Low Cost Neutron and Muon Detectors for Soil Moisture Monitoring

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Remote Sensing

Cosmic Ray Neutron Sensing (CRNS) is a novel way to continuously monitor volumetric soil moisture content of soils over long periods of time [1].

As neutrons are strongly moderated by hydrogen, large bodies of water absorb cosmic ray neutrons that would otherwise be backscattered from the soil.

There is an **inverse correlation between the number of neutrons detected above a soil, and local hydrogen content.**

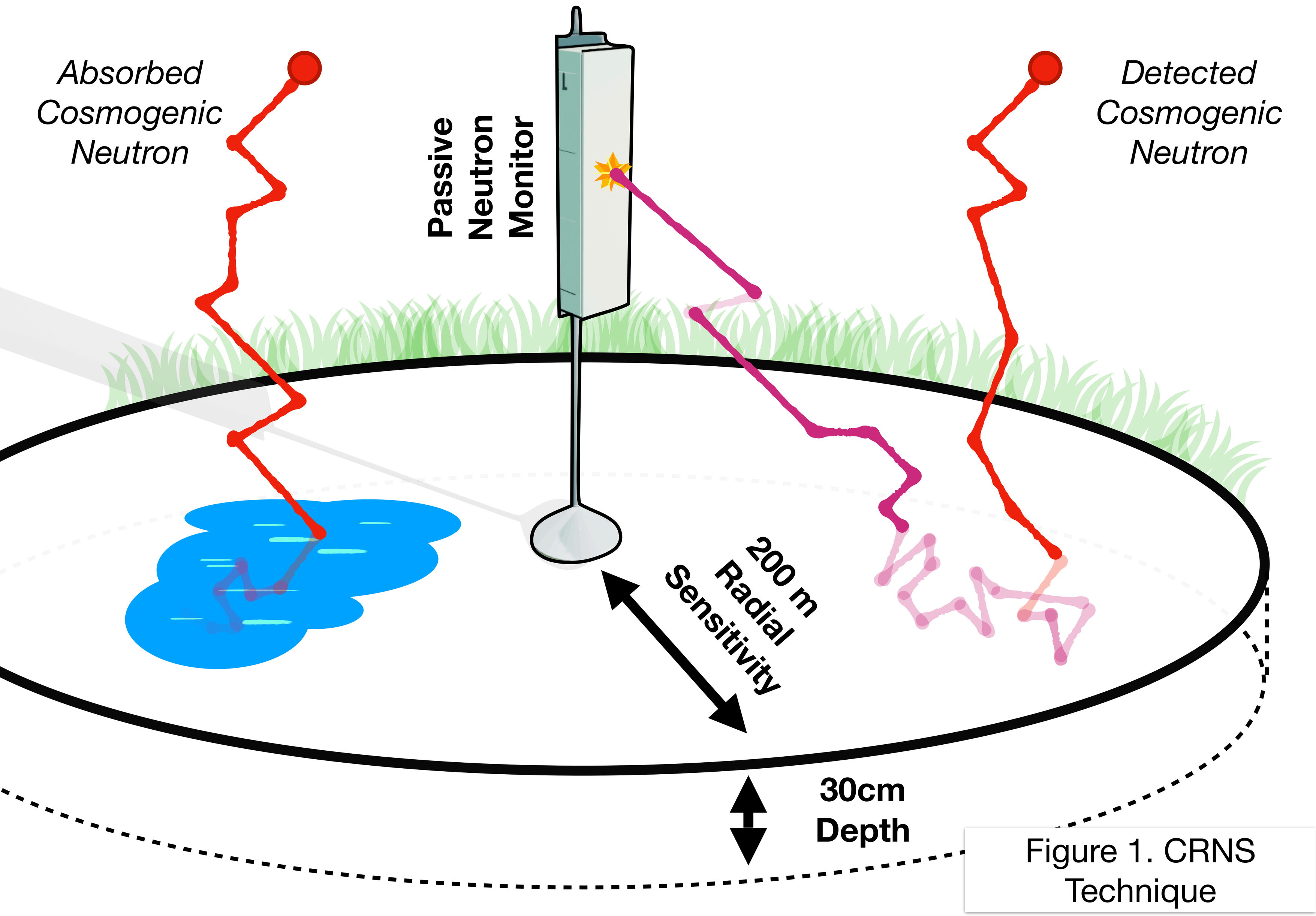

Figure 1. CRNS Technique

Water Extraction

An optimal neutron detector is sensitive to neutrons in the epithermal regime (1eV - 1MeV) where variations in counting rate due to soil moisture are maximal.

