MilliQan: First Results and Prospects for Run 3

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On behalf of the MilliQan collaboration

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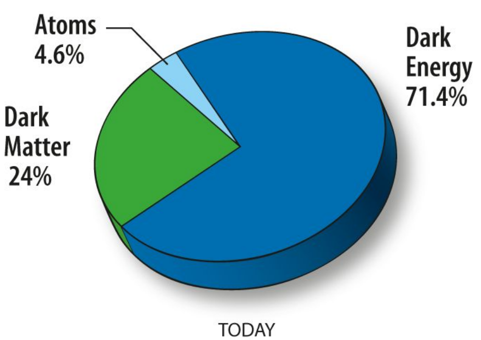
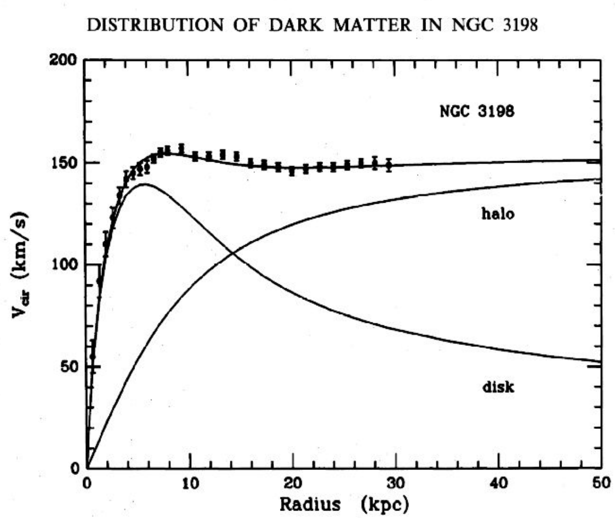
New physics and dark matter

- Standard Model of particle physics is incomplete
- No new physics discovered at the LHC yet
- Dark matter: Constitutes ~25% of the energy budget of the universe
  - No discovery in wide range of direct/indirect searches
  - Massive dark photon searches place stringent constraints
  - These constraints can be avoided by considering massless dark photon



WMAP



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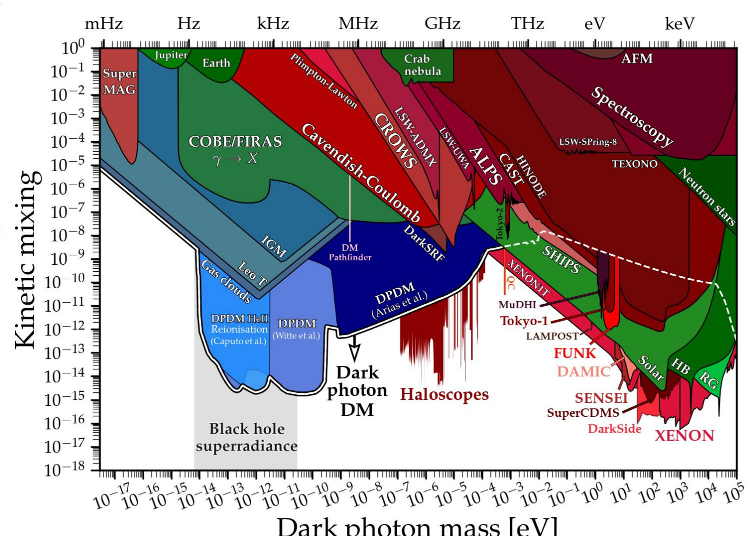
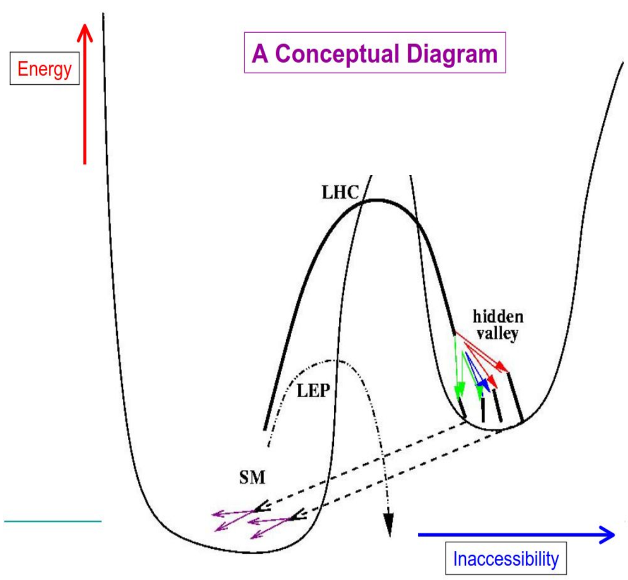


[arXiv:2105.04565] [hep-ph]

Hidden sector and milli charged particles

- LHC might provide access to hidden sector particles
- Hidden sector provides rich phenomenology including stable dark matter candidates



