Coulomb excitation of ^{60}Ni at the IJC Lab with the Nuball2+SiLCA DSSD setup

(+ *a brief report on the Coulomb excitation of ^{40}Ca*)

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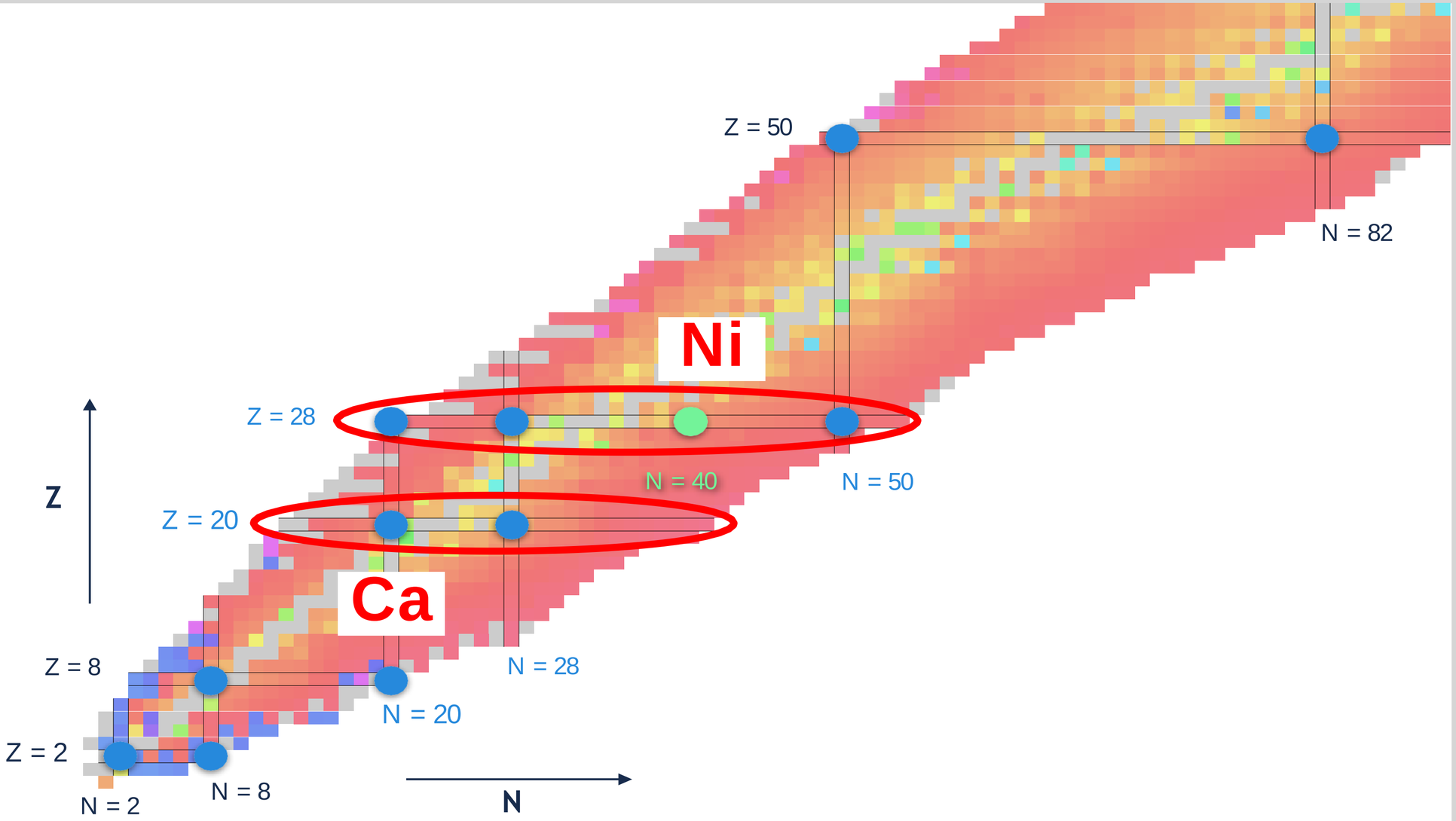
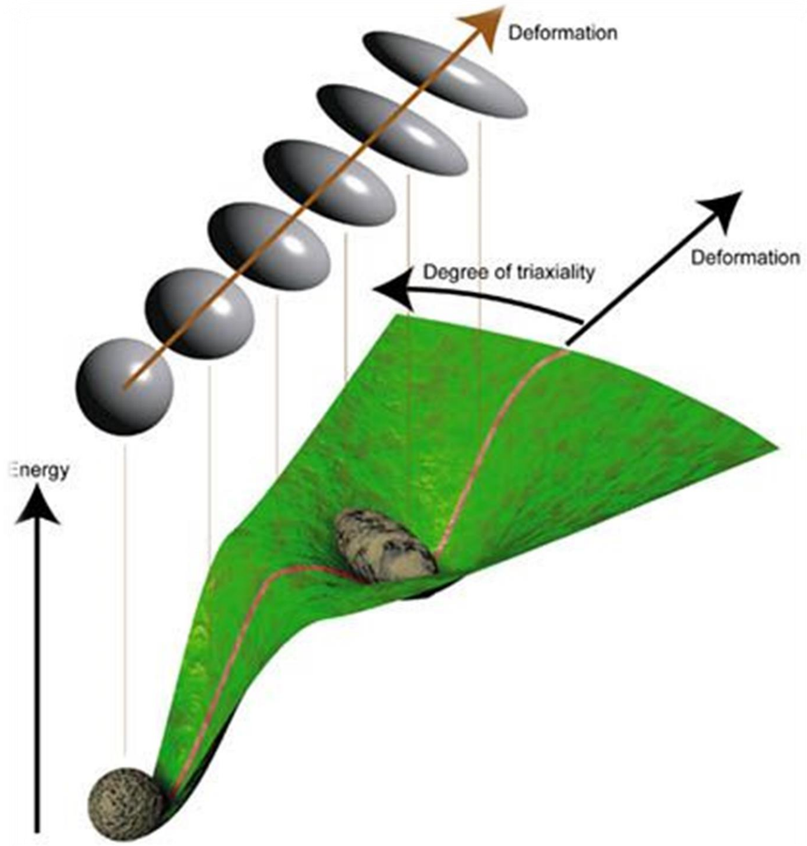
University of Warsaw

Scientific Workshop on nu-Ball2 2024 - Reports from the last campaign and prospects for future experiments

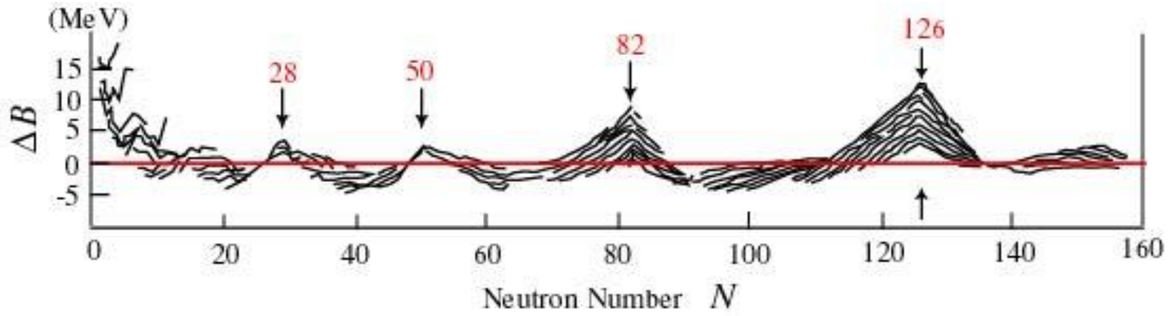
Milano, 3-5 July 2024


Z = 50
N = 82
Ni
Z = 28
N = 40
N = 50
Z
Z = 20
Ca
Z = 8
N = 28
N = 20
Z = 2
N = 8
N = 2
N

Nuclear magicity



Magic (or semi-magic) nuclei:
Z and/or N: 2, 8, 20, 28, 50, 82, 126 (N)



Spherical in their ground state

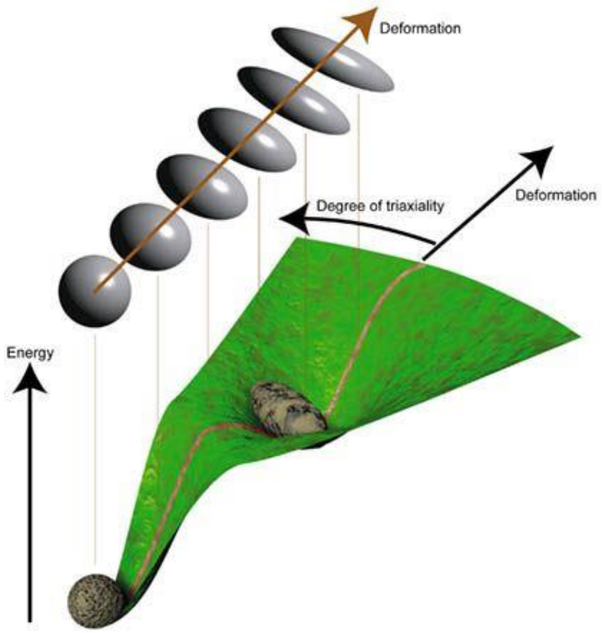
Or not?

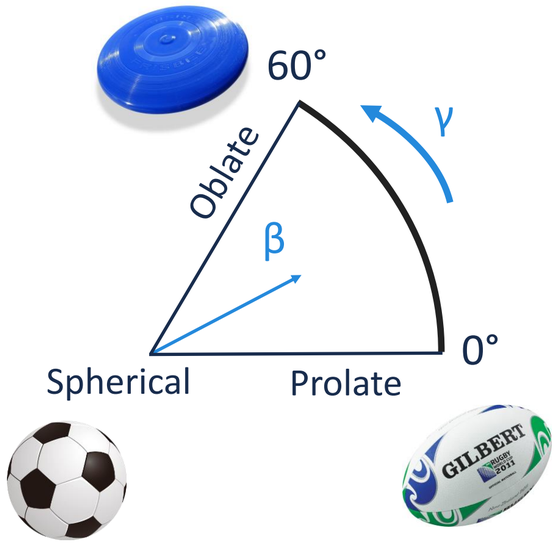
Are the magic nuclei deformed?

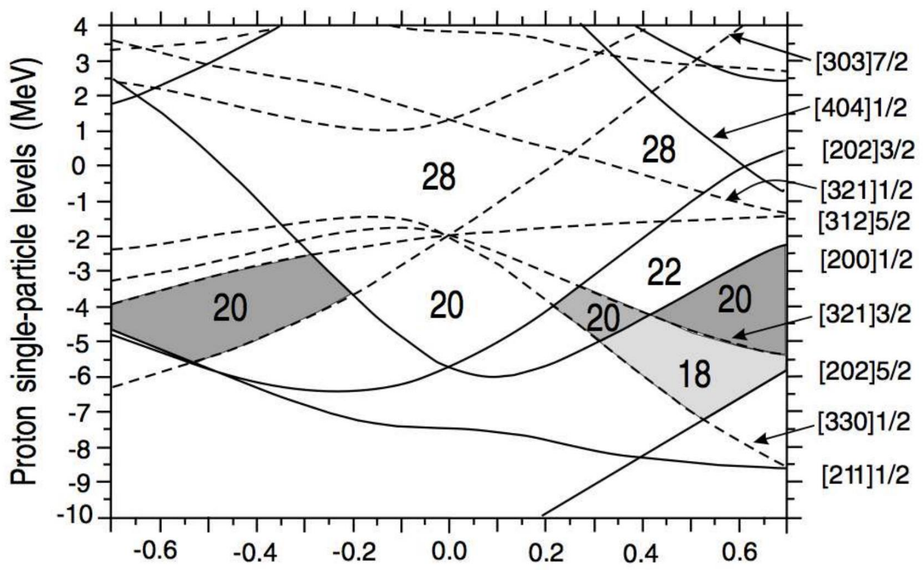
Are all magic numbers „good”?

http://ne.phys.kyushu-u.ac.jp/seminar/MicroWorld3_E/3Part2_E/3P25_E/magic_numbers_E.htm

