Isoscalar giant monopole resonance in ^{24}Mg and ^{28}Si: Effect of coupling between the isoscalar monopole and quadrupole strength

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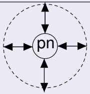
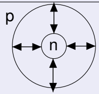
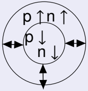
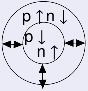
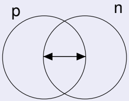
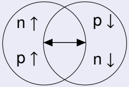
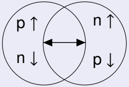
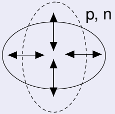
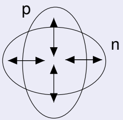
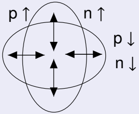
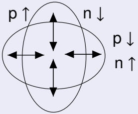
Introduction

Giant resonances (GRs) are defined as collective, small amplitude excitation modes which occur at excitation energy of 10 MeV and above in nuclei across the periodic table. They are characterised by the three quantum numbers L, S and T.

	Electric modes (ΔS = 0)		Magnetic modes (ΔS = 1)	
	Isoscalar (ΔT = 0)	Isovector (ΔT = 1)	Isoscalar (ΔT = 0)	Isovector (ΔT = 1)
ΔL = 0				
ΔL = 1	. . .			
ΔL = 2				

Motivations

- The study of the ISGMR is important since knowledge of its excitation energy provides information relevant to the nuclear matter incompressibility coefficient K_∞ which is crucial in the study of supernova collapse, neutron stars, etc.

- This study aims to investigate the two-peaked structure of the ISGMR in the prolate ^{24}Mg and oblate ^{28}Si nuclei and identify among a variety of energy density functionals based on Skyrme parameterisations the one which best describes the experimental data.

- This will allow for conclusions regarding the nuclear incompressibility. Because of the strong IS0/IS2 coupling, the deformation splitting of the ISGQR will also be analysed.

Experimental setup

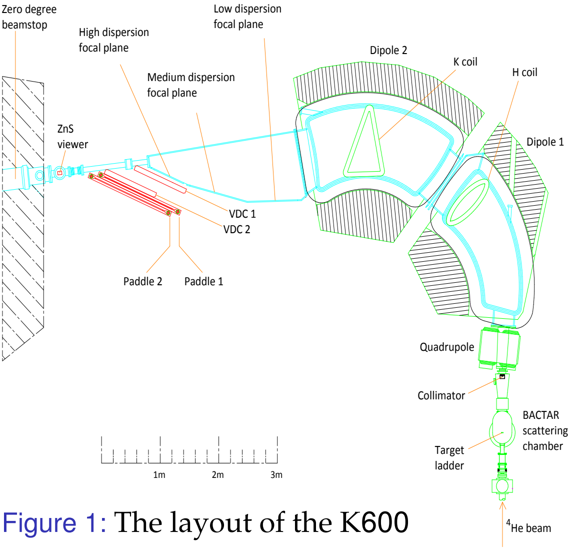
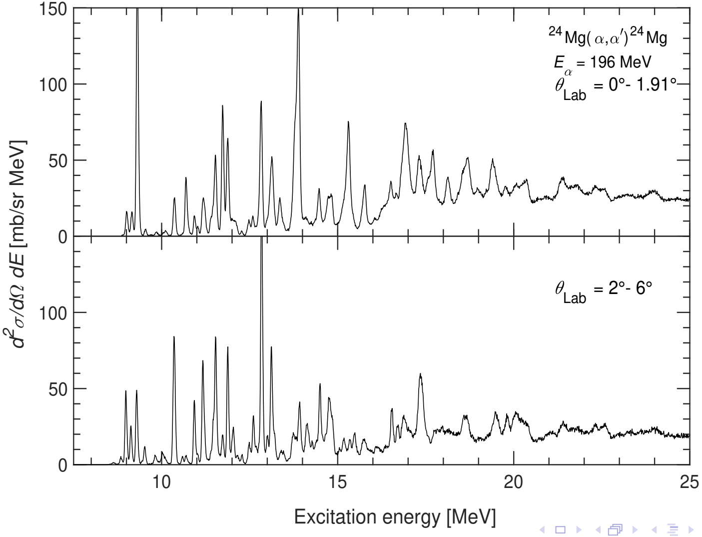


