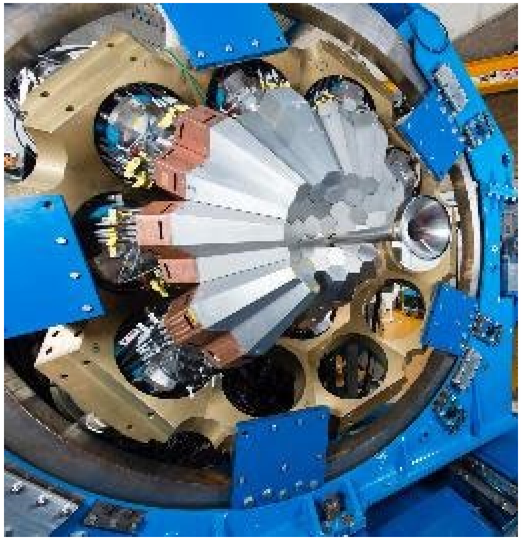
Lifetimes measurements with MNT reactions at the AGATA-VAMOS++ setup: Exploring the seniority conservation in the semimagic N=50 nuclei above Z=40.

A. Gadea, R.M. Peréz–Vidal (IFIC-CSIC, Spain)



Colloque GANIL 2023, Soustons, France 25th -29th September

IFIC INSTITUT DE FÍSICA CORPUSCULAR

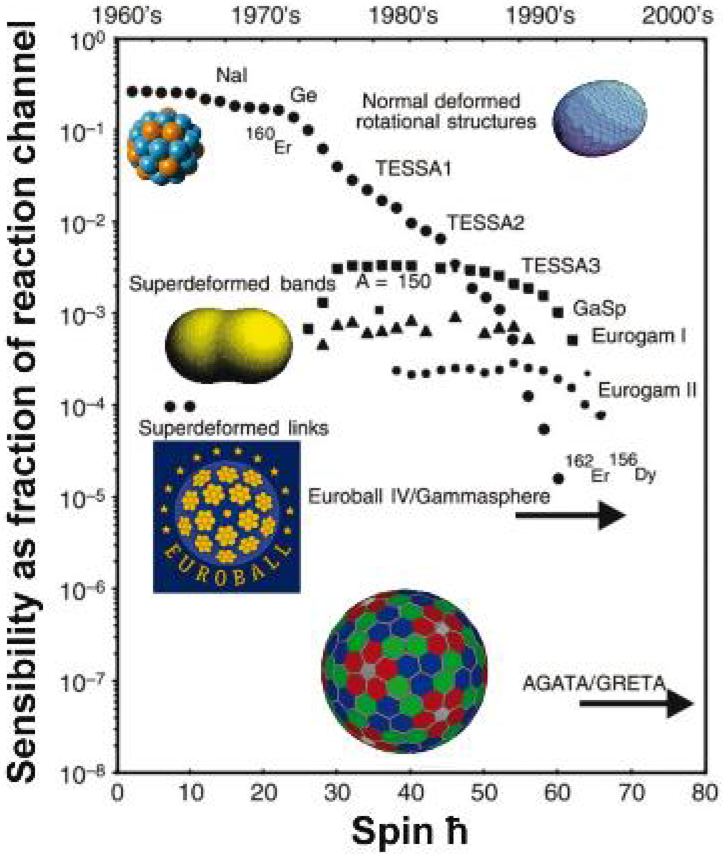
CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

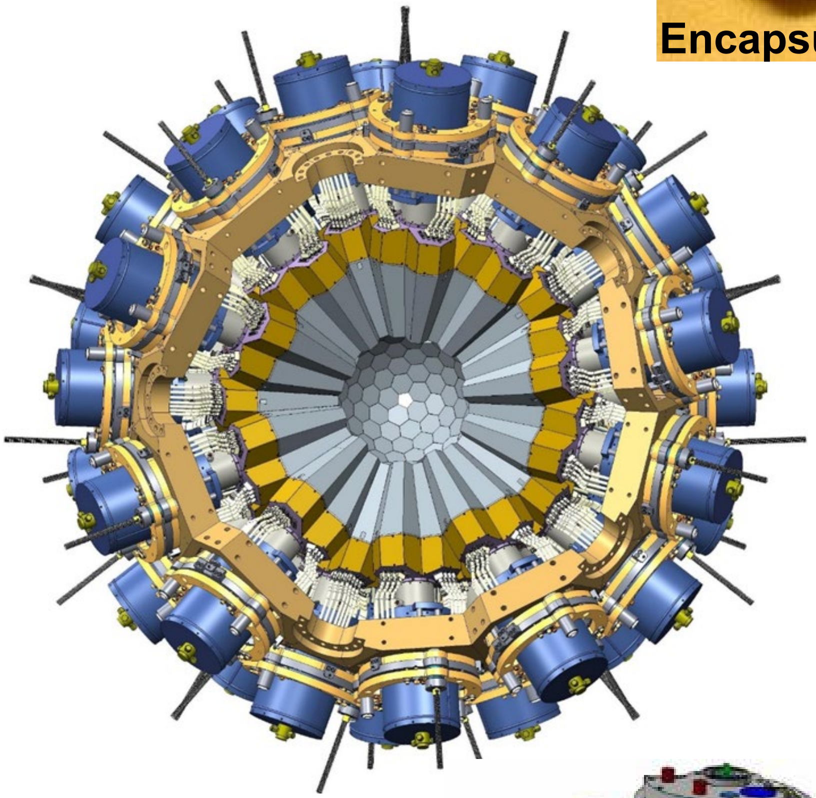
VNIVERSITAT DE VALÈNCIA

AGATA ADVANCED GAMMA TRACKING ARRAY

AGATA

(Advanced GAmma Tracking Array)





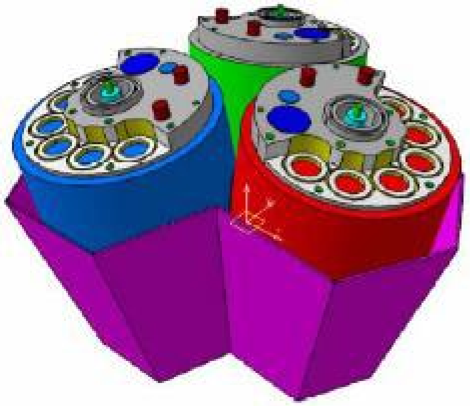
Encapsulation

6660 high-resolution digital electronics channels

High throughput DAQ / Capability to record sampled pulses

Pulse Shape Analysis → position sensitive operation mode

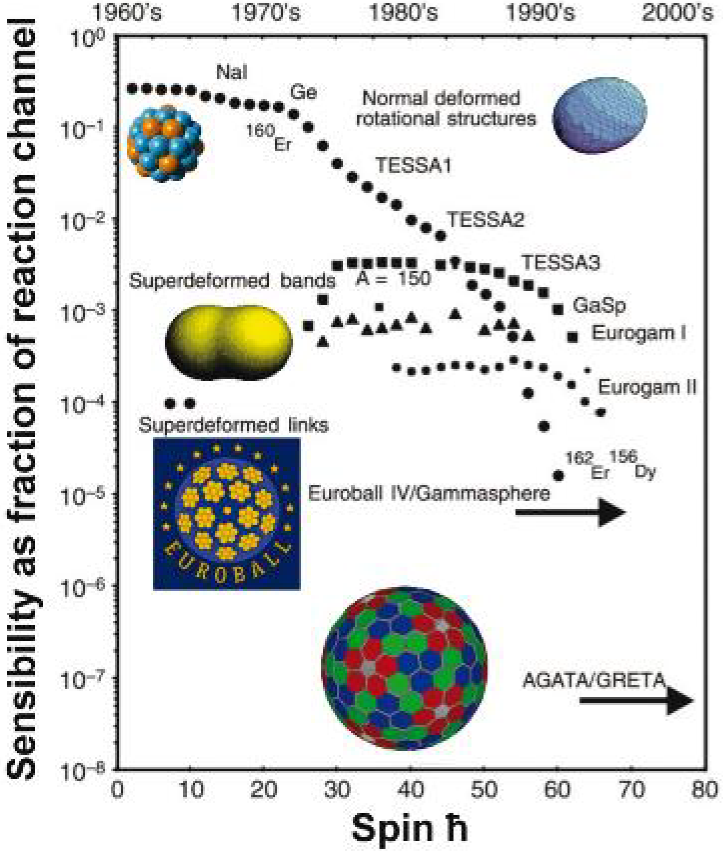
γ-ray tracking algorithms → maximum efficiency and P/T



AGATA

(Advanced GAmma Tracking Array)

Encapsulation



180 hexagonal crystals:	3 shapes
3 fold clusters (cold FET):	60 all equal
Inner radius (Ge):	23.5 cm
Amount of germanium:	362 kg
Solid angle coverage:	~82 %
36-fold segmentation	6480 segments
Crystal singles rate	~50 kHz
Efficiency (Mγ=1 [30]):	35% [23%]
Peak/Total (Mγ=1 [30]):	55% [46%]

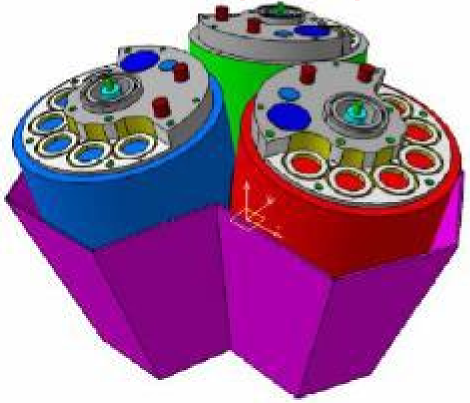
AGATA Collaboration NIM A 668 (2012) 26

6660 high-resolution digital electronics channels

High throughput DAQ / Capability to record sampled pulses

Pulse Shape Analysis → position sensitive operation mode

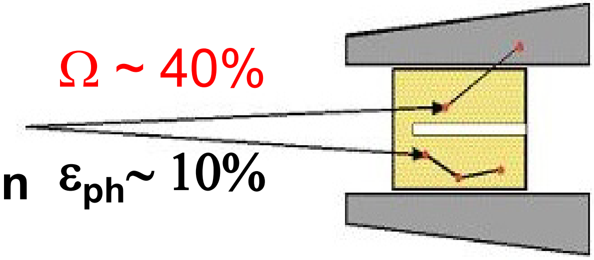
γ-ray tracking algorithms → maximum efficiency and P/T



Tracking Arrays

Primarily design to maximize Efficiency and P/T of the high resolution γ-ray detector arrays

1. **Maximizing the active solid angle without loosing signal/noise ratio**
2. **Improving the Energy resolution on all experimental conditions, even at high emission velocities**
3. **Maximizing the performance of the detectors, even in conditions of heavy duty with radiation damage**

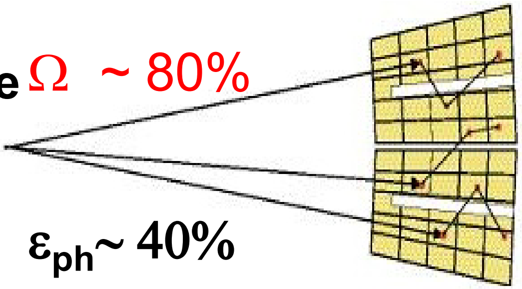


$\Omega \sim 40\%$

$\varepsilon_{ph} \sim 10\%$

Compton Suppressed

- solid angle taken by the AC shields
- large opening angle ➔ poor energy resolution



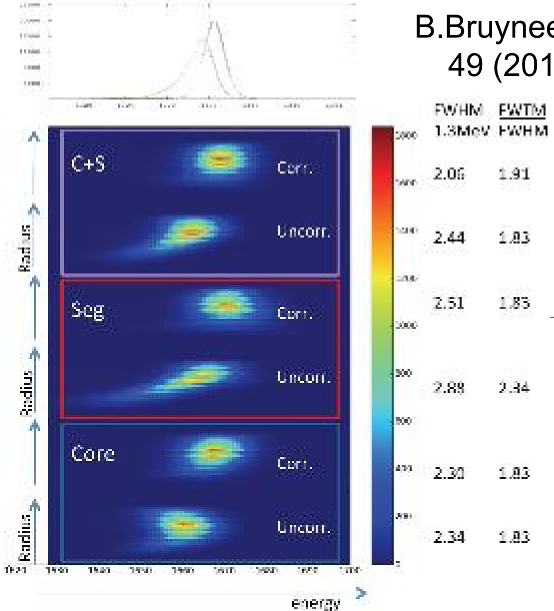
$\Omega \sim 80\%$

$\varepsilon_{ph} \sim 40\%$

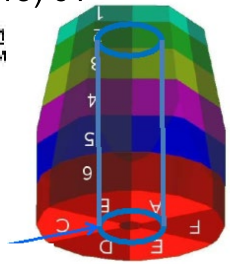
Tracking array

- Large solid angle
- Position sensitive mode using PSA
- Large P/T using tracking for γ-ray reconstruction