Volumetric Water Content (VWC) can be estimated from the total neutron counting rate and 'dry counting rate'.

$$VWC = \left(\frac{0.0869}{f_p f_c \frac{N}{N_0} - 0.1236} - 0.1236 \right)$$

***N* - Measured Neutron Counting Rate**
(hourly integrations)

N_0 - Dry Counting Rate
(Max detector rate estimated from field calibration)

f_p - Local environmental conditions correction
(derived from pressure, temperature, humidity)

f_c - High energy cosmic ray intensity correction
(derived from Jungfraujoch neutron monitor database [2])

Detection Technologies

Existing applications of the CRNS techniques have relied on He-3 or BF3 detection systems which can be expensive or toxic. **Lower cost and safer alternatives are needed for CRNS to be viable for use on smallholder farms.**

$$Li^6 + n \rightarrow He^4 + T^3 + 4.8\,\text{MeV}$$
$$B^{10} + n \rightarrow He^4 + Li^7 + 2.3\,\text{MeV}$$

EJ426 uses a Zinc-Sulphide (ZnS) phosphor coupled to Lithium-6 Fluoride (Li^6F) to detect neutrons [3]. A neutron captures result in a scintillator pulse with a long characteristic decay suitable for pulse shape particle discrimination techniques.

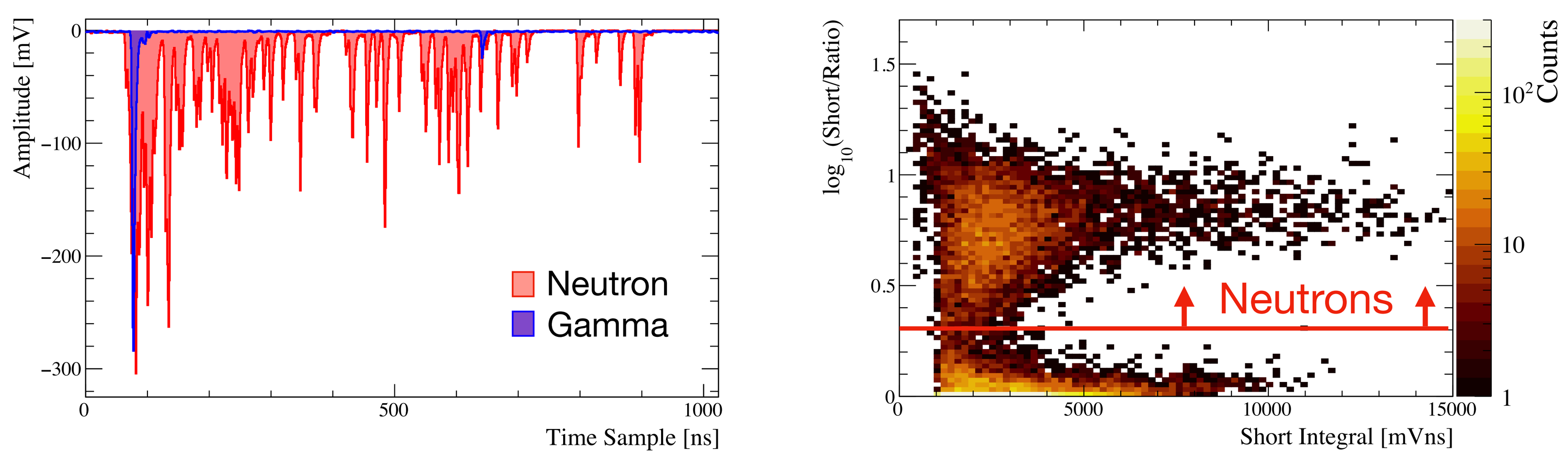

Figure 3. (left) EJ426 pulse shape for shown neutrons and gammas. (right) Pulse shape discrimination distribution for EJ426 detector exposed to Cf-252.

Coupled with a photomultiplier and a low power Internet-of-Things pulse shape discriminator board, EJ-426 can be used to monitor epithermal neutrons.

Three test EJ426 systems have recently been deployed in the UK at Leeds and Newcastle University farms to compare sensitivity of alternative systems to existing He-3/BF3 soil moisture monitors.

Figure 4. Neutron detectors deployed at Newcastle COSMOS Station (left), Newcastle Tower Hill (middle), Leeds University (right).

For widespread industrial adoption of CRNS within agriculture there is still a need for even lower cost detection technologies that avoid the nuclear safeguarding restrictions associated with Lithium-6.

BN:ZnS Scintillator

Un-enriched Boron Nitride (BN) is one possibility for ultra low cost neutron detector development [3]. **Natural BN contains ~20% B^{10} with a high neutron capture probability similar to Li^6F.** BN is readily available and non-toxic.

