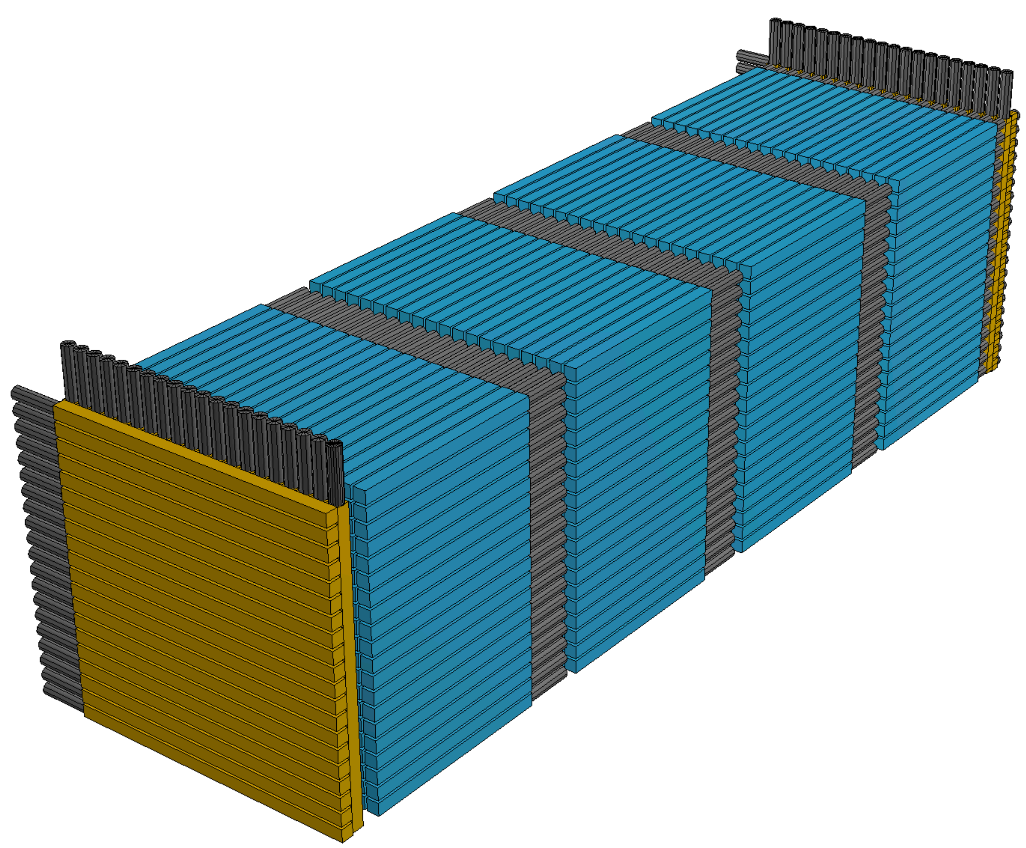
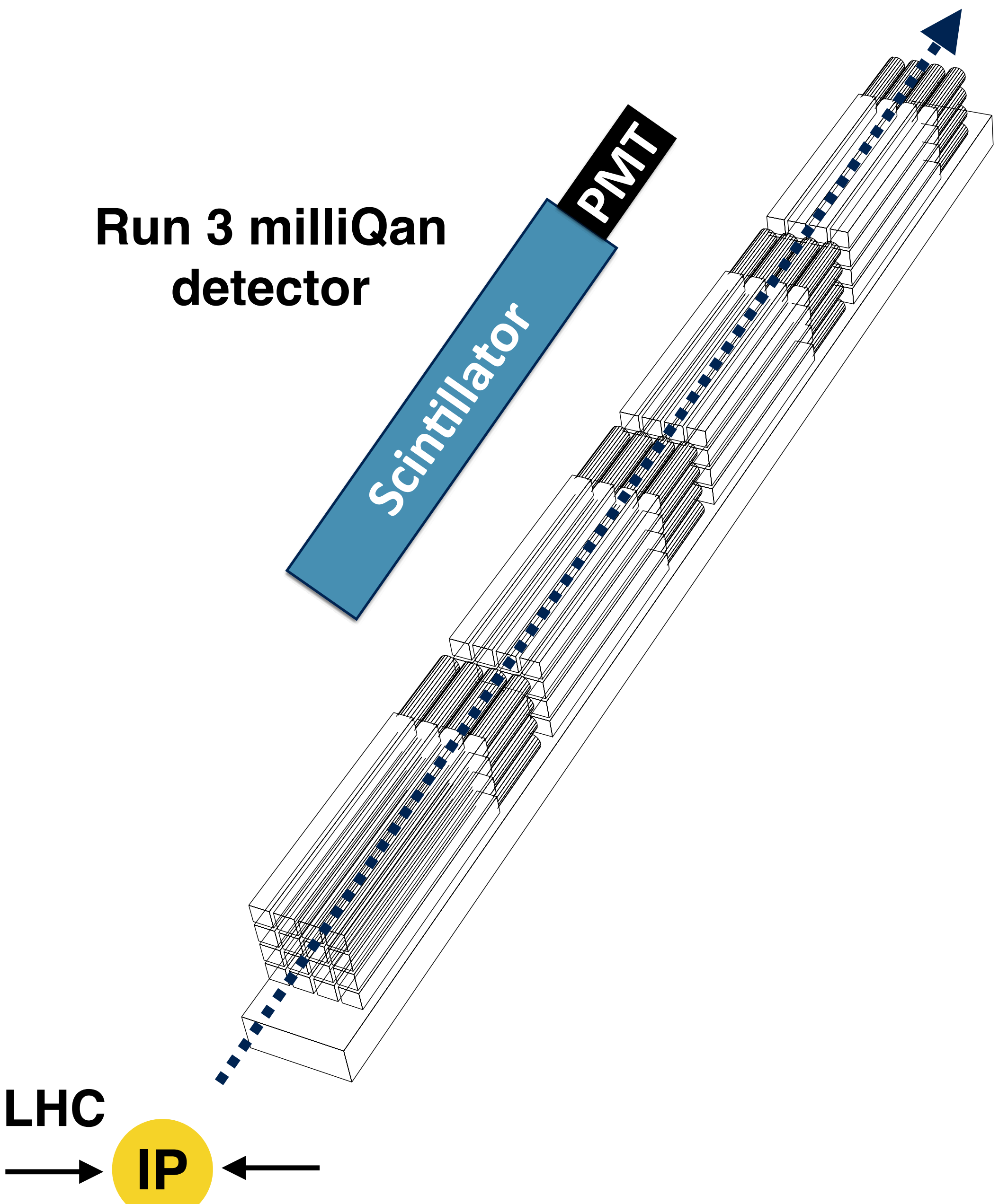
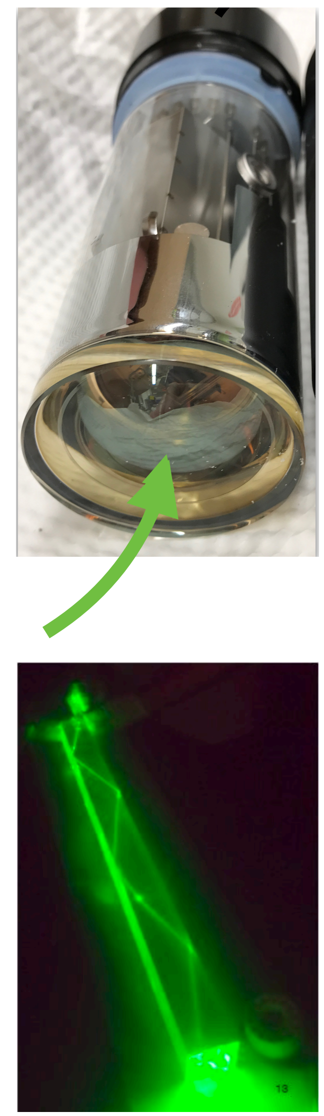
Update from FORMOSA