Strassler, Zurek

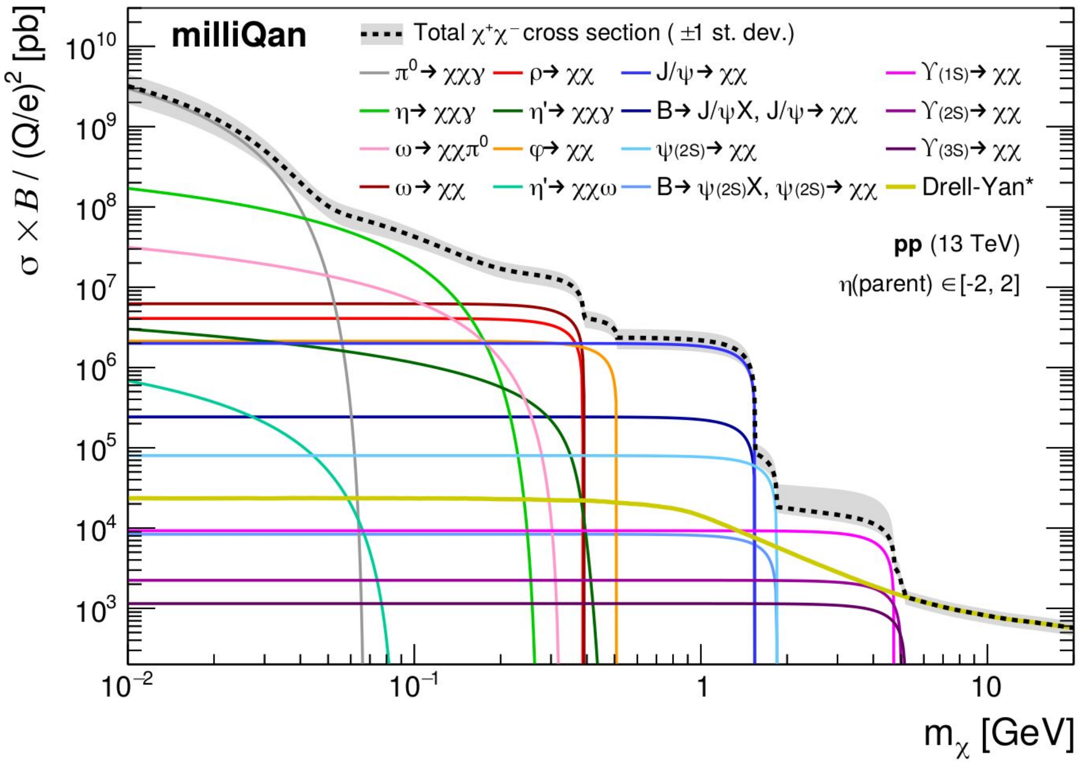
Consider dark sector containing U(1) abelian gauge field, A', interacting with SM hypercharge B through kinetic mixing

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

Results in a Dirac fermion with mass M_{mCP} and electric charge $\kappa e' \cos\theta_W$

Millicharged particles at LHC

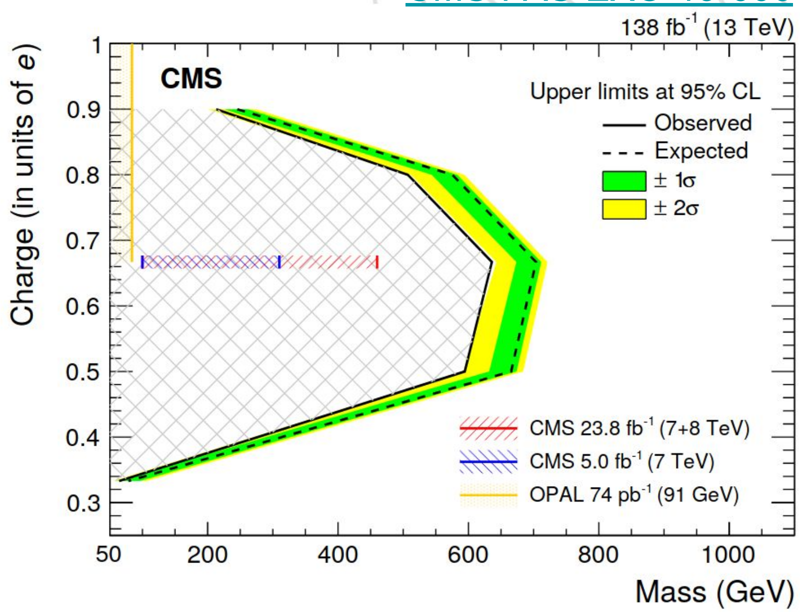
- Production mechanisms similar to e+e- but note the different mass and charge of the mCPs



Can the LHC detectors see mCPs?

- mCPs with mass>100 MeV loose energy through ionization and/or excitation
- Very small energy deposits in CMS for Q<0.3e
- Pair production of two mCPs results in MET

CMS-PAS-EXO-19-006

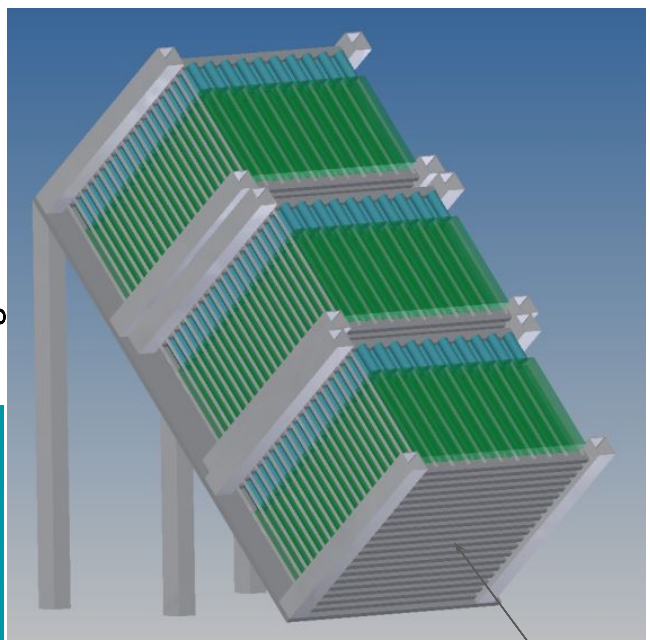


Dedicated mCP detector needed at the LHC!!

