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Birmingham Gaseous Detectors Laboratory

Neutron spectroscopy with Spherical Proportional Counters in Boulby

I. Manthos[1], I. Giomataris[2], I. Katsioulas[1], P. Knights[1], T. Neep[1], K. Nikolopoulos[1], T. Papaevengelou[2], B. Phoenix[1] and R. Ward[1]

[1] University of Birmingham, School of Physics and Astronomy, Birmingham, United Kingdom

[2] CEA-Saclay, IRFU, Gif-sur-Yvette, France

Dark Matter UK meeting

5/5/2022, Birmingham

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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)

Neutron spectroscopy with the Spherical Proportional Counter

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Dark matter underground experiments

- MeV neutrons produce signals in the region of interest for WIMP detection
  - ➢ Sources: Radioactivity of cavern, muon induced hadronic and electromagnetic showers (cosmic rays)
  - ➢ Elastic scattering with target nuclei of gas, interaction with detector material
- Neutron background can not be discriminated using event properties
- Neutron rejection: shielding and use of high-purity materials.
- Data analysis require an estimation of the neutron background expected in order to compare with the observed number of events.

Current neutron detector status

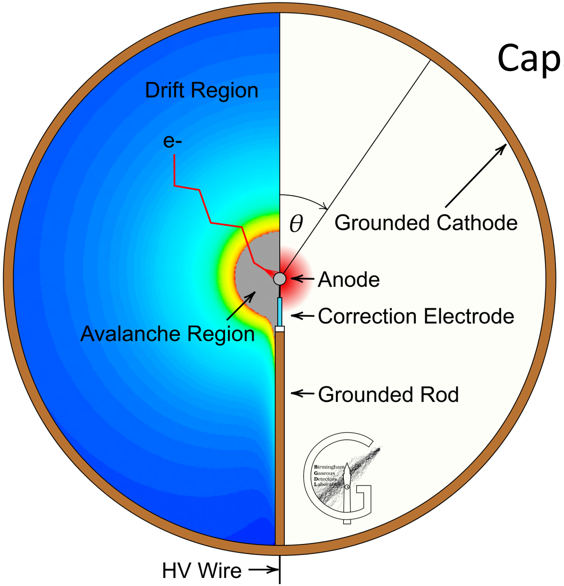
^{3}He proportional counters

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

✔ Efficient for thermal and fast neutrons, low efficiency in γ-rays

✘ Wall effect → high pressure (impractical)
^{3}He extremely expensive

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

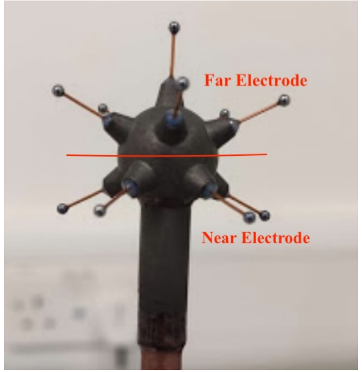
- Low electronic noise

r_c = cathode radius

r_a = anode radius

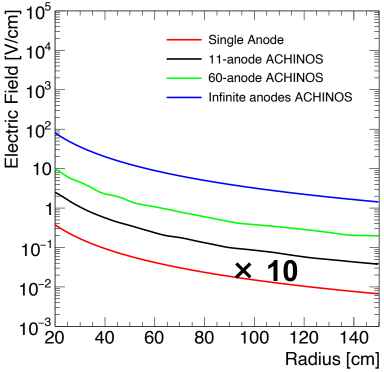
$$C = 4\pi\varepsilon_0 \frac{r_c r_a}{r_c - r_a} \approx 4\pi\varepsilon_0 r_a \sim 1\mathrm{pF}$$

- 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!



