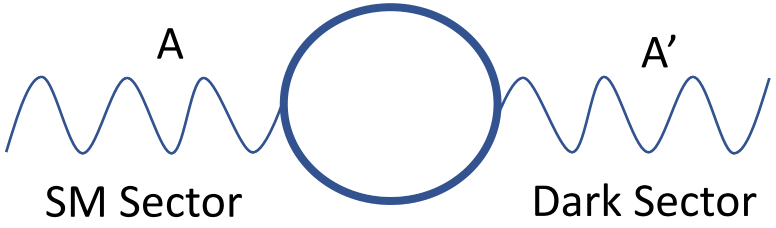
milliQan Run 3 Detectors

Michael Carrigan on Behalf of the milliQan Collaboration

June 22, 2022 – LLP13

What is a Millicharged Particle?

- Millicharged particles (mCP) are theorized particles that have fractional electron charge
- Particles would come from a “dark QED” field A'
- This field mixes with hypercharge creating the millicharged particle ψ with mass M_{mCP}
- Redefining $A'_\mu \rightarrow A'_\mu + \kappa B_\mu$ results in a coupling between ψ and hypercharge $\kappa e'$
- And a coupling to the photon gives a charge $\epsilon = \kappa e' cos\theta_w / e$



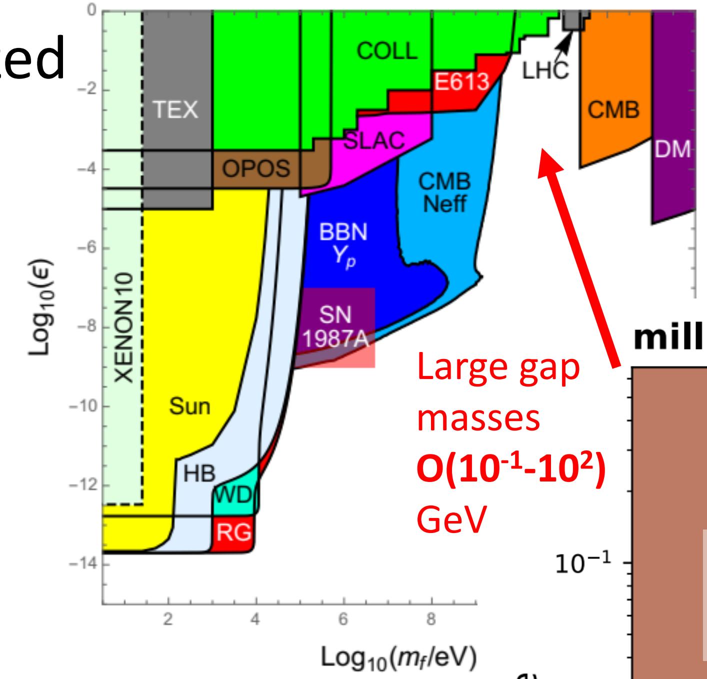
$$\mathcal{L} = \mathcal{L}_{SM} - \underbrace{\frac{1}{4}A'_{\nu\mu}A'^{\mu\nu}}_{\text{Dark Photon Term}} + \underbrace{i\bar{\psi}(\partial\!\!\!/ + ie'A\!\!\!/' + iM_{mCP})\psi}_{\text{Dark Fermion}} - \underbrace{\frac{\kappa}{2}A'_{\mu\nu}B^{\mu\nu}}_{\text{Kinetic Mixing Term}}$$

Dark Photon Term | Dark Fermion | Kinetic Mixing Term

$$\mathcal{L} = \mathcal{L}_{SM} - \frac{1}{4}A'_{\nu\mu}A'^{\mu\nu} + i\bar{\psi}(\partial\!\!\!/ + ie'A\!\!\!/' + -i\kappa e' B\!\!\!/ + iM_{mCP})\psi$$

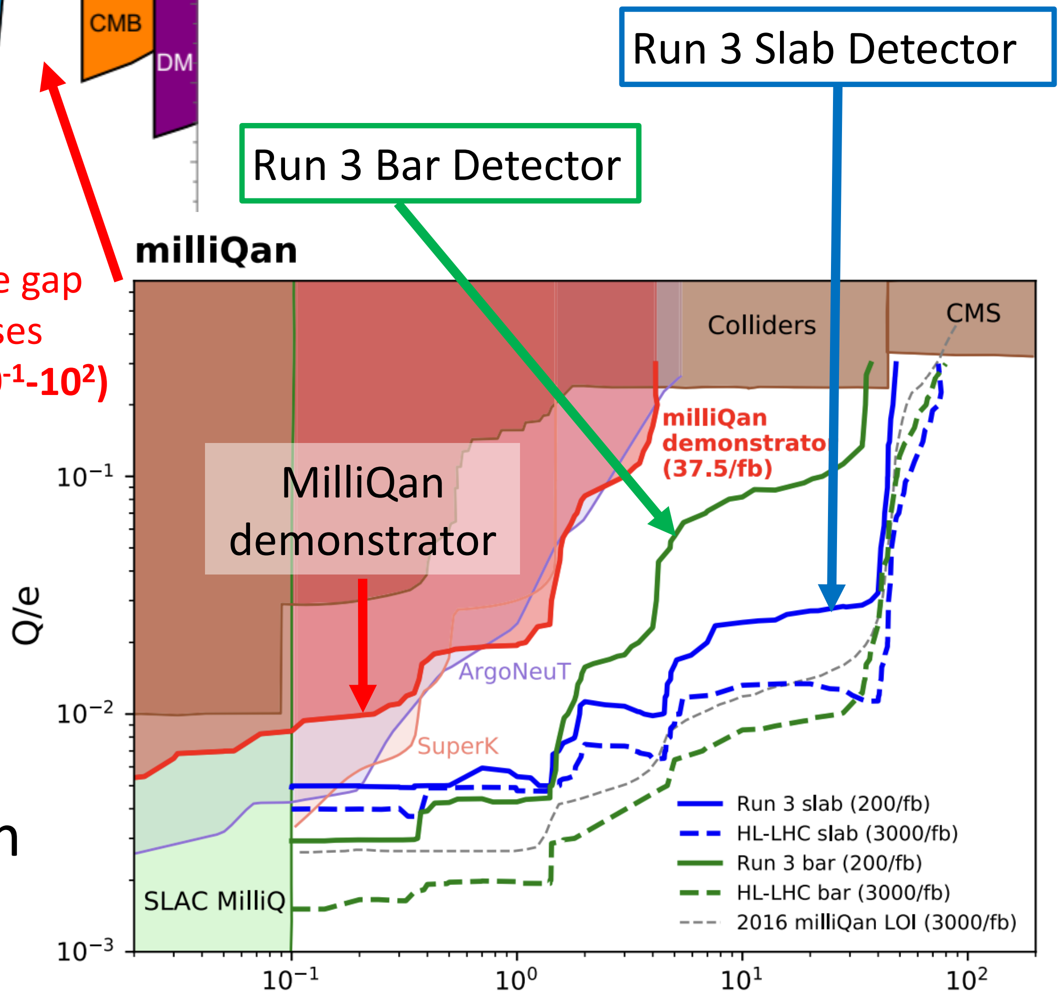
Improving Sensitivity

- Millicharged particle parameterized by mass and charge of particle
- Limits set on mCPs in effective charge (ϵ) and mass
  - Cosmological limits (left)
  - Collider experiments (CMS, SLAC MilliQ, etc) (right)
- milliQan detector aims to **probe undetected phase** space
  - $10^{-1} GeV < M_{mCP} < 10^{2}\mathrm{GeV}$
  - $10^{-3} < \frac{Q}{e} < 10$
- Bar & slab detector expected to set new sensitivity in run 3



