UNIVERSITY OF BIRMINGHAM

Birmingham Gaseous Detectors Laboratory

Fast neutron spectroscopy: The nitrogen-filled Spherical Proportional Counter

I. Manthos, I. Katsioulas , P. Knights, J. Matthews, T. Neep,
K. Nikolopoulos and R. Ward

HEP 2021, Thessaloniki (Online)

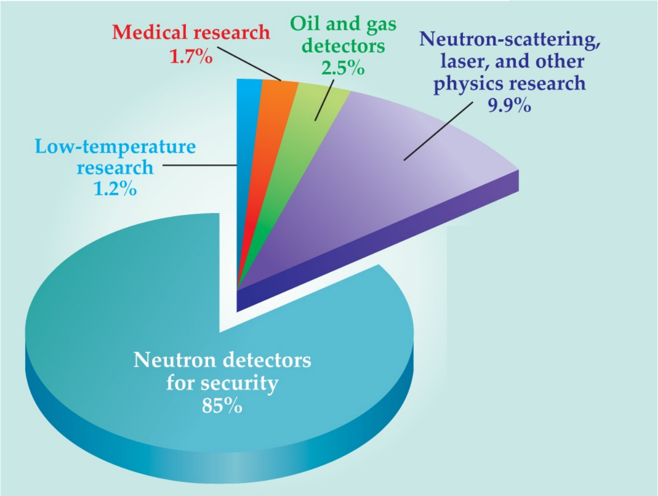
18/06/2021

MARIE CURIE ACTIONS

This research has been funded by the European Union’s Horizon 2020 Research and Innovation Programme under the Marie Sklodowska-Curie Grant Agreement No 845168 (neutronSphere)

The need for fast neutron detection

Fast neutrons are often detected by first moderating (slowing) them to thermal energies. However, during that process the information on the original energy of the neutron, its direction of travel, and the time of emission is lost. For many applications, **the detection of "fast" neutrons that retain this information is highly desirable.** (Wikipedia)



Physics Today 62, 10, 21 (2009)

Physics research → Dark matter underground experiments

- Identical signature to signal events
  - Sources: Radioactivity of cavern, cosmic rays
  - Elastic scattering with target nuclei of gas, interaction with detector material

Neutron detection with gaseous detectors

Current status

^{3}He proportional counters

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

Efficient for thermal and fast neutrons, low efficiency in γ-rays	Wall effect → high pressure (impractical) ^{3}He extremely expensive

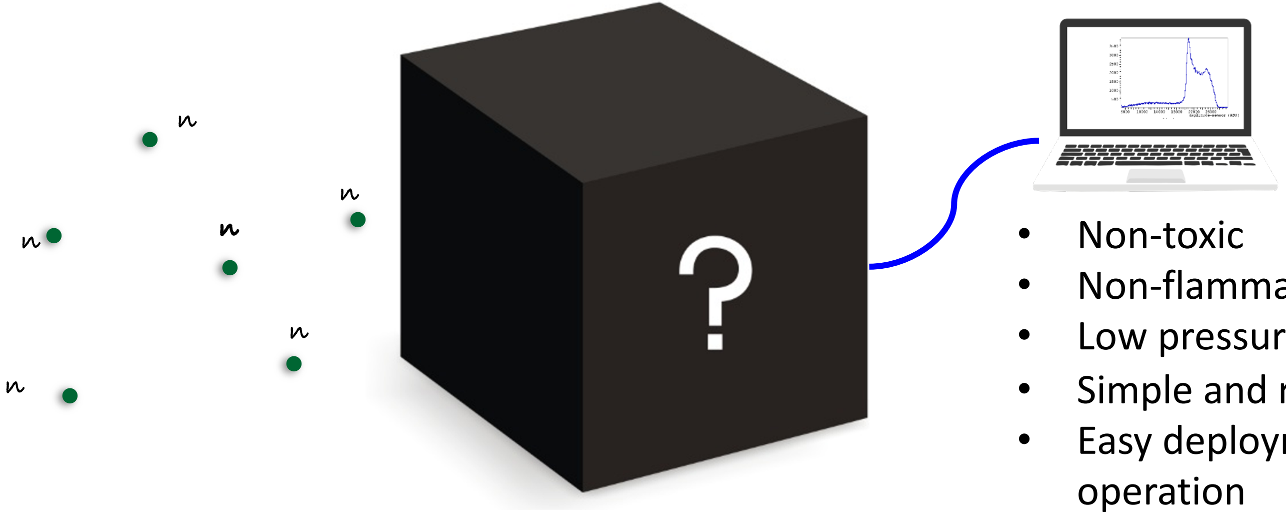
<u>Alternative technologies:</u>

BF_3-based proportional counters	Toxic and corrosive
^{10}B lined tubes	Poor efficiency, high cost
Bulk scintillators	Complicated response function, limited radiation hardness, insufficient γ/n discrimination
^6Li coated Ar-filled detectors	degraded energy resolution

UNIVERSITY OF BIRMINGHAM

Neutron detection with gaseous detectors

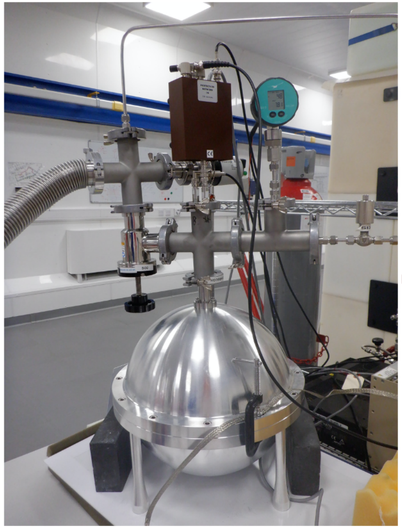
Desired characteristics of a fast neutron spectroscopy system (1-20 MeV range)

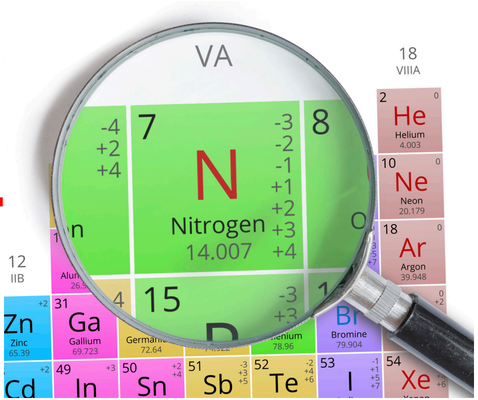


- Non-toxic
- Non-flammable
- Low pressure
- Simple and robust setup
- Easy deployment and operation
- Cost efficient

