Mapping of fragmented $\nu f_{5/2} \rightarrow \pi f_{7/2}$ transitions in neutron-rich Co isotopes

Shintaro Go
Kyushu University

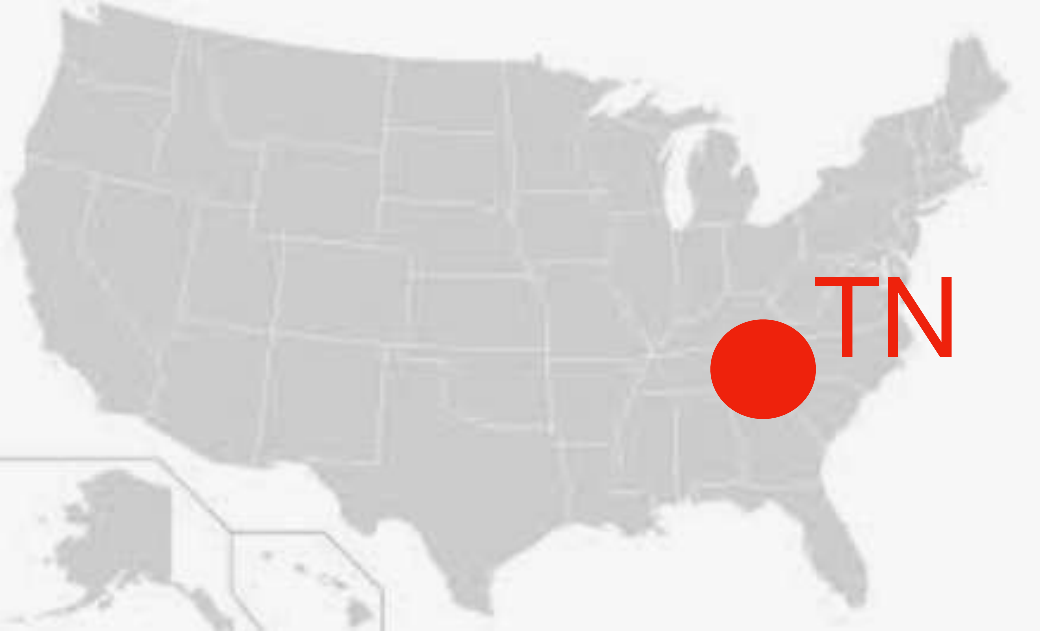
About me

Shintaro Go

Assistant Professor, Kyushu University, Japan

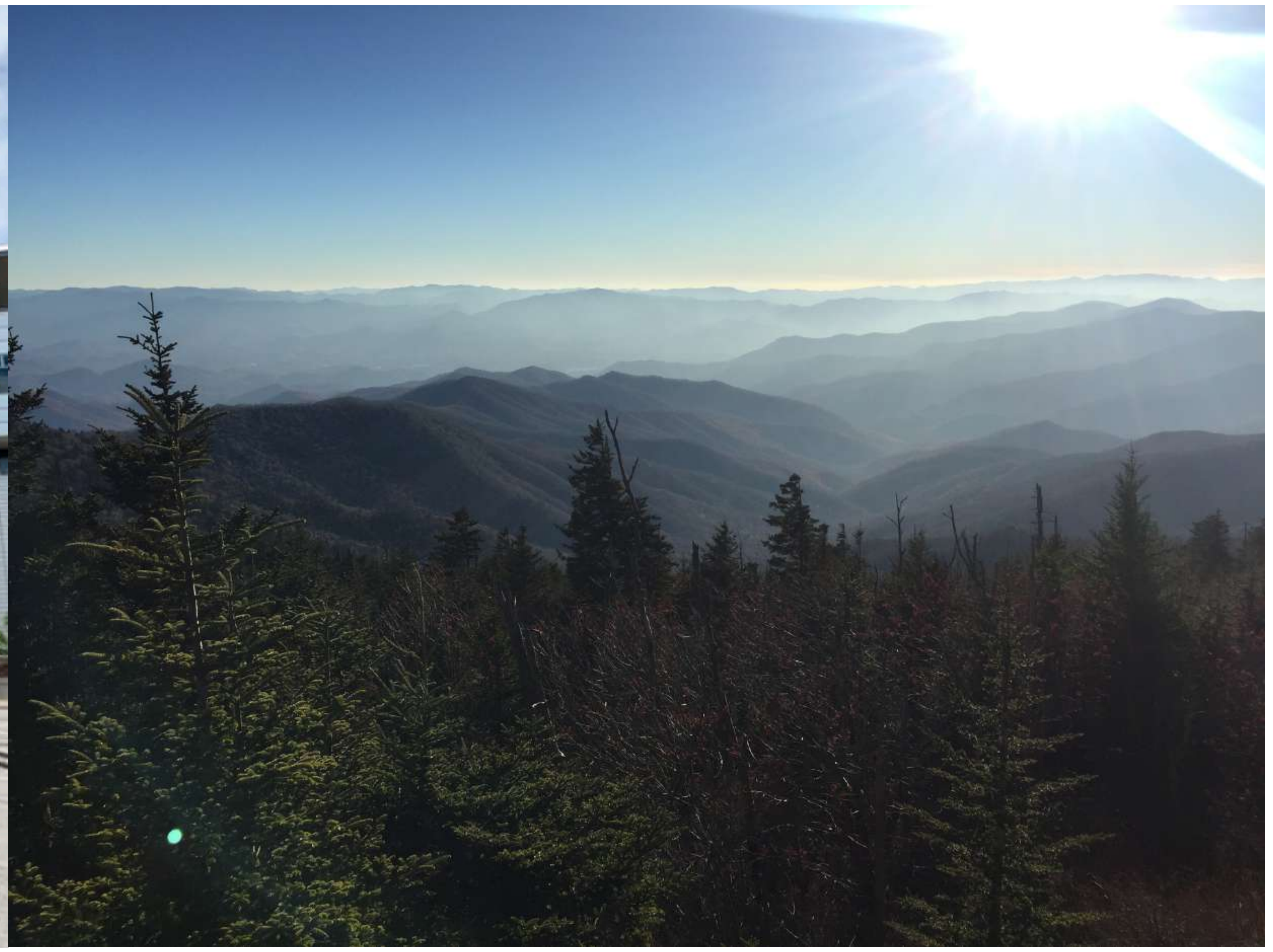
Ph.D. in Physics, University of Tokyo, Japan

2014.4-2017.3
Research associate in University of Tennessee, USA



University of Tennessee, Knoxville

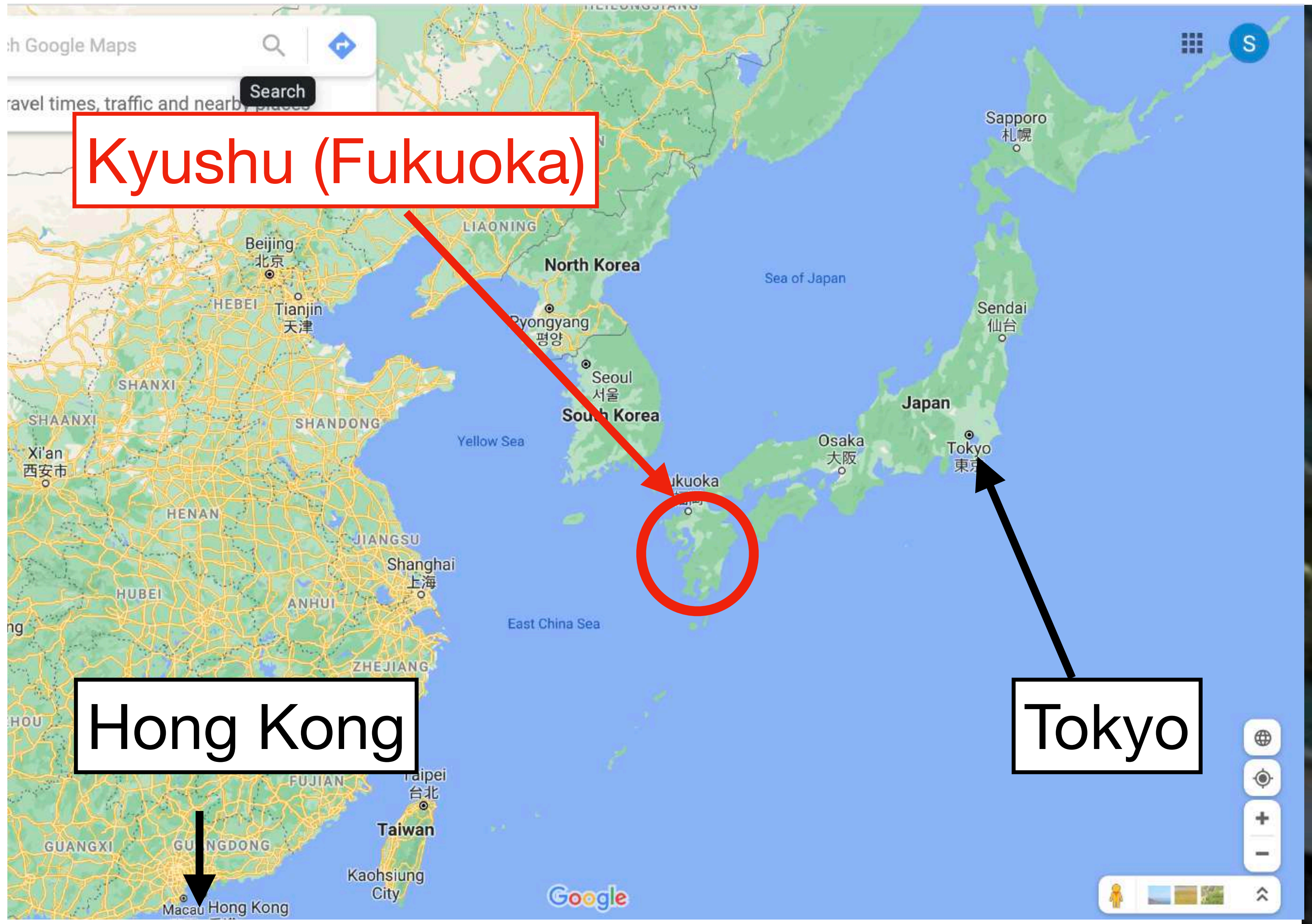
Oak Ridge National Laboratory



Great Smokey Mountains National Park

Cultural Slides : Kyushu University

Kyushu University (九州大学: “Nine-State” University)

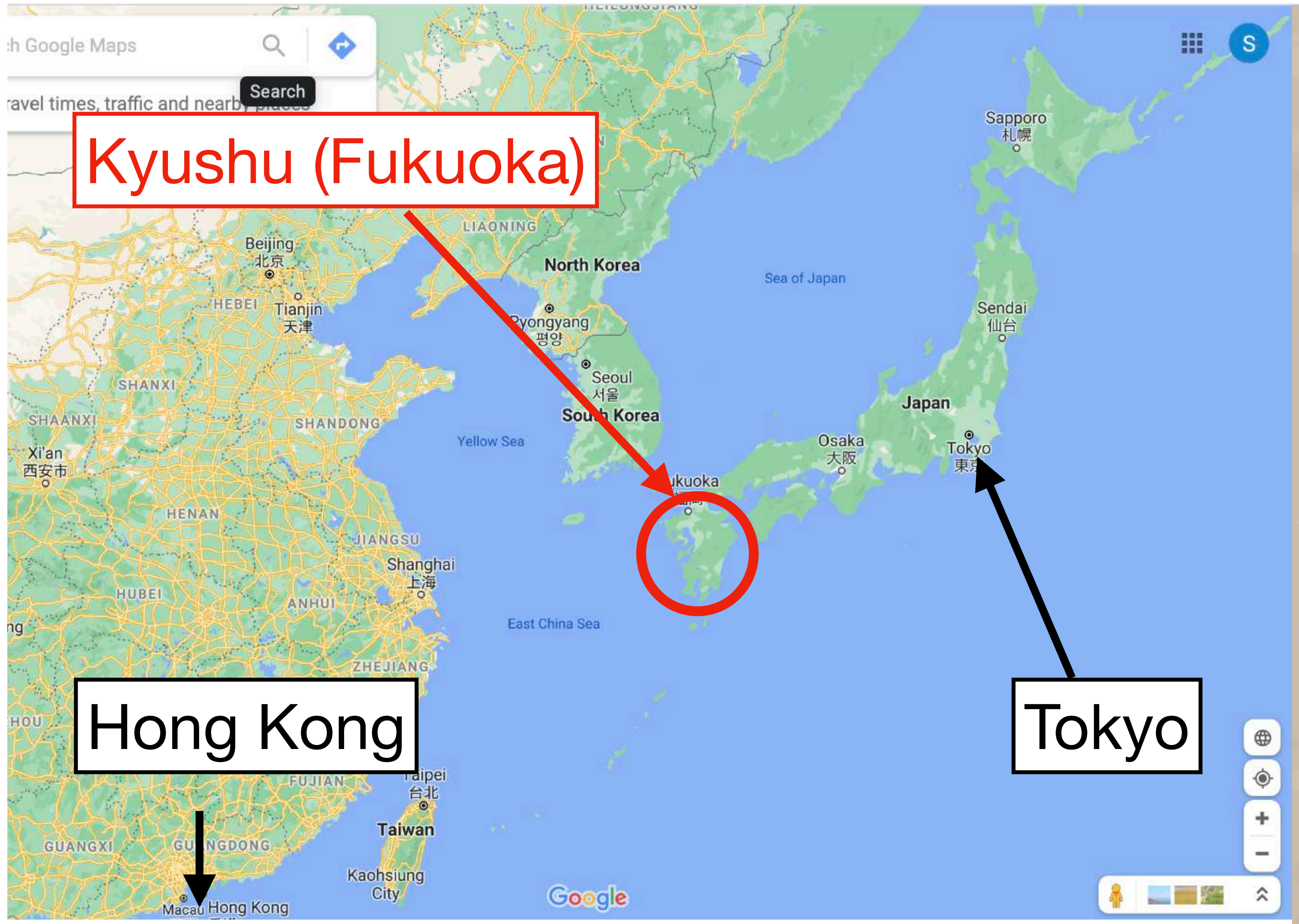


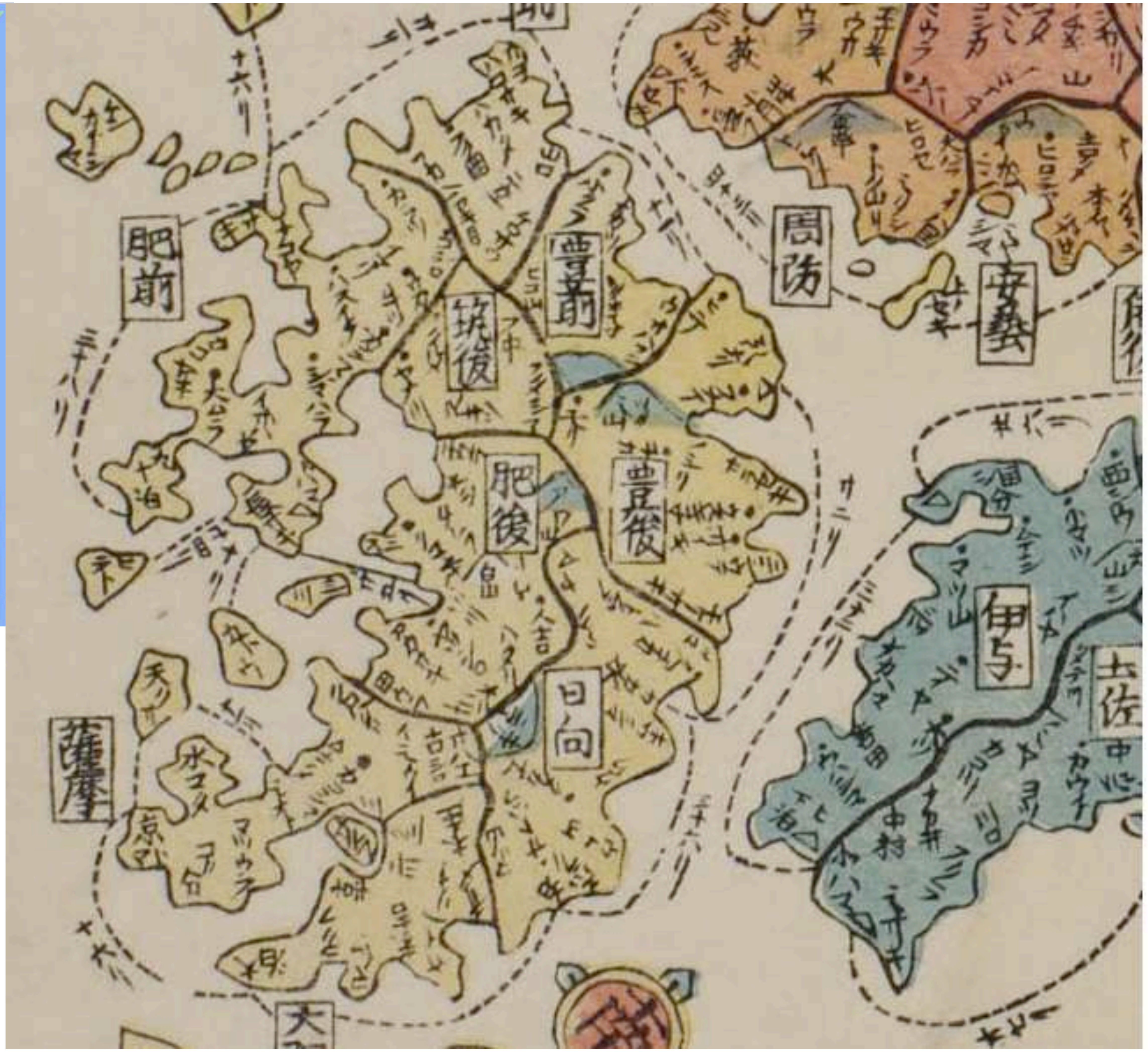
4th Imperial Universities in Japan
~16000 students
Largest campus in Japan (2.4 km^2)

Cultural Slides : Kyushu University

Kyushu University (九州大学: “**Nine-State**” University)

In the past, there are 9 states in Kyushu (currently 7 prefectures)





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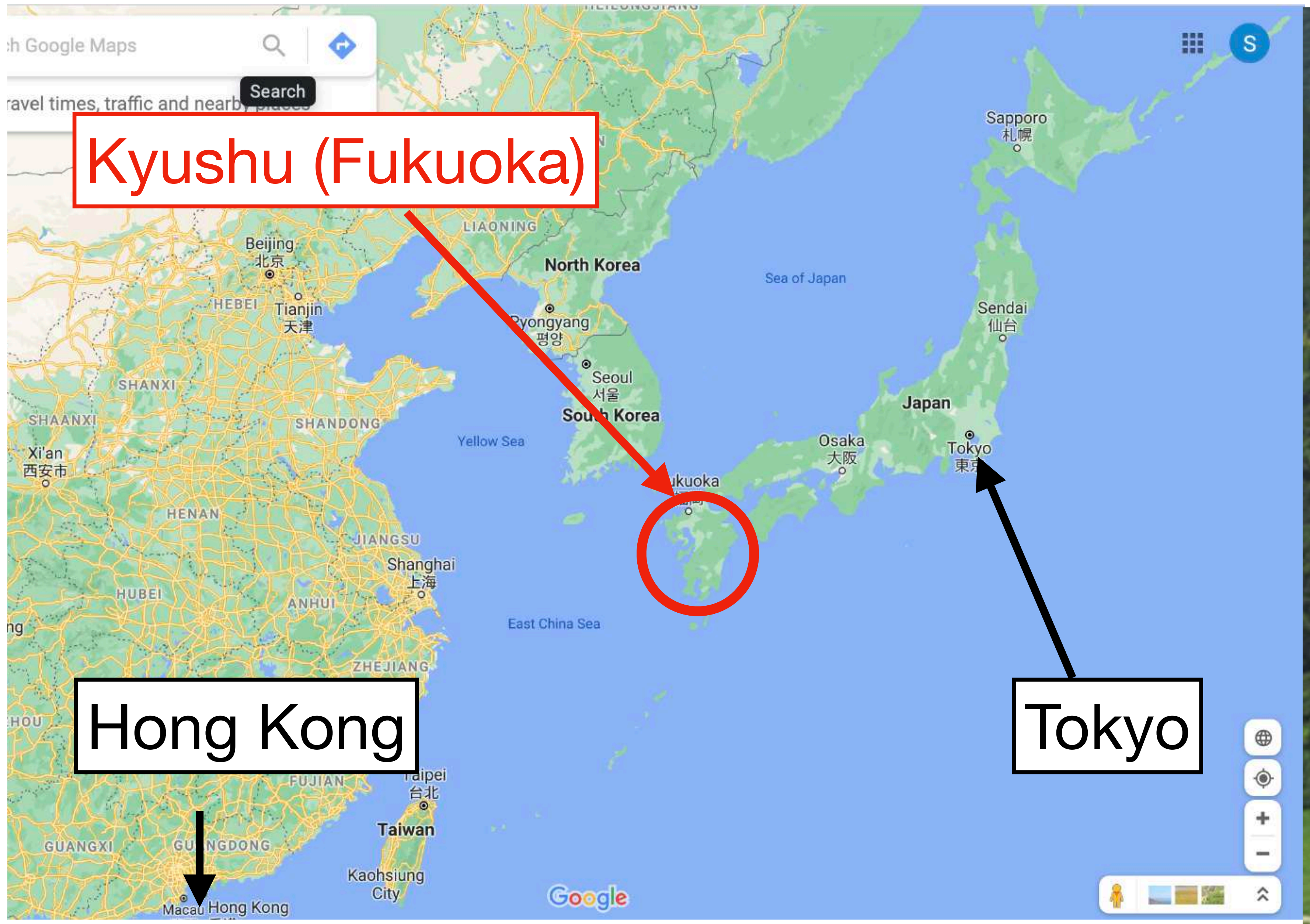
https://mag.japaaan.com/archives/85504

Kyushu University (九州大学: "Nine-State" University)



4th Imperial Universities in Japan
~16000 students
Largest campus in Japan (2.4 km^2)

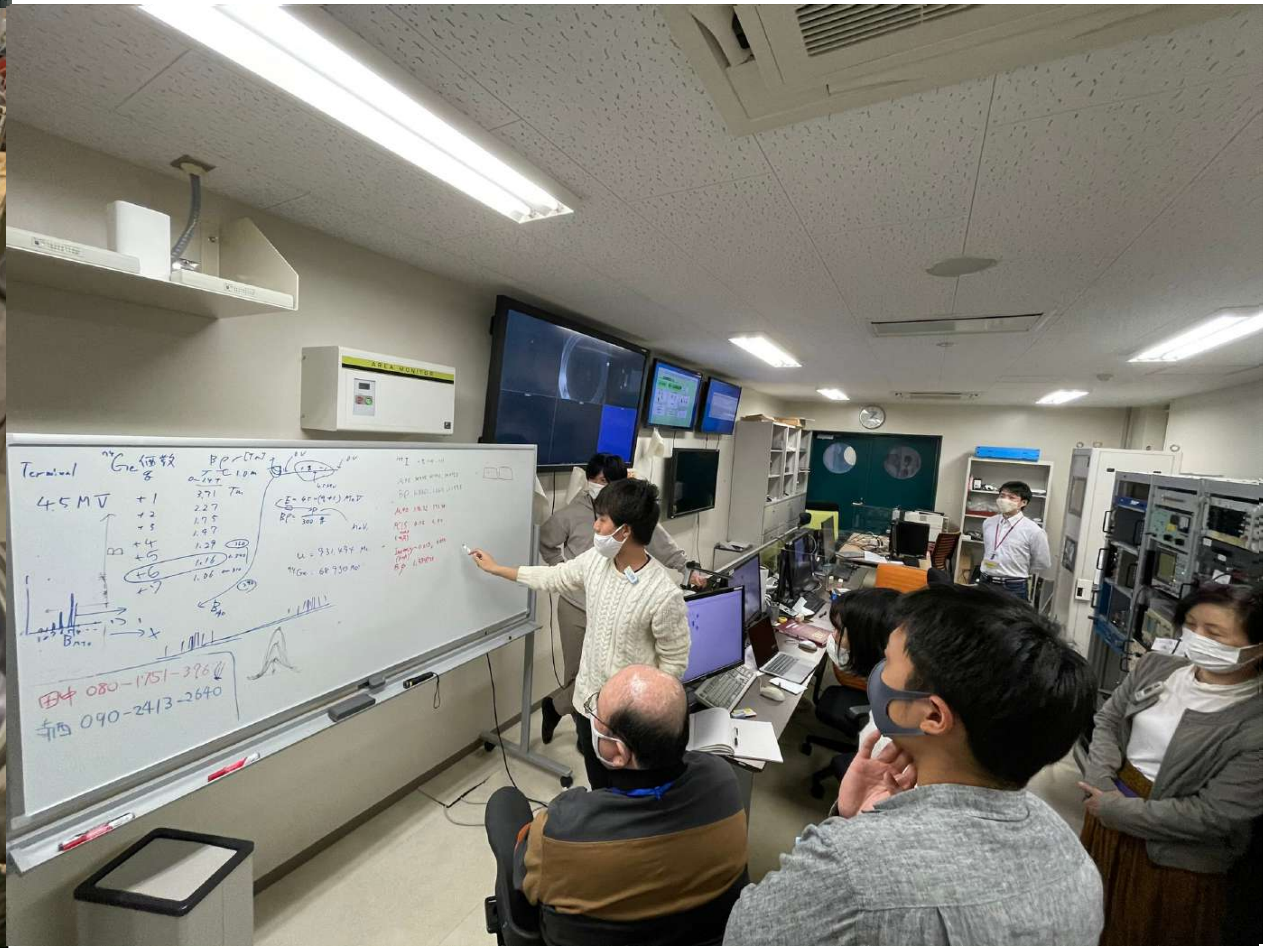
Top global university Japan :https://tgu.mext.go.jp/universities/kyushu-u/index.html

