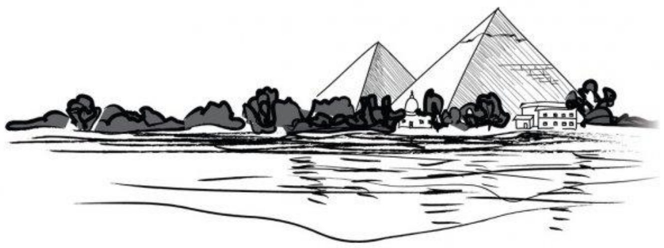
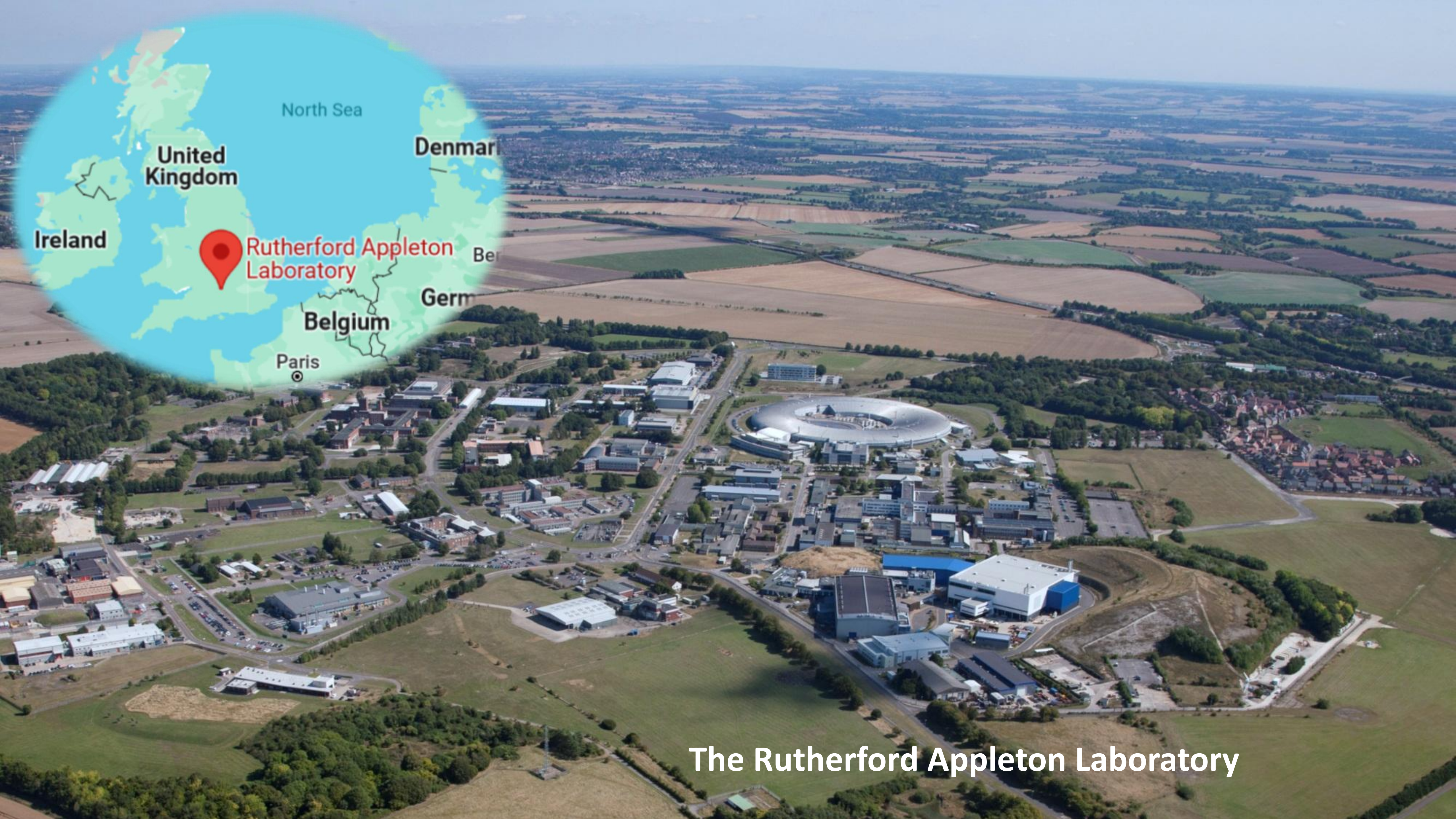
Science and Technology Facilities Council

ISIS Neutron and Muon Source

Neutron measurements for the characterisation of NILE, a facility based on compact neutron generators



Carlo Cazzaniga
17th September 2026



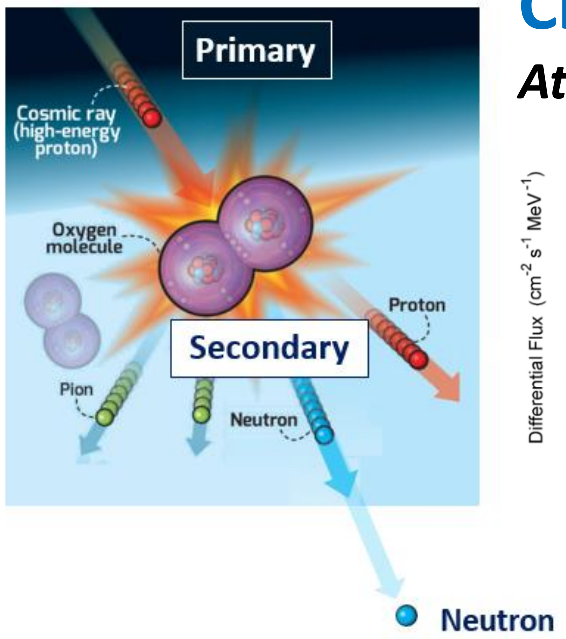
The Rutherford Appleton Laboratory

Neutron irradiation facilities at RAL: the ISIS neutron source

Pulsed proton accelerator (800MeV at ISIS) and spallation targets to produce intense beams of neutrons and muons.

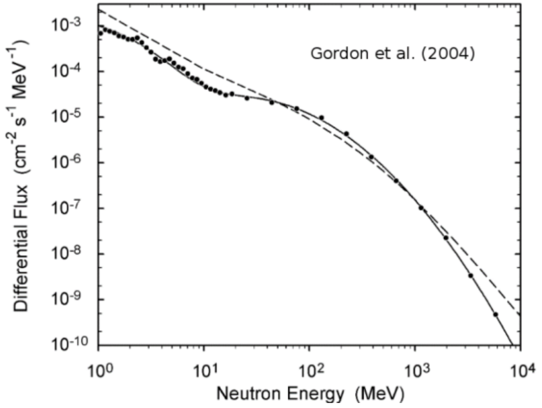
These beams are used for neutron scattering to study materials, devices and processes across physics, chemistry, engineering, biology, energy, heritage science and electronics irradiation.

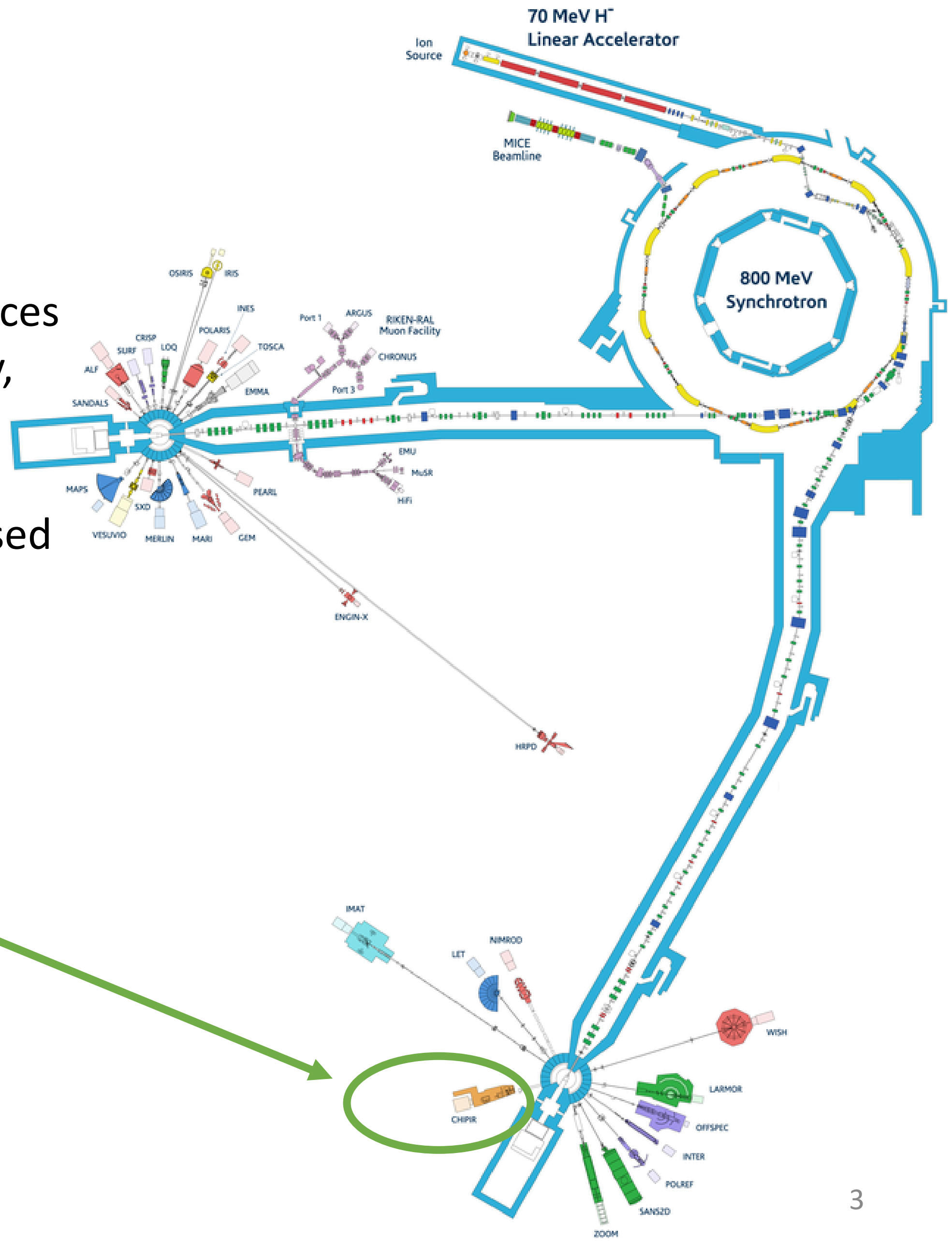
High energy neutrons with atmospheric like neutron spectrum are used for testing microelectronics.



ChipIR

Atmospheric neutrons





Neutron Irradiation Laboratory for Electronics (NILE)

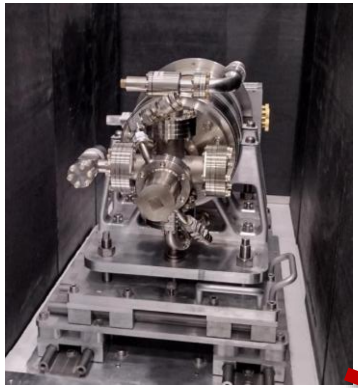
Motivation

Electronics testing:

- **Complementary to ChipIr** → methods and test setups.
- **Training**.
- **Reactors environment**.

Other applications:

- Nuclear Fusion technology
- Fast neutron imaging.
- Benchmark of Monte Carlo simulations
- Study of isotope production mechanisms
- Detector testing (eg. **Dark Matter** detector).

