

THE MILLIQAN

SEARCH FOR MILLI-CHARGED PARTICLES

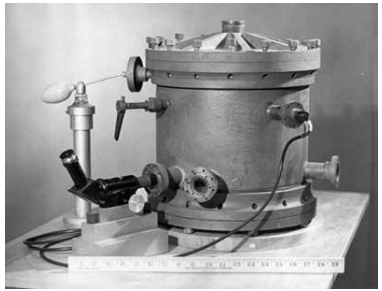
2026 IIHE Annual Meeting

Zahraa Zaher, Tiepolo Wybouw, Steven Lowette

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What is milliQan?

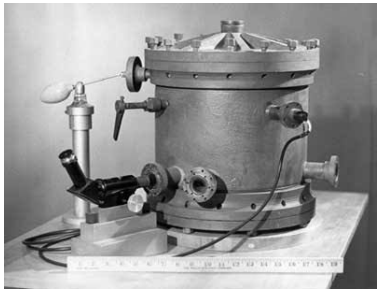
- Reminds you of Millikan? No coincidence!
- Oil drop experiment → first measurement of the elementary charge of electron (e)



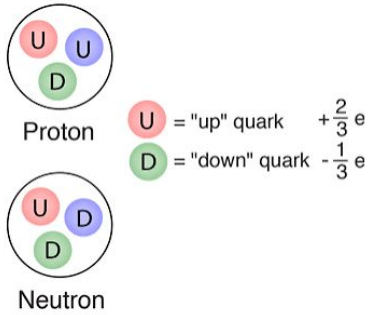


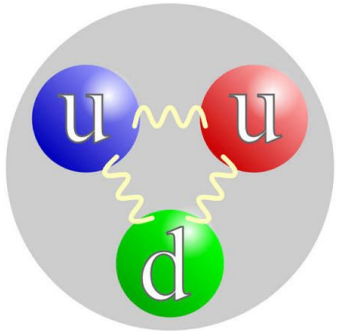
What is milliQan?

- Reminds you of Millikan? No coincidence!
- Oil drop experiment → first measurement of the elementary charge of electron (e)
- No explanation as to why charge is quantized
- Discovery of fractionally charged quarks
- Still fractional quantization: +/- 1/3 , 2/3









Does a milli-charge exist?

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- Think of a standard model extension
- Hidden U(1) with a dark photon field A’
- EM coupling to a dark fermion Ψ of charge e’ under U(1)
- Small kinetic mixing with SM photon field B

$$\mathcal{L}_{dark\,sector} = -\frac{1}{4}A'_{\mu\nu}A'^{\mu\nu}$$ dark photon kinetic term

$$+ i\bar{\Psi}'(\gamma^{\mu} + ie'\gamma^{\mu}A'_{\mu} + iM_{mCP})\Psi'$$

mCP with mass M_{mCP} , charge e’

$$-\frac{\kappa}{2}A'_{\mu\nu}B^{\mu\nu}$$

kinetic mixing

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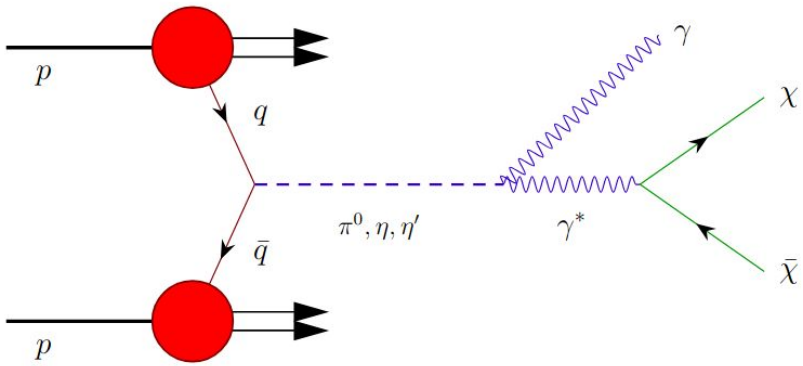
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kinetic mixing

