MilliQan

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On behalf of the milliQan collaboration

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LHC and millicharged particles

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

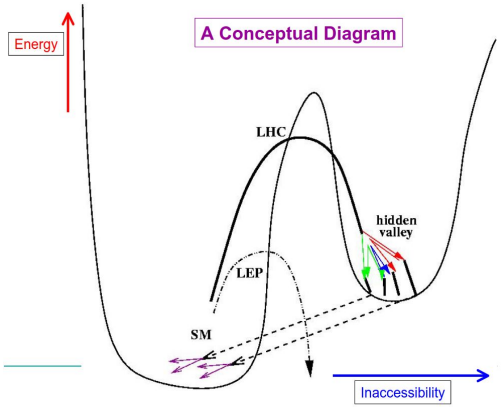
Consider dark sector containing U(1) abelian gauge field, A', interacting with SM hypercharge B through kinetic mixing

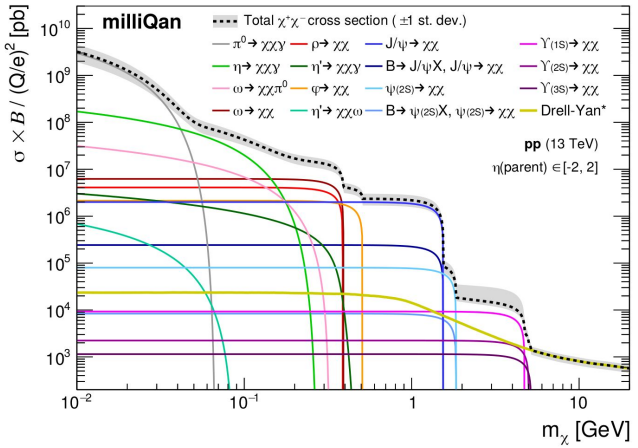
$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} - \frac{1}{4} A'_{\mu\nu} A'^{\mu\nu} + i\bar{\psi}\left(\partial\!\!\!/ + ie'A\!\!\!/' - i\kappa e' B\!\!\!/ + iM_{\mathrm{mCP}}\right)\psi$$

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

small ⇒ milli-charged particles (mCPs)

Strassler, Zurek



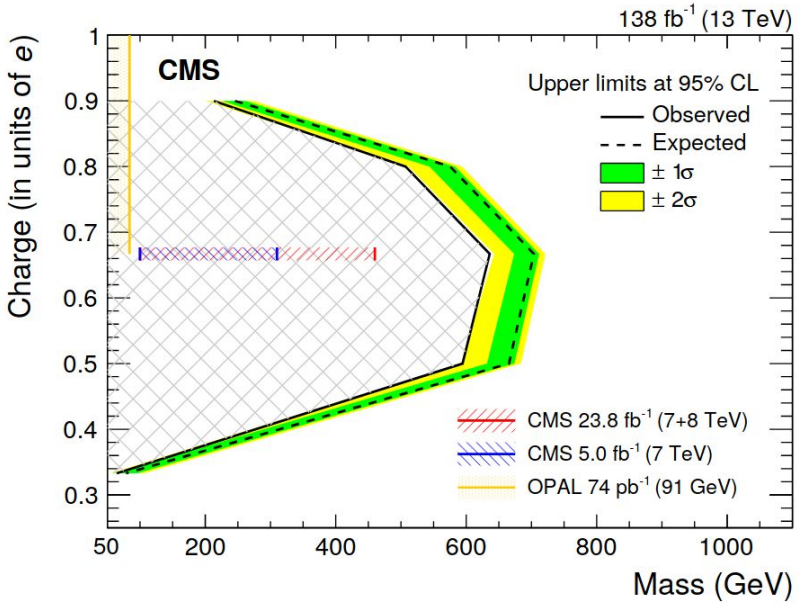


Can ATLAS/CMS see mCPs charge?

