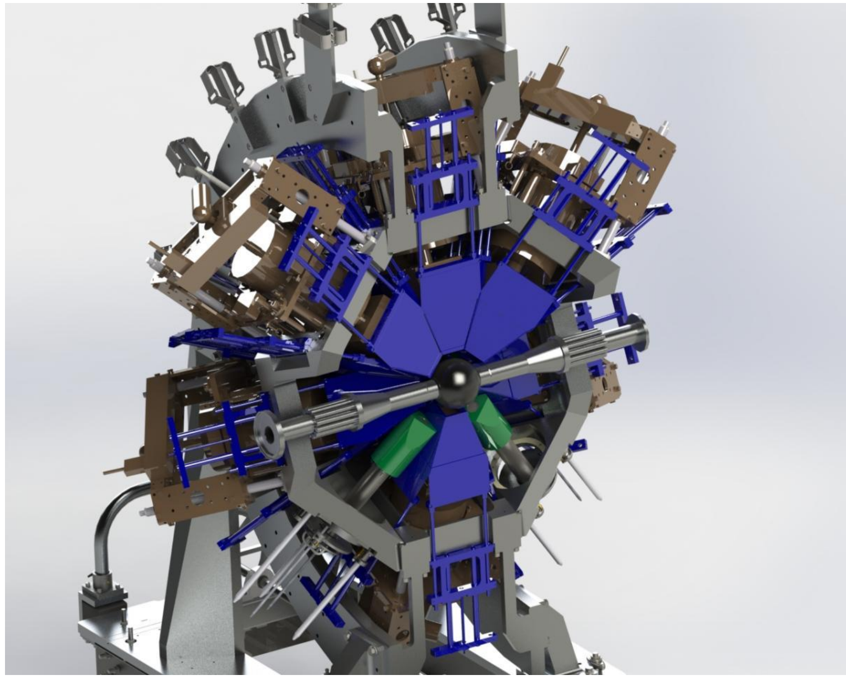
Estudio de Núcleos Exóticos



Bruno Olaizola

IEM-CSIC

Summary

- Typical nuclear physics experiment
  - Before the experiment
  - During the experiment
  - After the experiment
- Examples of nuclear physics experiments
  - Nuclear structure
  - Fundamental symmetries
  - Nuclear astrophysics
  - Nuclear medicine
  - Solid state/biology

Before the experiment

Have an idea

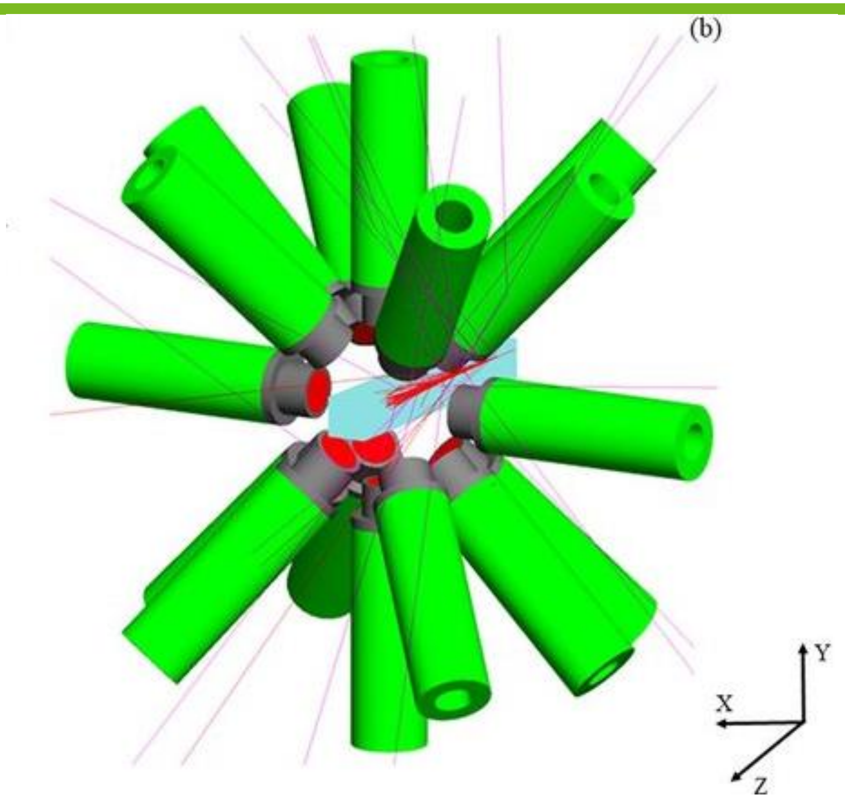
Have an idea

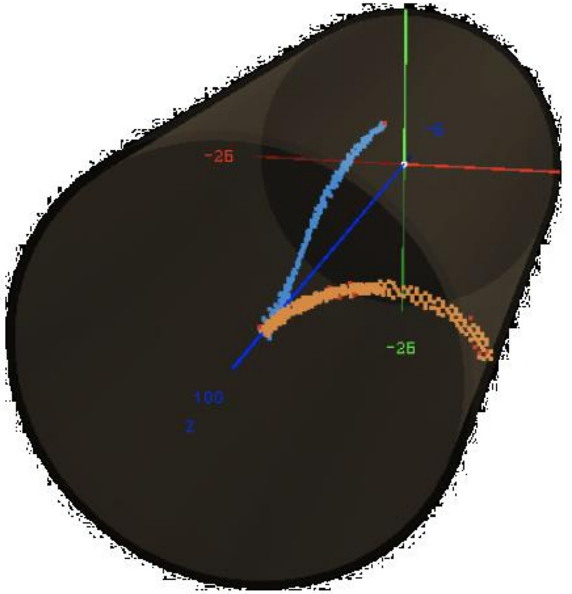
- Read 100s of papers
- Think you have had a novel idea
- Realize it was done already in USSR in the 70´s
- Read another 100 papers
- Have another idea
- Realize it is impossible to do
- Re-read 100s of papers and read another 100 new ones
- Come up with an idea that is feasible and has not been done

EUREKA!!

Design your experiment

- Which nucleus am I going to measure?
- Which properties?
- Which detectors do I need for that?
  - How many?
  - Where do I position them?
- Use Geant4 to simulate your experiment
  - Is it feasible?
  - How much beamtime would I need?





Experiment proposal

- Experiments are very expensive
- Beamtime is very competitive
- Write detailed experimental proposal
- Defend it in front of an international committee of experts
  - They are mean and ask very difficult questions
- Only the most interesting and feasible are approved

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Exploring shape coexistence across N=60 in $^{100}Sr_{62}$ using IDS

January 5, 2022

CERN-INTC-2022-007 / INTC-P-622
05/01/2022

B. Olaizola[1], S. S. Bhattacharjee[2], R. Kanungo[3], A. Algora[4], A. Andreyev[5], Y. Ayyad[6], M.J. Borge[7], J.A. Briz[8], R. Caballero-Folch[3], C. Costache[9], J. Cubiss[5], S. J. Freeman[1], L.P. Gaffney[10], A. Illana[11], P. Jones[12] U. Koester[13], R. Lică[1,9], N. Marginean[9], C. Mihai[9], R. E. Mihai[9], C. Page[5], J. Pakarinen[11], S. Pascu[9], V. Petousis[2], Z. Podolyak[14], M. Stryjczyk[11], A. Turturica[9], M. Veselsky[2], N. Warr[15], K. Wimmer[16], Z. Yue[5]

[1]*ISOLDE-EP CERN*, [2]*Technical University in Prague*, [3]*TRIUMF*, [4]*IFIC Valencia*, [5]*University of York*, [6]*Universidad de Santiago*, [7]*CSIC Madrid*, [8] *Universidad Complutense de Madrid*, [9]*IFIN-HH Bucharest*, [10]*University of Liverpool*, [11]*University of Jyväskylä*, [12]*iThemba LABS*, [13]*ILL Grenoble*, [14]*University of Surrey*, [15]*Universität zu Köln*, [16]*GSI Darmstadt*

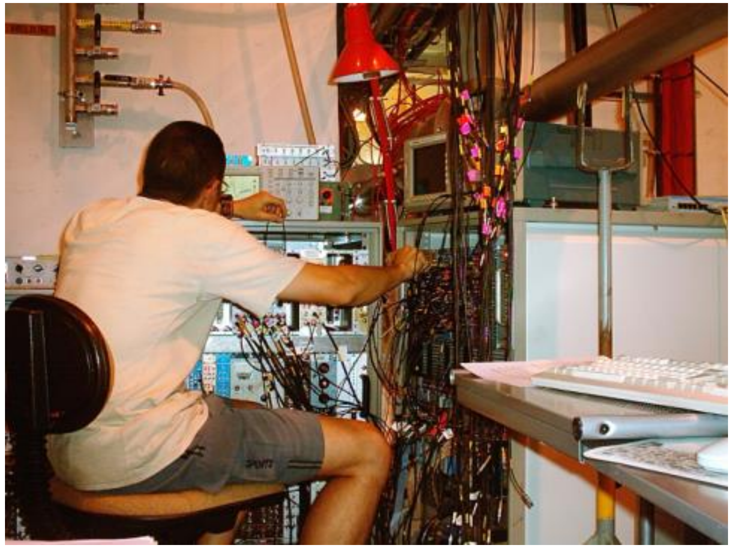
Spokesperson: B. Olaizola [bruno.olaizola@cern.ch]
Spokesperson: S. S. Bhattacharjee [Soumendu.Bhatt@cvut.cz]
Contact person: Razvan Lică [razvan.lica@cern.ch]

Abstract: This proposal aims to locate excited 0^+ state(s) in $^{100}Sr_{62}$ in order to unravel the nuclear structure responsible for the sudden change in deformation characteristic of the region. The excited states of Sr isotopes will be populated via β and β-n decay using ^{100,101}Rb beams at the ISOLDE Decay Station (IDS). The 0^+ state(s) will be firmly identified using $\gamma - \gamma$ angular correlations and by directly observing E0 transitions using the SPectrometer for Electron DEtection (SPEDE) ancillary detector. Secondary goals include measuring the P_n / P_{2n} values and nuclear level lifetimes by using fast-timing $LaBr_3(Ce)$ detectors. The proposed experimental data will provide critical information about the shape co-existence beyond $N = 60$ in Sr isotope.

