High-precision Measurement of the Proton Radius with TPC

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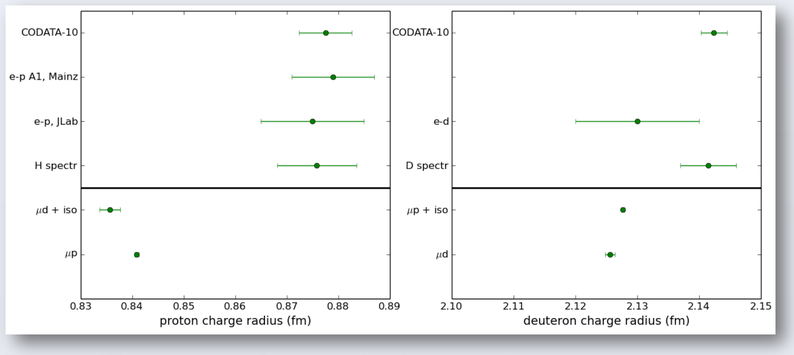
Proton Radius Puzzle

- Significant difference between values from muonic hydrogen (CREMA Coll., PSI) and CODATA
- Electron scattering: validity of the Q^2 range and choice of the fitting function?
- Hadronic corrections not sufficient to explain differences
- Exotic particle coupling differently to electrons and muons? Beyond Standard Model!

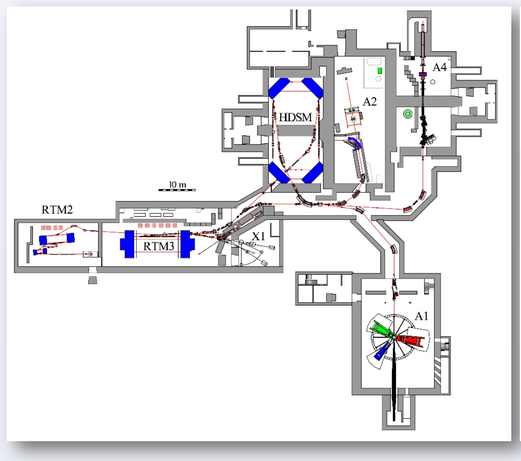
More than a comparison of two numbers:

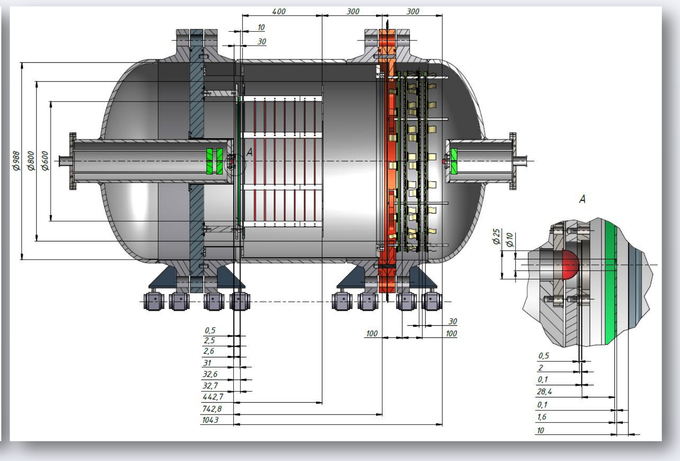
- Inconsistencies between atomic measurements
- Differences between electronic and muonic systems
- Discrepancy observed for the deuteron but not Helium isotopes



The solution to the problem will not come from a single experiment!

