Puli Lunar Water Snooper R&D activities at CERN

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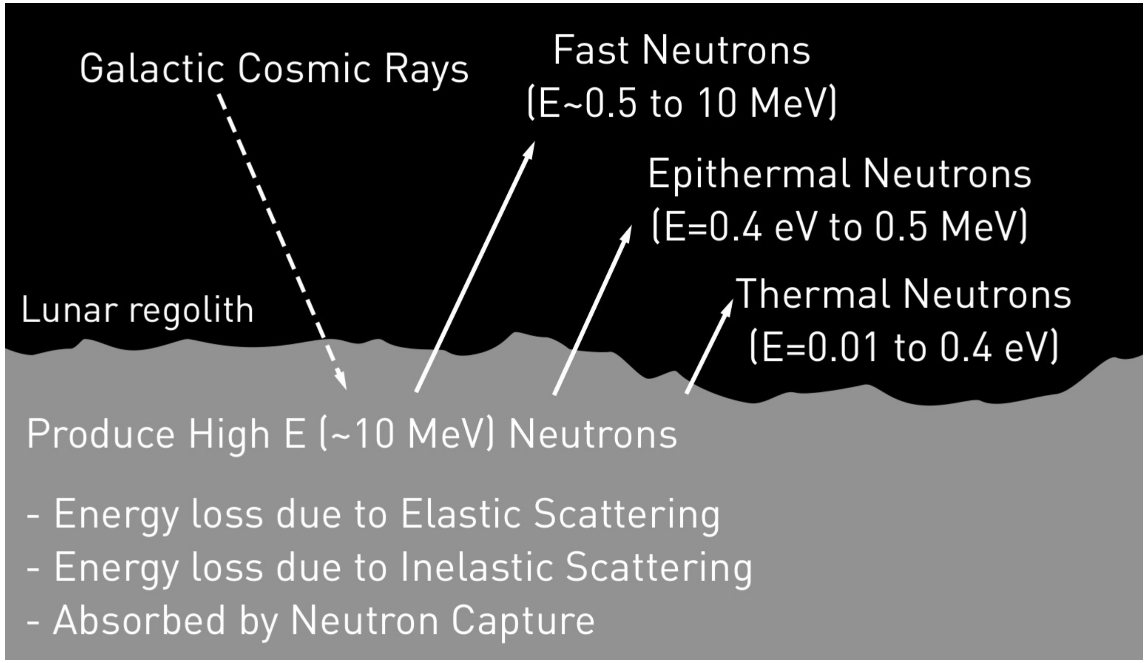
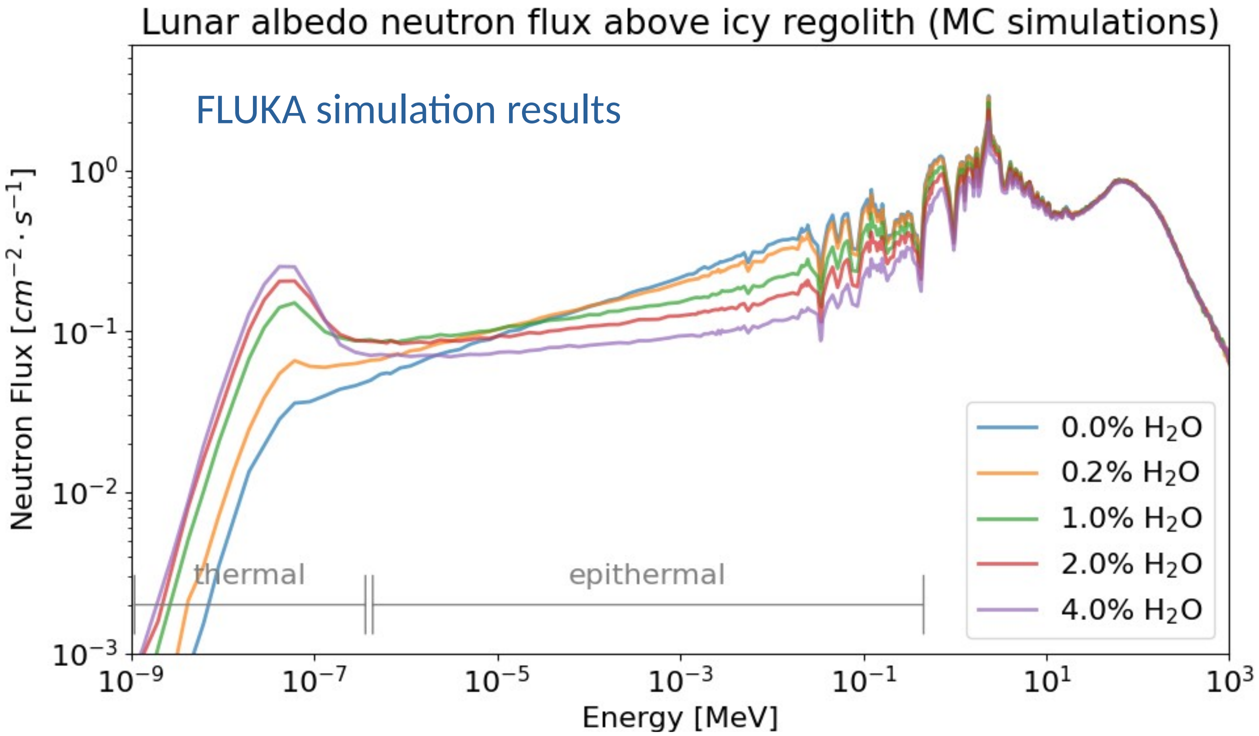
on behalf of Puli Space Technologies and R2E