Nuclear deformation – medium mass region

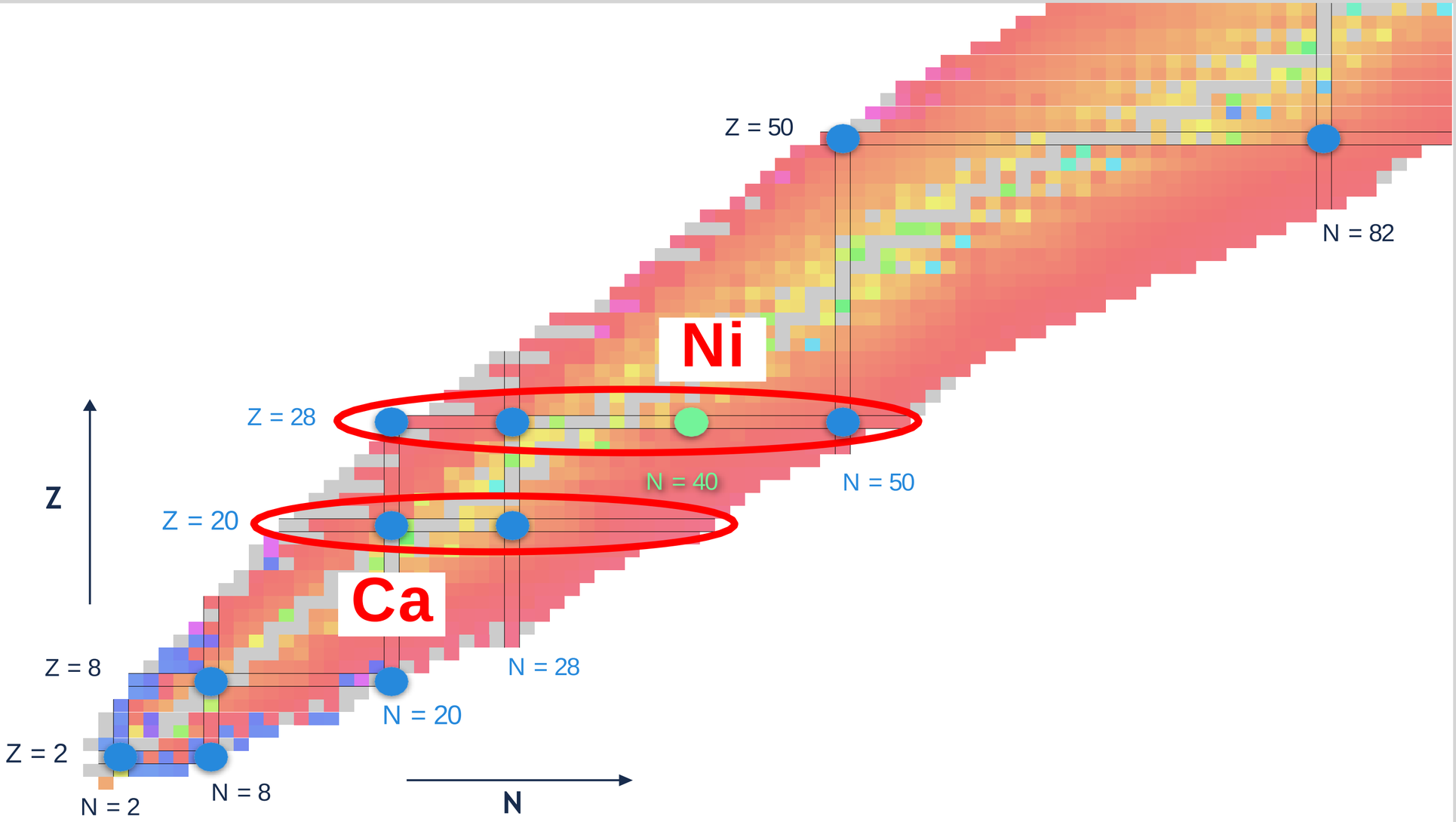




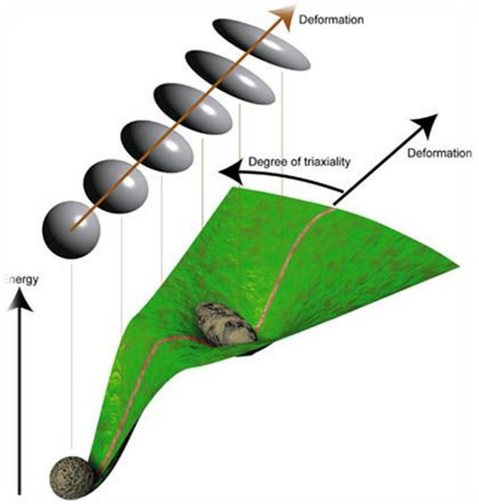


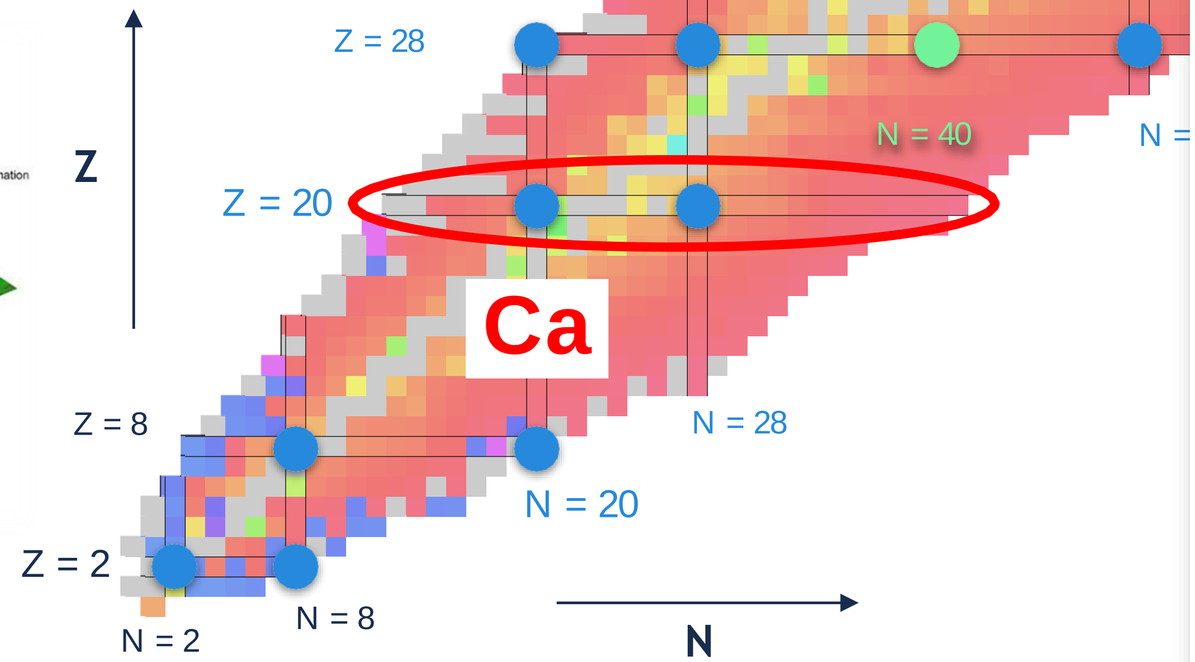
- Observation of the evolution of deformation in light and medium mass region
- Rotational and deformed bands of similar properties exist in a wide range of nuclei: built on the 0^+ states, decaying to the ground state bands with the discrete gamma transitions - mixing of configurations
- Triaxial highly-deformed vs spherical / weakly deformed structures
- Dramatic shape coexistence

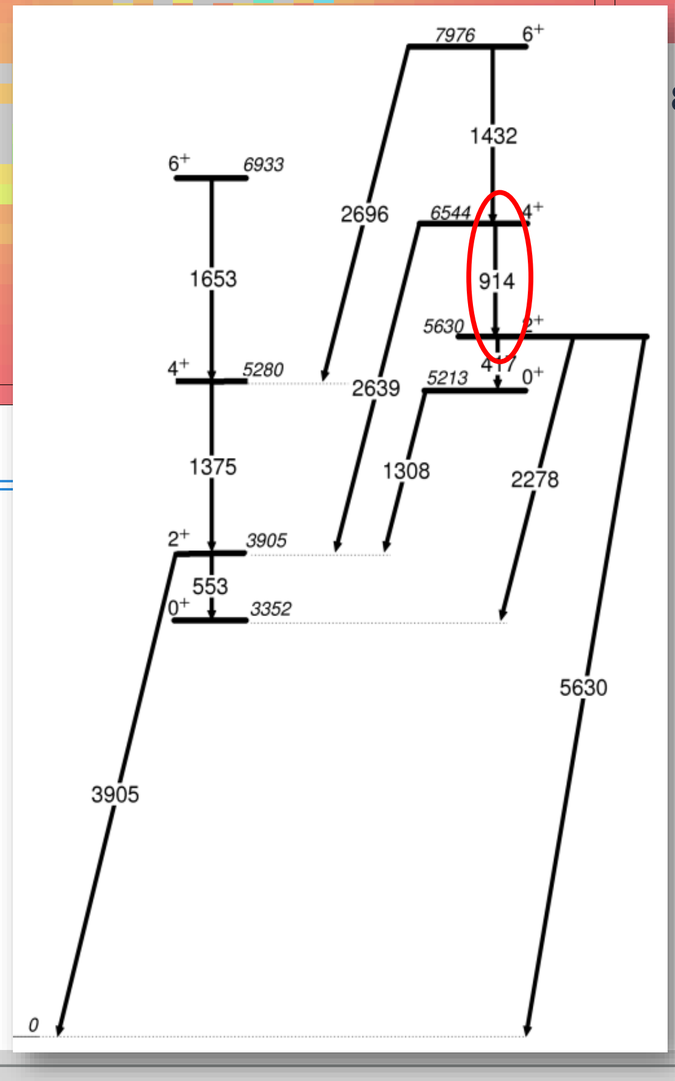
^{40}Ca (Z=N=20) versus ^{56}Ni (Z=N=28)



Deformation about ^{40}Ca (Z=N=20)

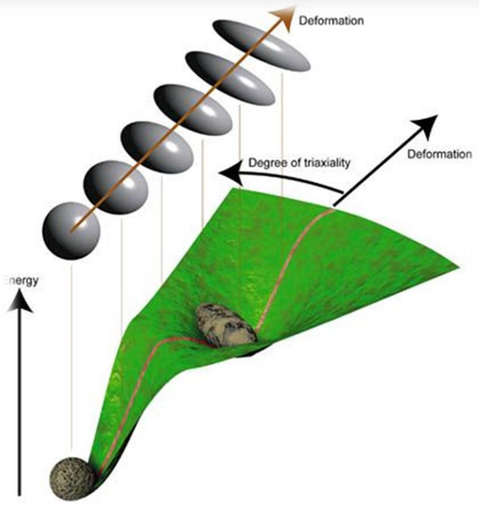


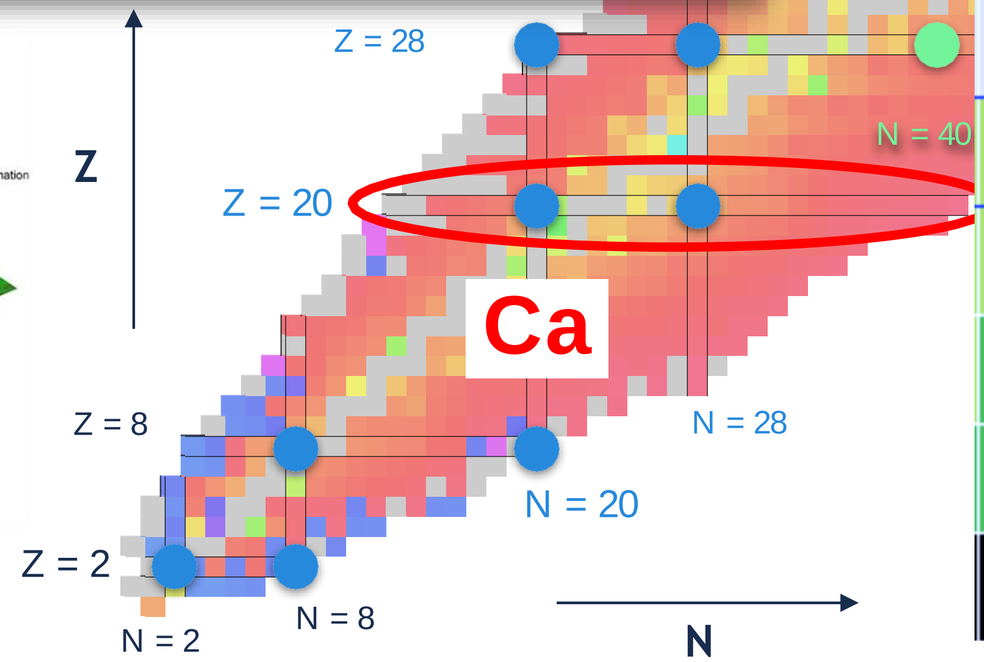


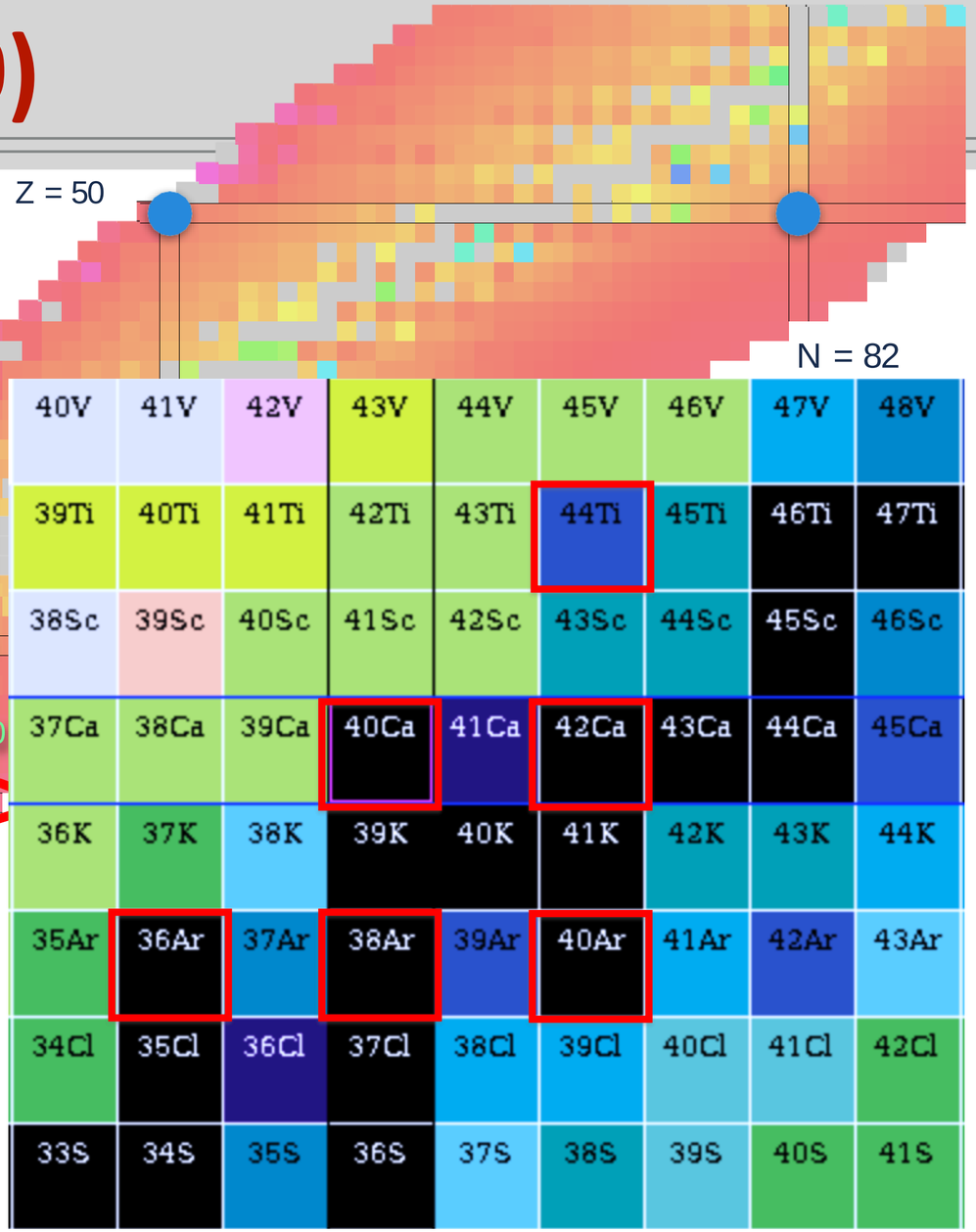


Deformation about ^{40}Ca (Z=N=20)

