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Birmingham Gaseous Detectors Laboratory

Neutron spectroscopy: The case of the Spherical Proportional Counter

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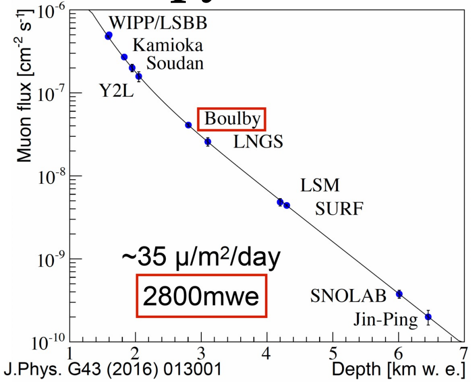
15th Pisa Meeting on Advanced Detectors

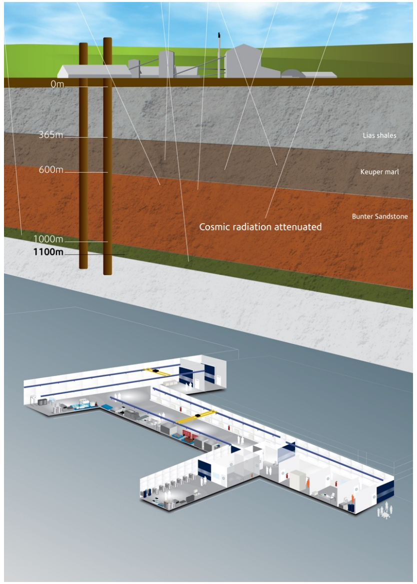
27/5/2022, Elba Island, Italy

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 Agreements No 845168 (neutronSphere), No 841261 (DarkSphere) and No 101026519 (GaGARin).

Neutron spectroscopy with the Spherical Proportional Counter





Dark matter underground experiments

- MeV neutrons mimic WIMP signals in the region of interest for Dark Matter 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 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

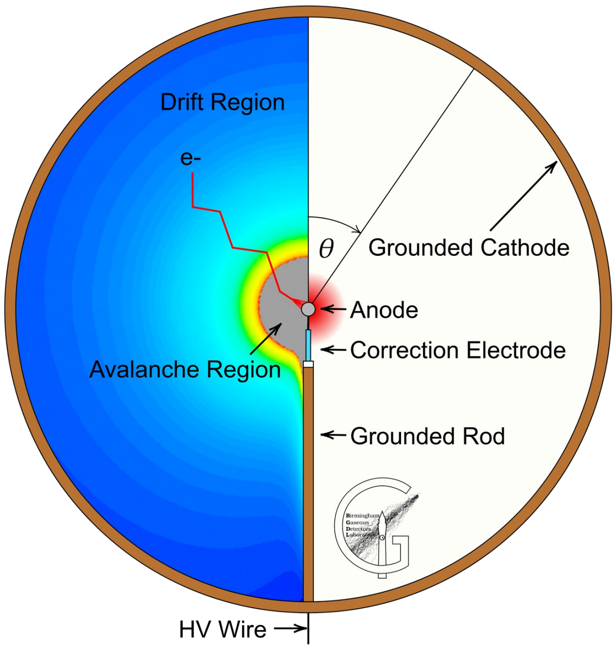
^{3}He proportional counters

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

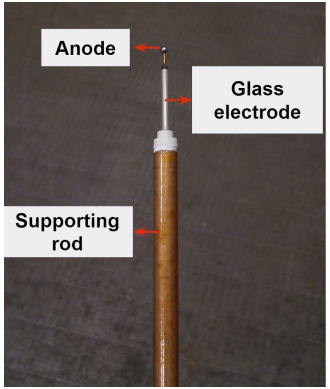
$$\vec{E} = \frac{V_1}{r^2}\frac{r_c r_a}{r_c - r_a}\hat{r} \approx \frac{V_1}{r^2} r_a$$

Capacitance independent of detector size

- Low electronic noise

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

- 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!



r_c = cathode radius
r_a = anode radius

10.1016/j.astropartphys.2017.10.009

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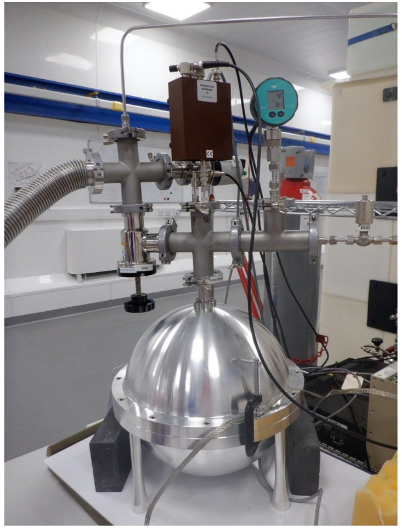
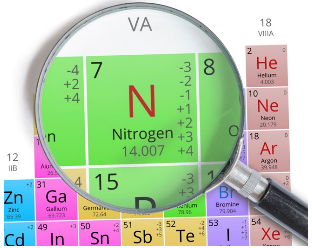
I.Giomataris et al, JINST, 2008, P09007
I.Katsioulas et al, JINST, 13, 2018, no.11, P11006

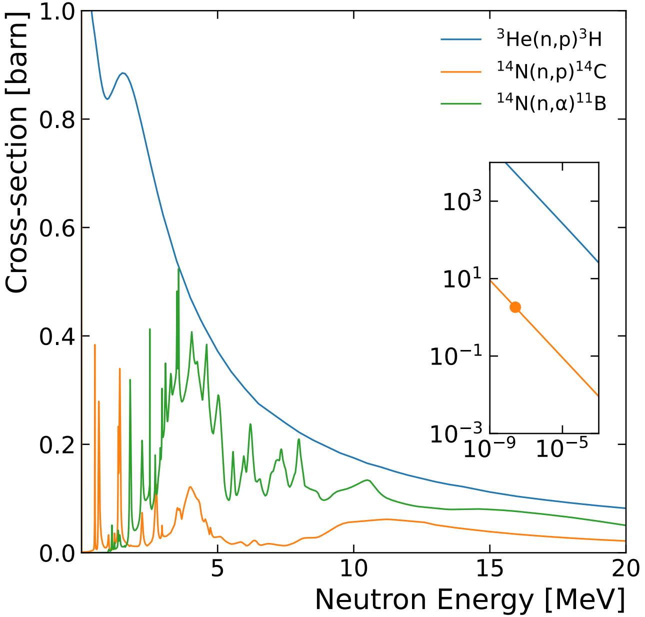
Neutron detection with the Spherical Proportional Counter





