NuPECC & Strategy for Nuclear Physics in Europe

Marek Lewitowicz
Chair of NuPECC

Disclaimer: ***Focus on Nuclear Physics Facilities***
Introduction to following talks

What is NuPECC ?

The European Expert Board for Nuclear Physics hosted by European Science Foundation

Representing
about 6000 scientists

Composition:

- 34 representatives from 21 countries, 3 ESFRI NP Infrastructures & ECT*

JINR Dubna – suspended in March 2022

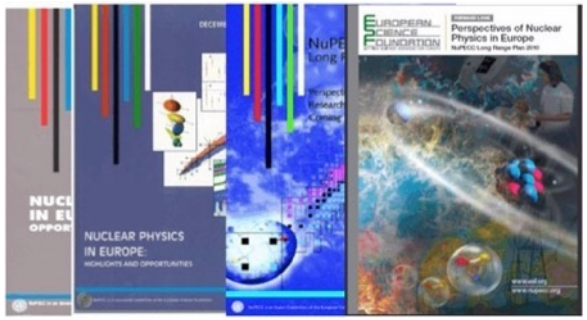
- 4 associated members
  - CERN,
  - Israel,
  - iThemba Labs
  - Nishina Center
- 9 observers (ESF, NPD/EPS, ECFA, NSAC, ANPhA, ALAFNA, CINP, IAEA, APPEC)

3 regular Committee meetings/y

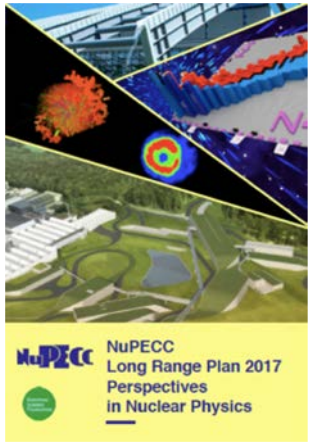
33 Years of NuPECC activities

Towards NuPECC Long Range Plan 2024

1991 1997 2004 2010



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



Assessment of Implementation of the NuPECC Long Range Plan 2017

February 2022

Liaisons: G. Aarts, D. Bettoni, S. Courtin, P. Giubellino, J. Gómez Camacho, A. Görgen, R.-D. Herzberg, D. Ireland, B. Krusche, M. Lewitowicz, A. Maj, U. Meissner, E. Nappi, G. Neyens, L. Popescu, B. Sharkov, E. Widmann,

Contributors: H. Abele, N. Alahari, W. Barth, D. Bemmerer, K. Blaum, F. Bossi A. Bracco, M. Chiossi, A. Denig, M. Doser, S. Freeman, M. Gazdzicki, F. Gélis, H. Goutte, M. Grecco, M. Harakeh, M. Hori, G. Imbriani, E. Khan, K. Kirch, W. Korten, A. Laird, J. P. Lansberg, D. Lunney, F. Maas, G. Martinez-Pinedo, S. Masciocchi, A. Mengoni, O. Navillat-Cuncic, D. Rifuggiato, P. Rossi, E. Scomparin, J. Simpson, H. Schmieden, O. Schneider, N. Severijns, Th. Stöhlker, J. Stroth, H. Ströher, U. Thoma, S. Ulmer, C. A. Ur, Ch. Weinheimer, U. Wiedner, H. Wittig

NuPECC LRP 2017

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

February 2022

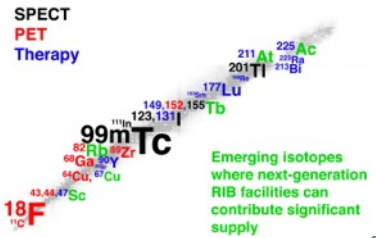
http://nupecc.org/2017_LRP_Assessment_of_Implementation_final.pdf

