Investigation of ^{70,72,74}Ni from β decay of ^{70,72,74}Co

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For the EURICA collaboration

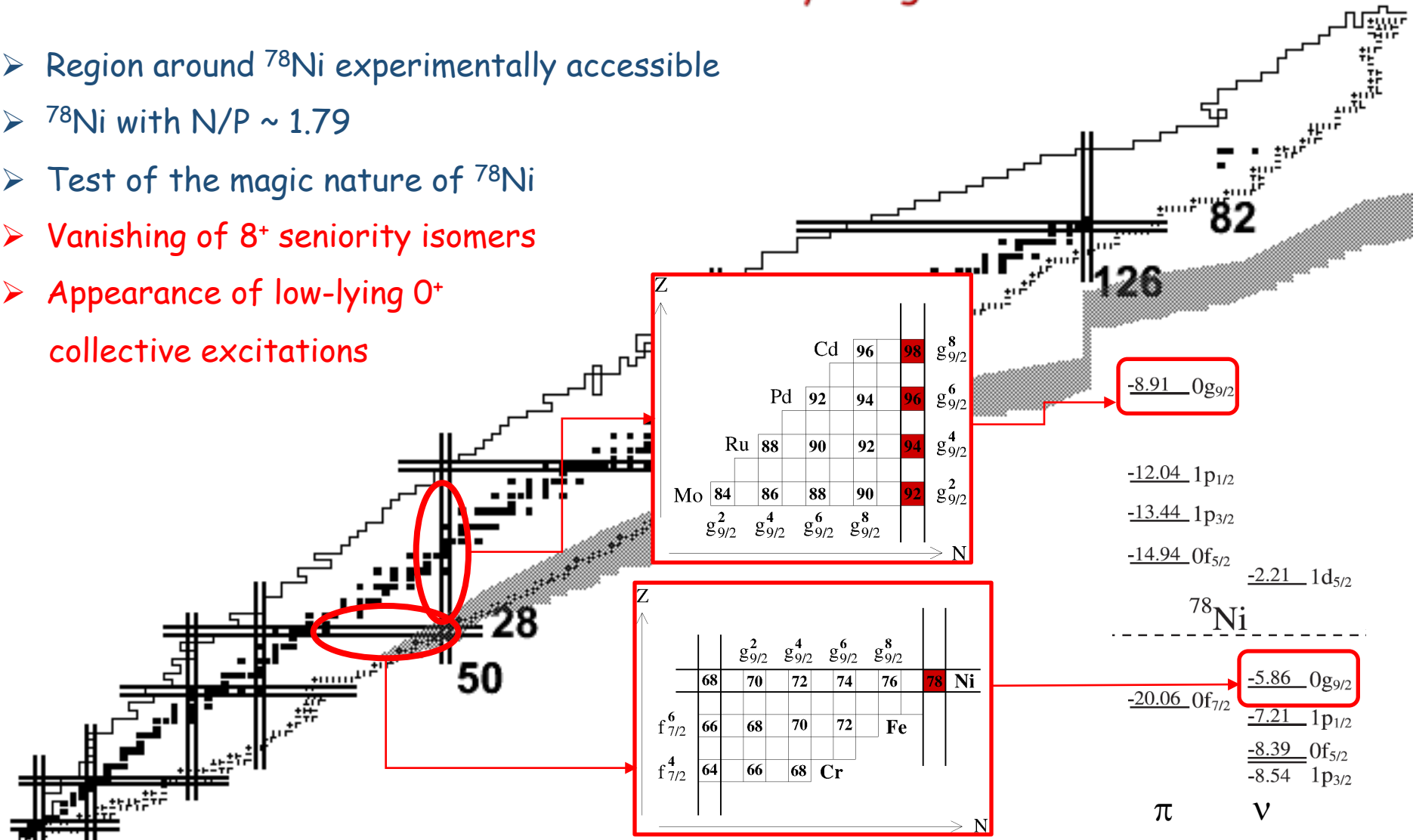
Outline:

- Motivation of studies and description of setup
- ^{70}Ni: shape coexistence
  - Late information
  - ^{70}Co -> ^{70}Ni decay
  - ^{71}Co -> ^{70}Ni
  - ^{70}Fe -> ^{70}Co -> ^{70}Ni
- ^{72}Ni: seniority isomer; shape coexistence
  - Updated knowledge
  - ^{72}Co-> ^{72}Ni
  - ^{72}Fe -> ^{72}Co -> ^{72}Ni
- ^{74}Ni: starting analysis

MOTIVATION

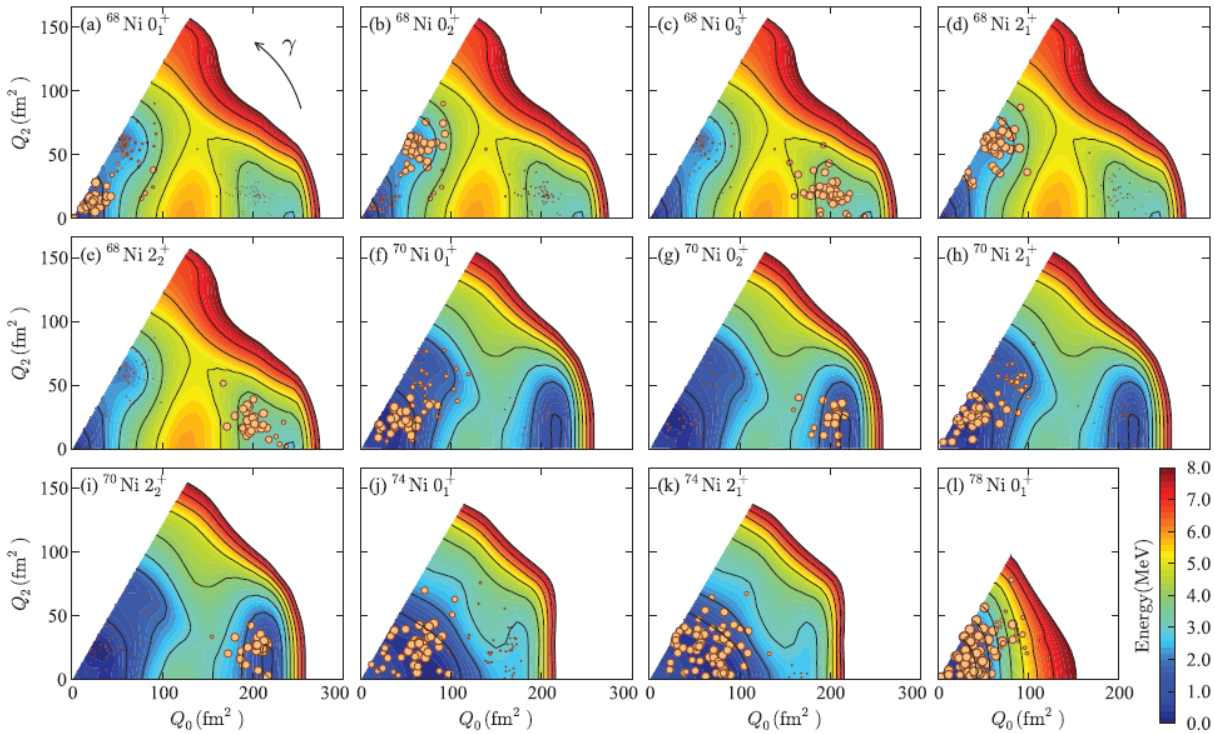
Study of atypical phenomena near the most n-rich doubly-magic nucleus

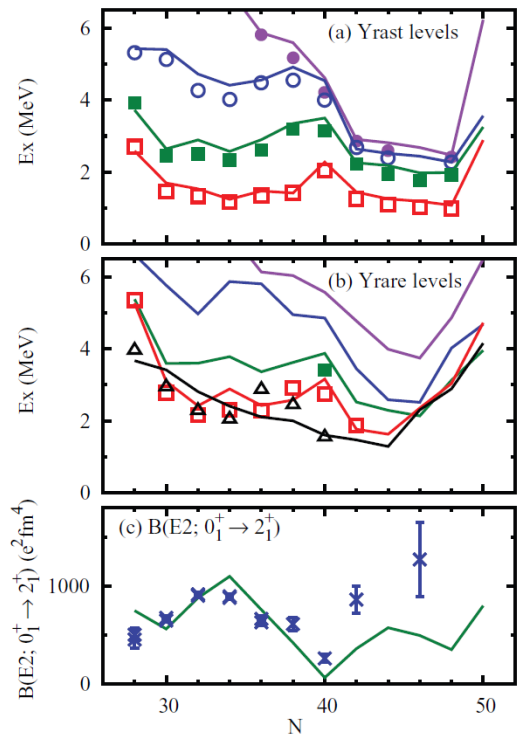
- Region around ^{78}Ni experimentally accessible
- ^{78}Ni with N/P ~ 1.79
- Test of the magic nature of ^{78}Ni
- Vanishing of 8^+ seniority isomers
- Appearance of low-lying 0^+ collective excitations



MOTIVATION

Low-lying collective excitations in Ni isotopes

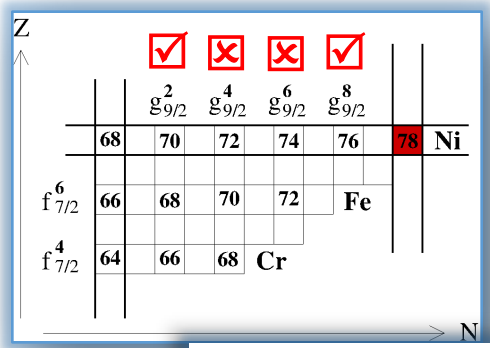




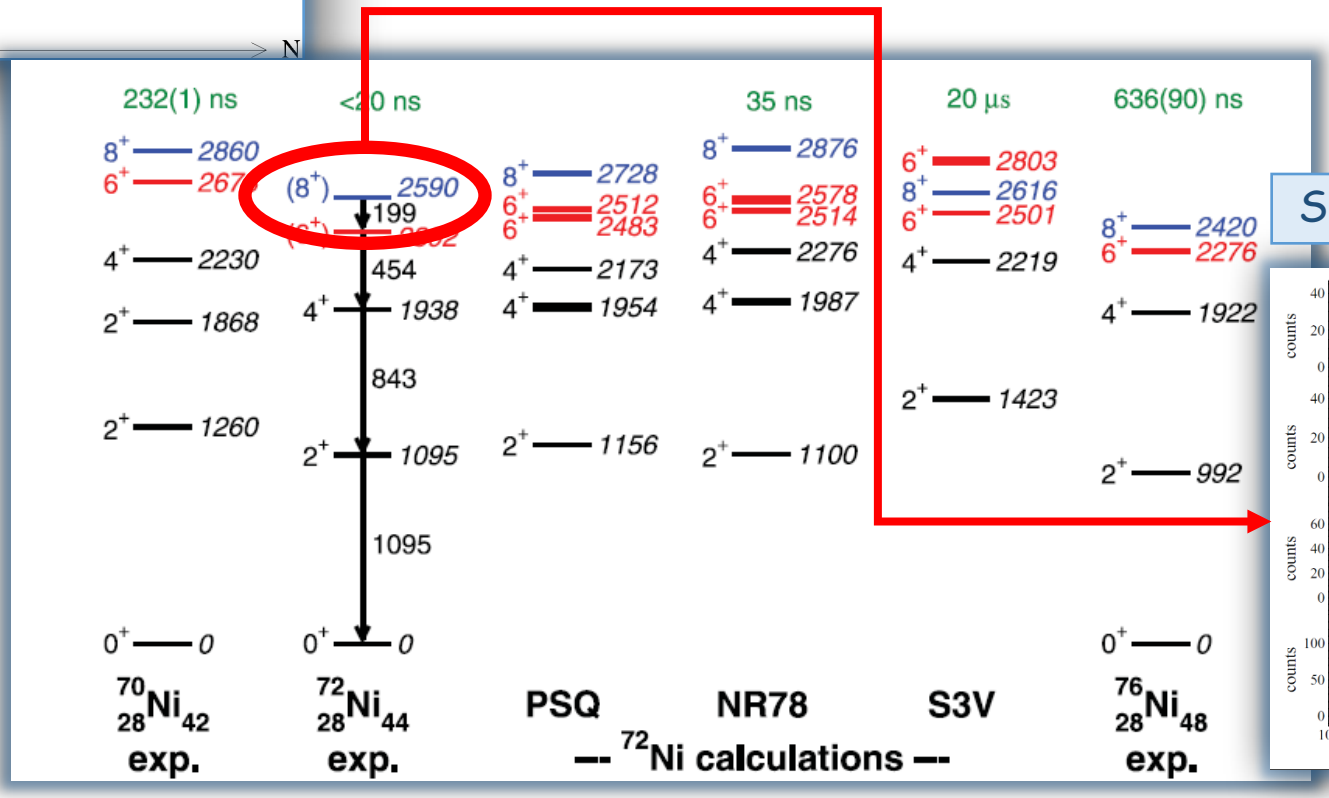
- MCSM calculations predict the coexistence of shapes at low excitation energies [Y. Tsunoda et al., PRC (2014)]
- Three 0+ excited states below 3 MeV have been identified in ^{68}Ni.

