Beta-delayed neutrons from oriented ^{137,139}I, and ^{87,89}Br nuclei

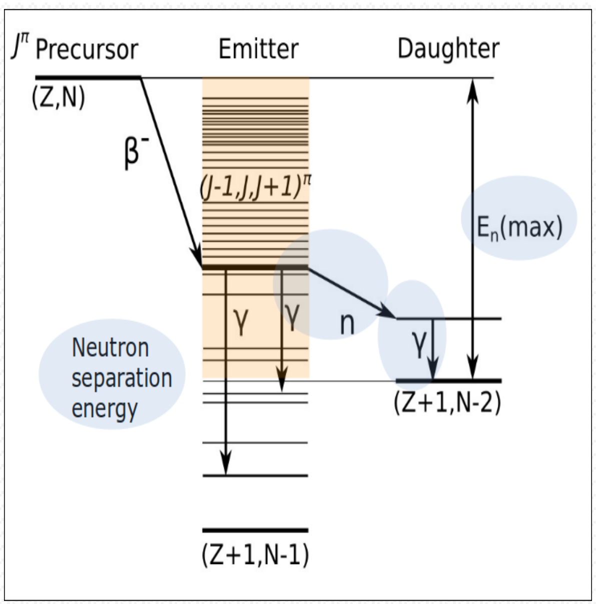
R.Grzywacz, J.R.Stone,N.J.Stone,U.Koester, B.Barlaj, C.Bingham, S. Gaulard, K.Kolos, M.Madurga, J. Nikolov, T. Ohtsubo, S.Roccia, M.Veskovic, P.Walker, W.B.Walters

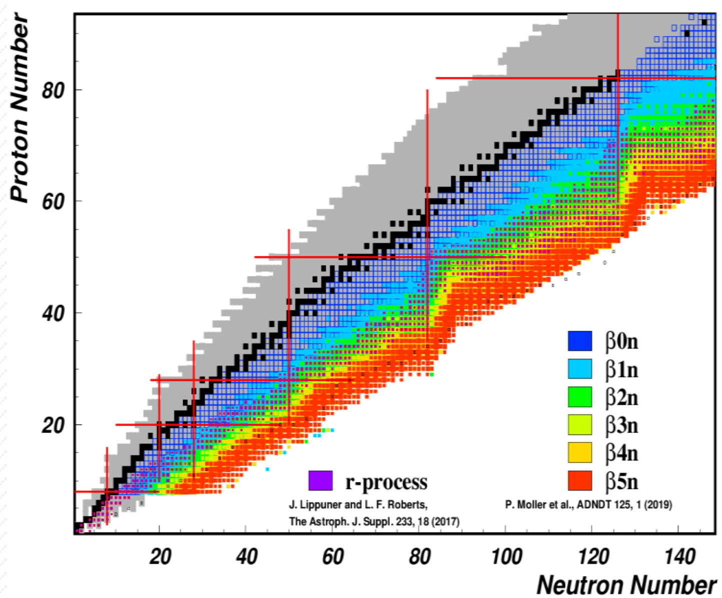
IS575 – 17shifts

Beta-delayed neutron emission is a dominant decay mode for all r-process nuclei, many emitters cannot be studied directly and will rely on global model predictions.

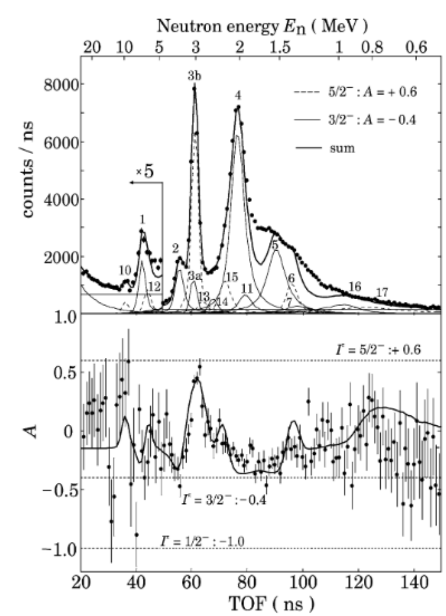
Recent surprises:

1. High energy neutrons from 84Ga decay (M. Madurga et al., VANDLE, ORNL)
2. One-neutron emission from 2n unbound state (R. Yokoyama, BRIKEN, RIBF)
3. Strong βn-neutron emission in FF decays and gamma emission from neutron unbound states (133,133mIn, Xu/Madurga, IDS, ISOLDE)





Y. Hirayama et al. / Physics Letters B 611 (2005) 239–247



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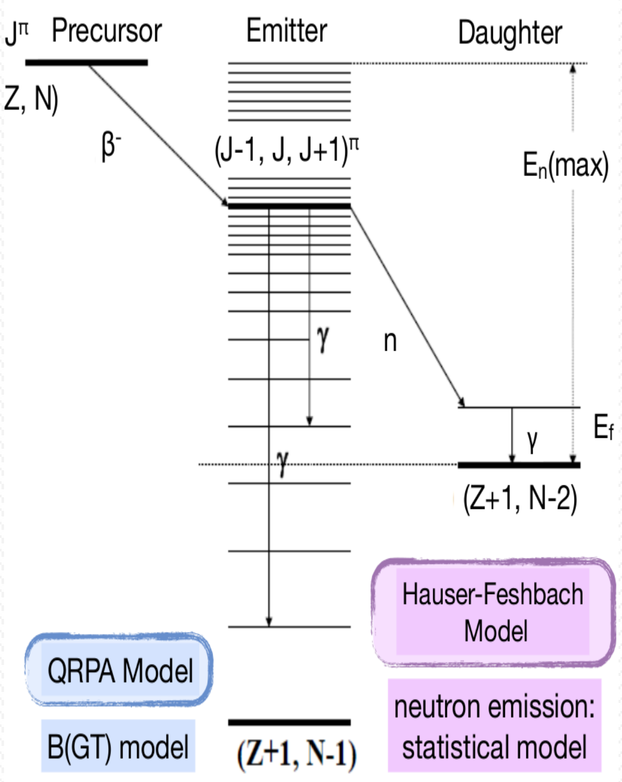
βn-"standard" model



B(GT) models provide information of the initial spin distribution of states populated in Gamow-Teller transitions. Beta-n emission proceeds via compound nucleus.

Neutron emission probability sensitive only to the spin and parity of emitting state and not the details of its structure.

Experiment will:
measure the L-value of emitted neutrons.
(demonstrate that it can be done for heavy nuclei !)

Are the spins and parities from neutron emitting states in agreement with B(GT) models ?

Do we observe only GT transitions βn in ?

Are measured neutron emission L values, energies and relative branching ratio in agreement with Hauser-Feshbach model predictions ?

