Structure of light neutron-rich nuclei probed with direct reactions

Simone Bottoni

Università degli Studi di Milano
INFN Sezione di Milano

S. Bottoni, D. Genna, G. Benzoni
K. Wimmer, F. Galtarossa
and the INFN-GAMMA collaboration

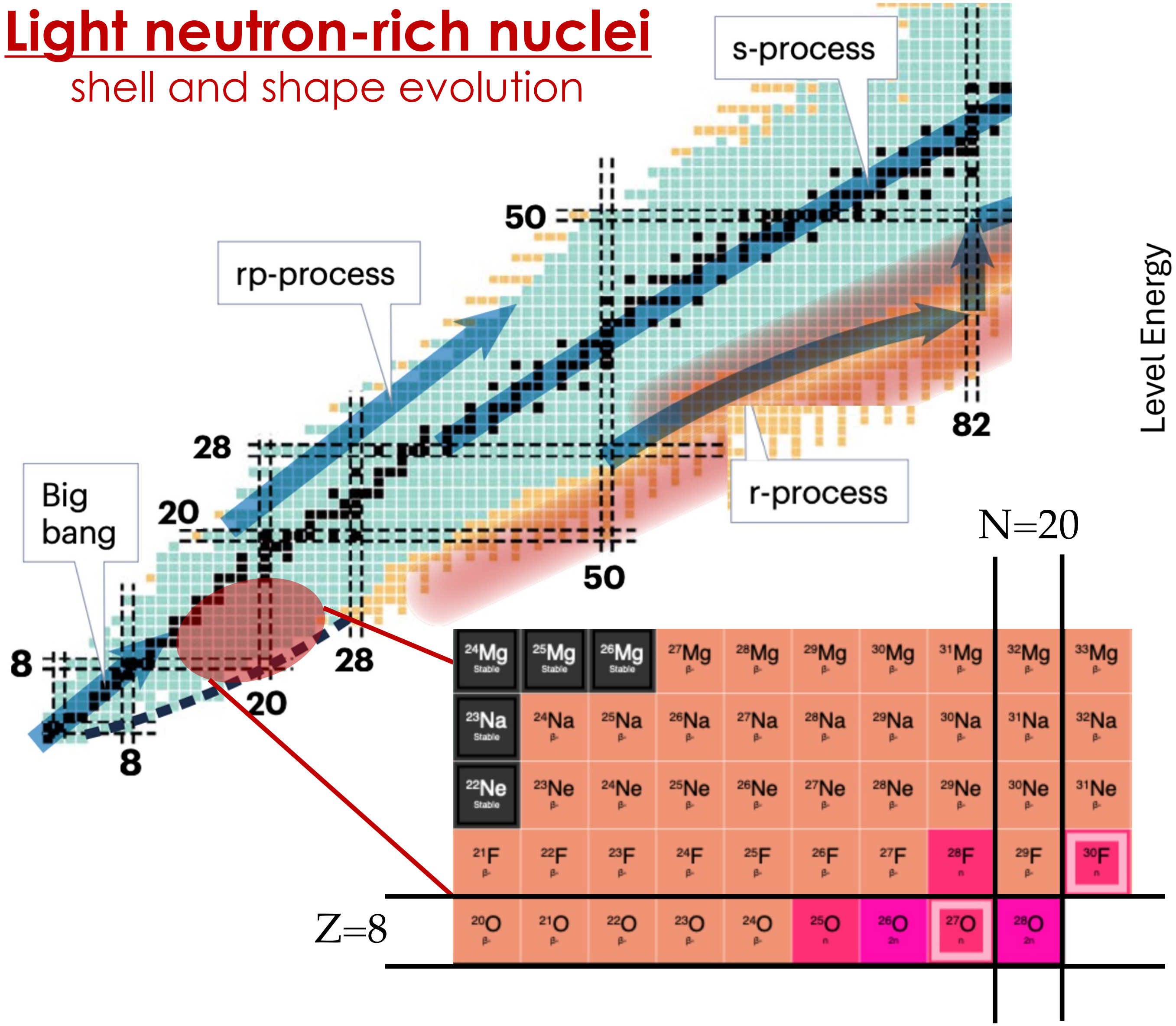
GRIT-AGATA-VAMOS
workshop

GANIL, June 2025

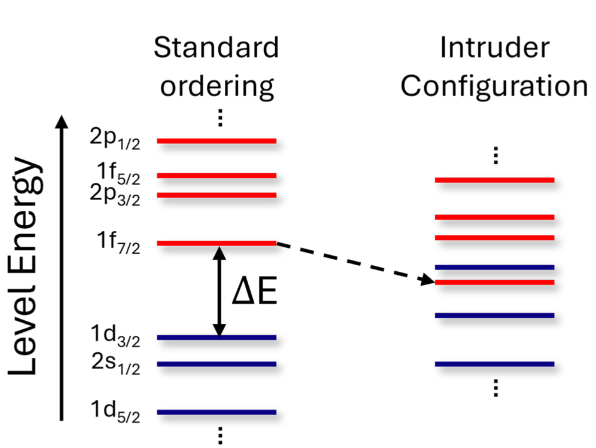
Simone Bottoni

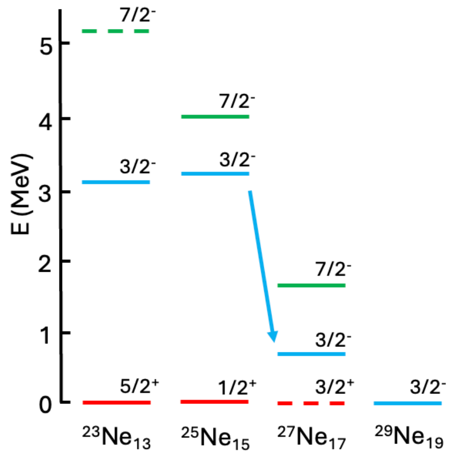
Light neutron-rich nuclei

shell and shape evolution

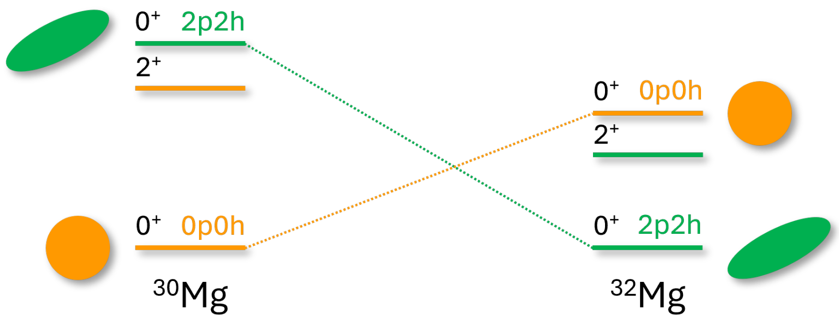


Shell evolution towards the IoI





Shape evolution towards the IoI



K. Wimmer et al., Phys. Rev. Lett. 105, 252501 (2010)

Spectroscopy approaching the Island of Inversion

test of different theoretical models

FOCUS ON:
neutron-rich Ne isotopes

GRIT-AGATA-VAMOS workshop

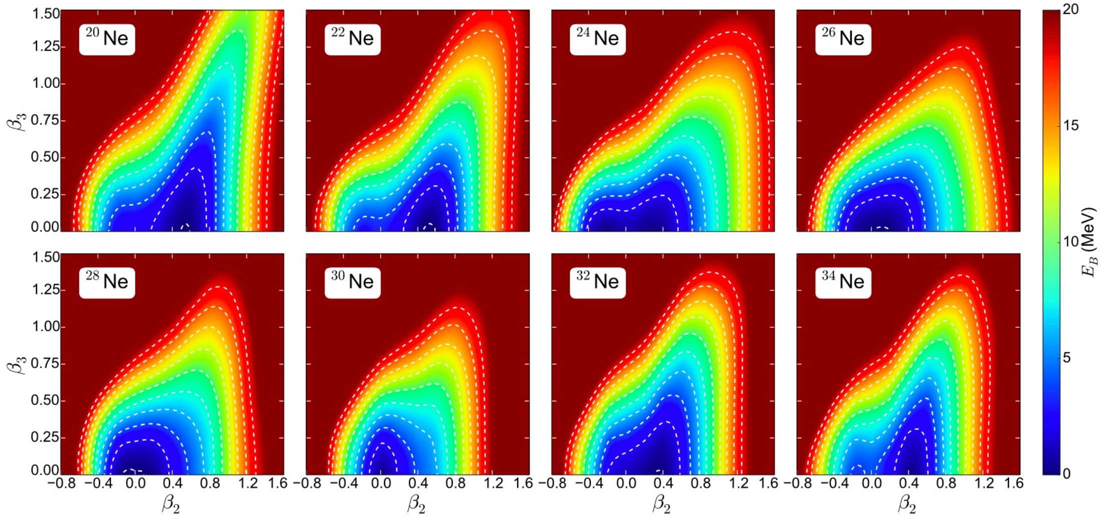
Global Energy Density Functional

configuration mixing and