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

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

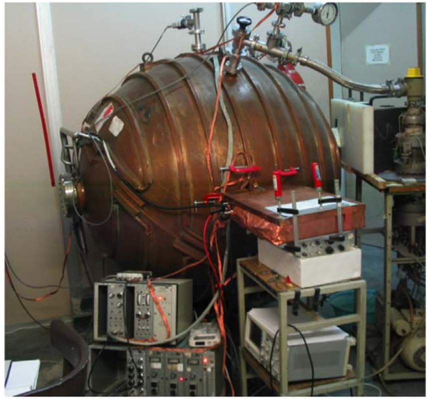


Nitrogen as target

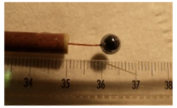
$^{14}N + n \rightarrow {}^{14}C + p$ + 625 keV, σ_{th}= 1.83 b

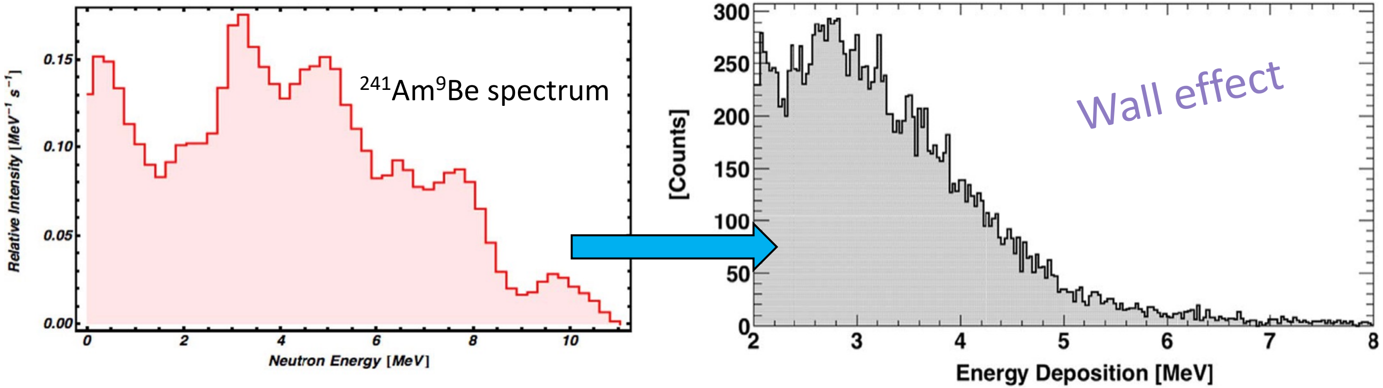
$^{14}N + n \rightarrow {}^{11}B + \alpha$ - 159 keV, thres=1.7 MeV

Neutron detection with the Spherical Proportional Counter
Proof of principle



SPC 140 cm Ø
Anode 8 mm Ø





Limiting Factors:

- Wall effect (i.e. recoiling particle escape the active volume)
- Sparking/Stability
- Low pressure operation (up to 0.5 bar)
- Impurities
- Charge collection efficiency

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

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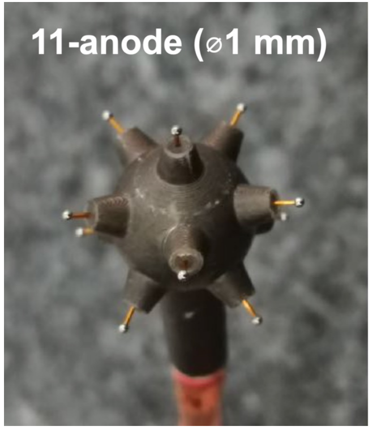
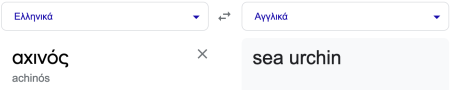
Neutron detection with the Spherical Proportional Counter

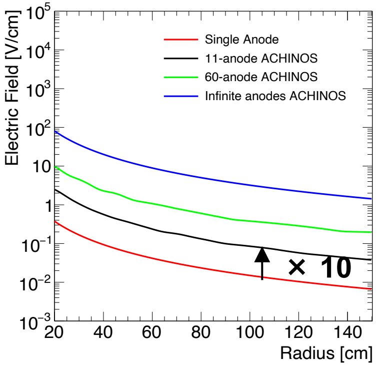
Instrumentation advancements

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
- ➢ Improves detector fiducialisation

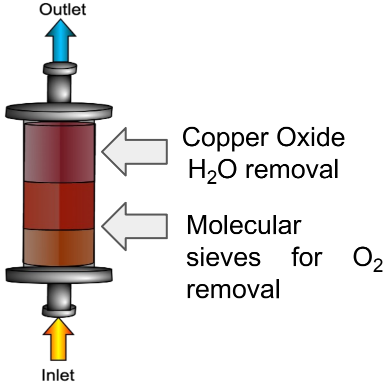




[I. Katsioulas et al, 2018 JINST, 13, 11, P11006](#)
[I. Giomataris et al 2020 JINST 15 P11023](#)