UNIVERSITY OF BIRMINGHAM

Neutron detection with the Spherical Proportional Counter





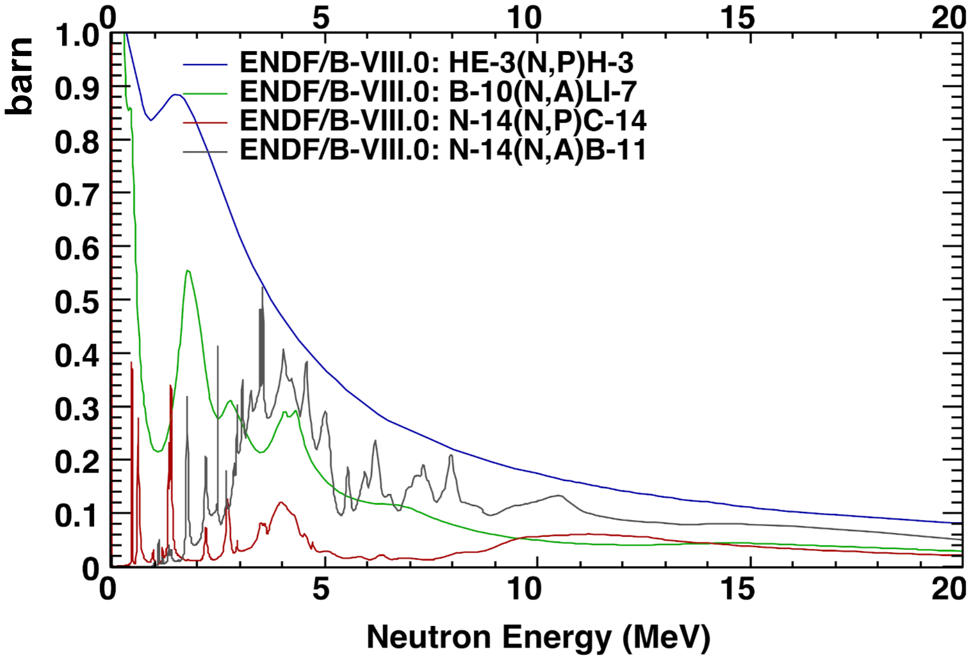
- ✓ Non-toxic
- ✓ Non-flammable
- ✓ Simple and robust setup
- ✓ Easy deployment and operation
- ✓ Cost efficient

- ✓ Wall effect suppressed due to higher atomic number of N relative to He → low pressure
- ✓ Good efficiency in detecting thermal neutrons in large volumes
- ✓ Low γ-ray efficiency
- ✓ Spectroscopic measurement of neutrons

UNIVERSITY OF BIRMINGHAM

Neutron detection with the Spherical Proportional Counter

Comparison of neutron absorption reactions



Common targets:

$^{3}He + n \rightarrow {}^{3}H + p$ + 765 keV, σ_{th}= 5330 b

$^{10}B + n \rightarrow {}^{7}Li^{*} + {}^{4}He$ + 2310 keV, σ_{th}= 3840 b
($^{7}Li^{*} \rightarrow {}^{7}Li$ +480 keV)

Nitrogen as target

$^{14}N + n \rightarrow {}^{14}C + p$ + 625 keV, σ_{th}= 1.83 b

$^{14}N + n \rightarrow {}^{11}B + \alpha$ - 159 keV, thres=1.7 MeV

UNIVERSITY OF BIRMINGHAM

Simulation of the detector response

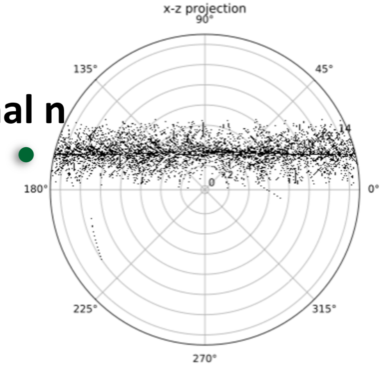
Simulation Parameters:
Ø vessel 30 cm
Nitrogen at 300 mbar
Anode Ø 2 mm

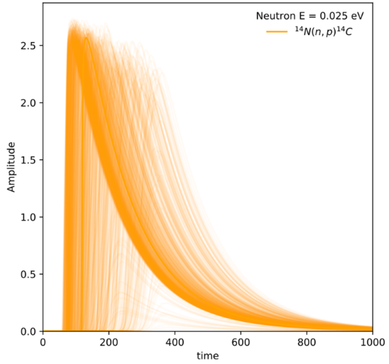
UoB simulation framework for complete simulation of a detection setup

- GEANT4 for particle transport in a geometry and their interaction with materials
- FEM simulation (ANSYS, COMSOL) of electromagnetic fields
- Garfield++ for the generation, drift and multiplication of primary electrons and signal generation

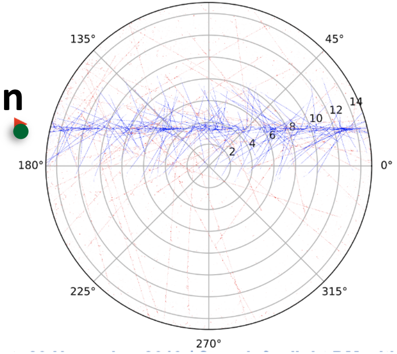
I. Katsioulas *et al* 2020 *JINST* 15 C06013

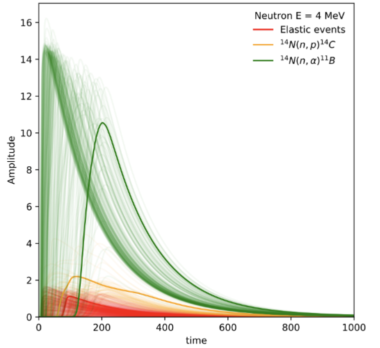
Thermal n



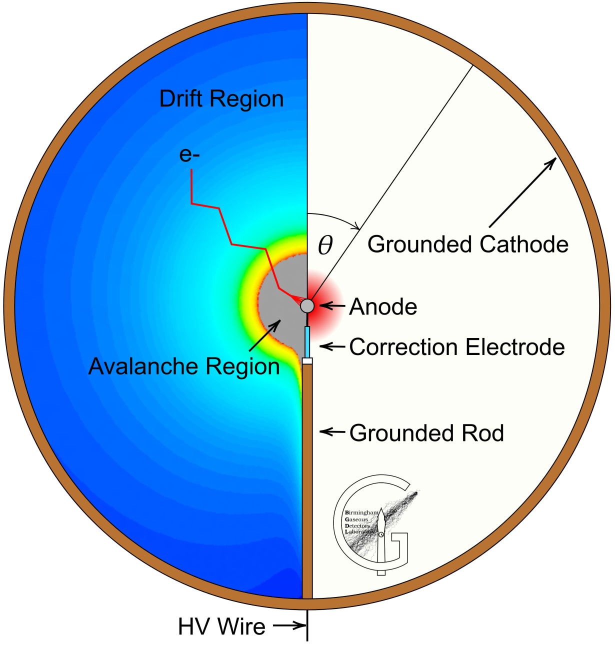


Fast n





The Spherical Proportional Counter



Electric field scales as $1/r^2$

- Divided into "drift" and "amplification" regions

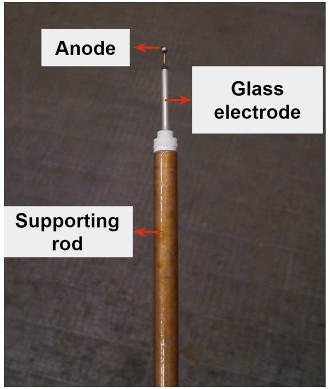
$$\vec{E} = \frac{V_1}{r^2}\frac{r_c r_a}{r_c - r_a}\hat{r} \approx \frac{V_1}{r^2} r_a$$

