Hardware Overview

Will Thompson

TAMBO Collaboration Meeting — Summer 2026

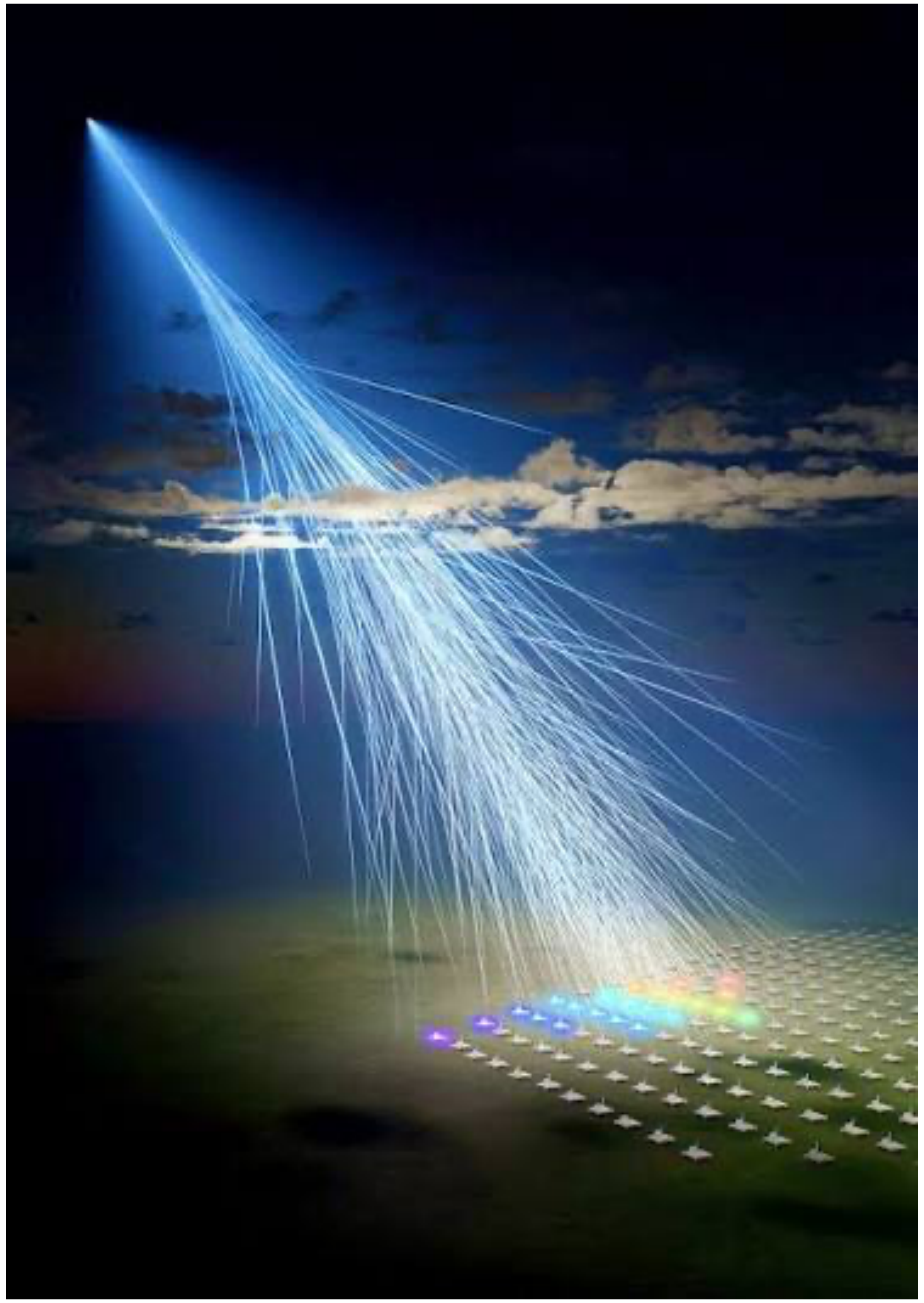
JOHN TEMPLETON FOUNDATION

VE RI TAS HARVARD

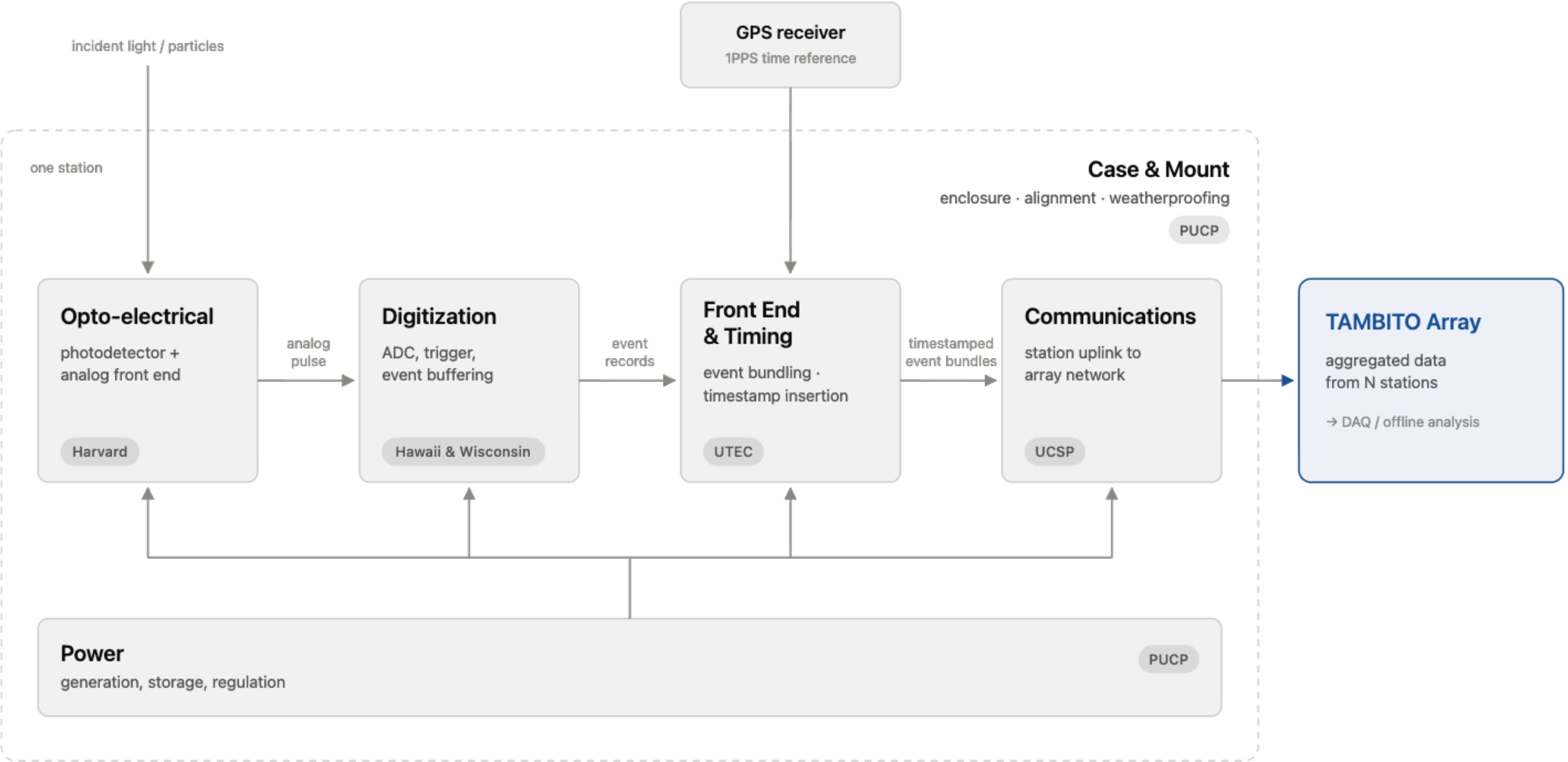
Big picture hardware requirements

Each individual detector must:

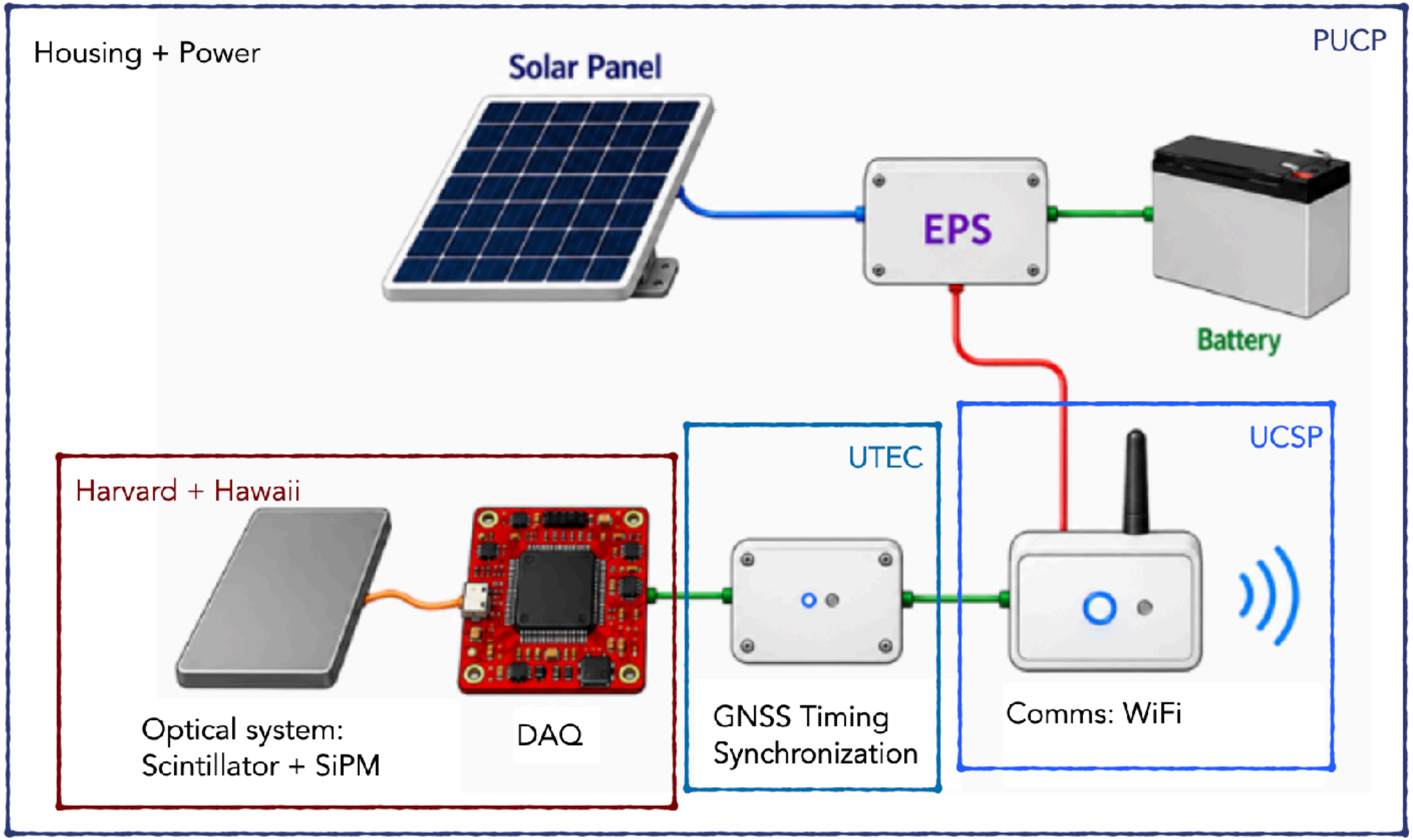
- Generate a response (electrical signal) when struck by an air-shower particle
- Digitize electrical signal
- Timestamp each event and bundle together all event information
- Send event to central DAQ system



TAMBITO array subsystems



TAMBITO array subsystems



Actually building the array requires a lot of engineering on each subsystem, so things are getting more serious

A set of requirements is essential for the engineering design!

What do our array requirements look like?

Some are very physics-driven:

- "Aperture $\geq 400\text{m}^2\text{sr} \times E_{PeV}^{1.5}$ from 1-10 PeV and 10x IceCube from 10-100 PeV"
- $\leq 1°$ air shower pointing resolution

Others are more operations driven:

- Power consumption less than xxx W per station
- Station failure rate less than xxx per year
- Construction compatible with local sourcing and repair

Example: 1° pointing requirement

Precise pointing important so we can:

