Multi-Input Readout Systems for ^{3}He/BF$_3$ Position Sensitive Neutron Detectors

Yuri Venturini (y.venturini@caen.it)

St. Catherine's College
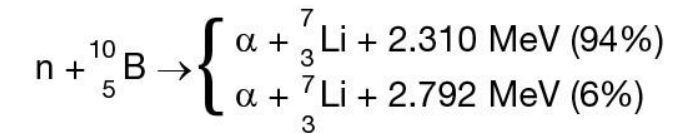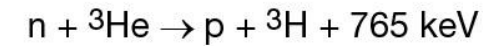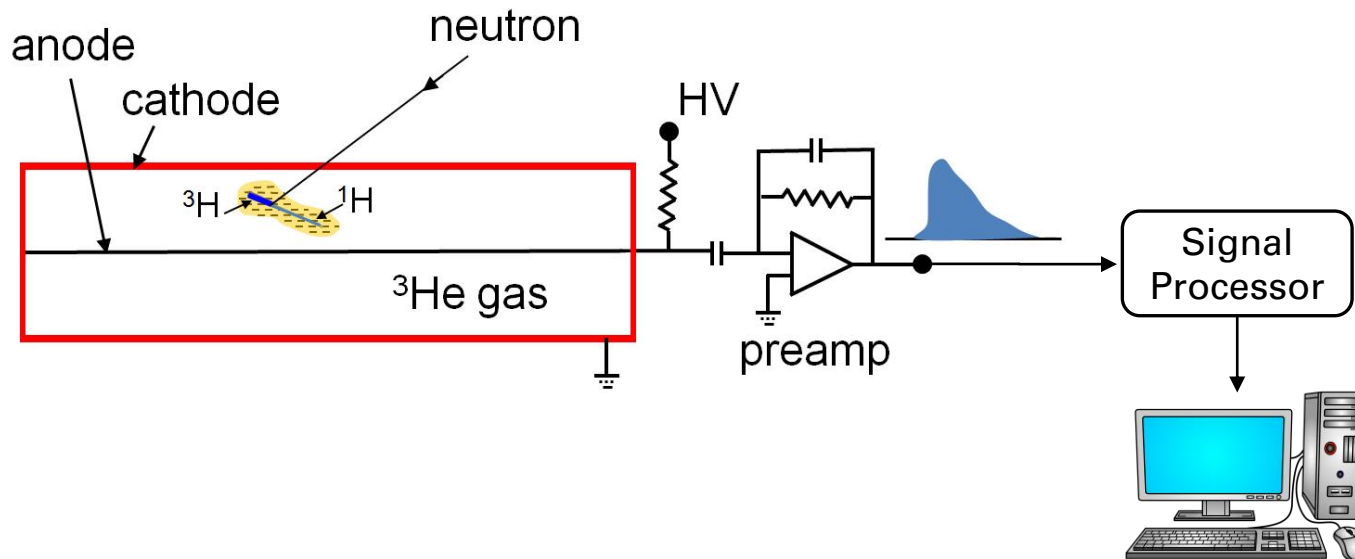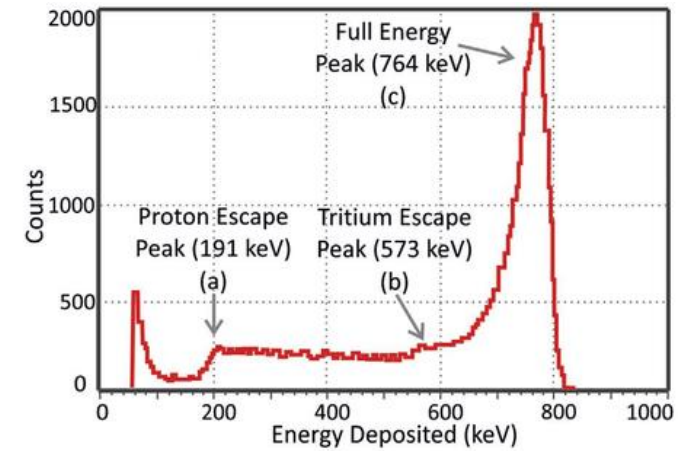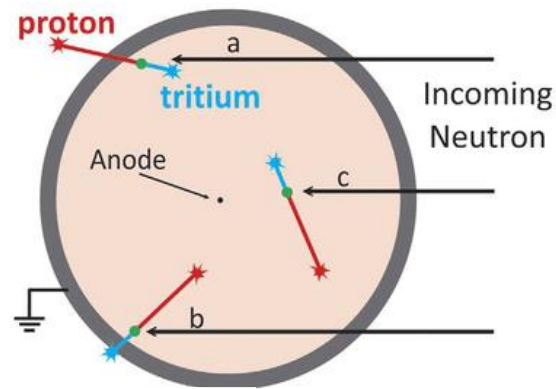September 3-8, 2023