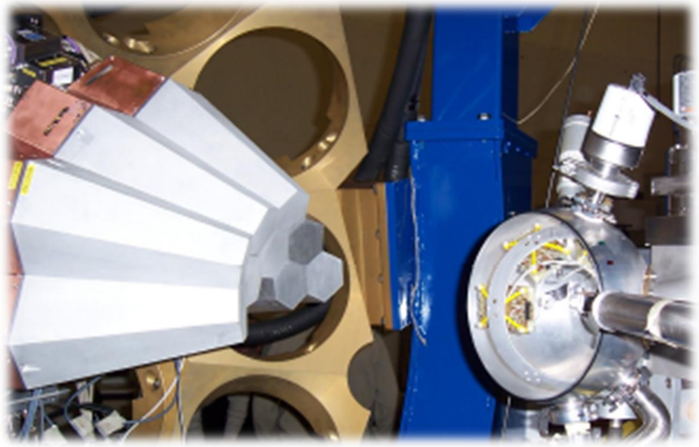
isotope	0^+ energy	experimental β_2	configuration	reference
^{40}Ca	5.2 MeV	$0.59^{+0.11}_{-0.07}$	8p-8h (SD)	E. Ideguchi et al., PRL 81 (2001) 222501
	3.4 MeV	0.27±0.05	4p-4h (ND)	
^{36}Ar	(4.3 MeV)	0.46±0.03	4p-8h	C. Svensson et al., PRL 85 (2000) 2693
^{38}Ar	3.4 MeV	$0.42^{+0.11}_{-0.08}$	4p-6h	R. Austin, PhD thesis (2004)
^{40}Ar	2.1 MeV	$0.48^{+0.16}_{-0.10}$±0.05	4p-4h	E. Ideguchi et al., PLB 686 (2010) 18
^{42}Ca	1.8 MeV	0.43(4) (0^+_2)	6p-4h	KHK et al., PRL 117 (2016) 062501
		0.45(4) (2^+_2)		KHK et al., PRC 97 (2018) 024326

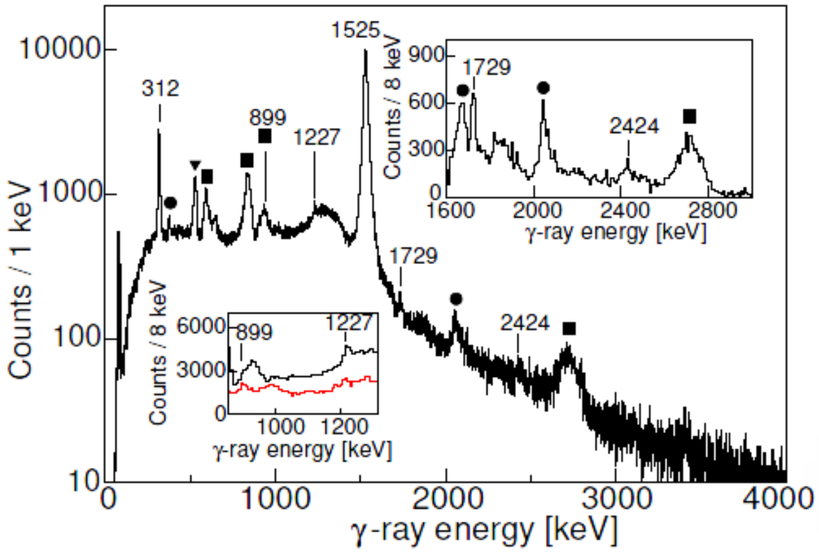


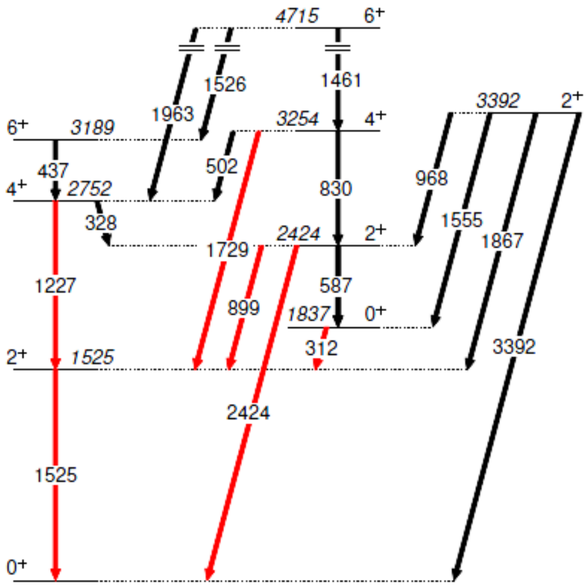




Superdeformation in ^{42}Ca (Z=20, N=22)





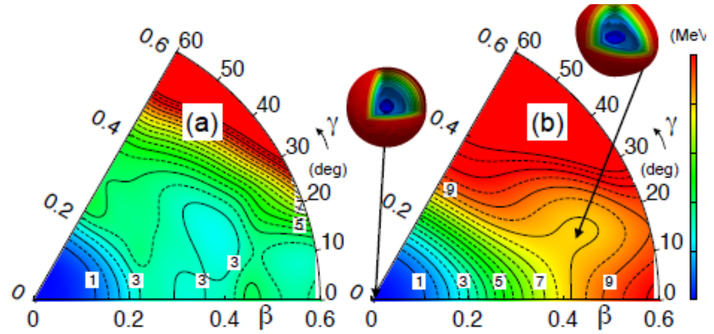


$\langle Q^2 \rangle_{SD} = \beta_{SD} = 0.43(4)$

$\langle \cos(3\delta) \rangle_{SD} = \gamma_{SD} = 13(^{5}_{6})^{\circ}$

Excited 0⁺:
Triaxial prolate - superdeformed

KHK et al., PRL 117 (2016) 062501 and PRC 97 (2018) 024326



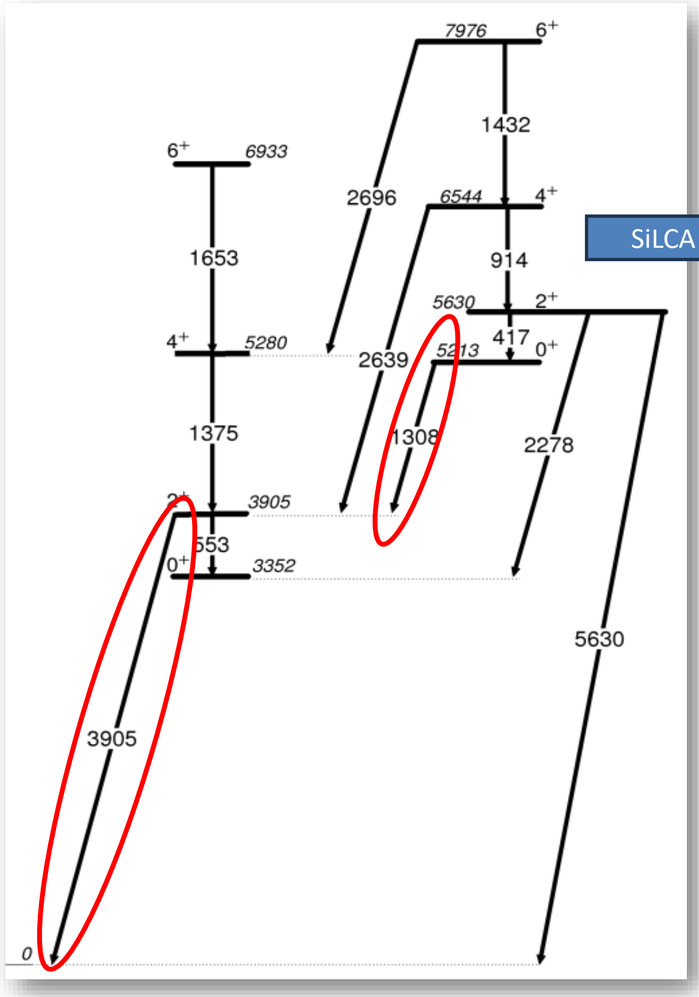
LSSM and BMF calculations

Ground state deformation:
spherical, with the large fluctuations
shape invariants:
$\langle Q^2 \rangle + \sigma(Q^2)$ and $\langle \cos(3d) \rangle$

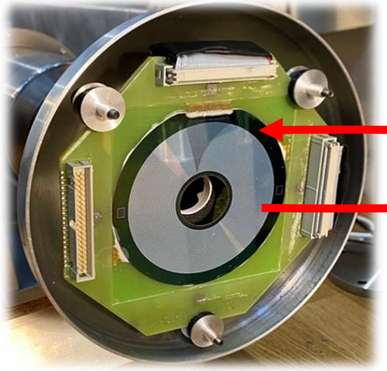
0_1^+ $\bar{\beta}$=0.26(2) and $\bar{\gamma}$=29(2)°

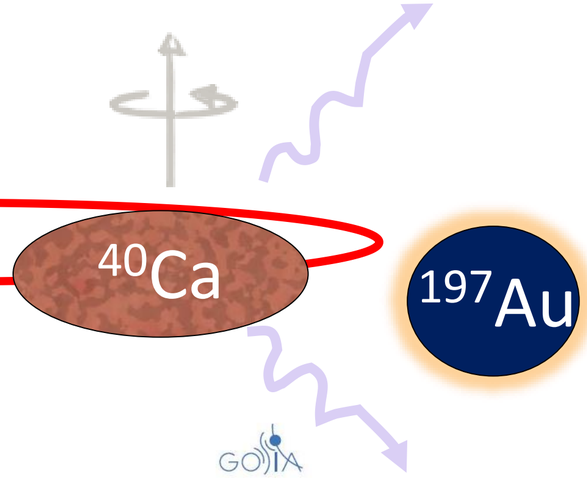
First evidence for the shape coexistence in the light mass region

Nuclear deformations: COULEX of ^{40}Ca



SiLCA DSSD





GOSIA

PARIS

nuBALL2 + PARIS

Transition	Energy [keV]	Counts/day
ND band transitions		
$2_1^+ \rightarrow 0_{GS}^+$	3905	115000
$2_1^+ \rightarrow 0_2^+$	553	250
$4_1^+ \rightarrow 2_1^+$	1375	8500
$6_1^+ \rightarrow 4_1^+$	1653	250
SD band transitions		
$2_{SD}^+ \rightarrow 0_{SD}^+$	417	200
$4_{SD}^+ \rightarrow 2_{SD}^+$	914	1200
$6_{SD}^+ \rightarrow 4_{SD}^+$	1432	50
SD→ND transitions		
$0_{SD}^+ \rightarrow 2_1^+$	1308	70000
$2_{SD}^+ \rightarrow 0_2^+$	2278	4000
$2_{SD}^+ \rightarrow 2_1^+$	1725	1500
$2_{SD}^+ \rightarrow 0_{GS}^+$	5630	17000
$4_{SD}^+ \rightarrow 2_1^+$	2639	2500
$4_{SD}^+ \rightarrow 4_1^+$	1264	70

nuBALL2:

2 rings of 12+12 HPGe CLOVERS + ACS

PARIS:

LaBr3 / CeBr3 + NaI array

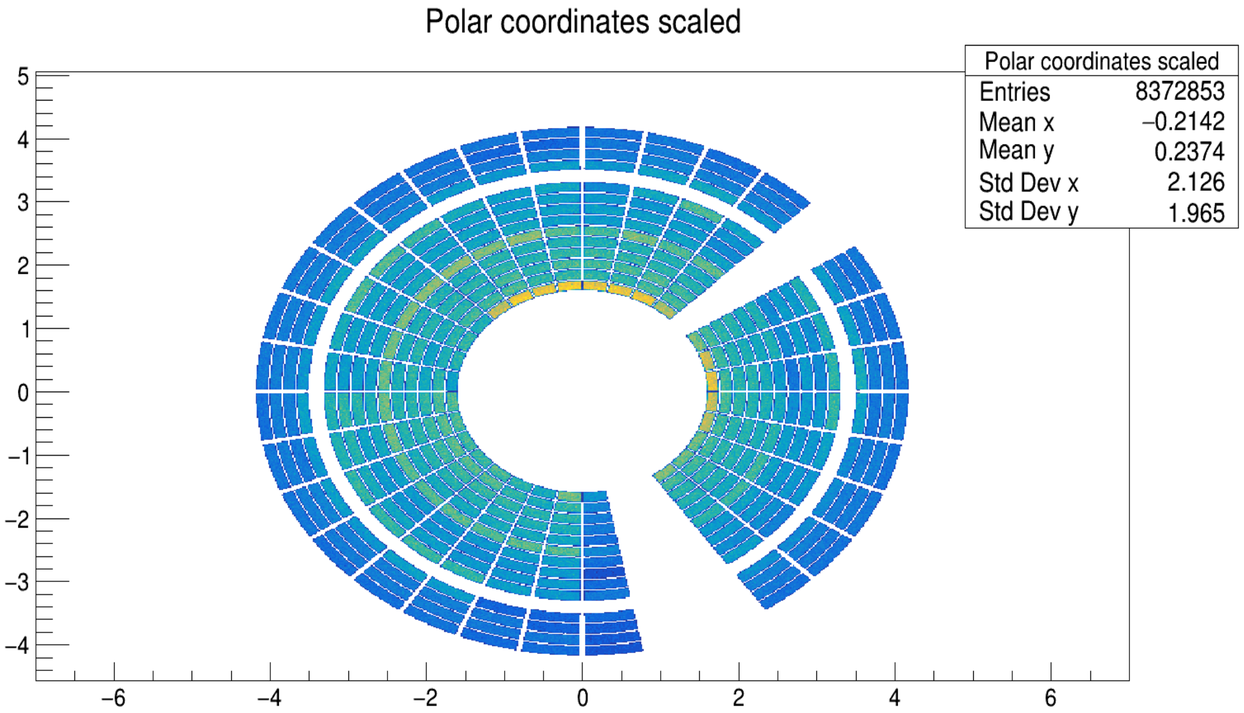
15 cm from the target

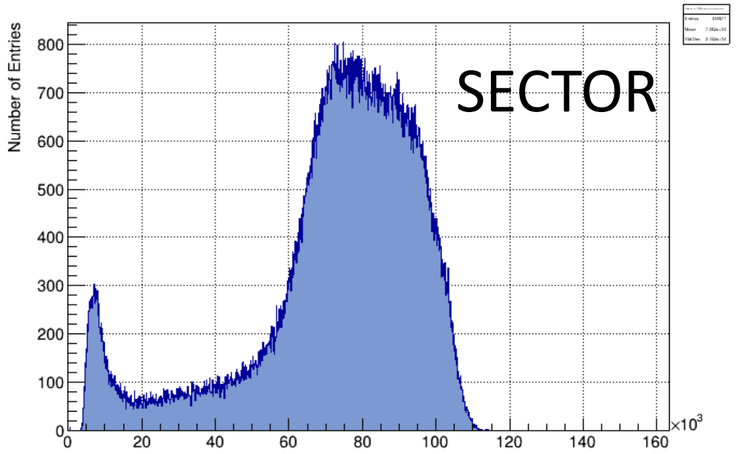
SiLCA DSSD:

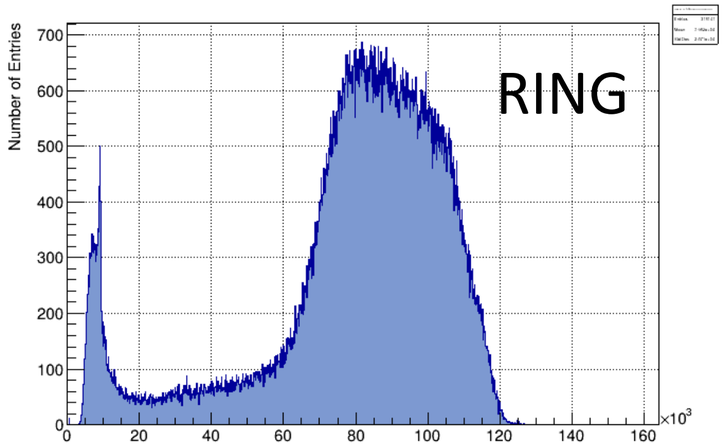
32 sectors + 16 rings

125-152º

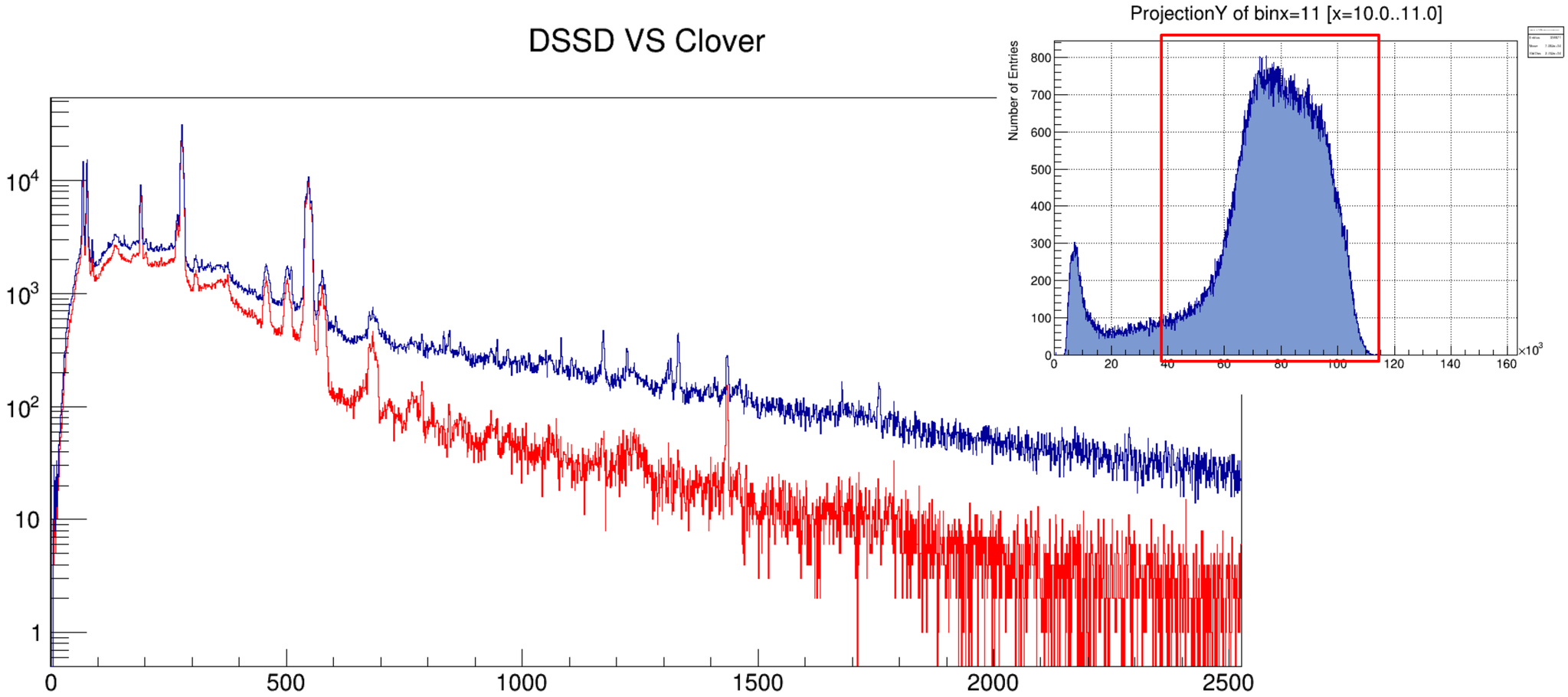
COULEX of ^{40}Ca - DSSD spectra



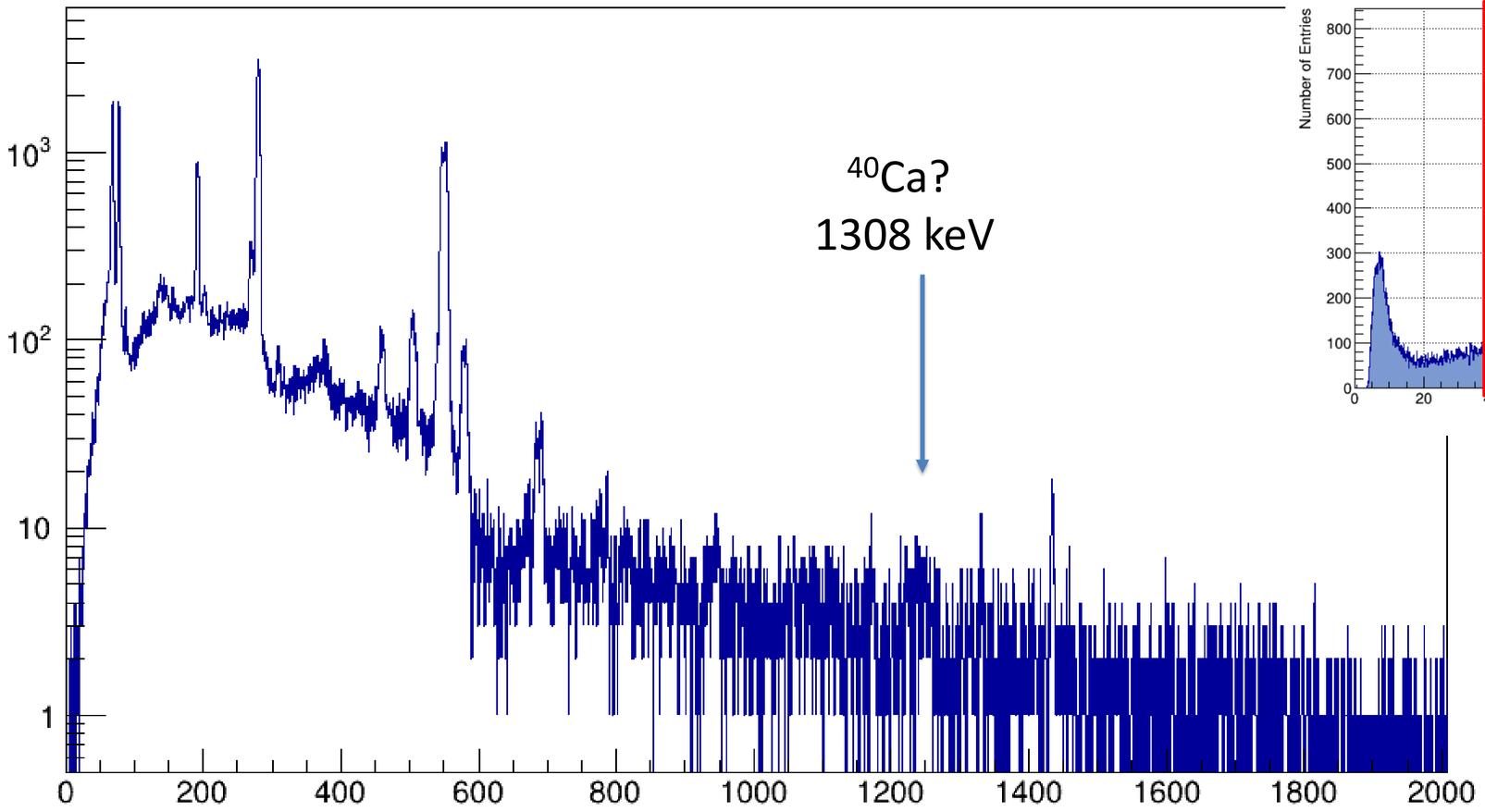


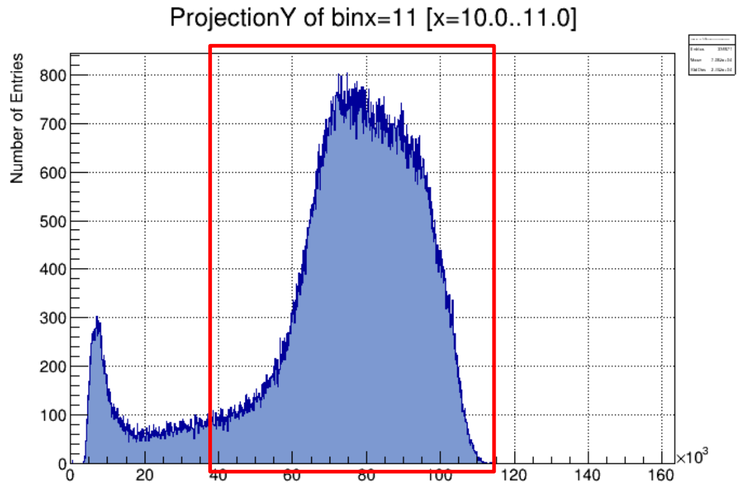


COULEX of ^{40}Ca - selection based on the DSSD



COULEX of ^{40}Ca - preliminary (av. Doppler Correction)