Cultural Slides: Tandem accelerator at Kyushu University

Tandem accelerator

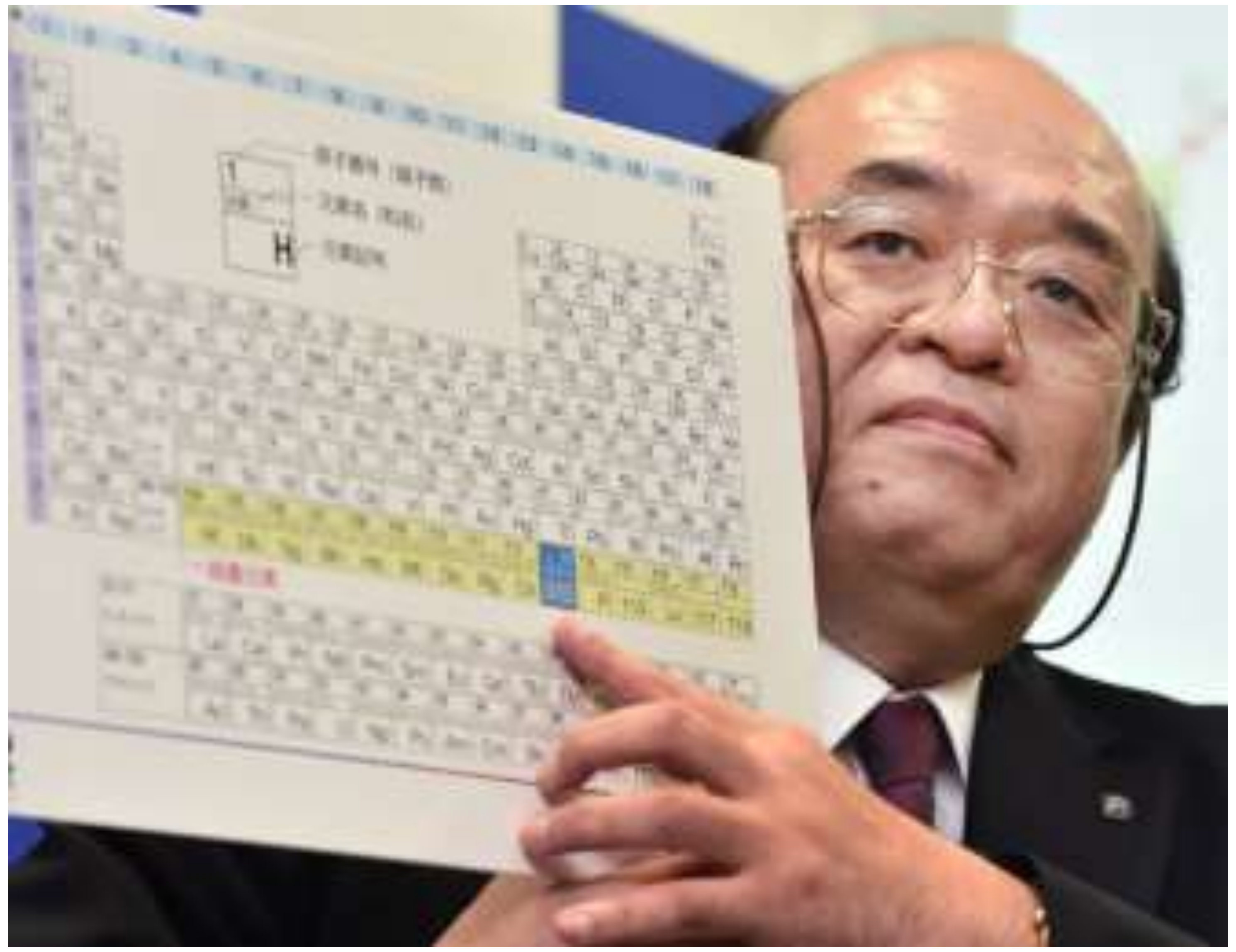
- Electrostatic accelerator
- Terminal Voltage : 7 MV
- Ions: p, d, He, Li…~ I

- Nuclear astrophysics
- Detector development
- AMS, Accelerator Mass Spectroscopy
- Experiments for undergraduate students

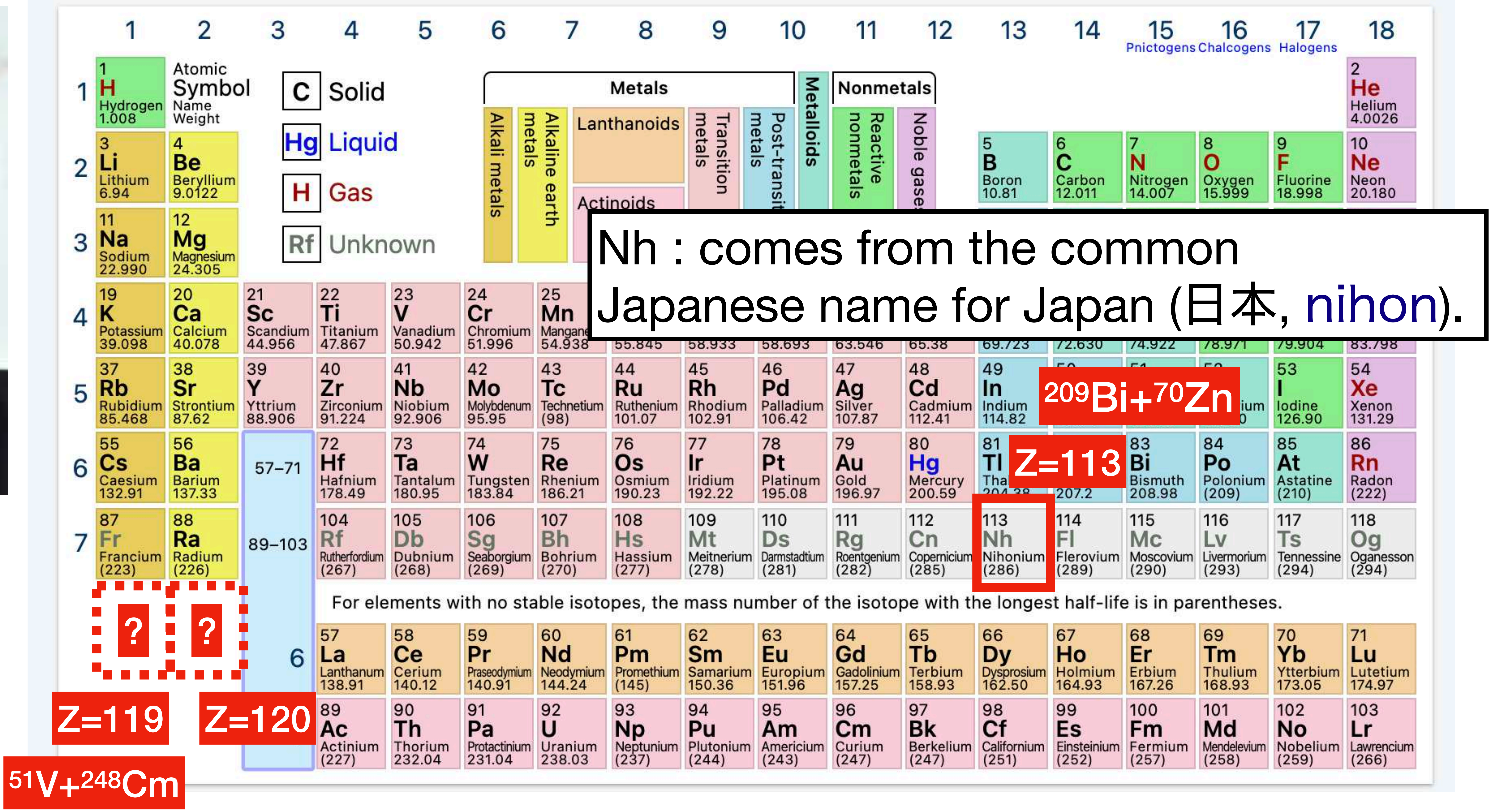


Cultural Slides: Superheavy element research in Kyushu University

Our group is strongly involved in the new element search at RIKEN, Japan



Kosuke Morita
Prof. at Kyushu Univ.



Mapping of fragmented $\nu f_{5/2} \rightarrow \pi f_{7/2}$ transitions in neutron-rich Co isotopes

Shintaro Go
Kyushu University

PHYSICAL REVIEW C **102**, 044331 (2020)

Mapping of fragmented $\nu f_{5/2} \rightarrow \pi f_{7/2}$ transitions in the ^{73}Co $\rightarrow$ ^{73}Ni decay

Achieved by excellent collaborators in/from Poland!

S. Go,[1,2] R. Grzywacz,[1,3] C. Mazzocchi,[4] S. N. Liddick,[5,6] M. Alshudifat,[7] J. C. Batchelder,[8] T. Baumann,[5] A. A. Ciemny,[4] T. N. Ginter,[5] C. J. Gross,[3] K. Kolos,[9] A. Korgul,[4] S. V. Paulauskas,[1] C. J. Prokop,[5,6] M. M. Rajabali,[10,11] K. P. Rykaczewski,[3] S. Taylor,[1] and Y. Xiao[1]

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[2]*Department of Physics, Kyushu University, Fukuoka 819-0395, Japan*
[3]*Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA*
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[5]*National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA*
[6]*Department of Chemistry, Michigan State University, East Lansing, Michigan 48824, USA*
[7]*Department of Physics, Al al-Bayt University, Mafraq 25113, Jordan*
[8]*Department of Nuclear Engineering, University of California, Berkeley, California 94702, USA*
[9]*Lawrence Livermore National Laboratory, Livermore, California 94551, USA*
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(Received 5 May 2020; revised 13 September 2020; accepted 13 October 2020; published 29 October 2020)

Excited states in ^{73,75}Ni were investigated through the β decay of ^{73,75}Co in an experiment performed at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU). The experimental results extended the level scheme of ^{73}Ni to 3.2-MeV excitation energy and provided the experimental information on excited states in ^{75}Ni. The β-delayed neutron branching ratio for ^{73}Co was obtained. The experimental results are discussed in comparison with shell-model calculations.

DOI: 10.1103/PhysRevC.102.044331

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[10]*Department of Physics, Tennessee Te*

[11]*TRIUMF, Vancouv*

(Received 5 May 2020; revised 13 Septem

- What are $\nu f_{5/2} \rightarrow \pi f_{7/2}$ transitions?
- What can we learn from neutron-rich Co decays?
- Why is the "Mapping" important?

Excited states in ^{73,75}Ni were investigated
National Superconducting Cyclotron Laboratory
results extended the level scheme of ^{73}Ni to 3.2-MeV excitation energy and provided the experimental informa-
tion on excited states in ^{75}N
results are discussed in com

If you have questions during my talk, feel free to ask!

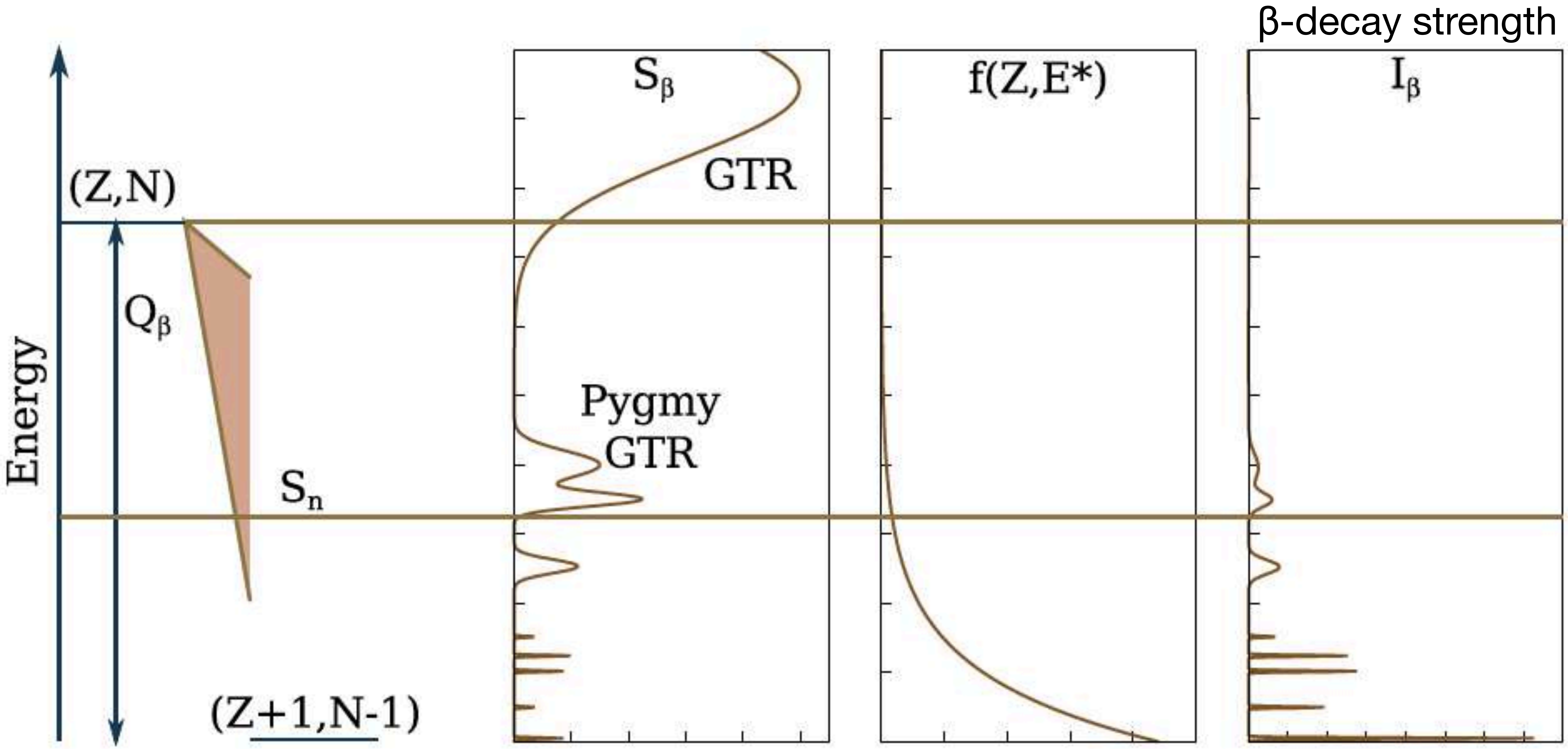
DOI: 10.1103/PhysRevC.102.044331

Schematic view of Beta-decay

β^- decay

$n \rightarrow p + e^- + \bar{\nu}_e$ (example: $^{60}Co \rightarrow {}^{60}Ni^* + e^- + \bar{\nu}_e$)

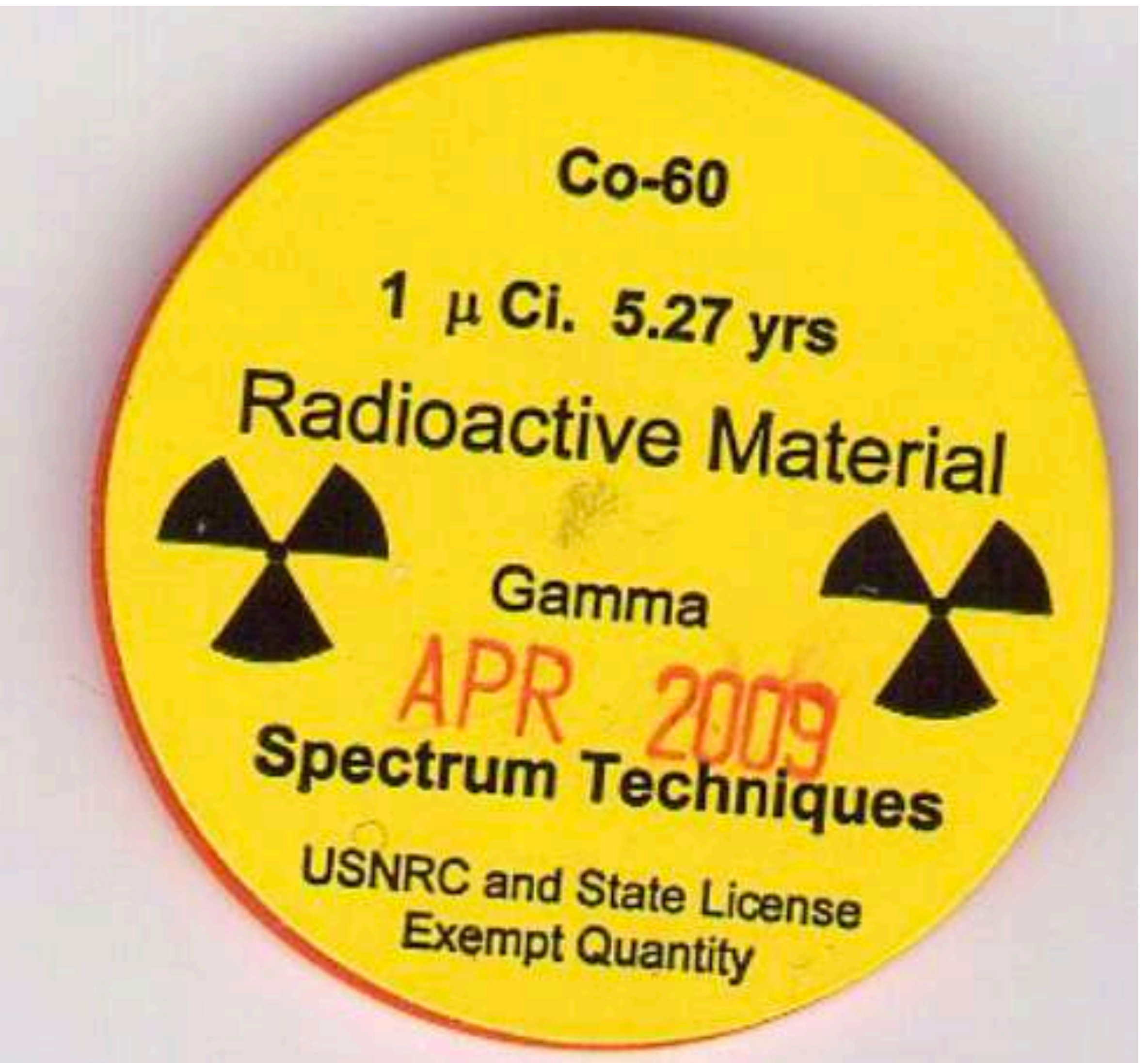
$$T_{1/2}^{-1} = \sum_{E_i \geq 0}^{E_i \leq Q_\beta} S_\beta(E_i) \times f(Z, Q_\beta - E_i).$$



β-γ spectroscopy can characterize low-excited states in nuclei

What can we learn from decay spectroscopy?

^{60}Co standard Gamma-source



https://en.wikipedia.org/wiki/Cobalt-60

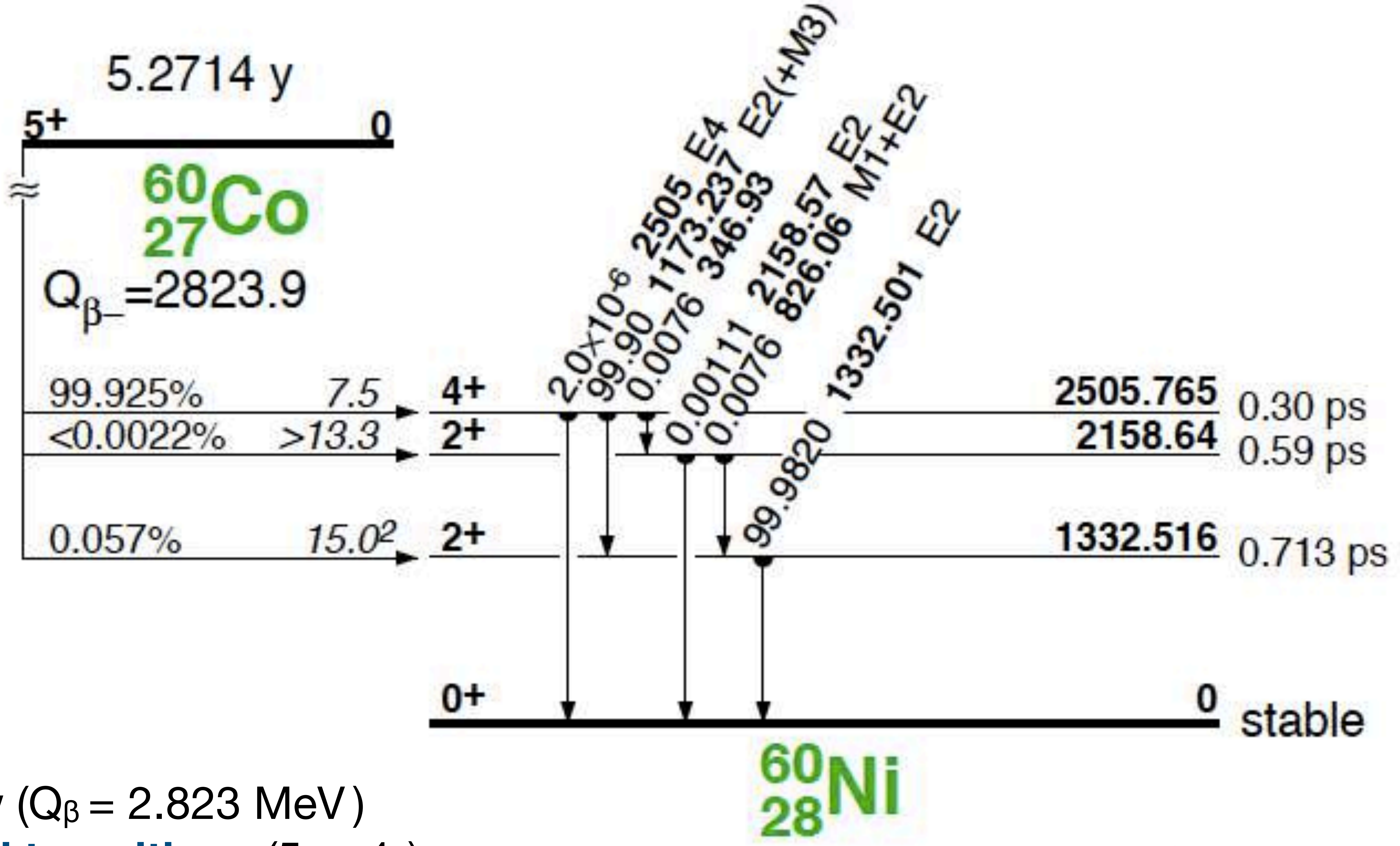


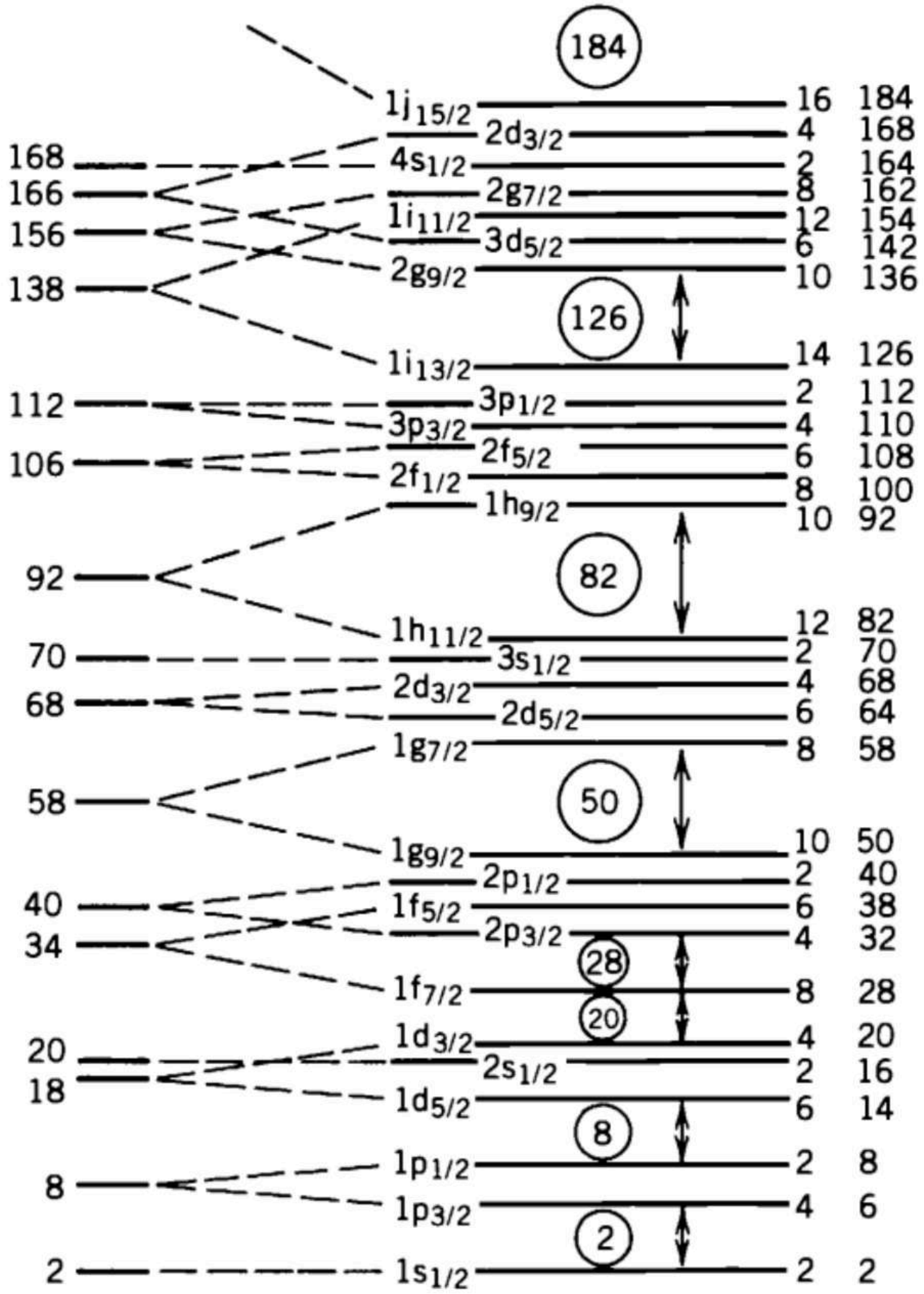
Table of isotopes

- Half-life $T_{1/2}$ = 5.27 year
- Excited states of ^{70}Ni (2^+,4^+ …)
- Decay within β-decay energy window (Q_β = 2.823 MeV)
- **Strong branching ratios for allowed transitions** ($5^+ \rightarrow 4^+$)

How do the excited states and decay properties change in extremely neutron-rich nuclei?

