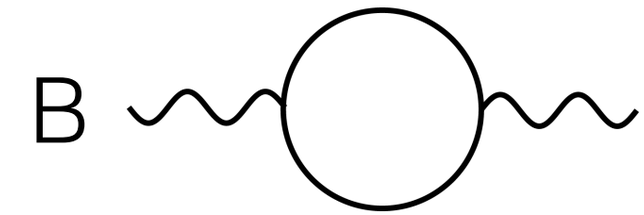
FORMOSA

Matthew Citron
for the FORMOSA collaboration

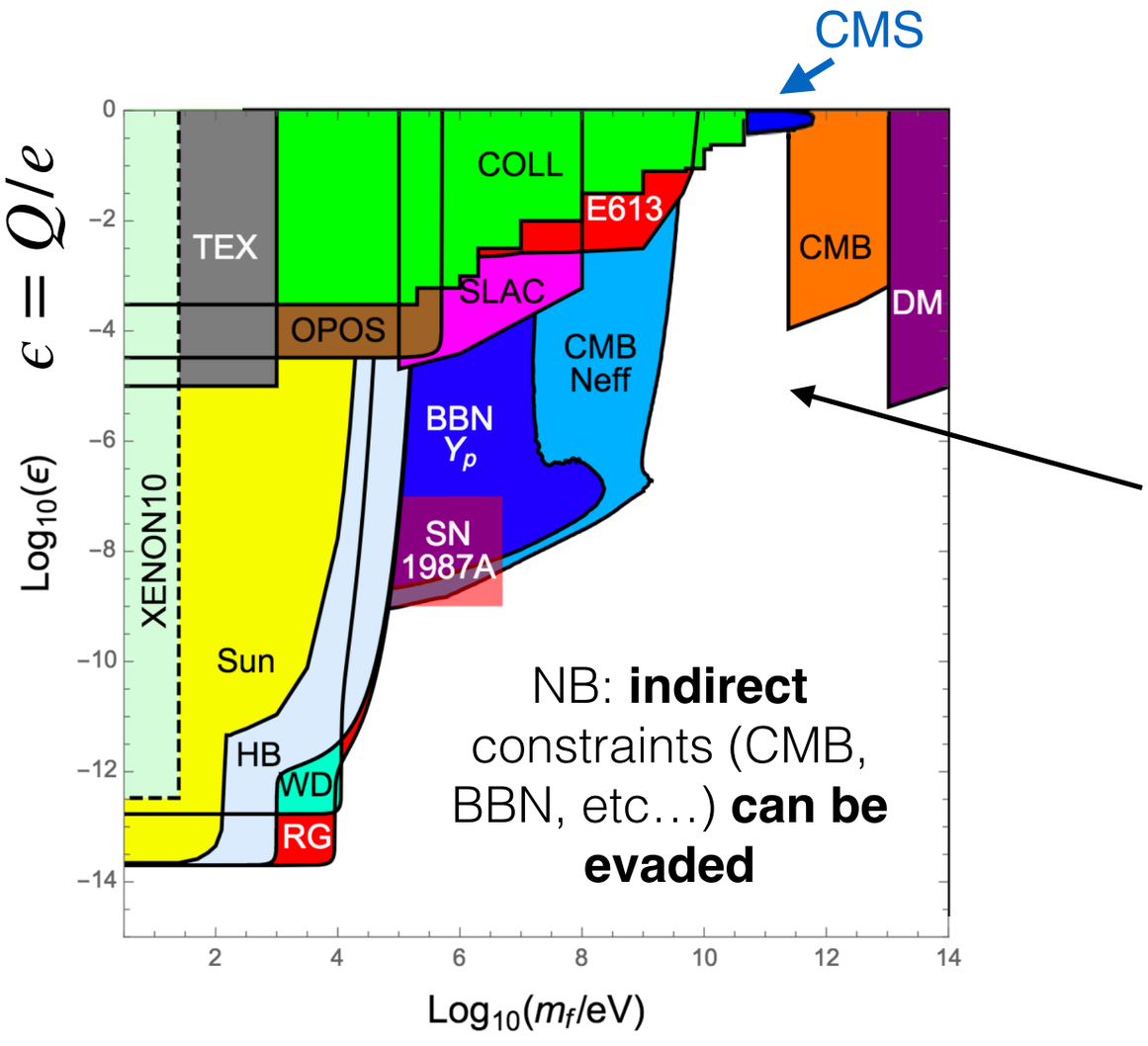
Why millicharged particles at the LHC?

Standard model



SM **dark sector**

Hidden sector



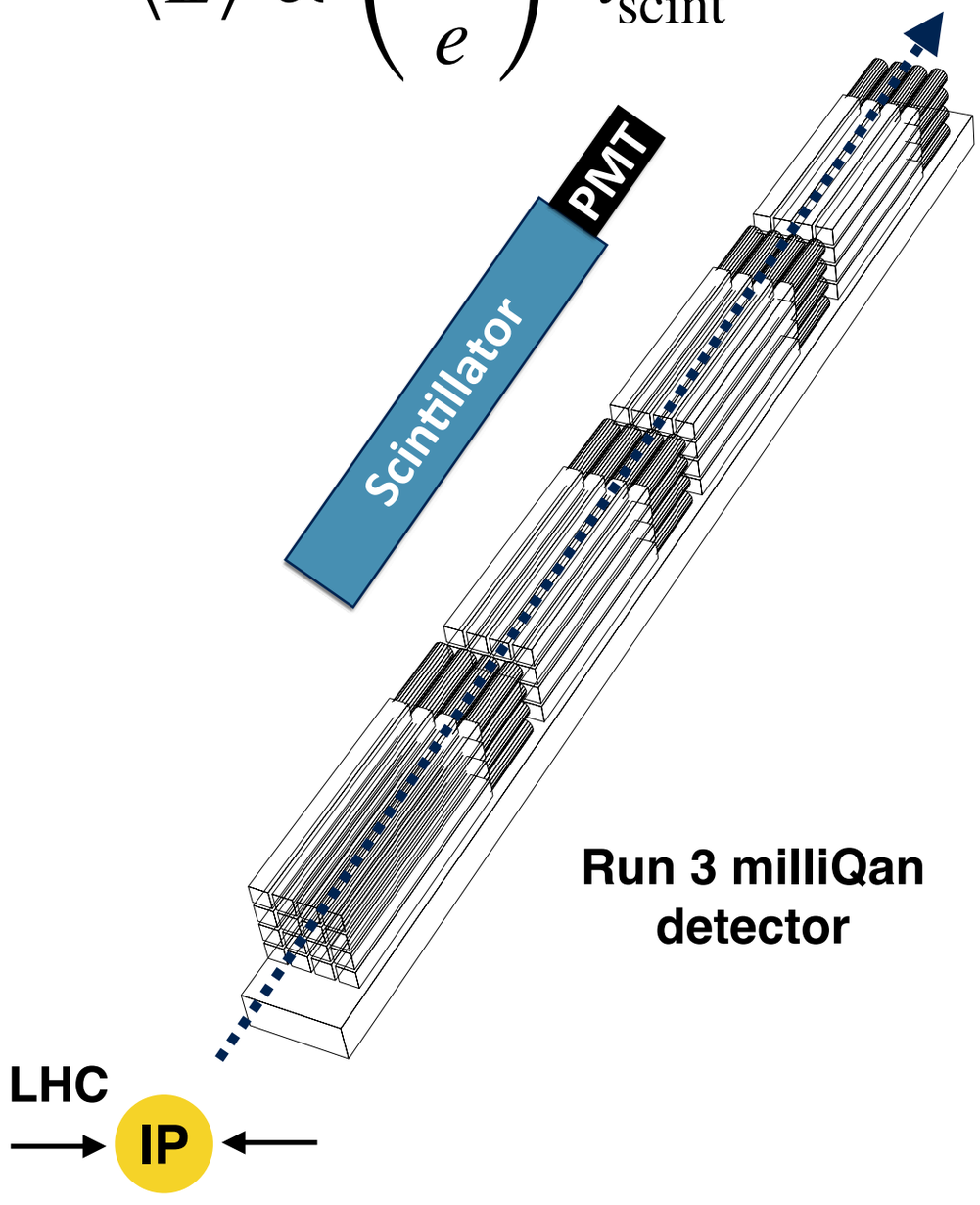
- MCPs arise in **dark sector** theories of DM that include a **massless dark photon**
  - Also appear in GUTs/string theory
- Past constraints leave big gap in reach for **~ GeV scale** MCPs
- Could be produced copiously at the LHC but energy depositions too small to see with CMS/ATLAS

→ target with **dedicated FORMOSA experiment at the LHC**

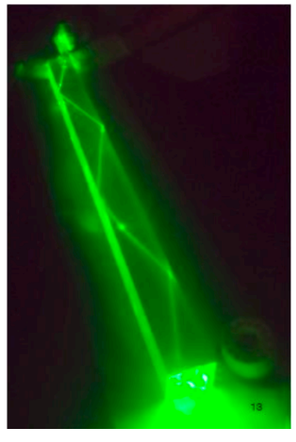
arXiv:1511.01122

Searching for millicharged particles

$$\langle E \rangle \propto \left(\frac{Q}{e}\right)^2 l_{\text{scint}}$$



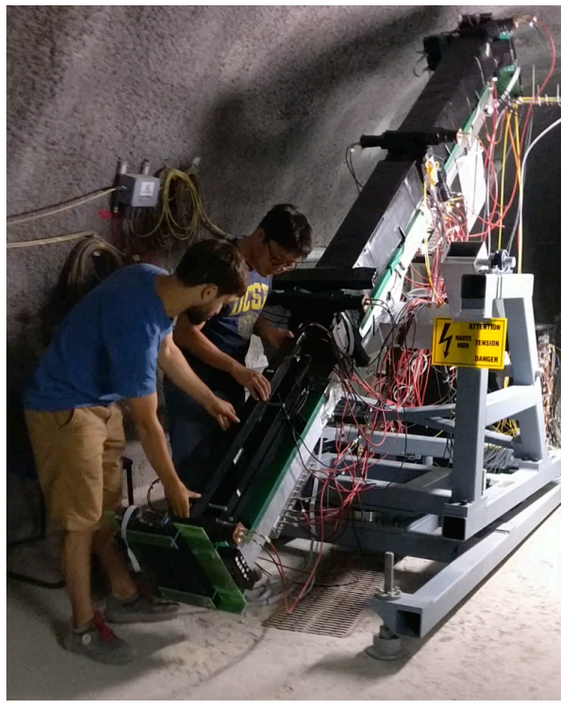
Run 3 milliQan detector

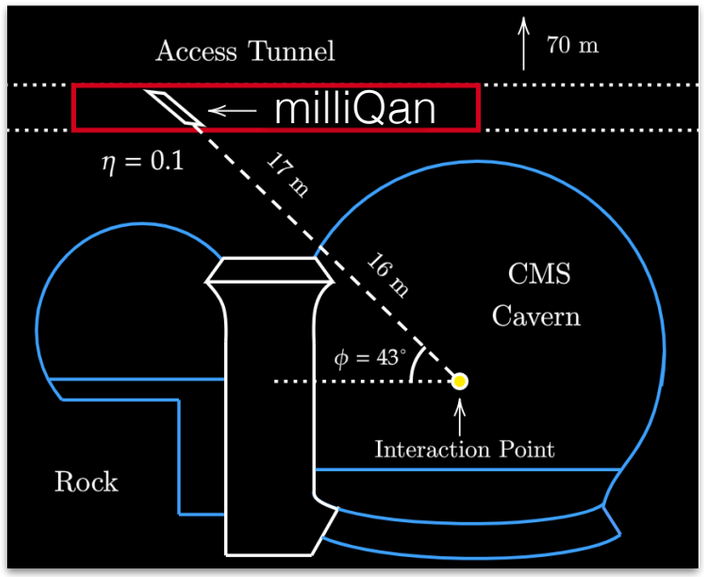


Scintillator bar

- Use scintillator bar array to detect **(very) small ionisation** from low charged particles
- **Expected signal**: few scintillation photons in multiple layers
- Each bar + PMT must be capable of detecting a **single scintillation photon**
- Control backgrounds: signal in each layer within small (~15 ns) time window and that points towards the IP

