The "isoscalar" pleasure to collaborate with Edoardo

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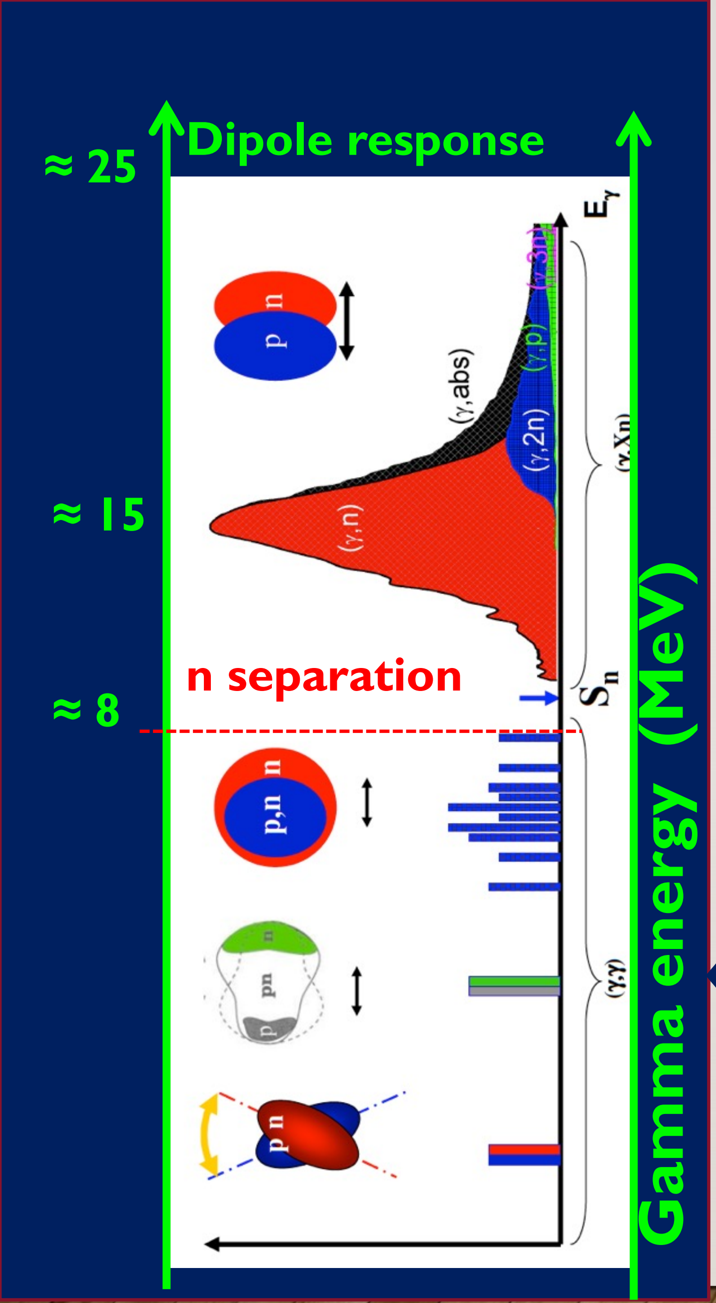
and INFN

Inspiration and collaboration on the topic of the dipole-response

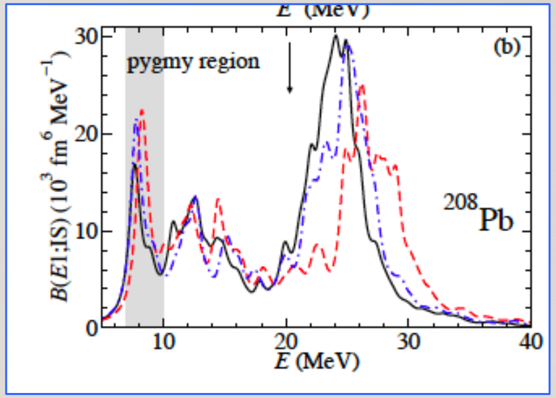
OUTLINE

- Why do we investigate the low-lying dipole strength function ?
- Where do we stand ?
- Which investigations could give further insight to the problem and could be made in the future ?--→ Edoardo will have a very dense agenda !



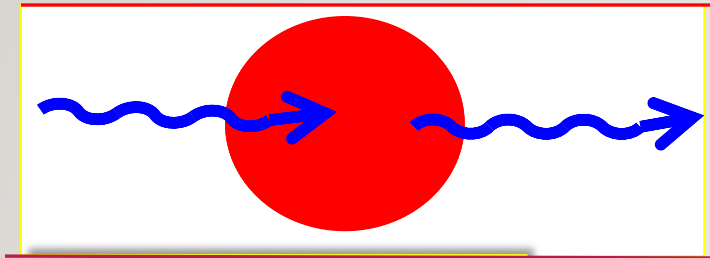
Why do we investigate low-lying E1 strength (minor component of the dipole response) ?

- For neutron rich nuclei is due to neutron excitations and thus of the neutron skin and the latter is related to the properties of neutron matter
- The gamma strength function contains these excitations and the excess as compared with a Lorenztian function is affecting reactions involved in astrophysical processes for nucleosynthesis
- Test bench for theory, in particular Nuclear Density Funtionals. Open problems are the dependence on interactions and on the level of complexity assumed to describe the microscopy of these nuclear excitations (isoscalar and isovector components)

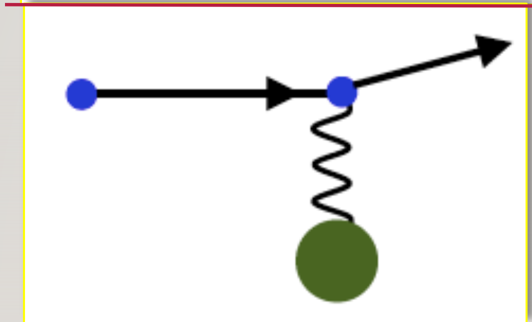


Bracco, A.; Lanza, E. G.; Tamii, A.
Progress in Part. and Nuc. Phys. 106(2019) 360-433

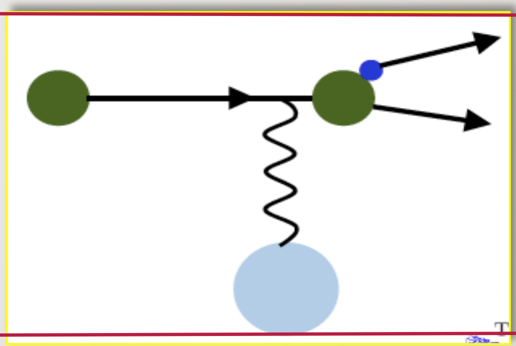
There is a need for a variety of experimental tools



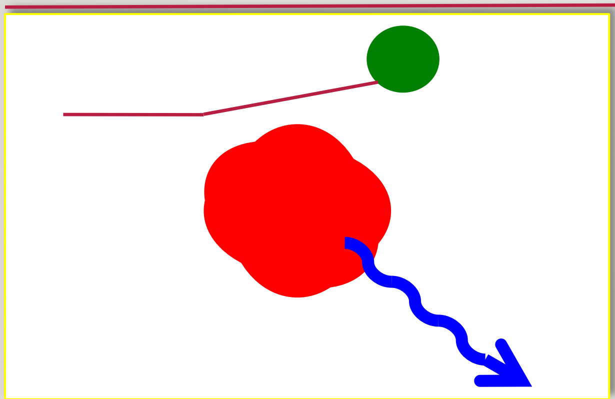
(γ,γ') real photons
on stable nuclei
Probing the entire nuclear volume



(p,p') virtual photons
at E_{beam} > 200 MeV
on stable nuclei
Probing the entire nuclear volume
Work at Osaka RCNP

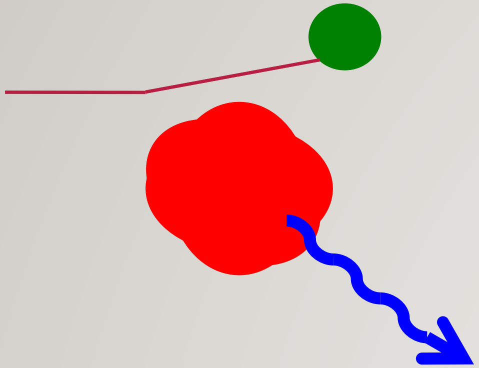


Coulomb excitation
with radioactive beams
virtual photons
Exotic nuclei



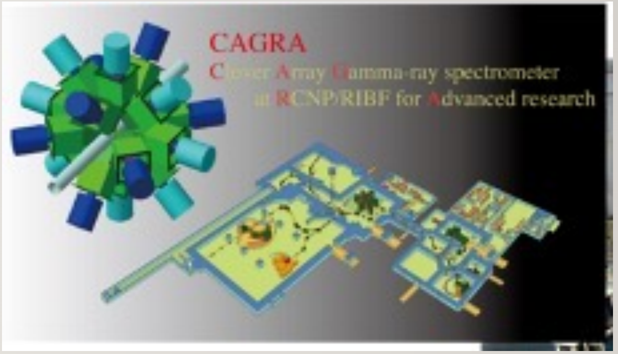
(α,α'γ) or (^{17}O,^{17}O'γ) and (p,p'γ)

Probing the nuclear surface mainly
– short range nuclear forces and low-energy of the collision

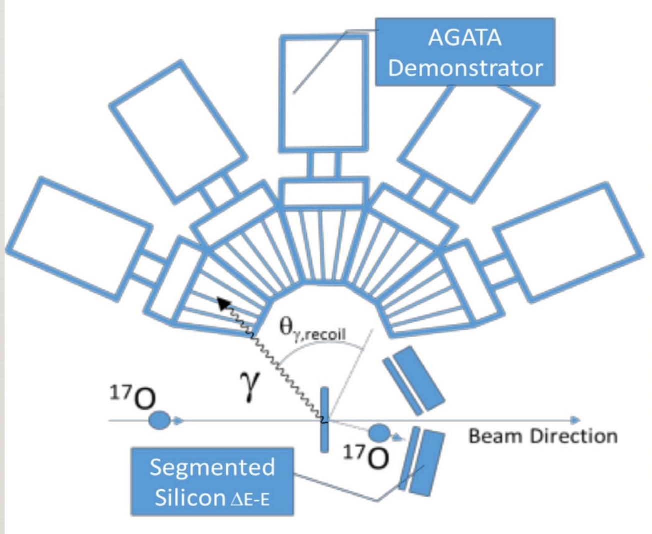


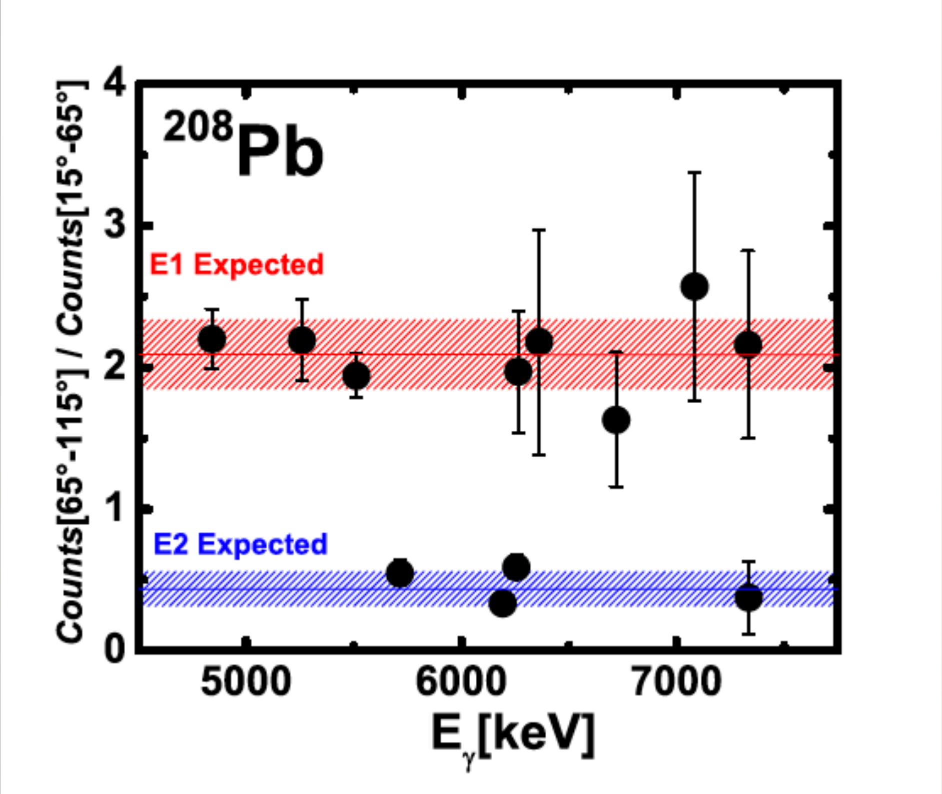
what have we learned so far from hadronic reactions ?

