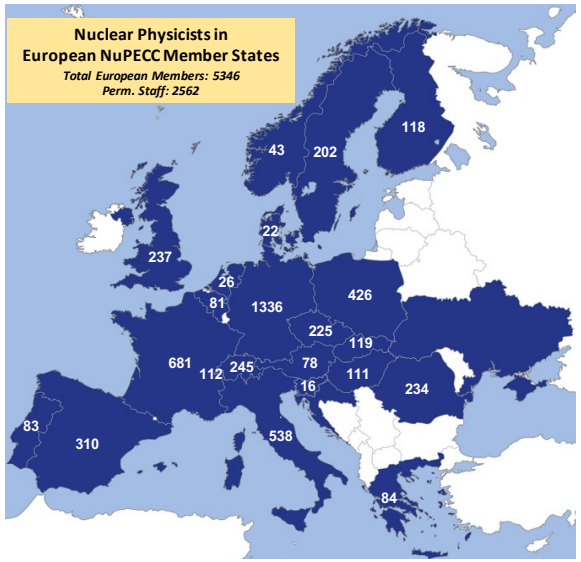
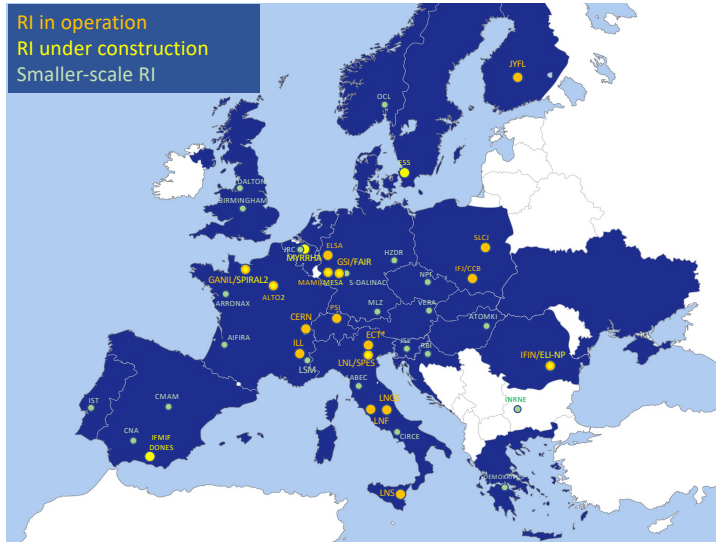
NuPECC Long Range Plan 2024

Marek Lewitowicz

Nuclear Physics European Collaboration Committee (NuPECC)



Present and future perspectives in Hadron Physics
Frascati
17/06/2024



- NuPECC and Long Range Plan
- Road to Long Range Plan 2024 for European Nuclear Physics
- Recommendations

What is NuPECC ?

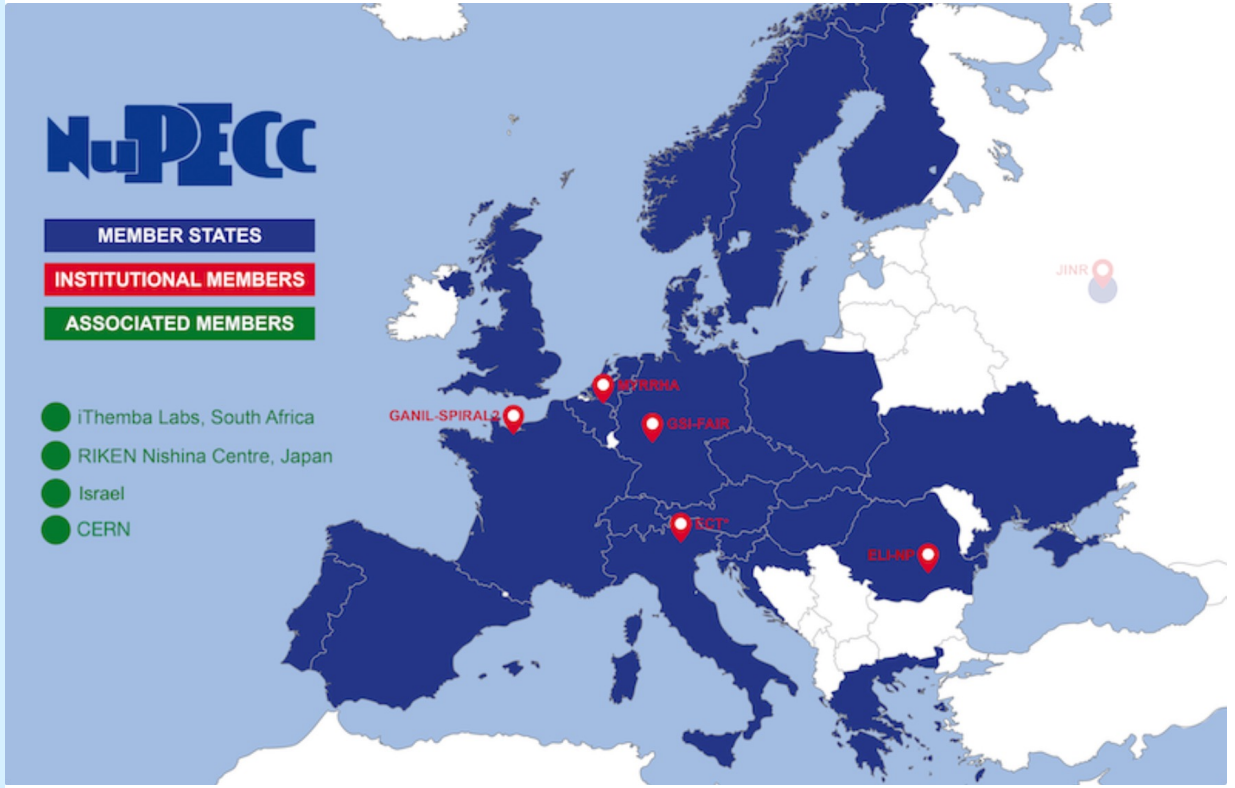
Nuclear Physics European Collaboration Committee (NuPECC)
Is the European Expert Board for Nuclear Physics
hosted by European Science Foundation

Representing

> 5000 scientists

Composition:

- 35 representatives from 23 countries (new member Ukraine), 3 ESFRI NP Infrastructures & ECT*
  JINR Dubna – suspended in March 2022
- 4 associated members
  - CERN
  - Israel
  - iThemba Labs
  - Nishina Center
- 10 observers: ALAFNA, ANPhA, APPEC, CINP, ECFA, ESF, EPS-NPD, EPS-HEPPD (new observer), IAEA, NSAC



