Nuclear Structure and Dynamics 2019

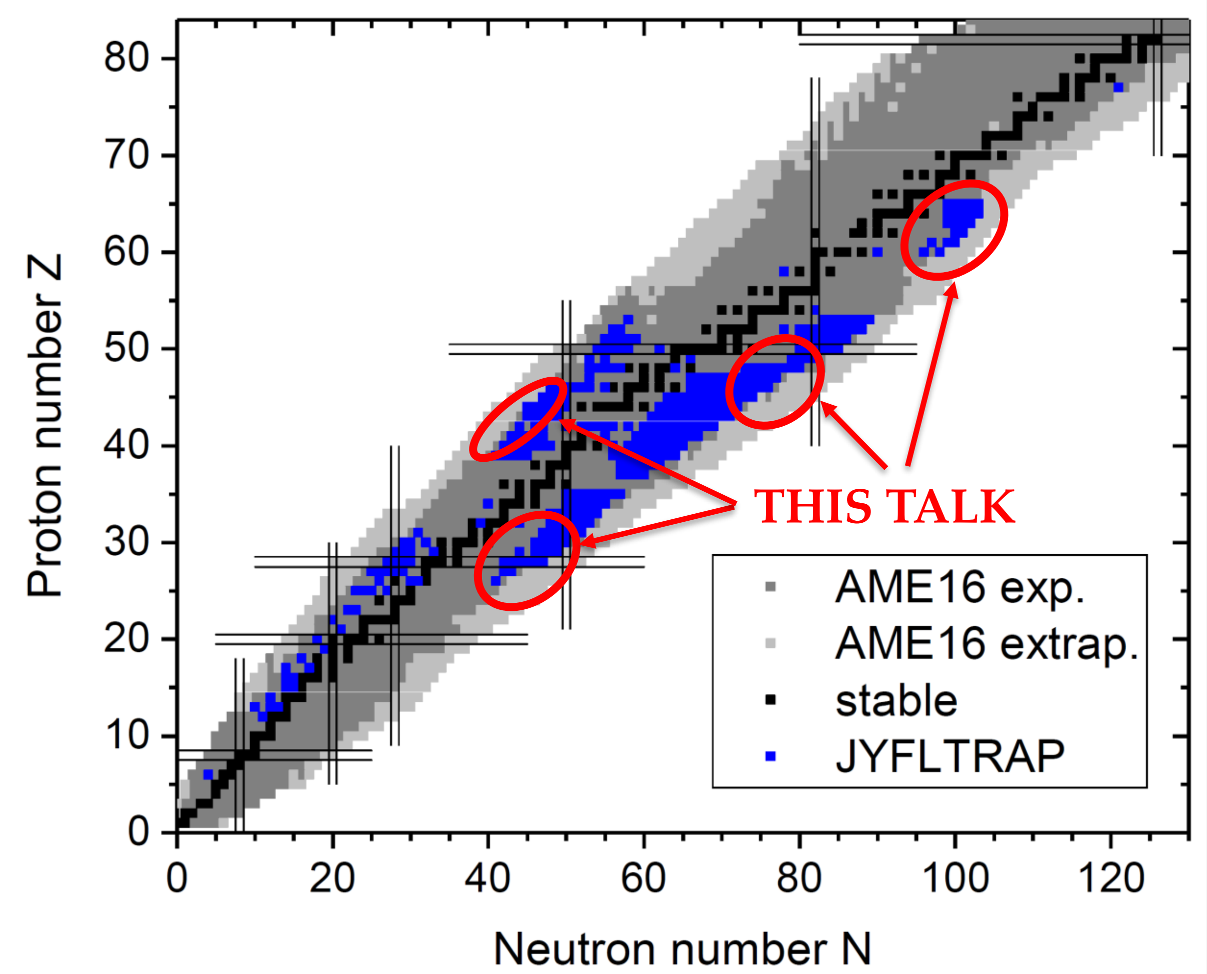
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

Dipartimento di Fisica e Astronomia Galileo Galilei
UNIVERSITÀ DEGLI STUDI DI PADOVA

- Nuclear structure and reactions far from stability
- Collective phenomena and symmetries
- Dynamics and thermodynamics of light and heavy nuclei
- Sub- and near-barrier reactions
- Fusion and Fission dynamics
- Ab initio calculations, cluster models and shell model
- Nuclear energy density functionals
- Nuclear astrophysics
- Fundamental interactions

Experiment

Nuclides measured with JYFLTRAP

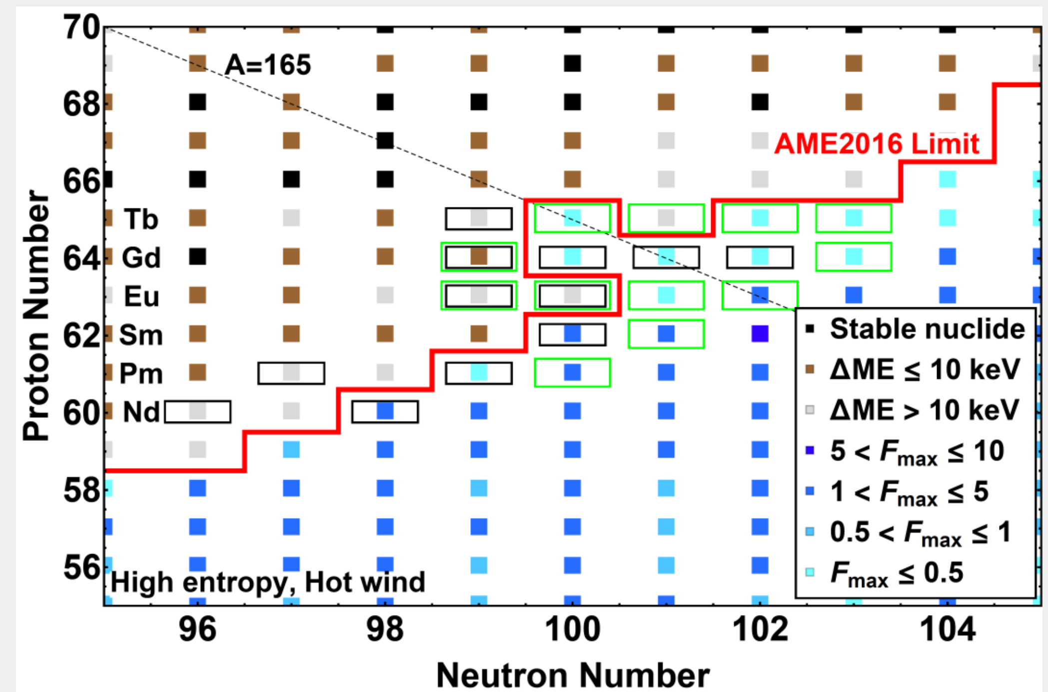


JYFLTRAP:

- Over 340 nuclides measured
  - ~100 neutron-deficient
  - ~220 neutron-rich
  - ~20 stable
- More than 50 isomeric states
- Typical precisions: ~10 ppb

Neutron-rich rare-earth isotopes

- 21 rare-earth isotopes measured
- 14 masses measured for the first time
- Mainly TOF-ICR, recently also PI-ICR
- Campaign I: *M. Vilén et al., PRL 120, 262701 (2018)*
- Campaign II: *in preparation*



Motivated by the rare-earth abundance peak in the astrophysical r process

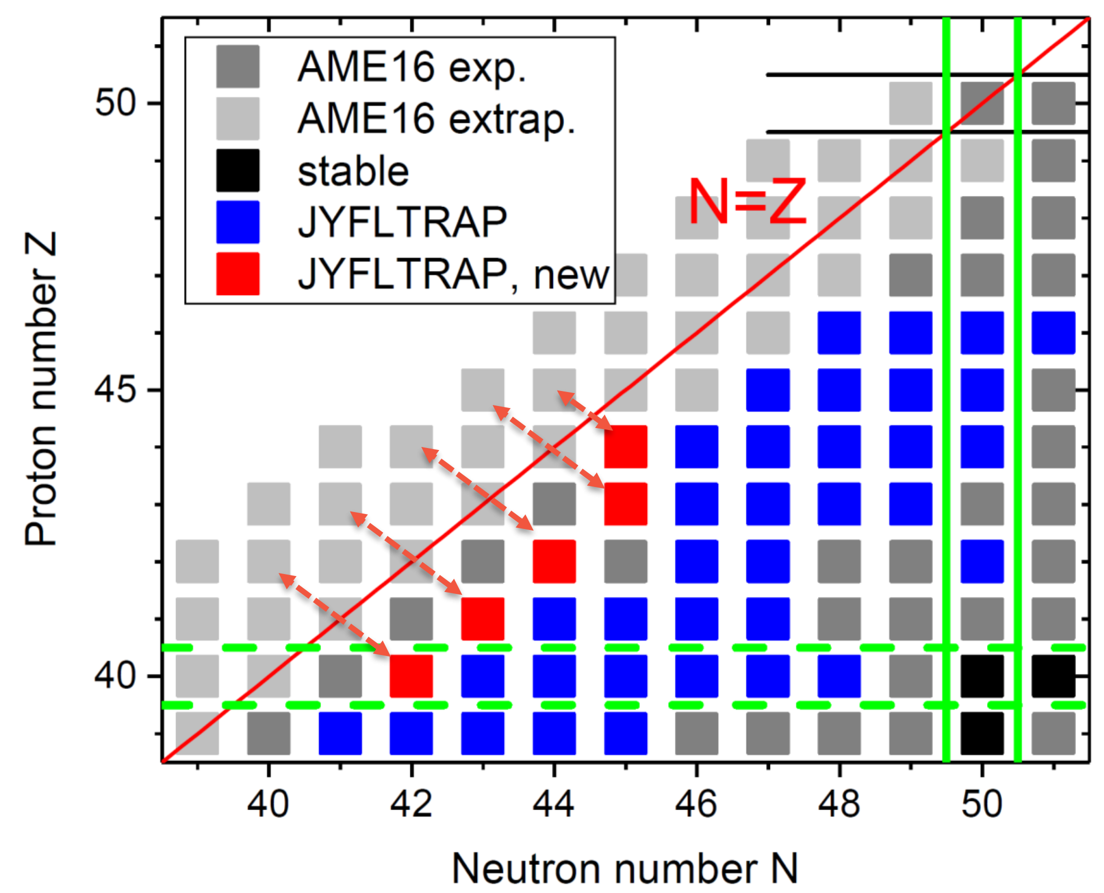
F.G. Kondev

CARIBU & ANL

Masses & Beta-Decay Spectroscopy of Neutron-Rich Nuclei: Isomers & Sub-shell Gaps with Large Deformation

Isospin symmetry in the heavier mass region

- Precision measurements of T_Z=+1 nuclei: **^{82}Zr, ^{84}Nb, ^{86}Mo, and ^{88}Tc**
- ^{88}Tc^{m} and ^{89}Ru (T_Z=+1/2) measured for the first time
- ^{89}Ru more bound than predicted in AME16
- MDE predictions for ^{82}Mo and ^{86}Ru also more bound and more precise than AME16 extrapolations

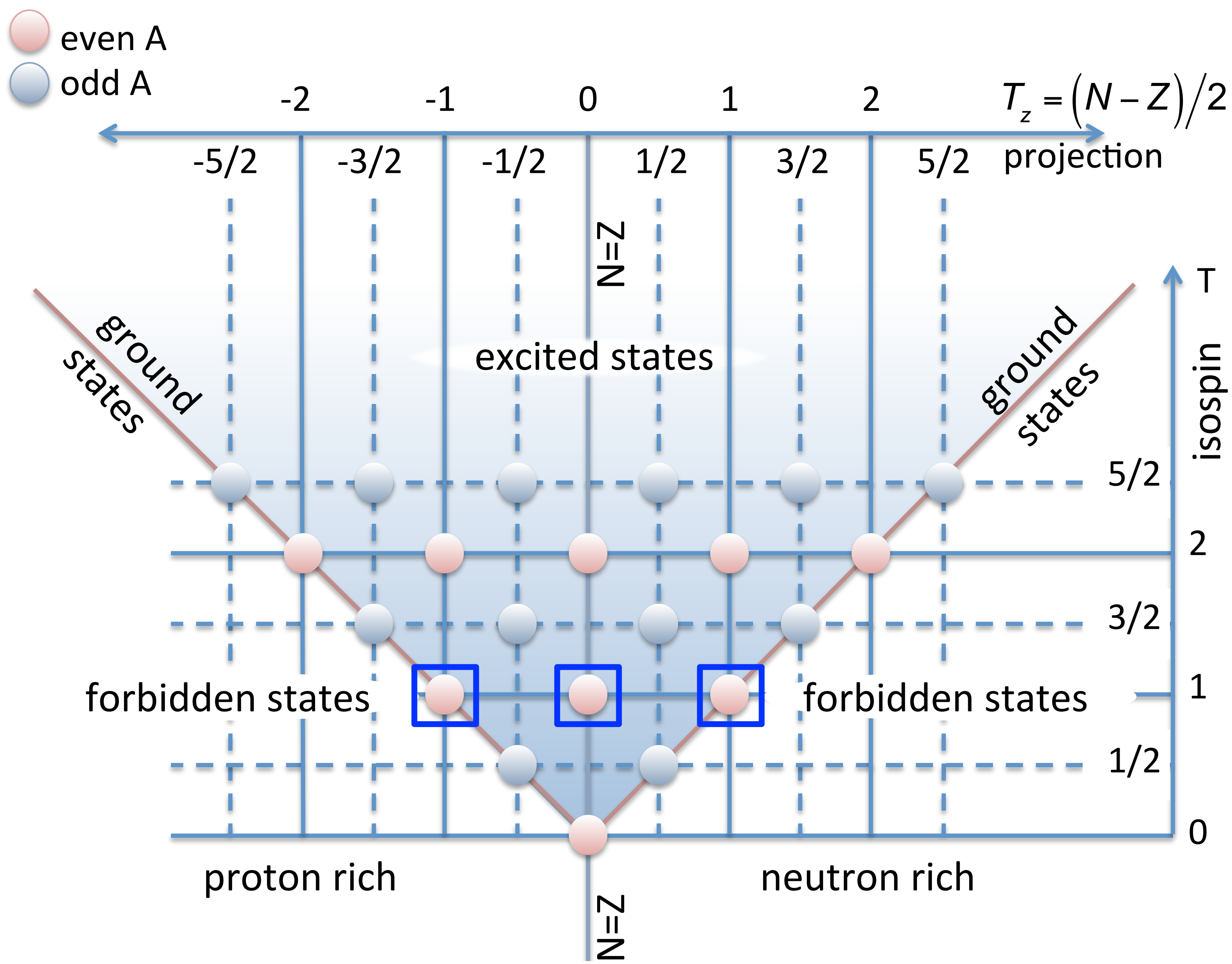


M. Vilen et al., to be submitted

Isospin Symmetry of the A=46 T=1 triplet studied with AGATA

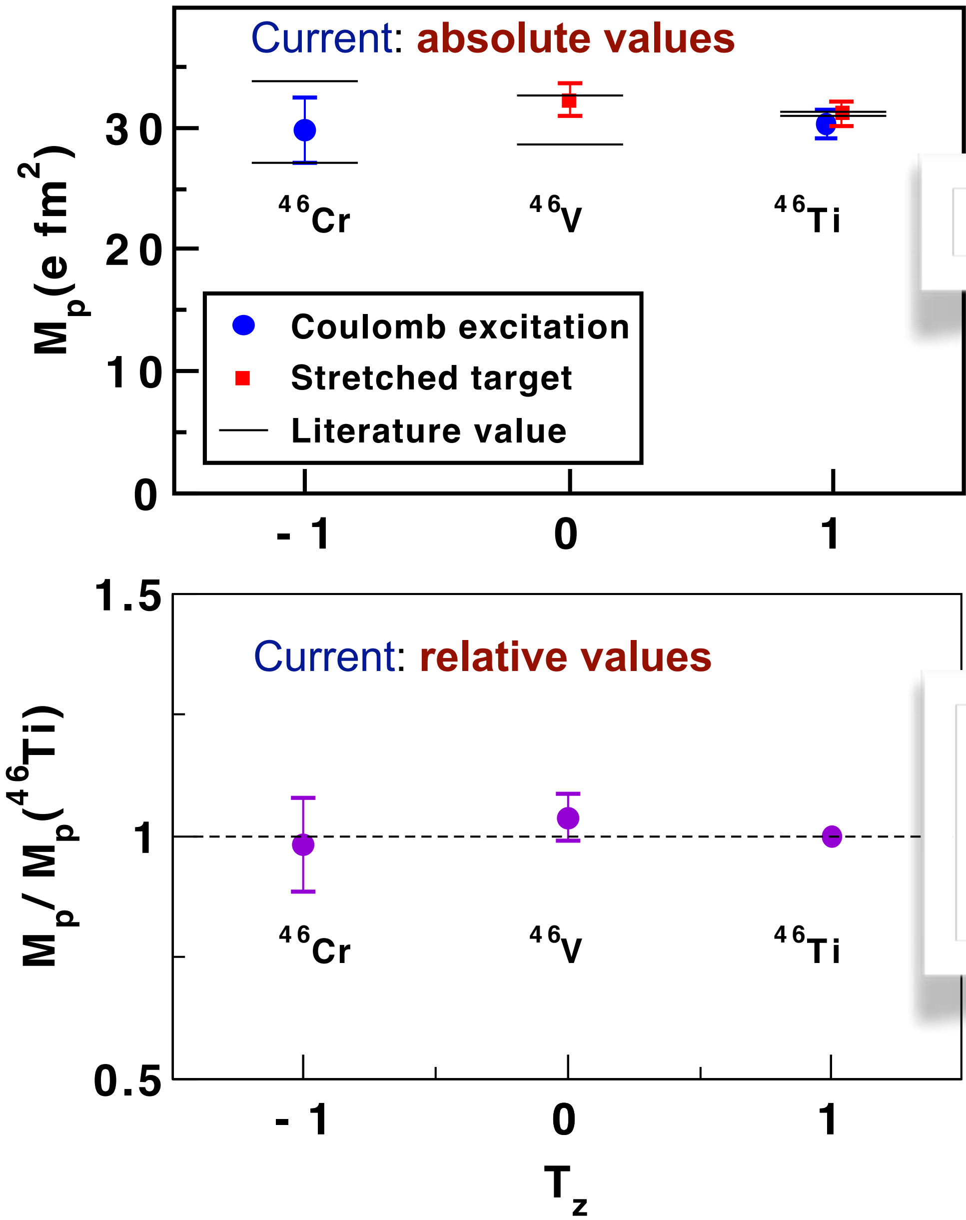
M.A.Bentley

Isospin Symmetry and T=1 Triplets



Isospin symmetry in the A=46 Isobaric Triplet

E2 matrix element as a function of T_z



Absolute values

Relative values:
^{46}Cr/^{46}Ti Coulex
^{46}V/^{46}Ti Stretched target
statistical errors only

