MilliQan upgrades

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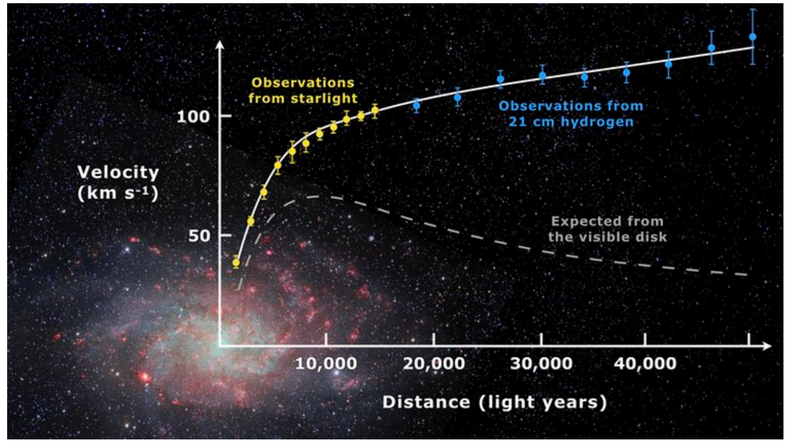
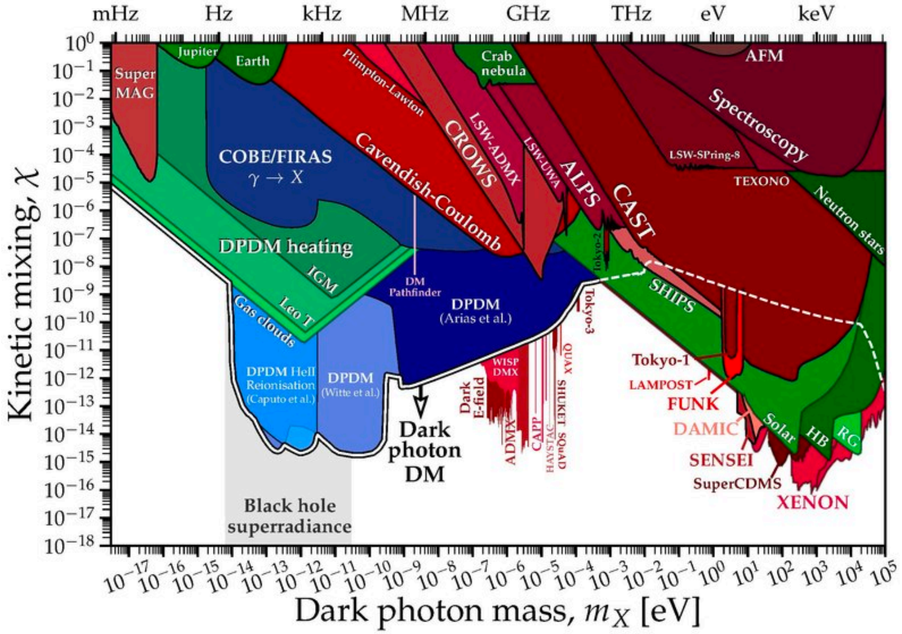
On behalf the MilliQan collaboration

A missing puzzle, the dark matter

- No obvious sign of new physics at the LHC yet
- Dark matter is well motivated from astronomical observations
- Many searches have been carried out for a massive dark photon
- Phenomenology of dark sectors with a massless dark photon is very different





Why millicharged particles

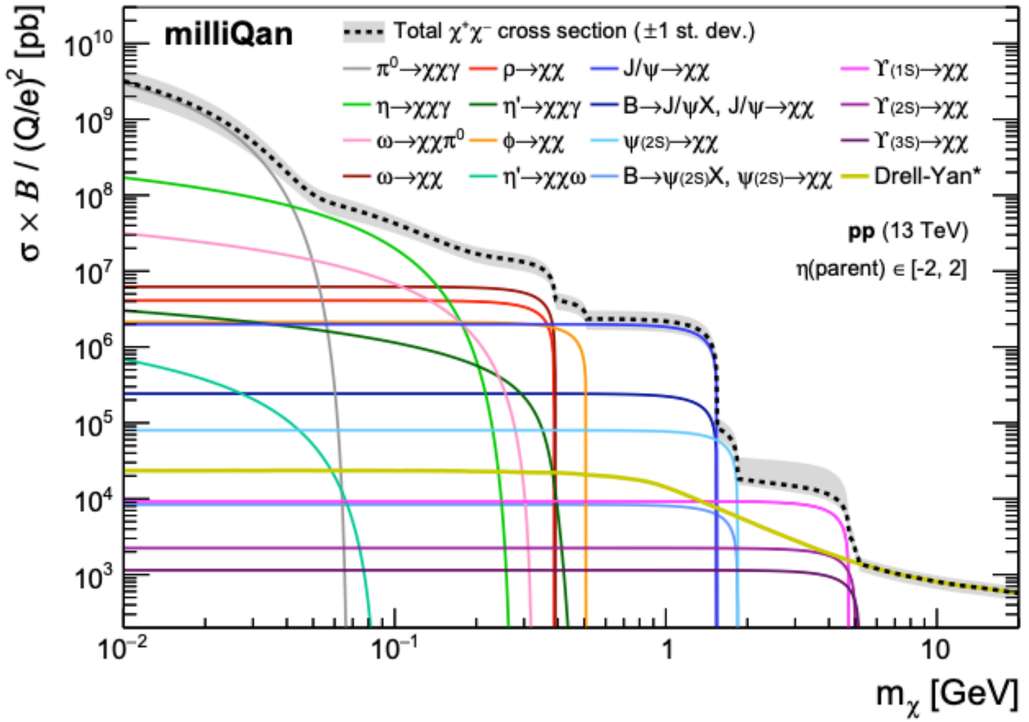
"Dark EM" Mixing of dark photon and SM photon

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} - \frac{1}{4} B'_{\mu\nu} B^{\mu\nu\prime} - \frac{\kappa}{2} B'_{\mu\nu} B^{\mu\nu} + i\bar{\psi}(\not{\partial} + ie'\not{B}' + iM_{\mathrm{mCP}})\psi$$

