CERN Beamline for Schools 2017 Student Experiment: Search for Isolated Fractionally Charged Particles

Journal Article

Author(s):
McKarris, Paul; Mourcos, Andrew; Billiau, Colin; Carli, Ina; Ferron, Lucas; Gilmour, Mathieu; Ibrahim, Mariam; Jacques, Denis; Joos, Markus; Lehmann, Jacob Taylor; Logojan, Denisa; Loke, Emily Jean; Morrison, Dominique; Mourcos, Caitlyn; Poirot , Mélanie; Ristic, Branislav; Robin, Marina

Publication date:
2020-06

Permanent link:
https://doi.org/10.3929/ethz-b-000511973

Originally published in:
The Physics Educator 2(2), https://doi.org/10.1142/S2661339520500079

The Physics Educator
Vol. 2, No. 2 (2020) 2050007 (10 pages)

DOI: 10.1142/S2661339520500079

CERN Beamline for Schools 2017 Student Experiment: Search for Isolated Fractionally Charged Particles

Paul McKarris*, Andrew Mourcos*, Colin Billiau*, Ina Carli†,
Lucas Ferron*, Mathieu Gilmour*, Mariam Ibrahim*,
Denis Jacques*, Markus Joos‡, Jacob Taylor Lehmann*,
Denisa Logojan*, Emily Jean Loke*, Dominique Morrison*,
Caitlyn Mourcos*, Mélanie Poirot*, Branislav Ristic§
and Marina Robin*

**Père-René-de-Galinée School,*
Cambridge, Ontario, Canada

†Charles University,
Prague, Czechia

‡CERN,
Geneva, Switzerland

§ETH Zurich, IPA,
Zurich, Switzerland

Received March 26, 2020; Revised April 21, 2020; Accepted April 27, 2020

This article was mainly written by a team of high school students that have won the CERN Beamline for Schools (BL4S) competition in 2017. They had some help from professional scientists, in particular Branislav Ristic. The team had proposed to set up an experiment to search for elementary particles with a fractional electric charge. This paper describes the preparation of their proposal, experimental setup, detectors and data analysis throughout the search for such particles using a $10\,\mathrm{GeV}\,c^{-1}$ proton beam with a fixed iron target. It was clear to the team that the chance for finding such particles in a relatively simple experiment was minimal but that by doing this experiment they would learn a lot about experimental physics. Due to large amounts of noise, the result of the experiment is inconclusive. Further experimentation to search for these hypothesized particle is encouraged.

Keywords: BL4S; CERN; science competition; search for new physics; fixed target experiment; fractional charge.

1. Introduction by the CERN Scientists and the BL4S Management

Every year between 150 and 200 teams participate in Beamline for Schools (BL4S),[a] a worldwide science competition, organized by CERN, in which high-school students propose particle physics experiments. Two winning teams are then invited to perform their experiment at a fixed target beamline.

As they are entirely free with respect to the experiment that they propose, the proposals reflect what these high school students know about particle physics, its applications and what they are generally interested in. Therefore we get, every year, many proposals that are very similar. Quite often the teams propose to perform an experiment that has already been done before by professional scientists, the result of which is known. This is not to be criticized because actually doing such an experiment in a real beamline and controlling its many parameters is a very challenging (and instructive) task for the students. What sets the proposal of the "Charging Cavaliers" apart is that they deliberately proposed an experiment that had never been done before (in the form proposed by them). They heard from a professor of physics of a university in Canada about particles with a fractional electric charge that are predicted by some theories but have never been detected. If such particles existed, a door would open to physics that goes beyond the Standard Model. In that respect they had the same spirit as professional scientists that look for axions, weakly interacting massive particles or supersymmetric particles. The team knew that finding such particles was very unlikely but they preferred the novelty over the certainty of a more conventional experiment. In their proposal they explained very well the likely properties of these fractionally charged particles as well as a set-up that would be able to detect them. They had also thought about background signals and the analysis of the data. It was for these qualities that their experiment was selected as one of the winning experiments of 2017.

2. Introduction by the Students

The current understanding of nature, which is expressed by the Standard Model of particle physics, stipulates that only particles with integer charge can be observed. However, the quantization of the electric charge is not entirely understood. Charges seem to be quantized based on experimental observation, up to some level of uncertainty.

Dirac demonstrated that the existence of magnetic monopoles could explain the quantization of electric charge.[1] However, these magnetic monopoles have yet to be discovered.

