Cosmic Ray Neutron Sensors for IoT Soil Moisture Monitoring

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IOP Institute of Physics

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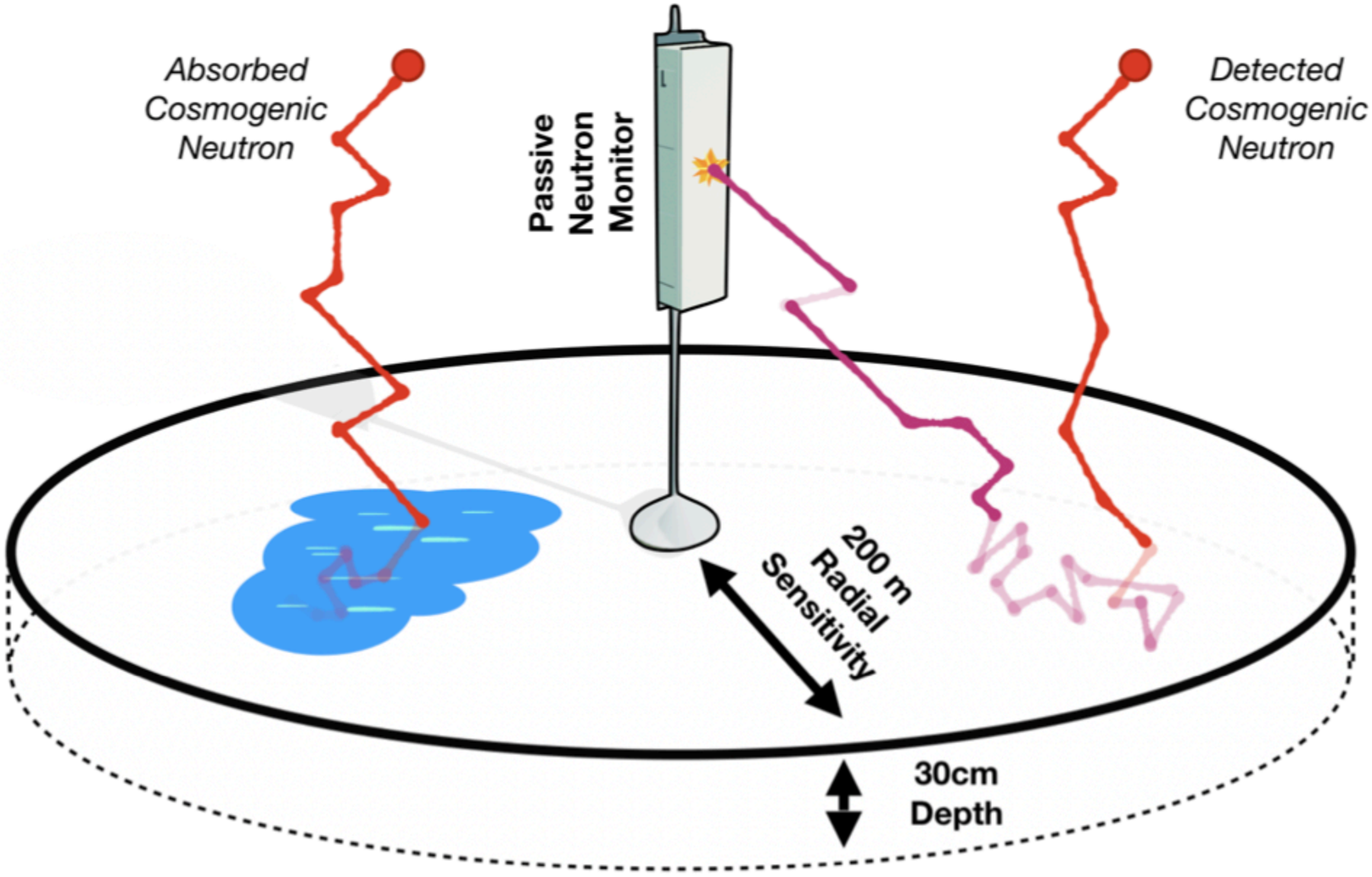
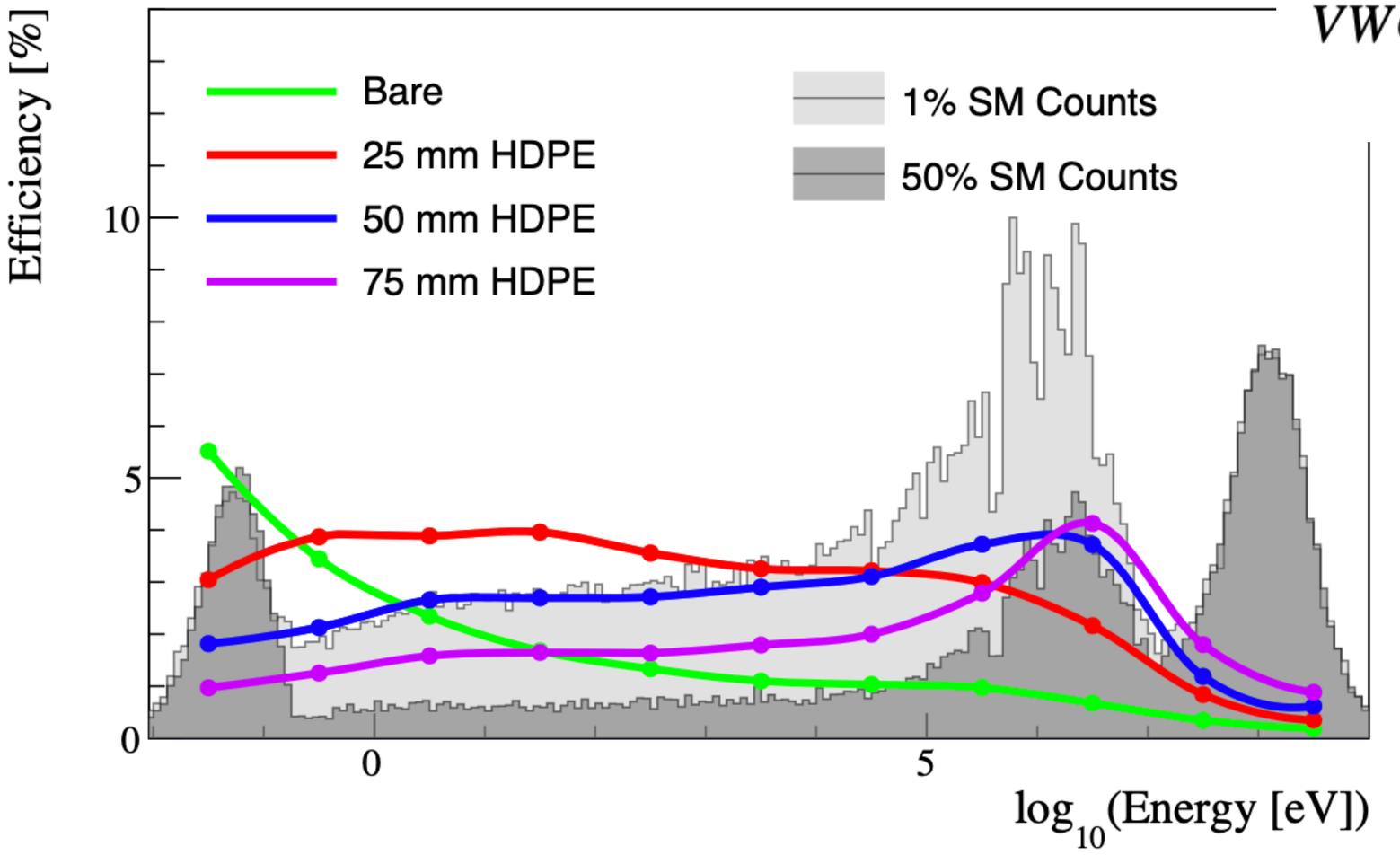
Neutron Sensing