Correction of neutron damage

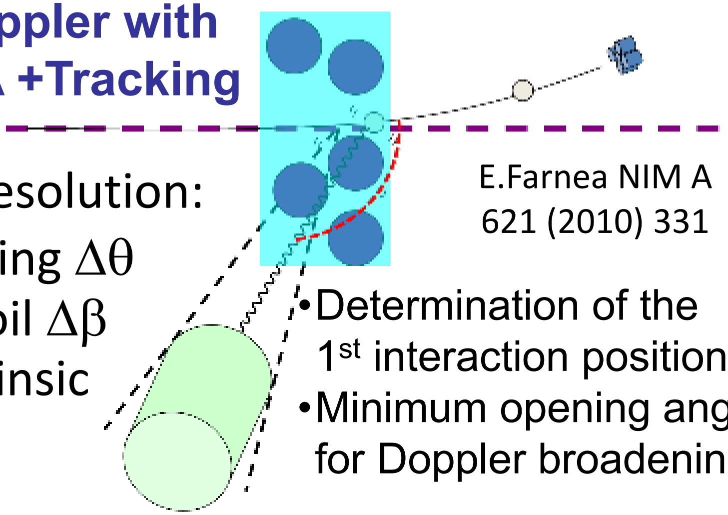


B.Bruyneel EPJ A 49 (2013) 61



- Radial dependency of charge trapping

Doppler with PSA +Tracking



E.Farnea NIM A 621 (2010) 331

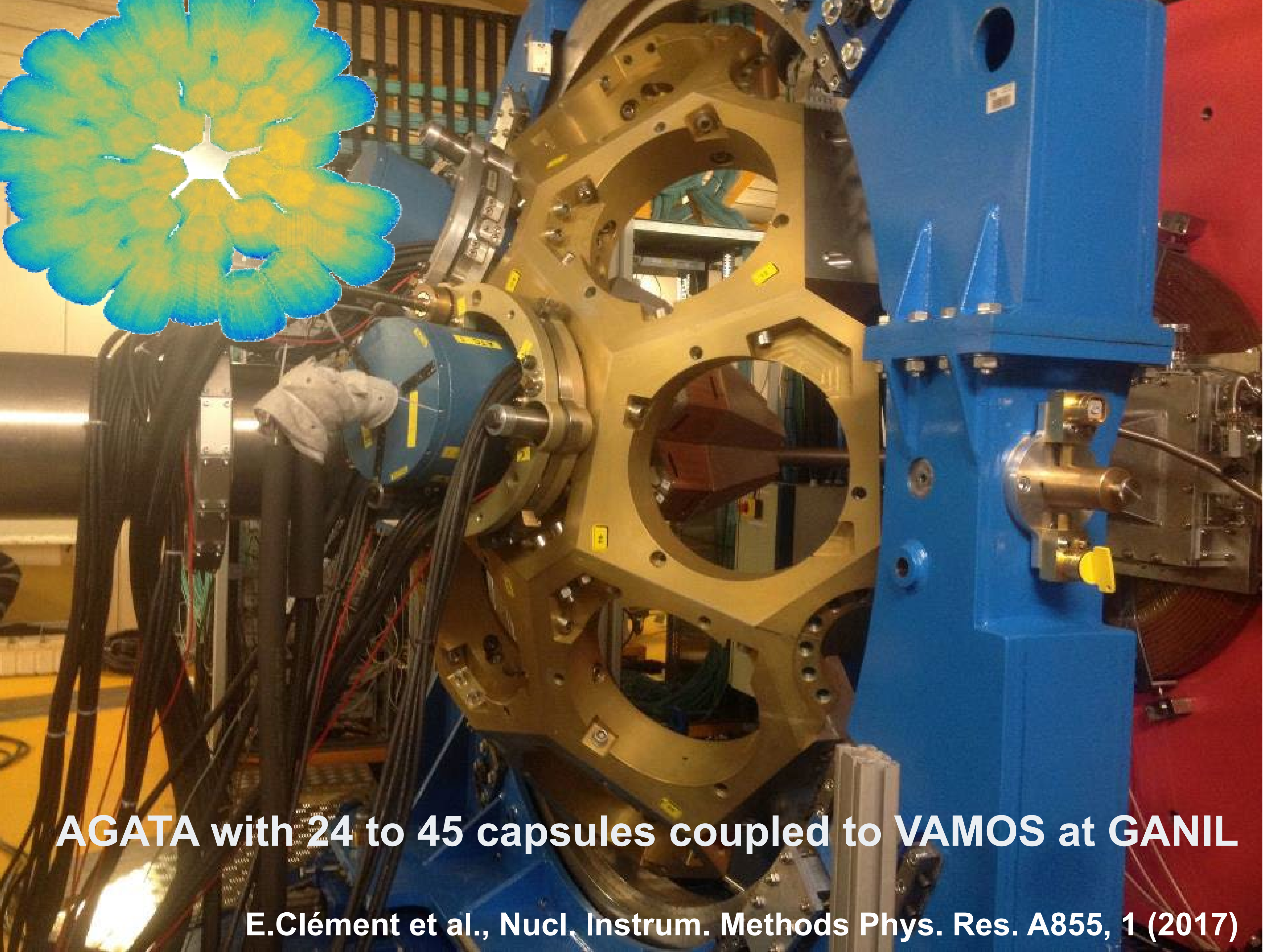
Total Resolution:

Opening $\Delta\theta$

Recoil $\Delta\beta$

Intrinsic

- Determination of the 1st interaction position
- Minimum opening angle for Doppler broadening



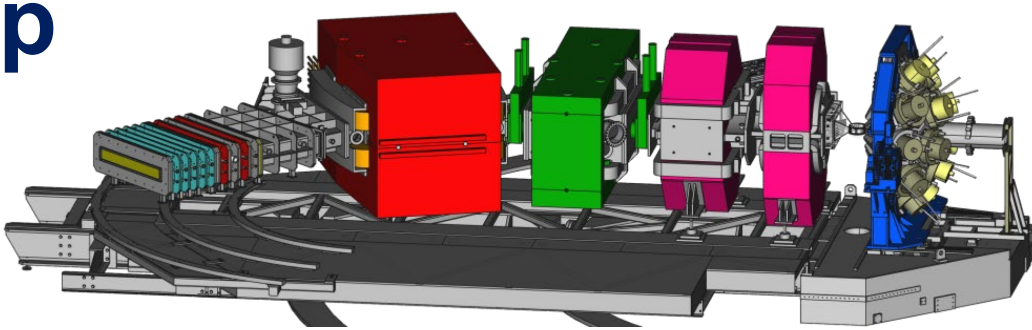
AGATA with 24 to 45 capsules coupled to VAMOS at GANIL

E.Clément et al., Nucl. Instrum. Methods Phys. Res. A855, 1 (2017)

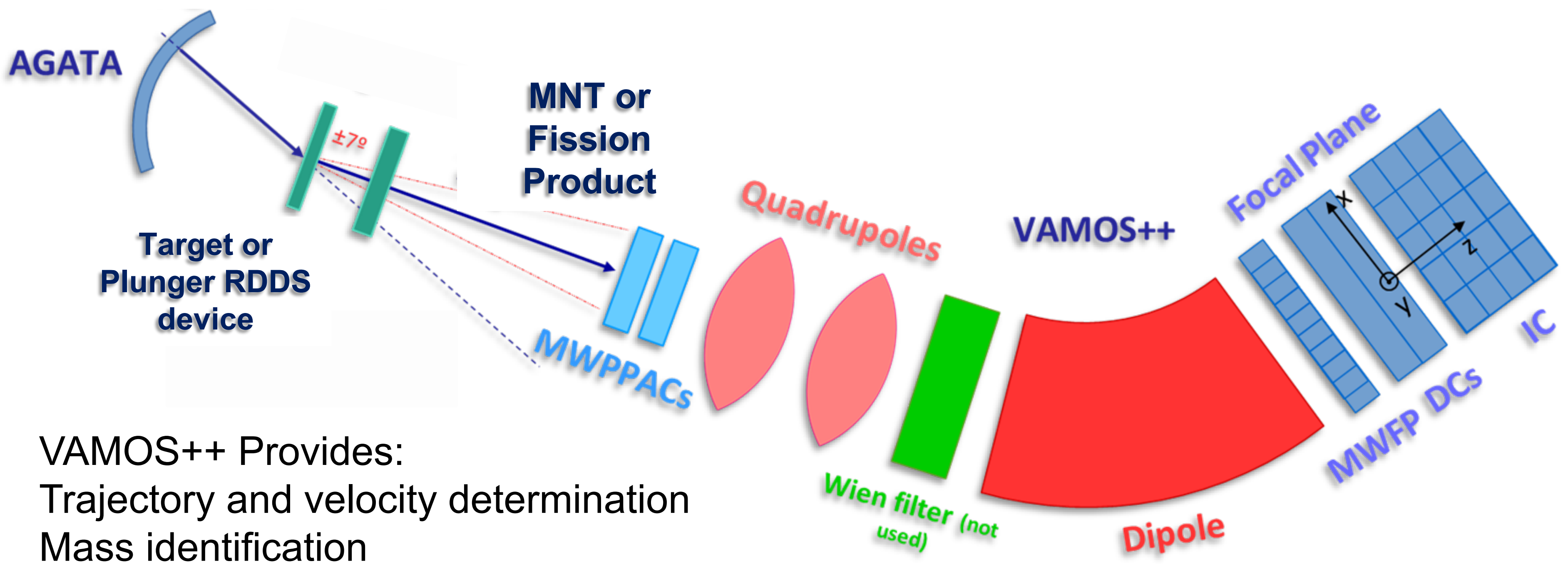
Experimental Setup

for AGATA + VAMOS++

Multi Nucleon Transfer, Deep Inelastic
and Reaction Induced Fission



GANIL Beam



VAMOS++ Provides:
Trajectory and velocity determination
Mass identification
- Nucleus trajectory reconstruction
- Velocity measurement
- Total energy measurement

Z identification
- Energy measurement (E-E method)

Trigger MWPPAC & MWFP & GAMMA

Lifetime measurements in MNT and DIC with AGATA coupled to Large acceptance magnetic Spectrometers

- The improved efficiency of AGATA, allows lifetime measurements following MNT or DIC reactions, making use of Doppler-shift-based techniques such as the Recoil Distance Doppler Shift (RDDS), in the range from few to hundreds of ps, and the Doppler Shift Attenuation Method (DSAM), in the range of fs to tens of ps.
- Both techniques are done in differential mode allowing the reaction products to be fully identified by the magnetic spectrometer.
- These techniques rely on a precise Doppler correction provided by:
    - angular resolution of the AGATA array
    - an accurate kinematic reconstruction (event by event) of the detected recoil, possible with large acceptance magnetic spectrometer, such as VAMOS++ and PRISMA
- In addition, by taking advantage of the Total Kinetic Energy Loss (TKEL) measurement, it is also possible both reduce and control the contribution from the feeding transitions, major sources of systematic errors.

Eur. Phys. J. A (2023) 59:114
https://doi.org/10.1140/epja/s10050-023-01027-2

THE EUROPEAN PHYSICAL JOURNAL A

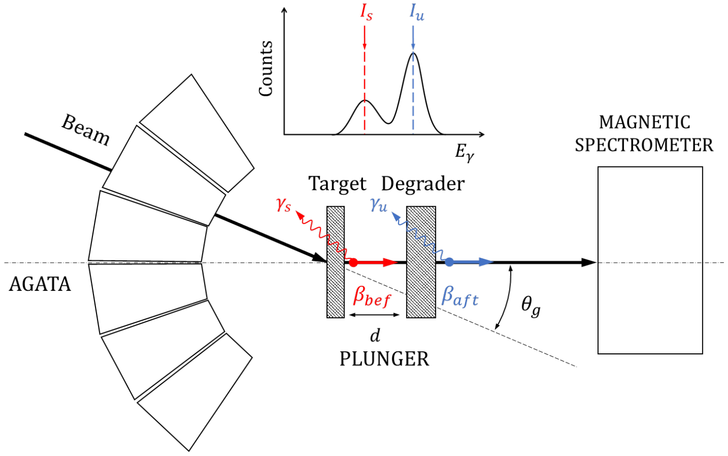
Regular Article - Experimental Physics

Nuclear structure advancements with multi-nucleon transfer reactions

R. M. Pérez-Vidal[1,2], **F. Galtarossa**[3], **T. Mijatović**[4], **S. Szilner**[4], **I. Zanon**[2], **D. Brugnara**[2], **J. Pellumaj**[2,5], **M. Ciemala**[6], **J. J. Valiente-Dobón**[2], **L. Corradi**[2], **E. Clément**[7], **S. Leoni**[8,9], **B. Fornal**[6], **M. Siciliano**[10], **A. Gadea**[1,a]

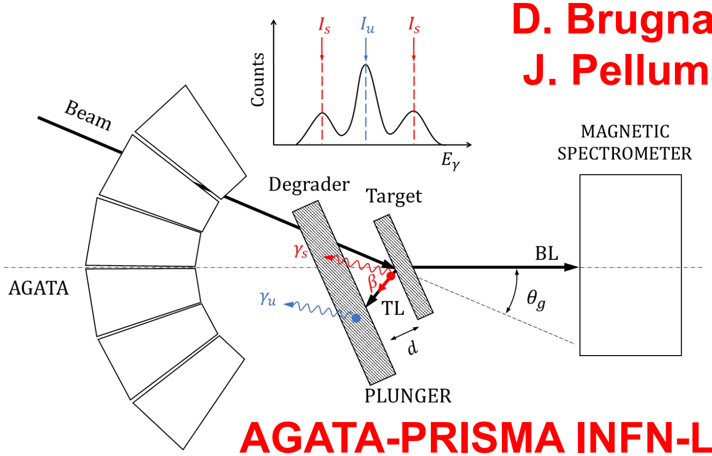
Recoil Distance Doppler Shift (RDDS) employing Differential plunger