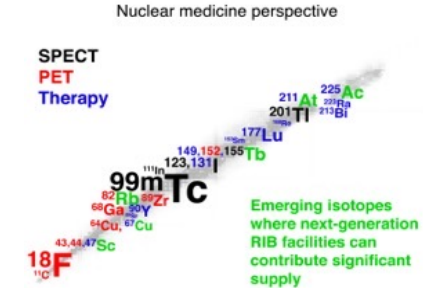
3 regular Committee meetings/y

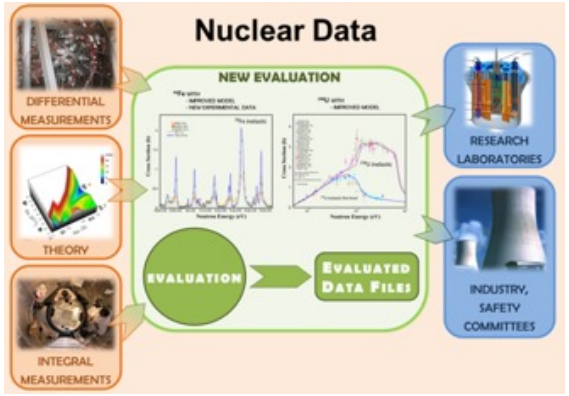
36 Years of NuPECC activities

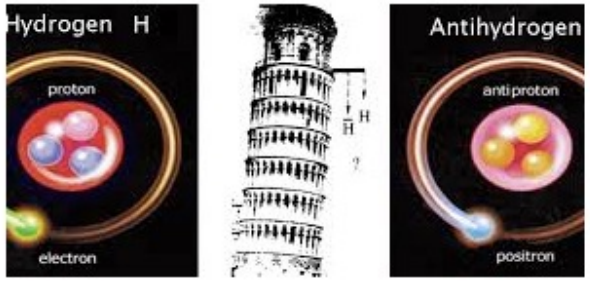
https://nupecc.org

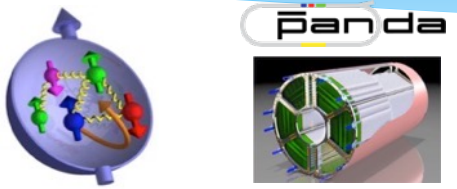
Nuclear Physics in Europe

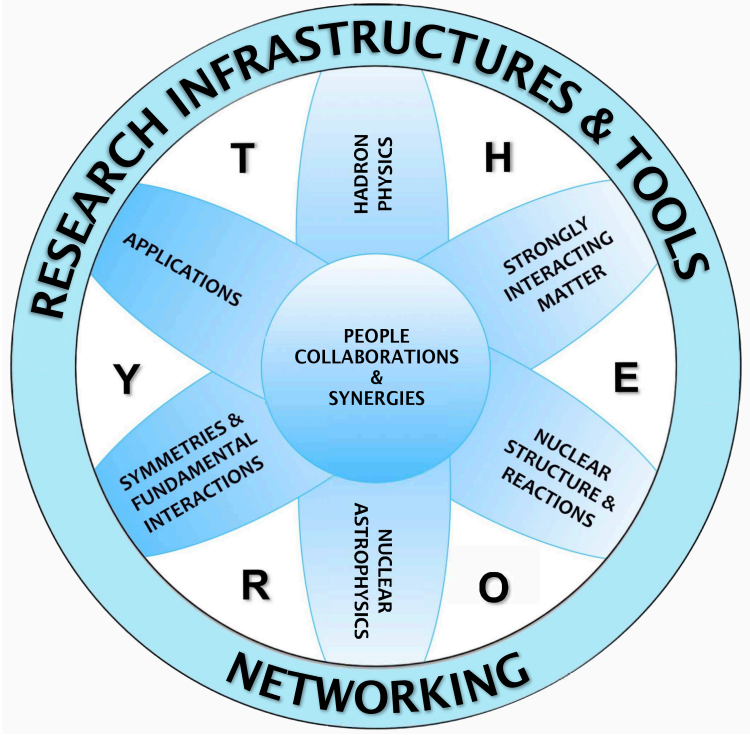
http://www.nupecc.org

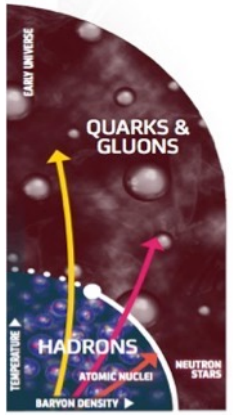


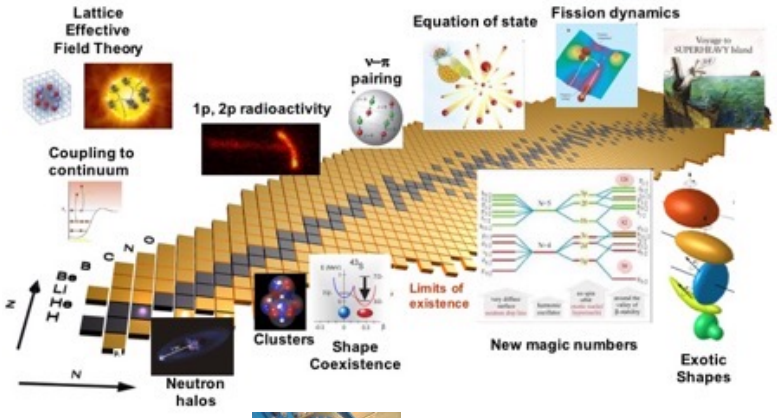


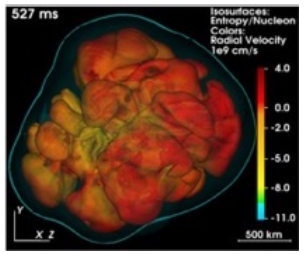


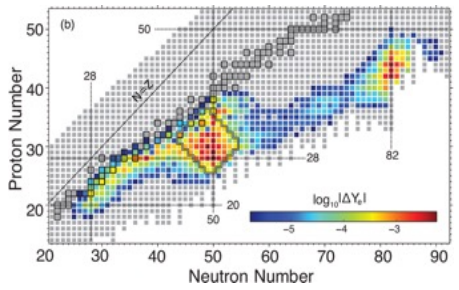


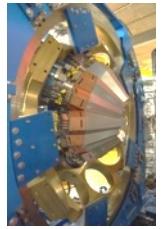










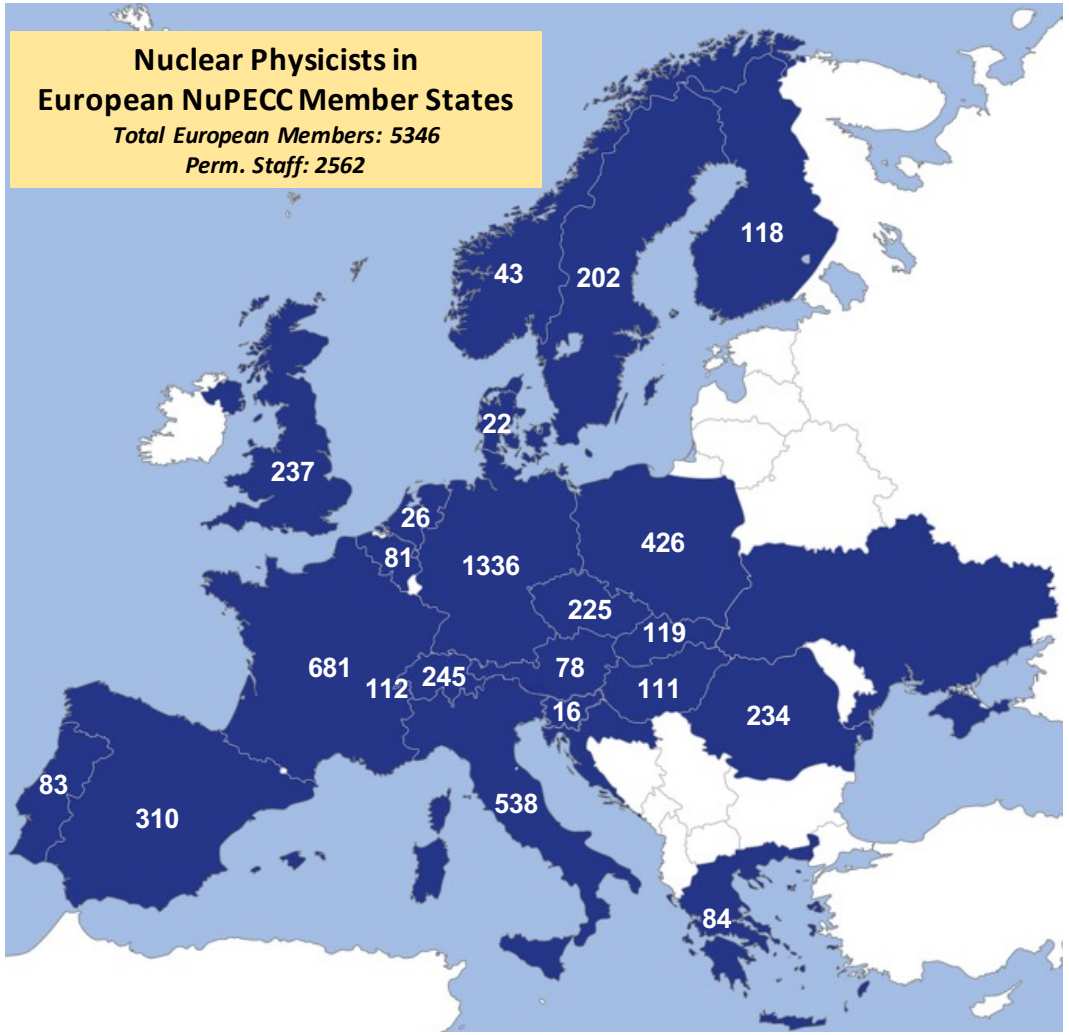


Nuclear Physics Workforce in Europe

5346 - total number of Nuclear Physicists (Exp. & Theory) in the European NuPECC Member States and the Associated Member CERN

2546 – *permanent staff*
2800 – *PhD students and non-permanent staff*

From NuPECC 2021& 2023 surveys



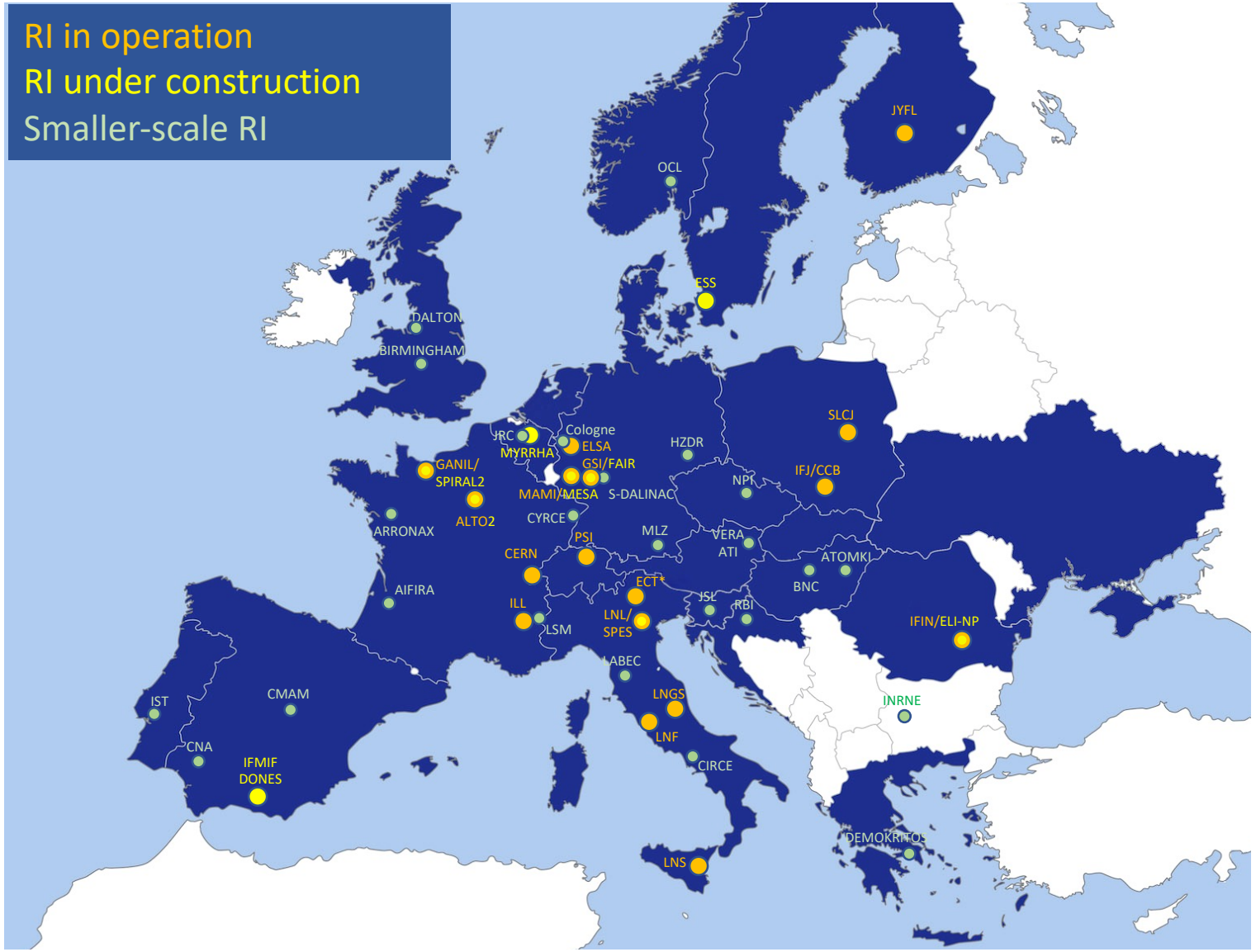
J. J. Gomez Camacho, Ulf-G. Meißner et al.

European Landscape of Nuclear Physics Infrastructures

Nuclear Physics Facilities in Europe

Taking data > 30

Under construction or upgrade ≥ 9



Nuclear Physics and Society

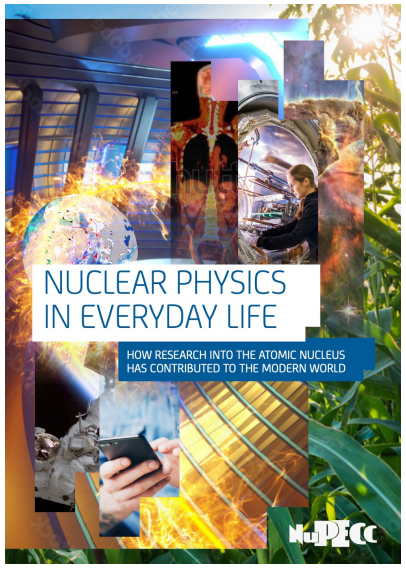
United Nations Sustainable Development Goals (SDGs) to which nuclear contribute the most.