UNIVERSITY OF OXFORD

Summary

❖ **Nbrick**: a system for neutron position measurements

❖ Details of the electronics

❖ Qualification and use cases

❖ Possible upgrades : n/gamma discrimination

❖ Equipment for **Neutron Counting**

Neutron detection

Proportional counters

- ^{3}He
- BF_3

$$n + {}^3He \rightarrow p + {}^3H + 765 \text{ keV}$$

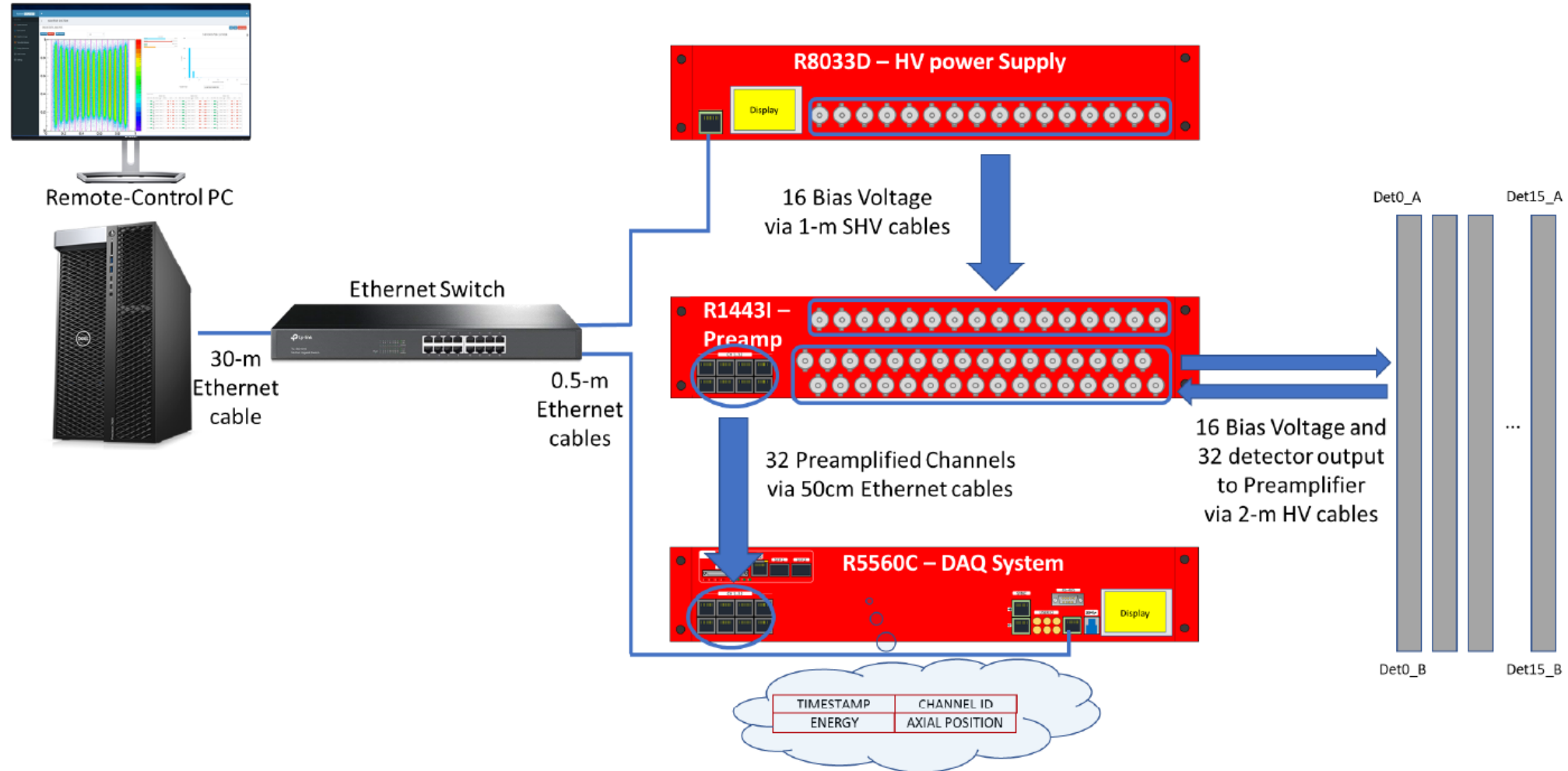$$n + {}^{10}_{5}B \rightarrow \begin{cases} \alpha + {}^{7}_{3}Li + 2.310 \text{ MeV (94\%)} \\ \alpha + {}^{7}_{3}Li + 2.792 \text{ MeV (6\%)} \end{cases}$$

Nbrick: neutron position measurements

32-ch preamplifier

- Fast, specifically designed for neutron detectors in collaboration with **ILL-France**
- 32 input channels with 16 independent HV lines (one for each position-sensitive tube)
- Rate capability: >100kHz per tube
- Differential outputs on RJ45 connectors - rise time <20ns, decay time 1µs
- Total gain: 2.25 V/pC
- Cross talk < 1%
- Resolution [1]: ~20 keV (with full scale range 36 MeV)
- Input residual Noise: about 0.8 fC

(1) measured with a CAEN 2745 digitizer with DPP-PHA FW with trapezoidal filter parameters (Rise Time = 2 us, Flat Top = 0.6 us, Tau = 0.95 us)

R5560C Digital Signal Processor

- 32 channels, 14-bit @125 MS/s Flash ADC Module

- Online Signal Processing → **Energy, Time, Position, PSD (Coming Soon)**

- Differential inputs on RJ45 connectors for direct coupling to R1443

- Cost-effective installation and minimum noise pick-up thanks to standard Ethernet CAT5/6e cables

- USB3.0 / 1 Gbps Ethernet Readout

Signal Processing

- **Thanos** Software - Remote High Voltage control and DAQ

- **Waveforms** inspection

- Trigger-less acquisition: each channel is self-triggered (digital timing filter and discriminator)