MOTIVATION

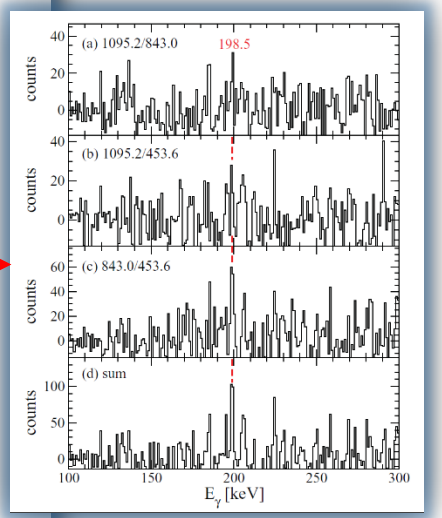
Is the seniority scheme valid around ^{78}Ni?



- 8^+ SI observed in ^{70,76}Ni [R. Gryzwacz, PRL (1998), C. Mazzocchi, PLB (2005)]
- No experimental evidence of 8^+ SI in ^{72,74}Ni
- $t_{1/2}(^{72}\text{Ni},8^+)$ < 20 ns or > 3-4 ms [M. Sawicka, PRC (2003)]
- Tentative 8+ @ 2590 keV [C.J. Chiara, PRC (2011)]



Scarce statistics!



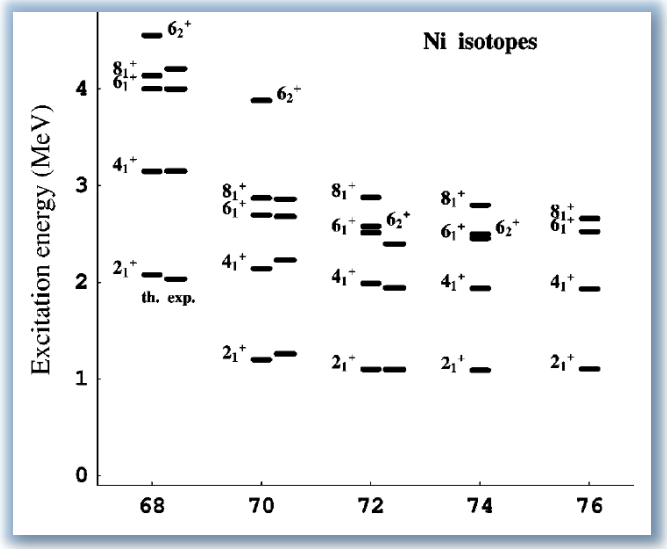
MOTIVATION

Theoretical hypothesis

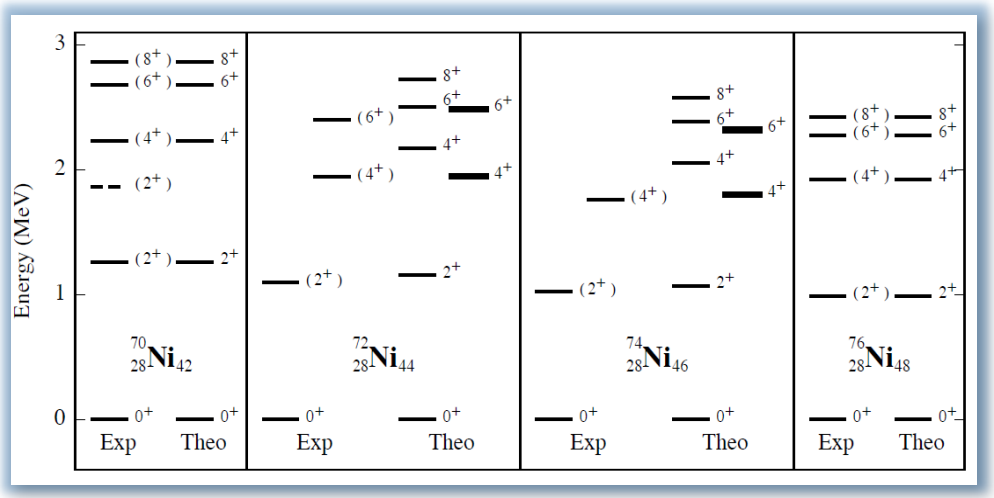
- The 6+ level with seniority ν=4 lies at about the same energy than the ν=2, 6^+ state. This would open a fast decay path between states of different seniority
  [H. Grawe, NPA (2002), A.F. Lisetskiy, PRC (2004), P. Van Isacker, IJMPE (2011)]

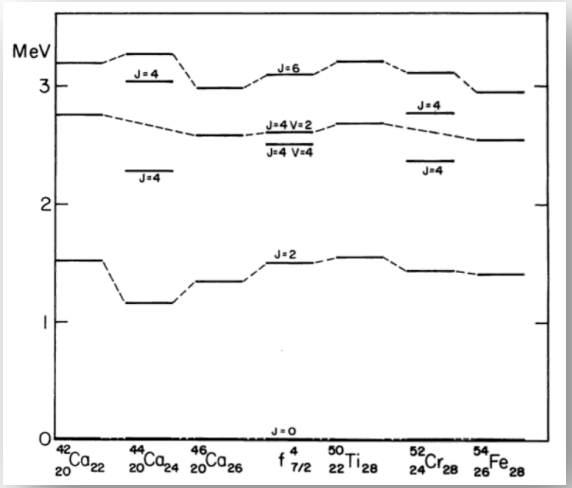
- Inversion of seniority ν=2, ν=4 previously observed only in the $f_{7/2}$ shell
  [I. Talmi, *Simple Models of Complex Nuclei*, Harwood Academic publishers,1993]

SM calculations [A.F. Lisetskiy, PRC (2004)]



PSQ calculations [P. Van Isacker, IJMPE (2011)]

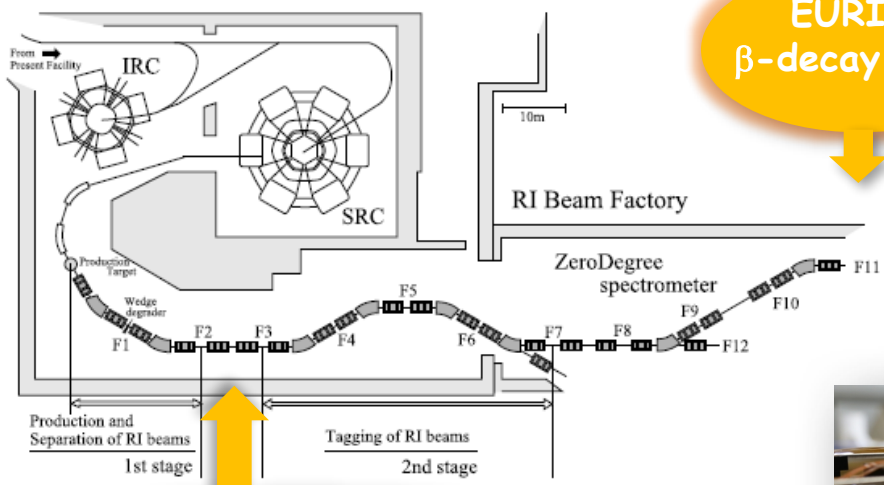




THE EXPERIMENT

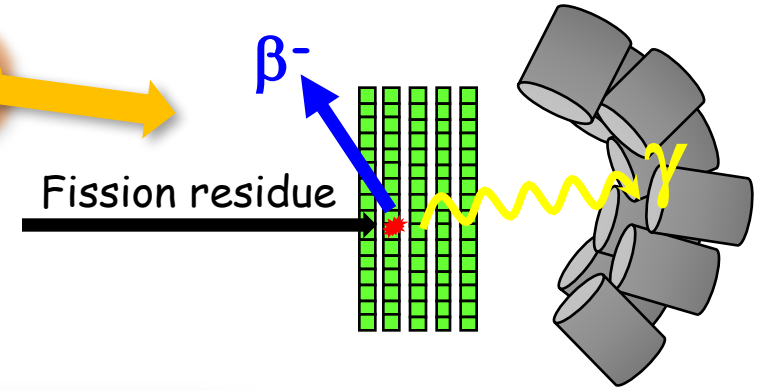
Radioactive Isotope Beam Factory (RIBF) @ RIKEN

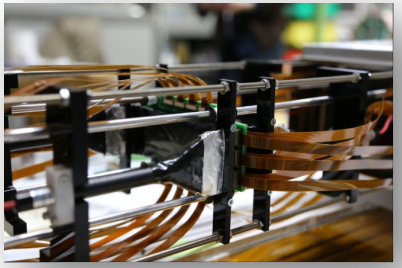
^{238}U + Be @ 345 AMeV, 10 pnA



EURICA β-decay setup

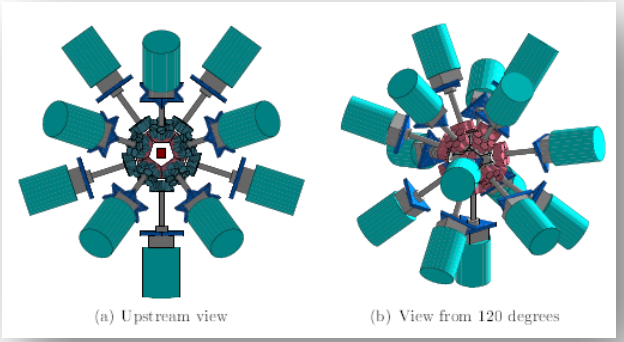
BigRIPS: Particle ID





➢ **WAS3ABI**

- 5 DSSSDs 60x40 strips
- 1 mm² pitch, 1 mm thick
- Ion-β correlations (~ ms)



➢ **EURICA**

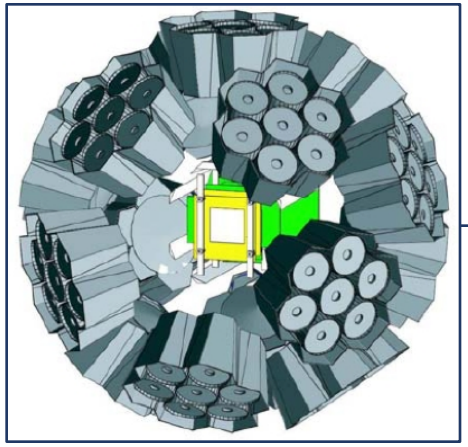
- 12 HPGe clusters
- 84 crystals
- Eγ=11% at 662 keV