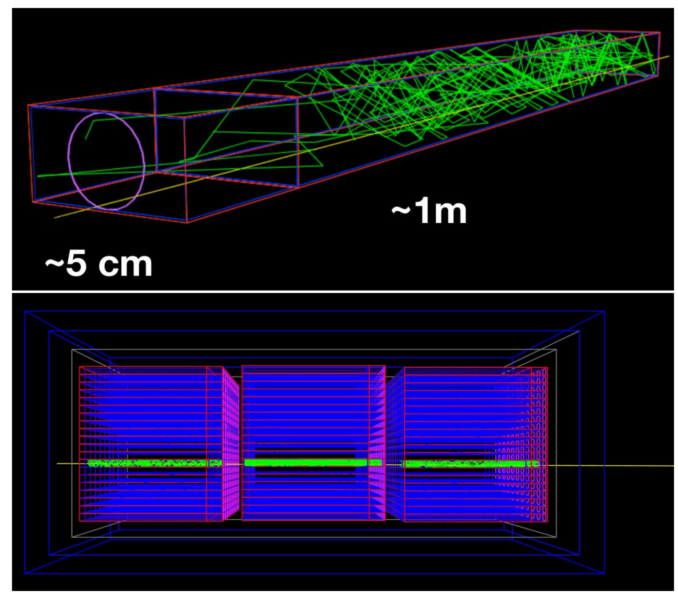
MilliQan detector: working principle

- Principle: Use scintillators to detect mCPs using their low ionization energy
- Through going mCPs can be detected using co-incident signal deposited in multiple layers of bars

Letter of Intent design



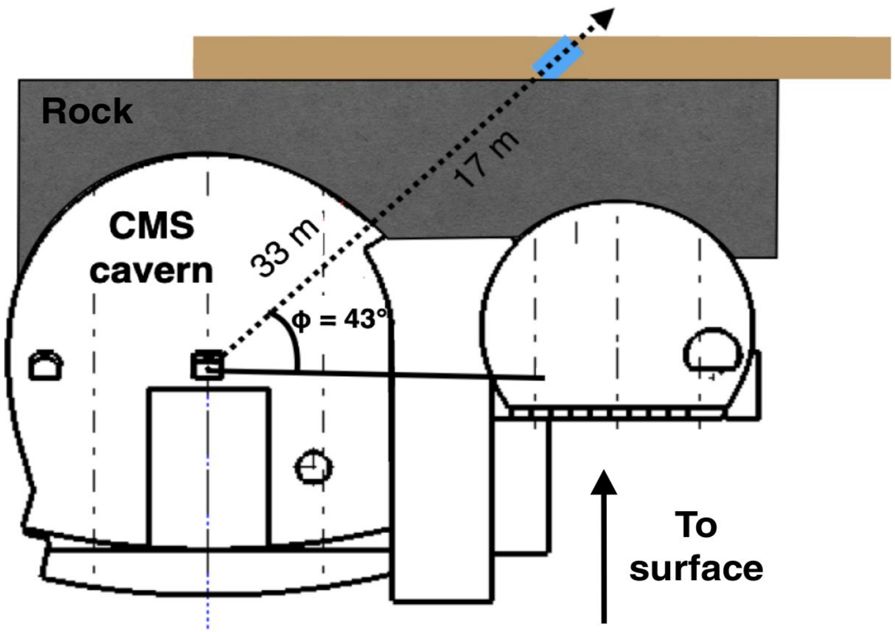
Bar is made of one scintillator and a PMT and is capable to detect single photons (sPE)