$(\alpha,\alpha'\gamma)$ $(^{17}O,^{17}O'\gamma)$ and $(p,p'\gamma)$



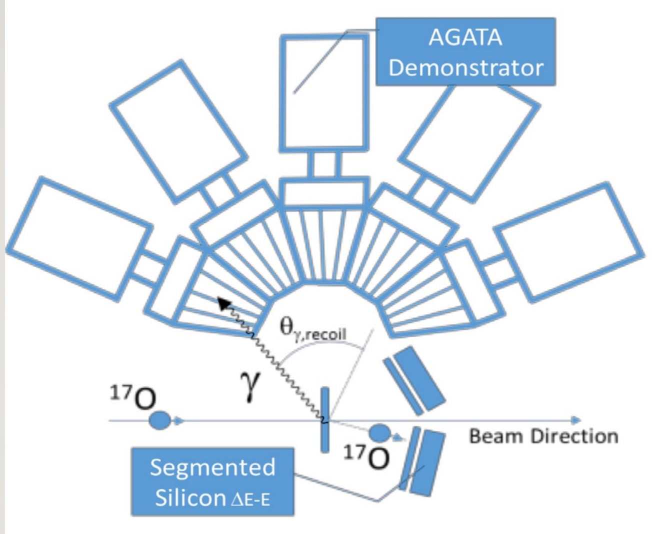
- Ground state gamma decay select preferentially 1^- states
- Measurements of cross sections
- Measurement of the angular distributions of the gamma-rays





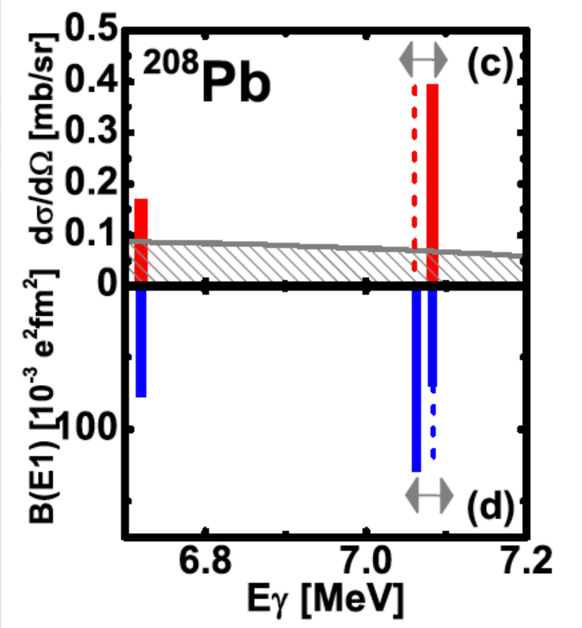
Angular distribution of the gamma rays-

In general one finds mostly 1$^-$ states

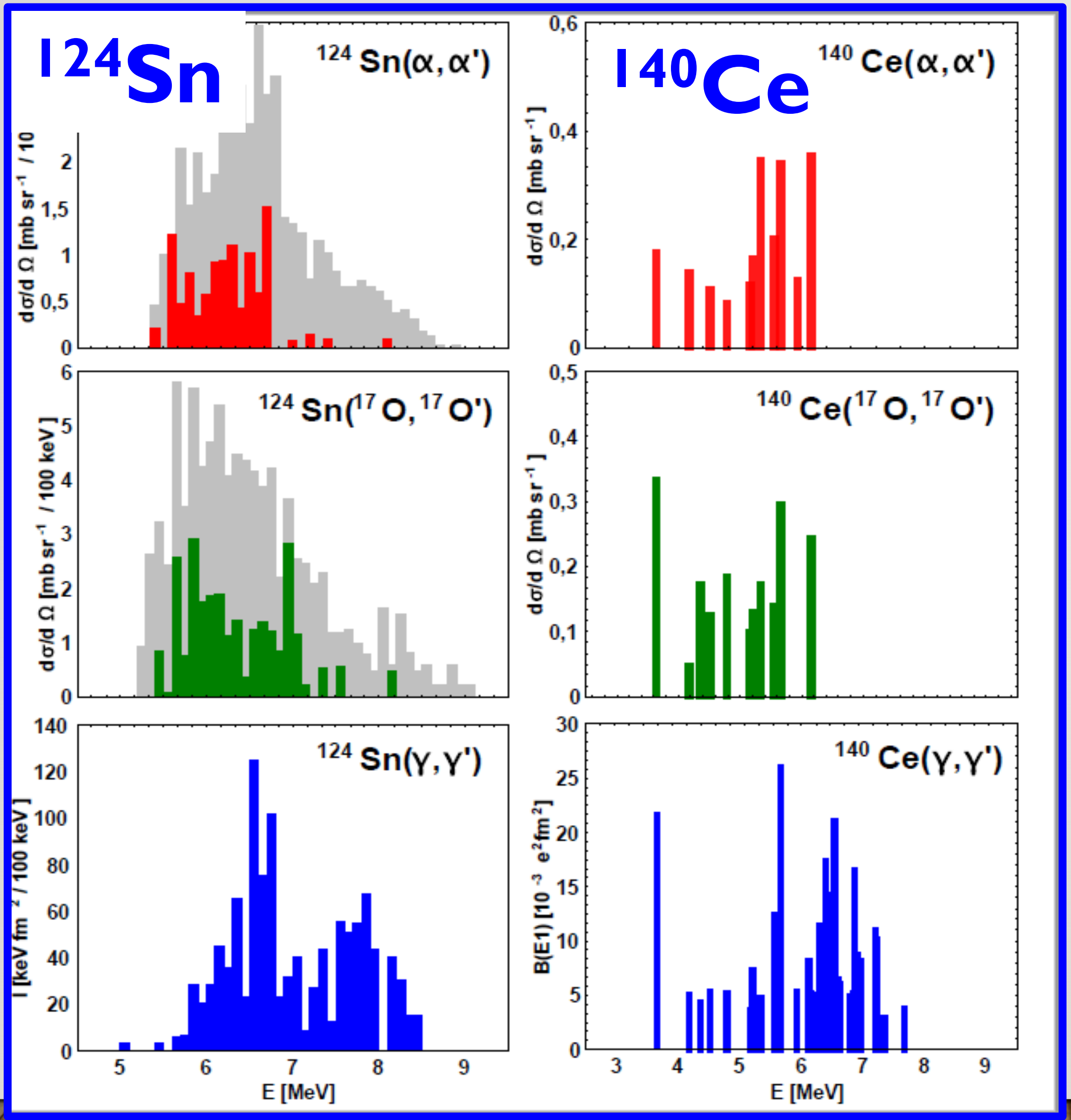


Effect of isospin breaking

Isospin mixing allows E1 decay from isoscalar excitations



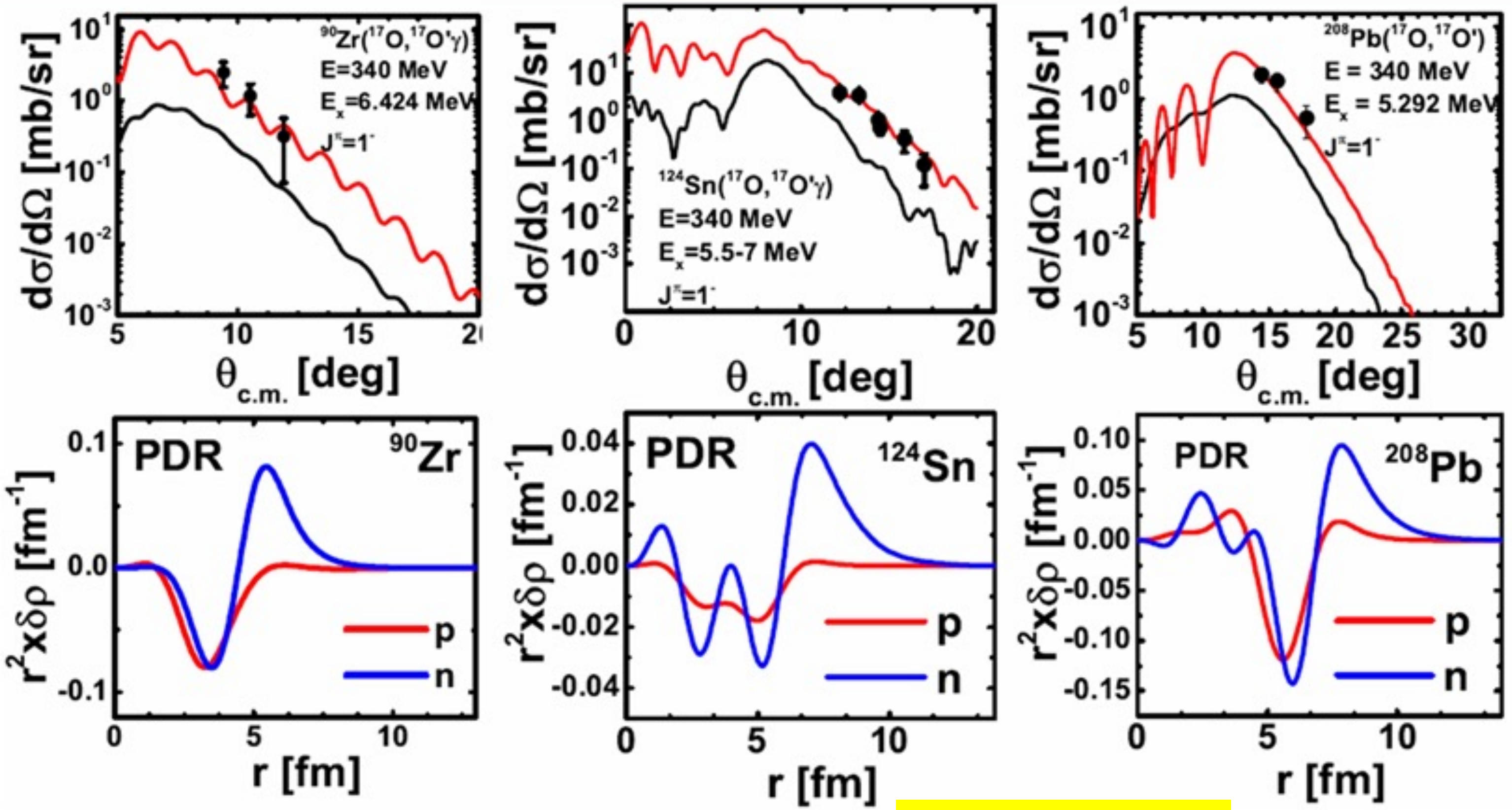
Main features of some existing results



1^- excitation with :
^{17}O 20 MeV/u
and alpha scattering
at 130 MeV
and their comparison

In all cases only the region < 6-7 MeV is populated by all reactions

Heavy Ion Inelastic Scattering



DWBA calculation (red solid lines) with microscopic form factors* based on the transition density associated to the E1 PDR states

