FORMOSA: Looking forward to millicharged particles at the LHC

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On behalf of the FORMOSA collaboration

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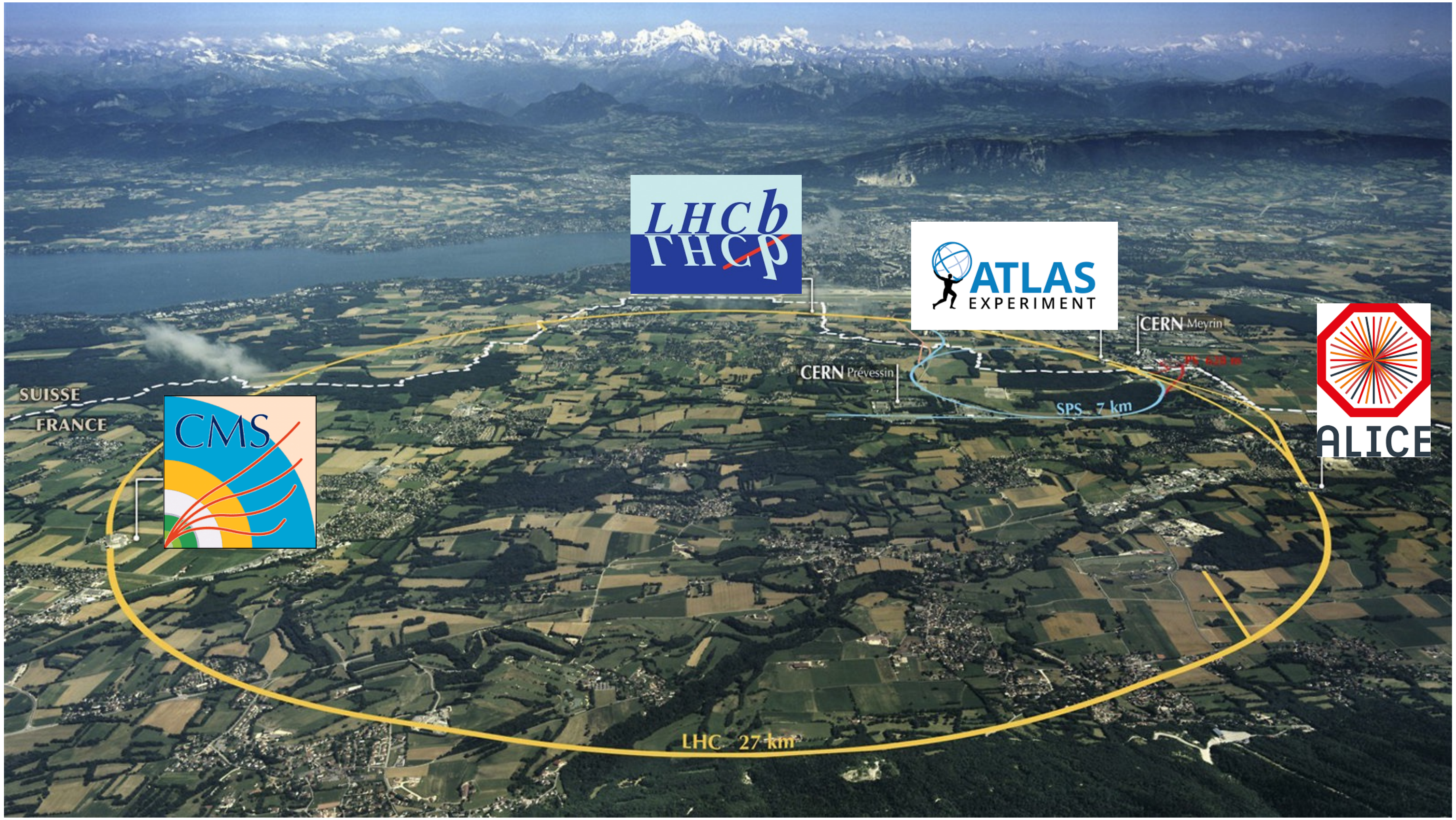
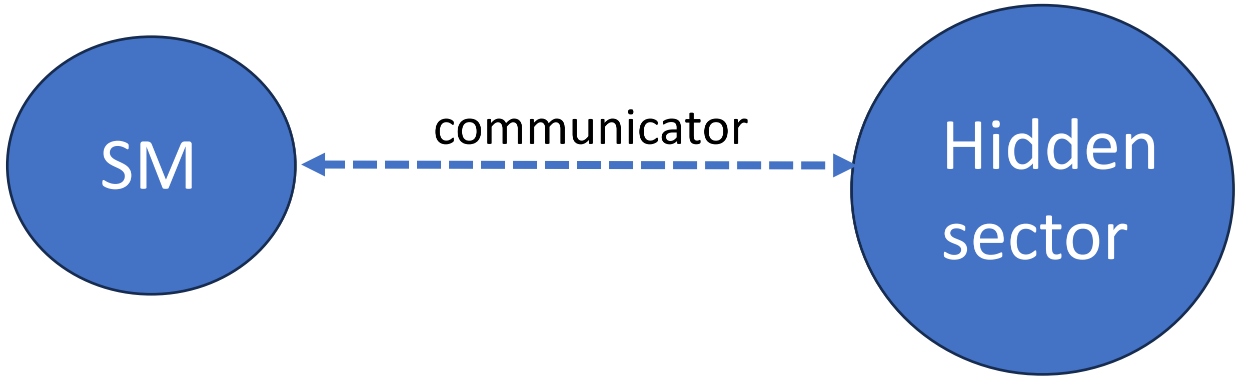
Large Hadron Collider (LHC)

- No sign of new physics seen at the LHC (yet)
- Where could it be hiding?

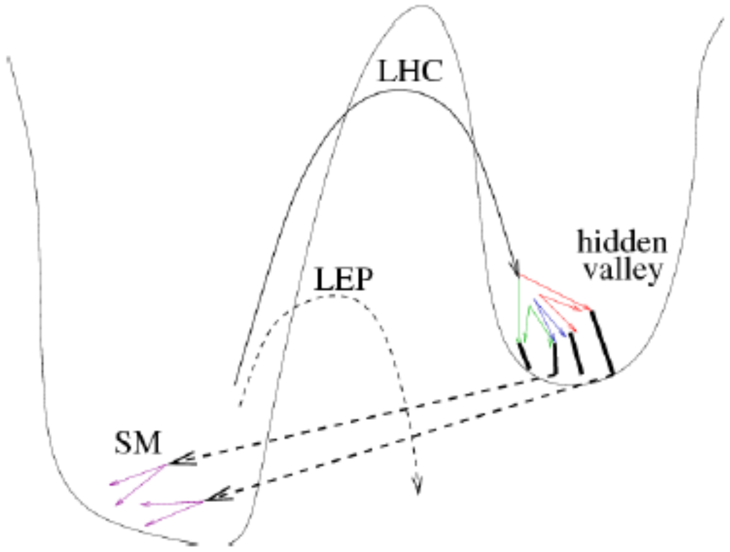


Hidden sector

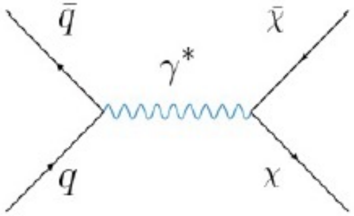
- Basic structure of hidden sector models:



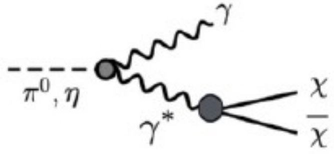
Zurek, Strassler



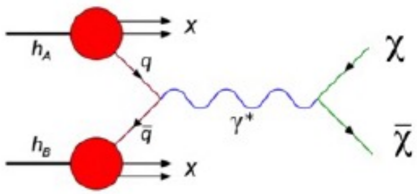
- Kinetic mixing between dark photon and SM photon provides portal to hidden sector
- The new particle(s) under "dark EM" get small SM charge $Q = \epsilon e$ -> millicharged particles (MCP)



