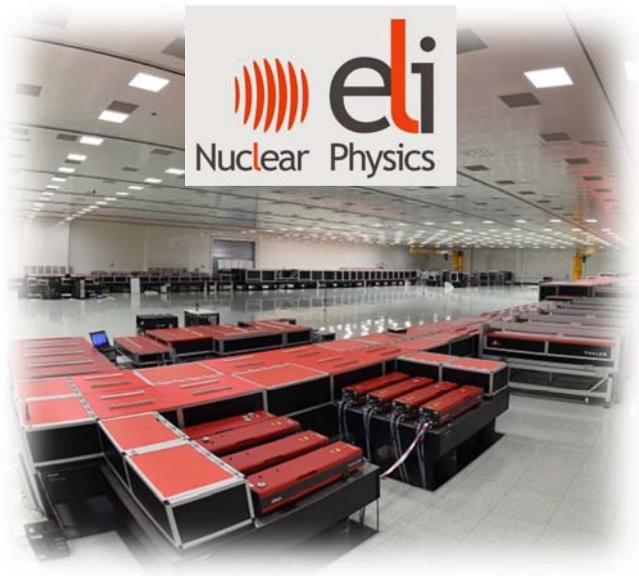
Status report ISOLDE and ELI-NP



TU Darmstadt ▪ Uni Greifswald ▪ Uni Jena ▪ Uni Köln ▪ Uni Mainz ▪ LMU München ▪ TU München

Andreas Zilges • Universität zu Köln • KHUK annual meeting • 12/2020

ISOLDE (Isotope Separator OnLine DEvice)

>50 years at CERN
First such facility worldwide

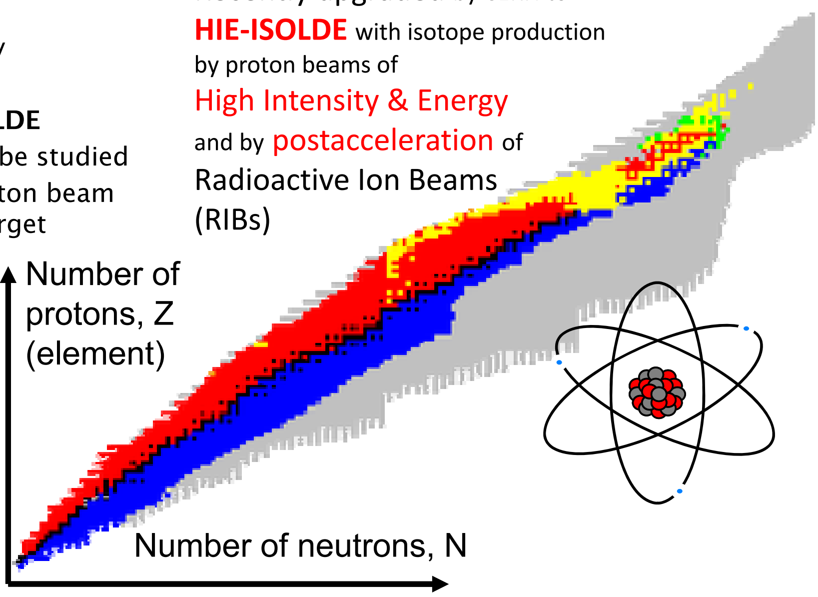
- ~0.1% of CERN budget
- ~ 8 % of CERN users scientists
- ~50 % of CERN protons

Operates ~ 8 months/year, 24/7
~ 100 ongoing experiments

~ 500 active users for physics
~ 50 staff/students/fellows

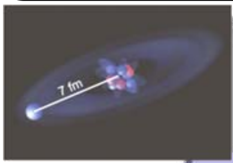
- ~6000 isotopes predicted by theory
- ~3000 isotopes already discovered
- **~1000 isotopes produced by ISOLDE**
- **75 different elements** … ready to be studied
- Method of production: 1.4 GeV proton beam from proton booster sent onto a target
- Challenge: select one (exotic) isotope out of hundreds others produced, most of them with several orders of magnitude higher abundance!