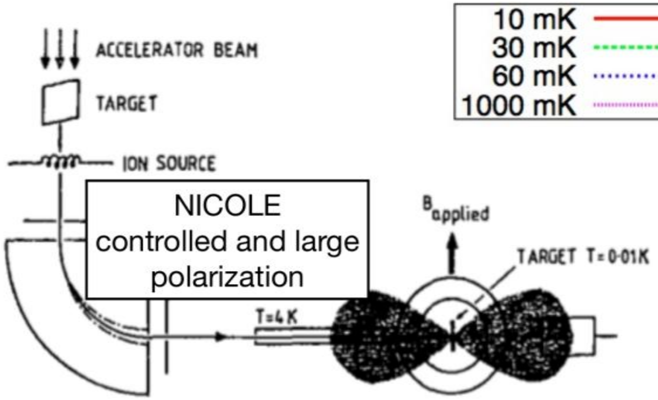
T. Kawano, P. Talou, I. Stetcu, and
M. B. Chadwick, Nuclear Physics A 913, 51 (2013).
M. R. Mumpower, T. Kawano, and P. Möller,
Physical Review C 94, 064317 (2016).

Beta-delayed neutron emitters with NICOLE@ISOLDE Long lived iodines and bromines ($^{137-140}$I and $^{87-90}$Br)

Provides a source of nuclei with close to 100% controllable polarization

Enables access to beta-n emitters relevant to r-process and suitable for LTNO (previous measurements only on light-mass nuclei)

Allows measurements of anisotropic angular distributions of beta delayed neutrons information on partial wave composition of the neutron transitions (unique capability for a foreseeable future).



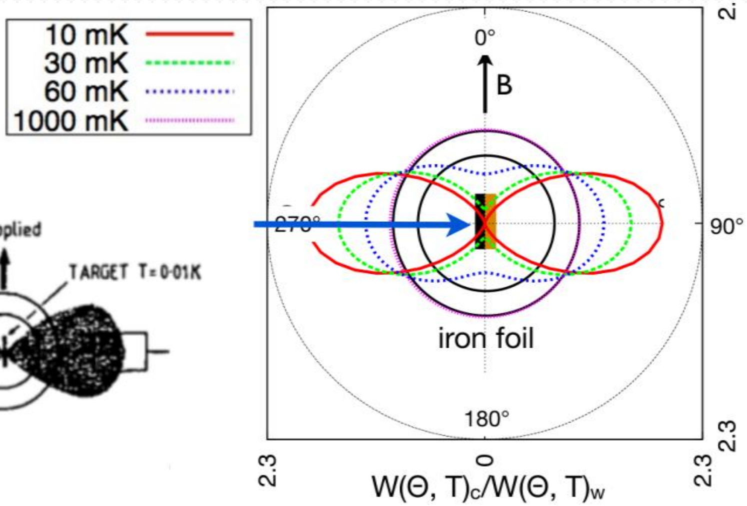


Fig. Neutron angular distribution (E_n = 500 keV).

N. J. STONE et al,

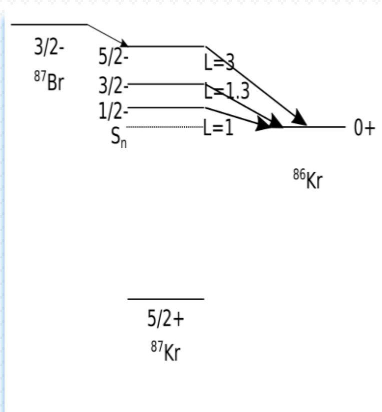
Hyp. Int. 136/137: 143–148 (2001).

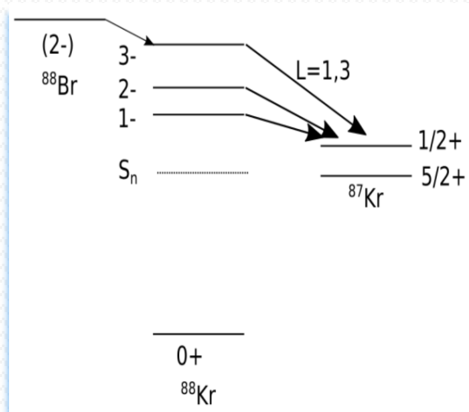
Pioneering and exploratory studies will lead to a long term experimental program at NICOLE and VITO.

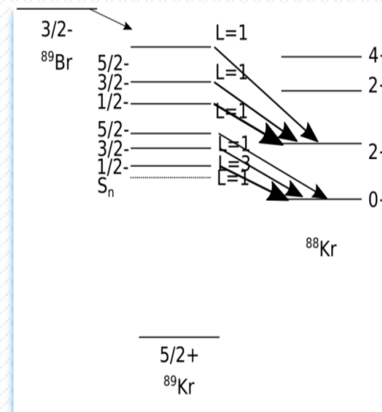
Eight cases of delayed neutron emitters at NICOLE
$^{137-140}$I and $^{87-90}$Br

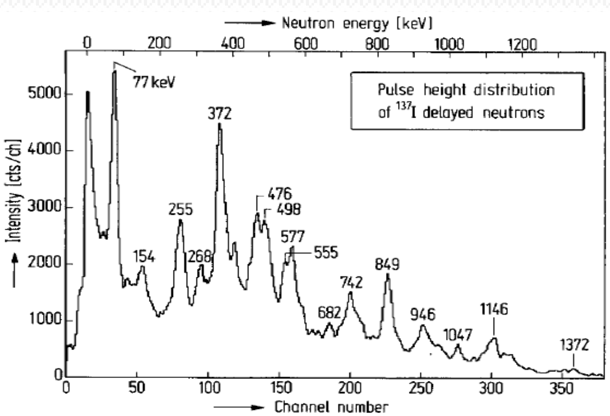
Measure L-value of emitted neutrons to ground and excited states, develop "canonical" measurements methods for typical scenarios.

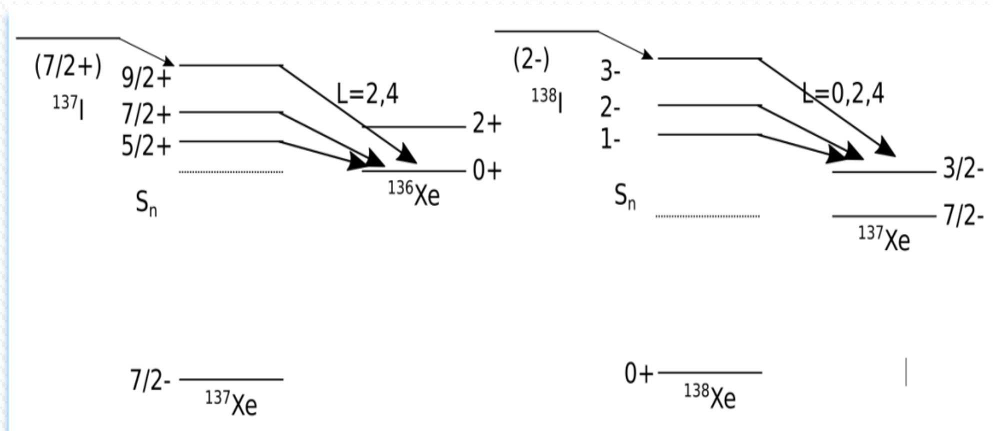
87Br L=1,3 neutrons from GT states to GS of 86Kr (no cascades).
88,89,90Br L=1,3 neutrons from GT states to GS and excited states of 87-89Kr
Any FF transitions will be followed by L=0,2 neutrons.



