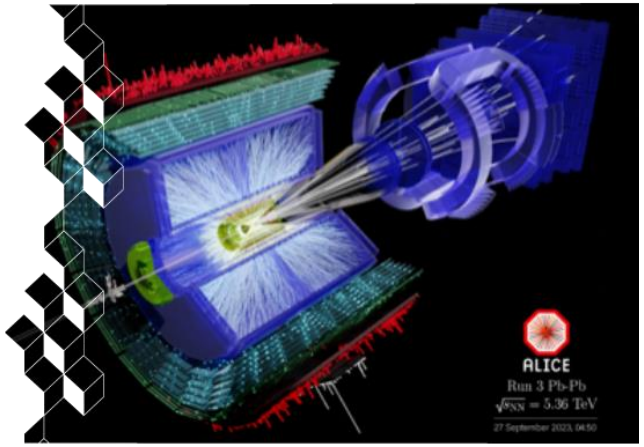
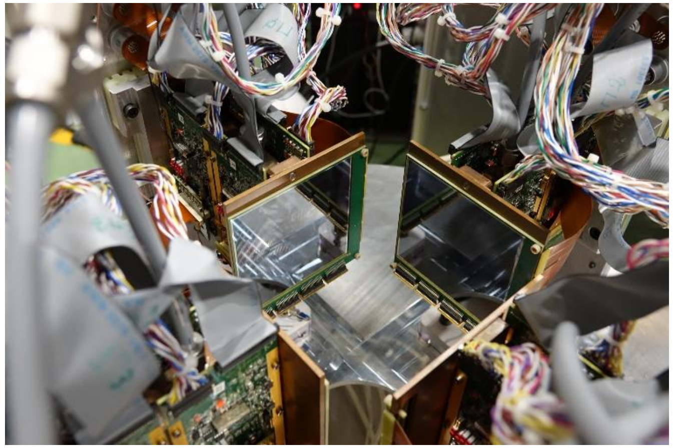
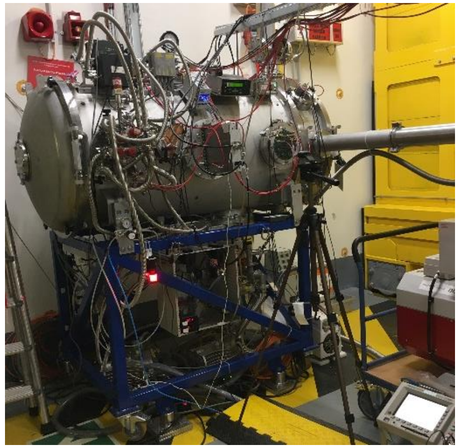
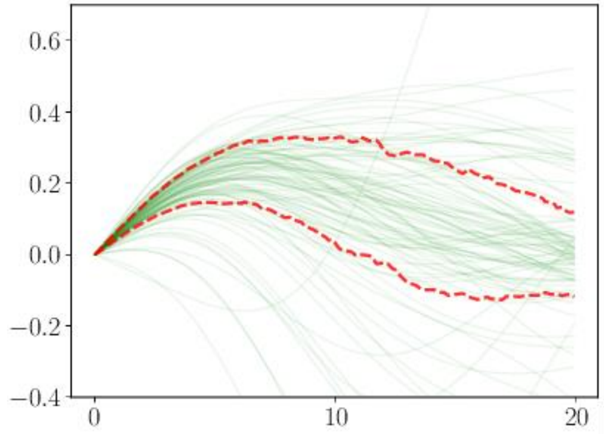
Nuclear physics roadmap: status and updates

Hervé MOUTARDE

1 June 2026



Introduction

A pivotal moment, against the backdrop of the resurgence of nuclear fission, with two major questions

1. What is the roadmap for low-energy nuclear physics activities?
2. How to programmatically integrate the DPhN's activities into the context of the revival of nuclear fission?

3e PPE, 13-02-2026

Le Gouvernement publie le vendredi 13 février 2026 la troisième Programmation pluriannuelle de l'énergie (PPE3) qui fixe la stratégie énergétique de la France pour la période 2026-2035 et trace la trajectoire vers la neutralité carbone à l'horizon 2050. Face à l'urgence climatique et aux impératifs de souveraineté, la PPE3 repose sur trois priorités : la souveraineté énergétique, la neutralité carbone et la compétitivité des prix.

La stratégie repose sur un **mix énergétique équilibré** associant nucléaire et énergies renouvelables.

- **La relance du nucléaire** : la construction de six EPR2 pour de premières mises en service dès 2038, une option pour huit EPR2 supplémentaires, la consolidation et la prolongation des 57 réacteurs existants et une optimisation du parc visant une production de 380 TWh dès 2030. ;

Cinquième conseil de politique nucléaire.

Publié le 12 mars 2026

Le Président de la République a réuni ce jeudi 12 mars 2026 un **5ème Conseil de politique nucléaire (CPN)**. Dans la continuité des précédents conseils de politique nucléaire qui se tiennent depuis 2022 ce conseil définit les grandes orientations de la politique nucléaire nationale.

Le contexte international récent confirme les orientations de politique énergétique prises par le Président de la République pour garantir l'indépendance énergétique de la France en sortant des énergies fossiles. Le Conseil de politique nucléaire confirme la nécessité de la relance du nucléaire en France afin de garantir la souveraineté de notre pays, à rendre l'énergie accessible pour les Français et nos entreprises ainsi qu'à lutter contre le changement climatique.

Face aux enjeux d'approvisionnement en uranium naturel à court, moyen et long-terme, sur la base des travaux préparatoires réalisés, le Conseil de politique nucléaire a confirmé le lancement d'un nouveau programme ambitieux de fermeture du cycle du combustible nucléaire ayant vocation à mobiliser l'ensemble des acteurs (donneurs d'ordre, recherche, acteurs émergents). En effet, le Conseil de politique nucléaire considère que les enjeux à long-terme d'approvisionnement en uranium justifient de lancer un tel programme, permettant de se passer de l'importation d'Uranium naturel à horizon 2100. Le Conseil de politique nucléaire a ainsi décidé de lancer une phase d'études de quatre ans permettant de concevoir ces installations sur la base du retour d'expérience national, puis d'envisager, à l'horizon 2030, le lancement de la construction d'un premier réacteur à neutrons rapides. Le Conseil de politique nucléaire décide d'instaurer une direction du programme intégrant des