Proof of principle from milliQan demonstrator





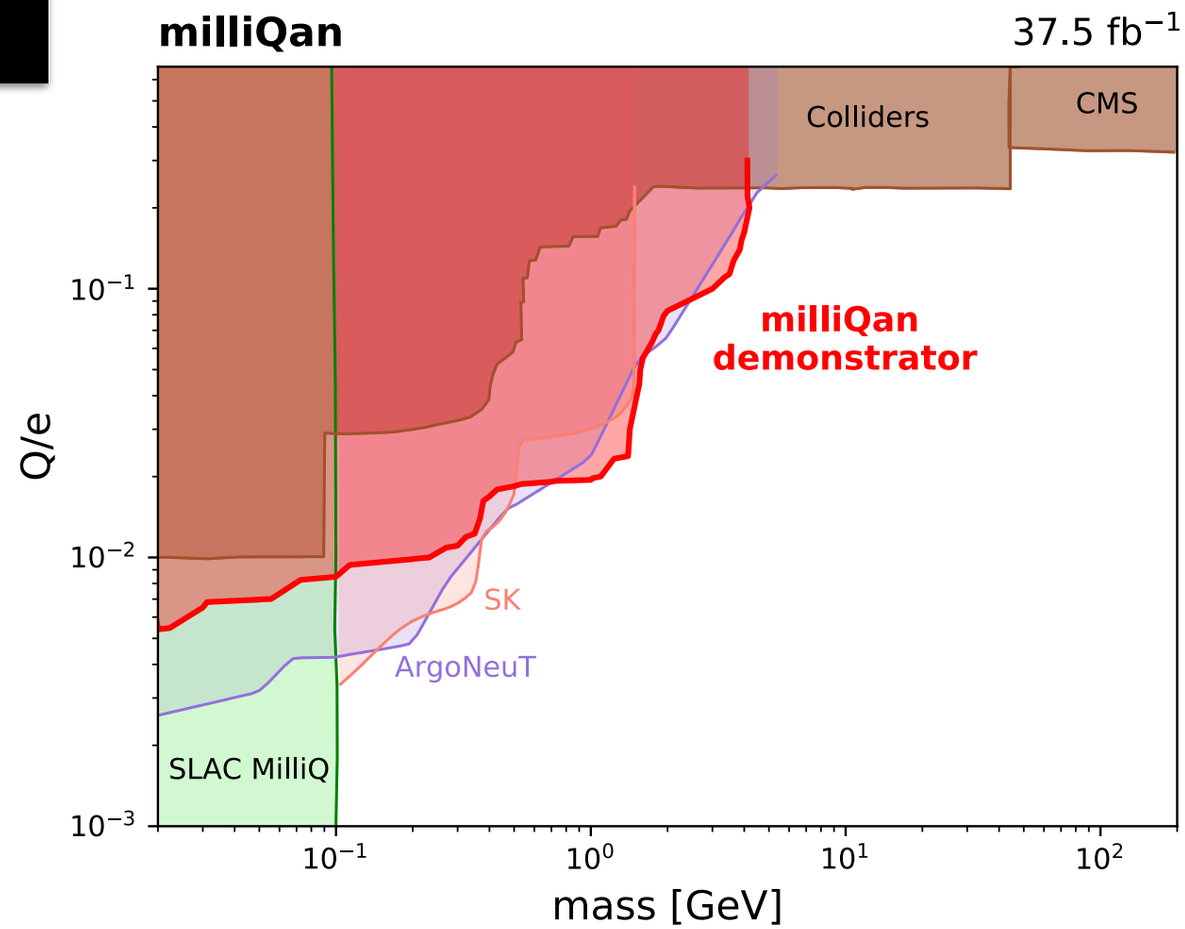
- A demonstrator experiment installed in the CMS cavern during LHC Run 2 ran very successfully

- Used for range of studies to prove feasibility of full detector: **alignment, calibrations, background measurements**

- **First search** for millicharged particles at a hadron collider with new sensitivity

- **Quantitative understanding** of backgrounds and detector performance

→ **Used this to guide future detectors!**

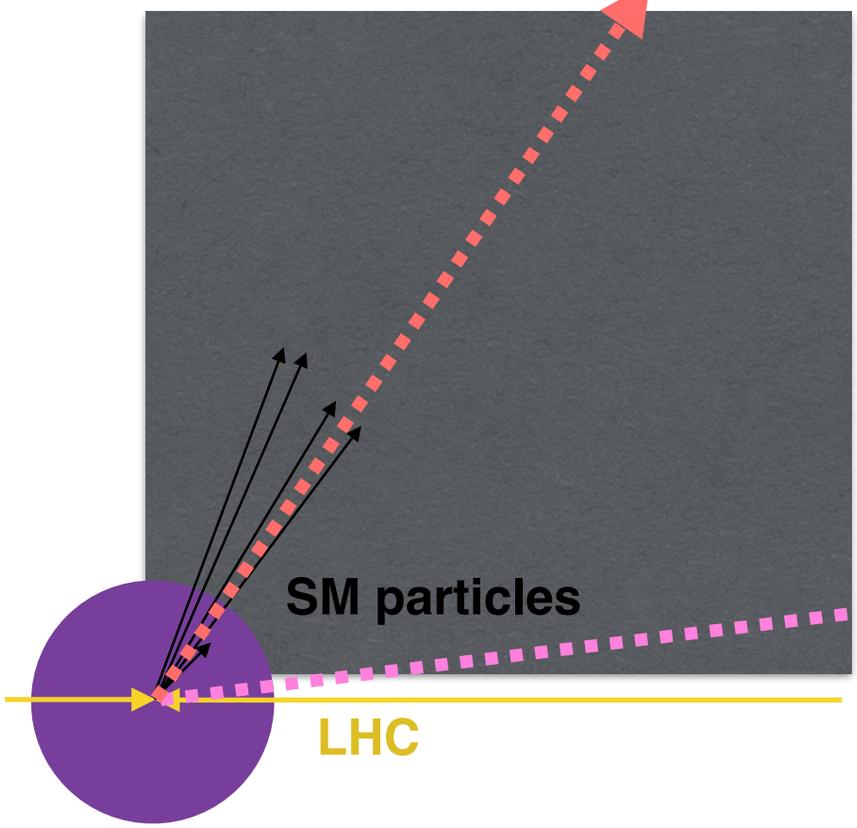


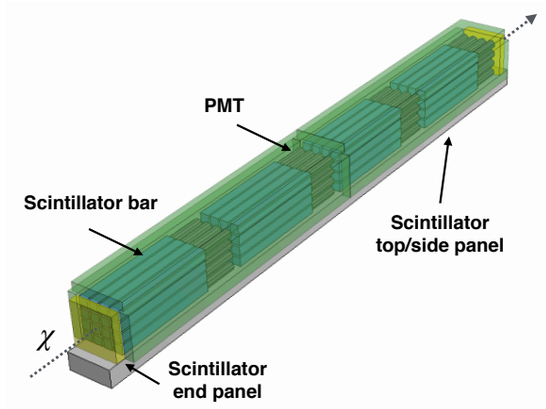
Published in PRD: PhysRevD.102.032002

Why forward?

$\eta \sim 0$

Transverse detector





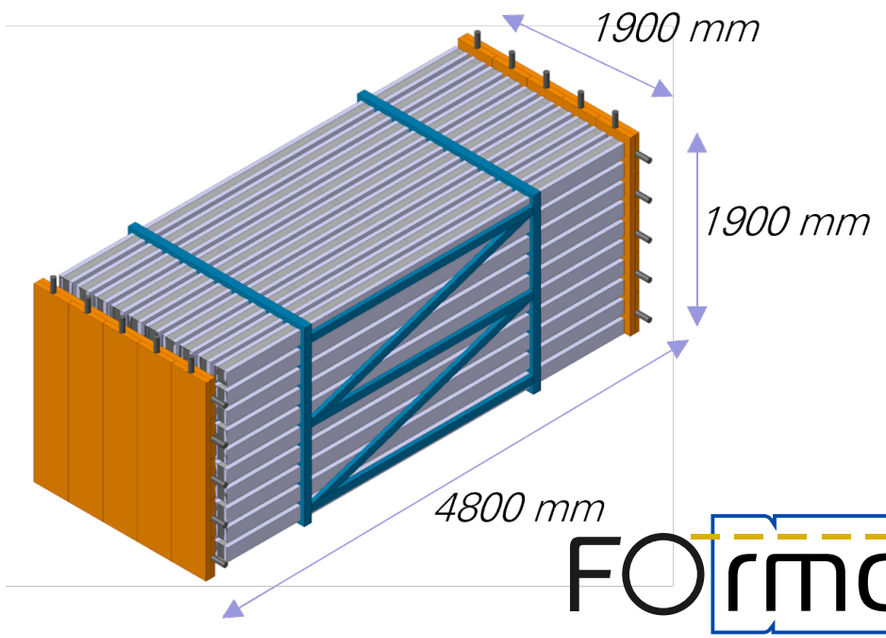
Run 3 milliQan experiment taking data since 2022

THE MILLIQAN EXPERIMENT

mcp flux over 1000 **times larger**!