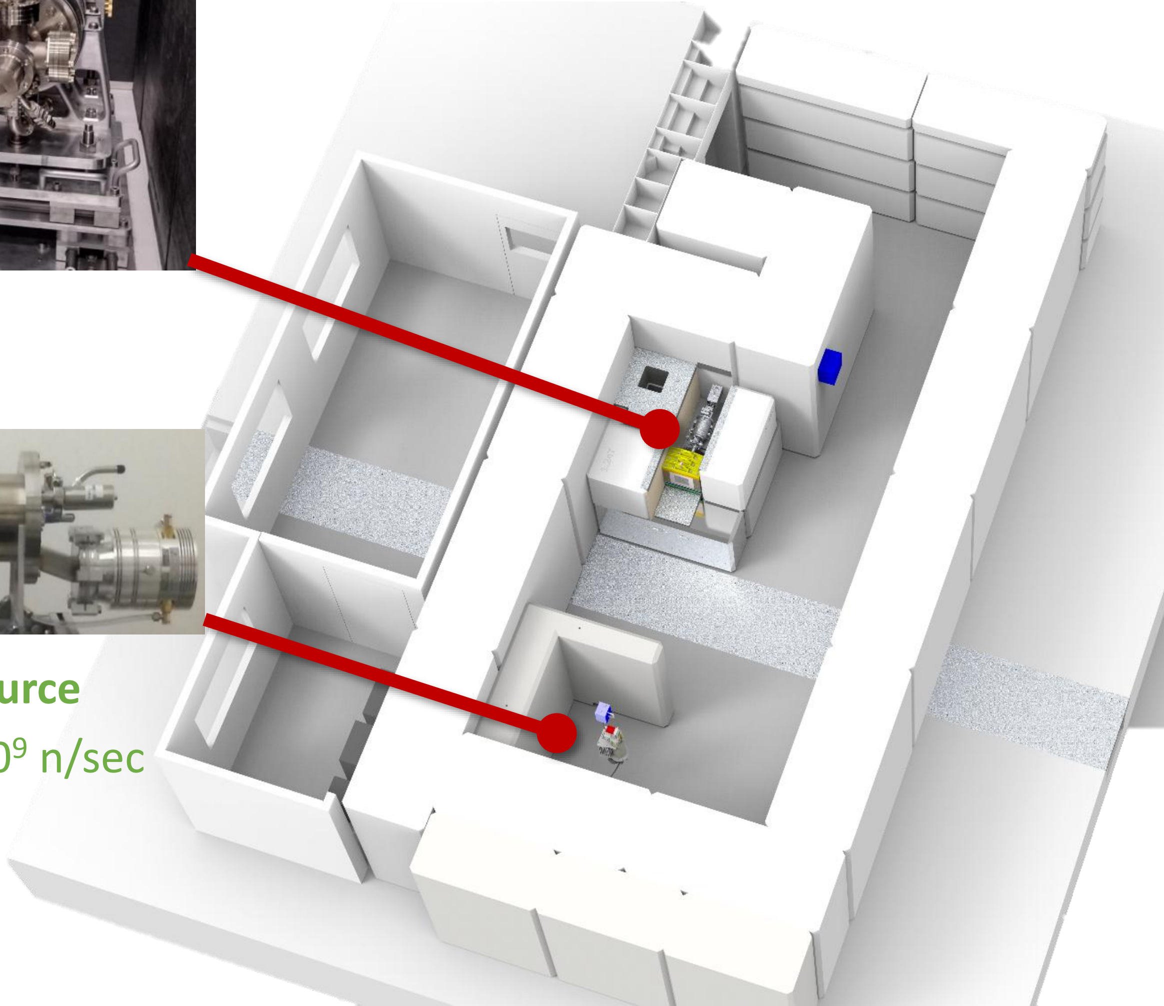


14 MeV D-T Source

Nominal Yield 10^{10} n/sec

2.5 MeV D-D Source

Nominal Yield 10^{9} n/sec



Role of monoenergetic sources for SEE testing

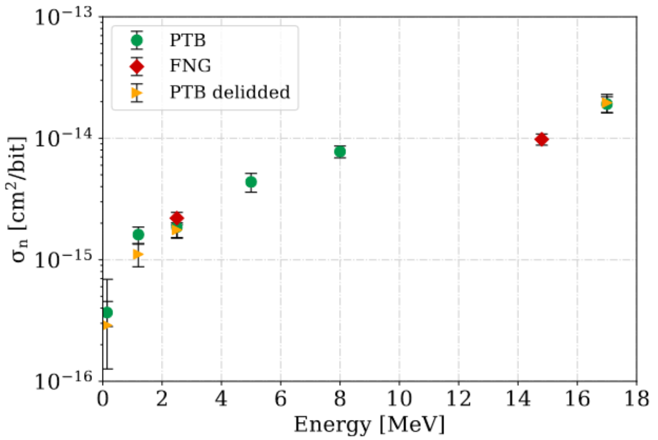
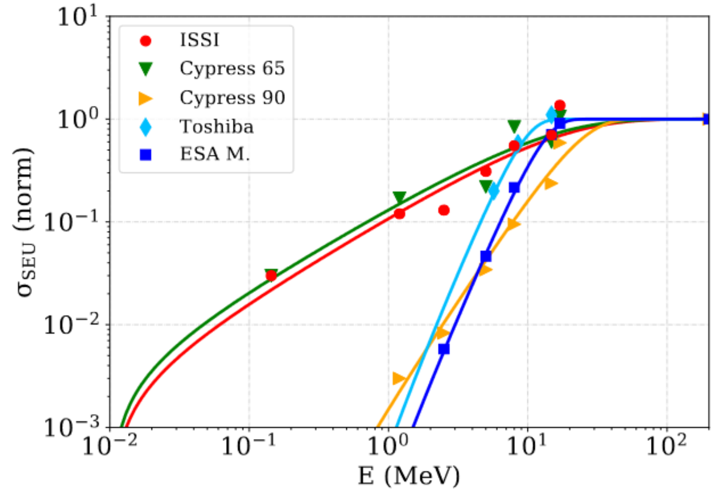


Fig. 1. ISSI 40 nm neutron cross sections, measured at FNG and PTB. Comparison with the delidded memory for some energies. Error bars are reported with 95% of confidence level, including statistical and fluence uncertainties.



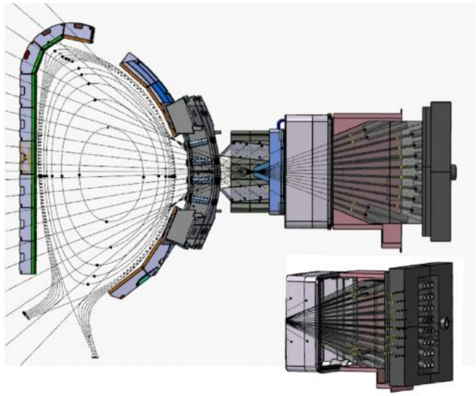
Source: Cecchetto et al. 2021

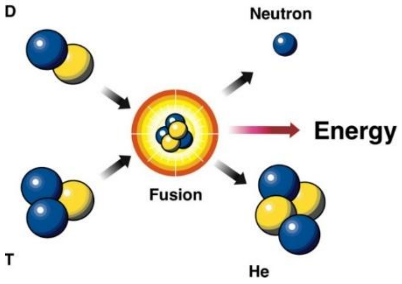
- Measurement of cross sections as a function of energy
  The results are close for single-event upset in most technologies
  For most devices, the higher energy atmospheric spectra produce more multiple-cell upset and single-event latch-up
- Application of electronics for nuclear technology because they are more representative of fusion (or fission) reactors environment.
- Comparative studies.
- Development of test setups and methods (more availability than spallation sources).
- Characterisation of dosimeters as a function of energy.

They are NOT fully representative of the atmospheric spectrum, but they can be used in a complementary way.

Role of small/medium scale facilities for nuclear fusion technology

Fusion Plasma Diagnostics / detectors

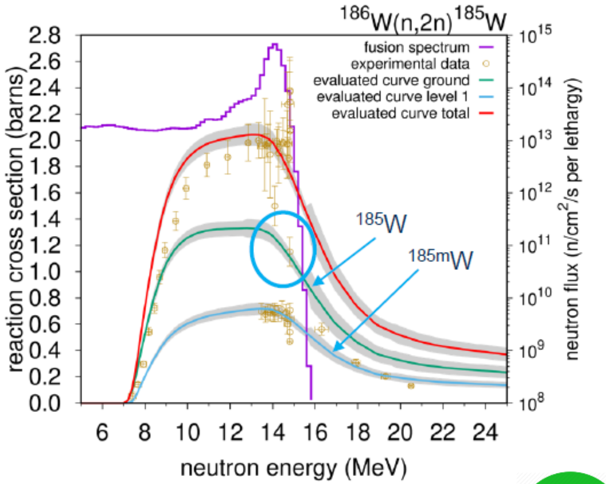




In particular, neutron diagnostics for the physics Q >> 1 tokamaks

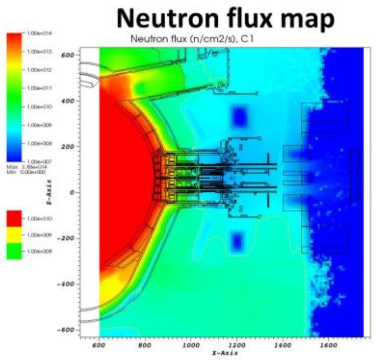
Nuclear data

E.g. Lack of cross section measurements for (n,2n) reactions on 186W(and other W isotopes)



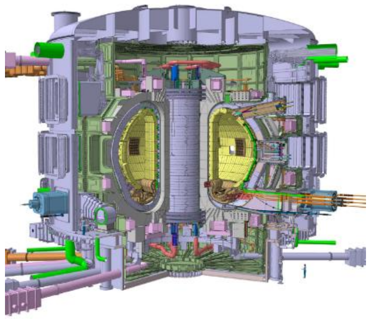
Important for both fission and fusion research.

Radioprotection



Eg. validation of shielding calculations

Material studies



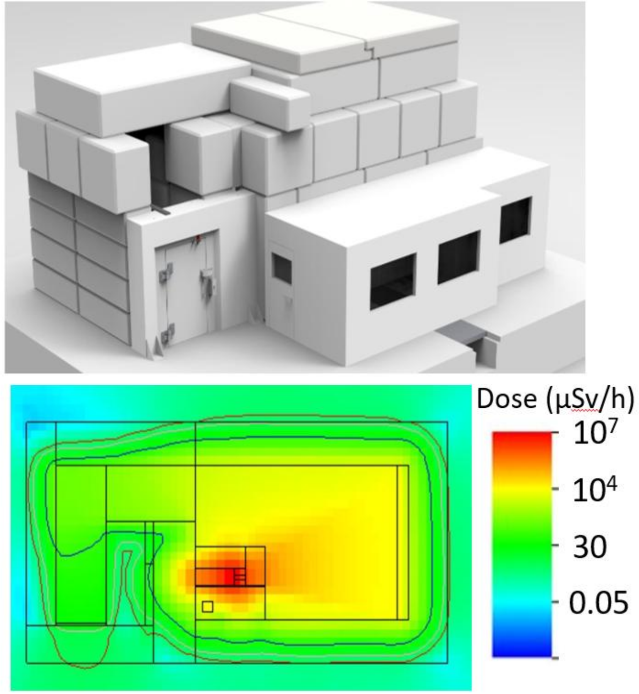
ITER

few dpa

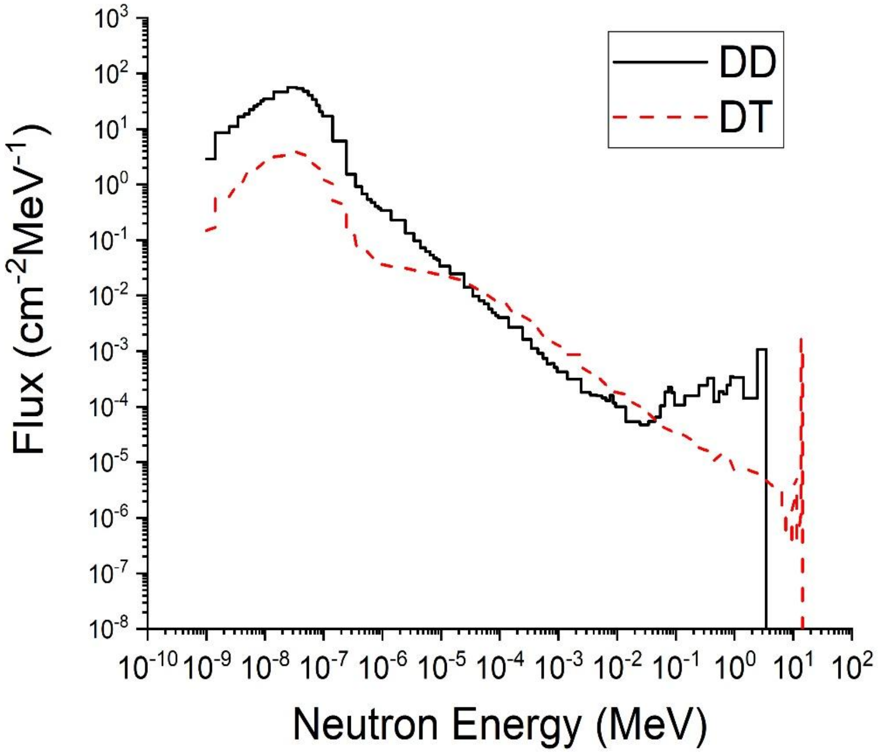
DEMO

10-100dpa

Monte Carlo Calculations



Model of the neutron bunker (top). Calculated dose rates (MCNP) for the DT generator operating in the bunker; contour lines indicate 100, 10 and 3 µSv/h limits (bottom).