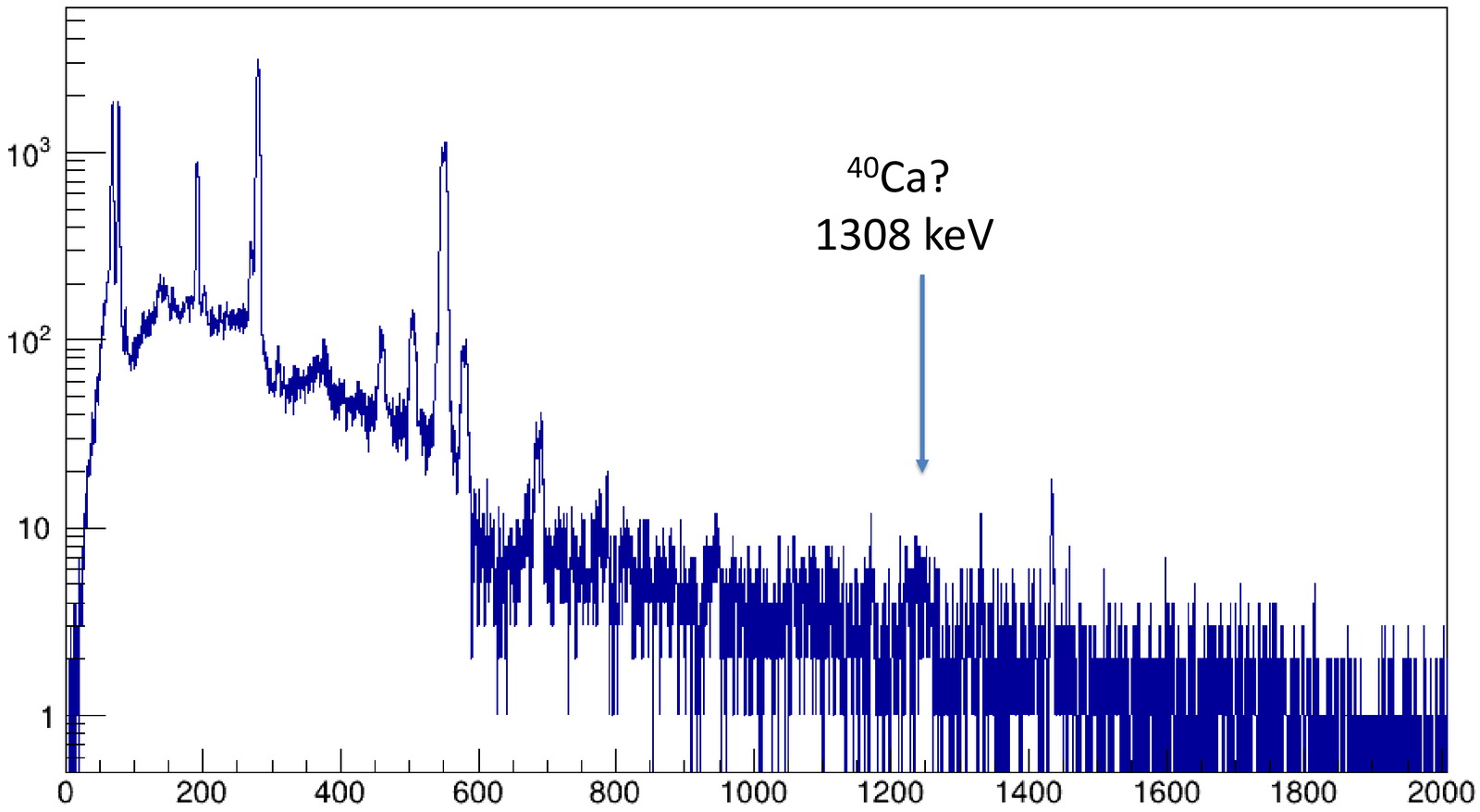


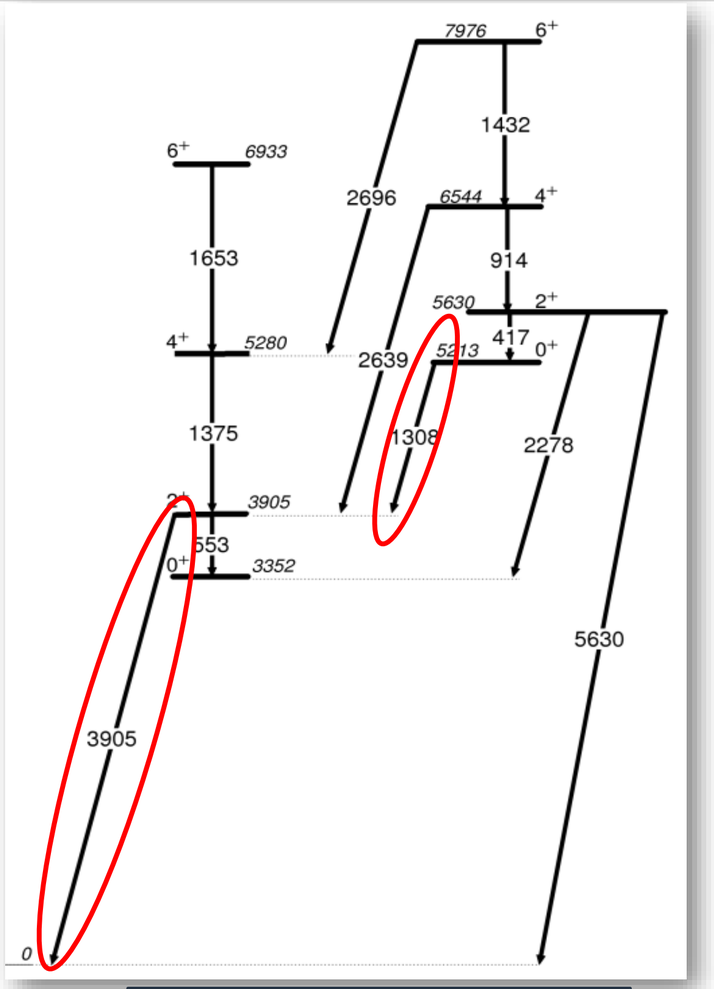


<2 days of the data taking only

Analysis is ongoing

COULEX of ^{40}Ca – preliminary (IJC Lab, Orsay)

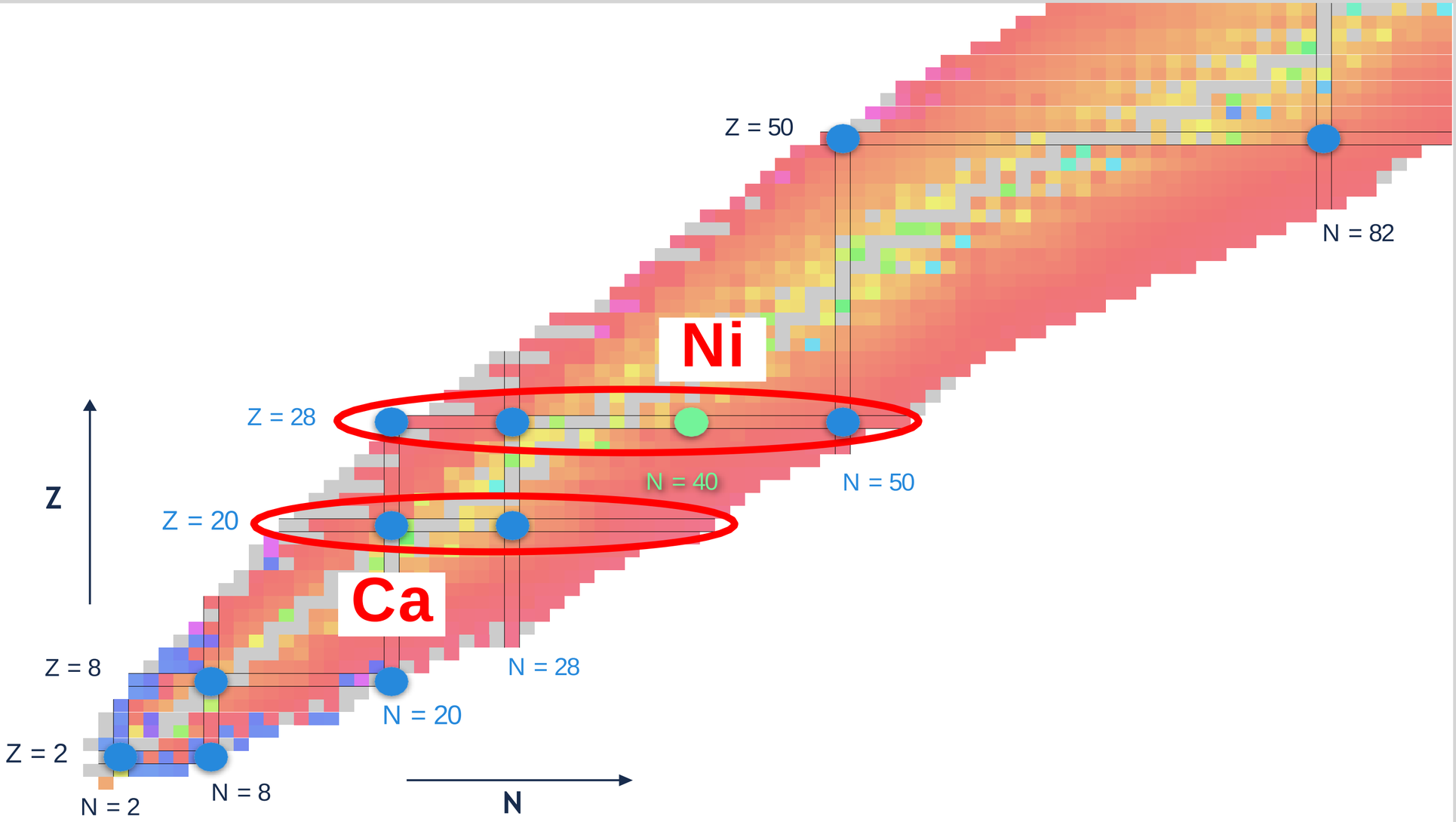




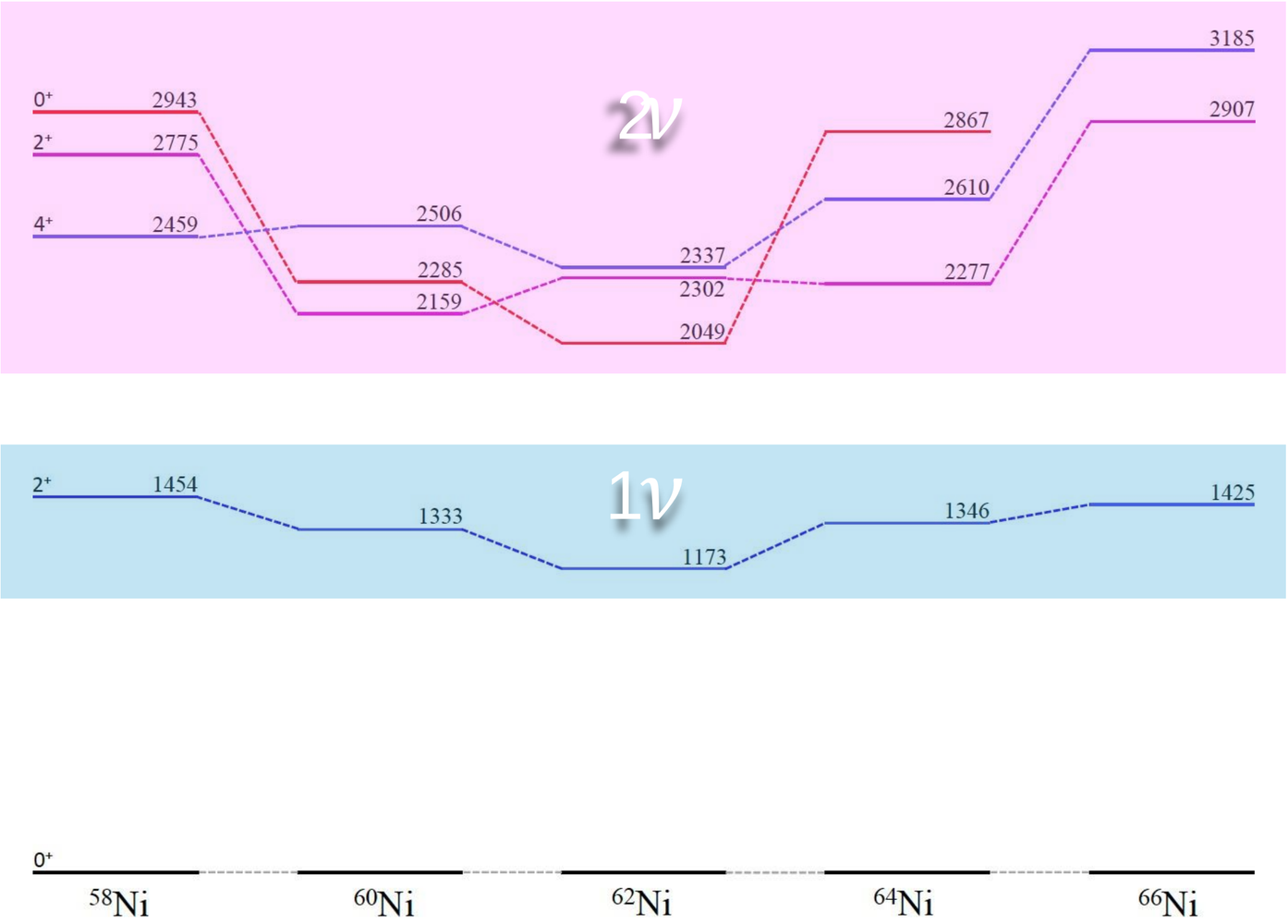
2 days of the data taking only

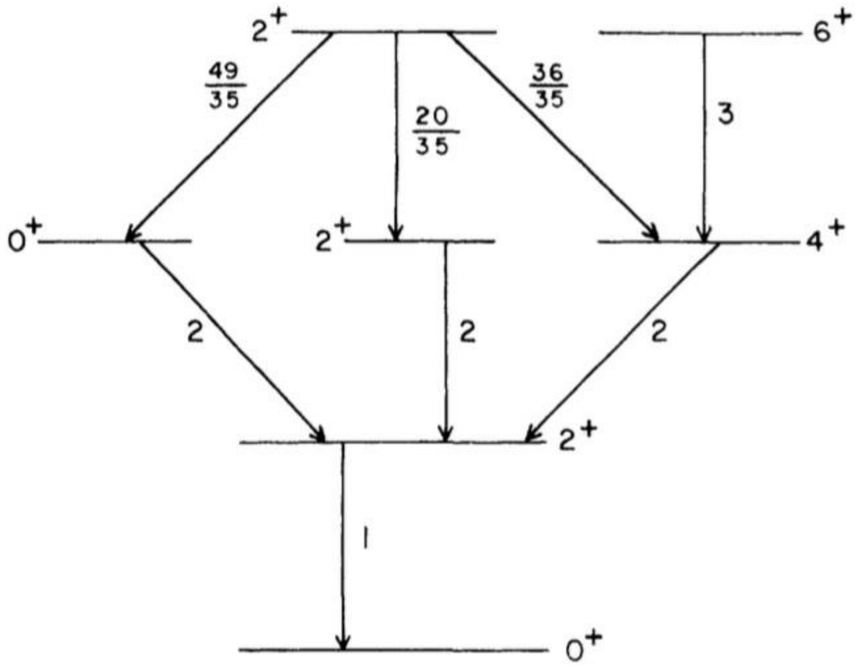
Analysis is ongoing

^{40}Ca (Z=N=20) versus ^{56}Ni (Z=N=28)



Stable Nickel isotopes: Vibrations?