- Cosmic Ray Neutron Sensing is a well established technique for monitoring soils.
- **Inverse relationship between observed neutron rate and soil moisture.**
- Path length of neutrons in air means technique has a large sensitive footprint (~100-200m)



Neutron Sensing (2)



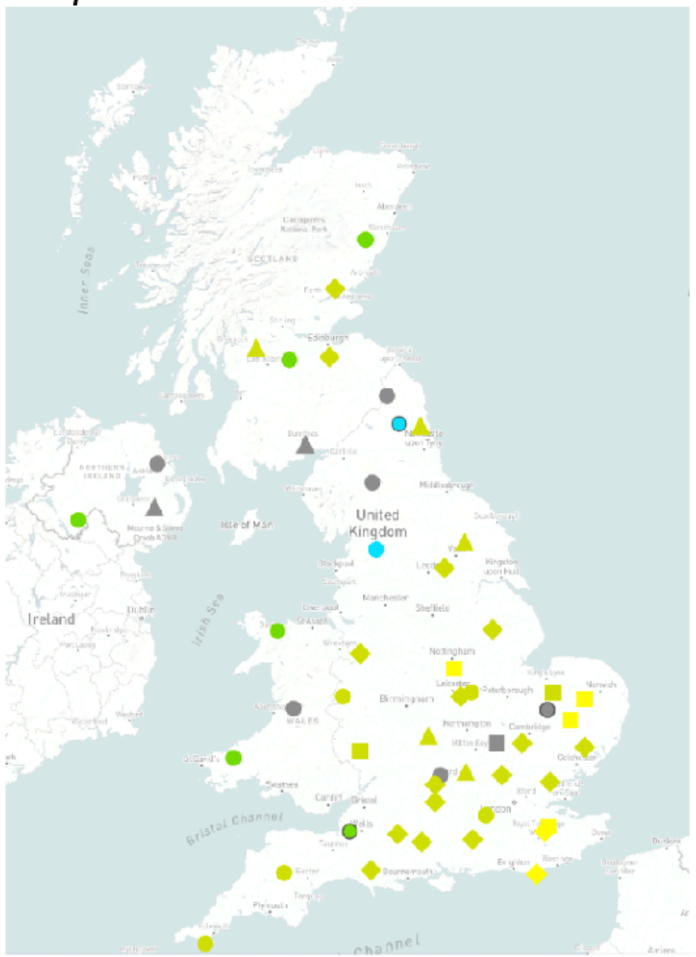
$$VWC \sim \left(\frac{0.0869}{f_p f_c \frac{N}{N_0} - 0.3720} - 0.1236 \right),$$

Epithermal neutron counts

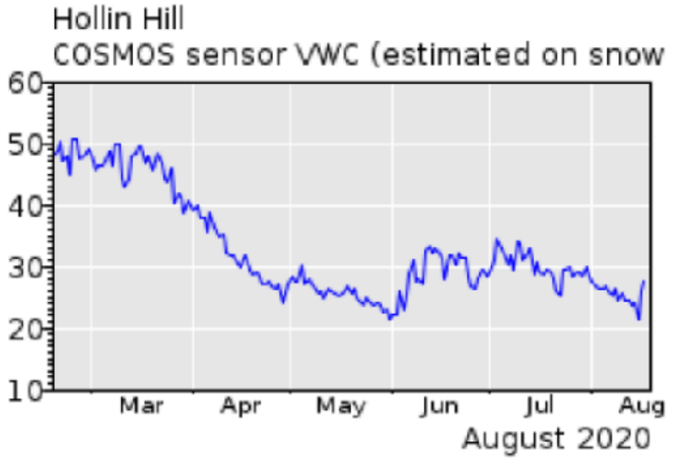
- Neutron sensors optimised for the 0.1eV - 10MeV region suitable for monitoring soil moisture.
- Corrections for environment, and incoming cosmic ray intensity required.