→Accelerator facilities can provide neutron-rich Co nuclei

Introduction : Nuclear Shell Structure



Krane, Introductory Nuclear Physics

Magic numbers were explained by introducing LS-interaction (1963 Novel Prize)

2, 8, 20, 28, 50, 82, 126…

New accelerator facilities started providing nuclei far from stability

Recent experimental works revealed
- Disappearance of the magic number
- Occurrence in the new stability

Mayer and Jensen

How do the magic number and stability change in extremely neutron-rich nuclei?

“New” magic number in neutron-rich Ca isotopes

Occurrence of new stability (magic number) at N=34

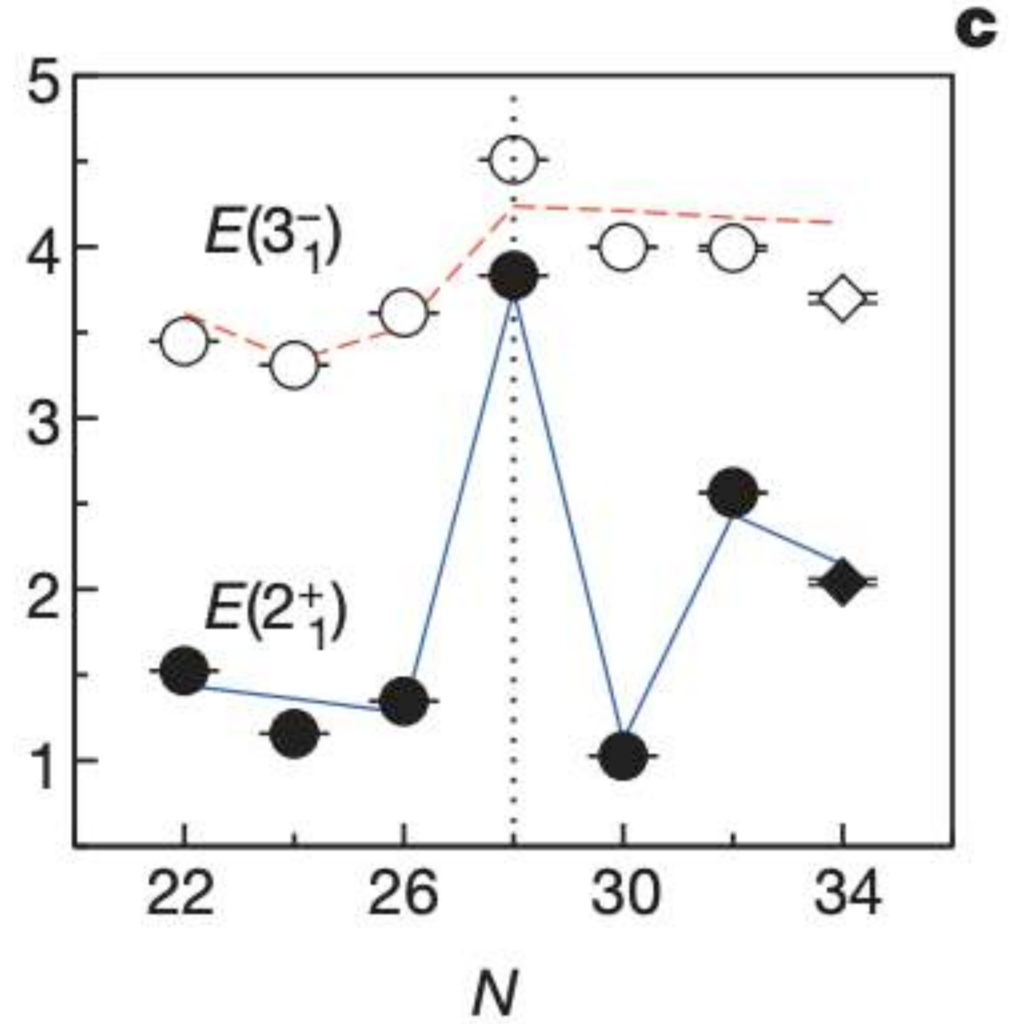
LETTER

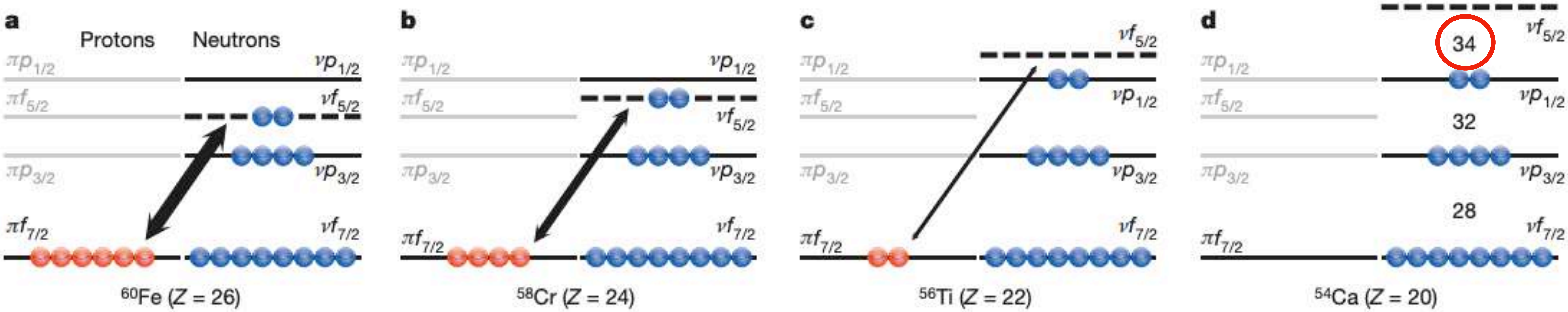
doi:10.1038/nature12522

Evidence for a new nuclear ‘magic number’ from the level structure of ^{54}Ca

D. Steppenbeck[1], S. Takeuchi[2], N. Aoi[3], P. Doornenbal[2], M. Matsushita[1], H. Wang[2], H. Baba[2], N. Fukuda[2], S. Go[1], M. Honma[4], J. Lee[2], K. Matsui[5], S. Michimasa[1], T. Motobayashi[2], D. Nishimura[6], T. Otsuka[1,5], H. Sakurai[2,5], Y. Shiga[7], P.-A. Söderström[2], T. Sumikama[8], H. Suzuki[2], R. Taniuchi[5], Y. Utsuno[9], J. J. Valiente-Dobón[10] & K. Yoneda[2]

D. Steppenbeck et al., Nature **502**, 209 (2013).





Attractive interaction between νf7/2-πf5/2 orbital reduced by removing f7/2 protons

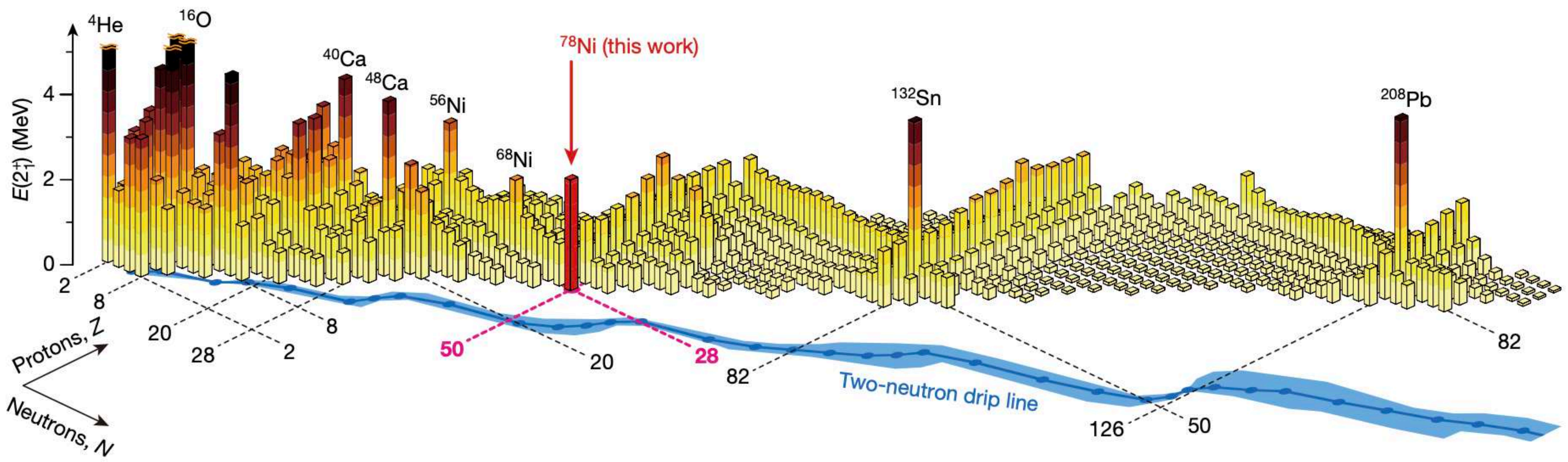
However, there is stronghold magic numbers in ^{78}Ni (Z=28, N=50)

ARTICLE

https://doi.org/10.1038/s41586-019-1155-x

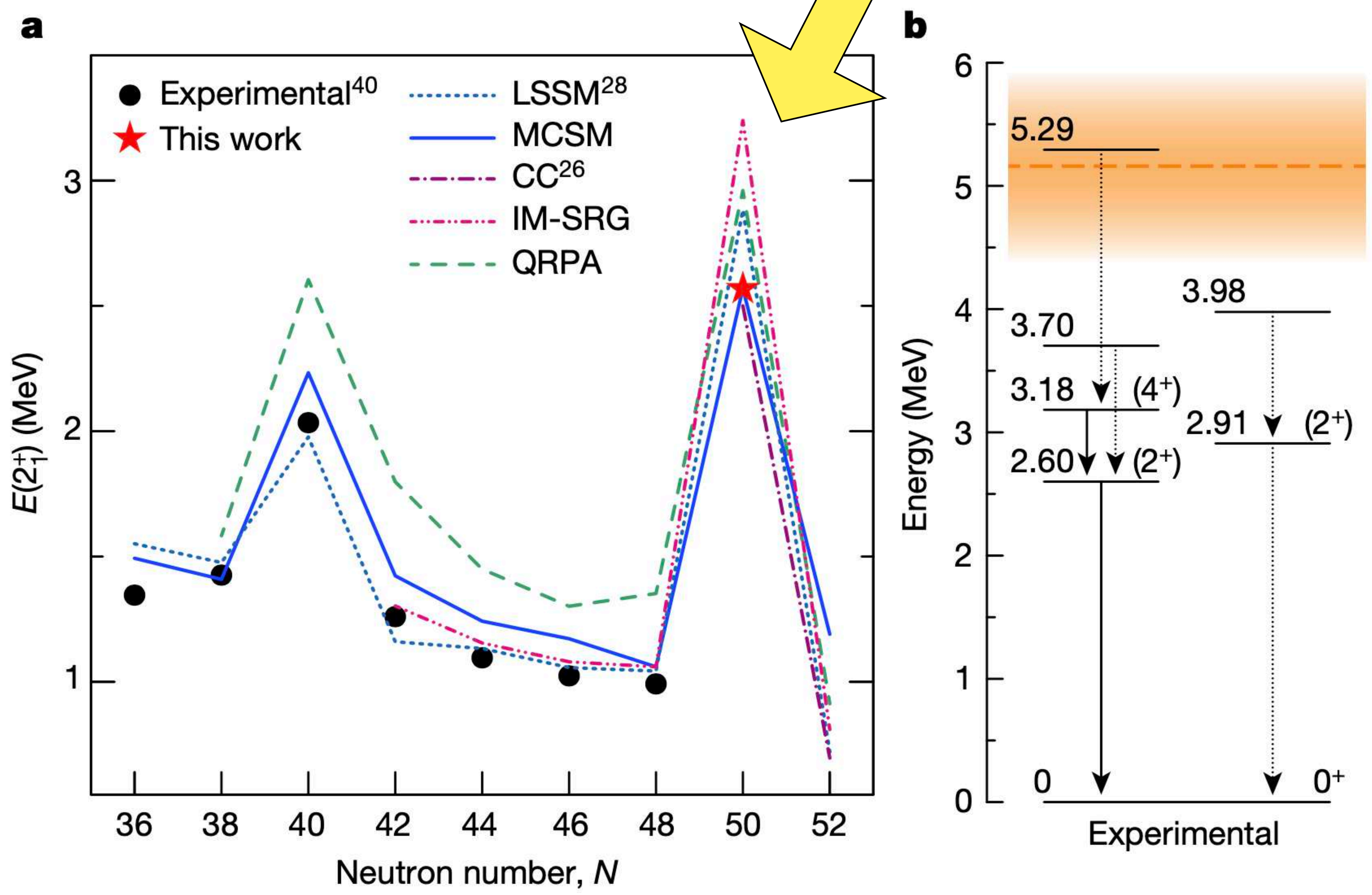
^{78}Ni revealed as a doubly magic stronghold against nuclear deformation

R. Taniuchi[1,2], C. Santamaria[2,3], P. Doornenbal[2*], A. Obertelli[2,3,4], K. Yoneda[2], G. Authelet[3], H. Baba[2], D. Calvet[3], F. Château[3], A. Corsi[3], A. Delbart[3], J.-M. Gheller[3], A. Gillibert[3], J. D. Holt[5], T. Isobe[2], V. Lapoux[3], M. Matsushita[6], J. Menéndez[6], S. Momiyama[1,2], T. Motobayashi[2], M. Niikura[1], F. Nowacki[7], K. Ogata[8,9], H. Otsu[2], T. Otsuka[1,2,6], C. Péron[3], S. Péru[10], A. Peyaud[3], E. C. Pollacco[3], A. Poves[11], J.-Y. Roussé[3], H. Sakurai[1,2], A. Schwenk[4,12,13], Y. Shiga[2,14], J. Simonis[4,12,15], S. R. Stroberg[5,16], S. Takeuchi[2], Y. Tsunoda[6], T. Uesaka[2], H. Wang[2], F. Browne[17], L. X. Chung[18], Z. Dombradi[19], S. Franchoo[20], F. Giacoppo[21], A. Gottardo[20], K. Hadyńska-Klęk[21], Z. Korkulu[19], S. Koyama[1,2], Y. Kubota[2,6], J. Lee[22], M. Lettmann[4], C. Louchart[4], R. Lozeva[7,23], K. Matsui[1,2], T. Miyazaki[1,2], S. Nishimura[2], L. Olivier[20], S. Ota[6], Z. Patel[24], E. Şahin[21], C. Shand[24], P.-A. Söderström[2], I. Stefan[20], D. Steppenbeck[6], T. Sumikama[25], D. Suzuki[20], Z. Vajta[19], V. Werner[4], J. Wu[2,26] & Z. Y. Xu[22]



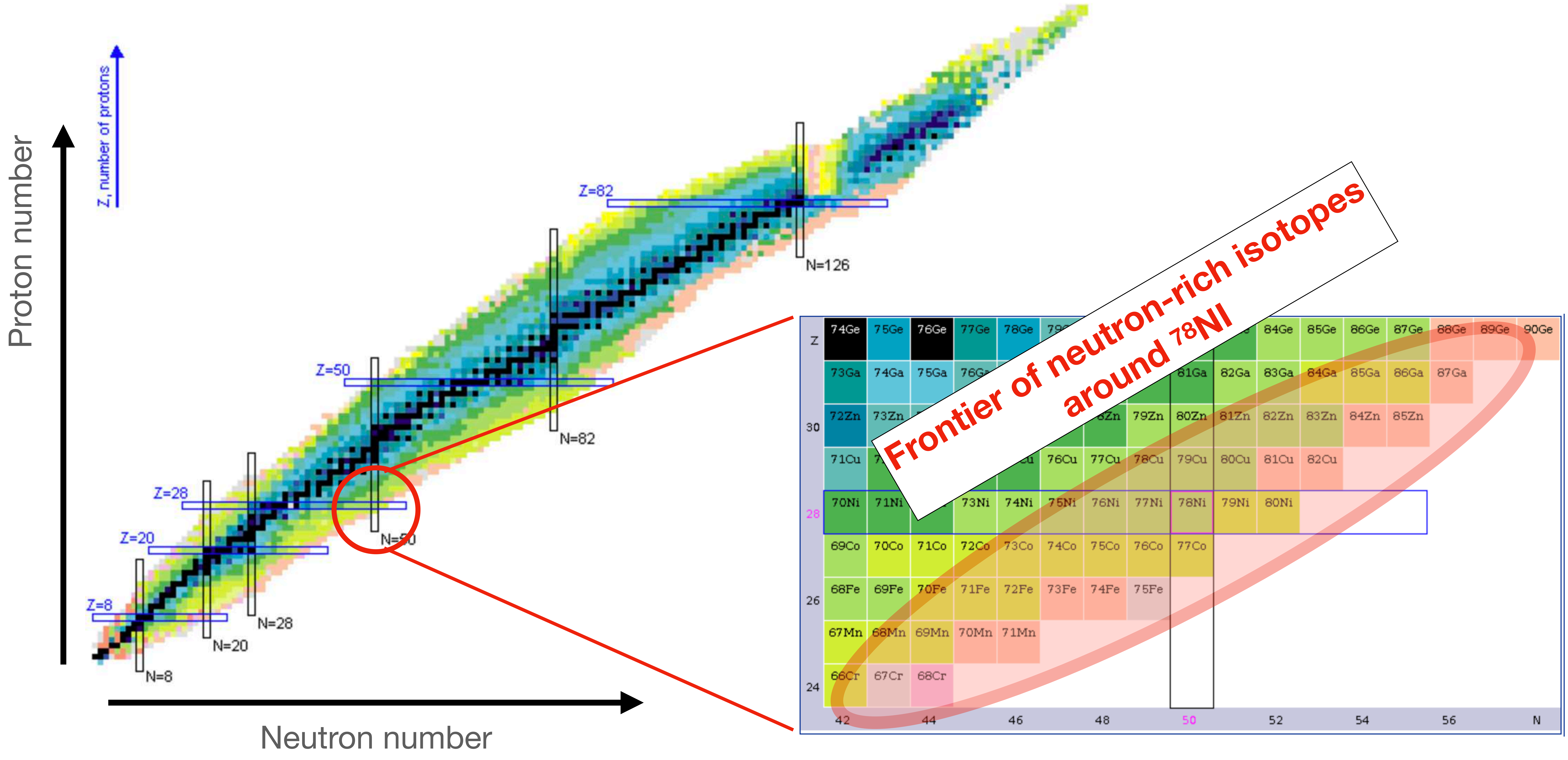
R. Taniuchi et al., Nature (2019)

Highly excited 2^+ state in ^{78}Ni



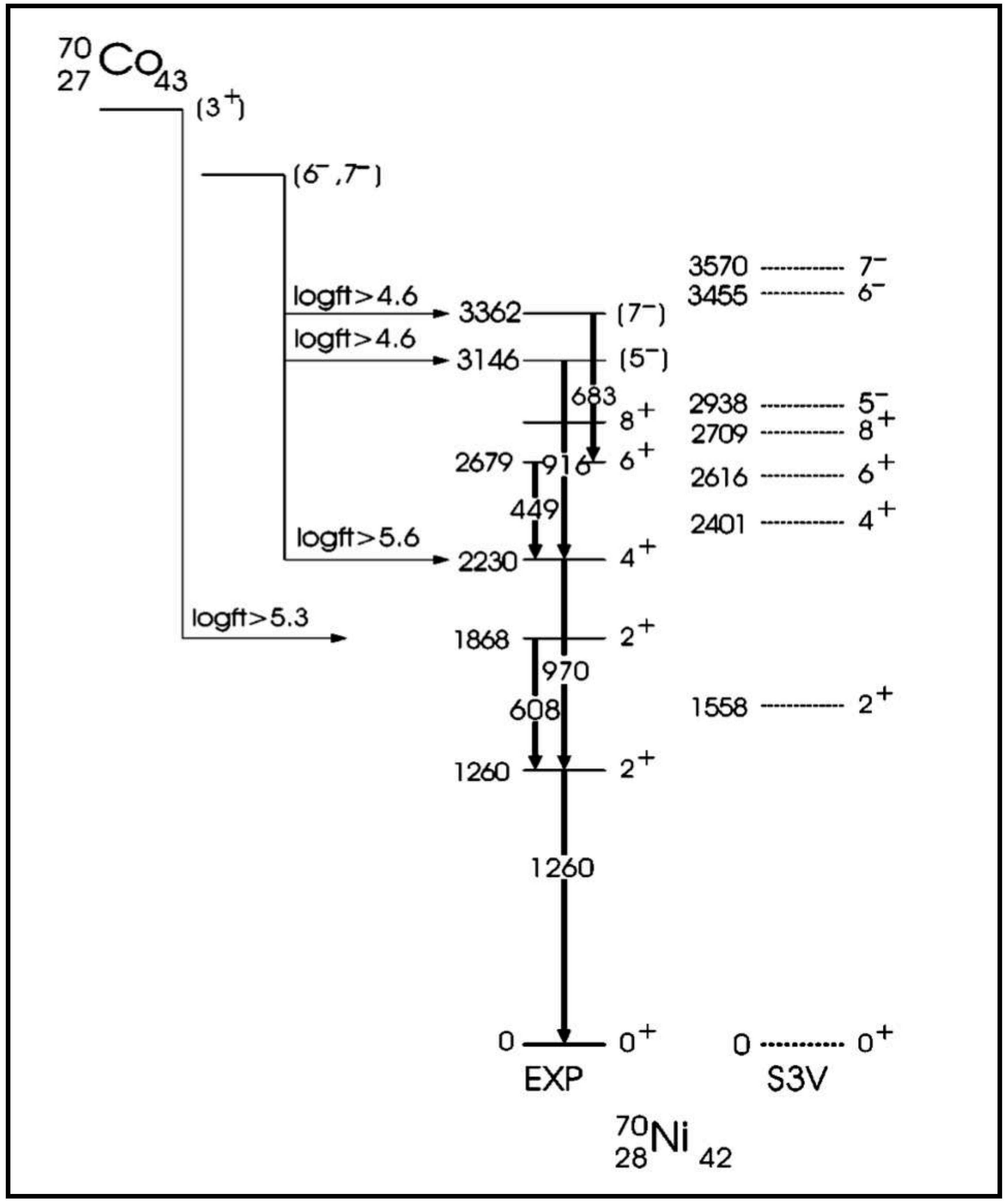
Spectroscopic data could provide information on the nuclear shell-structure

