

Recommendations

We wish to issue the following recommendations of how best to develop the field of Nuclear Physics in Europe in the next decade and beyond.

ESFRI facilities

Complete in a timely fashion the construction of the Nuclear Physics facilities on the ESFRI list of large-scale research infrastructure projects in Europe:

- **FAIR** at the GSI site in Darmstadt, including its four pillars, the PANDA experiment using antiprotons to study the structure and spectroscopy of strongly interacting particles (hadrons), the NuSTAR radioactive beam facility to produce nuclei far from stability and investigate their structure, the CBM experiment to measure the properties of dense baryonic matter, and the atomic, plasma, and applied physics programme APPA.
- **SPIRAL2** at GANIL in Caen, including high intensity stable beams which will allow the study of unstable nuclei at the S3 spectrometer, and ISOL radioactive beams of very neutron rich nuclei achieved via fission and used e.g. with DESIR.

Major Upgrades

Perform major upgrades of the following large-scale Nuclear Physics facilities, which complement each other regarding their physics scope and discovery potential:

- **HIE-ISOLDE** at CERN, including its radioactive beam experiments.
- **SPES** at INFN-LNL in Legnaro, including its radioactive beam experimental set-ups.
- **AGATA**, the γ -ray crystal ball consisting of semiconductor detectors

that will be used at the facilities SPES, HIE-ISOLDE, SPIRAL2 and FAIR.

- The new **Superconducting Linac** for the provision of high-intensity stable beams at GSI to search e.g. for superheavy elements.

ALICE

- Upgrade **the nuclear beams** at the LHC and the **ALICE detector** to expand the physics reach for studying quark-gluon matter at CERN.

Theory

Strengthen theory support to experiment by developing the collaboration between national theory groups through new transnational programmes

- Strengthen the financial basis of the theoretical research infrastructure **ECT*** in Trento to increase its involvement in European theory initiatives.
- Strongly support **advanced studies** related to the experimental roadmap and the improvement of the link between nuclear theory and quantum chromodynamics.
- Invest in **high-performance computing** facilities dedicated to Nuclear Physics projects.

Existing facilities

Fully exploit the currently existing large-scale research infrastructures (listed below in north to south order) and perform limited-size upgrades to ensure the best use of the large investments made in the past:

- The **lepton beam** facilities (electron/positron, muon beams) ELSA in Bonn, MAMI in Mainz, COMPASS at CERN, DAΦNE at INFN LNF Frascati, and the **hadron beam** facilities COSY at FZ Jülich and at GSI to perform detailed

studies of the structure of hadrons such as protons and neutrons.

- The **heavy ion beam** facilities JYFL Jyväskylä, KVI Groningen, GSI Darmstadt, GANIL Caen, IPN Orsay, ISOLDE at CERN, INFN-LNL Legnaro and INFN-LNS Catania to study the structure of nuclei and fundamental interactions.
- The nuclear astrophysics underground accelerator **LUNA** at INFN Gran Sasso, and the exploration of advanced new facilities.
- The **ELENA** upgrade of the Anti-proton Decelerator at CERN to study antimatter.

Fully exploit smaller scale **national and university Nuclear Physics laboratories** across Europe dedicated to nuclear structure and astrophysics experiments, fundamental interactions and nuclear applications.

Applications and Education

Secure and further develop the Nuclear Physics skills base in view of current and future needs, in particular regarding:

- Novel developments in **energy generation** (nuclear fission and nuclear fusion), **medicine** (e.g. imaging and tumour therapy) and **security**.
- Development of novel **sources**, (micro) **beams**, (high power) **targets** and **radiation detection** instrumentation that will also be used in other fields of science and engineering, and in the life sciences.

Future facilities

Continue the scientific and technical assessments for building new large-scale Nuclear Physics facilities in the future, and specifically promote:

- The inclusion of the high-intensity ISOL facility **EURISOL** in future updates of the ESFRI list, based on the successful EURISOL Design Study in FP7.
- The Technical Design Study for intense radioactive ion beams at **ISOL@MYRRHA**.
- The Technical Design Study for a polarised proton-antiproton, **PAX**, and an electron-nucleon/ion collider, **ENC**, at FAIR.
- The Technical Design Study for a high energy electron-proton/ion collider, **LHeC**, at CERN.
- The inclusion of Nuclear Physics programmes at the multi purpose facilities **ELI** and **ESS**.

Facilities Roadmap

We present on the next page the roadmap for building new large-scale Nuclear Physics research infrastructures in Europe. The time span ranges until the middle of the next decade. Facilities whose first phases have already been approved are coloured in pink and blue, future upgrades thereof in dark blue. SPIRAL 2, HIE-ISOLDE and SPES are designated to lead to the ISOL facility EURISOL indicated by the arrow in the roadmap. PAX and ENC at FAIR, EURISOL and the LHeC at CERN are still in the design or R&D phase.

