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

K. Kolos

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[5] ILL Grenoble, France,
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[7] CSNSM IN2P3 Orsay, France,
[8] University of Novi Sad, Novi Sad, Serbia,
[9] Niigata University, Japan,
[10] University of Surrey, Guildford, UK

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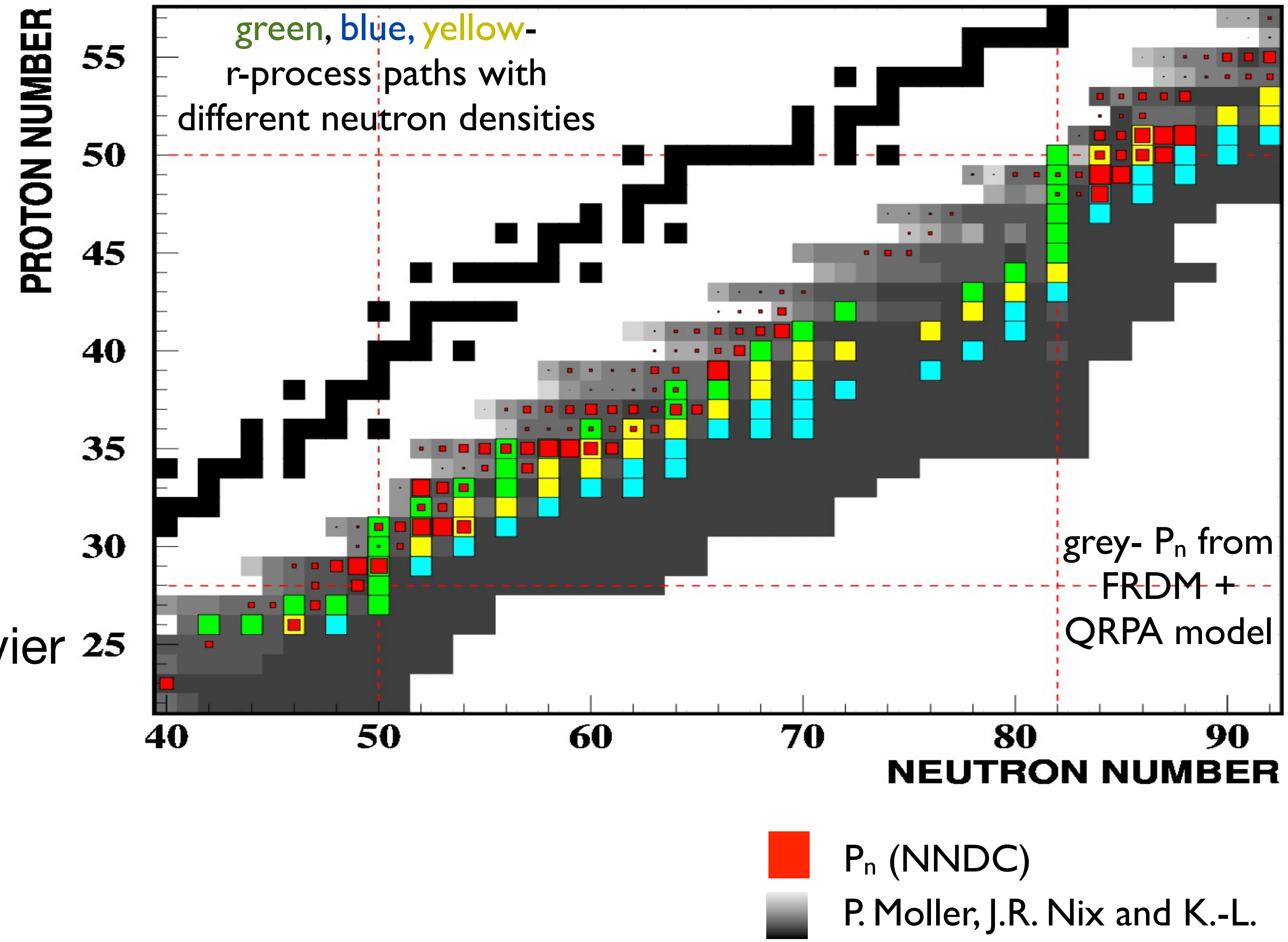
Beta delayed neutron emission, r-process and reactor (decay heat) modeling

→ **far from stability**
βn-decay becomes dominating decay channel

→ **only small fraction of P_n values are known**

→ **r-process path nuclei experimentally challenging**
theoretical extrapolations necessary especially for heavier nuclei



P. Moller, J.R. Nix and K.-L. Kratz
Atomic Data and Nuclear Data Tables,
Vol. 66 p. 131-343 (1997)

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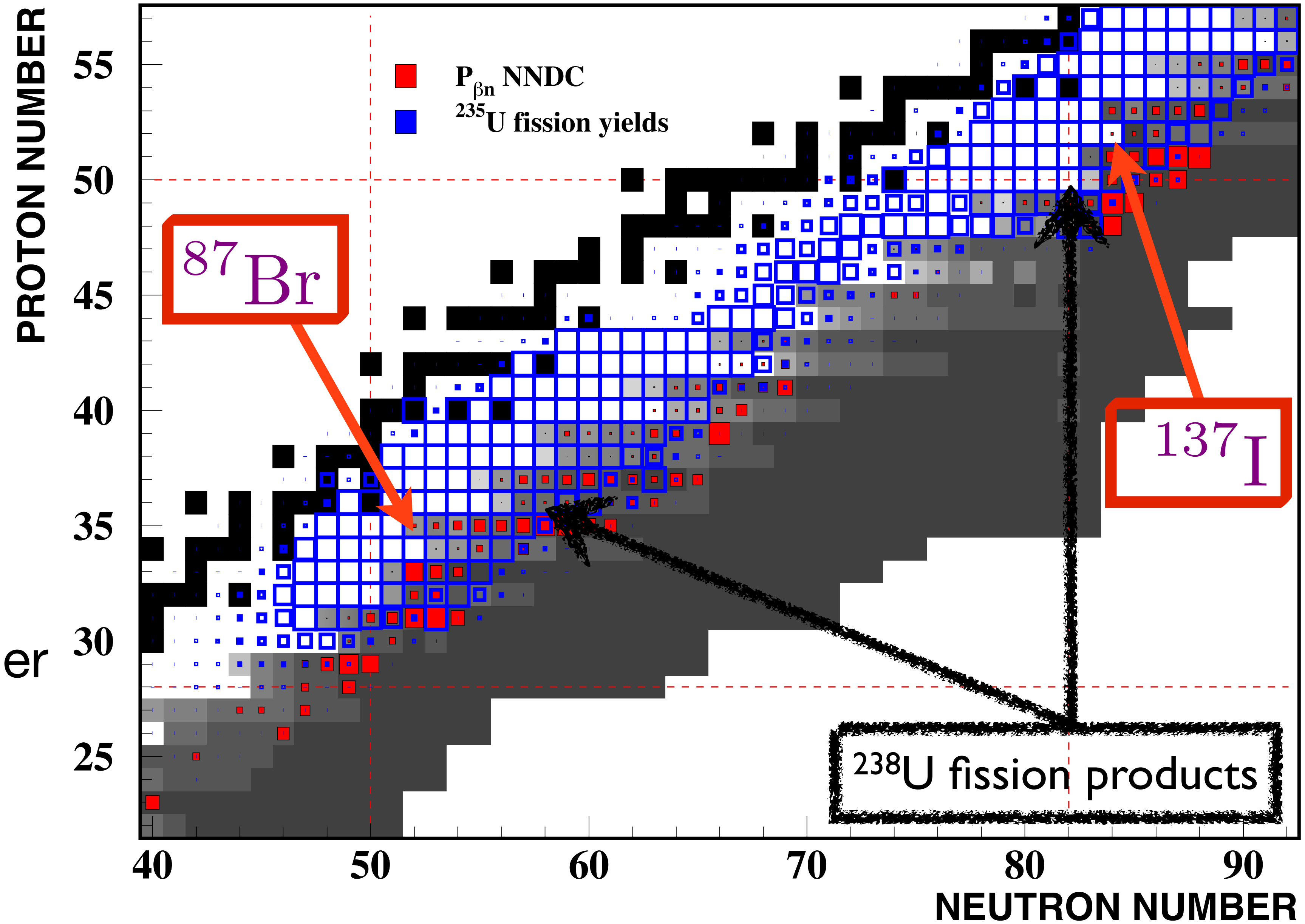
→ **decay heat calculations**
reactor physics

test of βn-decay models (structure & statistical components)



Coordinated Research Project (CRP) at the International Atomic Energy Agency (IAEA)

IAEA

1st Research Coordination Meeting (RCM) of the CRP on Beta-Delayed Neutron Emission Data

IAEA Headquarters, Vienna, Austria
26-30 August 2013

"Reference Database for Beta-delayed Neutron Emission Evaluation"

http://www-nds.iaea.org/beta-delayed-neutron/

Beta delayed neutron emission

Elements of theory (included in model):

1. Beta Decay
   Allowed GT (J, J+/-1) and 1st forbidden
2. Barrier penetration (tunneling)
   Optical Model
3. n-γ branching from neutron emitting states (determination of P_n)
   Assumed E1 as fastest.
4. Excited states in Daughter
   Separate n spectrum components to different daughter states

For the same theoretical S_β the predicted P_n depends on particle emission model assumptions.