- mCPs with mass>100 MeV lose energy through ionization and/or excitation
- Very small energy deposits in CMS for Q<0.3e, difficult to distinguish from noise
- The best limits are placed at ~0.67e

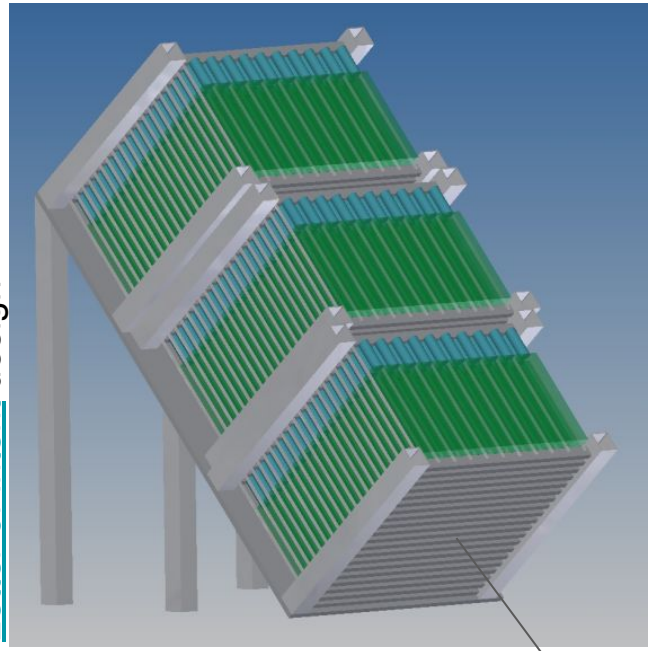
Dedicated mCP detector needed at the LHC!!

CMS-PAS-EXO-19-006

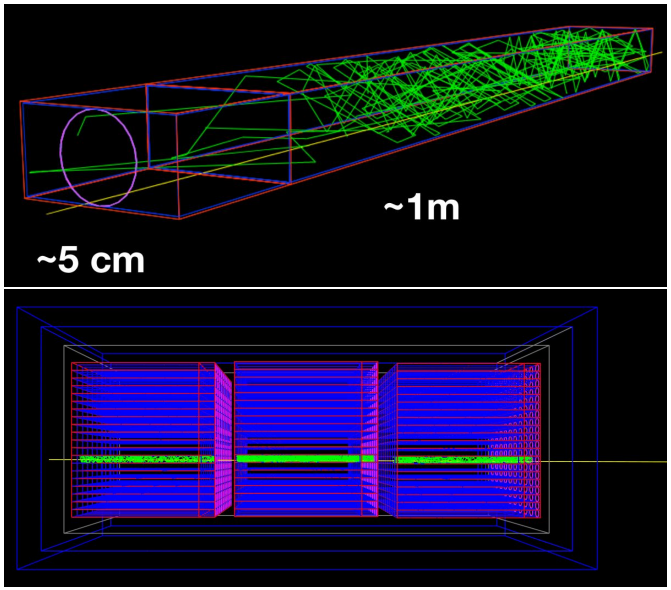


MilliQan detector: working principle

- 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
- Main background: PMT dark rate, muons and cosmic showers



