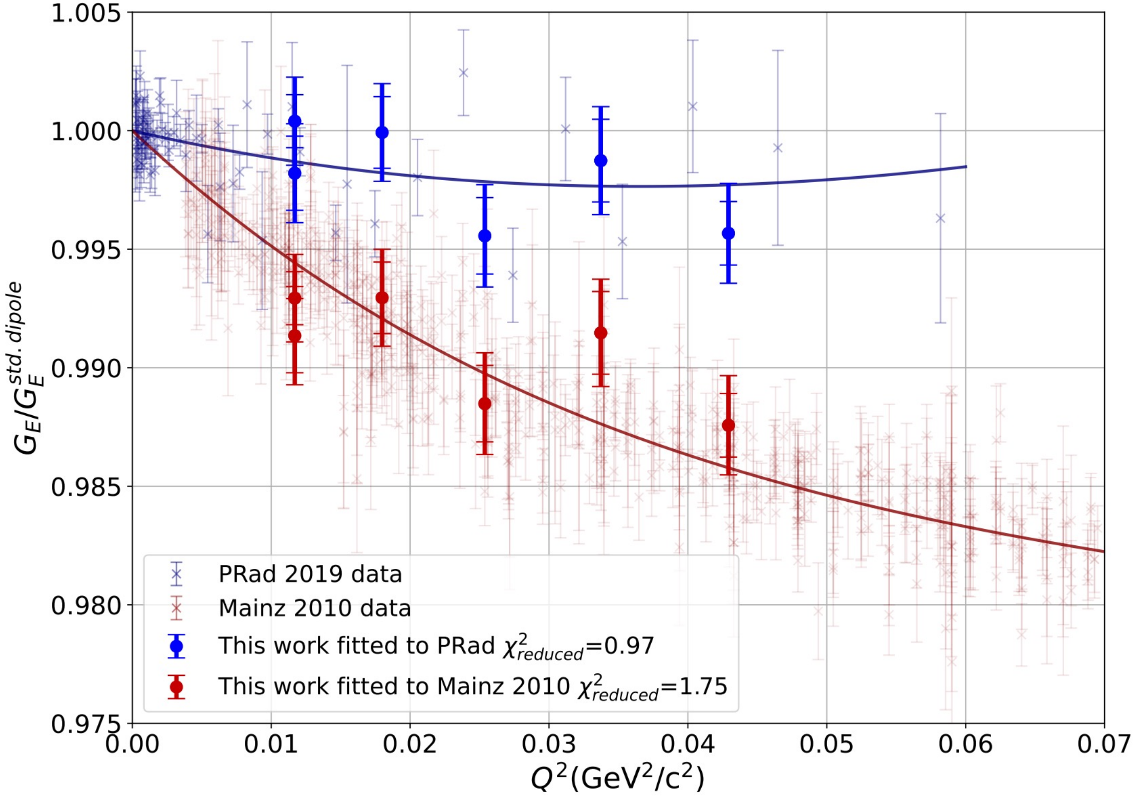


Mainz Jet Target Experiment

- Using novel gas-jet target, but limited by statistics
- Fit to PRad: $\chi^2_{reduced} = 0.97$, fit to Mainz $\chi^2_{reduced} = 1.75$



