A compact fast neutron spectrometer based on a single organic crystal

SANDA WP1 – Task 1.2.1

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Objective

- Determine the neutron response function of a detector made of a stilbene organic crystal for **fast neutron spectrometry in mixed *n*/γ fields extending down to the 100 keV range**

  Has implication for WP5 T5.3.2, LR-0 spectral characterization

- Investigate the low energy limit of *n*/γ discrimination, response anisotropy

Methodology

- Gamma-ray response
  - ✓ Energy calibration with gamma sources
  - ✓ Optimization of DAQ parameters and PMT voltage
- Neutron response
  - ✓ Energy characterization with neutron sources
  - ✓ MCNPX-PoliMi/Geant4 modelling
  - ✓ Construction of the response matrix
- Unfolding tests of well-known experimental spectra

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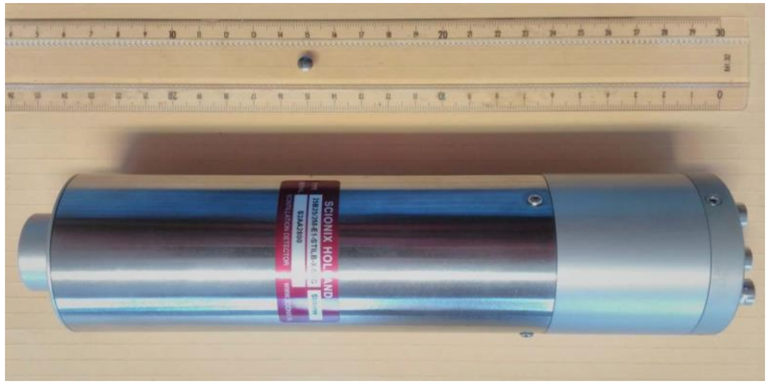
Detector

- Same detector as Dioni's, 2017
- Solution-grown stilbene crystal Ø25.4 mm × L25.4 mm from InradOptics
- PMT: Ø58.8 mm × 223.5 mm 9214B-series (Et-Enterprise)



Stilbene detector, assembled by Scionix

DAQ

- CAEN DT5730 digital acquisition system
- CoMPASS software
- Data analysis using ROOT (C++) framework

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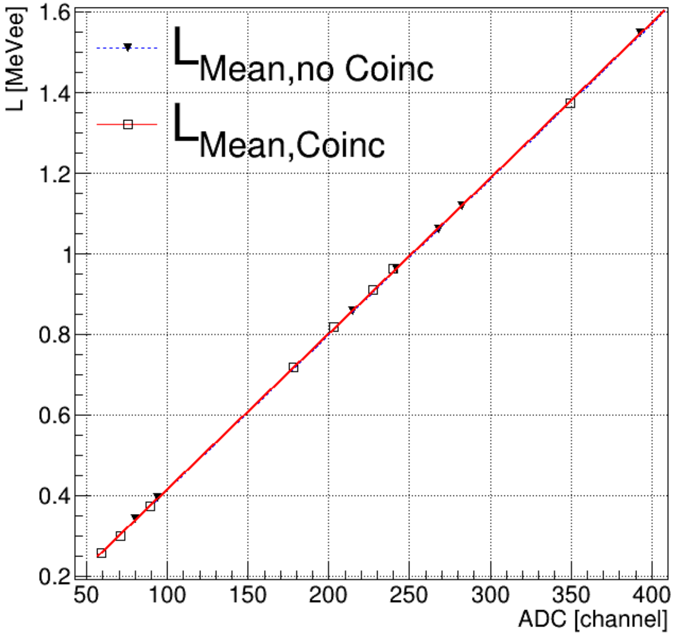
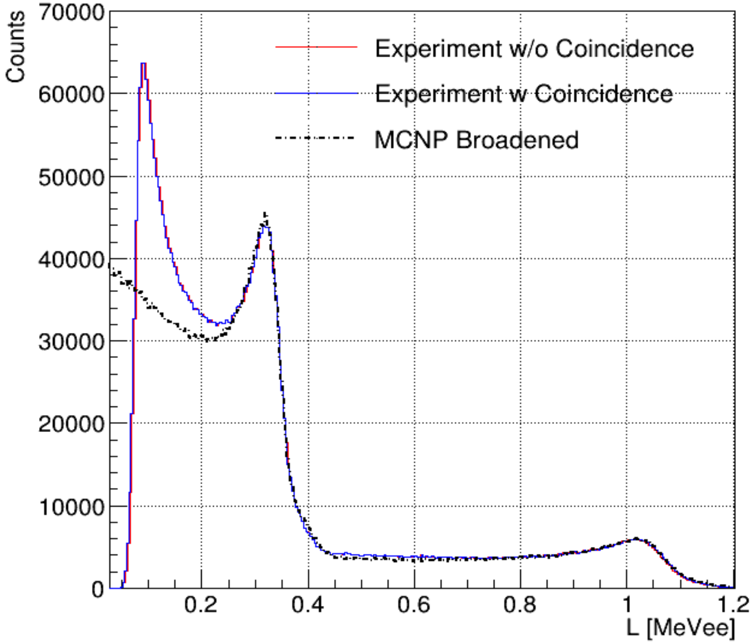
Photon response calibration

- Two methods used:
  - ✓ Direct, classical -> fast
  - ✓ Indirect, coincidence (second detector for TOF) -> slow, but better Compton edge localization
- Excellent coherence, direct calibration is sufficient, MCNPX model is accurate