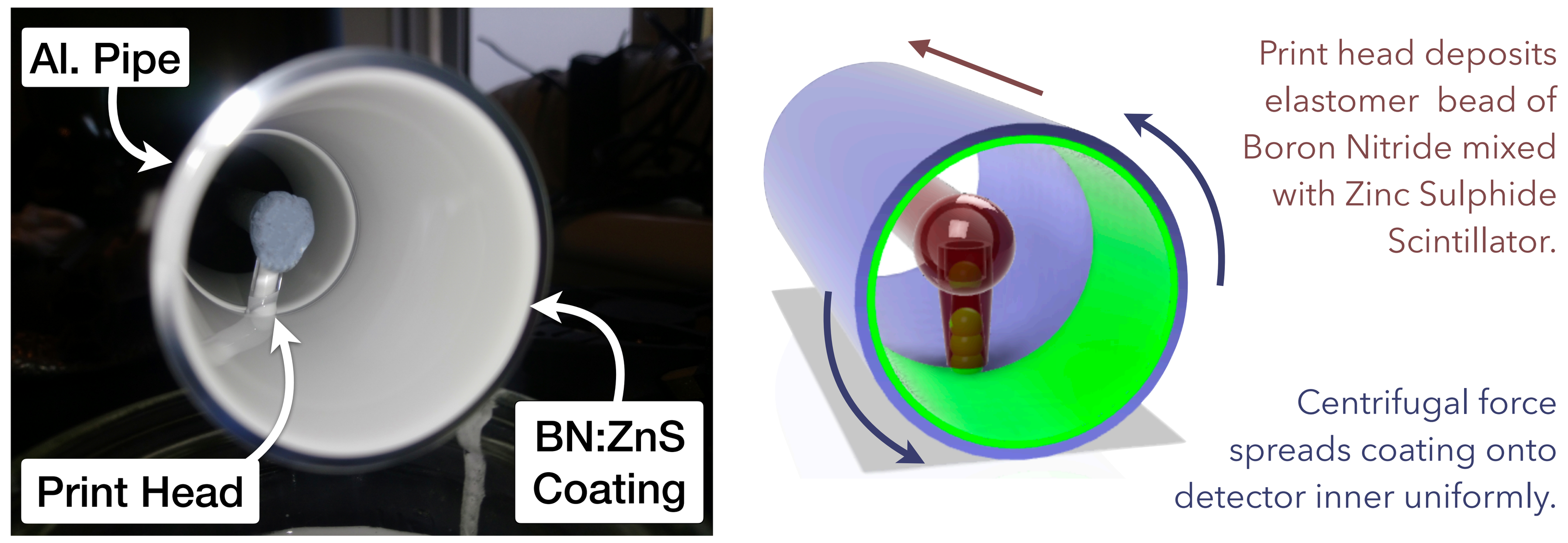

Figure 5. BN:ZnS Spin coating technique.

Developing 'spin-coating' procedures to coat aluminium detectors in BN:ZnS scintillator. **First BN detectors show sensitivity to neutrons, further work is ongoing to characterise response and standardise production methods.**

