

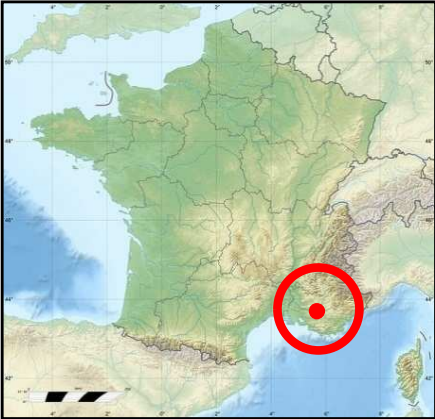
# Extended time-of-flight measurements down to 100 keV at the AMANDE facility with a stilbene scintillator

Michaël PETIT – IRSN / LNE-IRSN  
Augusto DI CHICCO – CEA  
Alix SARDET – CEA  
Richard BABUT – IRSN  
Robert JACQMIN – CEA  
Brian STOUT – Aix-Marseille University

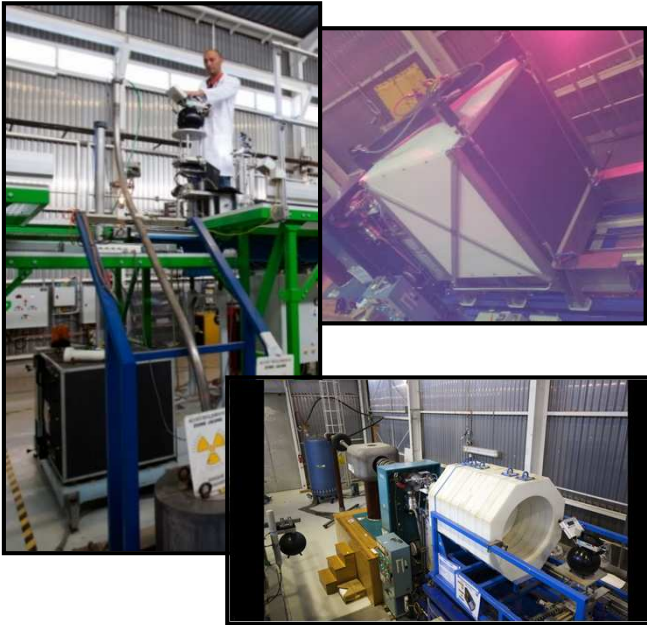


# The LMDN (LNE-IRSN) : the French neutron metrology laboratory

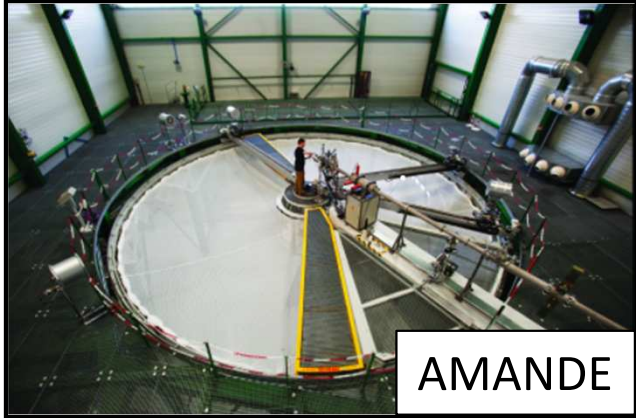
Cadarache France



**CEZANE Facility**  
Realistic neutron fields  
Thermal neutron field  
Irradiator  $^{252}\text{Cf}$  et  $^{241}\text{AmBe}$



**« AMANDE-MIRCOM » Facility**  
Monoenergetic neutron fields (AMANDE)  
Ion microbeam (MIRCOM)



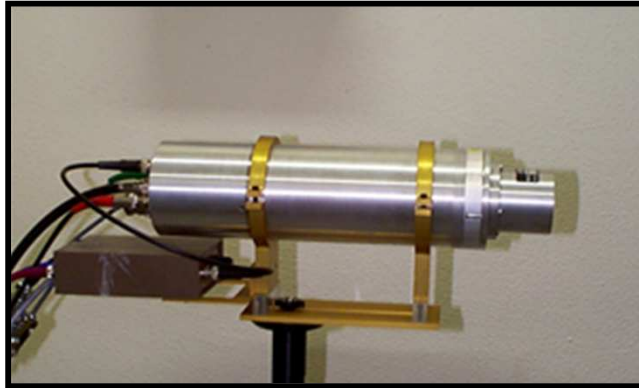
**AMANDE**

See K. LALANNE talk ←

# Scintillation detectors or, the "bread and butter" of the nuclear physicist

## A diverse and usefull family

- Plastic
- BC501A (liquid)
- EJ309 (liquid)
- Stilbene (cristal)
- Among many others