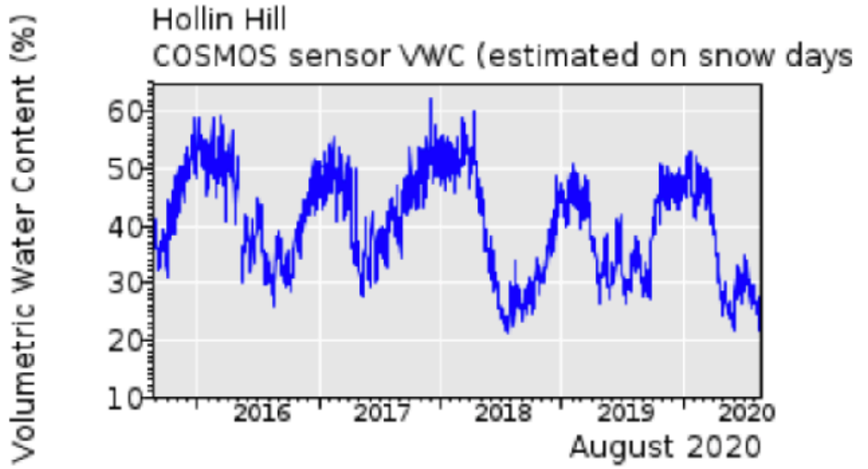
COSMOS-UK

https://cosmos.ceh.ac.uk/data



Data obtained from the COSMOS-UK Data Portal



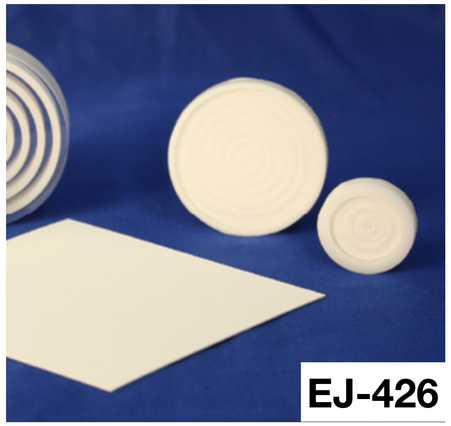


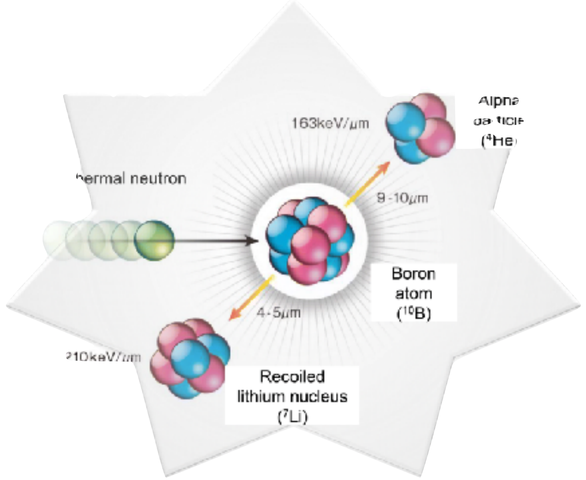
- Several CRNS networks already deployed to continuously monitor hydrology over many distributed sites (COSMOS, COSMOS-UK.

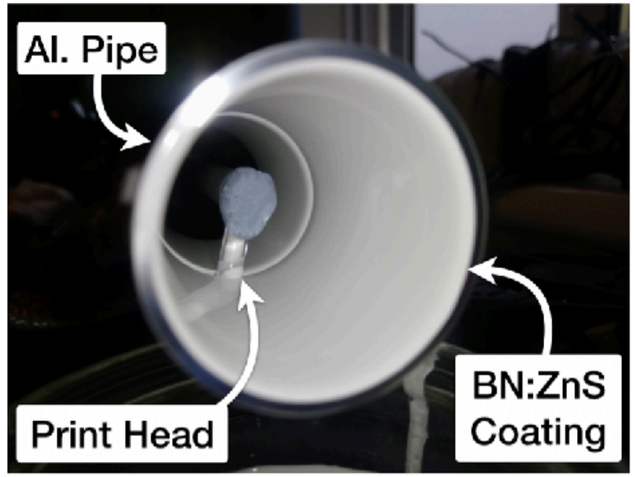
- Typically hourly neutron count measurements are made.

Alternatives to Helium-3

- Most monitoring stations worldwide use Helium-3 (Expensive) or Boron-Trifluoride (Toxic) gas tubes for efficient neutron detection.
- 1851 research fellowship assessing the use of scintillating lithium or boron nitride foils for low cost neutron detection in the field.
- **Temperature stability, power consumption, and safety all need considering.**