parity-angular momentum projection

PHYSICAL REVIEW C **97**, 024334 (2018)

Quadrupole and octupole collectivity and cluster structures in neon isotopes

P. Marević,[1,2] J.-P. Ebran,[1] E. Khan,[2] T. Nikšić,[3] and D. Vretenar[3]

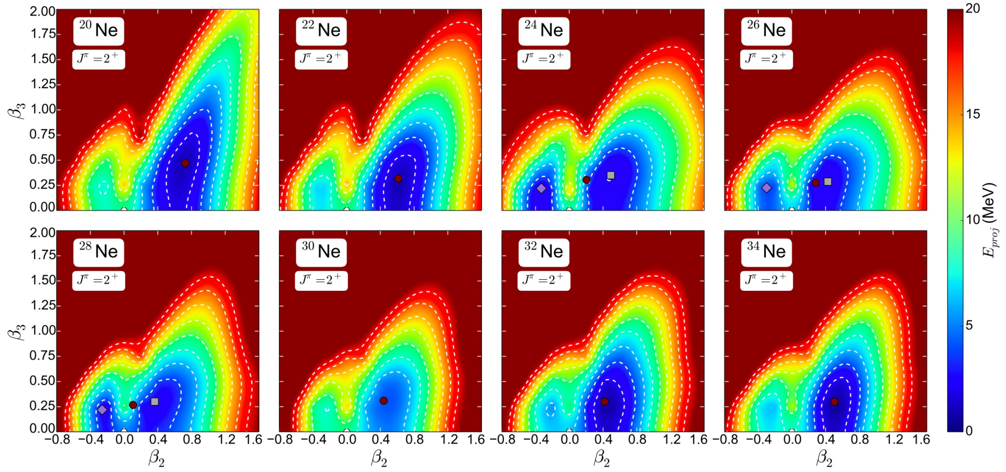


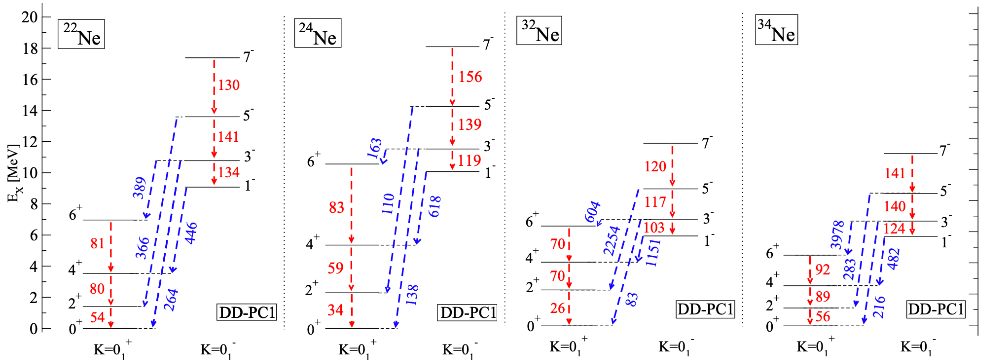
Ground state properties

- Prolate minimum for $^{20-22}$Ne
- Shape mixing in ^{24}Ne
- Spherical minimum in $^{26-30}$Ne
- Prolate minimum in the IoI

Excited states properties

absolute minimum always prolate
except for ^{24}Ne and ^{28}Ne





Shape mixing in ^{24}Ne impacts on
energies and reduced transition probabilities
predicted differences with ^{26}Ne

N^{3}LO χEFT Hamiltonians

with different many-body methods

Eur. Phys. J. A (2022) 58:63
https://doi.org/10.1140/epja/s10050-022-00693-y

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article - Theoretical Physics