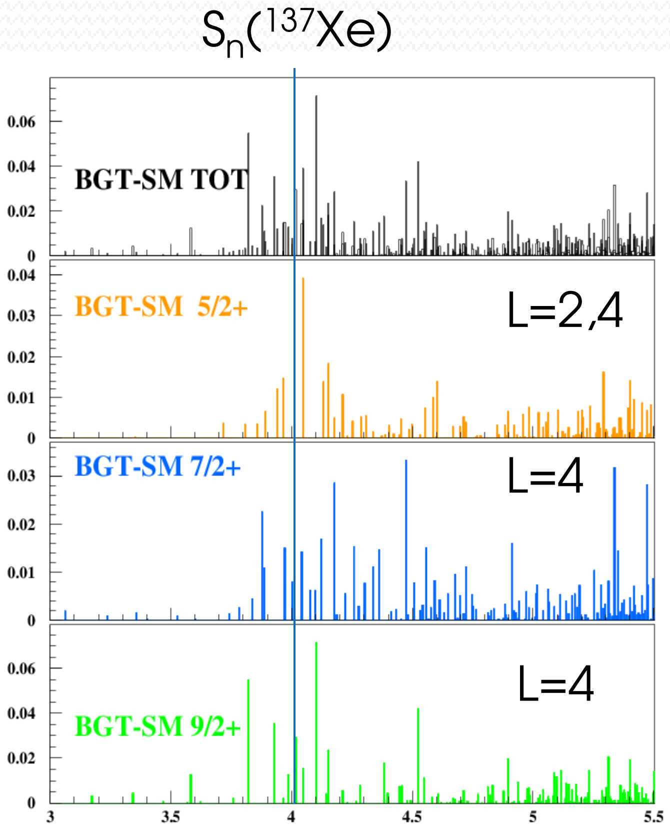




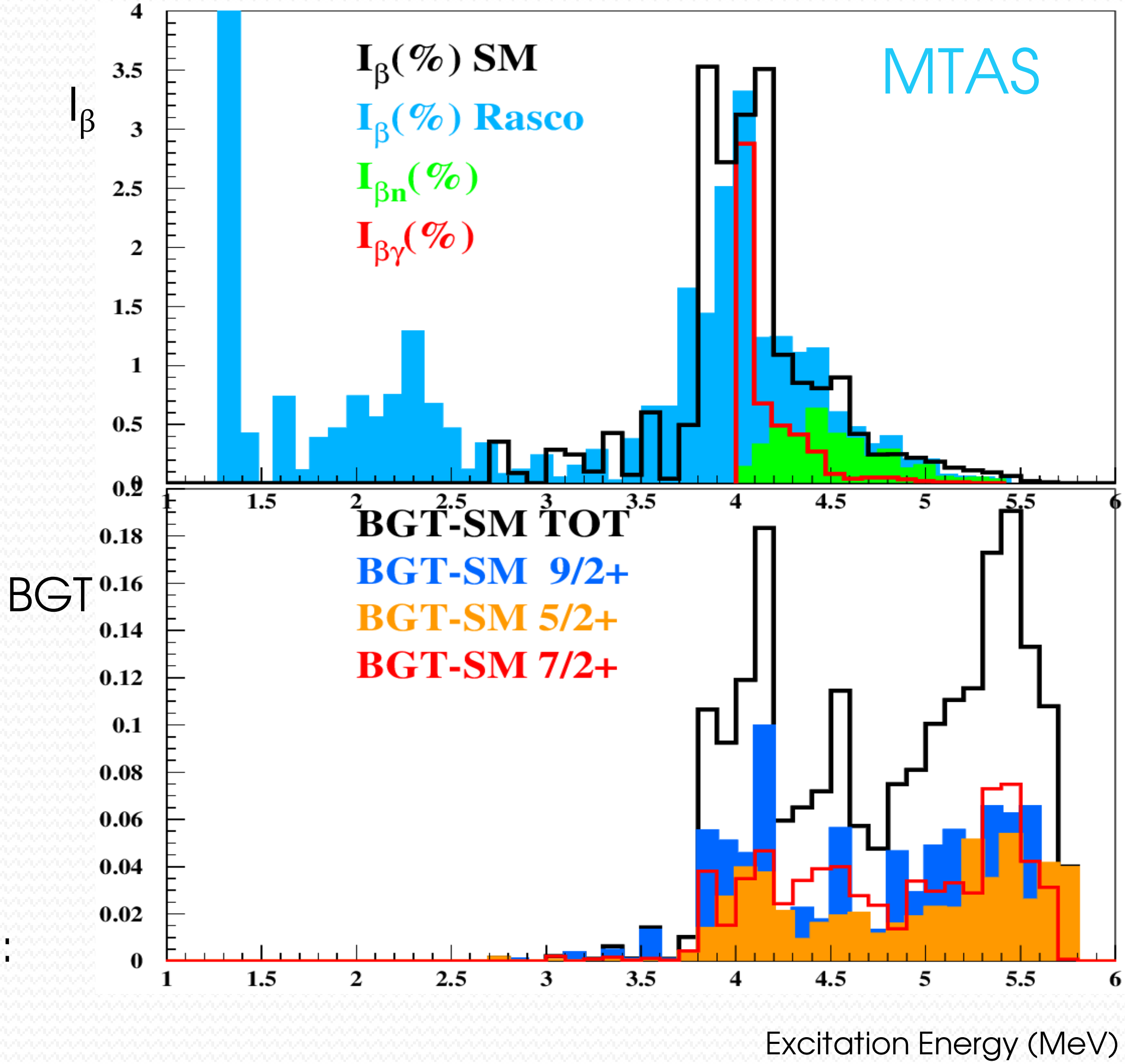




^{137}I decay: shell-model predictions for the GT population of states with spins 5/2+, 7/2+, 9/2+