Frontier of neutron-rich Ni isotopes

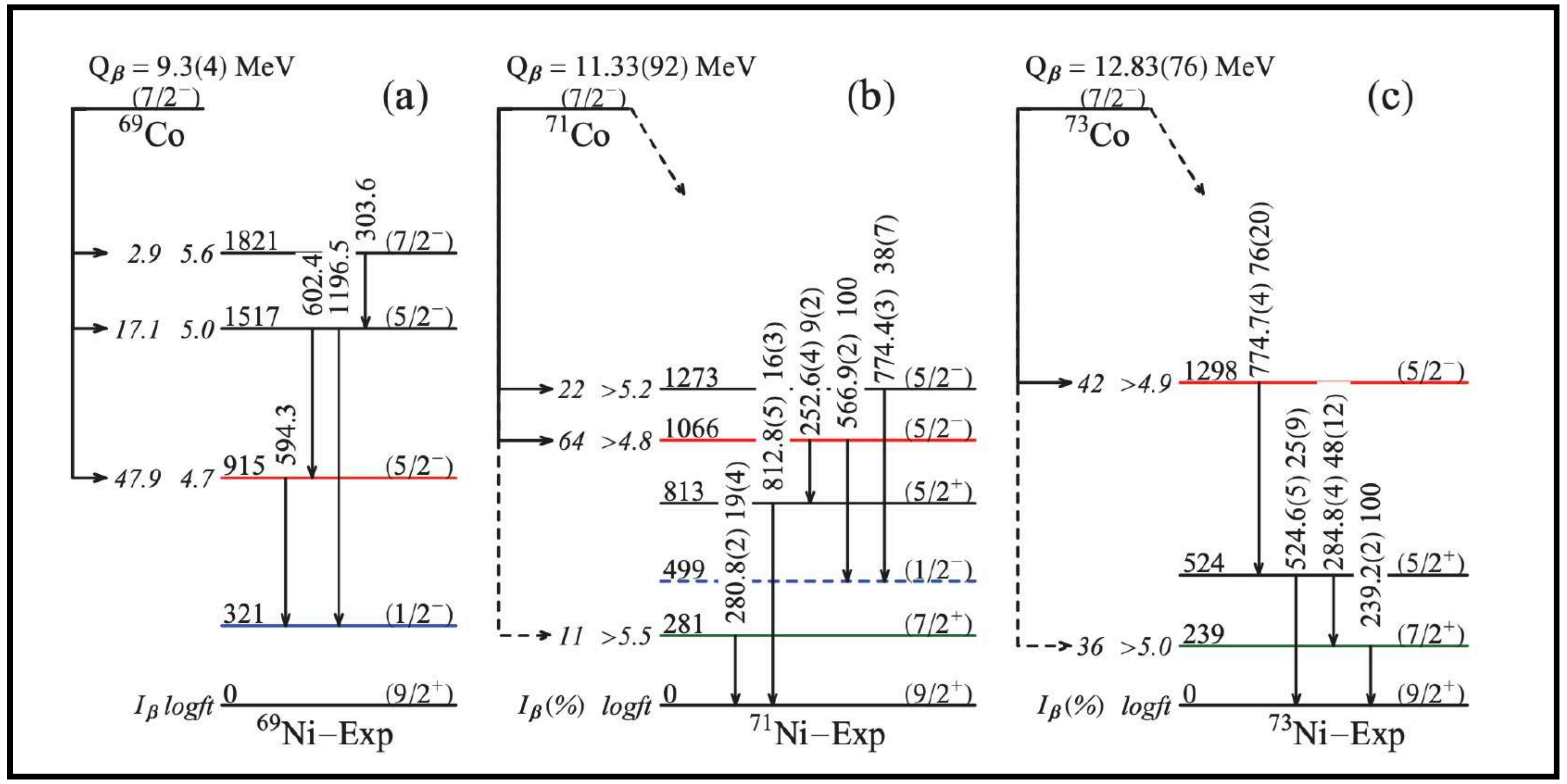


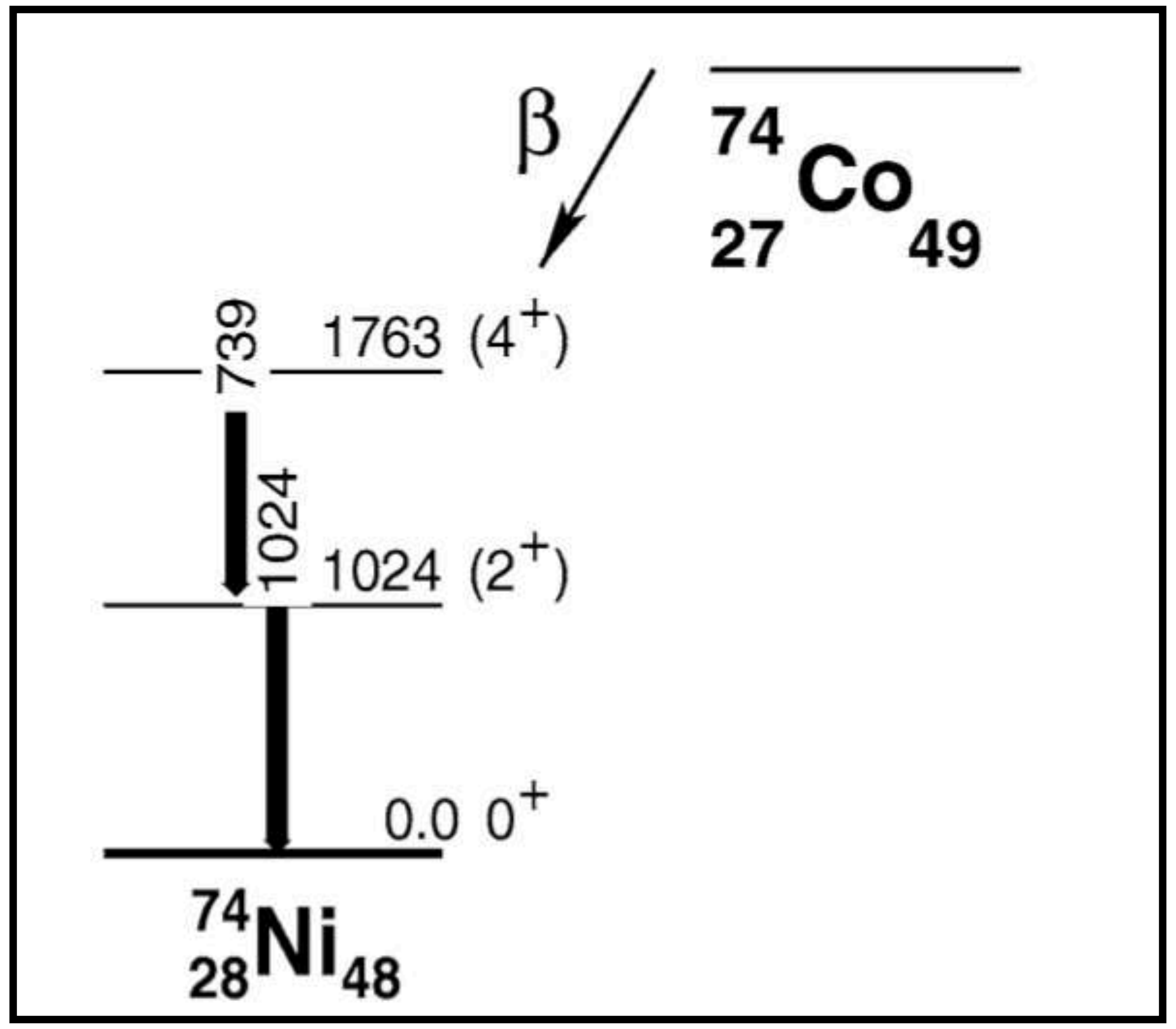
Decay spectroscopy around Ni isotopes

Excited states in Ni isotopes have been extensively studied by beta-gamma spectroscopy



M. Sawicka et al., PRC (2003)



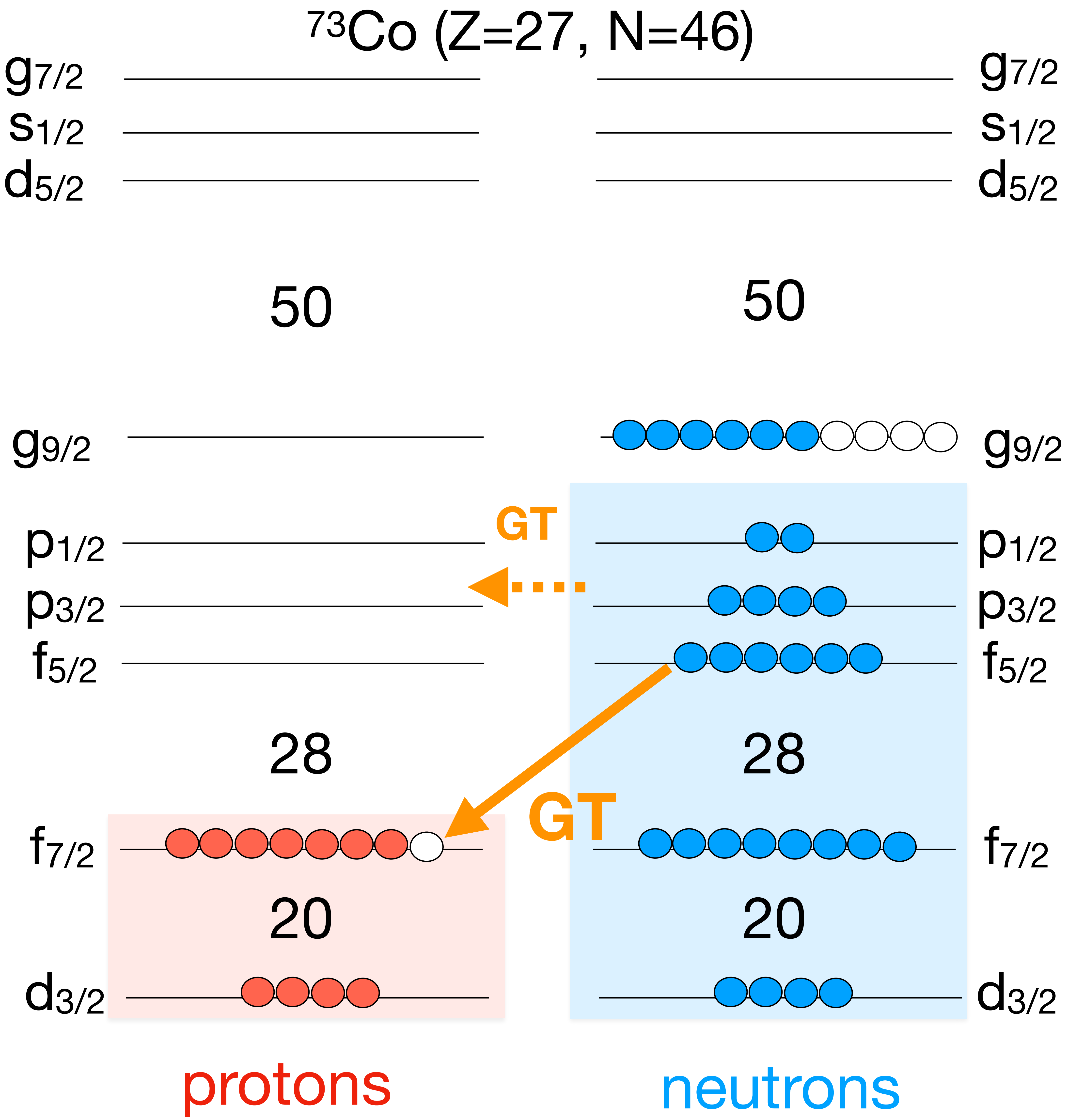


M. M. Rajabali et al., PRC (2012)

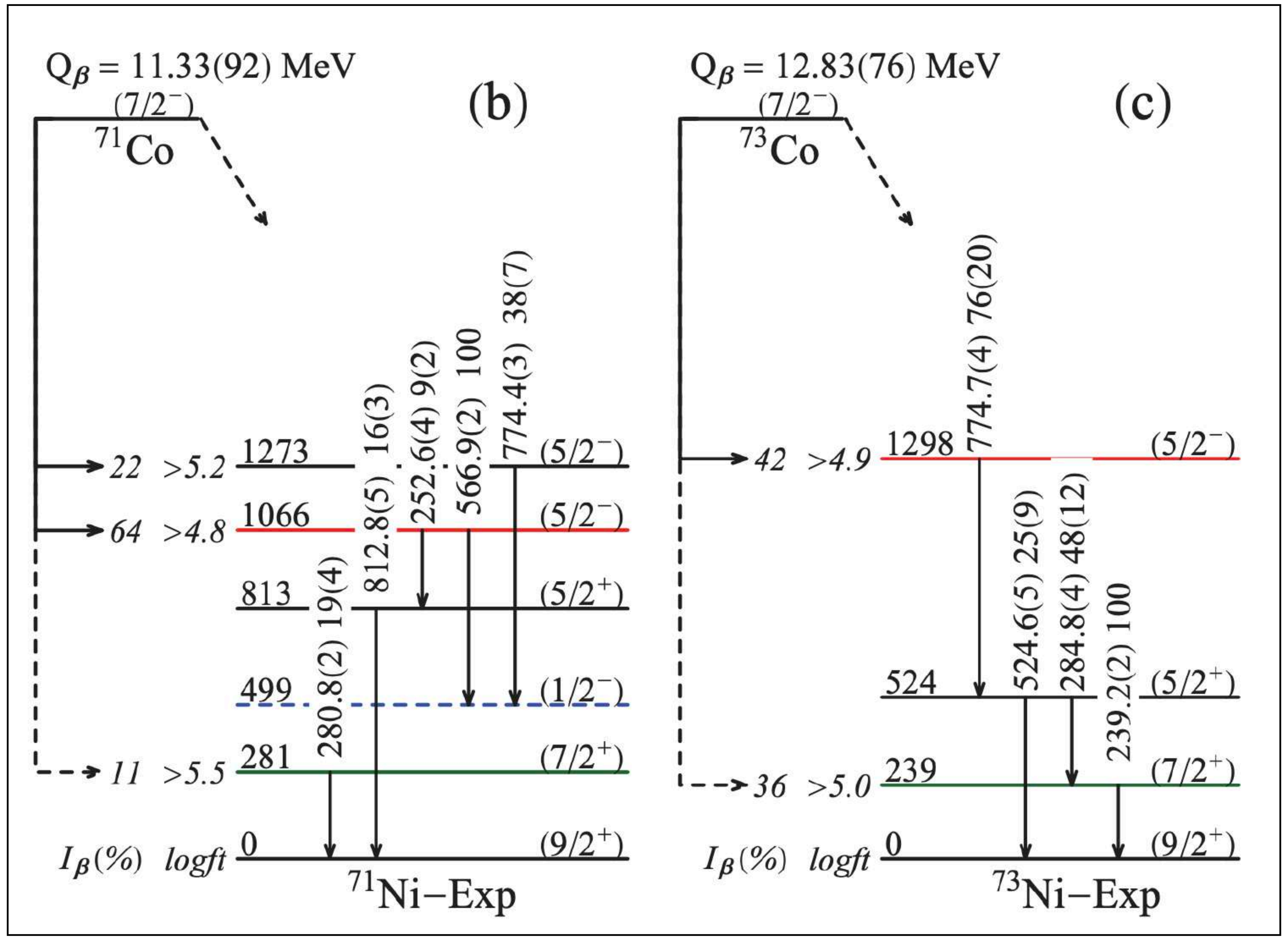
C. Mazzochi et al., PLB (2004)

What have we learned from the decay of Co isotopes?

"Very simplified" shell-structure still explains qualitative decay properties



- **Ground State of ^{73}Co : J^{π} = ($7/2^-$)**
  - Proton hole state $(f_{7/2})^{-1}$
- **Gamow-Teller (allowed) transitions observed in low-E states**
  - $\nu f_{5/2} \rightarrow \pi f_{7/2}$ to form Z=28 core
  - significant β decay intensities : ^{73}Co ($7/2^-$) to ^{73}Ni ($5/2^-$)

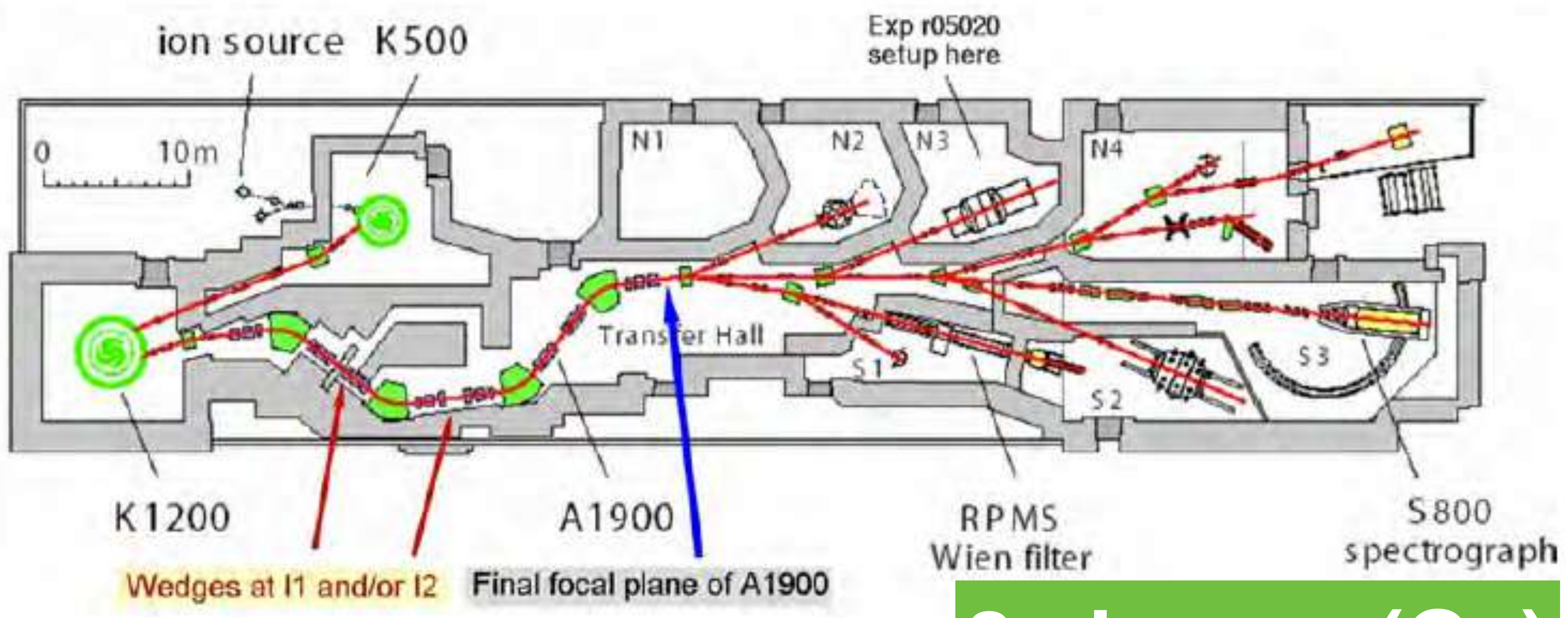


M. M. Rajabali et al., PRC (2012)

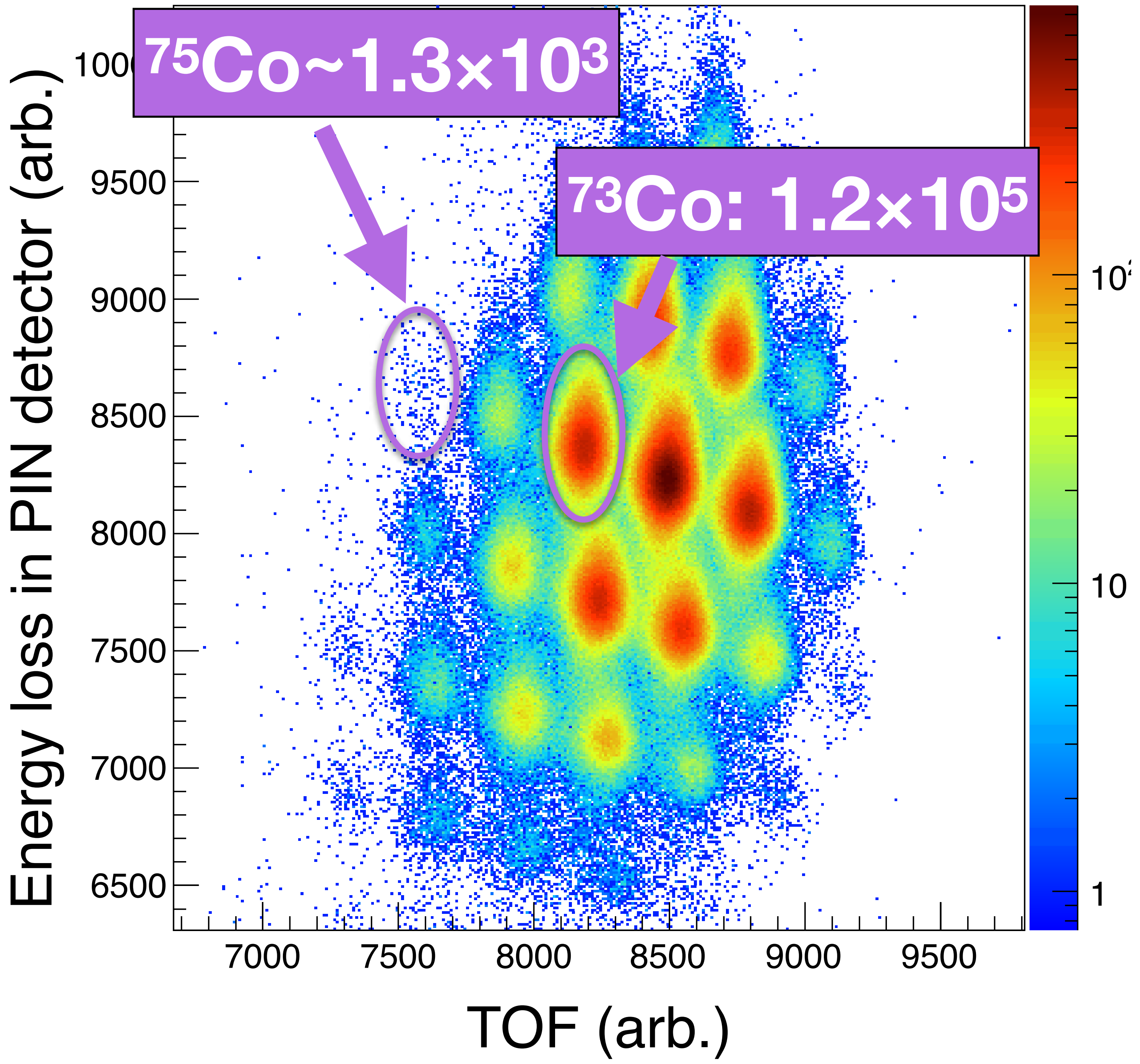
MSU/NSCL : Michigan State University, National Superconducting Cyclotron Laboratory