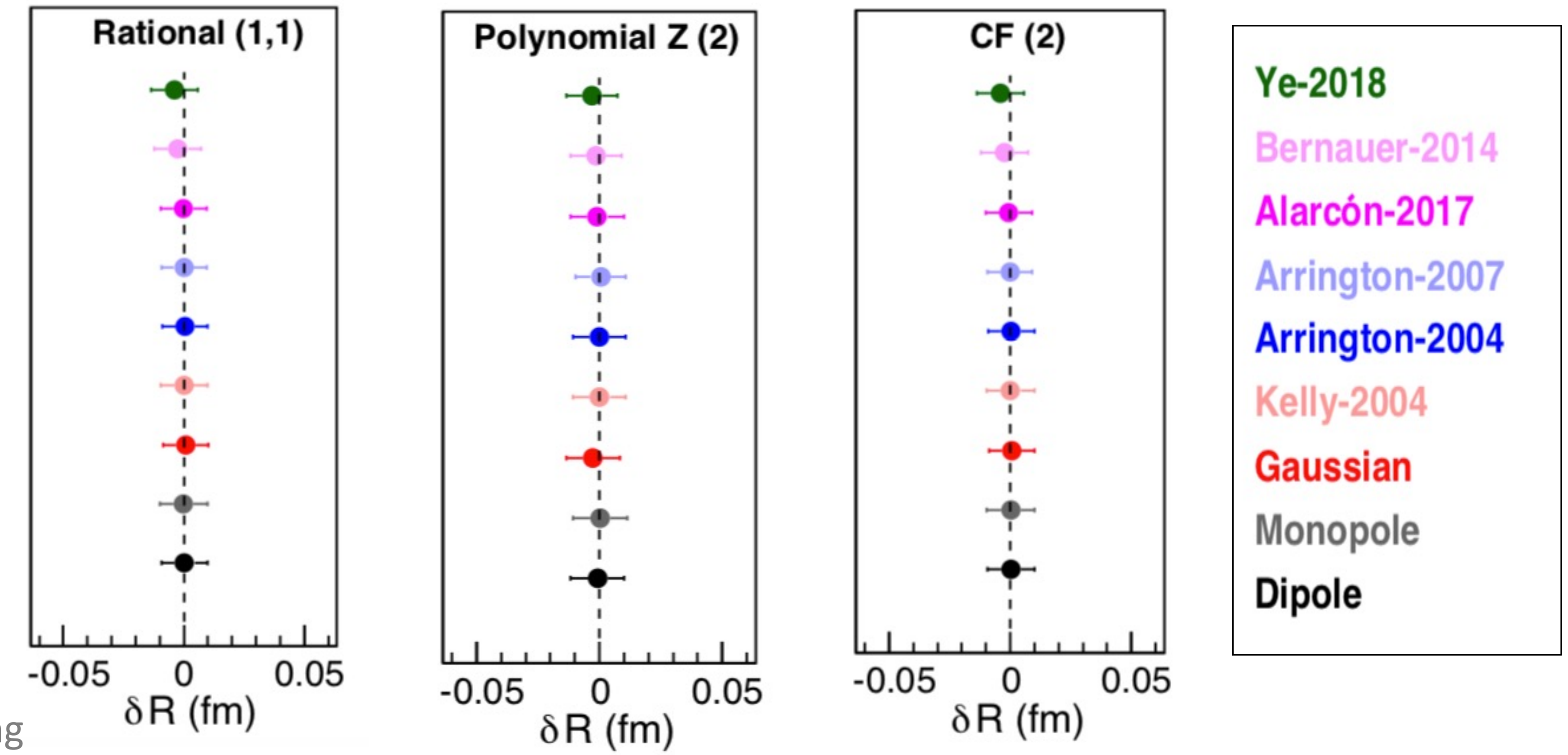
Y. Wang et al. PRC 106 (2022) 4, 044610



Searching the Robust Fitters

- Various fitters tested with a wide range of G_E parameterizations, using PRad kinematic range and uncertainties (X. Yan (严雪飞) *et al.* PRC 98, 025204 (2018))
- Rational (1,1), 2nd order z transformation and 2nd order continuous fraction are identified as robust fitters with also reasonable uncertainties
- Typically a floating parameter n is included to take care normalization uncertainties

$$f(Q^2) = n\, G_E^p(Q^2)$$



Rational (1,1)