R2E Annual Meeting – 1-2 March, 2022
https://indico.cern.ch/event/1116677

Neutron environment on the Moon

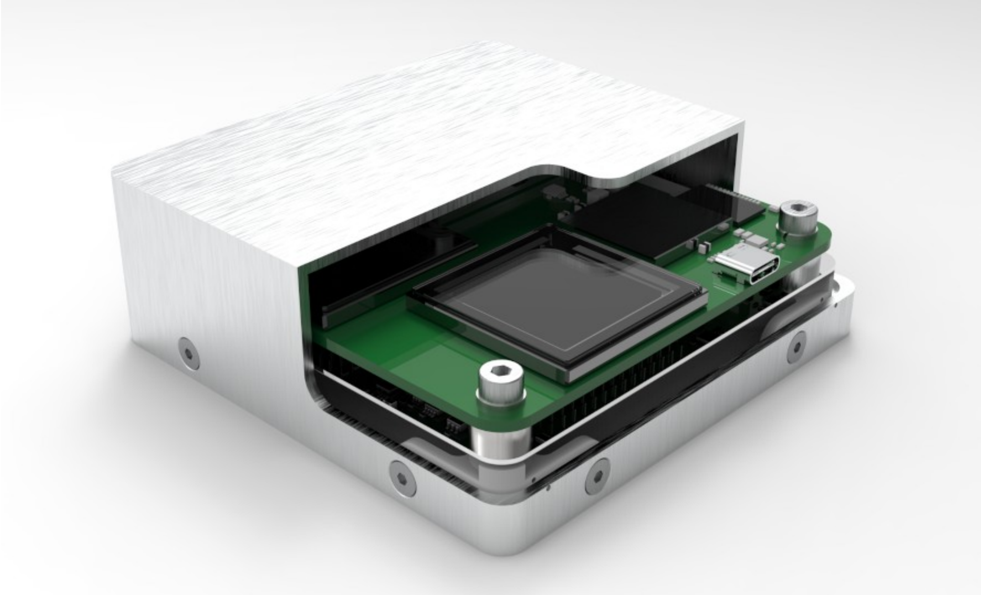
- Albedo neutrons produced by high-energy cosmics rays on the Moon (mixed radiation field)
- Neutron energy spectrum is characteristic to the local soil composition, strongly depending on H (H_2O & OH)

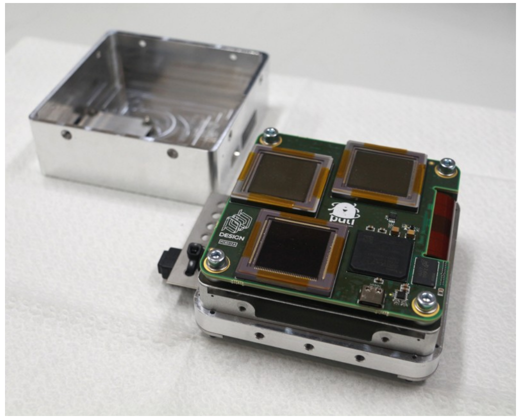


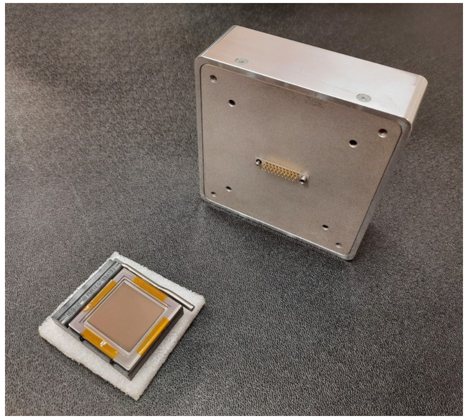


The PLWS instrument

- A novel neutron spectrometer payload to
  → characterize neutron (mixed) radiation environment
  → measure water equivalent hydrogen content in lunar soil
- Uses modified off-the-shelf sCMOS image sensors as thermal and epithermal neutron detectors, plus a 3rd reference sensor for the background
- Low-cost, COTS-based system
- 10cm × 10cm × 3.5cm, 382 grams, 7-12 VDC, ≤ 4 W
- Low-bandwidth serial communication
- Continuous, autonomous measurement
- NASA challenge winner concept ⇒ NASA funding (1 year)
- Delivered 3 identical, working prototypes at ≥TRL5 to NASA JPL on 17 February 2022
- 1st payload user might be NASA for lunar missions in 2024