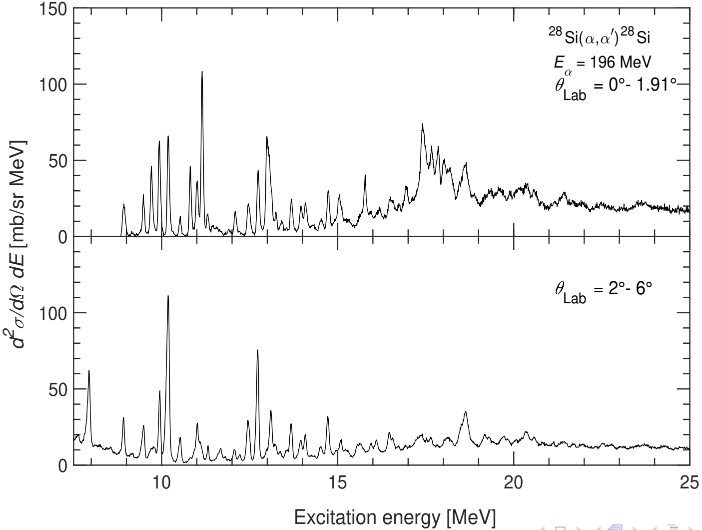
Figure 1: The layout of the K600 magnetic spectrometer.

- (α,α') scattering using the K600 magnetic spectrometer positioned at zero and four degrees (angular acceptance of $\pm$ 1.91°).
- 196 MeV α-particles beam interacts with either a 0.23 mg/cm^2 thick ^{24}Mg or a 0.23 mg/cm^2 thick ^{28}Si foil.
- "background-free" and high energy-resolution inelastic alpha scattering spectra were obtained.

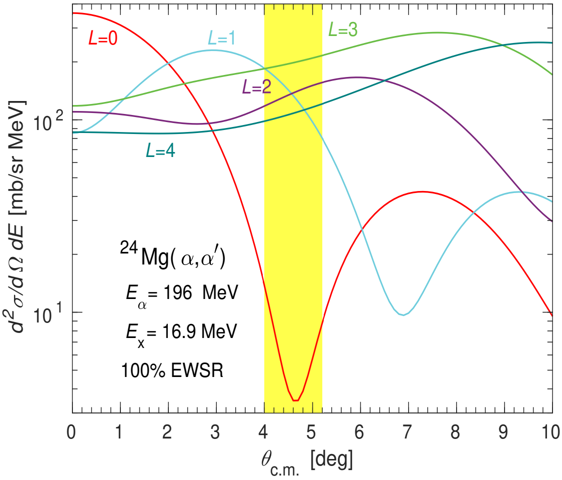
Double-differential cross sections: ^{24}Mg



Double-differential cross sections: ^{28}Si

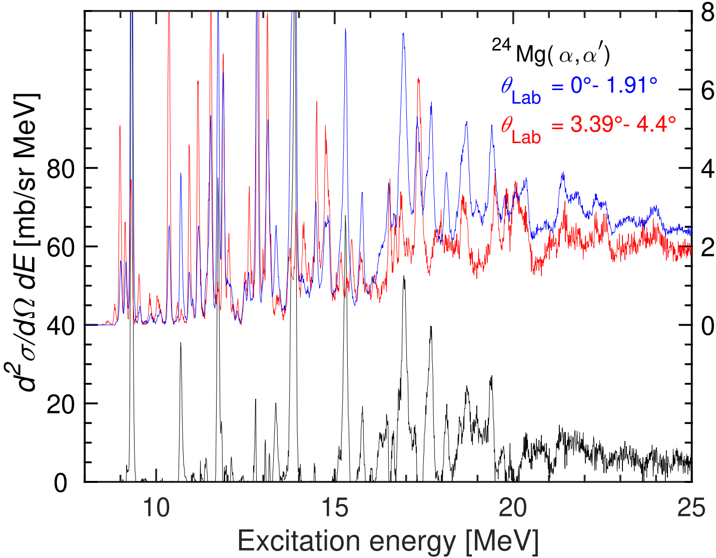


DWBA calculations for the application of the Difference-of-Spectra (DoS) technique.