Gas purification techniques

- ➢ Custom-made filter with negligible Rn emanation



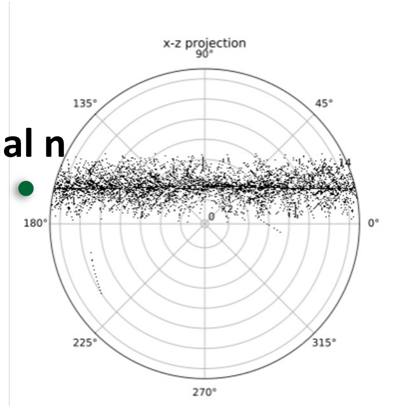
Simulation of the detector response

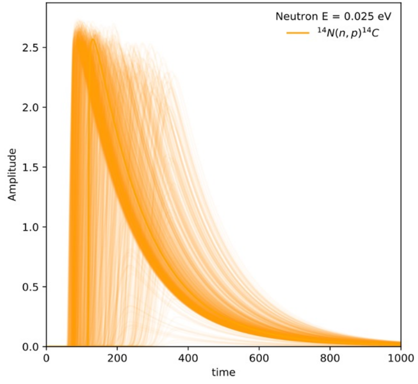
UoB simulation framework for complete simulation of a detection setup

- 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

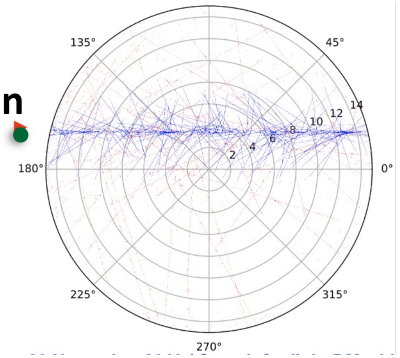
I. Katsioulas *et al* 2020 *JINST* 15 C06013

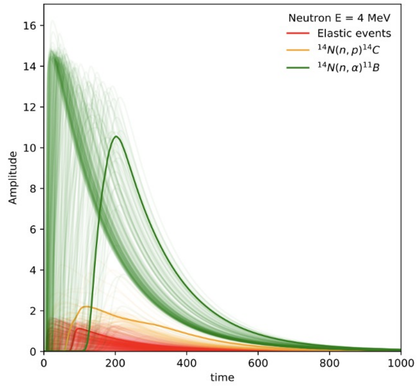
Thermal n





Fast n

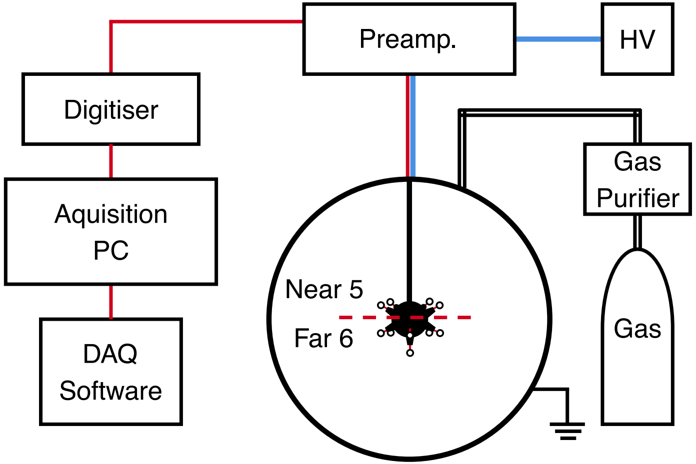




- ✓ Differentiate protons from alphas
- ✓ Identify possible wall effect

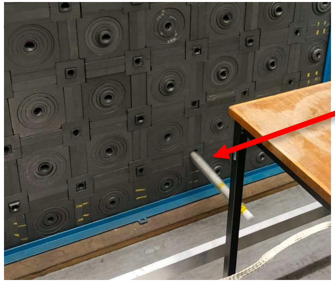
The Graphite stack @ University of Birmingham

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)

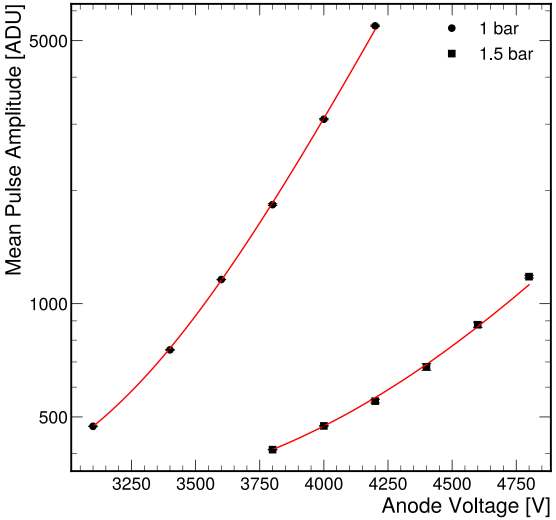


$^{241}Am^{9}Be$ neutron source
A = 2.6×10^6 Bq

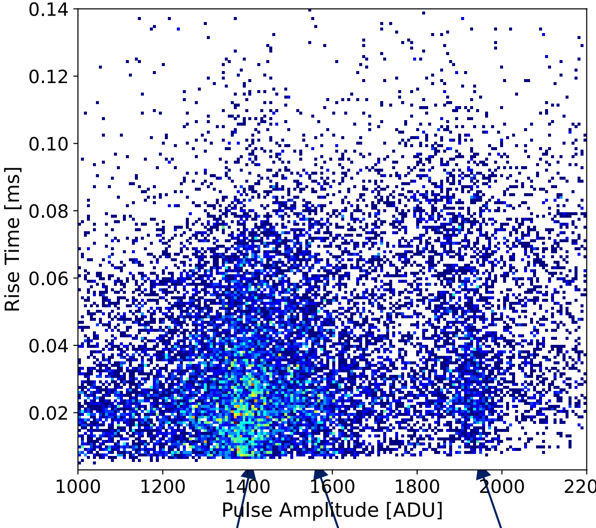
- Calibration measurements
- Thermal and fast neutrons at 1 bar and [3.6, 4.2] kV bias
- Thermal and fast neutrons at 1.5 bar and 4.5 kV bias
- Thermal neutrons at 1.8 bar and 6 kV bias

