

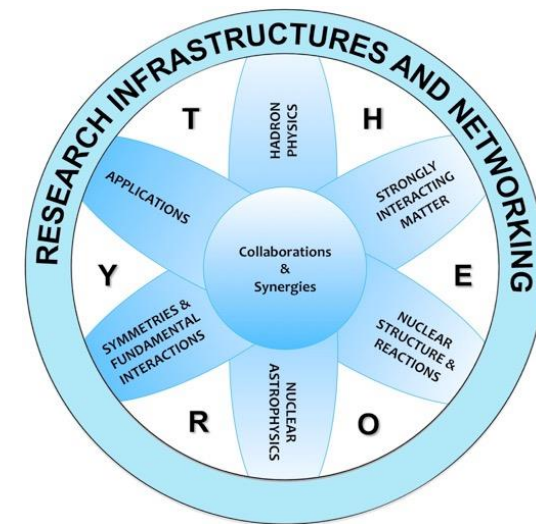


FAIR in the NuPECC Long Range Plan 2024 for European Nuclear Physics

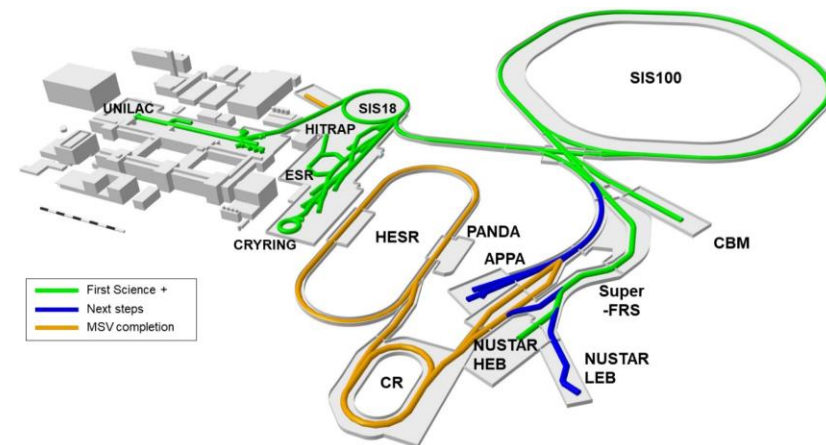


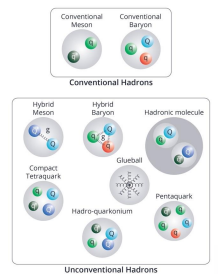
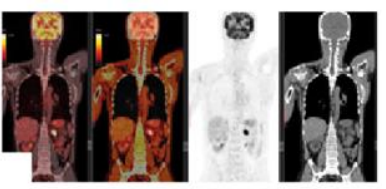
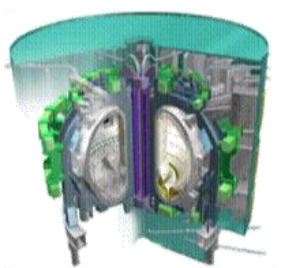
Marek Lewitowicz

*Past Chair of
Nuclear Physics European Collaboration Committee (NuPECC)
GANIL*

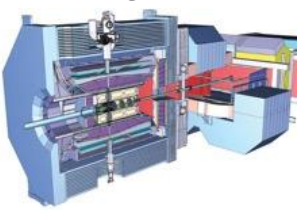


**FAIR Seminar
January 24, 2025
IFJ, Kraków**

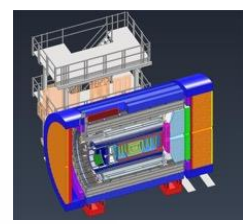




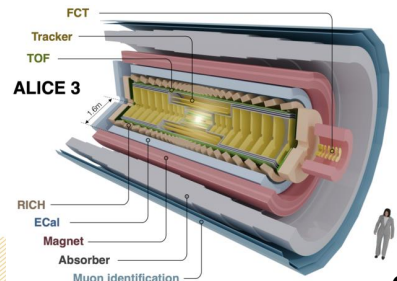
PANDA @ FAIR



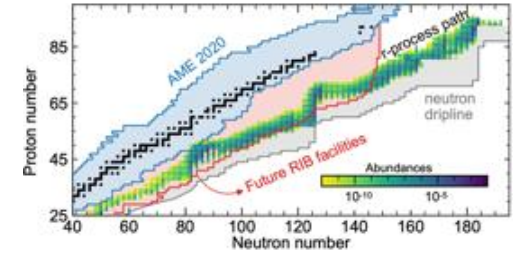
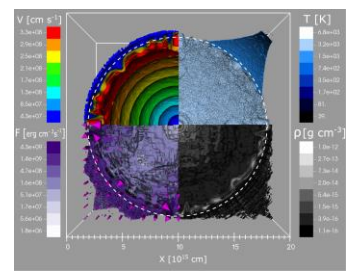
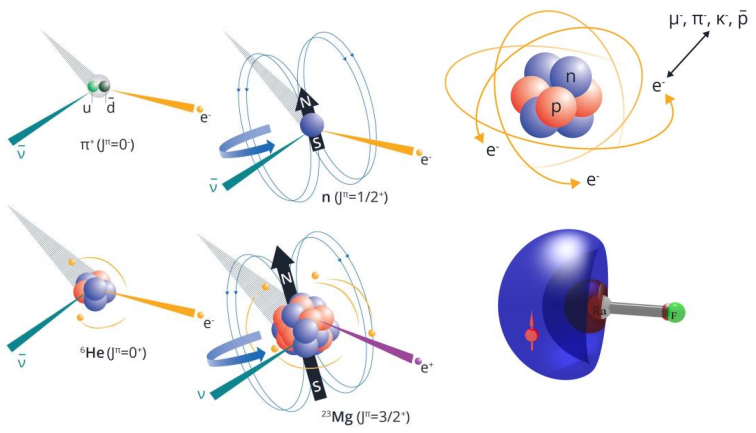
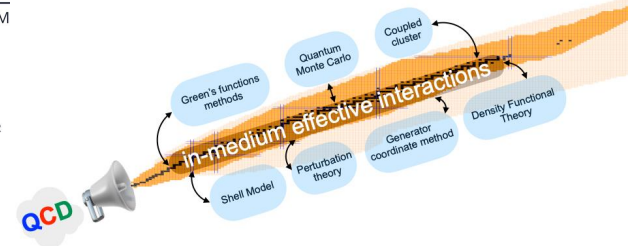
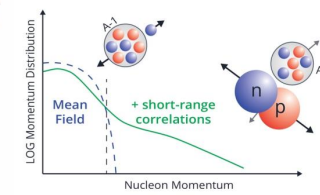
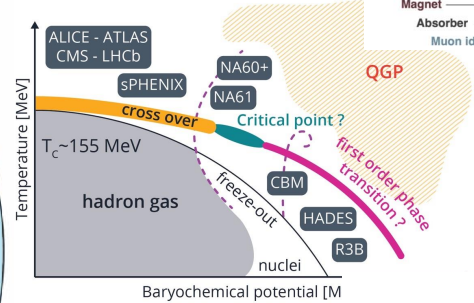
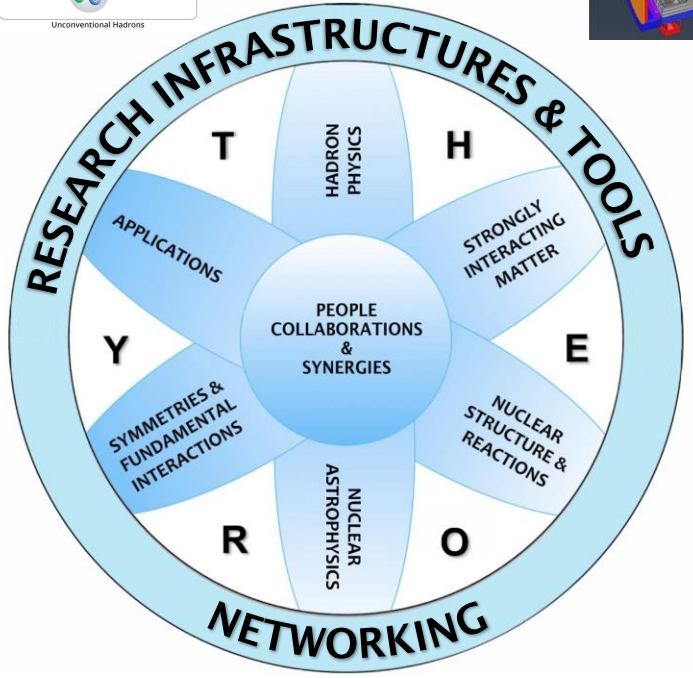
ePIC @ EIC



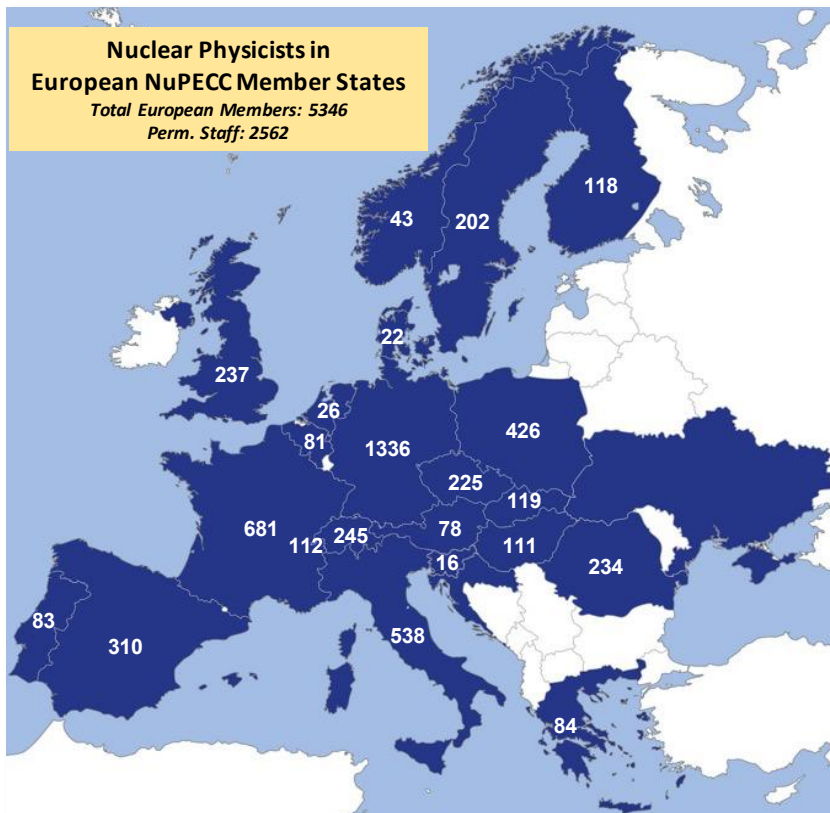
ALICE 3 @ LHC



CBM @ FAIR



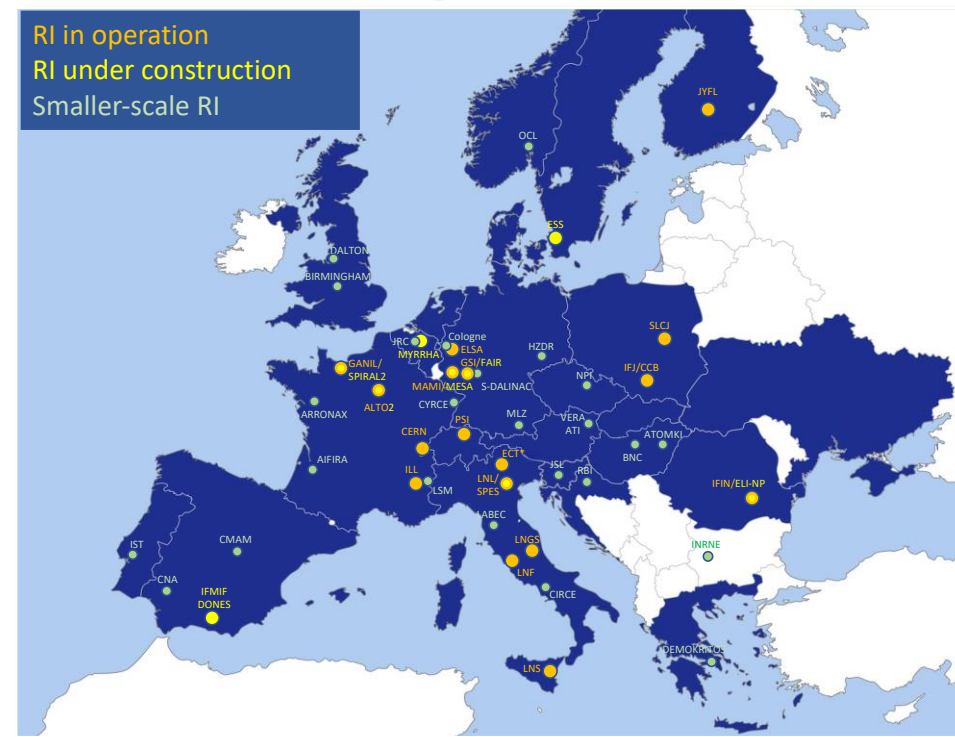
Nuclear Physics Workforce in Europe



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

European Landscape of Nuclear Physics Infrastructures



All infrastructures are multidisciplinary !

Taking data **> 30**;
Under construction or upgrade **≥ 9**

From NuPECC LRP 2024

24/01/2025

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

<https://nupecc.org>

Representing

> 5000 scientists

Composition:

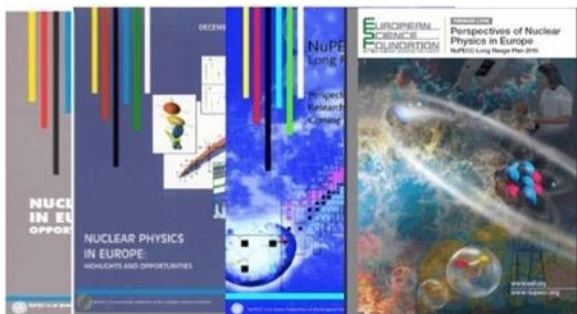
- 35 representatives from 23 countries, 3 ESFRI NP Infrastructures & ECT*
 - 4 associated members
 - CERN
 - Israel
 - iThemba Labs
 - Nishina Center
- 10 observers: ALAFNA, ANPhA, APPEC, CINP, ECFA, ESF, EPS-NPD, EPS-HEPPD, IAEA, NSAC

3 regular Committee meetings/y



36 Years of NuPECC activities

1991 1997 2004 2010



- The LRP identifies opportunities and priorities for nuclear science in Europe
- The LRP provides national funding agencies, European Strategy Forum on Research Infrastructures and the European Commission with a framework for coordinated advances in nuclear science in Europe

NuPECC LRP is a unique document on nuclear science perspectives in Europe !



