

ISOLDE: Focus on Exotic Beams



n_ToF Physics



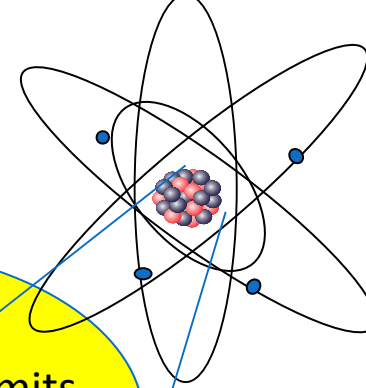
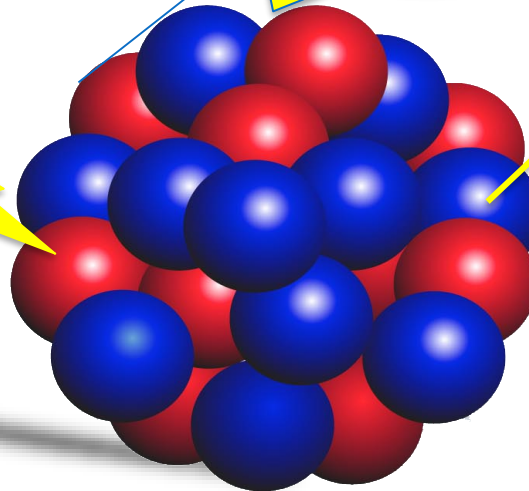
Maria J. G. Borge
ISOLDE-PH, CERN
(Isotope Separator On-Line)

Open Questions

¿ How does the complexity of nuclear structure arise from the interaction between nucleons?

What are the limits of nuclear stability?

How and where in the Universe are the chemical elements produced?



NuPECC NuPECC
Long Range Plan 2017
Perspectives
in Nuclear Physics

Observables:

Basic ground state properties:
mass, radius, moments J , μ , Q
Half-life γ decay process
Transition probabilities

Theoretical Models:

Shell Model (magic numbers)

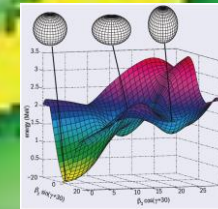
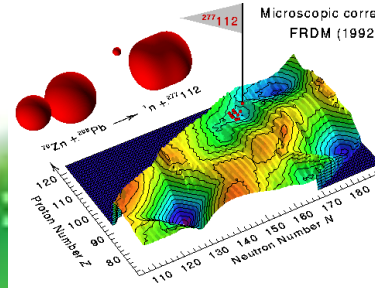
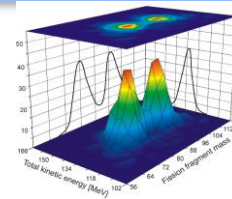
Mean field Calculations (collective properties)

Ab Initio Calculations (light nuclei)

Hot subjects in Nuclear Physics

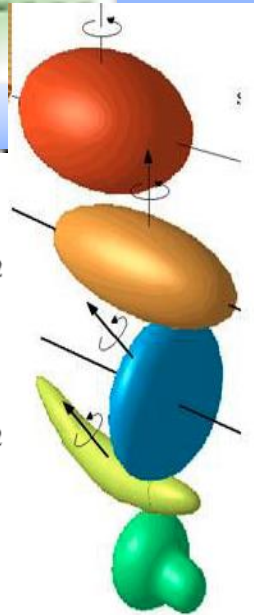
Nuclear Physics Magnificent Complexity

Fission Dynamics



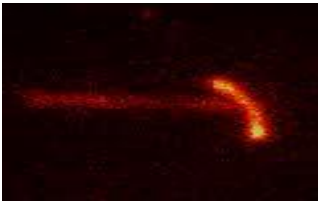
Shape Coexistence

Super-heavies



Exotic Shapes

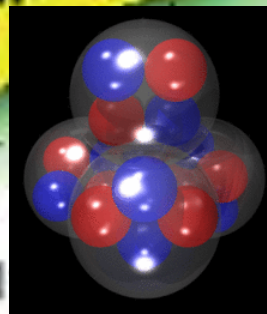
Exotic Decay Modes



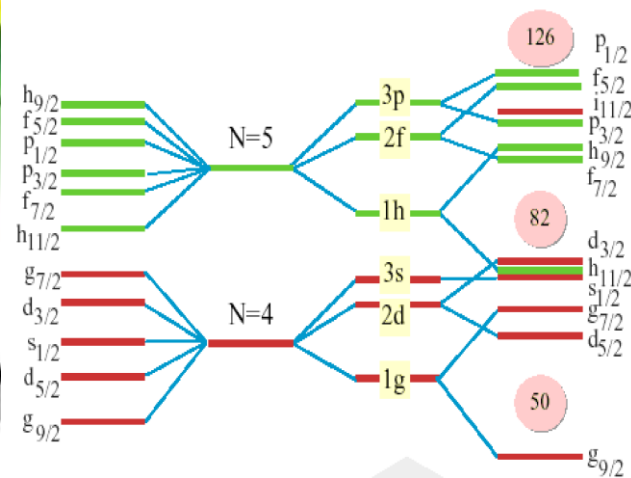
^{220}Ra



clusters



Neutron Halo



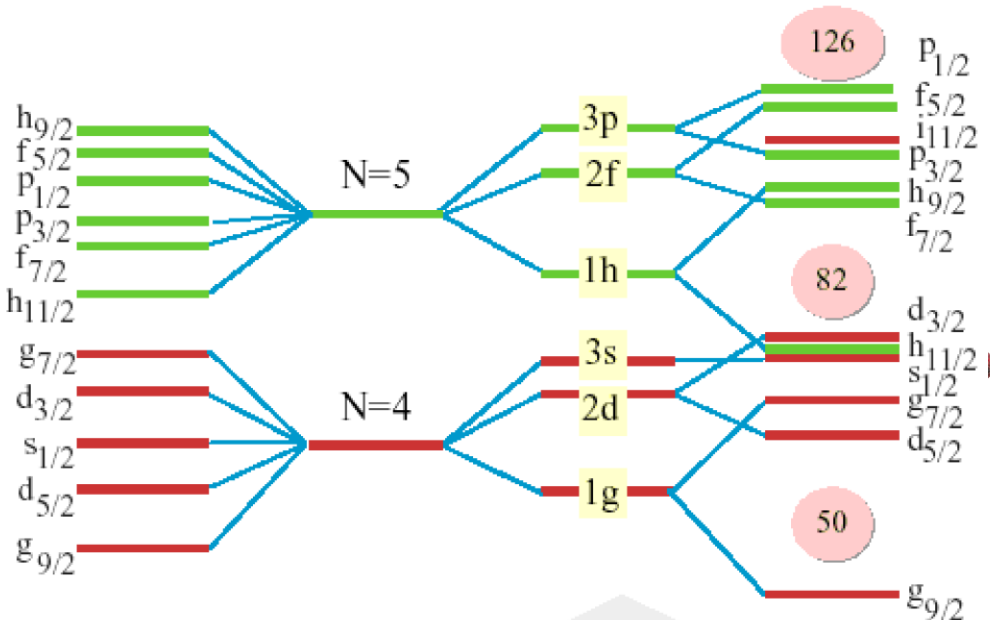
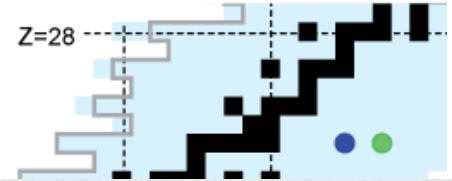
New Magic Numbers

The Nuclear Shell Model: Universal Magic Numbers ?