Neutron measurements with the Spherical Proportional Counter
Calibration of the detector

- Amplitude curve
  ^{210}Po source (alpha 5.41 MeV)
  1 and 1.5 bar N_2



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

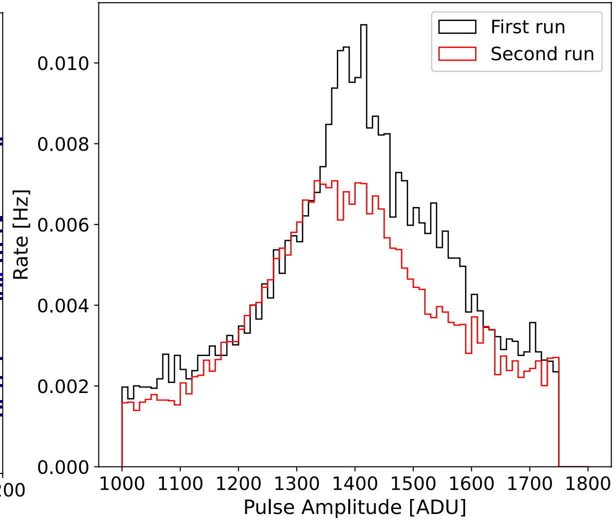


^{222}Rn 5.59 MeV

^{218}Po 6.12 MeV

^{214}Po 7.69 MeV

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



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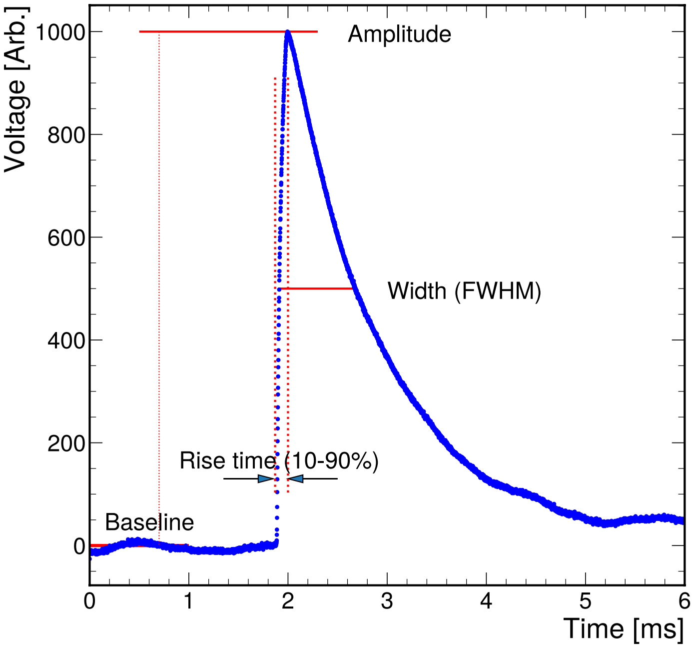
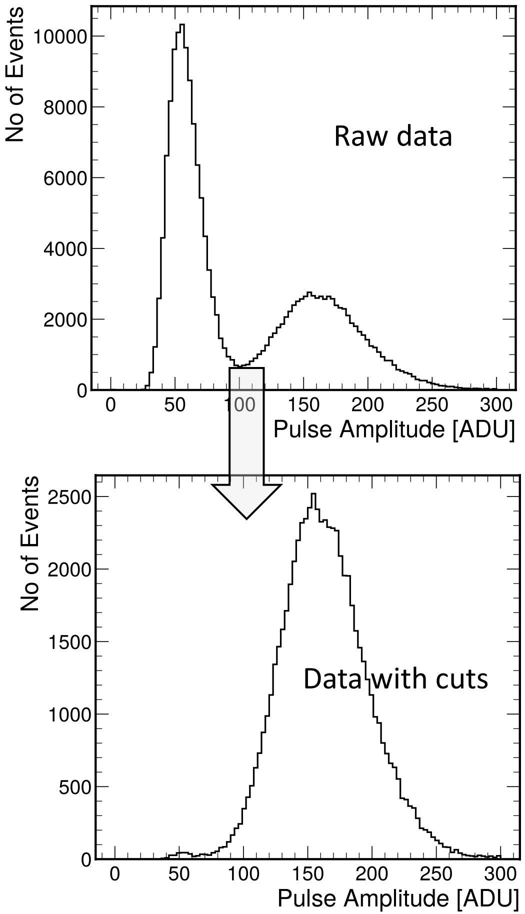
Neutron measurements with the Spherical Proportional Counter



Pulse shape analysis parameters:

- **Rise time** (10-90%)
- **Width** (FWHM)
- Fall time (exponential fit)
- FWHM/Amplitude
- Integral
- Baseline



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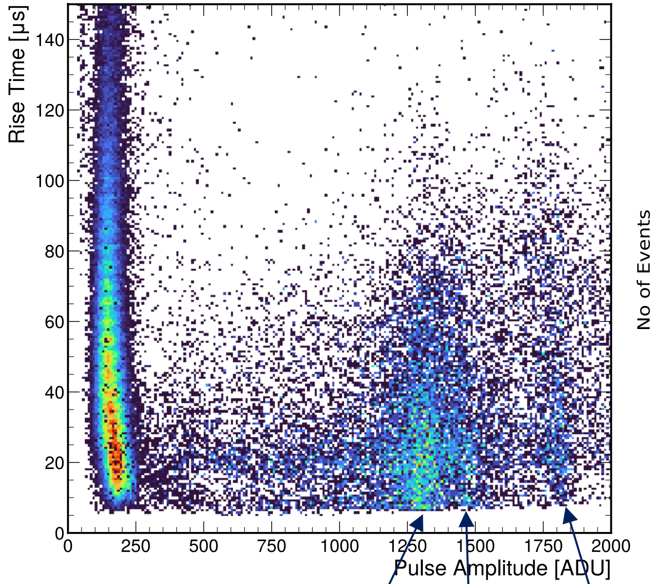
Neutron measurements with the Spherical Proportional Counter

