Reasons for candidature

The milliQan experiment is a dedicated scintillator-based detector proposed to search for millicharged particles produced in collisions at the LHC. I believe that I would be best suited to supporting the activities of the elementary particle physics group at Vrije Universiteit Brussel (VUB). The main aim of my proposed activities would be to support VUB in becoming a major contributor to the milliQan experiment.

The milliQan detector

The proposed milliQan detector is comprised of a scintillator array placed approximately 30m from the CMS interaction point (IP), with 17m of rock providing shielding from collisional backgrounds. Fractionally charged particles deposit only $(Q/e)^2$ of the energy deposited of a particle with charge e with the same mass and therefore a large path length of scintillator is required for detection. The milliQan detector is proposed as two 1 m $\times$ 1 m $\times$ 3 m plastic scintillator arrays positioned next to each other and each aligned with the CMS IP. These arrays are formed of four layers of 216 scintillator "bars" (864 bars per array)optically coupled to high-gain PMTs. The layers are separated by lead bricks to reduce correlated backgrounds between layers. Each array is surrounded by six scintillator "panels" that serve as an active veto of muons produced by cosmic rays and their shower particles. Finally, at the top and bottom of the array scintillator "slabs" serve to identify muons produced at the CMS IP which reach the detector. In order to control backgrounds, a hit in a bar in each of the four layers of the scintillator array within a small time window and in a path pointing at the CMS IP will be required. 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 physicists from around ten 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.

Main activities at VUB

The milliQan detector requires the assembly of a total of 1728 bars as well as the slabs and panels. Each scintialltor volume must be optically coupled to a PMT+base, wrapped with reflective material and light-tight black taping. Finally, after assembly each bar has to be checked for light leaks and calibrated before they can be sent to CERN for final assembly of the detector. Partly, my activities at VUB would involve providing expertise to allow the construction and calibration of the detector components, however, the main propose of the visiting position would be to pursue several studies that are crucial to finalising the design and optimising the performance of the milliQan experiment. This would be carried out in collaboration with Dr Lowette and could form a significant part of thesis work for undergraduates and graduates at VUB.

The active veto potential for the full detector must be studied in depth. This is of vital importance to achieve sensitivity to low charge signals, which face large backgrounds from correlated cosmic muon shower particles and radiation within the cavern. The panels surrounding the detector are too thin to efficiently identify deposits from such particles and so the veto performance of bars on the outer edges of the detector must be extensively studied. It may also be possible to improve the light collection efficiency of the panels using light guides or multiple PMT readouts such that lower energy deposits may be seen. In combination this could dramatically reduce the background for signals with $Q \sim 0.001e$. The active veto can be studied using scintillator bars and panels 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 of the DAQ. 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. The design of these slabs has not been finalised and would form another interesting and important project. A practical solution is to use four scintillator volumes each covering a quarter of the surface area. However, issues including eliminating edge spacing between the slabs, the required thickness and strategies for coupling PMTs have not been finalised. It is foreseen that the design and construction of these slabs could be driven by VUB.

It will be critical to calibrate the energy response and timing of the bars to identify signal deposits and effectively veto backgrounds. For the milliQan prototype this calibration was achieved using cosmic muons and their shower particles, however, the spread in position and energy of these processes entailed 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. This calibration could be undertaken by VUB students at CERN under supervision.

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 could be approximately six times larger than the previous prototype and could collect at least five times the data, allowing for significantly improved limits. The noise levels of the R878 PMTs are too high to allow triggering on single PE signals, however, from studies with the prototype have shown it is possible to reject this noise using a simple low pass filter. The performance of such a contingency experiment could be dramatically improved through the development of a filter and amplifier applied to the PMT output. This could be designed and studied at VUB and 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 DUNE or J-PARC also provides an opportunity for research at VUB, regardless of medium-term funding availability. In this case the production cross section for lower masses could 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 Steven Lowette and Dr Freya 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, with possible sensitivity to higher mass particles with $Q \gtrsim 0.1$, with obvious complementarity to the targets of the milliQan detector.

Funding

I would plan to take part in funding proposals from VUB for the full milliQan detector from the FWO funding agency. I have had experience helping to prepare a funding proposal for milliQan to the National Science Foundation in the USA and as I have extensive experience with both building detector components and coordinating a search for millicharged particles, I believe this would significantly strengthen the technical expertise of 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. Approximately six months is estimated for the construction with another size months 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.