

Development of a sensor for earthquake precursor measurements

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Overview

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The ArtEmis project

02

**Sensor hardware
development**

03

**Acoustic event
detection**

04

**Detector efficiency
and response
modeling**

01

The ArtEmis project



Earthquakes

~20,000

earthquakes located worldwide every year

~16

M ≥ 7 earthquakes per year on average

~56,700

deaths in the 2023 Türkiye-Syria earthquakes

WHEN?

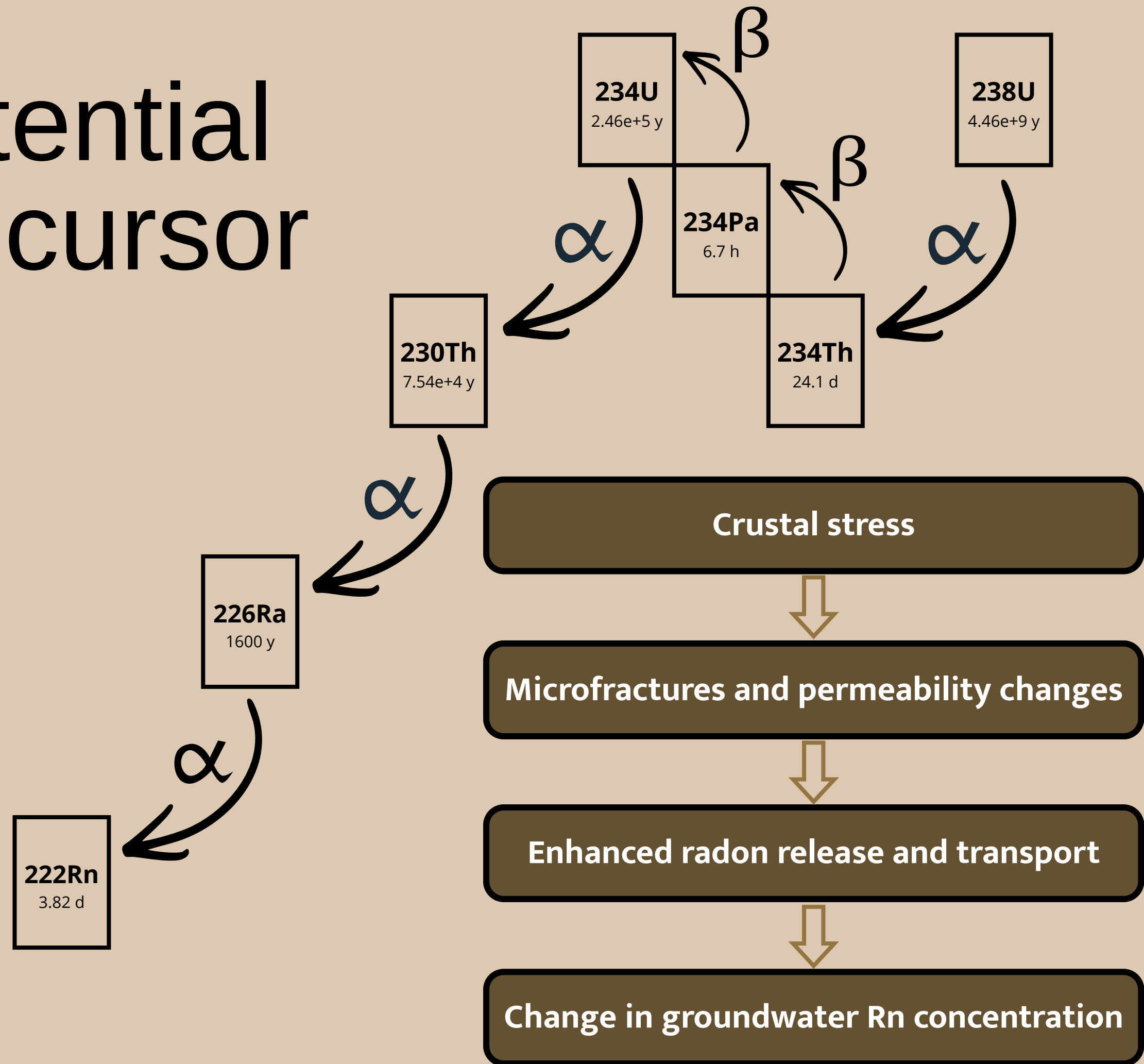
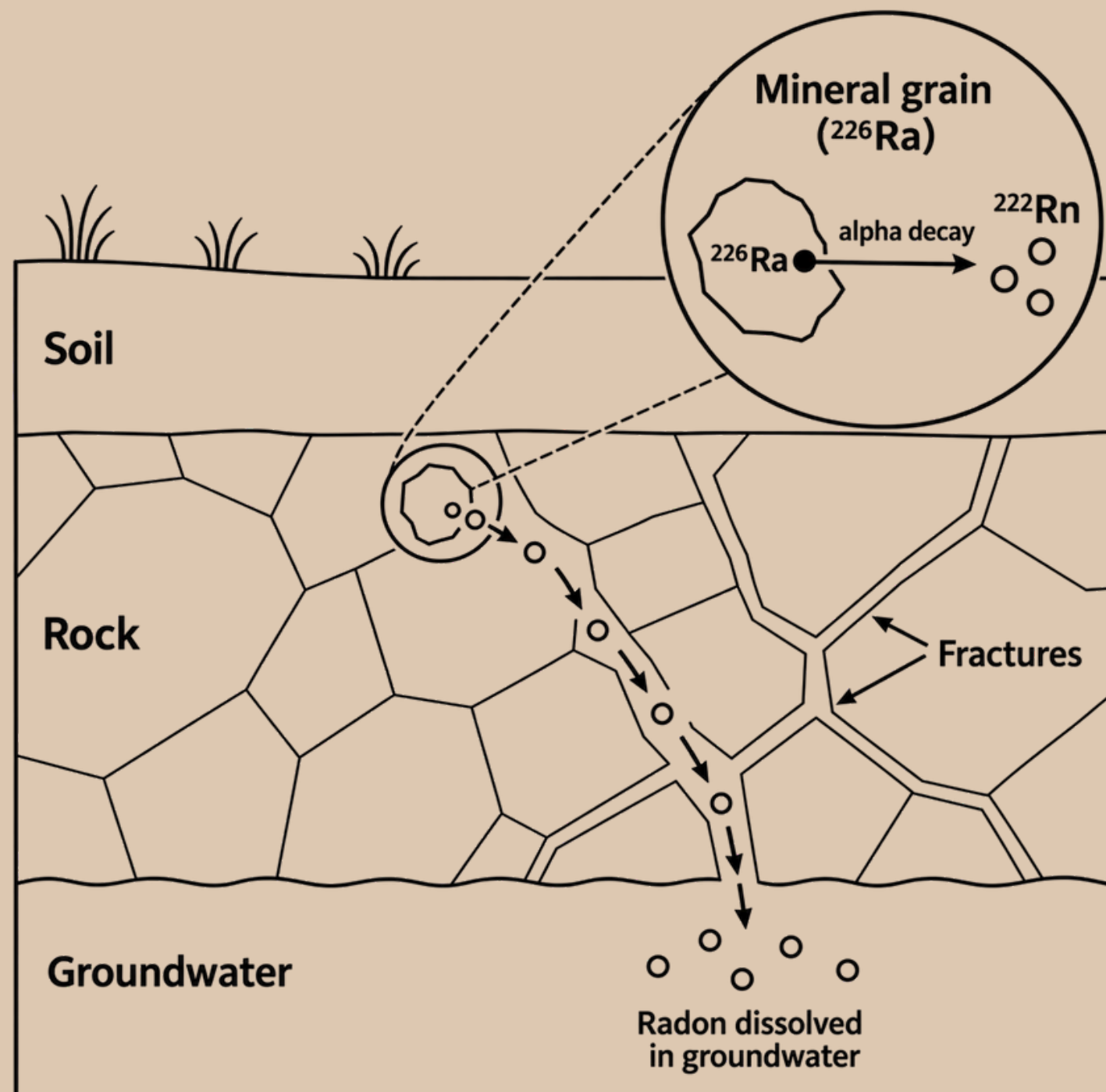
WHERE?

HOW STRONG?

There is currently no reliable method to predict the exact time, location and magnitude of an earthquake!

1976 Tangshan earthquake bent railway lines.
(Photo by Ge Changqiu/ChinaFotoPress)

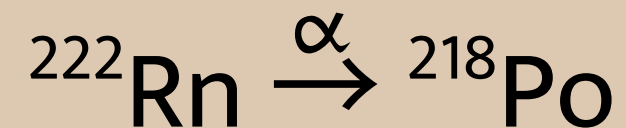
Radon as a potential earthquake precursor



ArtEmis project

a novel approach to radon monitoring

Conventional radon detection



α detection:

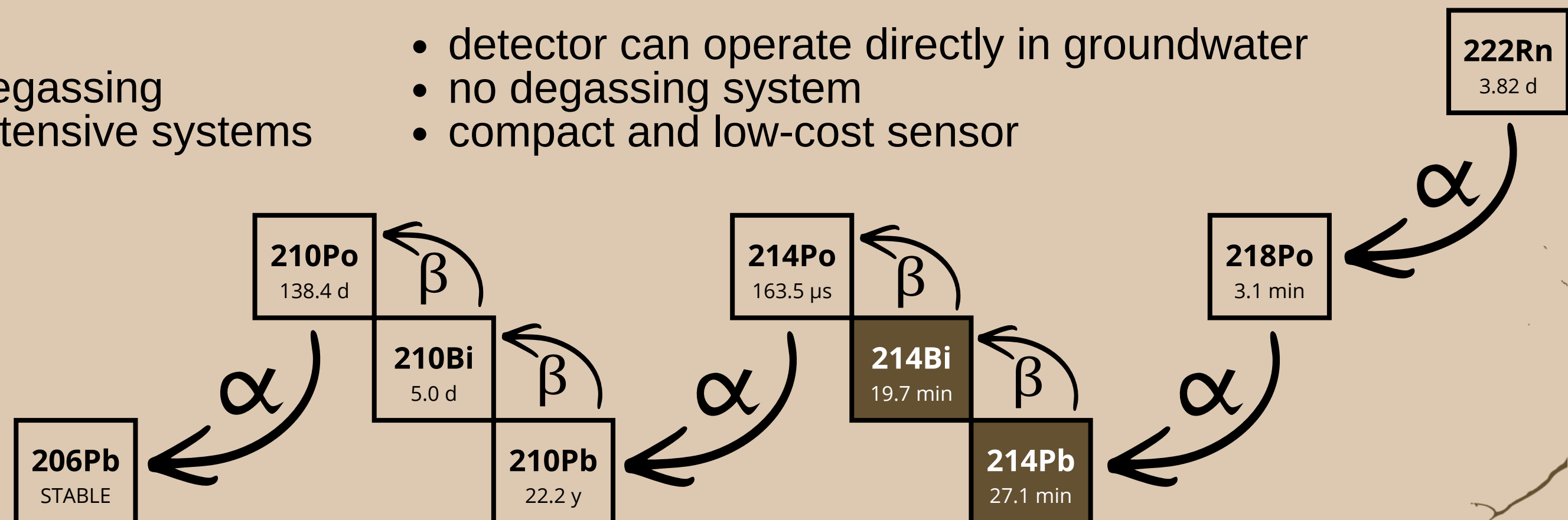
- α range in water $< 50 \mu\text{m}$
- typically requires radon degassing
- complex / maintenance-intensive systems

ArtEmis approach

γ -ray spectroscopy

Indirect measurement of ^{222}Rn through its short-lived daughters

- detector can operate directly in groundwater
- no degassing system
- compact and low-cost sensor



How does ArtEmis detect radon?

