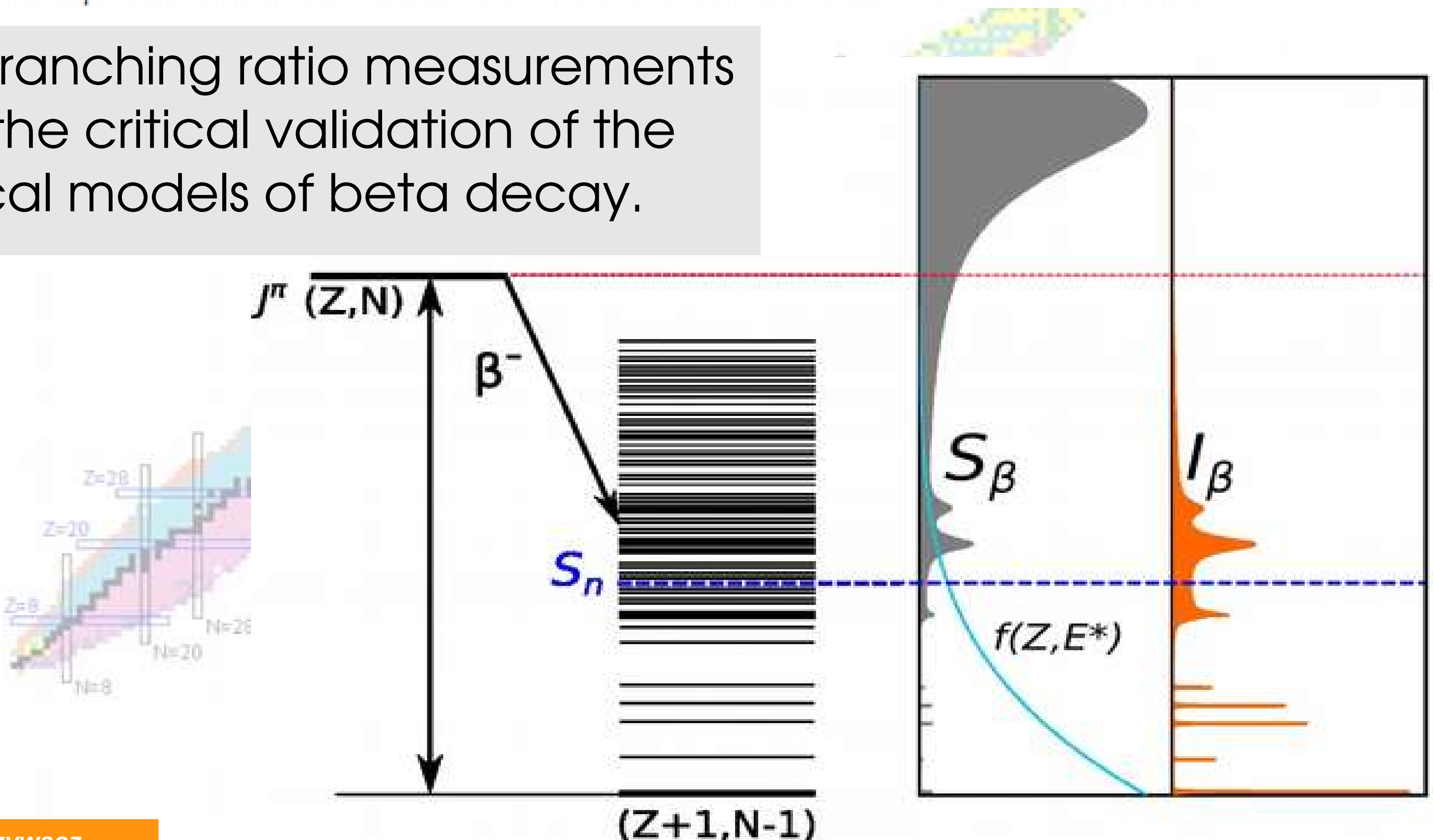
Decay strength distribution lifetimes and branching ratios

$$\frac{1}{T_{1/2}}=\sum_{E_i\geq 0}^{E_i\leq Q_\beta} S_\beta(E_i)\times f\left(Z,Q_\beta-E_i\right) \qquad S_\beta(E_i)=\langle\psi_f|\hat{O}_\beta|\psi_{mother}\rangle$$

Decay branching ratio measurements provide the critical validation of the theoretical models of beta decay.



Decay of FRIB r-process nucleus ^{124}Nb: from N=82 to Z=50

Q_β ~ 21 MeV

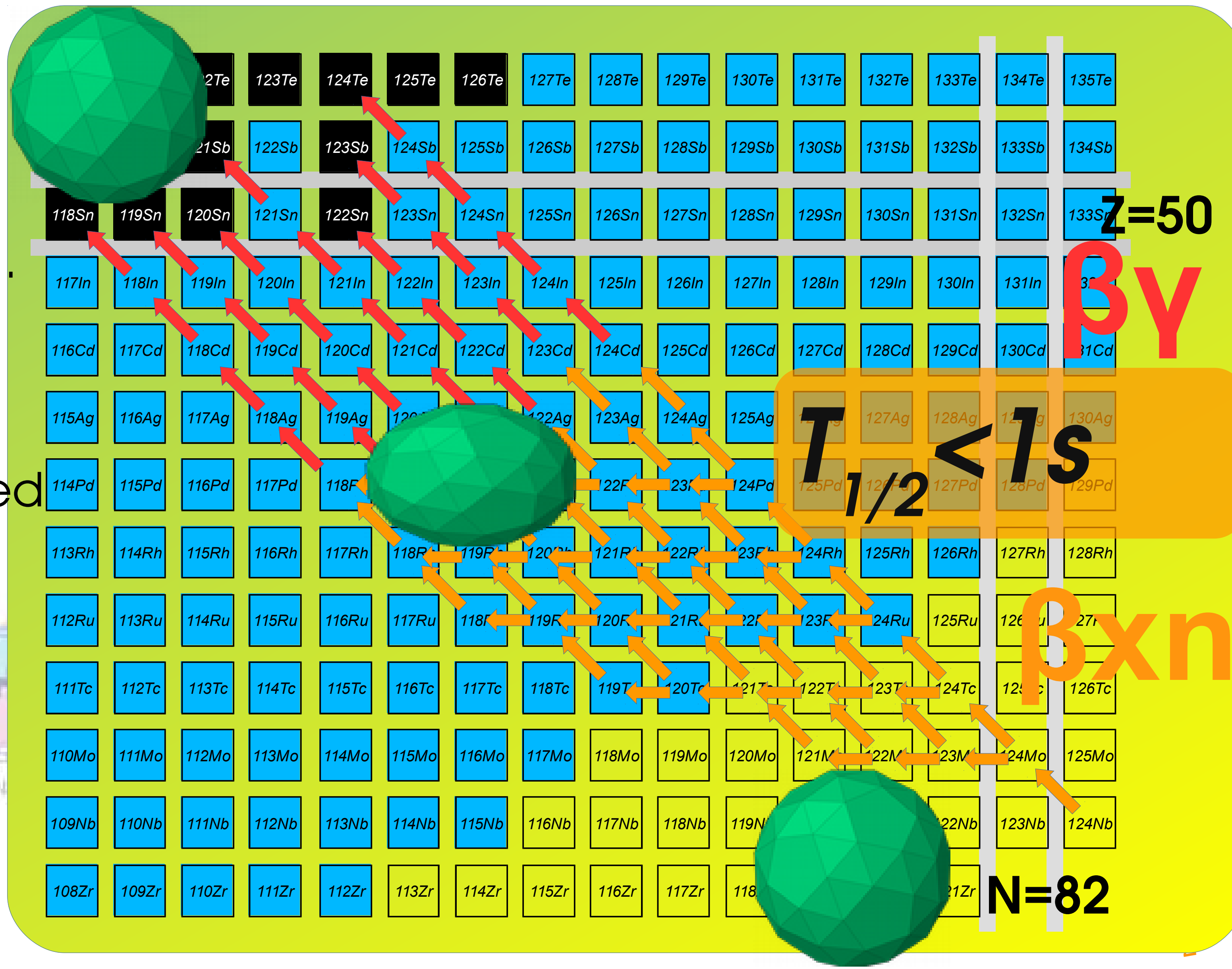
$T_{1/2}$ ~2 ms

Decay modes:

βγ, βn, β2n, β3n…

30 isotopes in 1s

~100 MeV released



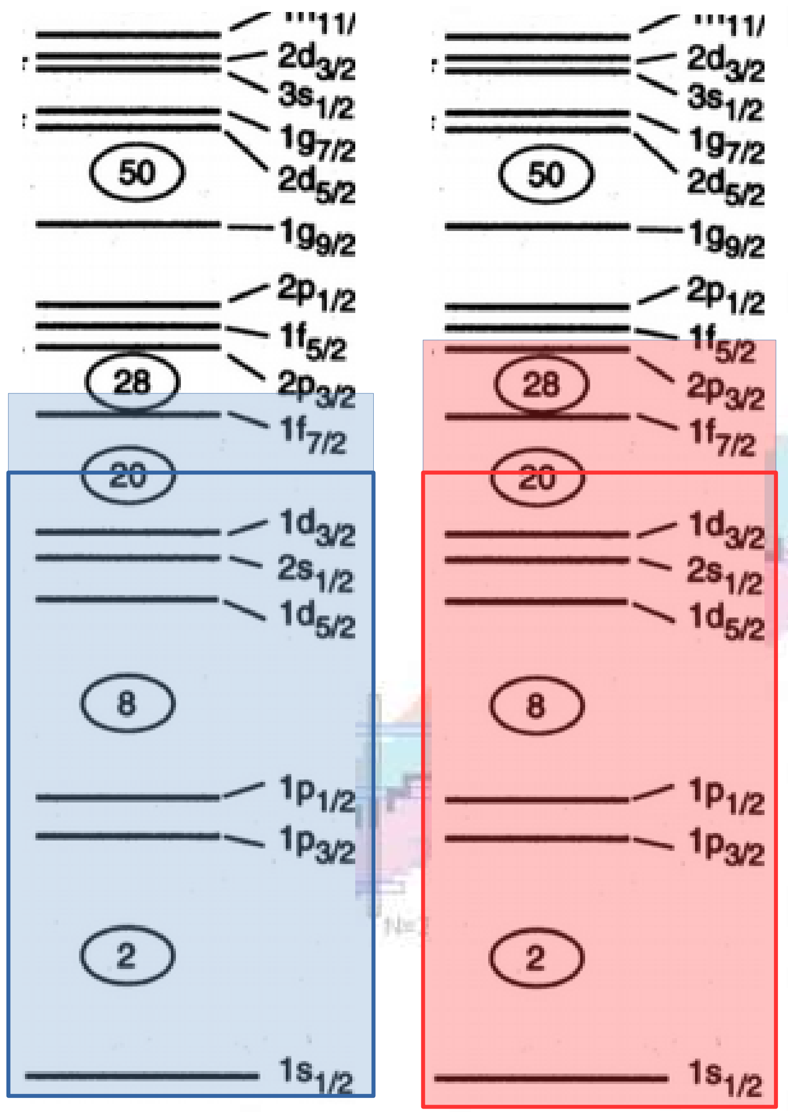
GT – decay of neutron rich nuclei
Core + valence nucleons

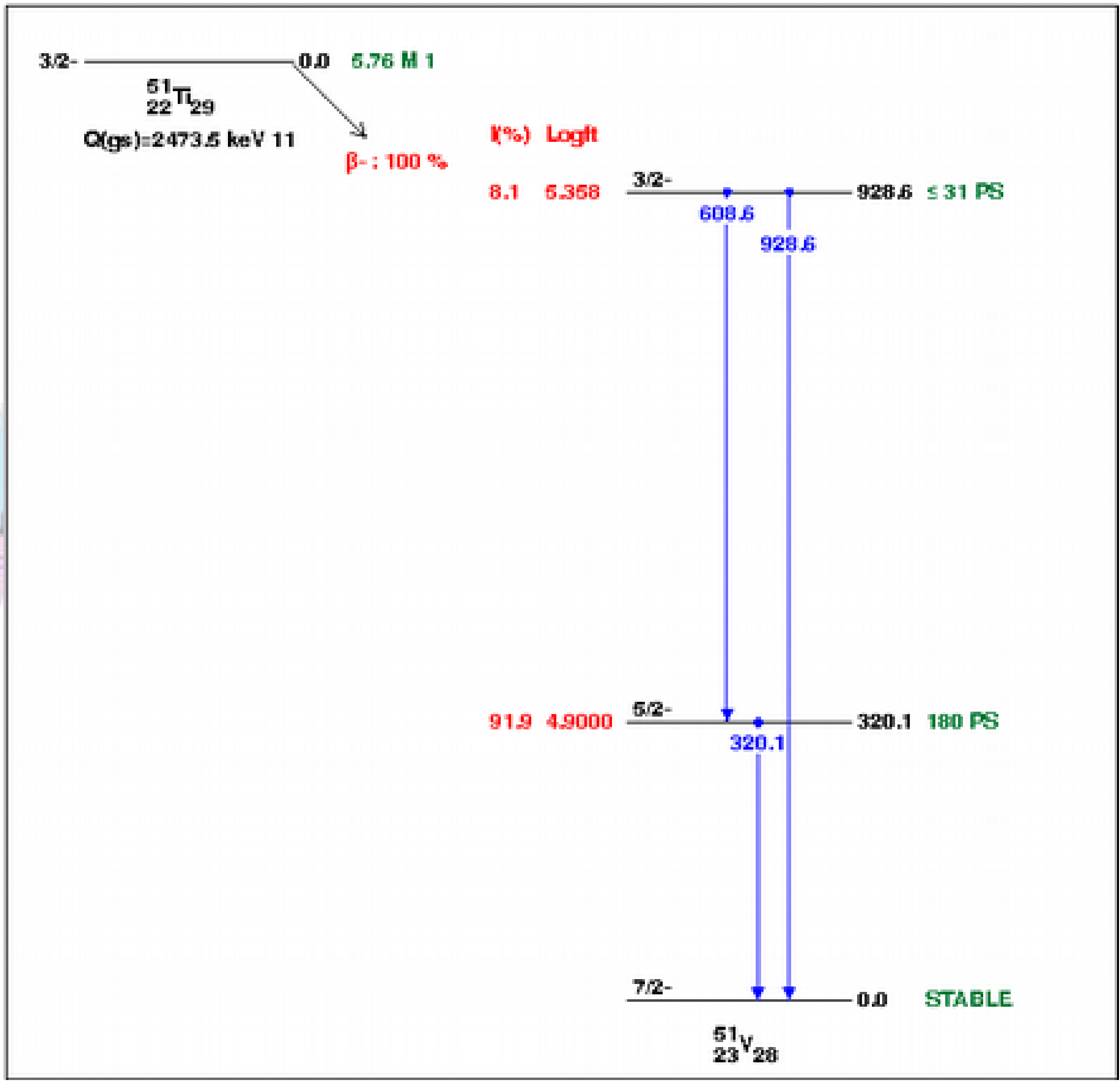
51Ti Z=22 N=29

GT – decay of neutron rich nuclei
Core + valence nucleons

$^{51}Ti \rightarrow {}^{51}V$

51Ti Z=22 N=29





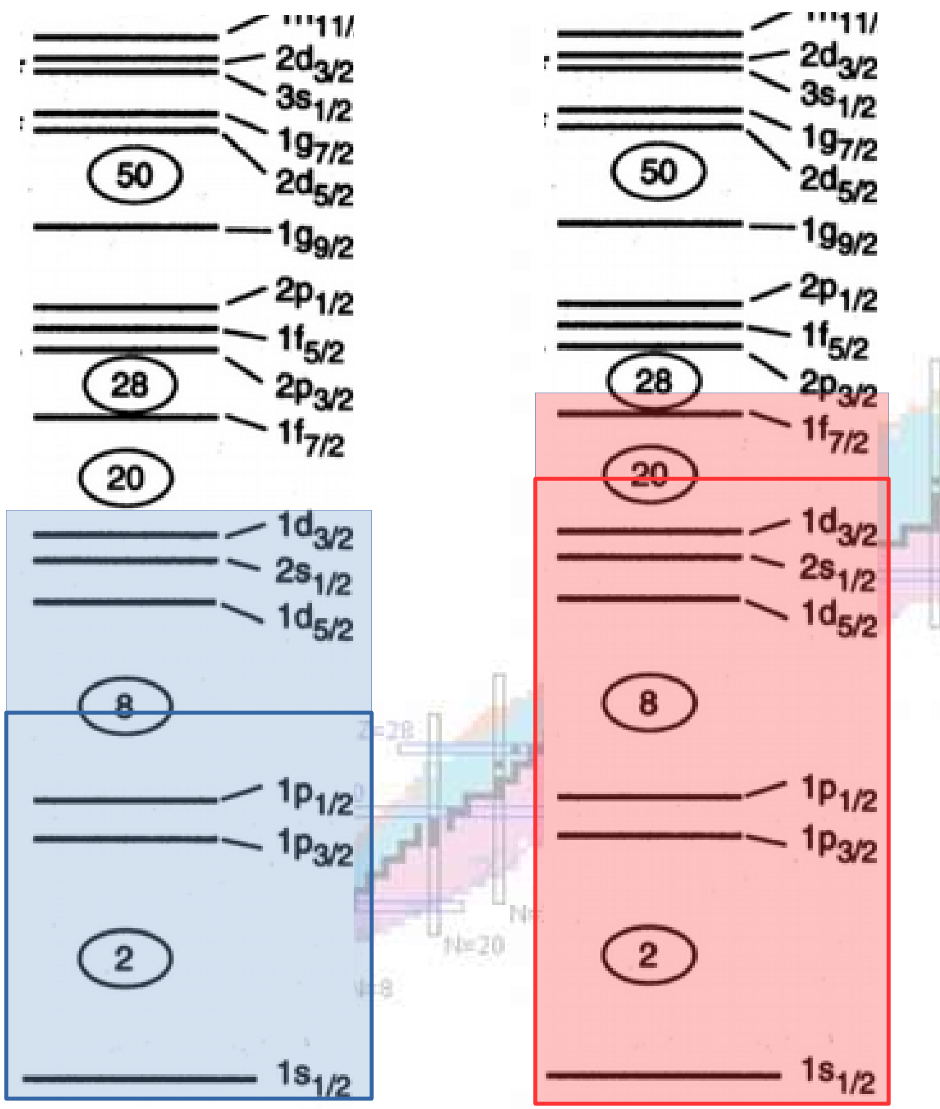
GT – decay of neutron rich nuclei
Core + valence nucleons