★ Close to stability: n and γ competition near the barrier (reactors)

★ Far from stability: 1n/2n competition (r-process)

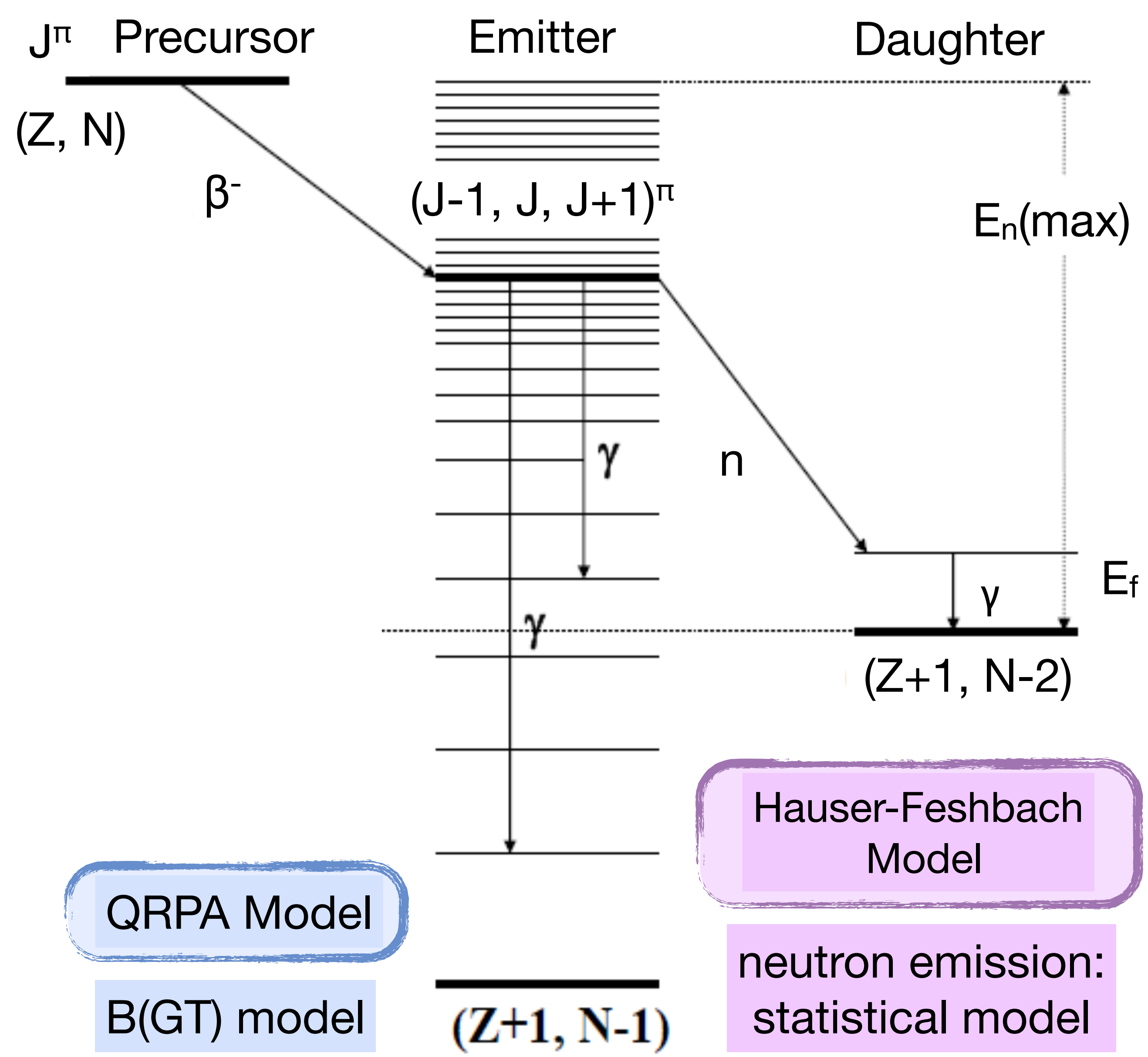


Fig. Schematic energy-level diagram for β-delayed neutron emission.

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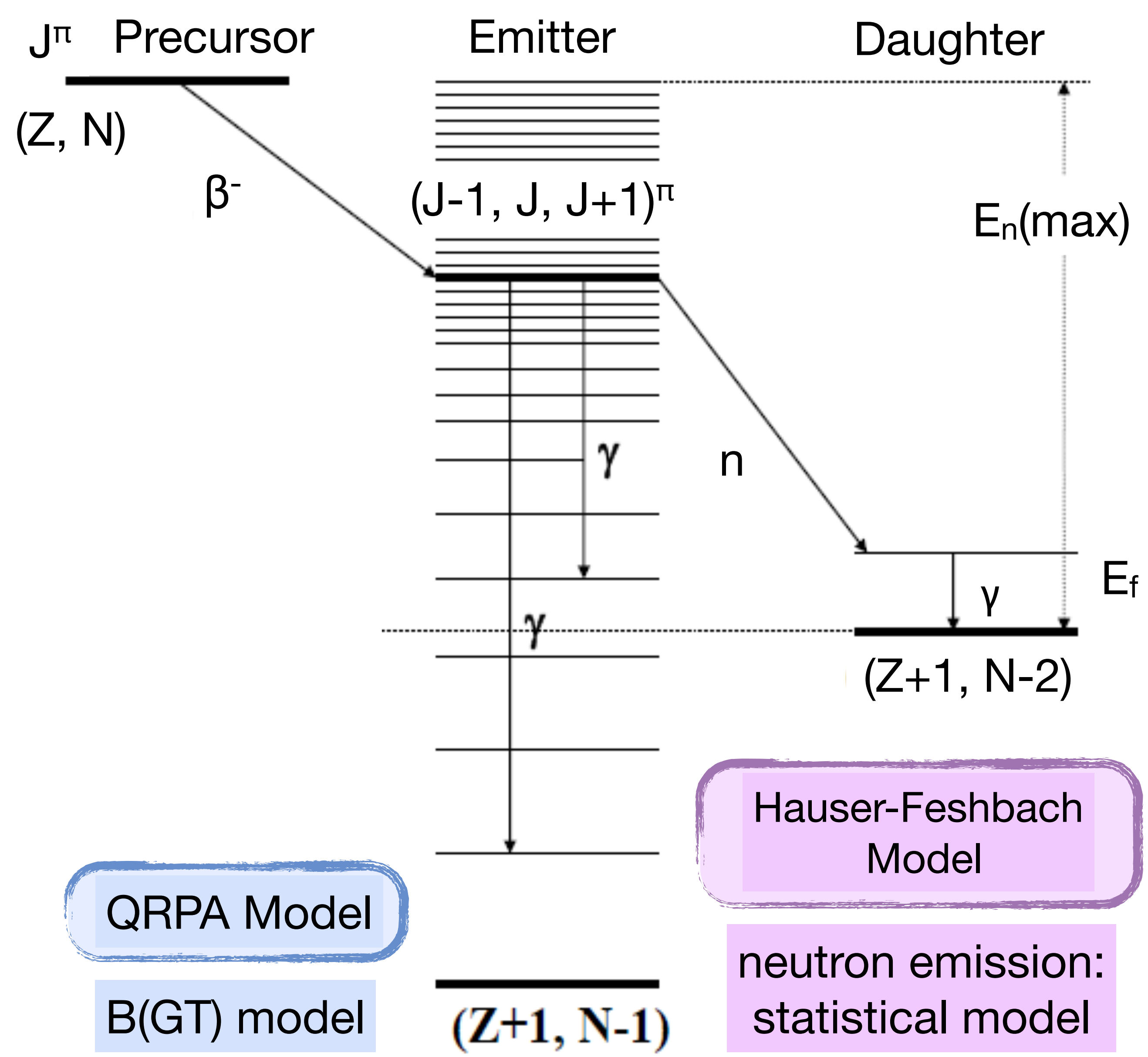


Fig. Schematic energy-level diagram for β-delayed neutron emission.

Conventional spectroscopy:

→ energies, level structures and intensities

angular distribution studies

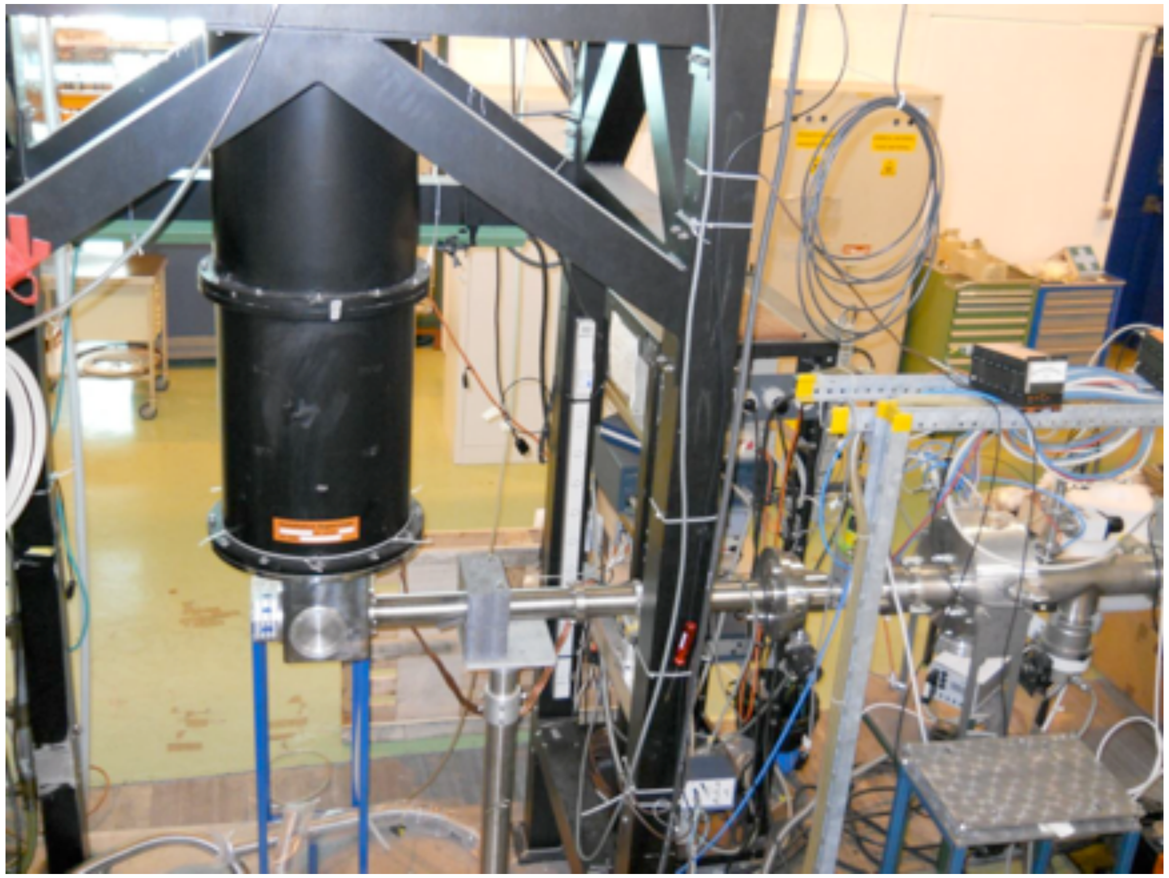
angular distribution of beta-delayed neutrons and γ's from oriented ^{137,139}I and ^{87,89}Br nuclei