²¹⁴Pb

27.06 min
 $\beta^- = 100\%$

242 keV

295 keV

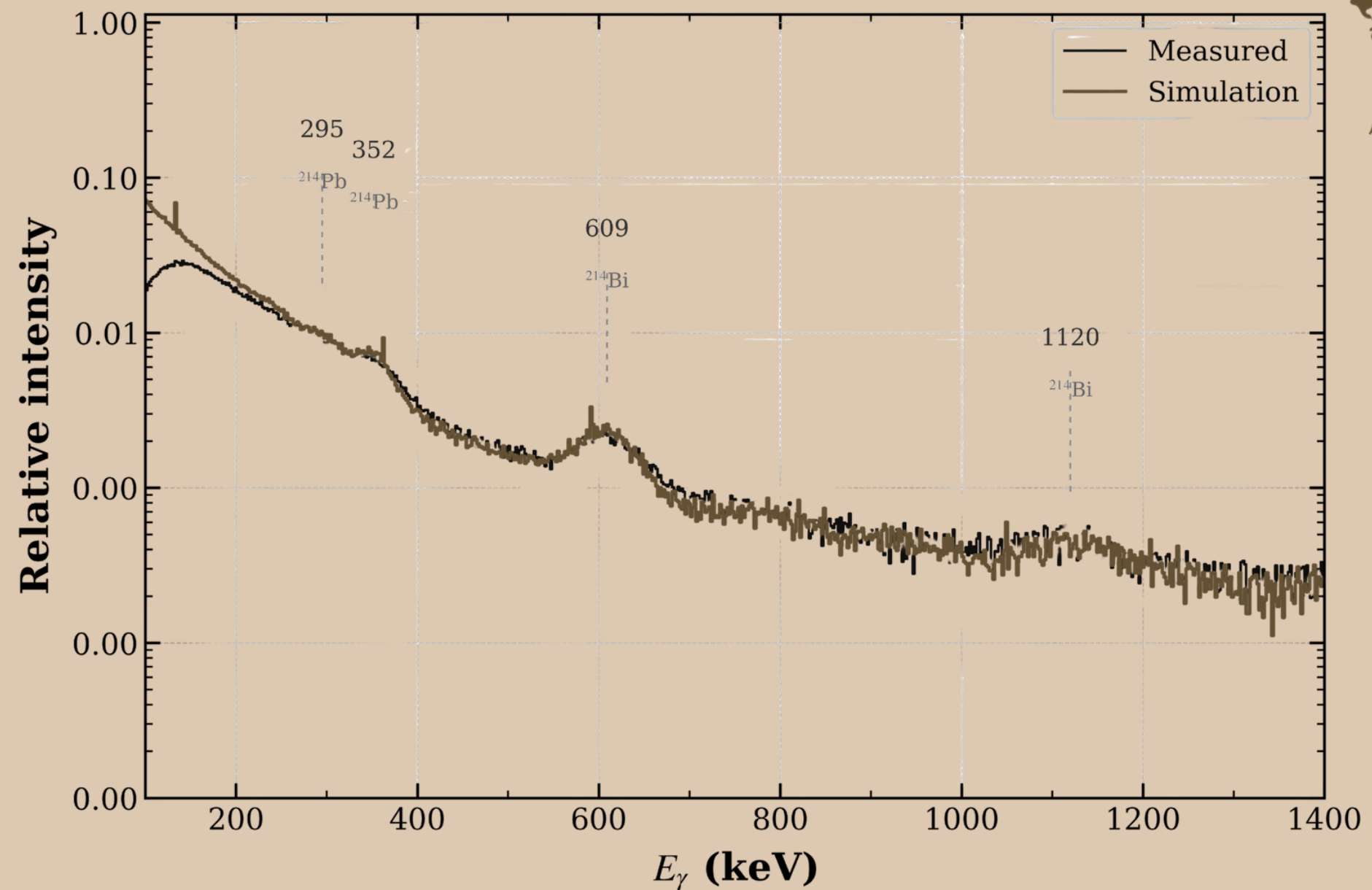
352 keV

²¹⁴Bi

19.71 min
 $\beta^- = 99.98\%$

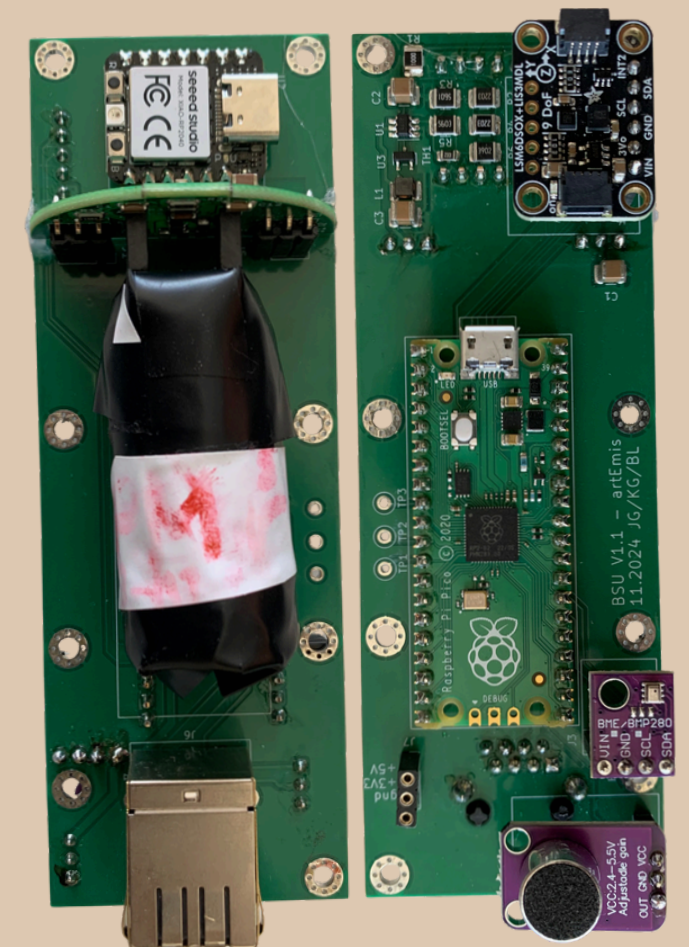
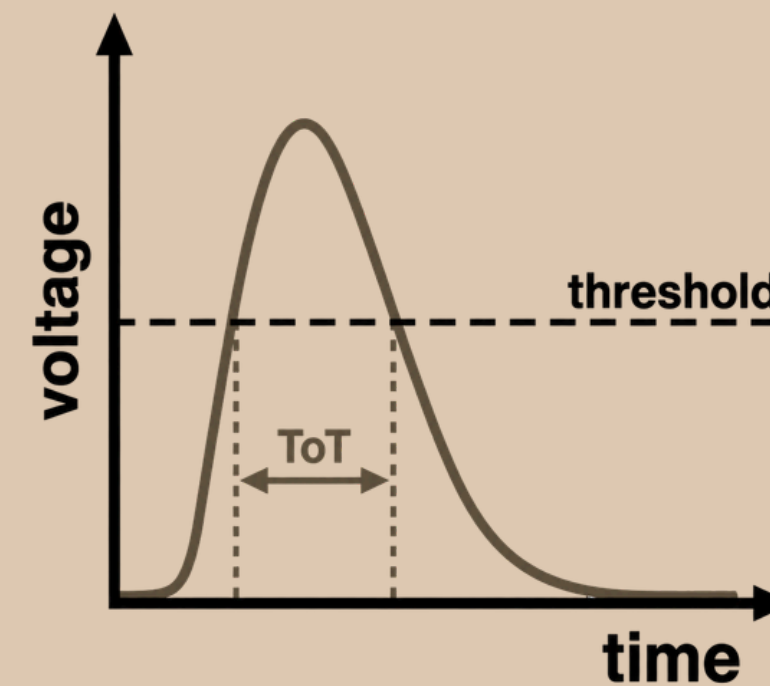
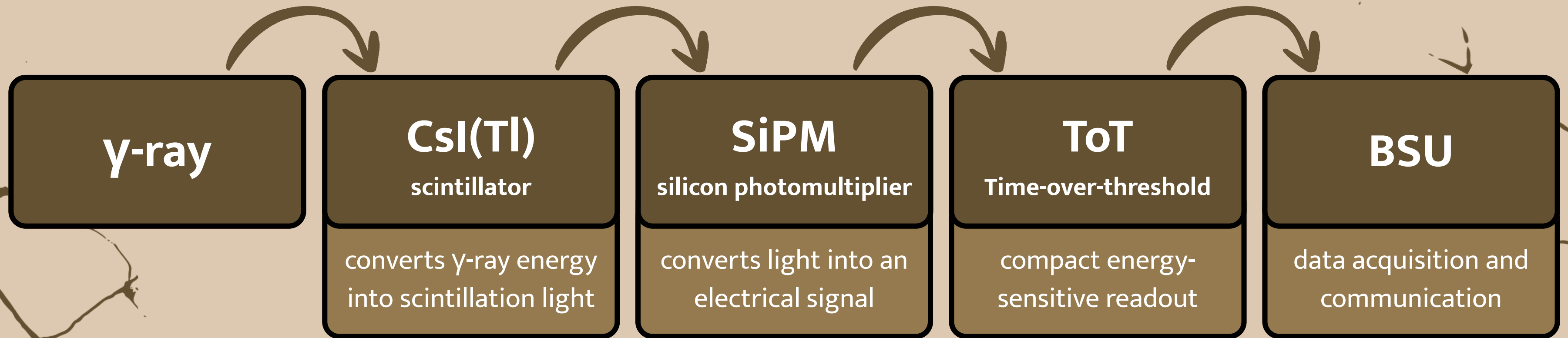
609 keV