Matthew Citron



Searching for milli-charged particles at the LHC



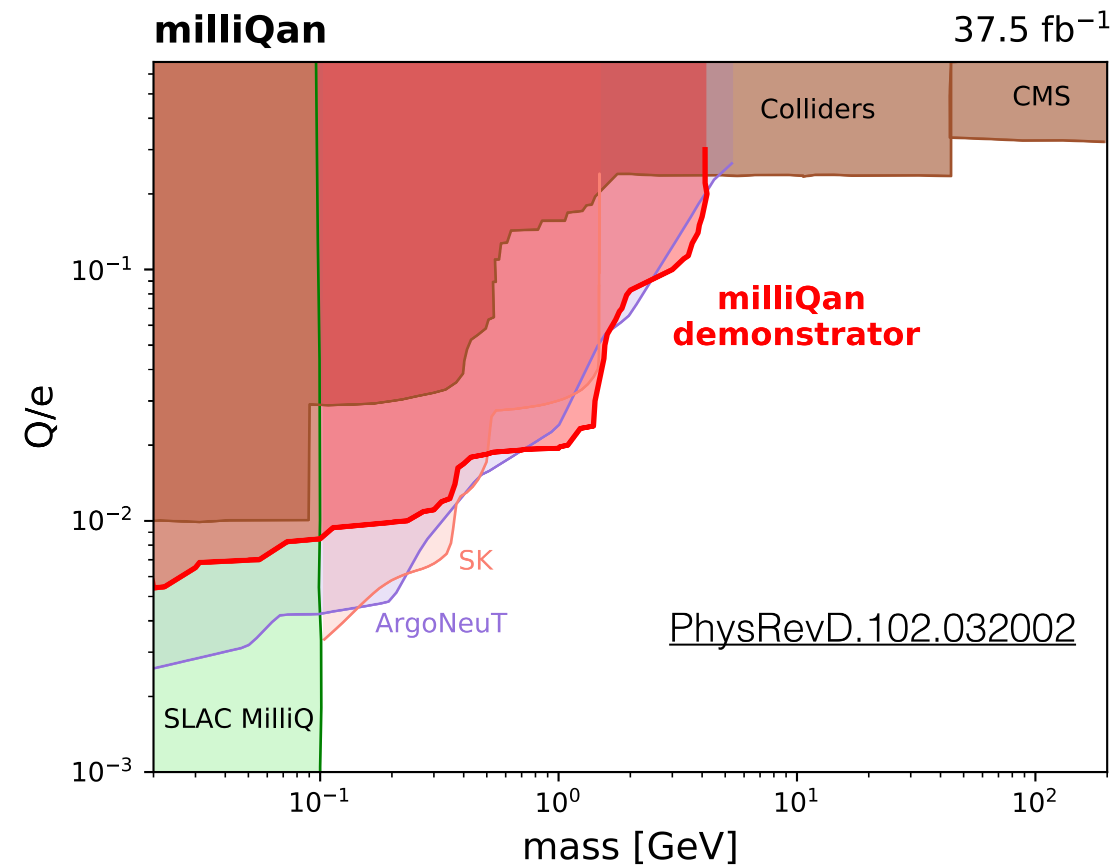


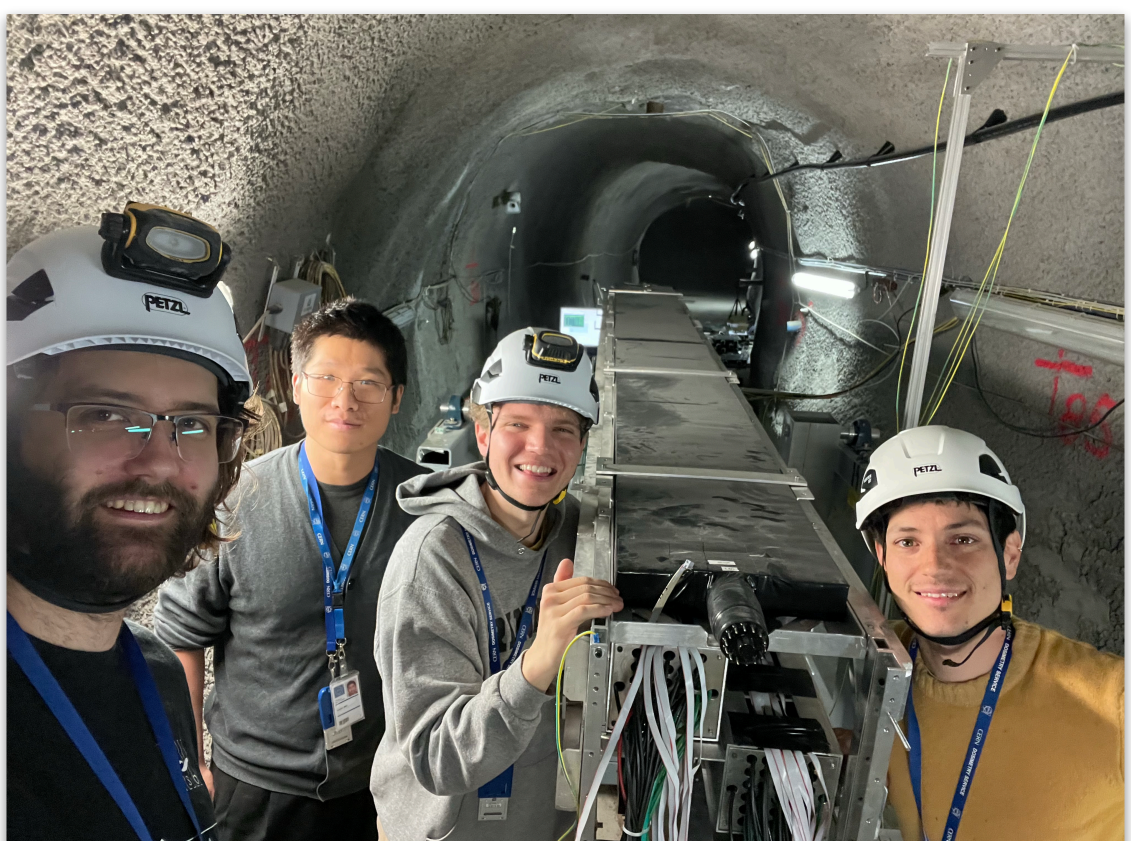
Scintillator bar

- **Key idea**: 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 time window and that points towards the IP
- Modular design is easy to scale and adapt!

milliQan has paved the way

- Demonstrator ran very successfully, collecting **~35/fb, 2000h** of data in 2018
- 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

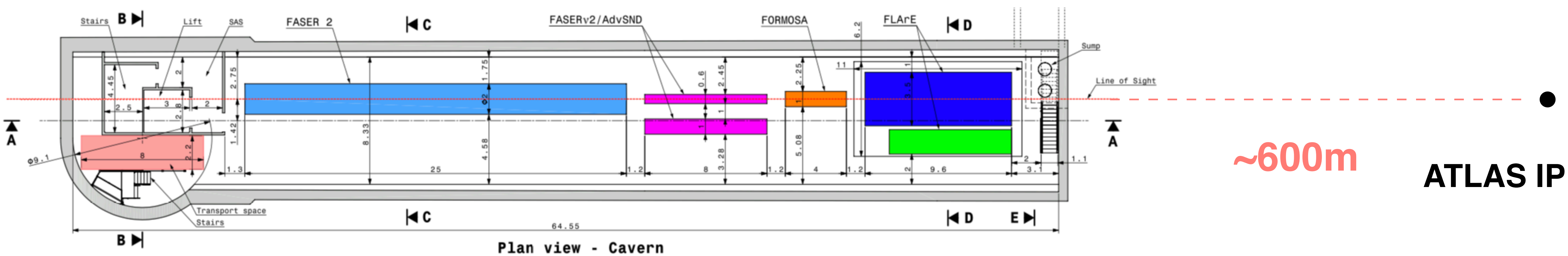


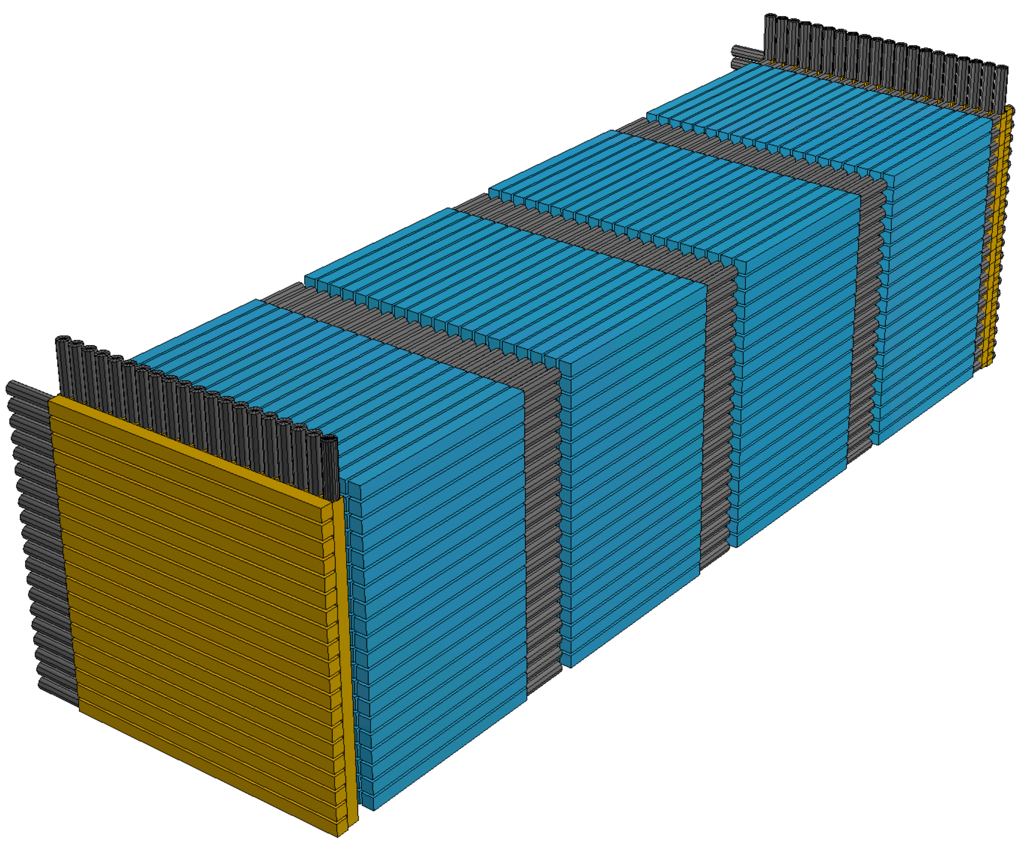


- **Quantitative understanding** of backgrounds and detector performance used to guide future detectors (PhysRevD.104.032002)
- Run 3 detectors **operational now** (see Neha's talk)