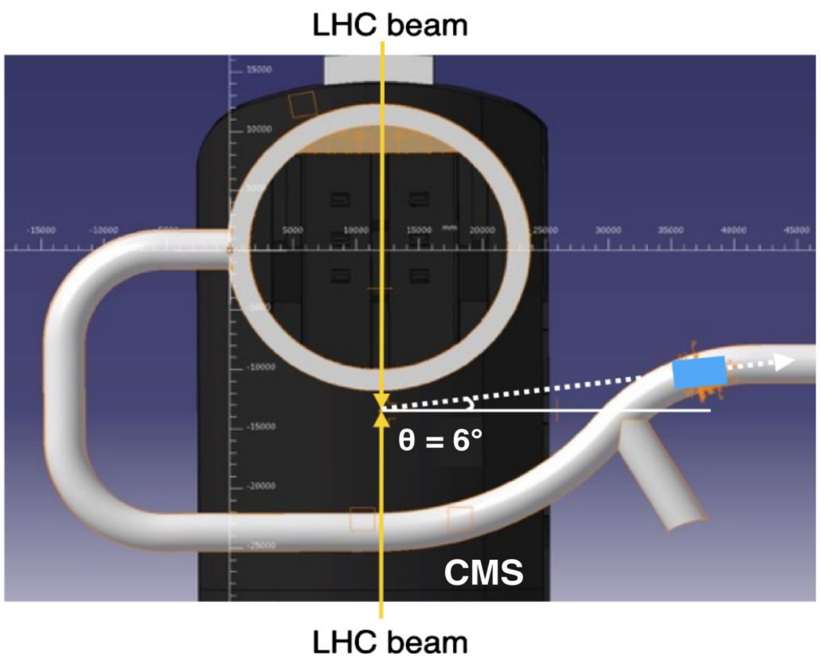


CMS Interaction Point

Location

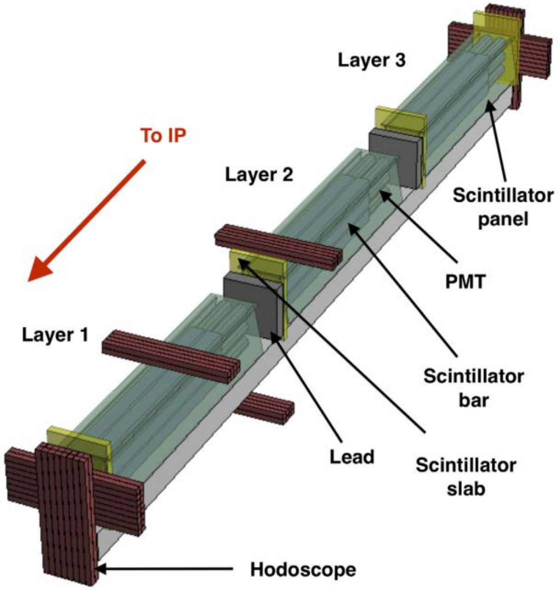
- MilliQan is housed in the unused drainage gallery of the CMS experiment
- 33m away from CMS IP at ϕ=43° and η=0.1 in CMS coordinate system
- Beam particles are shielded by the 17m rock
- Muon flux from cosmics is 100 times smaller than the surface

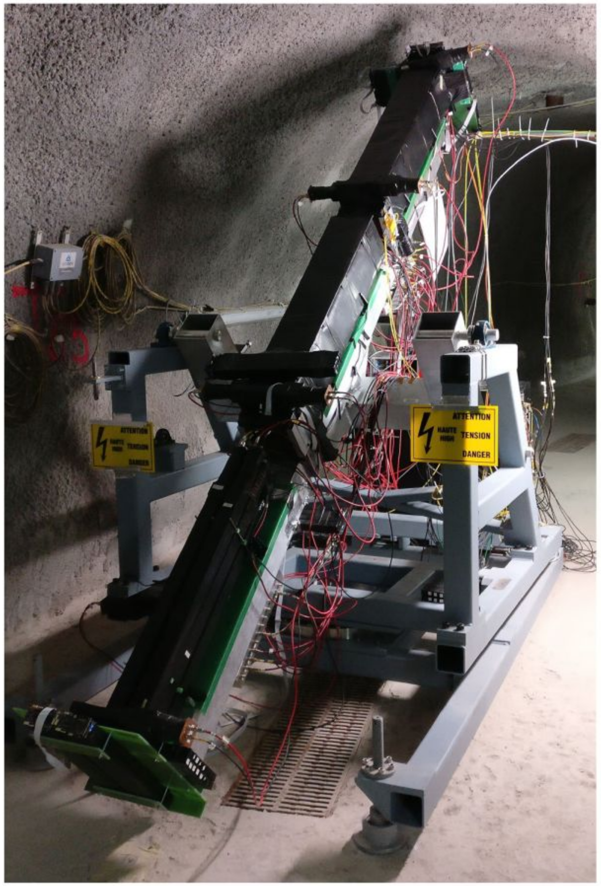




MilliQan demonstrator

- 3 layers, each containing 2x3 array of 80 x 5 x 5 cm bars, pointing to CMS IP
- Additional components like panels and hodoscope help reduce backgrounds like through-going muons, cosmic showers, neutrons etc
- Successful run in 2018 with 35 fb^{-1}, 2000h of data taking
- Provided proof of concept