TPC experiments with electron/photon beam at A2





TPC&FT at MAMI beam will open avenue for various experiments:

- **Experiments with both electron and photon beams in A2 with accurate detection of charged particles (including recoil fragments)**
- **Hydrogen, Deuterium, Helium gas filling possible**
- **In longer term, transfer of technology to MESA e.g. for complementary measurement of nucleon scalar polarizabilities**

Current Status of Research and Future

Worldwide Program of Scattering Experiments

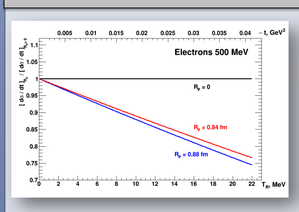
A1 Collaboration in Mainz:
Initial State Radiation (ISR) experiment, accessing Q^2 below values defined by the experimental kinematics.
Proton radius R_{pE} = 0.810 ± 0.035 (stat) ± 0.074 (syst) fm *(M. Mihovilovič et al., PLB 771 (2017))*
Further experiments reaching $Q^2 = 10^{-4}$ GeV^2 with improved systematics planned.

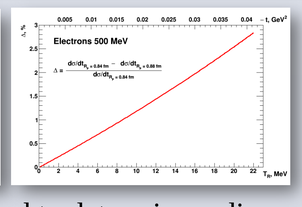
PRad experiment at Jlab:
Similar goals with the new experiments in Mainz (A2 Hall), but very different systematics:
Electron scattering on a hydrogen gas jet target studied in combination with a forward calorimeter.
Allows access to $Q^2 = 10^{-4}$ GeV^2.

MUSE Collaboration:
Preparing for a simultaneous measurement of the cross-sections for the *ep* and *μp* elastic scattering at low momentum transfer. The electron-muon universality will be tested in the context of the measurement of the proton radius.

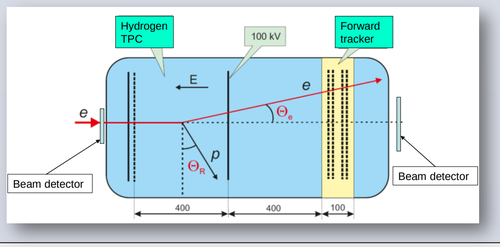
New experiments at MAMI (A2 Hall):
Accessing proton radius with dilepton photoproduction with a Hydrogen Time Projection Chamber (TPC) combined with Forward tracking detector.

Proton Radius Extraction with IKAR-TPC





High precision required to determine radius



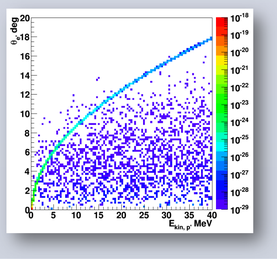
Measured quantities
Proton Energy E_p = 1-15 MeV, σ_{Ep} ~ 60 keV
Proton Scattering Angle θ_p = 0-90°, $\sigma_{\theta p}$ ~ 0.6-0.9°
Lepton Scattering Angle $\theta_{e.max}$ 32°
Vertex z-coordinate

Two ways to obtain the momentum transfer ($t = -Q^2$)

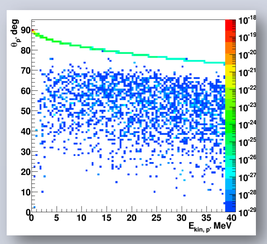
$$-t = 2M_p E_p \qquad -t = \frac{4e_e^2 \sin^2\left(\frac{q}{2}\right)}{1+\frac{2e_e}{M_p}\sin^2\left(\frac{q}{2}\right)}$$

Simultaneous detection of scattered electron and recoil proton
Lower radiative corrections
Low transfer momentum region: 0.002 – 0.02 (0.04) GeV^2
High resolution in Q^2 (~100 resolved points)
Absolute measurements of dσ/dt with accuracy of ~0.2%