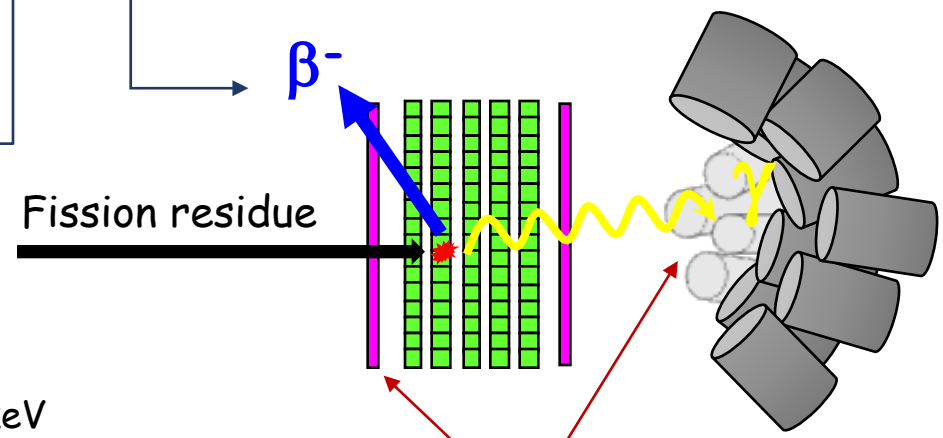
ION-β, β–γ and β–γ–γ Correlations

THE EXPERIMENT

Fast-Timing setup

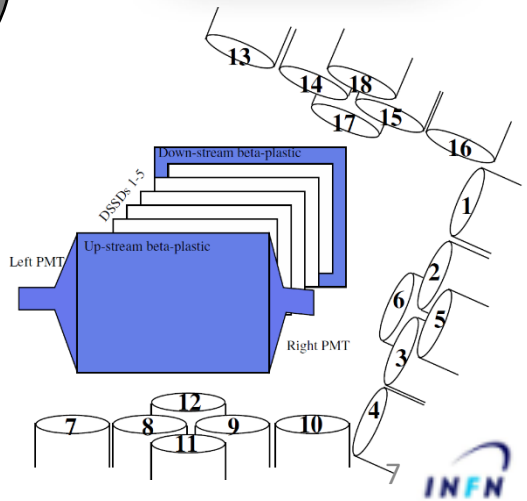
- Half-lives of excited states within the **ps-ns** range
  - ✓ Measure β_2 of 2^+, 4^+ states in even-even deformed nuclei
  - ✓ Inspect configuration mixing, seniority scheme in spherical nuclei
  - ✓ Search for β-delayed short-lived isomers



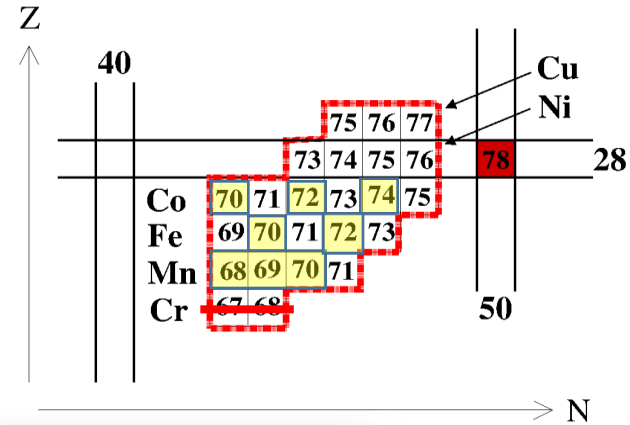


- **18 $LaBr_3$(Ce)**
  - 1.5"x 2"
  - 5 mm lead shields
  - Eff 1.5% @ 662 keV
- **2 BC-418 fast plastics**
  - 45x150 mm^2
  - 2 mm thick
  - 3-5 mm from WAS3ABi
  - Eff ~ 50%

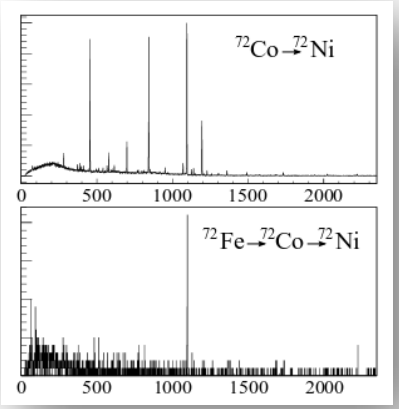
Fast-timing βγ correlations



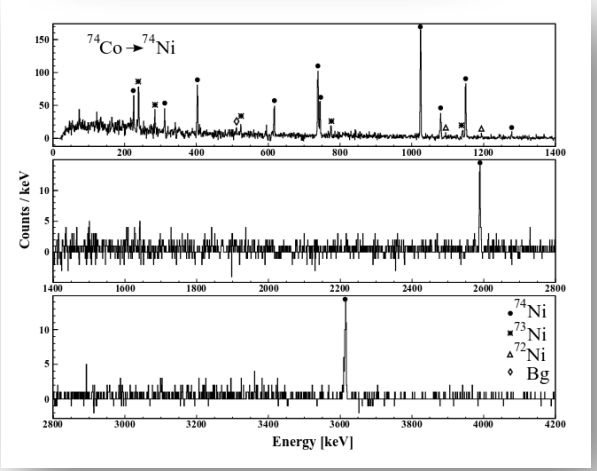
- ^{70}Ni: shape coexistence
  - ^{70}Co -> ^{70}Ni decay ➢ 1.4x10^{5} ^{70}Co
  - ^{71}Co -> ^{70}Ni ➢ 1.6x10^{6} ^{71}Co
  - ^{70}Fe -> ^{70}Co -> ^{70}Ni ➢ 1.8X10^{5} ^{70}Fe



- ^{72}Ni: seniority isomer; shape coexistence
  - ^{72}Co-> ^{72}Ni ➢ 9x10^{5} implantations ^{72}Co
  - ^{72}Fe -> ^{72}Co -> ^{72}Ni ➢ 5x10^{3} implantations ^{72}Fe
  - ^{73}Co -> ^{72}Ni ➢ 3x10^{5} implantations ^{73}Co



- ^{74}Ni: seniority isomer; shape coexistence
  - ^{74}Co-> ^{74}Ni ➢ 2x10^{4} implantations ^{74}Co



To be sorted out!

γ–γ coincidences are on the way

^{70}Ni: 0^+_2 , 2^+_2 state identified

- MNT reaction ^{70}Zn@440 MeV on ^{208}Pb target (ANL)
- Secondary fragmentation (NSCL)
- β decay at NSCL

Yrast sequence up to 8^+ ==> $\nu g_{9/2}$ charachter
Negative parity states ➔ excitation of neutrons from fp shell to g9/2
Non-yrast positive-parity states ➔ deformed states

PHYSICAL REVIEW C **91**, 044309 (2015)

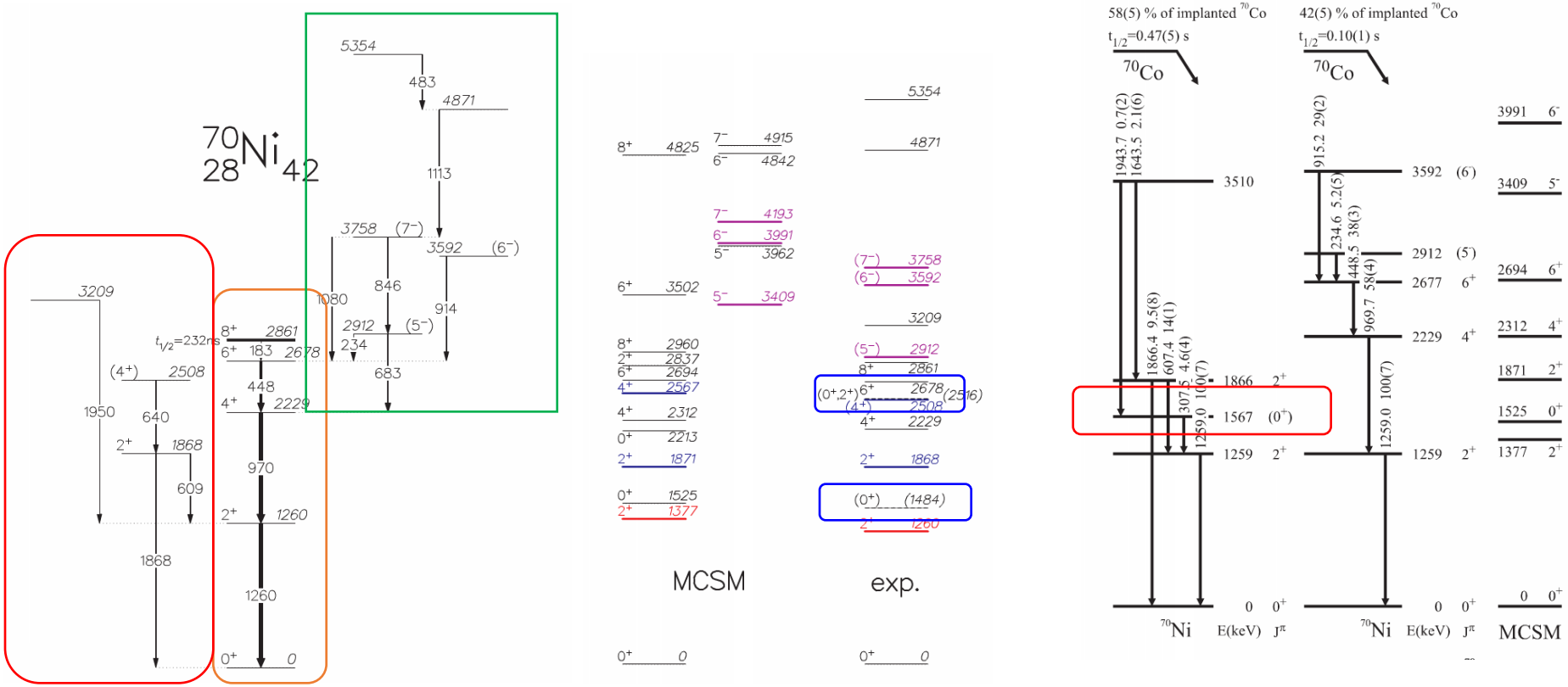
Identification of deformed intruder states in semi-magic ^{70}Ni

C. J. Chiara,[1,2,*] D. Weisshaar,[3] R. V. F. Janssens,[2] Y. Tsunoda,[4] T. Otsuka,[3,4,5] J. L. Harker,[1,2] W. B. Walters,[1] F. Recchia,[3,6]

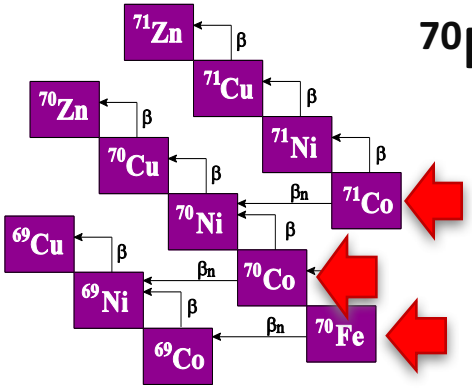
PHYSICAL REVIEW C **92**, 061302(R) (2015)

New low-energy 0^+ state and shape coexistence in ^{70}Ni

C. J. Prokop,[1,2,*] B. P. Crider,[1] S. N. Liddick,[1,2] A. D. Ayangeakaa,[3] M. P. Carpenter,[3] J. J. Carroll,[4] J. Chen,[1] C. J. Chiara,[5] H. M. David,[3,†] A. C. Dombos,[1,6] S. Go,[7] J. Harker,[3,8] R. V. F. Janssens,[3] N. Larson,[1,2] T. Lauritsen,[3] R. Lewis,[1,2] S. J. Quinn,[1,6] F. Recchia,[9] D. Seweryniak,[3] A. Spyrou,[1,6] S. Suchyta,[10] W. B. Walters,[8] and S. Zhu[3]