Assessment of implementation of LRP 2017

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

NuPECC LRP 2017

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



Launched in May 2022 in Madrid



NuPECC LRP 2024

LRP bottom-up approach

**10 Thematic Working Groups
266 Members and NuPECC Liaisons**



**Very good interaction with APPEC (Astroparticle Physics),
ECFA (Particle Physics), NSAC (USA) and ANPhA (Asia)**



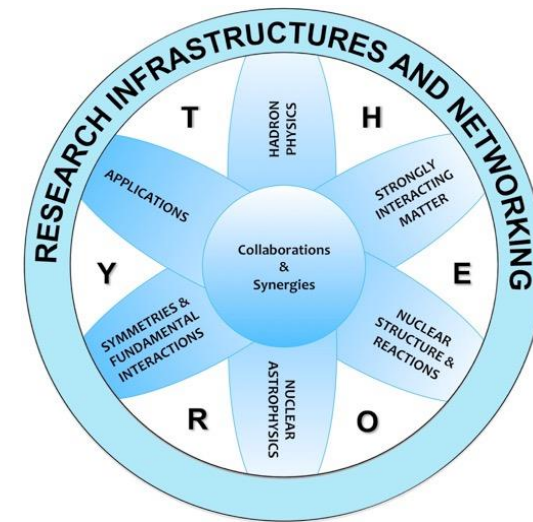
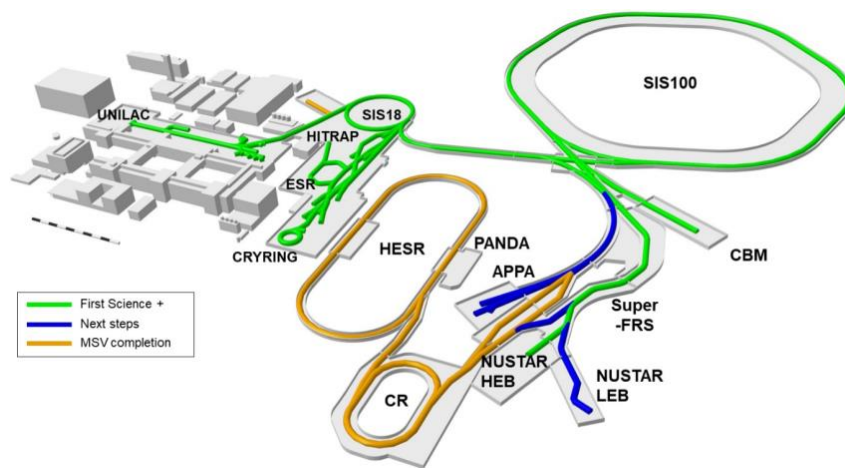
NuPECC Long Range Plan 2024 for European Nuclear Physics *in a nutshell*

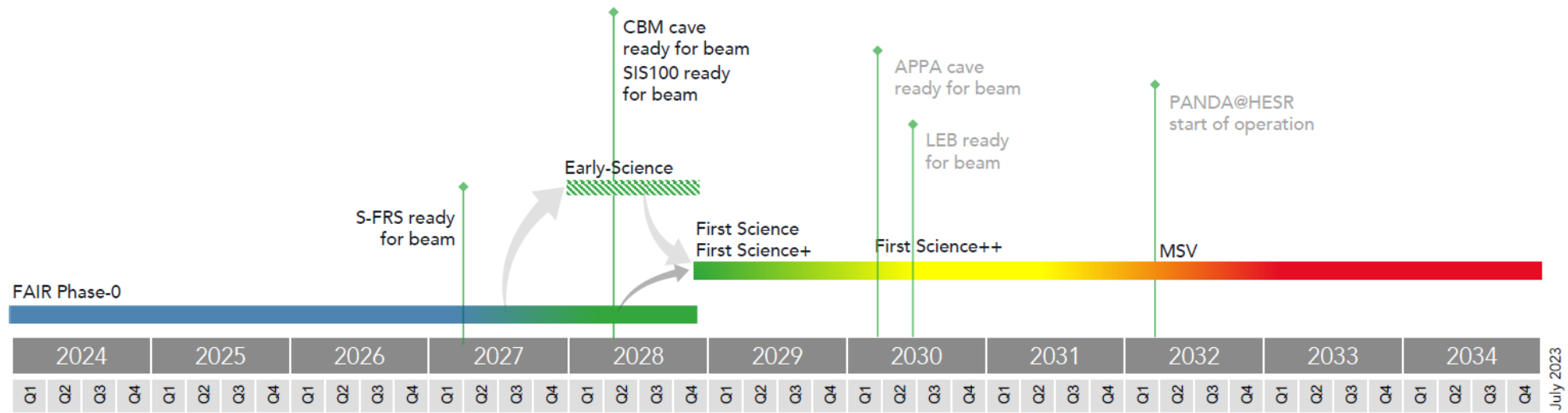
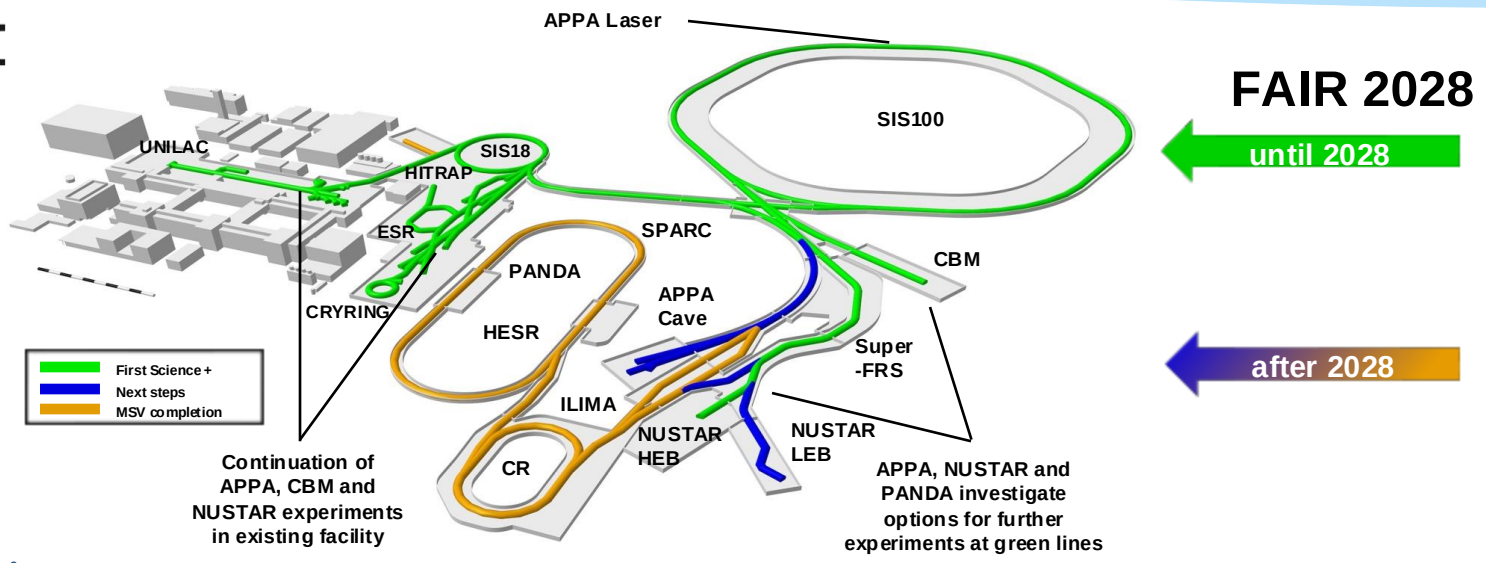


185 pages



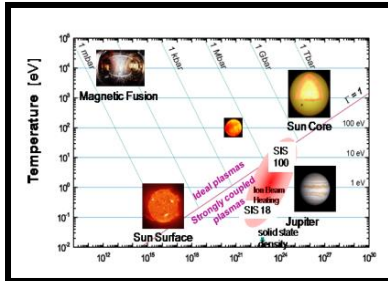
with emphasis on the facilities & projects the most relevant for the FAIR Facility





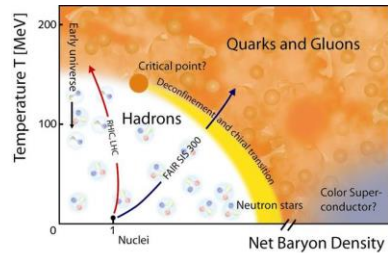
Courtesy of Paolo Giubellino

The FAIR science: four pillars



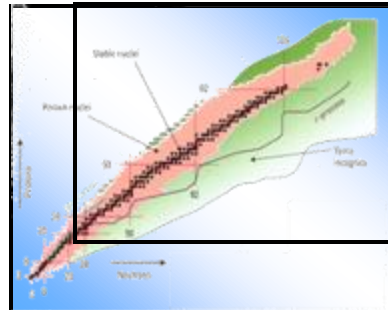
atomic physics, biophysics,
plasma physics, material
research

APPA



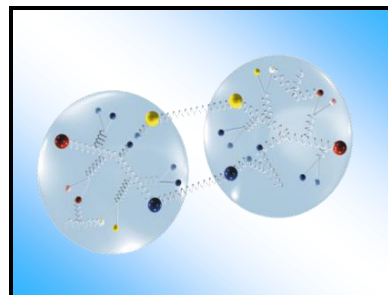
nuclear- and quark-matter

CBM



nuclear structure and
nuclear astrophysics

NuSTAR



hadron structure and dynamics

PANDA



Courtesy of Paolo Giubellino

FAIR facility on 70 out of 185 pages of the document!



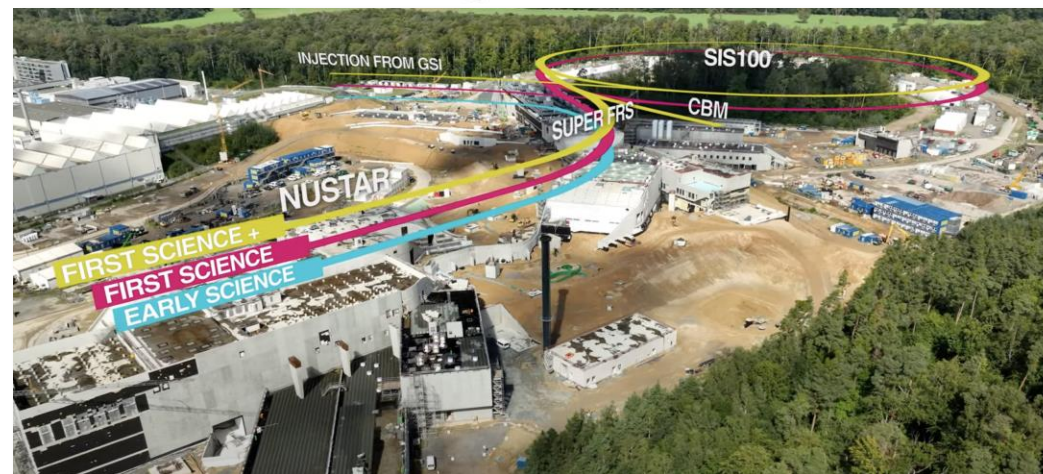
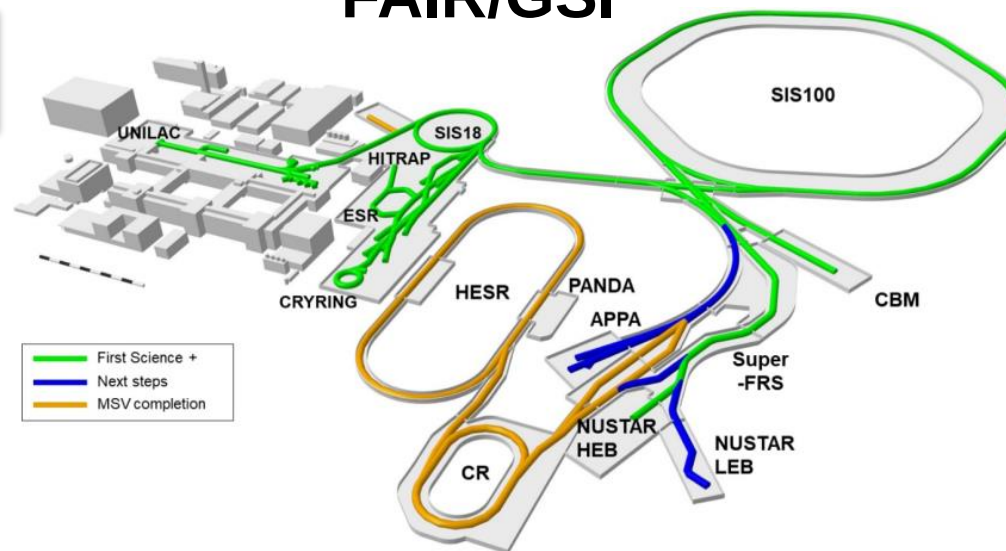
Table of Contents

1. NuPECC LRP2024 Executive Summary 
2. Hadron Physics 
3. Properties of Strongly Interacting Matter at Extreme Conditions of Temperature and Baryon Number Density 
4. Nuclear Structure and Reaction Dynamics 
5. Nuclear Astrophysics 
6. Symmetries and Fundamental Interactions 
7. Applications and Societal Benefits
8. Research Infrastructures 
9. Nuclear Physics Tools - Detectors and Experimental Techniques 
10. Nuclear Physics Tools - Machine Learning, Artificial Intelligence, and Quantum Computing
11. Open Science and Data 
12. Nuclear Science – People and Society 

FAIR facility, Darmstadt, Germany

- 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.

FAIR/GSI



<https://www.youtube.com/watch?v=kbvK5AGg8oM>

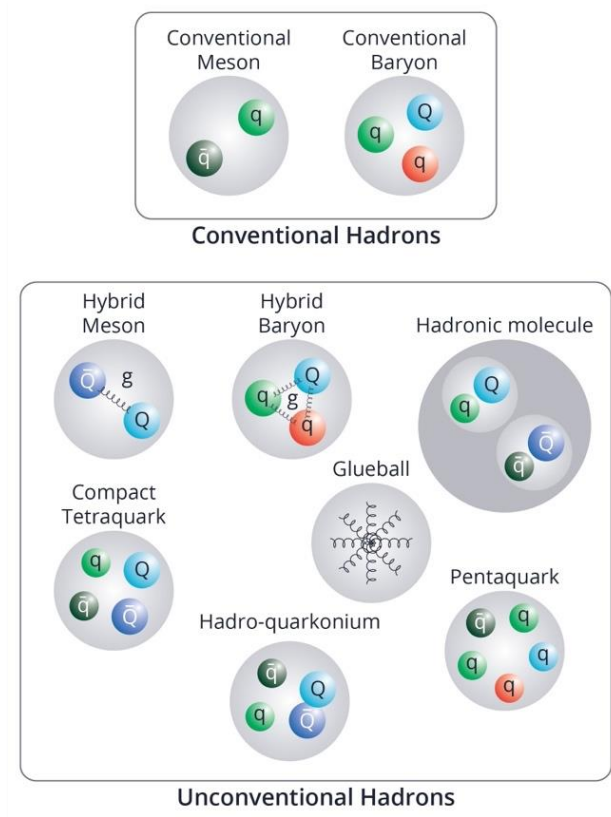
Key Questions & Goals

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?