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



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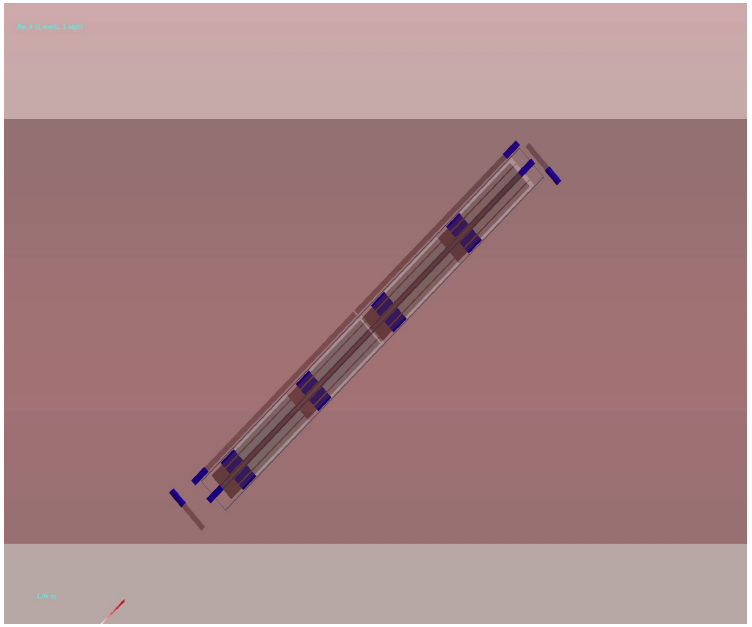
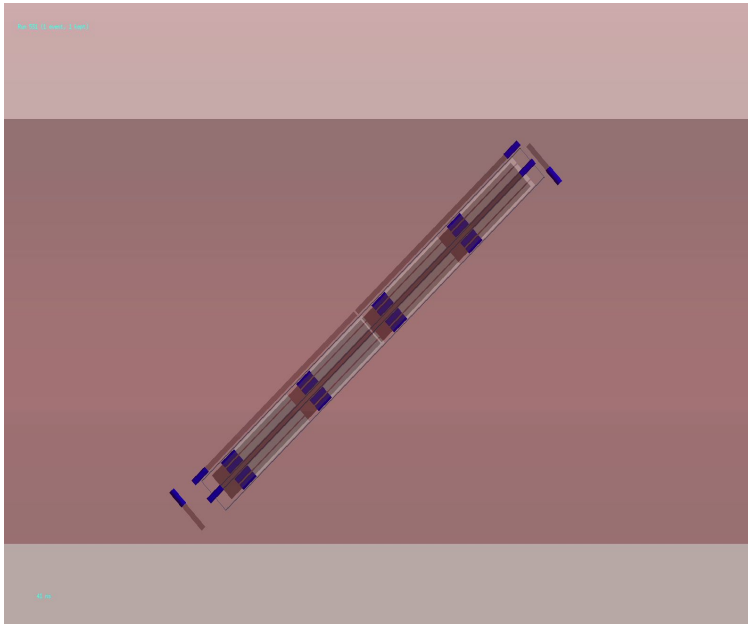
mCP vs through going muon

- mCPs leave a small energy deposit compared to the large deposits left by muons
- Vetoing on large, saturating pulses helps us cut down muon background