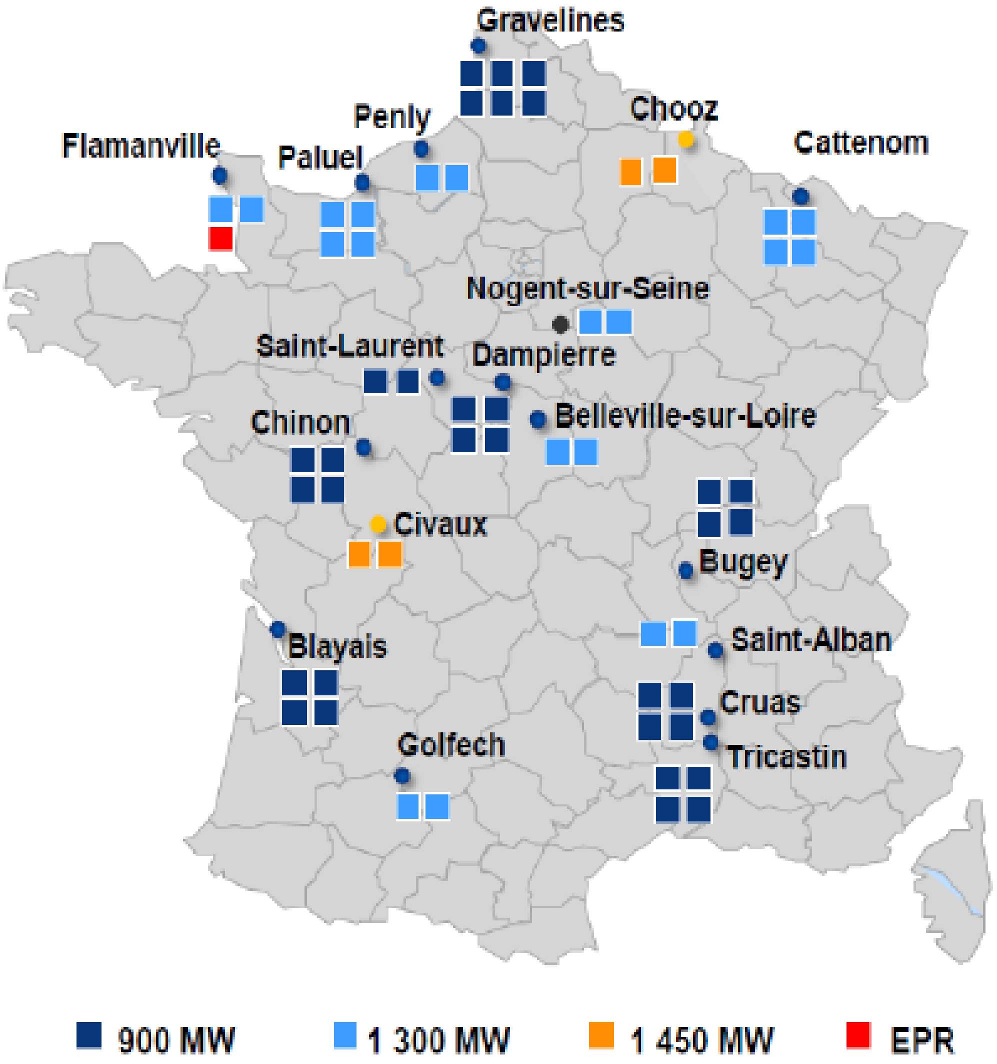
1. Nuclear energy

Some issues in reactor physics

Overview of nuclear reactors in France

- **57** reactors in operation at **18** sites:
  - 32 PWR 900 Mwe – average age: 41 years
  - 20 PWR 1300 MWe – average age: 35 years
  - 4 PWR 1450 MWe – average age: 23 years
  - 1 EPR 1650 MWe – **1st grid connection on 21 dec. 2024**

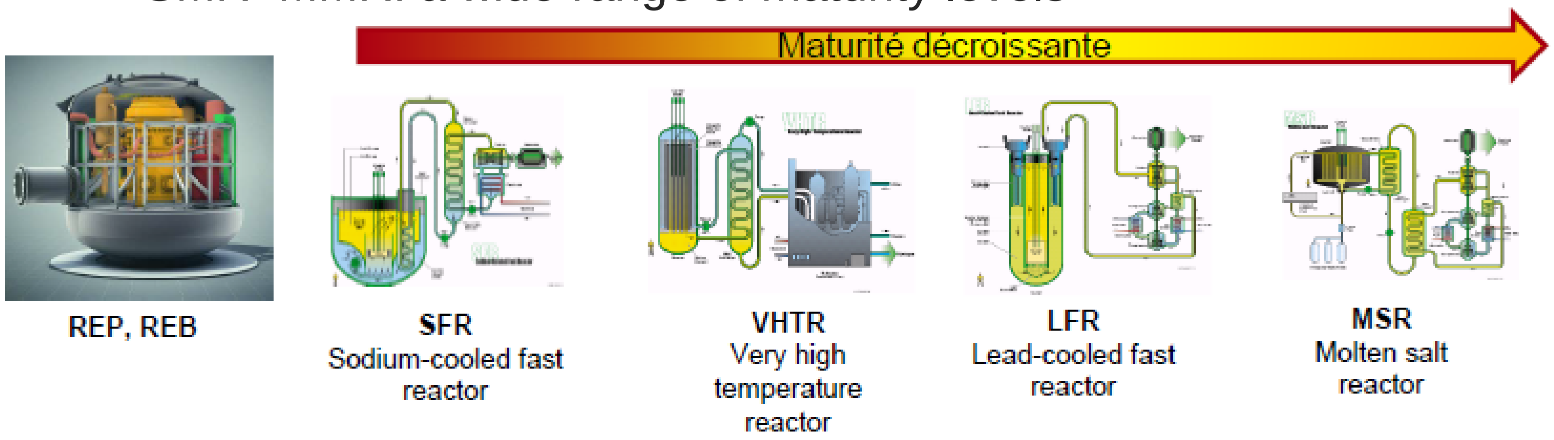
- **63 GWe** of installed nuclear capacity.
- All reactors are operated by EDF.
- 2 fuel suppliers: Framatome and Westinghouse.