FORMOSA

Forward Physics Facility **FORMOSA**



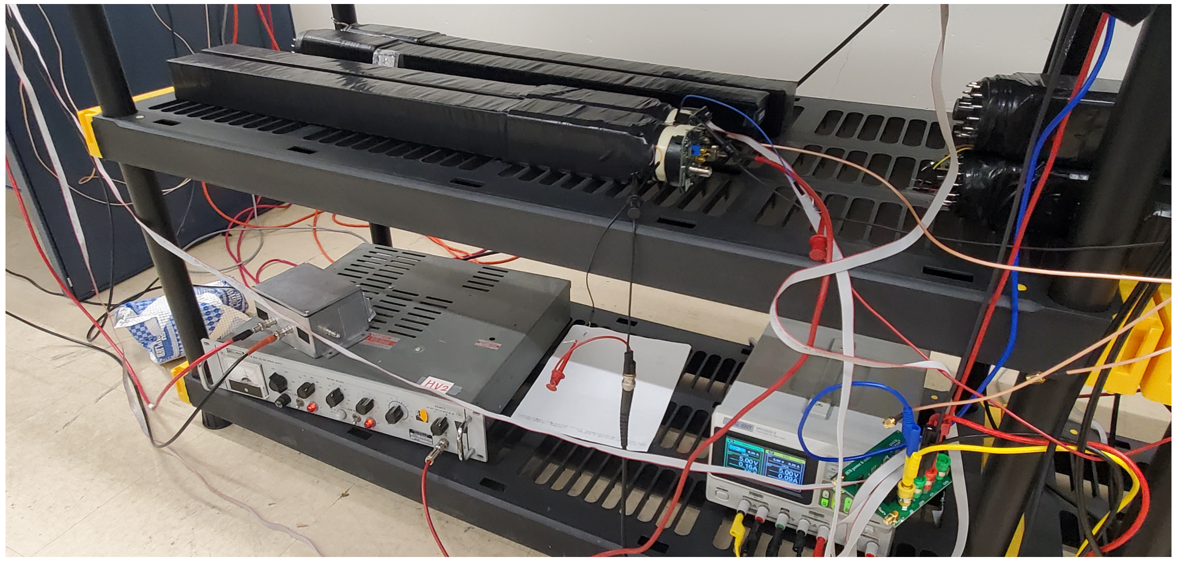


FORMOSA design in FPF paper

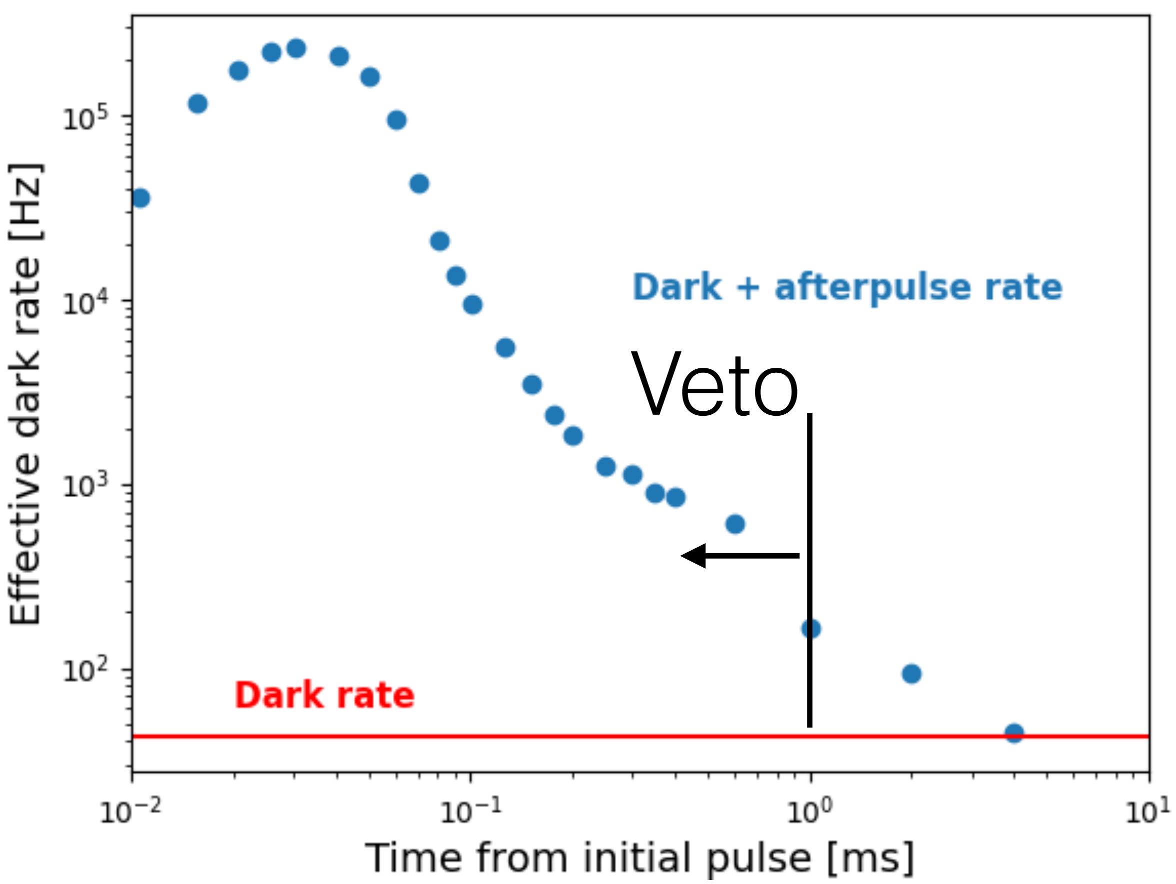
- FORMOSA: forward detector sees up to **factor ~ 250 higher** mcp rate compared to central location

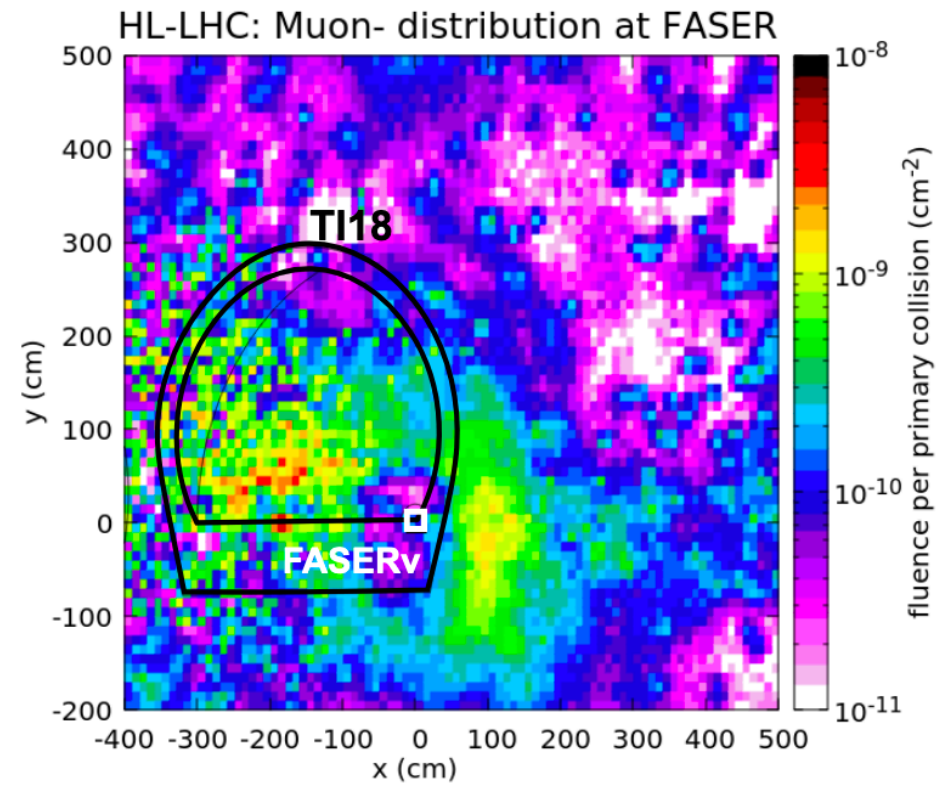
- Detector design outlined in FPF white paper: 20x20 array of scintillator bars