Isoscalar strength

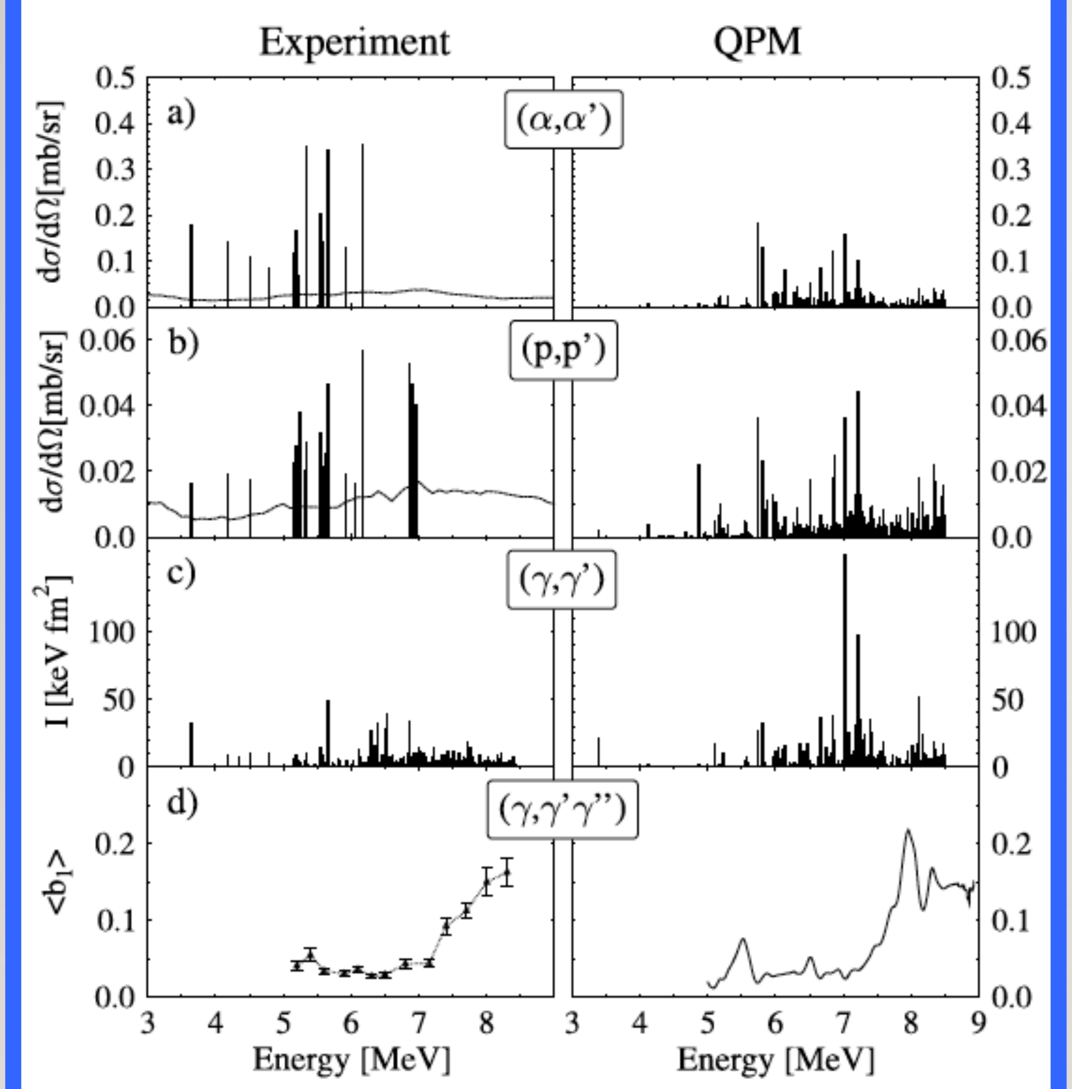
Isotope	Selection	Energy range [MeV]	Isoscalar strength [10^4 e^2 fm^6/MeV]	Isoscalar EWSR [%]	B(E1)↑ [10^{-3} e^2 fm^2]
^{90}Zr	in peaks	6.3–6.9	4.6(0.7)	4.0(0.6)	87
^{124}Sn	in peaks	5.5–7.0	10.8(1.4)	1.5(0.2)	214
^{124}Sn	in peaks	5.5–9.0	11.9(1.6)	2.2(0.3)	228
^{124}Sn	unresolved	5.5–9.0	41.1(3.7)	7.8(0.7)	228
^{208}Pb	in peaks	4.8–7.3	8.9(1.5)	9.0(1.5)	1084

F.C.L. Crespi, et al., PRL113 (2014) 012501
L. Pellegri, et al., PLB738 (2014)519

F.C.L. Crespi et al, PRC 91 (2015) 024323
A. Bracco, F.C.L. Crespi and
B. E.G. Lanza, EPJA(2015)51:99

*E. G. Lanza et al., Phys. Rev. C 84 (2011) 064602

Comparison alpha – protons for ^{140}Ce



Also protons!

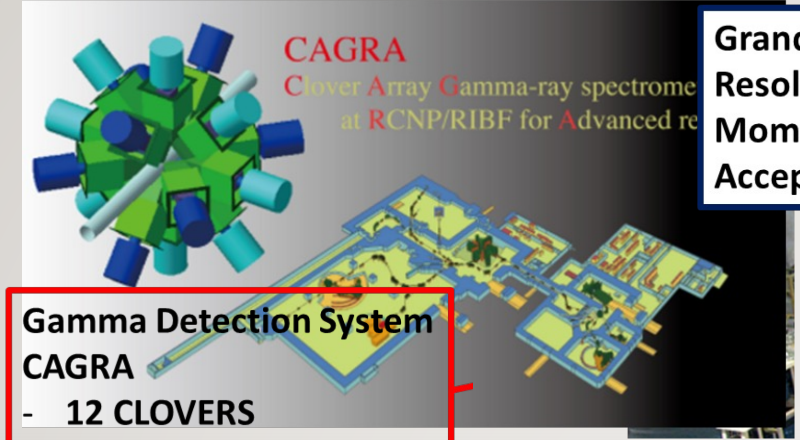
With this probe at low energy (80 MeV here) the isoscalar character is dominating

However the (p.p') is less peaked on the surface as compared with alpha scattering

Therefore if a state is due to excitations of nucleons at the nuclear surface its excitation cross section should follow the feature of the probing particle

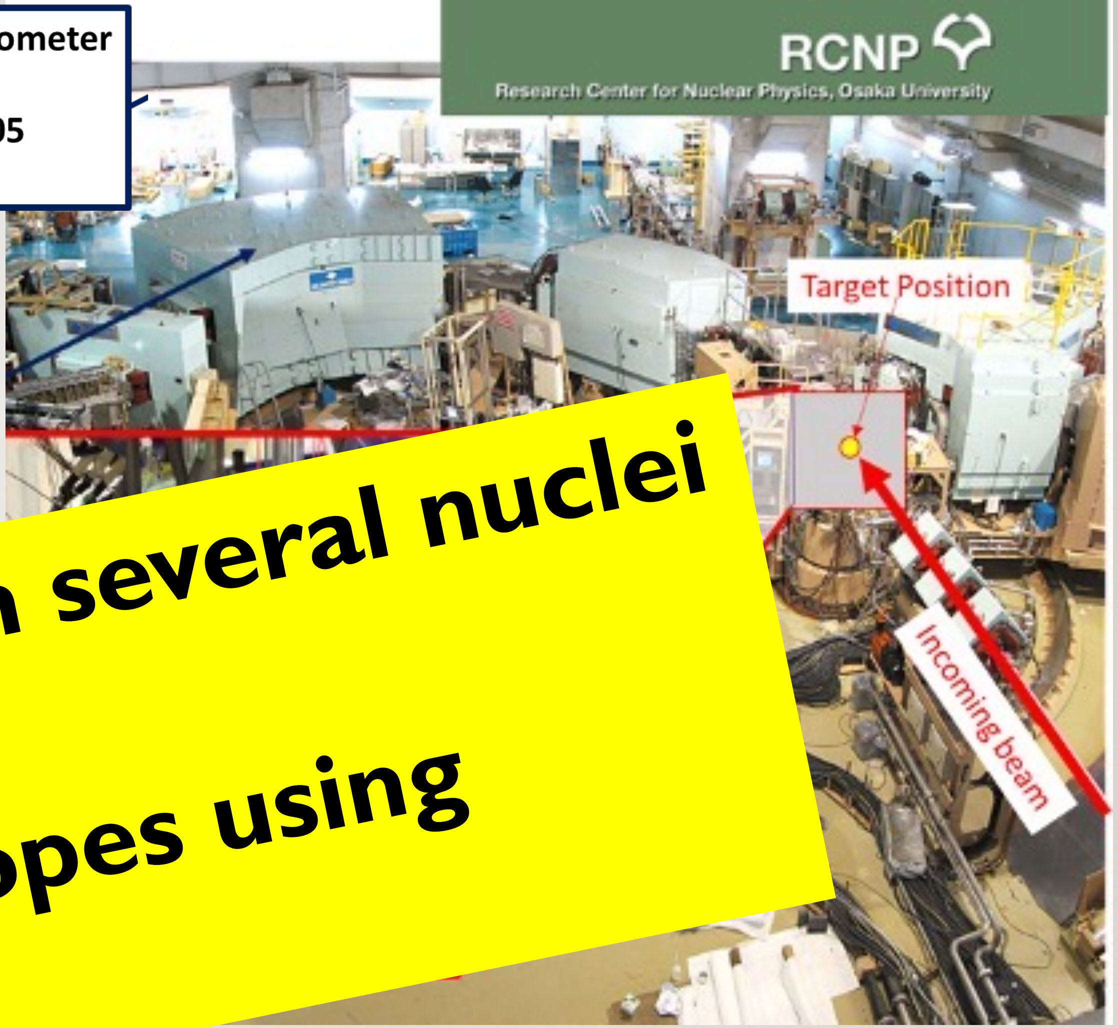
(cross sections smaller than those of alpha scattering)

Savran et al. PLB786(2018)16



Gamma Detection System
CAGRA
- 12 CLOVERS
- 4 LaBr3:Ce 3,5”x8”

Grand Raiden Spectrometer
Resolution: 37,000
Momentum Byte: 1.05
Acceptance: 5.6 msr