Requested shifts: [11] shifts, (split into [1] runs over [1] years)
Installations: IDS with 5 clovers and SPEDE

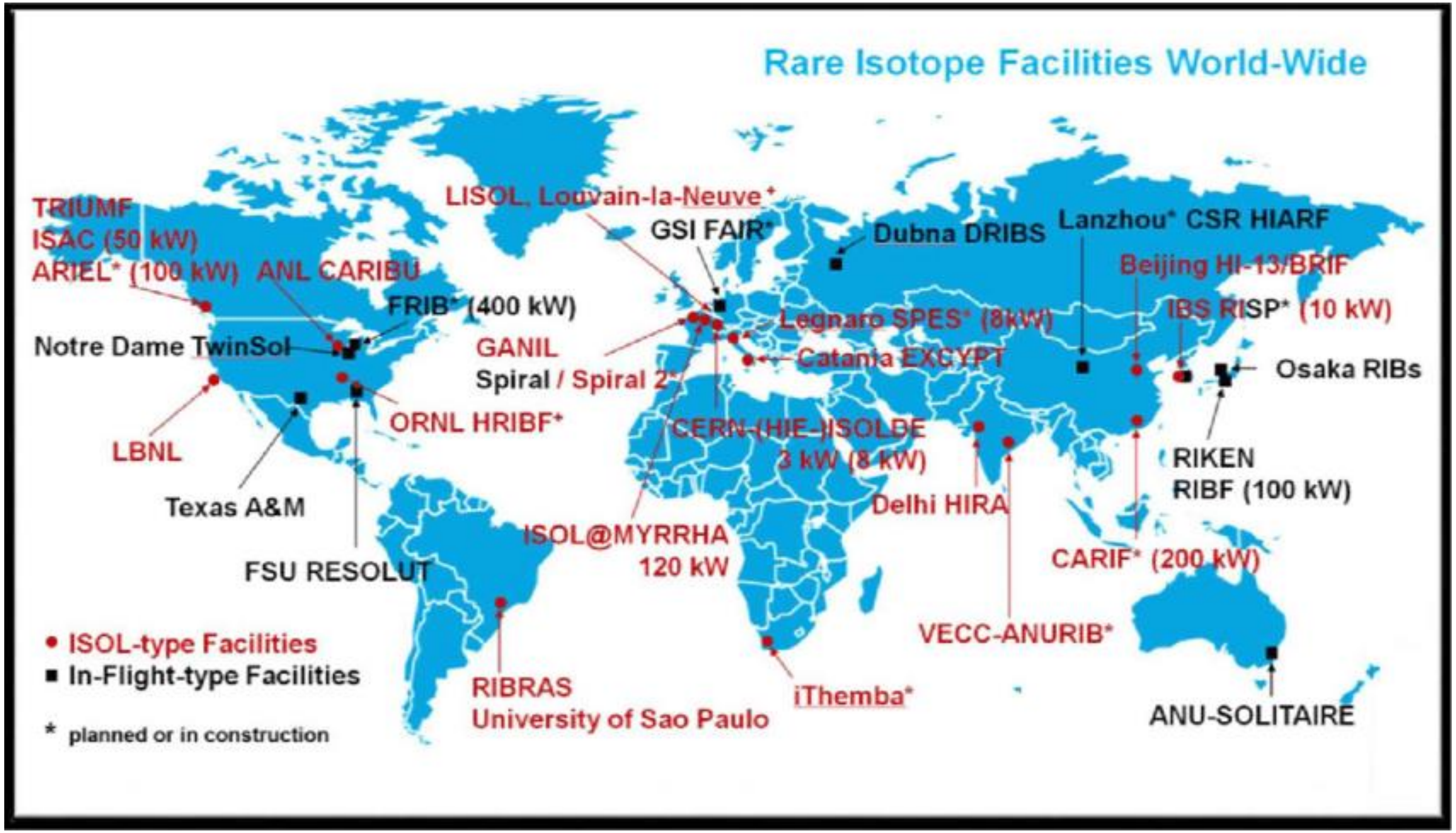
Detector testing

- Detectors:
  - ➢ Testing
  - ➢ Characterization
  - ➢ Optimization
- Electronics
- Data Acquisition System (DAQ)



Shipment and travel

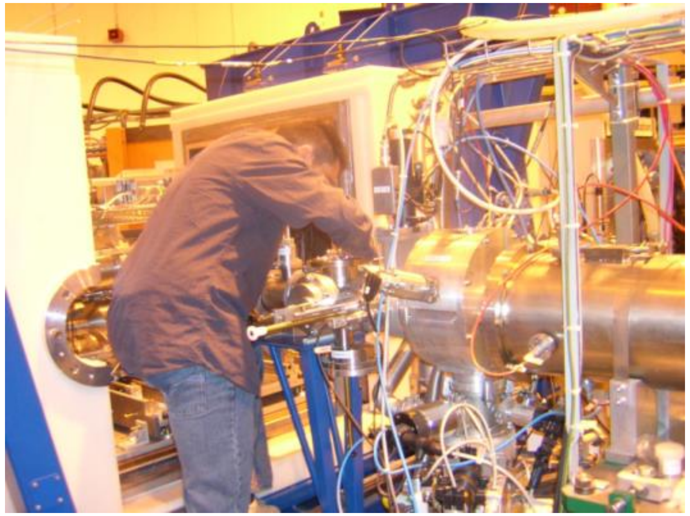
- Only a few laboratories around the world
- Shipping expensive scientific equipment is not trivial
- Large group of people travel to the lab

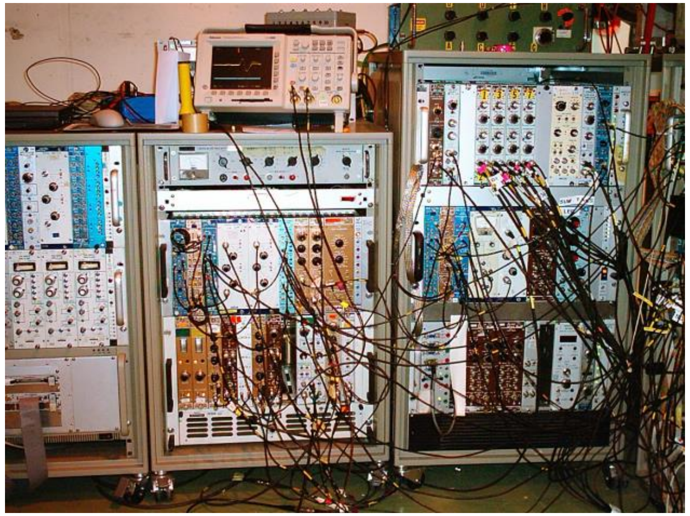


During the experiment

Setting up

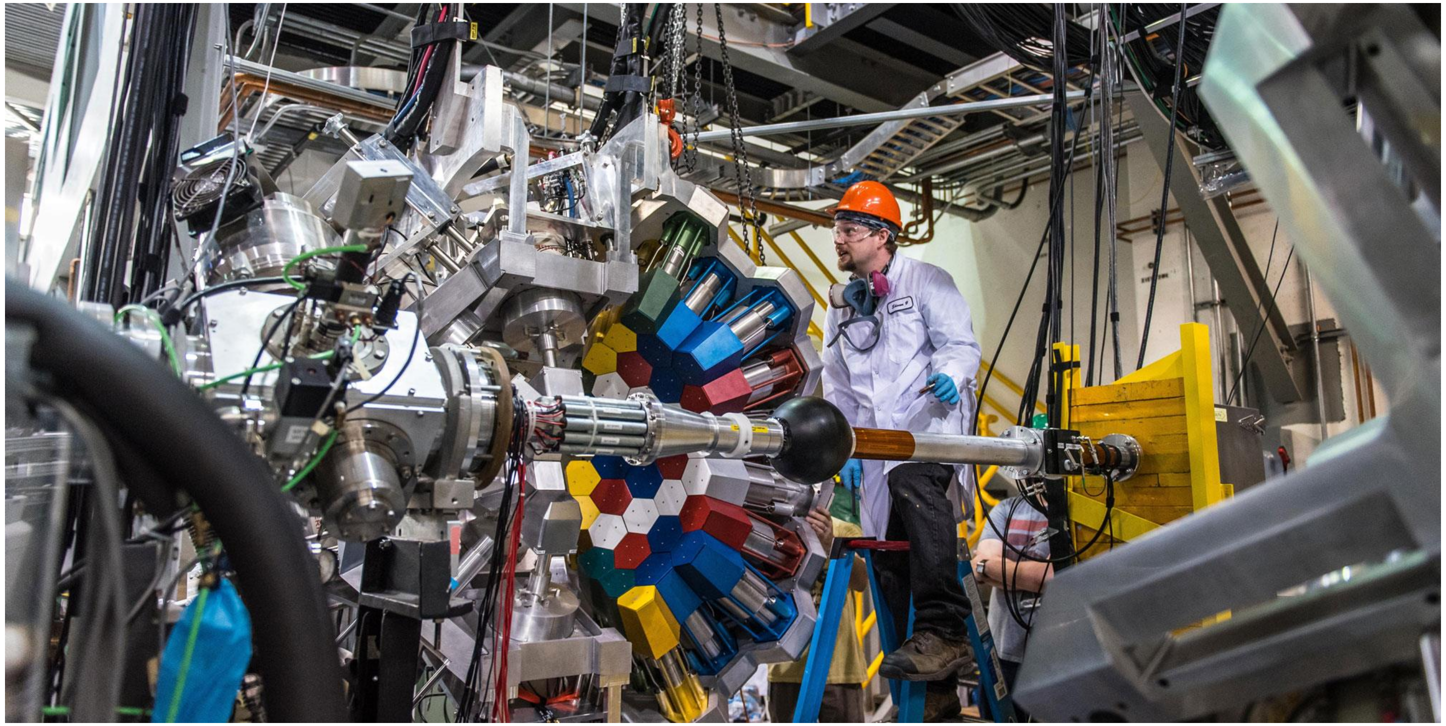
- Set up all the equipment
- Cross fingers everything works
- Spend the night fixing what it does not





Permanent large detector arrays

- International laboratories have large permanent setups that international users run experiments with