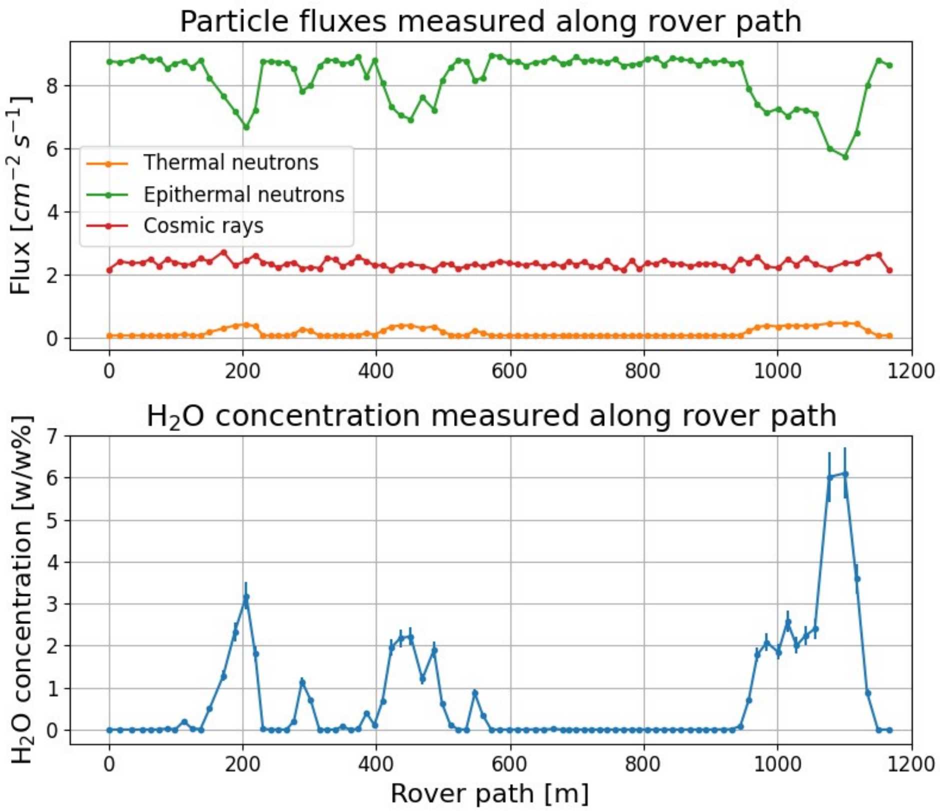


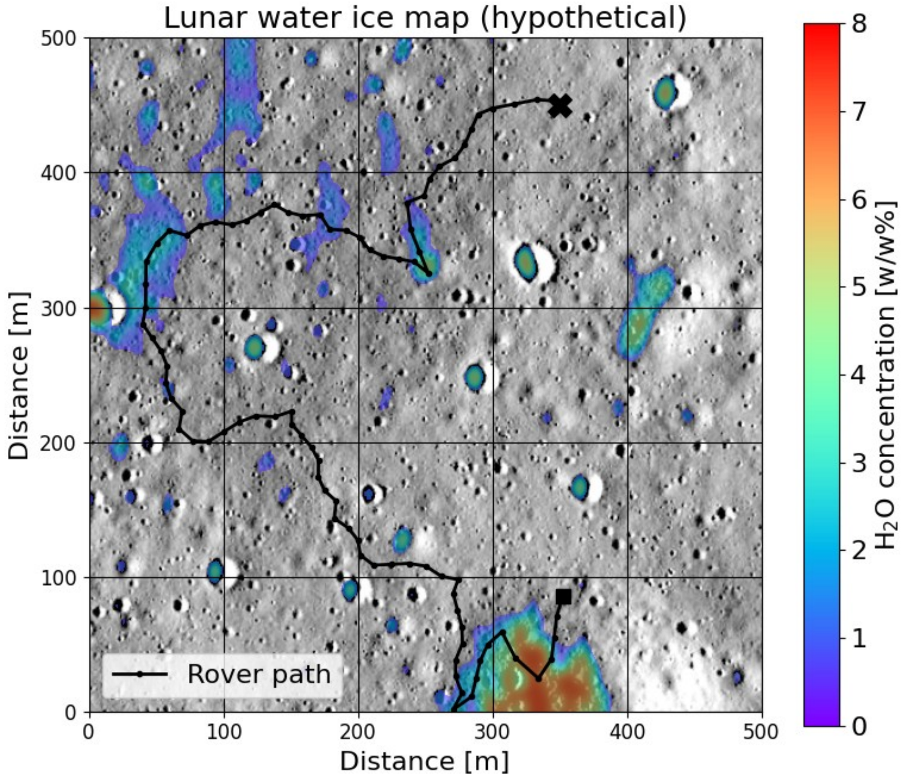
PLWS lunar applications – Mapping water deposits

- By detecting neutrons, lunar subsurface H resources can be mapped spatially with very high resolution
- Addressing scientific goals of NASA Artemis program, and needs of the Space Resources & ISRU community

Flux values based on FLUKA simulation results

Hypotetical H_2O conc. values





Directly measured particle flux (count rate) values

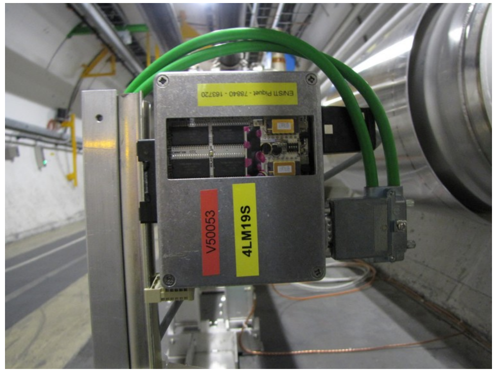
Indirectly measured H_2O conc. values

PLWS terrestrial spin-off applications

Radiation environment monitoring

in neutron/mixed-field/accelerator environments

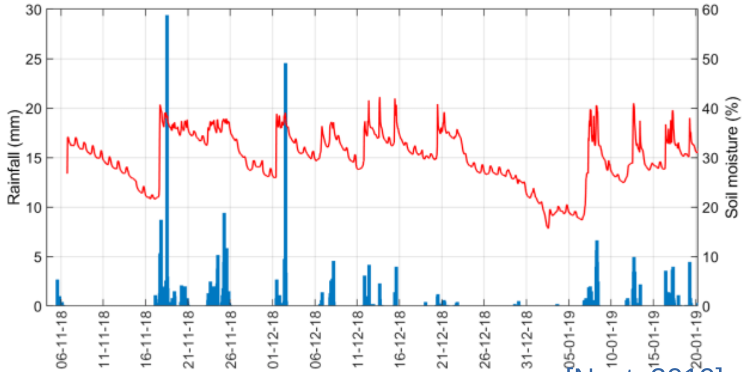
- Monitoring thermal, epithermal neutron fluxes, as well as particle energy deposition distributions
- Neutron environment: moderate flux, high fluence
- Modular design with CMOS image sensors
- Collaborator & potential 1st customer: CERN R2E
- Potential host system: RadMON/BatMON system