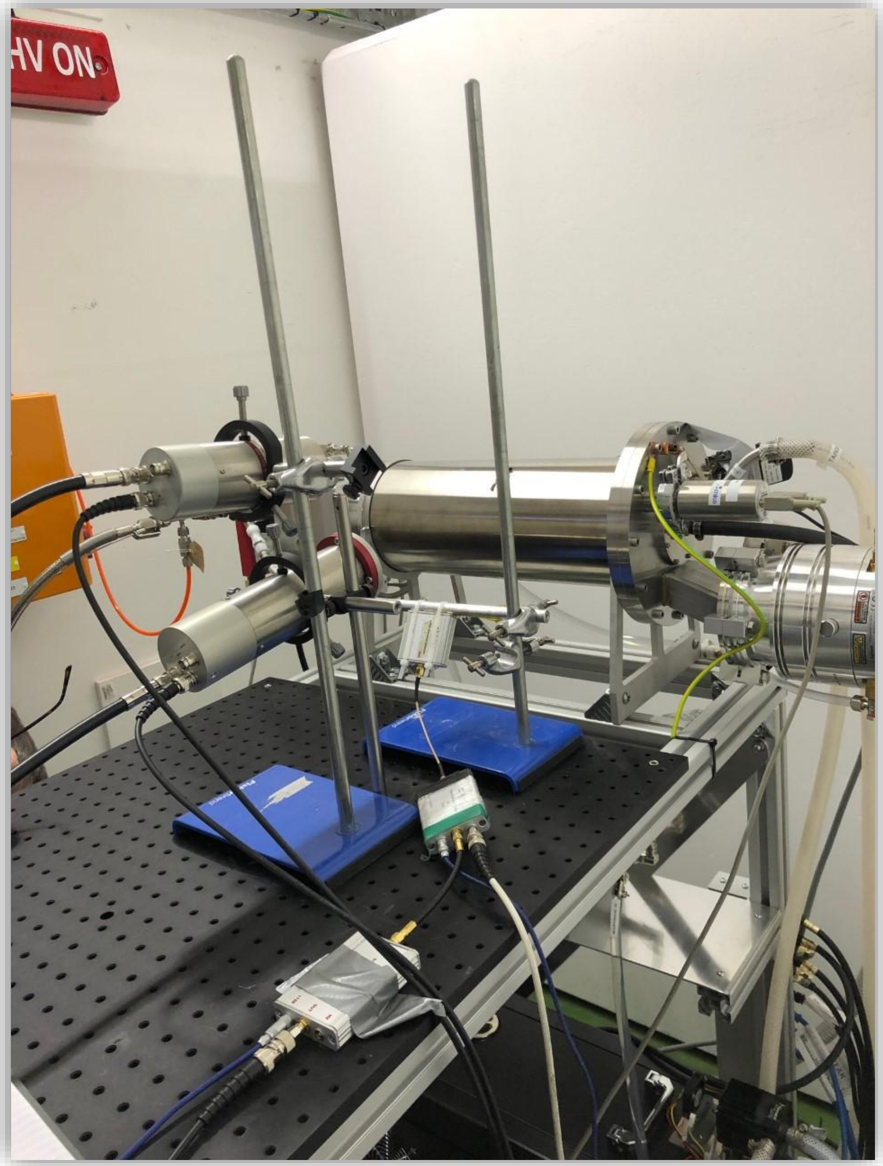
Calculated neutron spectra at 7 cm from the target for the DD and DT generators at the NILE facility.

UKRI Science and Technology Facilities Council

Neutron Measurements

	Absolute flux	Beam monitoring	Neutron Spectroscopy	Gamma/neutron discrimination
Activation foils	Primary			
Fission Chamber	Secondary	Primary		
Diamond Detectors	Secondary	Secondary	Primary	
EJ276 scintillator	Secondary	Secondary		Primary
7CLYC scintillator	Secondary		Secondary	Secondary
SRAM monitors	Secondary	Secondary		

Summary of measurement requirements and systems for the dosimetry of compact generators.



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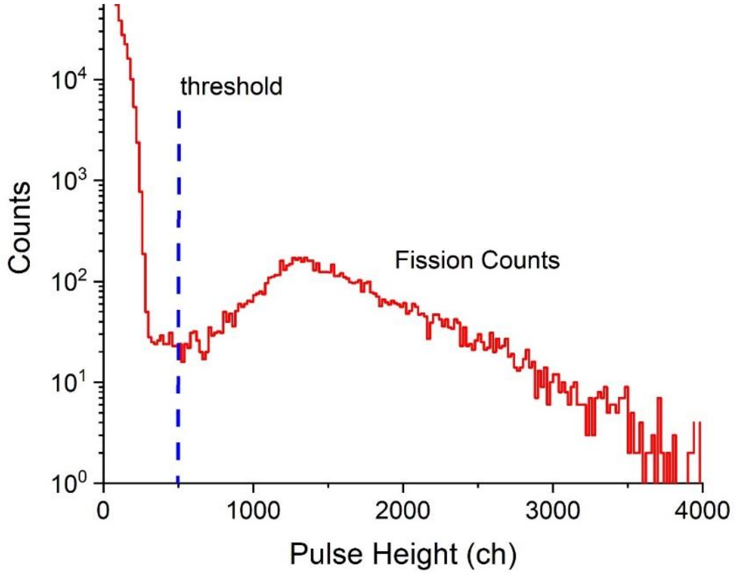
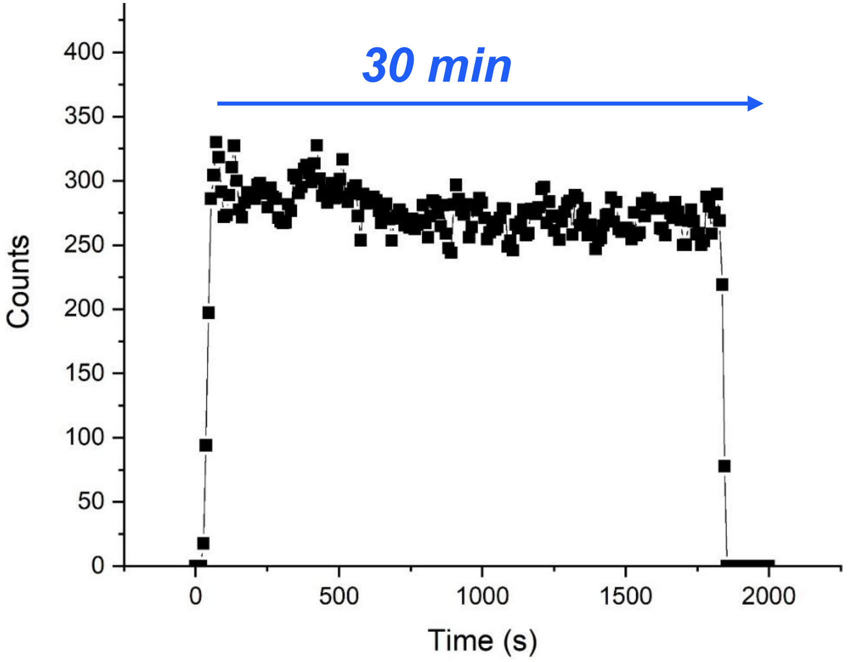
Fission Chamber for beam monitoring

Fission chamber with 130mg of U-238



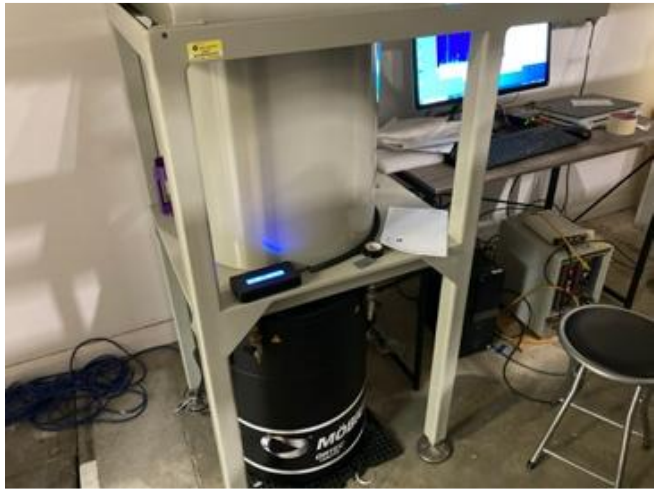


- U-238 sensitive only to fast neutrons > 1 MeV
- Very energetic interactions → good pulse height discrimination of neutron events and background

Activation Foils

		Cross section (b)	E_γ (keV)	Ig (%)	Half Life
DD	$^{115}In(n,n')^{115m}In$	0.38	336.24	45.8	4.486 h
DT	$^{56}Fe(n,p)^{56}Mn$	0.09	846.8	98.9	2.58 h
	$^{90}Zr\ (n,2n)^{89}Zr$	0.84	908.96	100	78.4 h
	$^{27}Al(n,\alpha)^{24}Na$	0.122	1368.6	100	14.99 h
	$^{93}Nb(n,2n)^{92m}Nb$	0.46	934.5	99.1	10.15 d

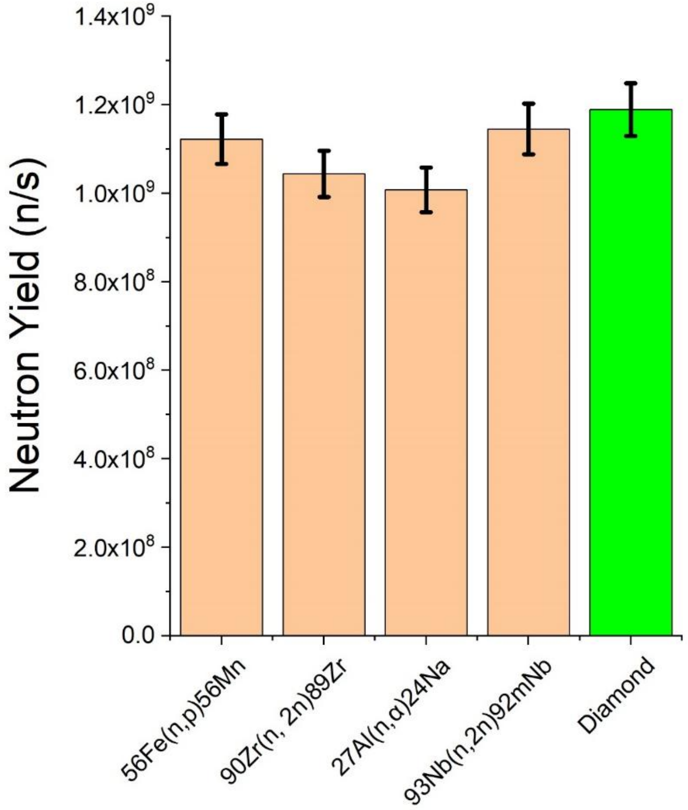
Details of reactions used for activation analysis.



