Appendix 2 - Funding application - PN-IV-ID-PCE-2023-1

The document, is in A4 format, uses Times New Roman font, 12 font size, 1.15 line spacing and 2 cm margins. Any modification to these parameters is forbidden (excepting the figures and their captions). The explanatory text is preserved. The imposed number of pages (Section C – Funding application) does not contain the requested Budget (Section C6) and Bibliographic references (Section C7), these will be written on additional pages. For each section the text marking the information and the mandatory sections of the application will be maintained.

B. Project leader

Name: DELION
Surname: DORU-SABIN

B1. Important scientific achievements of the Project leader (maximum 2 pages)

The most important contributions of the Project leader in her/his research domain will be presented (e.g. development of new research directions, elaboration of research theories, methodes, strategies and techniques, findings or results that have significantly led to a better knowledge in the domain, demonstrated trough reference publications and patents).

The project leader is an expert in the field of theoretical nuclear structure. He published as a single author a monograph in the field of emission processes [Delion(2010)], three review papers in the prestigious journal Physics Reports and several papers widely cited in scientific literature. His important contributions were obtained in two main areas:

(A) Theoretical nuclear structure studied through emission processes

(A.1) Explanation of the anisotropic alpha emission, in terms of the shell model preformation factor and semiclassical approach for the deformed Coulomb barrier penetration [Delion(1992)];

(A.2) Systematics of proton emission, expressing the half-lives reduced by centrifugal barrier in terms of the Coulomb parameter. This result is widely used by experimental groups when predicting new proton emitters [Delion(2006),Delion(2006)a];

(A.3) Analytic derivation of a universal rule for reduced decay widths, valid for all emission processes triggered by the strong interaction, in terms of a phenomenological surface cluster model [Delion(2009)];

(A.4) Microscopic description of alpha and cluster emission processes by using a mean field with a surface term, describing four-body correlations on the nuclear surface, able to reproduce the experimental trend of absolute decay widths versus the mass number [Delion(2013)];

(A.5) Coupled channels approach in terms of the Coherent State Model, able to simultaneously describe energy levels, electromagnetic transitions and alpha-decay intensities to excited states in vibrational, transitional and rotational nuclei, by using one deformation parameter [Delion(2015)];

(A.6) Systematics of the axial vector coupling strength for weak interactions in deformed nuclei by using a new version of proton-neutron deformed quasiparticle random phase approximation [Delion(2019)].

(B) Many-body description of nuclear systems

(B.1) Microscopic description of four-body resonances above doubly magic ^{208}Pb [Delion(2000)] and ^{40}Ca [Delion(2001)], in terms of a simplified version of the Multi-Step Shell Model (MSM);

(B.2) Microscopic Anharmonic Vibrator Model (MAVA), describing the structure of two-phonon states and their electromagnetic [Delion(2003)], beta and double beta decay transitions [Delion(2007)], by using the coupling of two spherical RPA phonons to a given multipolarity;

(B.3) Selfconsistent Random Phase Approximation (SCRPA), by using a coupled nonlinear system of Hartree-Fock and RPA equations. The numerical SCRPA description of the Goldstone zero energy mode became possible for the first time within the three-level Lipkin model [Delion(2005)];

(B.4) Explanation of the quasi-constant behavior for both energies and transition probabilities from the lowest collective levels of nuclei above the doubly magic nucleus ^{100}Sn, given in terms of the proton-neutron pairing interaction [Delion(2010)];

(B.5) Description of the deformed many-body systems în the laboratory system, by using a deformed single particle basis with a good angular momentum in terms of Wigner rotation functions, explaining the systematics of electromagnetic transitions from 2^+ states in even-even nuclei [Delion(2013)], beta and double beta decays from odd-odd emitters [Delion(2019)].

B2. The visibility and the impact of the scientific contribution of the Project leader

a) *Share of articles published in Q1 (red zone)/Q2 (yellow zone) journals, from the total number of published articles. For the Humanities 1) the share of publications published abroad from the total number of publications and 2) the share of publications from publishing houses and in classified A and B journals from the total number of publications published in Romania (Appendixes 7a, 7b), will also be mentioned;*
Total number of published articles https://www.nipne.ro/7369-staff_info.html = 168
Articles published in Q1 (red zone) = 12 (7.14%);
Articles published in Q2 (yellow zone) = 84 (50.00%); Total Q1+Q2 = 96 (57.14%)

b) *For Natural Sciences, Exact Sciences, Engineering Sciences and Social and Economic Sciences, the total number of citations and the average of citations per publications (without self-citations), according to the Web of Science Core Collection/Scopus; a maximum 10 citations that the Project leader considers relevant will be indicated, and in the case of the Humanities, the relevant reviews of the Project leader's books/volumes will also be indicated (maximum 10 together with the relevant citations);*
Total number of WoS citations (without self-citations) = 2.420 / 168 publications
= 14.40 citations/publication
The most relevant 10 citations by papers published in journals of Q1 red zone. The number in square brackets represents the corresponding paper in the list f) below
1) [1] cited by J.G. Deng and H.F. Zhang, Phys. Lett. B **816**, 136247 (2021).
2) [1] cited by J.M. Dong, et.al., Phys. Lett. B **813**, 136063 (2021).
3) [1] cited by D. Bai and Z.Z. Ren, Phys. Lett. B **786**, 5-10 (2018).
4) [1] cited by C. Qi, et. al., Phys. Rev. Lett. **103**, 072501 (2009).
5) [2] cited by F. Wang, et. al., Phys. Lett. B **770**, 83-87 (2017).
6) [2] cited by I. Celikovic, et. al. Phys. Rev. Lett. **116**, 162501 (2016).
7) [3] cited by K. Auranen, et. al., Phys. Rev. Lett. **128**, 112501 (2022).
8) [7] cited by S.M. Wang and W. Nazarewicz, Phys. Rev. Lett. **120**, 212502 (2018).
9) [10] cited by P. Mohr, et.al., Phys. Rev. Lett. **124**, 252701 (2020).
10) [10] cited by Z.Y. Zhang, et.al., Phys. Rev. Lett. **126**, 152502 (2021).

c) *Hirsch Index according to the Web of Science and Hirsch Index (without self-citation) according to Scopus;* **Hirsch index (WoS)=30, Hirsch index without self-citations (Scopus)=27**

d) *Personal link from the platform at* https://www.brainmap.ro/
   https://www.brainmap.ro/doru-sabin-delion
e) *The address of the profile from at least one of the following sites will be indicated: Scopus Author ID, ORCID, Researcher ID, Google Scholar, MR Author ID;*
   https://scholar.google.com/citations?user=i3AkpqgAAAAJ
   https://orcid.org/0000-0002-9982-0695
   http://www.researcherid.com/rid/B-9609-2011
f) *A maximum number of 10 representative scientific results from the domain of the project proposal will be indicated (according to the list of domains within which the projects are ranked, Appendix 5), regardless of their type (articles, book chapters, monographs, patents or any other result considered relevant by the Project leader). If more than 10 scientific results are indicated in this section, the project proposal will be excluded from the competition.*

Publications accepted for publication can also be indicated, specifying the date of acceptance. The evaluation will mainly focus on publications in which the Project leader is the main author. If there are publications published as a co-author that the Project leader considers relevant for her/his scientific production, they can be indicated.

The presentation format is the following:

Identification data:	Authors. *Title of the article*, Title of the Journal/Conference, Volume, Pages (year of publication), category (according to AIS Q1; Q2 etc). *Note: For the Humanities the number of libraries from the online catalogues (without the online bookstores) will be indicated for the articles published in collective volums at publishing houses from other EU member states or OECD member states, with the respective CNCS category for articles published in journals/collective volumes at publishing houses from Romania.*
Is she/he the main author?	*YES/NO (according to Appendix 6)*
Is it in the project domain?	YES/NO
Number of citations:	*According to the Web of Science Core Collection* (see Appendix 6) **Self-citations** will be **excluded**, according to the Web of Science *Core Collection.*
DOI (Digital Object Identifier):	*Optional*

[1]

Identification data:	D.S. Delion, A. Sandulescu, and W. Greiner, *Evidence for alpha-clustering in heavy and superheavy nuclei,* Physical Review C **69**, 044318 (2004). Q2
Is she/he the main author?	YES (according to Appendix 6)
Is it in the project domain?	YES
Number of citations:	**60** *without self-citations according to the WoS Core Collection*
DOI (Digital Object Identifier):	10.1103/PhysRevC.69.044318

[2]

Identification data:	D.S. Delion, R.J. Liotta, R. Wyss, *Theories of proton emission,* Physics Reports **424**, 113 (2006). Q1
Is she/he the main author?	YES (according to Appendix 6)
Is it in the project domain?	YES
Number of citations:	**81** *without self-citations according to the WoS Core Collection*
DOI (Digital Object Identifier):	10.1016/j.physrep.2005.11.001

[3]

Identification data:	D.S. Delion, R.J. Liotta, R. Wyss, *Systematics of proton emission,* Physical Review Letters **96**, 072501 (2006). Q1
Is she/he the main author?	YES (according to Appendix 6)
Is it in the project domain?	YES
Number of citations:	**78** *without self-citations according to the WoS Core Collection*
DOI (Digital Object Identifier):	10.1103/PhysRevLett.96.072501

[4]