Soil moisture monitoring

on agricultural arable lands

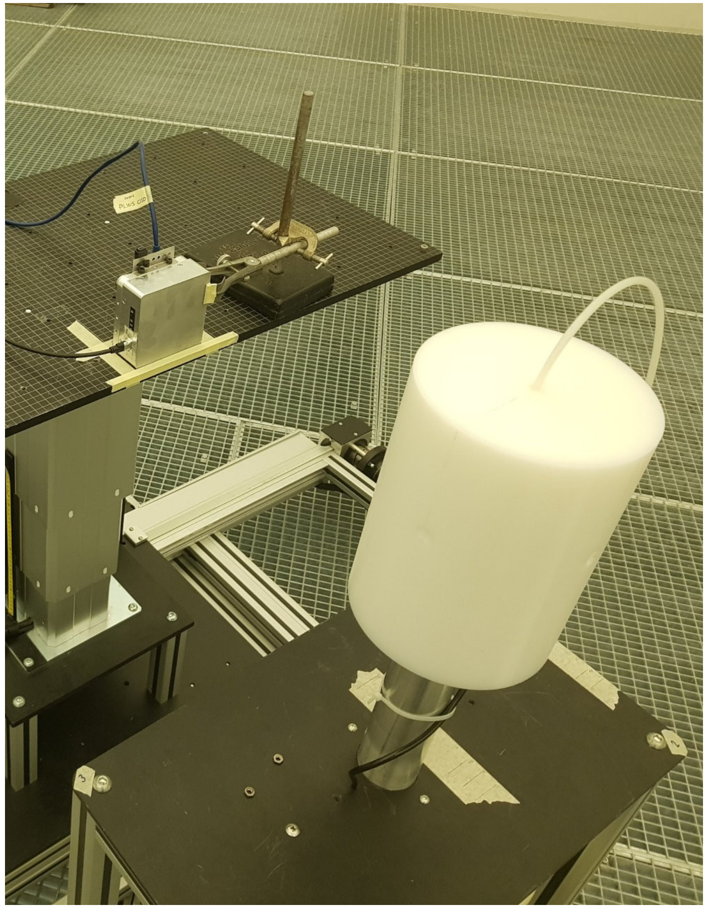
- Monitoring soil water content (Cosmic Ray Neutron Sensing) to save irrigation water and cost, increase crop yield
- Neutron environment: very low flux, low fluence
- Scalable design with silicon diode detectors
- Collaborators & potential 1st customers: KITE, Bonafarm
- Potential host system: Agro-meteorological stations



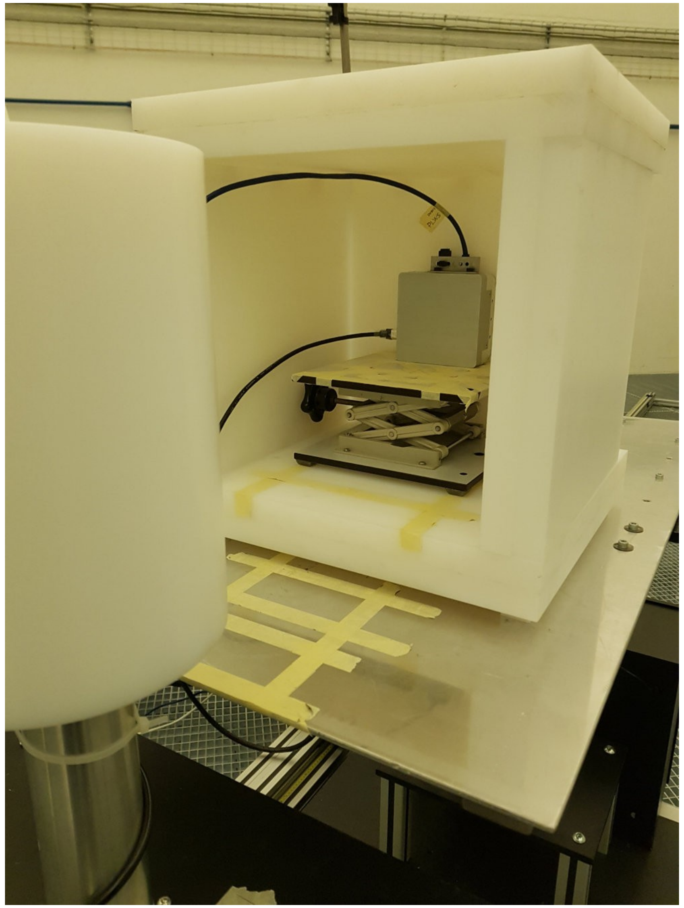
source: [Nasta2019]

Subjects of a 1-year ESA Space Resources study of Puli Space and CMBP starting in March 2022, in collaboration with CERN R2E, KITE and Bonafarm

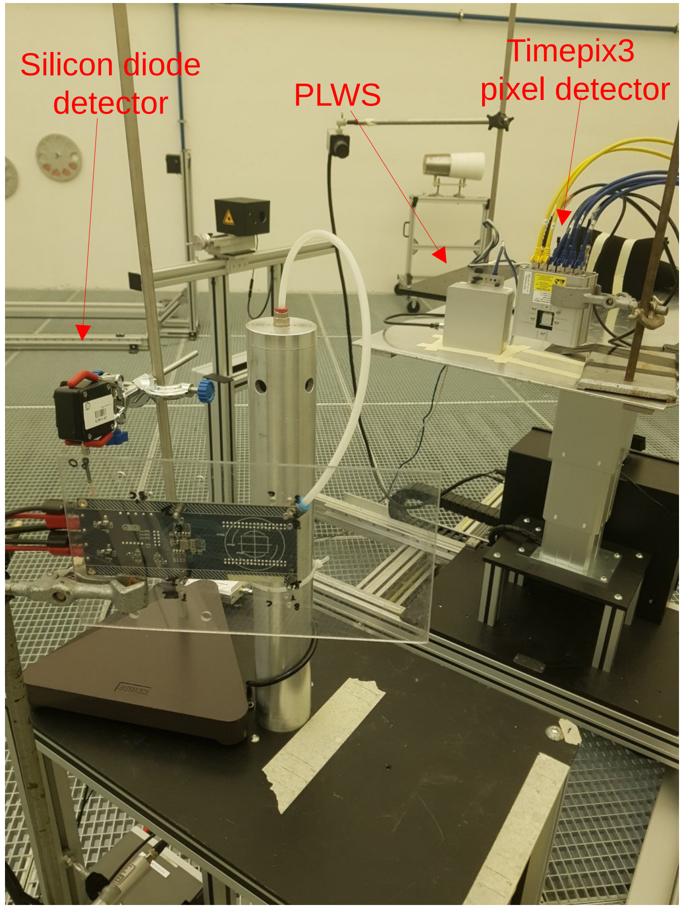
Neutron testing with Am-Be source at CERN