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

1 bar N_2, 3.6 kV

Response to thermal neutrons

- Thermal neutrons peak follows exponential form for various anode voltages at 1 bar N_2

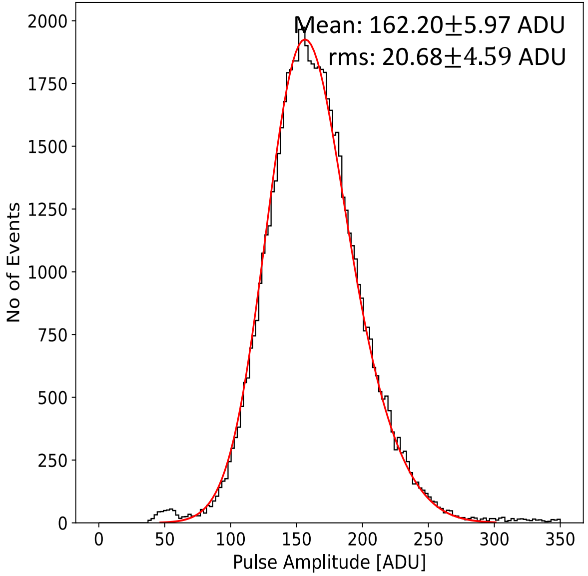


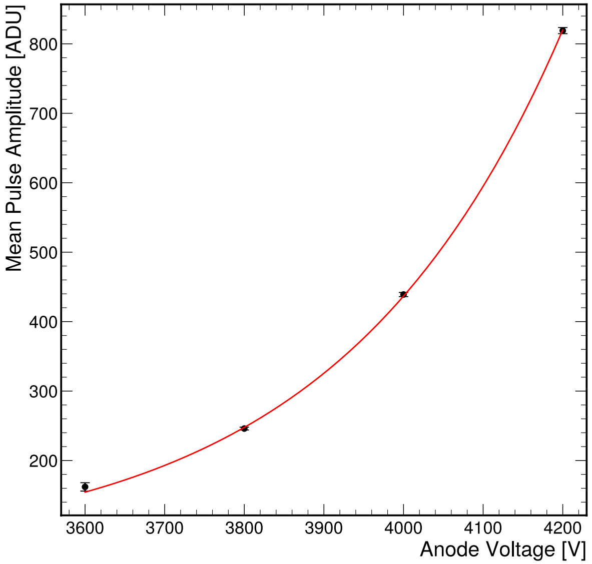
Rn decay chain peaks confirm thermal peak

^{222}Rn 5.59 MeV

^{218}Po 6.12 MeV

^{214}Po 7.69 MeV

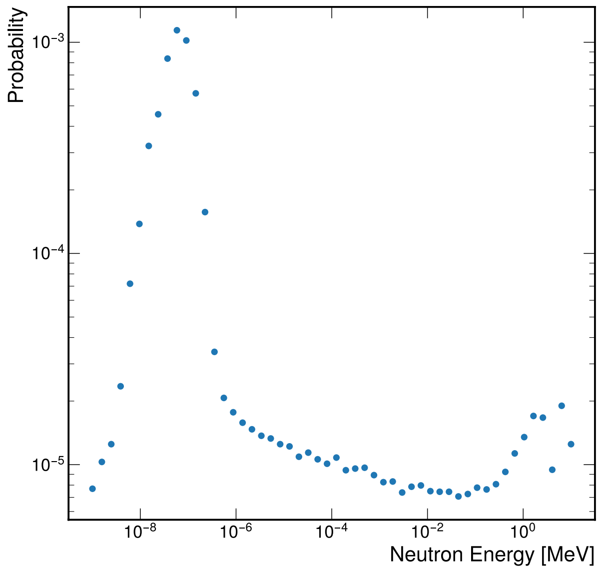




Thermal peak correspond to 625 keV recoil energy ($^{14}N + n \rightarrow {}^{14}C + p + 625$ keV)

Simulation of the detector response

- **Simulation study (**MCNP 6.1)**:** Probability of each neutron to reach detector volume after thermalized in graphite stack (~5x10^{-3})

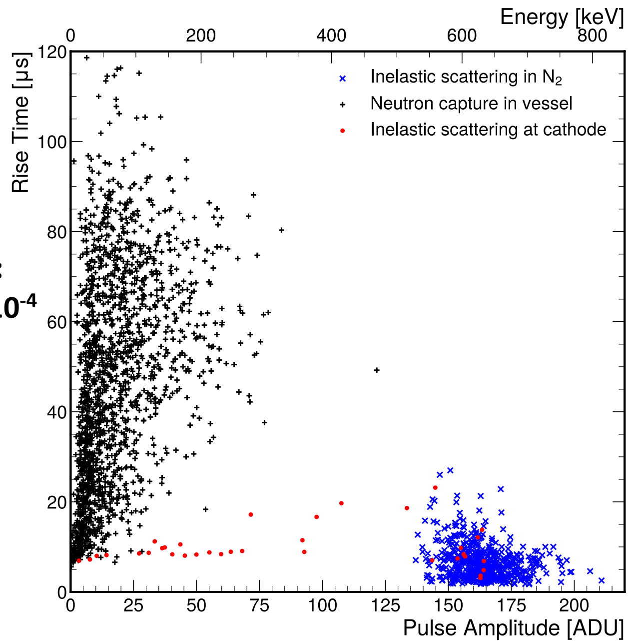


- Source activity: 2.6 MBq
- Probability to reach detector volume ~5x10^{-3}
- Detection rate:~5Hz