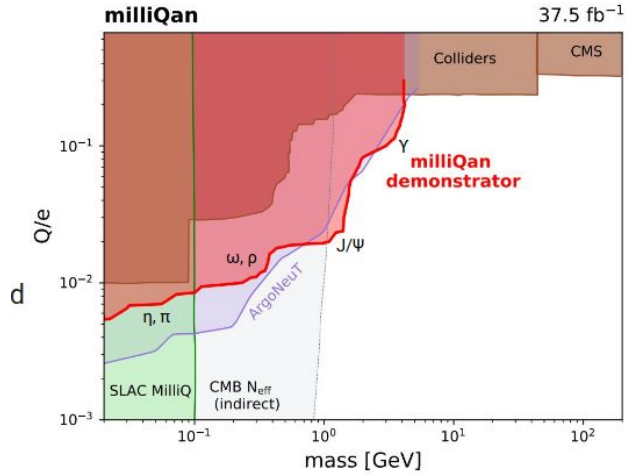
$$i\kappa e' \cos\theta_w A_\mu \gamma^\mu$$ Coupling with SM photon

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- Gauge transformation introduces coupling between dark fermion and SM photon B
- Search for milli-charged particles (mCP) in phase space of mass M_{mCP} and charge Q



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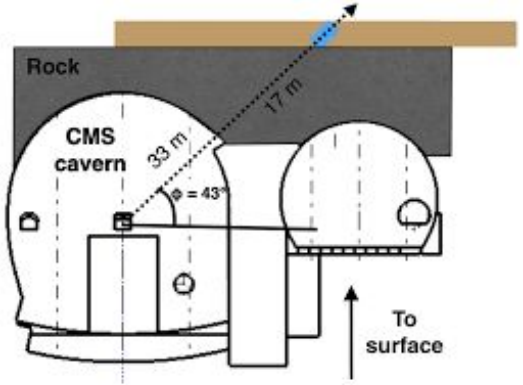


How to detect milli-charges?

- $dE/dx \sim Q^2$
- Very faint signal, need:
  - ❑ Minimal background
  - ❑ High sensitivity detector

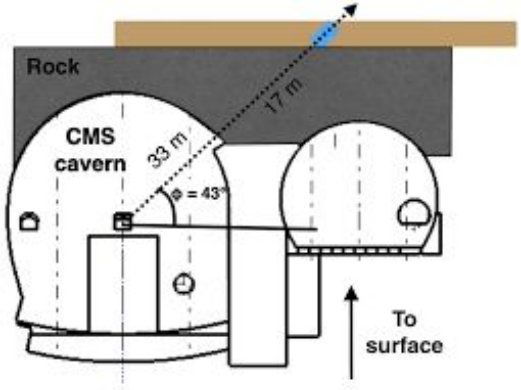
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- Only penetrating muons reach milliQan detectors (beam and cosmic muons)

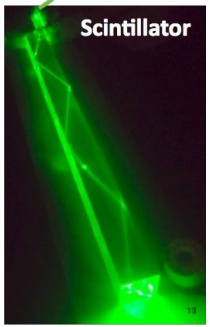


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- Long scintillators for sensitivity to smallest charges Q ~0.001e
- Signal detected at the level of single photoelectrons in PMT readouts