Standard configuration Plunger



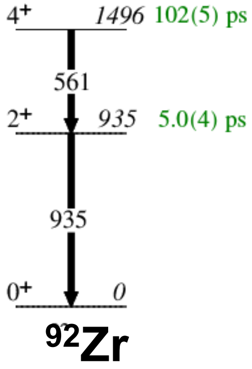
Reversed configuration Plunger

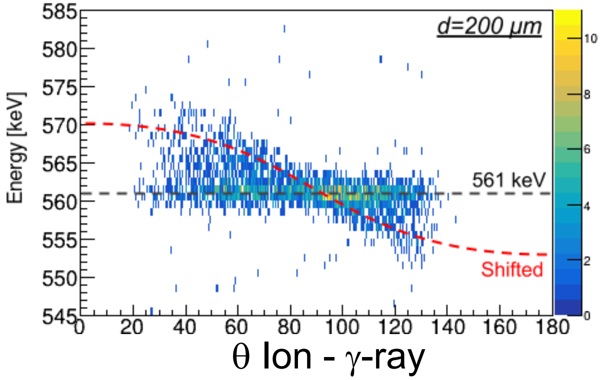
D. Brugnara
J. Pellumaj



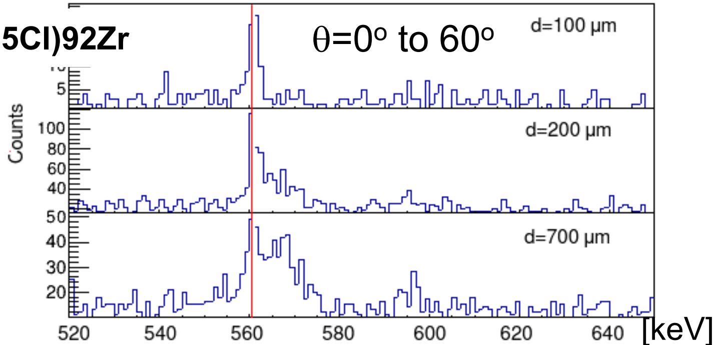
AGATA-PRISMA INFN-LNL

- Standard Configuration: when the reaction product of interest can be identified by the spectrometer
- Reversed Configuration: when the light reaction partner is identified with the spectrometer, measuring lifetimes in the heavier taget-like reaction product





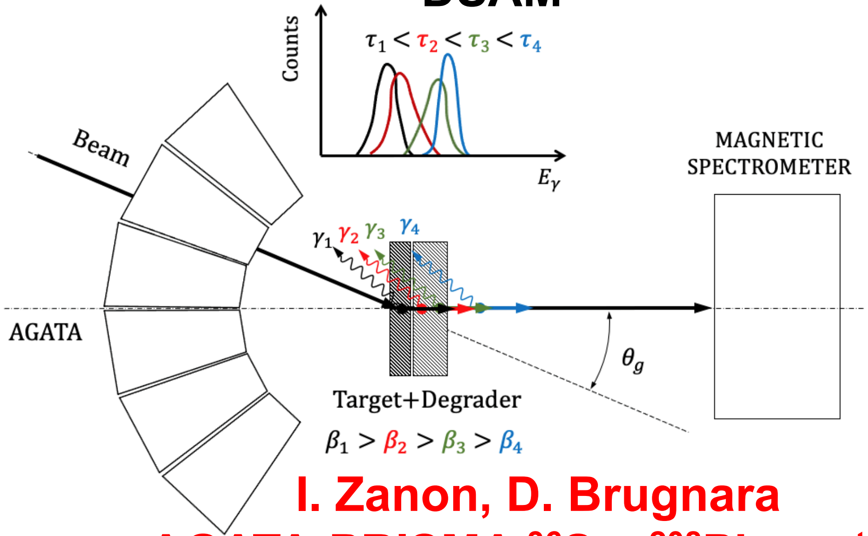
93Nb(34S,35Cl)92Zr



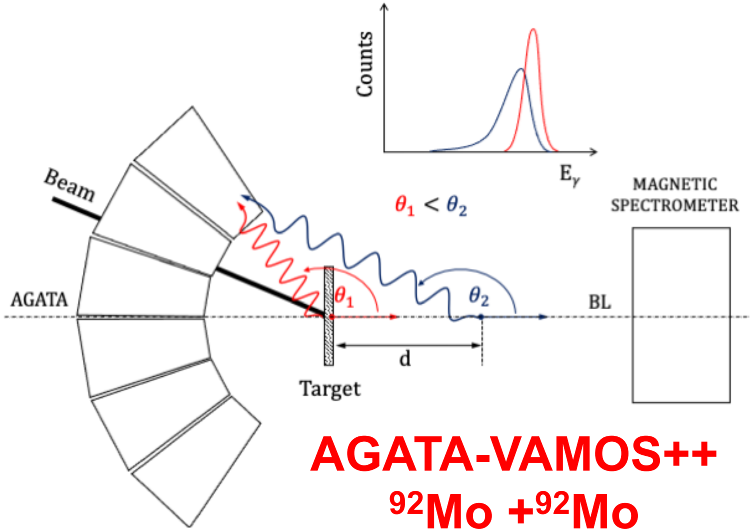
R. M. Pérez-Vidal et al., Eur. Phys. J. A 59 (2023)114

Doppler Shift Attenuation Method (DSAM) and Geometrical Doppler lineshape geoDSAM

DSAM



geoDSAM

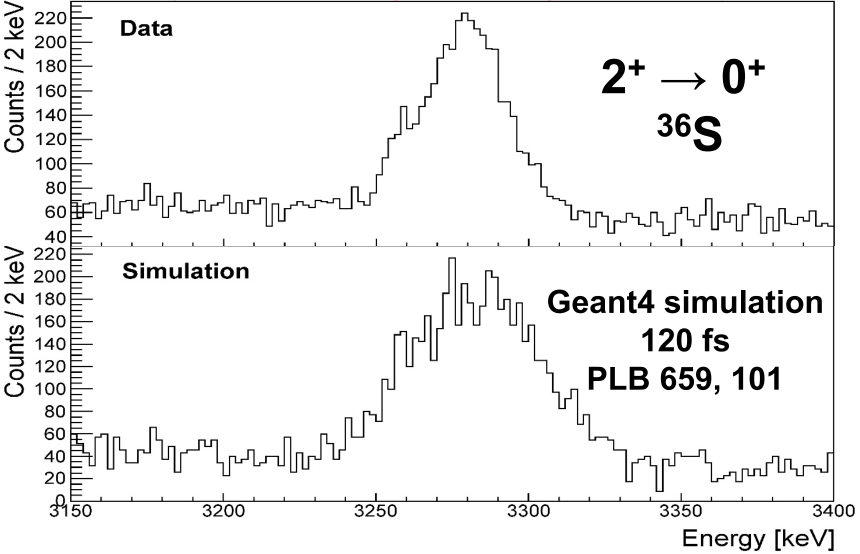


I. Zanon, D. Brugnara

AGATA-PRISMA ^{36}S + ^{208}Pb + ^{nat}Pd

AGATA-VAMOS++

^{92}Mo +^{92}Mo



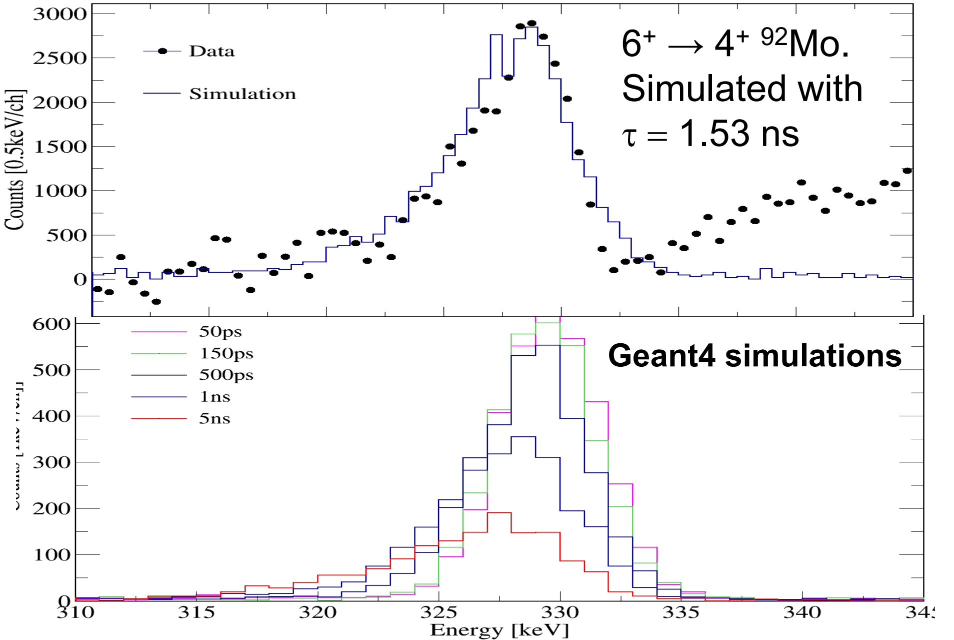
$2^+ \rightarrow 0^+$

^{36}S

Geant4 simulation

120 fs

PLB 659, 101



$6^+ \rightarrow 4^+$ ^{92}Mo.

Simulated with

τ = 1.53 ns

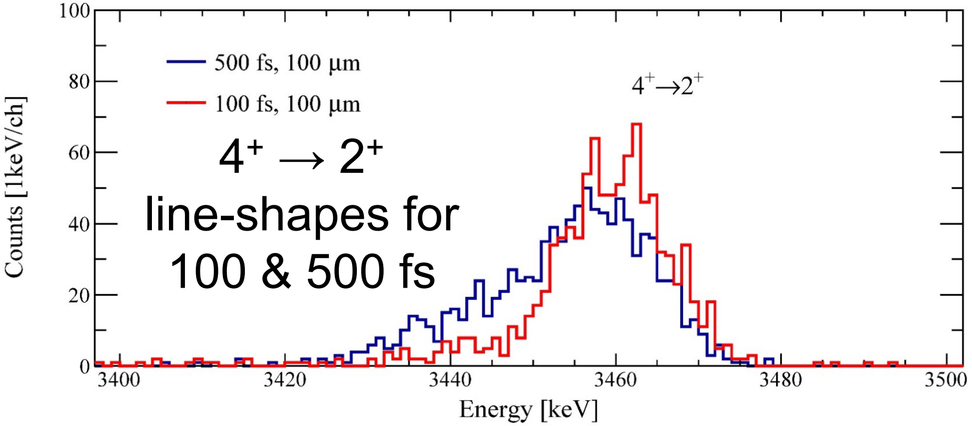
Geant4 simulations

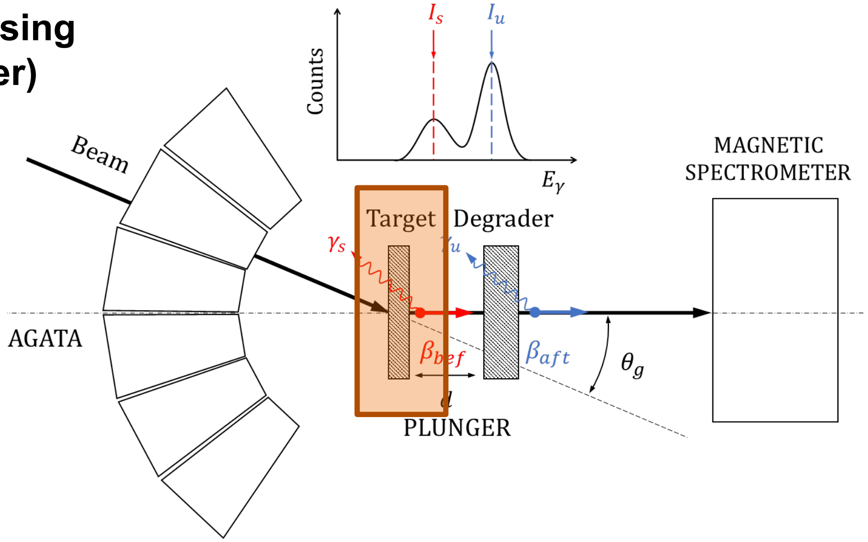
R. M. Pérez-Vidal et al., Eur. Phys. J. A 59 (2023)114

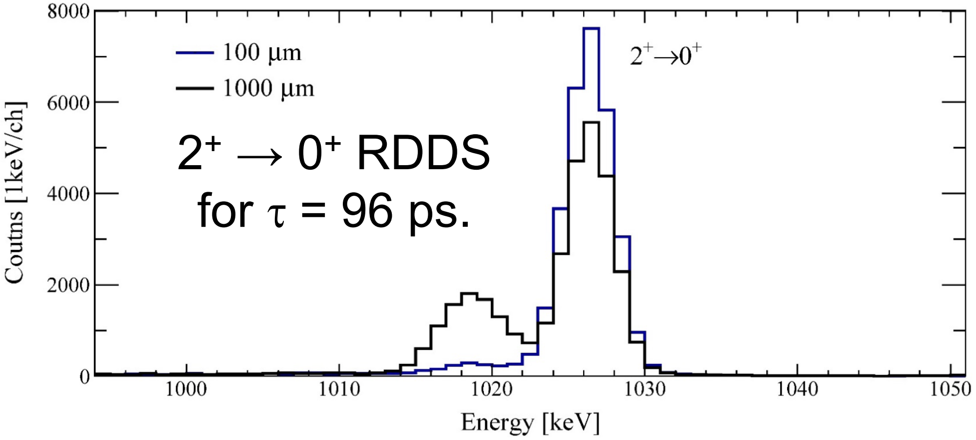
C. Stahl et al. Comp. Phys. Comm. 214, 174 (2017).