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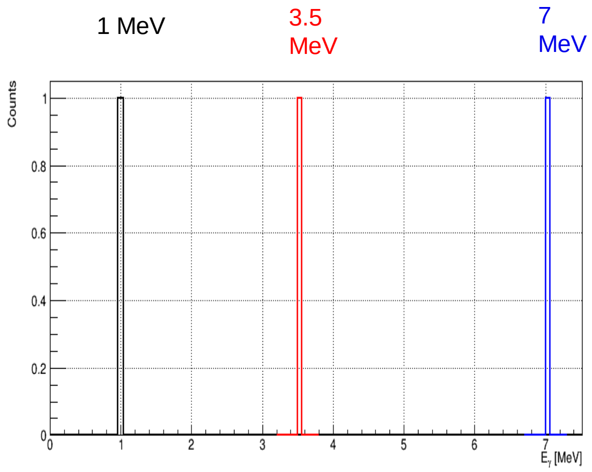
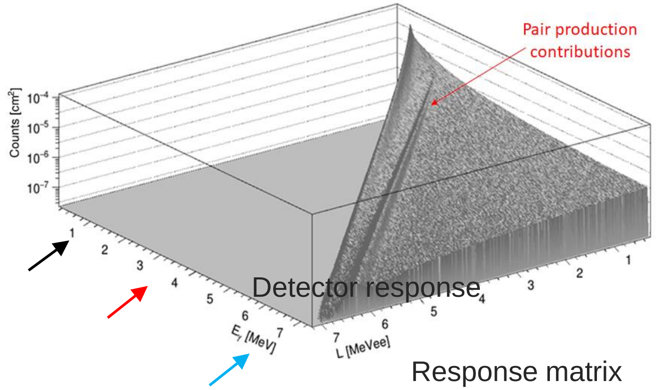
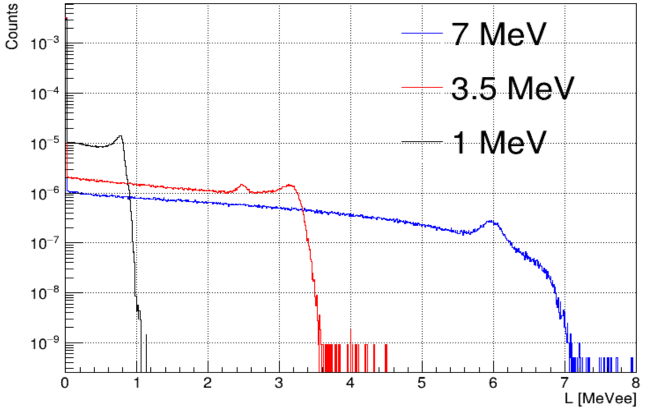
Photon response calibration







MCNPX: $E_\gamma \in [0.01,\ 7.3]$ [MeV], $\Delta E_n = 0.03$ [MeV] (243 energies)
$L \in [0,\ 8]$ [MeVee] (1024 bin)

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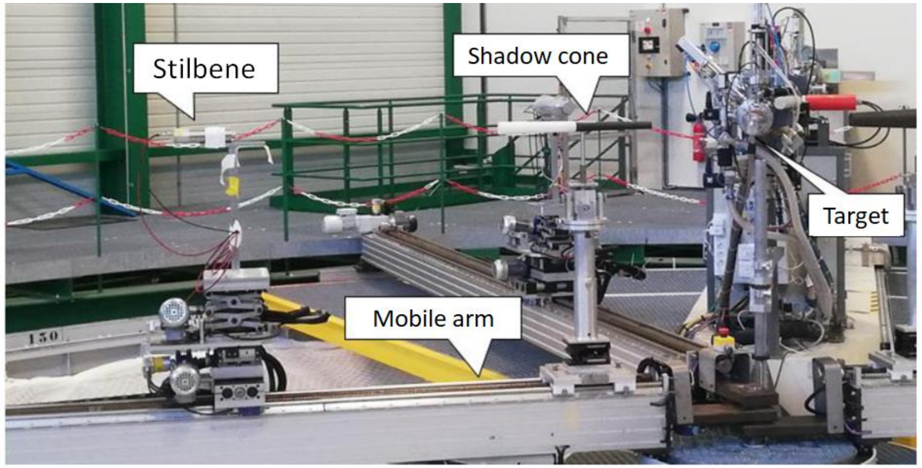
Neutron response calibration



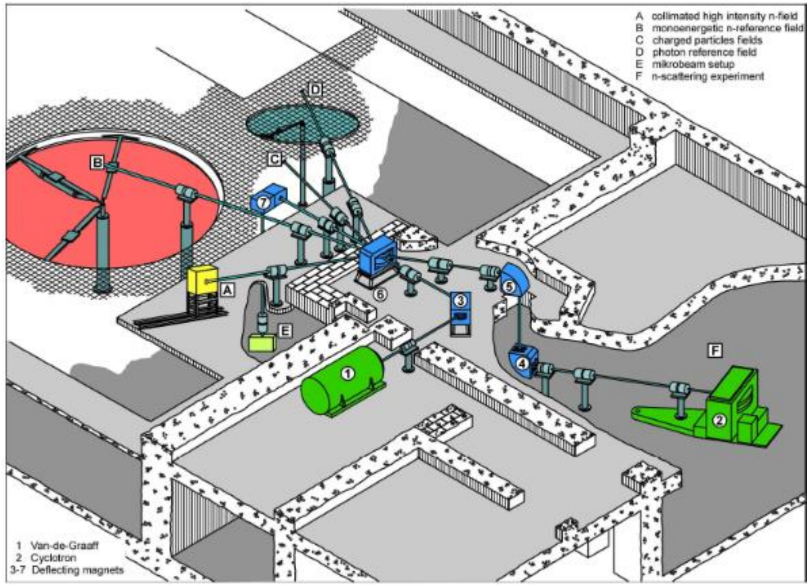
Measurements @AMANDE, IRSN Cadarache, France

