UNIVERSITÀ DEGLI STUDI DI BRESCIA

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First performance results of COMMAND: a COmpact and Multi-purpose Muon And Neutron Detector

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VCI
VIENNA CONFERENCE ON INSTRUMENTATION

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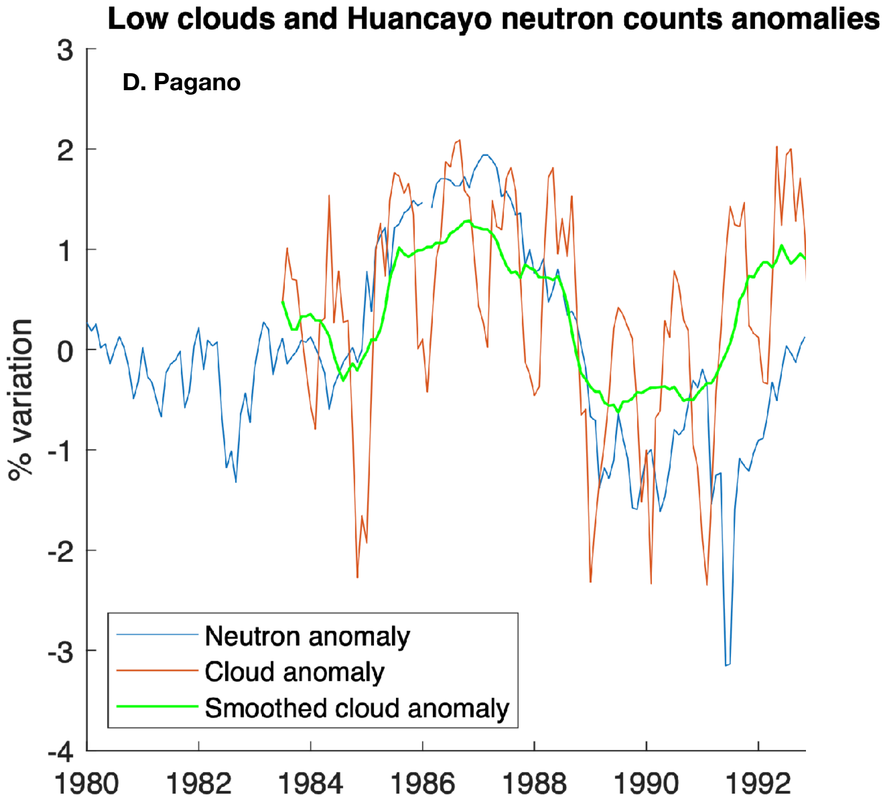
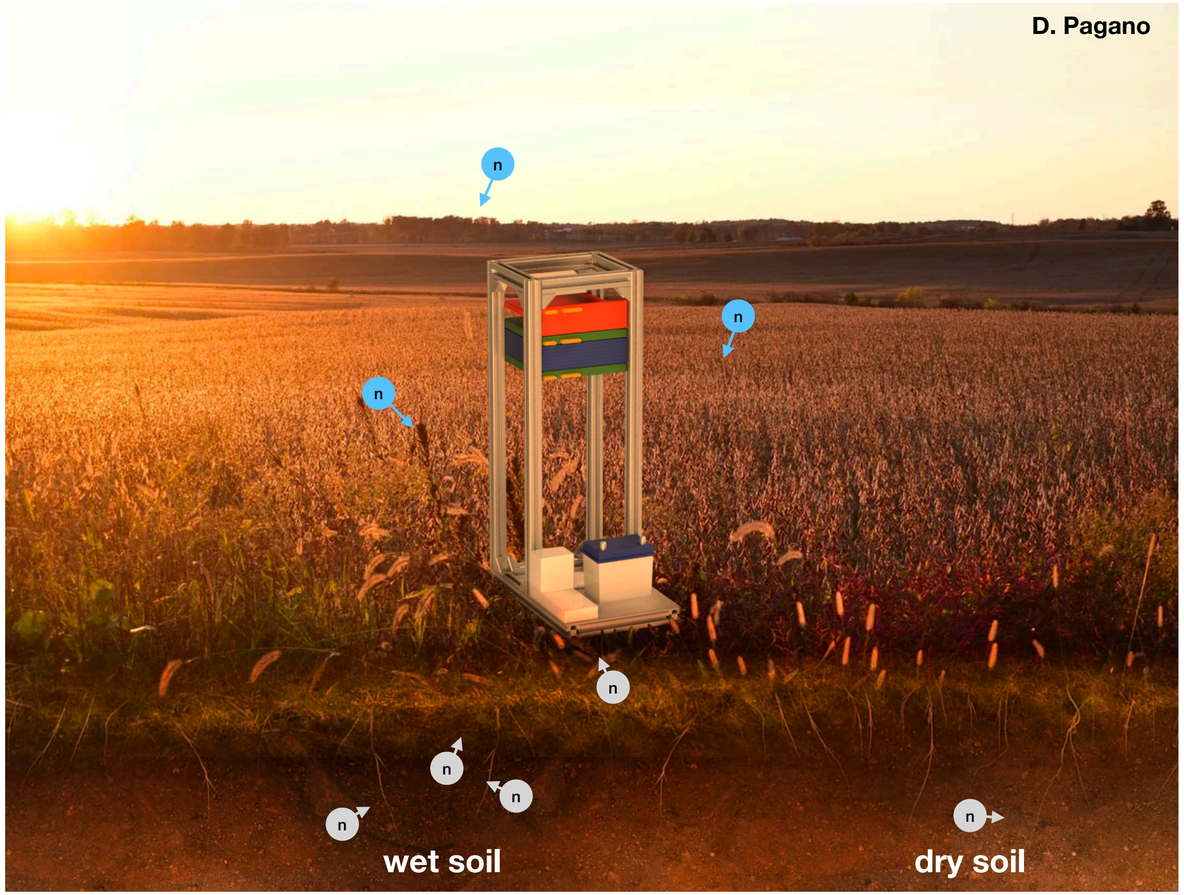
Motivations

- Our group, active in field of muography for almost 15 years, recently got involved in studies on the interplay between cosmic rays and climate and cosmic ray neutron sensing

