Precision measurement of the position of cathode wires in a system of proportional high-pressure chambers in an experiment to measure the charge radius of a proton in elastic electron-proton scattering

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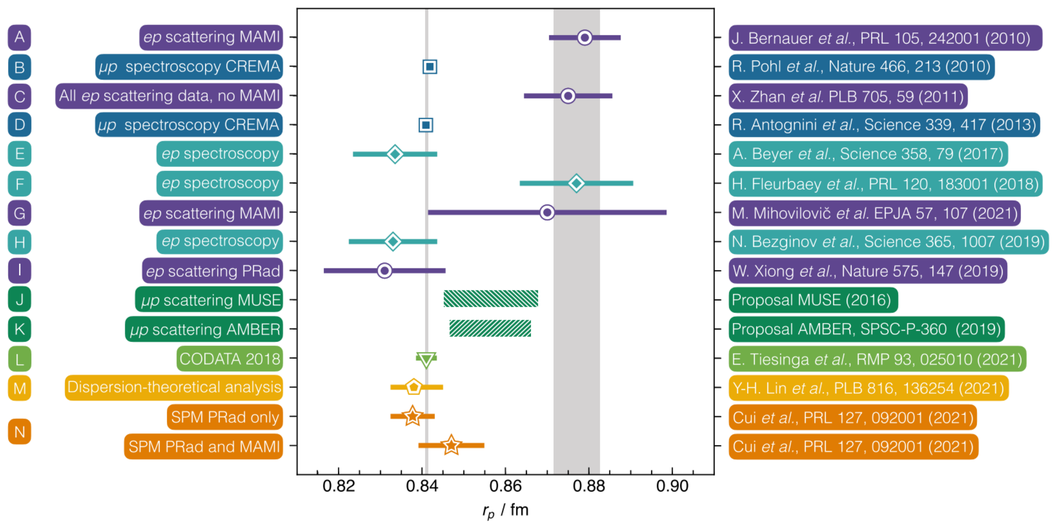
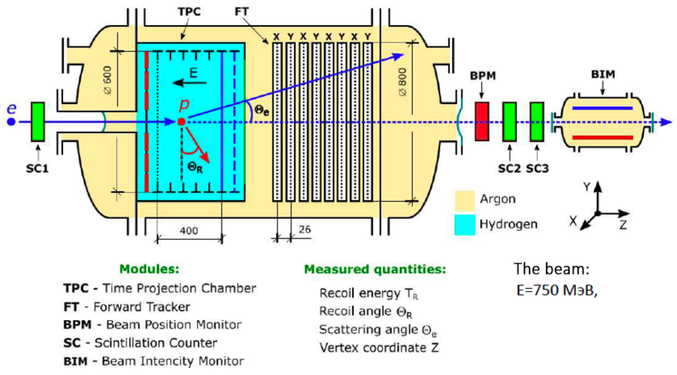
Motivation

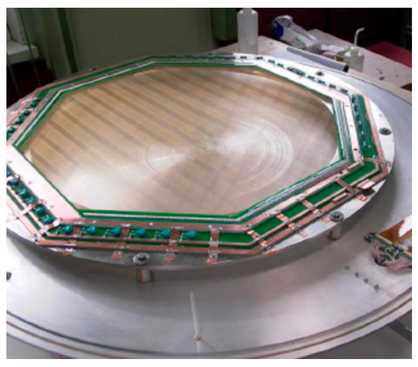


The charge radius of a proton is one of the fundamental quantities in particle physics. Currently, the **"the proton radius puzzle"** is actively discussed in the scientific world, associated with a significant discrepancy in the magnitude of the proton charge radius obtained in **experiments measuring the Lamb shift in muon atoms** ($R_p = 0.8409(4)\ fm$) and in **experiments on electron-proton scattering** ($R_p = 0.877(8)\ fm$). This fact could be the reason of some theoretical causes:

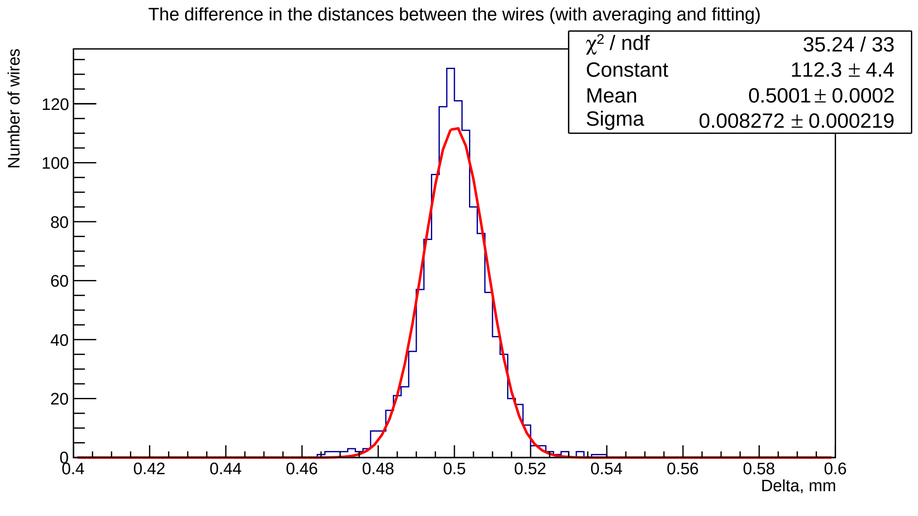
- Muonic/electron hydrogen: additional correction – not detected
- High-order moments in the electronic form factor – insignificant
- The principle of lepton (muon-electron) universality – it is being checked
- New Physics (forces) outside the Standard Model – not detected yet