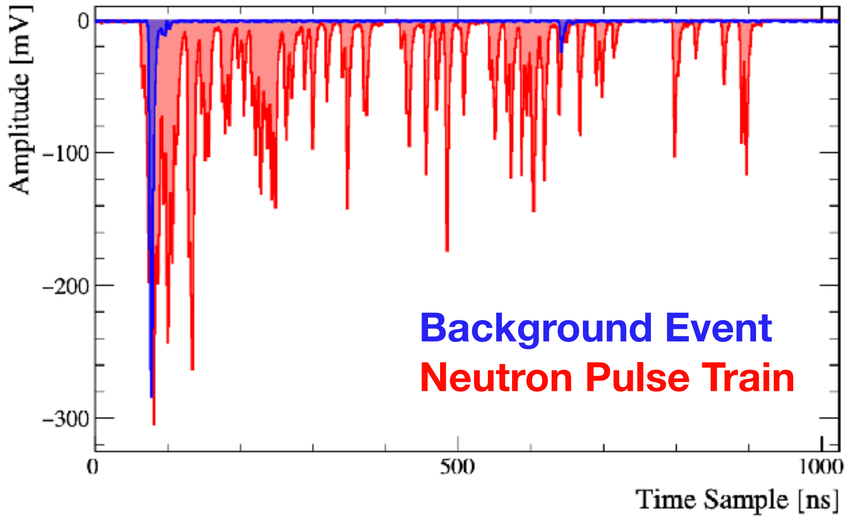


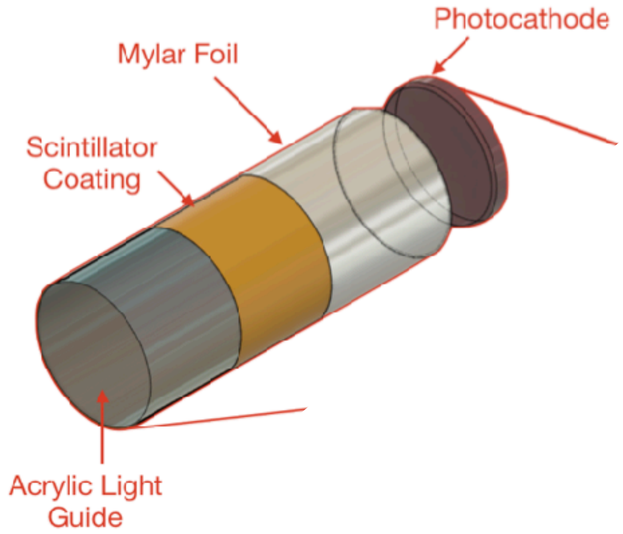




Thermal Neutron Foil Detectors

- Cylindrical design to allow for simple light tight enclosures and direct coupling to PMTs.
- First systems made of low cost acrylic light guides coupled to ^{6}LiF:ZnS scintillator.
- Bright and long decay time of ZnS results in a ‘pulse train’ whenever a neutron interacts.