Germanium Detector at NILE

Reference for absolute measurements as the neutron flux is traced directly to evaluated nuclear cross sections.

Passive technique. It cannot follow transient effects. Measurements and analysis is time expensive.



DT Results at NILE at HV = 105 kV

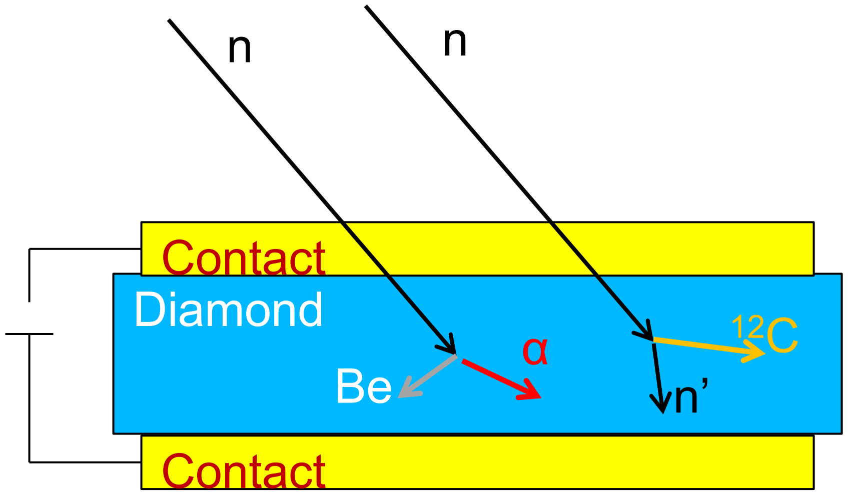
Diamond detectors

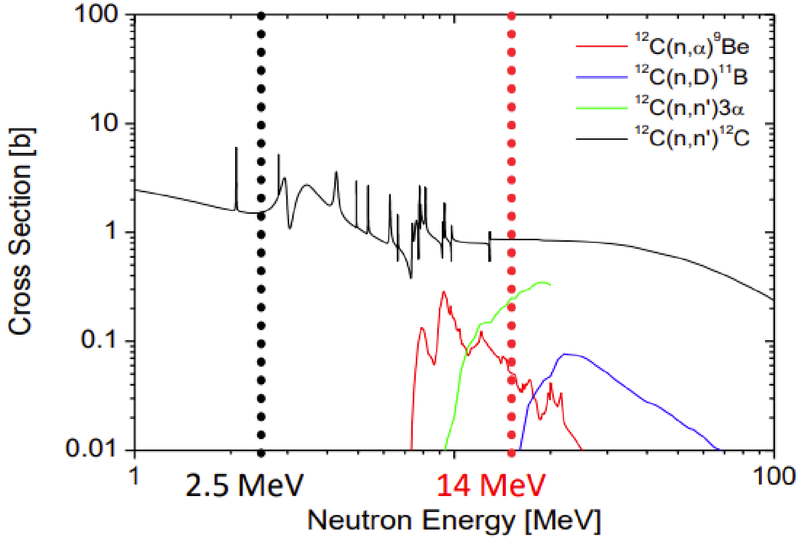
In common with Silicon diodes

- High mobility of free charges (→fast response, short signals).
- Good energy resolution on deposited energy
- Room temperature operation (E_g=5.5 eV)→ No Cooling.
- Compact volume solid state detector.

Diamond detectors

- Chemical Vapour Deposition, single-crystal, 300–500 µm thick
- Radiation hard (to >10^{16} n/cm²), low γ sensitivity
- Polarization effects possible at much lower fluences
- Used for 14 MeV DT spectroscopy (8.3 MeV peak from $^{12}C(n,\alpha)^{9}Be$)

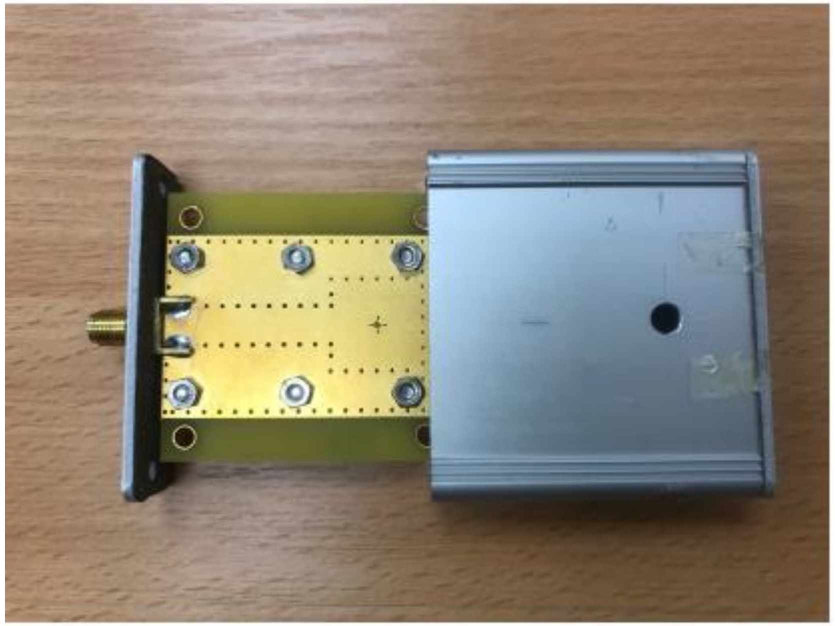


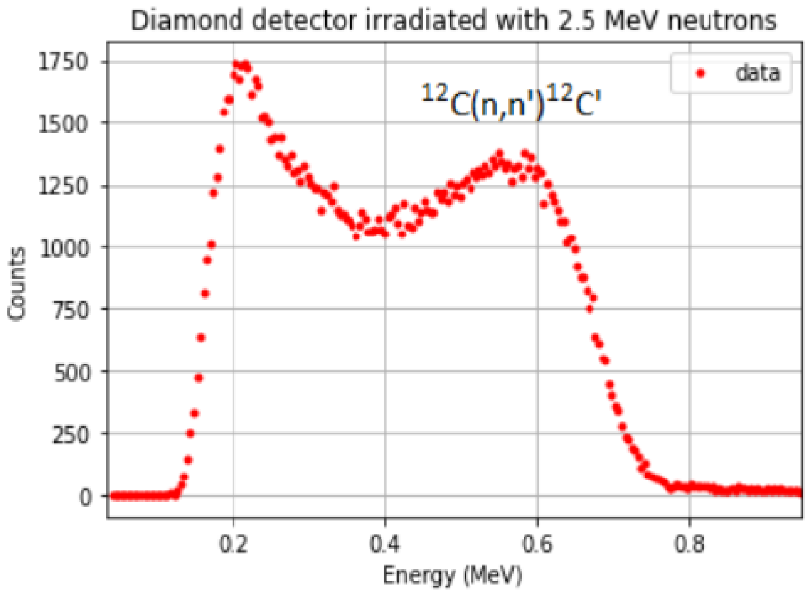


Neutron interaction cross section on ^{12}C. Data library, ENDF VII

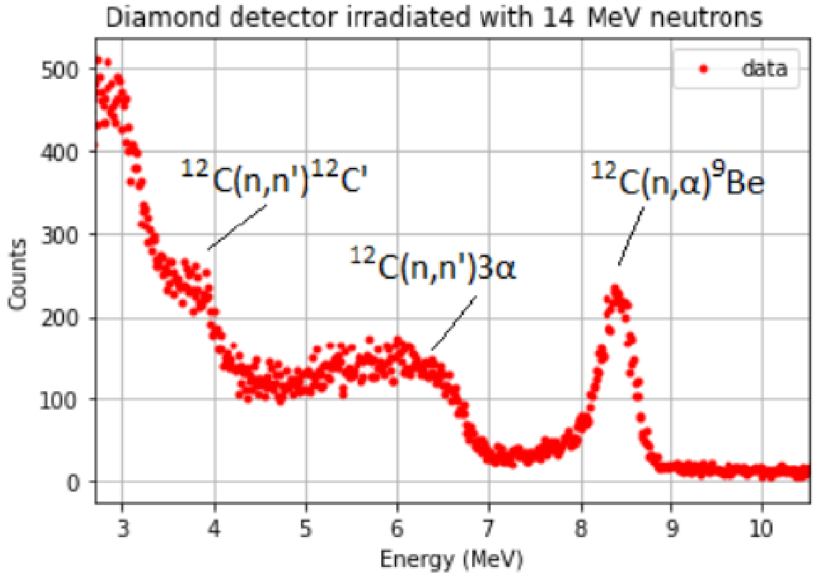
High Resolution Spectroscopy with a diamond detector

Single-crystal diamond grown by chemical vapor deposition of size 500 um x 4.5 mm x 4.5 mm.





2.5 MeV

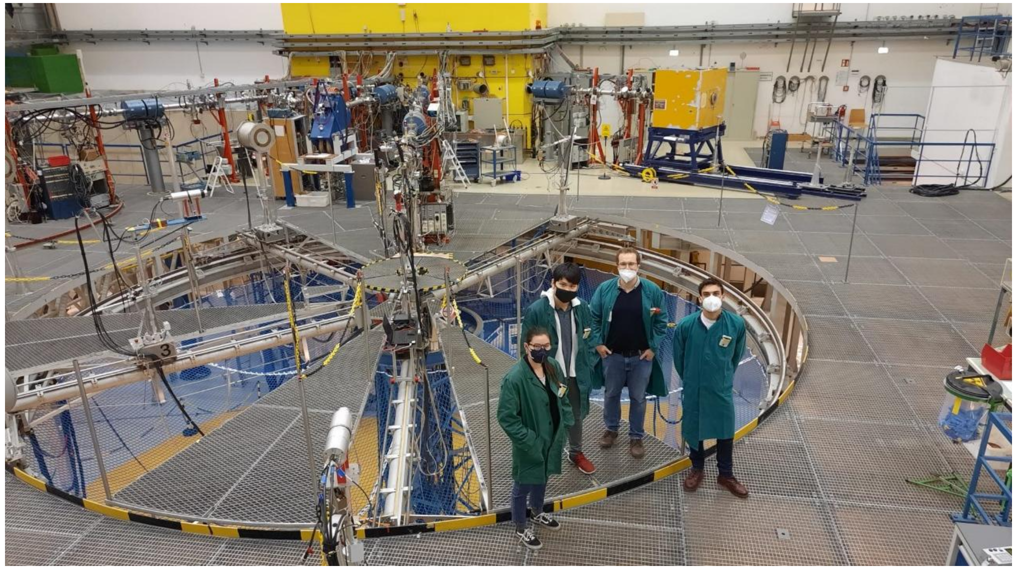


14 MeV

Neutron Response Characterization at Metrology Labs

The metrology labs: PTB (Germany), NPL (UK) offer:

- ✓ **Well-characterised neutron fields**
  energies from 1.5 MeV to 14.8 MeV.
- ✓ **Absolute fluence** given to metrology standards.
- ✓ **Low scatter experimental hall** and availability of tools to correct for scattering.