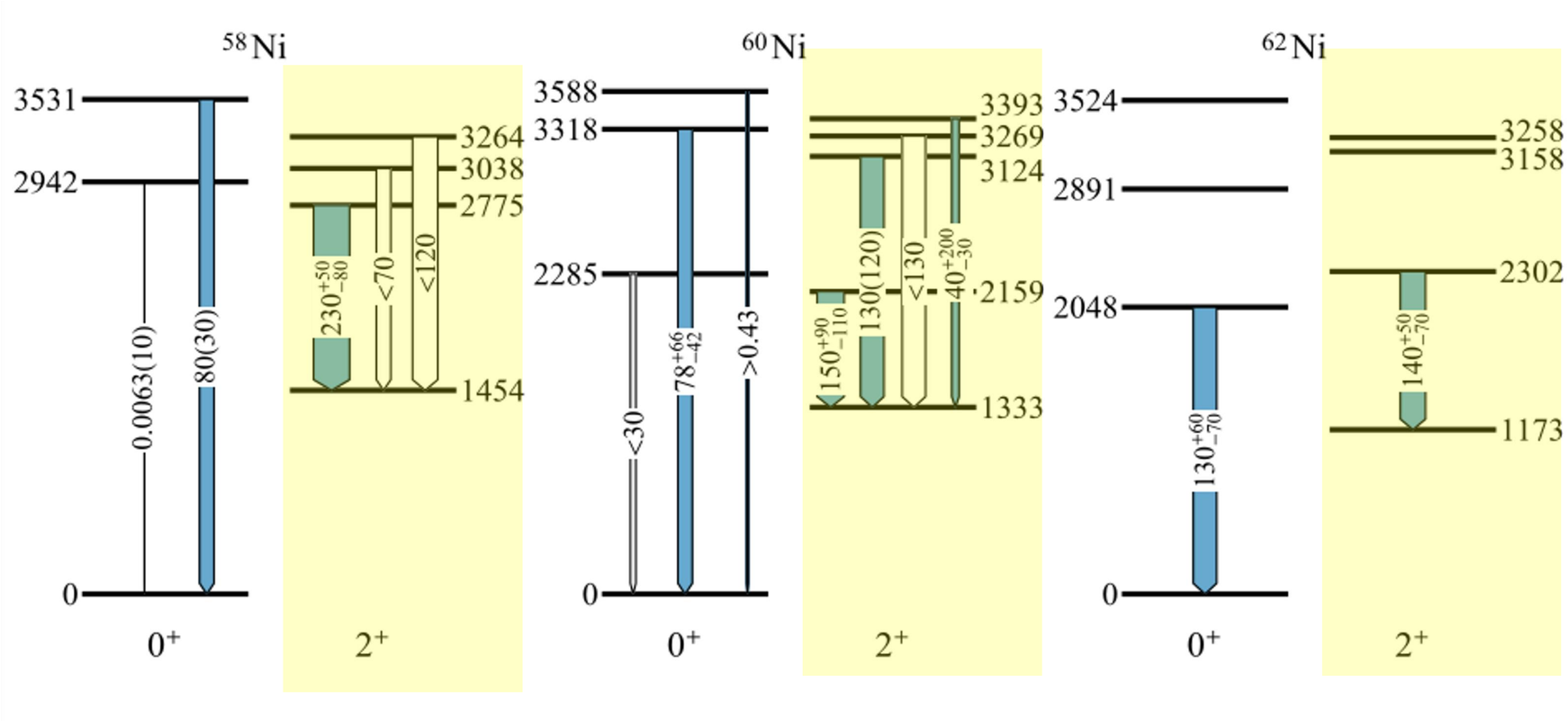
B(E2) VALUES FOR DECAY OF MULTI-PHONON STATES

B(E2) and Qs values needed

Not only the level scheme but the structure

Extremes of E0 transitions in the Ni chain

L.J. Evitts et al., Phys. Rev. C 99 (2019) 024306.



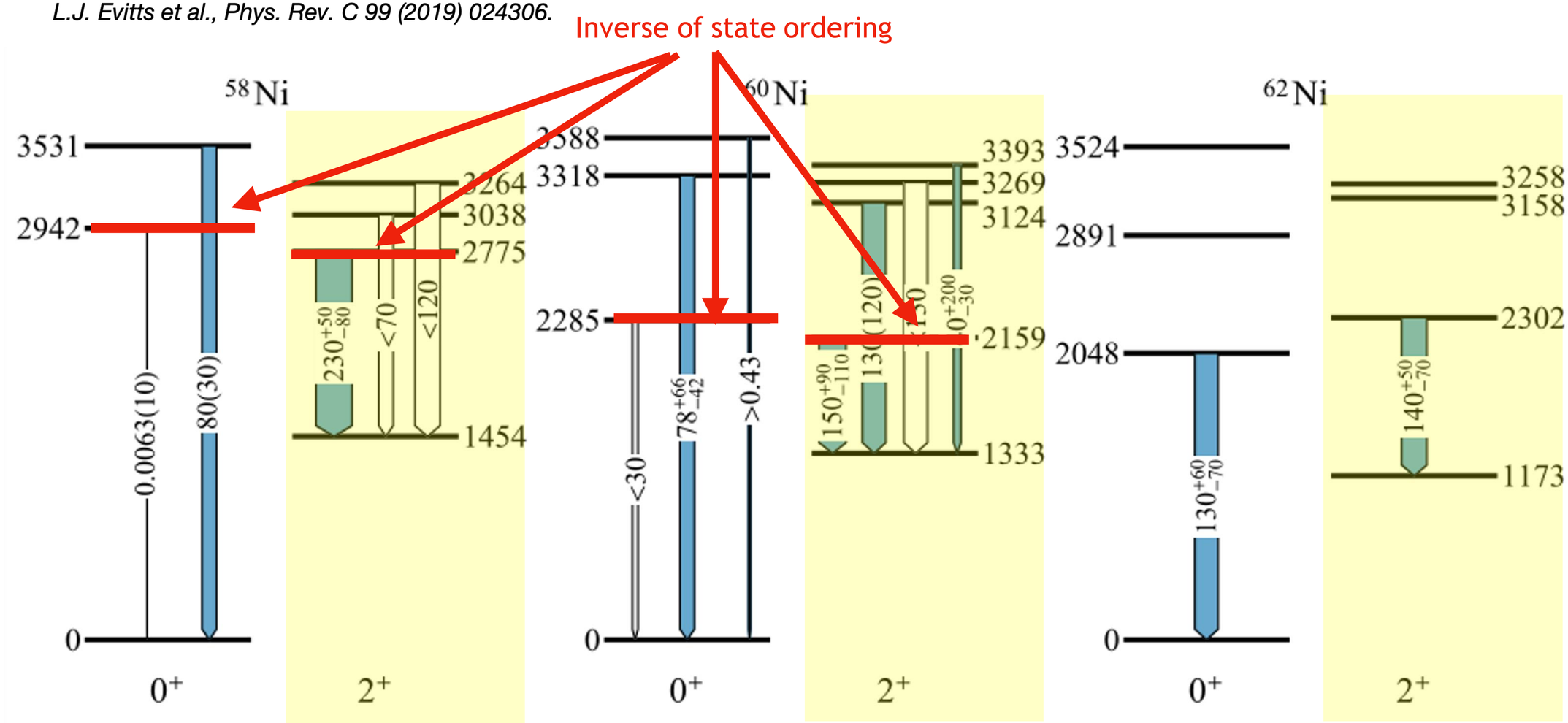
The largest $\rho^2(2_2^+ \rightarrow 2_1^+)$ values in medium and heavy nuclei reported to date

BREAKING the vibrational picture

A spherical vibrator - the E0 transitions are forbidden if the change in phonon number is one -> 2_2^+ CANNOT BE a 2v STATE

Extremes of E0 transitions in the Ni chain

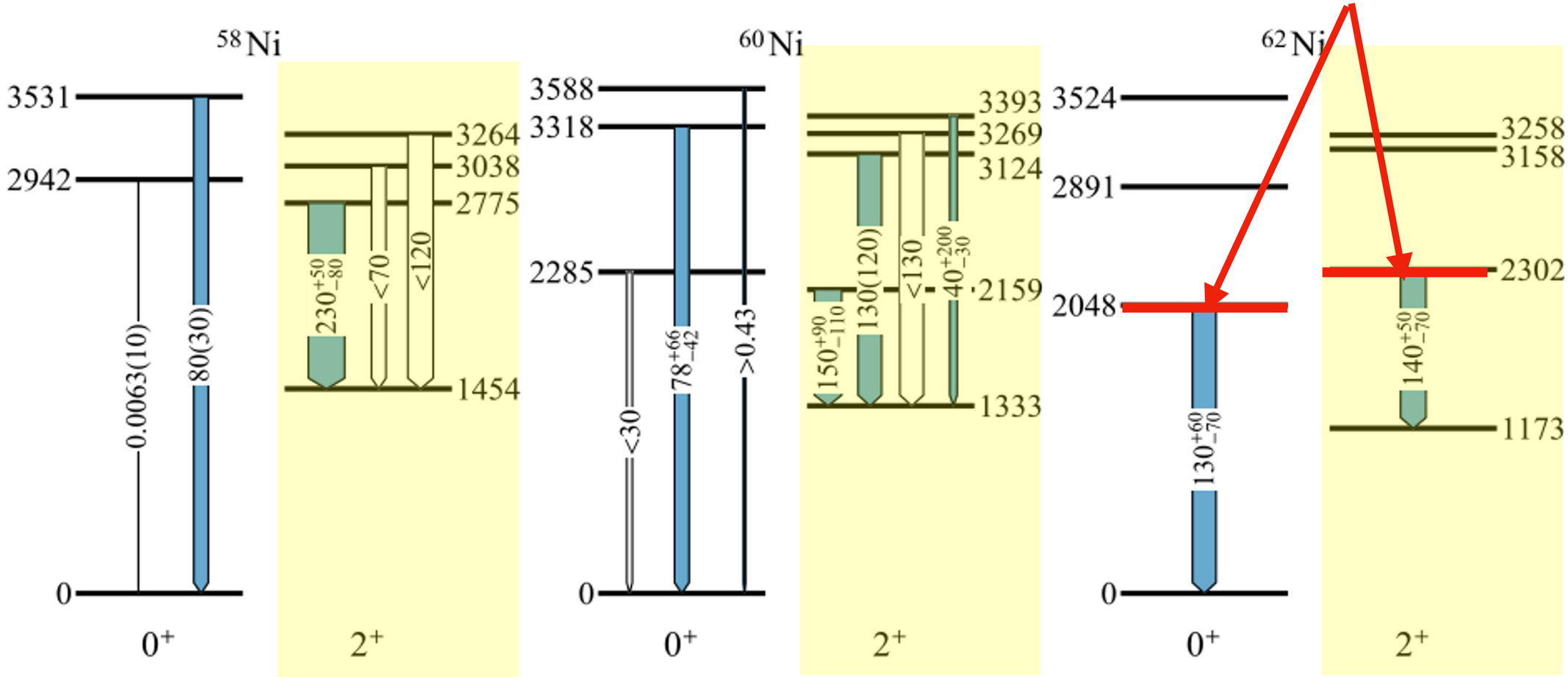
L.J. Evitts et al., Phys. Rev. C 99 (2019) 024306.



Extremes of E0 transitions in the Ni chain

L.J. Evitts et al., Phys. Rev. C 99 (2019) 024306.