Recently upgraded by CERN to **HIE-ISOLDE** with isotope production by proton beams of High Intensity & Energy and by postacceleration of Radioactive Ion Beams (RIBs)

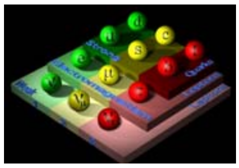


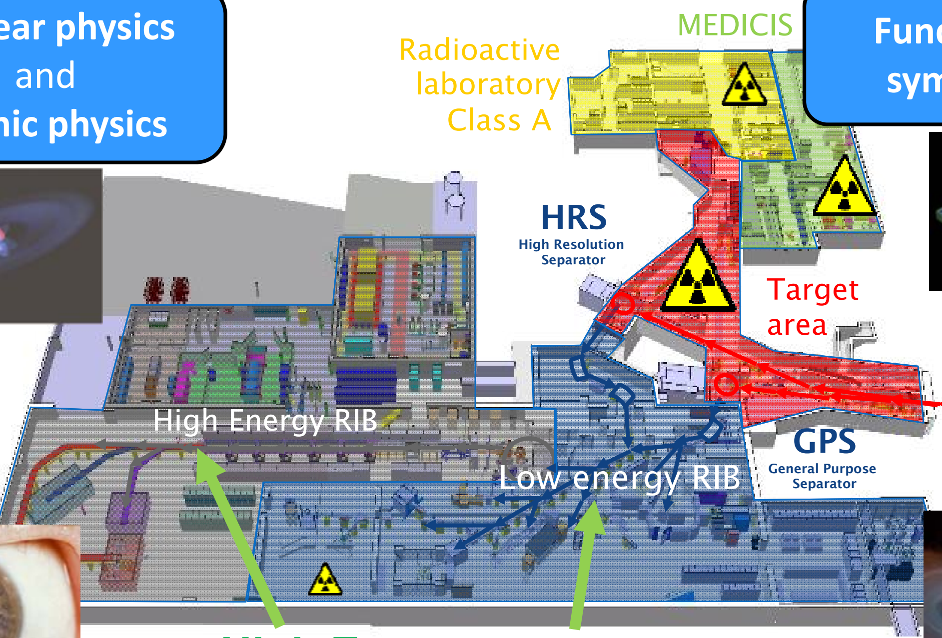
WHAT is studied at ISOLDE? And how?

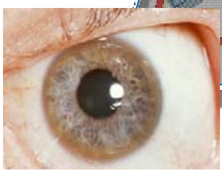
Nuclear physics and atomic physics



Fundamental symmetries







High Energy (up to 10 MeV/u) **Low Energy** (up to 60 keV)

branches of Radioactive Ion Beams (RIBs)

Material science and life sciences

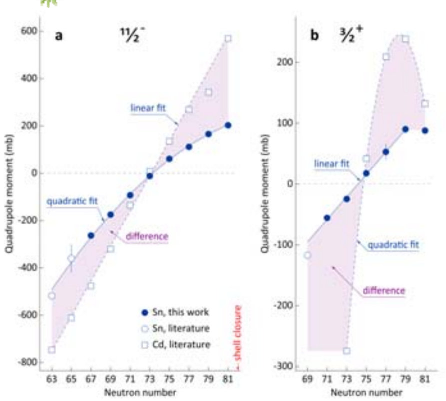
Astrophysics and nucleosynthesis

Research with Low-Energy RIBs

Laser spectroscopy

German university groups: **- TU Darmstadt (Nörtershäuser, Schwenk)**
(with BMBF proposals) **- Univ. Jena (Fritzsche)**
- Univ. Mainz (Wendt)