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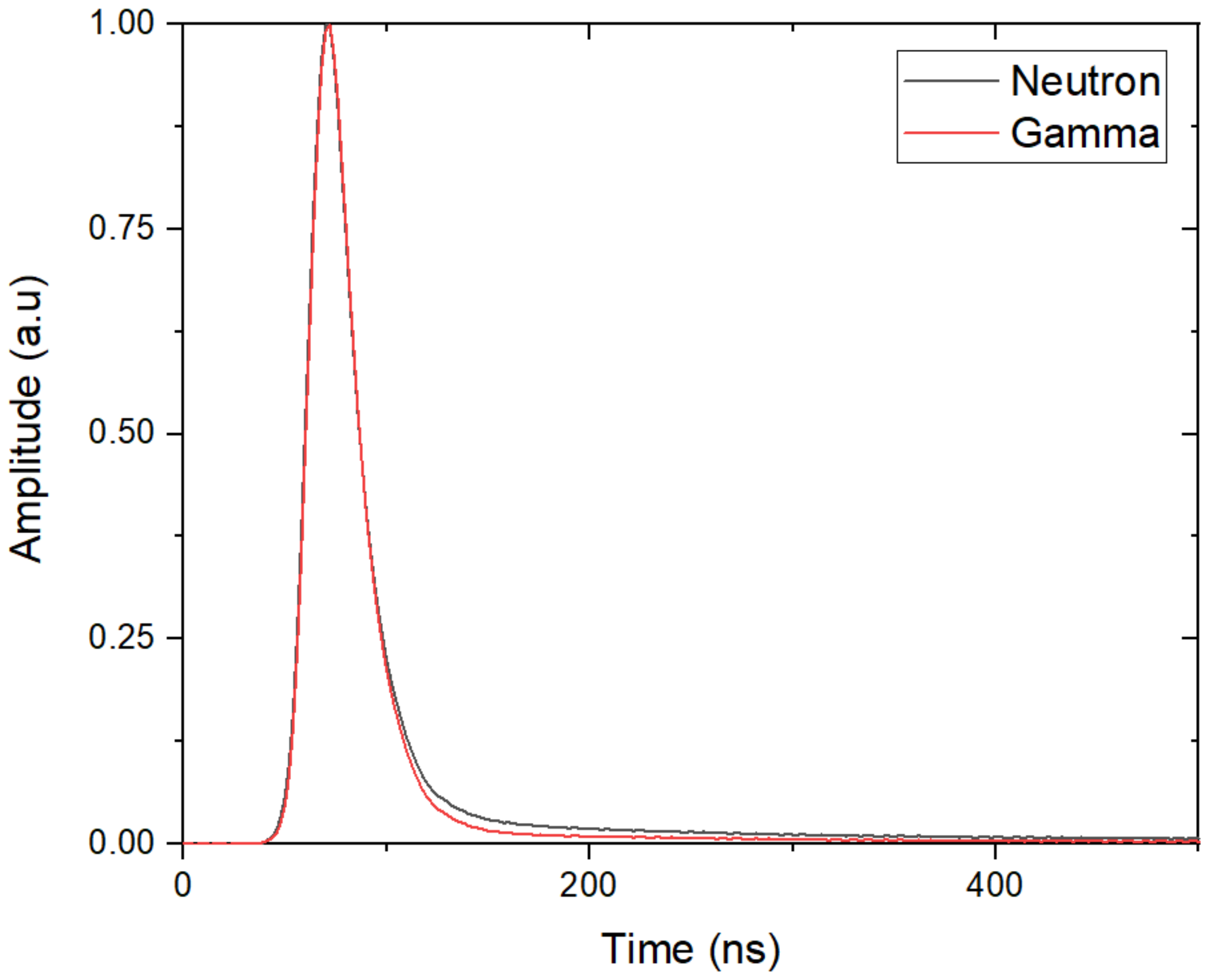
Scintillators used at NILE

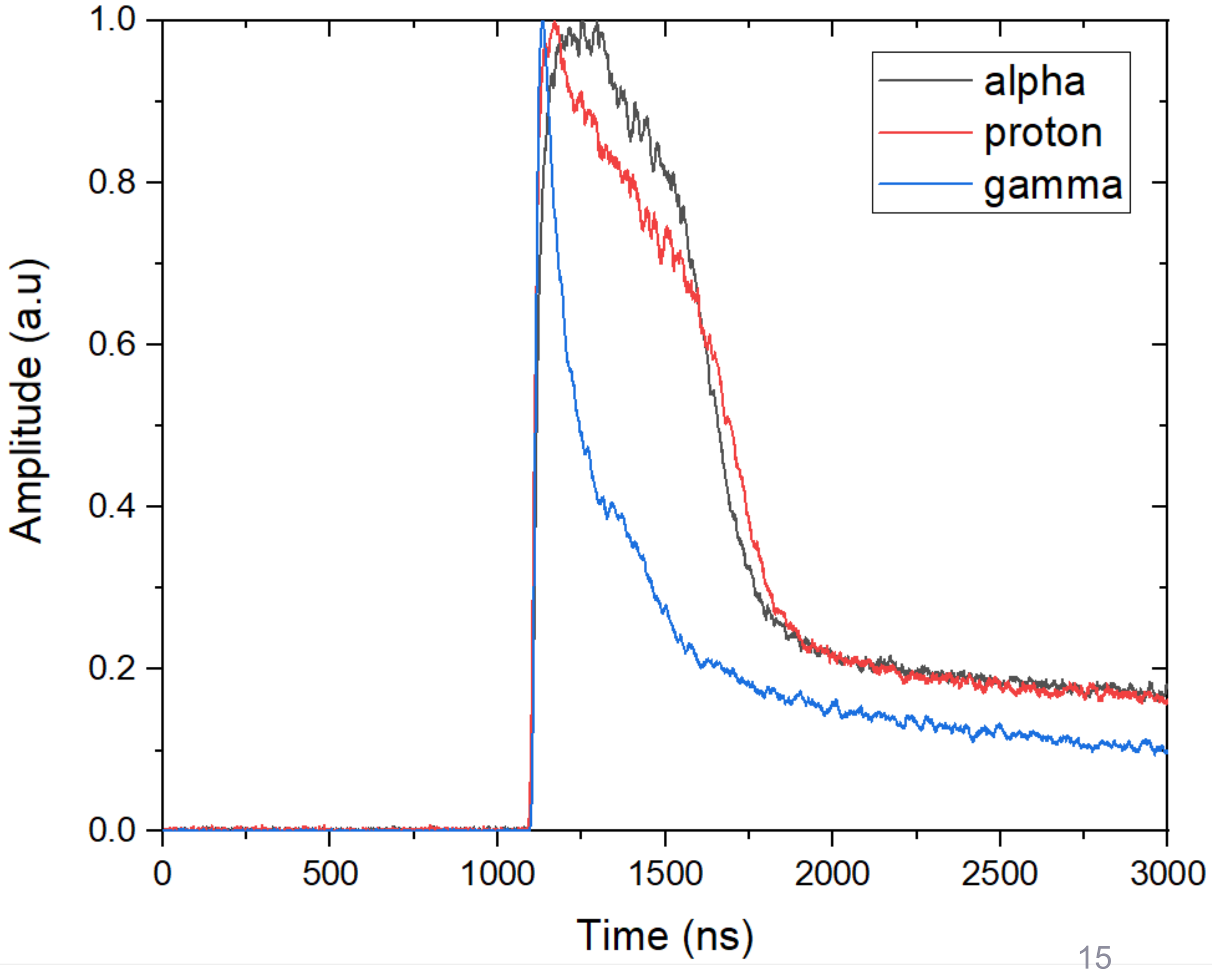
Detector Properties	**Plastic: EJ-276**	**Inorganic: 7CLYC Cs_2LiYCl_6:Ce**
Fast neutron detection	Proton elastic recoil	^{35}Cl(n,p)
Shape of neutron response	Continuum with shoulder	Peak structures
n/γ discrimination	Adequate	Superb
Signal speed	Fast	Slow
Neutron energy resolution	~20%	9-10%
Appearance	1”x1” With PMT 	1”x1” With PMT 

Pulse Shape Discrimination (our waveforms)

EJ-276

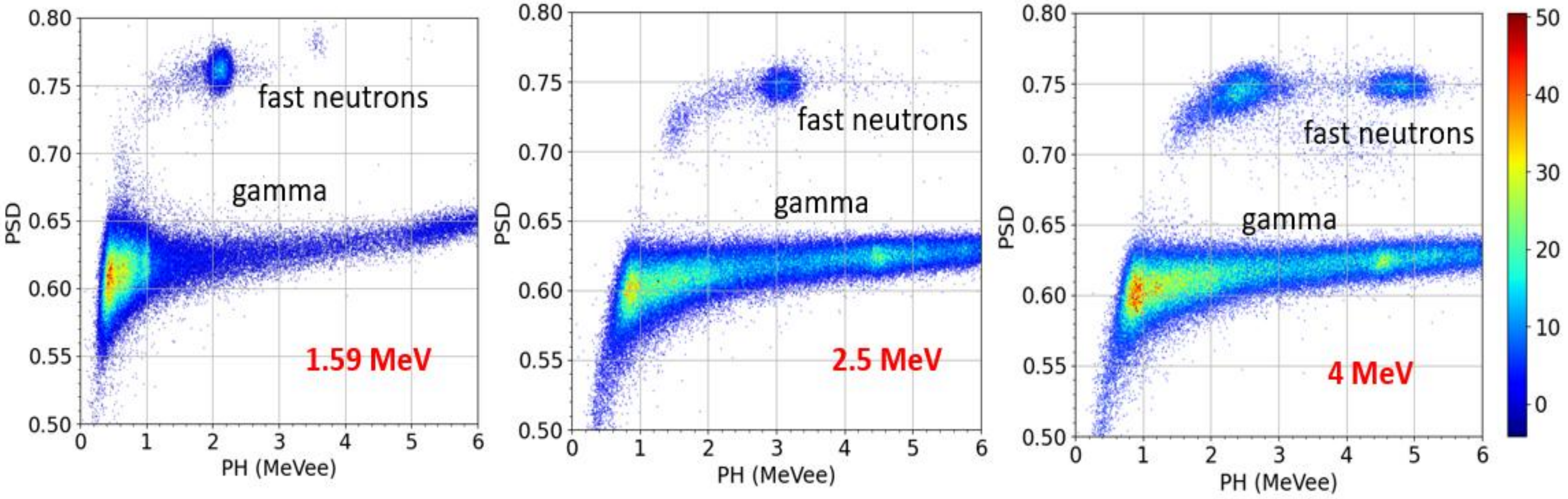


7CLYC



CLYC response close to 2.5 MeV

^{35}Cl(n,p) is a clear peak and separated



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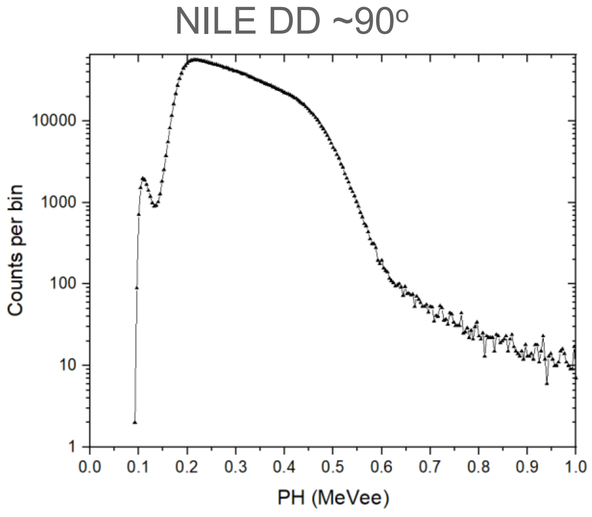
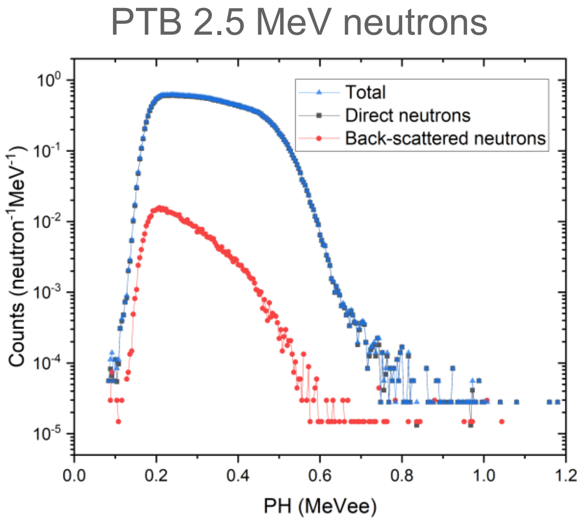
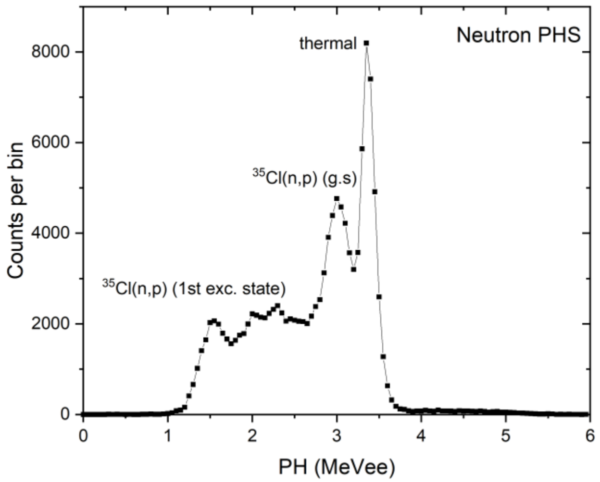
NILE DD measurements