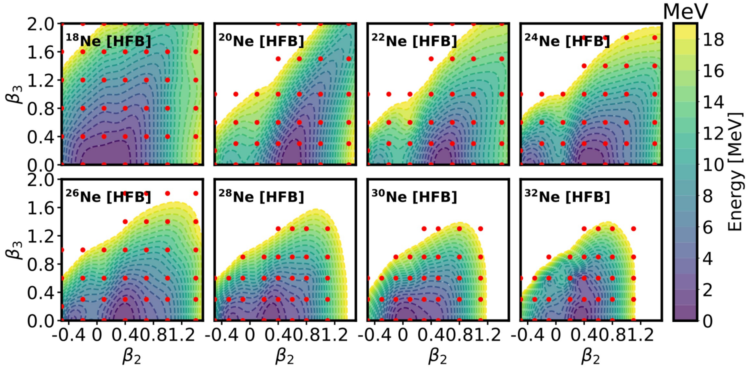
Multi-reference many-body perturbation theory for nuclei

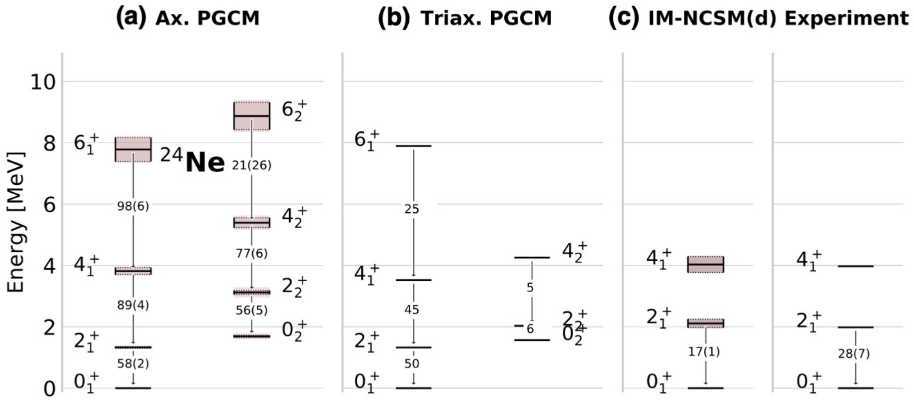
II. Ab initio study of neon isotopes via PGCM and IM-NCSM calculations

M. Frosini[1,a], T. Duguet[1,2,b], J.-P. Ebran[3,4,c], B. Bally[5,d], T. Mongelli[7,e], T. R. Rodríguez[5,6,f], R. Roth[7,8,g], V. Somà[1,h]

- Shape mixing in $^{24\text{-}28}$Ne
- Sphericity in ^{30}Ne

Difficulties to predict the features of the IoI





Discrepancies with experimental data start from ^{24}Ne

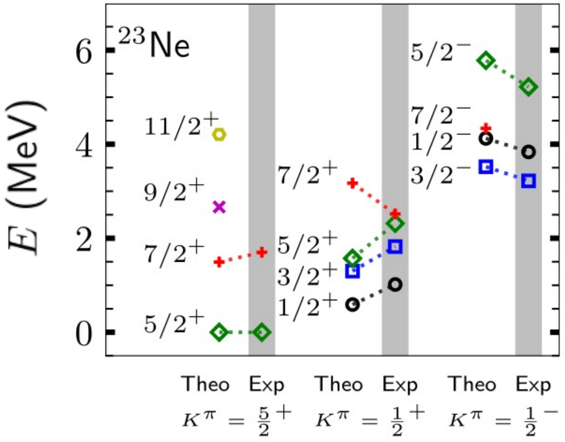
Couple cluster calculations

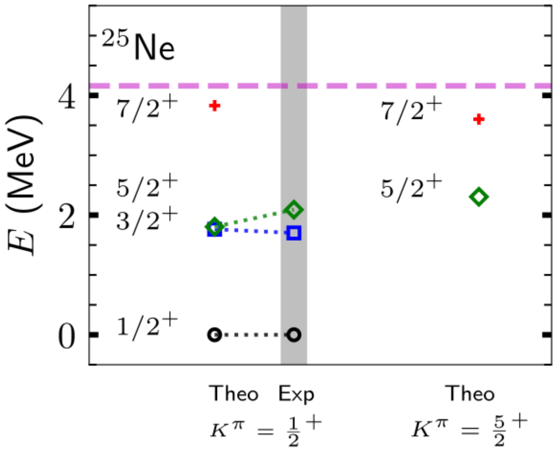
odd-mass Na,Ne,Mg isotopes

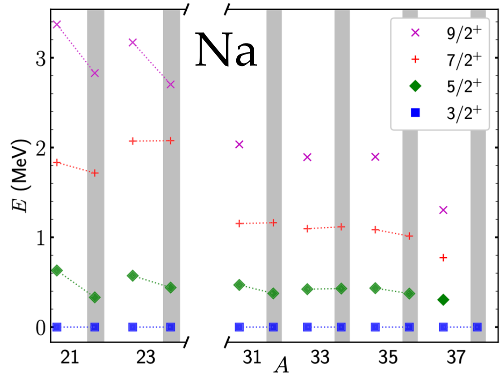
PHYSICAL REVIEW C 111, 044304 (2025)

Structure of odd-mass Ne, Na, and Mg nuclei

Z. H. Sun[1], T. R. Djärv[1,2], G. Hagen[1,3], G. R. Jansen[1,2] and T. Papenbrock[1,3]
[1]Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA
[2]National Center for Computational Sciences, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA
[3]Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996, USA