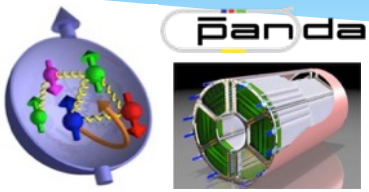
NuPECC LRP 2024

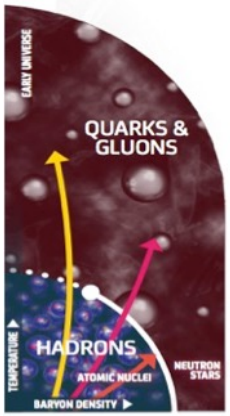
To be launched in May 2022

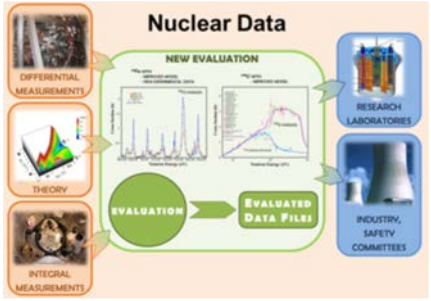
Nuclear Physics in Europe

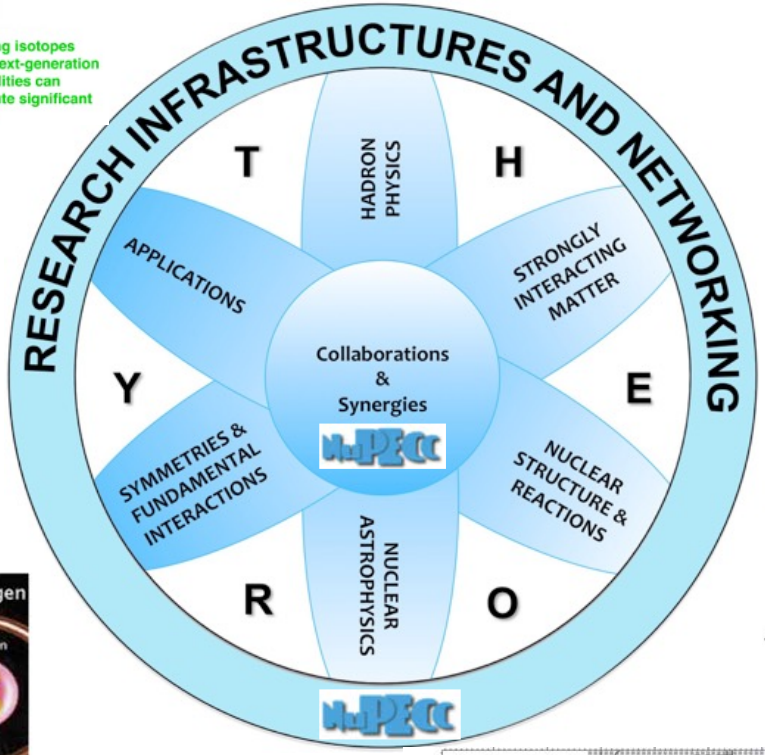
http://www.nupecc.org

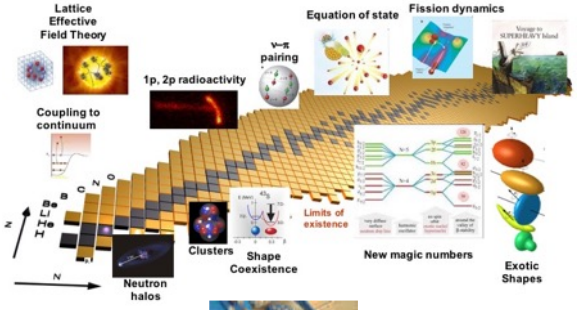


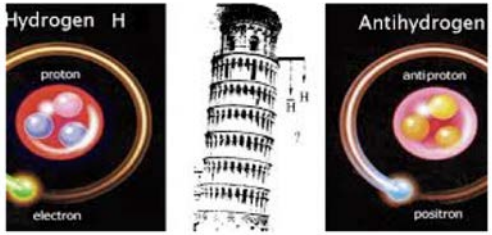


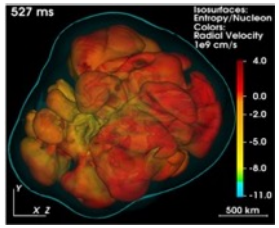


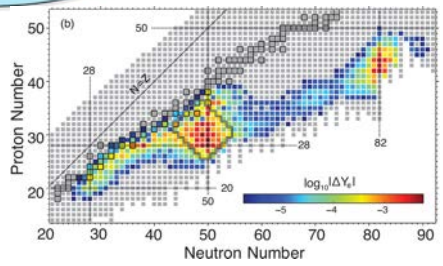


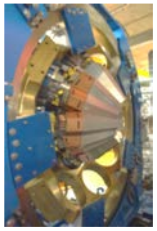








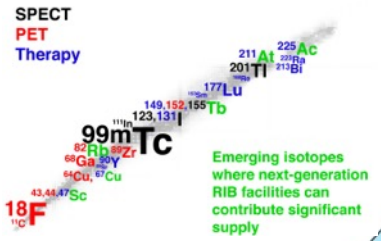


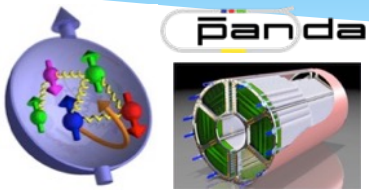


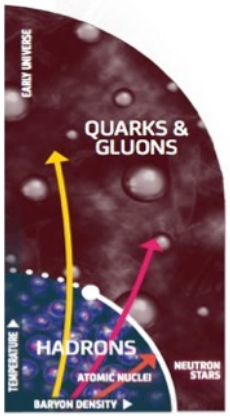
Talks of Gerda Neyens & Jorgen d'Hondt

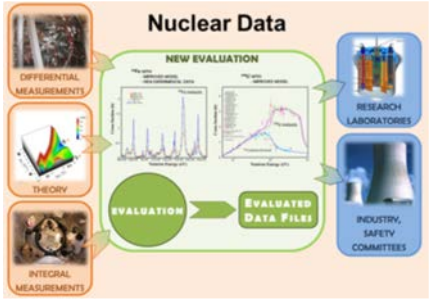
Nuclear Physics in Europe

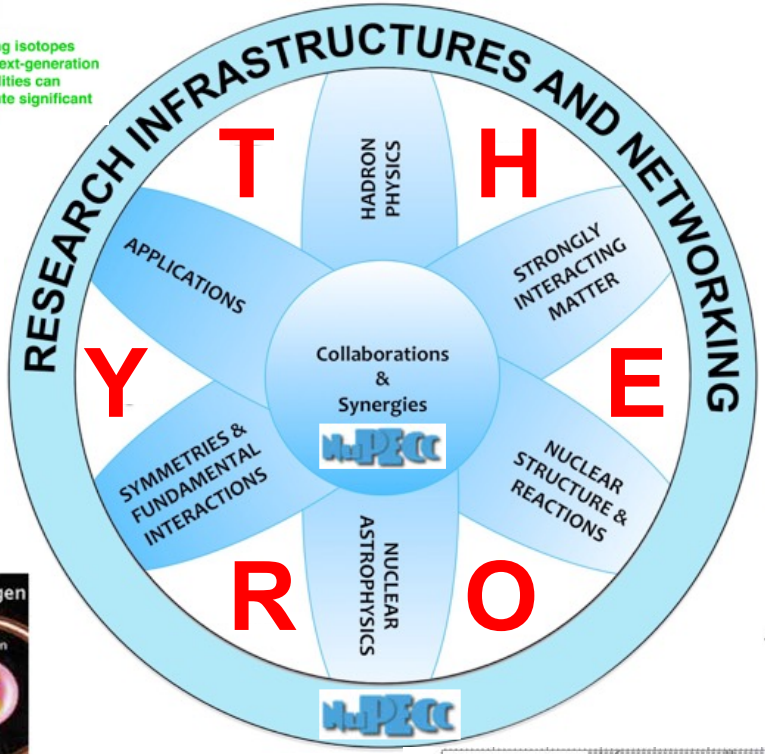
http://www.nupecc.org

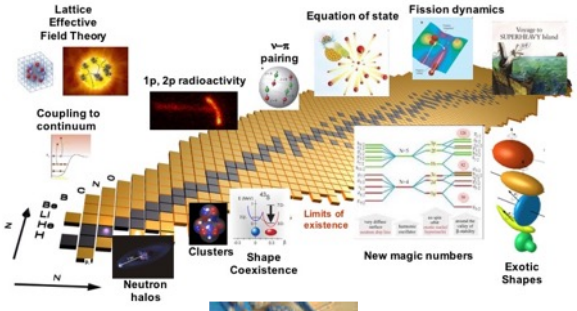


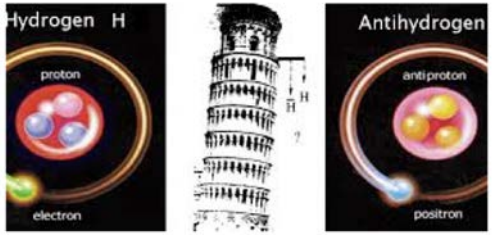


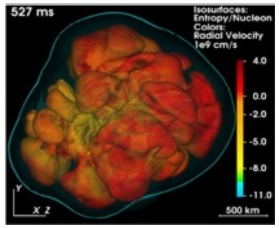


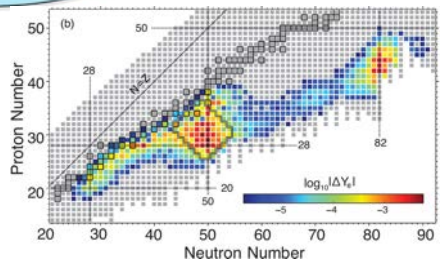


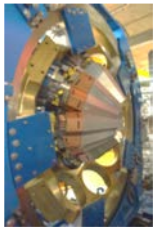






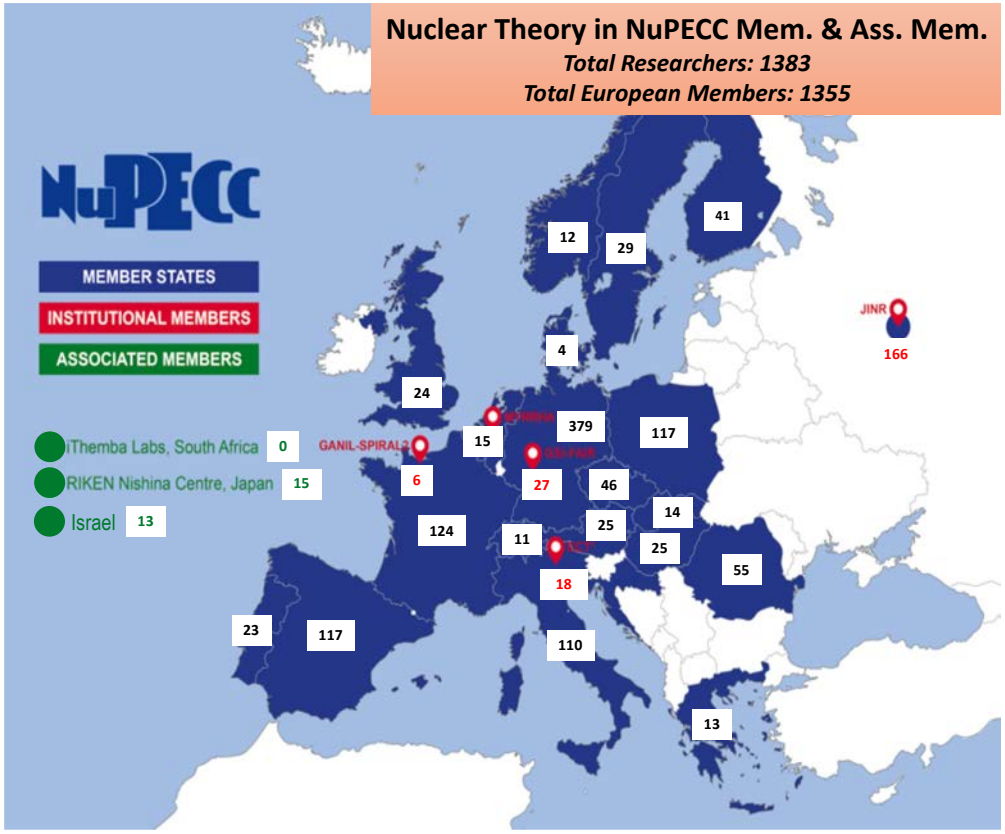




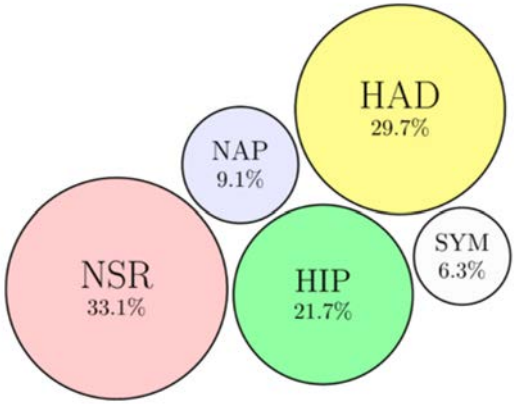


Talks of Gerda Neyens & Jorgen d'Hondt

2021 NuPECC Survey of Nuclear Theory in Europe



- Nuclear structure and reactions (**NSR**)
- Nuclear astrophysics (**NAP**)
- Heavy-ion physics (**HIP**)
- Hadron physics (**HAD**)
- Nuclei as laboratories/symmetry tests (**SYM**)



- **In order for the field to prosper, healthy nuclear theory is absolutely essential: the numbers show that this is indeed the fact**
- **There is an approximate equal partition among the big fields (except SYM)**
- **A concentration on specific sites/labs seems to occur (e.g. Germany, Czech Republic, Romania)**
- **Much lower number of PhD students & post-docs / permanent staff in some countries**

http://nupecc.org/snt/meissner_sep21.pdf

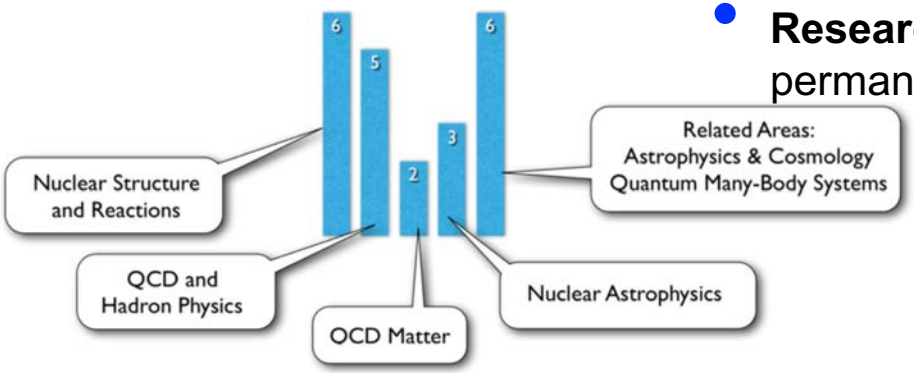
Ulf-G. Meißner et al.

Support for Nuclear Theory – ECT*

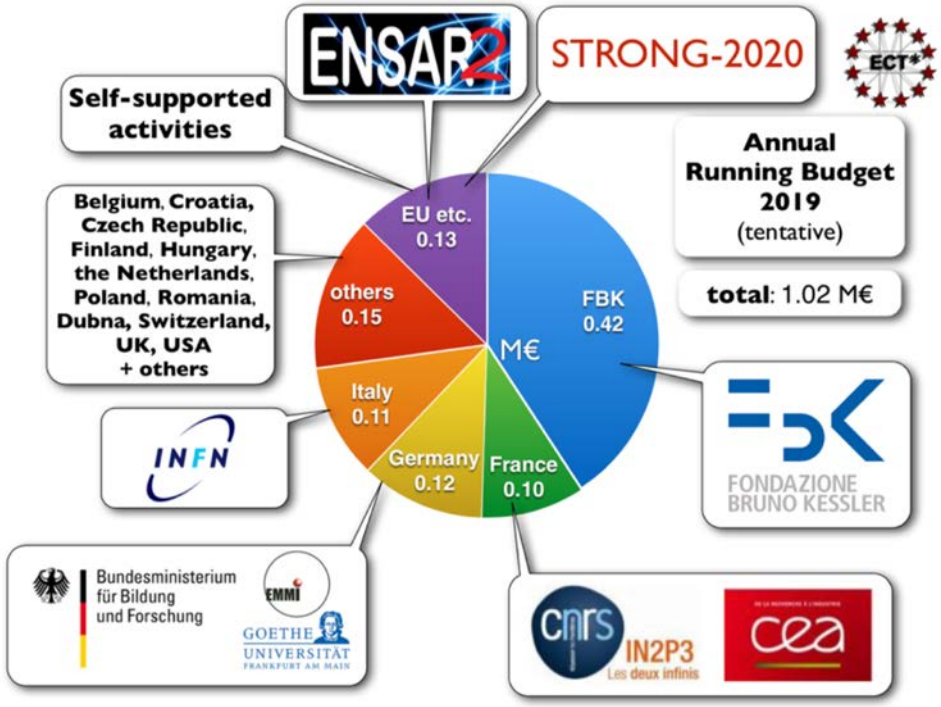
Scientific activities at ECT*

Trento, Italy

- International **workshops** and **collaboration meetings** (typically around 20-25 events per year)
- **Doctoral training** programs and **Talent schools** (4 weeks of lectures for advanced PhD students)
- **Research activities** of the local team composed of permanent and temporary staff members



ECT* budget



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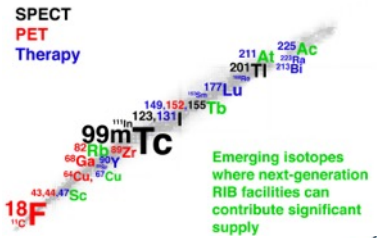
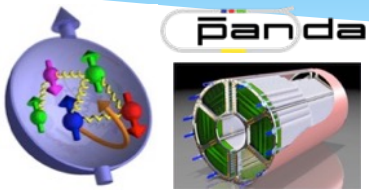
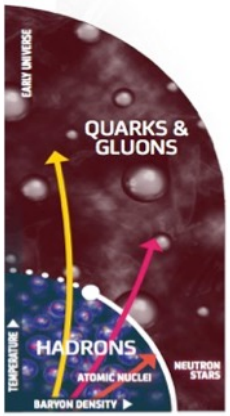
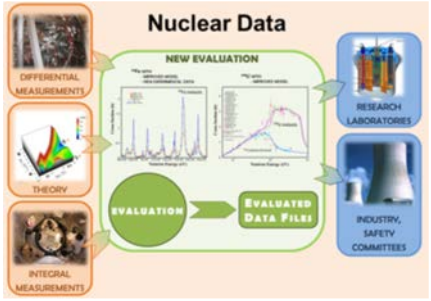
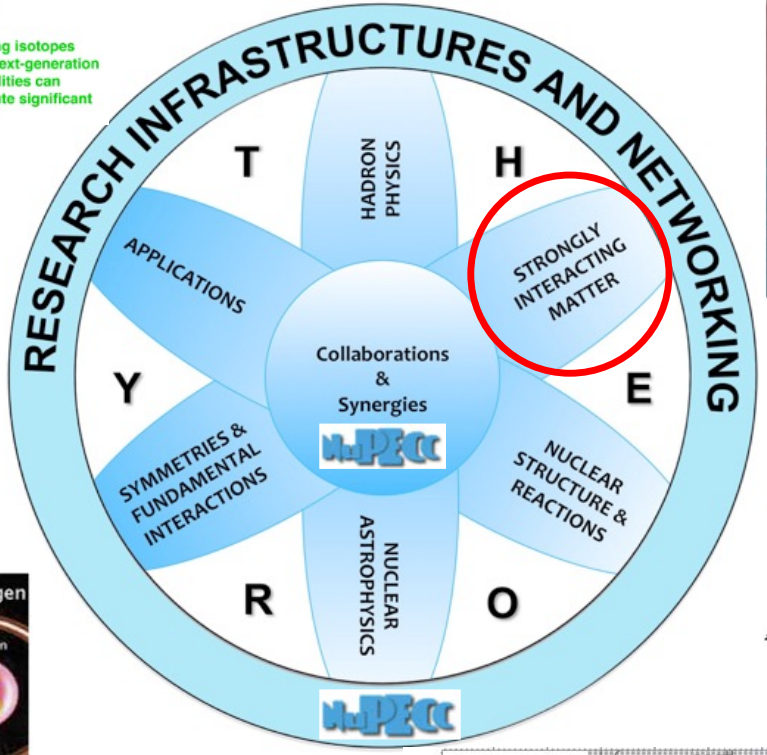
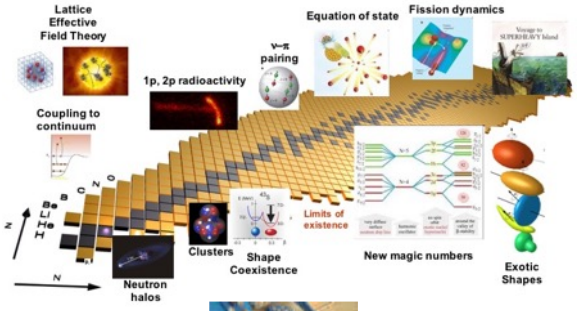