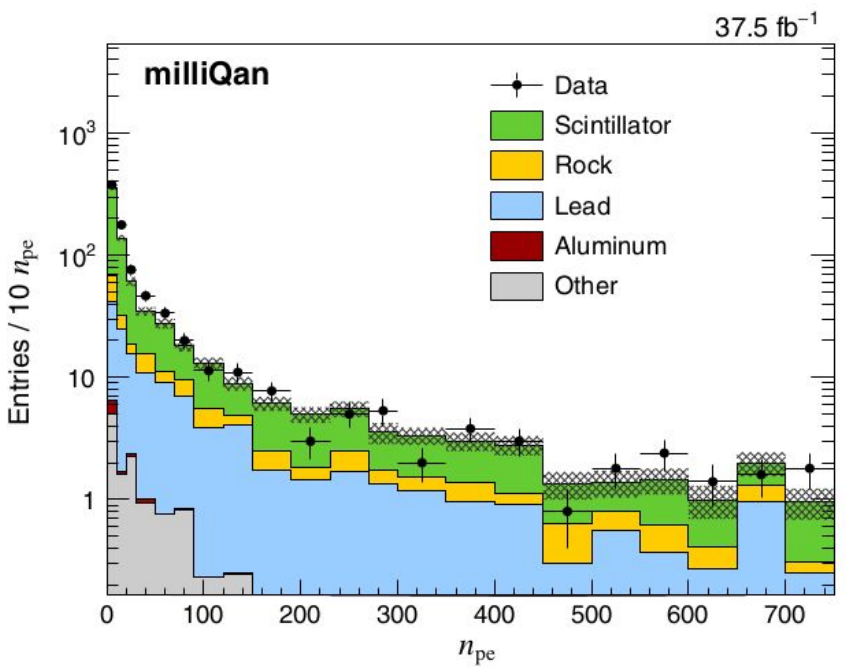


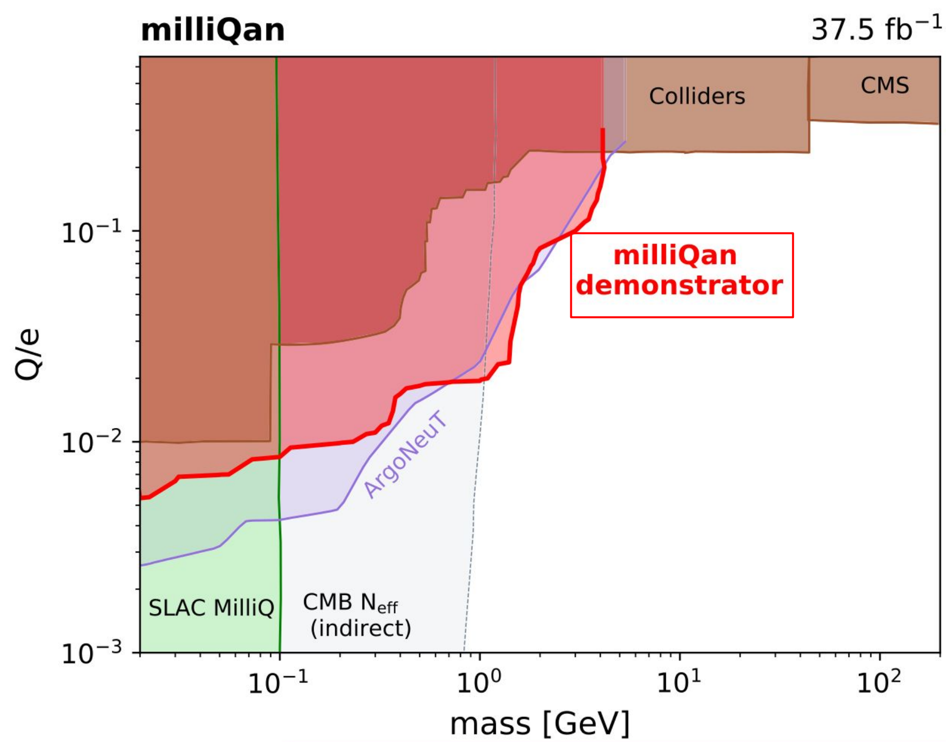
Results in [Phys.Rev.D102,032002]

MilliQan demonstrator results

- 95% CL limits placed on mCPs with 20-4700 MeV and charges between 0.006e-0.3e
- New sensitivity for masses above 700 MeV

Muon shower prediction and validation with data





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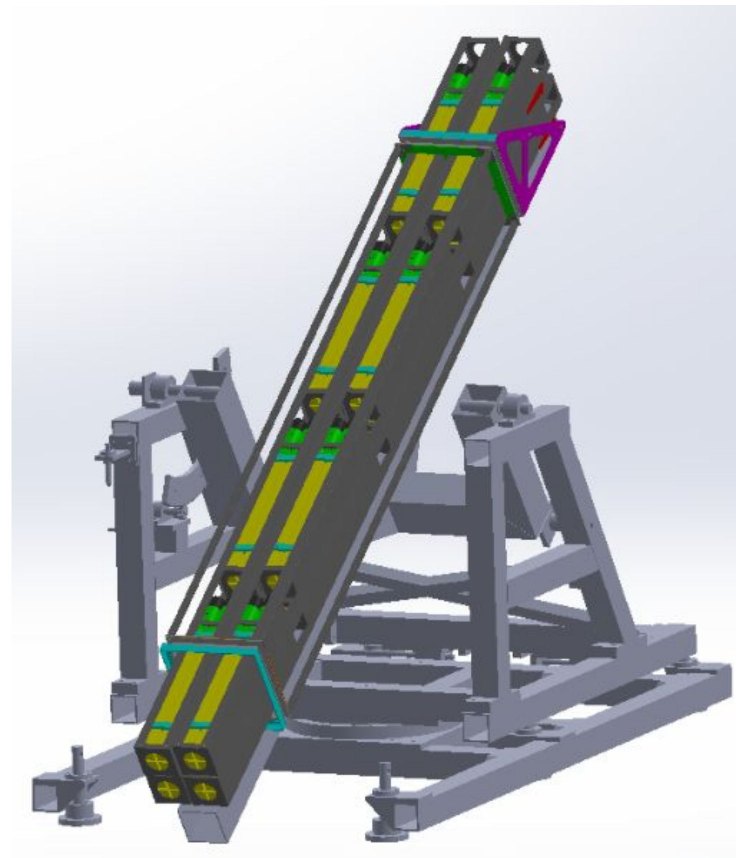
MilliQan Run 3 bar detector

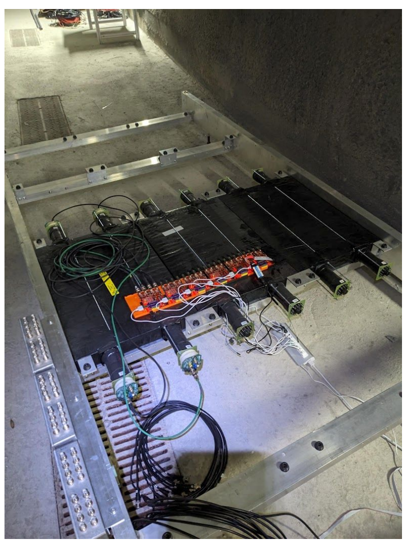
- Four layers of 5x5x60 cm scintillator bars provides better background rejection
- Each layer contains 4x4 scintillator bars increasing the signal acceptance
- 8 panels with increased thickness provide background rejection
- Improved single photo electron reconstruction
- Improved calibration and monitoring using LEDs
- Construction complete and operational now!

