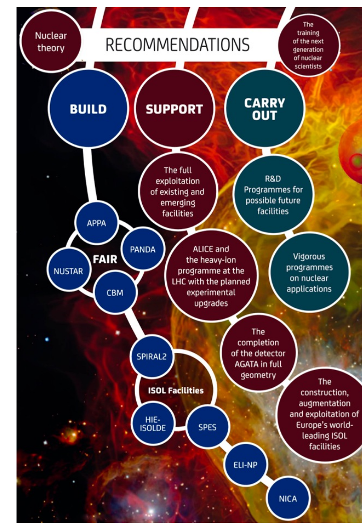
NuPECC
Long Range Plan

Open Symposium on the Update of European Strategy for Particle Physics

European Strategy
Update

Grenada, Spain, May 13-16, 2019



Marek Lewitowicz
Chair of NuPECC

What is NuPECC ?

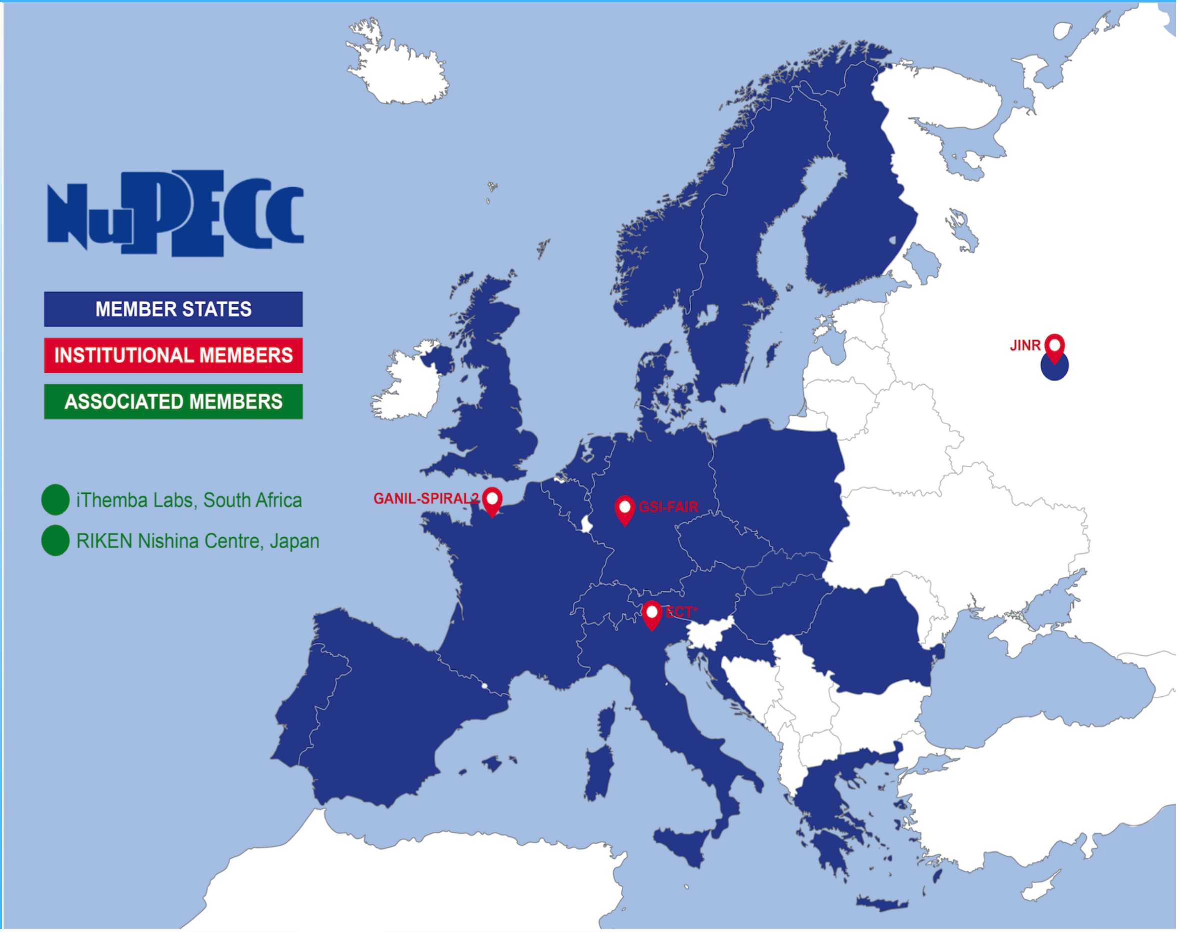
The European Expert Board for Nuclear Physics hosted by European Science Foundation

Representing

about 6000 scientists

Composition:

- 32 representatives from 21 countries, ESFRI NP Infrastructures & JINR Dubna
- 2 associated members (iThemba Labs and Nishina Center)
- 6 observers (NPD/EPS, ECFA, NSAC, ANPhA, ALAFNA, CINP)

