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#### What is NuPECC

- > What is the Long range plan of NuPECC and why?
- > Who did produce this strategic document?



- The science in a nutshell
- The areas of research



- The facilities and the cutting edge technologies
- The recommendations
- ....the next step : the implementation



What is NuPECC ?

The European Expert Board for Nuclear Physics associated to ESF

Representing about 6000 scientists

Members: 31 institutions from 21 countries JINR Dubna also joined

Main mission is strategy at European scale for the field Nuclear Physics news (4/years 6000 copies- 27 years)





#### What is the Long range plan of NuPECC



- 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

#### Who did produce this strategic document ?



# Study of nuclear matter in all its forms and exploring their possible applications Quark dynamics Nuclei at extremes Hot baryonic Nucleosyntheses matter **Nuclear Physics** today Fundamental int. Application

Nuclear physics is very broad !

Each area needs particular tools and technologies

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





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# Neutron star mergers: gravitational waves and production of heavy elements



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 drive of facilities with RIB)

# **The Physics of hadrons**

Origin of Mass

Strong force From quark Structure and dynamics

#### The proton

Studies have uncovered discrepancies in the proton radius (using different techniques).

New experiment planned to explain this (one at Mainz-MESA): new physics?



High resolution experiments with antiprotons (PANDA) at FAIR will address many issues to test in detail theory of QCD

-heon

EIC in USA contributions from European reserchers

Mainz Energy-Recovering Superconducting Acce

# Hadronic Matter at the very extremes



QGP turned into hadron few µs after BB. It is not seen in astronomical observations and thus is recreated in the lab with HI Matter at very high temperature and density (QGP) reveals the high energy processes that drove the evolution of the universe after its birth. (ALICE)

Its very exotic nature is

corpses : neutron stars

found in massively

compressed stellar



signals from deconfinement and chiral symmetry restoration





ALICE at LHC is built with technical features suited to study the properties of a plasma (a soup) of quarks and gluon the sources and carrier of the strong force

# **Nuclear structure and Reactions**

![](_page_10_Picture_1.jpeg)

#### Questions

• 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** ? (for neutron stars)

Nuperc

Protons and neutrons via the nuclear force can create as many as 7000 nuclear species (300 stable). The unstable ones are the precursors and found in stellar processes (explosion, merging)

![](_page_10_Figure_9.jpeg)

**Tools :** Heavy ion beam far from stability produced with different reaction types, Gamma beams and gamma decay

![](_page_11_Figure_0.jpeg)

<u>Search and UNDERSTAND</u> regular and simple patterns in the structure of complex nuclei By <u>characterizing</u> nuclei under <u>EXTREME conditions (E\*,J,T)</u>:

amplify different aspects of the interaction

Nuclear structure is needed for astrophysics, double beta decay and other domains ....

Courtesy of Navin Alhari

# **Nuclear astrophysics**

- Various nucleosynthesis processes
- **BBN**

oroton number

- **Fusion processes in stars** •
- Lead (82) Explosive nucleosynteses

![](_page_12_Figure_5.jpeg)

#### that drive the evolution of the stars, galaxies and the Universe?

R-process

Abandances [Si=10<sup>6</sup>]

What are the nuclear processes

184 ?

![](_page_12_Figure_7.jpeg)

#### **Interplay of:**

- nuclear structure
- nuclear decays

20

- half-lives •
- nuclear reactions
- nucler masses

Proton and neutron rich side nuclei - our precursors need to be investigated with different tools

# Nucleosyntheses (nuclear structure and reactions information) a large effort involving from small scale accelerators .... b local distribution <

![](_page_13_Figure_1.jpeg)

In particular at **small scale** accelerators :

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

![](_page_13_Figure_5.jpeg)

#### Scientific programs at :

- FAIR
- SPIRAL2- ISOLDE-SPES
- ELI\_NP
- Heavy factory (Dubna)
- 8 . . .

![](_page_14_Picture_0.jpeg)

#### **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
- <u>Symmetries in antimatter</u> (antihydrogen)
- Electron and neutrino correlations for the weak interaction

#### More and colder antiproton in ELENA

![](_page_14_Figure_9.jpeg)

![](_page_15_Picture_0.jpeg)

# **Applications and societal benefits**

#### 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.

![](_page_15_Picture_8.jpeg)

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

![](_page_16_Picture_0.jpeg)

# **PECC** Perspectives of Nuclear Physics in Europe

![](_page_17_Figure_1.jpeg)

Because of its nature (different beams of different energies ) and different sizes of specialized set-ups, the activities in Nuclear physics are distributed in several laboratories

NuPECC long range plan contains the future plans of the existing and 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

![](_page_18_Picture_0.jpeg)