Kinetic Mixing

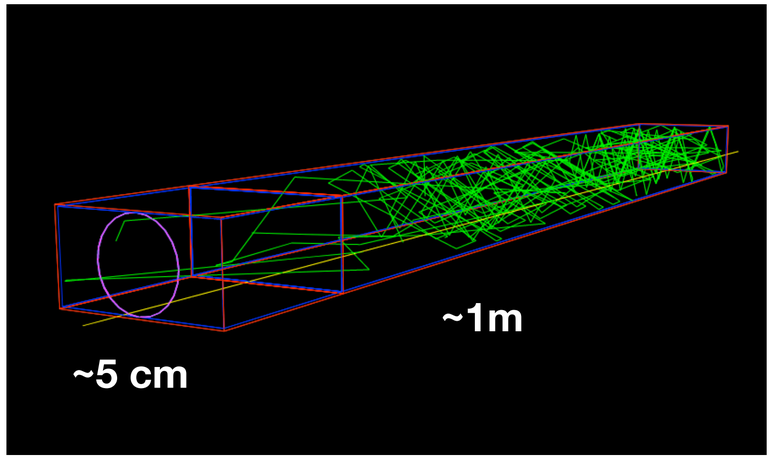
- Consider an dark sector containing a massless U(1) gauge field, B′
- Introduce kinetic mixing κ between B′ and SM hypercharge B ($\kappa \sim \alpha/\pi \sim 10^{-3}$)
- Redefine, $B' \rightarrow B' + \kappa B$, get rid of the mixing term
- After EWSB, $Q_{mCP} = \kappa e' \cos\theta_W$, hence millicharged particle
- These mCPs couple to photons with reduced strength $Q_{mCP}/e \sim 10^{-3}$

Millicharged particles production at LHC



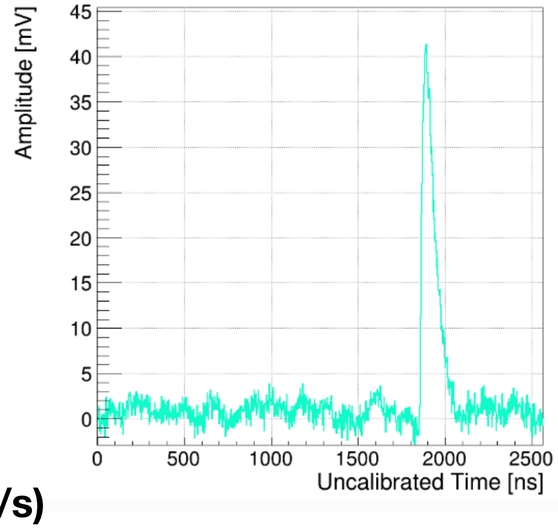
- Any meson decay into e^+e^- through a virtual photon, eg, $J/\Psi \rightarrow e^+e^-$, if kinematically allowed will also decay into mCP-pairs with branching ratio reduced by $(Q_{mCP}/e)^2$
  - Invisible to general purpose detectors at the LHC, need dedicated detectors

MilliQan detector principle



Bar = Scintillator + PMT arrays

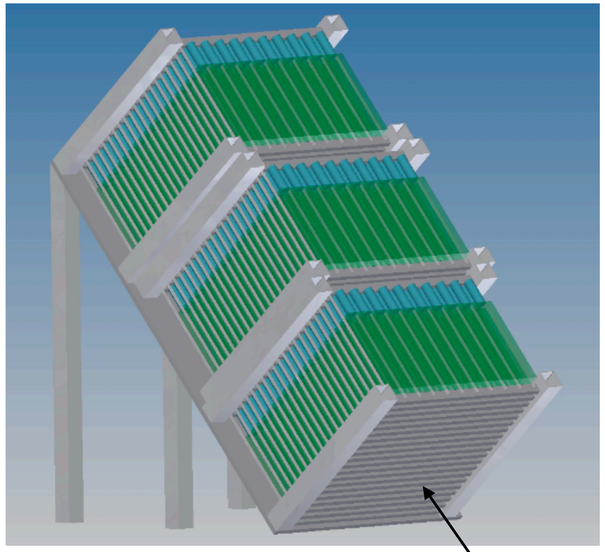
O(GHz/s)



Initial design in 2016 letter of intent:

1200 scintillating bars in 3 layers

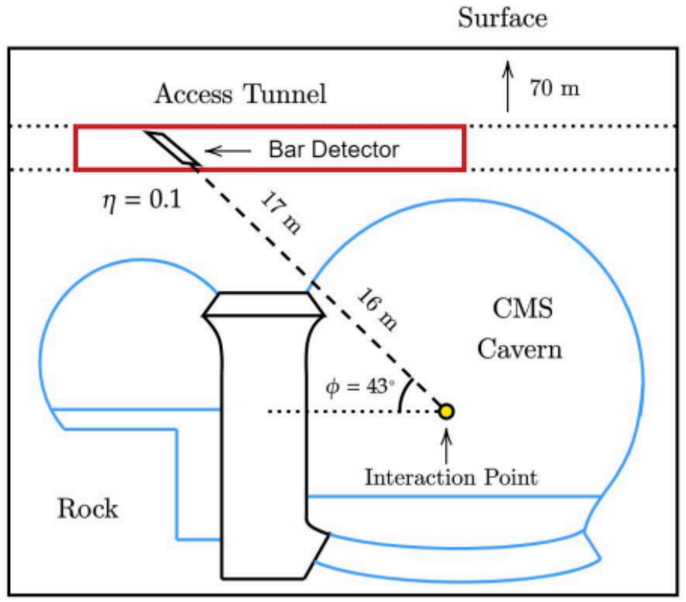
$20 \times 20 \times 3$

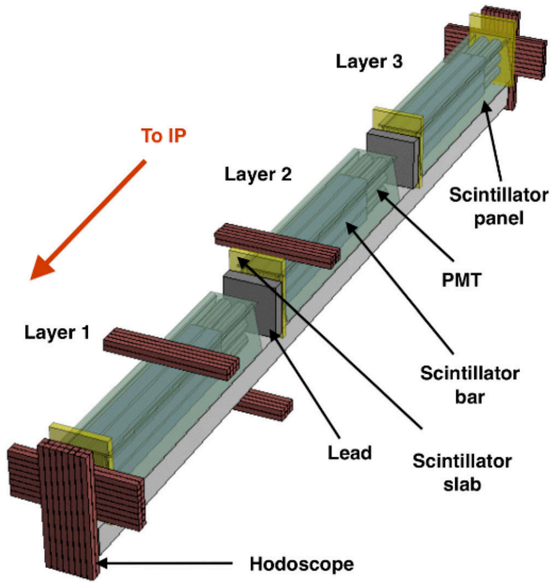


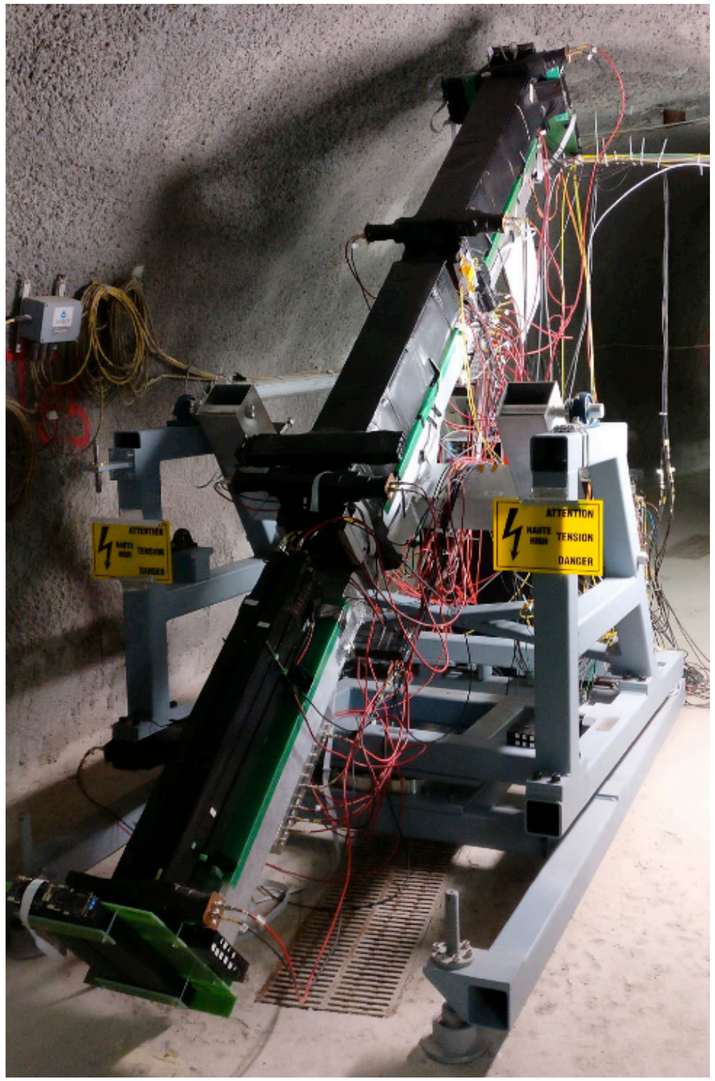
CMS IP

- Search for milli-charged particles produced at the LHC collisions
- Multi-layer of ~1m long scintillator bars + PMT arrays
- Sensitive to milli-charged particles, expect few photo-electrons (PEs) for particles with $O(10^{-3})$ charge
- Use high sampling frequency electronics to capture PE signals

MilliQan demonstrator

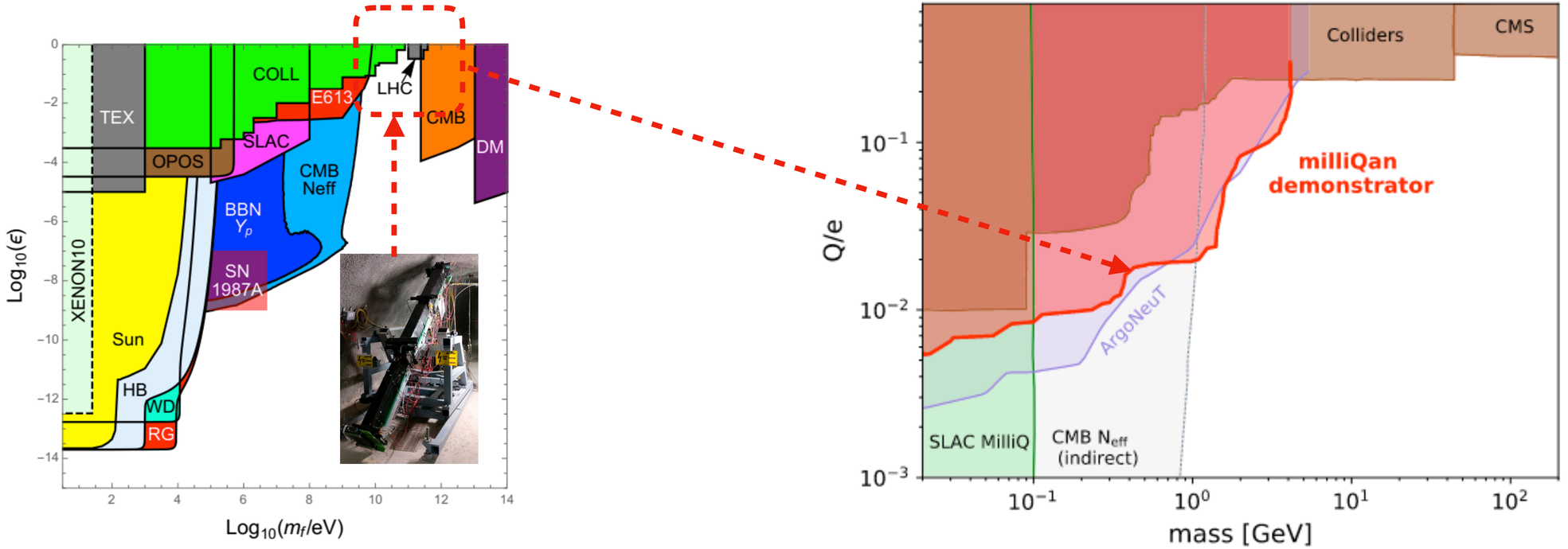






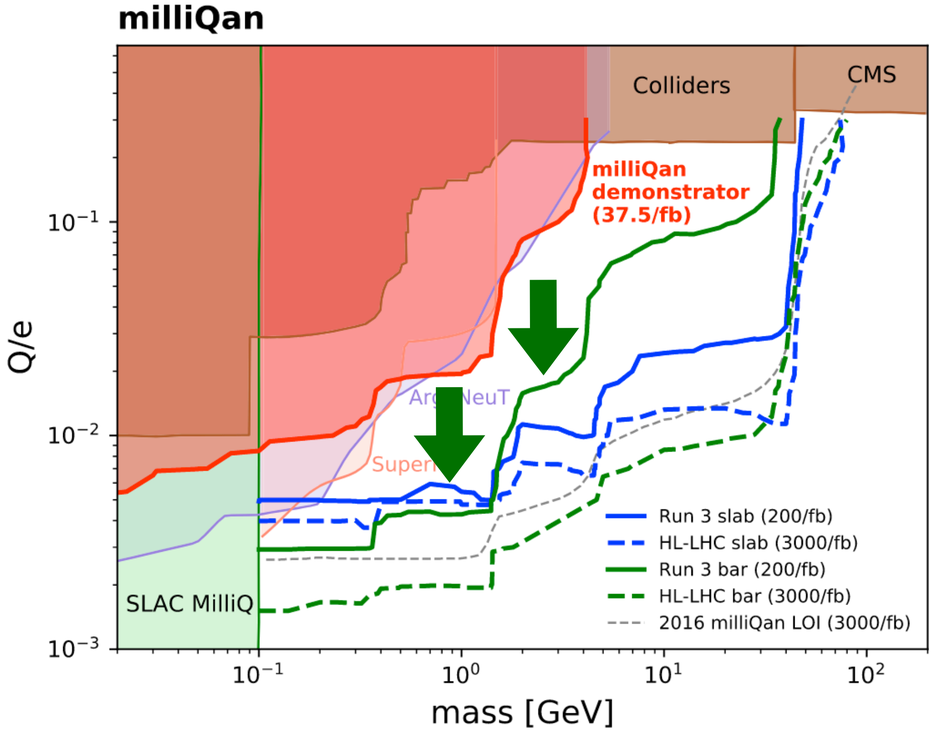
- In 2017, demonstrator was deployed at CMS site, 3 layers of 2×3 bars
- Other components (panel, hodoscope) to characterize/reduce certain background processes (through-going muon, neutrons etc)
- ~31m from CMS IP, ~17m of rock shielding