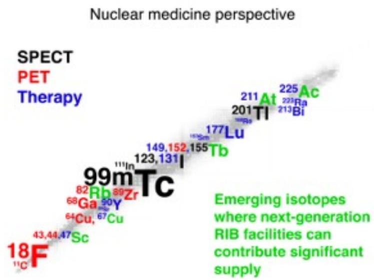


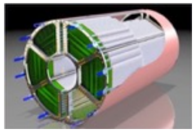
3 regular Committee meetings/y

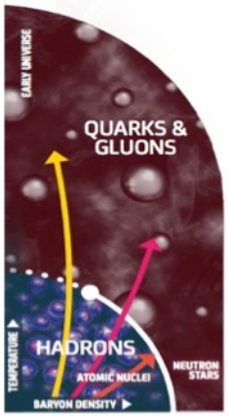
30 Years of NuPECC activities

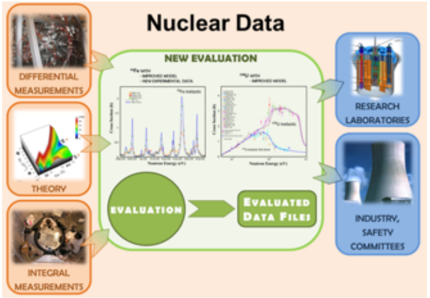
Nuclear Physics in Europe

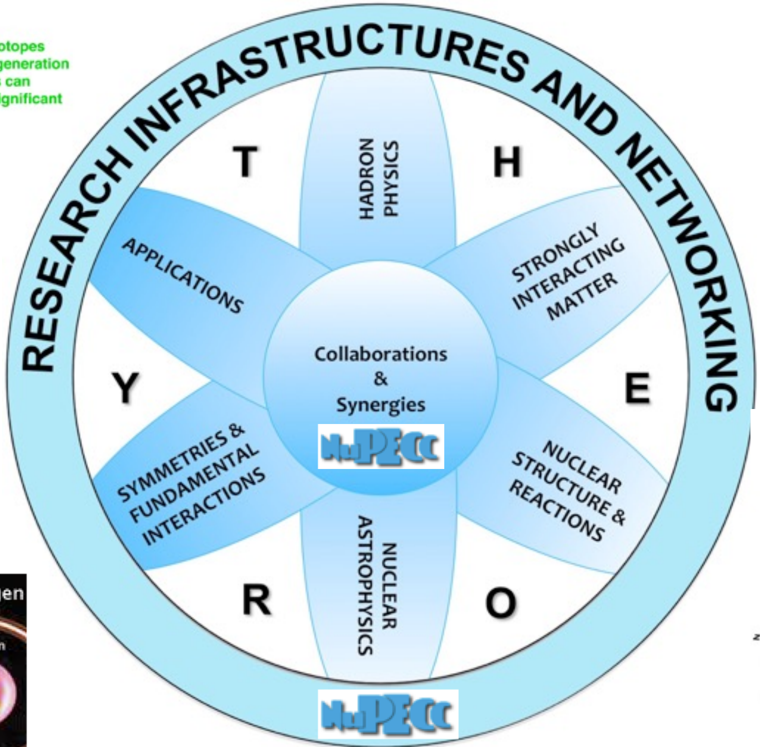
http://www.nupecc.org

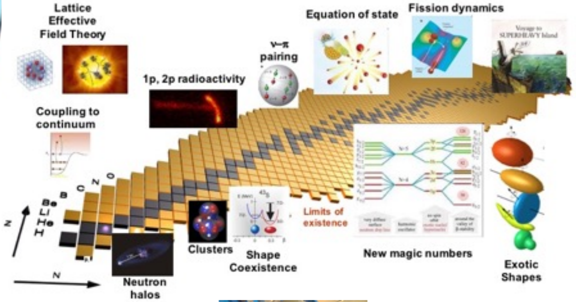


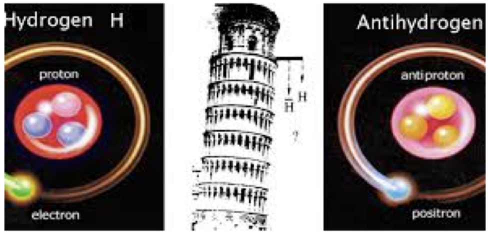


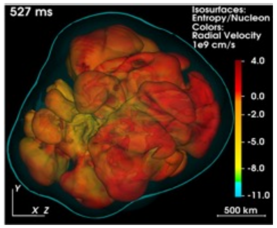


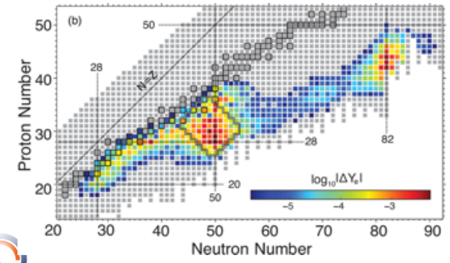


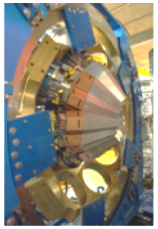






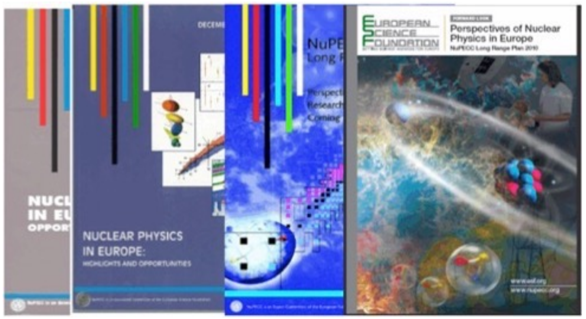






Long Range Plan organization & schedule

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

NuPECC

Community
200 experts
7 working groups

Town meeting
in Darmstadt
January 2017

Report
June 2017

LRP presentation
in Brussels
Nov. 27, 2017

Beginning of 2016 → End of 2017

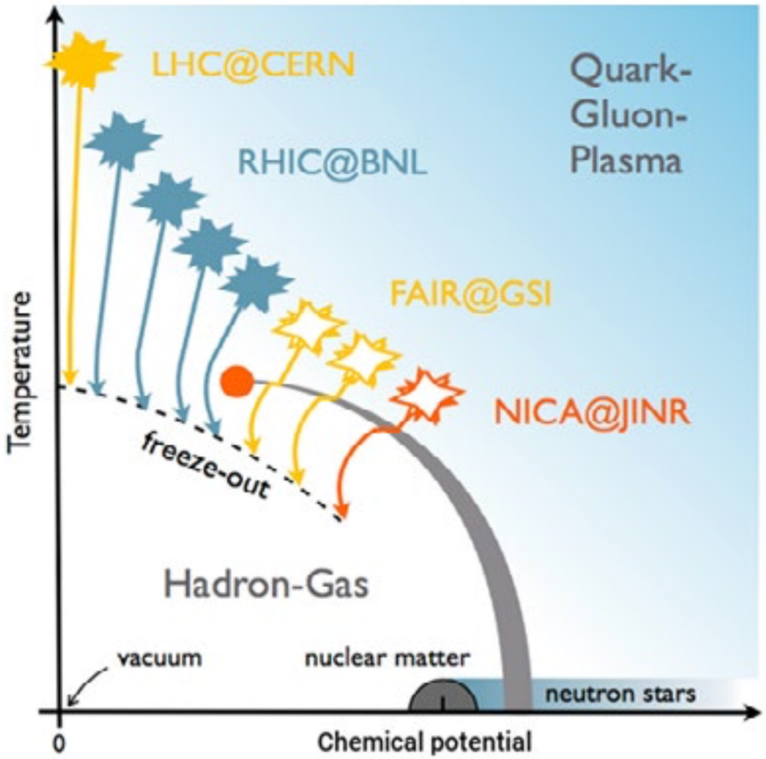
http://www.nupecc.org/lrp2016/Documents/lrp2017.pdf

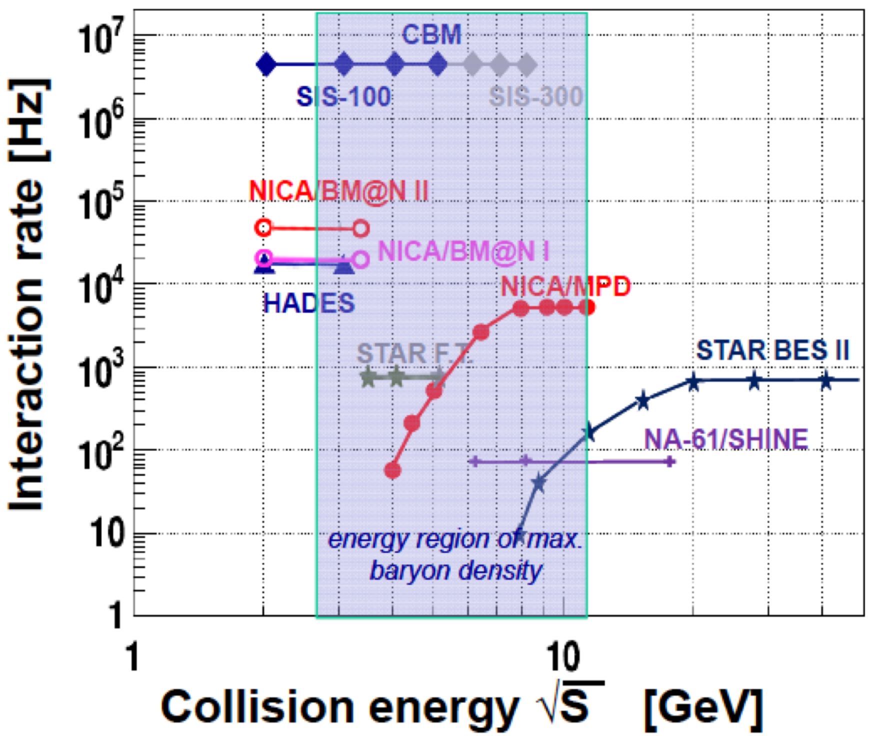
Central questions in Nuclear Physics

- **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?***

Hadronic Matter at the very extremes

- 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?

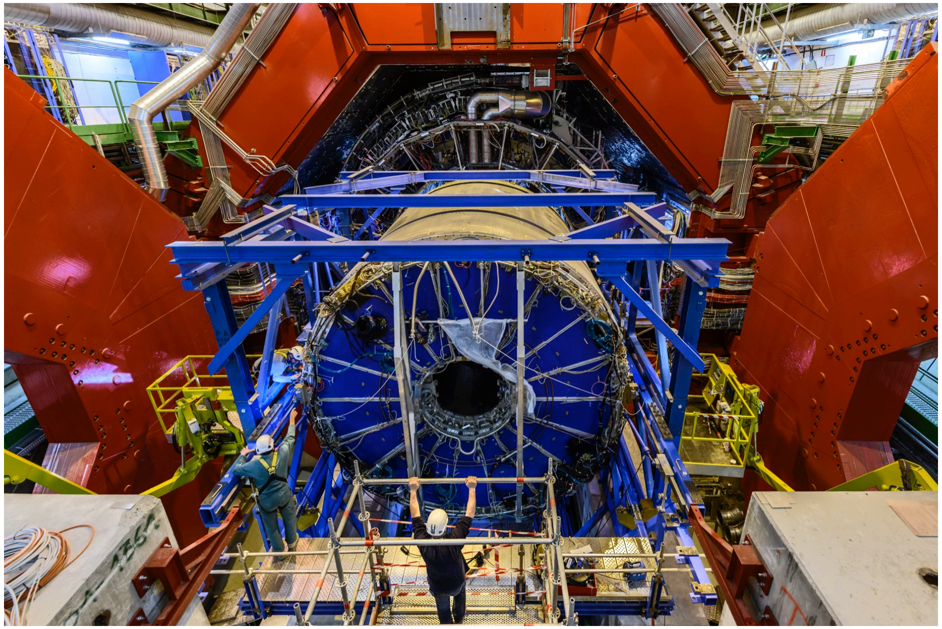




NuPECC LRP recommendation:
Fully develop synergies between ALICE, NICA and FAIR

Ongoing: Heavy-ion program at the LHC

- LHC Run 2 completed (Dec 2018)
  Target integrated luminosity 1nb^{-1} reached!
  Large harvest of physics results
- LHC Long Shutdown 2 (2019-2020)
  - Improvements on LHC injection chain to reach 50 kHz Pb-Pb collision rates
  - Major detector upgrades for ALICE and LHCb →
- 2021-2029: Run 3 and 4
  - Goal: 13nb^{-1} integrated luminosity
  - Heavy-ion physics program arXiv:1812.06772



Ideas for a new heavy-ion experiment for Run 5 (from 2031)

ESPP-INP-110

Main NuPECC LRP recommendation:
All aspects of the LHC heavy-ion programme, including manpower support and completion of the detector upgrades, are strongly supported.