To enforce the quantization of charge, physics beyond the Standard Model becomes necessary. In fact, most supersymmetric theories require charge quantization.[2–4] Consequently, the search for Fractionally Charged Particles (FCPs) has been performed in many direct and indirect experiments.[5,6] This type of experiment dates back to the early 1900s with Millikan's oil drop experiment.[7] More recently, however, CMS has done some research and put an upper limit on the cross-section for pair production of fractionally charged particles. They excluded at 95% confidence for massive spin-1/2 particles below 310 GeV with charge 2/3 and below 140 GeV with charge 1/3.[8]

This paper describes an experiment designed to search for FCPs using particle beams from CERN's Proton Synchrotron. The goal of the experiment was to produce FCPs by colliding ordinary hadrons with an iron target and distinguishing them by their energy deposit in a scintillating material. Given the analysis from the aforementioned CMS report,[8] no improvement on the current limits were expected from our setup. The main focus, however, was the learning outcome of performing such an experiment correctly and drawing valid conclusions through data analysis.

3. Preparing for CERN

In 2016, one of our team members — Paul McKarris — heard of the Beamline for Schools (BL4S) competition while interning at CERN. After returning to Canada, Paul decided to form a team and entered the competition. This led to the creation of our physics team — The Charging Cavaliers — at Père-René-de-Galinée secondary school, Ontario, Canada. Headed by the physics teacher Mr. Denis Jacques, the team consisted of seven female and six male students, between the ages of 16 and 18, who became interested in particle physics. Weekly meetings were put in place to work

[a] https://beamlineforschools.cern/home.

Fig. 1. Initial design of the FCP detector.

on the project proposal and ranged from an hour to four hours as the submission deadline approached. At least as much research time was spent individually by the team members. We discussed objectives that we had researched on our own and came back to the meetings with ideas and answers. More than forty hours were spent preparing the proposal and ten hours to finalize the video. As young scientists, our ultimate goal was to contribute to searches for new physics. We discussed topics such as gravitational interaction with antimatter and hypothetical particles. Through our research and with the support of Professor James Pinfold,[b] we chose to search for FCPs with the intention of producing a meaningful scientific contribution. We had designed the FCP detector (FCPD) as a liquid-based scintillator,[9] similar to those used in the SNO+ experiment at SNOLAB.[c] Our detector, designed with the help of the University of Alberta, would consist of a 2 m long tube with a 20 cm diameter and photomultiplier tubes (PMTs) on both ends, as shown in Fig. 1.

The PMTs were standard components available for our experiment and allowed for data collection with multiple channels. When used in coincidence with each other, the two-channel system would reduce the effect of noise and increase experimental confidence. Moreover, a custom-built liquid scintillator was ideal to maximize the ionization paths for FCPs. A large path length for FCPs in the scintillator is necessary to ensure that an adequate signal strength can be achieved, even as low as 1/10th of an electron charge (e). The liquid scintillator material we considered for use in the FCPD was mainly composed of linear alkyl benzene (LAB) and was therefore low in cost and environmentally friendly. Our team prepared a proposal[10] outlining the intended experimental setup as well as a short film[d] as required in the BL4S competition. After being selected as one of the winning teams of the 2017 competition, the news spread quickly among the Canadian particle physics community. Many physicists congratulated our team on its achievement and also offered their support. SNOLAB invited us to visit their facility in Sudbury, Ontario and proposed to supply our experiment with liquid scintillator. During the visit, we met Ontario's Minister for Research, Innovation and Science. We further discussed our intentions with the BL4S team at CERN and made some modifications to our initial experimental setup. Due to time constraints and concerns that the liquid scintillator would not meet CERN's safety requirements, the FCPD was instead built at CERN using plastic scintillators,[e] machined to an exceptionally large size, as seen in Fig. 2. Our final experimental setup is described further in Sec. 4. Following our experiment at CERN, we were invited to EDIT (Expo for Design, Innovation and Technology) in Toronto, where we presented our story to other students. We were also interviewed for local and national TV, radio and newspapers.

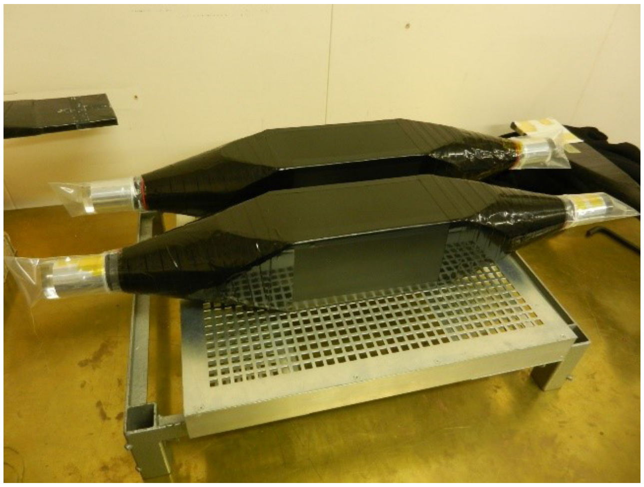


Fig. 2. Fractionally charged particle detector and trigger scintillators.