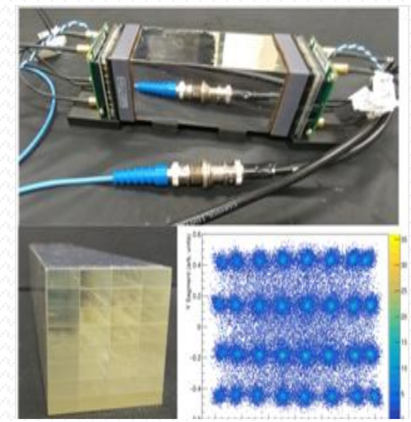


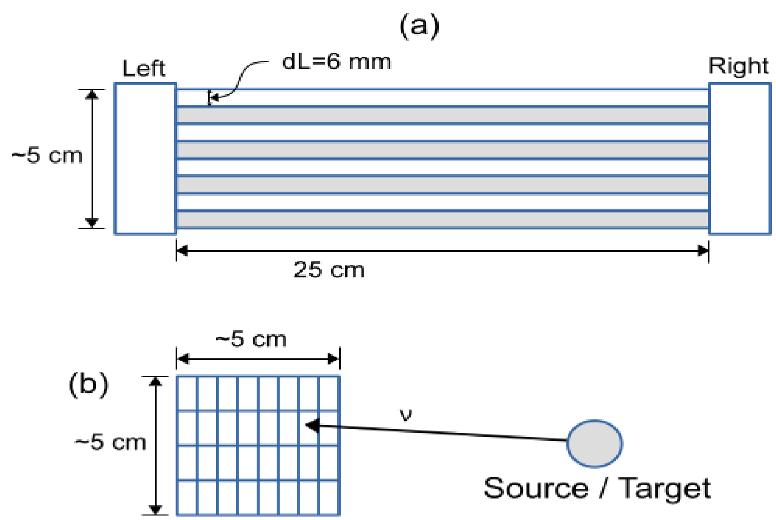
Neutron emission : no cascades



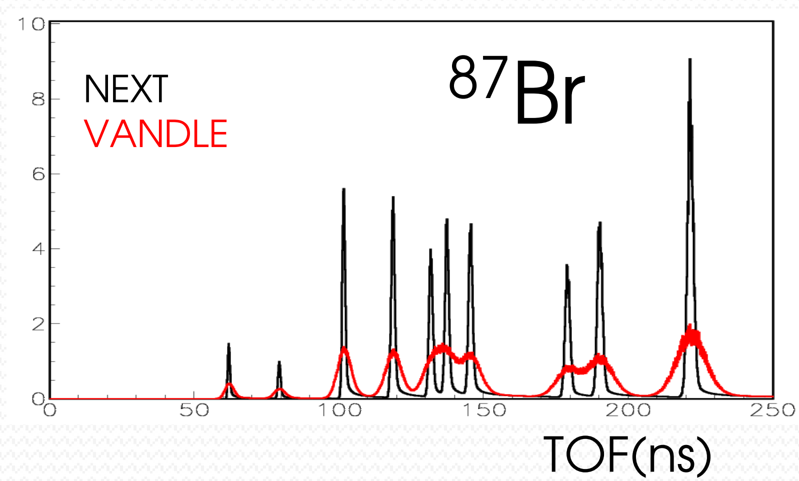
New NEXT neutron detector critical for measurements at NICOLE

5x gains in neutron energy resolution will enable new generation of measurements
Better resolve individual transitions
Neutron-gamma discrimination

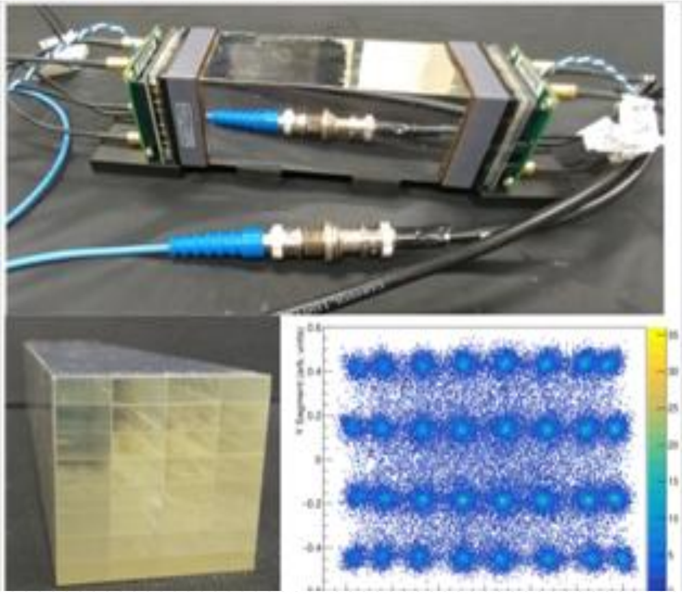


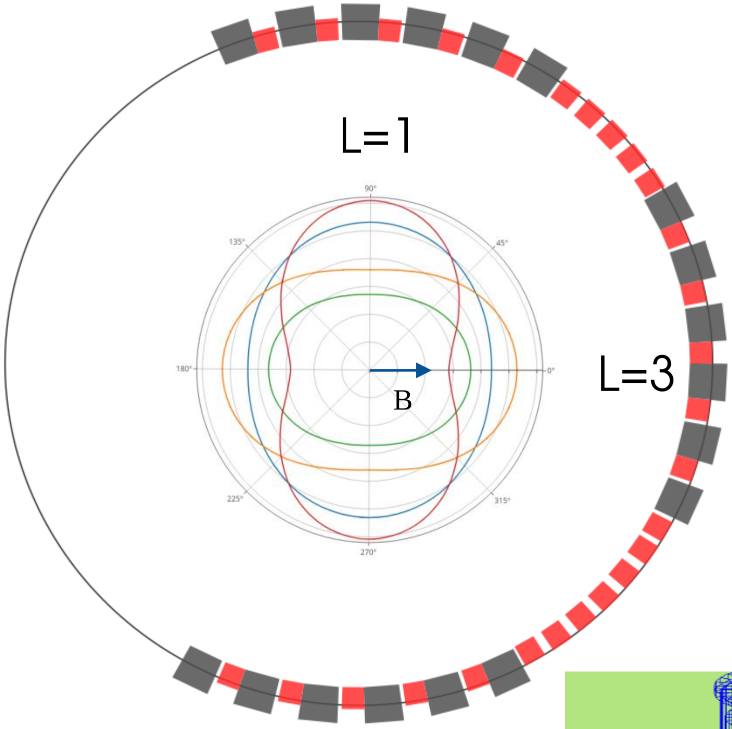


Conceptual design and first results for a neutron detector with interaction localization capabilities
J. Heideman et al. NIM A 946, (2019), 162528