Identification data:	D.S. Delion, S. Peltonen, and J. Suhonen, *Systematics of the alpha decay to rotational states,* Physical Review C **73**, 014315 (2006). Q2
Is she/he the main author?	YES (according to Appendix 6)
Is it in the project domain?	YES
Number of citations:	**112** *without self-citations according to the WoS Core Collection*
DOI (Digital Object Identifier):	10.1103/PhysRevC.73.014315

[5]

Identification data:	D.S. Delion, R.J. Liotta, and R. Wyss, *Alpha decay of high spin isomers in superheavy nuclei,* Physical Review C **74**, 044301 (2007). Q2
Is she/he the main author?	YES (according to Appendix 6)
Is it in the project domain?	YES
Number of citations:	**57** *without self-citations according to the WoS Core Collection*
DOI (Digital Object Identifier):	10.1103/PhysRevC.76.044301

[6]

Identification data:	D.S. Delion, *Universal decay rule for reduced widths,* Physical Review C **80**, 024310 (2009). Q2
Is she/he the main author?	YES (according to Appendix 6)
Is it in the project domain?	YES
Number of citations:	**62** *without self-citations according to the WoS Core Collection*
DOI (Digital Object Identifier):	10.1103/PhysRevC.80.024310

[7]

Identification data:	D.S. Delion, R.J. Liotta, and R. Wyss, *Simple approach to two-proton emission,* Physical Review C **87**, 034328 (2013). Q2
Is she/he the main author?	YES (according to Appendix 6)
Is it in the project domain?	YES
Number of citations:	**26** *without self-citations according to the WoS Core Collection*
DOI (Digital Object Identifier):	10.1103/PhysRevC.87.034328

[8]

Identification data:	D.S. Delion and R.J. Liotta, *Shell-model representation to describe alpha emission,* Physical Review C **87**, 041302(R) (2013). Q2
Is she/he the main author?	YES (according to Appendix 6)
Is it in the project domain?	YES
Number of citations:	**30** *without self-citations according to the WoS Core Collection*
DOI (Digital Object Identifier):	10.1103/PhysRevC.87.041302

[9]

Identification data:	D.S. Delion and A. Dumitrescu, *Systematics of the alpha decay fine structure in even-even nuclei,* Atomic Data Nuclear Data Tables **101**, 1 (2015). Q3
Is she/he the main author?	YES (according to Appendix 6)
Is it in the project domain?	YES
Number of citations:	**25** *without self-citations according to the WoS Core Collection*
DOI (Digital Object Identifier):	10.1016/j.adt.2014.09.001

[10]

Identification data:	D.S. Delion, Z.Z. Ren, A. Dumitrescu, and D.D. Ni, *Coupled channels description of the alpha-decay fine structure,* Journ. Physics/Topical Reviews G **45**, 053001 (2018). Q2
Is she/he the main author?	YES (according to Appendix 6)
Is it in the project domain?	YES
Number of citations:	**29** *without self-citations according to the WoS Core Collection*
DOI (Digital Object Identifier):	10.1088/1361-6471/aaac52

Monographs/critical editions of sources/collective volumes/dictionaries/encyclopedias/catalogues: *Only publications published by publishing houses from other EU member states or OECD member states will be indicated, with at least 30 entries in libraries from online catalogues (without online bookstores): for the Humanities the publications published by publishing houses from Romania from Category A and B according to the CNCS classification and from the Republic of Moldova will also be indicated. School or university textbooks are not taken into account even if they are published to prestigious international publishing houses.*

The presentation format is as follows:

Identification data:	Authors. *Book title*, Publishing house title (year of publication)
Is it in the project domain?	YES/NO
Number of libraries according to the online catalogues (without online bookstores):	
University libraries:	Names of the most important university libraries (maximum 10) that purchased the monograph (according to the online catalogues (without online bookstores) or according to the library catalogue).

Patents: *The patents/utility models especially those with techonogical transfer obtained in other countries from the EU or in OECD member countries will be indicated.*

The presentation format is the following:

Identification data:	Authors. *Title of the patent/utility model* (granting year)
Issuing patent bureau:	
Is it in the project domain?	YES/NO

Notes:
Providing false information in Section B2 will lead to the exclusion of the project proposal from the competition.
Section B2 of the application will be public. This will be uploaded to the submission platform, both as an integrated part of the funding application as well as filled in on the submission platform.

B3. The correspondence between the demostrated experience of the Project leader and the proposed theme (max. 1 page).

The relevancy of the scientific experience of the Project leader (demonstrated by her/his publications) for the theme of the proposed project will be underlined.

The main tool to investigate nuclear structure of weakly bound nuclei close to stability lines is given by emission phenomena involving strong as well as weak interaction processes. The project leader (PL) published a monograph on the theoretical description of emission processes induced by strong interaction [Delion(2010)], a review paper on theories of proton emission [Delion(2006)], a review paper on coupled channels description of the alpha-decay fine structure [Delion(2018)] and several publications as a first author in widely recognized scientific journals in the field of nuclear structure close to the proton stability line, concerning:

(a) Proton emission systematics of half-lives corrected by the centrifugal barrier in terms of two straight lines versus the Coulomb parameter, widely used by experimental groups in predicting new proton emitters [Delion(2006)a];

(b) Universal decay rule for the reduced widths, derived analytically in terms of the fragmentation potential (difference between the Colomb barrier and Q-value) and spectroscopic factor, valid for all kinds of particle and cluster emission processes induced by the strong interaction [Delion(2009)].

(c) Explanation of the quasi-constant behavior for both energies and transition probabilities from the lowest collective levels of nuclei above the doubly magic nucleus ^{100}Sn, given in terms of the proton-neutron pairing interaction [Delion(2010)];

(d) Simple approach of two-proton emission in terms of a coupled system of radial equations by using spherical harmonics instead of hyper-spherical ones [Delion(2013)a].

(e) Microscopic description of alpha and cluster emission processes, including surface four-body correlations in the nuclear mean field, simultaneously reproducing the experimental values of electromagnetic transitions and absolute decay widths [Delion(2013)].

(f) Microscopic description of alpha-like resonances, giving a simultaneous description of energy levels, electromagnetic and alpha transitions above doubly magic nuclei ^{208}Pb [Delion(2000)] and ^{40}Ca [Delion(2003)], by using a simplified version of the Multi Step Shell Model. The newly discovered negative parity states evidencing α-clustering in ^{212}Po [Astier(2010)] was mentioned as a Point of View by the American Physical Society https://physics.aps.org/articles/v3/8

PL was invited to give talks in this field at several international conferences and at institutes as a guest scientist, see Section B.4. He was director of several research projects obtained through competition in the field of stability of nuclear systems in various regions of the nuclear chart:

(1) CERES 1-64/2001 “Stability of hadron systems in extreme physical conditions”, IFA,

(2) CERES 4-162/2004 “Investigation of the nuclear structure by proton and cluster emission”, IFA,

(3) IDEI 119/2007 “Exploratory studies on stability of nuclear systems”, UEFISCDI,

(4) IDEI PN-II-ID-PCE-2011-3-0092 “N-body correlations in exotic nuclear systems”, UEFISCDI.

(5) Research grant “Description of the neutrinoless double beta decay in deformed nuclei“, Jyvaskyla University, Finland, 2022.08.01-31

B4. Curriculum Vitae (max. 2 pages)

https://www.nipne.ro/dbpub/cv/Doru.Delion.pdf

(a) Information about the degrees and diplomas

Studies: Faculty of Physics – Theoretical Physics, University of Sankt Petersburg-Russia (1976)

Scientific Title: Ph.D. in Physics, Institute of Atomic Physics, Bucharest-Măgurele (1989)

Thesis: "Description of M1 and M3 magnetic states in even-even nuclei and of M1 states in odd nuclei", Supervisor Prof. A.A. Raduta.

(b) Information about the professional experience and jobs

(1) Senior Researcher - first degree, CS1 (since 1999), Department of Theoretical Physics (DFT), Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest-Măgurele, Romania; **(2)** Associate professor, University of Bucharest, Physics Department-Doctoral School, (since 2001); **(3)** Vice-president of the IFIN-HH Scientific council (2012-2016); **(4)** Professor, Bioterra University, Bucharest (since 2011).

(c) Areas of scientific activity

Theoretical physics:

Nuclear structure: random phase approximation; multi-phonon states; collective magnetic states;

Emission processes: proton, two-proton, alpha and heavy cluster decays, beta and double beta decay, cold fission.

(d) Person in charge for international cooperations of IFIN-HH

(1) FAIR, Germany, Reprezentative of Romania as a member of the NUSTAR Council; (**2) INFN, Italy** (Nuclear structure) Catania University (prof. A. Insolia, M. Baldo and U. Lombardo) 1990-1995 (3 months/year); Napoli University (prof. N. Lo Iudice) 1993 (1 month); (**3) IN2P3, France** (Strongly correlated fermionic systems), Institute des Sciences Nucleaires Grenoble (prof. P. Schuck) 1996, 1998 (3 months/year) ; Institute de Physique Nucleaire Orsay (prof. P. Schuck and N.V. Giai) 2000-2018 (1 month/year) ; (**4) JINR, Dubna,** Russia (Study of the nuclear structure and dynamics), project No. 01-3-1136-2019/2023 (prof. N. Antonenko).