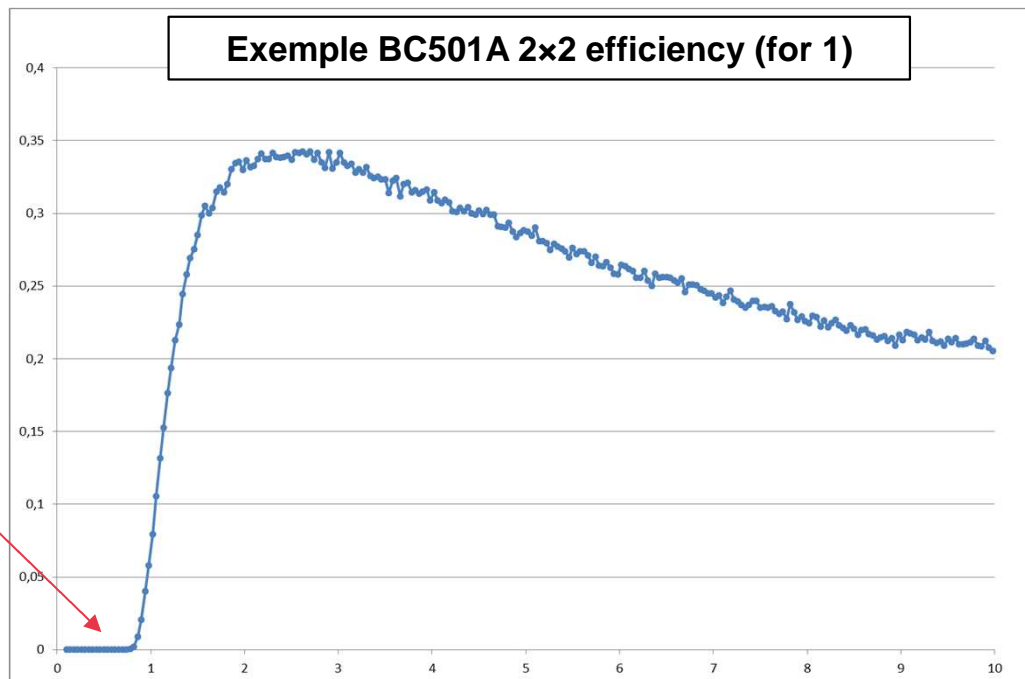
## Numerous advantages -> a popular type of detector in research and industry

- high efficiency for neutron and photon detection
  - Able to discriminate electrons from photons and protons from neutrons
- quick response (10 ns) with a time resolution of less than 1 ns
- Relatively cheap
- Easy to use - extensive literature and feedback
- Among many others

## But ...

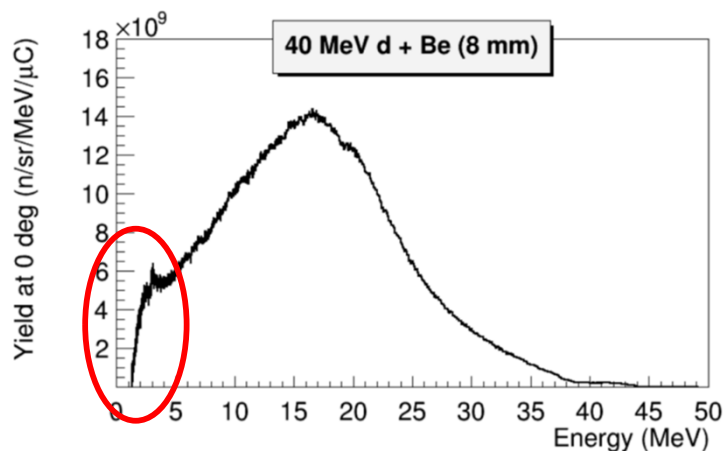
- One very annoying drawback for neutron metrology: "no" neutron efficiency below 1 MeV

