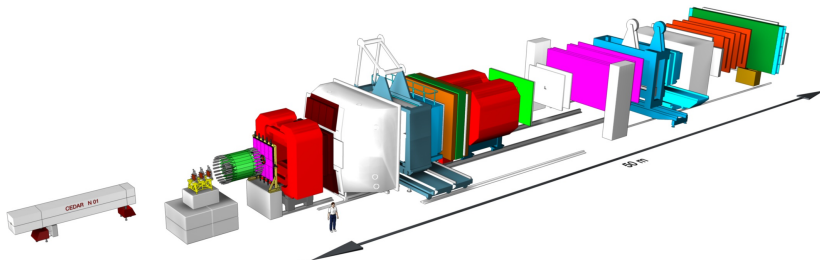


# Future Measurement of the Proton Radius at COMPASS

Sebastian Uhl  
On Behalf of the COMPASS Collaboration

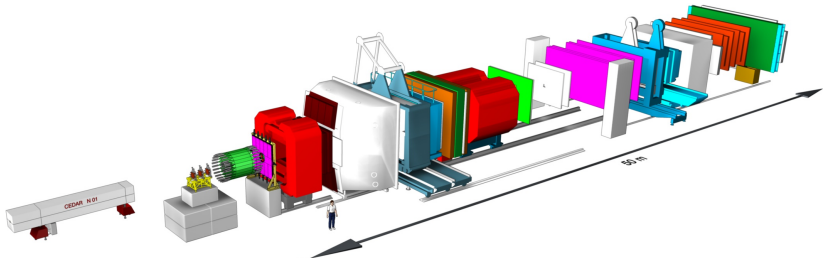


DPG Spring Meeting Bochum  
March 2018



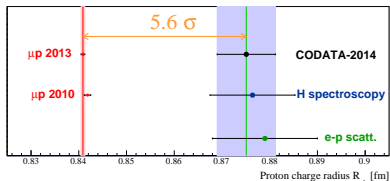
## COMPASS experiment at CERN SPS

- longest-running experiment at CERN
  - first physics data taking in 2002
- about to finish with the proposed physics programs

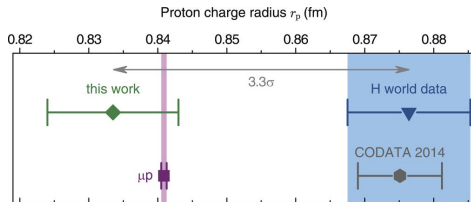


## COMPASS experiment at CERN SPS

- longest-running experiment at CERN
  - first physics data taking in 2002
- about to finish with the proposed physics programs
- versatile M2 beam line at high energies  $\mathcal{O}(100 \text{ GeV})$ 
  - secondary hadronic beams ( $\pi$ ,  $K$ ,  $p$ )
  - (naturally polarized) tertiary muon beams **unique in the world**



RP Gilman, Miller, Paschucki, *Annu. Rev. Nucl. Part. Sci.* 63, 175 (2013).

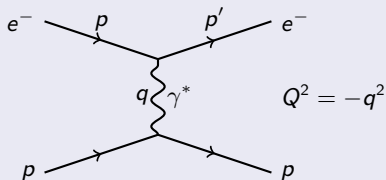


A. Beyer *et al.*, *Science* 358 (2017) 79

## proton radius "puzzle"

- discrepancy between scattering and spectroscopy data
  - measuring the same thing?
  - systematic effects for electron scattering, e.g. radiative corrections?
  - new physics? lepton non-universality?
  - ...

## scattering experiments



$$\frac{d\sigma}{dQ^2} = \frac{\pi\alpha^2}{Q^4 m_p^2 \vec{p}_e^2} \left[ \left( G_E^2 + \tau G_M^2 \right) \frac{4E_e^2 m_p^2 - Q^2 (s - m_\mu^2)}{1 + \tau} - G_M^2 \frac{2m_e^2 Q^2 - Q^4}{2} \right]$$