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

VANDLE@NICOLE

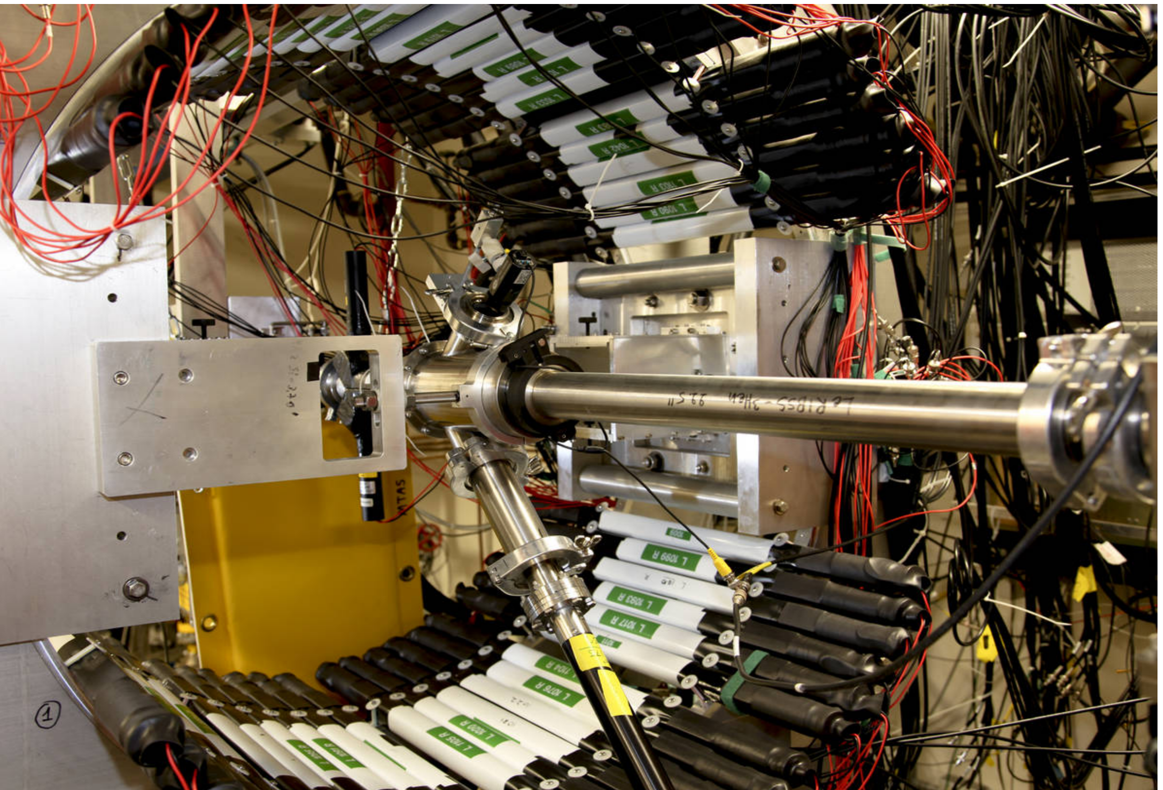
→ ^{137,139}I and ^{87,89}Br beams polarized with NICOLE

^{137}I	→	^{136}Xe	($T_{1/2}$ 24.5s, P_n 7.14%)
^{87}Br	→	^{86}Kr	($T_{1/2}$ 55.6s, P_n 2.6%)
^{139}I	→	^{138}Xe*	($T_{1/2}$ 2.28s, P_n 10%)
^{89}Br	→	^{88}Kr*	($T_{1/2}$ 4.4s, P_n 13.8%)



NICOLE at ISOLDE facility

VANDLE detector at HRIBF (Oak Ridge)



→ detection of neutrons and γ's:

✦ **Versatile Array of Neutron Detectors at Low Energy (VANDLE)**

-- two HPGermanium gamma detectors

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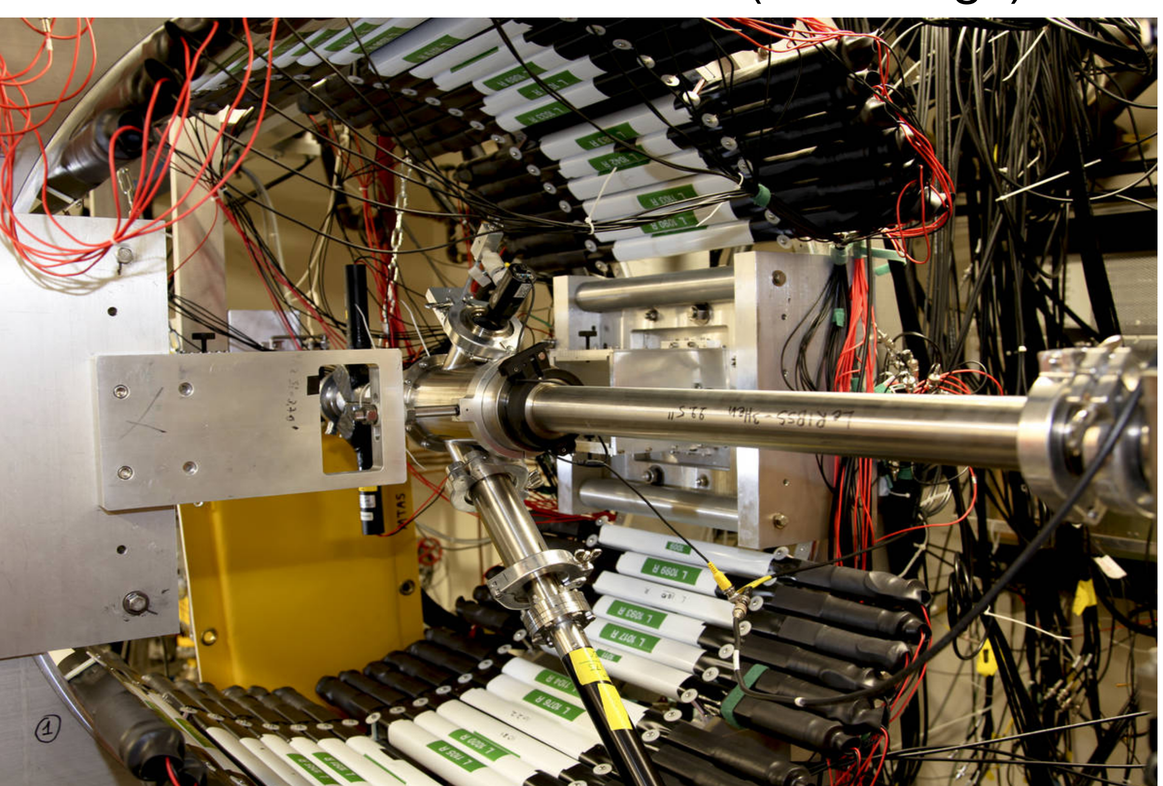