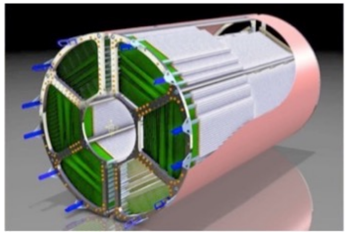
The Physics of Hadrons

- 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?

The proton

discrepancies in measurements of the proton radius made with different techniques.

"proton spin puzzle"



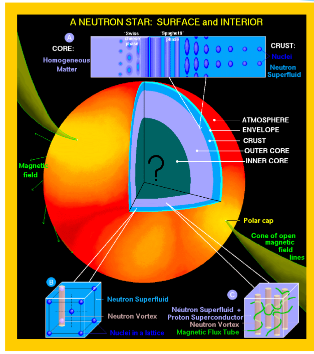
High resolution experiments with antiprotons (PANDA) at FAIR to test in detail QCD

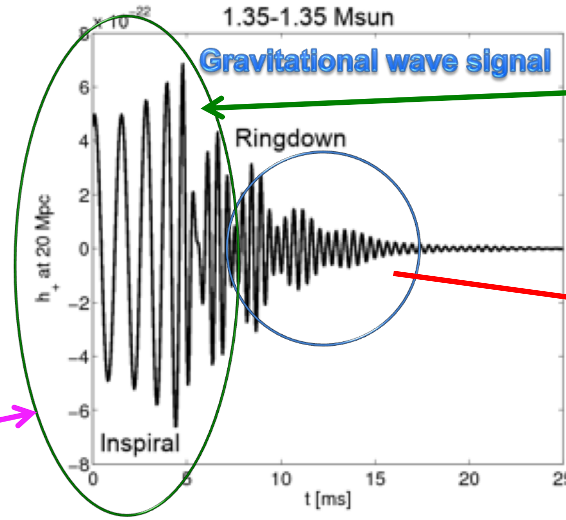
Main NuPECC LRP priority for this topic:

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, COMPASS).

A New QCD Facility at the M2 beam line of the CERN SPS **ESPP-INP-143**

Neutron star mergers: GW and production of heavy elements





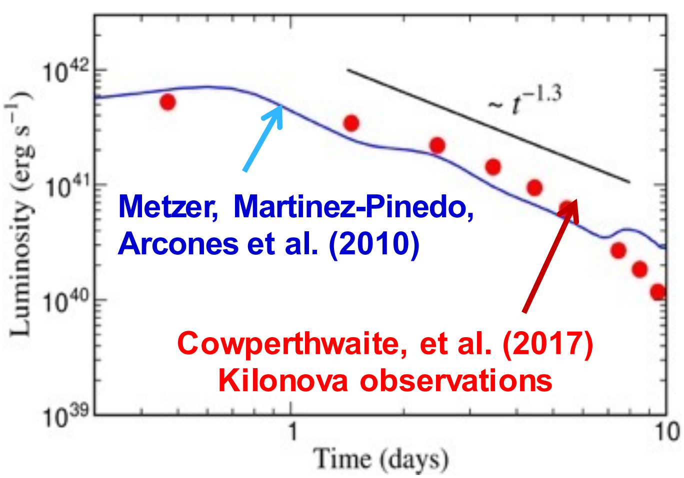
Neutron star mass

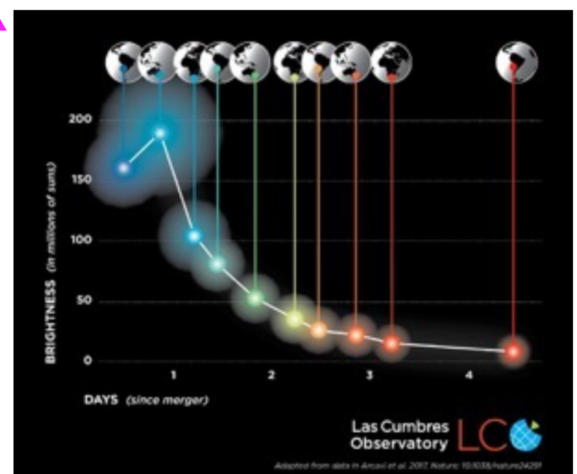
This depends on the Nuclear Equation of state

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

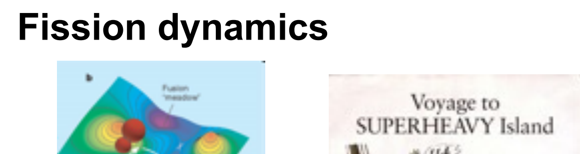


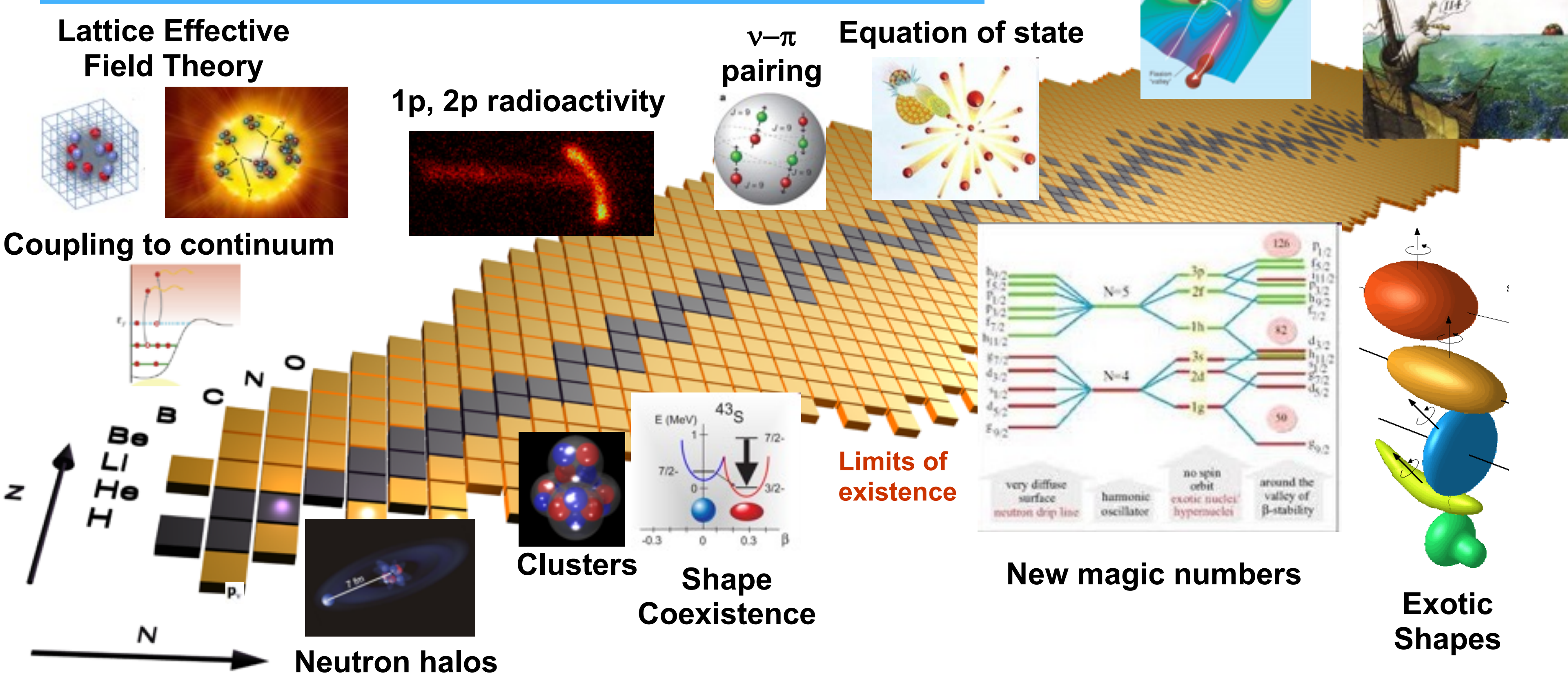


Time evolution determined by the radioactive decay of r-process nuclei (science drive of facilities with RIB)