Efficiency: ~3.7x10^{-4}

Simulation results → **Efficiency: 2. 2x10^{-4}**

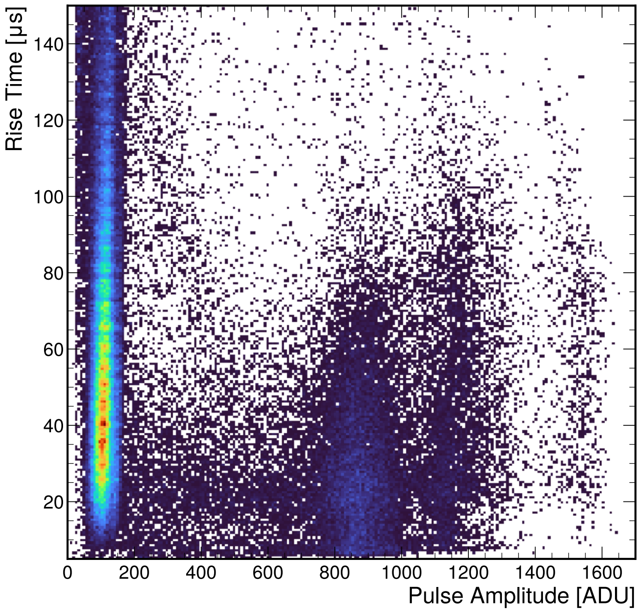
- Detector response to thermal neutrons with 1 bar N_2 and 3.6 kV bias voltage



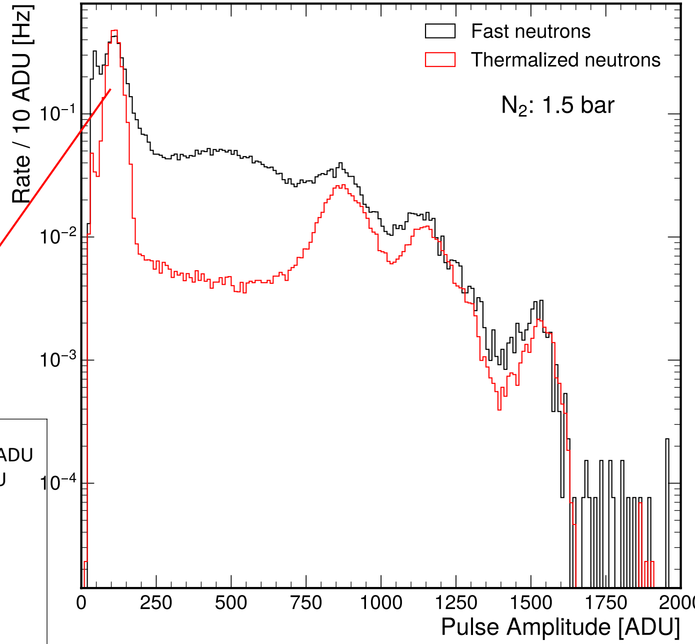
Neutron measurements with the Spherical Proportional Counter

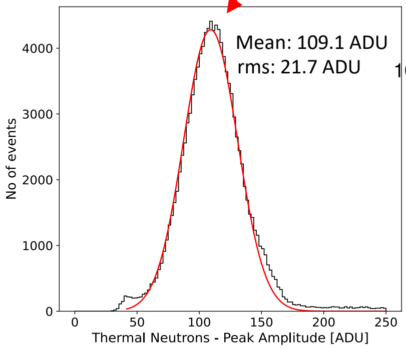
$^{241}Am^{9}Be$ neutron source

1.5 bar N_2, 4.5 kV



- Detection of thermal and fast neutrons





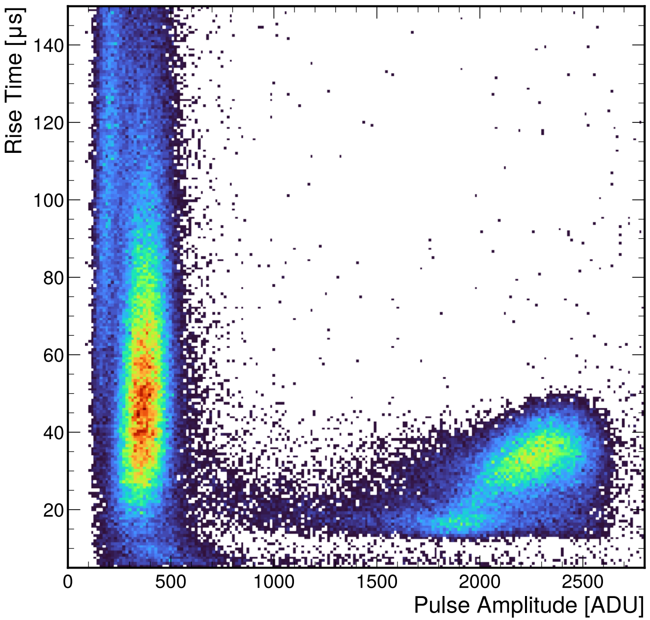
Confirmation of thermal neutrons peak from ^{222}Rn decay peaks

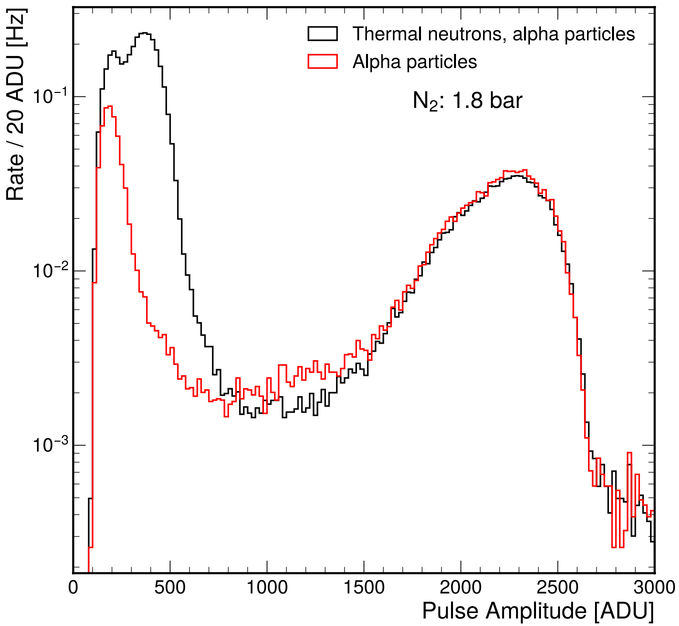
Neutron measurements with the Spherical Proportional Counter

