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Large-scale alternative detection systems for Cosmic-Ray Neutron Sensing

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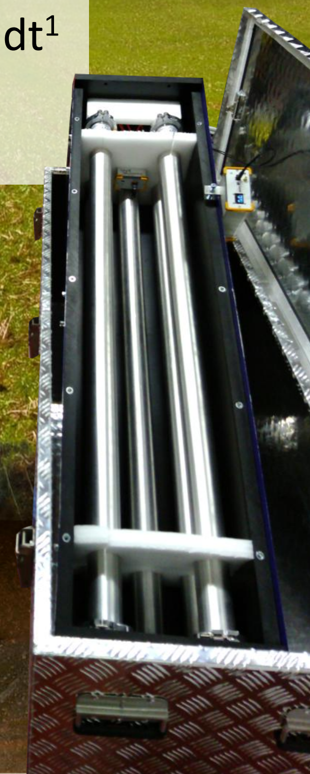

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Aim of CRNS detector development:
decrease uncertainty of neutron measurement (ΔN)

Key factor 1

Statistical uncertainty

Key factor 2

Systematic uncertainty

Precision

Statistical uncertainty

Count rate considerations

Poisson statistics:

$$\Delta N = \sqrt{N} \rightarrow \frac{\Delta N}{N} = \frac{1}{\sqrt{N}}$$

Low statistical uncertainty through high count rates N/s

Count rate [N/s] =

$$A\,[m^2] * R(E,\varphi)\,[\%] * I_n(E)\,[N/s/m^2]$$

Surface Area A:
The larger the detector the more often it is hit by neutrons

Response function R:
Probability to detect a neutron that hits the detector

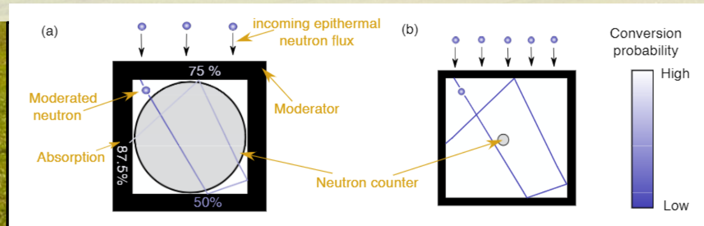
Neutron Flux I_n:
Relevant oberservable to determine soil moisture

Statistical uncertainty

Count rate considerations

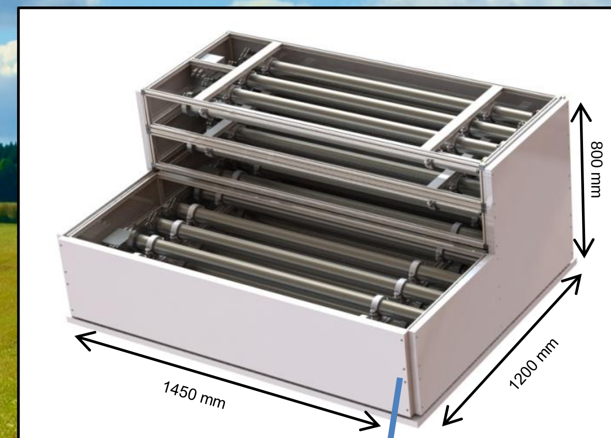
High sensor count rate by:

- large effective area
- moderate response function
- adaptable multi-counter system
- Boron-lined tubes (thermal efficiency 10 %)



