Reasons for candidature

I believe that I would be well suited to complementing the activities of the elementary particle physics group at Vrije Universiteit Brussel (VUB). The position at VUB provides the perfect opportunity over the next three years to strengthen my leadership role within the milliQan collaboration as we move towards construction of the detector, increase my opportunities for teaching and supervision, and make VUB a European centre for research and development of the milliQan detector.

The milliQan detector

The milliQan detector is a small dedicated detector designed to search for fractionally charged particles produced in the high energy proton-proton collisions of the LHC. Such particles deposit only $(Q/e)^2$ of the energy deposited by a particle with charge e of the same mass so a large path length of scintillator is required for their detection. The milliQan detector is proposed as two $1 \text{ m} \times 1 \text{ m} \times 3 \text{ m}$ plastic scintillator arrays in the CMS experimental cavern that are aligned with the proton-proton interaction point, where the LHC beams are brought together for collisions. The arrays are formed of four layers of 216 scintillator "bars" (864 bars per array) optically coupled to high-gain photo-multiplier tubes (PMTs). To provide sensitivity to the small energy deposits from fractional charges as low as $0.001e$, each PMT must be capable of detecting a single scintillation photon. Each array is surrounded by six scintillator "panels" that serve as an active veto of muons produced by cosmic rays. Finally, at the top and bottom of the array scintillator "slabs" serve to identify muons produced in LHC collisions. The detector is designed such that backgrounds can be greatly mitigated by requiring a hit in a bar in each of the four layers of the scintillator array within a small time window. The highly modular design of the milliQan detector has allowed the feasibility to be confirmed through the operation of a 1% prototype detector at the LHC.

The milliQan collaboration includes 38 physicists from 10 institutes in the US, Europe and Asia. Dr. Steven Lowette, a faculty member of the elementary particle physics group at VUB, has been a member of the collaboration since 2019. The reasonably small size of the collaboration means that a single institute can have a significant impact on the design and performance of the detector. With the visiting position at VUB, Dr Lowette and I can drive the development of the next phase of the milliQan experiment. In addition, there is significant scope for students to have vital contributions to achieving the physics goals of the experiment.

Main activities at VUB

The milliQan detector requires the assembly of a total of 1728 bars as well as the slabs and panels. Partly, my activities at VUB would involve providing expertise to allow the construction and calibration of the detector components, however, the main purpose for my application is to lead research projects that will allow VUB to make crucial contributions to the design and performance of the milliQan experiment. This would be carried out in collaboration with Dr Lowette and can form a significant part of thesis work for undergraduates and graduates at VUB.

The potential for the full detector to actively veto backgrounds from cavern radiation and cosmic muon shower particles is of vital importance to achieve sensitivity to signals with $Q \lesssim 0.01$. At VUB, I plan to evaluate the efficiency to identify backgrounds using bars on the outer edges of the detector. If a student is available, it will also be possible to study possibilities for improving the light collection efficiency of the panels with light guides or multiple PMT readouts. These studies can be undertaken both on the surface at VUB and CERN, and underground at the detector position.

Higher charge signals ($Q \gtrsim 0.05$) face lower backgrounds from cavern processes, however, distinguishing the signal from beam muons is difficult as both signatures will saturate the readout. The slabs that will be placed at the top and bottom of each milliQan array are therefore critical to discriminate higher charge signals from background. With this position I will be able to finalise the design of these crucial detector components such that the design and construction of these slabs will be driven by VUB.

It will be critical to calibrate the energy response and timing of the bars. This calibration could be achieved using cosmic muons and their shower particles, however, the spread in position and energy of these processes leads to large uncertainties. A radioactive source, such as Na22, would allow much greater control of these source properties and allow a higher precision calibration, crucial to efficiently rejecting backgrounds. With a student, I can design a source based calibration scheme at VUB that would be applied to the detector in the experimental cavern after construction.

It is possible that funding will not be available to construct the full milliQan detector in time for the next run of the LHC, due to begin in May 2021. In this case a smaller detector may be constructed using available Hamamatsu R878 PMTs from a previous experiment. Such a detector can be approximately six times larger than the previous prototype and collect at least five times the data, allowing for significantly improved limits. The noise levels of the R878 PMTs are too high to efficiently trigger on the low energy signatures of particles of $Q <\sim 0.005e$, however, studies with the prototype have shown it is possible to reject this noise using a simple filter. The performance of such a contingency experiment can be dramatically improved through the development of a filter and amplifier that I will design and study at VUB. This would be a clear opportunity for an undergraduate research project.

Alternative locations of the milliQan detector, either in the forward region or at a neutrino source at FNAL or J-PARC also provides an opportunity for research at VUB, regardless of medium-term funding availability. In this case the production rate for lower masses would be greatly enhanced.

In addition to shared interests in milliQan, my work on long-lived and exotic signatures at CMS overlaps with the research topics of Dr Lowette and Dr Blekman at VUB. While not being the main purpose of the position, I believe there would be ample opportunity to build new collaborations for searches with the CMS detector. One possible example would be the development of new dedicated triggers for fractionally charged particles to carry out a search using the muon system, having potential sensitivity to higher mass particles with $Q \gtrsim 0.1$, with obvious complementarity to the targets of the milliQan detector.

Funding

I plan to take part in funding proposals from VUB for the full milliQan detector from the FWO funding agency. I have had experience contributing to a National Science Foundation funding proposal for milliQan. I believe my extensive experience with both building detector components and coordinating a search for millicharged particles would strengthen the technical expertise of future proposals.

Timeline

The next run of the LHC is expected to begin in May 2021, however, only a small 20 fb^{-1} dataset is expected to be collected. Therefore a clear target for the completion of the detector is the beginning of 2022. Based on our experience constructing the initial prototype, approximately six months is estimated for the construction and a further six months is estimated for commissioning. This provides an ideal timeline for the visiting position at VUB as the studies outlined above can largely be undertaken before and during the construction of the detector. The dedicated calibrations can take place during the commissioning phase. These studies will also be required under the contingency scenario of a smaller detector with approximately the same timeline. In either scenario the detector would be expected to collect 100 fb^{-1} in 2022 and a further 100 fb^{-1} in 2023. Given the experience gained from the prototype, I believe a publication with the data set collected in 2022 could be achieved by early to mid 2023 and a second publication including data collected in both years in early 2024. The milliQan detector can then be upgraded during next the long shutdown (2024-2027), with the upgraded detector taking data at the High Luminosity LHC with a significantly increased instantaneous luminosity from 2027.