**Trasnational access within EU projects** 

Nuclear structure reactions and applications

- GANIL (France)
- LNL-LNS (Italy)
- ISOLDE (CERN)
- JYFL (Finland)
- ALTO (CNRS, France)
- GSI (Germany)
- KVI (The Netherlands)
- NLC
- (HIL/IFJ PAN, Poland)
- IFIN-HH/ELI-NP (Romania)
- ECT\* (Italy)

Hadron physics with hadronic and electromagnetic probes

- CERN
   (LHC, COMPASS, fixed target
- GSI/FAIR (Germany)
  LNF, Frascati Italy
- MAMI , Mainz Germany ECT\*, Trento Italy

ELSA, Bonn Germany COSY, Julich Germany

![](_page_18_Picture_19.jpeg)

![](_page_18_Picture_20.jpeg)

![](_page_18_Picture_21.jpeg)

![](_page_18_Picture_22.jpeg)

### Recommendations

![](_page_19_Picture_1.jpeg)

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

![](_page_20_Picture_0.jpeg)

# **The ISOL Facilities Roadmap**

An effort to perform a coordinated program with existing and planned radioactive beams produced with the ISOL technique and to do R&D for the next step

![](_page_21_Picture_2.jpeg)

V Pro- prov 3 0 DESTR CALL ULTE UN 2 DESTR

![](_page_21_Figure_4.jpeg)

#### **SPES at LNL using 70 MeV p .... under construction**

Unique features within ISOL faclities

RIB production and Post accelerator

exotic beams for sciel

# Tandem 18

![](_page_22_Picture_4.jpeg)

#### New infrastructure for:

cyclotron

6

- RIB (Radioactive Ion Beam)
- application facility

![](_page_23_Picture_0.jpeg)

# Tracking array for gamma spectroscopy High-sensitivity for nuclear structure of exotic nuclei – used in several laboratories

![](_page_23_Picture_2.jpeg)

![](_page_23_Picture_3.jpeg)

2012 → GSI/FRS 6TC+3 DC

![](_page_23_Picture_5.jpeg)

![](_page_23_Picture_6.jpeg)

![](_page_23_Picture_7.jpeg)

AGATA D.+PRISMA Total Eff <sub>Nominal</sub>. ~2.6% AGATA @ FRS Total Eff. (β=0.5) ~ 10%

AGATA @G1 Total Eff ~ 8% to 14%

# A **powerful traveling instrument** - its construction has to proceed in the next years!

![](_page_23_Picture_12.jpeg)

Long range plan presentation – Bruxelles 27 November 2017

**Angela Bracco** 

![](_page_24_Picture_0.jpeg)

In Bucharest : one pillar of the distributed facility ELI ( in the ESFRI list)

Assembled at INFN Frascati

# **Up-coming Facilities**

- 1) Ultra-short High power laser pulse (25fs) 2 X10 PW, 1/mn 2) GAMMA beams high flux,
- monochromatic,  $\Gamma \sim qqs 10^{-3}$ ,
- E= 0.2-19 MeV

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

**Experimental set ups under construction**scientifique program with electromagnetic probes unique

RF Photoinjector -S-band technology

C-band accelerator module Assembled at STFC Daresbury

## ....at JINR under construction

![](_page_25_Picture_1.jpeg)

# QCD test and hot barionic matter synergies with FAIR

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

![](_page_25_Picture_4.jpeg)

Experiments for  $\sigma$ <100 fb :

- Synthesis of new SHE....(Z = 119, 120)
- Study of decay properties of SHE

First exp 2018

![](_page_26_Figure_0.jpeg)

- Correlations and fluctuations
- Jet structure
- γ-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 for Nuclear Theory**

![](_page_27_Picture_1.jpeg)

European Centre for Nuclear Theory and related areas Eu Centre in Trento (Italy)

![](_page_27_Picture_3.jpeg)

The IBM Blue Gene/Q system JUQUEEN with 5.9 Pflops peak performance at the computing center of the Forschungszentrum Jülich

#### **Computing infrastructures**

# Perform R&D programmes for possible future facilities

Training the next generation of nuclear scientists

![](_page_28_Figure_0.jpeg)

#### **European Users**

and joint technical developments and contributions with European Laboratories and Institution (collaborations for EIC in USA) experiments at these facilities provide complementary information.

Nupecc ... in summary NuPECC recommendations

Build .....the new
 Support existing

 (all sizes) and emerging facilities
 Carry out R&D and Program – training

Programme at labs based on an integrated approach for:

- ♦ Basic science: the building block of our world
- Applications: the best use of nuclear techniques for the benefit of society

![](_page_29_Figure_5.jpeg)

#### The European Strategy for Particle Physics-2013

k) A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. The CERN Laboratory should maintain its capability to perform unique experiments. **CERN should continue to work with NuPECC on topics of mutual interest**