1120 keV



609 keV is the signature peak
in the spectrum

ArtEmis detector unit



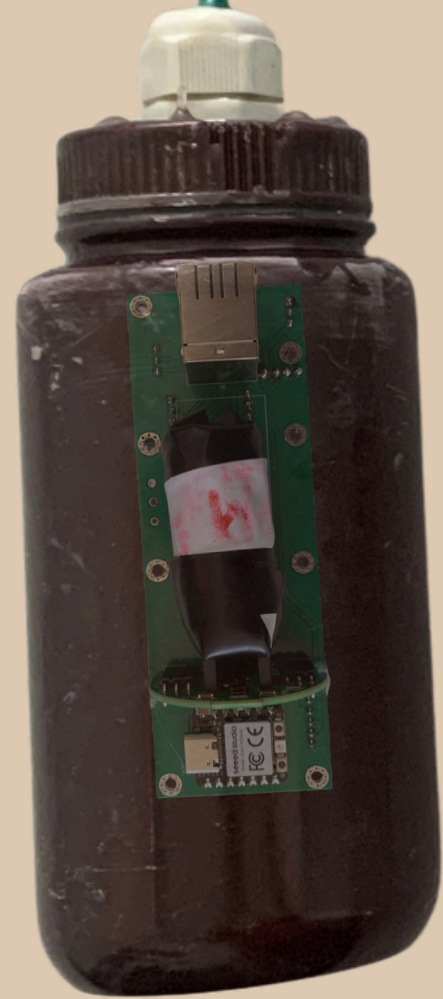
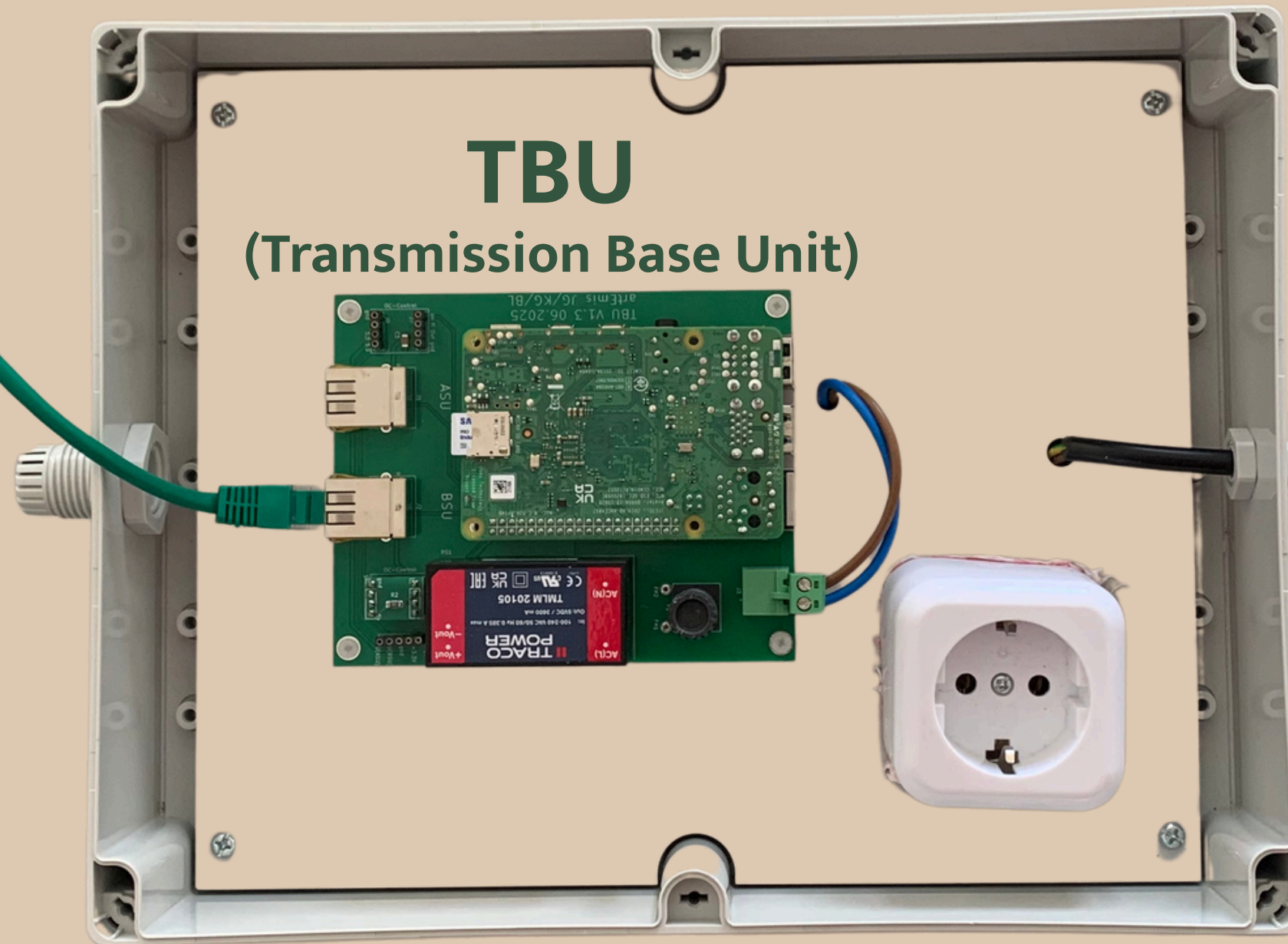
ArtEmis system architecture

Ethernet cable

TBU
(Transmission Base Unit)

Detector and BSU
inside the bottle

Data transmission to server



02

Sensor hardware development



Building and testing the detector

1

CRYSTAL PREPARATION

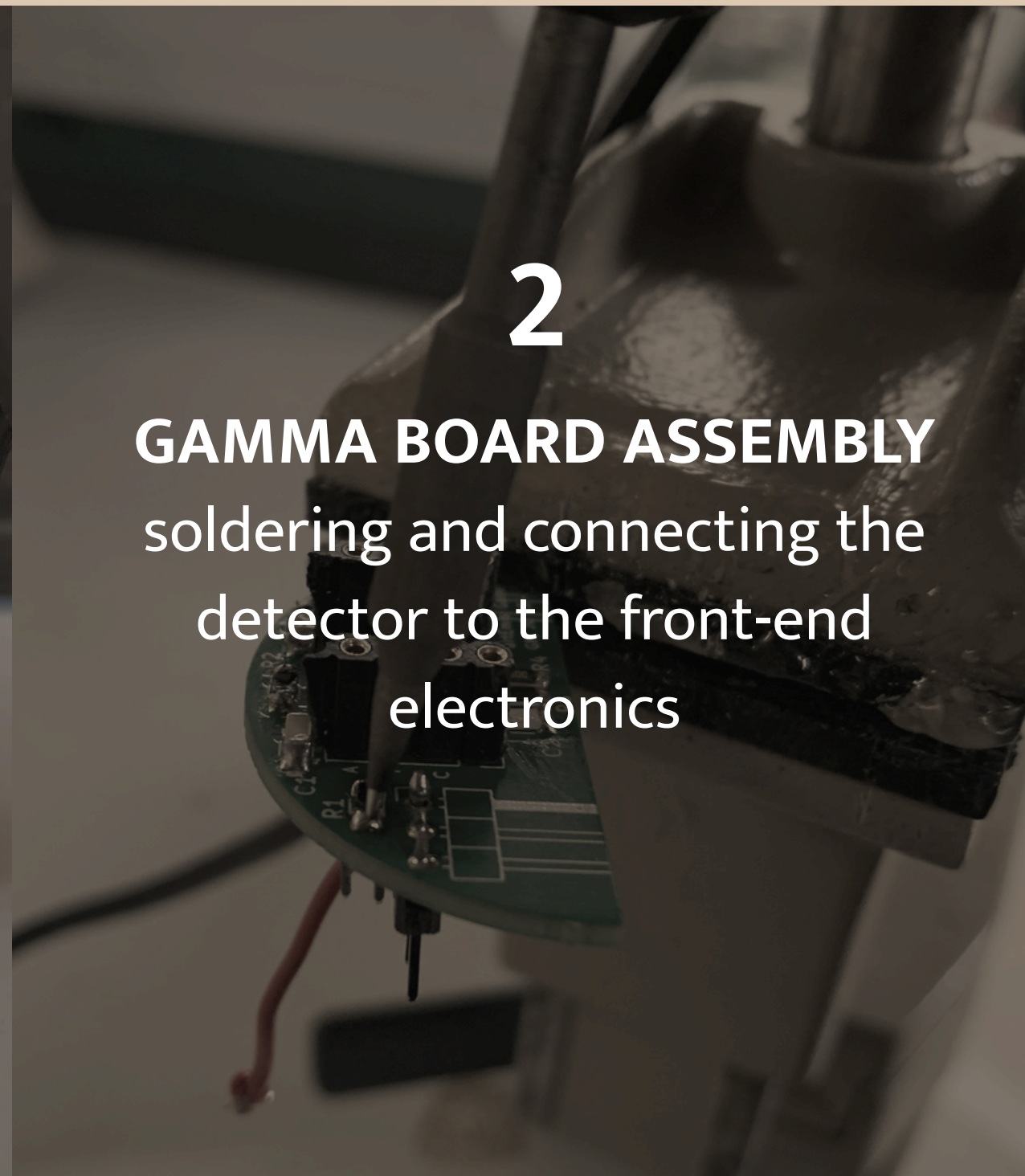
preparation and wrapping of the CsI(Tl) crystal



2

GAMMA BOARD ASSEMBLY

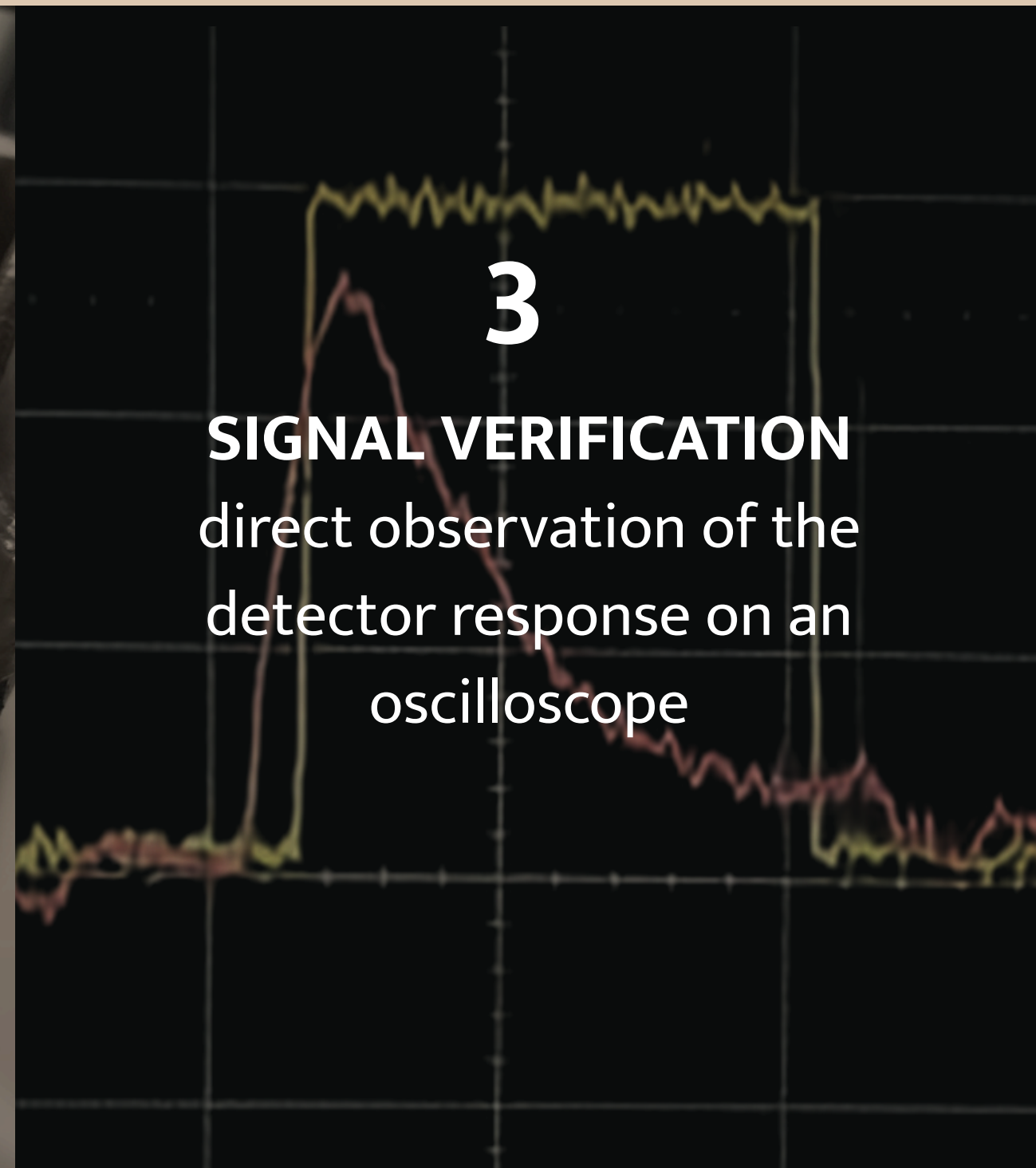
soldering and connecting the detector to the front-end electronics