FZJülich Stx Detector

Uni Potsdam Stx Detector



The UFZ Leipzig Stx Rover

Systematic uncertainty

- False positive signals, e.g. other particles

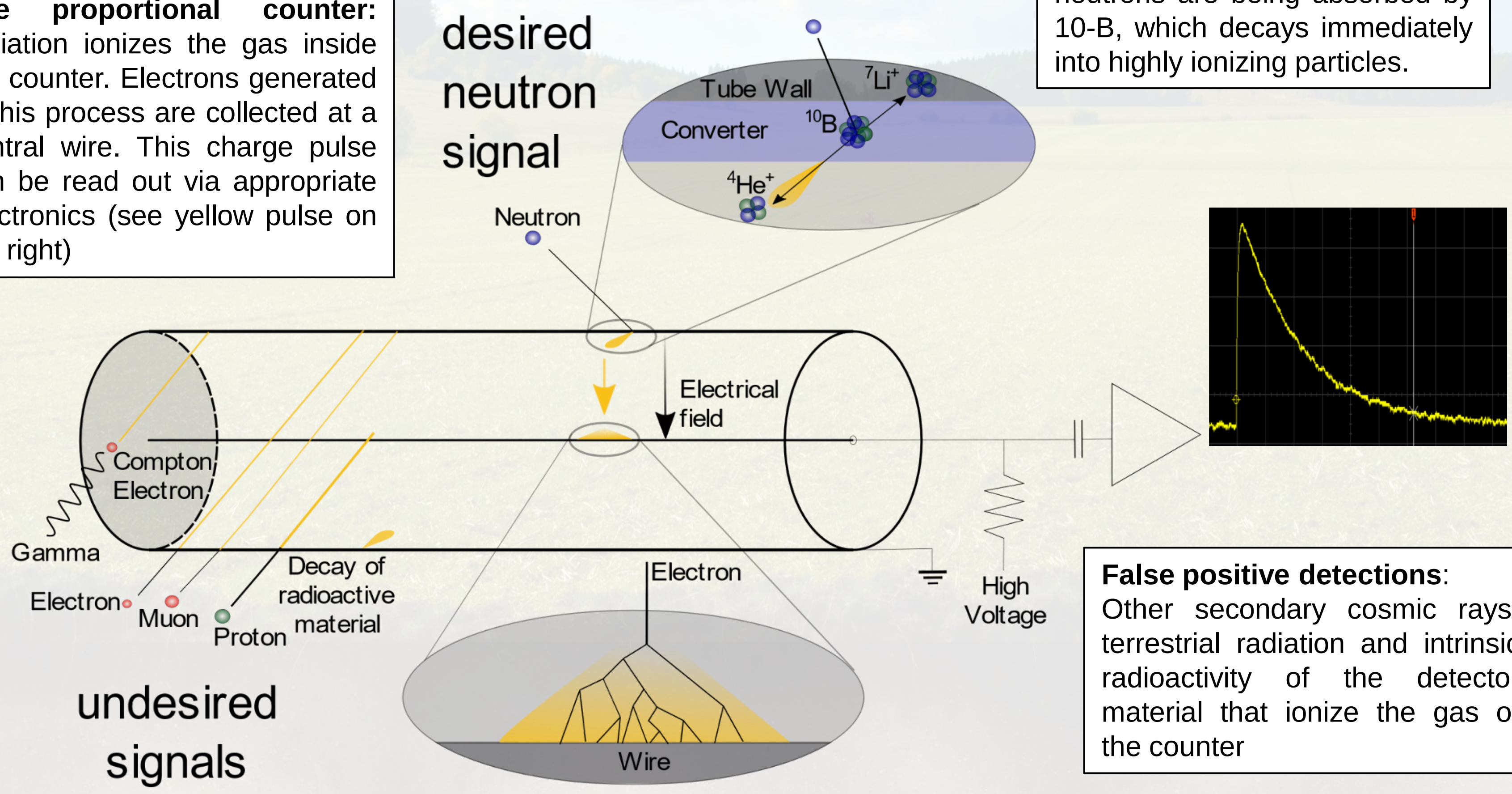
- Detection of neutrons that are weakly sensitive to water

Systematic uncertainty

False positive detections

The proportional counter: radiation ionizes the gas inside the counter. Electrons generated in this process are collected at a central wire. This charge pulse can be read out via appropriate electronics (see yellow pulse on the right)

Boron neutron conversion: neutrons are being absorbed by 10-B, which decays immediately into highly ionizing particles.

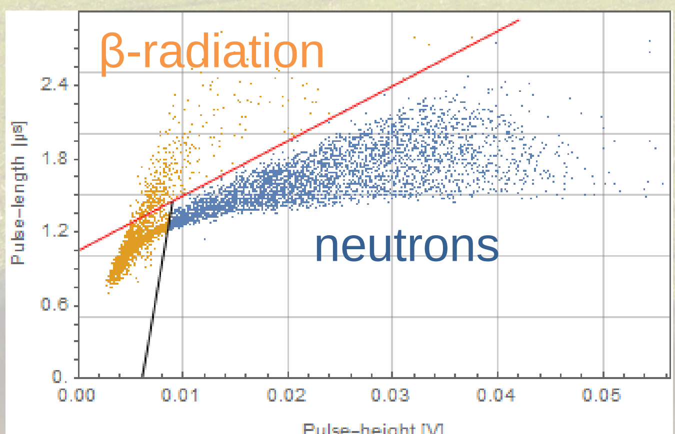


False positive detections: Other secondary cosmic rays, terrestrial radiation and intrinsic radioactivity of the detector material that ionize the gas of the counter