arXiv:1511.01122v2

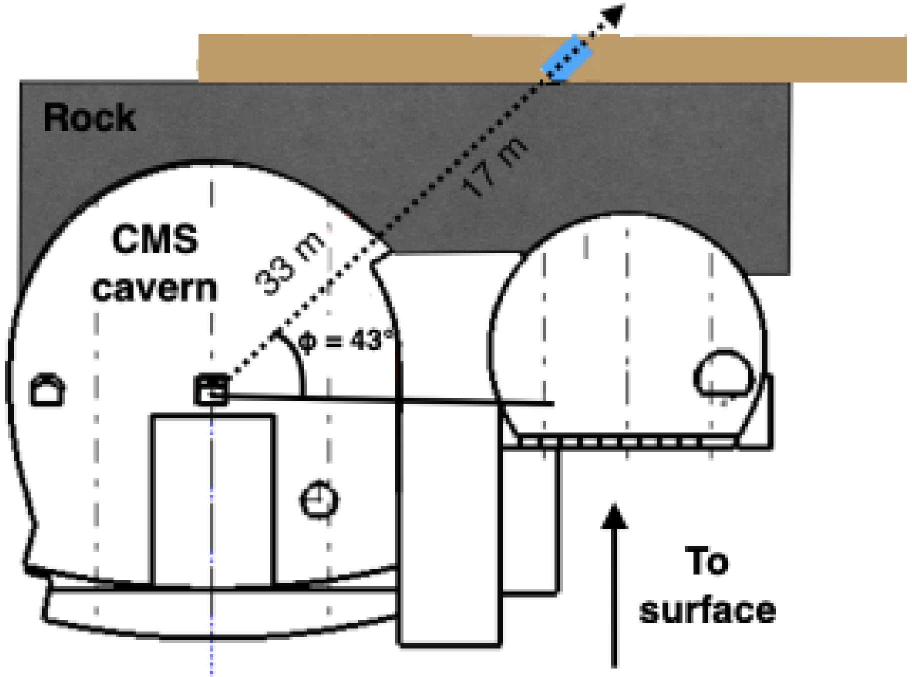
Large gap masses $O(10^{-1}\text{-}10^{2})$ GeV

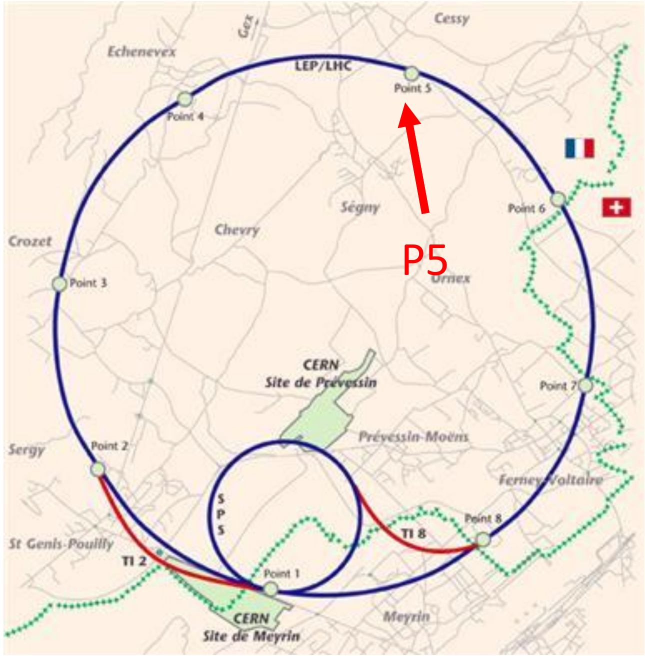


Phys. Rev. D **104**, 032002

milliQan Detector Location

- Detector in PX56 drainage gallery at P5 (above CMS)
- 33m from CMS IP at an angle $\eta \approx 0.1, \phi \approx 43$
- 17m of rock act as natural shielding against bkgd