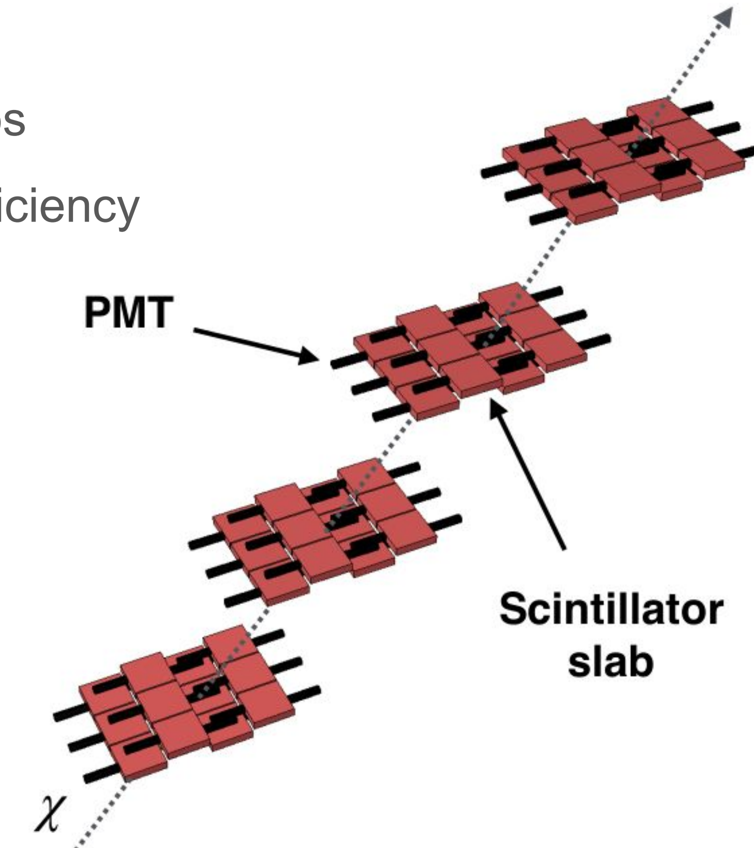


Phys. Rev. D 104 (2021) 032002

MilliQan Run 3 slab detector

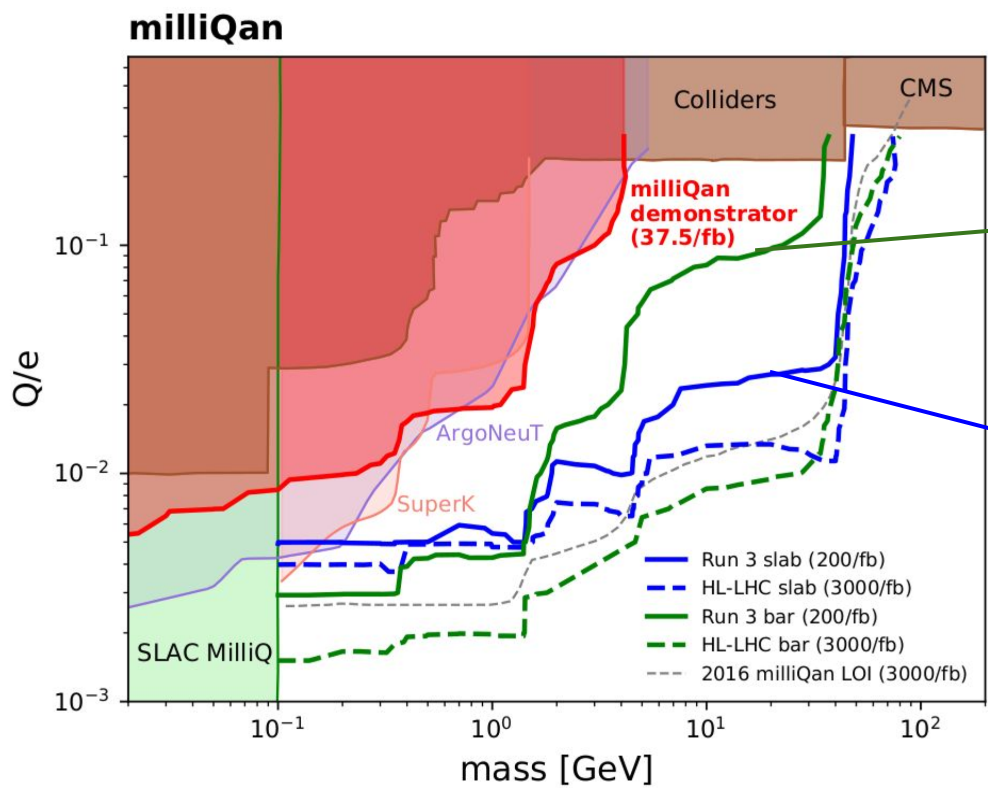
- Improved sensitivity for mCPs with masses above 1.4 GeV where the sensitivity is limited by acceptance
- Four layers of 3x4 array of 40x60x5 cm slabs
- Each slab has four PMTs to increase the efficiency
- Detector under construction right now!





