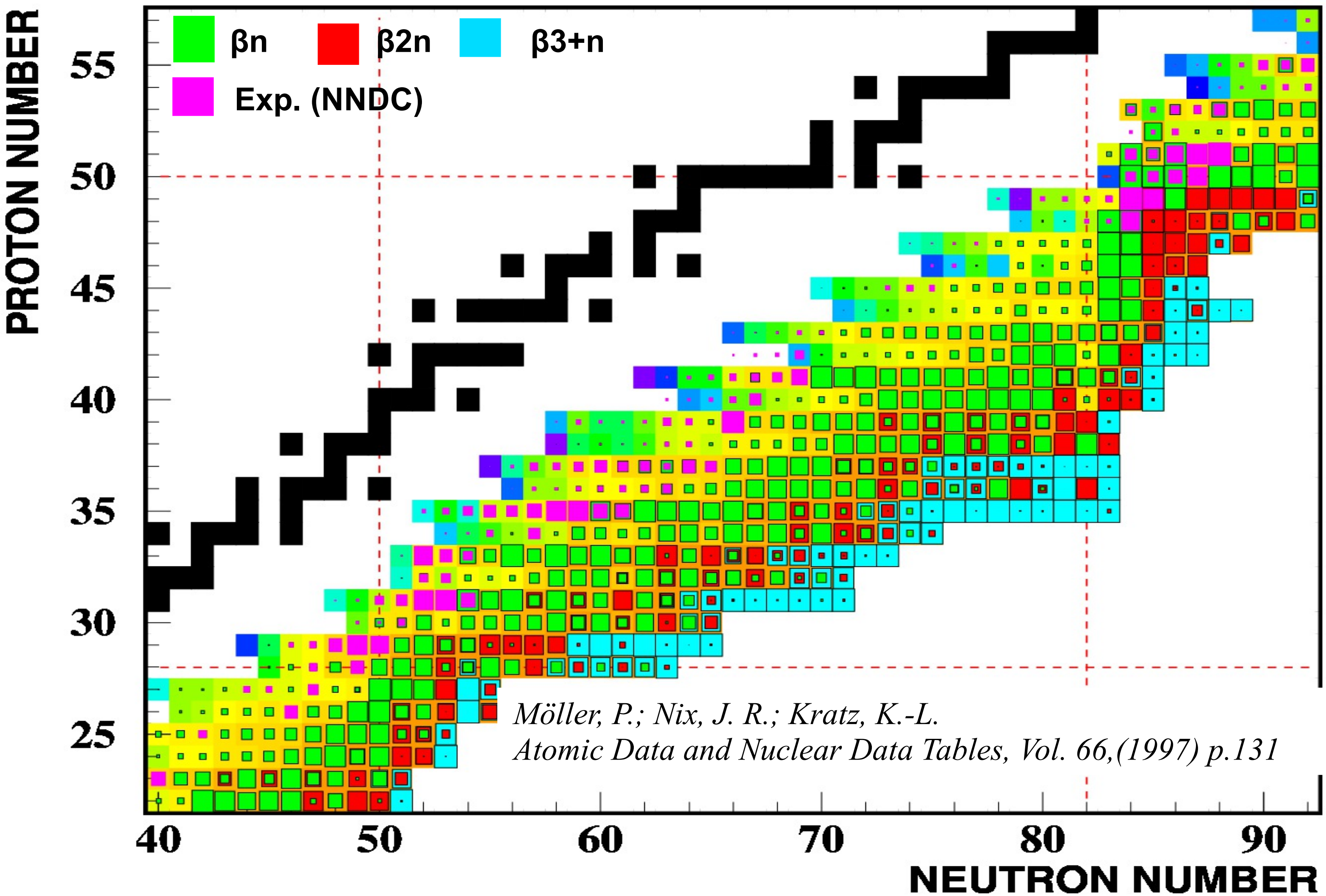
Gamow-Teller decays of nuclei beyond N>50

Robert Grzywacz, University of Tennessee and Oak Ridge National Laboratory

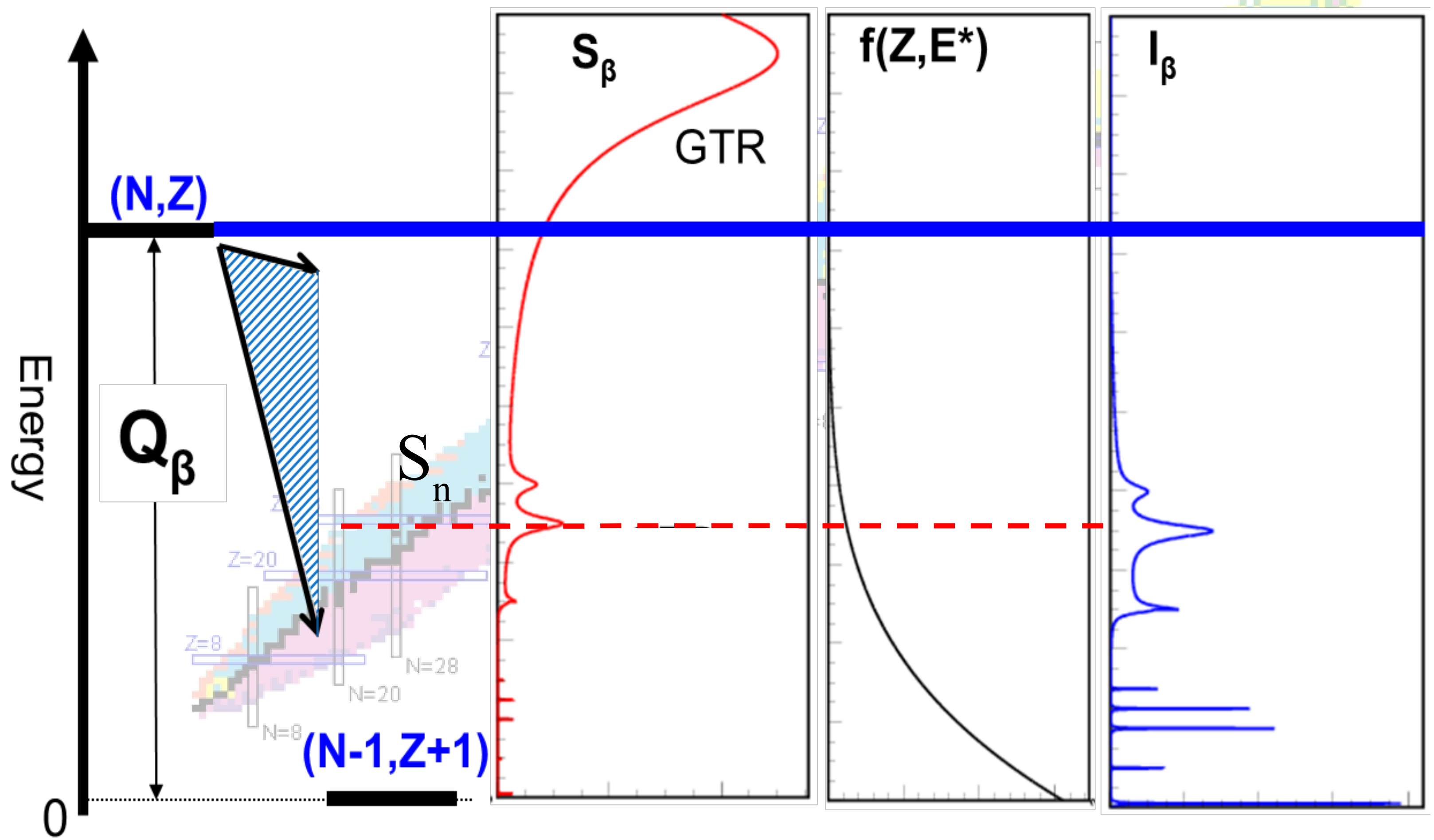


CENTER OF EXCELLENCE FOR RADIOACTIVE ION BEAM STUDIES FOR STEWARDSHIP SCIENCE

Decay strength distribution lifetimes and branching ratios

$$\frac{1}{T_{1/2}} = \sum_{E_i \geq 0}^{E_i \leq Q_\beta} S_\beta(E_i) \times f(Z, Q_\beta - E_i)$$

$$S_\beta(E_i) = \langle \psi_f | \hat{O}_\beta | \psi_{mother} \rangle$$



Decay strength distribution lifetimes and branching ratios

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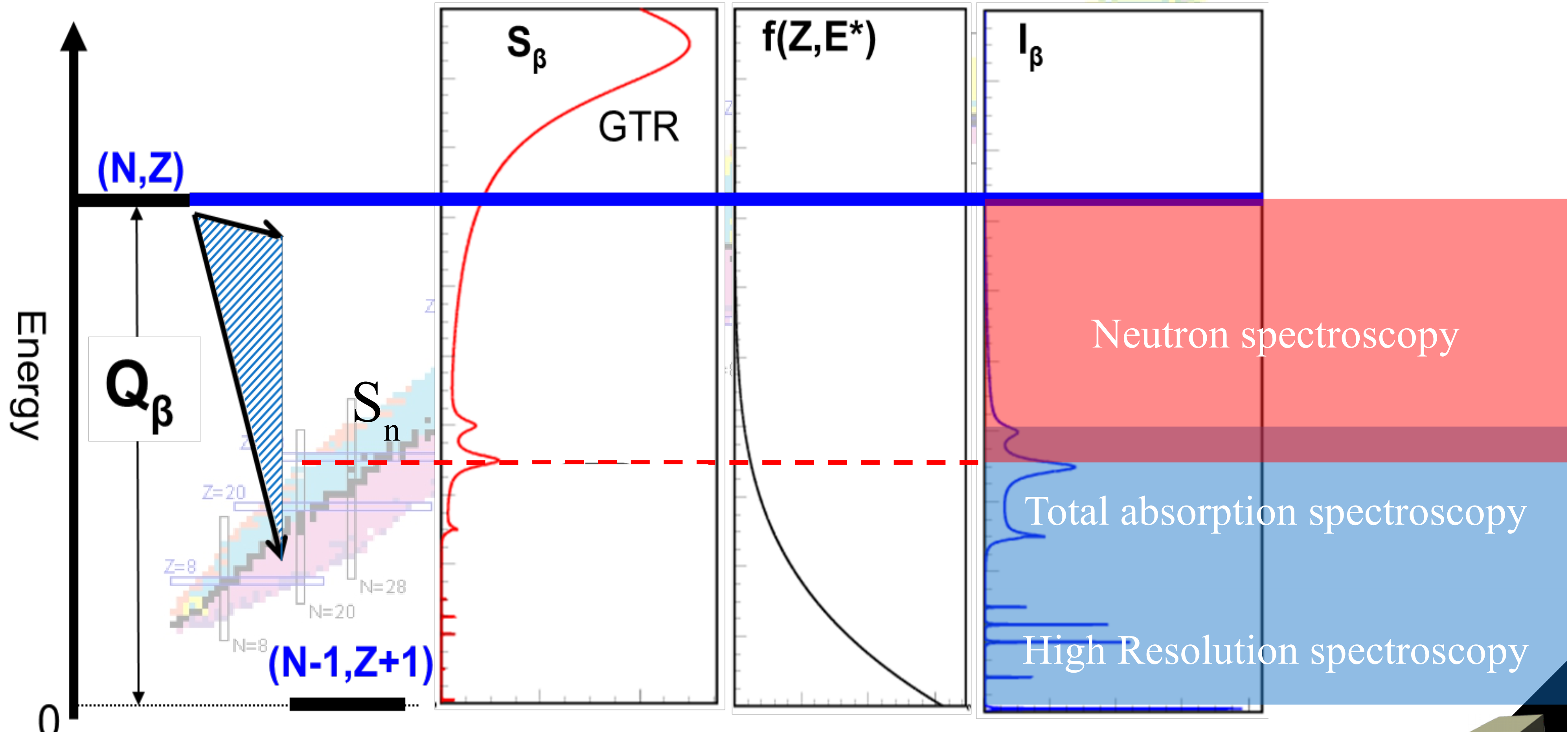
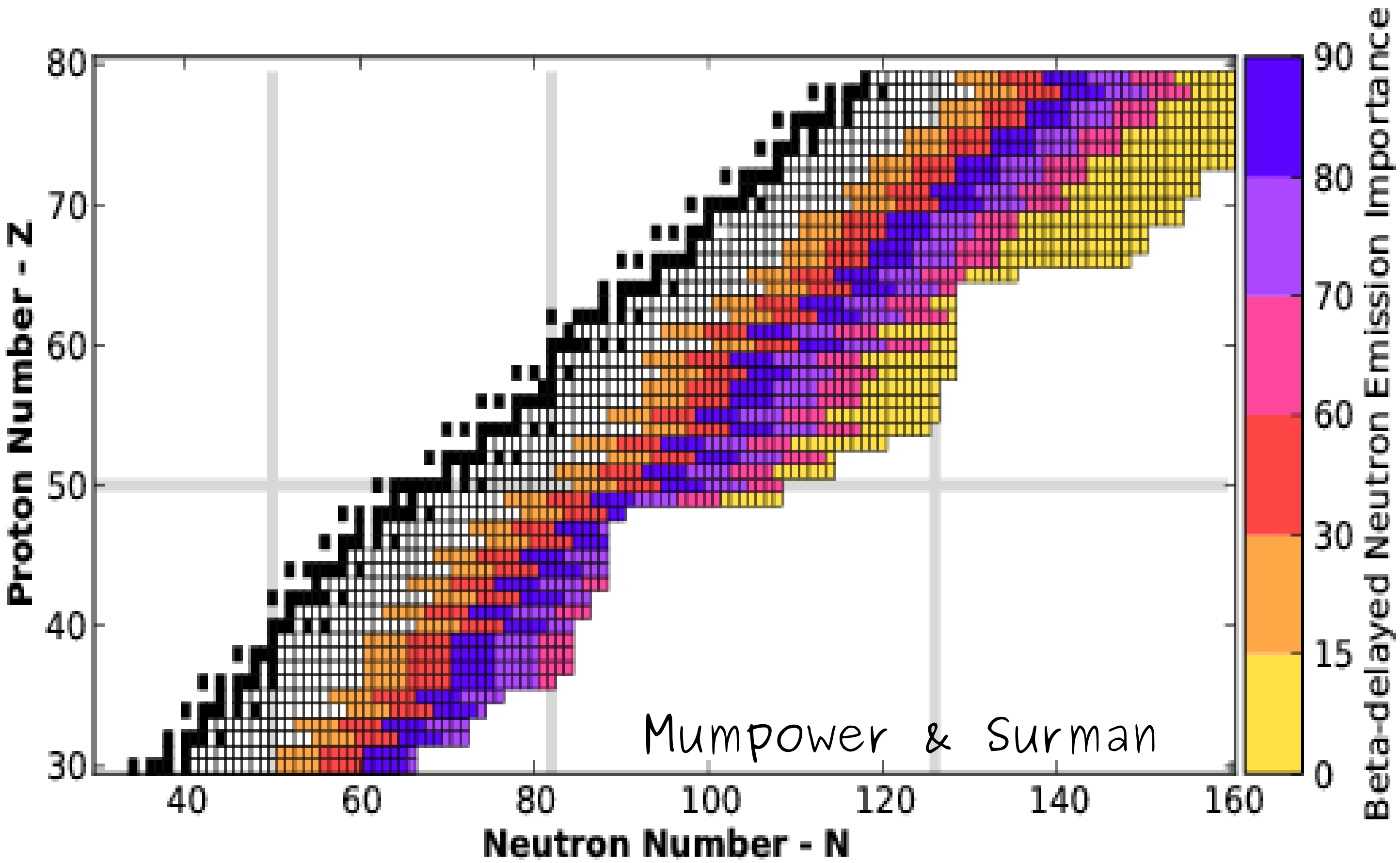


Importance of β-delayed neutron emitters



It might be hard to collect data for the nuclei which are really important …

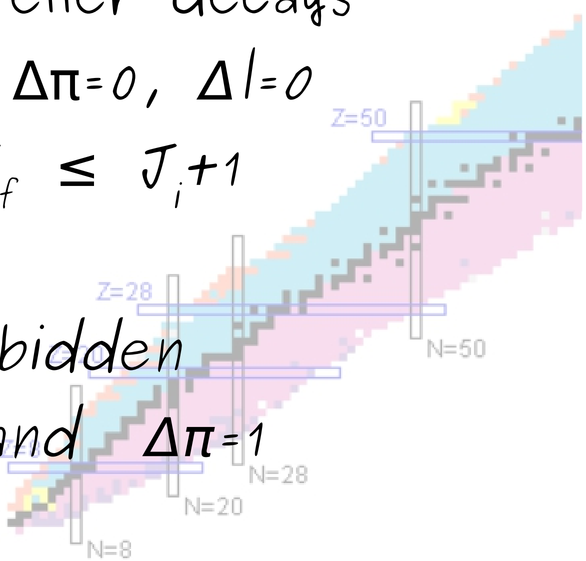
Single particle model of decays near ^{78}Ni

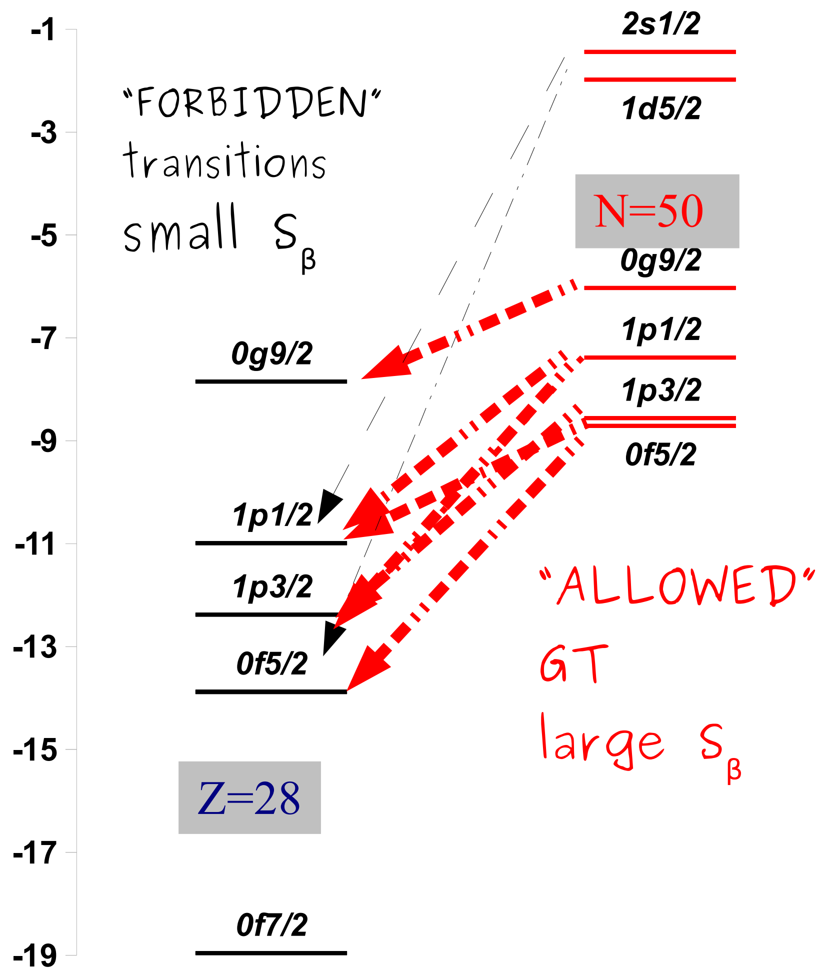
$$S_\beta(E_i) = \langle \psi_f | \hat{O}_\beta | \psi_{mother} \rangle$$

For neutron rich nuclei:
GT and FF.