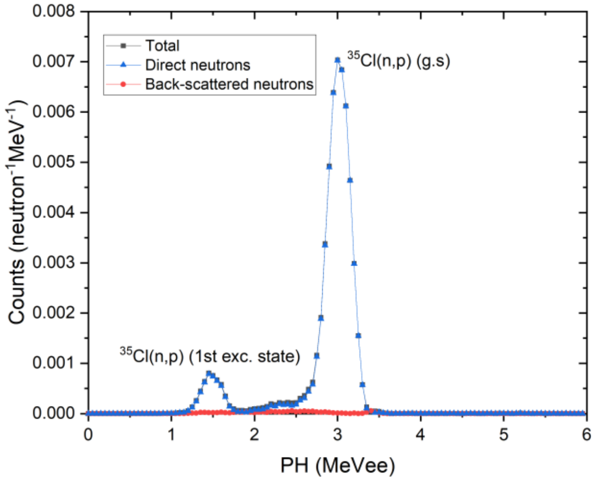
EJ-276

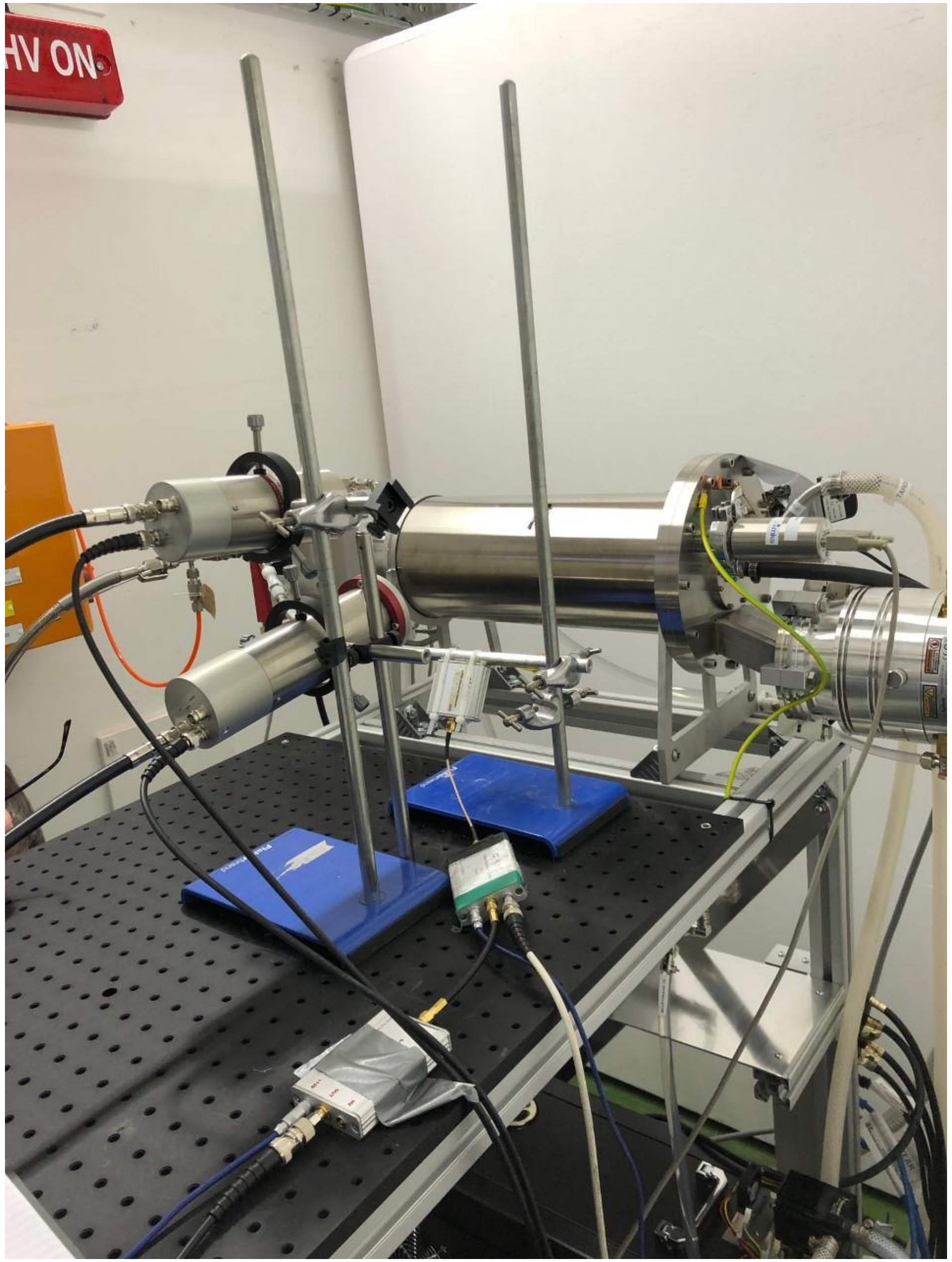




7CLYC



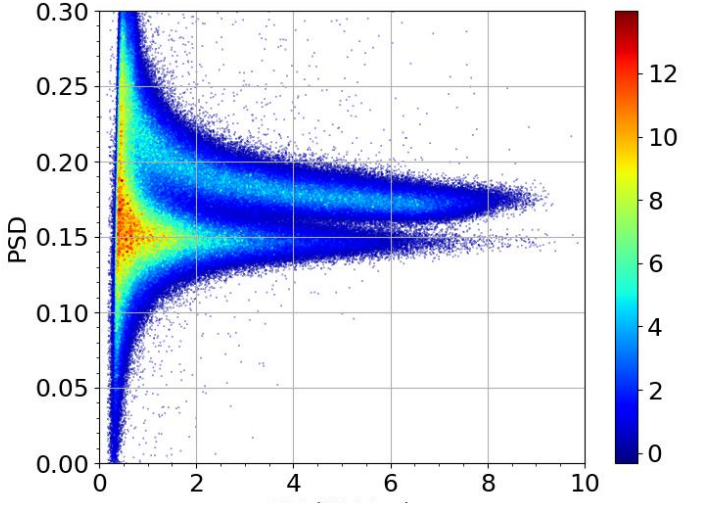


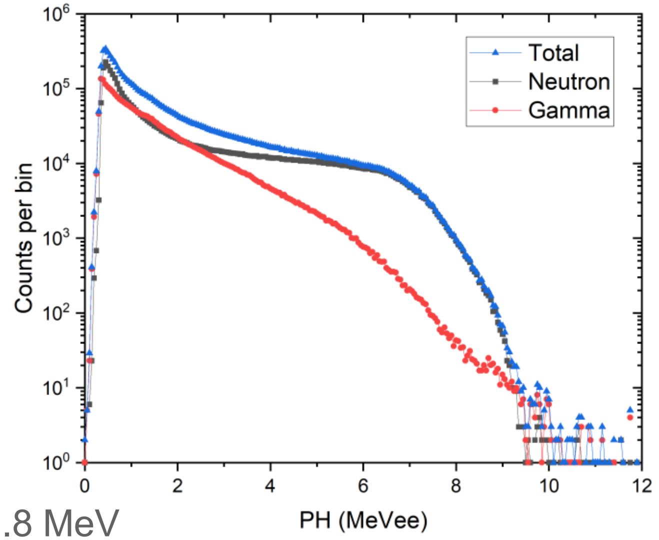


EJ-276 NILE DT measurements

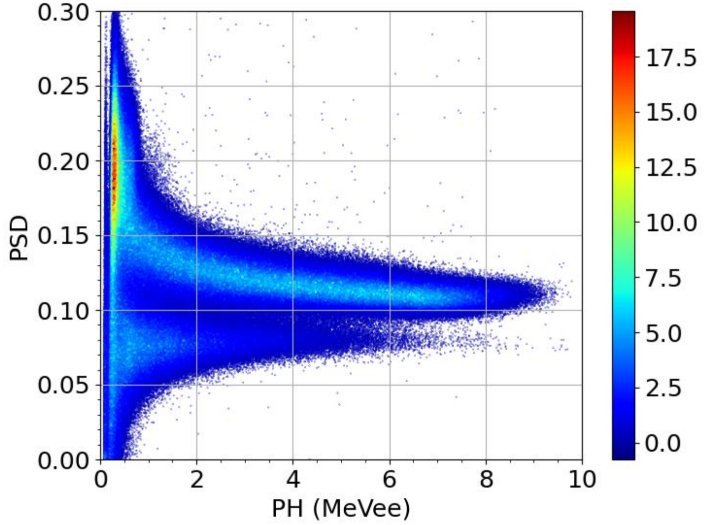
EJ-276

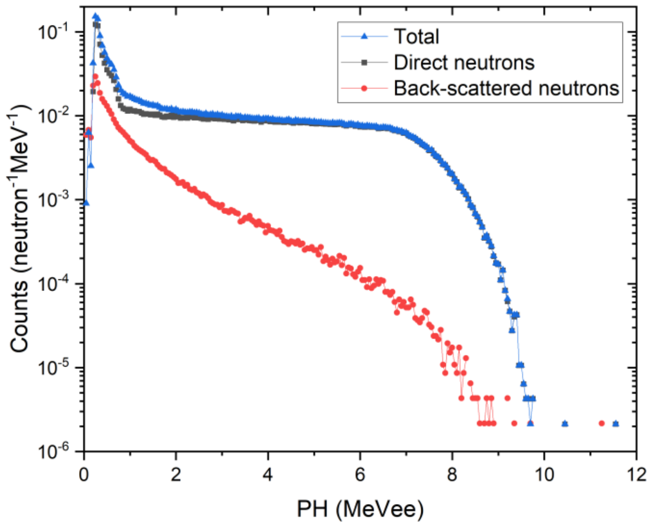
NILE DT ~0°

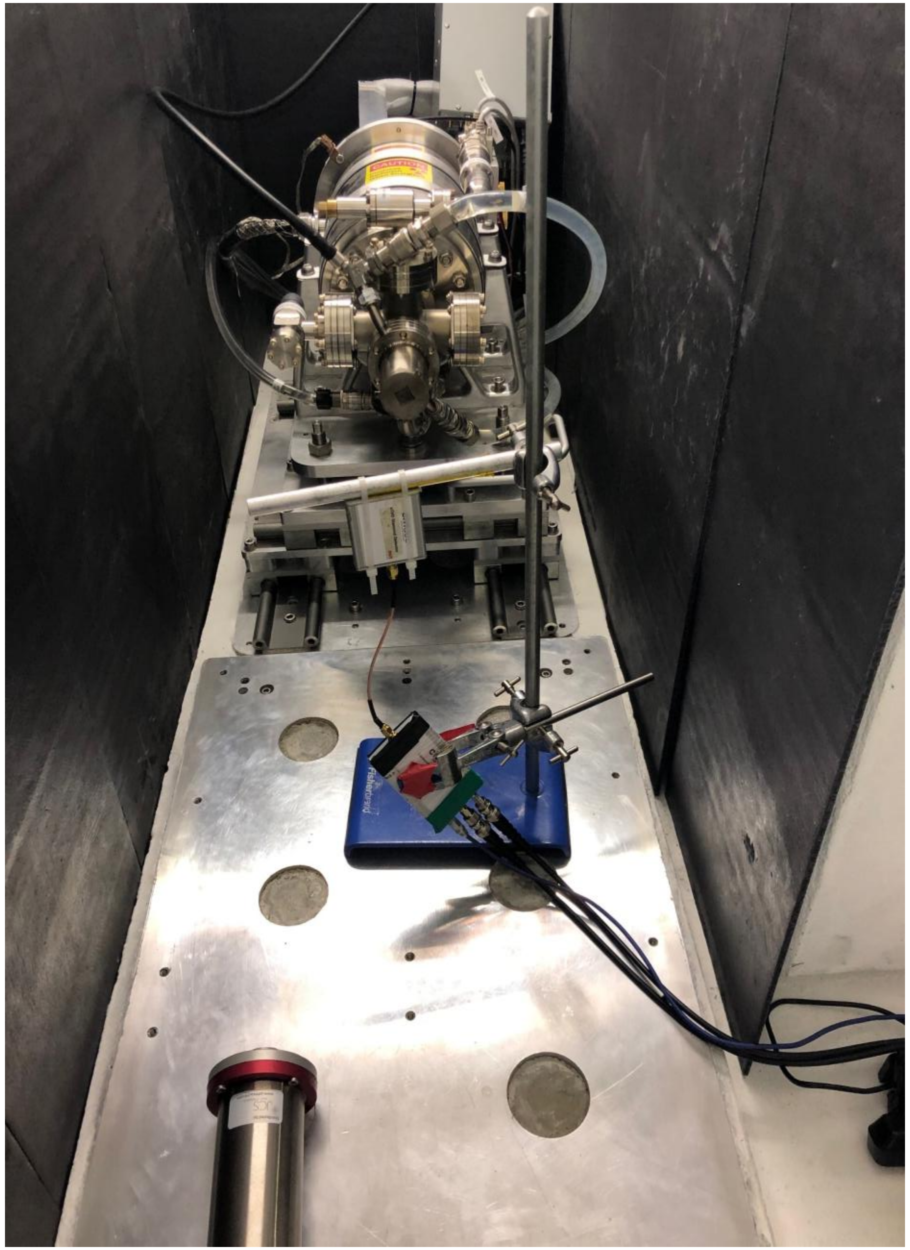




PTB 14.8 MeV







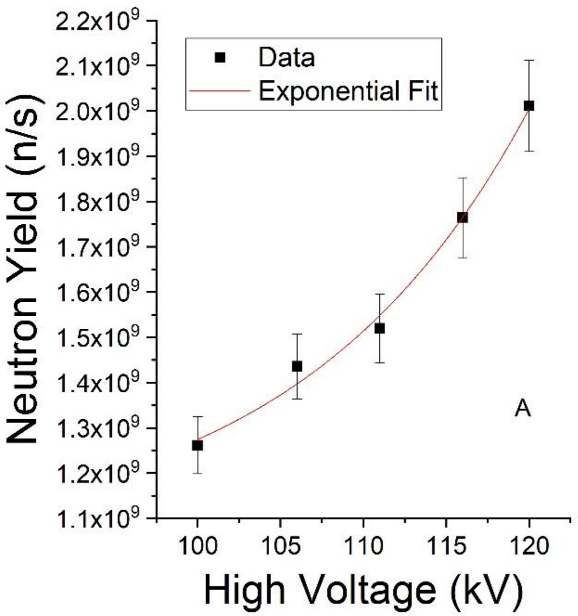
results

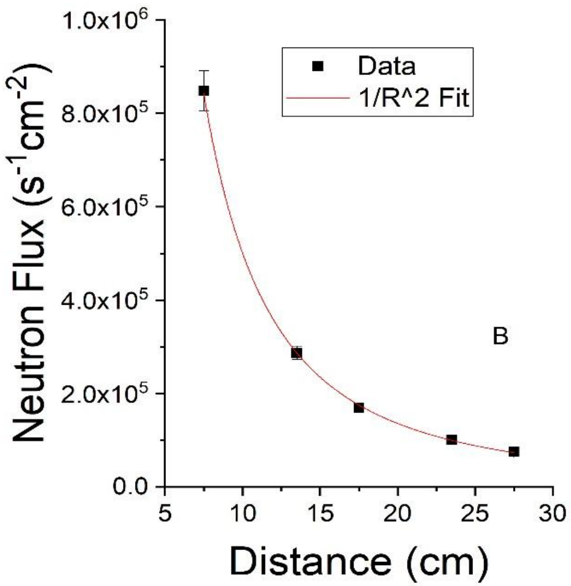
Neutron Yield and Fluxes

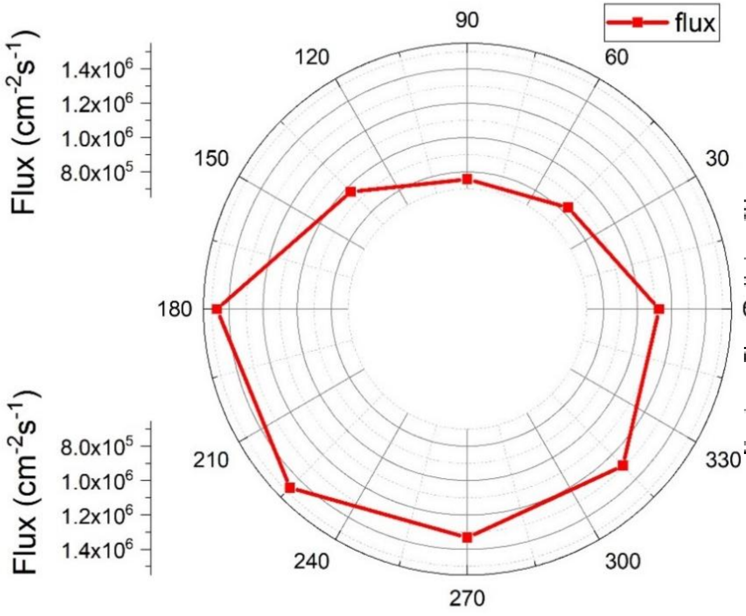
- **Neutron Yields** need to be measured as a function of the **parameters of operation** of the source.

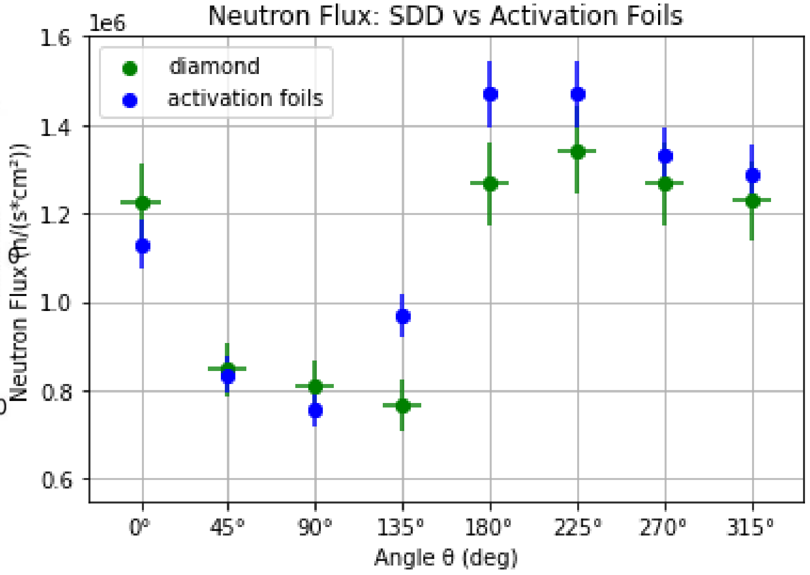
  Parameters:
  - High Voltage
  - Microwave Power
  - Pressure

- **Fluxes** need to be measured at **different positions and geometry**, or if materials are placed close to source or DUT.









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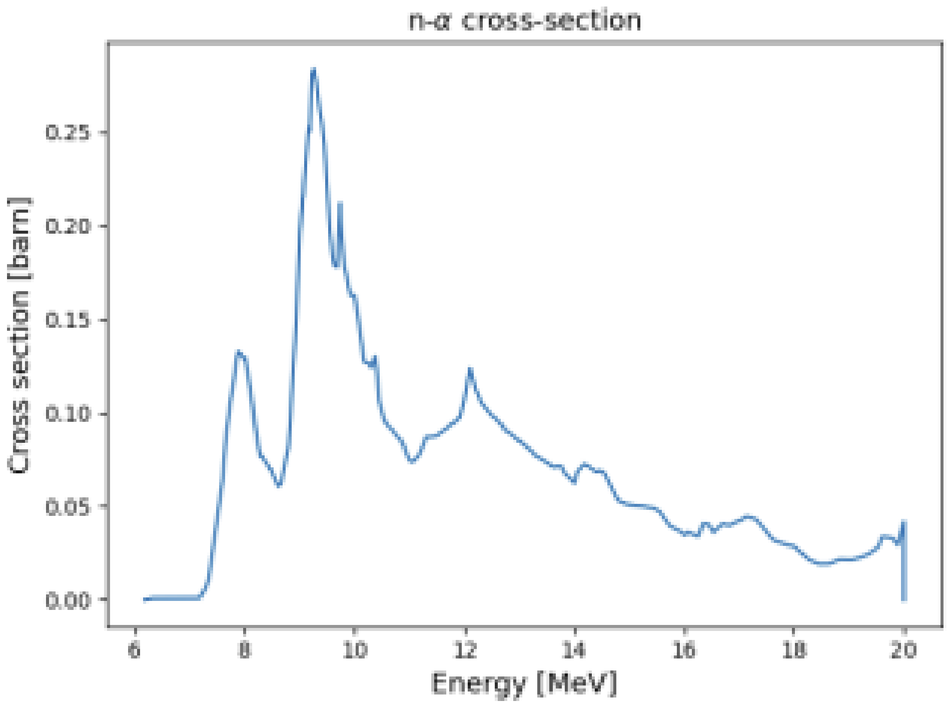
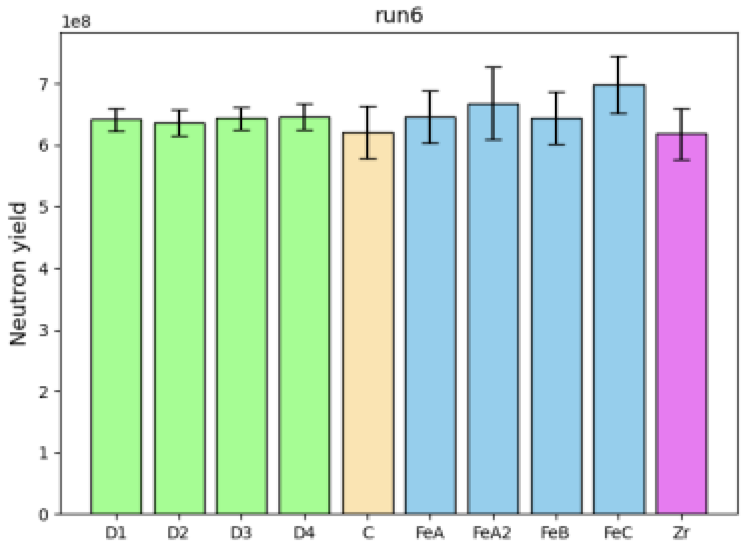
Comparisons between activation foils and diamond for absolute flux measurements



- Diamond calibrated at metrology lab
- Efficiency needs to be corrected taking into account the energy dependency of the cross section
- Monte Carlo simulation to take into account self shielding of foils



- Very good agreement!
- Uncertainty on the neutron yield with the diamond matrix within 3%!