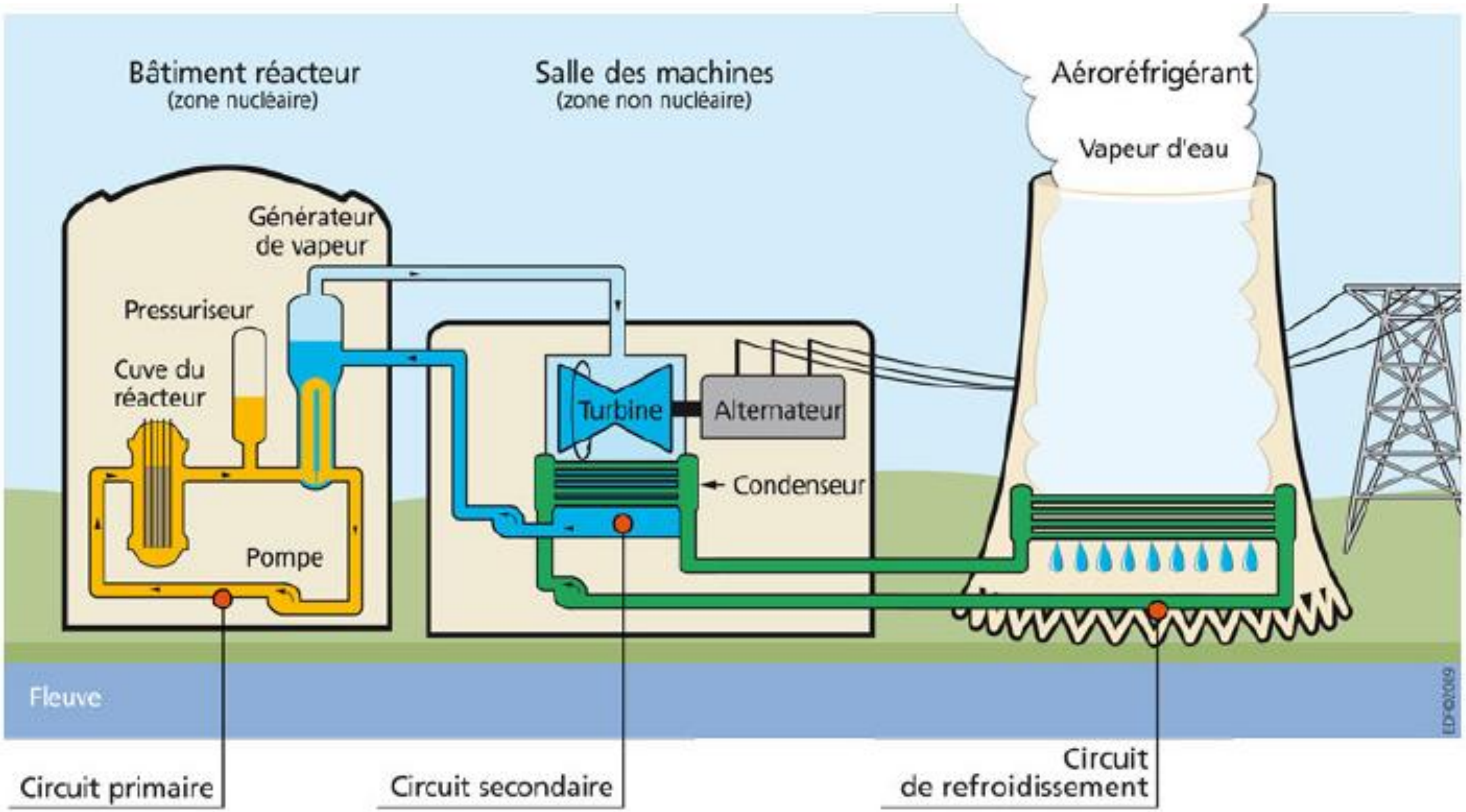
SMR, AMR and MMR

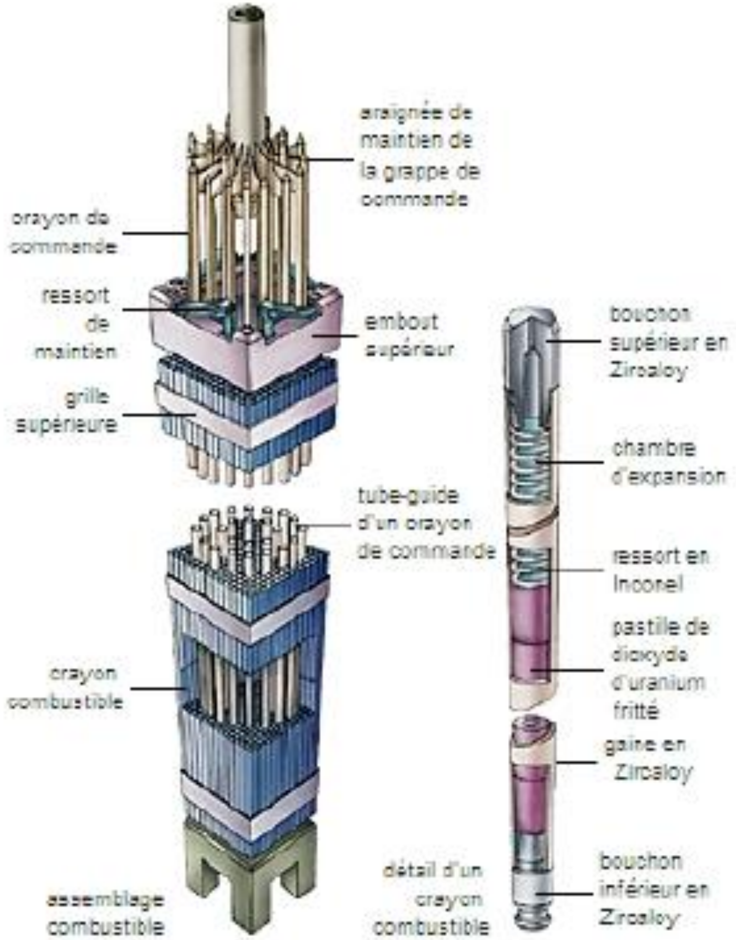
- **SMR** (Small Modular Reactor): proven PWR/BWR technology, 50 to 300 MWe.
- **AMR** (Advanced Modular Reactor): same power range and “Generation 4” technological breakthroughs: pressurized gas coolant, liquid metal, molten salt fuel, etc.
- **MMR** (Micro Modular Reactor) :
  - Very low-power reactor for electricity or heat generation:1 to 20 MWe.
  - Portable (smaller) reactor, remotely controlled, with little or no exclusion zone.
  - Market: industrial sites, remote areas or islands, maritime transport.
- **Micro-réacteur** for space: 1 kWe to 1 MWe for propulsion or power generation for a base on the Moon or Mars.

SMR+MMR: a wide range of maturity levels



Pressurized water reactor





Questions about:

- Nuclear data
- Structure and reaction models
- Neutron noise
- Uncertainties and simulation tools

2. CEA strategy in nuclear physics

Nuclear data: theoretical and experimental approaches at the CEA. A 10-year outlook.

CEA strategy in nuclear physics
From fundamental physics to applications

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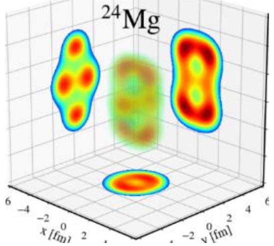
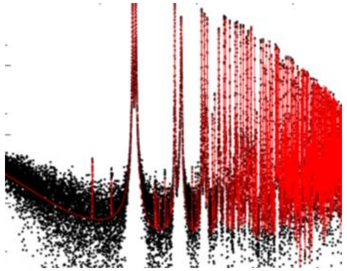
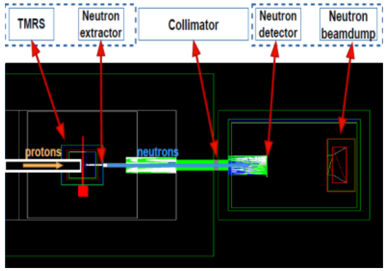
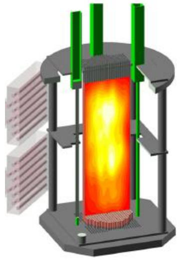
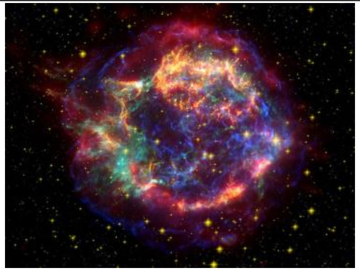
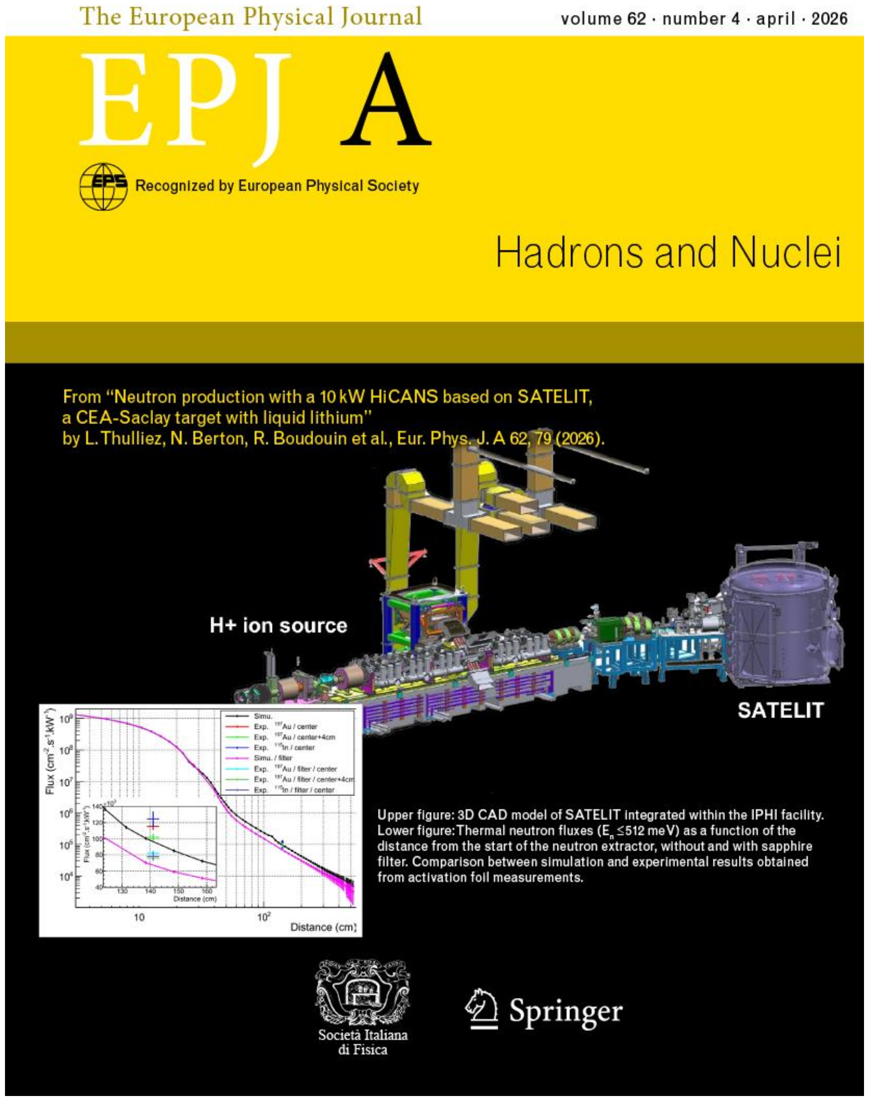
					
Experimental data	Theory	Data evaluation	Transport codes	Integral experiments	Applications

Continuum between fundamental inquiry and practical applications

Knowledge and expertise spanning both basic and applied research



SATELIT: fundamental skills for applications



The culmination of a long-term effort with a publication and cover in EPJA !

Eur. Phys. J. A (2026) 62:79
https://doi.org/10.1140/epja/s10050-026-01852-1

THE EUROPEAN PHYSICAL JOURNAL A

Check for updates

Regular Article - Experimental Physics

Neutron production with a 10 kW HiCANS based on SATELIT, a CEA-Saclay target with liquid lithium

L. Thulliez[1,a], N. Berton[1], R. Boudouin[1], N. Cavalière[2], S. Cazaux[1,b], T. Chaminade[1], N. Chauvin[1,c], D. Chirpaz[1], J.-L. Courouau[2], Q. Cridling[2], P. Daniel-Thomas[1], J. Darpentigny[3], G. Debras[1], G. Disset[1], A. Drouart[1,d], E. Dumonteil[1], R. Duperrier[1], R. Ferdinand[1], E. Giner Demange[1], J.-C. Guillard[1], N. Jonqueres[1], T. Lebrun[1], D. Loiseau[1], J. Mendes[1], B. Mom[1], F. Ott[3], C. Péron[1], J. Phocas[2], Y. Reinert[1], A. Roger[1], Y. Sauce[1], F. Senée[1], M. Trocmé[4], C. Veyssière[1], D. Vurpillot[1], X. Wohleber[1]

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Data evaluation

- Relative weight of information varies depending on evaluation methods.
- Estimates obtained using models with **parameters adjusted phenomenologically** to best represent as comprehensive a set of experimental constraints as possible.
- Most parameters adjusted without **strong theoretical constraints**.