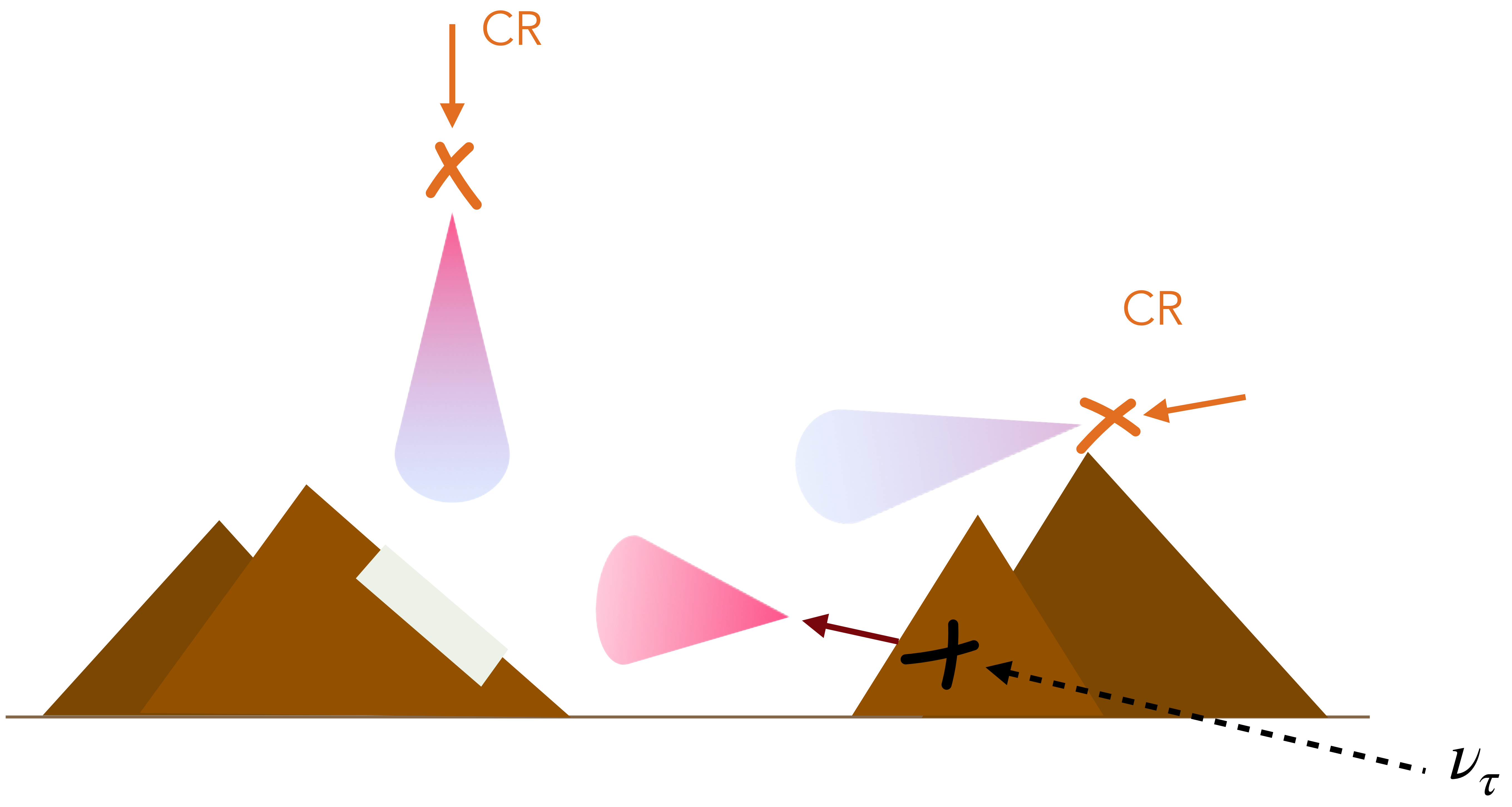
- Determine the direction of incoming neutrinos (e.g. what galaxy did they come from?)
- Reject cosmic ray backgrounds

Target: $\sigma_\theta \leq 1°$

Direction uncertainty goes roughly as:

$$\sigma_t \leq \frac{\sqrt{2} D \sigma_\theta \cos\alpha}{c} \approx 7 \text{ ns}$$

Assuming D = 150m, α = 35°



Note that 7 ns is a Gaussian 1σ uncertainty (~ 24 ns width uniform distribution)

Current timing budget by subsystem

	Front End	Scintillator	Digitization	Synchronization	Shower
Required	5.5	6.0	1.0	9.4	1.0
CBE	1.6	2.2	1.0	5.0	1.0

→

	Timing Error
Required	12.5
CBE	5.9

Technical Performance Reviews (TPRs)

Hardware design is progressing with TPRs every ~2 months

- These reviews make sure we are hitting our requirements and give an opportunity for outside feedback
- Our first TPR was in July, next in September

All information about the different subsystems can be found in the subsystem DSNs

¿Preguntas?

Scintillator R&D at Harvard

Will, Kiara, Shefali

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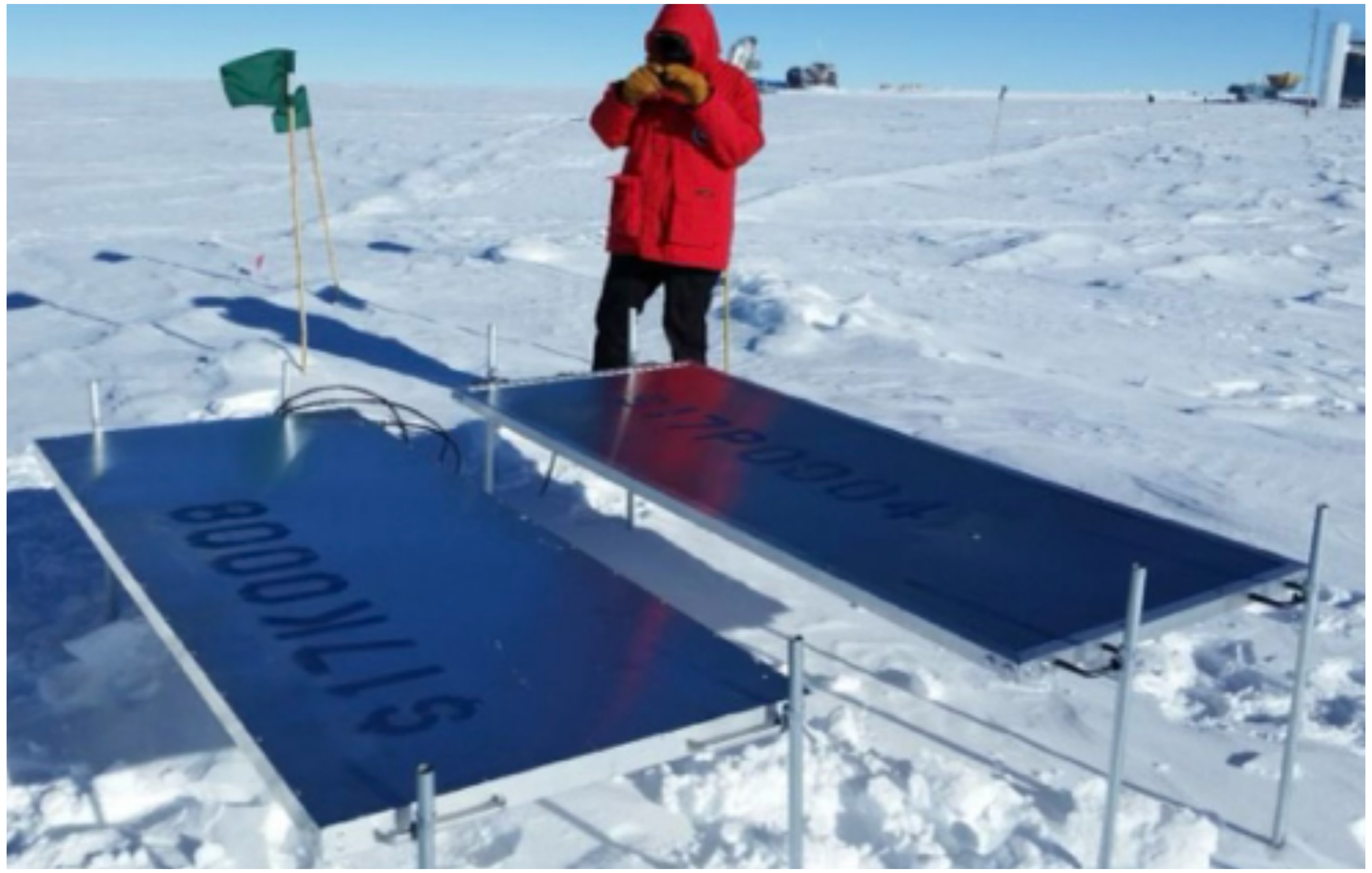
Opto-electrical system

Two main types of air shower detectors. Which should we use?



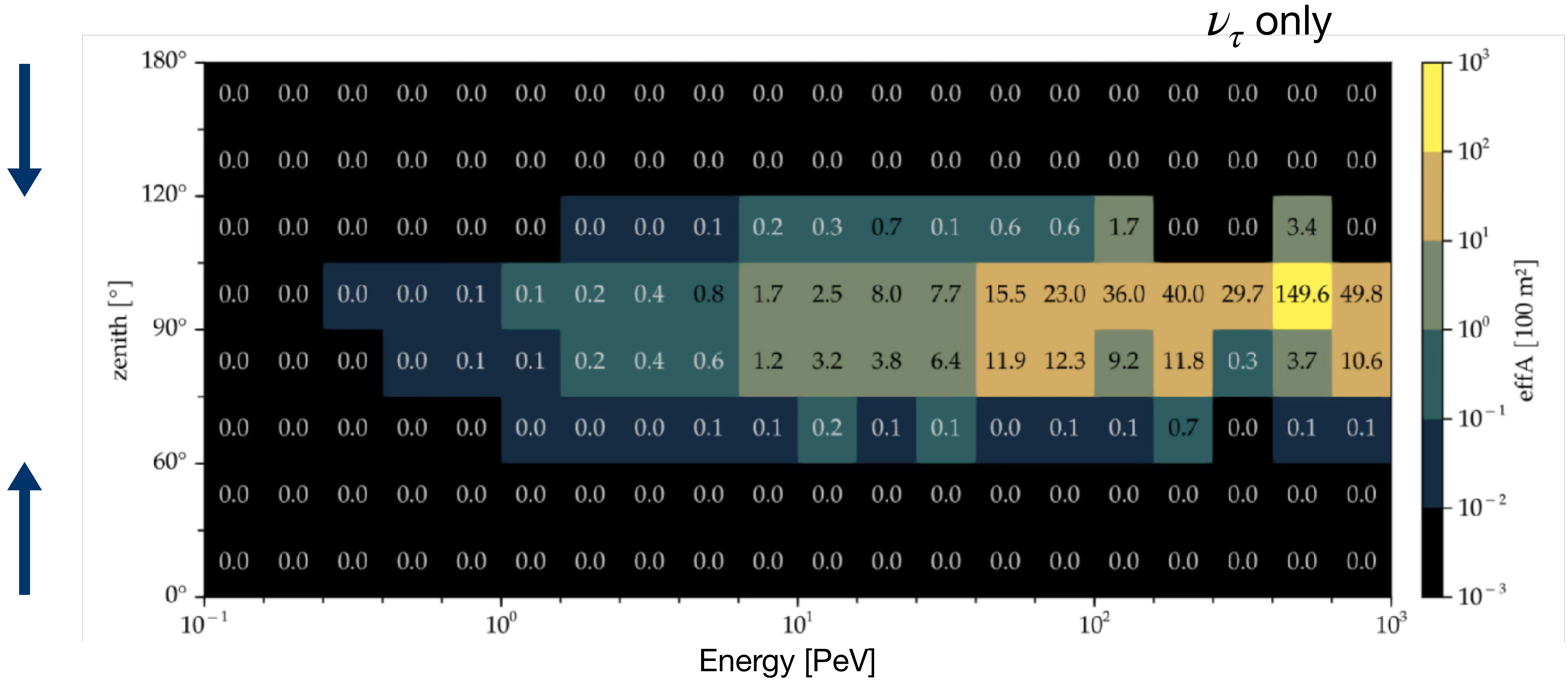
Water tanks:

- Highly gamma-sensitive (most abundant particle)
- Expensive to purify and transport water
- Difficult to deploy in canyon

Plastic scintillator panels

- Sensitive mostly to charged particles
- Can be built off-site and transported
- Easier to deploy in canyon