Capacitance independent of detector size

- Low electronic noise

$$C = 4\pi\varepsilon_0 \frac{r_c r_a}{r_c - r_a} \approx 4\pi\varepsilon_0 r_a \sim 1\text{pF}$$

- Large gain - Single e^- threshold
- Maximum volume-to-surface ratio
- High pressure operation
- Simple, robust design with a flexibility in target gas
- Applications in n-spectroscopy to DM!



r_c = cathode radius
r_a = anode radius

See also P. Knights talk

UNIVERSITY OF BIRMINGHAM

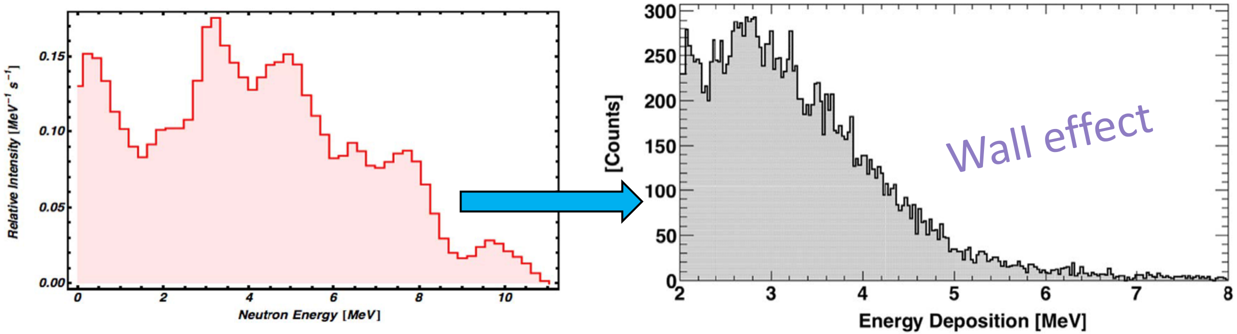
I.Giomataris et al, JINST, 2008, P09007
I.Katsioulas et al, JINST, 13, 2018, no.11, P11006

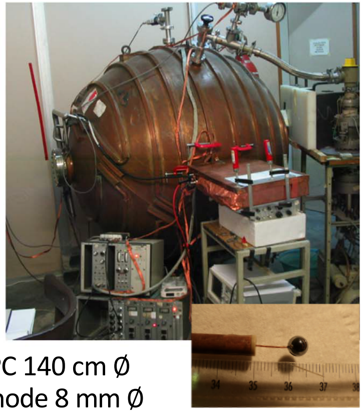
Neutron detection with the Spherical Proportional Counter

Proof of principle

- ^{252}Cf, $^{241}Am^{9}Be$ and ambient fast neutrons
- Thermal neutrons
- N_2 at 0.1-0.5 bar
- HV ~ 6 kV

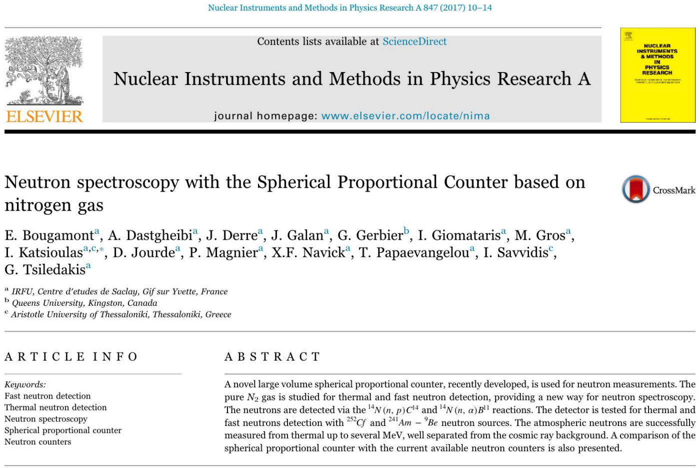
$^{241}Am^{9}Be$ spectrum





SPC 140 cm Ø
Anode 8 mm Ø

UNIVERSITY OF BIRMINGHAM



Nuclear Instruments and Methods in Physics Research A 847 (2017) 10–14

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

ELSEVIER

Neutron spectroscopy with the Spherical Proportional Counter based on nitrogen gas

CrossMark

E. Bougamont[a], A. Dastgheibi[a], J. Derre[a], J. Galan[a], G. Gerbier[b], I. Giomataris[a], M. Gros[a], I. Katsioulas[a,c,*], D. Jourde[a], P. Magnier[a], X.F. Navick[a], T. Papaevangelou[a], I. Savvidis[c], G. Tsiledakis[a]

[a] IRFU, Centre d'etudes de Saclay, Gif sur Yvette, France
[b] Queens University, Kingston, Canada
[c] Aristotle University of Thessaloniki, Thessaloniki, Greece

ARTICLE INFO

Keywords:
Fast neutron detection
Thermal neutron detection
Neutron spectroscopy
Spherical proportional counter
Neutron counters

ABSTRACT

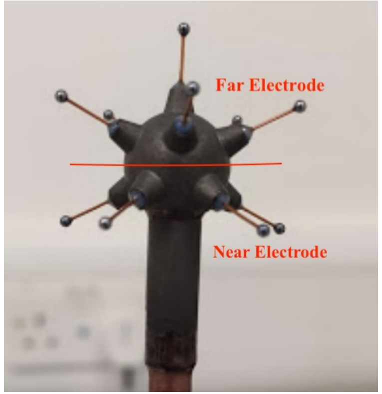
A novel large volume spherical proportional counter, recently developed, is used for neutron measurements. The pure N_2 gas is studied for thermal and fast neutron detection, providing a new way for neutron spectroscopy. The neutrons are detected via the $^{14}N(n,p)C^{14}$ and $^{14}N(n,\alpha)B^{11}$ reactions. The detector is tested for thermal and fast neutrons detection with ^{252}Cf and $^{241}Am-{}^{9}Be$ neutron sources. The atmospheric neutrons are successfully measured from thermal up to several MeV, well separated from the cosmic ray background. A comparison of the spherical proportional counter with the current available neutron counters is also presented.