MCSM using the A3DA interaction in the full fpg9/2d5/2 model space for both protons and neutrons



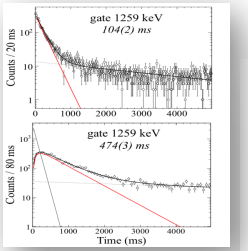
^{70}Ni

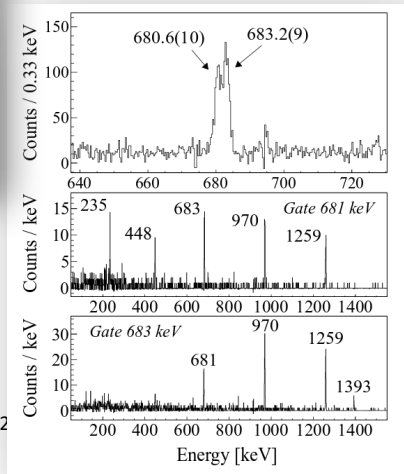
^{70}Co: 2 β decaying states:

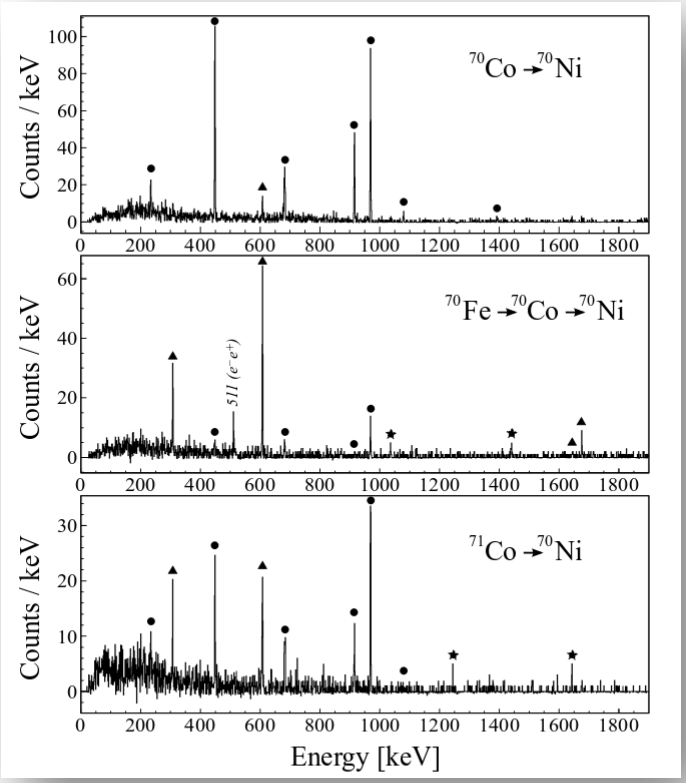
(6⁻,7⁻) 104 ms

(3⁺) 474 ms

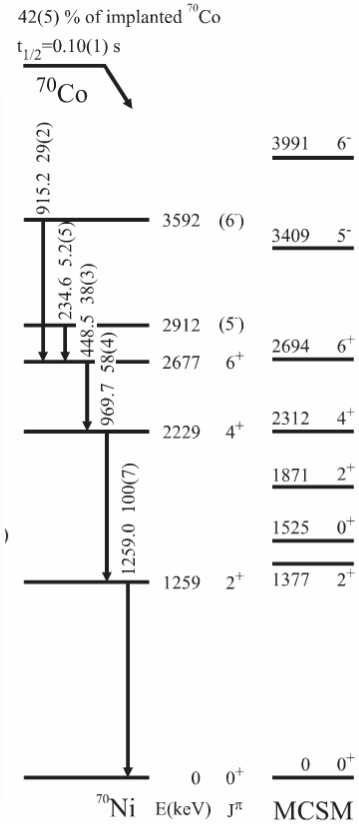
- IR = 45%
- Pn ~ 6.1(8)%



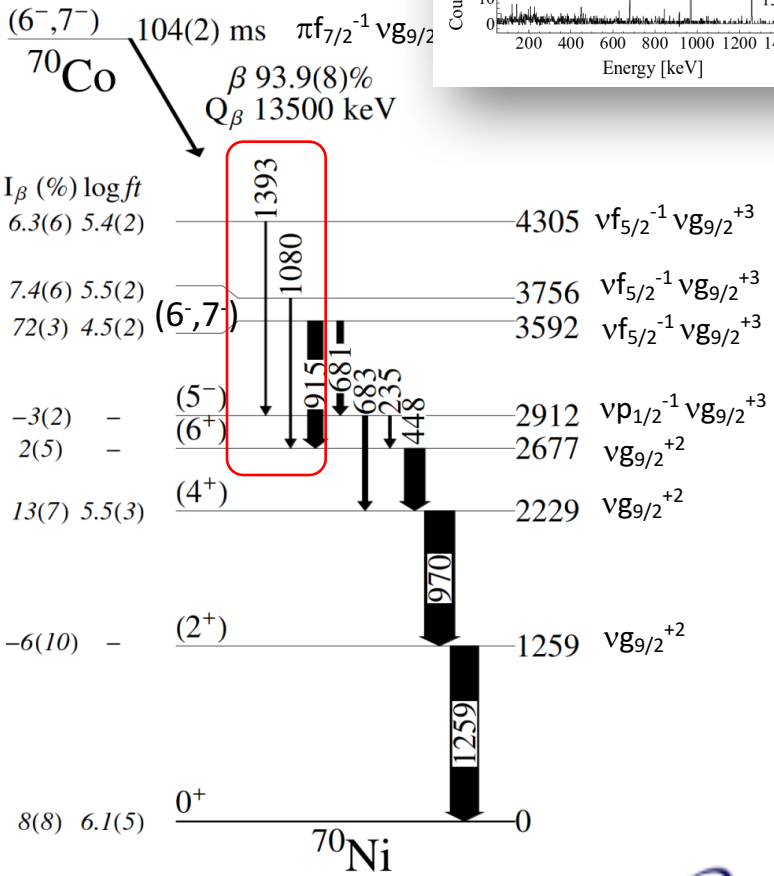




Decay from high-spin state

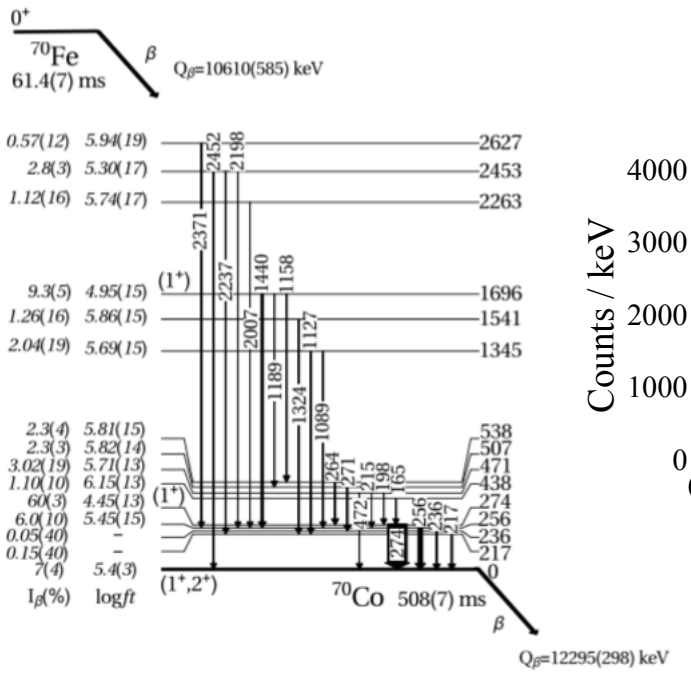


Prokop, PRC (2015)

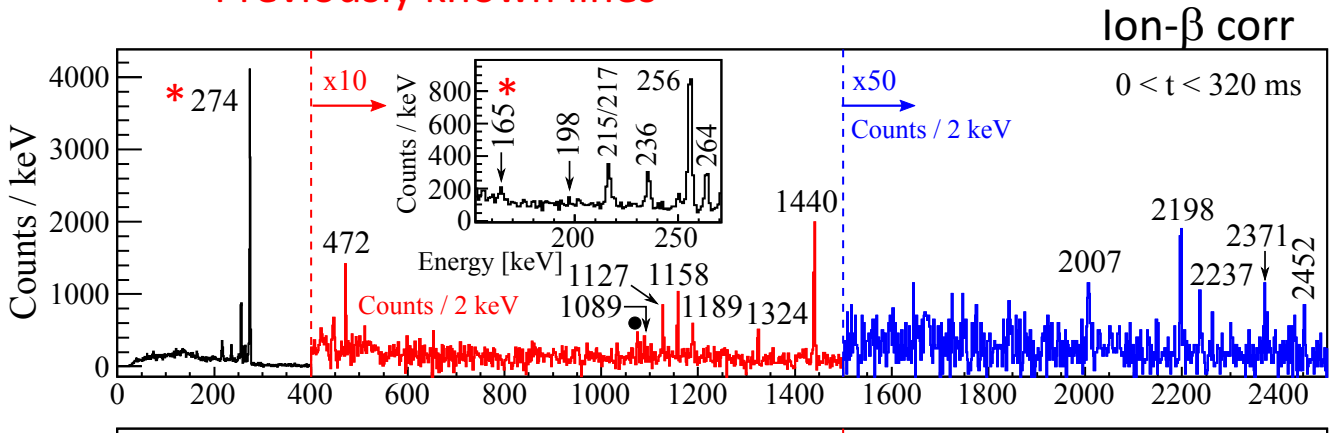


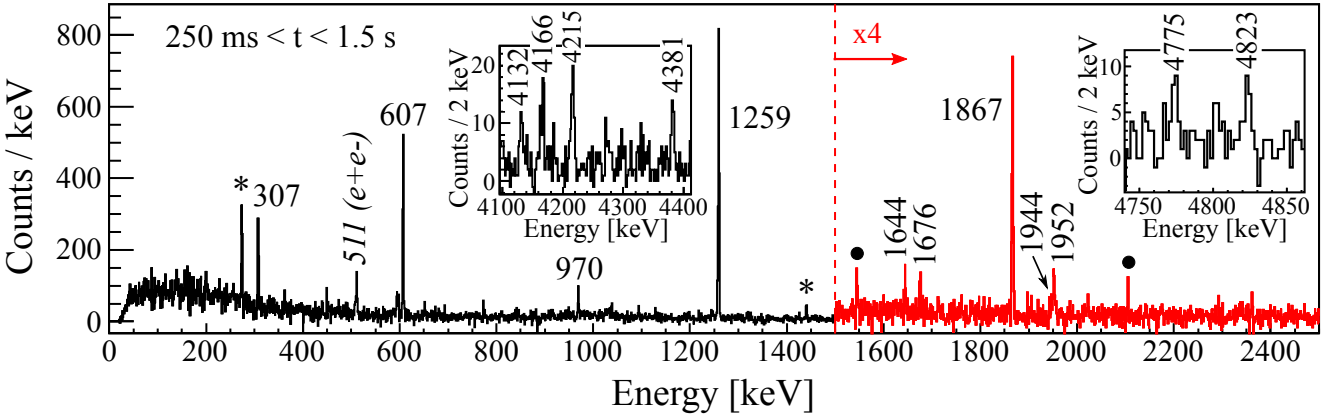
* Gate on 1259-keV transition

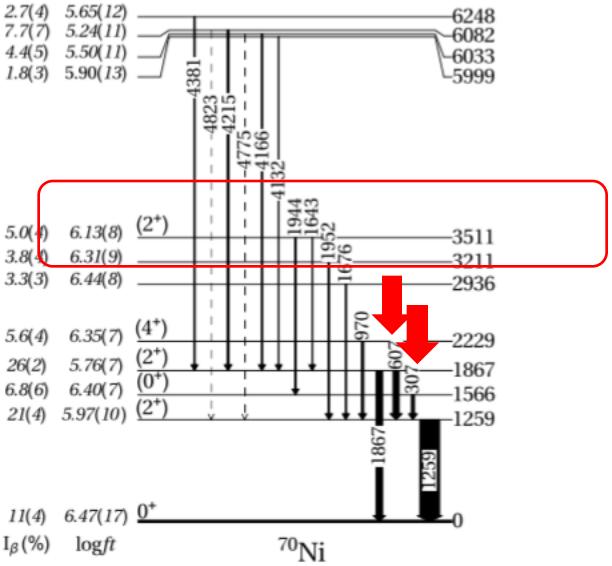
^{70}Fe->^{70}Co->^{70}Ni : natural selection of low-spin states