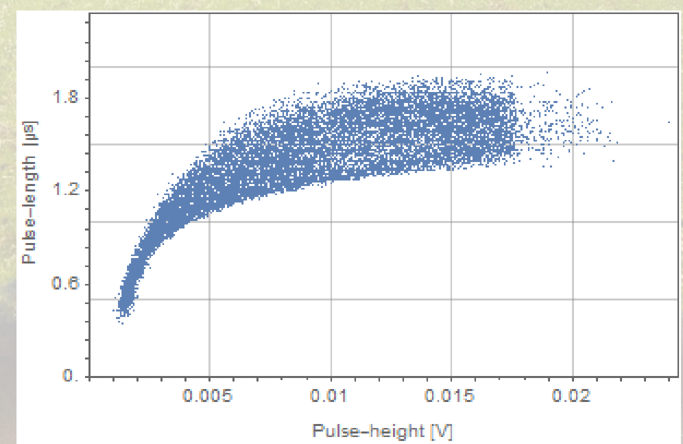
Systematic uncertainty

False positive detections

- Pulse shape is different for various particle species
- Use pulse length and pulse height to discriminate between neutrons and other particles



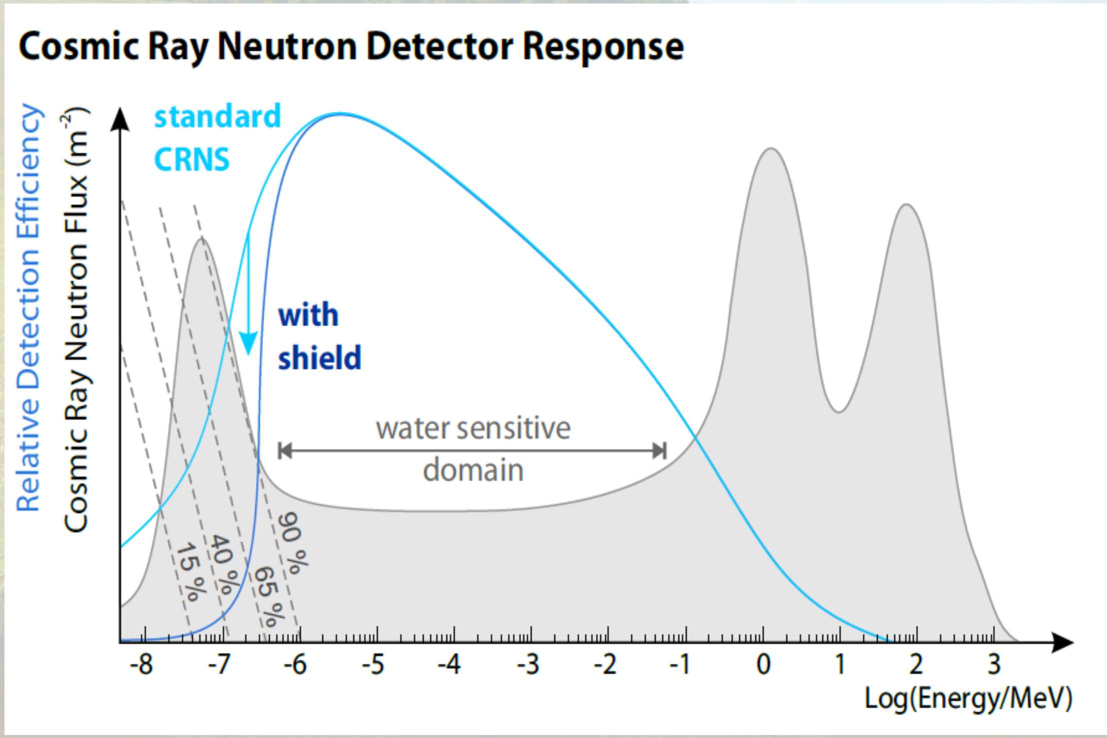
2-D information of pulse height and pulse length



