A Neutron Time-of-Flight Array for SPIRAL2-DESIR

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Low-energy neutron spectroscopy at SPIRAL2-DESIR

DESIR: Low-energy facility at GANIL/SPIRAL2

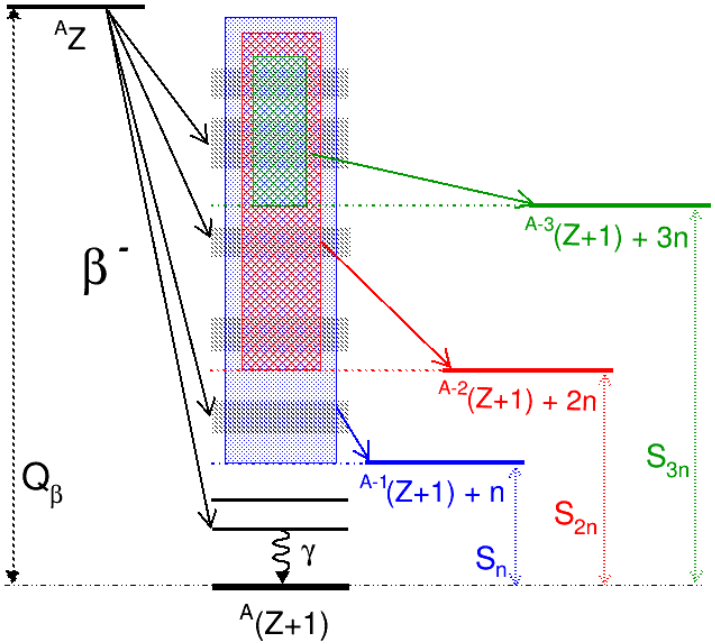
= *Désintégration, Excitation et Stockage d'Ions Radioactifs*

= *Decay, Excitation, Storage of Radioactive Ions*

β-decay of neutron-rich nuclei

- Delayed neutrons, $E_n \approx 0$ to 10 MeV
- Detect neutrons $\rightarrow E^*$, I_β, J^π
- Most n-rich systems: β-2n, β-3n

▷ Sequential/direct emission, nn correlations



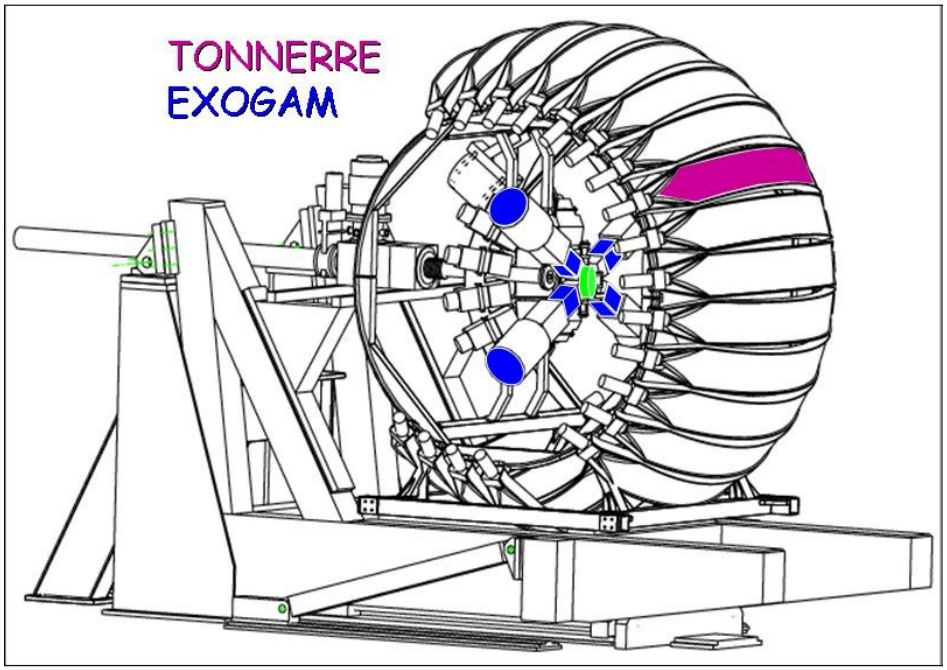
Detection requirements

- Low-energy neutrons: $E_n \approx 0$ to 10 MeV
- High efficiency $\rightarrow$ weak transitions, low-intensity beams, multiple neutrons, β-n-γ coincidences
- Good energy resolution $\rightarrow$ level density of intermediate-mass nuclei
- Multiple-neutron detection capability
- Coupling to β and γ detectors, tape system...