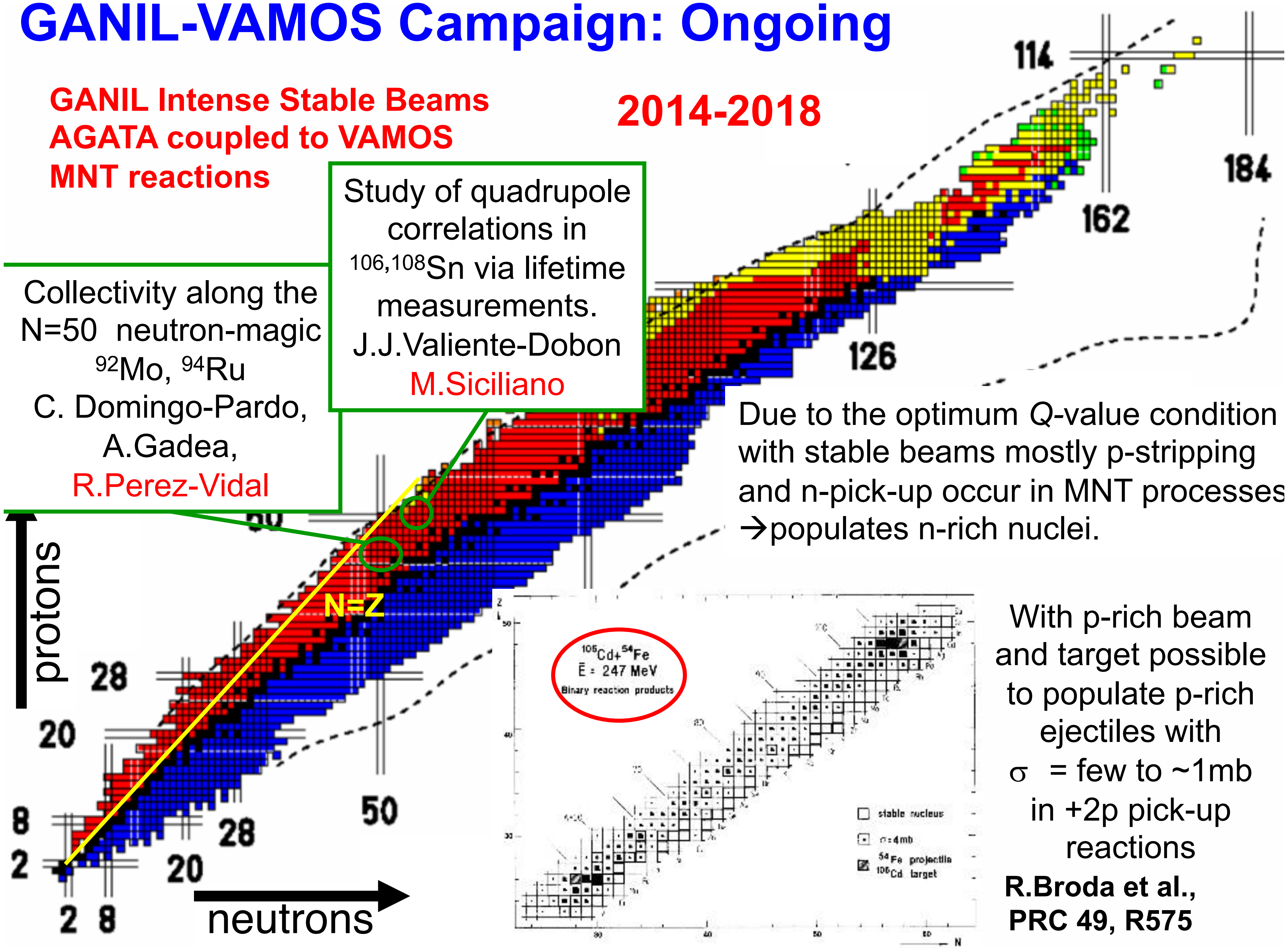
- High precision measurement of B(E2)s in T=1 triplet
- Heaviest triplet for which this has been done (so far!)
- No evidence for non-linear behaviour with T_z

AGATA

GANIL-VAMOS Campaign: Ongoing

GANIL Intense Stable Beams
AGATA coupled to VAMOS
MNT reactions

2014-2018



Study of quadrupole correlations in ^{106,108}Sn via lifetime measurements.
J.J.Valiente-Dobon
M.Siciliano

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

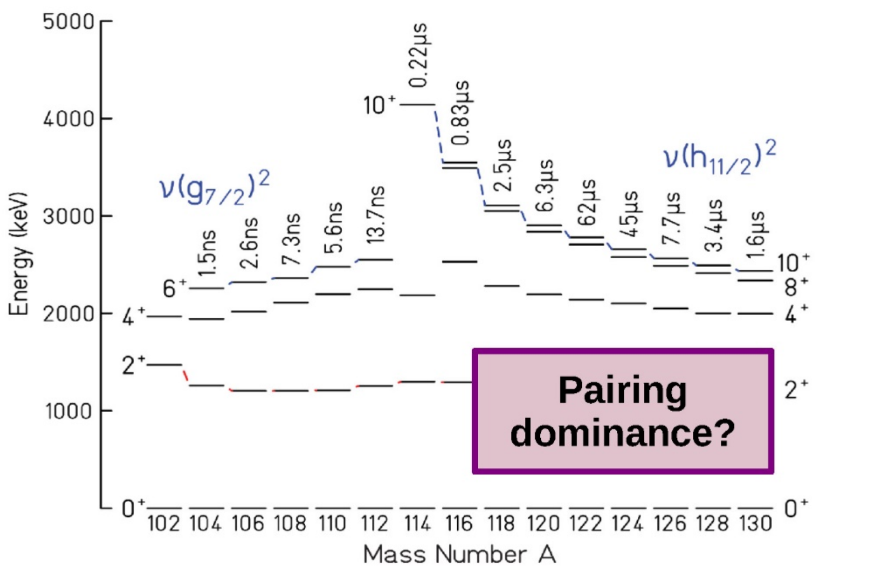
Due to the optimum *Q*-value condition with stable beams mostly p-stripping and n-pick-up occur in MNT processes
→populates n-rich nuclei.

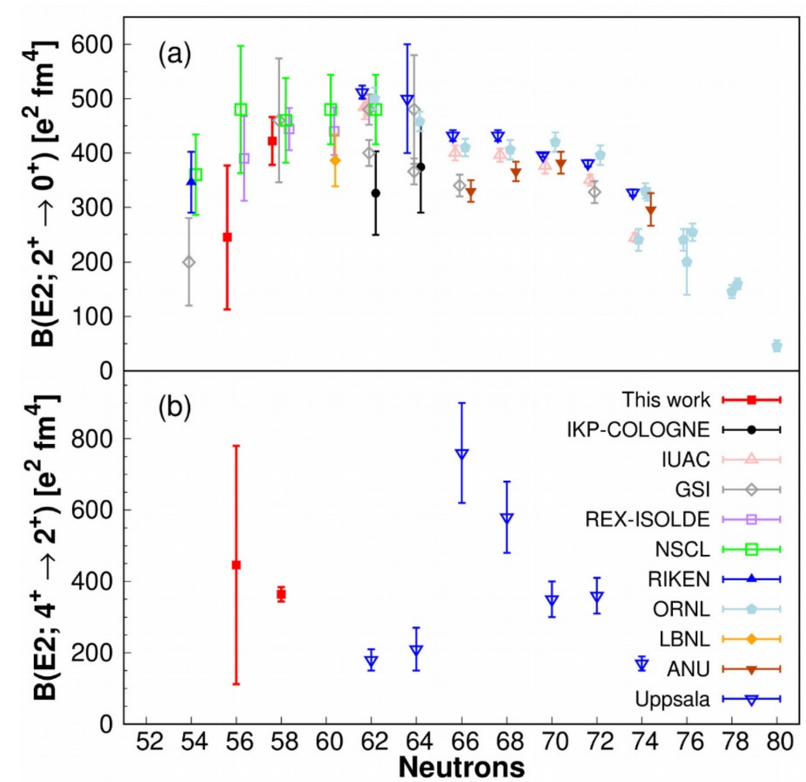
With p-rich beam and target possible to populate p-rich ejectiles with σ = few to ~1mb in +2p pick-up reactions

R.Broda et al., PRC 49, R575

Andres Gadea

Lifetime Measurements in ^{106,108}Sn.

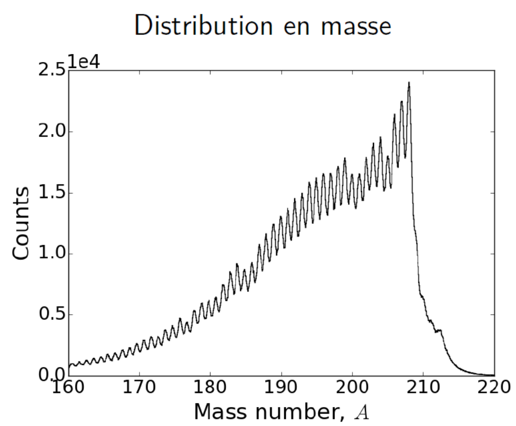


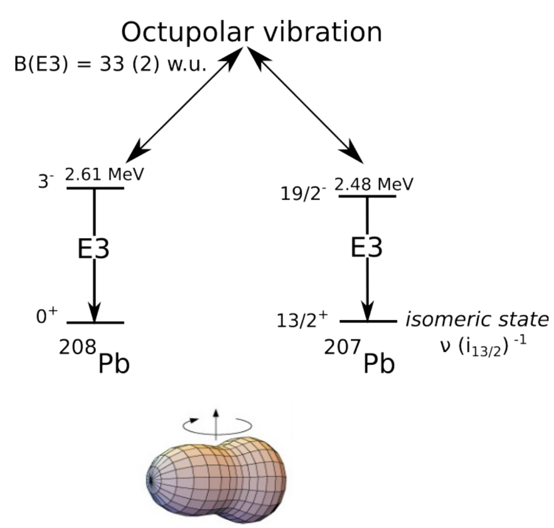


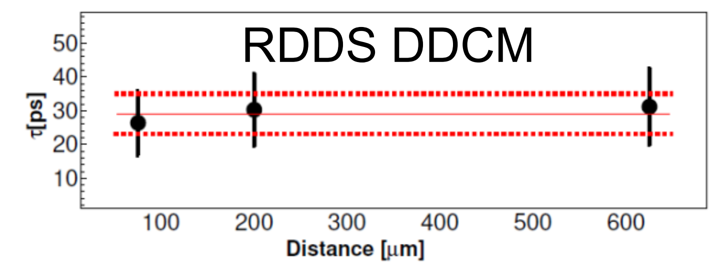
- **Direct population of the states**, avoiding the experimental limitations due to the “seniority” isomers
- **Complementary information** to Coulomb-excitation measurements
- Extend the investigation **above the 2_1^+** excited state

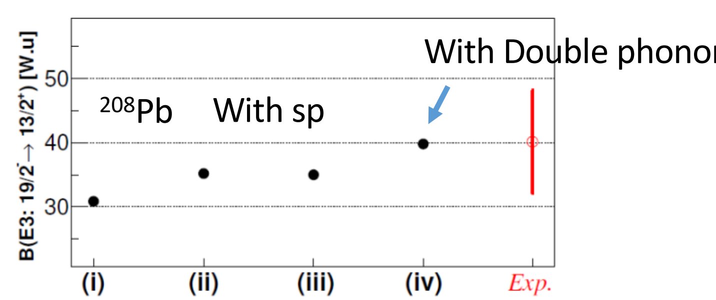
Evidence of octupole-phonon at high spin in ^{207}Pb : Study of the octupole phonon in the ^{208}Pb region.

- Case of the ^{207}Pb : 1 neutron hole in ^{208}Pb
- The first excited states of ^{207}Pb are part of the $\nu p^{-1}{}_{1/2} \times 3^{-}$ multiplet with slightly reduced B(E3) with respect to ^{208}Pb due to the $p_{1/2}$ blocking effect
- The $\nu(i_{13/2})^{-1}$ state band structure : strong coupling effect of the $i_{13/2}$ and $f_{7/2}$: enhanced B(E3) with respect to ^{208}Pb





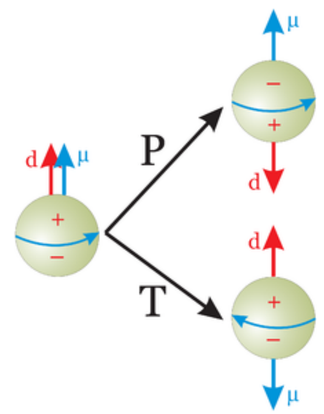


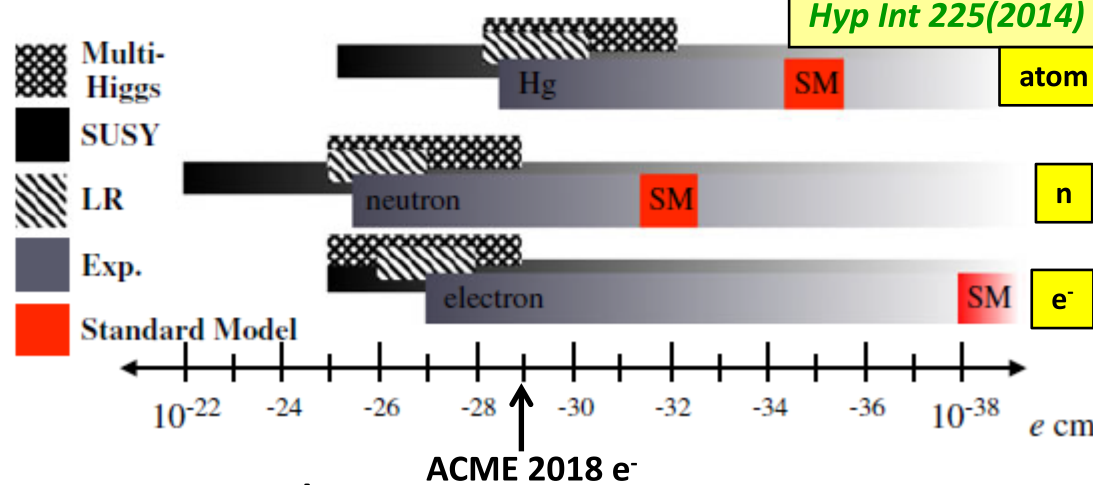


D. Ralet, E. Clément et al, submitted to PLB
D. Ralet et al., Phys.Scr. 92, 054004 (2017)

Pear-shapes and EDMs

ER Tardiff et al
Hyp Int 225(2014) 197

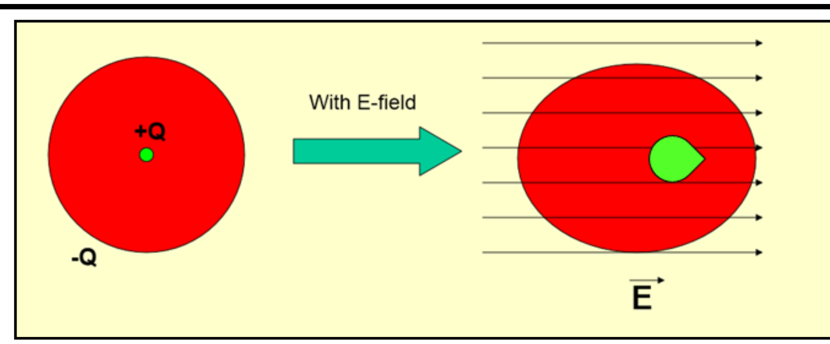




CP-violation
(matter-antimatter asymmetry in universe)

---

atomic EDM



^{225}Ra [Argonne]

ΔE ~ 50 keV
Q_3 known for ^{224,226}Ra

^{223}Rn [TRIUMF]

ΔE *not known*
Q_3 known for ^{220}Rn

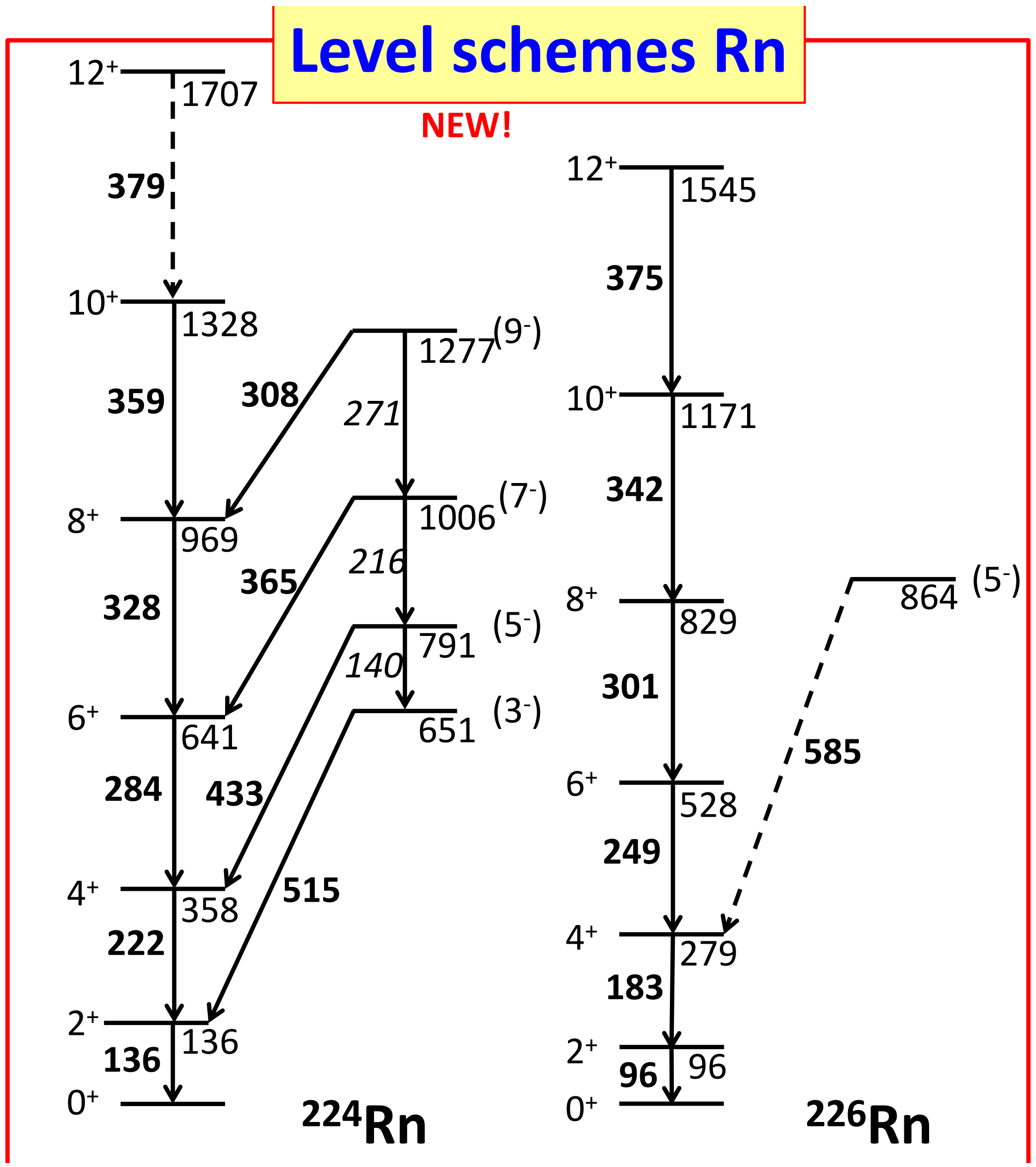
Schiff Moment

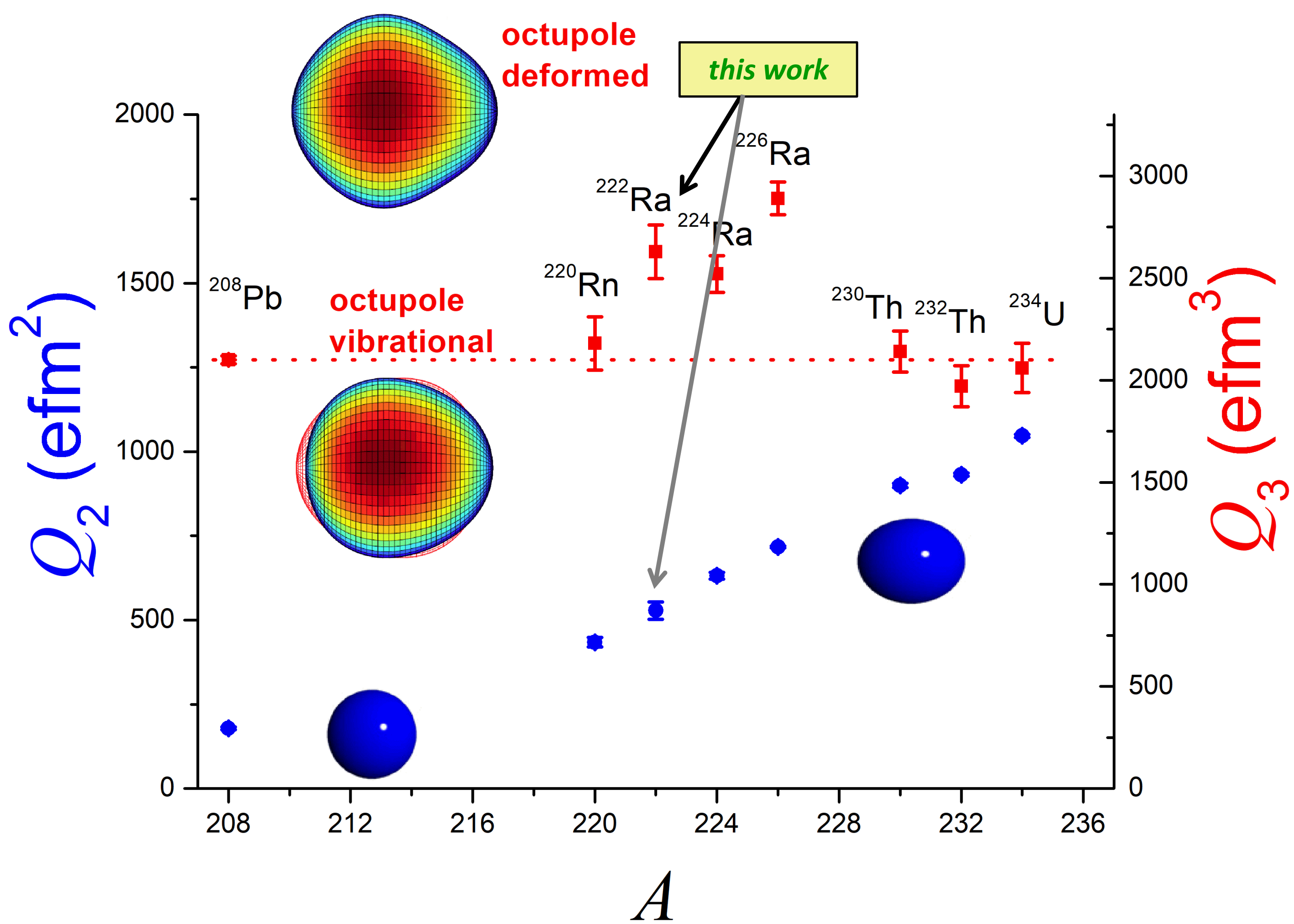
related to Q_3 — P,T-violating interaction