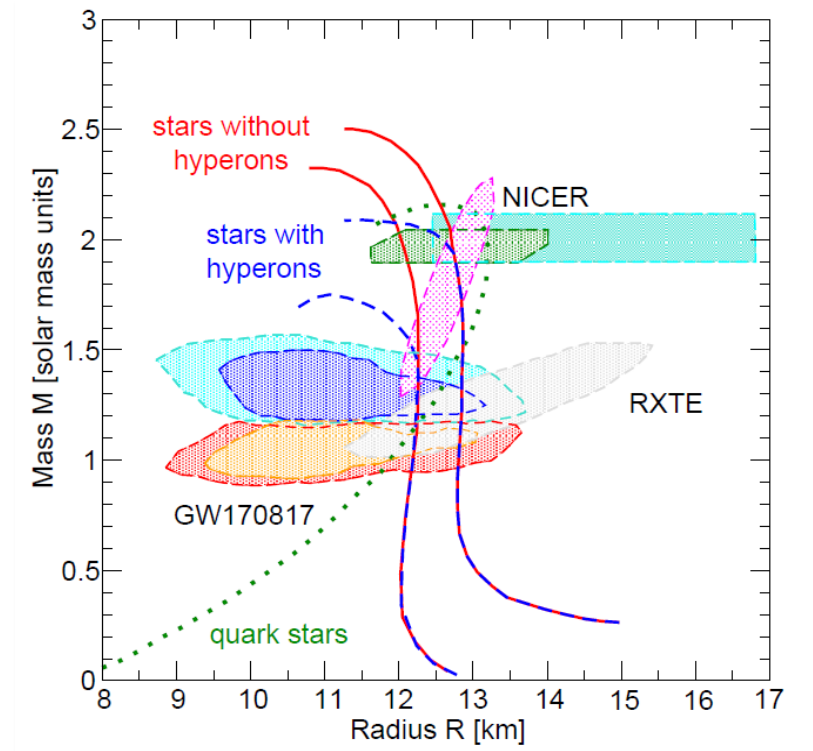
Hadron Structure Quarks and Gluons



Credit: <https://www.bnl.gov/eic/goals.php>



Valence content of conventional and exotic hadrons



The blobs represent the mass and radius constraints from the gravitational wave detectors LIGO and Virgo, as well as NASA's Neutron star Interior Explorer (NICER), while the dashed and solid lines represent the predictions obtained with various EoS models, with and without hyperons. Picture credit I. Vidana (Universita di Catania).

Recommendations (experiments)

Support of existing facilities and experiments:

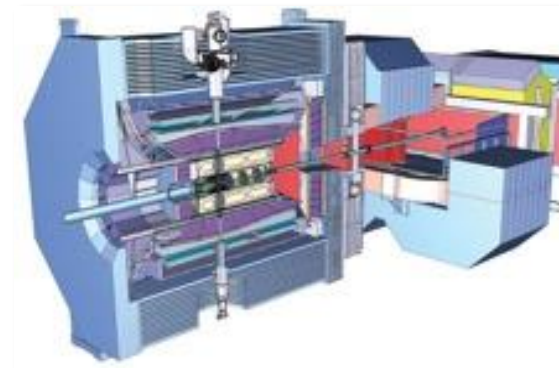
- **AMBER** at **CERN**
- **ELSA** in Bonn, **HADES** at GSI, **MAMI** and **MESA** in Mainz, Germany
- **Jefferson Laboratory** in Newport News, USA

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

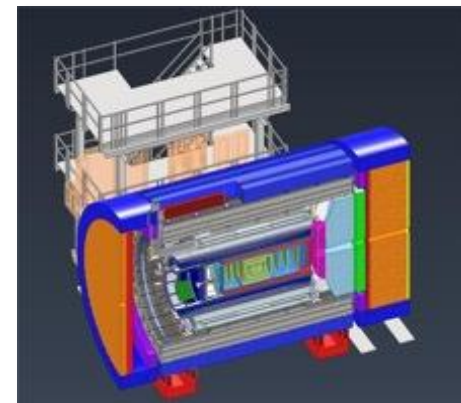
Future flagship facilities and experiments:

- 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.

PANDA @ FAIR



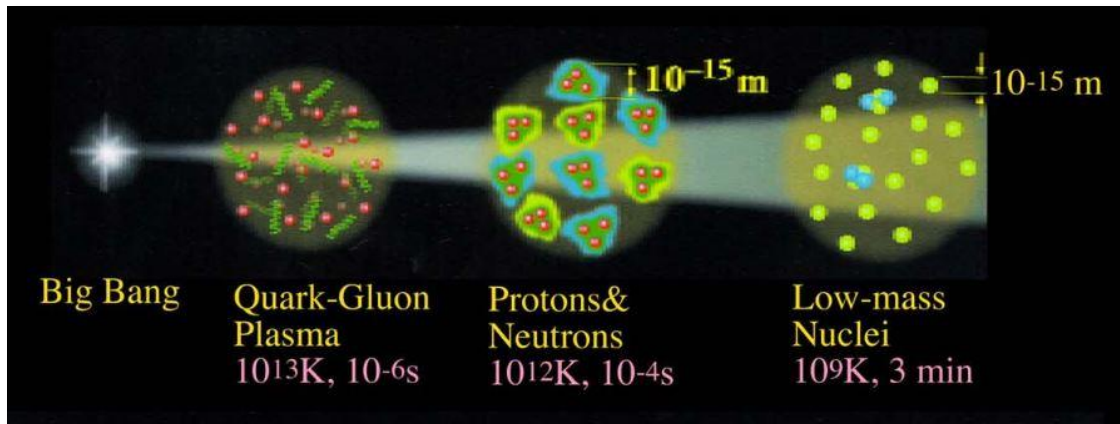
ePIC @ EIC



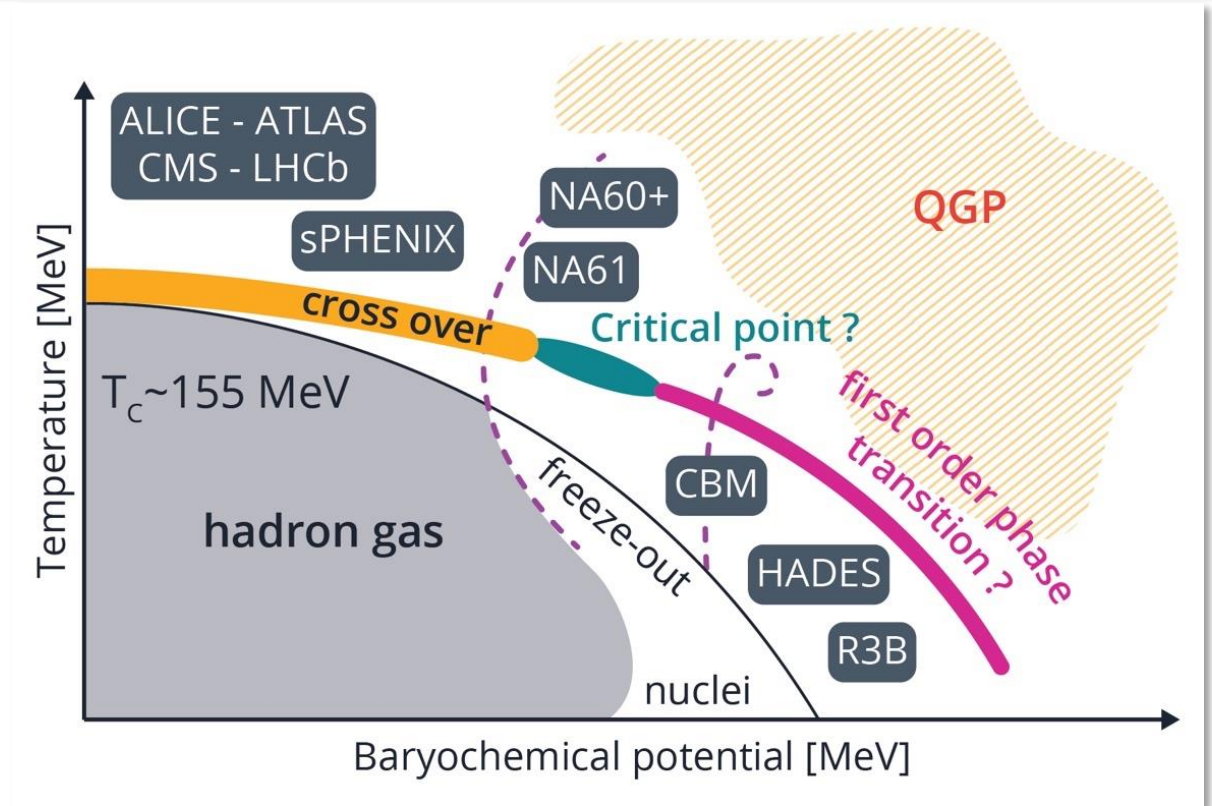
Key Questions & Goals

What are the properties of the quark-gluon plasma, which is the qualitatively novel state of nuclear matter at extreme conditions of temperature and density?

Objectives: Discover in microscopic detail the material properties of the Quark Gluon Plasma at the highest temperature reached at the LHC at CERN and find the expected onset of the first-order phase transition at finite baryon density at FAIR in Darmstadt.



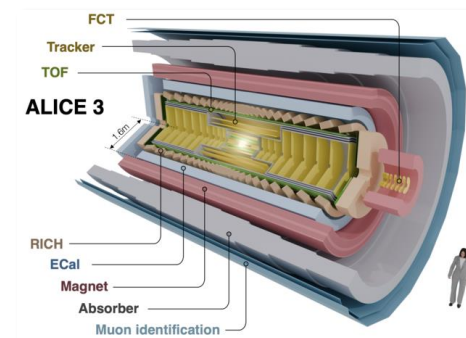
Mahnaz Q. Haseeb, *Introduction to Quark Gluon Plasma*, 2009



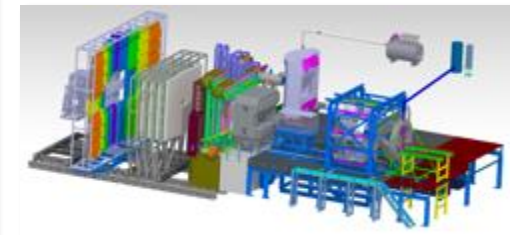
Recommendations (experiments)

- **Future flagship facilities and experiments**
 - **ALICE 3** at **CERN**
 - **SIS-100** at **FAIR** and the realization of the **CBM** experiment
 - **CERN LHC** after 2035 (Run 5 and 6), the **LHCb Upgrade2** and the fixed-target setup **NA60+** detector at the **SPS**
- **Support of existing facilities and experiments**
 - Maximise scientific output from the significant investment in current detector upgrades at the **LHC**
 - **HADES** and **R3B** at **SIS-18/SIS-100** should receive full support
 - The exploitation of **NA61** at **SPS** should receive full support

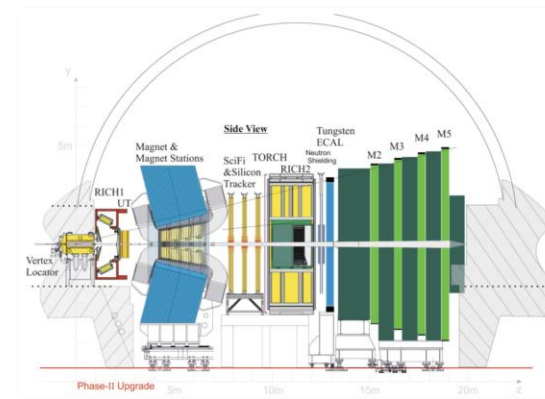
ALICE 3 @ LHC



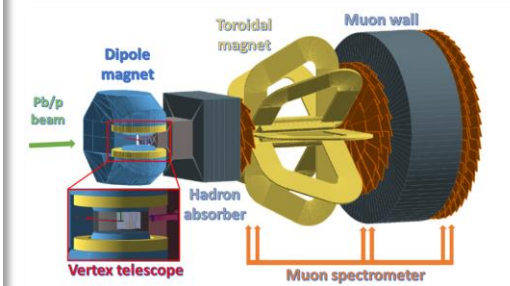
CBM @ FAIR



LHCb Upgrade II



NA60+



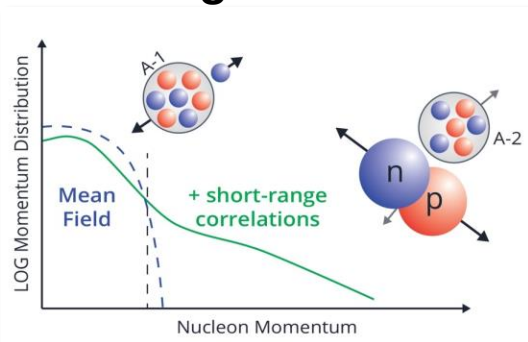
Credit: Framework TDR for the LHCb Upgrade II
CERN-LHCC-2021-012 ; LHCb-TDR-023

Credit: <https://na60plus.ca.infn.it>

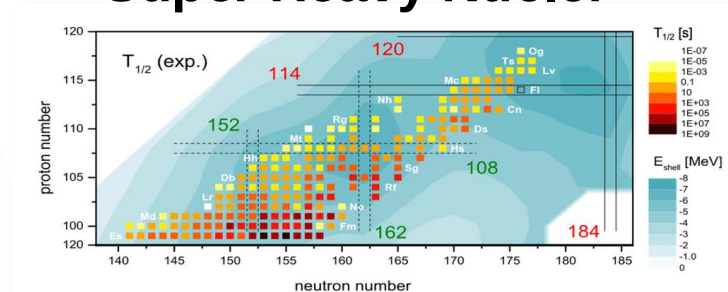
Key Questions & Goals

The main goals of Nuclear Structure and Reaction Dynamics in the next decade will be to answer the following questions: How do nuclei and nuclear matter emerge from the underlying fundamental interactions? What is the limit of nuclear existence and which phenomena arise from open quantum systems? How do nuclear shells evolve across the nuclear landscape, what kind of shapes can nuclei take, and what is the role of nuclear correlations? What are the mechanisms behind nuclear reactions and nuclear fission?