Multi anode ACHINOS sensor

- Decouples drift and amplification fields
- Allows for increased target mass



I.Giomataris et al, JINST, 2008, P09007

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

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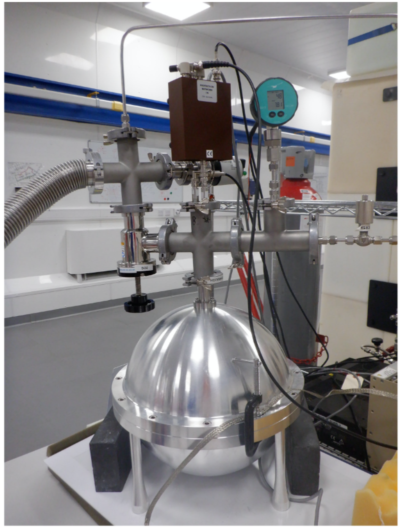
Neutron detection with the Spherical Proportional Counter



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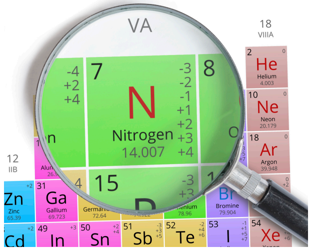
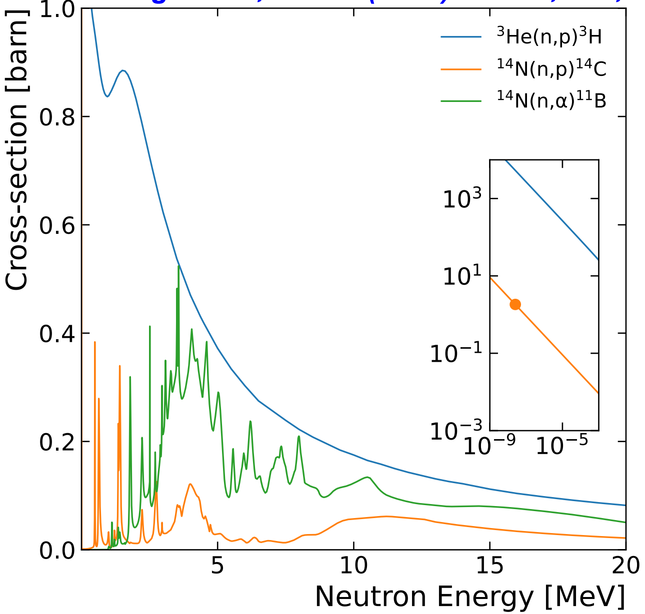


- ✓ Non-toxic
- ✓ Non-flammable
- ✓ Simple and robust setup
- ✓ Easy deployment and operation
- ✓ Cost efficient

- ✓ Wall effect suppressed due to higher atomic number of N_2 relative to ^3He → lower pressure
- ✓ Good efficiency in detecting thermal neutrons in large volumes
- ✓ Low γ-ray efficiency
- ✓ Spectroscopic measurement of neutrons

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



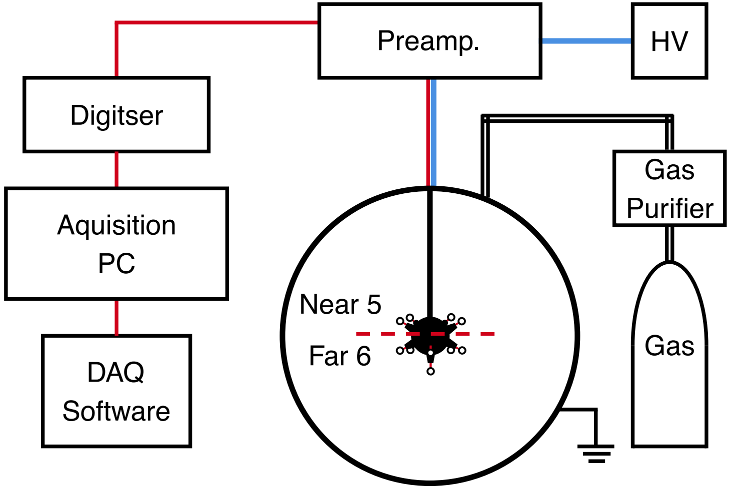
Nitrogen as target

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

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

The Graphite stack @ University of Birmingham

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



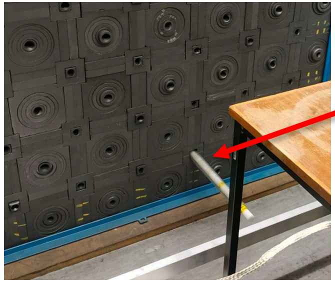
Spherical Proportional Counter

- 30 cm Ø
- N_2 gas filling

Multi-anode sensor

- 11 anodes
- 1mm Ø
- Reading in 2 channels (near – far)