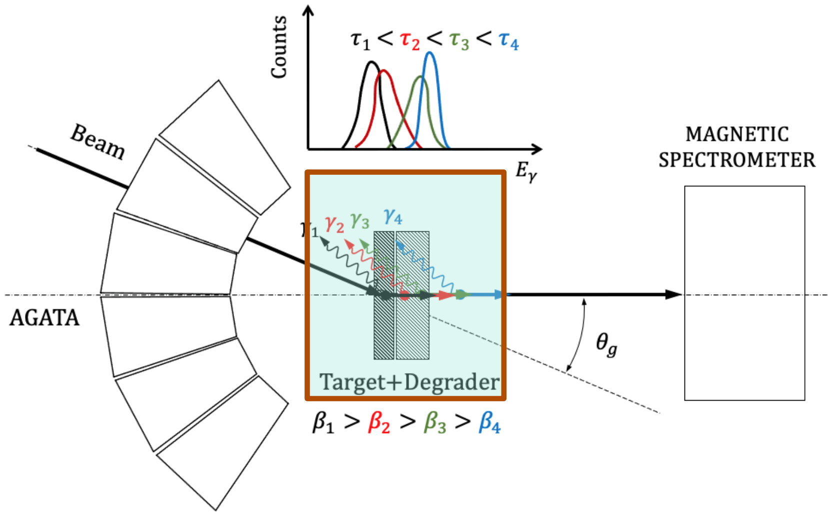
Possibility to combine RDDS & DSAM techniques covering lifetimes in different ranges

Geant4 simulations: Doppler corrected γ-ray spectra using the velocity from the spectrometer (after the degrader)


$4^+ \rightarrow 2^+$
line-shapes for
100 & 500 fs



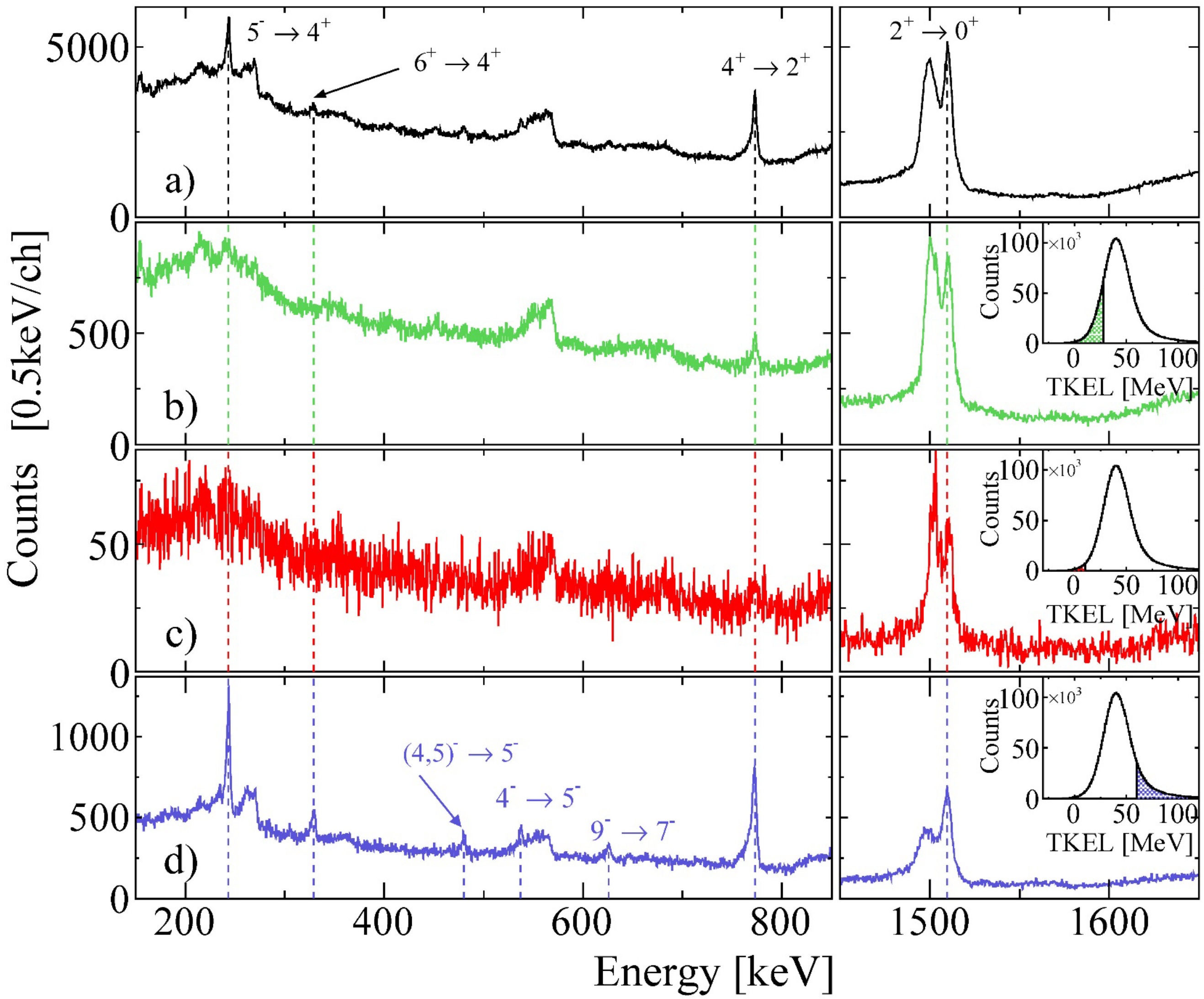

$2^+ \rightarrow 0^+$ RDDS
for τ = 96 ps.

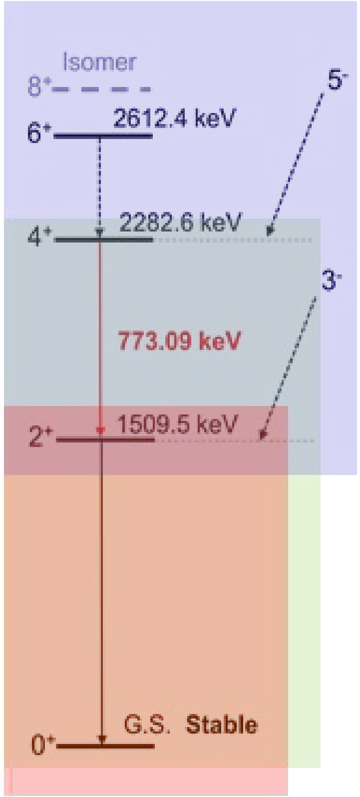


^{50}Ca DSAM and RDDS techniques.

R. M. Pérez-Vidal et al., Eur. Phys. J. A 59 (2023)114

Effect of the TKEL condition



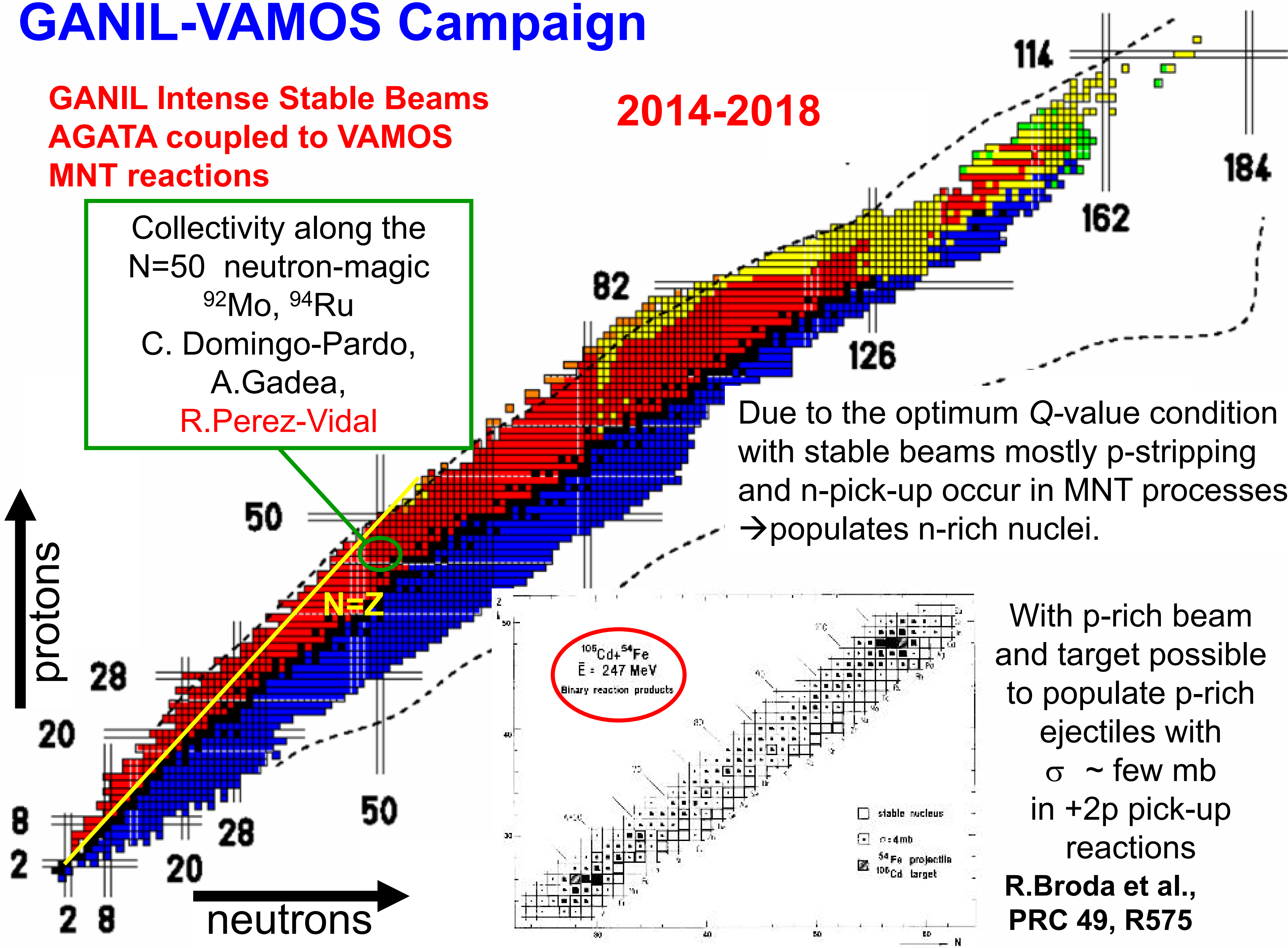


R. M. Pérez-Vidal, Ph.D thesis, Universidad de Valencia, 2019.

GANIL-VAMOS Campaign

GANIL Intense Stable Beams
AGATA coupled to VAMOS
MNT reactions

2014-2018



Collectivity along the
N=50 neutron-magic
^{92}Mo, ^{94}Ru
C. Domingo-Pardo,
A.Gadea,
R.Perez-Vidal

Due to the optimum *Q*-value condition with stable beams mostly p-stripping and n-pick-up occur in MNT processes →populates n-rich nuclei.

^{105}Cd+^{54}Fe
$\bar{E}$ = 247 MeV
Binary reaction products

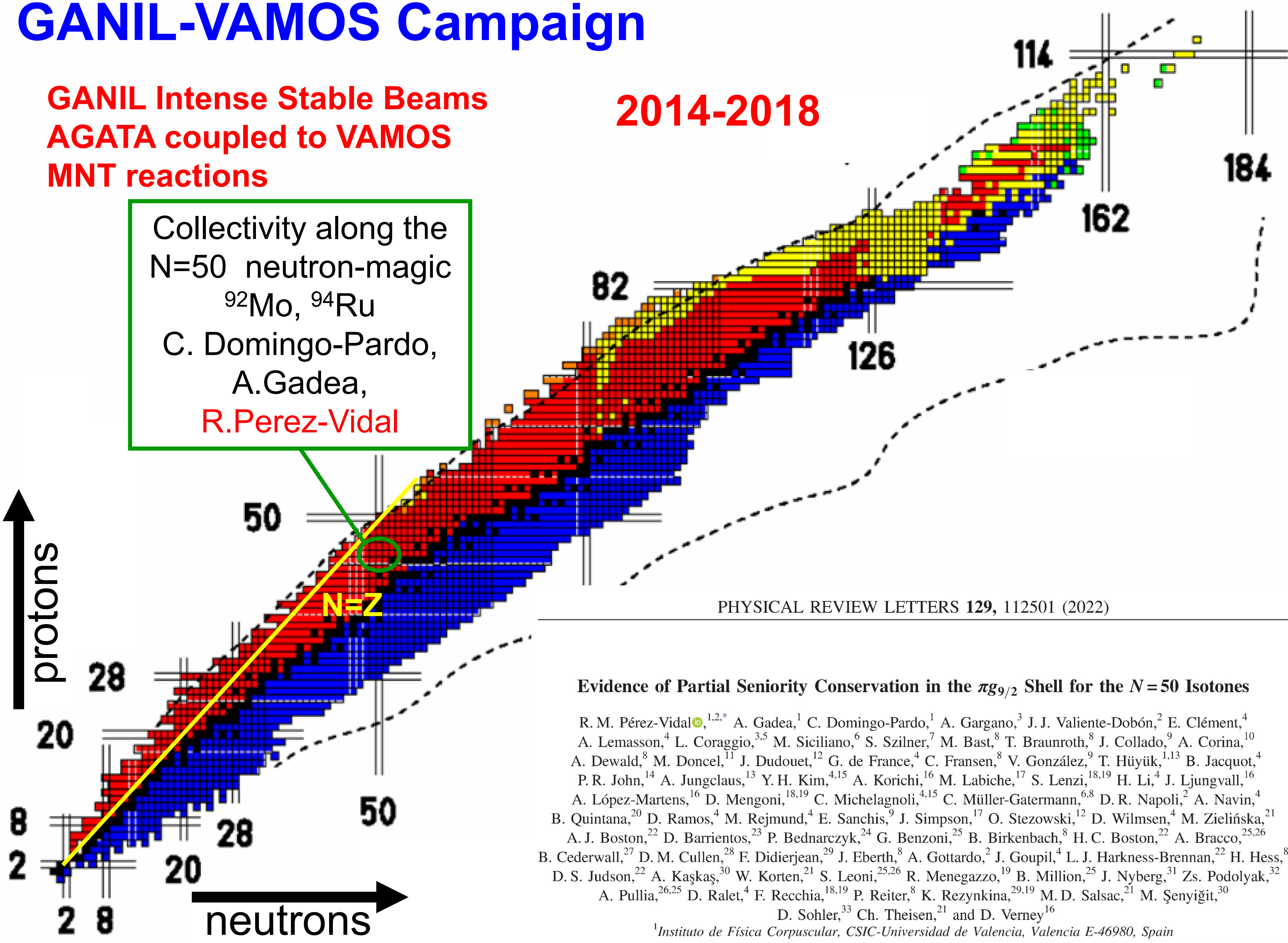
With p-rich beam and target possible to populate p-rich ejectiles with σ ~ few mb in +2p pick-up reactions