$$\frac{1 + p_1 Q^2}{1 + p_2 Q^2}$$

2nd order z transformation

$$1 + p_1 z + p_2 z^2,$$

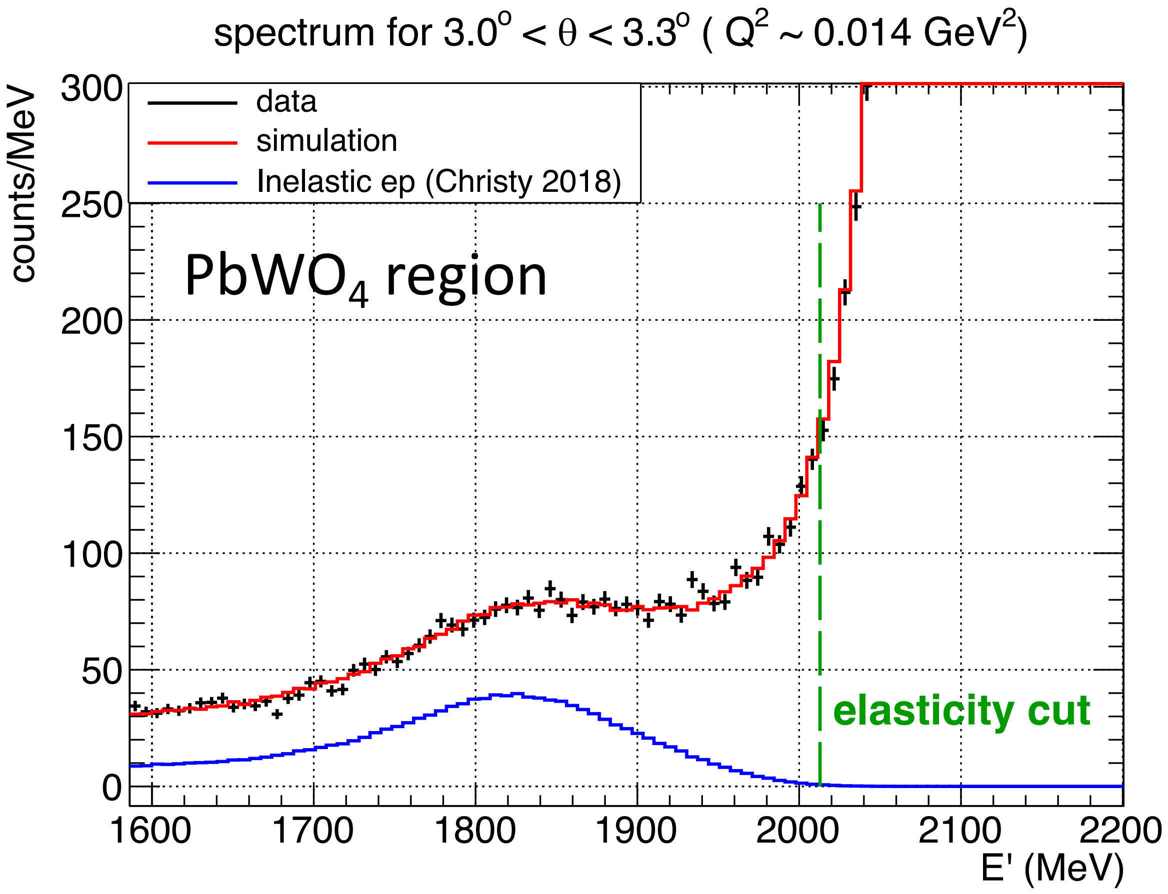
$$z = \frac{\sqrt{T_c + Q^2} - \sqrt{T_c - T_0}}{\sqrt{T_c + Q^2} + \sqrt{T_c - T_0}}$$