PLWS detects low energy neutrons thermalized by polyethylene cylinder



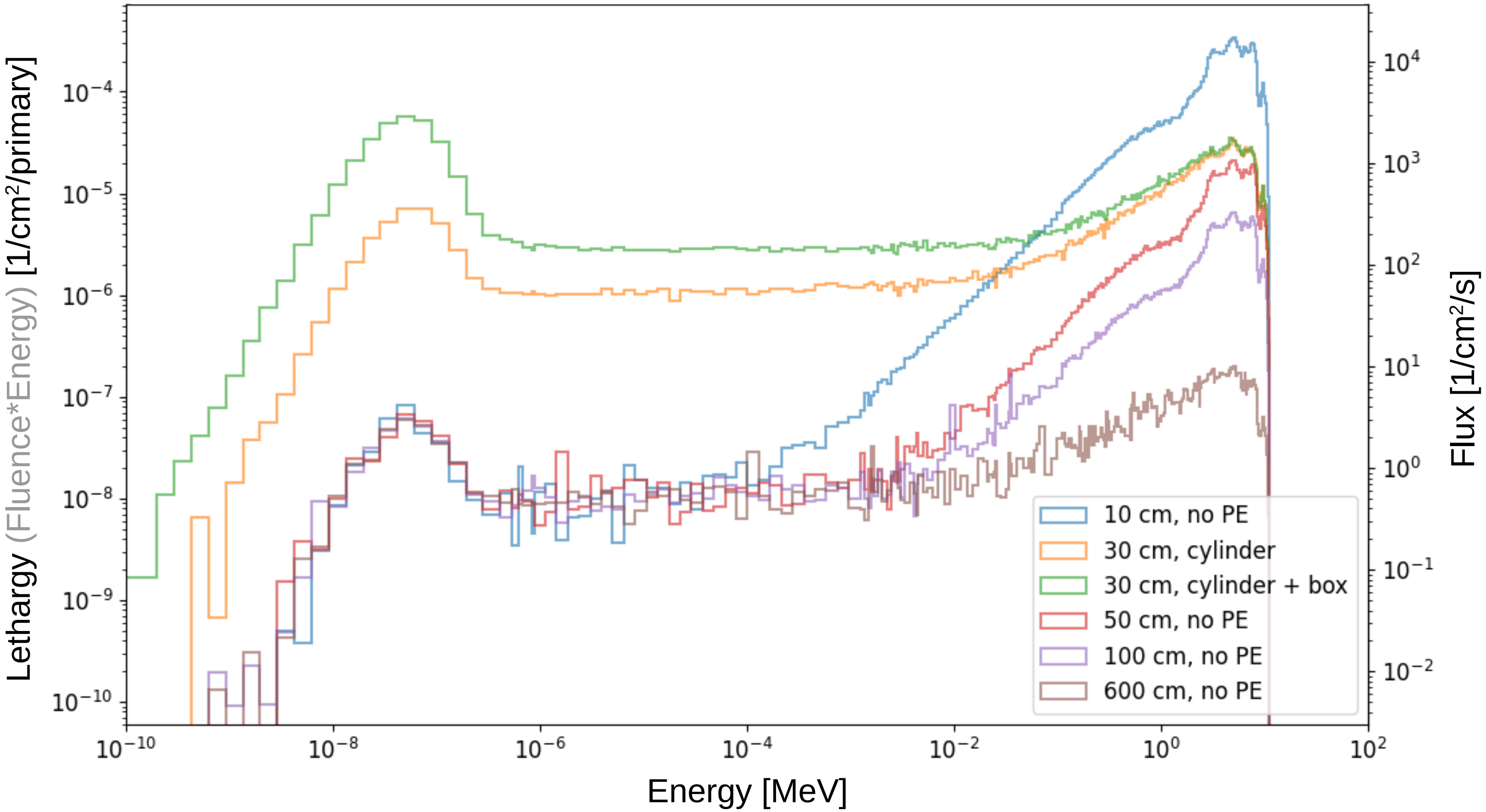
Enhanced thermal neutron flux with additional polyethylene reflector box



Fast neutron setup, comparing PLWS with Timepix3 and Si diode detectors

Neutron environment of Am-Be source

Am-Be neutron source spectrum (FLUKA Monte Carlo simulations)

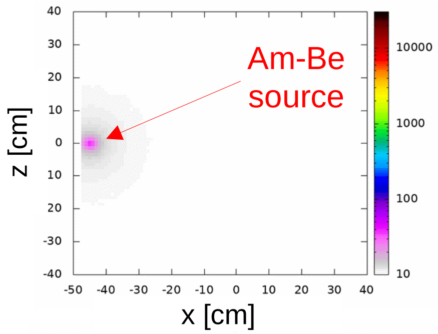


PE thermal neutron setup by CERN Radiation Protection group:

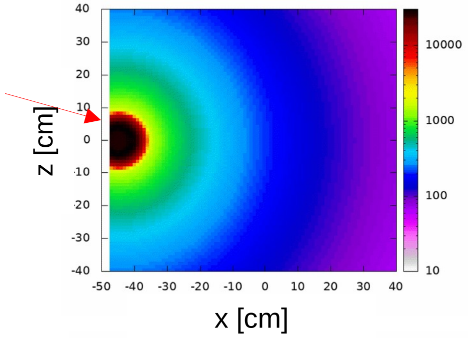
F. Ferrulli, M. Silari, F. Thomsen, G. Zorloni, *"A thermal neutron source for the CERN radiation Calibration Laboratory"*, Applied Radiation and Isotopes, Volume 178, 2021, doi: 10.1016/j.apradiso.2021.109977

Thermal neutron equivalent fluence (plan view)

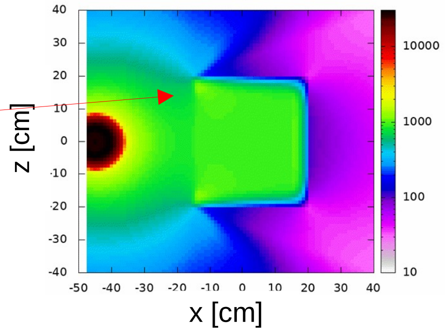
Standard setup (no PE) → fast neutrons only