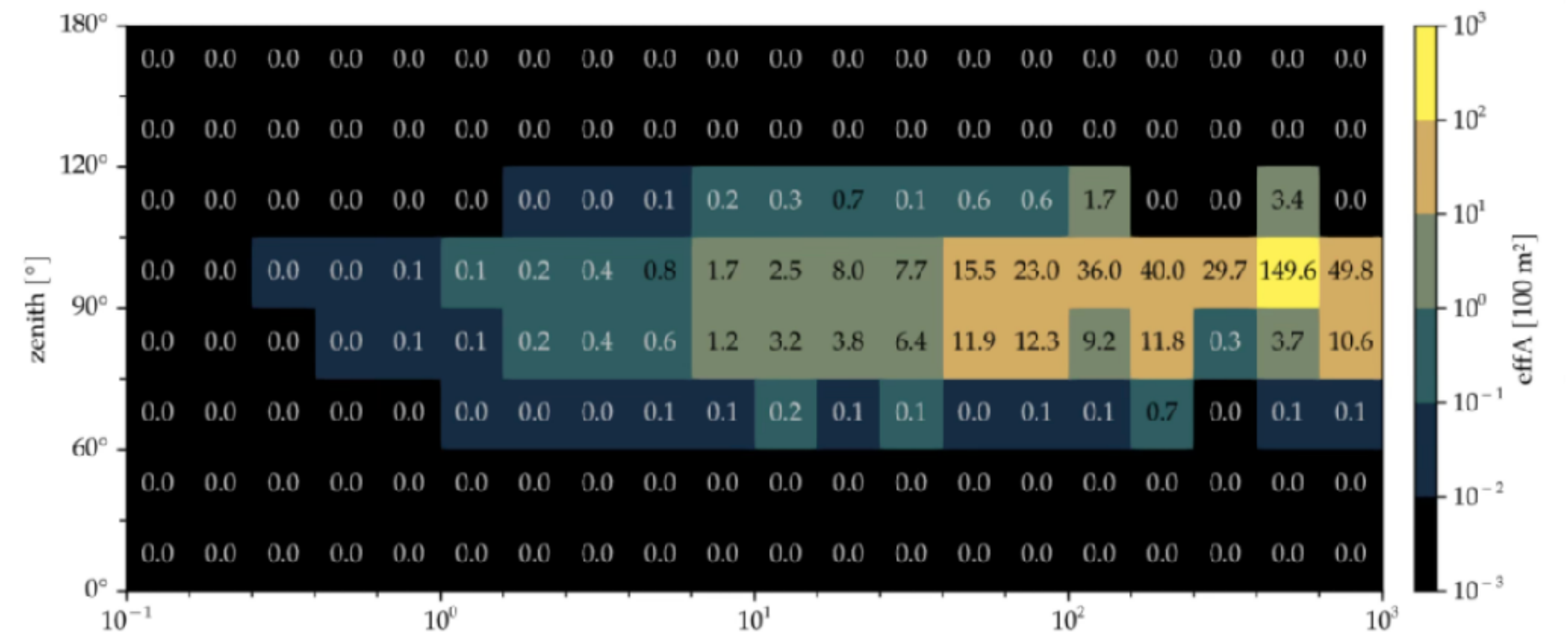
Tanks v. Panels



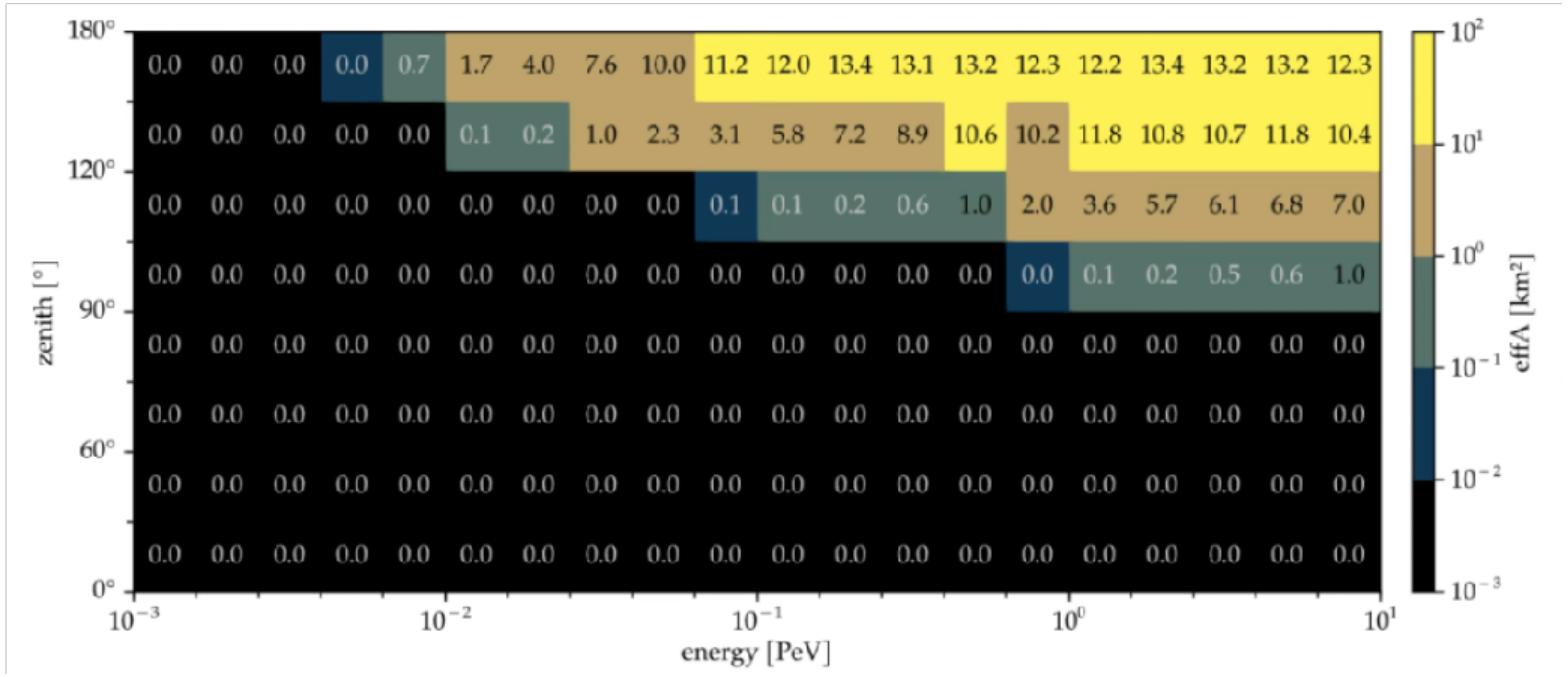
Tanks v. Panels

Filter condition: at least one hit on at least five modules

“water tank-like”

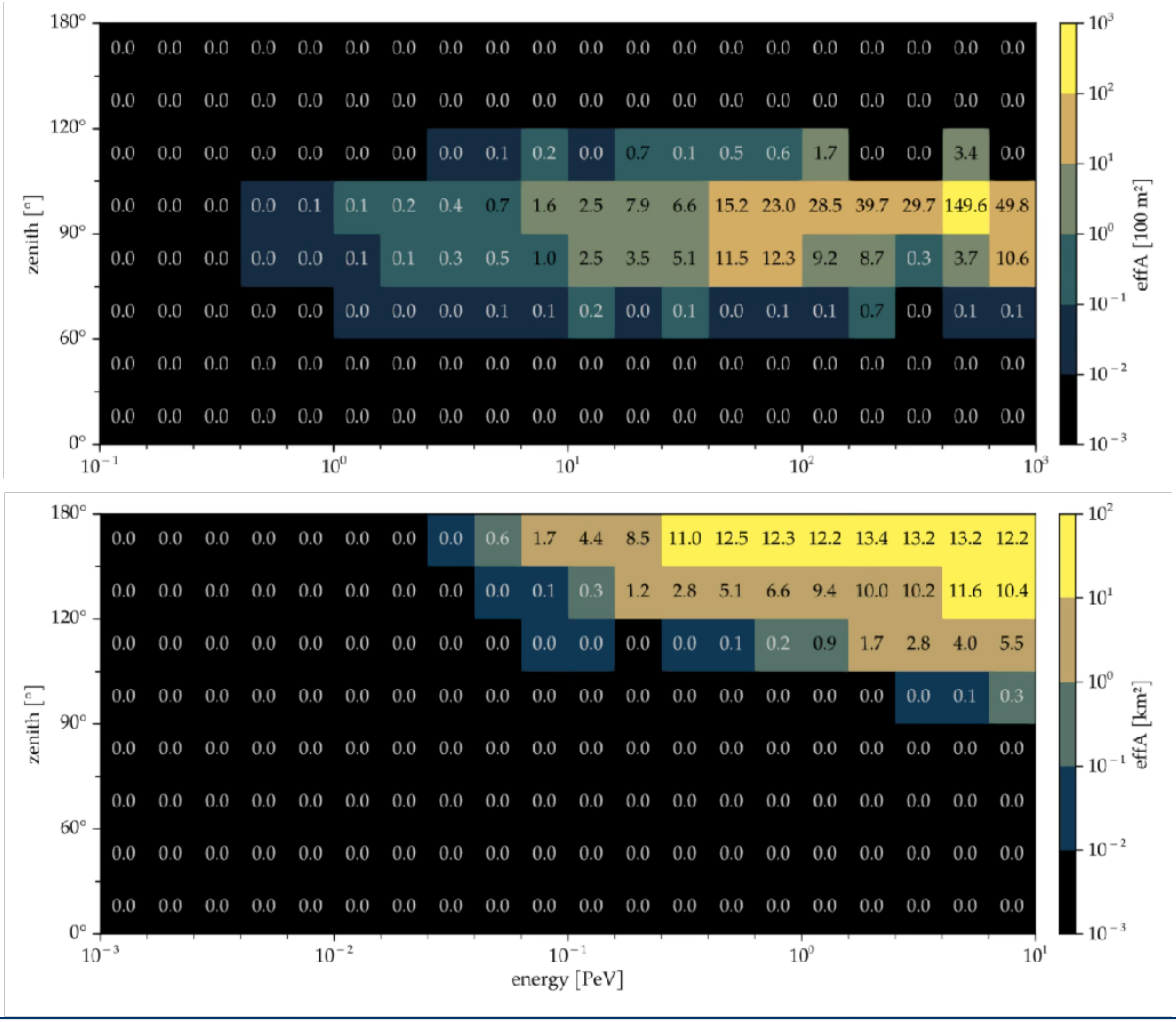


ν_τ rate: 0.47 / yr



CR rate: 30.2 kHz

Tanks v. Panels



ν_τ rate: 0.41 / yr

CR rate: 1.35 kHz

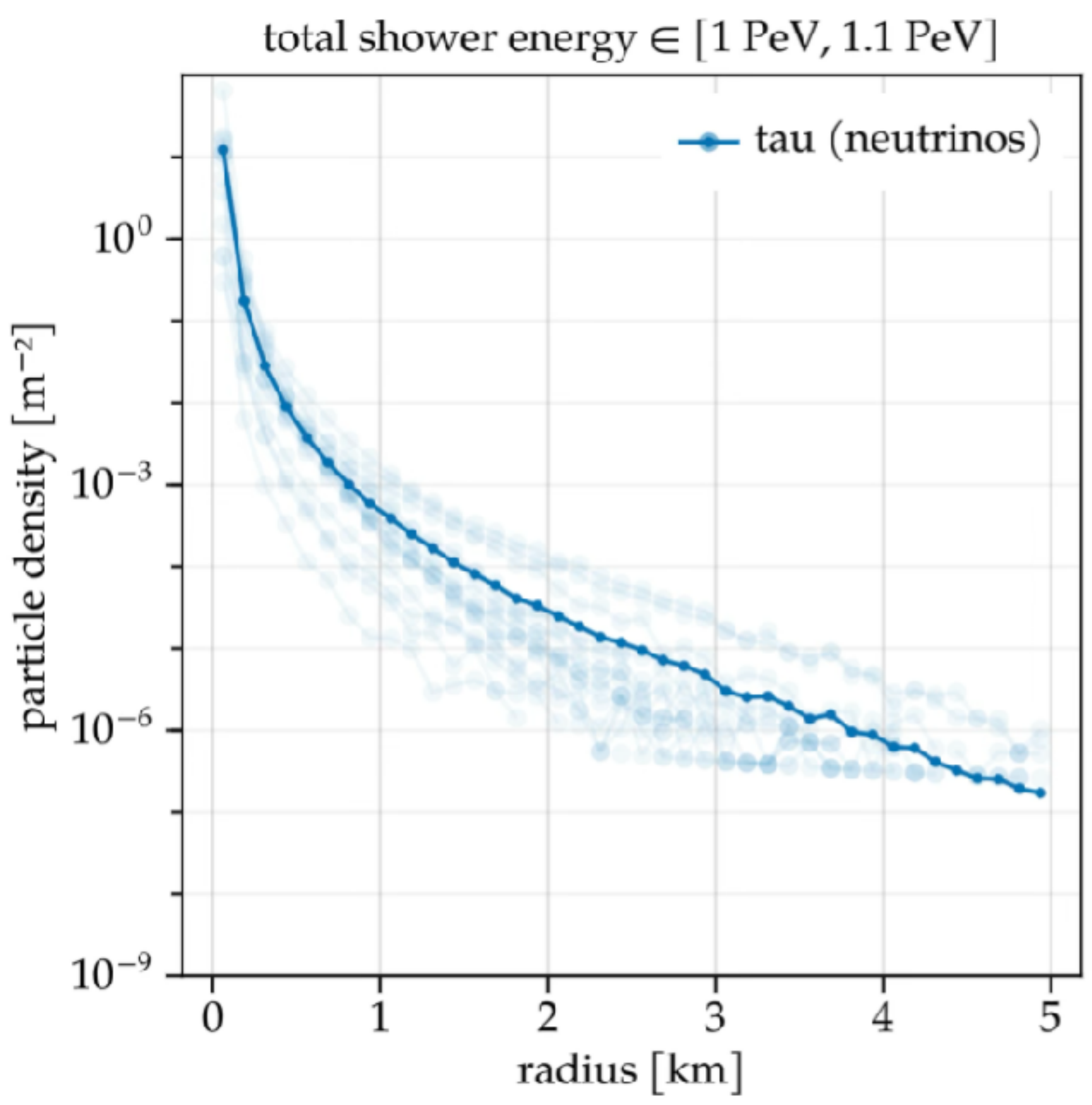
Filter condition: at least one (electron or muon) hit on at least 5 modules

“scintillator-like”

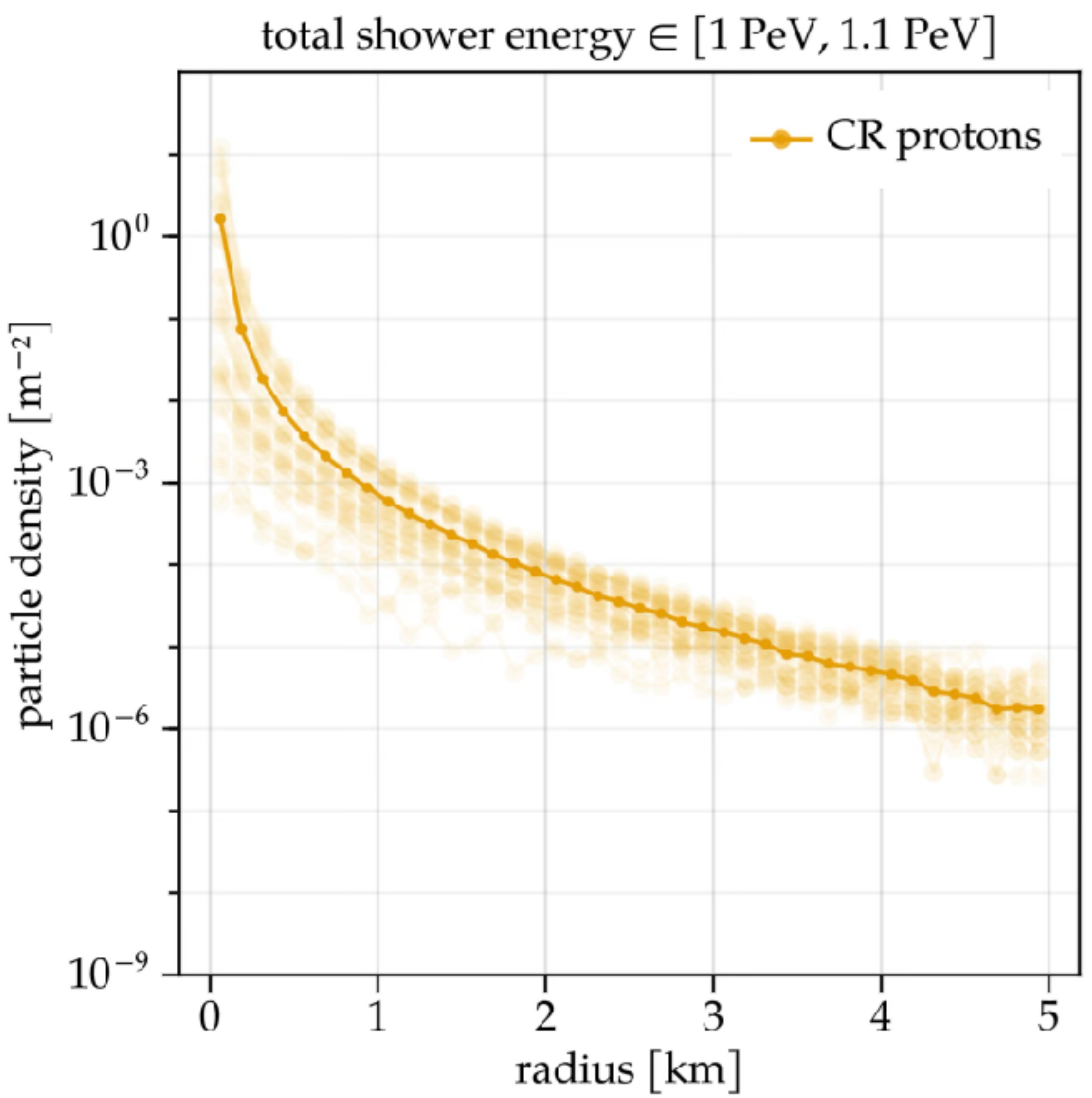
Upshot: big impact on CRs, ν_τ less affected

