Status of, and first data from, the milliQan Run 3 Detector

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Abstract

milliQan is a sub-detector of CMS dedicated to the search for millicharged particles produced in LHC proton collisions at CERN. In these proceedings, we present the operational status of the milliQan Run 3 detector, which was installed during the 2022-3 YETS and is presently recording data.

1 Introduction

As evidenced by the large number of talks in this conference, the exploration of dark sectors is an active and diverse area of high energy physics research. milliQan is a complementary LHC dark sector experiment that fills a niche in this panolply. milliQan searches for dark sector particles inaccessible to ATLAS/CMS detectors, but which have a distinctive signature "easily" observable with a "simple", 'cheap", ancillary detector. strategically positioned at a well shielded location. As has been known since 1986 [3], if one considers a BSM extension with a massless dark photon kinetically mixing with SM photon as many dark sectors do, then any "dark" fermions in the theory will have a fractional electromagnetic (EM) charge, proportional to the dark photon - SM photon mixing. Since this mixing must be small in order to avoid electroweak constraints, so must the fractional charge. With milliQan we target a Q/e of about 0.001 (as the name implies). We call such particles millicharged particles, or mCPs. even though milliQan is in fact sensitive to a range of Q/e.

2 milliQan Detector Design and Proof of Principle

For mCPs with Q/e of 10E-3, the energy loss due to ionization (dE/dx) will be 10E-6 that of the usual minimum ionizing particle with Q/e of 1. The milliQan detector therefore needs to be composed of sufficiently long active material elements in order to observe the passage of an mCP. We use "bars" of plastic scintillator optically coupled to photomultiplier tubes (PMT) arranged in a rectangular array pointing back to the CMS interaction point (IP). The dE/dx in these bars is such that an mCP will produce $\mathcal{O}(1)$ photoelectrons (PE). Finally, we arrange the array in radial "layers" in order to be able to use coincidence to control otherwise dominant random backgrounds (e,g, thermionic emission in a PMT commonly called dark current). This design was validated by a "demonstrator" prototype detector that was installed in PX56 during LHC Run 2. The demonstrator collected 37.5 fb^{-1} of physics data that was used to confirm understanding of background processes (as shown in Fig. 1), validate our GEANT simulation, develop analysis techniques, and obtain valuable operating experience [1].

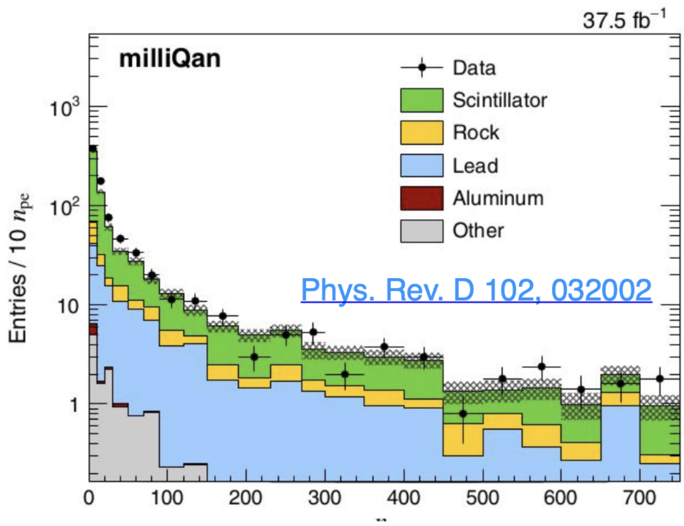

Figure 1: Validation of background estimate in Run 2 Demonstrator.

3 Run 3 Detector and Expected Sensitivity

While the demonstrator exceeded performance expectations, we nevertheless incorporated several lessons learned from its operation into the Run 3 detector design: added a fourth layer to suppress correlated random backgrounds from cosmic ray showers, added an FPGA based trigger board to allow for more flexible data taking, and added a second plastic scintillator array. This second array is composed of scintillator extruded in a wider rectangular geometry that we call "slabs." The two arrays complement each other; each is optimized for a different region in the Q/e vs mass plane as shown in Fig 2 taken from Ref. [2]. Combining the bar and slab arrays, milliQan will probe a significant region of unexplored parameter space with the data collected in LHC Run 3.