Bougamont, E et al (2017). NIM A, 847, 10–14

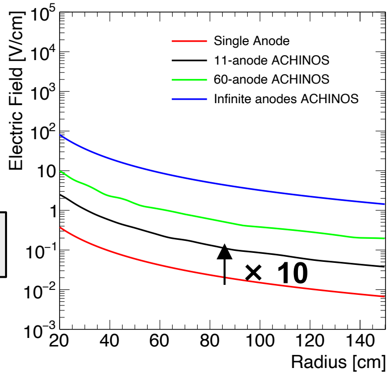
Neutron detection with the Spherical Proportional Counter

Exploit state-of-the-art advancements

Resistive Multi-anode sensor (achinos)



- Decouples drift and amplification fields
  - Small anode size → high gain
  - More anodes → Efficient charge collection
- Allows for increased target mass
  - Larger volume
  - Higher pressure



I. Katsioulas et al, JINST, 13, 11, P11006, 2018
10.1088/1748-0221/13/11/P11006

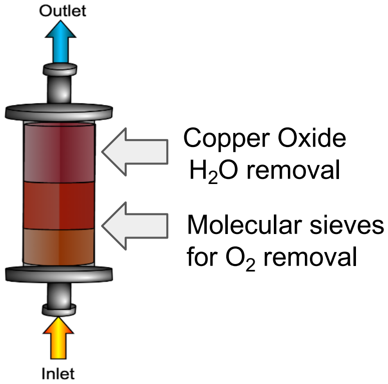
I. Giomataris et al, *JINST* 12 P12031

I. Giomataris et al, arXiv:2003.01068v1

See also G. Savvidis talk

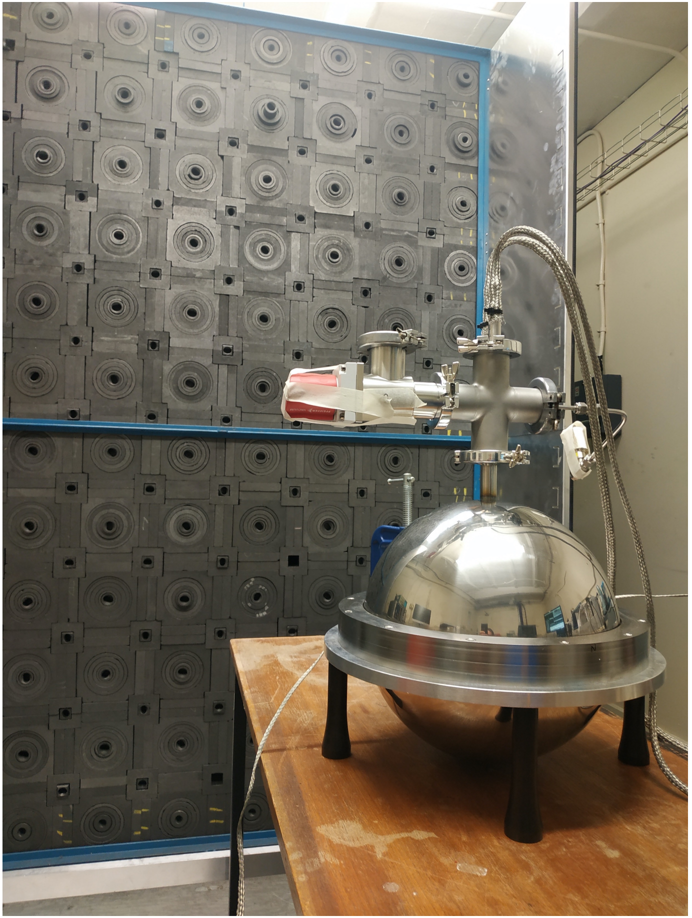
UNIVERSITY OF BIRMINGHAM

Gas purification techniques

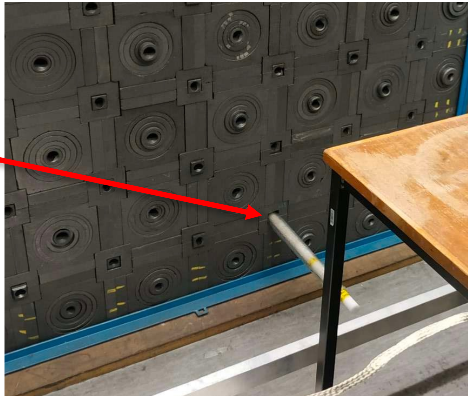


✓ Reduce wall effect
✓ Detect fast neutrons

The Graphite stack @ University of Birmingham



$^{241}Am^{9}Be$ **neutron source**
A = 2.6 x 10^6 Bq



<u>Spherical Proportional Counter</u>

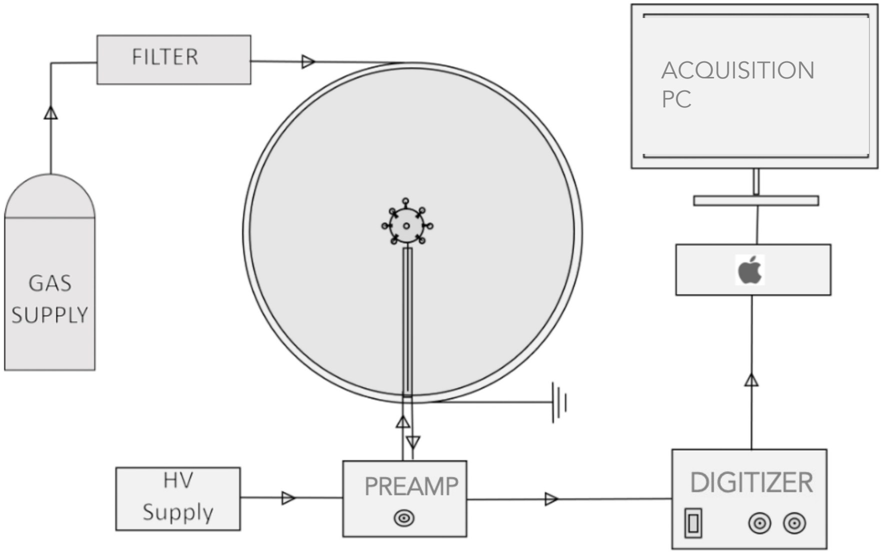
- 30 cm Ø
- N_2 gas filling

<u>Multi-anode sensor</u>

- 11 anodes
- 1mm Ø
- Reading in 2 channels

Investigate the capability of the SPC to detect fast neutrons and neutrons thermalized by the graphite.