$$S = -2\frac{J}{J+1}\frac{<\hat{S}_z><\hat{V}_{PT}>}{\Delta E}$$

energy splitting of parity doublet

Peter Butler

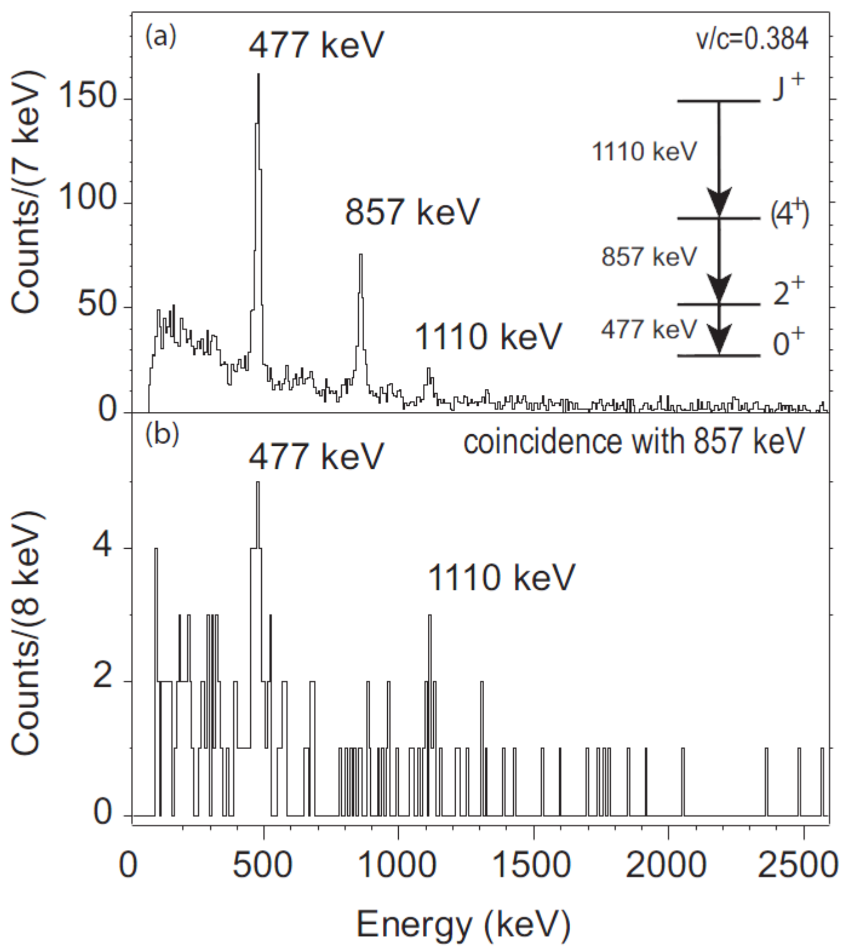




Peter Butler

Structure of ^{70}Fe: Single-particle and collective degrees of freedom

- Experiment
  - ^{9}Be(^{71}Co,^{70}Fe+γ)X at 87 MeV/u; typical ^{71}Co rate: 65/second
  - ^{70}Fe unambiguously identified in the S800, coincident γ rays event-by-event Doppler reconstructed from GRETINA's interaction points
- Results
  - Inclusive cross section for the reaction to happen: 11.0(8)mb
  - Three γ rays observed, one is new, two agree with previous results
  - All three are in coincidence → level scheme established
- A catch – Shell model predicts a ^{71}Co $7/2^-$ ground state and a $1/2^-$ isomer

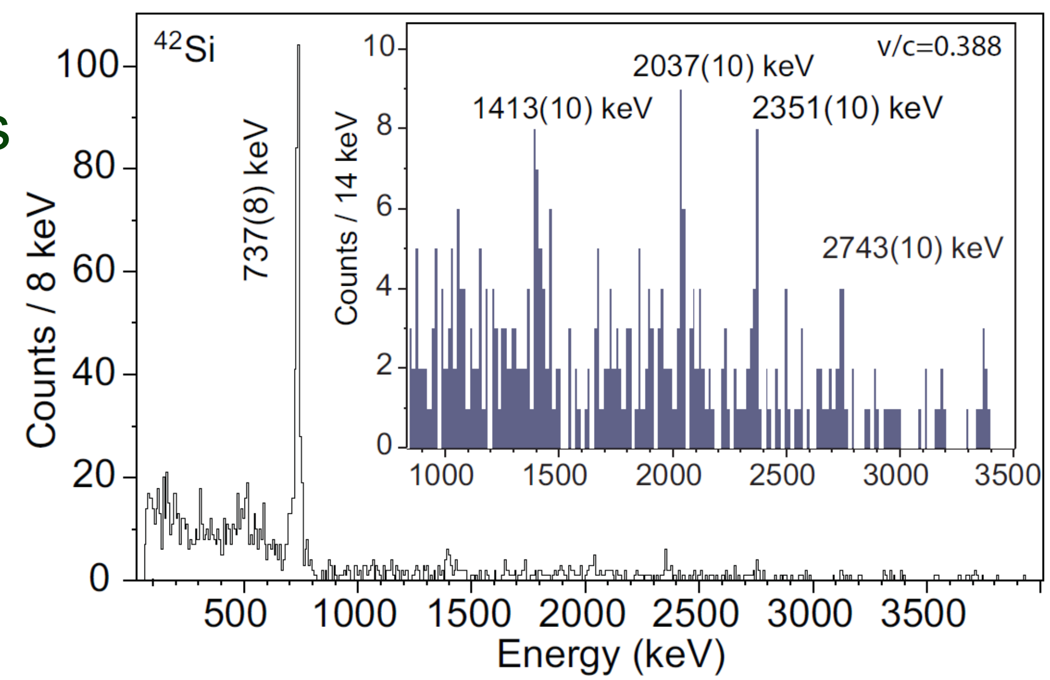


Alexandra Gade

Spectroscopy of ^{42}Si

The experiment – One-proton knockout from ^{43}P

- Again, one-proton knockout is a direct reaction → probes the single-particle degree of freedom
- ^{43}P: ground state is $1/2^+$
  L. A. Riley et al., PRC 78, 011303(R) (2008)
- This means, knockout of *sd*-shell protons cannot populate $J \geq 4$
- All γ-ray transitions except for the 2743 keV line had been reported in the RIBF two-proton removal experiment

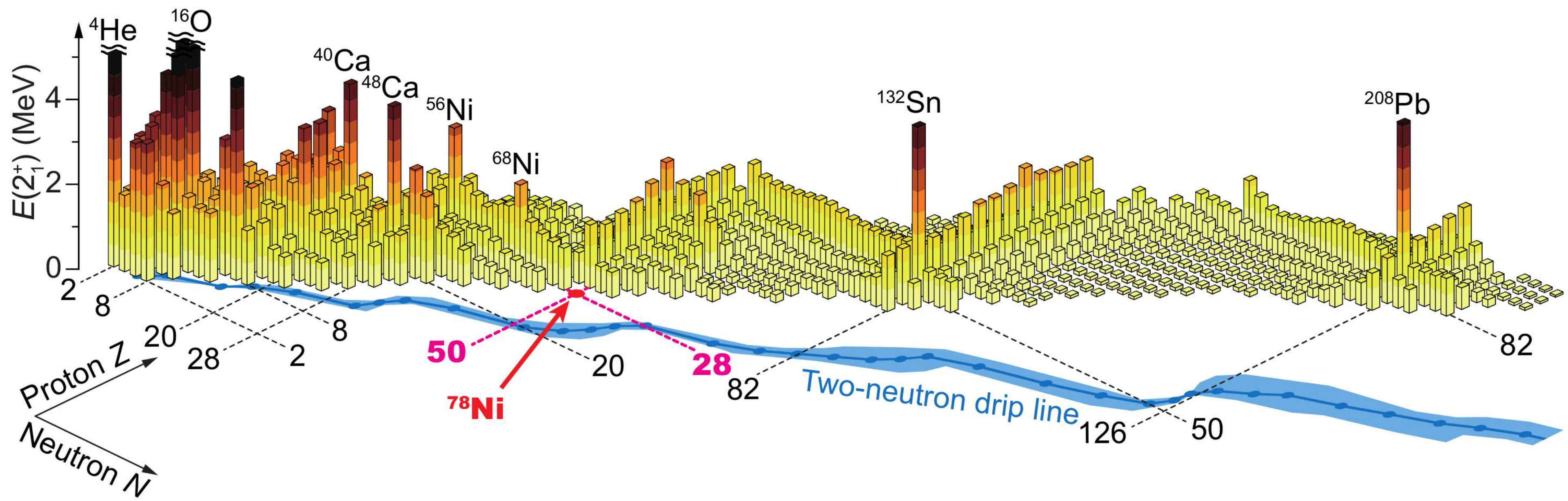


- ^{9}Be(^{43}P,^{42}Si+γ)X at 81 MeV/u
- Gamma rays in GRETINA and projectile-like reaction residues in the S800

Kathrin Wimmer
ウィマー　カトリン

東京大学 THE UNIVERSITY OF TOKYO

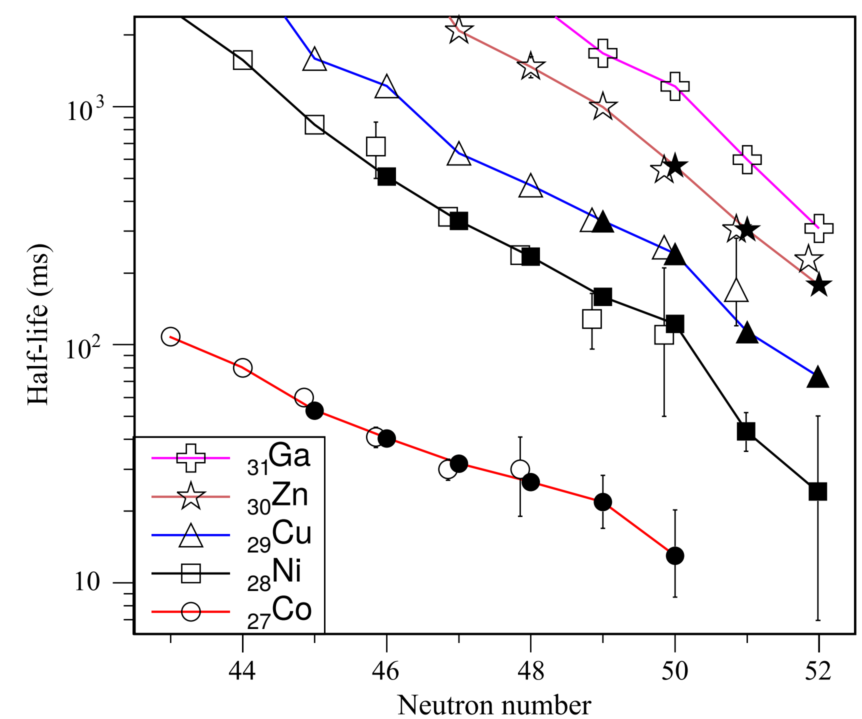
Doubly-magic ^{78}Ni



- ^{78}Ni is the only neutron-rich doubly-magic nucleus with unknown $E(2^+)$
- within the predicted neutron drip-line

  J. Erler et al., Nature **486** (2012) 509.
- magicity inferred from β-decay measurements

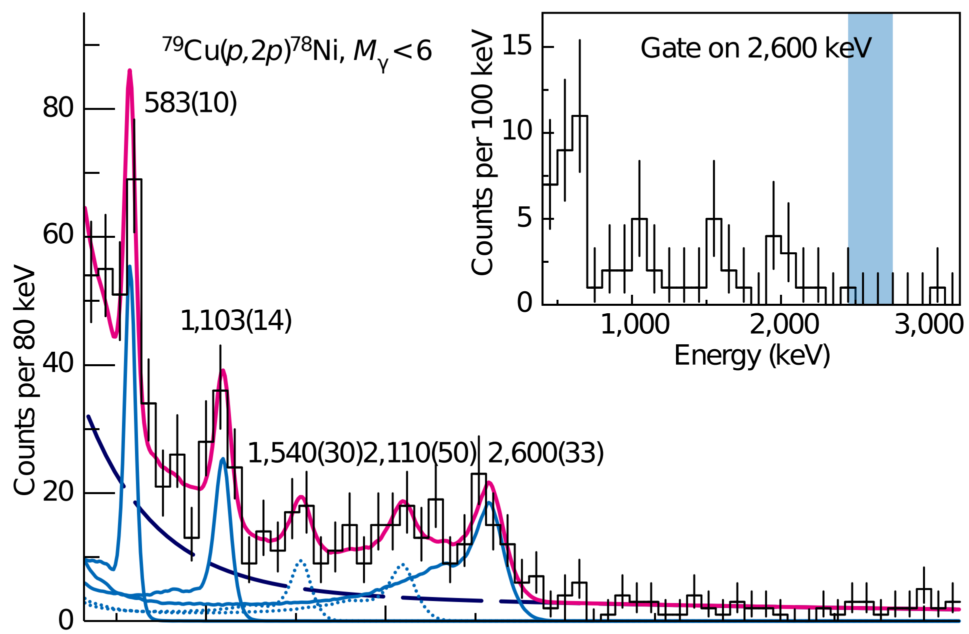
  P. T. Hosmer et al., Phys. Rev. Lett. **94** (2005) 112501,
  Z. Y. Xu et al., Phys. Rev. Lett. **113** (2014) 032501.
- prediction $E(2^+) = 2 - 4$ MeV



Kathrin Wimmer
ウィマー　カトリン

東京大学 THE UNIVERSITY OF TOKYO

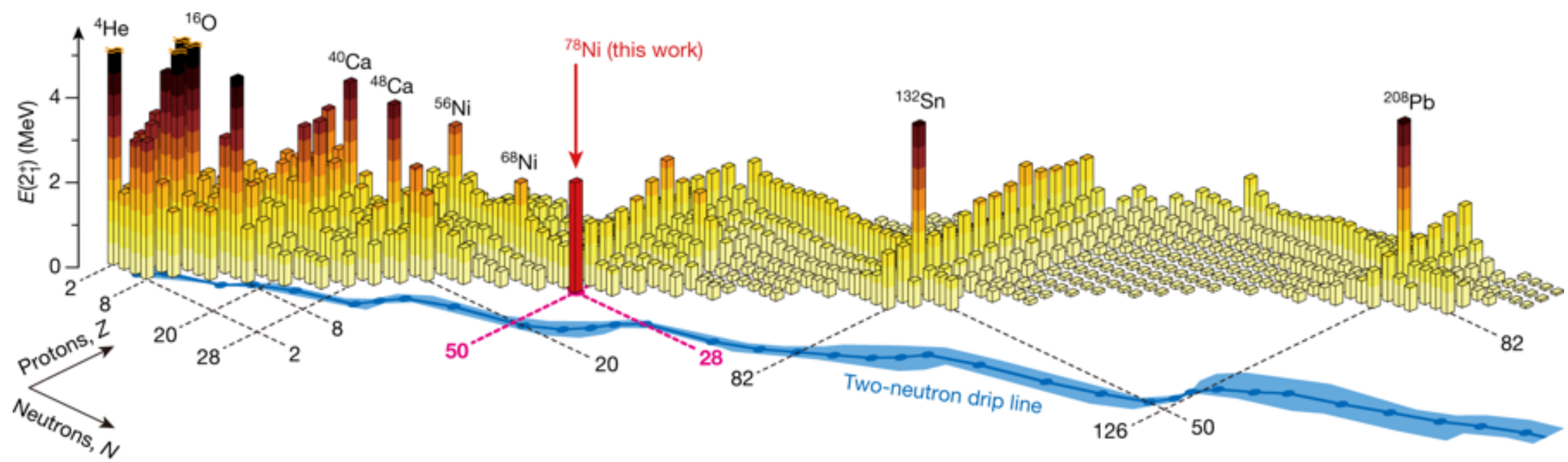
γ-ray spectra for ^{78}Ni



^{79}Cu$(p,2p)^{78}$Ni

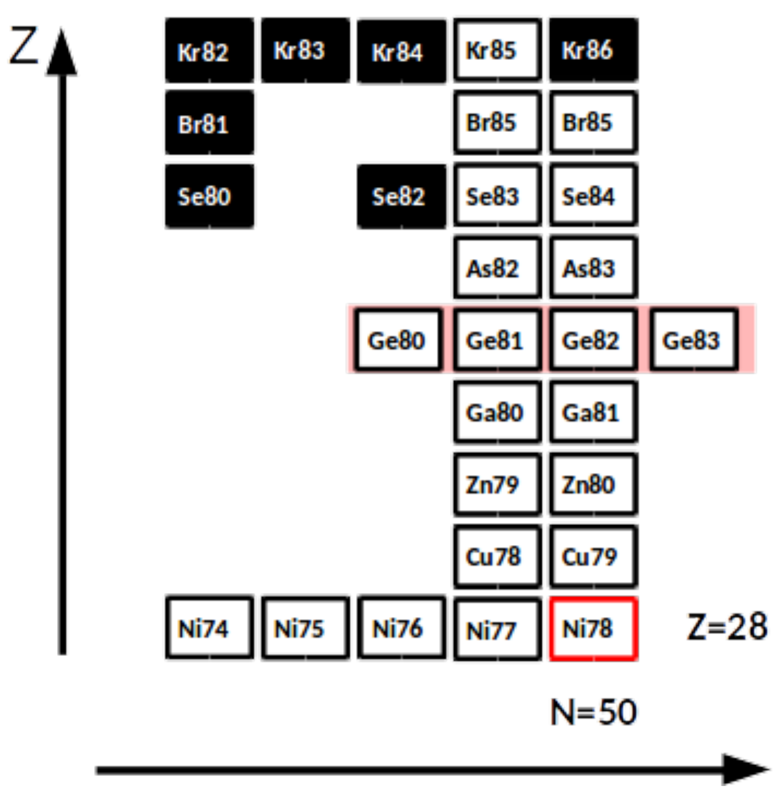
- inclusive cross section $\sigma = 1.7(4)$ mb
- highest intensity peak
  $\rightarrow E(2^+) = 2600(33)$ keV
- 583(10) keV transition:
  $4^+ \rightarrow 2^+$ candidate, $R_{4/2} = 1.22(2)$
  similar to other doubly magic nuclei