Mayer & Jensen (1949)



- Nuclei exhibit shell structure
 - Filled orbitals = « magic nuclei »
 - Valence nucleons are crucial
 - We rely on the Shell Model, with magic nuclei as the building blocks, to predict the structure of exotic nuclei



very diffuse surface
neutron drip line

harmonic oscillator

no spin orbit
exotic nuclei/
hypernuclei

around the valley of β -stability

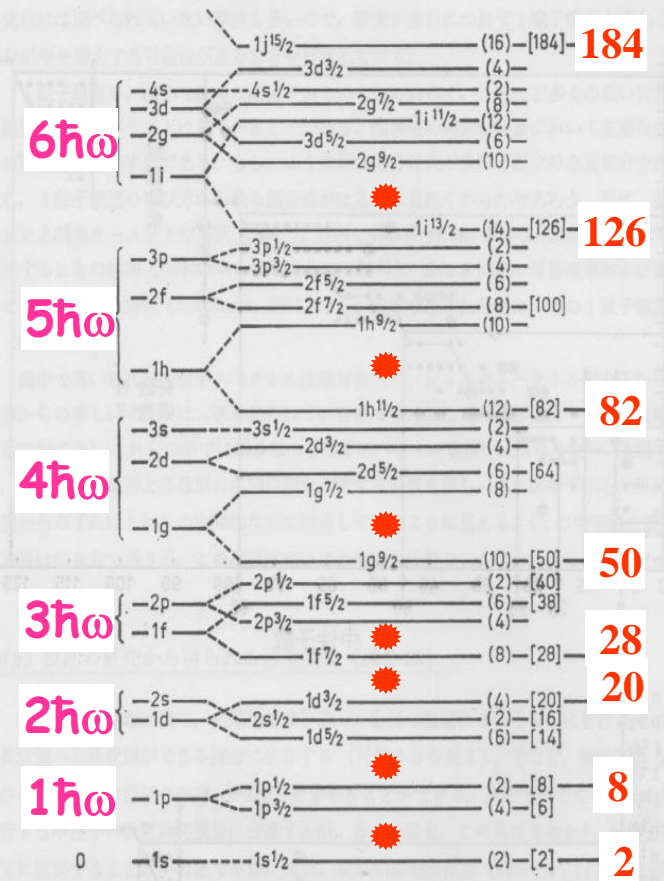


図2-23 1粒子軌道の順序。図は M. G. Mayer and J. H. D. Jensen, *Elementary Theory of Nuclear Shell Structure*, p. 58, Wiley, New York, 1955 からとった。

Nucleo-synthesis: Stellar scenario

- Protons & Neutrons are produced 10^{-6} s – 1s after the Big Bang (13.7×10^9 years ago)
- H, D, He, Li, Be, B were formed 3 - 20 min after the Big Bang
- Heavier nuclei are formed along the life of the star

rp-, p-process:

- masses at & beyond the proton drip-line
- (p, γ) , (γ, p) rates



Proton number, Z ↑

20
8
2

2 8 — Neutron number, N →

Synthesized

Stable

Nucleogenesis

UNKNOWN NUCLEI

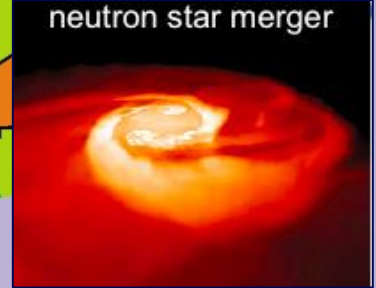
rp-process

r-process:

- masses, half-lives
- β -delayed neutron emission
- (γ, n) , (n, γ) rates
- shell structure



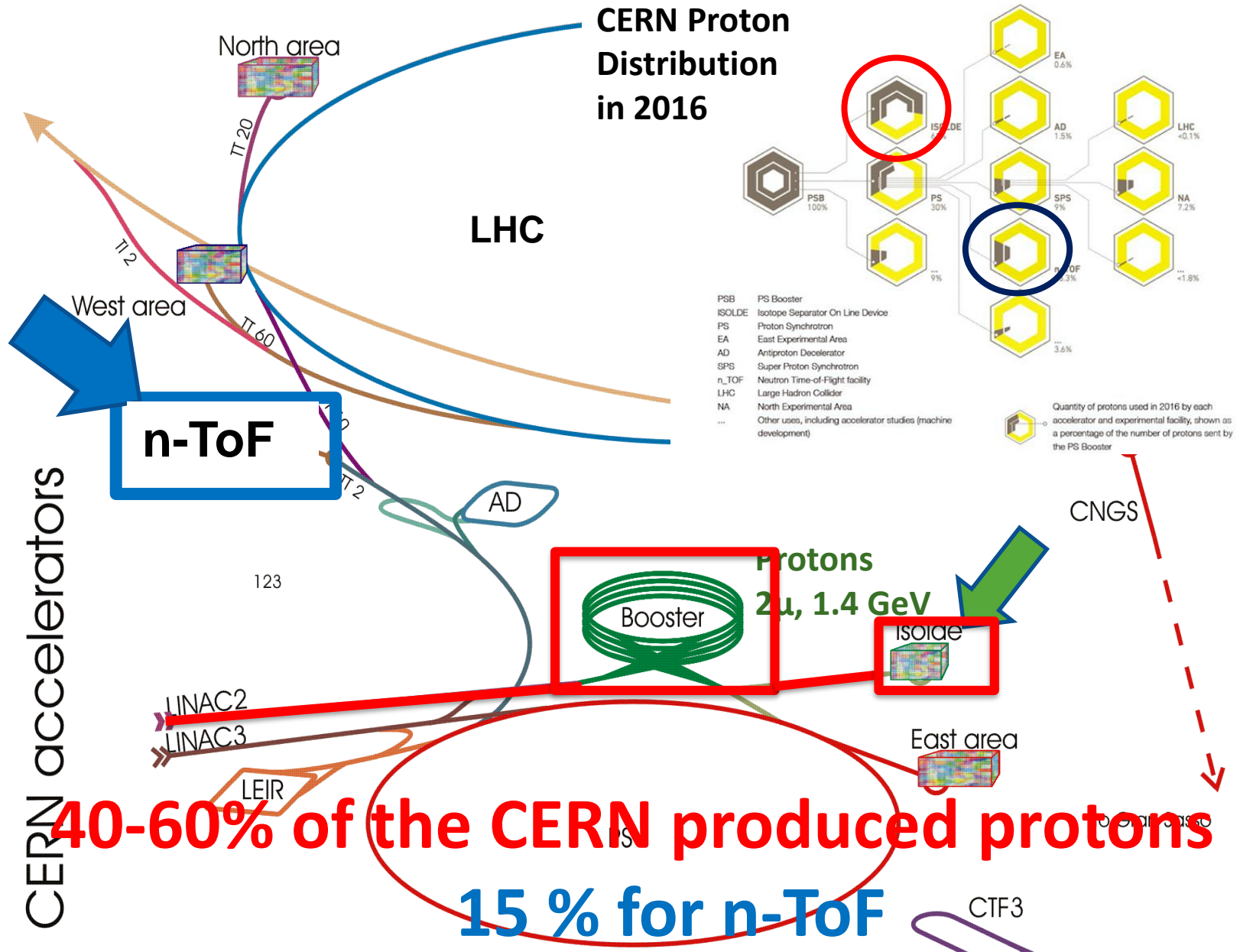
neutron star merger



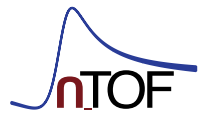
→ Combine accurate nuclear physics with precision astronomy to **constrain astrophysical scenarios**

