Referee Report on

MUSE: The MUon Scattering Experiment

This paper describes the MUSE experiment which is presently in commissioning phase at PSI. The goal of MUSE is to determine the proton charge radius r_p^2 by scattering muons and electrons on the proton. Exactly the same experimental setup for μ± and e± will be used, keeping many systematic effects between the use of these particles under control.

The introduction describes the basics of r_p^2 determination methods and gives a short review of previous measurements which lead to the famous "proton radius puzzle", a > 5σ difference of r_p^2 results between the method of laser induced transitions in muonic hydrogen and the classical method of electron-proton scattering.

The main chapter describes the MUSE apparatus in some detail. The PiM1 channel of PSI provides (besides pions) simultaneously a beam of muons and electrons. Both charges of μ/e will be used to elucidate corrections due to two-photon exchanges. The incoming particles are detected by a beam hodoscope and GEM chambers. The cyclotron RF provides particle identification. Scattering takes place in a liquid hydrogen cell in the center of a vacuum chamber. The scattered particles are measured symmetrically left and right with straw-tube trackers and scintillation counters. Downstream a beam monitor and a calorimeter are placed to veto unscattered particles and background, especially induced from the most abundant pions.

A big effort is made with simulation programs and measurements to understand the beam properties, starting with the process of pion production in the proton target and subsequent decays into muons and electrons, and by tracking them through the PiM1 channel using Turtle, Geant4 and other programs. The absolute momentum of the beam particles which must be known to ±0.2%, is determined by three different methods (TOF, RF and momentum dispersion at the intermediate focus). A blinded data analysis will be used, accompanied by Monte Carlo calculations.

The concluding chapter discusses anticipated results from simulations in comparison with published electron-proton scattering data. The big novelty of MUSE is, that μ-p scattering is measured in addition to e-p scattering. The importance of pion cross section measurements is pointed out for the understanding of backgrounds as well as for checking the hadron physics aspects.

General conclusions: 1)The authors present a comprehensive description of the MUSE experiment – presently in commissioning – and its goals toward elucidating the "proton radius puzzle". In figure 23.2 showing anticipated uncertainties of the electrical form factor $G_E/G_{std.dipole}$ vs. Q^2, results of previous e-p scattering experiments ("PRad", "Mainz") and two theoretical evaluations are presented, however with no explanation in the figure caption and only partial discussions in the text. The paper would benefit greatly if these data and curves would be explained and discussed more comprehensively. E.g. What is the "PRad" experiment and where does it stand with respect to "Mainz"? How helpful are the theoretical curves?

2) The pions – main component of the PiM1 beam – are treated only marginally although its role as backgrounds and cause of systematic effects may be quite significant. It should be emphasized in more detail what measurements and studies are planed i.o. to keep pions under control.