w/ PE cylinder → thermal neutrons

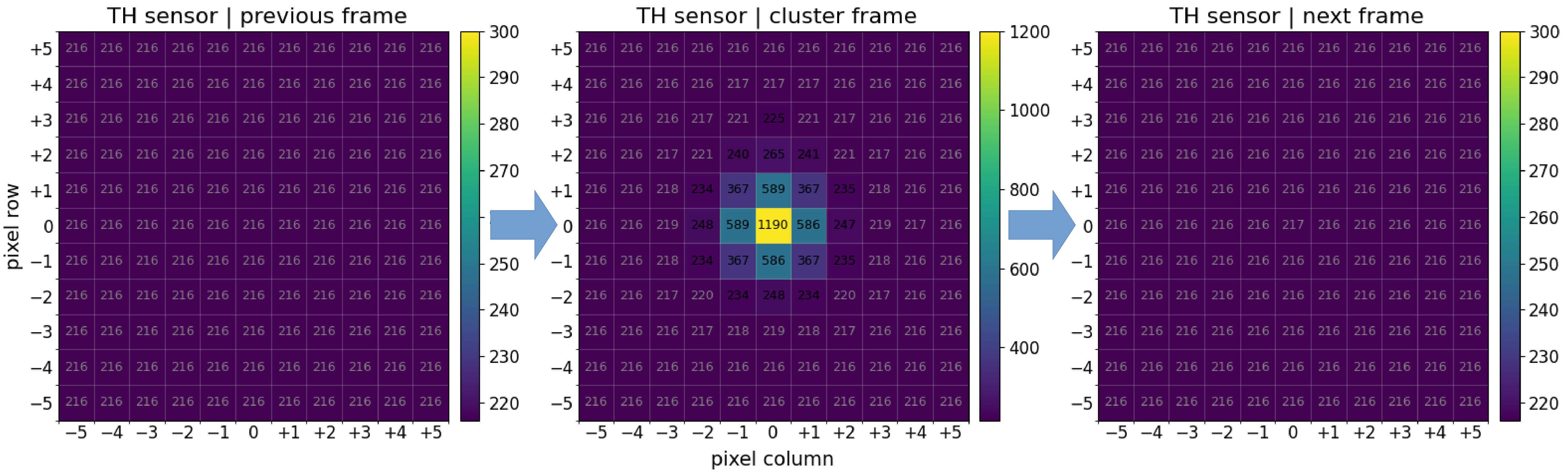


w/ PE cylinder w/ PE box → more thermal neutrons, isotropic

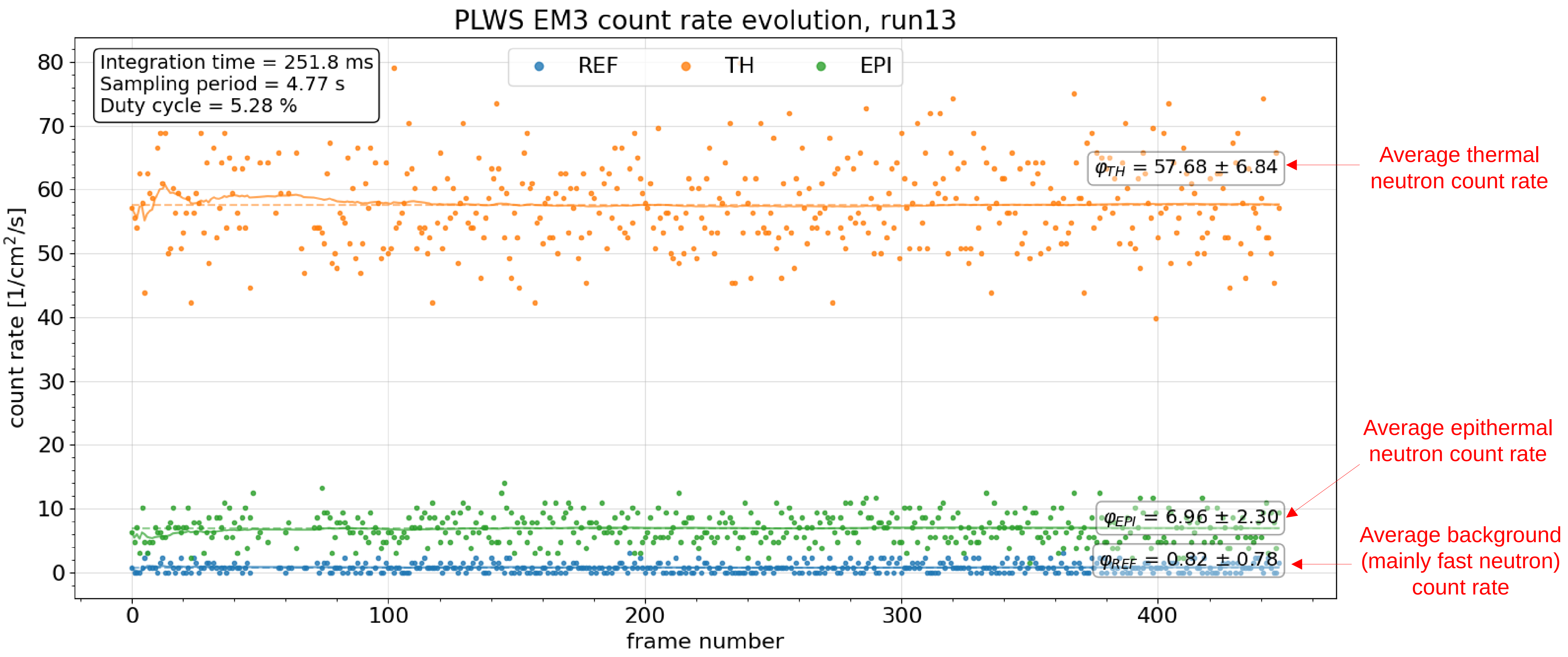


Neutron test results – Particle hit clusters

Average pixel cluster shape after a thermal neutron hits the PLWS thermal sensor



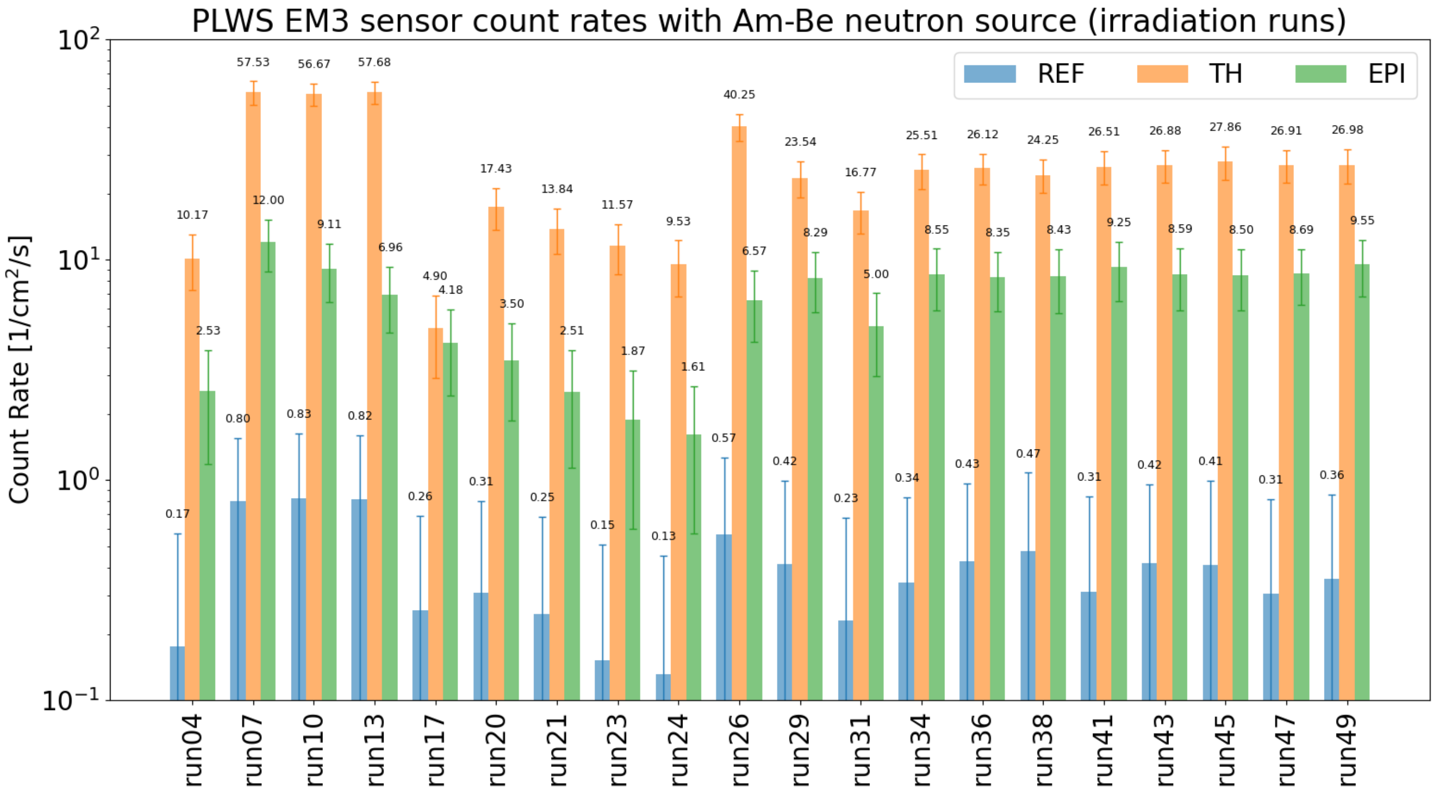
Neutron test results – Monitoring fluxes over time



(captured 1 frame per sensor in every 3.4 seconds)

Neutron test results – Thermal/Epithermal n ratio

- By changing the setup, different amount of thermal, epithermal and fast neutrons reached PLWS



Changes in setup run by run:
- PE configuration
- DUT position, distance from source
- DUT orientation
- EPI neutron filter