Neutron measurements @ University of Birmingham

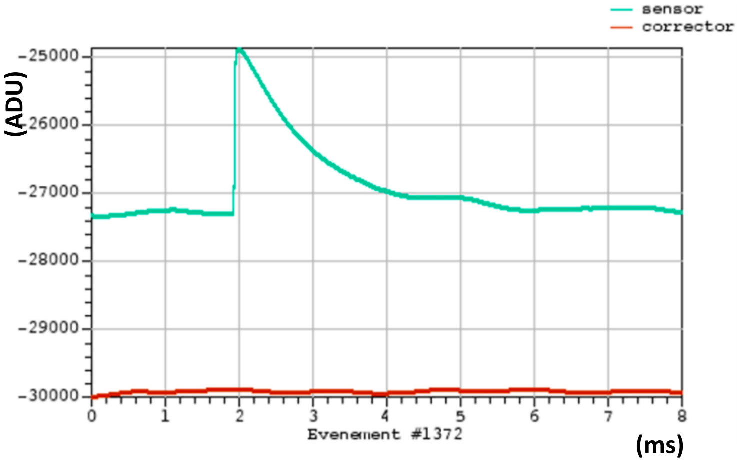


- Calibration measurements
- Thermal and fast neutrons at 1 bar and [3.6, 4.2] kV bias
- Thermal and fast neutrons at 1.5 bar and 4.5 kV bias
- Thermal neutrons at 2 bar and 5 kV bias

- Getter Filter purifies Nitrogen
- HV power supply
- Coaxial feedthrough
- 2 ortec preamp
- “CALI” box digitizer
- Acquisition PC

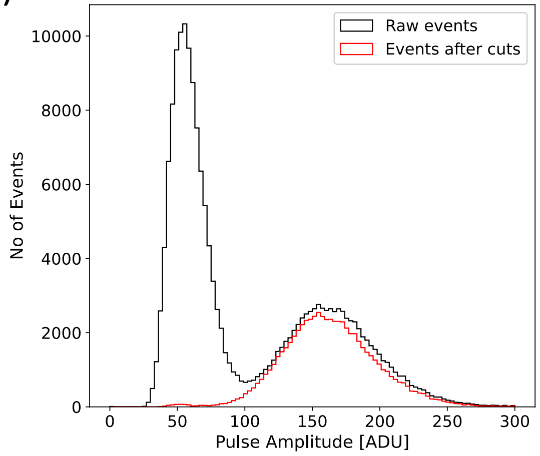
Neutron measurements with the Spherical Proportional Counter

Typical pulse



Pulse shape quality criteria:

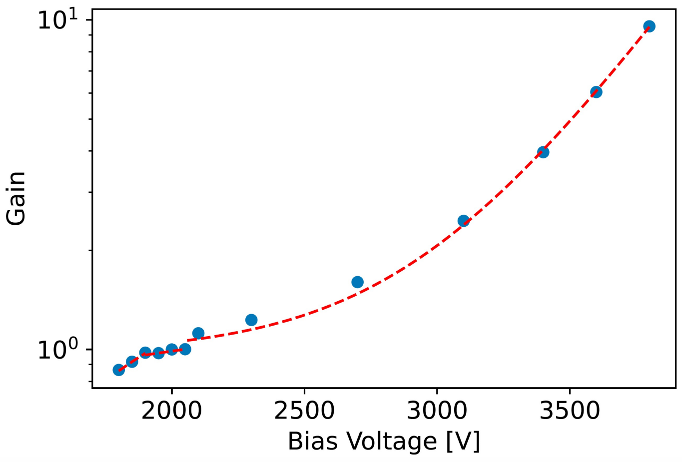
- Rise time (10-90%)
- Fall time (exponential fit)
- Pulse width (FWHM)
- FWHM/Amplitude



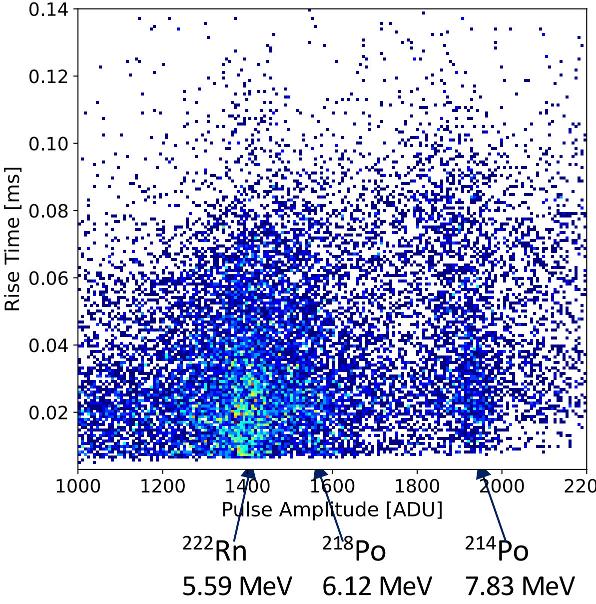
Neutron measurements with the Spherical Proportional Counter

Calibration of the detector

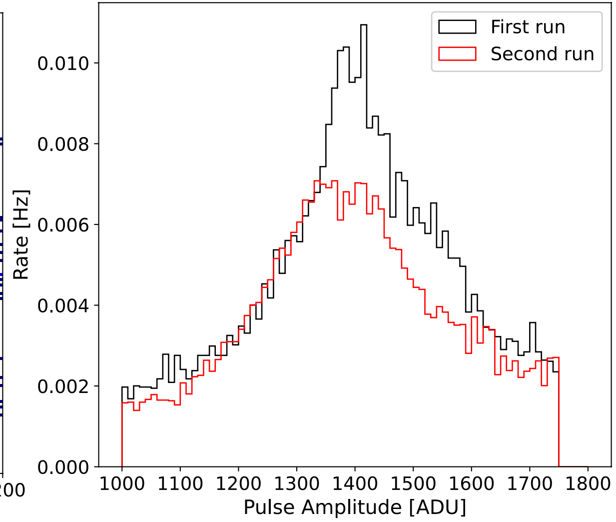
- Gain curve
  ^{210}Po source (alpha 5.41 MeV)
  1 bar N_2 filling



- Getter filter emits ^{222}Rn, Radon decay chain used for calibration



- Confirm Radon decay rate with 3% accuracy (half-life ~3.8 days)