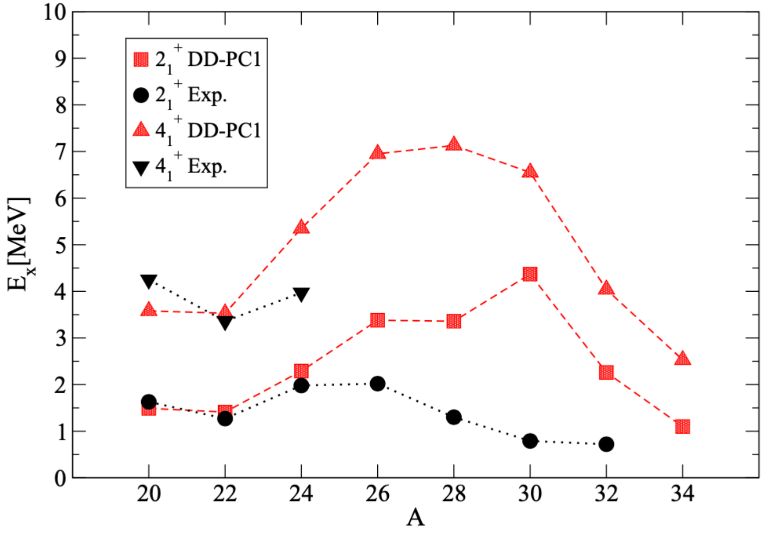






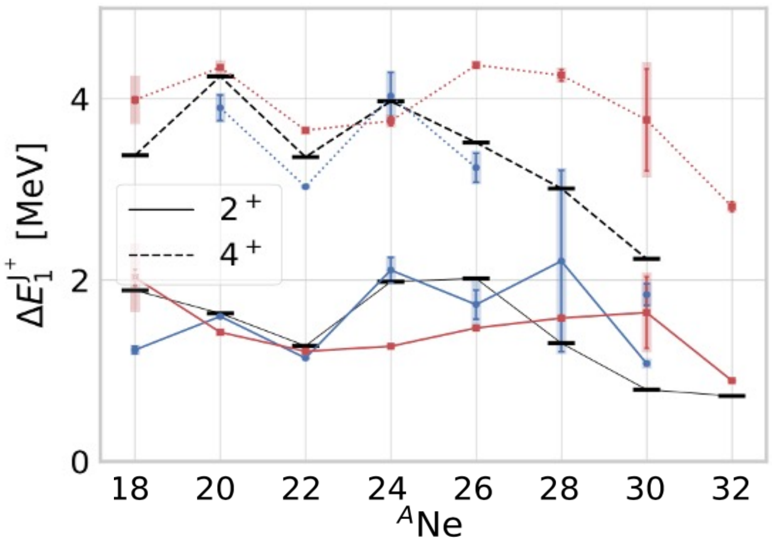
odd-even nuclei are very little explored

Relativistic HFB



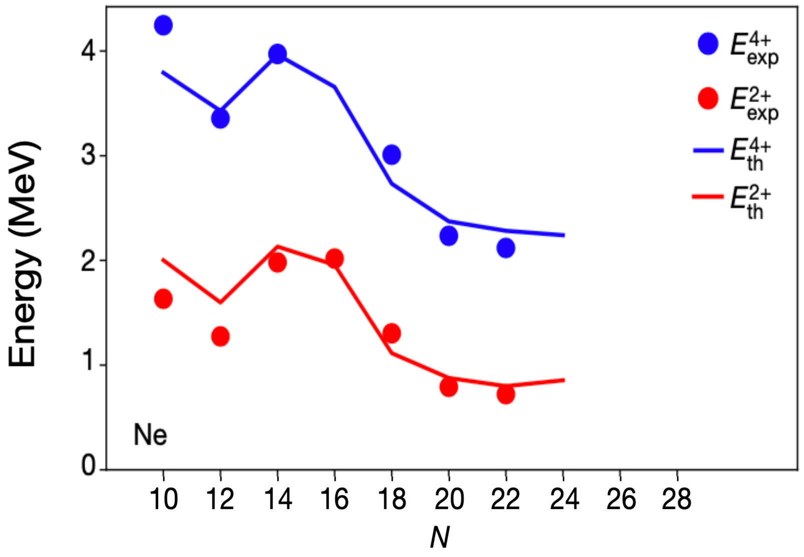
M. Marevic et al., PRC 97, 024334 (2018)

ab inito

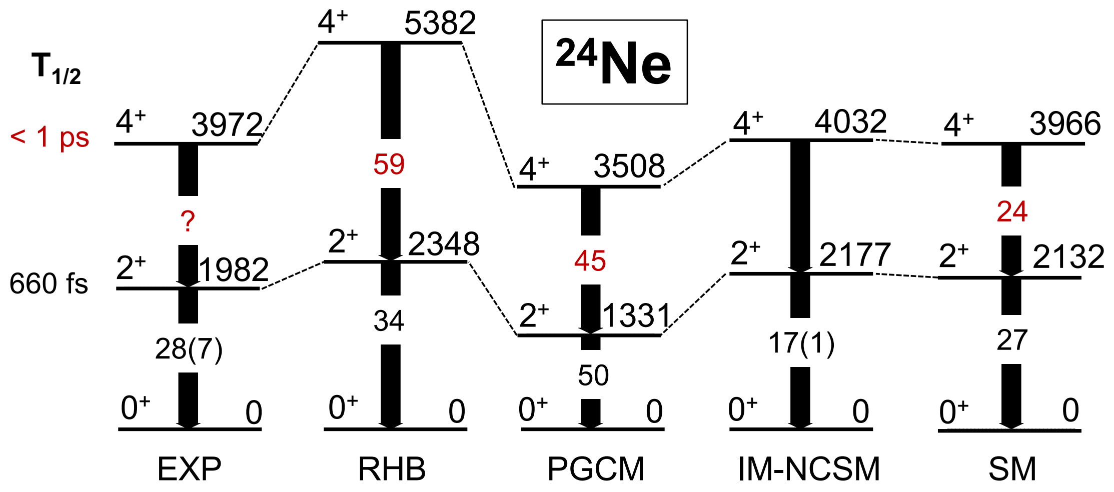


M. Frosini et al., EPJ A 58, 63 (2022)

shell model



T. Ostuka et al., Nature 587, 66 (2020)



To understand the physics of the IoI

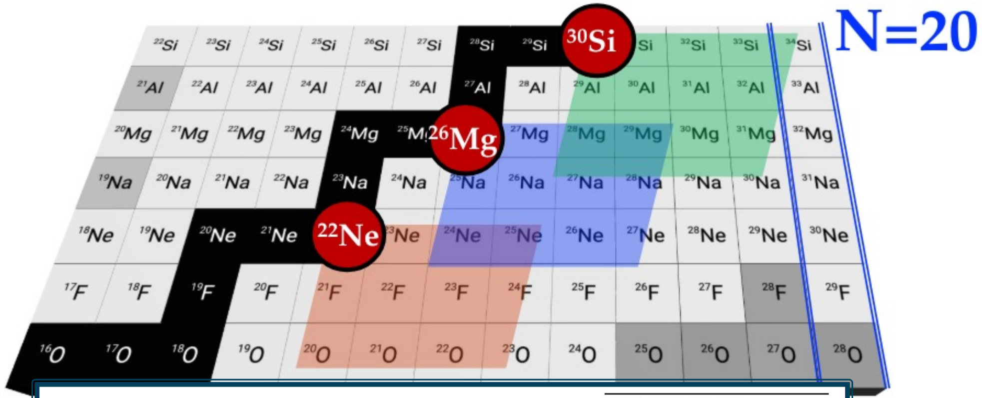
nuclei at and beyond *N=20*

- Spectroscopy of less exotic nuclei (both even and odd)
- Shell evolution (both neutrons and protons)
- Shape evolution and mixing