Tau showers have greater charged particle density than CR showers

* charged particles only



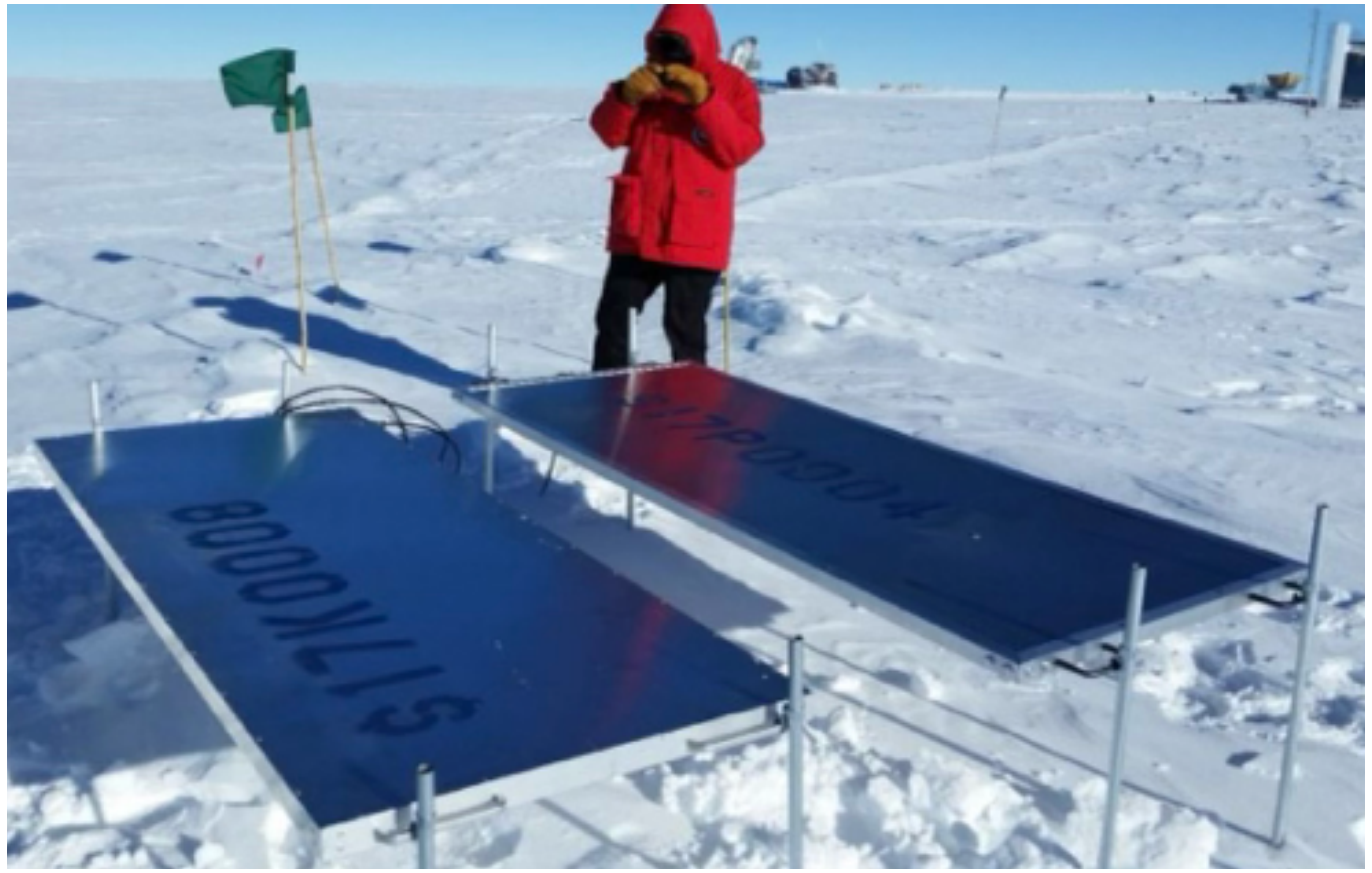
Average # in r < 125m: 12/m²



Average # in r < 125m: 1.6/m²

Opto-electrical system

Two main types of air shower detectors. Which should we use?



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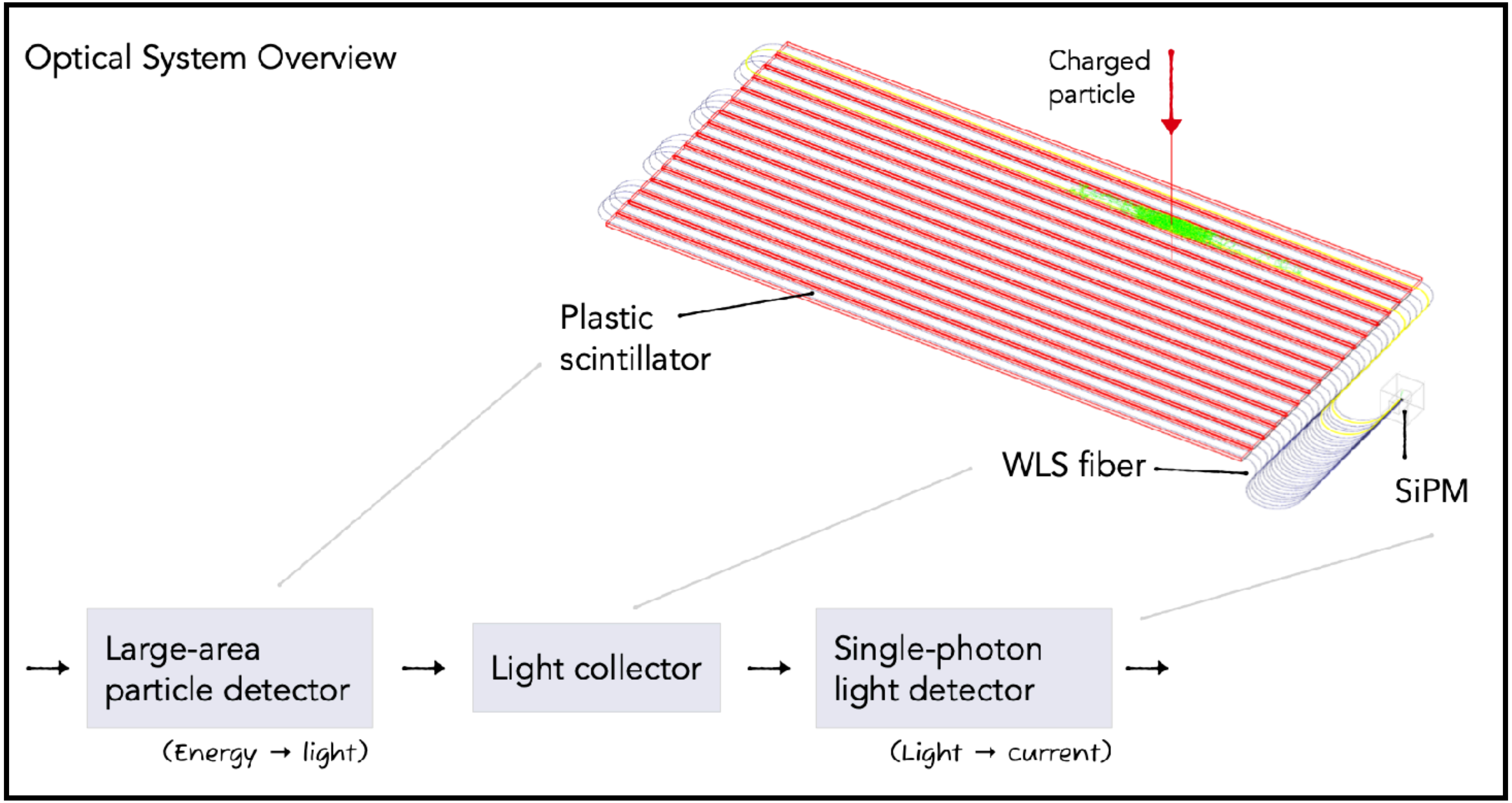
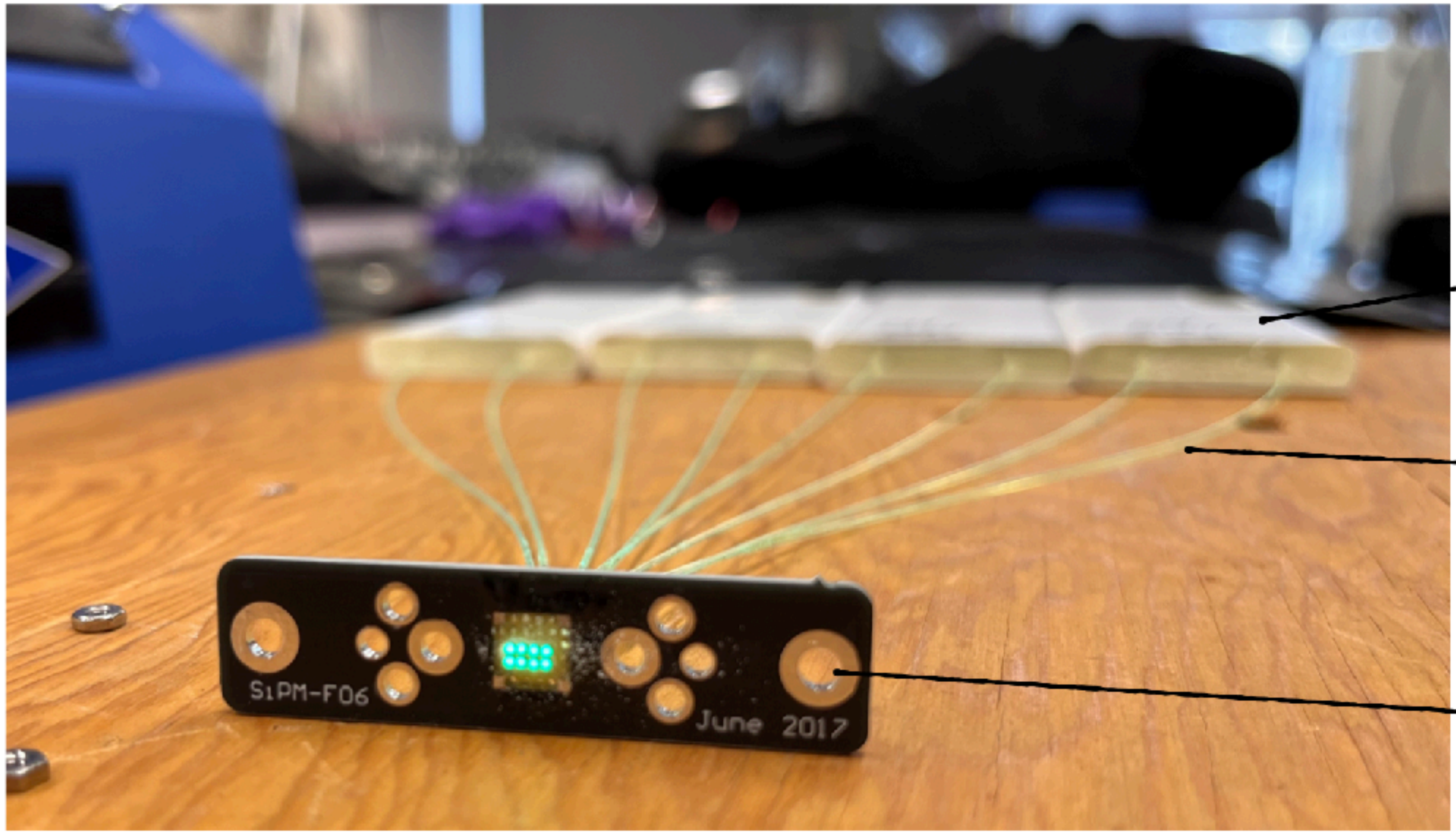
How does a scintillator panel work?



Stolen from Kiara

How does a scintillator panel work?

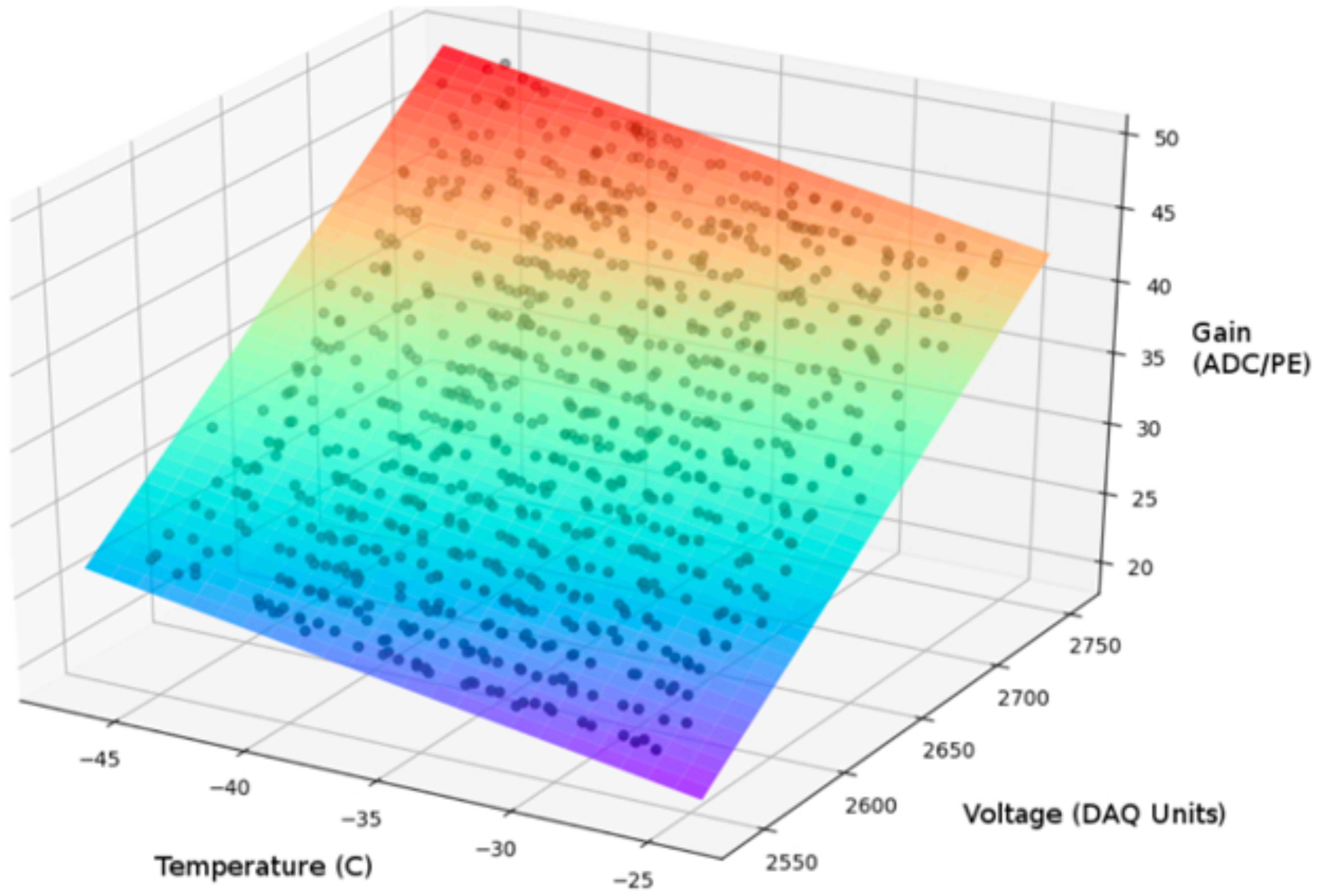


Scintillator calibration

Key requirement: must be able to calibrate detectors *in situ*

Why?