Gamow–Teller decays
S=1 and $\Delta\pi=0$, $\Delta l=0$
$J_i-1 \leq J_f \leq J_i+1$

First forbidden
$\Delta J=0,1$ and $\Delta\pi=1$



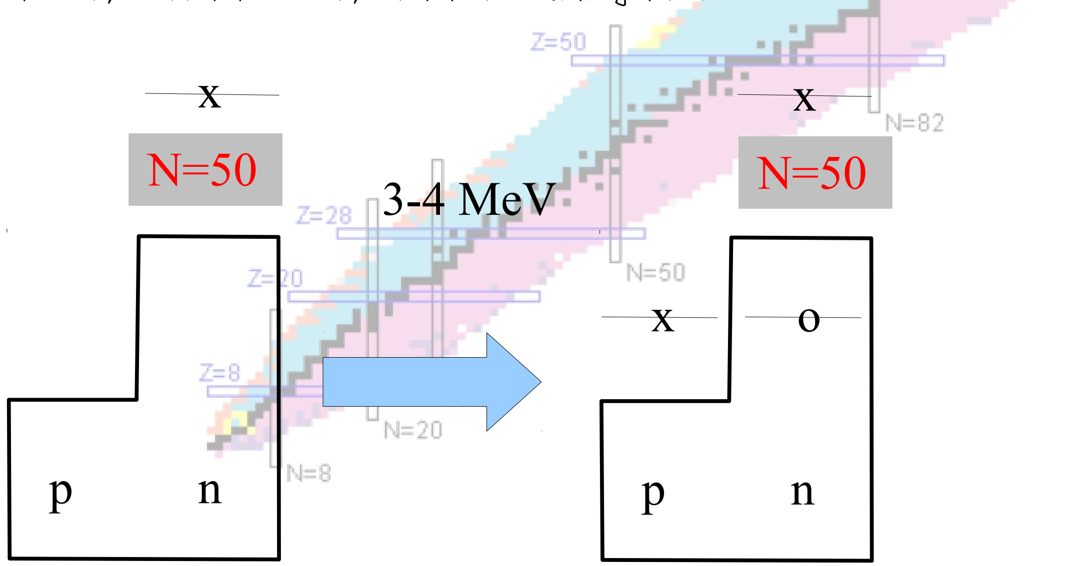


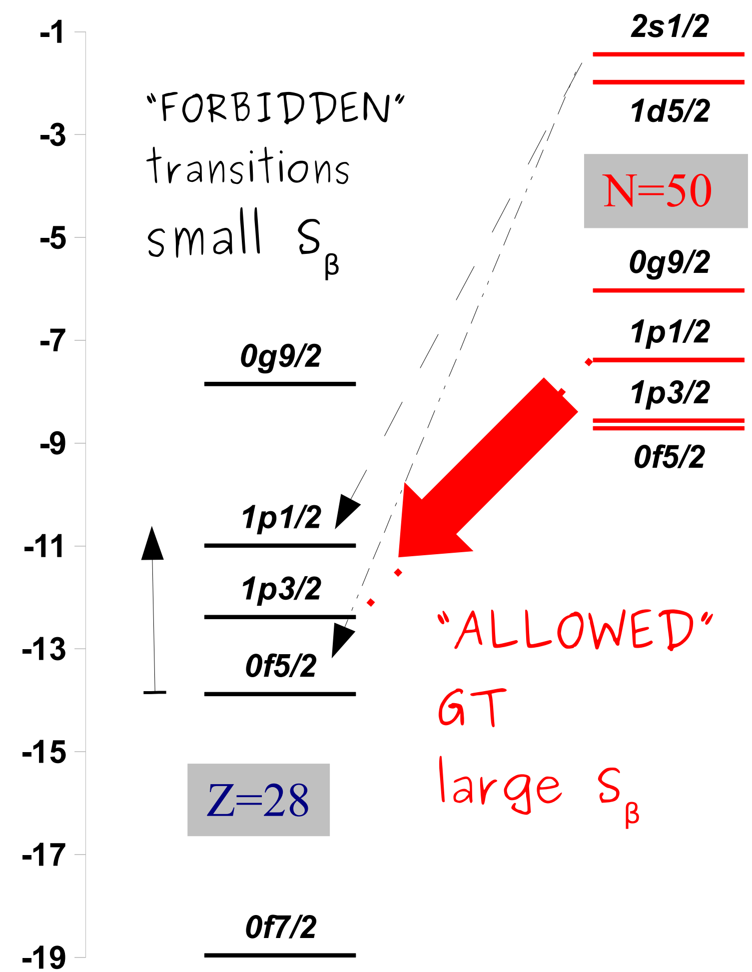
Single particle model of decays near ^{78}Ni for N>50

Single particle description:

- "Valence" nucleons cannot decay via allowed Gamow-Teller transitions between spin orbit partners
- Particle-hole excitations lead to population of high energy states
- Important role of forbidden transitions ($\Delta l>0$ and parity changing)

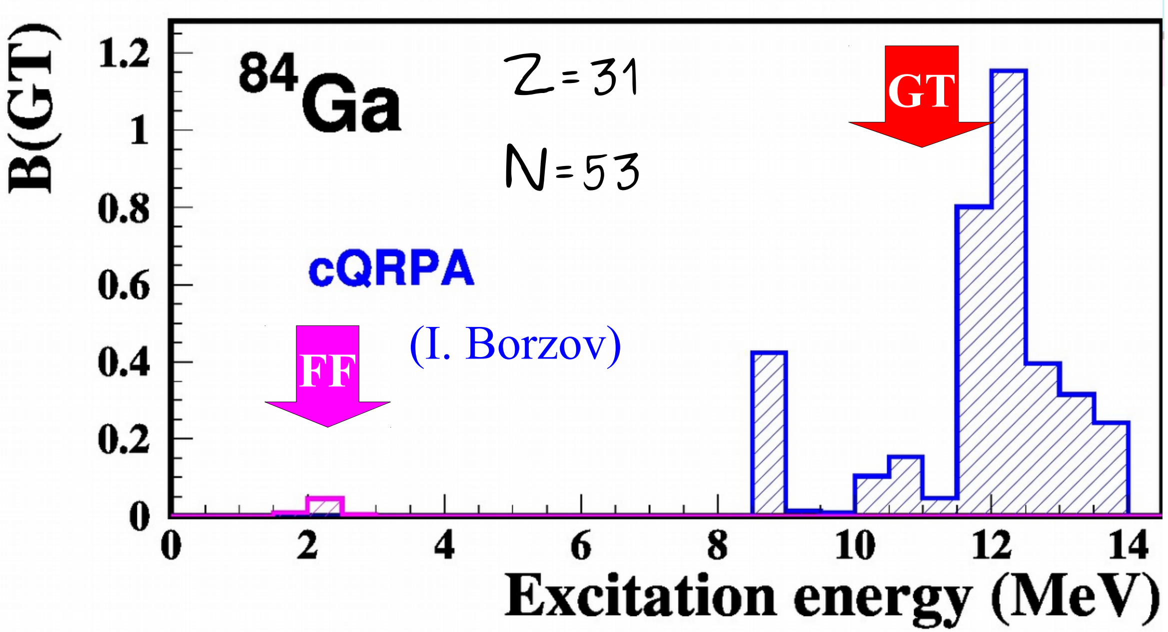
Speeding-up the classical r process Phys. Rev. C 67, 05580 (2003)
Peter Möller, Bernd Pfeiffer, and Karl-Ludwig Kratz

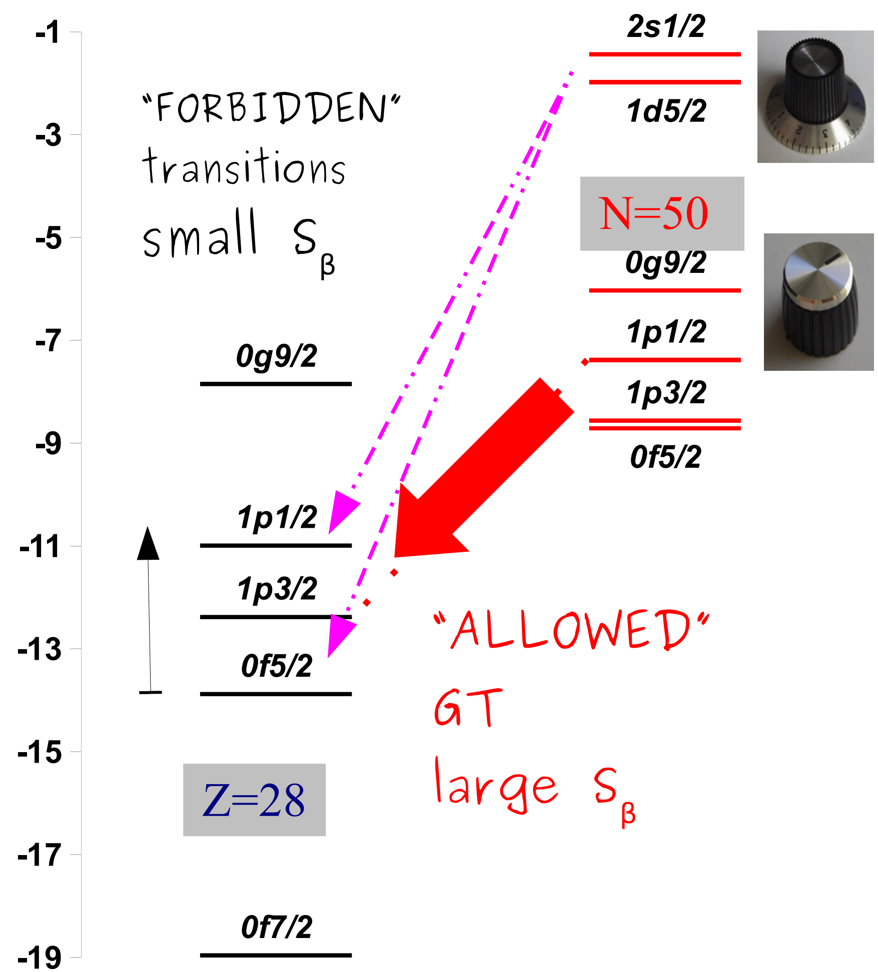




Beta decay of neutron rich nuclei beyond N=50

Forbidden and allowed transitions separated in energy scales (and decay modes).

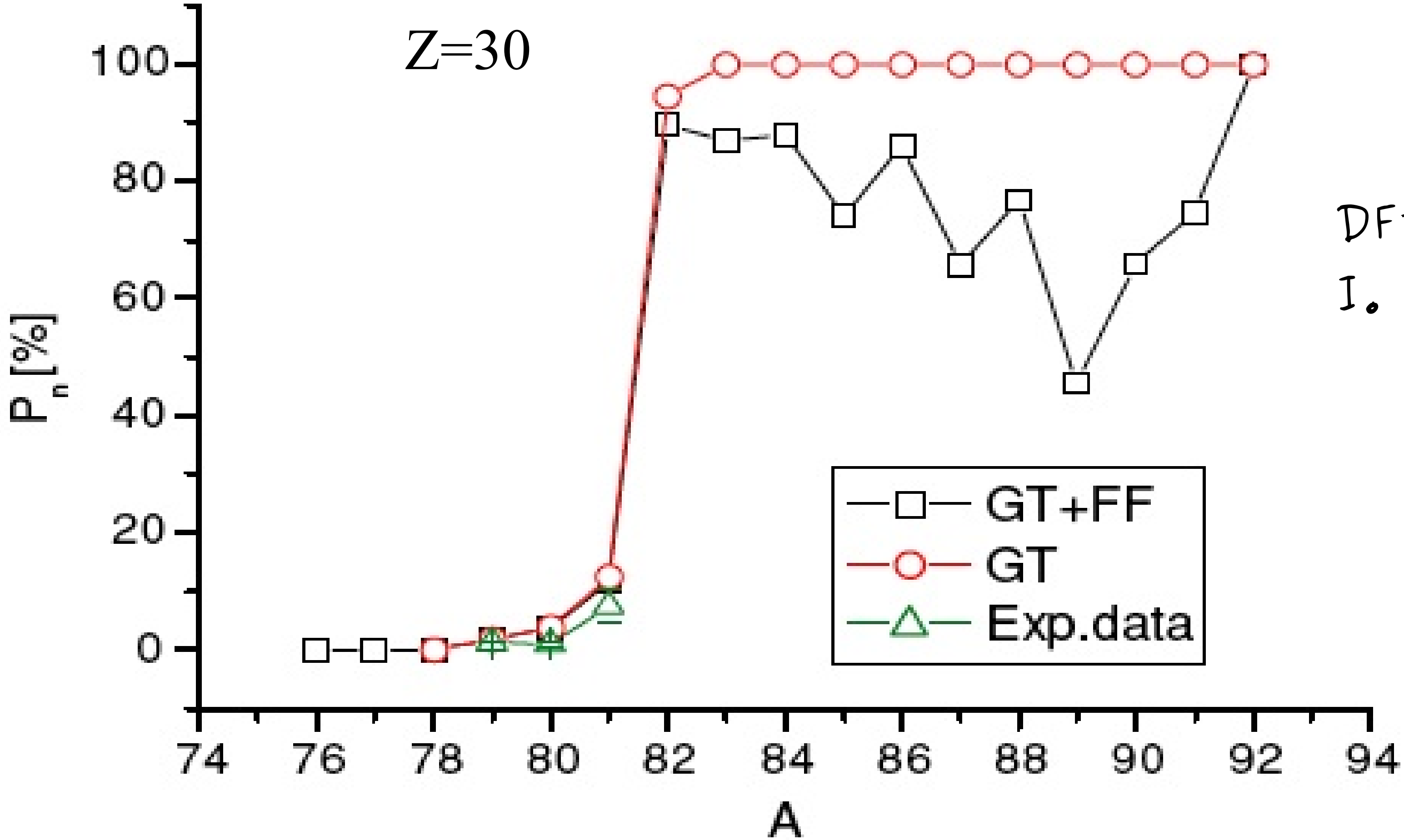




Allowed (GT) and "forbidden" (FF) transitions

GT – "saturate" the Pn past N=50

FF – "erode" the Pn



DF3a+QRPA
I. Borzov

GT dominates far from stability

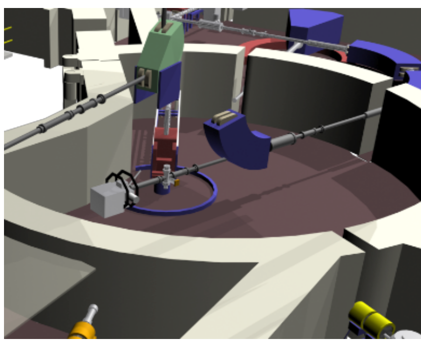
Holifield Radioactive Ion Beam Facility

Low-energy Radioactive Ion Beam Spectroscopy Station (LeRIBSS)

Intense beam (~10 μA) of (50MeV) protons on UCx targets

Isobar separation essential for success of the experiments !

IRIS-1/IRIS-2 platforms, negative and positive ions.



VANDLE – neutron time of flight and γ-ray detector

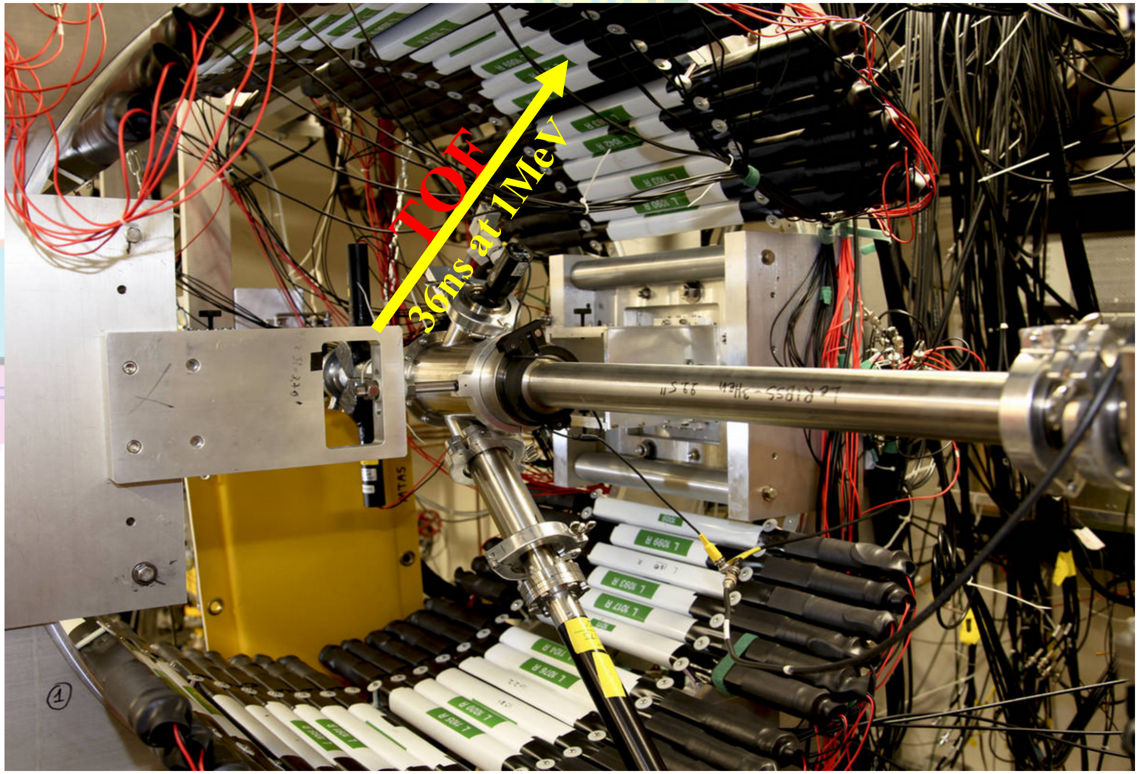
The Versatile Array of Neutron Detectors at Low Energy

Funding: Center of Excellence for Radioactive Ion Beam Studies for Stewardship Science – DOE NNSA

Design goal:
Maximize the detection efficiency in the broad energy range (100 keV – 6 MeV)
Measure neutrons and gammas .

First implementation at HRIBF experiment:
- 48 bars 3x3 x 60 cm^3
- Ω = 10% (23%) of 4π
- 3% (6%) total efficiency @ 1MeV
- 50 cm TOF radius
- 40–60% efficiency beta "START" detector

Gamma rays:
- 2 clovers, 3% efficient @ 1MeV



Fully digital system (250 MSPS):

Sub-nanonsecond timing with
4ns digitization period

Low neutron detection threshold

Portability and flexibility

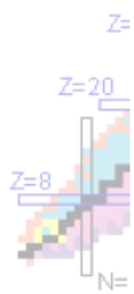
S. Paulauskas et al. NIM A737,22(2014)

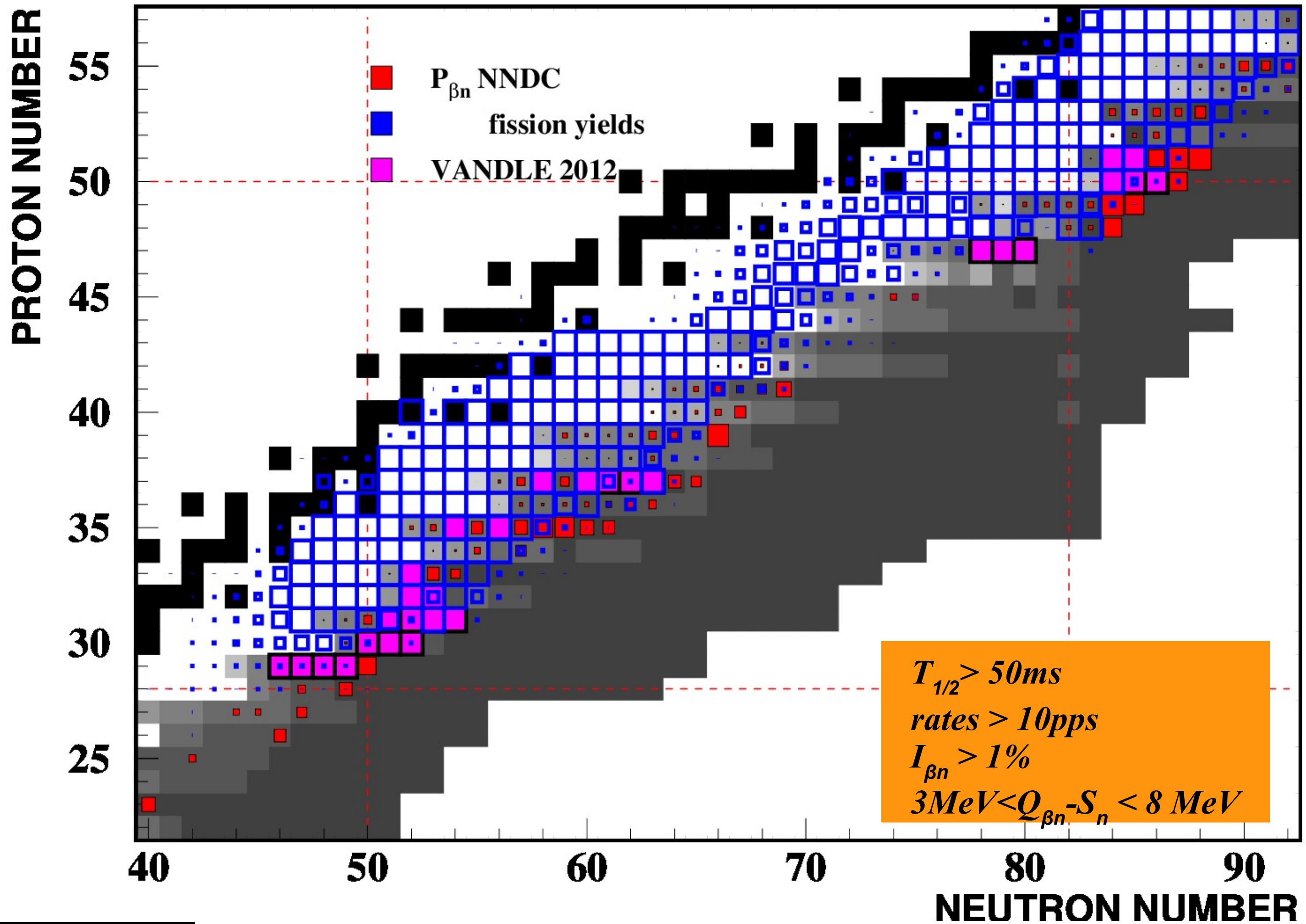
Beta-delayed neutron emitters near r-process path studied at HRIBF/LeRIBSS in February 2012