Background-suppressed neutron signals of a low pressure tube

Systematic uncertainty

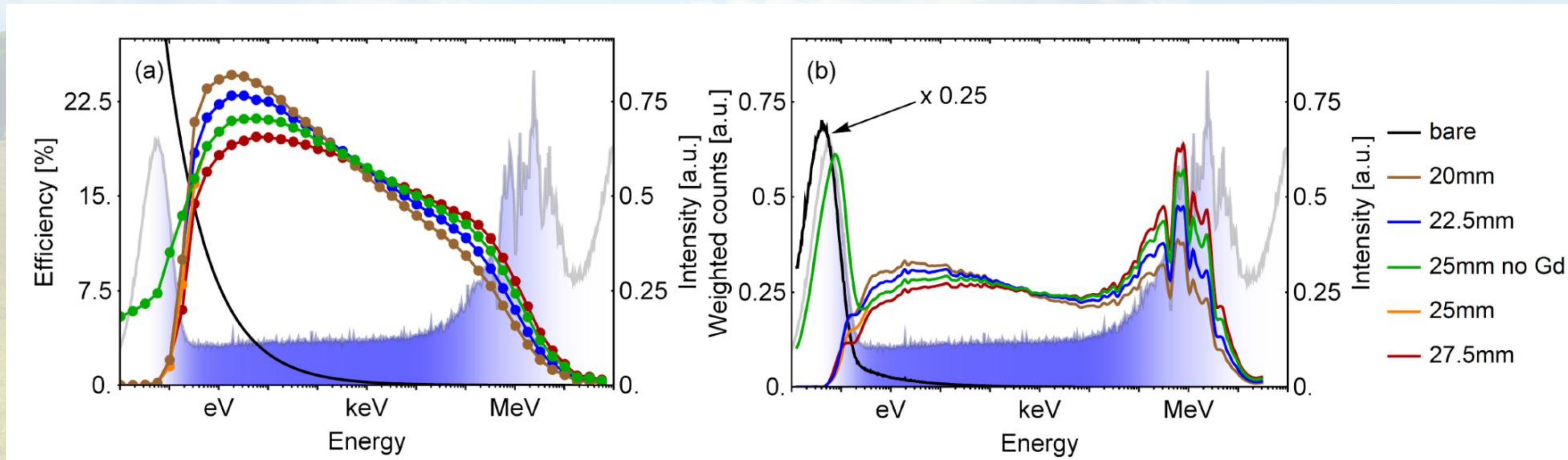
Detection of neutrons that are weakly sensitive to water

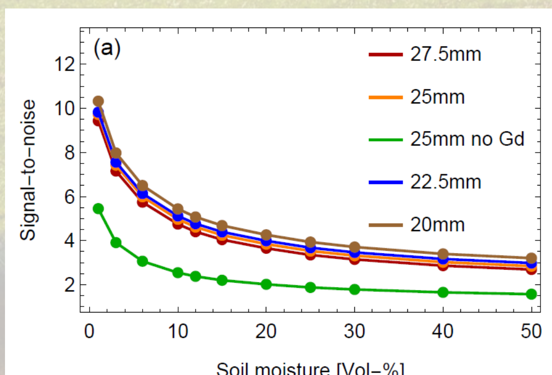


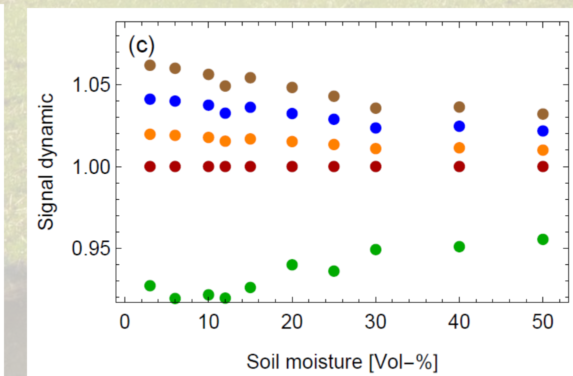
Thermal shield:
The thermal neutron intensity (leftmost peak) reacts differently and weaker to soil moisture changes than the epithermal to fast regime (water sensitive domain). By addiing a strong absorber at the outside of the detector these neutrons are excluded from the signal and the neutron count rate response to soil moisture improves.