Multi-nucleon transfer reactions

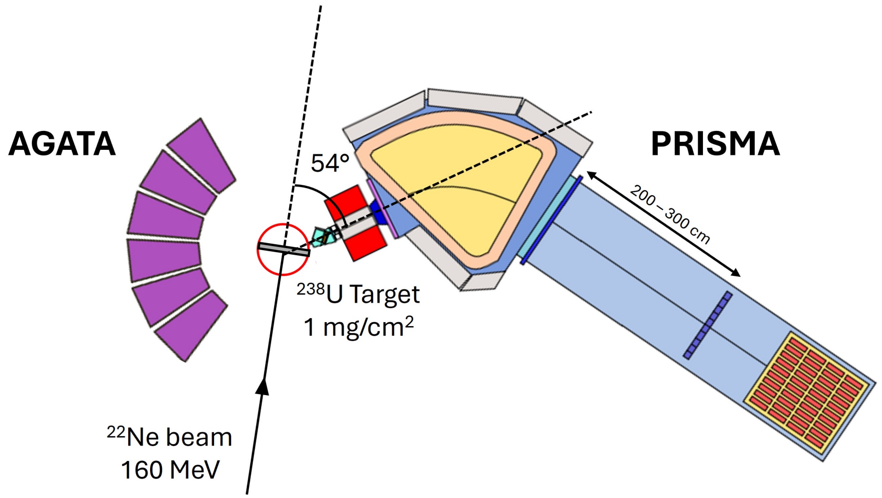
AGATA+PRISMA and ^{238}U target

K. Wimmer, S. Bottoni, G. Benzoni, P. Aguilera et al.

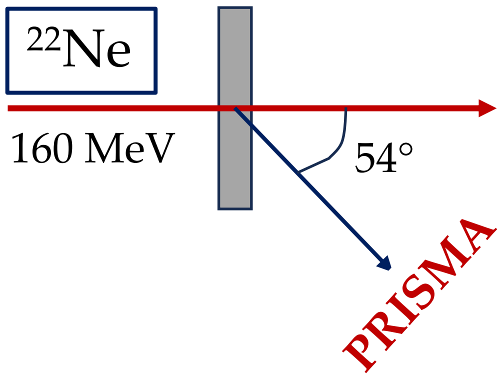


Eur. Phys. J. Plus (2023) 138:709
https://doi.org/10.1140/epjp/s13360-023-04249-x
THE EUROPEAN PHYSICAL JOURNAL PLUS
Regular Article

Nuclear physics midterm plan at Legnaro National Laboratories (LNL)