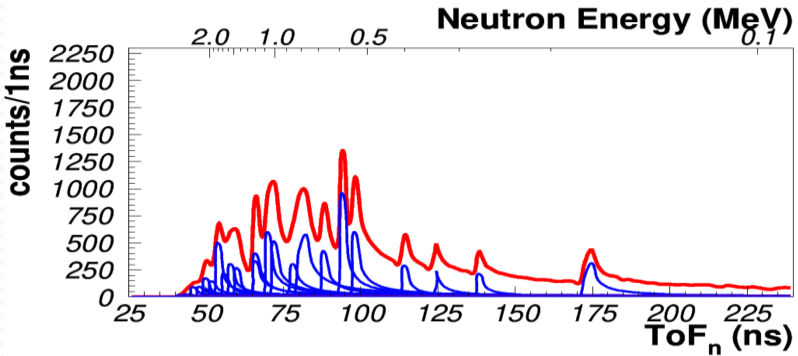


Detection geometry with NEXT+VANDLE at NICOLE

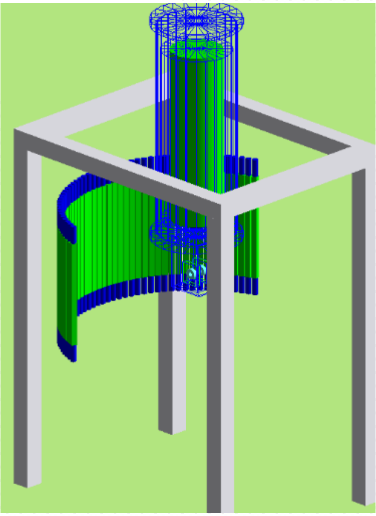




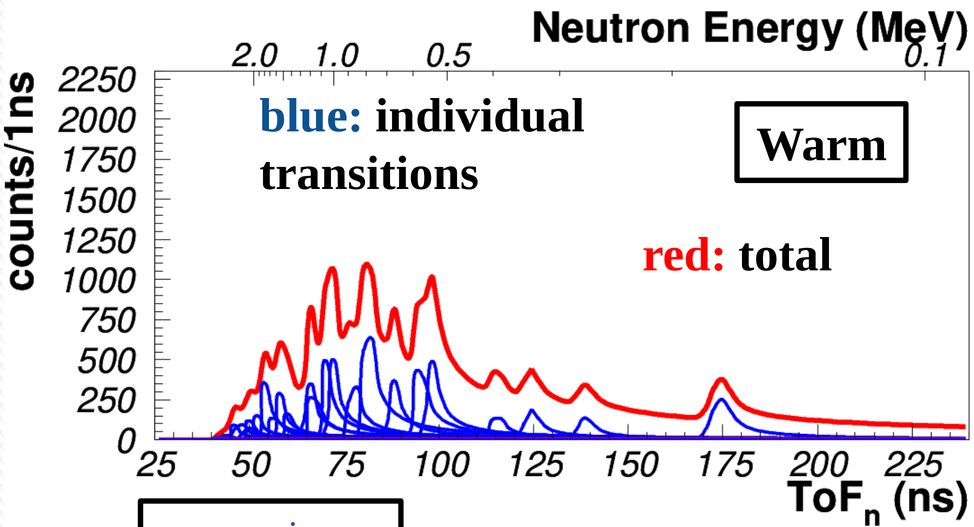
12-18 NEXT modules at 70 cm
Efficiency ~ 2%
27 VANDLE modules
Efficiency ~3%



cold/warm asymmetry



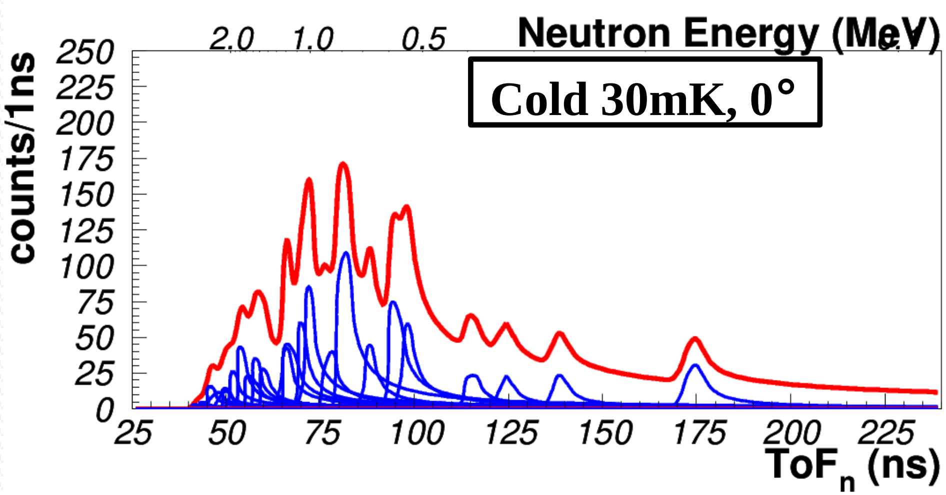
^{137}I decay simulations (VANDLE 3cm/70cm)
Angular asymmetries specific to the L-value of neutron partial waves

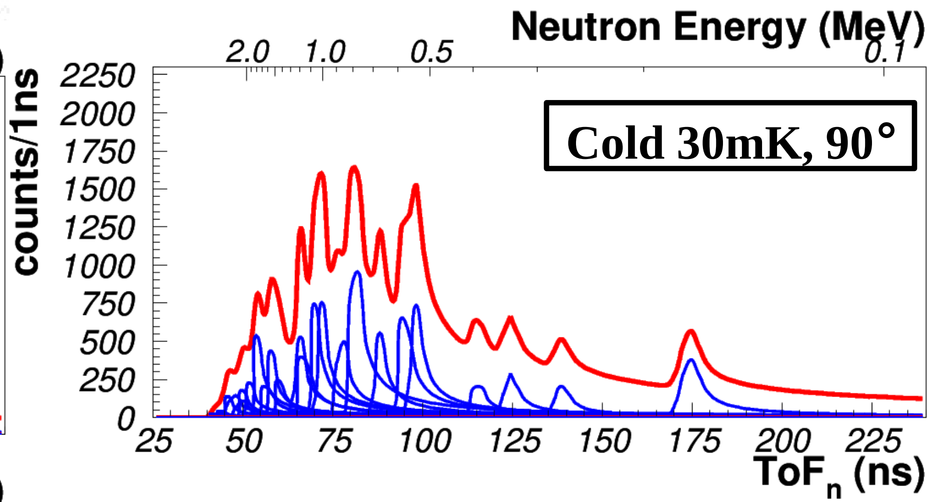


VANDLE@70cm from NICOLE

- intrinsic efficiency ~20%
- intrinsic resolution ~1-2 %
- alternate peaks allocated arbitrarily with L=4, L=2
- simulations include scattering off NICOLE (Ilyushkin, Madurga)

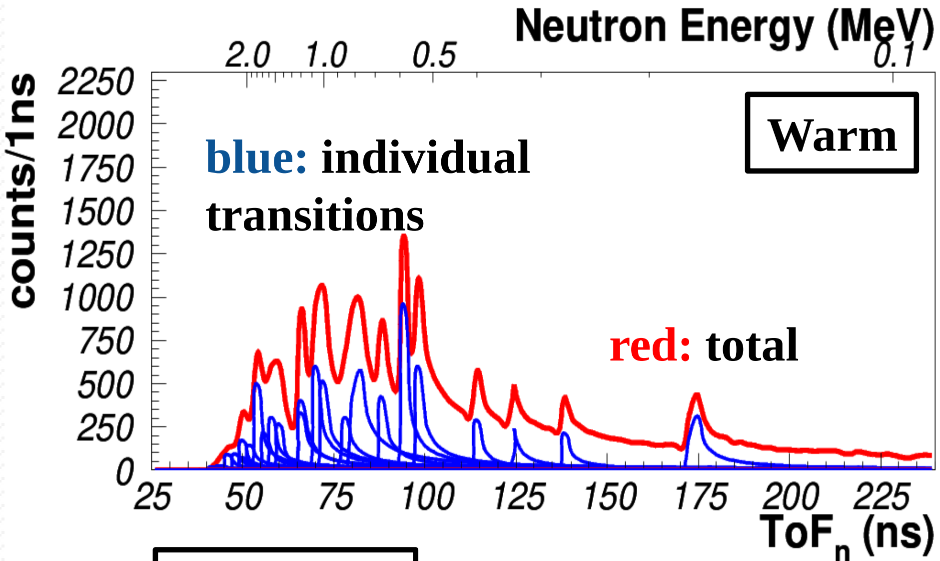
suppression by factor of 10





^{137}I decay simulations (NEXT)