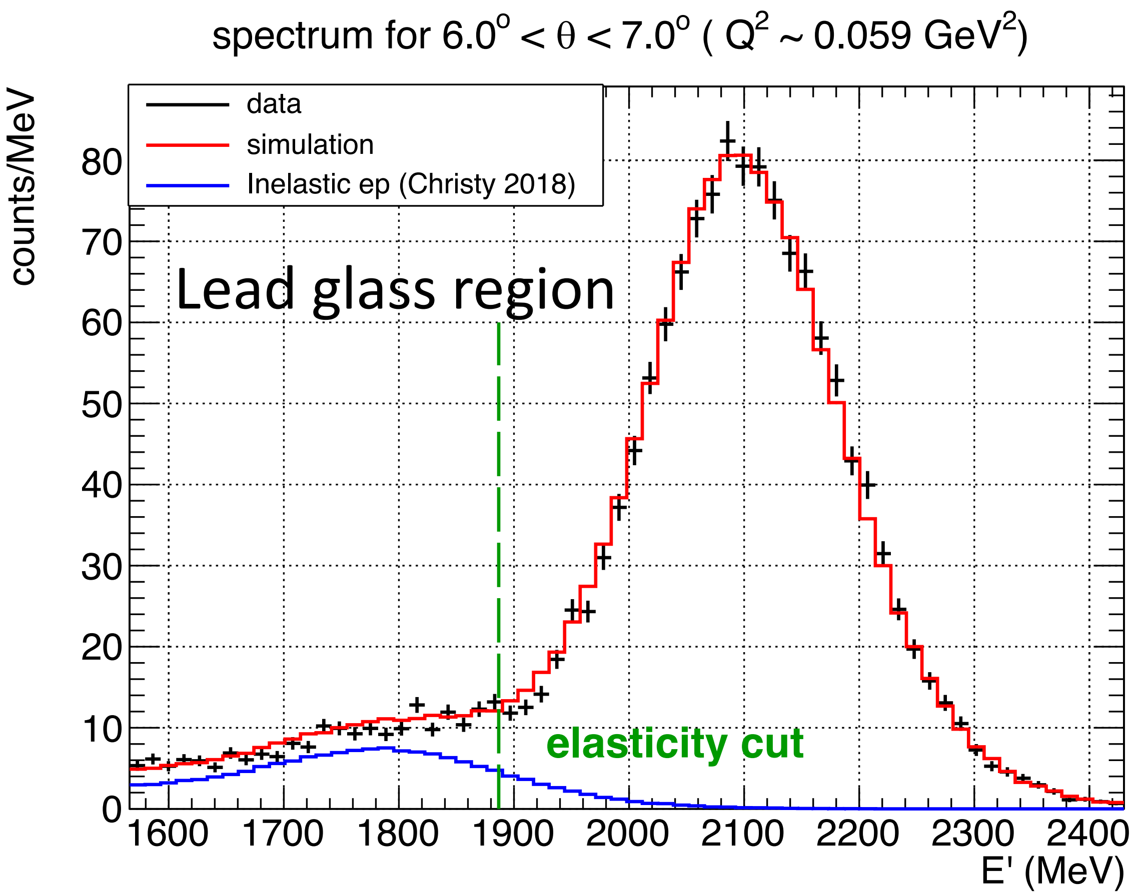
2nd order continuous fraction

$$\frac{1}{1 + \frac{p_1 Q^2}{1 + p_2 Q^2}}$$

Analysis – Inelastic ep Contribution

- Using Christy 2018 empirical fit to study inelastic ep contribution
- Good agreement between data and simulation
- Negligible for the $PbWO_4$ region (<3.5^o), less than 0.2%(2.0%) for 1.1GeV(2.2GeV) in the Lead glass region