Sensitivity projections

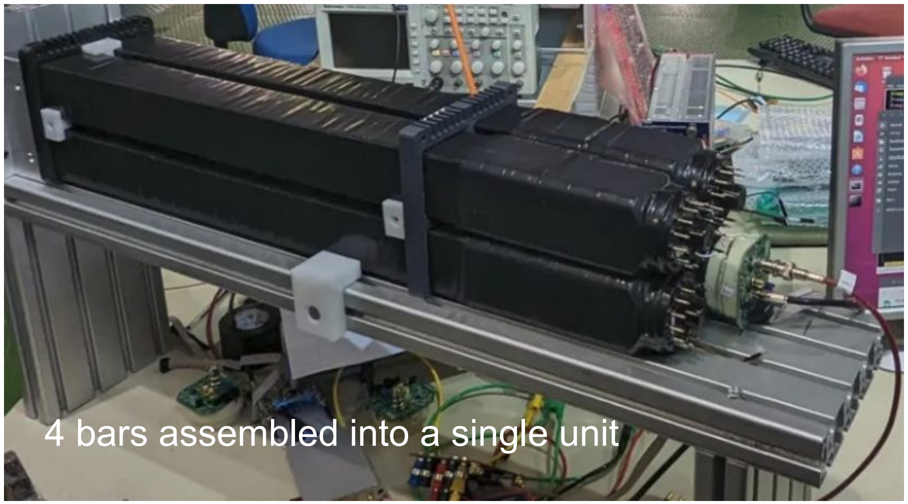
- Combination of the bar and the slab detectors provides the best sensitivity for masses above 100 MeV



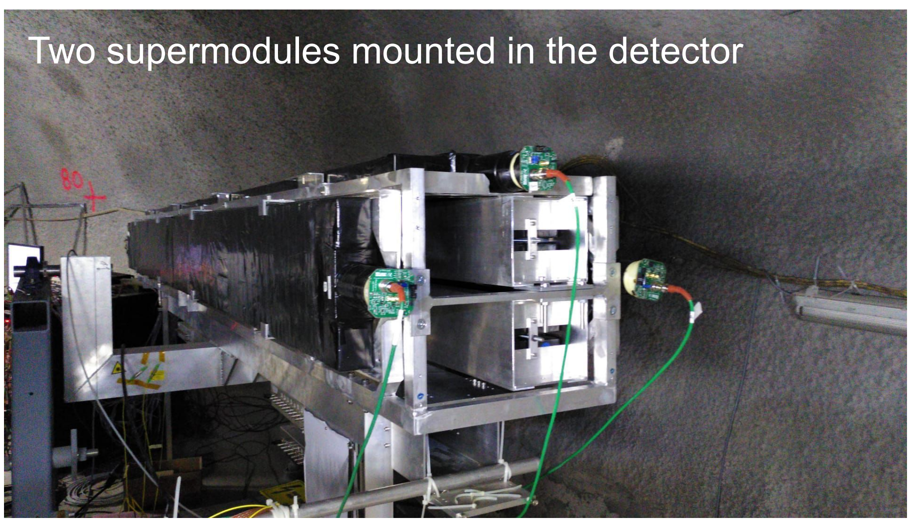
Run 3 bar detector
Great sensitivity at low mass and charge