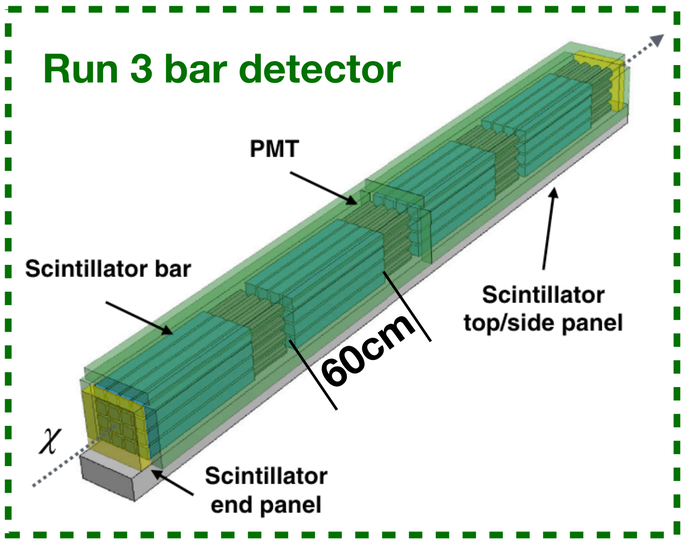
MilliQan demonstrator

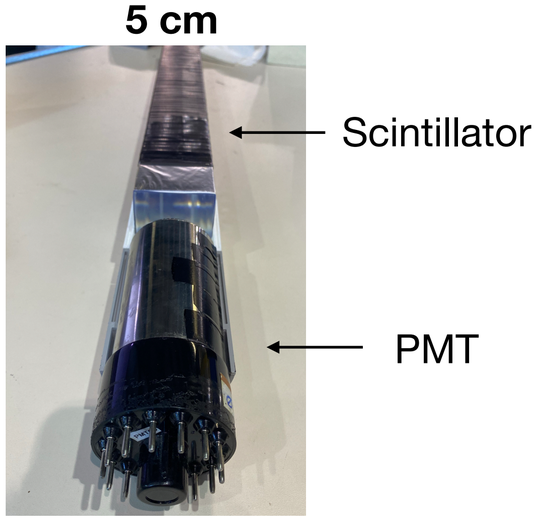


- Previous LHC experiments are not designed for searching for milli-charged particles
- MilliQan demonstrator, amount to ~1% of actual detector, can provide complementary sensitivity to milli-charged particles at the LHC
  - With ~2000 hours of data in 2018 during the LHC Run 2

MilliQan Run 3 detectors





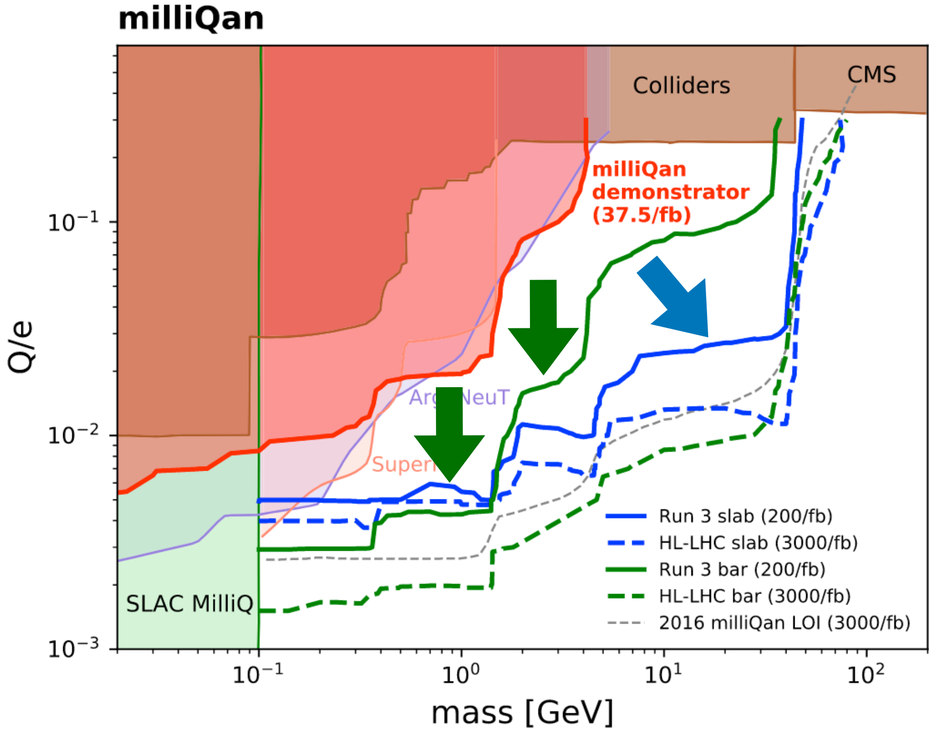


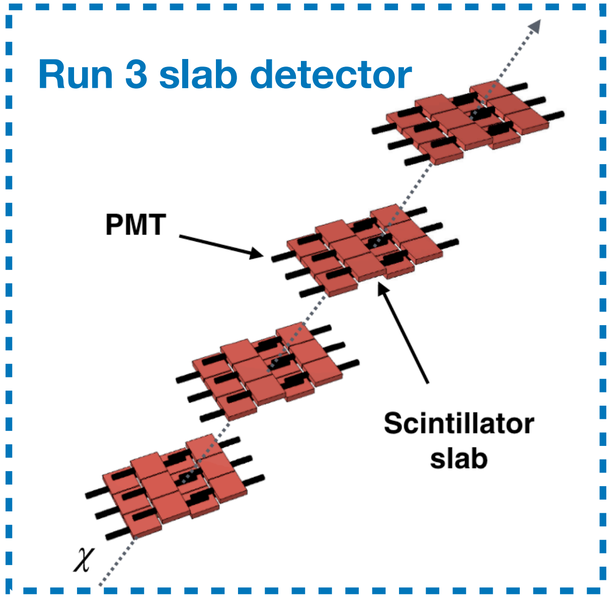
Two new detectors are under construction and commissioning!