- On board coincidences

- **Resistive Charge Division** to reconstruct position

- List Mode: output files with **time stamped energy** (or position) list

- **Energy Spectrum** of each single tube side

- **Image reconstruction** of the neutron flux
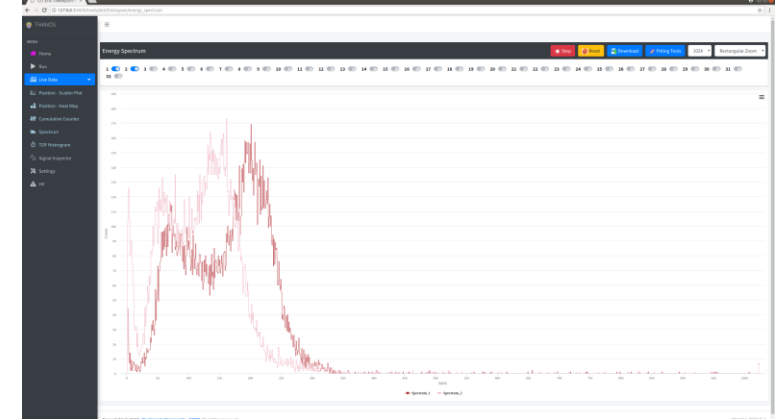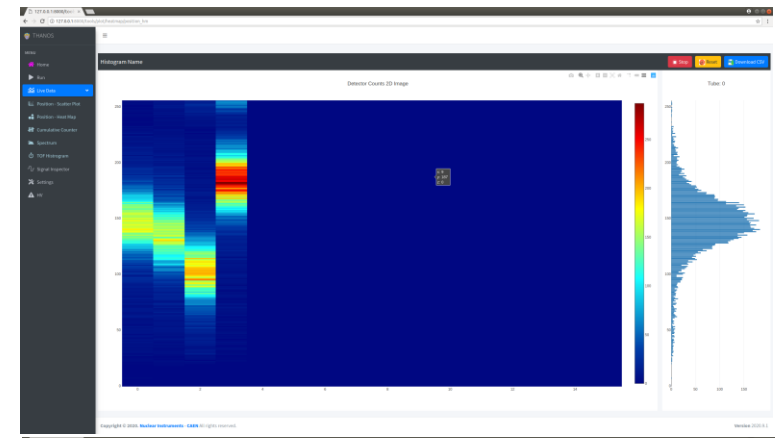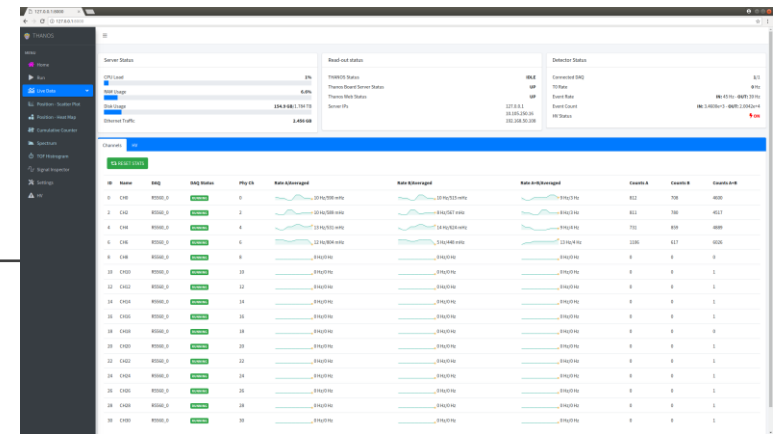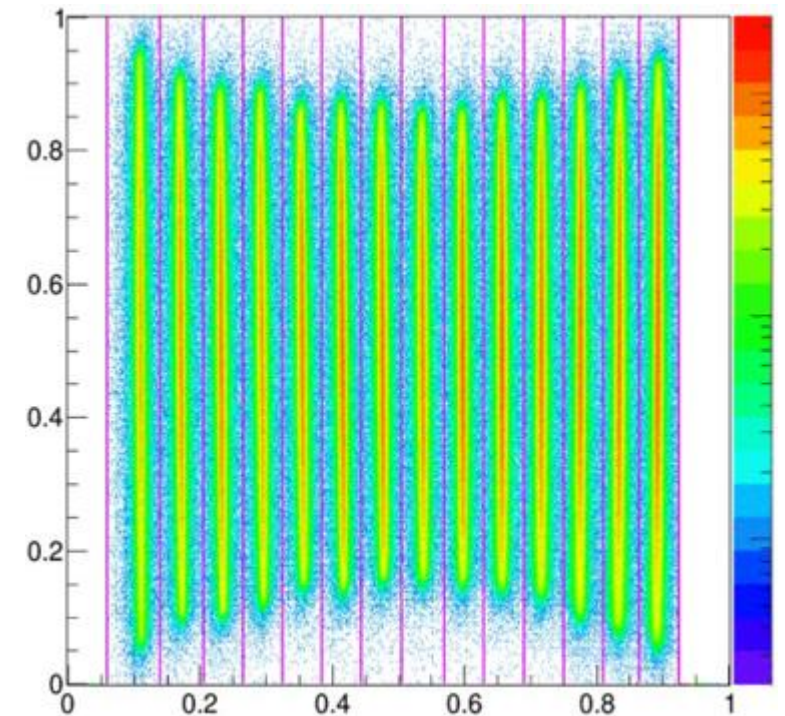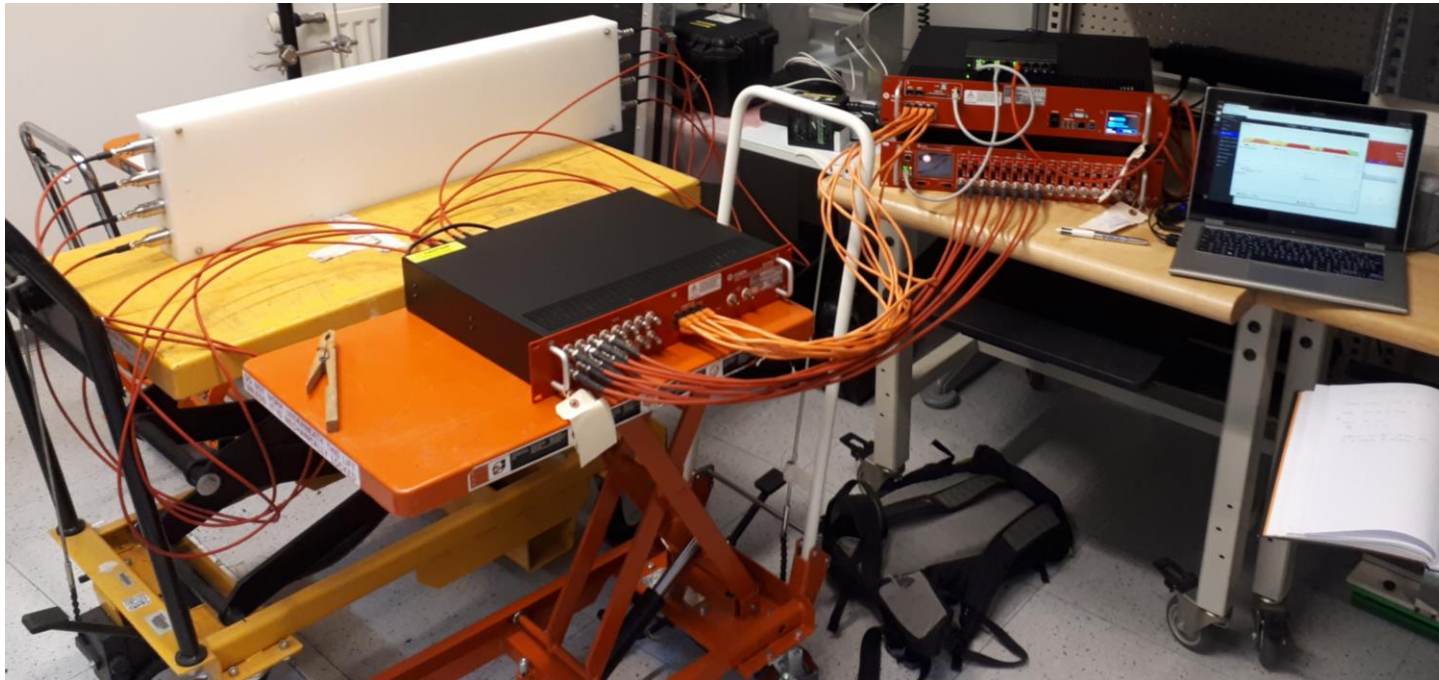
Total charge collection