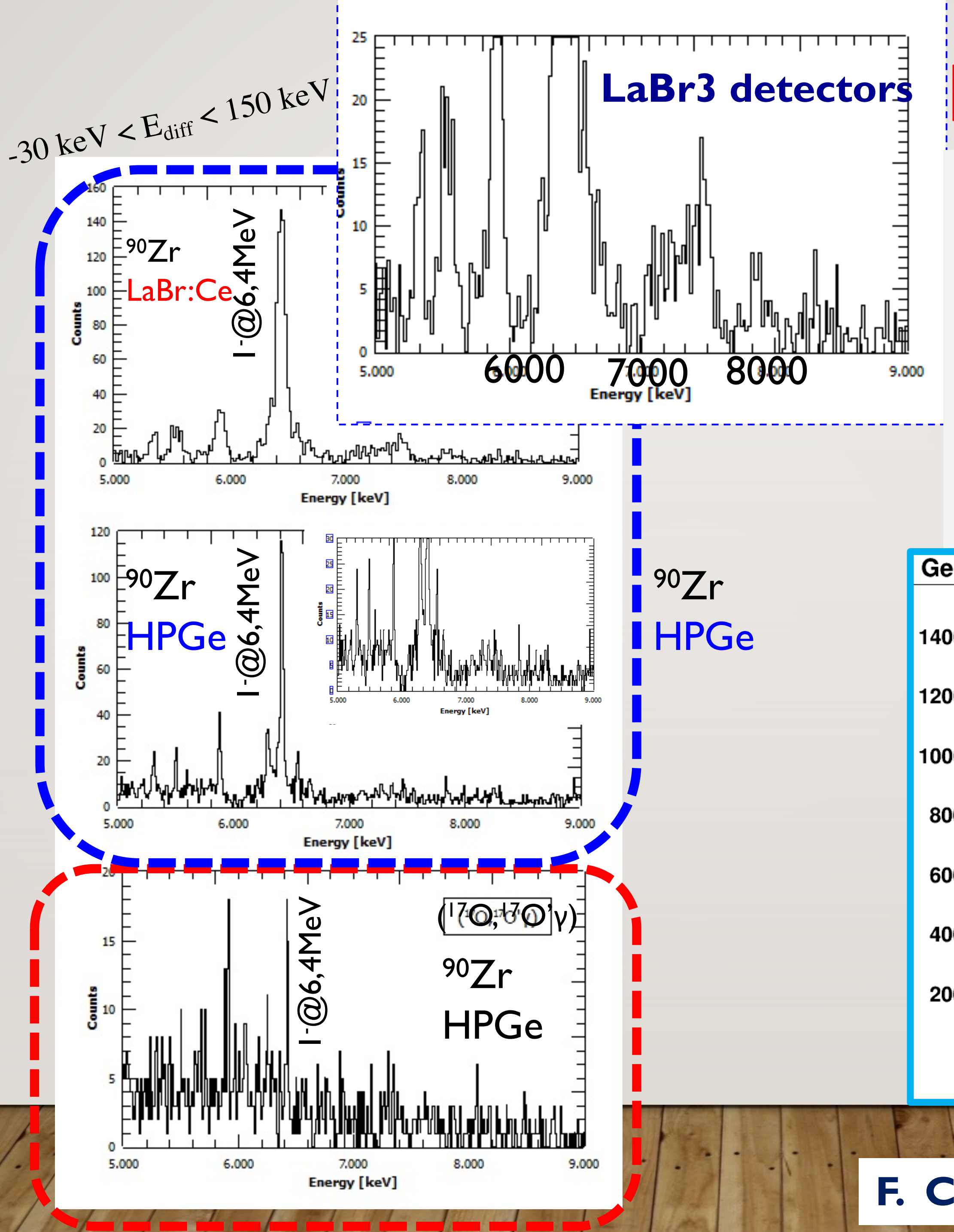
Experiments at RCNP on several nuclei Sn, Pb, Ni, Zr: some results on Zr isotopes using p and alpha beams

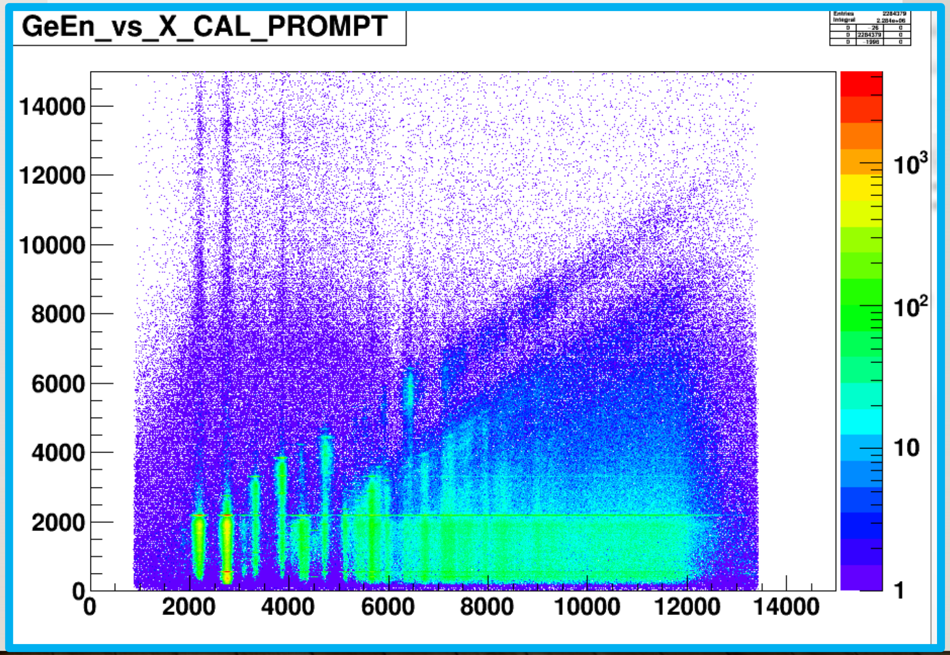
Data for ^{90}Zr (α,α’γ)

Several states at 7-9 MeV populated with this reaction selection of events corresponding to ground state decay