$\eta > 9$

Forward detector



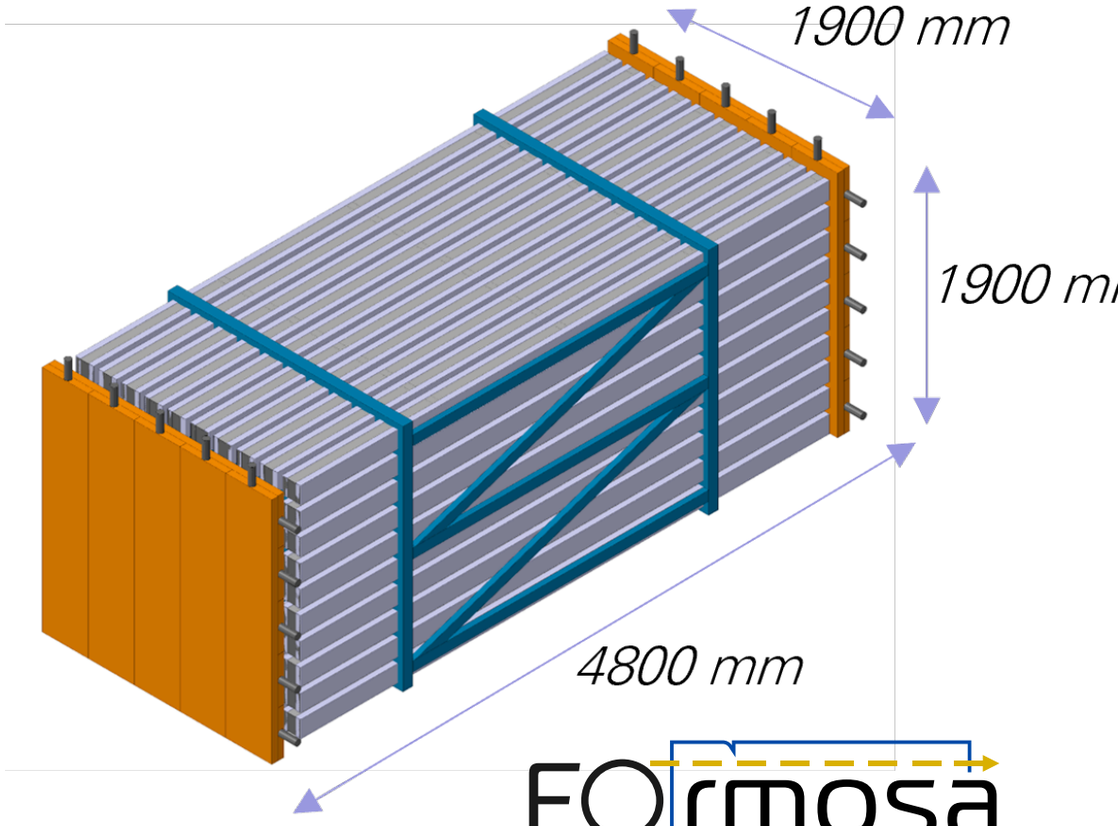
FORMOSA

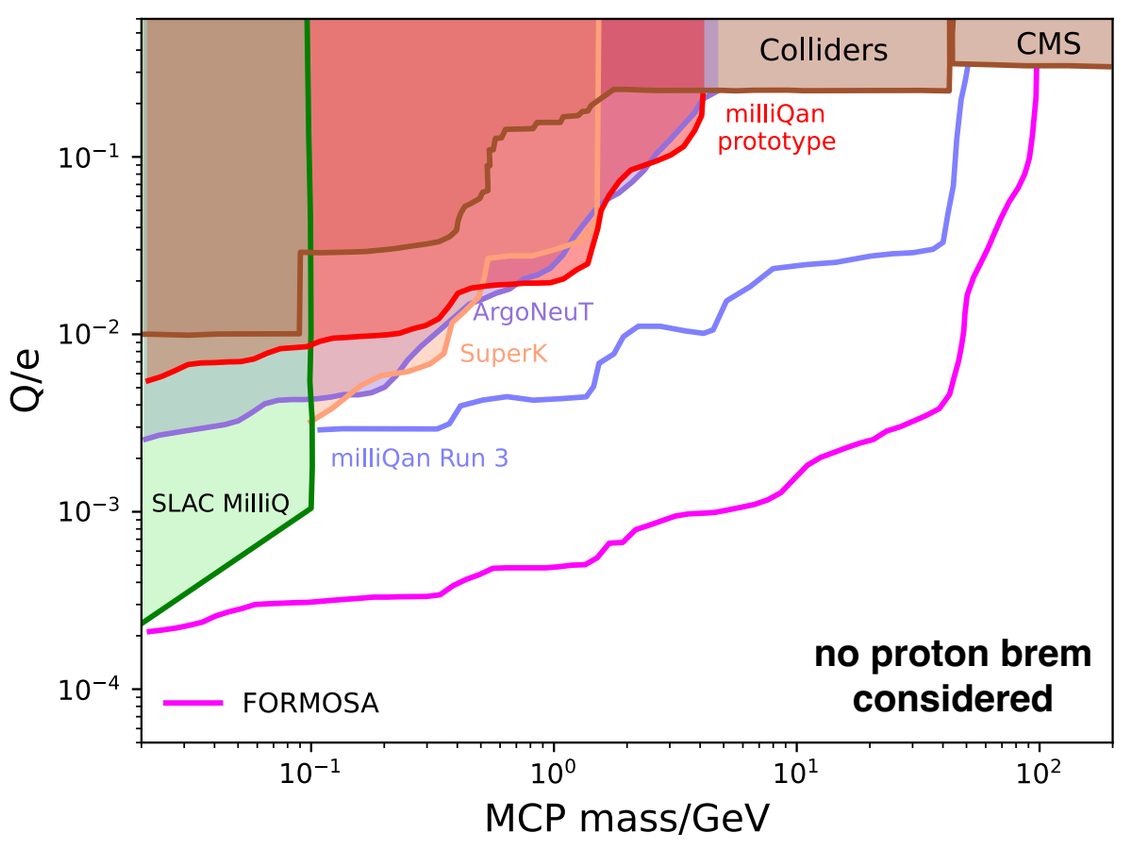
Look **forward** for greatly increased production of mcps!

FORMOSA

- FORMOSA: detector design outlined in FPF white paper: **20x20x4 array** of plastic scintillator bars (EJ-200) coupled to Hamamatsu 7725 PMTs

- Proton brem. production in far forward region could increase production by up to an additional 3 OOM below 1 GeV!





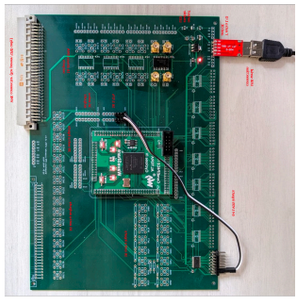
FORMOSA design in FPF paper

- World leading sensitivity across wide range of masses!

- New **challenge**: forward region location gives rise to a new background: “afterpulsing” from beam muons (muon flux ~1/cm²/s) → installed demonstrator to prove feasibility

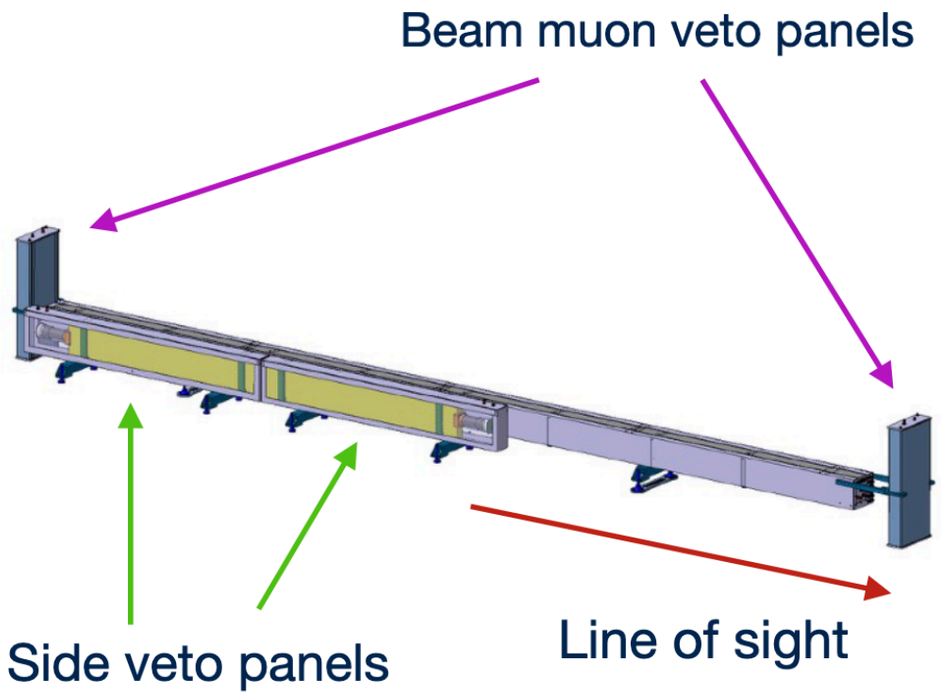
FORMOA prototype

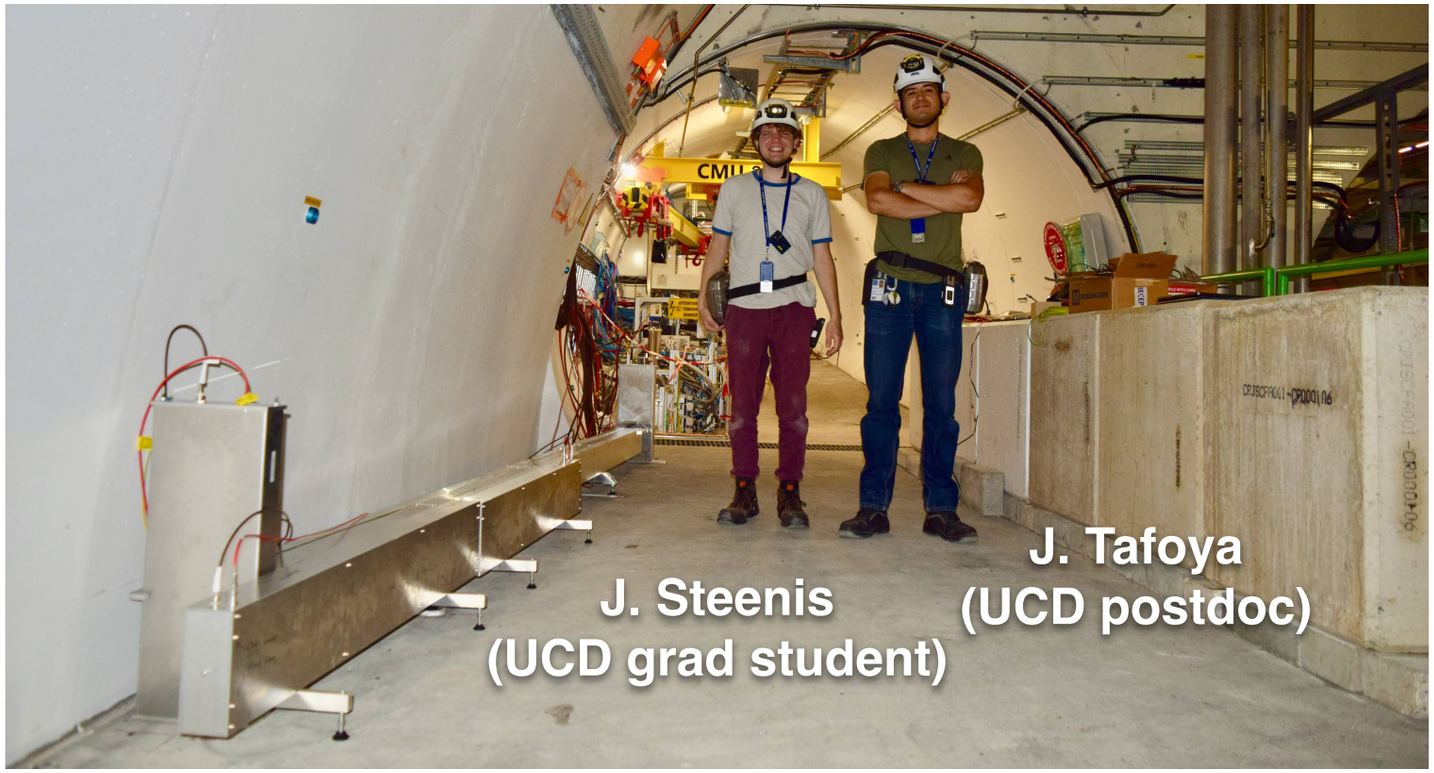
DAQ



Altera Cyclone IV FPGA

V1743

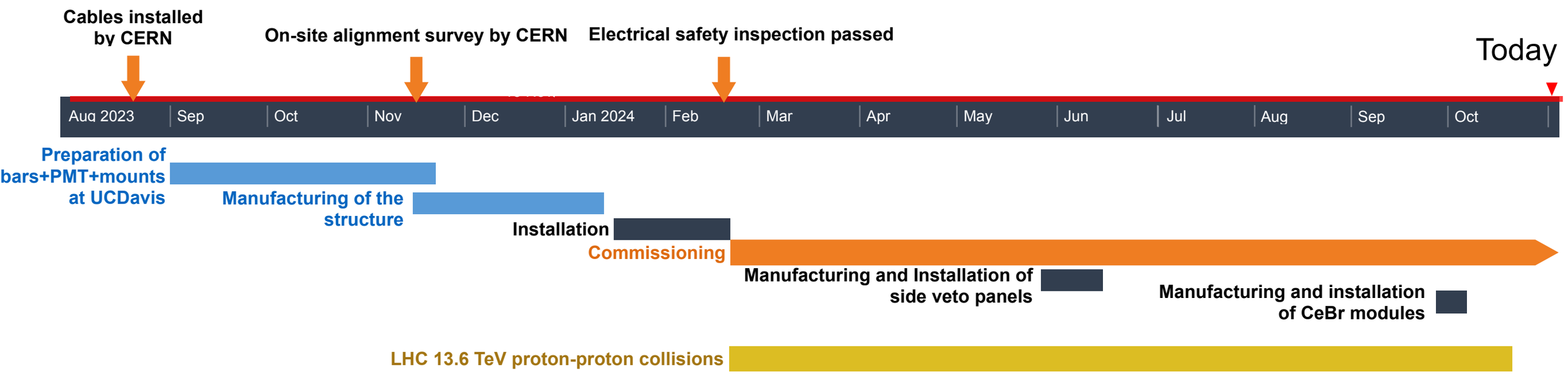




- A small-scale version of the full FORMOSA detector was installed behind FASER during YETS 2023 (2x2x4 bars + veto panels)