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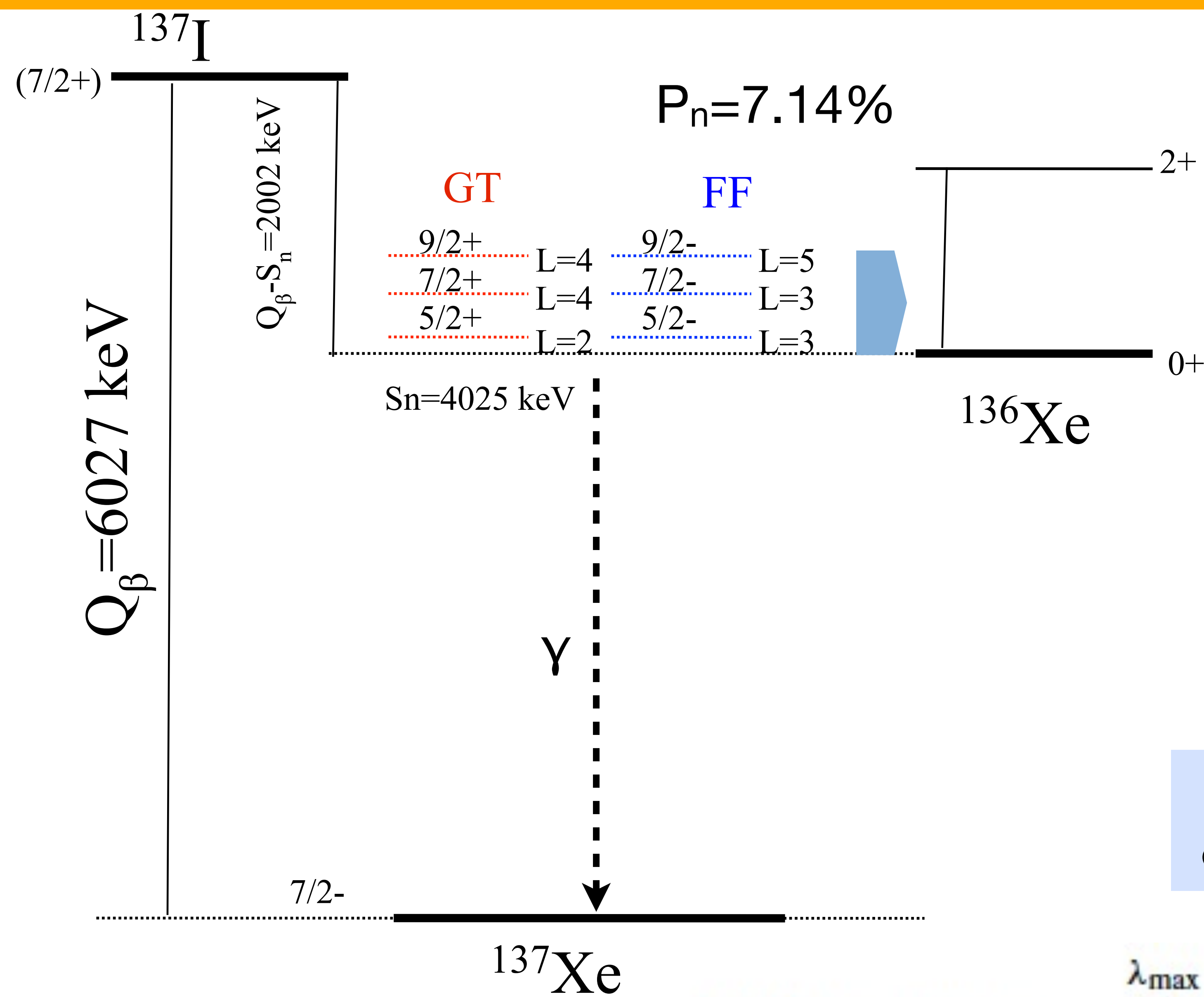
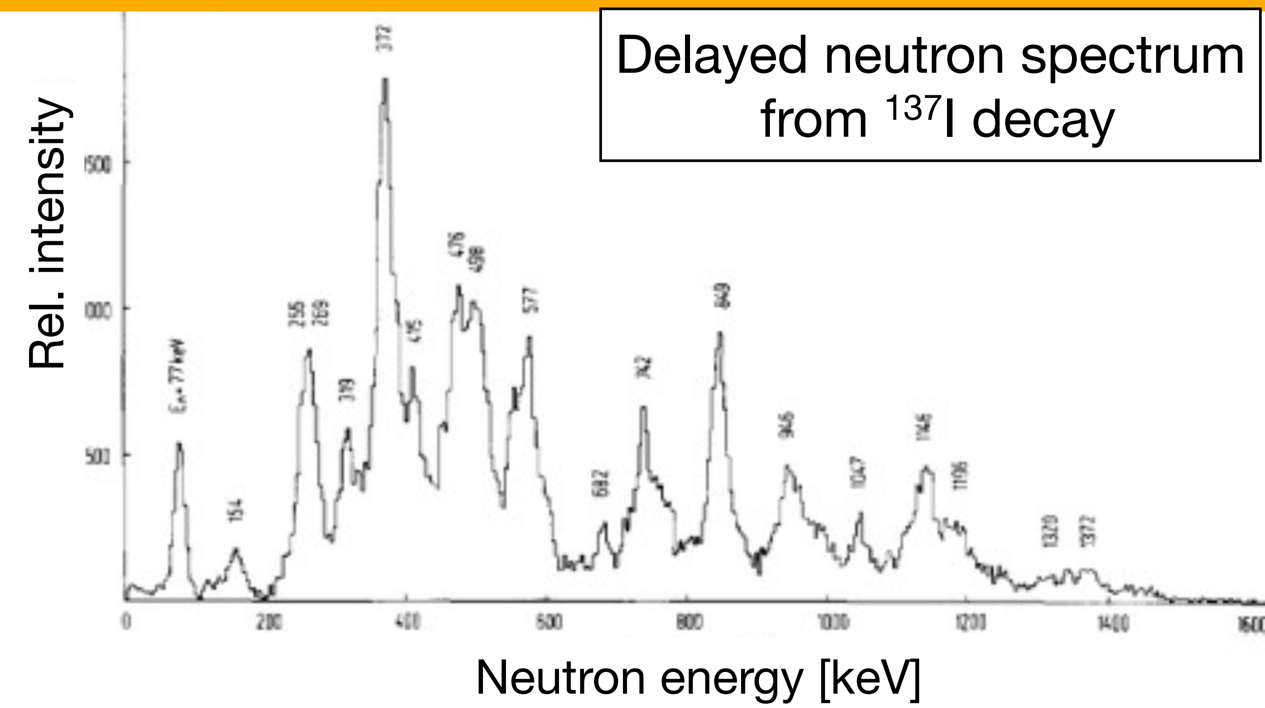
Experiment and theory





[H. Ohm et al. Physik A - Atoms and Nuclei 296, 23-33 (1980)]

parent orientation

β-decay (GT or FF)

The angular distribution:

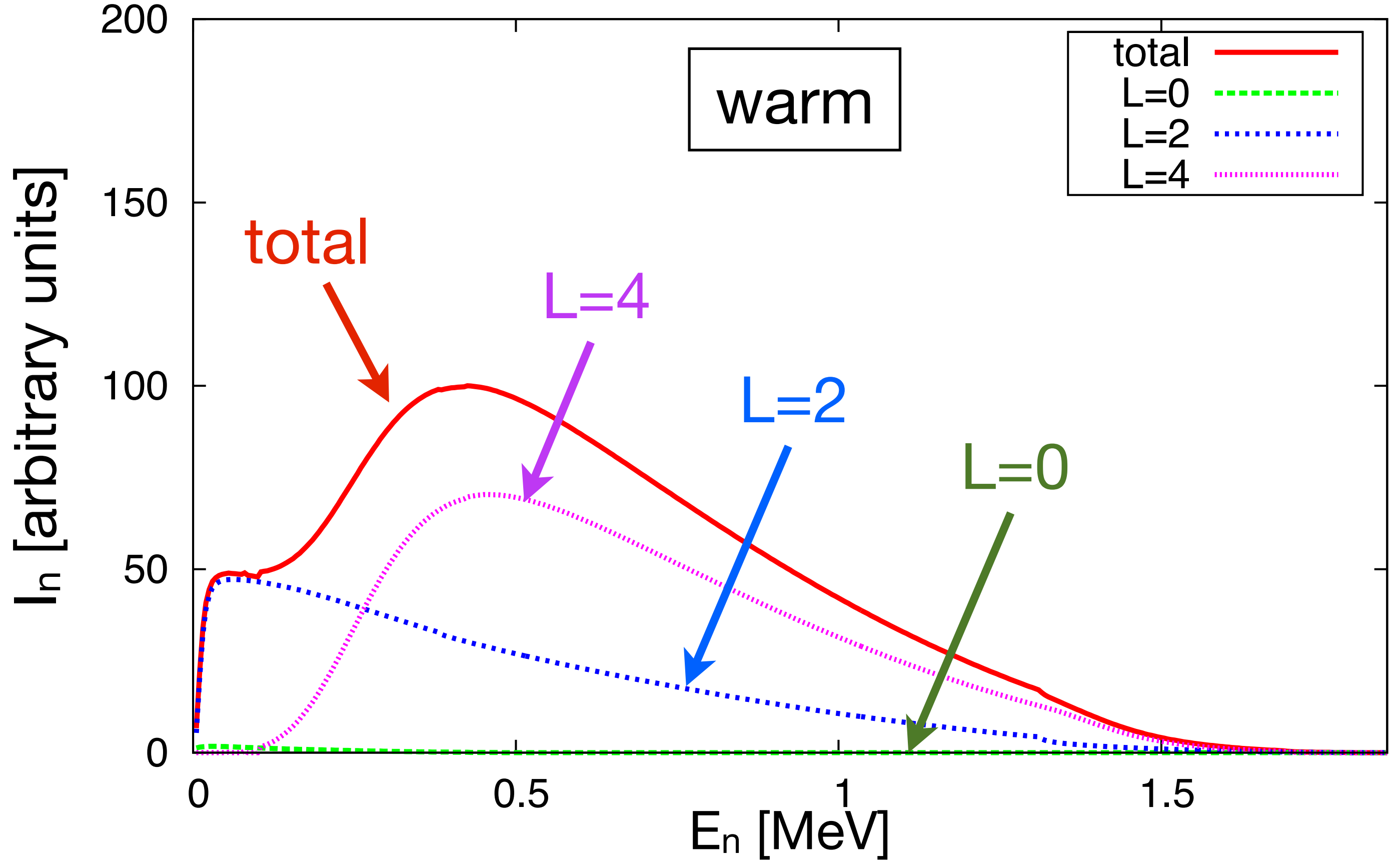
$$I_n^{cold}(E_n, T, \theta) = \sum_{\lambda=0}^{\lambda_{max}} B_\lambda(T) Q_\lambda \left\{ \sum_m \omega(m) U_\lambda(m) \times \left[I_\beta(E_1^*) I_n^m(E_1^*, L, 1/2) R_\lambda(L, I_c) + I_\beta(E_2^*) \sum_{L, I_c} I_n^m(E_2^*, L, I_c) R_\lambda(L, I_c) \right] \right\} P_\lambda(\cos\theta).$$