COLLAPS



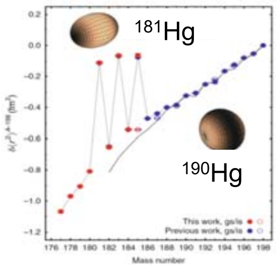
Linear and quadratic behavior of **quadrupole moments** in Sn and Cd revealed by **collinear laser spectroscopy** measurements
Yordanov *et al*., Commun. Phys. **3**, 107 (2020)

COMMUNICATIONS PHYSICS

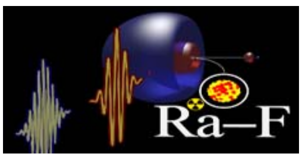
Charge Radii of tin across *A*=132:
Gorges et al.
Phys. Rev. Lett. **122**, 192502 (2019)

Upcoming: MIRACLS
Multi-Ion-Reflection Apparatus for Collinear Laser Spectroscopy

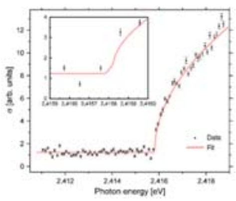
RILIS (resonance ionization laser ion source)



=> nuclear charge radii
=> shape staggering & shape coexistence
in mercury isotopes
Marsh et al. Nature Phys. 14, 1163 (2018)



RaF molecules for tests of fundamental symmetries
Nature 581, 396 (2020)



Electron affinity of At (astatine)
Nature Comm. 11, 3824 (2020)

Research with Low-Energy RIBs

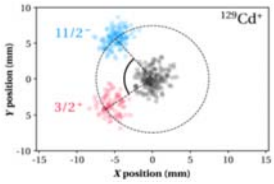
Mass spectrometry

Antiproton Interaction

German university groups: - TU Darmstadt (Obertelli)
(with BMBF proposals) - Univ. Greifswald (Schweikhard)

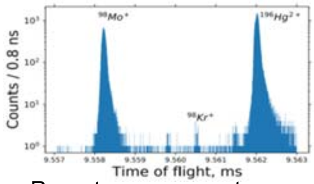
ISOLTRAP as mass spectrometer

=> nuclear binding energies
=> nuclear structure



Penning trap
Isomeric resolving power at half-lives of 150ms

Manea *et al.*, Phys. Rev. Lett. (2020)

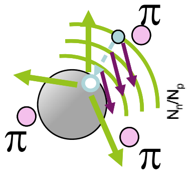


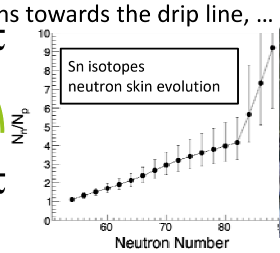
Multi-Reflection Time-of-Flight Mass Spectrometer (MR-ToF MS)

Recent measurement of ^{98}Kr (half-life 40ms)

PUMA (antiProton Unstable Matter Annihilation)

=> probing the skin of nuclei by
$\bar{p} + p \rightarrow ...$ vs. $\bar{p} + n \rightarrow ...$ different pion (charge) distrib.
=> targeting neutron (possibly proton) halos, neutron skins towards the drip line, ...

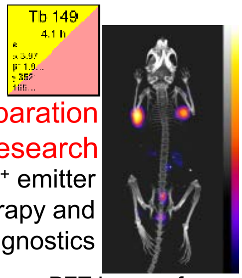




Antiprotons will be „shipped" from ELENA to ISOLDE

isotope separation for medical research

^{149}Tb is α and e⁺ emitter
=> therapy and diagnostics



PET Image of mouse

example

ISOLTRAP as mass separator

=> Highly selective & sensitive ion detector
=> Essential tuning/optimization/background-free detection for many other experiments => ISOLDE develops its own MR-ToF MS