NuPECC report on

Nuclear Physics in Everyday Life

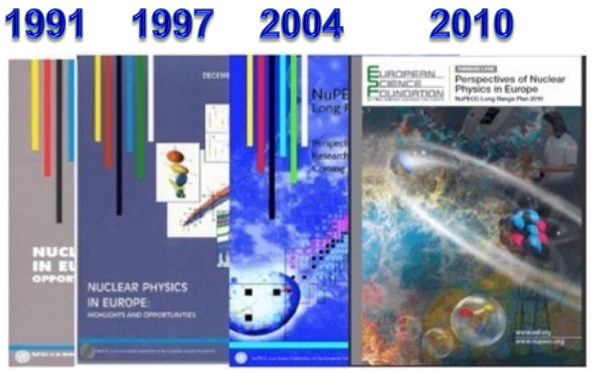
(100 pages, open access on-line)

https://nupecc.org/pub/np_life_print.pdf



Nuclear science and technology have benefited human progress, culture, and our understanding of our delicate environment in general, as well as health, economic growth, and security in nations all over the world.

Towards NuPECC Long Range Plan 2024



- **The LRP identifies opportunities and priorities for nuclear science in Europe**
- **The LRP provides national funding agencies, ESFRI and the European Commission with a framework for coordinated advances in nuclear science in Europe**

NuPECC LRP 2017

https://www.nupecc.org/lrp2016/Documents/lrp2017.pdf

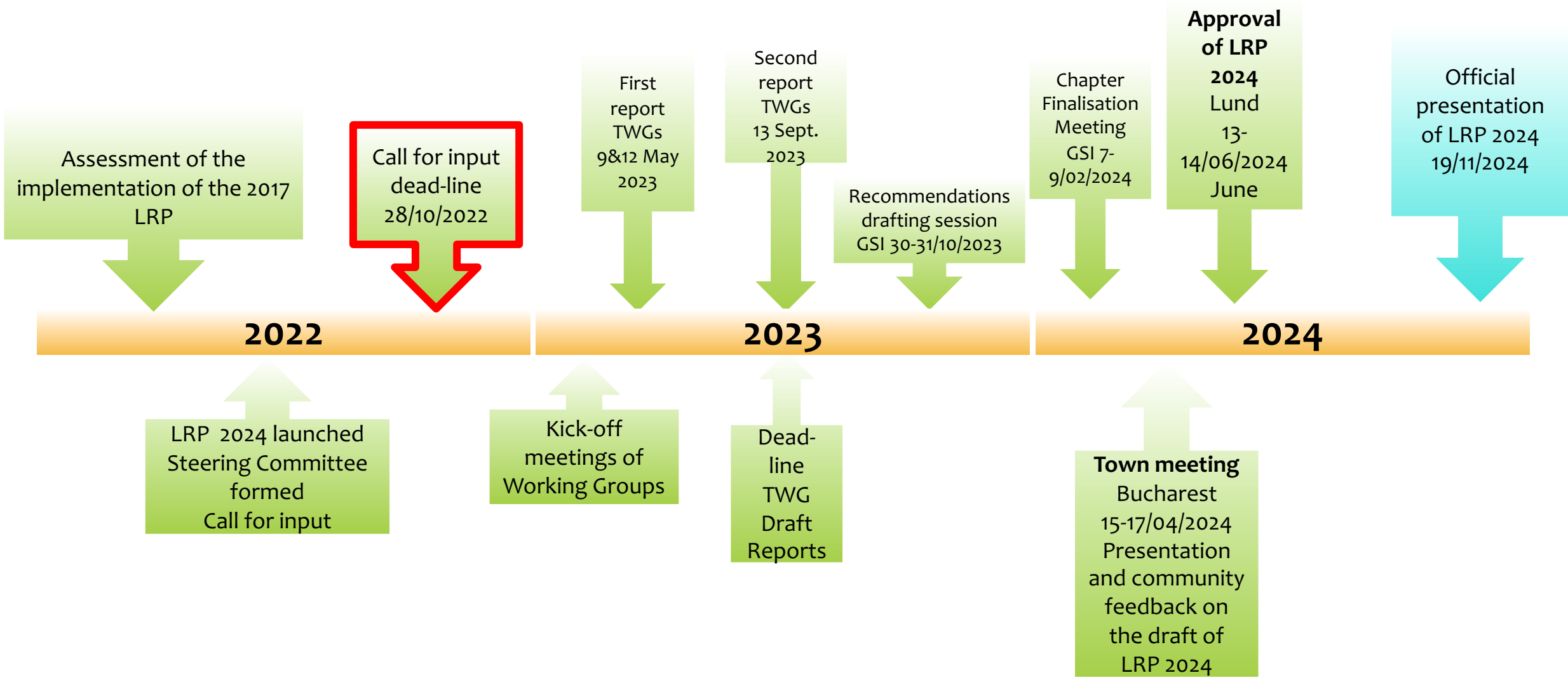
Assessment of implementation of LRP 2017

https://www.nupecc.org/2017_LRP_Assessment_of_Implementation_final.pdf

Launched in May 2022 in Madrid

NuPECC LRP 2024

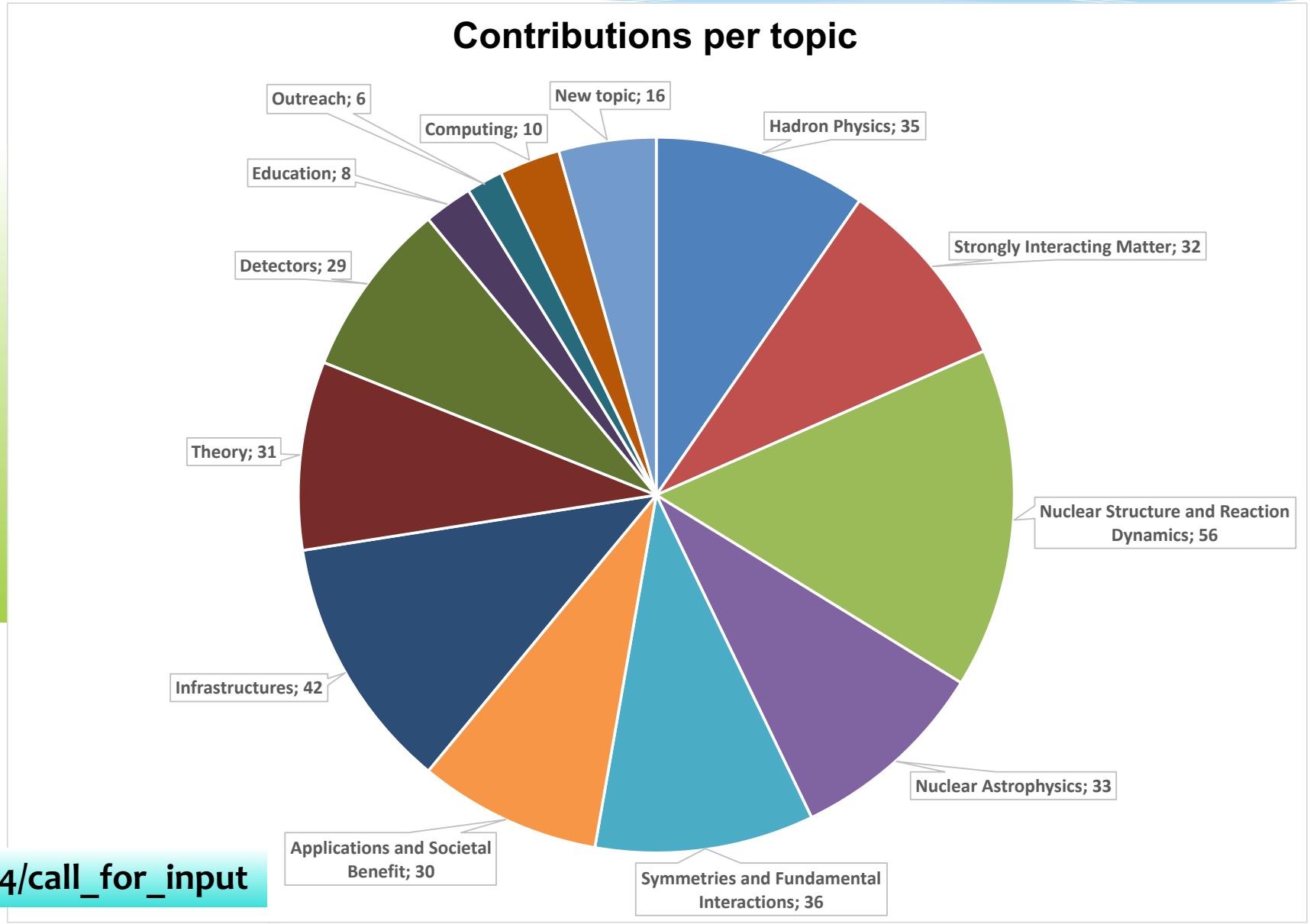
NuPECC LRP2024 Timeline



NuPECC LRP 2024 – Contributions of the community

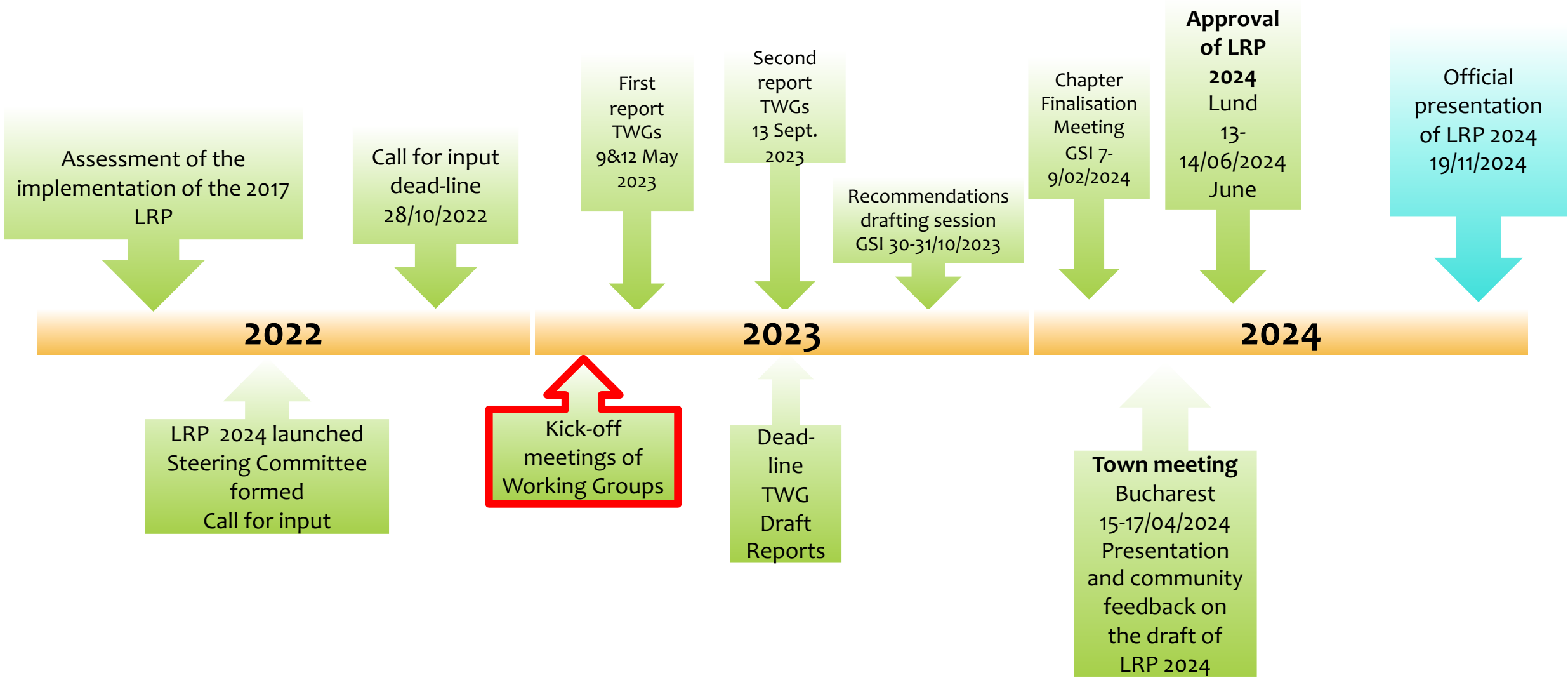
LRP Contributions:

- 159 contributions
- Submitted by > 400 individual scientists, collaborations, infrastructures, and research institutions in Europe



https://nupecc.org/?display=lrp2024/call_for_input

NuPECC LRP2024 Timeline



TWG coordinators and SC liaisons

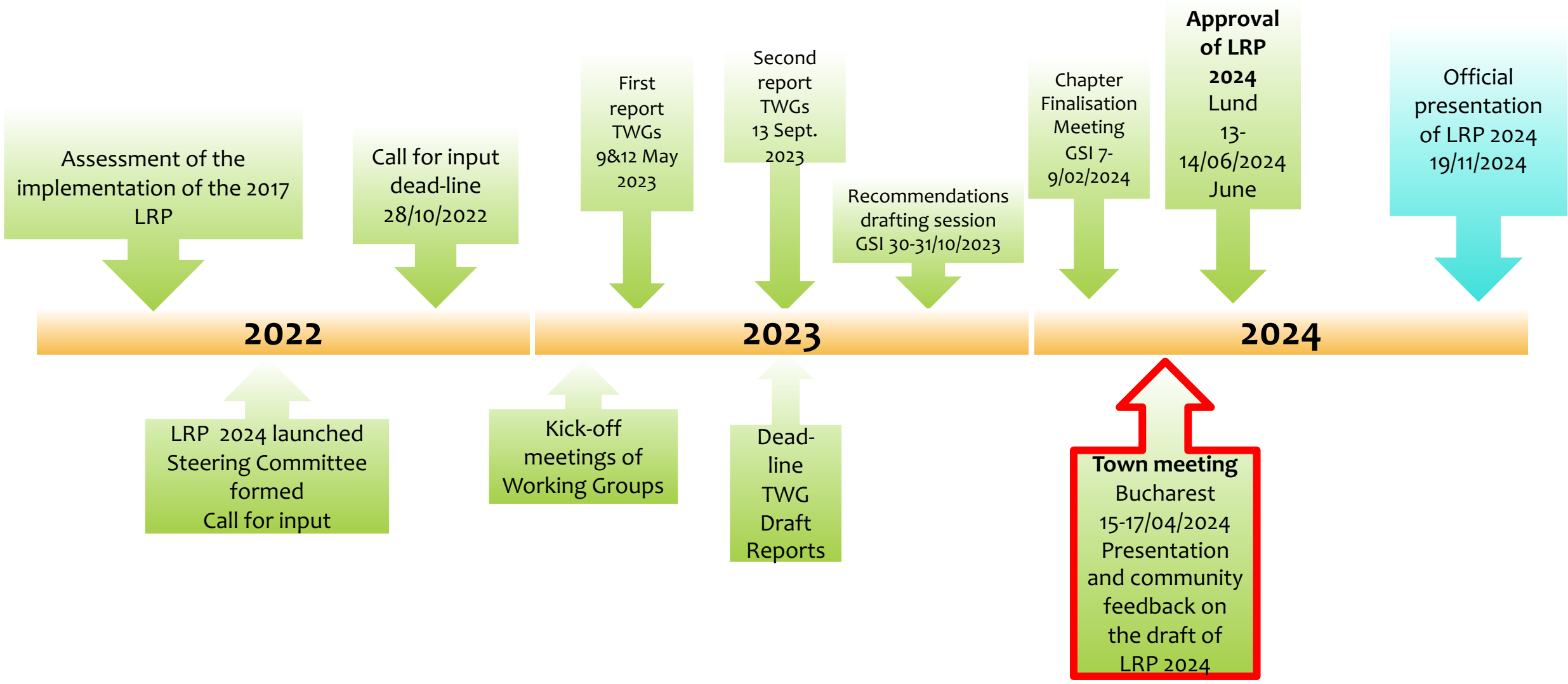
Theory/Exp.

TWG Number	TWG	Coordinators	Coord. e-mails	Liaisons	Liaisons e-mails
1	Hadron Physics	Karin Schönning (Uppsala)	karin.schonning@physics.uu.se	Diego Bettoni	bettoni@fe.infn.it
		Constantia Alexandrou (CY)	c.alexandrou@cyi.ac.cy alexand@ucy.ac.cy	Dave Ireland	david.ireland@glasgow.ac.uk
2	Strongly Interacting Matter at Extreme Conditions	Laura Fabbietti (TUM)	laura.fabbietti@ph.tum.de	Gert Aarts	g.aarts@swansea.ac.uk
		Urs Wiedemann (CERN)	Urs.Wiedemann@cern.ch	Raimond Snellings	R.Snellings@uu.nl
3	Nuclear Structure and Reaction Dynamics	Silvia Leoni (Univ. Milano)	silvia.leoni@mi.infn.it	Adam Maj	adam.maj@ifj.edu.pl
		Tomas Rodriguez(UCM)	tomasrro@ucm.es	Jelena Vesic	jelena.vesic@ijs.si
4	Nuclear Astrophysics	Anu Kankainen (JYFL)	anu.kankainen@jyu.fi	Daniel Bemmerer	d.bemmerer@hzdr.de
		Jordi Jose (Barcelona)	jordi.jose@upc.edu	Sandrine Courtin	sandrine.courtin@iphc.cnrs.fr
5	Symmetries and Fundamental Interactions	Pierre Delahaye (GANIL)	pierre.delahaye@ganil.fr	Eberhard Widmann	Eberhard.Widmann@oeaw.ac.at
		Paolo Crivelli (ETH)	Paolo.Crivelli@cern.ch	Klaus Kirch	klaus.kirch@psi.ch
6	Infrastructures	Wolfram Korten (CEA, Saclay)	w.korten@cea.fr	Joaquin Gomez-Camacho	gomez@us.es
				Patricia Roussel-Chomaz	patricia.chomaz@ganil.fr
7	Applications and Societal Benefit	Thomas Cocolios (KU Leuven)	thomas.cocolios@kuleuven.be	Lucia Popescu	lucia.popescu@sckcen.be
		Charlot Vandevoorde (GSI)	C.Vandevoorde@gsi.de	Vladimir Wagner	wagner@ujf.cas.cz
8	Nuclear Physics Tools Detectors and experimental techniques Computing, Machine Learning and Artificial Intelligence	Silvia Dalla Torre (INFN)	Silvia.DallaTorre@cern.ch	Eugenio Nappi	Eugenio.Nappi@ba.infn.it
		Valerio Bertone (CEA Saclay)	valerio.bertone@cea.fr	Hervé Moutarde	herve.moutarde@cea.fr
		Jana Guenther (U. Wuppertal)	jguenther@uni-wuppertal.de		
9	Open Science and Data	Antoine Lemasson (GANIL)	antoine.lemasson@ganil.fr	Marek Lewitowicz	marek.lewitowicz@ganil.fr
10	Nuclear Science - People and Society Training, Careers & Diversity Education and Outreach	María García Borge (Madrid)	mj.borge@csic.es	Rolf-Dietmar Herzberg	rdh@liverpool.ac.uk
		Christian Diget (York)	christian.diget@york.ac.uk	Yvonne Leifels	Y.Leifels@gsi.de

11 Thematic Working Groups
268 Members and NuPECC Liaisons

Important role of liaisons during the work of TWG and in preparation of their reports

NuPECC LRP2024 Timeline



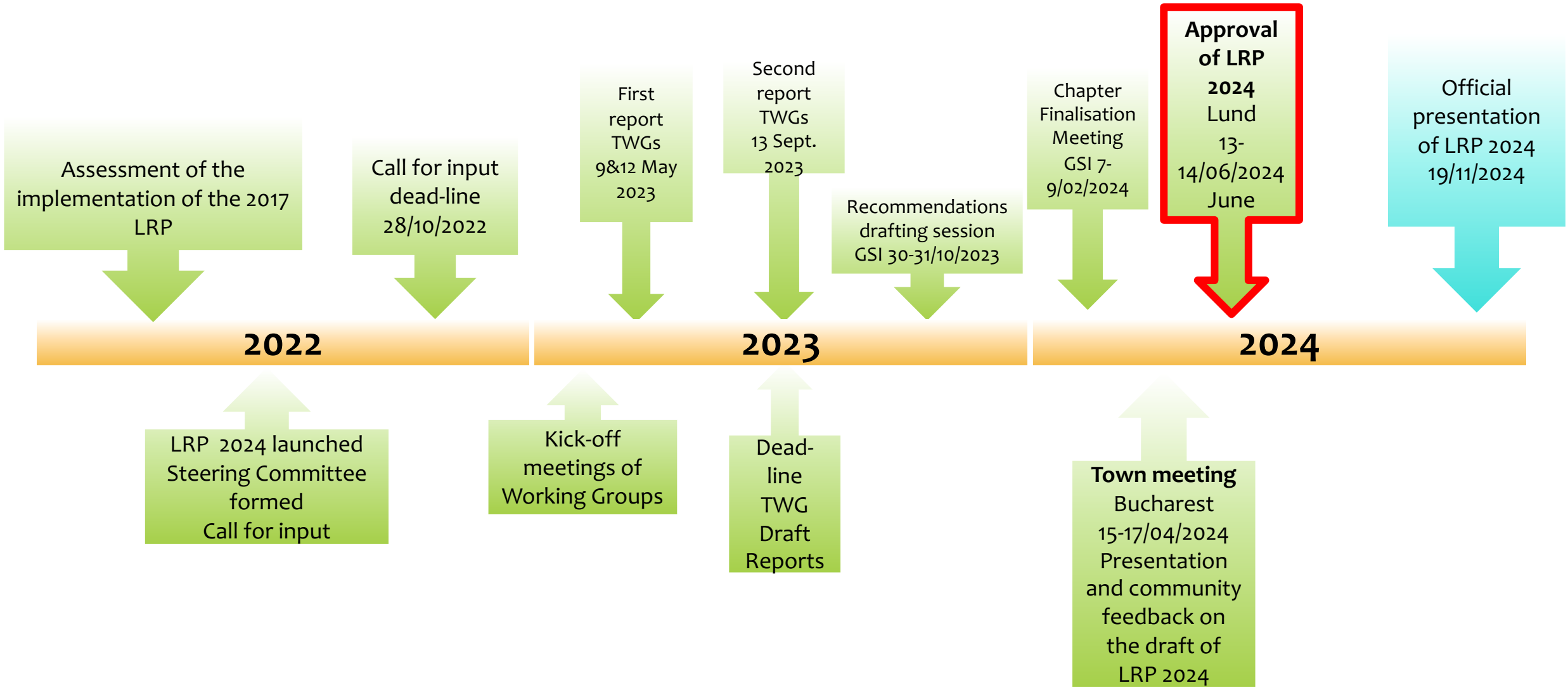
LRP2024 Town Meeting

LRP2024 Town Meeting 15 April (noon) - 17 April (noon) 2024 in Marriott Hotel, Bucharest