Nature ***569***, *53–58 (2019)*



Shape coexistence in the vicinity of ^{78}Ni

Clément Delafosse

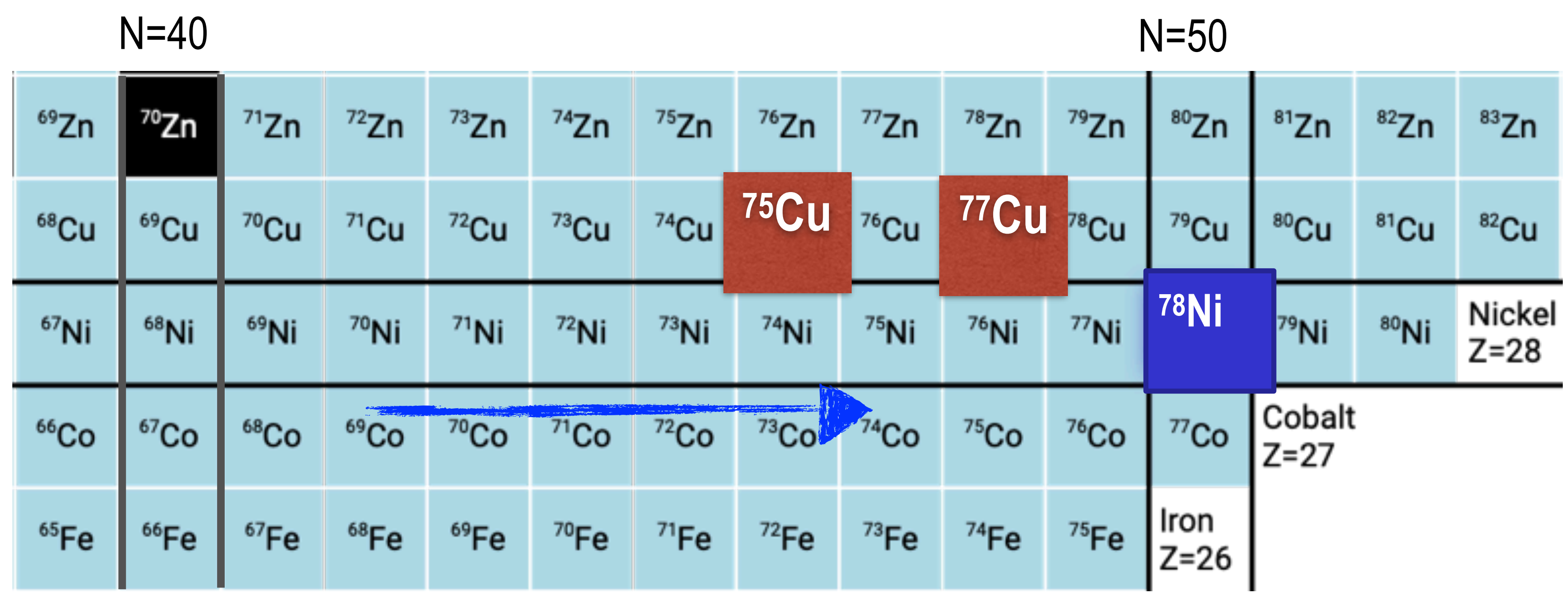


Complete β-delayed γ-spectroscopy of ^{83}Ge

Excited states lifetime measurement of ^{85}Se (better precision) and ^{83}Ge (first time)

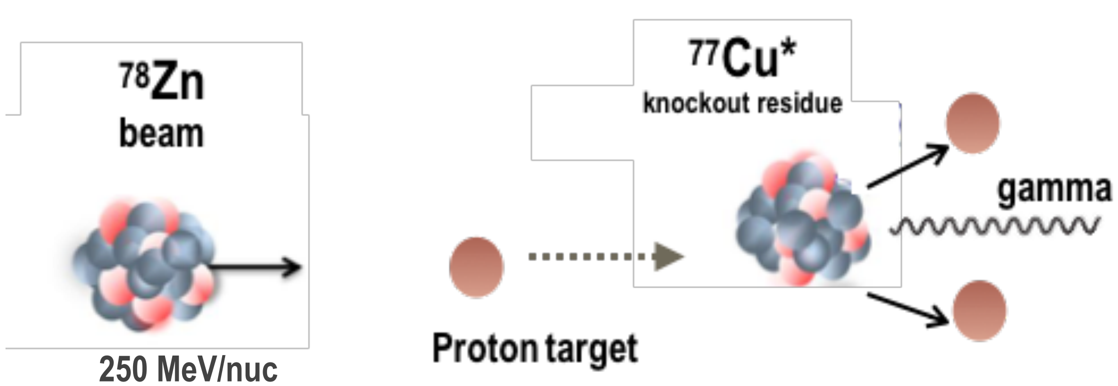
First observation of a 2p-1h state in a N=51 isotone far from stability : shape coexistence towards N=50

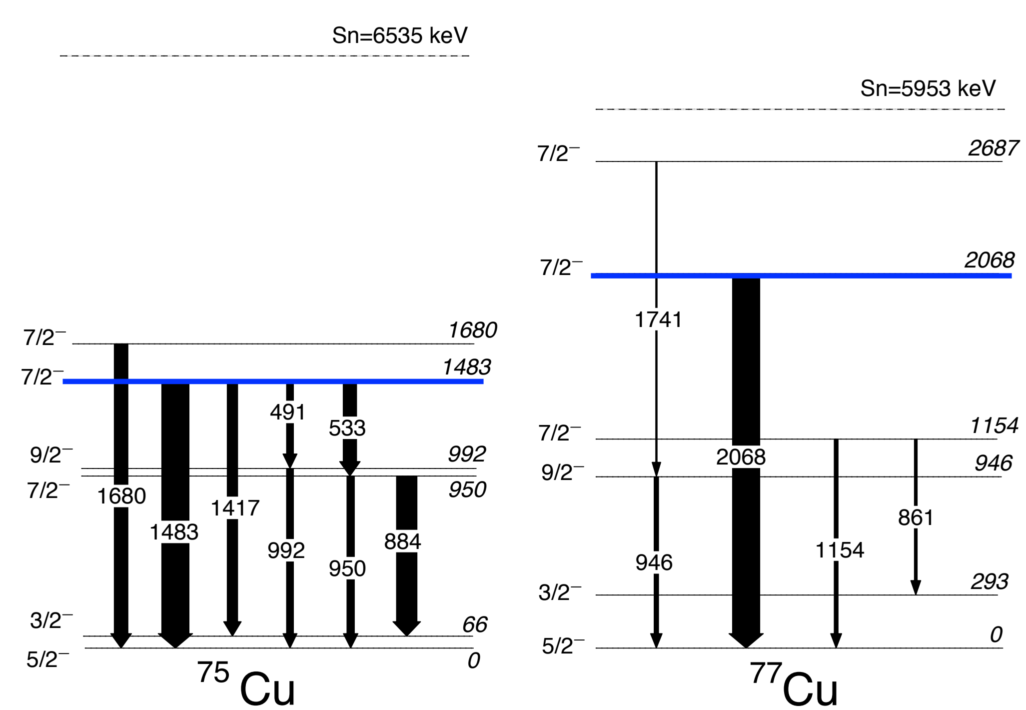
Eda Sahin



one-proton knockout reaction at RIKEN: ^{75}Cu and ^{77}Cu

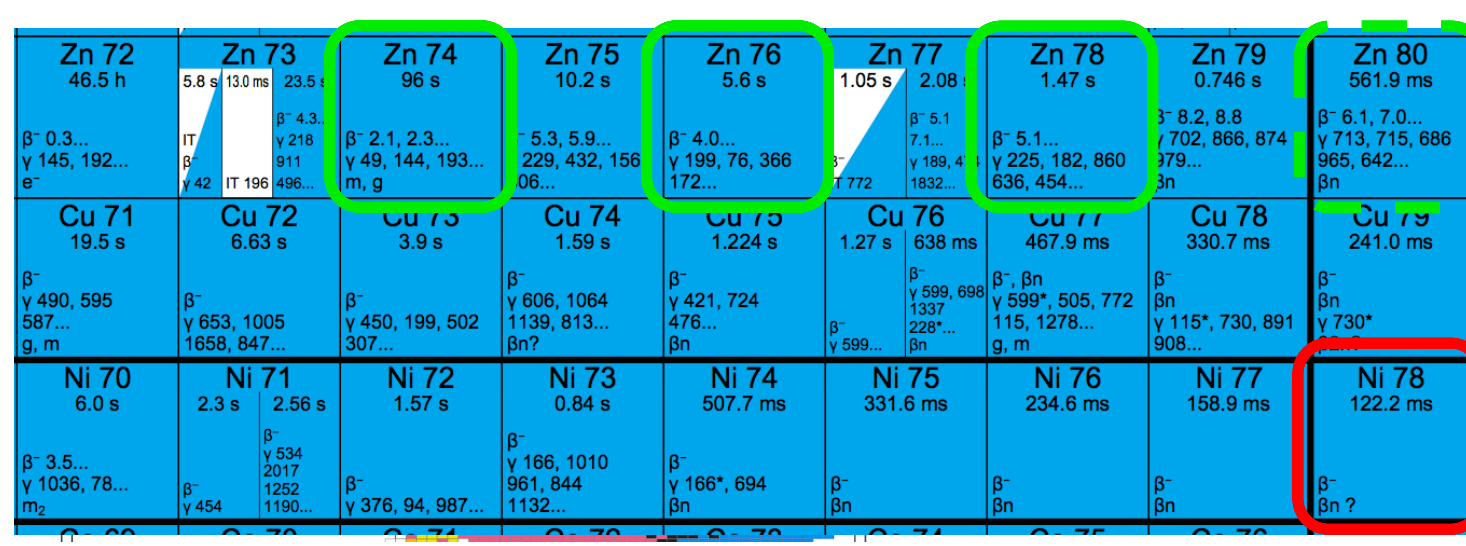
SEASTAR Level schemes

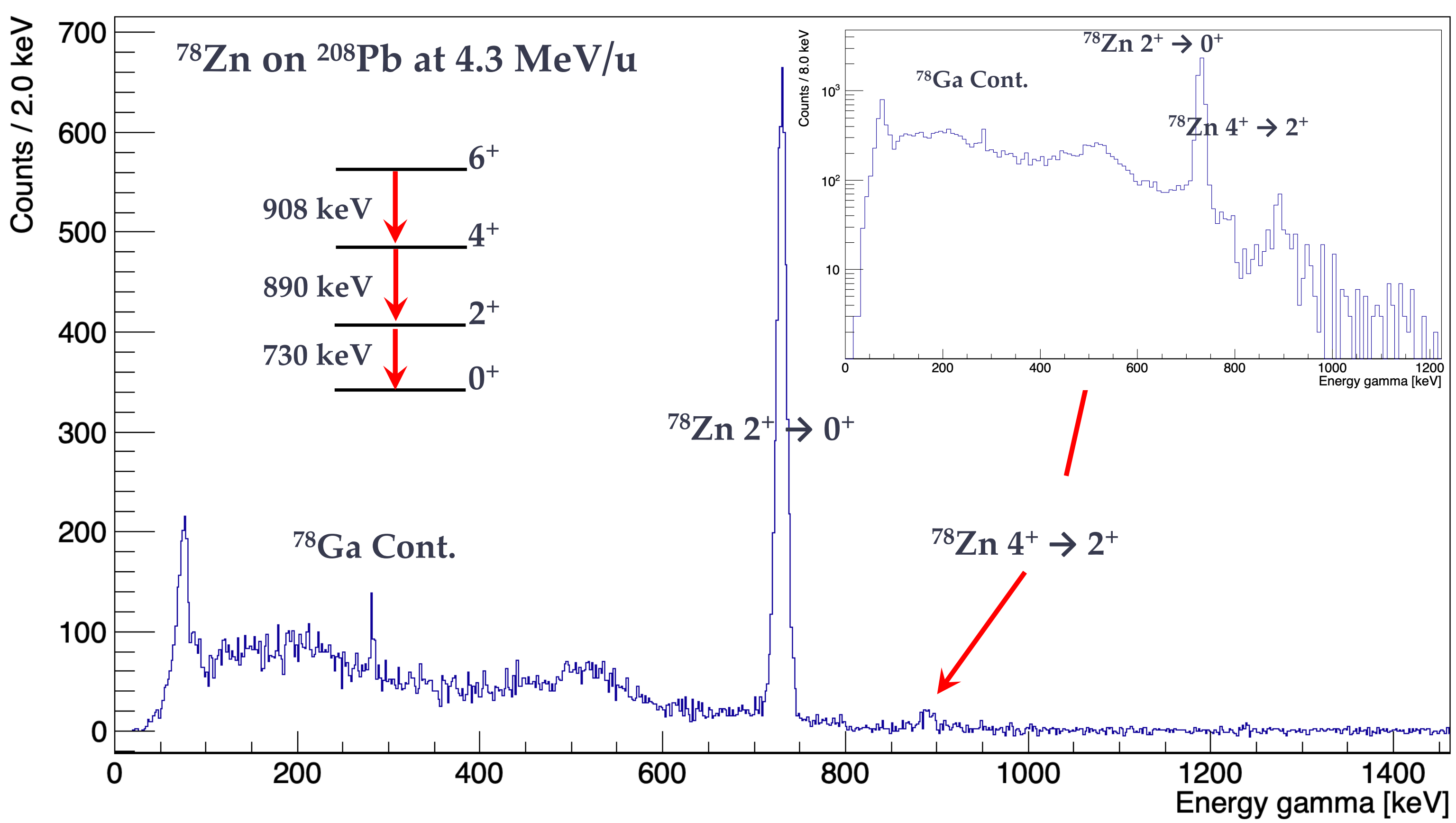


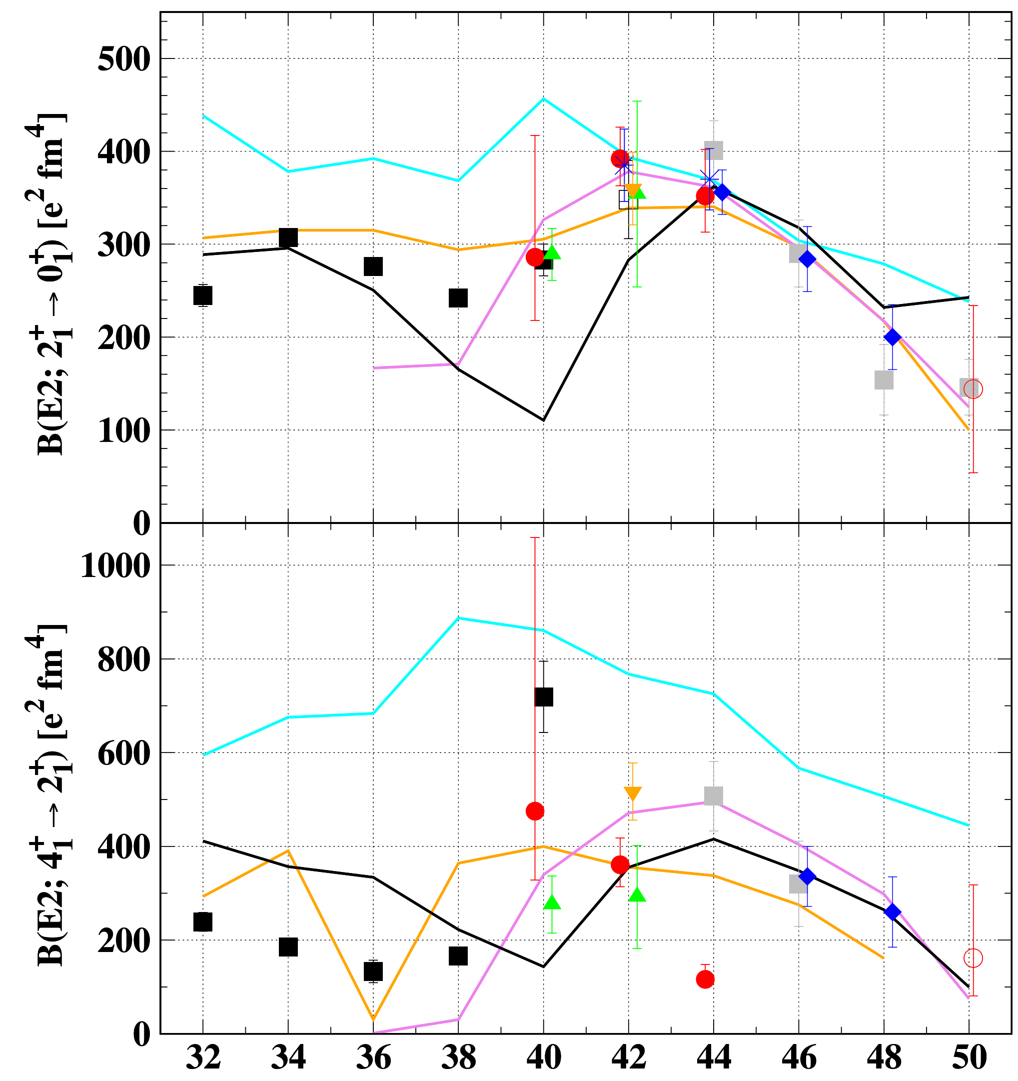


Collectivity in the vicinity of ^{78}Ni: Coulomb excitation of neutron-rich Zn at HIE-ISOLDE

A. Illana Sison

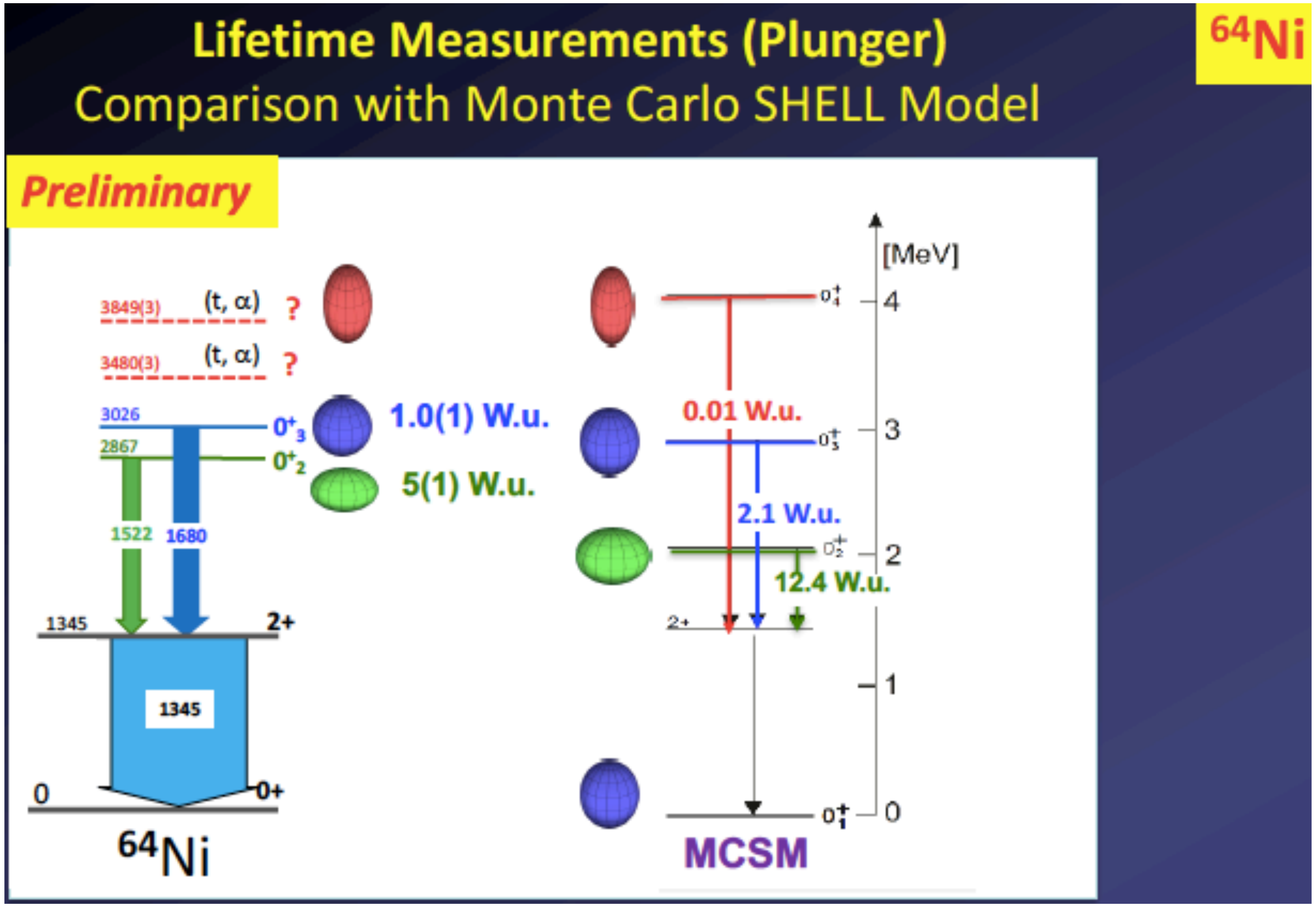






Silvia Leoni

Revealing microscopic origins of shape coexistence in the Ni isotopic chain



Suzana Szilner

Heavy ion transfer reactions

neutron rich nuclei

heavy nuclei

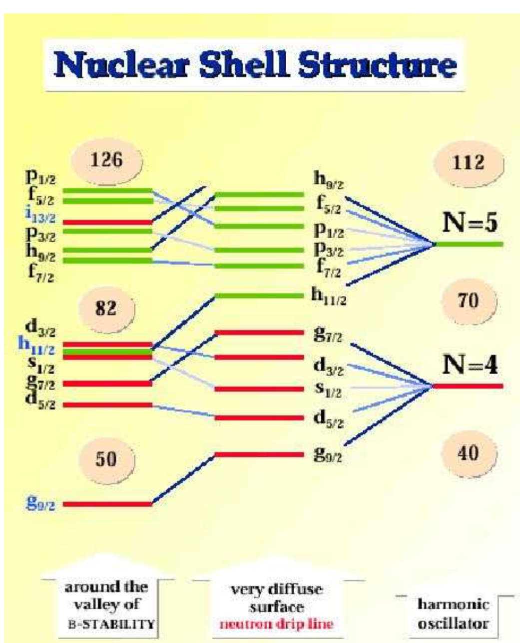
synthesis in lab

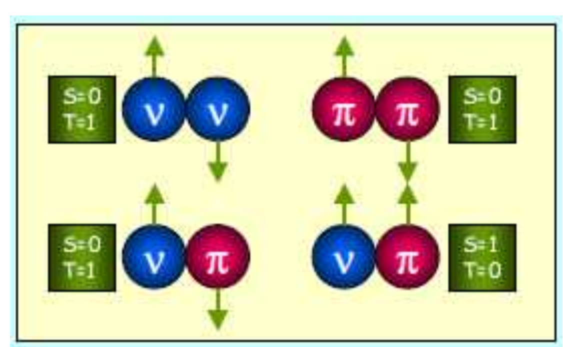
correlations → nucleon - nucleon → studies of pairing in nuclei