VANDLE commissioning experiment

Selection of isotopes with large $Q_\beta - S_n$ and $I_{\beta n}$

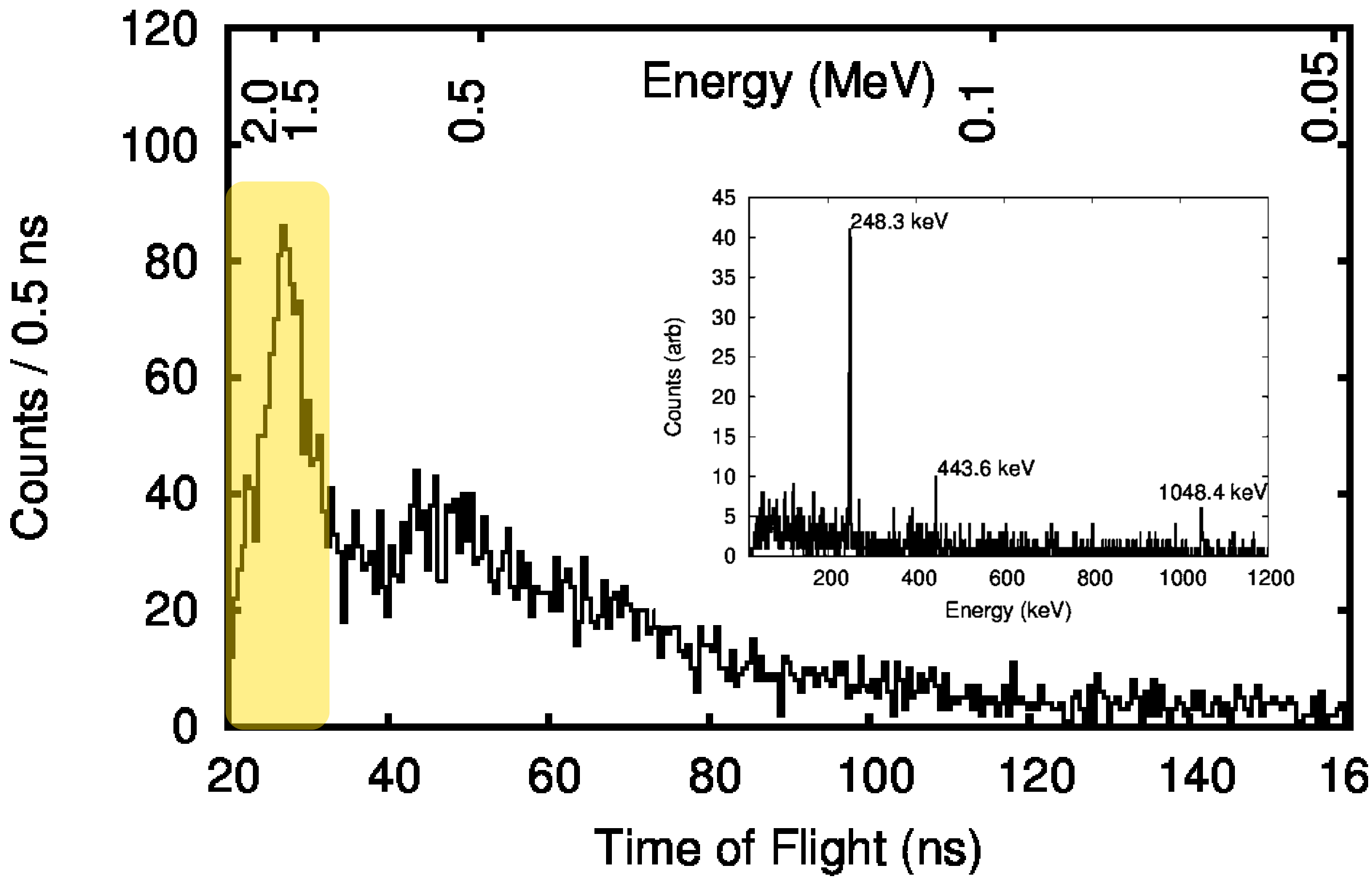
29 cases measured, focus on new data

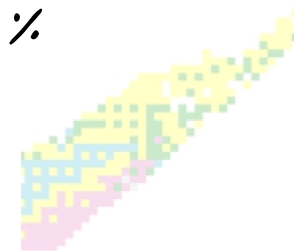


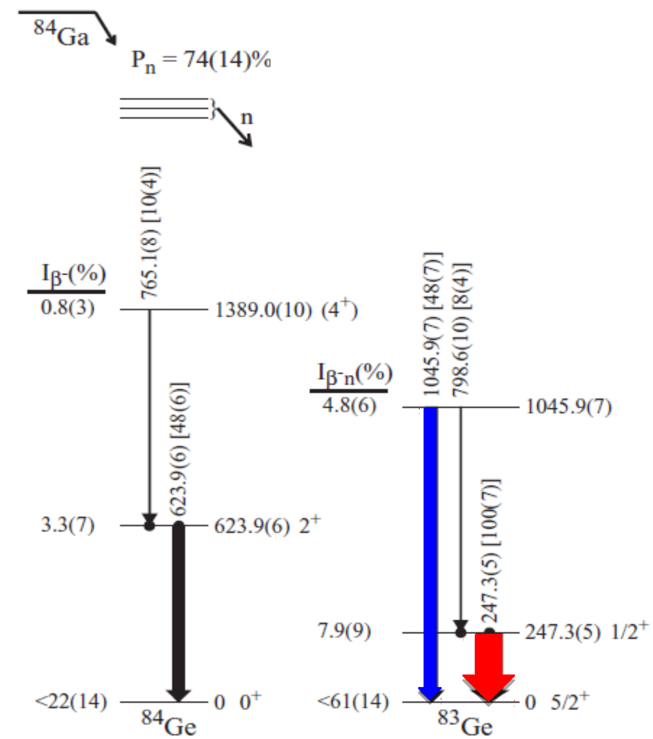


"Resonant" decay of ^{84}Ga (~30 h measurement)

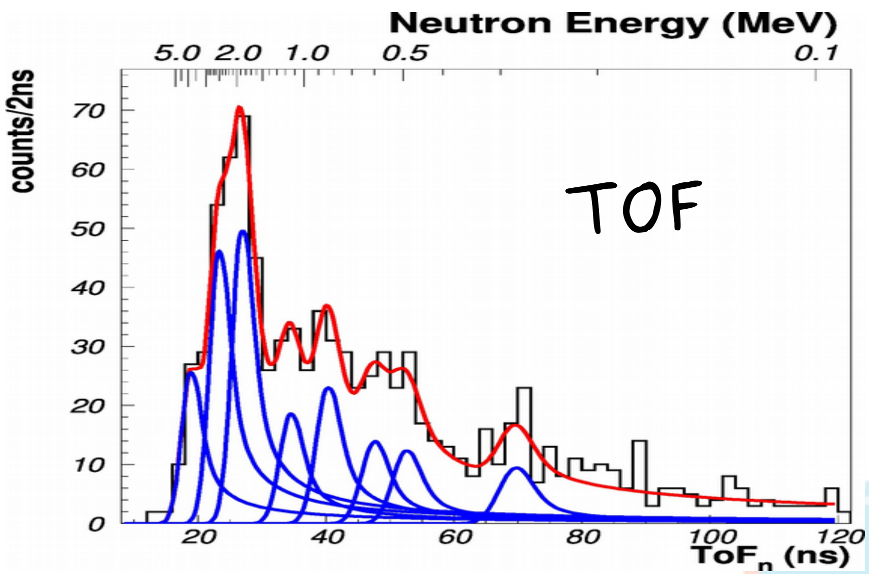
- Q_β = 13.69 $T_{1/2}$=85(10) ms
- $Q_\beta - S_n$ = 8.5 MeV, Pn = 74(14)%

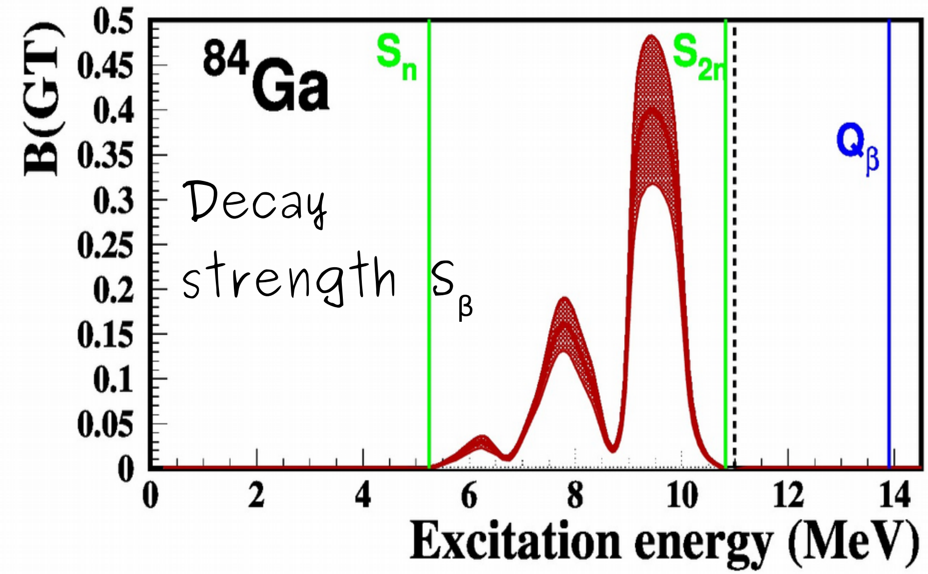


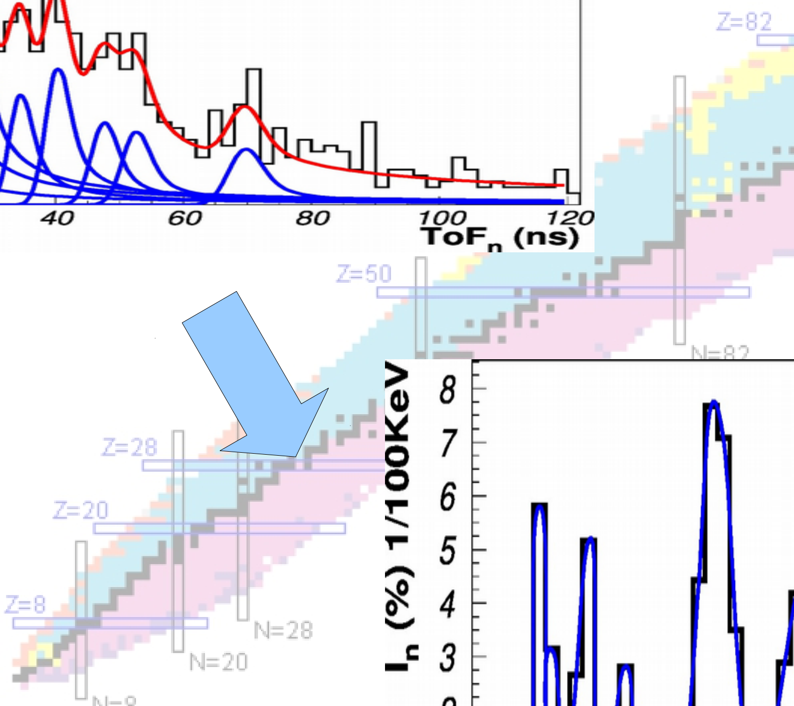


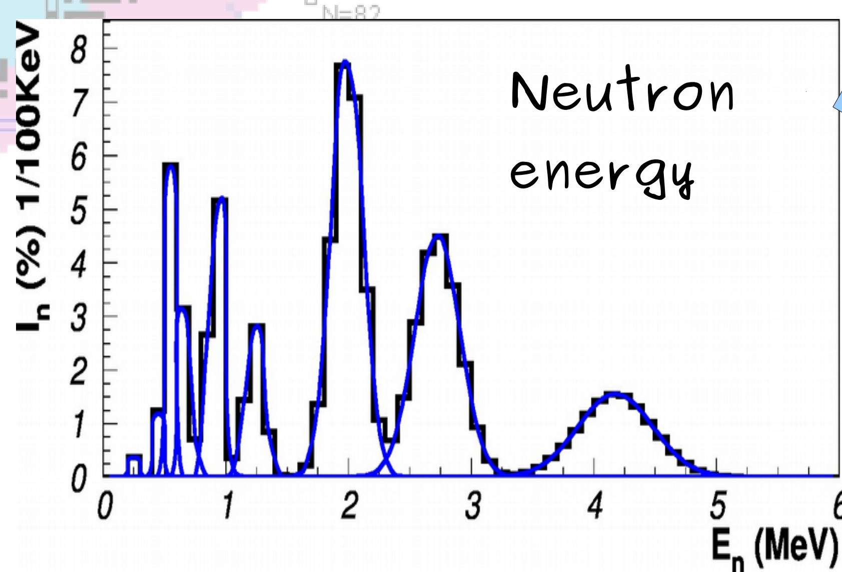


Spectrum deconvolution - from TOF to decay strength





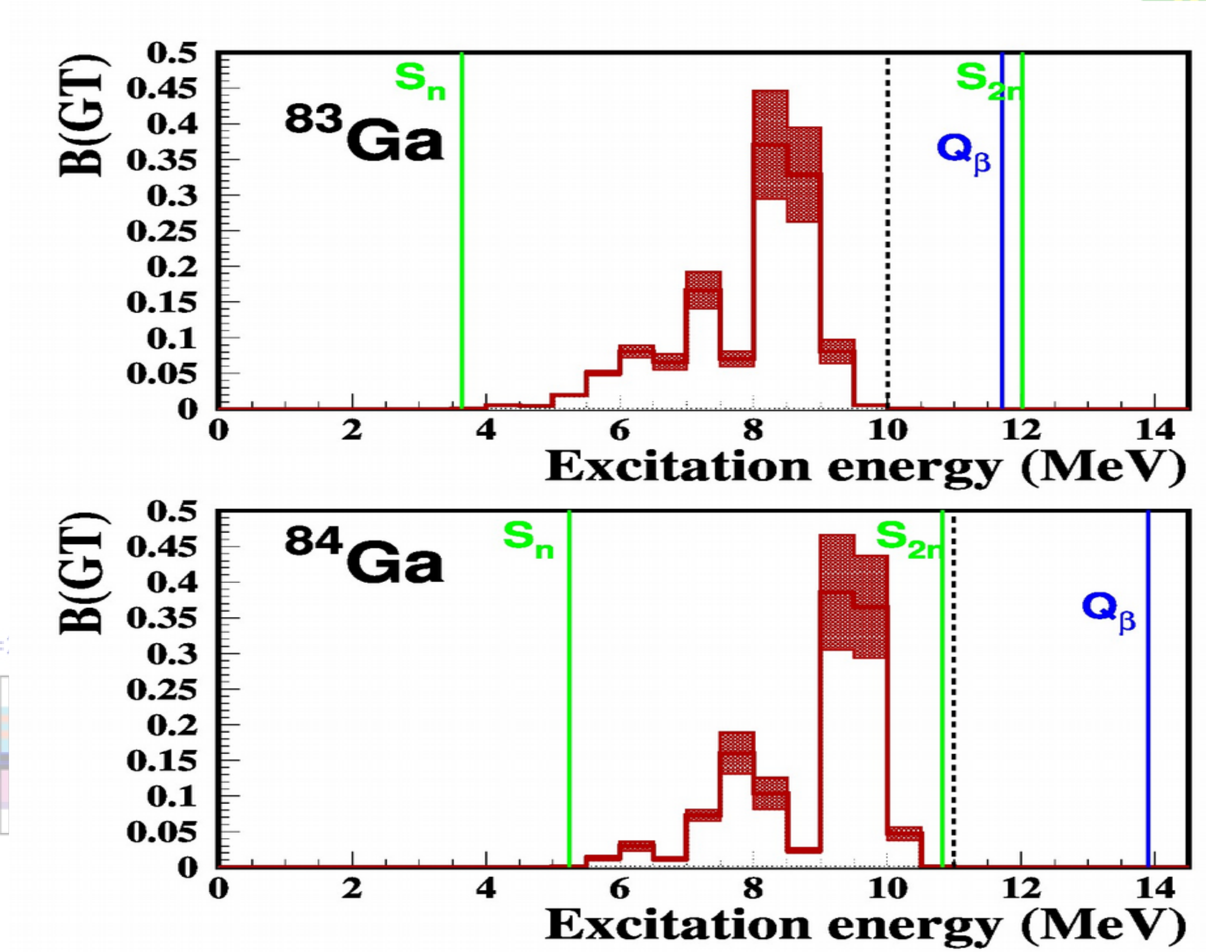




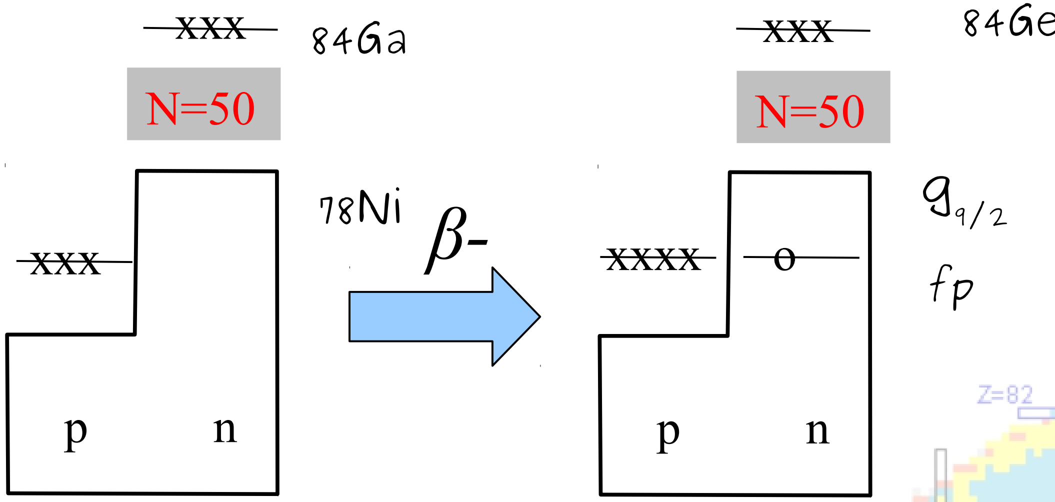
B(GT) in MeV^{-1}

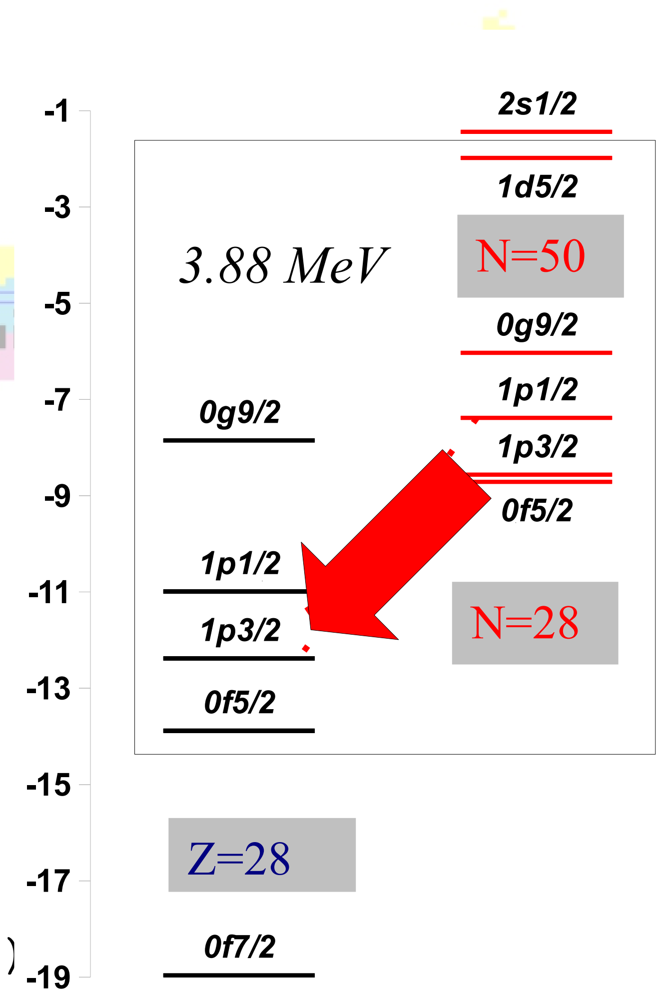
^{84}Ga and ^{83}Ga decay strength from neutrons

- observed large beta strength at high excitations in the daughter
- structures in the neutron spectrum



Shell-model interpretation with $d_{5/2}$-neutrons explicit calculation of strength

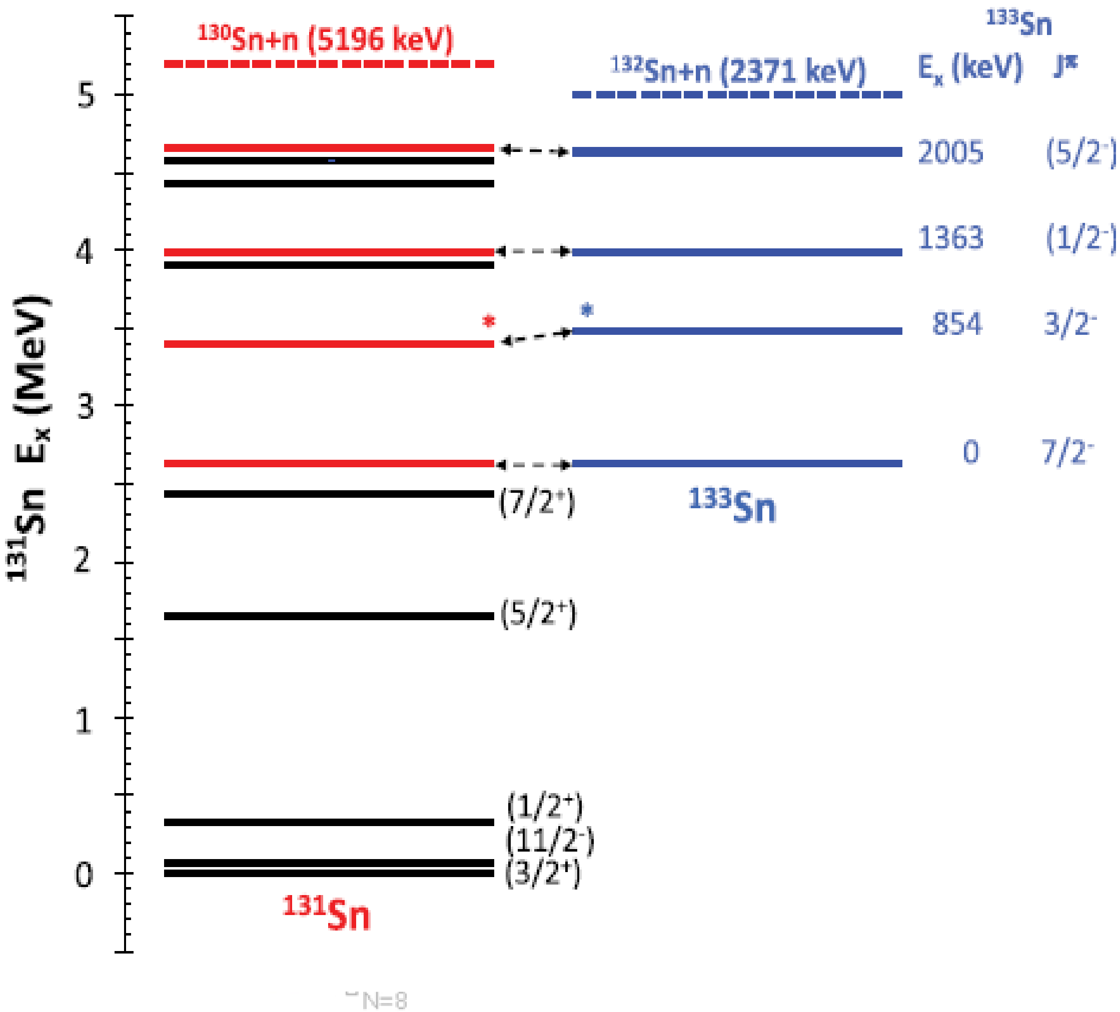


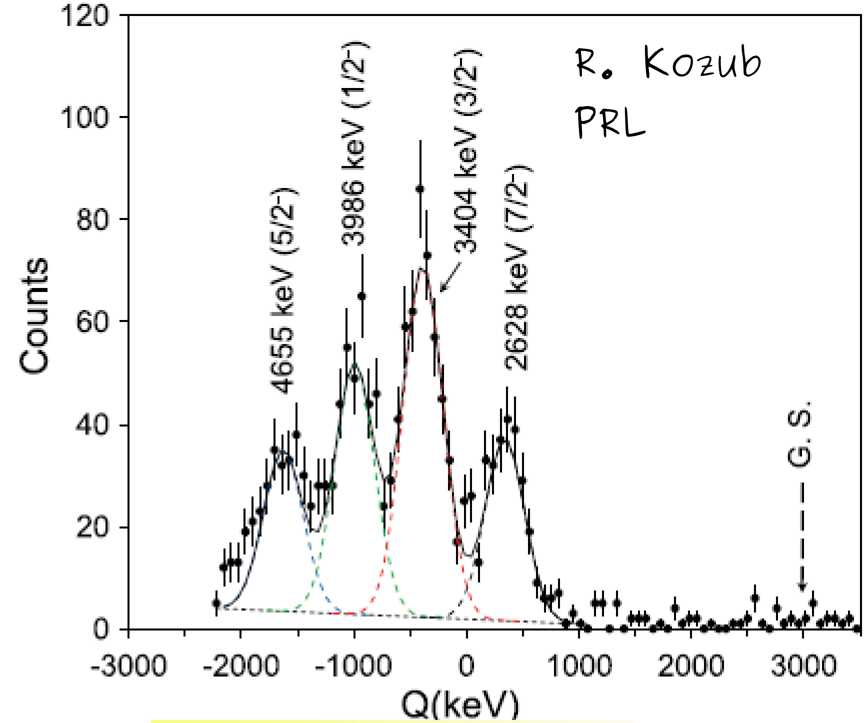


Nushellx (parallel B.A.B. with ^{56}Ni core)
jj44bpn interactions for fpg Lisetskiy&Brown,
GOOD DESCRIPTION OF N<50 ISOTOPES
(empirical adjustments)
added attractive d5/2+fpg
f5/2,p3/2,p1/2, g9/2 for protons
… + d5/2 for neutrons
d5/2 neutrons "blocked" for B(GT) calculations
Single Particle Energies - experimental systematics (Grawe)