Structure of complex nuclei

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





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

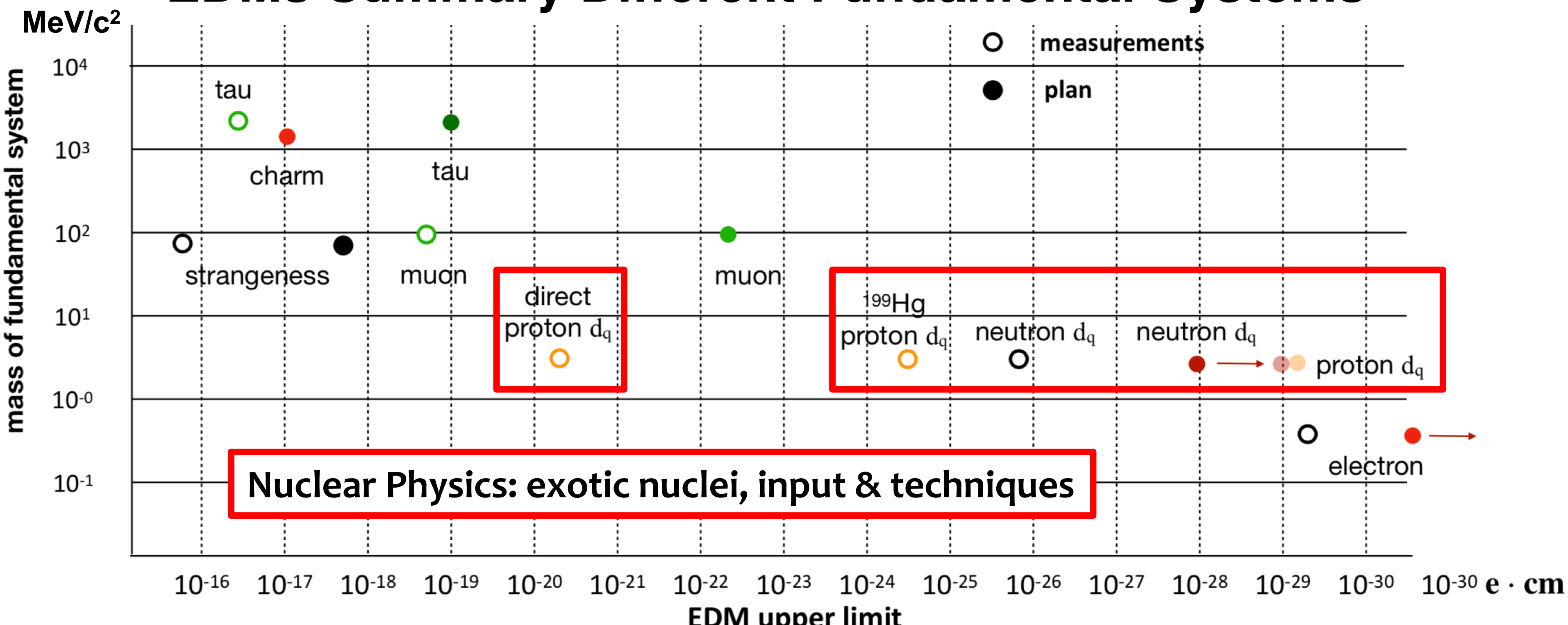
Fundamental interaction and symmetries

Talks of Klaus Kirch, Stephan Paul, Gunar Schnell, …

- **EDMs**
- **Symmetries in antimatter (antihydrogen)**
- **Electron and neutrino correlations for the weak interaction**

- **High precision measurements at low energies**
- **Complementary to experiments at the highest energies and offering sensitivities to new effects beyond the Standard Model**

EDMs Summary Different Fundamental Systems



Courtesy of Stephan Paul

Fundamental interaction and symmetries

- **EDMs**
- **Symmetries in antimatter (antihydrogen)**
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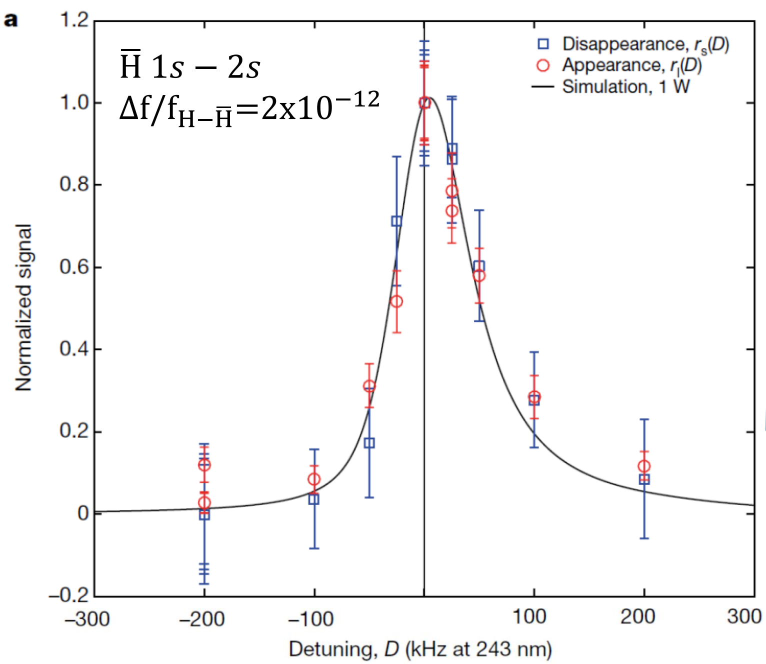
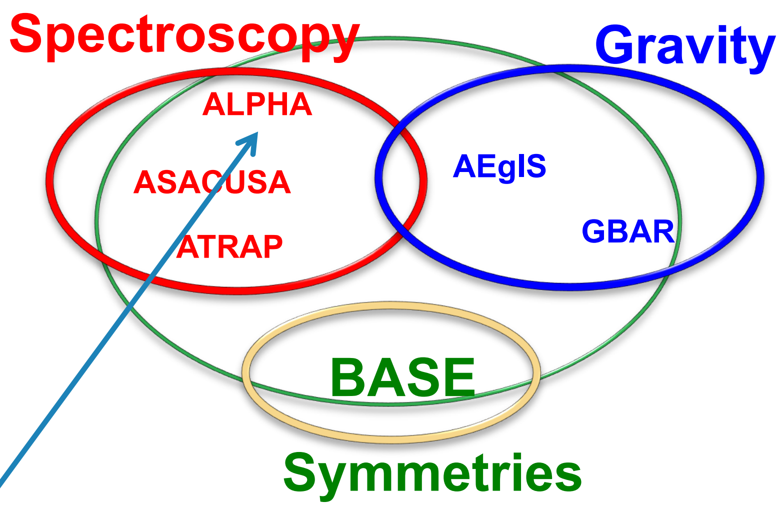
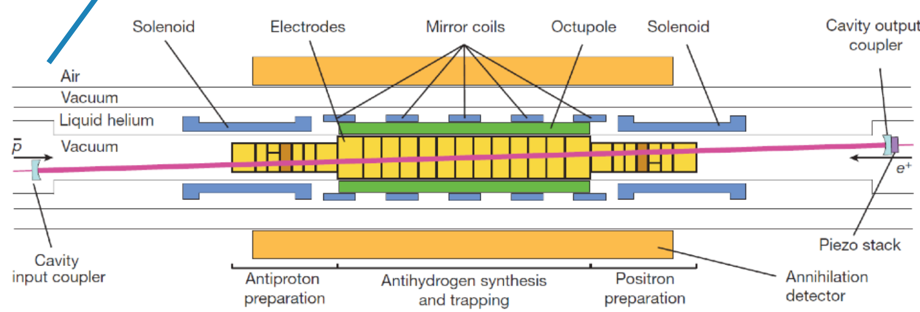
Experiments at AD (antiproton and antihydrogen)







ALPHA-2 apparatus at CERN

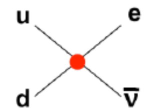
Ahmadi, M. et al. (ALPHA collaboration). Characterization of the 1S–2S transition in antihydrogen. *Nature* **557**, 71–75 (2018)