Alpha cross section larger than proton about a factor of 5

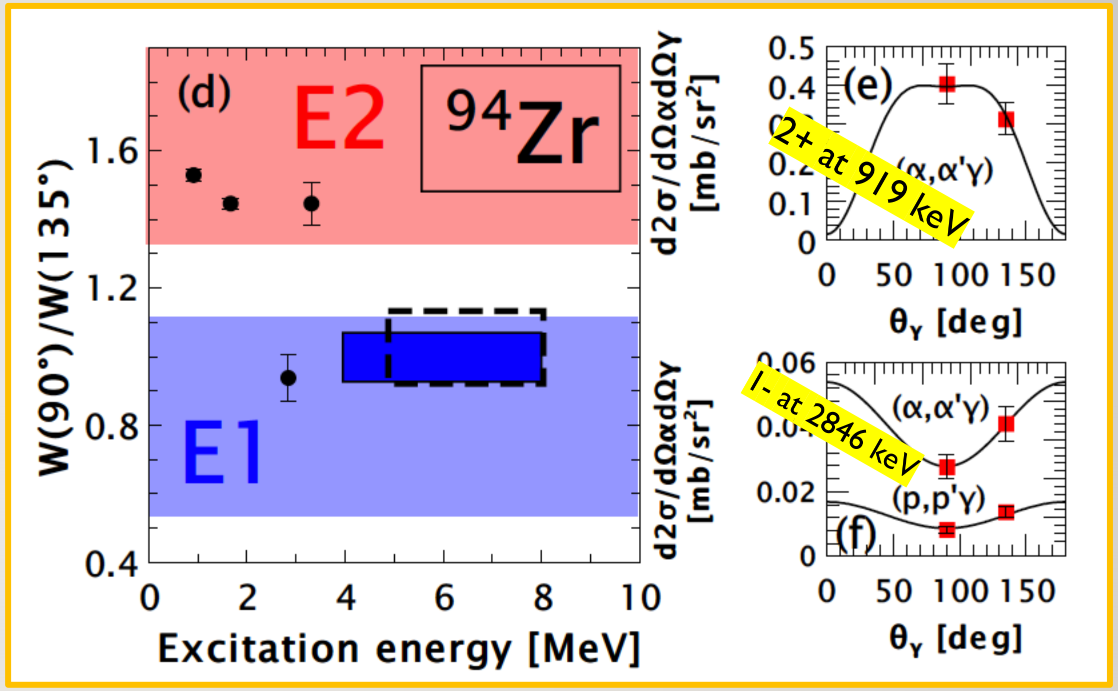
Alpha angle = 4.5
Proton angle = 6

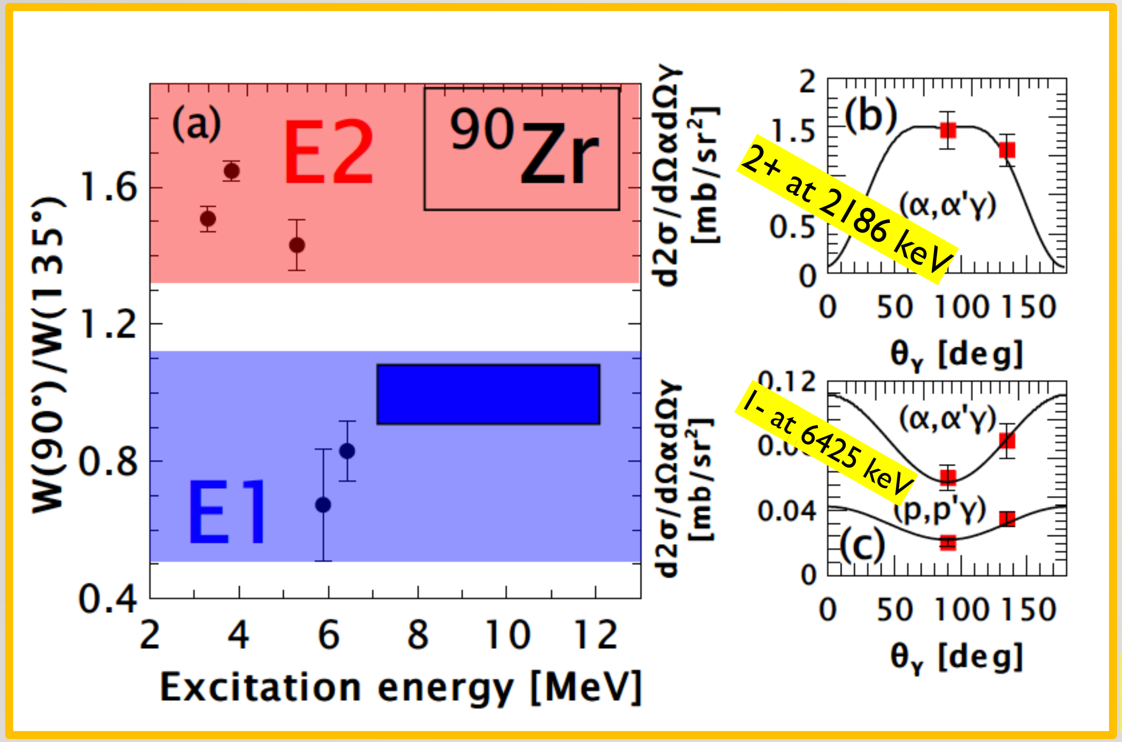




F. Crespi et al., PLB816, (2021) 136210

Angular anisotropy for ^{90,94}Z for proton and alpha Inelastic Scattering





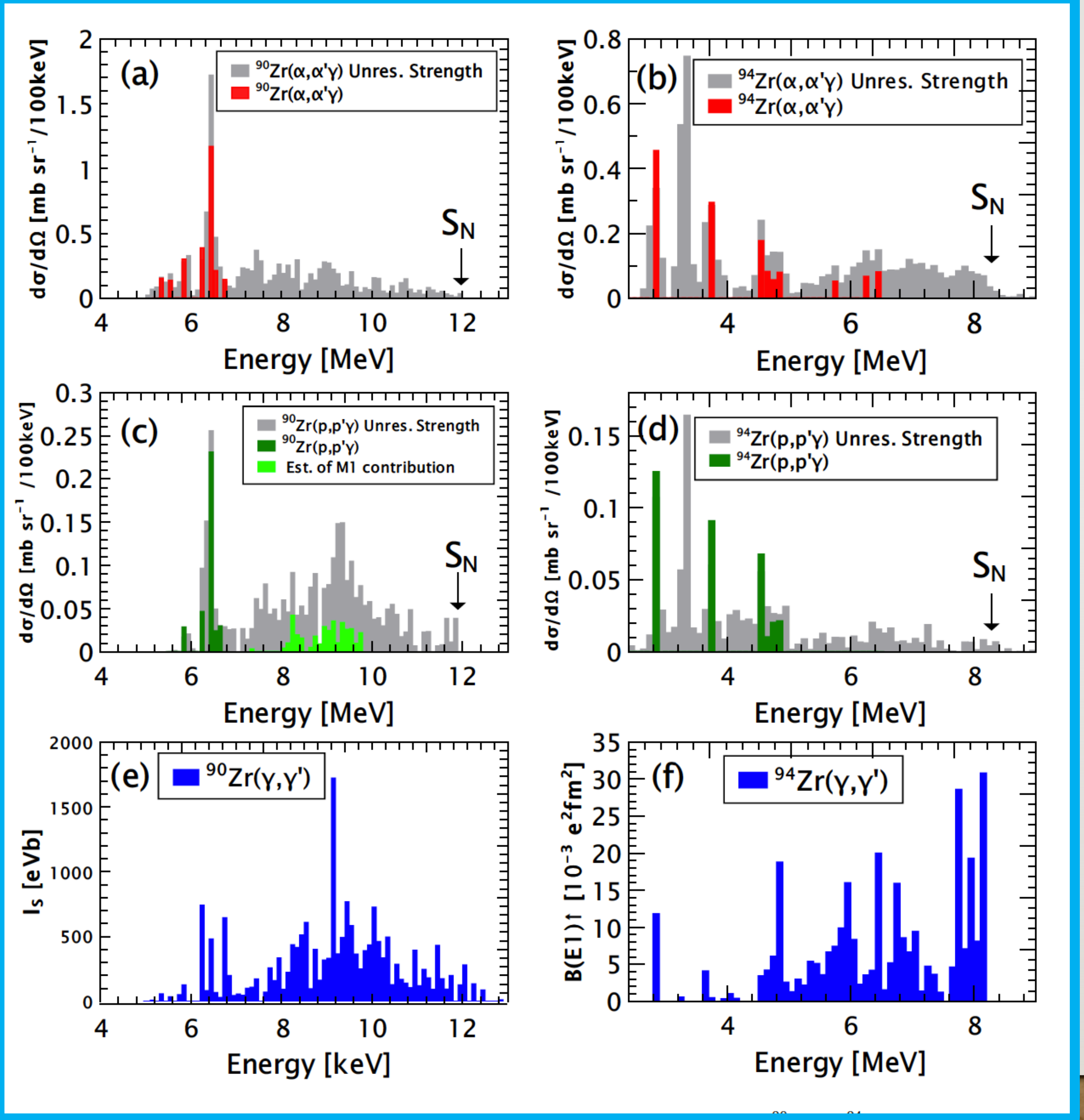
B_n about 12 MeV in ^{90}Zr

B_n about 8 MeV in ^{94}Zr

in both cases the continuum region has dipole character

Calculations performed with the DWBA approach

F. Crespi et al., PLB816, (2021) 136210



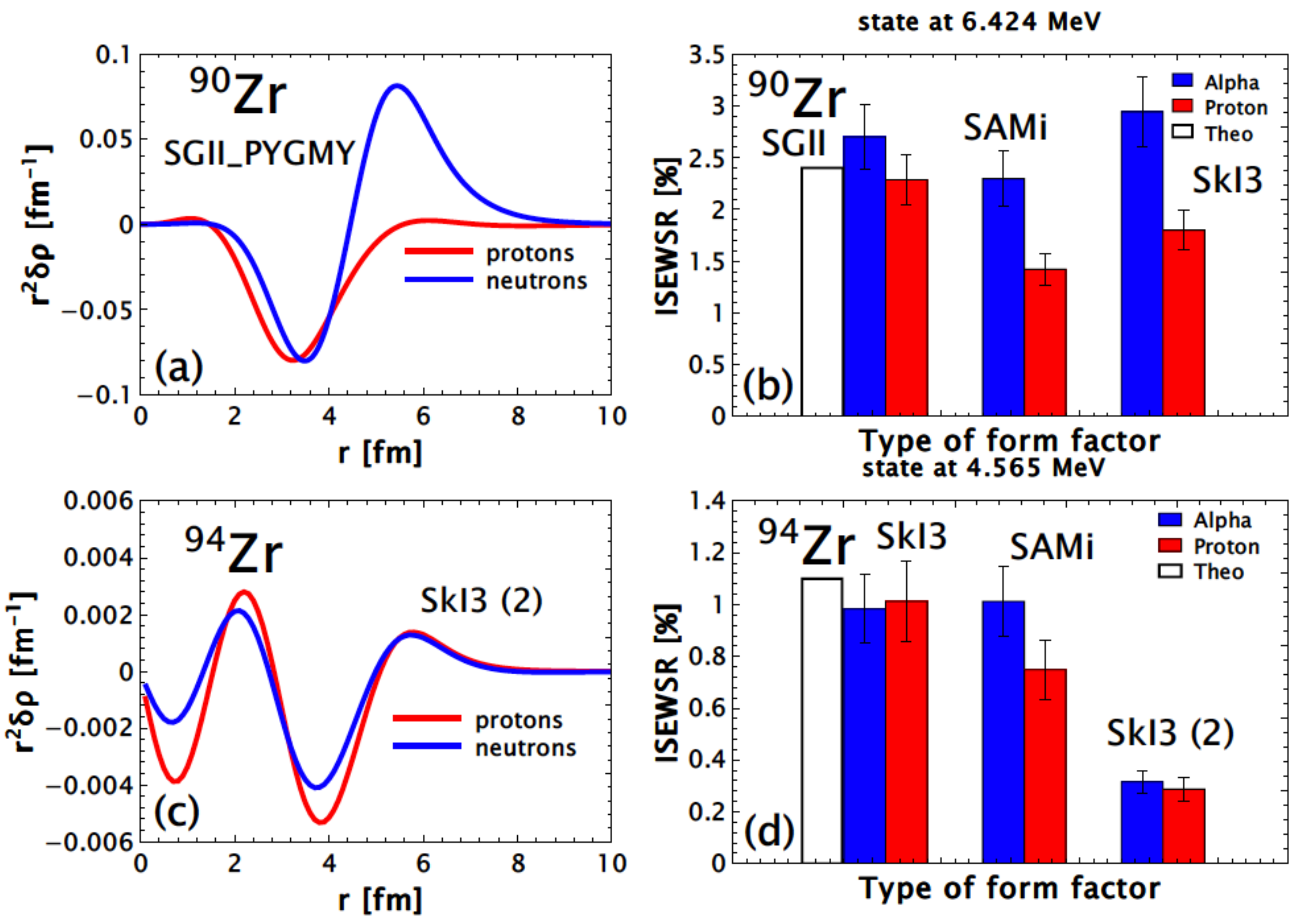
F. Crespi et al., PLB816, (2021) 136210

Comparison of cross section data for proton and alpha Inelastic Scattering on the ^{90,94}Z target nuclei

There is a region where only (γ,γ') populate states

Colored bars denote descrete transitions

In ^{90}Zr some M1 strength should be present in the case of proton scattering. Evaluation of it using existing data at higher energy where M1 strength was measured (light green)

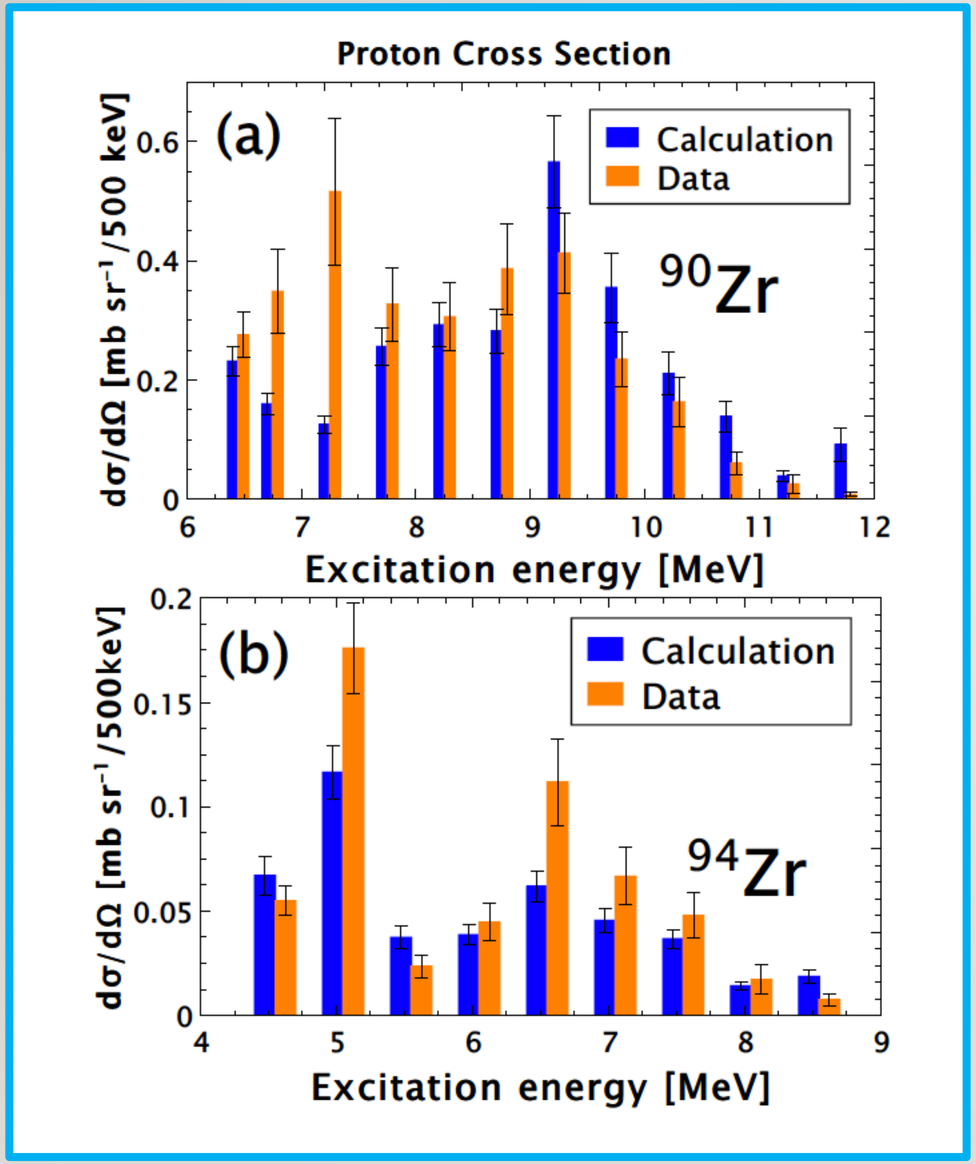


F. Crespi et al., PLB816, (2021) 136210

Isoscalar EWSR deduced for proton and alpha Inelastic Scattering on the $^{90,94}Z$ target nuclei

Selected form factors associated to transition densities computed within RPA starting
with different interactions

Cross section calculated with the DWBA approach



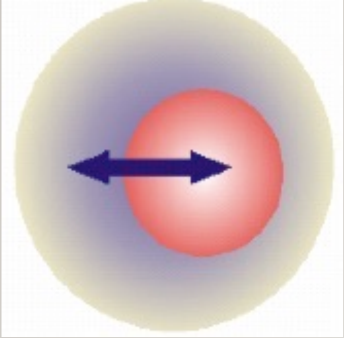
F. Crespi et al., PLB816, (2021) 136210

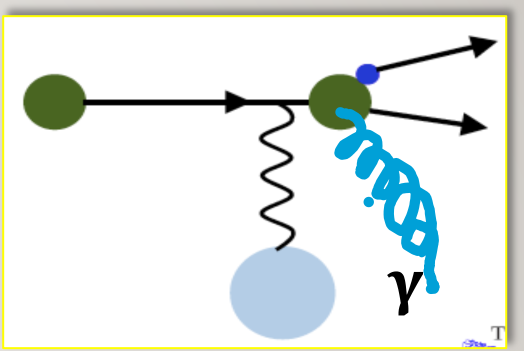
Comparison of data with calculations for proton Inelastic Scattering on the ^{90,94}Z target nuclei

Cross section calculated with the DWBA approach with:

- The choice of form factor for which the normalization was about 0.9 for the discrete peaks
- Value of the ISEWSR deduced from fit to the alpha data

Only in some cases discrepancies out of the error bars





……with radioactive beams

experiments measuring gamma decay from dipole excitations

what we have learned so far

IsoVector and IsoScalar

dipole excitation measurement at RIKEN

DALI2+LaBr3:Ce+ZeroDegreeSpectrometer and different TARGETs

Physics Letters B 768 (2017) 387–392

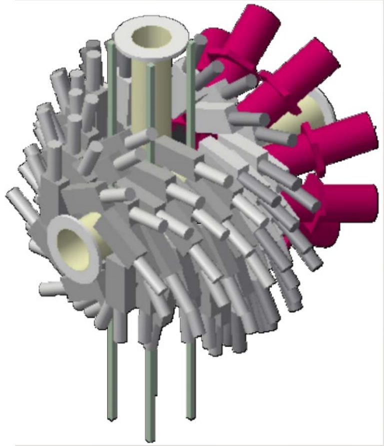
Contents lists available at ScienceDirect