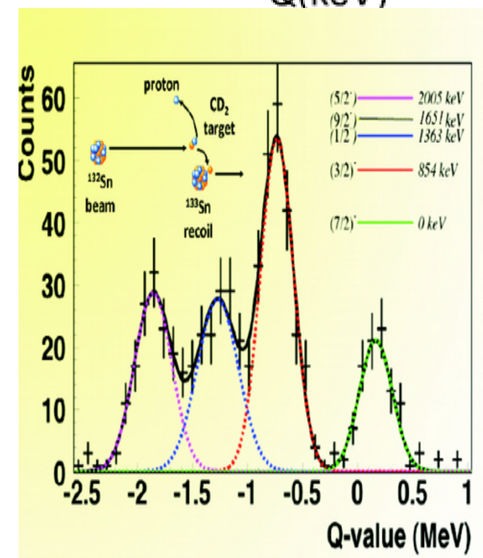
A. F. Lisetskiy, B. A. Brown, M. Horoi, and H. Grawe
Phys. Rev. C 70, 044314 (2004)

(d,p) on ^{130}Sn and ^{132}Sn



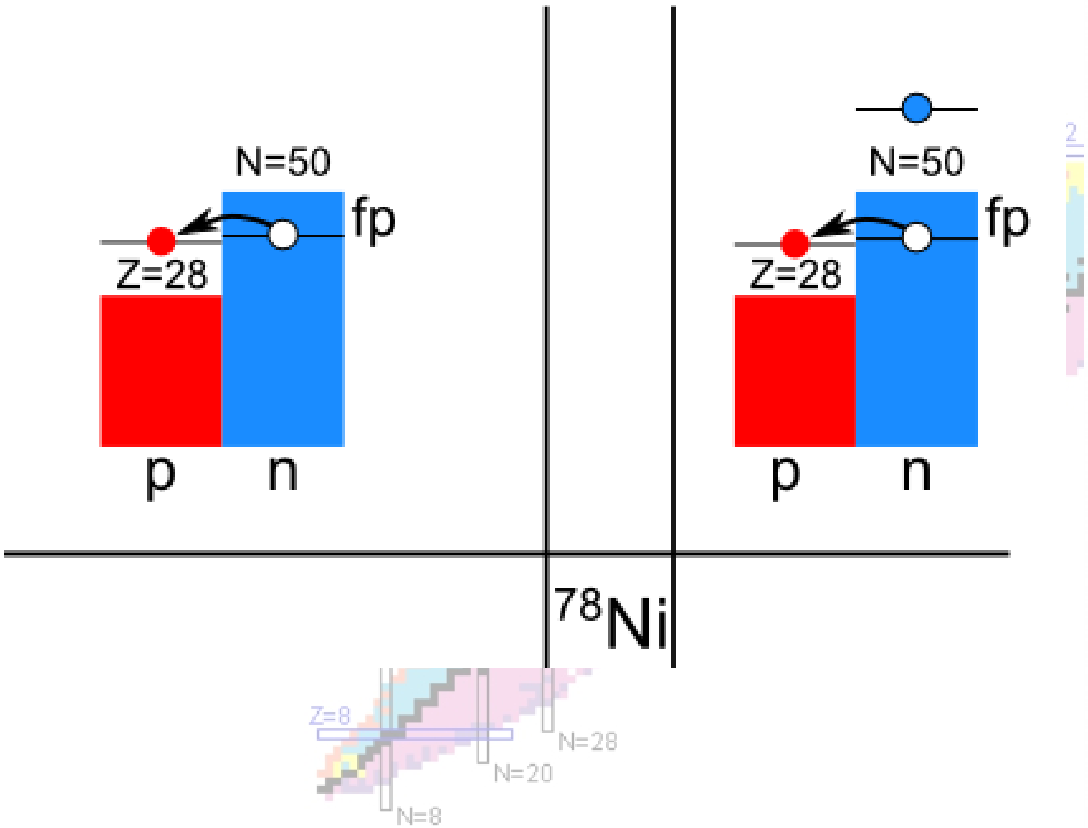


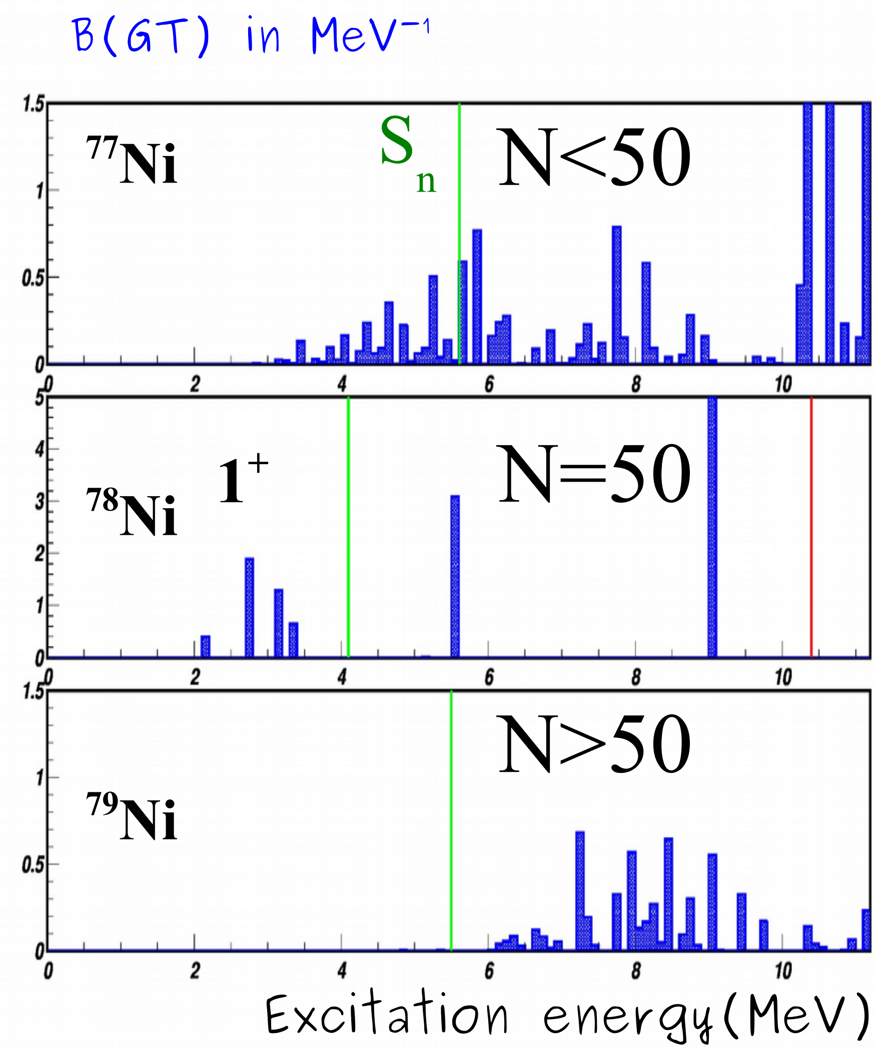
R. Kozub PRL



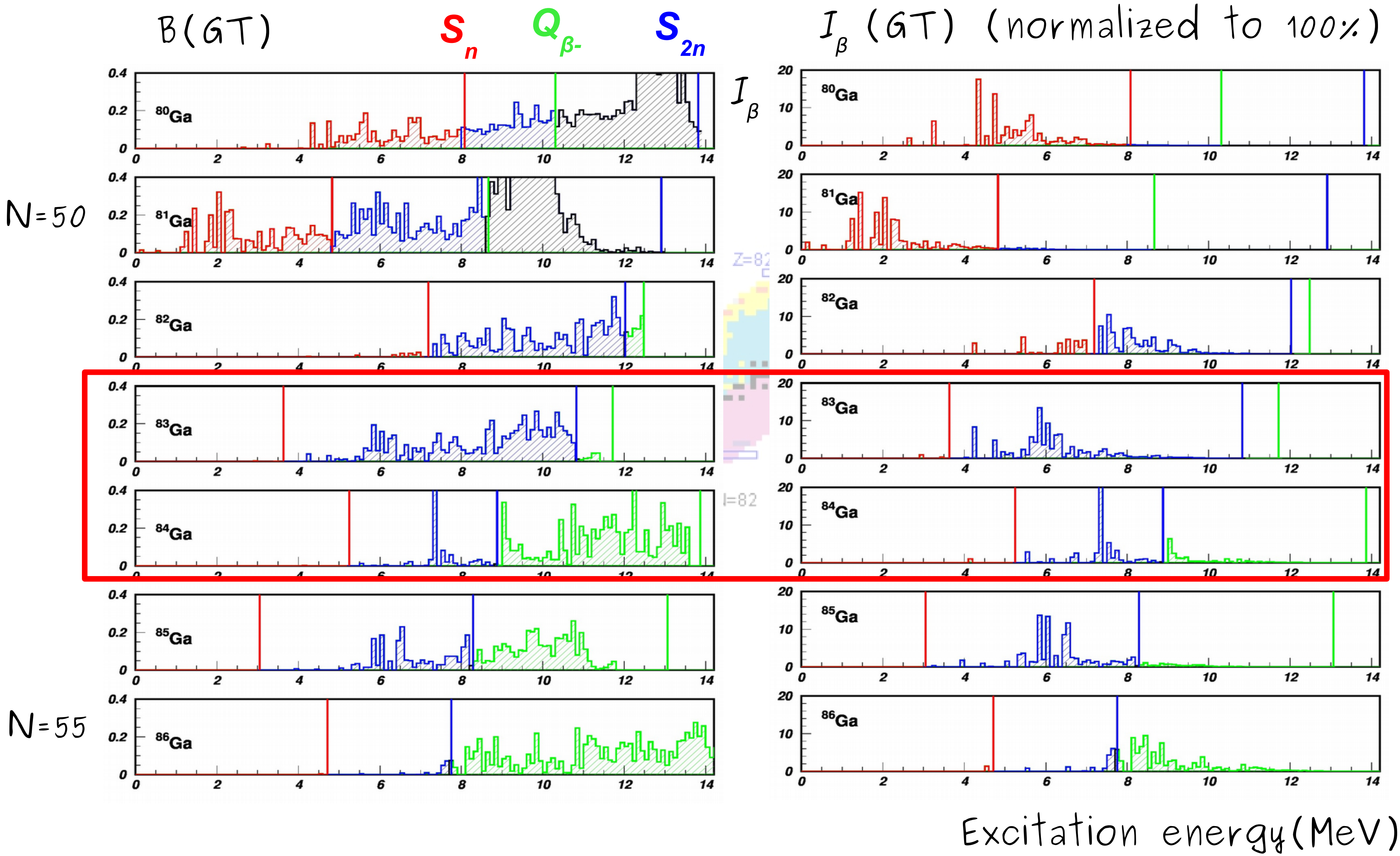
K.L.Jones Nature

Calculations: Nushell (B.A.B.) with jj44bpn interactions – effects of the shell gap





B(GT) and feedings: Ga decays



S_n, S_{2n}, $Q_{\beta-}$ from 2012 mass evaluation

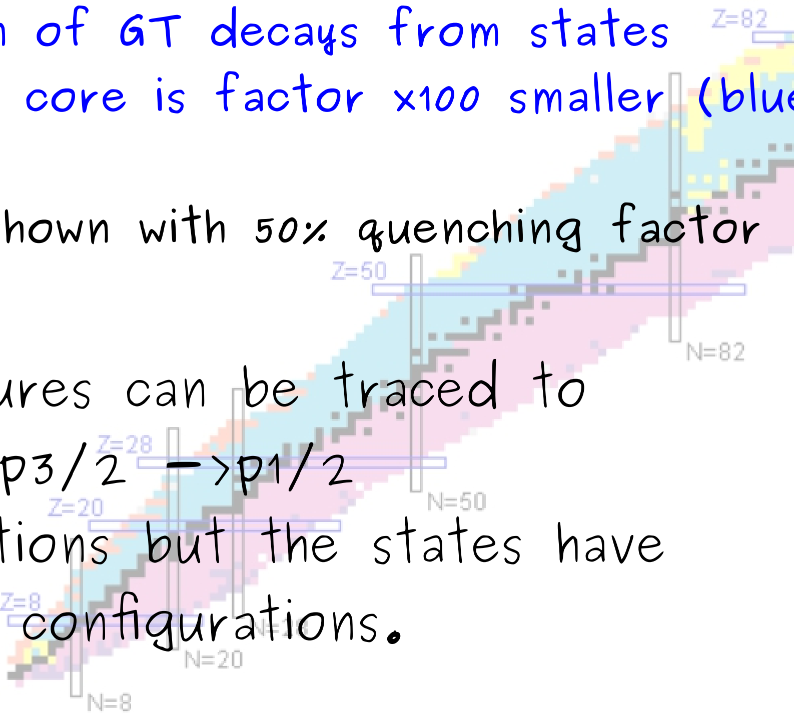
B(GT) for ^{84}Ga and shell model

-observed large beta strength at high excitations compatible with GT-decay of 78Ni core states

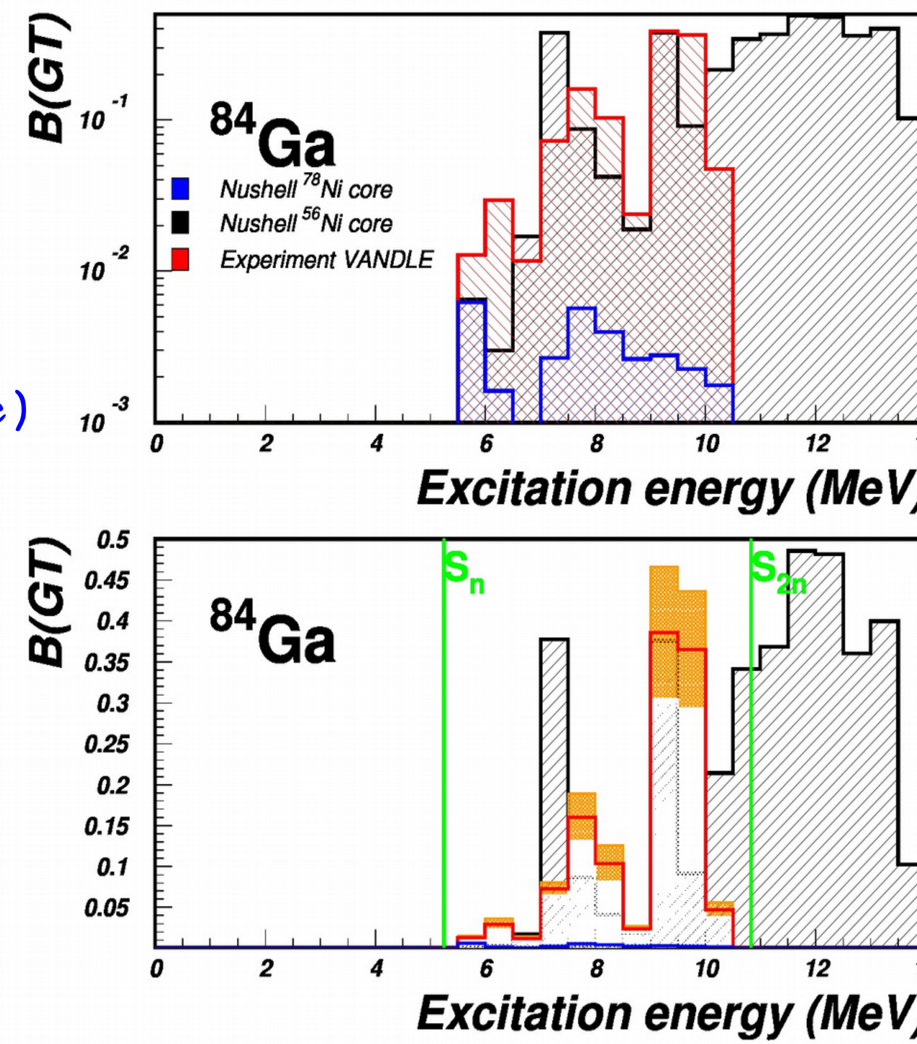
-contribution of GT decays from states outside 78Ni core is factor x100 smaller (blue)

- B(GT) is shown with 50% quenching factor

The structures can be traced to dominant p3/2 ->p1/2 transformations but the states have very mixed configurations.



for B(GT)=0.1/MeV: log ft = 4.6



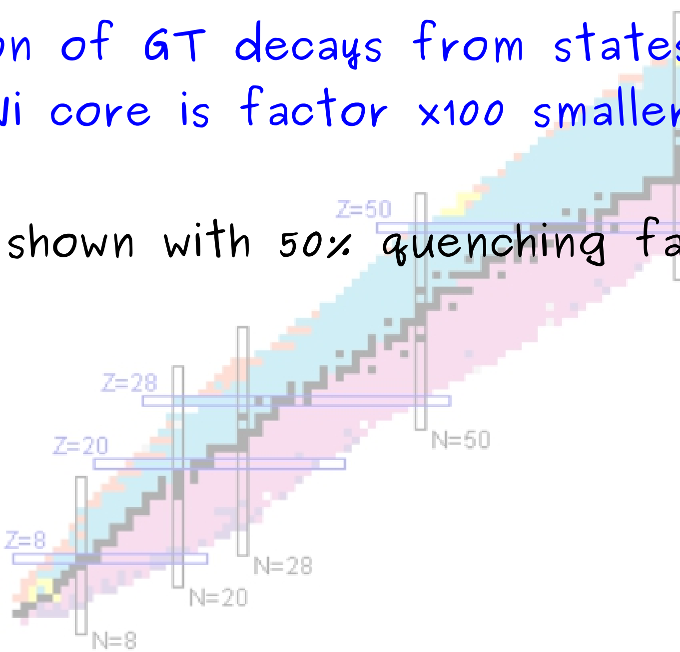
M. Madurga et al.