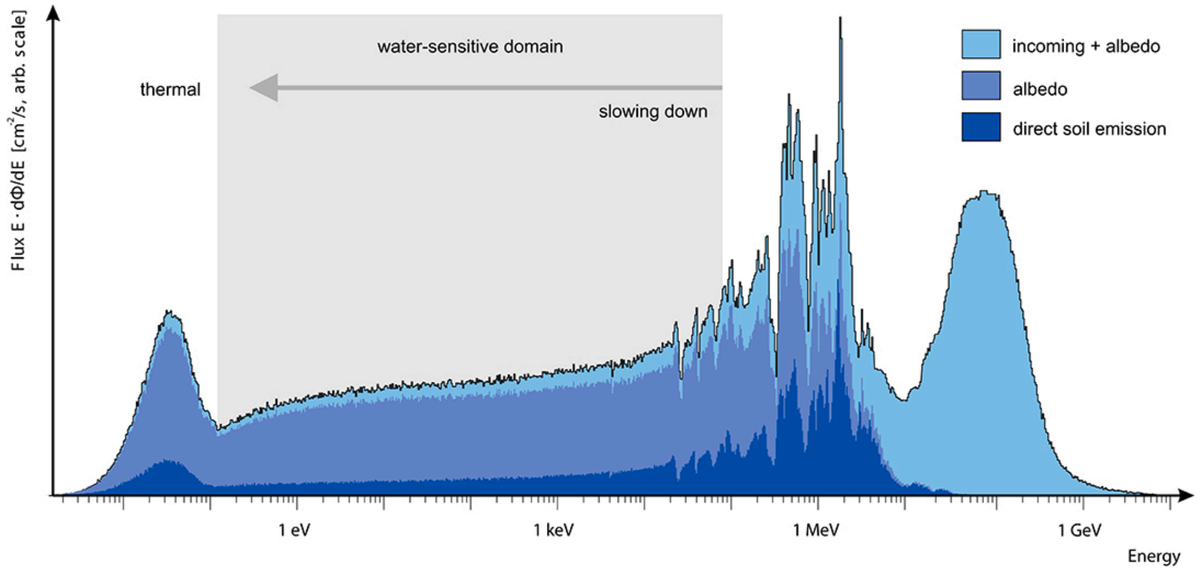




Requirements for the detector

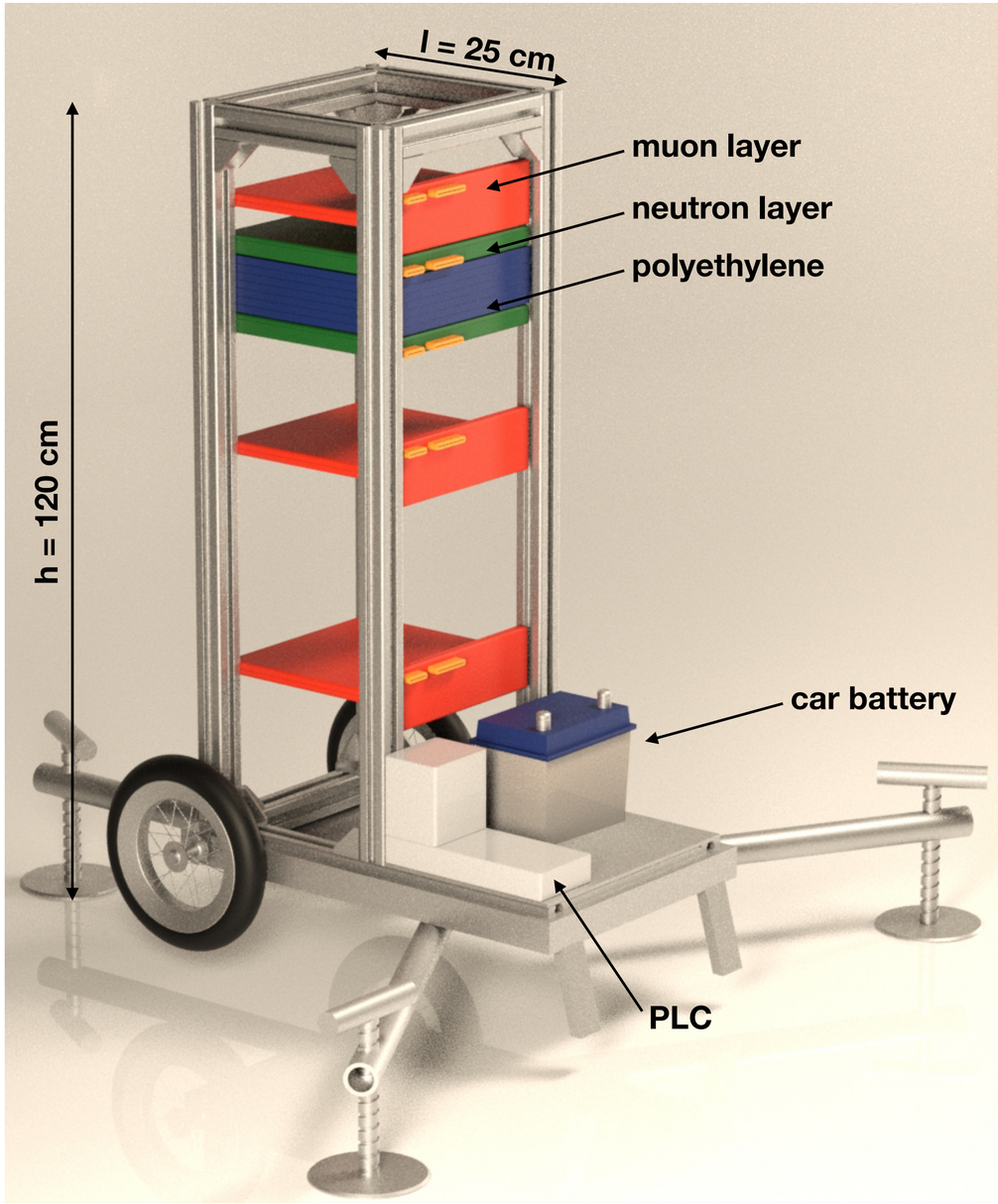
- Two layers for the detection of thermal ed epithermal neutrons
- Three layers for the detection of muons with an angular resolution better than 10 mrad on the zenith angle
- Independent and detachable layers
- Low power consumption (to run on battery)
- Weather resistance for field operation
- Modular design for future upgrades
- Budget for the project: ~20k euro

Köhli, Markus, et al. "Soil Moisture and Air Humidity Dependence of the Above-Ground Cosmic-Ray Neutron Intensity." *Frontiers in Water* 2 (2021): 66.