[b]James Lewis Pinfold, Professor of Physics, University of Alberta, Canada. https://www.ualberta.ca/science/about-us/contact-us/faculty-directory/james-pinfold.

[c]SNOLAB is a Canadian underground physics laboratory at a depth of 2 km. SNO+ is the successor SNO experiment https://www.snolab.ca/.

[d]https://www.youtube.com/watch?v=ckhPq1he3ow.

[e]https://eljentechnology.com/products/plastic-scintillators/ej-200-ej-204-ej-208-ej-212.

4. Methods

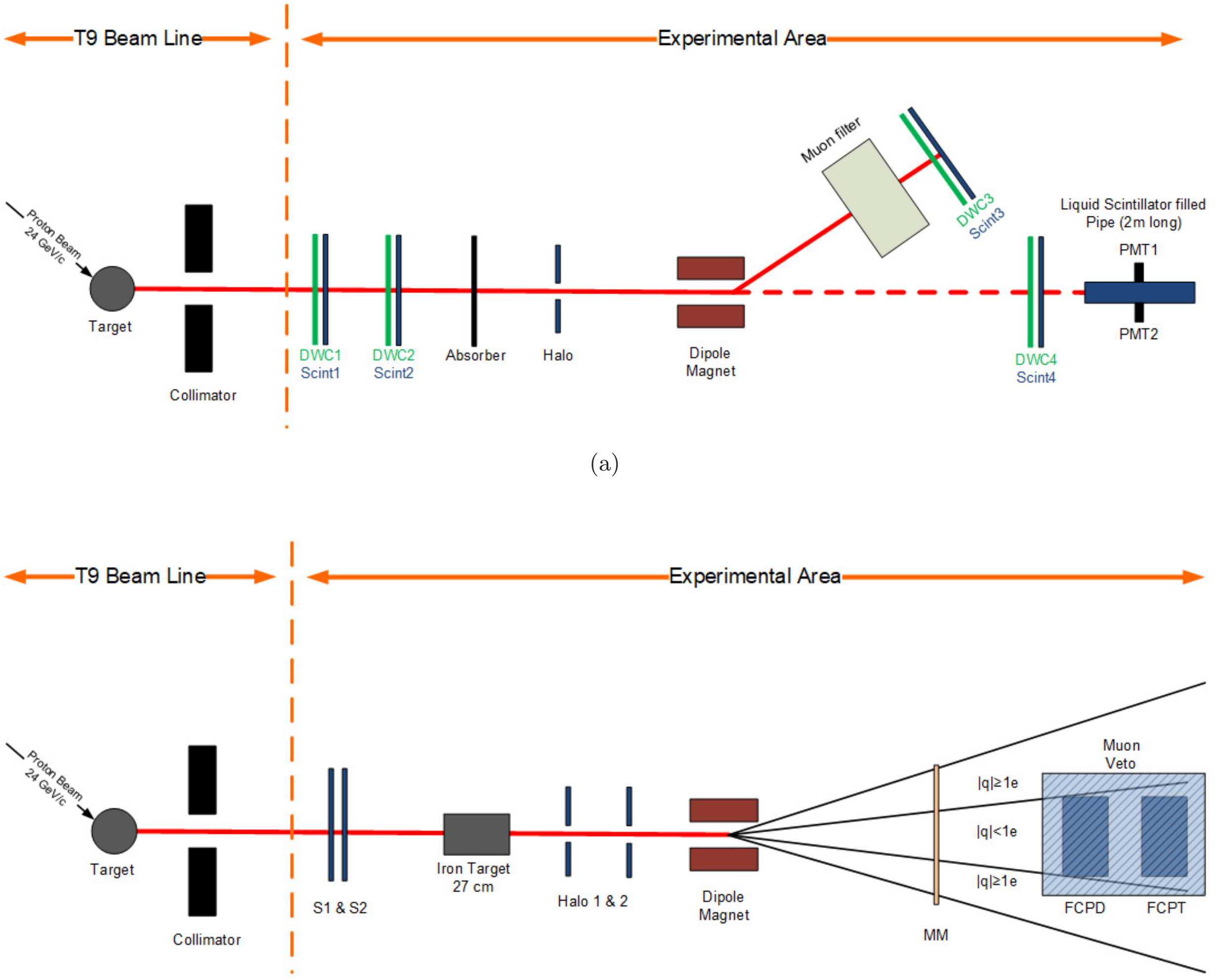
Based on the Beamline for Schools documents[f] we had initially designed our experiment as illustrated in Fig. 3(a) with liquid scintillator as the main FCPD. The final setup of the experiment after modifications is shown in Fig. 3(b).