114
184

ISOLDE & n_ToF at CERN

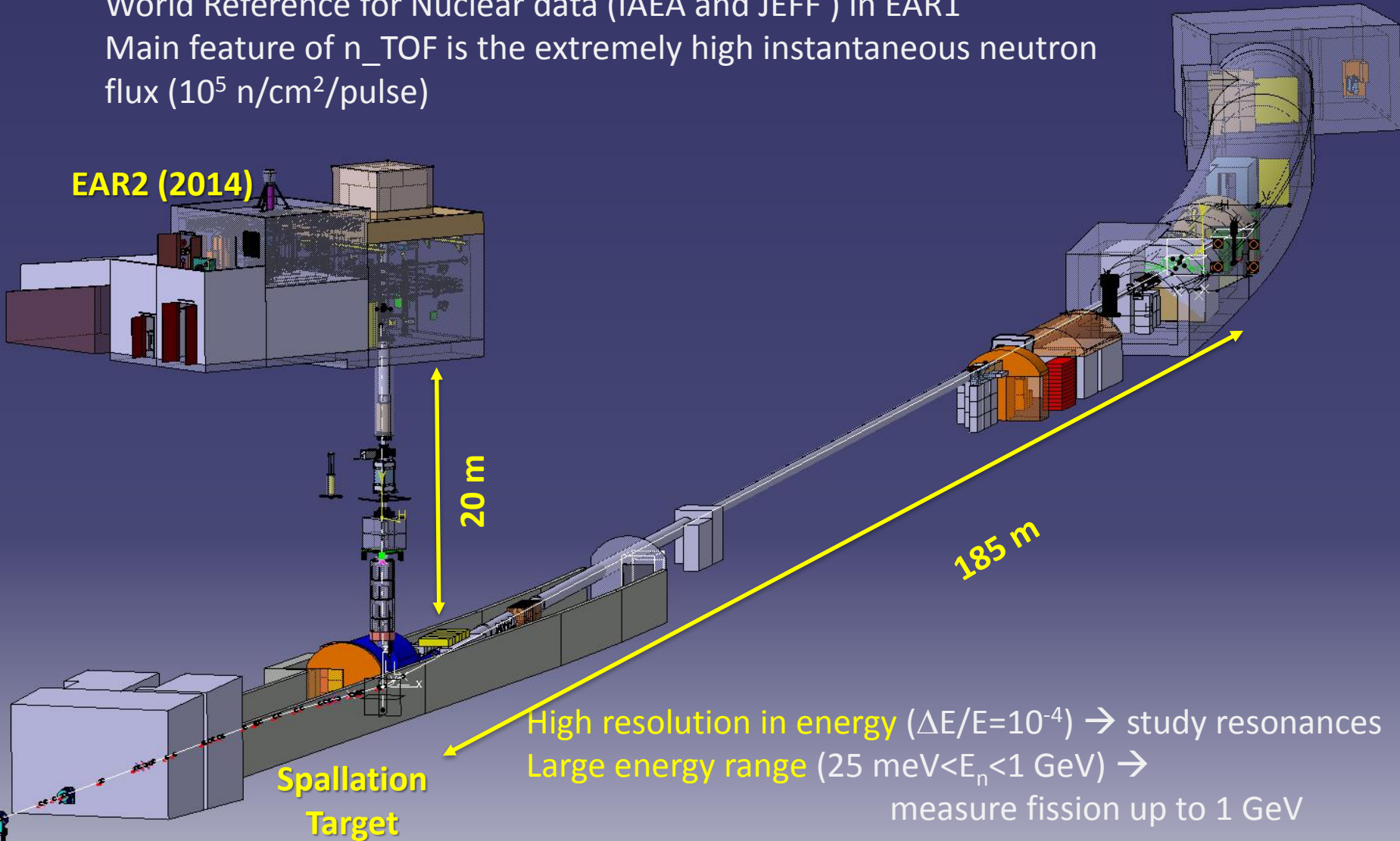


The neutron time of Flight Facility



World Reference for Nuclear data (IAEA and JEFF) in EAR1
Main feature of n_TOF is the extremely high instantaneous neutron flux (10^5 n/cm²/pulse)

EAR2 (2014)



High resolution in energy ($\Delta E/E=10^{-4}$) \rightarrow study resonances
Large energy range ($25 \text{ meV} < E_n < 1 \text{ GeV}$) \rightarrow
measure fission up to 1 GeV

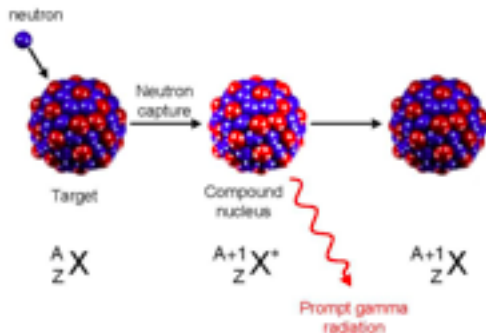
Physics at n-ToF

104 ISOTOPES MEASURED

- ◆ Fission (n,f)
- ◆ radiative capture (n, γ)
- ◆ charged particle (n,cp)

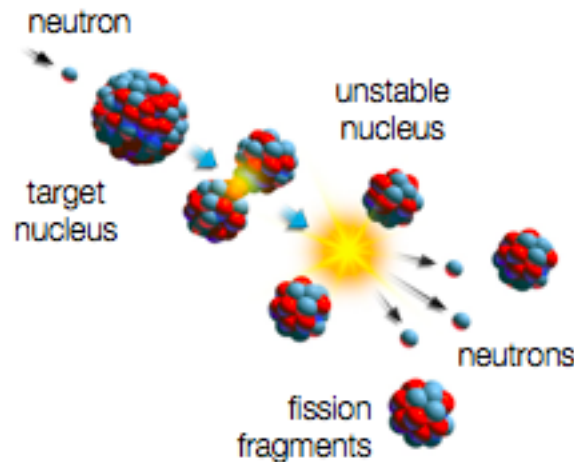
EAR2		SI	7 Be
SI		26 Al	
SI	7 Be	MGAS	237 Np

Radiative capture (n, γ)



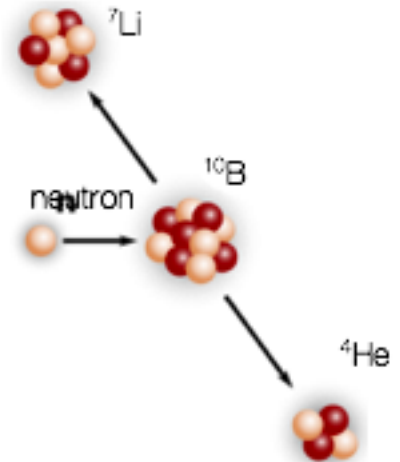
Particle to be detected:
 γ ray

Fission (n, f)