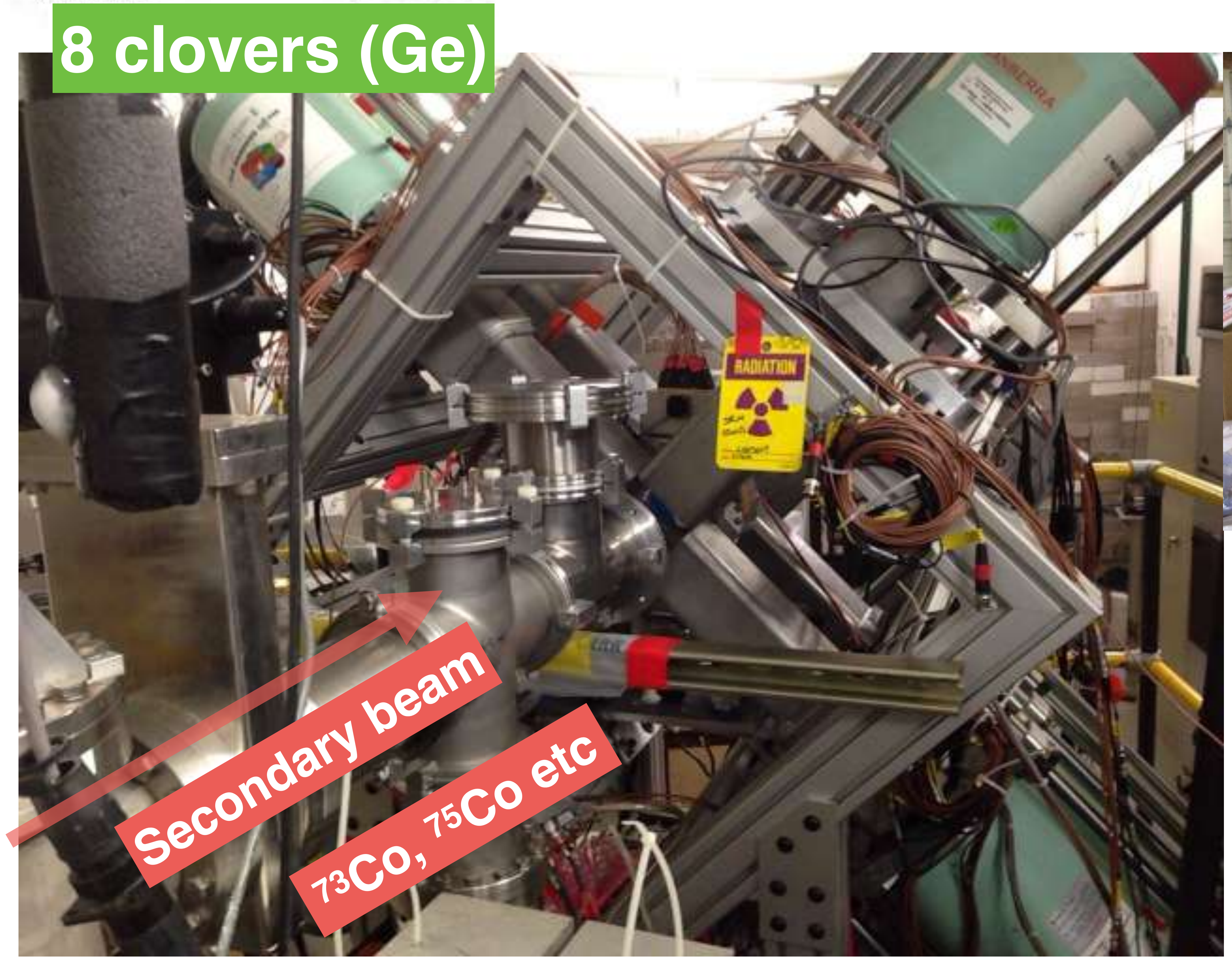
Investigation on beta-decay of ^{73}Co and ^{75}Co was conducted at MSU/NSCL

Experimental details at MSU/NSCL



Primary beam: **^{84}Se** (140 MeV/u)
Particle Identification : **ΔE-TOF method**
Space-Time correlation for implant and beta : **GeDSSD**
γ-detection : **Clover Ge detectors** ×8



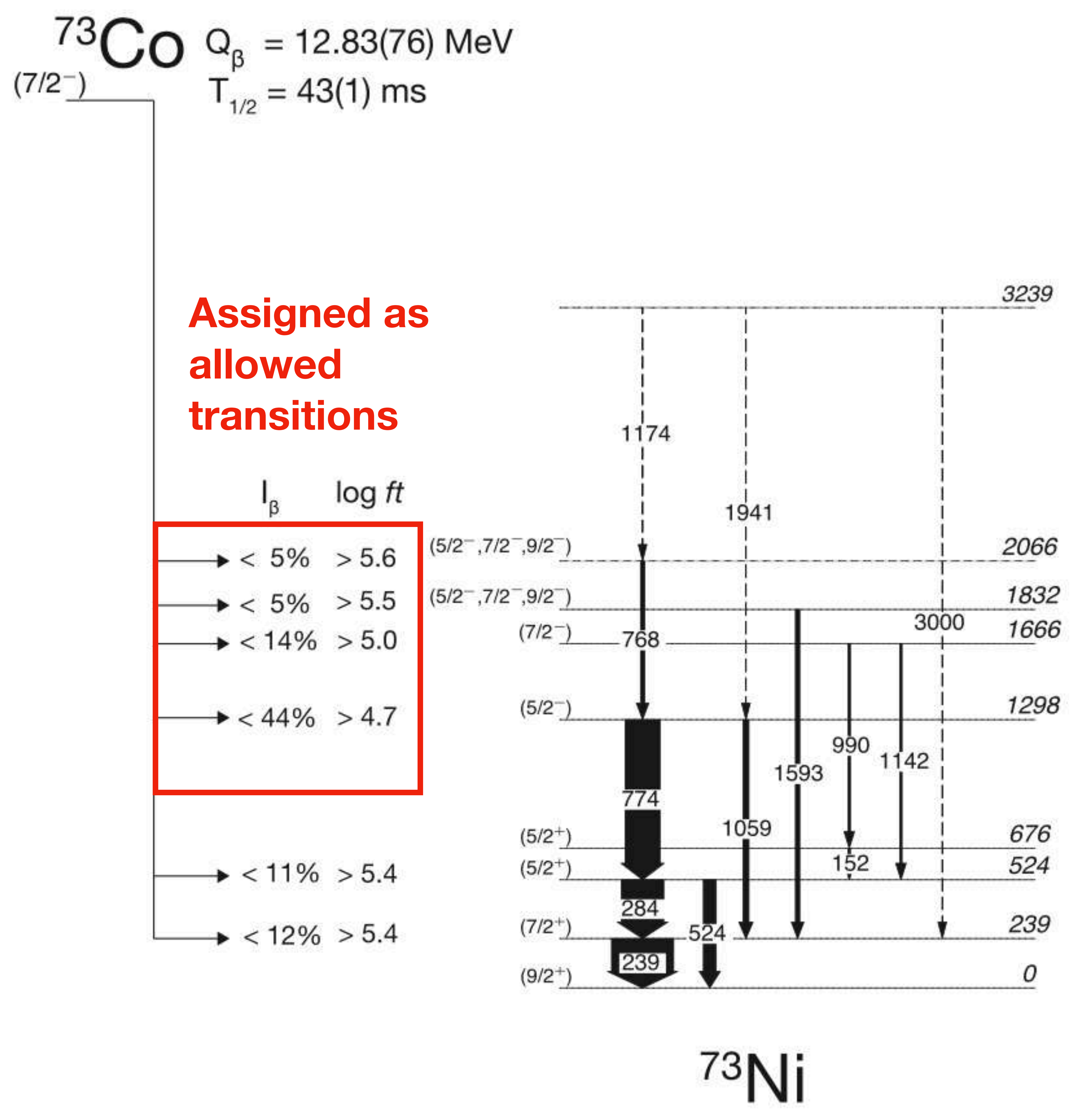


N. Larson et al., NIM A (2013).

GeDSSD
- 9 cm circular disk
- 1 cm thick
- 16 strips both in front and back

New level scheme for ^{73}Ni in this work

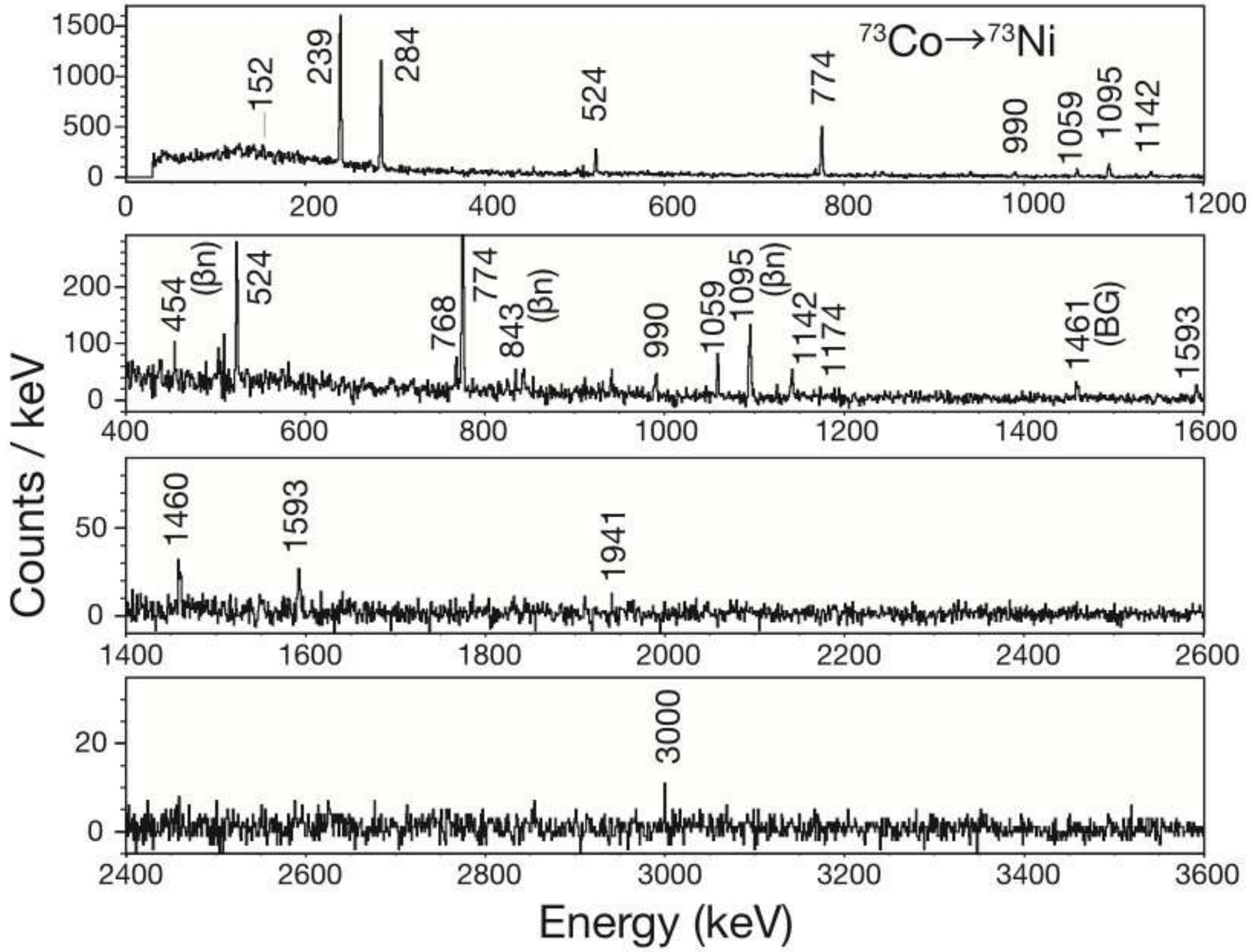
Level scheme was updated up to 3.2 MeV



To construct the level scheme…

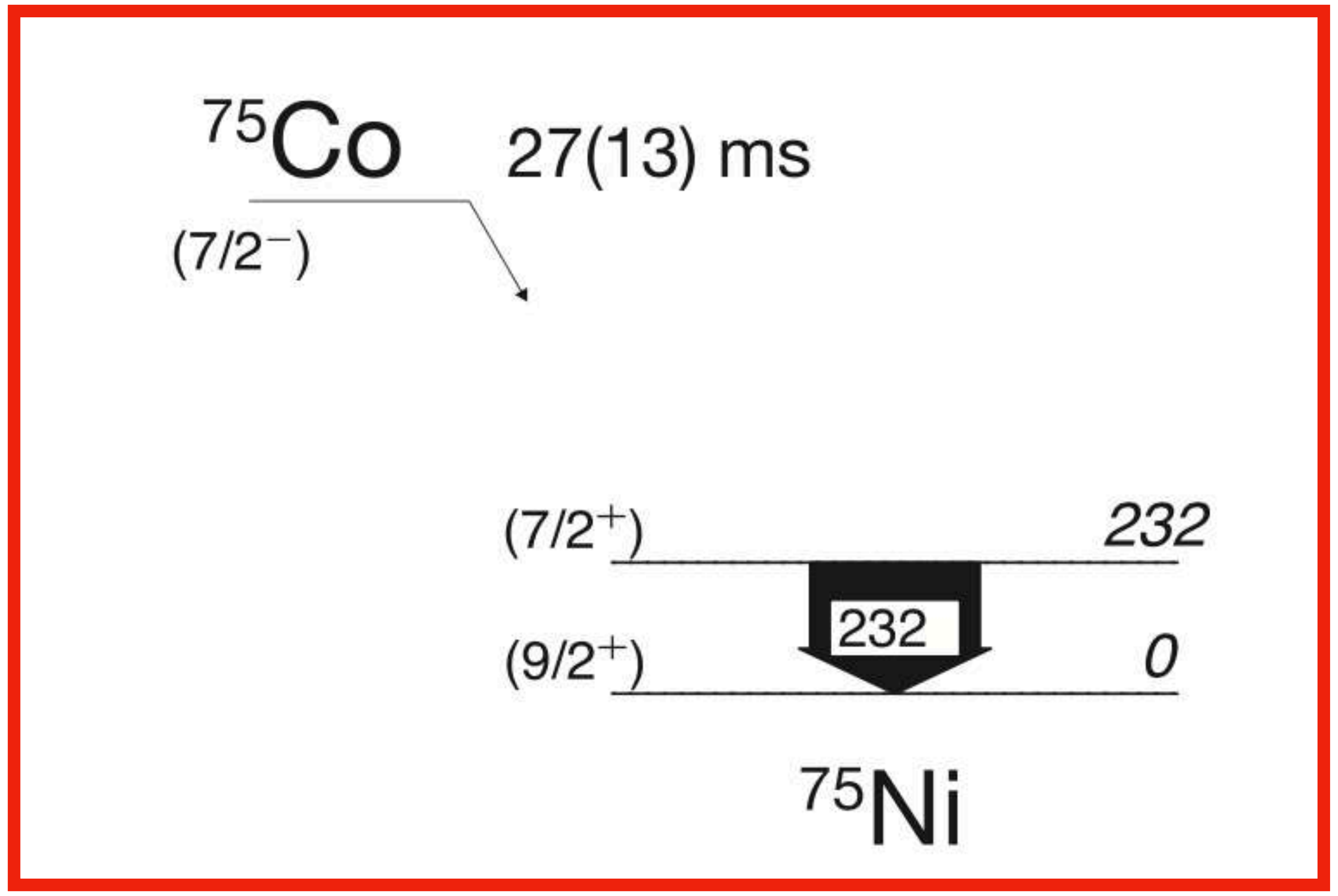
- Transition energy
- γ-γ coincidence analysis
- Half-life analysis

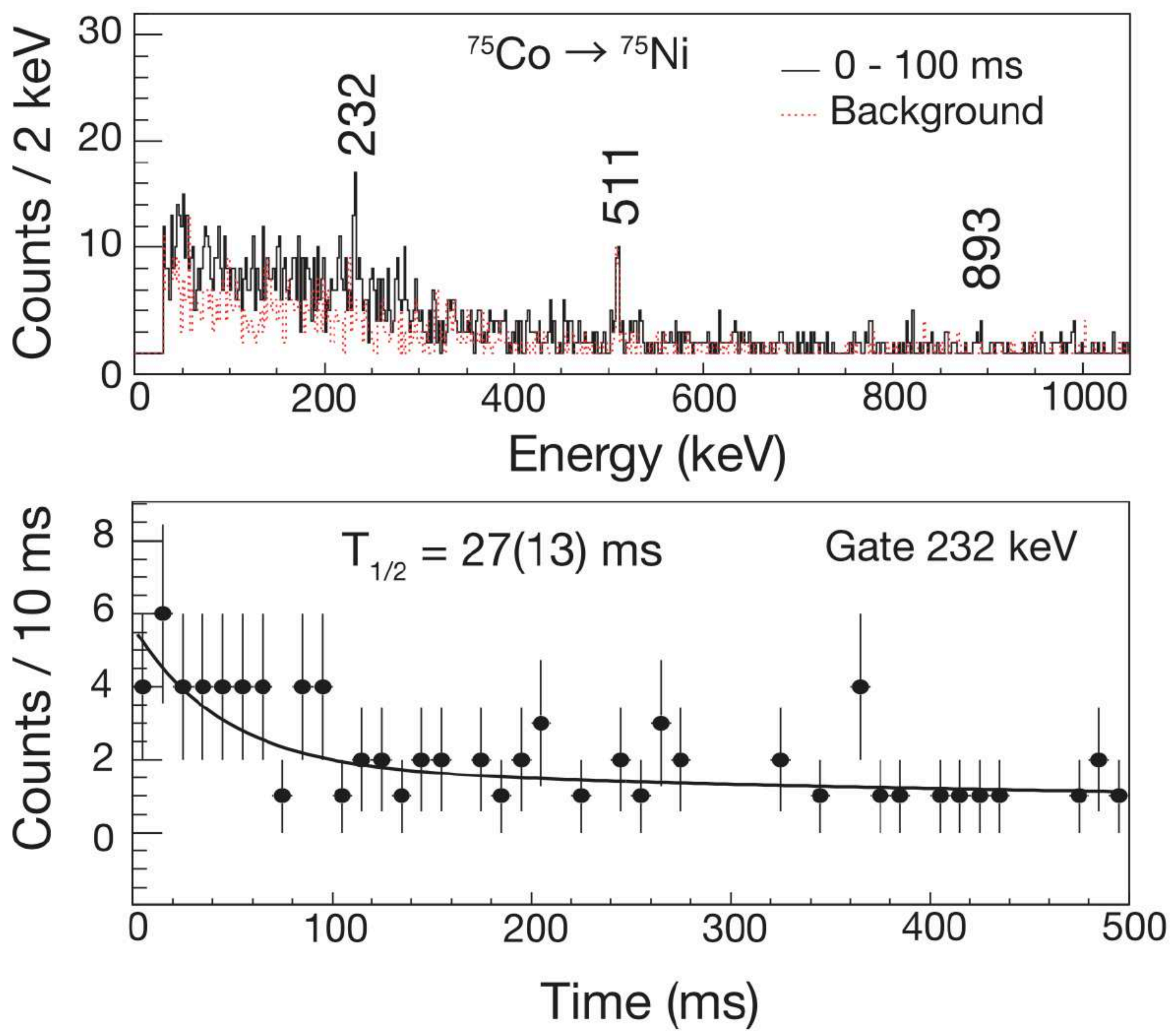
gamma-ray spectra by Clover Ge detectors