3

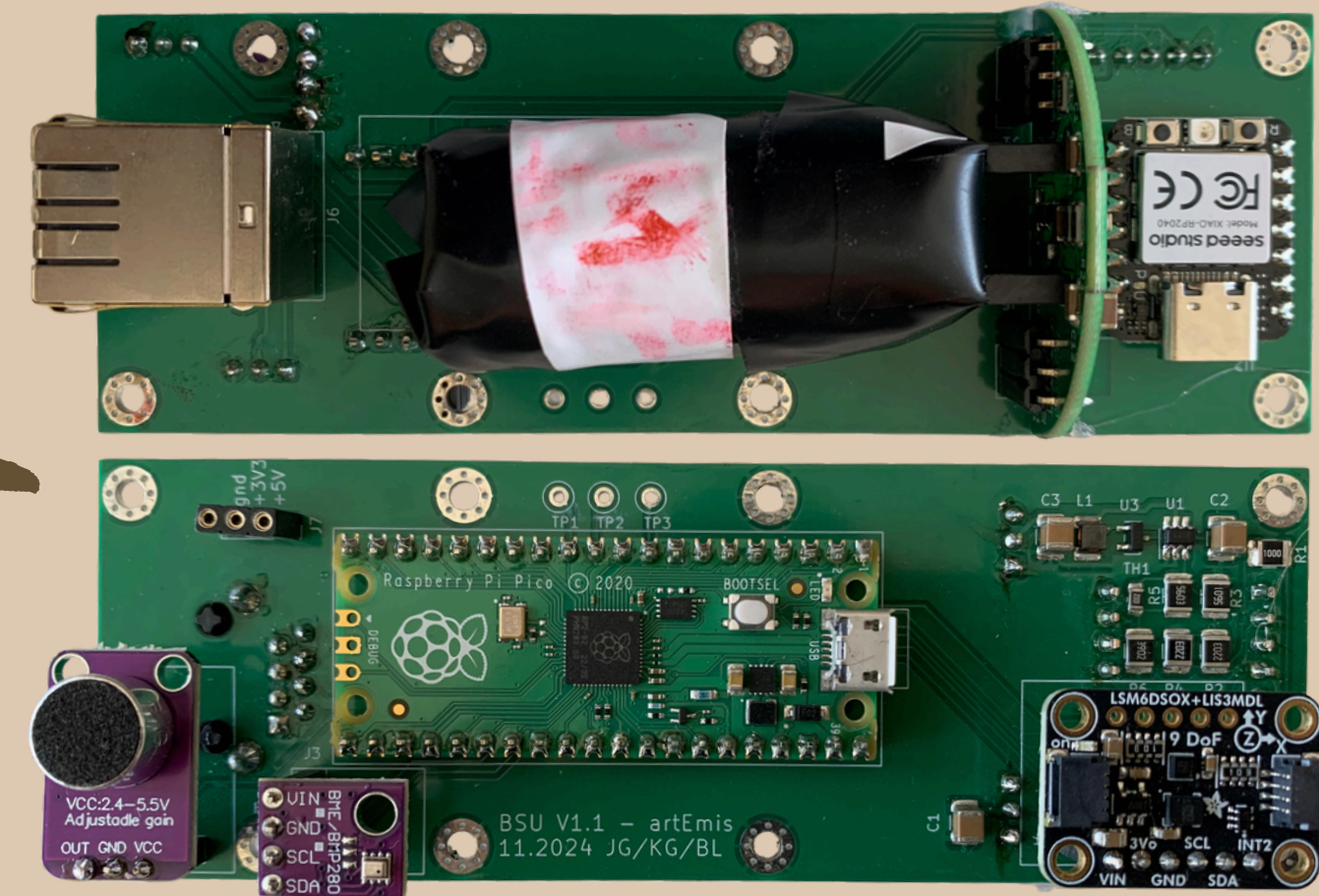
SIGNAL VERIFICATION

direct observation of the detector response on an oscilloscope



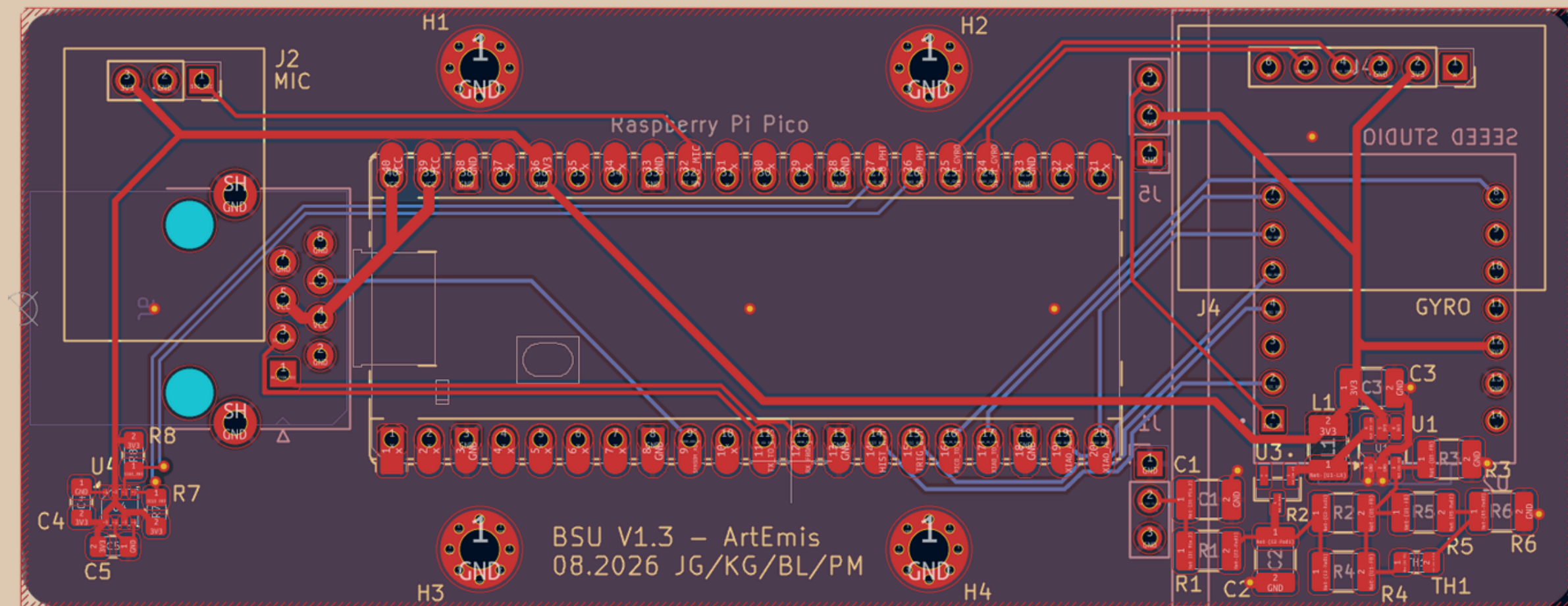
Redesigning the Base Sensor Unit

- adapt the electronics to the detector and casing geometry
- improve component placement and connectivity
- simplify integration and future assembly



Current status:
design completed and checked

Next step:
PCB fabrication and hardware
validation



03

Acoustic event detection

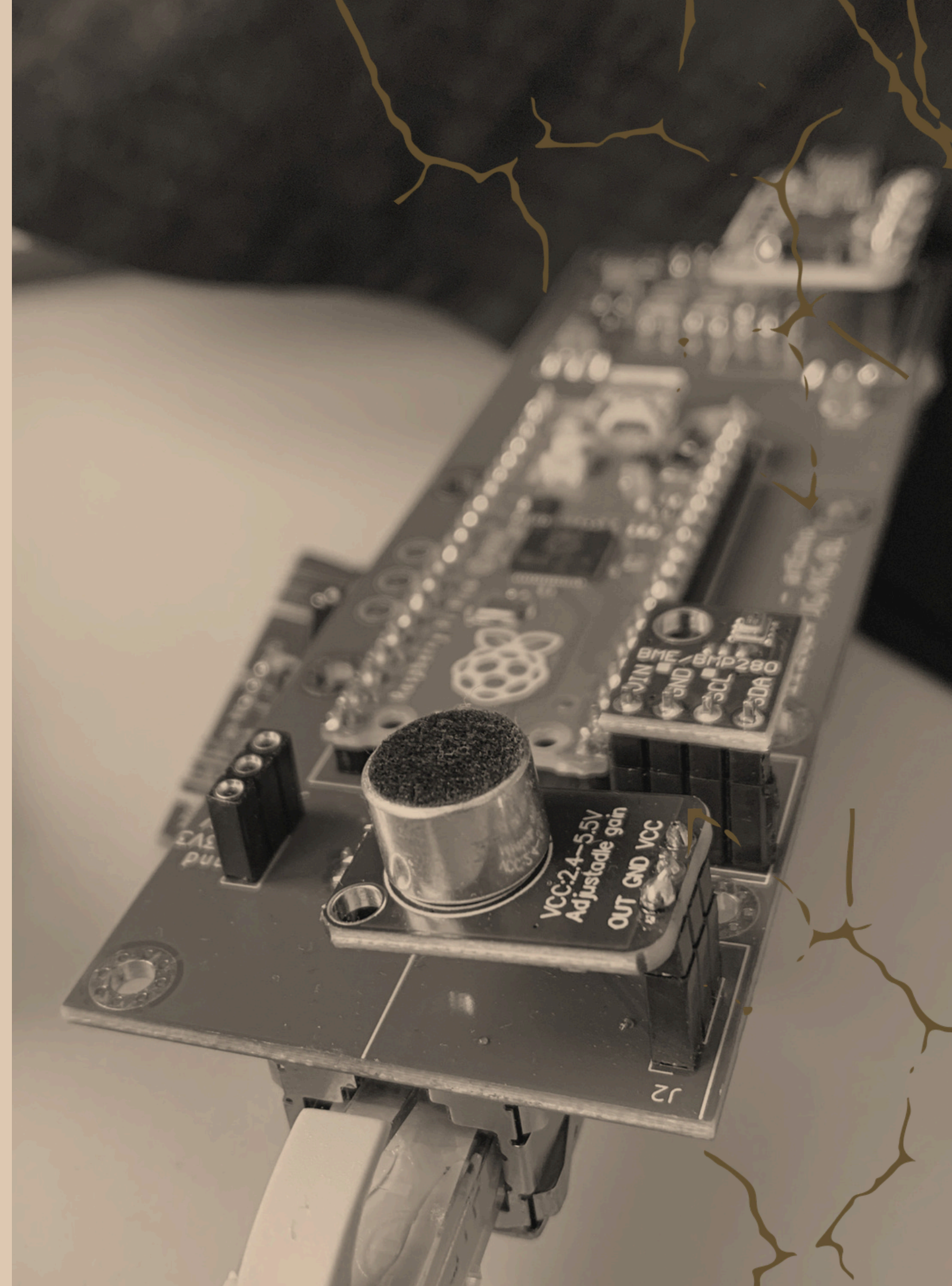


Adding acoustic monitoring

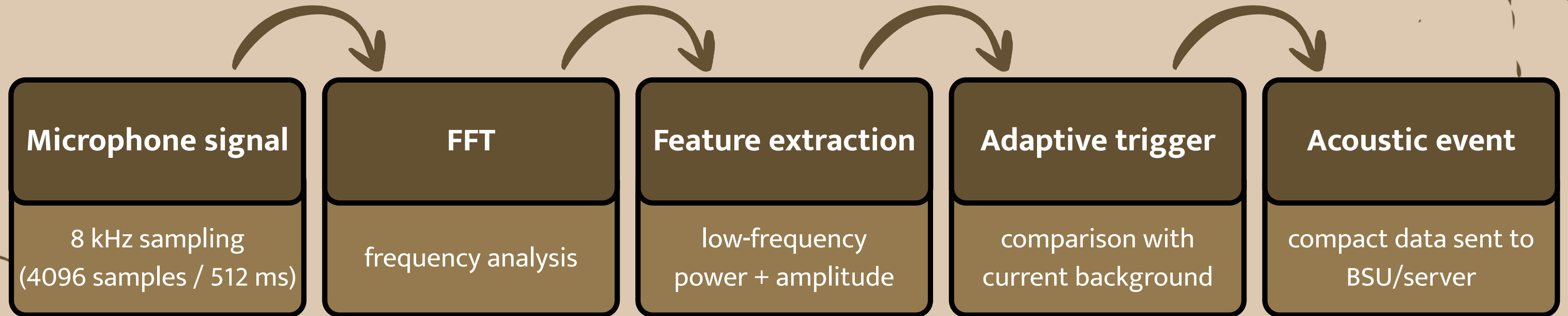
**Monitoring of acoustic disturbances
around the sensor**

**Particular interest in low-frequency
signals**

**Additional context for interpreting
detector data**



Real-time event detection on Pico



DETECT LOCALLY, TRANSMIT ONLY WHAT MATTERS

Why process data locally?