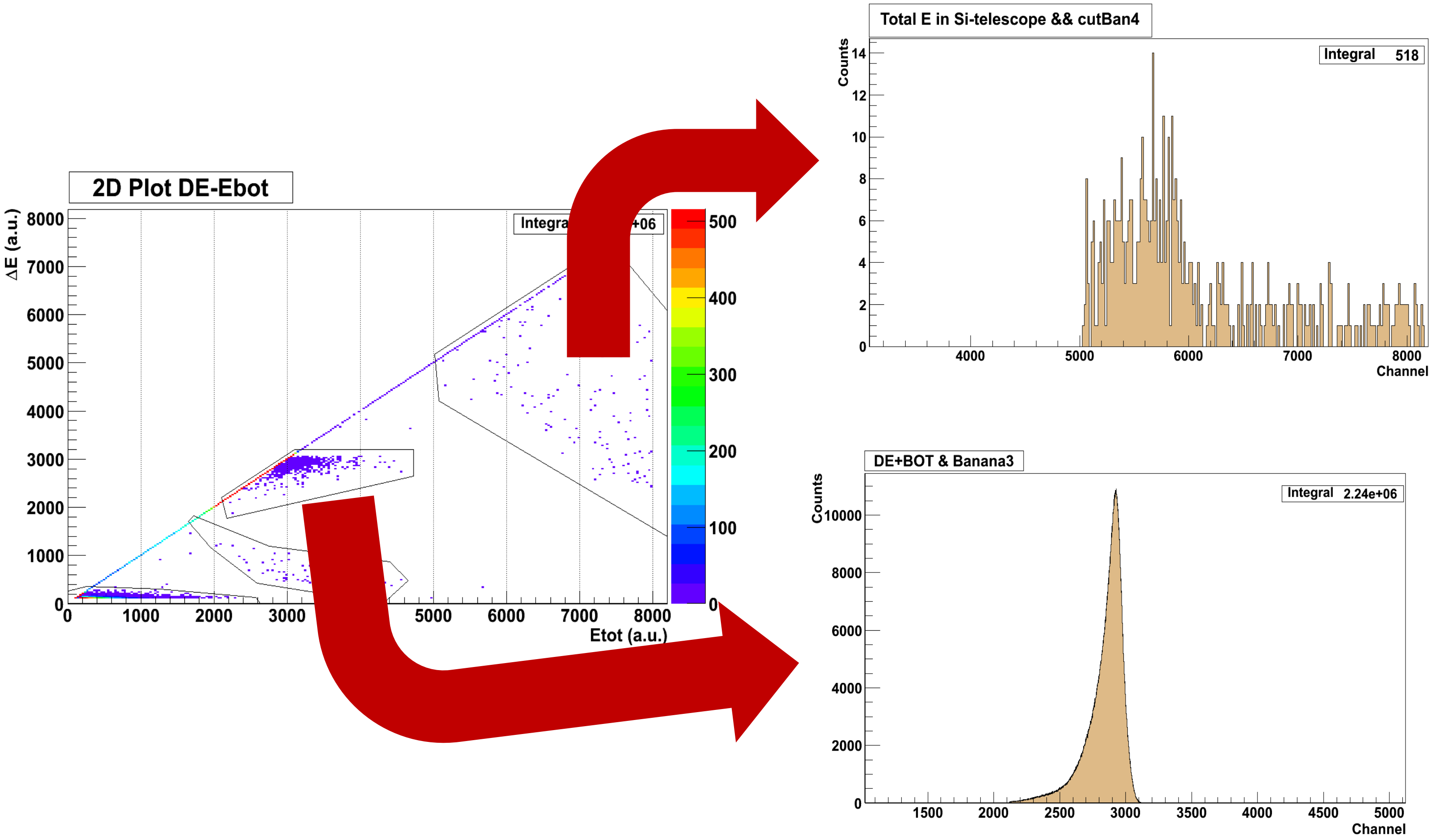
Beamtime

- The actual experiment: the beamtime
- It runs 24/7: 8-hour shifts
- Typical experiment runs for 5-7 days

After the experiment

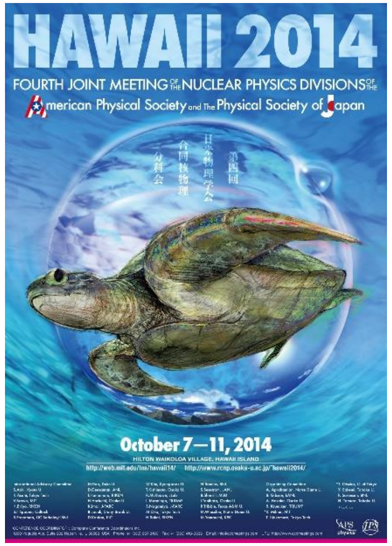
Data analysis

- Modern nuclear experiments collect large amount of data (TBs)
- Need to be sorted and filtered
- Some programming skills are needed
- Most common C++ for ROOT
- Analysis usually led by PhD students



Present in conferences

- As analysis progress, results are shared with the community
- Disseminate your new findings
- Engage on interesting discussions
- Network
- Travel to cool places

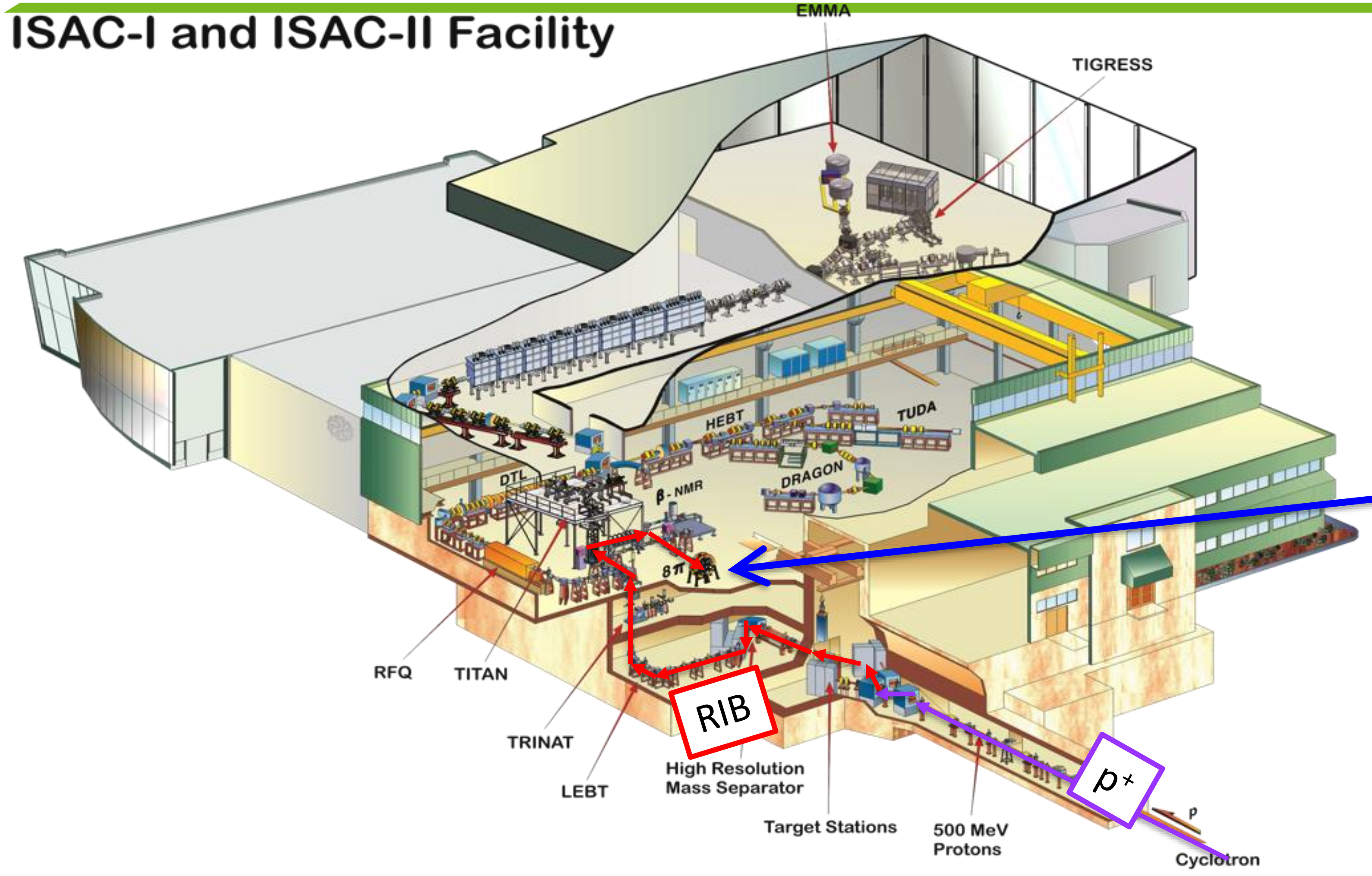


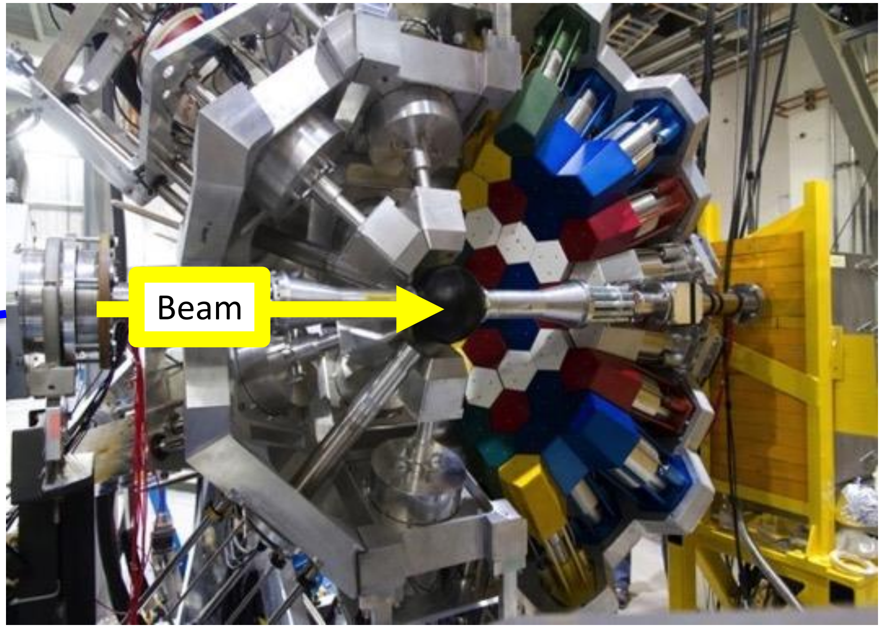
Publication

- The final step of research is to publish the results on peer-reviewed journals
- (And defend PhD thesis)

Examples of nuclear physics experiments

Decay experiments



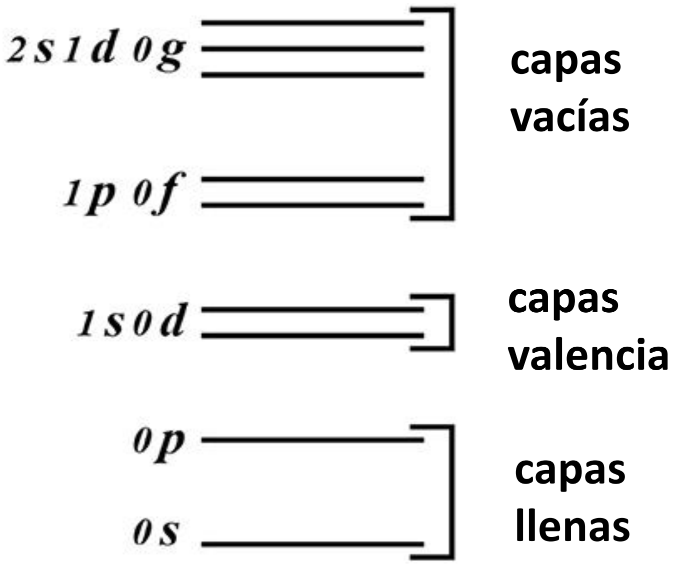


TRIUMF

Nuclear structure

Nuclear Shell model

- El núcleo exhibe estructura de capas
  - Capas cerradas= « numeros mágicos»
  - Nucleones de Valencia esenciales
  - El modelo de capas es la base para explicar la espectroscopia nuclear