Current β-delayed neutron arrays

TONNERRE array (LPC Caen, IFIN Bucharest)

A. Buta et al., NIM A455 (2000) 412



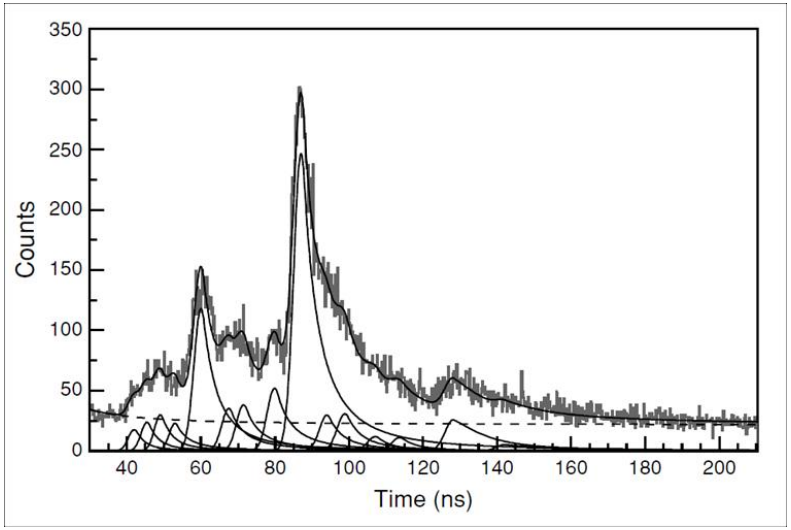
- 32 bars, $160 \times 20 \times 4$ cm^3
- BC400 plastic
- E_n from TOF ($d_{flight} = 1.2$ m)
- Resolution: $\delta E_n / E_n \approx 10$ %
- Up to 45 % of 4π
- Intrinsic $\epsilon_n \approx 45$ % at 1 MeV
- Threshold: $E_n \approx 300$ keV

TONNERRE Limitations

β-**1n**

^{52}K β-1n at ISOLDE

F. Perrot *et al.*, PRC 74,014313 (2006)



No discrimination → background

$\delta E_n/E_n$ limited by thickness & d_{flight}

Asymmetric TOF lineshape

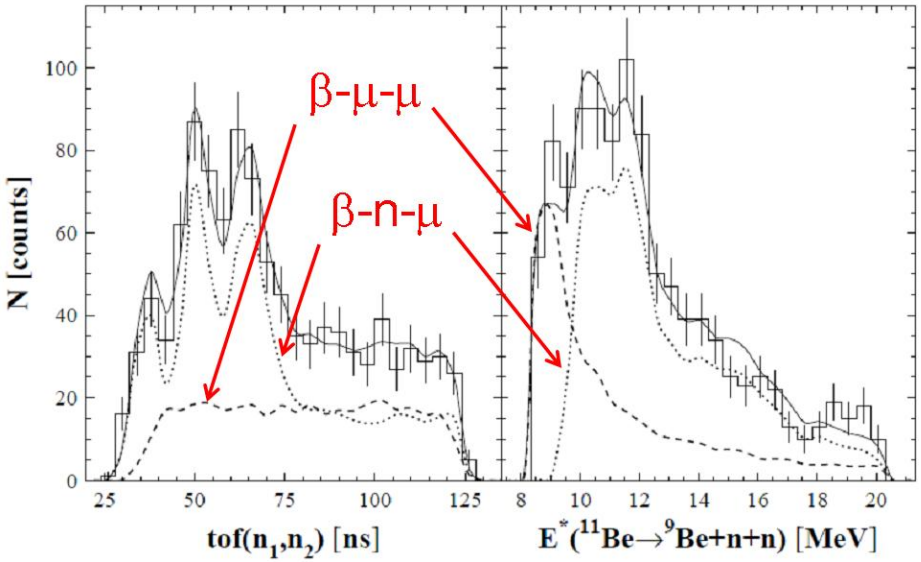
Relatively high threshold

β-**2n**

2 n in coincidence → energies & angles

Attempt with ^{11}Li, GANIL-LISE3

F. M. Marqués *et al.*



No discrimination → 80 % of random coincidences (β, ambient γ, cosmic μ)