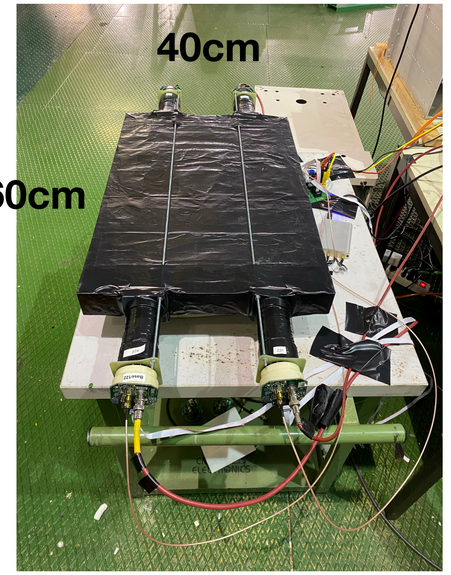
arXiv:2104.07151

- 4 layers of bars, better background rejection
- Bar design similar to demonstrator
- Each layer has 4×4 bars, 2.5 higher sensitive area
- Improve PMT signal amplification, better SPE reconstruction efficiency
- LED system for calibration and monitoring

MilliQan Run 3 detectors







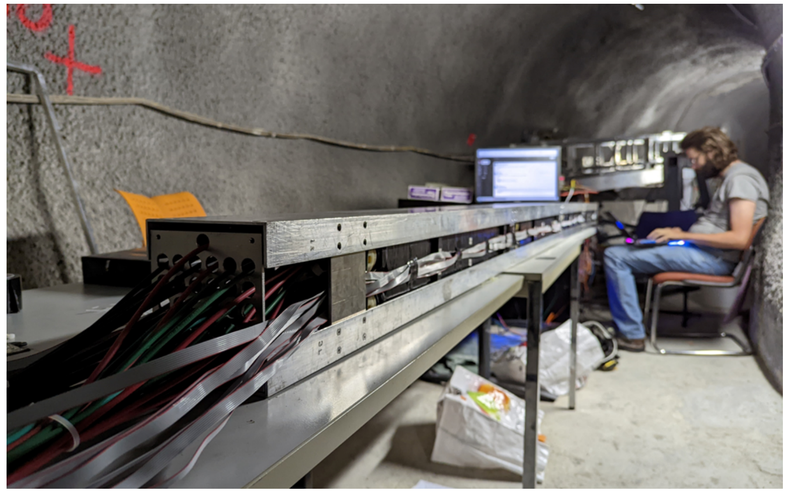
Two new detectors are under construction and commissioning!

arXiv:2104.07151

- 4 layers of slabs, thinner scintillator with larger active area
- Improve sensitivity for milli-charged particle with large mass (>~1GeV)
- Each layer has 3×4 slabs
- Each slab has 4 PMTs attached to increase light collection efficiency
- Same PMT amplification and LED calibration system as bar detector

Run 3 bar detector construction

4 bars assembled into an unit, all bars are made light-tight with black taps



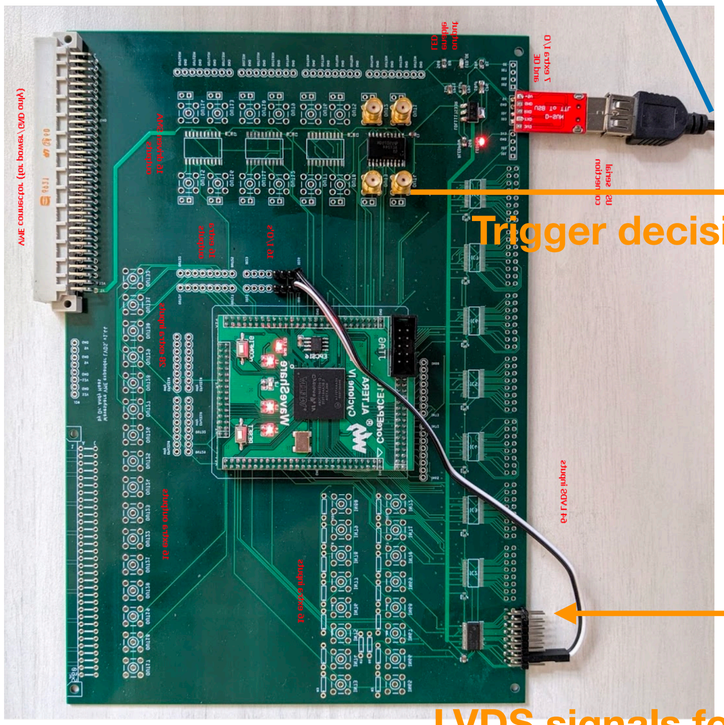
4 units (= 16 bars) assembled into a supermodule, HV/LV/signal cables are attached to customized PMT readout unit

4 supermodules (= 64 bars) put into the cage to make the final bar detector

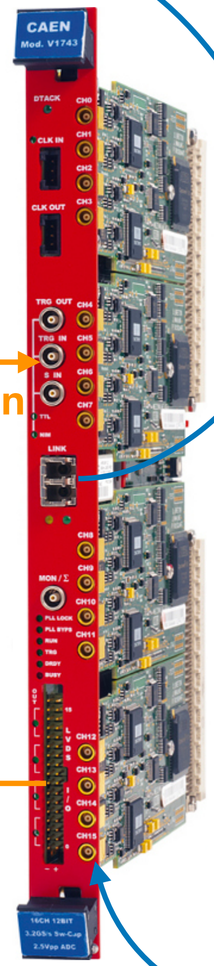
DAQ system

Trigger information

Digitized pulses

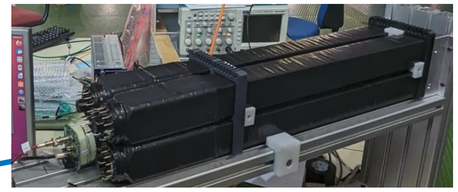


Trigger decision



LVDS signals for trigger decision

Amplified PMT pulse



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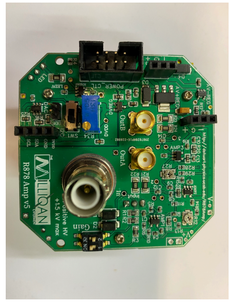