- Beams of single energy neutrons

  E_n between 0.481 and 17 MeV

Measurements @PTB, Germany

- Cyclotron ToF, ^{9}Be(p,n), E_n between 0.5 and 16.5 MeV
- Tandetron T(p,n)^{3}He, E_n = 2.5 and 1.2 MeV
- Different detector orientations
- Remote control by CEA & IRSN teams (COVID19)
- ARIEL support under TAA_1_6



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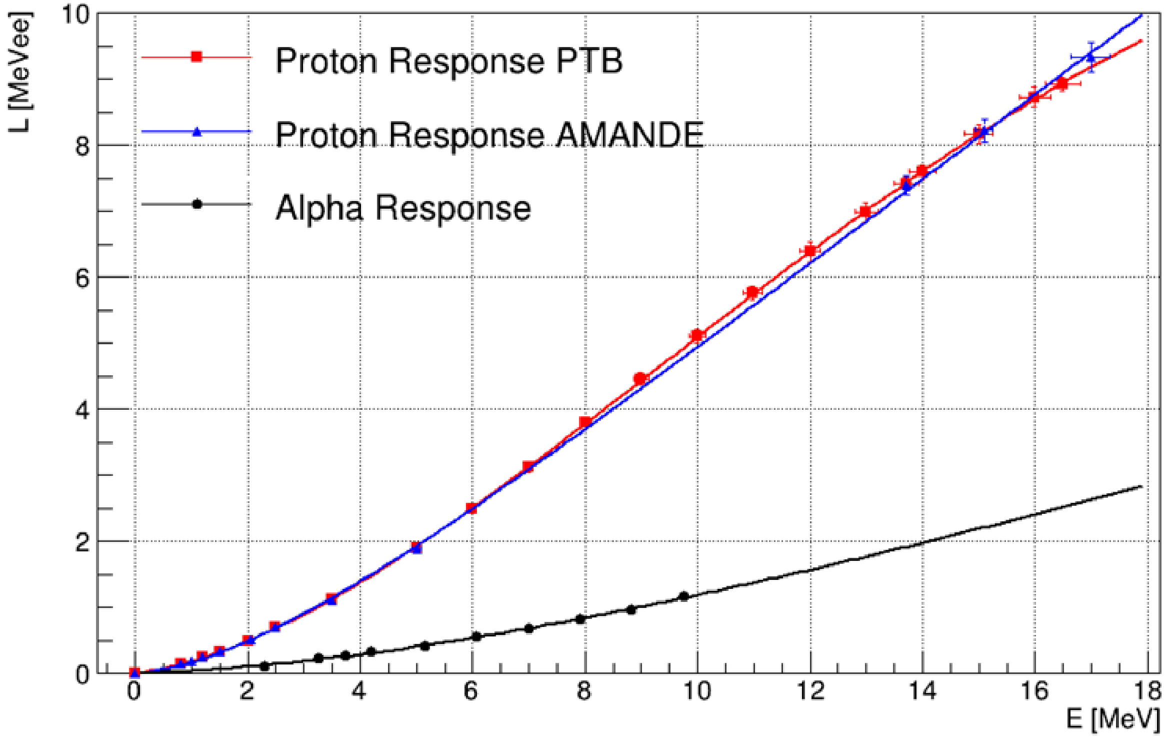
Neutron response calibration

- No discrimination *n*/γ problems over the entire energy range
- Use of semi-empirical equations for the particle response parametrization
- Complete (protons and alpha recoil particles) parameterizations of the neutron response



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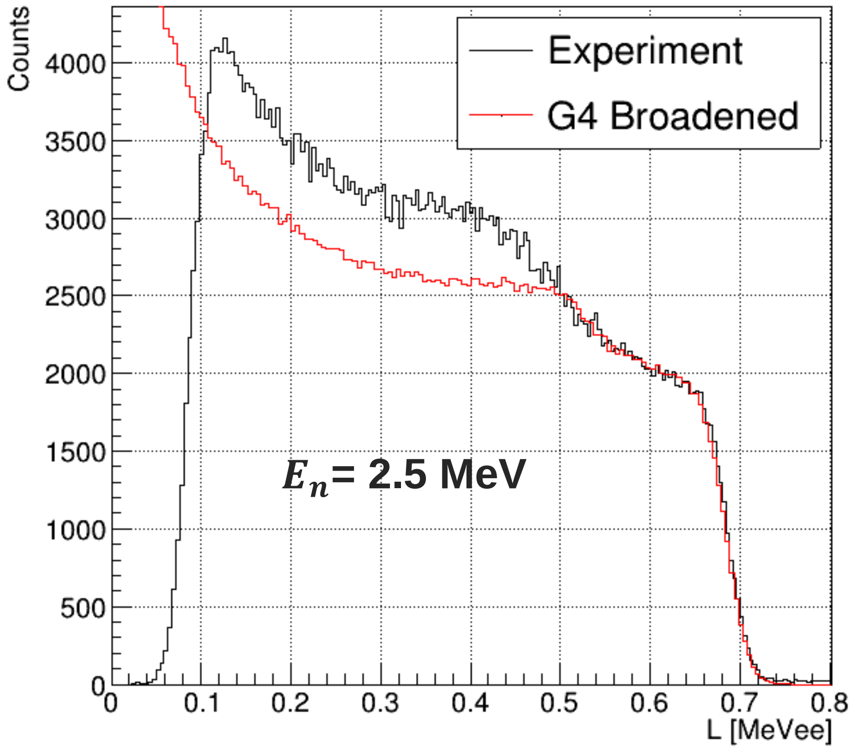
Comparison between GEANT4 simulations and measurements

- Good overall agreement between experimental and simulated results
- Good agreement on maximum energy deposition position for protons (and alphas)