Energy Spectrum of moderated neutrons by **Thanos** software
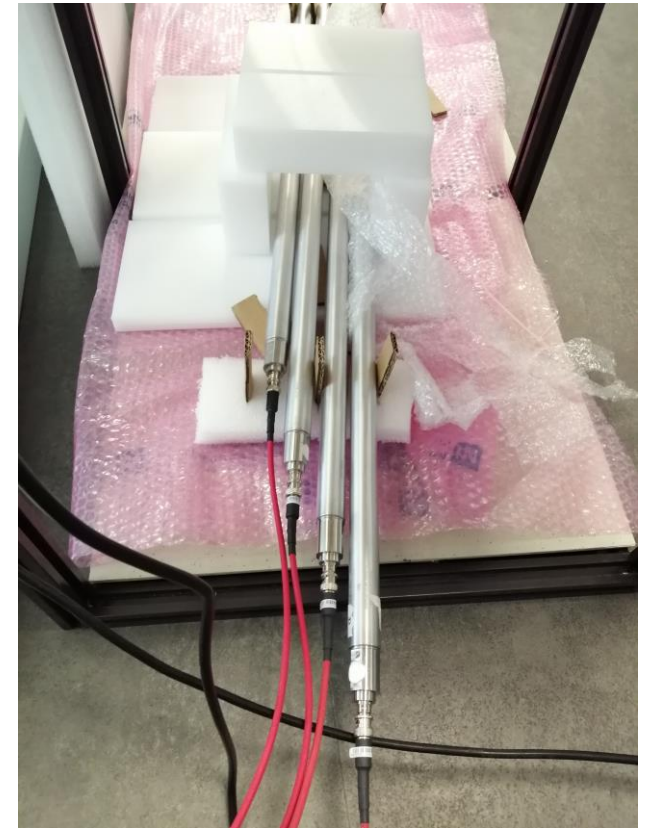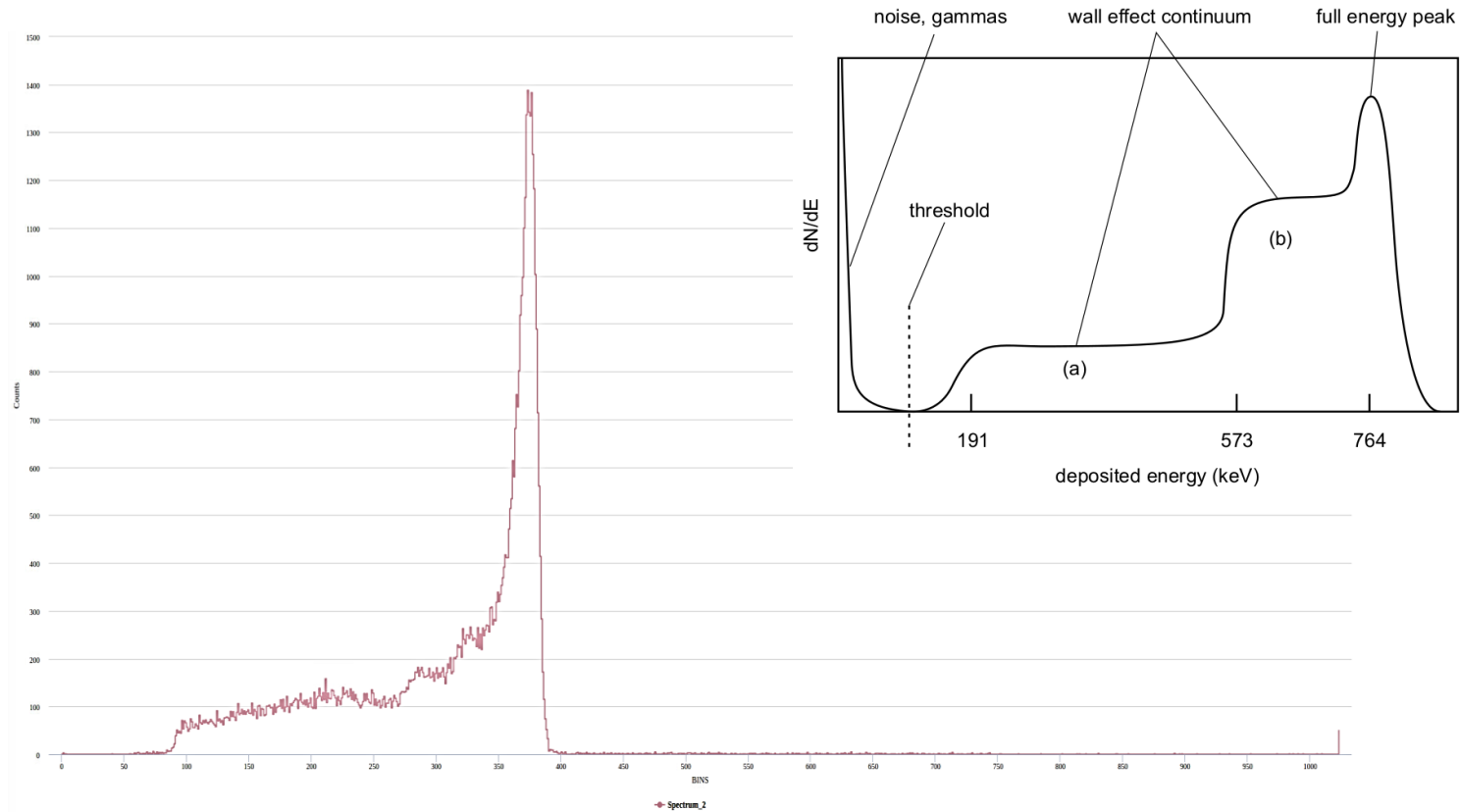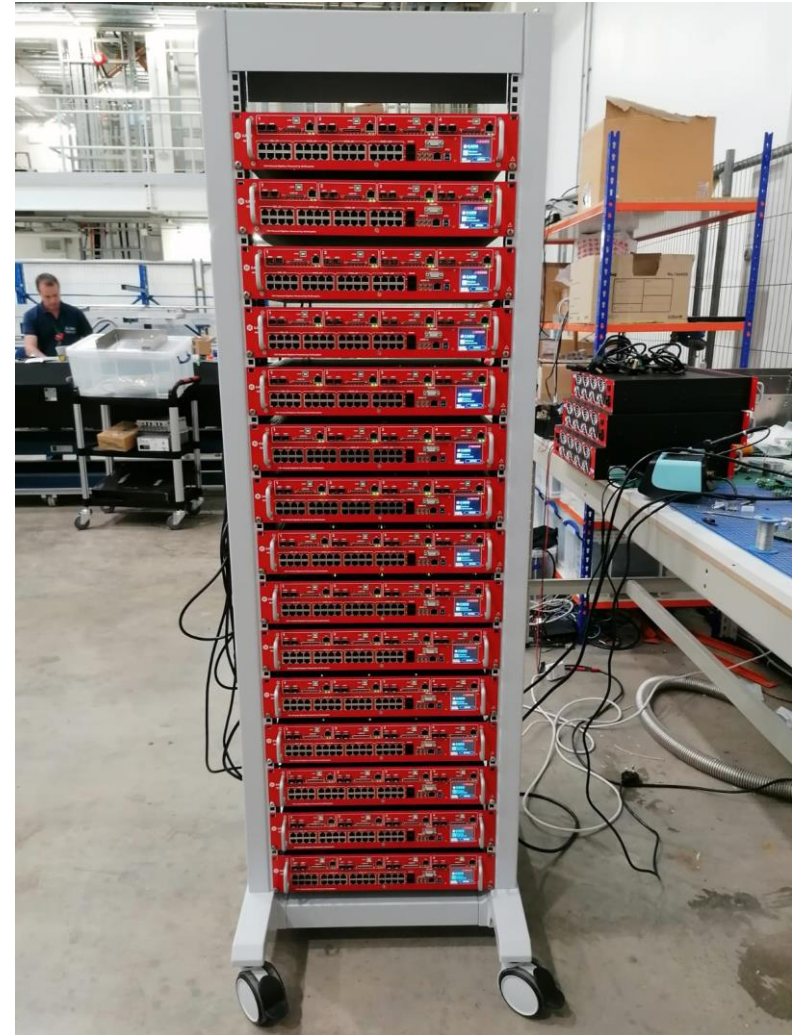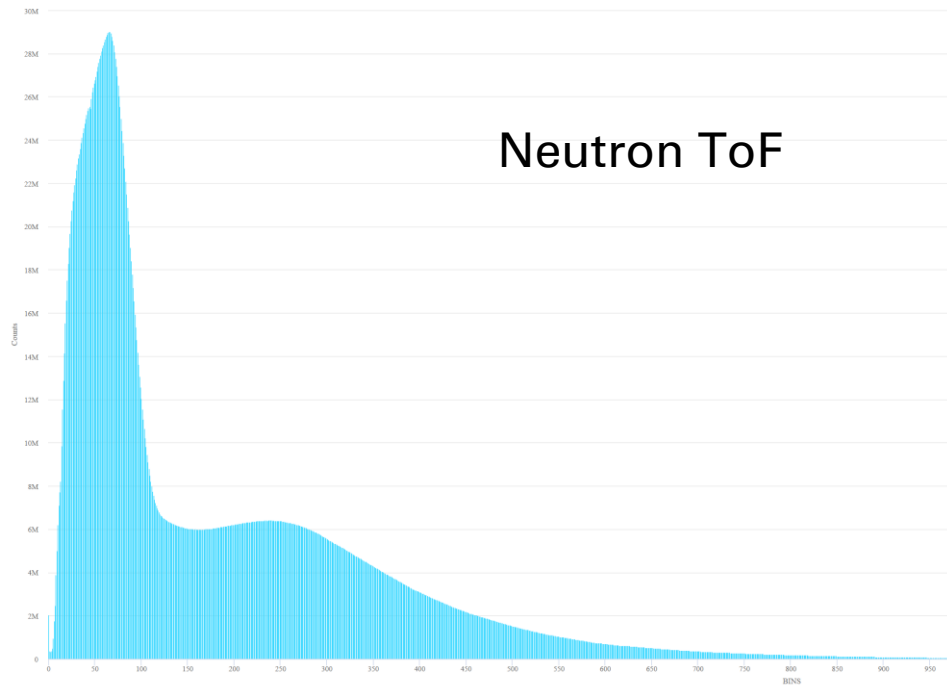
Use case: neutron flux measurements