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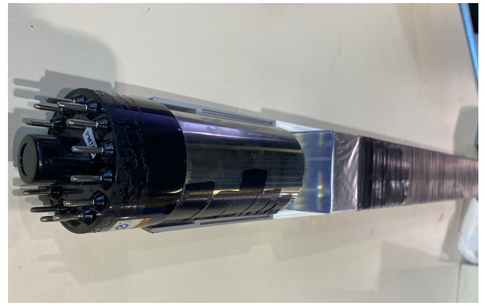
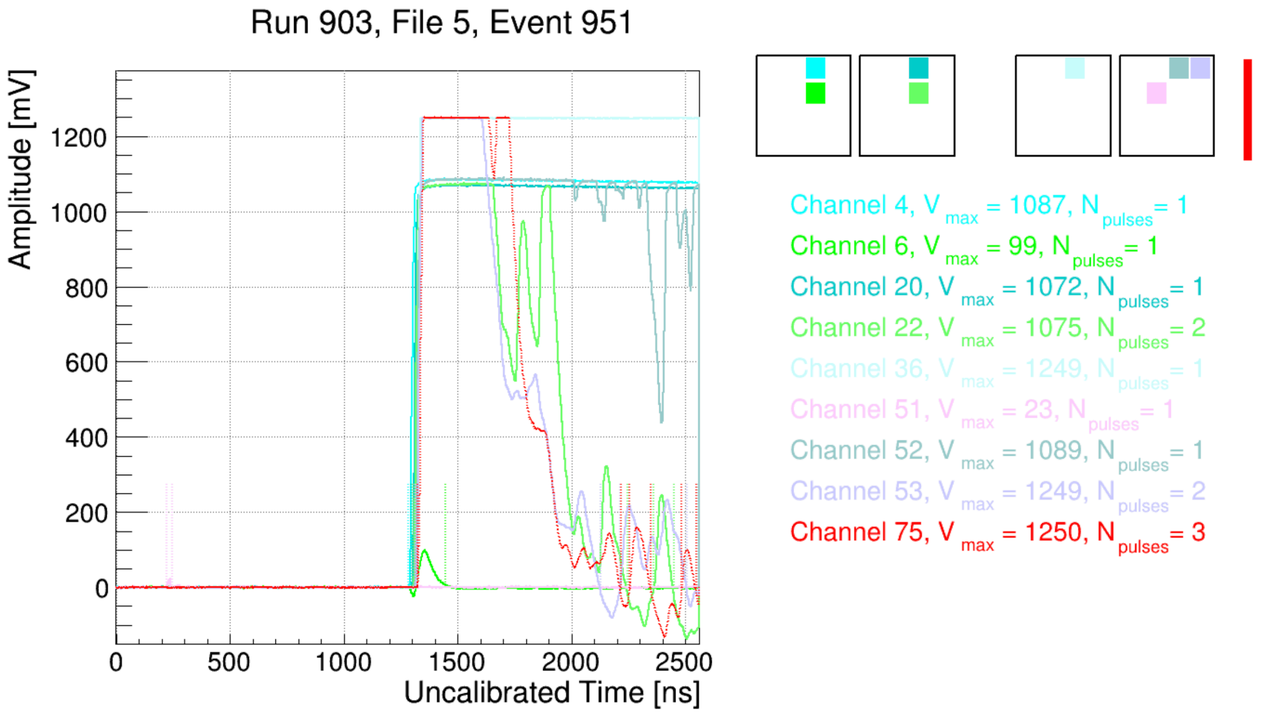


- PMT output amplified with customized base, O(100) ns long output pulse shape => **high SPE efficiency**
- CAEN V1743 digitizer to sample PMT pulses, 16 channel, O(GHz) sampling frequency, O(1000) ns readout window **=> reconstruct complete pulse information**
- Customized trigger board equipped with Altera Cyclone IV FPGA for trigger decision making => **max flexibility**