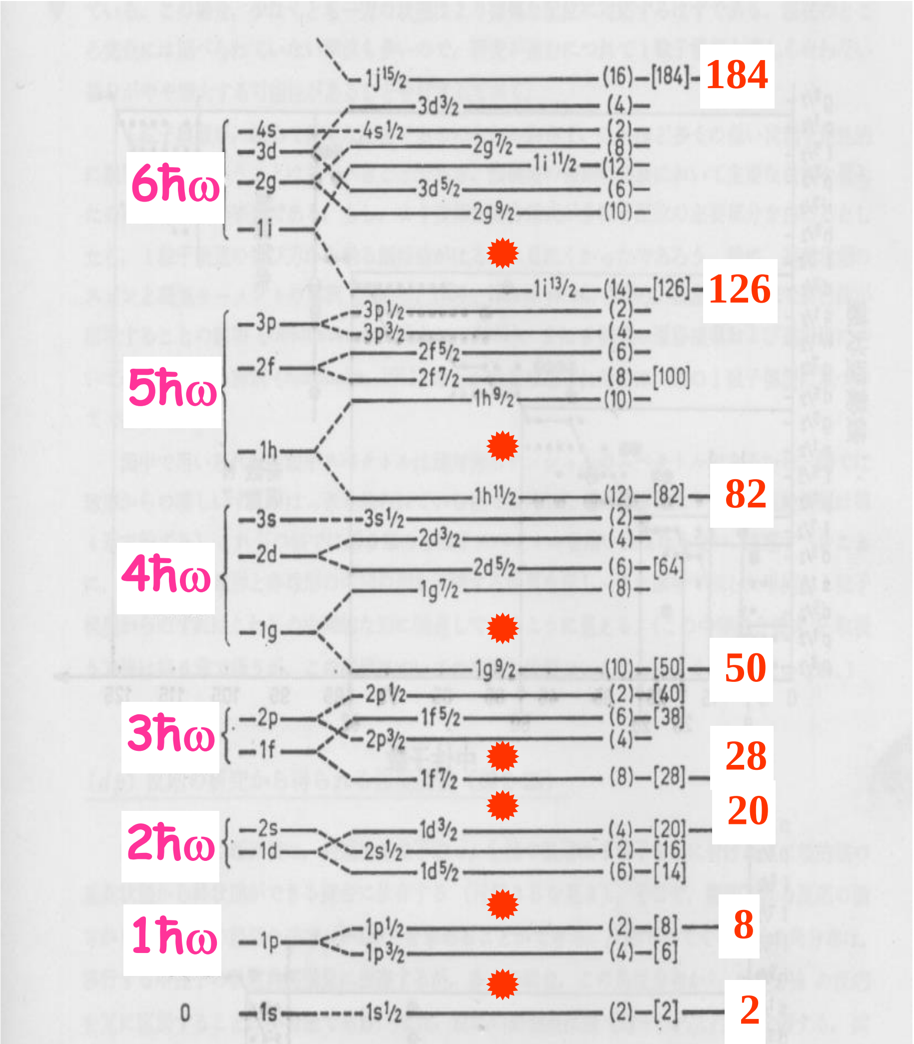
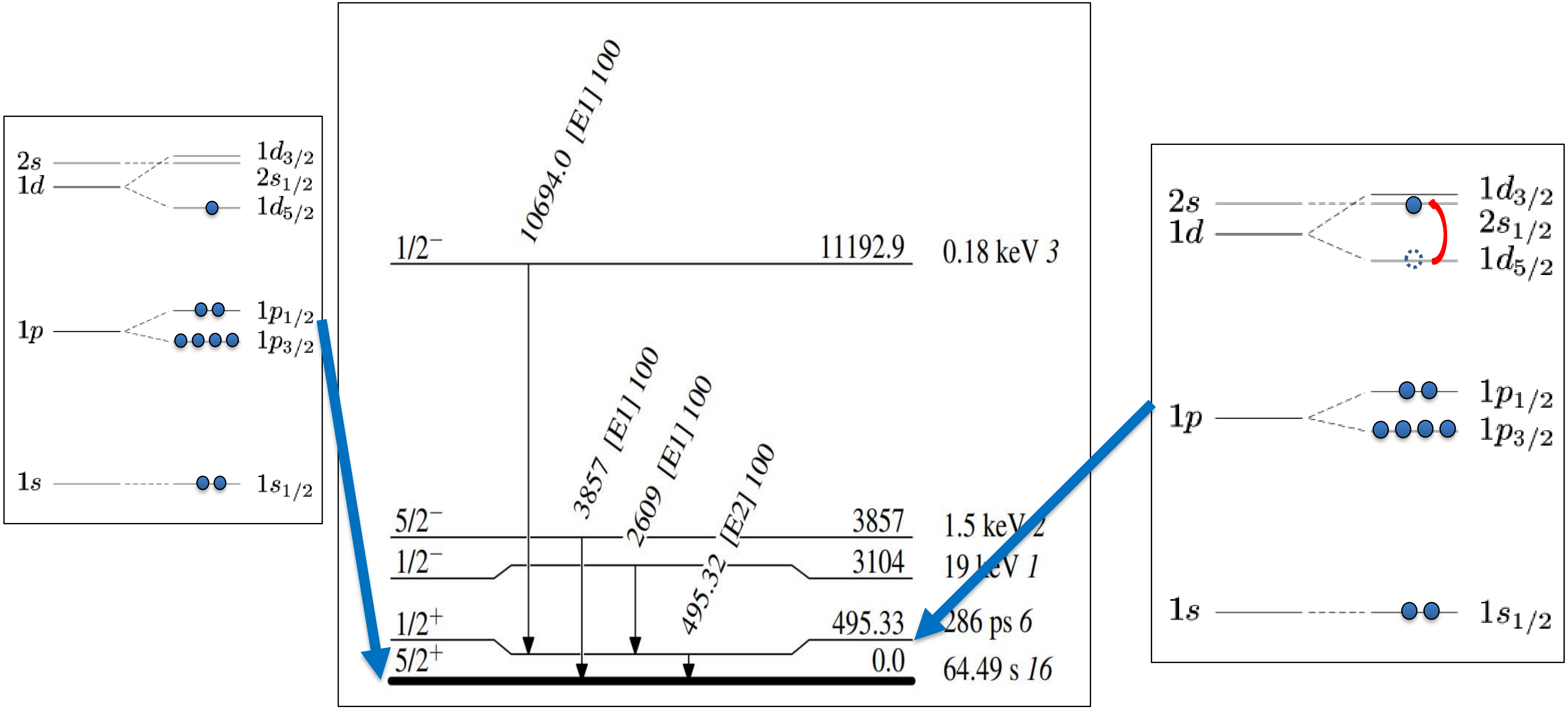
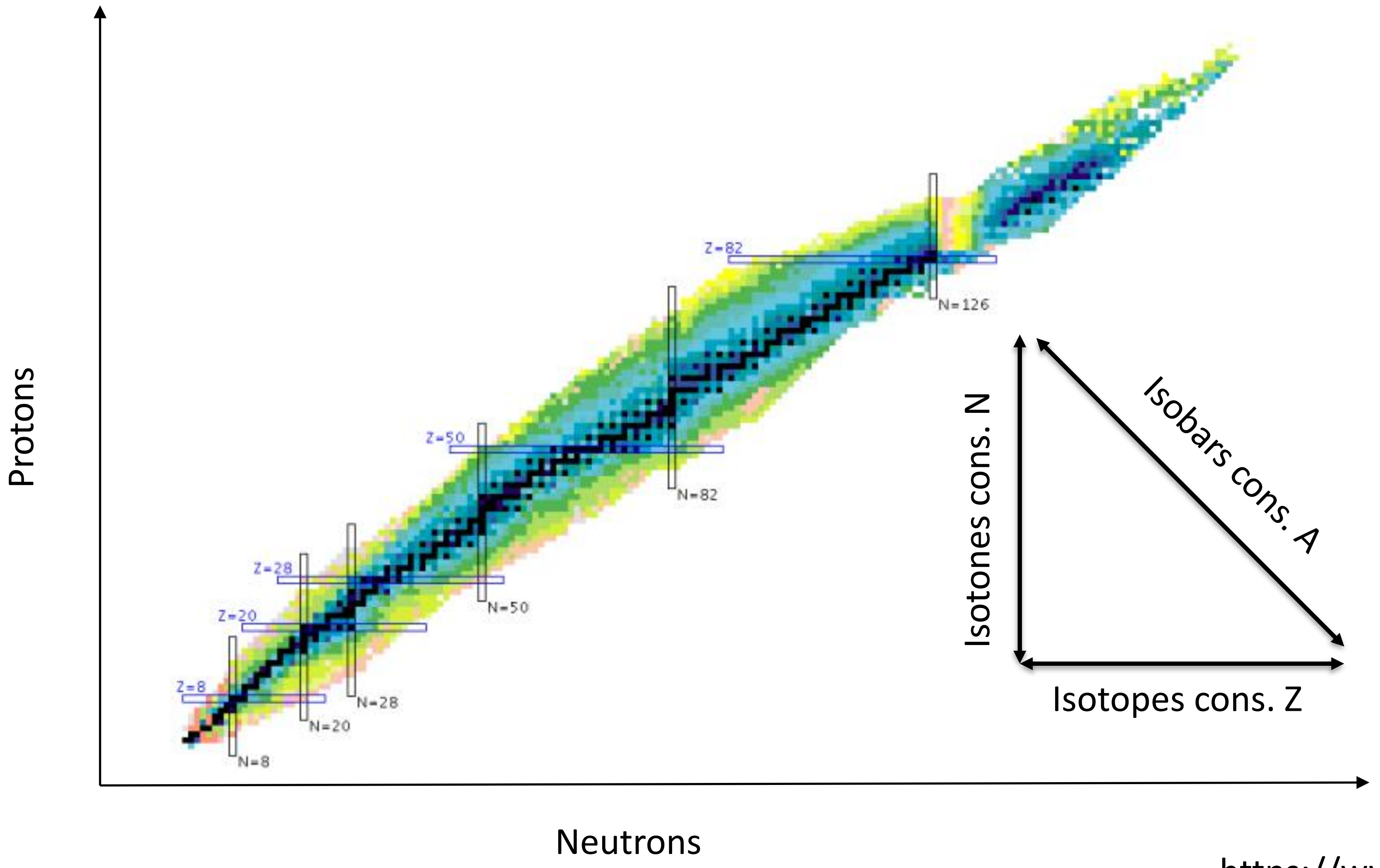


図 2-23 1粒子軌道の順序. 図は M. G. Mayer and J. H. D. Jensen, *Elementary Theory of Nuclear Shell Structure*, p. 58, Wiley, New York, 1955 からとった.