Standards

AME
Masses

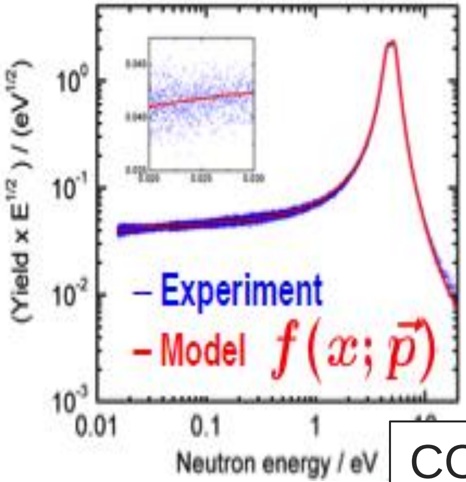
ENSDF
Structure

EXFOR

Differential measurements

Integral measurements

Microscopic experiments
Nuclear reaction models

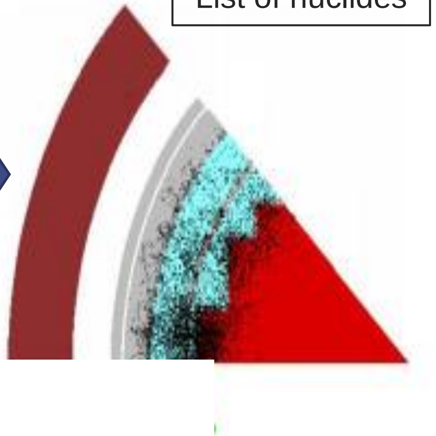


Evaluated file
JEFF (OECD/NEA)

Applied library

Neutron transport

List of nuclides

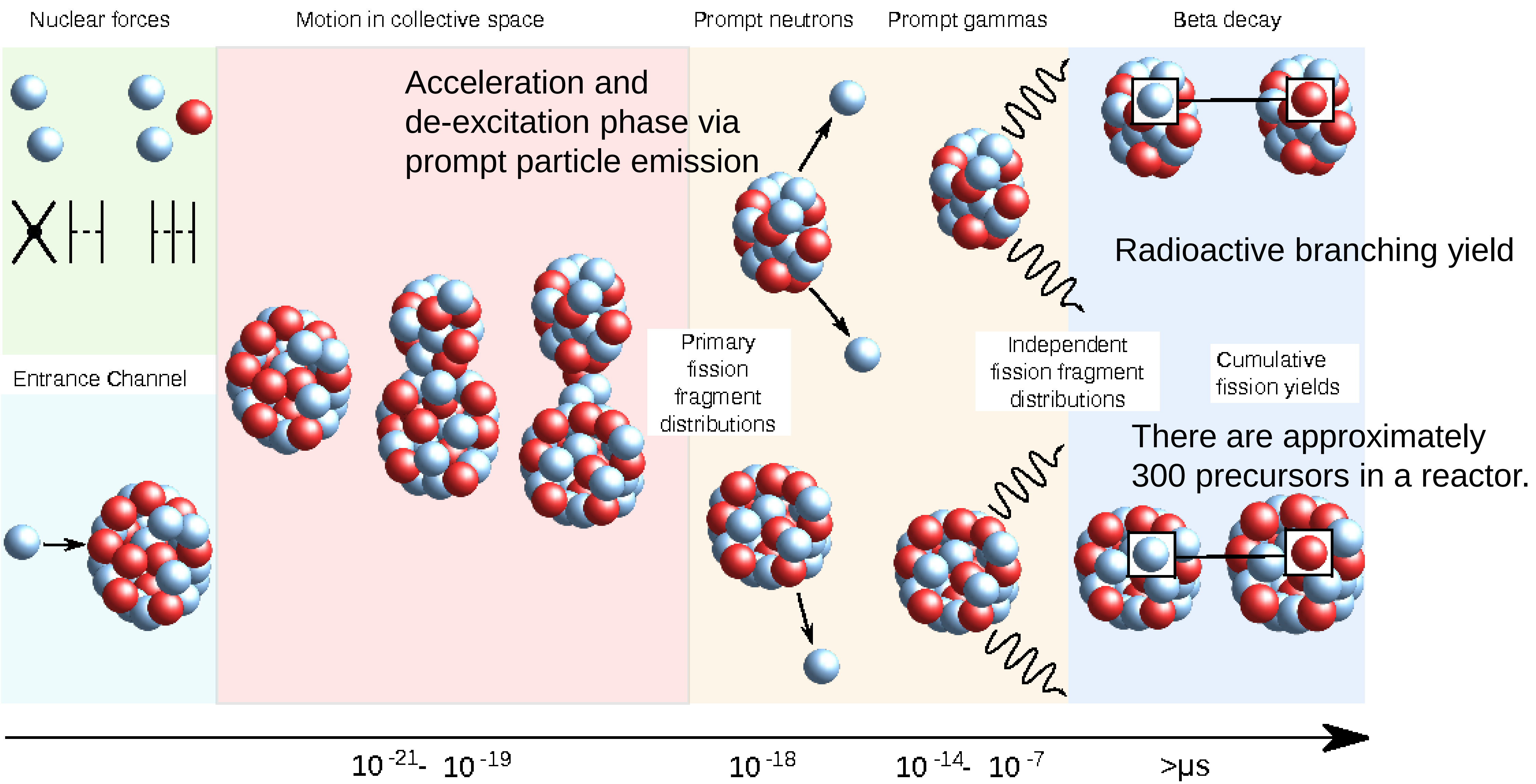


CONRAD and FIFRELIN

3 types of experiments:

- **Exploration**: enable significant advances in knowledge.
- **Systematics**: validate/invalidate/discriminate between models.
- **Calibration.**

Observables and multiple time scales



M. Bender et al., J. Phys. G: Nucl. Part. Phys. 47 (2020) 113002

Measurable quantities and their significance

Measurable quantities	Understanding the fission process	Applications
Fission cross-sections	▪ Spectroscopy of fission states in the second well. ▪ Height and width of fission barriers.	Essential data for applications related to energy and nucleosynthesis. A few percent are required for certain nuclei in the HPRL.
Fission vs capture cross-sections	Separation of states of second well from states of fundamental well.	
Mass and charge yields of fission products	Effect of the structure of the nascent nucleus on fission.	Production of pions, delayed neutron emitters, neutrinos, and gamma-ray heating.
Kinetic energy distribution of fission products	Deformation of the fragments at the scission point.	Energy storage in fuel.
Angular distribution of fission products	Origin of the angular momentum of the composite nucleus	
Prompt neutrons (number + kinetic energy)	Reconstruction of the excitation energy of fission fragments upon scission.	Reactor reactivity.
Delayed neutrons		Reactor control, waste package characterization.
Prompt gammas	Angular momentum content of the fragments.	Released power.
Delayed gammas	Spectroscopy of exotic nuclei.	Residual power.

Application requirements for nuclear data

Nuclear physics program at DES

- Physics of existing and future reactors, nuclear propulsion, RJH, SMRs and fuel cycle closure technologies.
- Support for industrial fuel management projects (Generation 3 MOX fuel, re-enriched reprocessed uranium, calculation of residual power at short and long time scales, etc.).
- Calculation of material damage under irradiation for the back end of the fuel cycle and the qualification of nuclear instrumentation, etc.

