Status of MilliQan Run 3 detectors

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On behalf the MilliQan collaboration
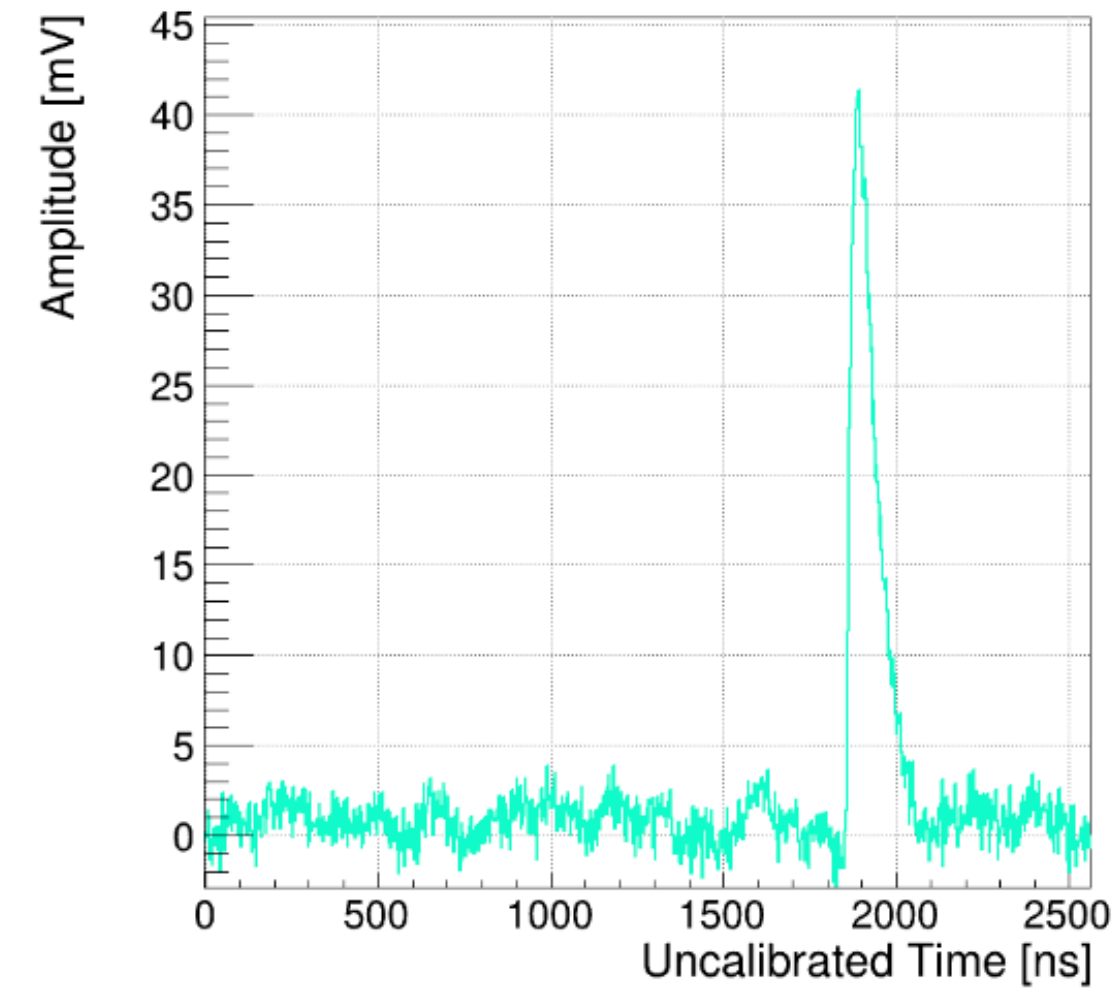
Milli-charged particles

"Dark EM"

Mixing of dark photon and SM photon

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} - \frac{1}{4} B'_{\mu\nu} B^{\mu\nu\,\prime} - \frac{\kappa}{2} B'_{\mu\nu} B^{\mu\nu}$$

- A dark U(1) section that couples with massive fermion could generate particles with small effective charge through kinetic mixing, refers to as milli-charged particles in this talk

- Such milli-charged particles could be produced at the LHC via pair production through as Drell-Yan, light meson decay (J/ψ, Υ, φ, ρ, ω), and Dalitz decays ($π^0$, η, $η^0$, ω)

- They are invisible to general purpose detectors at the LHC as the ionization is suppressed by Q^2, thus dedicated detecting strategy is required

MilliQan detector principle
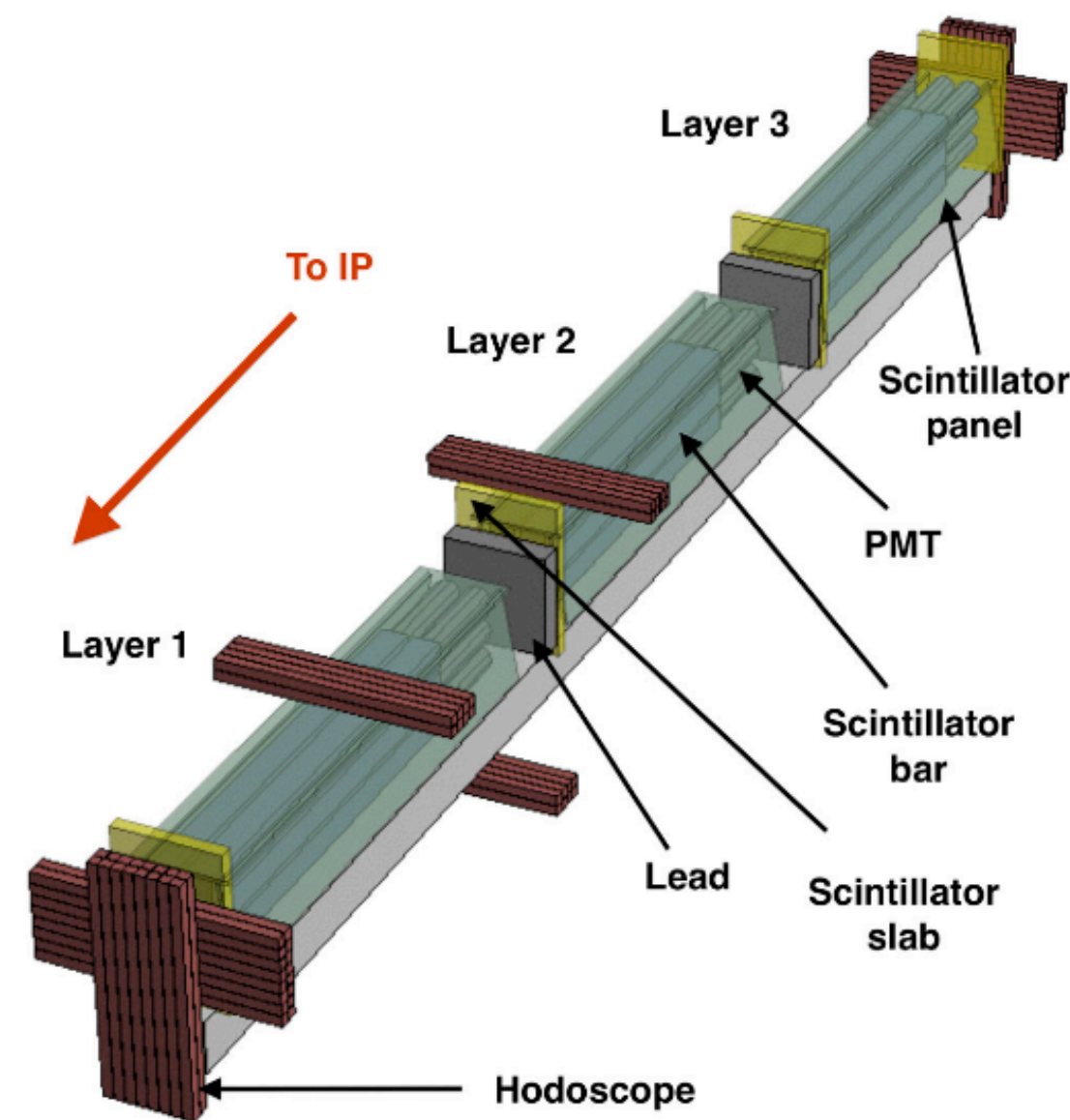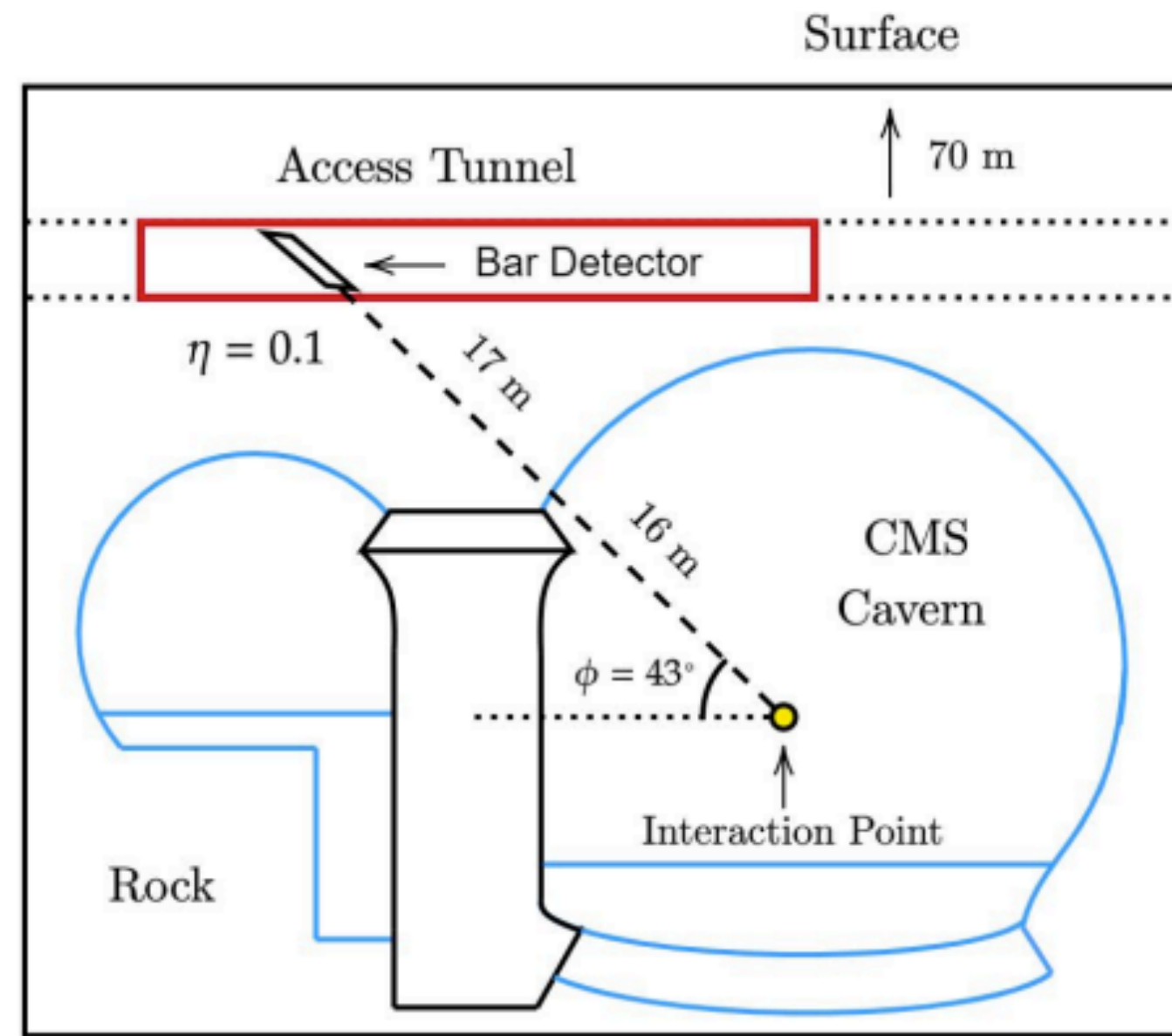