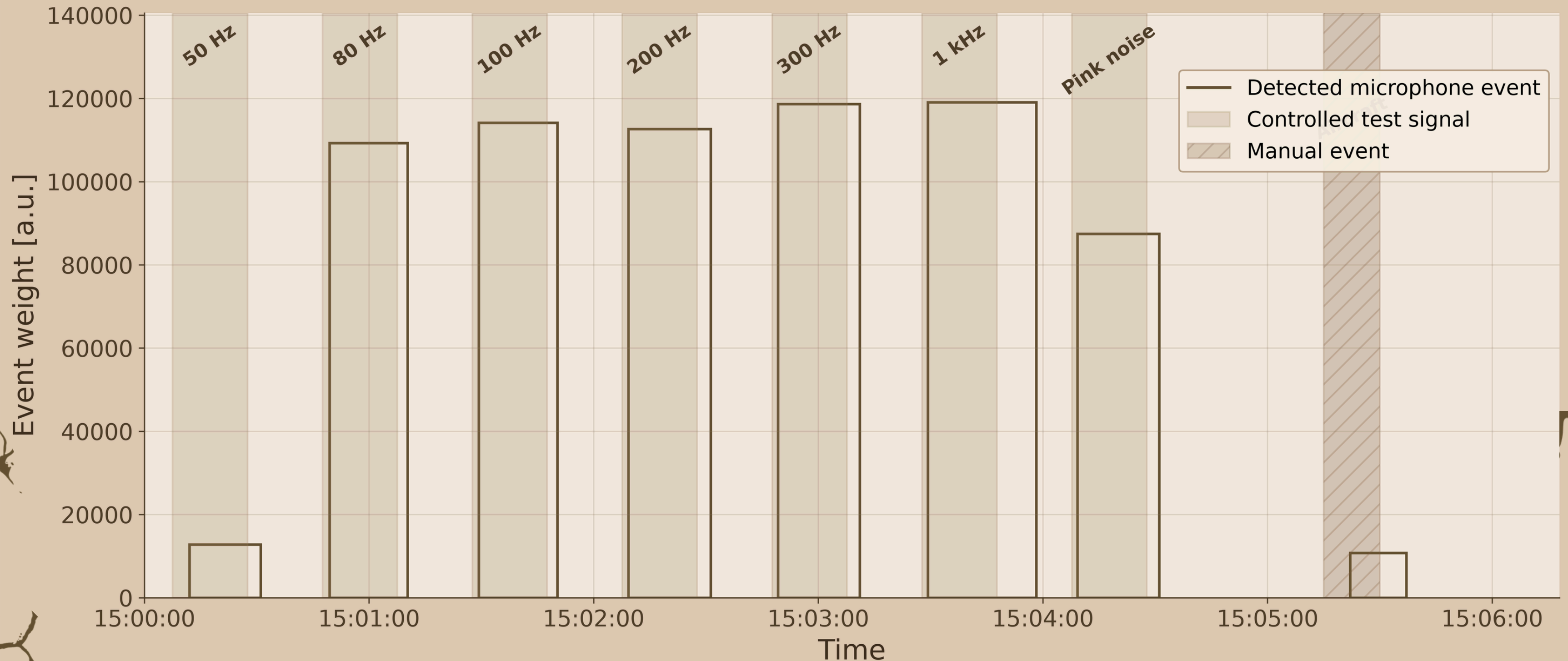
- limited computing resources**
- limited wireless bandwidth**
- continuous raw audio is unnecessary**

Trigger features

- low-frequency spectral power**
- peak-to-peak amplitude**
- adaptive background estimation**

Testing and optimizing the acoustic trigger

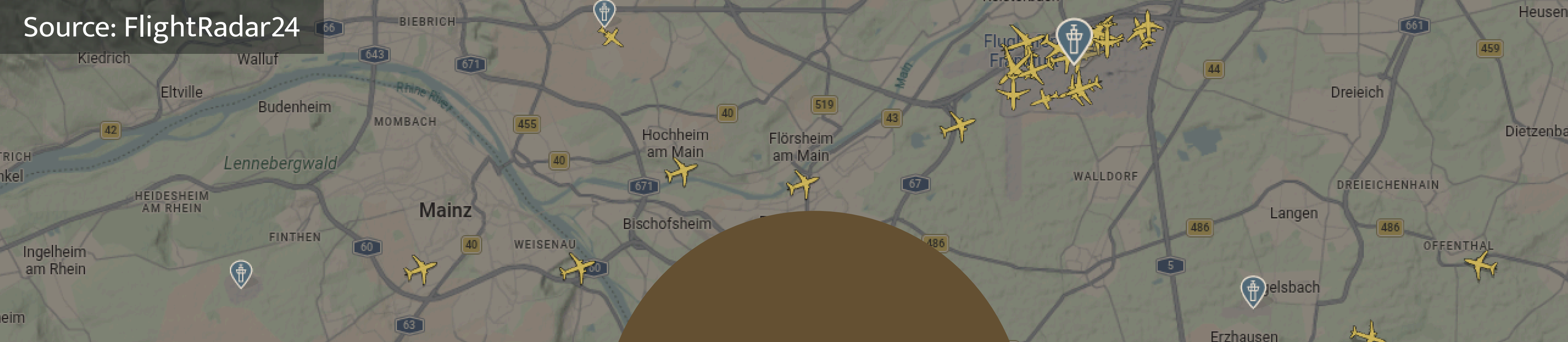
Microphone trigger response during a controlled acoustic test





**What generates low-frequency
sound and is very common near GSI?**

Source: FlightRadar24



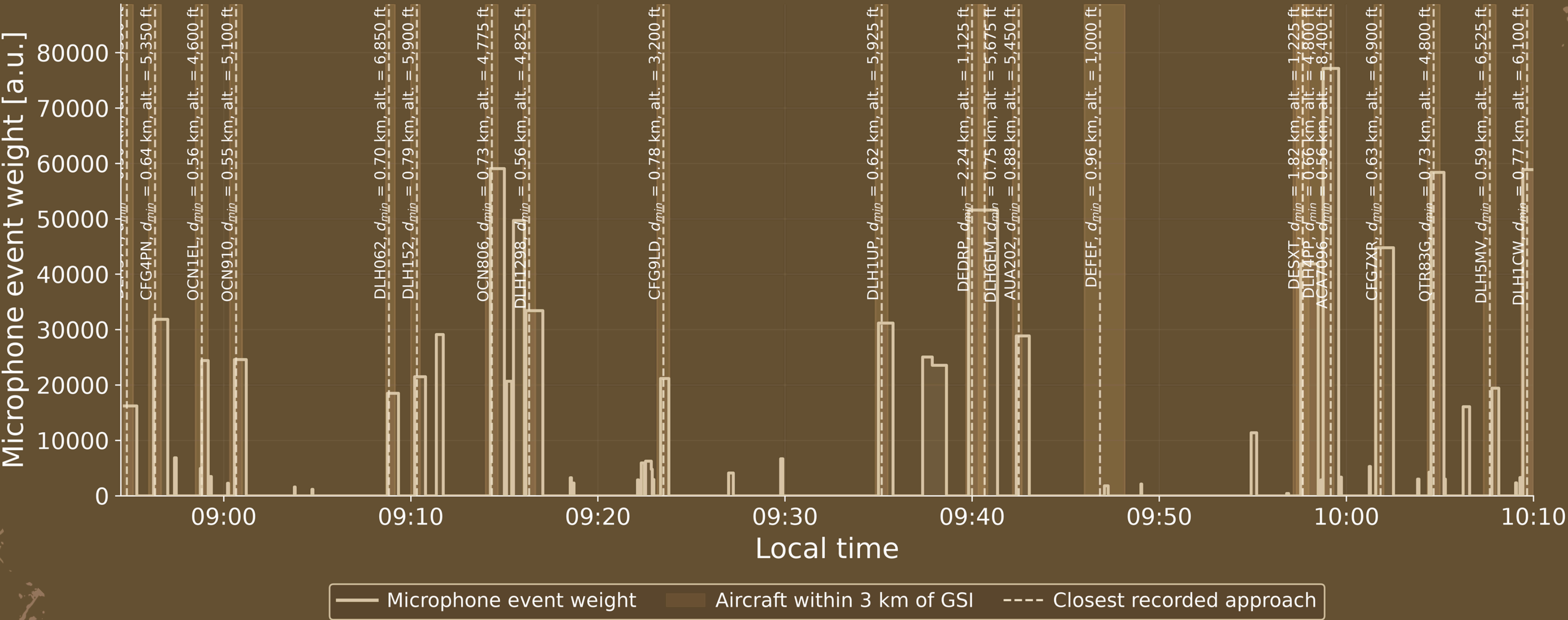
Aircraft!



Photo: Fraport AG

Comparison with microphone detections

Microphone trigger response during nearby aircraft passages



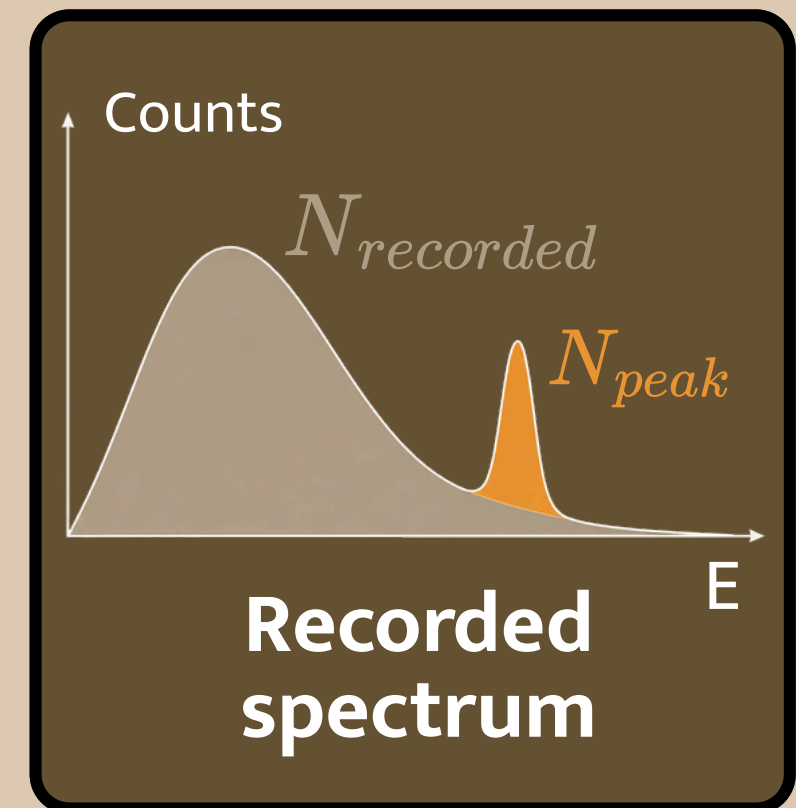
Trigger is sensitive to real low-frequency environmental events
and can be cross-checked against external reference data.