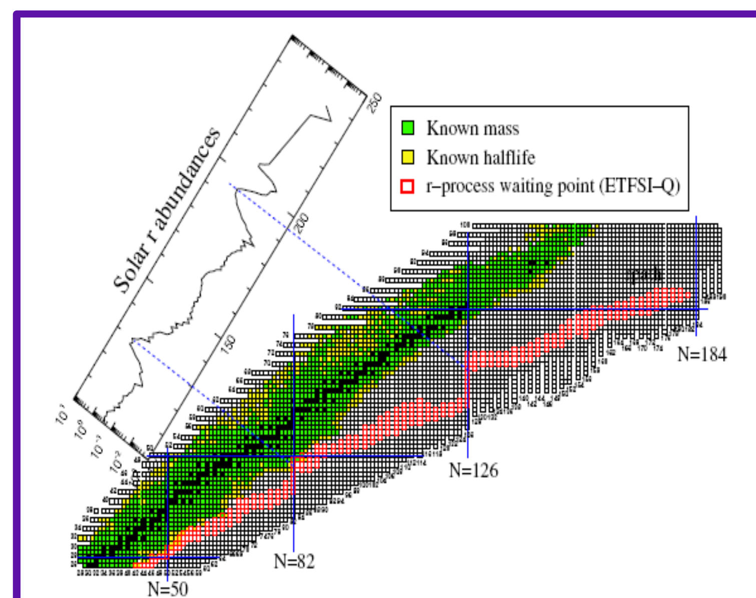
correlations → mass – mass → instrumental: coincident detection of partners → studies of production of heavy neutron-rich nuclei

reaction mechanism → above the barrier

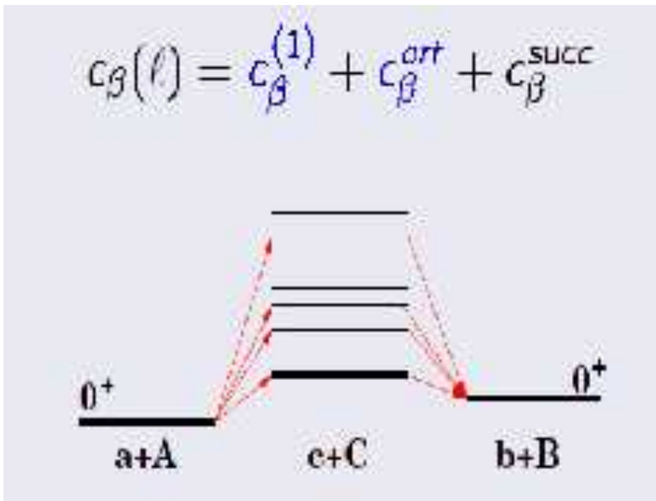
reaction mechanism → below the barrier

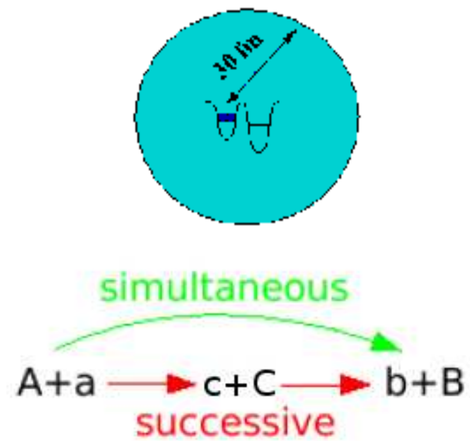


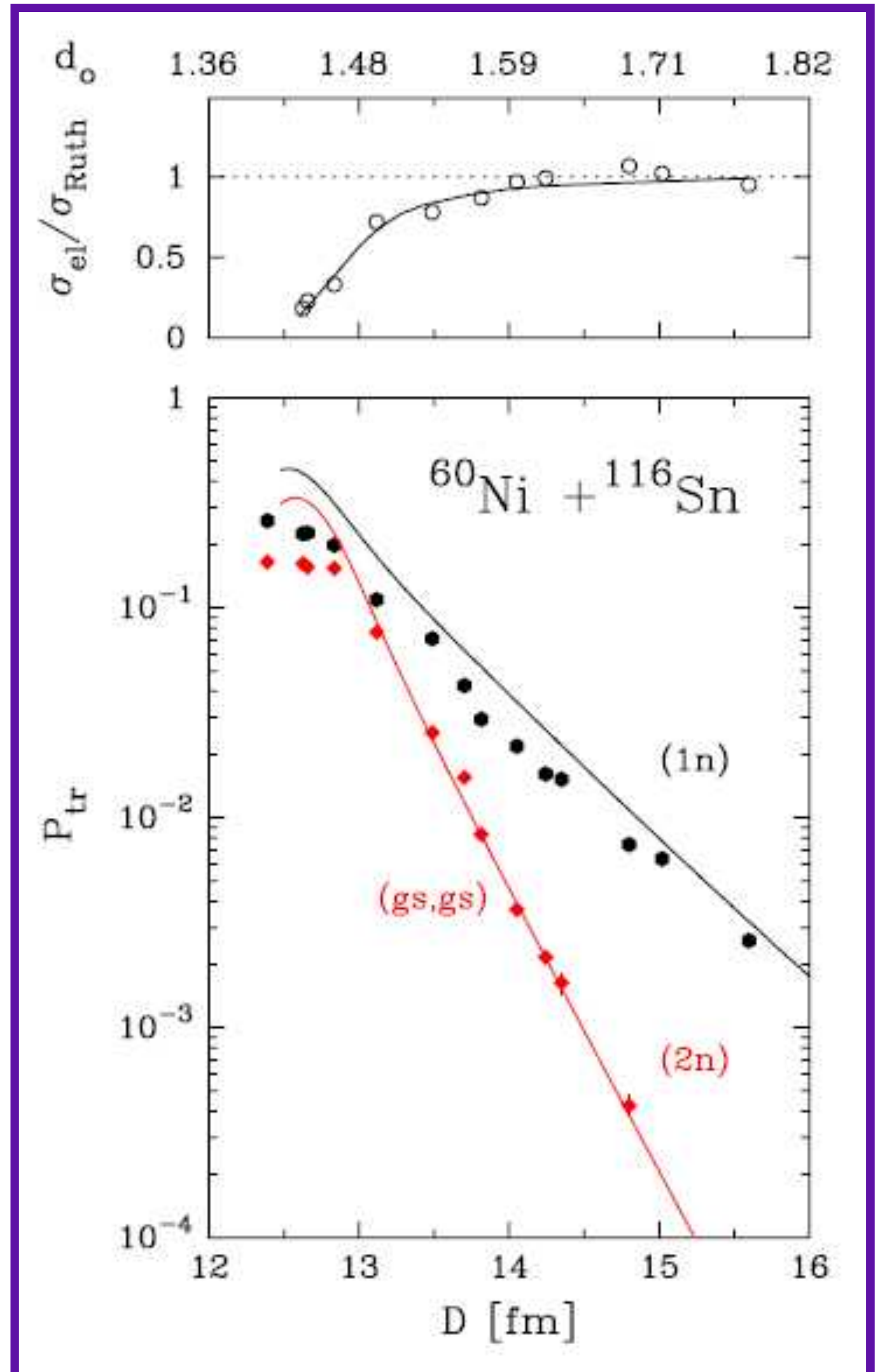




$^{60}Ni+^{116}Sn$: neutron pair transfer far below the Coulomb barrier







The experimental transfer probabilities are well reproduced, in **absolute values** and in **slope** by **microscopic** calculations which incorporate nucleon-nucleon **correlations:**

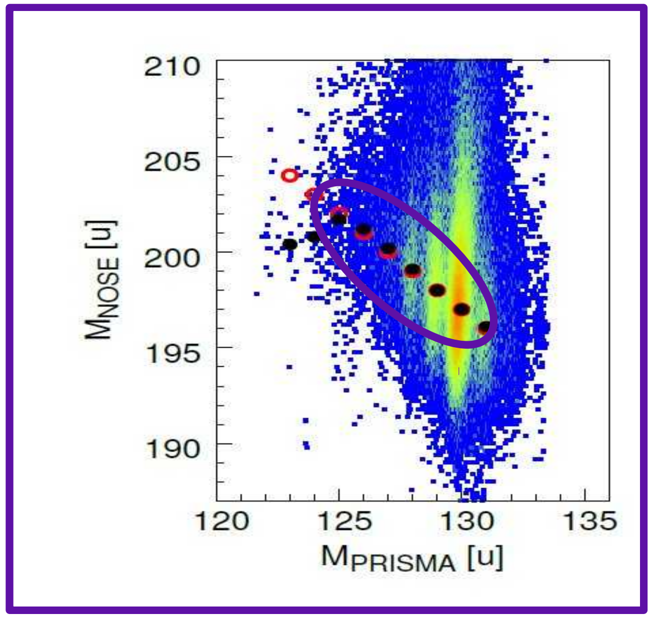
✓ a consistent description of (1n) and (2n) channels

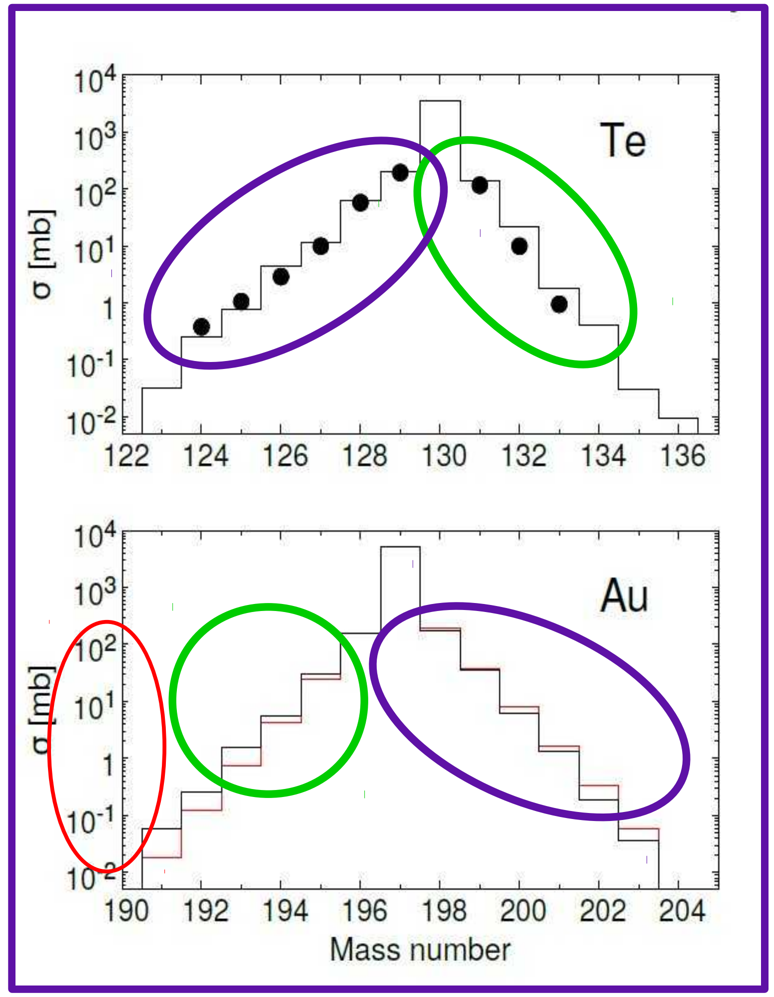
✓ the formalism for (2n) incorporates the contribution from both the **simultaneous** and **successive** terms (only the **ground-to-ground-state** transition has been calculated)

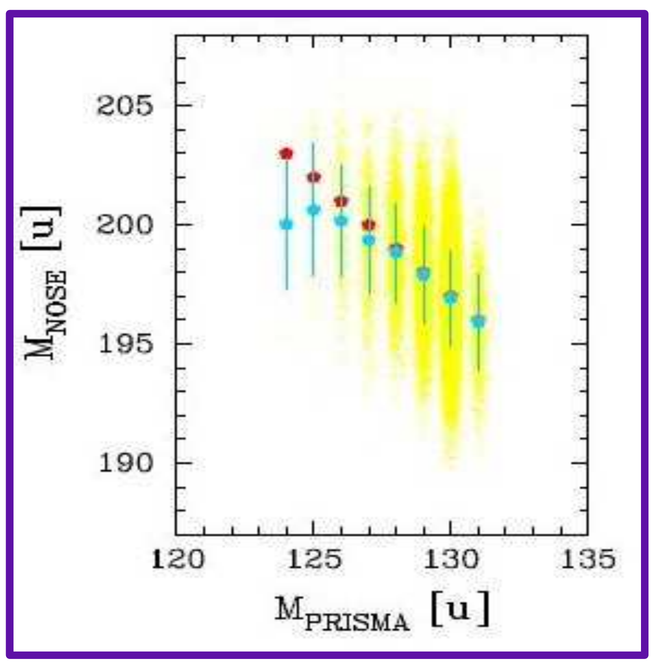
✓character of pairing correlations manifests itself equally well in simultaneous and in successive transfers due to the correlation length

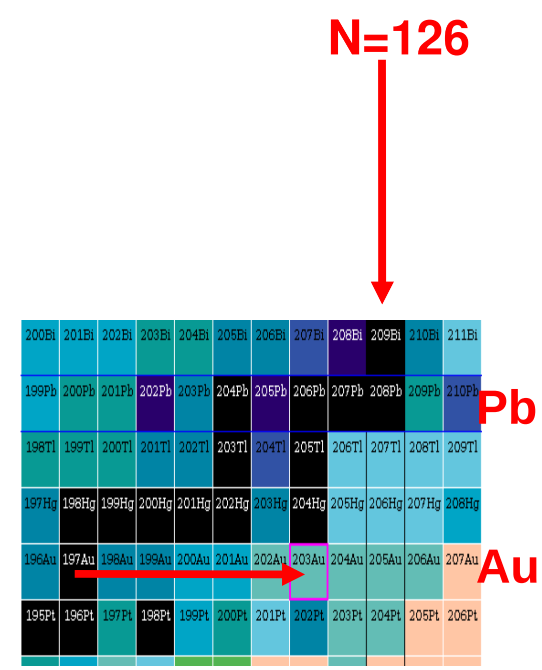
Synthesis of heavy neutron rich nuclei in labs

^{197}Au+^{130}Te: coincident detection of binary partenrs









Multinucleon transfer reactions are suitable tool for the production of the heavy neutron-rich nuclei

Te isotopes with “more” neutrons than in ^{130}Te

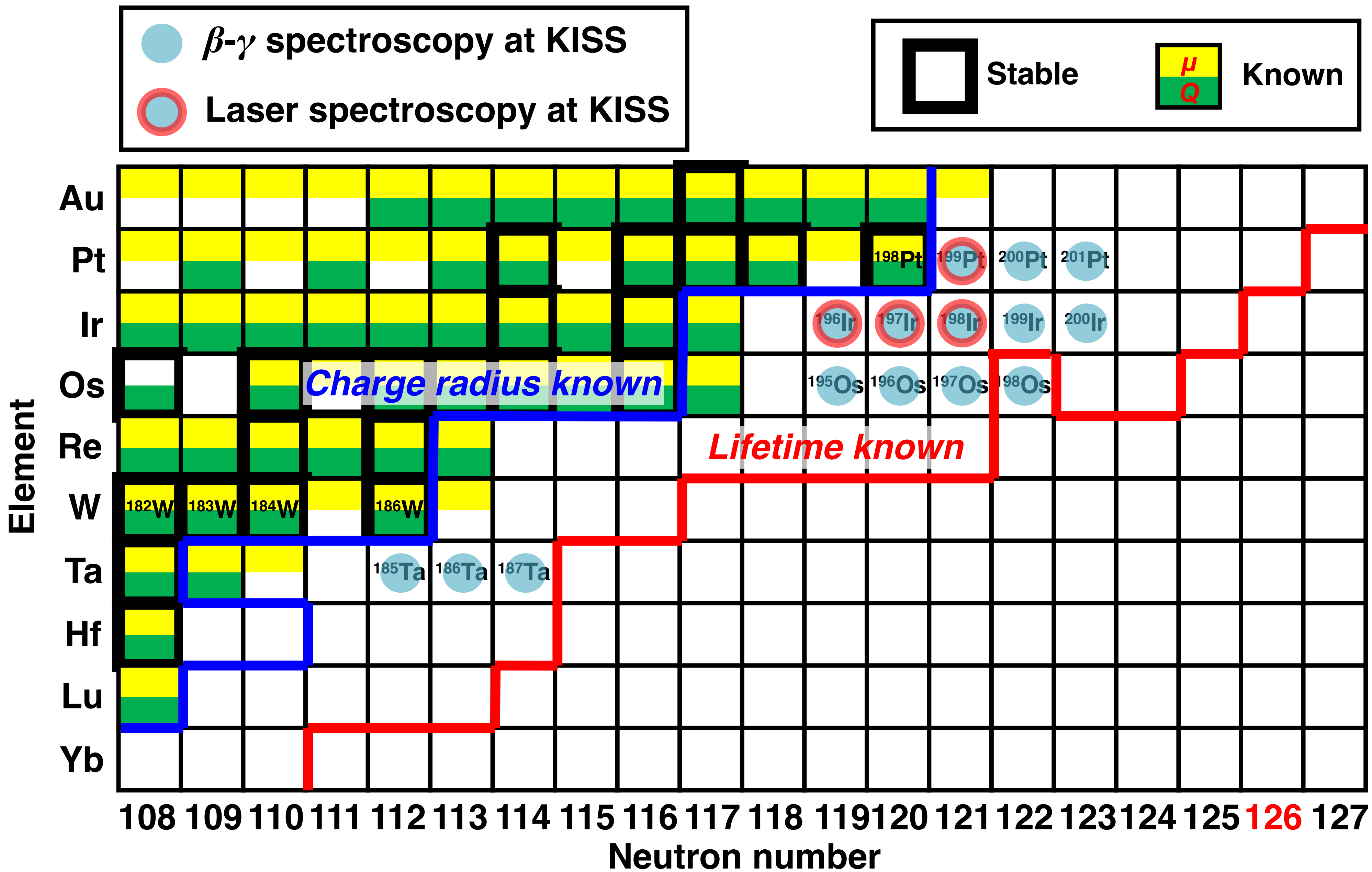
Au isotopes with “more” neutrons than in ^{197}Au