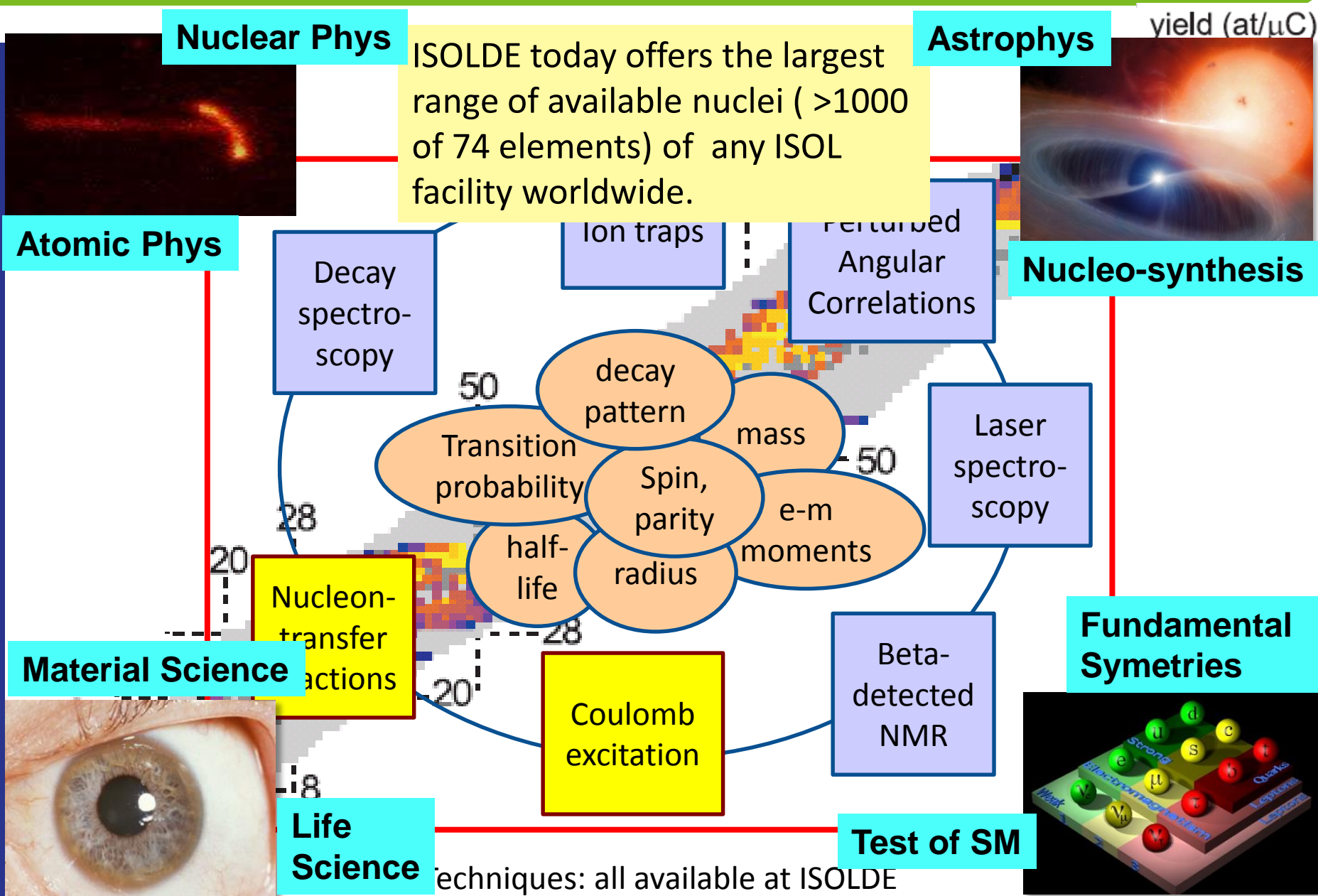
Particle to be detected:
fission fragments

Charged particle emission (n, cp)



Particle to be detected:
light charged particles

Research with radioactive nuclides @ ISOLDE



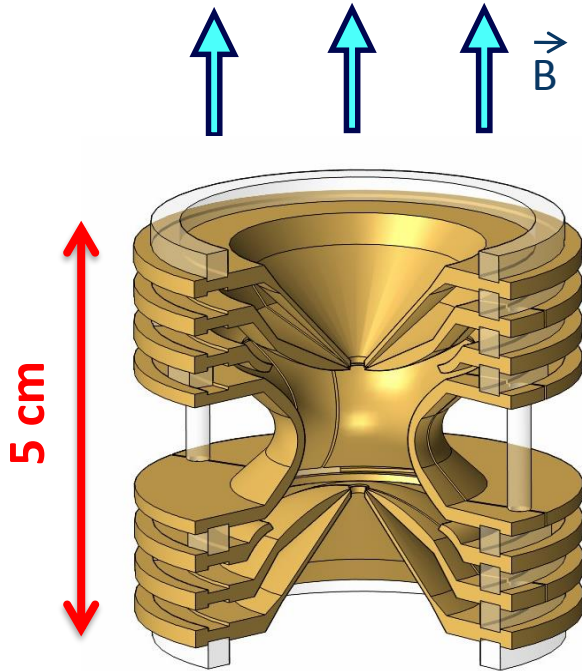
Masas & Números mágicos



$$M_{\text{Atom}} = N \cdot m_{\text{neutron}} + Z \cdot m_{\text{proton}} + Z \cdot m_{\text{electron}} - (B_{\text{atom}} + B_{\text{nucleus}}) / c^2$$