- Goal: validate **DAQ strategy**, **measure backgrounds** and prove search for mcps is **feasible** in the forward region

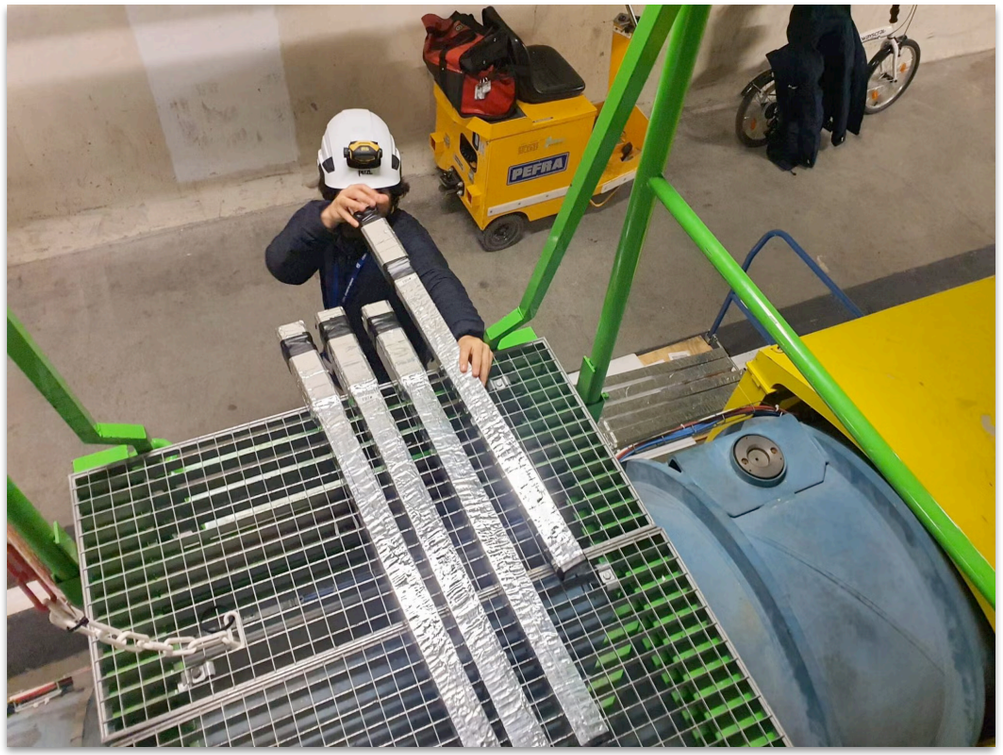
Construction timeline

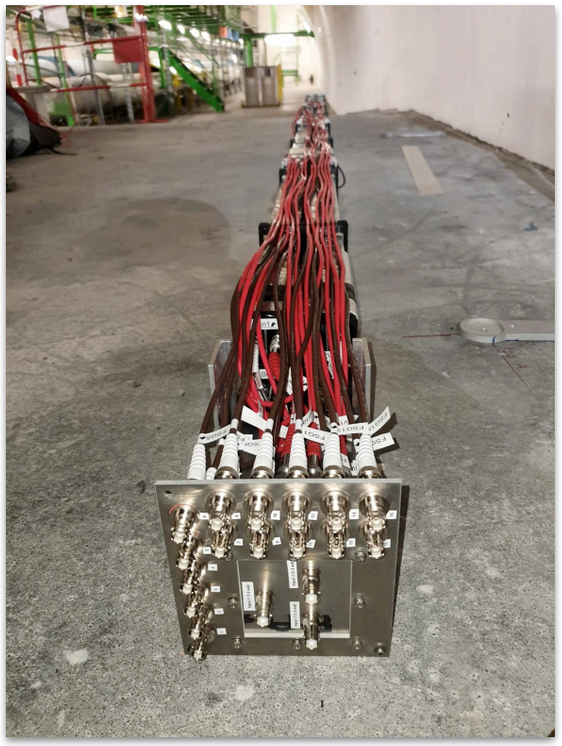


- Used previous experience to build and install detector, structure, DAQ,… in **just ~6 months**
- Construction carried out **entirely by UGs**
- Detector collected data throughout 2024 running and will soon upgrade with hermetic veto panels in YETS

REU student Noe Gonzalez (now at Stanford)

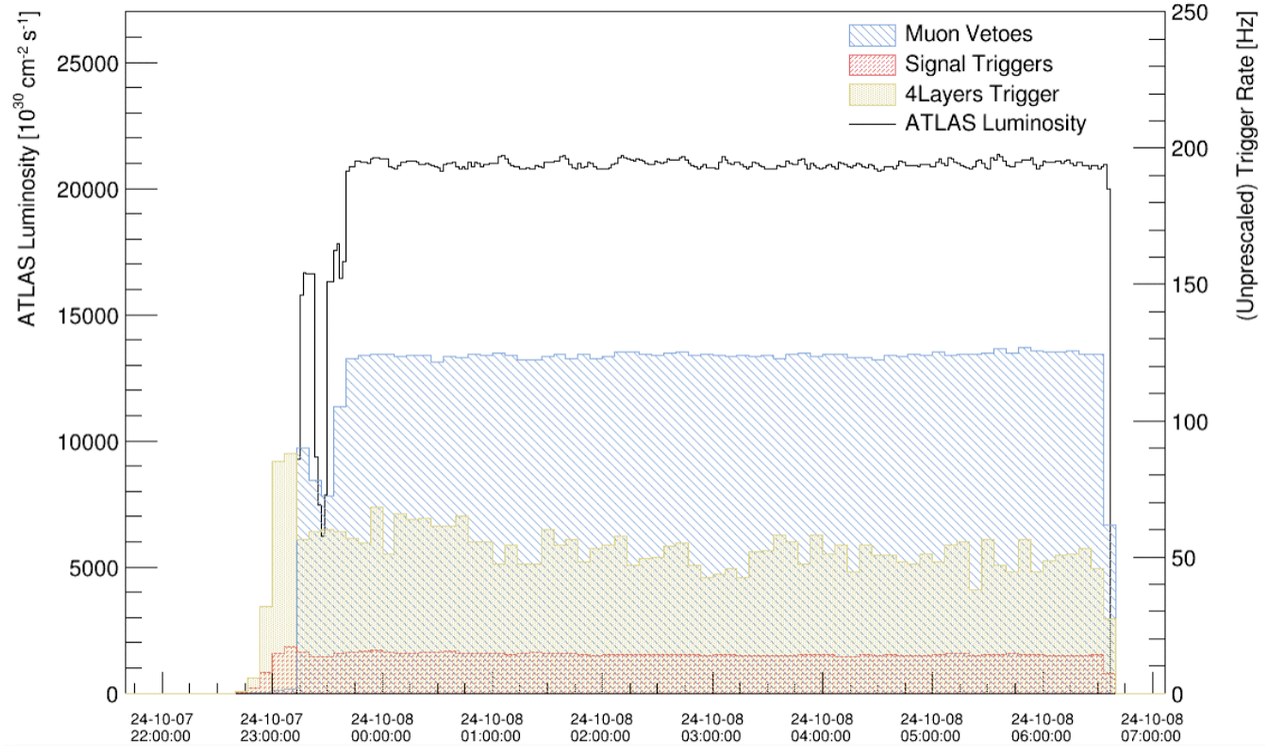
Installation (Feb 2024)

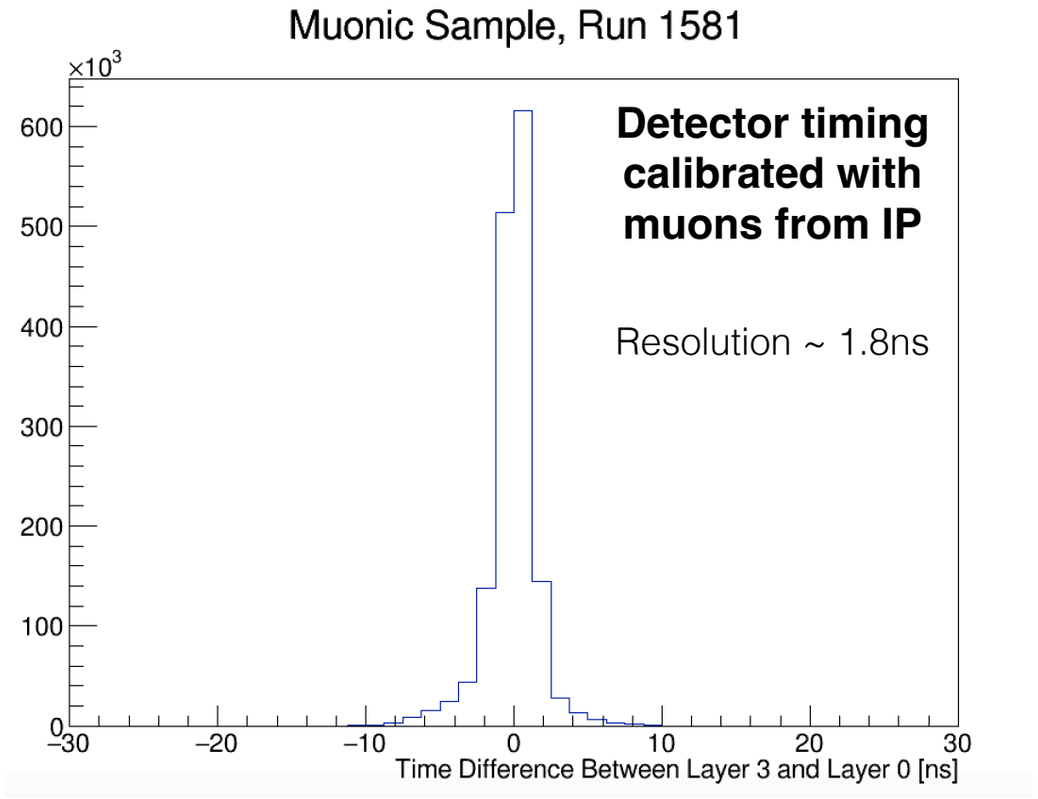




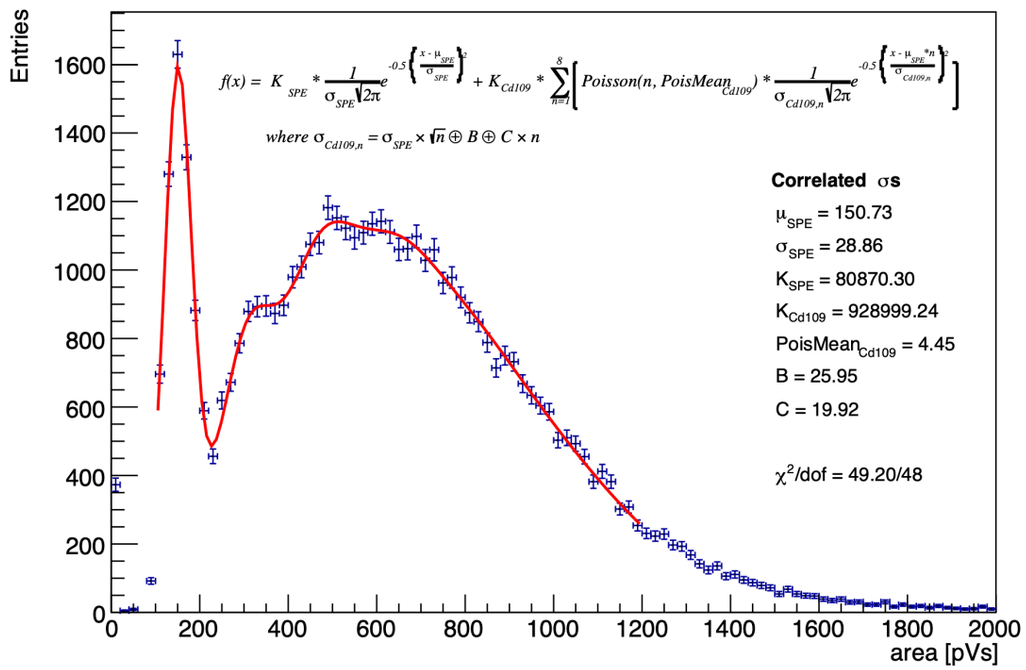
More commissioning plots in backup

Detector commissioning





- DAQ system **fully validated**: we can efficiently veto muons and beam related backgrounds!
- **Response** and **timing** fully calibrated - finalizing offline background measurements now (paper out soon)