- 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 1.8 bar and 6 kV bias



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

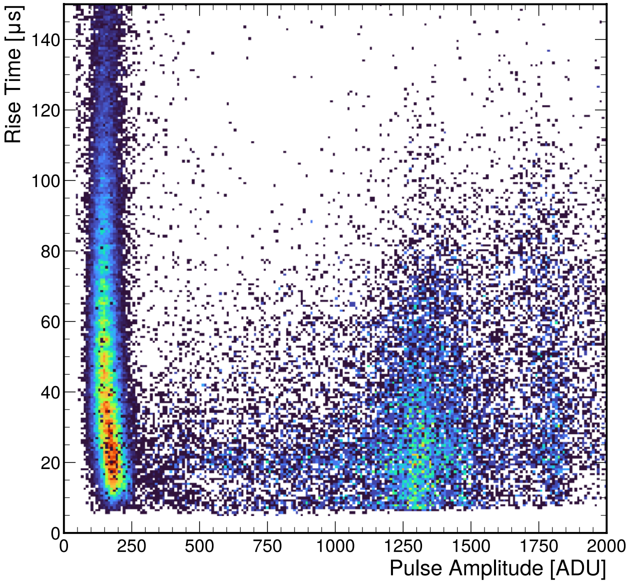
A = 2.6 x 10^6 Bq

Neutron measurements with the Spherical Proportional Counter

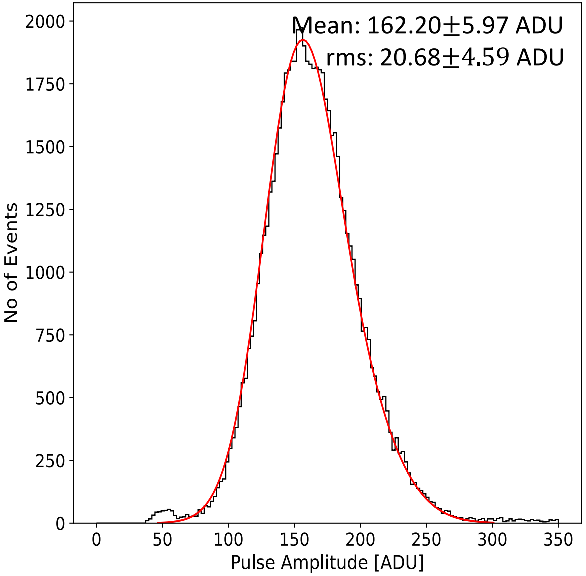
$^{241}Am^{9}Be$ neutron source

1 bar N_2, 3.6 kV

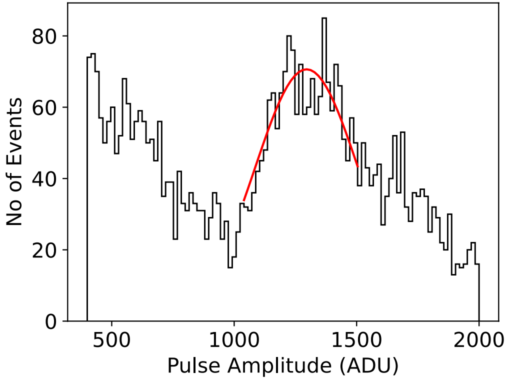
Response of near channel to thermal neutrons