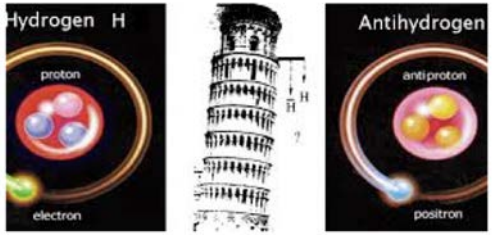


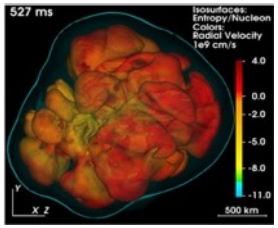


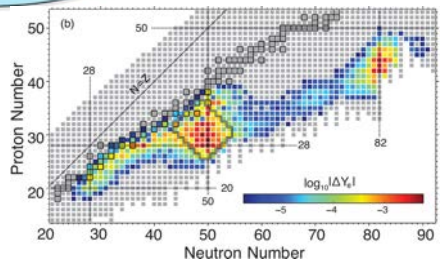


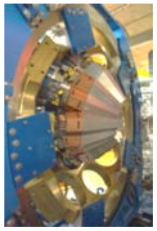






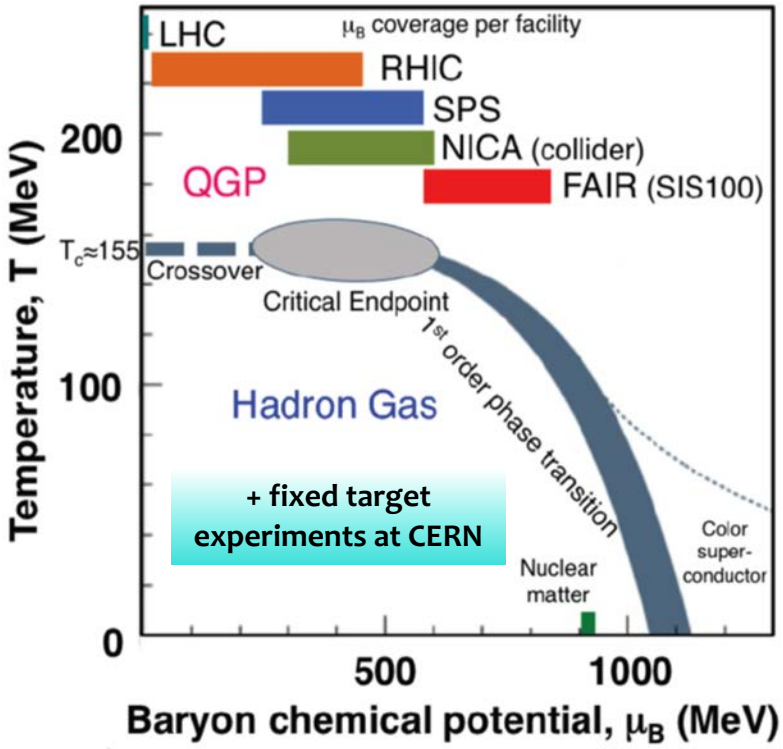


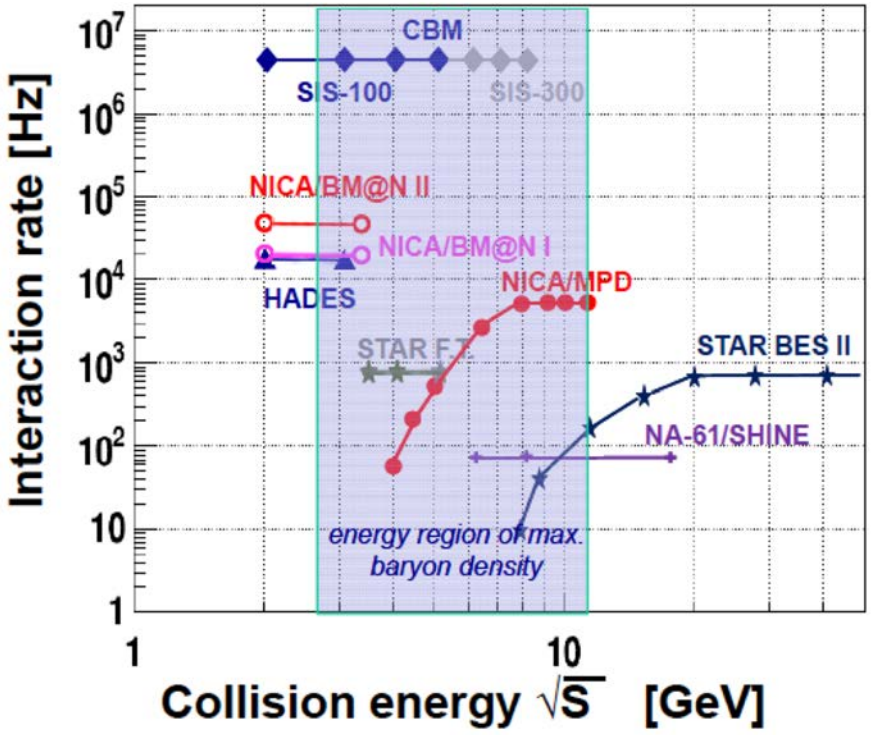




Talks of Gerda Neyens & Jorgen d'Hondt

Hadronic Matter at the very extremes





NuPECC LRP recommendation:
Fully develop synergies between ALICE, NICA, FAIR and fixed target experiments at CERN

NuPECC has expressed its support for the hh and heavy-ion programs at FCC

ALICE ⇨ ALICE3

Fundamental questions will remain open after LHC Run 3 & 4
→ **next-generation heavy-ion programme for LHC Run 5 & 6**

- What is the nature of interactions between highly energetic quarks and gluons and the quark-gluon plasma?
- To what extent do quarks of different mass reach thermal equilibrium?
- How do quarks and gluons transition to hadrons as the quark-gluon plasma cools down?
- What are the mechanisms for the restoration of chiral symmetry in the quark-gluon plasma?

Curtesy of B. Erazmus

Letter of Intent for ALICE 3 endorsed by LHCC

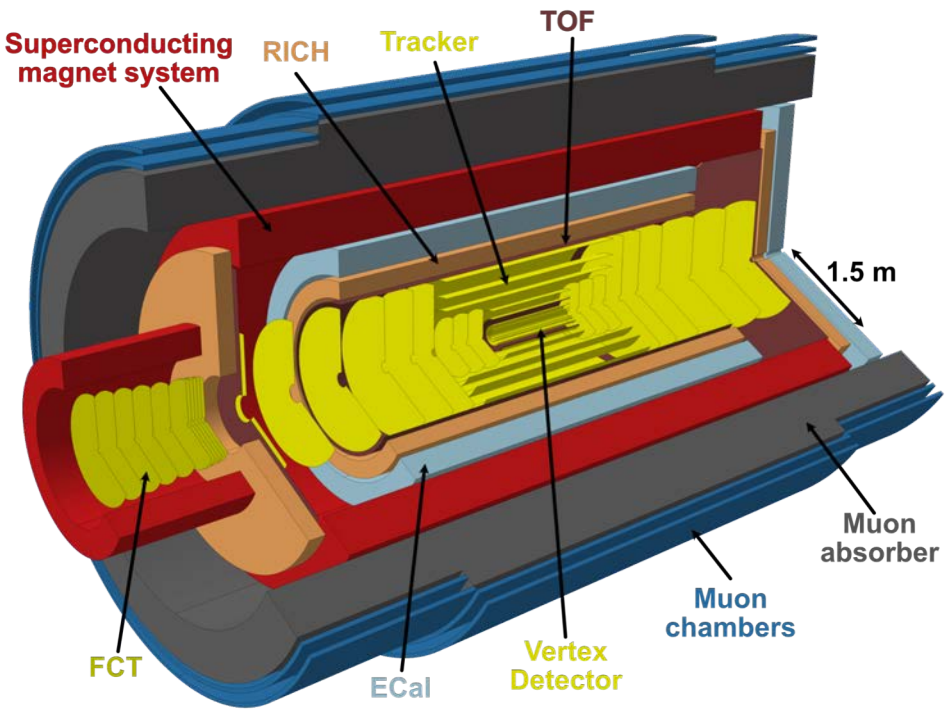
provides "a road map for exciting heavy-ion physics starting in 2035"

"ALICE 3 detector concept […] is well matched to the proposed, ambitious physics program"

Letter of Intent: CERN-LHCC-2022-009
LHCC minutes: LHCC-149

ALICE ⇨ ALICE3

- Compact all-silicon tracker
  → clean separation of signal and background
- Vertex detector with excellent pointing resolution
  → clean reconstruction of decay chains
- Particle identification
  → background suppression
- Large acceptance
  → statistics and correlations
- Superconducting magnet system
  → effective provision of required magnetic field
- Continuous read-out and online processing
  → large data sample to access rare signals



Novel detector concept based on innovative technologies relevant for all future HEP experiments

Curtesy of B. Erazmus

The Physics of Hadrons

- How is mass generated in QCD and what are the static and dynamical properties of hadrons?
- How does the strong force emerge from the underlying quark-gluon structure of nucleons?

European contribution to the EIC project in US

NuPECC EIC Task Force

High resolution experiments with antiprotons (PANDA) at FAIR to test QCD in detail

EoI 6 - Synergies between EIC and LHC experiments

Main NuPECC LRP 2017 priority for this topic:

The antiproton programme at the FAIR/PANDA facility combined with programmes with polarised protons in Dubna (NICA) and those with lepton and hadron beams at existing facilities (MAMI, Bonn, INFN-Frascati).

Nuclear Physics in Europe

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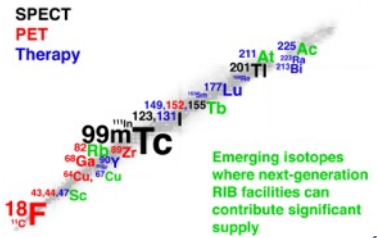
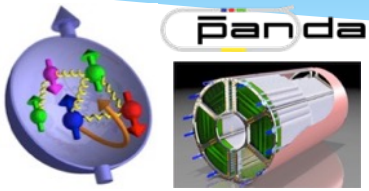
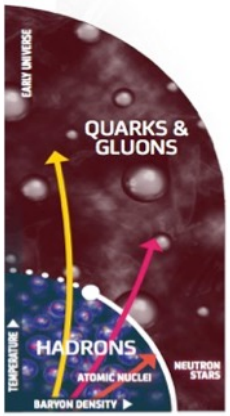
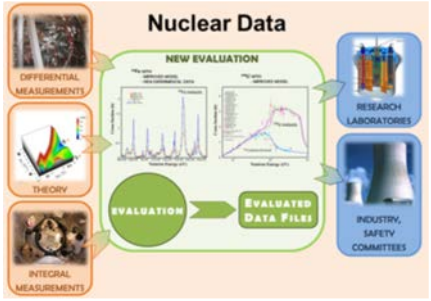
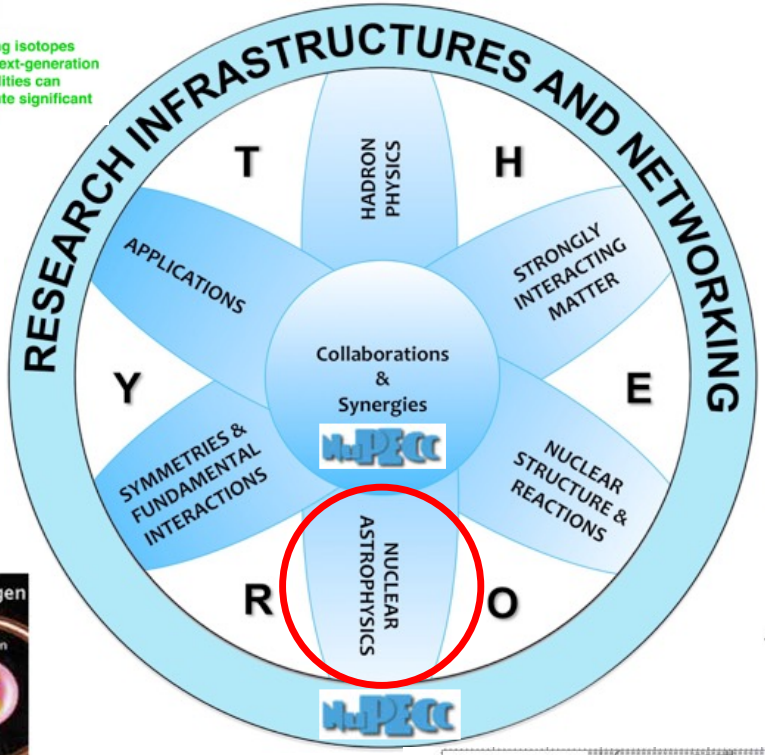
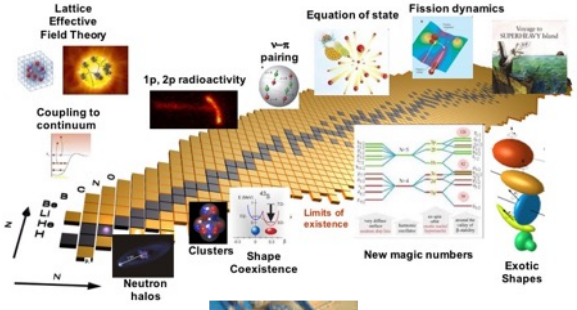