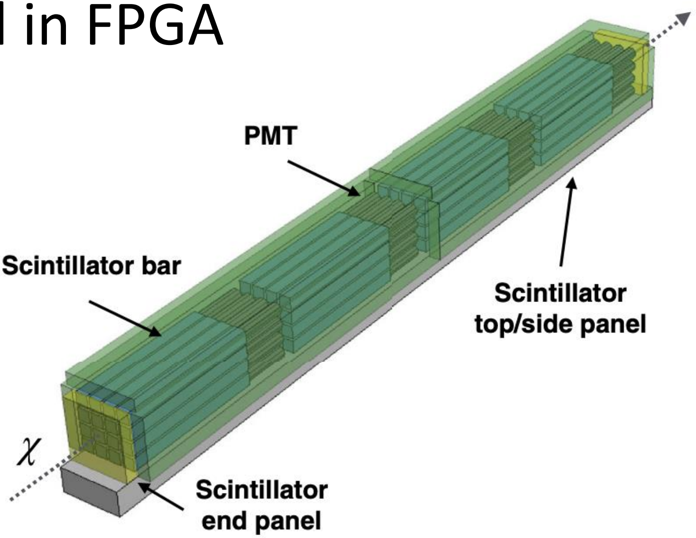


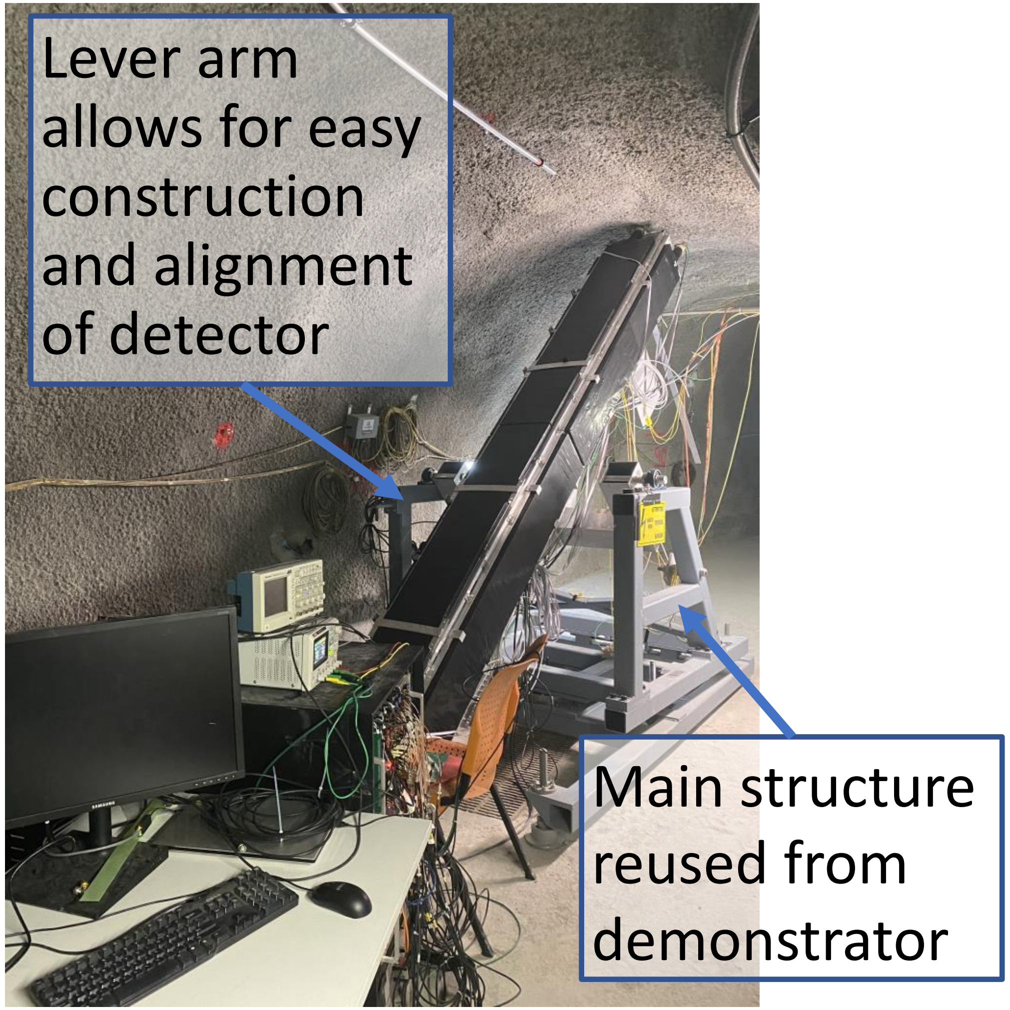


drainage gallery

milliQan Bar Detector

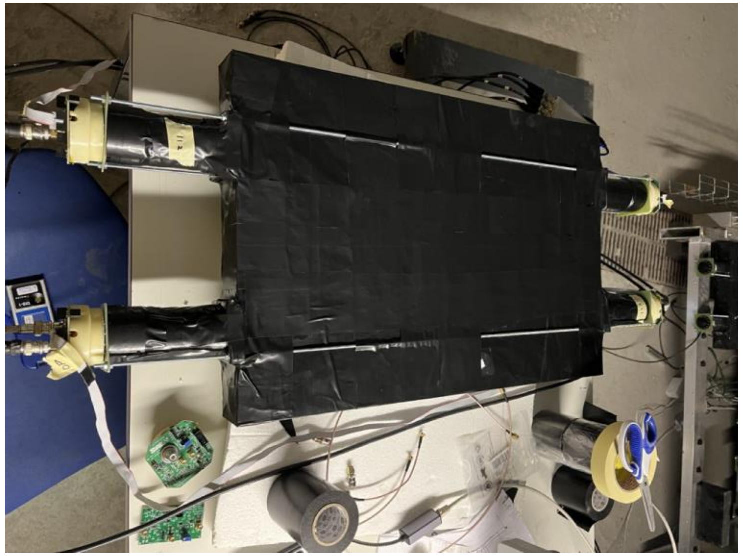
- 4 layers each composed of 16 (5x5x60cm) bars
- Scintillator panels on front and back, top and sides for background veto
- Many improvements from demonstrator:
  - Special PMT amplifiers to efficiently reconstruct single photoelectrons
  - LED flasher system for calibration of sPEs
  - Triggers implemented in FPGA
  - Thicker pannels to improve cosmic vetos
  - Readout window 4x bigger -> better analyze after pulses

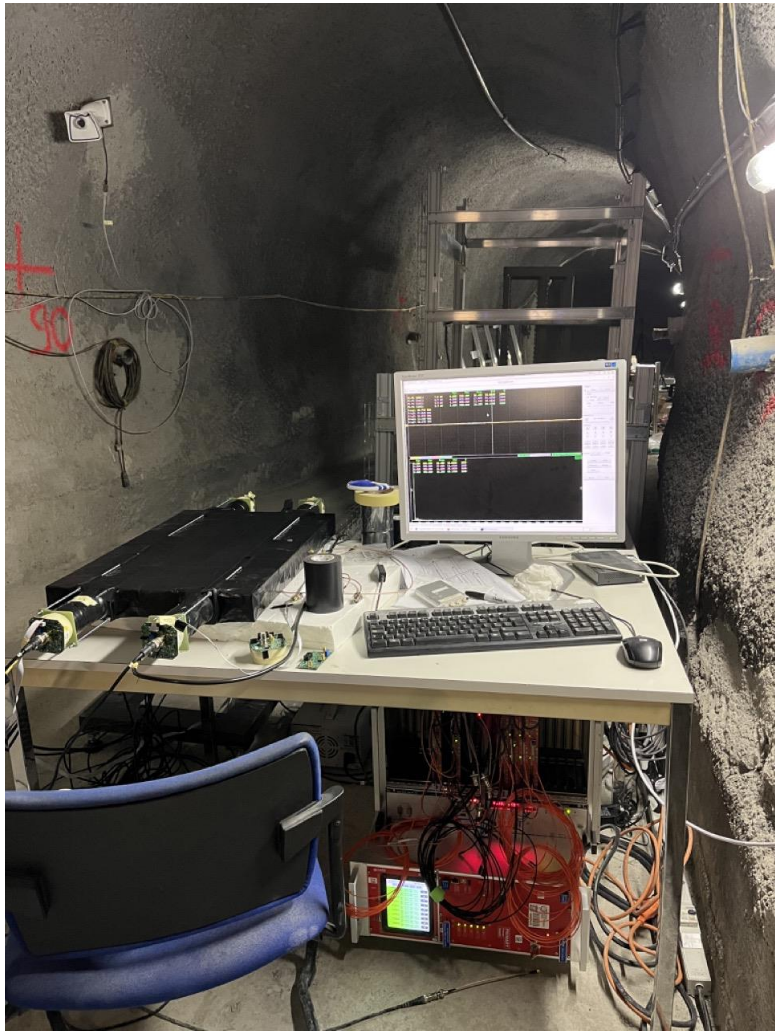




milliQan Slab Detector

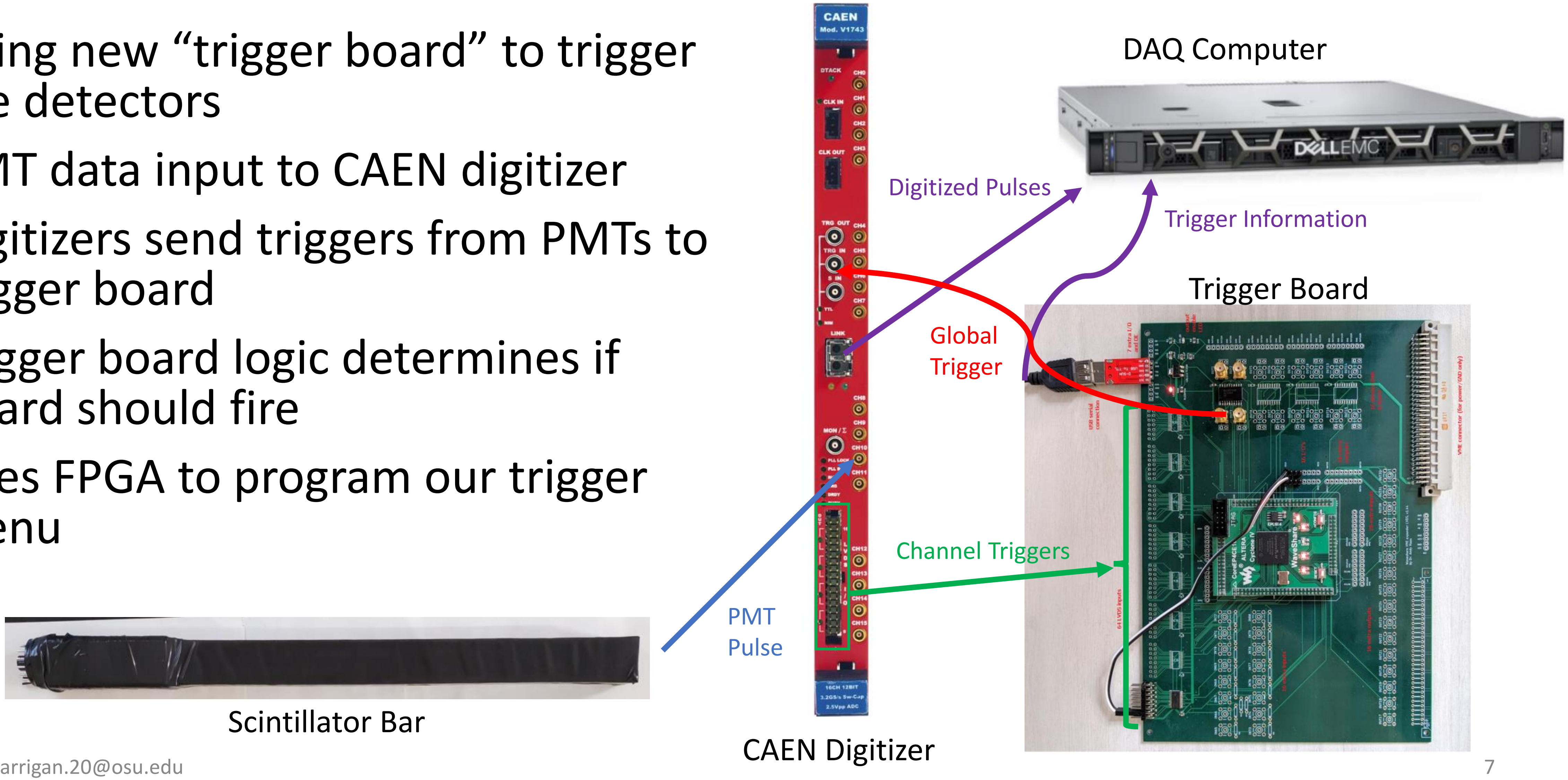
- Run 3 detector includes separate slab detector
  - 4 layers of 12 scintillator slabs (40cm x 60cm x 5cm)
- Larger area increases signal acceptance at higher masses ($M_{mCP} \gtrsim 1.4 GeV$)
- 4 PMTs per slab to increase collection efficiency