Y.X. Watanabe

Nuclear production around $N = 126$ by MNT reaction

KEK Isotope Separation System (KISS)

Experimental results



Fusion hindrance in light and heavy systems

G. Montagnoli

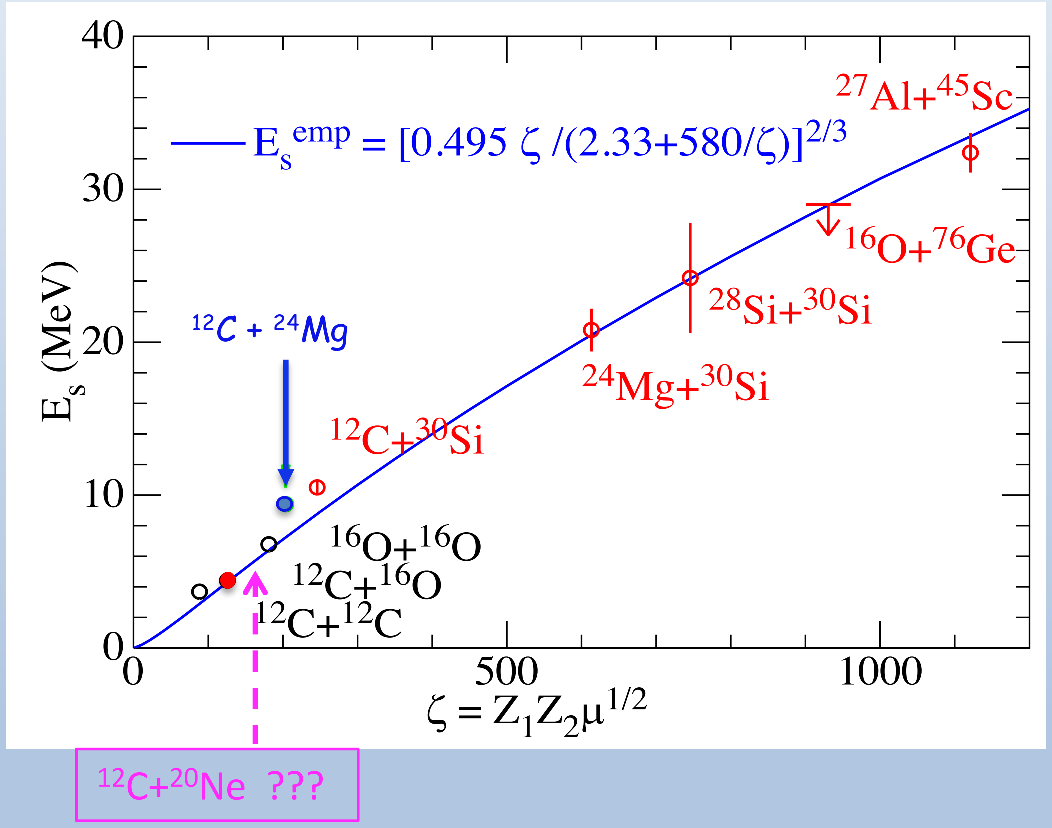
Threshold energies for hindrance in light systems

The system $^{12}C + {}^{30}Si$ has a ζ parameter very near to the lighter systems important for stellar evolution. Its Q-value for fusion is positive (Q=+14.1 MeV)

$^{12}C + {}^{24}Mg$ (Q=+16.3 MeV) is even closer to the light systems and has been measured very recently

The case of $^{12}C + {}^{20}Ne$ raises questions ....

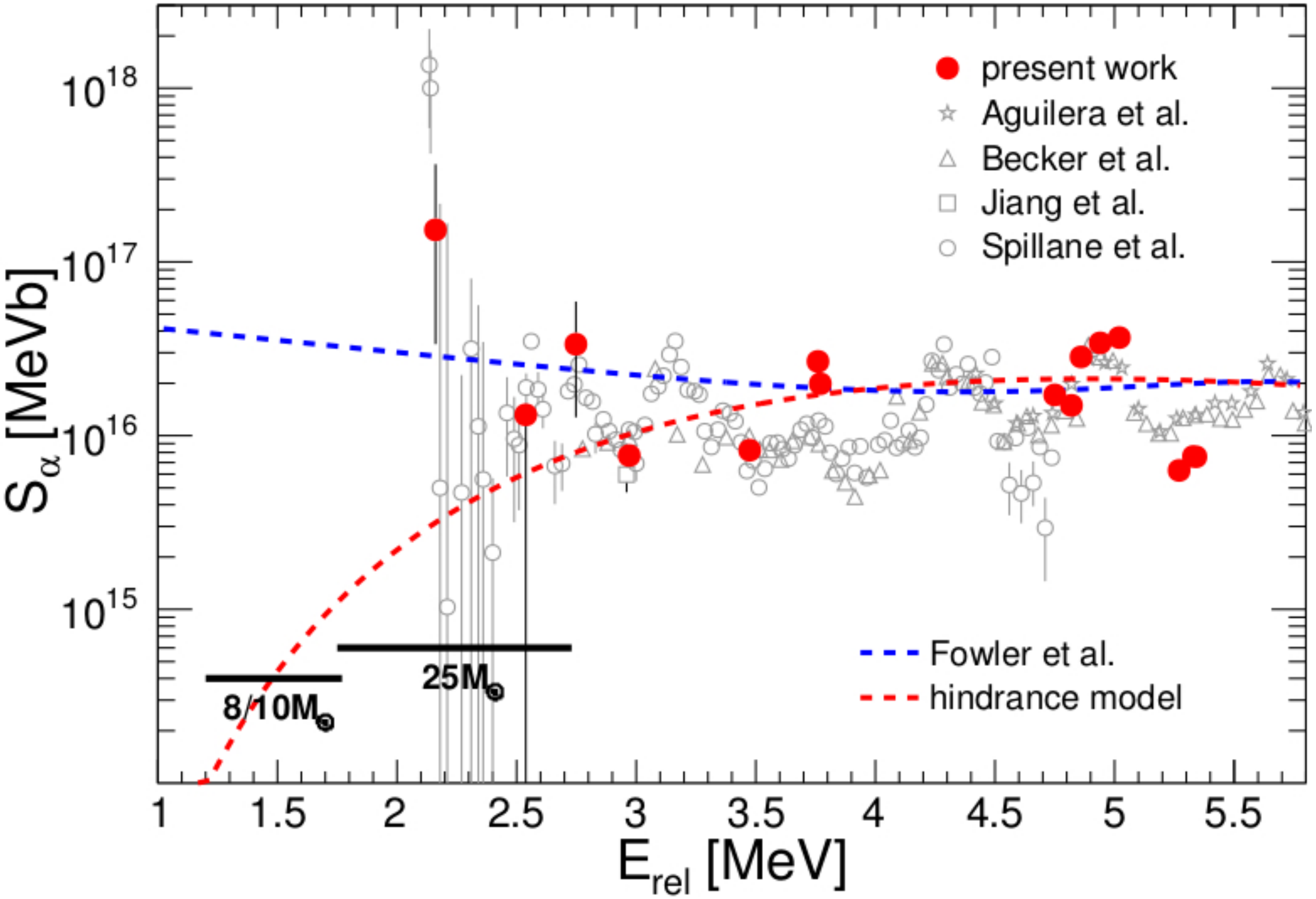
N.B. (the points of C+C and O+O are obtained only from extrapolations)



Pushing the $^{12}C+^{12}C$ cross-section to the limits with the STELLA experiment at IPN Orsay

David Jenkins

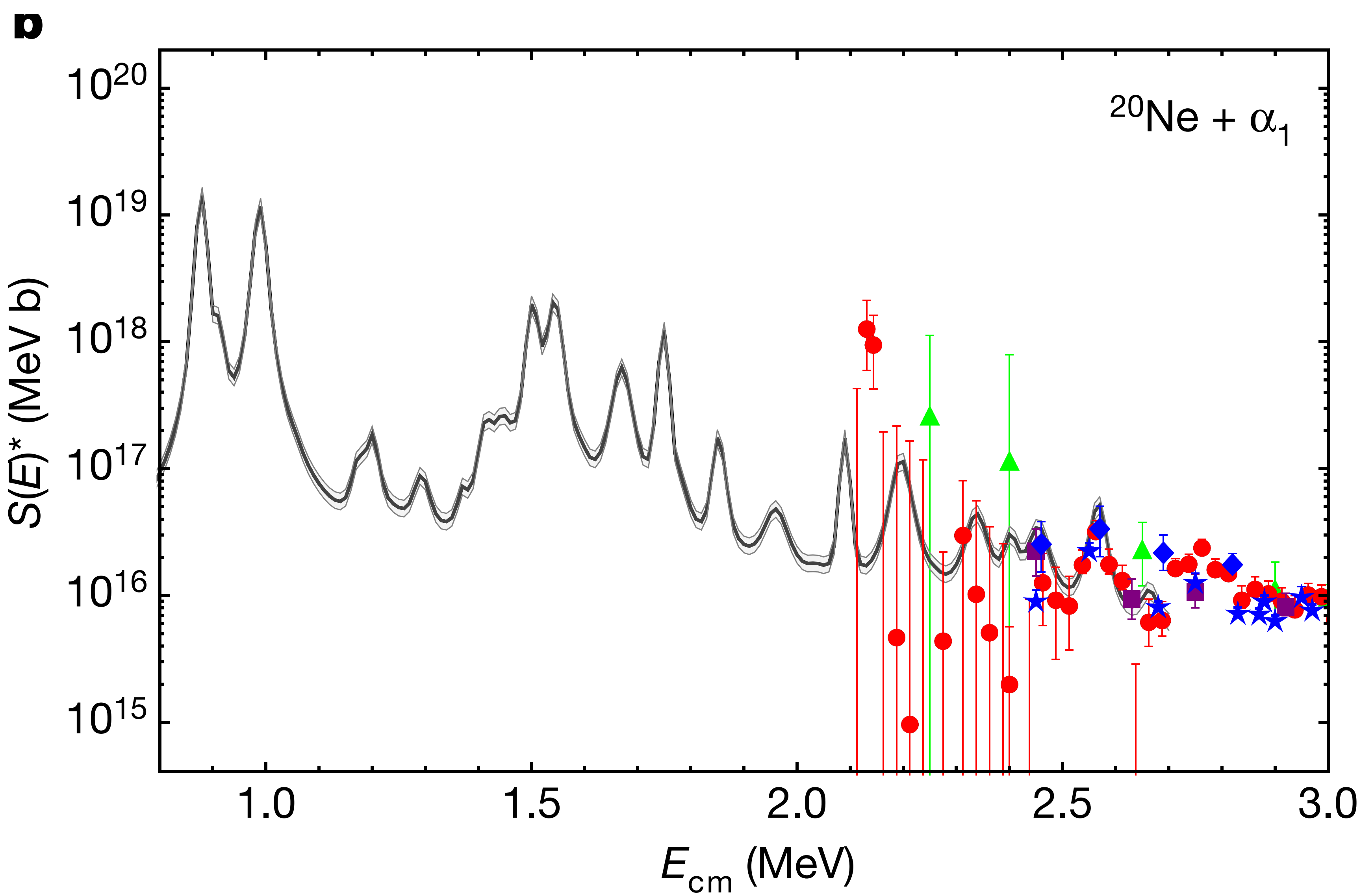
…measurement of the *S*-factor with particle-gamma coincidence.



RESEARCH LETTER

An increase in the $^{12}C + {}^{12}C$ fusion rate from resonances at astrophysical energies

A. Tumino[1,2]*, C. Spitaleri[2,3], M. La Cognata[2], S. Cherubini[2,3], G. L. Guardo[2,4], M. Gulino[1,2], S. Hayakawa[2,5], I. Indelicato[2], L. Lamia[2,3], H. Petrascu[4], R. G. Pizzone[2], S. M. R. Puglia[2], G. G. Rapisarda[2], S. Romano[2,3], M. L. Sergi[2], R. Spartá[2] & L. Trache[4]



Recent results on heavy-ion induced reactions of interest for neutrinoless double beta decay

Manuela Cavallaro

A new experimental tool

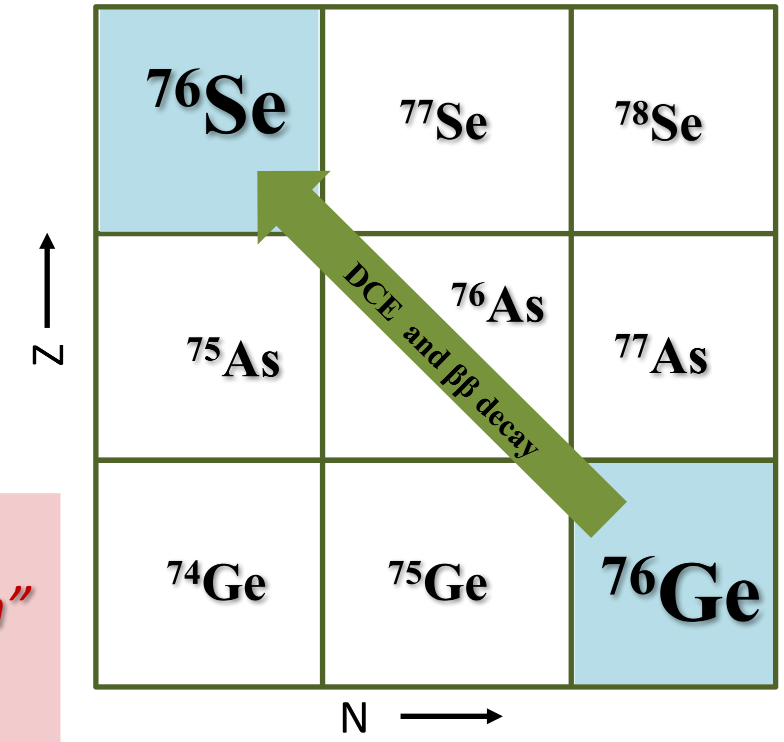
Nuclear reactions
Heavy-Ion induced Double Charge Exchange reactions (DCE)
to stimulate in the laboratory the same nuclear transition (**g.s. to g.s.**) occurring in 0νββ

NUMEN

European Commission

erc

NURE



The dream:

Extraction from measured cross-sections of *"data-driven"* information on NME for all the systems candidate for 0νββ

H. Lenske

Theory of Heavy Ion Charge Exchange Reactions as Probes for Beta-Decay

Nunzio Itaco

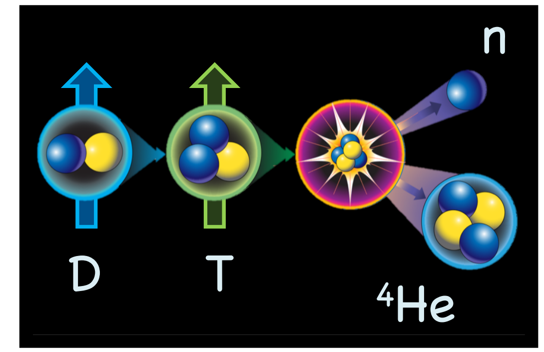
Neutrinoless Double-Beta Decay and Realistic Shell Model

Hiroyuki Sagawa

Single and Double Charge exchange excitations of Spin-Isospin mode

Theory

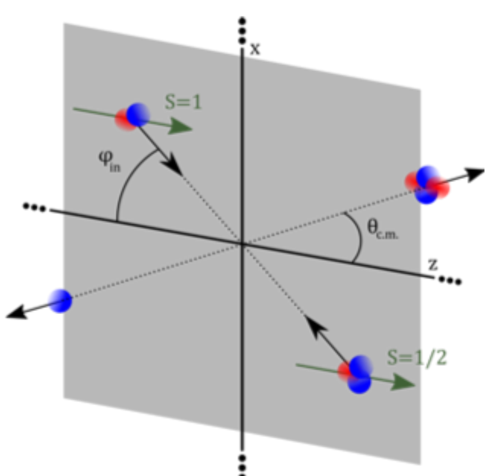
Petr Navratil *ab initio* no-core shell model with continuum (NCSMC)

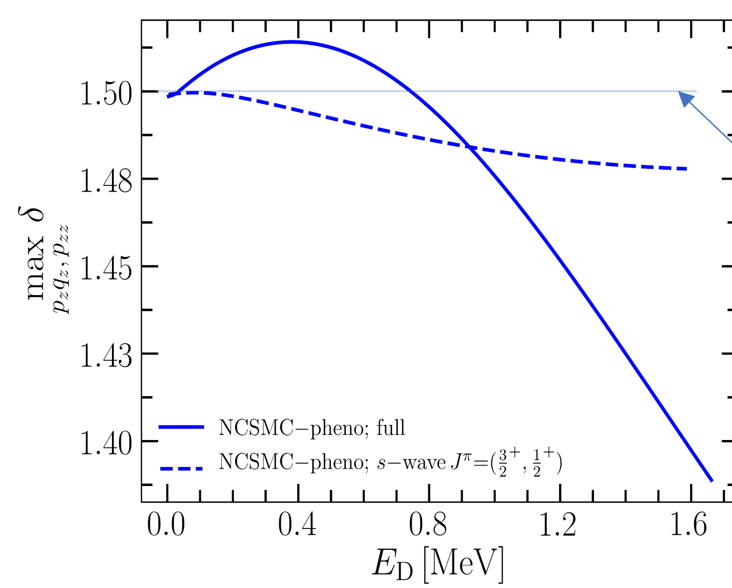


^{3}H(d,n)^{4}He with chiral NN+3N(500) interaction

Polarized fusion

$$\frac{\partial \sigma_{pol}}{\partial \Omega_{c.m.}}(\theta_{\rm c.m.}) = \frac{\partial \sigma_{unpol}}{\partial \Omega_{c.m.}}(\theta_{\rm c.m.})\left(1+\frac{1}{2}p_{zz}A_{zz}^{(b)}(\theta_{\rm c.m.})+\frac{3}{2}p_z q_z C_{z,z}(\theta_{\rm c.m.})\right)$$





$$\sigma_{unpol} = \sum_J \frac{2J+1}{(2I_D+1)(2I_T+1)}\sigma_J$$

$$\approx \frac{1}{3}\sigma_{\frac{1}{2}} + \frac{2}{3}\sigma_{\frac{3}{2}}$$

$$\sigma_{pol} \approx 1.5\, \sigma_{unpol}$$

nature COMMUNICATIONS

ARTICLE

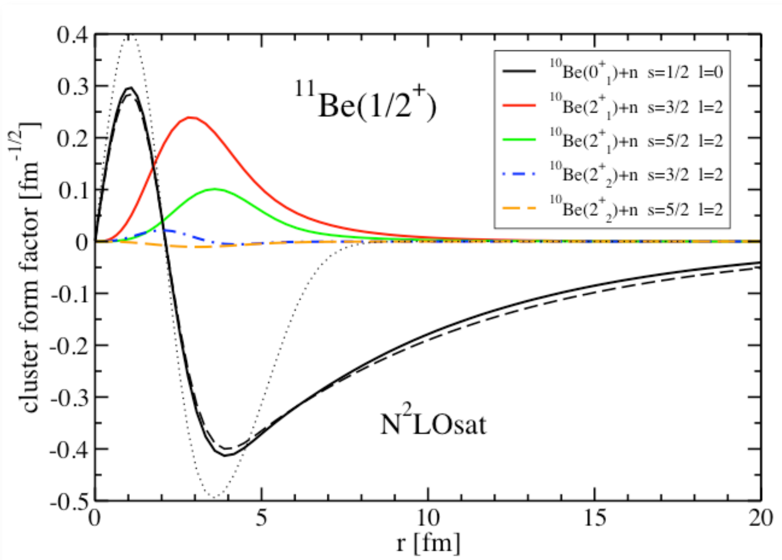
https://doi.org/10.1038/s41467-018-08052-6 OPEN

Ab initio predictions for polarized deuterium-tritium thermonuclear fusion

Guillaume Hupin[1,2,3], Sofia Quaglioni[3] & Petr Navrátil[4]

NCSMC calculation demonstrates impact of partial waves with *l* > 0 as well as the contribution of *l* = 0 $J^\pi = ½^+$ channel

NCSMC wave functions of ^{11}Be used as input for other studies



PHYSICAL REVIEW C **98**, 054602 (2018)

Systematic analysis of the peripherality of the ^{10}Be(d,p)^{11}Be transfer reaction and extraction of the asymptotic normalization coefficient of ^{11}Be bound states

J. Yang[1,2,*] and P. Capel[1,3,†]

PHYSICAL REVIEW C **98**, 034610 (2018)

Dissecting reaction calculations using halo effective field theory and *ab initio* input

P. Capel,[1,2,3,4,*] D. R. Phillips,[5,3,4,†] and H.-W. Hammer[3,4,‡]

Physics Letters B 790 (2019) 367–371

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

ELSEVIER

Reliable extraction of the $dB(E1)/dE$ for ^{11}Be from its breakup at 520 MeV/nucleon

L. Moschini[a,*], P. Capel[b,a]

PRL **117**, 242501 (2016) PHYSICAL REVIEW LETTERS week ending 9 DECEMBER 2016

Can *Ab Initio* Theory Explain the Phenomenon of Parity Inversion in ^{11}Be?