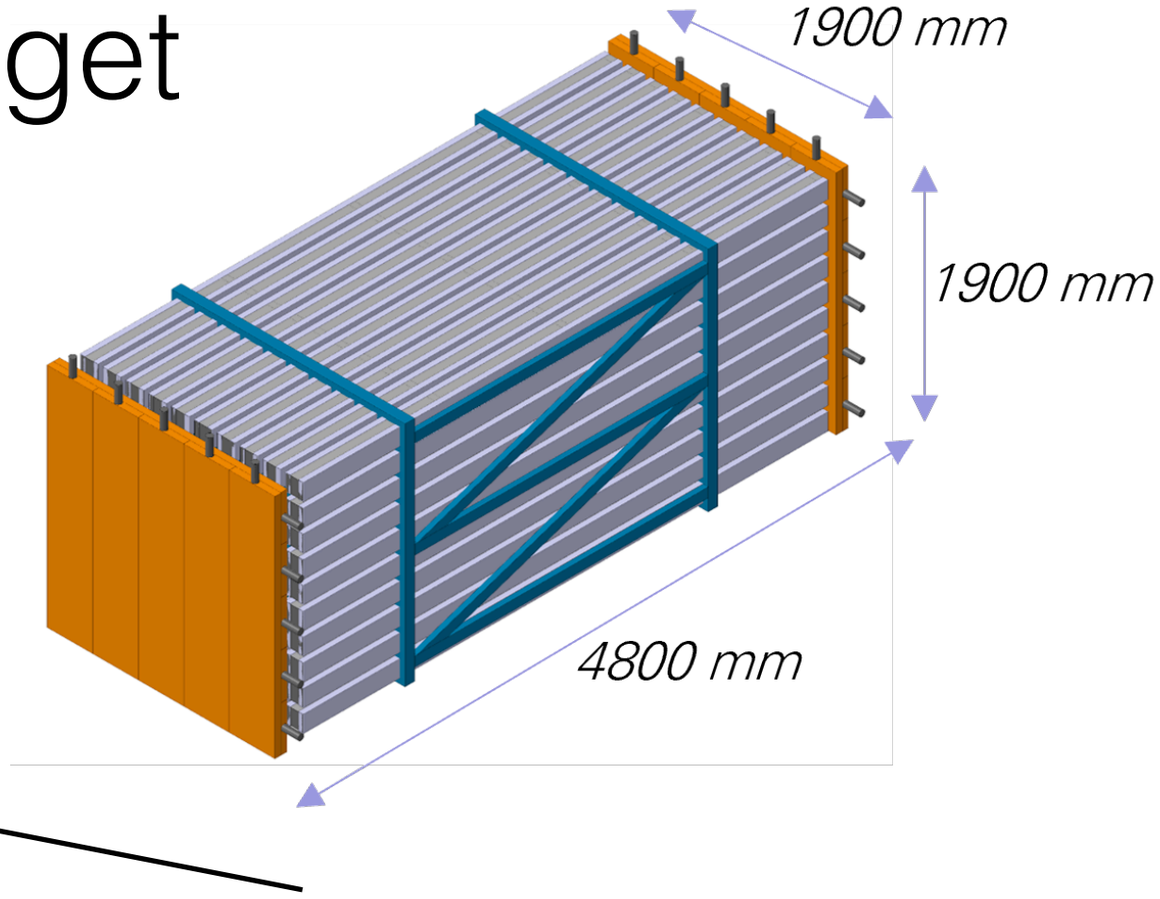
Response calibration using Cd_{109} source

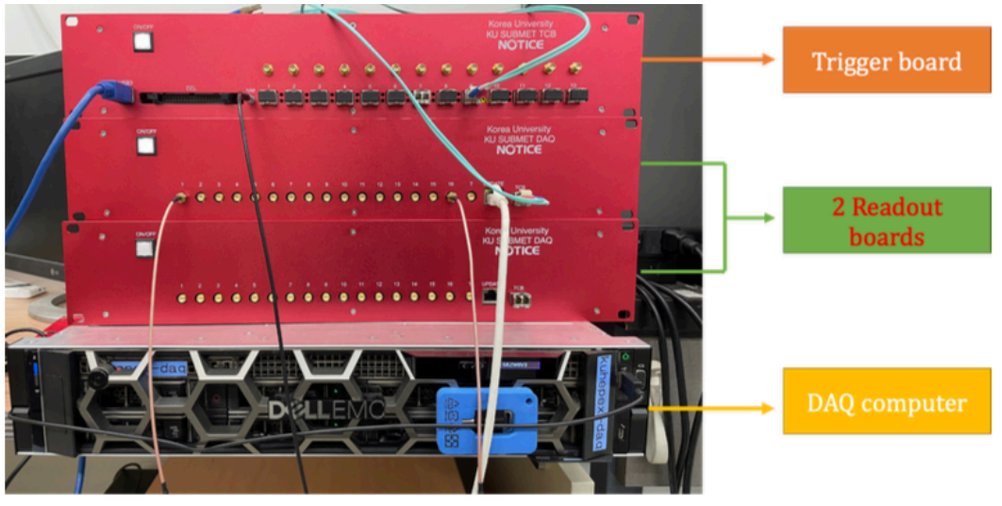
FORMOSA material budget

Item	cost k US$
Scintillator	240
PMTs+bases	1280
HV and readout cables	129
DAQ: CAEN readout	816
(DAQ: bespoke readout)	(129)
panels	37
slabs	22
mechanics	25
amplifiers	5
Infrastructure	100

Total = $1.7-2.4M

Costs based on quotes from established suppliers for milliQan/prototypes

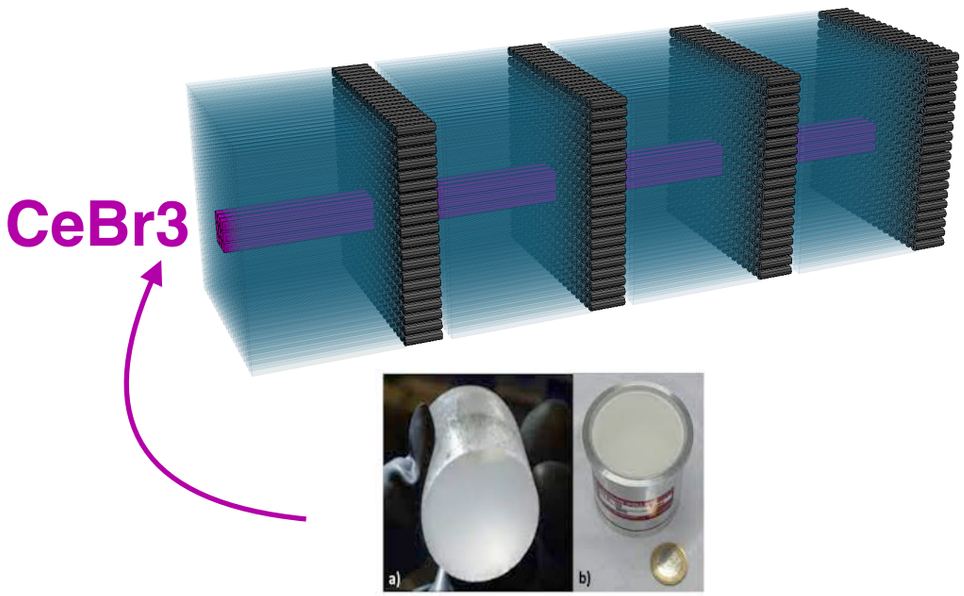




Opportunity for cost saving with alternative DAQ strategy (used for SUBMET experiment)

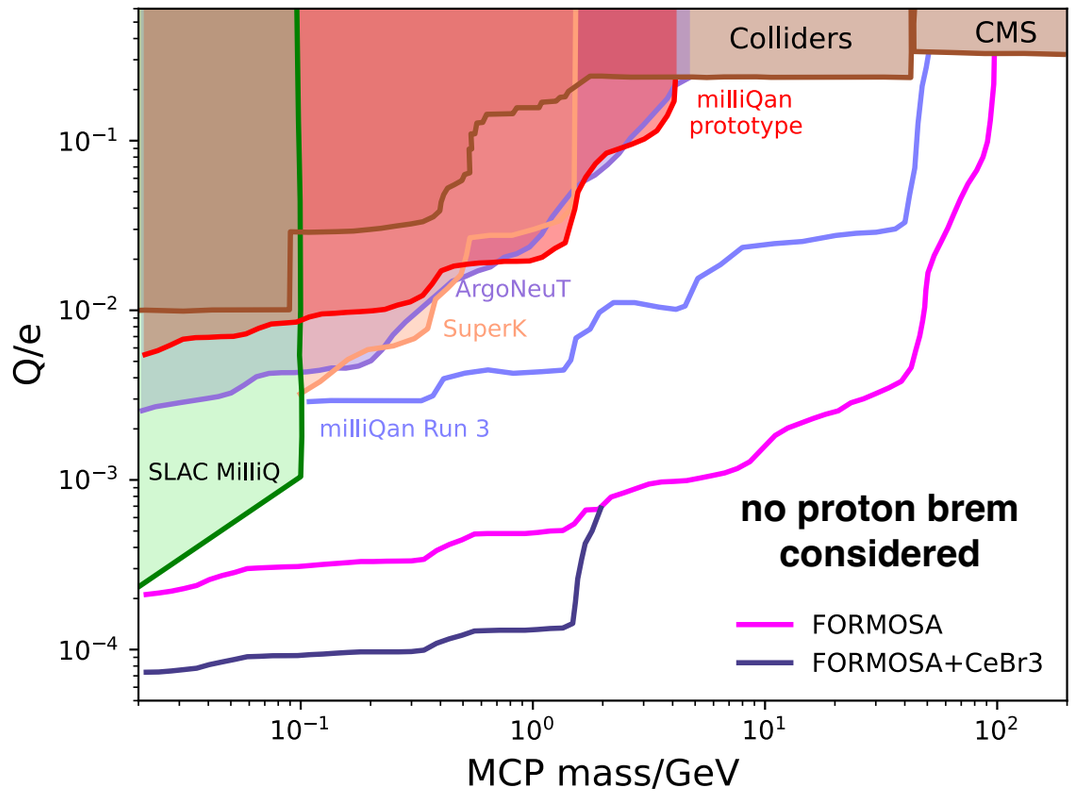
Labor costs in backup

Extending FORMOSA sensitivity



- FORMOSA subdetector made from high performance scintillator such as CeBr3
  - Factor **~35 larger light yield for same length** compared to plastic, **fast** with **low internal radioactivity**
- Considerable sensitivity gain possible!
- More prototype upgrades planned for YETS (see backup)