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

1.8 bar N_2, 6 kV

Thermal neutrons detection





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

Neutron measurements at MC40 cyclotron

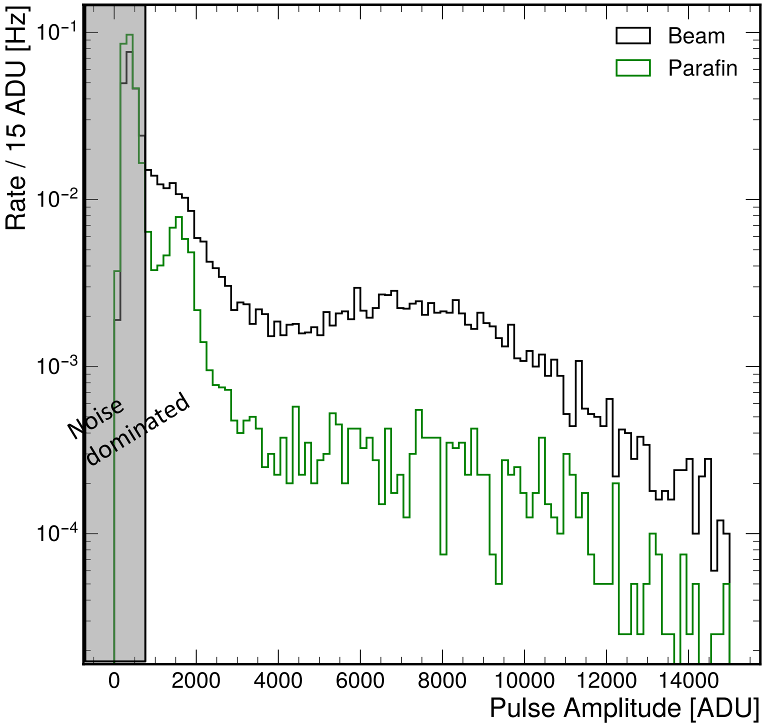
Spectroscopic measurement of fast neutrons

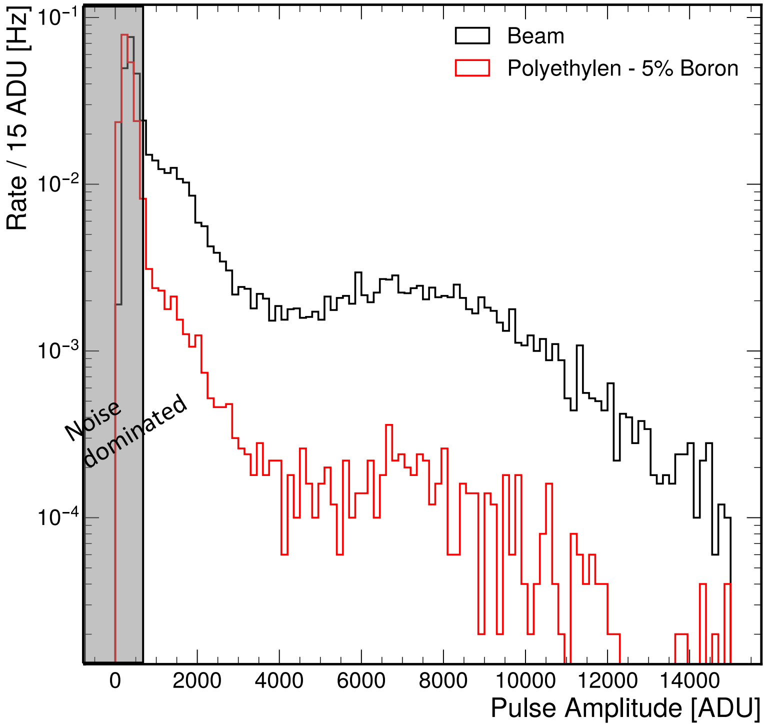
^{9}Be target on deuterium beamline

- 5.90±0.08 MeV deuterons
- ^{9}Be(d,n) reaction
- Same detector setup
- Moderators used to study neutron detection (paraffin, Polyethylene +5% Boron, lead)

Neutron measurements at MC40 cyclotron

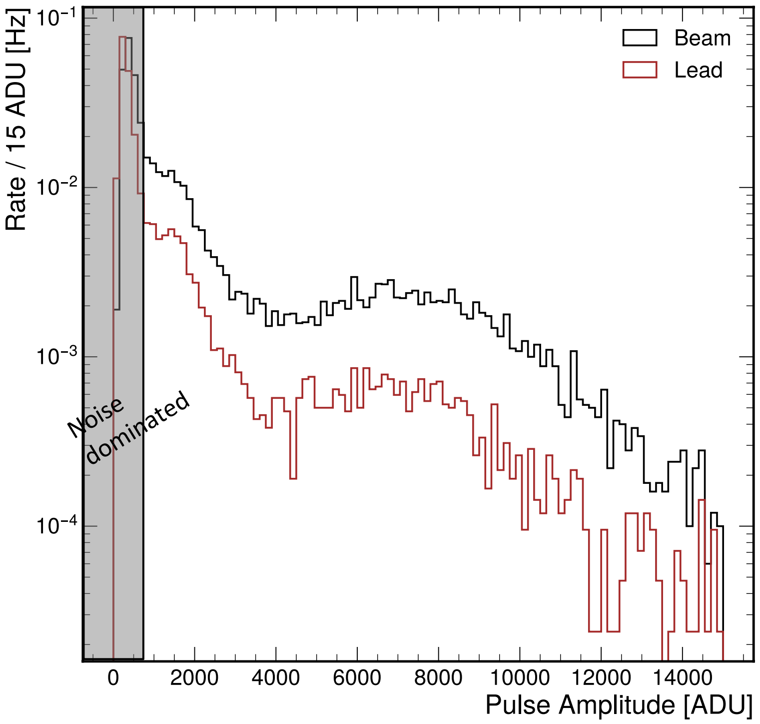
Spectroscopic measurement of fast neutrons