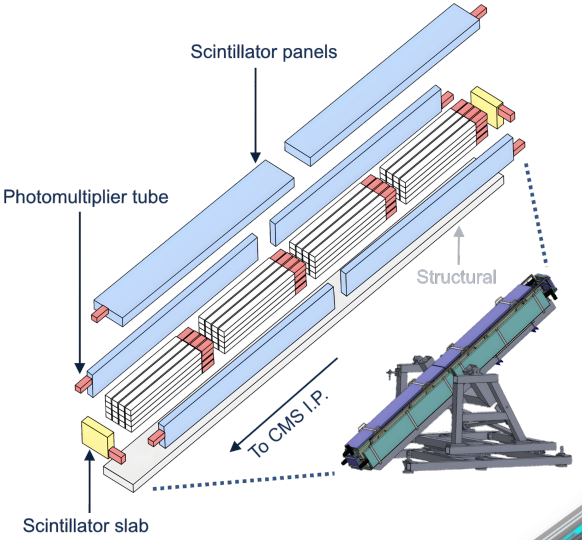


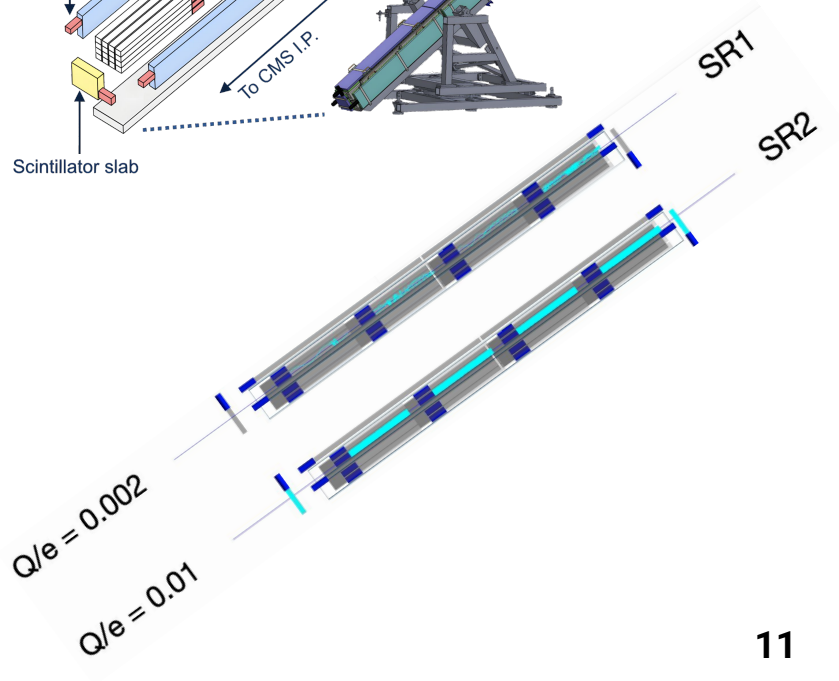




The milliQan Bar Detector

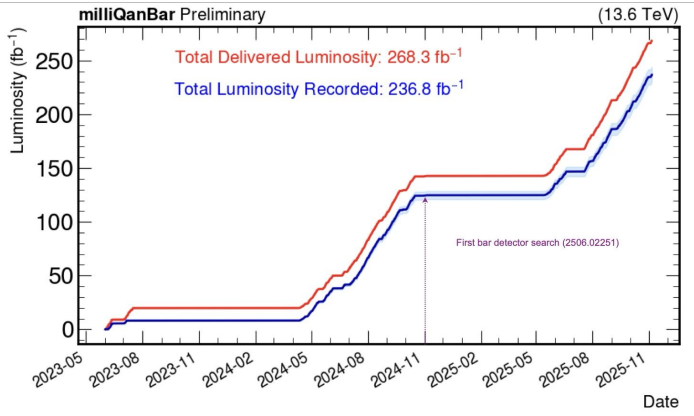
- Orthogonal signal regions SR1 and SR2
  - SR1 → smallest charges, no bar saturation
  - SR2 → larger charges, saturate bars
- To distinguish from saturating muons
- Scintillator slabs : front and back sides
- Outer envelope panels veto cosmic events

