

The Quest for Fractionally Charged Particles

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Introduction

Generally, the idea that electric charge exists in integer multiples of electron charges is well supported by the scientific community. Be that as it may, the Standard Model, which includes three generations of quarks and leptons, does not establish charge quantization. To be able to enforce charge quantization, physics beyond the limits of the Standard Model is imperative. This area of study has led to the exploration of mechanisms through which the currently upheld laws of charge quantization might be defied. The natural results of some of these mechanisms include particles with small fractional charges. Over the years, the existence of fractionally charged particles, existing independently, has been explored through many direct experiments and indirect observations. Our experiment will search for fractionally charged particles using proton interactions at the Proton Synchrotron with the goal of identifying fractionally charged particles by observing their light emission in a liquid scintillator, comparatively to a conventionally charged particle.

Why We Want to Go

Since learning of the Beamline for Schools initiative, we have been motivated and excited to design an experiment that could be accomplished on a larger scale at CERN. Our expanding comprehension of fractionally charged particles, an as of yet unproven field of research, has inspired us to explore the world of quantum physics. Being selected for this experience would give us the incredible opportunity to implement our knowledge of physics with the invaluable guidance of the experts at CERN and, more importantly, broaden it.

Our Experiment

Aim

Our experiment aims to observe and measure the light emitted by a liquid scintillator when interacting with a variety of particles, including fractionally charged particles.

Experimental setup

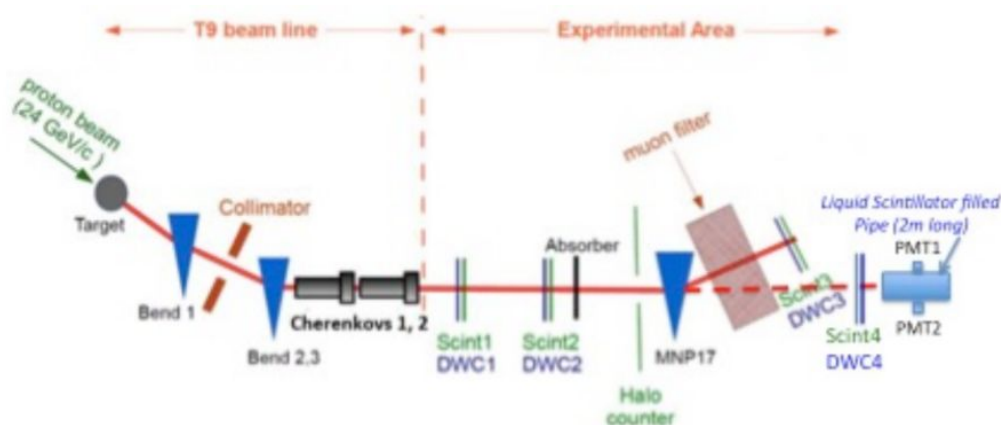


Figure 1 The layout of the experiment in the t9 experimental area



Method

It is possible to use the setup shown in Figure 1 to search for Fractionally charged particles using the process

Proton+Target → Fractionally charged particles + X (anything else)

To elaborate, this explains how when the protons from the CERN beam hit the target, they will produce fractionally charged particles in addition to anything else (X). The process that will unfold subsequently to the collision of the beam with the target goes as follows:

- a) The stream of particles will follow the T9 Beamline and undergo Bend 1, the collimator, Bends 2 and 3, and Cherenkovs 1 and 2, before entering the experimental area.
- b) The beam intensity will be measured by scintillator 1 and 2 before the charged particles in the beam are blocked by the absorber.
- c) The halo counter will then identify any particles on the periphery of the beam.
- d) Any charged particles remaining in the beam will then be diverted by the magnet MNP17 and sent through the muon filter before being measured by scintillator 4.
- e) Neutral particles will not be deviated by the magnetic field, but since they will not be detected by the liquid scintillator they will not affect our results. Any fractionally charged particles will only suffer small deflections and will thus continue to move forwards along with neutral particles.
- f) The fractionally charged particle detector (FCPD-liquid scintillator) will be placed along the central axis of the magnet so that only the neutral and fractionally charged particles will hit it. While neutral particles will give no signal in the detector, fractionally charged particles will produce an "ionization" signal in the detector that is proportional to the square of the charge. For example, a particle with the charge of $1/3$ will give an ionization of $1/9$ that of a singly charged particle.
- g) The light emitted by the liquid scintillator will be detected with photomultiplier tubes (PMTs). The photoelectrons generated in the photocathode of the PMTs are amplified in the PMTs dynode chain by a factor of approximately a million, in order to make the signal detectable and measurable.
- h) Finally, we will examine our data for the presence of fractionally charged particles being careful to include an estimate of the backgrounds to our signal, as well sources of systematic error.

Calibration

By switching off the magnet MNP17, the muons can enter the FCPD, and thus help identify the average pulse height of singly charged muons. In order to measure the fractionally charged particles (FCPs), the magnet is switched on to divert the muons from the FCPD. In this case only neutral and fractionally charged particles would be detected. The signal for a FCP in the FCPD would have a significantly smaller pulse height than that measured in the muon calibration run. Thus, our experiment will need to be conducted twice, with the magnet MNP17 turned either on or off, to allow us to calibrate and compare our results.

Material

According to the “Beamline for Schools” document, most of the instrumentation needed to complete this experiment is available at CERN. However, the fractionally charged particle detector will be provided by us, with the help of our contact at the University of Alberta. It would be a very simple and cost effective detector made of a two metre long PVC pipe with a 20 cm diameter and filled with liquid scintillator that would be measured and interpreted by the two photomultipliers, as shown by figure 2. The liquid scintillator we will be using used in the FCPD is LAB based and therefore low cost and environmentally friendly.¹ A large path length for the FCP in the scintillator ensures that an adequate signal can be achieved despite the charges as low as 1/10th of the charge of an electron. A coincidence between the two PMT signals can be used to reduce the “noise” found in our results. The readout for two PMTs (standard parts of the CERN detector) can be used to service the FCPD.



Figure 2 The fractionally charged particle detector.

Predictions

Because this theory remains hypothetical, it is highly unlikely that we will be able to prove or disprove it. In the likely event of the non-observation of a signal we will present a Confidence Level limit on the cross-section for the production of fractionally charged particles.. Be that as it may, discoveries are often made by accident, so it is possible that we will make interesting and unexpected observations through our experiment. In addition, through our experiment, we will be able to test and calibrate the effectiveness of this new liquid scintillator in the collider environment.

What We Hope to Take Away

Physics is a discipline in constant evolution and discovery. Should we be honoured with the opportunity of overseeing this experiment at CERN, our scientific critical thinking abilities and our laboratory knowledge and skills would expand considerably, allowing us to further grow as learners. This experience would also grant us the possibility of teaching younger students on the importance of scientific research and the gratifying feeling of experiencing discovery and innovation on a firsthand level. It is our duty to encourage the pursuit of knowledge, and beginning with this privileged occasion would only advocate for this cause. We must think forward, and this would be our first big step toward doing so.

¹ This is the liquid scintillator used in the SNO+ solar neutrino astroparticle physics experiment at SNOLAB.



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