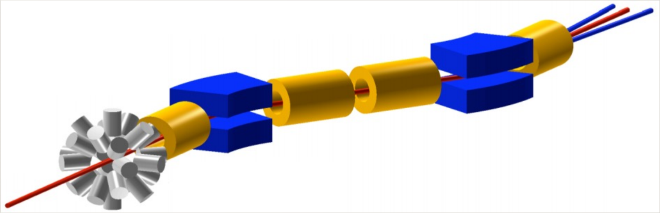
Physics Letters B

www.elsevier.com/locate/physletb

Observation of isoscalar and isovector dipole excitations in neutron-rich ^{20}O

N. Nakatsuka[a,b,*], H. Baba[b], T. Aumann[c,d], R. Avigo[e,f], S.R. Banerjee[g], A. Bracco[e,f], C. Caesar[c,d], F. Camera[e,f], S. Ceruti[e,f], S. Chen[h,b], V. Derya[i], P. Doornenbal[b], A. Giaz[e,f], A. Horvat[c,d], K. Ieki[j], T. Inakura[k], N. Imai[l], T. Kawabata[a], N. Kobayashi[m], Y. Kondo[n], S. Koyama[m], M. Kurata-Nishimura[b], S. Masuoka[l], M. Matsushita[l], S. Michimasa[l], B. Million[e], T. Motobayashi[b], T. Murakami[a], T. Nakamura[n], T. Ohnishi[b], H.J. Ong[o], S. Ota[l], H. Otsu[b], T. Ozaki[n], A. Saito[n], H. Sakurai[m,b], H. Scheit[c], F. Schindler[c,d], P. Schrock[c], Y. Shiga[j,b], M. Shikata[n], S. Shimoura[l], D. Steppenbeck[b], T. Sumikama[b], I. Syndikus[c,d], H. Takeda[b], S. Takeuchi[b], A. Tamii[o], R. Taniuchi[m], Y. Togano[n], J. Tscheuschner[c], J. Tsubota[n], H. Wang[b], O. Wieland[e], K. Wimmer[m], Y. Yamaguchi[l], K. Yoneda[b], J. Zenihiro[b]





DALI2 and Hector⁺ and He(lq) and Au (solid) Target with ^{2X}O-Beam

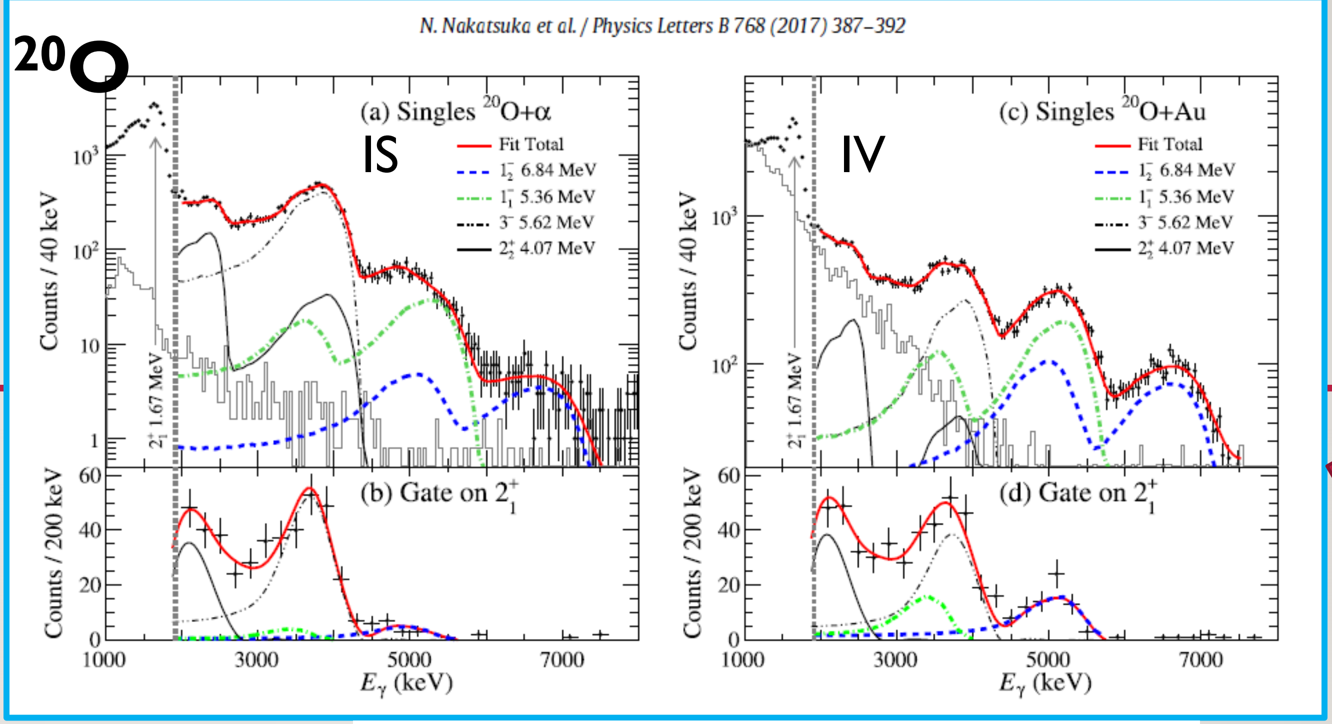
P. Adrich

IS-GDR

IV-PDR

Courtesy H.Baba, N. Nakatsuka

Comparison of data for Coulomb excitation and alpha Inelastic Scattering on the ^{20}O beam nuclei



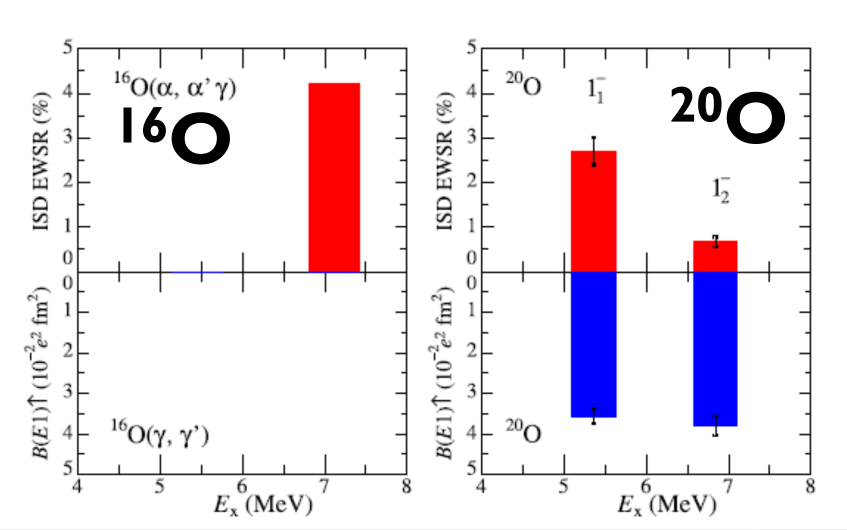
20O

Spectral shape is very different

Isoscalar and isovecor EWSR deduced

IS

IV (NO strength seen)



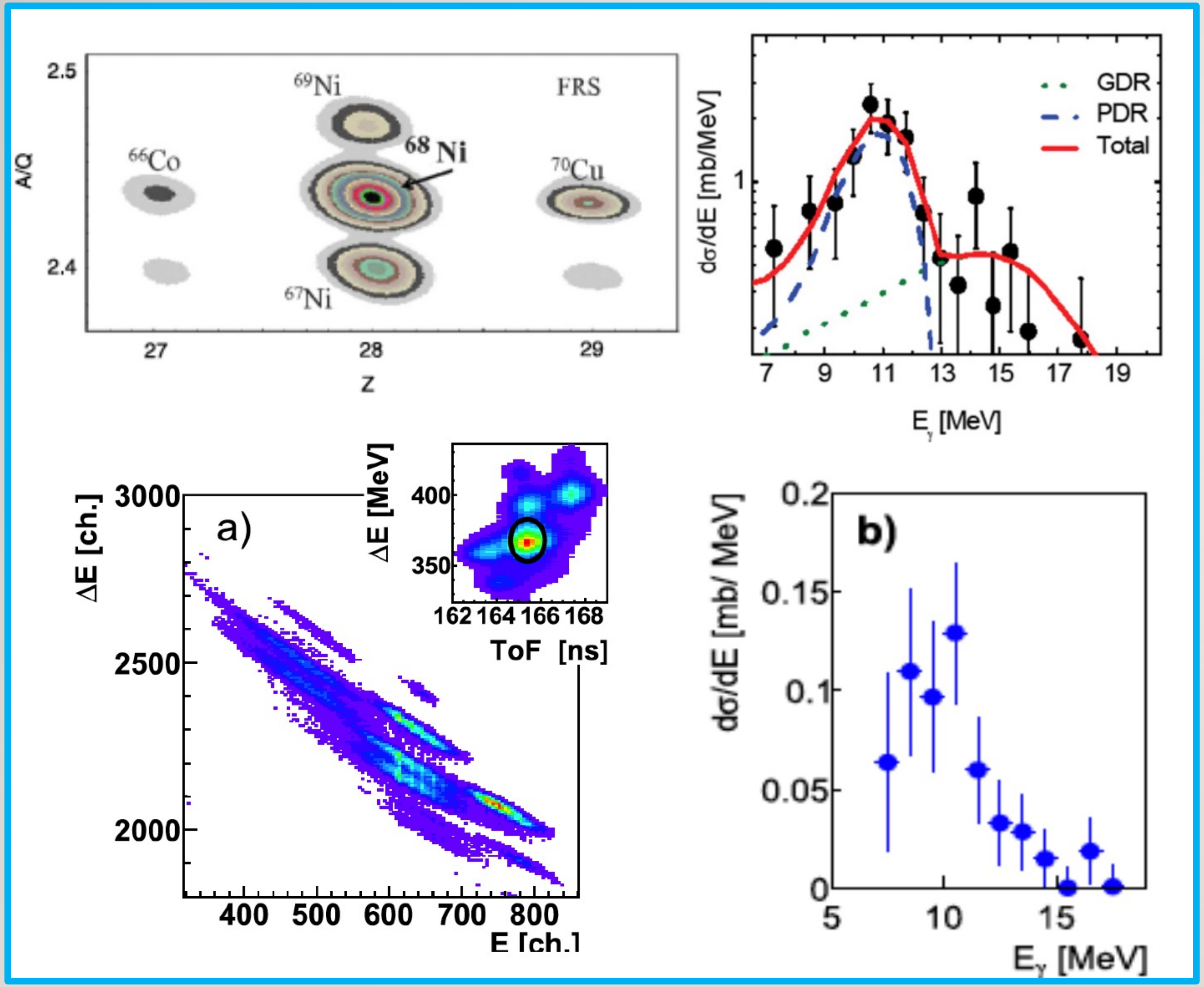
IS

IV

(from excess Neutrons)