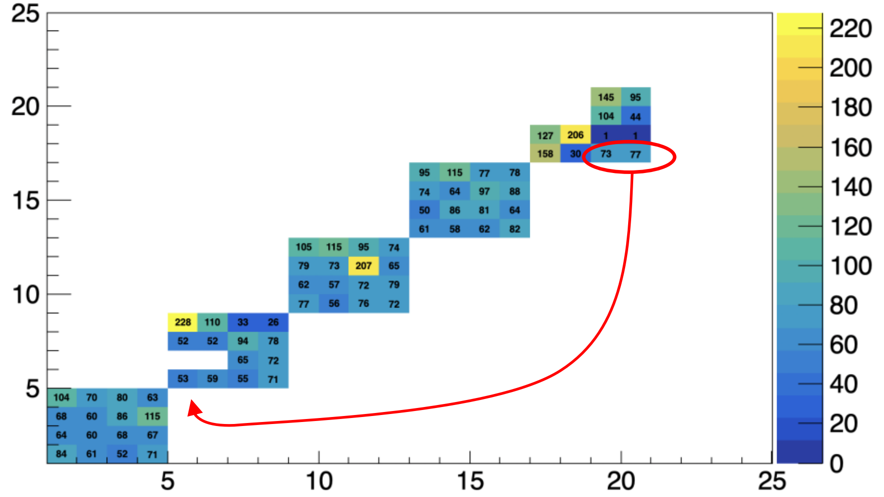
Run 3 DAQ

- Using new "trigger board" to trigger the detectors
- PMT data input to CAEN digitizer
- Digitizers send triggers from PMTs to trigger board
- Trigger board logic determines if board should fire
- Uses FPGA to program our trigger menu



Bar Detector Status

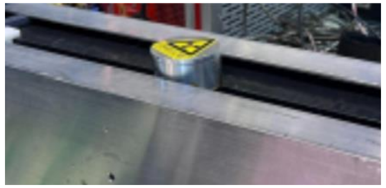
Heat Map Run 1038, File 1

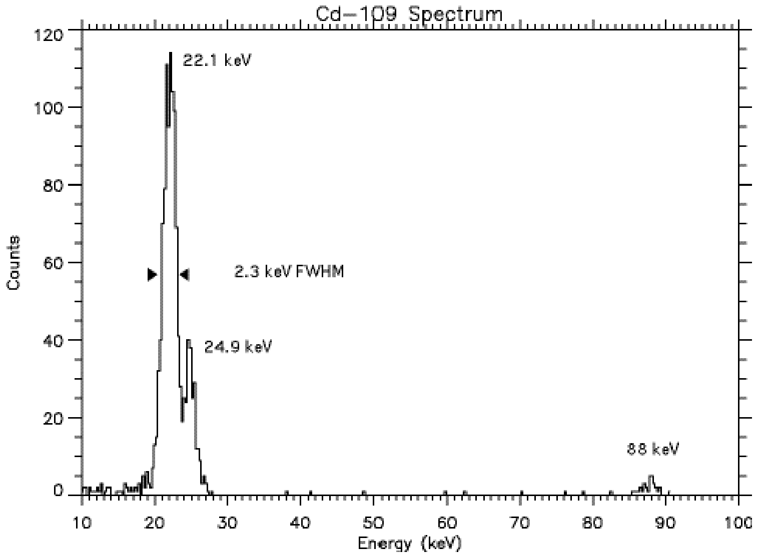


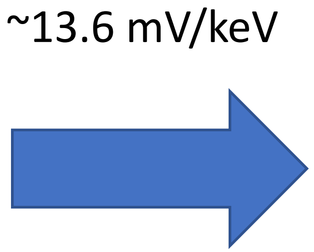
- Bar detector is fully assembled and taking data since June 1!
- Calibrating timing and nPE/keV
  - Use beam/cosmic muons to calibrate timing
  - Radioactive source to calibrate energy deposited

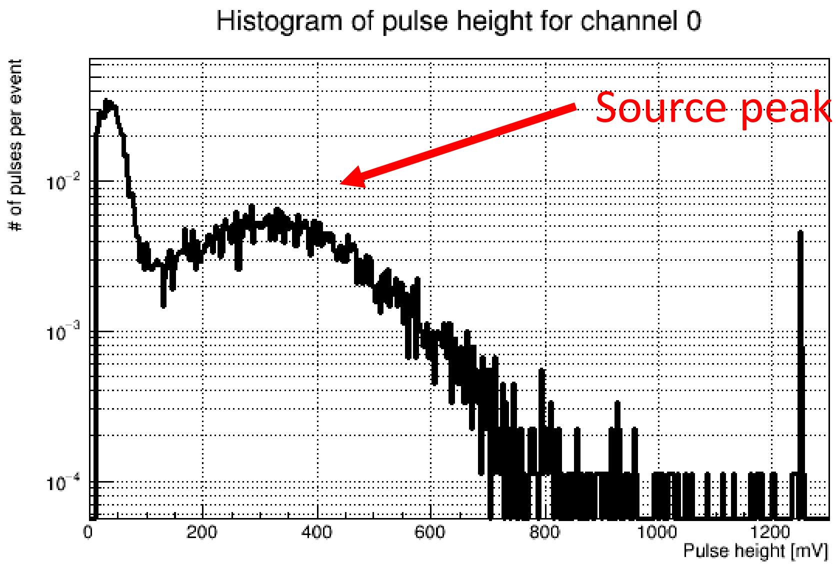
Calibration of PMTs

- Signal output is voltage -> how does this correspond to mCP?
- Need a particle with known energy -> check the voltage of this particle
- Bars are calibrated using Cd-109 source
- X-ray from source registers ~300mV





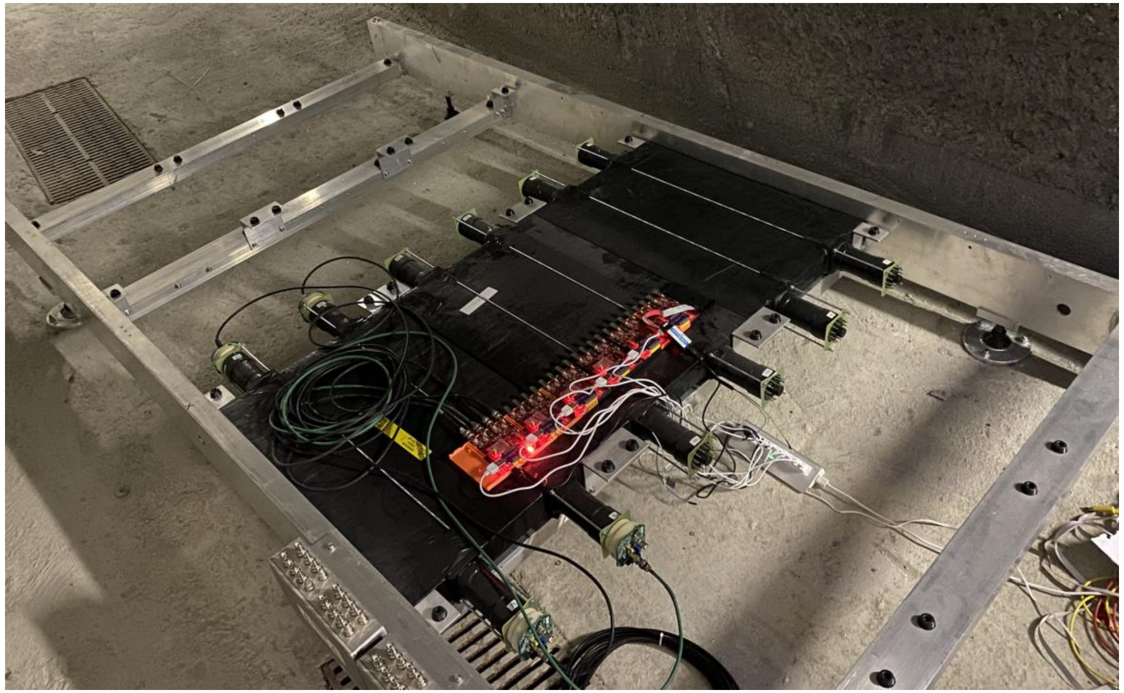




[1] https://asd.gsfc.nasa.gov/archive/infocus/detect.html

Slab Detector Construction

- Ongoing construction of slab detector
- First layer is in installed and is being calibrated
- Full detector will be installed and calibrated by end of summer