(e) Invited scientist at several universities and institutes

(1) Royal Institute of Technology Stockholm, Sweden (alpha and heavy cluster decays), prof. R.J. Liotta and R. Wyss, 1996 (6 months), 1997-2018 (1 month/year); **(2) Jyvaskyla University**, Finland (alpha clustering, beta and double beta decays), prof. J. Suhonen 1997-2022 (1 month/year); **(3) Tubingen University**, Germany (double beta decay), prof. A. Faessler, 1992, 1994, 1996 (1 month/year); **(4) Frankfurt/Main University**, Germany (cold fission), prof. W. Greiner, 2001-2003 (2 months/year); (**5) Buenos Aires University,** Argentina (alpha clustering), prof. G.G. Dussel, 1999 (1 month); (**6) KAVLI Institute of theoretical physics, Bejing**, China (alpha decay), prof. Z.Z. Ren and F.R. Xu, 2013, 2016 (1 month/year).

Invited seminars were given at each of the above mentioned universities and institutes.

(f) List of publications: https://www.nipne.ro/7369-staff_info.html

- Papers published in scientific journals: 168 (mean number of authors: 3)

Q1: Phys. Rep. (3), Phys. Rev. Lett. (5), Phys. Lett. B (4), **Total Q1=12**; **Q2**: Phys. Rev. C (68), Phys. Rev. A (1), Phys. Rev. E (1), J. Phys. G (12), Eur. Phys. J. A (2), **Total Q2=84**; **Q3**: Nucl. Phys. A (14), Europhys. Lett. (4); , At. Data Nucl. Data Tab. (2), **Total Q3=20**; **Q4**: Int. J. Mod. Phys. E (2), Journals of the Romanian Academy (37), **Total Q4=39**.

- Invited talks published in Proceedings of international conferences (41);

- Books (1), Springer-Berlin;

- Editor of Conference Proceedings: World Scientific (2), Institute of Physics (2).

(g) Organizer of international conferences

(1) International Summer School "New Trends in Theoretical and Experimental Nuclear Physics", Predeal,1991 (scientific secretary); **(2)** International Summer School "Topics in Atomic and Nuclear Collisions", Predeal, 1992 (scientific secretary); **(3)** International Summer School "Collective Motion and Nuclear Dynamics", Predeal, 1995 (scientific secretary); **(4)** International conference "Shell-Model 1997", Stockholm, 1997 (scientific secretary); **(5)** International Summer School "Dynamics of open nuclear systems", Predeal, 2012 (director); **(6)** International conference "Advanced Many-body and Statistical Methods in Mesoscopic Systems I", Constanta, 2011 (director); **(7)** International conference "Advanced Many-body and Statistical Methods in Mesoscopic Systems II", Brasov, 2014 (director) https://web.theory.nipne.ro/Brasov-Meso2014/ **(8)** International conference "Advanced Many-body and Statistical Methods in Mesoscopic Systems III", Busteni, 2017 (director) https://web.theory.nipne.ro/Meso2017/

(h) Scientific referee

Physical Review C, Physical Review Letters, Journal of Physics G, Nuclear Physics A, European Physical Journal A, Physics Letters B, International Journal of Modern Physics E, Chinese Physics C, Indian Journal of Physics, Romanian Journal of Physics.

(i) International awards

(1) Outstanding Referee for the journals of the American Physical Society (2015); **(2)** Outstanding Contribution in Reviewing for Nuclear Physics A, Elsevier (2017); **(3)** Outstanding Contribution in Reviewing for Physics Letters B, Elsevier (2017); **(4)** Distinguished Referee for European Physical Journal (2022).

(j) Didactic activity

(1) University of Bucharest, Physics Faculty, Doctoral School: Lectures on nuclear structure;

(2) IFIN-HH: Lectures on theoretical nuclear structure for young researchers;

(3) Bioterra University Bucharest: Lectures on biophysics for medical assistants (in English).

(k) Member of the Editorial board
(1) Digest Journal of Nanomaterials and Biostructures
http://www.chalcogen.ro/index.php/journals/digest-journal-of-nanomaterials-and-biostructures?showall=&start=2
(2) Annals of the Academy of Romanian Scientists/Series on Physics and Chemistry
http://aos.ro/editura/analeleaosr/annals-on-physics-and-chemistry

C. The funding application (max. 12 pages), C1 – C5

In this chapter, the scientific context, goal, objectives, how the objectives will be implemented (project activities), deliverables and necessary resources will be mentioned in detail.

C1. Motivation of the proposed theme in the current scientific context. Originality and degree of innovation

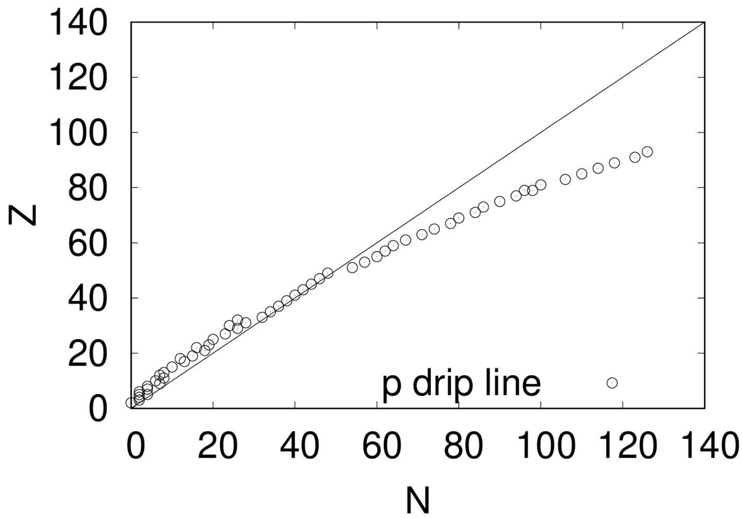
The scientific motivation of the project theme will be justified, by delimiting the approached issue in the current scientific context. The following two aspects will be highlighted:

(1) the importance of the issue from a scientific, technological, socio-economic or cultural point of view (according to the case and depending on the domain of the project), the difficulty elements of the issue, the limitations of current approaches, by analyzing the current state of knowledge related to the theme of the project;

TITLE: Investigation of the nuclear structure at the proton stability line (PROLINE)

The investigation of stability lines on the nuclear chart is a central topic of the nuclear many-body theory [Erler(2012)]. In particular, the stability limit of proton rich nuclei characterized by the largest Z/N ratio (where the proton at the Fermi level becomes unbound), called proton drip-line, plotted in Fig. 1 by open symbols, is intensively investigated from both experimental and theoretical points of view. The nuclear mean field and pairing properties on nuclear stability lines were analyzed in a systematic way by using nonrelativistic [Dobaczewski(1996), Neufcourt(2020)] and relativistic approaches [Lallazissis(2003)]. Due to the relatively high instability of nuclei in this region ($T_{1/2}$<100 s) they can be obtained only in laboratory conditions up to Z=90. They allow to investigate the nuclear interaction at stability lines, the main probing tool being emission processes involving proton, two-proton, α, β^+ and γ emission processes [Woods(1997), Delion(2010), Pfutzner(2012)]. It is important to stress that this nuclear region plays an important role in astrophysics and stellar nucleosynthesis, for instance the rapid proton (rp) capture process, which is the mirror counterpart of the r-process on the neutron drip line [Arnould(2007)].

Fig. 1. Proton drip line (open symbols)



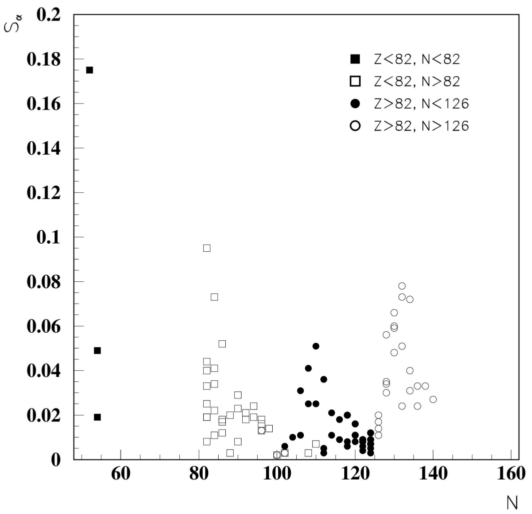
The state of knowledge and limitations of current approaches describing the nuclear structure in this region refer to the following aspects connected to this proposal:

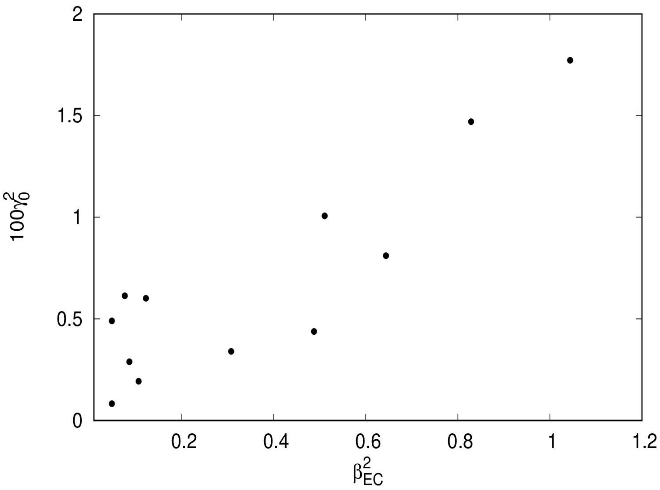
(a) Proton emission from the ground state is the main phenomenon defining the position of the proton-drip line on the nuclear chart. A review paper on proton emission was written by the project leader (PL) [Delion(2006)]. Here, it was shown that an important region in this area is at the charge number Z=67, where nuclei exhibit the most important shape transition in the nuclear chart from large prolate $\beta_2 \approx 0.3$ to oblate $\beta_2 \approx -0.2$ quadrupole deformations, evidenced in reference [Delion(2006)a] by two separate regions of the proton and alpha emission systematics. This feature was explained in Ref. [Delion(2009)] in terms of the dependence between reduced width on the fragmentation potential.