Meson decays

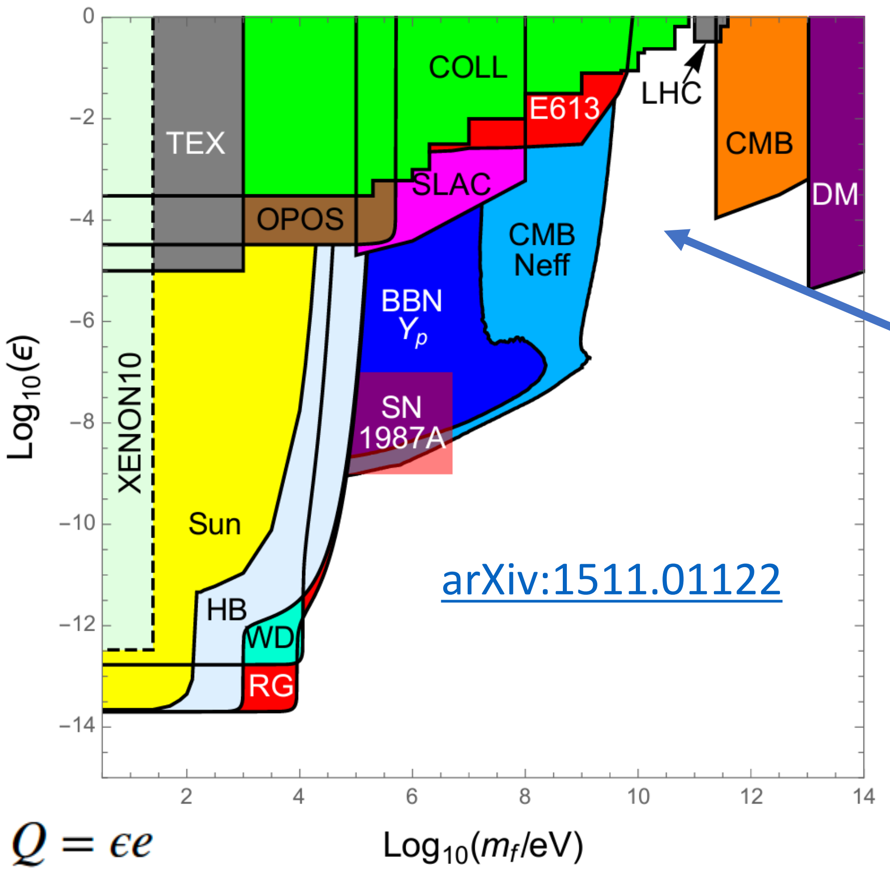


Dalitz decays



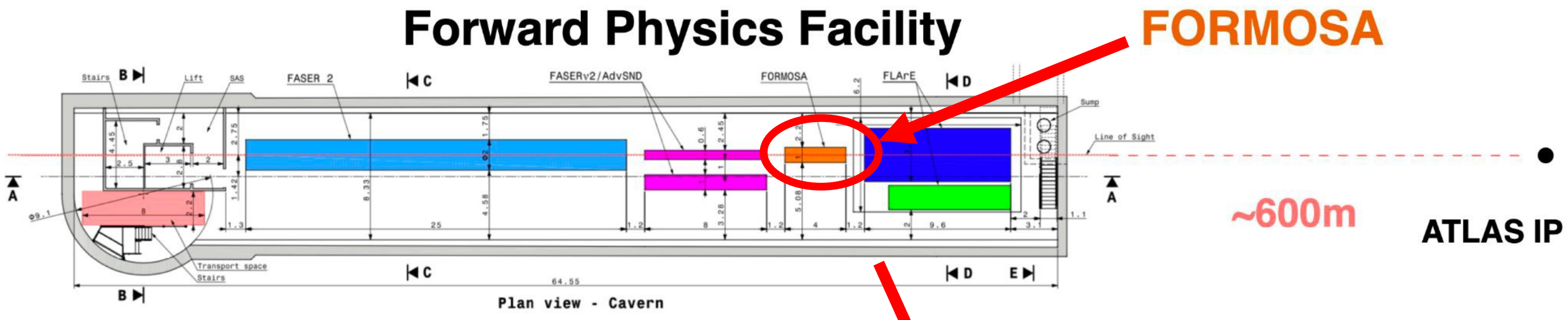
Drell-Yan

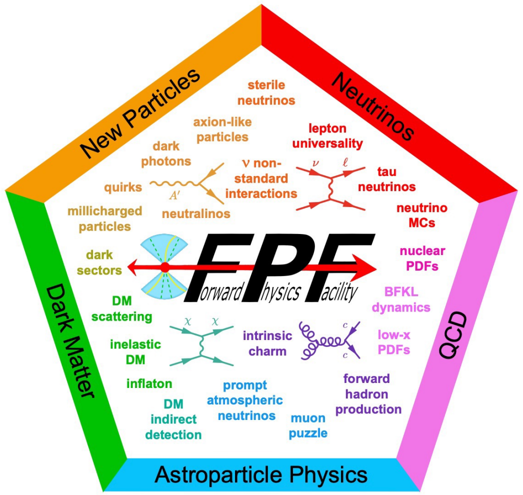
Searching for MCPs at the LHC



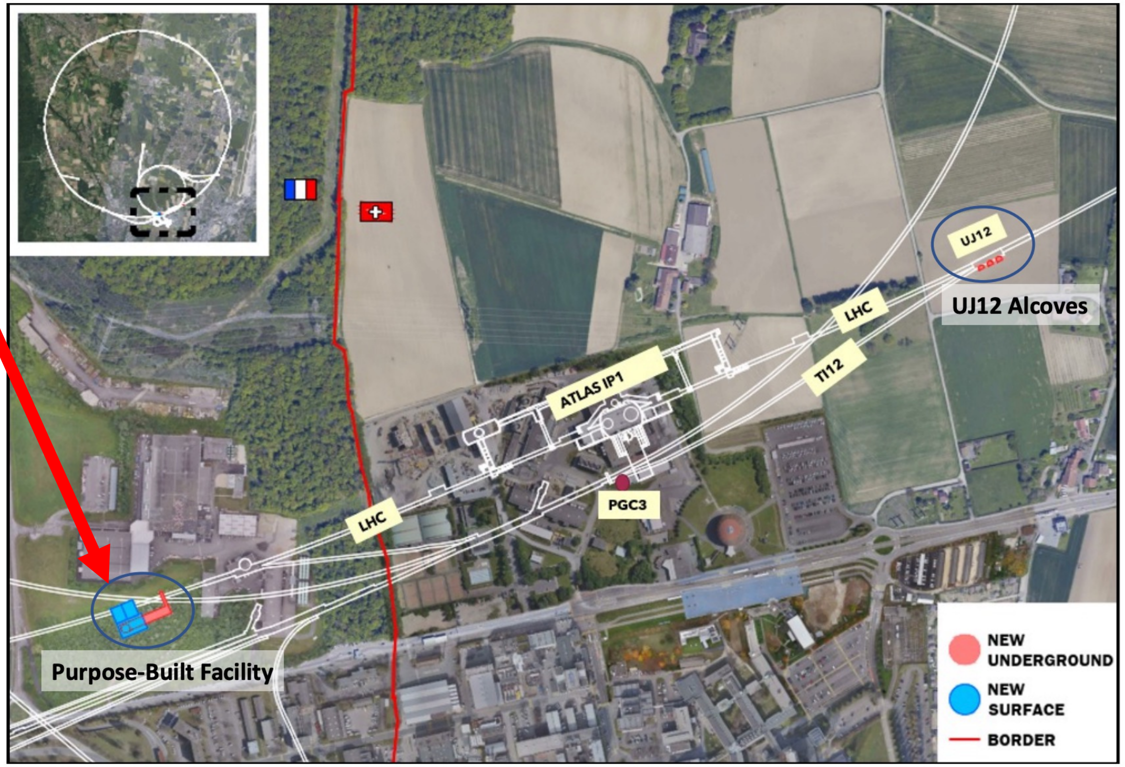
- General purpose LHC detectors not great for this since dE/dx ~ Q^2
- Gap in coverage for ~ GeV, low-charged particles
- Target with FORMOSA and milliQan