Completely different systematics compared to other experiments

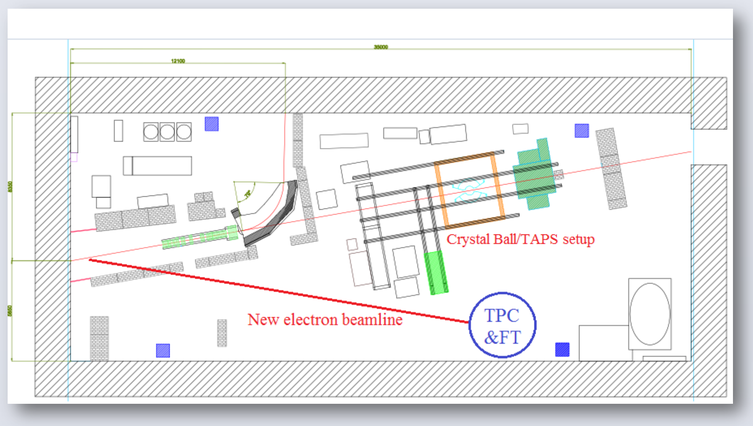


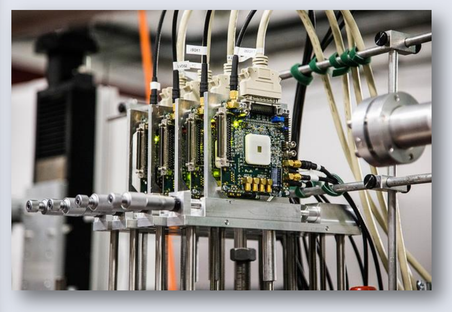
Background suppression
(θ_e; E_p), (θ_p; E_p), and (θ_e; θ_p) correlations can be used to suppress background. Left (θ_e; E_p), Right (θ_p; E_p) shown calculated for ep- scattering and ep → epπ^0 at ε_e = 900 MeV



Final Goals and First Steps

Building of electron beamline at MAMI in A2 hall





Construction of a new electron beamline in A2

Distance ~20 m: additional dipole magnet, 3-4 quadrupole magnets, beam monitors
Multilayer beam monitoring system for the TPC (HV-MAPS)

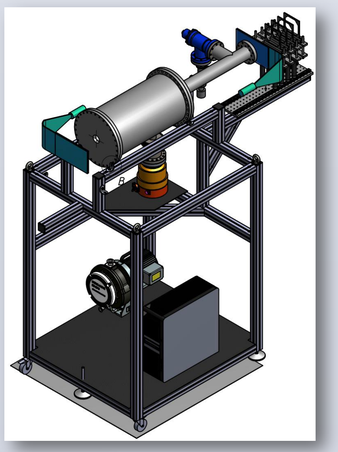
Test Beam Time and Final Aim

Preparation of the IKAR-M (TPC & FT) in the A2 Hall

Agreement signed between KPH Mainz and PNPI (2017-2020)
TPC prototype (ACTAR) in Mainz from GSI in April 2017

Construction of a new electron beamline in the A2 Hall (KPH)
Constructon of the beam monitoring detector system for IKAR-M (KPH)
Construction of IKAR-M detector (PNPI)

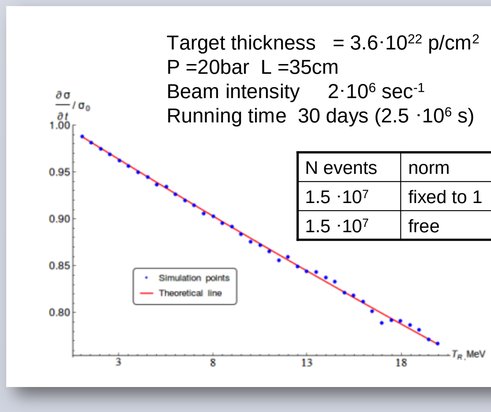
Test run in August-September 2017 at MAMI



Expected statistical accuracy in the main experiment

Target thickness = 3.6·10^{22} p/cm^2
P =20bar L =35cm
Beam intensity 2·10^6 sec^{-1}
Running time 30 days (2.5 ·10^6 s)

N events	norm	t-scale	σ(Rp)
1.5 ·10^7	fixed to 1	fixed	± 0.002 fm
1.5 ·10^7	free	fixed	± 0.003 fm



Acknowledgements

Supported by the Deutsche Forschungsgemeinschaft within Collaborative Research Centre 1044