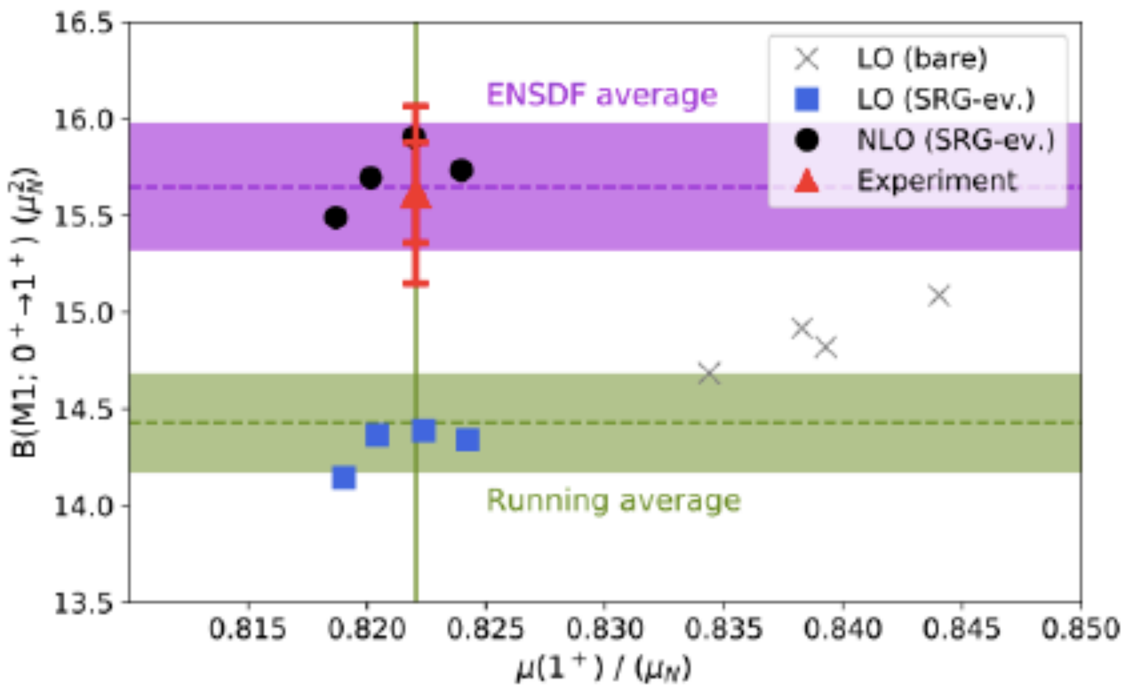
Angelo Calci,[1,*] Petr Navrátil,[1,†] Robert Roth,[2] Jérémy Dohet-Eraly,[1,‡] Sofia Quaglioni,[3] and Guillaume Hupin[4,5]

Neutron transfer reactions in halo effective field theory

M. Schmidt,[1,2] L. Platter,[2,3] and H.-W. Hammer[1,4] arXiv:1812.09152

- *Ab initio* calculations of nuclear structure and reactions becoming feasible beyond the lightest nuclei
  - Make connections between the low-energy QCD, many-body systems, and nuclear astrophysics

Comparison with theory



- χEFT calculations of B(M1;1⁺→0⁺) and μ(1⁺) in the no-core shell model
- SRG-evolved next generation chiral NN+3N interactions up to N4LO+N3LO

  D.R. Entem, R. Machleidt, Y. Nosyk, PRC **96** (2017)

- Unevolved M1 operator, evolved M1 operator at LO, and evolved M1 operator at NLO

→ First complete chiral calculation of these observables

High experimental precision crucial to test state-of-the-art theory!

Tokuro Fukui[1],

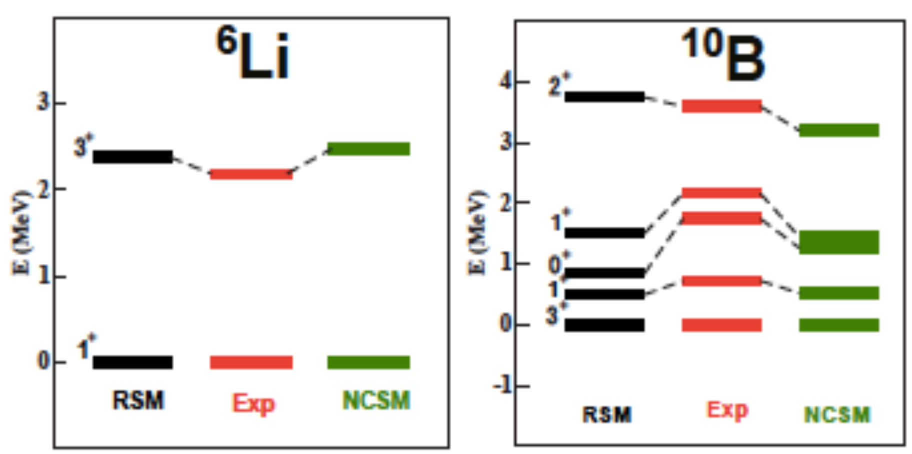
Chiral three-body force and monopole properties of shell-model Hamiltonian

Chiral N^{2}LO 3NF for shell model

3-body MEs with nonlocal regulator

$${}_A\left\langle \left[[\bullet\bullet]\bullet \right]_{JT} \right| V_{3N} \left| \left[[\bullet\bullet]\bullet \right]_{JT} \right\rangle_A$$

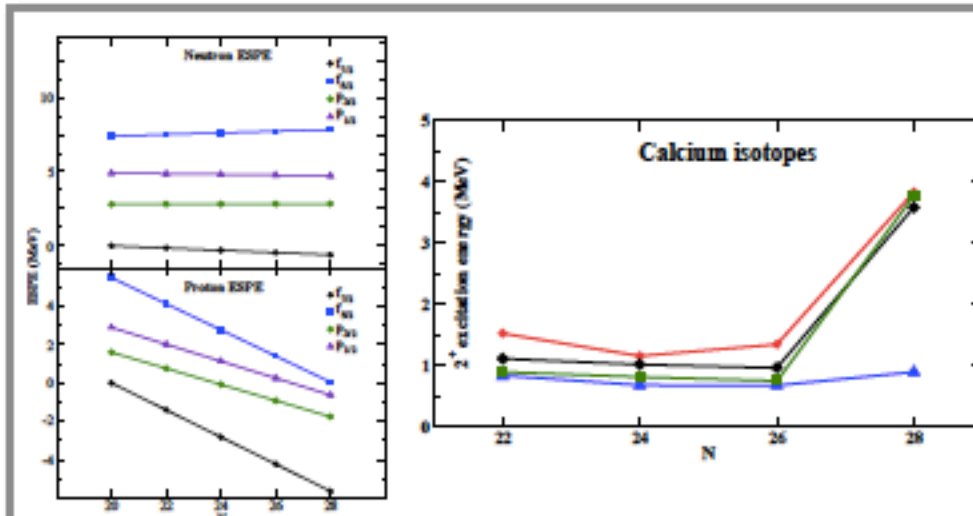
Benchmark test for *p*-shell



→ **Our RSM calculations with 3NF are satisfactorily comparable to the *ab initio* results.**

T. Fukui *et al.*, Phys. Rev. C 98, 04430 (2018).

Monopole properties of *fp*-shell

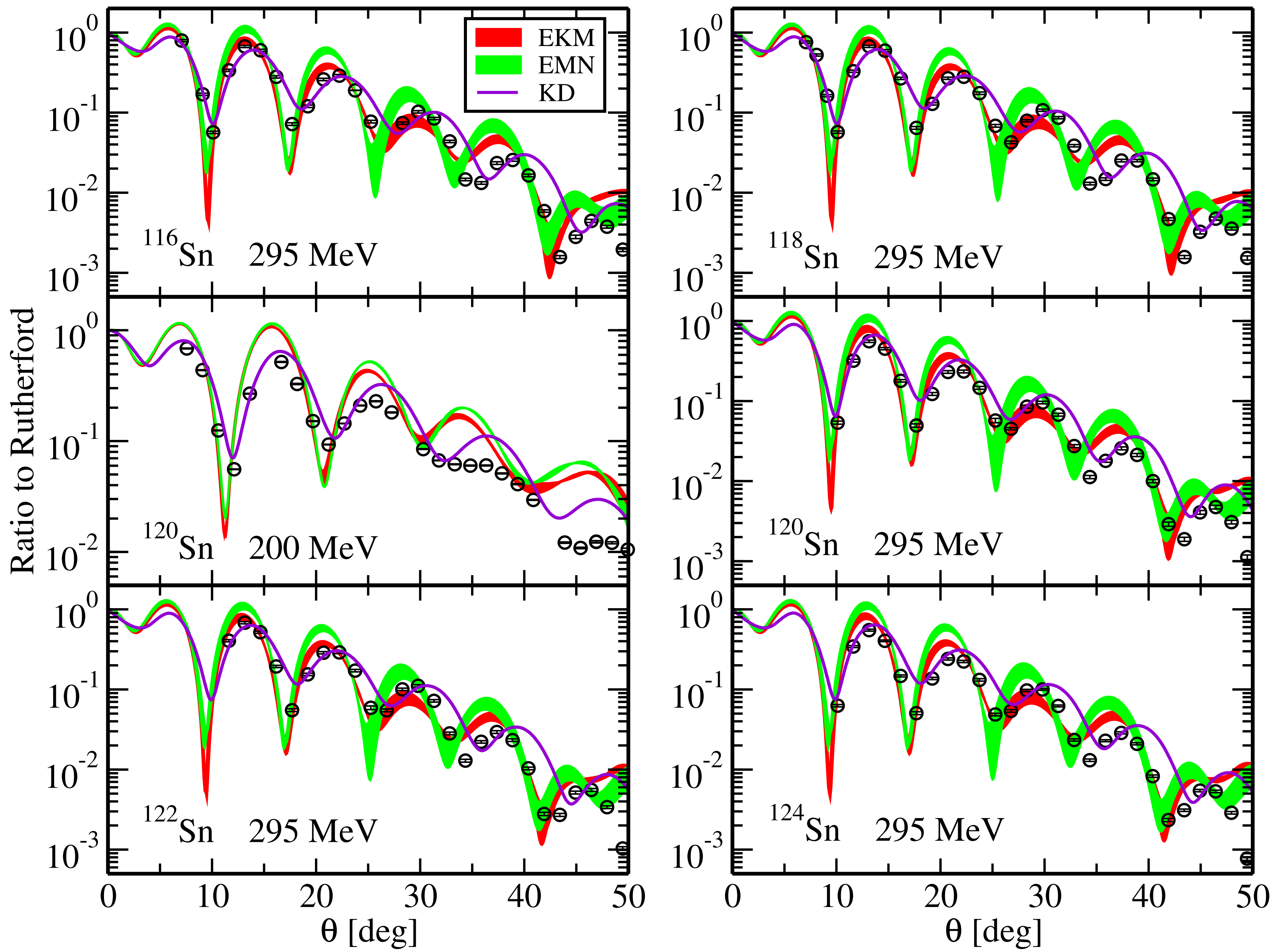


→ **The 3NF-induced monopole Hamiltonian is essential to explain the measured shell evolution.**

Y. Z. Ma *et al.*, arXiv:1812.03284.

Microscopic optical potential from chiral forces

Paolo Finelli

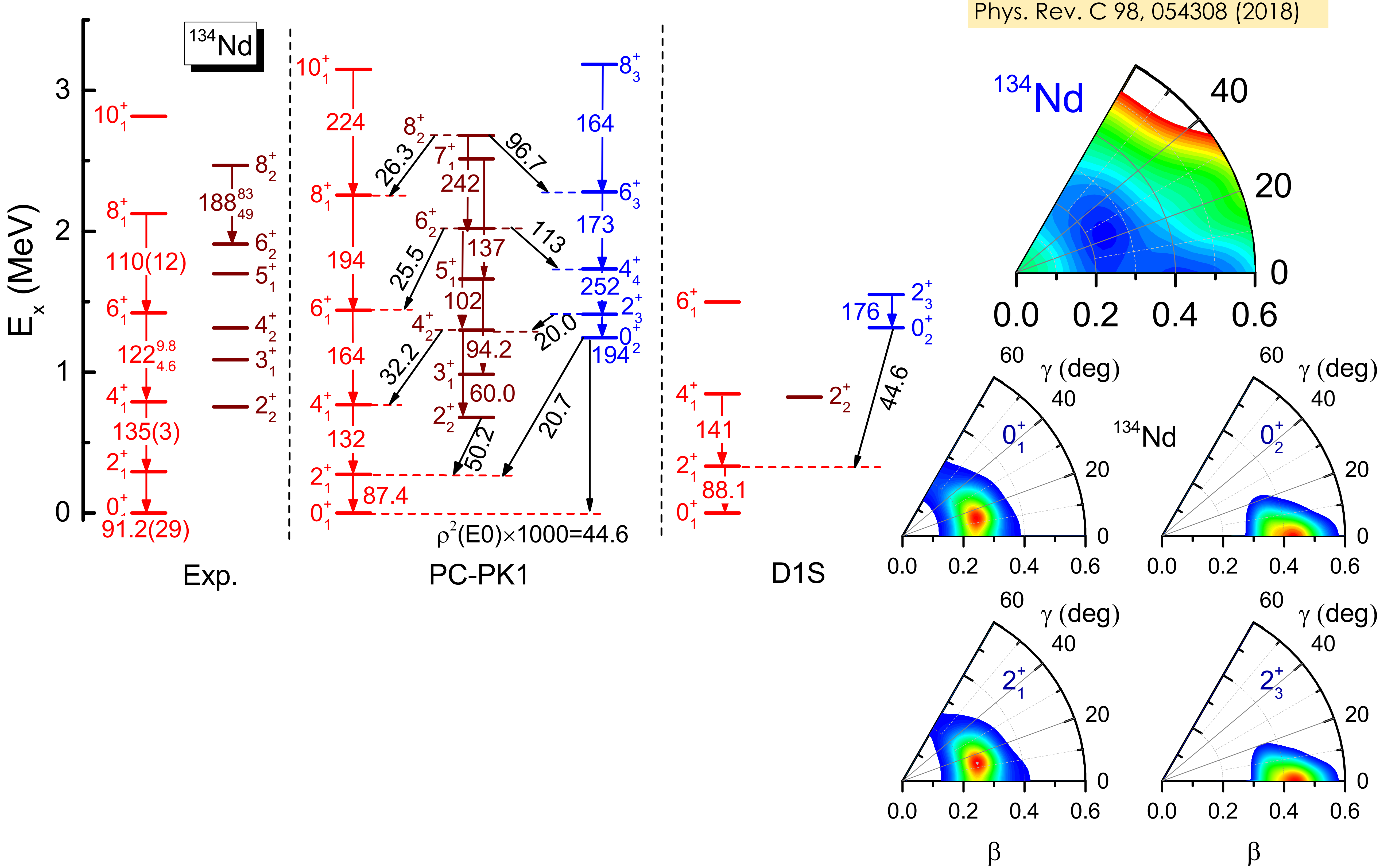


Phys. Rev. C 98 (2018) 064602

Tamara Nikšić

Coexisting shapes in neutron-deficient Nd and Sm isotopes

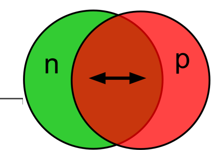
Phys. Rev. C 98, 054308 (2018)

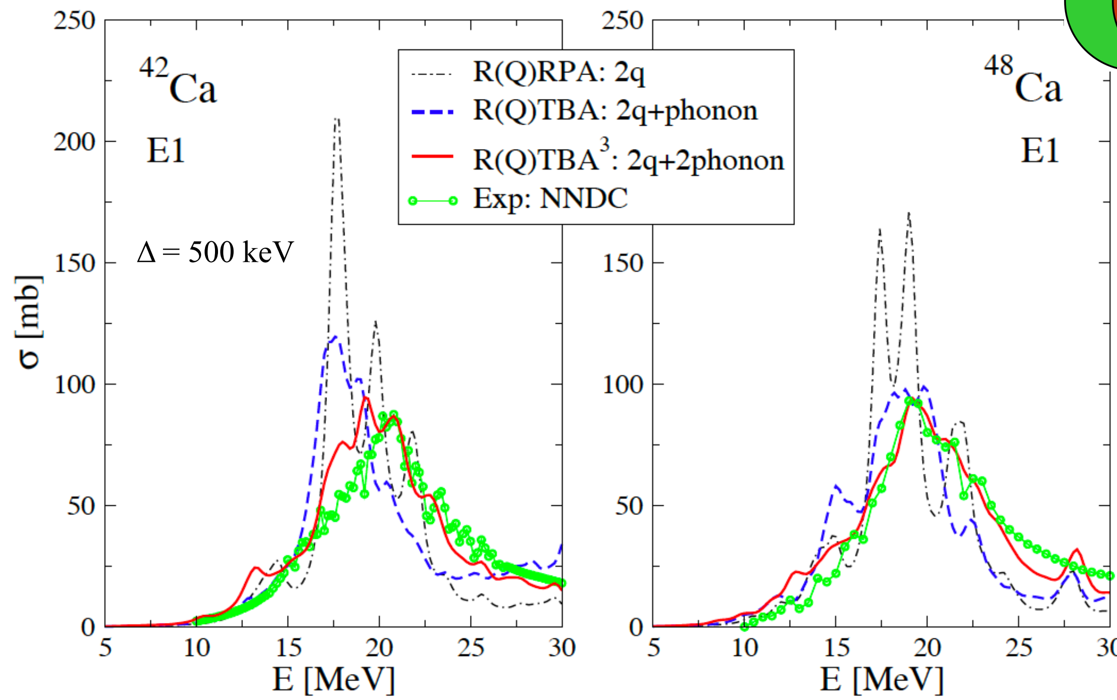


Elena Litvinova

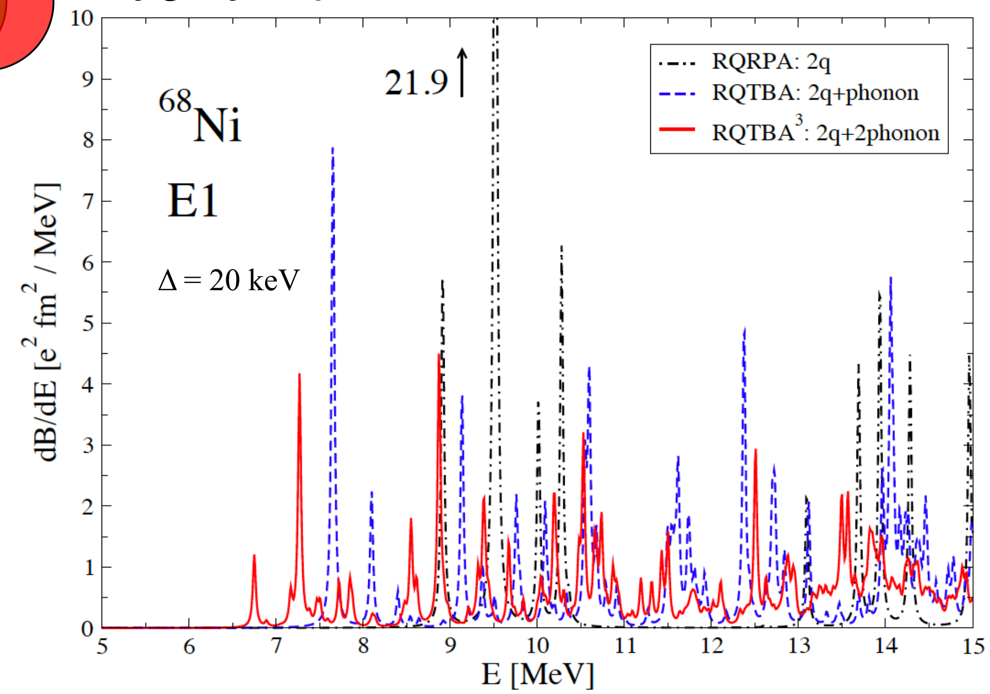
RQTBA^3: partly correlated 3p3h configurations (preliminary results)