Moving forward



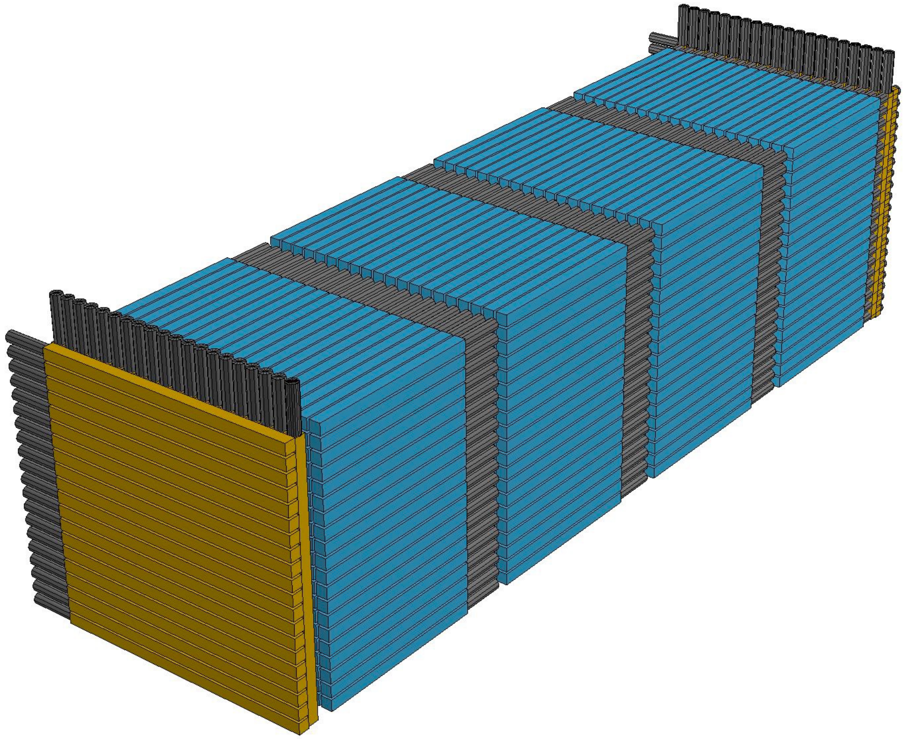


- Detector in forward region sees up to ~250x MCP rate compared to central (milliQan) location
- Ideal location for forward MCP detection
- But this is a challenging location... prove feasibility with FORMOSA demonstrator in Run 3!



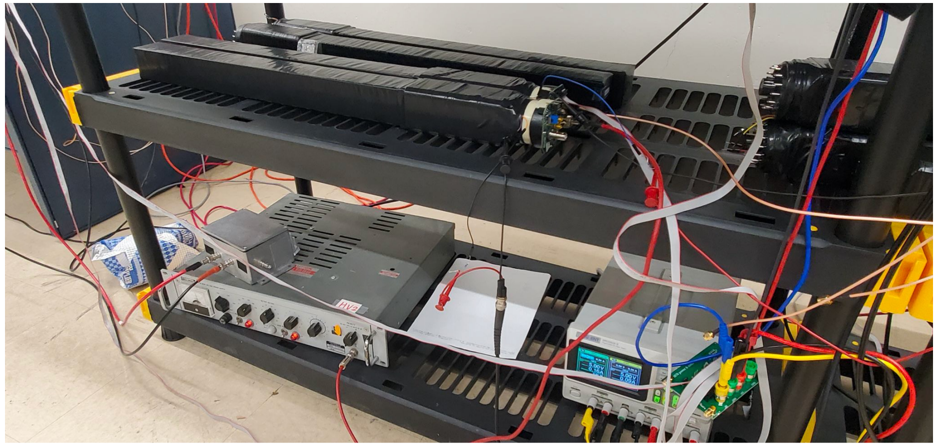
FORMOSA at the FPF

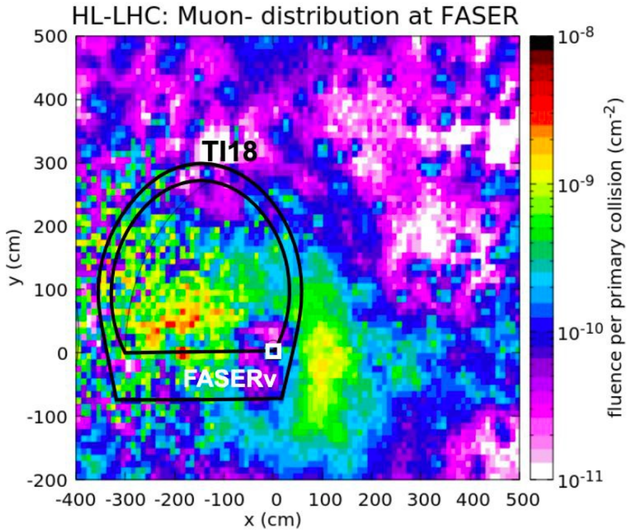
- Four 20 x 20 layers of scintillating bars coupled with PMTs
- Segmented beam-muon veto panels on front and back
- Oriented to point at ATLAS IP
- Quadruple coincidence for signal
- Dominant background → through-going muons

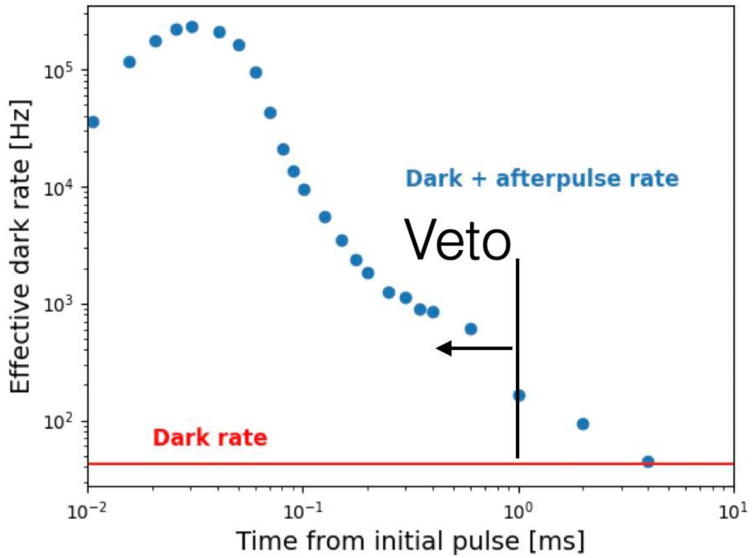


Background

- Beam-muons are dominant background
  - through-going flux > ~1 Hz/cm^2
  - Cause afterpulses
  - Can veto by cutting on time relative to initial pulse