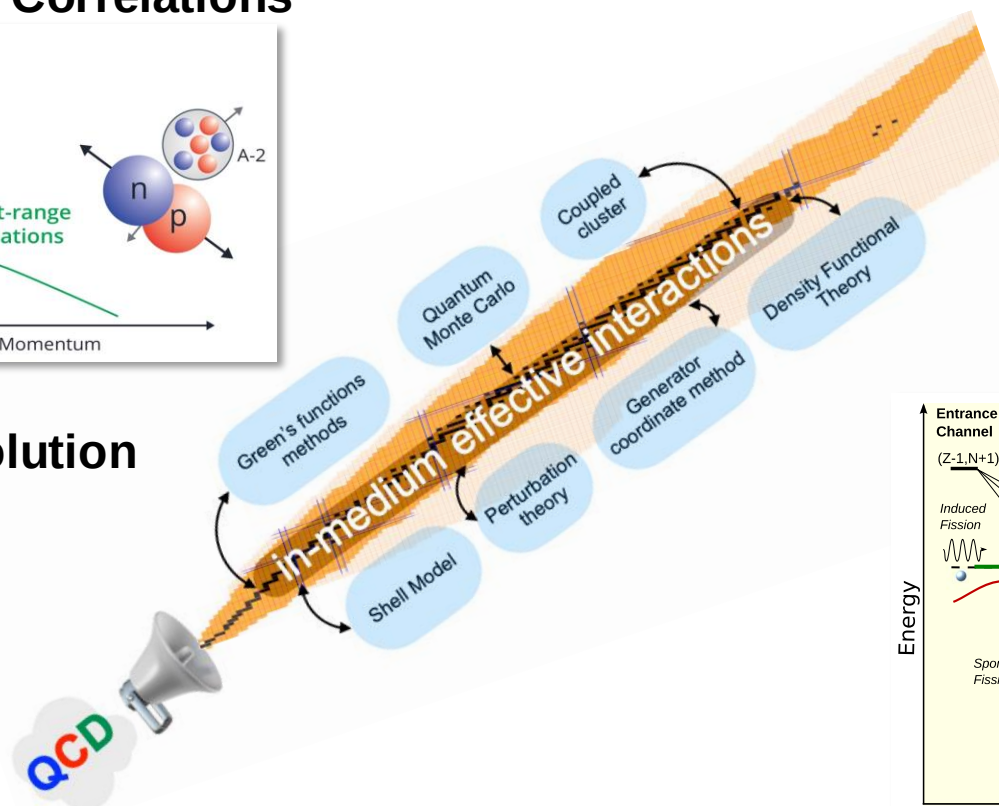
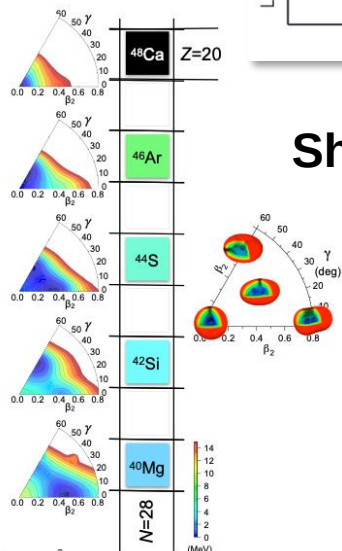
Short Range Correlations



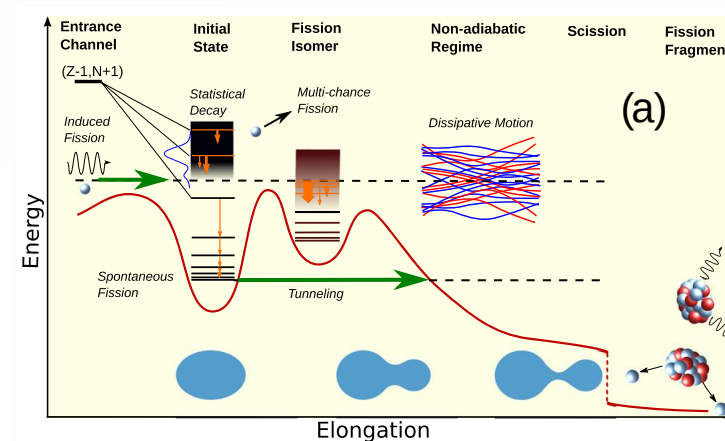
Super Heavy Nuclei



Shell Evolution

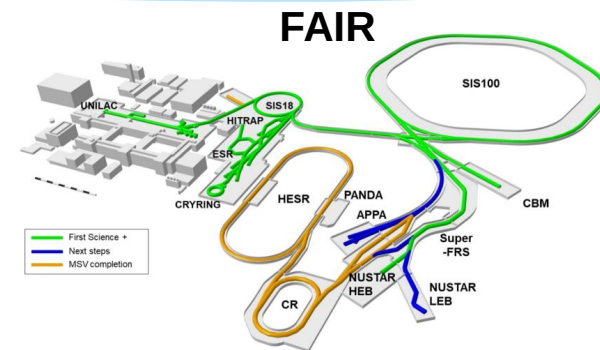


Fission of nuclei

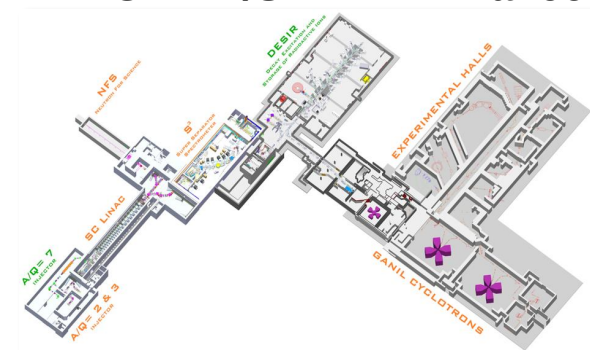


Recommendations (experiments)

- **Support of existing facilities and experiments**
 - To ensure complementarity in experimental programmes, it is essential to strongly support *large- and small-scale facilities* which guarantee access to the whole community
 - The coordinated effort amongst the **ISOL facilities** in Europe ... will secure the leading position of Europe
 - The full completion of the European flagship gamma spectrometer **AGATA-4 π** (with ancillaries) is mandatory
- **Future flagship facilities and experiments**
 - **FAIR facility (with Low-Energy-Branch), SPIRAL2, SPES, ELI-NP, ISOL@MYRRHA, and ISOLDE** upgrades
 - **Future rings at FAIR and HIE-ISOLDE**



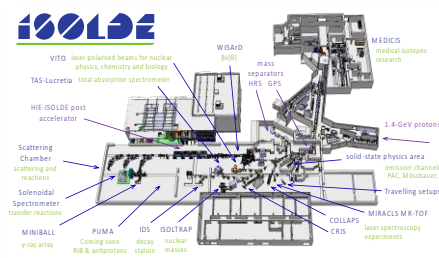
GANIL/SPIRAL2 France



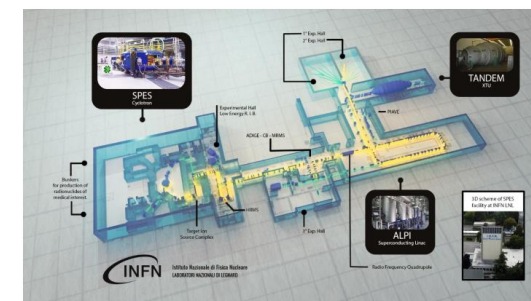
AGATA



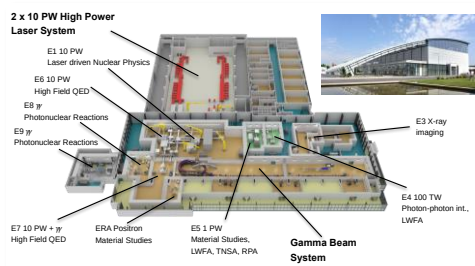
ISOLDE CERN



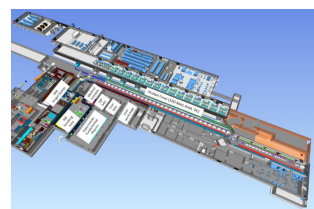
SPES/LNL Italy



ELI – NP Romania



ISOL@MYRRHA Belgium

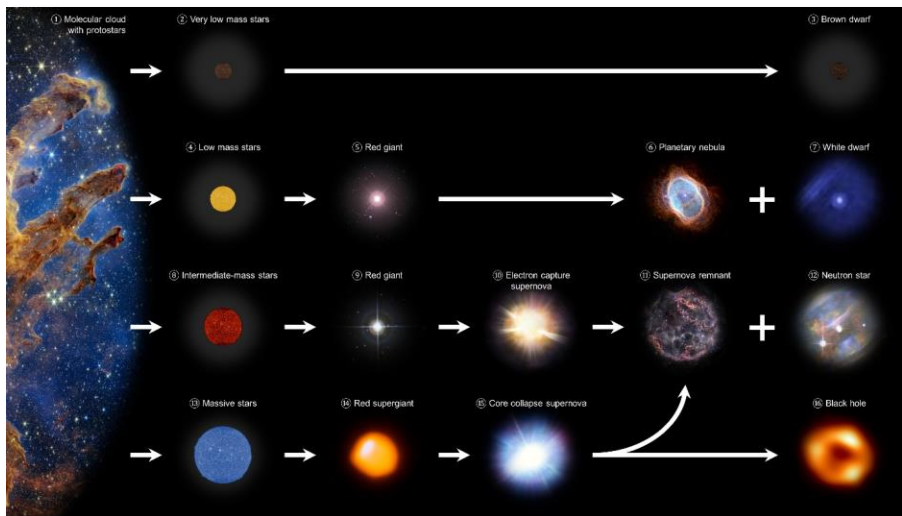


Key Questions & Goals

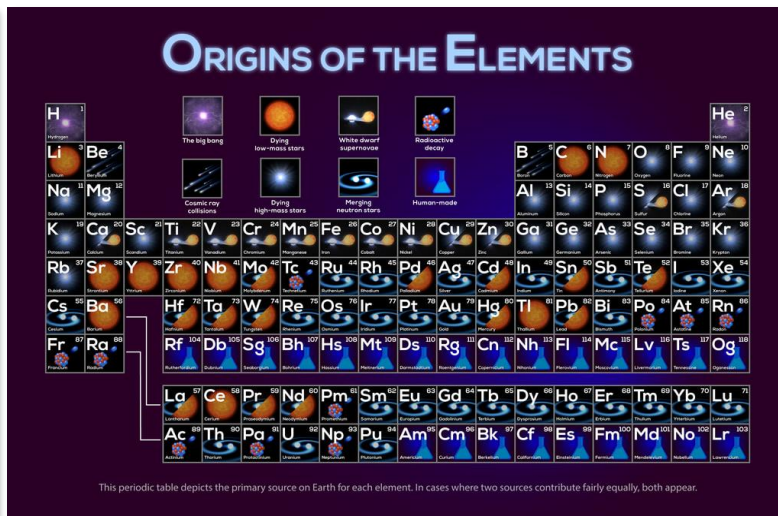
Nuclear astrophysics is the study of nuclear processes in astrophysical objects such as stars, covering the wide range of physical scenarios found in space. The key research questions are: How can we better understand the synthesis of heavy elements and the chemical evolution of the visible universe? What is the nature of matter in the extreme conditions of compact astrophysical objects such as mergers or pulsars?

Gravitational wave telescopes have opened a new window to astrophysics. These multi-messenger studies need a nuclear physics foundation (ex. equation of state of nucl. matter)

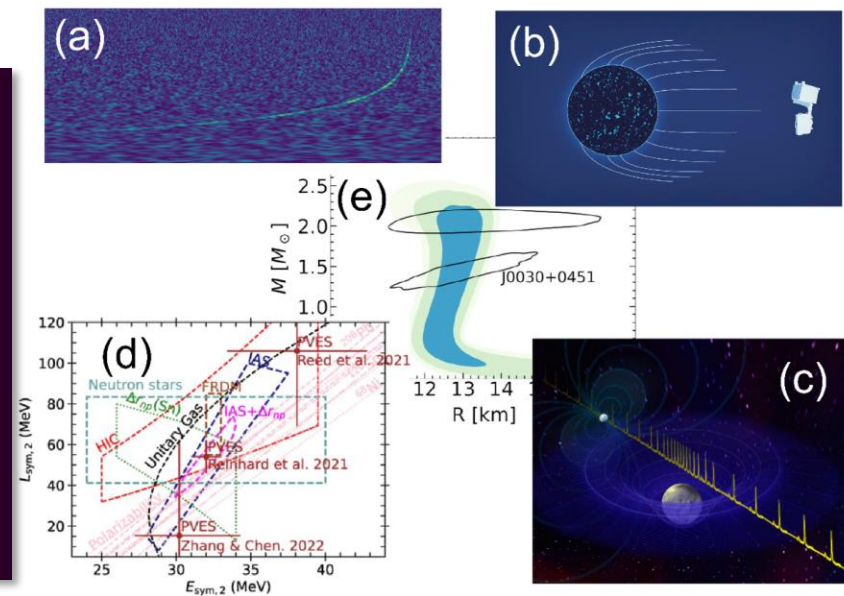
Stellar evolution for low-, intermediate - mass and massive stars



Origin of the Elements



Neutron stars and Equation of State

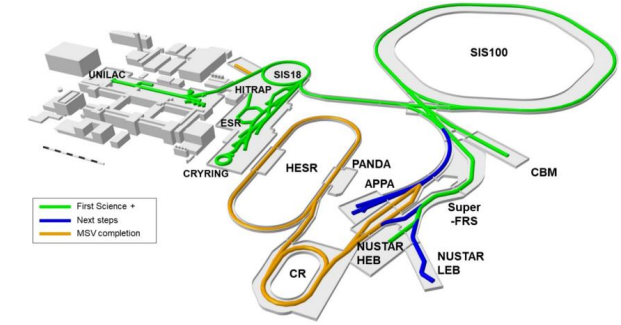


(See LRP2024 for details)

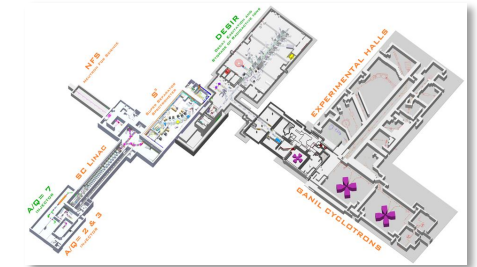
Recommendations (experiments)

- We recommend to strengthen nuclear astrophysics networks in Europe (e.g. **ChETEC-INFRA**) and to make them sustainable.
- **Support of existing facilities and experiments**
 - Small-scale facilities are key for nuclear astrophysics research and should be supported
 - European underground laboratories (**LNGS Bellotti** Ion Beam Facility and **Felsenkeller**) are essential
 - **CRYRING** and **ESR** storage rings at FAIR, which open important new physics cases, and **n_TOF** at CERN should be fully exploited
- **Future flagship facilities and experiments**
 - We strongly recommend the completion of Radioactive Beam Facilities in Europe, in particular the **Super-FRS** at FAIR, including the Low-Energy-Branch, the **upgrade of ISOLDE**, and **SPIRAL2**
 - A large (> 10 MV) **Atomic Mass Spectrometry** system is currently missing in Europe

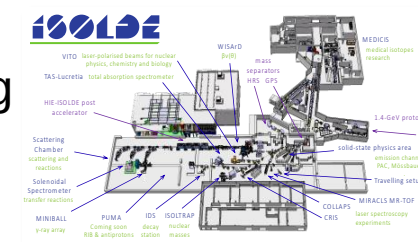
FAIR



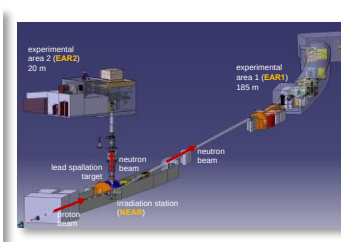
GANIL/SPIRAL2 France



ISOLDE CERN



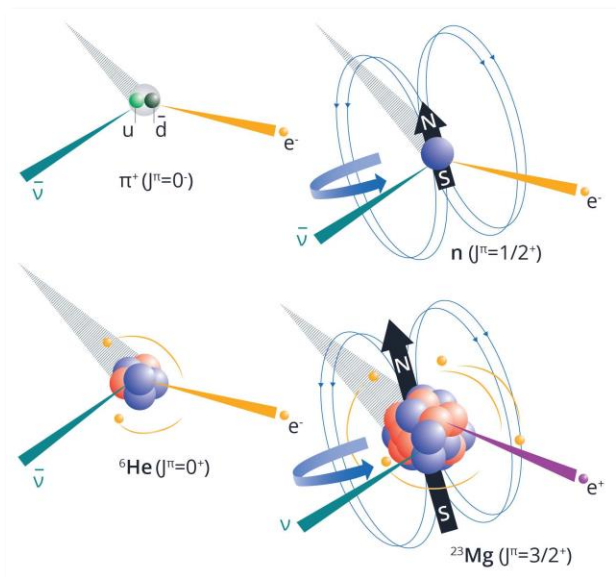
n_TOF CERN



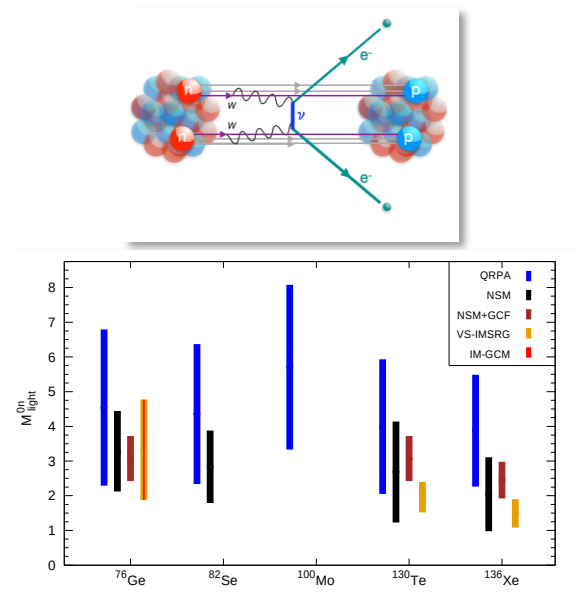
Key Questions & Goals

Symmetries, referred to as the invariance of the laws of physics under a given transformation, play a fundamental role in physics. They can be studied by powerful low-energy probes. As such, precision measurements are complementary to collider searches for new physics. Pioneering techniques are under development to produce, manipulate, cool and trap a diverse range of particles, including radioactive nuclei, neutrons, antiprotons, pions, muons, exotic atoms, and highly charged ions.