Sensitivity

Improve detector response



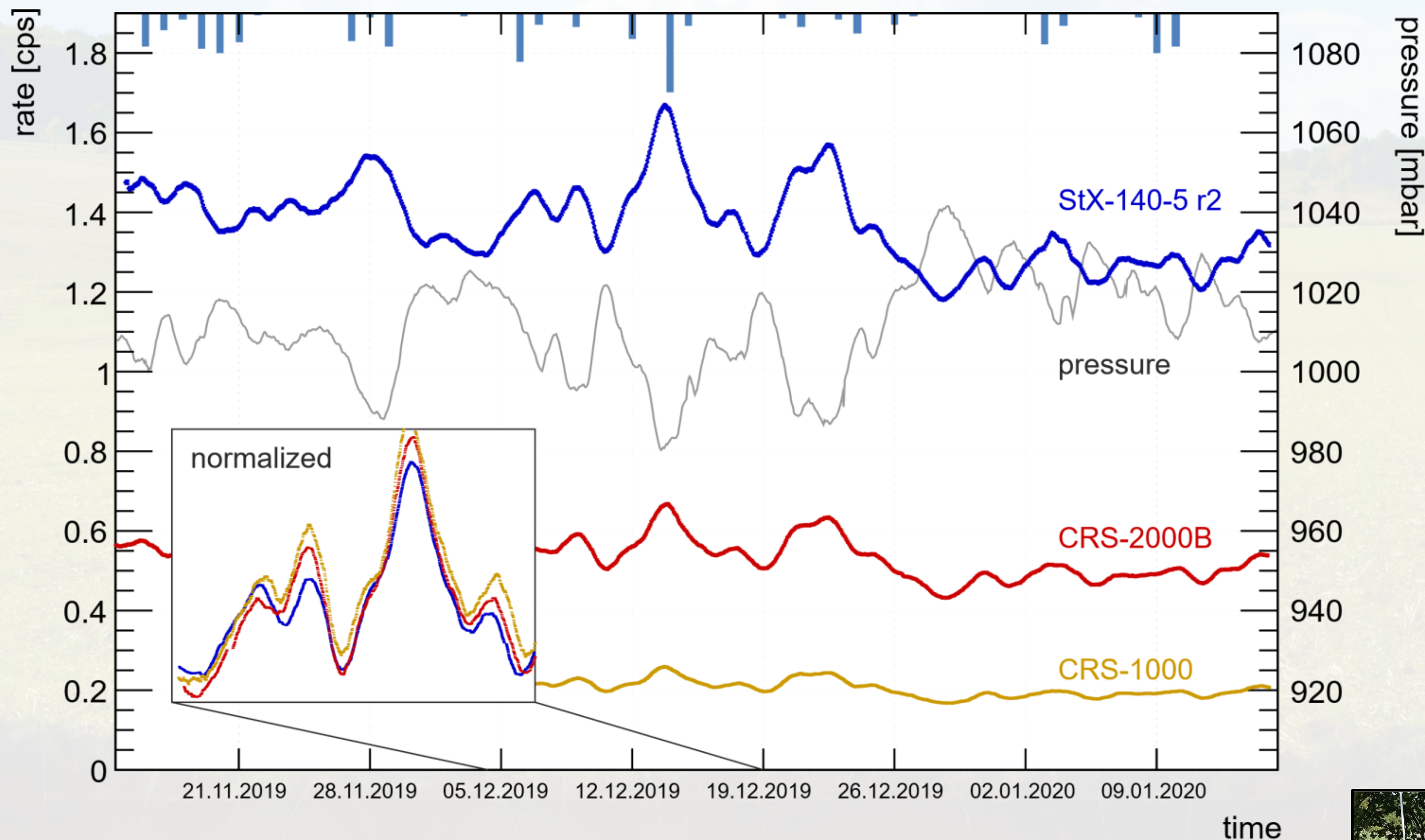




The signal-to-noise ratio (SNR) describes the ratio between the detected neutrons that relate to the environmental hydrogen content (signal) to such which do not (noise). It determines the change in detected neutron count rate per hydrogen content change. With increasingly moist conditions, the sensitivity to hydrogen content changes decreases steadily until it eventually saturates due to the hyperbolic relationship to theta. In close-to saturated conditions a high ratio is critical for the assessment of water resources.

Detector response to soil moisture dependent on the moderator thickness. All detector configurations feature a thermal shield except for '25mm no Gd'. (a): SNR according to the definition of sec. 3.1. (c): dynamical range or signal contrast, rates normalized to the detector setup with 27.5mm moderator thickness and a thermal shield.

Field tests



Comparison of different CR probes installed at the Marquardt site (University of Potsdam, Germany). The time series show raw data from the probes, which mainly accounts to atmospheric pressure changes. The inlet shows two weeks of data with all probes scaled to each other.

High count rate

Precise measurement

Exclude thermal neutrons

Low susceptibility to other radiation