- Thin scintillator layers means gamma interactions produce much smaller energy deposition.





Scintillating thermal neutron detectors for cosmic ray soil moisture monitoring

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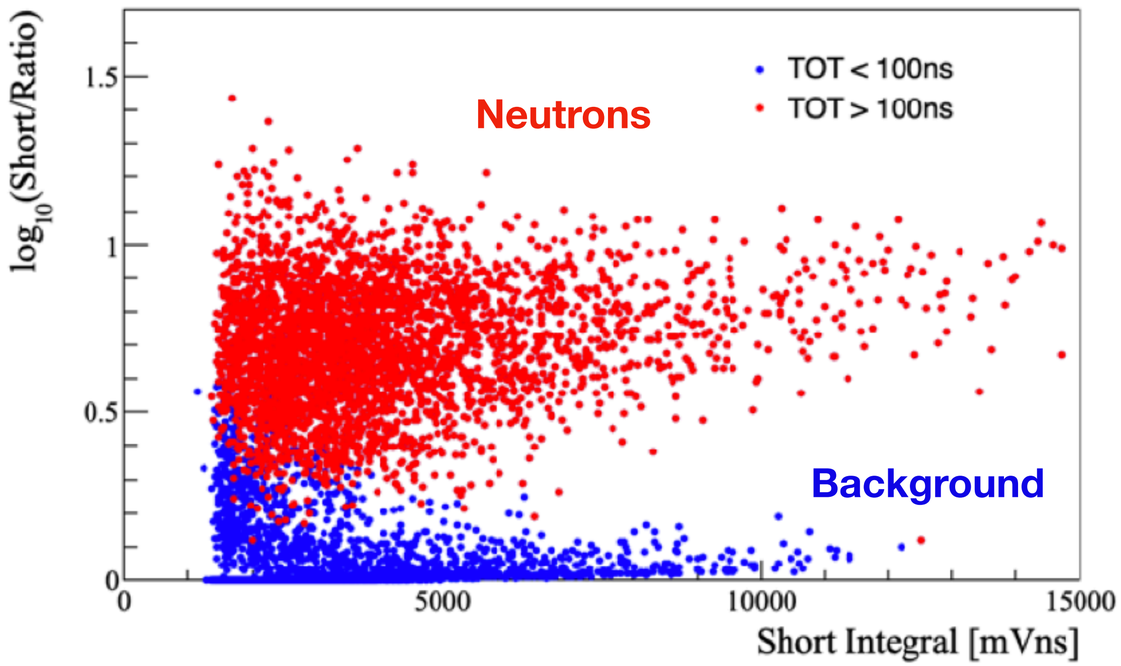
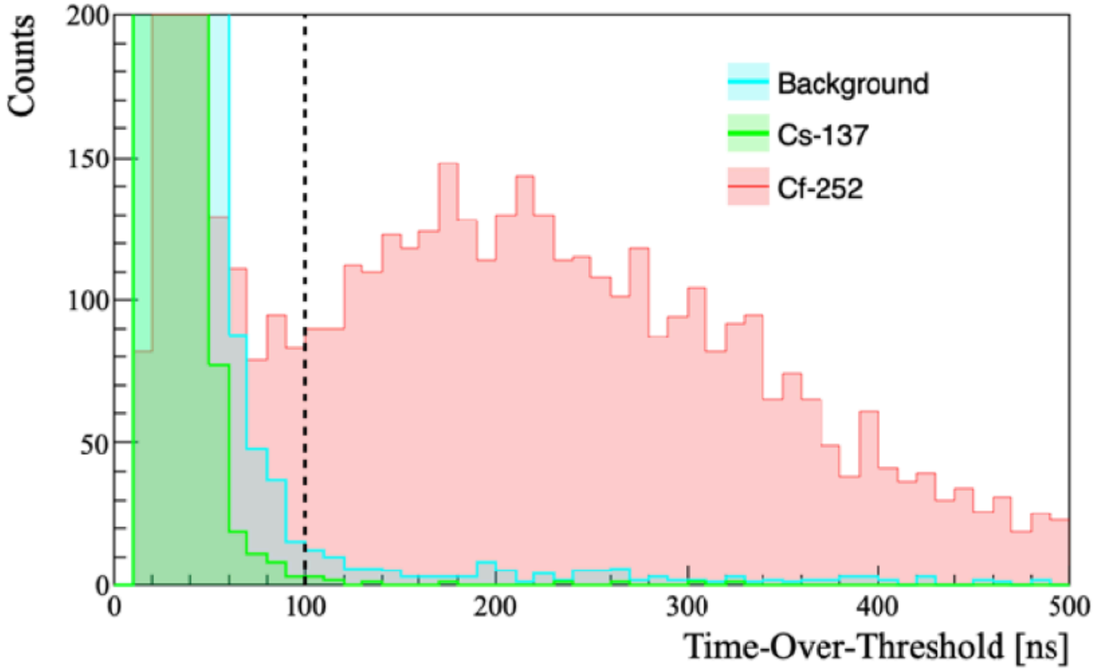
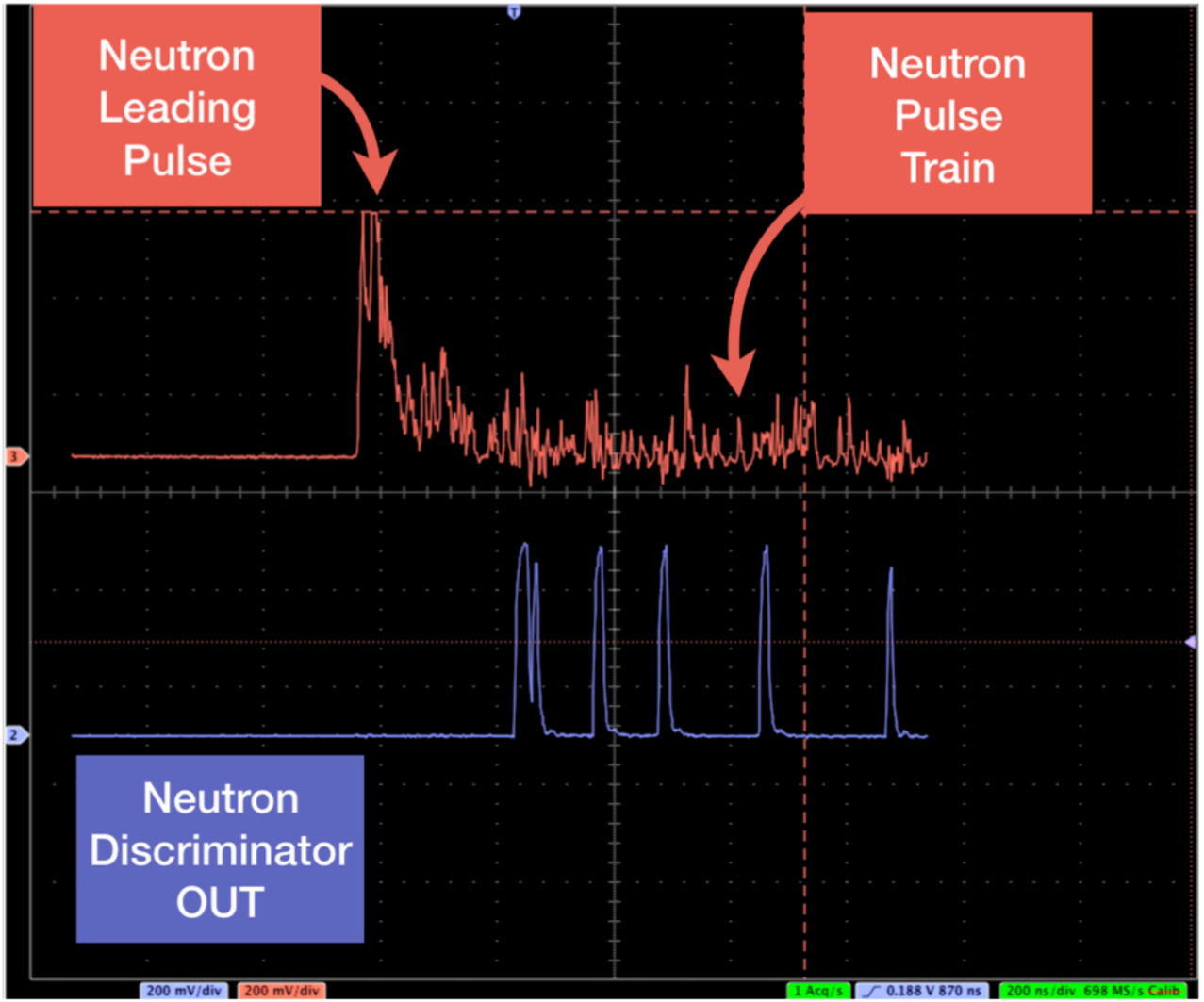
Pulse Shape Discrimination