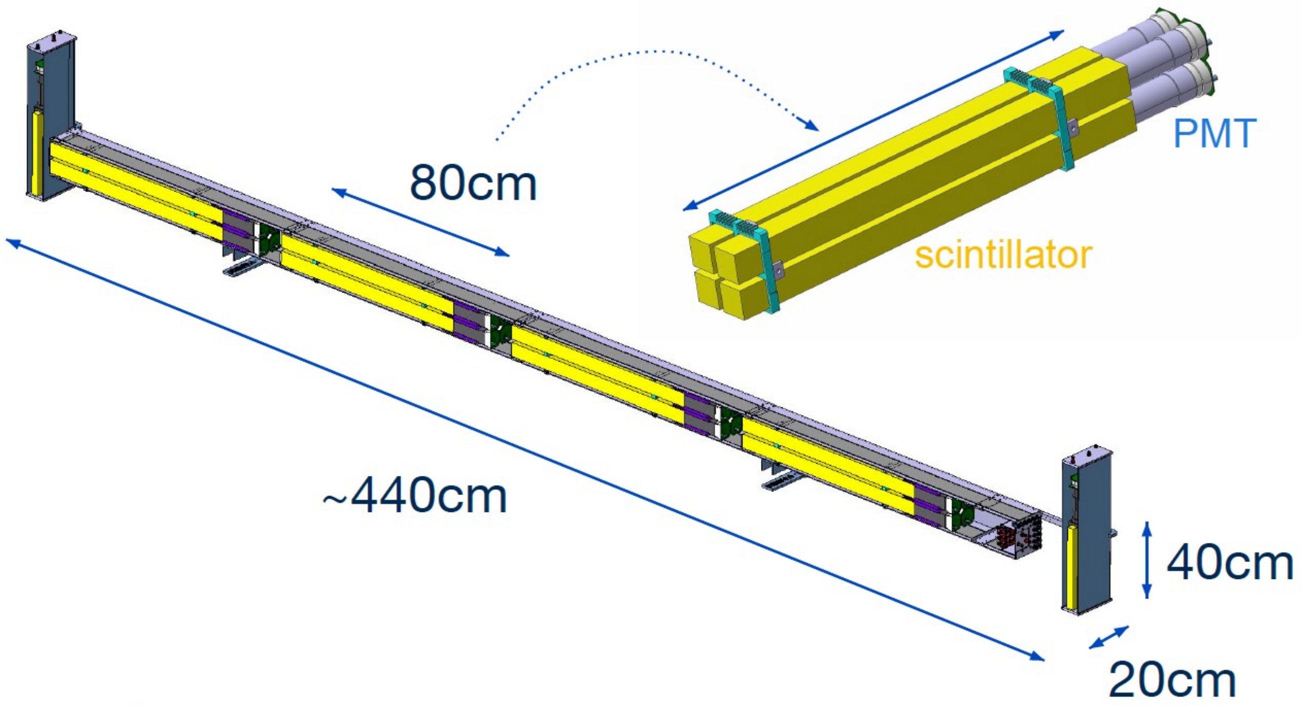


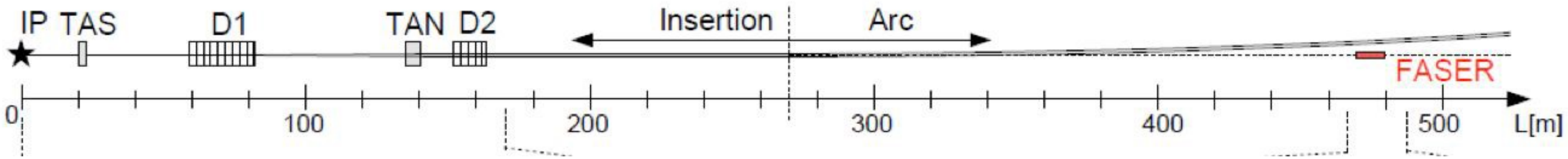




The FORMOSA demonstrator

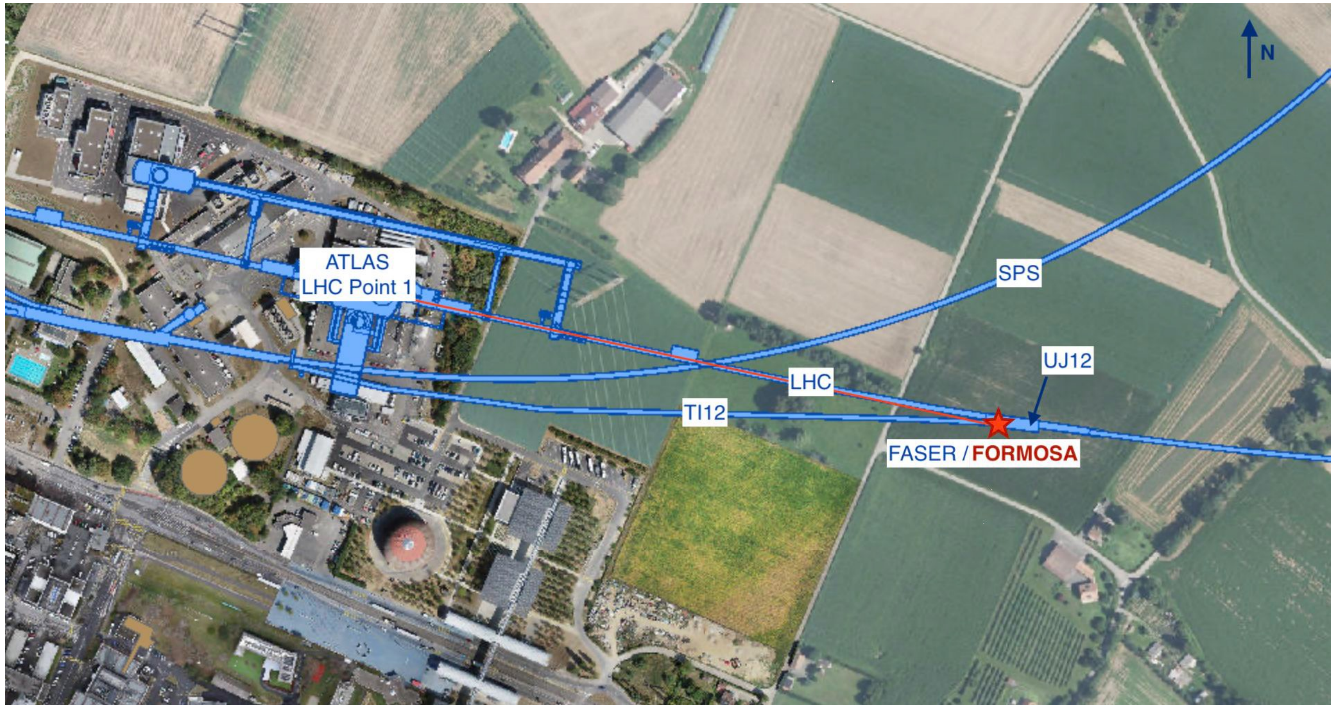
- 4 layers of 2x2 scintillator bar arrays with PMTs
  - 5x5x80 cm bars
- 2 veto panels with PMTs
  - 20x40x2.5 cm panels
- Installed in the UJ12 cavern behind FASER





Installation

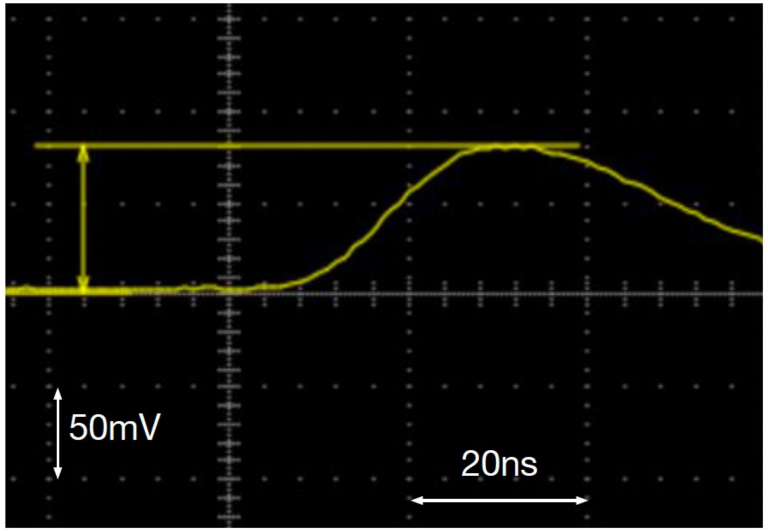
- Installation completed in early Feb
- LHC tunnel closed for Run 3 operations → remote running and commissioning ongoing