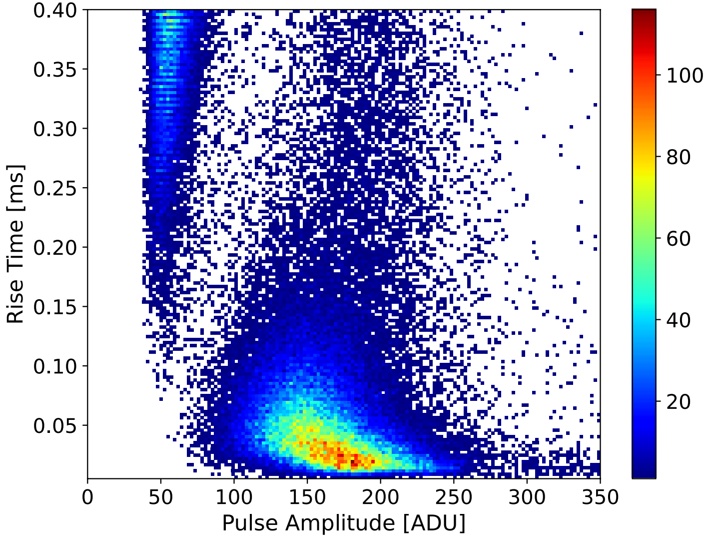


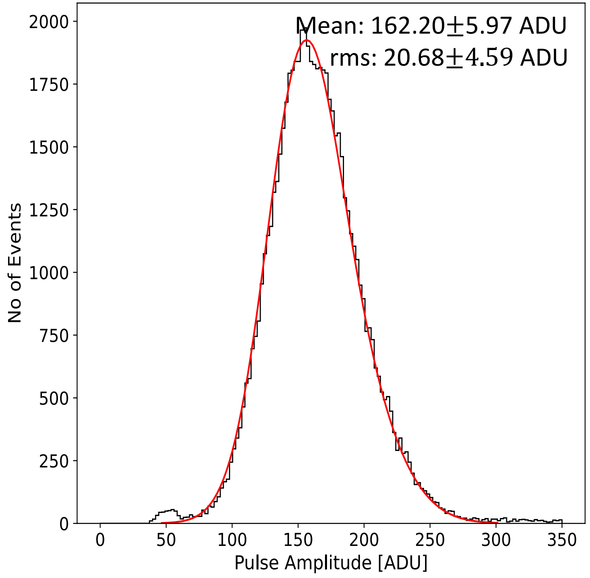
Neutron measurements with the Spherical Proportional Counter

$^{241}Am^{9}Be$ neutron source

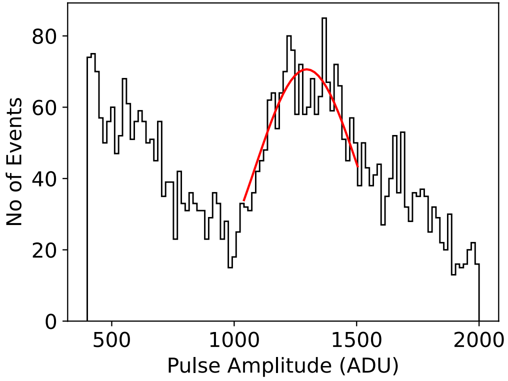
1 bar N_2, 3.6 kV

Response of near channel to thermal neutrons





Rn peak at 1295 ADU (5.59 MeV) confirms thermal peak (625 keV)

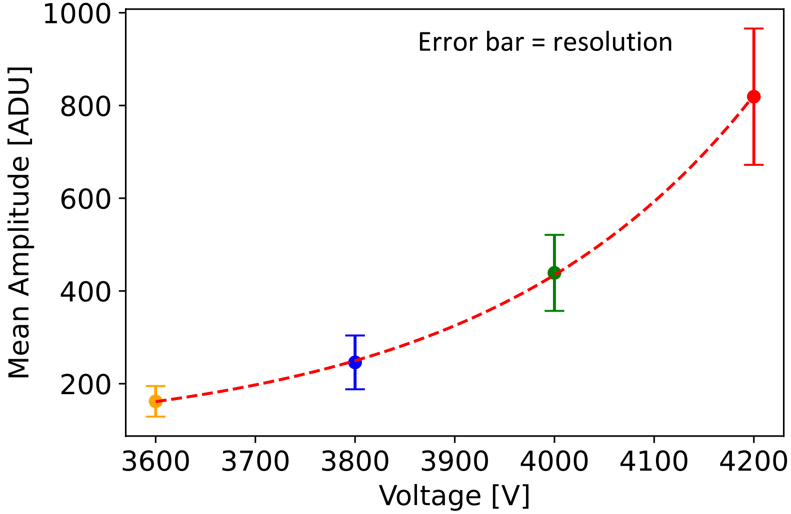


Thermal peak correspond to 625keV recoil energy ($^{14}N + n \rightarrow {}^{14}C + p + 625$ keV)

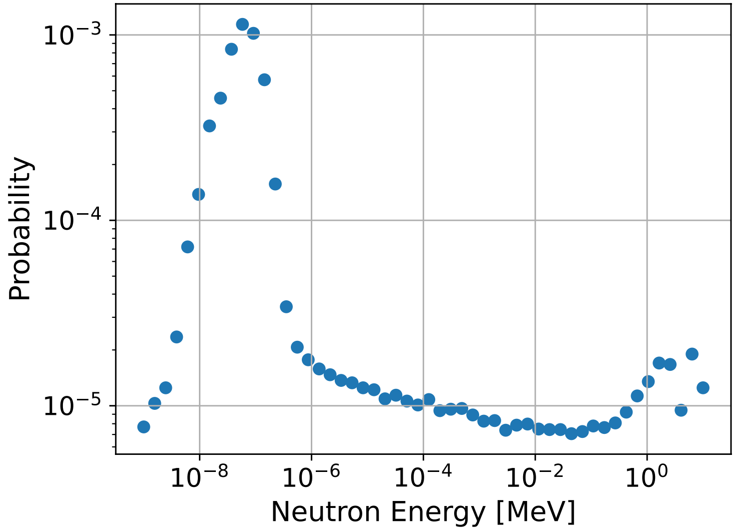
Neutron measurements with the Spherical Proportional Counter

$^{241}Am^{9}Be$ neutron source

- Thermal neutrons peak follows exponential form for various biases



- **Simulation study:** Probability of each neutron to reach detector volume after thermalized in graphite stack (~5x10^{-3})



Source activity: 2.6x10^{6} Bq
Detection rate:~5Hz
→ Efficiency: ~3.7x10^{-4}

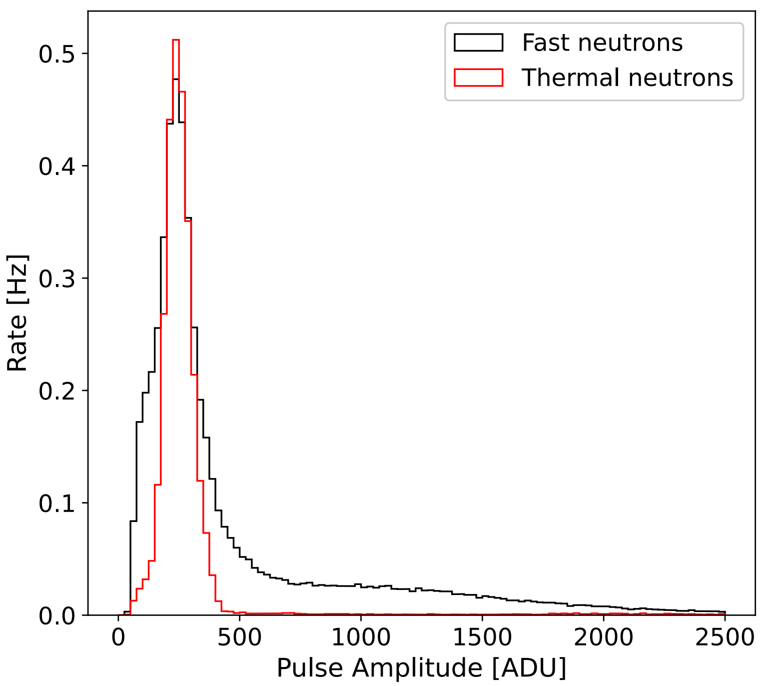
Simulation preliminary results → Efficiency: ~2.2x10^{-4}