~1m
~5 cm
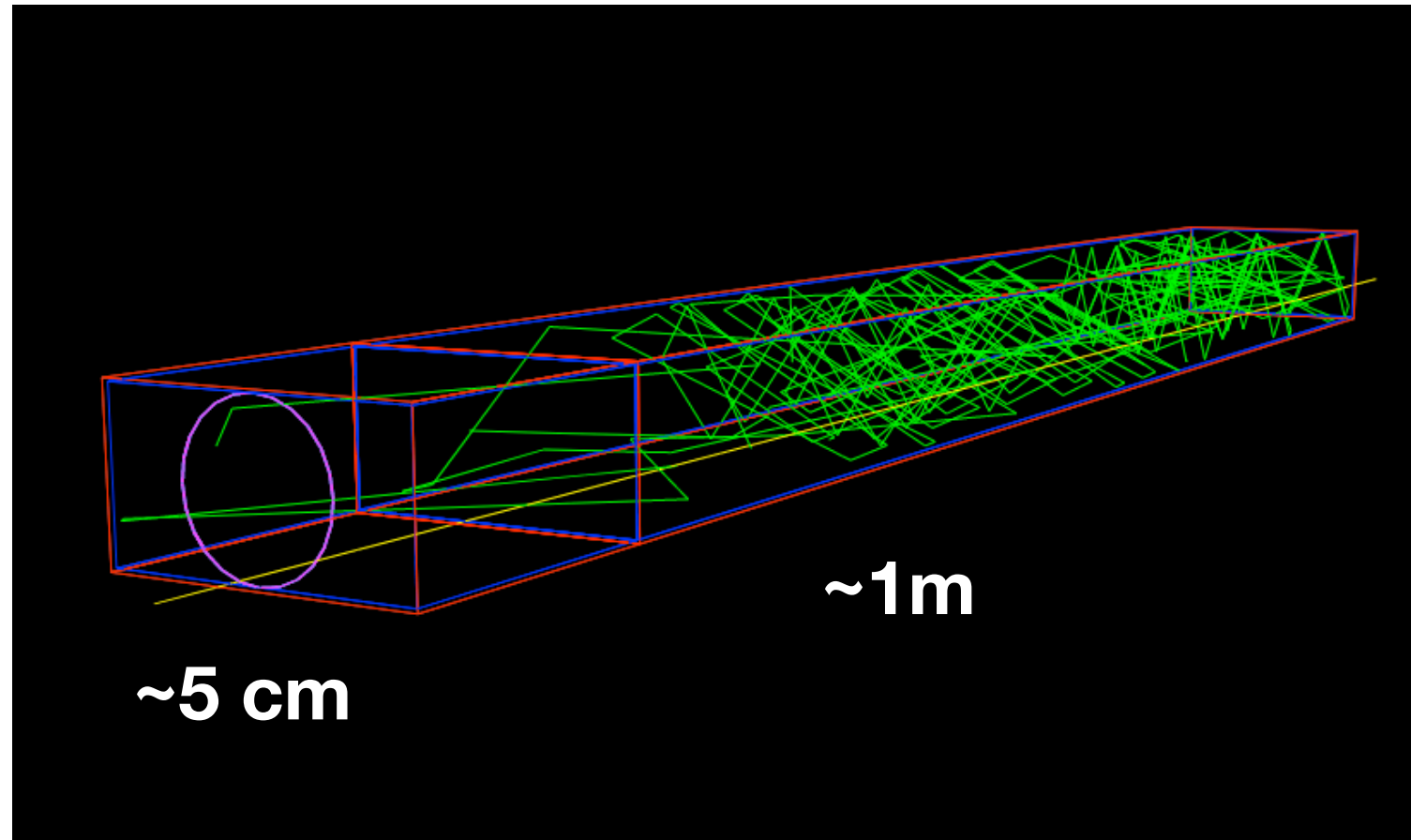
**Bar = Scintillator + PMT arrays**

O(GHz/s)
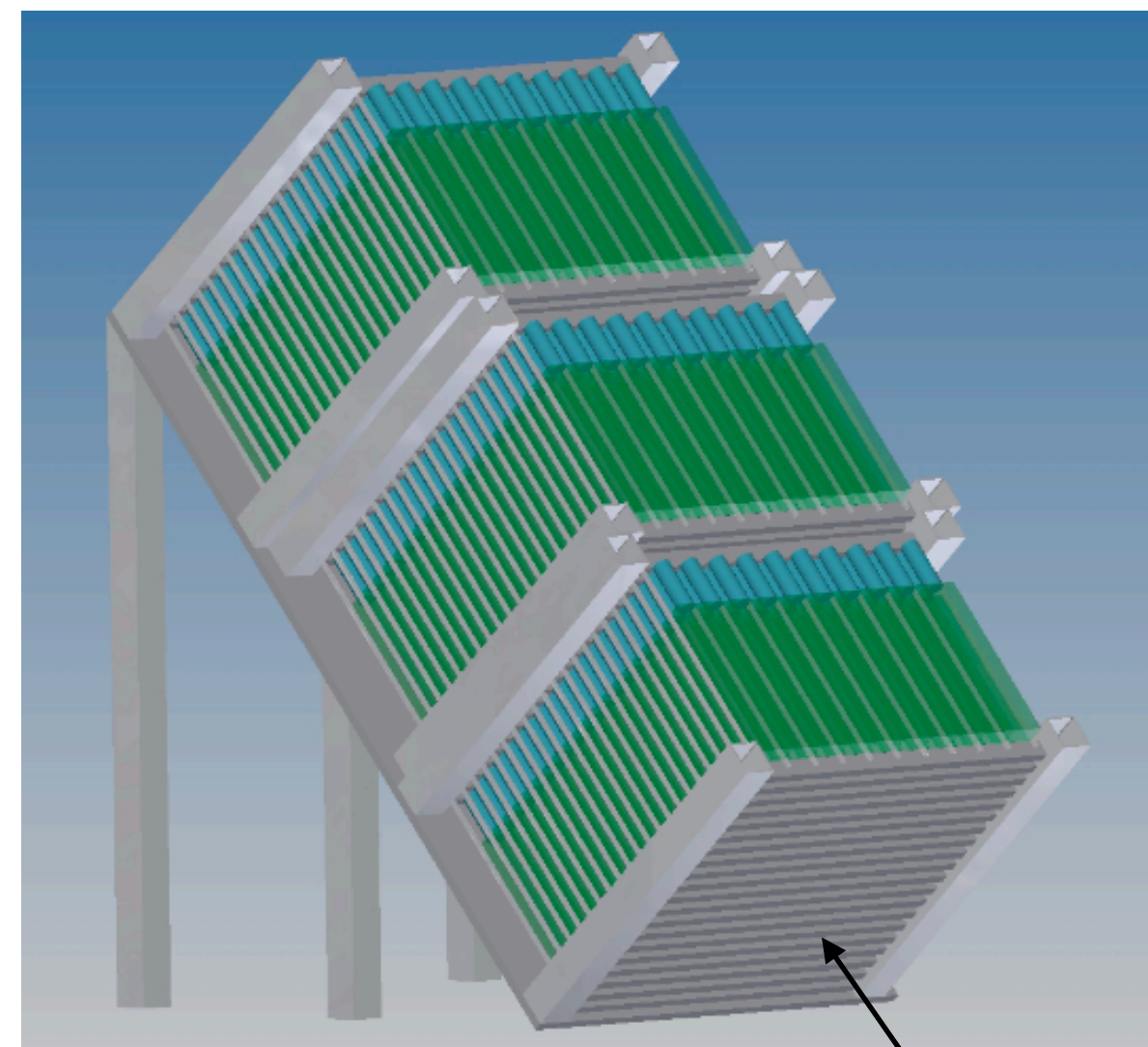
CMS IP

- 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
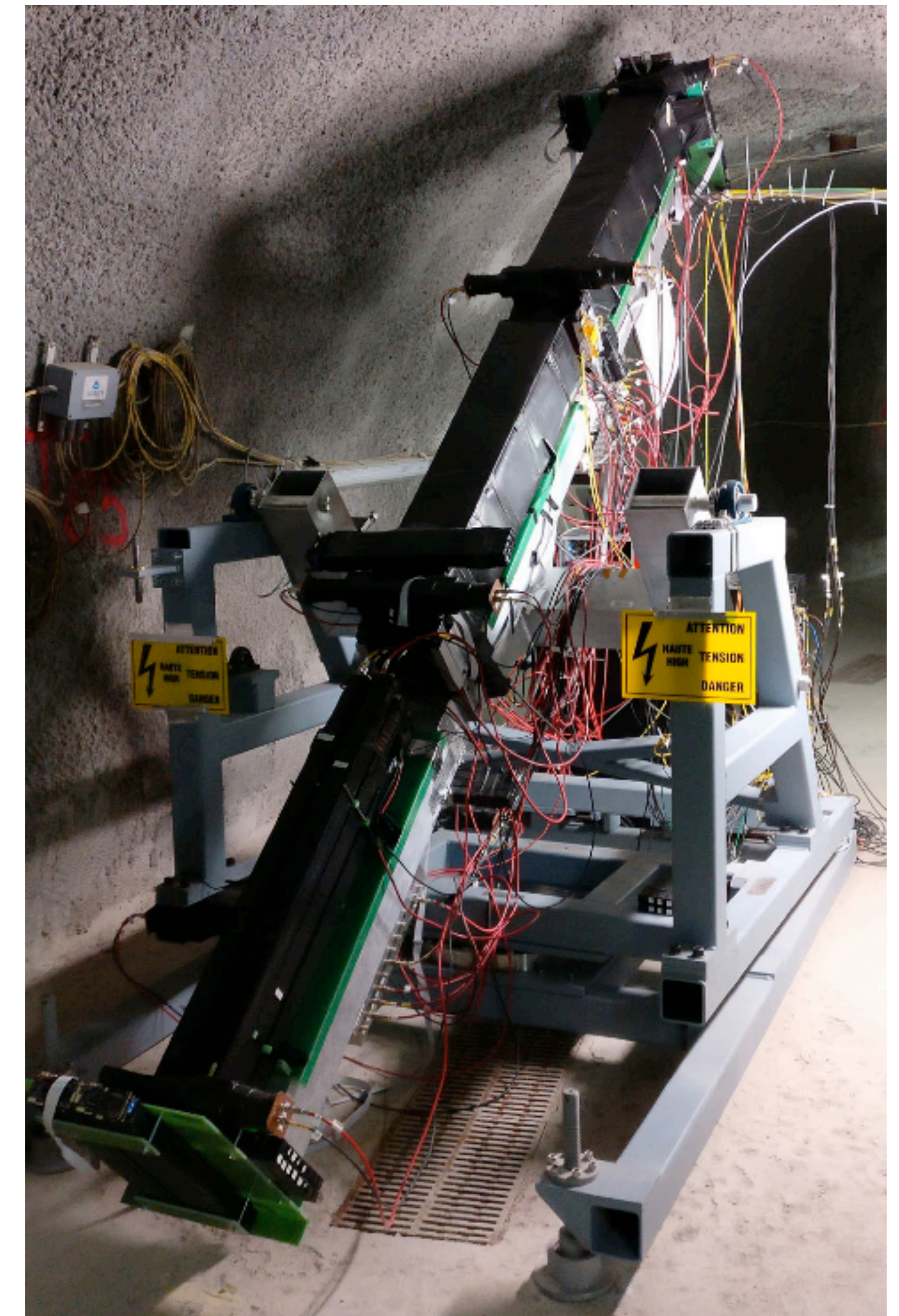
- In 2017, demonstrator was deployed at CMS site, 3 layers of 2×3 bars