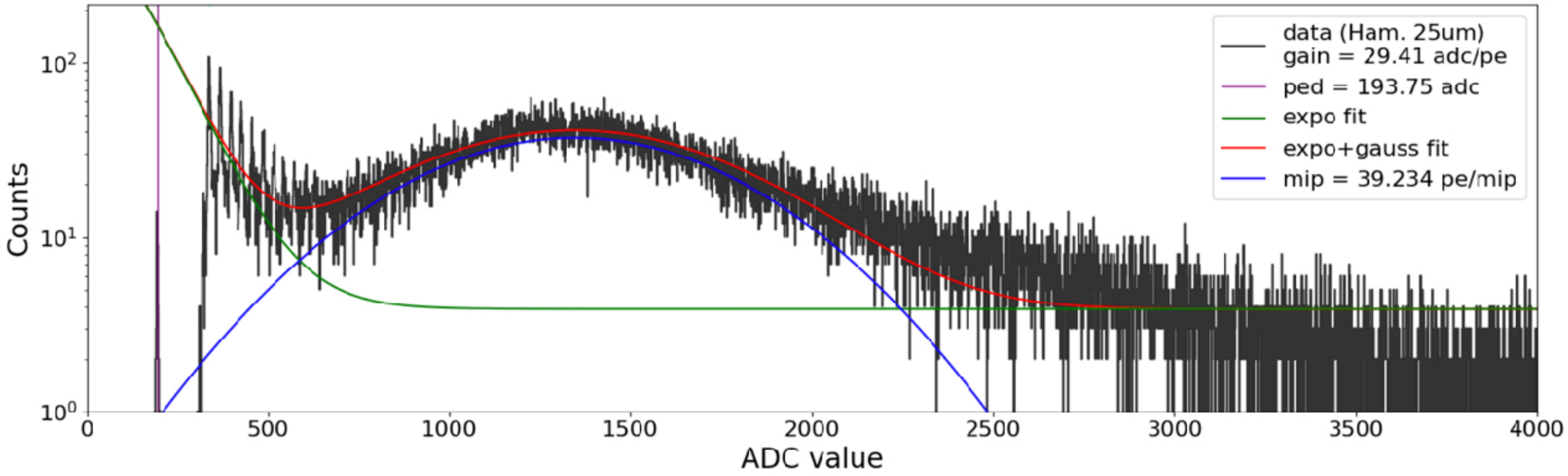
- SiPM gain known to vary with temperature
- Will be corrected in real-time via bias voltage adjustment, but want to verify this correction



Scintillator calibration

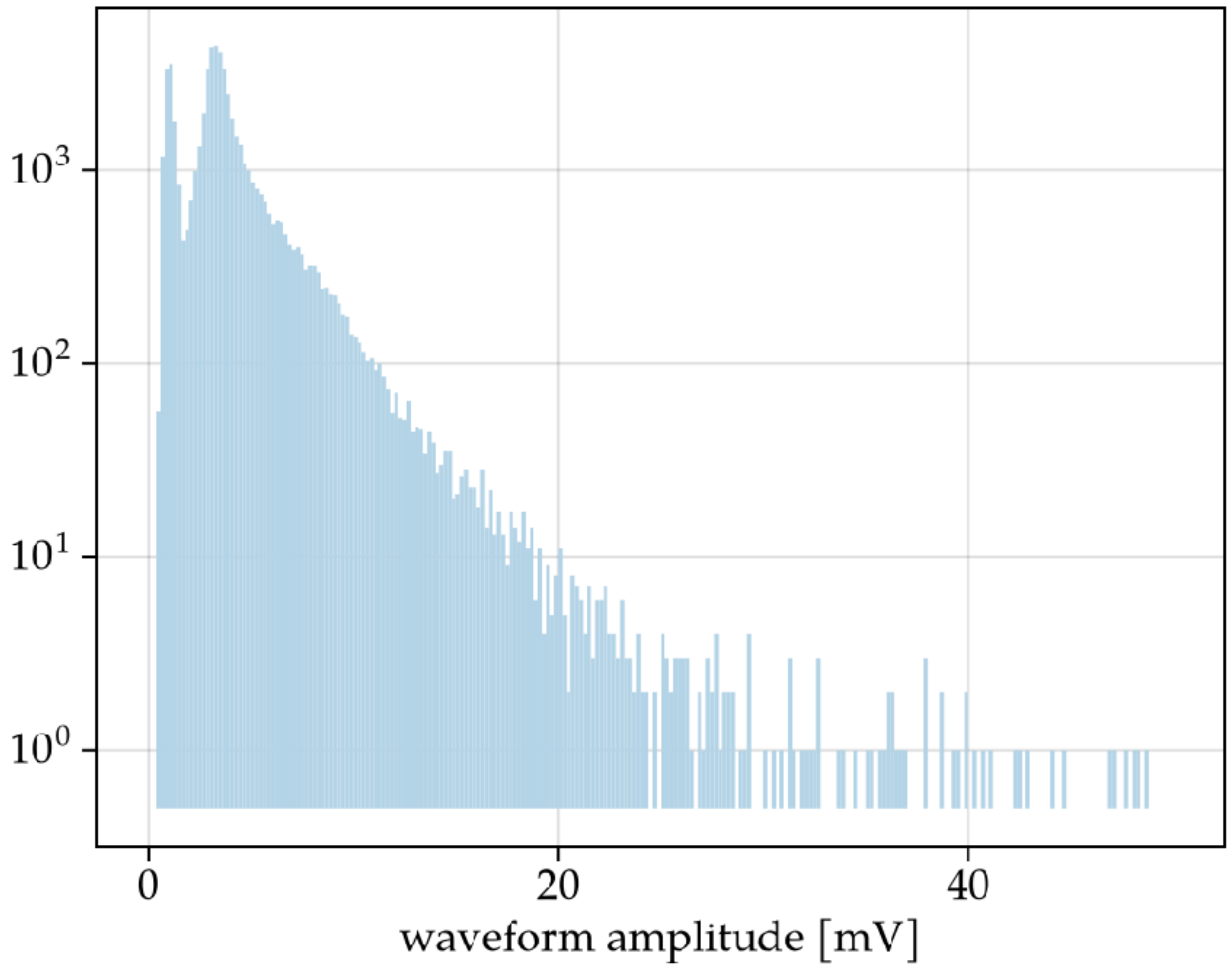
Essentially only way to calibrate *in situ* is with muons

Detectors must be designed so that we can see the muon peak



Example muon peak from IceTop panel

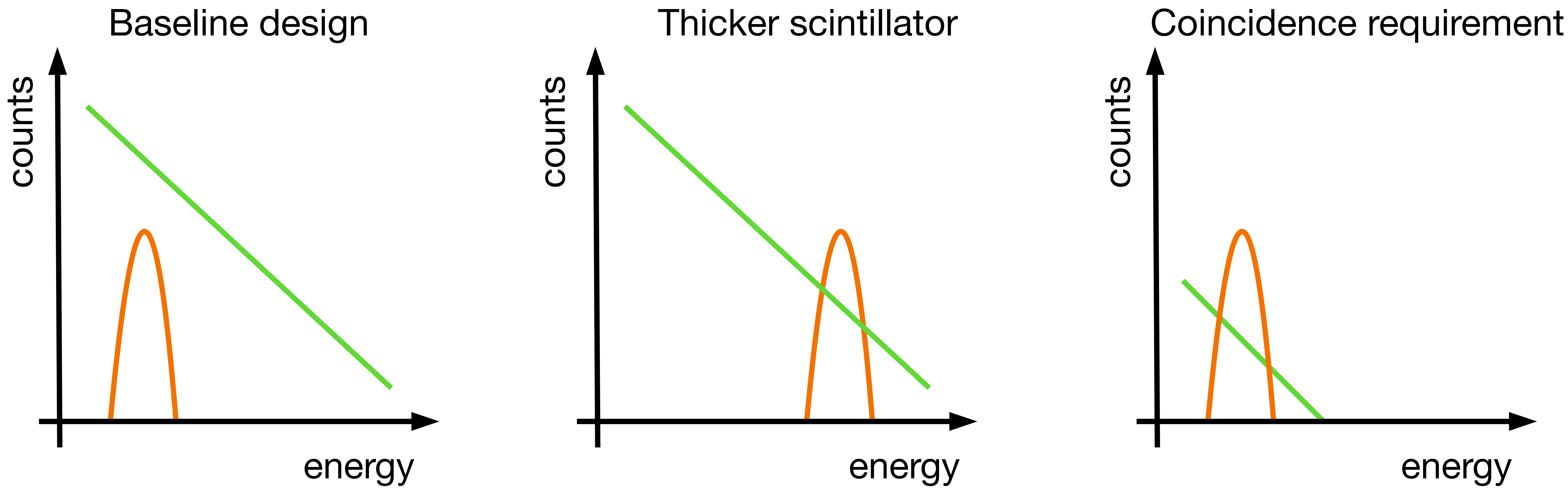
What do we see with one “baseline-style” detector?



Not much, actually

What’s the deal?

Radioactive backgrounds can mask muon signal



If radioactive backgrounds are high they can mask our muon peak!

Prototype concepts: improving μ peak visibility

Concept #M1

- Stacked, fully overlapping detectors
- Use coincidence between detectors to extract muon peak
- Pros: simple, only one style of detector, increased thickness also increases sensitivity to tau showers
- Cons: heavier, more expensive, additional electronics

Prototype concepts: improving μ peak visibility

Concept #M2

- Stacked, partially overlapping detectors
- Use coincidence for muon peak, but partial overlap gives more detector area
- Pros: simple, one detector style, more area compared to M1
- Cons: more expensive, additional electronics, inconsistent response across detector

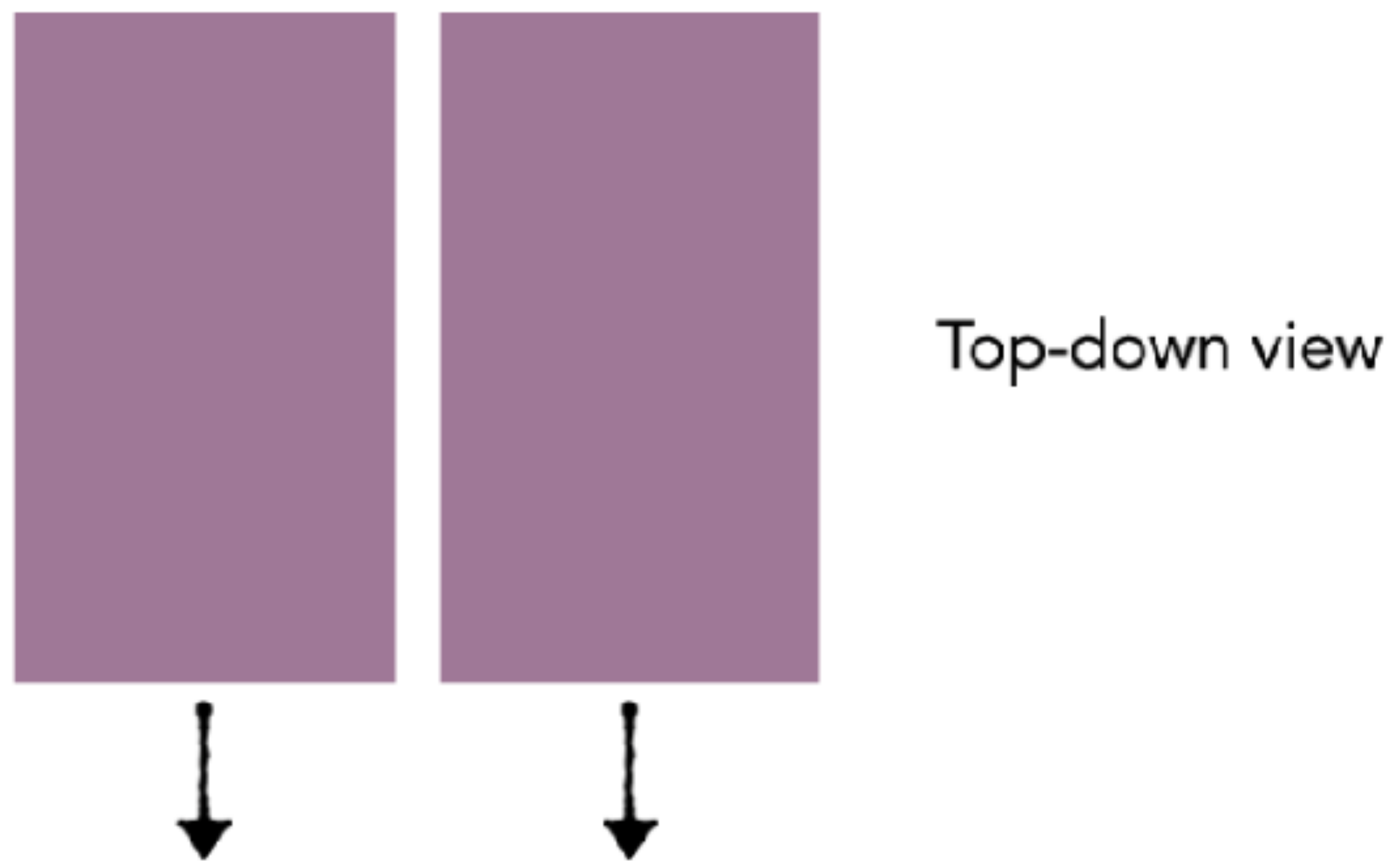
Prototype concepts: improving μ peak visibility

Concept #M3

- Small coincidence tagger on top of scintillator
- Same as first two concepts, but small scintillator saves money
- Pros: light, cheap

Concept #M4

- Adjacent detectors
- Tag coincident muons from same shower
- Pros: no loss of area from overlap
- Cons: lower rate?