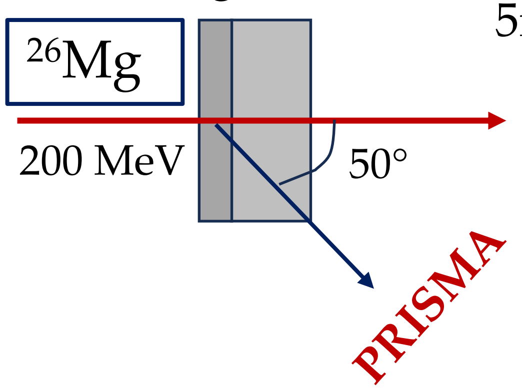


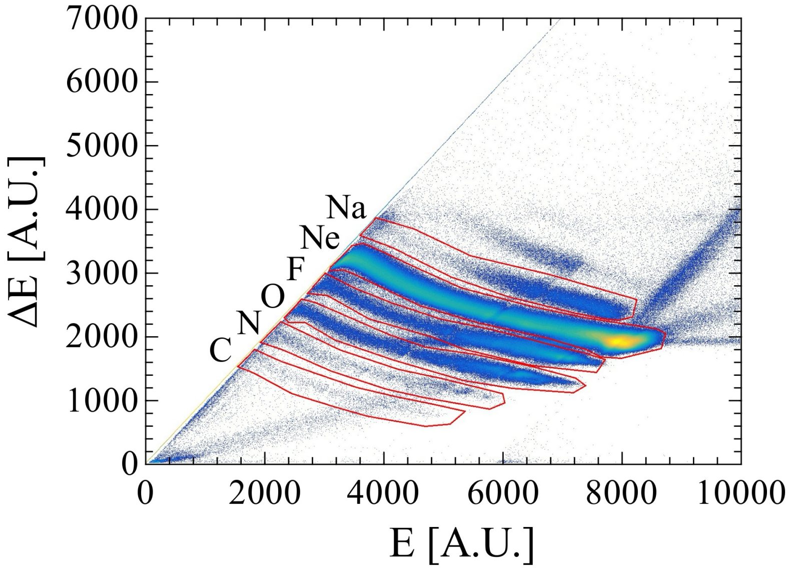
April 2023



June 2024

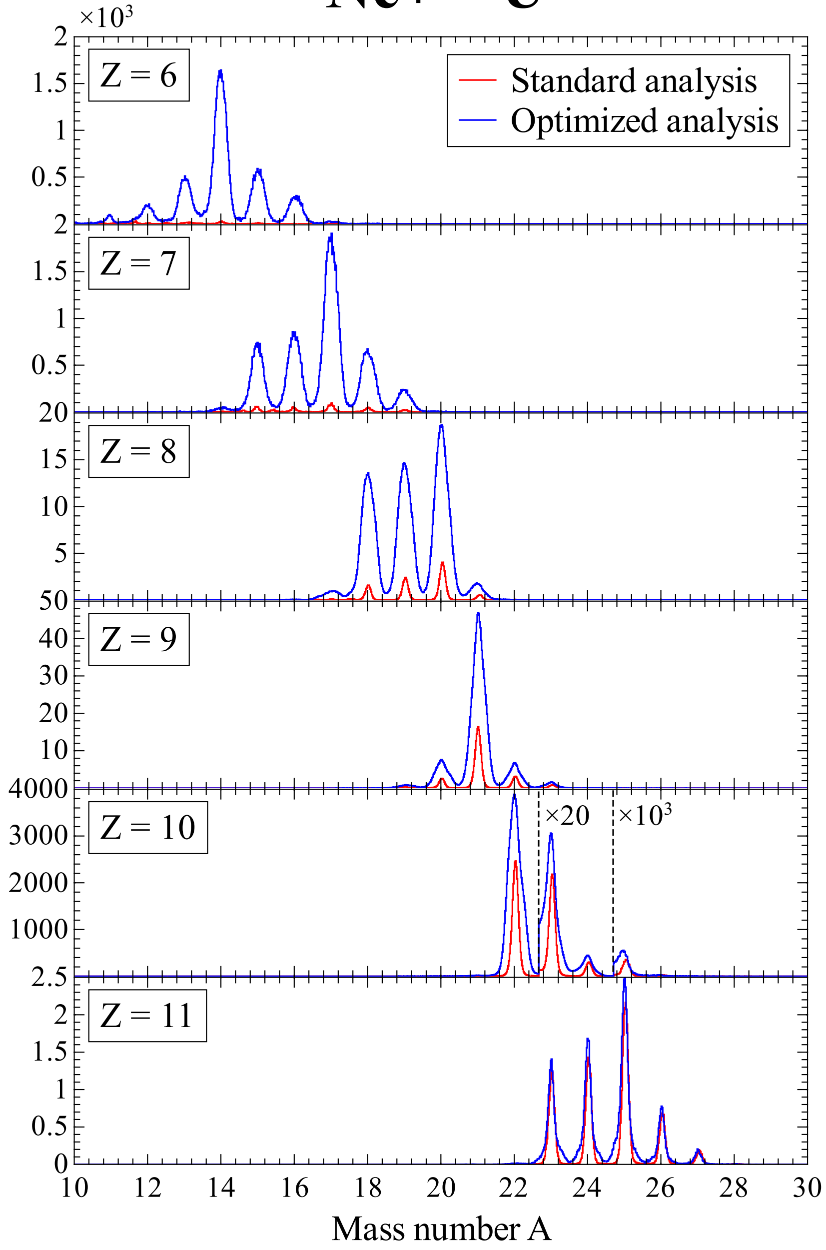
DSAM

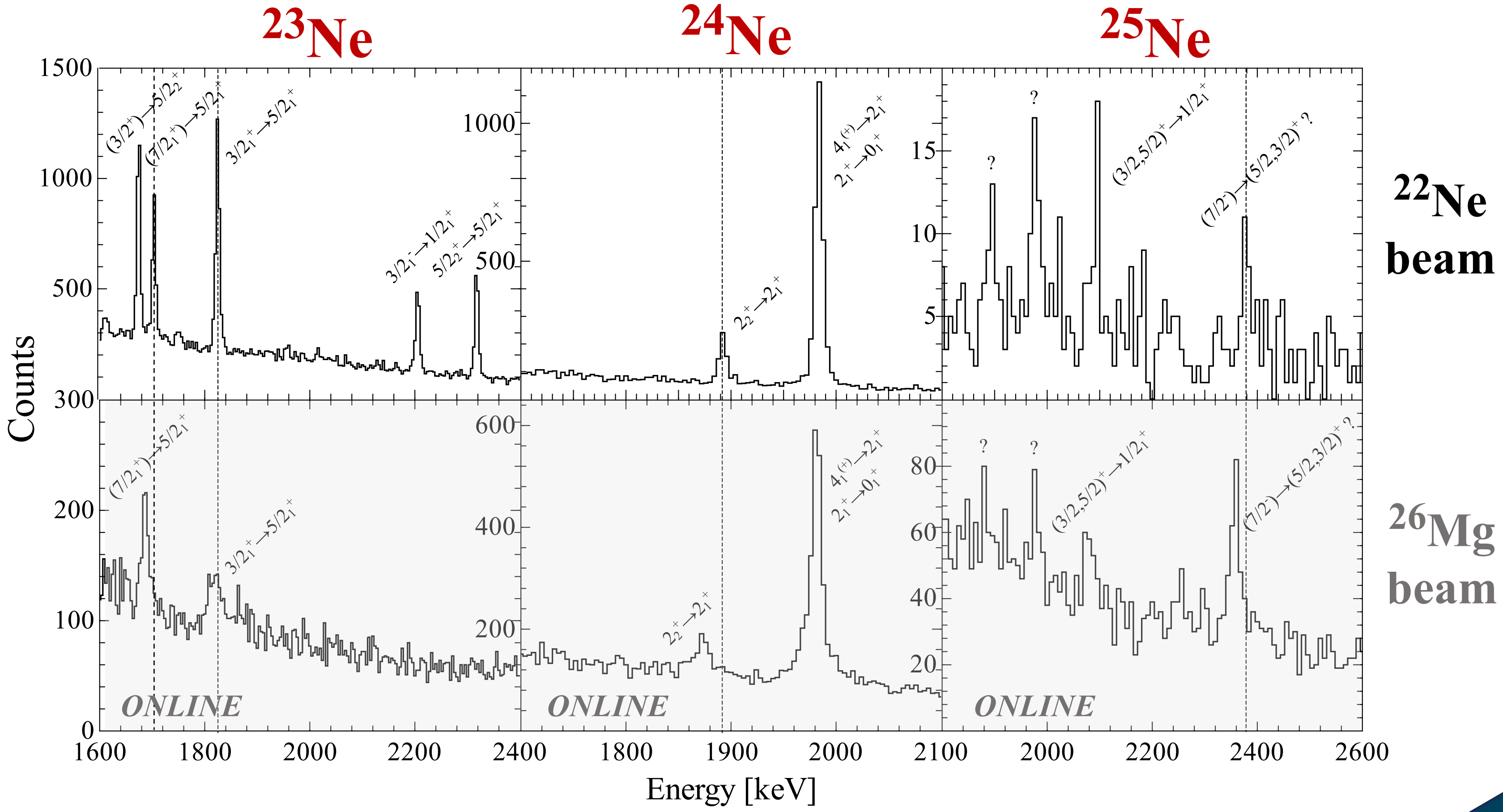




ONGOING ANALYSIS

$^{22}Ne+^{238}U$





Different states population in *x*p and *x*n channels

New γ ray transitions

Lifetimes of excited states with DSAM

PhD work by D. Genna and F. Drent

Transfer reactions with ^{24}Ne beam

already available at GANIL at ~ 2E5 pps

PRL **104,** 192501 (2010) PHYSICAL REVIEW LETTERS week ending 14 MAY 2010

Migration of Nuclear Shell Gaps Studied in the $d(^{24}\text{Ne}, p\gamma)^{25}$Ne Reaction