The is meeting aimed to bring together the Nuclear Physics community in Europe to discuss the long-range perspectives in our field and decide how best to develop it in the next ten to fifteen years. A draft of the LRP2024 Report and its Recommendations were presented and discussed during the meeting.
This was an excellent opportunity for you to learn about and discuss the strategic choices of the community for the future of Nuclear Physics research in Europe.

- **Open to all community**
- **The meeting was in person only to favour the lively discussion**

NuPECC LRP2024 Timeline



The NuPECC LRP 2024

364 pages

- Executive Summary *(includes Recommendations)*
- Hadron Physics
- Strongly Interacting Matter at Extreme Conditions
- Nuclear Structure and Reaction Dynamics
- Nuclear Astrophysics
- Symmetries and Fundamental Interactions
- Research Infrastructures
- Applications and Societal Benefits
- Nuclear Physics Tools
  - Detectors and experimental techniques
  - Machine Learning (ML), Artificial Intelligence (AI) & Quantum Computing (QC) in nuclear physics
- Open Science and Data
- Nuclear Science - People and Society

LRP2024 approved at the NuPECC meeting in Lund 13/06/2024

Executive Summary

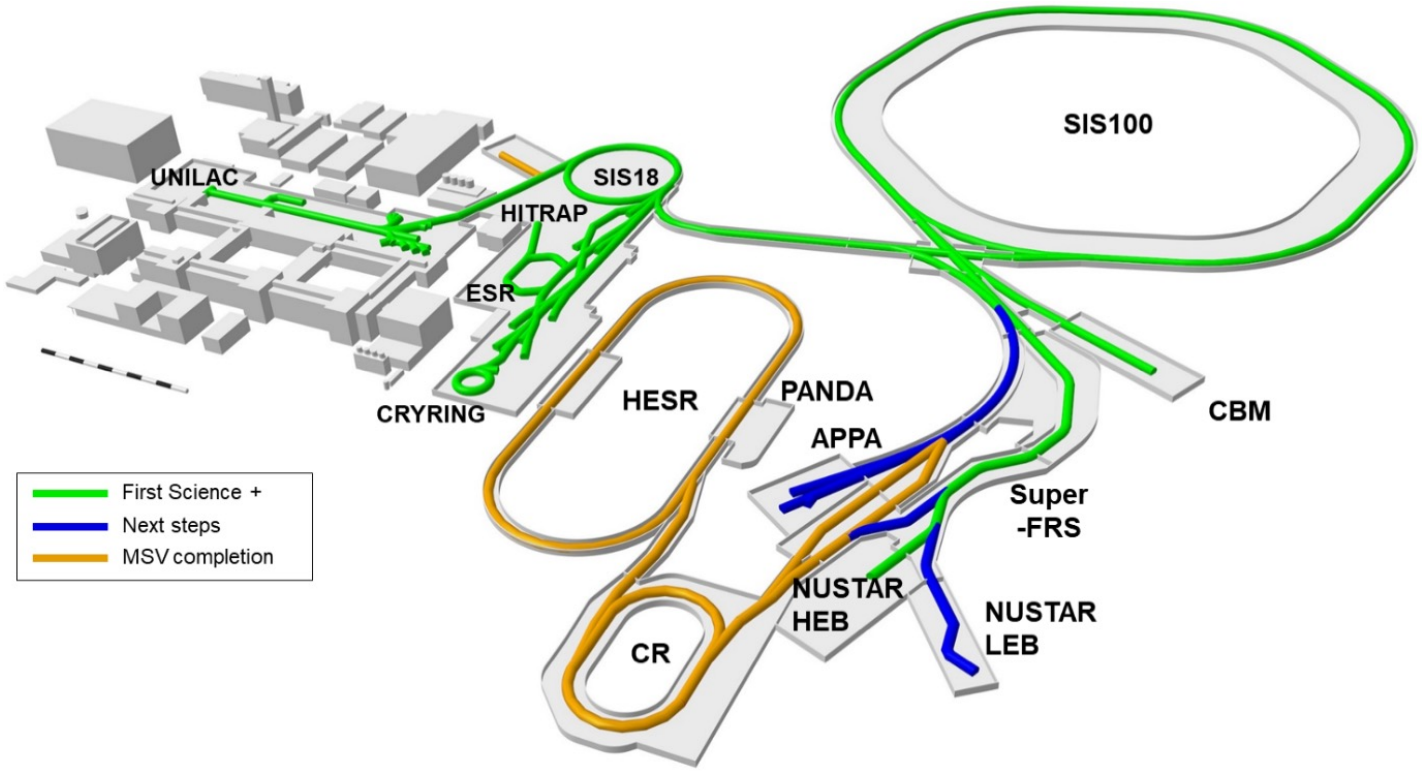
- Introduction
- What does Nuclear Physics stand for?
- Nuclear Physics and Society
- European landscape of nuclear physics
- **Recommendations for Nuclear Physics Infrastructures**
- International and Interdisciplinary Context
- **Recommendations**
  - Fundamental Nuclear Physics
    - **Hadron Physics**
    - **Strongly Interacting Matter at Extreme Conditions**
    - Nuclear Structure and Reaction Dynamics
    - Nuclear Astrophysics
    - Symmetries and Fundamental Interactions
  - Applications and Societal Benefits
  - Nuclear Physics Tools
    - Detectors and experimental techniques
    - Machine learning (ML) and artificial intelligence (AI), Quantum computing (QC), Numerical tools, techniques and resources
  - Open Science and Data
  - Nuclear Science - People and Society

LRP2024 approved at the NuPECC meeting in Lund 13/06/2024

Recommendations for Nuclear Physics Infrastructures

ESFRI

- **The first phase of the international FAIR facility is expected to be operational by 2028, facilitating experiments with SIS100 using the High-Energy Branch of the Super-FRS, the CBM cave and the current GSI facilities. Completing the full facility including the APPA, CBM, NUSTAR and PANDA programs will provide European science with world-class opportunities for decades and is highly recommended.**



Recommendations for Nuclear Physics Infrastructures

ESFRI

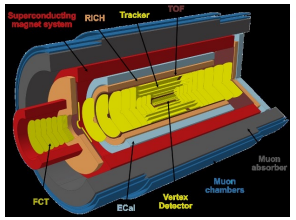
- **At GANIL/SPIRAL2 the Super-Separator Spectrometer S^3 is in an advanced stage of completion and the low-energy DESIR facility and heavy-ion injector NEWGAIN, will be operational from 2027/28. The refurbishing of the cyclotrons will ensure their operation for the next decades. Timely completion and full exploitation of these GANIL/SPIRAL2 projects are recommended. The future evolution of the facility towards a very high-intensity reaccelerated RIB facility of up to 100 MeV/u should be actively planned.**

Recommendations for Nuclear Physics Infrastructures

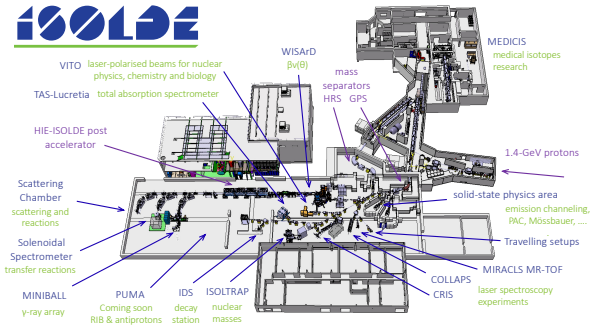
- **Nuclear physics opportunities at CERN constitute a world-leading research programme. The construction of ALICE 3 as part of the HL-LHC plans is strongly recommended. Continued support for exploitation and new developments are recommended to maximise the scientific output of ISOLDE, n_TOF, SPS fixed-target program and AD/ELENA. As the roadmap for the post-LHC future of CERN is developed, a strategy should be prepared to secure future opportunities for continuing world-leading nuclear-physics programmes that are unique to CERN.**

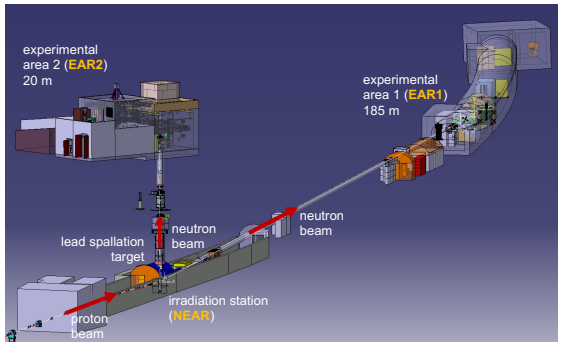
ESFRI

ALICE3



H⁻ (hydrogen anions) · p (protons) · ions · RIBs (Radioactive Ion Beams) · n (neutrons) · p̄ (antiprotons) · e⁻ (electrons) · μ (muons)