4.1. *Beam setup*

The 24 Gev c^{-1} primary proton beam from the Proton Synchrotron collides with the target and provides a variety of particles. The T9 secondary beam was set up to select a mixed beam of particles with a fixed momentum in the range of 0.5 to 10 Gev c^{-1} (positive: proton, positron, $\pi+$, $K+$; negative: antiproton, electron, $\pi-$, $K-$). The momentum and profile of the beam could be set by adjusting the magnet and collimator settings. The beam collides with a 27 cm thick iron block (secondary target) which produces a spread of different particles — hypothetically including FCPs.

4.2. *Diagnostics*

Before the secondary collision, particles in the beam were counted by the scintillators S1 and S2. These were fixed detectors in the T9 beamline. The MicroMegas chamber (MM) is a gaseous positional detector.[11] Two superimposed chambers, used to track the position of charged particles in both the x and y directions, are placed after the secondary target. This allowed for alignment of the beam with



(a)

(b)

Fig. 3. Experimental setups. (a) Initial setup and (b) final setup.

[f]https://twiki.cern.ch/twiki/pub/BL4S/2017ChargingCavaliers/BL4S-Beam-and-detectors_2017.docx.

respect to the FCPD and also validates the deflection by the magnet.

4.3. *Detector*

Following the secondary collision, two halo scintillators (H1, H2) are used to immediately detect and veto any particles on the periphery of the beam from the data collection system. This is to ensure a mostly narrow beam after an interaction with the fixed target. The particles with small deflection passed through two identical scintillators with two PMT channels each. The first scintillator is referred to as the Fractionally Charged Particle Detector (FCPD) and the second scintillator is the Fractionally Charged Particle Trigger (FCPT). Both scintillators were custom-made from EJ-200 polymer to be quite large (10 cm × 20 cm × 10 cm) as shown in Fig. 2. Typical plastic scintillators available for BL4S are about 1 cm thick and are only equipped with a single PMT. When charged particles pass through a scintillator, some of their energy is absorbed by the electrons in the material, which become excited. As they fall back to a lower energy state, they emit photons which are guided into the photocathode of one of the PMTs. Since ionizing particles lose energy in the scintillator proportionally to the square of their charge, FCPs will logically produce a smaller signal than a fully charged particle. For this reason, it is vital to maximize the ionization path length to increase signal strength by increasing the size of the scintillator. The signal from each PMT was integrated by a charge-to-digital converter (QDC) and values were saved in units of QDC counts. Another plastic scintillator was placed above the FCPD and FCPT to veto readings of particles coming from cosmic rays.

4.4. *Magnetic deflection*

To compute the deviation caused by the dipole magnet, consider a particle of charge q having momentum p in a magnetic field of strength B and length l. For simplicity we will assume that the path length the particle travels, s, in the magnetic field is the length of the magnet, l. In other words,

$$d\theta = \frac{ds}{\rho} \approx \frac{dl}{\rho}, \tag{1}$$

where θ is the deflected angle and ρ is the radius of convergence. The radius of convergence is computed by,

$$\rho = \frac{p}{qB}\,[\mathrm{m}]. \tag{2}$$

Putting Eqs. (1) and (2) together and integrating we get,

$$\theta = \frac{qBl\,[\mathrm{C\,T\,m}]}{p\,[\mathrm{kg\,ms^{-1}}]}.$$

The result is computed in SI units. We wish to express this in more suitable units. So, we arrive at the following:

$$\theta = \frac{0.29979qBl\,[\mathrm{e\,T\,m}]}{p\,[\mathrm{GeV}/c]}. \tag{3}$$

In order to compute the deflection Δx at a distance d from the magnet, we use trigonometry and Eq. (3) for the angle and obtain Eq. (4).

$$\Delta x = d\tan(\theta)\,[\mathrm{m}]. \tag{4}$$

In our experimental setup $l = 0.5\,\mathrm{m}$, $p = 10\,\mathrm{GeV}\,c^{-1}$ and the magnet is set to its maximum strength of $B = 1\,\mathrm{tesla}$. Table 1 shows the deflection of particles with different charge between the magnet and the MM computed for $d = 8.4\,\mathrm{m}$.

