The NuPECC Long Range Plan

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Outline

- NuPECC mission
- The new long range plan
  the science
  facilities and recommendation

The role of nuclear structure

- ....few remarks on the world wide context
- Conclusion
The European Expert Board for Nuclear Physics associated to ESF

Representing about 6000 scientists
Members: 31 institutions from 21 countries
JINR Dubna recently joined

In global context with Member of WG9 of IUPAP
- AnPHA (Asia)
- NSAC (USA)
- Canada
- ALAFNA (south America)
**Mission and activities**

**Nuclear Physics European Collaboration Committee**

founded **1988** by subscribing **national research councils**, who nominate nuclear scientists as their representatives.

**Objective of NuPECC:**

“To strengthen European collaboration in **nuclear science** through the promotion of **nuclear physics** and its trans-disciplinary use and **application** in collaborative ventures between research groups within Europe”

**Major Tasks**

- Advise Funding Agencies
- Identify key scientific issues – specific focus reports were issued
- **Develop Long Range Plan for Nuclear Science in Europe in a global perspective**

**Nuclear Physics News (4 issues per year) – distributed worldwide**
The LPR identifies opportunities and priorities for the nuclear science in Europe.

The LRP provides the European Commission and national funding agencies with a framework for coordinated advances in nuclear science in Europe.
NuPECC town meeting in Darmstadt January 2017

Exciting discussions were triggered and conducted by the community at town meeting and working group meetings.
• Executive summary with recommendations

• Main features of existing and up-coming facilities

• 6 chapters on achievements and plans for the different themes defining *today* Nuclear Physics
Nuclear physics and the evolution of the Universe

Nuclear Physics with its different research domains addresses several key issues for the understanding of the different stages of the evolution of the universe.

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

Main issue: coordination and connections among the different activities.
The Nuclear Physics domain

Study of nuclear matter in all its forms and exploring their possible applications

1) Hadron Physics
2) Phases of Strongly Interacting Matter
3) Nuclear Structure & Dynamics
4) Nuclear Astrophysics
5) Fundamental Interactions
6) Nuclear Physics Tools & Applications

Nuclear physics is very broad!
Test of non-perturbative QCD to address particular aspects:
- the spatial quark distribution in $p$
- connection between quark dynamics and quantum numbers (spin and orbital angular momentum)
- spectroscopy and dynamics at different energy scales.

Needs:
large variety of complementary exp. in Nuclear Physics laboratories (electromagnetic, hadrons) designed for these questions

PANDA / FAIR antiprotons:
open issues in quarks dynamics of meson and baryons with high resolution

• 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?

Figure 4: Compilation of data for the proton electric form factor $G_E$ (PRC 90 (2014) 015206 and references therein). The charge radius is extracted from the slope at $Q^2=0$.

Proton radius puzzle:
New measurements planned at MESA (MAMI Mainz)
Properties of Strongly Interacting Matter at extreme conditions of temperature and baryon number density

QGP turned into hadron few $\mu$s after BB. QGP not seen in astronomical observations and thus is recreated in the lab with HI within volumes of nuclear size.

From QCD: above a critical energy density ($0.3 \text{ GeV/fm}^3$), a gas of hadrons undergoes a deconfinement (and chiral symmetry restoration)

**ALICE devoted** to study the different properties (flow and particle production) of the QGP ---
Many Studies also at LHCb, ATLAS and CMS

NA61/SHINE for properties at the onset
**AFTER** fix target under exploration

Enhanced production of multi-strange hadrons in high-multiplicity p-p collisions
Nuclear structure and reaction dynamics

- Where are the limits of stability and what is the heaviest element?

- How does nuclear structure evolve (also with T and L) and what shapes can nuclei adopt?

- How complex are nuclear excitations?

- How do correlations appear in dilute neutron matter?

- What is the density and isospin dependence of the nuclear equation of state?

**discovery frontier** (new isotopes, new elements, etc.), and moreover measure the different nuclear properties.
What are the nuclear processes that drive the evolution of the stars, galaxies and the Universe?

Interplay of:
- nuclear structure
- Nuclear decays
- half-lifes
- nuclear reactions
- Nuclear masses

Various nucleosynthesis processes
- BBN
- Explosive nucleosynthesis

Contributions

$^7$Be$(n, \alpha)^4$He n_TOF results and the cosmological $^7$Li problem


mass data favour Core Colapse Supernova in this region

129-131Cd
Symmetries and Fundamental Interactions

- **High precision** studies at low energies to test interactions and symmetries
- Complementary to experiments at the highest energies and offer **sensitivities** to new effects beyond the Standard Model

Among them:
- **EDM of the Neutron**
- **Symmetries in antimatter (antihydrogen)**
- **Electron and neutrino correlations** for the weak interaction (at ISOLDE)

More and colder antiproton in ELENA From 2017

Experiments at AD (antiproton and antihydrogen)

- Spectroscopy
- Gravity
- **ASACUSA**
- **ALPHA**
- **ATRAP**
- **GBAR**
- **AEgIS**
- **BASE**
- **ACE**

Matter-antimatter interaction

G. B. Andresen et al., *Nature* 468, 673–676 (02 December 2010)

**ASACUSA results (pHe⁺ spectroscopy)**

By comparing the calculated and experimental pHe⁺ frequencies, the ratio $M_\mu/m_e$ can in principle be determined to a fractional precision of $<1 \times 10^{-10}$
Applications from basic Nuclear Physics Research have a large impact on everyday life.