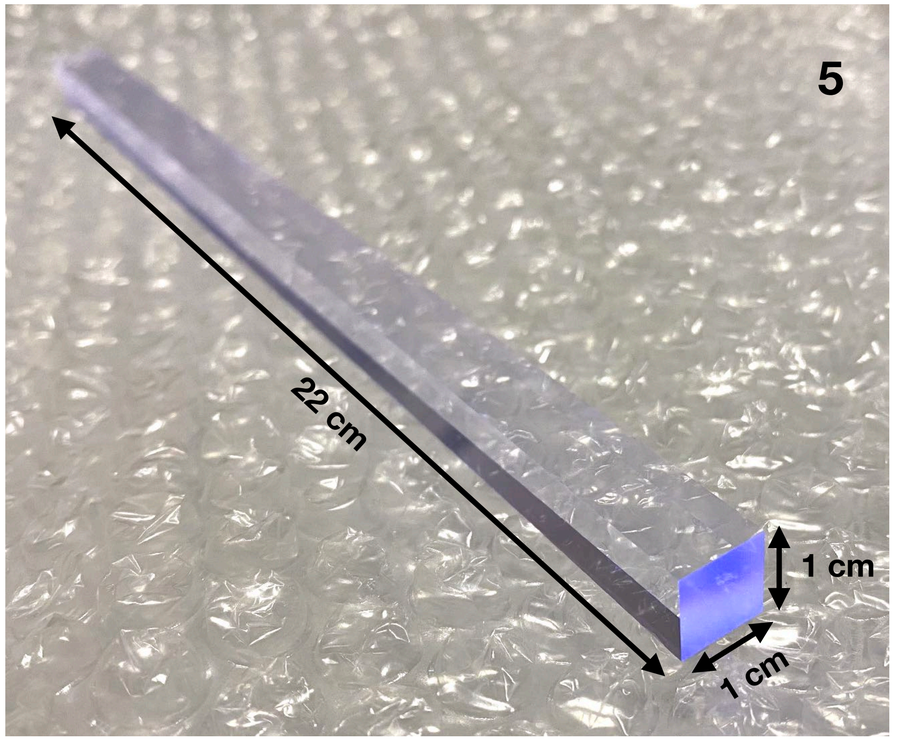
Detector design

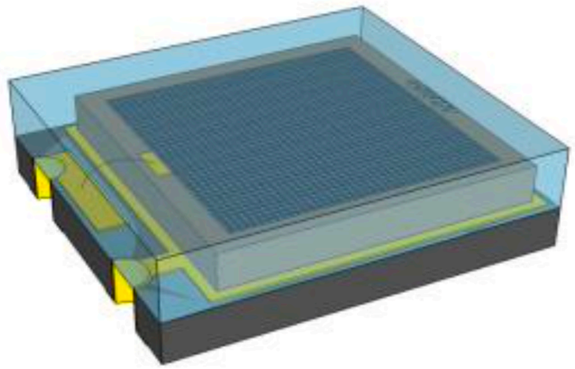
- 3 layers for muon detection each consisting of:
  - 22 scintillating fibers of size $(1 \times 1 \times 22)$ cm^3
  - each fiber is coupled to a (4×4) mm^2 SiPM
  - front-end electronics
- 2 layers for neutron detection each consisting of:
  - EJ-426HD2-PE2 + EJ-280 (WLS)
  - signal are read by four (4×4) mm^2 SiPM
  - front-end electronics
- Polyethylene for the moderation of epithermal and slow neutrons
- PLC for DAQ, calibration, storage, etc.
- Car battery (50 Ah) - expected operability > 24 h

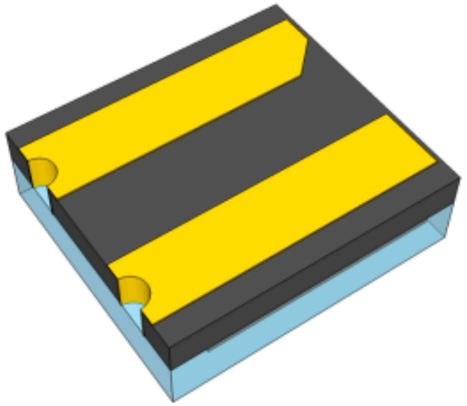


Muon module

- Each module consists of 22 scintillating fibers (EJ-200 from Elijen Technology) of size (1 x 1 x 22) cm^3
- Each fiber is coupled to a (4 x 4) mm^2 SiPM (ASD-NUV4S-P from AdvanSiD)
- No WLS and no mirror at the opposite end of the fiber







PROPERTIES	EJ-200
Light Output (% Anthracene)	64
Scintillation Efficiency (photons/1 MeV e-)	10,000
Wavelength of Maximum Emission (nm)	425
Light Attenuation Length (cm)	380
Rise Time (ns)	0.9
Decay Time (ns)	2.1
Pulse Width, FWHM (ns)	2.5
Density (g/cm^3)	1.023
Refractive Index	1.58
Light Output vs. Temperature	At 60°C, 95% of that at 20°C No change from 20°C to -60°
Temperature Range	-20°C to 60°C