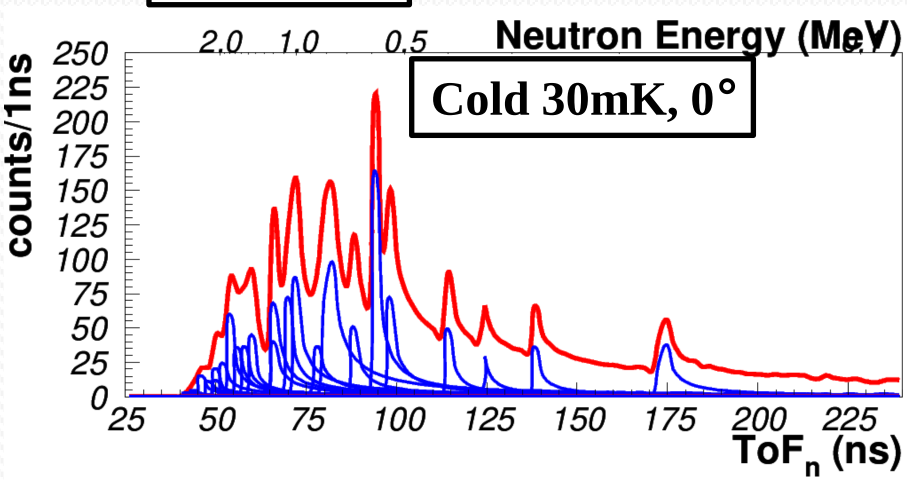
Angular asymmetries specific to the L-value of neutron partial waves

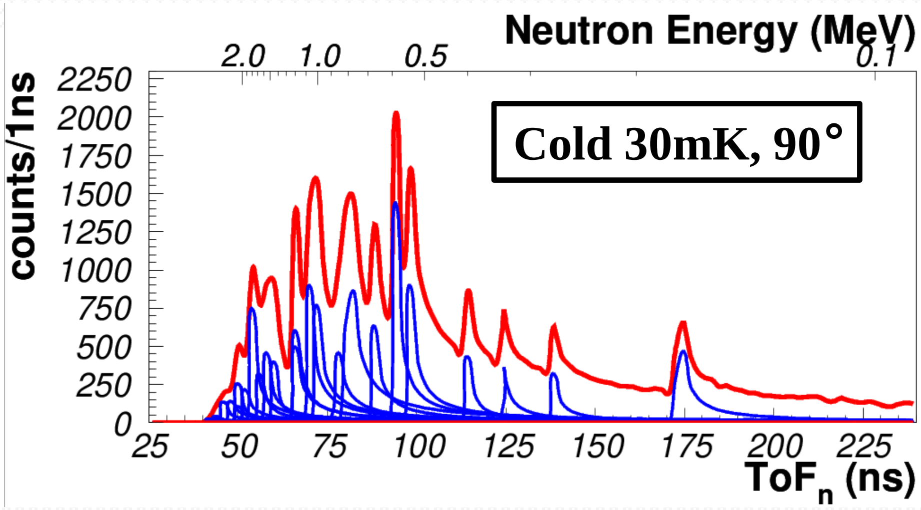


NEXT@70cm from NICOLE

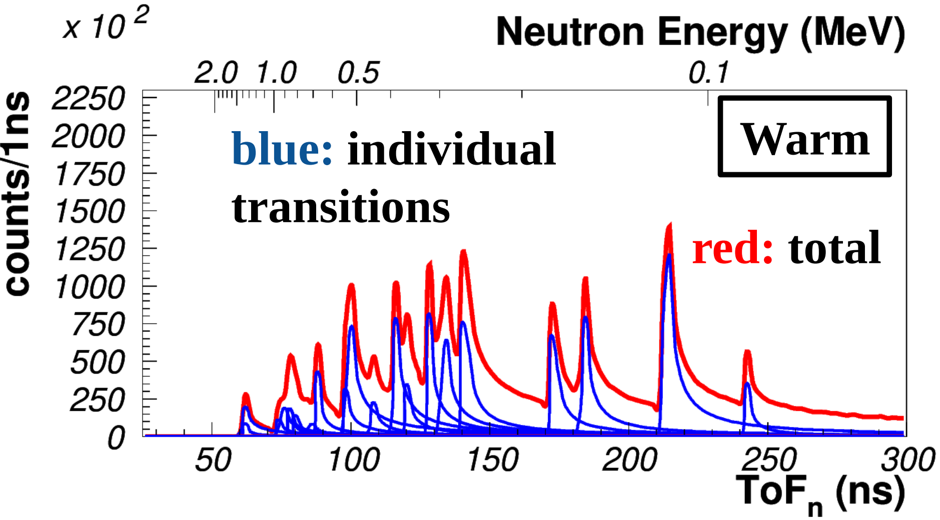
- intrinsic efficiency ~40%
- intrinsic resolution ~1-2 %
- alternate peaks allocated arbitrarily with L=4, L=2
- simulations include scattering off NICOLE (Ilyushkin, Madurga)

suppression by factor of 10



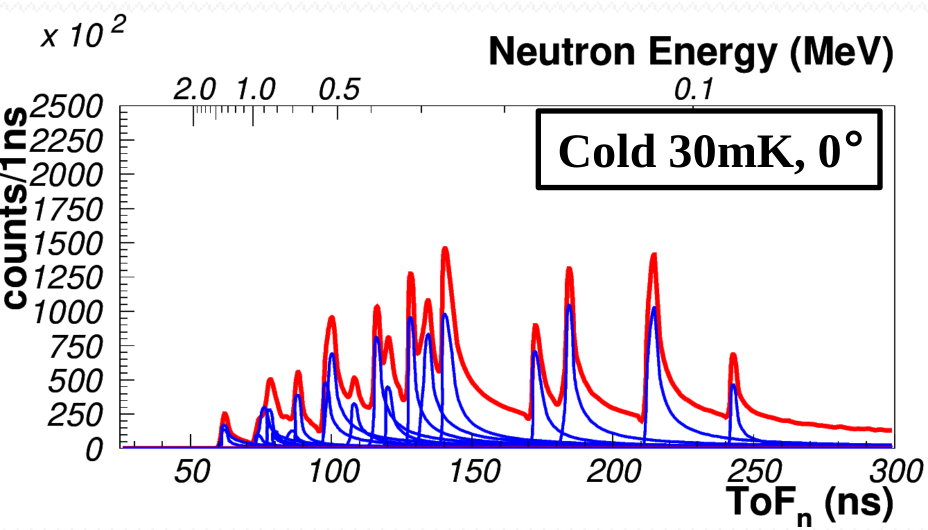


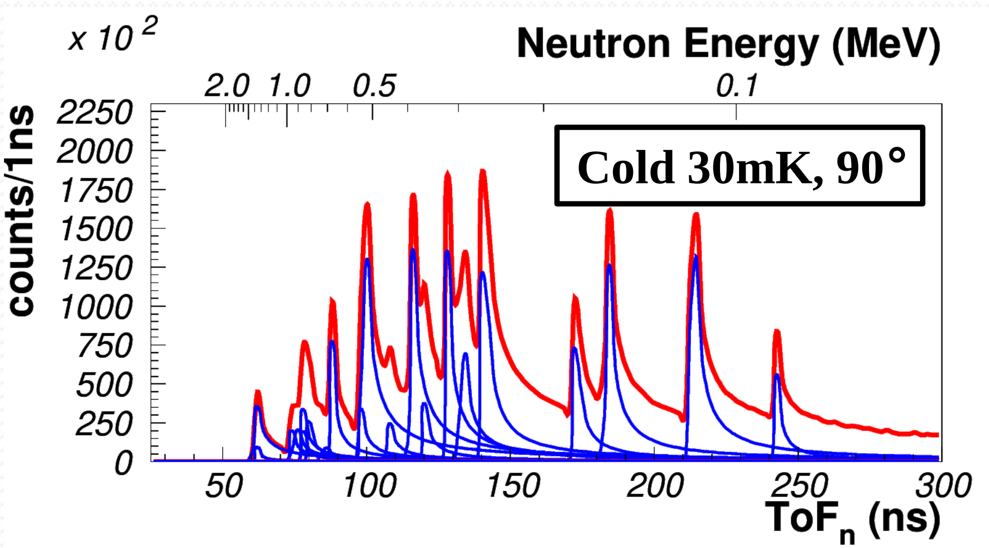
^{87}Br decay simulations (NEXT)