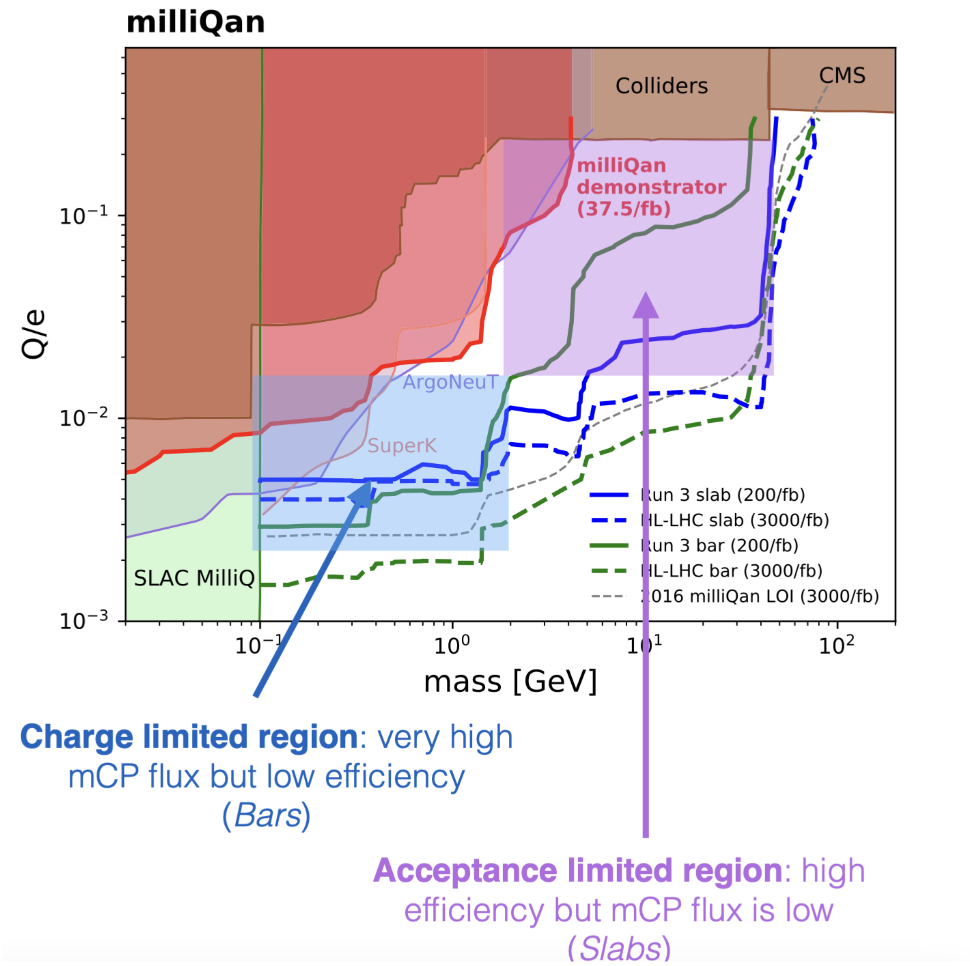

Figure 2: Expected sensitivity of the milliQan Run 3 detector.

4 Operational Status of the Run 3 Detector

Both the bar and slab detectors are composed of layers of modules arranged in four radial layers pointing at the CMS IP. Each module consists of a wrapped and calibrated scintillator+PMT unit connected to custom amplifying electronics. Bar and slab modules were built at US institutes and shipped to CERN in 2022, where they were aggregated into "super modules" and installed onto their respective mechanical support structure in PX56 in 2023. Pictures of this assembly are shown for the bar detector in Fig. 3and Fig. 4 and slab detector in Fig. 5. At the time of writing, the bar detector is installed and commissioned, with all channels fully operational, while 1/3 of the slab detector is installed. As illustrated in Fig. 6, web-based interfaces for DAQ and trigger monitoring are used to operate the detector remotely. Modules from both detectors have been continuously taking data since June 1, 2023. A combination of radioactive sources and integrated LEDs are used for energy calibration of single photo electron pulses. Throughgoing muons originating from the CMS IP are used for timing calibration and alignment.