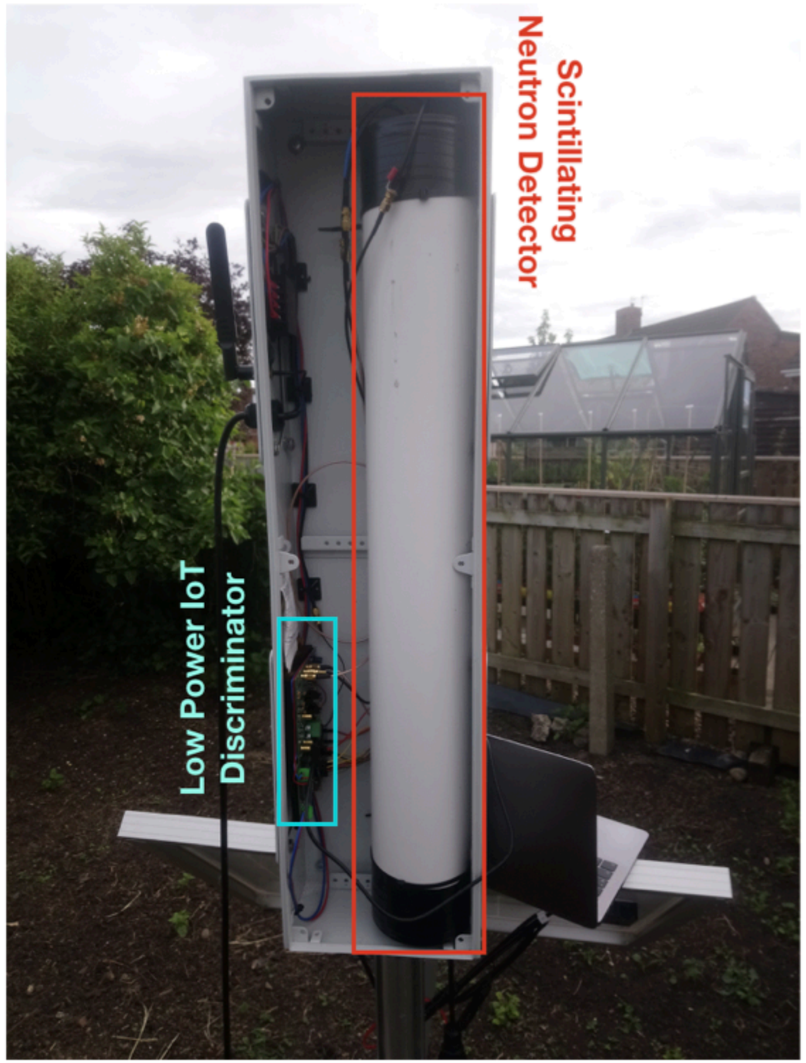




- Developed discrimination algorithm using `Staged Time-over-Threshold` cuts.
- Counting ToT across the train allows triggering using single channel discriminator.

V1 Detector

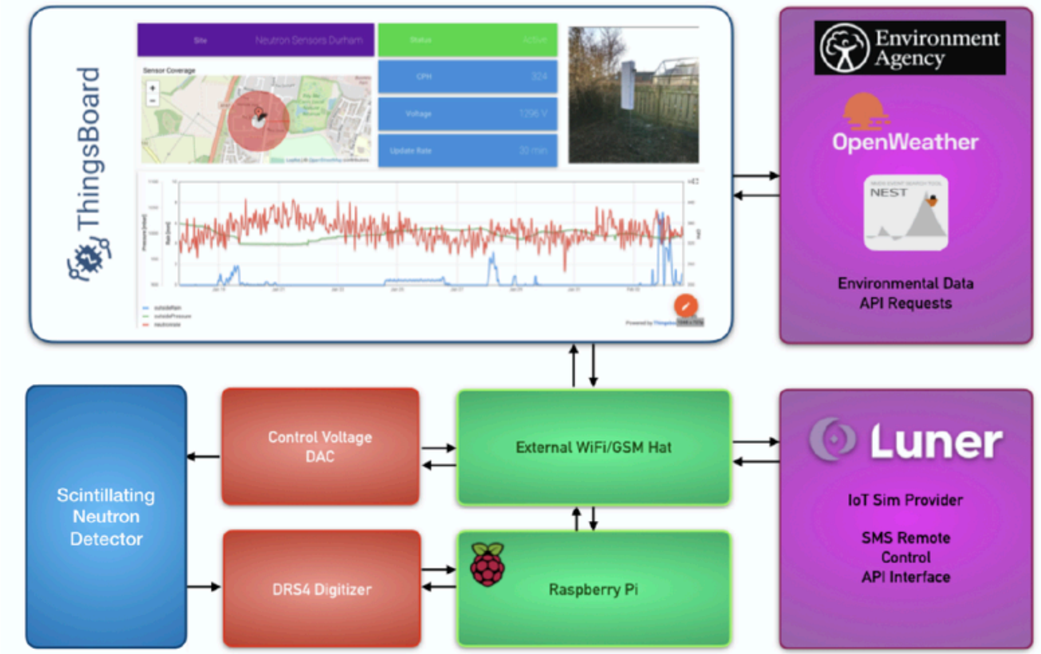

Neutron Leading Pulse
Neutron Pulse Train
Neutron Discriminator OUT
200 mV/div
200 mV/div
1 Acq/s
0.188 V 870 ns
200 ns/div 698 MS/s Calib

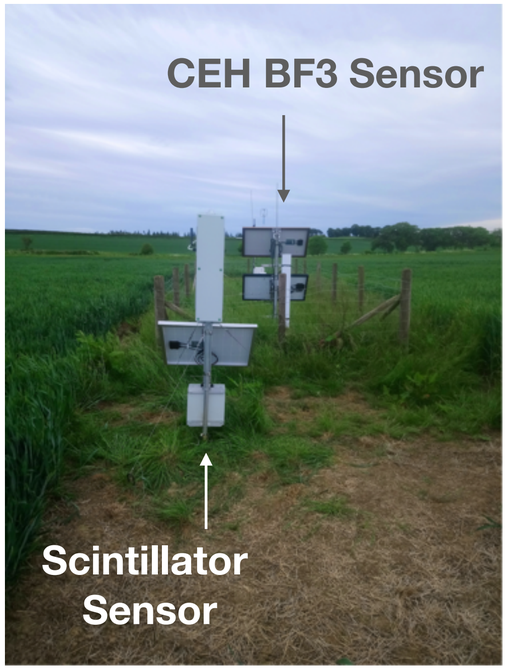

Scintillating Neutron Detector
Low Power IoT Discriminator

Benchmarking Tests

- STFC Food Network+ Funding received to benchmark a LiF:ZnS neutron detector system at Newcastle Cockle Park farm.