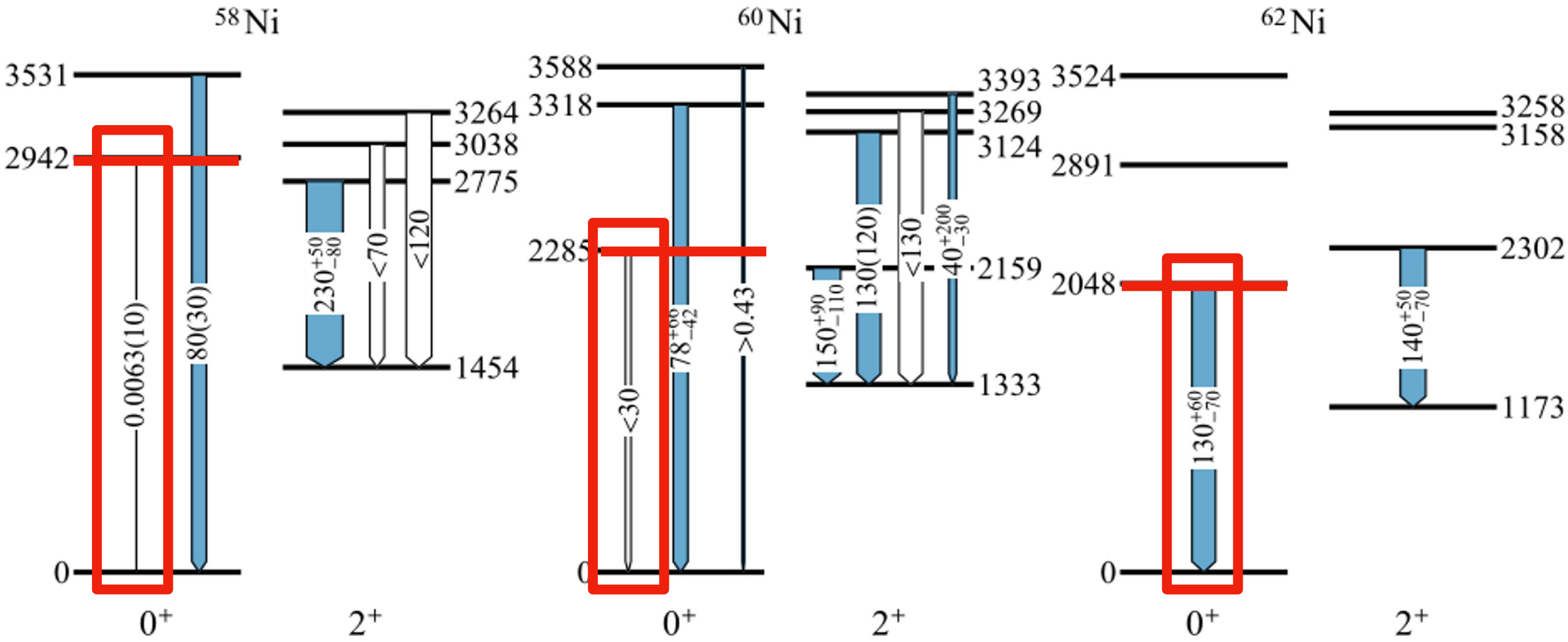
Sudden change of ordering - change of structure



Extremes of E0 transitions in the Ni chain

L.J. Evitts et al., Phys. Rev. C 99 (2019) 024306.

Large B(E0) between 0^+ states in ^{62}Ni

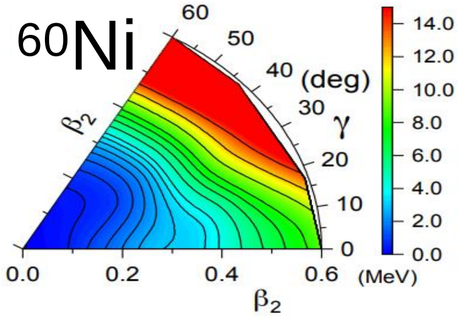


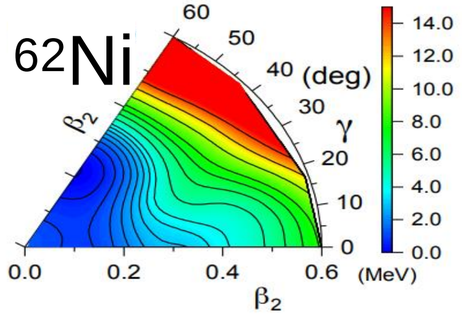
Ni - theory

PES - BMF

(SCCM-D1S Gogny triaxial calculations)

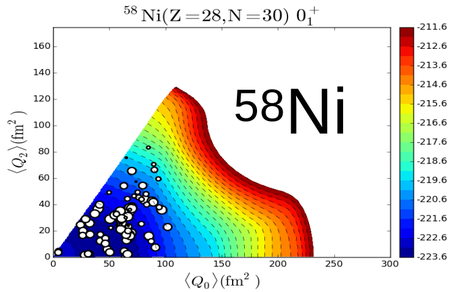
T. Rodriguez

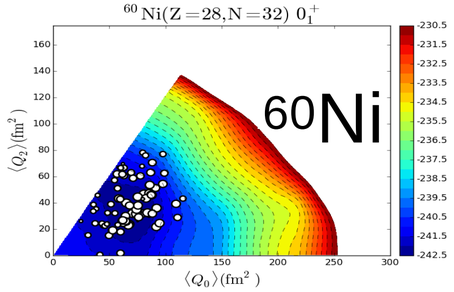


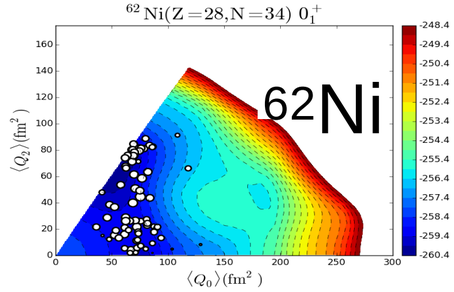


Monte Carlo Shell Model

T. Otsuka, Y. Tsunoda



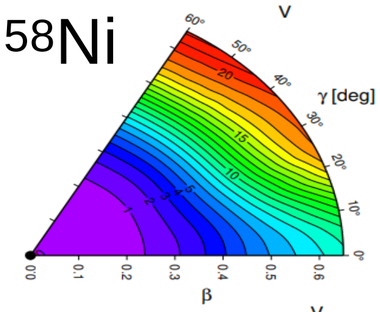


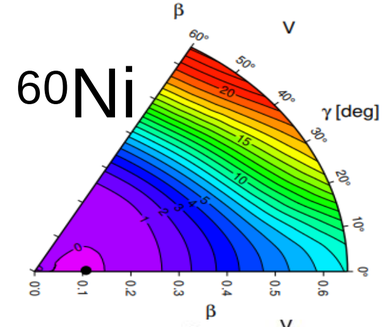


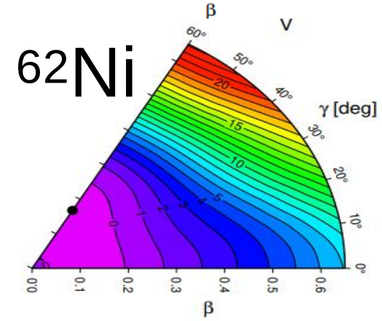
PES - UNEDF1

(General Bohr Hamiltonian)

L. Próchniak

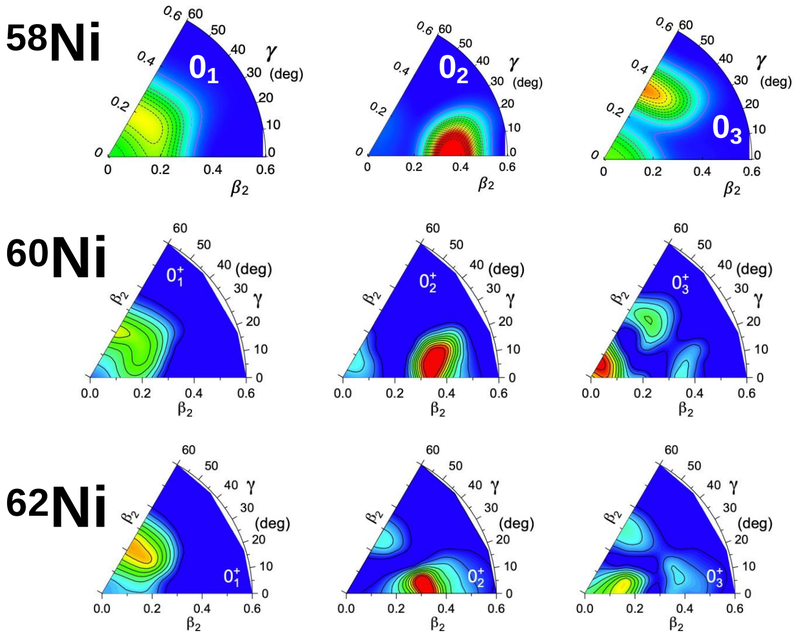




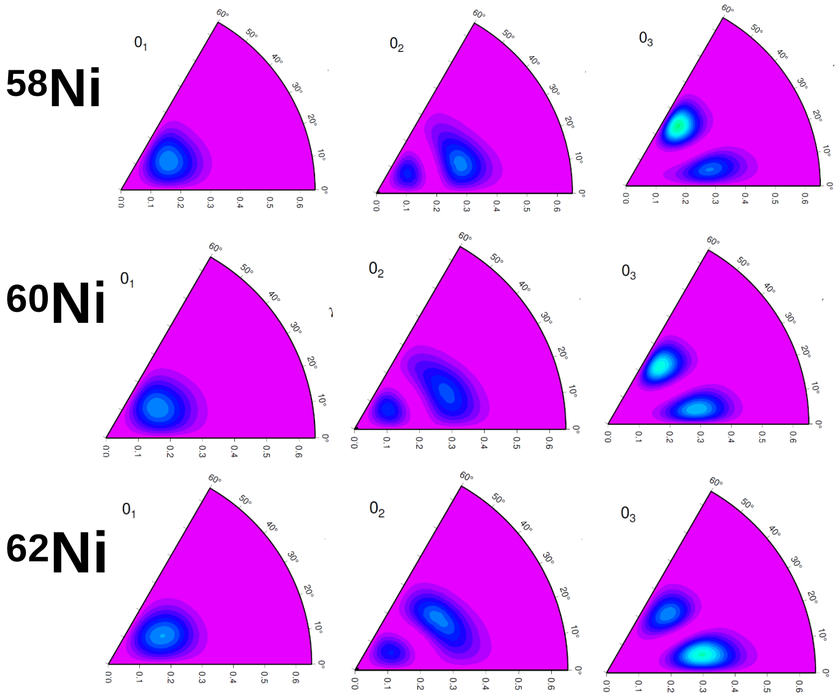


Ni – gamma-soft?

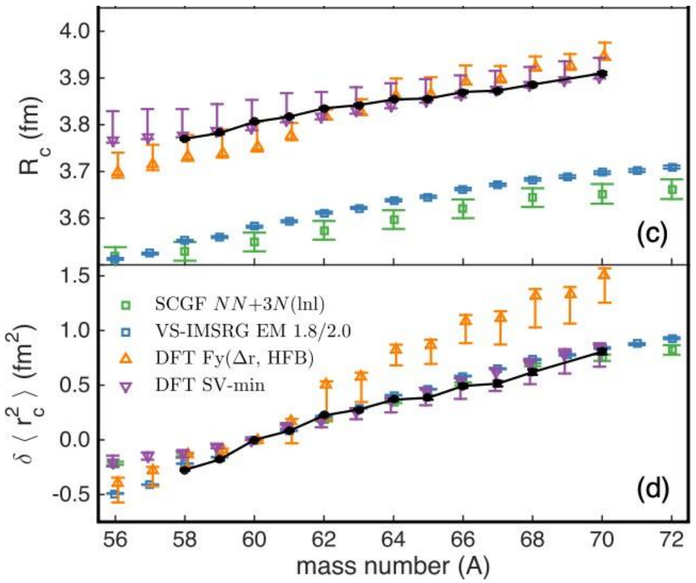
Collective wave functions BMF
(SCCM-D1S Gogny triaxial calculations)
T. Rodriguez, priv. comm.



Collective wave functions UNEDF1
(General Bohr Hamiltonian)
L. Próchniak, priv. comm.

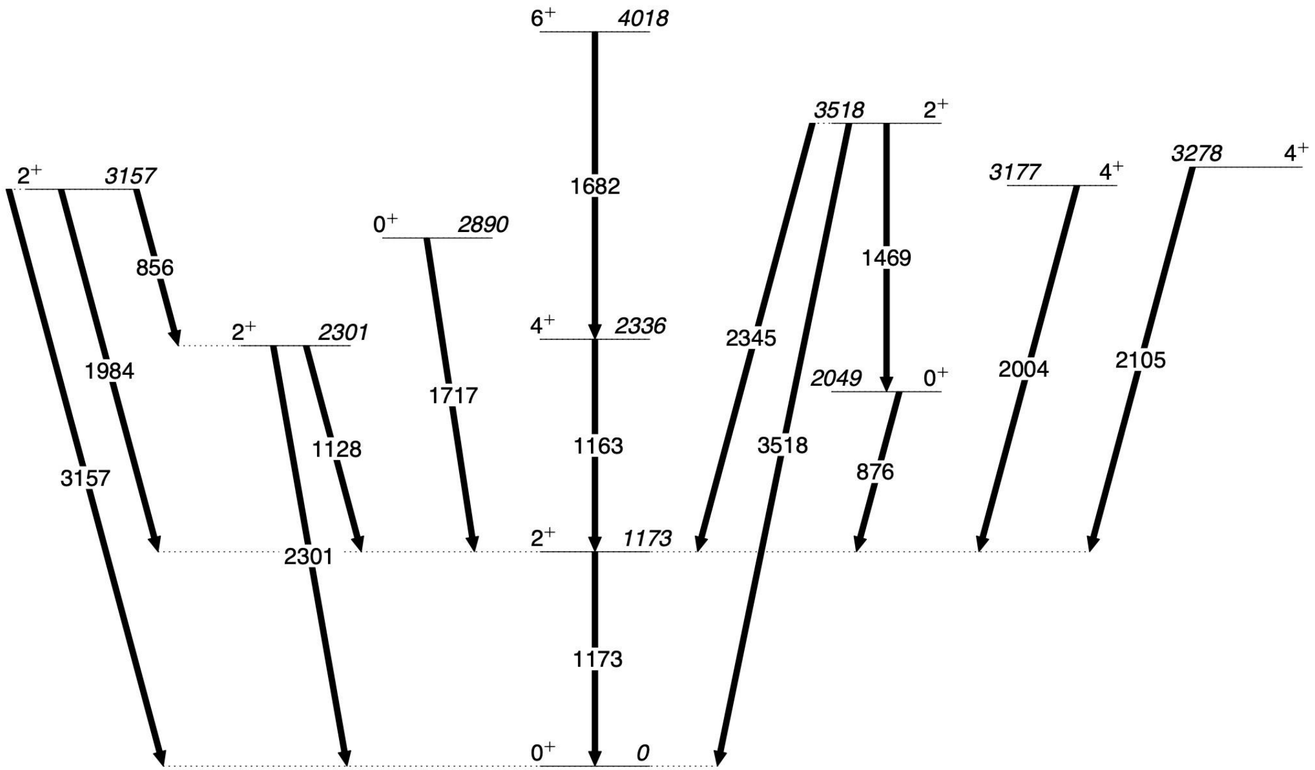


Collinear laser spectroscopy results from ISOLDE-CERN - charge radii compared to DFT: γ-soft



