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RECENT RESULTS WITH THE ACTIVE TARGET MAYA*

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for the MAYA and ACTAR collaborations

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The active target MAYA, built at GANIL in the beginning of the years 2000, is a Time Projection Chamber (TPC) for low-energy nuclear reactions where the gas is employed as a target. By increasing the luminosity, it allowed several type of experiments, in particular with secondary beams, from resonance scattering to fission study. We will present here some of the last results, focusing on the study of giant resonances in exotic nuclei. Preliminary results of the prototype of the future active target: the "ACTive TARget and Time Projection Chamber" (ACTAR TPC) built with a denser (16384 pixels) pad plane and digital electronic is also discussed.

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1. The active target MAYA

MAYA is an active target *i.e.* a detector where the medium (here gas) is used for both detection and (nuclear) reaction.

1.1. Description

MAYA [1] can be characterized as a $28 \times 25 \times 20\,\mathrm{cm}^3$ TPC (Fig. 1). The electrons produced by the particles ionizing the gas drift down the electric field to amplifying wires set parallel to the beam, which also provides timing for the drifted electrons. The amplified signal is induced on the anode, a matrix of 32×32 hexagonal pads of 5 mm size organized like a honeycomb. Charged particles that escape the active volume in the forward direction can have their position and energy measured by ancillary detectors (see below for details).

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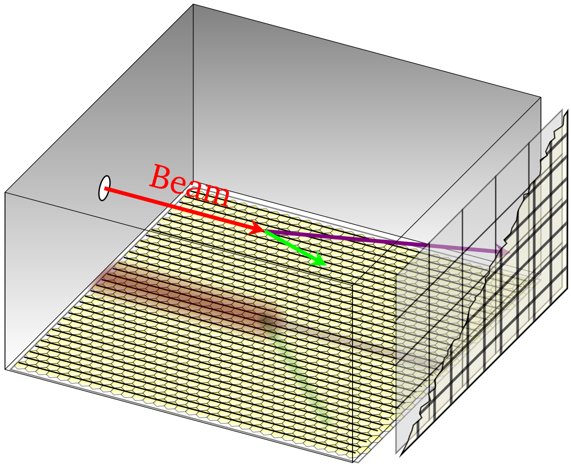

Fig. 1. (Color online) "Artist view" of the active target MAYA. The beam is coming from the left, reacts and "produces" two particles (black/violet and light gray/green arrows) detected in the gas (bottom projection on the anode pads) and in the ancillary detectors for the black/violet track (Si/CsI array).

1.2. Evolution

From the first design, several improvements were performed. The granularity of the ancillary detectors (Si/CsI array) has been improved (4×5 array to 8×10 CsI) and a small drift chamber was added before the silicons to improve position measurements perpendicularly to the beam. Active masks to be put around the beam were developed. They reduce (or cancel) the amount of electrons collected on the anode, increasing the sensitivity to the recoiling particles [2, 3]. A retractable source was added in order to monitor MAYA without the need to open it. Finally, we optimized gas mixing in order to fill MAYA with helium gas with the minimum amount of CF_4 or CO_2 as the quencher.

1.3. List of performed experiments

Several types of experiments were carried out using MAYA: from inelastic scattering or transfer reactions to fission. An exhaustive list is presented in Table I showing also that this detector was moved from GANIL to CERN/ISOLDE or TRIUMF. In the following, we will focus on the study of giant resonances in unstable nickel isotopes.

TABLE I

List of experiments performed with MAYA at different sites: (1) GANIL, (2) TRIUMF and (3) ISOLDE.