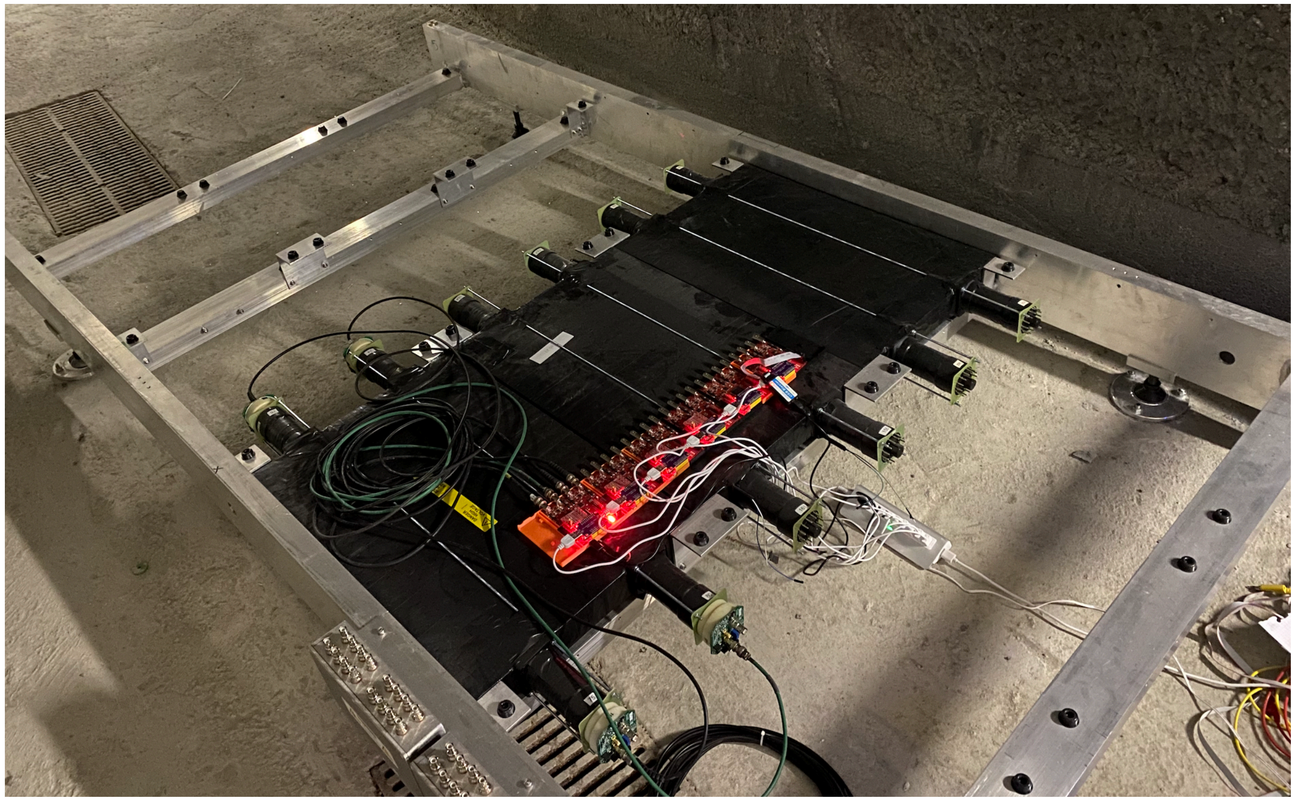
Current status of the bar detector

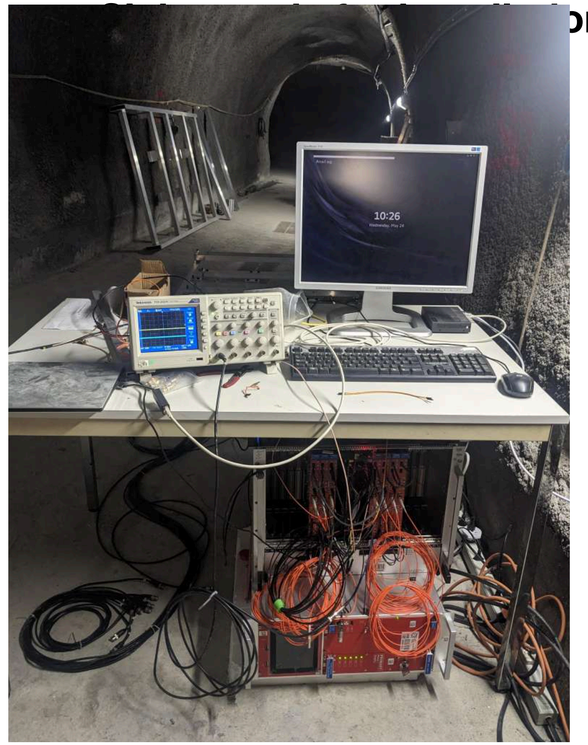
A muon candidate



- The full bar detector has been installed in the final position
- Actively taking data to commission and calibrate the detector, expect physics data taking in coming weeks

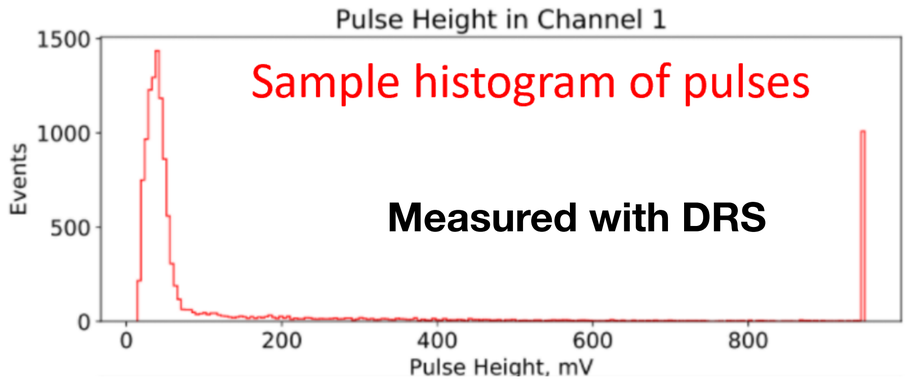
Current status of the slab detector



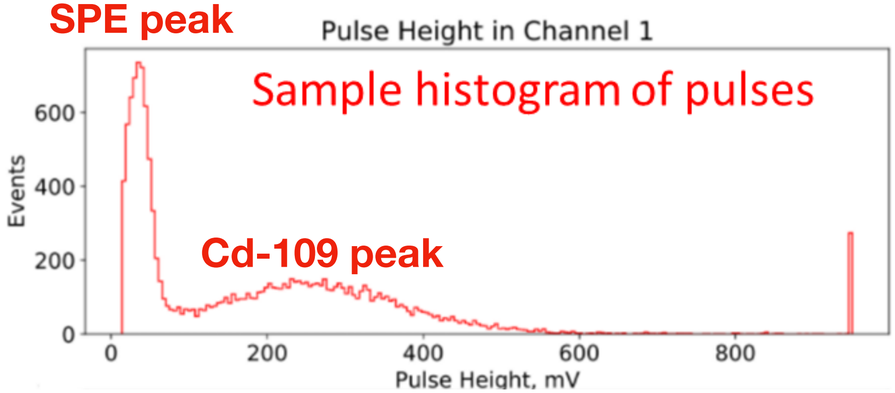


- First layer of the slab detector and its DAQ system is being installed
- Full slab detector will be installed and commissioned in the coming 1-2 months