➤ **IRSN** – France: readout system for 8 position sensitive ^{3}He tubes
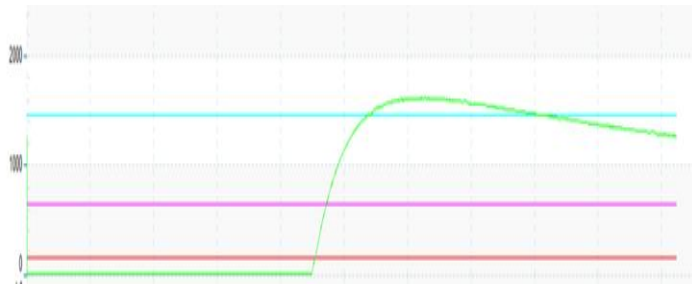
Use case: Small Angle Neutron Scattering

➢ **Loki @ ESS**/RAL-ISIS: 3He tubes readout by more than 30*R5560 synchronized and interfaced with pre-existing systems
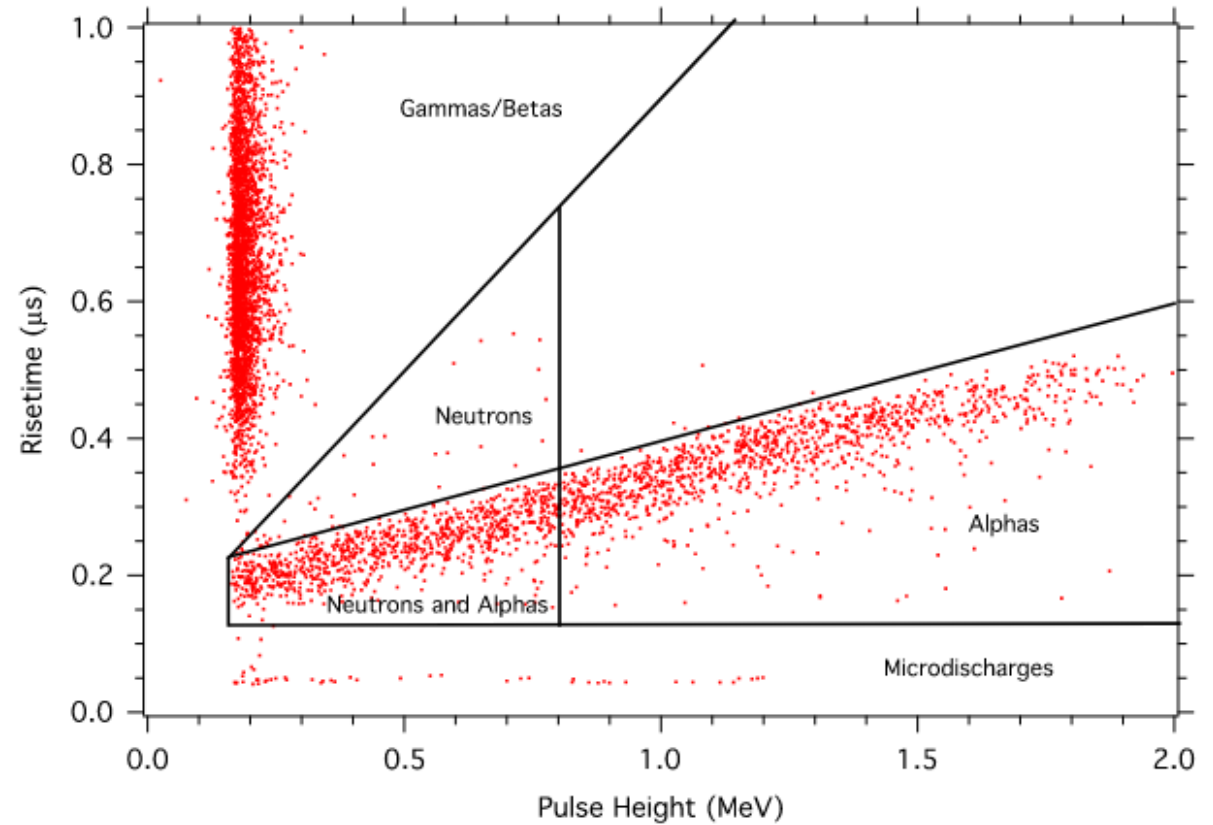
Neutron ToF

Next steps: gamma/n Pulse Shape Discrimination

- **Plasma diagnostic** need: PSD at event frequency < 100 Hz – no pileup issues

- Three parameters: T10, T40, T90
  - T90 is to remove the microdischarges

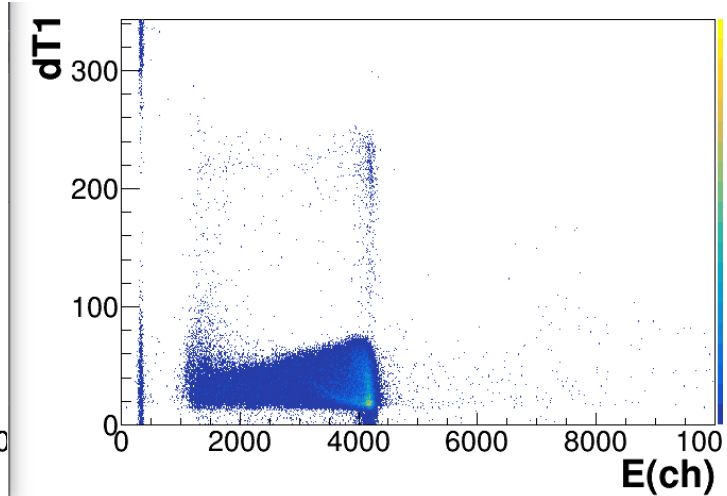$$PSD = \frac{t_{rise\ 40\%} - t_{rise\ 10\%}}{Energy}$$