Nuclear Shell model

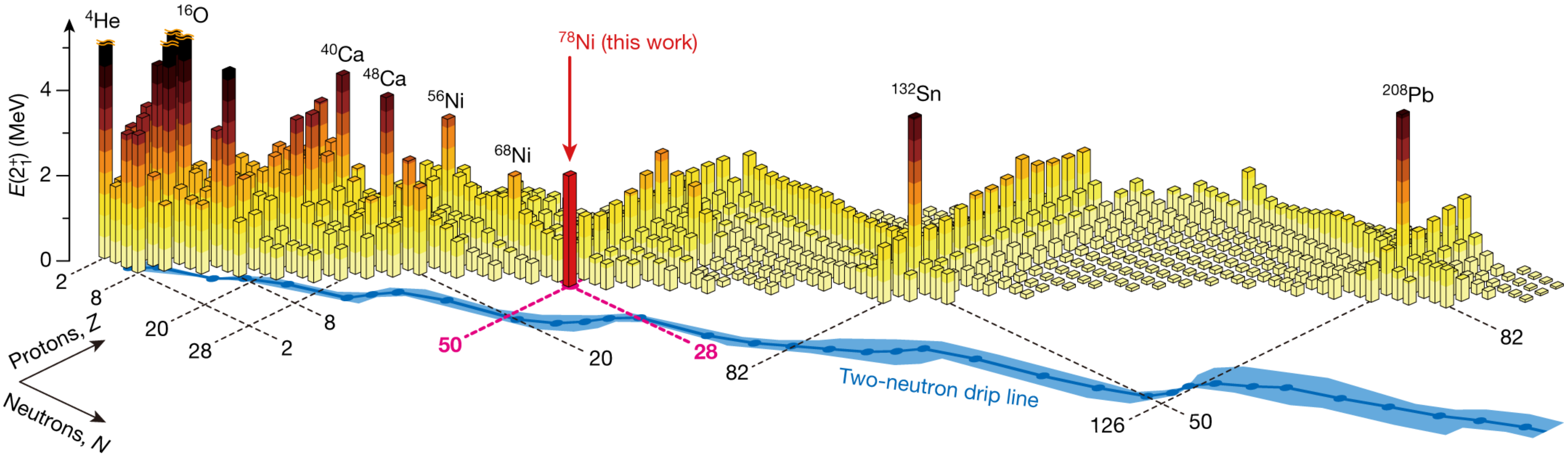


Nuclear chart



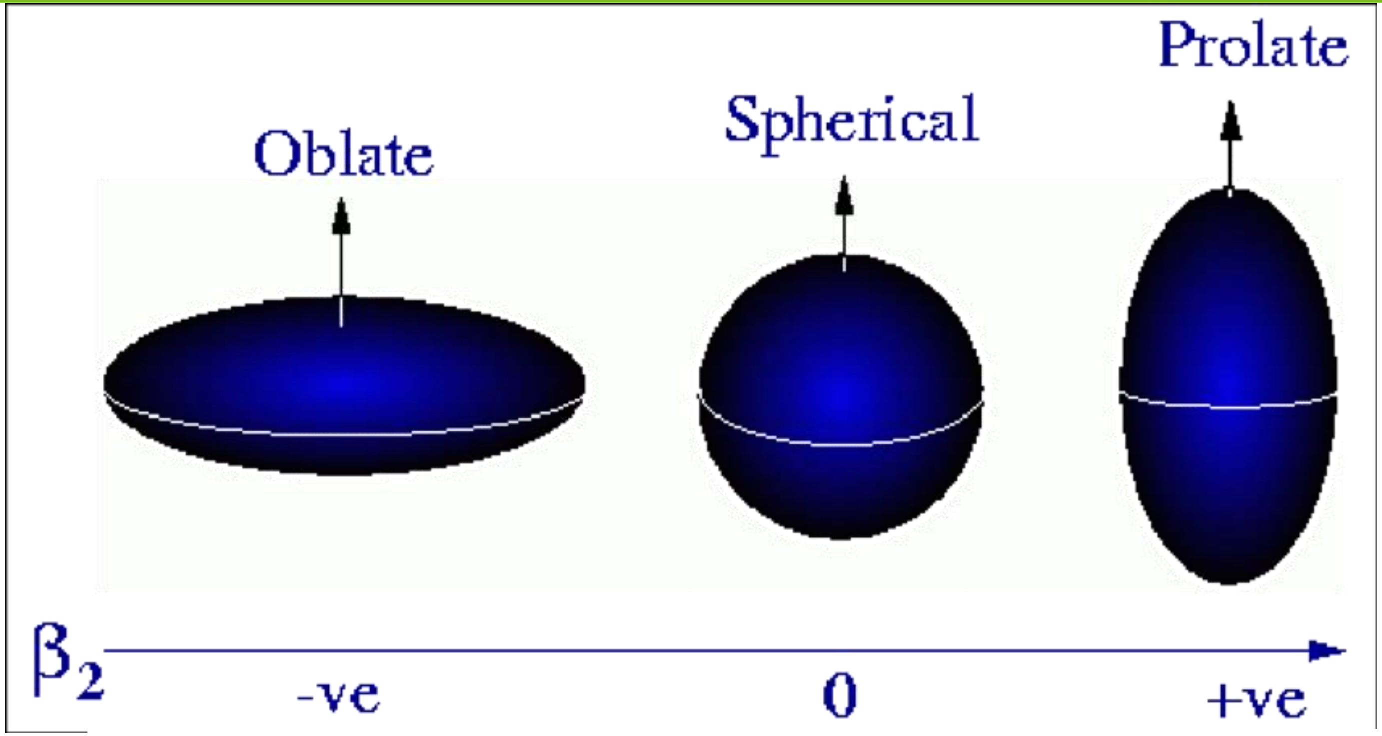
https://www.nndc.bnl.gov/

Data analysis



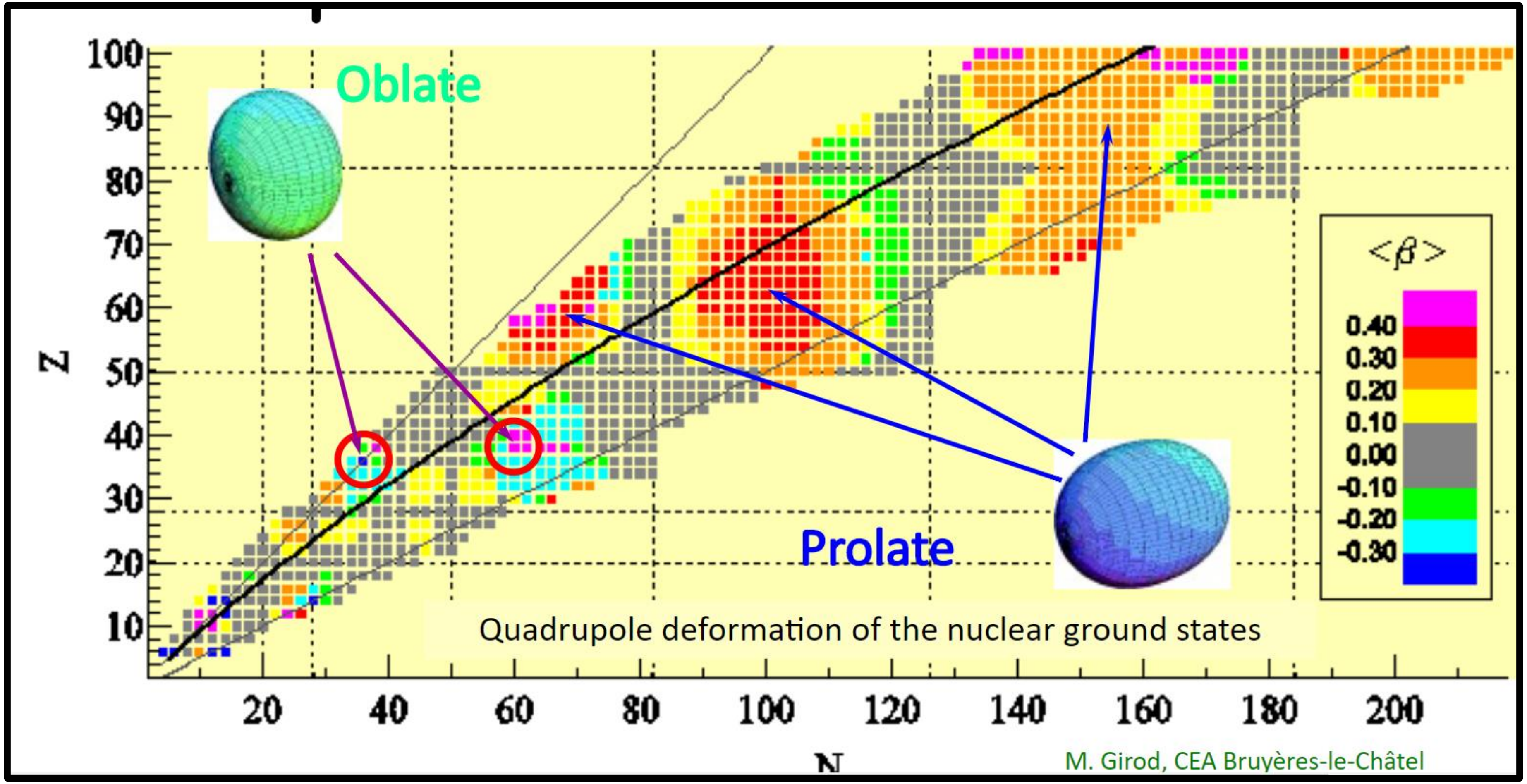
- Check closed shells by measuring energy of first excited states
- Turns out, far from stability new magic numbers appear
- Some “standard” magic numbers may dissapear