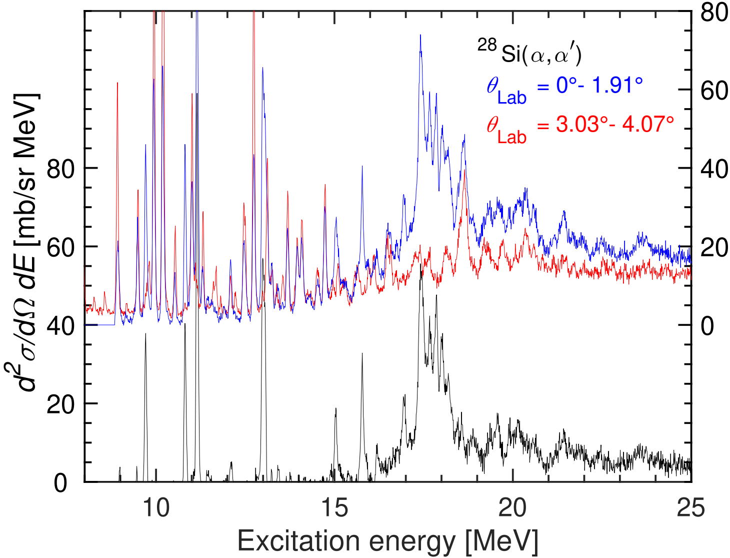


- The method consists of subtracting a spectrum obtained from an angle cut of the 4° data where the angular distributions for the other multipolarities except $L = 0$ are nearly flat, and that of GMR is at a minimum, from the spectrum obtained with data taken at 0°.

Difference-of-Spectra (DoS) results: ^{24}Mg



Difference-of-Spectra (DoS) results: ^{28}Si



IS0 strength distributions determination

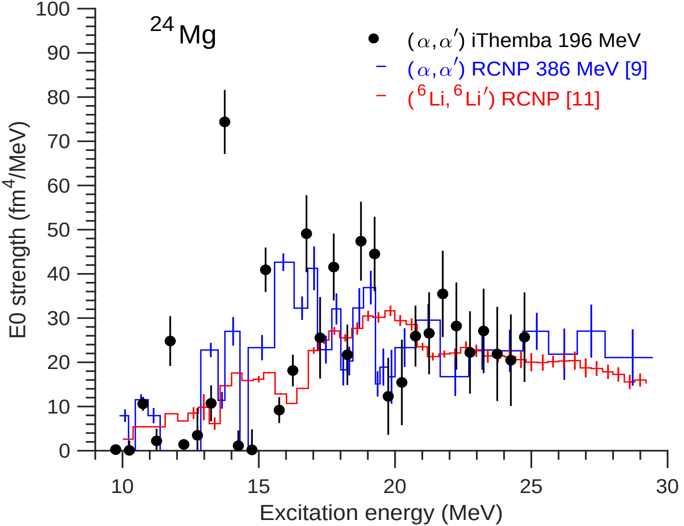
- The measured cross sections can be converted to fractions of the EWSR (a_0) by comparing with DWBA calculations assuming 100% EWSR.

- The strength is then calculated using the a_0 values and is expressed as

$$S_0(E_x) = \frac{2\hbar^2 A\langle r^2\rangle}{mE_x} a_0(E_x) \,, \tag{1}$$

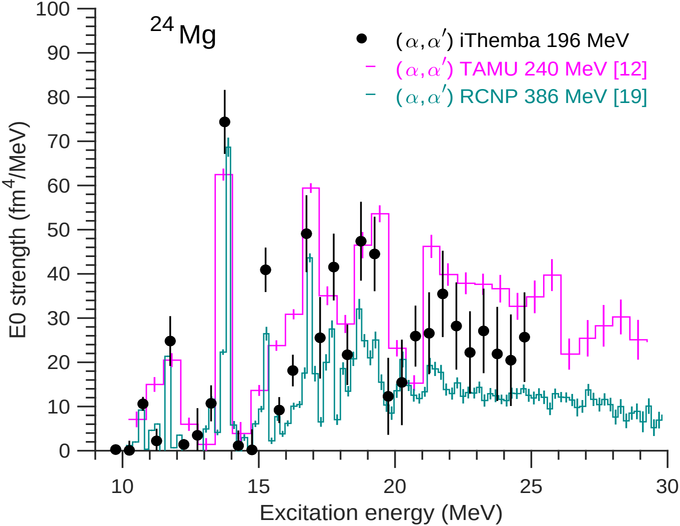
where m is the nucleon mass, E_x is the excitation energy corresponding to a given state or energy bin, and $\langle r^2\rangle$ is the second moment of the ground-state density. We use $\langle r^2\rangle = 9.345$ fm^2 for ^{24}Mg and 9.753 fm^2 for ^{28}Si.