- Some discrepancies in simulations vs. exp. results
- Possible improvements:
  - ✓ Detector model
  - ✓ Neutron cross sections (ENDF/B-VII.0 -> JENDL-4.0u)
  - ✓ Account for anisotropy effects by including crystal orientation

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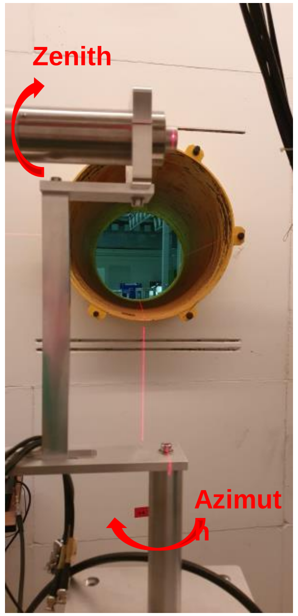
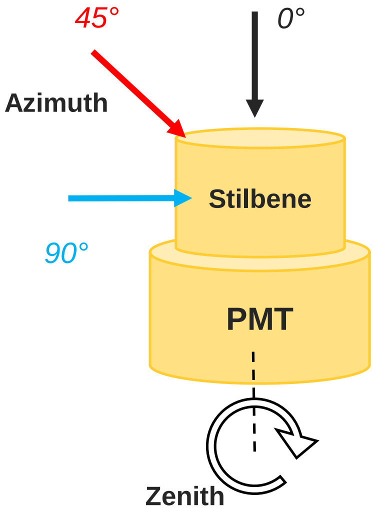
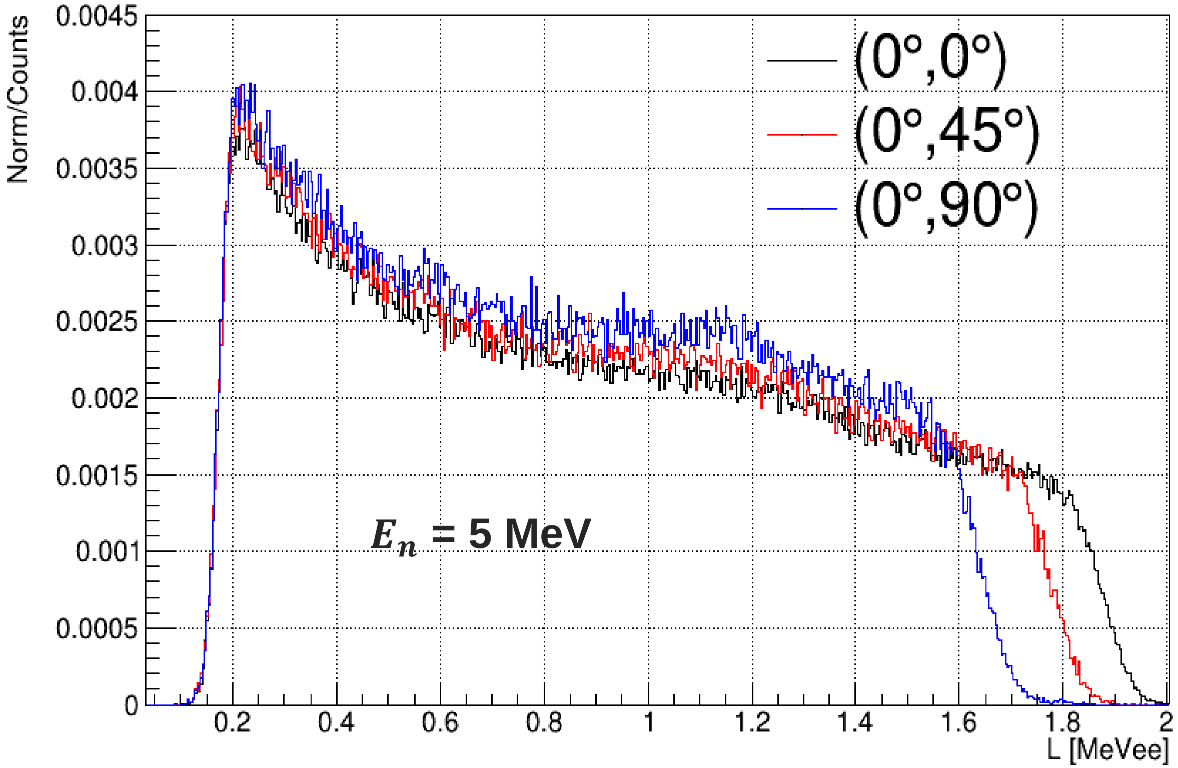
Anisotropy of the neutron response → Different Zenith-Azimuth orientations studied @PTB





Zenith	Azimuth				
0°	0°	30°	45°	60°	90°
45°		30°	45°	60°	90°
90°		30°	45°	60°	90°