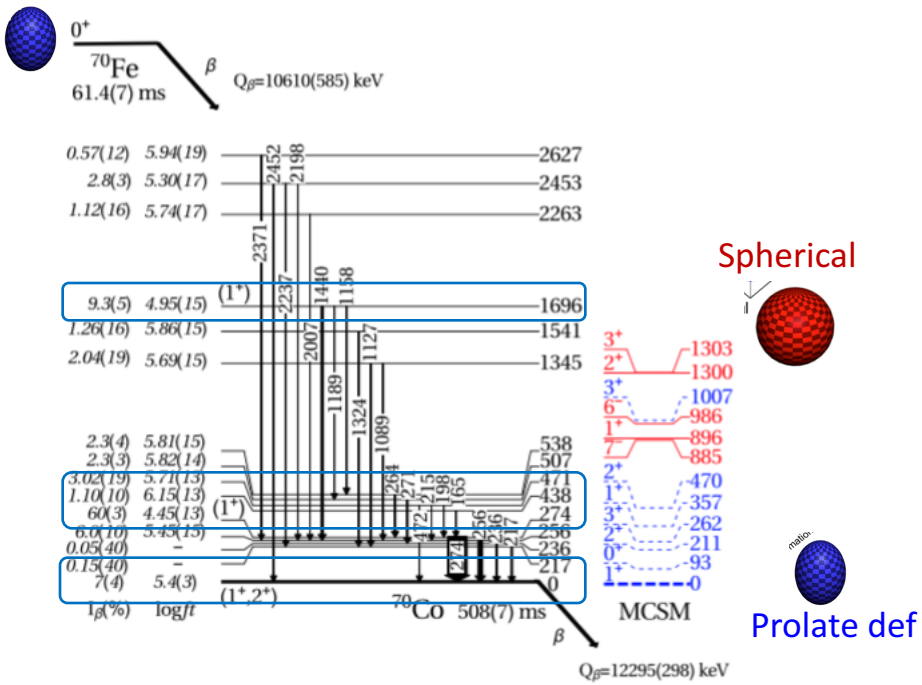
* Previously known lines

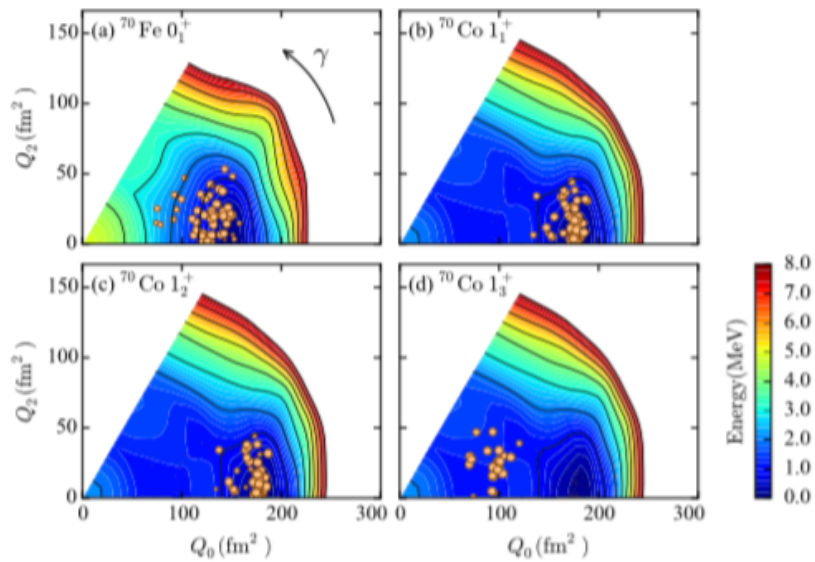




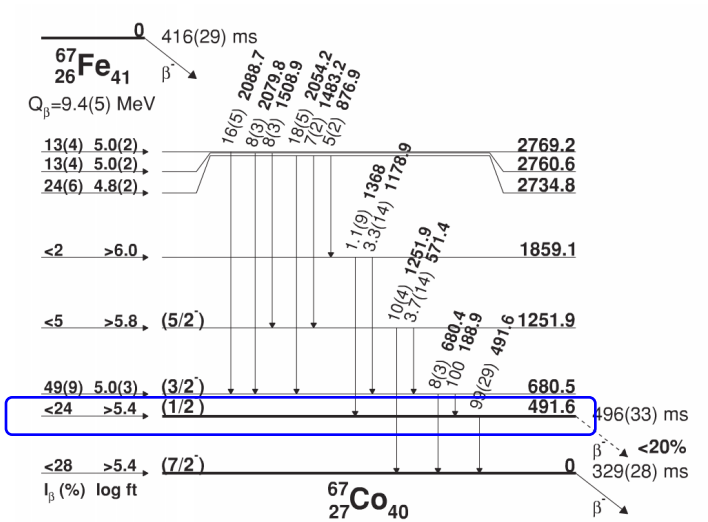


^{70}Fe->^{70}Co->^{70}Ni : Shape-Selective β Decay of A = 70 Isobars

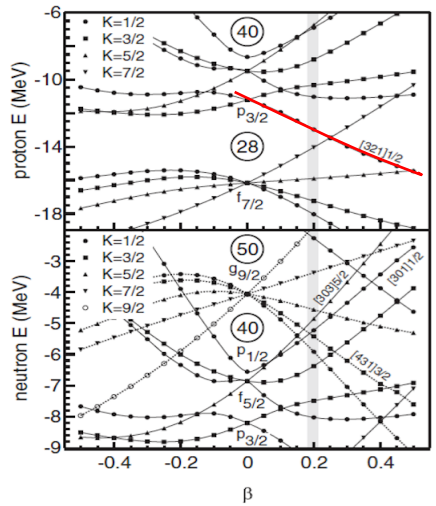




Low-spin β decay state is 1+,2+



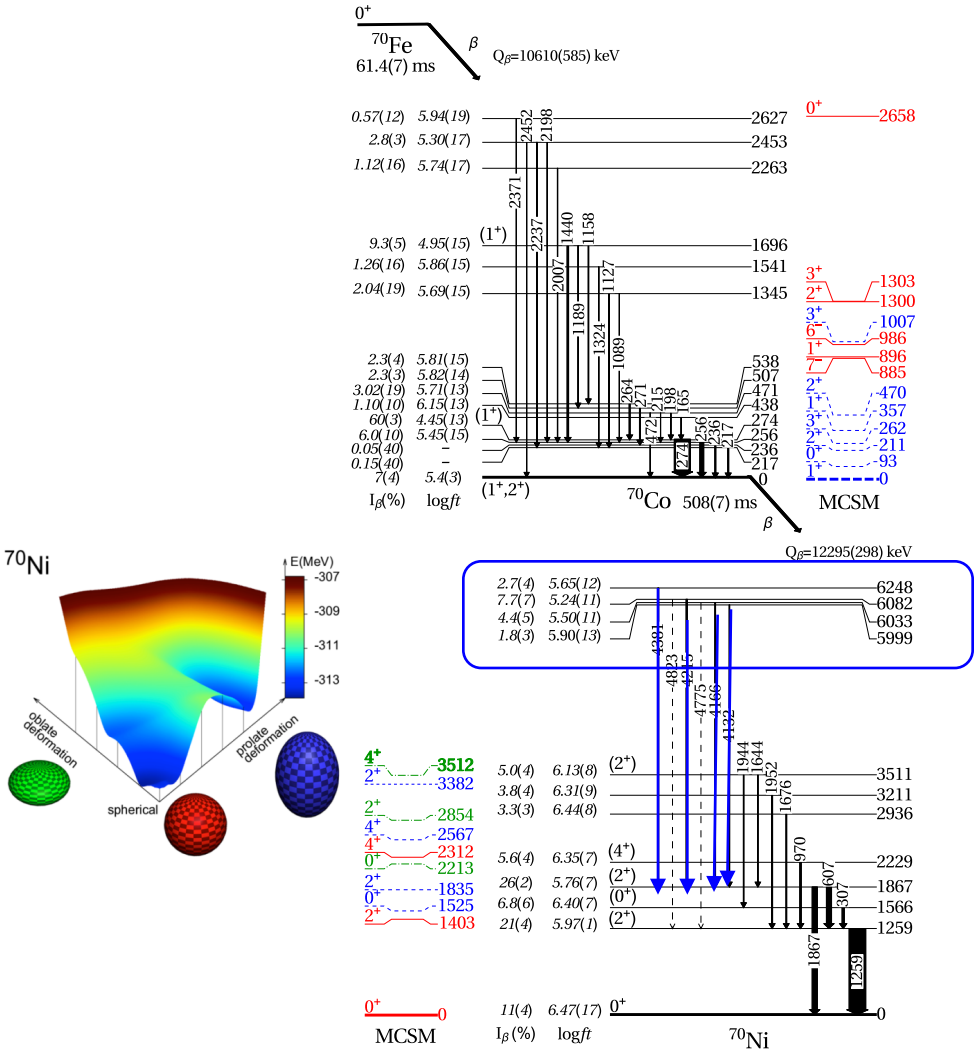
Pauwels et al. PRC 78 (2008) 041307R

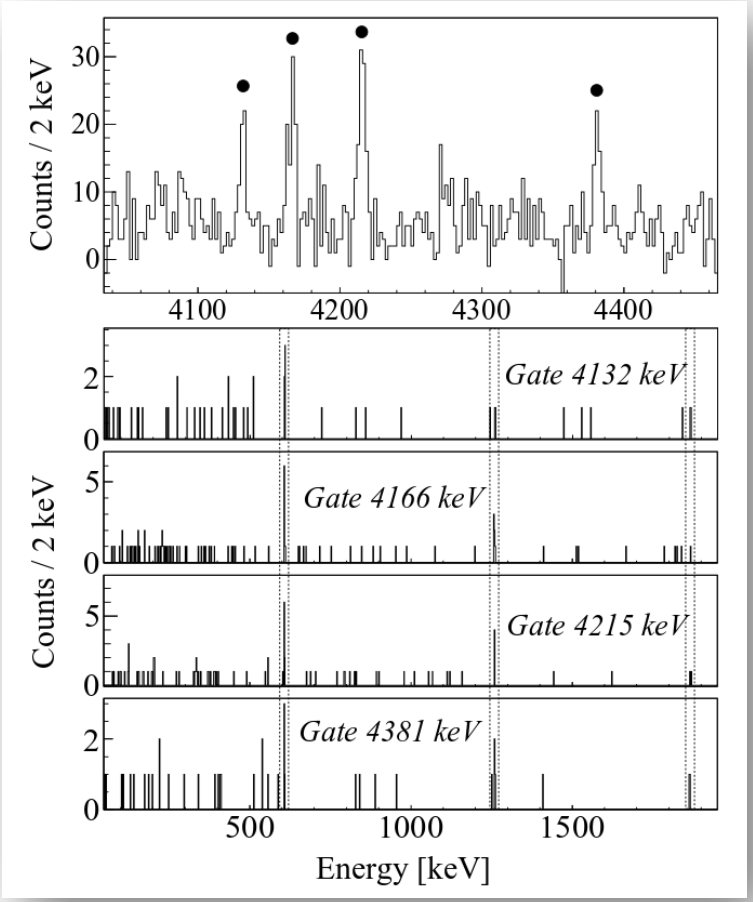


½- state in 65-67Co already attributed to downsloping [321]1/2 proton orbit pointing towards prolate deformations