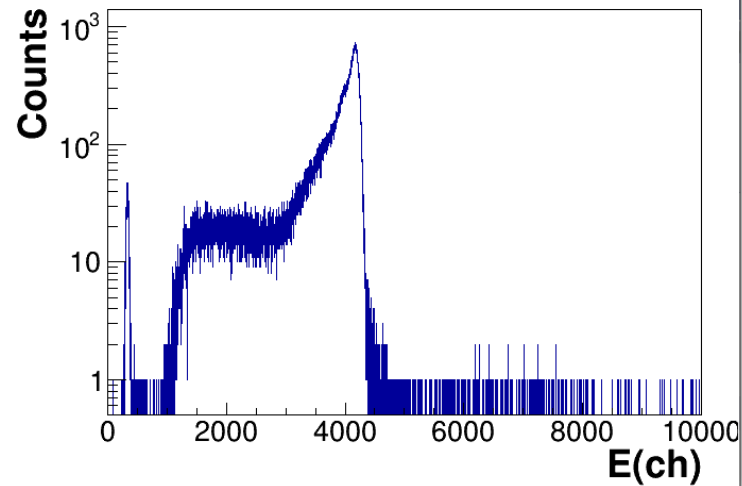Peak Sensing   Trapezoidal filter
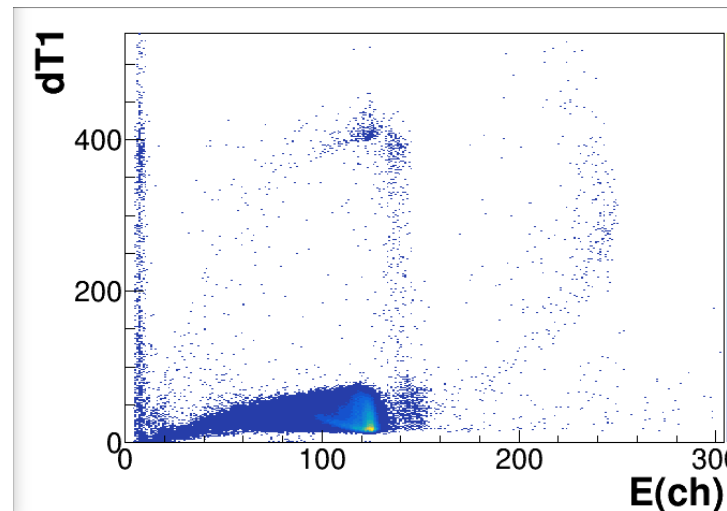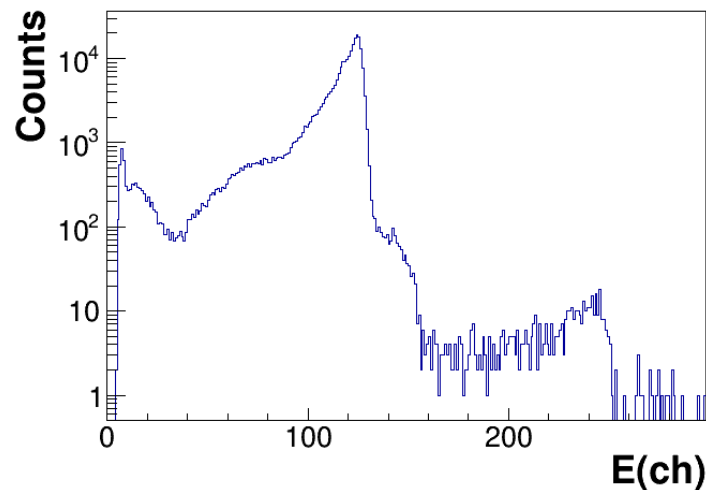

http://dx.doi.org/10.1016/j.nima.2013.03.062

Preliminary results from PSD algorithms

Peak Sensing

Poor low energy resolution causes a gap in the PSD

Trapezoidal filter

High energy resolution (even at low energies) and PSD plot more in agreement with theory
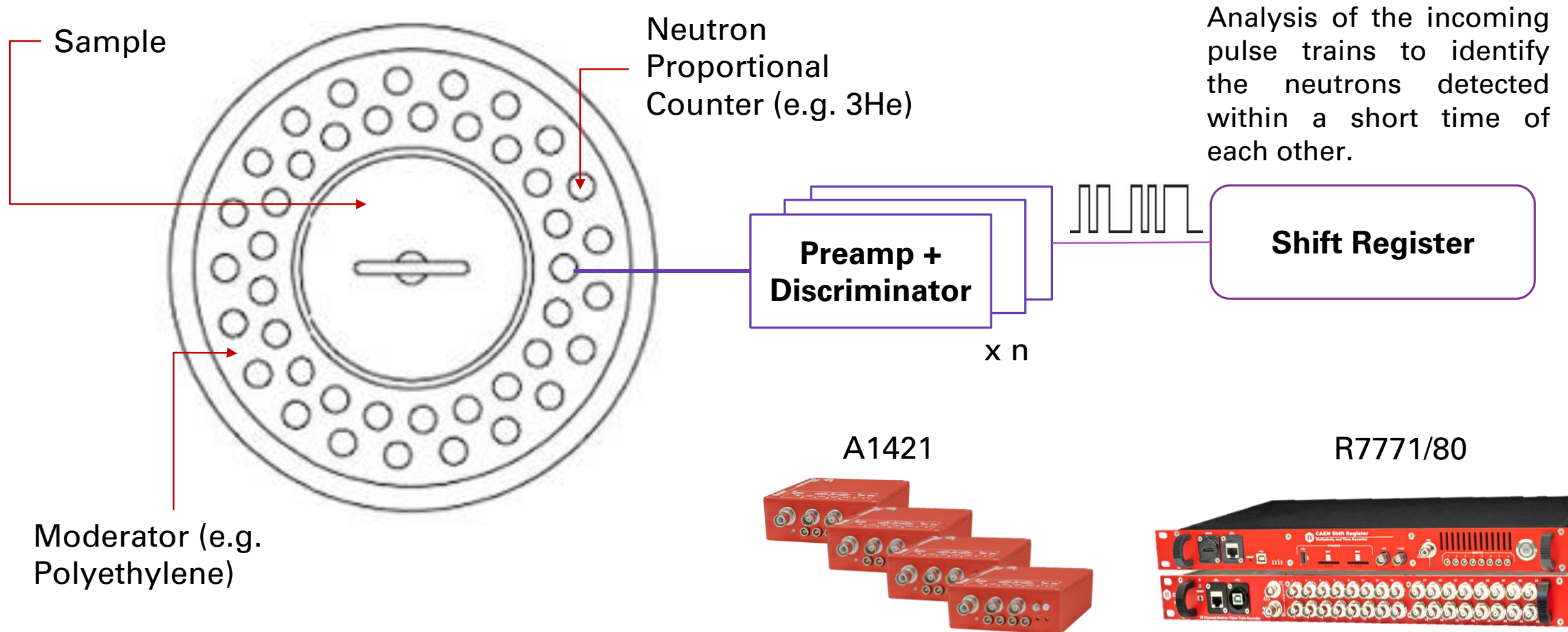
Neutron counting challenges

- Nuclear Safeguards → Assay of fresh fuel materials (^{238}Pu, ^{240}Pu, ^{242}Pu, ^{239}Pu, ^{235}U, ^{238}U) for non-proliferation and security purposes

- Non-destructive **quantification** of Pu and U mass inside a high-density sample (Spontaneous Fission or Active Interrogation)

- γ-rays by the fissile element drawn into a background due to ligther elements (already present or products of the fission)

- Most n would come from (α,n) reactions induced by lighter elements → Random

- Fission produces **multiple n simultaneously → Neutron Coincidence Counting**

- Distribution of the number of n emitted in coincidence → **Multiplicity**

Neutron Coincidence Counting

Sample

Neutron Proportional Counter (e.g. 3He)

Analysis of the incoming pulse trains to identify the neutrons detected within a short time of each other.