IS0 strength distributions results: ^{24}Mg



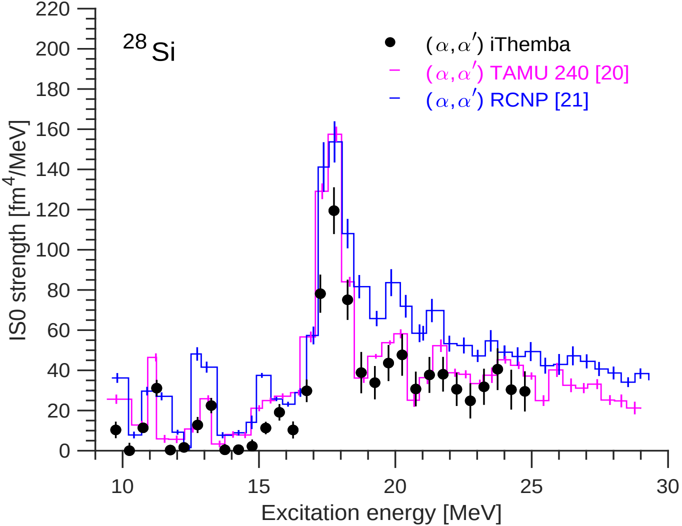
[9] Y. K. Gupta *et al*, Phys. Lett. B 748, 343 (2015), [11] J. C. Zamora *et al*, Phys. Rev. C 104, 014607 (2021)

IS0 strength distributions results: ^{24}Mg



[12] D. H. Youngblood *et al*, Phys. Rev. C 80, 064318 (2009), [19] T. Kawabata, Few-Body Syst. 54, 1457 (2013)

IS0 strength distributions results: ^{28}Si



[20] D. H. Youngblood *et al*, Phys. Rev. C 76, 027304 (2007), [21] T. Peach *et al*, Phys. Rev. C 93, 064325 (2016)

The strengths S(IS0) and % EWSR exhausted by the strongest discrete states: ^{24}Mg

E_x (MeV)[1]	E_x (MeV)[2]	E_x (MeV)[3]	% EWSR[1]	% EWSR[2]	S(IS0)[1] (fm^4)
9.31(1)	9.30539(24)		1.0(1)	1.4(3)	19.9(20)
10.68(1)	10.6797(4)		0.31(5)	0.29(6)	5.32(61)
11.73(1)	11.7281(10)		0.77(11)	1.0(2)	12.1(16)
13.36(2)		13.37(1)	0.40(5)	0.5(1)	4.32(71)
		13.79(1)		1.7(3)	
13.87(2)	13.884(1)	13.89(1)	2.8(3)	2.6(5)	37.7(38)
15.32(2)		15.33(3)	1.7(2)	1.9(4)	20.7(25)

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[1] Present experiment.

[2] National Nuclear Data Center (NNDC), `http://www.nndc.bnl.gov/ensdf/`.

[3] P. Adsley *et al*, Phys. Rev. C 103, 044315 (2021).

The strengths S(IS0) and % EWSR exhausted by the strongest discrete states: ^{28}Si

E_x (MeV)[4]	E_x (MeV)[5]	% EWSR[4]	% EWSR[5]	S(IS0)[4] (fm^4)
9.70(2)	9.71(2)	0.22(4)	0.38(8)	5.2(6)
10.81(2)	10.81(3)	0.27(4)	0.35(7)	5.7(6)
11.14(2)	11.142(1)	0.8(1)	0.9(2)	15.3(17)
13.00(2)	12.99(2)	0.95(12)	0.8(2)	16.9(18)
15.03(3)	15.02(3)	0.40(9)	0.8(2)	6.0(15)
15.77(3)		0.7(1)		9.7(16)

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[4] Present experiment.

[5] P. Adsley *et al*, Phys. Rev. C 95, 024319 (2017).