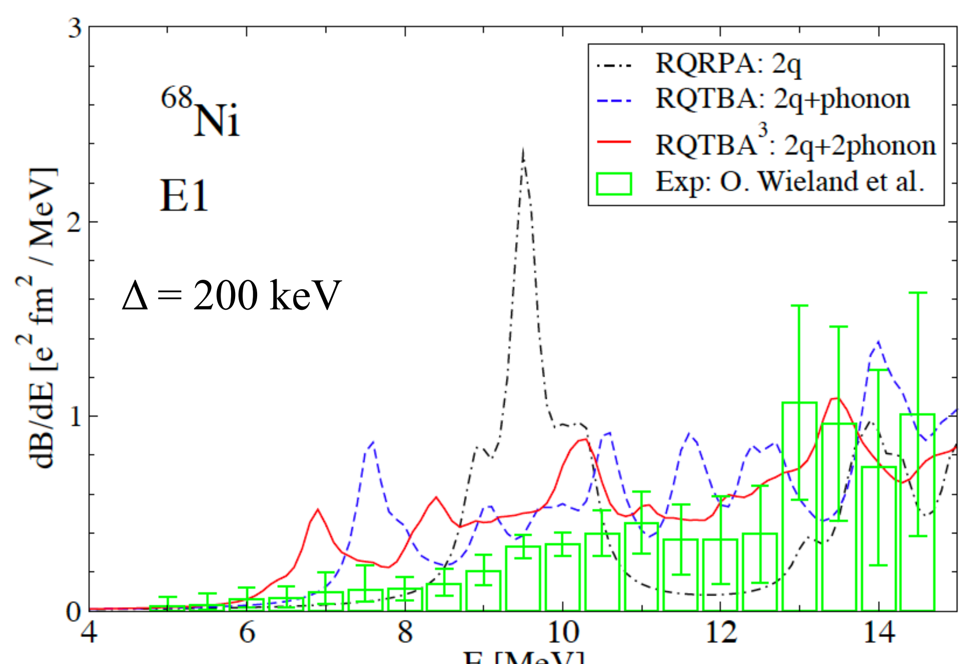
Giant Dipole Resonance in Ca isotopes





Pygmy Dipole Resonance in ^{68}Ni





- *The new complex configurations 2q+2phonon included for the first time enforce fragmentation and spreading toward higher and lower energies, thus, modifying both giant and pygmy dipole resonances;*
- *Exp. Data: V.A. Erokhova et al., Bull. Rus. Acad. Phys. 67, 1636 (2003) O. Wieland et al., Phys. Rev. C 98, 064313;*
- *RQTBA^3 demonstrates an overall systematic improvement of the description of nuclear excited states heading toward spectroscopic accuracy without strong limitations on masses and excitation energies.*

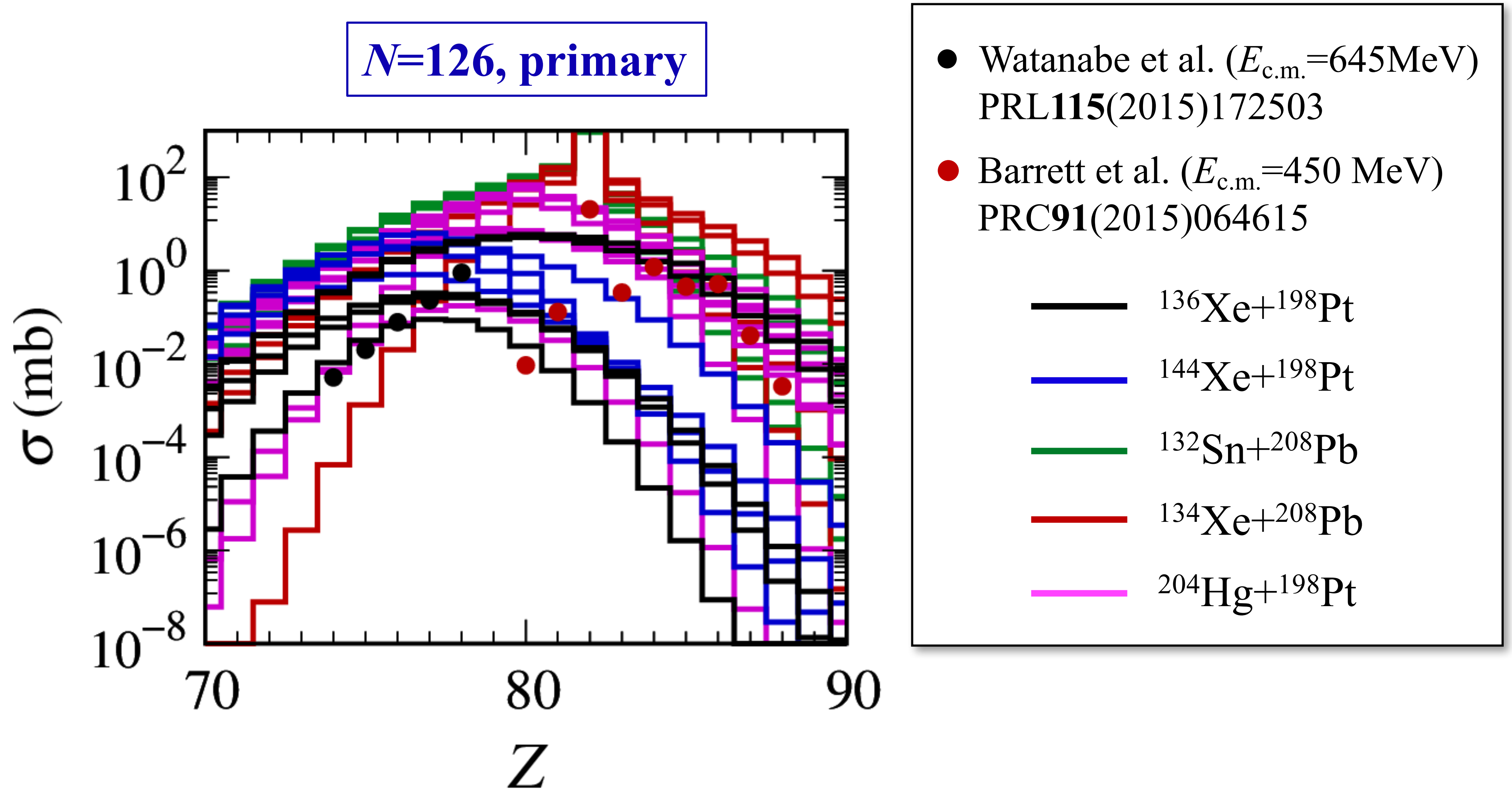
Time-Dependent Hartree-Fock Theory for Multinucleon Transfer Reactions:

Kazuyuki Sekizawa

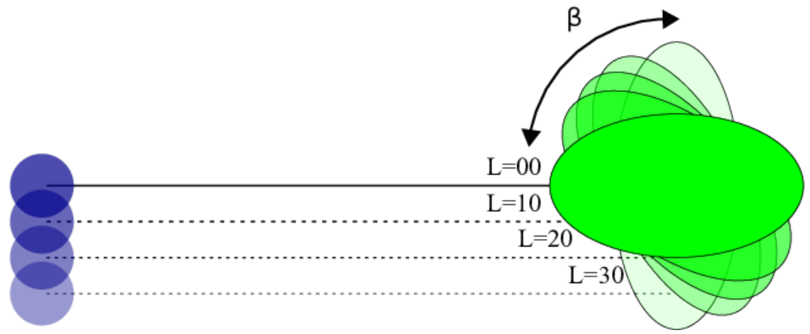
Production cross sections for N=126 isotones

Preliminary

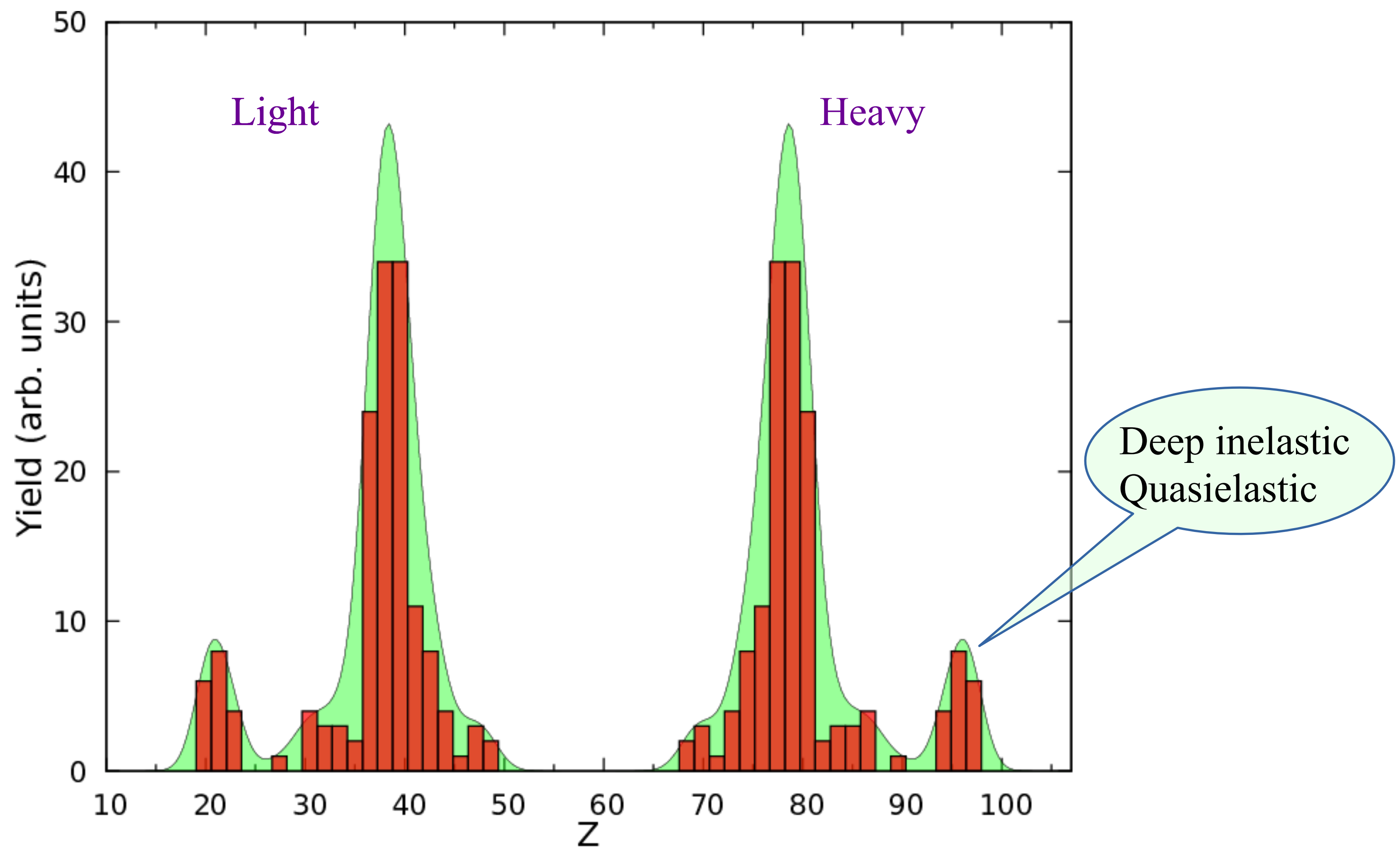
Isotonic distributions for various systems



Quasifission – ^{48}Ca + ^{249}Bk – orientation and shell effects



- Most comprehensive QF calculation
- All β in range (0°,180°) Δβ=15°
- Entire L range for each β
- Each (β,L) run takes 1-3 days on 20 core CPU



Quantum equilibration dynamics

Time to equilibrium

Mass — ~ 10 zs — **QF**

$^{40,48}Ca+^{238}U,^{249}Bk$
Cr+W and many others
Slowed by shell effects

Isospin — ~ 1 zs

$^{78}Kr+^{208}Pb$

Energy — ~ 1.5 zs

$^{78}Kr+^{208}Pb$
$^{58}Ni+^{60}Ni$

Mass Fluctuations — ~ 3 zs

$^{58}Ni+^{60}Ni$, Xe+Pb
SMF, TDRPA
S. Ayik, et al. arXiv:1904:09619 (2019)
Williams et al., PRL **120**, 022501 (2018)

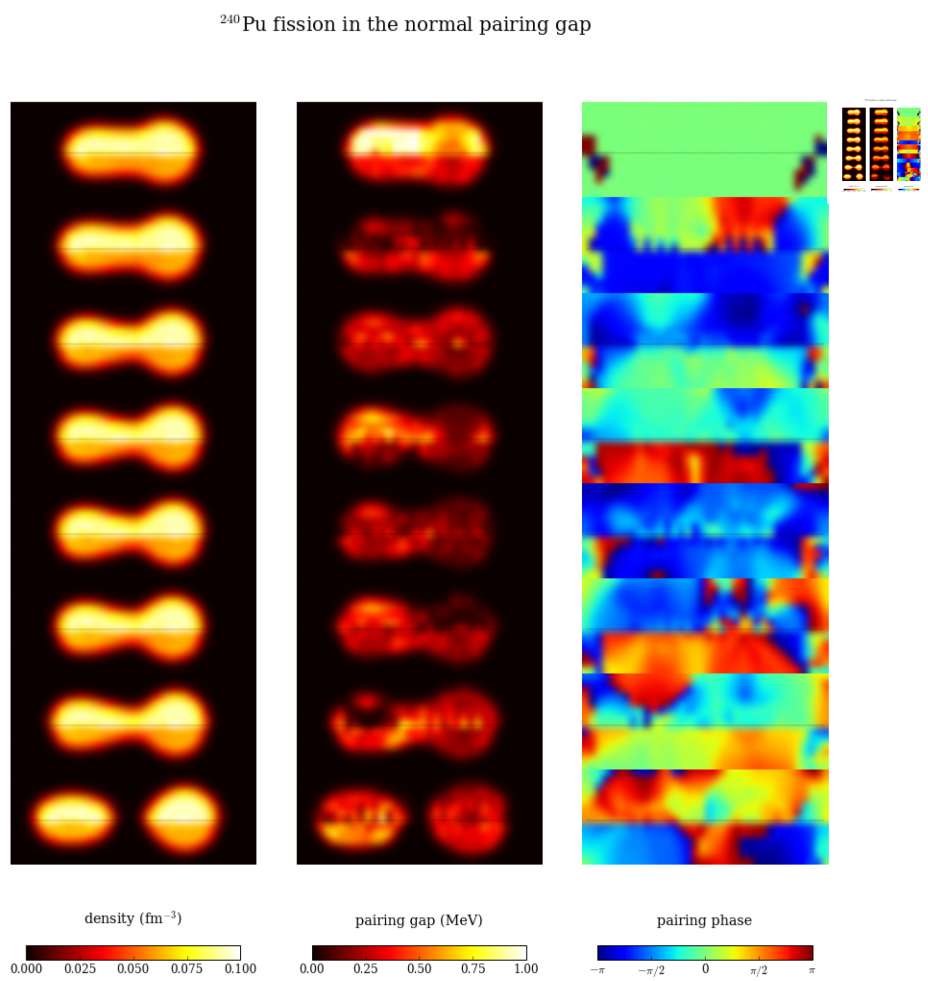
DIC (Isospin, Energy, Mass Fluctuations)

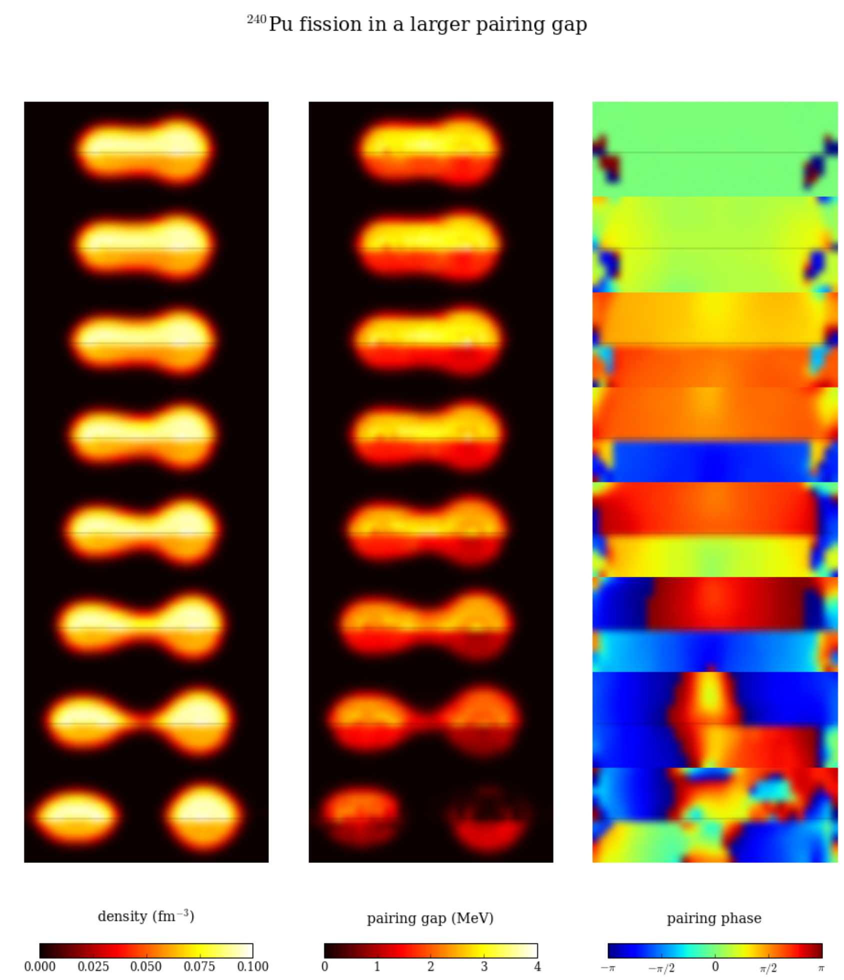
Aurel Bulgac

TDDFT Fission Dynamics

Agreement with observations is pretty good and without any fitting parameters, as long as the basic nuclear properties (saturation, surface tension, symmetry energy, Coulomb, spin-orbit, pairing) are well described !

How important is pairing?





Normal pairing strength
Saddle-to-scission 14,000 fm/c

Enhanced pairing strength
Saddle-to-scission 1,400 fm/c !!!

Symmetry-guided and algebraic approaches:

Jerry Draayer	'Symmetry Adapted' NCSM Campaign
Jerzy DUDEK	**Systematic Search for Tetrahedral and Octahedral Symmetries*) in Subatomic Physics:**
A. Leviatan	Intertwined Quantum Phase Transitions in the Zr Isotopes
Kosuke Nomura	Coexistence and evolution of shapes: mean-field-based interacting boson model
Nobuo Hinohara	Pairing rotation and pairing energy density functional

G. de Angelis (INFN Legnaro) - Chair
L. Corradi (INFN Legnaro) - Chair

E. Fioretto (INFN Legnaro)
F. Galtarossa (INFN Legnaro)
T. Marchi (INFN Legnaro)
M. Mazzocco (Uni. and INFN Padova)
D. Mengoni (Uni. and INFN Padova)
J.J. Valiente-Dobón (INFN Legnaro)

A. D'Este (INFN Legnaro) - Secretary
A. Schiavon (Uni. Padova) - Secretary