Calibration

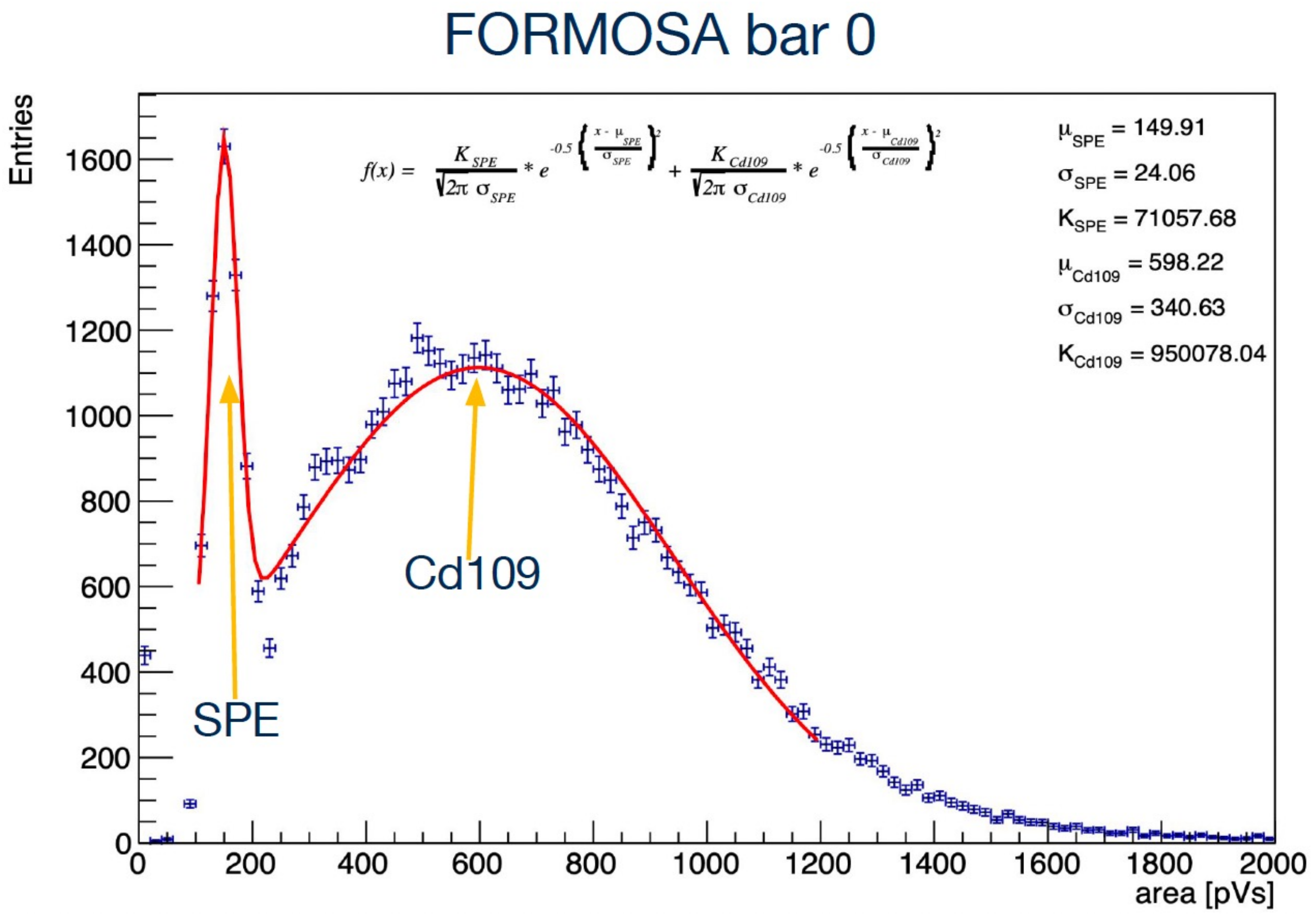
- Expect MCPs to only produce a few scintillation photons
  - Must be able to identify single photo electron pulses (SPEs)
  - Must be well calibrated
- Calibration runs:
  - Dark rate → measure SPE peak
  - Source data → signals induced with Cd109 radioactive source
    - performed on each bar prior to installation

Example of SPE pulse



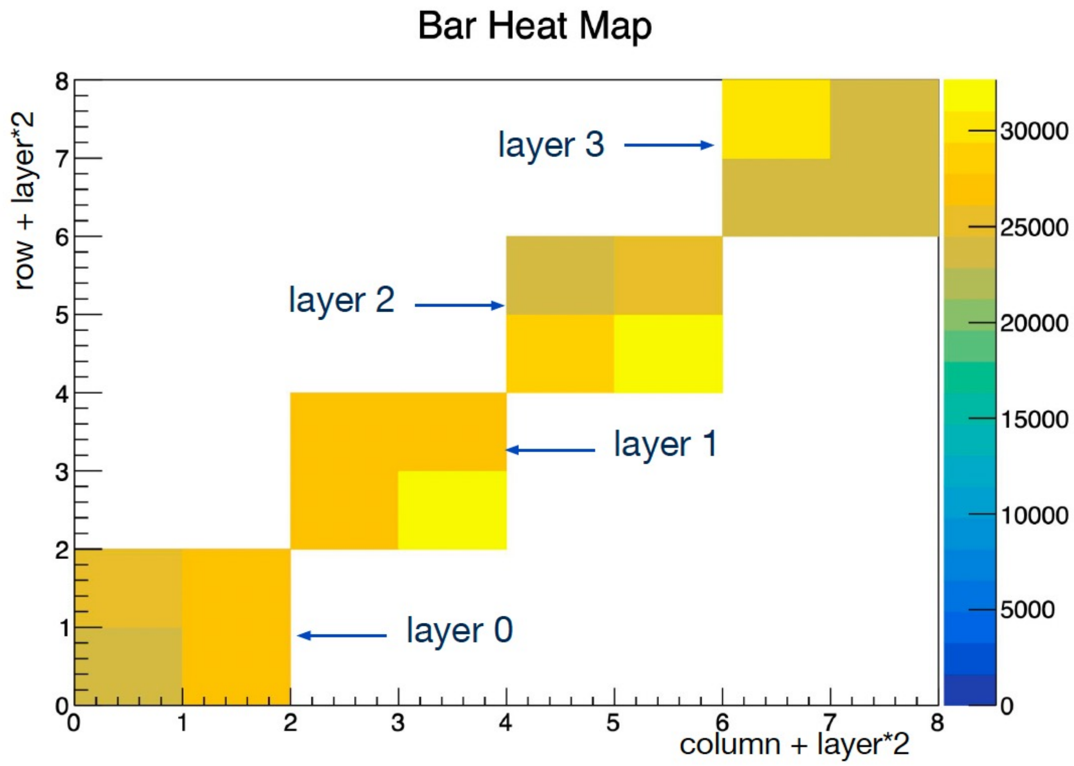
Calibration

- Good SPE peak definition
  - In 30-60 mV range
- Clear separation seen between SPE and source-induced signals → particularly when looking at integrated charge
- Comparable results seen on surface and underground → no indication of damage during transportation



First look at data!

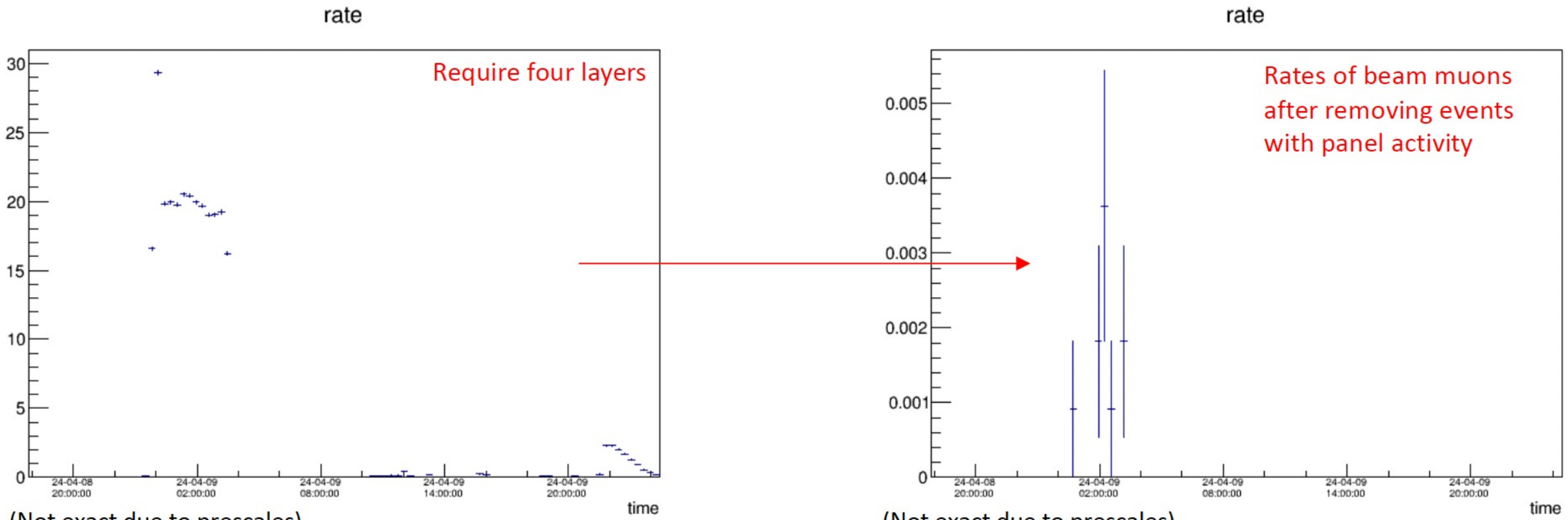
- Data taken with different conditions:
  - no beam
  - circulating beam, no collisions
  - stable beams
- No-beam data consistent with pre-installation measurements



*Measured from a day-long run taken on 2024/02/27 (**no beam**, shortly after the installation)*

First look at data!