(b) **Two-proton emission** takes place in the vicinity of the proton drip line and is fundamental in the investigation of two-body interactions, in particular pairing, in continuum. This three-body process is described as a very elaborate procedure by using the coupled channels equations in terms of hyper-spherical coordinates for three-body resonances [Grigorenko(2003)]. Let us mention that a simplified approach to describe this process was proposed by the PL [Delion(2013)] in terms of a standard coupled system of radial equation by using spherical harmonics. Recently a hybrid treatment was proposed by PL in terms of the internal pairing function matched to external three-body Coulomb waves [Ghinescu(2022)]. At the same time, a simple systematics of two-proton emission in terms of the fragmentation potential and pairing gap was recently proposed by PL in Ref. [Delion(2022)].

(c) Nuclear structure above the doubly magic ^{100}Sn is connected to an important region, under a very active investigation, where the proton-neutron interaction can directly be probed in N~Z proton-rich nuclei [Delion(2010)]. The nuclear structure is intensively investigated in the region ^{100}Sn. Here, the alpha decay spectroscopic factor has abnormally large values, as seen in Fig. 2 for Z>50. This behavior is still not reproduced in a satisfactory way by current theoretical approaches [Pfutzner(2012)].

Fig. 2. α-decay spectroscopic factor vs neutron number   Fig. 3 α-decay reduced width vs $(\beta^+)^2$ m.e.





(d) The weak beta-plus/electron capture (β^+/EC) processes occur in this proton-rich region and they are intensively investigated by several laboratories in order to determine the dependence of effective value of the axial-vector coupling strength g_A , involved in 1^+ Gamow-Teller transitions, upon the mass number [Suhonen(2006),Delion(2019)]. The description of medium/heavy deformed odd-odd beta decay emitters is given at present within the standard proton-neutron quasiparticle random phase approximation (pn-QRPA) in the intrinsic system of coordinates, which violates the particle number and angular momentum conservation. The projection procedure in the laboratory system to extract physical observables is performed after variation. Recently PL evidenced a linear correlation between experimental alpha decay reduced width γ^2_0 and β^+/EC reduced matrix element squared, as seen in Fig. 3 [Delion(2019)], which still remains unexplained.

(e) Beta-delayed proton emission is intensively investigated in the last decade in the whole region between the proton drip and stability line. This is a two step process in which a proton-rich precursor nucleus beta-decays into a state which is proton unbound. Proton decay from this state occurs rapidly, so the overall half-life is characteristic of the β decay half-life. This type of decay is energetically possible when the mass of the parent precursor (A, Z) is larger than the mass of the β -p daughter (A-1, Z-2) plus the mass of the emitted proton. For nuclei that are across the proton drip-line (i.e. the proton separation energy S is negative), direct proton emission is a competing decay mode. When emission of a proton is energetically possible, the proton can tunnel through the Coulomb and centrifugal barriers. While the decay rate of β decay changes relatively slowly as the Q-value increases, emission of a proton from an unbound state changes rapidly as the proton energy increases. A similar process exists for β-delayed α emission (β-α). In spite of an intense experimental effort producing more than 200 experimental values of proton-delayed total half-lives, a systematics of delayed proton emission in terms of the Coulomb parameter is still missing.

(f) **The concept of chirality** is associated with the geometry of three mutually perpendicular angular momentum vectors. It was originally suggested [Frauendorf(1997)] for a system composed of two quasiparticle spins coming from opposite extremes of their valence orbitals and the angular momentum corresponding to the rotation of the core. The broken chiral symmetry is restored in the laboratory reference frame which is then reflected in the observation of a degenerated doublet of bands with ΔI=1 and the same parity. The identification of such bands is equivalent to establishing the stable triaxial shape of the considered nuclei, which is a never ending quest of nuclear physics. Recently, the possibility to find this effect close to the proton drip line became a reality. Such bands are presently reported in over 50 nuclei covering A ~80, 100, 130, and 190 mass regions [Xiong(2019)], including multiple chiral doublet bands (MχD) [Meng(2006)] and combining diverse nuclear structure effects. The major theoretical tools for the nuclear chirality studies are based on Particle-Rotor Model (PRM) [Bohr(1975)] and the Tilted Axis Cranking (TAC) approach [Frauendorf(1993)]. Their variations include the core-plus-quasiparticle model [Starosta(2017)] and the TAC plus random phase approximation [Almehed(2011)]. Alternative descriptions are based on boson expansions [Raduta(2014), Raduta(2016)], projected mean-field [Chen(2018)], the collective Hamiltonian [Wu(2018)] and the semiclassical method [Budaca(2018), Budaca(2019), Budaca(2021)]. The observed bands are rarely degenerated due to the soft chiral symmetry breaking where the states associated with each handedness have a nonvanishing overlap. This leads to the so-called chiral vibration [Starosta(2001)]. The overlap of the two chiral configurations can be maintained by deviations of all three angular momentum vectors from the perfect trihedral alignment. The single-particle alignments depend on their quasiparticle character, while the core can suffer deviations from the uniform rotation due to triaxial deformation [Budaca(2019), Budaca (2021)]. The semiclassical formalism established by one of the project members is presently versatile enough to be successfully applied for the understanding of the diverse spectral characteristics of chiral bands observed in proton rich nuclei. The region of interest is the mass interval 116-118 of I and Cs isotopes which are the most proton rich nuclei exhibiting bands built on quasiparticle alignments with possible chiral interpretation. Indeed, chiral symmetry breaking was reported only in the ^{118}I nucleus [Starosta(2001)], while some bands in ^{119}Cs were recently interpreted as revolving chiral partners [Zheng(2022)]. It is then expected that the similar spectral characteristics found in lighter more proton rich isotopes could be also interpreted in terms of chiral symmetry breaking and provide information on the alignment and quasiparticle nature of the involved intruder orbitals. This is especially important for the intended Cs isotopes, which are right at the edge of the proton drip line. Therefore, the project undertakes to make model calculations with adjustable triaxiality and tilting of the quasiparticle alignments for the chiral bands in proton rich nuclei.

(2) the elements of originality and innovation that the proposed project brings to the domain, related to the current state of knowledge. If the proposed theme has been addressed in previous projects, their details will be indicated (the funder, title and project code, website, obtained results, the grade obtained at the final evaluation) and the novelty elements in relation to previous studies will be clearly mentioned.

The elements of originality of this proposal refer to the explanation of some new physical properties of nuclei close to the proton drip line in terms of improved theoretical methods.

(a) We will use a self-consistent Cluster-Hartree-Fock-Bogoliubov (CHFB) procedure to generate a nuclear mean field containing a pocket-like component on the nuclear surface, properly describing four-body correlations, giving large values of the alpha clustering on the nuclear surface, especially in the drip line region above the doubly magic nucleus ^{100}Sn;

(b) We will study the influence of alpha-clustering on the stability of nuclei close to the proton drip line revealed by the change of the equilibrium quadrupole deformation parameter, by using the CHFB method generalized to deformed nuclei (dCHFB);

(c) We will use the theoretical description of collective proton-neutron states close to the proton drip line, in particular Fermi and Gamow-Teller resonances, in terms of the generalized proton-neutron deformed quasiparticle random phase approximation (pn-dQRPA), projecting particle number and angular momentum before variation, replacing approximate descriptions in the intrinsic system of coordinates restoring physical symmetries after solving dynamical equations.

(d) In particular, by using the methods proposed in (b) and (c) we hope to explain the above mentioned linear correlation between the alpha decay reduced widths and β^+/EC decay squared matrix elements for nuclei close to the proton drip line.

(e) We will perform a systematic investigation of the beta delayed proton emission close to the proton drip line, by using pn-dQRPA in order to extract beta decay reduced matrix elements from experimental half-lives.

(f) We will investigate the role of the unbound proton on the chiral symmetry breaking, by using a semiclassical description of nuclear dynamics related to triaxial shapes and wobbling bands in proton-rich nuclei.

C2. Objectives, methodology and work plan

The approach of the project at the principle and theoretical level will be presented, by highlighing the following three aspects:

(1) the concrete objectives of the project;

The concrete objectives of the project are the following:

(O1) We will search for a self-consistent deformed nuclear mean field close to the proton stability line, by using a deformed Cluster-Hartree-Fock-Bogoliubov (dCHFB) approach, the major goals being: (i) to investigate how the alpha-clustering changes the equilibrium nuclear deformation along the proton drip line; (ii) to perform a systematic analysis of the nuclear mean field parameters for nuclei close to the proton drip line, by using experimental proton decay half-lives; (iii) to analyze rp-capture process with astrophysical implications, as the inverse of the proton emission.

(O2) We will analyze low-lying energy levels, electromagnetic rates and alpha decay reduced widths in N~Z nuclei above the doubly magic nucleus ^{100}Sn in terms of a simplified version of the Multistep

Shell Model (MSM) proposed by PL, by using a self-consistent single particle basis generated by the spherical version of Cluster-Hartree-Fock-Bogoliubov (CHFB) procedure.