R.Broda et al., PRC 49, R575

GANIL-VAMOS Campaign

GANIL Intense Stable Beams
AGATA coupled to VAMOS
MNT reactions

2014-2018



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C. Domingo-Pardo,
A.Gadea,
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PHYSICAL REVIEW LETTERS **129,** 112501 (2022)

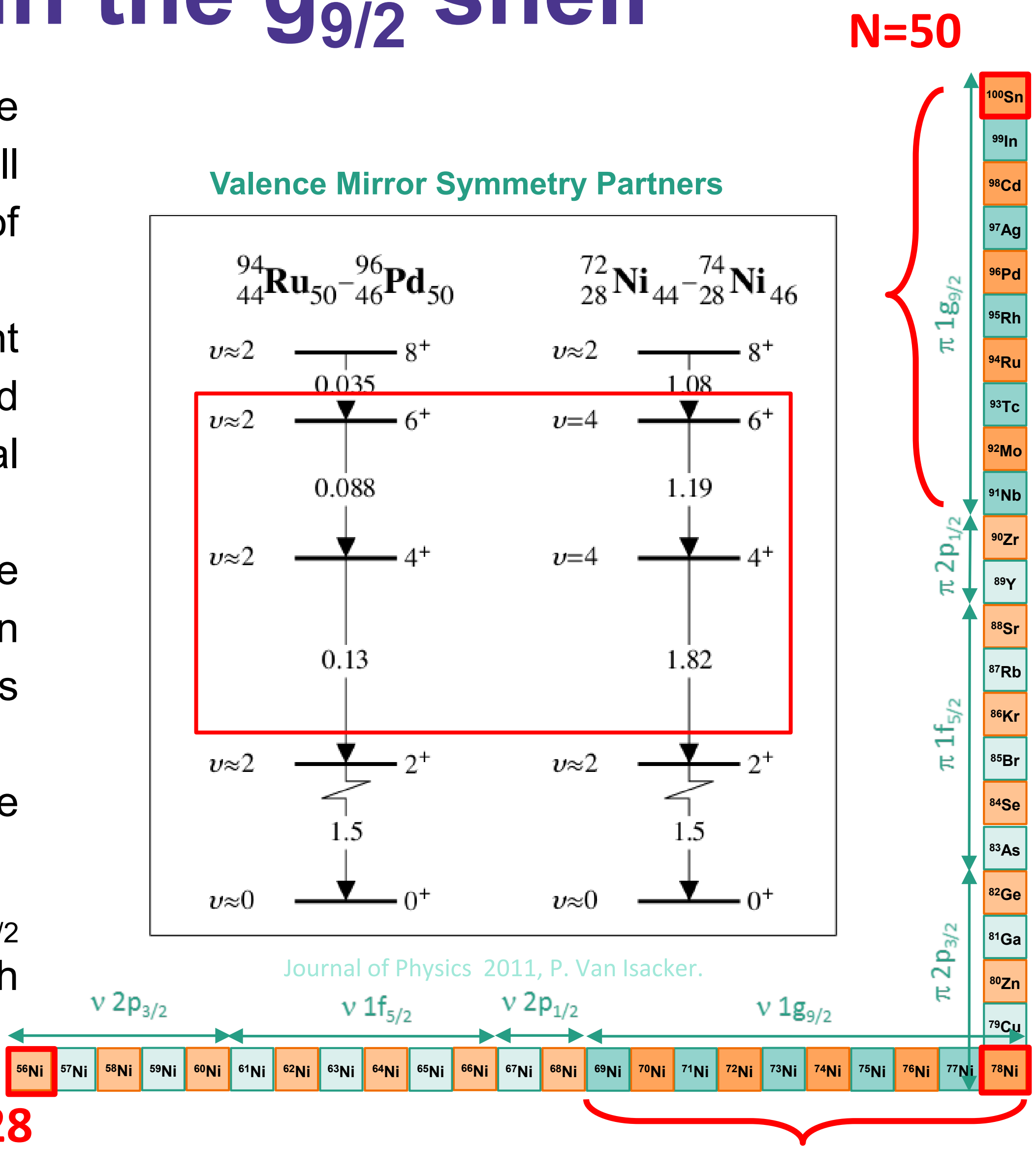
Evidence of Partial Seniority Conservation in the $\pi g_{9/2}$ Shell for the $N = 50$ Isotones

R. M. Pérez-Vidal,[1,2,*] A. Gadea,[1] C. Domingo-Pardo,[1] A. Gargano,[3] J. J. Valiente-Dobón,[2] E. Clément,[4] A. Lemasson,[4] L. Coraggio,[3,5] M. Siciliano,[6] S. Szilner,[7] M. Bast,[8] T. Braunroth,[8] J. Collado,[9] A. Corina,[10] A. Dewald,[8] M. Doncel,[11] J. Dudouet,[12] G. de France,[4] C. Fransen,[8] V. González,[9] T. Hüyük,[1,13] B. Jacquot,[4] P. R. John,[14] A. Jungclaus,[13] Y. H. Kim,[4,15] A. Korichi,[16] M. Labiche,[17] S. Lenzi,[18,19] H. Li,[4] J. Ljungvall,[16] A. López-Martens,[16] D. Mengoni,[18,19] C. Michelagnoli,[4,15] C. Müller-Gatermann,[6,8] D. R. Napoli,[2] A. Navin,[4] B. Quintana,[20] D. Ramos,[4] M. Rejmund,[4] E. Sanchis,[9] J. Simpson,[17] O. Stezowski,[12] D. Wilmsen,[4] M. Zielińska,[21] A. J. Boston,[22] D. Barrientos,[23] P. Bednarczyk,[24] G. Benzoni,[25] B. Birkenbach,[8] H. C. Boston,[22] A. Bracco,[25,26] B. Cederwall,[27] D. M. Cullen,[28] F. Didierjean,[29] J. Eberth,[8] A. Gottardo,[2] J. Goupil,[4] L. J. Harkness-Brennan,[22] H. Hess,[8] D. S. Judson,[22] A. Kaşkaş,[30] W. Korten,[21] S. Leoni,[25,26] R. Menegazzo,[19] B. Million,[25] J. Nyberg,[31] Zs. Podolyak,[32] A. Pullia,[26,25] D. Ralet,[4] F. Recchia,[18,19] P. Reiter,[8] K. Rezynkina,[29,19] M. D. Salsac,[21] M. Şenyiğit,[30] D. Sohler,[33] Ch. Theisen,[21] and D. Verney[16]

[1] *Instituto de Física Corpuscular, CSIC-Universidad de Valencia, Valencia E-46980, Spain*

Seniority in the $g_{9/2}$ shell

- Seniority υ was introduced to classify the jj-coupling of nucleons in a single j shell and extended latter to configurations of several orbitals
- $g_{9/2}$ is the first shell in which seniority might not be conserved [1], it can be preserved for a subset of solvable eigenstates (partial dynamical symmetry) [2]
- Lightest semi-magic nuclei involving the $g_{9/2}$ are the N=50 isotones towards ^{100}Sn for protons and the Z=28 isotopes towards ^{78}Ni for neutrons
- Effective two-body interactions are different in the $g_{9/2}$ near ^{100}Sn and ^{78}Ni [3]
- Calculations using a simple single-shell $g_{9/2}$ model suggest yrast 4^+ and 6^+ states with υ=2 in ^{94}Ru-^{96}Pd and υ=4 in ^{72,74}Ni [2]



[1] A. Escuderos and L. Zamick. Phys. Rev. C, 73(044302), 2006
[2] P. Van Isacker Int. Jour. of Mod. Phys. E, Vol . 20, 191 (2011)
P. Van Isacker et al., Phys. Rev. Lett. 100, 052501 (2008)

[3] A.F. Lisetskiy et al., Eur. Phys. J. A 25, s01, 95 (2005)
A.F. Lisetskiy et al,. Phys. Rev.C 70, 044314 (2004).

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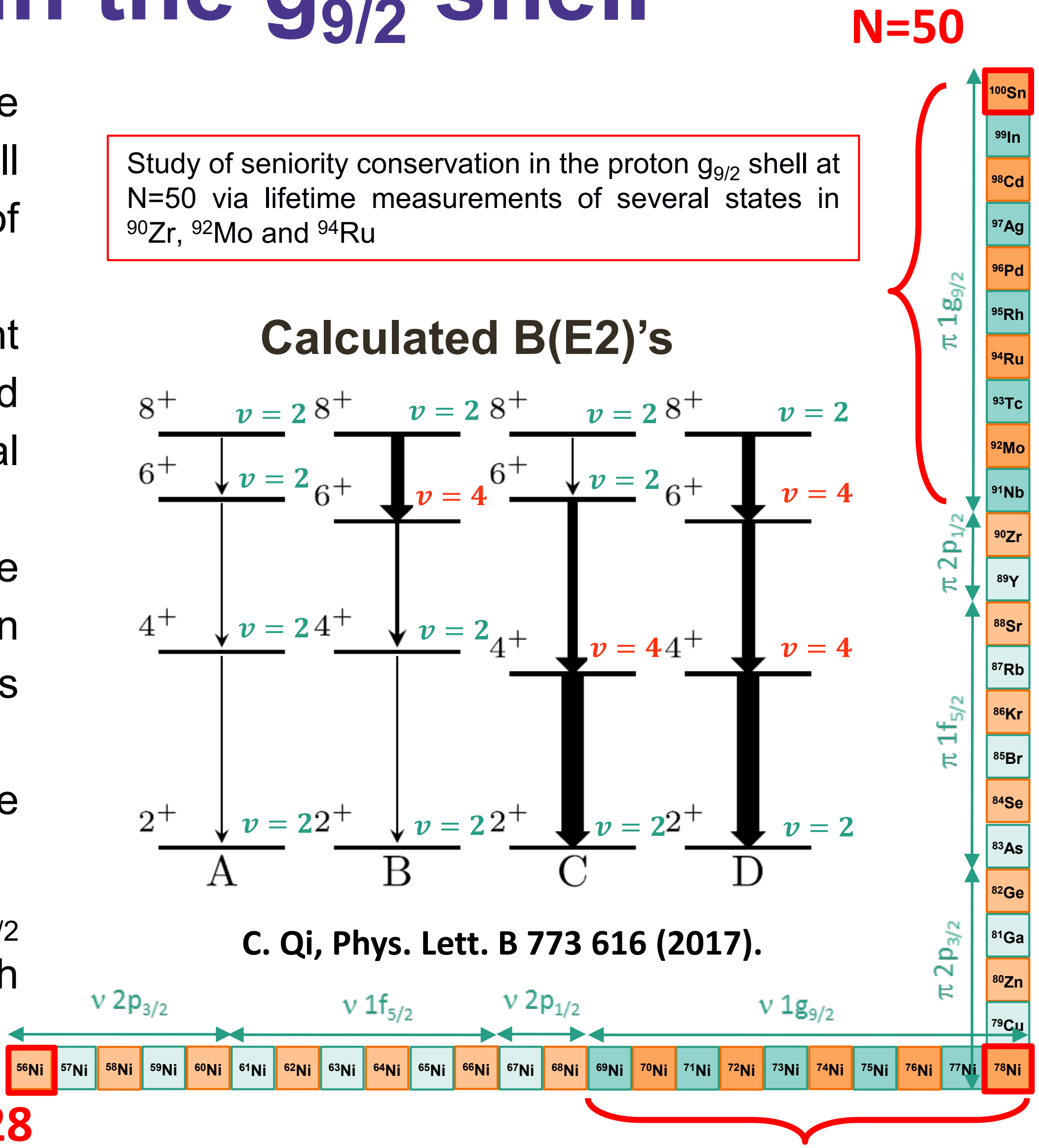


Study of seniority conservation in the proton $g_{9/2}$ shell at N=50 via lifetime measurements of several states in ^{90}Zr, ^{92}Mo and ^{94}Ru

Calculated B(E2)'s

C. Qi, Phys. Lett. B 773 616 (2017).

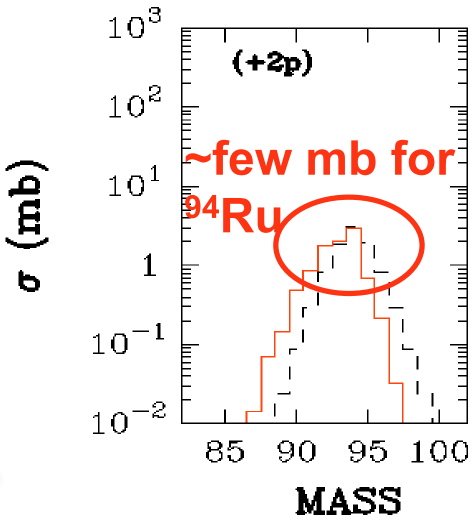
[1] A. Escuderos and L. Zamick. Phys. Rev. C, 73(044302), 2006
[2] P. Van Isacker Int. Jour. of Mod. Phys. E, Vol . 20, 191 (2011)
P. Van Isacker et al., Phys. Rev. Lett. 100, 052501 (2008)

[3] A.F. Lisetskiy et al., Eur. Phys. J. A 25, s01, 95 (2005)
A.F. Lisetskiy et al,. Phys. Rev.C 70, 044314 (2004).