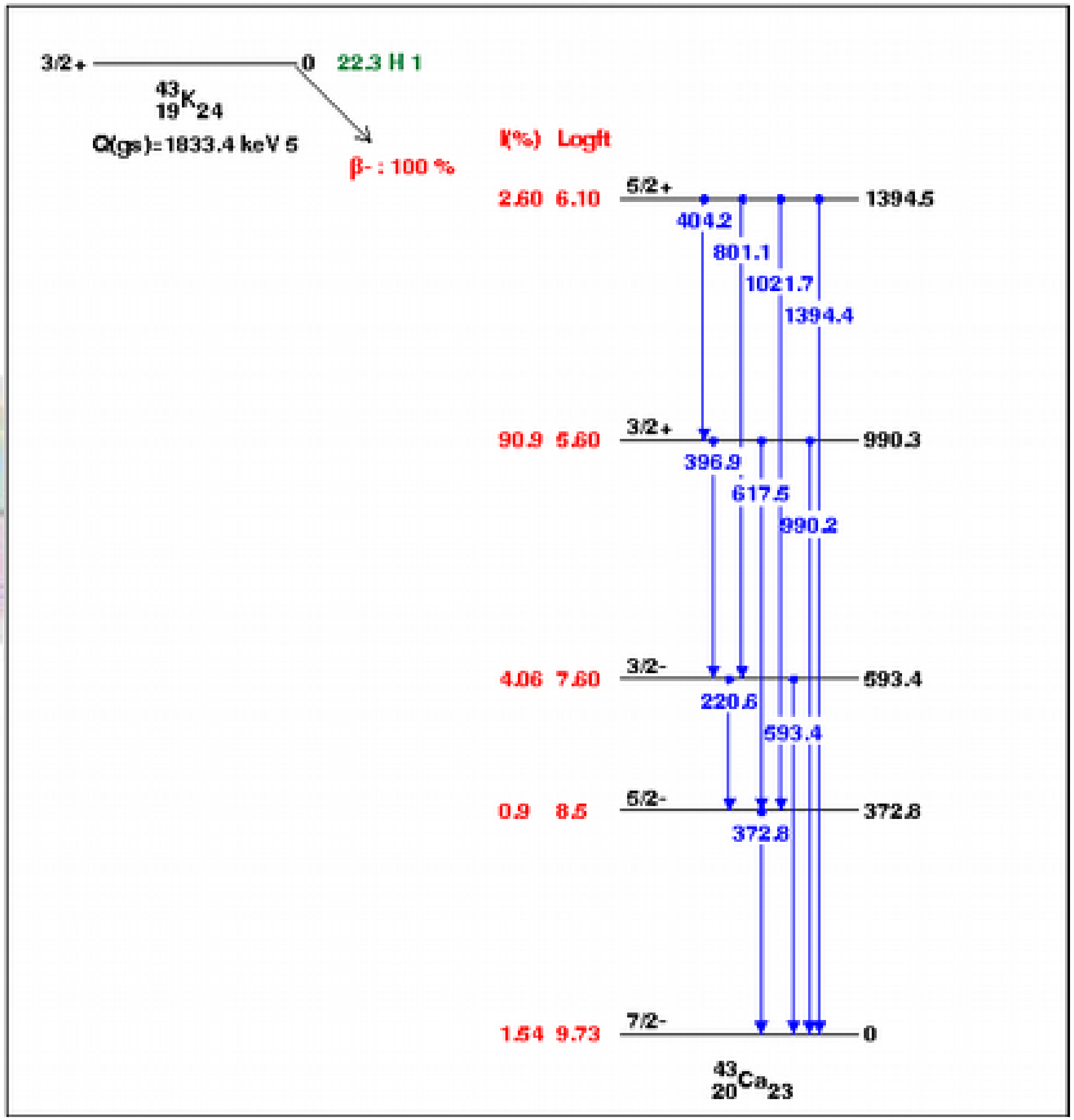
43K Z=19 N=24

GT – decay of neutron rich nuclei
Core + valence nucleons

$^{43}K \rightarrow {}^{43}Ca$

43K Z=19 N=24

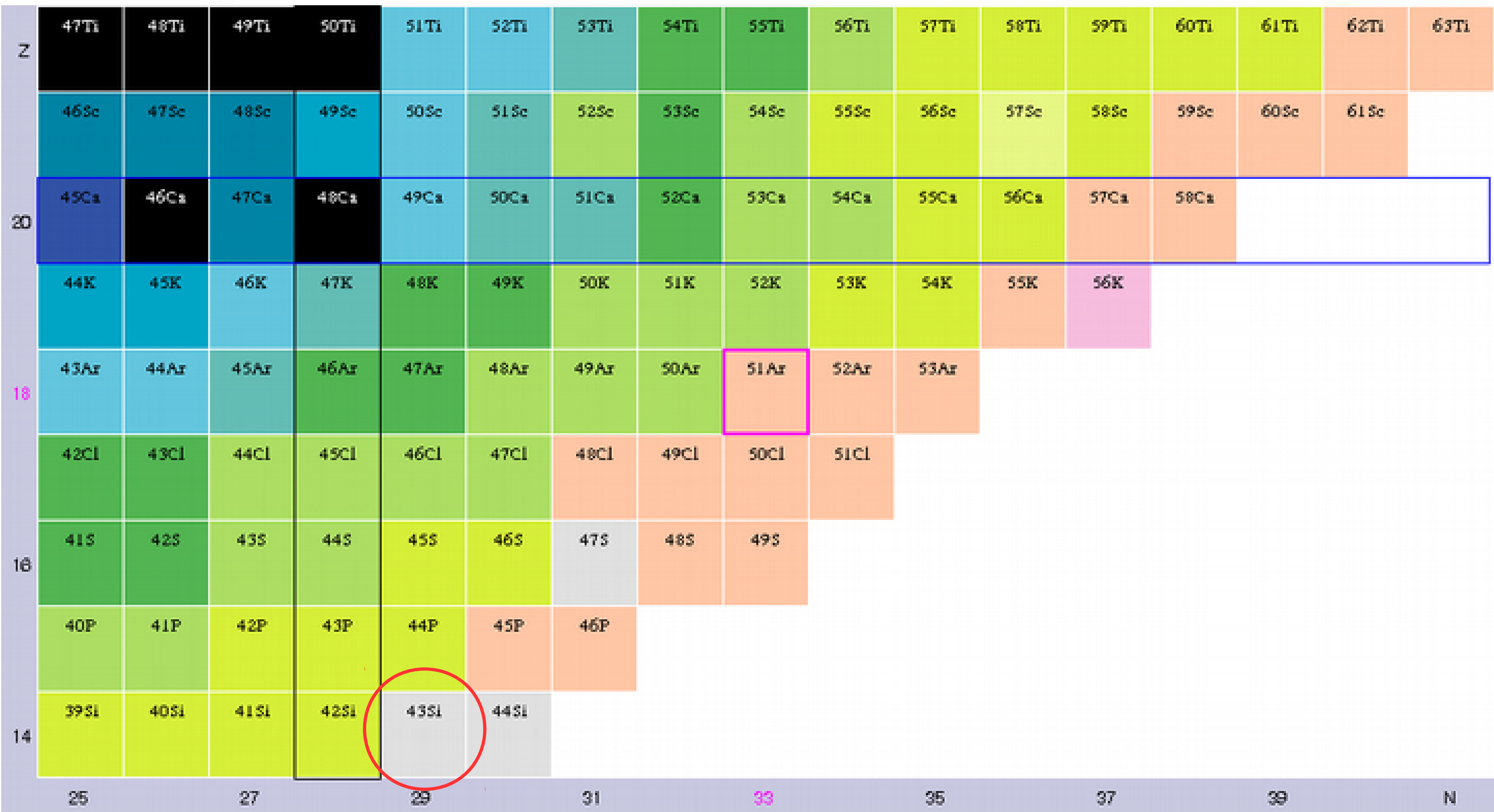




GT – decay of neutron rich nuclei
Core + valence nucleons

$$^{43}Si \rightarrow {}^{43}P$$

43Si Z=14 N=29

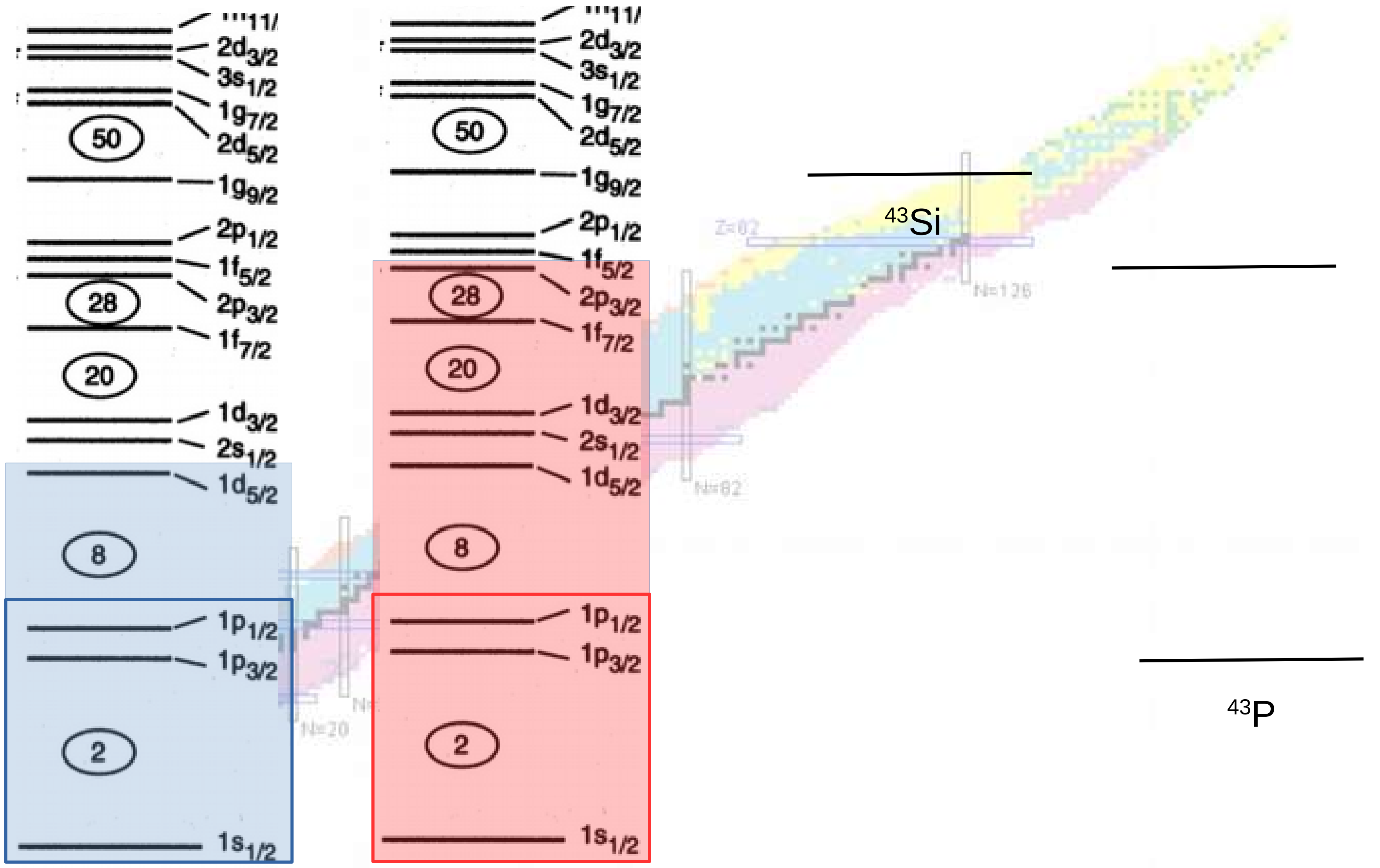


43Si Z=14 N=29

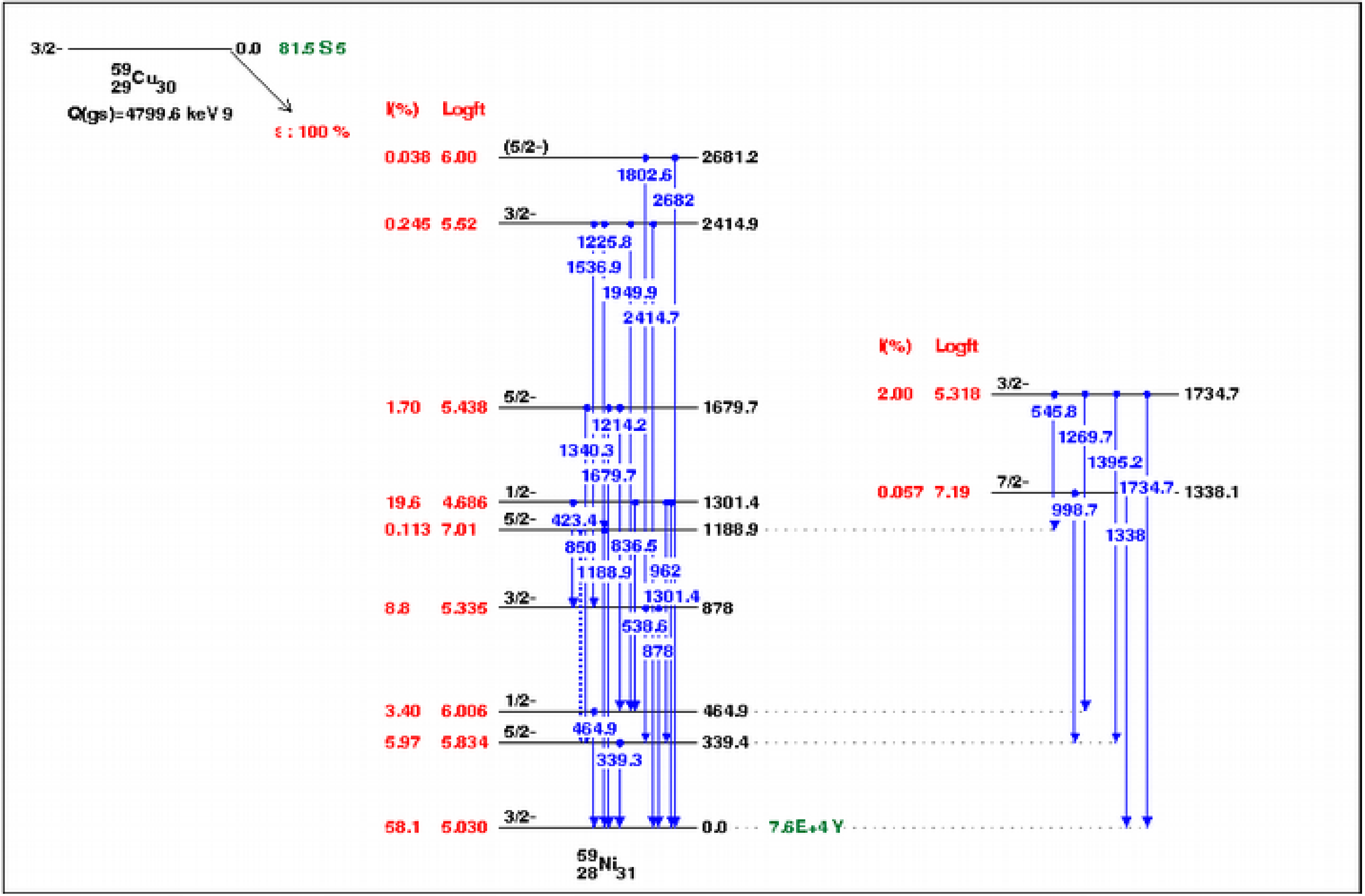
GT – decay of neutron rich nuclei
Core + valence nucleons

$^{43}Si \rightarrow {}^{43}P$

43Si Z=14 N=29

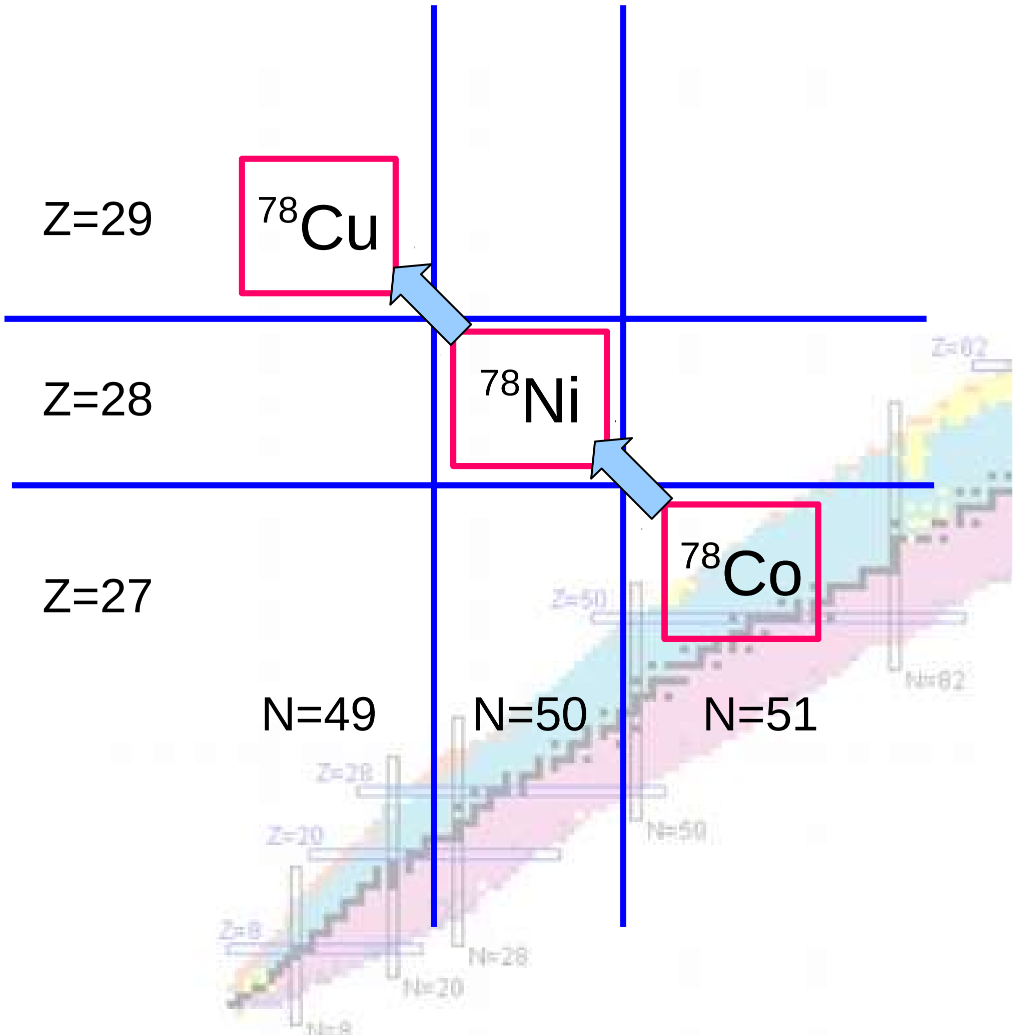


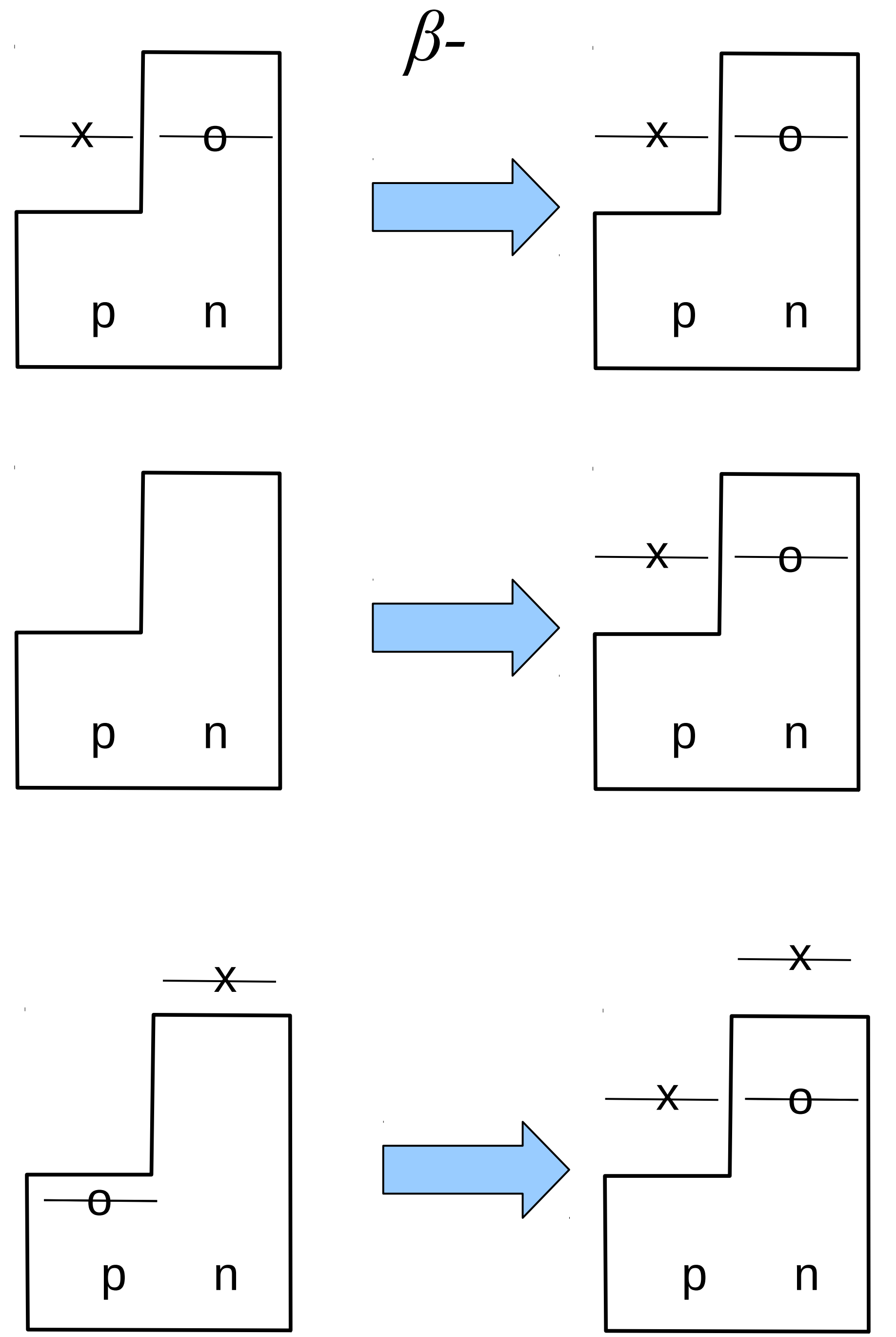
GT – decay of neutron rich nuclei
Core + valence nucleons



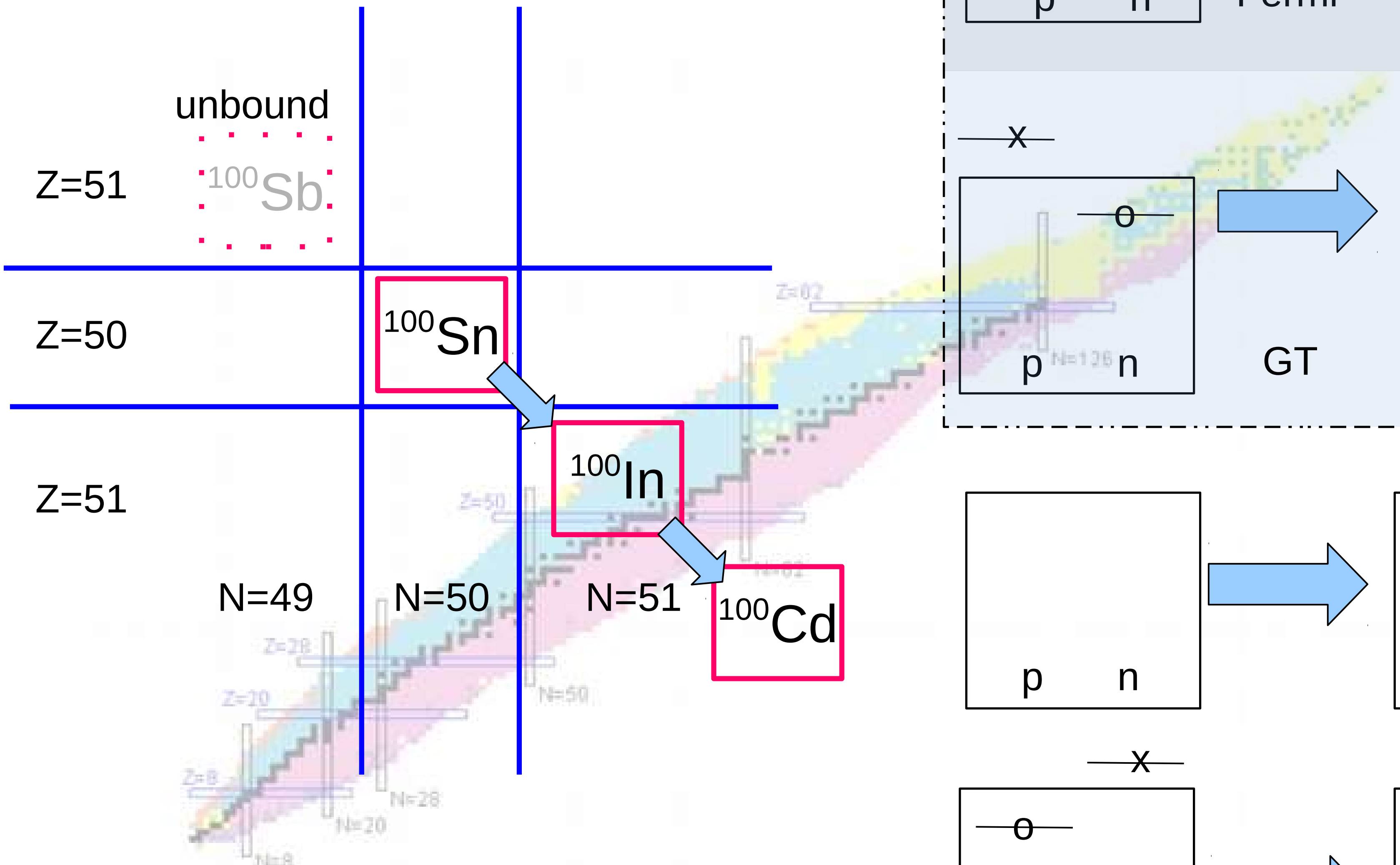

126
82
50
28
20
8
2
3p1/2
2f5/2
3p3/2
1i13/2
1h9/2
2f7/2
1h11/2
2d3/2
3s1/2
1g7/2
2d5/2
1g9/2
2p1/2
1f5/2
2p3/2
1f7/2
1d3/2
2s1/2
1d5/2
1p1/2
1p3/2
1s1/2
Z=82
N=82