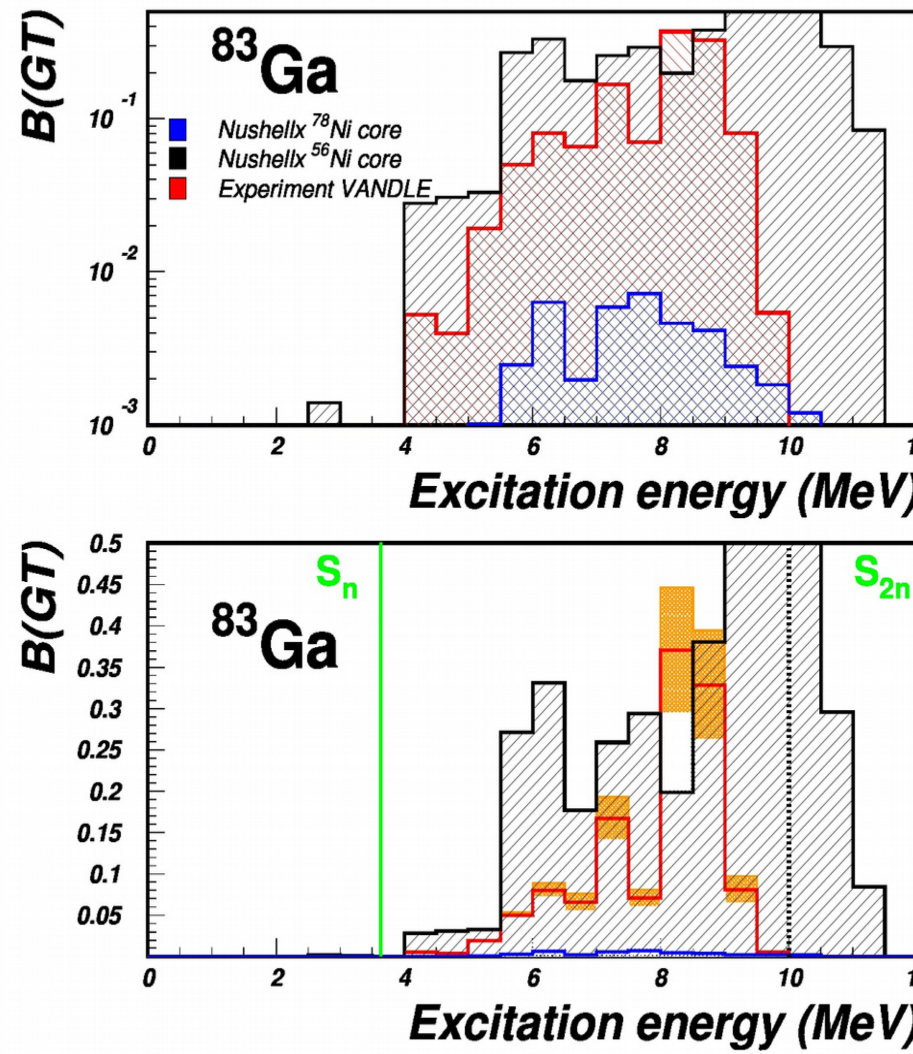
B(GT) for ^{83}Ga and shell model

- observed large beta strength at high excitations compatible with GT–decay of 78Ni core states

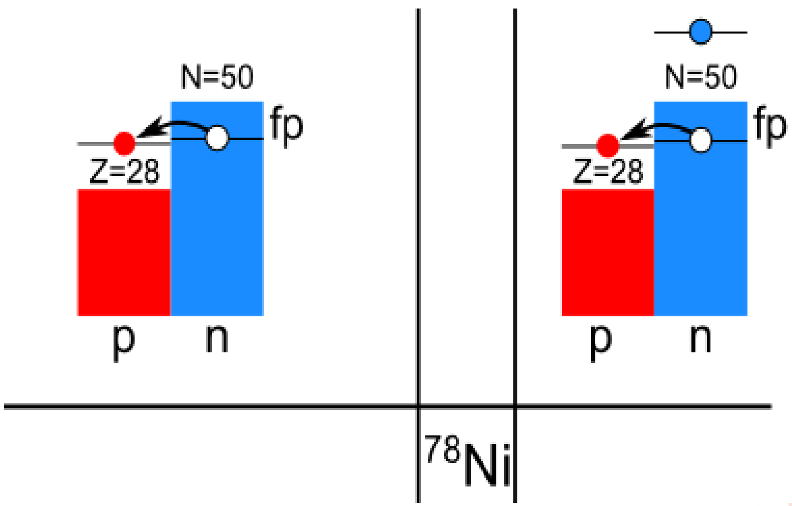
- contribution of GT decays from states outside 78Ni core is factor x100 smaller

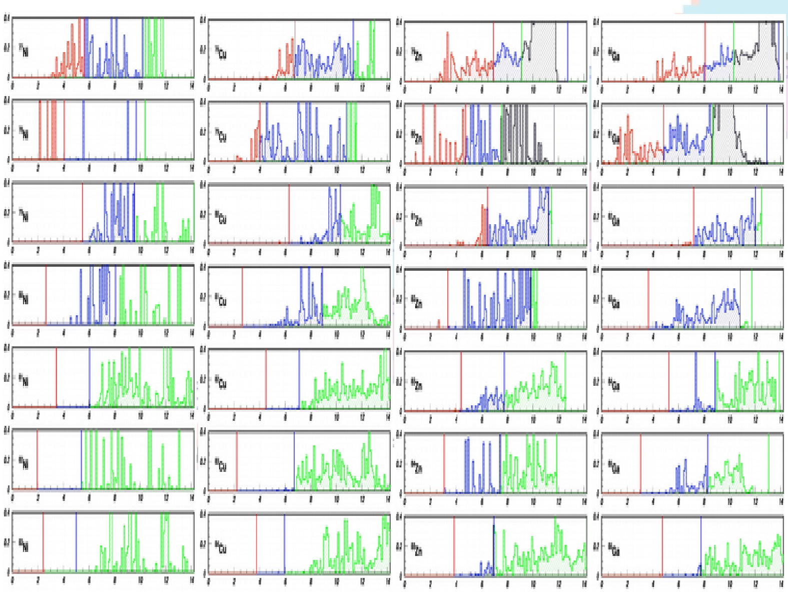
- B(GT) is shown with 50% quenching factor

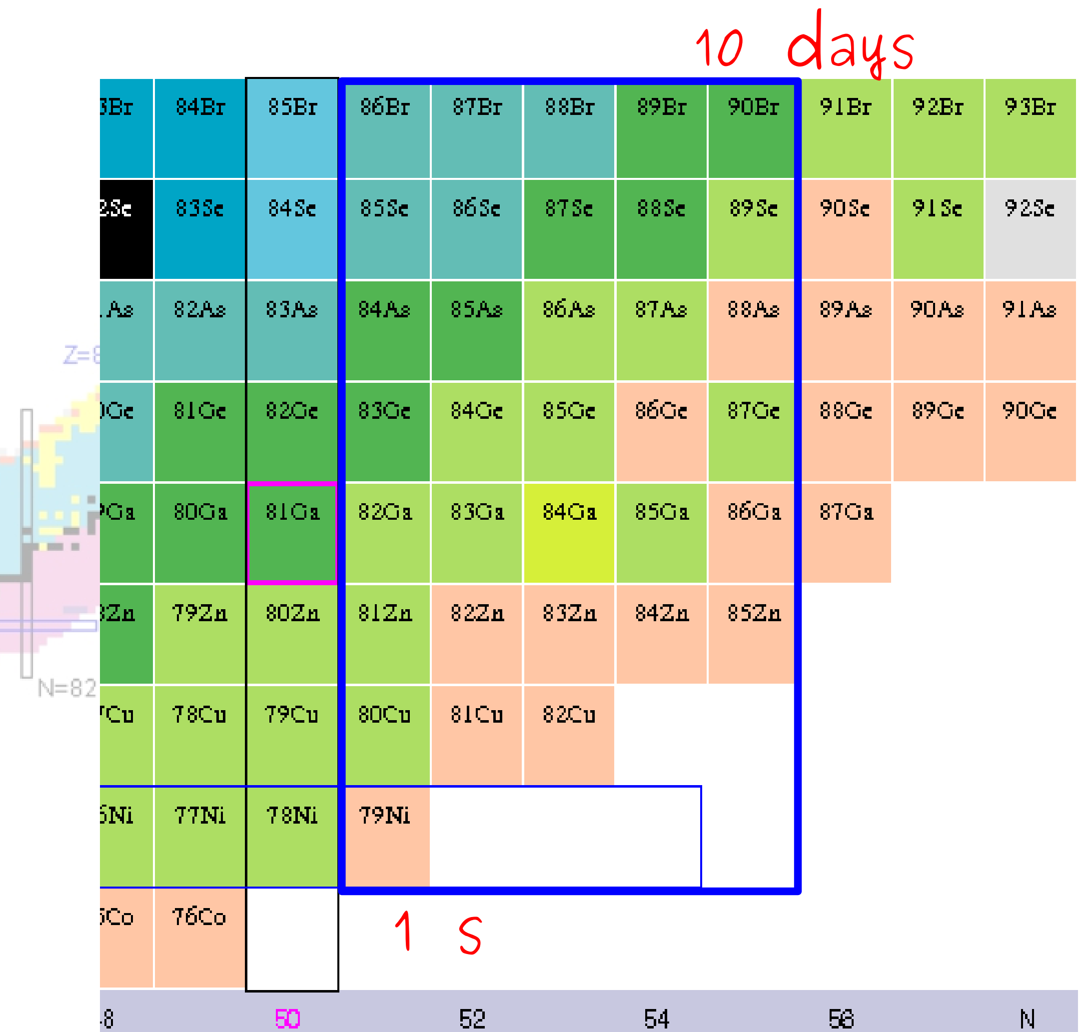




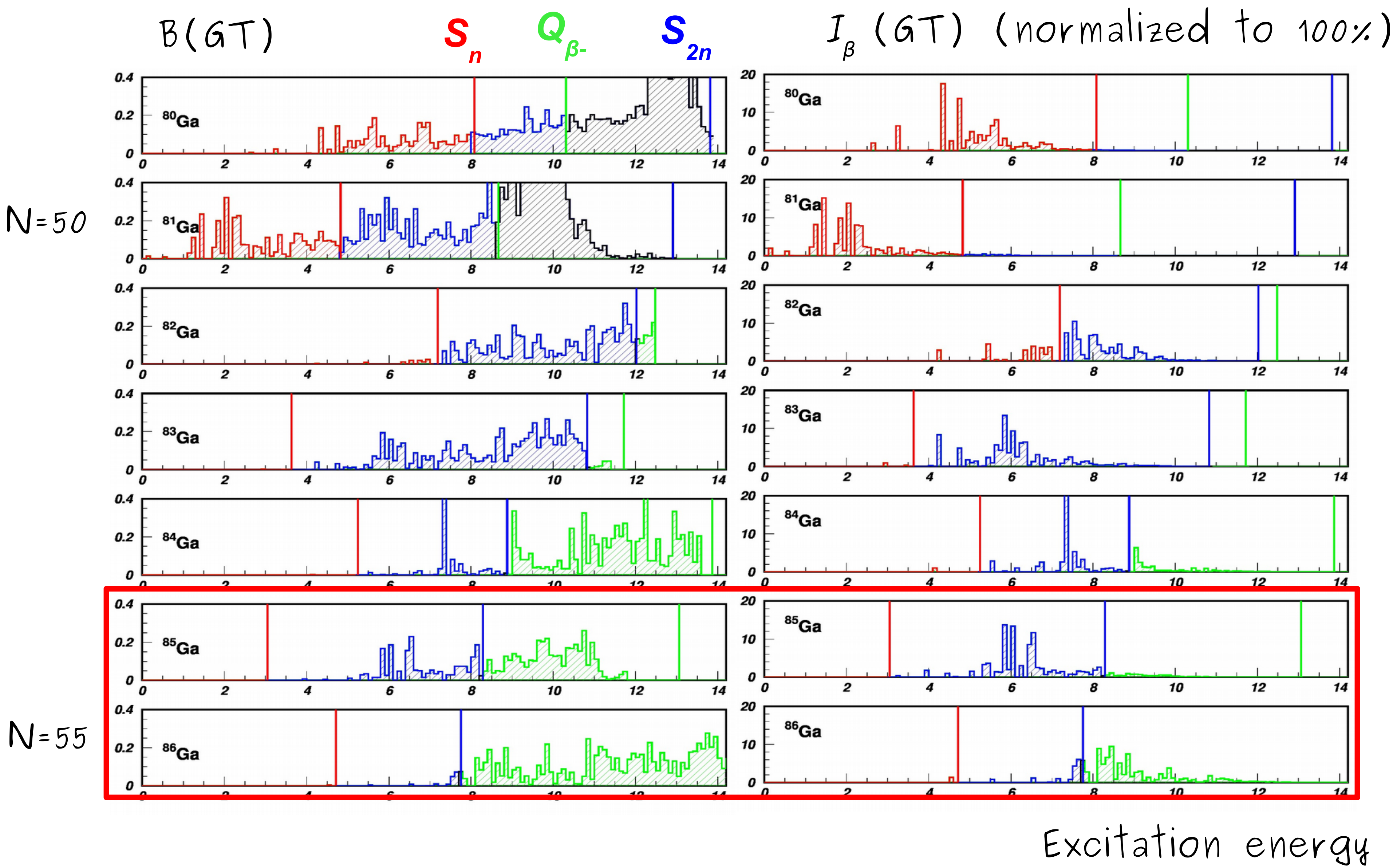
B(GT) for beta delayed neutron emitters shell model calculations







B(GT) and feedings: Ga decays



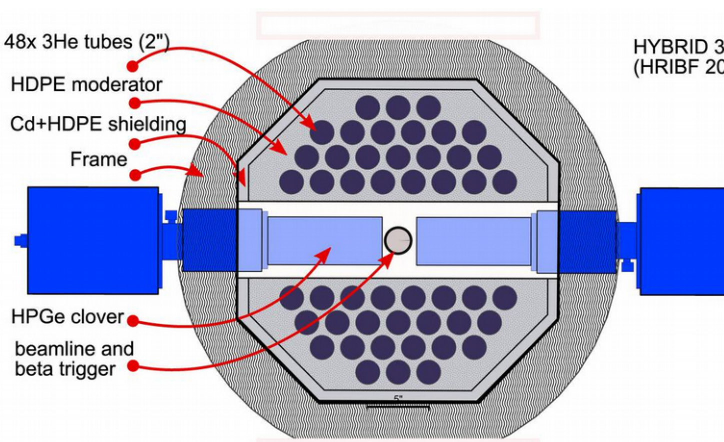
S_n, S_{2n} , $Q_{\beta-}$ from 2012 mass evaluation

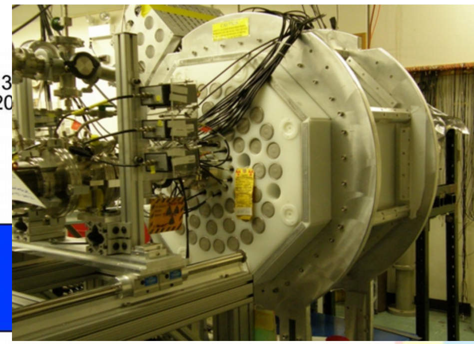
Hybrid-3Hen (HRIBF)

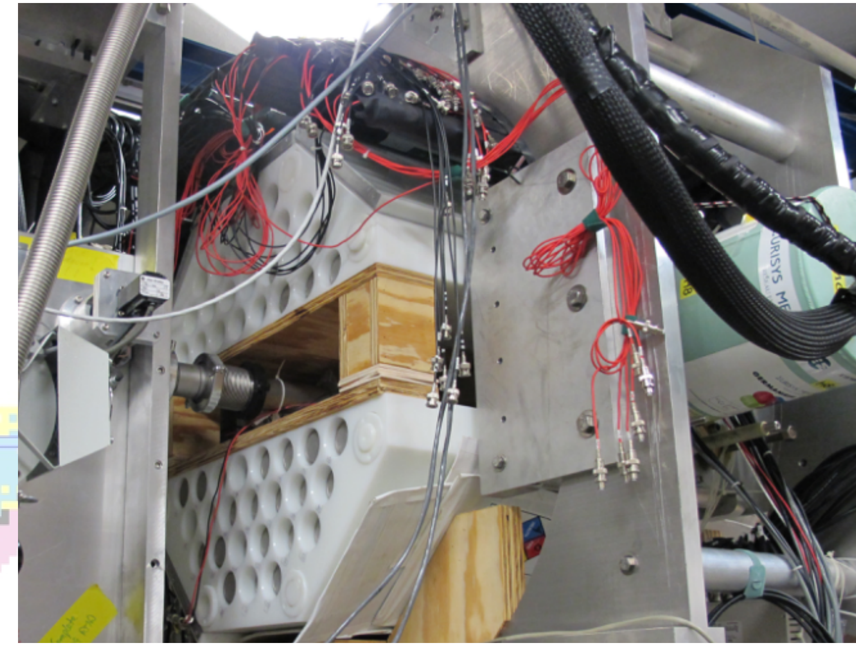
combination of gamma and neutron detection !

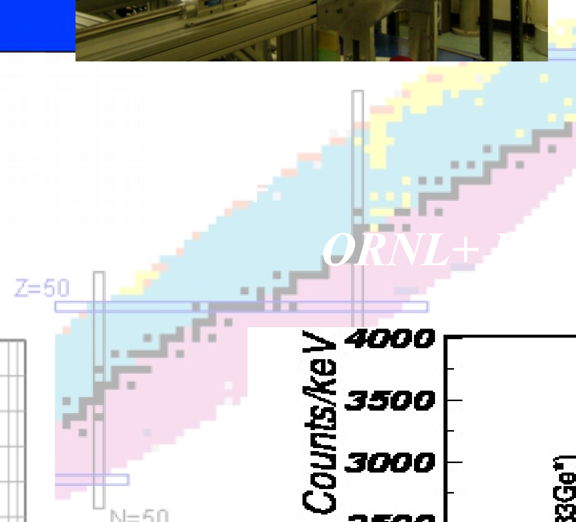
$^{3}He + n \rightarrow {}^{3}H + {}^{1}H + 765keV$

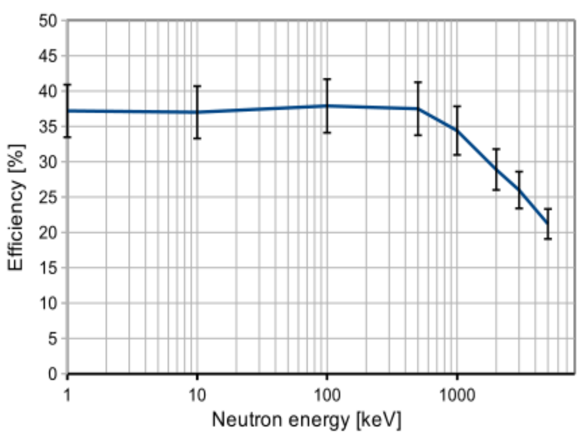
48x ^{3}He tubes + 2 clover detectors



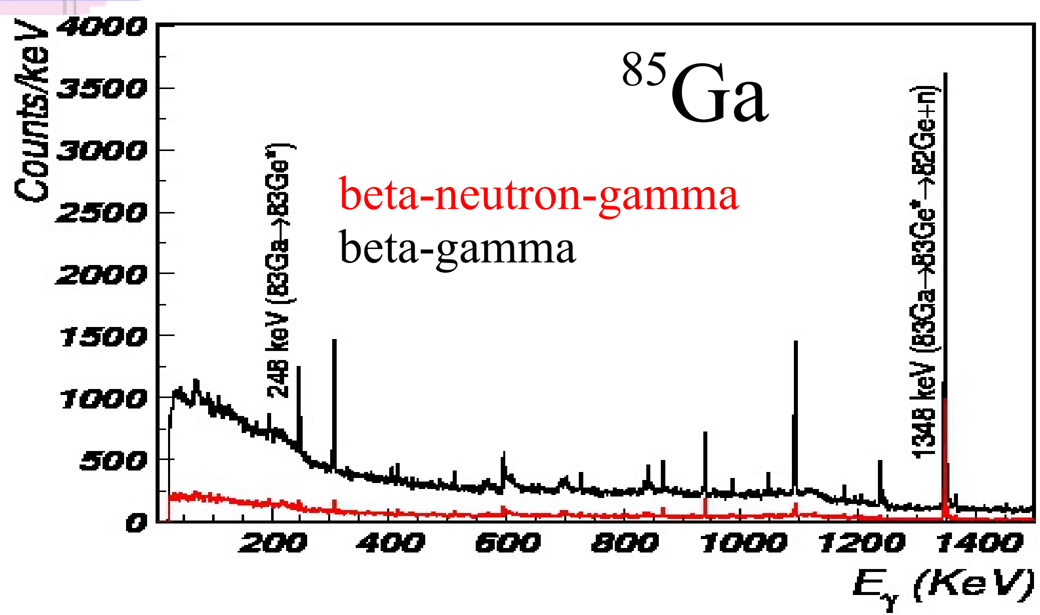








R. Grzywacz et al. Act. Phys. Pol. 45(2014) 217



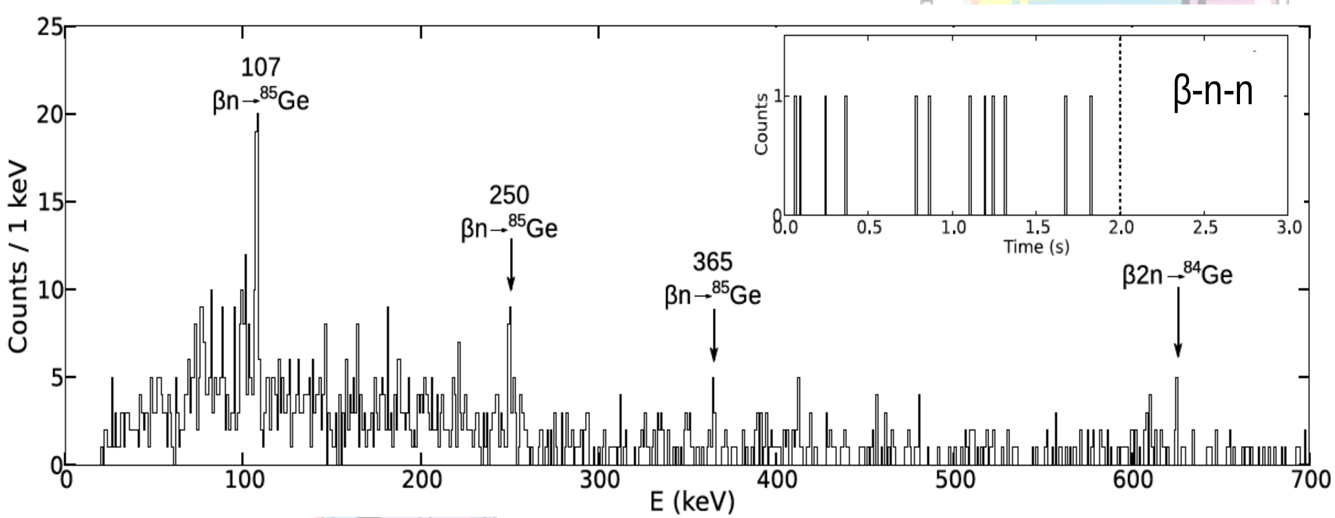
Beta-delayed 2n emission in ^{86}Ga decay
β1n:60(10)%, β2n: 20(10)%

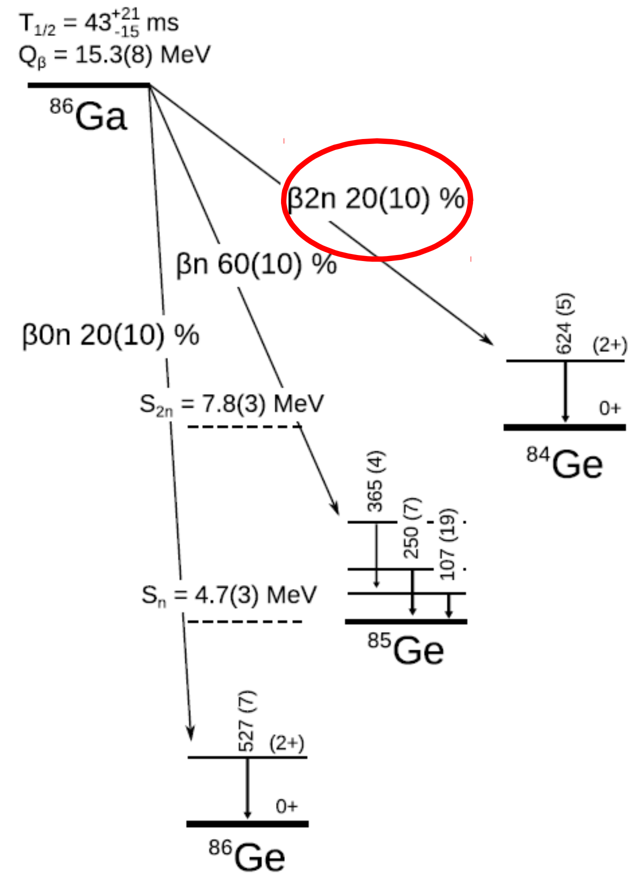
Very powerful combination of RILIS +Isobar separator+3Hen!