(O3) We will investigate beta delayed proton, two-proton and alpha decay processes at the proton stability line, by describing weak interacting reduced matrix elements in terms of the proton-neutron deformed Quasiparticle Random Phase Approximation (pn-dQRPA) in laboratory system and by using a dCHFB nuclear mean field describing alpha-clustering effects. The main goals are: (i) to explain the linear correlation between the alpha reduced width and beta plus reduced matrix element; (ii) to give a systematics of proton, two-proton and alpha half-lives reduced by the centrifugal barrier, by extracting the weak-interacting part from the beta delayed emission data; (iii) to perform a systematics of the weak axial-vector coupling strengths for nuclei close to the proton drip line; and (iv) to investigate the rp capture rates with implications in astrophysics, including the role of Z=67 line, where the quadrupole deformation abruptly changes.

(O4) We will investigate the chiral symmetry breaking near the proton stability line. The major goals to be achieved by this objective are: (i) semiclassical description of nuclear dynamics related to triaxial shapes; (ii) phenomenological interpretation of chiral and wobbling bands; and (iii) the description of rotational phase transitions in proton rich nuclei.

(2) the proposed work strategy, including investigation methods, models, directions, techniques and tools;

(O1) The most important ingredient to investigate nuclear structure by using microscopic approaches is the nuclear mean field [Stoitsov(2003)]. For nuclei at the proton stability line, the nucleons close to Fermi surface and having positive energy are weakly bound. The nuclear density has a low value for these orbitals and therefore two protons and two neutrons are able to perform a Mott transition into an alpha-particle [Ropke(1998)]. This effect was phenomenologically simulated in Ref. [Delion(2013)] by a mean field with a surface gaussian additional correction. Recently we have shown in Ref. [Dumitrescu(2023)] that this kind of single particle mean field potential can be generated within the standard Hartree-Fock-Bogoliubov procedure, for instance for the direct part mean field potential [Ring(1980)]

$$V_{MF}(\mathbf{r}) = \int d\mathbf{r'}\, v(\mathbf{r},\mathbf{r'}) \sum_{\tau k} |\varphi_{\tau k}(\mathbf{r'})|^2 = \int d\mathbf{r'}\, v(\mathbf{r},\mathbf{r'})\, \rho(\mathbf{r'})\,. \qquad (1)$$

Here we denoted spherical single particle orbitals by $\varphi_{\tau k}(\mathbf{r})$ and used a residual nucleon-nucleon residual interaction peaked on the nuclear surface (surface gaussian interaction: SGI)

$$v(\mathbf{r},\mathbf{r'})=v(r,R) = -v_0 \exp(-r^2/b^2)\, \{1+ x_c \exp[(R- R_0)^2/B^2]\}\,, \qquad (2)$$

$$r=r-r',\ R=(r+r')/2,\ R_0=r_0 A^{1/3}$$

The radial shape of this interaction is similar to the Gogny force used in large scale calculations [Hilaire(2011)], but corrected by a surface term. We have analytically shown that a spherical SGI is able to produce a Gaussian correction on the mean field with a larger radial parameter r_0=1.6, added to the standard Wood-Saxon potential [Dumitrescu(2023)], similar to the interaction used in Ref. [Delion(2013)] to describe alpha emission from even-even nuclei, without solving numerically the CHFB system of equations. In this project we will self-consistently solve this system first for spherical nuclei and then we will generalize the procedure to deformed nuclei, within the dCHFB procedure, by using a deformed nuclear radius

$$\mathbf{R_0} = R_0\, [1+\beta\, Y_{20}(\vartheta)]\,, \qquad (3)$$

in Eq. (2), defining the nucleon-nucleon SGI. We will use in the diagonalization procedure an harmonic oscillator basis, because the lowest proton states in continuum are bound by a relative high Coulomb barrier and therefore their behavior is very close to a bound state [Delion(2010)].

Let us mention that the radial ansatz (2), able to produce an alpha-cluster at small densities (i.e. on the nuclear surface), is equivalent to the standard density dependent particle-particle interaction

$$v(\mathbf{r},\mathbf{r'}) = -v_0 \exp[-(r-r')^2/b^2][1 - f(\rho(\mathbf{R})/\rho_0)] \ , \qquad (4)$$

used to describe the enhancement of the pairing interaction on the nuclear surface [Dobaczewski(1996)]. As an alternative approach we will look for the above interaction, able to change the standard mean field and therefore to enhance the radial tail of single particle orbitals forming an alpha-cluster on the nuclear surface, where the nuclear density decreases.

We will investigate the influence of the alpha-clustering on the deformation parameter (given by the minimum of the dCHFB energy) for nuclei close to the proton drip line.

(O2) The N~Z nuclei above the doubly magic ^{100}Sn have a similar quartet structure compared to nuclei above doubly magic ^{208}Pb and ^{40}Ca, described by us in terms of a simplified, but successful, version of the original multi-step-shell-model (MSM) [Liotta(1982)] proposed by PL in Ref. [Delion(2000)]. We propose to extend the use of this method in the above mentioned N~Z region by introducing a new ingredient. Namely, we will generate the single-particle basis with quarteting correlations in a self-consistent way, by involving the CHF (Cluster Hartree-Fock) procedure, as a particular case of the dCHFB approach, described in (O1) for spherical nuclei in the normal (non-superfluid) phase.

(i) In the first step we describe the nuclei with an additional pair of nucleons above the doubly magic core ^{100}Sn. We will consider the collective proton-proton pairs (pp) describing the low-lying states for ^{102}Te, neutron-neutron pairs (nn) for ^{102}Sn and proton-neutron pairs (pn) for ^{102}Sb, written in the second quantization formalism as a superposition of basis pair operators with spin/parity labeled J

$$P^{+}_{JM}(n;\tau\tau') = \sum_{kk'} X_J(n;\tau k,\tau' k') \ [\ c^{+}_{\tau k} \times c^{+}_{\tau' k'}]_{JM} \ , \quad \tau=p,n \ , \qquad (5)$$

where n labels the pair eigenvalue index. Here, $c^{+}_{\tau k}$ denote single particle particle creation operators, depending on standard spherical quantum numbers: k=energy, angular momentum, spin and its projection. The symbol × denotes angular momentum coupling. The pair dynamics is given by the Hamiltonian H=T+v with a particle-particle residual interaction v defined above in (3). By using the Equation of Motion (EOM) technique for pairs, the expectation value on the vacuum state leads to the standard Tamm-Dankoff Approximation (TDA) [Ring(1980),Delion(2000)].

(ii) In the second step we build quartet collective state $Q^{+}_{\lambda\mu}(q)$ in terms of collective pairs

$$Q^{+}_{\lambda\mu}(q) = \sum_{\alpha} Z_{\lambda}(q;\alpha) \ [\ P^{+}_{J}(a) \times P^{+}_{L}(b) \ ]_{\lambda\mu} \ , \quad \alpha \equiv (Ja;Lb) \ , \qquad (6)$$

where q labels the quartet eigenvalue and λ the quartet spin/parity. Then we estimate the expectation value on the vacuum state for the quartet EOM. By using pair TDA equations one obtains the system of equations for Z-coefficients depending only upon the pair energies $E_J(a)$ and the norm matrix

$$\sum_{\beta} [\ E(\alpha)+E(\beta) \ ] \ N_{\lambda}(\alpha\beta) \ Z_{\lambda}(q;\alpha\beta) = E_{\lambda}(q) \sum_{\beta} N_{\lambda}(\alpha\beta) \ Z_{\lambda}(q;\beta) \ , \qquad (7)$$

where we used the short-hand notation $E(\alpha) \equiv [E_J(a)+E_L(b)]/2$ [Delion(2000)].

(iii) This process can further be extended to describe more complex nuclei, by adding new pairs as new building blocks in the wave function and applying the corresponding EOM. The generalization to superfluid nuclei in terms of quasiparticles is straigthforward.

Thus, the resulting equations, describing the (N_π , N_ν) system of pairs, have a similar structure, depending only on the energies of the smaller (N_π-1 , N_ν) or (N_π , N_ν-1) system.

(iv) Finally we will compare the eigenvalues and electromagnetic reduced matrix elements to the available experimental data for even-even nuclei above ^{100}Sn. Additionally, we will estimate the alpha-particle formation amplitude as the overlap integral between the parent (P) and daughter (D) times alpha-particle wave function $\gamma_\alpha \sim < \Psi_P \mid \Psi_D \Psi_\alpha >$, computational details being given in Ref. [Delion(2010)].

We will simultaneously describe energy levels, electromagnetic, alpha and beta transitions in even-even nuclei above ^{100}Sn close to the drip line.