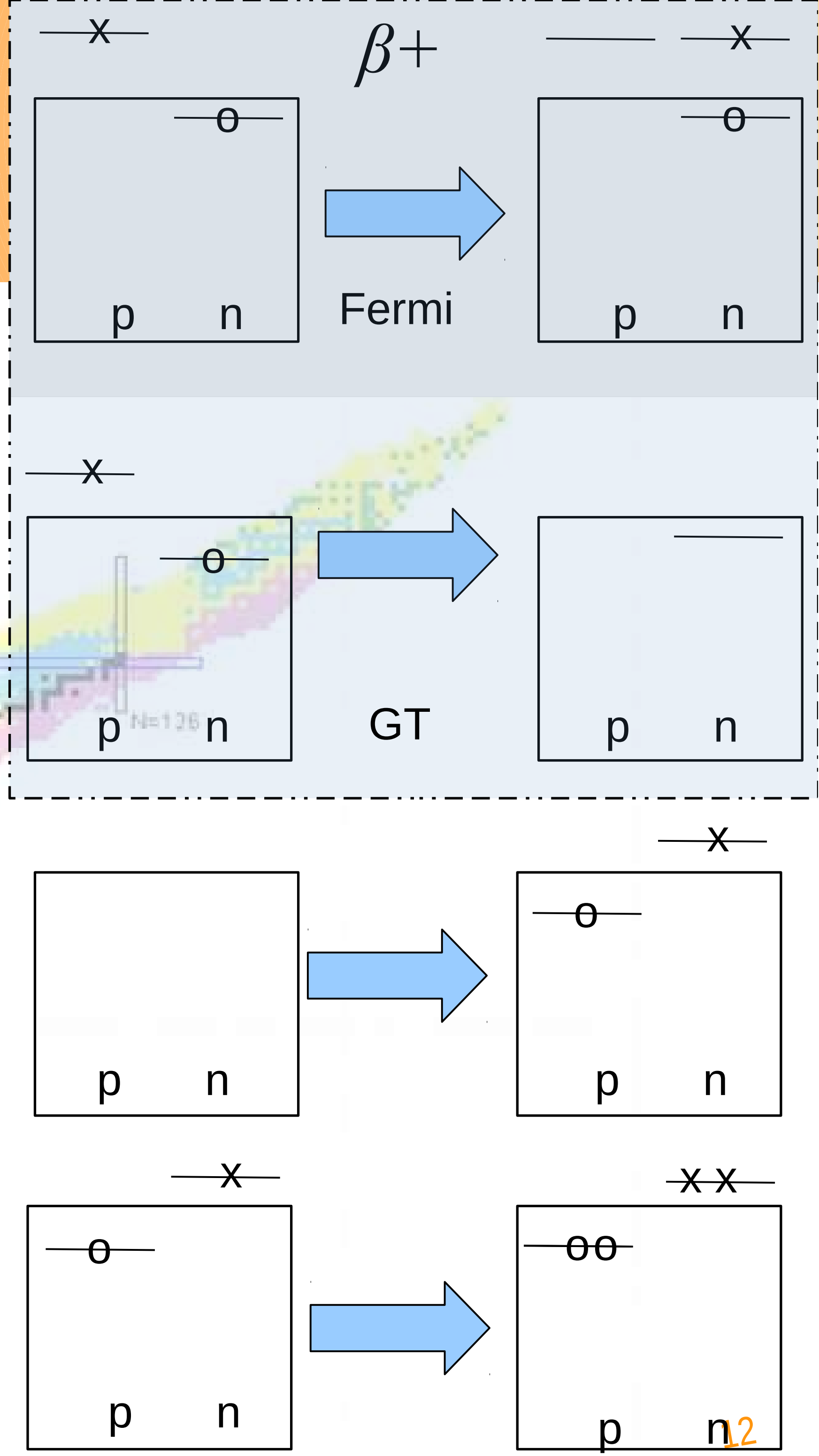
GT near closed shells





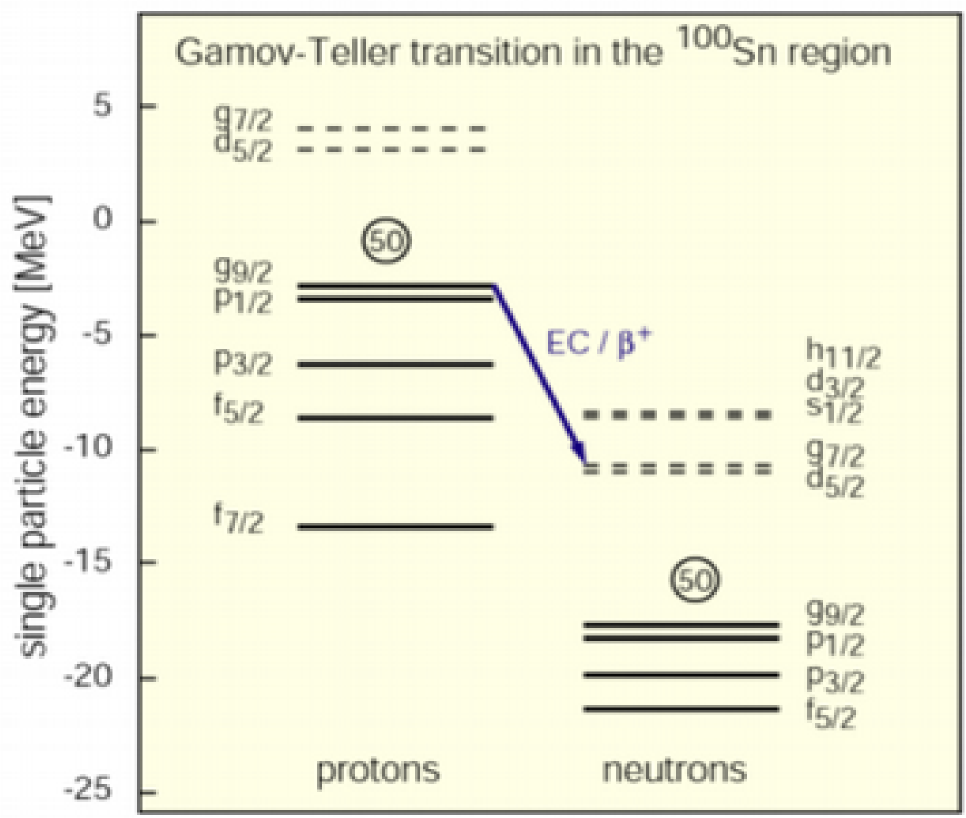
GT near closed shells

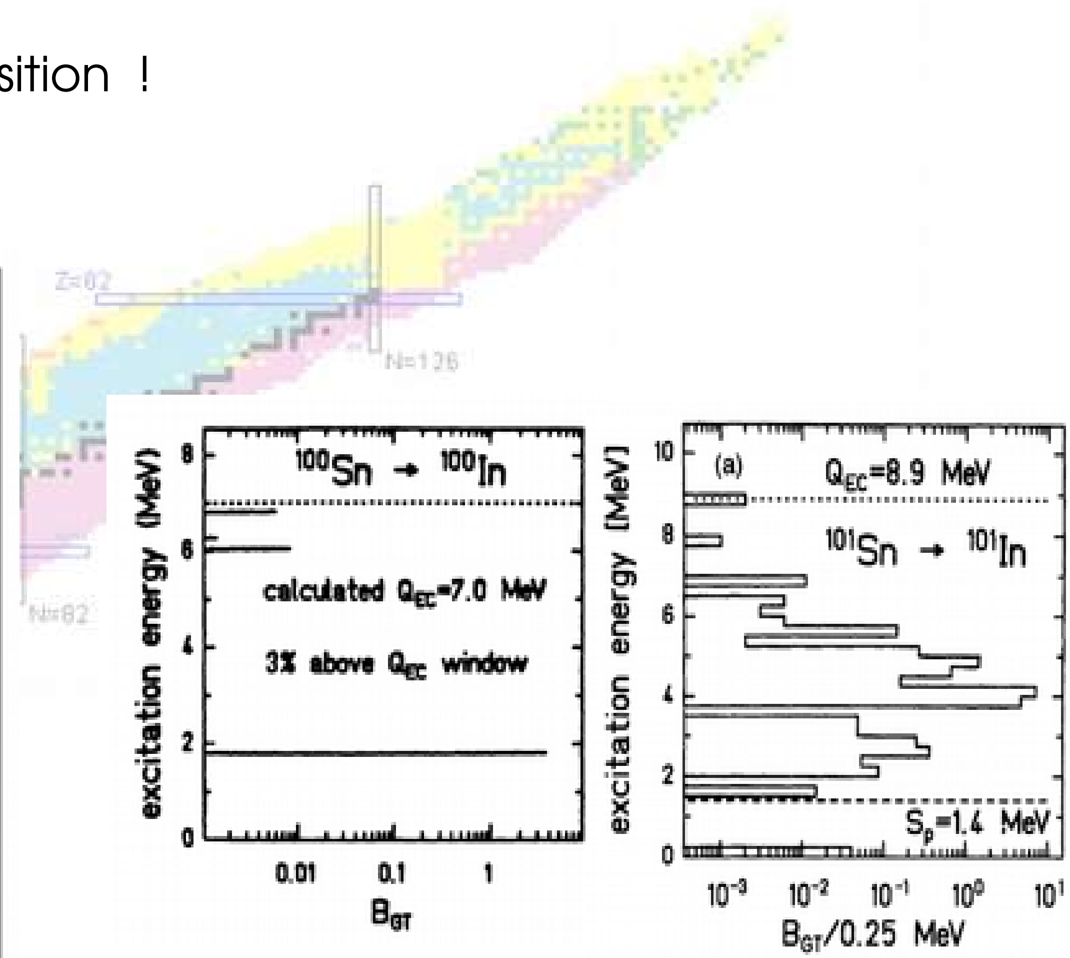




Gamow-Teller decay of 100Sn !
Spin-flip "proton" decay

Decay dominated by one strong transition !





Brown, Rykaczewski PRC 50(1994)

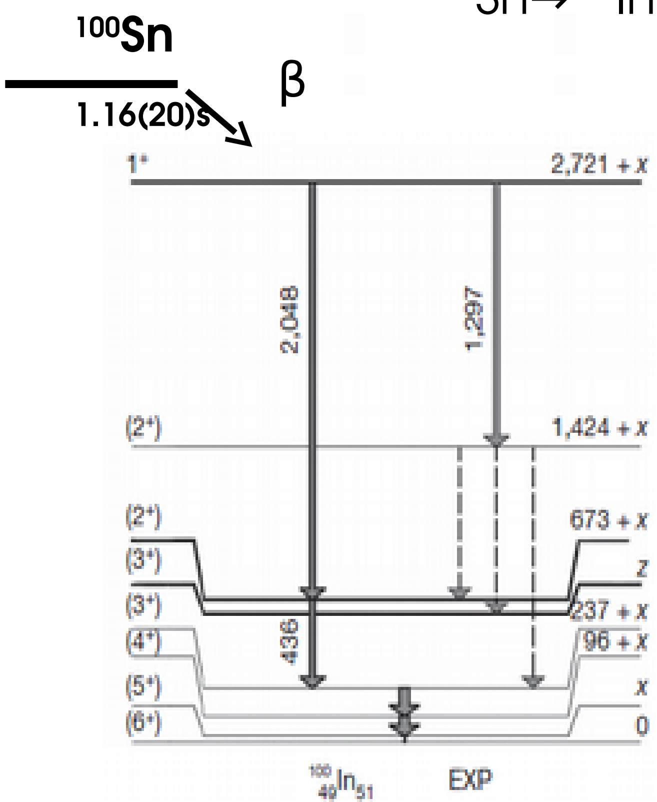
Superallowed GT-Decay of ^{100}Sn

C.B. Hinke et al., Nature 486, 345 (2012)

FRS GSI experiment

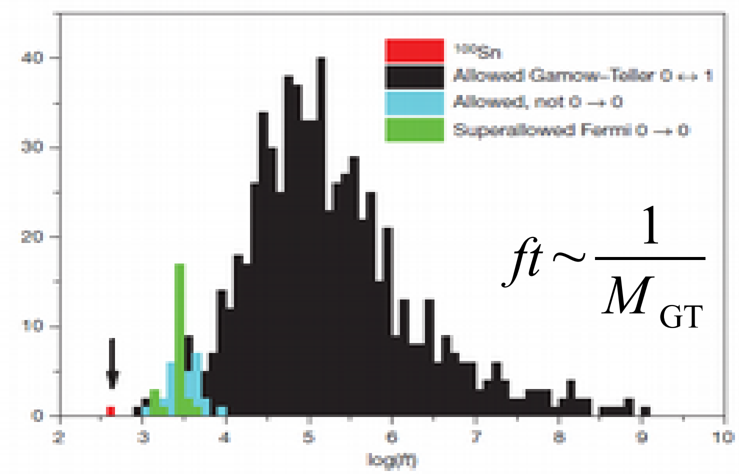
Gamow-Teller decay

$^{100}Sn \rightarrow {}^{100}In$



strongest β-decay matrix element ever observed

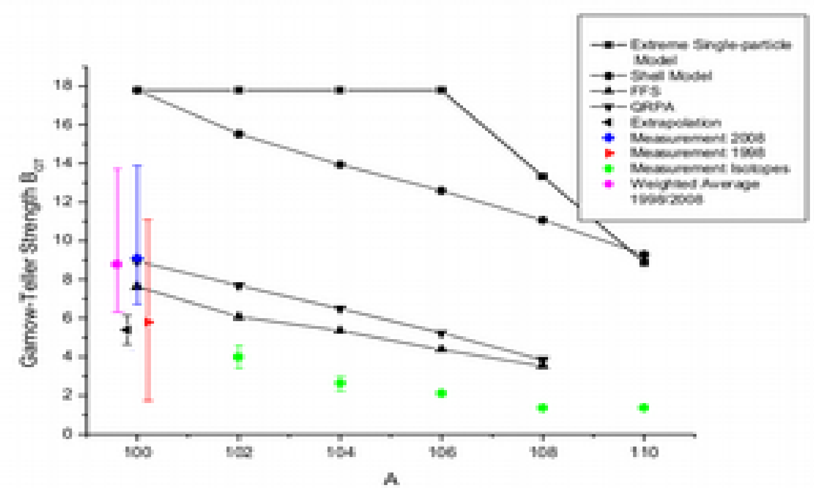
log ft ~ 2.62(13) M_{GT} ~ 9(3)



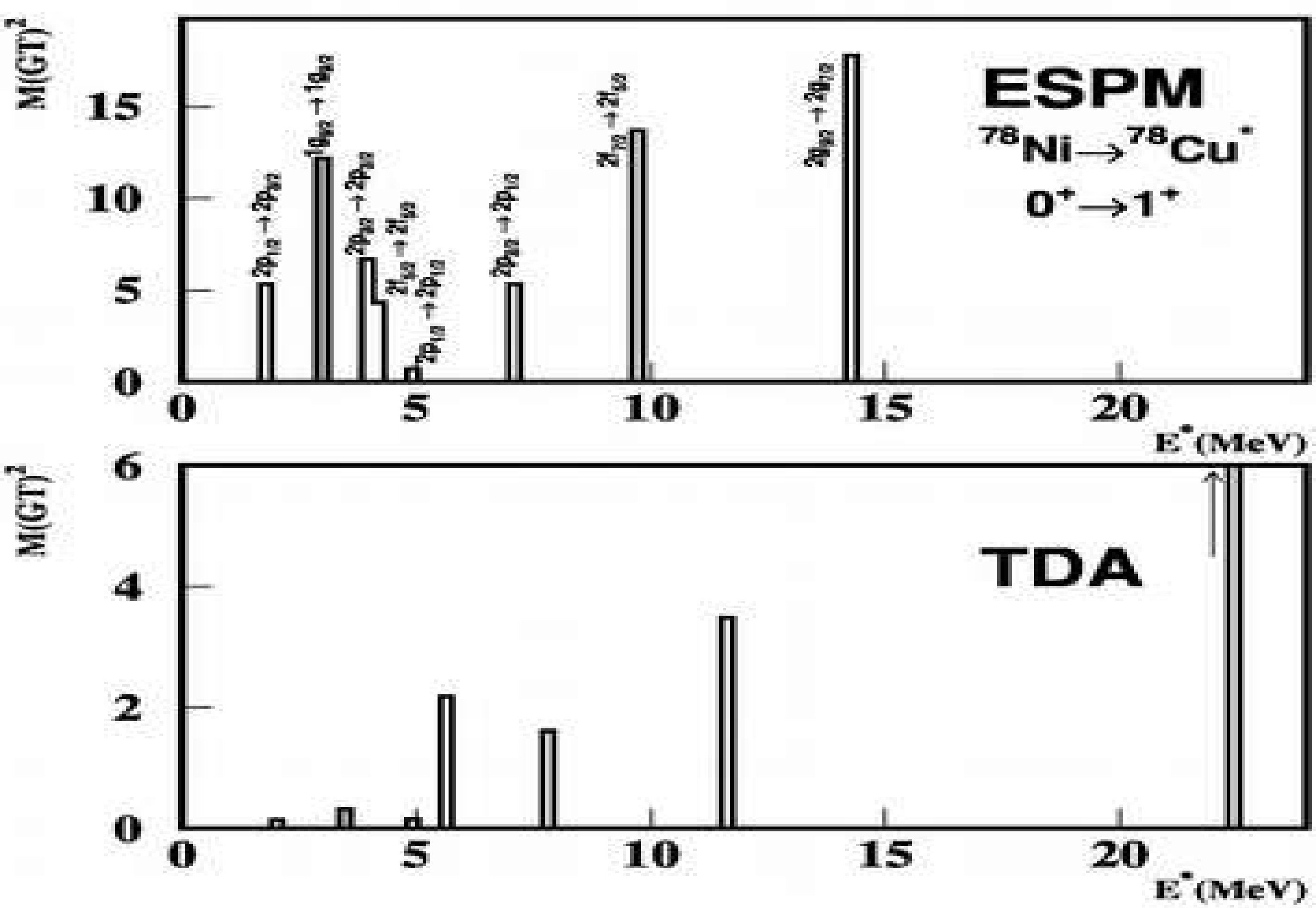
$$ft \sim \frac{1}{M_{GT}}$$

B(GT) for 100Sn less quenched compared to other less exotic Sn isotopes.

Is the experiment incomplete or the predictions too simplistic ?