Q = e



Q = 0.01e



Legend: μ, γ, mCP, e^-, optical photon

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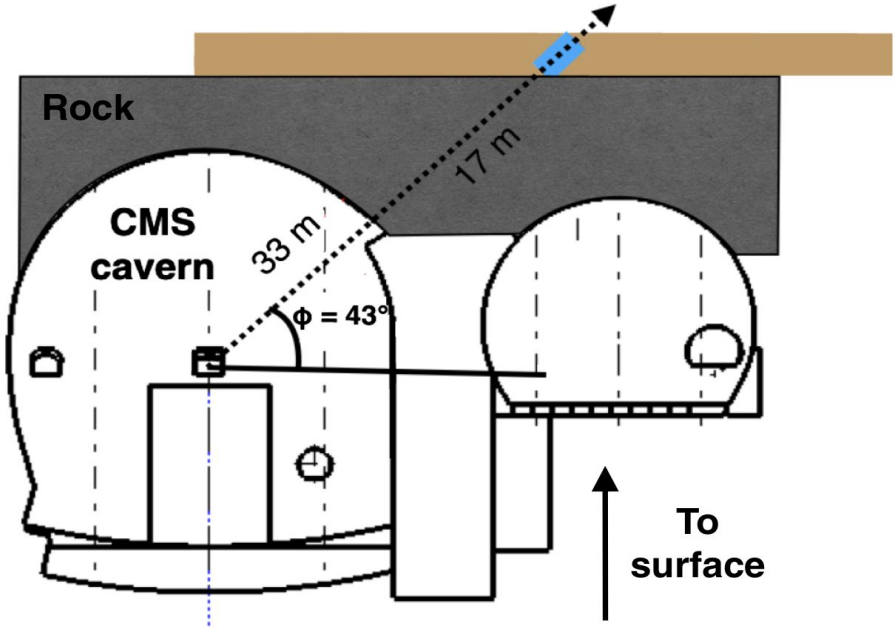
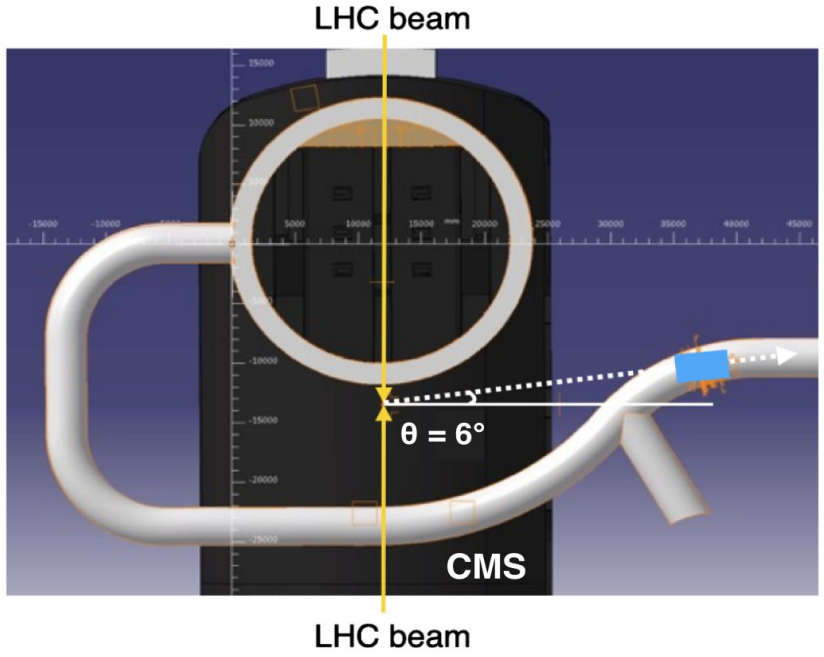
Location

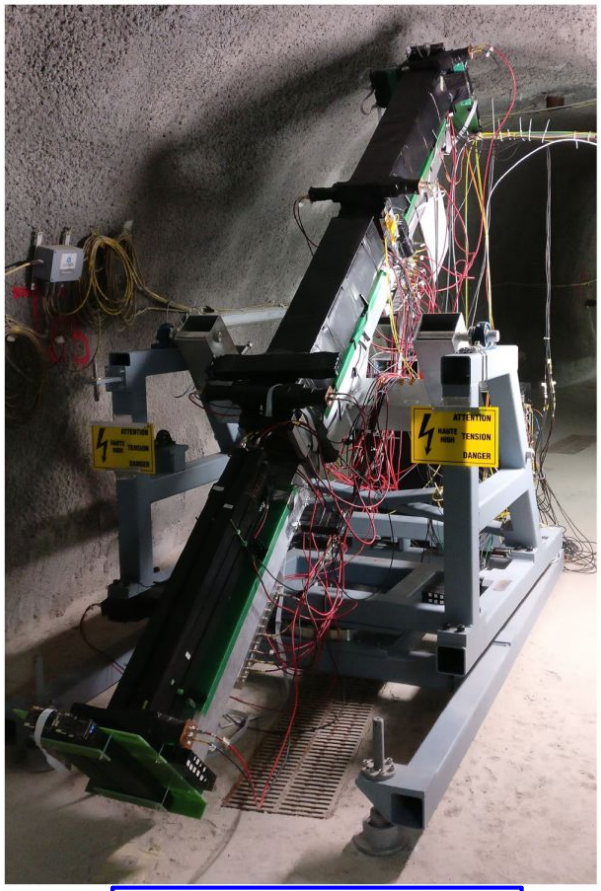
- MilliQan is housed in the unused drainage gallery of the CMS experiment
- 33m away from CMS IP at ϕ=43^o and η=0.1 in CMS coordinate system
- Beam particles are shielded by the 17m rock
- Muon flux from cosmics is 100 times smaller than the surface