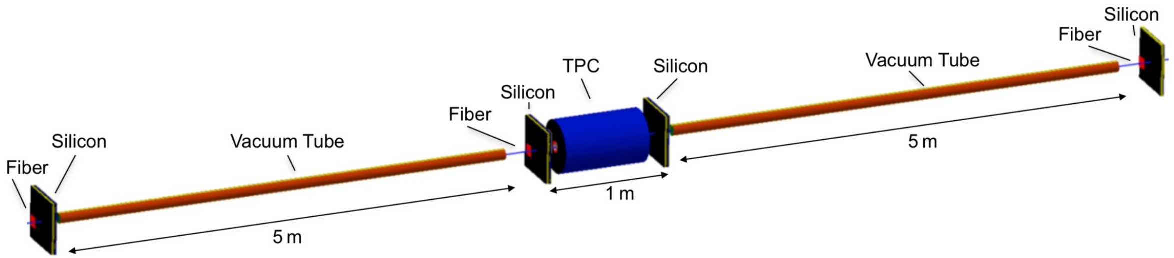


M. E. Christy and P. E. Bosted, PRC 81, 055213 (2010)

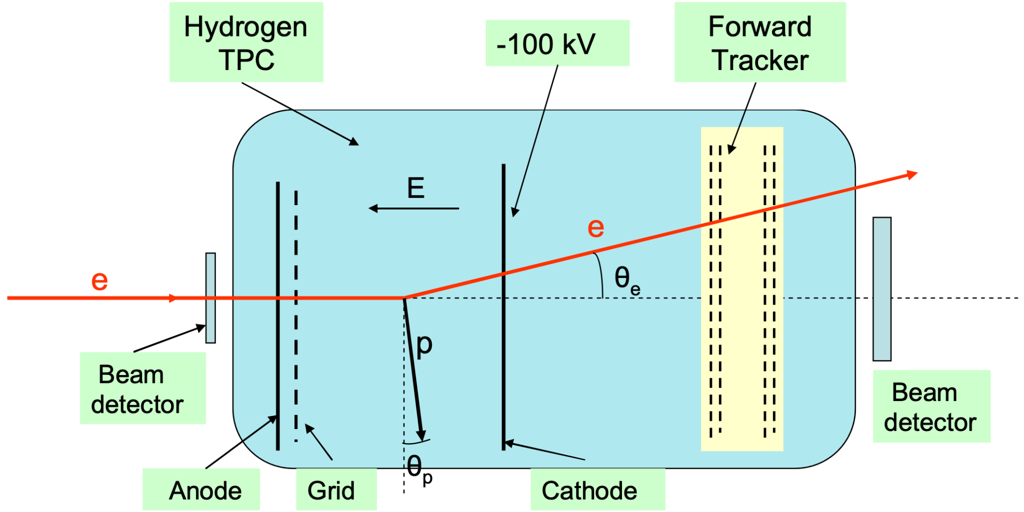
AMBER and PRES Experiments

- AMBER@CERN uses high energy (~100 GeV) muon beam
- PRES@Mainz uses 720 MeV electron beam
- Both use time-projection chamber as active target, detecting both scattered electron and recoil proton
- Q^2 can be reconstructed by recoil proton, largely suppress radiative effect