- 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
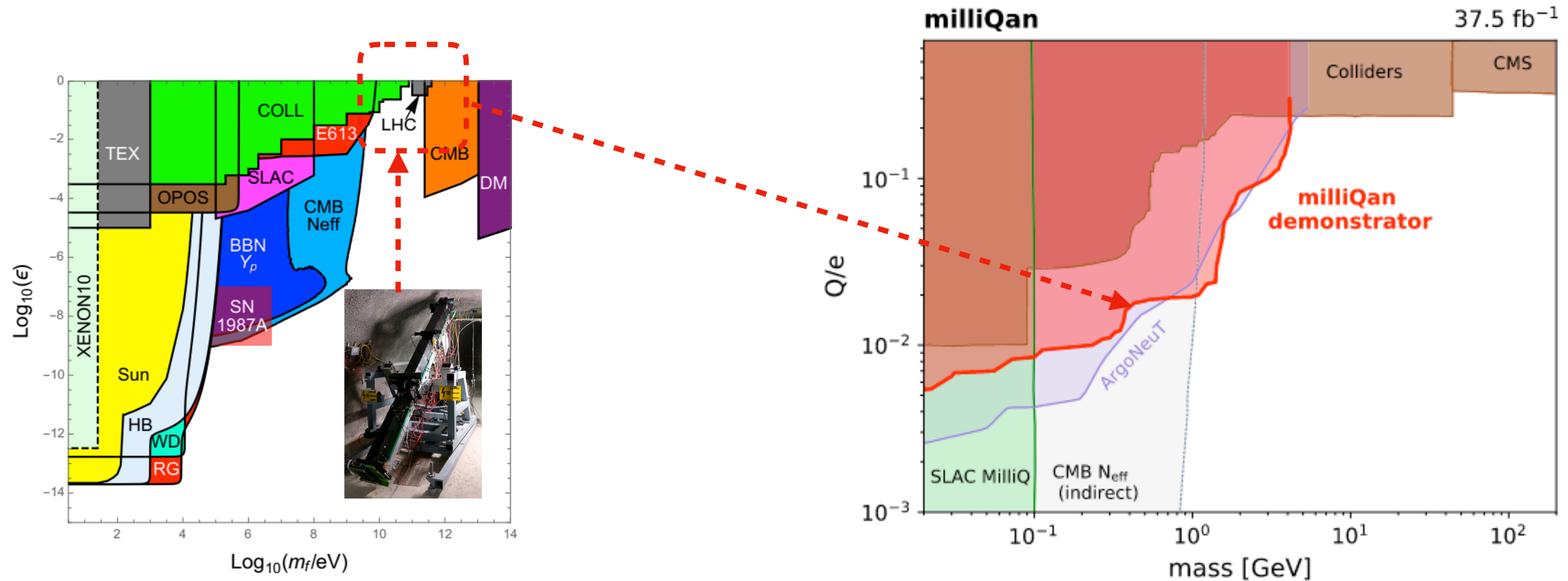
- Previous LHC experiments are not designed for searching for milli-charged particles

- 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
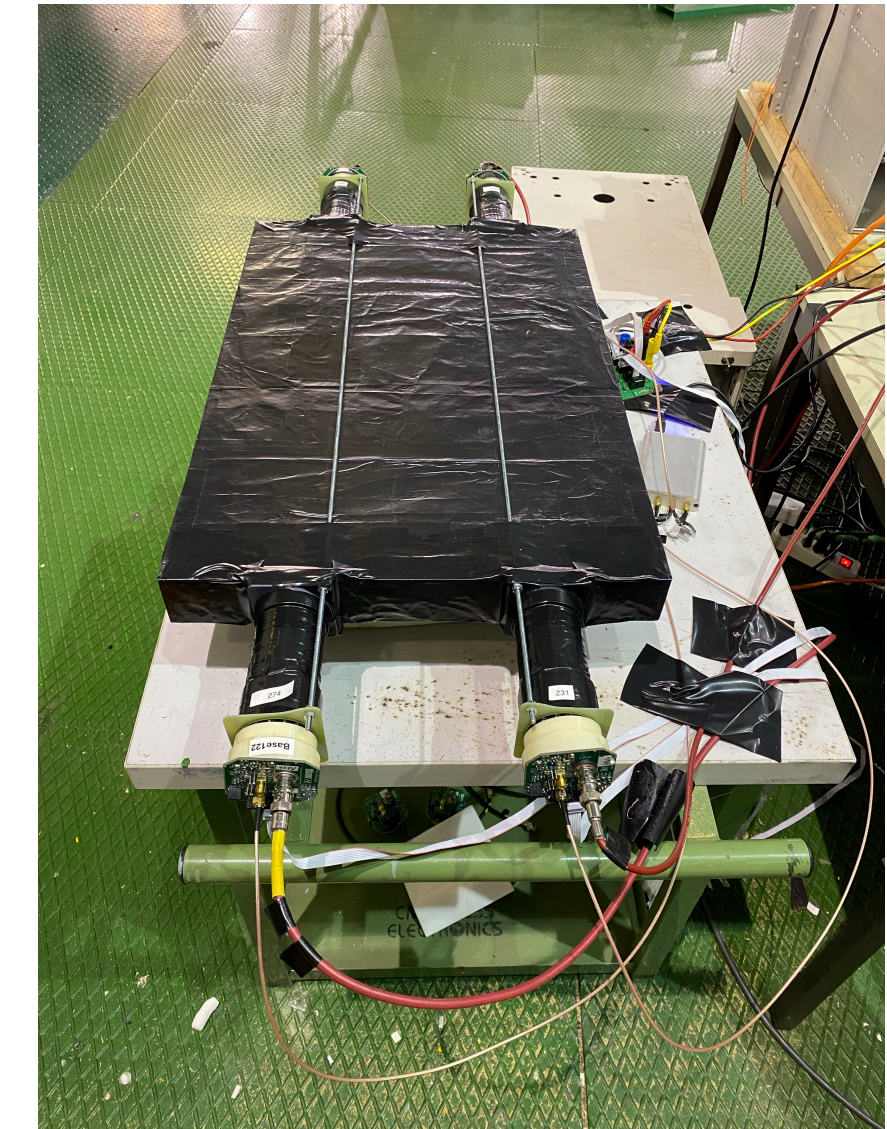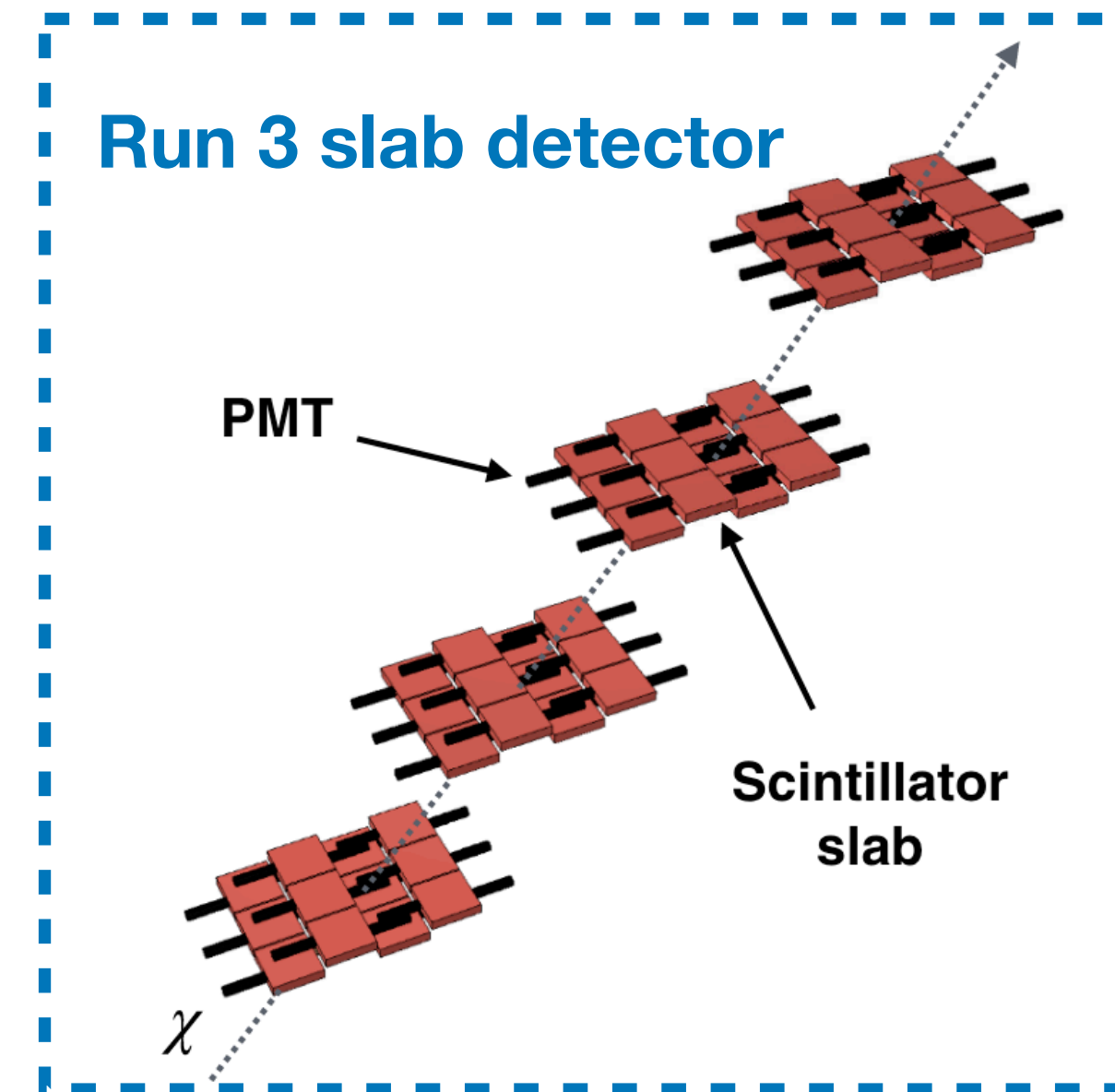
MilliQan Run 3 detectors