W. N. Catford,[1] C. N. Timis,[1] R. C. Lemmon,[2] M. Labiche,[3,2] N. A. Orr,[4] B. Fernández-Domínguez,[5] R. Chapman,[3] M. Freer,[6] M. Chartier,[5] H. Savajols,[7] M. Rejmund,[7] N. L. Achouri,[4] N. Amzal,[3] N. I. Ashwood,[6] T. D. Baldwin,[1] M. Burns,[3] L. Caballero,[8] J. M. Casadjian,[7,9] N. Curtis,[6] G. de France,[7] W. Gelletly,[1] X. Liang,[3] S. D. Pain,[1] V. P. E. Pucknell,[2] B. Rubio,[8] O. Sorlin,[7] K. Spohr,[3] Ch. Theisen,[9] and D. D. Warner[2]

Eur. Phys. J. A **45**, 287–292 (2010)
DOI 10.1140/epja/i2010-11011-4

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Experimental Physics

Study of collisions of the radioactive ^{24}Ne beam at 7.9 MeV/u on ^{208}Pb

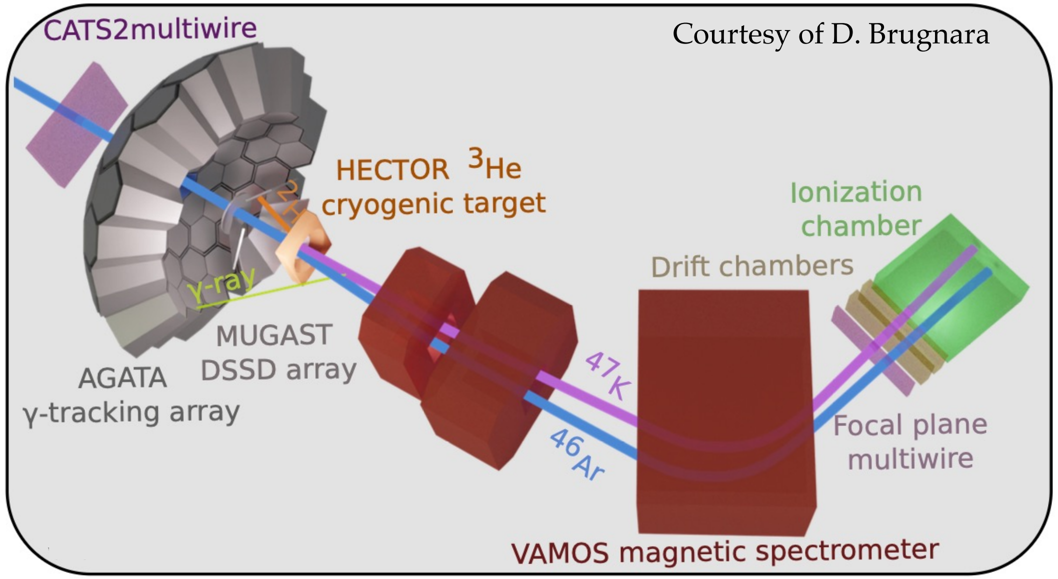
G. Benzoni[1,a], F. Azaiez[2], G.I. Stefan[2,3], S. Franchoo[2], S. Battacharyya[3], R. Borcea[4], A. Bracco[1,5], L. Corradi[6], D. Curien[7], G. De France[3], Zs. Dombradi[8], E. Fioretto[6], S. Grevy[3], F. Ibrahim[3], S. Leoni[1,5], D. Montanari[1,5], G. Mukherjee[3], G. Pollarolo[9], N. Redon[10], P.H. Regan[11], C. Schmitt[3,10], G. Sletten[12], D. Sohler[8], M. Stanoiu[2,4], S. Szilner[13], and D. Verney[2]

No need of further beam developments

unless more intensity can be achieved

AGATA-GRIT-VAMOS setup

same as MUGAST campaign



VAMOS configuration for light ions

Proton-transfer reactions

^{24}Ne(^{3}He,d)^{25}Na and ^{24}Ne(t,α)^{23}F

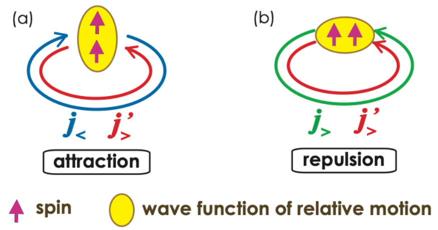
Two-neutron-transfer reactions

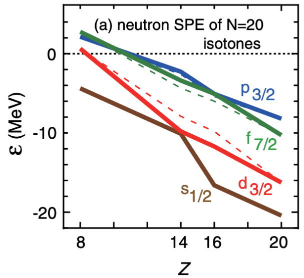
^{24}Ne(t,p)^{26}Ne

Proton single-particle configuration of ^{24}Ne

occupancies and vacancies in the sd shell

the island of inversion[12], the inversion occurs also for N = 21 and 22, but not for N > 22. The contribution from protons is also needed for a strong deformation: the deformation can be stronger for Z = 10–12, owing to particular occupations of proton single-particle orbits. Thus, the island of inversion picture suggests that the intruder ground states (that is,