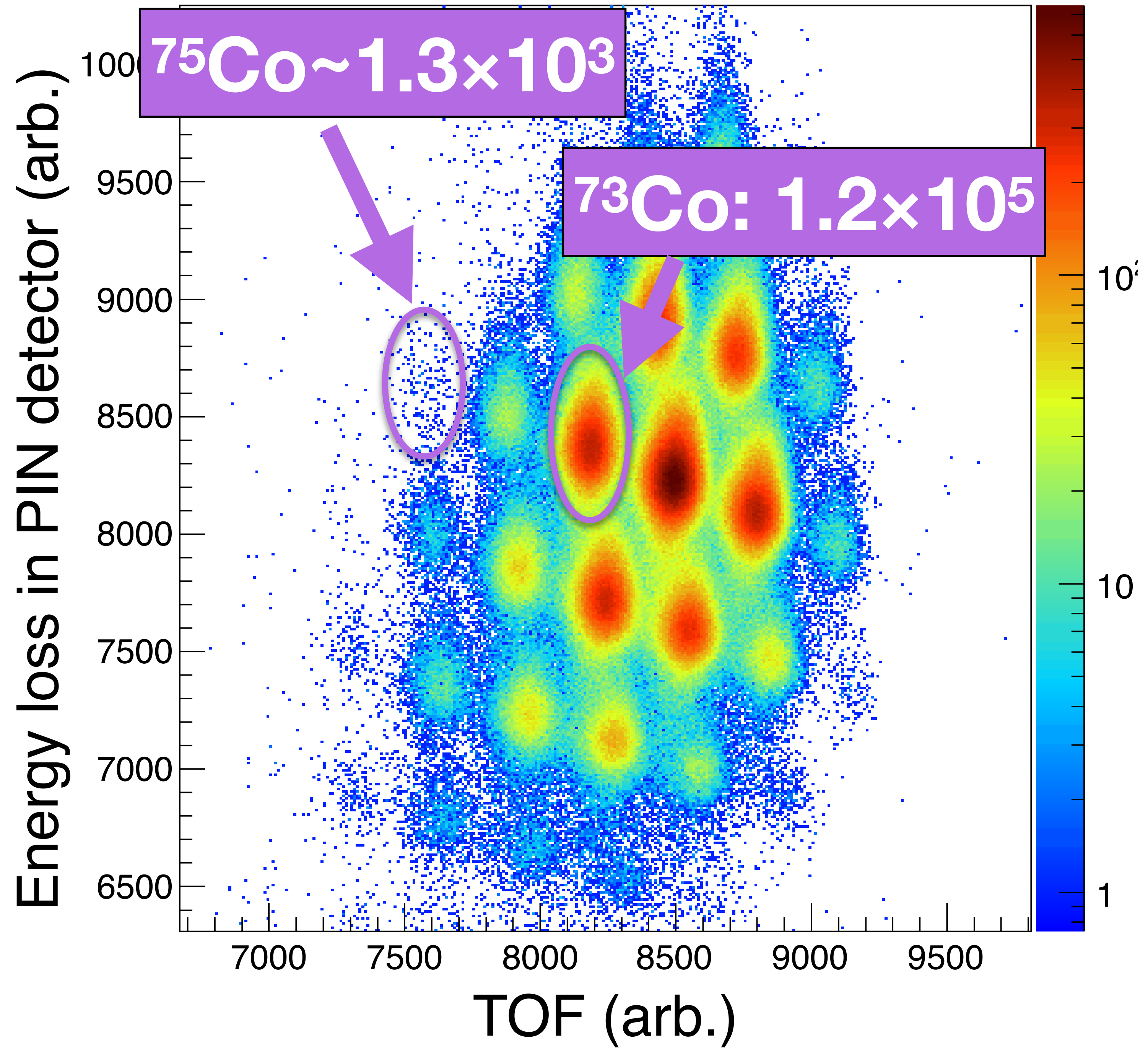


New level scheme for ^{75}Ni in this work

First Report on the first excited state of ^{75}Ni

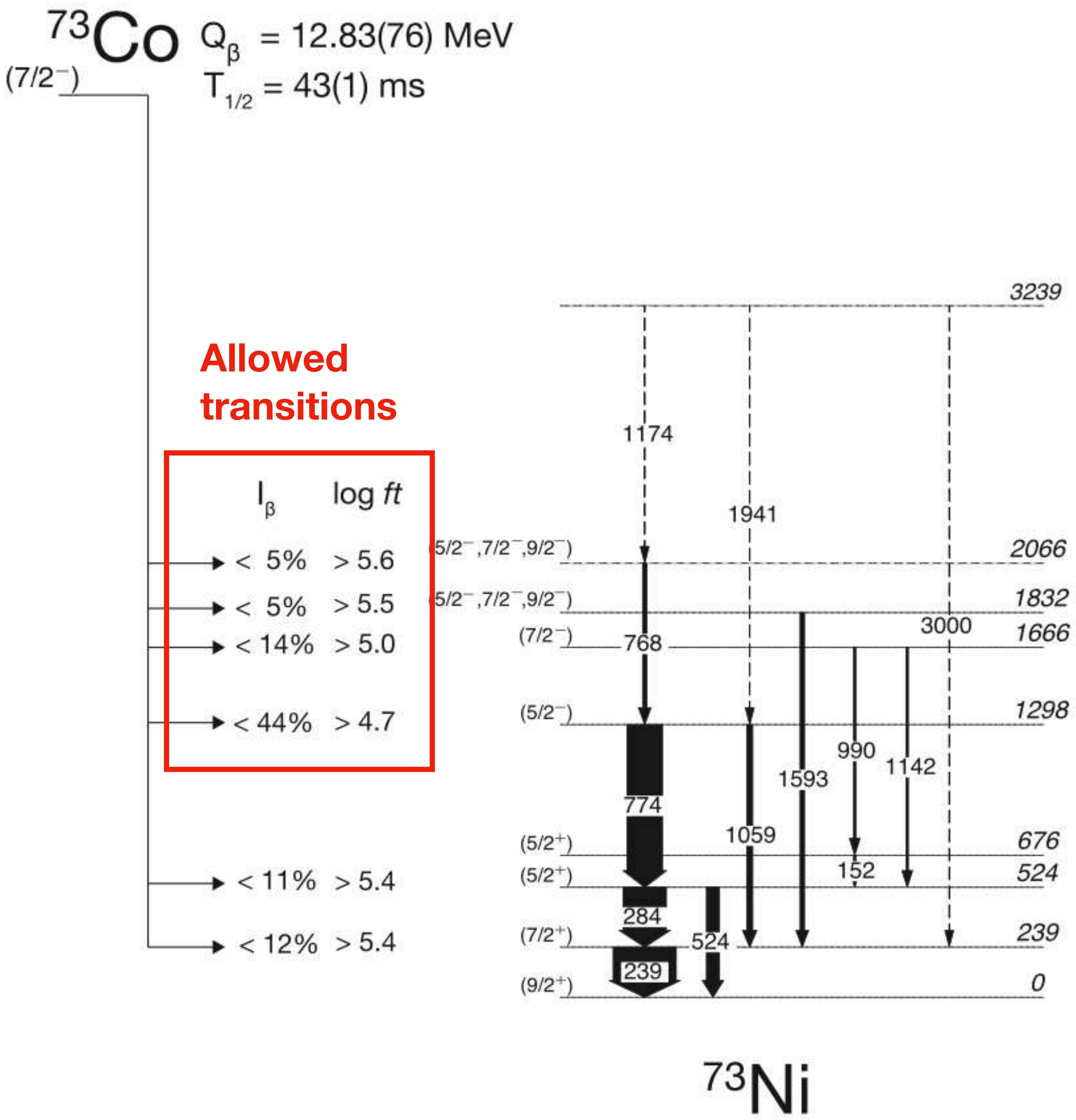






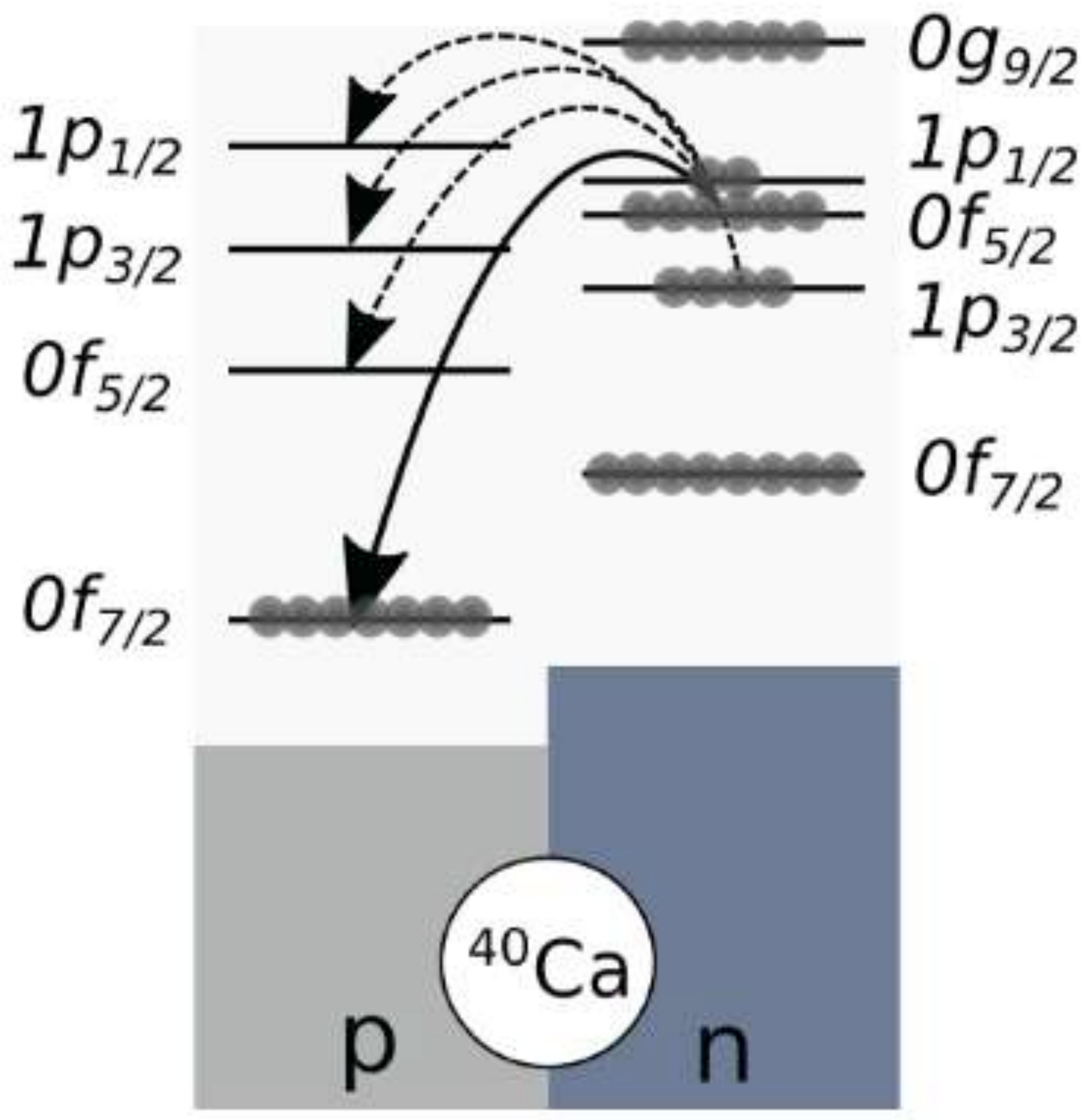
very tough analysis was needed to extract this spectrum…

Shell-model calculations to interpret the obtain levels



Shell model calculations
- ^{40}Ca core
- *fpgpn* interaction

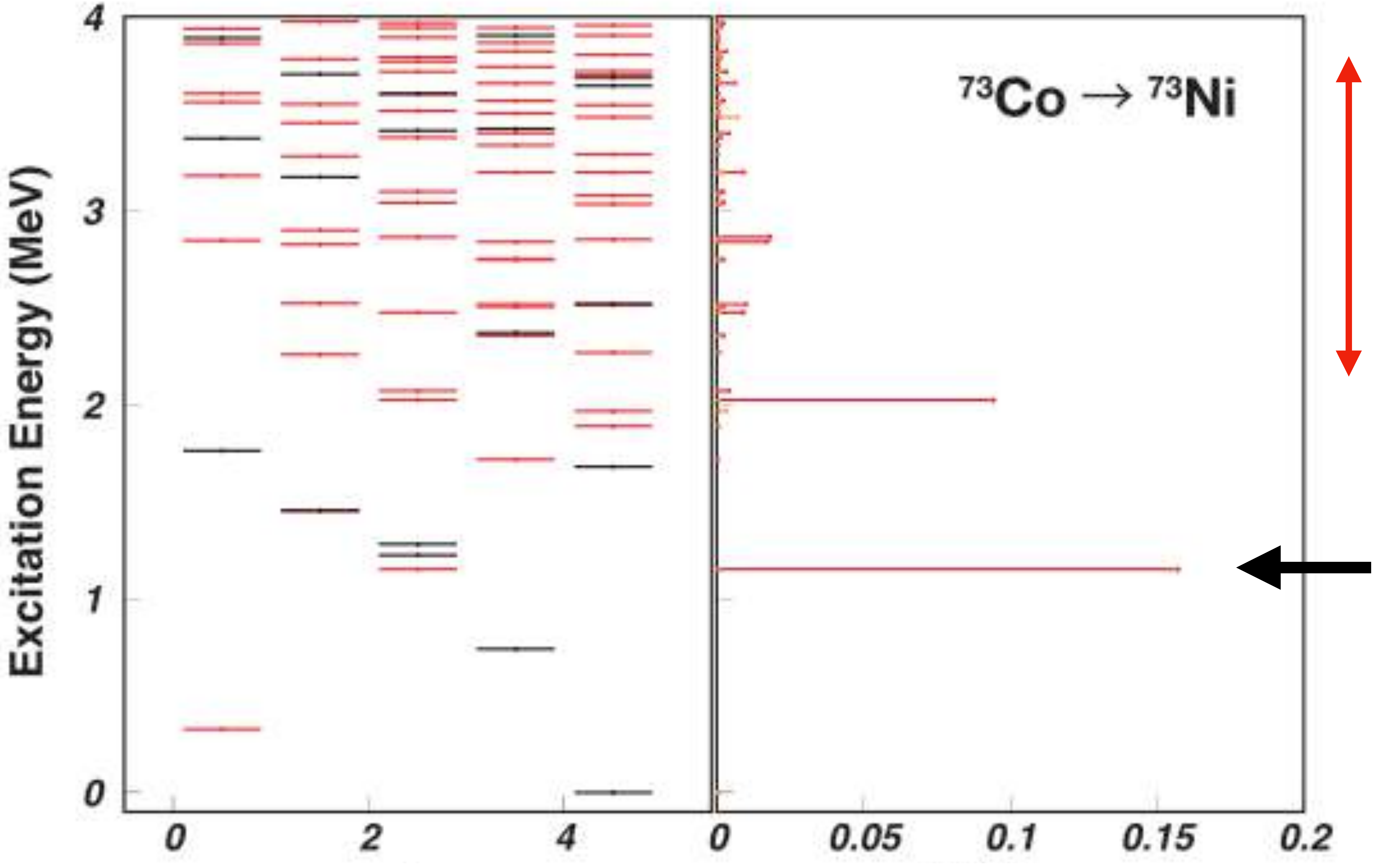
Same as ref. A. Spyrou et al., PRL (2016)



Excited levels and B(GT) strength distribution

Low-excited states and the B(GT) values were reproduced relatively well in the calculations

Red : Negative parity
Black : Positive parity



Spin

Calculated B(GT)

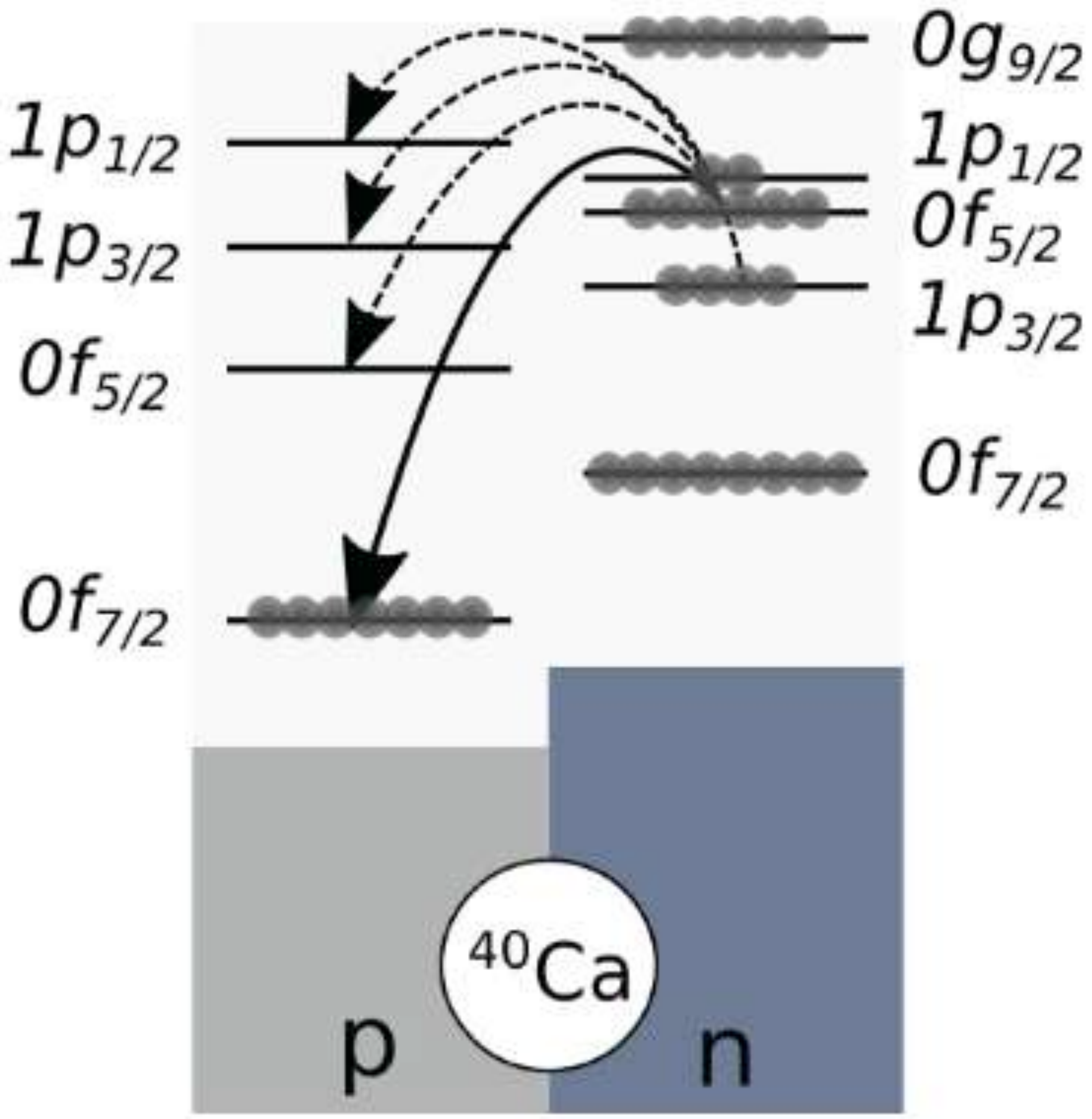
Small fragmented allowed transitions in highly excited states

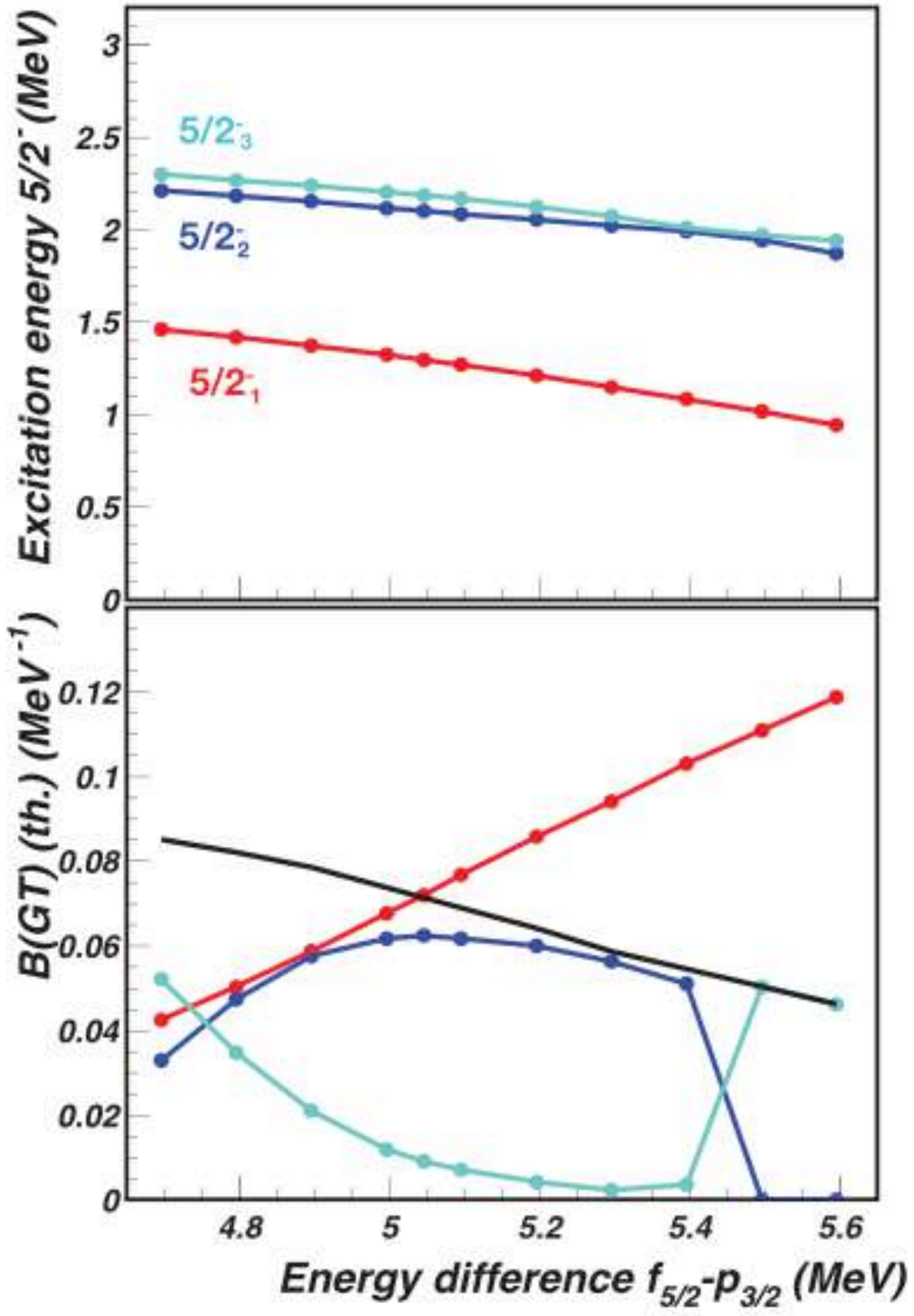
Strong Gamow-Teller transition
$\pi f5/2 \rightarrow \nu f7/2$

→ What is the detail of the fragmented transition strength?

Investigation on the relatively high-excited states

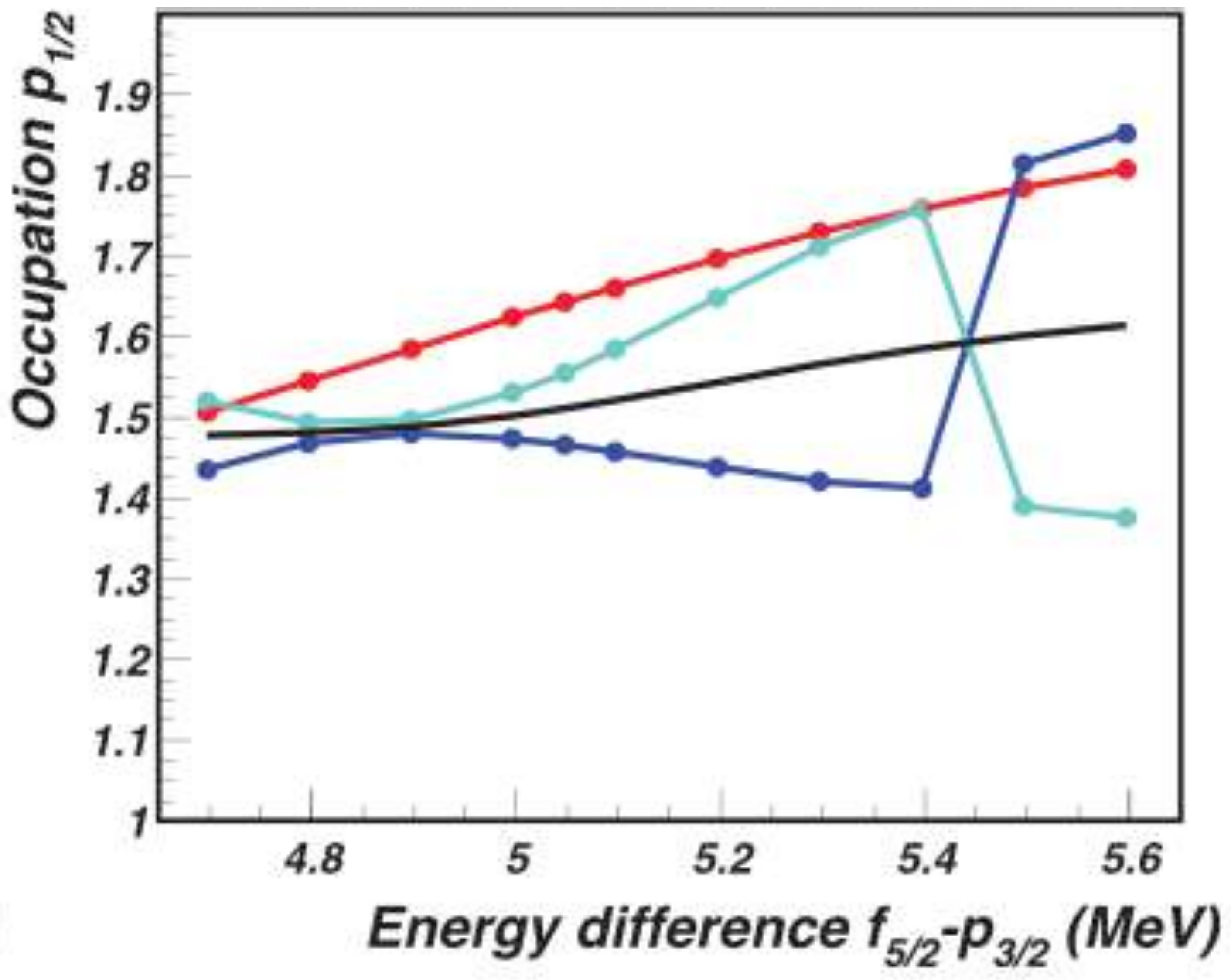
Excitation energies and B(GT) were investigated by changing energy difference of f5/2-p3/2 orbital





- Reproduced mutltiple 5/2- states well
- Weak energy sensitivity for relative splitting
- Level crossing between second and third 5/2-
- Strong variation of B(GT) distributions

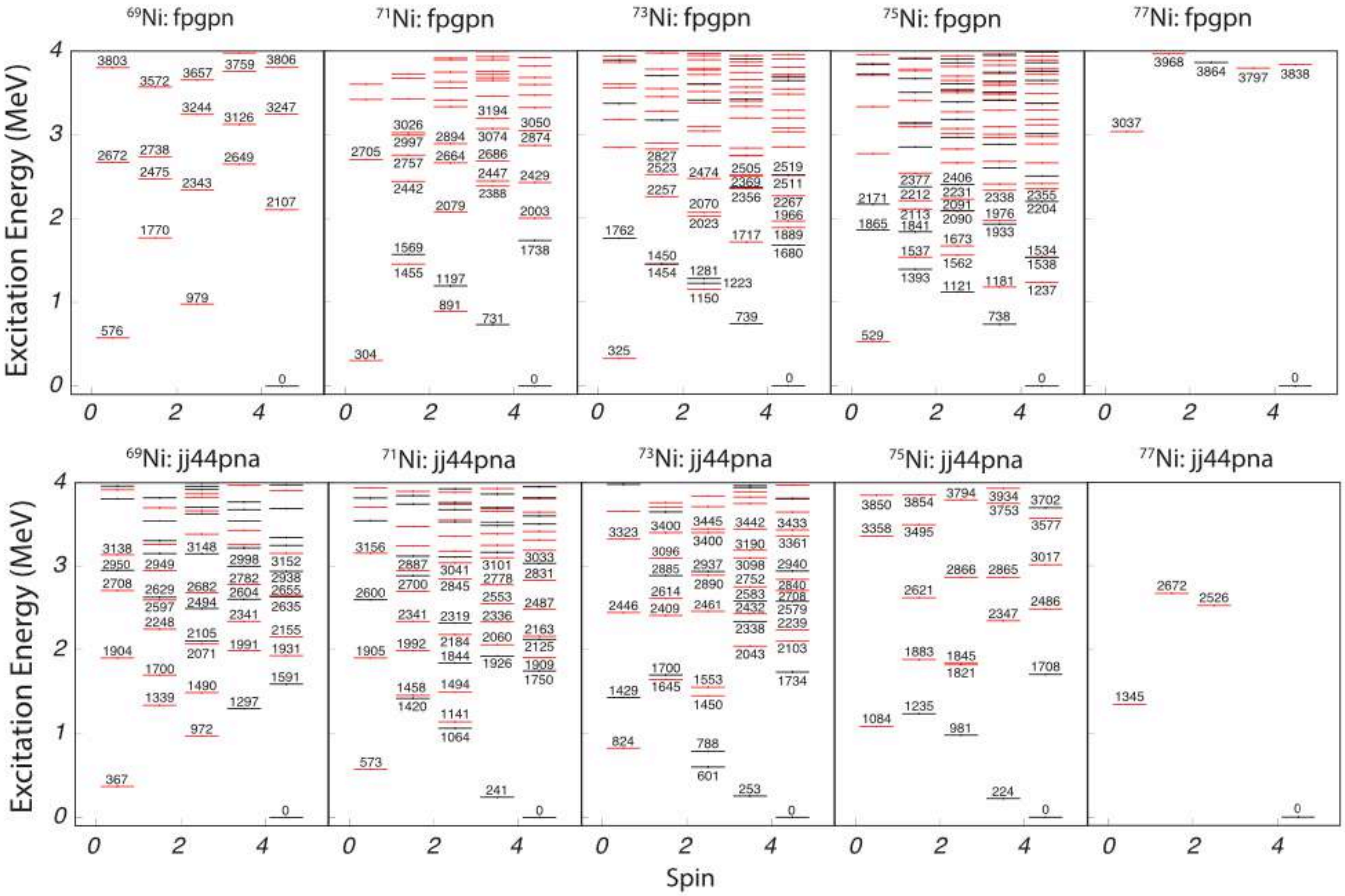
Rapid change of configuration was observed in the calculations



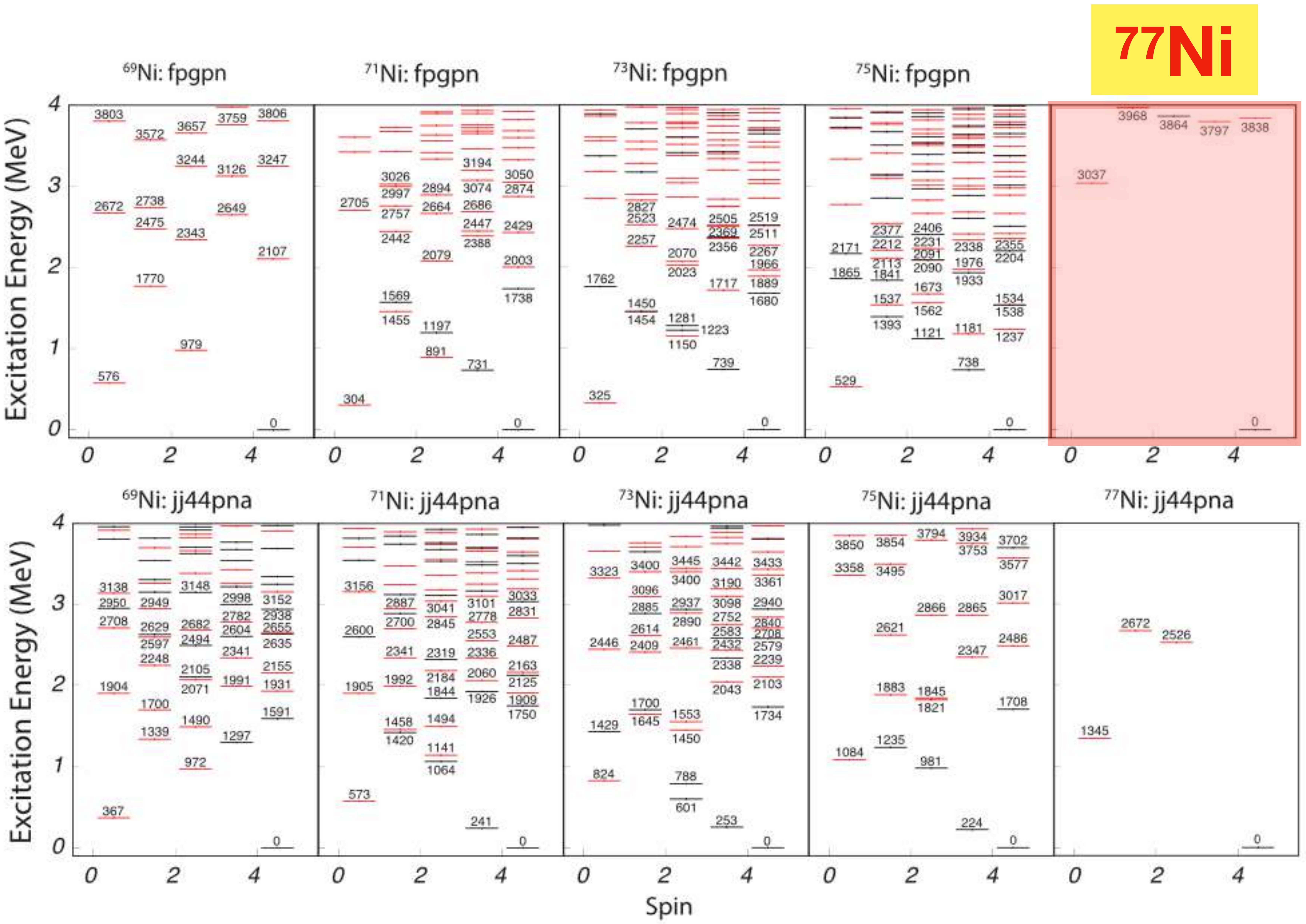
Selectivity of β-decay experiments could state the structural sensitivity with theoretical calculations!