AMBER@CERN

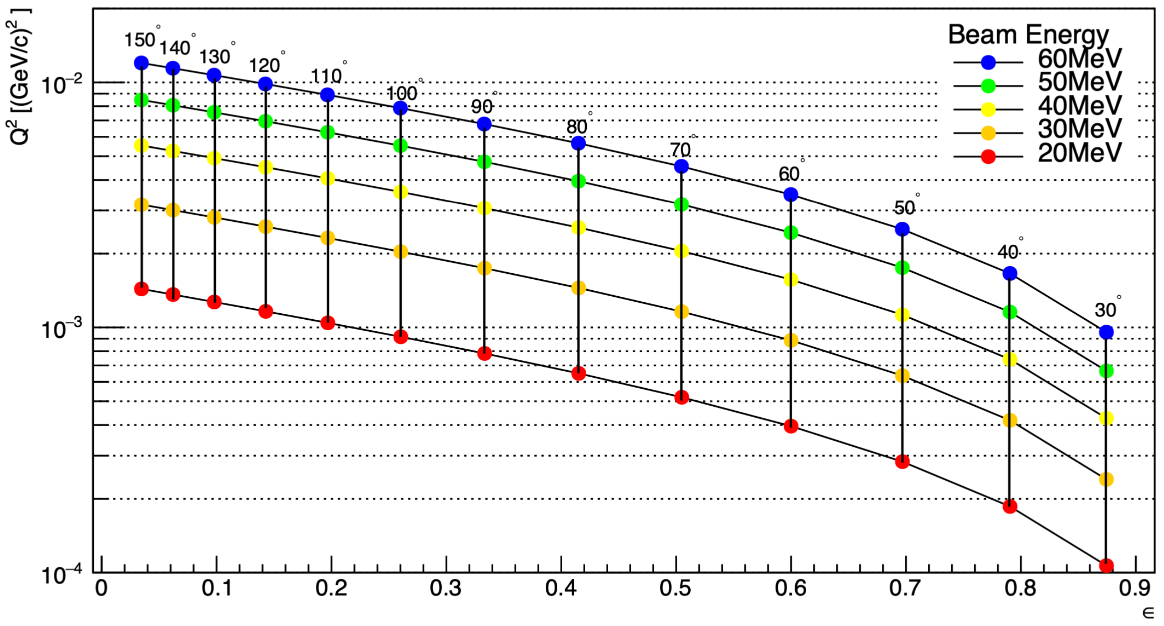


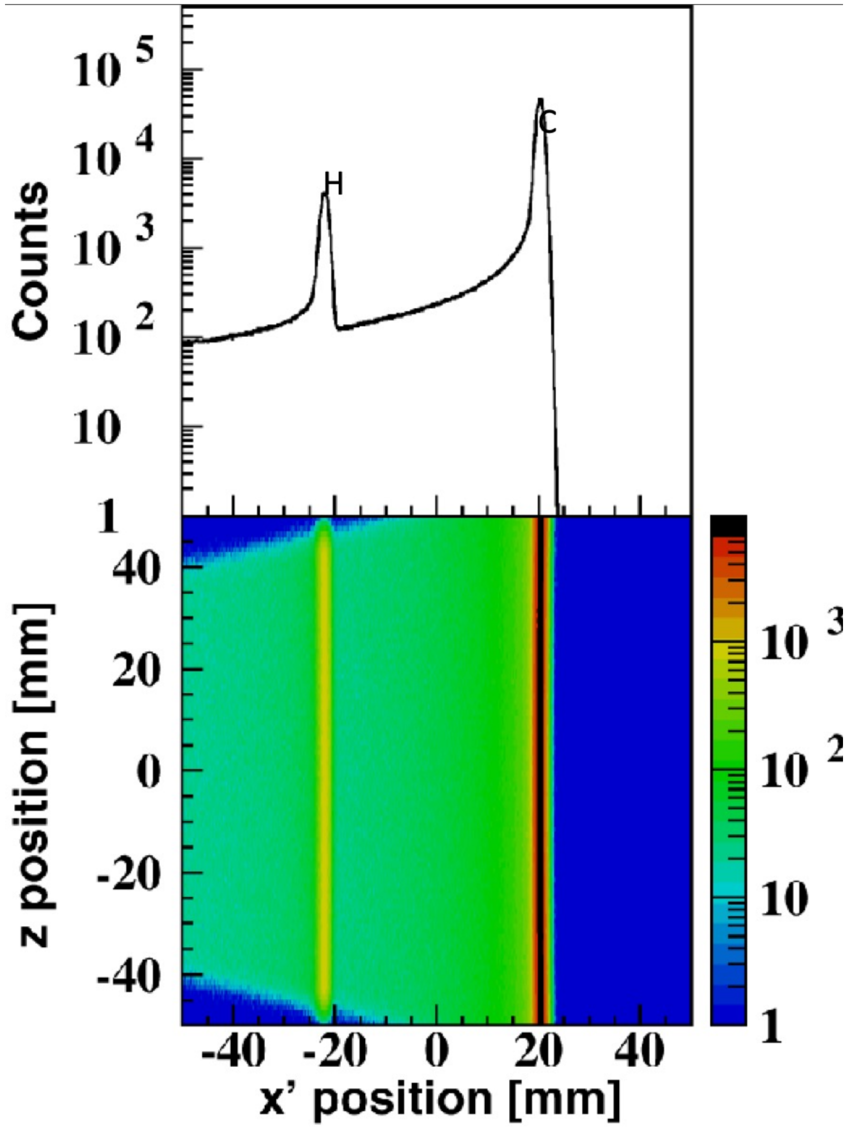
PRES@Mainz



ULQ2 Experiment

- ULQ2 experiment at Tohoku University, Japan
- 20-60 MeV electron beam
- Normalize to the well-established *e-^{12}C* cross section
- Rosenbluth separation to measure both G_E and G_M
- Projected uncertainty for G_E ~0.1%
- Q^2: 3 x 10^{-4} ~ 8 x 10^{-3} GeV^2