No efficiency below  
1 MeV neutron



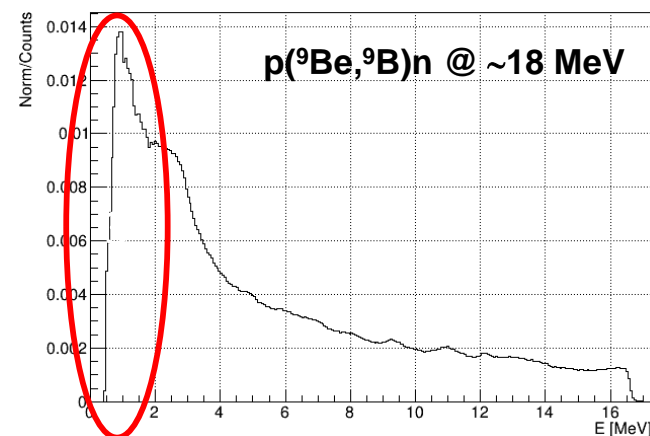
Neutron energy (MeV)

White spectrum at NFS (France)



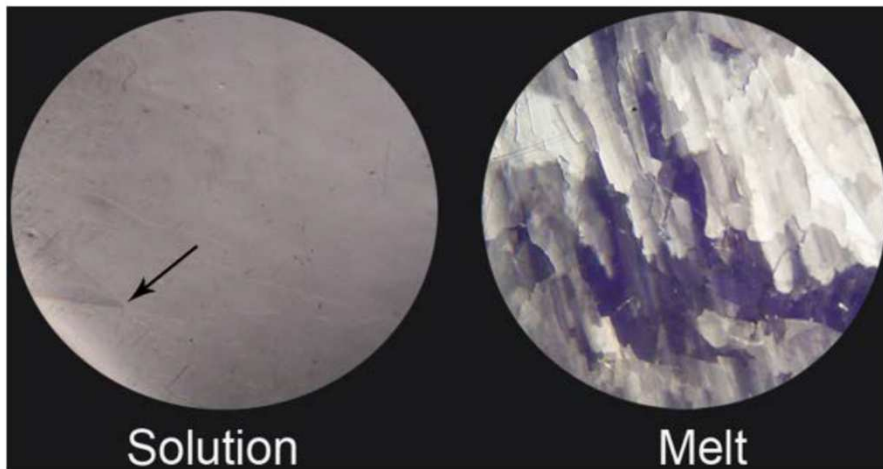
From NFS in ARIEL meeting 2022

White spectrum at PTB (Germany)

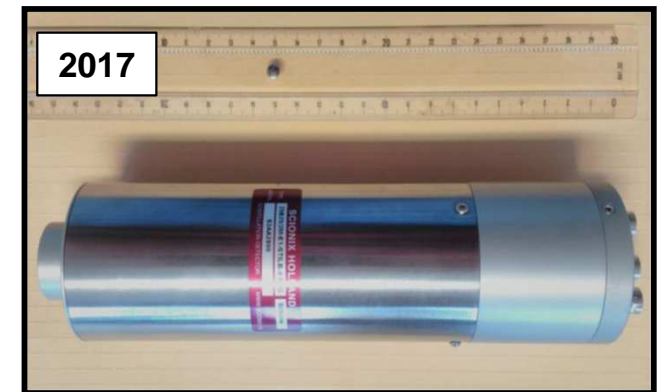


From "H. J. Brede, G. Dietze, K. Kudo, U. J. Schrewe, F. Tancu, and C. Wen, 'Neutron yields from thick Be targets bombarded with deuterons or protons', Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 274, no. 1, pp. 332–344, Jan. 1989