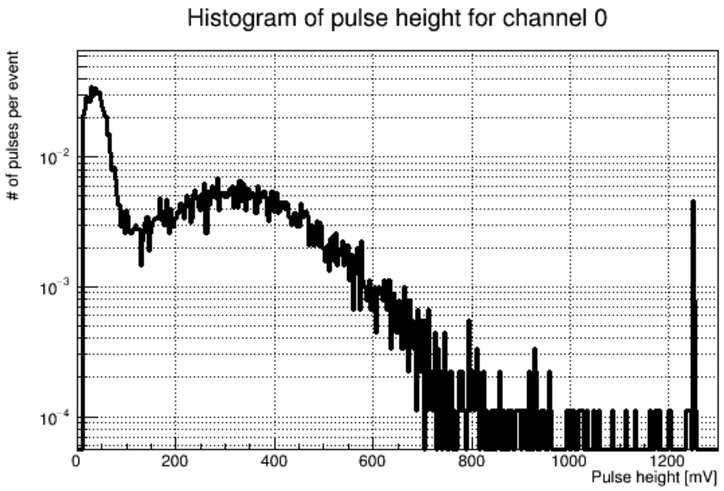
Various calibration activities



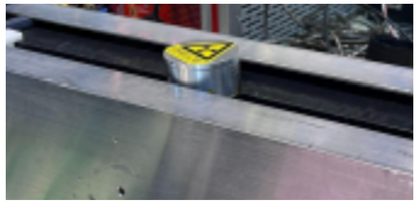
SPE peak



Measured with DAQ



Calibration with Cd-109

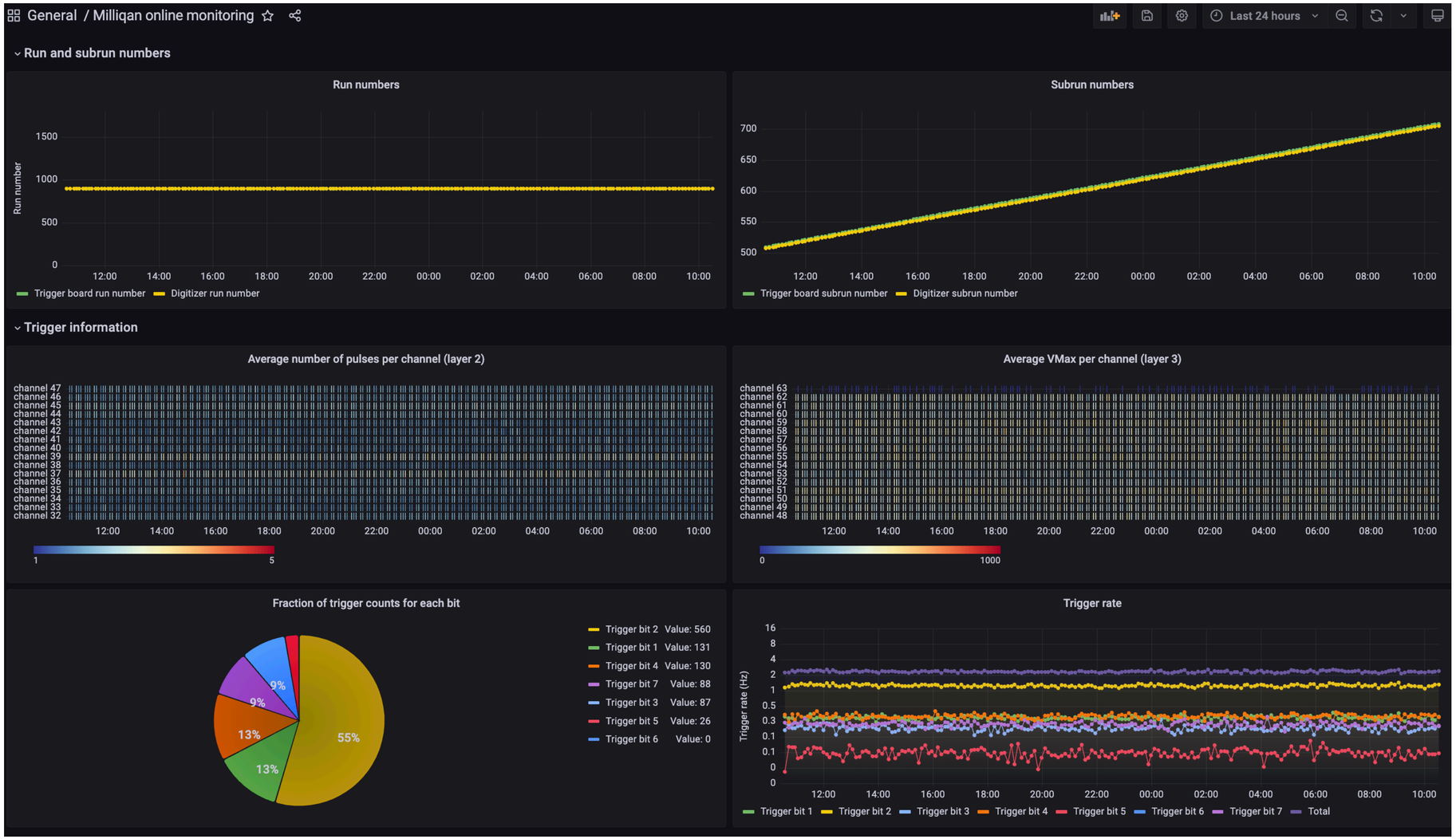


3.1.1 X Radiations

	Energy (keV)	Relative probability
X_K		
$K\alpha_2$	21,9906	53,05
$K\alpha_1$	22,16317	100
$K\beta_3$	24,9118	27,7
$K\beta_1$	24,9427	
$K\beta_5''$	25,146	
$K\beta_2$	25,4567	4,82
$K\beta_4$	25,512	

- Before/after installation, each PMT's response to SPE and radioactive source are measured using digital oscilloscope and actual DAQ chain of the experiment => a measure of NPE/keV (energy response)
- Carefully optimize the use of mu-metal to shield magnetic field from the CMS magnet
- Use through-going muon (cosmic or from CMS IP) for timing calibration

Online monitoring



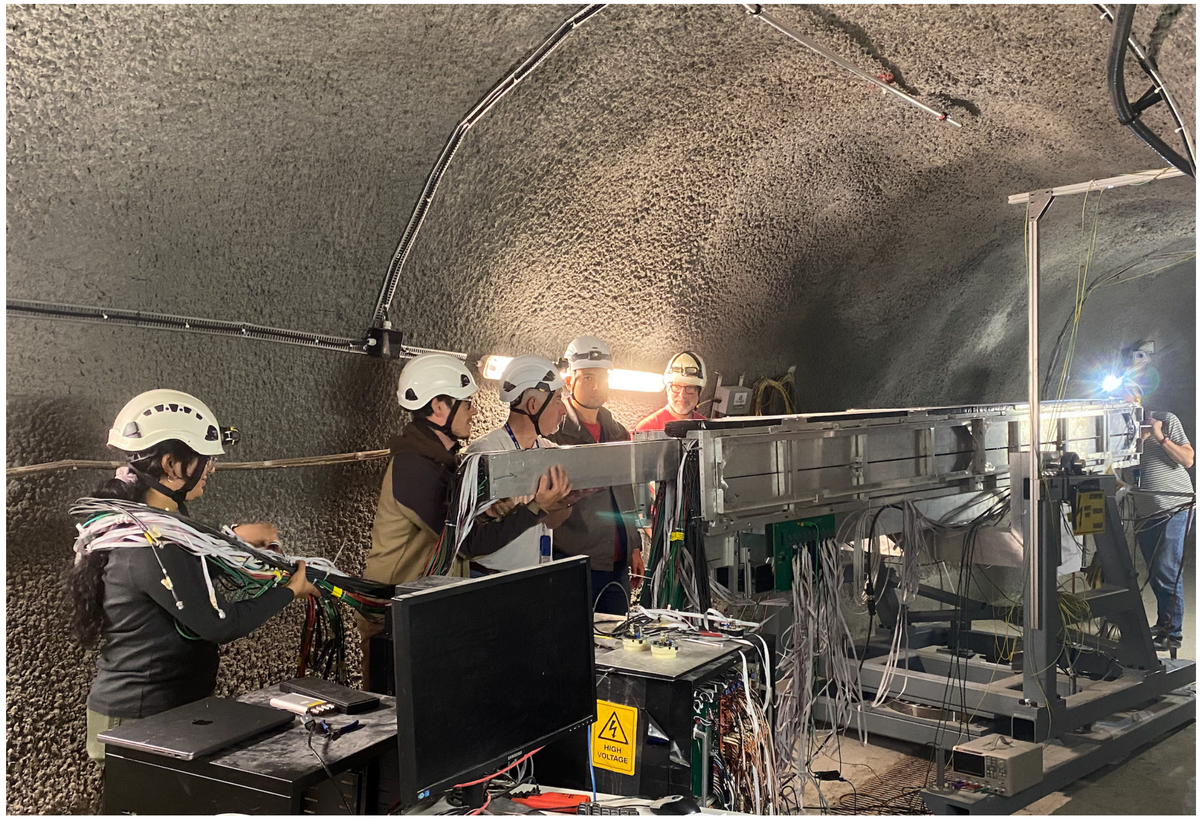
- Web based monitoring and run control tools have been developed to facilitate smooth operation

PMT pulse properties

Trigger rate profile

Summary

- The MilliQan demonstrator has been able to exclude unexplored phase space in terms of the search of millicharged particle
- 2 new detectors (bar and slab) will be used for Run 3 to increase the sensitivity to millicharged particles
- Looking forward to new result on millicharged particles using Run 3 data, stay tuned!



Backup