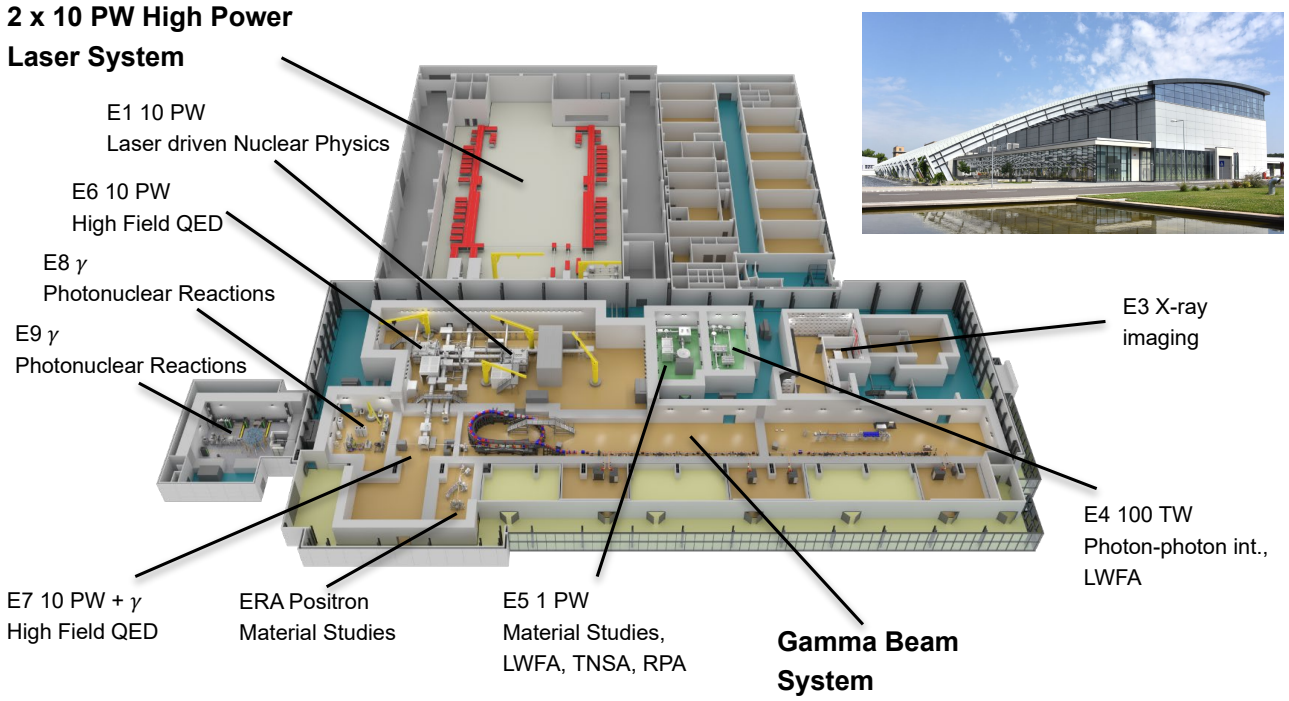




Recommendations for Nuclear Physics Infrastructures

ESFRI

- **At ELI-NP studies will focus on addressing key topics, such as laser-driven ion and electron acceleration. Implementing the gamma beam system to achieve the full completion of the facility to allow breakthrough results in the field of nuclear photonics is of high importance and is strongly recommended.**

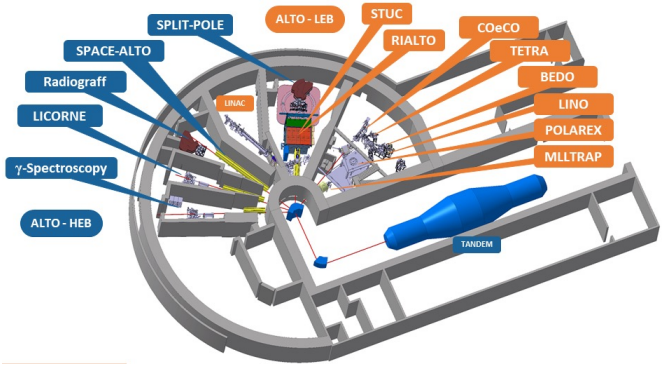


LRP 2024 Findings and Recommendations

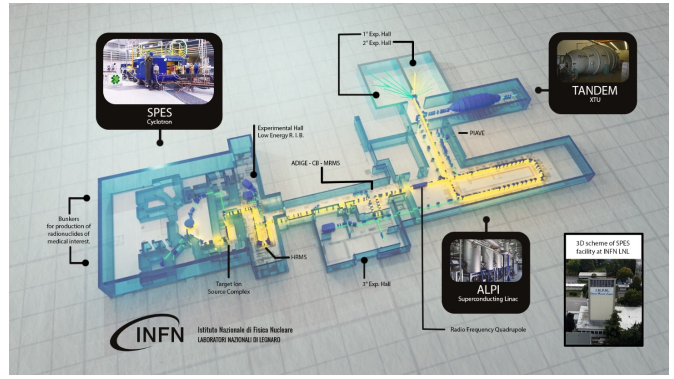
Recommendations for Nuclear Physics Infrastructures

- **Timely completion of the SPES facility and continuing coordinated efforts in developing the ALTO, IGISOL, ISOLDE, SPES, and SPIRAL ISOL facilities in Europe, will be key to maintaining their world-leading position in many areas of radioactive isotope science and are strongly recommended. Extending these efforts towards future facilities, such as ISOL@MYRRHA, TATTOOS@PSI, and RIB@IFIN, together with the development of common instrumentation, will secure the European leading position for radioisotope production, separation, and acceleration techniques, and create new avenues for the future and should therefore be actively pursued.**

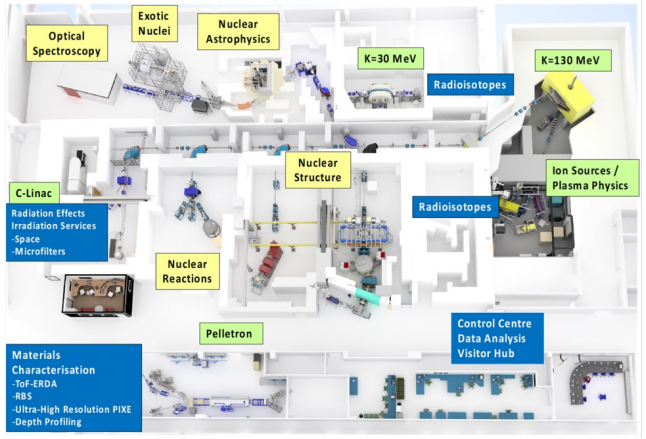
ALTO/IJCLab



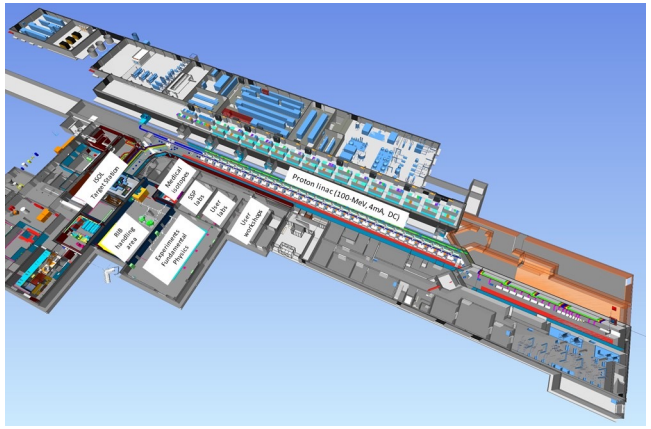
SPES/LNL



IGISOL/JYFL



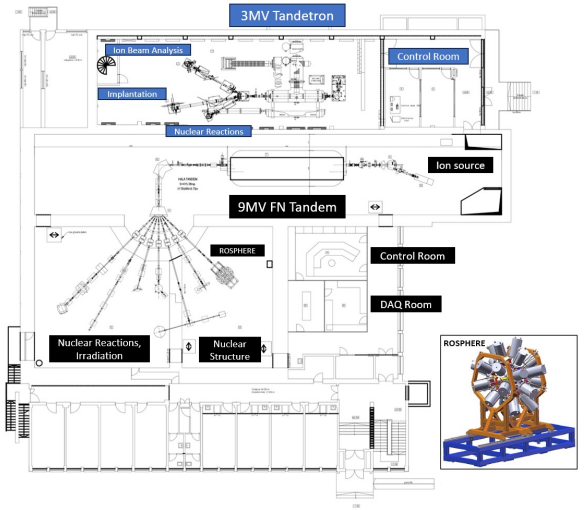
ISOL@MYRRHA



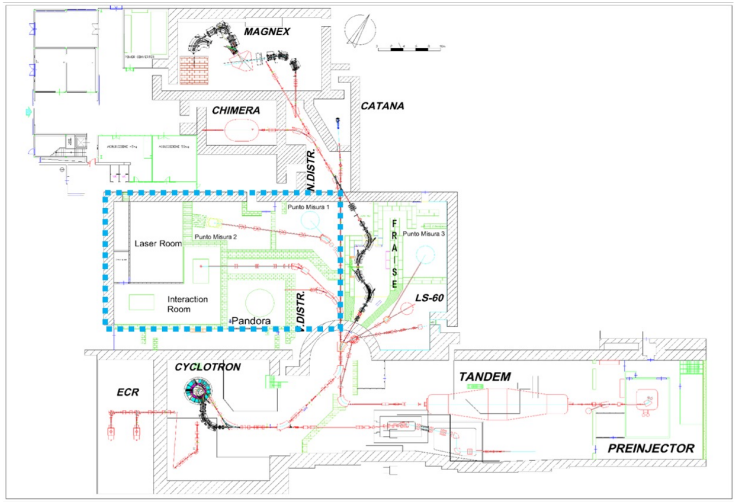
Recommendations for Nuclear Physics Infrastructures

- **Large-scale stable beam facilities, such as FAIR/GSI, GANIL/SPIRAL2, IFIN, JYFL-ACCLAB, LNL, LNS, NLC (SLCJ and IFJ-PAN), and smaller ones, such as tandems, underground facilities and AMS systems, should be optimally exploited. Developments of novel and more intense beams and capabilities are also recommended to open new opportunities for basic science and applications. It is recommended that synergies between all these facilities, irrespective of size, be reinforced.**