Main challenge: muon afterpulsing background



Measure afterpulsing induced by LED pulses





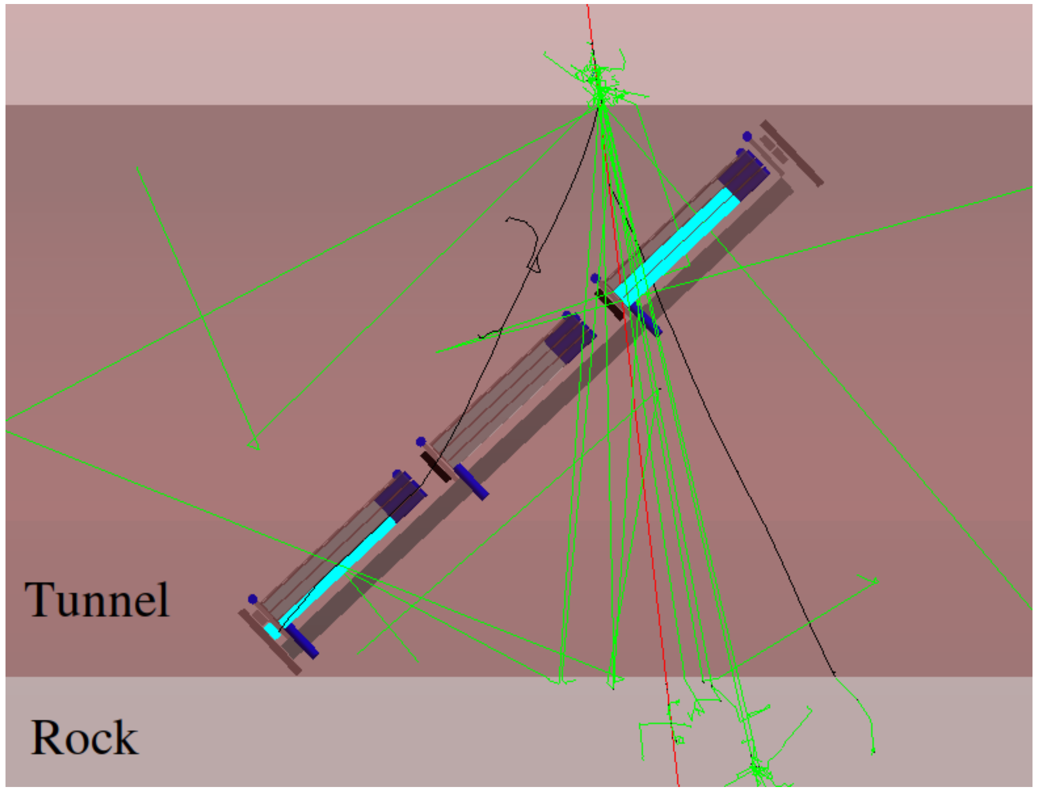
Muon rate through each "path" ~1/40ms

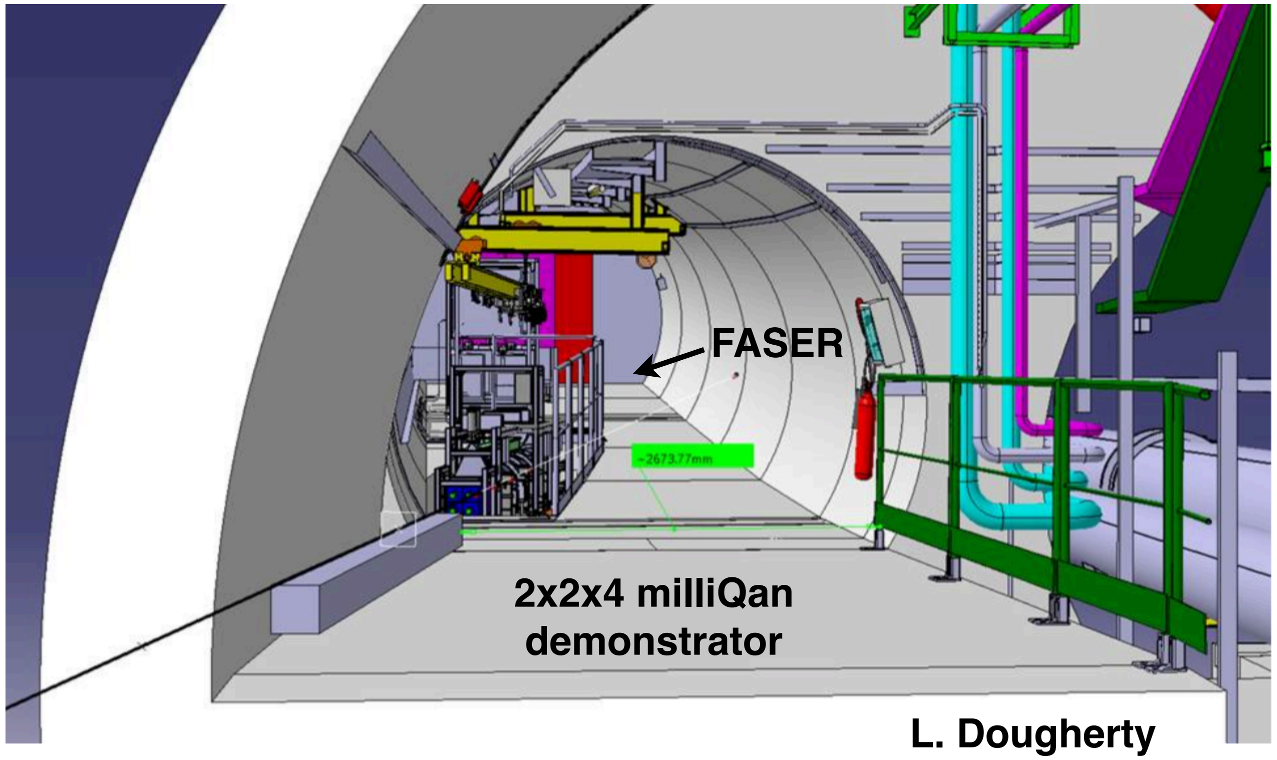
- Dominant background: **afterpulses** initiated by through-going muons
- Bench studies suggest veto possible with ~ few % deadtime
- Plan "FORMOSA demonstrator" in FASER cavern to provide **critical insights** into backgrounds/operation in forward environment

What do we want to learn?

- How can we operate in high through-going muon environment?
  - Both at DAQ/trigger level and offline analysis
- Are there any well motivated design changes/upgrades?
  - e.g. PMT choice, DAQ design, scintillator, …

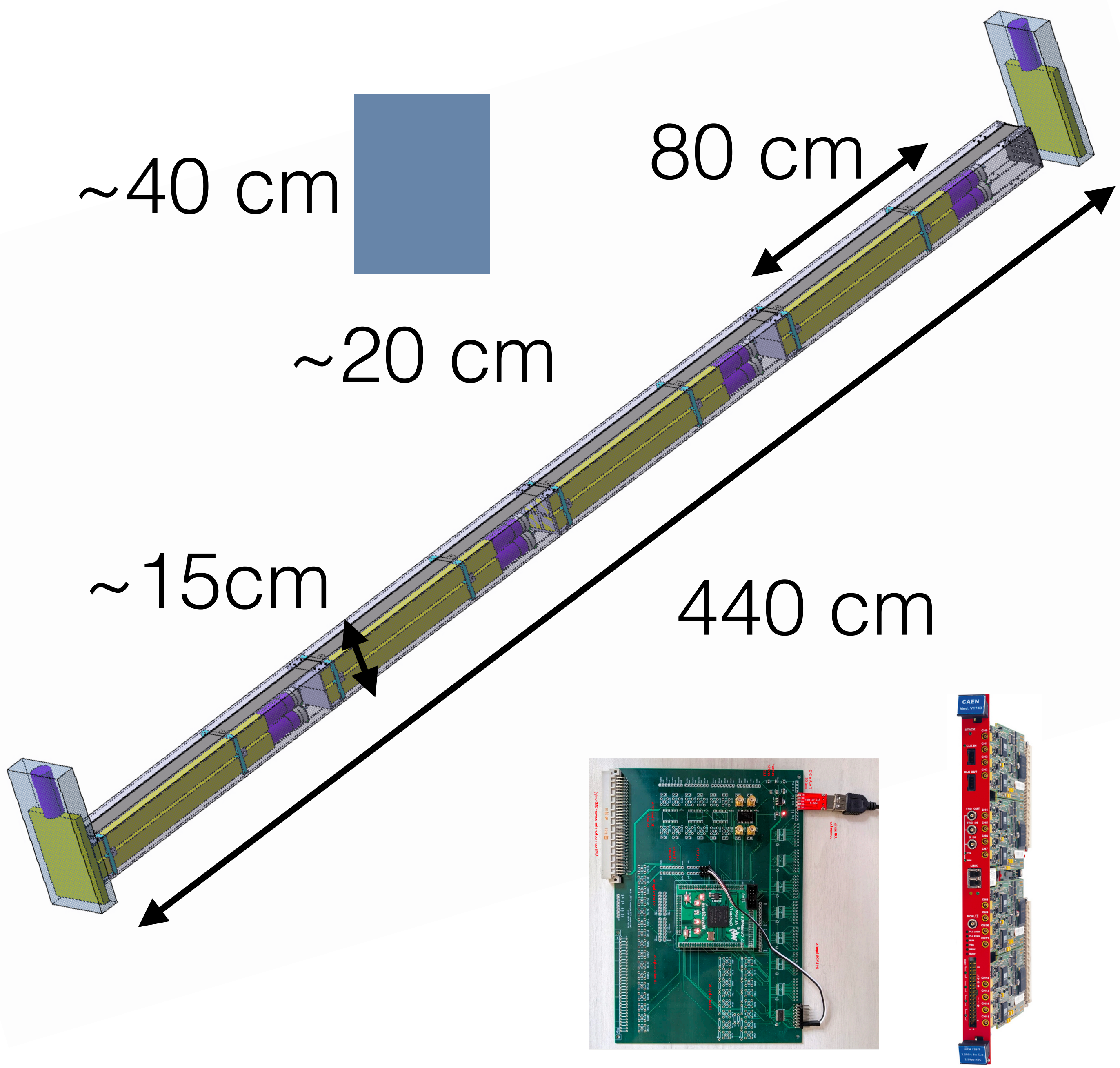
Cosmic shower background





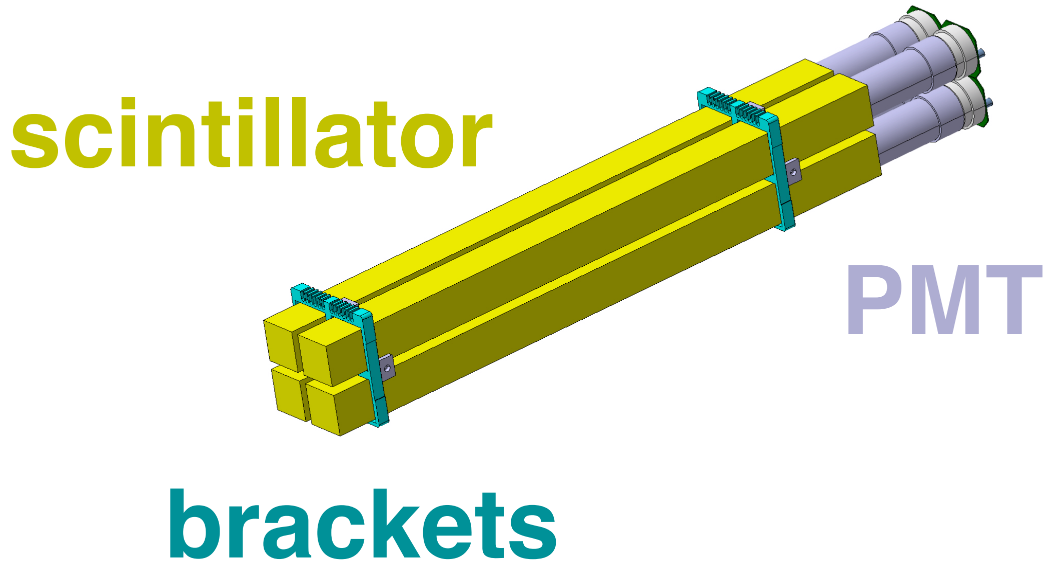
- **Measure backgrounds** and prove search for mcps is **feasible** in the forward region
- Have **funding and person power** available to target installation ~ end of 2023