Decay to ^{70}Ni:

2^+_1 and 2^+_2 show similar populations, even if the population of prolate 2^+_2 is enhanced





High energy states ➔ populating 2^+_2 state

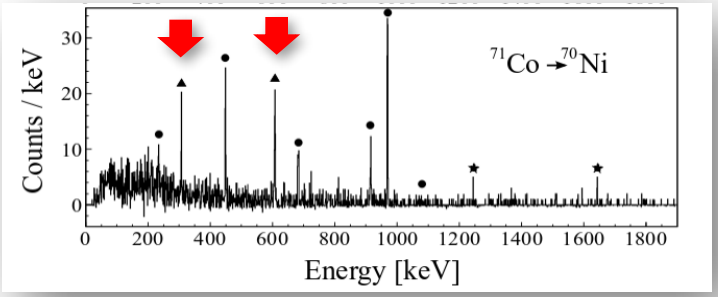
➔ proton-two qp configurations with Jπ=0+,1+,2+

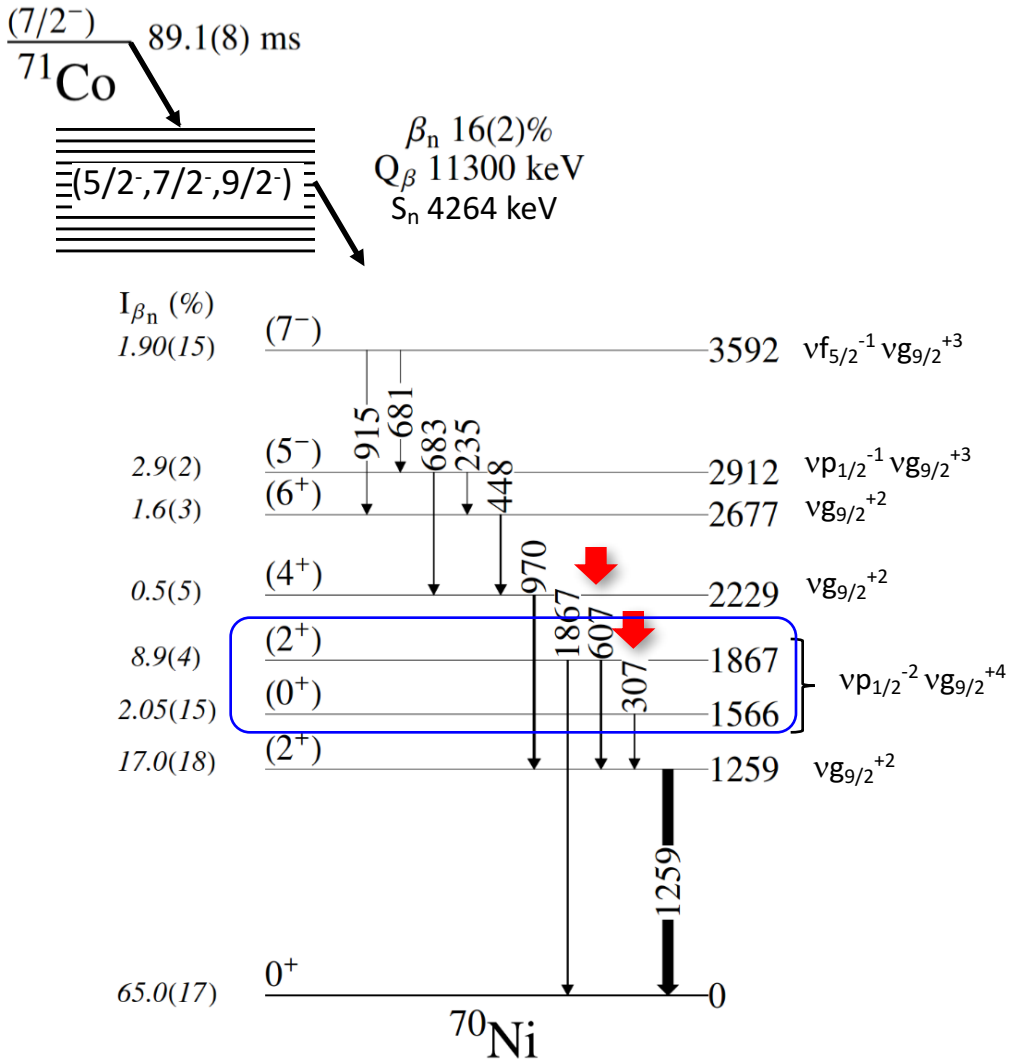
A.I.Morales, submitted

Low-lying excitations in ^{70}Ni

β_n decay of ^{71}Co

- Observation of a 0^+ candidate



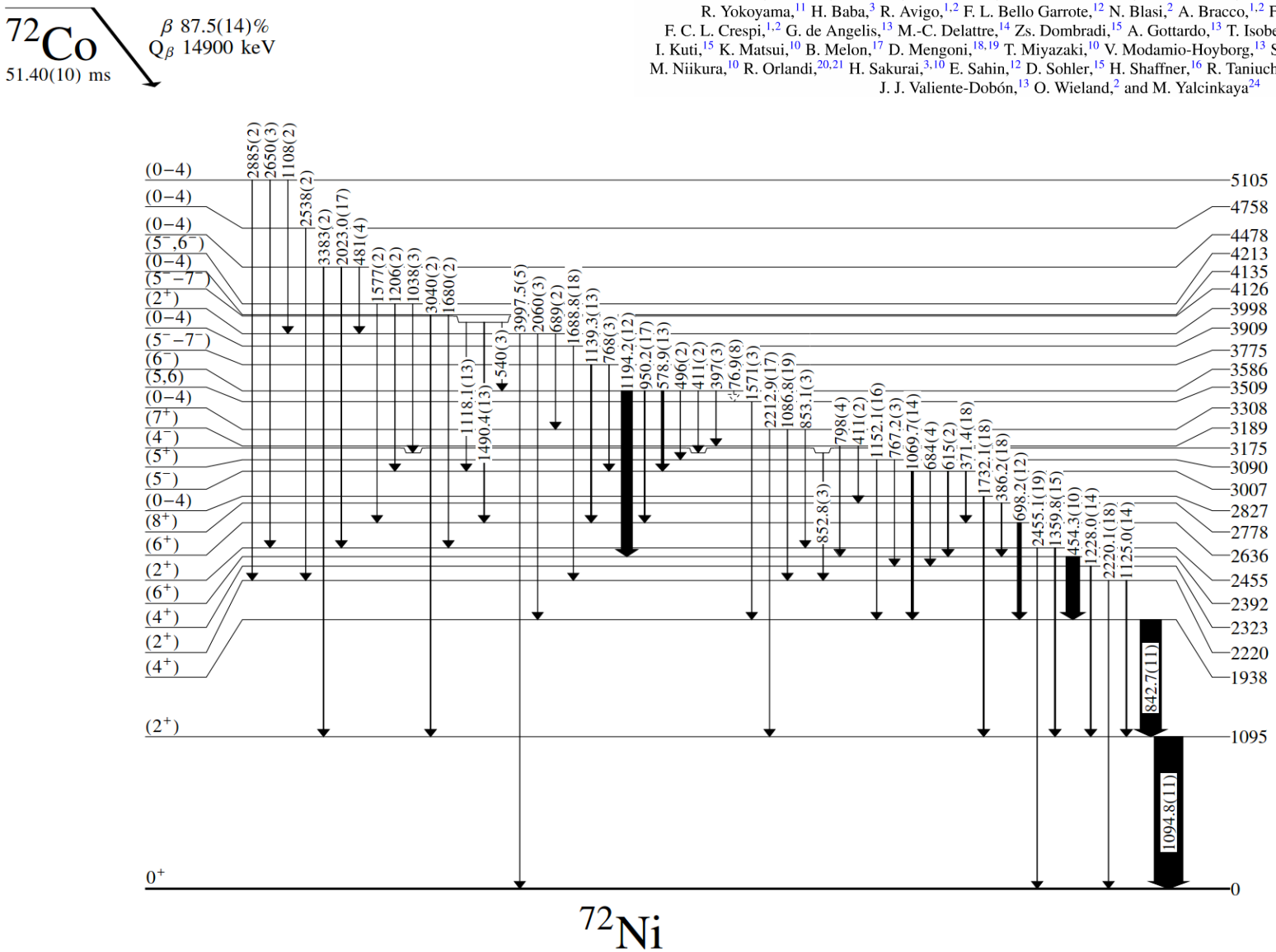


Low-lying excitations in ^{72}Ni

PHYSICAL REVIEW C **93**, 034328 (2016)

Low-lying excitations in ^{72}Ni

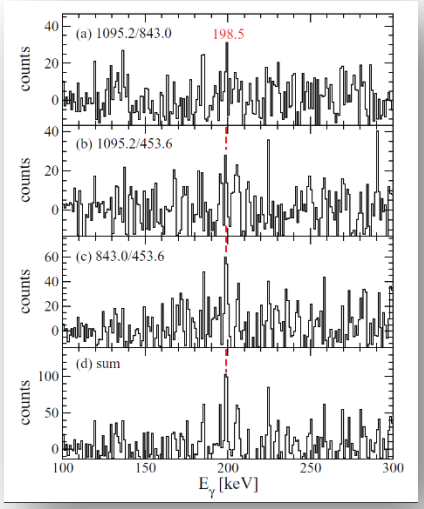
A. I. Morales,[1,2,*] G. Benzoni,[2] H. Watanabe,[3,4] S. Nishimura,[3] F. Browne,[5,3] R. Daido,[6] P. Doornenbal,[3] Y. Fang,[6] G. Lorusso,[3] Z. Patel,[7,3] S. Rice,[7,3] L. Sinclair,[8,3] P.-A. Söderström,[3] T. Sumikama,[9] J. Wu,[3] Z. Y. Xu,[10,3] A. Yagi,[6] R. Yokoyama,[11] H. Baba,[3] R. Avigo,[1,2] F. L. Bello Garrote,[12] N. Blasi,[2] A. Bracco,[1,2] F. Camera,[1,2] S. Ceruti,[1,2] F. C. L. Crespi,[1,2] G. de Angelis,[13] M.-C. Delattre,[14] Zs. Dombradi,[15] A. Gottardo,[13] T. Isobe,[3] I. Kojouharov,[16] N. Kurz,[16] I. Kuti,[15] K. Matsui,[10] B. Melon,[17] D. Mengoni,[18,19] T. Miyazaki,[10] V. Modamio-Hoyborg,[13] S. Momiyama,[10] D. R. Napoli,[13] M. Niikura,[10] R. Orlandi,[20,21] H. Sakurai,[3,10] E. Sahin,[12] D. Sohler,[15] H. Shaffner,[16] R. Taniuchi,[10] J. Taprogge,[22,23] Zs. Vajta,[15] J. J. Valiente-Dobón,[13] O. Wieland,[2] and M. Yalcinkaya[24]