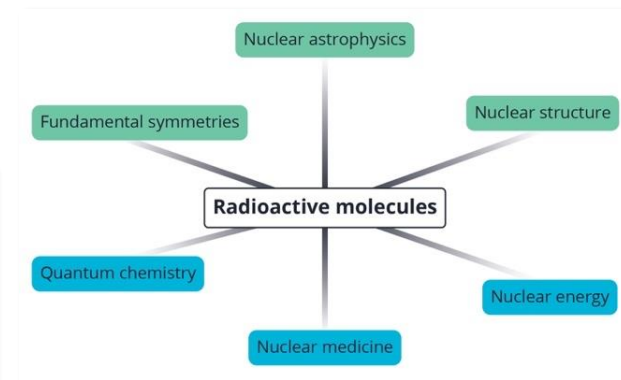
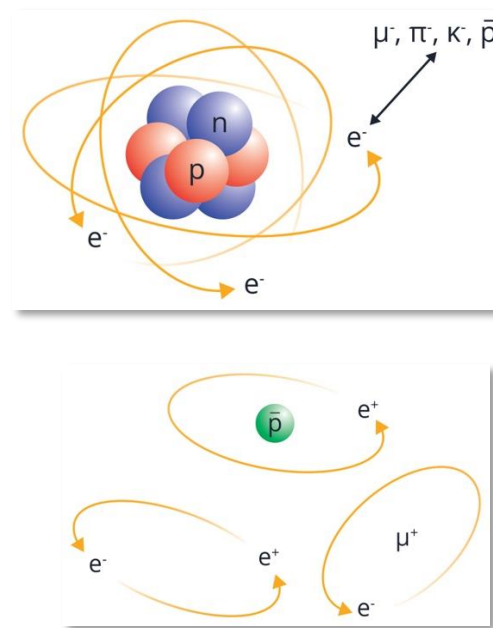
Examples of beta decays used to probe the weak interaction



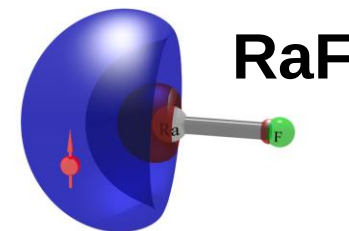
Neutrinoless double-beta decay research



Exotic atoms



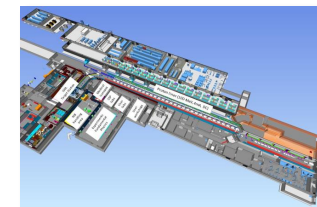
Schematic representation of the radium monofluoride (RaF) molecule



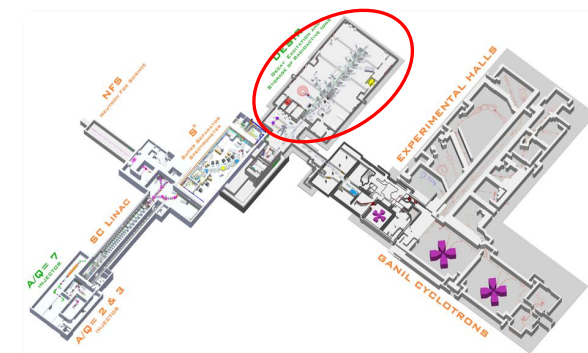
Recommendations (experiments)

- **Support of existing facilities and experiments**
 - The multidisciplinary research infrastructures **ILL**, **FRM-II** and **PSI** provide unique opportunities. Operation of **ILL** should be ensured beyond **2033**
 - Continued support for **ESR**, **CRYRING** and **HITRAP** at GSI/FAIR, and high-energy **EBITs** in other labs
 - The **AD/ELENA** physics program at CERN should be strongly supported
 - Customised instrumentation and beam time availability should be guaranteed for fundamental tests at RIB facilities like ISOLDE, GANIL-SPIRAL2, and JYFL-ACCLAB/IGISOL
 - **Multiple and complementary experimental searches for neutrino-less double beta decay** have to be encouraged as they can reach into the inverted hierarchy in the next decade
- **Future flagship facilities and experiments**
 - Specialization of upcoming Radioactive Ion Beam facilities such as **ISOL@MYRRHA** and **DESIR** at **GANIL-SPIRAL2** should be regarded as an opportunity not to be missed
 - At **ESS**, a fundamental neutron physics beamline should be installed
 - The realisation of future **CR** and **HESR** at FAIR should be vigorously pursued

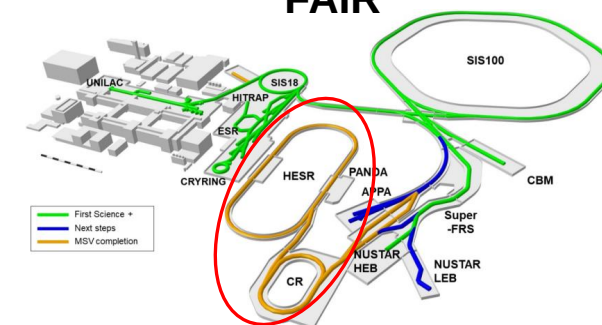
ISOL@MYRRHA Belgium



GANIL/SPIRAL2 France



FAIR



Key Questions & Goals

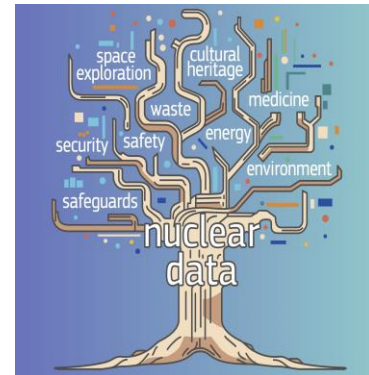
How might nuclear physics strengthen its role in society's sustainable development?

The United Nations Sustainable Development Goals (SDGs) call to action for all governments across the globe, but also a call for all research communities to contribute. The nuclear science community contributes to all SDGs but more specifically, it directly addresses some of these goals (#3 Good health and well-being, #7 Affordable and clean energy, #9 Industry, innovation and infrastructure, #13 Climate action) or indirectly (#4 quality education, #5 gender equality, #10 reduced inequalities) through innovative and collaborative approaches.



Recommendations

- Improving **nuclear data**, including both the measurement and the evaluation of nuclear data is needed to support research in the fields of energy, health, space, and materials science.
- Capacity building**: in radiochemistry and radiobiology maintaining nuclear application competencies, developing the landscape of smaller-scale facilities, in coordination with the large-scale facilities.
- New generations of nuclear energy sources and the management of nuclear waste through partition and transmutation, depend on sustained technological developments in the present facilities, as well as the completion of **MYRRHA** and **IFMIF-DONES**.
- Upscaling the production capacity of novel medical radionuclides**: **MEDICIS** separator at CERN, the expansion of the **EU PRISMAP** project, and the completion **ISOLPHARM** at SPES, **ISOL@MYRRHA**, **IMPACT-TATTOOS** at PSI, and **SMILES** at Subatech
- Completion of the first **galactic cosmic ray simulator** in Europe at GSI/FAIR
- The installation of a **high-energy AMS** in Europe (>10 MV) is recommended.
- Isotope-sensitive techniques in environmental, heritage, and materials science: sustained operation of research reactors



A PET-CT scan of the human body.

Key Questions & Goals

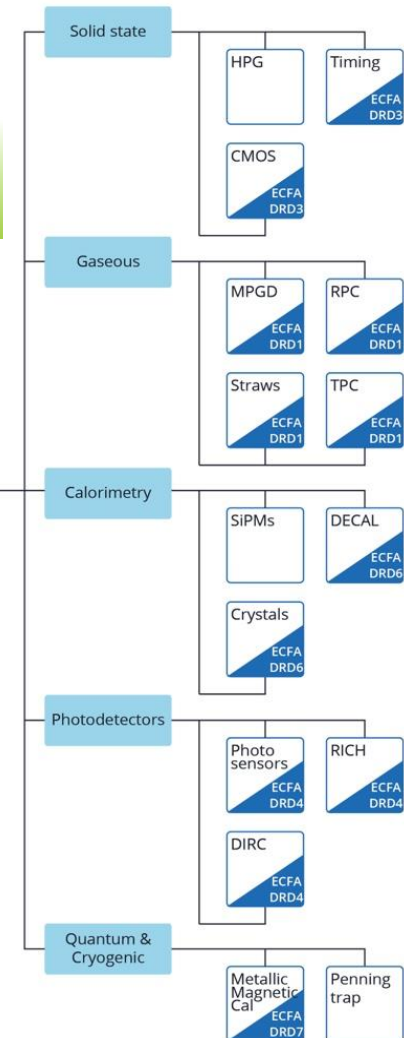
Advancement in the understanding of fundamental physics is intimately related to progress in the development of tools for experimental and theoretical investigations. These tools are used for detector R&D, detector operation, data acquisition and analysis, theoretical interpretation of experimental results and genuine theoretical developments.

Recommendations

Includes: R₃B, COCOTIER liquid hydrogen target, CBM, PANDA, GRIT, gas catcher, NeuLAND, MONSTER

- Elaboration of a **roadmap for detector R&D** dedicated to the specific needs of **low-energy nuclear physics** and applications in radiation monitoring and heritage science must be supported
- **Strengthening of the collaborative effort in developing cutting-edge detector technology** for identified applications in accelerator experiments with respective activities in high-energy particle physics and other adjacent research fields
- Enhance precision and efficiency in **high-resolution laser spectroscopy and mass spectrometry**, to study the structure of rare isotopes and test fundamental symmetries
- Establish infrastructures to **ensure the provision of stable and radioactive targets**, such as a **dedicated mass separator** for providing radioactive samples and targets – **foreseen to be built at PSI**
- Secure a strategic **supply of stable enriched isotopes** for fundamental research and applications as is the case for the installation of a **European Electro-Magnetic Ion Separation facility**, providing material of the highest enrichment in rare stable isotopes
- To develop **novel efficient neutron detectors** to replace those based on ³He

Strategic R&D for NP detector Technologies



Selected list of major complementary or/and competing facilities with FAIR

HIAF – China

RIBF – Japan

FRIB – USA

ISOL facilities: in Europe (ISOLDE, GANIL/SPIRAL2, SPES) and TRIUMF in Canada

EIC – USA

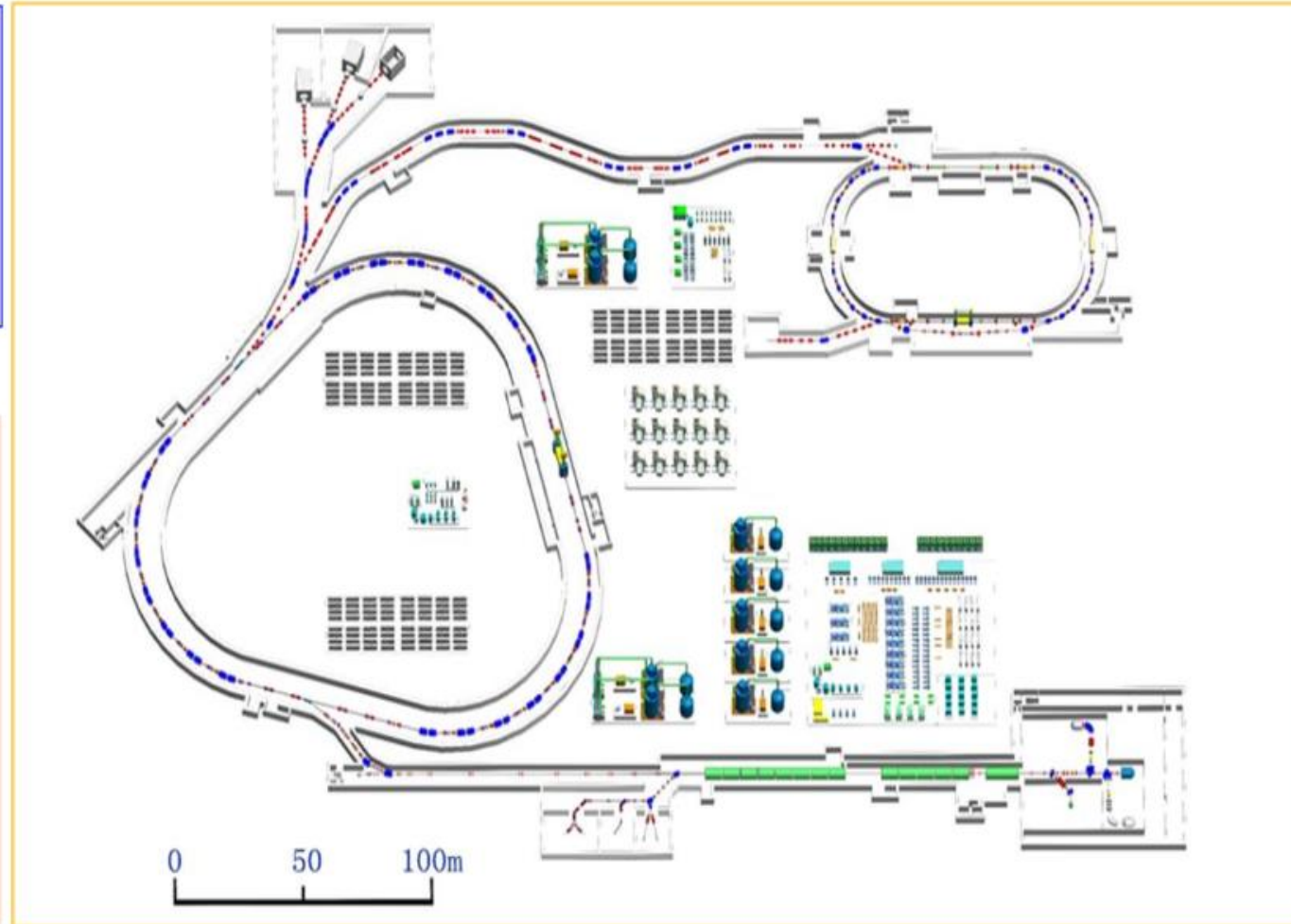
NICA - Russia

□ General information

- HIAF (High Intensity heavy-ion Accelerator Facility) is one of the mega-scientific projects under constructed in China

- Mainly designed to provide high energy ($\sim 800\text{MeV/u}$) and high intensity (10^{11}ppp) heavy ion beams (up to U^{35+})
- Civil construction was started in the end of 2018
- Beam commissioning date is December 2025