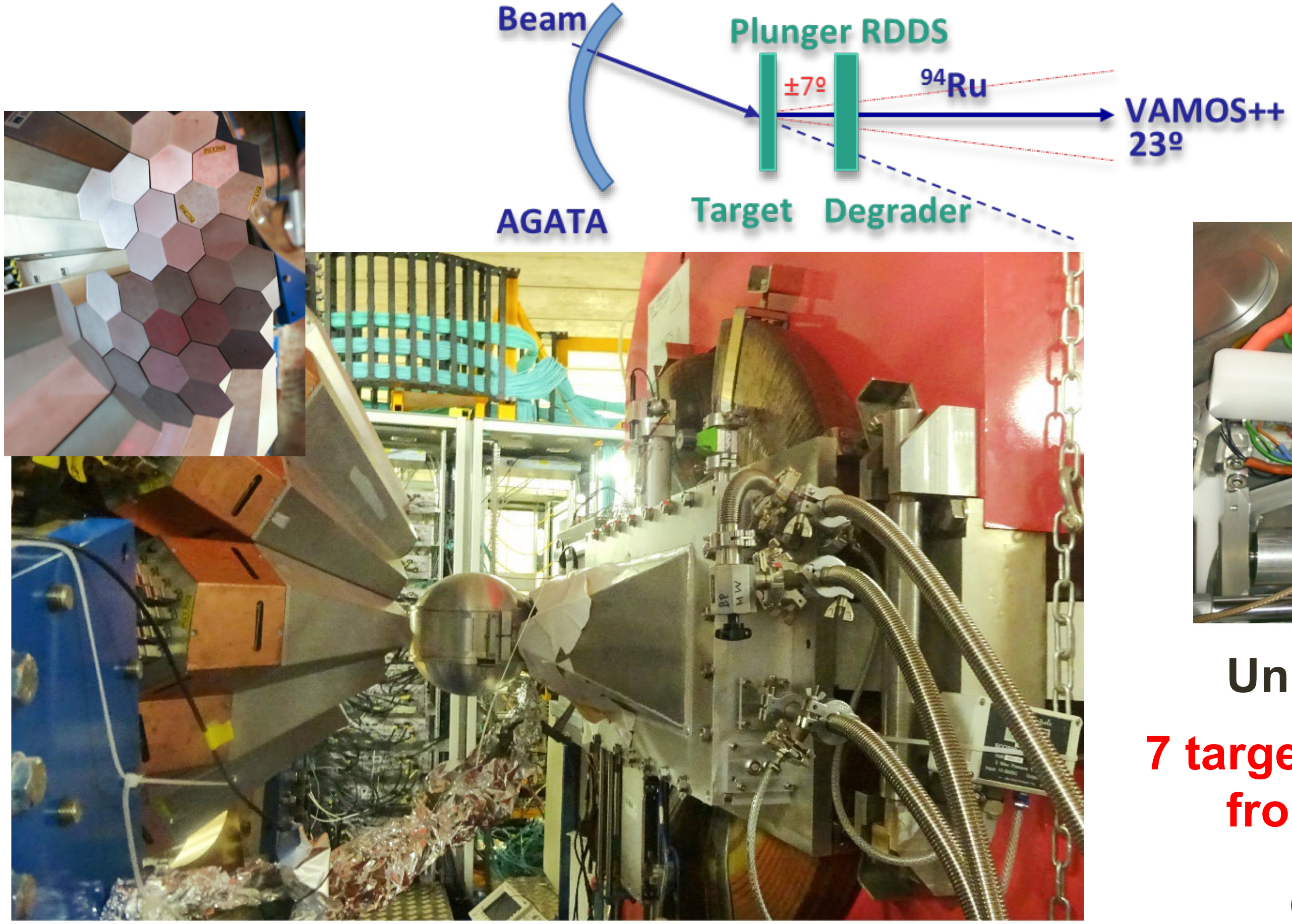
Experiment

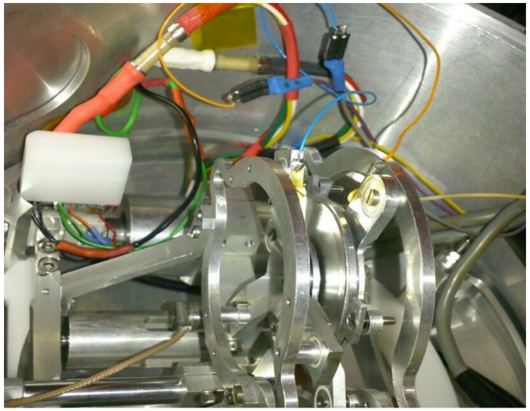
Reaction MNT *^{92}Mo + ^{92}Mo*:

- **Beam energy: 716.9MeV**
- **Grazing angle LAB: ~23 º**
- ***Target 0.78 mg/cm^2, Degrader ^{24}Mg 1.9 mg/cm^2***
- **E_{CM}/V_B ~1.75**
- **Q value=-2.27 MeV**



~few mb for ^{94}Ru





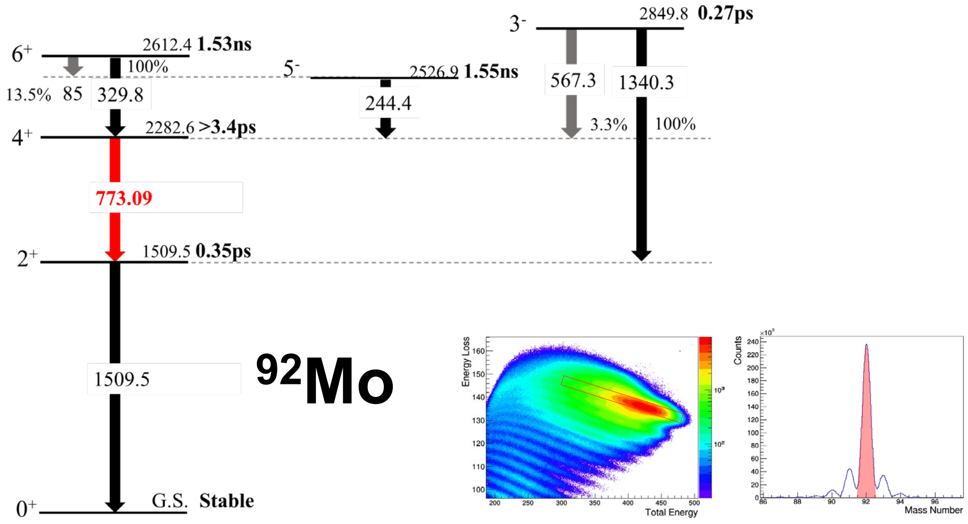
Uni. Cologne Plunger

7 target - degrader distances from 19μm to 4000μm

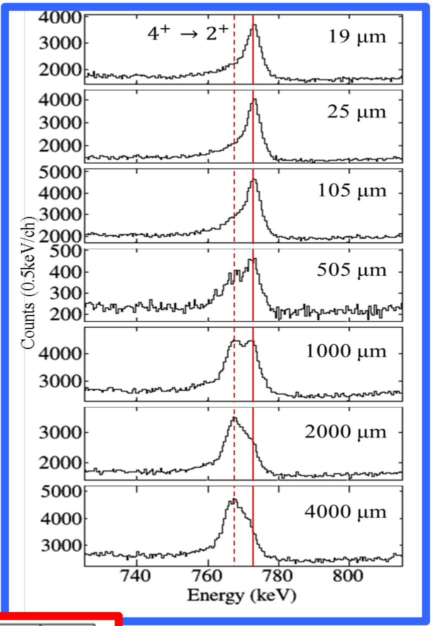
Checked with lifetimes in ^{93}Te and ^{94}Mo

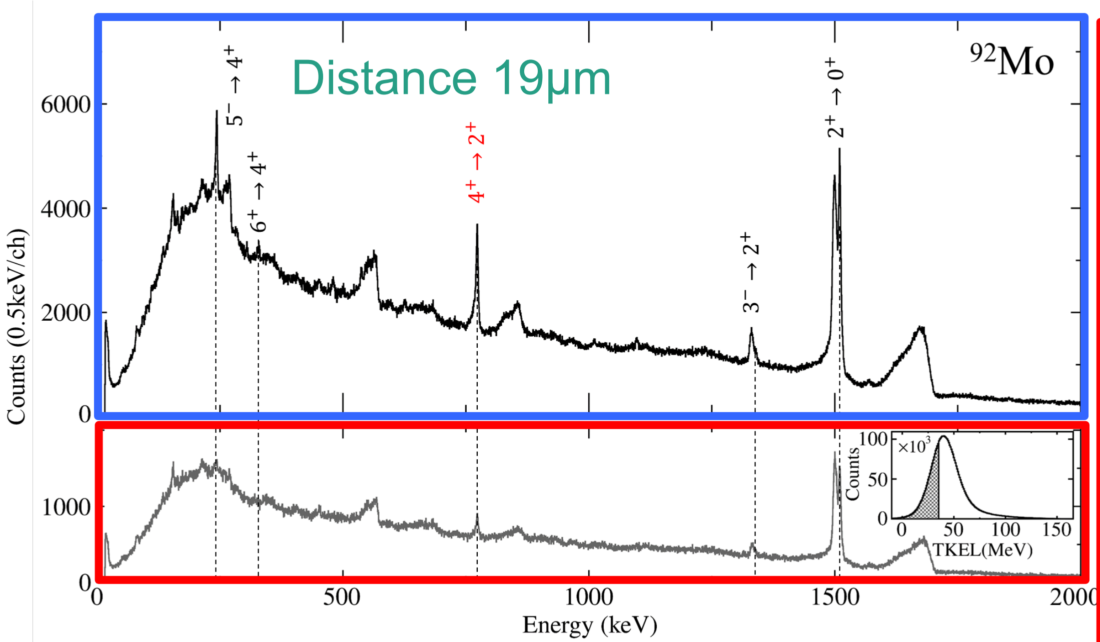
R. M. Pérez-Vidal , A. Gadea et al. Phys. Rev. Lett. 129 (2022) 112501

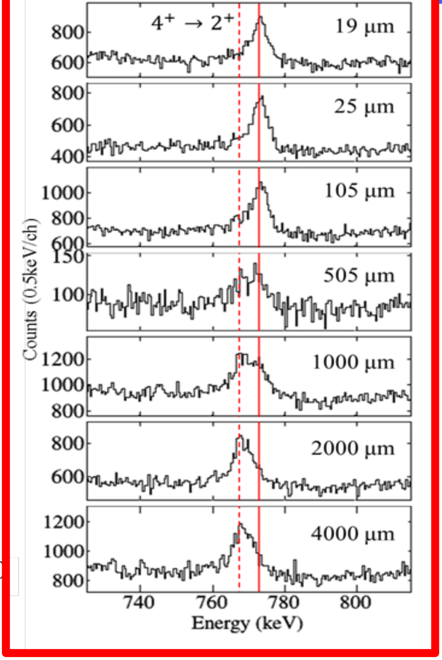
Analysis: 4+ Lifetime determination in 92Mo



Subtraction of the feeders with their geoDSAM lineshape

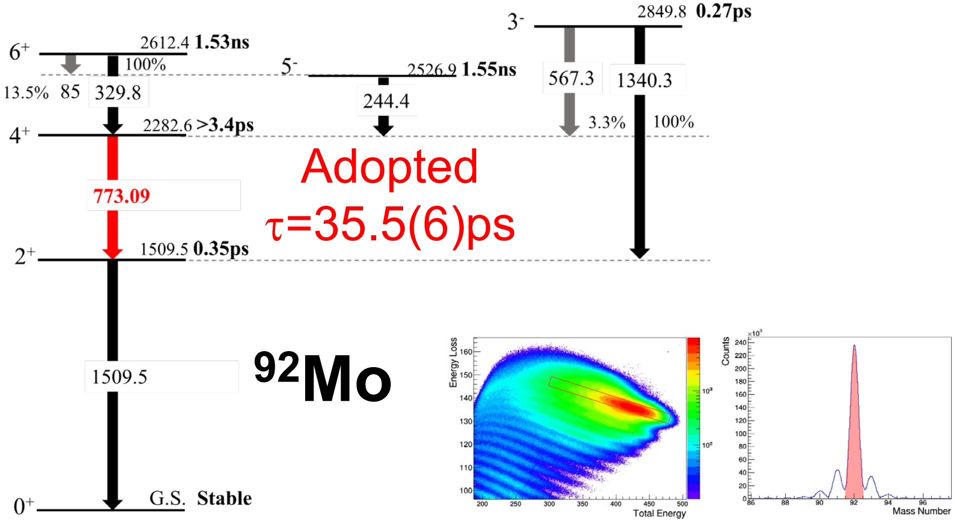






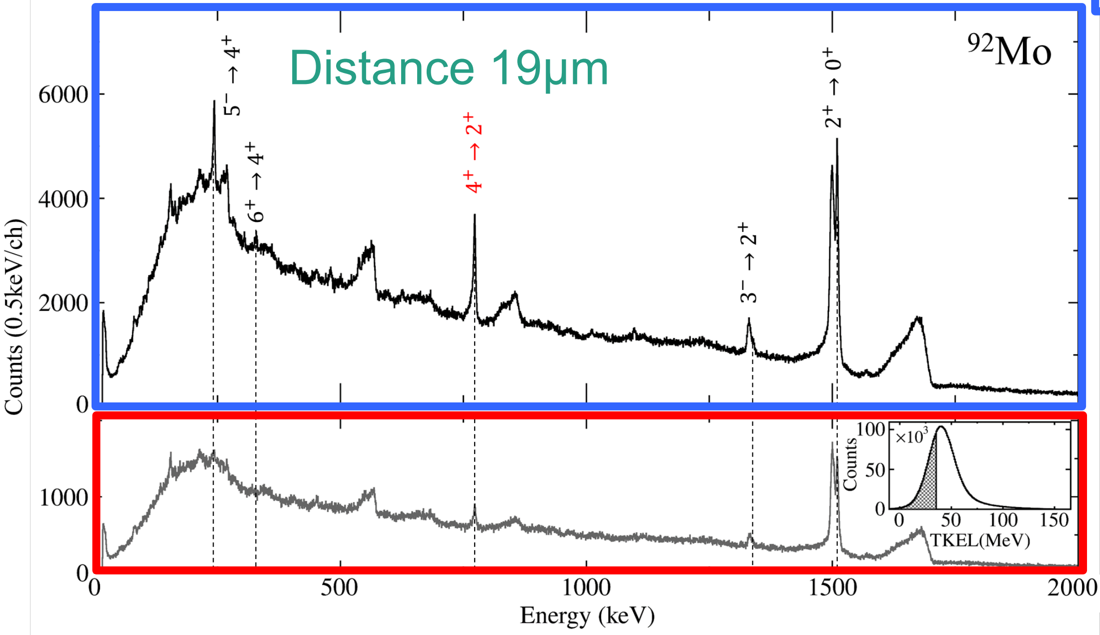
TKEL gate and subtraction of remaining feeders