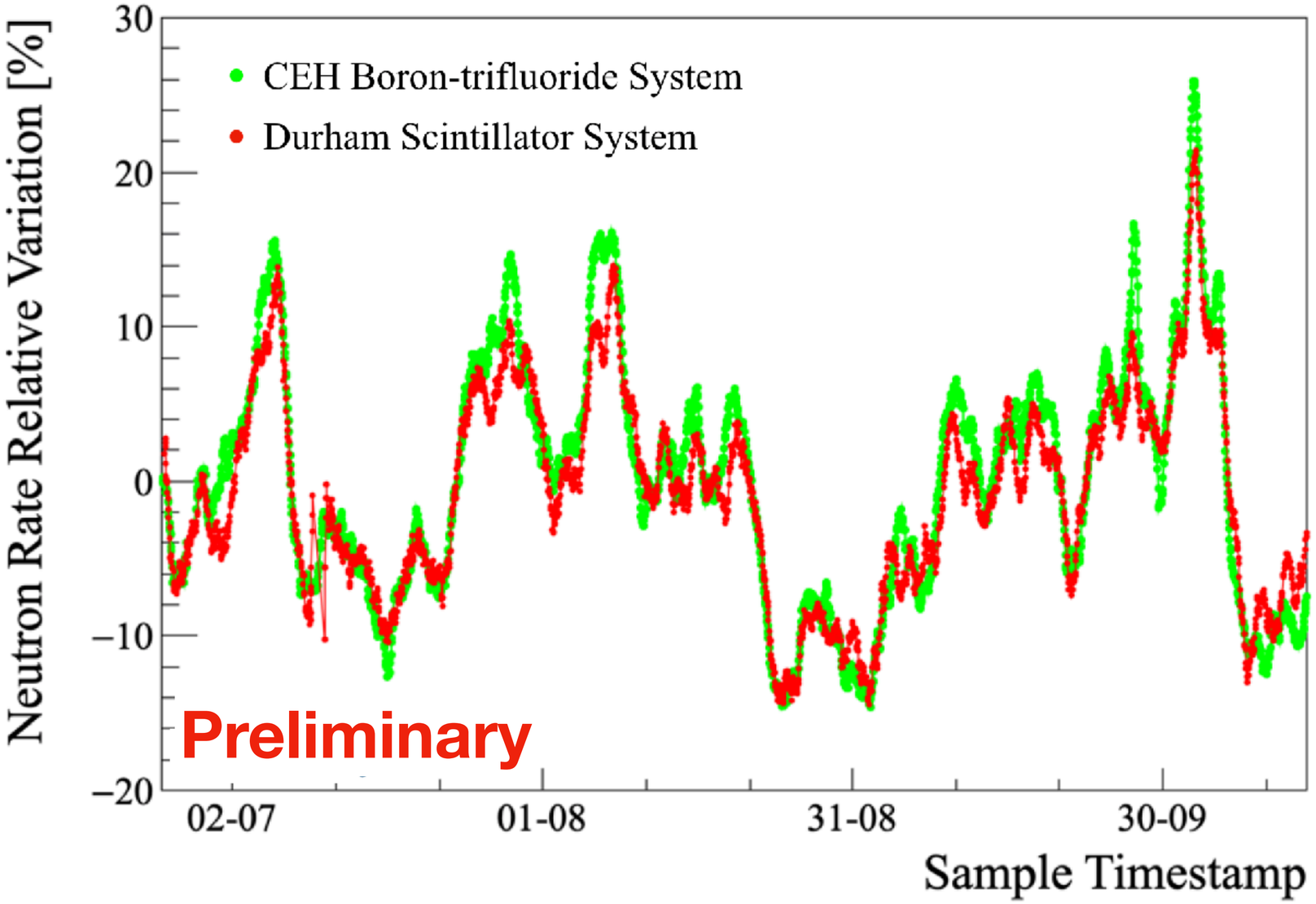
- 3 month remote deployment next to a BF3 COSMOS-UK station.