Run 3 slab detector
Improved sensitivity at high mass

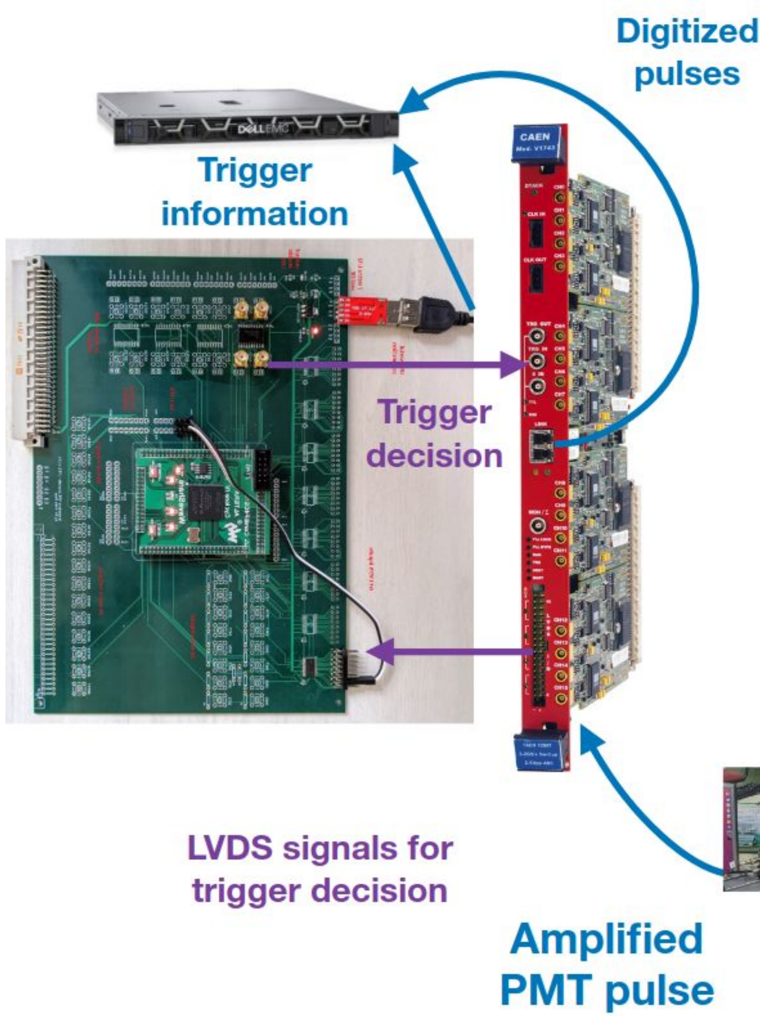
Bar detector construction

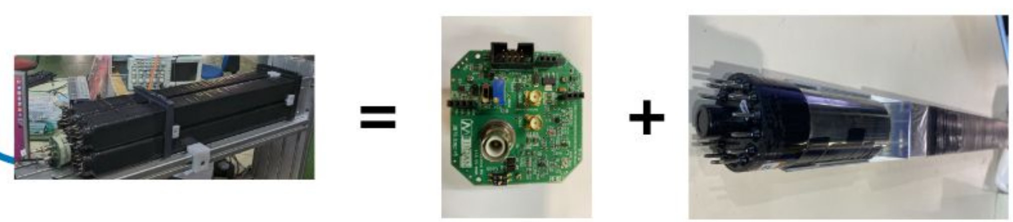

4 bars assembled into a single unit

Supermodule assembly using 4 units


Two supermodules mounted in the detector

Trigger and DAQ





- Amplified output from each bar is recorded using a 16 channel CAEN digitizer with 0.4 GHz sampling frequency and 2.5 μs readout window
- Trigger decisions are made using a customized trigger board with Altera Cyclone IV FPGA

Run 3 detector status

- Construction completed in May
- All channels operational
- Source calibrations performed using Cd109 source
- **Stable run since June 1st**

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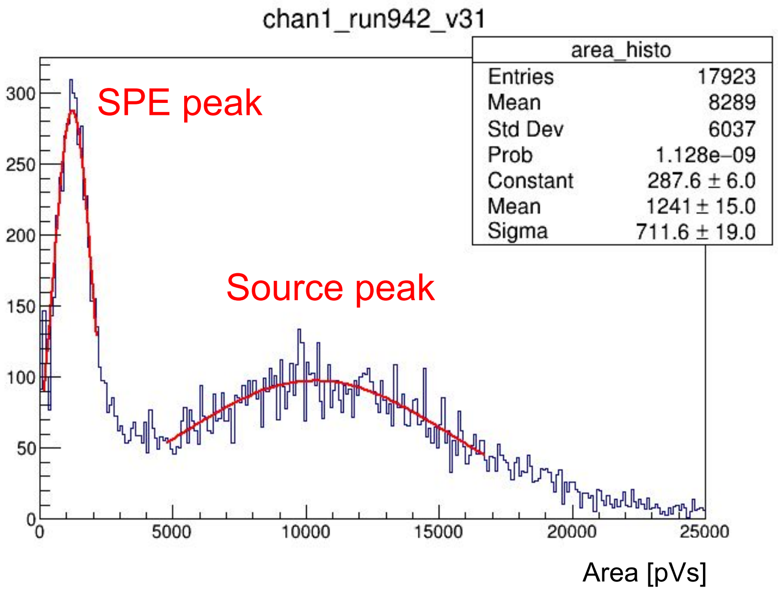
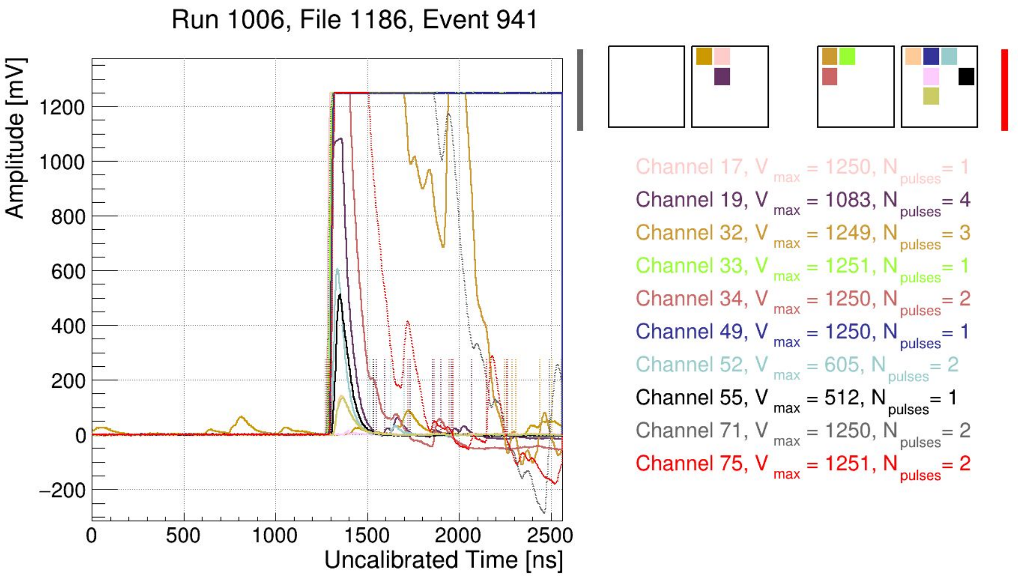
First results

- Cd109 source runs show good performance and the ability to separate the source peak from the SPEs
- We are looking into the first few physics runs at the moment





Summary and outlook

- MilliQan provides a highly sensitive model-independent probe for milli charged particles
- Run 3 bar detector construction has concluded
    - Physics runs have started on June 1st
- Run 3 slab detector is under construction right now
- Expect ~30 fb^{-1} data in 2023! Stay tuned for results!

2022 MilliQan collaboration meeting