222Rn 218Po 214Po



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

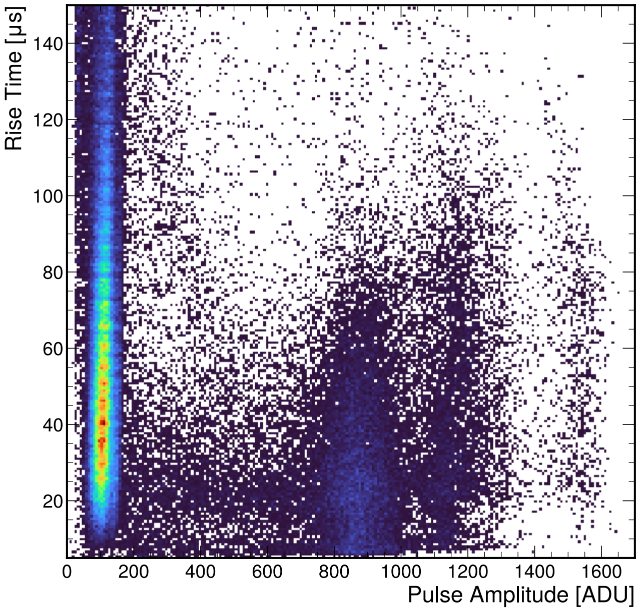


Thermal peak correspond to 625 keV recoil energy ($^{14}N + n \rightarrow {}^{14}C + p + 625$ keV)

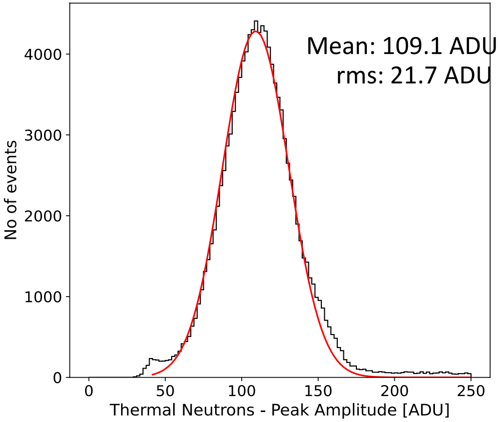
Neutron measurements with the Spherical Proportional Counter