Analysis with other O isotopes will follow

Courtesy H.Baba, N. Nakatsuka



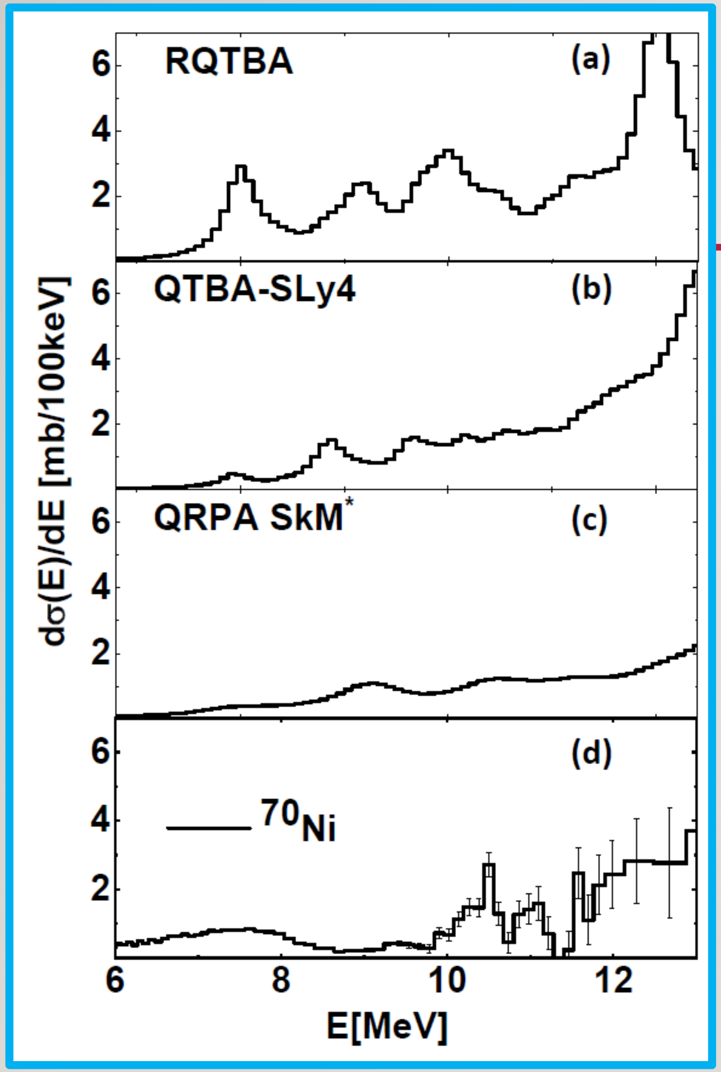
Comparison of data for Coulomb Excitation and ^{12}C Inelastic Scattering on the ^{68}Ni beam nuclei

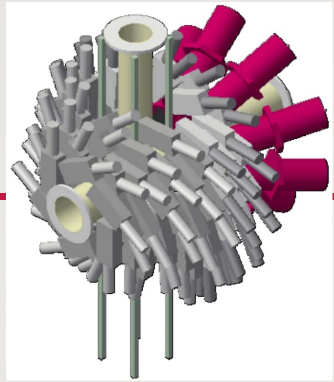
GSI experiment Radioactive beam with a Au target
Wieland et al. PRL102(2009)092502

LNS experiment Radioactive beam with a ^{12}C target
Martorana et al. PLB782(2018)112

Isoscalar and isovector components the presence of two components is predicted by theory

^{70}Ni PYGMY measurement @ Riken Coulomb excitation and comparison with theory





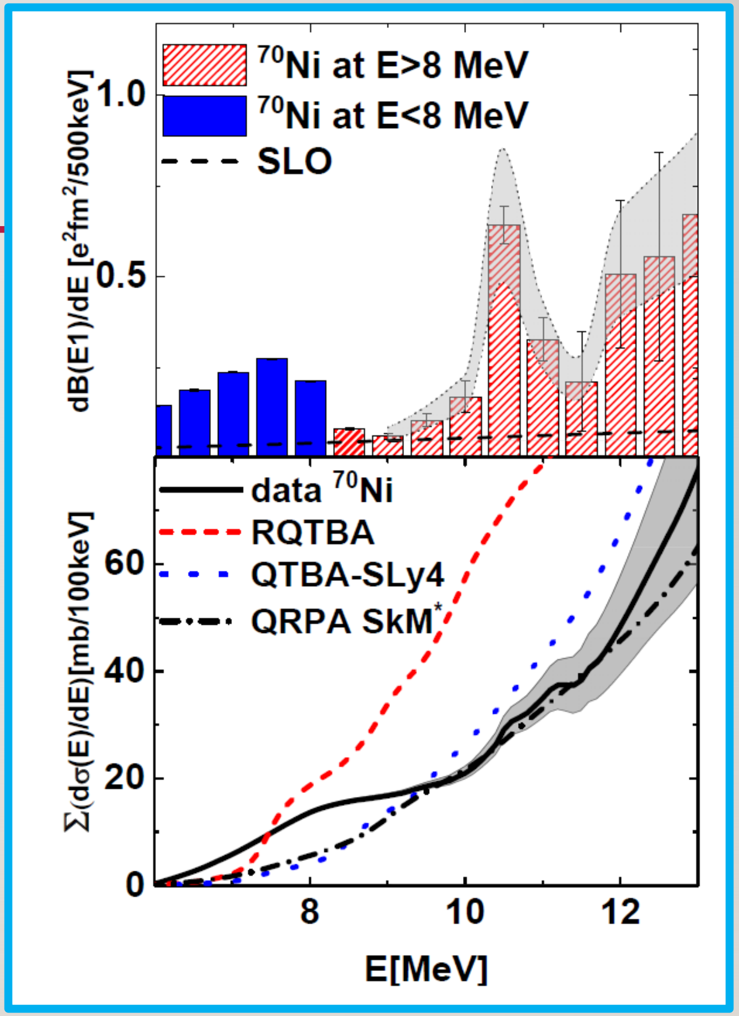
← Cross-section

Strength →

Shift in energy between experiment and theory

More excess seen in the data in the region below the binding energy

In would be very interesting to have data with alpha scattering at 30-40 MeV/u

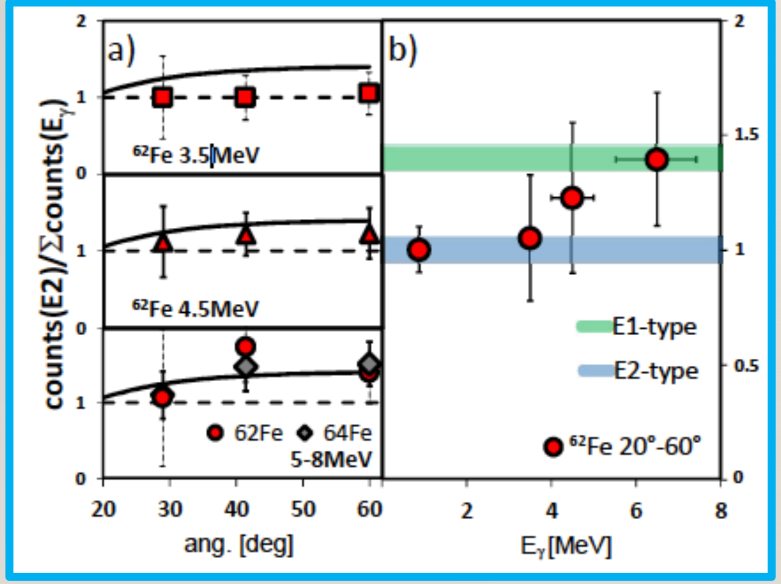


Error Bars mainly from LD

O Wieland, et al. Phys. Rev. C 98, 064313 – 2018

^{64,62}Fe nuclei

PYGMY measurement @ GSI Coulomb excitation - AGATA   for the gamma rays



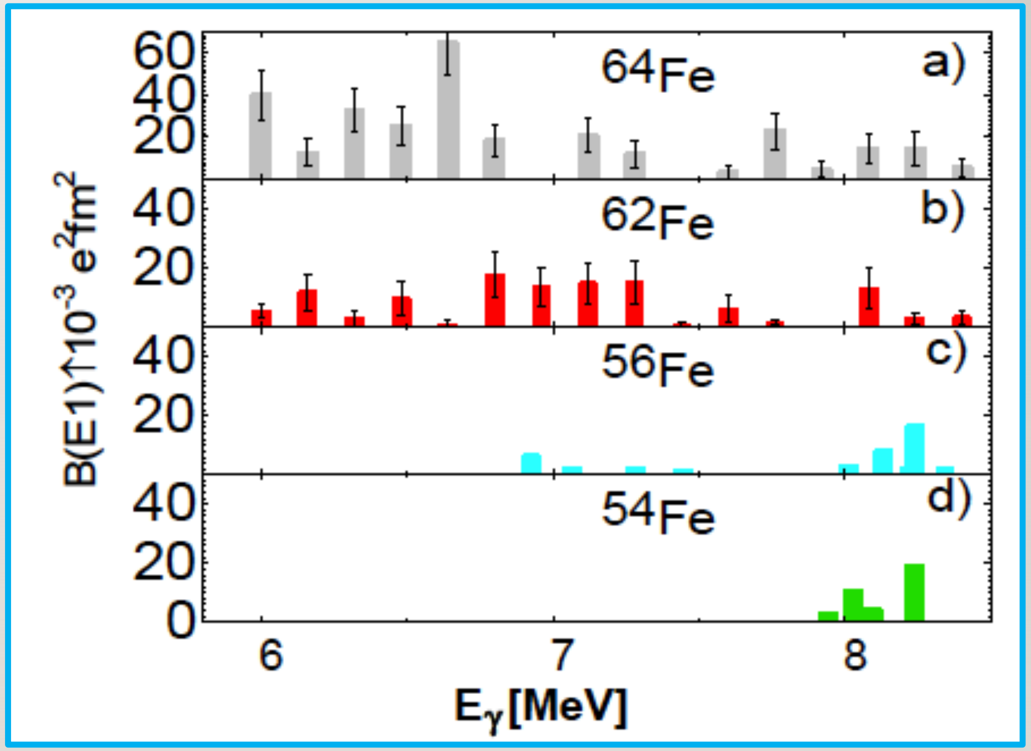
More E1 strengh in the region 5.5-7.5 MeV

There is an increase with neutron number and thus could be attributed to neutron excitations

It is important to have indication that these neutrons are mainly those to neutron at the surface
it would be interesting to populate these states with isoscalar probes

Ratio with counts in the first 2^+ excited states

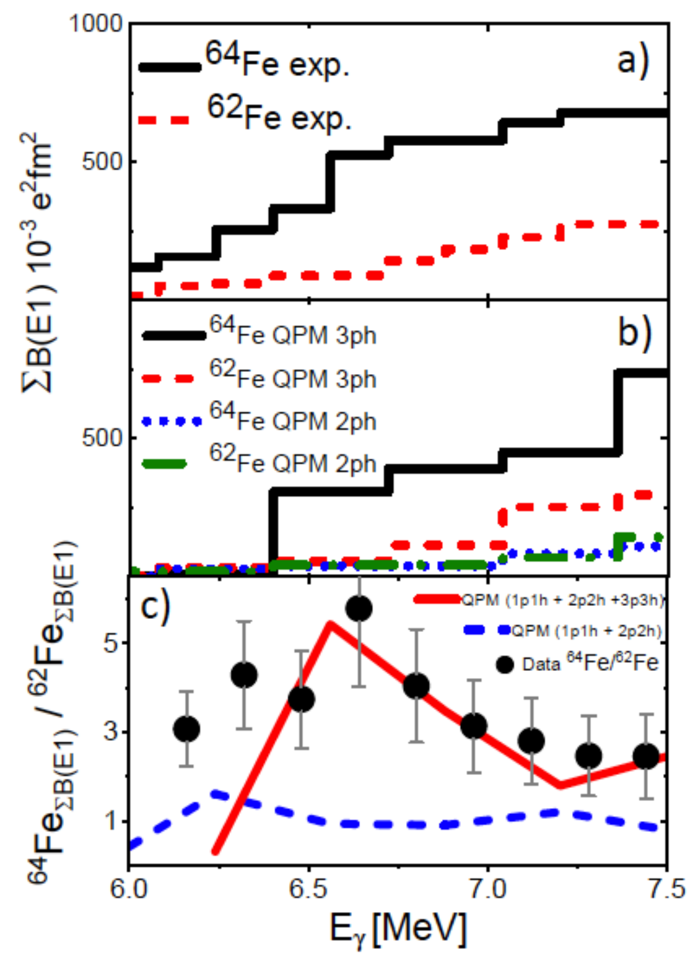
Comparison of data of Coulomb Excitation in unstable nuclei ^{64,62}Fe and gamma scattering on stable targets



Measured spectra of continuum type
R. Avigo et al., Phys. Lett. B 811, 135951 (2020).