NEXT@70cm from NICOLE

- intrinsic efficiency ~40%
- intrinsic resolution ~1-2 %
- alternate peaks allocated arbitrarily with L=1, L=3
- simulations include scattering off NICOLE (Ilyushkin, Madurga)





The beta-n program at NICOLE

IS575 – 17 shifts

NICOLE seem to be in operational condition. The conclusive measurement (60Co nuclear thermometer) planned for March 2020.

Availability of negative ions may delay the program until 2022
we propose to prioritize on bromines, with HRS and positive ion source (plasma source VADIS).

- Carry out the proposed experiments with 87Br,89Br
  positive ions, HRS, 8 shifts (2021)

(IF successful: the beam purity can be achieved)

- Carry out the proposed experiments with 88Br,(90Br)
  positive ions, HRS, 9 shifts (2021)

OR

- Carry out the proposed experiments with 137I,138I
  negative ions, HRS, 9 shifts (2022)

Submit future proposals for remaining cases in optimized conditions and/or more exotic isotopes after first successful run.

The beta-n program at NICOLE

The result of the proposed measurement will be angular asymmetry as a function of neutron energy with/without coincidences with gamma-rays.

Each measurement will take ~ 3 shifts per isotope
(1 shift warm+ cool down, 1 shifts at T≤30K and 1 shift warm up)

Use NEXT/VANDLE neutron detectors and germanium/$LaBr_3$ gamma-ray detectors at angles around 0°, 90°, and 180°.

Bromine and iodine ions are available at ISOLDE with rates >10^{5-7} pps.

We require min. 10^4 detected neutrons in a single neutron detector module (ε=0.001).
Published ISOLDE yields exceed the required ion rates (10^3-10^4 pps), negative ions (SC).

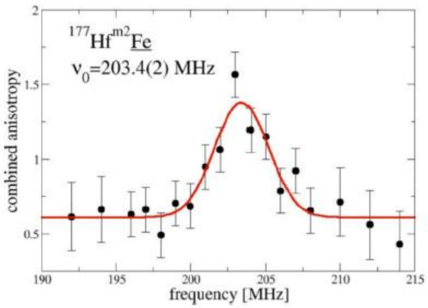
	Pn	neutrons/ shift	ions	pps	ISOLDE yield (ions/μC)
87Br	0.02	10000	1.00E+09	3.47E+04	3.00E+07
88Br	0.066	10000	3.04E+08	1.06E+04	1.20E+06
89Br	0.138	10000	1.45E+08	5.03E+03	4.40E+06
90Br	0.252	10000	7.94E+07	2.76E+03	7.40E+05
137I	0.071	10000	2.80E+08	9.73E+03	1.30E+07
138I	0.056	10000	3.60E+08	1.25E+04	3.30E+06
139I	0.1	10000	2.00E+08	6.94E+03	9.00E+05
140I	0.093	10000	2.15E+08	7.47E+03	1.00E+05

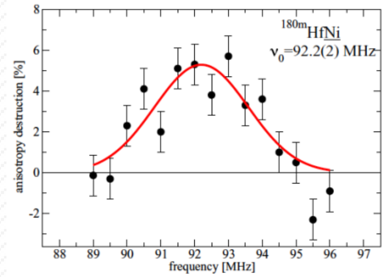
Magnetic Dipole Moments of High-K isomers in Hf Isotopes

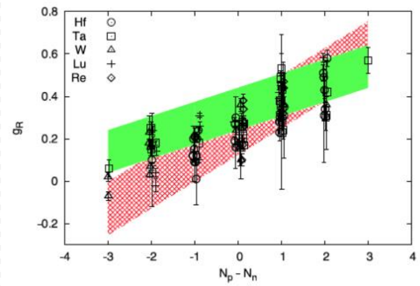
N.J.Stone , J.R.Stone ,T.Ohtsubo, C. Gaulard, U.Köster, M.Madurga, J. Nikolov, G.Simpson, S.Roccia, M.Veskovic, A.Vranicar, M.Travar and W.B.Walters

IS460 – 12 shifts

First results, $|\mu|(^{177}\mathrm{Hf}^{m2}, 37/2^{-}, 51.4\mathrm{m}) = 7.33(9)\ \mu_N.$ a (S. Muto et al., PRC89, 044309 (2014) and the systematic dependence of collective gR factor on quasi-particle occupation, deduced for the first time, (N.J.Stone et al, PLB 726,675 (2013) were published.







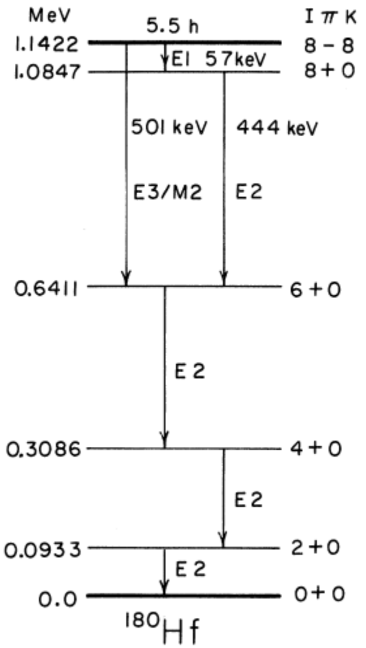
NMR/ON resonance was observed as planned for ^{180m1}Hf, I = 8^{+} implanted into Ni.
NMR/ON of ^{177m2}Hf in Ni, is required to give an accurate value for the hyperfine field for Hf in Ni needed to calculate the moment of ^{180m1}Hf.
6 shifts requested

Additional shifts were requested and granted under second Addendum to IS460 to complete this experiment and study 169Hf and 179Hf.
Redirection request (6 shifts):
Change the 169Hf and 179Hf investigations for oriented 180Hfm1 with the aim to test P- and T-invariance in nuclear states using gamma-ray polarimetry.

Fundamental symmetry tests in nuclear interactions:

Parity, Time and simultaneous P and T violating admixtures in nuclear states

Oriented nuclei - provide direction in space - used to perform the symmetry operation
- anisotropic angular distribution of the emitted radiation
- linear polarization serves as analyzer.