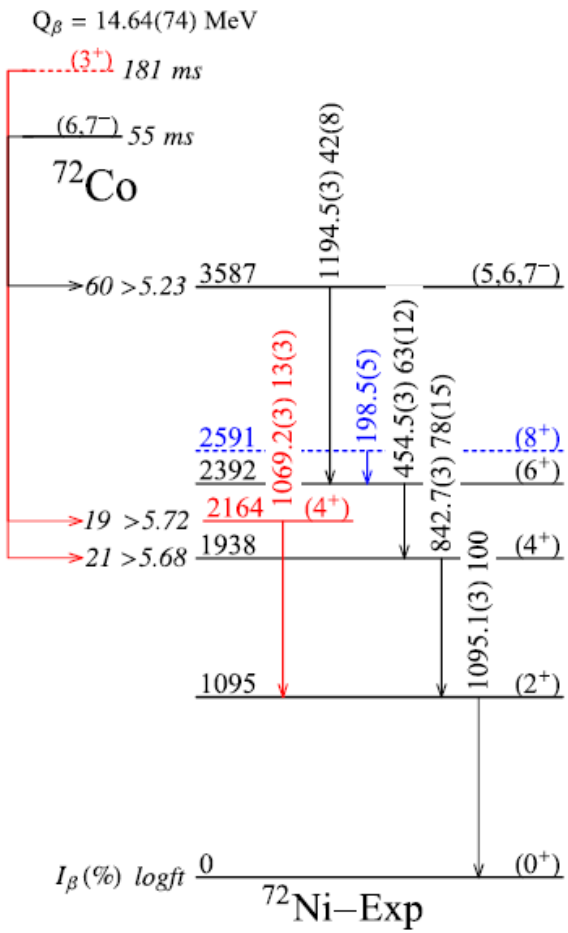
Low-lying excitations in ^{72}Ni

Conservation of seniority in ^{72}Ni

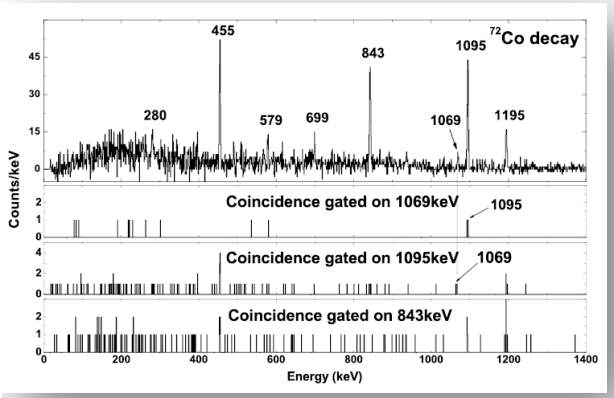
Scarce statistics!



[C.J. Chiara et al, PRC (2011)]

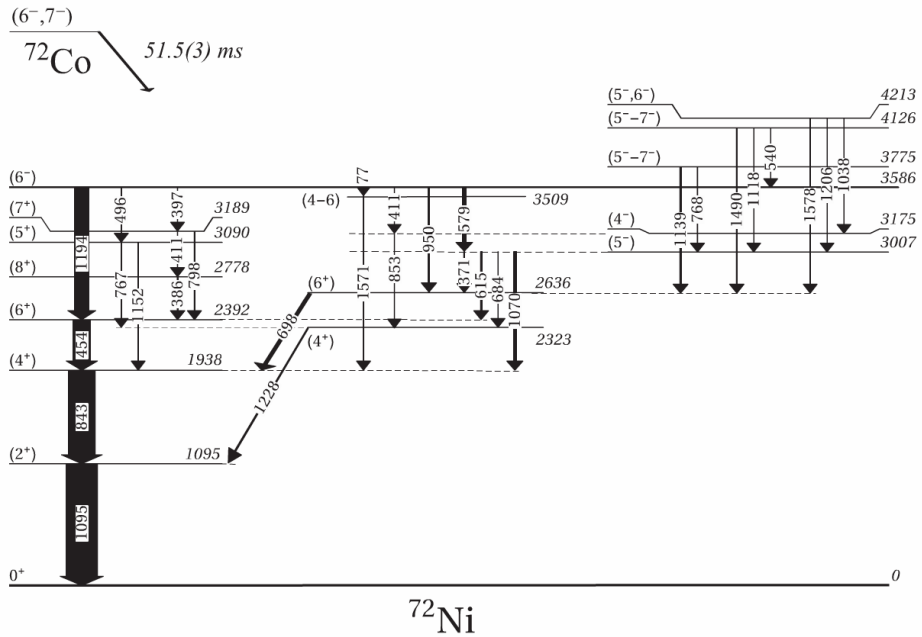


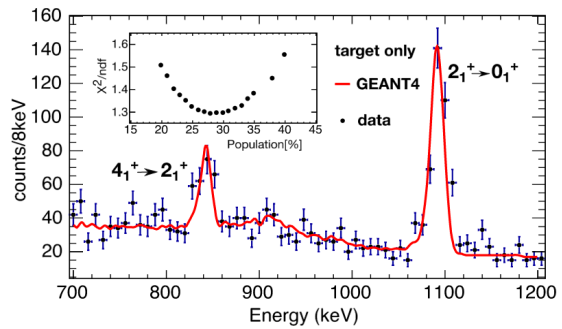
Scarce statistics!



[M. Rajabali et al, PRC (2014)]

^{72}Co->^{72}Ni Existence of 2 β-decaying isomers

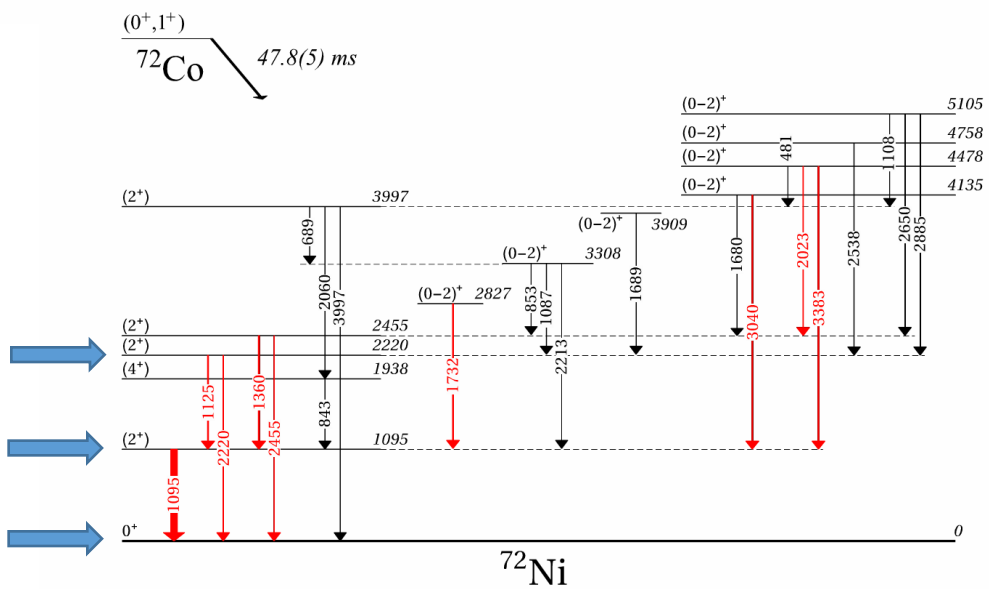




RDDS measurement on 1p knock-out at NSCL

K.Kolos et al. PhysRevLett 116 (2016) 12250

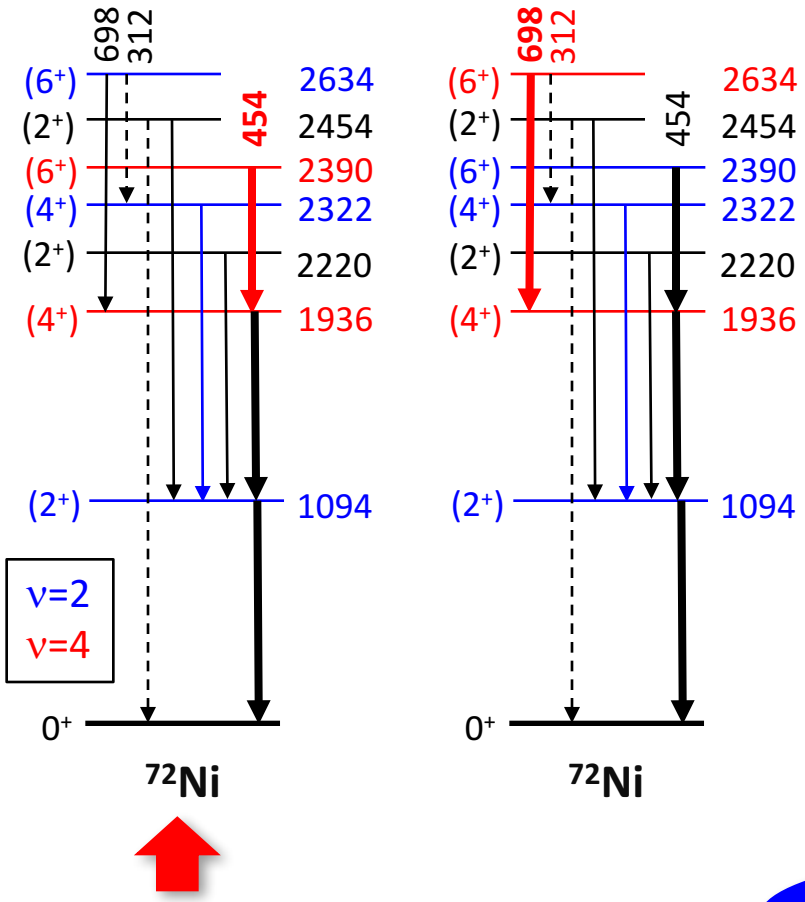
Obtained both from ^{72}Co->^{72}Ni decay
And ^{72}Fe->^{72}Co->^{72}Ni
Much stronger feeding to gs <40%
And hindered decays to 2^+ states
Non observation of prolate 0^+ state
MCSM calculation expect reduction
of def. already starting from ^{72}Ni

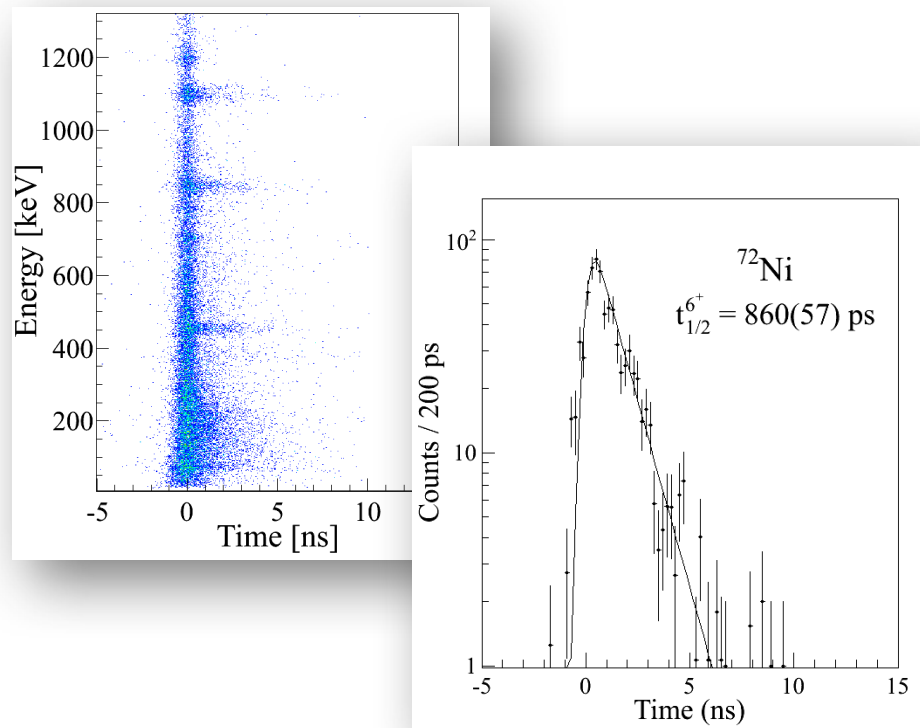


Low-lying excitations in ^{72}Ni

A.I.Morales to be submitted

- Fast-timing measurements performed to investigate the seniority configuration of ^{72}Ni