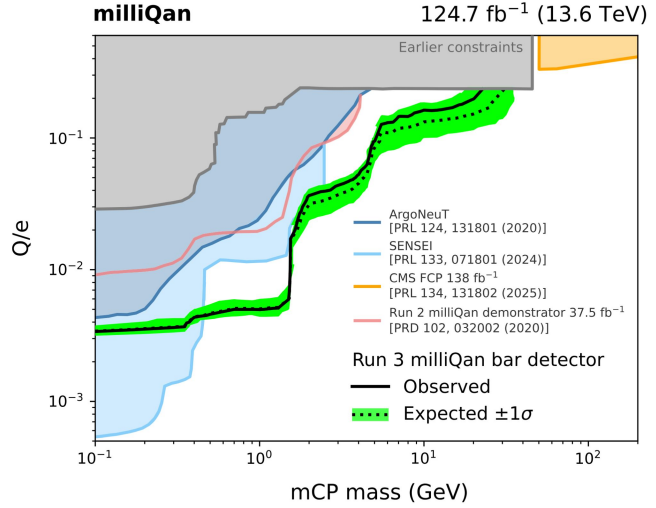




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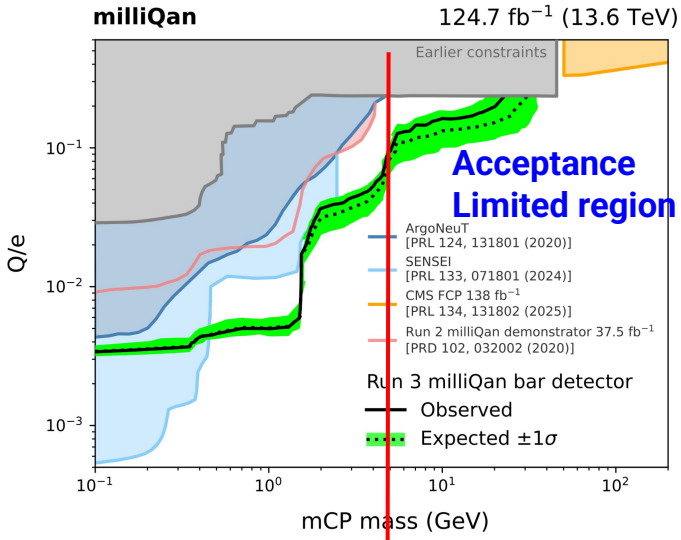
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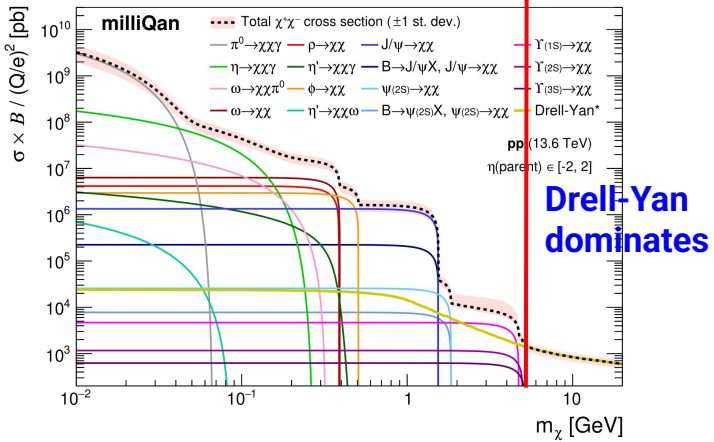




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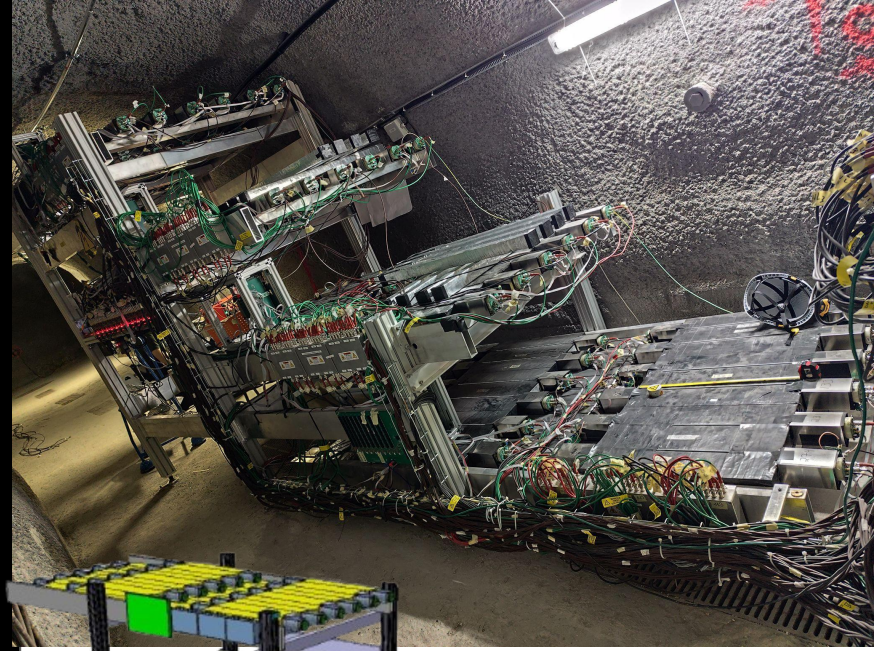
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- Acceptance limited high mass region → Slab detector