Since the FCPT is 20 cm wide, only particles deflected by a maximum of 10 cm to either side of its center will be detected.

4.5. *Experimental sensitivity*

This experimental setup is sensitive to long-lived fractionally charged particles with an absolute charge lower than 0.8 e, because they will at most have a momentum of $10\,\mathrm{GeV}\,c^{-1}$. It assumes that the FCPs are produced by collisions of the beam with iron at these energy levels and that it occurs

Table 1. Computed deflection distance Δx of charged particles passing through the MM.

Charge [e]	Δx [m]
1.0	0.126
0.9	0.113
0.8	0.101
0.7	0.088
0.6	0.076
0.5	0.063
0.4	0.050
0.3	0.038
0.2	0.025
0.1	0.013
0.0	0.000

sufficiently often to overcome noisy signals. The FCPs will also have to ionize matter to be detected.

5. Calibration

To calibrate the experiment, the dipole magnet was turned off, the beamline collimators were closed and the secondary target was removed, thereby allowing muons to enter the secondary portion of the beamline. This enabled us to identify the average energy deposit of 1 e charged particles in the FCPD. Figure 4 displays the integrated charge pulses from PMT channel 2 on the FCPT (FCPT2) during a calibration run.

The most probable value (MPV) is extracted from the fitting. This is done for all four PMT channels and is shown in Table 2.

This represents the energy deposited in the scintillators by 1 e charged particles in units of QDC counts. These values were later used to compute charge from the experiment. Specifically, they were useful to perform cuts on the data to consider only the signals below those thresholds as potential FCPs. Moreover, by using the MPV from all four channels, it was possible to avoid false-positives from particles which may have given a small signal in only one of the channels due to detector inefficiency.

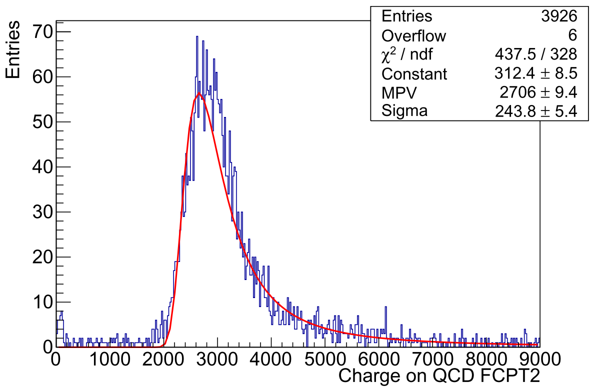
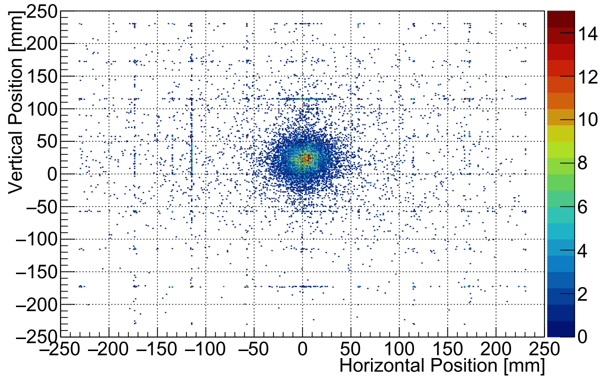


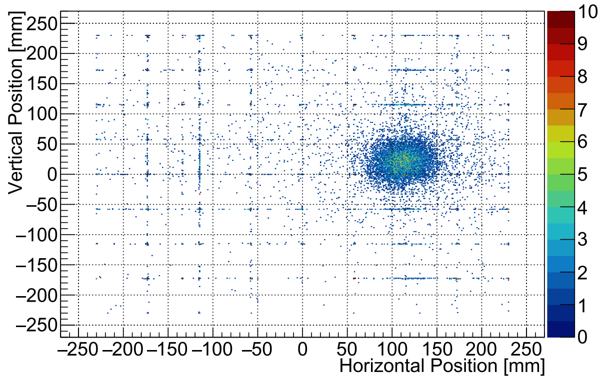
Fig. 4. Calibration plot for channel 2 of the fractionally charged particle trigger and fitted by a Landau distribution.