Systematics of level structure in neutron-rich Ni isotopes in calculations

More detailed predicted levels were studied by different interactions

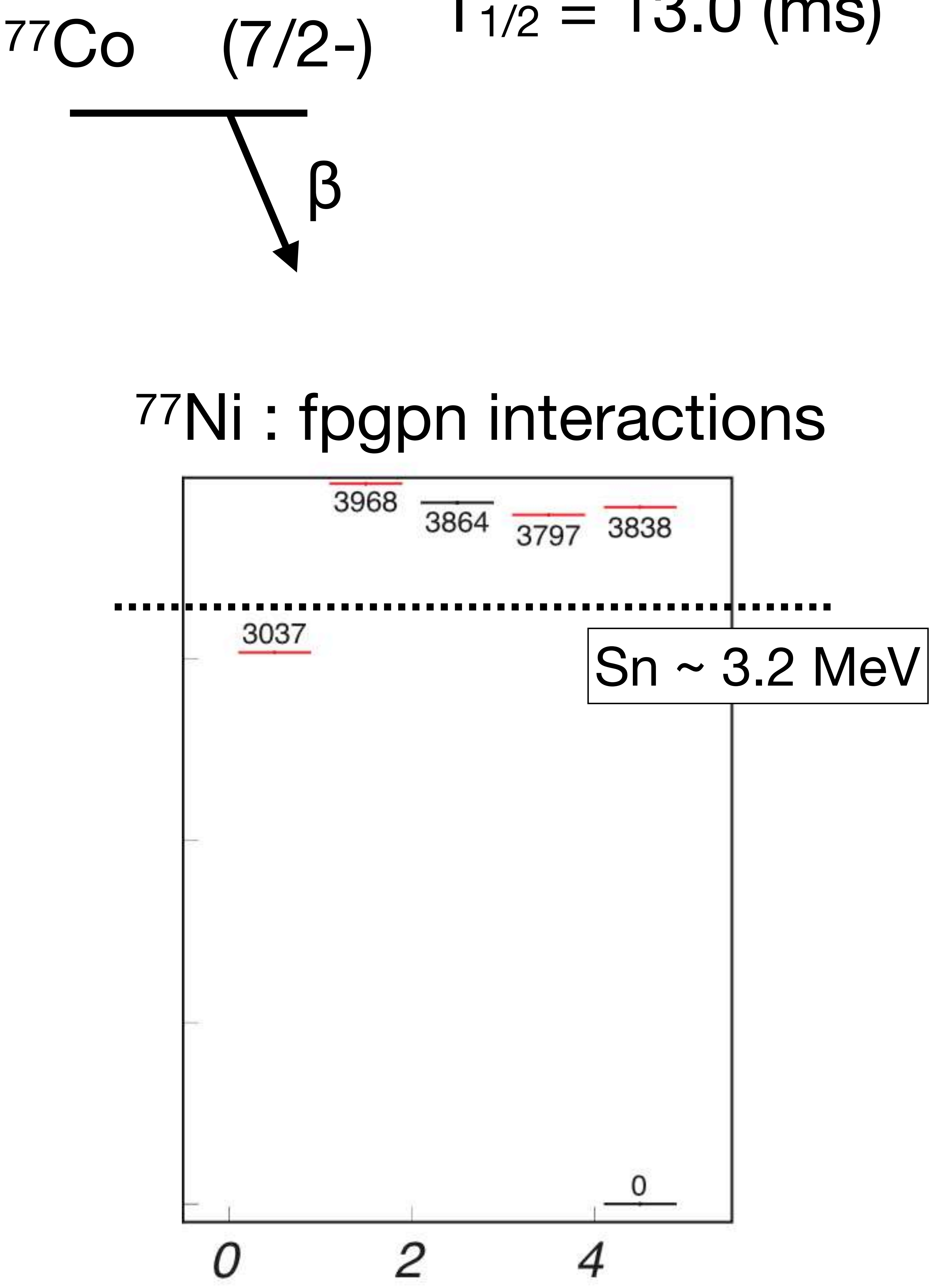


Systematics of level structure in neutron-rich Ni isotopes in calculations



What would we expect in the decay of very-neutron-rich ^{77}Co?

$T_{1/2}$ = 13.0 (ms)



- The g.s. of ^{77}Co : (7/2-)
- The g.s. of ^{77}Ni : (9/2+)

The allowed transition dose not occur between the ground states

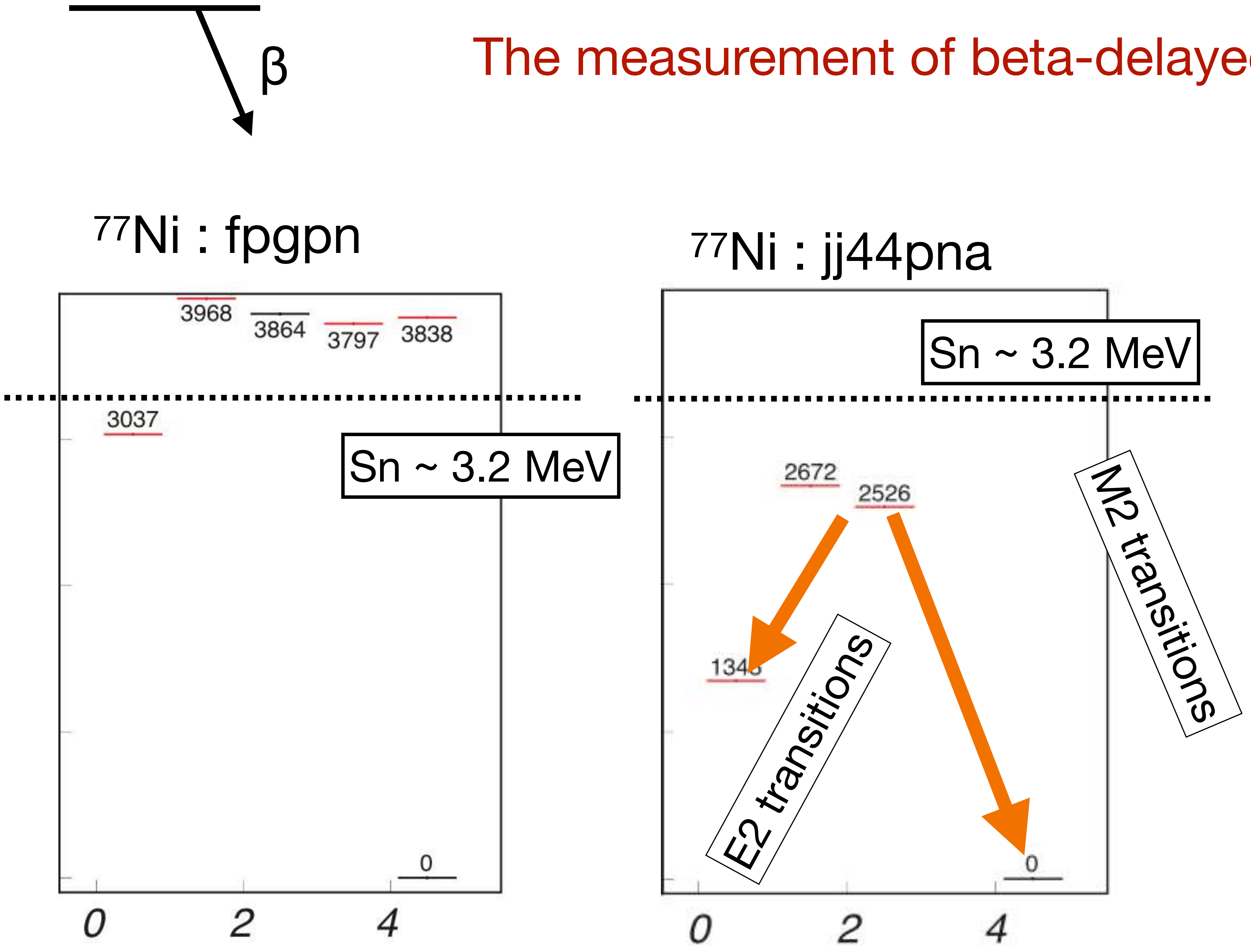
- Neutron-separation energy Sn = 3240(640) keV
- 5/2- state is not predicted below 4 MeV

The transition strength is above neutron-threshold energy, may result in the **strong neutron emission in the β-decay**

What would we expect in the decay of very-neutron-rich ^{77}Co?

^{77}Co (7/2-) $T_{1/2}$ = 13.0 (ms)

The measurement of beta-delayed neutron-emission is important



fpgpn predictions

- strong neutron emission

jj44pna predictions

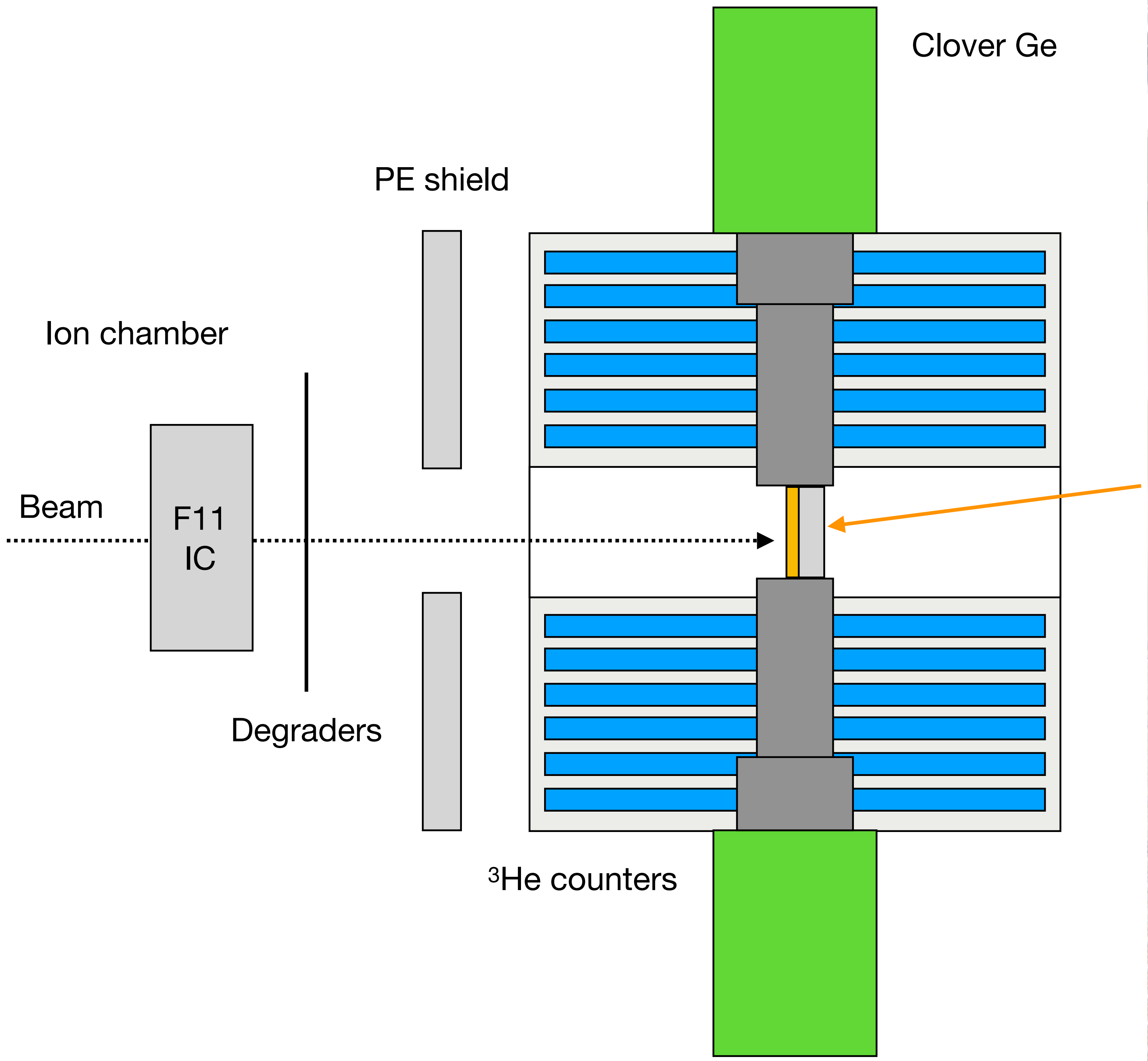
- High-energy M2 transition
- E2 transition to isomeric states ($1/2^-$)

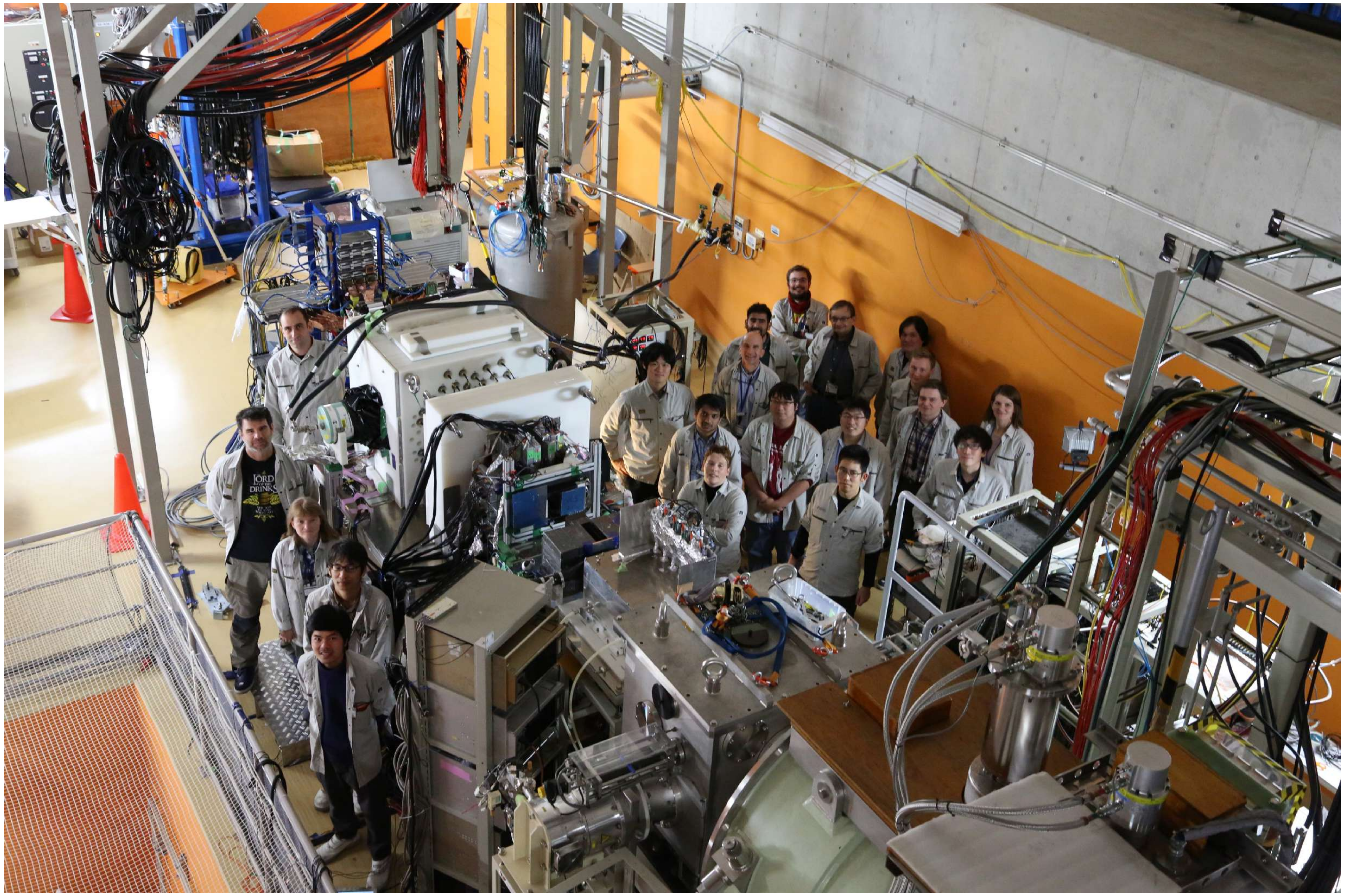
What kind of measurement is important?

Beta-delayed neutron measurement project (BRIKEN at RIKEN RIBF)

^{3}He counter

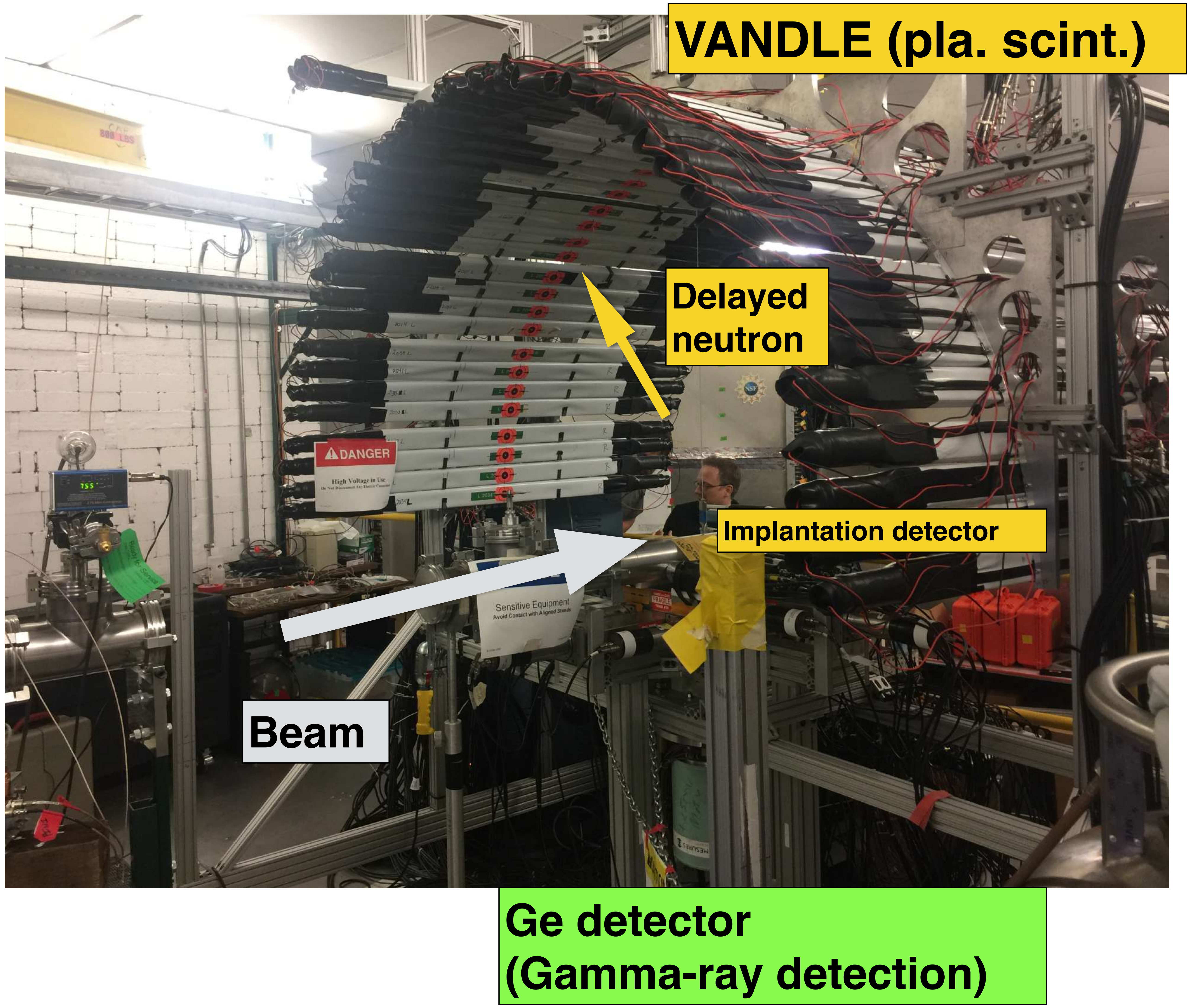
(n+^{3}He→^{3}H+^{1}H+0.764 MeV)

