Letter of intent for the 5th AGATA PREPAC- ^{238}U beam

Lifetimes of excited states along and around the N=50 shell closure

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Physics case

Isotopes around ^{78}Ni are at the very edge of the present knowledge in nuclear shell structure. The *N* = 50 region nearby has been the object of an intense research in the last years, with the first spectroscopic study of ^{78}Ni having been published recently [1]. The development of deformation around the *N* = 50 shell closure [1, 2] as well as the reduction of the *N* = 50 shell gap [3, 4] when approaching ^{78}Ni, have motivated many different measurements. The *N* = 50 gap size has been deduced by mass measurements up to ^{80}Zn [3, 4], showing a decrease of the gap from *Z* = 40 to *Z* = 32, before increasing again towards ^{80}Zn [3, 4]. In these nuclei, an alternative estimate of the gap size is provided by the medium-spin states $5^+,6^+,7^+$ in *N* = 50 even-even isotones, and analogous $13/2^-$ and $15/2^-$ states in the odd isotones: their wave function involves one particle-one hole neutron excitations across *N* = 50 (the protons in the *fp* shells above *Z* = 28 can only generate spins up to 4^+ by breaking one pair). The lowering in the energy of the *N* = 50 core-breaking 5^+, 6^+ and 7^+ levels in $^{86}Kr_{50}$, $^{84}Se_{50}$ and $^{82}Ge_{50}$ [5, 6] mirrors the mass measurement until $^{82}Ge_{50}$. However, the "spectroscopic gap" seems to continue decreasing in ^{81}Ga [7], while no $5^+,6^+,7^+$ states are known in ^{80}Zn to verify a possible re-increase in analogy with the mass measurements [8].
Indeed, the first spectroscopy of ^{78}Ni and ^{79}Cu has opened some questions. In ^{78}Ni, recent large-scale shell- model calculations predict an intruder structure close to and even lower than the first 2^+ state, which is already lying at a rather low energy for a s doubly-magic nucleus Gamma-ray spectroscopy of ^{78}Ni has provided tentative evidence of intruder states [1]. In ^{79}Cu the first spectroscopy via proton-knockout has revealed a number of states around the ^{78}Ni 2^+ energy quite difficult to disentangle [9], with no evidence of a low-lying proton $f_{7/2}$ strength coming from a *Z* = 28 core break, important for the ^{78}Ni 2^+ level energy [1, 2].
A strictly correlated issue is the appearance of shape coexistence close to ^{78}Ni. The discovery of a low-lying 0^+ state in *N* = 48 ^{80}Ge was interpreted as an evidence of shape coexistence [10], although a subsequent work could not observe this state [11]. Odd-even *N* = 49 isotones from *Z* = 38 to *Z* = 30, are characterized by the presence of intruder $1/2^+$ and $5/2^+$ states which lower to an excitation energy of only $\sim$ 500 keV in $^{83}Se_{49}$, at mid of the proton *Z* = 28 − 40 shell [12]. These non-yrast intruder states may appear as long-lived β-decaying isomers if they become the first excited state, like the $1/2^+$ isomer in $^{81}Ge_{49}$ and $^{79}Zn_{49}$ [12], because their γ-ray decay to the $9/2^+$ ground state is hindered by the spin difference. The isomer in ^{79}Zn was found to have a

large mean square radius compared to the ground state [13], a convincing evidence of shape coexistence. Also in odd-odd *N* = 49 isotones experimental evidence of low-lying intruder states has been found [14].

From this discussion, it follows that there is a need to probe the wave functions of nuclei around the N=50 shell closure, to detect intruder structures as well as to understand the quadrupole collectivity developing towards the new predicted island of inversion below ^{78}Ni.
This LoI thus has two aims:

a) Searching for single-particle E2 or suppressed M1 transitions in ^{85,87}Se, ^{82,83}Ge, ^{80,81,82}Ga, ^{80}Zn. The energy of states breaking the N=50 shell closure, as well as of intruder states, is a crucial probe for both the N=50 spherical gap as well as the correlations moving towards ^{78}Ni. Such states will decay with weak, if not suppressed, transitions to the normal spherical configurations. On the contrary, intruder states should be linked by large E2 strengths.

b) Measuring lifetimes of yrast and yrare 2^+, 4^+ and 6^+ states in ^{86}Se,^{88}Se, ^{84}Ge (to confirm the large B(E2) found at GANIL) and ^{86}Ge. The lifetime of the 4^+ of ^{80}Zn could also be an aim. Here the aim is to understand how rotational/triaxial collective structures develop in the valence space beyond N=50, a crucial probe for how well shell-model interactions can describe this largely unexplored region of the Segré chart.

Experiment

We propose to use a ^{238}U beam at 6.3 MeV/u and 0.4 pnA on a ^{9}Be target (around 1.8 mg/cm^2). The degrader will be either Mg or Nb, with a thickness around 5 mg/cm^2 in the case of Mg. PRISMA will be placed at an angle as forward as feasible with the counting rate, typically around 24-26 degree. The foreseen beam time request is 21 days.
The gain with the LNL Prisma-AGATA compared to the previous VAMOS-AGATA setup at GANIL is quantified in the table below.

	AGATA-VAMOS	AGATA-PRISMA	Gain factor
Beam	238U @ 6.3 MeV/u, 25enA: 0.2 pnA at 28 degrees	238U @ 7.2 MeV/u: ~0.4 pnA at 28 degrees	~2
Dead Time	0.5kHz of trigger (no deadtime)	1kHz (no deadtime)	1
Crystals	24	33	
Agata position	Compact (14cm to target)	Compact	
Single efficiency	~2% *	~6.5% (measured at 1 MeV)	3
Target	9Be, 10um (1.85mg/cm2)	9Be, 10um (1.85 mg/cm2)	1
Beam Time	6 days	21 days	3.5
Acceptance	$\Delta\theta$_± 6∘;$\Delta\phi$_± 10∘	$\Delta\theta$_± 6∘;$\Delta\phi$_± 9∘	0.8
Total			18

With the predicted gain in the product yield, we propose to run for three weeks with a ^{238}U beam at 6.2 MeV/u (0.5 pnA) on a ^{9}Be target with the AGATA-PRISMA setup.

*Private communication: Dudouet measured the efficiency for 100Zr add-back for 497.3 keV transition 6+ → 4+
The efficiency was 2.75%: scaled for 1 MeV it was ~ 2%, not the predicted 4%.

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