Apart from technological uncertainties, **most of the biases and uncertainties arising from numerical simulations are now attributable to the nuclear data used to feed these codes.**

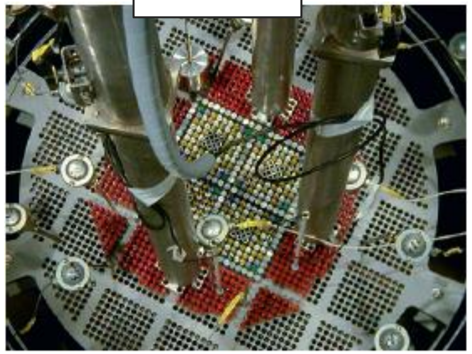
Remarks :

- Good performance of current nuclear data files for **existing reactors and the fuel cycle**.
- **Long cycles of nuclear data improvement**.
- **Error compensations** in cross-section files that are difficult to eliminate and numerous missing covariance data points.
- Sensitivity studies to determine the **data required** for the design of each of the **future reactor types**.
  - HPRL list of physical observables to be measured by the Nuclear Energy Agency (NEA).
  - Energy range, reaction, and maximum acceptable uncertainty.

Background information

- A **strategy that needs to be rethought** to improve neutron calculation tools :
  - Recent closures: EOLE critical facility and MINERVE reactor (2017), MASURCA reactor (2018), ORPHÉE reactor (2019)).
  - Postponement of the decision to build new critical facilities.
- **Increased use of modeling** made possible by academic advances in theoretical physics and the advent of HPC.
- Context similar to that surrounding the **phase-out of full-scale nuclear tests at the CEA/DAM** in 1996, with a shift from a phenomenological approach toward a more coherent methodology based on modeling at a more fundamental scale, supported by experiments conducted on dedicated facilities.
- Evolution of a pragmatic yet empirical approach to nuclear data production that lacks internal consistency and involves **error compensation**.
- Understanding nuclear physics **must be based on a solid and coherent theoretical foundation**, grounded in a microscopic description of the structure of atomic nuclei.

EOLE



MASURCA

Basic/upstream research for nuclear energy

Need for diverse experimental programs

- Requiring a wide range of instruments:
  - Neutrons: angular and energy distributions.
  - Gammas: angular and energy distributions.
  - Fission fragments: identification, mass distributions, excitation energy, decay.
  - Actinides : decay, neutron capture, induced fission.

- Drawing in particular on major research infrastructure
  - Neutron sources
    - Research reactors: ILL.
    - Neutron beams: Neutrons for Science (GANIL), Neutron Time-of-flight (CERN), Los Alamos Neutron Science center.
  - Heavy ion beams : GANIL, GSI.
  - Production of fission fragments: GANIL, GSI, ILL, Aquaspec.
  - Production of isotopically pure materials (particularly actinides): Oak Ridge NL (US), Geel, Mainz

There are uncertainties surrounding a number of them

Basic/upstream research for nuclear energy

Research prospects (1/2)

- Identify and design new facilities for experimental programs :
  - **Manufacturing/supply of spectroscopic-grade targets**

    Ex. : Fabrication of thin actinide targets for spectroscopy experiments.
  - **A state-of-the-art facility for the study of radioactive neutron rich nuclei**

    Beams of fission fragments and actinides.
  - A program to replace neutron sources, which are becoming obsolete.

    Towards **compact neutron sources.**
- Design multi-parameter instrumentation (particularly for fission)

  Progress toward the **most comprehensive correlated measurements** possible.
- Improve the predictive power of theoretical models
  - **Consolidating current theories of fission through microscopic approaches.**
  - **Extending ab initio theories to fission fragments.**
    - Combinatorial complexity: **new mathematical methods to be developed**.
    - **Computational optimization** of calculations**.**
    - Objective: to propagate and control uncertainties at the percent level.

Basic/upstream research for nuclear energy

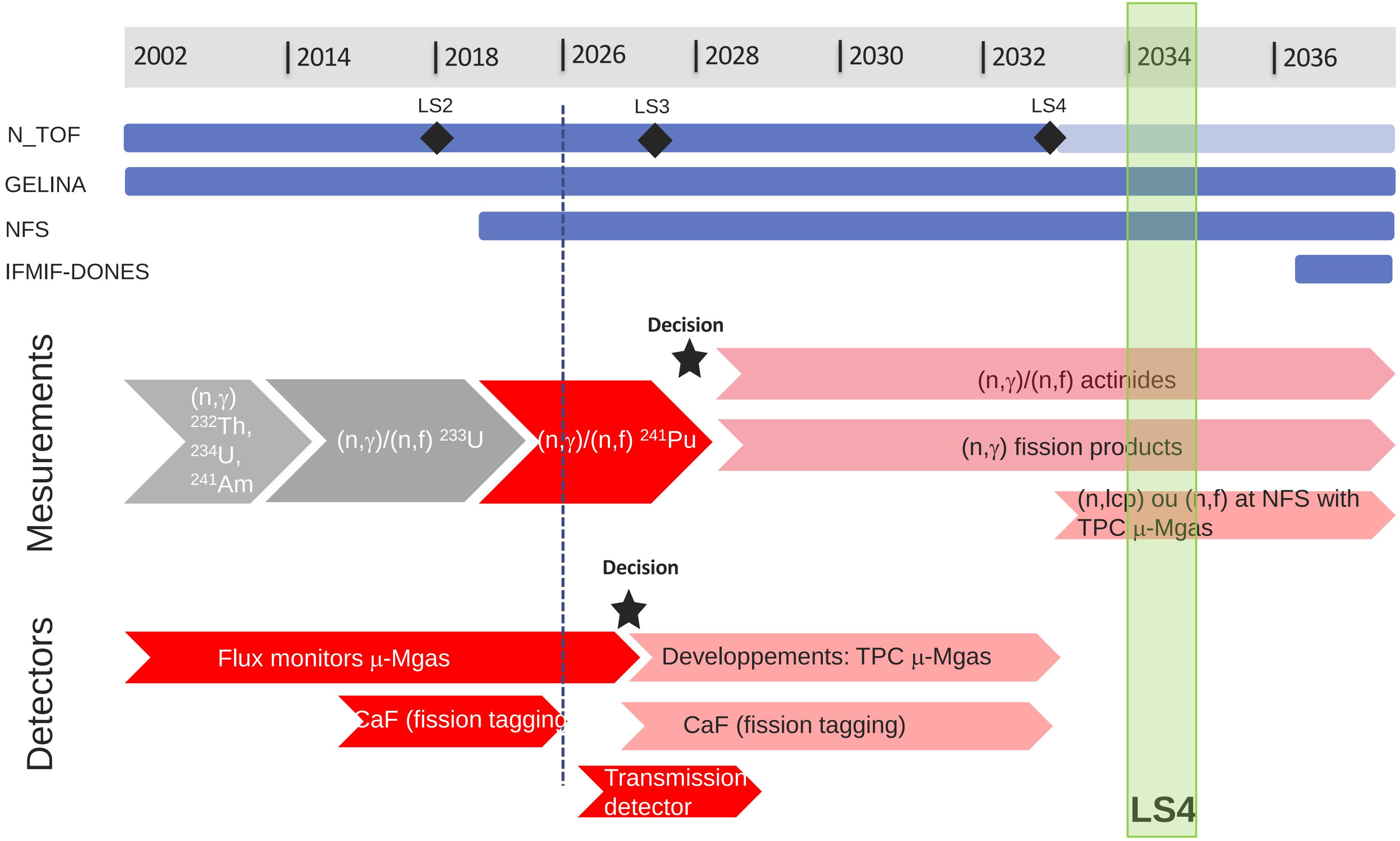
Research prospects (2/2)

- **Continue active R&D on “upstream” areas that can inform the simulation codes of the future** : study of fission chain fluctuations, neutron noise (with potential applications in the detection of reactor anomalies), random geometries, etc.
- Conduct active R&D on **variance reduction methods** used in Monte Carlo codes (significant attenuation in the far field, etc.).
- **Continue efforts and work on advanced methods to support improvements in the modeling process** (multi-output Gaussian processes, model reduction methods, etc.).

3. Programs and roadmaps

Work in progress. To be completed by the end of 2026.