04

Detector efficiency and response modeling



How efficiently do we detect γ -rays?



$$\epsilon_{peak} = \frac{N_{peak}}{N_\gamma}$$

photopeak efficiency

$$\epsilon_{total} = \frac{N_{recorded}}{N_\gamma}$$

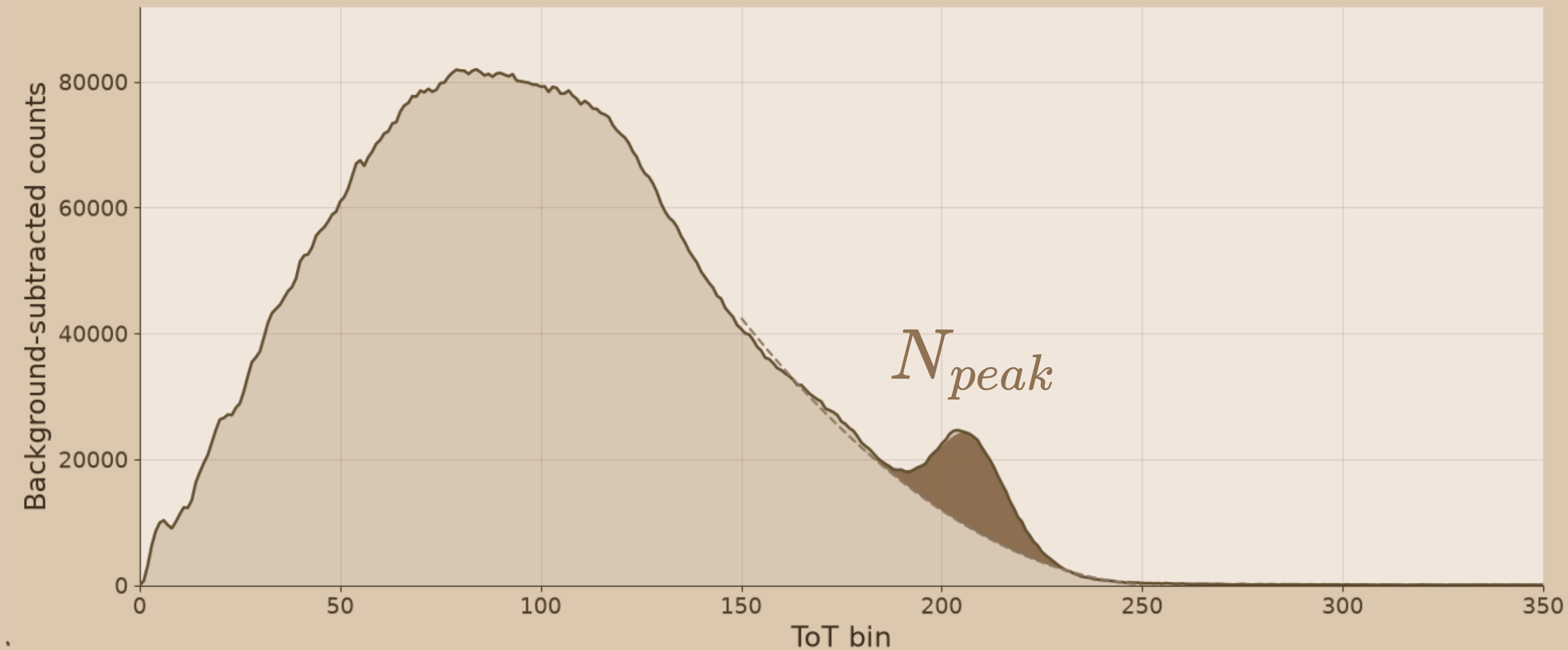
total efficiency

Depends on:

- energy
- distance
- geometry

Experimental efficiency measurements

^{137}Cs spectrum in water — $d = 21.5\text{ cm}$



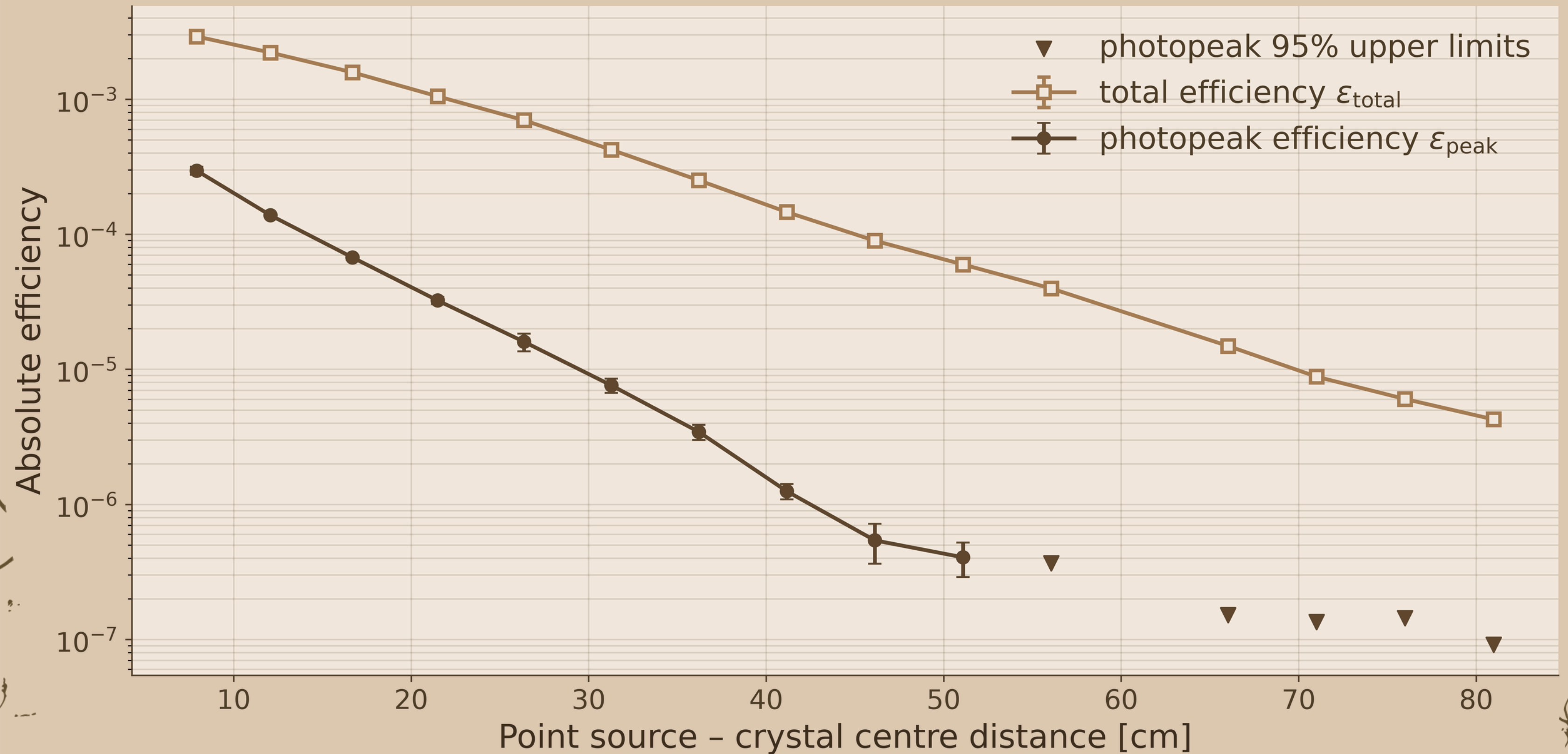
$$\varepsilon_{peak}(d) = \frac{N_{peak}(d)}{N_{\gamma}} \quad N_{\gamma} = A(t)I_{\gamma}t_{live}$$