•Pure beam (Laser Ion Source)
First confirmation of the predicted large **β2n** branching ratios

$I_{\beta 1n} / I_{\beta 2n}$ (FRDM+QRPA) 21% / 44%,

$I_{\beta 1n} / I_{\beta 2n}$ (DF3a+CQRPA) 28% / 22%

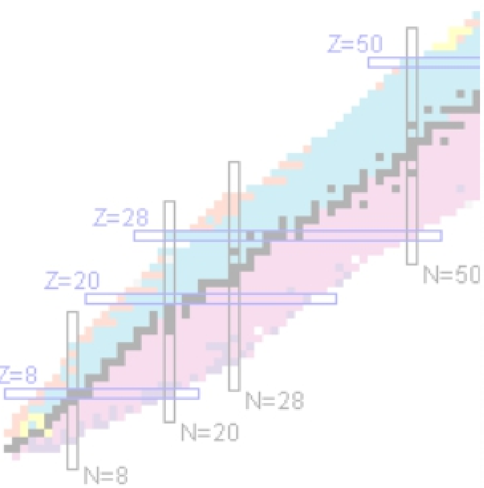


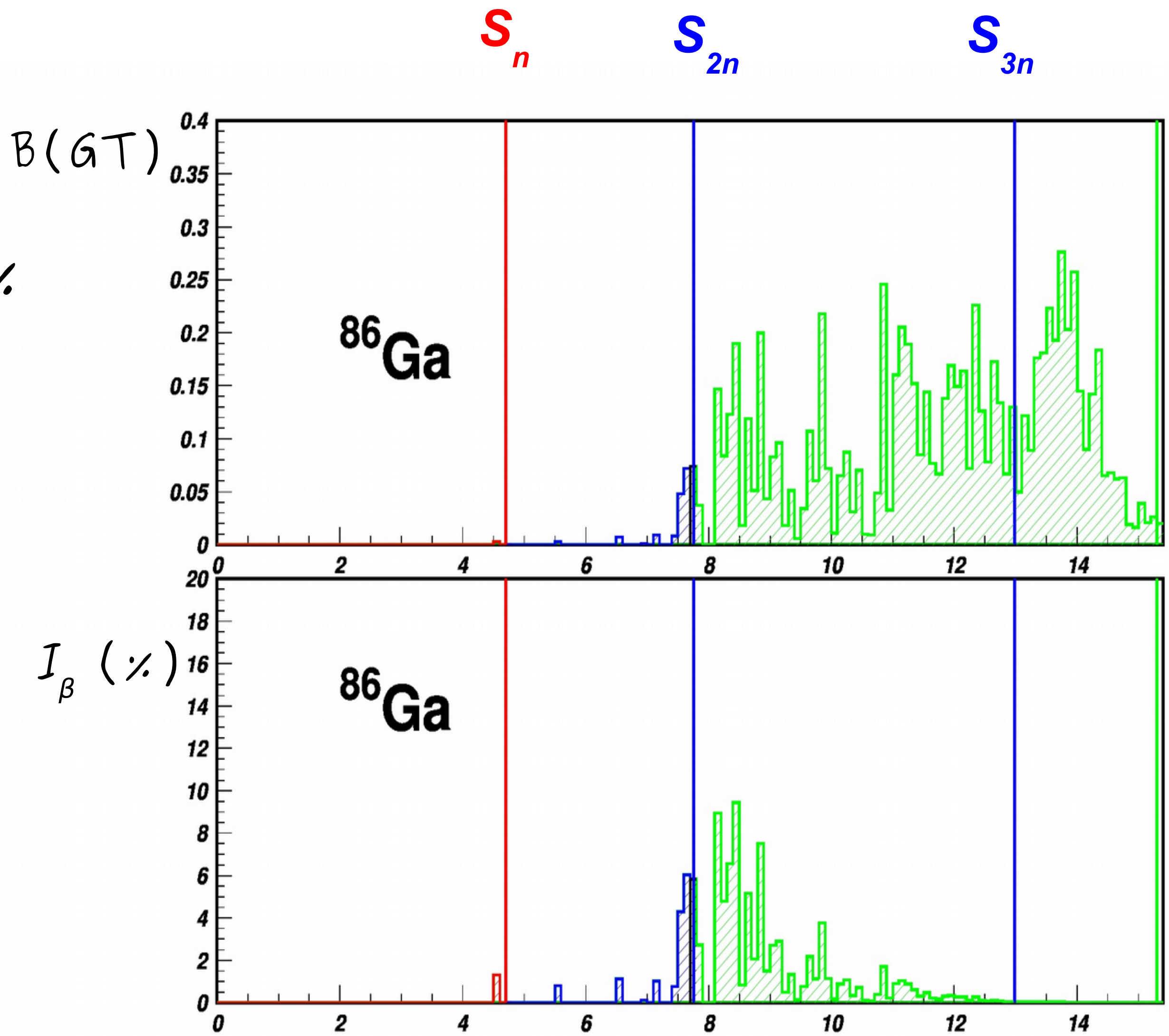


86Ga: neutron β+n+g spectrum
K. Miernik et al. Phys. Rev. Lett, 2013 Phys Rev Lett. 111(2013),132502.
RILIS : Y. Liu et al., Nucl. Instrum. Methods Phys. Res., Sect. B 298, 5 (2013).

Beta-decay of ^{86}Ga (shell model)

$P_{1n+2n}(GT) = (85+14)\% = 99\ \%$

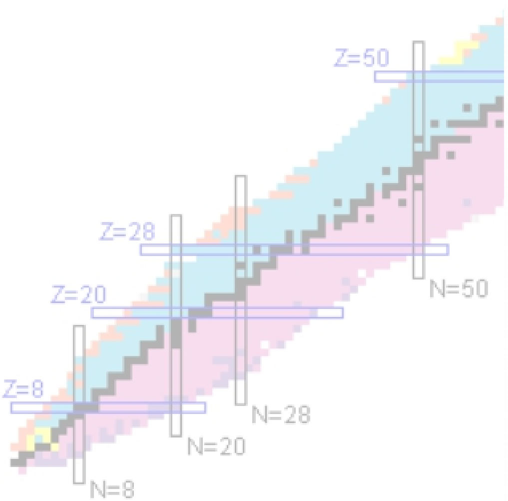


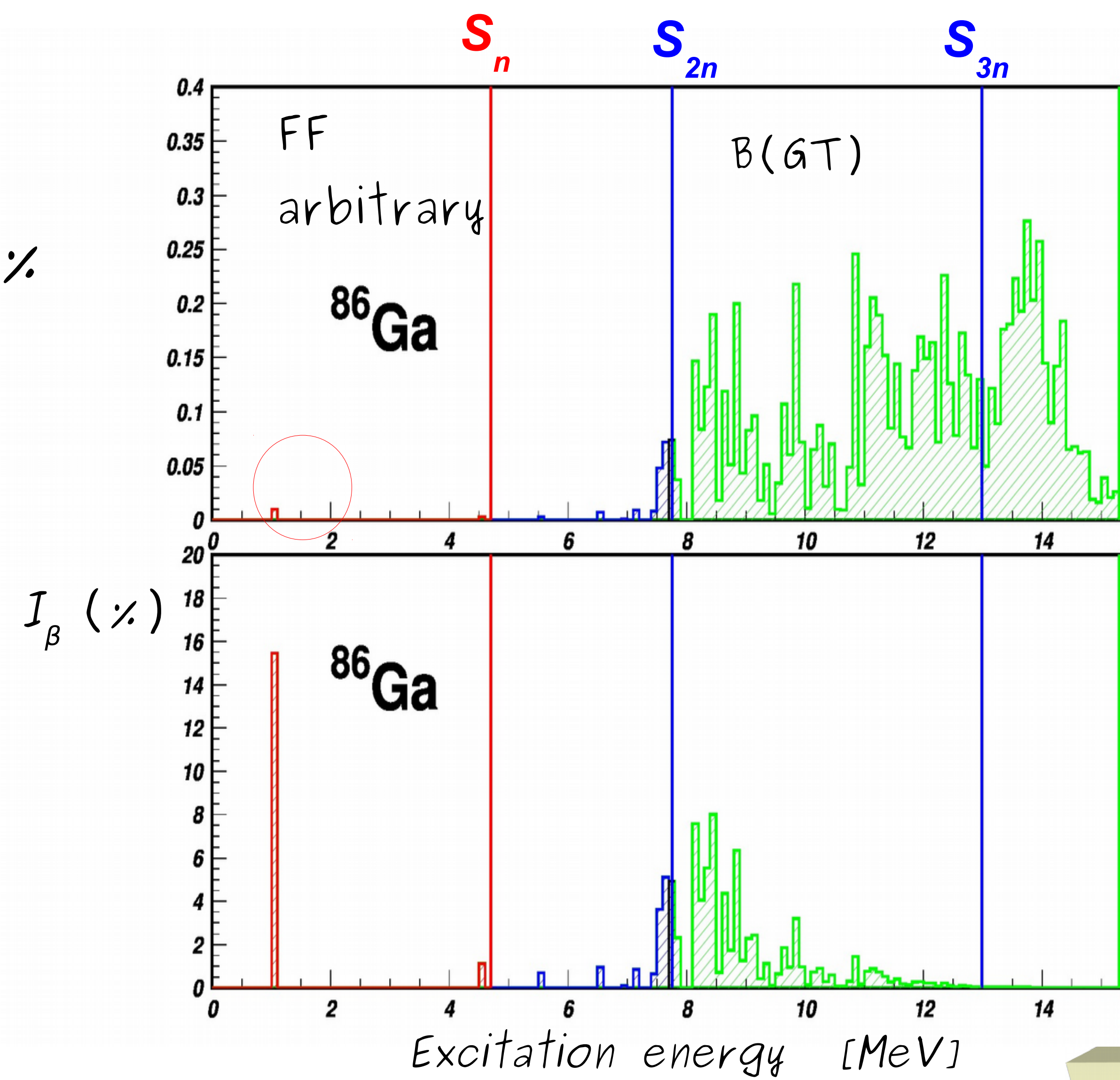


Beta-decay of 86Ga (shell model)
Role of FF transitions

$$P_{1n+2n}(GT) = (12+71)\% = 83\ \%$$

$$P_{1n+2n}(exp) = 60(10)+20(10)\%$$





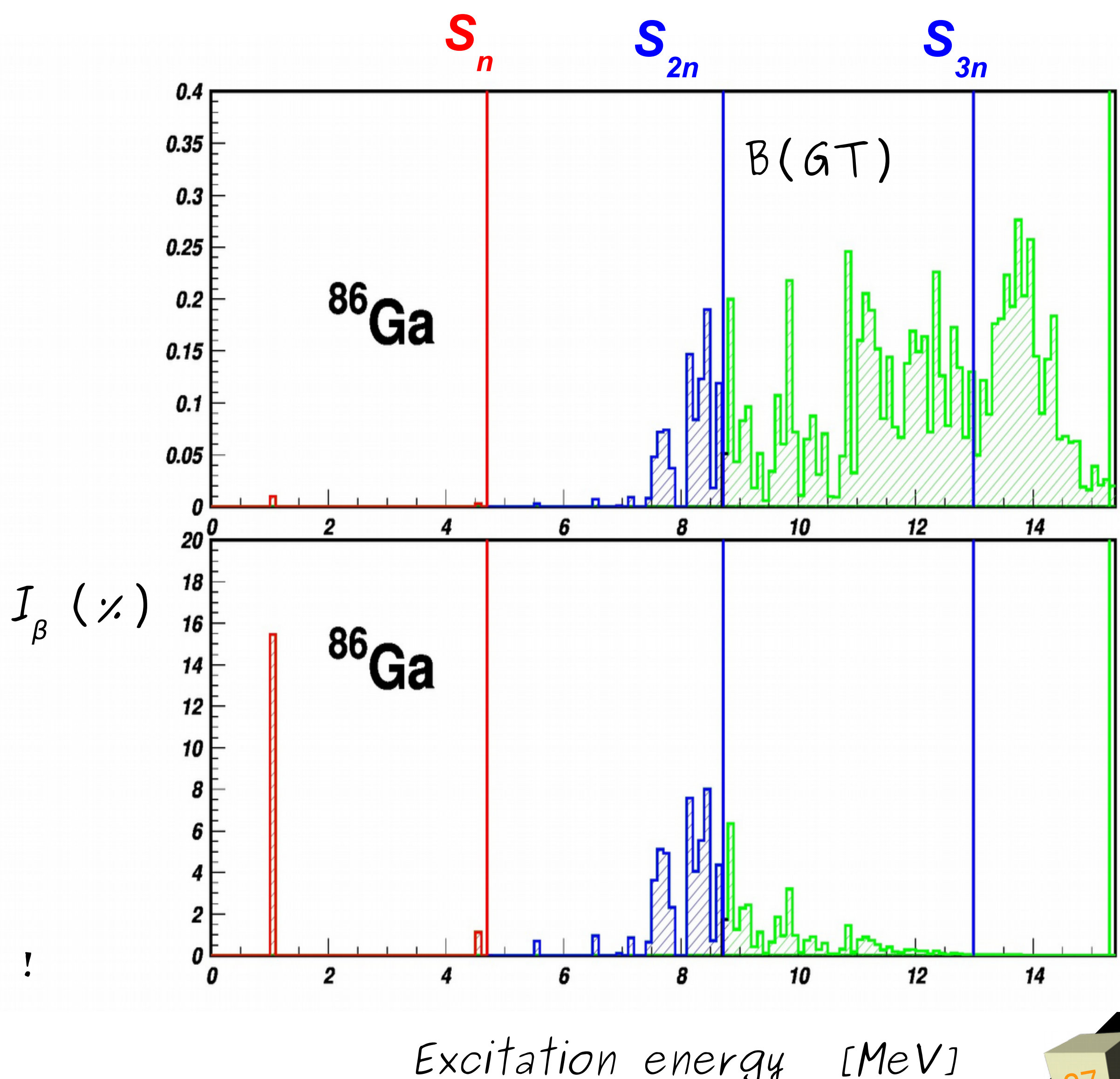
Beta-decay of 86Ga (shell model)
Role of FF transitions and S_{2n}

$P_{1n+2n}(GT) = (45+38)\% = 83$

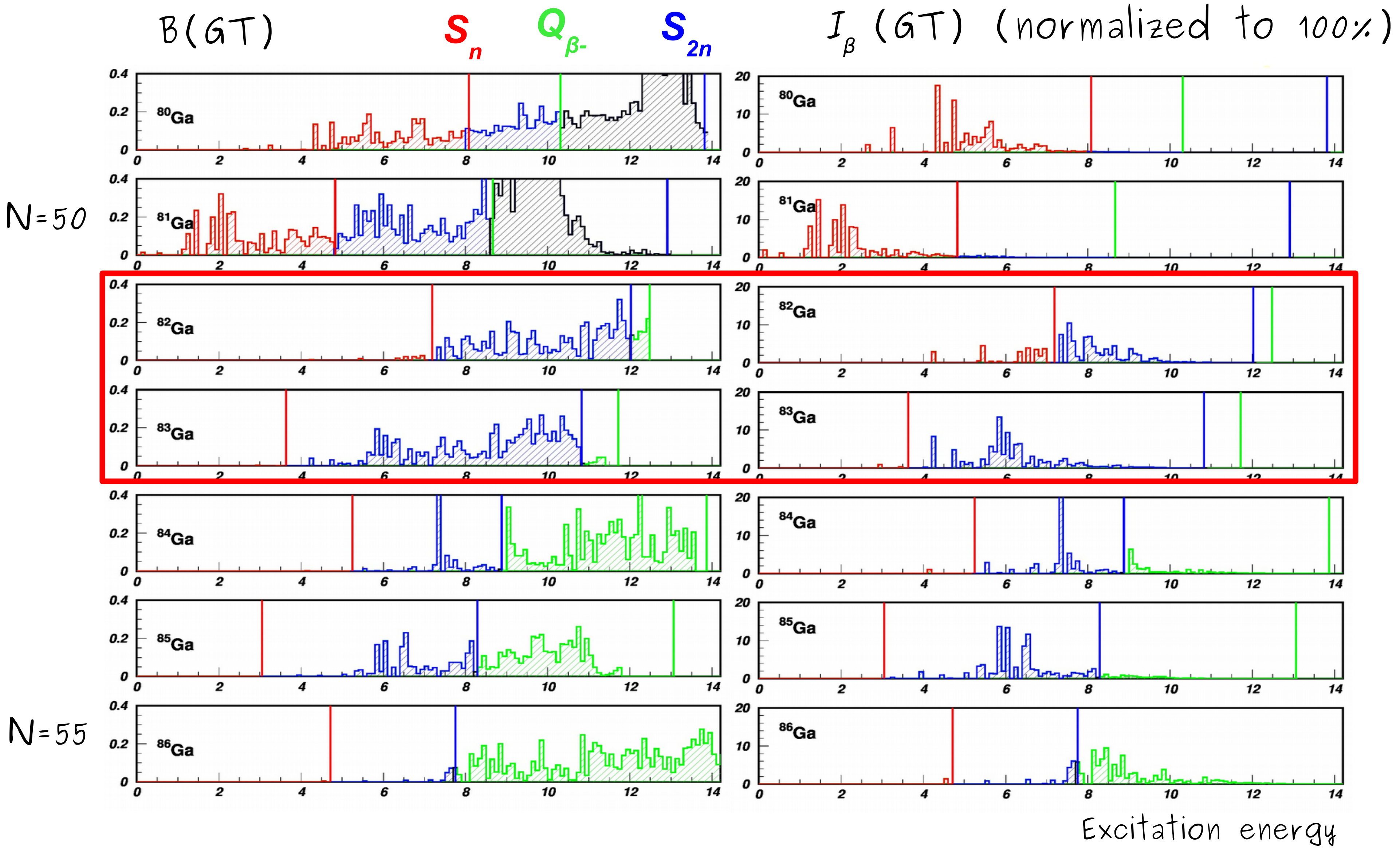
$P_{1n+2n}(exp) = 60(10) + 20(10)\%$

This Pn's do not include the competitions between 1n/2n neutron emission.

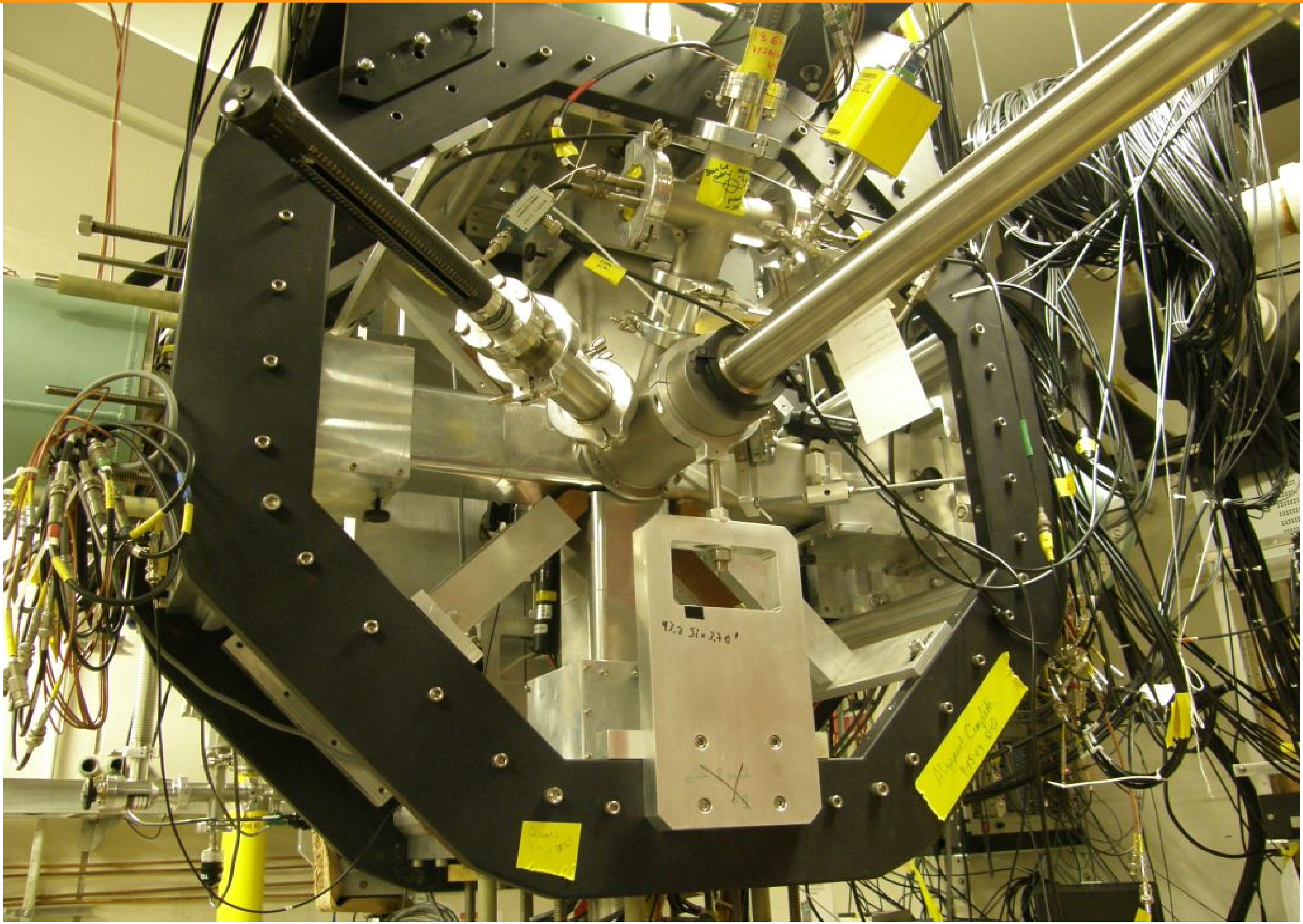
Neutron energy measurements !