neutron emission angular distribution

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

Orientation experiment - schematic model

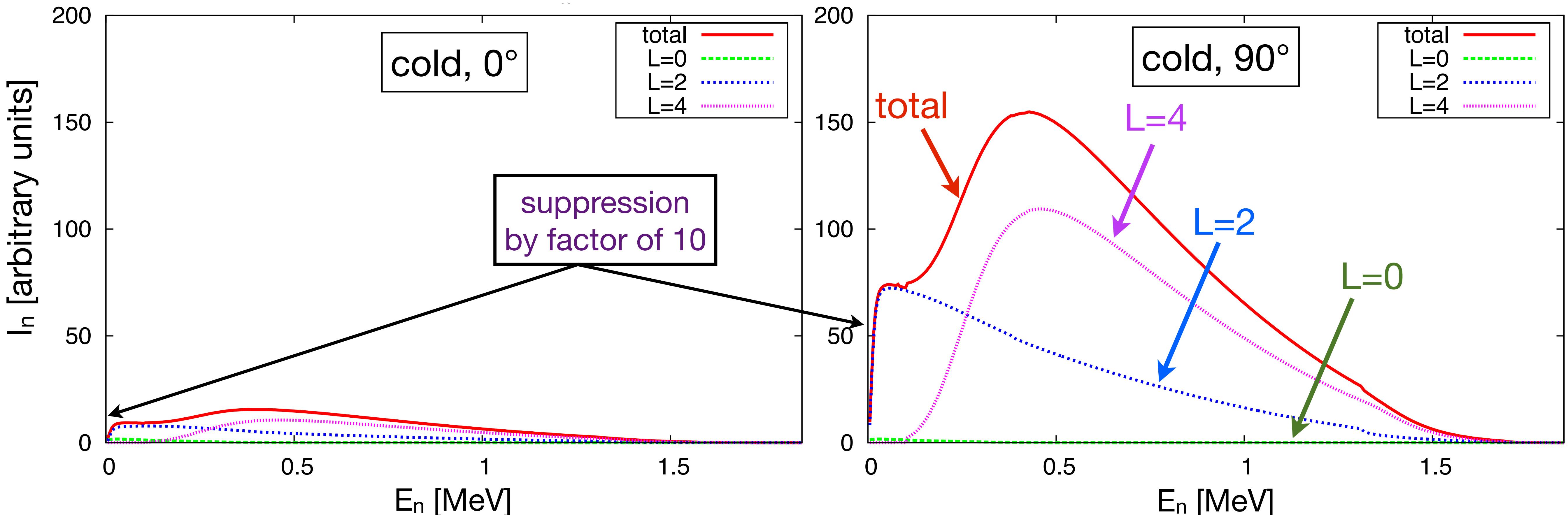
[N. Stone et al. Hyperfine Interactions 136/137: 143–148, 2001]



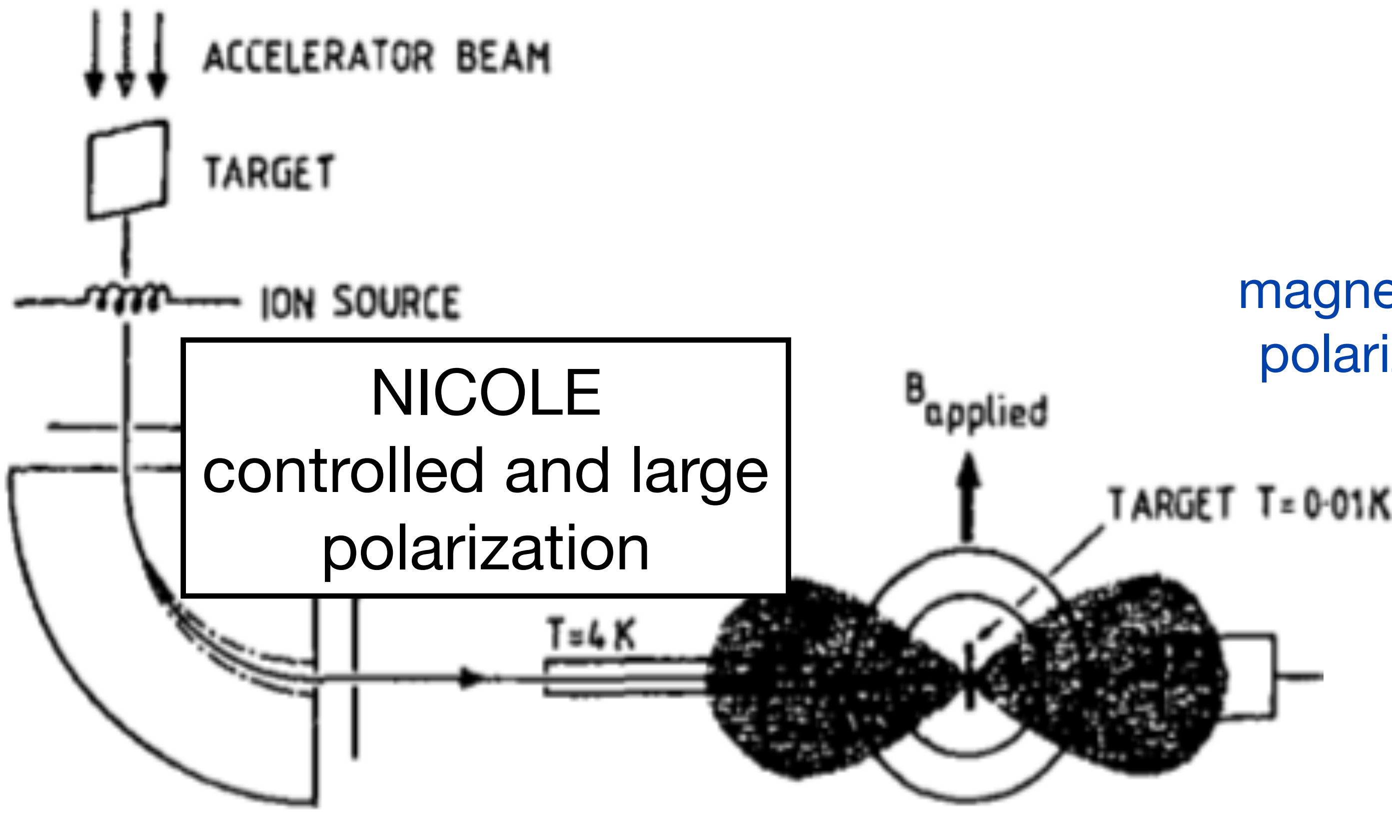
Simulations J. Stone and N. Stone

→ partial waves distribution for different angular momenta

→ example of expected level of anisotropy: ratio of warm to cold at a given angle and temp.