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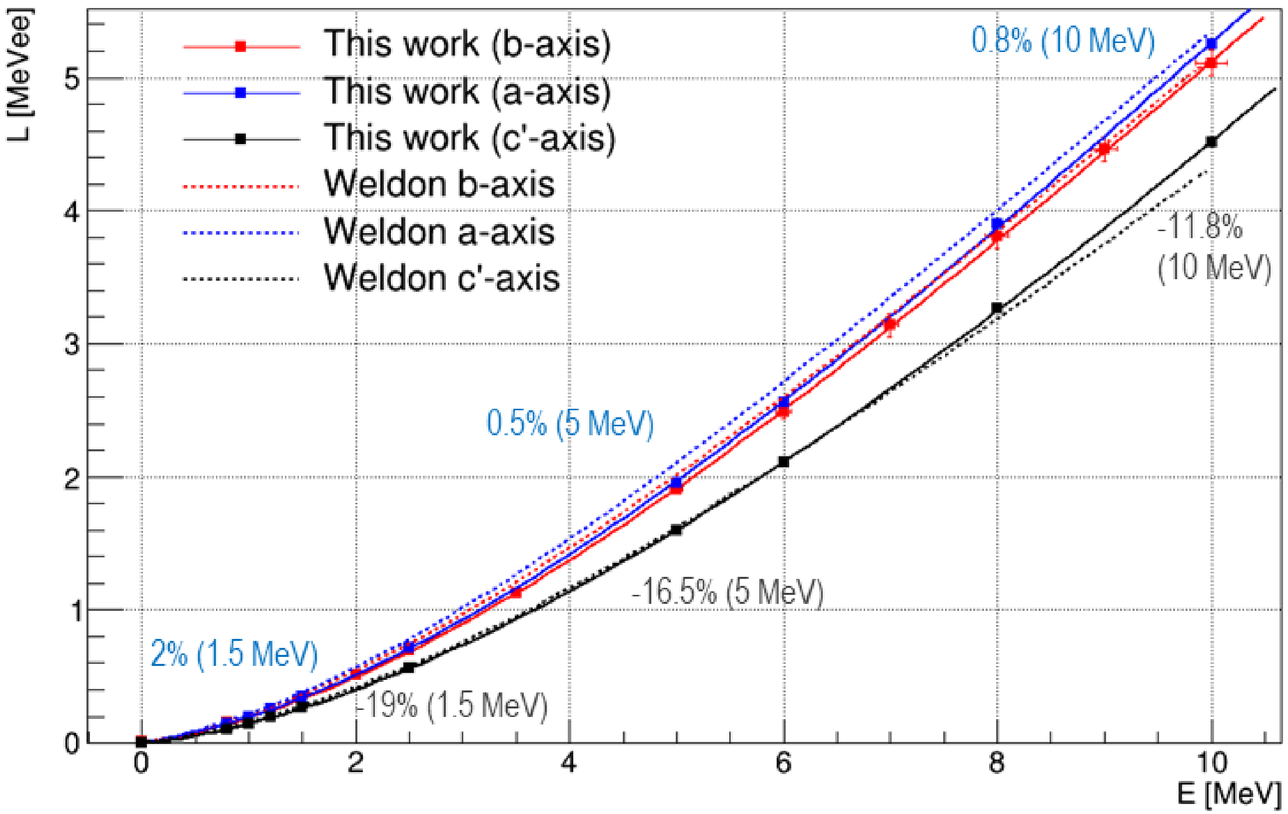
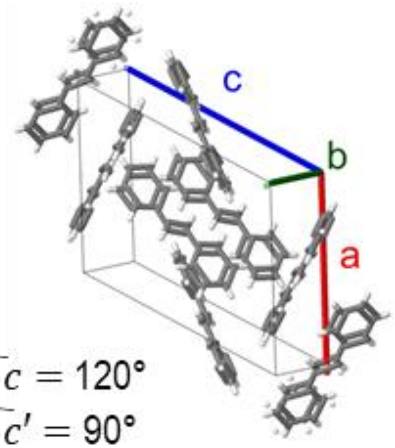
Anisotropy of the neutron response → Different Zenith-Azimuth orientations studied @PTB





$\widehat{(ab)}c = 120°$
$\widehat{(ab)}c' = 90°$

Zenith	Azimuth				
0°	0°	30°	45°	60°	90°
45°		30°	45°	60°	90°
90°		30°	45°	60°	90°

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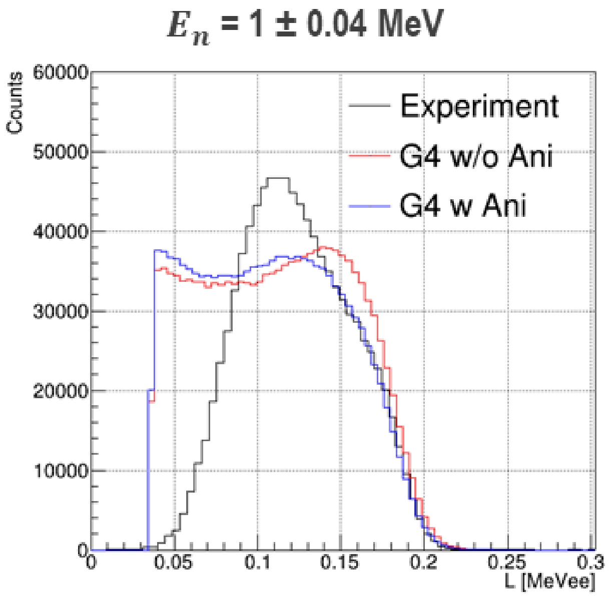
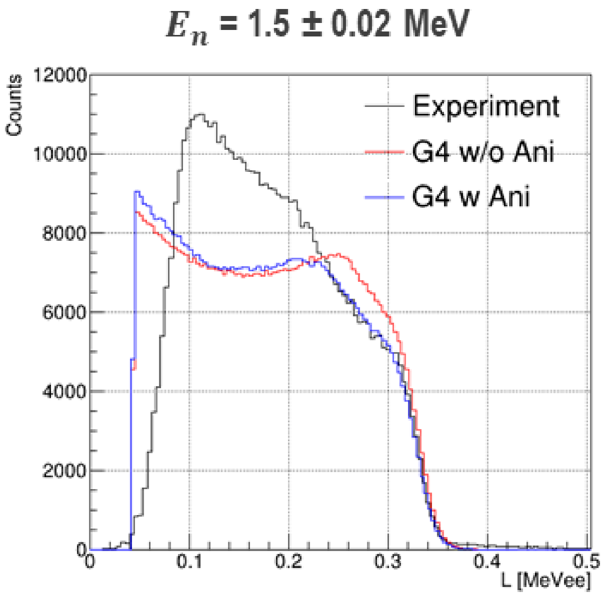
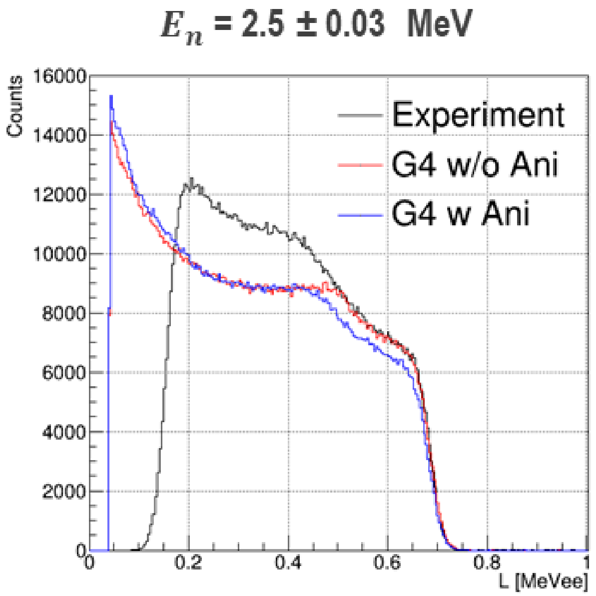
Anisotropy of the neutron response → Attempt to introduce it into GEANT4 model