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Run 3 bar detector
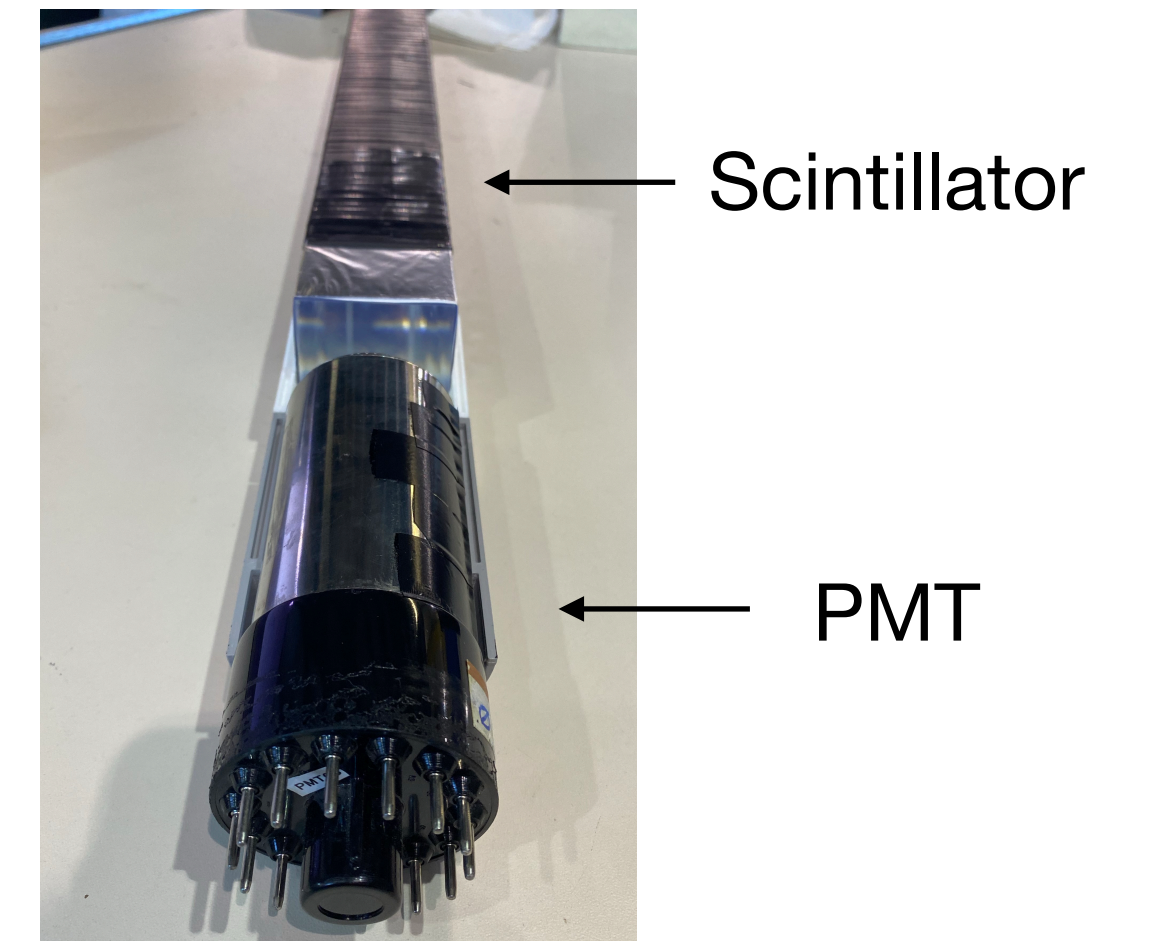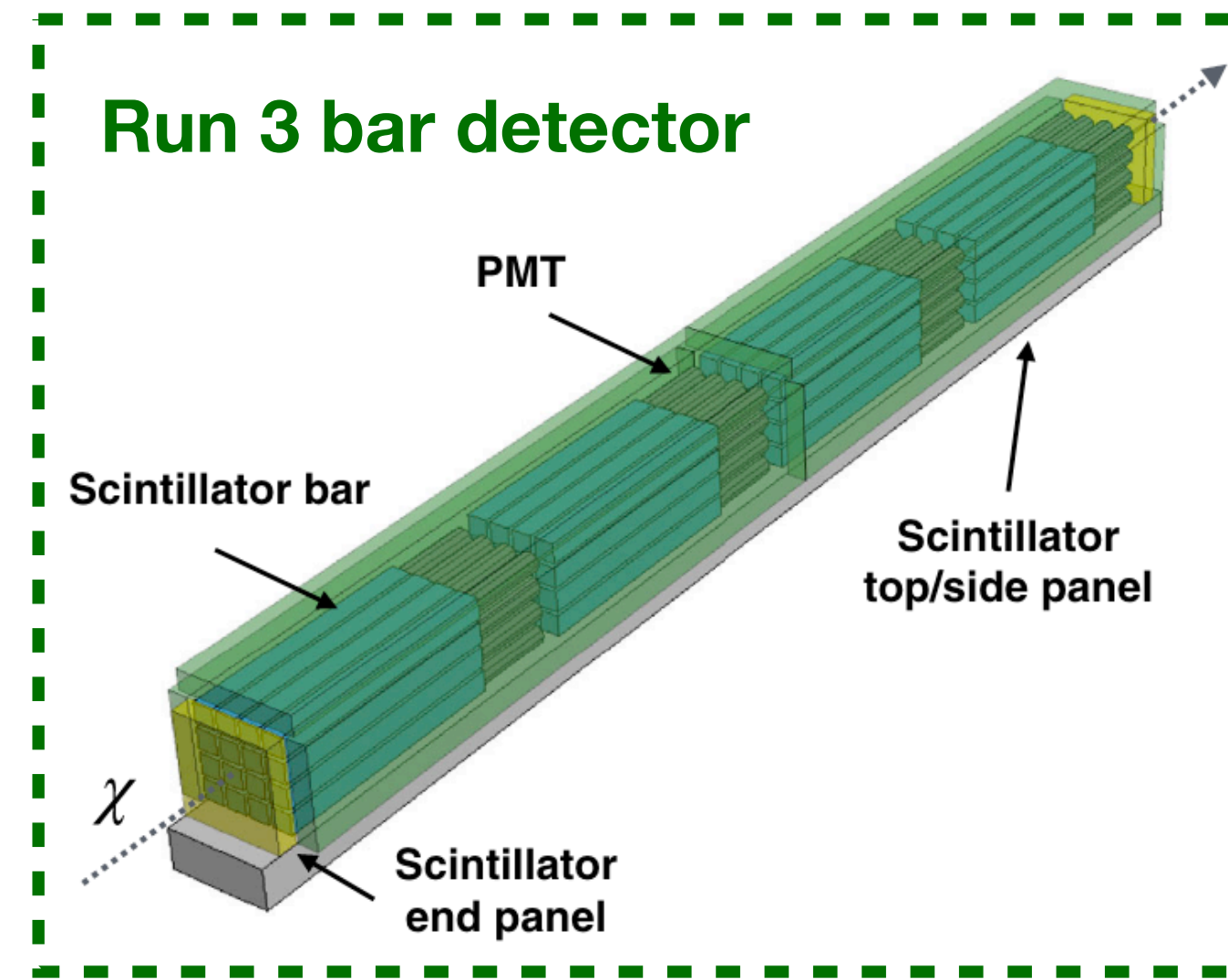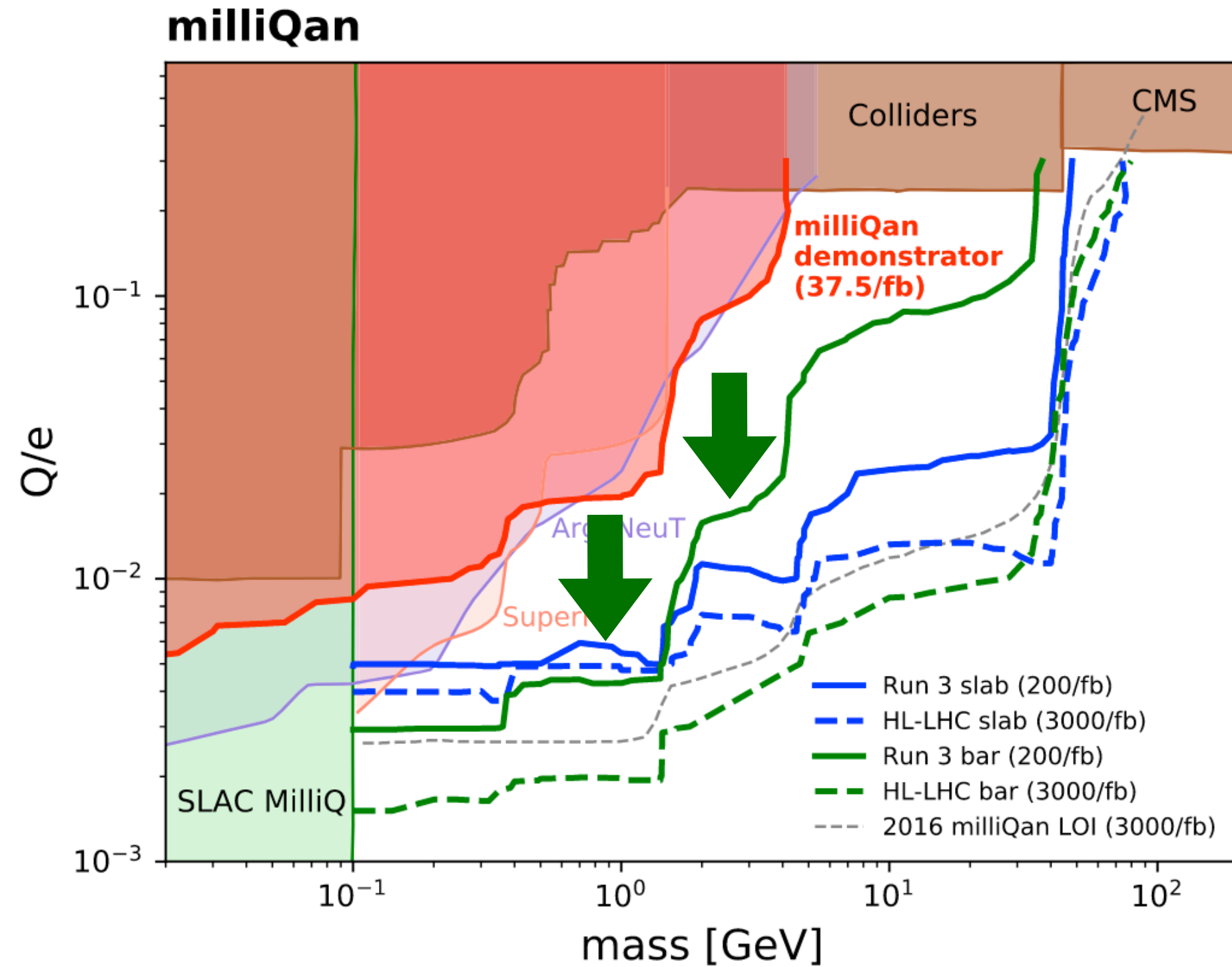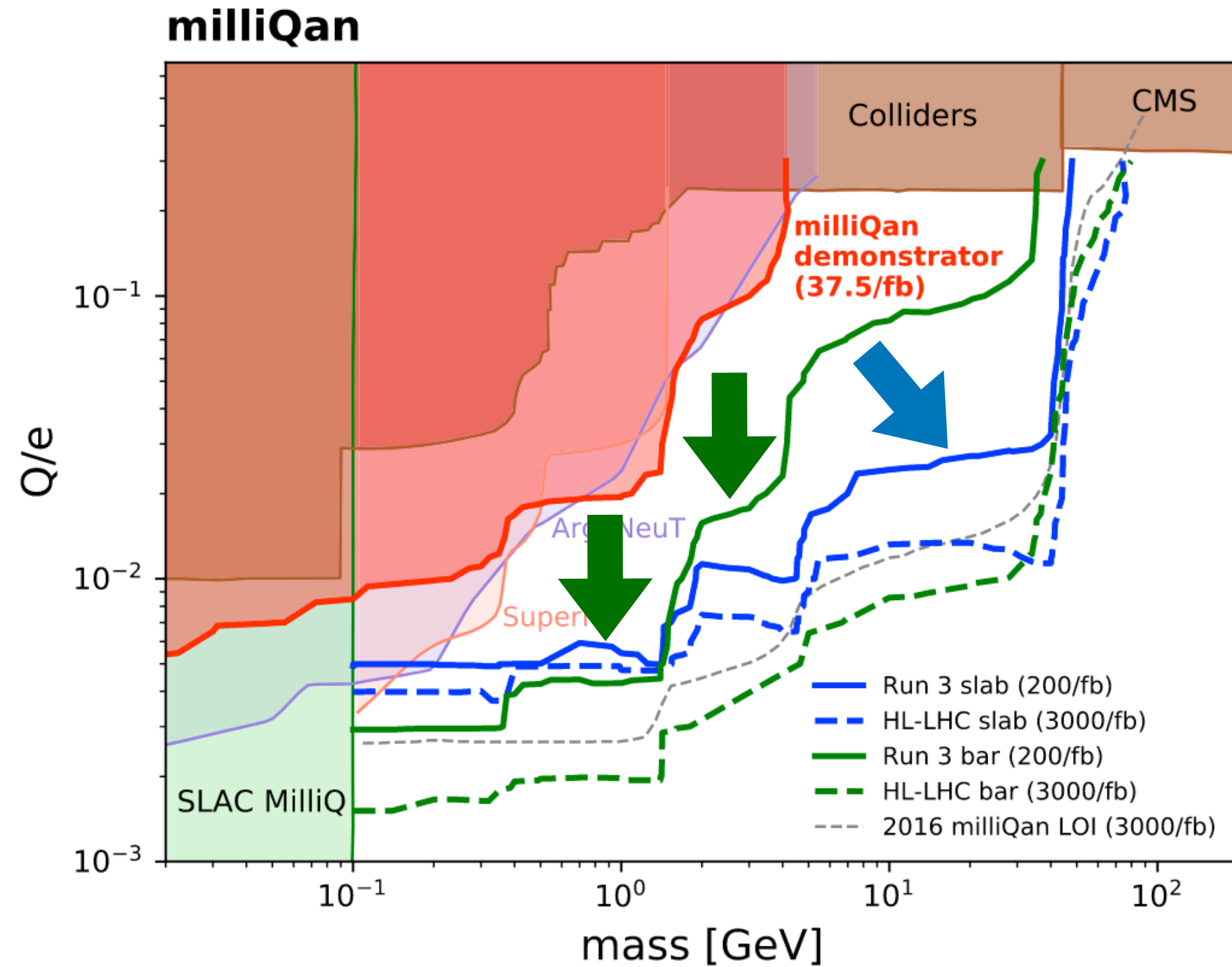