S. Malbrunot-Ettenauer et al.,
Phys. Rev. Lett. 128 (2022) 022502

^{62}Ni - IJC Lab Orsay - 2023

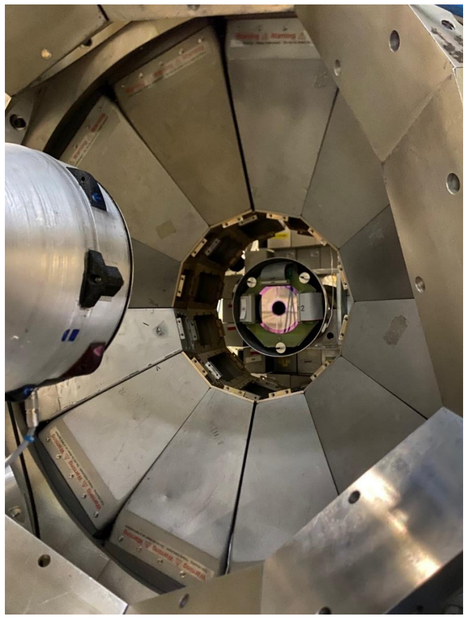


- Start was OK
- Then many unexpected issues with the beam
- Unstable, sparks… even with the lover E
- We decided to change the beam to **^{60}Ni**

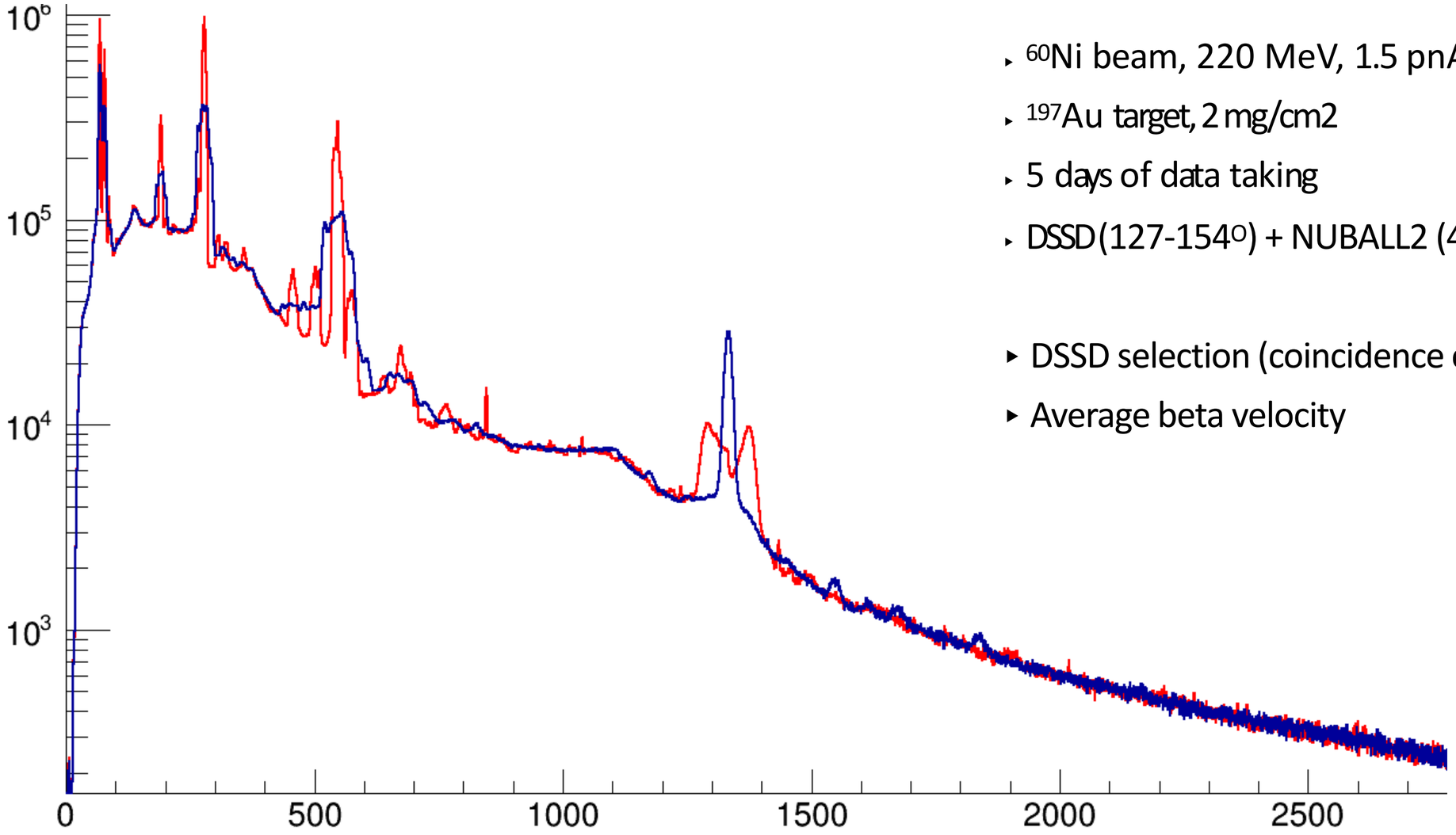
- ^{62}Ni beam, 233 MeV, 1 pnA
- ^{208}Pb target, 1 mg/cm^2
- 7 days of data taking requested
- DSSD (127-154^O) + NUBALL2 (4% at 1.3 MeV)

Project scheduled: June 2023

➔ ^{62}Ni target + ^{20}Ne beam accepted by the HIL PAC – (HIL 113)



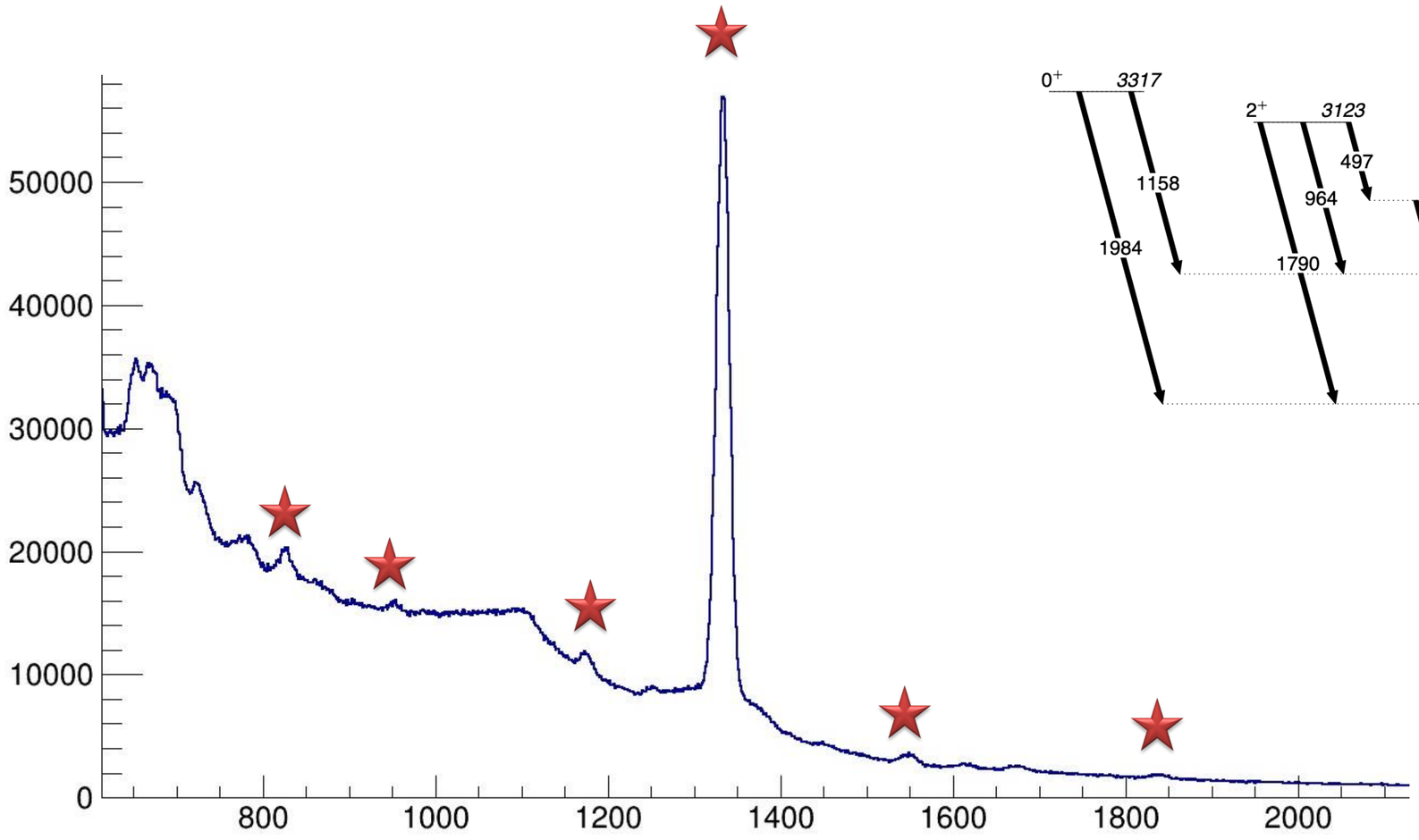
COULEX of ^{60}Ni - spectra with and without DC

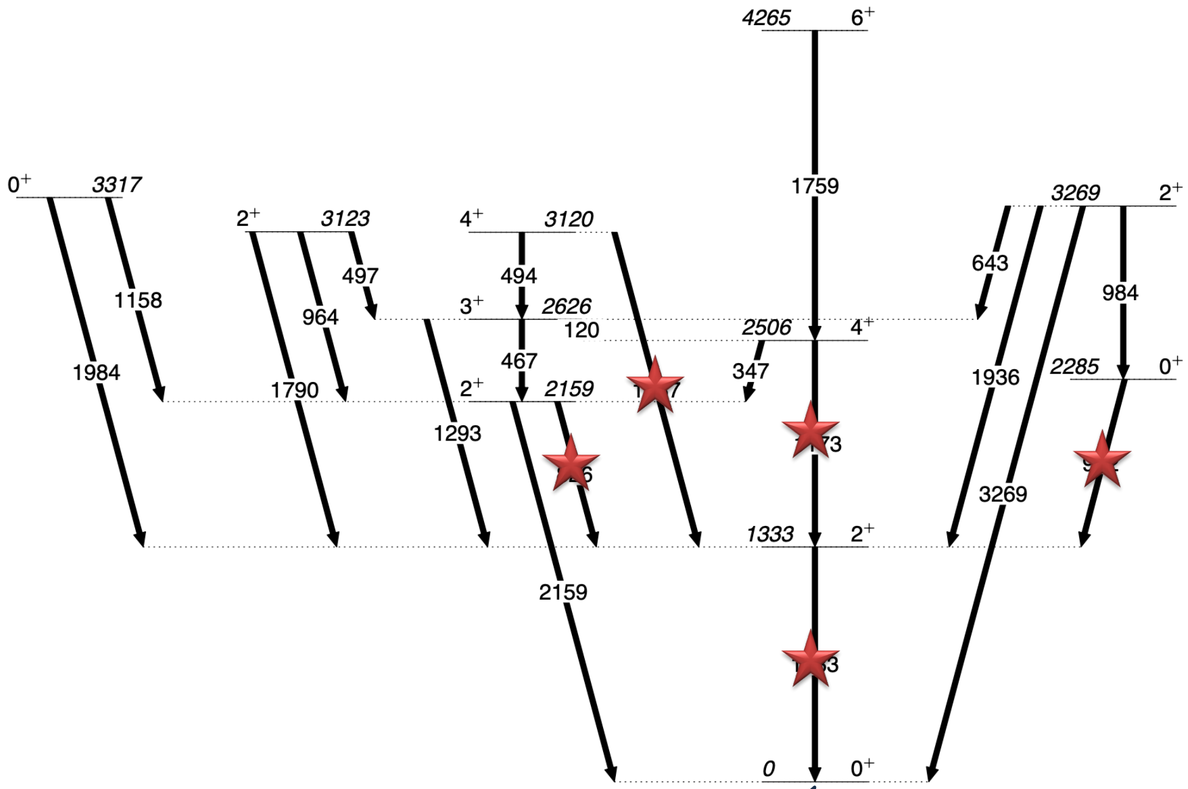


- ^{60}Ni beam, 220 MeV, 1.5 pnA
- ^{197}Au target, 2 mg/cm2
- 5 days of data taking
- DSSD(127-154^{O}) + NUBALL2 (4% at 1.3 MeV)

- DSSD selection (coincidence condition)
- Average beta velocity

COULEX of ^{60}Ni - preliminary gamma spectrum (DC)





Other transitions? Better DC needed

OUTLOOK

- Some data from >1 day of ^{62}Ni beam -> ^{60}Ni more stable
- A bonus gem - ^{197}Au target used in both ^{40}Ca and ^{60}Ni – a possibility to study polarisation effects in COULEX with nuball2 with two different beams – M1/E2 mixing and its influence on the COULEX XS
- Data analysis ongoing

Thank you