AMANDE results with absolute normalization

- Shape discrepancies with/without anisotropy
- Absolute normalization: better with anisotropy below 2 MeV
- Conclusion : Improved Geant4 model still insufficient to reproduce experimental data

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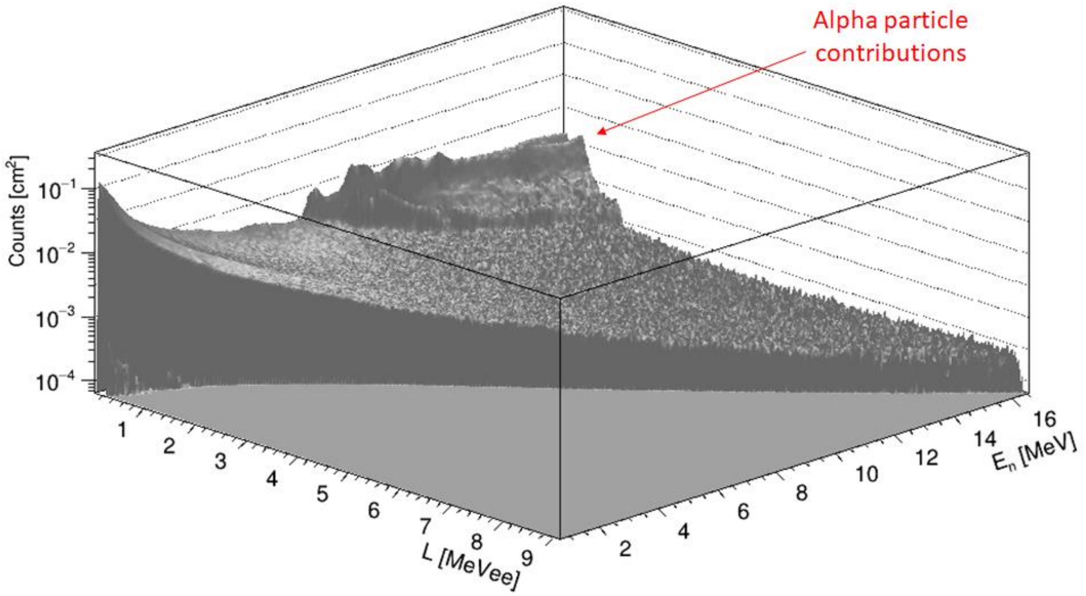
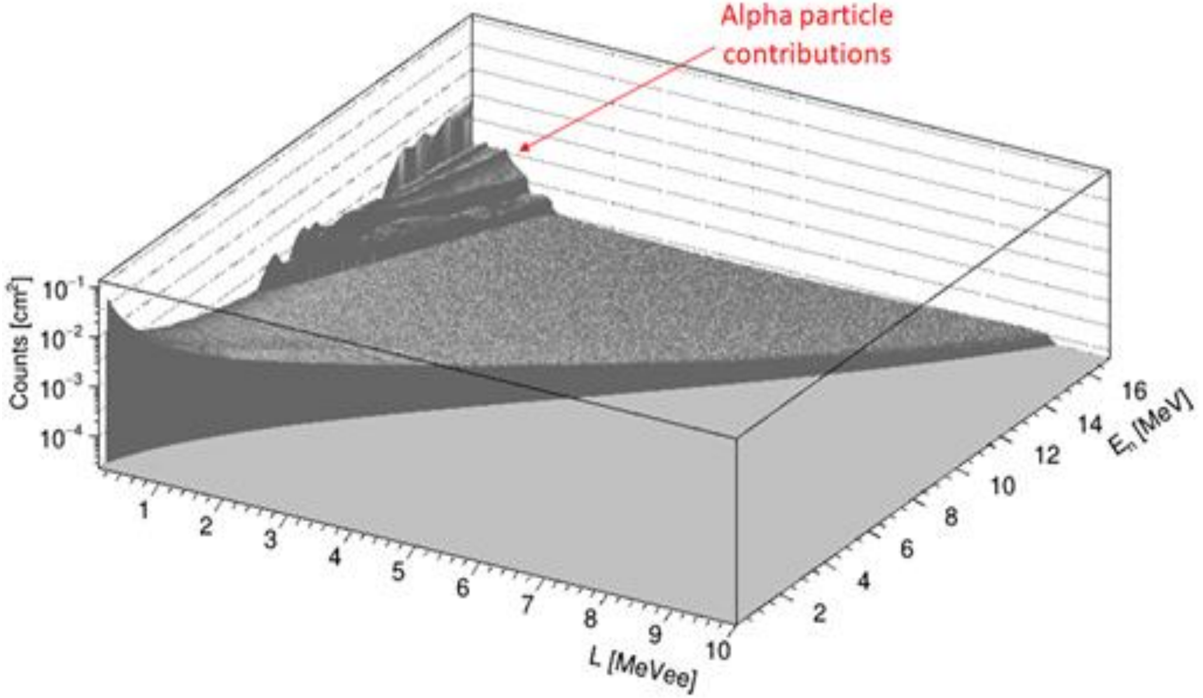
Neutron response matrix