Two new detectors are under construction and commissioning!

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

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milliQan demonstrator (37.5/fb)

- Run 3 slab (200/fb)
- HL-LHC slab (3000/fb)
- Run 3 bar (200/fb)
- HL-LHC bar (3000/fb)
- 2016 milliQan LOI (3000/fb)

Two new detectors are under construction and commissioning!

arXiv:2104.07151

Run 3 slab detector

PMT

Scintillator slab

χ

- 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

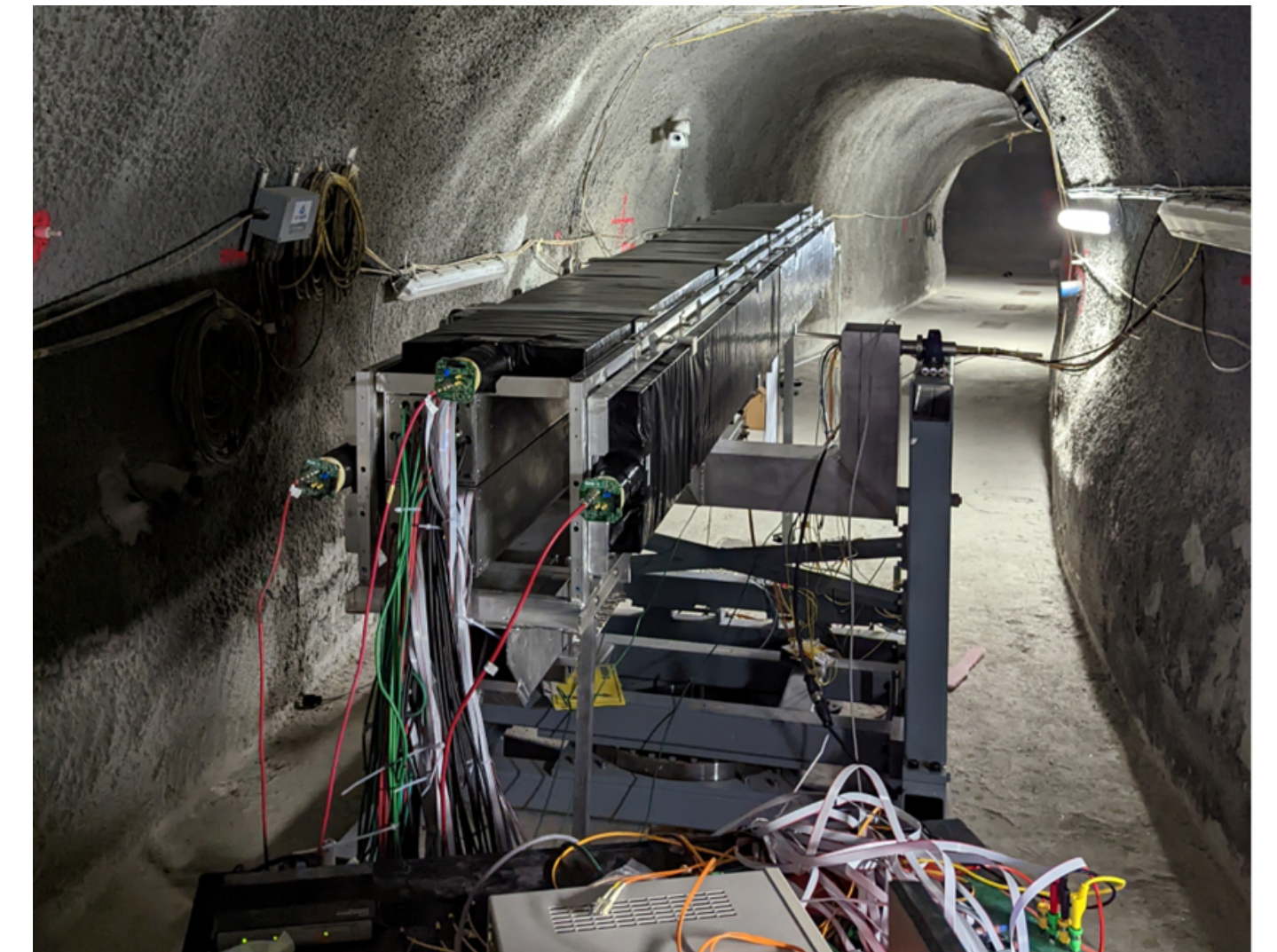- Same PMT amplification and LED calibration system as bar detector