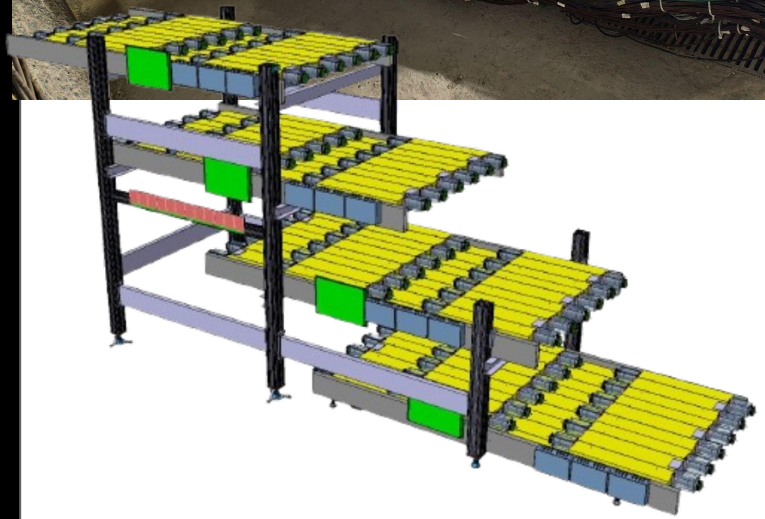




The milliQan Slab Detector

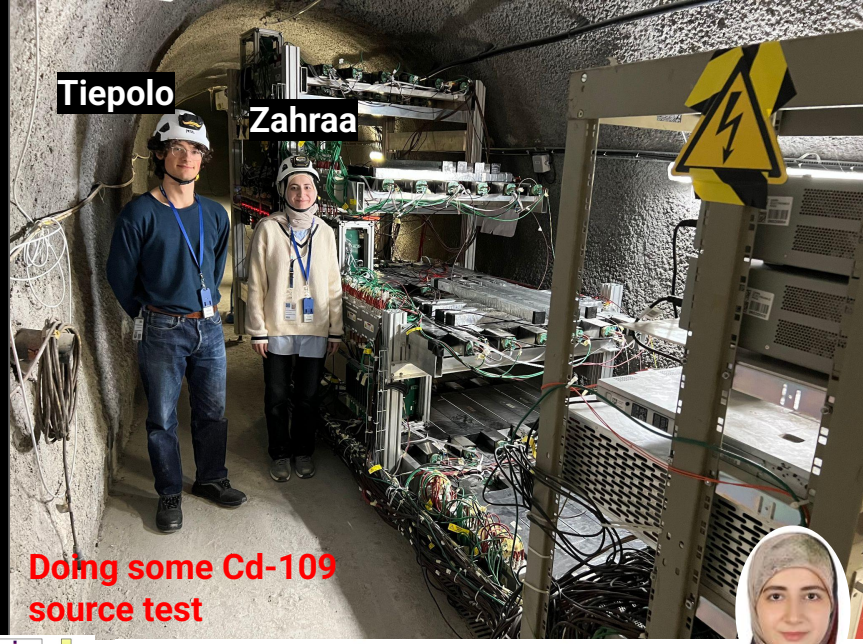
- Targeting less probable higher masses
- Trading acceptance for thick scintillation
- To increase light collection, a slab is readout by four PMTs instead of only one