Beam @ Energy [A MeV]	Facility	Reaction	Gas	Pressure [mbar]	Goal	Reference(s)
^{8}He @ 3.9	SPIRAL$^{(1)}$	$p(^{8}\mathrm{He},^{8}\mathrm{He})p$	C_4H_{10}	1×10^{3}	^{9}He	[4]
^{8}He @ 15.4	SPIRAL$^{(1)}$	$^{12}\mathrm{C}(^{8}\mathrm{He},^{7}\mathrm{H})^{13}\mathrm{N}$	iC_4H_{10}	30	^{7}H	[5, 6]
^{56}Ni @ 50	SISSI$^{(1)}$	$d(^{56}\mathrm{Ni},^{56}\mathrm{Ni}^{*})d$	D2	1×10^{3}	ISGMR	[7, 8]
^{11}Li @ 3.6	ISAC2$^{(2)}$	$p(^{11}\mathrm{Li},^{9}\mathrm{Li})t$	C_4H_{10}	100–600	^{11}Li	[9–11]
^{11}Li @ 4.5	⋮	$p(^{11}\mathrm{Li},^{10}\mathrm{Li})d$ …				
^{9}Li @ 3.6	⋮	$p(^{9}\mathrm{Li},^{9}\mathrm{Li})p$				
^{68}Ni @ 50	LISE$^{(1)}$	$d(^{68}\mathrm{Ni},^{68}\mathrm{Ni}^{*})d$	D2	1×10^{3}	ISGMR	[12, 13]
^{68}Ni @ 50	⋮	$\alpha(^{68}\mathrm{Ni},^{68}\mathrm{Ni}^{*})\alpha$	He/CF_4	500	ISGMR	[13, 14]
^{56}Ni @ 50	LISE$^{(1)}$	$\alpha(^{56}\mathrm{Ni},^{56}\mathrm{Ni}^{*})\alpha$	He/CF_4	500	ISGDR	[15, 16]
^{8}He @ 15.4	SPIRAL$^{(1)}$	$^{19}\mathrm{F}(^{8}\mathrm{He},4n{+}^{3}\mathrm{H})^{20}\mathrm{Ne}$	CF_4	20	^{7}H	
^{12}Be @ 3.	REX$^{(3)}$	$p(^{12}\mathrm{Be},^{12}\mathrm{B})n$	iC_4H_{10}	100	^{13}Be	[17, 18]
^{238}U @ 6.	GANIL	^{238}U, fission	iC_4H_{10}	50	Surrogate	
^{12}C @ 7.	ORSAY	$^{12}\mathrm{C}(\alpha,3\alpha)\alpha$	He/CF_4	10^{3}	3α TEST	→ ACTAR test

2. Giant resonances

Measurements of giant resonances in exotic nuclei could help clarify problems related to nuclear incompressibility [19]: despite significant progress in our understanding, one cannot converge towards a value that is more accurate than the 10%–20% level. The measurement of compression modes in exotic nuclei is, therefore, of paramount importance and would significantly improve our understanding of nuclear matter incompressibility.

This type of measurement is a particularly challenging task and has, until now, been mainly limited to the isovector (protons and neutrons out of phase) giant dipole resonance in neutron-rich radioactive isotopes [20]. We present here a summary of the few measurements of compression modes in exotic nuclei, all obtained with the active target MAYA at GANIL.

2.1. ISGMR and ISGDR in Nickel–56

To study IsoScalar Giant Monopole Resonance (ISGMR) and IsoScalar Giant Dipole Resonance (ISGDR), both compression modes, it is necessary to use isoscalar probes, if possible with the minimum of structure (deuteron or alpha). In these experiments performed on unstable nuclei, the nucleus of interest is obtained as a secondary beam (with a weak intensity), forcing to perform experiments in reverse kinematics. The direct consequences are that the recoil particle of interest is emitted at a very low energy and around zero degree in the laboratory frame. These challenging conditions can be overcome by the use of active target which increases the target thickness while still allowing the low energy recoil particles to be detected.

Two experiments were carried out in the neutron deficient ^{56}Ni: both were inelastic scattering either on deuteron [7, 8] or alpha [15, 16]. They both independently extracted the position (19.3±0.5 MeV) and the strength (136 ± 27% EWSR) of the ISGMR. The second experiment also provided hints on the strength distribution of the ISGDR (see Fig. 2) which is comparable to the neighboring stable ^{58}Ni.