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

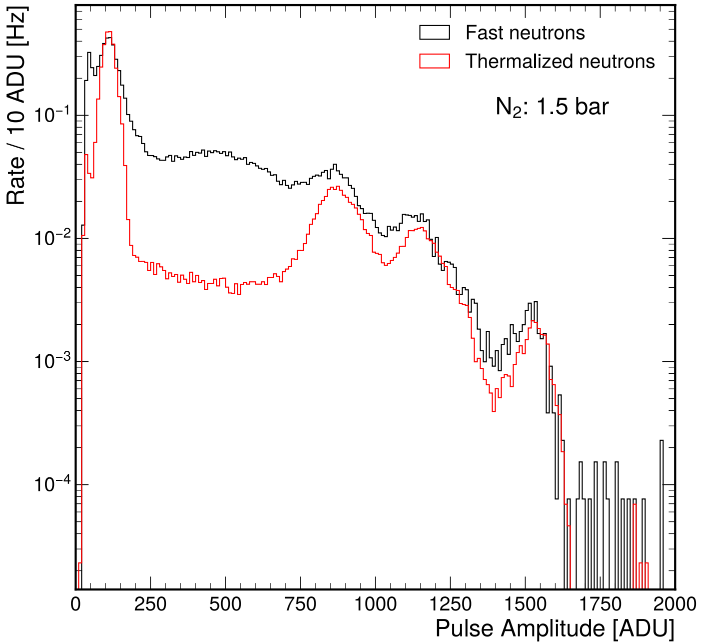
1.5 bar N_2, 4.5 kV



Confirmation of thermal neutrons peak from ^{222}Rn decay peaks



- Detection of thermal and fast neutrons

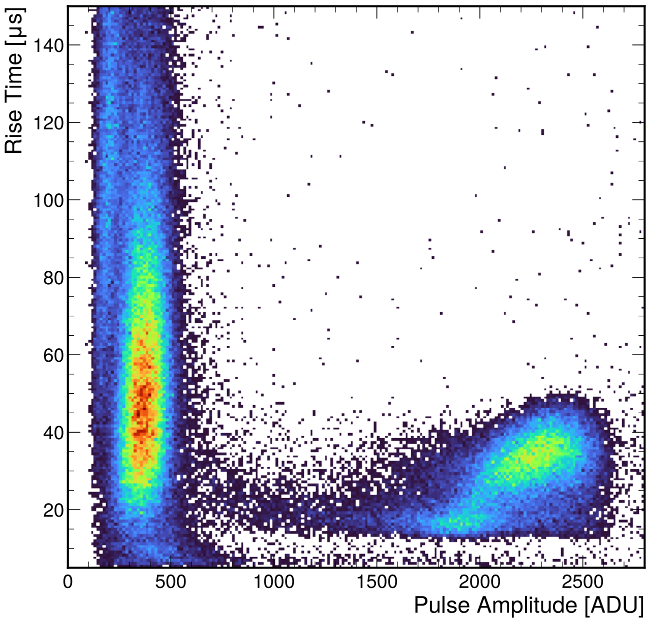


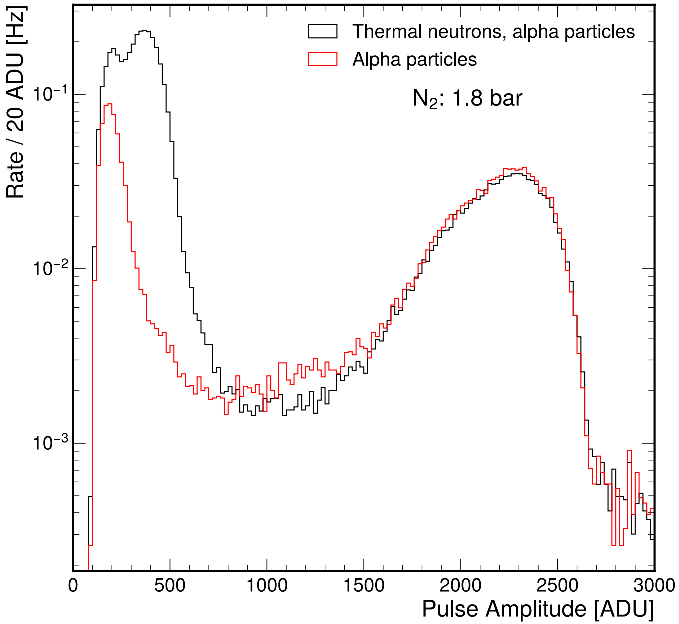
Neutron measurements with the Spherical Proportional Counter

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

1.8 bar N_2, 6 kV

Thermal neutrons detection





^{210}Po alpha (5.4MeV) sample, inside the detector→ energy reference

Simulation of the detector response

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

GEANT4 Ansys

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

✓ Differentiate protons from alphas

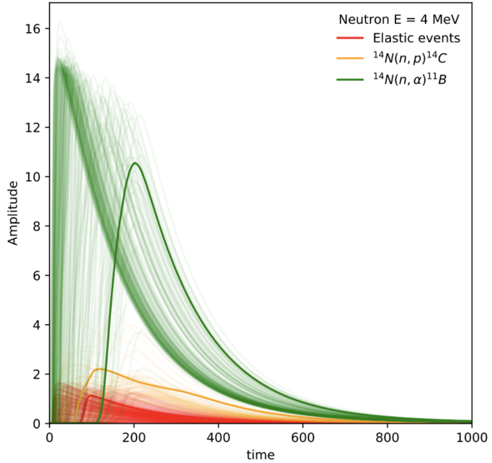
✓ Provide initial interaction point

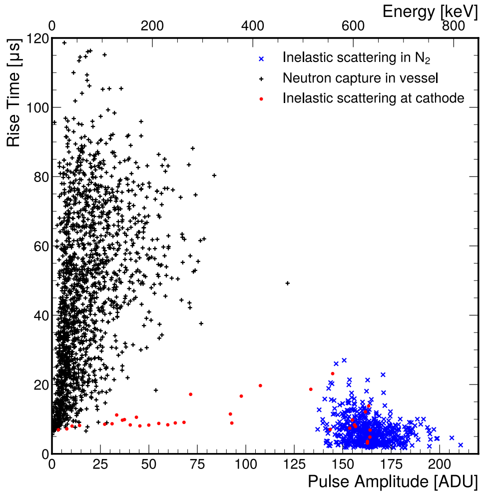
✓ Identify possible wall effect

- Source activity: 2.6 MBq
- Probability to reach detector volume ~5x10^{-3}
- Detection rate:~5Hz