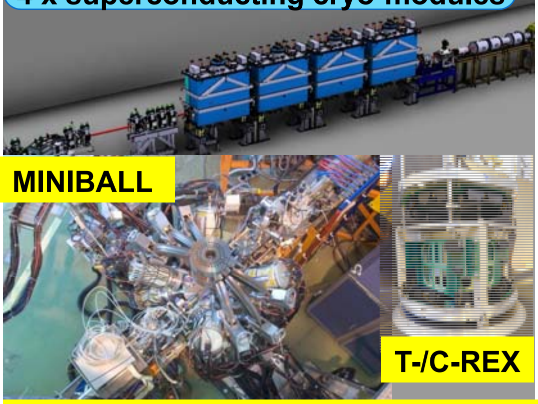
In addition, **IDS** (ISOLDE Decay Station)

Several German univ. groups

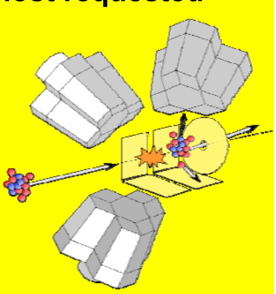
Research with High-Energy RIBs

HIE ISOLDE

Beam energies increase at HIE-ISOLDE up to 10 MeV/u
4 x superconducting cryo-modules

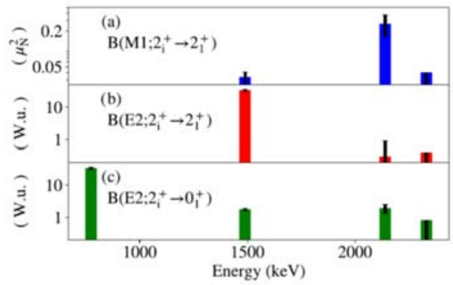


MINIBALL is the most requested instrumentation for experiments with beams from HIE-ISOLDE:
- **Coulomb excitation**
- **nucleon transfer reactions**

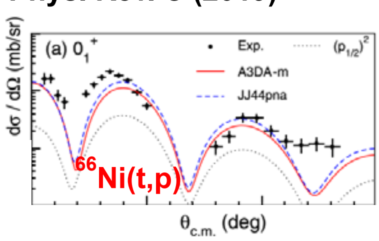


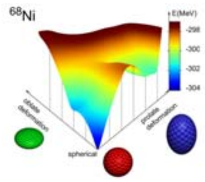
Groups: Jolie, Kröll, Pietralla, Reiter

Coulomb excitation
→ **Valence-shell stabilization in ^{140}Nd**
PRC, Rapid Communication (2020)



Nucleon transfer reactions
→ **shape-coexistence of 0⁺ states in doubly-magic ^{68}Ni**
Phys. Rev. C (2019)



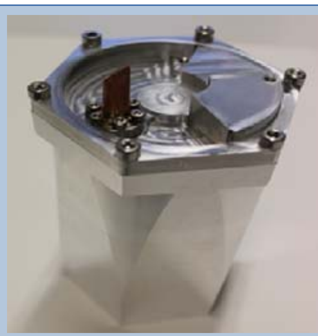


Research with High-Energy RIBs: Upgrade projects

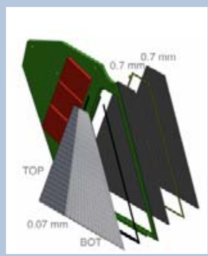
After more than 20 years of operation at ISOLDE, MINIBALL requires upgrades to allow for a successful continuation …

Topics carried out by the German groups:
- completion of exchange of cryostats
- replacement of capsules by advanced reuseable versions

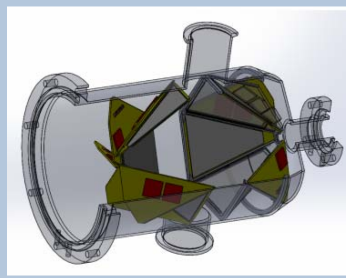
Prototype of new reuseable MINIBALL capsule