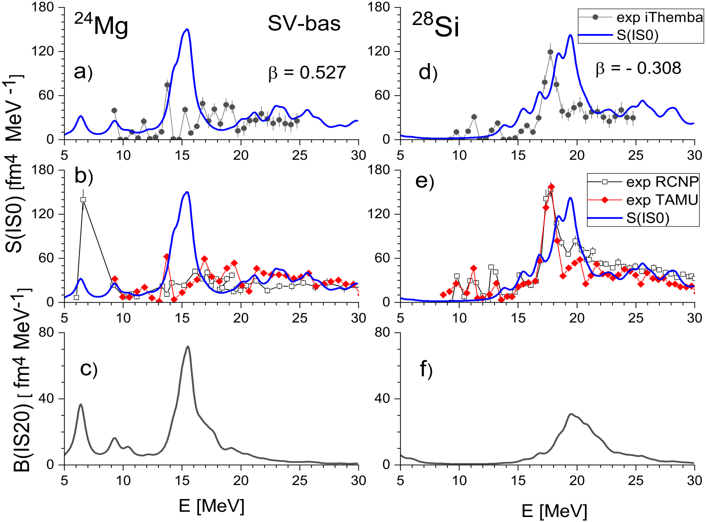
QRPA calculations and comparison with experiment

- The calculations were performed within the quasiparticle random-phase approximation (QRPA). A representative set of Skyrme forces is used.

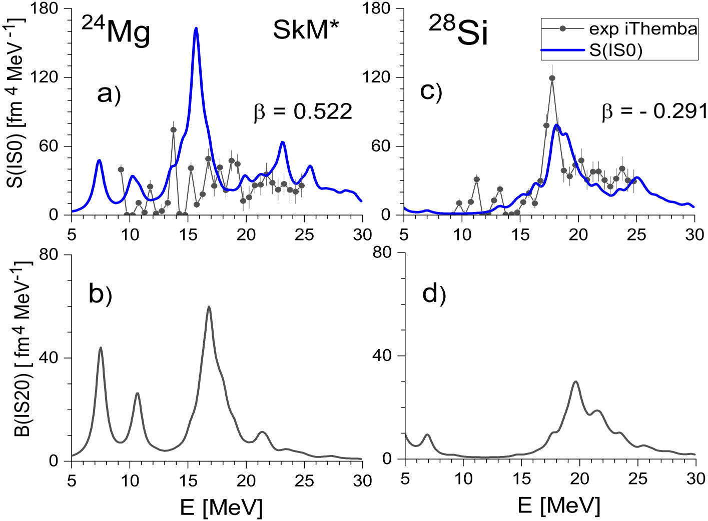
- Incompressibility K_∞ and isoscalar effective mass m_0^*/m for the Skyrme forces SV-bas, SkM*, SkP$^\delta$, SkT6 and SV-mas10 used in the present analysis.

	SV-bas	SkM*	SkP$^\delta$	SkT6	SV-mas10
K_∞ (MeV)	234	217	202	236	234
m_0^*/m	0.9	0.79	1	1	1

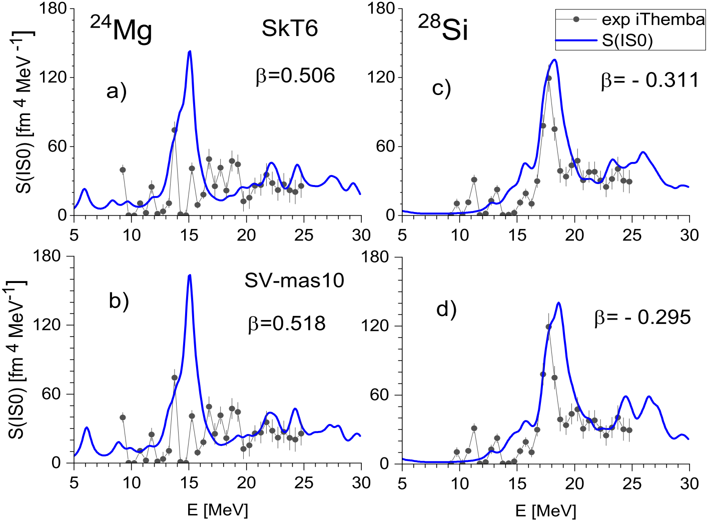
QRPA calculations and comparison with experiment: SV-bas force ($K_\infty = 234$ and $m_0^*/m = 0.9$)