Nuclear orientation experiment with VANDLE at NICOLE



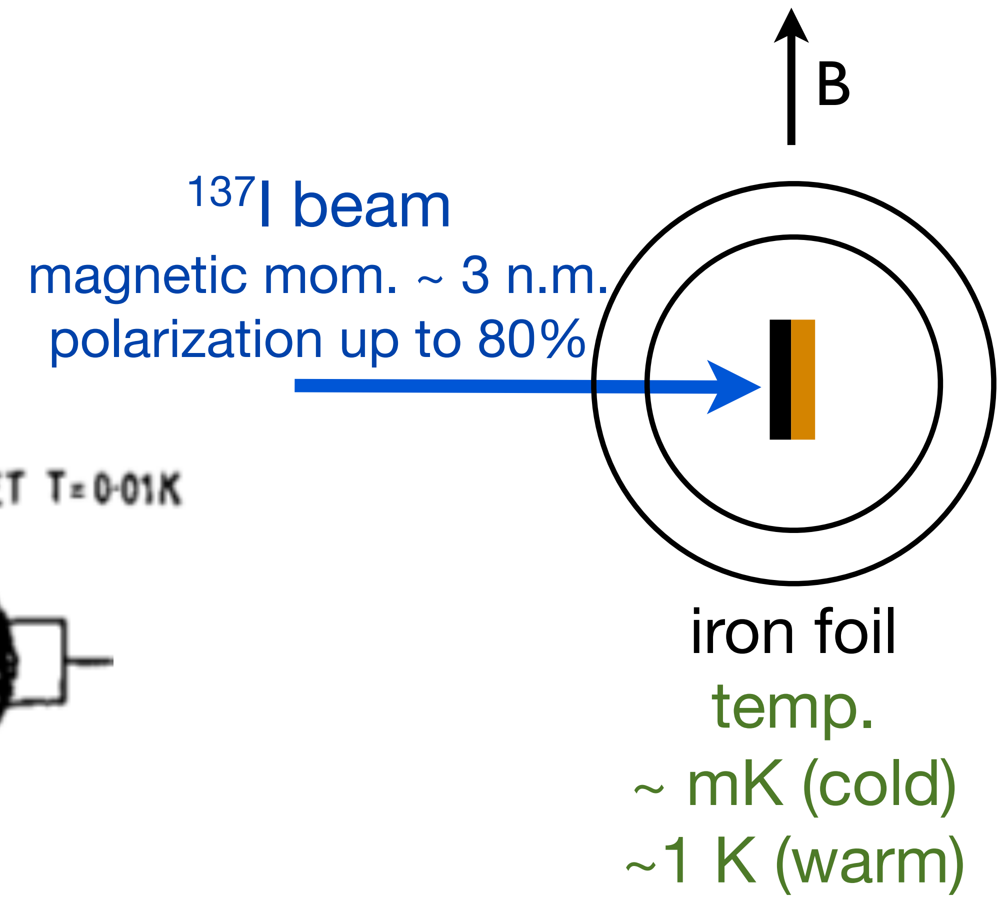
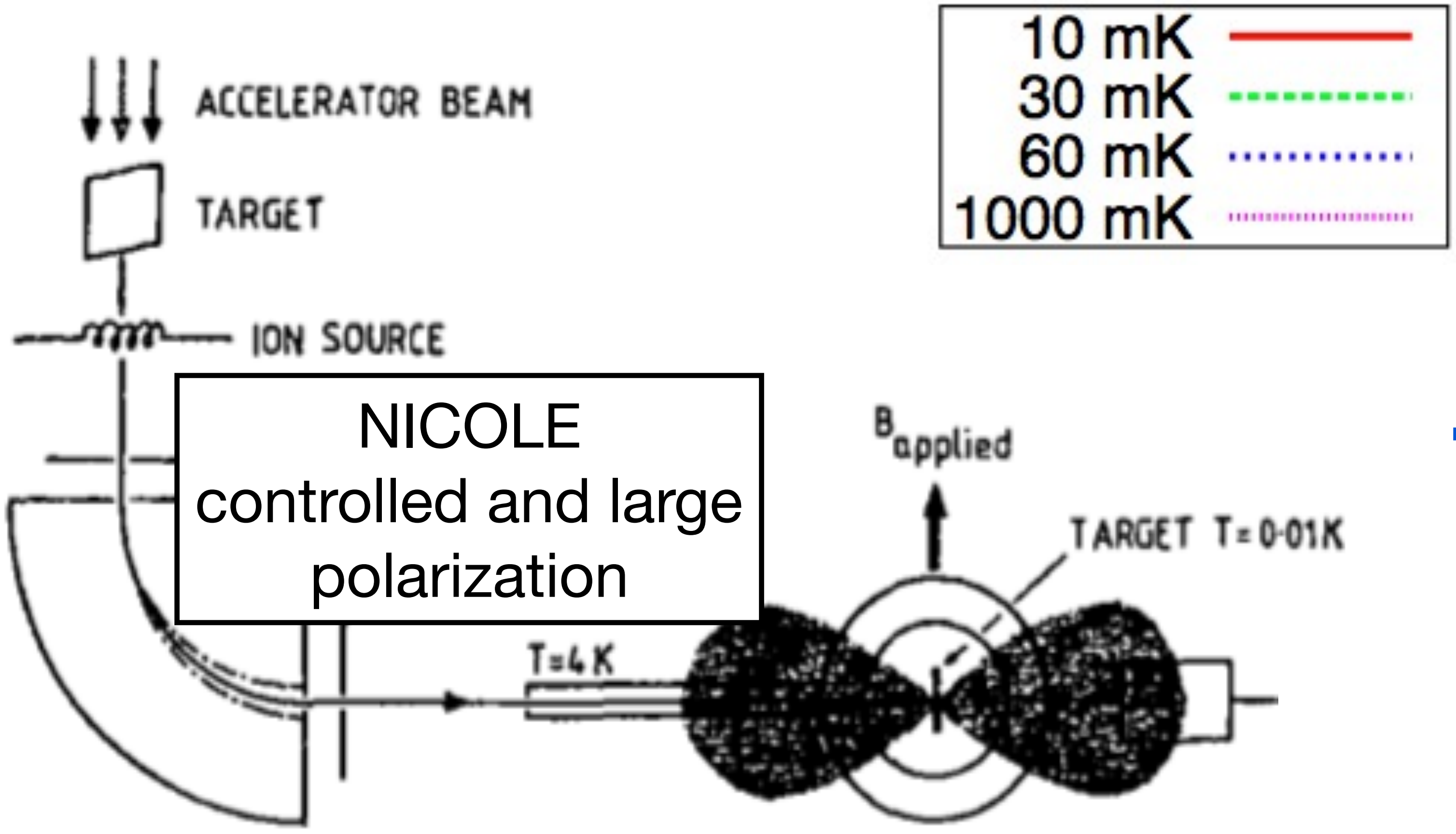


Fig. Schematic on-line nuclear orientation experiment.

Nuclear orientation experiment with VANDLE at NICOLE



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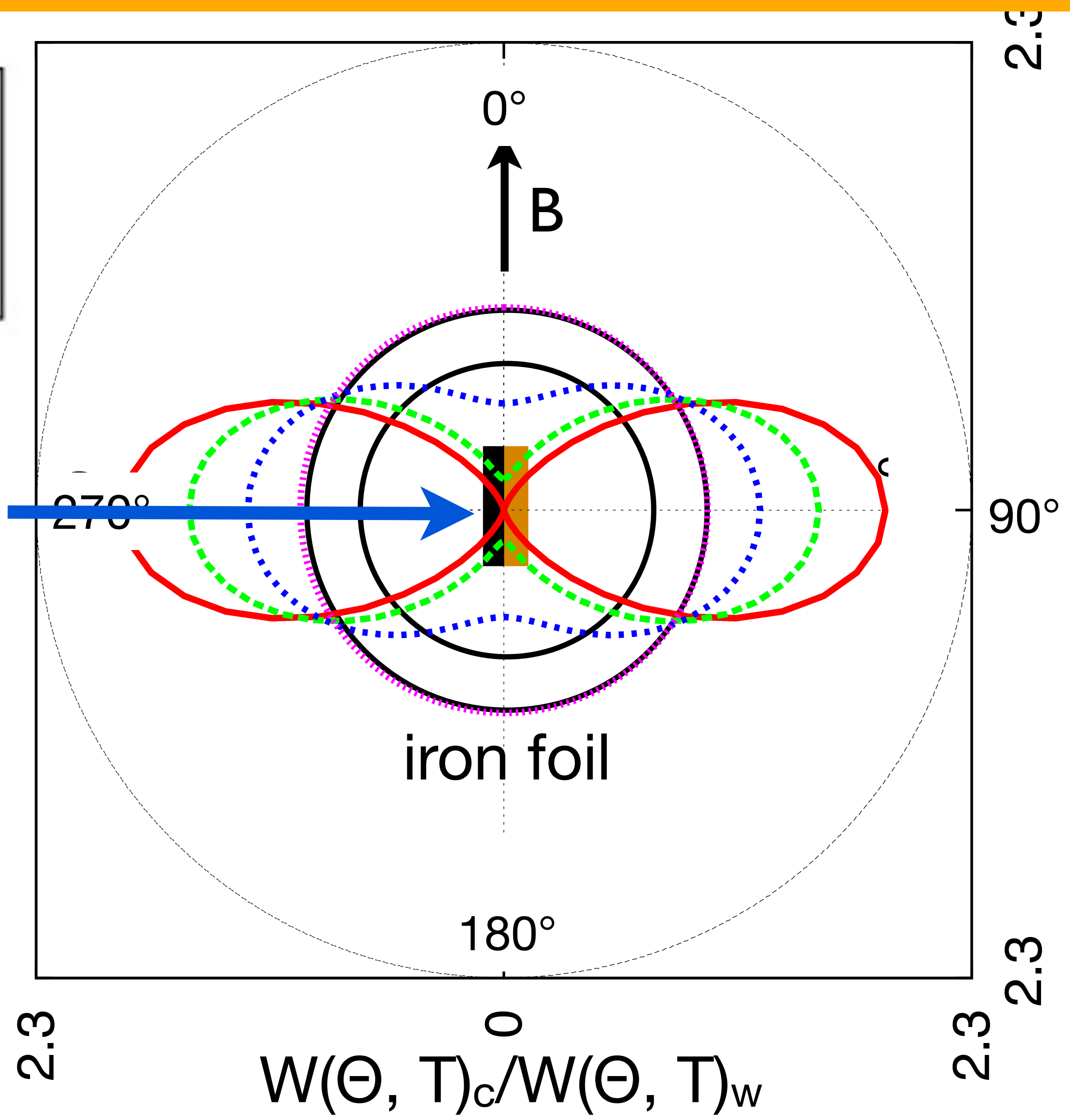
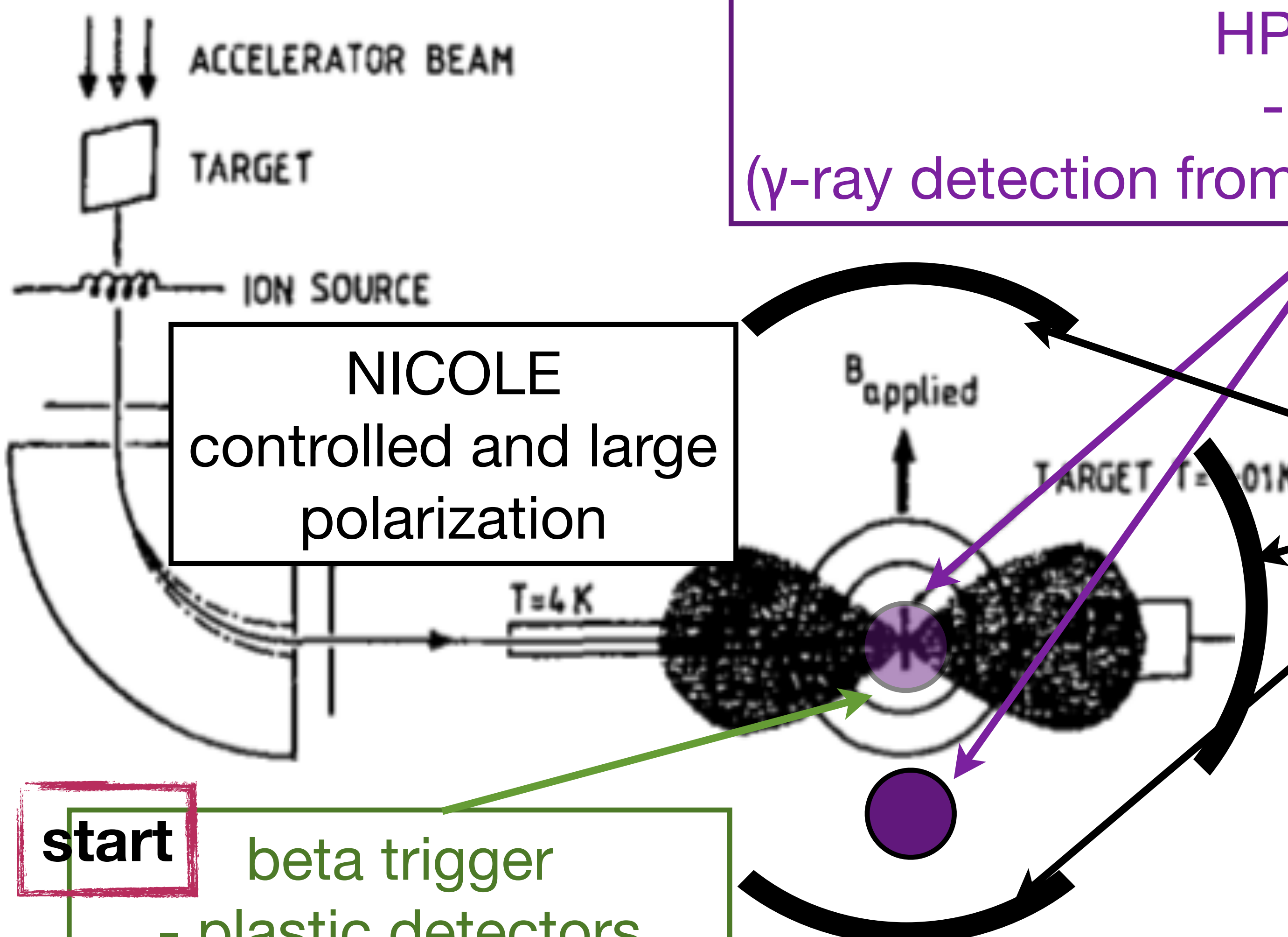