# Improvement in crystallography -> News in the scintillation landscape

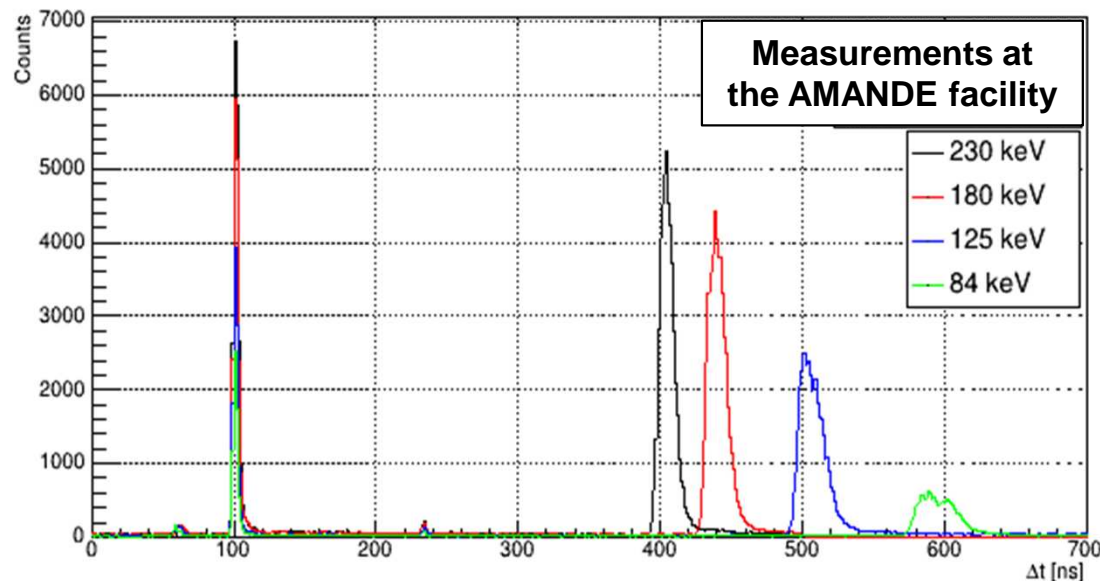


From : "N. Zaitseva et al., 'Scintillation properties of solution-grown trans-stilbene single crystals', Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 789, pp. 8–15, Jul. 2015, doi: 10.1016/j.nima.2015.03.090."



## Detector assembly:

- Scintillator:  $\varnothing 25.4 \times 25.4$  mm<sup>3</sup> solution-grown stilbene crystal (InradOptics)
- PMT:  $\varnothing 58.8 \times 223.5$  mm<sup>3</sup> 9214B-series (Et-Enterprise)

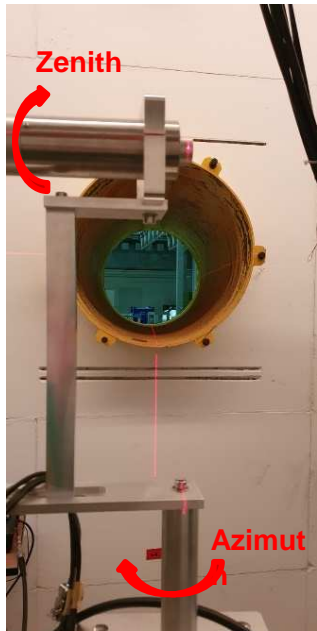


## Acquisition system and data analysis:

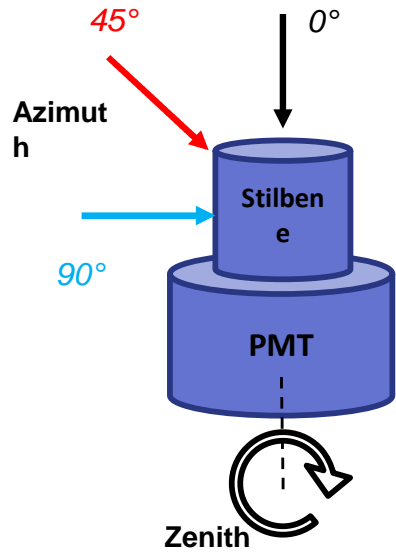
- DT5730 digital acquisition system

From : A. DI CHICCO and al. "Investigation of the neutron-gamma ray discrimination performance at low neutron energy of a solution-grown stilbene scintillator" EPJ Web of Conferences 225, 04013 (2020) ANIMMA 2019 <https://doi.org/10.1051/epjconf/202022504013>