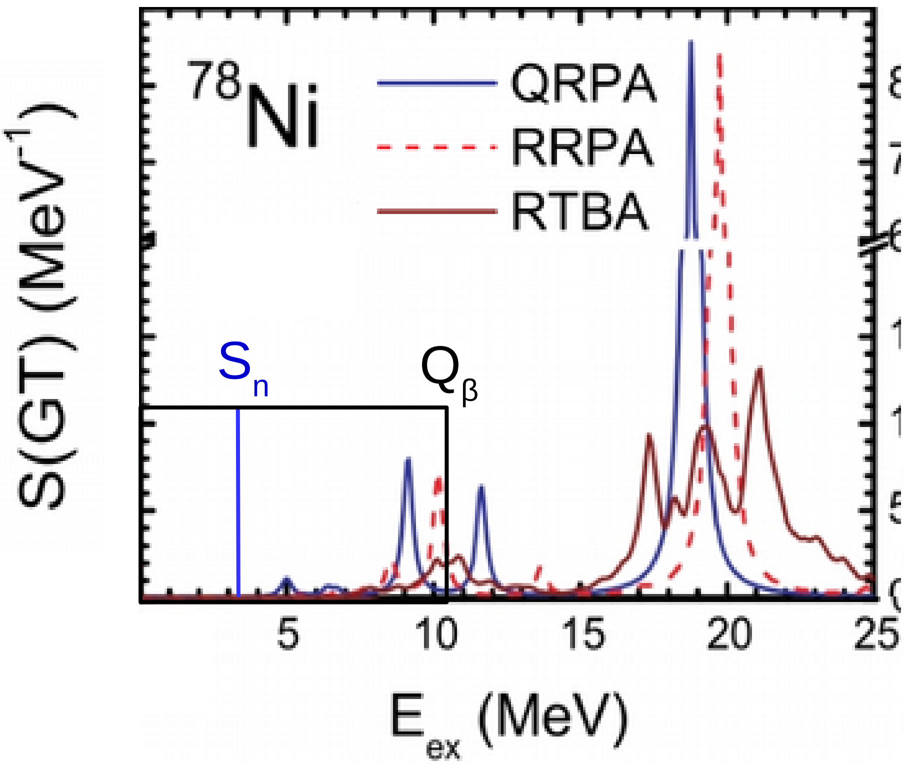
GT decay of doubly magic 78Ni



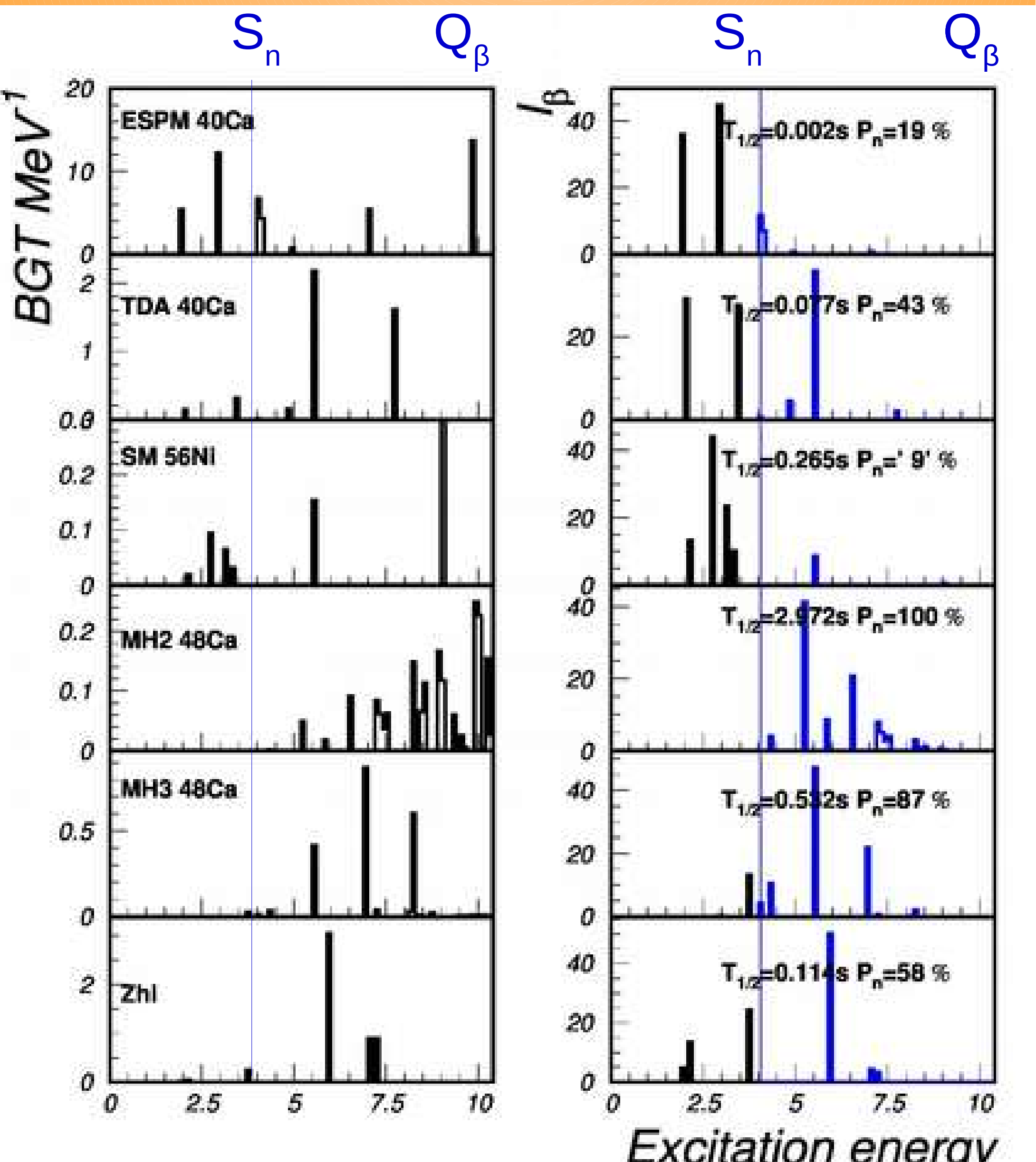
$j_f \backslash j_i$	$l+\frac{1}{2}$	$l-\frac{1}{2}$
$l+\frac{1}{2}$	$\frac{2l+3}{2l+1}$	$\frac{4(l+1)}{2l+1}$
$l-\frac{1}{2}$	$\frac{4l}{2l+1}$	$\frac{2l-1}{2l+1}$

$$B_{GT} = |M_{GT}|^2 = N_\nu \cdot \left(1 - \frac{N_\pi}{2j_f+1}\right) \cdot |M^0_{GT}|^2$$

Response to Gamow-Teller operator

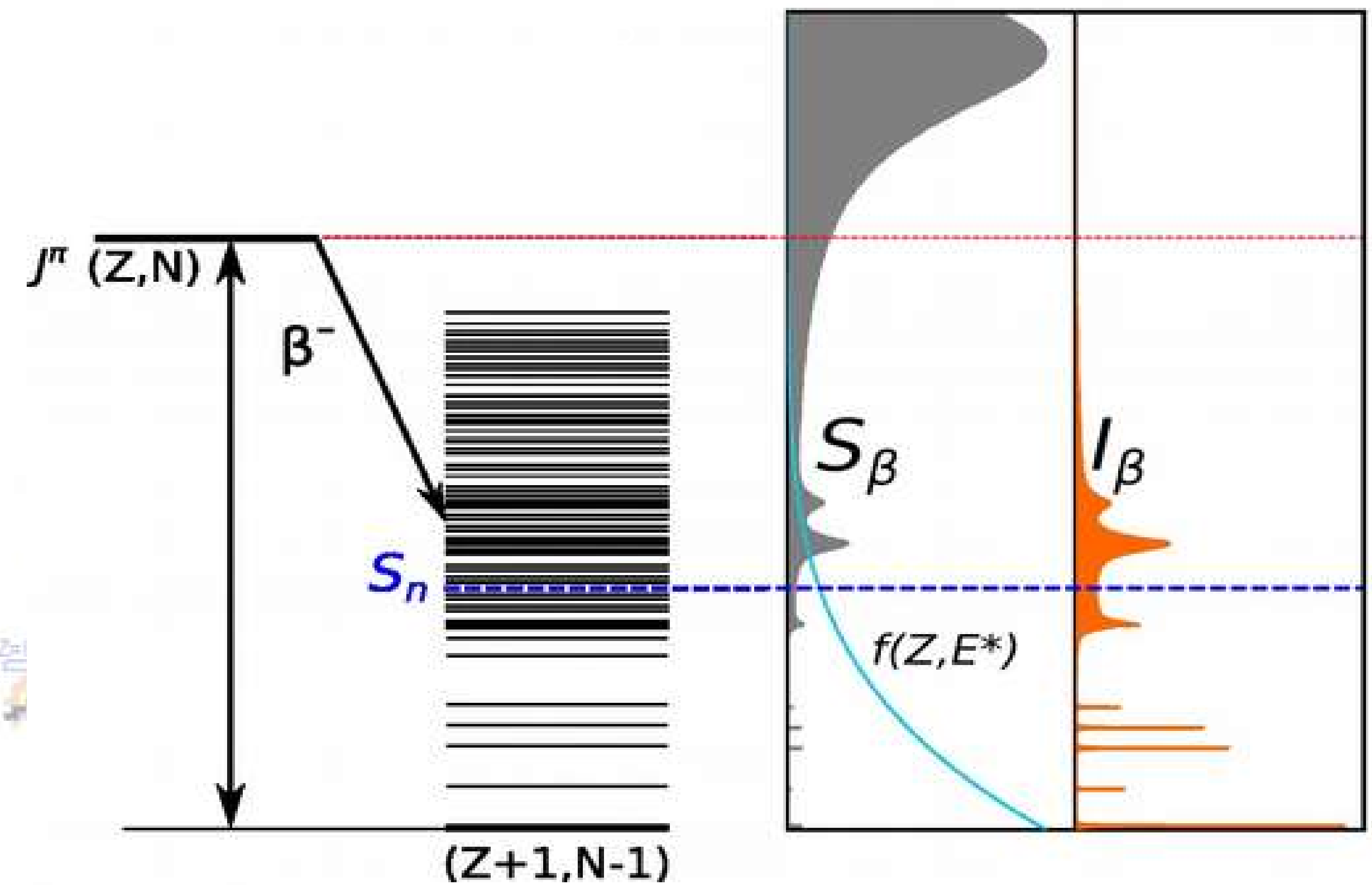


E. Litvinova, B. A. Brown D. L. Fang, T. Marketin, R. Zegers
ArXiv: 1402,0877v1



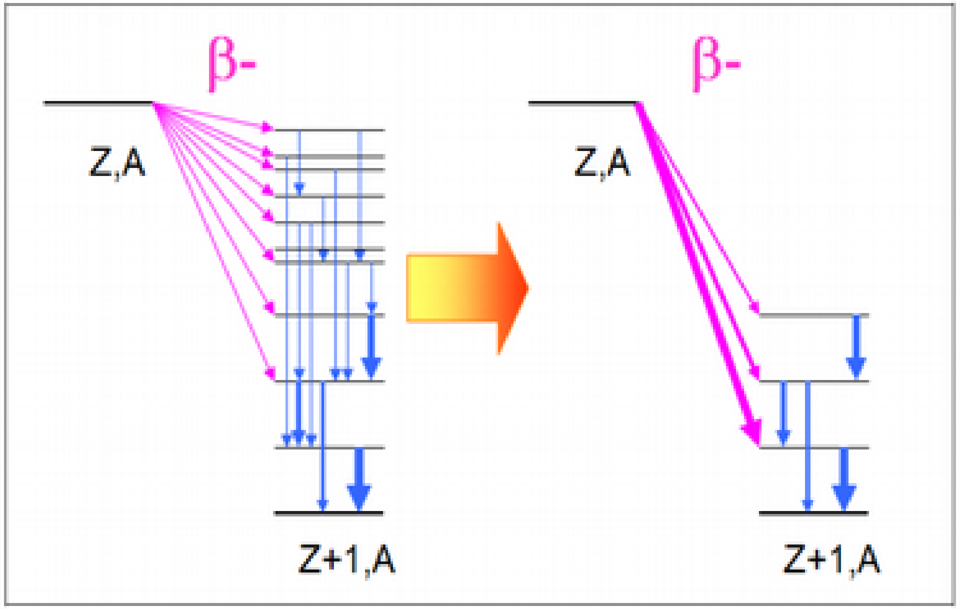
Decay strength distribution lifetimes and branching ratios

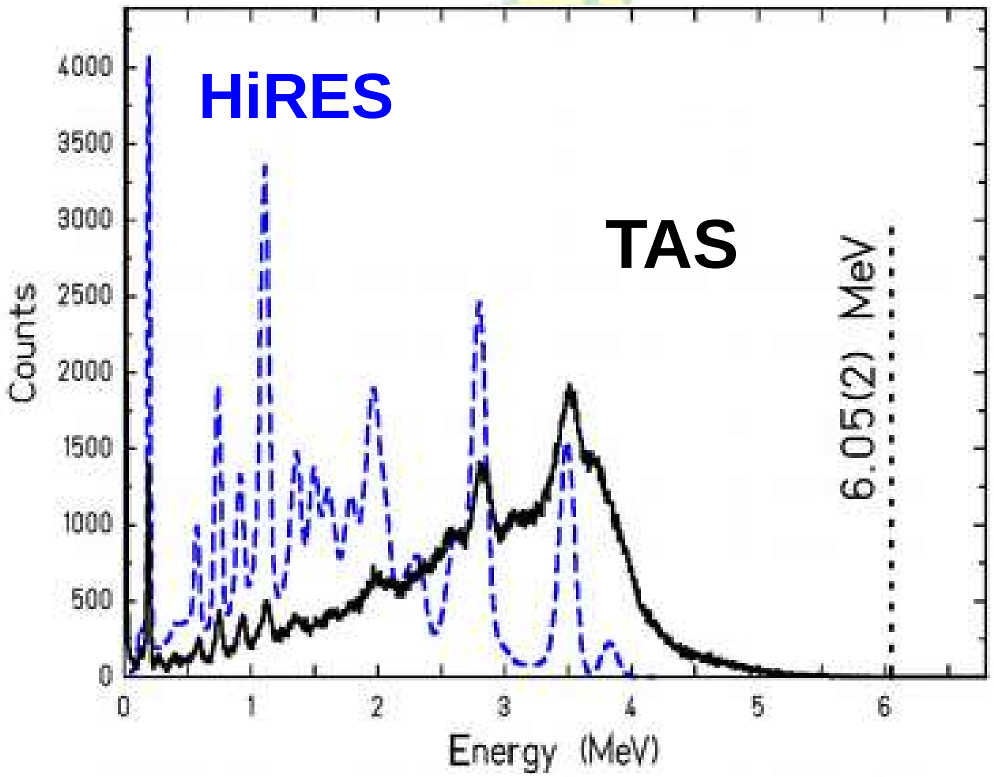
$$\frac{1}{T_{1/2}} = \sum_{E_i \geq 0}^{E_i \leq Q_\beta} S_\beta(E_i) \times f(Z, Q_\beta - E_i) \qquad S_\beta(E_i) = \langle \psi_f | \hat{O}_\beta | \psi_{mother} \rangle$$



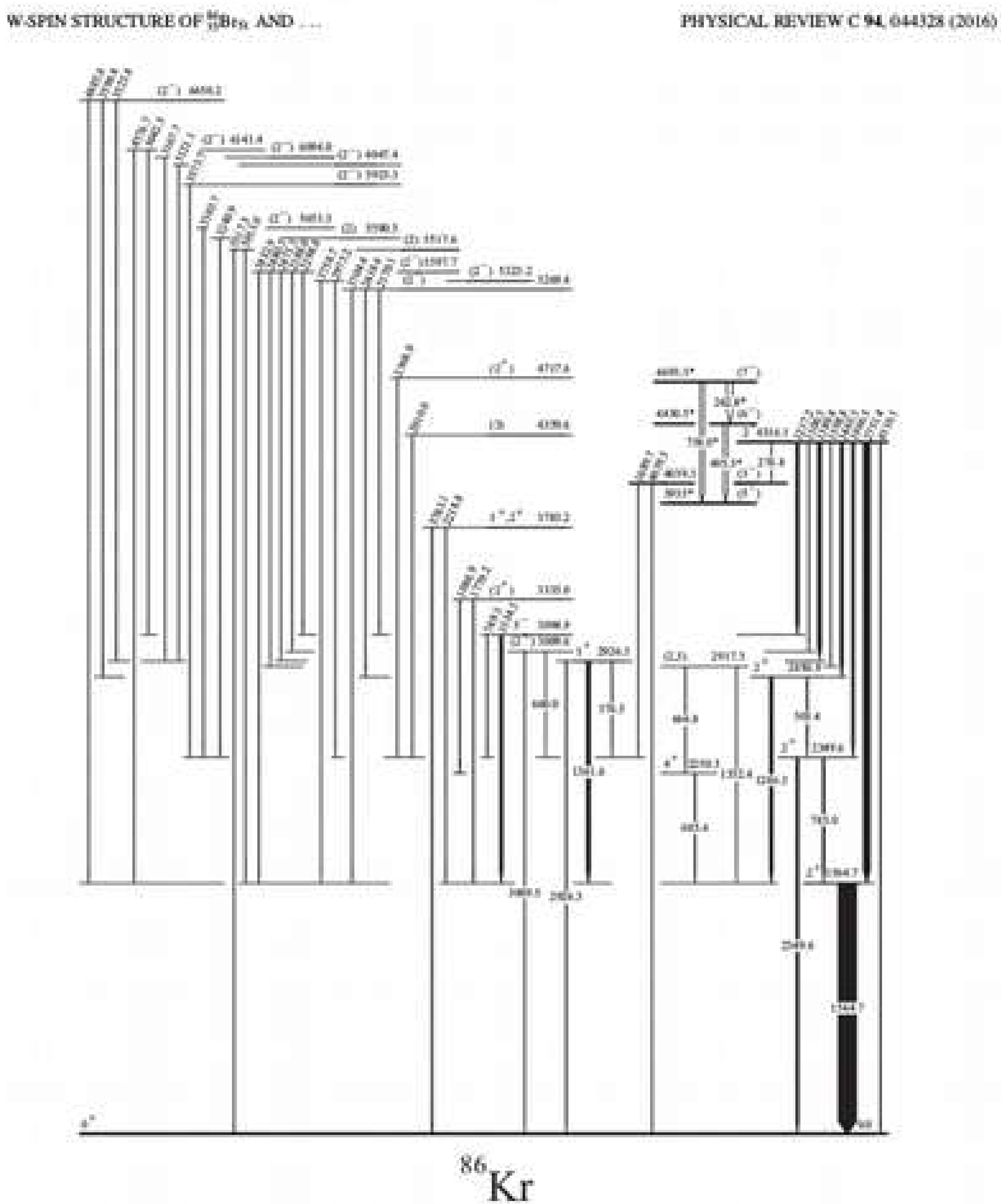
TOTAL ABSORPTION SPECTROSCOPY AND THE PANDEMONIM PROBLEM

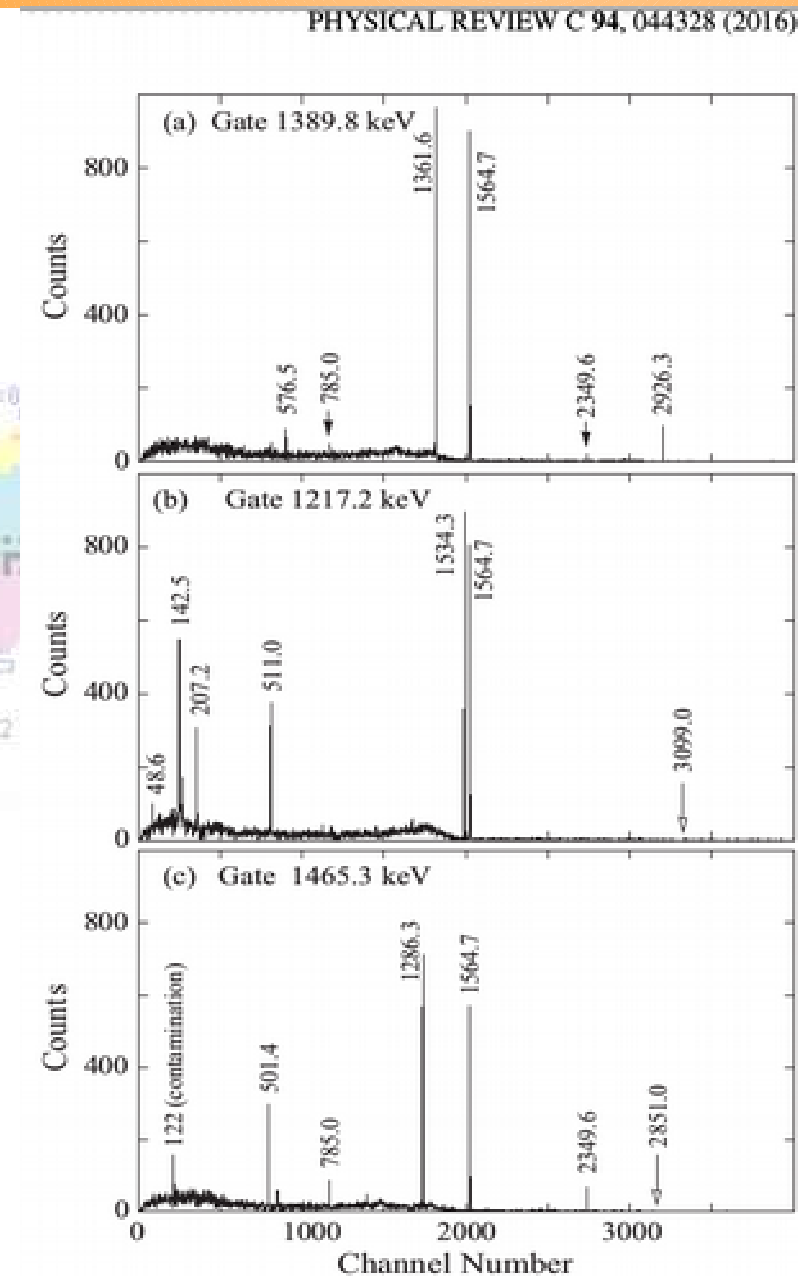
TRUE **APPARENT**





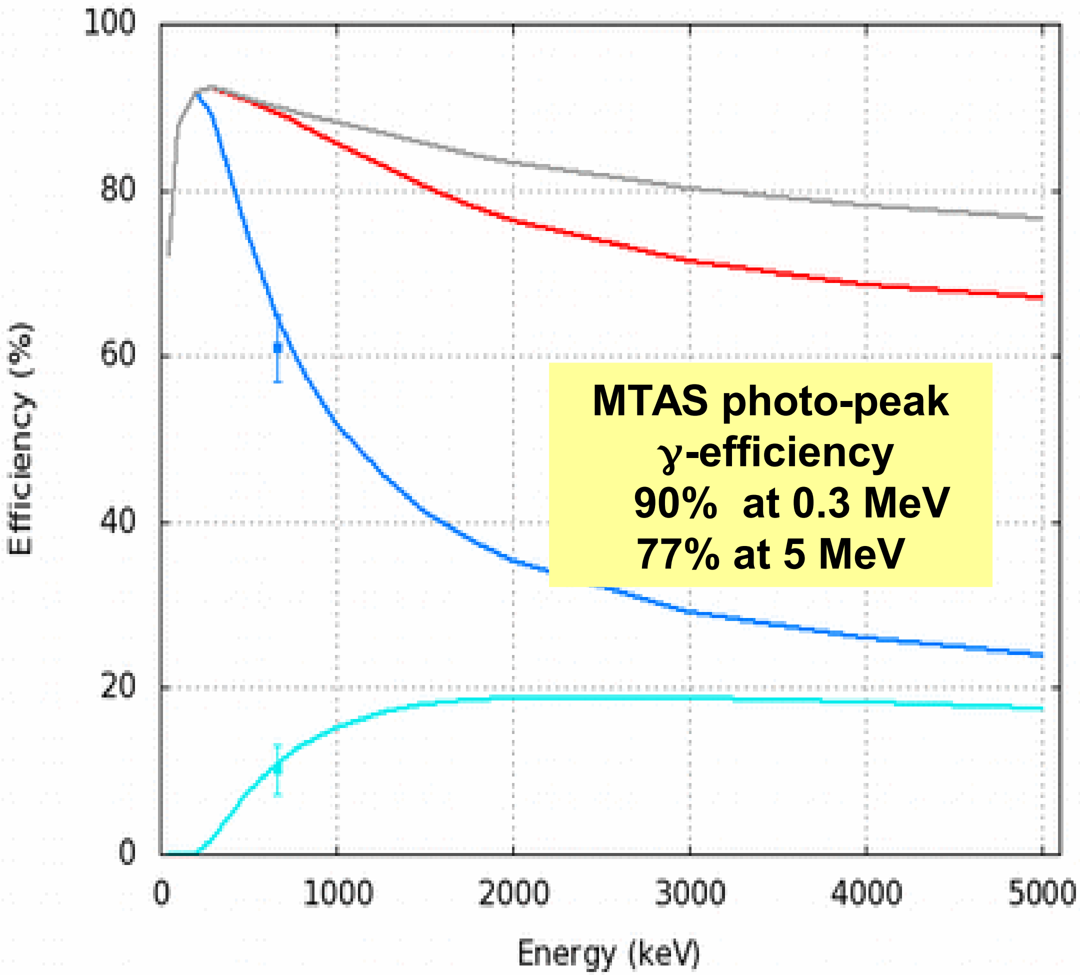
High resolution spectroscopy



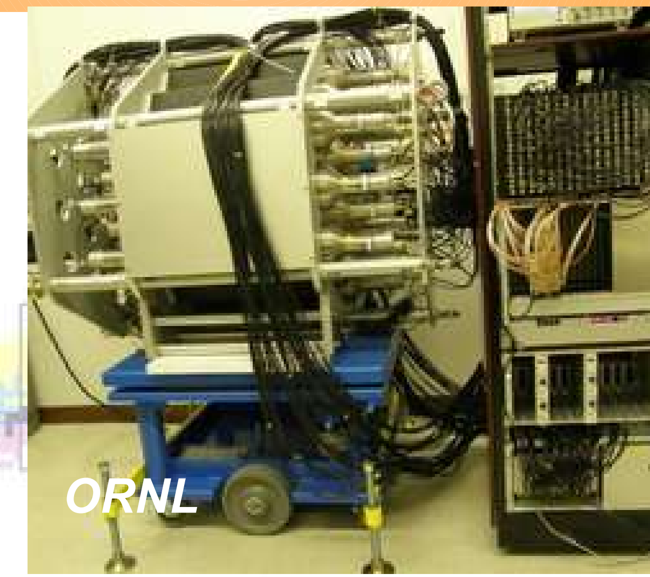


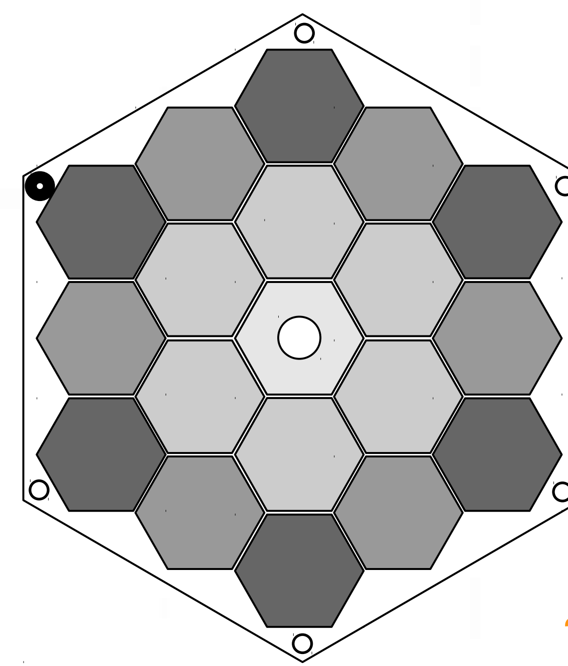
Gamma rays

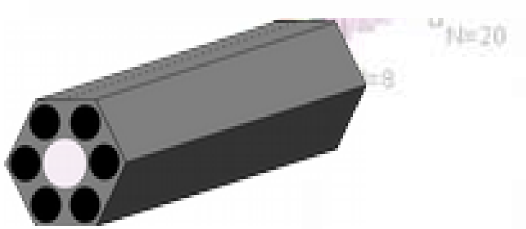
Modular Total Absorption Spectrometer (MTAS @ HRIBF)