→ Efficiency: ~3.7x10^{-4}

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





Neutron measurements at MC40 cyclotron

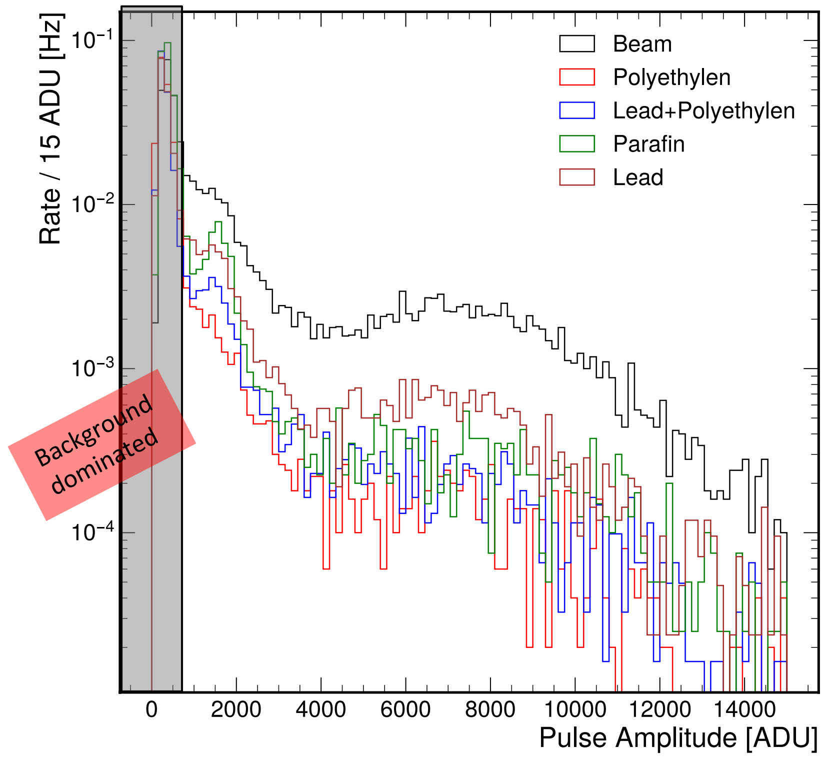
Spectroscopic measurement of fast neutrons