^{137}Cs source at different distances



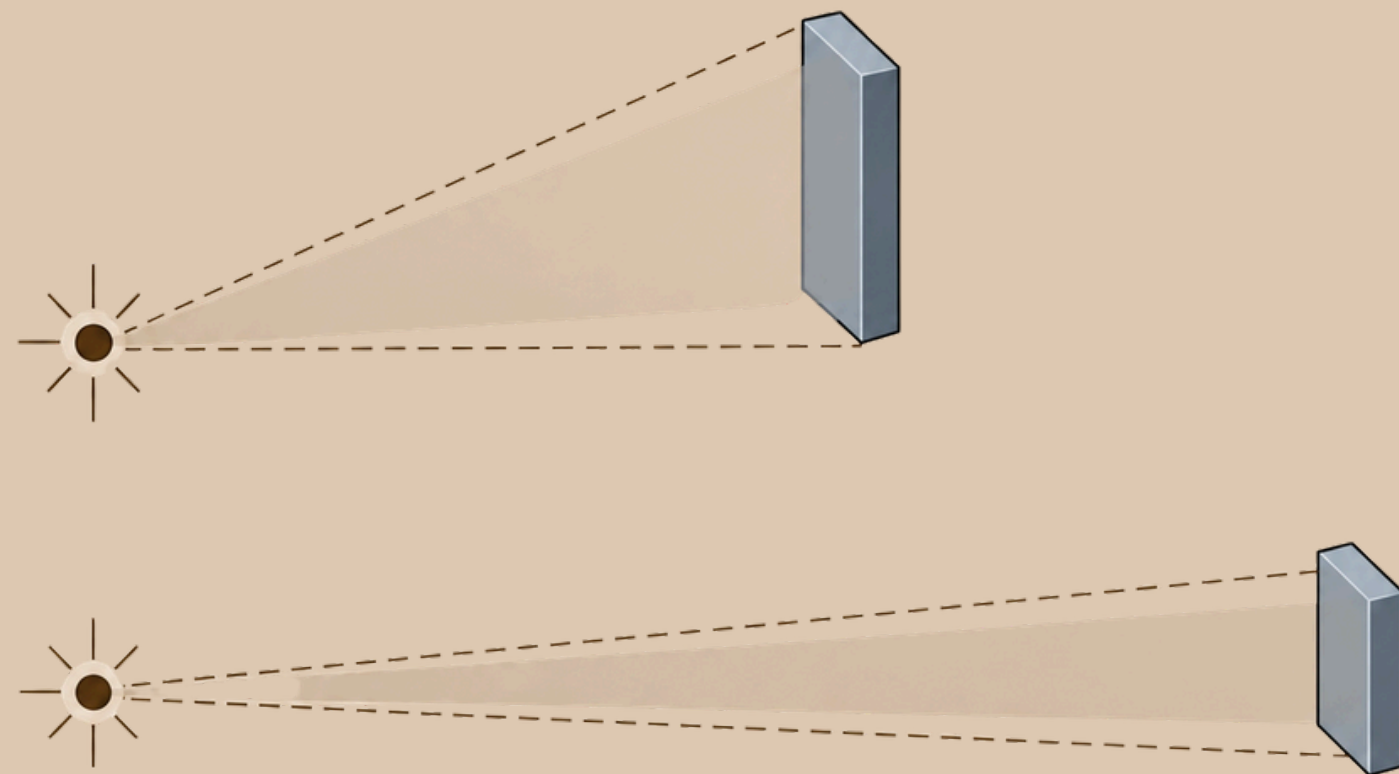
Experimental efficiency results

^{137}Cs in water



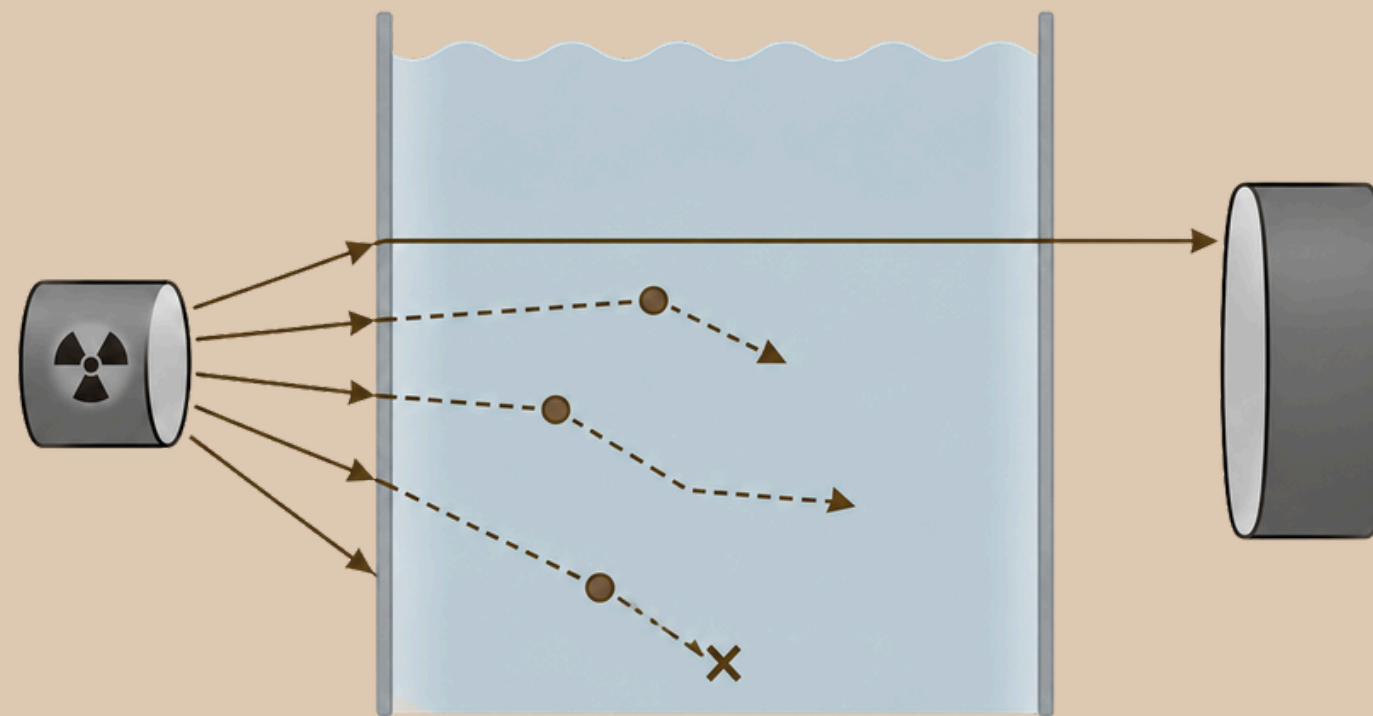
Why does the measured efficiency drop?

Geometrical loss



smaller detector solid angle

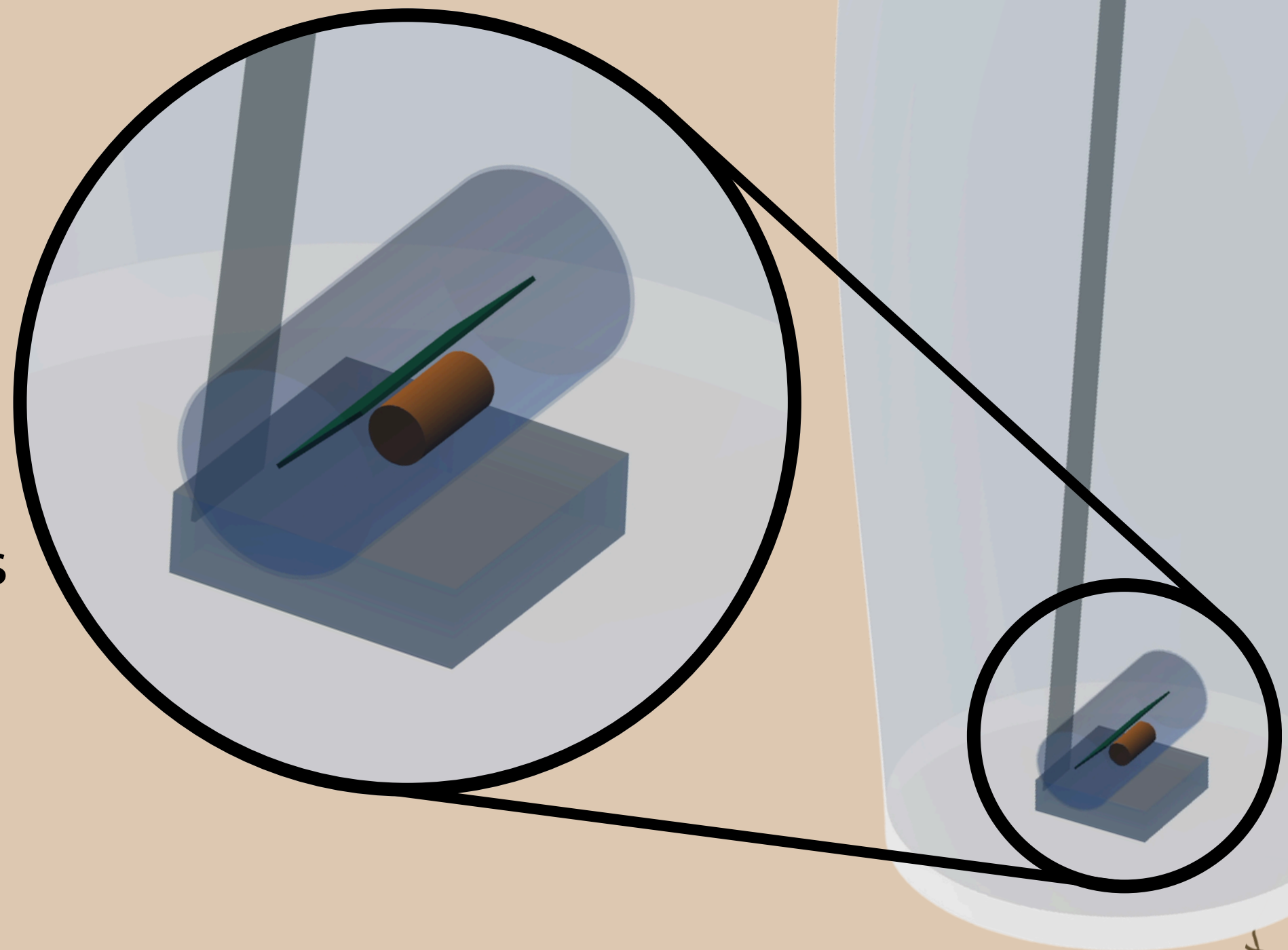
Attenuation in water



fewer unscattered γ -rays

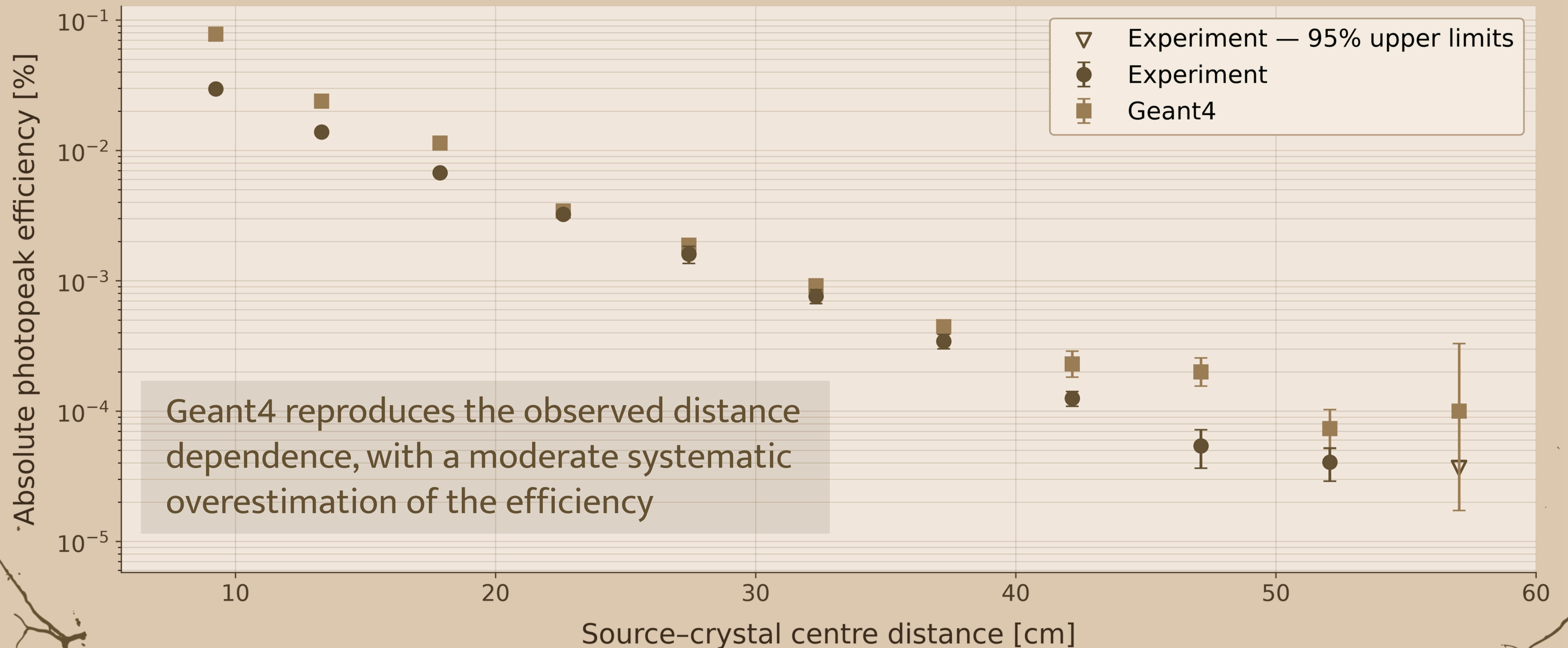
Building the Geant4 detector model

- Measured experimental geometry reproduced in Geant4
- Water barrel, bottle and detector position included
- CsI(Tl) crystal + PCB modeled as a rigid detector assembly