Run 3 bar detector construction

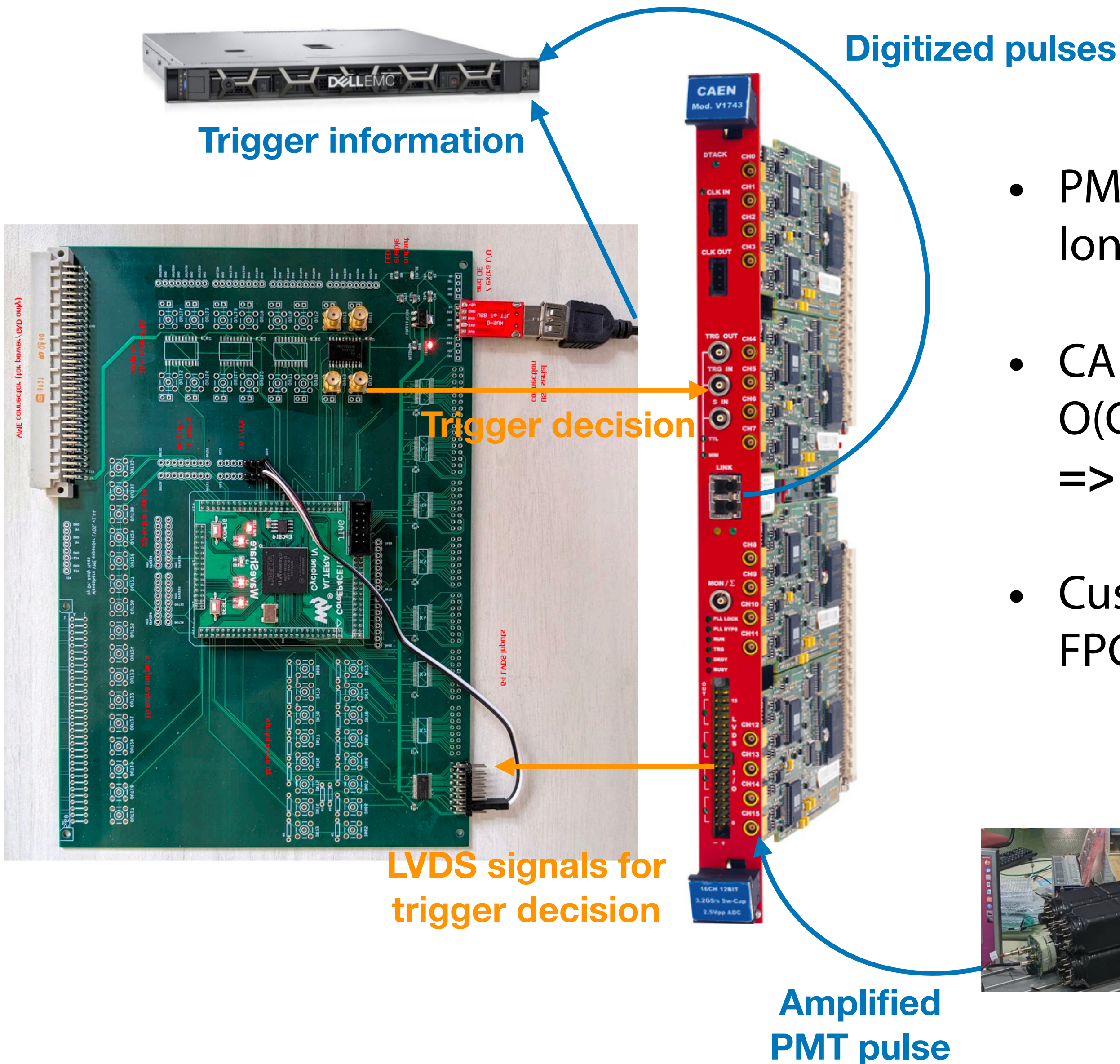4 bars assembled into an unit, all bars are made light-tight with black taps
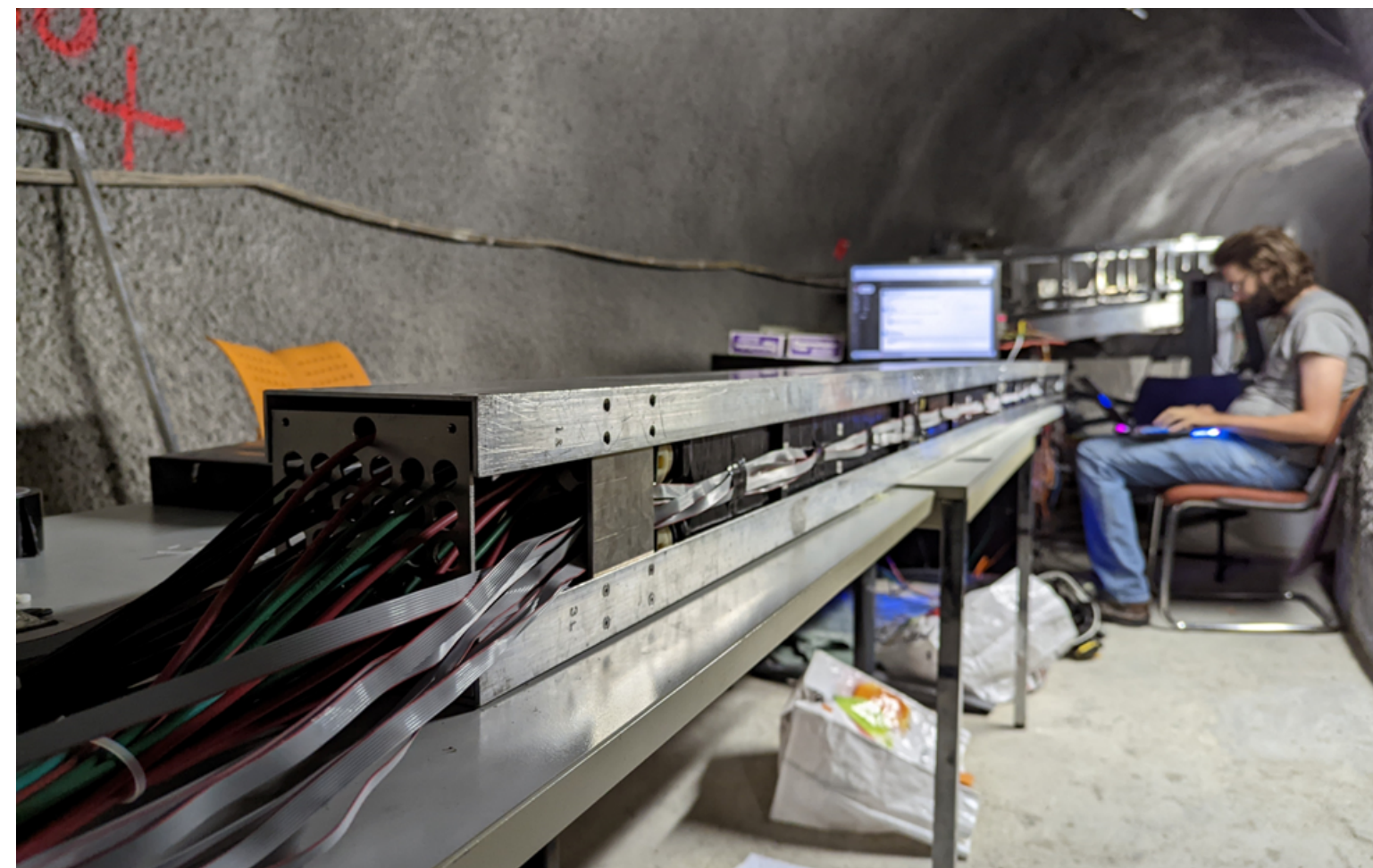
4 units (= 16 bars) assembled into a supermodule, HV/LV/signal cables are attached to customized PMT readout unit

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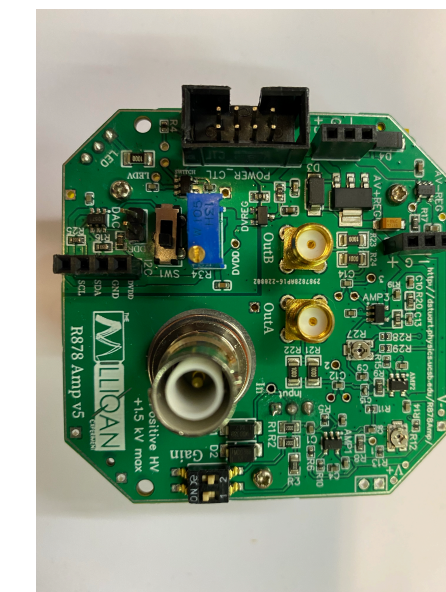
DAQ system

Digitized pulses

Trigger information

Trigger decision

LVDS signals for trigger decision

Amplified PMT pulse
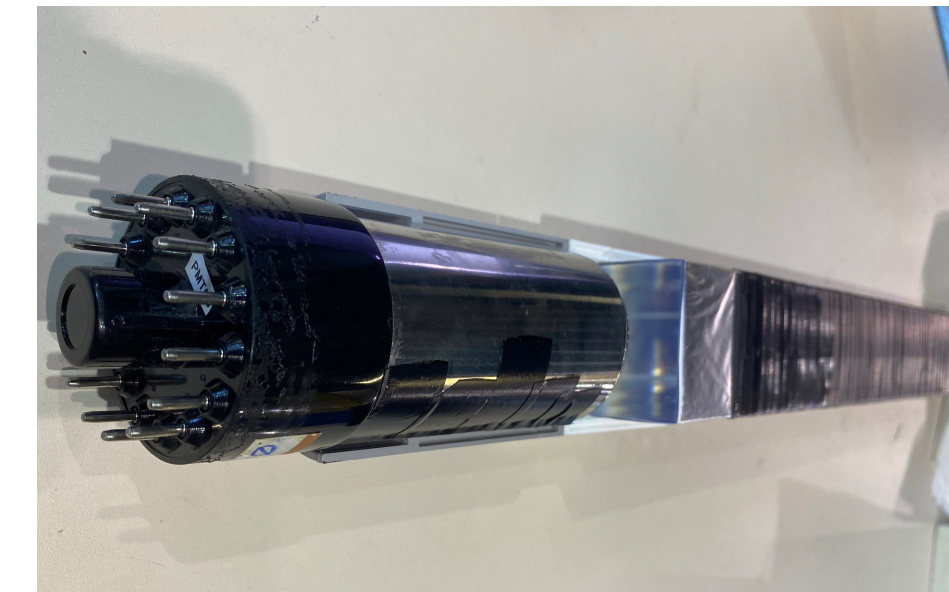
- PMT output amplified with customized base, O(100) ns long output pulse shape => **high SPE efficiency**