STFC Food Network+

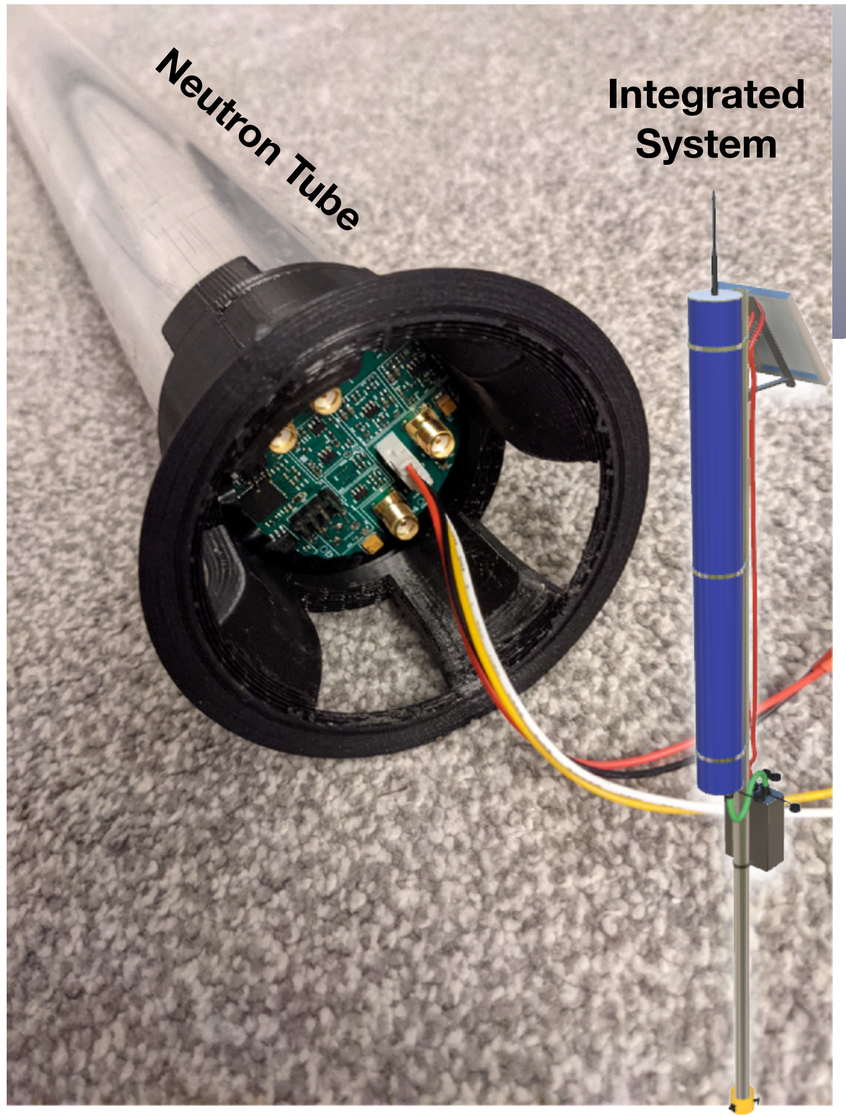
V1 Detector Results

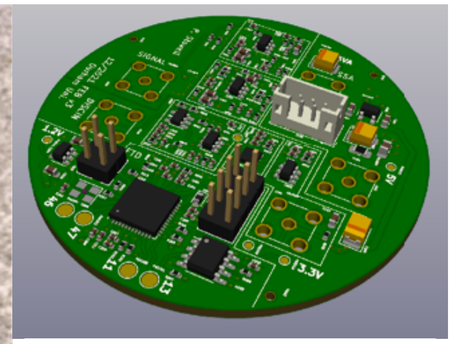


Acknowledgement: COSMOS-UK data owned by UK Centre for Ecology & Hydrology

Next Steps

- New robust neutron system has been developed at Durham that could be mass produced.
  - Move to low cost non-toxic BN:ZnS scintillator composites for neutron detection.
  - Improvements to light guide mounts and hermetic sealing of scintillator assembly.
  - Development of a dedicated trigger and slow control PCB.



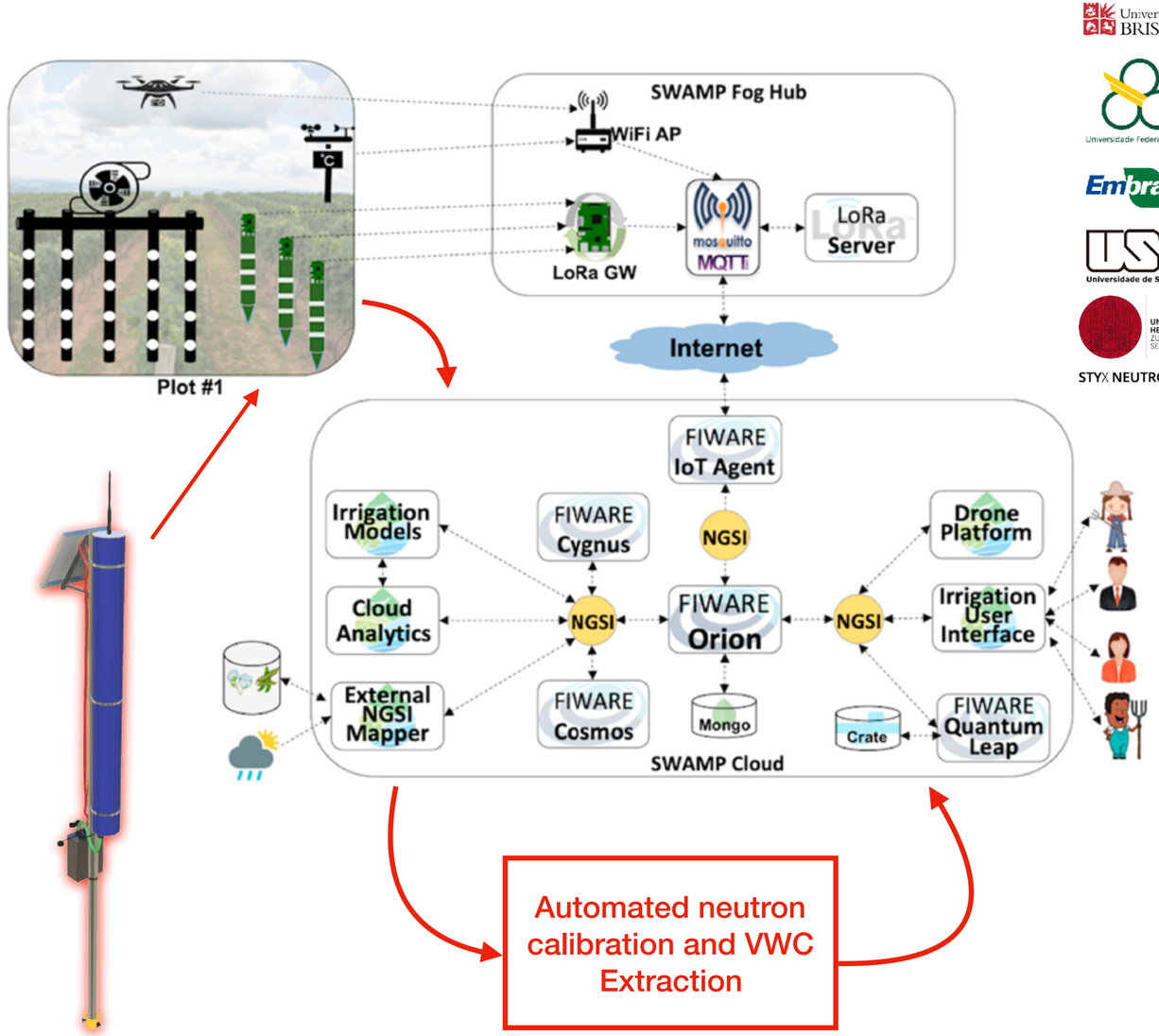


Integrated Neutron Cap

- Onboard environmental sensing
- Fast front end amp and discriminator
- FPGA Staged TOT Trigger
- List or Histogram mode data acquisition
- I2C Control Interface
- 300mW Power

COSMIC-SWAMP

- Low cost neutron sensors opens up complex remote sensing techniques for precision agriculture.
- “COSMIC-SWAMP” NERC network looking at integration of cosmic ray sensors with machine-learning powered irrigation systems.
- Automatic calibration of field neutron measurements, combining local weather data and measurements from the online neutron monitor database.



Conclusions

- Inverse relationship between observed neutron rate and soil hydrogen can be used to measure local soil moisture across large areas.

- Scintillator neutron detectors a viable solution for measuring epithermal neutrons in the field.

- To support adoption of the CRNS technique by COSMIC-SWAMP network is developing hardware/software solutions to automatically process raw counting data from IoT neutron sensors in the field.

STFC Food Network+

Interested in how your research could be used in the agri-tech industry? Come speak to me after the talk!

https://www.stfcfoodnetwork.org