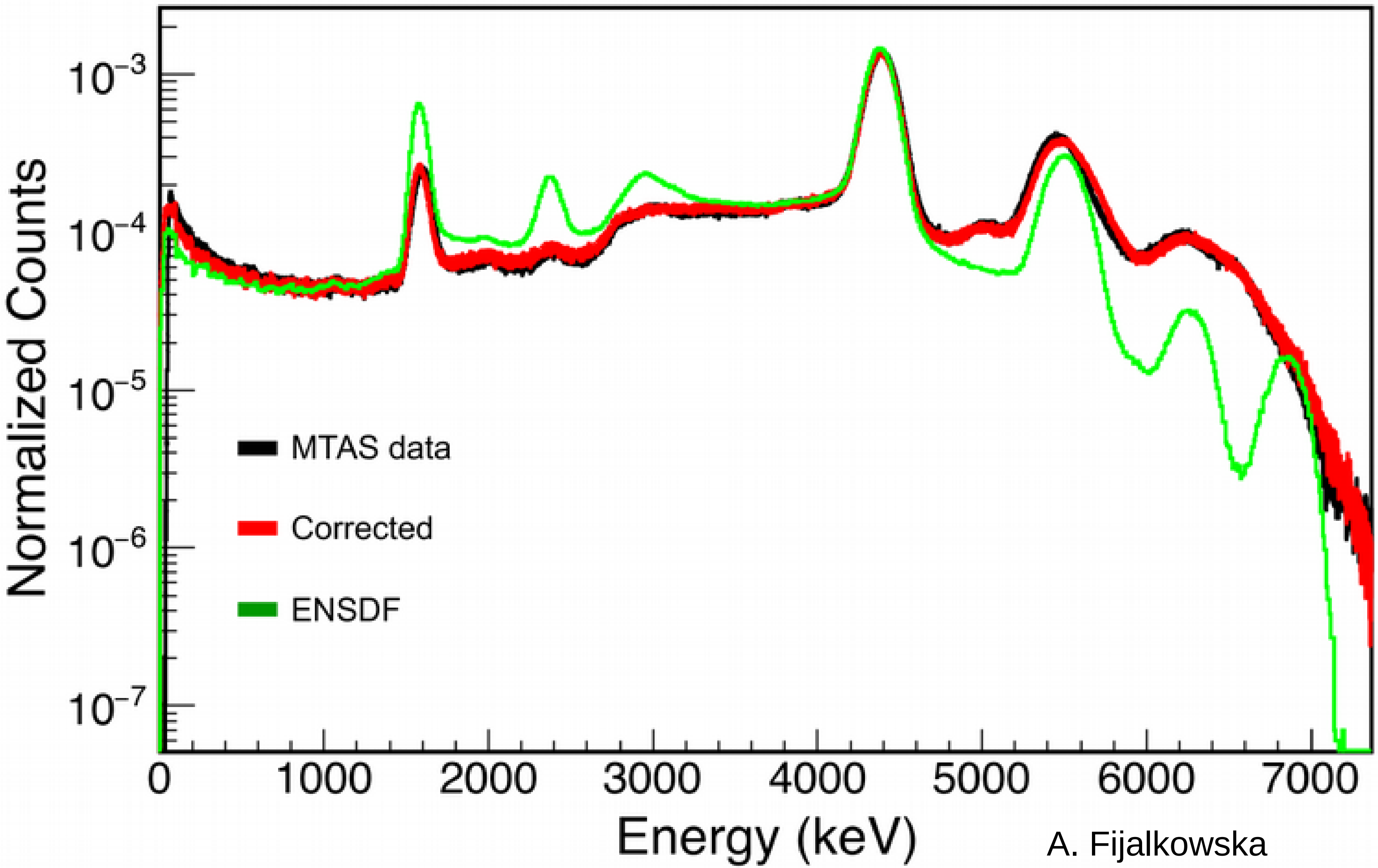
MTAS photo-peak
γ-efficiency
90% at 0.3 MeV
77% at 5 MeV





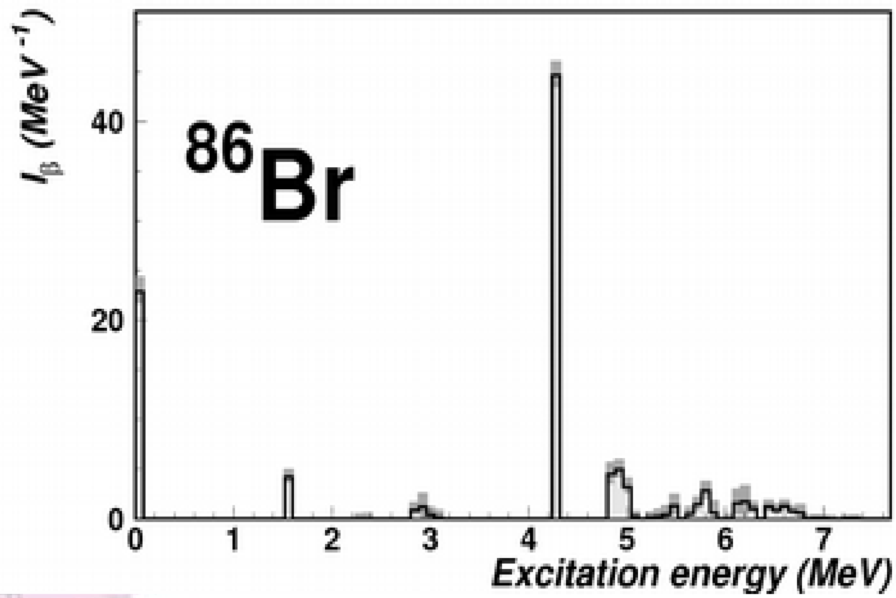


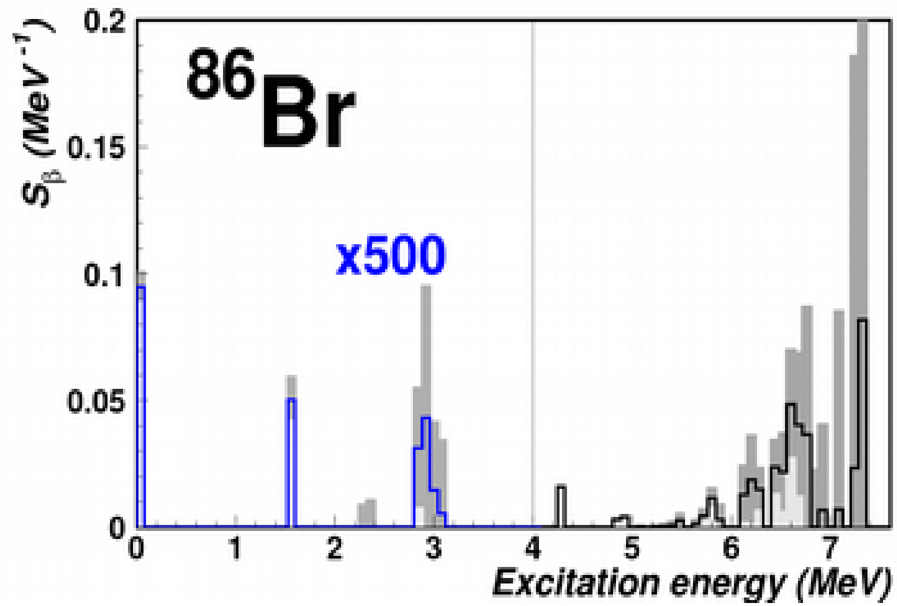
TOTAL ABSORPTION SPECTROSCOPY of N=51 86Br



A. Fijalkowska
C. Goetz

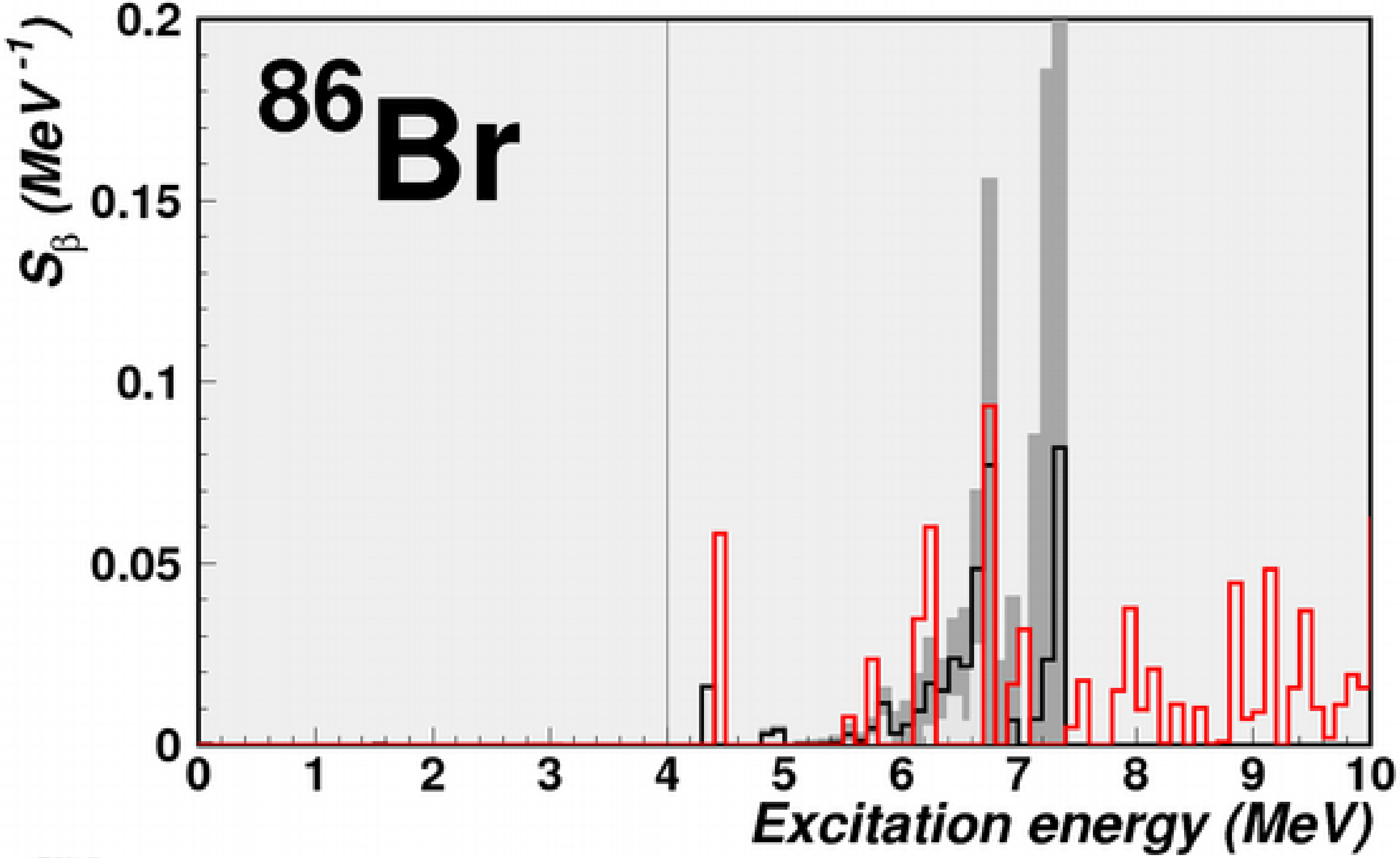
TOTAL ABSORPTION SPECTROSCOPY of N=51 86Br





C. Goetz

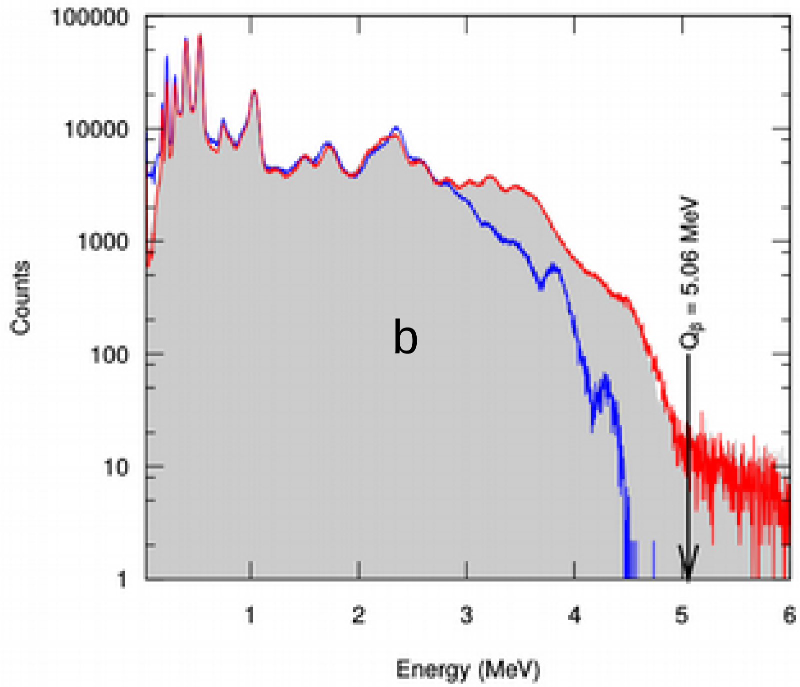
TOTAL ABSORPTION SPECTROSCOPY of N=51 86Brc

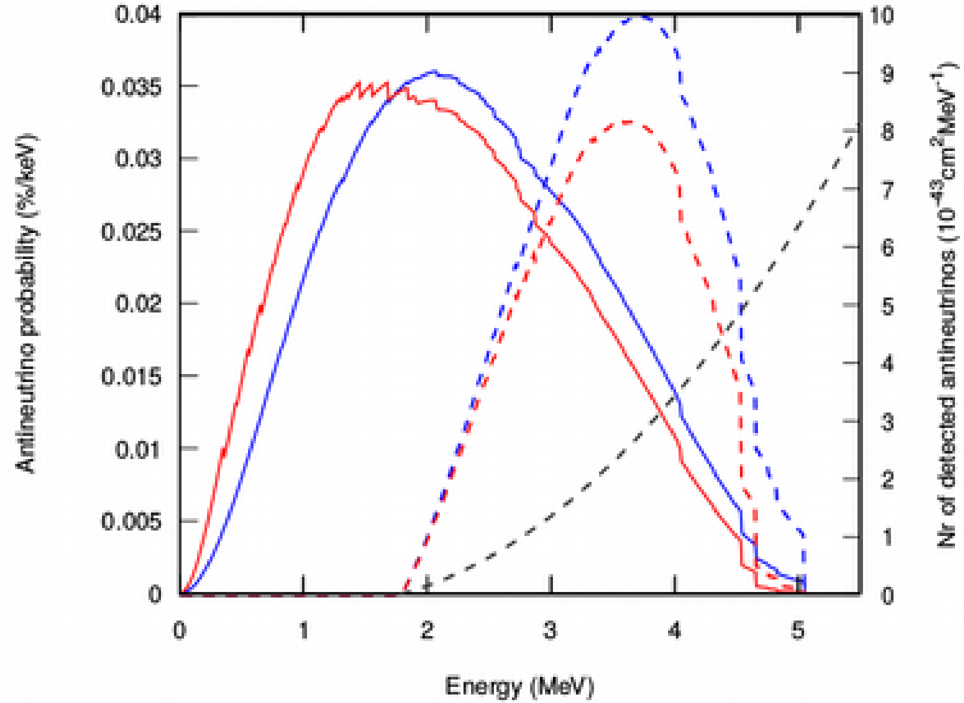


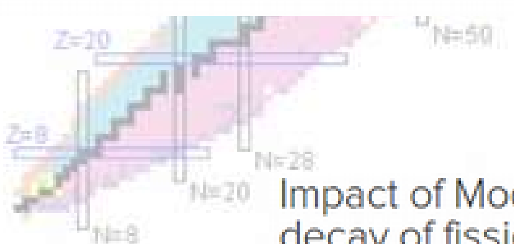
C. Goetz

Experiment vs. Shell model

TOTAL ABSORPTION SPECTROSCOPY of 139Xe







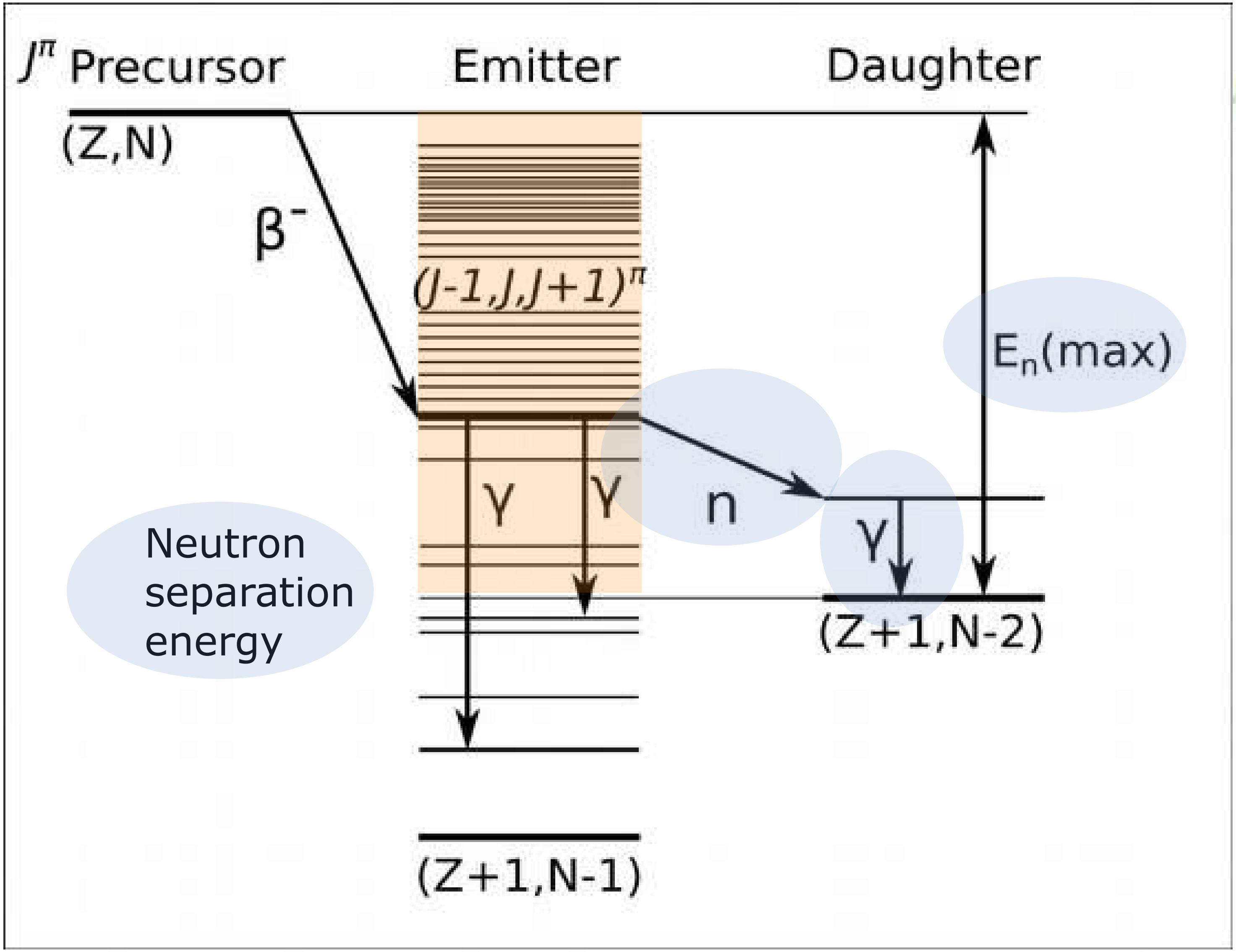
Impact of Modular Total Absorption Spectrometer measurements of \beta decay of fission products on the decay heat and reactor \overline{\nu}$_e$ flux calculation

Phys. Rev. Lett.