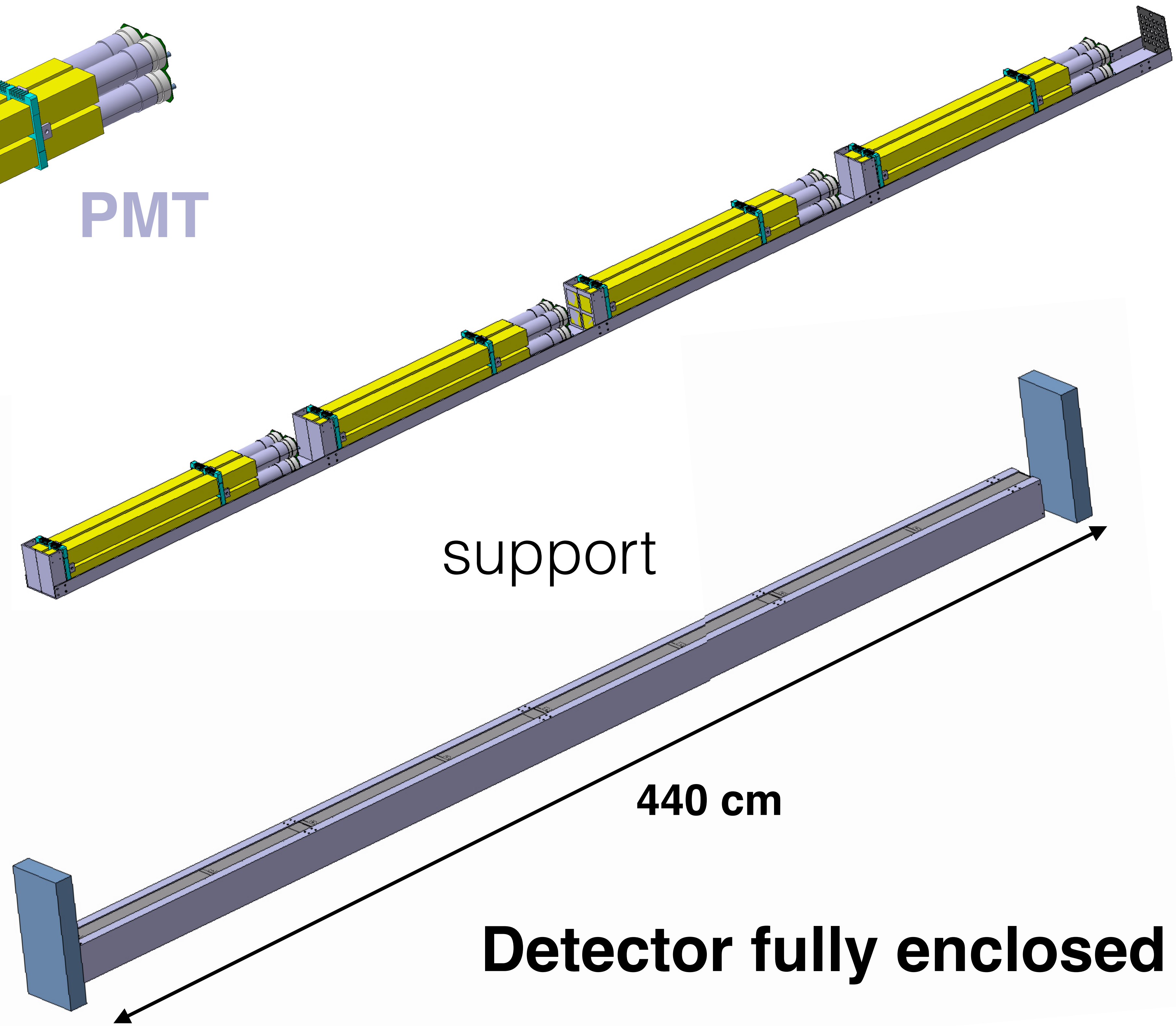
FORMOSA demonstrator



- Plastic scintillator coupled to Hamamatsu R7725 PMTs
- Four layers of 2x2 bars attached to PMTs
- Panels at the front and back for muon veto
- DAQ: CAEN V1743 and dedicated trigger board

Support structure

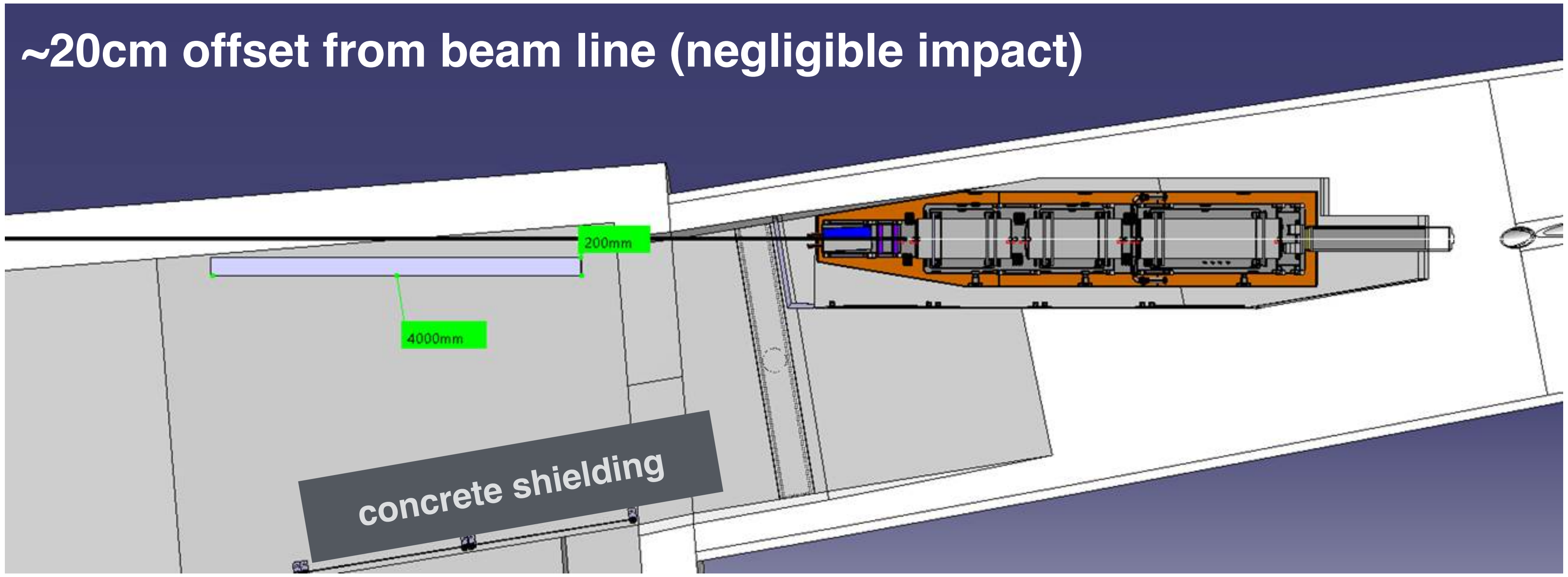


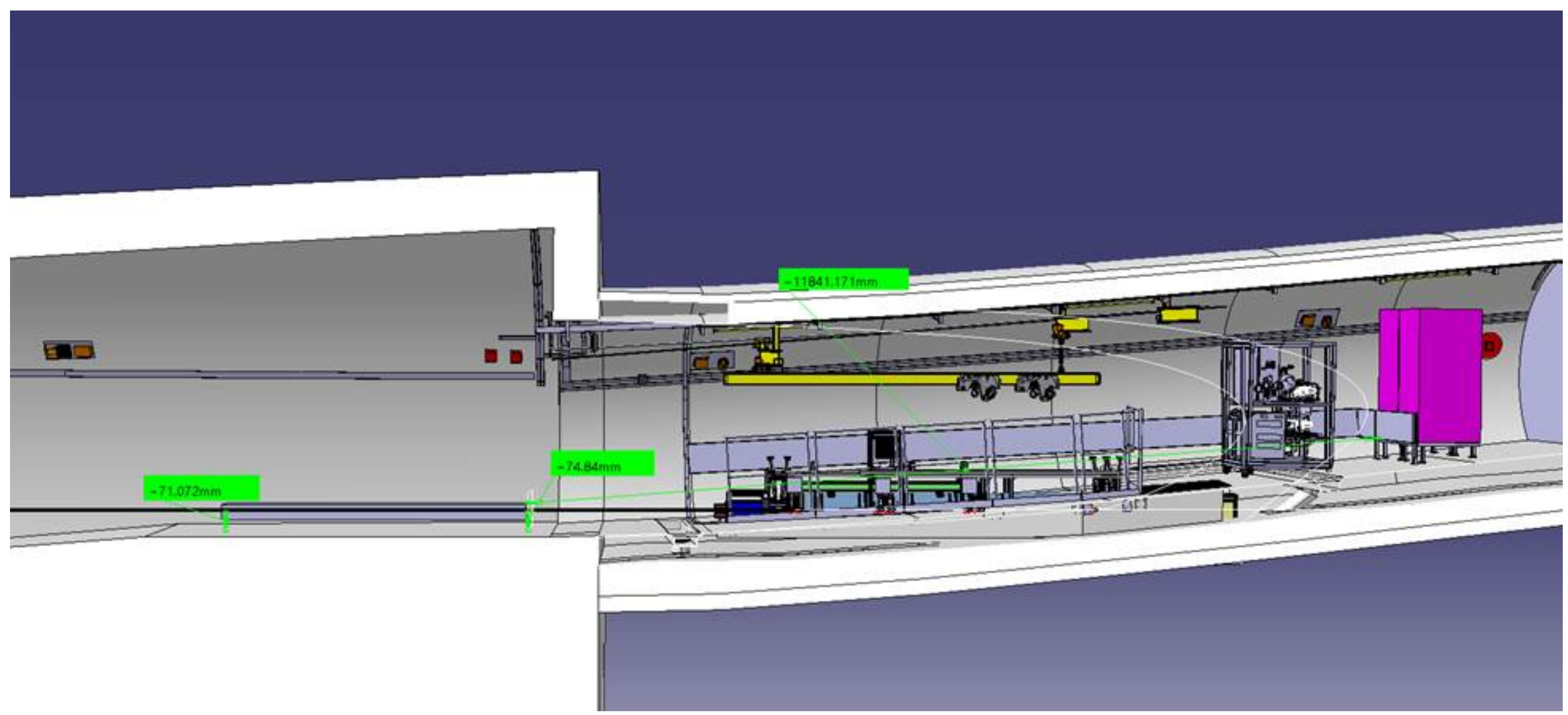


Around 50kg total weight (scintillator + structure)

Detector fully enclosed

Integration study (from Liam Dougherty)