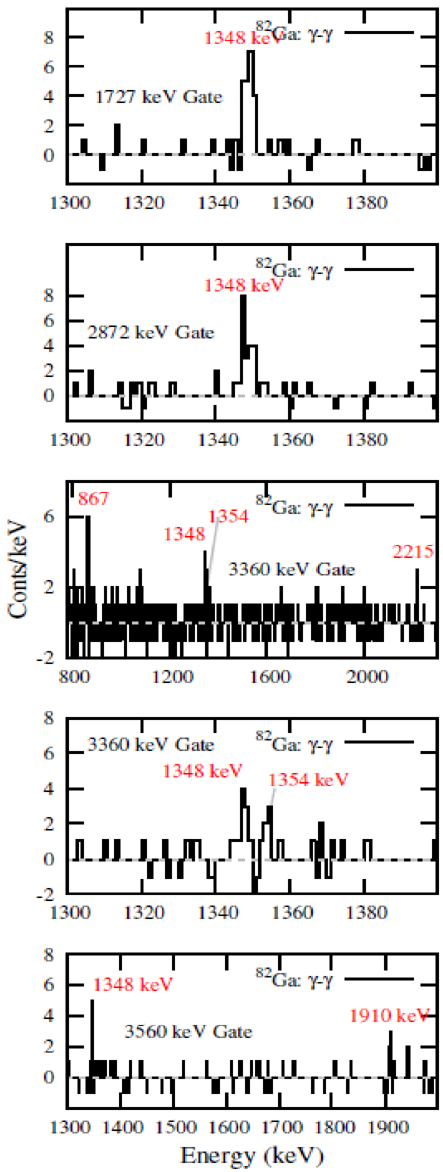
B(GT) and feedings: Ga decays

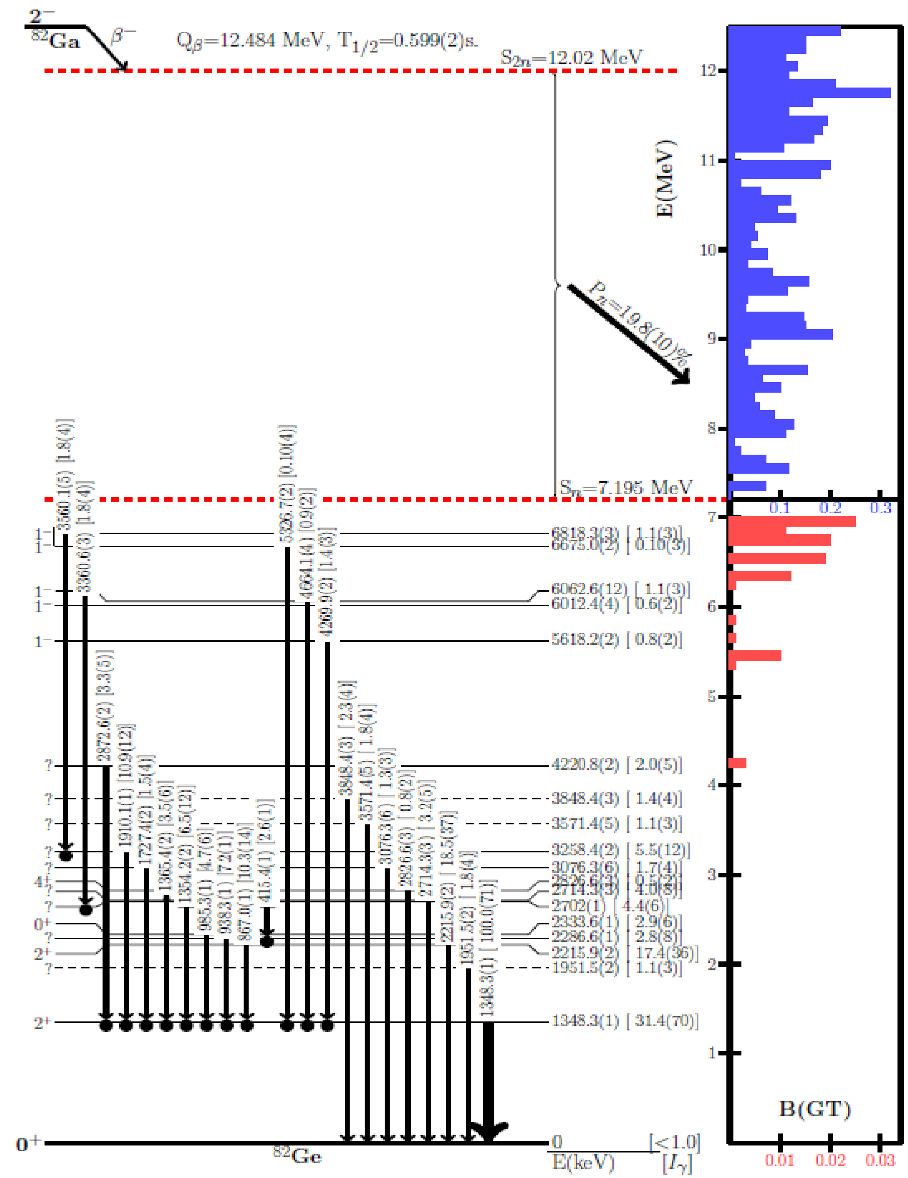


Clover array (CARDS) at Leribss decay spectroscopy station



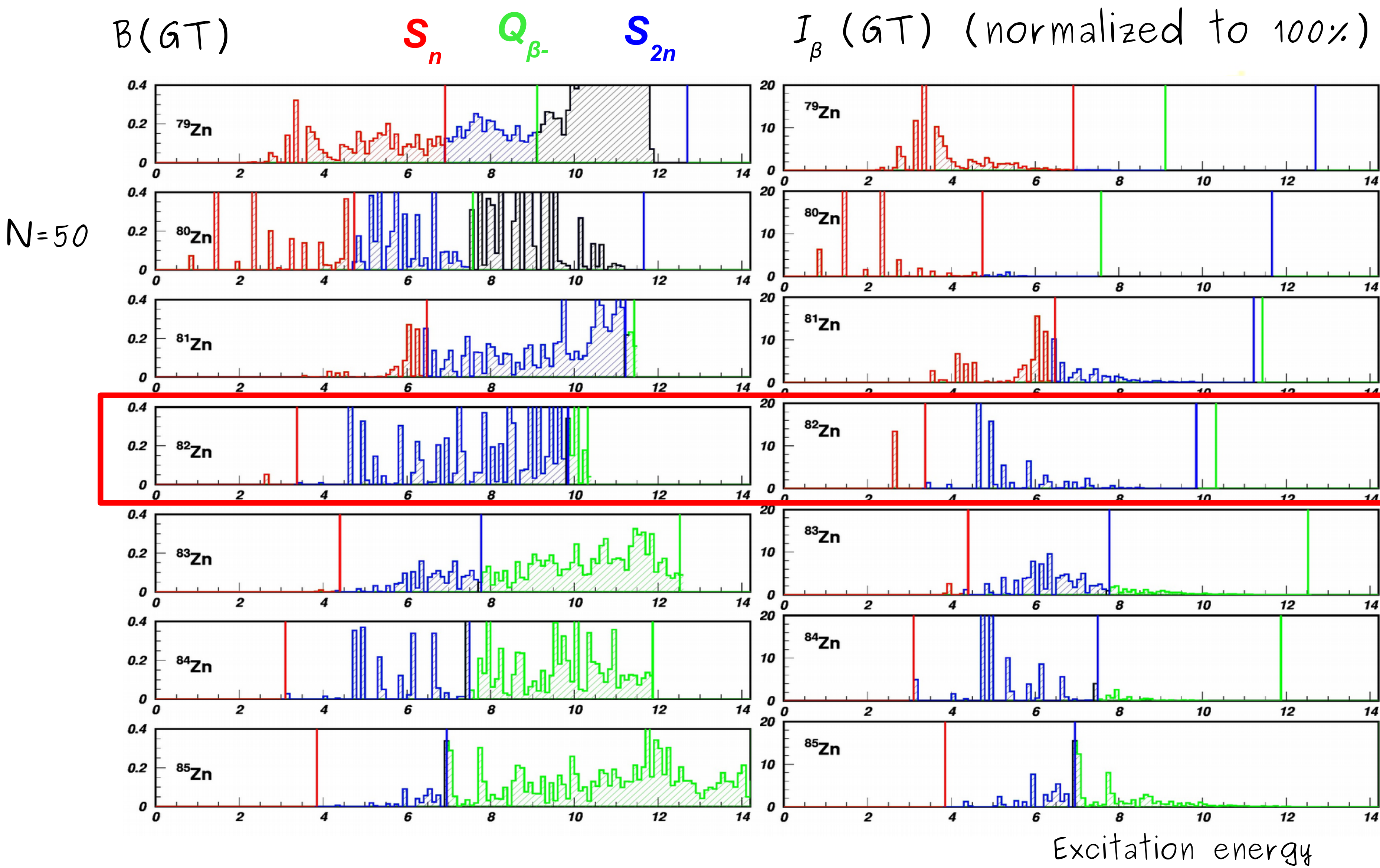
Decay of N=51 ^{82}Ga



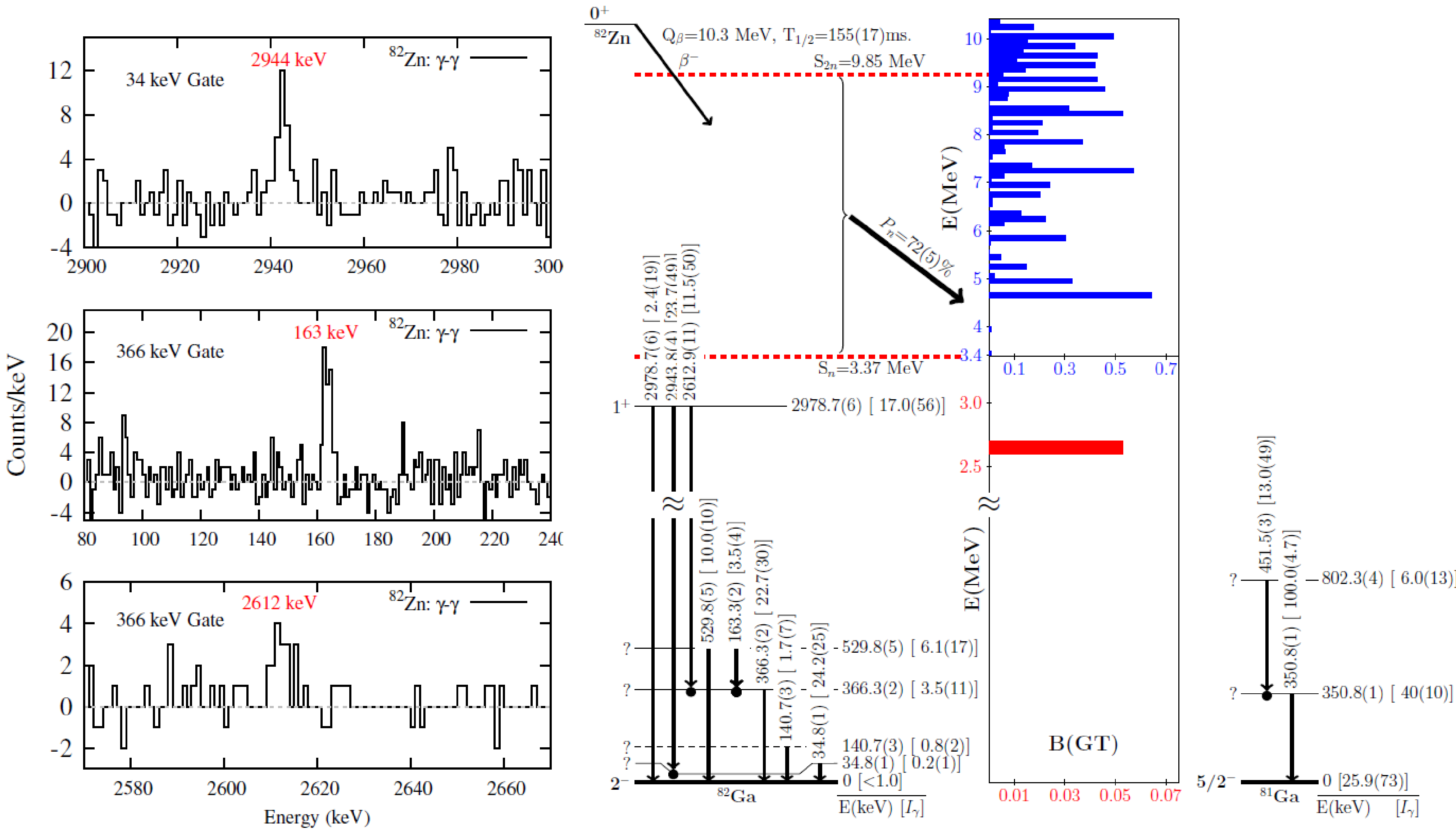


M. Alshudifat et al. (UTK)

B(GT) for Zn


B(GT)
S_n
$Q_{\beta-}$
S_{2n}
I_β (GT) (normalized to 100%)
N=50
^{79}Zn
^{80}Zn
^{81}Zn
^{82}Zn
^{83}Zn
^{84}Zn
^{85}Zn
Excitation energy

Decay of N=52 ^{82}Zn



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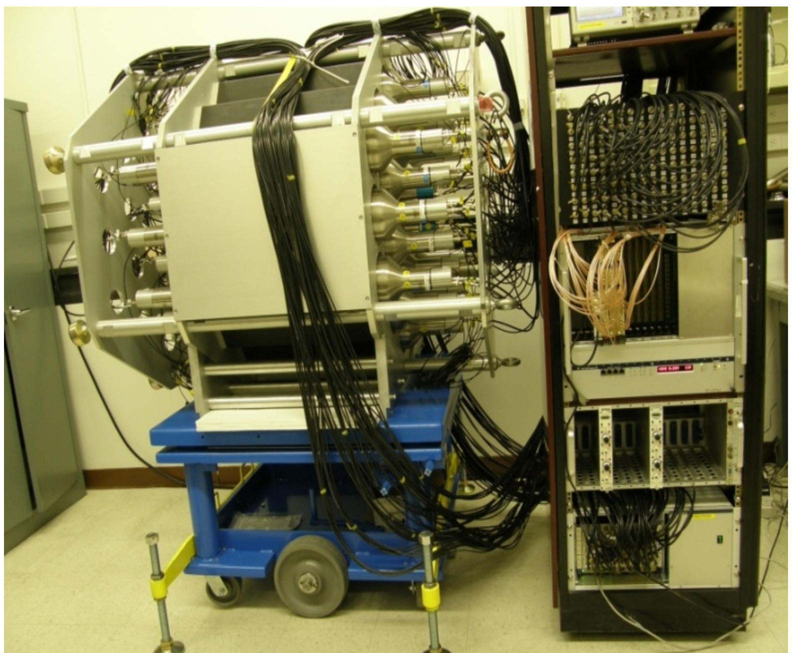
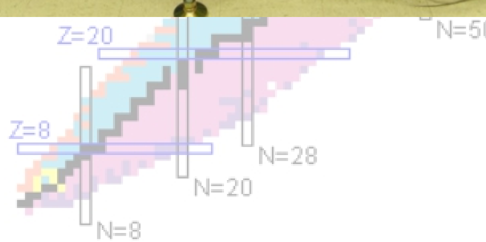
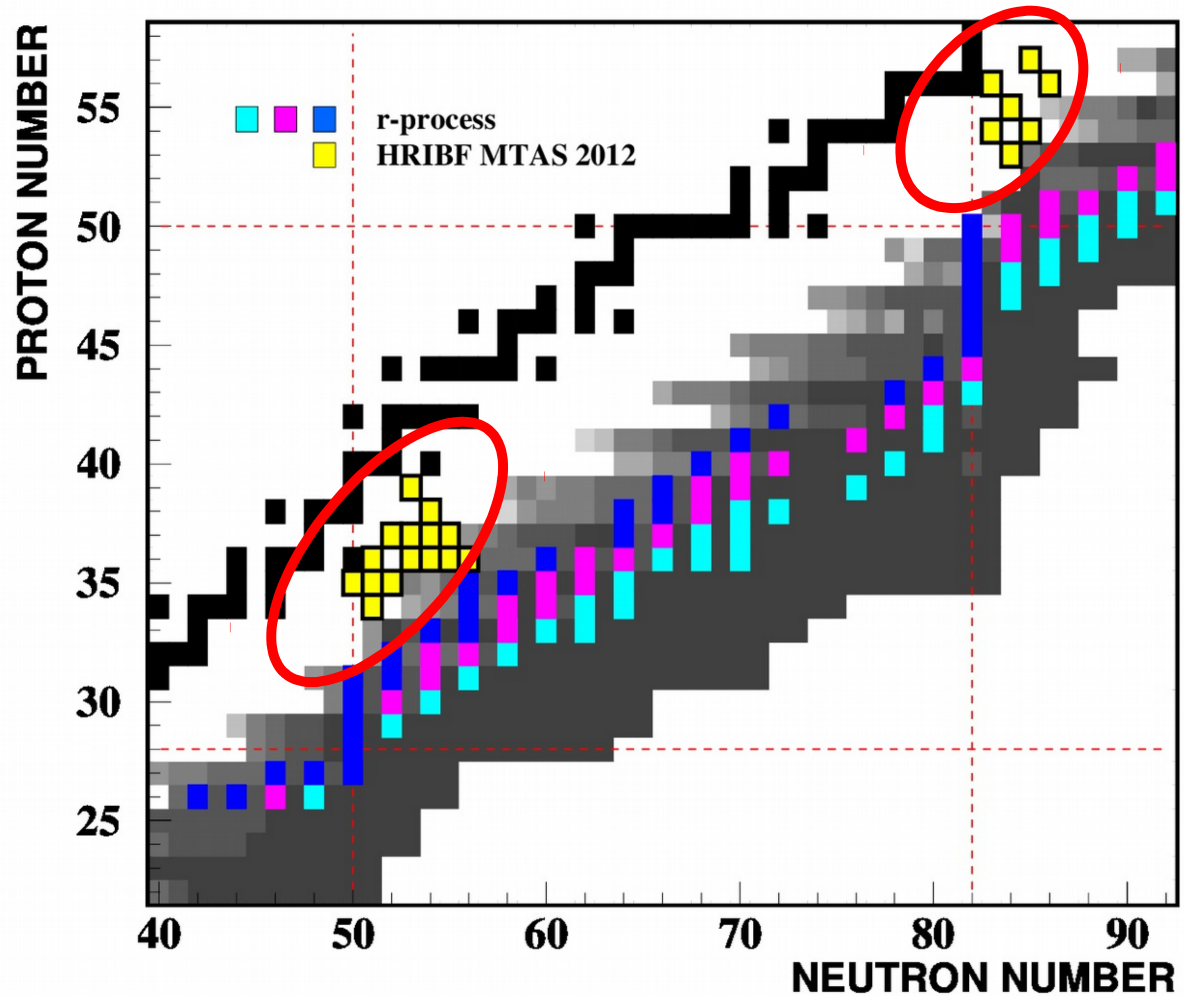
B(GT) from total absorption spectroscopy