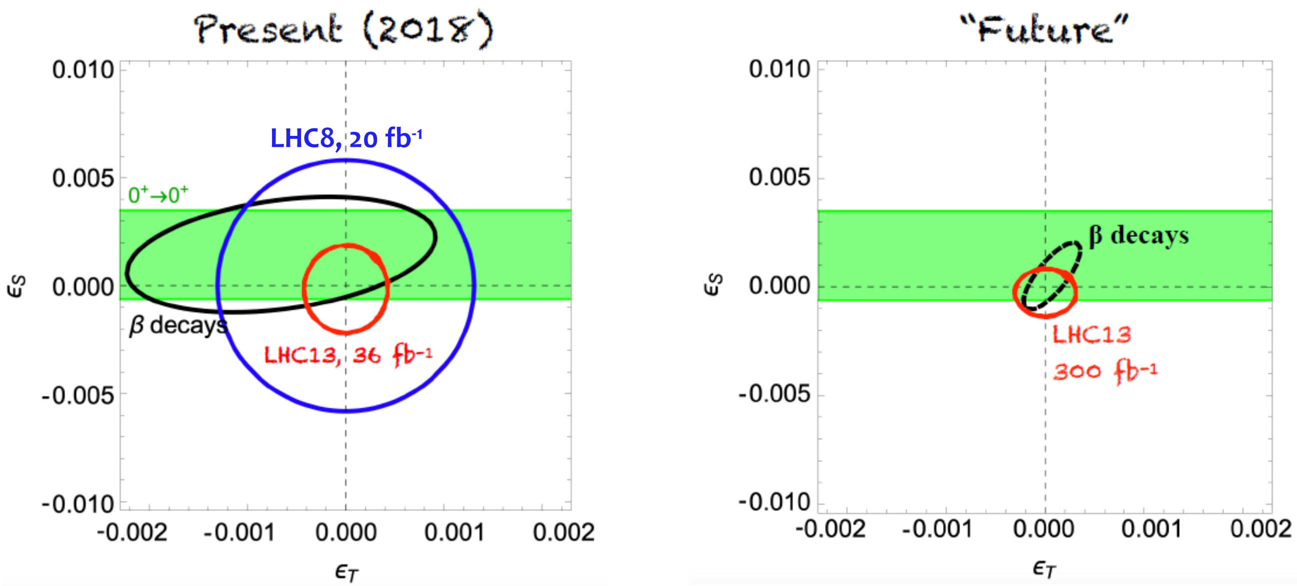
Courtesy of Eberhard Widmann

EXAMPLE: new interactions – future limits for beta-decay and LHC

- **Electron and neutrino correlations for the weak interaction**

Scalar & tensor interactions





WISArD (^{32}Ar)
+ TRIUMF
+ TA&M

Benchmark numbers
(from ongoing / planned experiments):

$\delta\tau_n = 0.1\,s$

$\tilde{A}_n,\ a_n,\ \tilde{a}_F\ a_{GT}$ at 0.1%

$b_{GT} = 0.001$

[M. Gonzalez-Alonso, O. Naviliat Cuncic, N. Severijns, Prog. Part. Nucl. Phys. 104 (2019) 165; Gupta et al. Phys.Rev. D98 (2018) 034503]

Courtesy of M. Gonzalez-Alonso, N. Severijns, B. Blank

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

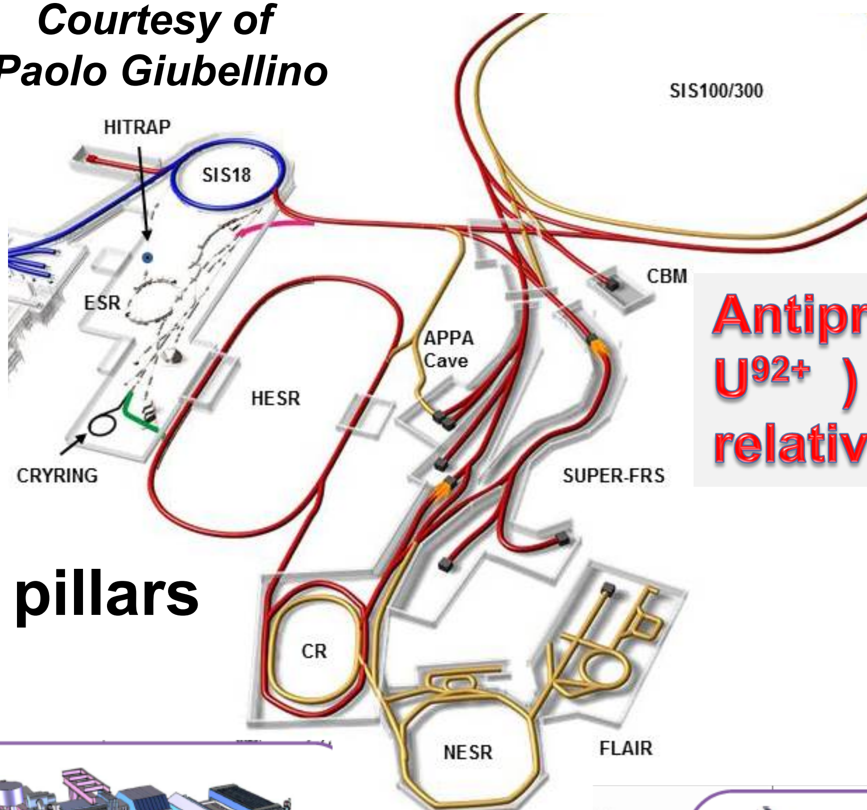
ELI-NP
NICA, SHEF
MYRRHA
IFMIF-DONES

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

Support to the completion of **AGATA** array in full geometry

Roadmap NP facilities

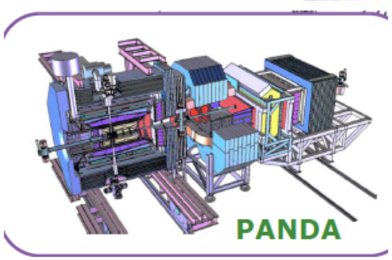
Courtesy of Paolo Giubellino

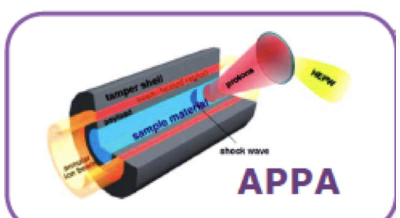


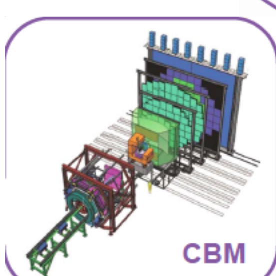
Large facility covering all nuclear physics domains !

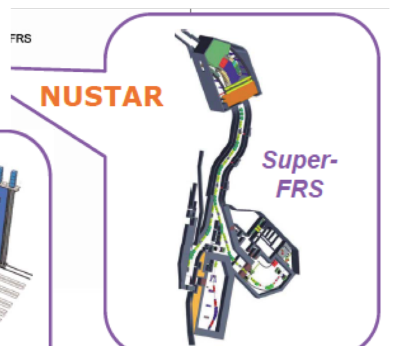
Antiprotons, highly charged ions (e.g. U^{92+}) and exotic Nuclei) from rest to relativistic energies 4.9 GeV/A

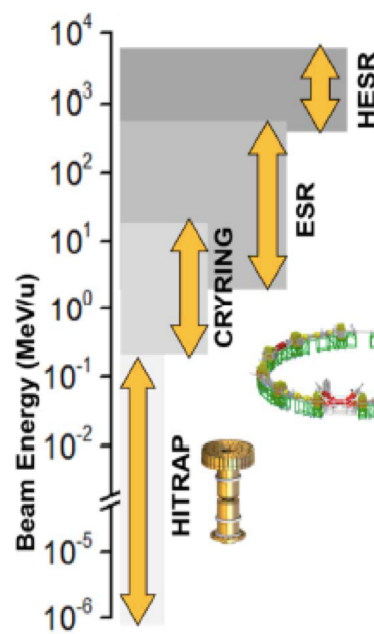
4 pillars

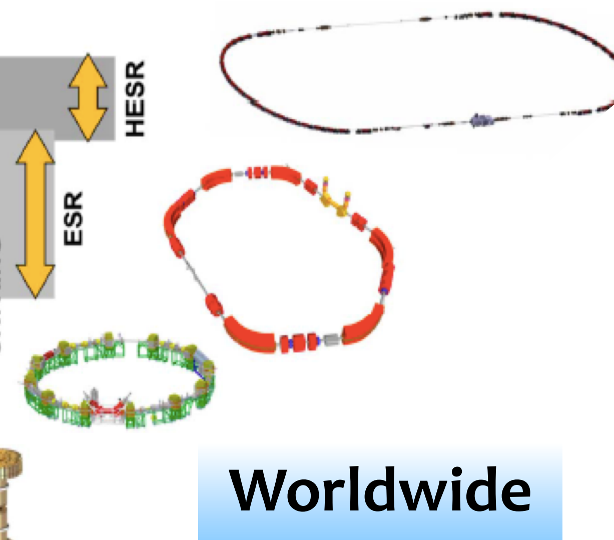












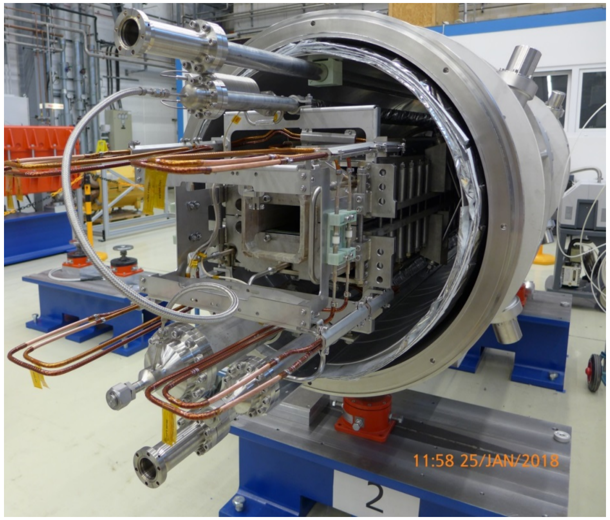
Worldwide Unique

Ongoing experiments FAIR Phase-0 (run 2019)