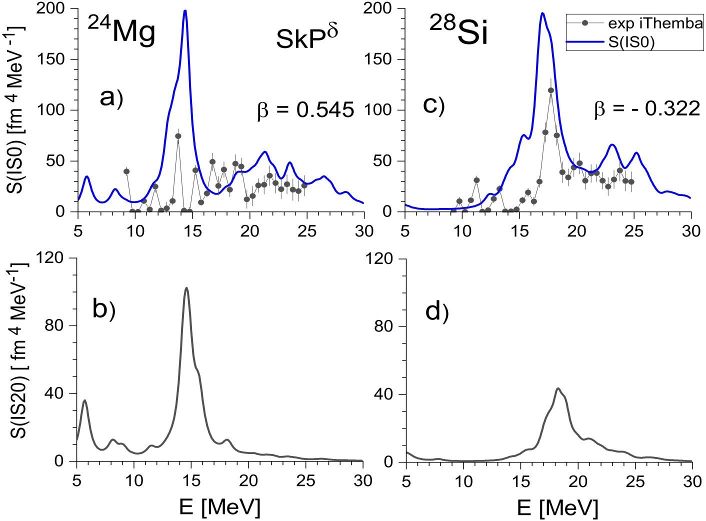
QRPA calculations and comparison with experiment: SKM* force ($K_\infty = 217$ and $m_0^*/m = 0.79$)



QRPA calculations and comparison with experiment: SkT6 and SV-mas10 forces ($K_\infty = 236/4$; $m_0^*/m = 1$)



QRPA calculations and comparison with experiment: SkP$^{\delta}$ force (K_{∞} = 202 and $m_0^*/m = 1$)



QRPA calculations and comparison with experiment

- Peak energy E_p of the narrow IS0 resonance and summed strength $\sum_\nu B_\nu$(IS0) in the energy interval 9 – 25 MeV from various Skyrme forces compared with the present experimental data.

		^{24}Mg		^{28}Si	
	K_∞ (MeV)	E_p (MeV)	$\sum B$(IS0) (fm^4)	E_p (MeV)	$\sum B$(IS0) (fm^4)
Exp.		13.75(2)	728(41)	17.75(3)	895(40)
SkP$^\delta$	202	14.3	796	17.0	908
SkM*	217	15.6	706	18.0	780
SVbas	234	15.4	634	19.4	685
SV-mas10	234	15.0	613	18.6	677
SkT6	236	15.0	575	18.2	640

Conclusions

- The isoscalar monopole strength in the energy interval $9 \leq E_x \leq 25$ MeV in ^{24}Mg and ^{28}Si has been investigated using α-particle inelastic scattering with a 196 MeV beam at scattering angles $\theta_{\mathrm{Lab}} = 0^\circ$ and 4°.

- The DoS technique was applied in order to extract the IS0 strength distributions. Overall, the strength distributions obtained in this study show a reasonable agreement with results from both groups, with exception of the RCNP data[a].

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[a] [9] Y. K. Gupta *et al*, Phys. Lett. B 748, 343 (2015)

- The extracted IS0 strength distributions were compared to calculations performed in the framework of QRPA. A representative set of Skyrme forces (SkM*, SV-bas, SkP$^\delta$, SkT6 and SV-mas10) with different incompressibility values was used.

Conclusions

- The present iThemba LABS experimental data for the ISGMR in ^{24}Mg and ^{28}Si are best described by the force SkP$^{\delta}$ with a low incompressibility $K_{\infty} = 202$ MeV. This force allows the reproduction of both i) the energy of the narrow IS0 peaks at 13.8 MeV in ^{24}Mg and 18 MeV in ^{28}Si and ii) the integral IS0 strengths $\sum B(\mathrm{IS0})$.

- The comparison of IS0 and IS2 strength distributions justifies that the narrow IS0 peak appears due to the deformation-induced coupling between the ISGMR and the $K = 0$ branch of the ISGQR.[a]

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[a] A. Bahini *et al*, Phys. Rev. C **105**, 024311 (2022)

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LABS
Laboratory for Accelerator
Based Sciences

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