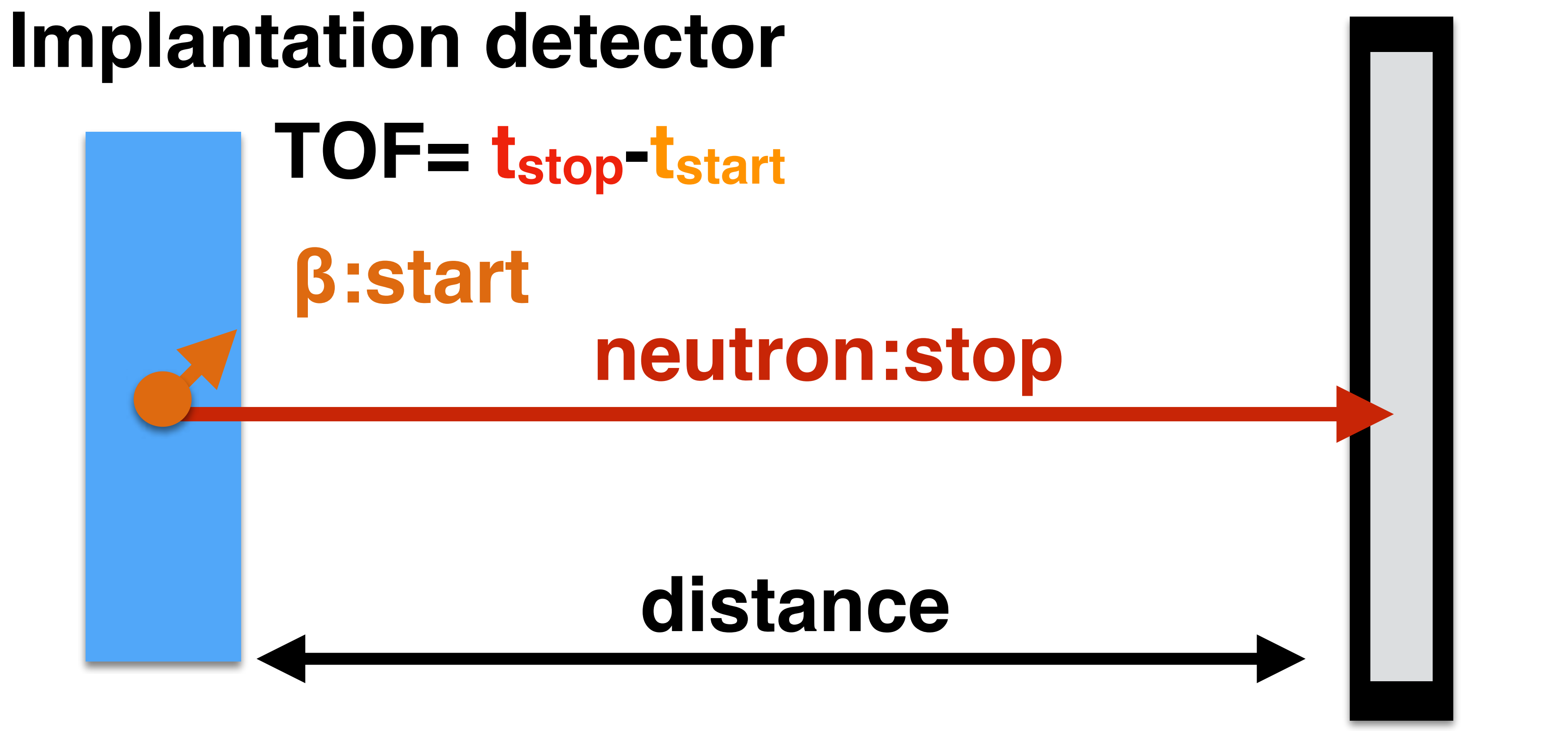


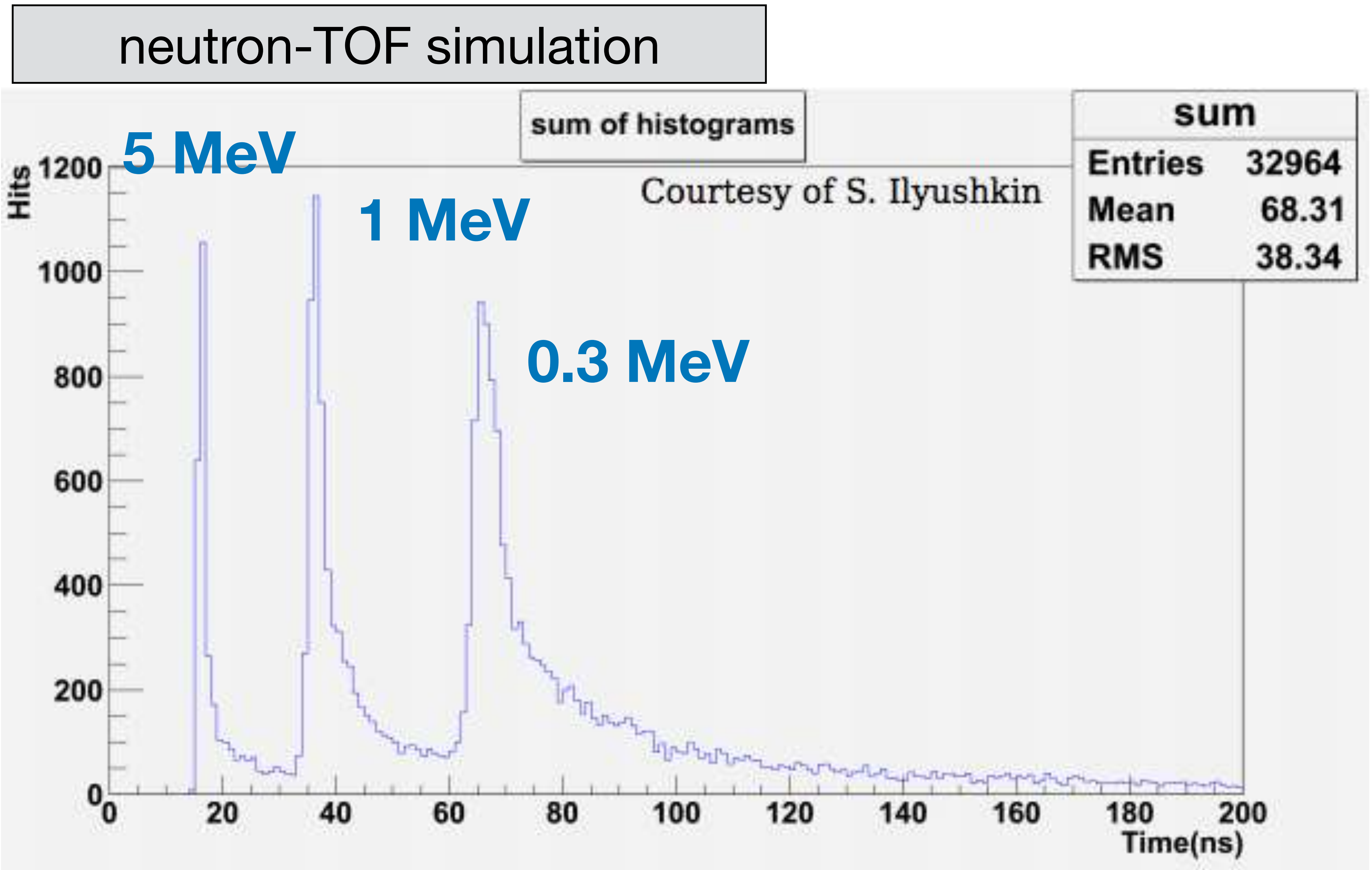


Neutron-time-of flight measurement with β-γ spectroscopy

Neutron-energy spectroscopy with neutron time-of-flight measurements



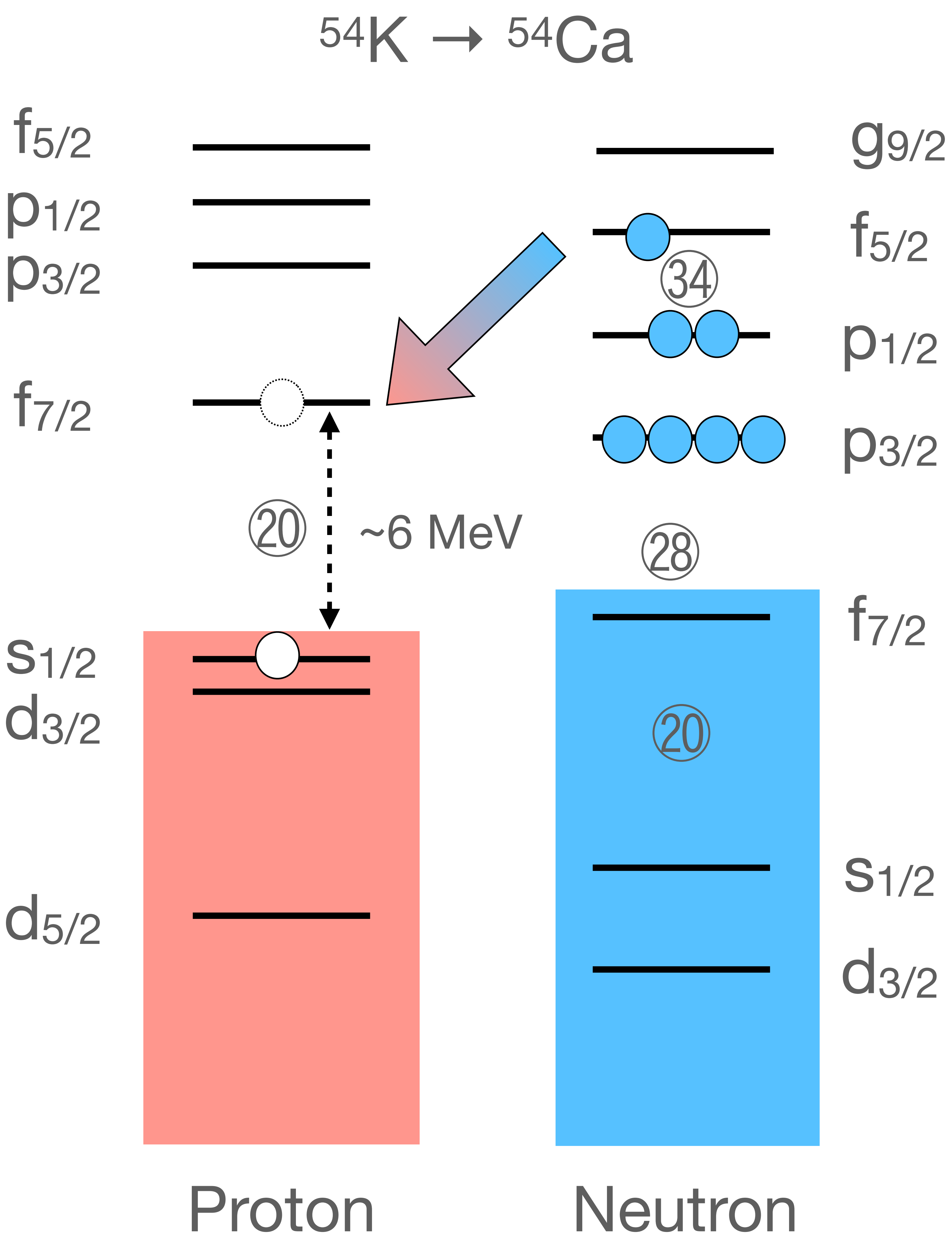




Developed by University of Tennessee Group

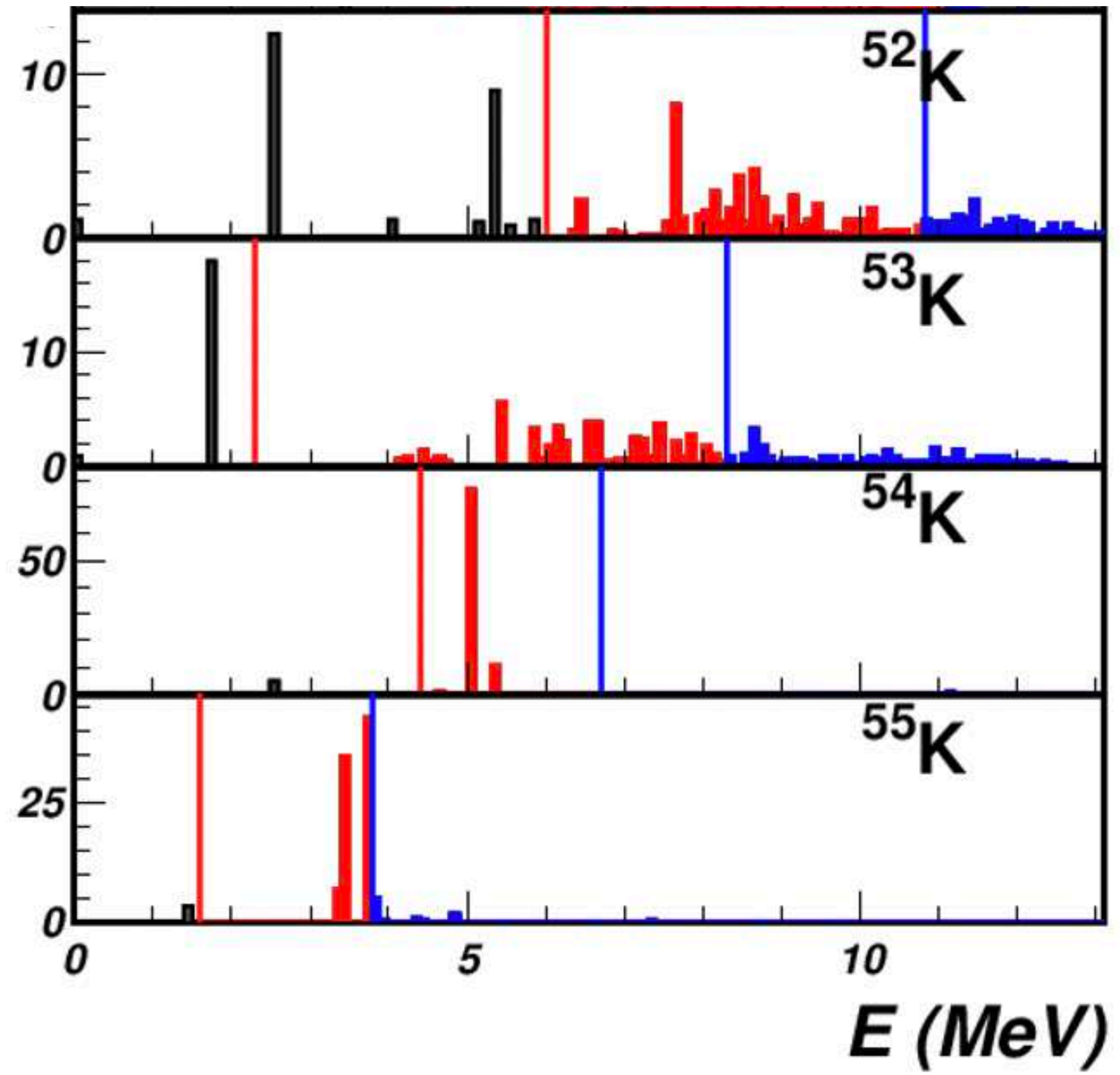
Gamow-Teller transitions could be expected in several nuclei

Ex. Strong neutron emission is expected in ^{54}K decay



Shell-model calculations

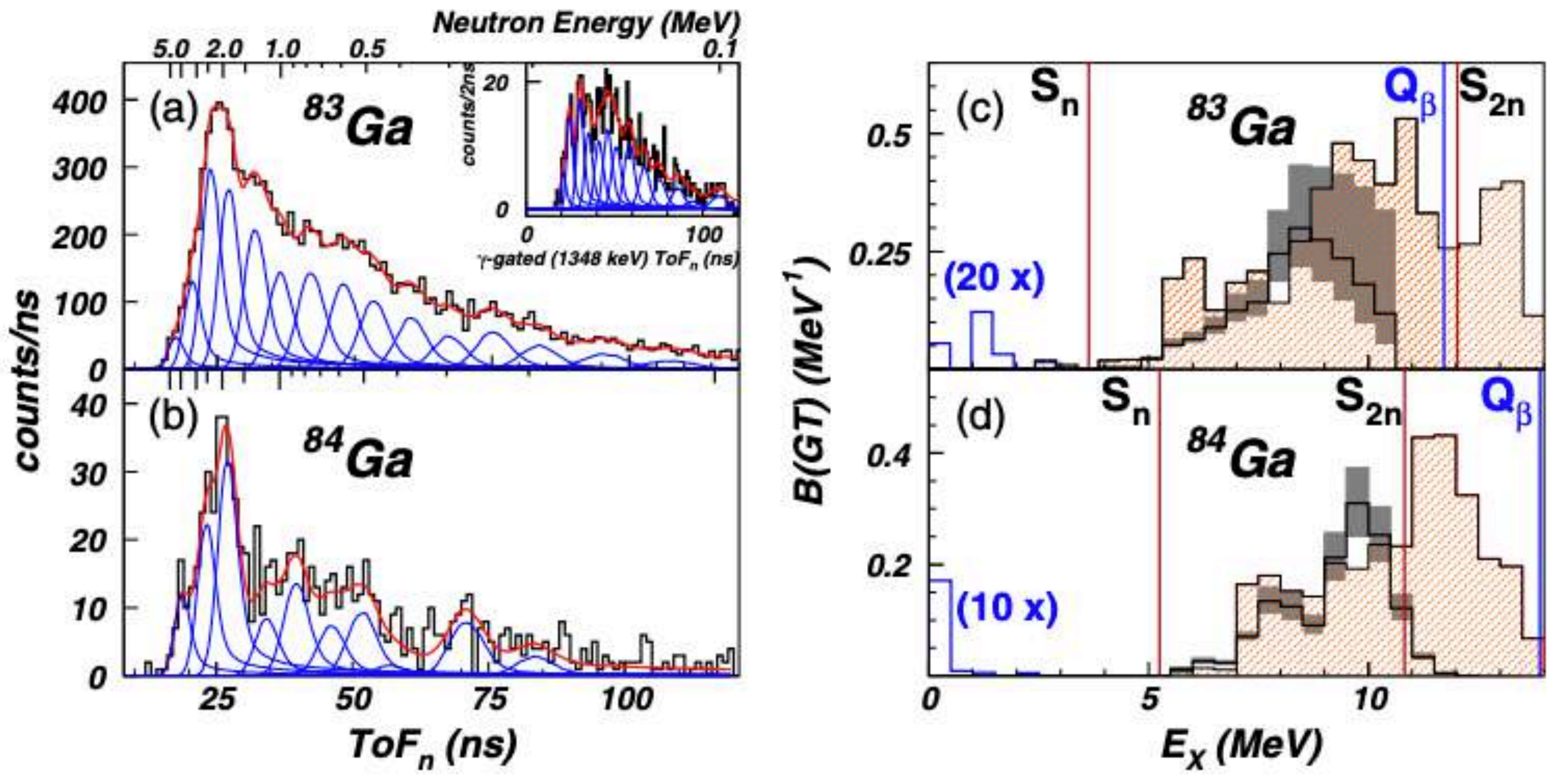
Courtesy R. Grzywacz



Intersting works above neutron-separation energies

Intense neutron emission (^{83,84}Ga)

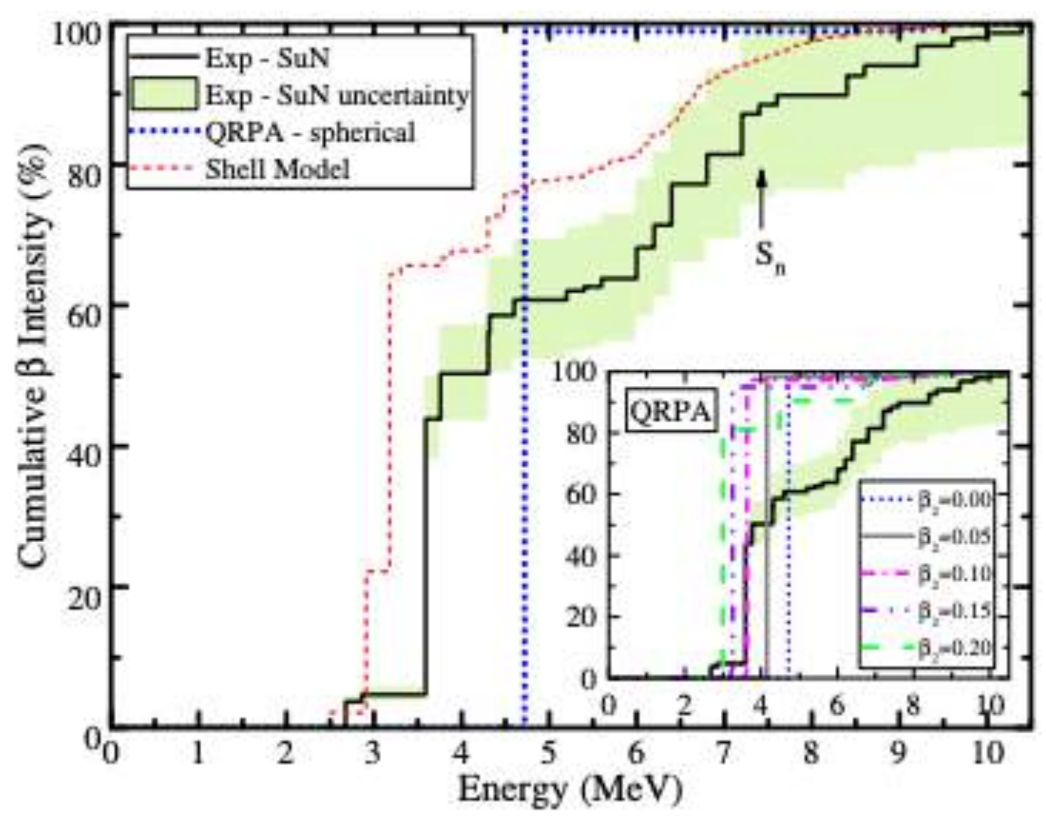
neutron ToF (VANDLE) at ORNL



M. Madurga et al., PRL (2016)

Strong n-γ competition above Sn energy (^{70}Co)

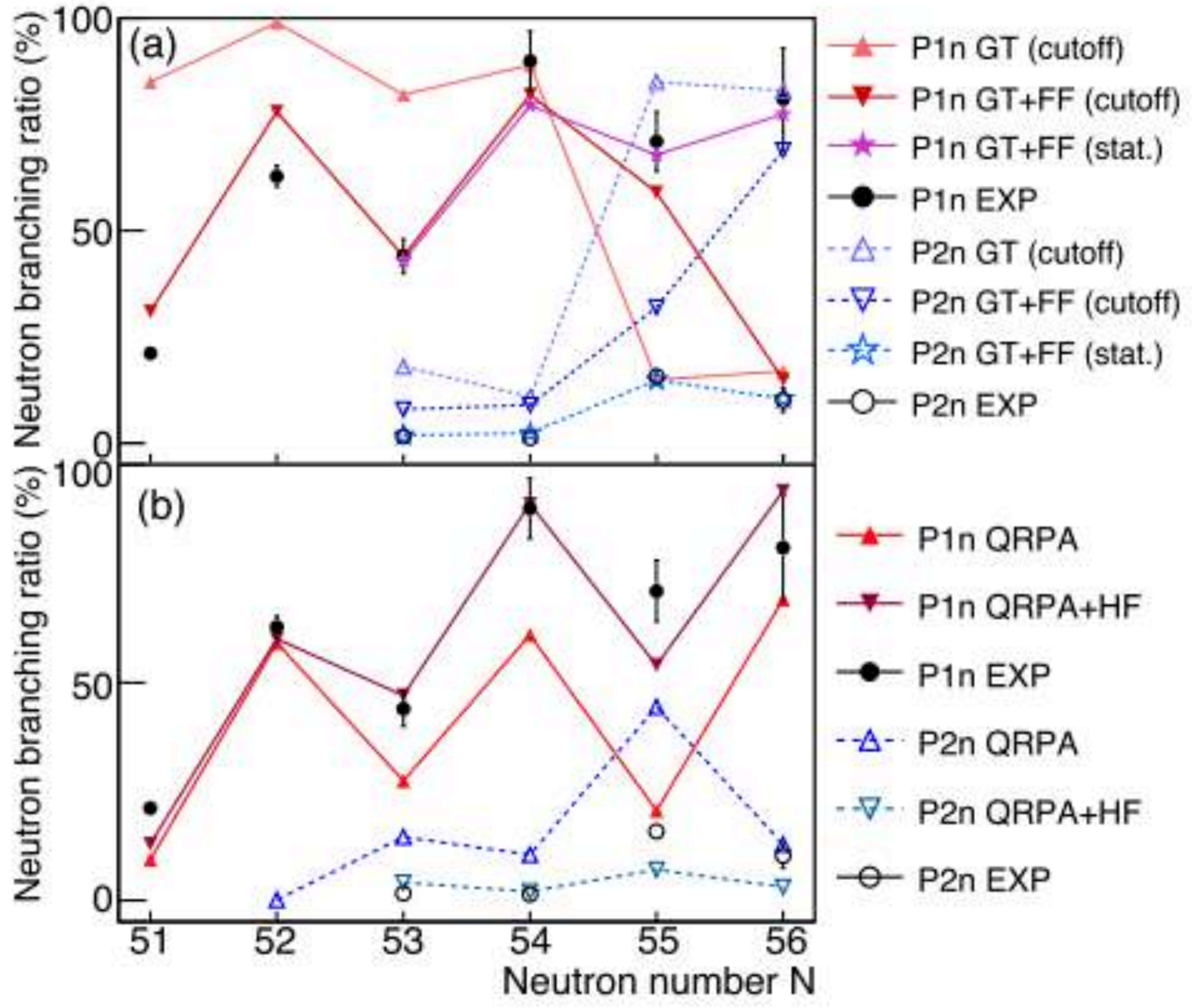
Total Absorption γ Spectroscopy (SuN) at MSU/NSCL



A. Spyrou et al., PRL (2016)

Strong 1n emission from 2n unbound states (^{86,87}Ga)

^{3}He counter array (BRIKEN) at RIKEN



R. Yokoyama et al., PRC(R) (2019)

Several interesting phenomena have been observed above neutron threshold energies

Summary

- β-γ spectroscopy on neutron-rich $^{73,75}Co$ at MSU/NSCL
- New excited levels for $^{73,75}Ni$ were obtained
- Fragmented strength distribution was observed in the decay of $^{73}Co \rightarrow ^{73}Ni$
- The multiple $5/2^-$ states were investigated via shell-model calculations
- Possibility of strong-neutron emission in some nuclei (^{77}Co, ^{54}K…)
  - More accurate mapping of GT transitions in less neutron-rich nuclei is important
- Decay above neutron threshold is now extensively studied

Dziękuję za zaproszenie i Waszą uwagę!