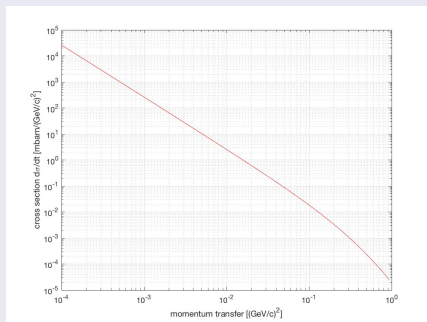
$$\text{with } \tau = Q^2 / (4m_p^2)$$

mean squared charge-radius

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

$$G_E(Q^2) \approx G_M(Q^2) / \mu_p \approx$$

$$G_D(Q^2) = (1 + Q^2/a^2)^{-2}$$

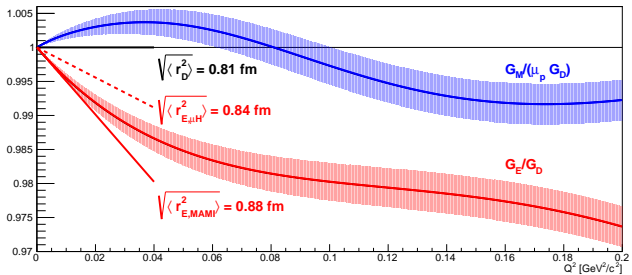


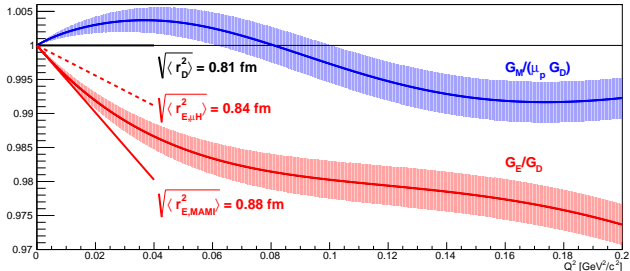
$$\frac{d\sigma}{dQ^2} = \frac{\pi\alpha^2}{Q^4 m_p^2 \vec{p}_e^2} \left[ \left( G_E^2 + \tau G_M^2 \right) \frac{4E_e^2 m_p^2 - Q^2(s - m_\mu^2)}{1 + \tau} - G_M^2 \frac{2m_e^2 Q^2 - Q^4}{2} \right]$$

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mean squared charge-radius

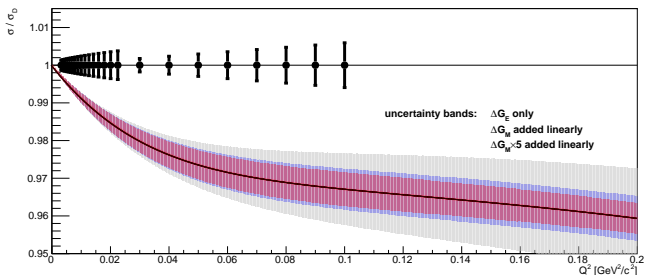
$$\langle r_E^2 \rangle = -6\hbar^2 \left. \frac{dG_E(Q^2)}{dQ^2} \right|_{Q^2 \rightarrow 0}$$





## opportunity for new generation experiment at M2 beam line

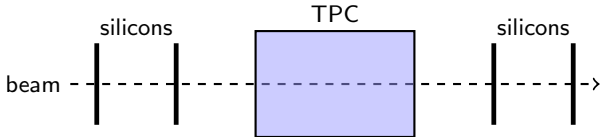
- scatter muon beam off proton target
- measure cross-section dependence on  $Q^2$
- obtain combination of electric and magnetic form factor  $G_E^2 + \tau G_M^2$ 
  - form factors cannot be separated due to high beam energy
- compared to  $e^-$  beam: smaller radiative corrections
- compared to  $\mu$  beam at low energies: much smaller Coulomb corrections



## requirements for measurement

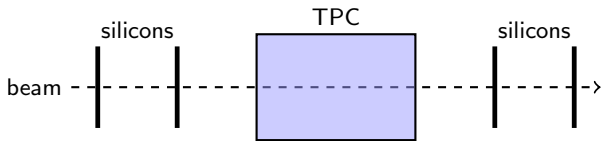
assuming one year of data taking

- goal: uncertainty on  $\sqrt{\langle r_E^2 \rangle} \approx 0.01$  fm
- systematics:  $Q^2 \gtrsim 1 \cdot 10^{-3} \text{ (GeV/c)}^2$
- uncertainty on  $G_M$ :  $Q^2 \lesssim 0.2 \text{ (GeV/c)}^2$



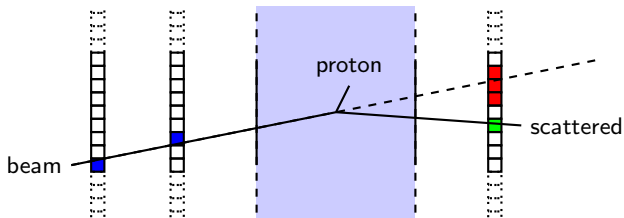
### proposed set-up

- hydrogen TPC acting as active target
  - measurement of energy of recoil proton
  - between 0.5 and 100 MeV
  - required resolution:  $\Delta \approx 60 \text{ keV}$
- silicon telescopes up- and downstream of target
  - measurement of muon scattering angles
  - $300 \mu\text{rad}$  at  $Q^2 \approx 10^{-3} (\text{GeV}/c)^2$
  - required resolution  $\sigma \lesssim 100 \mu\text{rad}$



### proposed set-up

- trigger on recoil proton signal
  - drift time in TPC  $\mathcal{O}(100 \mu\text{s})$
  - trigger-less readout of all detectors
  - online event reconstruction to correlate proton and muon signals



### proposed set-up

- trigger on recoil proton signal
  - drift time in TPC  $\mathcal{O}(100 \mu\text{s})$
  - trigger-less readout of all detectors
  - online event reconstruction to correlate proton and muon signals
- trigger on small kink in muon track

- measurement of proton charge-radius with high-energy muon beam
  - unique opportunity to verify results from electron scattering
- first test measurement this year
  - compatibility of TPC with “broad” muon beam
  - correlation of proton and muon signals
- aim for real measurement in 2022