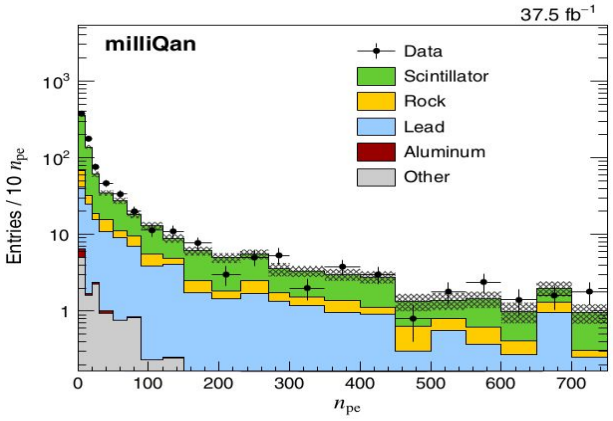


MilliQan demonstrator - Run 2

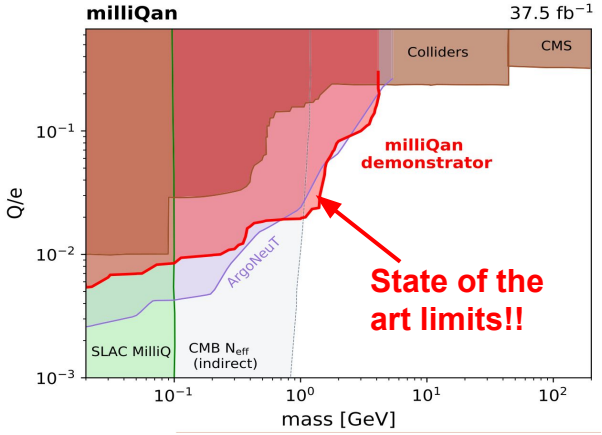
- 3 layers, each containing 2x3 array of 80 x 5 x 5 cm^3 bars, pointing to CMS IP
- Additional components like panels and hodoscope help reduce backgrounds like through-going muons, cosmic showers, neutrons etc
- Successful run in 2018 with 35 fb^{-1}, 2000h of data taking
- Provided proof of concept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



Muon background validation



Results



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MilliQan Run 3 bar detector

- **Four layers** of 5x5x60 cm^3 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 stable data taking since ***1st June 2023!***