A. Fijałkowska, M. Karny, K. P. Rykaczewski, B. C. Rasco, R. Grzywacz, C. J. Gross, M. Wolińska-Cichocka, K. C. Goetz, D. W. Stracener, W. Bielewski, R. Goans, J. H. Hamilton, J. W. Johnson, C. Jost, M. Madurga, K. Miernik, D. Miller, S. W. Padgett, S. V. Paulauskas, A. V. Ramayya, and E. F. Zganjar

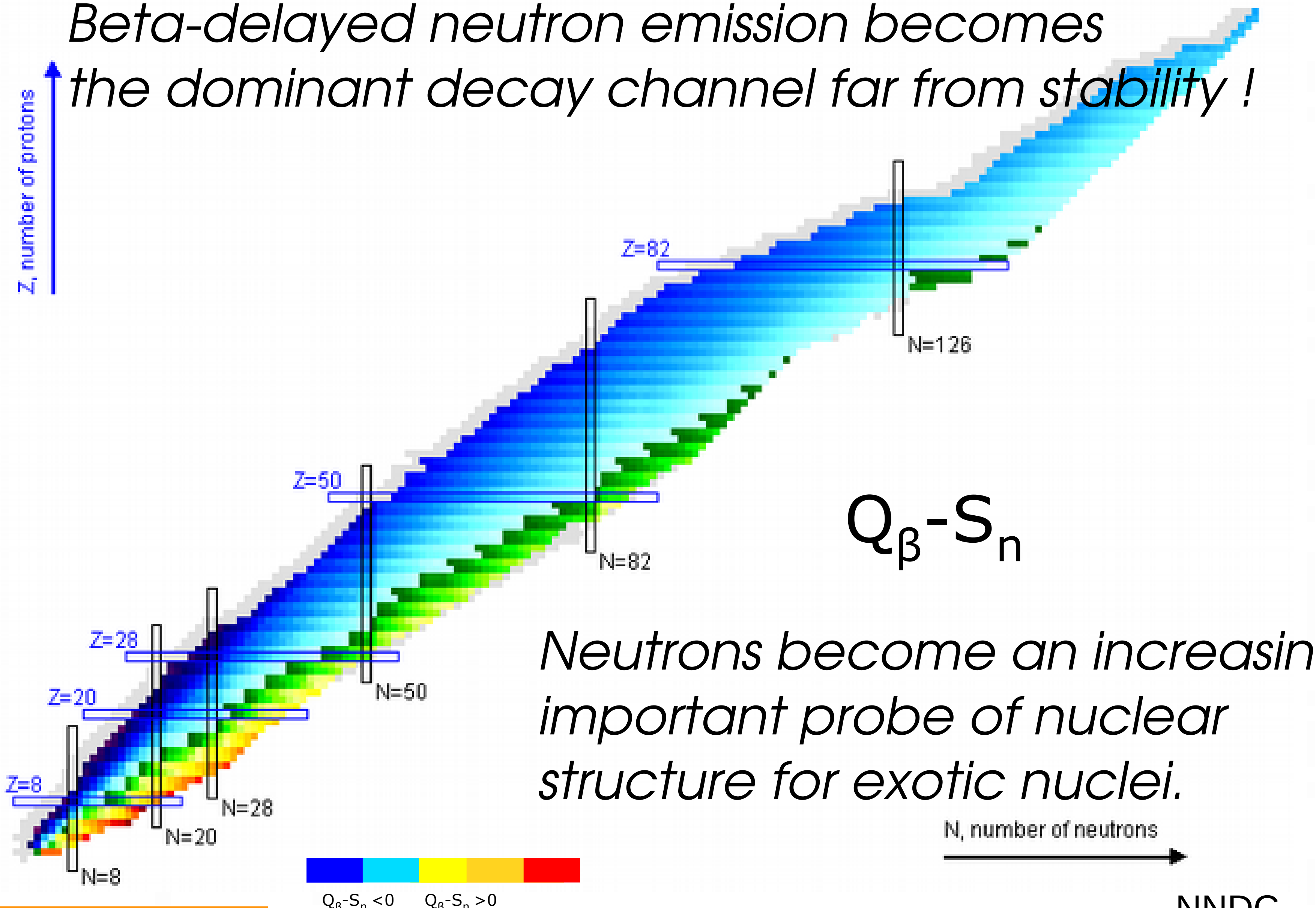
Accepted 26 June 2017

Beta-delayed neutron emission



Energy window for beta-delayed neutron emission

Beta-delayed neutron emission becomes the dominant decay channel far from stability !

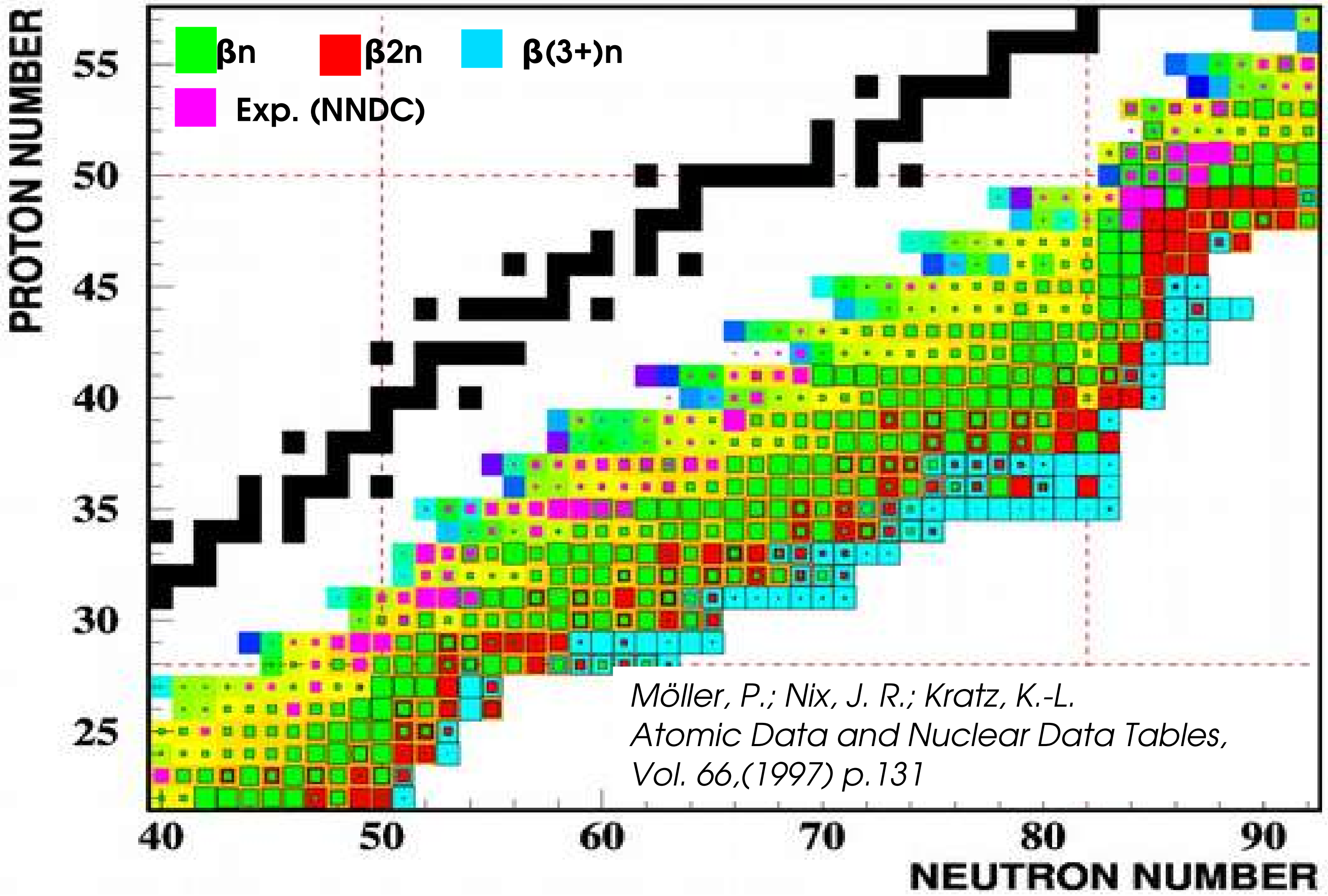


Q_β-S_n

Neutrons become an increasingly important probe of nuclear structure for exotic nuclei.

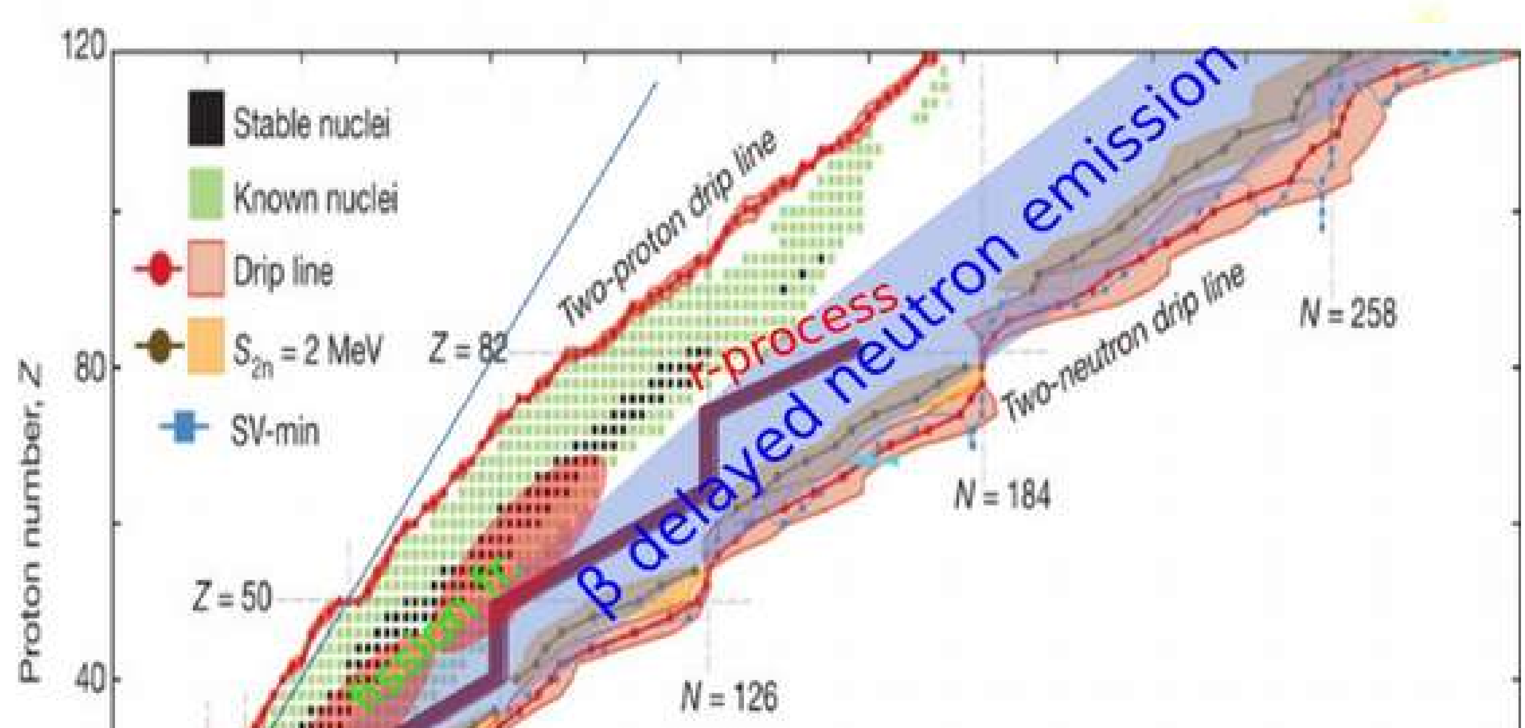
NNDC

Multi-neutron emission
Landscape of neutron emission between Z=28 and Z=50

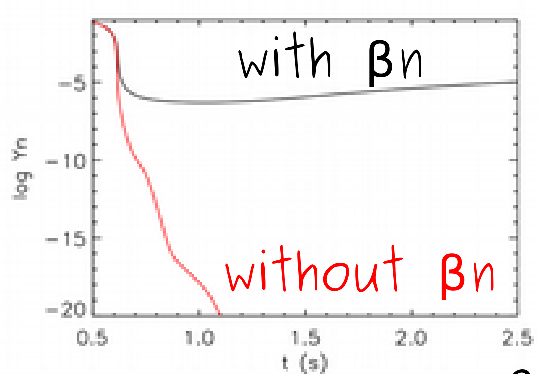


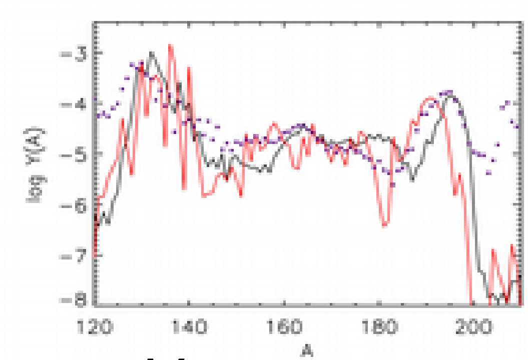
The need for βn-emission studies: all r-process nuclei are βn-precursors

Provide reliable data on decay strength distribution



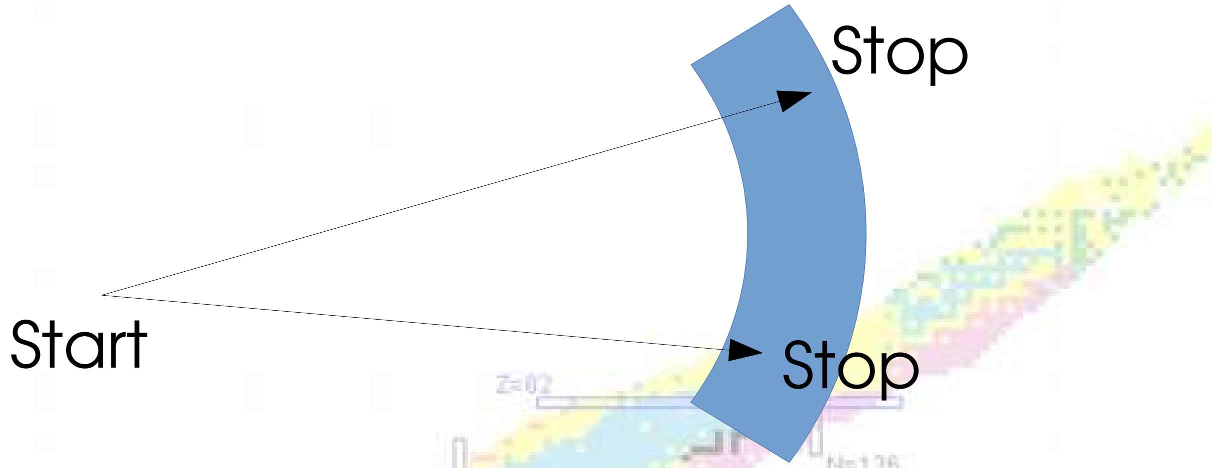
The limits of the nuclear landscape
J. Erler et al. Nature 486, 509–512, (2012)



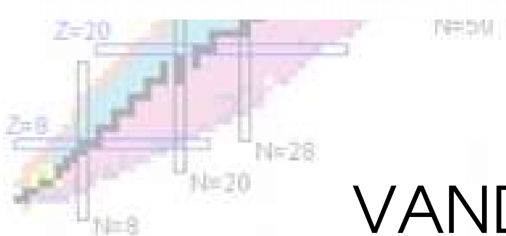


Surman, Mumpower

TOF based neutron detectors
What determines the energy resolution ?



$$\left(\frac{dE}{E}\right)^2 = \left(\frac{2dt}{t}\right)^2 + \left(\frac{2dL}{L}\right)^2$$



Timing resolution

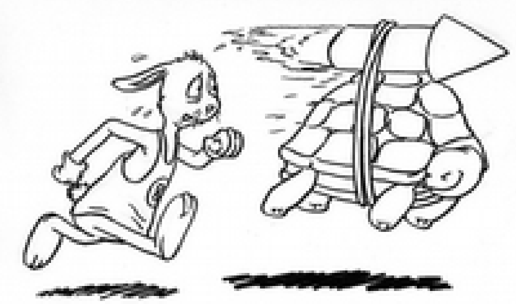
Detector Thickness

VANDLE: 1 ns
Improve to 0.3 ns

VANDLE:3 cm
Improve to 3mm

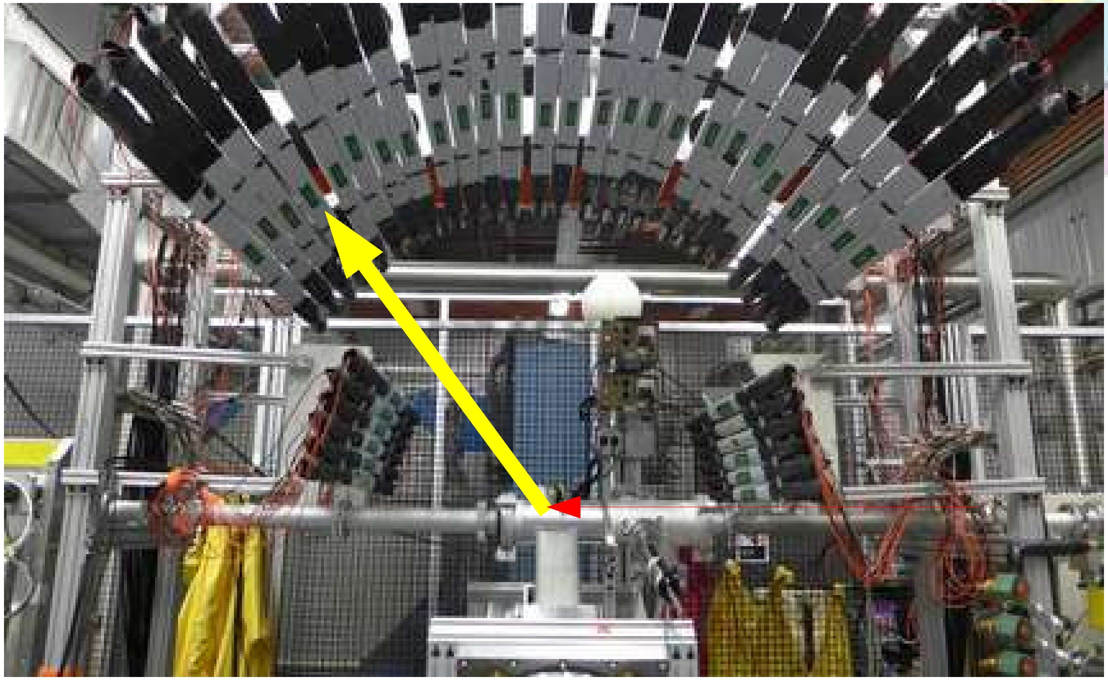
Detect neutrons with time of flight method

Start – beta decay
(measure electron
in plastic scintillator)

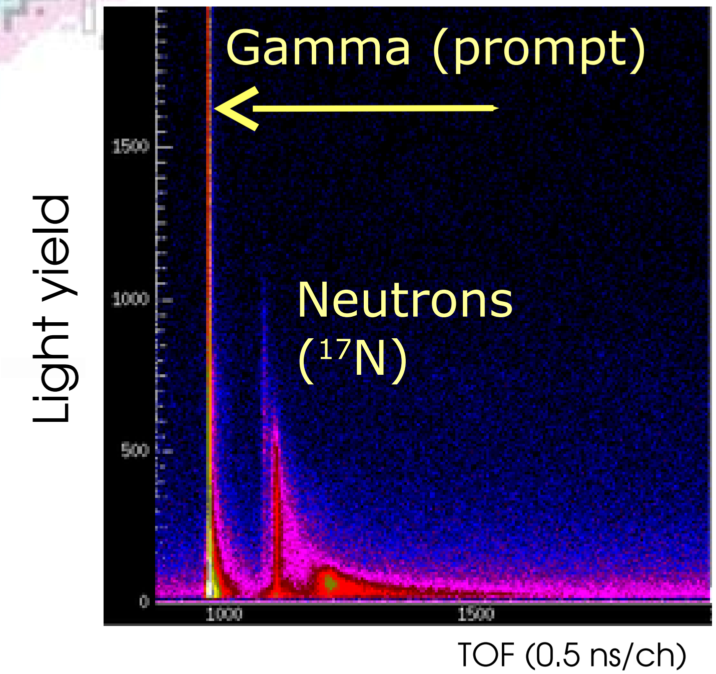


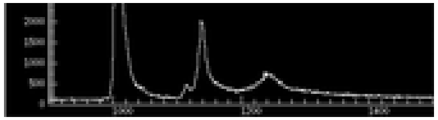
$$E_n \sim (D/TOF)^{-2}$$

Stop – neutron arrives
to the detector
(measure proton recoiling
from the neutron
in plastic scintillator)