Front-end electronics: Muon modules

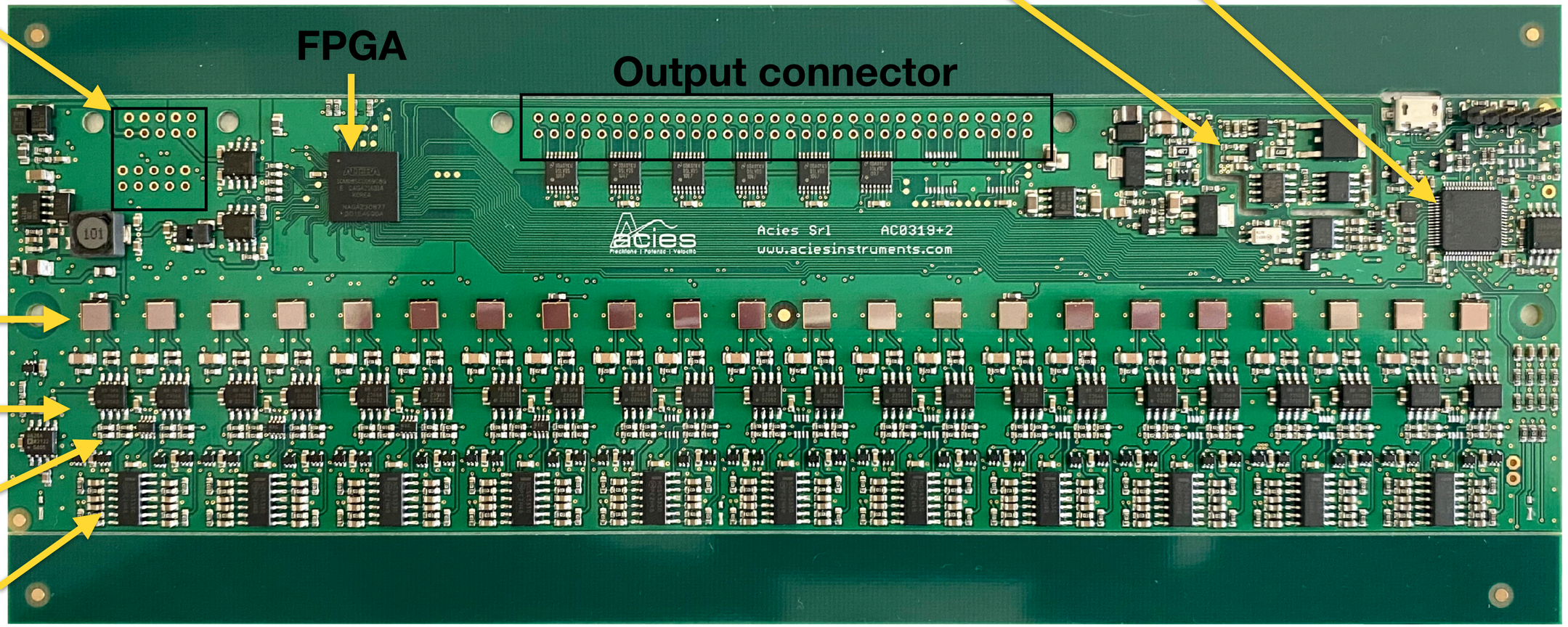
Cortex-M
- SEPIC control
- UART
- USB 2

Supply and control connector

Global V_b generator

FPGA

Output connector



SiPM

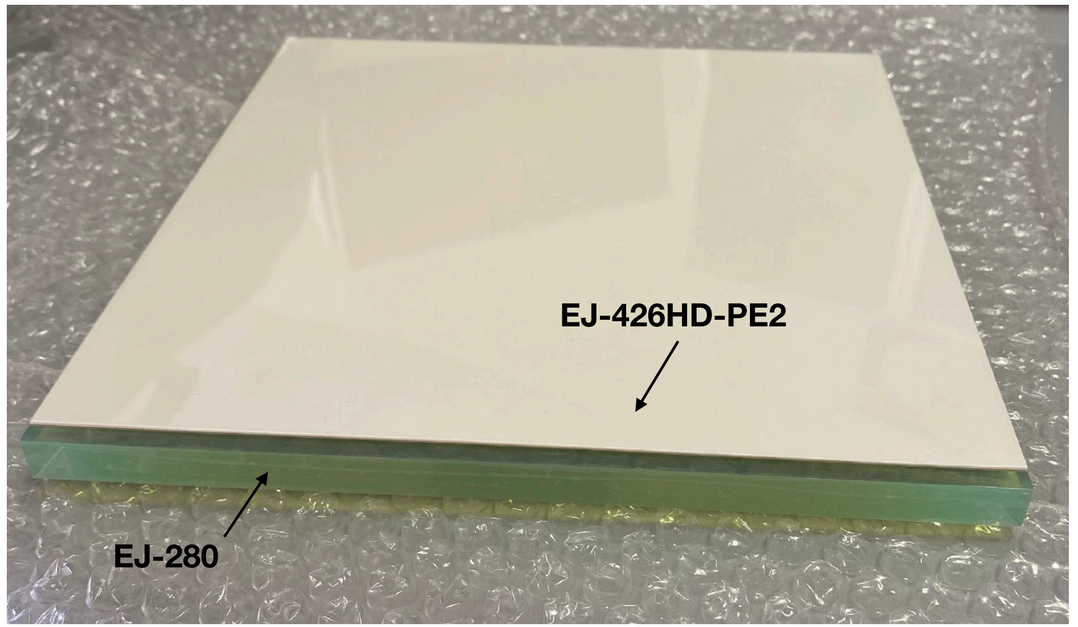
Amplification

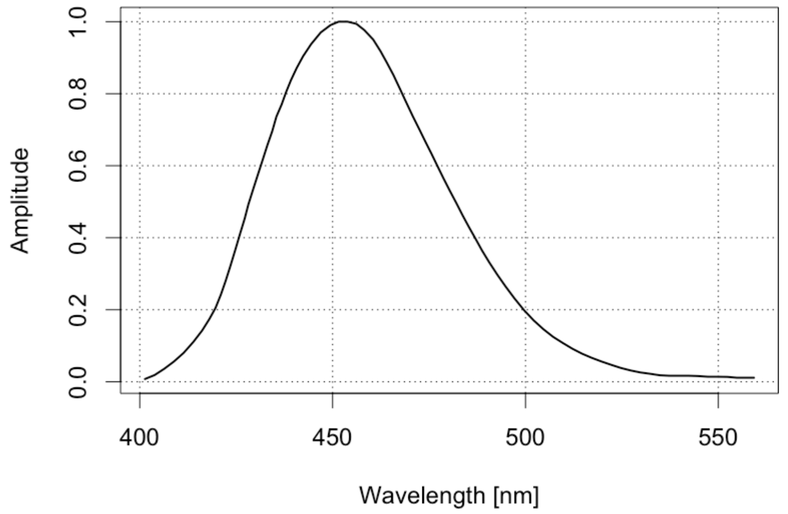
Discrimination

16 bit trim

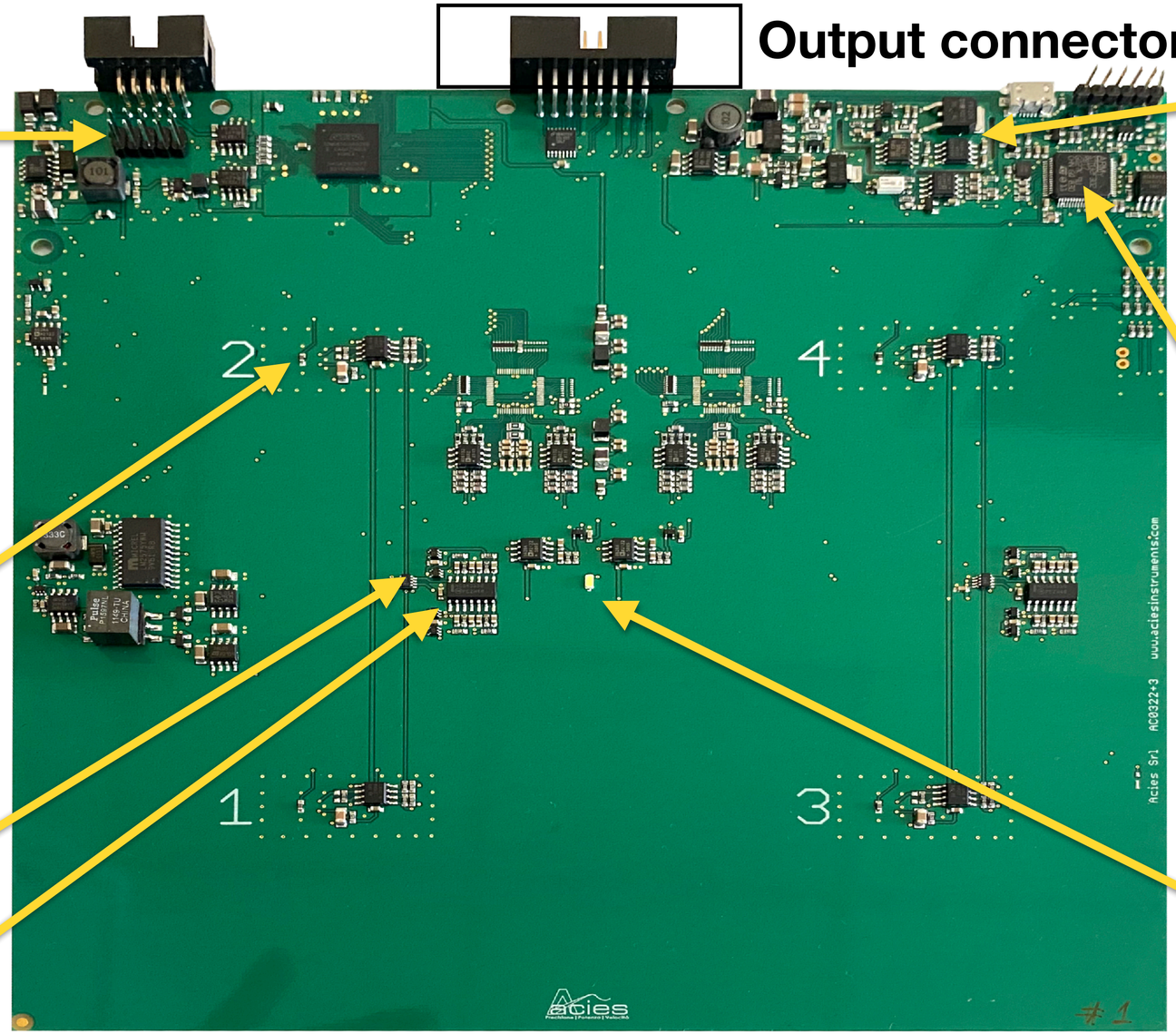
Front-end electronics: Neutron modules

- Each module consists of a lithium-enriched foil (EJ-426HD-PE2 from Elijen Technology) coupled to WLS (EJ-280 from Elijen Technology)
- High efficiency for thermal neutrons with low sensitivity to gamma radiation