Preamp + Discriminator

x n

Shift Register

Moderator (e.g. Polyethylene)

A1421

R7771/80
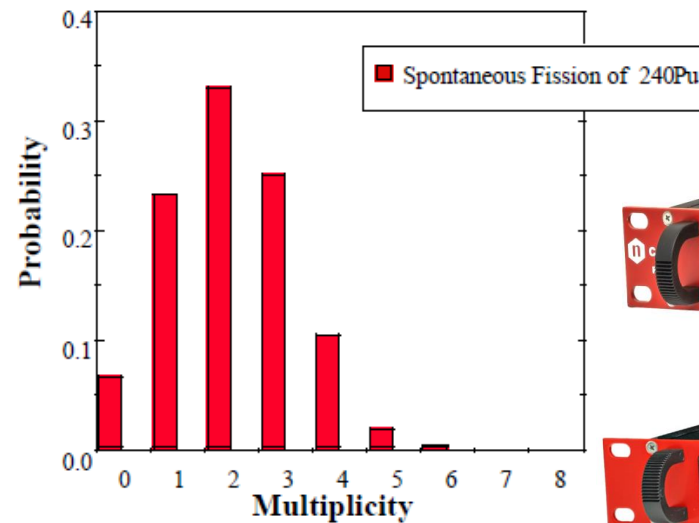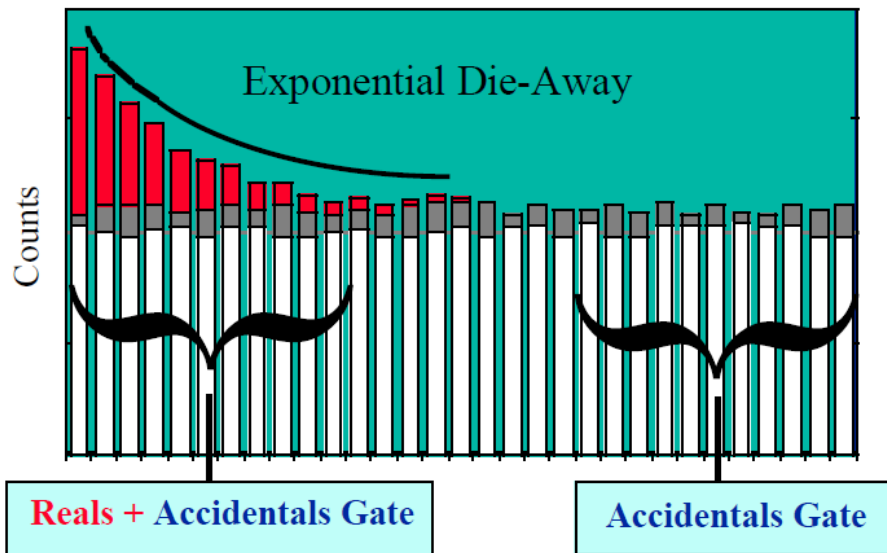
Shift Register operation

- Trains of pulses → Identification of n events within a certain gate from the triggering event

- Probability of coincidence n counts decays as an exponential

- **Rossi-Alpha** distribution takes into account coincident and random n

- **Multiplicity** distribution takes into account the number of coincident n → Fissile material signature

Conclusions

❖ All-in-one system for ^{3}He/BF$_3$ neutron detectors

  ✓ Tested in real scenarios: position reconstruction, spectroscopy, timing.

  ✓ Performances are satisfactory for both Research and Security applications

  ✓ Ongoing support and upgrades

  ✓ Open to discuss your needs and wishes!

❖ Neutron Counting Electronics for Nuclear Safeguards

  ✓ Particular attention to robustness, reliability, ease of use

  ✓ Validated by IAEA and currently in use

Thank you for your attention

Any question/curiosity?

y.venturini@caen.it

Backup slides

32-ch N-brick rackmount solution

Readout of up to 16 position-sensing tubes

^{3}He/ BF$_3$ tube
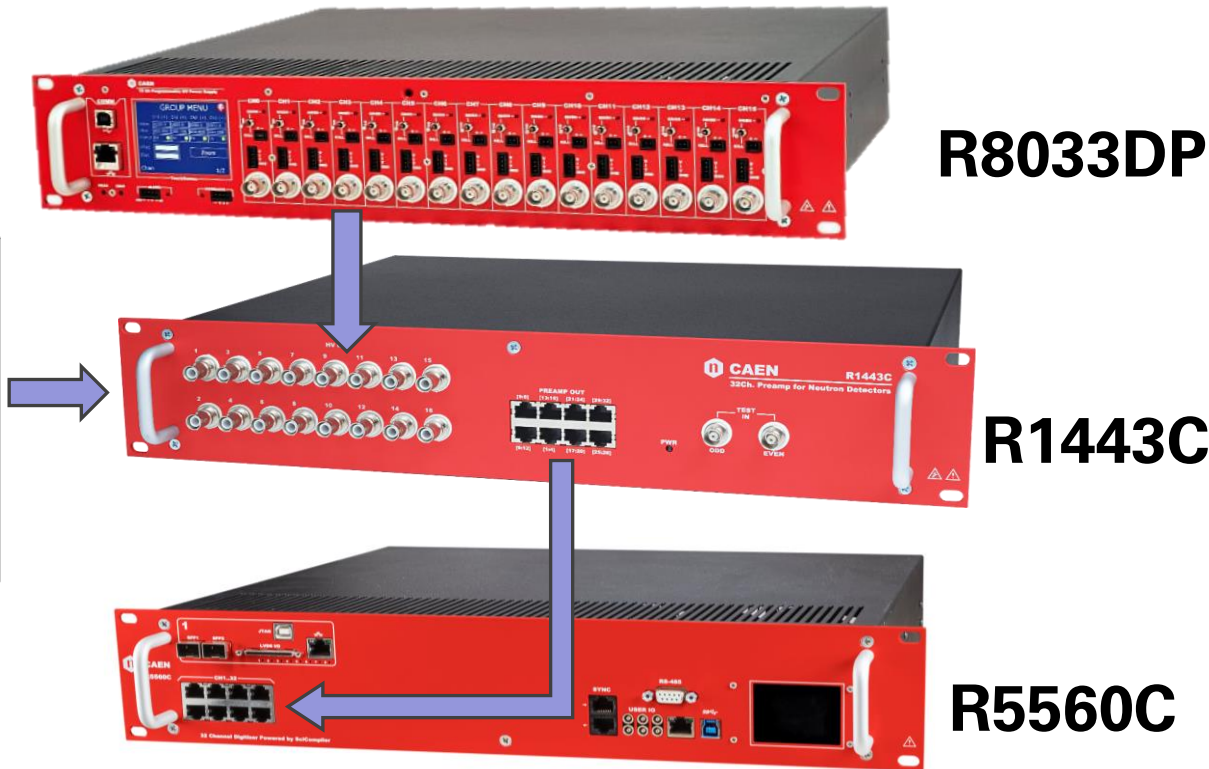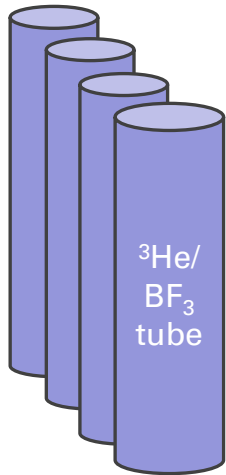
R8033DP