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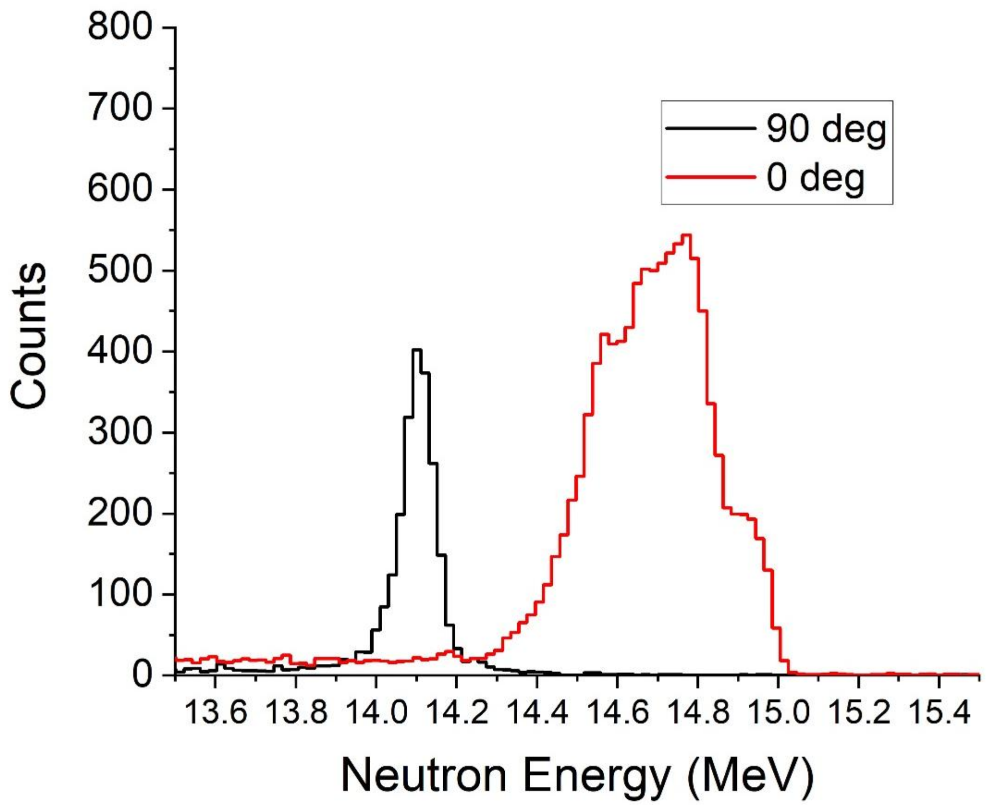
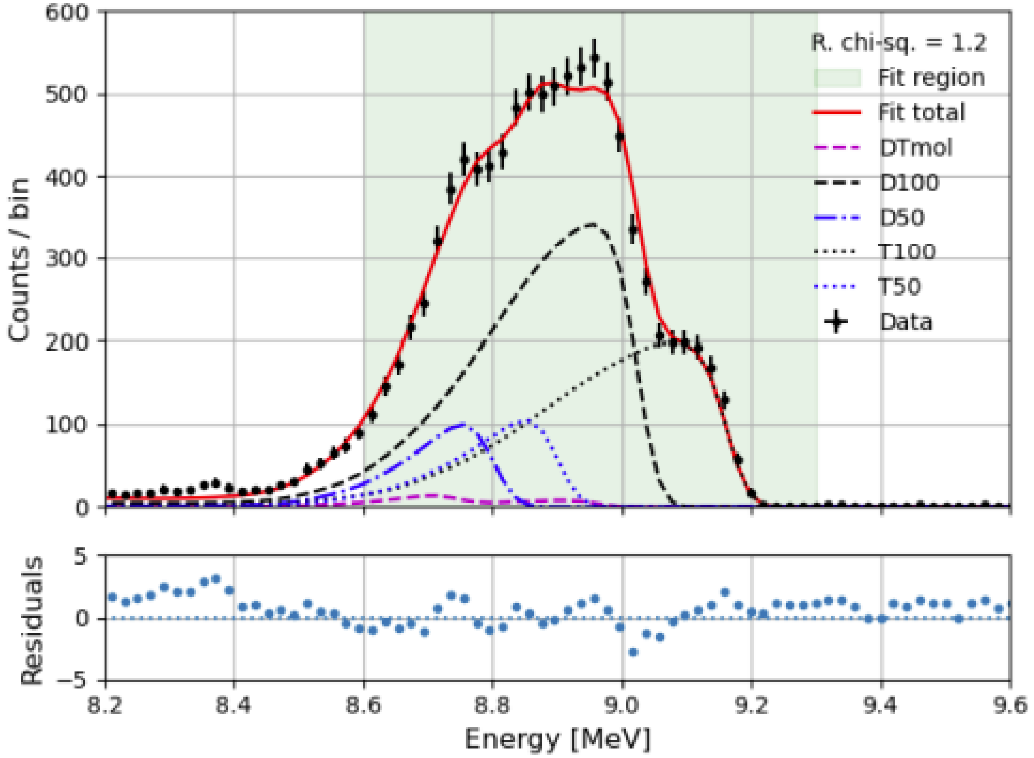
High-resolution spectroscopy



- Sharpest peak is at 90 deg because of kinematics
- Broadening of peak at 0 deg is due to kinematics and different species in the ion beam, D_2, T_2 DT, D, T



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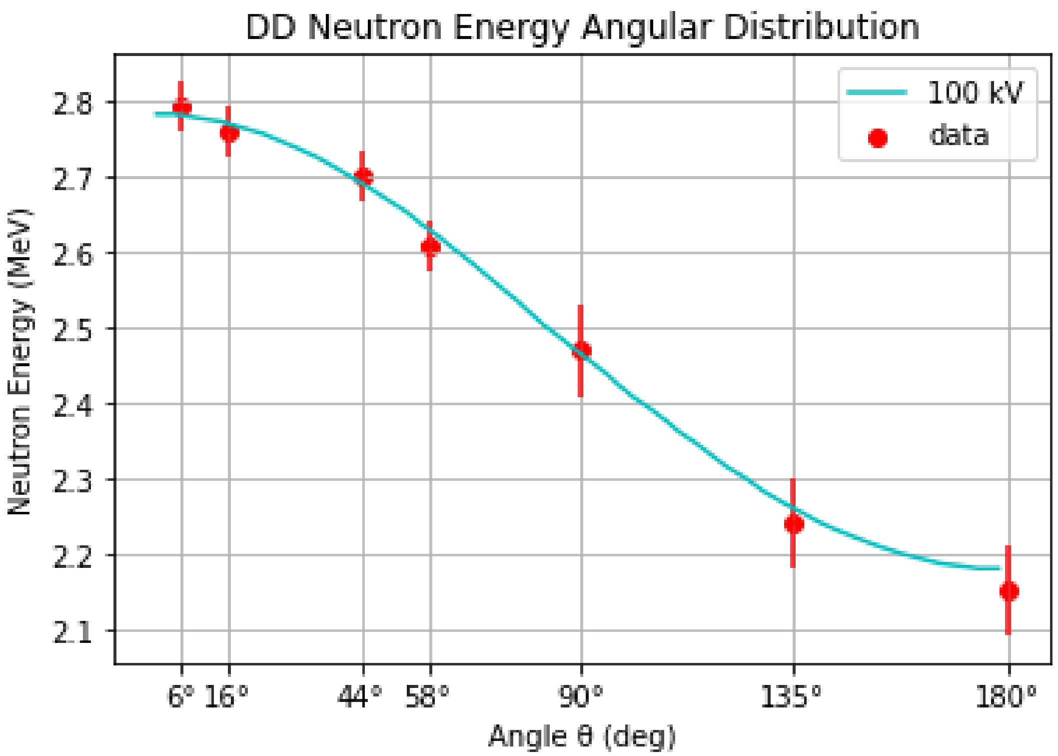
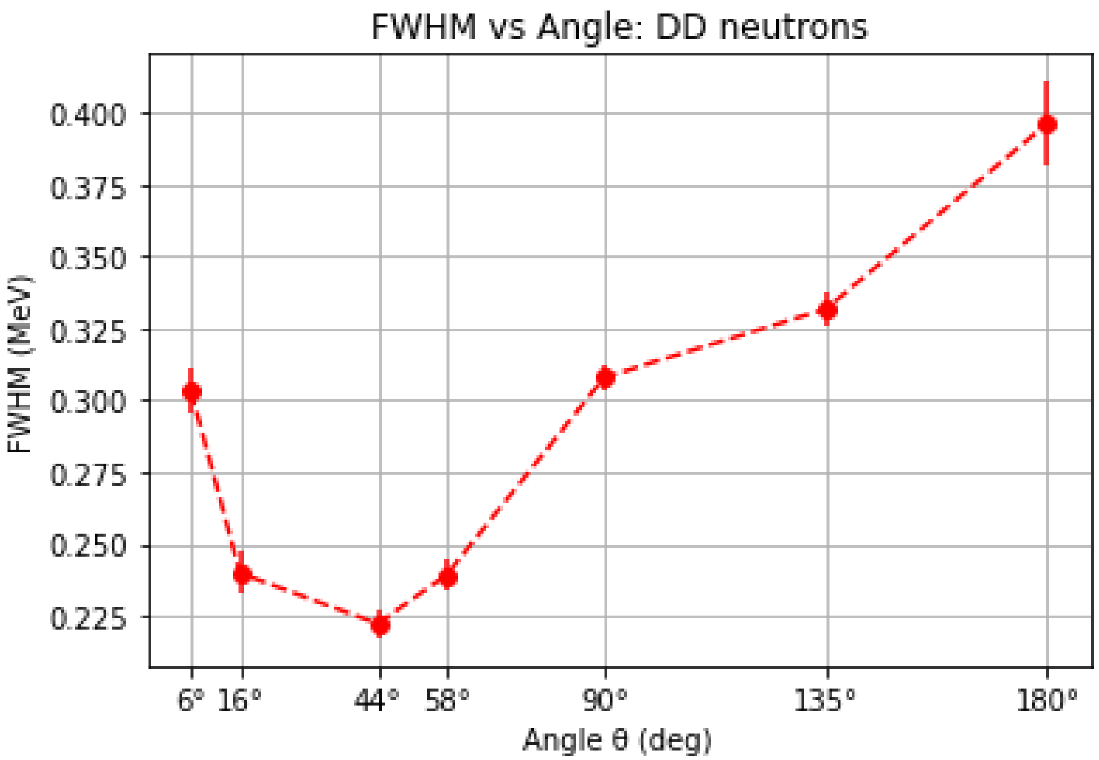
High-resolution spectroscopy



Neutron Energy
Analytical curve from kinematics



Broadening
Due to multiple effects:
- Geometry/solid angle
- Thickness of the target/kinematics
- Purity of the beam

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Access to the facility

Academic access

- Proposals are peer-reviewed
- Two main calls per year (October and April)
- Selection on the basis of scientific excellence and readiness
- Free at the point of access
- Results need to be published

Industrial access

- Paid access to the facility
- Application for beamtime open all year around
- NDA if needed
- Results are proprietary

Thanks!

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