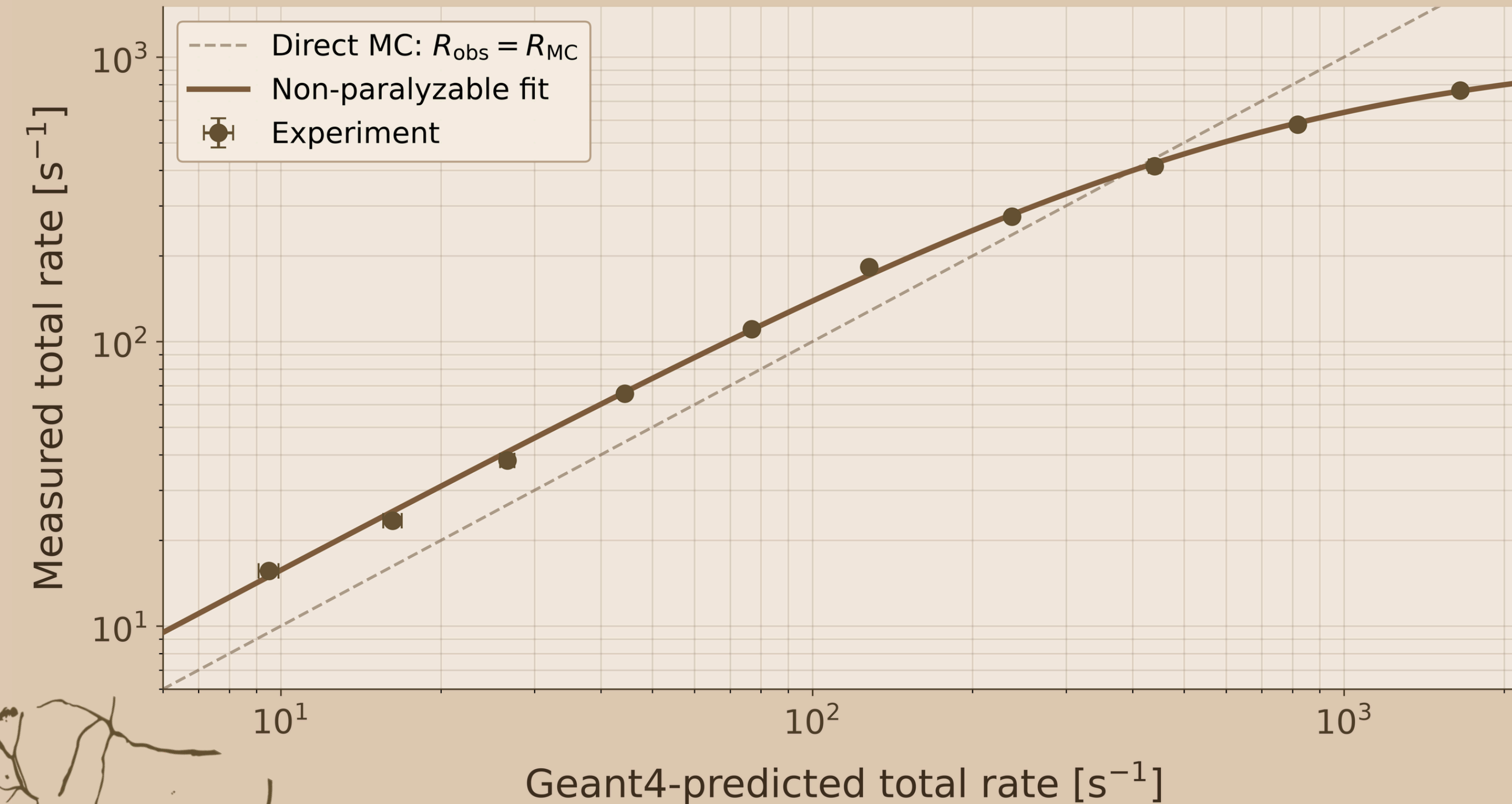
Experiment vs Geant4

^{137}Cs photopeak efficiency



Determining the effective dead time

¹³⁷Cs rate response



$$R_{\text{obs}} = \frac{k R_{\text{MC}}}{1 + k R_{\text{MC}} \tau_{\text{eff}}}$$

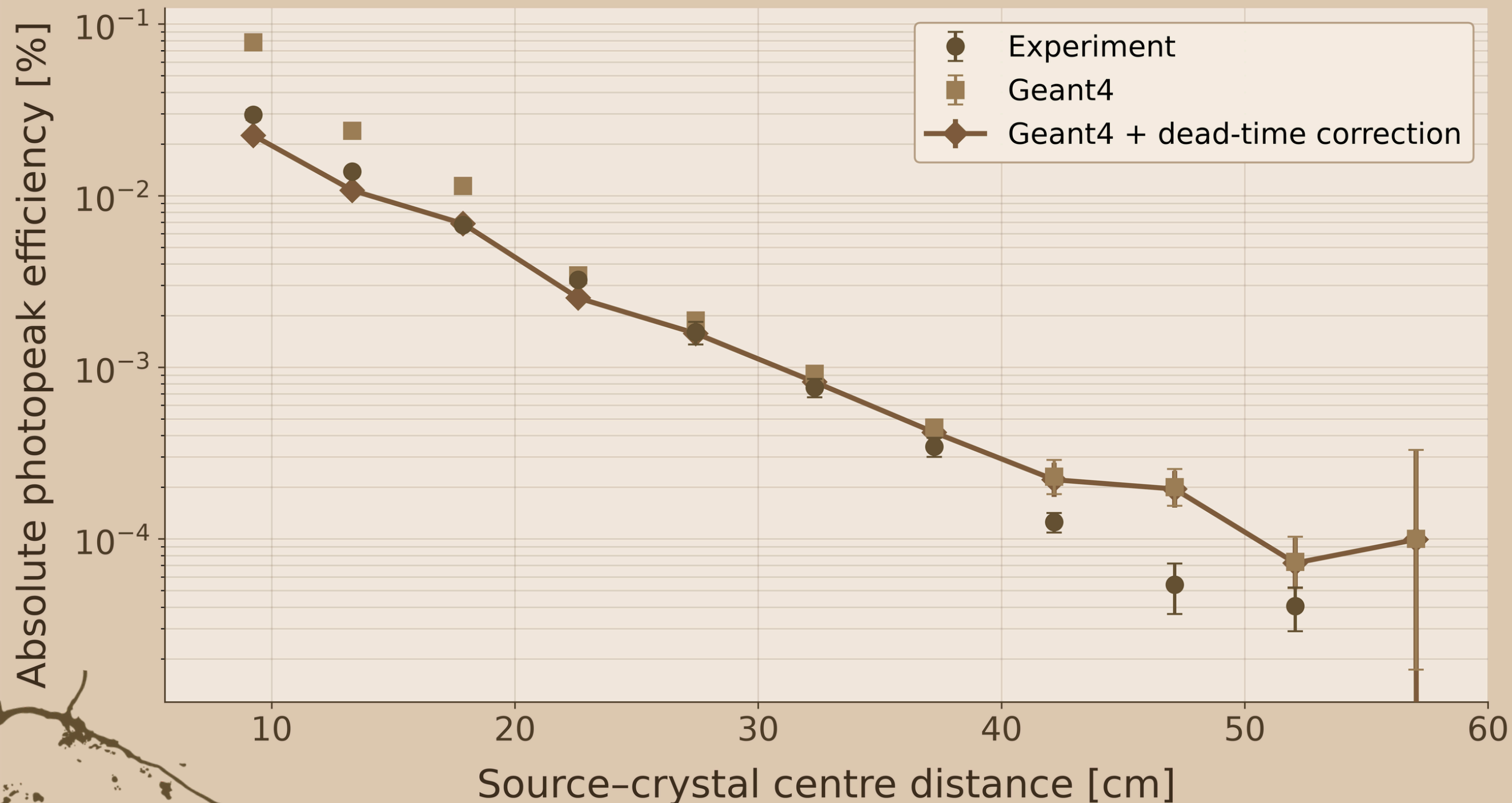
G. F. Knoll, Radiation Detection and Measurement

$$\tau_{\text{eff}} = 938 \pm 16 \mu\text{s}$$

The measured rate saturates at high activity due to the finite effective dead time of the acquisition chain.

Dead-time corrected efficiency

^{137}Cs photopeak efficiency with dead-time correction



Accounting for the effective dead time improves the agreement with Geant4, especially at short distances.

Conclusions

Detector hardware

- CsI(Tl) detector assembled and successfully tested
- BSU redesigned for easier integration

Acoustic monitoring

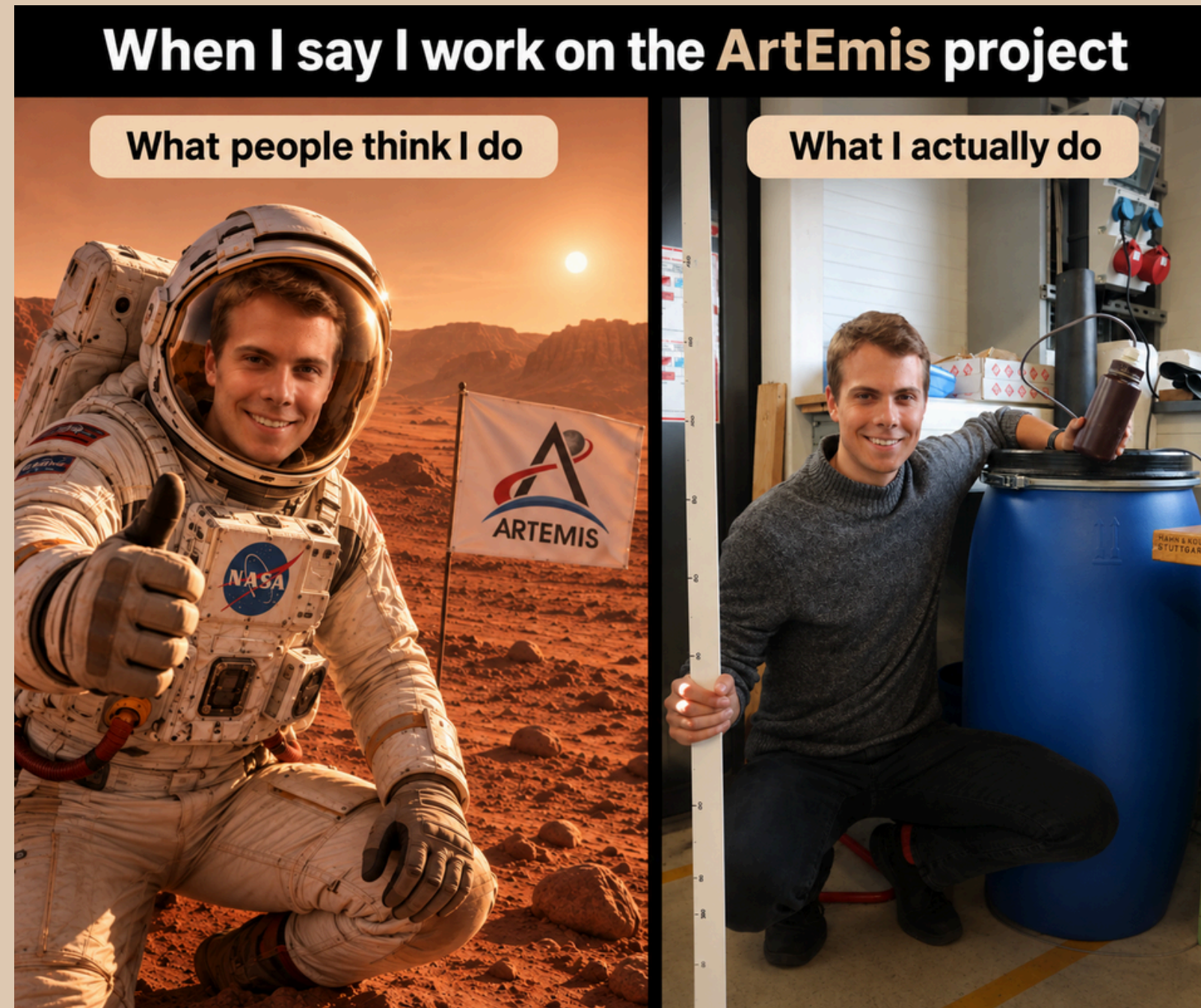
- Real-time low-frequency event detection implemented on a Raspberry Pi Pico
- Trigger validated with controlled signals and real environmental events

Detector characterization

- Experimental γ -ray efficiency measured and modeled with Geant4
- Effective dead-time correction improves experiment-simulation agreement

Thank you for your attention!

Questions?



Special thanks to Dr. Jürgen and Guru for their guidance, support and valuable feedback throughout the project.