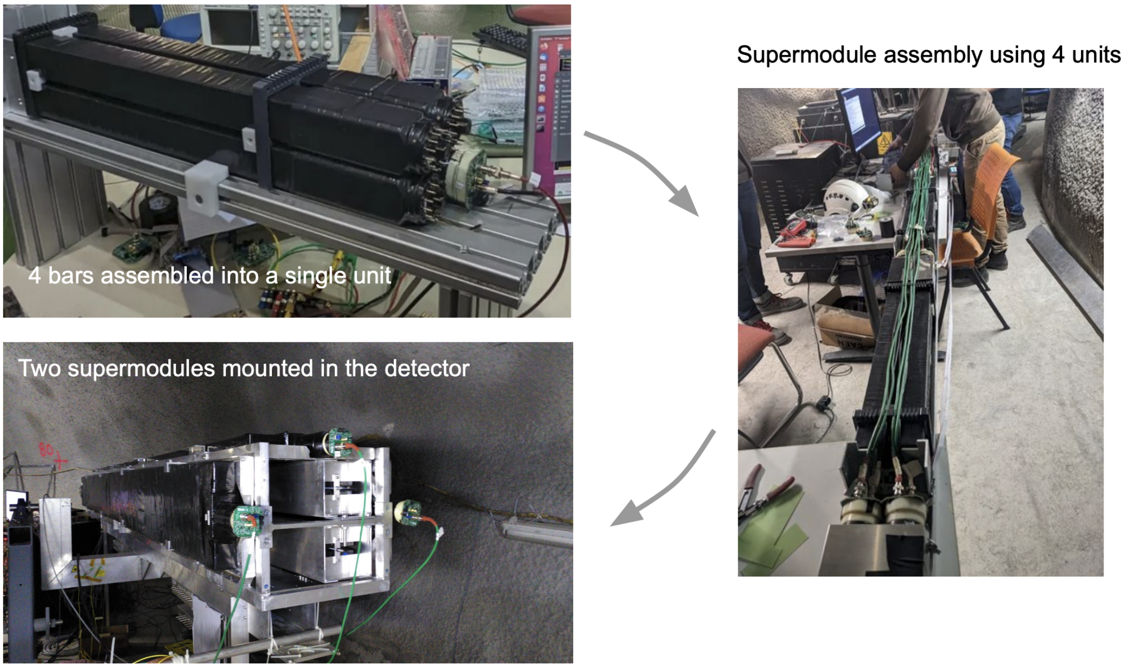

Figure 3: Bar Detector assembly in PX56.

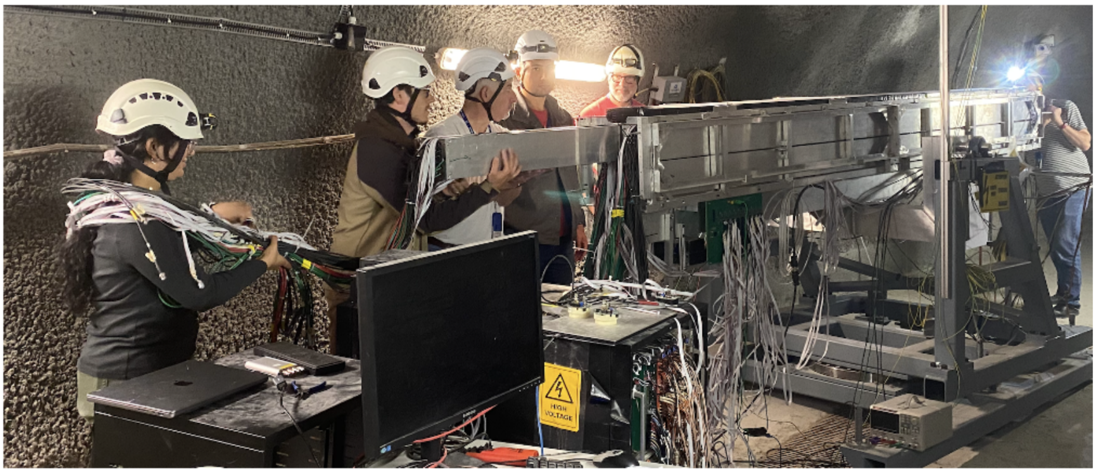

Figure 4: Insertion of a supermodule into the bar detector in PX56.