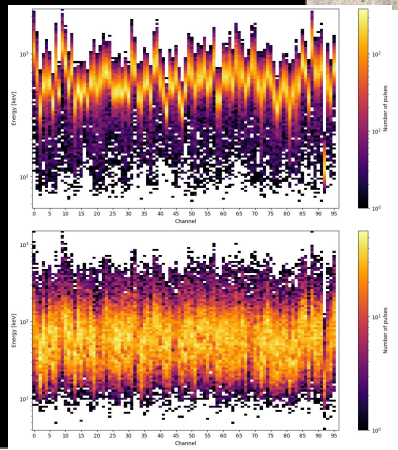




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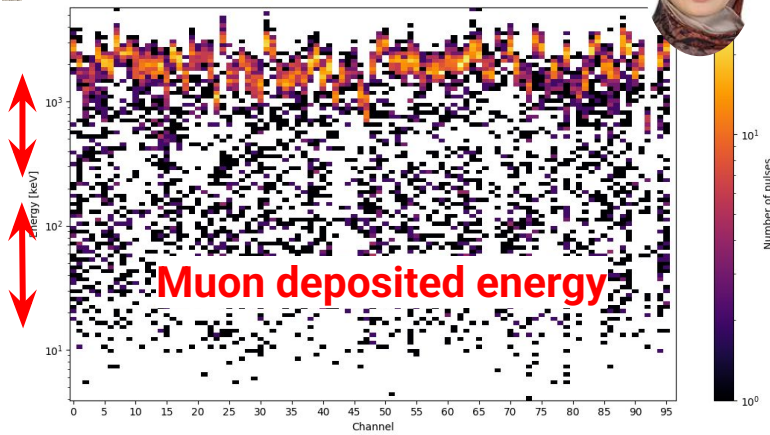
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- Calibration efforts going on:
  - Energy calibration





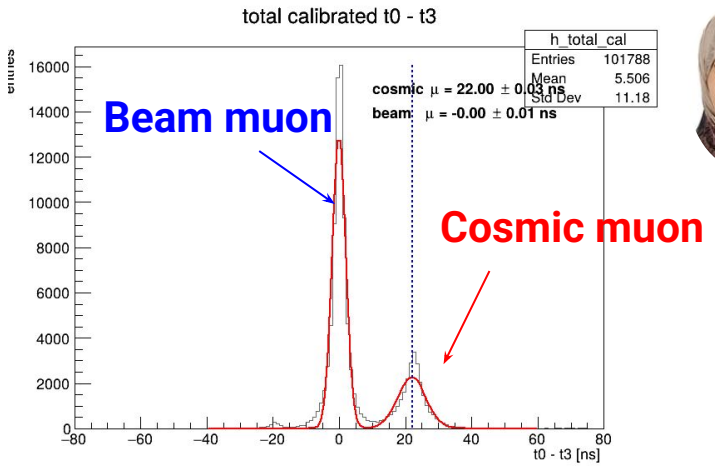
mCP Q=0.2 e

mCP Q=0.05 e



The milliQan Slab Detector

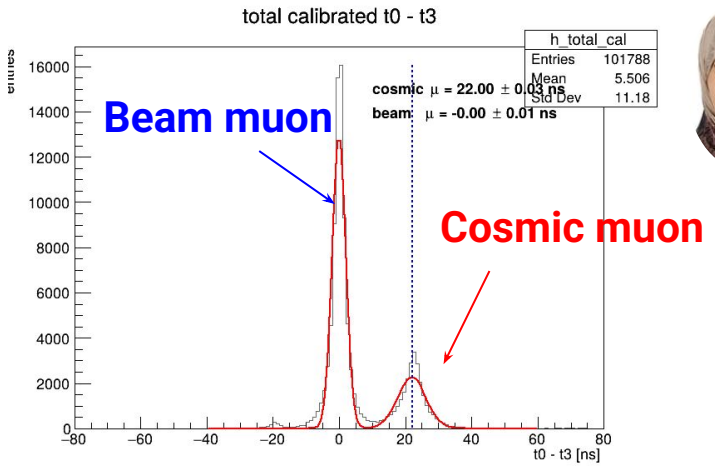
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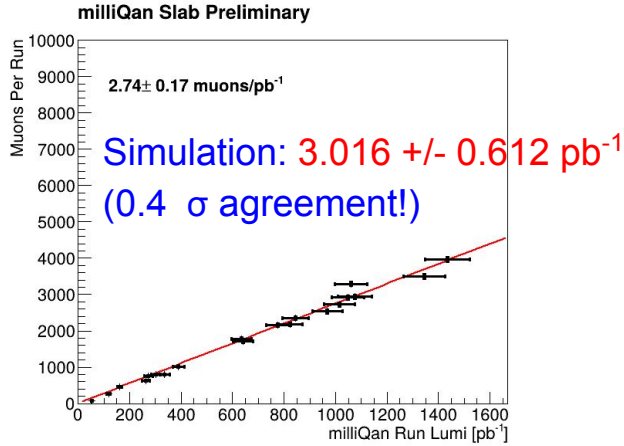