Online DAQ/DQM

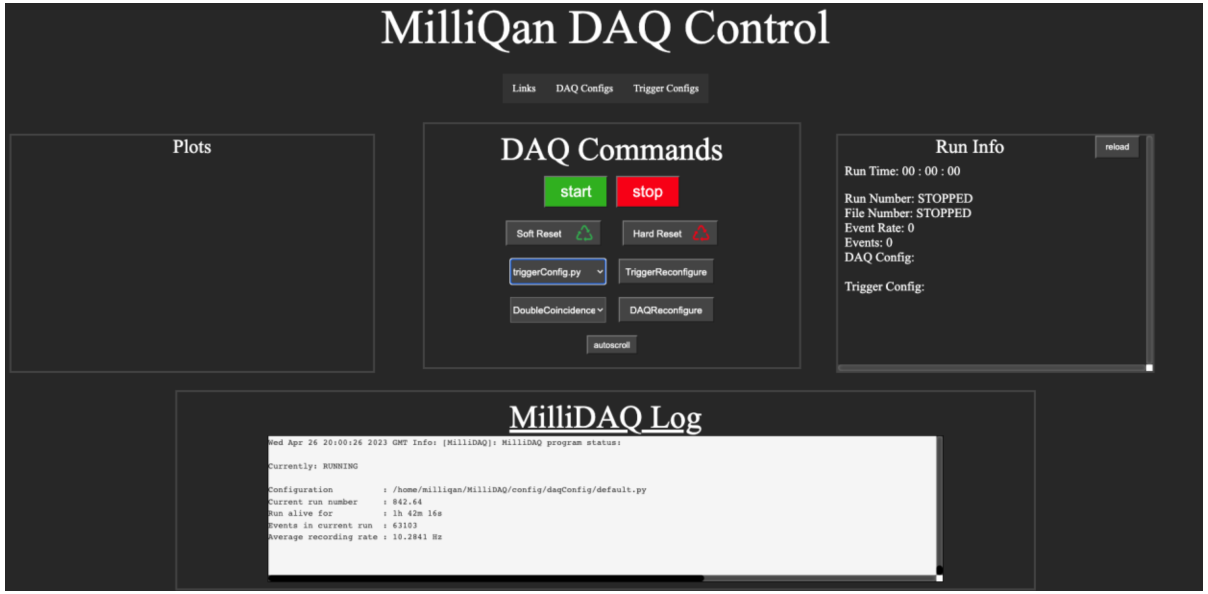
- Developed web-based interfaces to run and monitor the detector

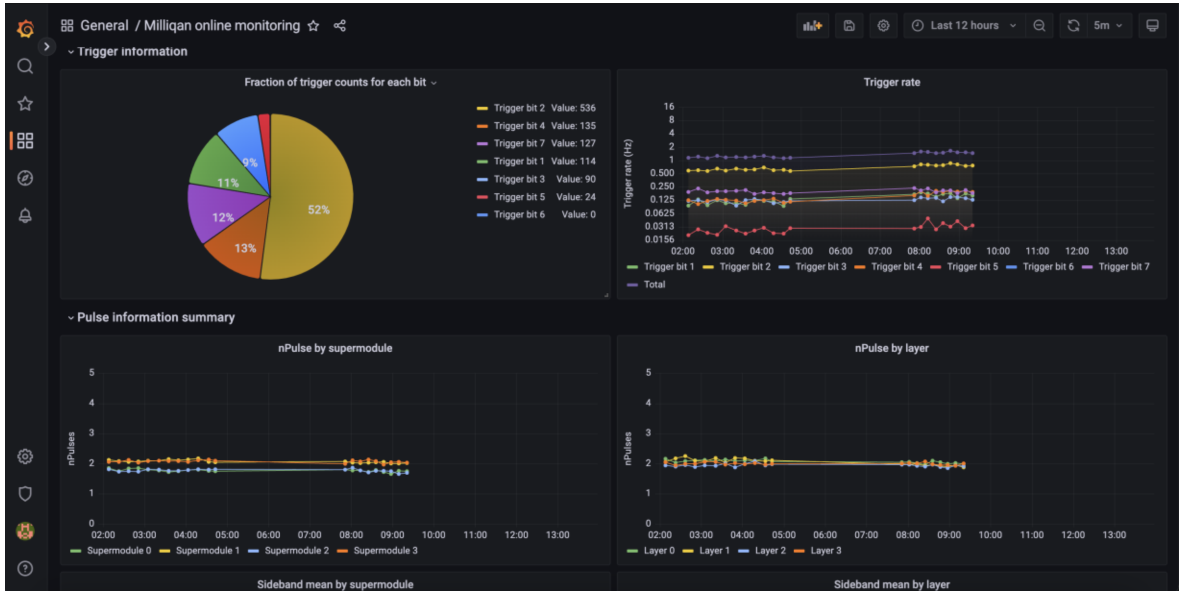
<u>DAQ App</u>

- DAQ is run through Flask based web app
- Allows easy remote running of DAQ

<u>DQM Grafana</u>

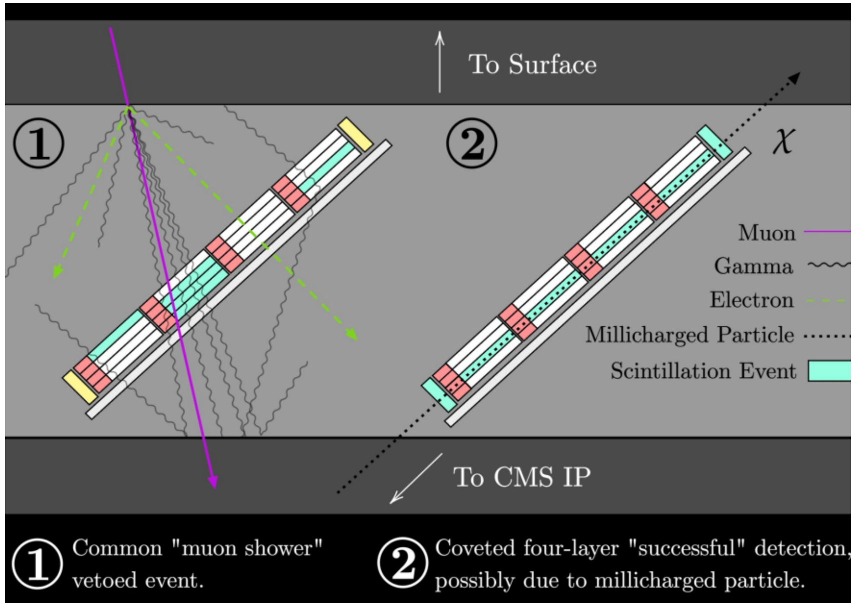
- Local Grafana server run on DAQ computer
- Process data and save to influxDB database