- $^{6}Li + n \rightarrow {}^{3}H + {}^{4}He + 4.78\ MeV$
- Triton and α-particle detected by ZnS:Ag phosphor with broad blue fluorescent spectrum
- Scintillating light read by 4 (4 x 4) mm^2 SiPM (ASD-NUV4S-P from AdvanSiD)



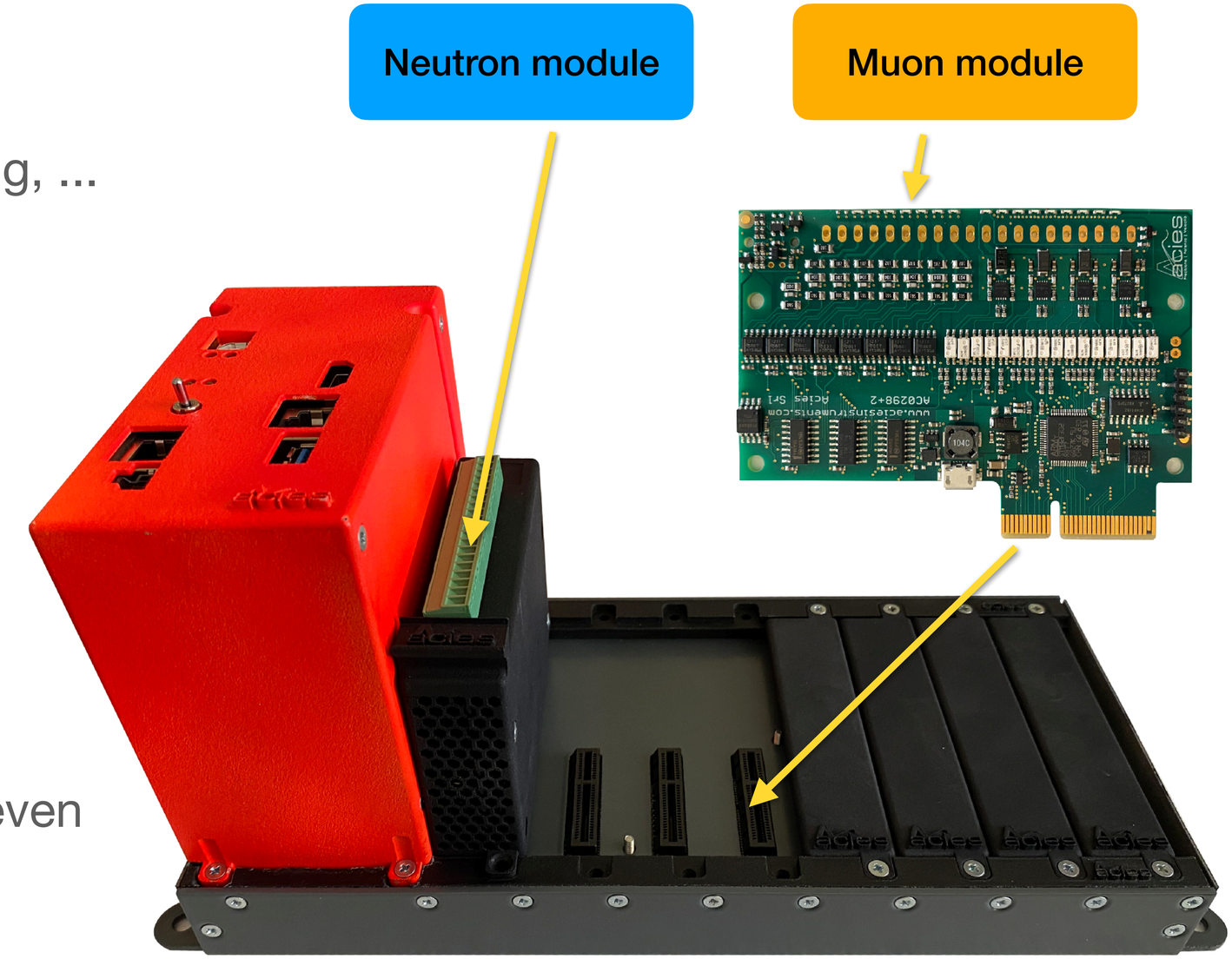


Front-end electronics: Neutron modules



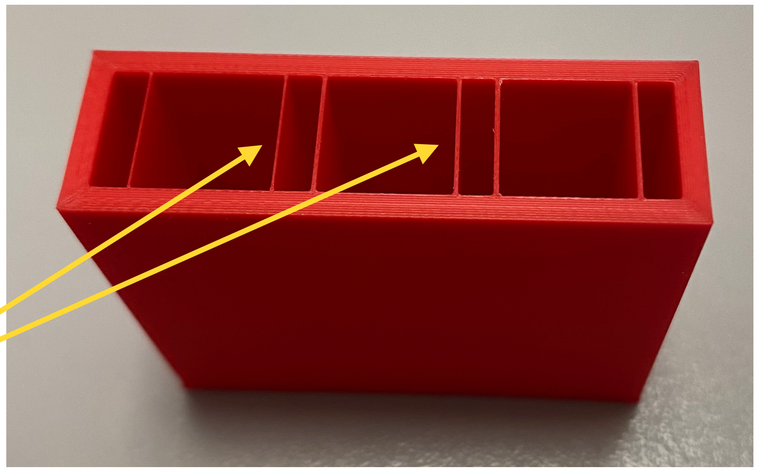
DAQ electronics

- Dual core CPU with on USB3
  - Real-time: timing, time-stamping, ...
  - SBC running ARC Linux: data acquisition, storage, network interface, ...
- GPS module
- WiFi + ethernet communication
- Supply management
  - If plugged into the socket can even charge the battery