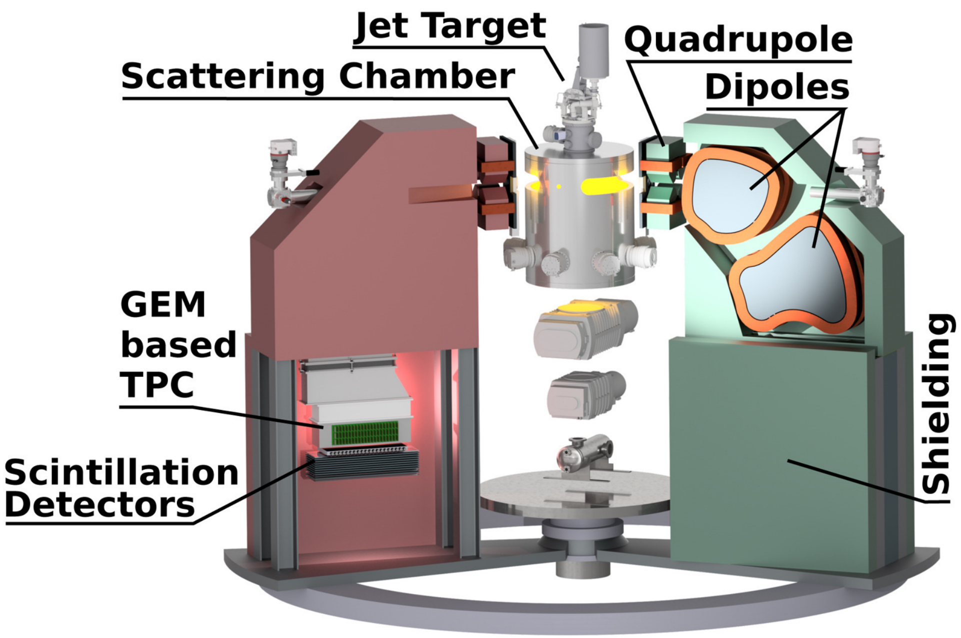


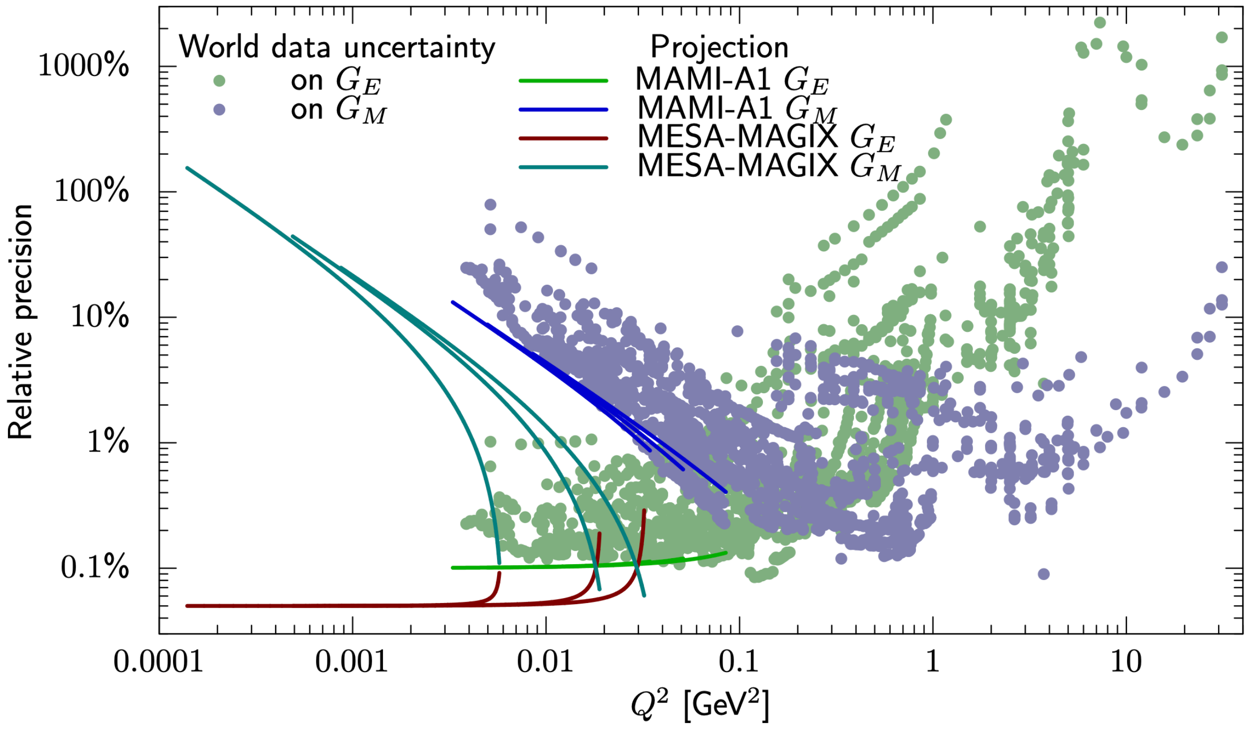


https://indico.mitp.uni-mainz.de/event/132/contributions/552/attachments/420/451/24_1_Suda_PRP_2018.pdf

MAGIX Experiment

- Will use the new MESA accelerator at Mainz (under construction), 20-105 MeV electron beam up to 1 mA
- Will use the fully tested jet target and two new multi-purpose spectrometers
- Strong sensitivity on both G_E and G_M, can achieve an order of magnitude better precision for low Q^2 G_M





Future Muonic 1S Hyperfine Splitting Measurements

- Precise measurement of the 1S hyperfine splitting in μH

$$E^{\langle 2\gamma\rangle}_{nS\text{-hfs}} = \frac{E_\mathrm{F}}{n^3}\left(\Delta_\mathrm{Z} + \Delta_\mathrm{recoil} + \Delta_\mathrm{pol}\right).$$