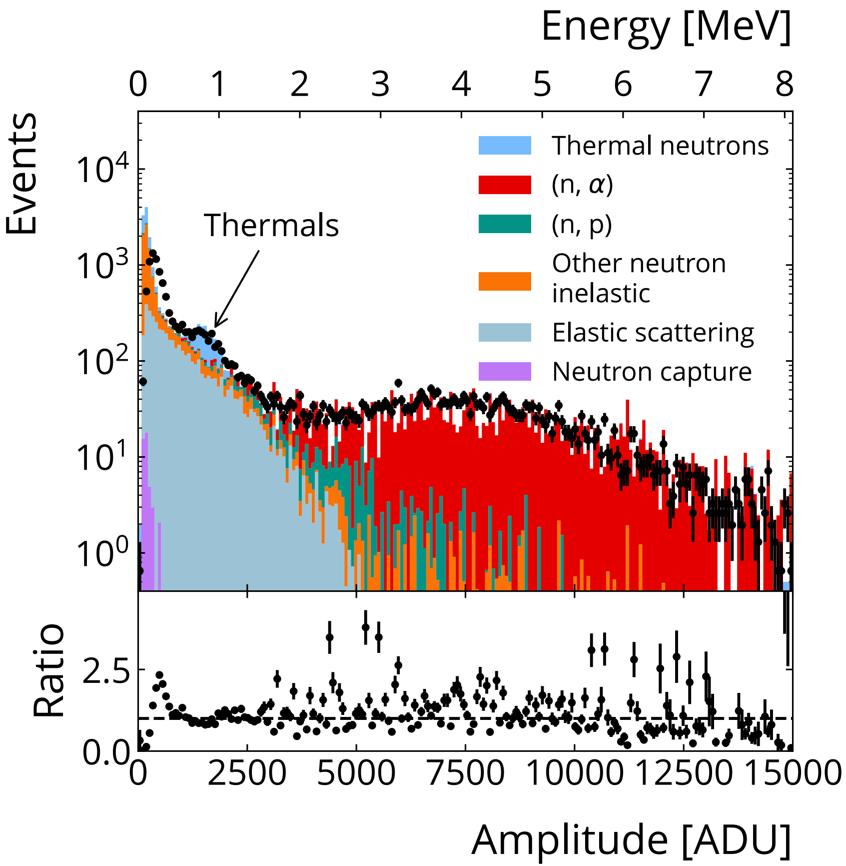




Neutron measurements at MC40 cyclotron

Spectroscopic measurement of fast neutrons





Neutron measurements at the 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
- ^{252}Cf neutron source available
- Measurements and analysis ongoing

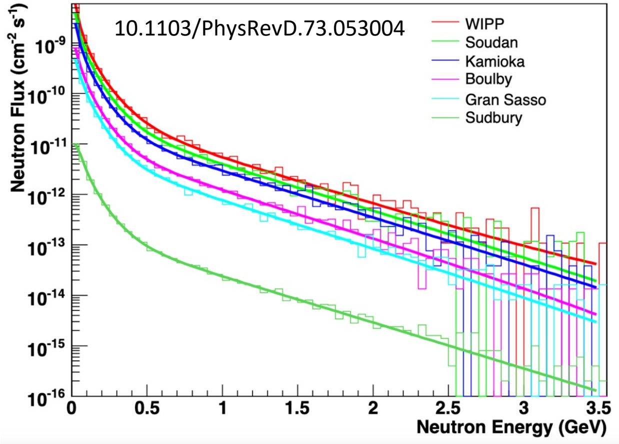
Science and Technology Facilities Council

Boulby Underground Laboratory

Birmingham Gaseous Detectors Laboratory

Expected thermalized neutron background flux with 2 bar N_2 filling with…

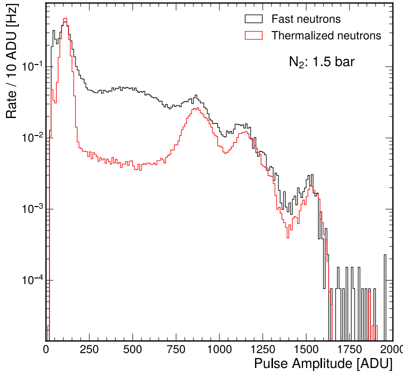
	60 cm SPC	140 cm SPC
neutrons/day	2.2	11.4
neutrons/month	67.1	351.9
neutrons/year	791.9	4142.8

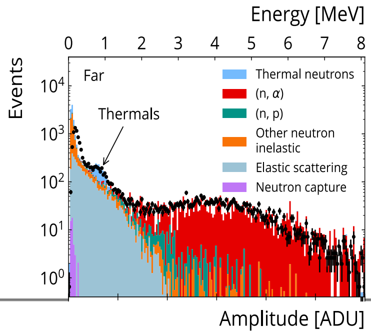


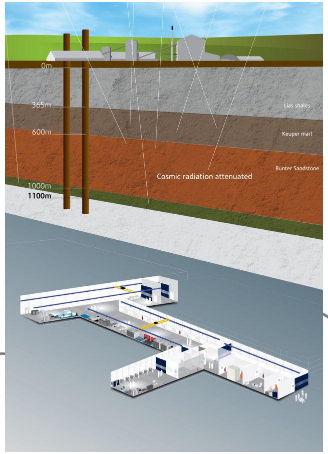
Neutron detection with the Spherical Proportional Counter

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 (e.g. @ Demokritos, Greece)







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Back up slides

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

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