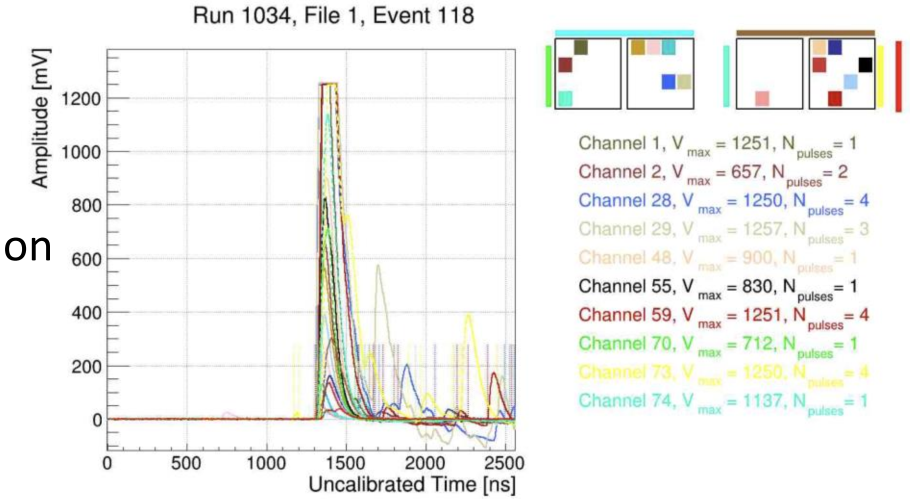


Analysis

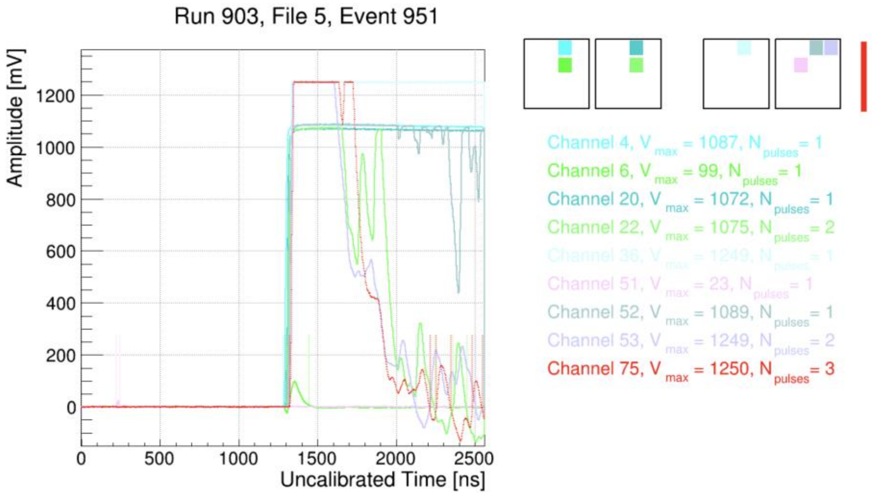
- Starting to analyze bar detector data
- Cosmic muons: Hits in top panels, large hits in many channels
- Beam muons: Few hits, in straight line



Possible Cosmic Muon



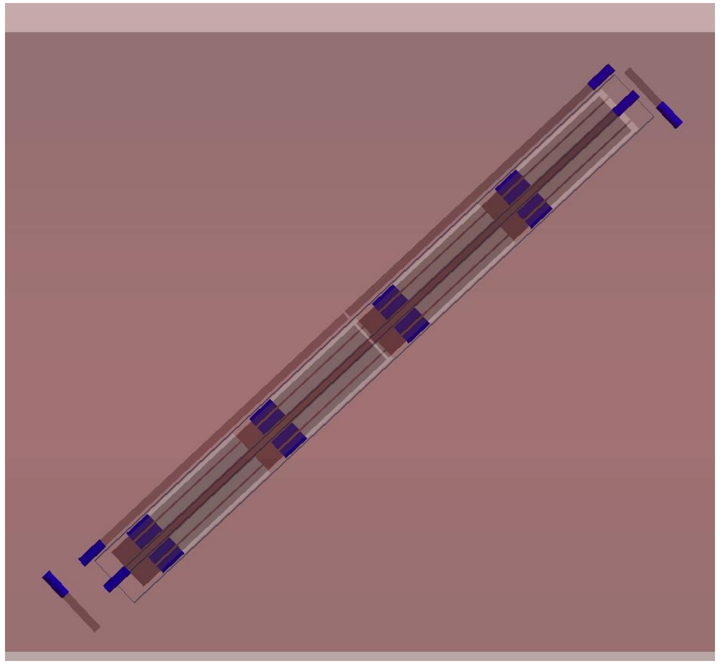
Possible Beam Muon



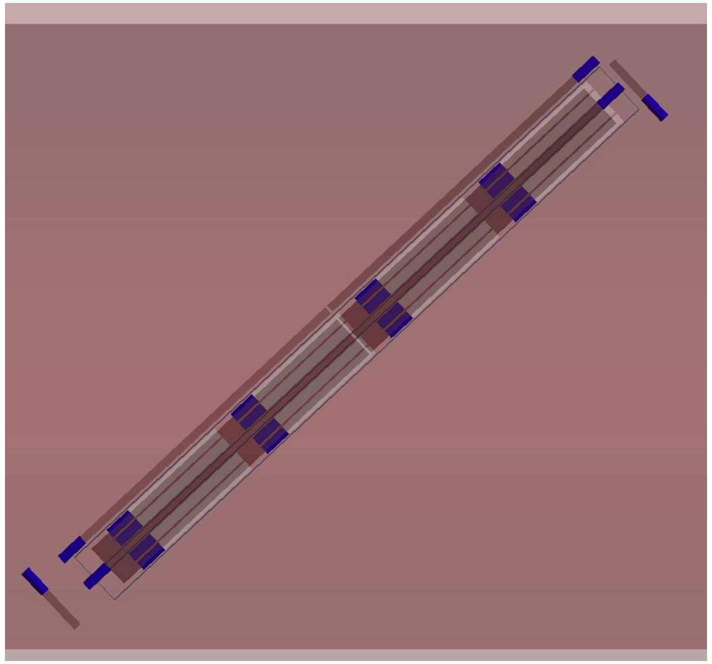
Simulation

- Calibrate each PMT response to in situ version
- Use real pulses as input for simulation (pulse injection)
- Visualizations of particle interactions with detector