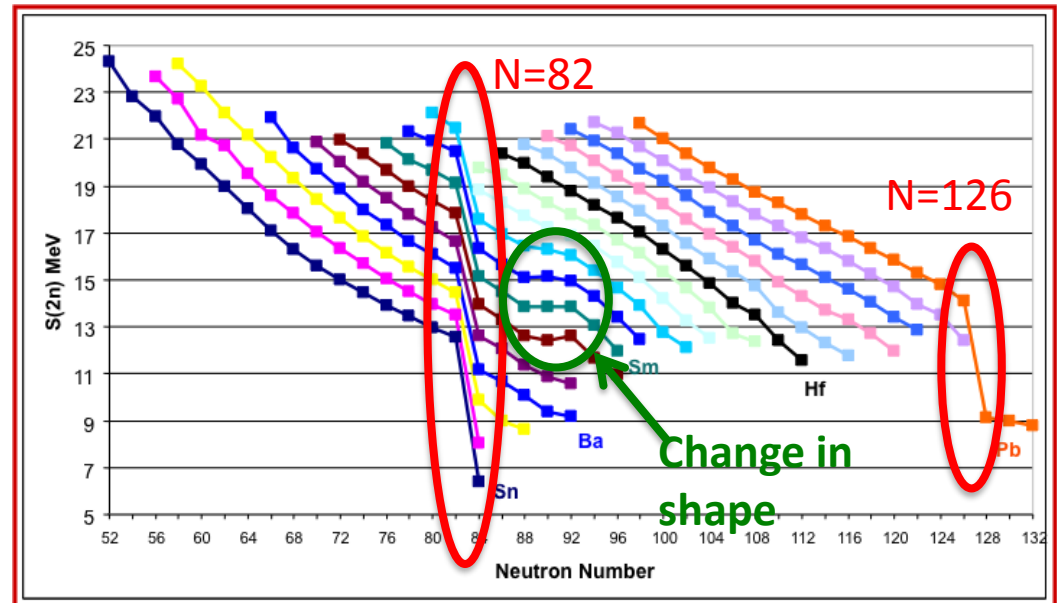
$$\delta m / m < 10^{-10}$$

$$\delta m / m = 10^{-6} - 10^{-8}$$

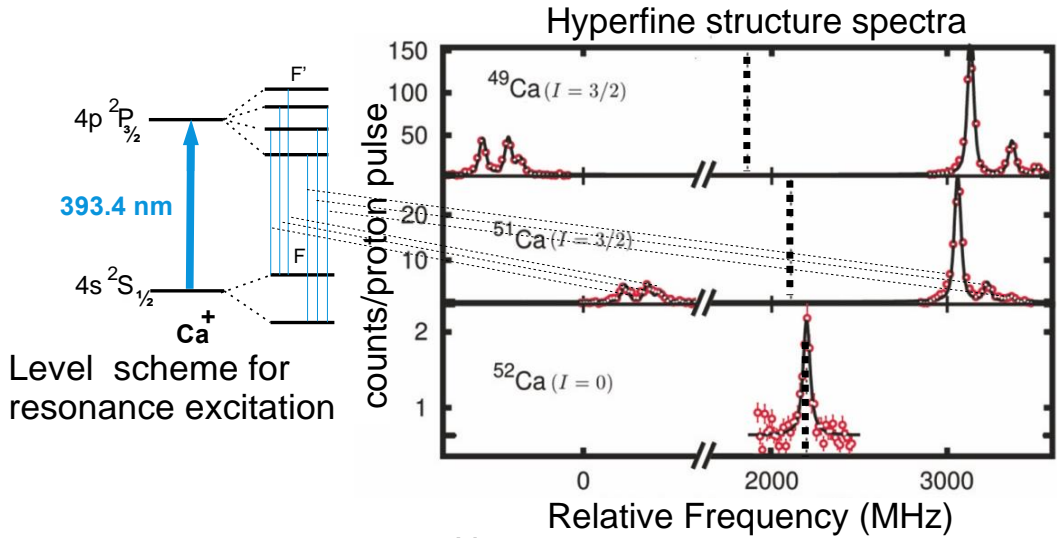


$$\omega_c = qB / m$$

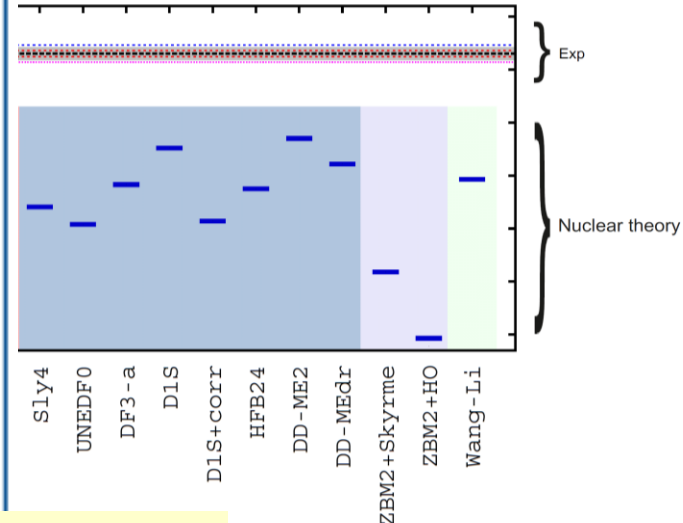
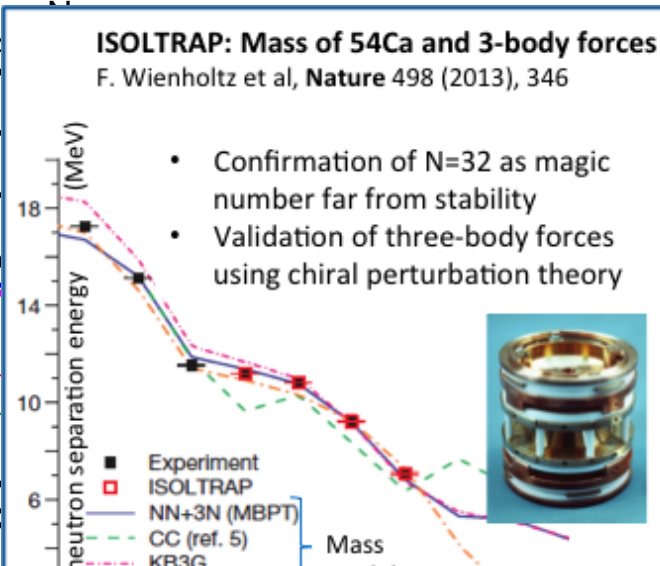
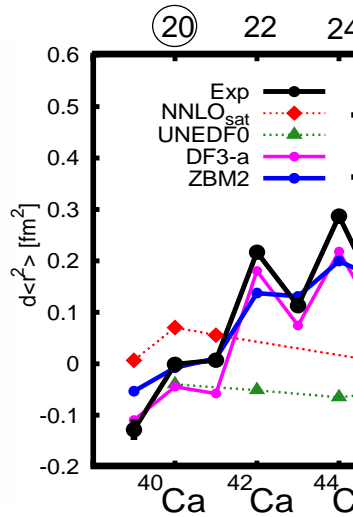
$$S_{2n}(N, Z) = ME(N-2, Z) - ME(N, Z) + 2 \cdot ME(n)$$



Exploring the nature of N=32



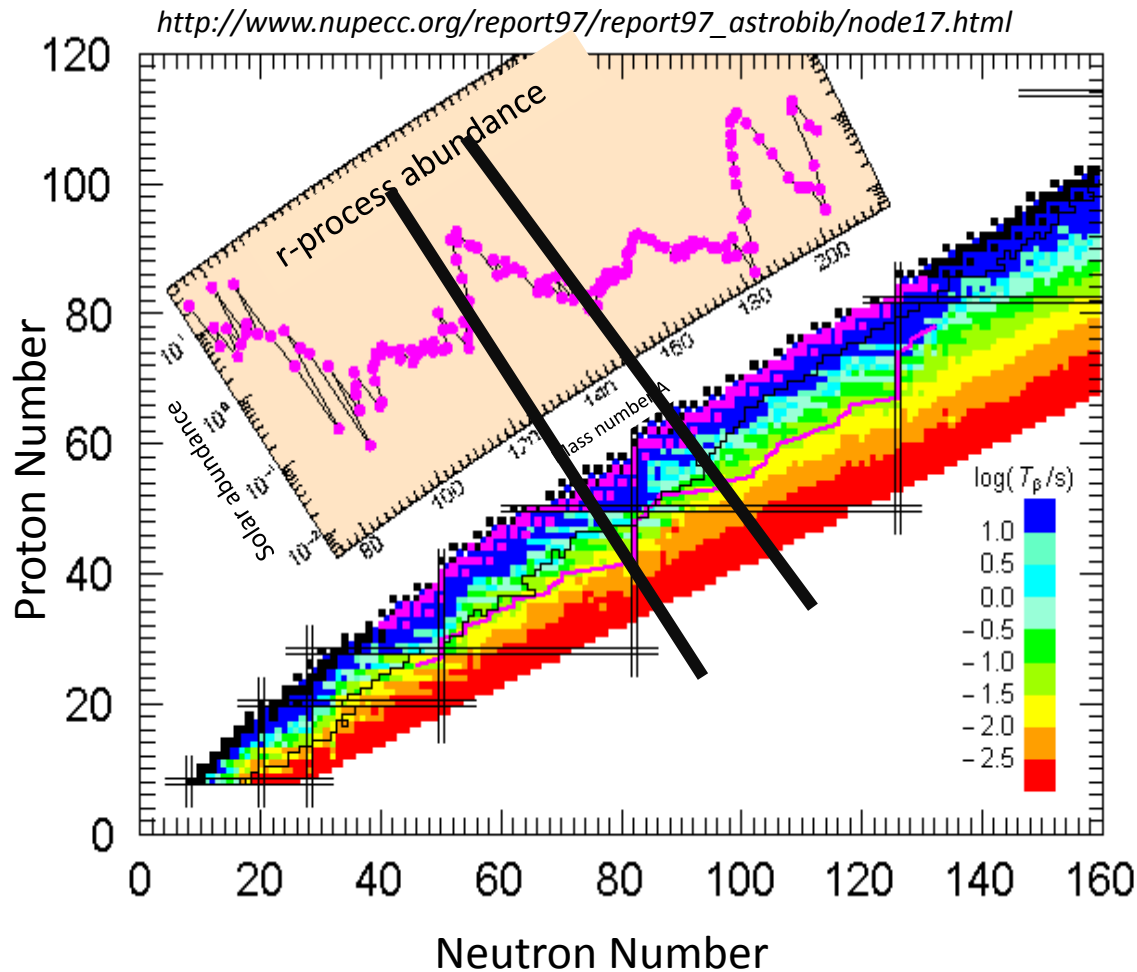
- Collinear laser Spectroscopy study of Ca-isotopes: $^{40-52}\text{Ca}$
- Change in nuclear size produces a shift in the hfs.