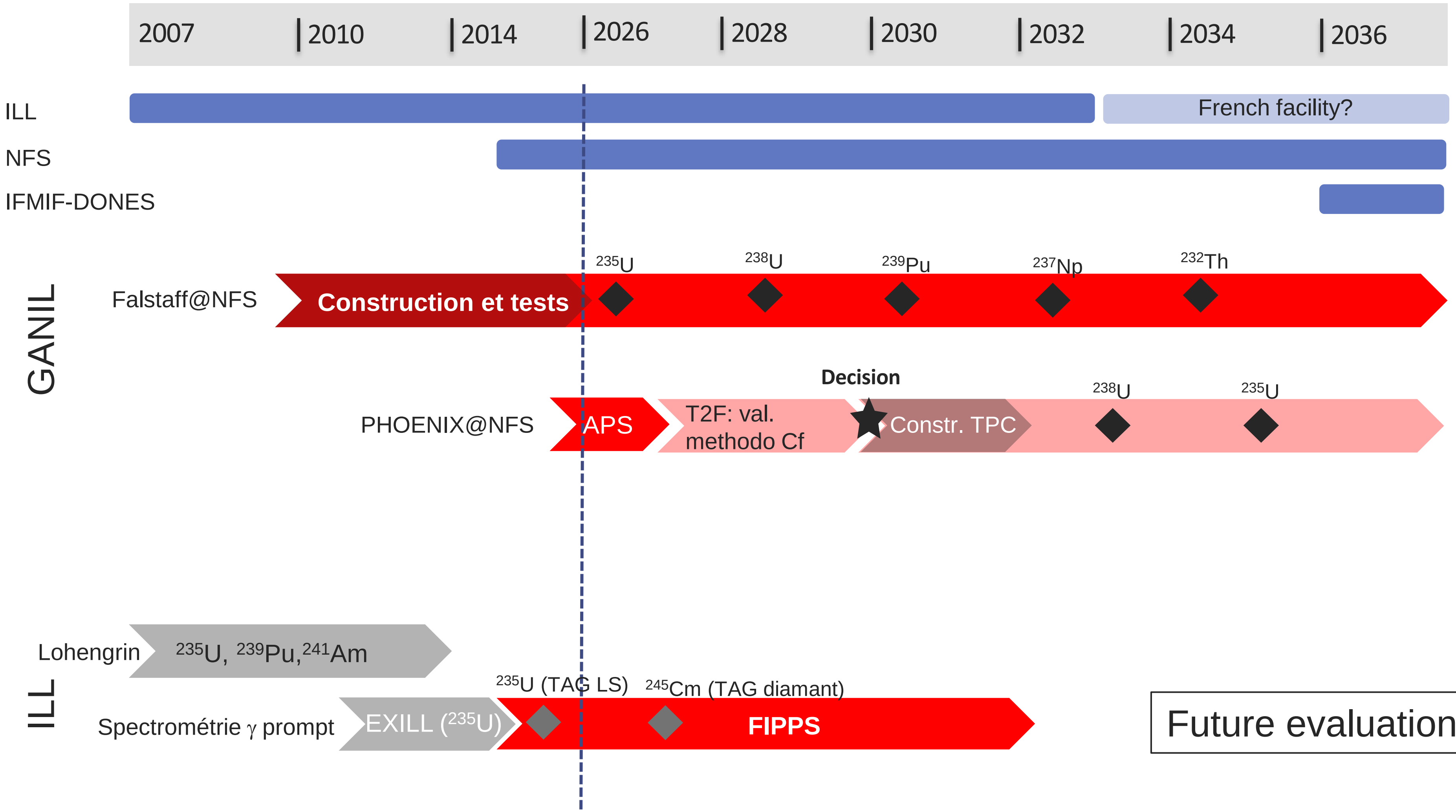
Roadmap: « neutron measurements »



- High-precision data relevant to the current and future cycles (closed cycle, SMR).
- Data relevant to constraining microscopic calculations of nuclear structure (energy level density and gamma strength function).

Evaluation at CSTD on 01 June 2026

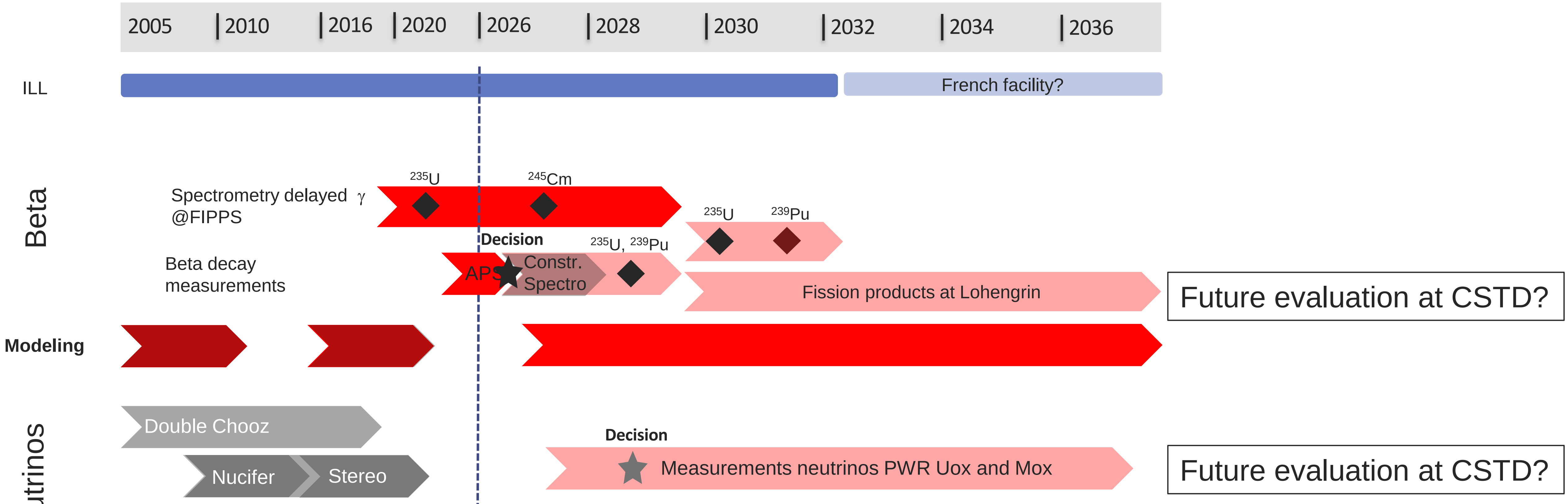
Roadmap: « fission »



- Validate the microscopic foundations of fission and decay models using selective methods.
- Generate useful data for the current and future cycles.

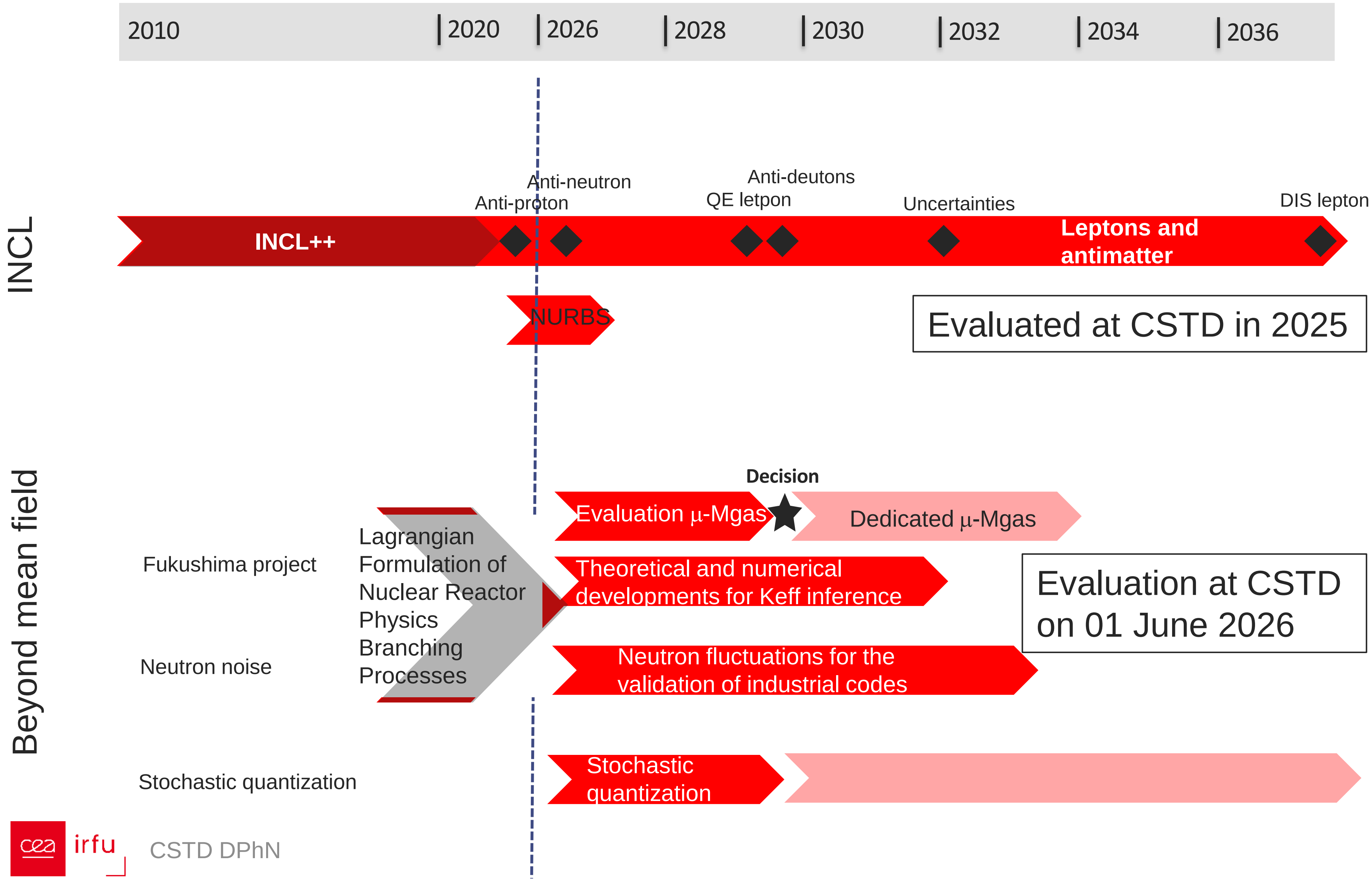
Future evaluation at CSTD?