# However, crystal scintillators type have a hard drawback, an anisotropic response to neutrons

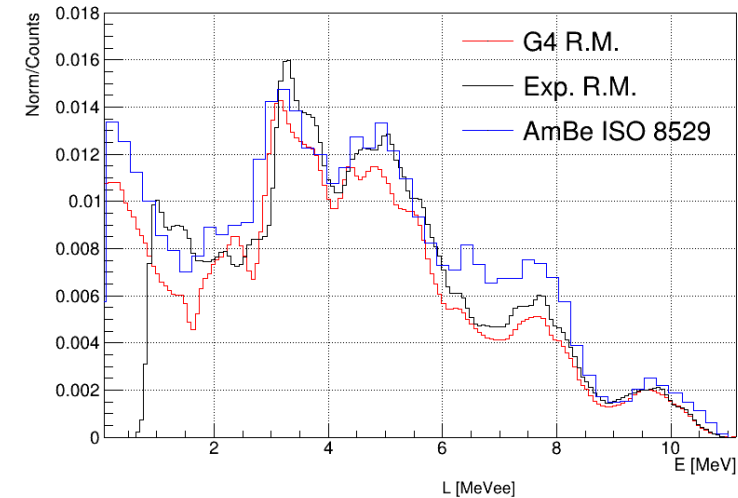
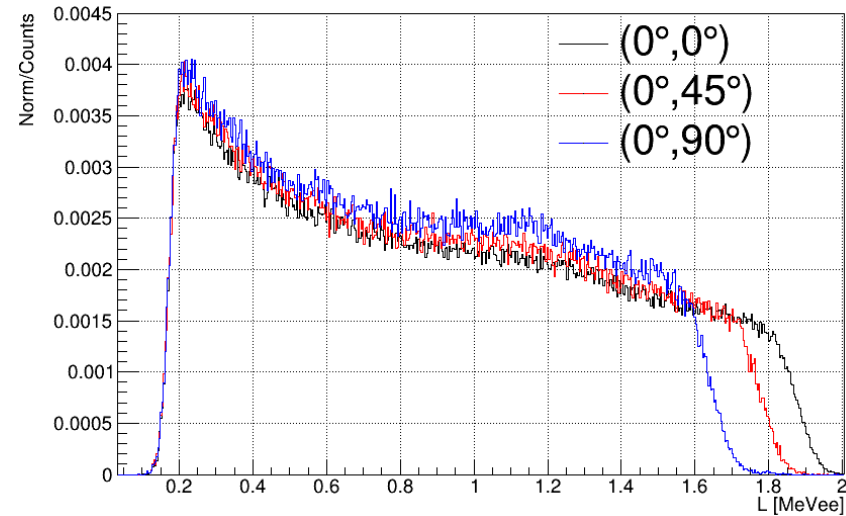


Measurements at PTB cyclotron facility



Measurements on 13 incidence's angles

## Neutron response: anisotropic



## Incorporation of anisotropy in GEANT4 simulations

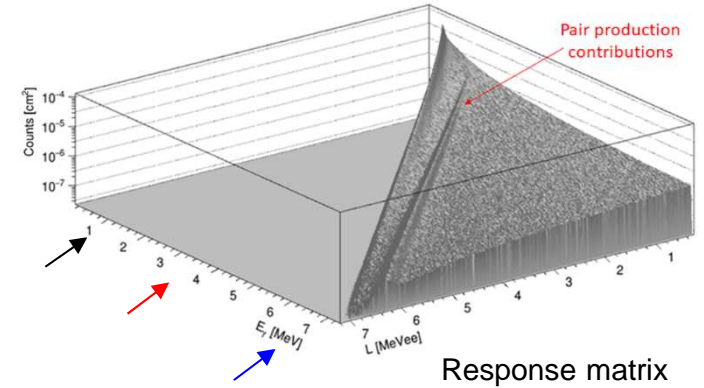
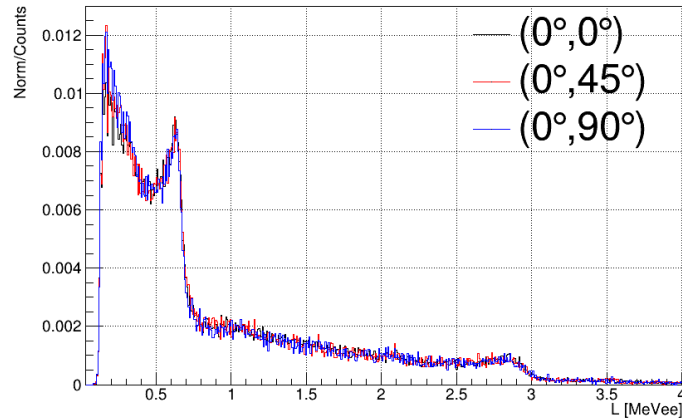
- By taking into account the direction of the recoil protons
- "small" Improvement in simulation/measurement comparisons
- But unexplained discrepancies remain