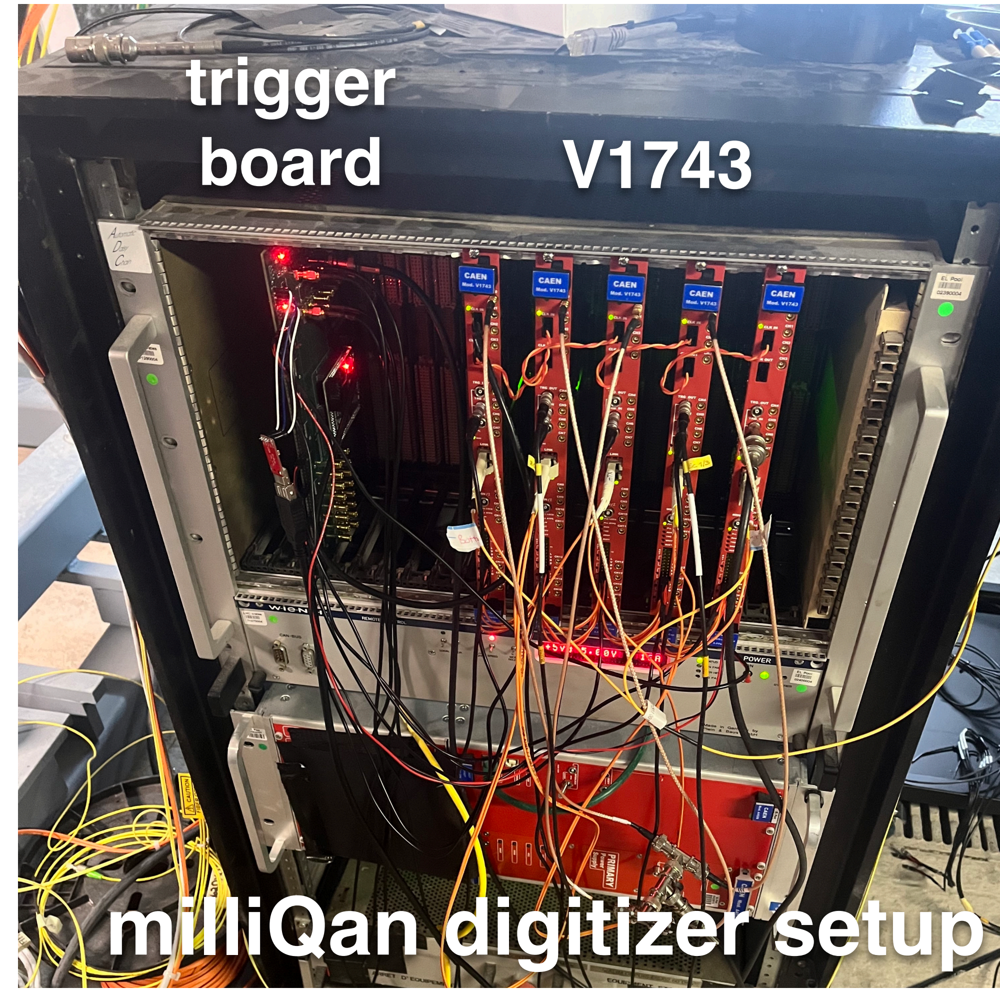


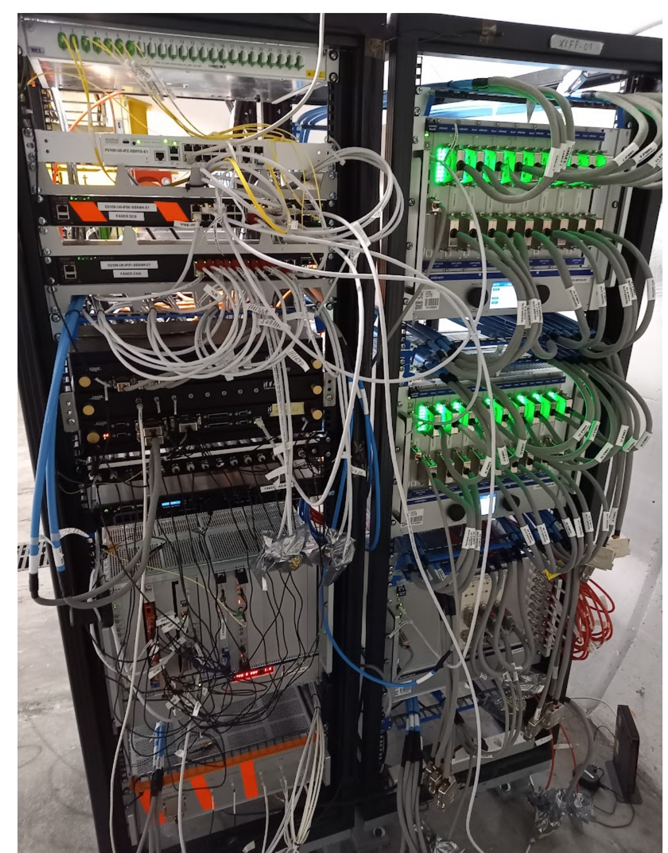


Pictures of site

Plan for readout/HV

- Preliminary plan agreed with FASER experts
- Space for DAQ and HV in spare FASER rack slots
- Will allow exploration of DAQ strategy for FORMOSA
    - Use trigger board to veto muons using end panels
- Store beam muon veto times to allow offline study of after pulse impact





FASER crate

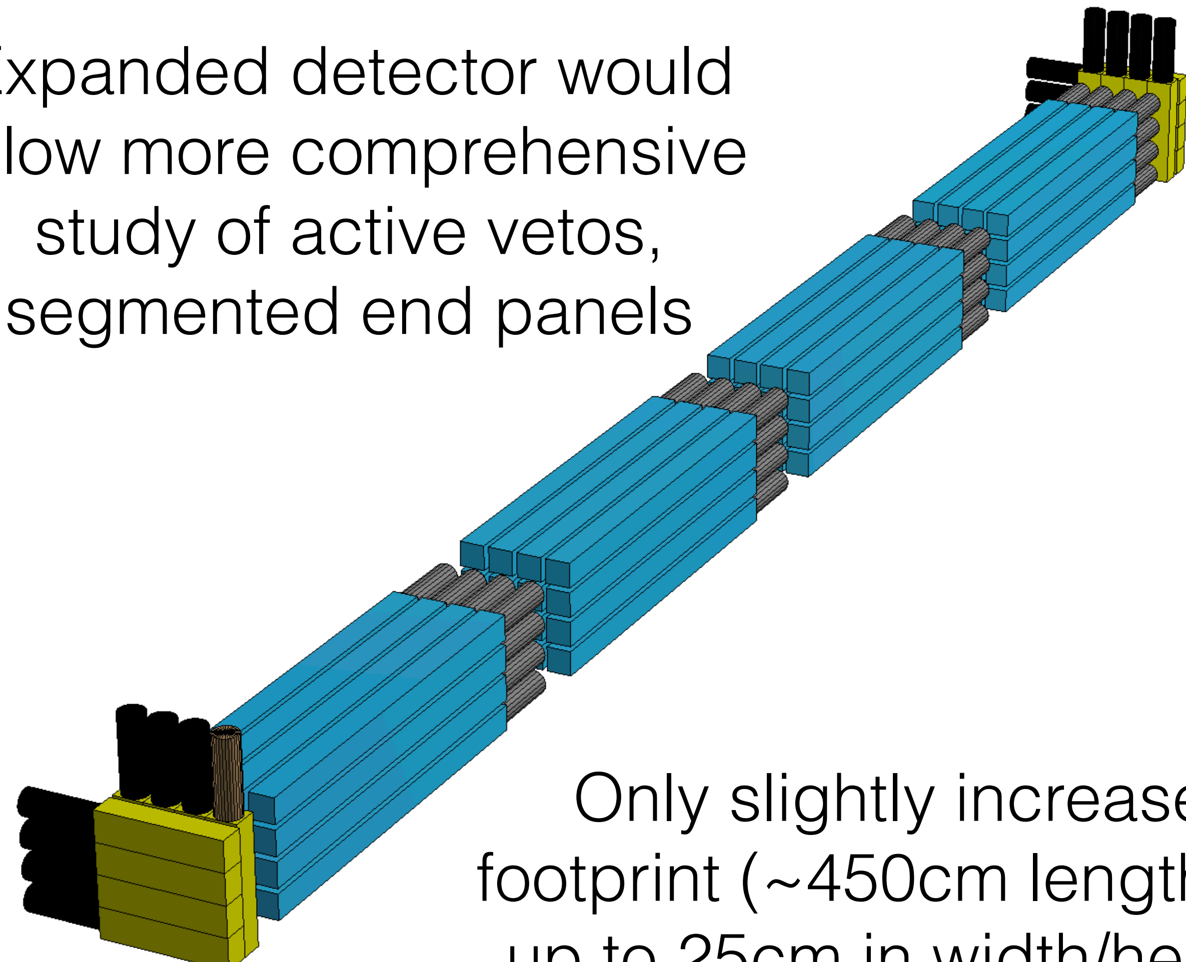
Timeline for the FORMOSA demonstrator

- Plan supported by FASER and PBC study group
    - Moving quickly through CERN safety, integration, TREX, … (many thanks to Jamie!)
- Materials ordered and arriving ~ now
- Construction summer/fall 2023 (wrapping scintillator, testing bars etc…)
- Installation over late 2023 or early 2024 for commissioning and Run 3 data taking in 2024/2025

Expansions/alterations for the demonstrator

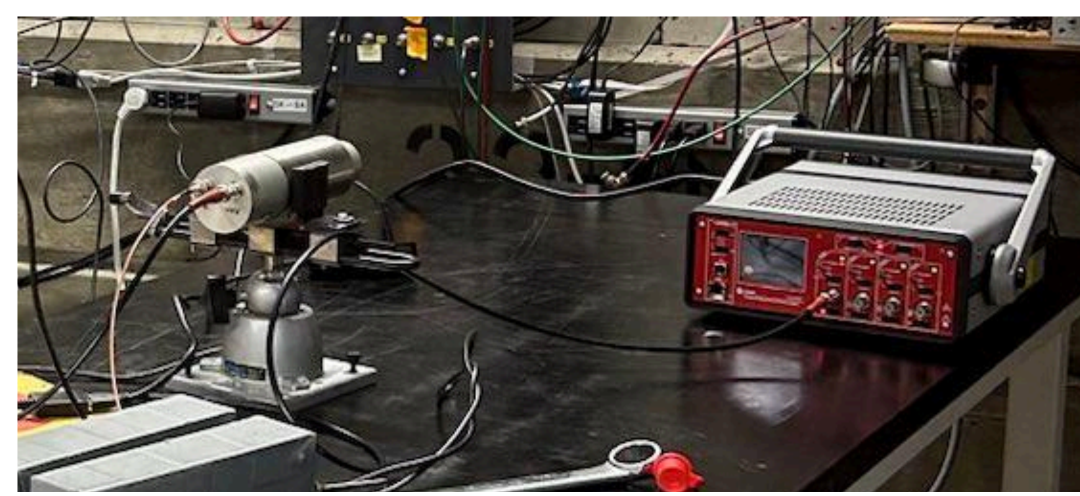
Alternative scintillator: CeBr3 has very promising performance (see next slide)