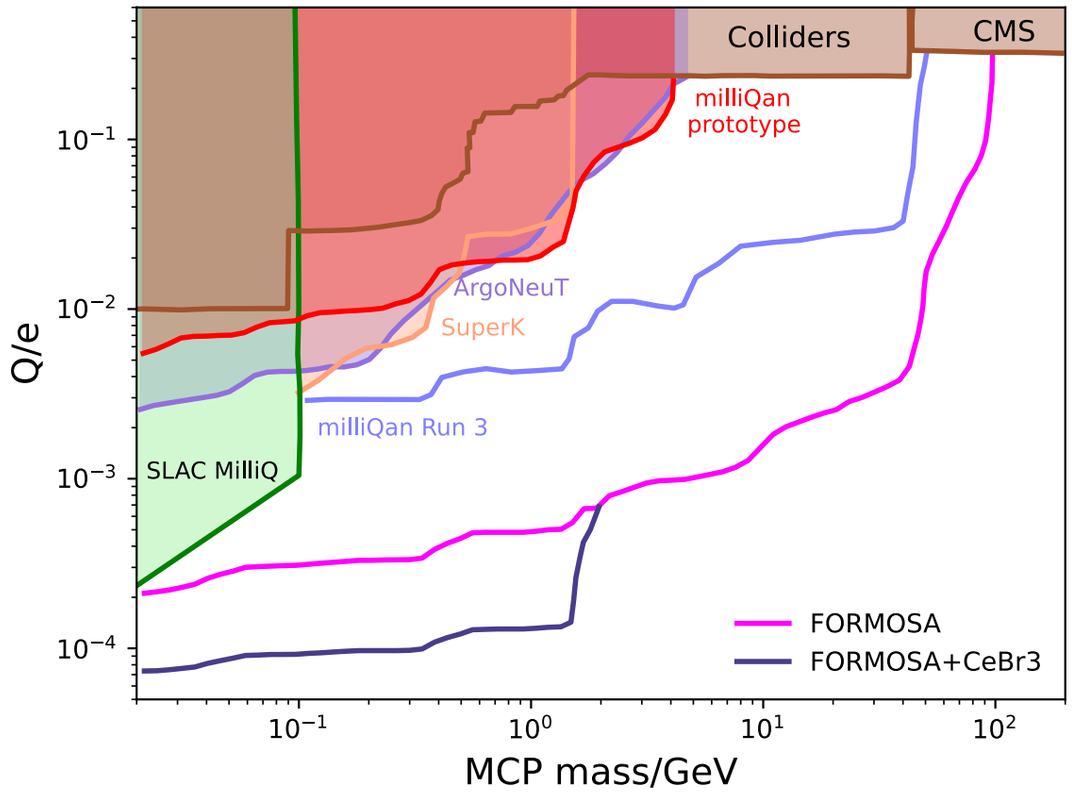
Incorporated module into demonstrator in Sept 2024

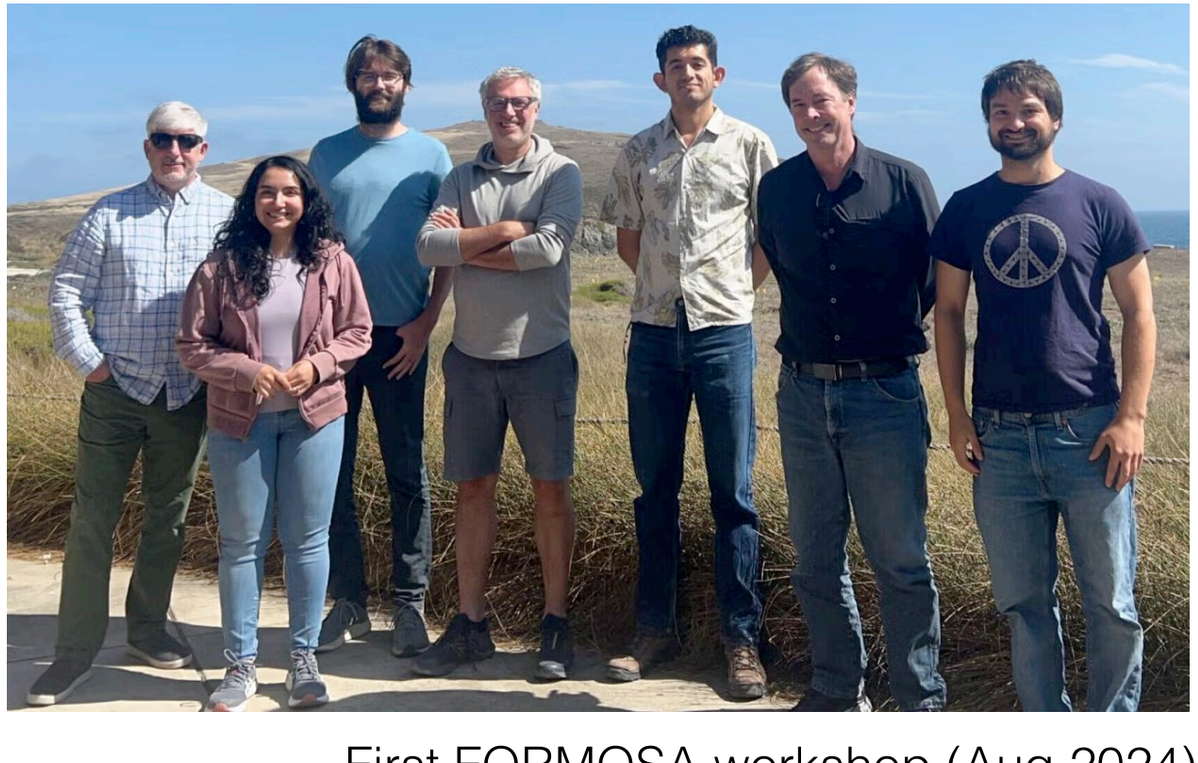


FORMOSA collaboration

Institutes across **three continents** with **extensive experience** building, commissioning, and operating millicharge particle detectors!

Summary





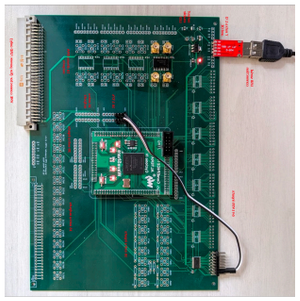
First FORMOSA workshop (Aug 2024)

- FORMOSA is an **agile experiment** to explore the dark sector!
- Collaboration brings **extensive experience** in detector **construction, commissioning and operation** from both past and on-going scintillator-based detectors
- FORMOSA detector **design mature** and feasibility in challenging forward location **fully validated** with **prototype** detector

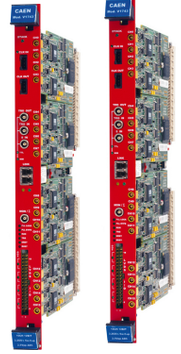
Backup

FORMOSA demonstrator

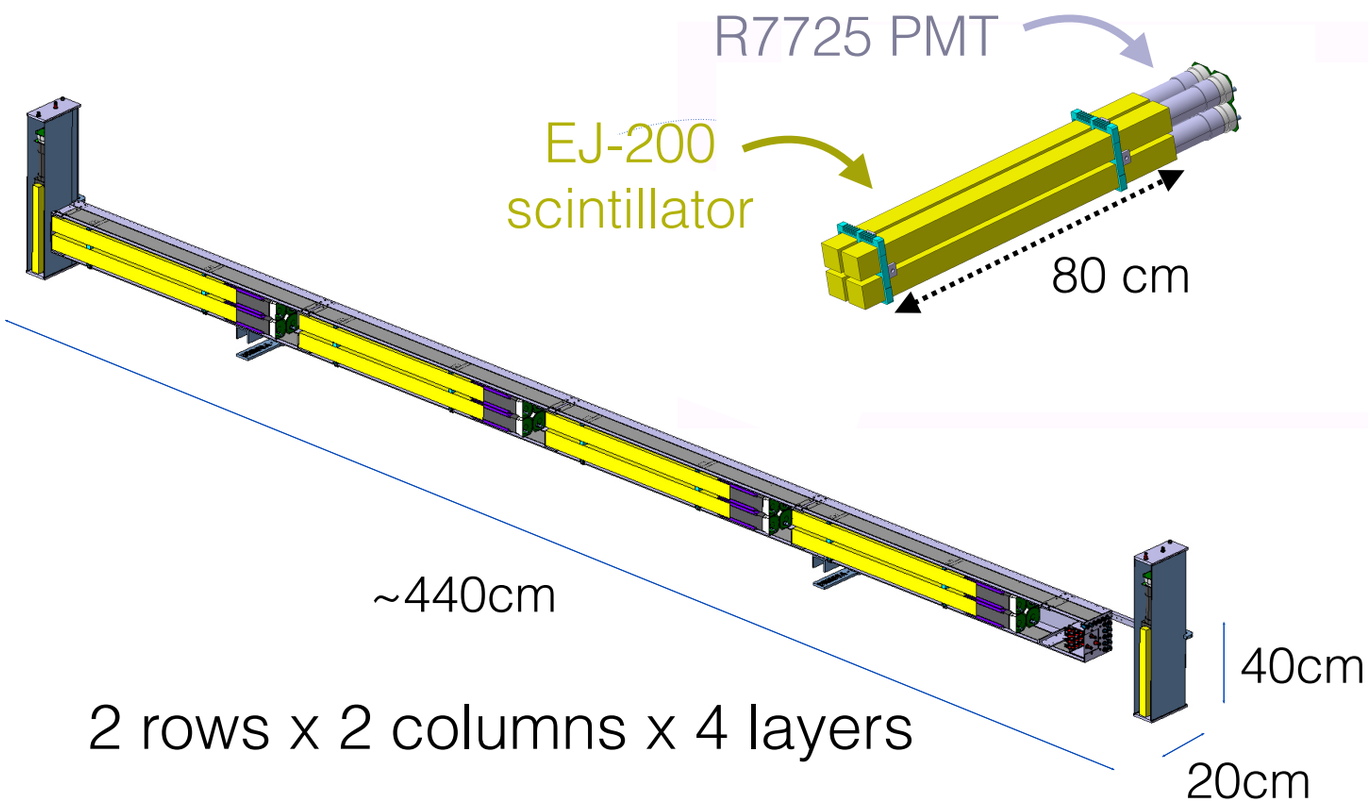
- A small-scale version of the full FORMOSA detector was installed during YETS 2023
- Located in the UJ12 cavern (behind FASER)
- Goal: validate **DAQ strategy**, **measure backgrounds** and prove search for mcps is **feasible** in the forward region
- **DAQ**: CAEN V1743 digis with Altera Cyclone IV FPGA trigger board (similar to milliQan)