Table 2. Most probable value for 1 e charges in each PMT.

Detector Channel	Most Probable Value [QDC counts]
FCPT1	3580.0 ± 9.0
FCPT2	2706.0 ± 9.4
FCPD1	$22\,334.0 \pm 29.0$
FCPD2	$36\,927.0 \pm 46.5$



(a)



(b)

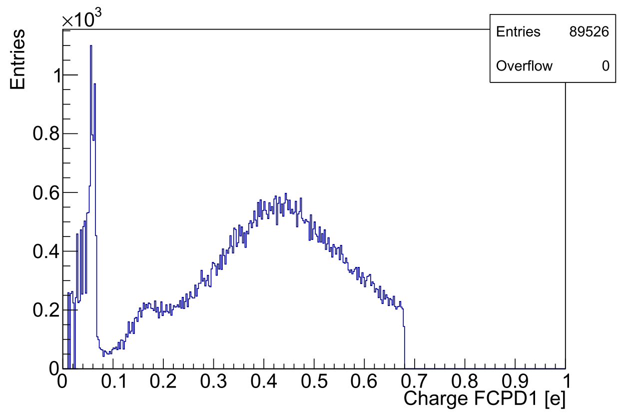
Fig. 5. Hitmaps on the MicroMegas. Beam position on the MicroMegas with the magnet: (a) off and (b) on.

To search for FCPs, the magnet was switched on to deflect the integer-charged particles from the FCPD. The two MM chambers were used to align the beam with the FCPD and FCPT. The beam profiles are shown in Fig. 5.

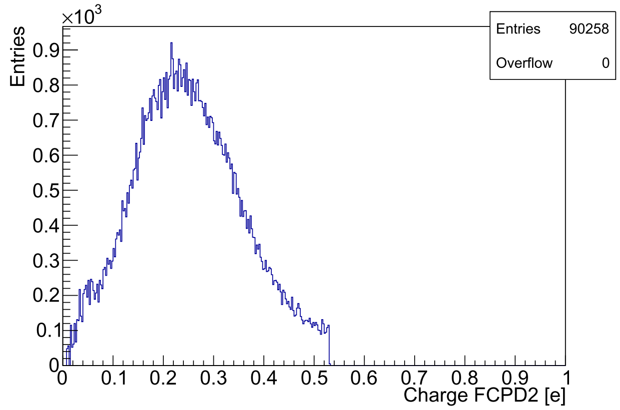
These two hitmaps demonstrate where the particles hit the MM. The x- and y-axis represent the horizontal and vertical positions of the beam, while the z-axis is the number of particles in each bin. In Fig. 5(a) when the magnet was turned off, the mean was located at $(x, y) = (0.27 \pm 1.7\,\text{cm}, 2.3 \pm 1.8\,\text{cm})$. In Fig. 5(b) when the magnet was on, the mean shifted to $(x, y) = (11.2 \pm 2.0\,\text{cm}, 2.0 \pm 2.1\,\text{cm})$. This was a shift of 10.9 ± 2.6 cm to the right and remained in the same vertical position. Using Eqs. (3) and (4) with a distance of 690 cm we got a theoretical prediction of 10.3 cm, which lies within the acceptable error range. With the magnet activated for a negative 10 GeV c^{-1} beam, the FCPD was measuring too many 1 e charged particles — potentially due to air scattering. To mitigate this problem, the main detectors were moved an additional 6 cm in the direction of the positive deflected particles. Due to charge conservation and with the negative beam, positively charged particles were sparse. Therefore, only these integer particles (which were not frequent) and FCPs were being detected.

6. Results

After obtaining the muon MPV and adjusting the magnet, it was possible to gather some FCP data. According to the Bethe–Bloch formula, energy deposited in a material is proportional to the charge squared of the particles. Additionally, the MPV of the 1 e charged particles from our calibration is known from Table 2. We applied cuts to the FCPD data using these values. By filtering data points above these thresholds, we removed 1 e particles from our dataset and obtain the plots shown in Fig. 6.



(a)



(b)

Fig. 6. Initial (above) and final (below) experimental setups. (a) Channel 1 and (b) channel 2 of the fractionally charged particle detector after applying cuts and rescaling.

FCPD1 and FCPD2 both have a main Gaussian distribution. In Fig. 6(a), we show FCPD1 with mean around 0.45 e and in Fig. 6(b), FCPD2 with mean around 0.22 e. FCPD1 has two additional peaks at 0.18 e and at 0.06 e. It would be important to note that no events over 1 e were recorded due to the cuts.