Roadmap: « beta decays and neutrinos »



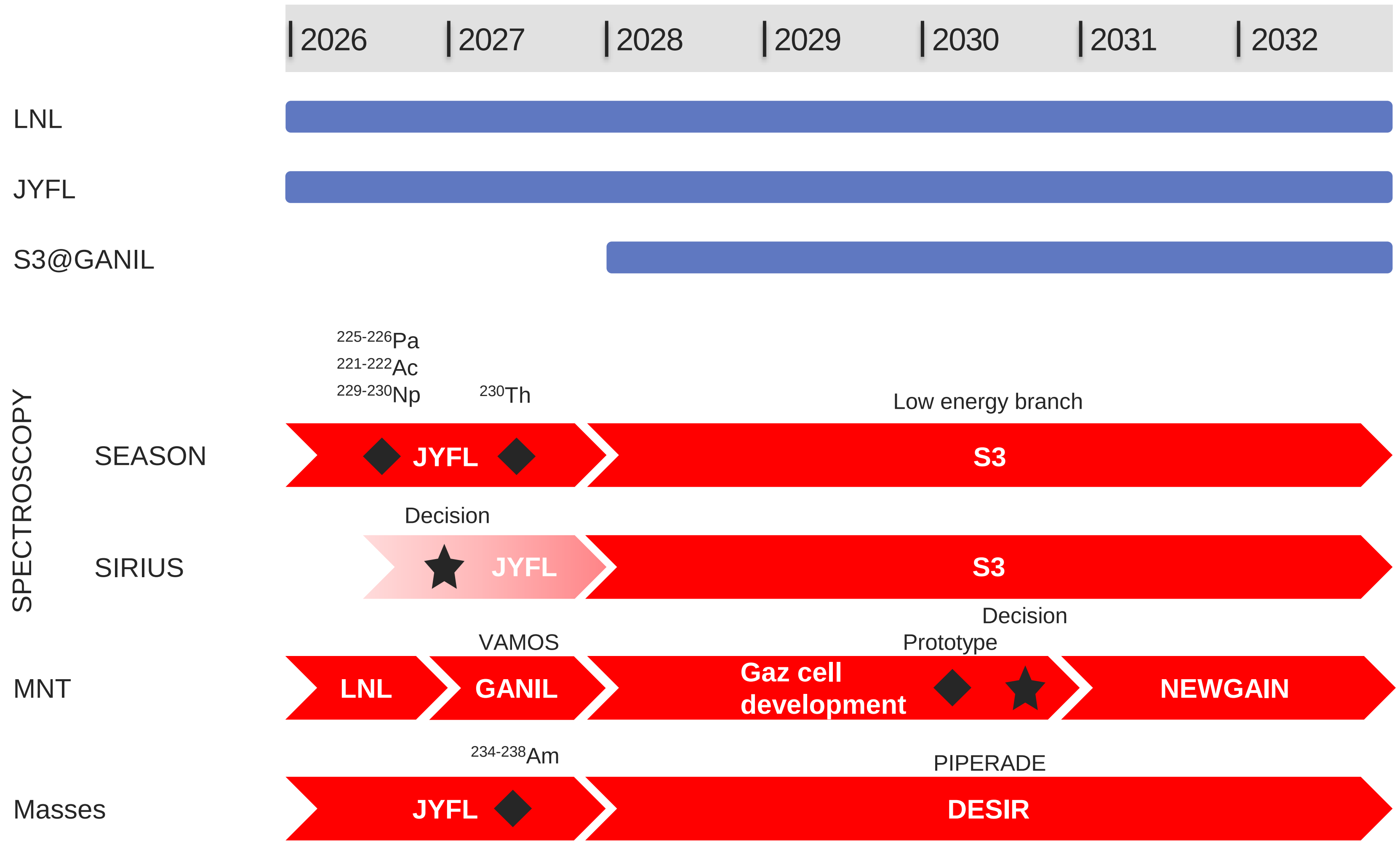
- Understanding the propagation properties of neutrinos.
- Improving the modeling of beta decay in fission products.

Roadmap: « stochastic transport»



- Developing a precise reaction model that accounts for uncertainties for future neutrino experiments and applications at the frontiers of science.
- Develop tools and methods for studying fluctuations in transport processes.
- Neutronics: nonlinear behavior of stochastic noise and power that cannot be captured by codes.

Roadmap: « heavy and superheavy nuclei »