Deformation



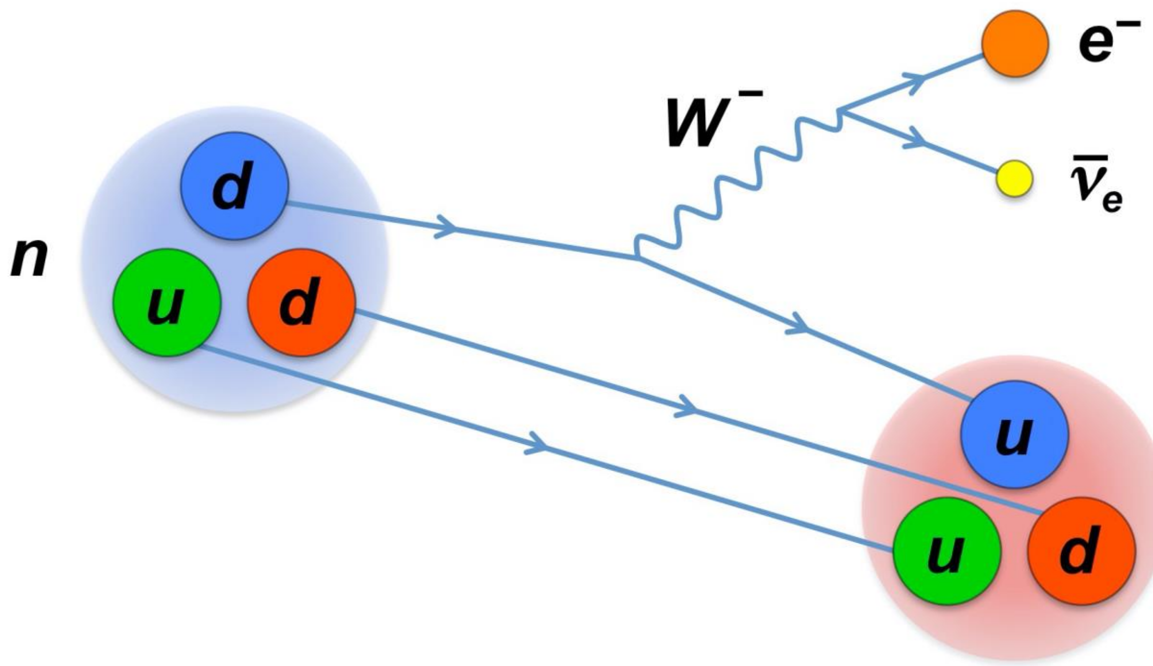
25

Deformation is a common phenomenon



Fundamental symmetries

Beta decay



- Protons and neutrons are made of quarks
- In beta decay, a *down* quark becomes an *up* one
- They interact via the weak force

The Standard Model of particle physics

The Cabibbo–Kobayashi–Maskawa (CKM) matrix plays a central role in the Standard Model and underpins all quark flavour-changing interactions:

weak interaction eigenstates ≠ quark mass eigenstates

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$|d'\rangle = V_{ud}|d\rangle + V_{us}|s\rangle + V_{ub}|b\rangle$$

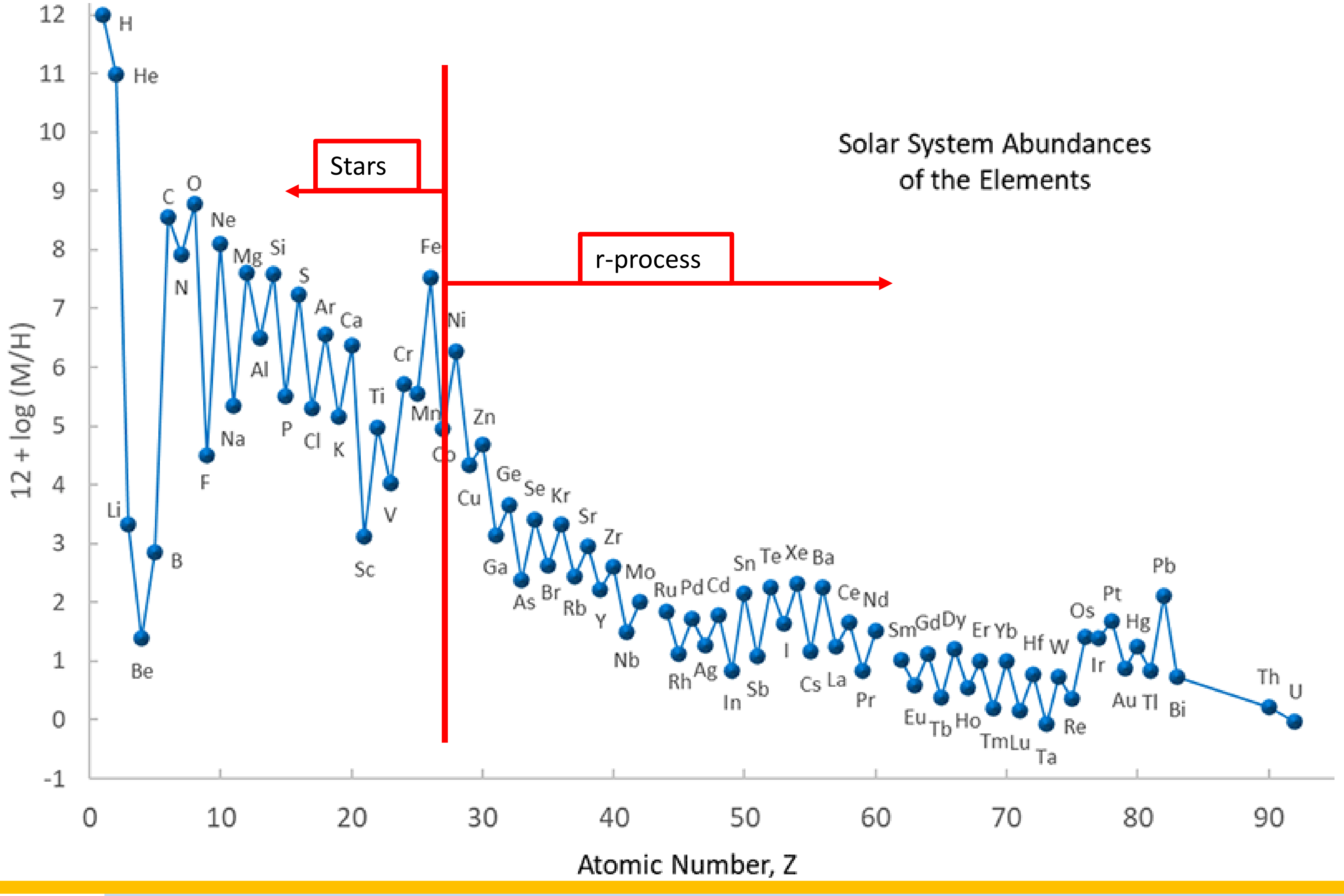
In the Standard Model the CKM matrix describes a unitary transformation:

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1$$

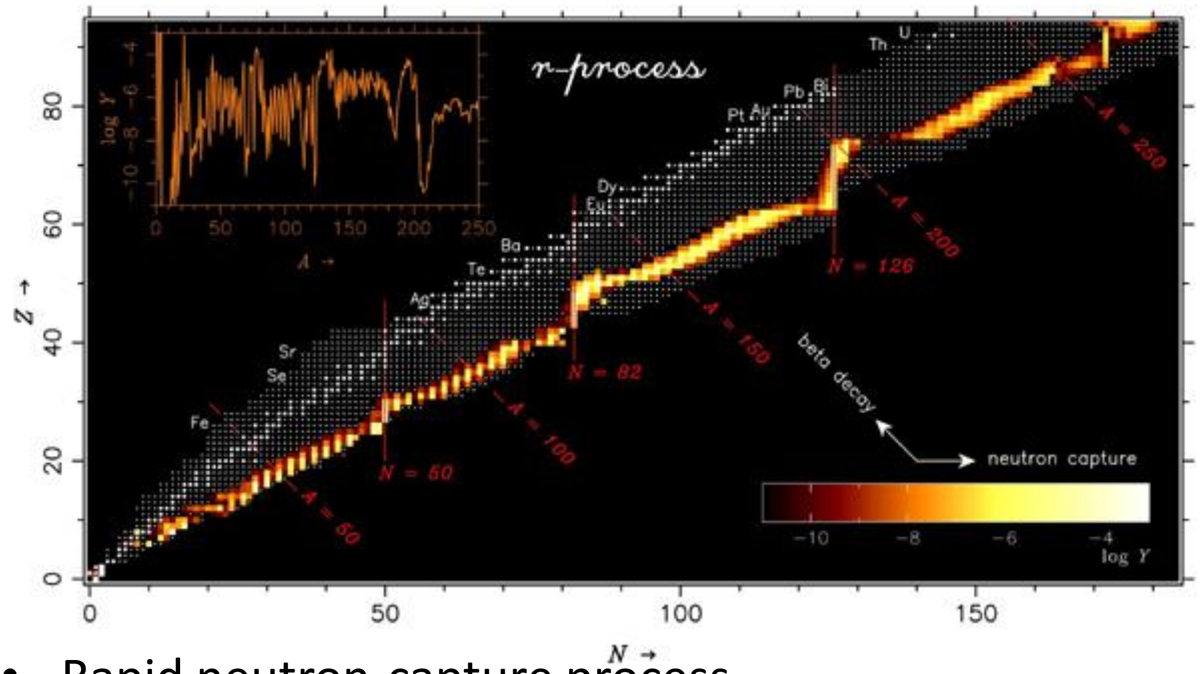
- Superallowed beta decays (beta decay between two special nuclei) is a pure transformation between *up* and *down* quarks
- We measure some nuclear properties (lifetime, nuclear mass, decay probability)
- Most precise measurement of the V_{ud} term

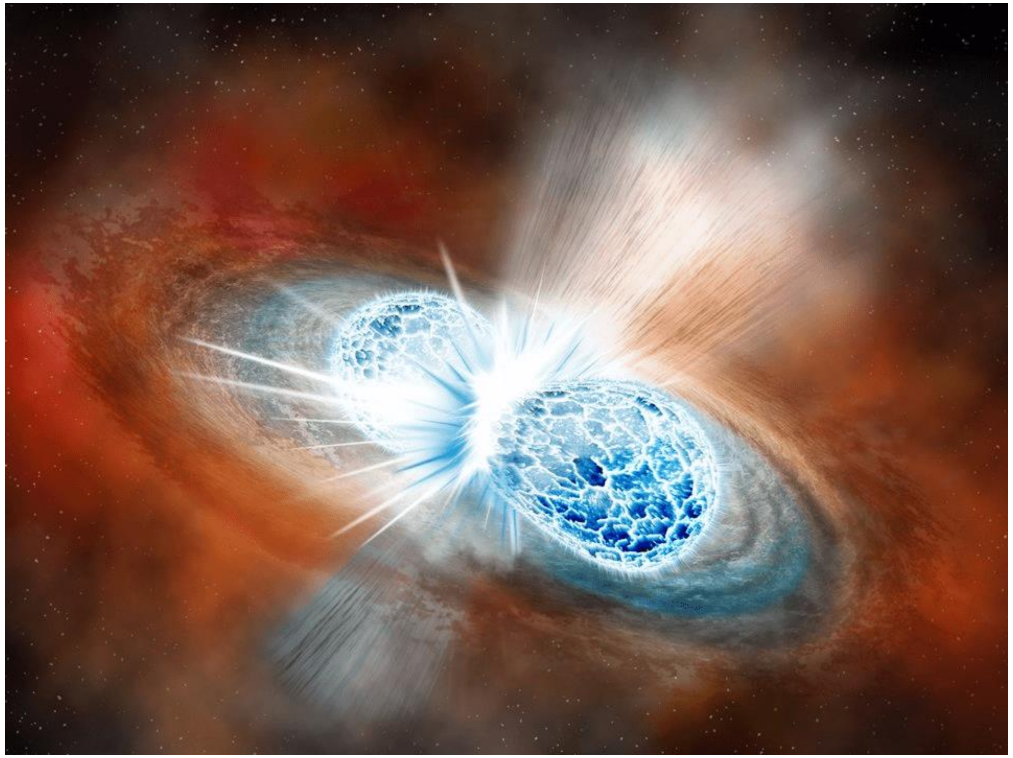
Nuclear astrophysics

Solar abundance



r-process





- Rapid neutron-capture process
- Neutron start mergers
- Competition between beta decay and neutron absorption
- Most relevant observables:
  - Beta decay half life (g.s. and isomers)
  - Neutron emission
  - Neutron capture cross section