Roadmap NP facilities

Courtesy of Paolo Giubellino

24 SIS100 (of 120) dipole magnets delivered and cold-tested

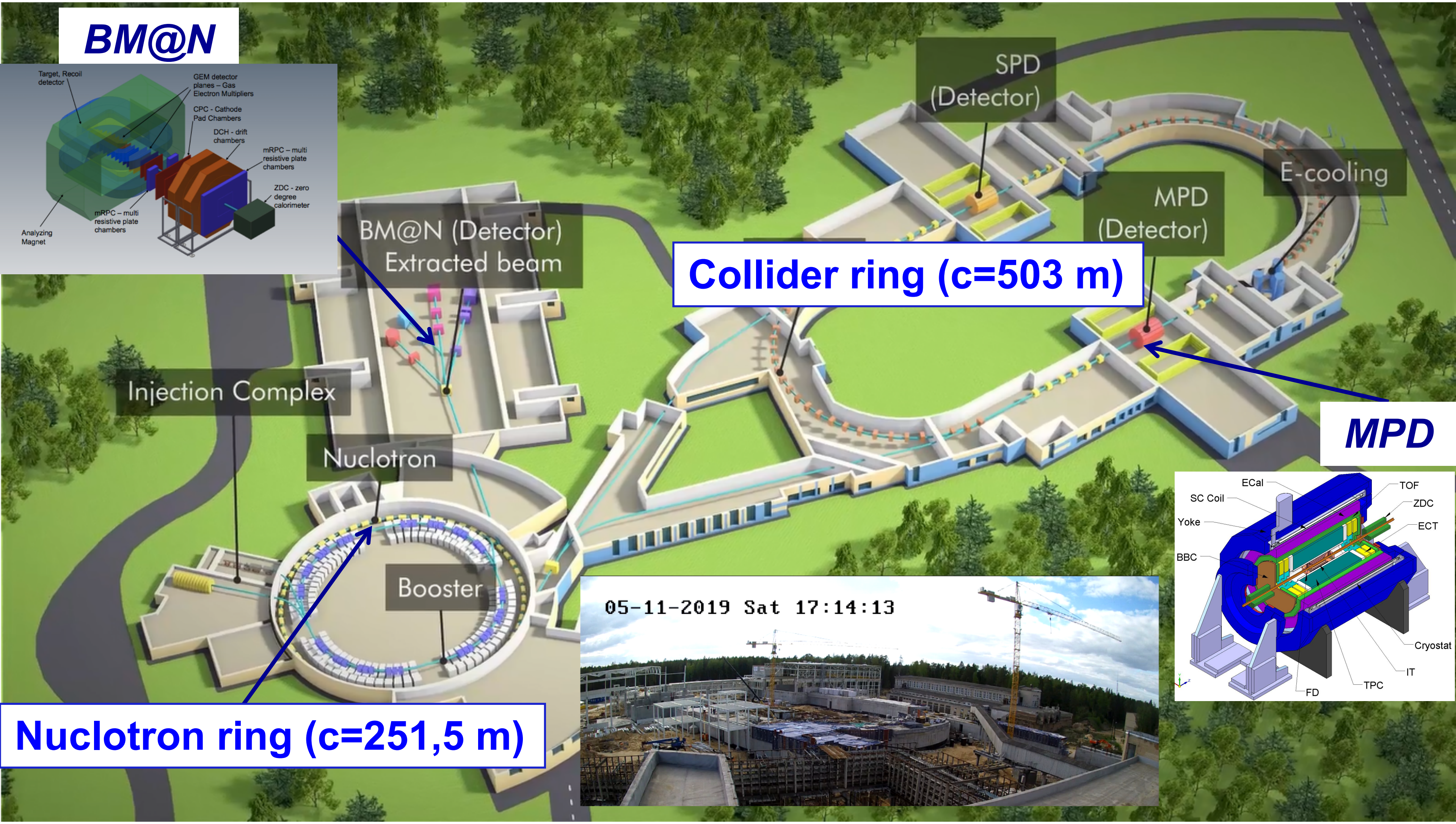


All HESR Dipoles are produced, in Jülich and 65% are delivered to FAIR

FAIR CONSTRUCTION SITE
STATUS MARCH 2019

FACILITY FOR ANTIPROTON AND ION RESEARCH IN EUROPE GMBH
DARMSTADT, GERMANY

Roadmap NP facilities NICA at JINR



Courtesy of Boris Sharkov

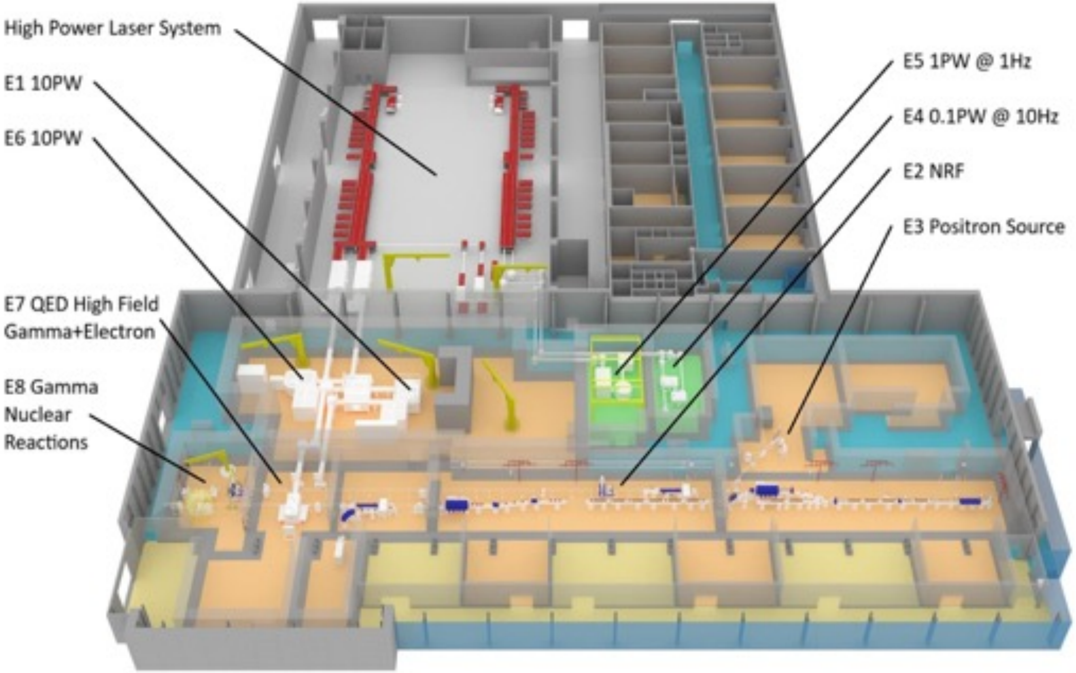
Roadmap NP facilities

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

First SPIRAL2 beams beginning of 2020

Courtesy of Navin Alahari

Roadmap NP facilities



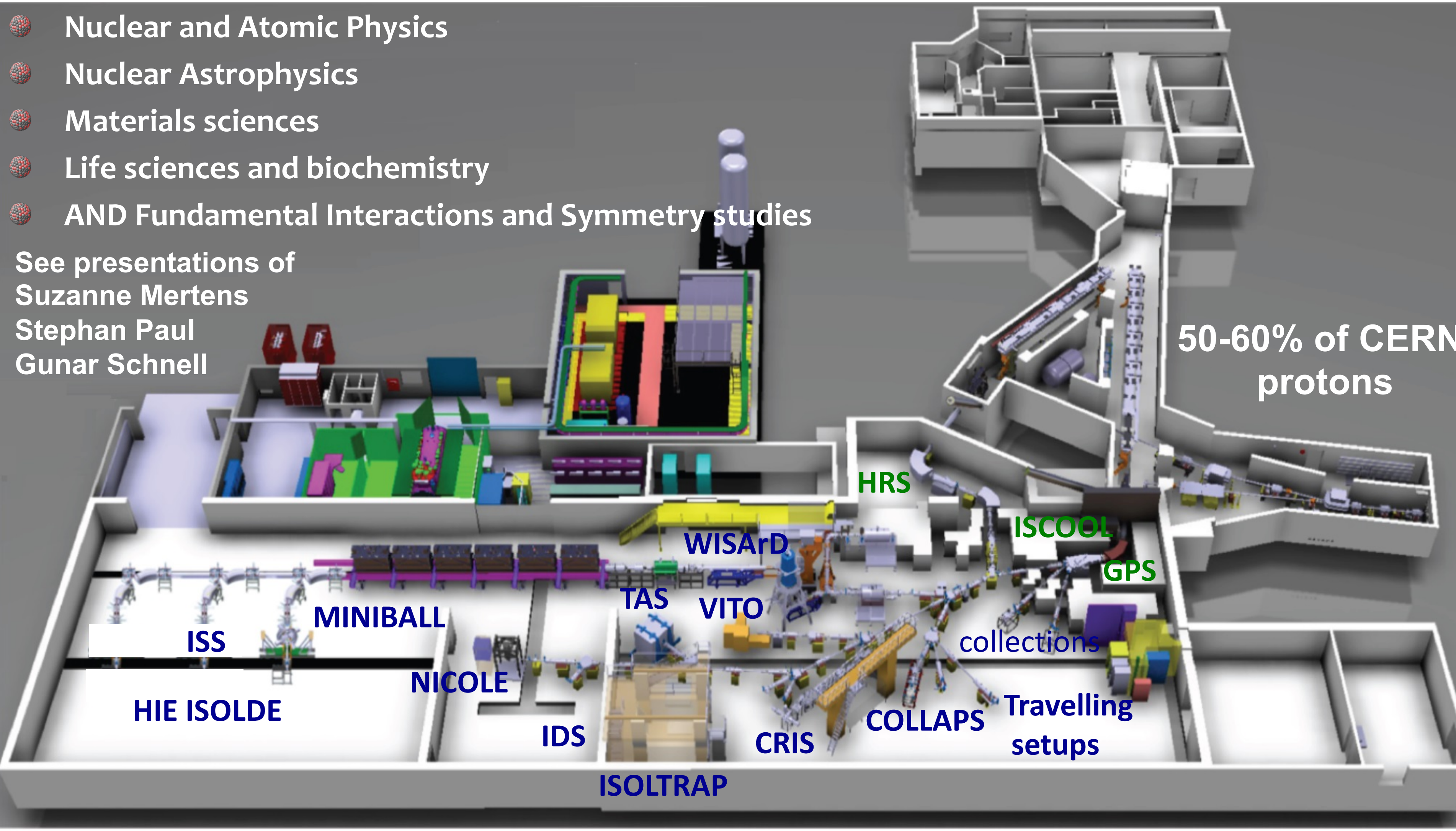
The nominal power of 10 PW laser system was achieved in March 2019, making HPLS from ELI-NP the most powerful laser in Europe

Courtesy of Dan Gabriel Ghiță & Ionel Andrei

CERN / ISOLDE
World-leading ISOL facility

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

See presentations of
Suzanne Mertens
Stephan Paul
Gunar Schnell



Future: Exploiting the Potential of ISOLDE at CERN - EPIC | **ESPP-INP-39**

NuPECC LRP

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

Joint activities of ECFA, ApPEC & NuPECC

- **Joint "JENAS" seminar – Oct. 2019**
- **Diversity Charter**
- **…**

Nuclear Physics inputs to the ESPP Update

> 60/160 inputs related to nuclear physics and techniques

Physics & methods

- **Symmetries & Fundamental Interactions**
- **Hadron physics**