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  - Timing calibration → beam muon rate (for a fraction of data @ 13.6 fb^{-1})

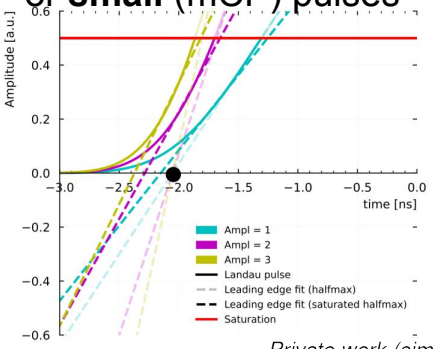




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- Targeting less probable higher masses
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  - Timing calibration → pulse arrival time

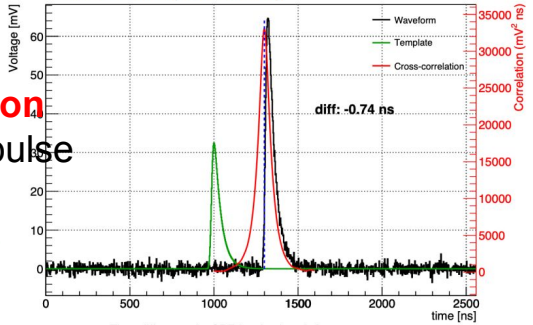
Leading-edge-fit method biases arrival time for **saturating** (muons) or **small** (mCP) pulses





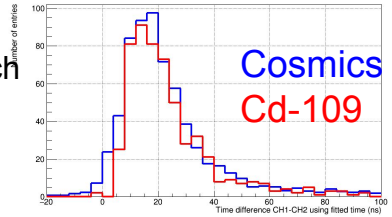
Private work (simulation)

cross -correlation matches entire pulse shape against a known **template**



Time difference for SPE-level pulses in bar1

Verified on the bench
D. Stuart @ UCSB

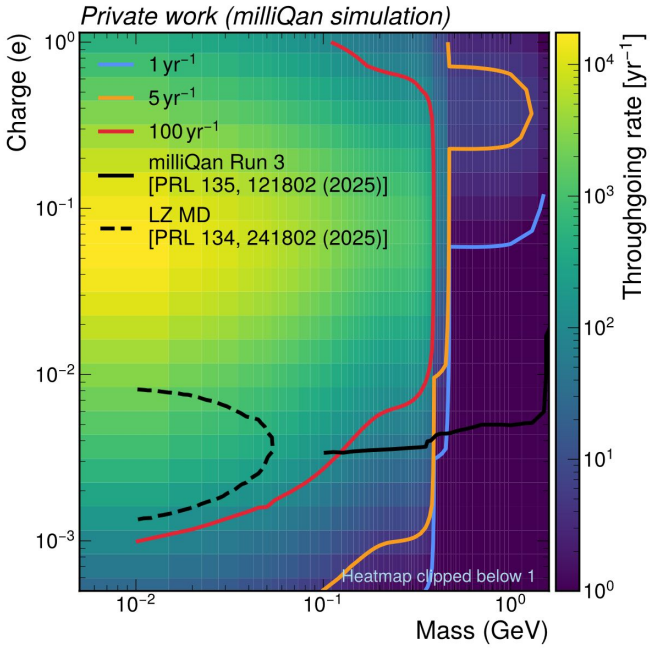


Beyond beam mCP: atmospheric mCPs!

- Louise and Tiepolo are preparing to publish a framework, which takes care of 100% efficient generation
- Latest atmospheric fluxes with fast but accurate energy loss computations!
- All one needs to do:
  - ❑ Define geometry coordinates
  - ❑ Prepare atmospheric flux model
  - ❑ The framework samples trajectories and attenuates them (by default in homogeneous media, can be customized (e.g. volcano))







*outdated fluxes and energy losses, to be updated

Stay tuned !



Check APS video on milliQan