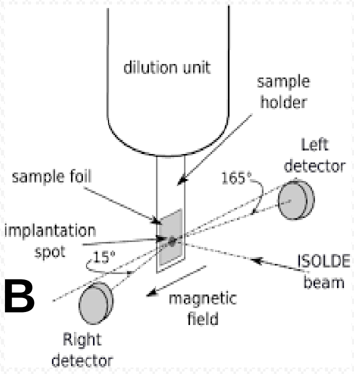


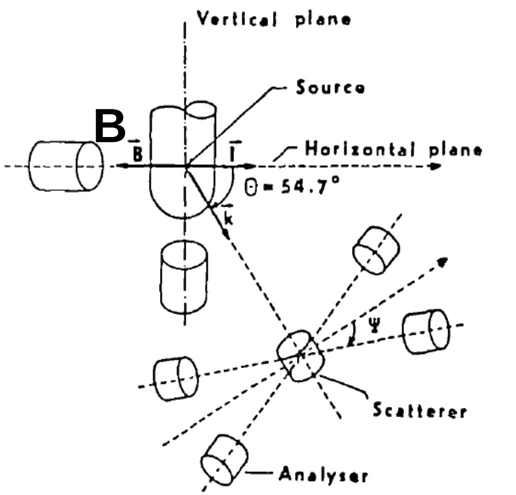
Measurement of the R-L asymmetry in counts at 0 and 180 degrees when B $\rightarrow$ -B.
Successful experiment completed:
P violating admixture of the 8+ 1084 keV in the 8- 1142 keV isomeric state in 180Hfm

(PRC76, 025503 (2007))

Proposal to test T invariance:
Measure the asymmetry In linear polarization of the 501 keV transition when B $\rightarrow$ -B and the polarimeter (see below).
(Hyp. Int. 43 (1988) 107-116):

Advantage of 180mHf: violating effects enhanced:
-Proximity of the 1084 and 1142 keV states
-ΔK=8 forbideness of 501 keV transition





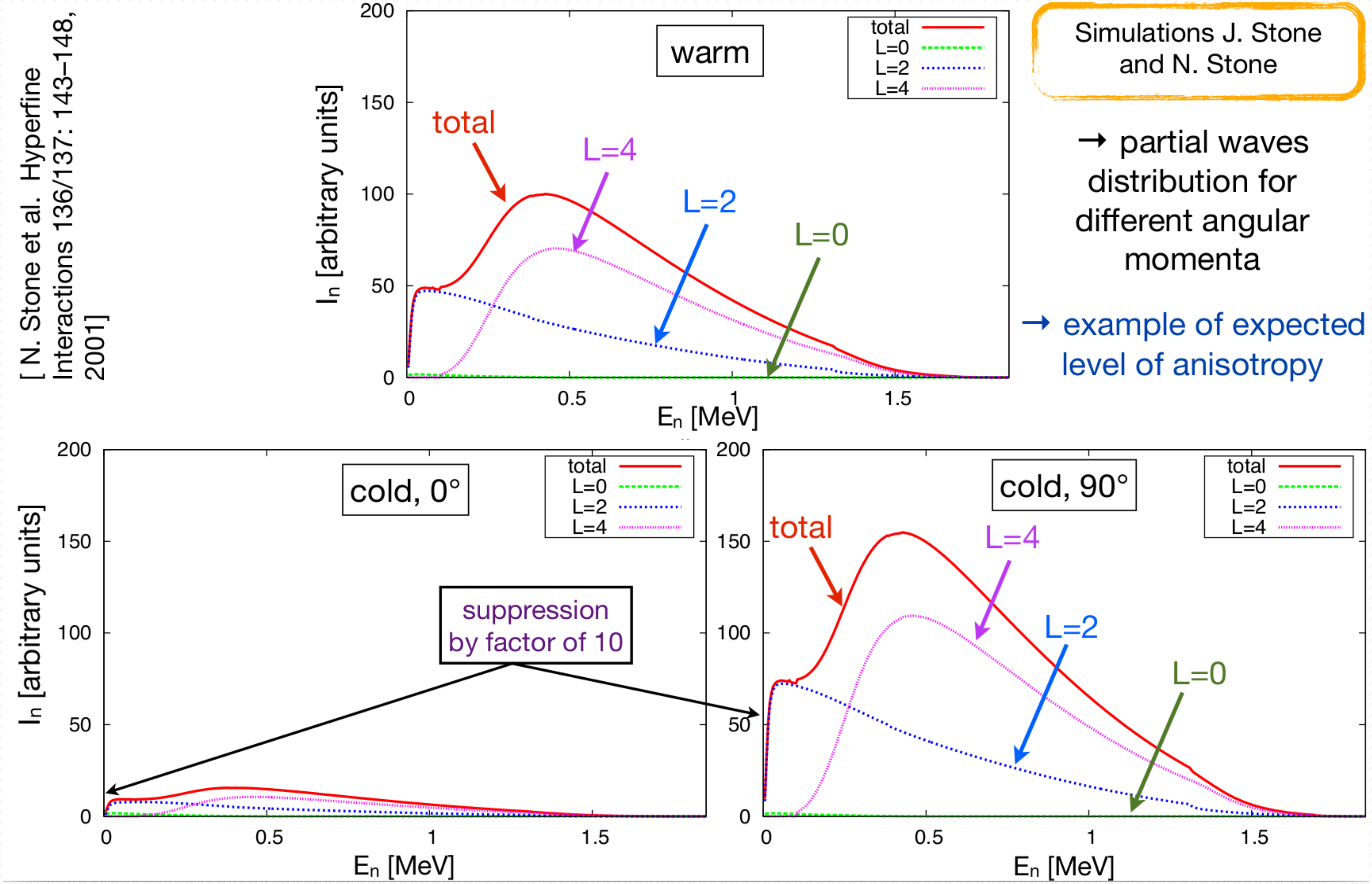
Measure linear polarization of the 501 keV transition and search for PT and T violation effects.

CERN-INTC-2013-024, INTC-P-384,
Beta-delayed neutrons from 137,139I and 87,89Br oriented nuclei

The Committee welcomes the repair of the NICOLE dilution refrigerator and hopes that the full system will be soon operational at ISOLDE. The aim of the proposal is to investigate β-delayed neutron and gamma radiation from oriented 137,139 I and 87,89 Br nuclei. Spin and parity of excited states will be determined through the angular distribution of neutrons and gammas. Such information is required for providing nuclear physics inputs to the network calculations which simulate the astrophysical processes and for the reference database.
The committee finds the proposal of high interest since the method proposed is innovative and of high relevance for the study of exotic nuclei where particle emission is a relevant mechanism of decay. It is important to validate the sensitivity of the proposed method on one case, e.g. Br.
A question was also raised concerning the possible background due to neutrons scattered from the large NICOLE setup. The committee thus asks for a clarification letter concerning the background, before the 17 shifts for studies on Br isotopes can be scheduled. The shifts for the iodine studies can be requested once the Br experiment takes place and a status report is submitted.
Therefore, the committee recommended for the approval of the Research Board 17 shifts, under the condition that a clarification letter is received concerning the neutron background.

137I decay: schematic model predictions
Large directional asymmetry for L=2 and L=4

[N. Stone et al. Hyperfine Interactions 136/137: 143–148, 2001]



Simulations J. Stone and N. Stone

→ partial waves distribution for different angular momenta

→ example of expected level of anisotropy