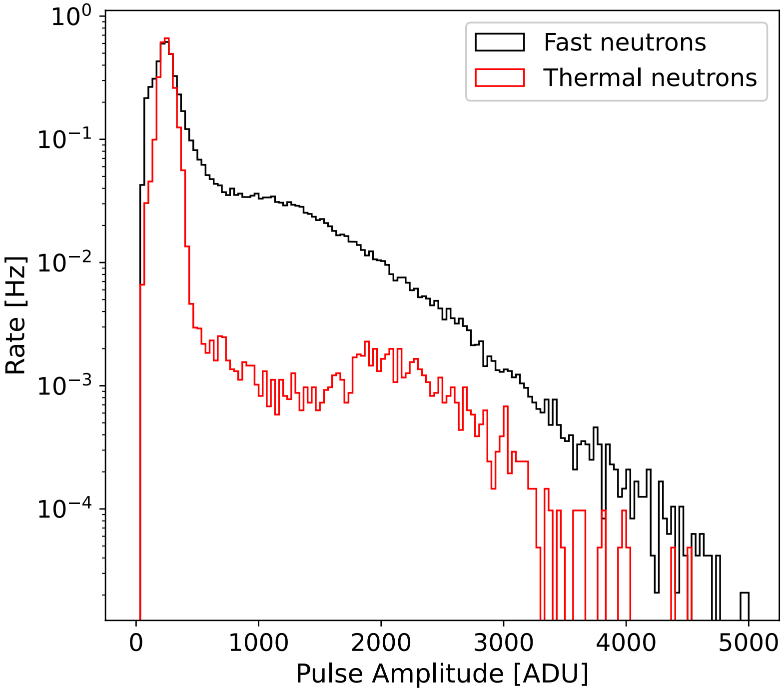
Neutron measurements with the Spherical Proportional Counter