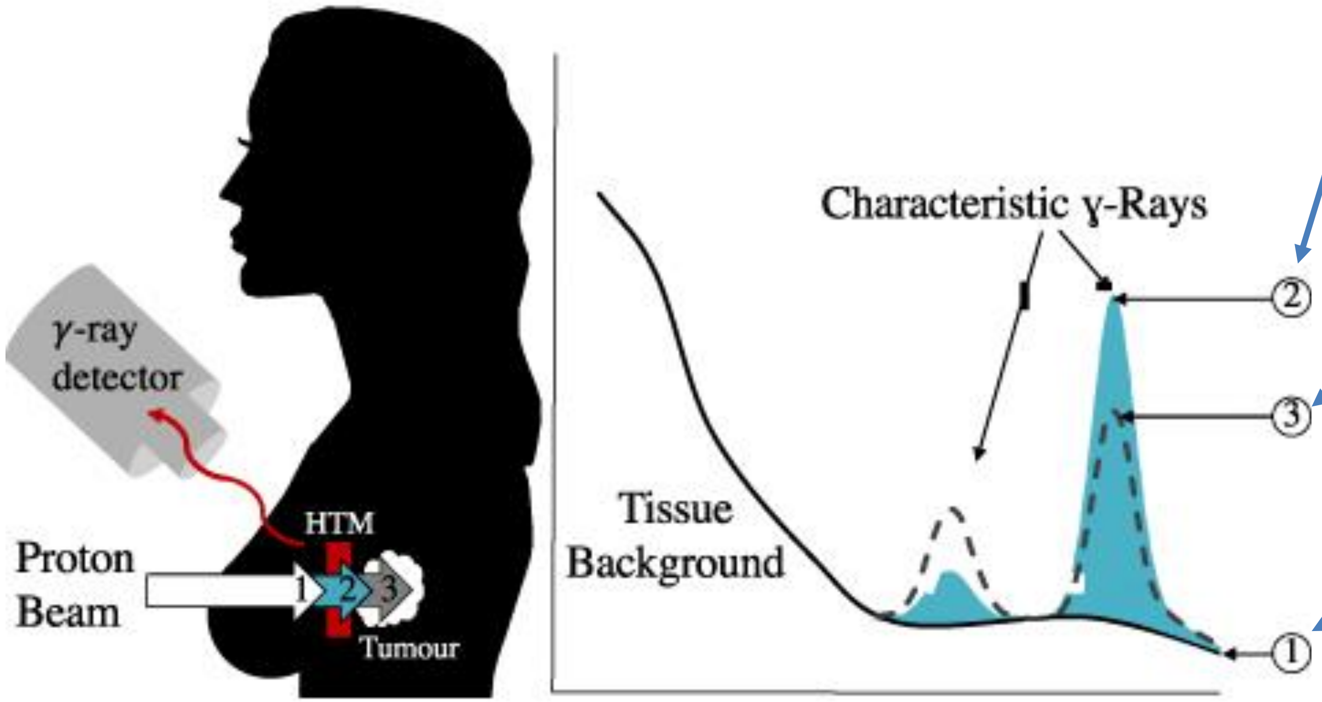
http://www.ph.sophia.ac.jp/~shinya/research/research.html

https://physicsworld.com/a/merging-neutron-stars-create-more-gold-than-collisions-involving-black-holes/

Nuclear medicine

Proton therapy range verification

- We insert a metal foil (Mo) in front of the tumor
- Nuclear reaction with p^+ emits characteristic gamma rays
- Ratio between peaks depends on p^+ energy



2- Good peak ratio→ Bragg peak next metal marker, correct energy

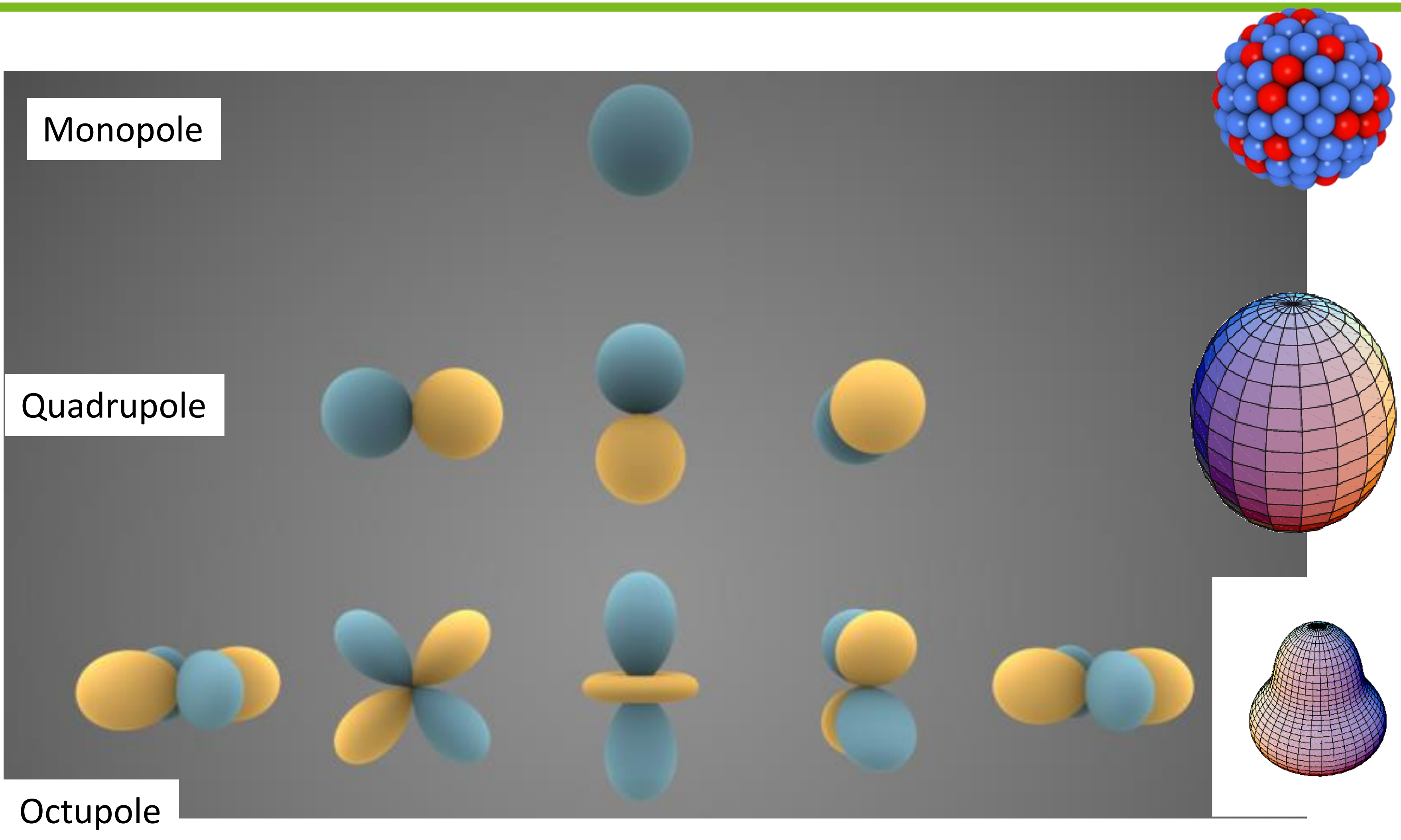
3- Wrong peak ratio→ Bragg peak beyond metal marker, too high energy