(O3) Proton rich nuclei close the proton drip line are beta-plus/electron capture (β^+/EC) emitters. The states involved in these processes are the Gamow-Teller 1^+ or Fermi 0^+ proton-neutron resonances. They are usually described in terms of the shell-model (SM) for light emitters and proton-neutron Quasiparticle Random Phase Approximation (pn-QRPA) in the case of medium and heavy nuclei [Delion(2019)]. The main observable is the reduced $\beta^\pm$ matrix element from an initial state with spin J_i expressed in terms of the axial-vector g_A (or vector g_V) coupling strength and the experimental logft value [Suhonen(2006)] $g_X \beta^\pm = [\ 6147\ (2J_i+1)\ /\ 10^{\log ft}\ ]^{1/2}$, X=A,V. The main drawback of the SM description is the use of a very large basis, while standard pn-QRPA does not conserve the particle number and angular momentum. In order to improve the description of weak processes we will extend pn-QRPA, namely:

(i) We use an axially deformed single particle basis in the laboratory system of coordinates by rotating deformed single particle proton (p) and neutron (n) orbitals to the laboratory system

$$a^+_{\tau jm}(\Omega)= \sum_{jJk} z^{Jk}_j\ [D^J_{\cdot 0}(\Omega)\times c^+_{\tau k}]_{jm}\ ,\ \tau = p, n\ , \qquad (8)$$

where $D^J_{M0}(\Omega)$ denotes the Wigner rotation matrix depending upon Euler angles (Ω) and z-coefficients are expressed in terms of standard Nilsson expansion coefficients found by diagonalization in the intrinsic system given by the nuclear symmetry axis [Delion(2019)].

(ii) We build the proton-neutron phonon state describing proton-neutron collective excitations

$$\Gamma^+_{\lambda\mu}(\Omega)= \sum_{ij} \left(X^{ij}_\lambda\ [\alpha^+_{pi}(\Omega) \times \alpha^+_{nj}(\Omega)]_{\lambda\mu} -\ Y^{ij}_\lambda\ [\alpha^+_{pi}(\Omega) \times \alpha^+_{nj}(\Omega)]^+_{\lambda\mu} \right), \qquad (9)$$

in terms of usual quasiparticle operators $\alpha^+_{\tau jm}(\Omega)=u_{\tau j}c^+_{\tau jm}(\Omega) + v_{\tau j}c_{\tau j-m}(\Omega)$. The expansion X, Y amplitudes are found by using the EOM procedure described in [Delion(2019)]. The original ingredient with respect to the standard procedure [Ring(1980)] is the integration of EOM over Euler angles, entering the definition of the phonon operator (10), thus performing the projection of the angular momentum λ. We call this procedure proton-neutron deformed quasiparticle RPA (pn-dQRPA). One thus obtains a coupled system of equations which is similar to the standard RPA case, but containing the deformed reduced matrix elements and deformed single particle spectrum. In this way we are able to cure the above mentioned deficiencies by describing collective proton-neutron excitations in deformed nuclei with good angular momentum, in particular Gamow-Teller (GT) or Fermi (F) transitions including both proton-neutron pairing and quarteting mean field correlations.

The main ingredient is the transition matrix element, expressed in terms of X, Y amplitudes and beta decay reduced matrix element <f||O_K||i>, with $O_{GT}=\boldsymbol{\sigma}$, $O_F=\mathbf{1}$.

(iii) As a new ingredient we will search for the possibility to generalize the decoupled quasiparticle representation used in the pn-QRPA phonon [Delion(2019)] to the proton-neutron (pn) channel

$$\alpha^{+}_{jm}= u_{pj}\, a^{+}_{pjm} + v_{pj}\, (-)^{j+m} a_{pj-m} + u_{nj}\, a^{+}_{njm} + v_{nj} (-)^{j+m}\, a_{nj-m}\ , \qquad (10)$$

by using the particle number projection within the Lipkin-Nogami procedure [Nogami(1964)], extended to the proton-neutron case [Sieja(2006)]. Here, for simplicity we dropped the Euler angles. We will compare this method for a few levels model to the exact results obtained within the diagonalization procedure. In Ref. [Baran(2020)] we have shown that a similar number projected quasiparticle representation for spherical nuclei has a vacuum state close to the wave function of the quartet condensate model (QCM) [Sandulescu(2012)]. We expect similar result for the deformed case.

(iv) Finally we will extract from the beta delayed emission data the corresponding proton (or alpha) decay widths by using the energy weighted strength function [Delion(1997)], or standard R-matrix factorization of the total probability between the feeding G_k and proton emission Γ_k decay widths, corresponding to the channel energy E_k [Lane(1958), Warburton(1986)]

$$P(E) \sim \sum_k G_k^{1/2}\, \Gamma_k^{1/2} / (E_k - E - i\Gamma/2)\ . \qquad (11)$$

In this way we will be able to perform an extended systematics of proton, two-proton and alpha emission half-lives induced by beta decays. Additionally we will investigate the effective axial-vector g_A in the proton rich nuclei area. By using dCHFB to compute the nuclear mean field described in Section O2, we will explain the linear correlation between alpha reduced widths and beta reduced matrix elements squared.

(**Q4)** The starting point in the investigation of chiral symmetry breaking is the quantum PRM Hamiltonian. The core is defined with moments of inertia in the hydrodynamic model. The quasiparticle alignments are considered as frozen to an adjustable tilting angle within the principal planes. This is achieved by replacing the corresponding single-particle spin operators with real numbers. The only active operator is then the total angular momentum of the system. The dynamical features of the resulting system are then studied within a semiclassical approach. The variational state is chosen to be a coherent state for the total angular momentum vector having stereographic coordinates. Solving the variational principle one will acquire a classical energy function and a set of equations of motion. The latter will be brought to Hamilton canonical form by considering the angular momentum projection and the azimuth angle of its orientation as canonical generalized momentum and coordinate. The obtained classical picture will be used to ascertain the evolution of the classical orbits of the rotation axis with the increase of total angular momentum for different alignment and core deformation conditions extracted from experimental data and defining distinct dynamical phases. The quantum observables are extracted by quantizing the classical energy function through the correspondence principle applied to the canonical variables. There will be an investigation into the evolution of the quantum potential and the associated probability distribution of the projection variable along and between different dynamical phases: chiral vibration, static chirality, three-dimensional wobbling. Their correspondence to the classical picture is essential for the understanding of the associated rotational dynamics. The spectra and wave functions will be computed for a grid of values for triaxiality and the tilting angles of the rigidly aligned quasiparticles, both in one degree increments in a relevant interval. **The experimental data concerning mostly A∼100, 130 proton**

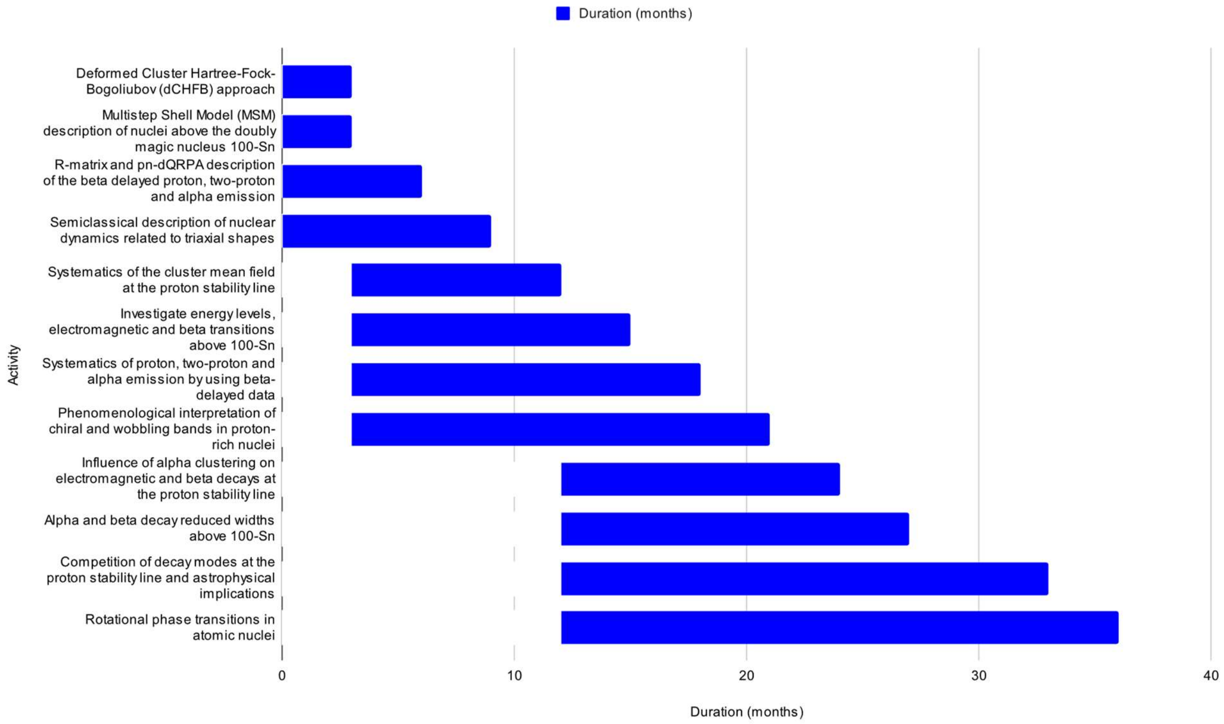
rich nuclei, will be fitted with the constructed model. This will provide the most suitable triaxial deformation and quasiparticle alignments, and consequently the associated rotational dynamics. In particular, new geometries of the angular momentum vectors will be sought by considering non-chiral quasiparticle alignments. Alternatively, the revolving alignment geometry predicted by other theoretical models can be used as input in order to extract dynamical information. The obtained parameters will then be used to compute E2 and M1 transition probabilities. For this, the total wave function will be expanded in rotational matrices weighted by the probability distribution obtained from the quantized Schrödinger equation. The expansion coefficients will be also confronted with the results of exact diagonalization in the basis of rotational matrices.