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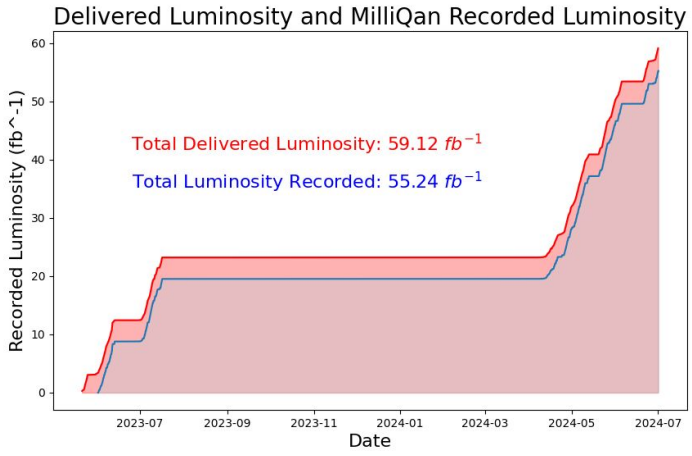
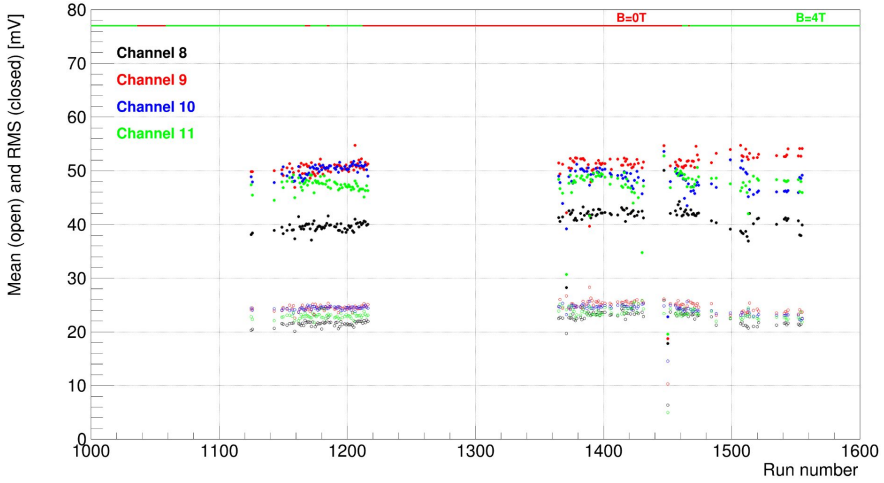
MilliQan Run 3 bar detector status

- >55 fb-1 data recorded in 2023 + 2024 (so far)
- Trigger rate is stable at 2 Hz
  - Includes 3 hits in a line signal trigger (unprescaled), dedicated background triggers to study cosmics, beam muons
- Operations: Shift system in place to ensure smooth operations and swift interventions if needed



Pulse height vs run number for Channels 8, 9, 10, and 11



Trigger rate in 24 hour time period

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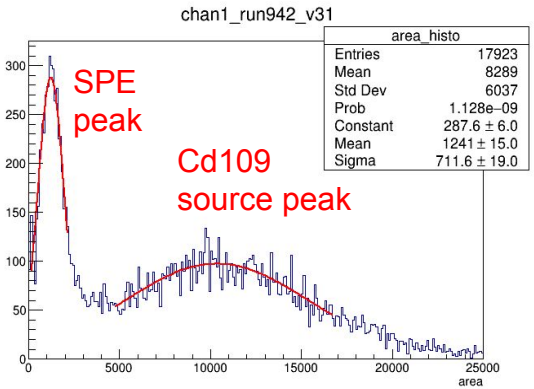
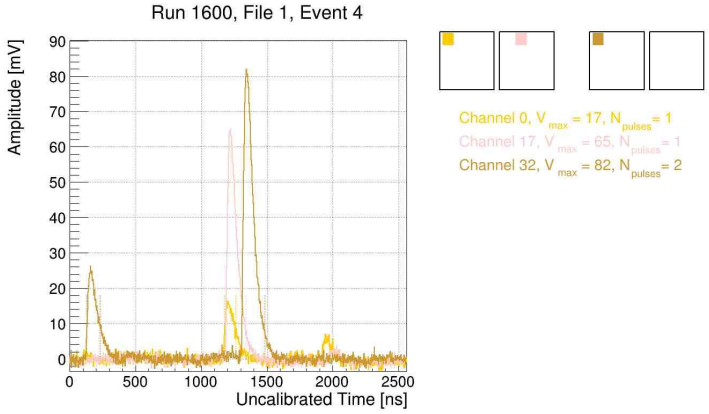
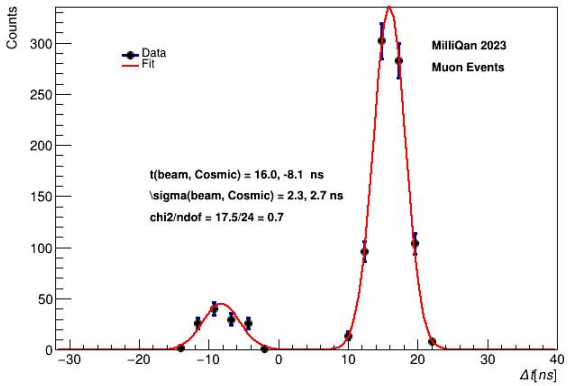
Validation validation validation!!