- Superconducting ECR ions source provides highly charge heavy ions
- CW linac is used as the injector of synchrotron
- The booster is used to accumulated and accelerated ions
- 6 experimental terminals will be constructed for nuclear physics, atomic physics and application studies



□ Status of the HIAF construction

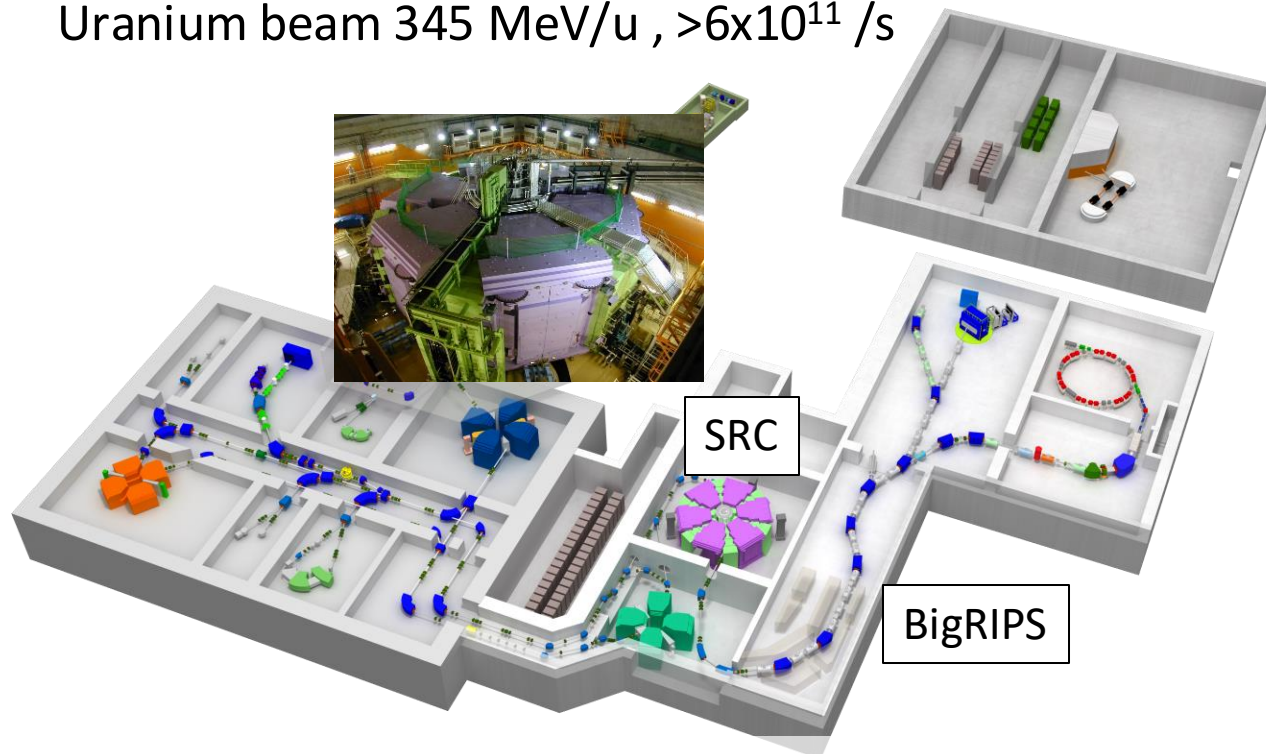
- The civil construction was started in **Dec. 2018**
- The first dipole of BRing moved to the tunnel in **Mar. 2024**
- We plan to finish the installation of BRing **in the end 2024**

The day-one experiment is expected **in the end of 2025**



Strong collaboration with GSI/FAIR

SRC: Superconducting Ring Cyclotron
World's First and Strongest K2600 MeV
Uranium beam 345 MeV/u , $>6 \times 10^{11}$ /s



SRC

BigRIPS



BigRIPS Superconducting RI beam Separator
In-flight separator
World's Largest Acceptance
High magnetic rigidity 9 Tm
 ~ 250 MeV/u

Three spectrometers for reaction studies
with fast RI beams

ZeroDegree



SAMURAI



SHARAQ + OEDO (univ. of Tokyo, CNS)



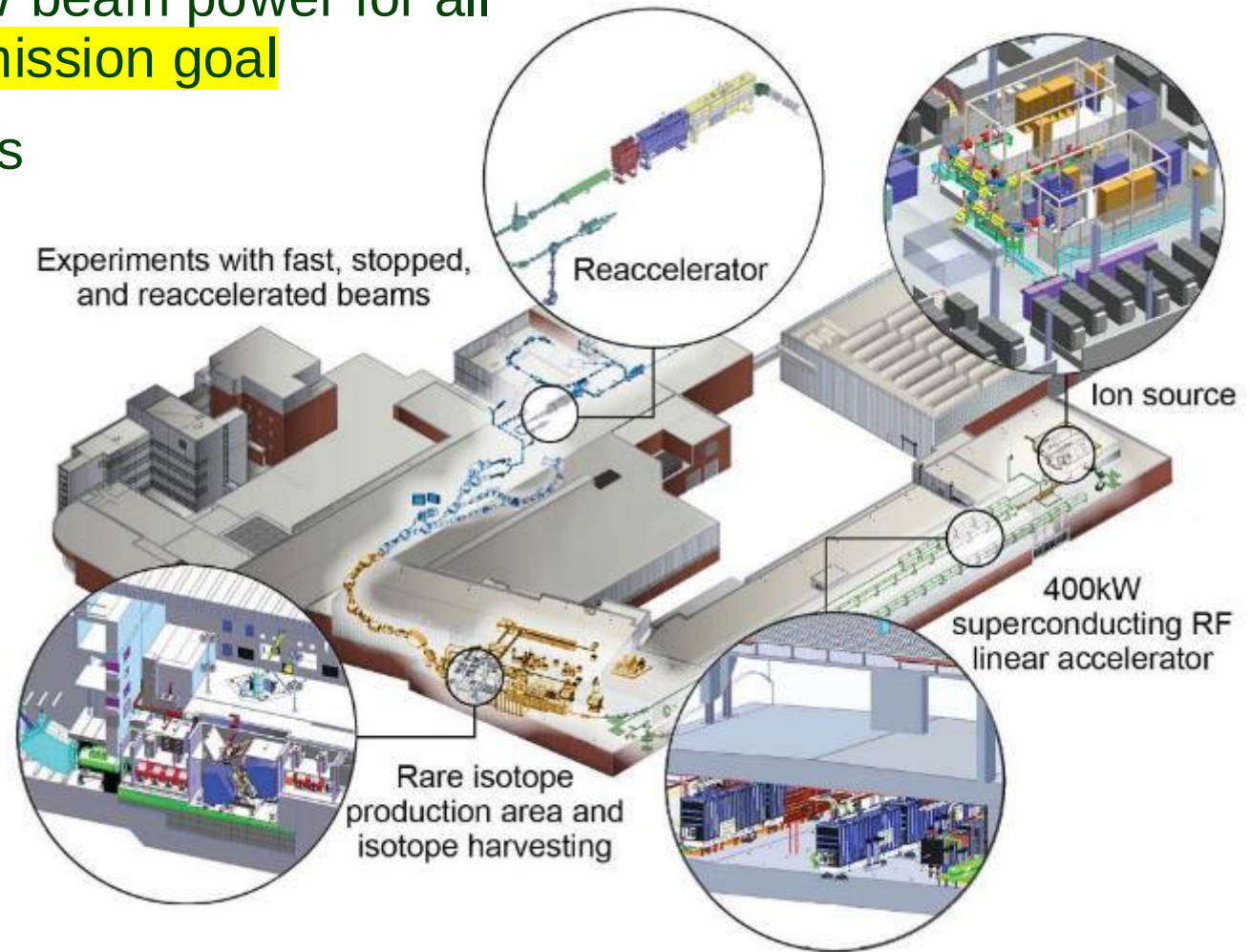
A storage ring (Rare RI Ring)
dedicated to mass measurement



Courtesy of Hiroyoshi Sakurai

FRIB Optimized for Science with Fast, Stopped and Reaccelerated Rare Isotope Beams

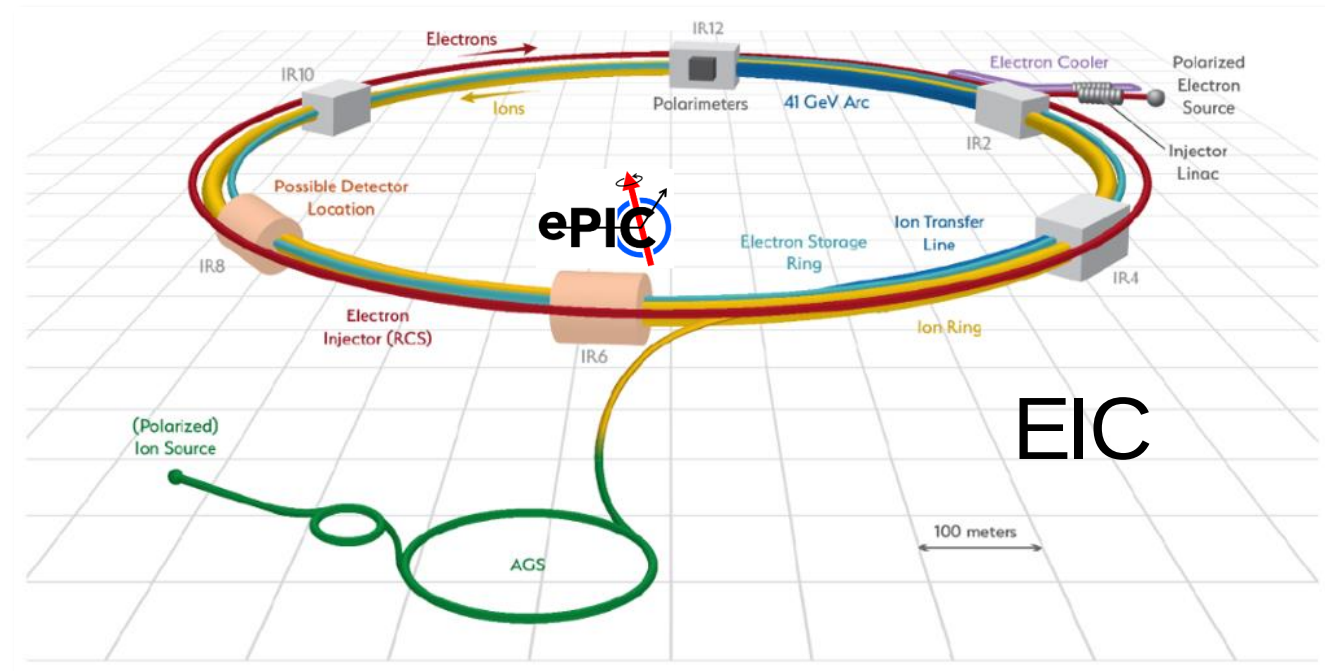
- Key feature is 400 kW beam power for all ions ($5 \times 10^{13} {}^{238}\text{U/s}$) **mission goal**
- Separation of isotopes in-flight provides
 - Fast development time for any isotope
 - Beams of all elements and short half-lives
 - Fast, stopped, and reaccelerated beams
- Isotope harvesting capability from beam dump water (where 75% of beam particles fragment)



European contributions to the non-European 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.

ePIC at EIC Brookhaven USA

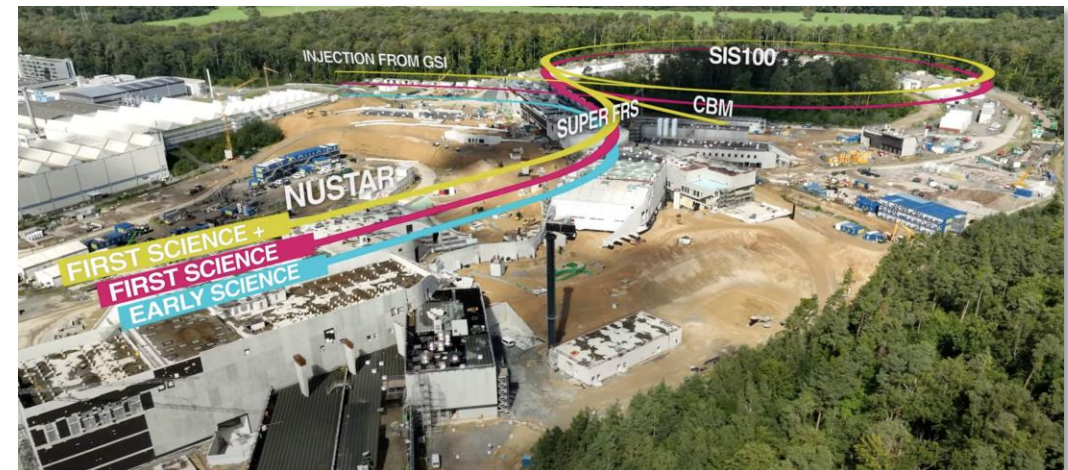
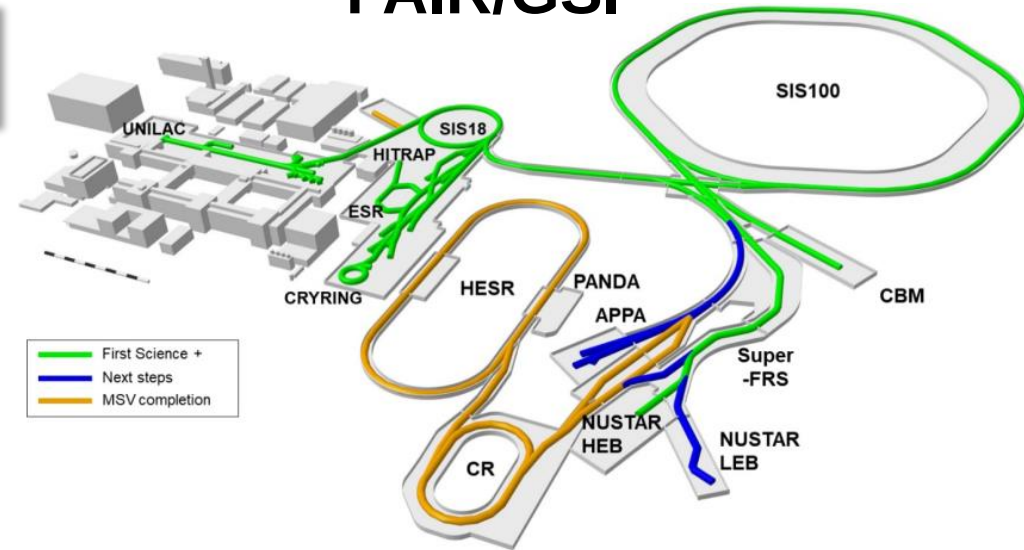


CONCLUSION

FAIR facility, Darmstadt, Germany

- 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.