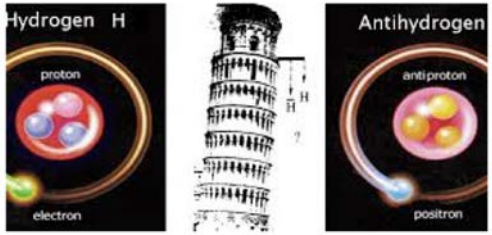


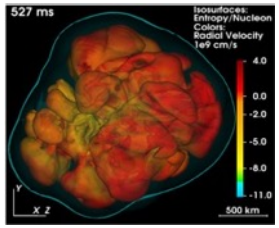


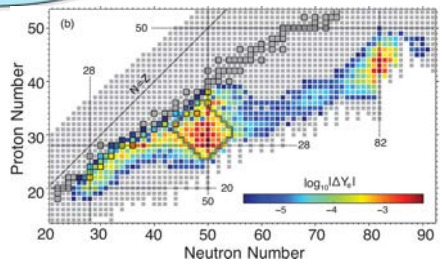


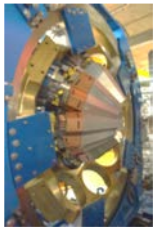












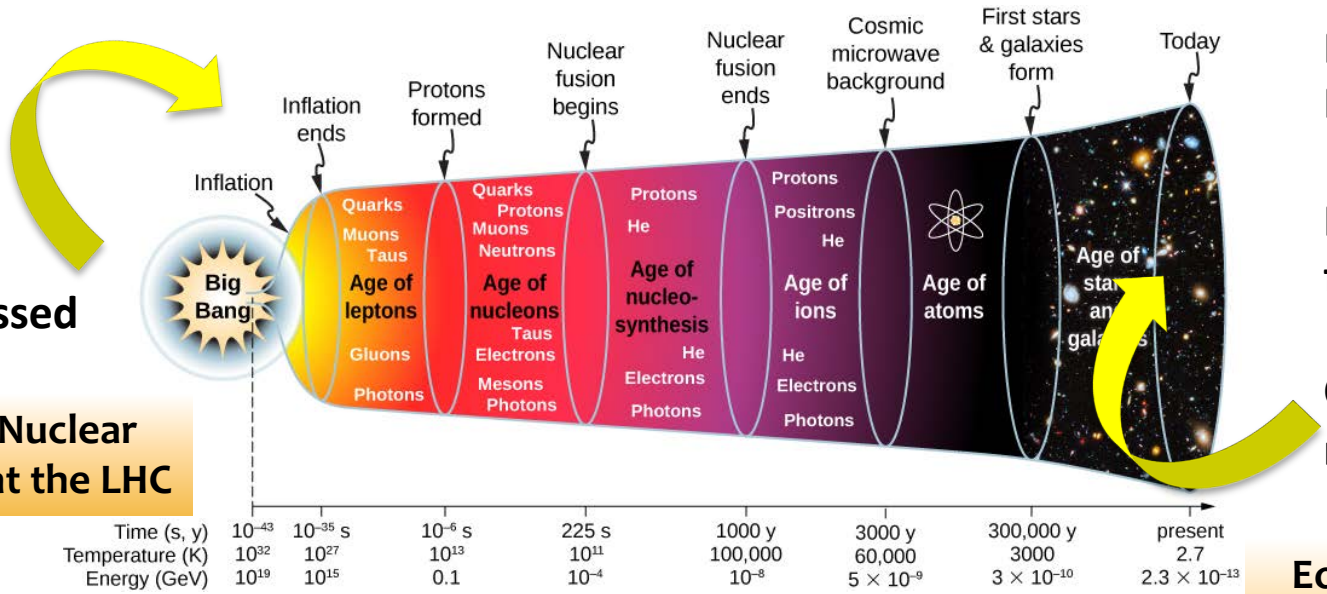
Talks of Gerda Neyens & Jorgen d'Hondt

Nuclear physics and the evolution of the Universe

- What are the properties of nuclei and strong-interaction matter as encountered shortly after the Big Bang, in catastrophic cosmic events, and in compact stellar objects?
- How and where in the universe are the chemical elements produced?

QCD

QCD in hot compressed matter



Nuclear structure
Nucleosynthesis

Reactions for astrophysics

Compressed nuclear matter

EoI 4 - Nuclear Physics at the LHC

EoI 2 - Gravitational Waves for fundamental physics

GW- Interdisciplinary and multi-messenger science

To tackle the different related problems one needs a distributed approach and efforts : different accelerator types and energies

Nucleosynthesis (nuclear structure and reactions information)

Strong support for a large effort

involving small scale accelerators …… & large infrastructures

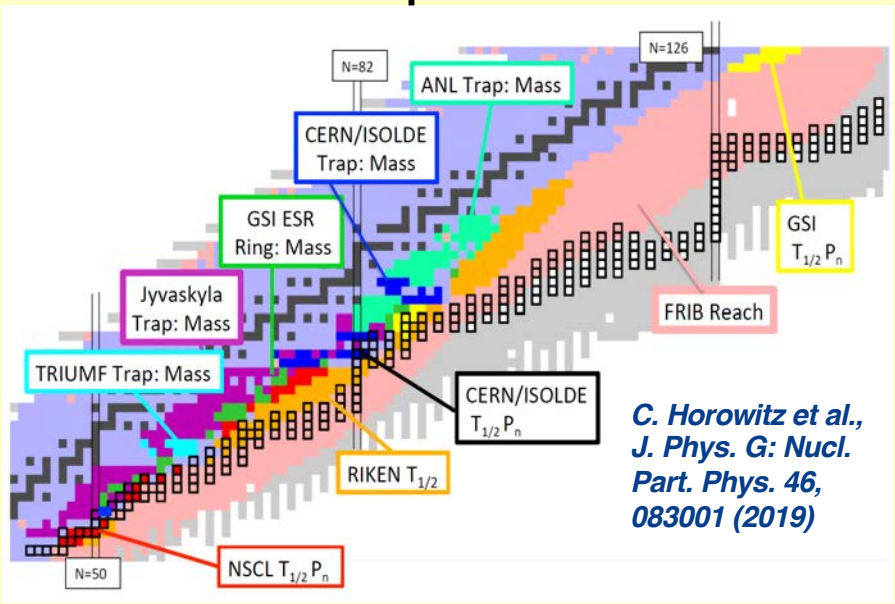
In particular at smaller scale accelerators :

- **BBN and fusion reaction in stars for light nuclei nucleosynthesis**
- **reactions for energy generation**

LUNA, LNS, ALTO,…

Nucleosynthesis of medium to heavy nuclei

Example: Mass measurements & r-process



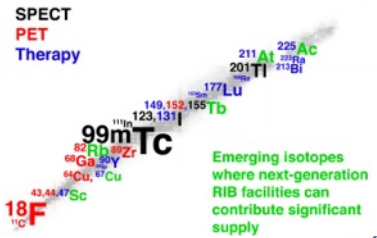
C. Horowitz et al., J. Phys. G: Nucl. Part. Phys. 46, 083001 (2019)

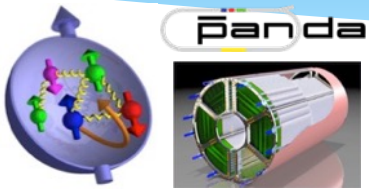
Scientific programs at :

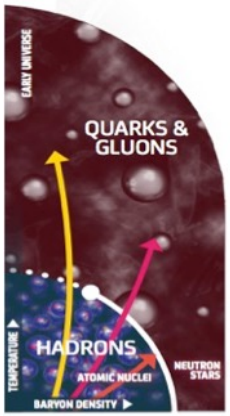
- **FAIR**
- **ISOLDE-SPES-JYFL**
- **GANIL**