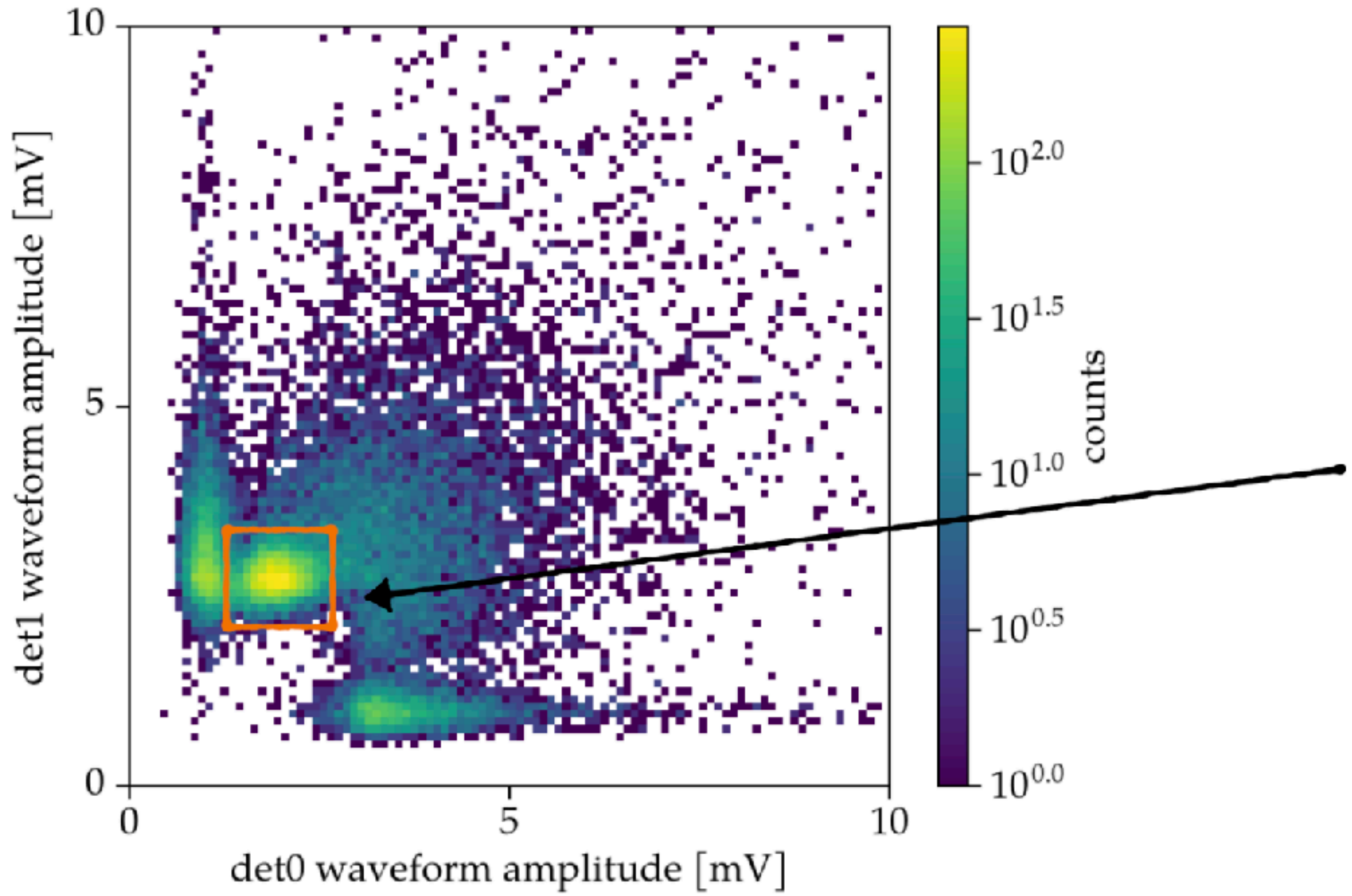


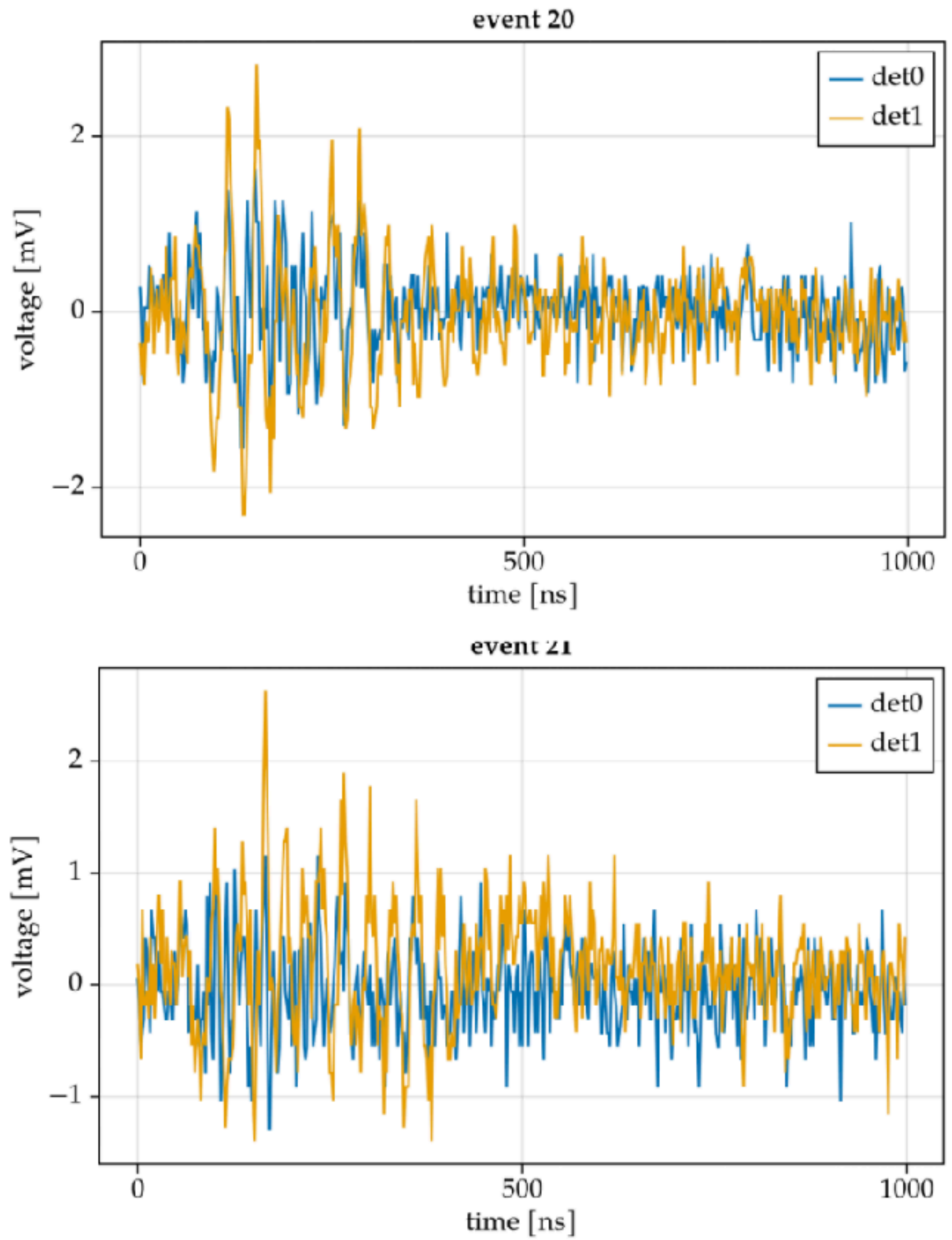
Prototype concepts: improving μ peak visibility

Concept #M5

- Thicker (2 cm) scintillator
- See muon peak in single detector (?) with nothing extra
- Pros: simple, increased sensitivity to taus
- Cons: more expensive, heavier