(3) a work plan, staggered in time, which includes all activities, results (deliverables) for each activity, the delivery deadlines for the results that will describe the organization of the project, in relation to the proposed objectives. A Gantt chart of the project will be added. If funded, the implementation plan of the project will contain (only) the activities that were presented in the funding application, without including other activities or sub-activities.

The work plan staggered in time on the period of 36 months (03.2024-02.2027) is given below.

No	**Activity**	**Delivrable**	**Date**
O1.1	Deformed Cluster Hartree-Fock-Bogoliubov (dCHFB) approach	Computer code	06.2024
O2.1	Multistep Shell Model (MSM) description of nuclei above doubly magic nucleus ^{100}Sn.	Computer code, Scientific paper	06.2024
O3.1	R-matrix/pn-dQRPA description of the beta delayed proton, two-proton and alpha emission	Computer code, Scientific paper	09.2024
O4.1	Semiclassical description of nuclear dynamics related to triaxial shapes	Scientific paper, Report	12.2024
O1.2	Systematics of the cluster mean field at the proton stability line	Scientific paper	03.2025
O2.2	Investigate energy levels, electromagnetic and beta transitions above ^{100}Sn	Scientific paper	06.2025
O3.2	Systematics of proton, two-proton and alpha emission by using beta-delayed data	Scientific paper	09.2025
O4.2	Phenomenological interpretation of chiral and wobbling bands in proton-rich nuclei	Scientific paper, Report	12.2025
O1.3	Influence of alpha clustering on electromagnetic and beta decays at the proton stability line	Scientific paper	03.2026
O2.3	Alpha and beta decay reduced widths above ^{100}Sn	Scientific paper	06.2026
O3.3	Competition of decay modes at the proton stability line and astrophysical implications	Review paper	12.2026
O4.3	Rotational phase transitions in atomic nuclei	Final report	02.2027

Gantt chart of the project



C3. Project feasibility: available resources and research team structure

Both the existing resources in the host institution that are relevant for the implementation of the project will be presented (the link from the platform https://eeris.eu/ will be indicated), as well as the necessary ones that will be purchased within the project. In particular, the following aspects shall be specified:

(1) the estimation of the time allocated to the project by each member of the project team (including the Project leader), in months/member units, in accordance with the work plan presented in section C2;

Proposed research team

No	Forename Name	Position	Allocated time	Obs.
1	Doru Delion	Sci. Res. 1	36 months	Project leader IFIN-HH
2	Radu Budaca	Sci. Res. 1	18 months	Member IFIN-HH
3	Alexandru Dumitrescu	Sci. Res. 3	18 months	Member IFIN-HH
4	Stefan Ghinescu	Asist. Res.	18 months	Member IFIN-HH
5	Alexandru Pencu	Mast. Stud.	18 months	Member Univ. Bucharest

Google Scholar profiles of the team members

2. https://scholar.google.com/citations?hl=ro&user=szxZYTUAAAAJ

3. https://scholar.google.com/citations?hl=ro&user=_Hf8FfsAAAAJ

4. https://scholar.google.com/citations?hl=ro&user=_mLY18MAAAAJ

(2) the motivation of the adequacy of the project team and the research infrastructure available to meet the project objectives in the allocated time; for the vacancies, the expected competencies will be briefly described;

PL and members 3, 4 of the research team are experts in theoretical nuclear structure, concerning objectives O1-O3 and member 2 in an expert concerning the objective O4. Member 5 is a master Student involved in the objectives O2, O3. Members 3, 4 obtained their PhD under the PL supervision. The institute provides access to international data bases and libraries needed for a proper scientific documentation. Each member of the team has a laptop computer. In addition, we will acquire a workstation needed for large scale systematic parallel calculations by using d-CHFB procedure.

(3) the preliminary results that support the working hypothesis of the project (the lack of preliminary results does not constitute a reason for downgrading the score, but their presence can be considered an argument in favor of the feasibility of the project, and can be scored).

As a preliminary result we will solve the dCHFB system of equations and will investigate the total energy of the nuclear system versus the quadrupole deformation parameter in order to find its minima. We will use parallel technique to increase the computational speed.

C4. Risks and alternative approaches

The potential risks that could affect the smooth implementation of the project will be described as well as the approaches through which these risks would be addressed. The risks will be estimated and alternative solutions will be presented.

The potential risks are connected to the proposed innovative approaches. They contain new physical ideas and techniques, which should be able to describe in a relatively simple manner the experimental situation and to have predictive power. The past results of the team members and recent publication record of the PL guarantee the feasibility of the project. Major impediments are not expected because the used methods are well established and the treated phenomena are experimentally confirmed. Although the proposed activities are feasible, in the case that our starting ideas will not materialize exactly as in our aim, some other knowledge will emerge deserving of investigation. So, we do not infer a risk to exclude new results. The possibility to analyze alternative solutions for each of the proposed research directions is the way to mitigate the risks. For instance we proposed two alternative interactions in order to estimate the self-consistent nuclear mean field by using the Cluster-Hartree-Fock-Bogoliubov method with a surface gaussian interaction, or a density dependent interaction. One could also mention that most often there is a discrepancy between the rotational behavior of the chiral bands and the spin-dependence of the relative energy difference between them. If the proposed premise is not enough to address both features in a consistent way, full PRM diagonalization with few major shell or casting the problem into a Fock space by means of a boson realization of angular momentum operators are both available alternatives. One major concern is the possibility of long running times of the developed codes, which could be efficiently improved by code optimizations, parallel computing, alternative use of different available computing software for full calculations or intermediate steps.

C5. Impact and dissemination

The expected impact of the project in the wider scientific domain framework will be discussed, with emphasis on the following aspects:

(1) the estimated scientific results of the project, specifying the expected result indicators;

We expect to bring a new and more deep physical insight concerning: (a) the properties of the nuclear mean field in the region close to the proton drip line by using dCHFB approach; (b) the nuclear structure details, in particular the role of the proton-neutron interaction, revealed by electromagnetic and alpha transitions of low-lying states in nuclei N~Z above the doubly magic nucleus ^{100}Sn by using an improved MSM approach; (b) the structure of proton-neutron excited states of proton-rich odd-odd nuclei, revealed by the relative simple pn-dQRPA wave function explaining the correlation between alpha and beta-plus observables; (c) an extended proton, two-proton and alpha emission systematics by using beta delayed data; (d) the role of chirality for nuclei in close to proton drip line.

(2) the potential impact of the project on the host institution and the project team;

The results of the project, published in highly ranked journals and presented at prestigious international conferences, will increase the scientific visibility of the host institution and the project team. This will translate in a wider global acknowledgement of the results obtained at IFIN-HH, more numerous and consistent international collaborations for the project team and more opportunities for further joint projects focused on fundamental nuclear physics research that involve the team members.

(3) the impact over the scientific, technological, social, economic or cultural environment (if they are relevant to the domain or theme of the project);

We expect that the new proposed approaches have enough simplicity and efficiency to be used by experimental groups in analyzing existing data and planning new experiments for nuclei close to the proton drip line. More generally, these results will improve the understanding of fundamental nuclear physics and also will impact related fields of very active research, having implications going as far as astrophysics and elementary particle physics. They will further the understanding of current problems in these fields and perhaps open new avenues for future research. There is a relevant social and economic impact to the project, as it helps with the professional development of the student and young researchers on the project team.

(4) the concrete elements of the strategy for dissemination and communication of the scientific results;

We expect to publish minimum three scientific papers/year (9 papers in total) in highly ranked scientific journals (Physics Letters B, Physical Review C, Journal of Physics G, European Physical Journal A) and one review paper. The obtained results will be reported at minimum one international conference /year (three in total) dedicated to nuclear structure and astrophysics. We will give minimum one seminar / year (three in total) within the international cooperations with Prof. J. Suhonen (Jyvaskyla University, Finland) and Prof. R. Liotta and Chong Qi (Royal Institute of Technology KTH-Stockholm, Sweden).

(5) how "open publication" practices will be used to disseminate the results.

Some of the journals where we will aim to publish our results, like Physics Letters B, have an open access publication policy. Furthermore, we will report our results in preprint repositories like the arXiv preprints database https://arxiv.org/. arXiv is a free distribution service and an open-access archive for millions of scholarly articles in many research fields that include physics. It is widely used by the nuclear and astrophysics community and located at the forefront of research. Many top scientists present their results as arXiv preprints prior to formal publication in peer-reviewed journals and often times the preprint publication date is used in order to claim primacy over a given discovery or result. We will make active use of social media tools to distribute our results to the scientific community and public at large. Significant results will be privately communicated to prestigious international experts in the field of the project. The development of the project and intermediate results will be available on the project's web page, which will be updated regularly.

C6. Requested budget *(except the 12 pages)*

The following aspects will be presented in detail:

(1) the distribution of the budget by types of expenses and by project years must be indicated and motivated;

We will use logistic expenses in the first year to acquire a workstation for parallel computing. Travel expenses will be used to atend international conferences and for short visits at our partners in KTH-Stockholm (Sweden) and Jyvaskyla university (Finland).

(2) justification of the purchase of new equipment with a value higher than 75.000 lei (price without VAT), by referring to the project objectives;

It is not the case to purchase new equipment with a value higher than 75.000 lei.

(3) the minimum number of hours/month to be dedicated to the project for the Project leader will be specified. The types of expenses on which the budget is distributed are: personnel expenses, logistics expenses, travel expenses and indirect expenses (overheads).