- Tested veto panels by requiring activity in both panels + activity in all four bar layers

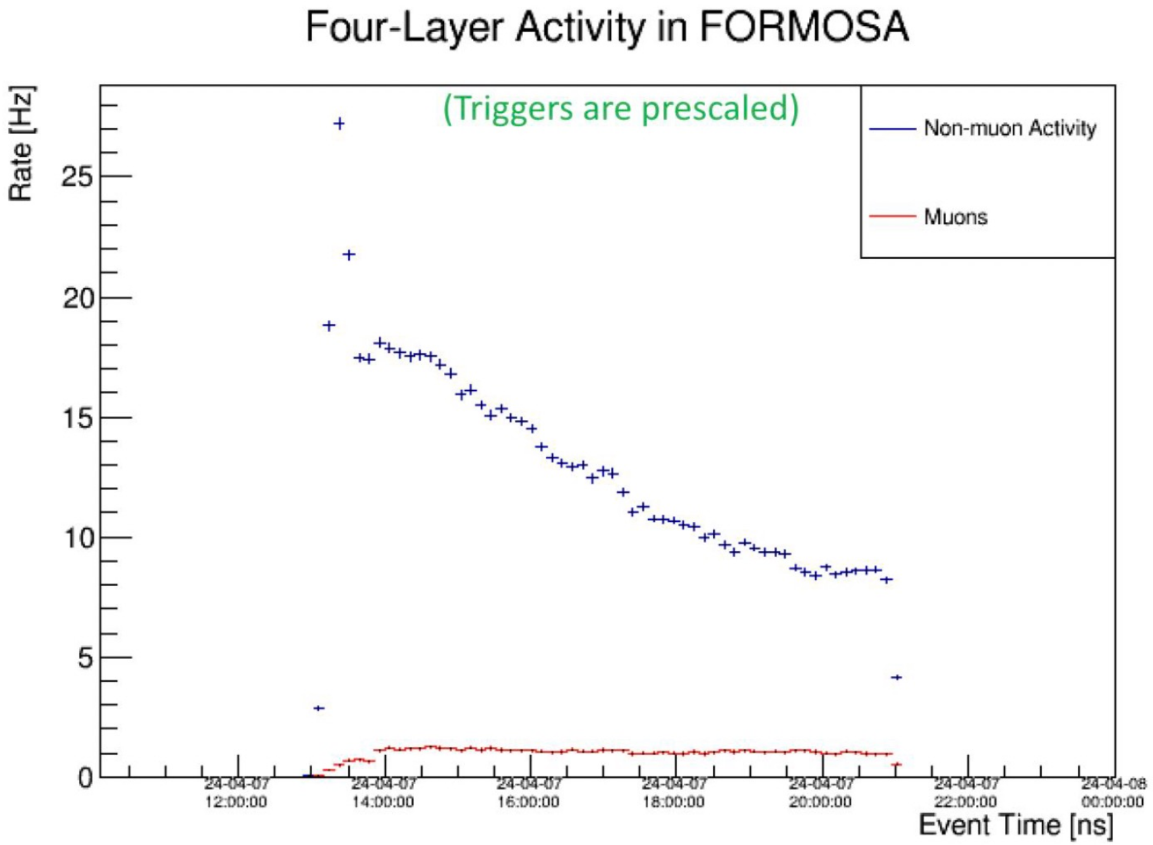


(Not exact due to prescales) (Not exact due to prescales)

- Veto panels works quite well!

First look at data!

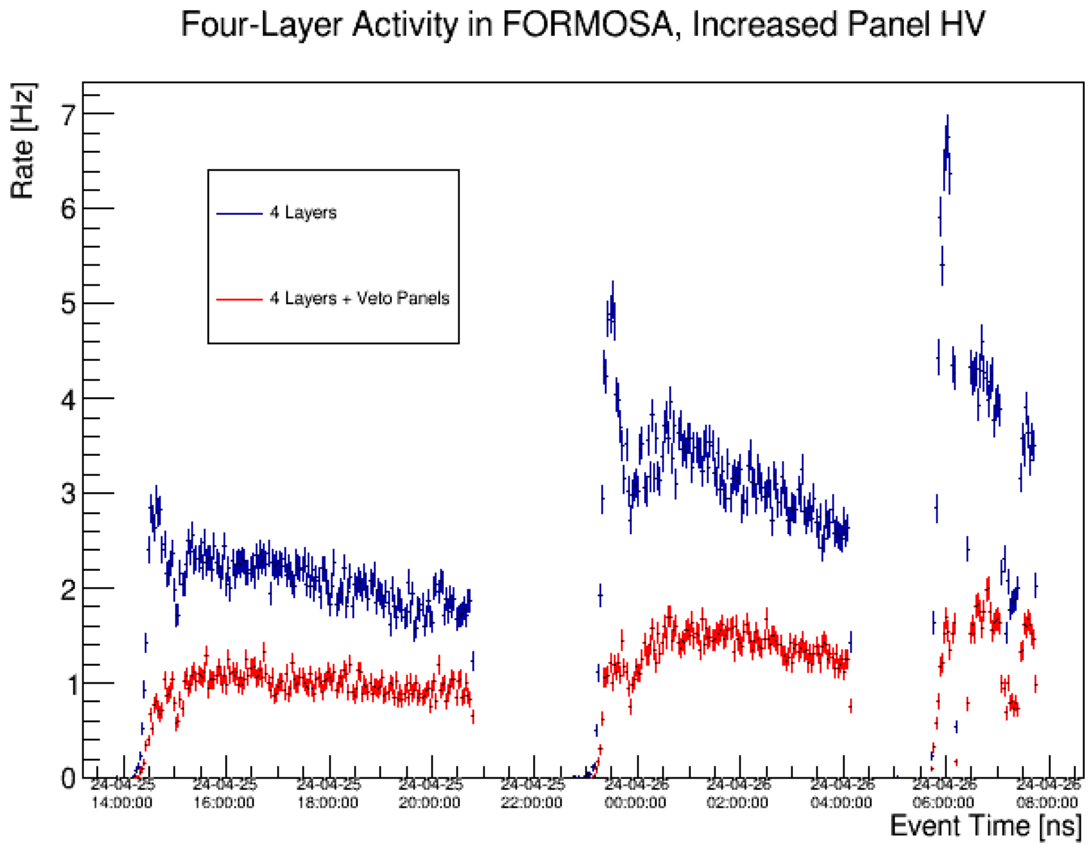
- We see a lot of activity that is not associated with muons
- This looks like we are picking up beam background
- So how does it relate to beam status?