$^{64,62}Fe$ nuclei – comparison with theory of

PYGMY measurement @ GSI Coulomb excitation - AGATA for the gamma rays

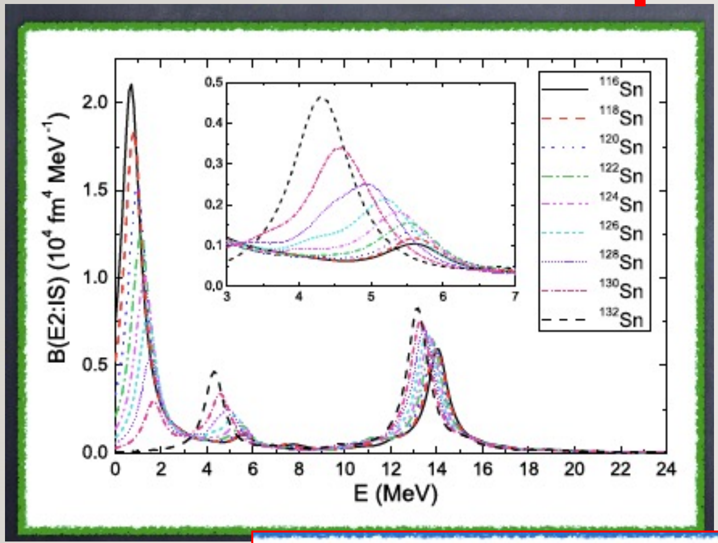


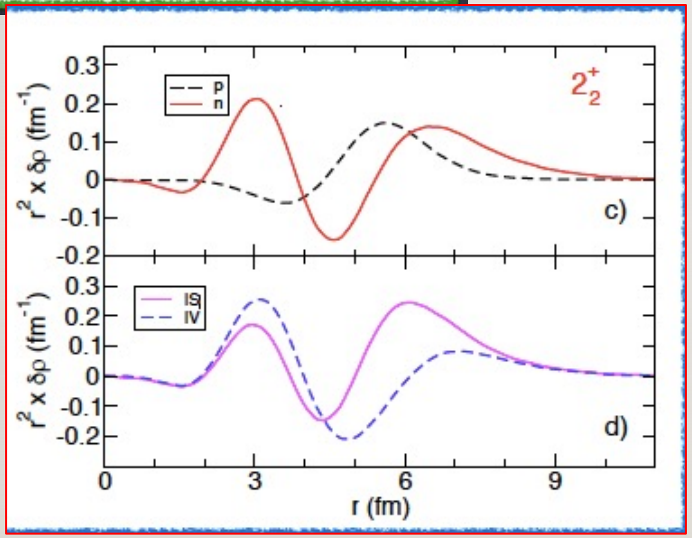
R. Avigo et al., Phys. Lett. B 811, 135951 (2020).

- for the two nuclei $^{62,64}Fe$ the ratio of the B(E1) summed over energy (running sum) is found to be of the order of 3 in average
- This ratio was also calculated within the framework of QPM (quasi-particle phonon model), widely used from the late 90's to describe the extensive existing data of pygmy states
- An important feature of this model is the inclusion of complex configurations by going beyond the simple one-particle one-hole (1p-1h).
- The QPM predictions, shown in comparison with the data that (3p-3h) congurations have to be also included.

Pygmy Quadrupole? Another property of the neutron skin?

THEORY on Sn isotopes



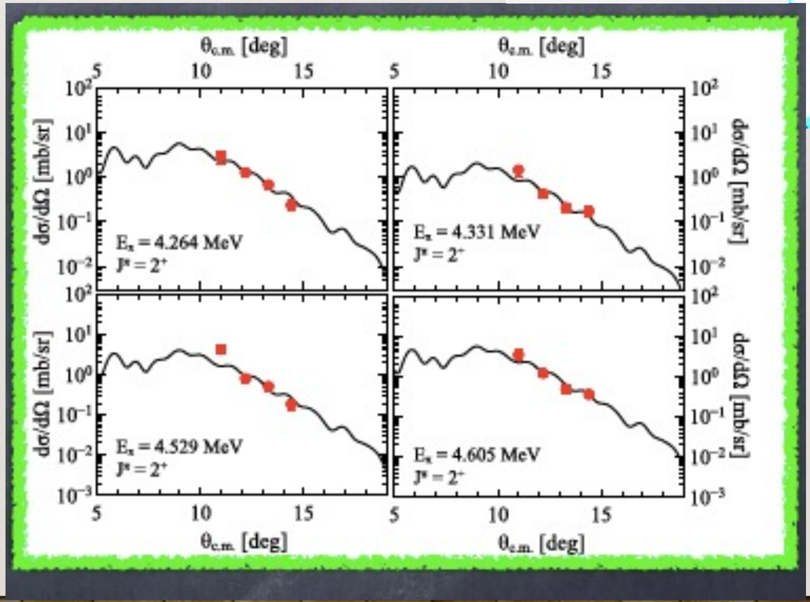


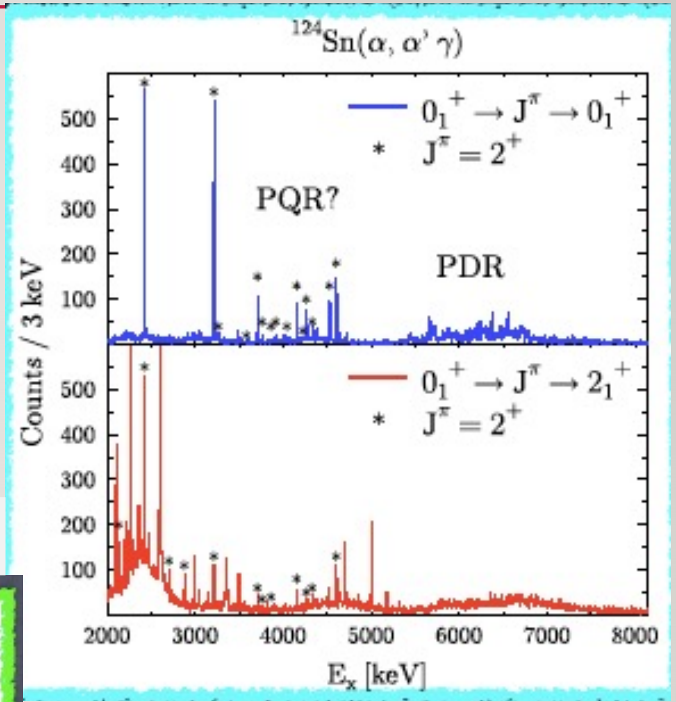
E.Yuksel et al.
PRC97(2018)0604308

EXPs on ^{124}Sn

Experiments with different probes show population of several 2^+ discrete states

(^{17}O ,^{17} O')





PLB 752(2016)102

Experimental data in comparison with DWBA approaches using B(E2) values from gamma scattering

PRC92(2015)014230

Tonseva et al.- PLB 752(2016)102

Progress in Particle and Nuclear Physics 106 (2019) 360–433

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journal homepage: www.elsevier.com/locate/ppnp

ELSEVIER

Review

Isoscalar and isovector dipole excitations: Nuclear properties from low-lying states and from the isovector giant dipole resonance

Check for updates

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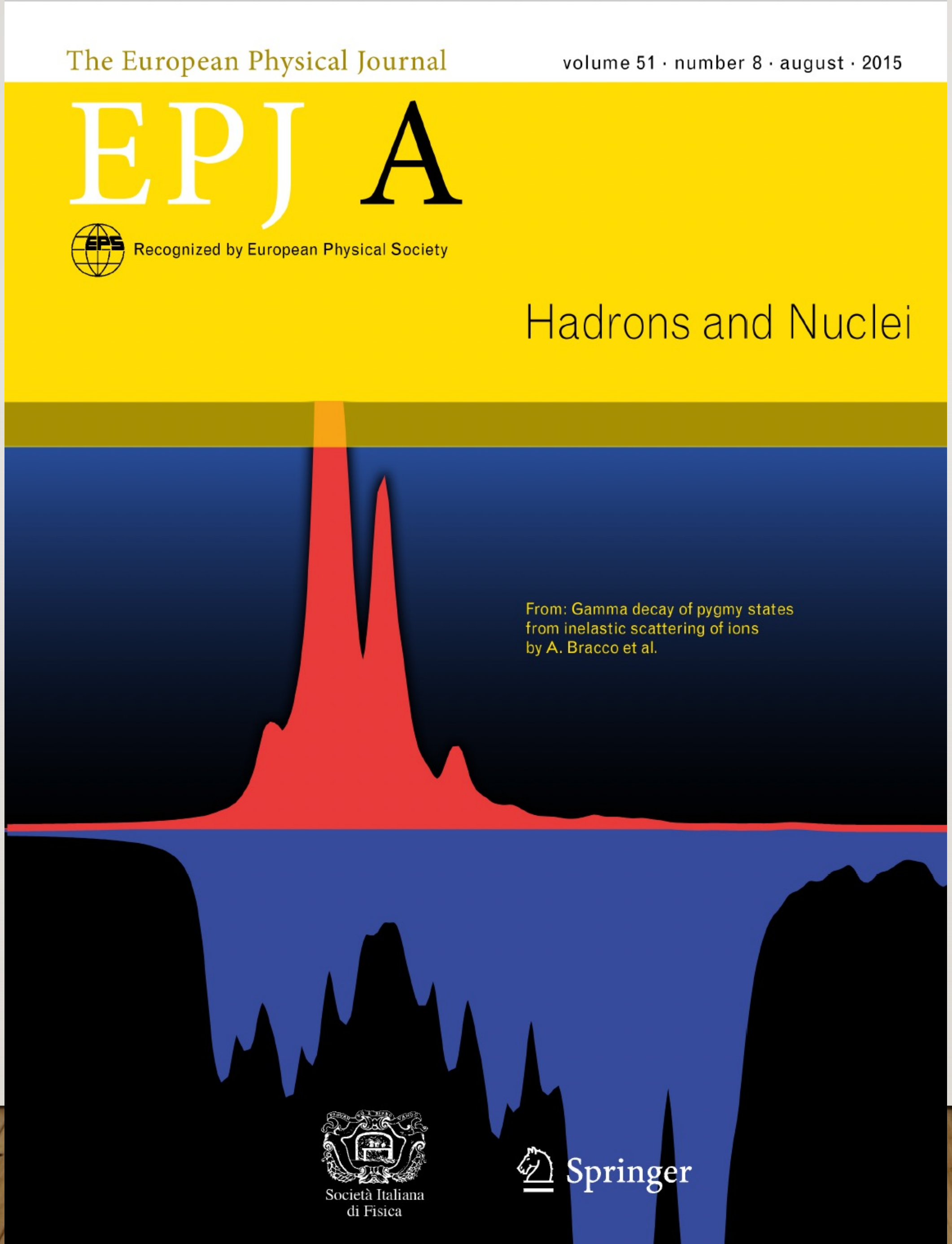
[c] *INFN, Sezione di Catania, Italy*
[d] *Research Center for Nuclear Physics, Osaka University, Japan*


The European Physical Journal
volume 51 · number 8 · august · 2015
EPJ A
Recognized by European Physical Society
Hadrons and Nuclei
From: Gamma decay of pygmy states
from inelastic scattering of ions
by A. Bracco et al.
Società Italiana
di Fisica
Springer

Conclusion

- The collaboration with Edoardo was very productive and I hope it will be in the future!

- Many open problems which need the competence, dedication and vision and ingenuity of Edoardo

I count also in the future to have "isoscalar" pleasure to collaborate with Edoardo