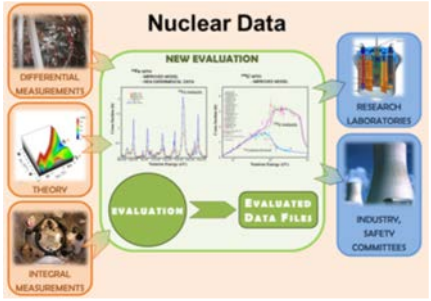
Nuclear Physics in Europe

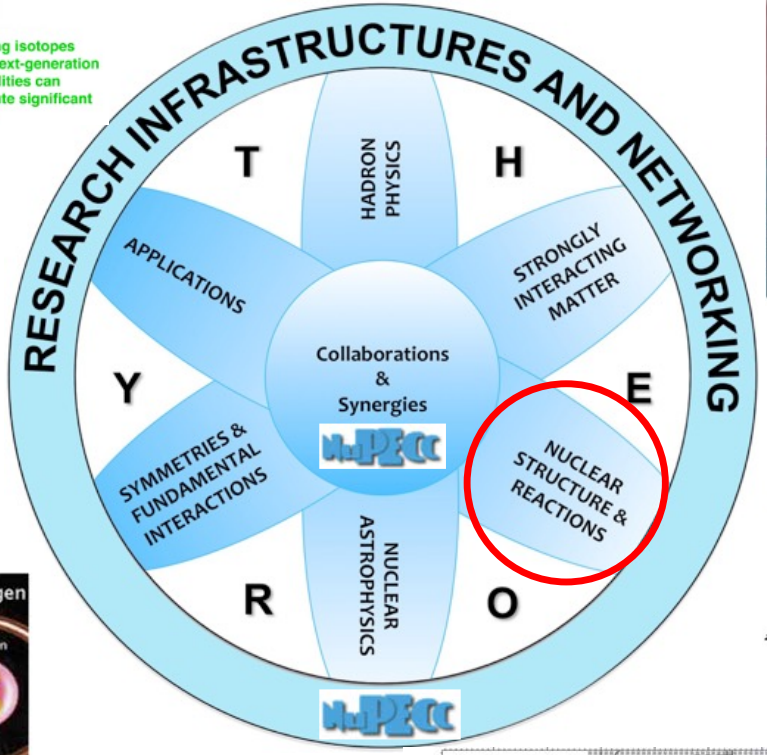
http://www.nupecc.org

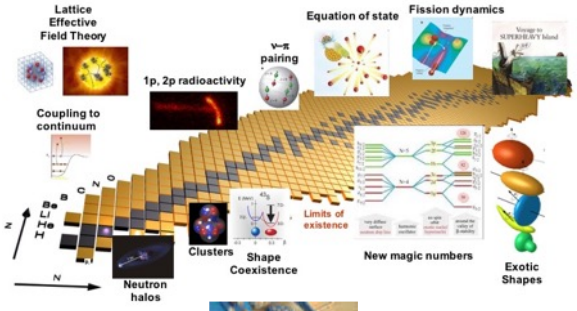


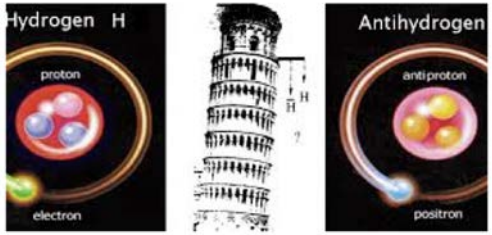


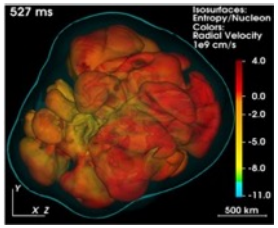


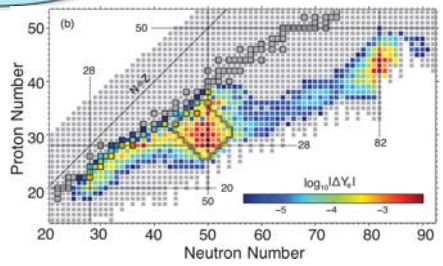


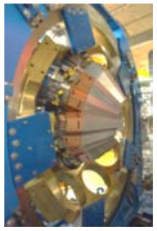






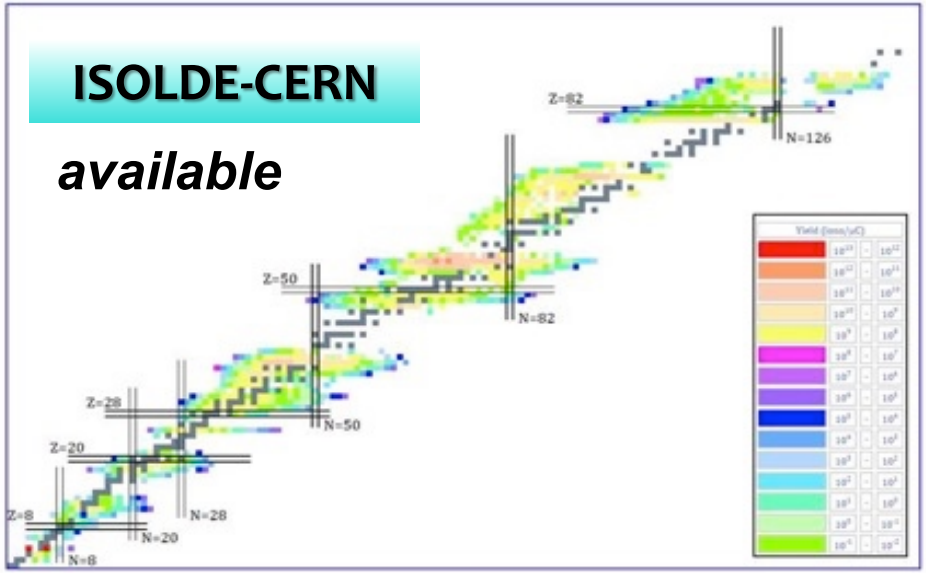


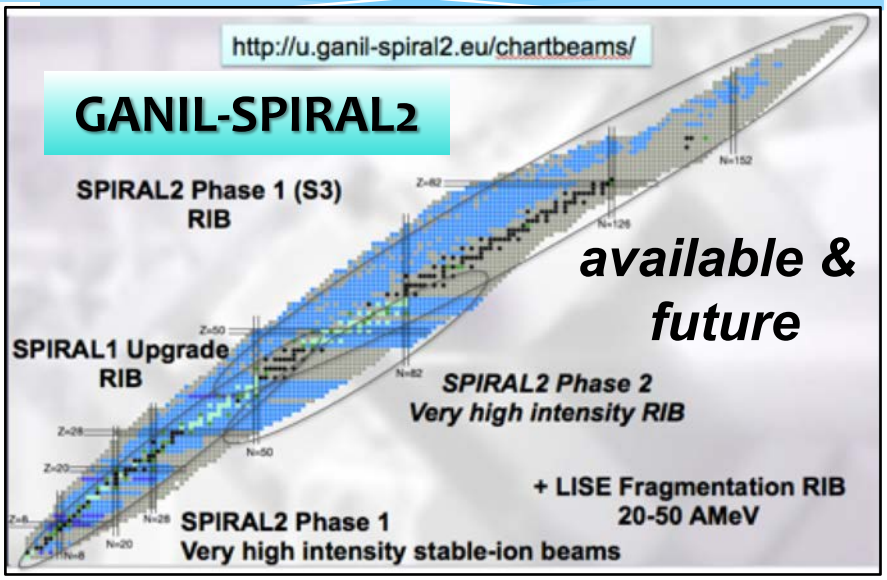


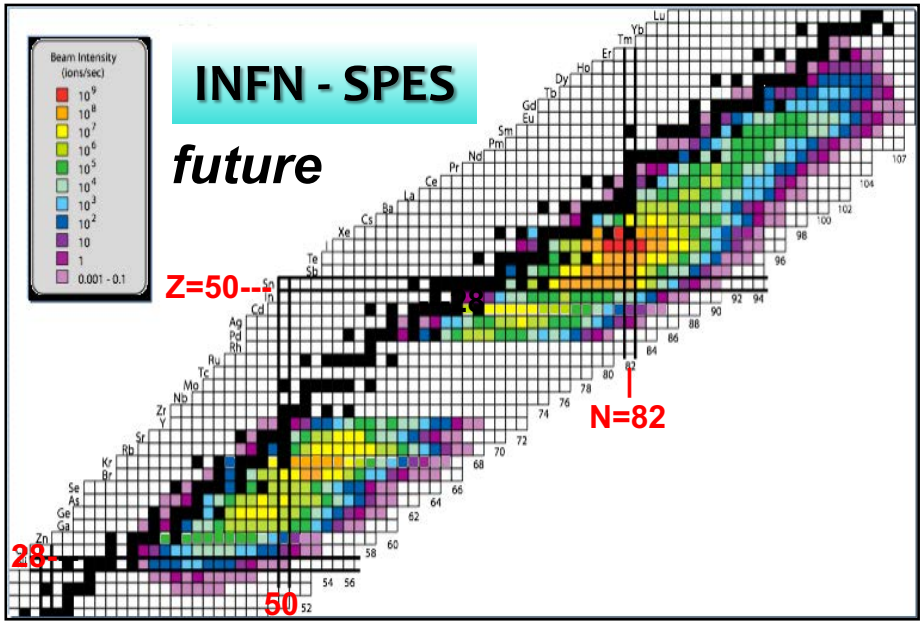


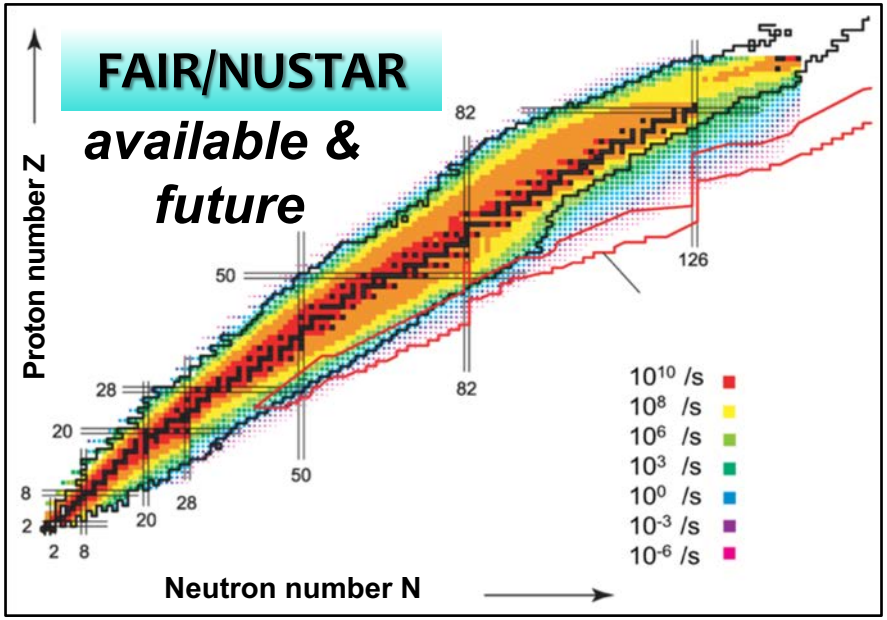
Talks of Gerda Neyens & Jorgen d'Hondt

RIBs at Major EU Facilities



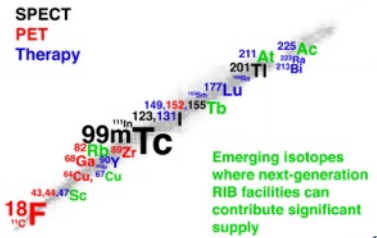


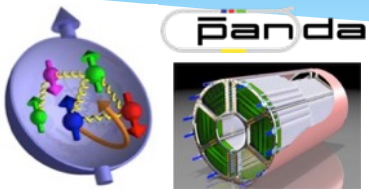


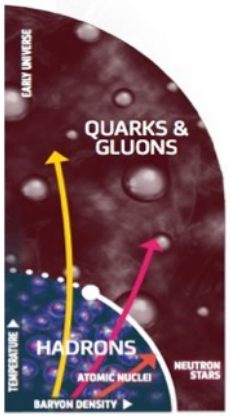


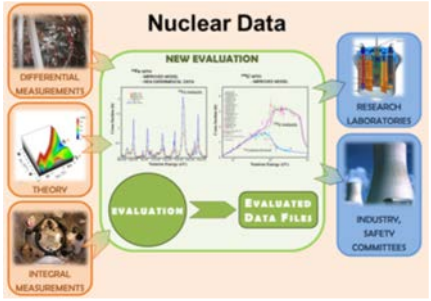
Nuclear Physics in Europe

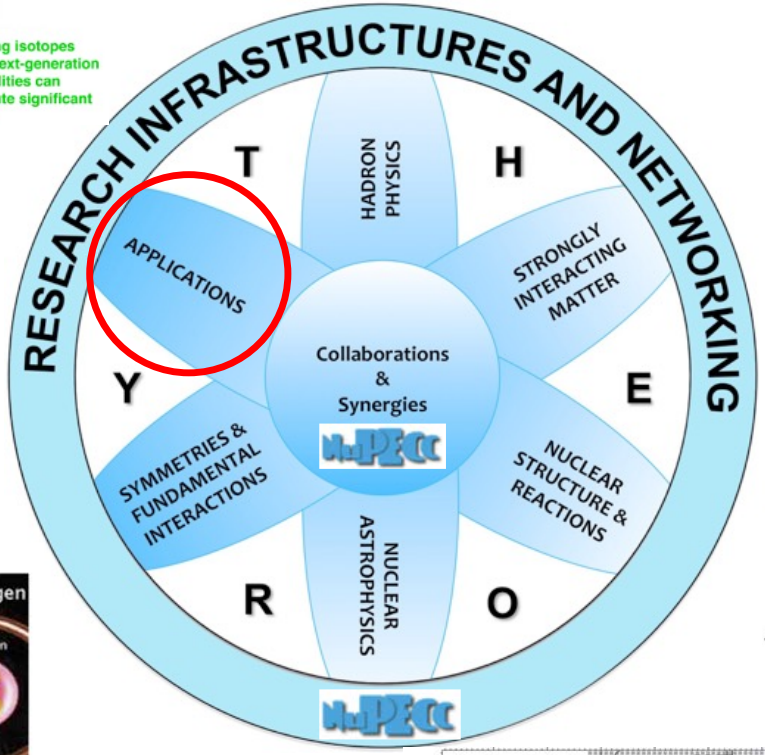
http://www.nupecc.org

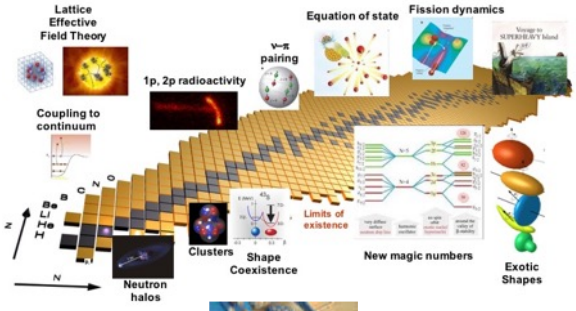


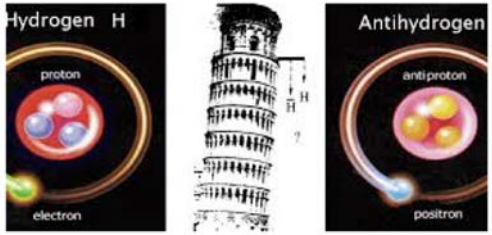


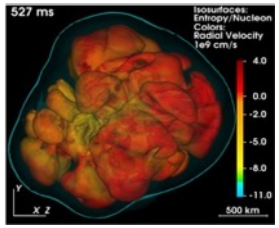


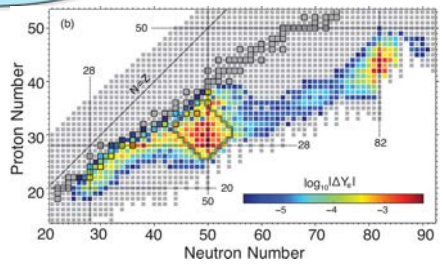


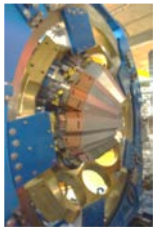






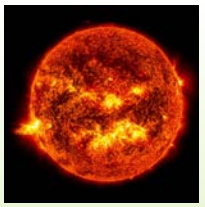






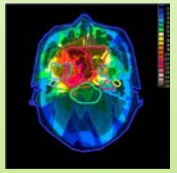
Applications of nuclear science

- Climate & Environment (Sun activity, heat in the Earth interior, ocean monitoring, wastewater treatment, mapping of groundwater resources, ...)