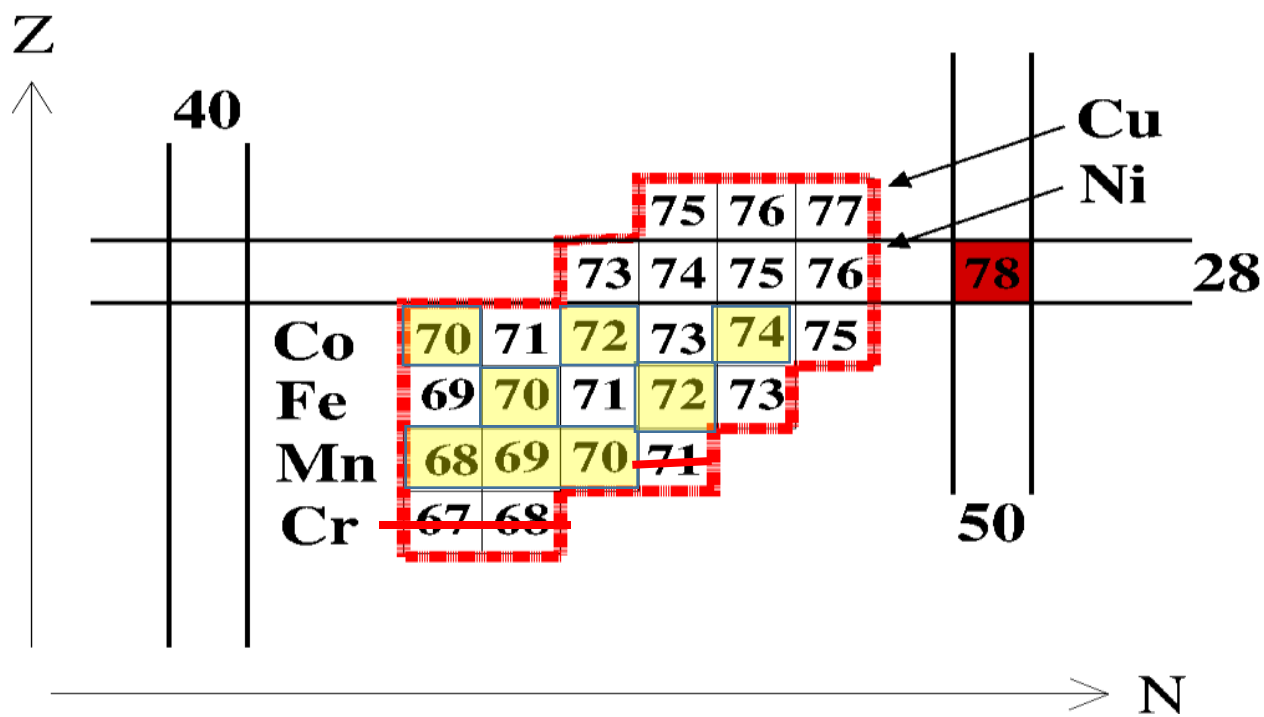
454-keV long-lived transition!

Conclusions:

- Ni isotopic chain is a lively area where many phenomena are found

- Strong interest worldwide to attack this region with many different reaction mechanism
- Shape coexistence phenomena described in terms of Type II Shell Evolution

- EURICA campaign successfully ended in June 2016



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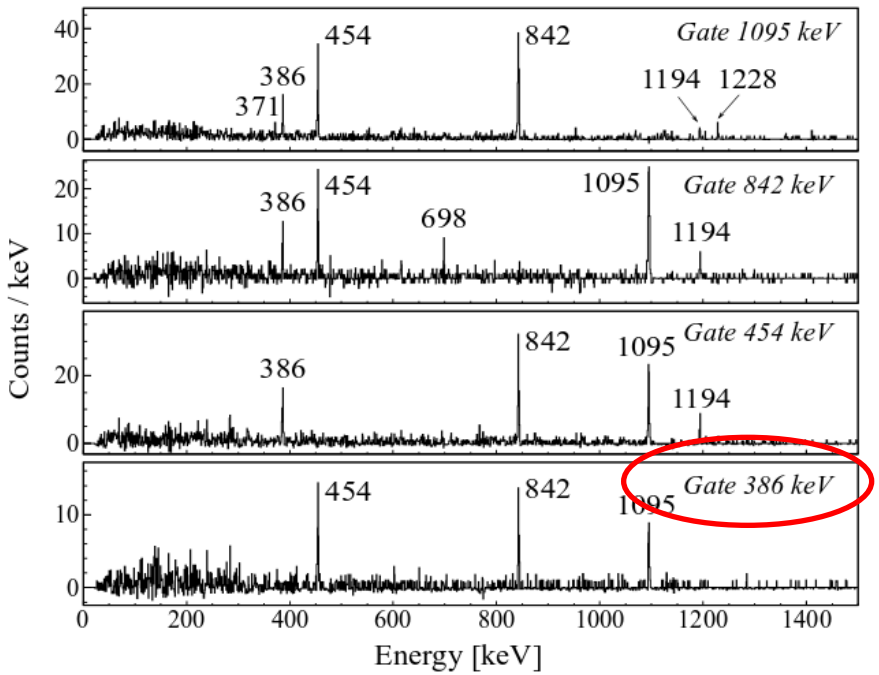
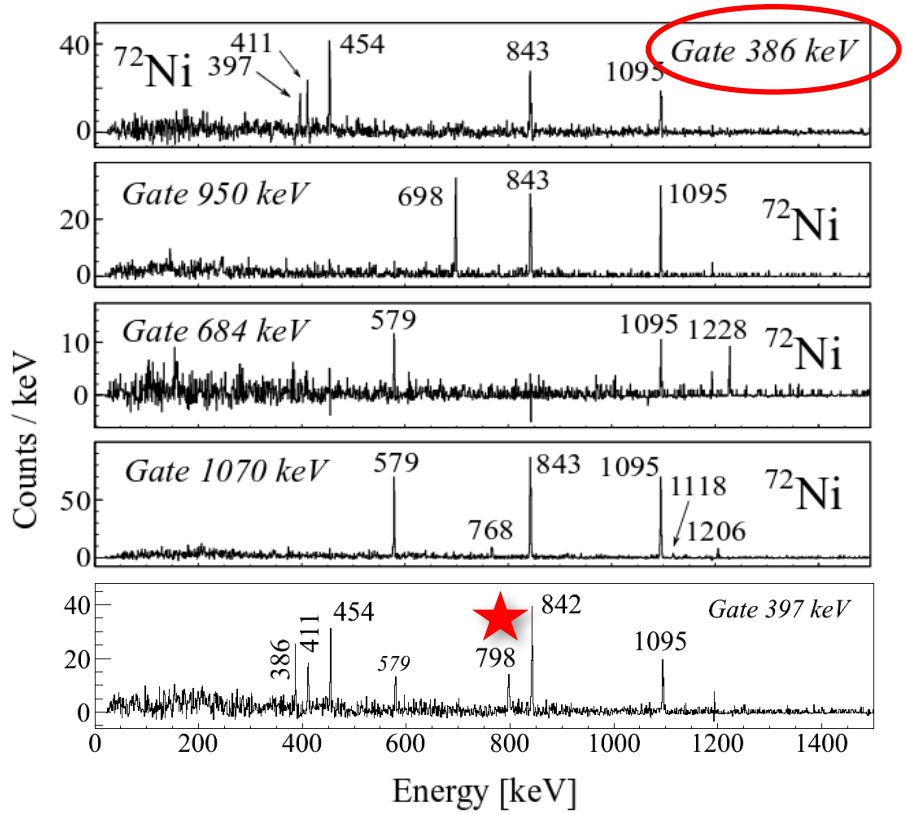
Low-lying excitations in ^{72}Ni

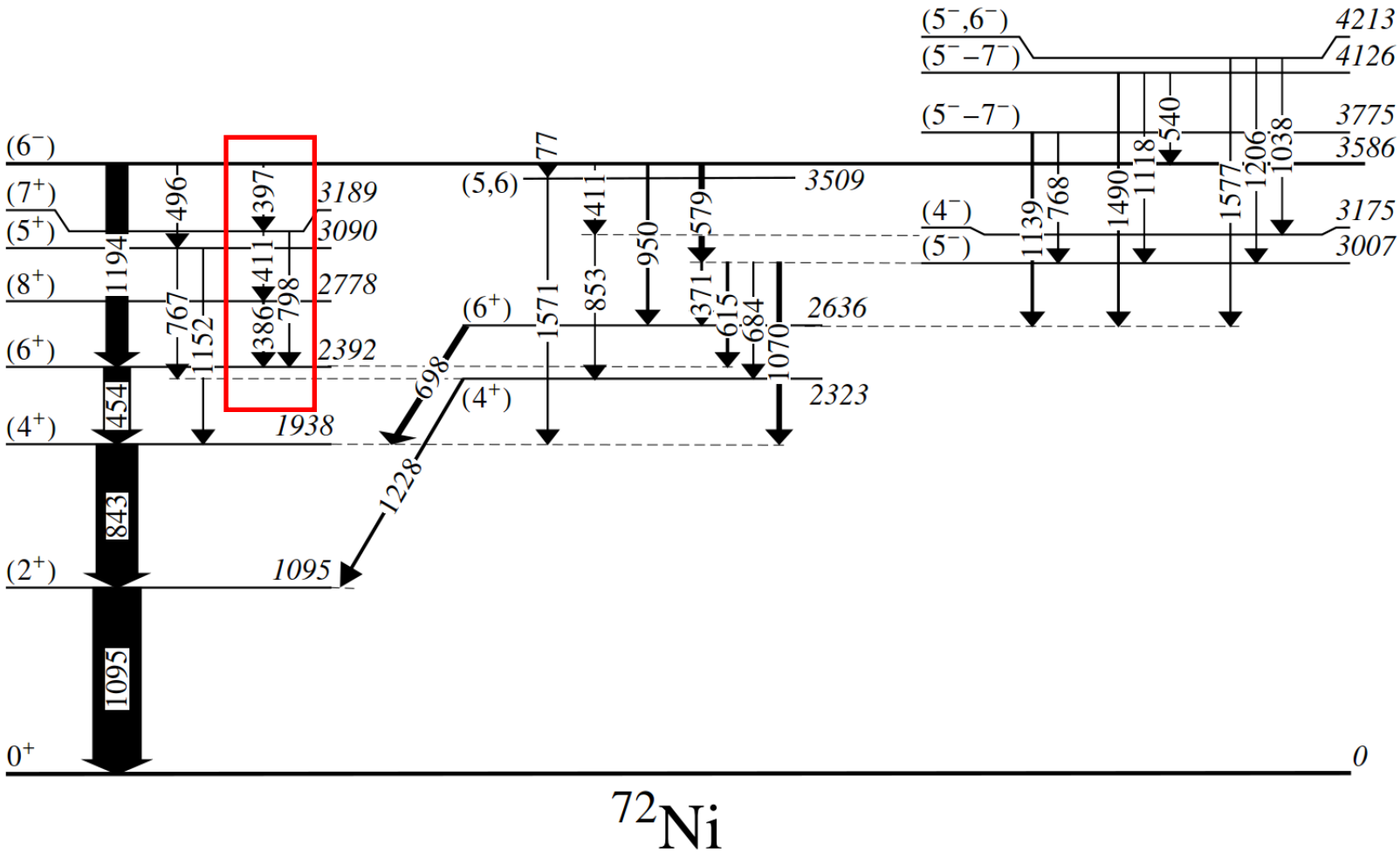
(Reliable) Experimental evidence for the observation of the 8$^+$ seniority-two state

- ^{73}Co $\rightarrow$ ^{72}Ni



- ^{73}Co $\rightarrow$ ^{72}Ni



Low-lying excitations in ^{72}Ni

High-spin structure