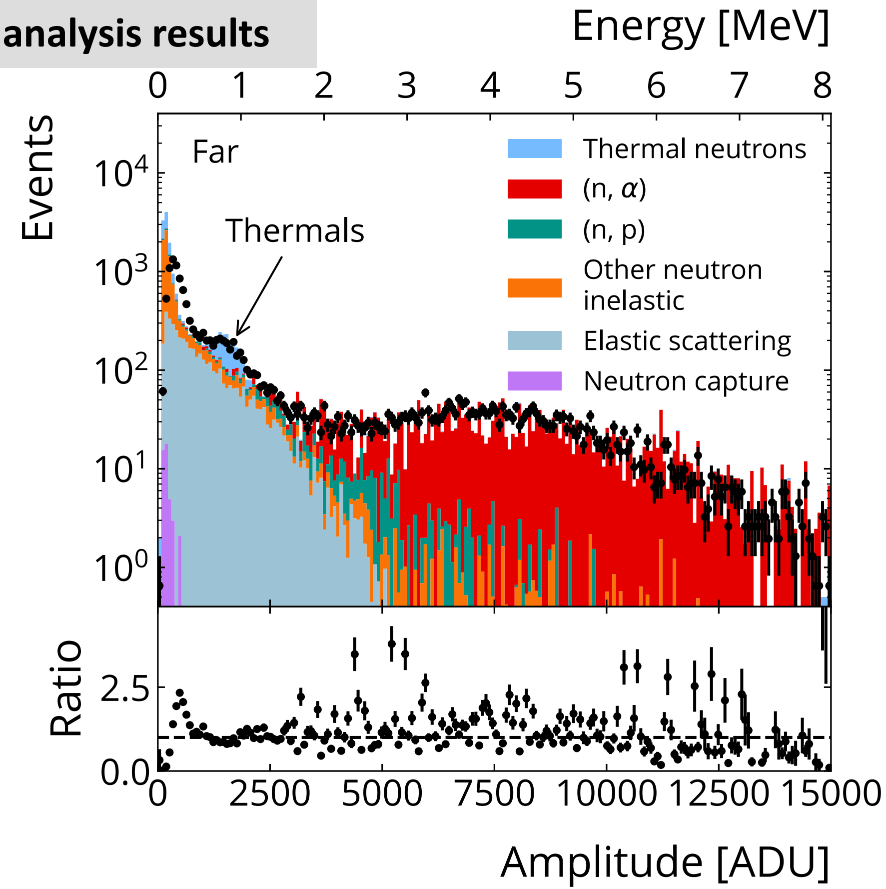
^{9}Be target on deuterium beamline

- 5.90±0.08 MeV deuterons
- ^{9}Be(d,n) reaction
- Same detector setup
- Moderators used to study neutron detection (paraffin, boron dopped polyethylene, lead)

Neutron measurements at MC40 cyclotron

Preliminary analysis results





Neutron measurements at the Boulby Underground Laboratory

- Spectroscopic neutron measurements.
- 30cm Ø Spherical Proportional Counter installed and operating
- ^{252}Cf neutron source available
- Measurements and analysis ongoing

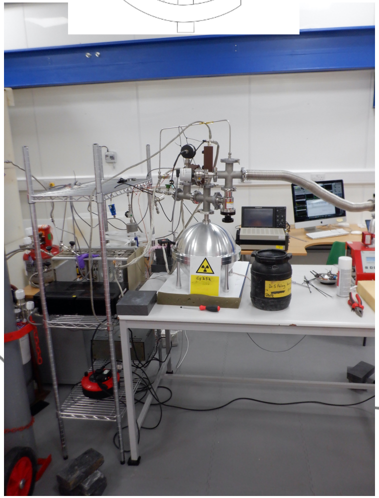
Expected thermalized neutron background flux with a…

	60 cm SPC	140 cm SPC
neutrons/day	2.2	11.4
neutrons/month	67.1	351.9
neutrons/year	791.9	4142.8

Science and Technology Facilities Council

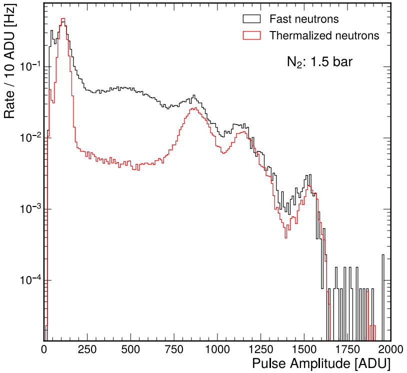
Boulby Underground Laboratory

Birmingham Gaseous Detectors Laboratory

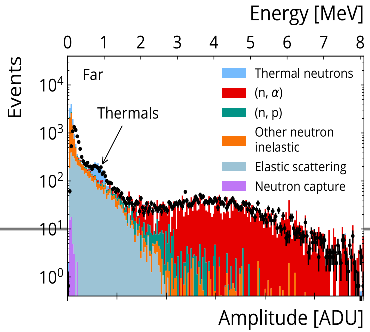


Neutron detection with the Spherical Proportional Counter

Summary



- Neutron measurements set up accomplished
- Neutron detection performed in the Graphite stack and at the MC40 cyclotron facilities in Birmingham
- Corresponding measurements in Boulby
- Mono-energetic neutron measurement (@ Demokritos, Greece)



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