-> use of the experimental response matrix

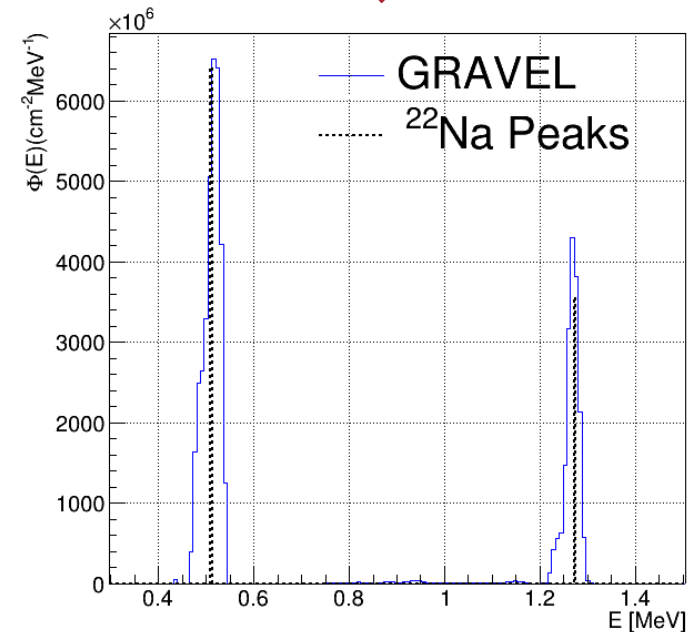
From A. DI CHICCO phd defence 30/03/2022

# Using of the stilbene scintillator as an alternative gamma spectrometer

Photon response: isotropic



Response matrix

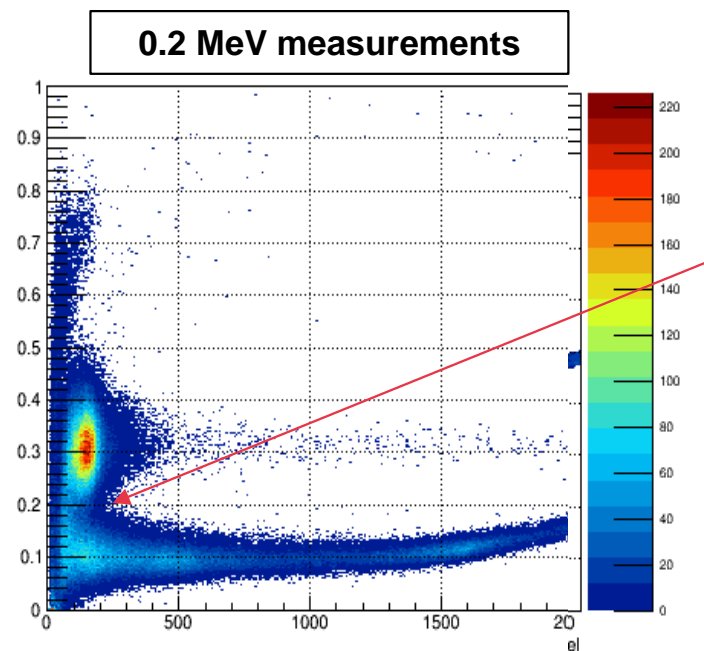
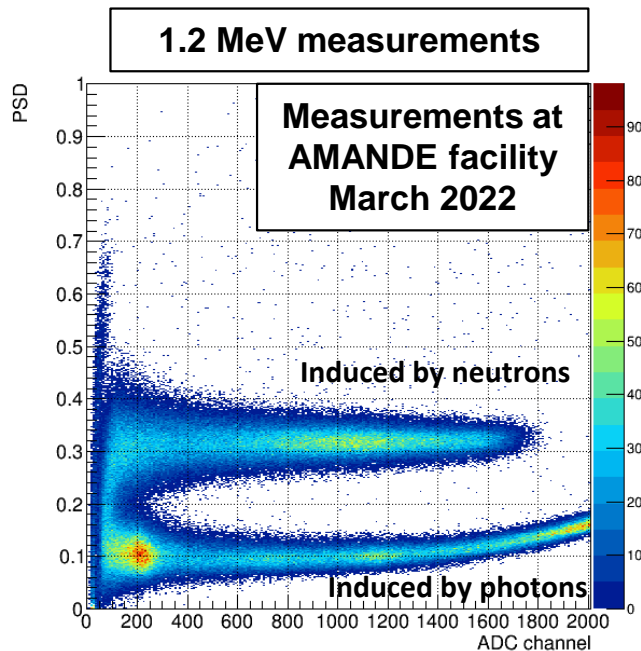


A. DI CHICCO and al. "Gamma-response characterization of a solution-grown stilbene scintillators in the 59 keV - 4.44 MeV energy range; an alternative low-resolution gamma spectrometer". Accepted for publication in NIM-A (March 2022)