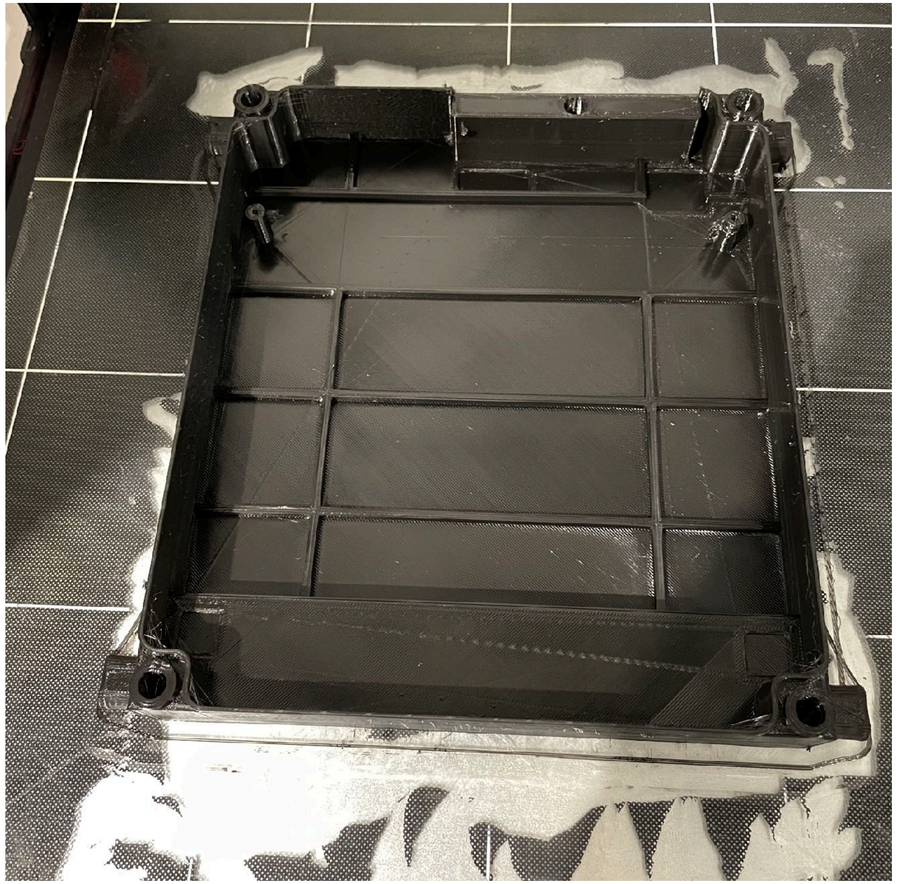
Shells for muon and neutron modules

- Shells for all modules made by means of addictive manufacturing (3D printing)
- Light-proof and weather resistance requirements make the use of this technique challenging
- Tests ongoing on materials, thicknesses and different designs
- Almost no literature on this subject