R1443C

R5560C

High Voltage for detector bias
16-ch Rack-mount Programmable HV Power Supply(+4KV, 3mA)

Charge Sensitive Preamplifier
32-ch Preamplifier unit with 16 independent High Voltage distribution and decoupling lines

Digital Signal Processor
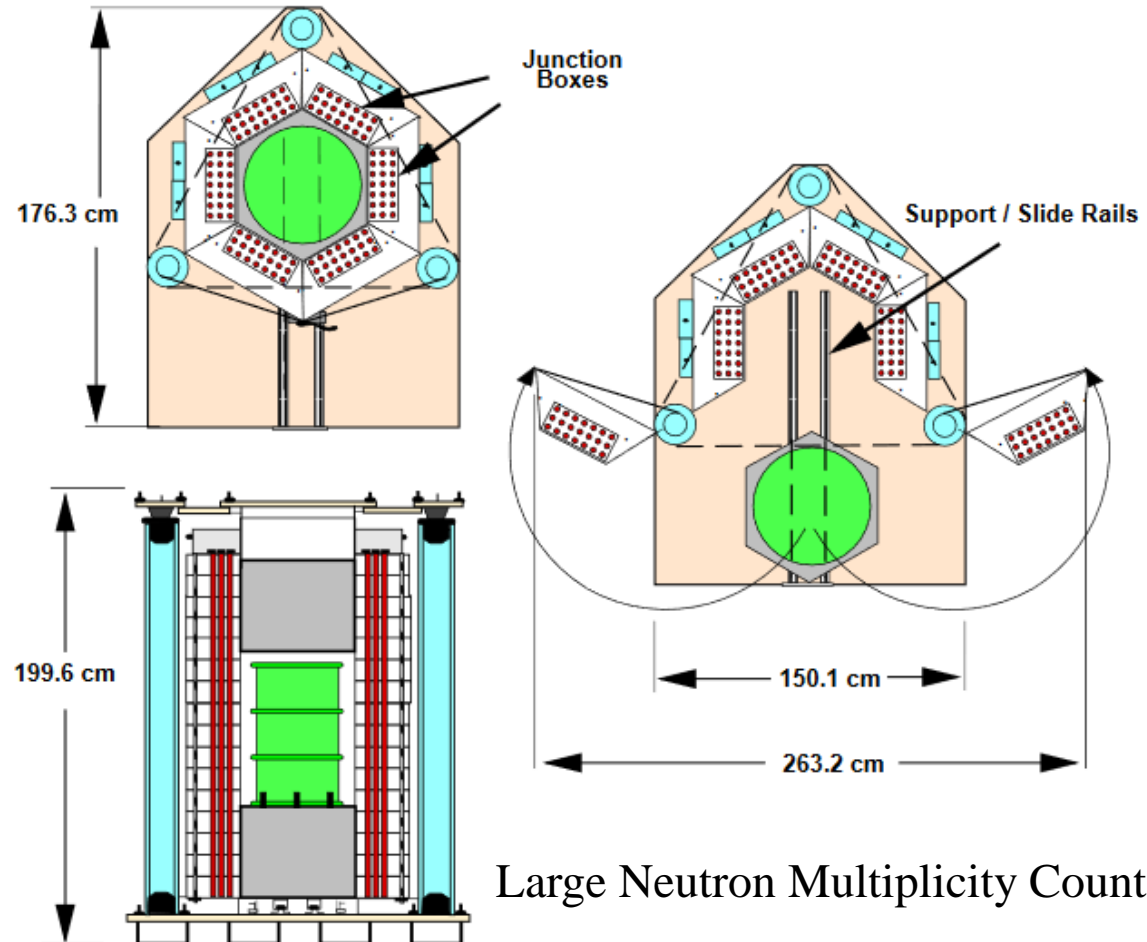32-ch, 14-bit @125MS/s Flash ADC with online signal processing algorithm

Neutron counting for Nuclear Safeguards

Neutron Coincidence Counting

Plutonium Scrap Multiplicity Counter

Junction Boxes

Support / Slide Rails

176.3 cm

199.6 cm

150.1 cm

263.2 cm

Large Neutron Multiplicity Counter

Preamplifier and discriminator

Full chain in a box

- 1 Ch, compact size **preamp + shaper + discriminator**

- Gain: 30 mV/fC on HiZ

- Shaping: 120 ns rise time + 460 ns fall time

- Analog and **TTL output**

- Fast recovery time suitable for **passive** as well as for **active** interrogation measurements.

Preamplifier + Discriminator for n detectors

- A1421 is specifically designed for neutron detectors as ^{3}He or BF_3 tubes in counting applications

- 1 Ch, compact size preamp + shaper + discriminator

- Gain: 28 V/pC, Sensitivity: 1 V/pC

- Output signal total duration: 700 ns

- Analog and **TTL output** → match with R7771/80 Shift Registers

- Fast recovery time suitable for **passive** as well as for **active** interrogation measurements.

Preliminary picture - mechanical t.b.d.

R7771 - 32-Ch Neutron Pulse Train Recorder

- 32 inputs on BNC connectors (TTL, 1 kΩ)

- 10 ns time stamp resolution

- 10 ns of pulse pair resolution and minimum pulse width detection

- **Rossi-Alpha** and **multiplicity** distribution

- Possibility to recall pulse trains for off-line analysis (files in **INCC** format)

- High Voltage for detectors bias and Low Voltage for preamp power

- 10/100 Ethernet and USB 2.0 interfaces

CAEN Shift Register Software

R7780 - 8-Ch Unattended Monitoring System

- Multiplicity, Time recorder and Shift Register adopted as **IAEA UDL1**

- 8 inputs on LEMO connectors (TTL, 50 Ω)

- 10 ns time stamp resolution

- **Unattended** operation with data logging capability (two removable SD cards and USB stick)

- **Redundant storing mechanism implemented for higher reliability in unattended operation**

- Special video output (HDMI) to monitor the state-of-health of the device

- Time-stamped lists saved to **PTR-32** compatible file format and compliant to **INCC** software package

- 10/100 Ethernet and USB 2.0 interfaces