The scheme of the planned experiment

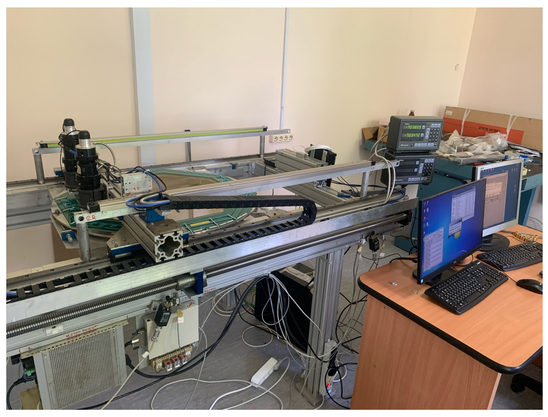


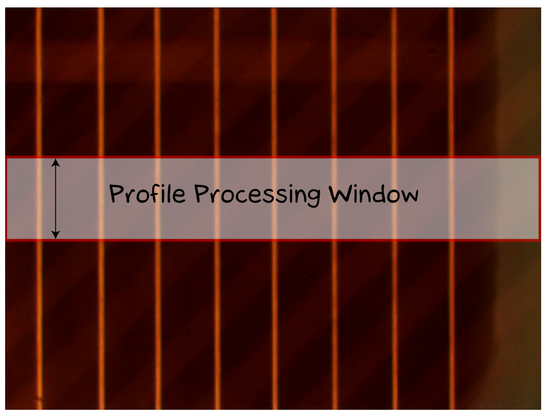


The forward trackers (FT) is designed for **high absolute precision** in measuring the X **and** Y **coordinates** of the electron track relative to the beam line. Also, it measures the **arrival times of the scattered electrons**. The FT acceptance is **from 4 to 460 mrad**, which provides full coverage of the θ_e distribution corresponding to the selected Q^2 range at the electron **beam energy 500–750 MeV**. The FT consists of **four pairs of cathode strip chambers (CSC)**: X_1/Y_1, X_2/Y_2, etc. Each chamber is a symmetric **multiwire proportional chamber (MWPC)** with a **3.0 mm gap** between the cathode and the anode planes. The size of the chamber is **600 × 600 mm^2**. The readout is from both cathode planes. The anode wire **plane contains 30 µm wires spaced by 3 mm**. Both cathode planes are made of **50 µm wires wound with 0.5 mm step**. The cathode wires are orthogonal to the anode wires in one cathode plane and inclined by 45° in the other cathode plane. The wires in the inclined cathode **plane are grouped into 10 mm strips**. The key element of the CSC is the **cathode plane with orthogonal cathode-to-anode wires**. It determines the absolute measurements of the coordinate along the anode wire. In this plane, 2.5 mm strips are formed by joining together five wires. Using the **centre-of-gravity method**, the coordinate of each detected track is determined with $\sim$ **30 µm** resolution.



Measurement of the cathode wires position





In the process of scattering of electron, we must detect it using a **MWPC**, each of which plains consists of **1200 wires**, one of the factors increasing the error is the incorrect determination of the wires coordinates, which leads to exceeding the permissible error of the experiment ($12\mu m$).

To ensure accurate restoration of the electronic track coordinates, a comprehensive system for measuring the cathode wires position is being developed. This system includes **high-precision microscopes** capable of taking high-resolution profiles of cathode chamber wires and the **automated rail system** that helps move microscopes along the chamber.

To implement the idea, an analysis of chamber photo profiles taken by a system of precision microscopes was proposed. **Process of determining cathode wires coordinates was divided on 3 steps:**

1. **Peak Maxima Determination:**
   - Use a derived method to find profile peak maxima.
   - Calculate absolute coordinates relative to the entire chamber:

$$x_{ij}^{abs} = X_i + \chi \cdot x_j \tag{1}$$

   where χ represents microscope resolution.
2. **Working Approximation Window:**
   - Define parameters σ and μ for a single wire:

$$fit\_func(x, \theta) = Gaus(x, \theta) + pol1(x, \theta) \tag{2}$$

3. **Cluster Averaging:**
   - Identify unique wire clusters (total 1200 clusters).
   - Average coordinates within each cluster.

During the approximation process, several additional variables are considered, which may affect the accuracy of wire coordinate determination:

- The window for building an image profile in ImageJ – **insignificant**
- Positioning the profile relative to the entire photo – **insignificant**
- The width of the approximation window of a separate wire. – **insignificant for values larger than the size of the wire itself.**

Also, using the implemented algorithm, it is possible to fix defects in the chamber, such as: sagging wires (analyzing the distribution of each σ), lack of wires etc.

Summary and Outlook

- This work focuses on accurately determining the positions of cathode wires within a Multi-Wire Proportional Chamber (MWPC). The system employs high-precision microscopes and an automated rail system. The process involves peak maxima determination, working with approximation windows, and cluster averaging. Optimizing wire position accuracy is crucial for reliable measurements in the experiment to determine the charge radius of a proton in elastic electron-proton scattering.
- In the perspective of solving this problem, the construction of a common Forward Tracker (FT) coordinate system will be considered, which allows to reconstruct the track of a scattered electron with high accuracy.

KEY REFERENCES

[1] Vorobyev, A. A., et al. "PROJECT FOR PRECISION MEASUREMENT OF THE PROTON CHARGE RADIUS IN AN ELECTRON-PROTON SCATTERING EXPERIMENT." HIGH ENERGY PHYSICS DIVISION. IN SINTIFI TIVITIS 2013-2018. 2019. 316-325.

[2] Cui, Zhu-Fang, et al. "Hadron and light nucleus radii from electron scattering." Chinese Physics C 46.12 (2022): 122001.

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