- 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**
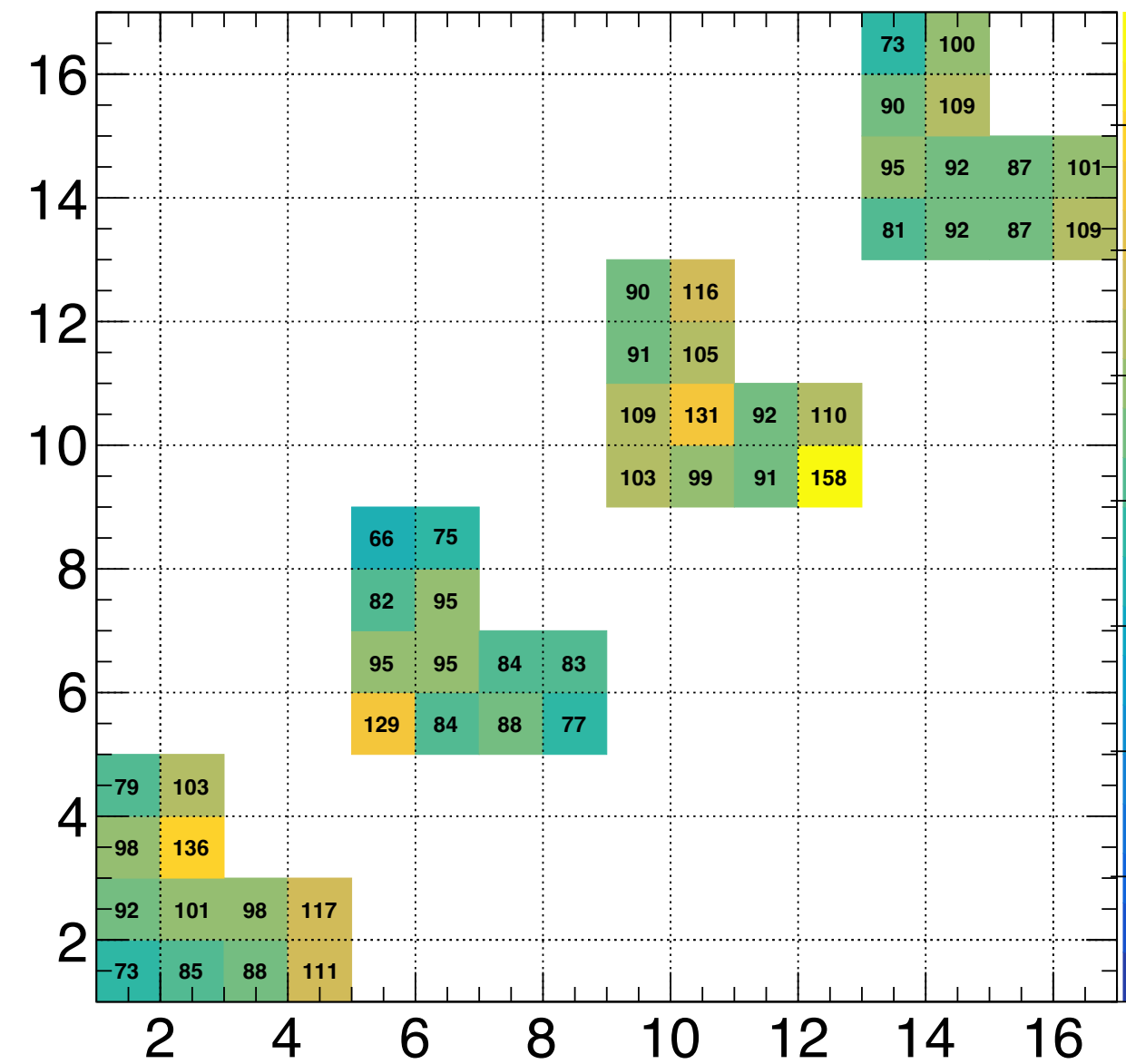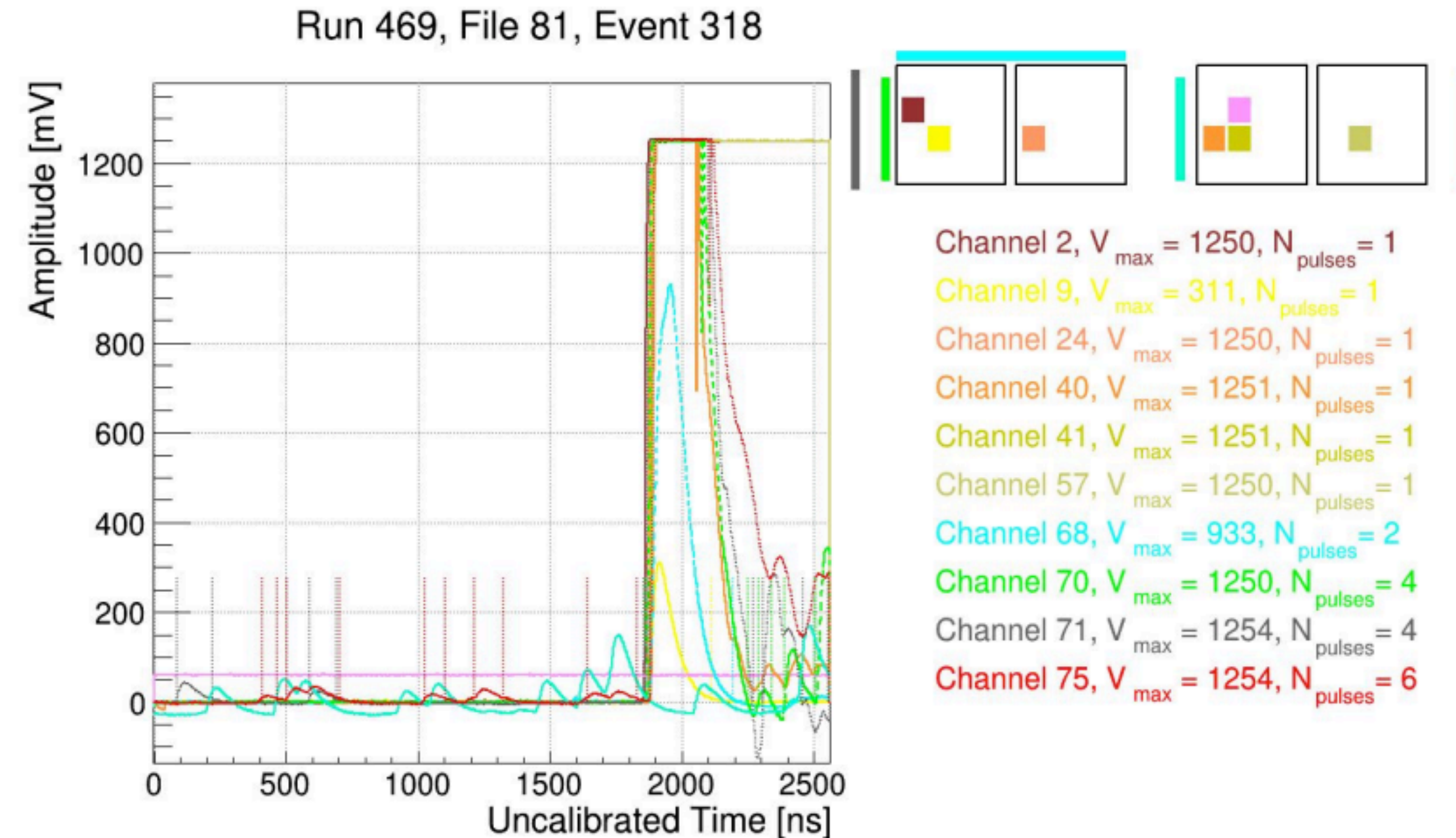
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Current status of the bar detector

Rate heat map

A muon candidate

Run 469, File 81, Event 318

Channel 2, V_{max} = 1250, N_{pulses} = 1
Channel 9, V_{max} = 311, N_{pulses} = 1
Channel 24, V_{max} = 1250, N_{pulses} = 1
Channel 40, V_{max} = 1251, N_{pulses} = 1
Channel 41, V_{max} = 1251, N_{pulses} = 1
Channel 57, V_{max} = 1250, N_{pulses} = 1
Channel 68, V_{max} = 933, N_{pulses} = 2
Channel 70, V_{max} = 1250, N_{pulses} = 4
Channel 71, V_{max} = 1254, N_{pulses} = 4
Channel 75, V_{max} = 1254, N_{pulses} = 6

- 3 out of 4 supermodules are inserted into the final position, all channels alive in DAQ

- Actively taking data to commission the detector for physics data taking starting from 2023