- Then, PLWS could measure the fluxes as they changed, demonstrating that it can be used as a neutron spectrometer, measuring reliably and efficiently 3 different parts of the neutron spectrum

Ongoing and future activities at CERN

Ongoing work:

- Neutron testing (i.e. characterization) with Am-Be neutron source in RP CALLAB, incl. comparison with Timepix3 and Si diode detectors
- Monte Carlo particle transport simulations:
  - → Am-Be thermal neutron environment using FLUKA
  - → PLWS sensor responses using G4SEE (Geant4)

Near future work:

- Testing in CHARM [forseen in April 2022]
  - → System-level radiation effect testing (SEE, DD)
  - → Characterization in mixed-field environment
- Design & optimization of the spin-off version
  - → Compatibility and interfacing with RadMON/BatMON (TBD)
  - → System-level radiation hardening and SEE mitigation (TBD)

Thank you for
your attention!

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PLWS Collaboration

System Design, Integration, R&D: puli space technologies

Funding & First User: NASA

Hardware Design: PCB DESIGN; FPGArt – The way to parallelize

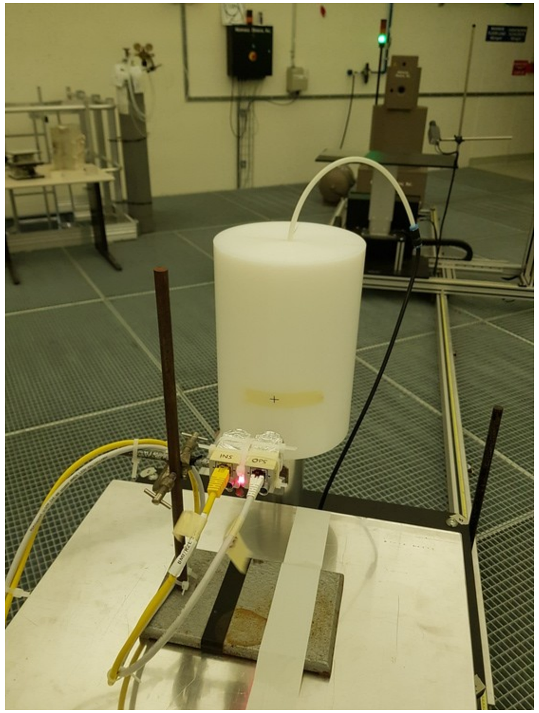
Manufacturing: NANOSENSORS – Centre for Energy Research, Institute of Technical Physics and Materials Science; ElektroMont; *Kiskutya Ltd.*

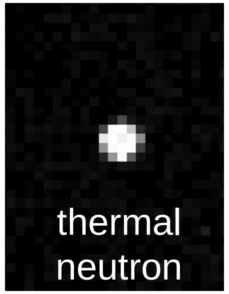
Testing & Terrestrial spin-off: CERN; R2E (not official yet)

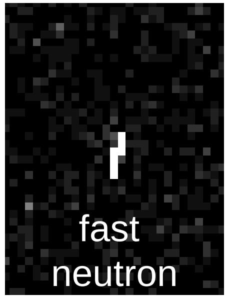
Business: MBP CONCORDE MB PARTNERS | IMAP

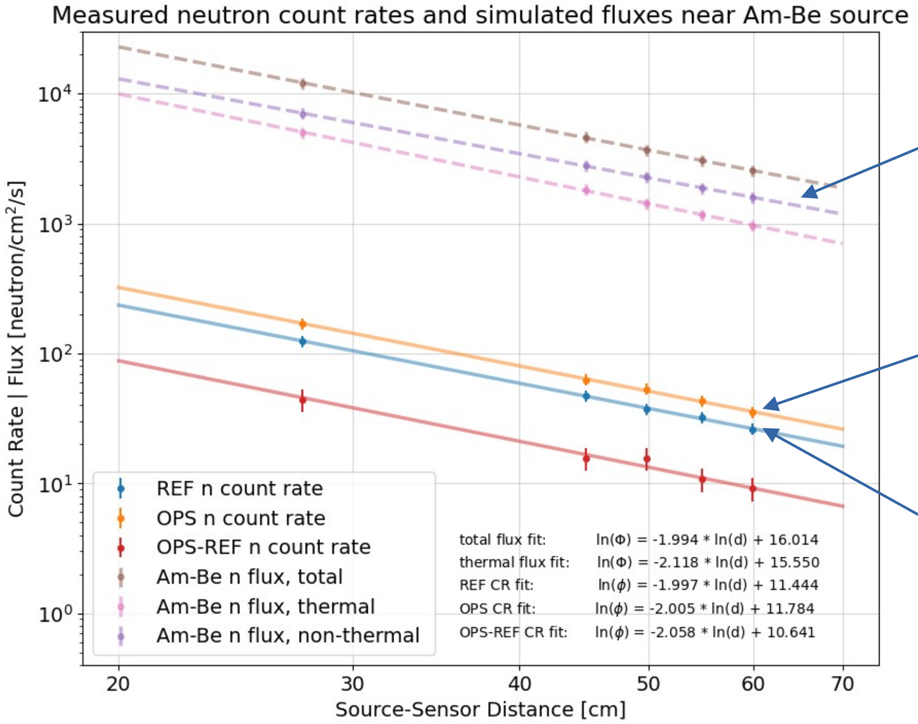
PLWS Proof of Concept

- Neutron tests at CERN CALLAB in March 2021, in collaboration with CERN RP
- Demonstrated successful neutron flux monitoring using modified off-the-shelf cameras
- Significantly enhanced sensitivity (detection efficiency) for thermal neutrons









Simulated neutron fluxes using FLUKA

Thermal neutron sensitive camera count rate

Reference camera count rate