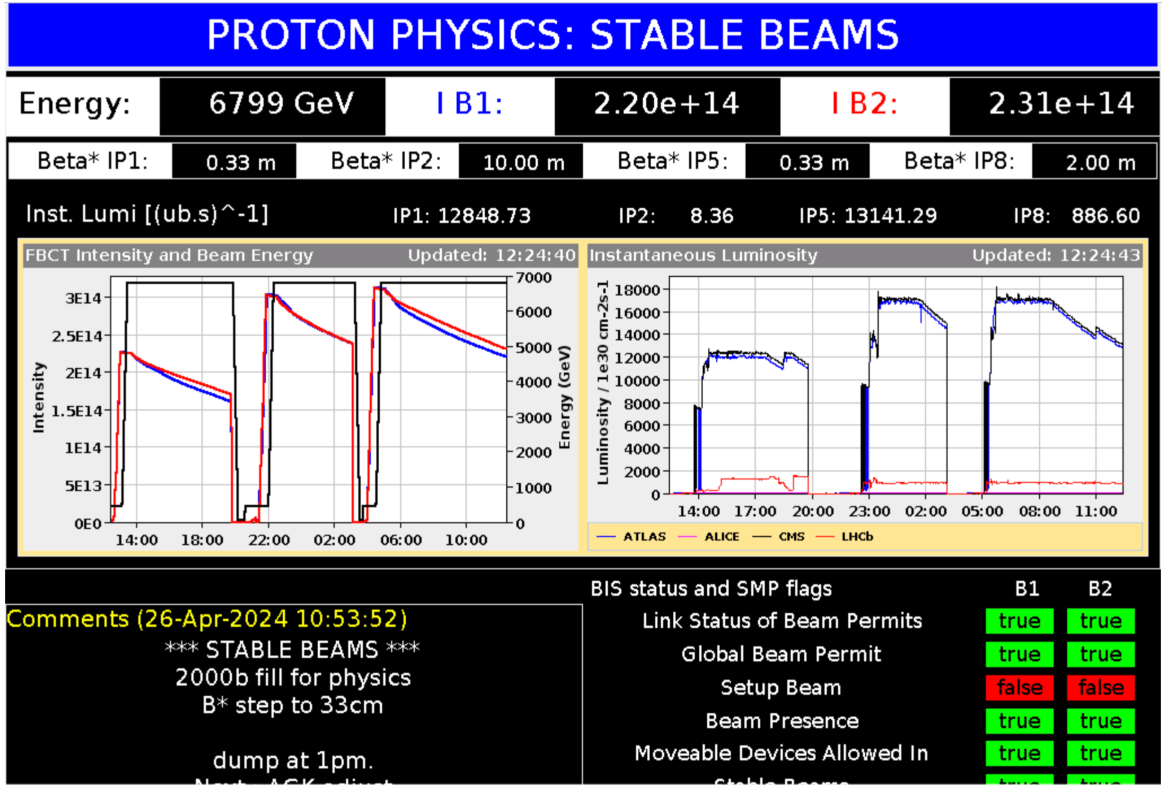


*Very nice study **done by Jacob** in a Stable beams run (72 bunches)*

- *Non-muon Activity = Events with pulses in all 4 layers, without activity in the panels*
- *Muons = Events with pulses in all 4 layers + activity in the panels*

First look at data!

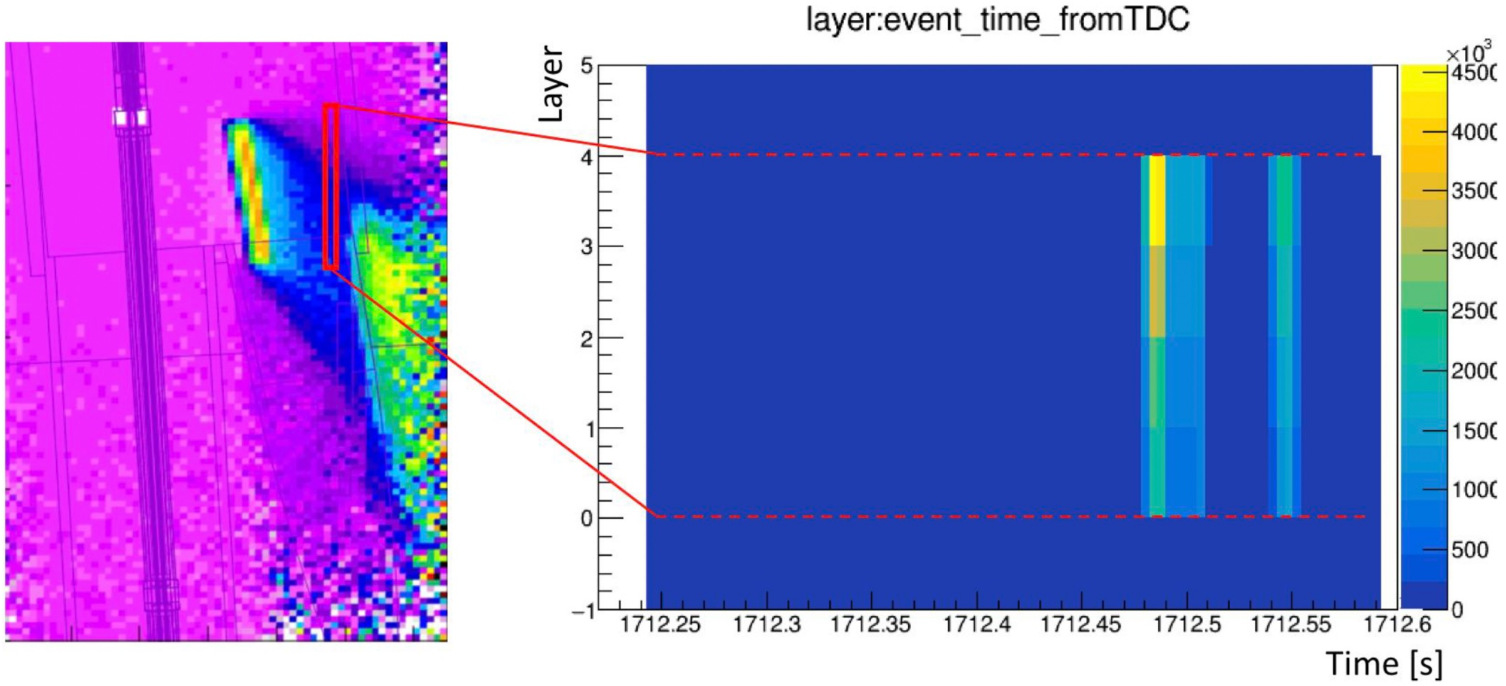




- We see the increased activity in FORMOSA when beam circulates regardless of type
- The 4-layer rate aligns with beam conditions while 4-layer + panel veto aligns with collisions

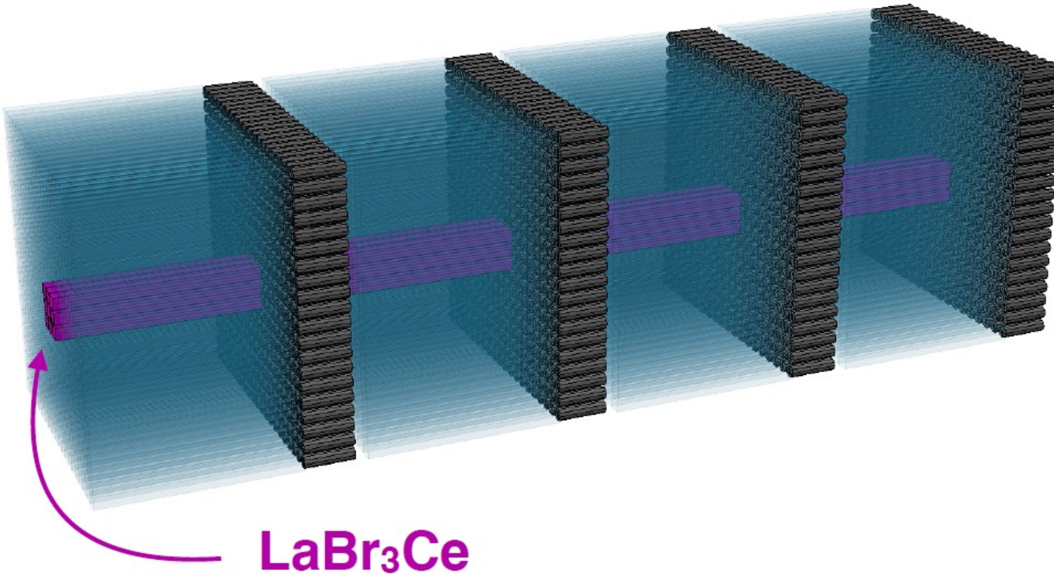
First look at data!