- **Strongly Interacting matter at extreme conditions of temperature and baryon number density**
- **Nuclear Physics methods for neutrino physics and search for dark matter**

Experiments and accelerators

- **ALICE and future RHI exp. at CERN**
- **Physics beyond colliders (ELENA, COMPASS, …)**
- **FAIR at Darmstadt, NICA at Dubna**
- **ISOL-type Nuclear Physics facilities (ISOLDE,…)**
- **Applications (n-TOF, MEDICIS,…)**

Importance of proton and HI beams for the nuclear physics experiments and applications at CERN – to be considered for the future projects

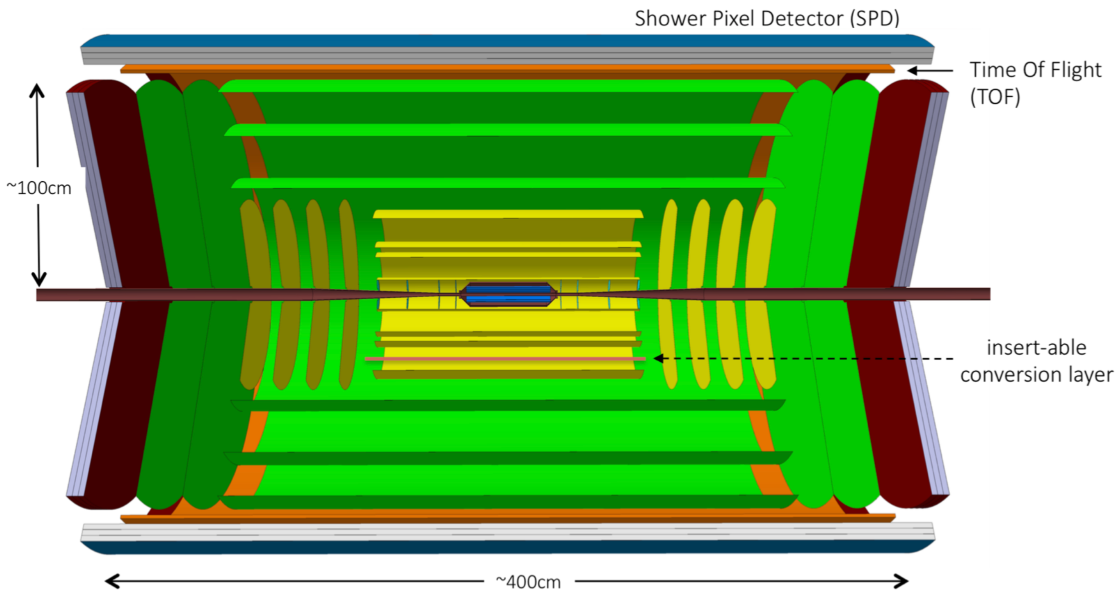
Warm thanks to all contributing colleagues

Thank you for your attention

Future: A next-generation LHC heavy-ion experiment

Ideas for a new heavy-ion experiment for Run 5 (from 2031), after LS4

capable to handle extremely high rates for rare probes (heavy flavors, heavy quarkonia, light (anti-)(hyper-)nuclei), and measure ultra low momentum particles



arXiv:1902.01211

Ultra-light all-silicon apparatus:

Tracker: ~10 tracking barrel layers based on CMOS sensors (blue, yellow, green)
Spatial resolution: 1-5 µm

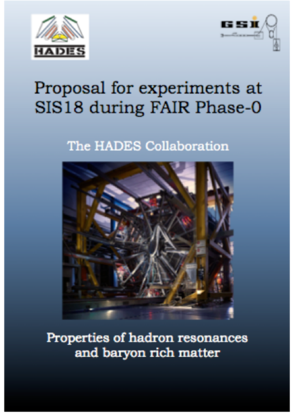
Hadron ID: TOF with outer silicon layers (orange)
Time resolution: ~30 ps

Electron ID: pre-shower (outer blue)

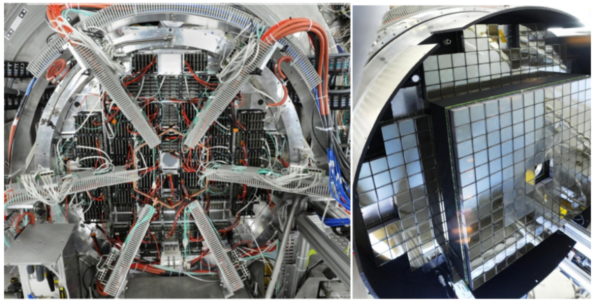
Ongoing: FAIR Phase-0 (run 2019)

HADES

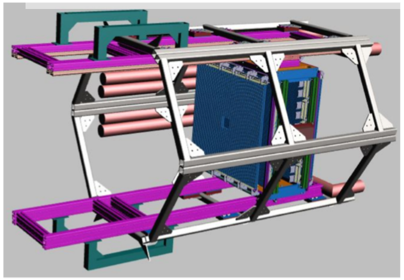
Ag+Ag (1.58 AGeV), 4 weeks, 50 billion events