IFIN-HH



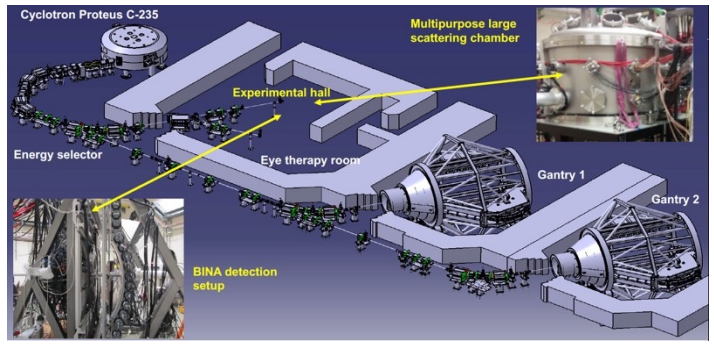
LNS



NLC

SLCJ

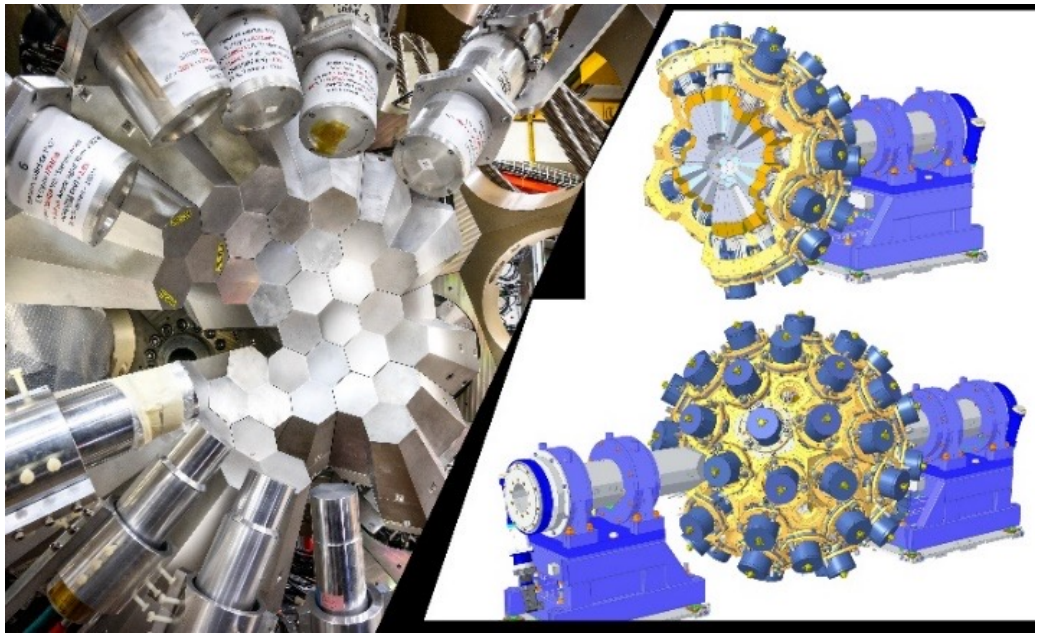
CCB



Recommendations for Nuclear Physics Infrastructures

- **It is strongly recommended to complete the AGATA gamma tracking array to its full configuration as a key instrument for studying atomic nuclei in both stable and radioactive ion beam facilities.**

AGATA gamma tracking array

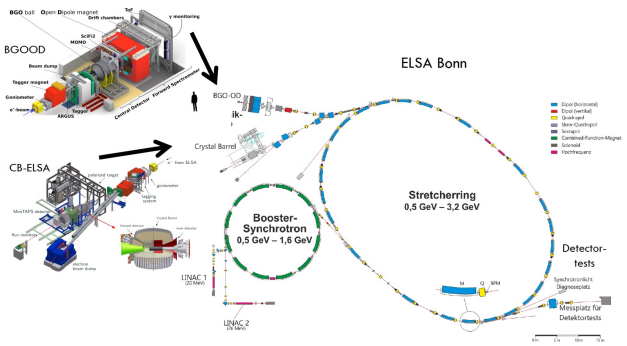


LRP 2024 Findings and Recommendations

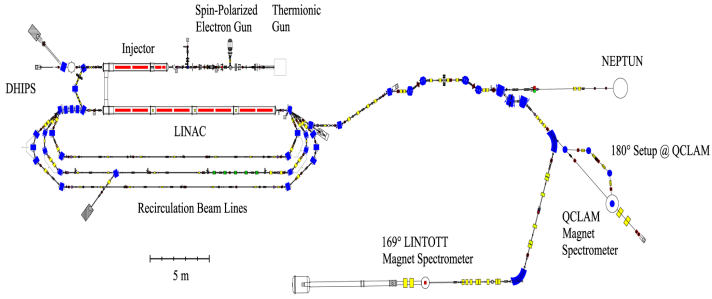
Recommendations for Nuclear Physics Infrastructures

- **Exploitation and optimisation of the European lepton beam facilities, including ELSA, MAMI, and S-DALINAC, are needed to realise their full physics potential. The completion of the MESA facility and the High-Intensity Muon Beams project at PSI, are recommended.**

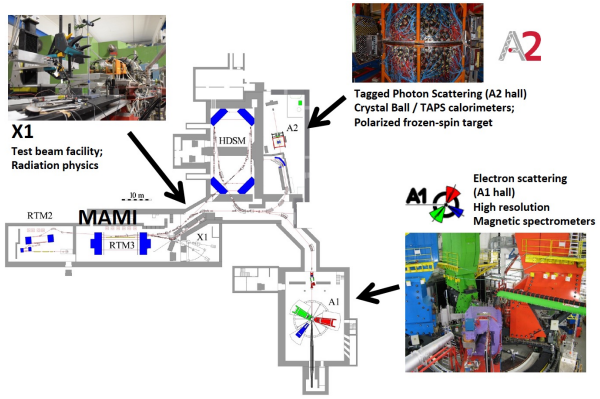
ELSA



S-DALINAC



MAMI



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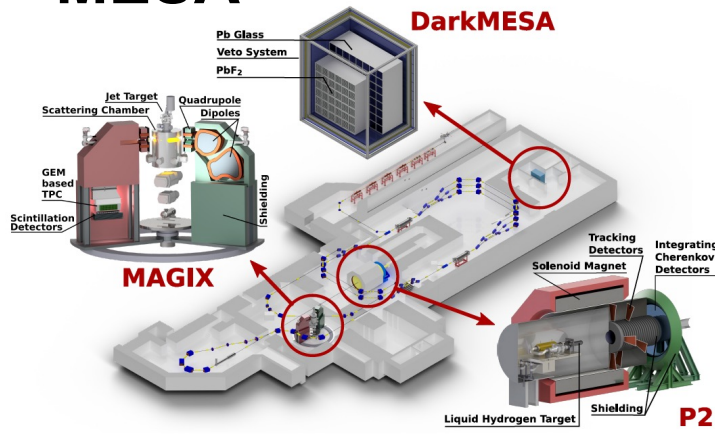
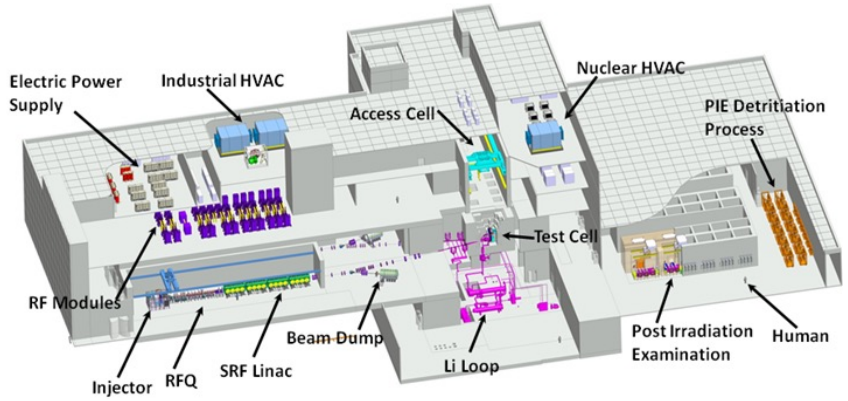


Recommendations for Nuclear Physics Infrastructures

- **Neutron facilities are playing a significant role in nuclear fundamental research and applications, producing unique and valuable experimental outcomes. The new NFS facility, located at SPIRAL2, is now providing a highly intense neutron flux of fast neutrons, attracting a broad scientific community. It is crucial and strongly recommended to maintain the operation of exceptional neutron facilities like ILL and n_ToF at CERN. ESS facility and the future infrastructure IFMIF-DONES will provide advanced tools for interdisciplinary research and their unique capabilities to serve advances in nuclear physics should be explored.**