Parts of new MINIBALL cryostats



New HI-TREX
NIM A (2021)



German university groups:
- TU Darmstadt (Kröll/Pietralla)
- Univ. zu Köln (Jolie/Reiter/Warr)
- TU/LMU München (Bishop/Gernhäuser/Thirolf)

Spokesperson of MINIBALL collaboration: Th. Kröll

CERN developments

Upgrades for ISOLDE as in the planning of CERN :

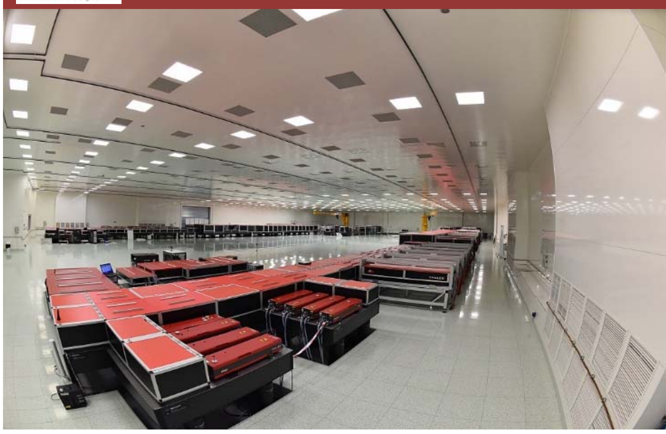
- **Higher RIB beam intensities (factor 2 to 50)** thanks to LHC intensity upgrades (LIU) at CERN
  - Higher proton beam intensity and
  - Higher proton beam energy (up to 2 GeV) from booster
- **New (additional) target stations**
  - to have multiple simultaneous beams (e.g. for low- and high-energy users)
- **Improved mass separation capabilities**
  - for purer beams (less contaminations, also better for efficient reacceleration)

ELI-NP (Extreme Light Infrastructure – Nuclear Physics)

- high power laser system **HPLS**, 2 x 10 PW maximum
- high intensity photon beam system **VEGA**, E_γ = 1-20 MeV from laser-Compton backscattering

ELI-NP is part of the BMBF roadmap for research infrastructures

HPLS – the world‘s most powerful laser system



intensities up to 10^{23} W/cm^2 ● electric fields up to 10^{15} V/m ● 25 fs

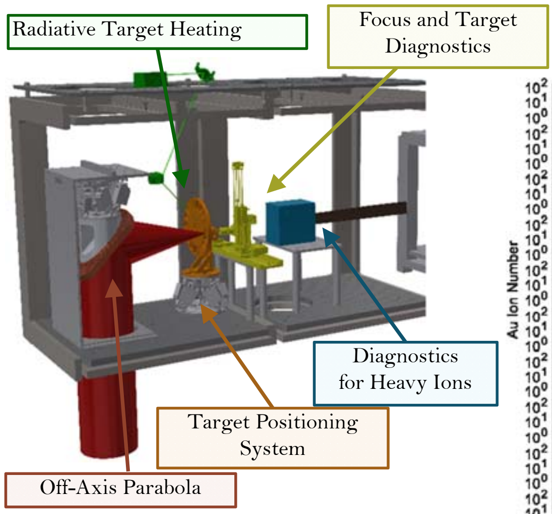
- March 2019: **10 PW reached**
- March 2020: **first experiment**
- November 2020: **inaugural symposium**
- 2021: **start of normal user operation mode**

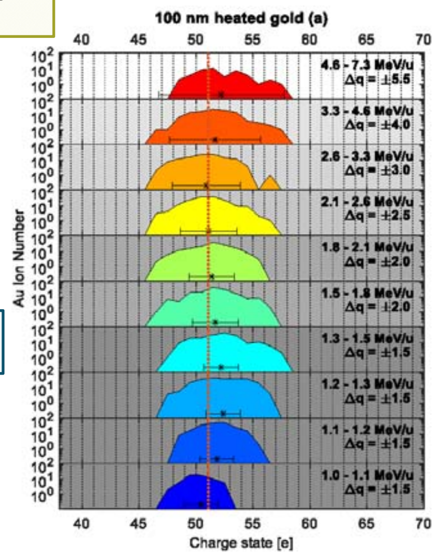
HPLS – unique properties of laser accelerated ions

P.G. Thirolf et al.