Fig. Neutron angular distribution (E_n = 500 keV).

→ the anisotropy of the angular distribution is defined by the ratio of cold to warm intensities at a given angle and temperature.

Nuclear orientation experiment with VANDLE at NICOLE

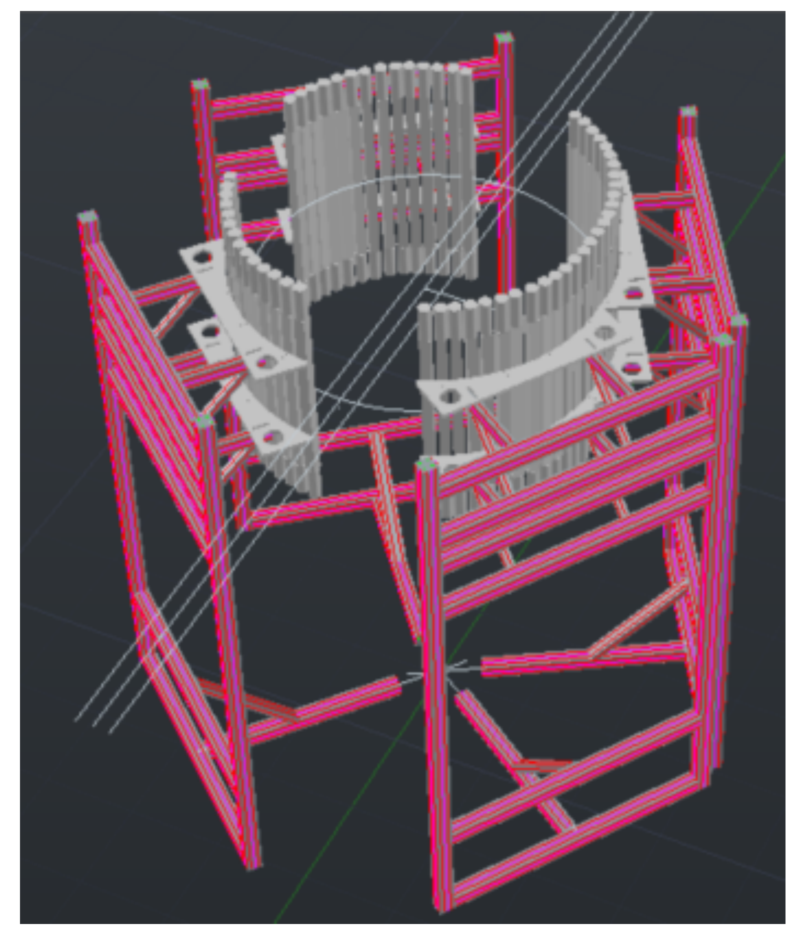


HPGe detectors
- γ detection
(γ-ray detection from ^{137}Xe and ^{60}Co temp. monitor)

NICOLE
controlled and large polarization

stop

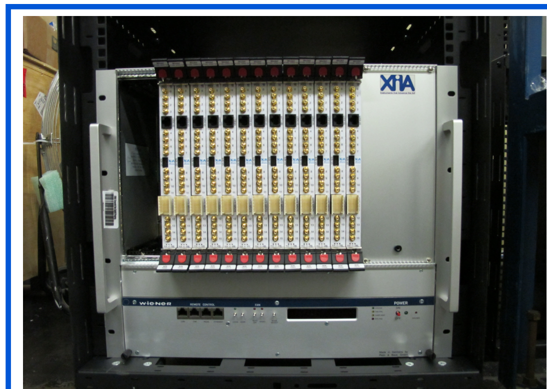
VANDLE
- neutron TOF measurement
placed at the distance of 50cm
3x16 bars 3x3x60cm^3 each
Timing resolution ~1ns



start

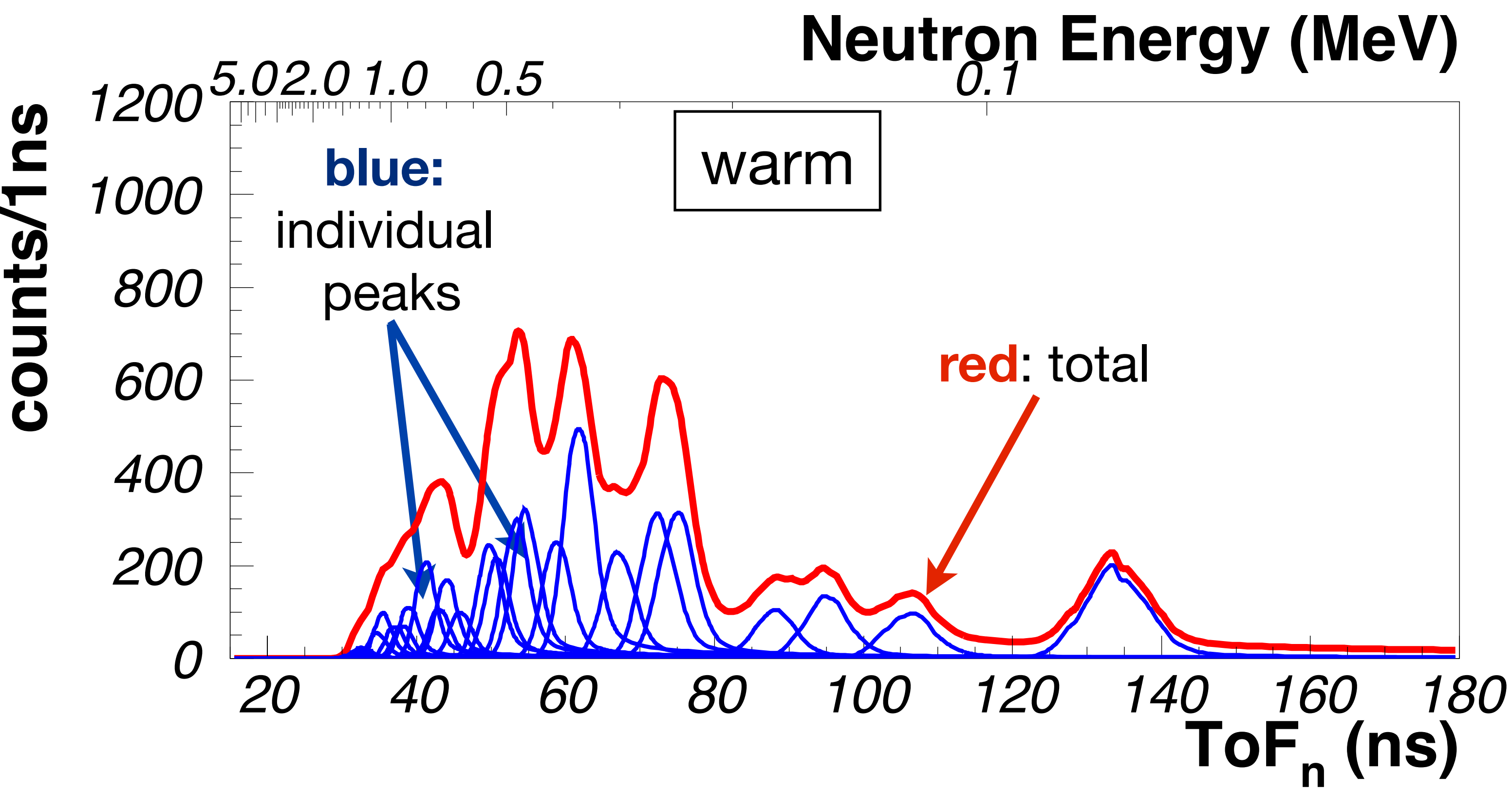
beta trigger
- plastic detectors
as trigger from VANDLE

Fig. Schematic on-line nuclear orientation experiment.