MAPMT based Cherenkov Photon Detector
Joint project of CBM and HADES

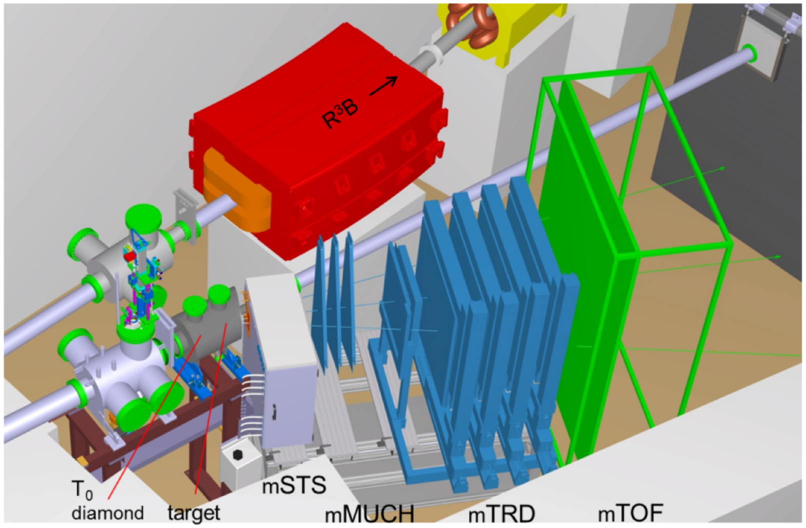


Forward Detection System (2020)
Based on PANDA Straw Technology



mCBM

A CBM full-system test-setup at SIS18

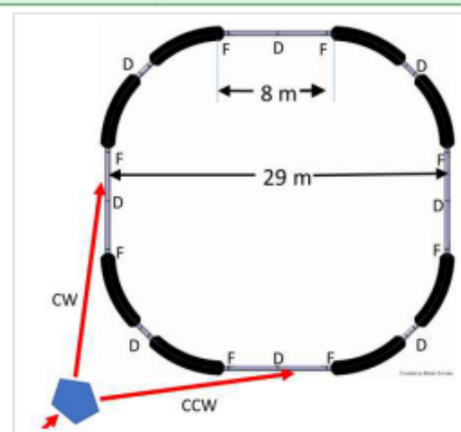


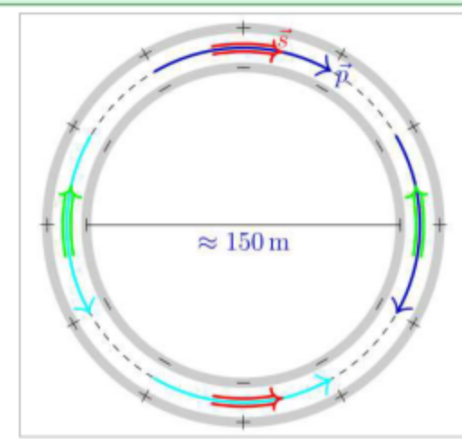
- CBM prototype detector systems
- free-streaming read-out and data transport to the mFLES inside the GreenITCube
- up to 10 MHz collision rate

EXAMPLE: Charged-particle (proton, deuteron) EDM-searches in storage rings

- Science case: high EDM sensitivity (10^{-29} e.cm); essential to determine EDM sources (also: axion DM search)
- Technique: observation of time-development of polarization vector in E-fields (out-of-plane precession)
- Requirements: polarized proton/deuteron beams; dedicated precision storage rings; polarimetry

1 Precursor Experiment →	2 Prototype Ring →	3 All-electric Ring
dEDM proof-of-capability (orbit and polarization control; first dEDM measurement)	**pEDM proof-of-principle** (key technologies, first direct pEDM measurement)	**pEDM precision experiment** (sensitivity goal: 10^{-29} e cm)





Timeline: Ongoing now — 5 yrs — 10 yrs

Sensitivity: $10^{-(18-19)}$ e.cm — $10^{-(23-24)}$ e.cm — $10^{-(28-29)}$ e.cm

Curtesy of Hans Stroeher

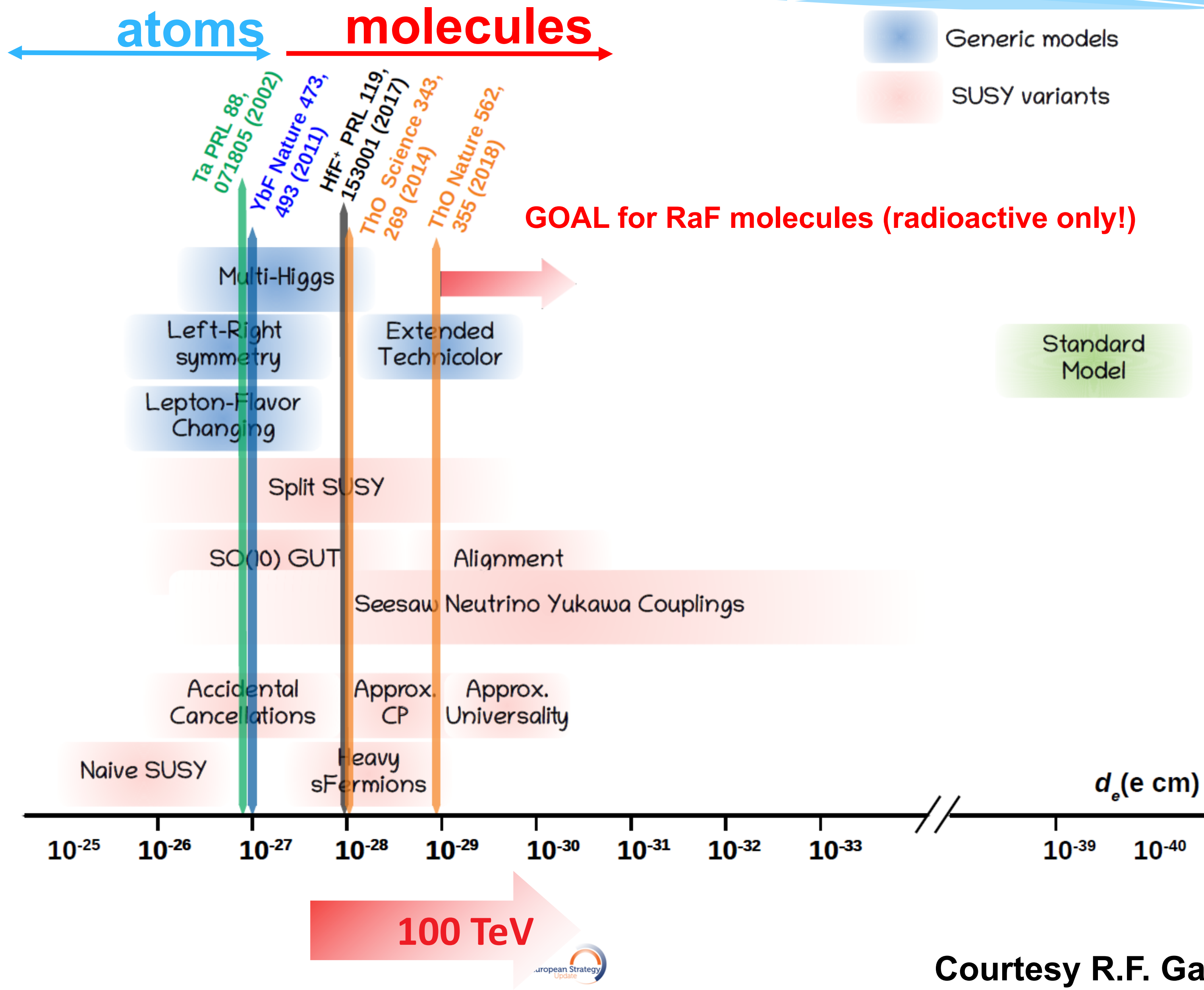
Nuclear physics contributions

2. **SM parameters**
   - 2.1 Leptons
     - 2.1.1 Neutrinos
     - 2.1.2 Charged leptons and fundamental constants
   - 2.2 Baryons
     - 2.2.1 Semi-leptonic decays
     - 2.2.2 Quark mixing matrix
     - 2.2.3 Nucleon and nuclear properties from atomic-physics measurements
       - *Muonic hydrogen and the proton charge radius*
       - *Nucleon and nuclear polarizabilities*
       - *Combining muonic-atom spectroscopy with elastic electron scattering*
       - *Heavy muonic atoms*
       - *Kaonic atoms*
       - *Precision nuclear spectroscopy of thorium-229*
3. **Searches beyond the SM**
   - 3.1 Fundamental-symmetry tests
     - *Searches for CP and T violation*
     - *P violation in atoms, ions and molecules*
     - *Searches for CPT and Lorentz violation*
     - *Spin-statistics tests*
     - *Search for cLFV*
   - 3.2 Dark Matter, Dark Energy and exotic forces
     - 3.2.1 Direct Search for Dark Matter Particles
     - 3.2.2 Test of Dark Energy models with precision experiments
     - 3.2.3 Exotic forces
   - 3.3 Temporal and spatial variation of fundamental constants

- **High precision measurements at low energies**
- **Complementary to experiments at the highest energies and offering sensitivities to new effects beyond the Standard Model**

See talks of Klaus Kirch, Stephan Paul, Gunar Schnell,…

EXAMPLE: best limit on the electron EDM comes from molecules



Courtesy R.F. Garcia Ruiz