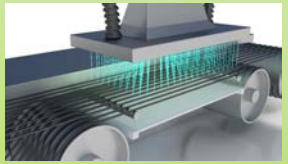


- Energy (electric power generation, waste management, nuclear data)

- Health (radioisotopes for therapy and diagnosis, hadrontherapy)



- Everyday life products (sterilization, radiation processing, cross-linked coatings, material modification, food and agriculture)



- Cultural heritage and Forensics

- Space technology & exploration

Important role of large and smaller scale facilities

NuPECC report on Nuclear Physics in Everyday Life (soon)

Nuclear Energy in Europe

In 2019, nuclear plants generated 25 % of the electricity produced in the European Union, with nuclear reactors operating in 13 Member States

128 nuclear power reactors (119 GWe)
Under construction:
3 reactors in EU & 2 in UK

New reactors will be constructed in Bulgaria, France (14), Poland and UK

A Complementary Climate Delegated Act including, under strict conditions, specific nuclear and gas energy activities in the list of economic activities covered by the EU taxonomy was formally adopted in all EU official languages on 9 March 2022. The criteria for the specific gas and nuclear activities are **in line with EU climate and environmental objectives** and will help accelerating the shift from solid or liquid fossil fuels, including coal, towards a climate-neutral future.

ESFRI

First phase of MYRRHA ADS facility under construction in Belgium

IFMIF-DONES - test facility for fusion materials under design

MYRRHA Accelerator Driven System
SCK-CEN Belgium

- **Phase 1 (funded) : R&D and licensing-related activities for the MYRRHA reactor, together with the construction of MINERVA, comprising the first section of the accelerator (100-MeV protons) coupled to a Full Power Facility (FPF) and a Proton Target Facility (PTF)**

Objective MINERVA

- 100 MeV SC-proton accelerator
  - Accelerator reliability
- Proton Target Facility – ISOL@MYRRHA
  - Fundamental Physics research
  - Production of isotopes for medical applications
- Fusion Target Station implemented within the Full Power Facility
  - Materials R&D

- **Phase 2: extension of the accelerator to 600 MeV**
- **Phase 3: construction and coupling of the sub-critical reactor**

Curtesy of L. Popescu

Licensing application (mid 2021) → Ground breaking (mid 2022) → Buildings ready (end 2024) → Accelerator commissioning (2026) → PTF commissioning (2027)

Recommendations for European Nuclear Physics facilities

Complete urgently the construction of the ESFRI flagship **FAIR** and develop and bring into operation the experimental programme of its four scientific pillars APPA, CBM, NUSTAR and PANDA.

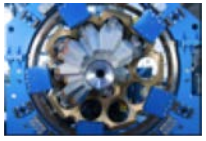
Support for construction, augmentation and exploitation of world leading ISOL facilities in Europe towards EURISOL.

GANIL/SPIRAL2
ISOLDE, SPES,
JYFL

Support for the full exploitation of existing and emerging facilities

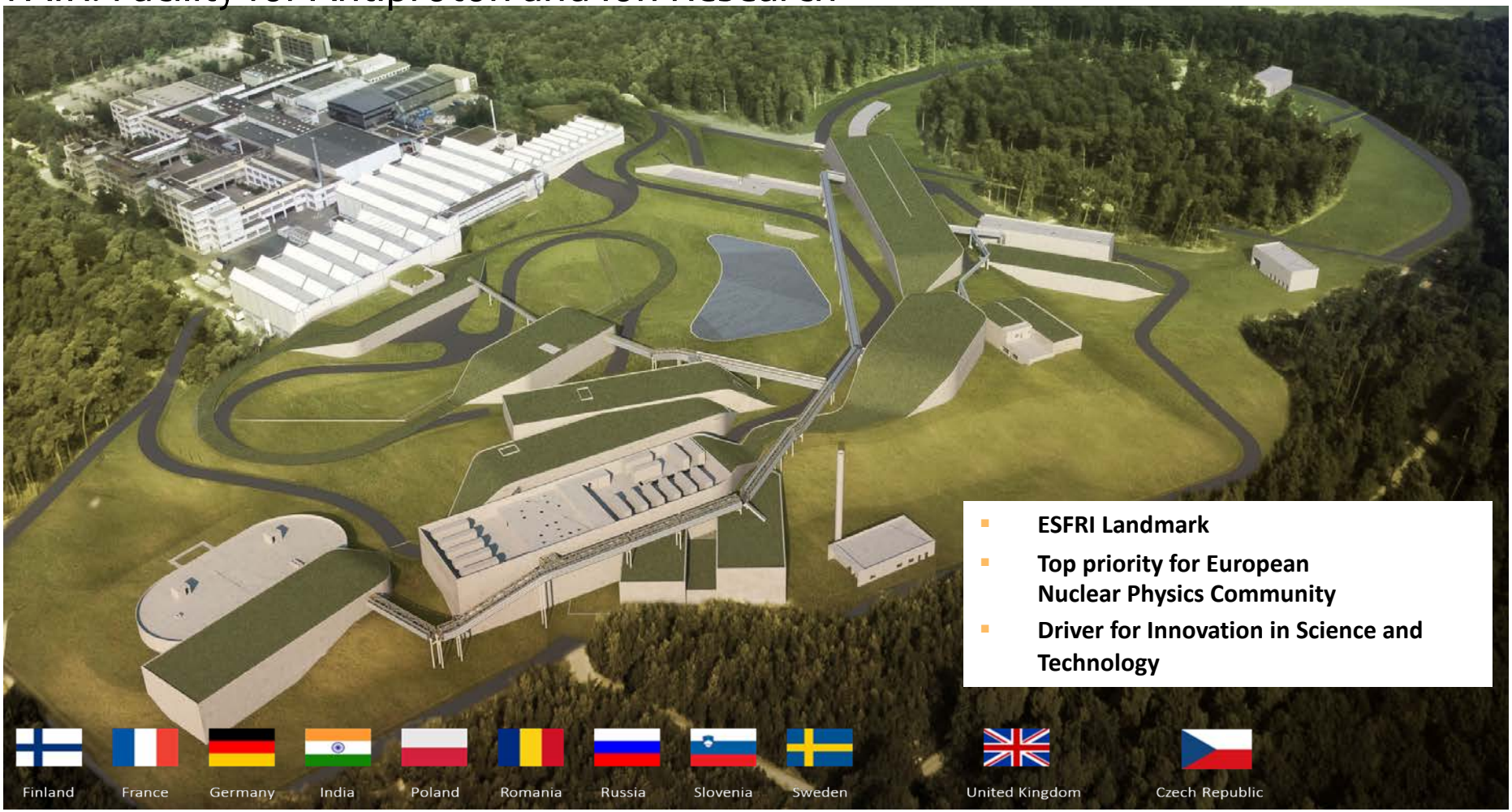
ELI-NP
NICA, SHEF
MYRRHA
IFMIF-DONES

Support for ALICE and the heavy-ion programme at the LHC with the planned experimental upgrades.



Support to the completion of AGATA in full geometry.

FAIR: Facility for Antiproton and Ion Research



- **ESFRI Landmark**
- **Top priority for European Nuclear Physics Community**
- **Driver for Innovation in Science and Technology**

Courtesy of P. Giubellino and Y. Leifels

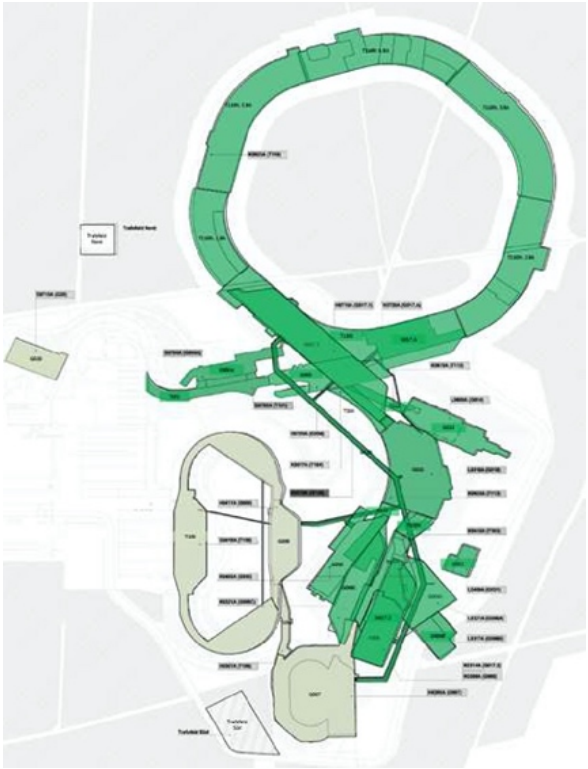
Full facility MSV and Intermediate Objective

- **All FAIR shareholders remain committed to the realization of the full facility („Modularized Start Version“ – MSV) enabling the comprehensive scientific research program**
- **FAIR Council defined in 2019 the Intermediate Objective (IO) as an interim step towards full MSV. The IO comprises**
  - **full scope of accelerator and experiments for the MSV**
  - **realization of the buildings for MSV except the buildings for CR, HESR and p-Linac.**
- **The international shareholders are at various stages of their national approval processes to obtain the financial resources of the three buildings of CR, HESR, and p-Linac (highlighted in light green).**

Courtesy of P. Giubellino and Y. Leifels

Status of realization (April 2022)

- 60 % of the concrete works for the Intermediate Objective are completed
- all orders for the technical building equipment for the IO have been placed
- 40 % of accelerator components for the the full facility (MSV) have been produced and tested
- 46 % of the experiments for MSV are finalized



Courtesy of P. Giubellino and Y. Leifels

Roadmap NP facilities

FAIR- Construction Site
(October 2021)

FAIR - Construction Site South
(April 2022)

Courtesy of P. Giubellino and Y. Leifels

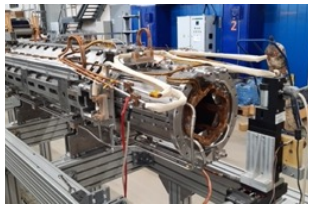
Roadmap NP facilities

FAIR full facility – Worldwide production and delivery of accelerator and experiment components


p-Linac: RFQ-Entwicklung

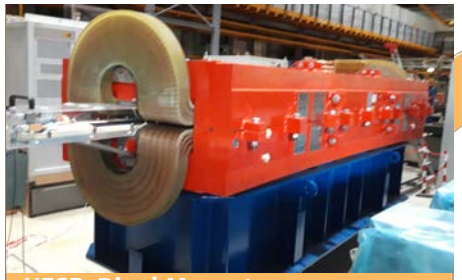

HEBT: Dipol-Magnet


Netzgeräte Gesamtanlage


SIS100: Quadrupol-Magnet


HESR: Quadrupol-Magnet


SIS100: Vakuumkammern


HESR: Dipol-Magnet


CR: Dipol-Magnet im Bau


Teststand


SIS100: Dipolmagnete

Roadmap NP facilities

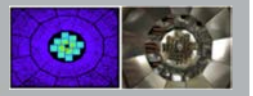
NFS

S3

DESIR

AGATA
VAMOS

FAZIA
INDRA



HI SC LINAC

SPIRAL2 Phase 1

SPIRAL2 Phase 2
under discussion

SPIRAL1

0 10 20 30 40 50 m

5mA 14-20 MeV/n light and 1mA heavy ions

New High-intensity heavy-ion injector under development

LINAC nominal light-beam intensity capabilities demonstrated in 2021
First SPIRAL2 experiments at Neutron For Science facility performed successfully in 2021

Roadmap NP facilities

Commissioning of experimental setups

- with expert users – involved in defining the TDRs
- experiments approved by ELI-NP ISAB
- demonstrate the performance of the systems but also perform relevant physics experiments

Gradual transition from implementation to operation

Beam time delivered
June – December 2021:
100 TW – 16 weeks
1 PW – 20 week
2022: started in March
100 TW & 1 PW