Society benefits from basic Nuclear Physics research (knowledge on nuclear structure, decay, nuclear reactions) in areas as:

• nuclear medicine,
• energy, environment
• cultural heritage
• nuclear stewardship and security.

A report on Nuclear Physics For medicine Released in 2014 by NuPECC

Selection of some relevant CERN contributions

Exploitation of competence from ISOLDE

Heavy ions heated plasma
Because of its nature (different beams of different energies) and different sizes of set ups, the activities in Nuclear physics are distributed in several laboratories.

NuPECC long range plan contains the future plans of the existing and planned facilities.

LRP concerns the several facilities in the field of Nuclear science (of different size and types) in Europe. NuPECC enhances their coordination and connections.
Recommendations

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.

Support for the full exploitation of existing and emerging facilities

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
To realize in phases: phase 0 ongoing using GSI

- Conception of FAIR 4 scientific pillars
  - APPA (atomic and plasma)
  - CBM
  - NUSTAR
  - PANDA

Large facility covering all thematics in the nuclear physics domain
It is vital to increase further the impact of ISOLDE by:
- Complete HIE-ISOLDE with its phase 3
- Construct a storage RING, Unique for a facility of this type

To be submitted for application in the ESFRI list
In Bucharest: one pillar of the distributed facility ELI (in the ESFRI list)

Nuclear astrophysics-Nuclear structure-applications – start in 2019-20

1) Ultra-short High power laser pulse
   (25fs) 2 X10 PW, 1/mn

2) GAMMA beams high flux ,
   monochromatic, \( \Gamma \sim qqs10^{-3} \), \( E = 0.2-19 \text{ MeV} \)

NICA -commissioning in 2019
\( \sigma \text{sNN} = 4-11 \text{ GeV heavy ions} \quad L \sim 10^{27} \text{ cm}^{-2} \text{ c}^{-1} \) (Au)
\( p \uparrow (d \uparrow) \) of \( \sigma \text{sNN} \) up to 26 (13) GeV \quad L \sim 10^{32} \text{ cm}^{-2} \text{ c}^{-1}

QCD test and hot barionic matter
synergies with FAIR

Experiments for \( \sigma < 100 \text{ fb} \):
- Synthesis of new SHE….\((Z = 119, 120)\)
- Study of decay properties of SHE
First exp 2018
Support for ALICE and the heavy-ion programme at the LHC with the planned experimental upgrades.

- Run-3 and Run-4: 2021-29
  - $\sqrt{s_{NN}} = 5.5$ TeV
  - $L_{int} > 10$ nb$^{-1}$
  - Major experiment upgrades

- Correlations and fluctuations
- Jet structure
- $\gamma$-jet and $Z$-jet correlations
- Low-mass dileptons
- (Anti-)(hyper-)-nuclei

- Charm and beauty energy loss and degree of thermalization in the medium
- Charm production mechanism(s)
- Charm elliptic flow (in-medium hadronization or at phase boundary)
Support to the completion of AGATA in full geometry

Coupling with ancillaries is essential point

AGATA represents the **state-of-the-art** in gamma-ray spectroscopy and is an essential precision tool underpinning a broad programme of studies in nuclear structure, nuclear astrophysics and nuclear reactions.

AGATA will be exploited at all of the large-scale radioactive and stable beam facilities and in the long-term must be fully completed in full 60 detector unit geometry in order to realise the envisaged scientific programme.

AGATA will be realised in phases with the goal of completing the first phase with 20 units by 2020.
Support for Nuclear Theory

European Center for Nuclear Theory and related areas
Eu Center
In Trento (Italy)

Computing infrastructures

Perform R&D programmes for possible future facilities

Training the next generation of nuclear scientists
European Users
and joint technical developments with European Laboratories and Institutions (collaborations for EIC in USA)

experiments at these facilities provide complementary information.
Nuclear Physics is and remains to be a very vital field. Exciting science world wide – Europe has strong impact

**NuPECC LRP** will play a role for Nuclear science in giving it the deserved **visibility** towards the funding agencies and other communities in the international general landscape (e.g. ESFRI). Recommendations are made to **enhance European leadership**

The community has to make efforts to realized as much as possible of what is foreseen in the LRP