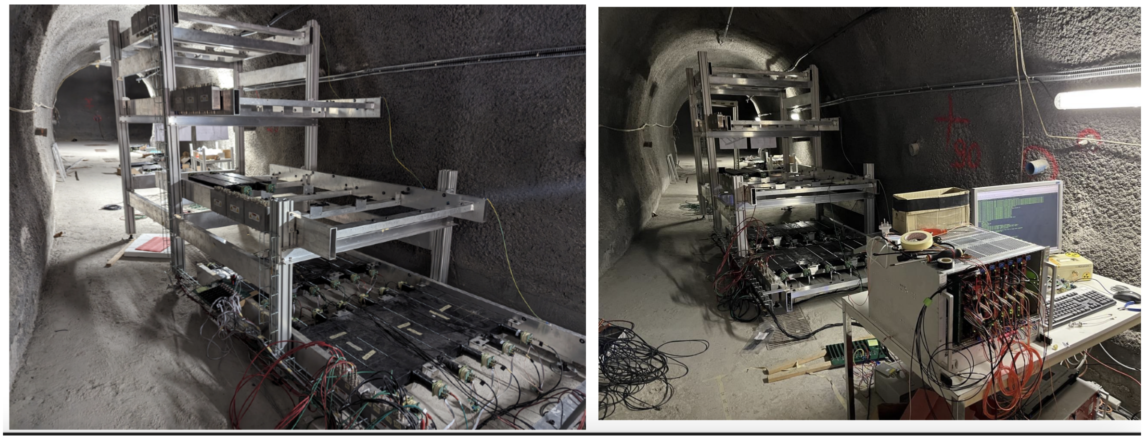

Figure 5: Slab Detector assembly in PX56.

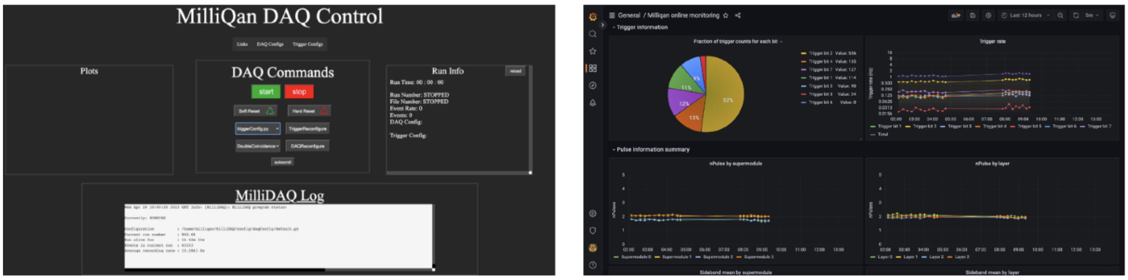

Figure 6: Web-based interfaces for remote DAQ and trigger monitoring.

5 Summary

The milliQan Run 3 detector consists two dedicated detectors sensitive to millicharged particles produced by the LHC at the CMS IP. milliQan provides a complementary approach to search for dark sector particles with $Q/e < 0.3$ particles over wide mass range from 100 MeV – 100 GeV. The bar detector is fully assembled and taking physics data. A photo of the completed bar detector is shown in Fig. 7. The slab detector is being assembled, and is expected to be completed by the end of summer 2023. LHC Run 3 proton collision data recorded by both detectors is currently being analyzed. It is anticipated that milliQan will collect approximately 30 fb^{-1} in 2023. First physics results are expected by Winter 2024.

References

[1] A. Ball et al. Search for millicharged particles in proton-proton collisions at $\sqrt{s} = 13$ TeV. *Phys. Rev. D*, 102(3):032002, 2020.

[2] A. Ball et al. Sensitivity to millicharged particles in future proton-proton collisions at the LHC with the milliQan detector. *Phys. Rev. D*, 104(3):032002, 2021.