Section C6 will not receive a score in the evaluation, but the expert evaluators' comments associated with this sub-criterion will be used, if the project will be funded, in the negotiation and contracting process.

The minimum number of hours/month to be dedicated to the project by the PL = 32 hours/month.

Pre-calculation estimate (in lei, per calendar year):

Budget chapter	Year I (lei)	Year II (lei)	Year III (lei)	Total budget (lei)
Personnel expenses	292.000	292.000	292.000	876.000
Logistics expenses	30.000			30.000
Out of which the value for the equipment expenses	30.000			30.000
Travel expenses	20.000	20.000	20.000	60.000
Indirect expenses, 25% *)	78.000	78.000	78.000	234.000
Total	420.000	390.000	390.000	1.200.000

Pre-calculation estimate (in Euro, at the project level):

Budget chapter	Total budget (euro) 1€=5lei
Personnel expenses	175.200
Logistics expenses	6.000
Out of which the value for the equipment expenses	6.000
Travel expenses	12.000
Indirect expenses	46.800
Total	240.000

*) The overhead justification is attached below.

C7. Bibliography (except the 12 pages)

[Delion(2010)] D.S. Delion, *Theory of Particle and Cluster Emission* (Springer, Berlin, 2010).
[Delion(1992)] D.S. Delion, A. Insolia, R.J. Liotta, Physical Review C **46**,1346 (1992).
[Delion(2000)] D.S. Delion and J. Suhonen, Phys. Rev. C **61**, 024304 (2000).
[Delion(2001)] D.S. Delion and J. Suhonen, Phys. Rev. C **64**, 061306(R) (2001).
[Delion(2003)] D.S. Delion and J. Suhonen, Phys. Rev. C **67**, 034301 (2003).
[Delion(2005)] D.S. Delion, P.Schuck, J. Dukelsky, Phys. Rev. C **72**, 064305 (2005)].
[Delion(2006)] D.S. Delion, R.J.Liotta, R.Wyss, Physics Reports **424**, 113 (2006).
[Delion(2006)a] D.S. Delion, R.J. Liotta, R. Wyss, Phys. Rev. Lett. **96**, 072501 (2006).
[Delion(2007)] D.S. Delion and J.Suhonen, Nucl. Phys. A **781**, 88 (2007).
[Delion(2009)] D.S. Delion, Physical Review C **80**, 024310 (2009).
[Delion(2010)] D.S. Delion, R. Wyss, R.J. Liotta, Bo Cederwall, *et.al.*, Phys. Rev. C **82**, 024307 (2010).
[Delion(2013)] D.S. Delion and R.J. Liotta, Phys. Rev. C 87, 041302(R) (2013).
[Delion(2013)a] D.S. Delion, R.J. Liotta, and R. Wyss, Phys. Rev. C **87**, 034328 (2013).
[Astier(2010)] A. Astier, P. Petkov, M.-G. Porquet, D.S. Delion, and P. Schuck, Phys. Rev. Lett. 104 (2010) 042701.
[Delion(2013)b] D.S. Delion and J. Suhonen, Phys. Rev. C **87**, 024309 (2013).
[Delion(2015)] D.S. Delion, A. Dumitrescu, Atomic Data Nuclear Data Tables **101**, 1 (2015).
[Delion(2018)] D.S. Delion, Z.Z. Ren, A. Dumitrescu, and D.D. Ni, J. Phys. G **45**, 053001 (2018).
[Delion(2019)] D.S. Delion, A. Dumitrescu, and J. Suhonen, Phys. Rev. C **100**, 024331 (2019).
[Erler(2012)] J. Erler, N. Birge, M. Kortelainen, W. Nazarewicz, E. Olsen, A.M. Perhac1 and M. Stoitsov, Nature **486**, 509 (2012).
[Dobaczewski(1996)] J. Dobaczewski, W. Nazarewicz, T.R. Werner, J.F. Berger, C.R. Chinn, and J. Decharge, Phys. Rev. C **53**, 2809 (1996).
[Neufcourt(2020)] L. Neufcourt, Y. Cao, S.A. Giuliani , W. Nazarewicz , E. Olsen , and O.B. Taraso, Phys. Rev. C **101**, 044307 (2020).
[Lallazissis(2003)] G.A. Lallazissis, D. Vretenar, and P. Ring, Nucl. Phys A **719**, C209 (2003).
[Woods(1997)] P. J. Woods and C. N. Davids, Ann. Rev. Nucl. Part. Science **47**, 541 (1997).
[Pfutzner(2012)] M. Pfützner, M. Karny, L.V. Grigorenko, and K. Riisager, Rev. Mod. Phys. **84**, 567 (2012).
[Arnould(2007)] M. Arnould, S. Goriely, and K. Takahashi, Phys. Rep. **450**, 97 (2007).
[Grigorenko(2003)] L.V. Grigorenko and M.V. Zhukov, Phys. Rev. C **68**, 054005 (2003), and references therein.
[Suhonen(2006)] J. Suhonen, *From nucleons to nucleus*, (Springer, Berlin, 2006).
[Dobaczewski(1996)] J. Dobaczewski, W. Nazarewicz, T.R. Werner, J.F. Berger, C.R. Chinn, and J. Decharge, Phys. Rev. C **53**, 2809 (1996).
[Liotta(1982)] R.J. Liotta and C. Pomar, Nucl. Phys. A **362**, 137 (1981); A **382**, 1 (1982).
[Delion(1996)] D.S. Delion, A. Insolia, R.J. Liotta, Phys. Rev. C **54**, 292 (1996).
[Ring(1980)] P. Ring and P. Schuck, *The Nuclear Many-Body Problem* (Springer, Berlin, 1980).
[Hilaire(2011)] https://inis.iaea.org/search/search.aspx?orig_q=RN:44039652
[Baran(2016)] V.V. Baran and D.S. Delion, Phys. Rev. C **94**, 034319 (2016).
[Nogami(1964)] Y. Nogami, Phys. Rev. **134**, B313 (1964).
[Sieja(2006)] K. Sieja and A. Baran, Acta Phys. Polonica **37**, 107 (2006)
[Sandulescu(2012)] N. Sandulescu, D. Negrea, J. Dukelsky, and C.W. Johnson, Phys. Rev. C **85**, 061303 (2012).
[Baran(2020)] V.V. Baran, D. R. Nichita, D. Negrea, D.S. Delion , N. Sandulescu, and P. Schuck, Phys. Rev. C **102**, 061301(R) (2020).

[Delion(2022)] D.S. Delion and S.Ghinescu, Phys. Rev. C **105**, L031301 (2022).
[Ghinescu(2022)] S.Ghinescu and D.S. Delion, Phys. Rev. C **106**, 034602 (2022).
[Stoitsov(2003)] M.V. Stoitsov, J. Dobaczewski, W. Nazarewicz, S. Pittel, and D.J. Dean, Phys. Rev. C **68**, 054312 (2003).
[Ropke(1998)] G. Ropke, A. Schnell, P. Schuck, and P. Nozieres, Phys.Rev.Lett. **80**, 3177 (1998).
[Dumitrescu(2023)] A. Dumitrescu and D.S. Delion, Phys. Rev. C **107**, 024302 (2023).
Delion(1997)] D.S. Delion, D. Santos, and P. Schuck, Phys. Lett. B **398**, 1 (1997).
[Lane(1958)] A.M. Lane and R.G. Thomas, Rev. Mod. Phys. **30**, 257 (1958).
[Warburton(1986)] E.K. Warburton, Phys. Rev. C **33**, 303 (1986).
[Frauendorf(1997)] S. Frauendorf and J. Meng, Nucl. Phys. A **617**, 131 (1997).
[Xiong(2019)] B. W. Xiong and Y. Y. Wang, At. Data Nucl. Data Tables, **125**, 193 (2019).
[Meng(2006)] J. Meng, J. Peng, S. Zhang and S. Zhou, Phys. Rev. C, **73**, 37303 (2006).
[Bohr(1975)] A. Bohr and B. R. Mottelson, Nuclear Structure Vol. 2, Reading: Benjamin (1975).
[Frauendorf(1993)] S. Frauendorf, Nucl. Phys. A **557**, 259c (1993).
[Starosta(2017)] K. Starosta and T. Koike, Phys. Scr. **92**, 093002 (2017).
[Almehed(2011)] D. Almehed, F. Dönau and S. Frauendorf, Phys. Rev. C **83**, 054308 (2011).
[Raduta(2014)] A. A. Raduta, C. M. Raduta, and A. Faessler, J. Phys. G **41**, 035105 (2014}.
[Raduta(2016)] A. A. Raduta, Al .H. Raduta, and C. M. Petrache, J. Phys. G **43**, 095107 (2016).
[Chen(2018)] F. Q. Chen, J. Meng, and S. Q. Zhang, Phys. Lett. B 785, 211 (2018).
[Wu(2018)] X. H. Wu, Q. B. Chen, P. W. Zhao, S. Q. Zhang, and J. Meng, Phys. Rev. C, **98**, 064302 (2018).
[Budaca(2018)] R. Budaca, Phys. Rev. C **98**, 014303 (2018).
[Budaca(2019)] R. Budaca, Phys. Lett. B **797**, 134853 (2019).
[Budaca(2021)] R. Budaca, Phys. Lett. B **817**, 136308 (2021).
[Starosta(2002)] K. Starosta et al., Phys. Rev. Lett. **86**, 971 (2001).