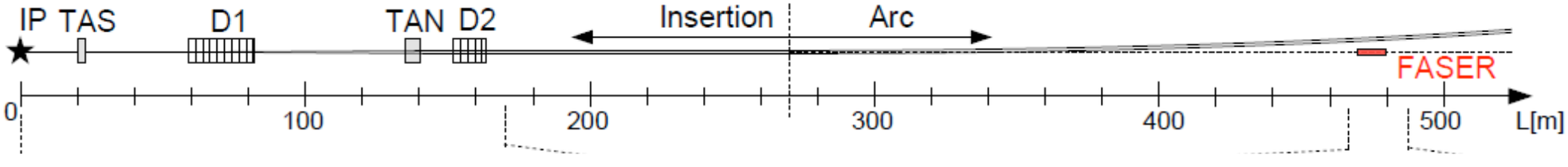
Altera Cyclone IV FPGA



V1743

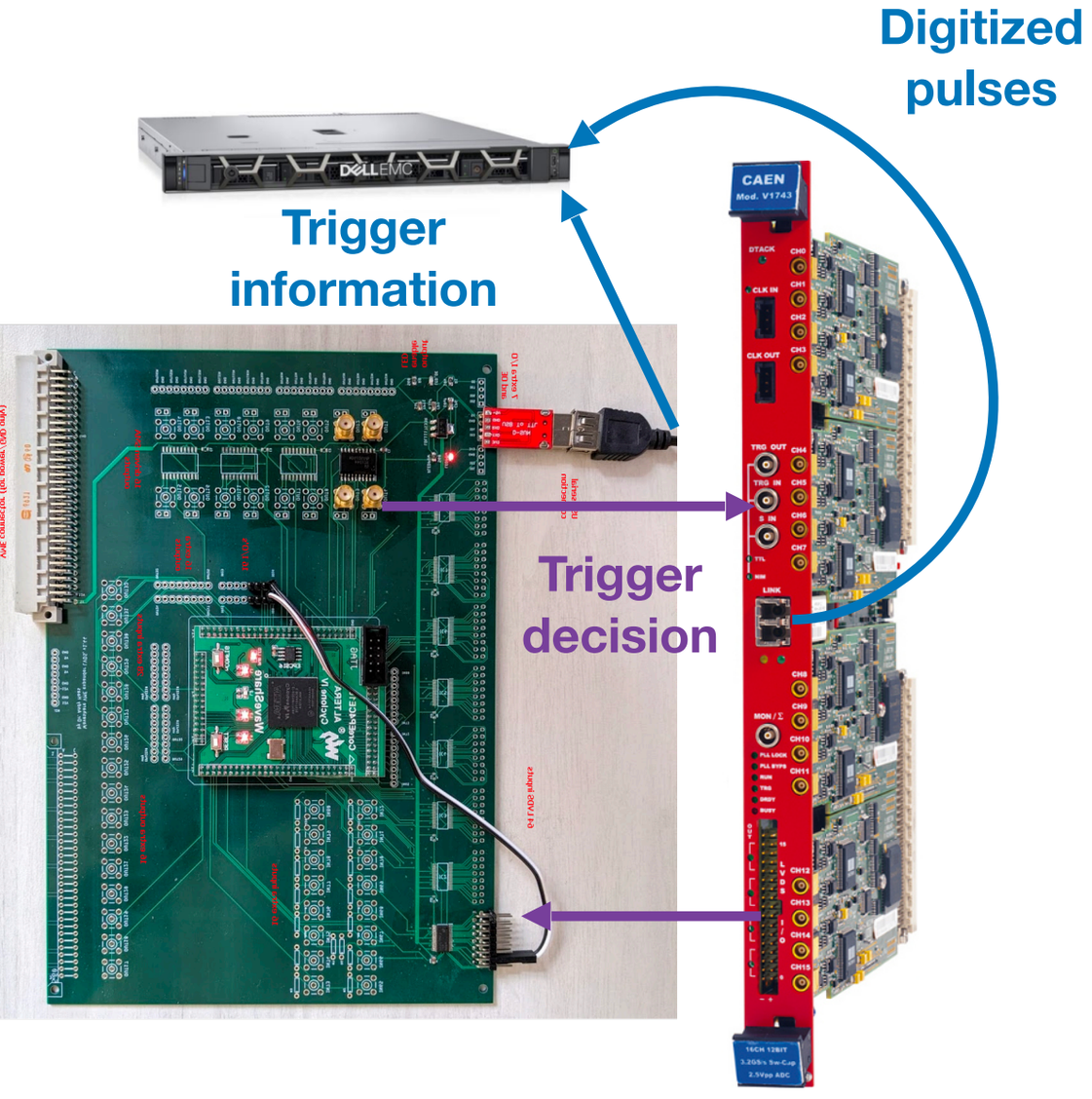


2 rows x 2 columns x 4 layers

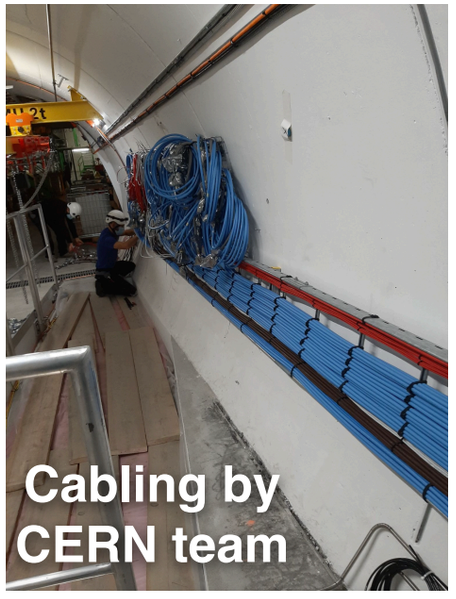


place detector here!

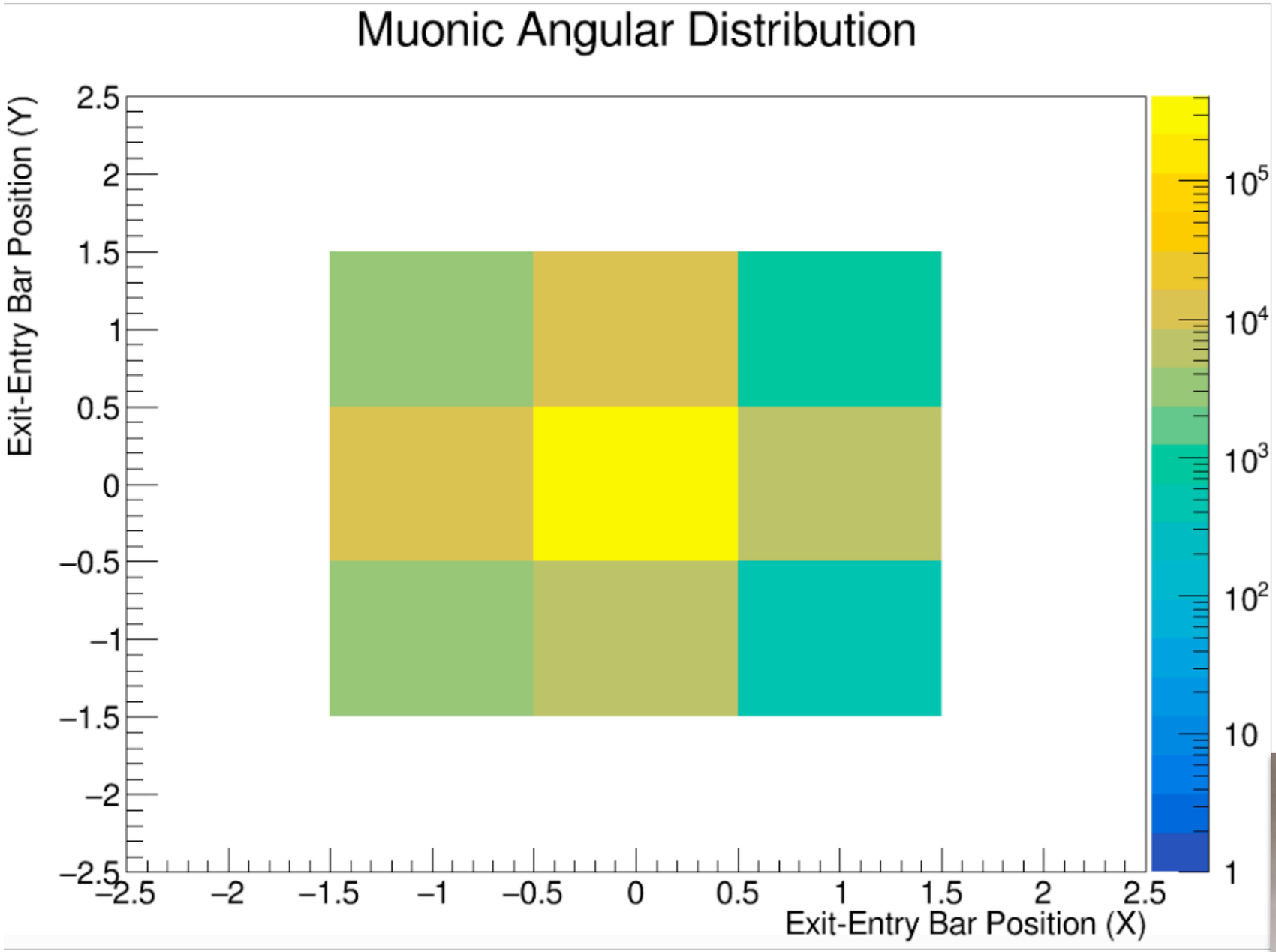
FORMOSA DAQ and HV

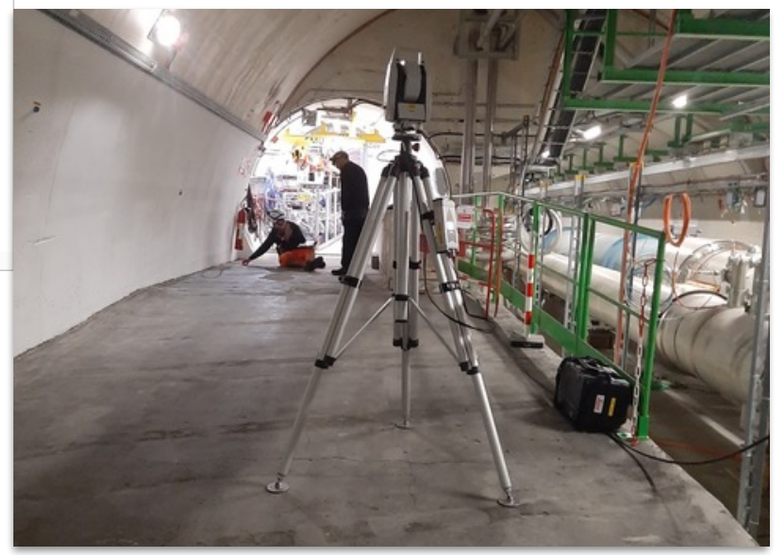


- Reconstruct complete pulse information using two 16 channel CAEN V1743 digitizer
- Flexible trigger decisions using customized trigger board equipped with Altera Cyclone IV FPGA
- DAQ boards and HV in FASER crate
- Many thanks to the FASER collaboration (particularly Jamie Boyd, Brian Petersen) for their help!