Strong connection with neutron orbitals and shell/shape evolution

T. Ostuka et al., Nature 587, 66 (2020)

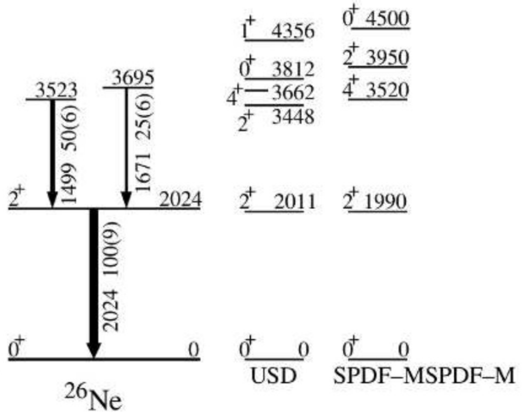
Possible experiments

^{24}Ne (^{3}He,d)^{25}Na — need of cryo target

^{24}Ne(t,α)^{23}F — Q = 3.3 MeV
Q for (d,^{3}He) is -11 MeV

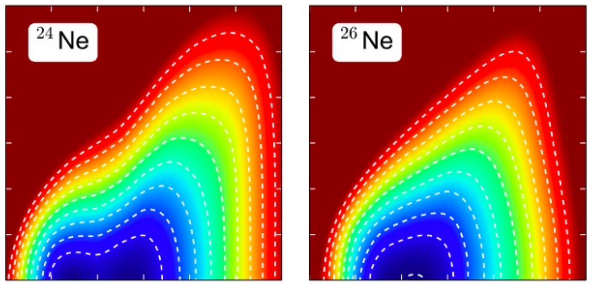
Deformed structures in ^{26}Ne

Shape evolution towards the IoI



Courtesy of K. Wimmer

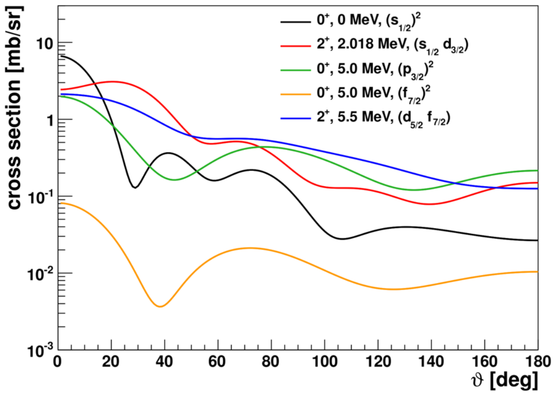
Overlap with ^{24}Ne ground state



M. Marevic et al., PRC 97, 024334 (2018)

Possible experiments

^{24}Ne(t,p)^{26}Ne



Courtesy of K. Wimmer

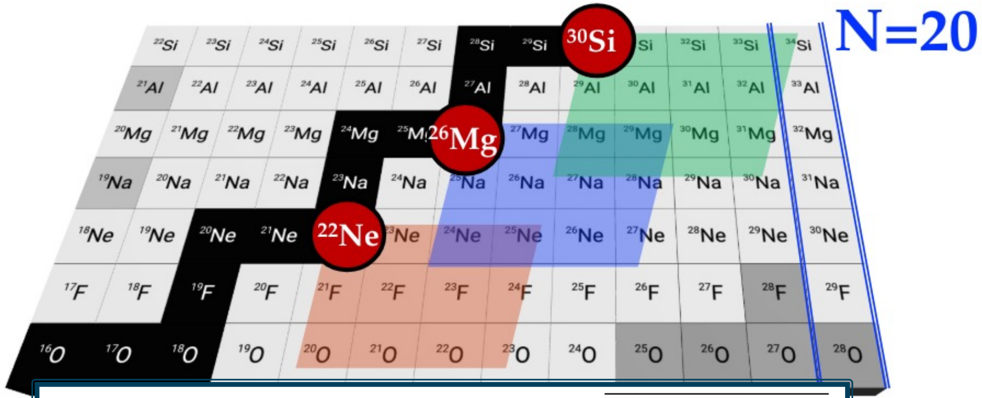
Sensitivity to 2n components of the wave function

Summary

The LNL campaign

AGATA+PRISMA and ^{238}U target

K. Wimmer, S. Bottoni, G. Benzoni, P. Aguilera et al.



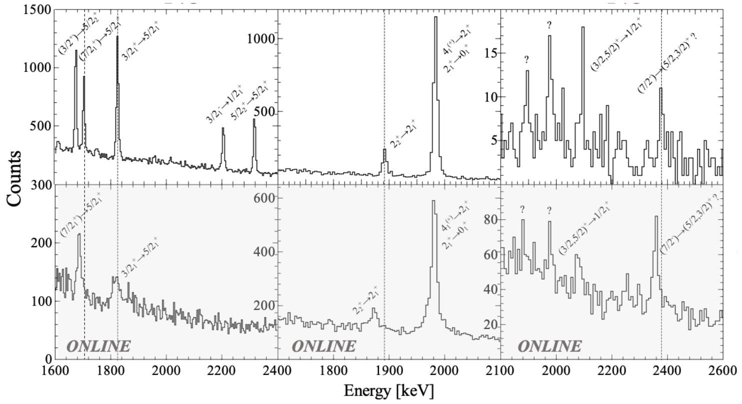
Eur. Phys. J. Plus (2023) 138:709
https://doi.org/10.1140/epjp/s13360-023-04249-x

THE EUROPEAN PHYSICAL JOURNAL PLUS

Regular Article

Nuclear physics midterm plan at Legnaro National Laboratories (LNL)

spectroscopy and lifetime measurements



PhD work by D. Genna and F. Drent

Follow-up experiments at GANIL

transfer reaction with ^{24}Ne beam and AGATA-GRIT-VAMOS

Proton-transfer reactions

^{24}Ne(^{3}He,d)^{25}Na and ^{24}Ne(t,α)^{23}F

Two-neutron-transfer reactions

^{24}Ne(t,p)^{26}Ne

- ^{24}Ne available at ~2E5 pps
- Use of cryo taget and radioactive tritium target
- Mainly backward but also forward GRIT
- (t,p) and (t,α) can be done simultaneously

Considering typical cross sections at 6-10 MeVA

8–10-day experiments

Similar reactions possible
with other light SPIRAL beams

I think we should invest in the tritium target for this campaign as done at ISOLDE and FRIB

GRIT-AGATA-VAMOS workshop

Thank you!

Simone Bottoni

Università degli Studi di Milano
INFN Sezione di Milano

INFN

S. Bottoni, D. Genna, G. Benzoni
K. Wimmer, F. Galtarossa
and the INFN-GAMMA collaboration

GRIT-AGATA-VAMOS workshop

GANIL, June 2025