FAIR/GSI



<https://www.youtube.com/watch?v=kbvK5AGg8oM>

**Warm thanks to all
contributors to the
NuPECC LRP 2024!**



https://www.nupecc.org/lrp2024/Documents/nupecc_lrp2024.pdf

**Thank you for your
attention!**



NuPECC LRP 2024 Town Meeting, Bucharest, April 2024

Backup Slides

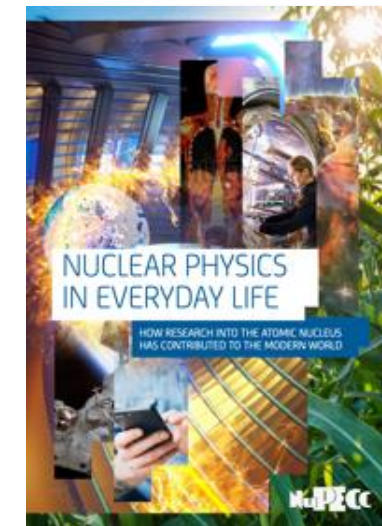
Nuclear science and technology have benefited human progress, culture, and our understanding of our delicate environment in general, as well as health, economic growth, and security in nations all over the world



The nuclear science research community contributes to all of the 17 sustainable development goals of the United Nations.

NuPECC report on
Nuclear Physics in Everyday Life
(100 pages, open access on-line)

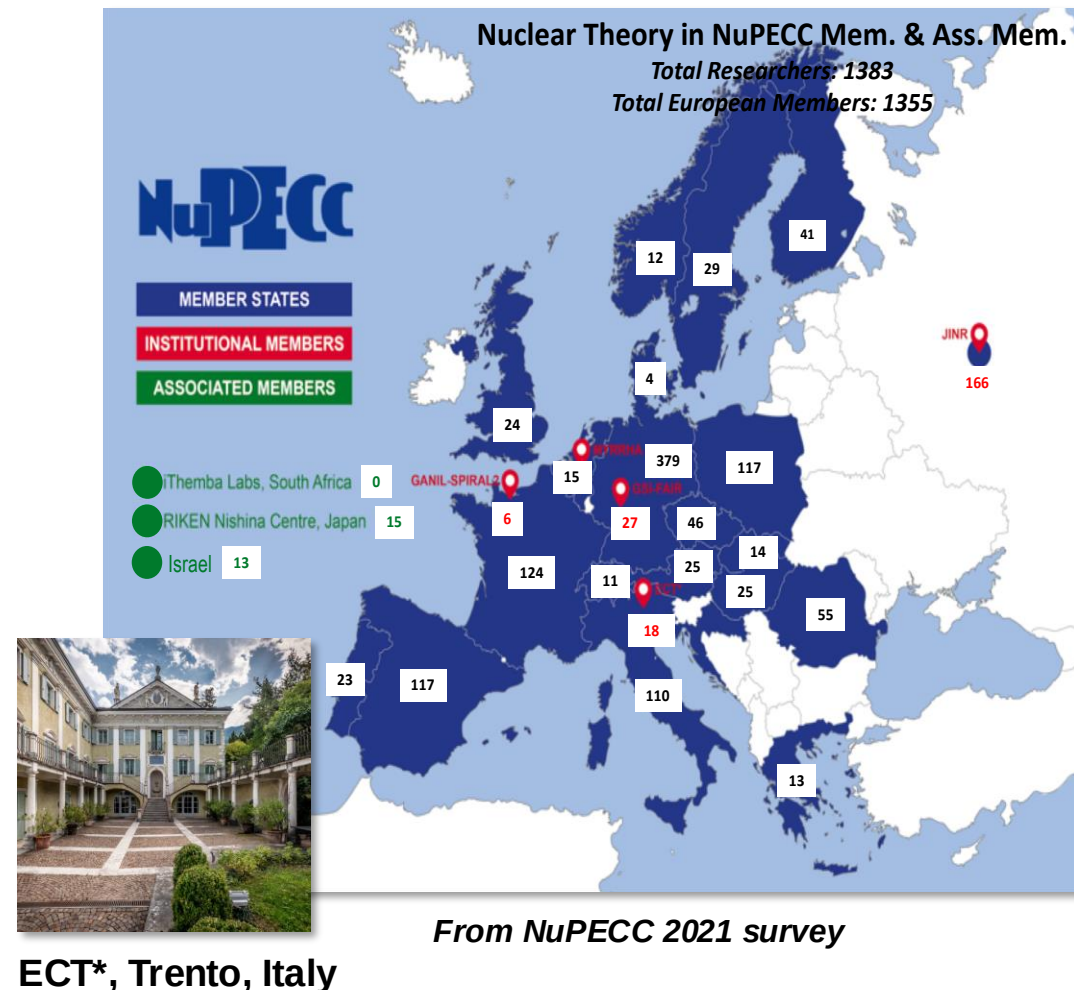
https://nupecc.org/pub/np_life_print.pdf



Fast development of theory is essential for all sub-fields of nuclear physics

Recommendations

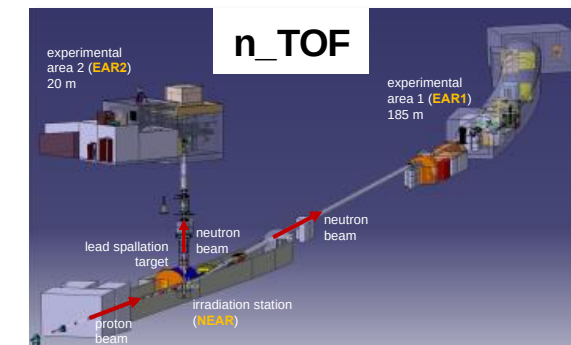
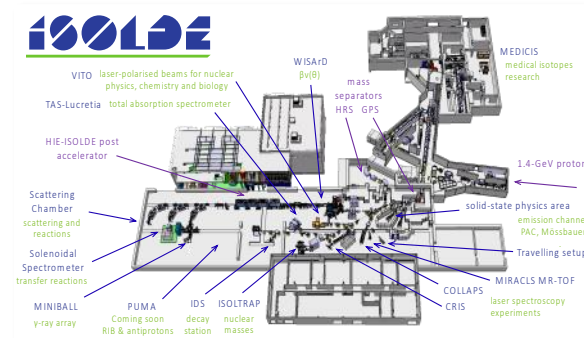
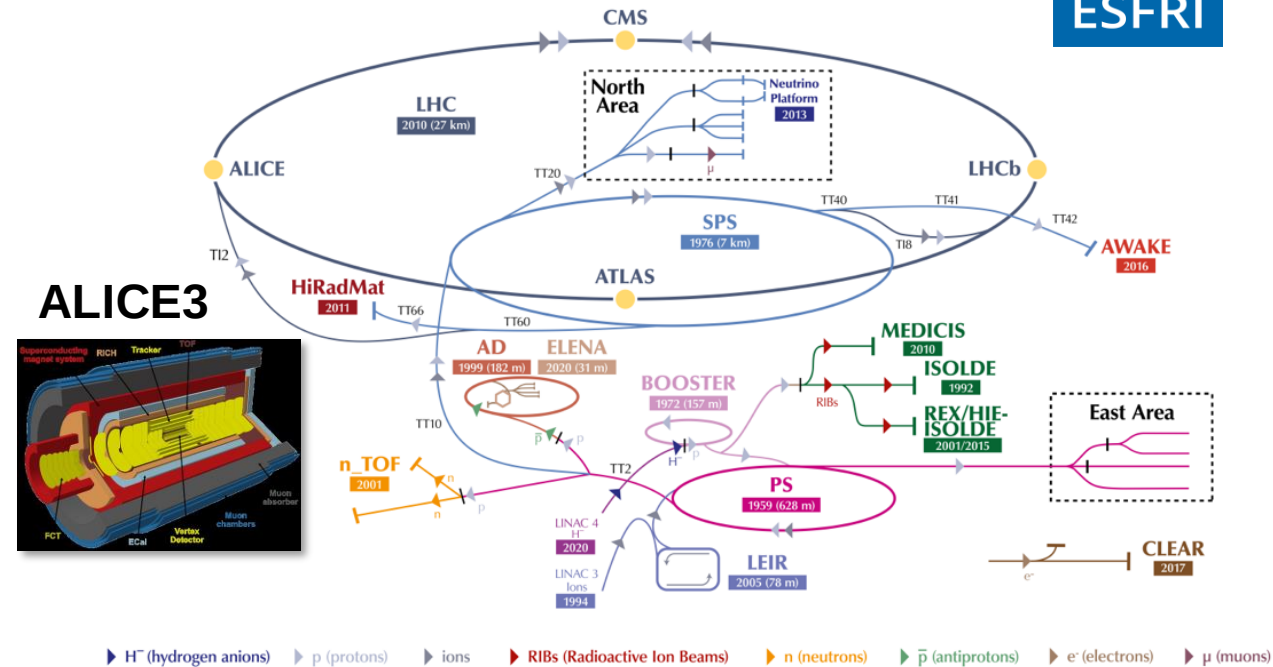
- Theory centres and groups should be strongly supported throughout Europe, in particular the European Centre for Theoretical Studies (**ECT***, **Trento, Italy**), which is a unique European centre dedicated to theoretical nuclear physics in the broadest sense.
- Support of theory groups ... to benefit from European investments in supercomputing and quantum computing infrastructure
- Support emerging virtual access facilities, which provide theory results for experimentalists (e.g., Virtual Access facilities in the **STRONG 2020** and **EURO-LABS** projects)



CERN Nuclear Physics facilities and experiments

ESFRI

- Nuclear physics opportunities at **CERN** constitute a world-leading research. 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.



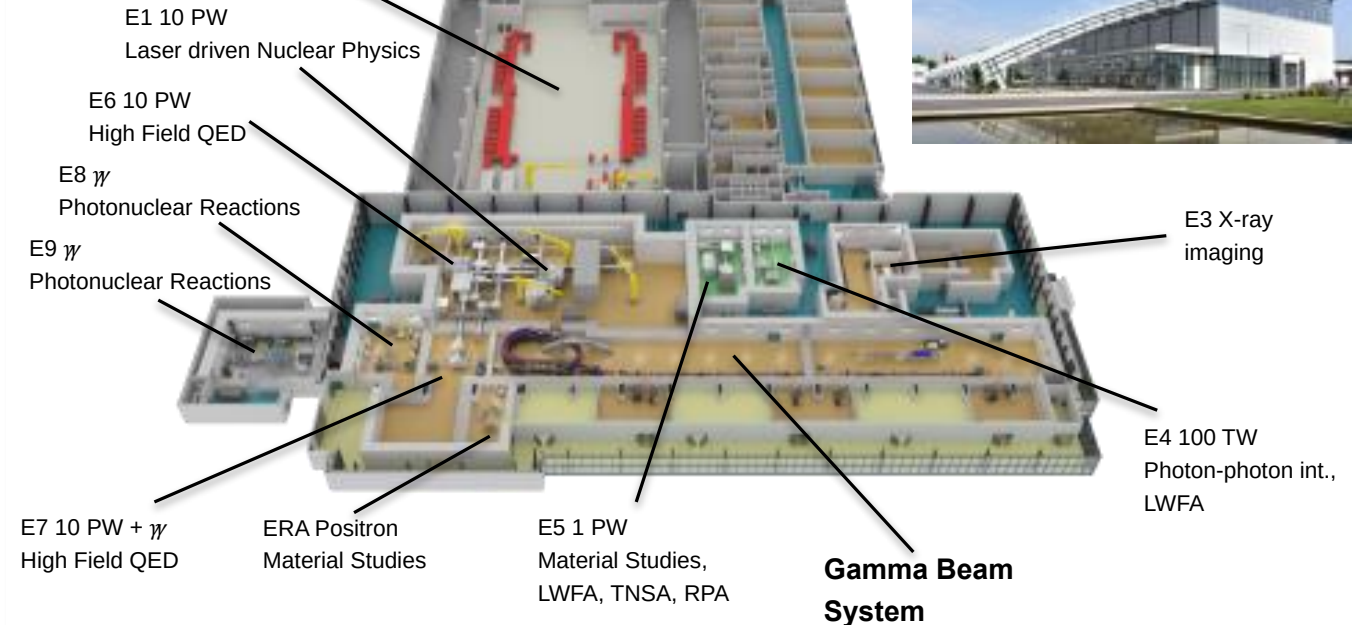
Extreme Light Infrastructure - Nuclear Physics, Magurele, Romania

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.

ELI – NP Romania

2 x 10 PW High Power Laser System

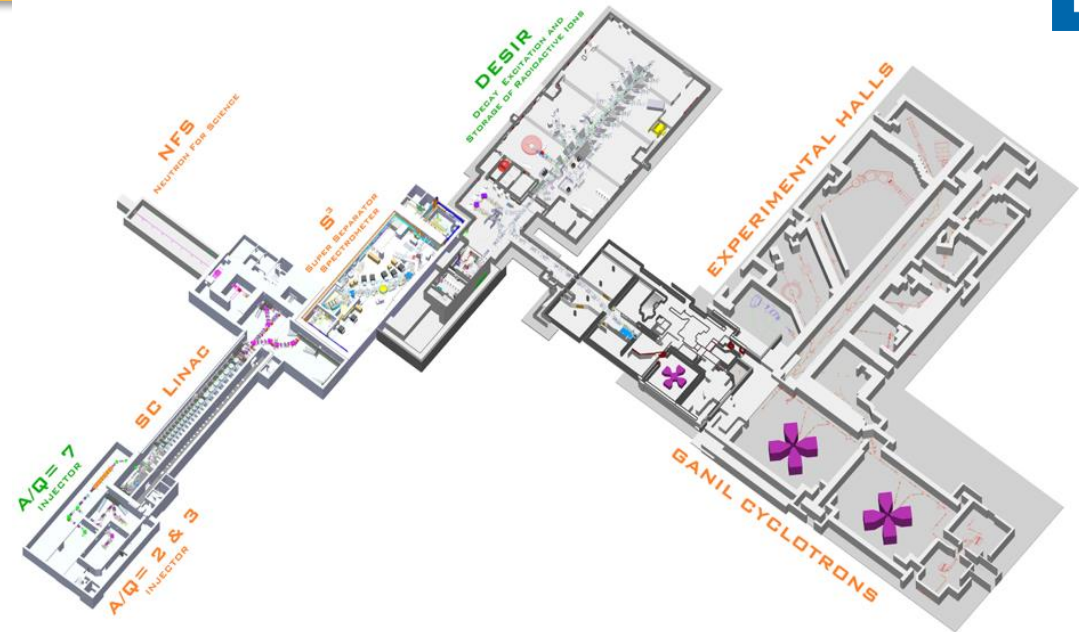


GANIL/SPIRAL2 facility, Caen, France

- At **GANIL/SPIRAL2** the Super-Separator Spectrometer **S³** 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 infrastructure towards a very high-intensity reaccelerated RIB facility of up to 100 MeV/u should be actively planned.

GANIL/SPIRAL2 France

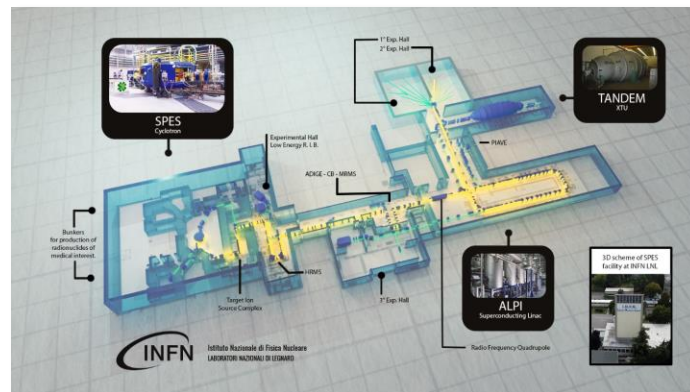
ESFRI



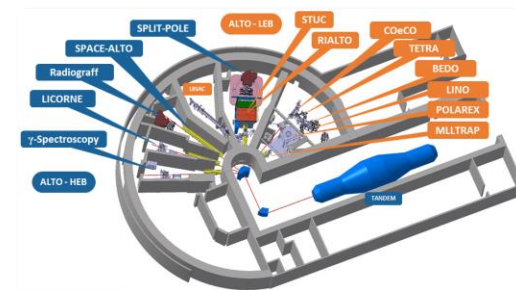
ISOL radioactive ion beam facilities

- 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.