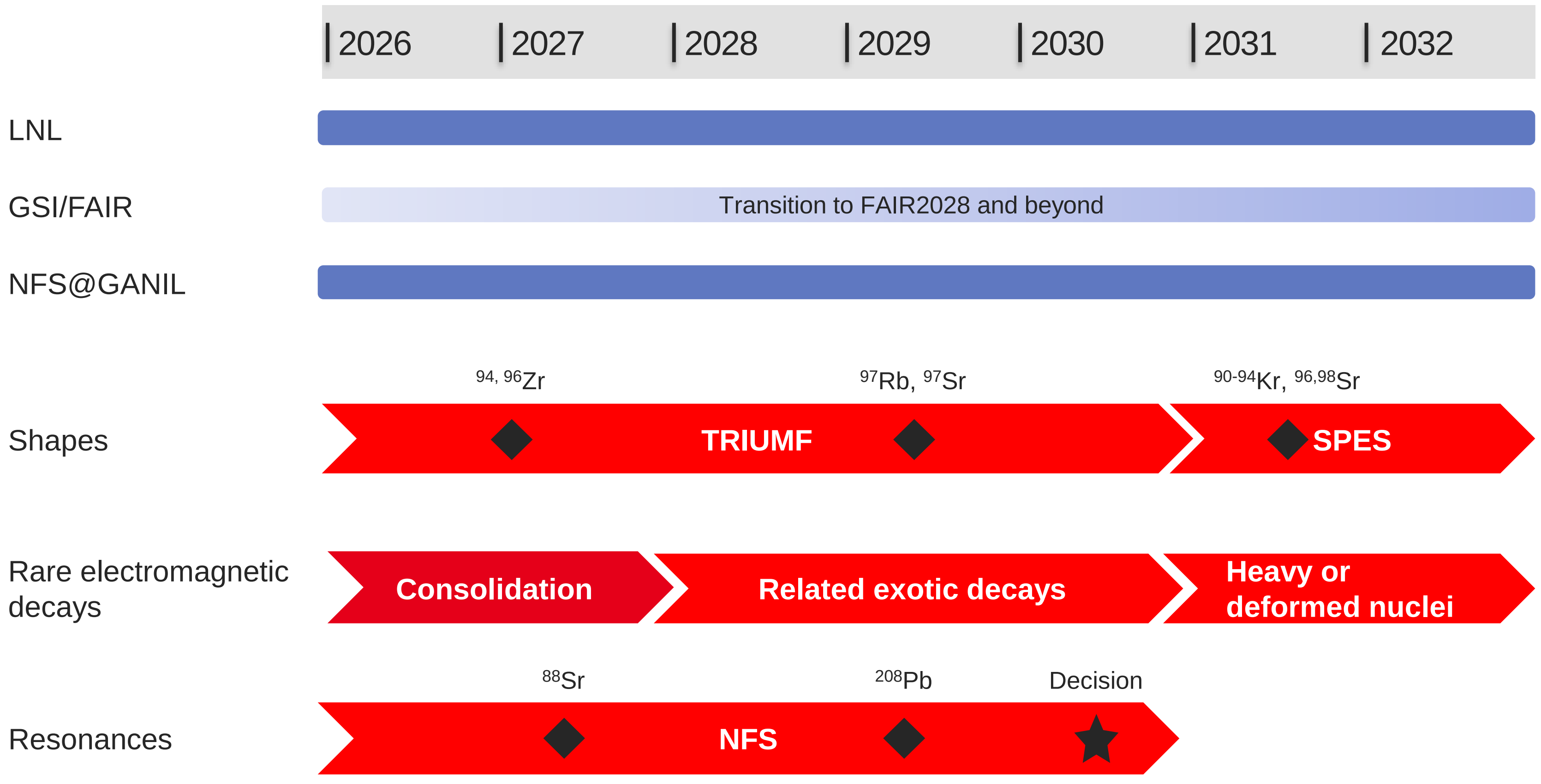


- Exploration of structural characteristics:
  - Mass
  - Deformation
  - Energy levels
  - Charge radius
  - Decay modes
- Impact on stability.

Evaluated at CSTD in 2025

Future evaluation at CSTD?

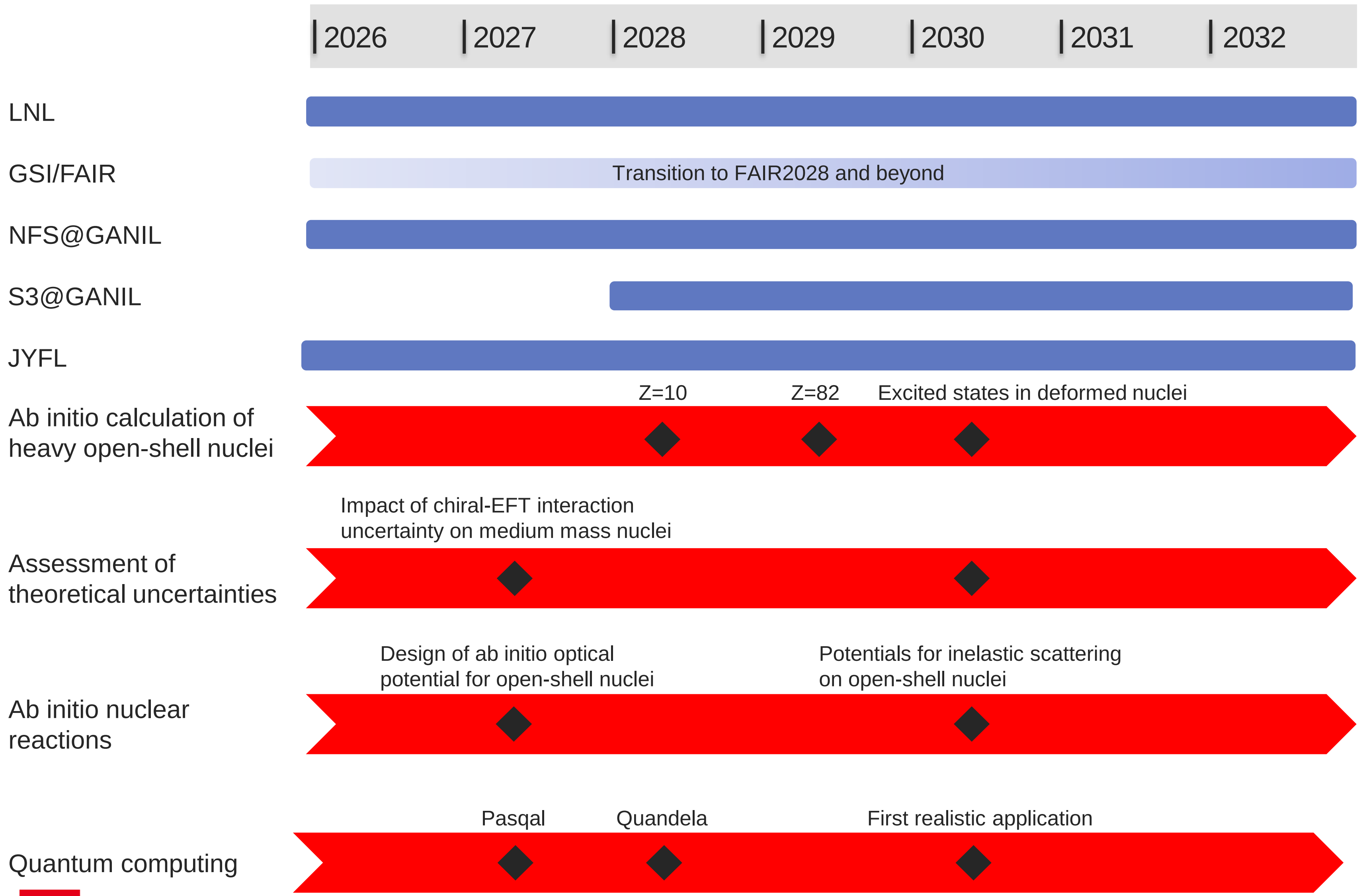
Roadmap: « other nuclear structure activities »



Evaluated at CSTD in 2022

- Comprehensive experimental data on shape coexistence at N=60.
- Access to previously unobserved quantities related to nuclear structure and nuclear polarizability.
- Investigation of collective modes in nuclei, and the role of isospin degrees of freedom in nuclear excitations.

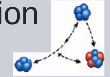
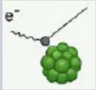
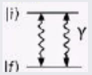
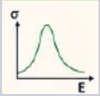
Roadmap: « theory »



- Description of complex nuclei (open, heavy, deformed) and directly link to experimental observations.
- Recent exploration of the relationship between nuclear structure and ultrarelativistic ion collisions.

Evaluated at CSTD in 2020

Observables, theory, and future experiments

Physics topics	Key observables	Contribution of theory	Experiments and setups	Contribution of theory at DPhN	Grounded theory experiments
MNT and (super)heavy nuclei production 	▪ MNT cross-sections ▪ Isotopic distributions ▪ Excitation functions ▪ Structure	▪ Transport models ▪ Prediction of favored channels ▪ N/Z rebalance, energy dissipation ▪ Optimization of production conditions	▪ AGFA@ANL ▪ MNT@LNL ▪ MNT@GANIL	**To be built** Mid-to-long terme developments required	MNT data will guide future theoretical developments
Structure and deformation (low and intermediate masses) 	▪ Energy levels ▪ Quadrupolar moments ▪ Deformation and shape coexistence ▪ Form factors	▪ Ab initio, shell model, EDF, GCM ▪ Predictions of spectrum and transitions ▪ Correlations and collectivity ▪ Deformation maps	▪ AGATA ▪ SIRIUS@S3 ▪ Coulomb excitation ▪ Transfert reactions	**Under control** Robust results for low to intermediate mass nuclei: spectrum, shape, etc.	Choice of isotopes and key excitations to explore
Charge densities 	▪ Charge radii ▪ Nuclear densities ▪ Form factors ▪ EM responses	▪ Ab initio computation of densities ▪ Ab initio optical potentials ▪ Uncertainty quantification ▪ Links to other observables	▪ Electron-nucleus scattering ▪ Laser spectrometry	**Under control / under development** Ab initio computation of optical potentials	Contraints on densities and N/Z symmetry in exotic nuclei
Rare decays (2γ) 	▪ Half-lives ▪ Multipolarities ▪ Electric polarisabilities	▪ Computation of nuclear polarisabilities ▪ Contribution of correlations ▪ Constraints on decay mechanisms	▪ GSI/ESR ▪ γ-ELBE@HIGS ▪ HIGS@Duke	**In progress** Computation of polarisabilities and correlations	Interpretation and prediction of new high impact decays
Giant resonances and collective excitations 	▪ Energy, width, forces ▪ 2-phonons resonances	▪ Computation of nuclear responses ▪ QRPA, RPA and EDF models ▪ Photon-phonon coupling ▪ Global predictions	▪ AGATA, S3, SIRIUS ▪ NFS (Pygmy GDR)	**In progress** Improvements for couplings and 2-phonon resonances	Identification of collective modes and test of effective interactions

Thanks for your attention

Any questions?

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