Open access based on scientific merit/evaluation

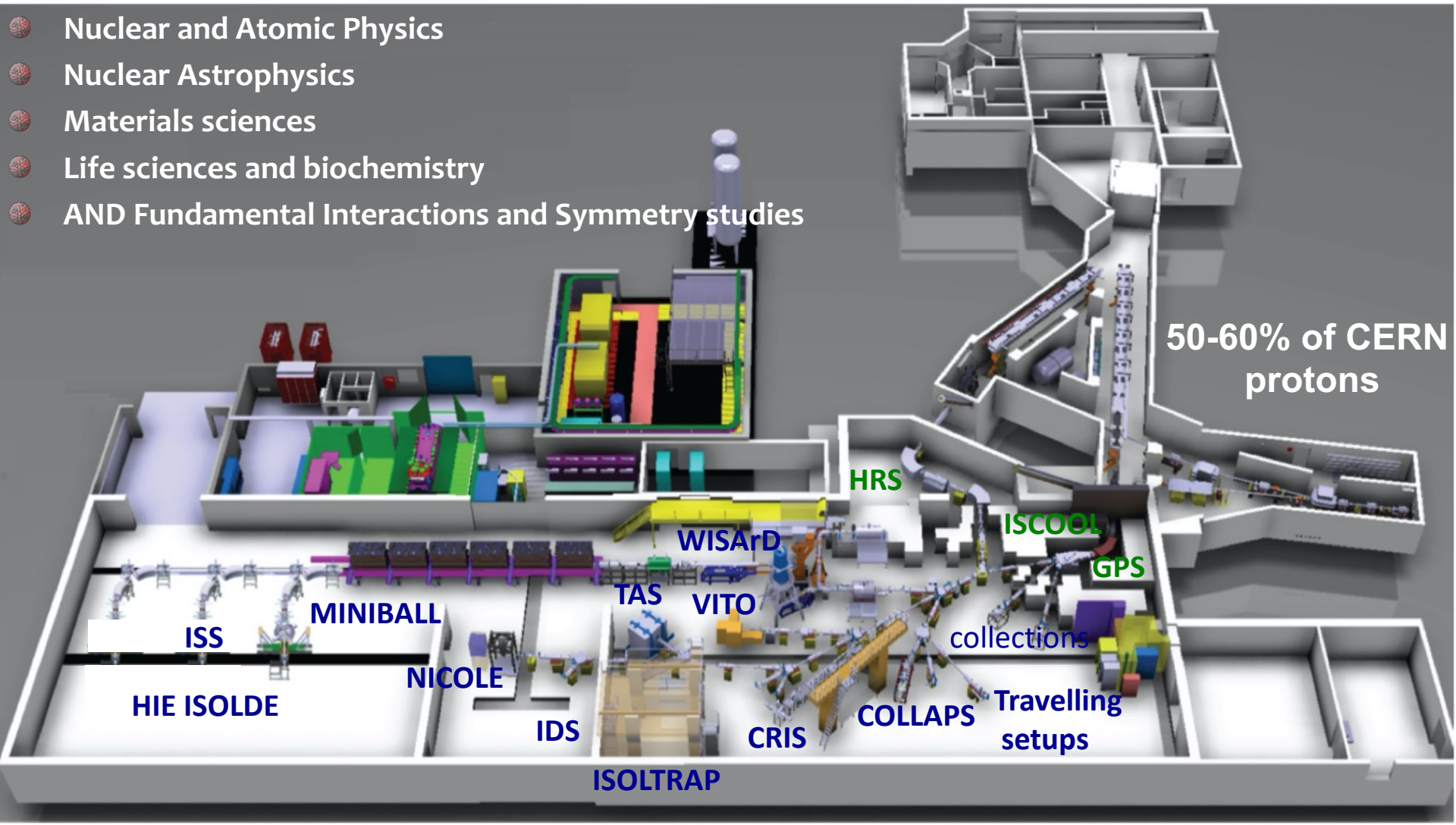
- evaluation by international PAC
- first call for proposals organized together with ELI ERIC for the period October 2022 – March 2023 (100 TW, 1 PW)

- 100 TW : *ongoing*
  Four-wave mixing in vacuum, in search of dark matter candidates
  X ray production through betatron emission
- 1 PW : *ongoing*
  Benchmark TNSA proton acceleration
  Benchmark LWFA electron acceleration
- 10 PW solid target : *start in 2022*
  Demonstrate extreme focal intensity through laser-γ conversion ("γ-flash")
  Demonstrate over 200 MeV proton acceleration
  Dense heavy ion beams for nuclear physics
- 10 PW gas target : *start in 2023*
  10 PW laser wakefield acceleration of multi-GeV electron beams

Courtesy of N. Marginean and C. Ur

CERN / ISOLDE
World-leading ISOL facility

- Nuclear and Atomic Physics
- Nuclear Astrophysics
- Materials sciences
- Life sciences and biochemistry
- AND Fundamental Interactions and Symmetry studies



Courtesy of G. Neyens and S. Freeman

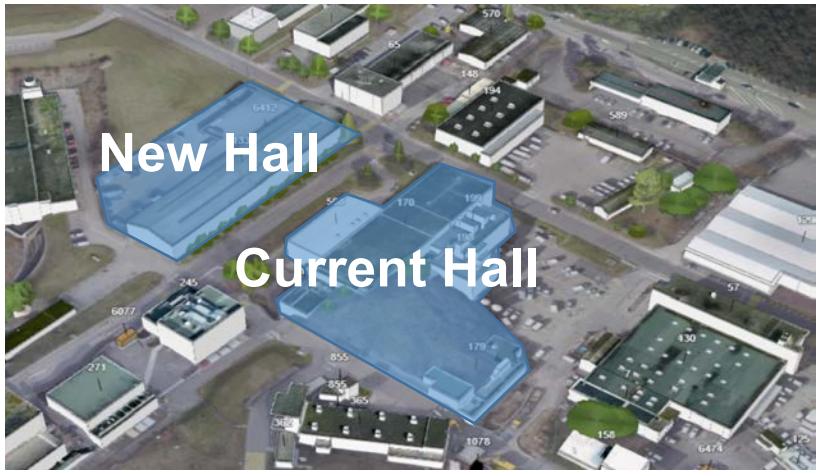
CERN / ISOLDE
World-leading ISOL facility

Mid-term goals (up to and including LS3 2026-28)

- New lab for nano-material based targets
- Parallel RIB operation
- Upgrades to receive higher energy protons at higher intensity
- Upgrade of transfer line from Booster to ISOLDE to deliver 2-GeV
- …

Long-term goals (> LS3): EPIC

- A new ISOLDE building + target stations.
- Dedicated space and facilities for new (and existing) low-energy experiments.
- Improved beam purity (mass resolution) and quality (time structure).
- Parallel operation with existing (HIE-ISOLDE) facility.
- Improvements to post-accelerators
- Extra space for new re-accelerated RIB experiments, including a compact storage ring.

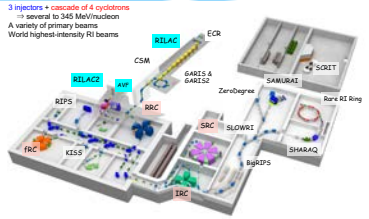


Collaboration working on science case before considering funding strategies.

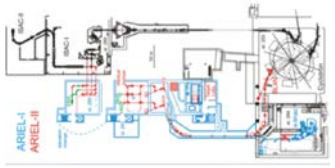
Courtesy of S. Freeman

European involvement in the overseas Nucl. Phys. facilities

RIBF RIKEN, Japan (operational) – strong involvement including advanced detectors

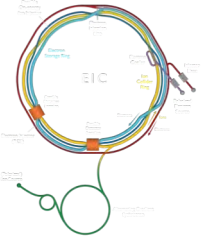


TRIUMF, Vancouver, Canada (operational & construction of ARIEL) - involvement in experiments & instrumentation

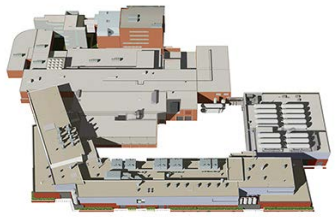


iThemba Labs, South Africa (operational & construction of SAIF) – involvement in experiments

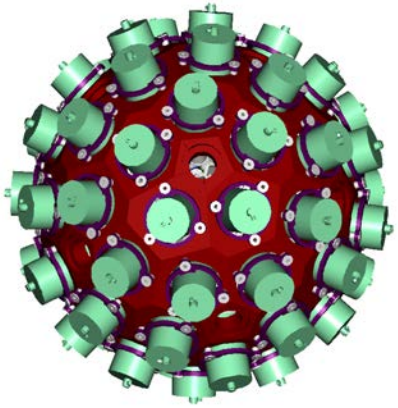
EIC, Brookhaven, New York, US (construction) – strong interest of the European community



FRIB, East Lansing, Mi, US (beginning of operation, ribbon cutting ceremony 02/05/20022) – involvement of European groups

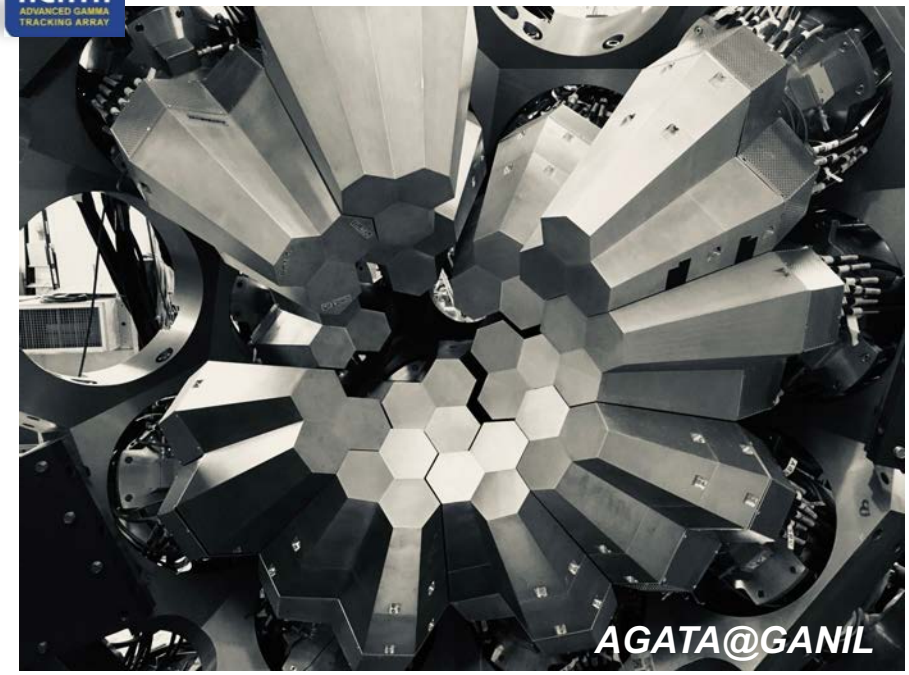


AGATA: THE ultimate γ-ray spectrometer



- 180 (60 triple-clusters) 36-fold segmented crystals
- Amount of germanium: 362 kg
- Solid angle coverage: 82 %
- Singles rate >50 kHz
- Efficiency: 43% (M_γ=1) , 28% (M_γ=30)
- Peak/Total: 58% (M_γ=1), 49% (M_γ=30)
- Angular Resolution: ~1°

NuPECC LRP 2017 priority

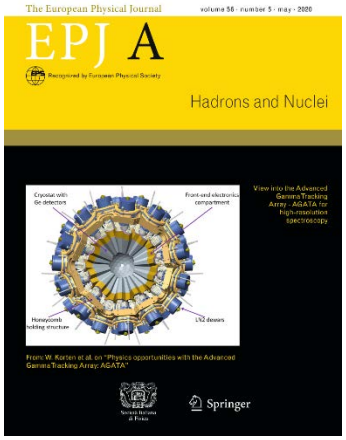


AGATA White Book : W. Korten et al, Eur. Phys. J. A (2020) 56:137

The project timeline is to complete the array by 2030

Combination of:

- ❑ segmented detector
- ❑ pulse-shape analysis
- ❑ tracking the γ rays
- ❑ digital electronics



Courtesy of E. Clement

AGATA: THE ultimate γ-ray spectrometer

AGATA is operated under a Memorandum of Understanding

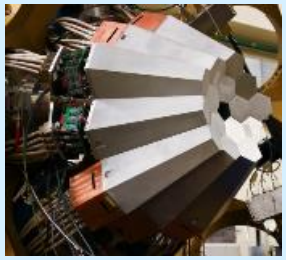
All partners have signed on the 25th of March 2022