Current status of the slab detector
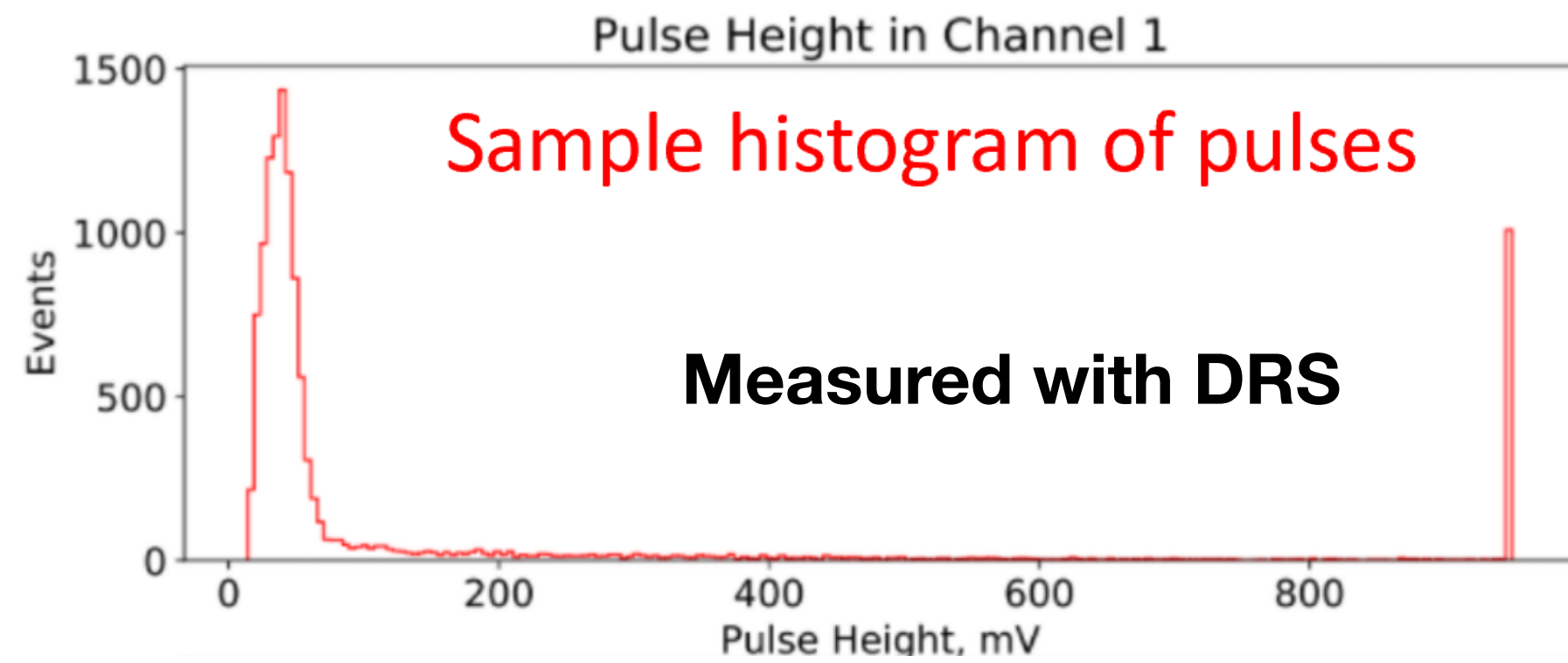

Slab testing setup
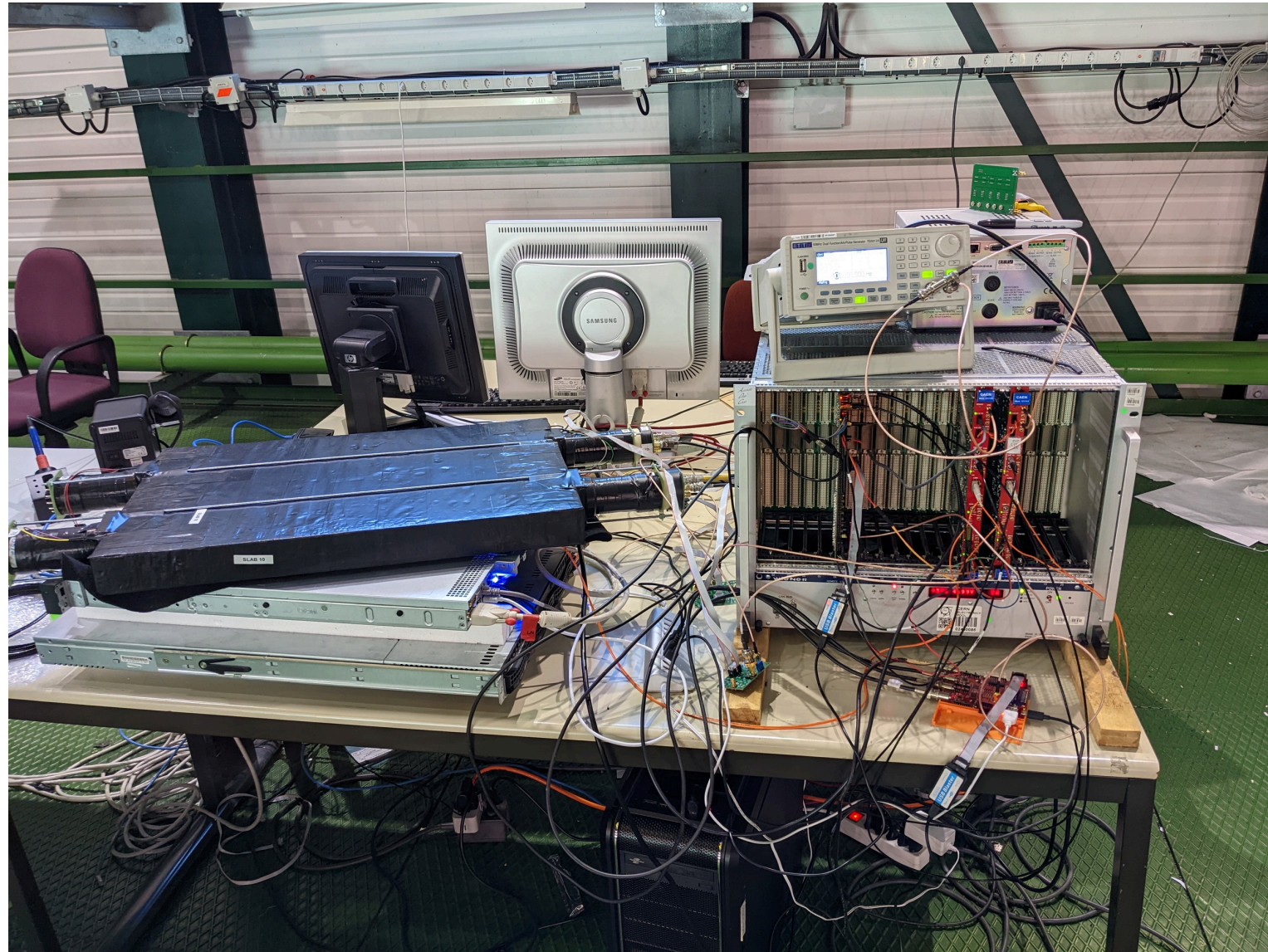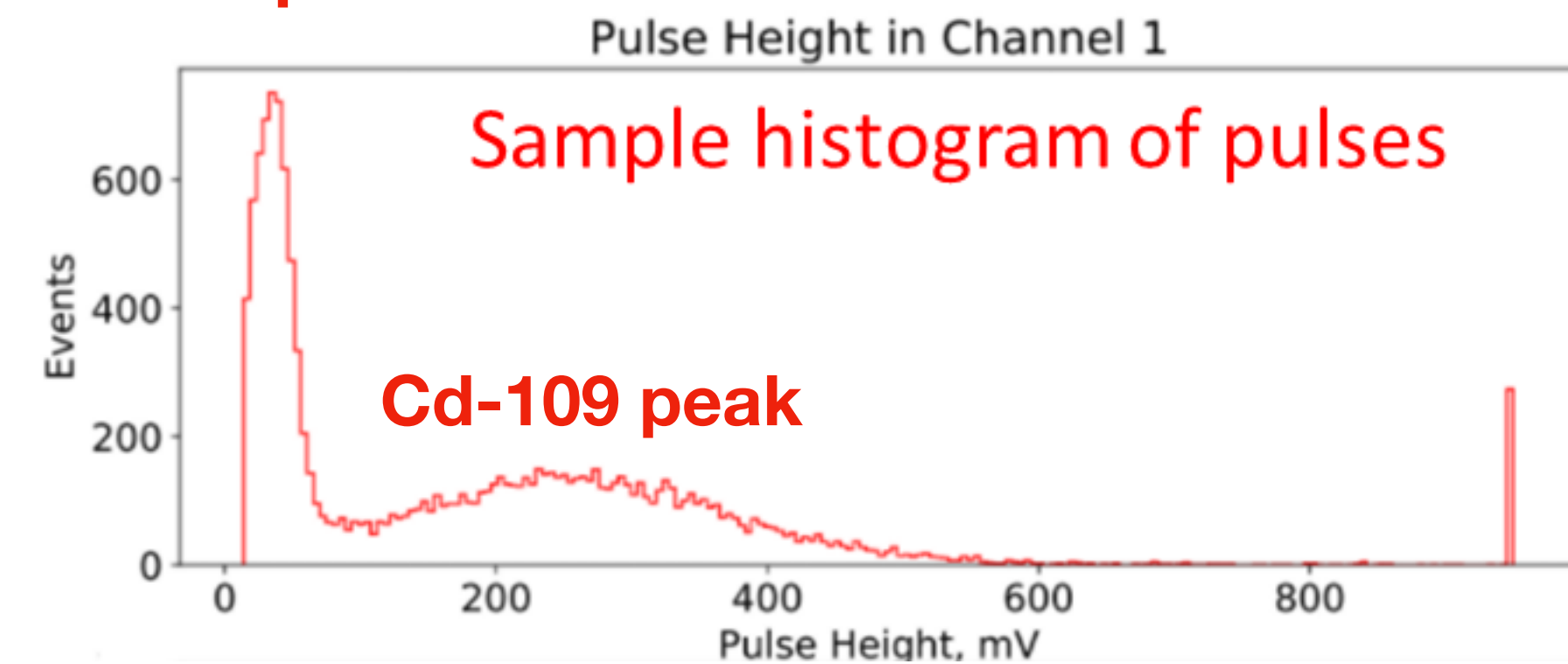
Slabs ready for installation

- 20% of the slab detector are ready to be installed, the rest are finishing testing

- Full slab detector will be installed and commissioned during the Year-End-Technical-Stop
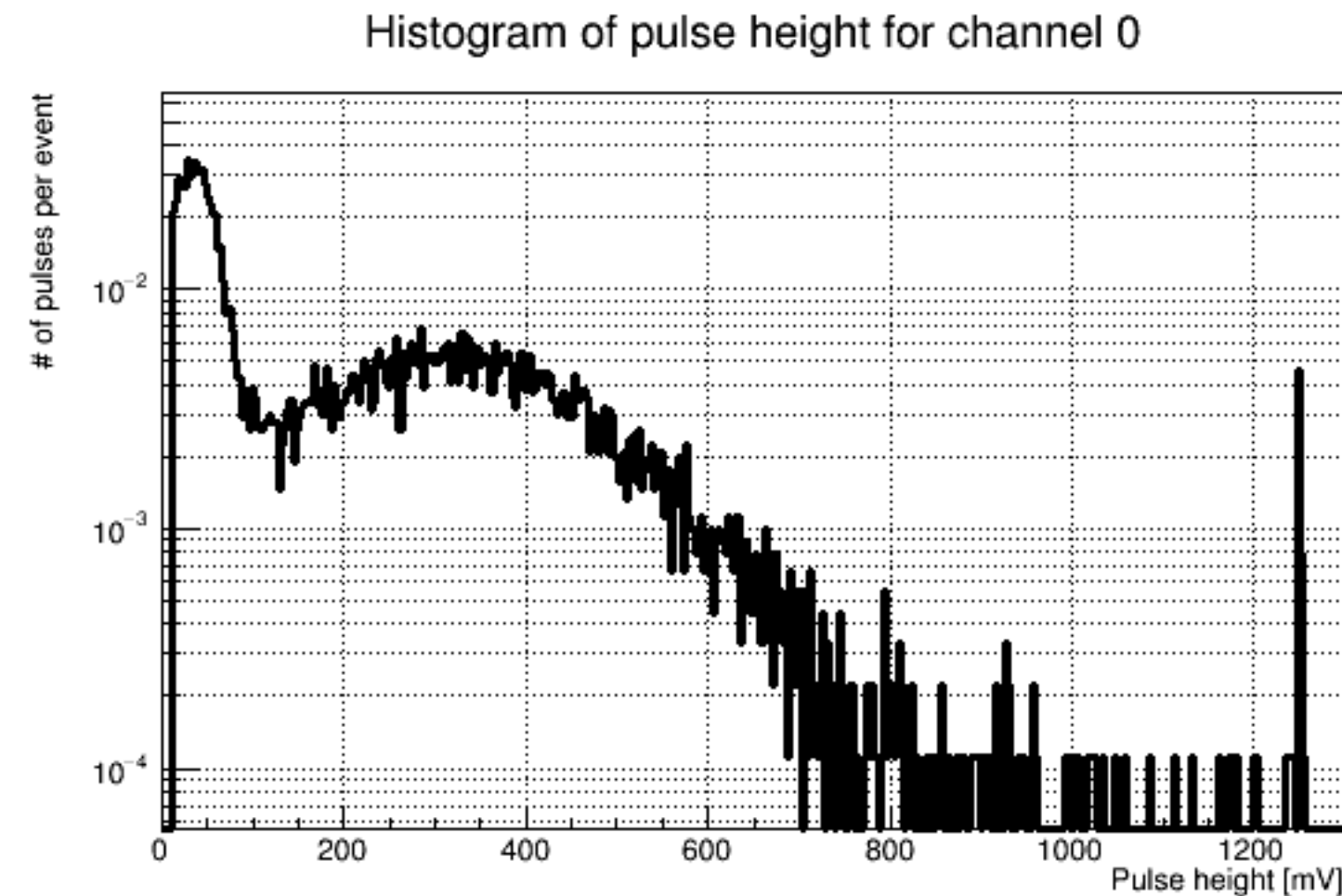
Various calibration activities

Sample histogram of pulses

Measured with DRS

SPE peak

Sample histogram of pulses

Cd-109 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	
	$K\beta_1$	24,9427	27,7
	$K\beta_5''$	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)

- Will also use through-going muon (cosmic or from CMS IP) for timing calibration in the coming weeks

Summary

- The MilliQan demonstrator has been able to exclude unexplored phase space in terms of the search of milli-charged particle

- 2 new detectors (bar and slab) are under preparation to further increase the sensitivity to milli-charged particles

- On-track for Run 3 physics data taking starting from next year

The MilliQan collaboration