- Cd109 source calibrations performed to calibrate all accessible channels
- Event displays help identify any issues like light leaks, after pulses, electronic noise, etc
- Trigger validation and efficiency studies helped optimize our trigger!
  - We have >99% trigger efficiency for signal!
- Beam muons and cosmics are used to perform timing calibrations and studies
- Analysis efforts ramping up with Run 3 data… stay tuned!







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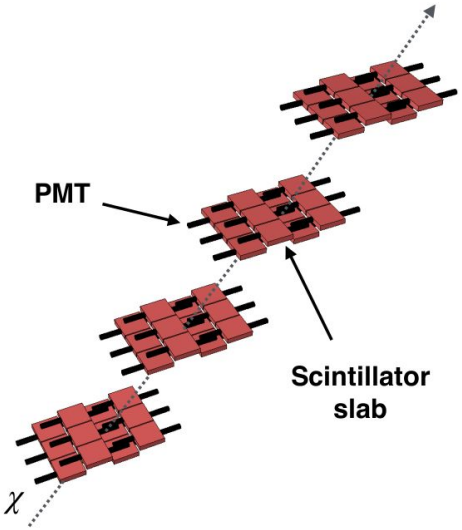
MilliQan Run 3 slab detector

- Improved sensitivity for mCPs with masses above 1.4 GeV due to increased acceptance
- Four layers of 3x4 array of 40x60x5 cm^3 **slabs**
- Each slab has four PMTs to increase the efficiency
- Detector under construction right now!
  - Expected to complete by the end of summer!



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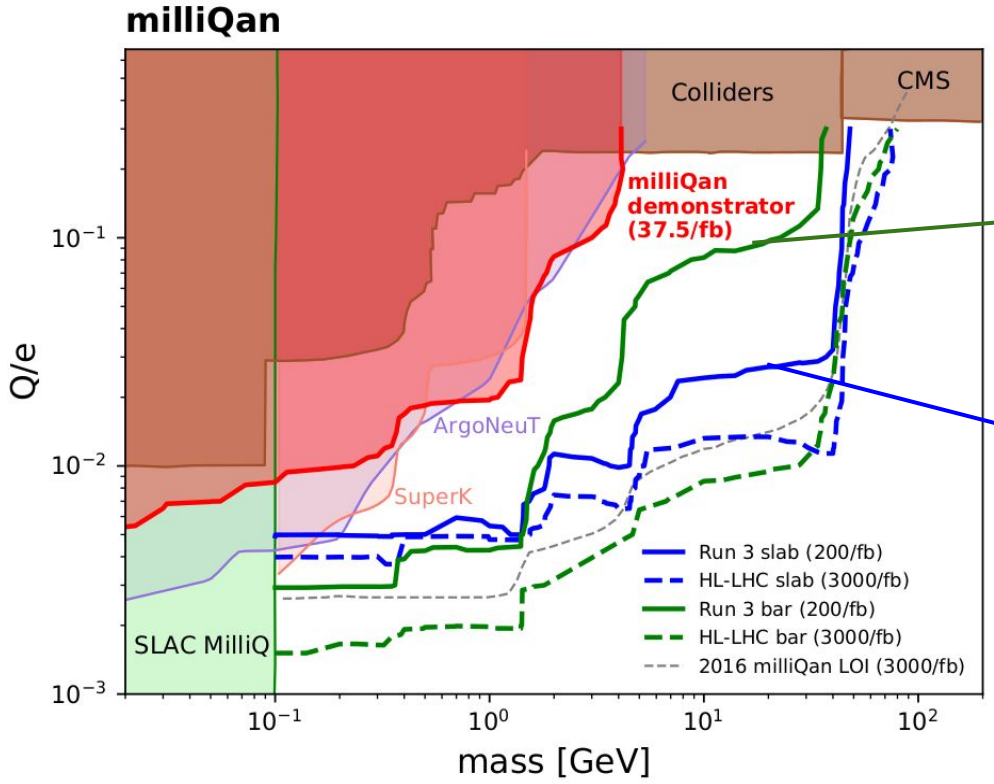
Sensitivity projections