Spacers for fibers

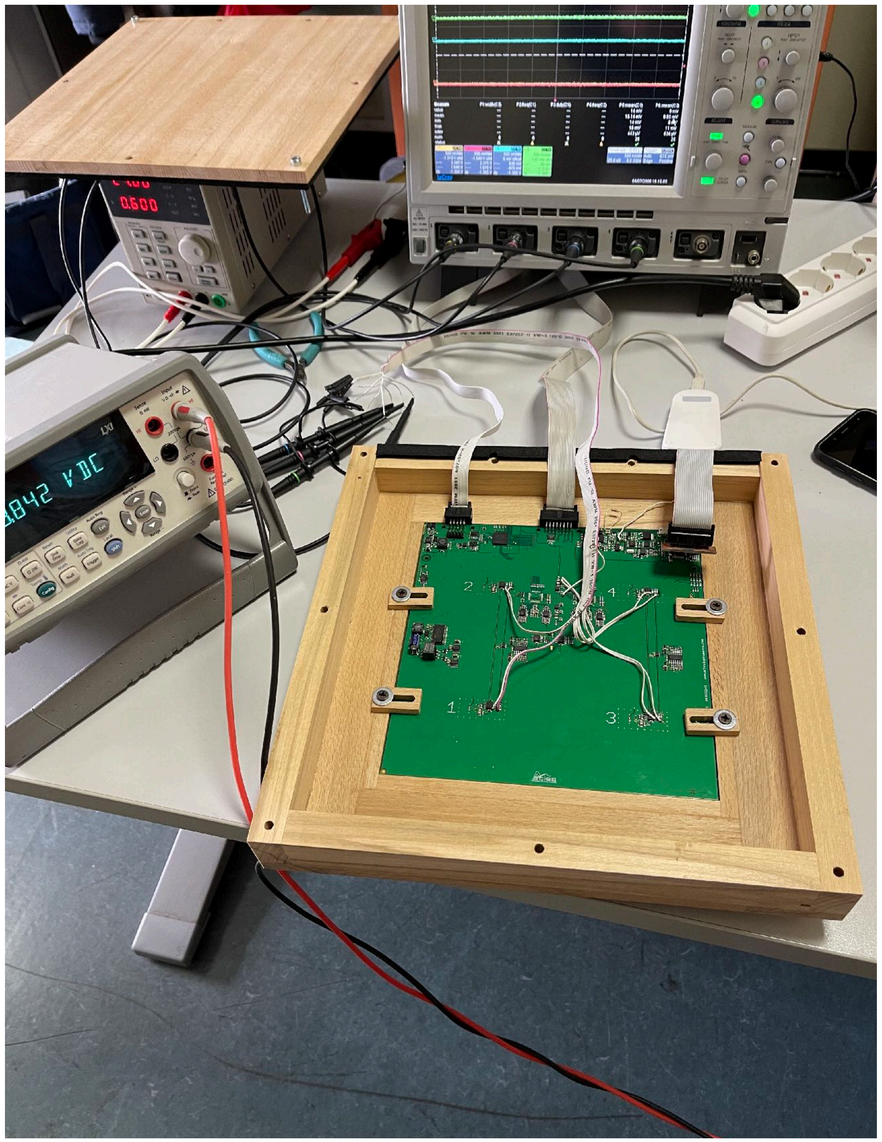
Shell prototype for the neutron module

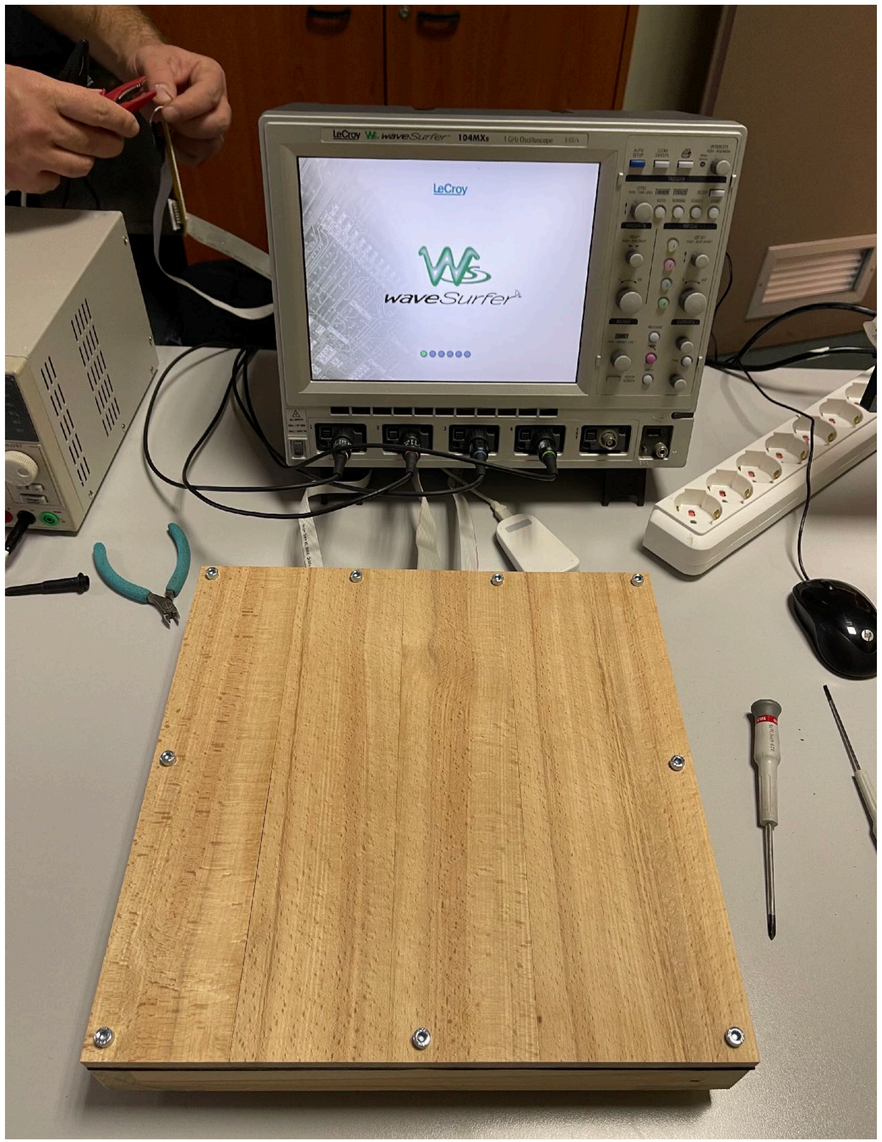


L. Giorleo - Laboratorio di Prototipazione Avanzata

Tests of the modules

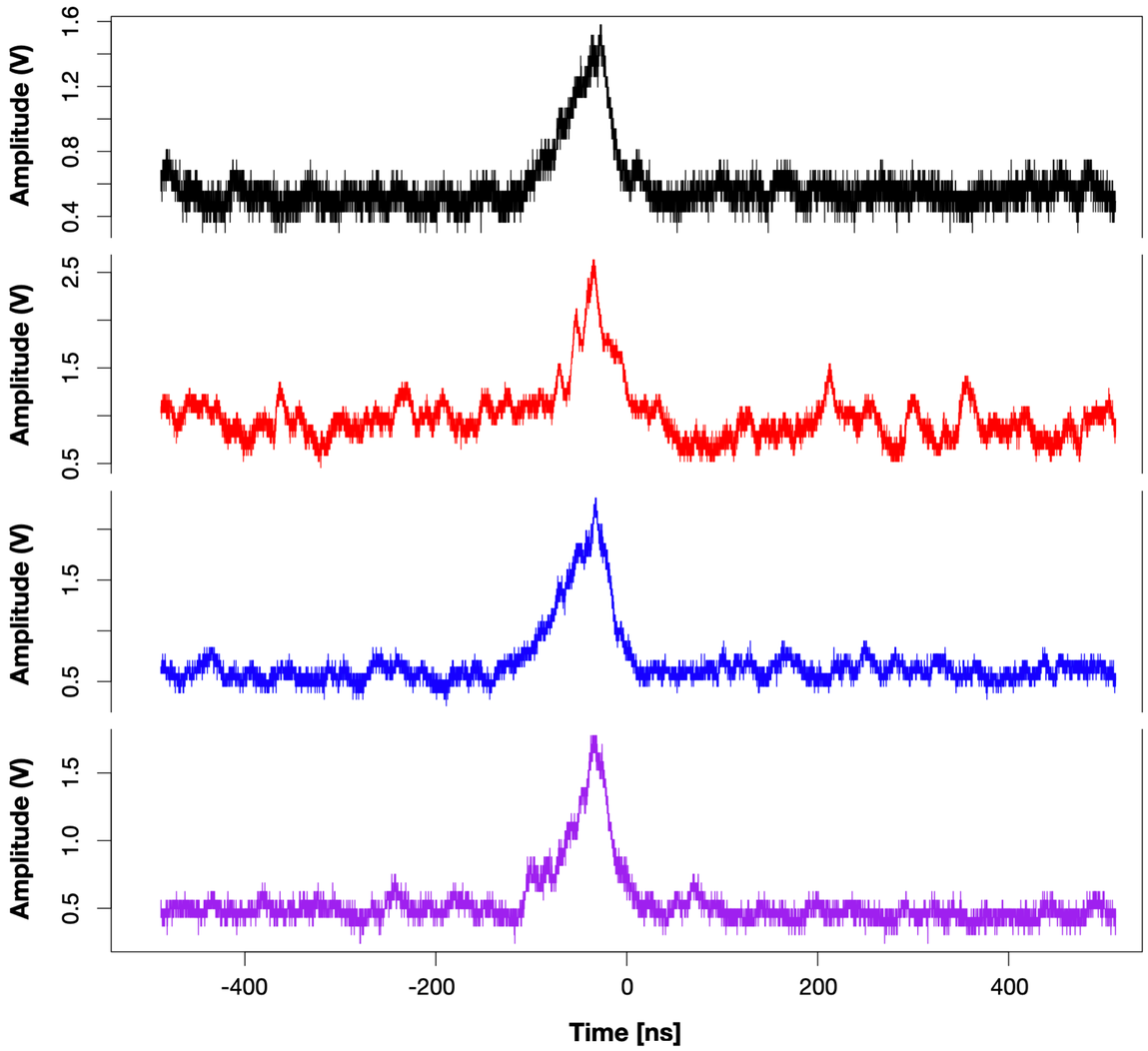
- Each module is under testing with a dedicated setup
- Oversize light-proof wooden boxes are used of the tests
- Boxes are sealed with neoprene