Expanded detector would allow more comprehensive study of active vetos, segmented end panels



Studying on the bench and could incorporate sample into demonstrator

Only slightly increased footprint (~450cm length and up to 25cm in width/height)

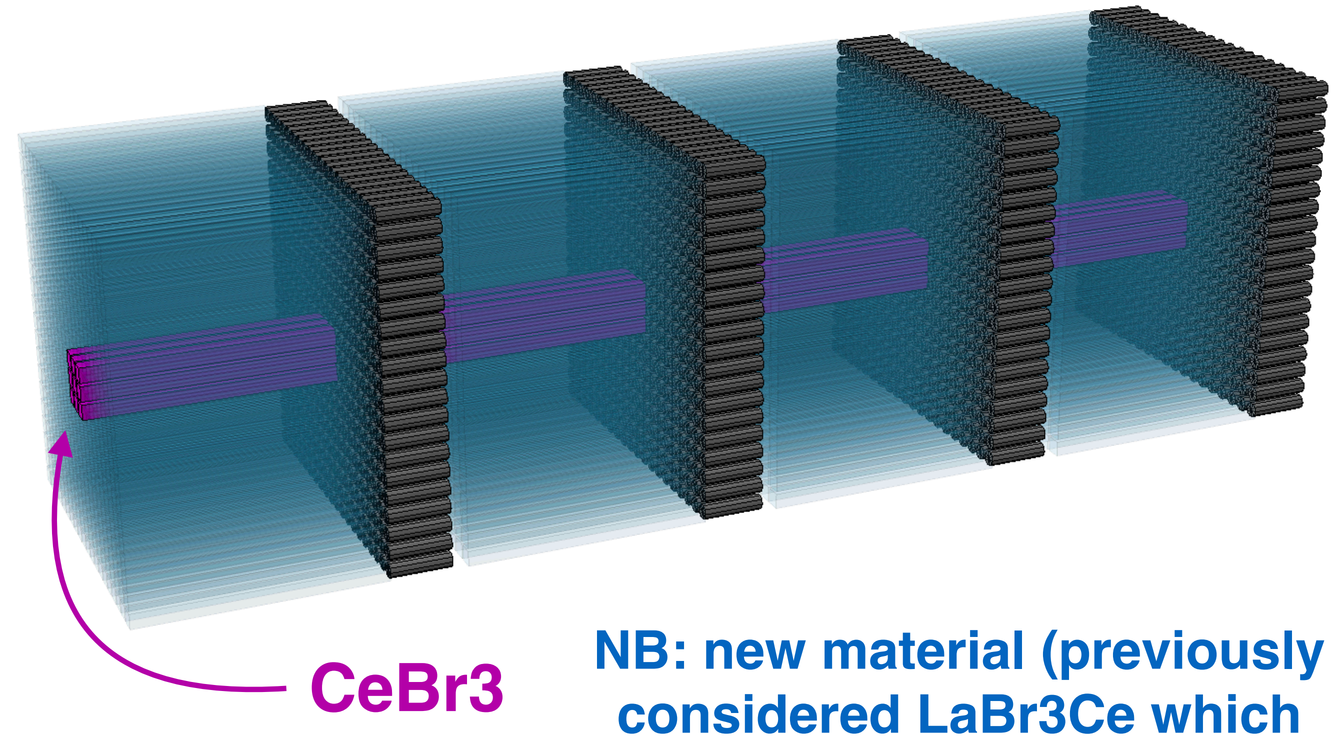


Can implement in 2024 depending on experience with initial demonstrator

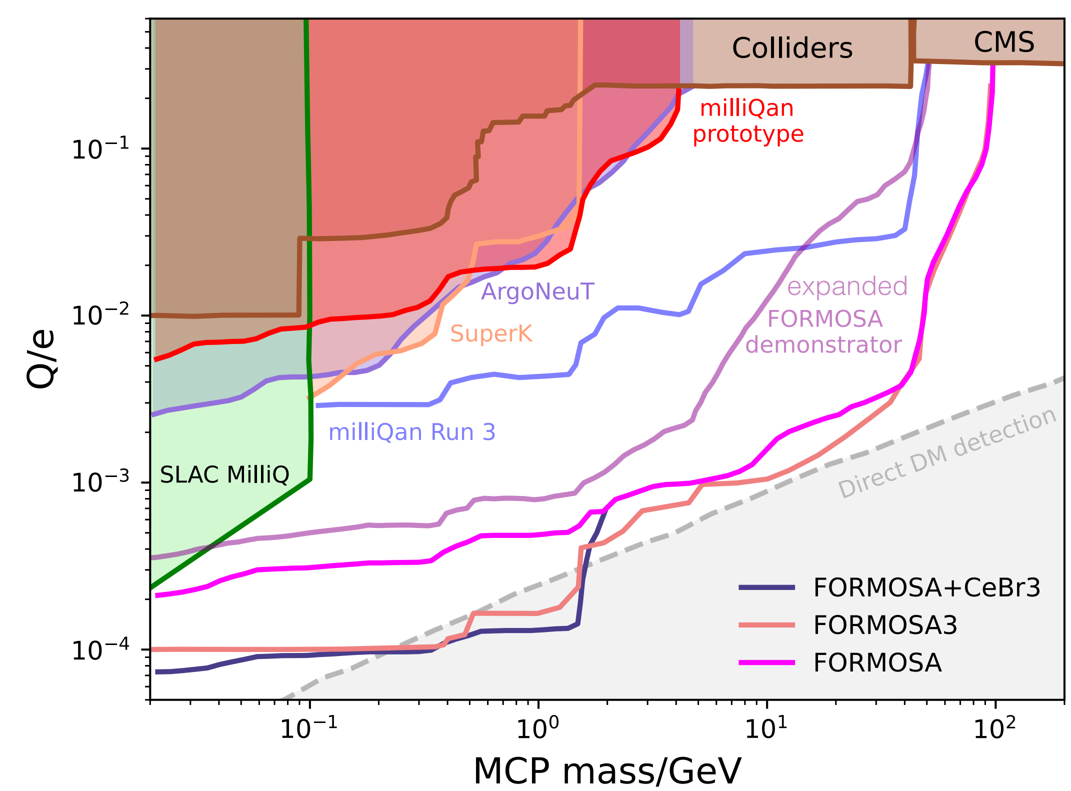
+ study bespoke DAQ (prototyping with SUBMET)

Design updates for FORMOSA

- Considering sub detector made from CeBr3
  - Factor ~35 more photons/cm of scintillator compared to plastic, fast with low internal radioactivity
- Another possibility: could we achieve low background with three layers? Can potentially mitigate cosmic showers by using a separated “satellite” layer or one hit in FlarE
- Working to update projections (also using improved simulation and propagation) with S. Foroughi-Abari, R. Schmitz, Y. D. Tsai



NB: new material (previously considered LaBr3Ce which has radioactivity issues)



FORMOSA cost/timeline (unchanged from FPF5)

from P5 input document

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033-34
(HL)-LHC nominal schedule	Run3	Run3	Run3	Run3	LS3	LS3	LS3	Run4	Run4	Run4	Run4	LS4
FPF/FLARE milestones		Pre-CDR and physics proposal	R&D and detetor prototypes	CDR- long lead item magnet	Start of civil constr. TDR for detectors	Detector construction start	Long lead items for detector	End of civil constr. Install services	Detector install	Detector Commission ing and physics start	Physics running with full complement of detectors	
US-DOE FORMOSA (kUS$)						800	1600	4000	1600			

Cost

- Overall cost (with labor) for nominal FORMOSA ~$7-8M (materials only ~$2-3 M)
- Alternative designs/scintillator small impact on overall cost
- To be discussed further tomorrow…

Timeline

- Conservative estimate of ~3 years to construct full experiment
- NB: we could easily be ready earlier if facility allows
- With demonstrator/expansions collaboration will be active from ~now

Collaboration status

- Bulk of the collaboration originates from milliQan
- We have the expertise in construction, commissioning, operations, analysis, simulation to rapidly produce physics once the site is available
- Plan workshop to focus efforts