From A. DI CHICCO phd defence 30/03/2022

# What's next?

- IRSN has since 2020 2 stilbene 2"×2"
  - 1 stilbene is dedicated to the range 0.5 MeV - 22 MeV
  - 1 stilbene is dedicated to the 0.1 MeV - 1.4 MeV
  - Optimization of the two detectors's configuration
  - The whole system is operational and ready to be calibrated

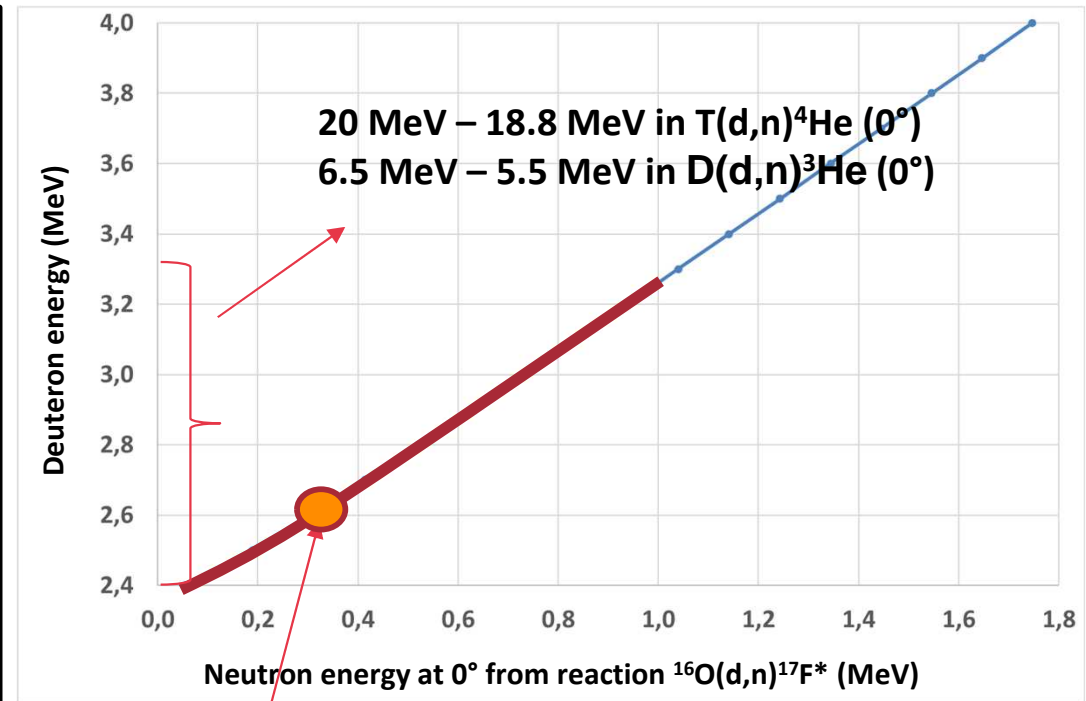
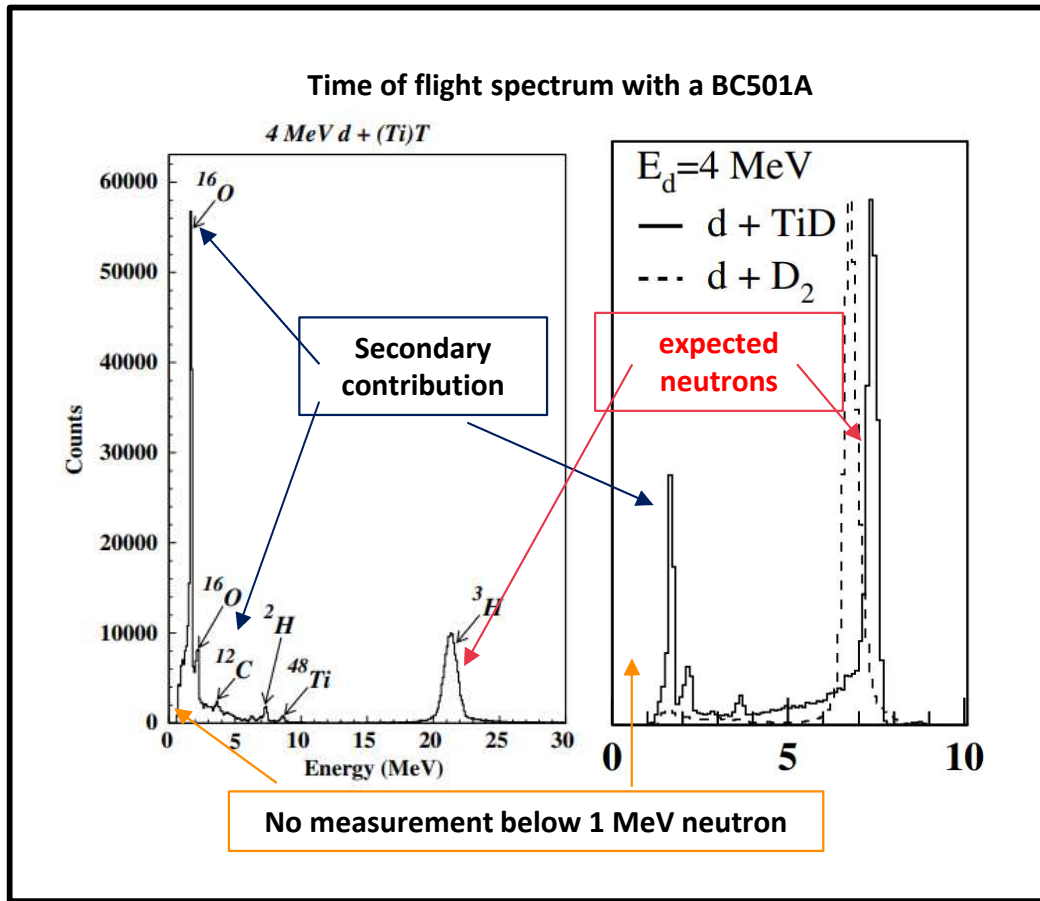