7. Discussion

If we obtained a peak in the distribution of deposited energy for both the FCPD1 and FCPD2 at the same value of charge, it would indicate that particles of that charge were produced in our target. Unfortunately, a large amount of noise was already being observed in data collection for both the FCPD1 and FCPD2. Even after removing events for which the signal in the FCPT was consistent with singly-charged particles, the background remained significant. Discussing with experts at CERN, we learned that it probably came from the PMT power supply and from readout electronics. Additional signals might have been from particles scattered in the air which crossed only a fraction of FCPD. In both FCPD channels we have a main Gaussian distribution which is probably the background noise. In the FCPD1 since the peaks at 0.18 e and 0.06 e are not present in FCPD2, we can conclude that it is noise that comes from the detector.

8. Conclusion

In summary, our search for fractionally charged particles was inconclusive due to large amounts of background noise from the electronics. The technique could be improved by using less noisy PMTs and studying other sources of background in the beamline.

Experience

The members of the scientific staff at CERN who welcomed us were incredibly enthusiastic about sharing their knowledge with us. We received safety training that consisted of both online and hands-on classes (fire safety and emergency evacuation). We also visited CERN exhibitions and learned about numerous experiments performed at CERN. We had the privilege of having direct insight into professional research in particle physics. It built our understanding of how large-scale experiments are initiated and operated. Moreover, having the opportunity to connect with accomplished physicists, engineers and other staff members crowned the experience. The environment was consistently professional, and ultimately made for a very enriching experience for the entire team. This experience has further motivated the team members to pursue their education mainly in STEM fields.

Acknowledgments

The authors wish to acknowledge the assistance and encouragement from colleagues, special work by technical staff or financial support from the organizations. In particular, we would like to thank Professor James L. Pinfold, University of Alberta, Canada for his invaluable assistance in the preparation of the experiment. Additionally, the CERN BL4S organizers and scientists, Lau Gatignon and Christoph Rembser for their guidance during the experiment. SNOLAB for offering the liquid scintillator and the visit of the facility in Sudbury, Canada. Also, Arconic Foundation, Motorola Solutions and National Instruments through the CERN and Society foundation for sponsoring the competition.

References

1. P. A. M. Dirac, Quantised singularities in the electromagnetic field, *Proc. Roy. Soc. A* **133**, 60 (1931).
2. P. Nath, *Supersymmetry, Supergravity, and Unification* (Cambridge University Press, Cambridge, 2017).
3. P. H. Frampton and T. W. Kephart, Fractionally charged particles as evidence for supersymmetry, *Phys. Rev. Lett.* **49**, 1310 (1982).
4. I. Antoniadis and K. Benakli, Fractionally charged particles and supersymmetry breaking in 4D, *Phys. Lett. B* **295**, 219 (1992).
5. M. Marinelli and G. Morpugo, Searches of fractionally charged particles in matter with the magnetic levitation technique, *Phys. Rep.* **85**, 161 (1982).
6. M. L. Perl, E. R. Lee and D. Loomba, Searches for fractionally charged particles, *Ann. Rev. Nucl. Particle Sci.* **59**, 47 (2009).
7. R. A. Millikan, On the elementary electrical charge and the avogadro constant, *Phys. Rev.* **2**, 109–143 (1913).
8. CMS Collaboration, Search for fractionally charged particles in pp collisions at $\sqrt{s} = 7\,\text{TeV}$, *Phys. Rev. D* **87**, 17 (2013).
9. M. C. Chen, The SNO liquid scintillator project, *Nucl. Phys. B — Proc. Supplements* **145**, 65–68 (2005).
10. Charging Cavaliers, *The Quest for Fractionally Charged Particles* (2017).
11. Y. Giomataris and Ph. Rebourgeard and J. P. Robert and G. Charpak, MICROMEGAS: a high-granularity position-sensitive gaseous detector for high particle-flux environments, *Nucl. Instrum. Meth. Phys. Res. Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **376**, 29–35 (1996).