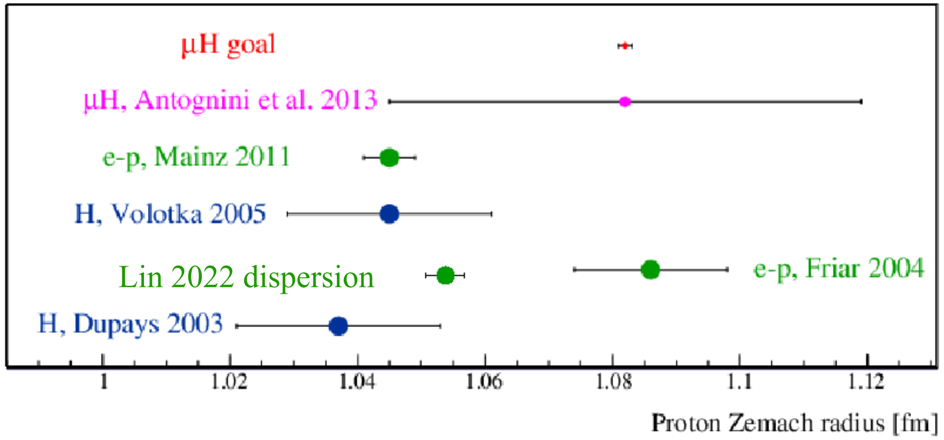
$$r_\mathrm{Z} = -\frac{4}{\pi}\int_0^\infty \frac{\mathrm{d}Q}{Q^2}\left[\frac{G_E(Q^2)G_M(Q^2)}{1+\kappa_N} - 1\right].$$

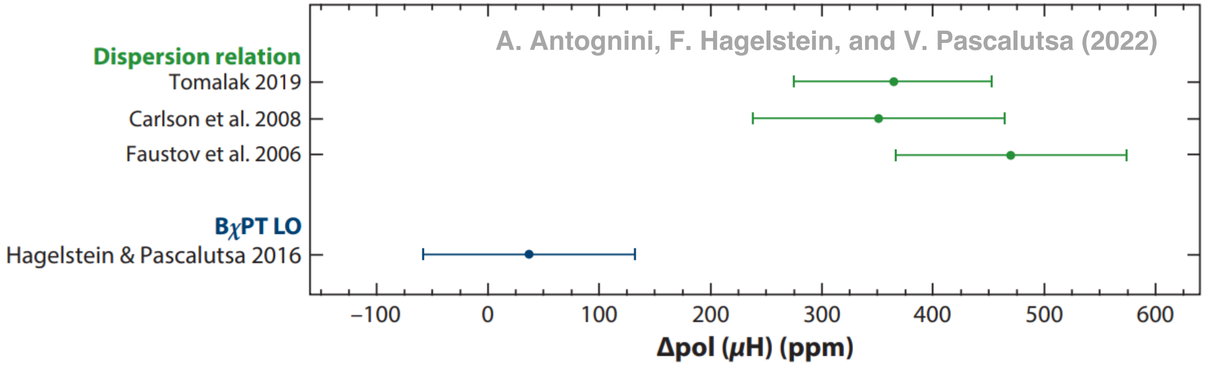
$$\Delta_1 = \frac{9}{4}\int_0^\infty \frac{dQ^2}{Q^2}\left[\left(\frac{G_M(Q^2)+G_E^2(Q^2)}{1+\tau}\right)^2 + \frac{8M_p^2}{Q^2}\int_0^{x_{th}} \widetilde{\beta_1}(x, Q^2)\, g_1(x, Q^2)\, dx\right]$$

$$\Delta_2 = -24M_p^2\int_0^\infty \frac{dQ^2}{Q^4}\int_0^{x_{th}} \widetilde{\beta_2}(x, Q^2)\, g_2(x, Q^2)\, dx$$

Proton Zemach radius term, related to proton electromagnetic FF

Proton polarizability term, related to proton spin structure functions g_1 and g_2





➢ Investigated by three collaborations: CREMA, FAMU and J-PARC

Remaining Issues for Lepton Scattering

- Need other experiments to confirm/reject PRad result
- Is r_p the same in lepton scattering and spectroscopy?
  - ➢ C. Peset *et al. Prog. Part. Nucl. Phys.* 121 (2021) 103901
- Why $\mathrm{G_E}$ data are different?
  1. Problem with RC?
  2. Unknown systematics?
  3. Problem with fitting procedure?

- J. Zhou (周璟怡) *et al.* PRC 106 (2022) 6, 065505
- Use rational (1, 1) to fit Mainz data up to Q^2~$0.5\mathrm{GeV}^2$