S. Paulauskas et al. NIM A737,22(2014)
W.A. Peters et al. NIM A836, 122 (2016)



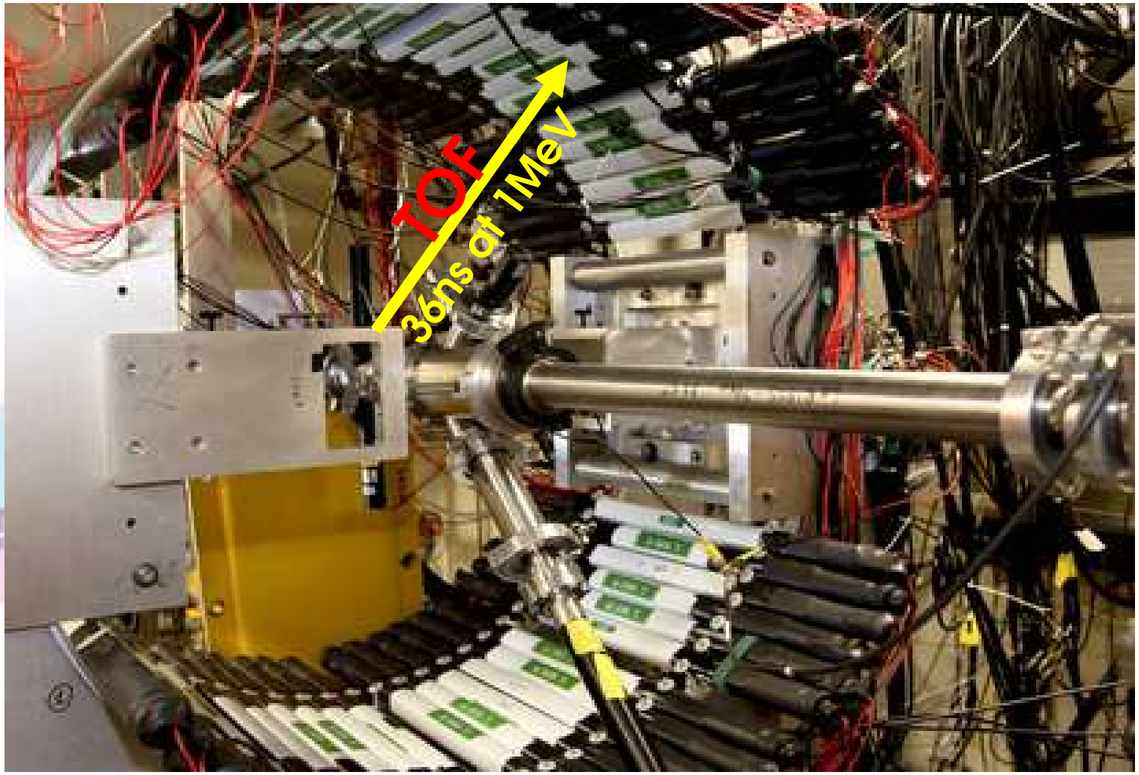


The Versatile Array of Neutron Detectors at Low Energy

VANDLE - neutron time of flight and γ-ray detector

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
(Pixie16, 250 MSPS, 12bit)

Sub-nanonsecond timing with 4ns digitization period

Low neutron detection threshold

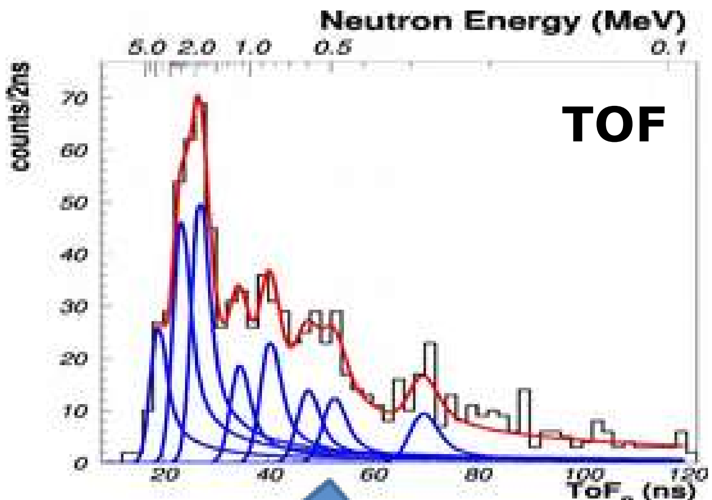
Portability and flexibility

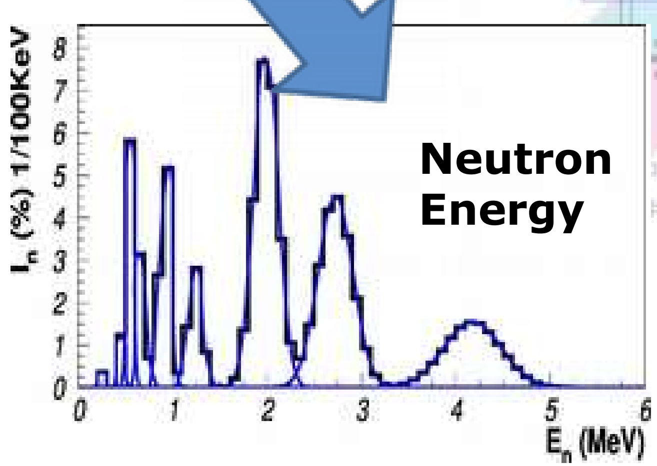
GEANT4 model

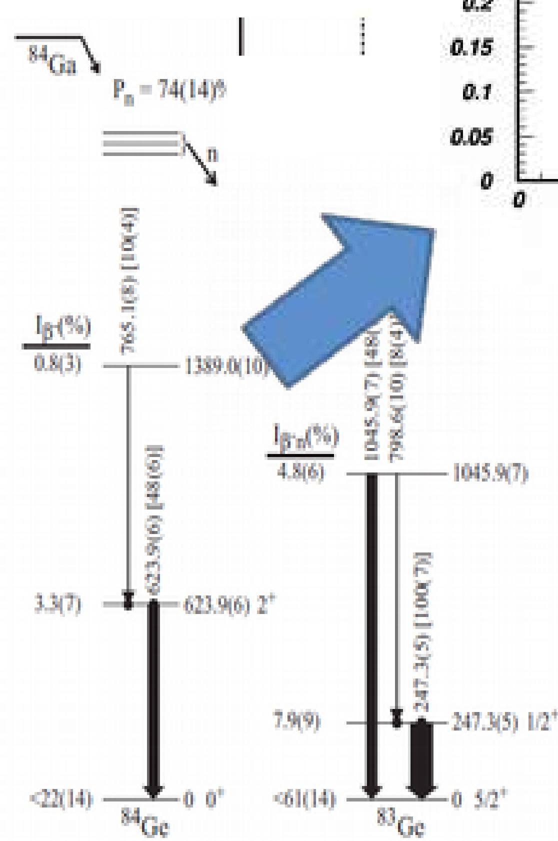
S. Paulauskas et al. NIM A737,22(2014)
W.A.. Peters et al. NIM in press

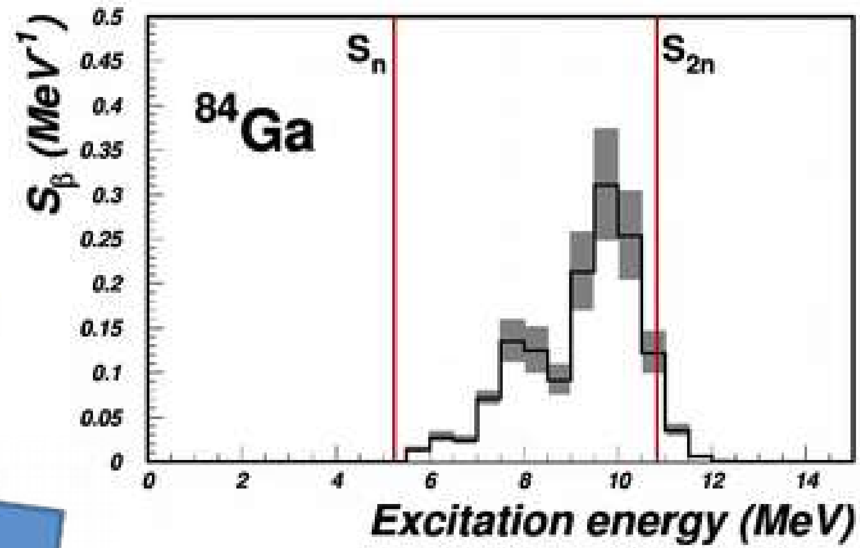
Spectrum de-convolution – from TOF to decay strength (^{84}Ga:~30 h measurement)

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

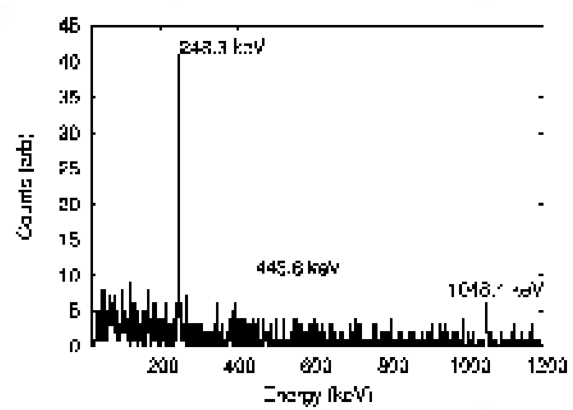








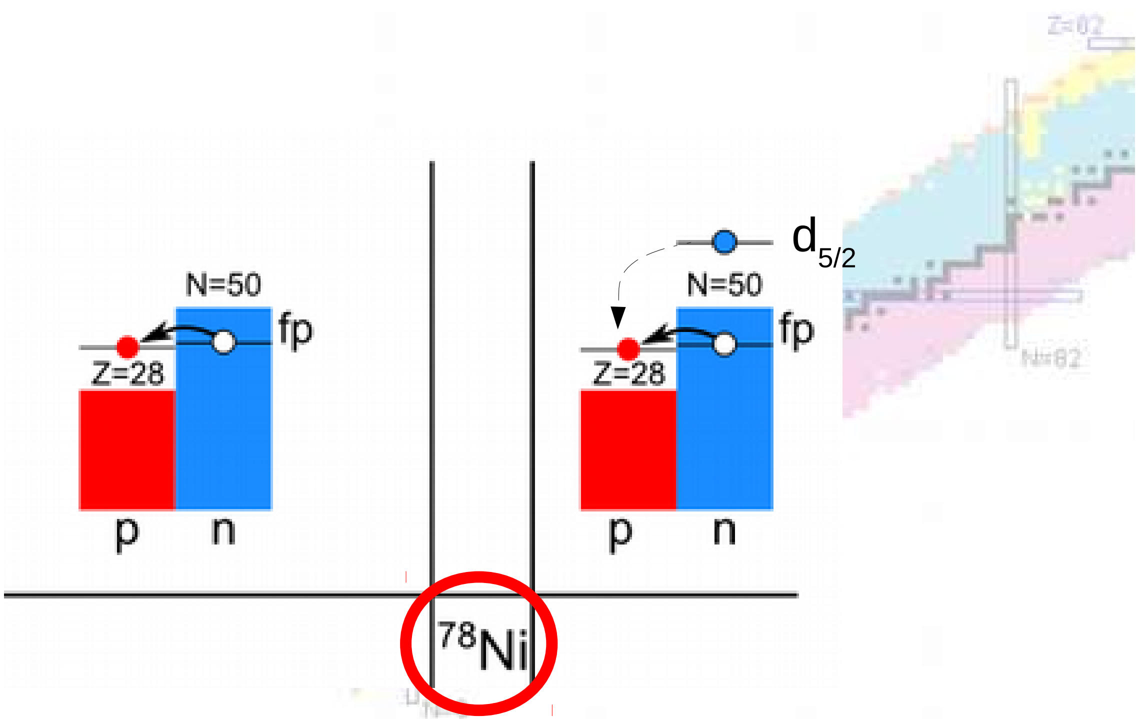
Neutrons in coincidence with gammas

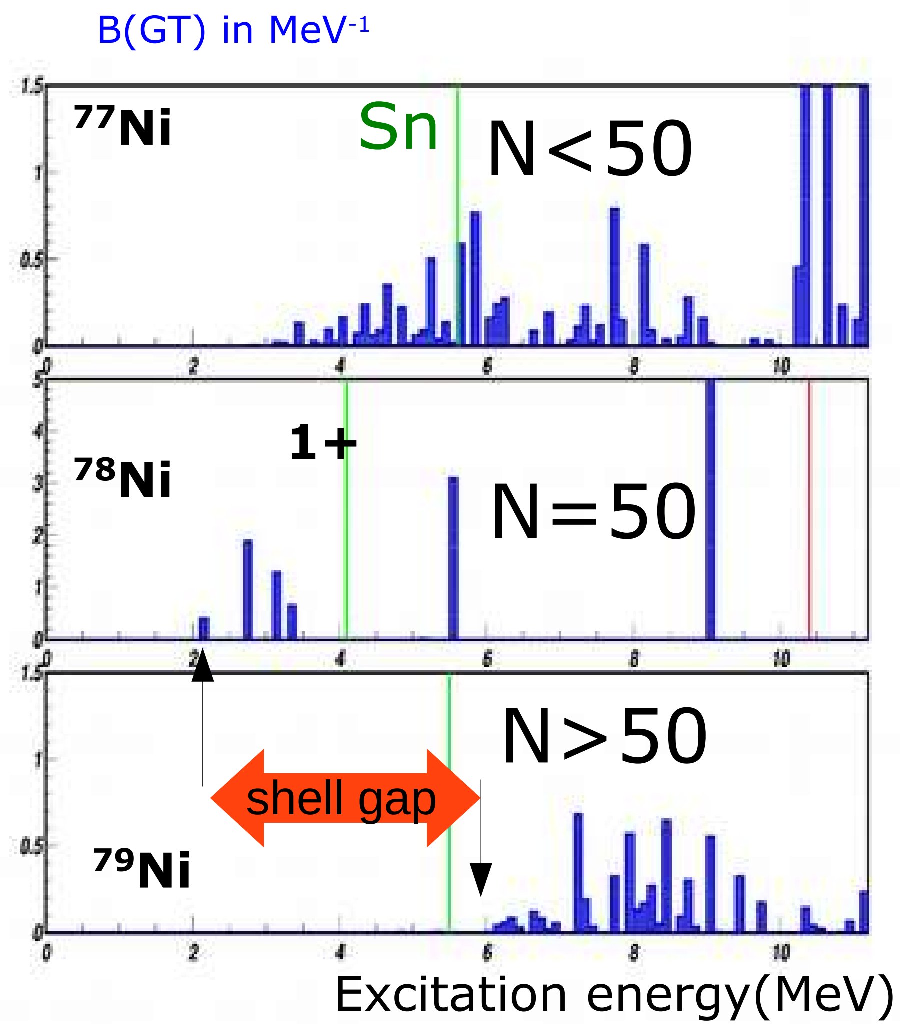


Vandle Analysis Software Toolkit (VAST)
S. Paulauskas

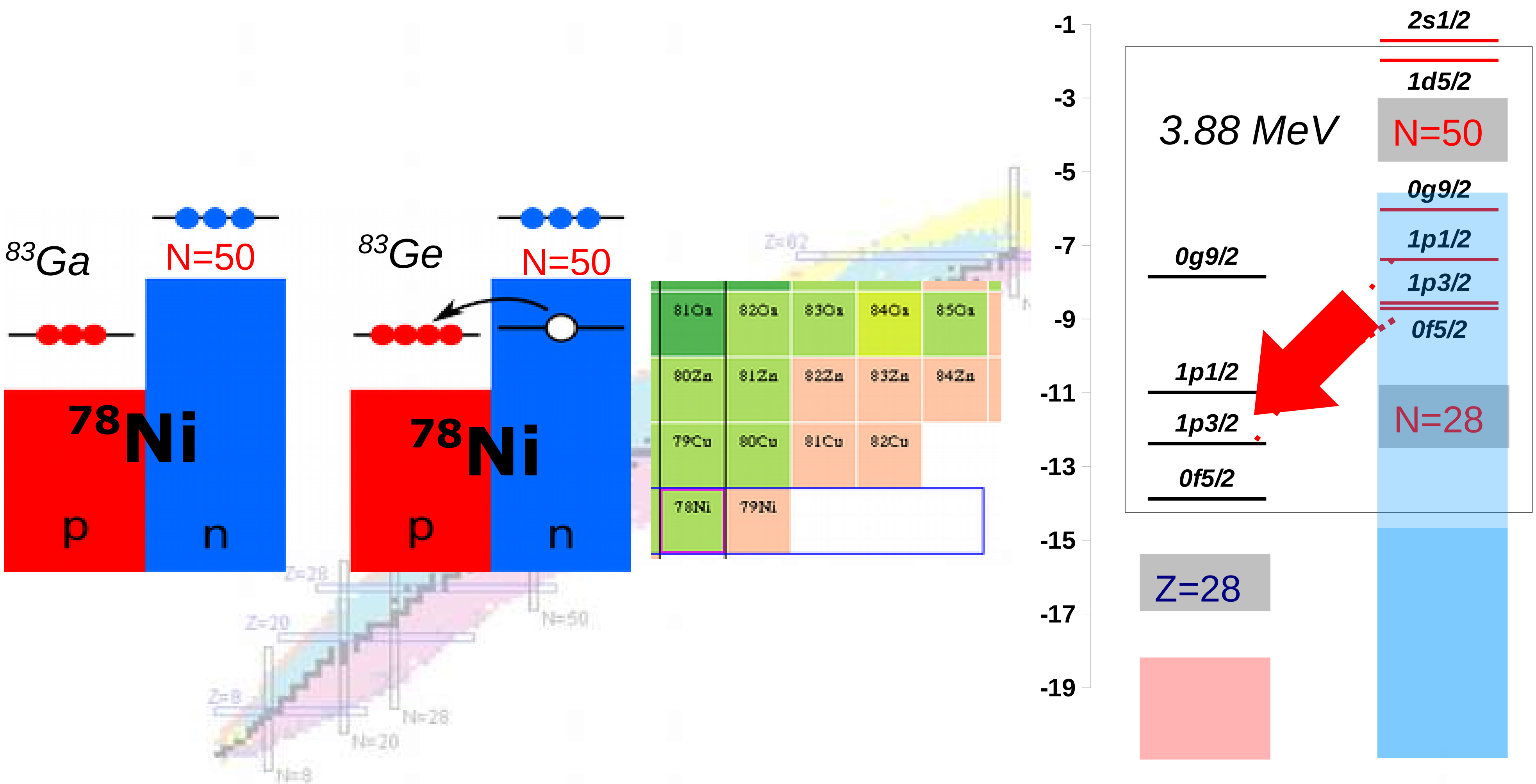
Effects of the shell gap on the decay of isotopes with N>50

Gamow-Teller operator connects spin-orbit partner orbitals.

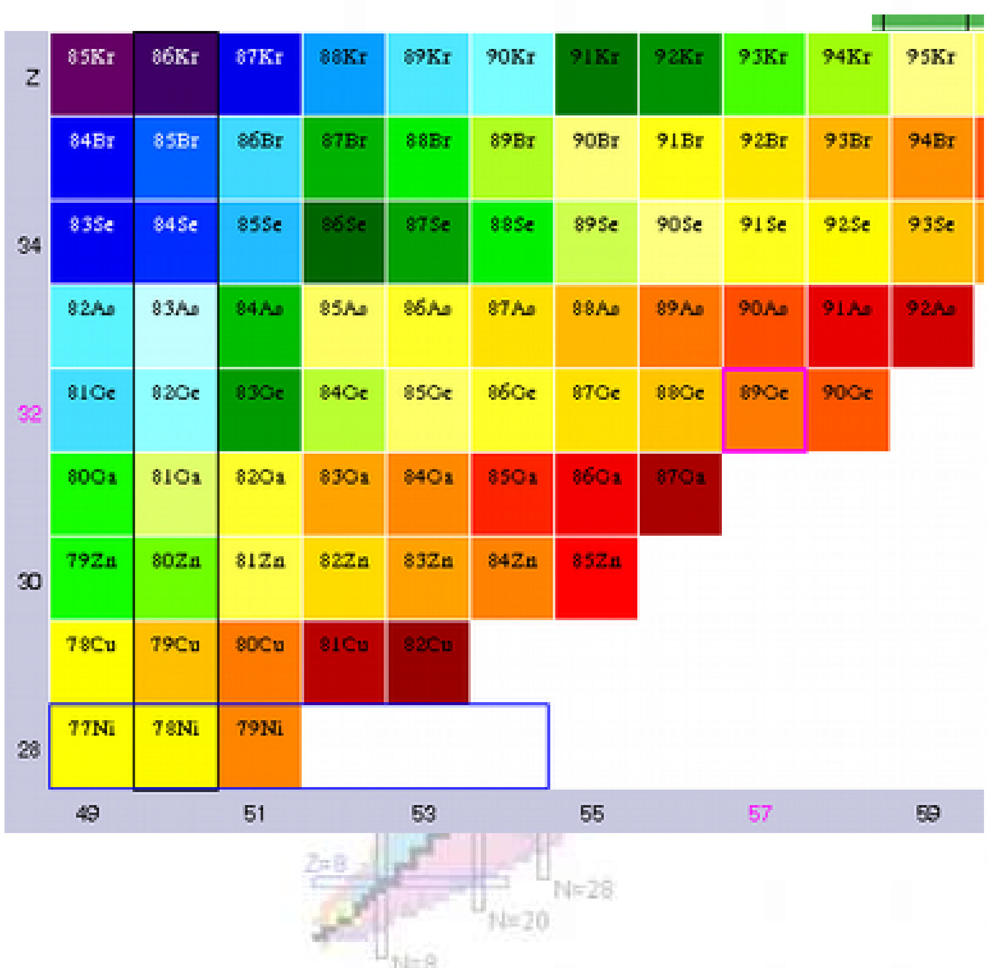


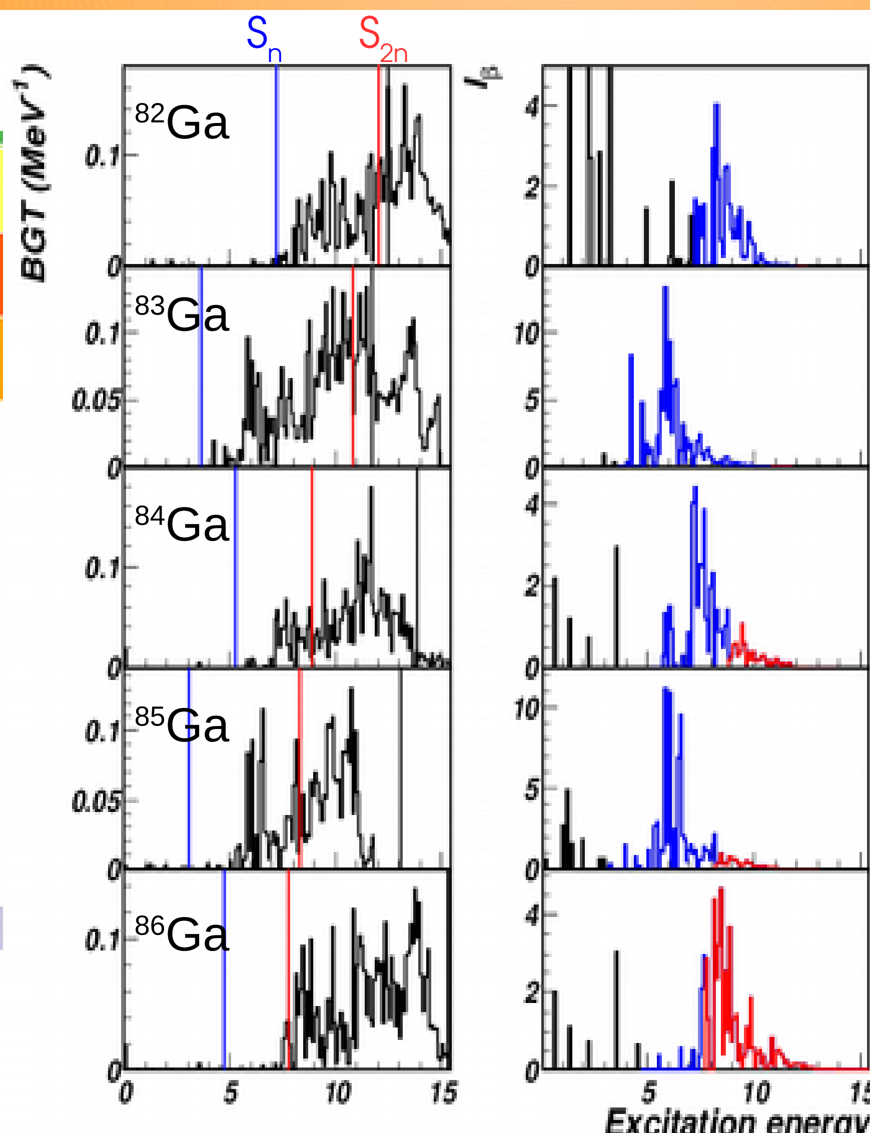


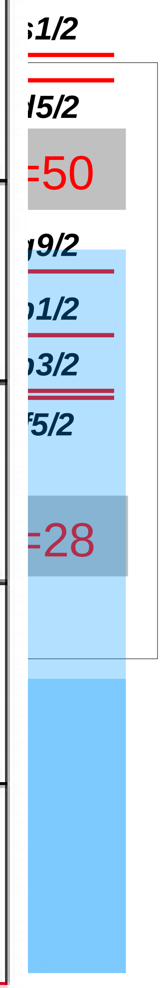
Shell-model interpretation
"realistic" calculation of decay strength