Summary

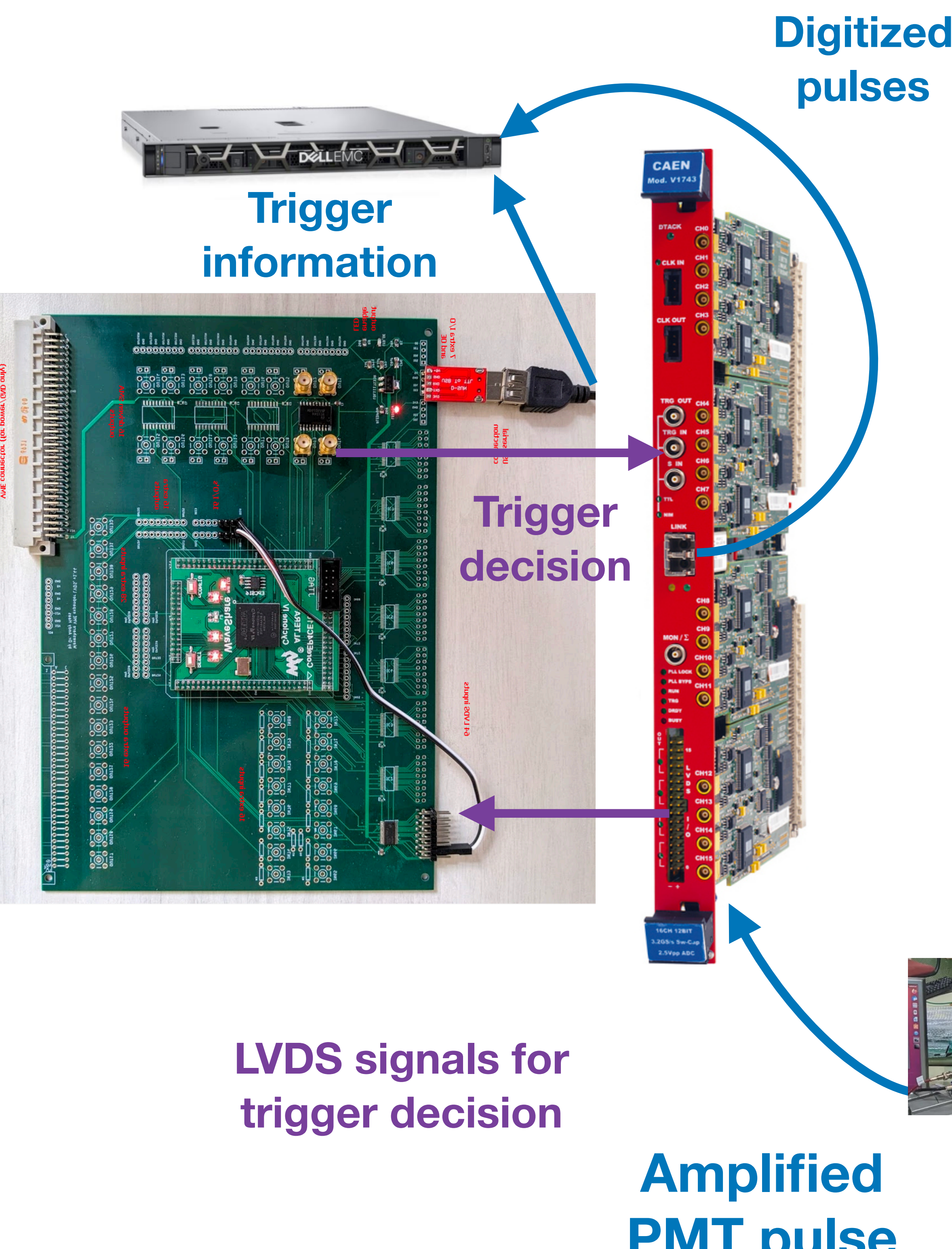
- FORMOSA design mature and collaboration taking shape

- Demonstrator advancing rapidly for 23/24 YETS installation → will prove feasibility and provide crucial inputs to experimental design, DAQ, search, …

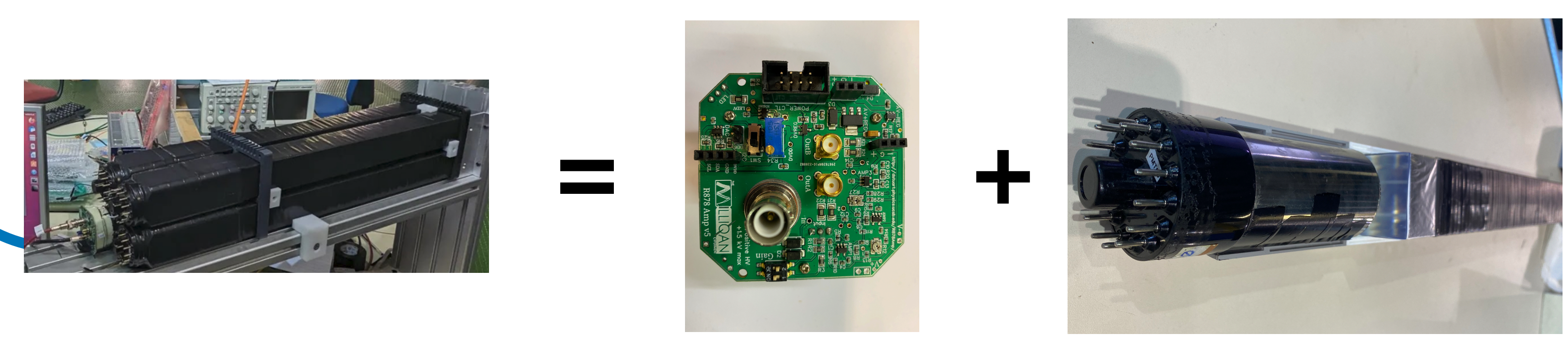
- For full detector we expect construction within ~3 years → aim to be ready as soon as there's a location!

Backup

milliQan DAQ



- **High SPE efficiency** provided by PMT output amplified with customized base (~100ns pulse length)
- **Reconstruct complete pulse information** using 16 channel CAEN V1743 digitizer with ~GHz sampling frequency over ~ μs readout window
- **Flexible trigger decisions** using customized trigger board equipped with Altera Cyclone IV FPGA



Plan for HV

- Preliminary plan agreed with FASER experts
- Each of 18 channels needs ~0.25mA at -1600V
- Could be easily accommodated by two channels (3mA max each) from CAEN ISEG EHS F030n already in rack
  - Can split to 18 at either detector or near rack

Background considerations

- Expect backgrounds from **cosmics/ dark rate** to be similar/smaller than central milliQan detector

- **Beam muon** background large (particularly **afterpulses**): 1 muon per 100μs → ~100 billion in HL-LHC dataset

  - Afterpulses: ionisation in PMTs that causes signals at regular intervals after initiating pulse (under study - see next slide)

  - Would benefit from sweeper magnet to reduce rate!

- **Environmental radiation**

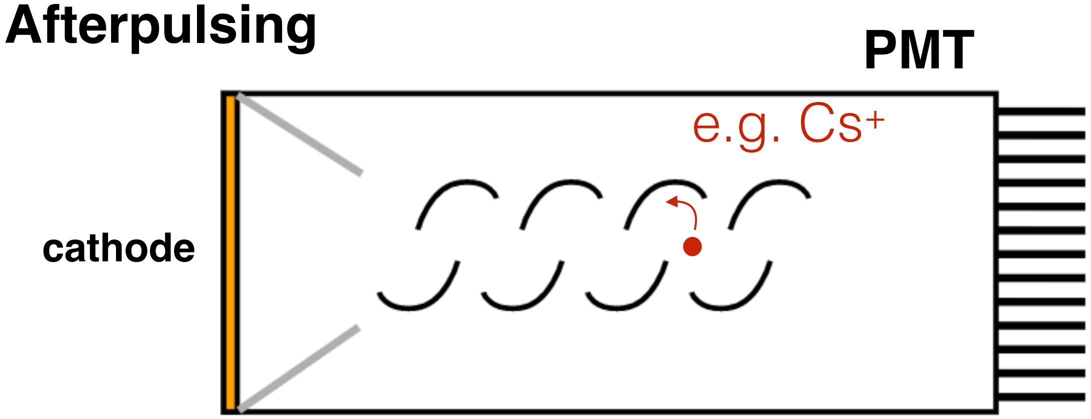
  - UJ12 measurements for FASER suggest low but demonstrator to measure in-situ ideal

Cosmic shower background from milliQan projection paper

Selection	Run 3	HL-LHC
≥ 1 per layer	8.1×10^5	8.2×10^7
$= 1$ Per Layer	6.0×10^3	1.1×10^4
Panel Veto	1.1×10^3	3.1×10^3
Slab Veto	780	3.0×10^3
Four In Line	0.19	2.9×10^{-4}
Max n_{pe}/Min $n_{pe} < 10$	0.061	9.1×10^{-5}
-15 ns $< \Delta t_{max} <$ 15 ns	0.012	2.0×10^{-5}

Dark-rate expect ~0-1 event in full HL-LHC dataset depending on dark current

Afterpulsing



afterpulse source	duration (typ.)
luminous reactions	20 to 100 ns
ionization of residual gases:	
- in the electron-optical input system	H_2^+: 0.3 μs
	He^+: 0.4 μs
	CH_4^+: 1 μs
- in the electron multiplier	1 to several μs, e.g. 3 μs for Cs^+

Photonis

Material Cost (based on milliQan experience)

Item	Cost per unit	N required	Cost
Scintillator Bars	$150	1600	$240k
PMTs + bases*	$800	1600	$1280k
HV and readout cables	$40	3216	$129k
Readout (CAEN)	$8k	102	$816k
Custom DAQ: Readout (no CAEN)	$40	1608	$129k
Panels	$6.1k	6	$37k
Slabs	$11k	2	$22k
Mechanics	$25k	1	$25k
Amplifiers	$3	1.6k	$5k
		Total No CAEN	**$1.9M**
		Total CAEN	**$2.6M**

Labor costs (based on milliQan experience)

Person	Salary + fringe	FTE/yr	Yrs	Cost (k$)
Mechanical Engineer	$150k	0.25	5	187.5
Electrical Engineer	$200k	0.10	5	100
Technicians	$75k	0.2	5	75
Postdocs	$100k	4.0	5	2000
Students	$50k	6.0	5	1500
PIs	0*	1.0	5	-
		Total		**$3.9M**

Infrastructure cost (based on milliQan experience)

- How much of these will CERN pay for?

Item	N required	Cost
FPS	1	$25k
DSS	1	$25k
DCS	1	$25k
Crates, Racks, etc	4,2	$7.5k k
Misc	-	$5k
	Total CAEN	**~$0.1M**

Construction (based on milliQan experience)

- Construction breaks down to following tasks:

1 year
- Finalize design **only small changes expected**
- PMT testing
- Bar wrapping
- PMT mounting

1 year
- SPE calibration in lab
- Mechanics - support
- Mechanics - supermodules
- Infrastructure at CERN

0.5 year
- Shipping to CERN

1 year
- DAQ system development
- Trigger system development
- HV system development

0.5 year
- Installation
- In situ calibrations
- Commissioning

1 year
- Simulation **underway**
- Offline

- Ready for physics

only small changes expected