New AGATA Spokesperson, chair of the steering :
A. Bracco (INFN-Milano) since 31st of March

Core investment ~22 M€

MoU Phase 1 + Addendum → **MoU Phase 2**

2010-2012
Legnaro, Italy
Intense stable beams
15 detectors



AGATA Demonstrator + PRISMA at LNL

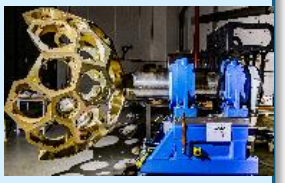
2012-2014
GSI, Germany
Fast fragmentation beams
25 detectors

AGATA at GSI

2014- 2021
GANIL, France
ISOL and stable beams
approaching 1π (45)

AGATA at GANIL

2021--
LNL, Italy
Stable beams
SPES radioactive beams



AGATA at LNL 2.0

>2026
FAIR, Germany
ISOLDE, CERN
GANIL, France
RIB at low and high energies

Courtesy of E. Clement

Integrating community with EU projects

Support for users and facilities

New! Joint PP – NP EU project EURO-LABS

Contract 2022-2026 (14,5M€)

Coord. Navin Alahari
GANIL, France
Coordinating institution INFN, Italy
39 Research Infrastructures

- CERN
- GANIL (France)
- LNL-LNS (Italy)
- JYFL (Finland)
- IJCLab (CNRS, France)
- FAIR/GSI (Germany)
- NLC (HIL/IFJ PAN, Poland)
- IFIN-HH(Romania)
- ECT* (Italy)
- …

Hadron physics STRONG-2020

Contract 2019 -2023 (10M€)

Coord. Barbara Erazmus IN2P3, France
Coordinating Inst. IN2P3/CNRS, France

- CERN
  LHC & fixed target exp.
- GSI/FAIR (Germany)
- LNF, Frascati (Italy)
- MAMI, Mainz (Germany)
- ECT*, Trento (Italy)
- ELSA, Bonn (Germany)
- COSY, Jülich (Germany)

EU H2020 Ongoing Projects

PRISMAP - *PRoduction of hIgh purity iSotopes by Mass separation for medical APplication*

23 partners, 13 countries, 5M€

Coord. Thierry Stora – CERN, Coordinating Inst. CERN

ChETEC-INFRA - Chemical Elements as Tracers of the Evolution of the Cosmos – Infrastructures for Nuclear Astrophysics

32 partners, 17 countries, 5M€

Coord. Daniel Bemmerer - HZDR, Coordinating Inst. HZ Dresden-Rossendorf, Germany

RADNEXT - RADiation facility Network for the EXploration of effects for indusTry and research

30 partners, 12 countries, 5M€

Coord. Rubén García Alía – CERN, Coordinating Inst. CERN

NuPECC Strategy for Nuclear Physics

Strategy Pillars

- **Science: Interplay between Theory & Experiment**
- **Applications - huge societal impact**
- **Facilities – in Europe (FAIR, SPIRAL2, ELI-NP, ISOLDE, SPES) and at other continents (RIBF, TRIUMF, iThemba, EIC, FRIB)**
- **Detectors - ex. ALICE3 and AGATA**
- **Data and Open Science – ex. ESCAPE**
- **Synergies with neighbouring fields - DM, GW, neutrinos, EDMs, detectors,…**

Strategy Development

- The 2017 NuPECC Long Range Plan defined an ambitious strategy for European Nuclear Physics
- NuPECC efforts to transform the LR Plan into reality -> Task Force meetings in European countries
- **Next NuPECC LRP 2024 begins now**
- Development of a global international approach to nuclear science in collaboration with CERN, IUPAP, NPD/EPS, ECFA, APPEC, NSAC (US), ANPhA (Asia), ALAFNA (S. America), CINP (Canada)

Warm thanks to all colleagues for their contribution

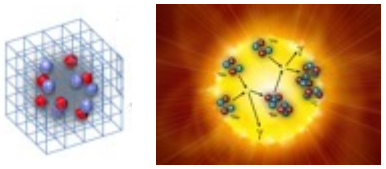
Warm thanks to Andreas and Karl for close and fruitful collaboration

Thank you for your attention

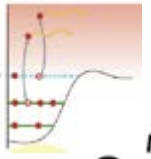
Structure of complex nuclei

- How does the complexity of nuclear structure arise from the interaction between nucleons?
- What are the limits of nuclear stability?

Lattice Effective Field Theory



Coupling to continuum

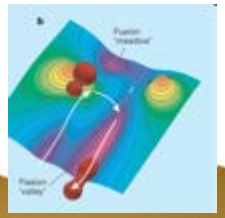


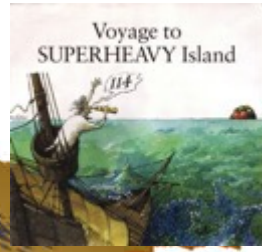
1p, 2p radioactivity

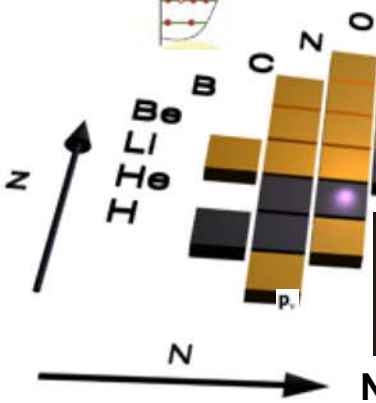
ν–π pairing

Equation of state

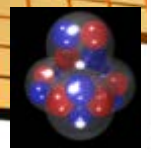
Fission dynamics



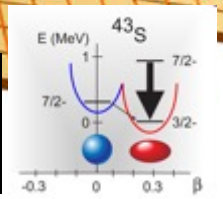




Neutron halos

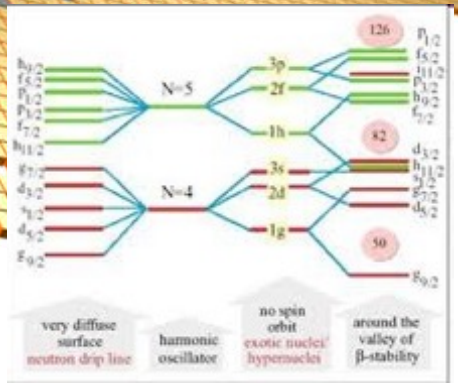


Clusters

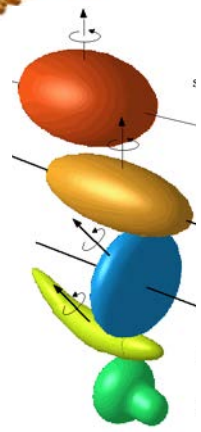


Shape Coexistence

Limits of existence



New magic numbers



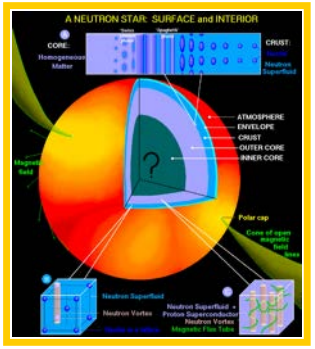
Exotic Shapes

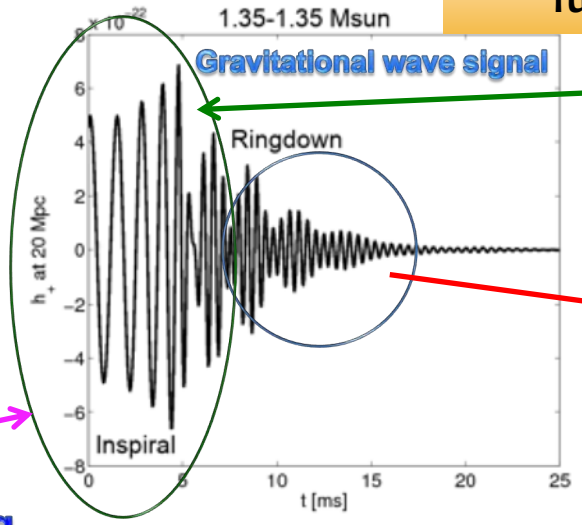
Talk of Gerda Neyens

Main NuPECC LRP recommendation:
Construction of FAIR/NUSTAR, ISOL Facilities, ELI-NP and full AGATA array

Neutron star mergers: GW and production of heavy elements

EoI 2 Gravitational Waves for fundamental physics





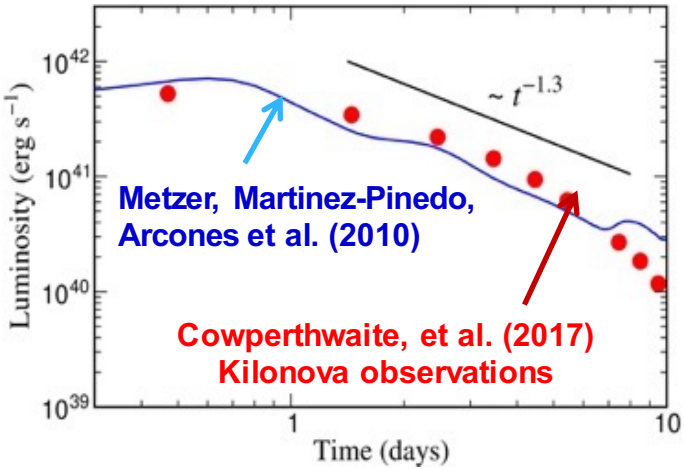
Neutron star mass

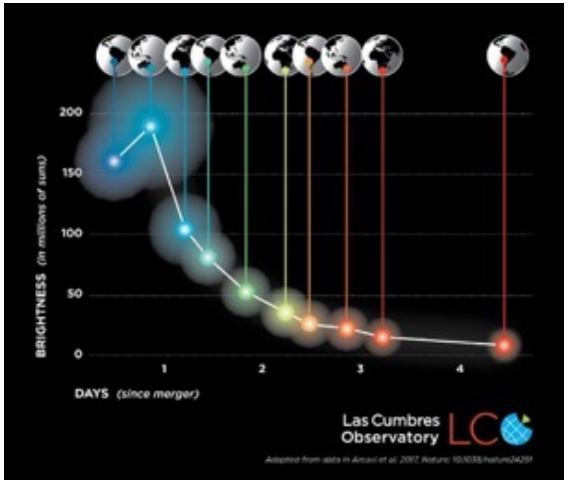
Ringdown depends on the Nuclear Equation of state

The messengers from neutron star mergers :

- **Gravitational waves**
- **Electromagnetic signals characterizing the nuclei in the ejecta**
- **neutrinos**

Gravitational wave emission seen together with electromagnetic signals





Time evolution determined by the radioactive decay of r-process nuclei (science driver of RIB facilities)

Synergies with other fields

Deliberation Document on the 2020 update of the European Strategy for Particle Physics

* 5. Synergies with neighbouring fields

a) A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments and facilities. **Europe has a vibrant nuclear physics programme at CERN**, including the heavy-ion programme, and at other European facilities. In the global context, a new electron-ion collider, **EIC**, is foreseen in the United States to study the partonic structure of the proton and nuclei, in which there is interest among European researchers. **Europe should maintain its capability to perform innovative experiments at the boundary between particle and nuclear physics, and CERN should continue to coordinate with NuPECC on topics of mutual interest.**

The synergies between particle and nuclear physics are driven by the ambition to achieve first-principle understanding of strong dynamics based on QCD. In addition, they share similar experimental tools. The CERN baseline programme includes not only the ISOLDE and n_TOF facilities but also the heavy-ion programme at the SPS and the LHC. Future European facilities such as FAIR, NICA and ESS envisage research programmes that are of interest to particle physics. The nuclear physics roadmap in Europe is coordinated by the Nuclear Physics European Collaboration Committee (NuPECC) and **there are well established communication lines between the nuclear and the particle physics communities. NuPECC has expressed strong support for the extension of the heavy-ion programme into the HL-LHC era and beyond, should a high-energy hadron collider be built at CERN in the future.** Electron-proton colliders, such as LHeC or FCC-ep, with the option of including ion-targets, are also of interest to NuPECC, which is preparing a support statement for the participation of Europe in the Electron-Ion Collider in the United States.

Central questions in Nuclear Physics

- How is mass generated in QCD and what are the static and dynamical properties of hadrons?
- How does the strong force between nucleons emerge from the underlying quark-gluon structure?
- What are the properties of nuclei and strong-interaction matter as encountered shortly after the Big Bang, in catastrophic cosmic events and in compact stellar objects?
- How and where in the universe are the chemical elements produced?
- How does the complexity of nuclear structure arise from the interaction between nucleons?
- What are the limits of nuclear stability?