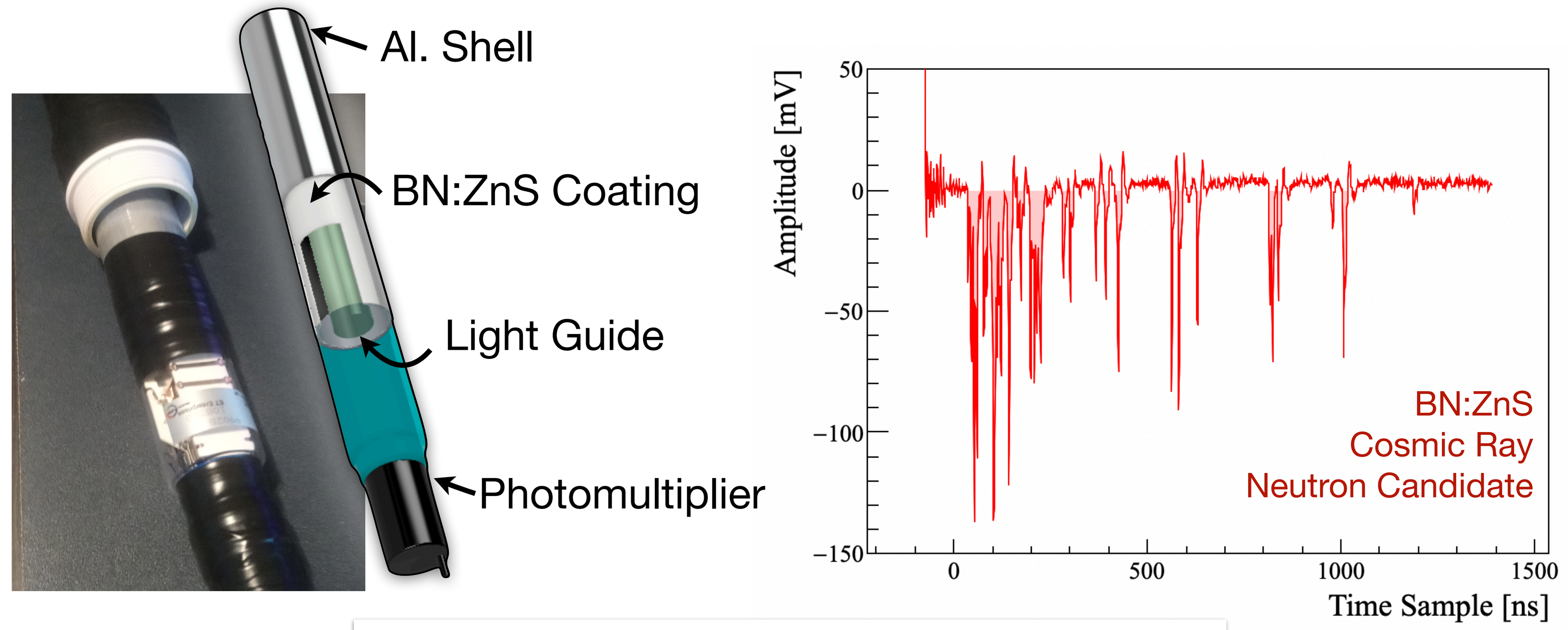

Figure 6. (left) First BN:ZnS Detector Prototype, (right) prototype detector neutron pulse.

Local Cosmic Ray Variations

Data from the Jungfraujoch neutron monitors is commonly used to correct variations in cosmic ray intensity. **Need for low cost techniques/methods to measure local cosmic ray intensity.**

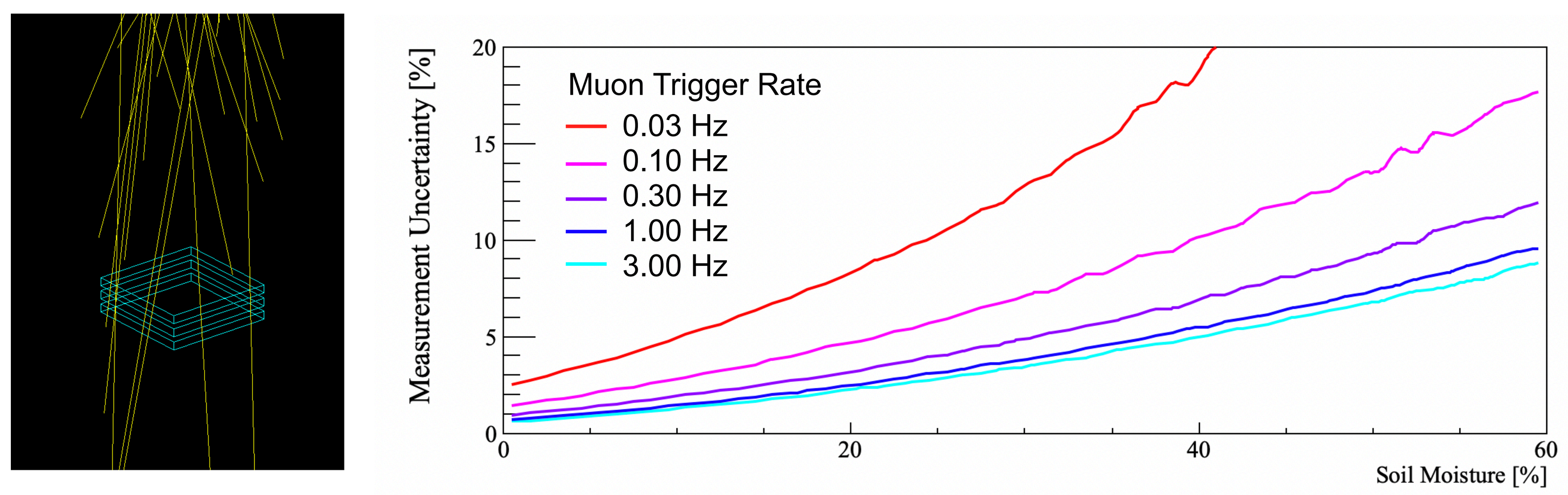

Figure 7. (left) Geant4 Geometry Optimisation of Muon Tracker, (right) expected measurement statistical uncertainty when using local muon counting rates to correct cosmic ray intensity.

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References: [1] Köhli, M., Schrön, M., Zreda, M., Schmidt, U., Dietrich, P., & Zacharias, S. (2015). Footprint characteristics revised for field-scale soil moisture monitoring with cosmic-ray neutrons. *Water Resources Research*, *51*(7), 5772-5790. [2]https://www.nmdb.eu, [3] EJ-426 Eljen Thermal Neutron Scintillator.