R. F Garcia Ruiz et al., Nature Physics 12 (2016) 594

The astrophysical r-process

- The r-process is a two step process:
 1. Neutron capture until n- γ equilibrium
 2. beta-decay

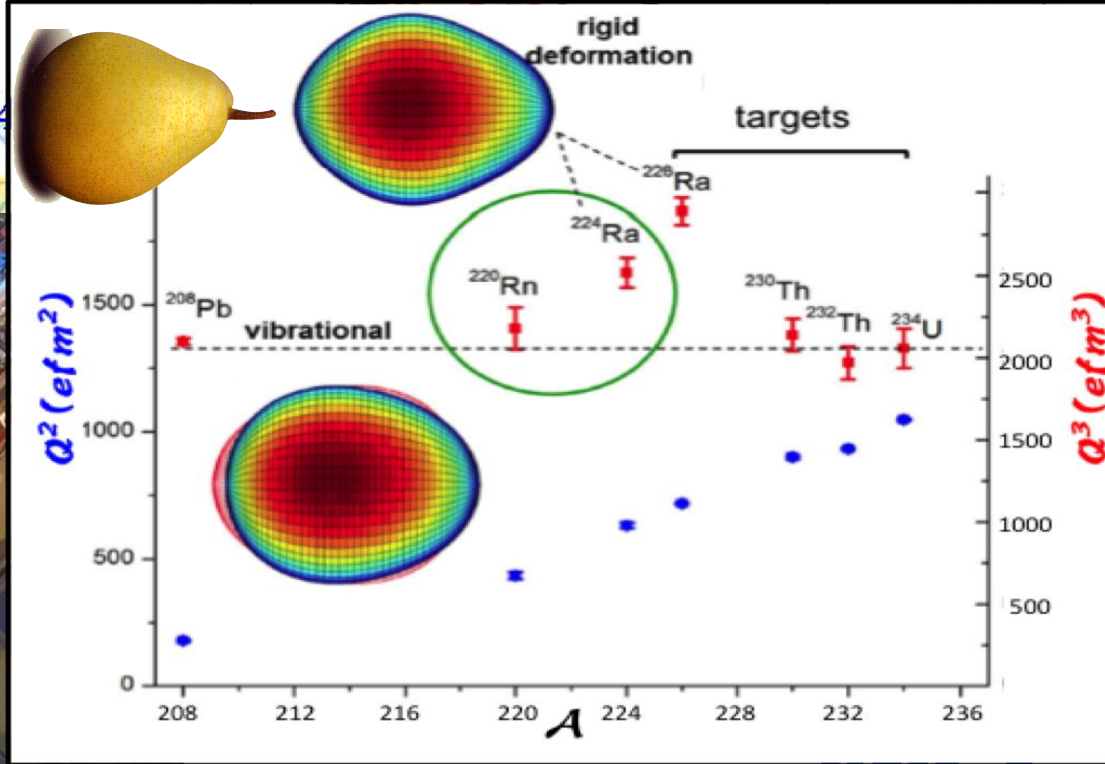
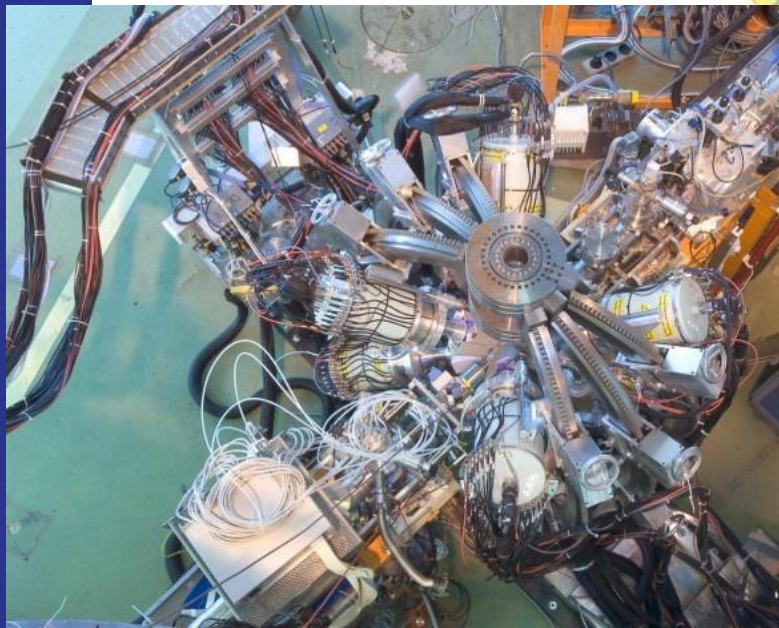
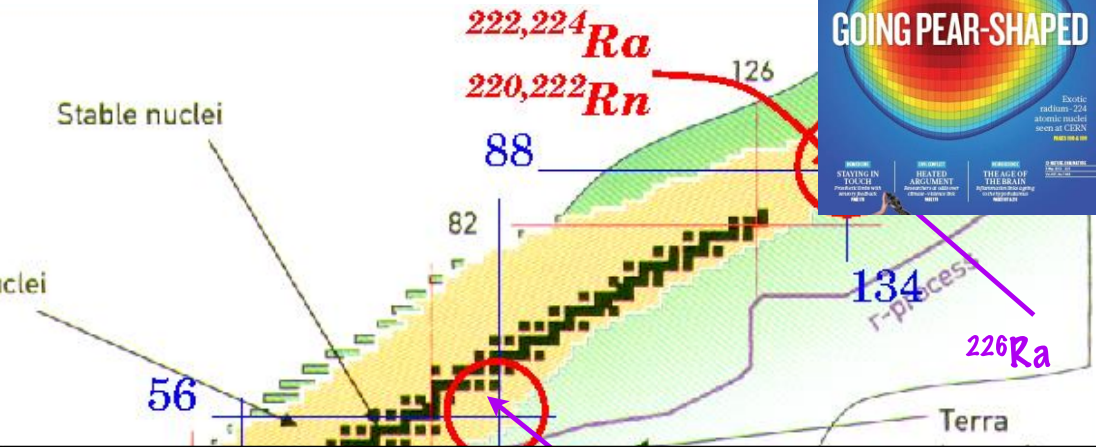
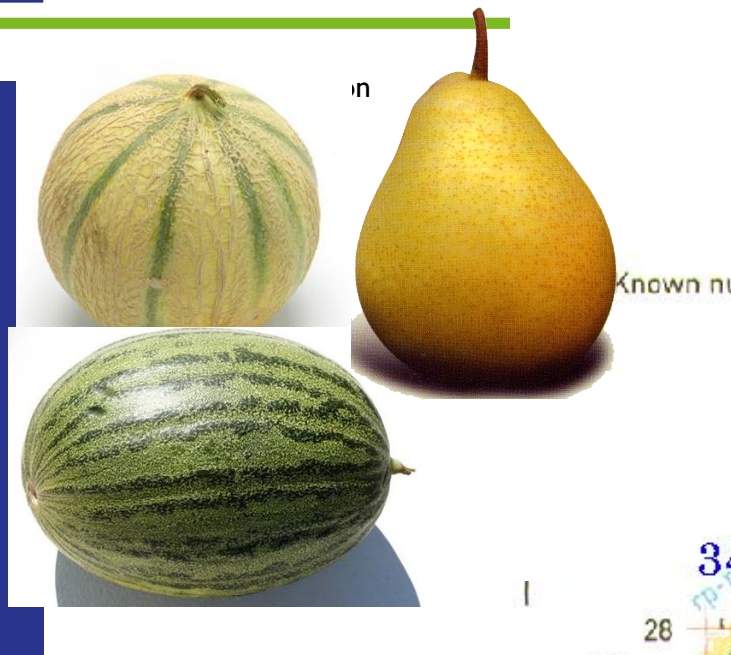


- N-rich Cd isotopes important for the r-process:
- $^{129-131}\text{Cd}$ masses @ISOLTRAP
- βn with VANDLE @ IDS
- Radii and Q-moments @ COLLAPS

Pure Cd-beams thanks to

- UC-target with neutron converter and cold quartz line, and ionized with RILIS.