- 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

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Summary and outlook

- *MilliQan provides a highly sensitive model-independent probe for mCPs*
- **Run 3 bar detector has been stably collecting data**
  - >55 fb-1 data recorded as of today
  - Data monitoring, quality checks, trigger studies underway continuously
  - Timing and sPE calibrations in place
  - Beam muons control region being studied and comparisons to simulation are underway
- Run 3 slab detector is under construction right now
  - Nearly 25% of the detector built
  - **Expected to finish construction by end of summer**
- Stay tuned for physics results in the near future!

SubMET and FORMOSA use same principle to search for mCPs and offer complimentary sensitivity

milliQan collaboration

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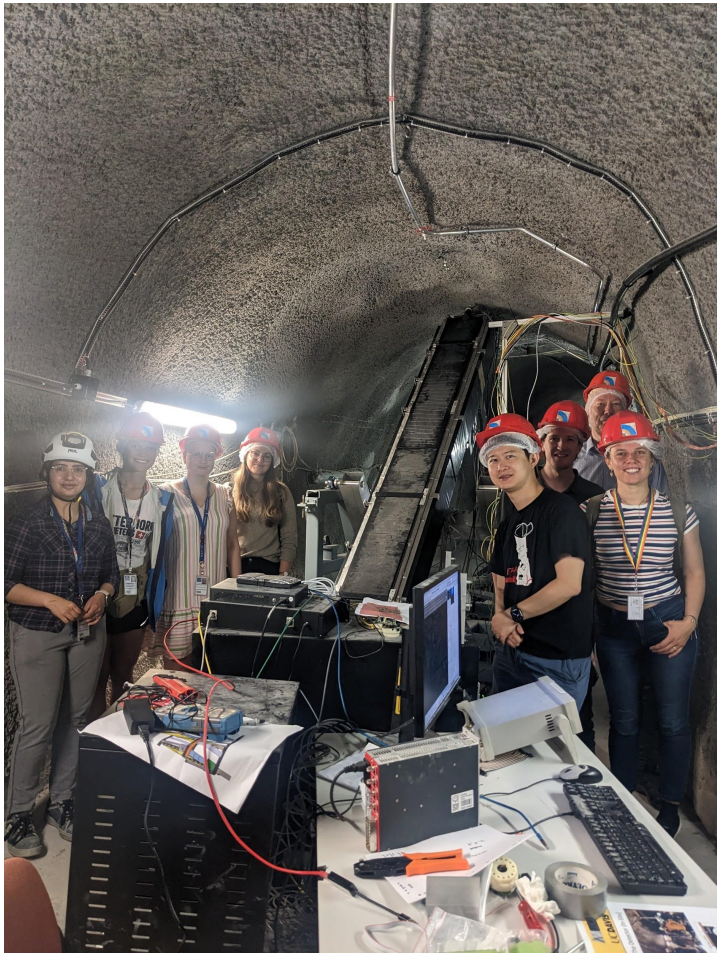
milliQan tour in LLP2023!



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