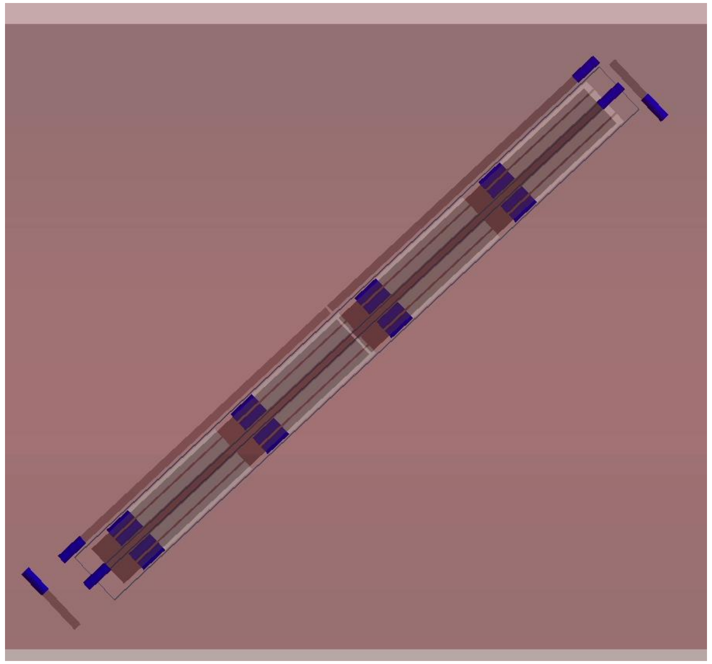
Cosmic Muon



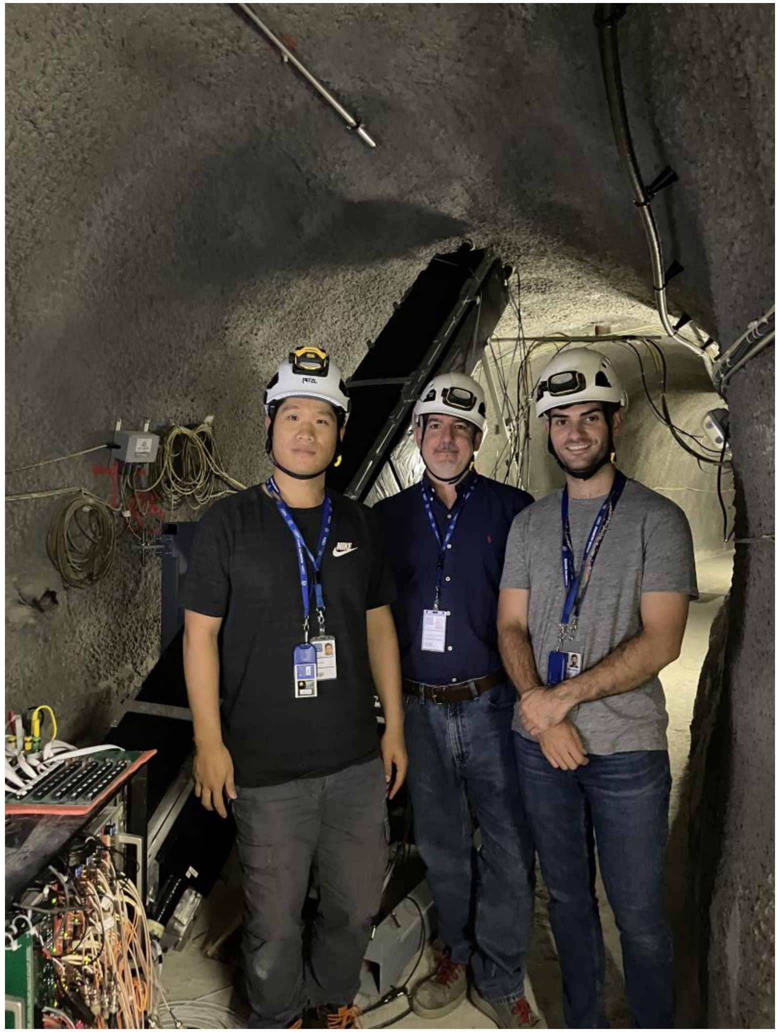
Beam Muon



mCP

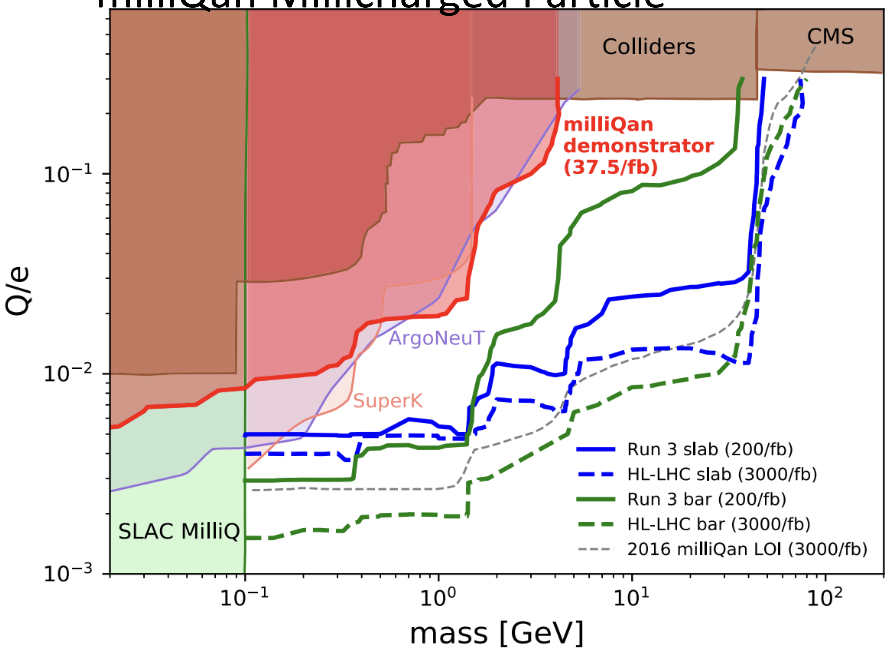


Summary



- Bar detector is fully assembled and taking physics data!
- Slab detector is in assembly and will be done by end of summer
- Beginning to analyze data!
- Expect to collect ~$30 fb^{-1}$ in 2023 run