Signals from the neutron modules

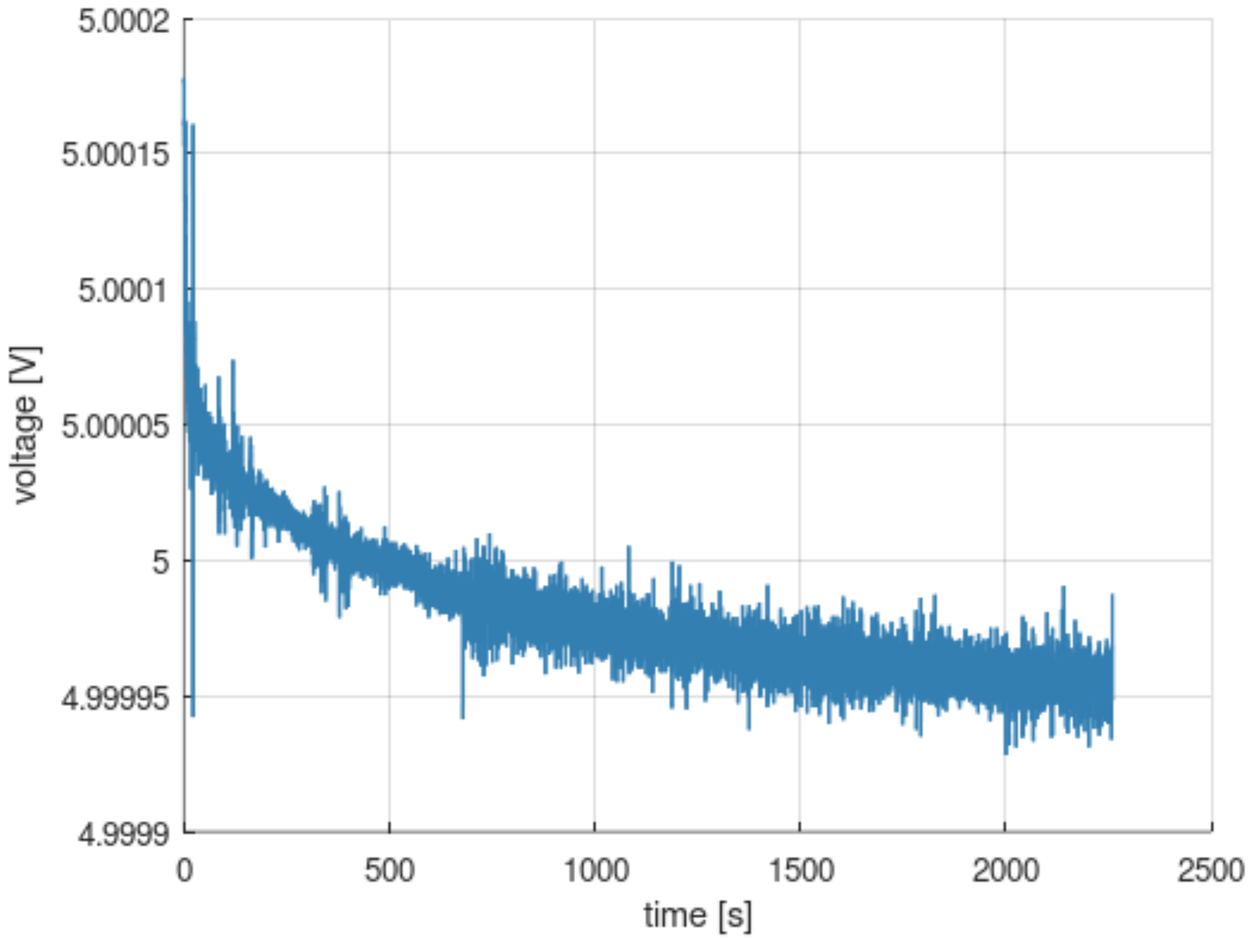
candidate neutron event



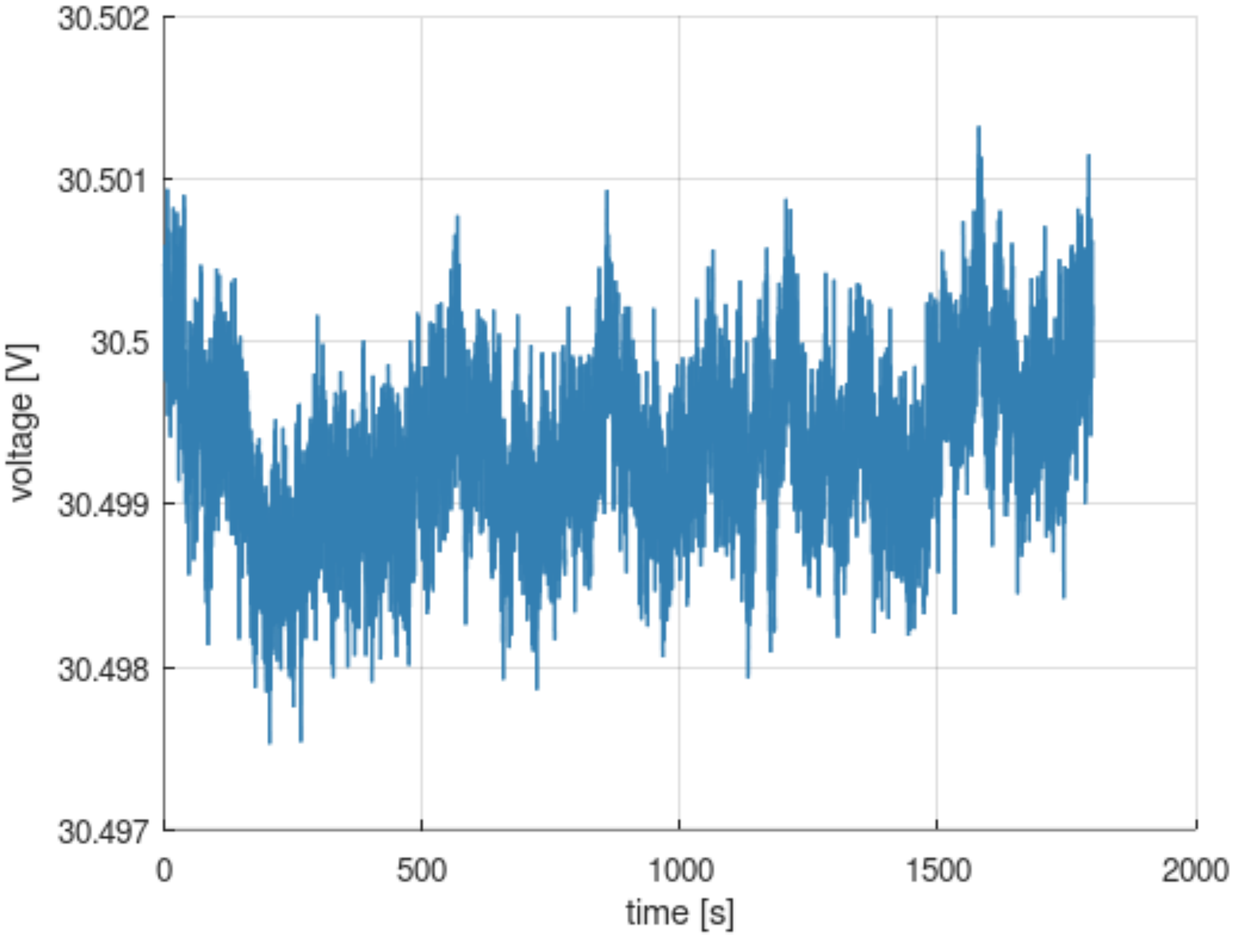
onboard LED events

Tests of the electronics

Reference bias voltage stability (cold start)



SIPM bias voltage stability (after running for 30 min)



Conclusions

- We designed and developed a compact (and multi-purpose) muon and neutron detector
- Designed for autonomous field operations: run on battery, no need of PC or other devices
- Custom-made electronics from Acies Instruments (http://www.aciesinstruments.com/)
- Shells made by means of addictive manufacturing
- Modular design: easy to upgrade for possible future muography applications
- Current status:
  - Electronics has been finalized and it is currently under test
  - We are also testing different materials and designs for the 3D printing of the shells
- First field measurements expected for the next months