## Preliminary results:

- Discrimination limit  $\approx 0.2$  MeV
- Detection limit  $< 0.1$  MeV



# Application for AMANDE time of flight measurement

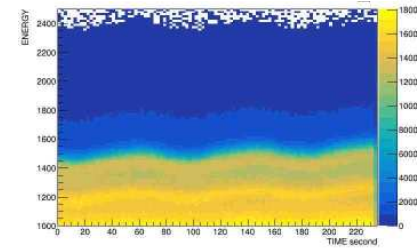


- From : C. Varignon et al. / Nucl. Instr. and Meth. in Phys. Res. B 248 (2006). CEA measurements (France)

Extract from ISO8529-1 standard  
(news and old version)  
-> some of the recommended  
neutron energy production (MeV)

0,565 <sup>a</sup>	Accelerator-produced neutrons from reaction $\text{T}(p,n)^3\text{He}$ and $^7\text{Li}(p,n)^7\text{Be}$
1,2 <sup>a</sup>	Accelerator-produced neutrons from reaction $\text{T}(p,n)^3\text{He}$
2,5 <sup>a</sup>	Accelerator-produced neutrons from reaction $\text{T}(p,n)^3\text{He}$
2,8 <sup>a, b</sup>	Accelerator-produced neutrons from reaction $\text{D}(d,n)^3\text{He}$
5,0 <sup>a</sup>	Accelerator-produced neutrons from reaction $\text{D}(d,n)^3\text{He}$
14,8 <sup>a, b</sup>	Accelerator-produced neutrons from reaction $\text{T}(d,n)^4\text{He}$
17,0	Accelerator-produced neutrons from reaction $\text{T}(d,n)^4\text{He}$
19,0 <sup>c</sup>	Accelerator-produced neutrons from reaction $\text{T}(d,n)^4\text{He}$

# Conclusions



- Scintillators are detectors widely used in research and industry
  - These type of detectors are usually not efficient below 1 MeV neutron
- Advances in crystal production allow to have specific scintillators able to go below the usual limit of 1 MeV down to 100 keV neutron
- These detectors can be used for neutrons from their experimental response matrix and for photons as a low resolution spectrometer down to 59 keV
- The use of these detectors will allow to improve the references thanks to the measurement of the neutron contribution below 1 MeV in complex fields (but it is complicated in practice!!!)
- An IRSN thesis co-financed by LNE and in collaboration with the CEA and the Aix-Marseille University should start on these subjects in October 2022

## THANKS TO THE COLLABORATION TEAM

MICHAËL PETIT – IRSN (LMDN) / LNE-IRSN

AUGUSTO DI CHICCO – CEA

ALIX SARDET – CEA

RICHARD BABUT – IRSN (LMDN) / LNE-IRSN

ROBERT JACQMIN – CEA

BRIAN STOUT – AIX-MARSEILLE UNIVERSITY

Thank you for your  
time and attention  
At your disposal