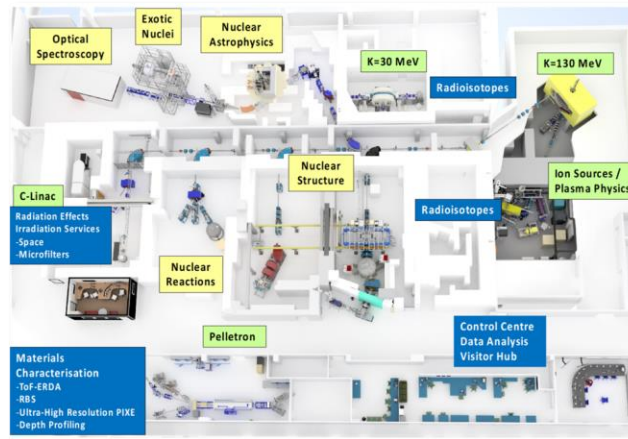
SPES/LNL Italy



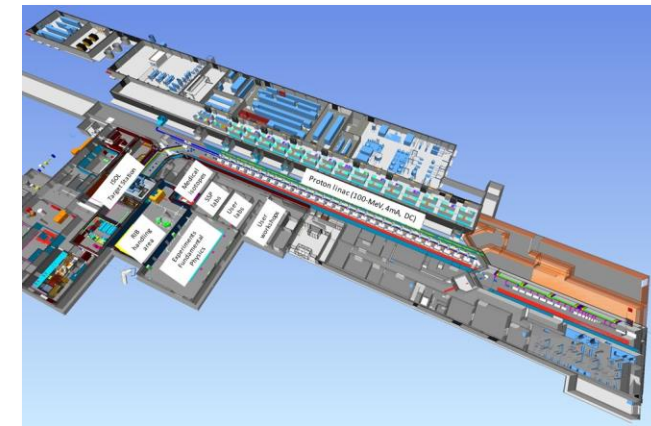
ALTO/IJCLab France



IGISOL/JYFL Finland



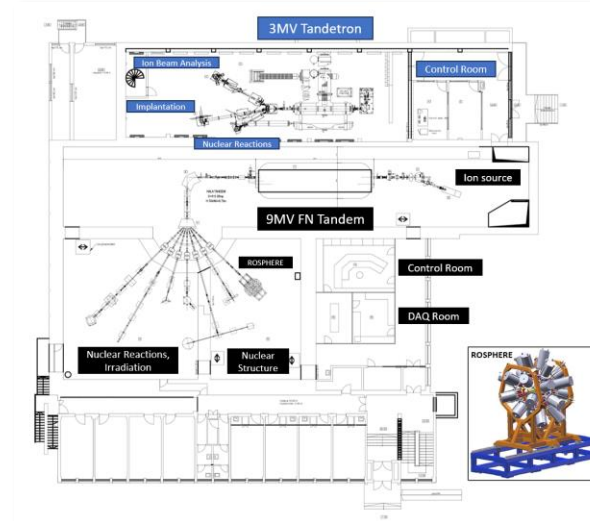
ISOL@MYRRHA Belgium



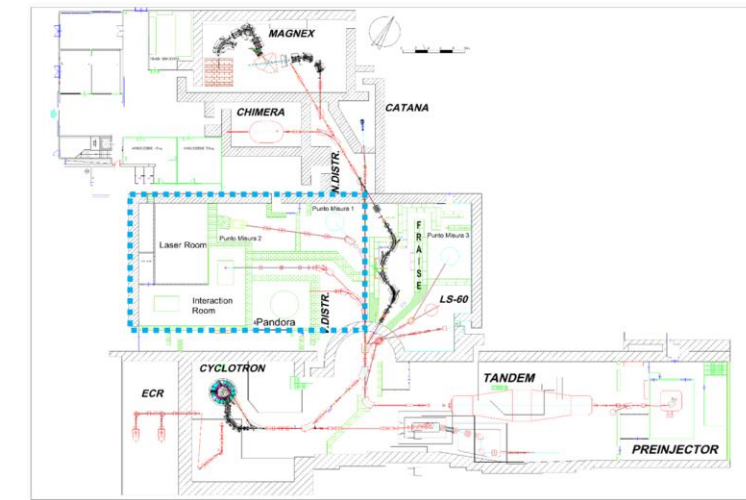
Stable Ion Beam facilities

- 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 Romania

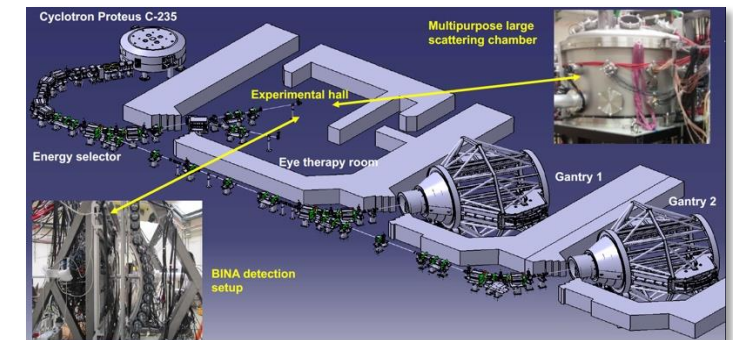
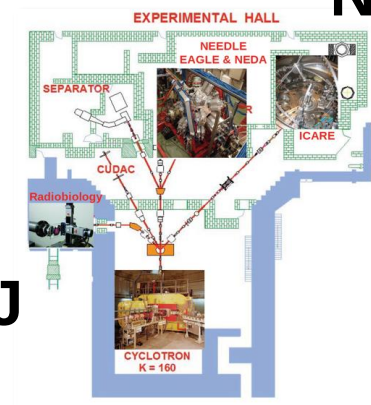


LNS Italy



NLC Poland

SLCJ

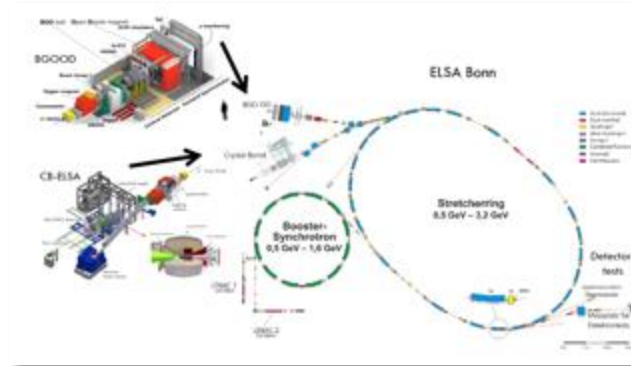


CCB

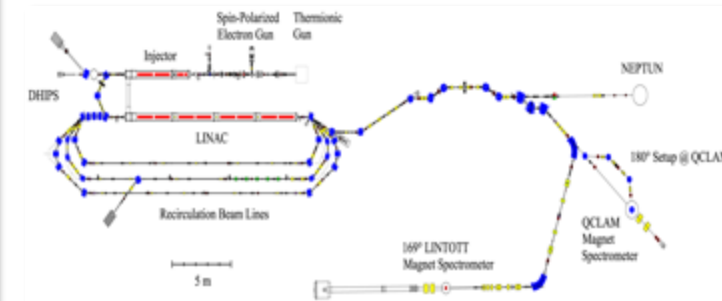
Lepton beam infrastructures

- 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.

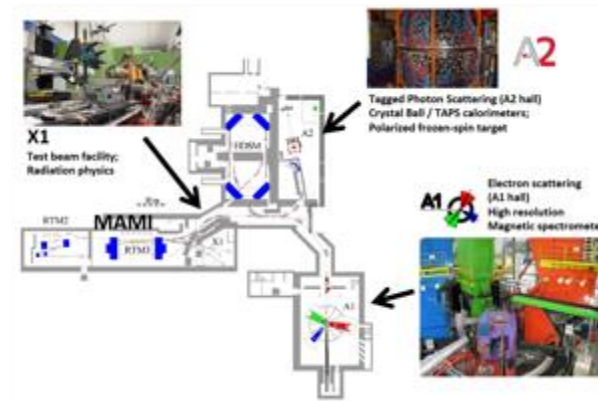
ELSA Germany



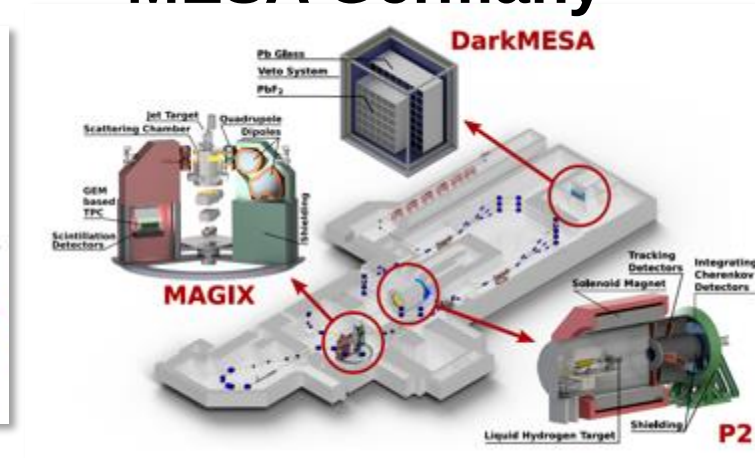
S-DALINAC Germany



MAMI Germany



MESA Germany



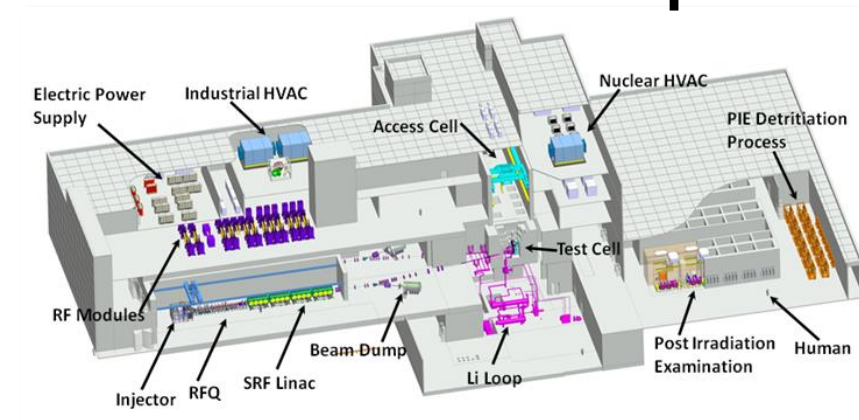
Neutron facilities

- 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. The **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 France



IFMIF-DONES Spain



Theory/Exp.

TWG Number	TWG	Coordinators	Liaisons
1	Hadron Physics	Karin Schönning (Uppsala) Constantia Alexandrou (CY)	Diego Bettoni Dave Ireland
2	Strongly Interacting Matter at Extreme Conditions	Laura Fabbietti (TUM) Urs Wiedemann (CERN)	Gert Aarts Raimond Snellings
3	Nuclear Structure and Reaction Dynamics	Silvia Leoni (Univ. Milano) Tomas Rodriguez(UCM)	Adam Maj Jelena Vesic
4	Nuclear Astrophysics	Anu Kankainen (JYFL) Jordi Jose (Barcelona)	Daniel Bemmerer Sandrine Courtin
5	Symmetries and Fundamental Interactions	Pierre Delahaye (GANIL) Paolo Crivelli (ETH)	Eberhard Widmann Klaus Kirch
6	Infrastructures	Wolfram Korten (CEA, Saclay)	Joaquin Gomez-Camacho Patricia Roussel-Chomaz
7	Applications and Societal Benefit	Thomas Cocolios (KU Leuven) Charlot Vandevoorde (GSI)	Lucia Popescu Vladimir Wagner
8	Nuclear Physics Tools Detectors and experimental techniques Computing, Machine Learning and Artificial Intelligence	Silvia Dalla Torre (INFN) Valerio Bertone (CEA Saclay) Jana Guenther (U. Wuppertal)	Eugenio Nappi Hervé Moutarde
9	Open Science and Data	Antoine Lemasson (GANIL)	Marek Lewitowicz
10	Nuclear Science - People and Society Training, Careers & Diversity Education and Outreach	María García Borge (Madrid) Christian Diget (York)	Rolf-Dietmar Herzberg Yvonne Leifels

**10 Thematic Working Groups
266 Members and NuPECC Liaisons**

**Recommendations Drafting Session
30-31 October, 2023 GSI Darmstadt**



**Chapters Finalisation Meeting
7 – 9 February 2024 GSI Darmstadt**

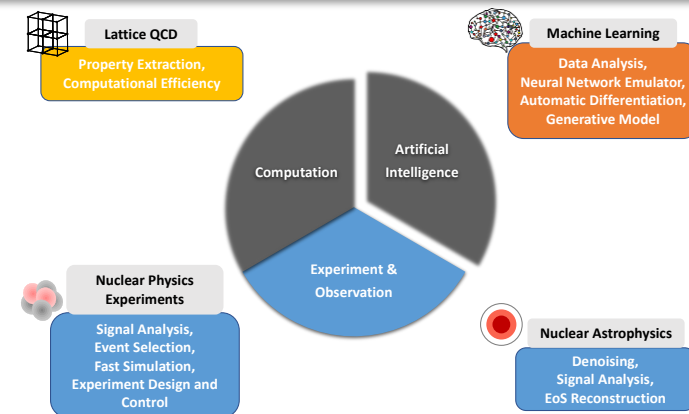


Key Questions & Goals

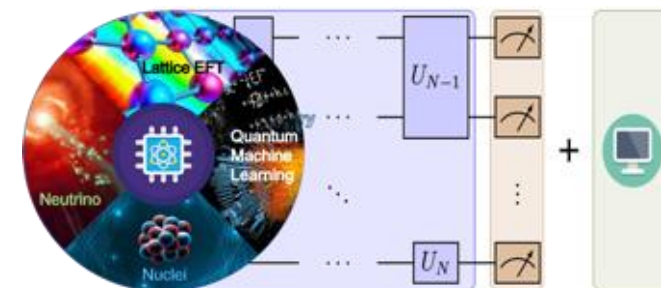
The tremendous progress in the field of nuclear physics has led to the pressing need for appropriate numerical tools aimed at addressing the most relevant experimental, theoretical and technological challenges, such as those encompassed by the Joint ECFA-NuPECC-APPEC (JENA) initiatives. To this end, the advent of algorithms based on Machine Learning (ML) and Artificial Intelligence (AI) techniques, and the fast progress in the field of Quantum Computing (QC) has opened an entire new world of possibilities.

Recommendations

- Provide **long-term career perspectives** for software developers in the field
- **Facilitate and strengthen access** for nuclear physics researchers to large **High Performance Computing** centres
- Develop research into explainable AI; **Enhance transparency and interpretability** in scientific AI applications in nuclear physics and adjacent fields
- Facilitate **access to quantum platforms**
- Establish a **European network** on quantum activities related to nuclear physics



ML application in nuclear physics



Quantum Comp. in nuclear and particle physics