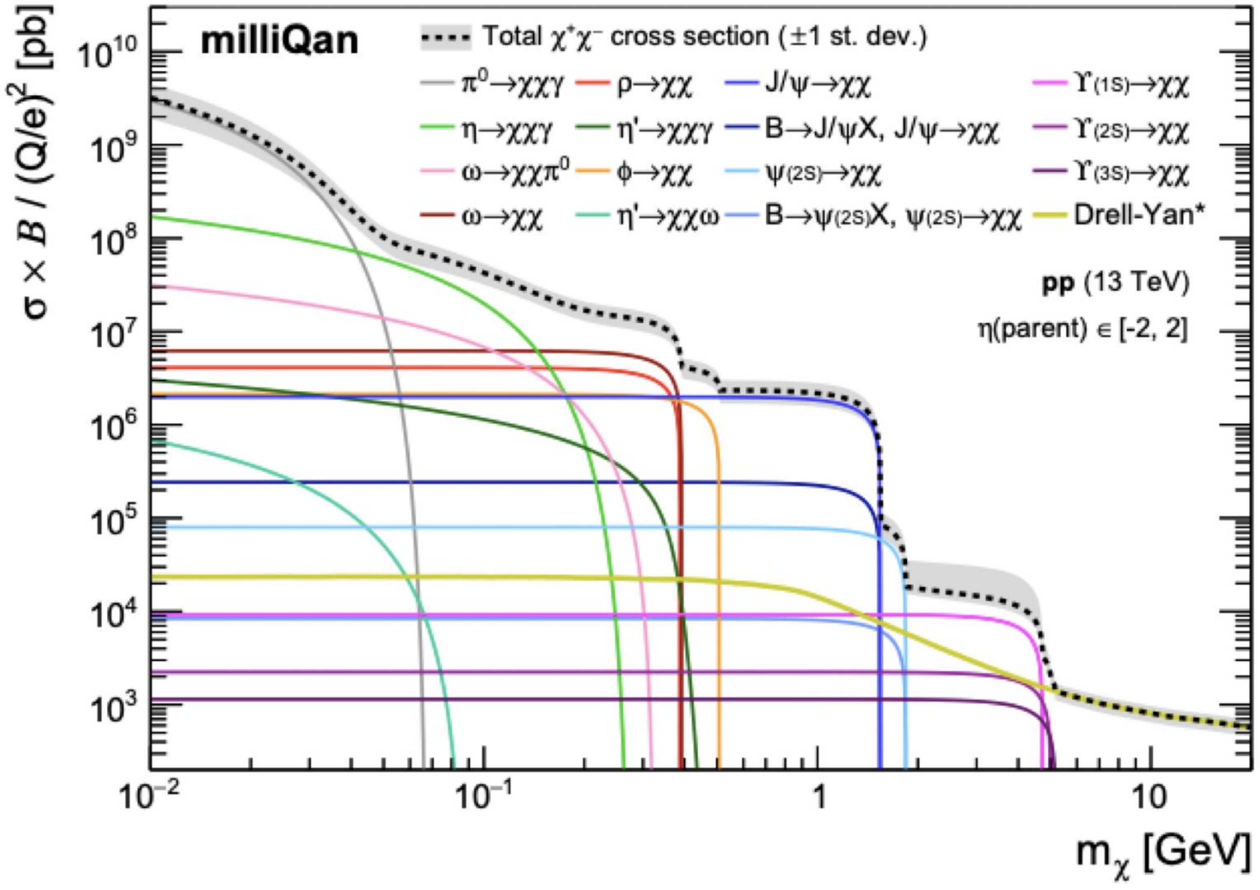
milliQan Millicharged Particle



Backup

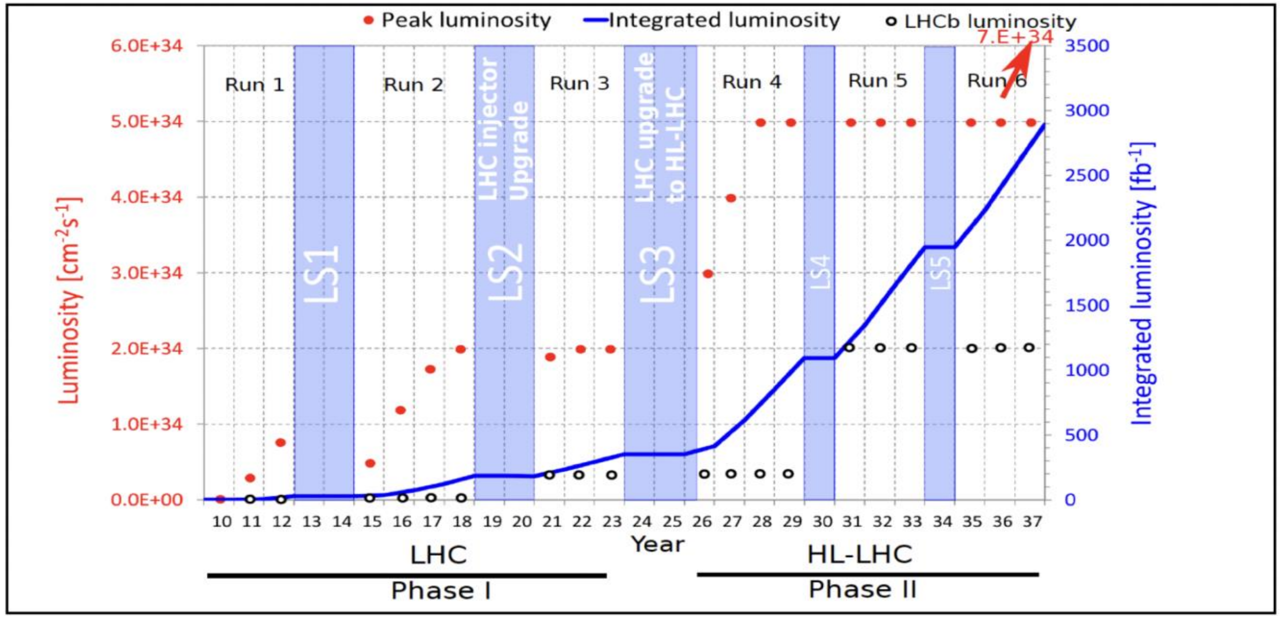
Production in LHC

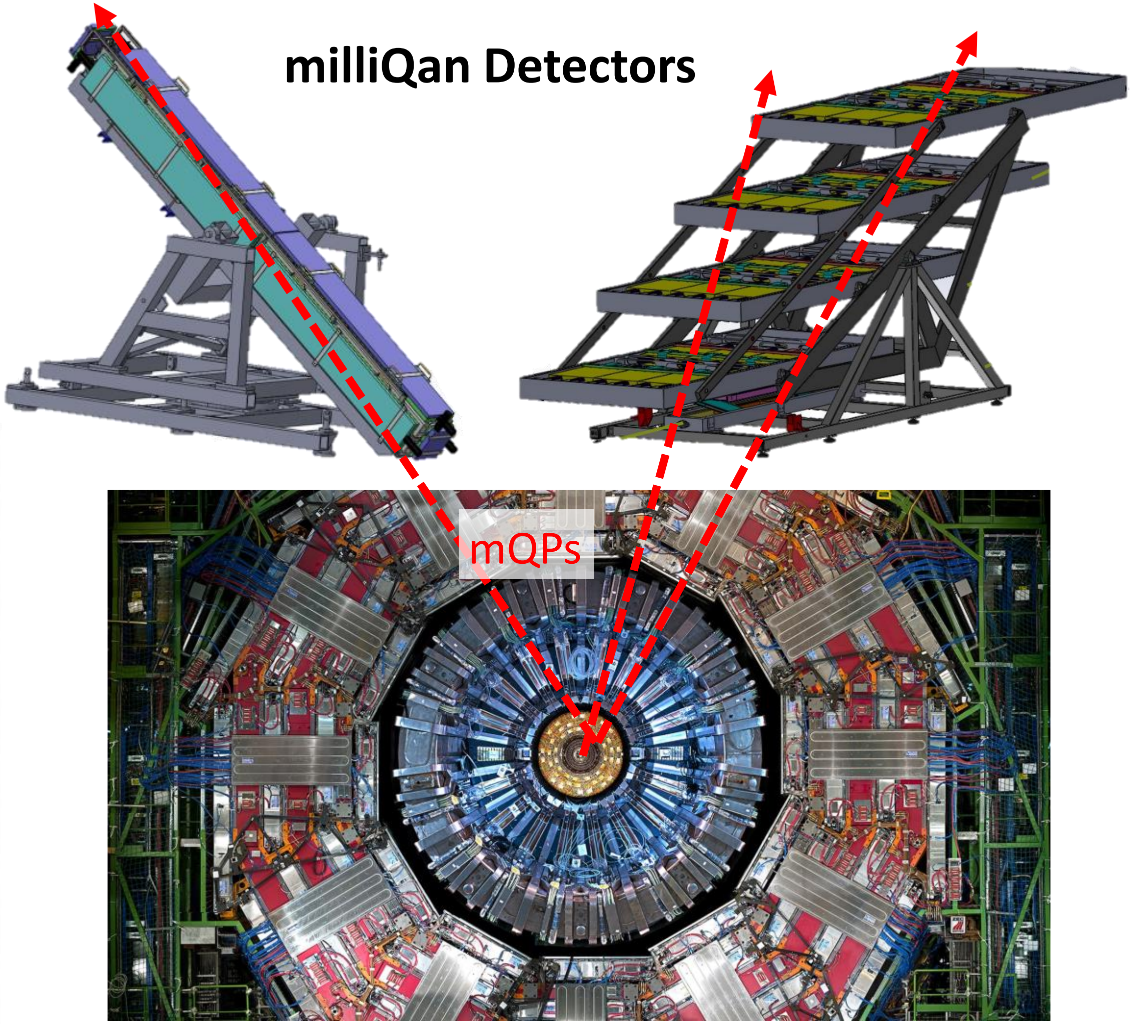
- Production of mQPs in LHC is the same as e+e-
  - Leptonic meson decays
- $Br(x \to q^+q^-) \propto (\frac{q}{e})^2 Br(x \to e^+e^-)$
- Simulate mQPs in pythia
- Propagate through rock/detector with Geant



LHC Run 3

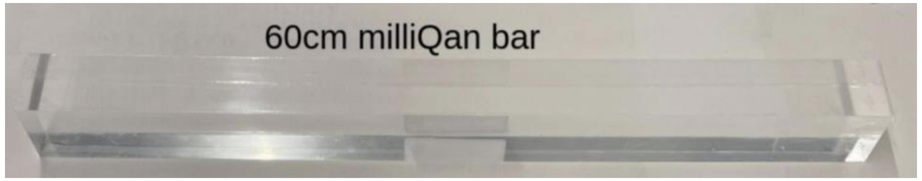
- The LHC is aiming to collect ~300fb^{-1} of data in run 3
- Plan to use milliQan detector to set new limits on production of millicharged particles





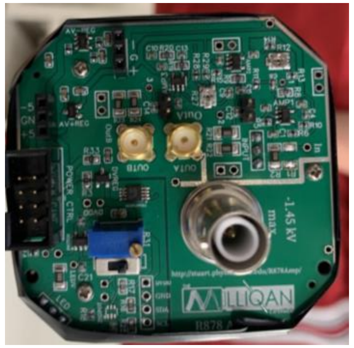
milliQan Detector Overview

- Can use scintillator detectors to detect mCPs:
  1. mCP will create photon(s) in scintillator
  2. Attached PMTs will detect the photon(s)
- milliQan is composed of two scintillator arrays:
  1. Bar Detector (larger version of demonstrator)
  2. Slab Detector (new detector)
- Scintillation is dependent on charge (Q)
  - To probe small charge must be sensitive to O(1) photoelectron (sPE)



Bethe-Bloch

$$-\left\langle \frac{dE}{dx} \right\rangle \sim Q^2$$



Custom PMT amplifier board

carrigan.20@osu.edu