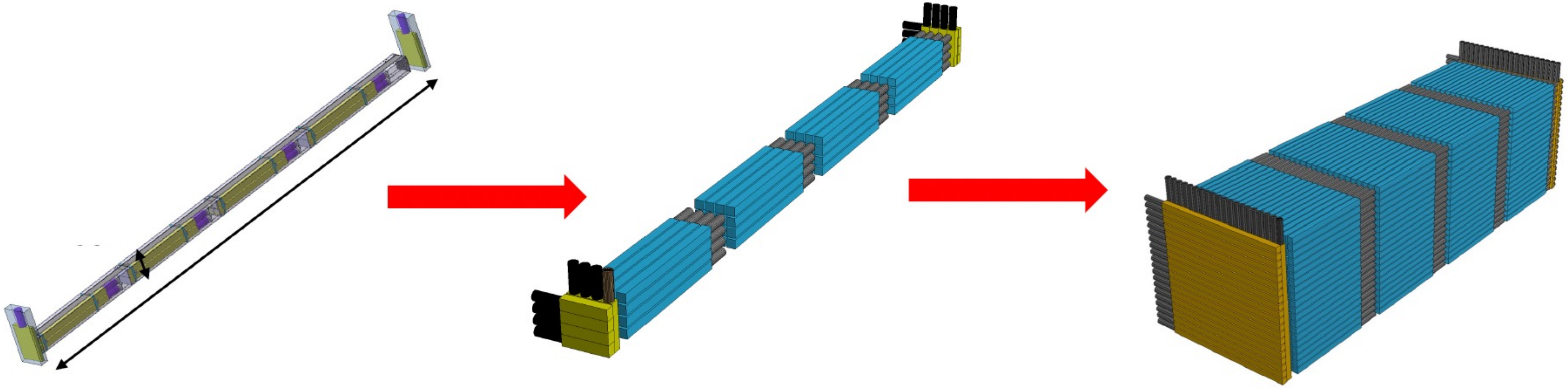
- Comparing what we see to with simulation (provided by FASER) of beam background
- We see the corresponding gradient from simulation in FORMOSA
- Plan to add large lateral veto panels in June (at the mercy of LHC schedule)



Looking forward

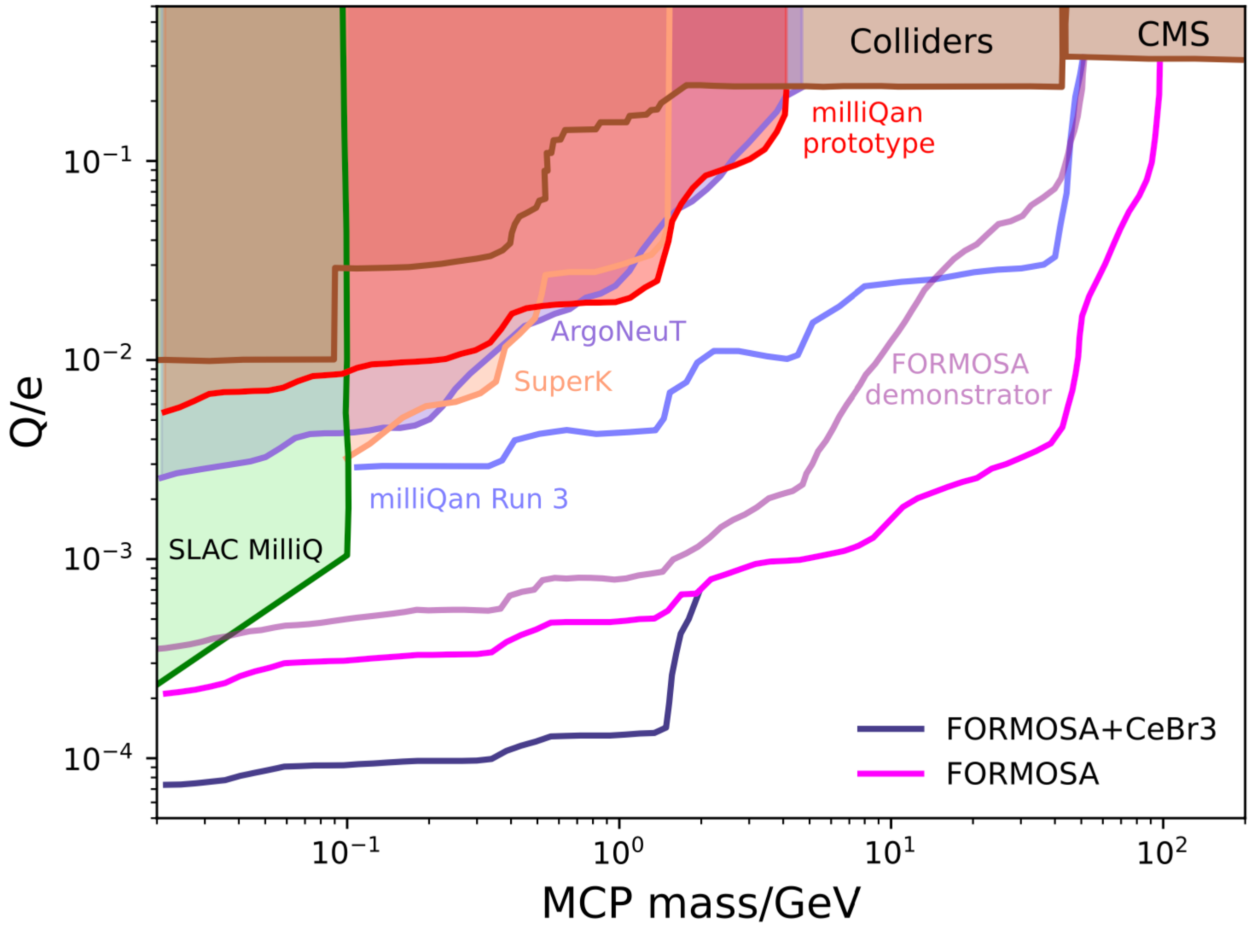
- Expand over time to full size FORMOSA detector
    - Learn from smaller iterations to optimize final form
- Consider smaller subdetector using CeBr3
    - has factor ~35 more photons/cm compared to plastic
- Can place 2x2x4 detector within plastic scintillator
- Provides up to factor of ~4 improvement in low charge sensitivity (below Q/e = 10^{-4}!)





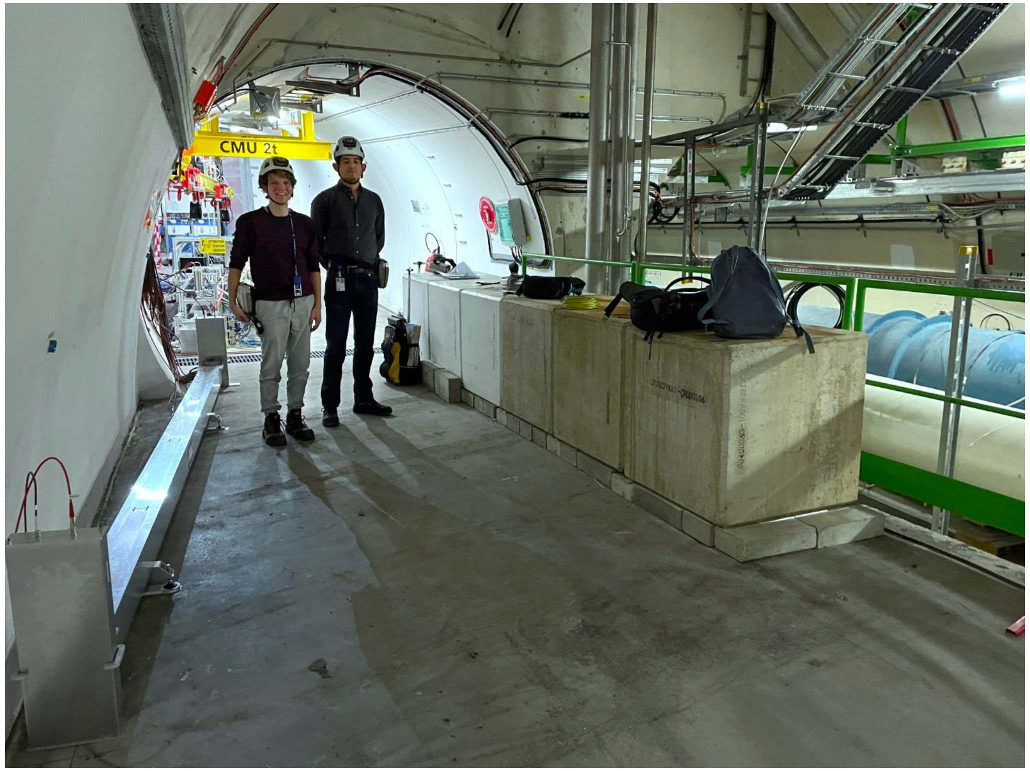
Expected sensitivity

- The FORMOSA looks very promising to improve coverage!
- Charge range:
  - ~(10^{-4} to 0.1)e
- Mass range:
  - (0.01 – 100)GeV



Summary

- FORMOSA offers excellent sensitivity to MCPs
- Demonstrator installed at UJ12
- No-beam tests and calibrations look promising
- We are understanding new backgrounds and adapting
- Opportunity to expand actively studied while we analyze demonstrator data



Graduate student: Jacob Steenis
Postdoc: Juan Salvador Tafoya Vargas

FORMOSA collaboration

Backup

Production at LHC