Paul McKarris *led the Canadian Beamline for Schools winning team in 2017 as a high school student. He is studying mathematical physics at the University of Waterloo in Canada and in 2019, he was a CERN summer student. This summer 2020, he will be working on two research projects in mathematics and philosophy of general relativity.*

Andrew Mourcos *was a member of the winning BL4S team from Canada in 2017. The following year, he began his undergraduate studies as a Mechatronics Engineering student at the University of Waterloo, Canada. Since then, he has completed two internships in the field of machine learning and continues to work on his personal robotics projects.*

Colin Billiau *was a member of the winning BL4S team from Canada in 2017. He began his post-secondary studies in video game design and aspires to become a game designer, set on making games that many will enjoy.*

Ina Carli *is an experimental particle physicist with a passion for science communication. In* 2017 *she worked as a support scientist on Beamline for Schools project and helped students to perform their experiments. Currently she is a postdoctoral researcher at the LHCb experiment at CERN and contributes to testing of new detectors.*

Lucas Ferron *was a member of the winning BL4S team from Canada in 2017. He is studying software engineering at the University of Guelph in Canada. He hopes to work and make contributions to this field in the near future.*

Mathieu Gilmour *was a member of the winning BL4S team from Canada in 2017. He is currently completing his degree in software engineering with a minor in business at the University of Guelph. He has worked with Nokia as a component project coordinator for security and UXR teams, and has a big interest in the field of cybersecurity and data security.*

Mariam Ibrahim *was a member of the winning BL4S team from Canada in* 2017. *She is studying at Massachusetts College of Pharmacy and Health Science* (*MCPHS University*), *working towards her PharmD. In March* 2020 *she started her internship at Joslin Diabetes Center, a teaching and research affiliate of Harvard Medical School. In* 2019 *until the present, Mariam has been the President of the Canadian Student Organization at MCPHS University. Mariam has conducted many research projects in allergy and clinical immunology, more specifically on unintentional injection to the bone with a pediatric epinephrine auto-Injector.*

Denis Jacques *received his bachelor's degree in Science from Bishop's University in Canada. In 1998, he became a science and math teacher and continues to work at Père-René-de-Galinée High School in the province of Ontario. He currently teaches Physics and is the school coordinator for the Specialist High Skills Major Program, which brings together science, math, arts and technology.*

Markus Joos *has studied technical engineering at a University of Applied Science in Germany. In 1993, he joined CERN where he has focussed on the development of software for modular electronics used in data acquisition systems. He is a co-organizer of the ISOTDAQ schools and the technical coordinator of Beamline for Schools.*

Jacob Taylor Lehmann *was a member of the winning BL4S team from Canada in* 2017. *He began studying physics the same year, and is now a working jack-of-all-trades in residential construction.*

Denisa Logojan *was a member of the winning BL4S team from Canada in 2017. She is currently completing her Honours Specialization in Philosophy at the University of Western Ontario and will graduate in 2021. During this time, she has conducted supervised research in bioethics and medical ethics, on the use of CRIPR-Cas9 and on teaching and diagnosing PTSD in military members. She is also a medic in the Canadian Armed Forces Reserves, and a writer. She writes anything ranging from philosophy* (*primarily existential and moral philosophy*) *to fiction.*

Emily Jean Loke *was a member of the winning BL4S team from Canada in 2017. She is currently studying Animal Biology at the University of Guelph. She volunteers at the Kitchener Humane Society's veterinary clinic and at Camar farm in order to explore her interests in relation to her field of study.*

Dominique Morrison *was a member of the winning BL4S team from Canada in 2017. She is currently studying towards a Bachelor of Applied Sciences in Civil Engineering at the University of Waterloo and will graduate in 2023. They have worked in residential development, water resources and hospital construction throughout their degree.*

Caitlyn Mourcos *was a member of the Canadian Beamline for Schools winning team in 2017. Since then, she has completed 2 years of Biomedical Science and continues to work towards a Bachelor of Science in Translational and Molecular Medicine at the University of Ottawa, Canada. In the course of her studies, she worked on research projects in muscular dystrophy and cancer. She plans to continue her research on cancer metastasis for her honours thesis.*

Mélanie Poirot *was a member of the Canadian Beamline for Schools winning team in 2017. She is currently studying biology, specialized in ecology, evolution and behaviour at the University of Ottawa and is preparing for her honours.*

Branislav Ristic *has studied Physics at the TU Dortmund, Germany. He obtained his PhD from CERN and the University of Geneva where he worked on novel pixel sensors in HV-CMOS technology and instrumentation for beam-based detector evaluation. In* 2017 *he was a support scientist for Beamline for Schools. Currently he works as a postdoc at ETH Zurich for the CMS experiment.*

Marina Robin *was a member of the winning BL4S team from Canada in 2017. She is a PharmD candidate at the University of Waterloo, with a special interest in pharmaceutical oncology. She has participated in several student-led research and advocacy initiatives, such as iGEM at the University of Waterloo and the role of Internal Relations with the University of Waterloo Oncology Pharmacy Interest Group.*