Modular Total Absorption Spectrometer

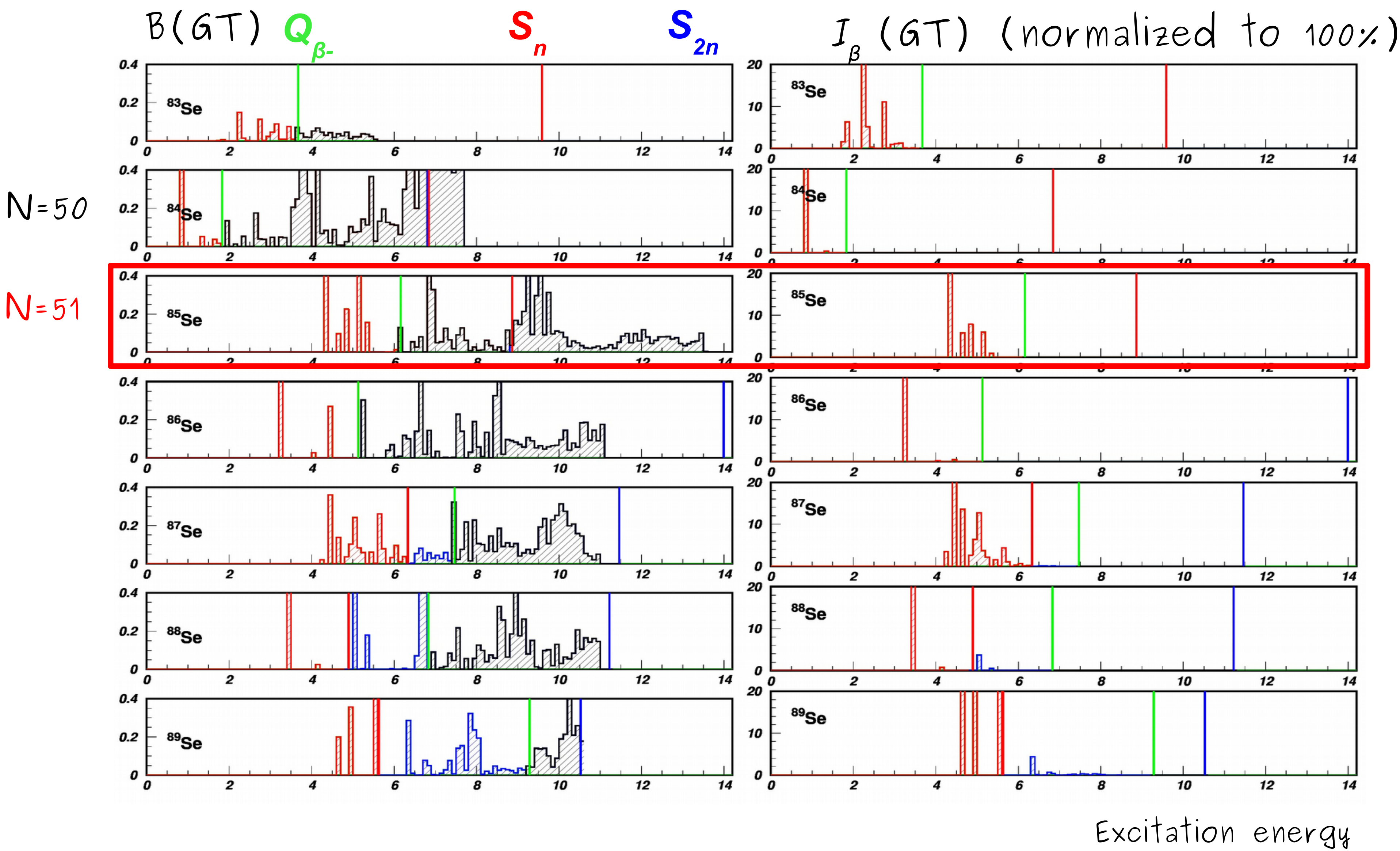






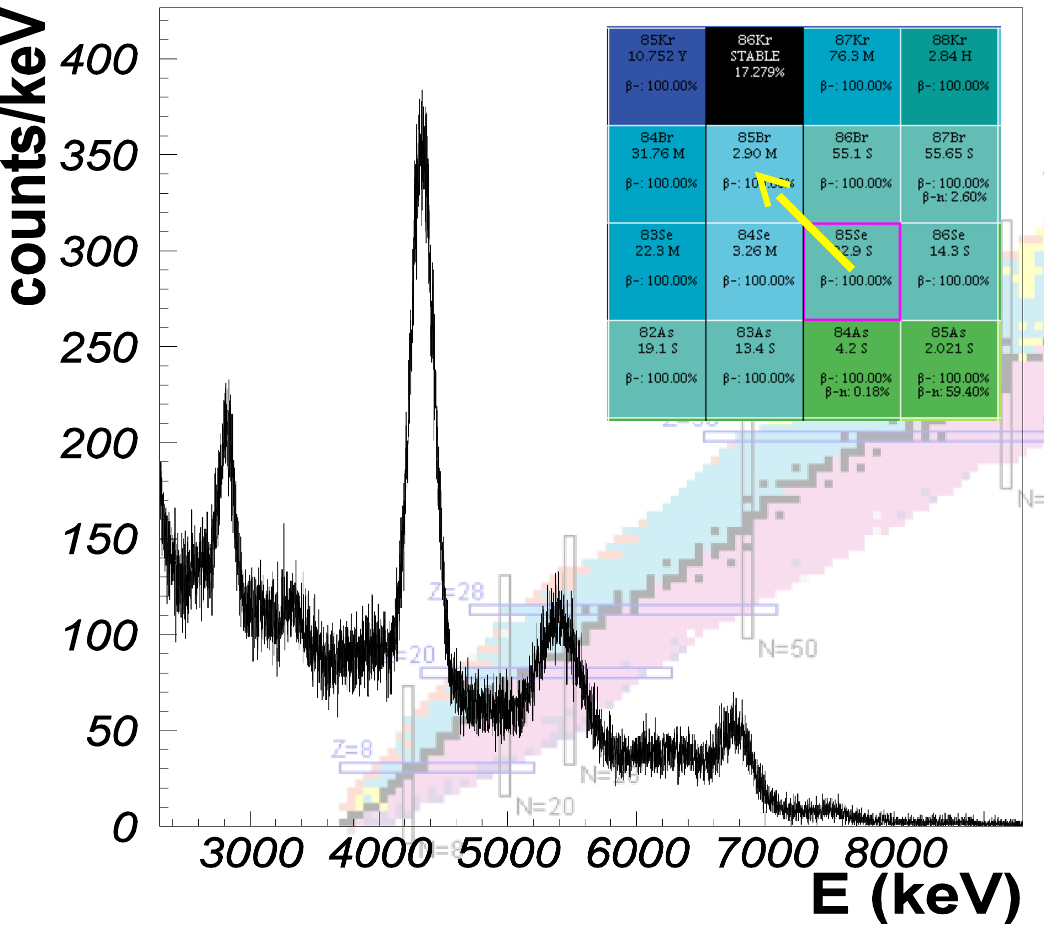
- 22 fissions products of 238U studied at HRIBF

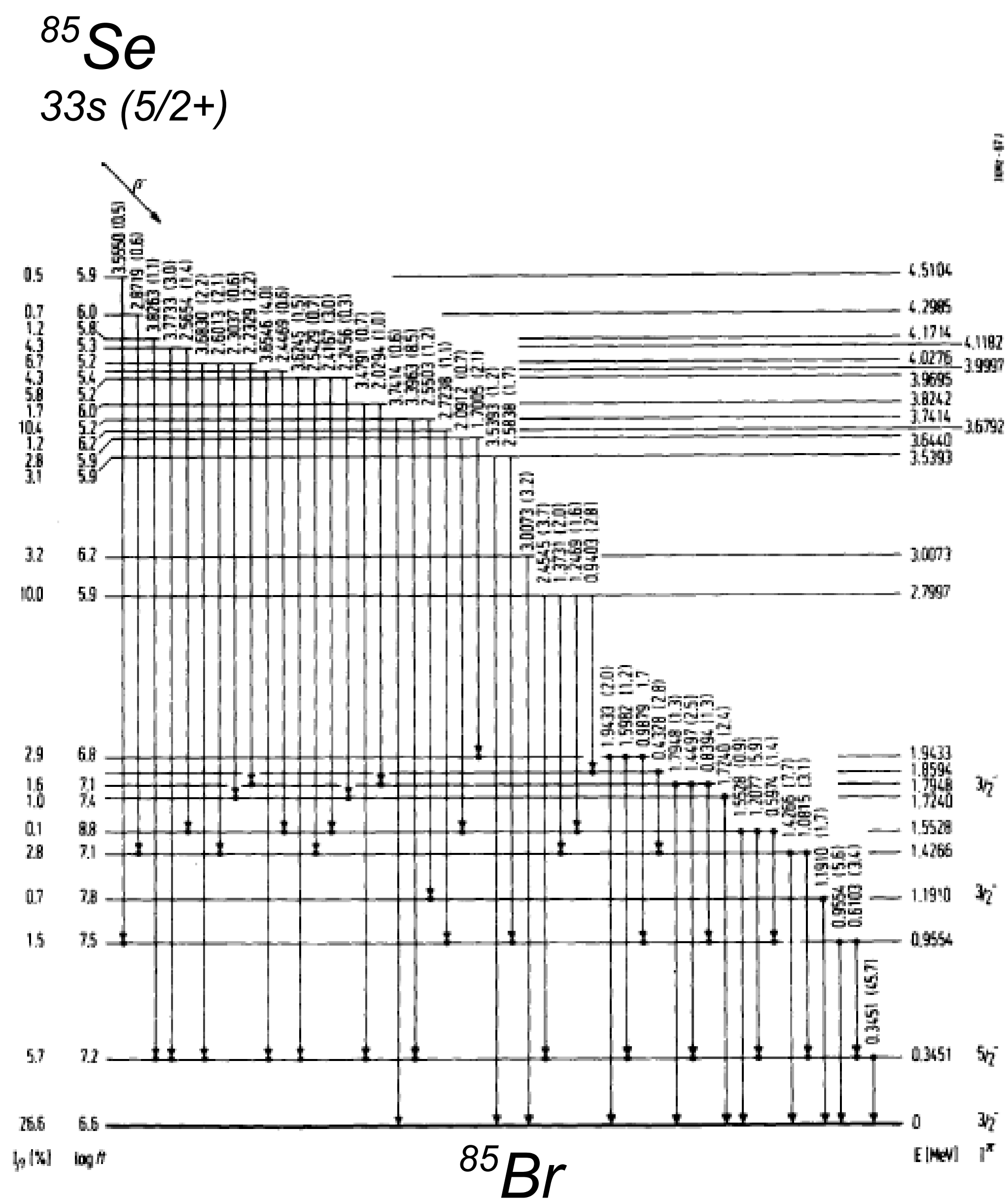
B(GT) for Se



B(GT)
$Q_{\beta-}$
S_n
S_{2n}
I_β (GT) (normalized to 100%)
N=50
N=51
83Se
84Se
85Se
86Se
87Se
88Se
89Se
Excitation energy

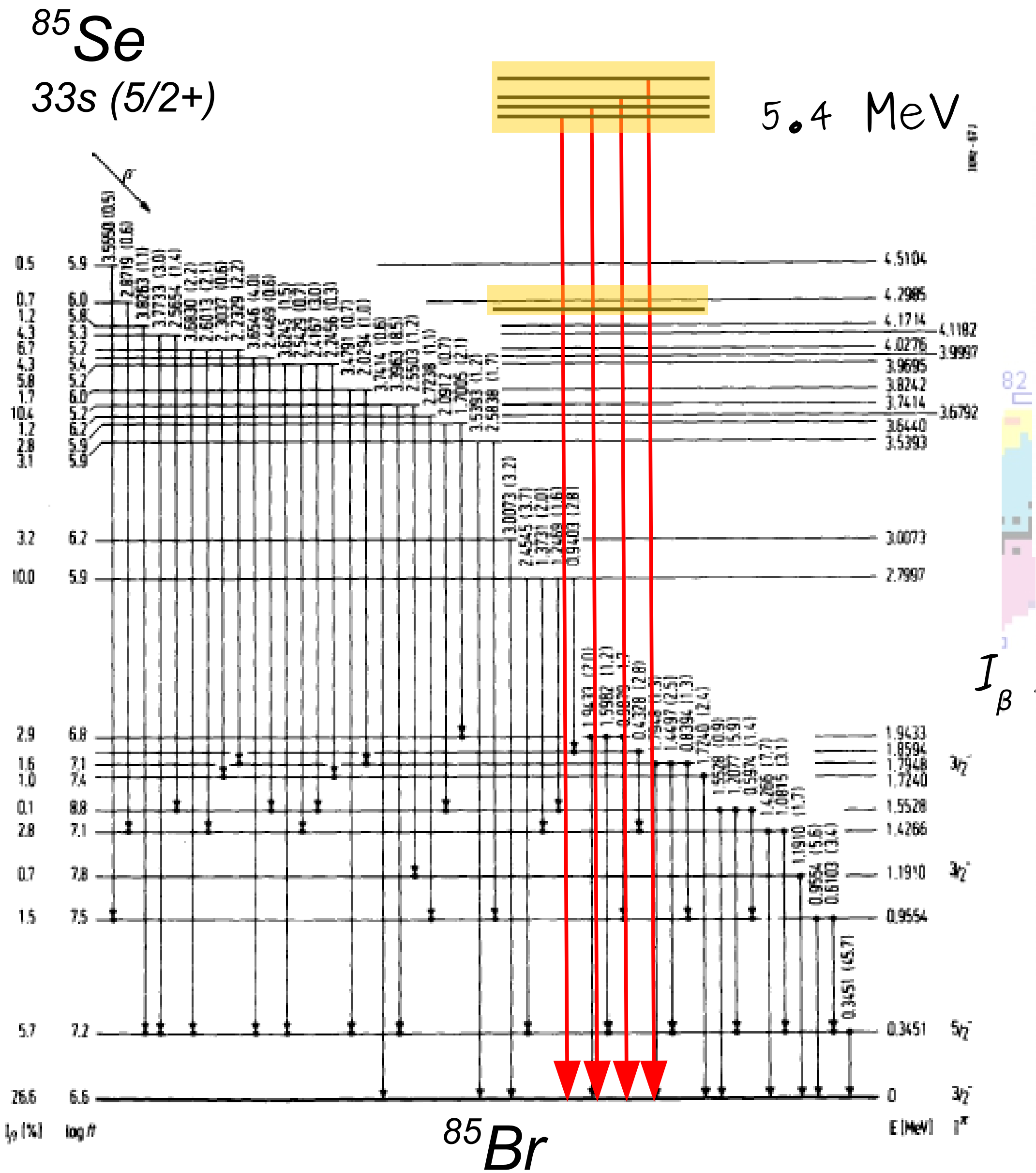
Decay of N=51 ^{85}Se with MTAS



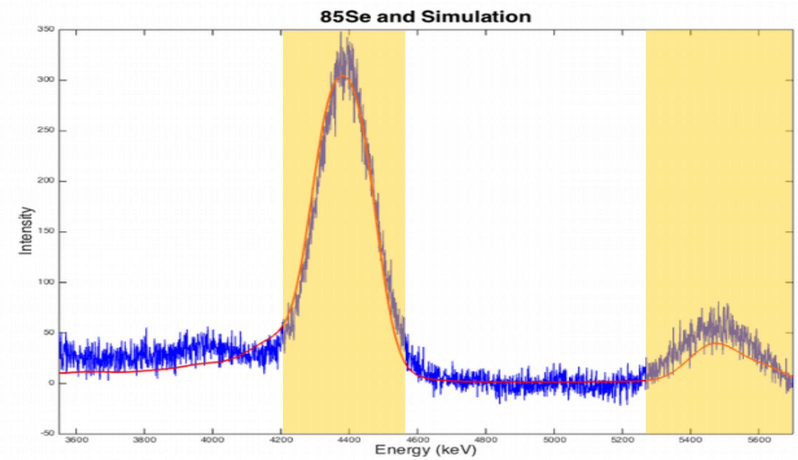


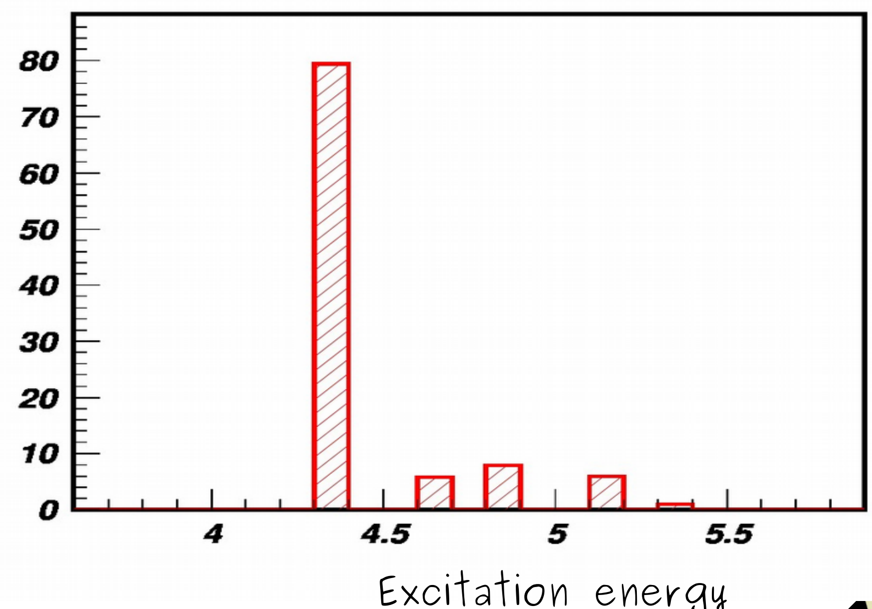
J. Inorg. nucl. Chem. Vol. 42, 1387 (1980)

Decay of N=51 ^{85}Se with MTAS



K. Goetz (UTK)
A. Fijalkowska (Warsaw)

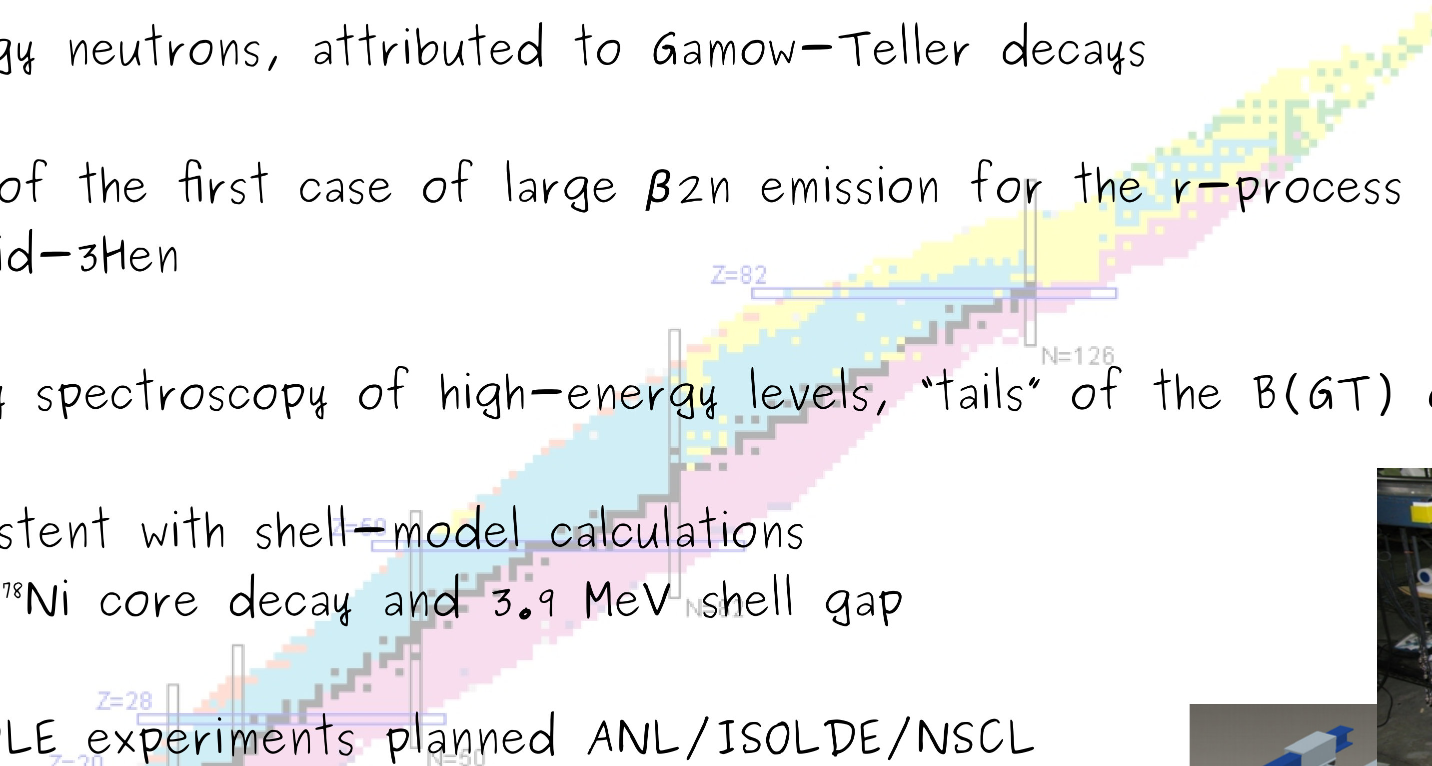


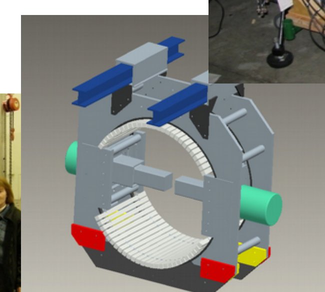


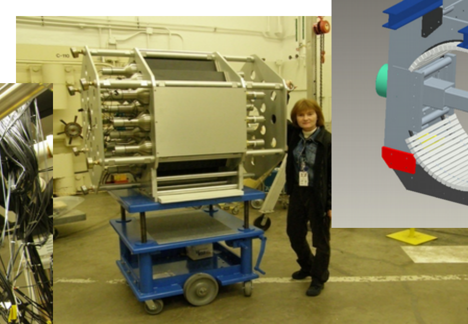
Zendel J. Inorg. nucl. Chem. Vol. 42, 1387 (1980)

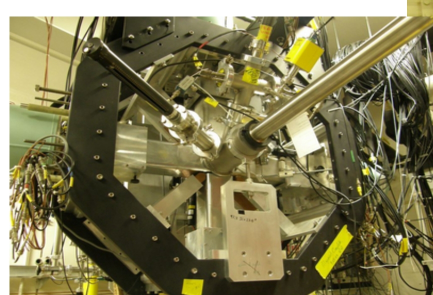
GT decays of very neutron rich nuclei
Dominating role of GT transitions far from stability

- Survey of ~30 isotopes near the r-process path at HRIBF
- High-energy neutrons, attributed to Gamow-Teller decays
- Discovery of the first case of large β2n emission for the r-process nucleus ^{86}Ga with Hybrid-3Hen
- Gamma-ray spectroscopy of high-energy levels, "tails" of the B(GT) distribution
- Data consistent with shell-model calculations based on ^{78}Ni core decay and 3.9 MeV shell gap
- New VANDLE experiments planned ANL/ISOLDE/NSCL
- Improvements in calculations to address the remaining discrepancies









THANK YOU !

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