Concept #M1

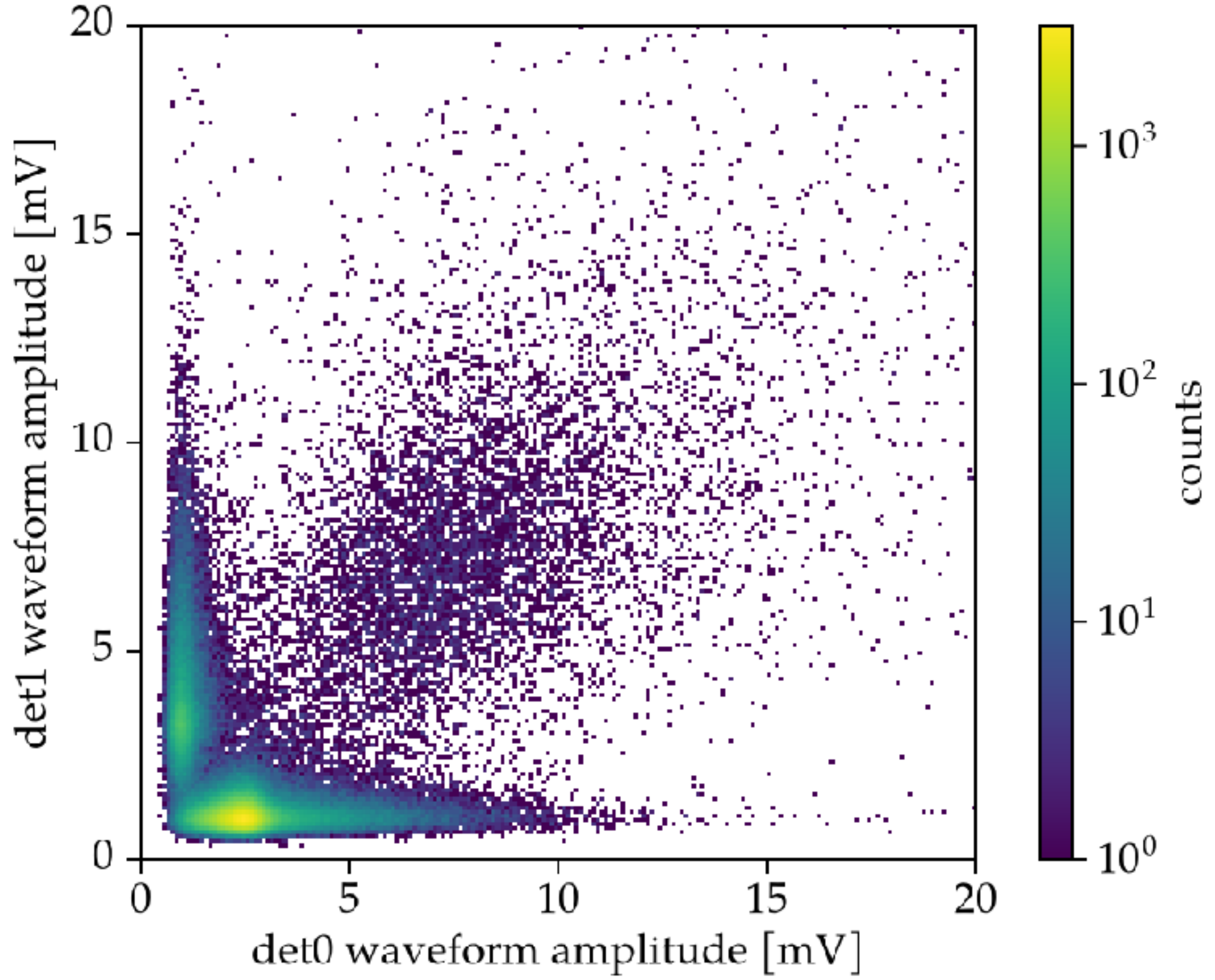


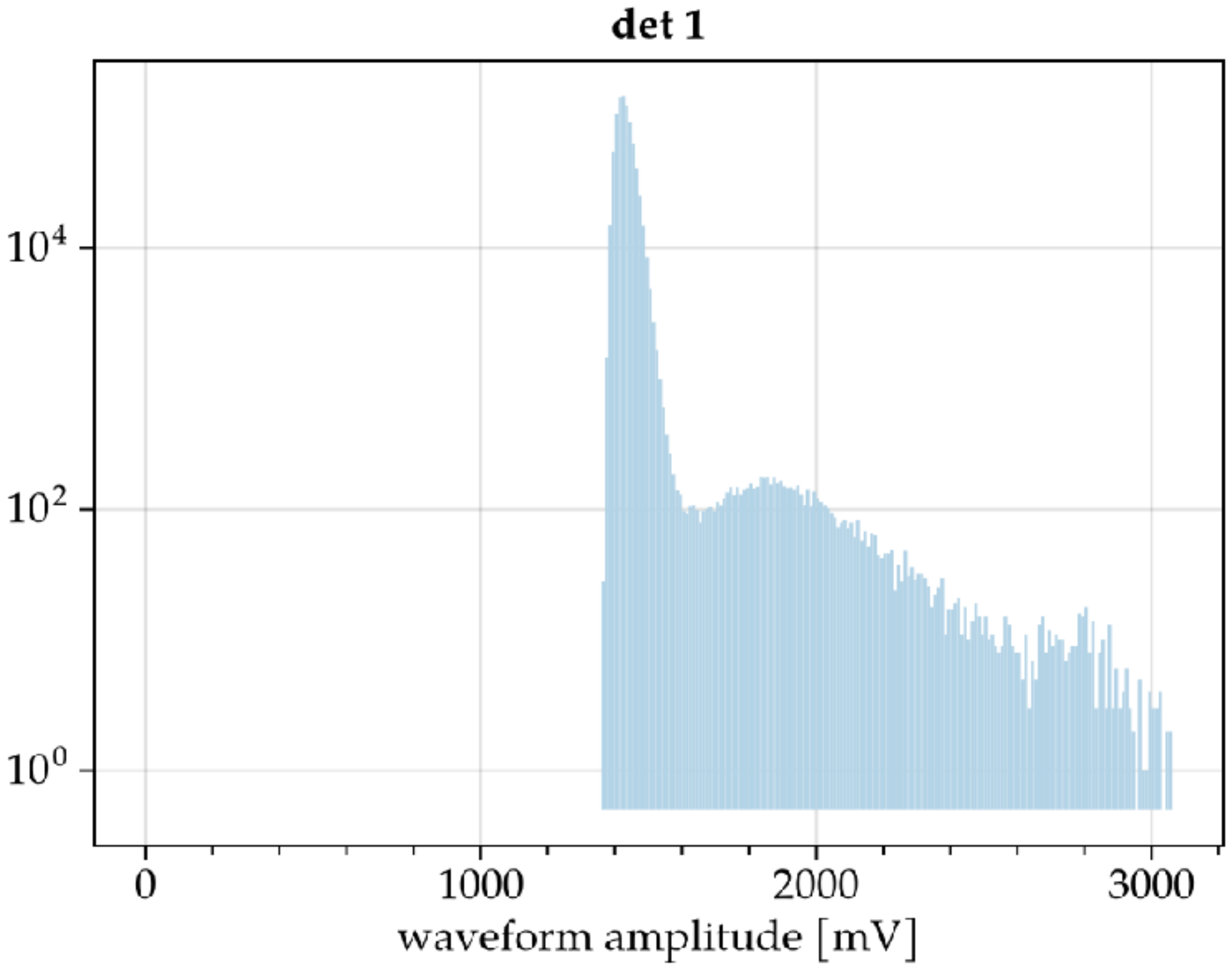


Run contaminated with EMI from scanner robot(!)

Nonetheless, can still see it's difficult to distinguish muon peak from backgrounds

Concept #M1

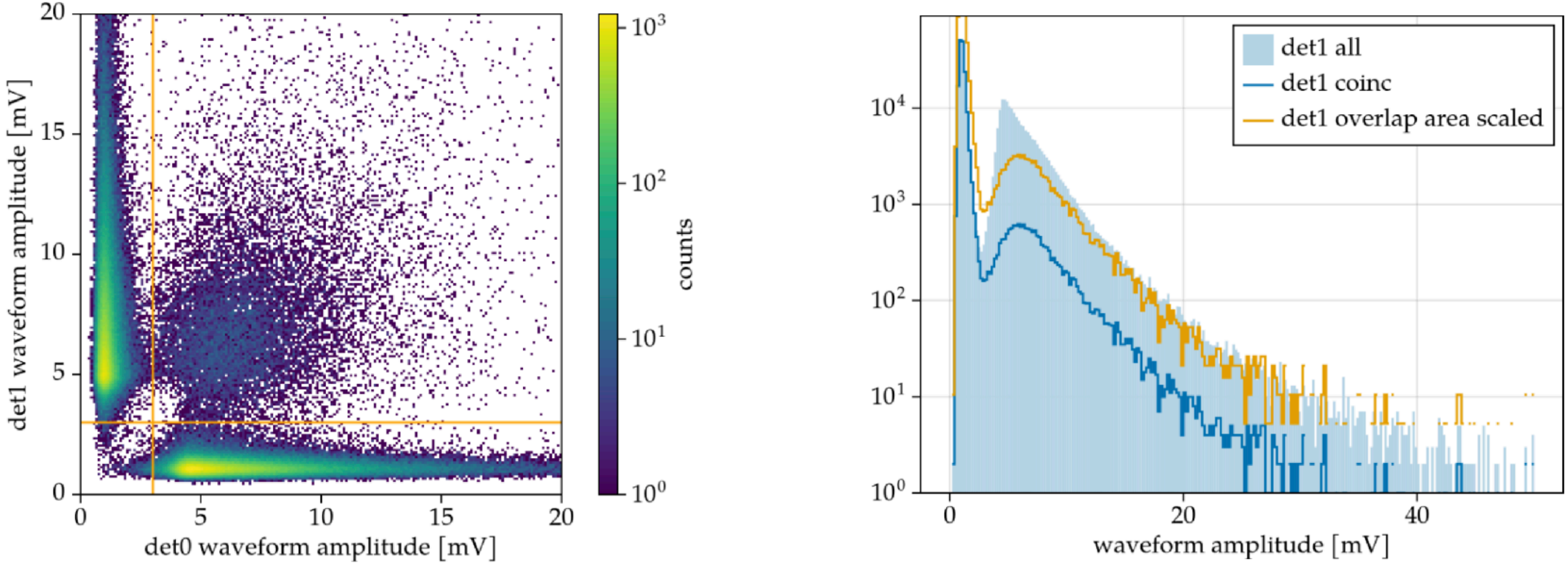




At least that's what we thought before we made this measurement with half-length panels