- Construction of
  - An experimental (white spectrum of PTB) response matrix, left hand plot
  - A simulated (Geant4) response matrix, right hand plot





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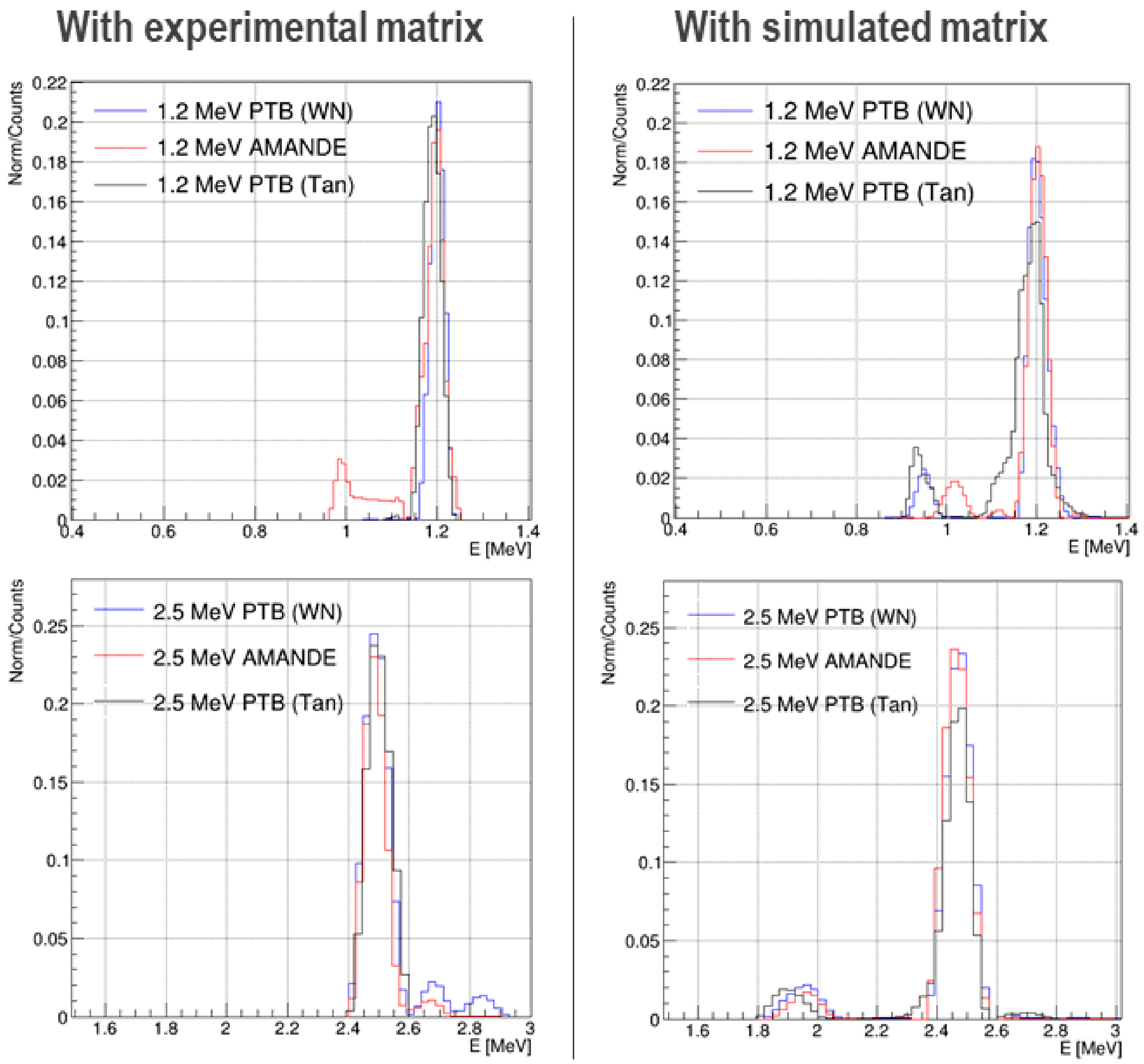
Unfolding tests using GRAVEL

- ➢ Correct identification of neutron energies down to 0.8 MeV (≈2%)
- ➢ Some issues: absolute fluence (not measured), resolution?
- ➢ Matrices ~validated for (quasi-)monoenergetic spectra