[3] Bob Holdom. Two U(1)'s and Epsilon Charge Shifts. *Phys. Lett. B*, 166:196–198, 1986.

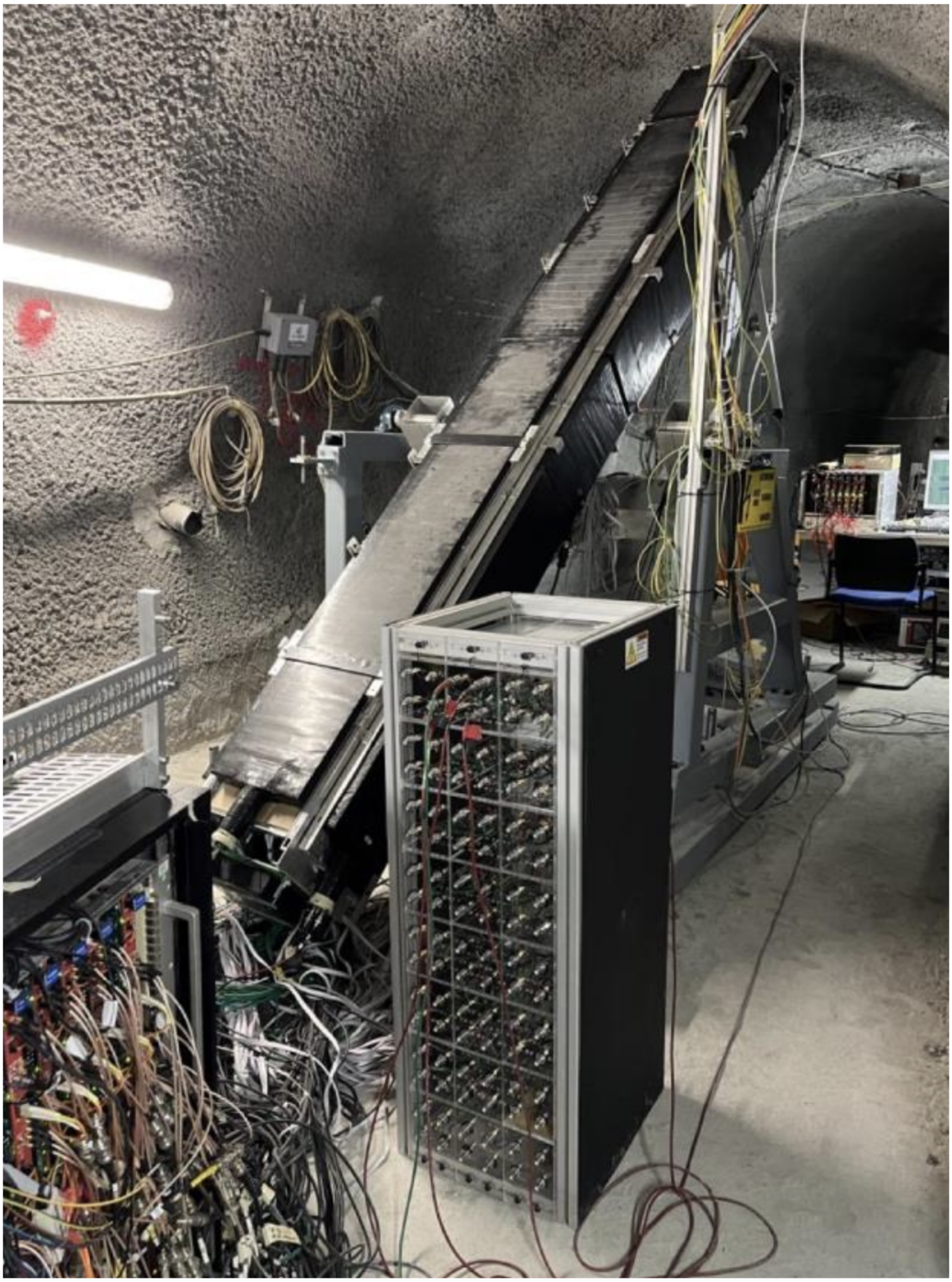

Figure 7: A photo of the completed bar detector pointing at the CMS IP in PX56.