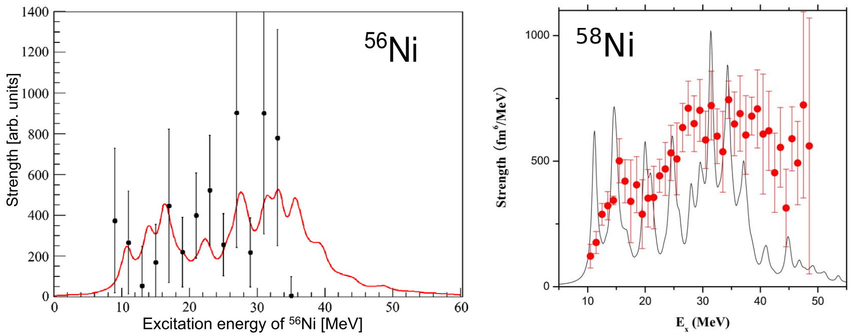

Fig. 2. Experimental ISGDR strength for ^{56}Ni [15] and the stable ^{58}Ni [21] (points), compared to calculations (lines).

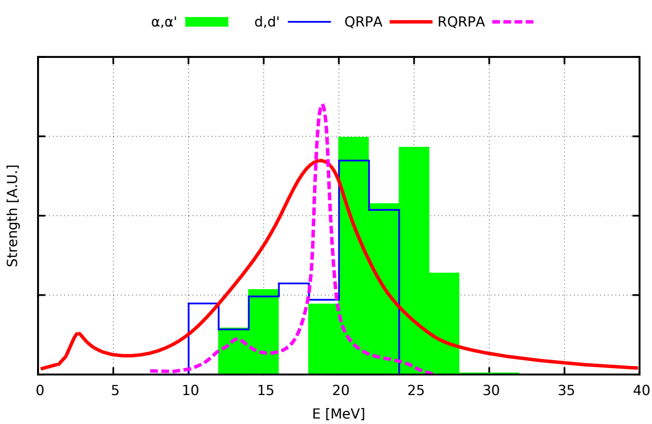

Fig. 3. (Color online) Experimental ISGMR strength for ^{68}Ni obtained with inelastic scattering on deuteron (thin black/blue line) and alpha (gray/green areas) compared to QRPA [22] and RQRPA [23] calculations.

2.2. ISGMR and soft compression mode in Nickel–68

The ISGMR was also studied using this different probes in the neutron-rich ^{68}Ni [12–14]. Results of the different analysis (target and procedures) are compiled in Fig. 3 which shows the ISGMR strength extracted compared to theories. In the (α, α') experiment, an indication of a soft monopole mode, as predicted by theories, was observed around 13 MeV.

3. ACTAR TPC and ACTAR demonstrator

3.1. ACTAR TPC

Studies on giant resonances will be pursued in the future at GANIL using the new active target ACTAR TPC. This detector, founded by ERC, was designed to be highly versatile and differs from MAYA, especially in the detection system based on Micro-MEsh GAseous Structure (micromegas) [24]. The 16,384 square pads of 2×2 mm^2 are equipped with the General Electronics for TPC (GET) [25] which is a digital electronic allowing complex triggering conditions.

3.2. Demonstrator

The demonstrator is a smaller version (2,048 pads) of ACTAR TPC [24], and several experiments and tests were already performed at ALTO/Orsay and at GANIL. In particular, the accepted beam time for the 3α experiment listed in Table I was used with demonstrator of ACTAR TPC. Preliminary results for the excitation energy built using only the scattered alpha in the Si/CsI array shows the principal states of ^{12}C. Analysis of the coincidence with the 3α decaying from Hoyle states will certainly provide insight in the structures of this states. Another test was also performed at GANIL with a ^{58}Ni beam impinging on isobutane. Although the conditions were different from those of the ISGMR experiments, preliminary results show that the resolution for the excitation energy is of approximately one order of magnitude better that with MAYA.

4. Conclusion

We presented here recent and pioneer results obtained with the active target MAYA. This type of detector is well-suited for the new generation of radioactive beams produced around the world. In addition to the new ACTAR TPC device built in Europe, several projects are now developed — among them AT-TPC at MSU (USA) or the Center for nuclear study Active Target (CAT) at CNS (Japan). In parallel to active targets, electromagnetic storage rings are promising device to perform experiments with very low-energy recoiling particles.

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