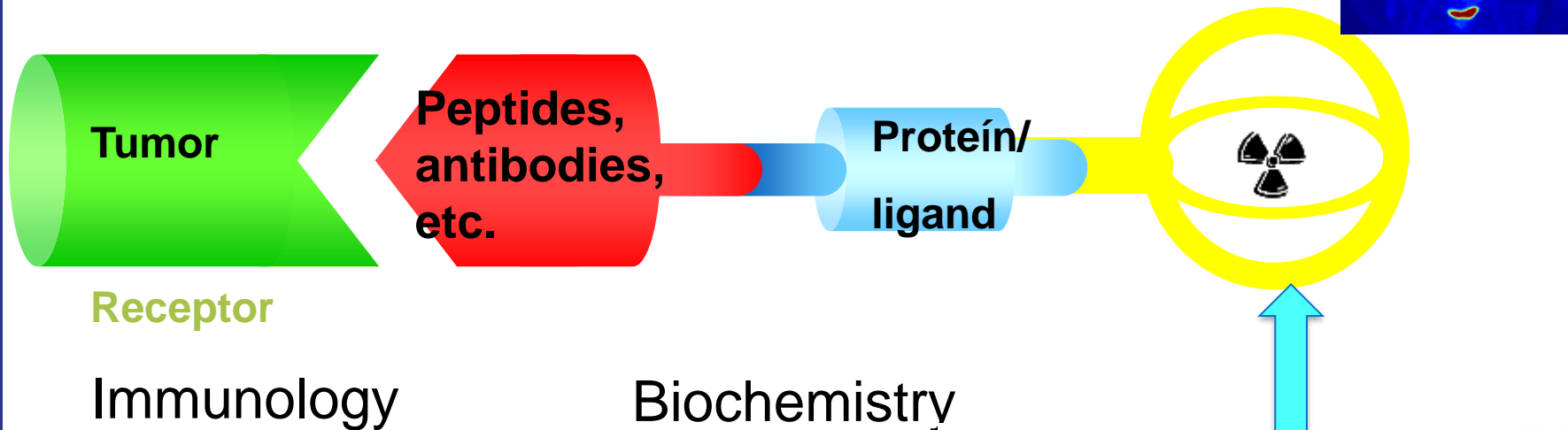
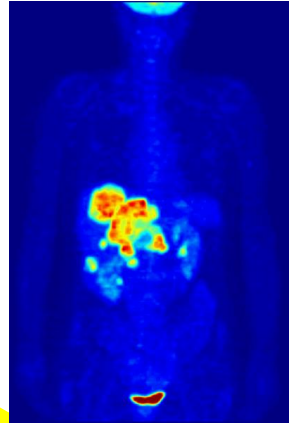
Searching for pear-shaped nuclei @ ISOLDE



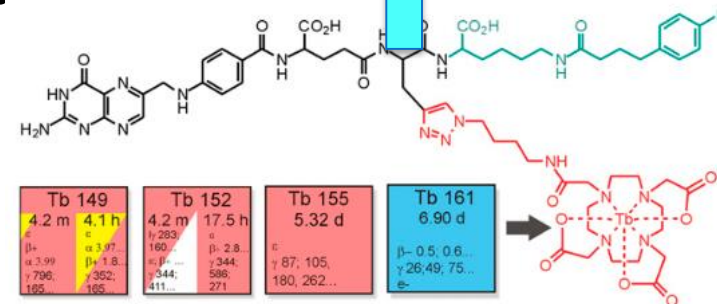
L. P. Gaffney, et al. (2013). Nature, 497(7448), 199–

Multidisciplinary Efforts to fight the cancer

Personalised Treatment ↔ Different responses to the same drug
 Same Chemical elements of Diagnosis and Treatment : Theranostics

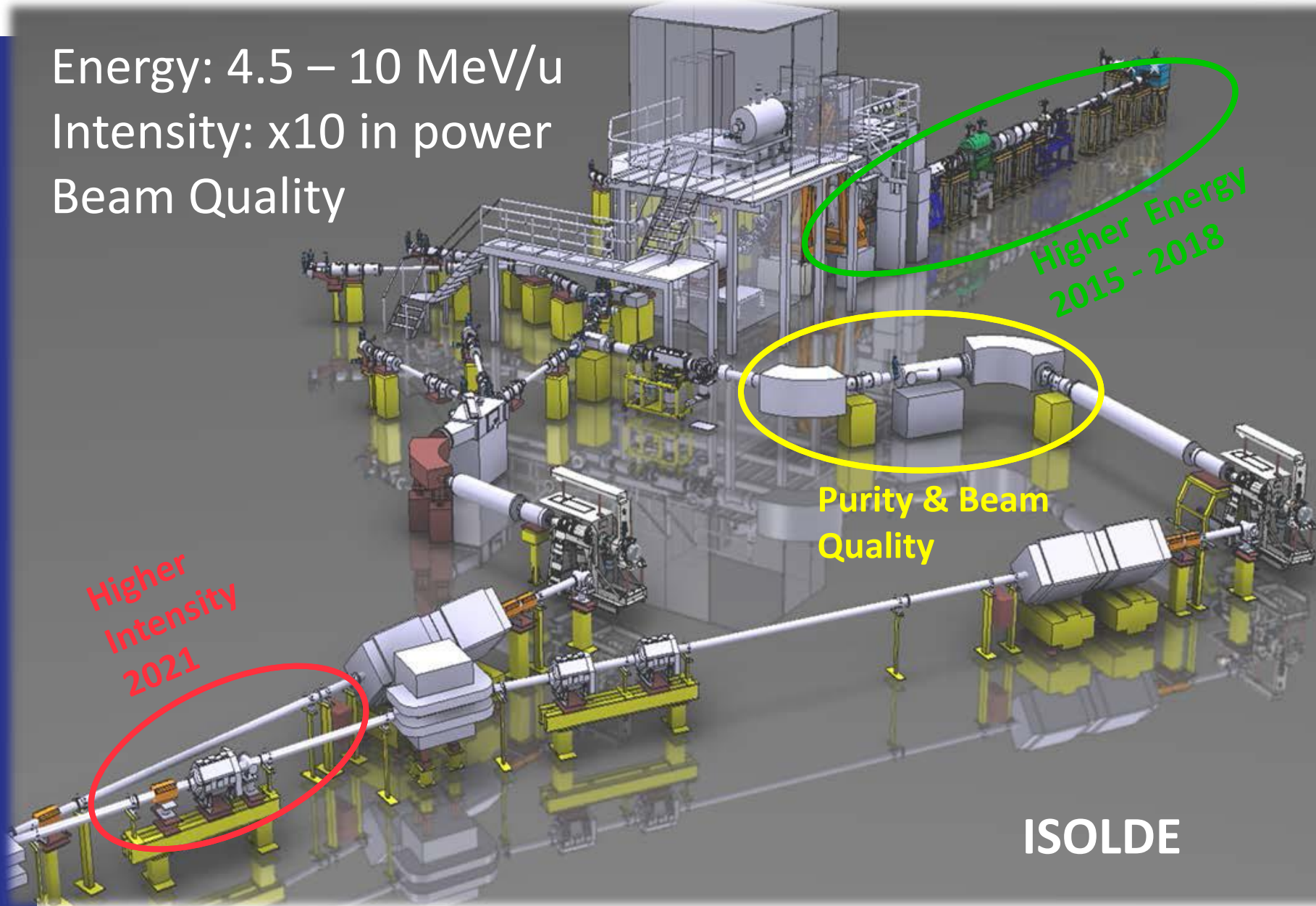


Bombesin is a ligand successfully used with ^{155}Tb (5 d) and ^{125}I (59 d) for prostate, mama and stomach cancers