Shell-model interpretation
“realistic” calculation of strength







Mazzocchi et al. Phys. Rev. C C.92.054317
Alshudifat et al. Phys. Rev. C 93, 044325
Madurga et al. Phys. Rev. Lett. 117 (2016) 092502

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

Observed large beta strength at high excitations compatible with GT-decay of ^{78}Ni core states

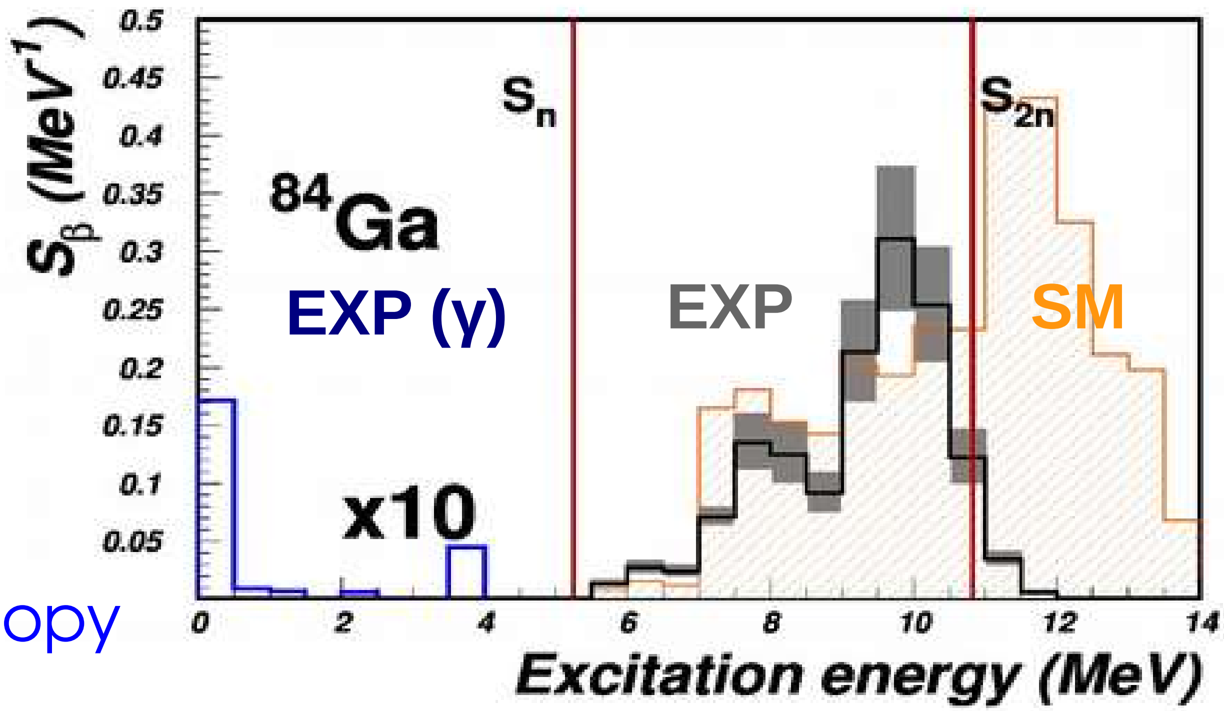
Contribution of GT decays from states outside 78Ni core is factor x100 smaller

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

N=50 shell gap
3.88 MeV

Applied 50 % quenching $B(GT)_{SM}$

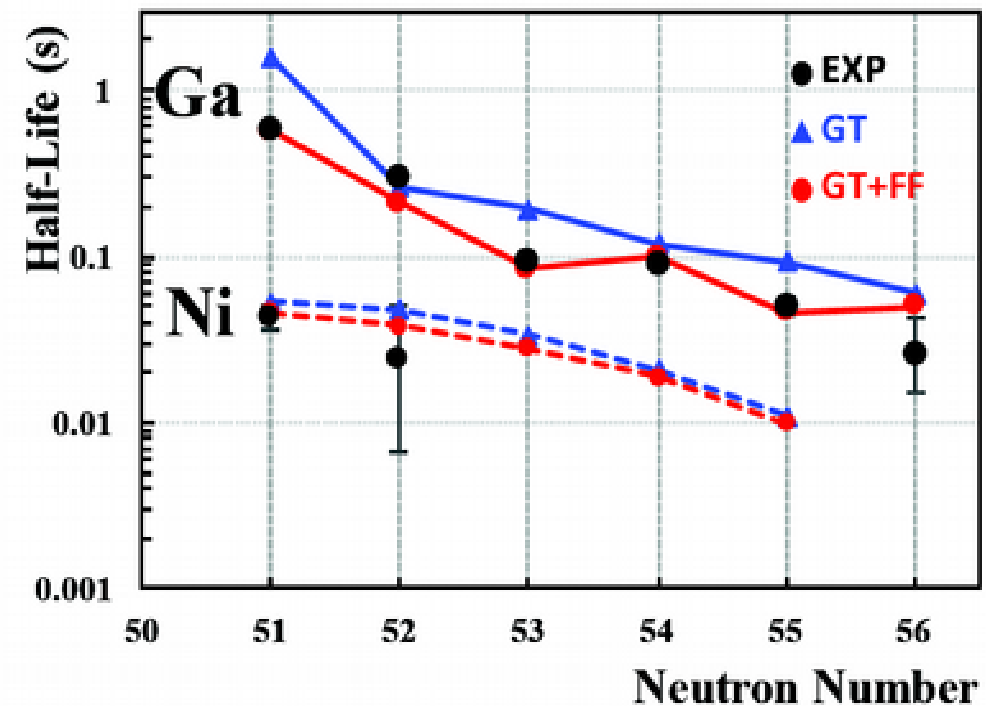
Strength below S_n
from gamma spectroscopy

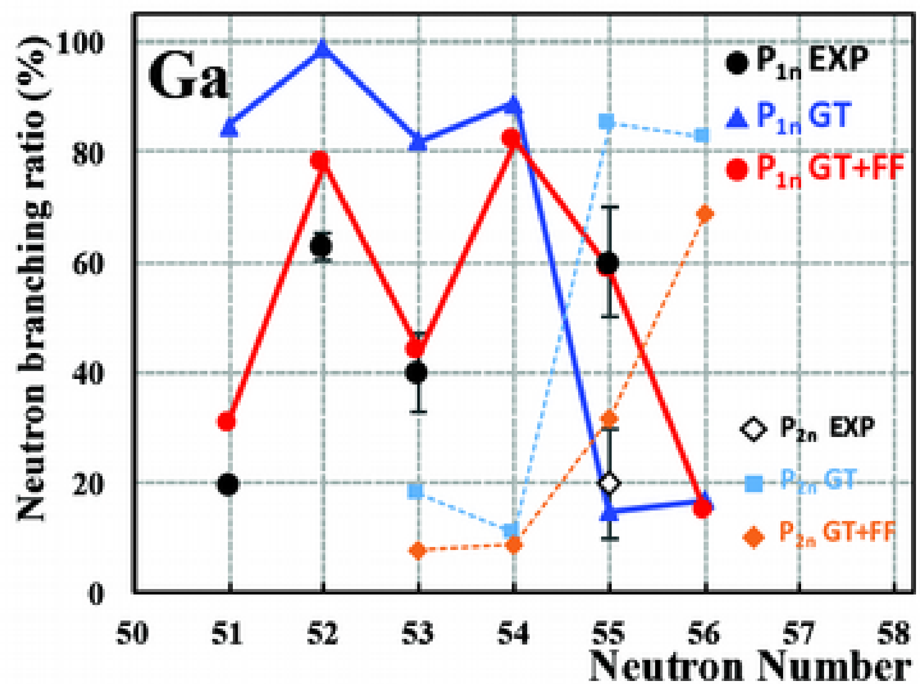


Kolos et al Phys. Rev. C 88, 047301 (2013)

Dominant: $\nu p_{1/2} \longrightarrow \pi p_{3/2}$ transformations

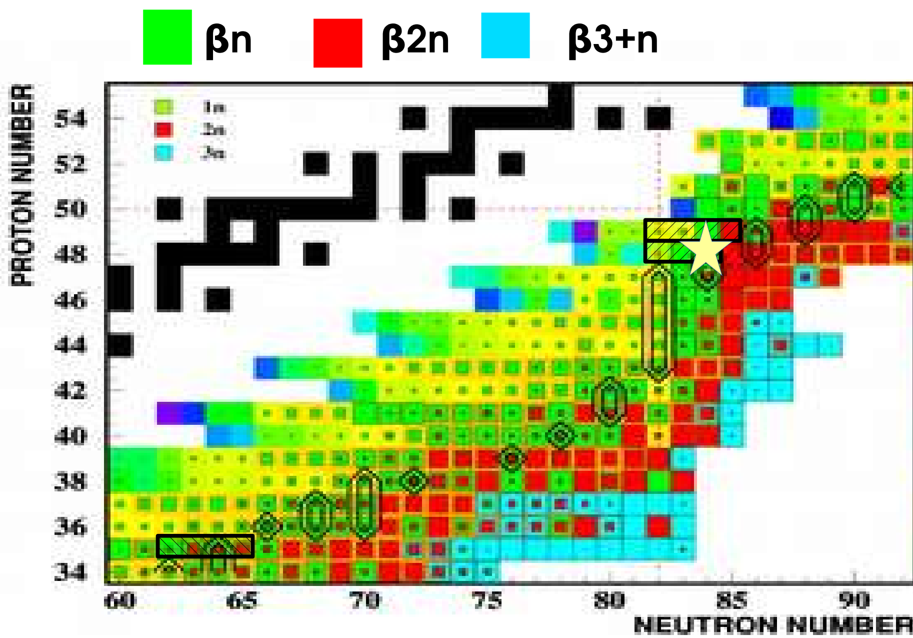
Shell model half-life predictions

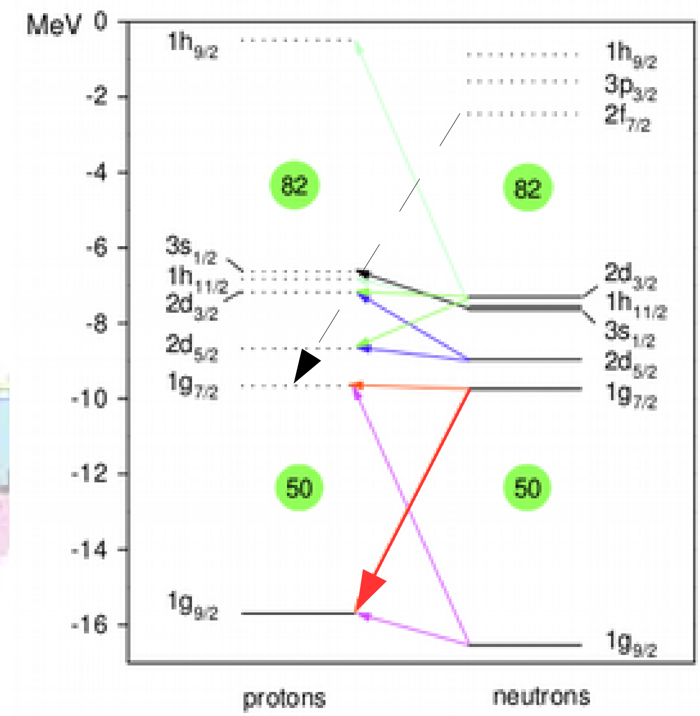


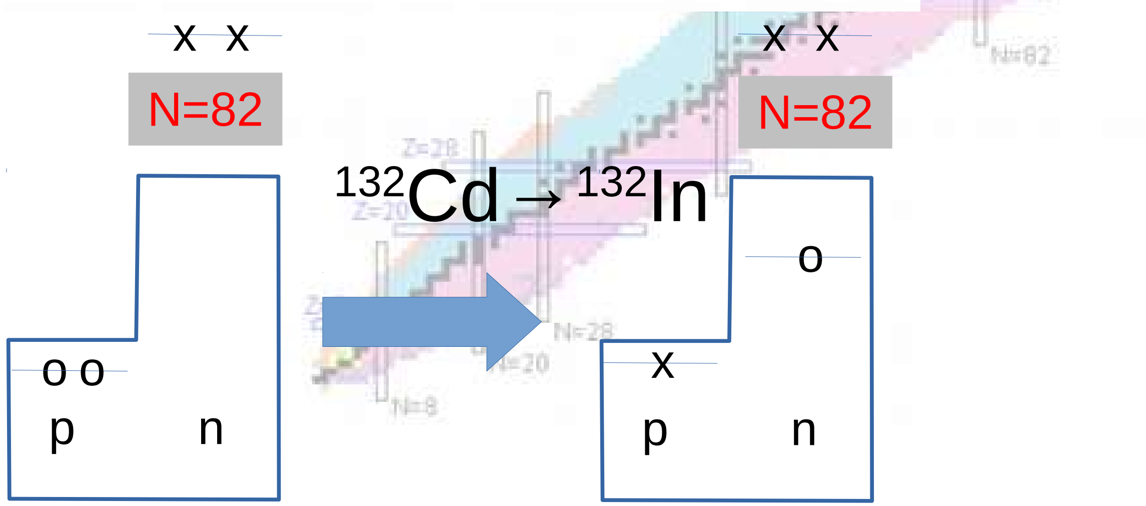


M. Madurga et al. Phys. Rev. Lett. 117(2015) 092502

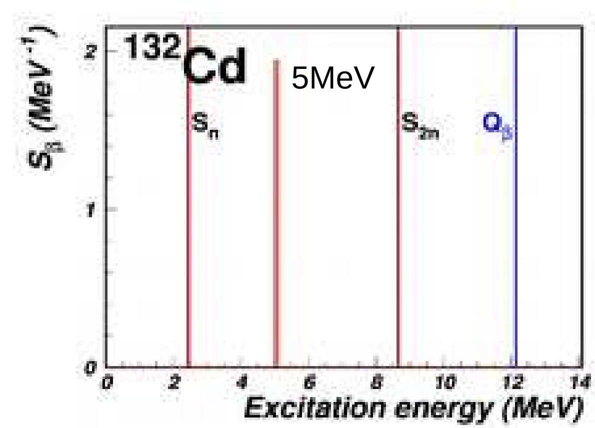
Gamow-Teller decay near ^{132}Sn
Single particle transitions ?







Decay of ^{132}Cd should be dominated by a single GT transition:

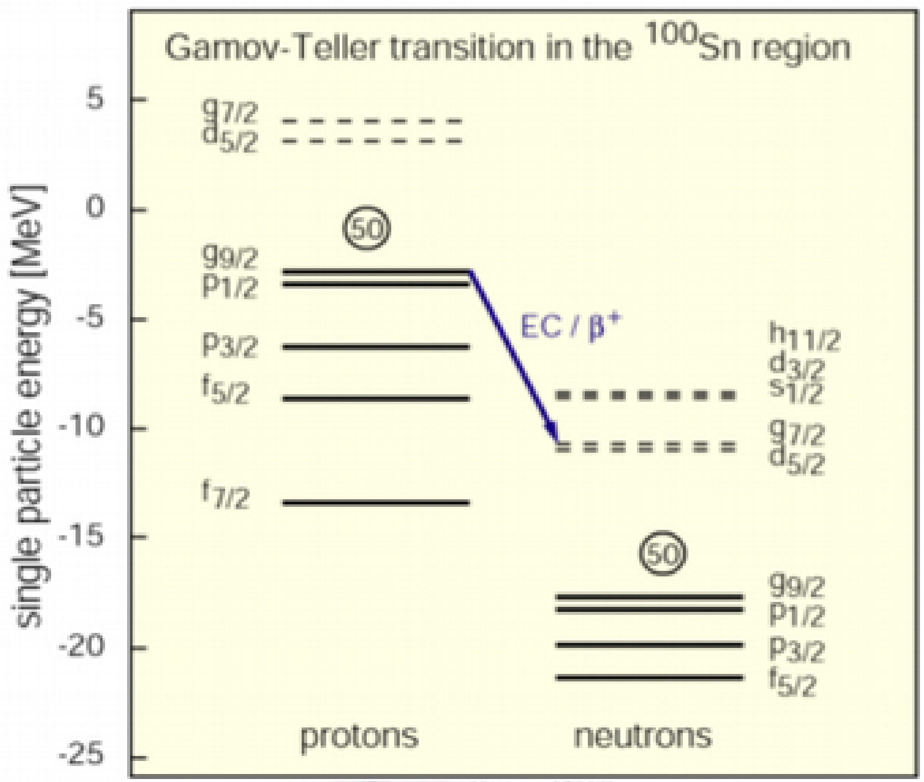


^{100}Sn and ^{132}Sn

$$B_{GT} = |M_{GT}|^2 = N_\nu \cdot \left(1 - \frac{N_\pi}{2j_f + 1}\right) \cdot |M^0_{GT}|^2$$

$l = 4$

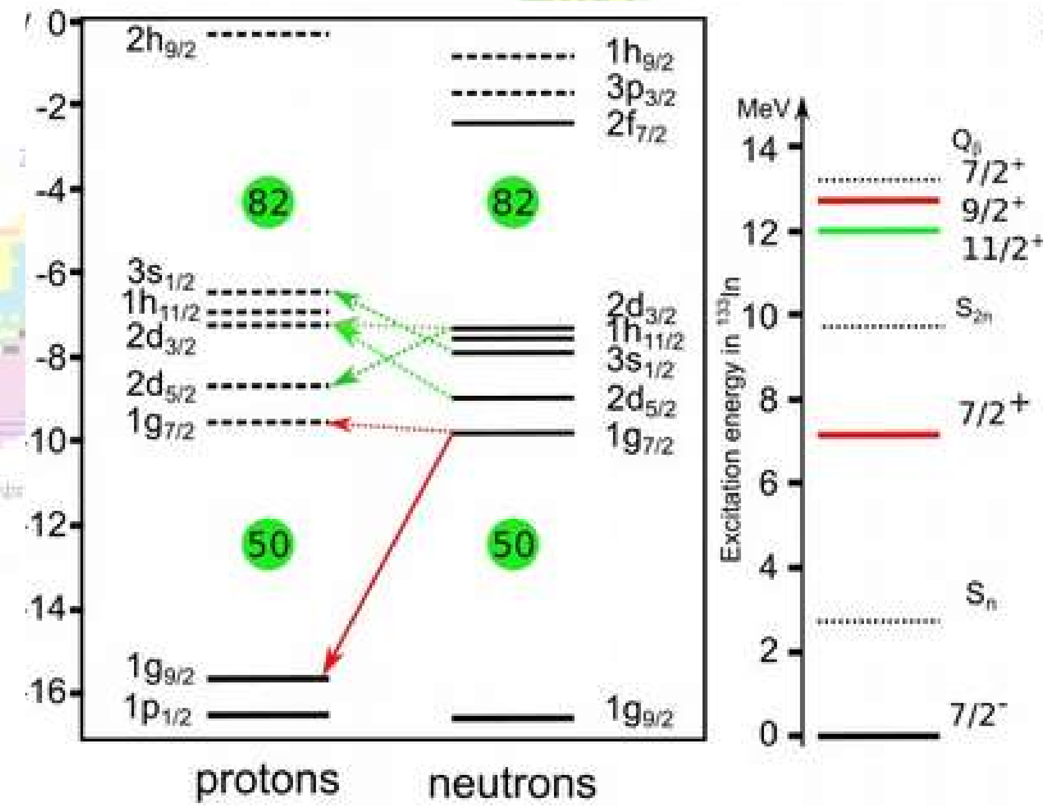
j_f \ j_i	$4+\frac{1}{2}$	$4-\frac{1}{2}$
$4+\frac{1}{2}$	11 / 9	20 / 9
$4-\frac{1}{2}$	16 / 9	7 / 9



BGT(ESPM)=17.8

Measured

log ft ~ 2.62(13) M_{GT} ~ 9(3)



BGT(ESPM)=1.78