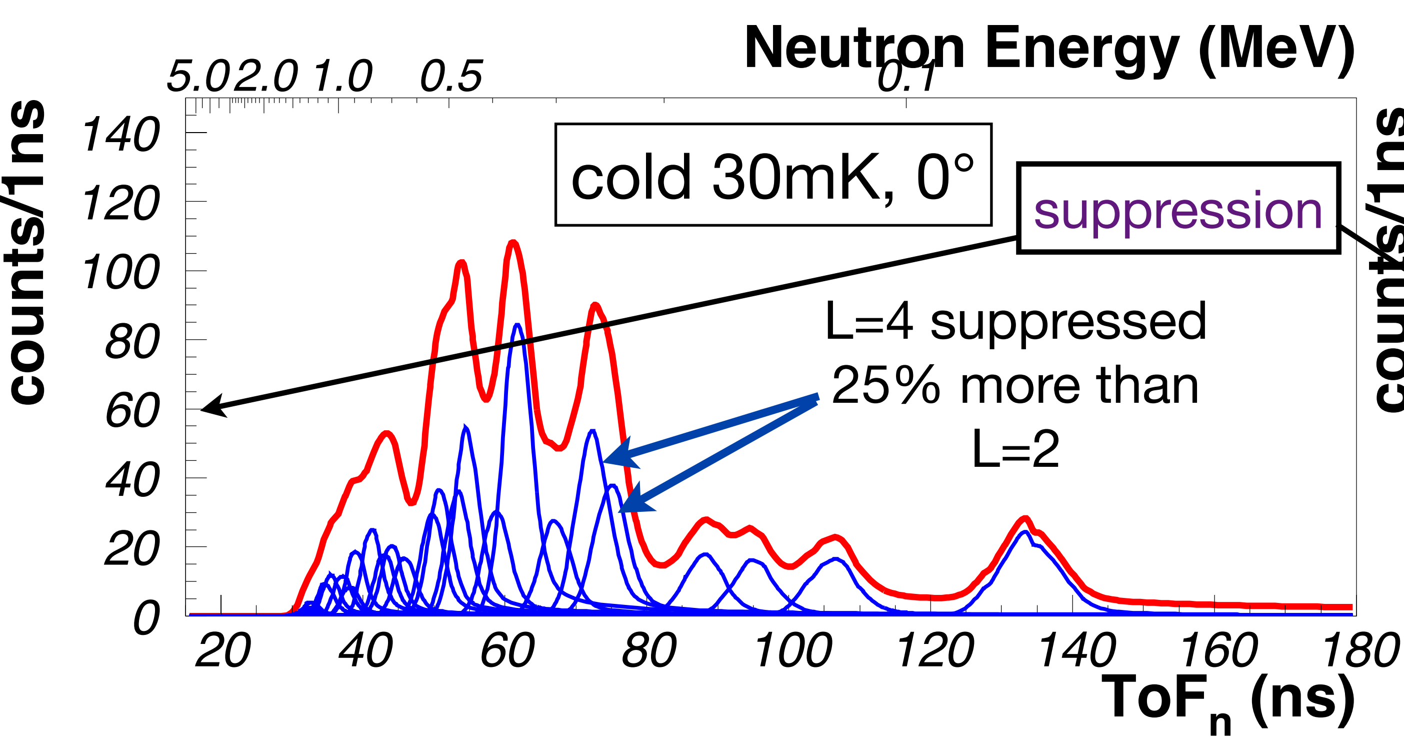
digital electronics
- Pixie16 modules
nano-second time resolution required for TOF measurements

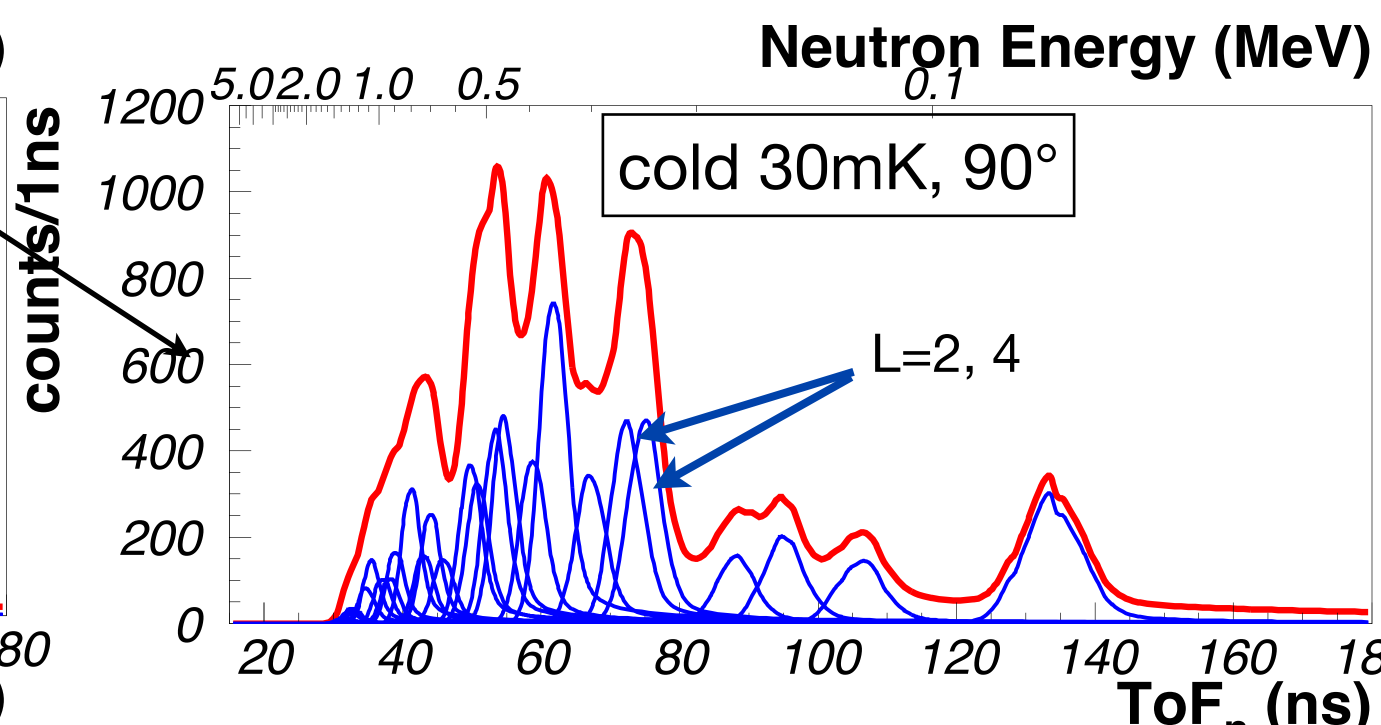
Expected neutron spectra (simulations)



GEANT4 simulations
M. Madurga (UTK)
and S. Ilyushkin (CSM)

- VANDLE@50cm from NICOLE
- VANDLE intrinsic efficiency 20% (conservative estimate)
- intrinsic resolution: 6%
- alternate peak allocated arbitrarily L=4,2





Beam request

1. **Iodine and bromine beams (${}^{137,139}I$ and ${}^{87,89}Br$ - U. Köster)**

minimum $1x10^5$ ions/s (max. $1x10^6$)
(at ISOLCE-SC beams of Br and I were produced from ThO_2 and UC_x with MK4 negative ion source with yields $9x10^5$ and $2.9x10^7$ ions/uC [1, 2])

2. **Preferred negative ions beam**

(alternative solution to ensure at least 20% purity of the beam:
a standard UCx target, a neutron converter and a "hot plasma source" MK5/D5)

3. **34 shifts requested**

15 shifts in 2014 (${}^{137}I$ and ${}^{87}Br$ each at three temp. and warm)
and 15 shifts in 2015 (${}^{139}I$ and ${}^{89}Br$ - feeding daughter excited states)
with a ThO_2 (or UC_x) with MK4 negative ion source,
in addition two shifts of ${}^{9}Li$ and ${}^{8}He$ with warm fridge are needed
prior to experiment for calibrations
(alternatively 15 shifts with a standard UCx target, a neutron converter,
${}^{40}Ca$ mass marker and a "hot plasma source" MK5/D5)

[1] P.D. Kleinschmidt and D.L. Hildenbrand, J. Chem. Phys. 68, 2819 (1978)
[2] K. Hilpert and M. Mileer, J. Chem. Phys. 97, 6674 (1992)

Summary

VANDLE@NICOLE

We propose first angle and energy resolved beta delayed neutron measurement on medium heavy nuclei

- Purpose: study relatively complex nuclei $^{137,139}I$ and $^{87,89}Br$ to test statistical models for the understanding of the βn-decay models

- NICOLE@ISOLDE provides unique combination of high intensity beams and a very high degree of polarization which is essential for the proof of principle experiment

- VANDLE: neutron detection with energy and angle resolution combined with digital electronics

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Update on NICOLE

- the fridge has been repaired (ICE-Oxford) and comes back to ISOLDE by the end of November