$^{241}Am^{9}Be$ neutron source

1 bar N_2, 3.8 kV

Detection of fast neutrons

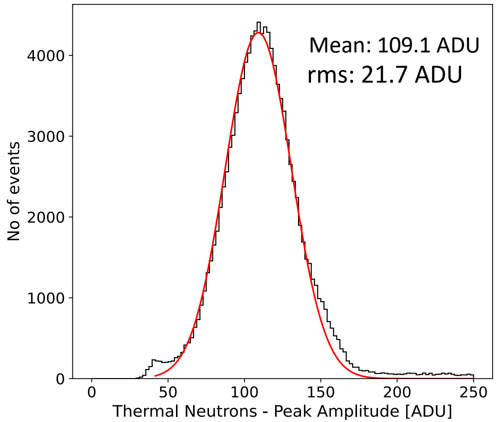


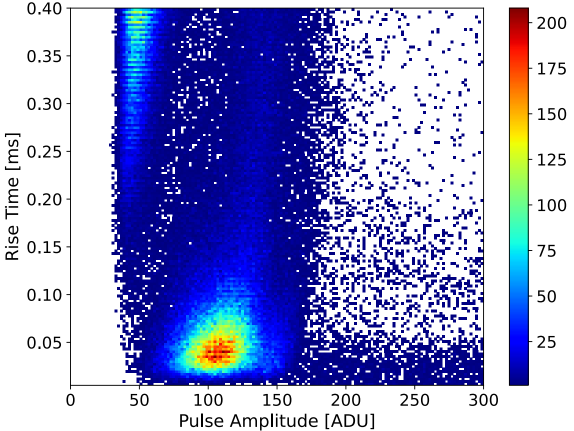


Neutron measurements with the Spherical Proportional Counter

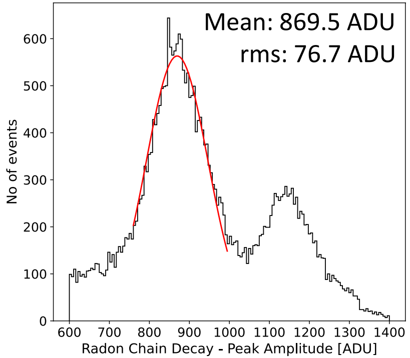
$^{241}Am^{9}Be$ neutron source

1.5 bar N_2, 4.5 kV

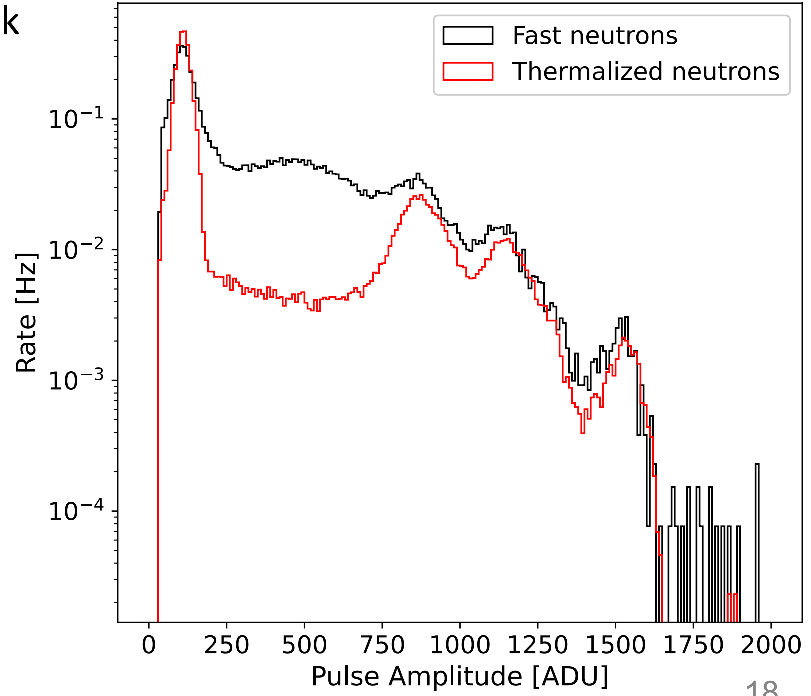




Confirmation of thermal neutrons peak from Rn peak



- Detection of thermal and fast neutrons

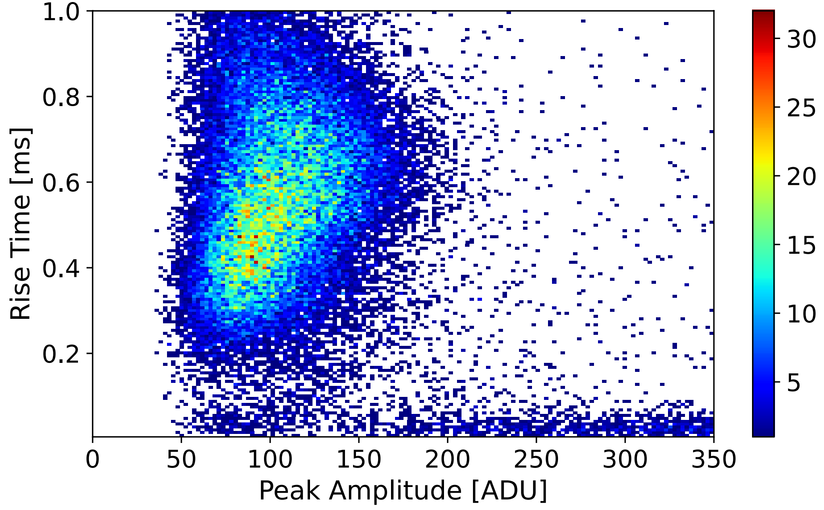


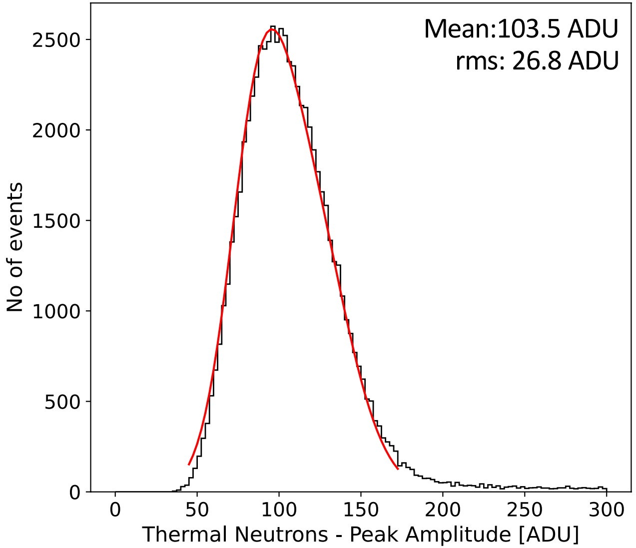
Neutron measurements with the Spherical Proportional Counter

$^{241}Am^{9}Be$ neutron source

2 bar N_2, 5 kV

Thermal neutrons detection





Activities at the Boulby Underground Laboratory

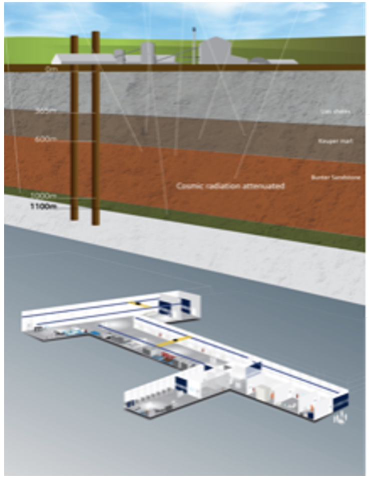
Science and Technology Facilities Council

Boulby Underground Laboratory

- Underground facility 1100 m under surface, North Yorkshire (UK)
- Instrumentation R&D and neutron measurements at controlled environment.
- 30cm Ø Spherical Proportional Counter installed and operating

See also J. Matthews talk

Birmingham Gaseous Detectors Laboratory



UNIVERSITY OF BIRMINGHAM

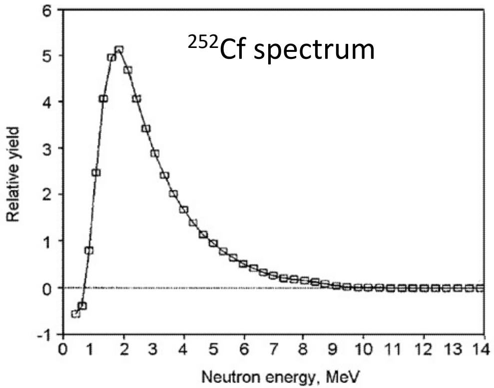
Activities at the Boulby Underground Laboratory

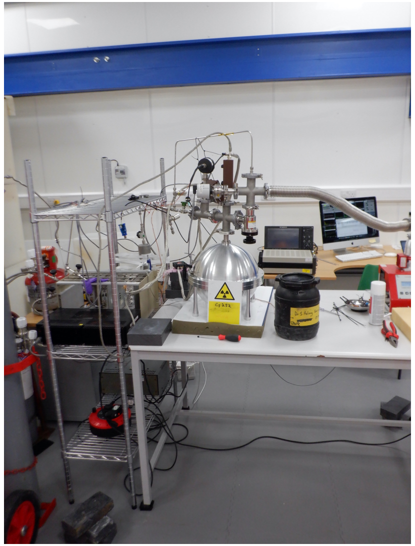
Instrumentation R&D and neutron measurements at controlled environment.

Science and Technology Facilities Council

Boulby Underground Laboratory

- ^{252}Cf neutron source available
- Data acquisition ongoing



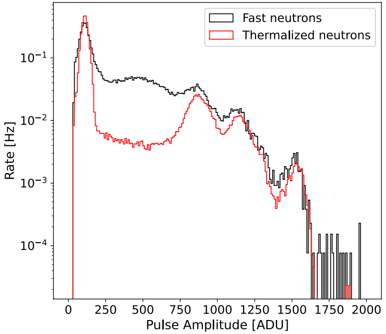


Birmingham Gaseous Detectors Laboratory

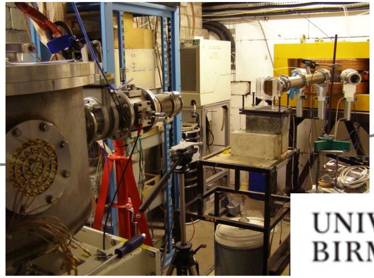
UNIVERSITY OF BIRMINGHAM

Neutron detection with the Spherical Proportional Counter

Summary



- Neutron measurements set up accomplished
- Graphite stack facility on Birmingham
- Performed 1st phase of characterization
- Corresponding measurements in Boulby ongoing
- Mono-energetic neutron measurement (possibly @ Demokritos, Greece)
- Medical application - Measurement of energy spectra of the neutron-induced dose to patients during proton therapy treatment sessions @ MC40 cyclotron facility (UoB)



MARIE CURIE ACTIONS

UNIVERSITY OF BIRMINGHAM | CYCLOTRON FACILITY

Thank you for your attention!