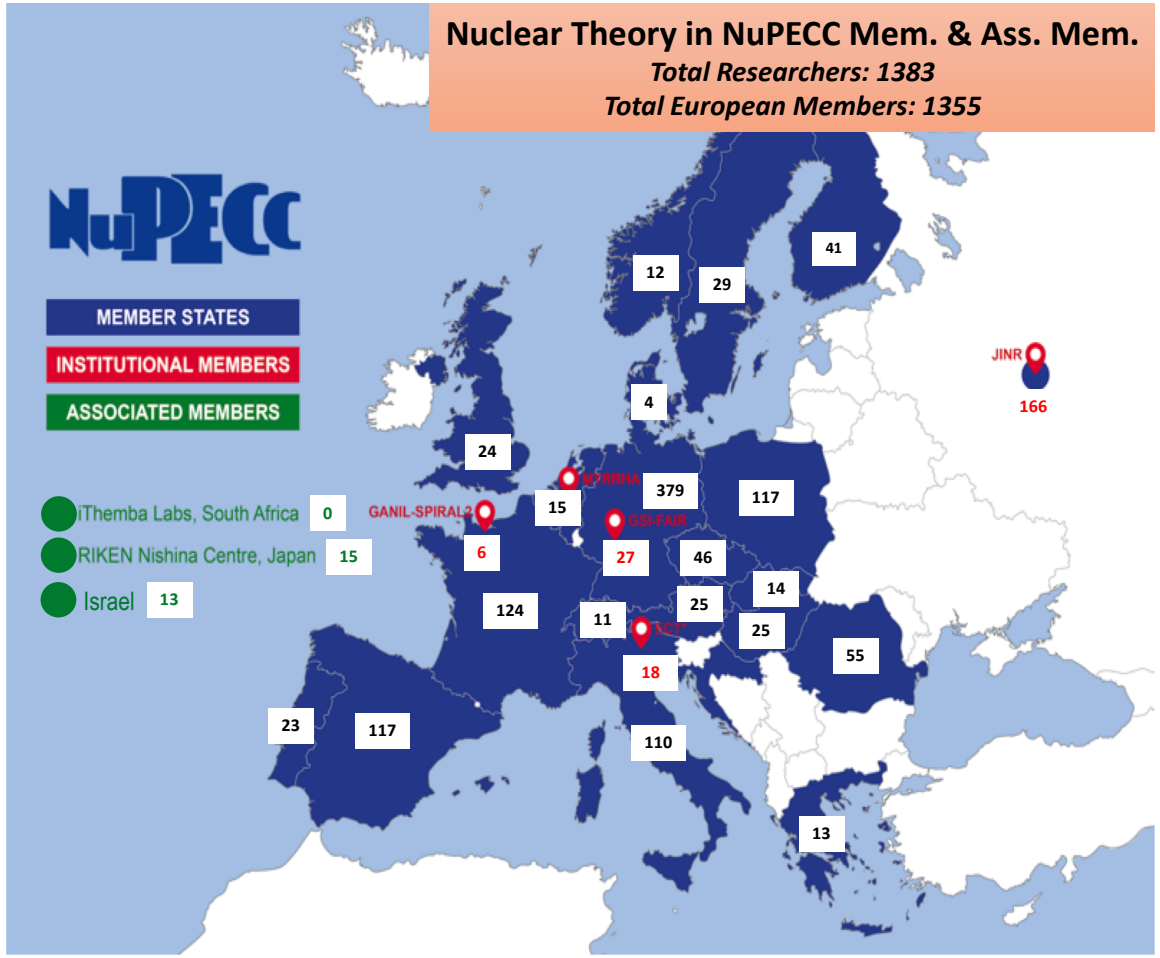
ILL

IFMIF-DONES



Recommendations for Nuclear Physics Infrastructures

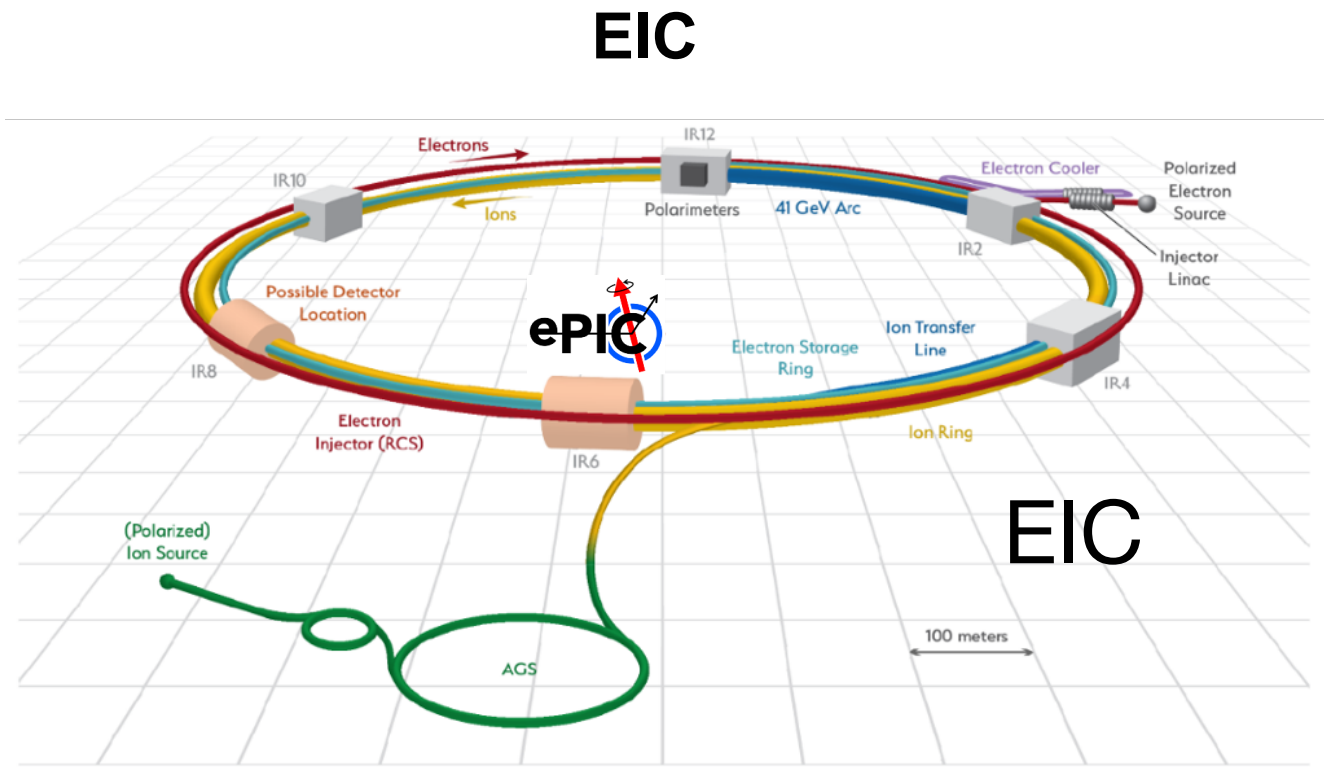
- **Theory centres and groups should be strongly supported throughout Europe, in particular the European Centre for Theoretical Studies (ECT*, Trento, Italy), which is a unique European centre dedicated to theoretical nuclear physics in the broadest sense. A stronger pan-European support which will ensure that ECT* activities continue to play a strategic role in the development of nuclear physics in Europe is recommended.**



ECT*

Recommendations for Nuclear Physics Infrastructures

- **Collaboration with non-European infrastructures should be fostered in all areas of nuclear research to seize unique scientific opportunities and synergies that complement scientific programmes based in Europe. In particular, European participation in the construction of the ePIC experiment at the future international flagship facility EIC is recommended.**



Recommendations for Hadron Physics 1/4

The goal of hadron physics is to understand the rich and complex features of the strong interaction. How does the major part of the visible mass of the universe emerge from the almost massless quarks? Can massless gluons form massive, exotic matter? What is the role of strong interactions in stellar objects, and in precision tests of the Standard Model? Answering these questions requires a diverse set of experimental and theoretical approaches. European hadron physicists play a leading role by conducting experiments at facilities within Europe, with great success, but also at the global level. These facilities, their planned upgrades, and the approved flagships PANDA at FAIR, Germany and ePIC at EIC, USA, open new avenues for ground-breaking discoveries.

Recommendations for Hadron Physics 2/4

Existing facilities: We recommend the continuing support of the successful hadron physics programs in Europe and the participation of European groups at global facilities. Particularly important hadron physics facilities are

- **AMBER** at **CERN**
- **ELSA** in Bonn**, HADES** at GSI**, MAMI** and **MESA** in Mainz, Germany
- **Jefferson Laboratory** in Newport News, USA

Furthermore, we recommend the support of ongoing hadron physics activities at the multi-purpose facilities Belle II, BESIII and those at the LHC.

Recommendations for Hadron Physics 3/4

Future flagships: We recommend the expedited realisation of the antiproton experiment PANDA, and the support of European groups to contribute to the electron-ion experiment ePIC. By virtue of their different beam species and energy regimes, PANDA and ePIC will explore complementary physics aspects. In a ten-year perspective, these two next-generation experiments must be made ready to launch.

- **PANDA**: The physics program, including the prospect of unravelling exotic matter, remains unique and compelling. PANDA will strengthen the European position on the global scene and act as a unifying force for the community. Therefore, we recommend support for its construction and for the development of instrumentation, software and analysis tools.
- **ePIC**: Here, European researchers will be able to explore unknown features of quarks and gluons inside nucleons and nuclei. We recommend supporting the participation of European groups in ePIC and reinforcing scientific and technological activities which synergise with European projects.

Recommendations for Hadron Physics 4/4

Theory / Computing:

We recommend the support of theory groups at universities and research centres such as ECT* to prepare the community to benefit from European investments in supercomputing and quantum computing infrastructure.

Theorists play an essential role in interpreting experimental results but also in providing input and predictions for new experiments. To match experimental progress, sophisticated approaches need to be developed. In lattice QCD, the rapid evolution of computational techniques and hardware calls for new algorithms and software. Similarly, quantum computing requires appropriate algorithms and tests on quantum hardware. Support for theoretical groups in terms of positions and career prospects is, thus, essential for progress in hadron physics.

Recommendations for Strongly Interacting Matter at Extreme Conditions 1/4

Ultra-relativistic heavy ion collisions aim at producing and studying the quark-gluon plasma (QGP), which is the qualitatively novel state of nuclear matter at extreme conditions of temperature and density. Different collision energies realize the QGP at different temperatures and densities. The experimental focus is discovering in microscopic detail the material properties of the QGP at the highest temperature reached at the LHC, and to find the expected onset of the first-order phase transition at finite baryon density at FAIR. Given the long timescales necessary for the R&D and construction of these experiments, a sustained research effort is required to advance the development of the next-generation experiments in parallel with the ongoing exploitation of existing facilities and detectors. The priorities in this multi-pronged endeavour can be summarized as follows:

Recommendations for Strongly Interacting Matter at Extreme Conditions 2/4

- **Future flagship facilities and experiments**
  - **ALICE 3** at **CERN** is a completely new dedicated high-energy nuclear physics experiment based on innovative detector concepts that will be essential for continuing after 2035 a scientifically leading role of Europe in high-energy nuclear physics. The programme relies on innovative R&D that will benefit neighbouring fields of nuclear and particle physics. Strong support for R&D should be given to maintain the opportunity of installing ALICE3 for Run 5 at the LHC.
  - To investigate nuclear matter at high baryonic density, the timely completion of **SIS-100** at **FAIR** and the realization of the **CBM** experiment are of utmost importance. Efforts should continue to support R&D activities related to advanced **CBM** silicon vertexing and tracking devices.
  - To exploit physics opportunities at the **CERN LHC** after 2035 (Run 5 and 6), the **LHCb Upgrade2** and the fixed-target setup will have a strong impact on the heavy ion programme. **ATLAS** and **CMS** will play an important role in the characterization of high-momentum transfer processes up to the end of the LHC programme in Run 6.
  - The **NA60+** detector at the **SPS** will address the remaining open questions in the electromagnetic and charm sector at the SPS with unprecedented event rates. R&D and construction for this detector deserve strong support.

Recommendations for Strongly Interacting Matter at Extreme Conditions 3/4

- **Support of existing facilities and experiments**
  - To maximise scientific output from the significant investment in current detector upgrades at the **LHC**, the continuation of the heavy-ion programme with Runs 3 and 4 (up to 2029) should receive full support. Timely support for the further **ALICE** upgrades in long shutdown 3 will provide a unique opportunity to enhance the physics reach in Run 4.
  - With its Upgrade I detector and with the new particle-identification subdetectors to be installed during long shutdown 3, **LHCb** is equipped to pursue a unique fixed target program at the LHC and to perform competitive measurements for Pb-Pb systems in collider mode. The exploitation of these opportunities should receive full support.
  - The full exploitation of the existing detectors and facilities, in particular **HADES** and **R3B** at **SIS-18/SIS-100**, should receive full support.
  - The full exploitation of **NA61** at **SPS** should receive full support.

Recommendations for Strongly Interacting Matter at Extreme Conditions 4/4

- **Theory developments**
  - Theoretical work in the field of heavy-ion collisions should be guaranteed continuous support, both in its phenomenological aspects (theoretical support needed to interpret the results and to provide feedback to the experimental programme) and from first principles (quantum chromodynamics).
  - Collaborations should be particularly encouraged and nurtured in theoretical centres such as ECT* to strengthen the relation between heavy-ion physics and neighbouring fields, including astrophysics and particle physics. These collaborations would stimulate novel ways of computing and data analysis, as well as improve the interplay between theory and experiment.

Hadron Physics

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Properties of Strongly Interacting Matter at Extreme Conditions of Temperature and Baryon Number Density

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NuPECC LRP2024 Timeline

- ***Still to be done: proofreading by science writer, graphic design, colourful brochure***
- ***The PDF version will be available on the NuPECC Web site by September 2024***
- ***The printed version of the brochure and full version (if requested) will be sent to ministries, funding agencies and institutions***

- **Official presentation of LRP 2024 on 19/11/2024 at the University Foundation in Brussels**

Thank you for your attention!