1- No peaks → proton energy too low

C Burbadge *et al* 2021 *Phys. Med. Biol.* **66** 025005

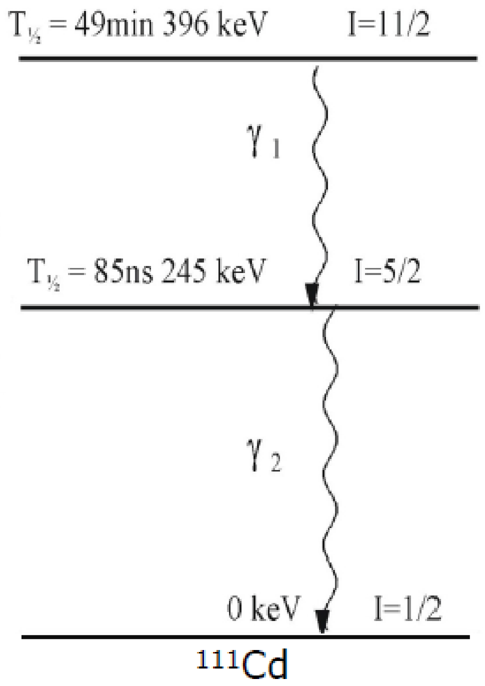
Solid state and biology

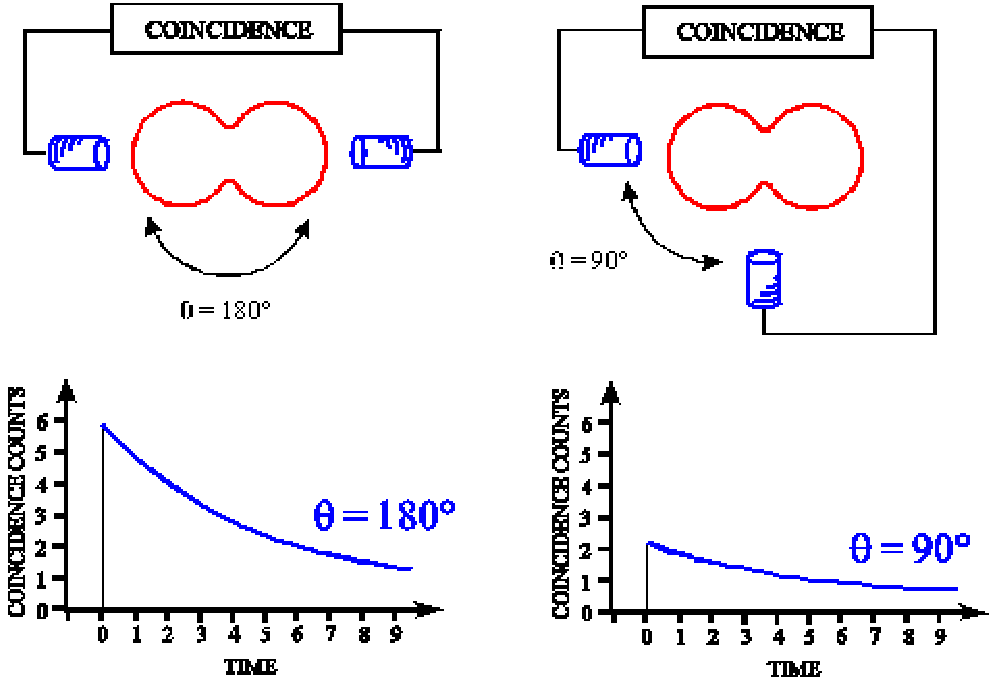
Multipole radiation



PAC Spectroscopy

γ - γ angular correlation

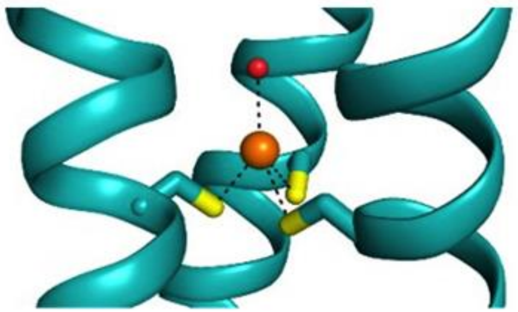


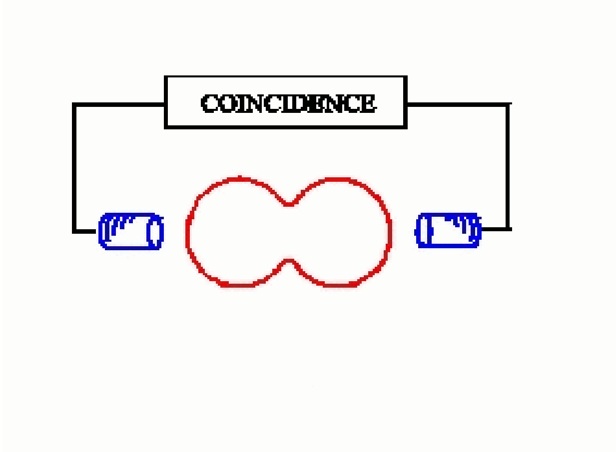


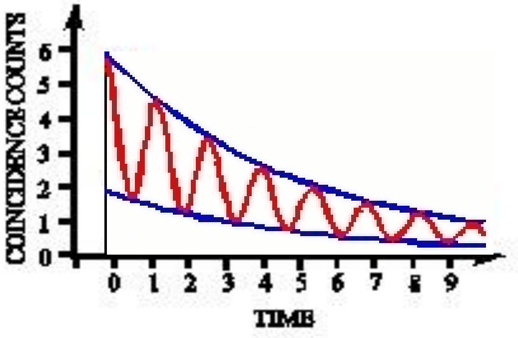
(www.uni-leipzig.de)

Perturbed angular corellation

Now if the electric/magnetic field is created by other atoms in a molecule then the Perturbed γ - γ angular correlation is a very sensitive probe!



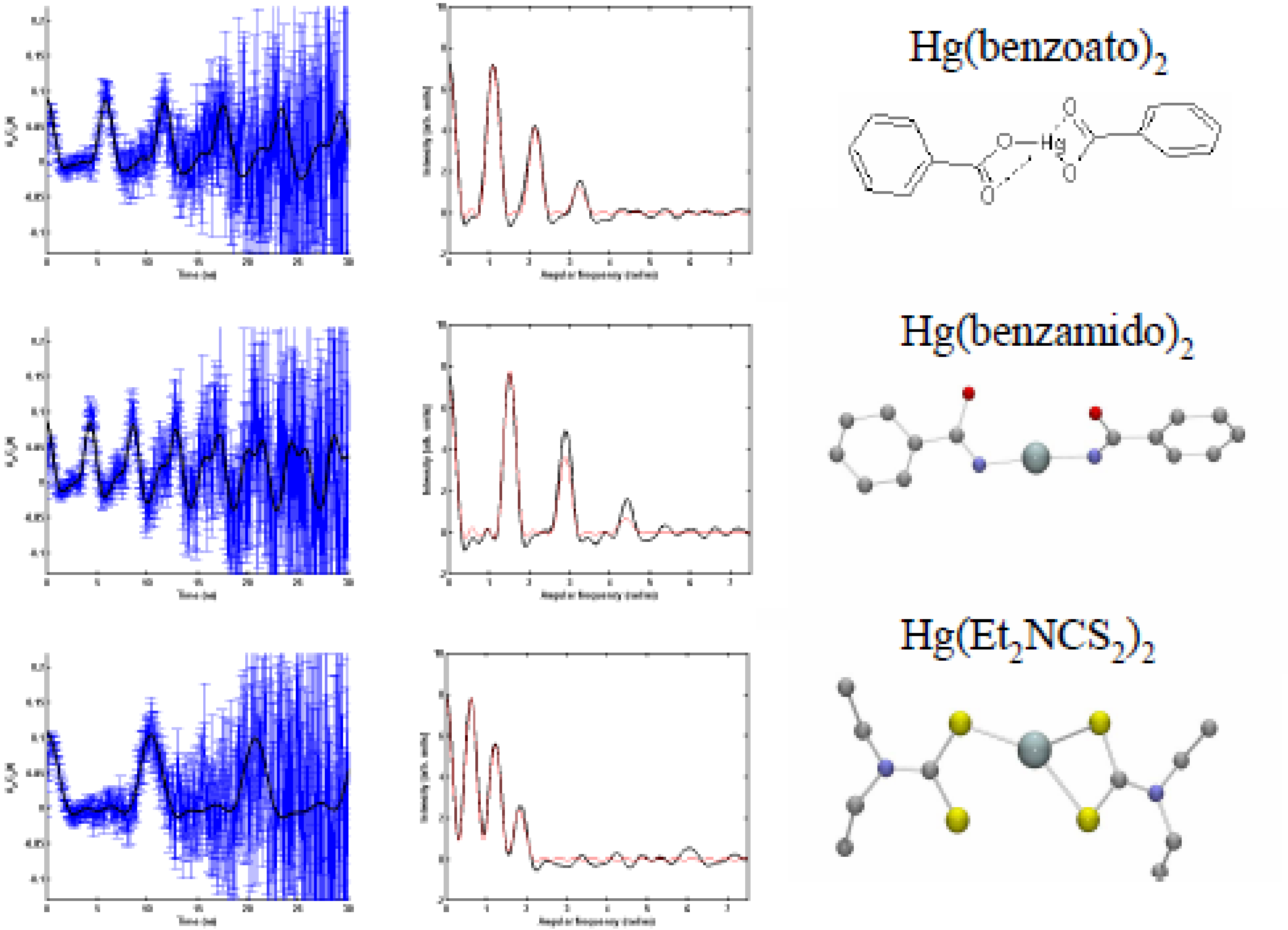




(www.uni-leipzig.de)

- This technique requires detectors with good energy resolution and excellent timing resolution.
- $LaBr_3$ scintillators are the ideal choice.

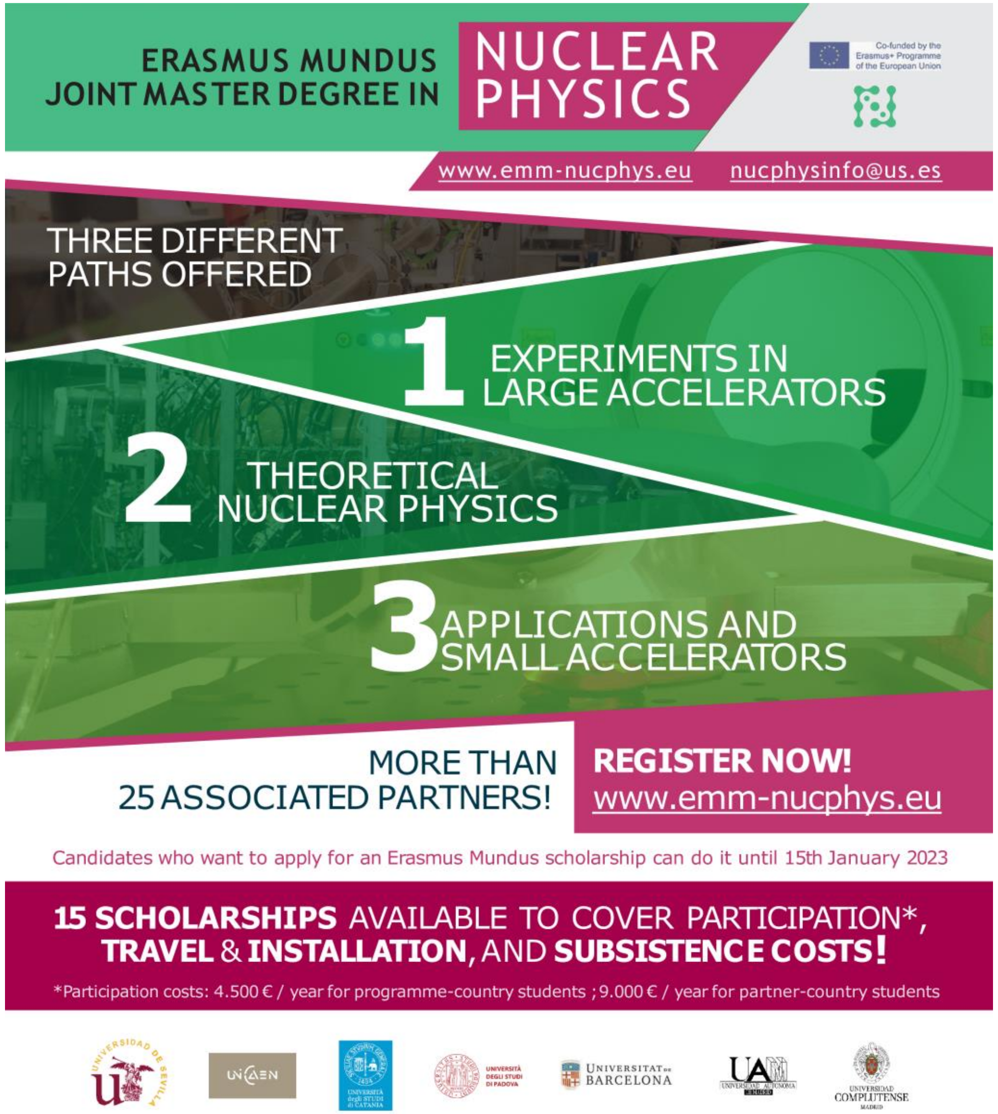
PAC Spectroscopy reveals coordination chemistry



Summary

- Typical nuclear physics experiment
  - Before the experiment
  - During the experiment
  - After the experiment
- Examples of nuclear physics experiments
  - Nuclear structure
  - Fundamental symmetries
  - Nuclear astrophysics
  - Nuclear medicine
  - Solid state/biology

Nuclear physics masters



Any questions?

You can always contact me at
bruno.olaizola@csic.es