High-power (PW), short pulse (30 fs) laser ion acceleration:

→ unprecedented ion-bunch densities („solid-state“)
  („fission-fusion“ mechanism creating extremely n-rich nuclei)





F. Lindner et al., Phys. Plasm. Contr. Fusion 61, 055002 (2019)

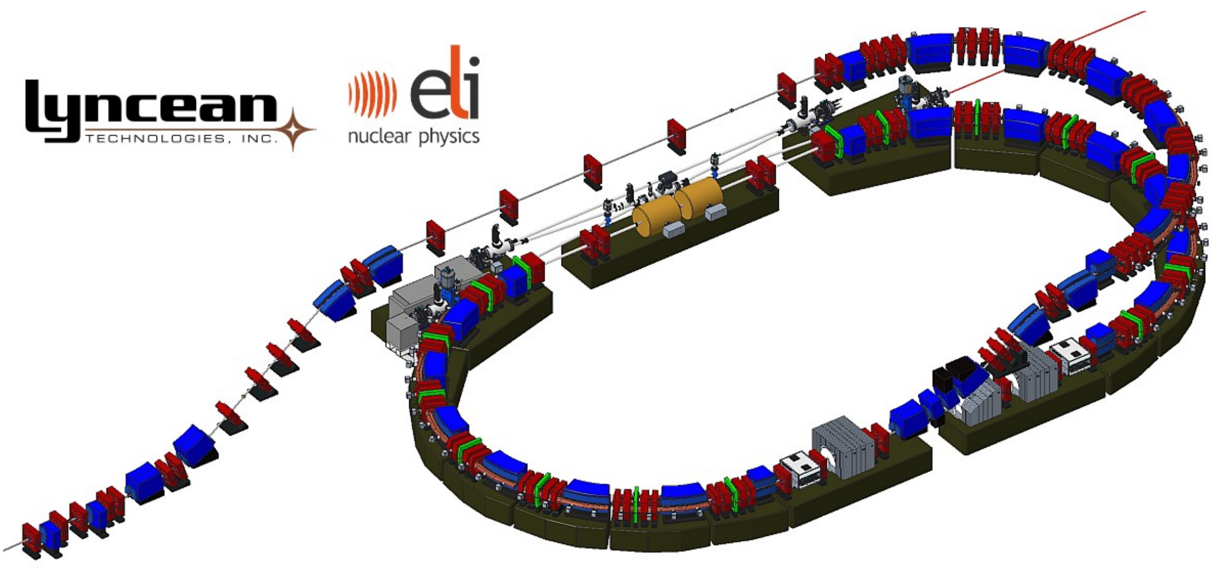
recent highlights:

- world record for laser acceleration of heavy ions (^{197}Au: 7 MeV/u)
- first-time resolution of charge states
- target positioning, cleaning, diagnostics

VEGA – a gamma beam with highest brilliance

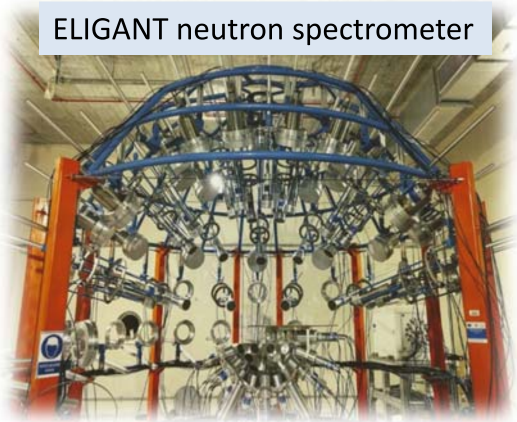
Intense laser beam with λ = 532 nm (1064 nm) colliding with electrons (E = 234-742 MeV) in storage ring