Analysis: 4+ Lifetime determination in 92Mo

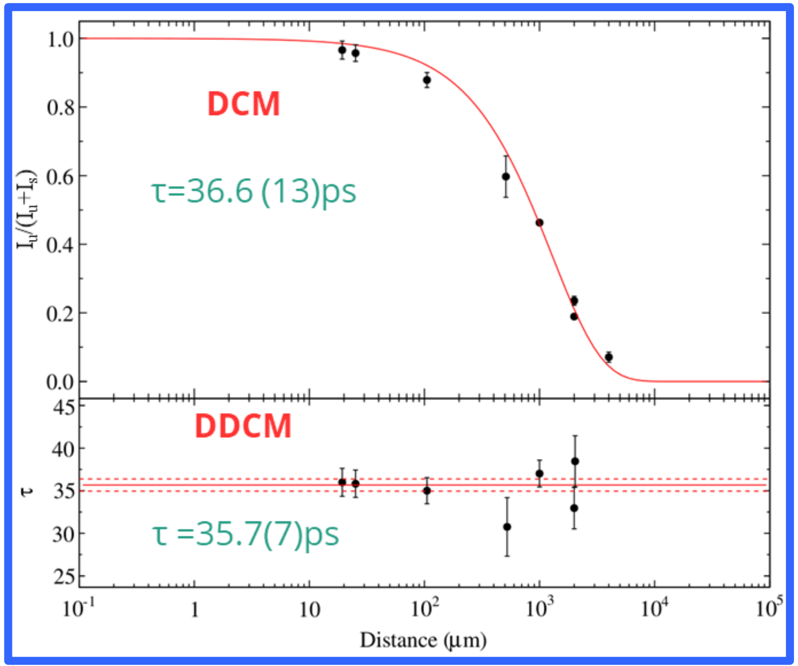


Adopted
τ=35.5(6)ps

^{92}Mo



Distance 19µm

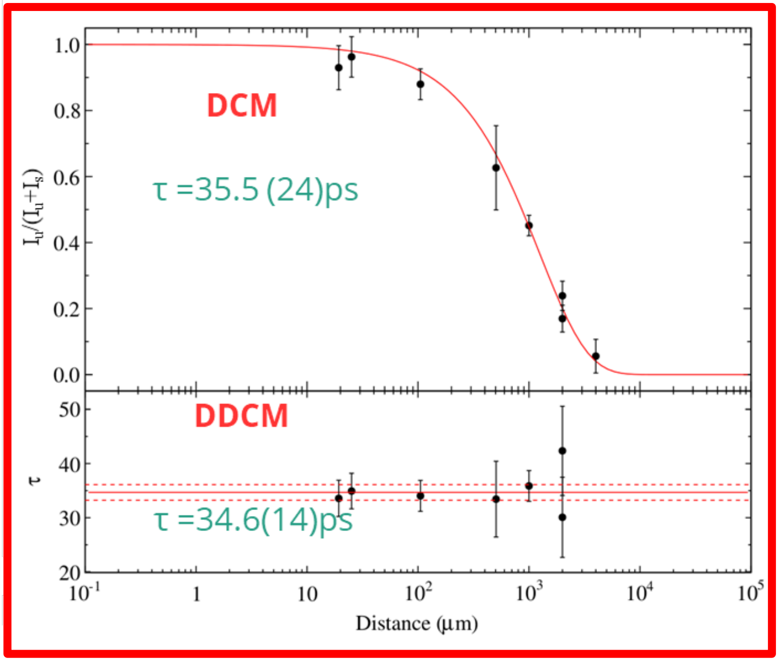


DCM

τ=36.6 (13)ps

DDCM

τ =35.7(7)ps



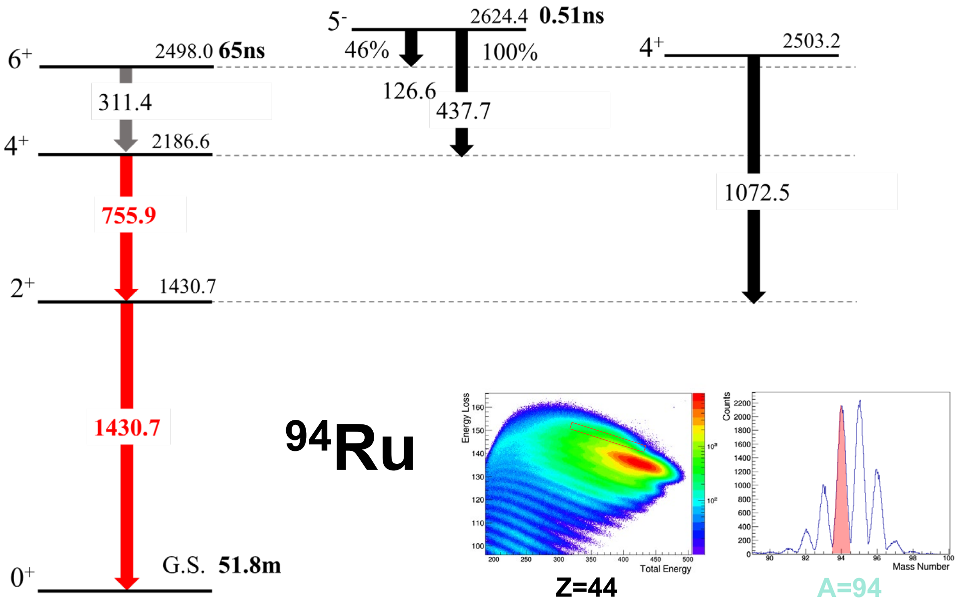
DCM

τ =35.5 (24)ps

DDCM

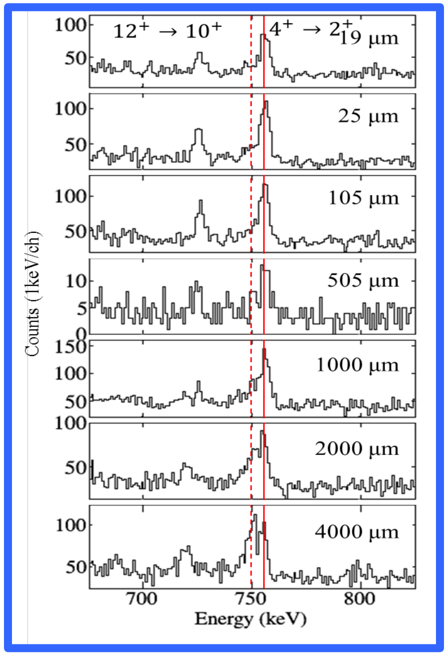
τ =34.6(14)ps

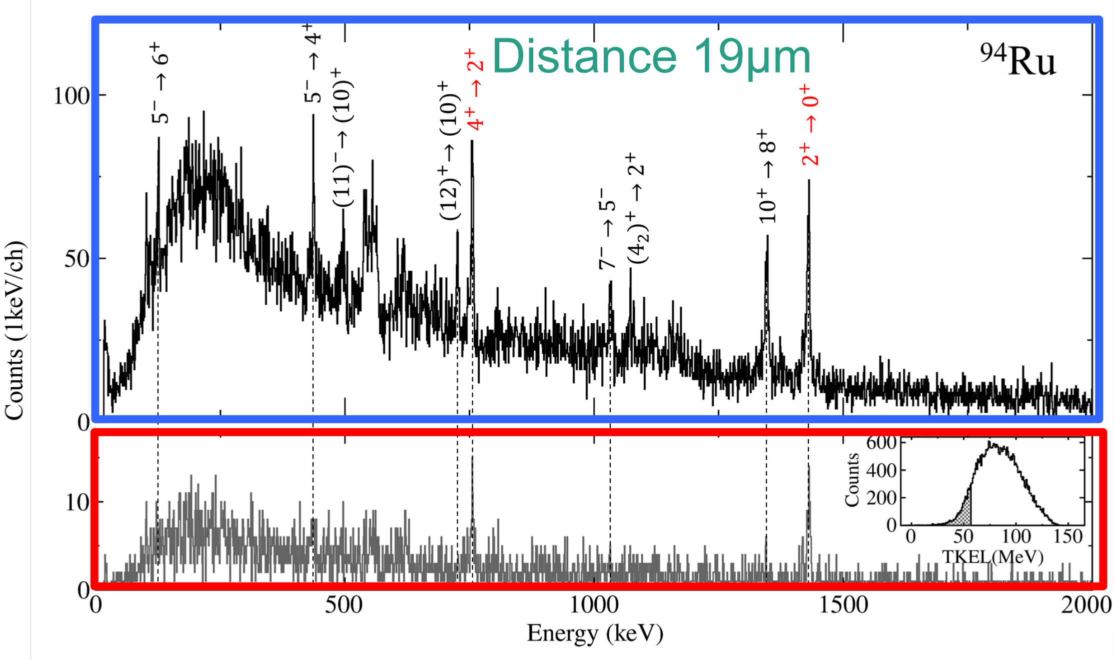
Analysis: 4+ Lifetime determination in ^{94}Ru