The HIE-ISOLDE project: I ↗, E ↗

Energy: 4.5 – 10 MeV/u
Intensity: x10 in power
Beam Quality

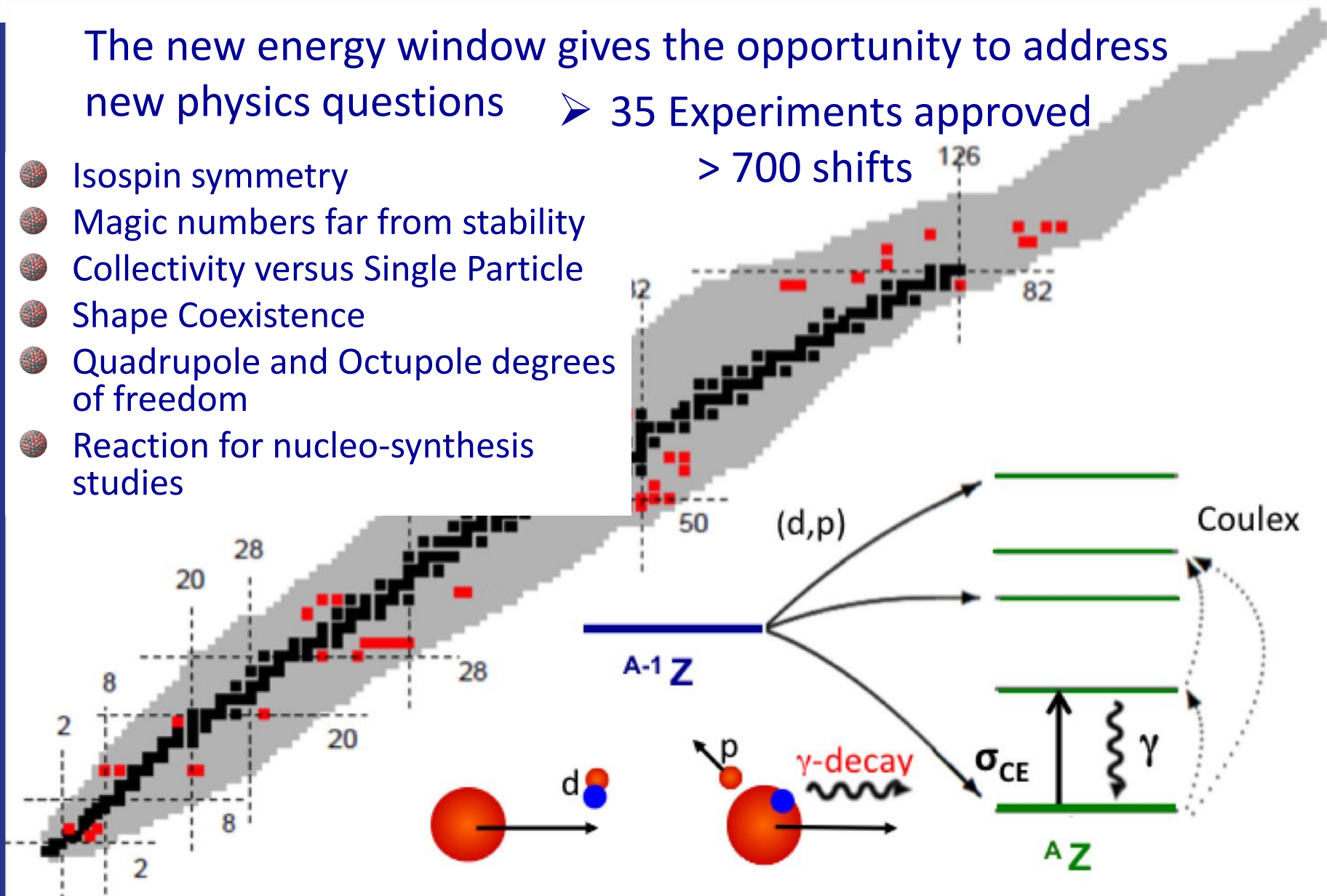


Physics at HIE-ISOLDE

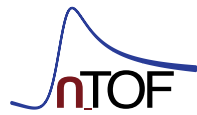
The new energy window gives the opportunity to address new physics questions ➤ 35 Experiments approved

> 700 shifts

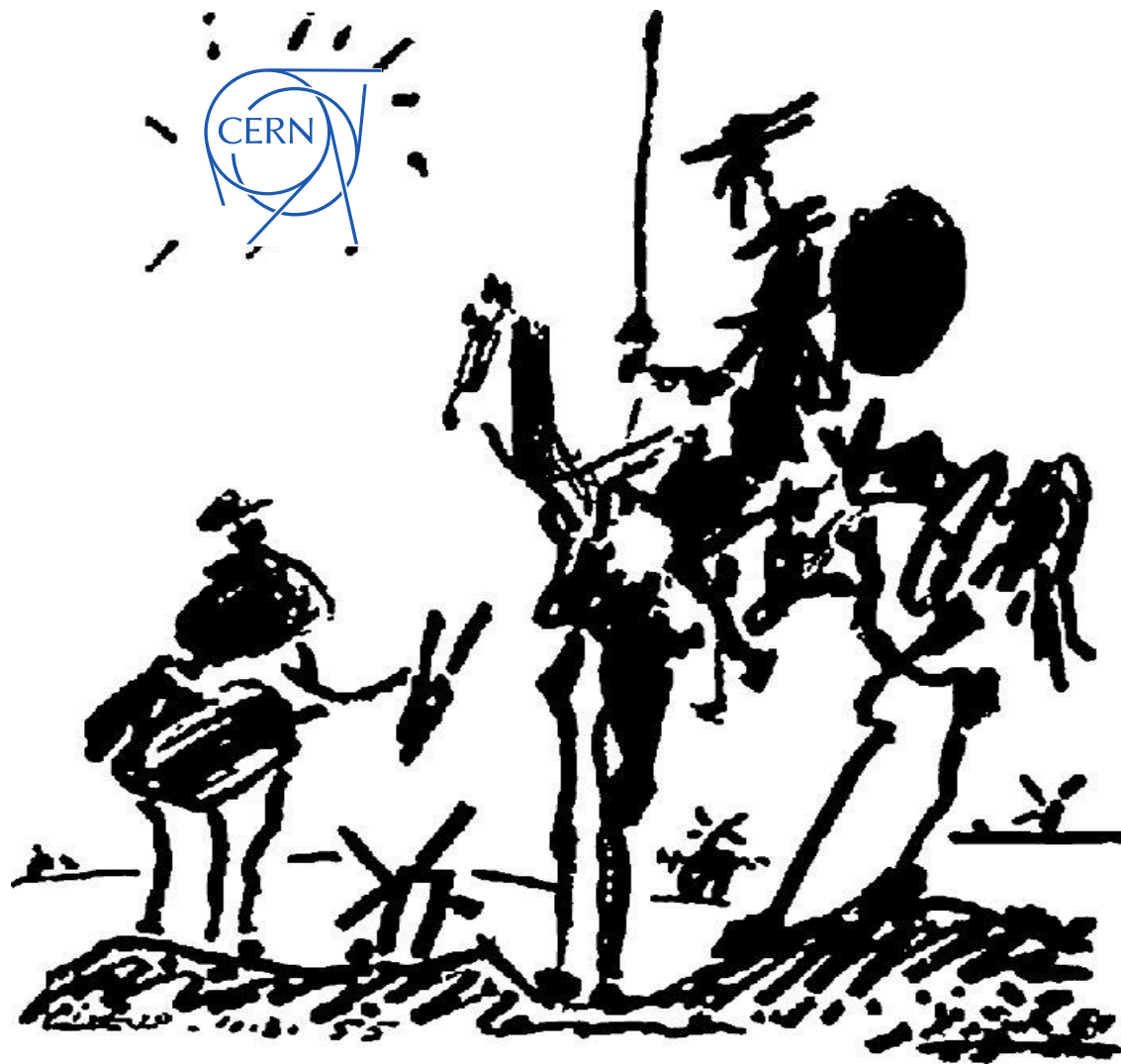
- Isospin symmetry
- Magic numbers far from stability
- Collectivity versus Single Particle
- Shape Coexistence
- Quadrupole and Octupole degrees of freedom
- Reaction for nucleo-synthesis studies



Summary & Outlook



- ISOLDE offers **largest variety** of radioactive and post-accelerated beams in the World. Plenty of challenging physics
- ISOLDE, operative since 50 years (first radioactive beam October 16, 1967), is in continuous transformation to stay at the forefront of nuclear physics research.
- The energy upgrade, up 10 MeV/u in 2018. Many new devices and groups have been attracted by the increase of energy of the post-accelerated beams.
- Main features of n_TOF is the **high instantaneous neutron flux, high resolution in energy and large energy range**
- Since 2001, n_TOF is contributing to the **world efforts** aimed at collecting high quality data, mostly on capture and fission
- **The new EAR2 (since 2014)** offers the unique opportunity to perform challenging measurements involving short-lived radioisotopes or sub-mg samples



¡Thanks for your attention!