→ variable energy, fully polarized photon beam with E_γ = 1-20 MeV, bandwidth < 0.5%, intensity > 10^{11} γ/s, 35 MHz repetition rate



VEGA – a gamma beam with highest brilliance

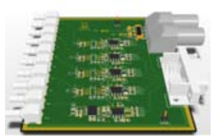
- October 2019: **contracting with Lyncean Technologies, USA**
- March 2020: **TDR accepted**
- November 2022: **operation with intermediate parameters**
- February 2023: **full implementation**

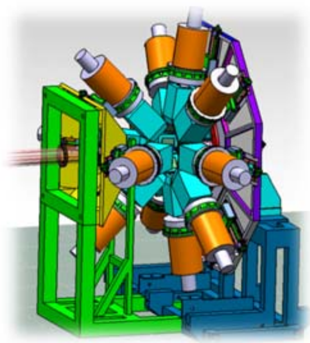


all experimental setups fully financed
and (nearly) ready for day-zero experiments

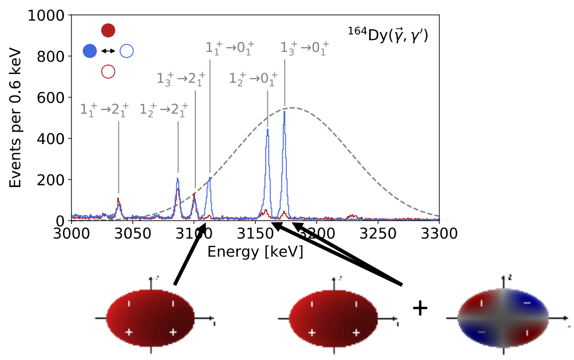
Preparatory work of German university groups (examples)

- **Development and test of instrumentation for ELI-NP**
  - online γ-beam monitor
  - double-Frisch grid photofission chamber
  - ELIADE γ-array signal processing
  - photon-target interaction zone





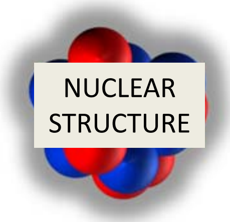
- **Precision spectroscopy of exotic nuclear modes with photons**
  - E2 properties of the scissors mode (*T. Beck et al., PRL 118 (2017) 212502.*
  - identification of excitations with negative R symmetry *(T. Beck et al., PRL 125 (2020) 092501)*
  - photon strength function of ^{87}Rb: s process branching *(J. Wilhelmy et al., PRC 102 (2020) 044327)*

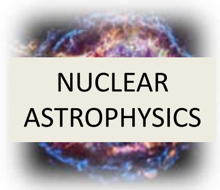


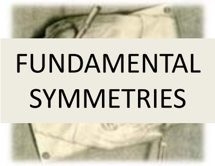
ELI-NP: Nuclear Photonics

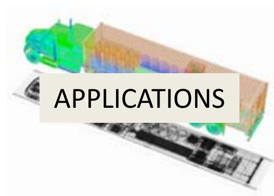
Scientific program for day-one experiments (user workshop and LoIs 2019/20):

- photon scattering on rare isotopes
- mapping the fission barrier of ^{232}Th, ^{234,238}U
- dipole modes in actinides
- low-lying doorways in ^{180}Ta
- cluster structures in heavy isotopes
- total photoabsorption in nuclei









→ nuclear photonics

„With ELI-NP, we are now standing on the threshold of a renaissance in Nuclear Physics field, in which photons may also be used to directly manipulate and excite nuclear structure.“

Gérard Mourou, The Nobel Prize in Physics 2018