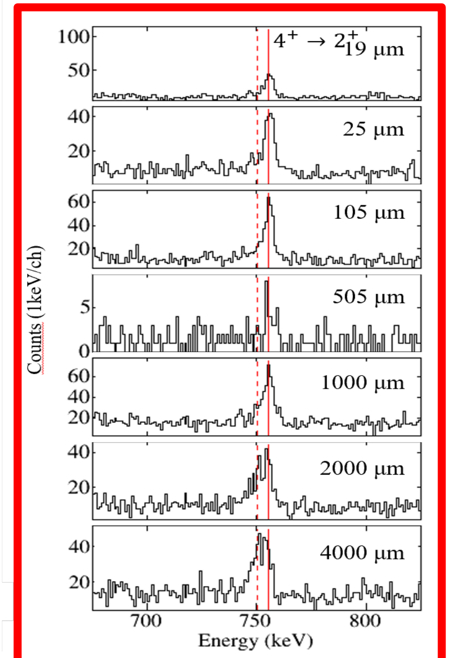


^{94}Ru

Subtraction of the feeders with their geoDSAM lineshape

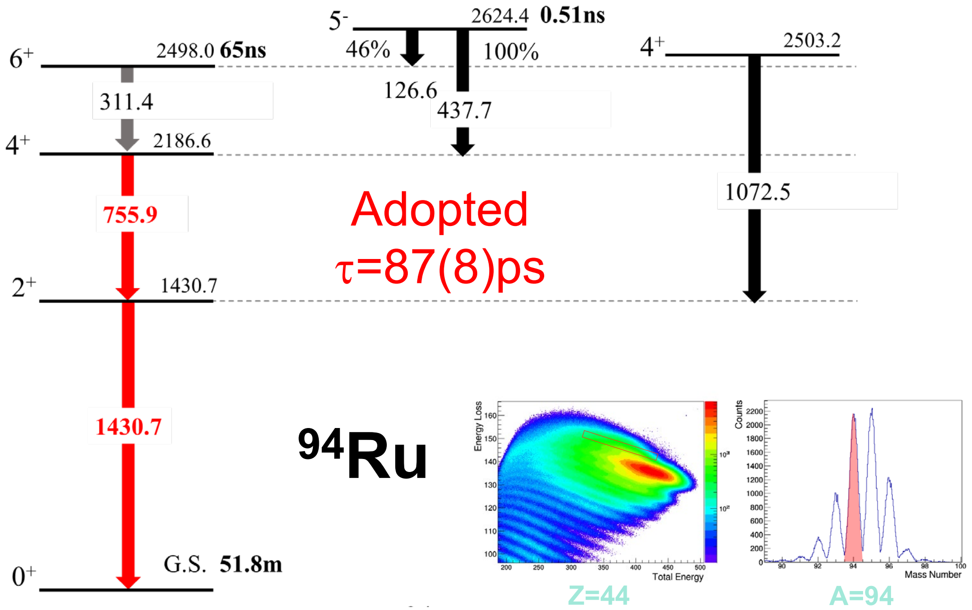






TKEL gate and subtraction of remaining feeders

Analysis: 4+ Lifetime determination in ^{94}Ru

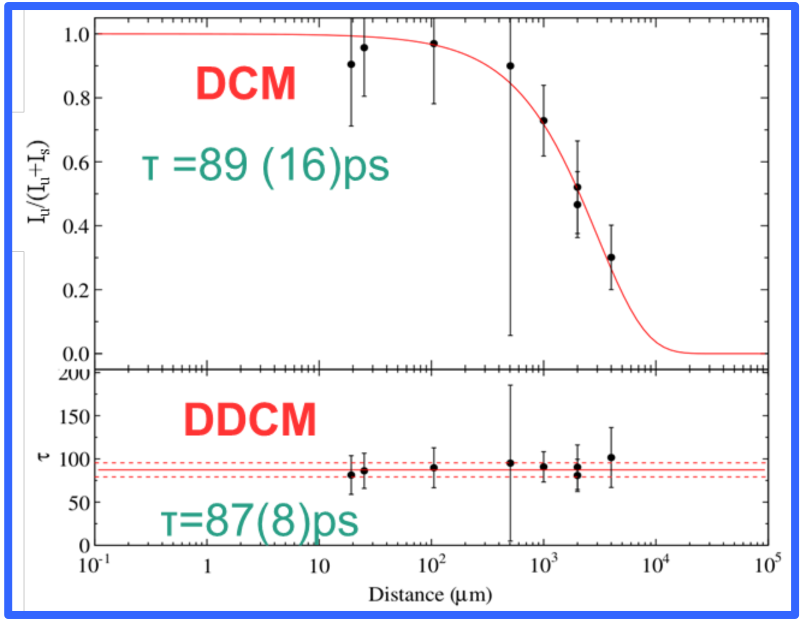


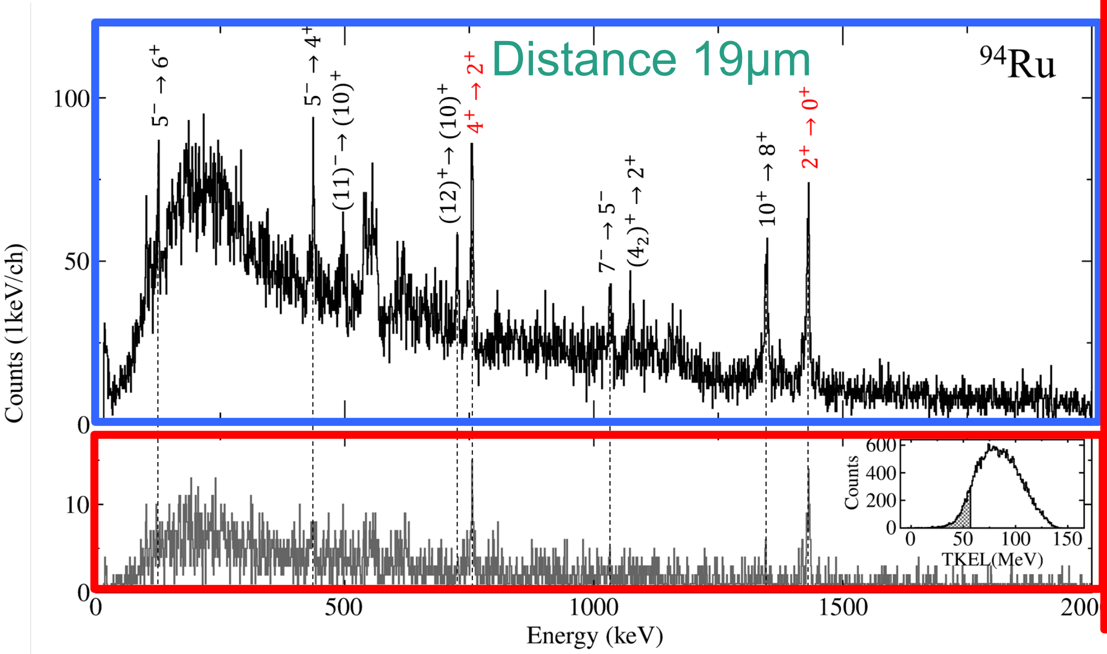
Adopted
τ=87(8)ps

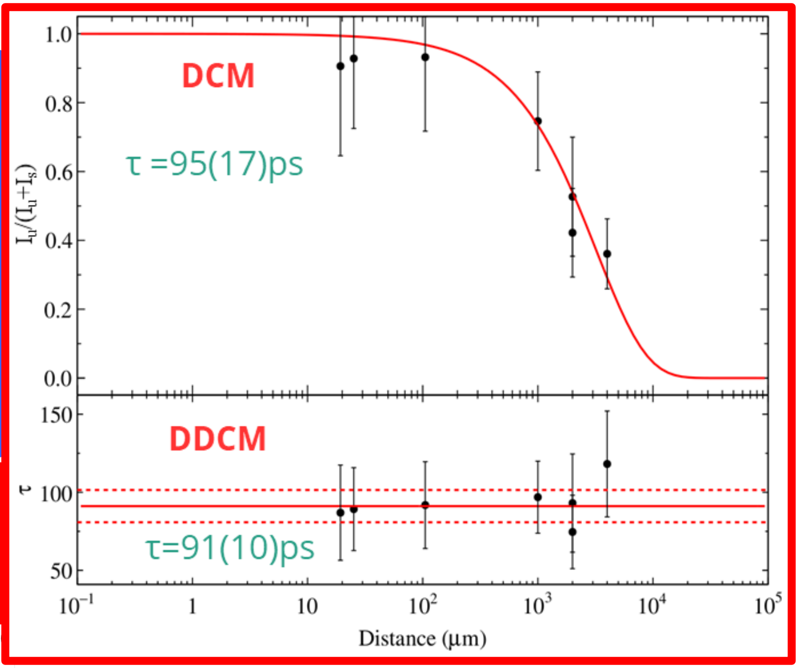
^{94}Ru

Z=44

A=94





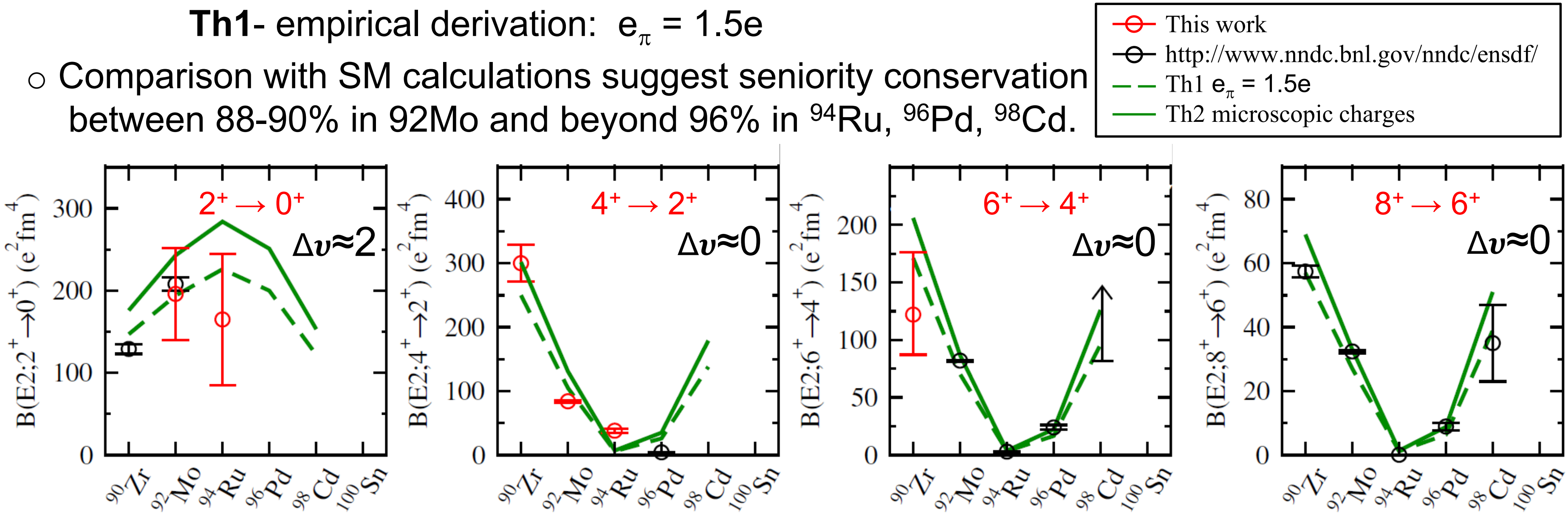


Results and discussion

- ○ Shell-model calculations with ANTOINE, based on the realistic effective interaction*
- ○ Model space $f_{5/2}$, $p_{3/2}$, $p_{1/2}$, $g_{9/2}$ above ^{56}Ni core, shell closed for neutrons filling N=50
- ○ Effective interaction from CD-Bonn *N N* potential
- ○ Effective charges for the E2 transition probabilities:

  Th2- microscopic Effective proton charges are calculated consistently with the SM Hamiltonian by following the Suzuki-Okamoto formalism

  Th1- empirical derivation: $e_\pi = 1.5e$
- ○ Comparison with SM calculations suggest seniority conservation between 88-90% in 92Mo and beyond 96% in ^{94}Ru, ^{96}Pd, ^{98}Cd.



*performed by A. Gargano and L. Coraggio (INFN, Complesso Universitario di Monte S. Angelo, Napoli, Italy)

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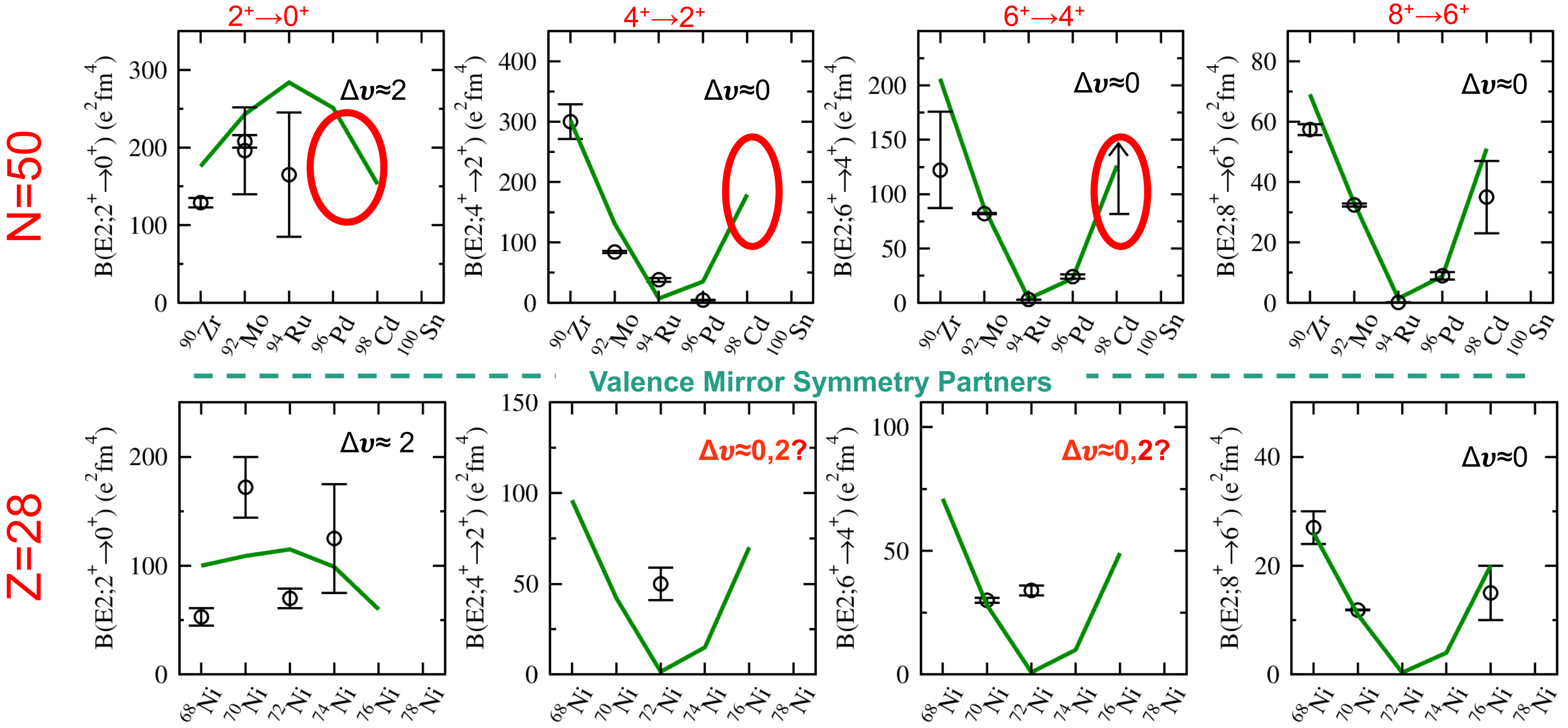
Outlook

- We consider stablished that seniority is largely preserved in the first $\pi g_{9/2}$ shell
- Planning to proceed with measurements of the missing lifetimes in ^{96}Pd and ^{98}Cd
- Missing lifetime data in the Ni isotopos beyond ^{68}Ni, to shed light on the seniority conservation in the $\nu g_{9/2}$ at Z=28.



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and the AGATA Collaboration

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