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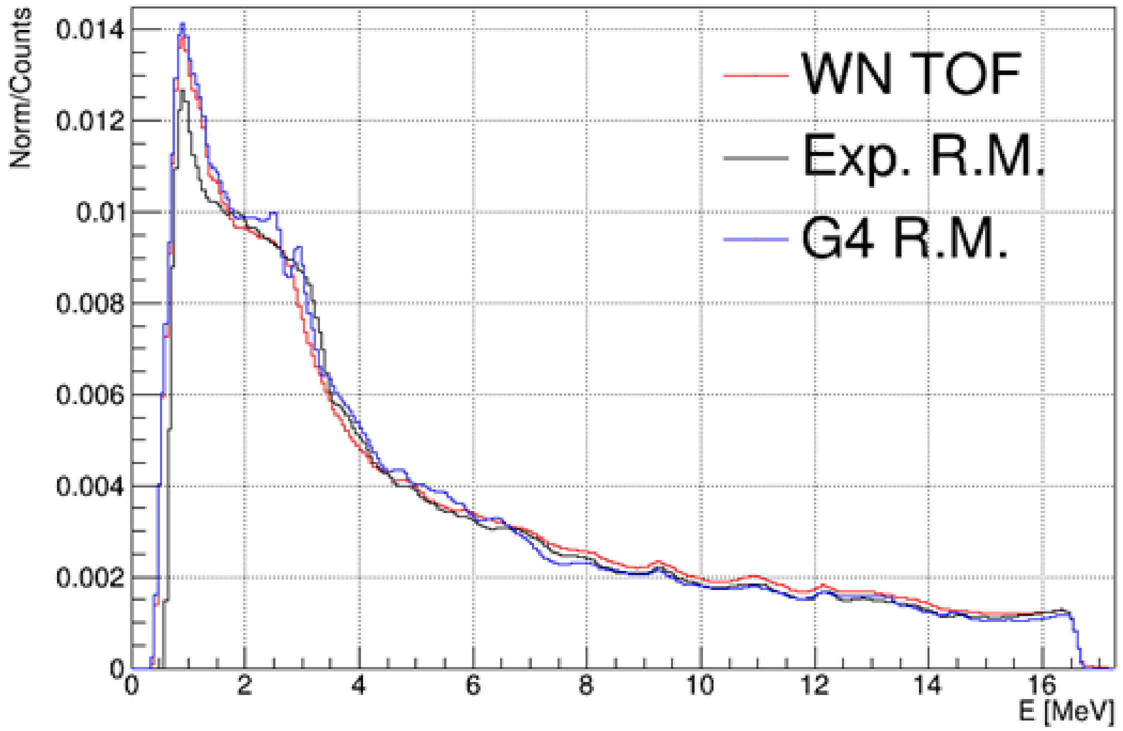
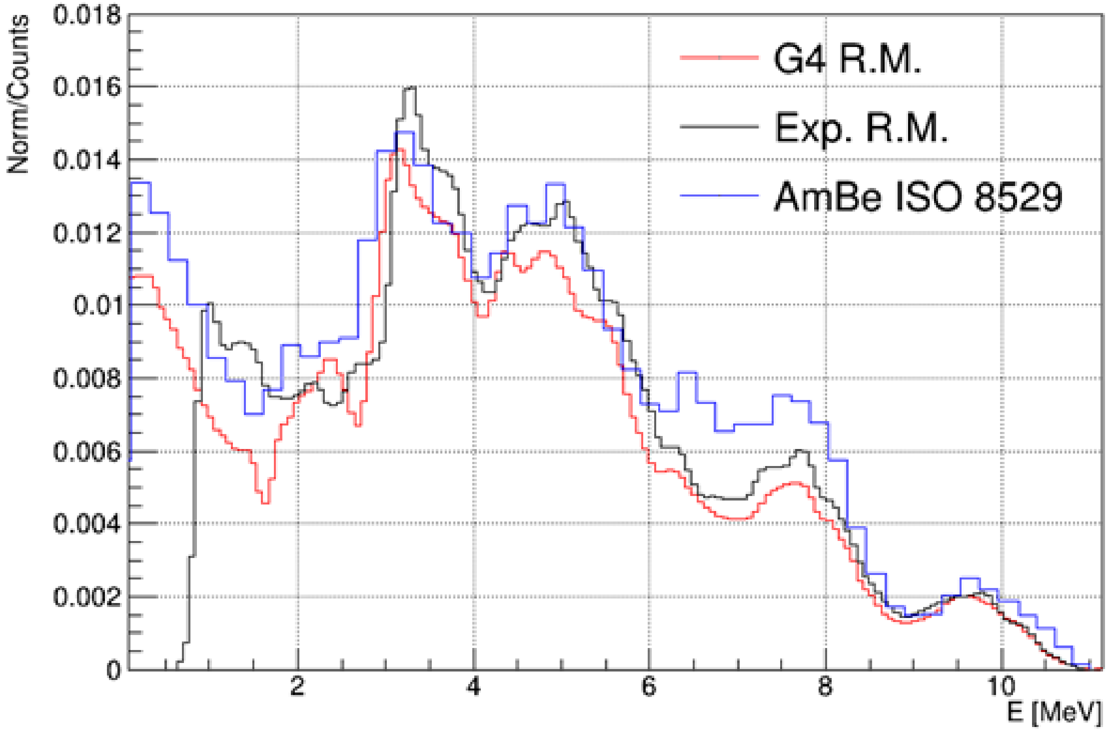
Unfolding tests

- White neutron: good agreement with the reference spectrum, with some fluctuations
- AmBe: Main peaks identified, discrepancies in intensities, possible issue with ISO source around 6-8 MeV





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Conclusion

- Extensive spectral characterization of a stilbene single crystal detector response using calibration measurements at AMANDE and PTB
- Gamma and neutron response matrices derived separately from experiments and simulations
- Study of anisotropy effects observed in neutron response, attempt at characterizing them with Geant4
- Good performance in spectrum unfolding tests, possible model improvements identified
- Excellent n/γ discrimination
- Exploitable neutron energy range: 0.7-17 MeV
- SANDA D.1.4, “Commissioning of a compact broad-band fast neutron spectrometer”

Acknowledgements

- SANDA and ARIEL supports
- Special thanks to the PTB and AMANDE staff