Maybe due to less attenuation in fiber? TBD

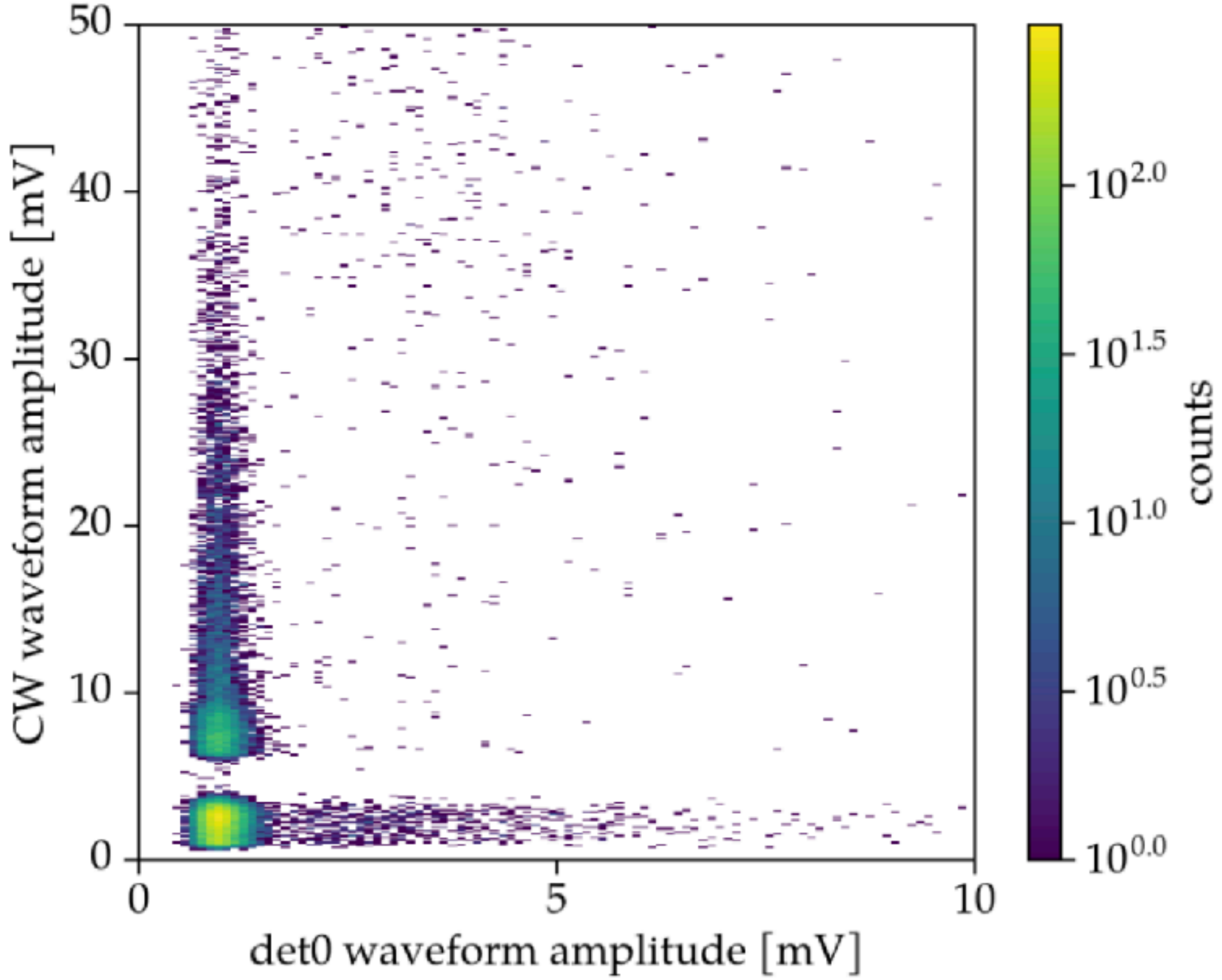
Concept #M2

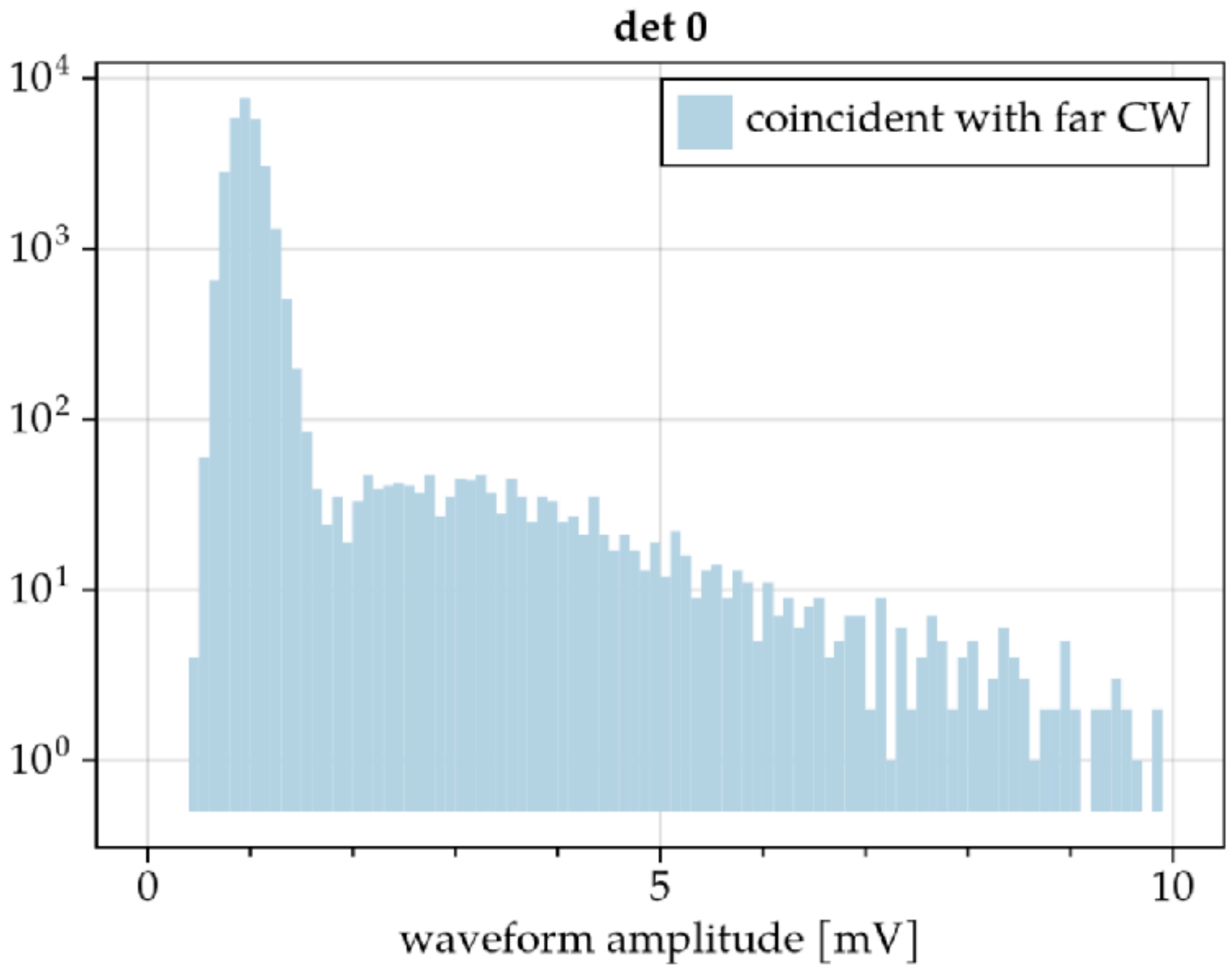


Separation between muons & background is meh

Seems to work as a proof of principle though

Concept #M3

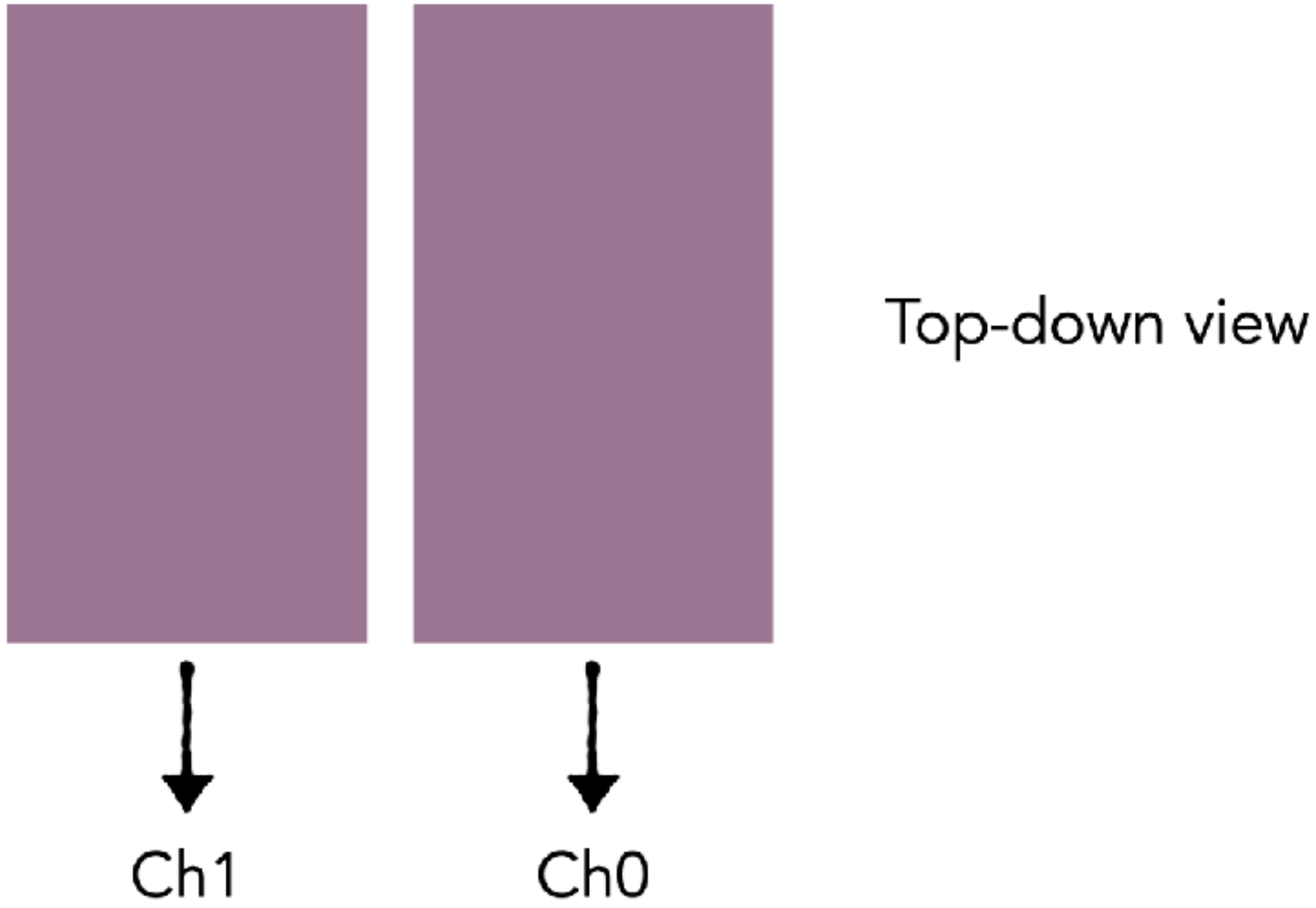


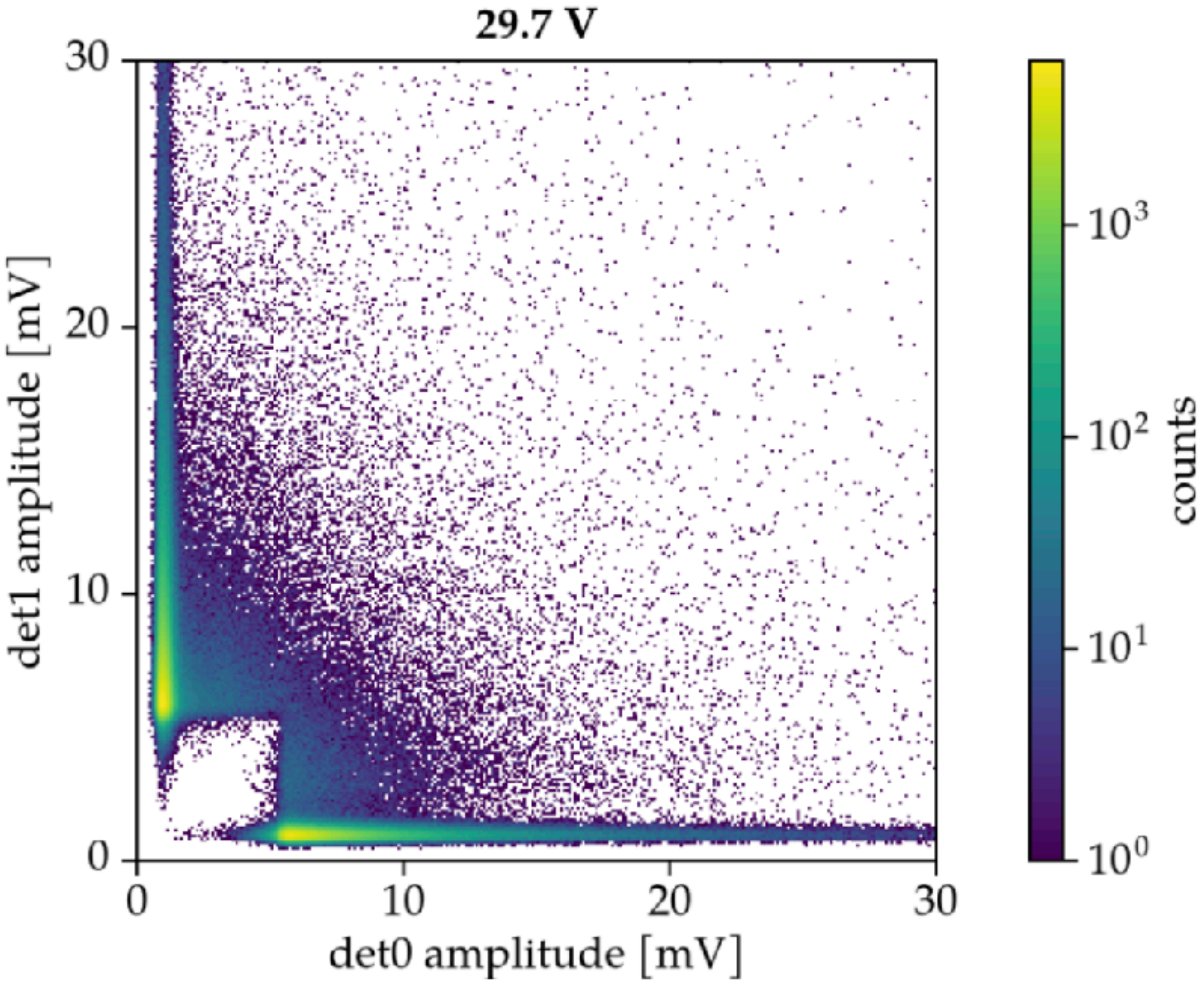


Higher light yield of CW makes it easier to pull out muon peak

Should try again with half-length detector

Concept #M4





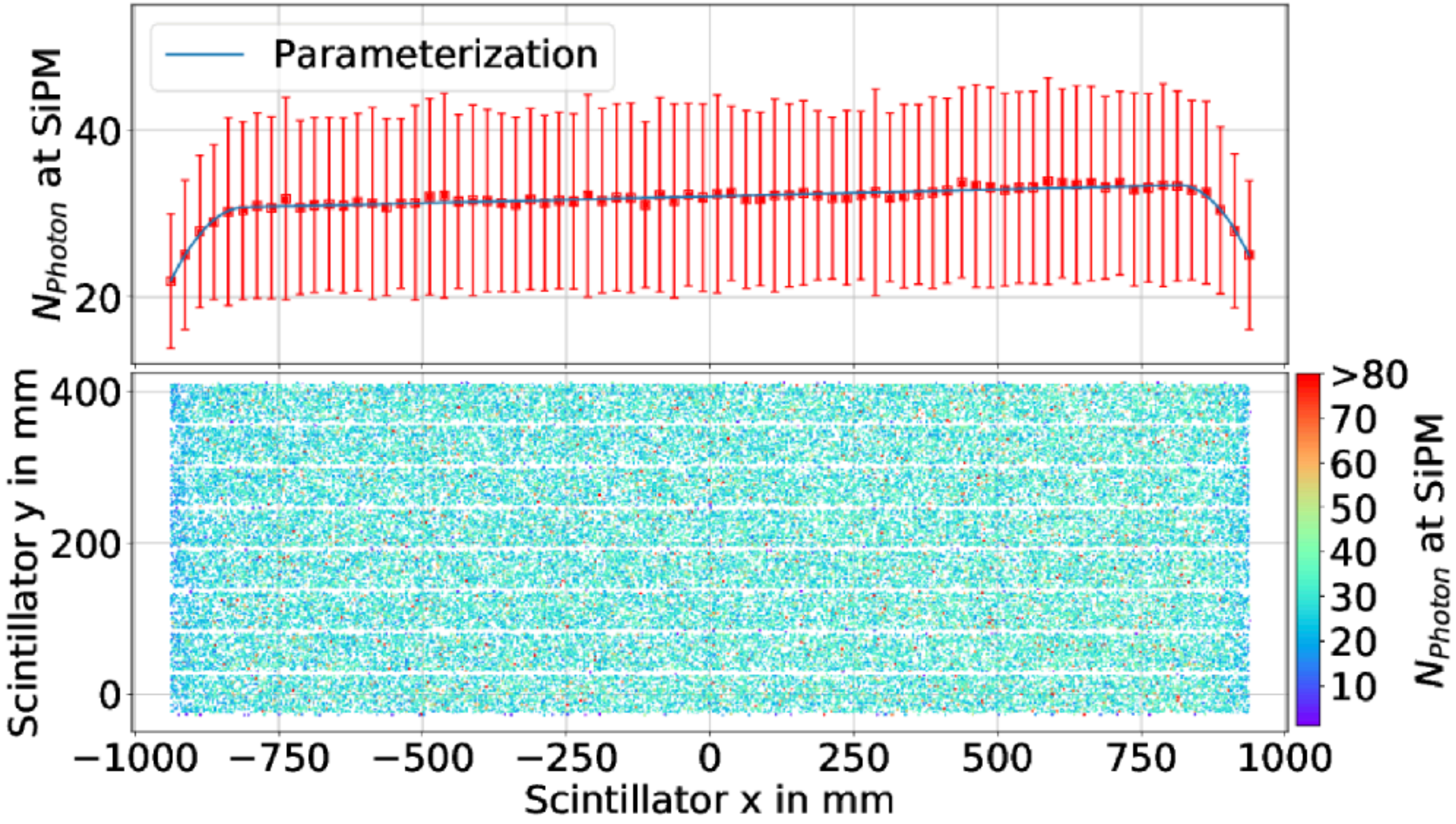
Not a very clear peak here, maybe we need to be outside?

Better evaluation of this in progress

Concept #M5

To be tested (maybe)

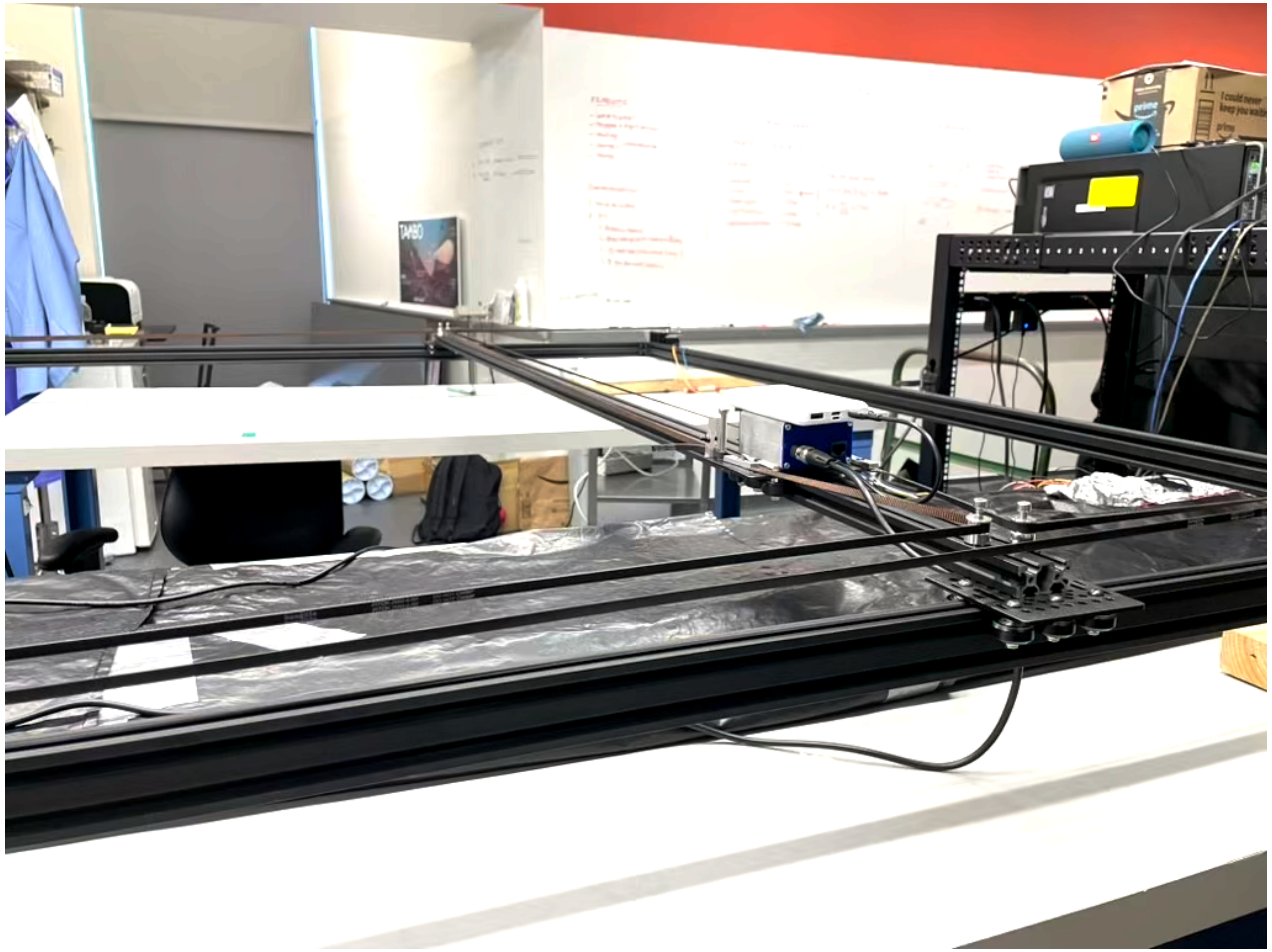
Prototype concepts: optimizing scintillator length



Some approximate ratios:

-934mm / +771mm	~31.5%
-778mm / +771mm	~7.5%

TAMBO Scanning Robot



Ashley (summer undergrad) build a CoreXY scanner for detector characterization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¿Preguntas?