Strategies for an improved neutron TOF array

- **Reduce background**
  - ▷ n-γ discrimination: liquid scintillator
- **Improve energy resolution, reduce lineshape asymmetry**
  - ▷ thin, small volume detectors, large PMTs
  - ▷ increase flight distance ($\approx$ 3 m or higher)
- **Lowest possible threshold for neutrons**
  - ▷ thin, small volume detectors, large PMTs
  - ▷ digital electronics
- **Multiple neutron detection**
  - ▷ background reduction: n-γ discrimination
  - ▷ cross-talk reduction: modular array, high granularity, variable geometry

Envisaged array: LENA

"**L**ow **E**nergy **N**eutron **A**rray"

- Modular array ($\lesssim$ 100 modules)
- Module design
  - ▷ 5 cm thick, 20 cm in diameter
  - ▷ Liquid scintillator (BC501A)
  - ▷ Large-diameter ($\approx$ 13 cm) PMT
  - → Similar to EDEN[1]: NE213, XP4512B PMT
- $E_n < 1$ MeV: smaller modules? ($\rightarrow$ better n-γ discrimination)
  $\rightarrow$ Candidate materials to be tested (WP2)
- Digital DAQ - DSP

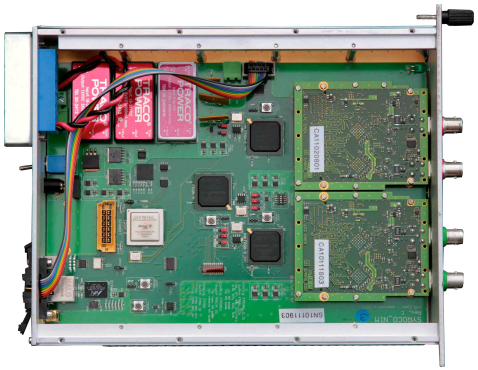
Collaboration with D. Cano-Ott et al., CIEMAT
(MONSTER array, JYFL & FAIR/DESPEC)

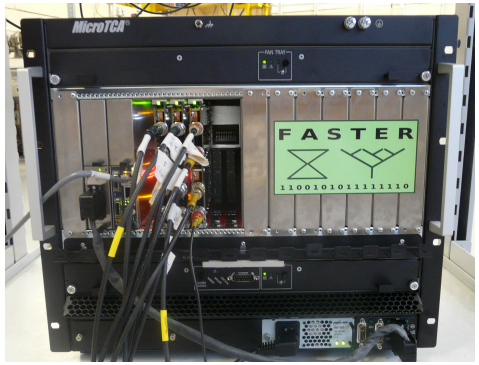
[1] H. Laurent *et al.*, NIM A326 (1993) 517

Development status: Digital DAQ

Digital DAQ - DSP: FASTER project[2]

- 2005-2008: single-channel digital functions (FPGA-based)
  → **spectroscopy amplifier + ADC, QDC + CFD, RF**
- 2010: ≈ **10-channel capability** (4-channel NIM-size modules)
- 2012: ≈ **50-channel capability** (μTCA standard bins)





- **Spec. amp. + ADC**: 125 Ms/s, 14 bits, range ≤10 V, BW 25 MHz
  → ≈ 2 keV FWHM with Ge detectors (ϵ = 10 % and 70 %)
- **QDC-CFD**: 500 Ms/s, 12 bits, range 2.3 V, BW 100 MHz
- Base-line correction, no common dead-time, time-stamp, oscilloscope mode...

[2] D. Etasse *et al.*, LPC Caen

Characterisation of modules with monoenergetic neutrons

CEA Bruyères-le-Châtel, Oct. 2011 & Oct. 2012

Neutron energies:

- 2011: 0.3 to 5 MeV
- 2012: 2.1, 5 & 16 MeV

▷ EDEN & MONSTER module characterisation

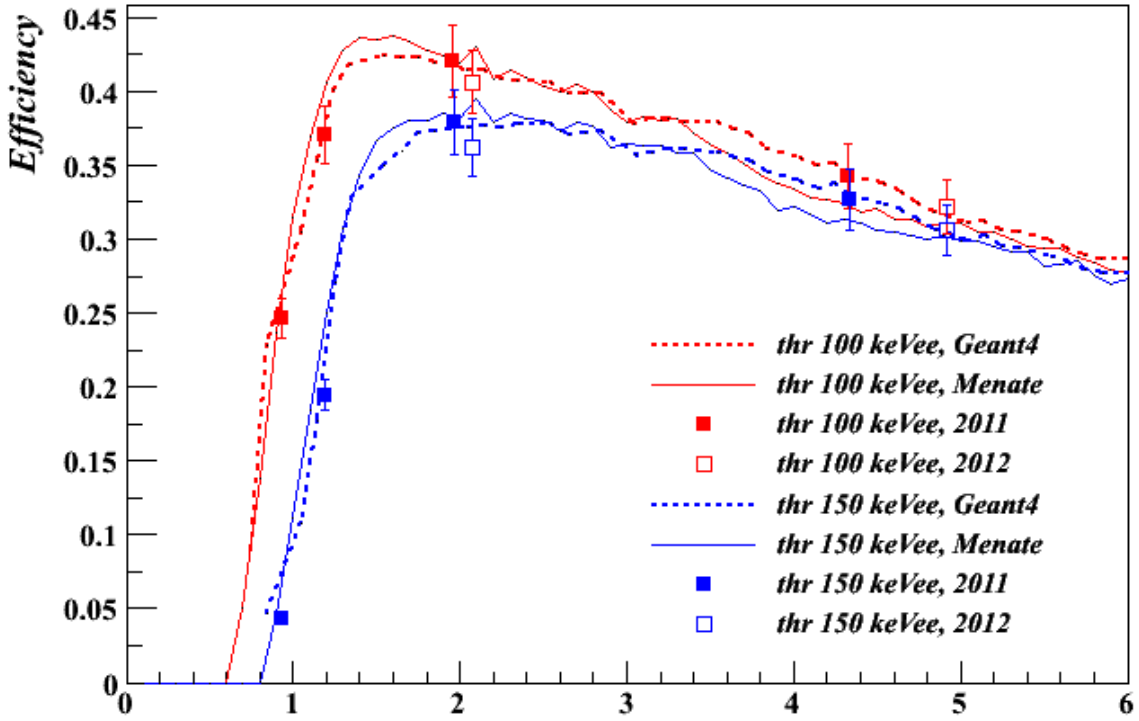
- Intrinsic efficiency
- Cross-talk (no data $<$ 14 MeV) $\rightarrow$ validate simulations & cross-talk filter[3]
- TOF response to monoenergetic neutrons $\rightarrow$ lineshape

[3] F. M. Marqués *et al.*, NIM A450 (2000) 109

Intrinsic efficiency

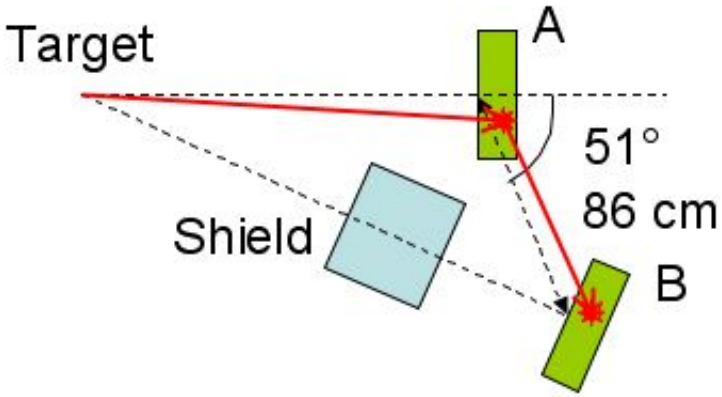
Neutron flux monitoring: BF_3 ($E_n < 6$ MeV) & BC501A ($E_n = 16$ MeV) detectors

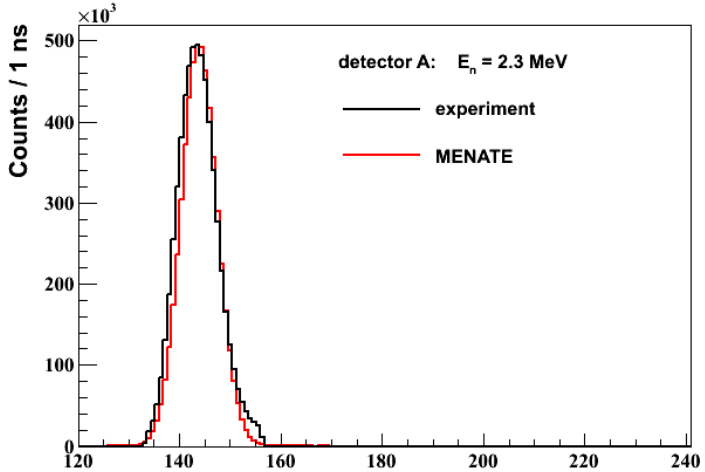
Results for MONSTER module:

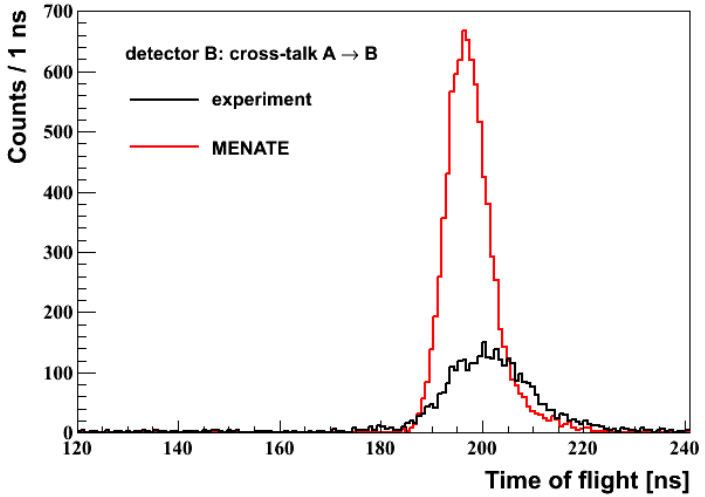


MENATE: P. Désesquelles, NIM A 307 (1991) 366

Cross-talk







Preliminary results at $E_n = 2.3$ MeV
Threshold = 100 keVee

Cross-talk probability:
$(N_{AB}/N_A)_{exp} = (5.5 \pm 0.1) \times 10^{-4}$

Simulations (MENATE)
$(N_{AB}/N_A)_{sim} = (15.5 \pm 0.5) \times 10^{-4}$

→ Realistic Geant4 simulations including detector structure and support structure

Multiple neutron emission

Study of multi-neutron emission in the β-decay of ^{11}Li

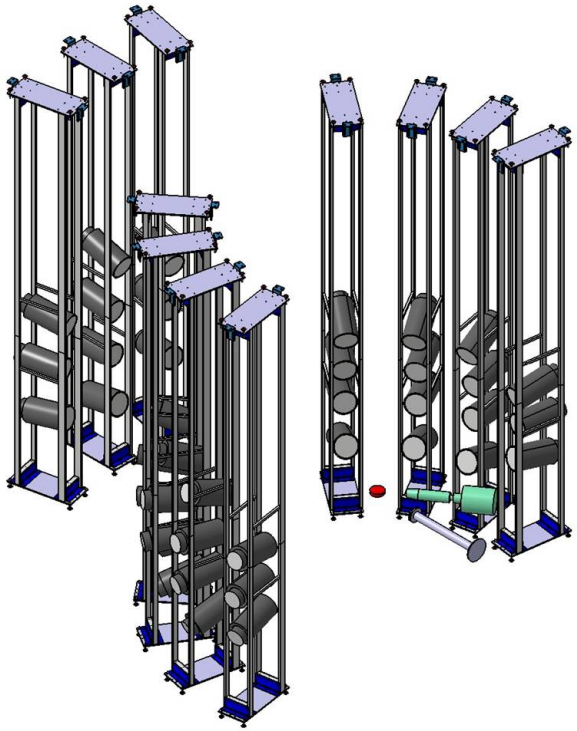
LPC, CIEMAT, IEM, Chalmers Univ., IFIC, UPC, Univ. Aarhus, IPNO, CEA/DAM/DIF

Approved experiment at ISOLDE

- → **Viability of liquid-scintillator arrays for β-n**
- → **β-2n capability, with TOF & angles**
- → **Feasibility of nn correlation studies**

Setup

- n's: 30 MONSTER + 6 CEA + 4 EDEN
- β-rays: plastic
- γ-rays: 2 HPGe detectors



Timeline

2013	Implementation of $\approx$ 50 digital DAQ channels Realistic test ($\approx$ 10 dets + digital DAQ) for 2n coincident detection
2014	^{11}Li-β-2n at ISOLDE
2014-...	Stepwise acquisition of new liquid scintillator modules
2018(?)	SPIRAL2-DESIR "Day 1 experiment" $\rightarrow$ β-n decay of n-rich Kr isotopes

Conclusions

- A TOF array for β-delayed n spectroscopy at DESIR is being developed
- Goal: Improved characteristics compared to previous arrays
- Emphasis on resolution / lineshape , background reduction (n-γ discrimination), multiple neutrons (cross-talk), digital DAQ
- The module design is being characterised with sources and monoenergetic neutrons
- Proof of principle of β-2n studies with TOF array: ^{11}Li-β-2n, ISOLDE