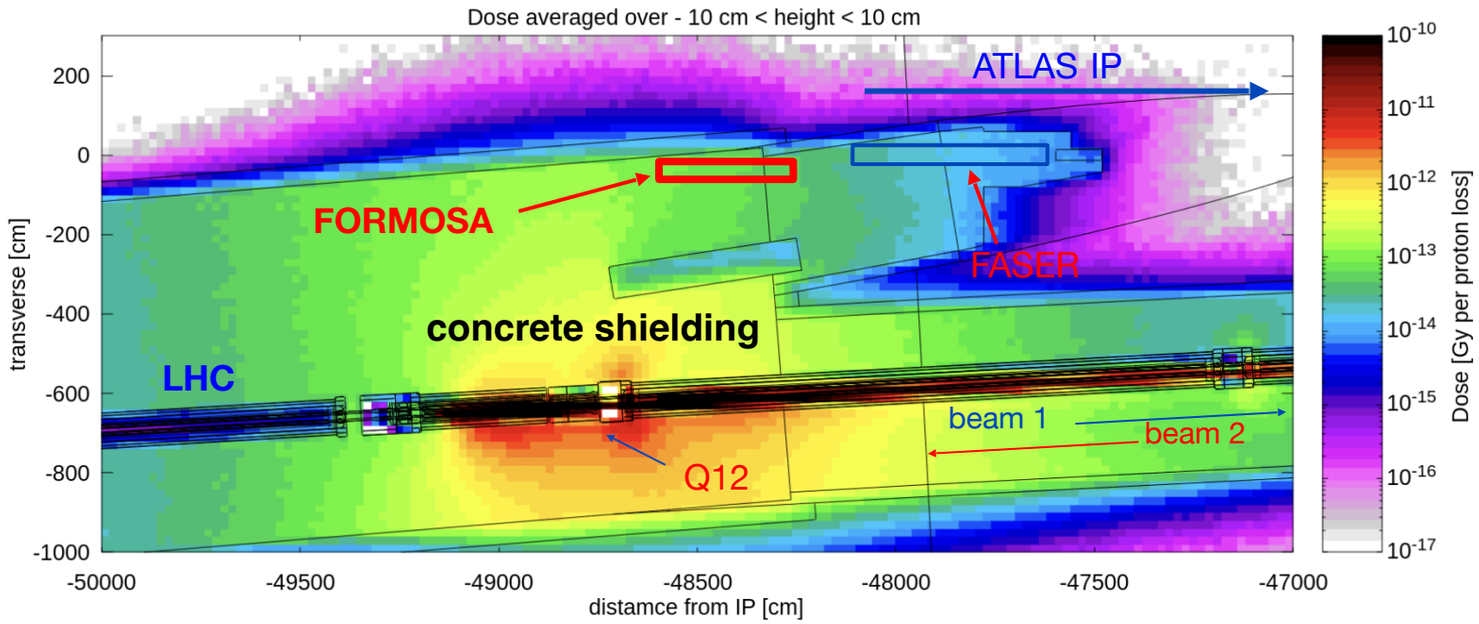
Alignment with beam muons



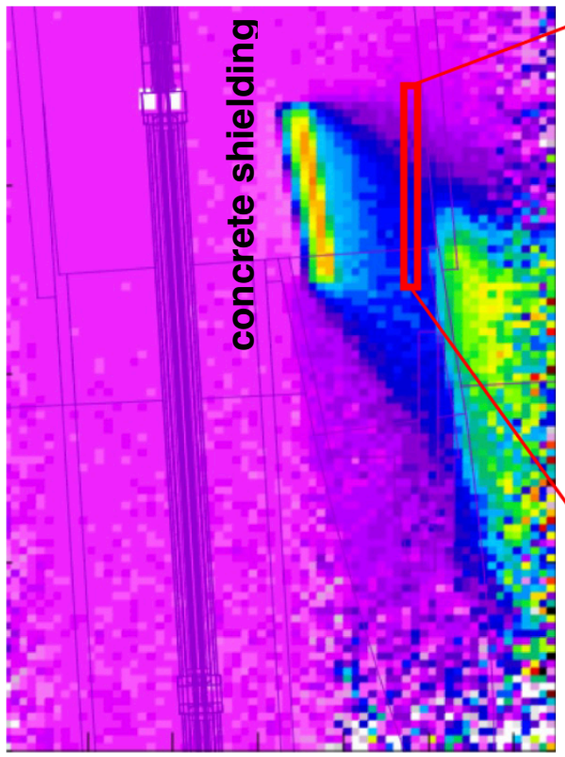


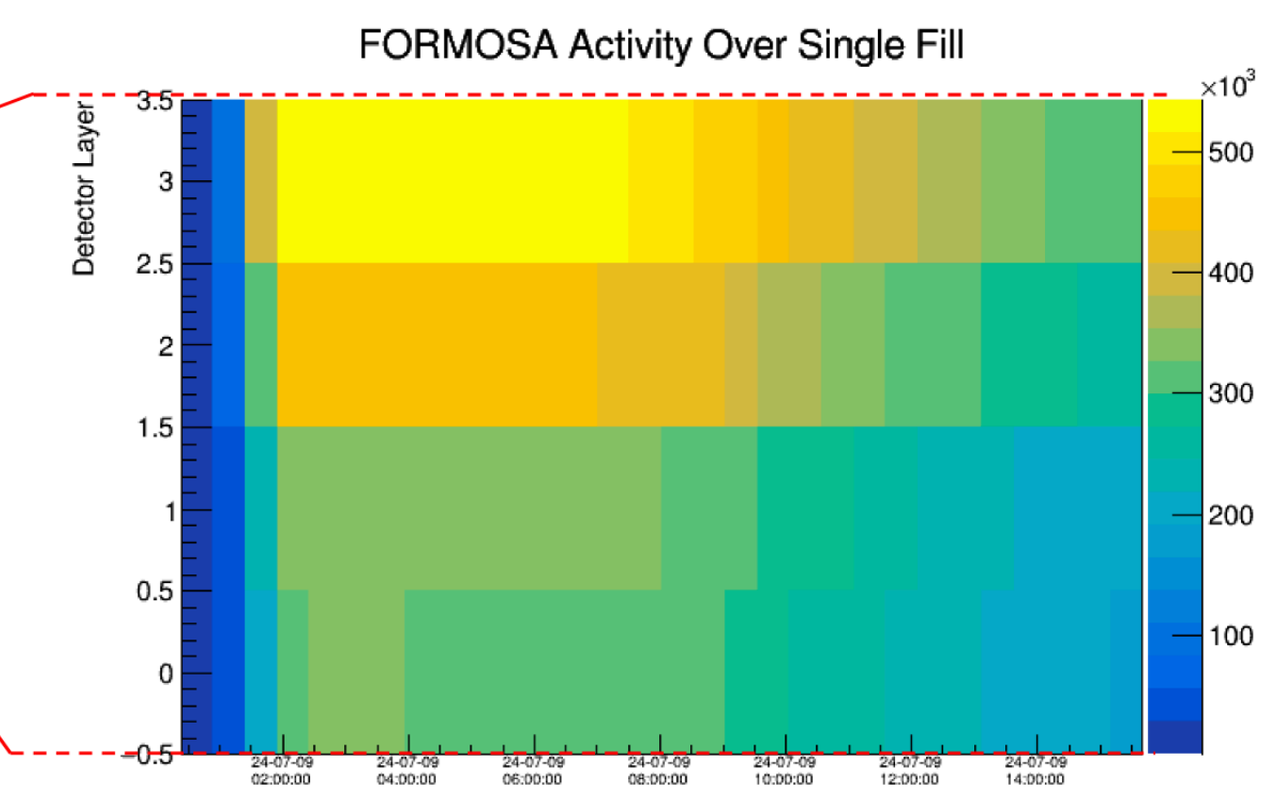
LHC collisional data confirms alignment!

Beam backgrounds



- Initially beam backgrounds (not present at FPF) overwhelmed our trigger
- Addressed by adding **side panels** + vetoes on multiple bars hit in each layer





Activity follows expected gradient

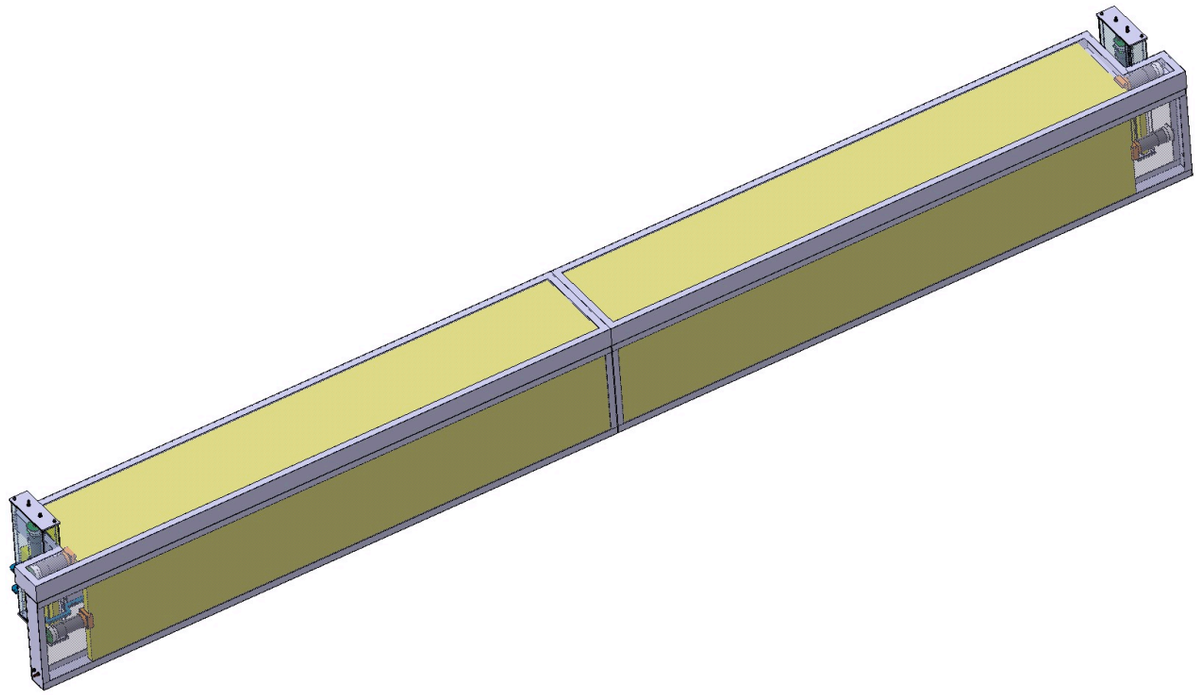
Labor costs

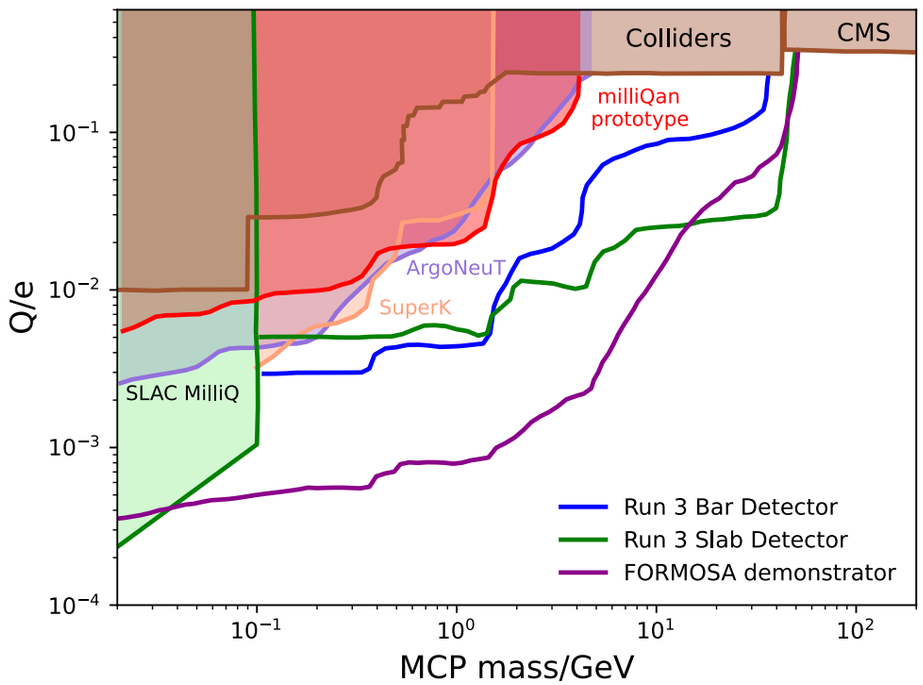
Position	FTE/year	N years	cost k US$
Mechanical engineer	0.25	5	187.5
electrical engineer	0.1	5	100
technicians	0.2	5	75
postdoc	4	5	2000
students	6	5	1500
Total			3862.5

Future plans for the FORMOSA demonstrator

- Adding hermetic veto panels in 2024 YETS

- Finish analysis of collected data to measure backgrounds for full detector





- Depending on funding could continue to expand detector to have physics capability in 2026/early HL-LHC

- milliQan bar sized detector would have excellent sensitivity!

+ quirk sensitivity