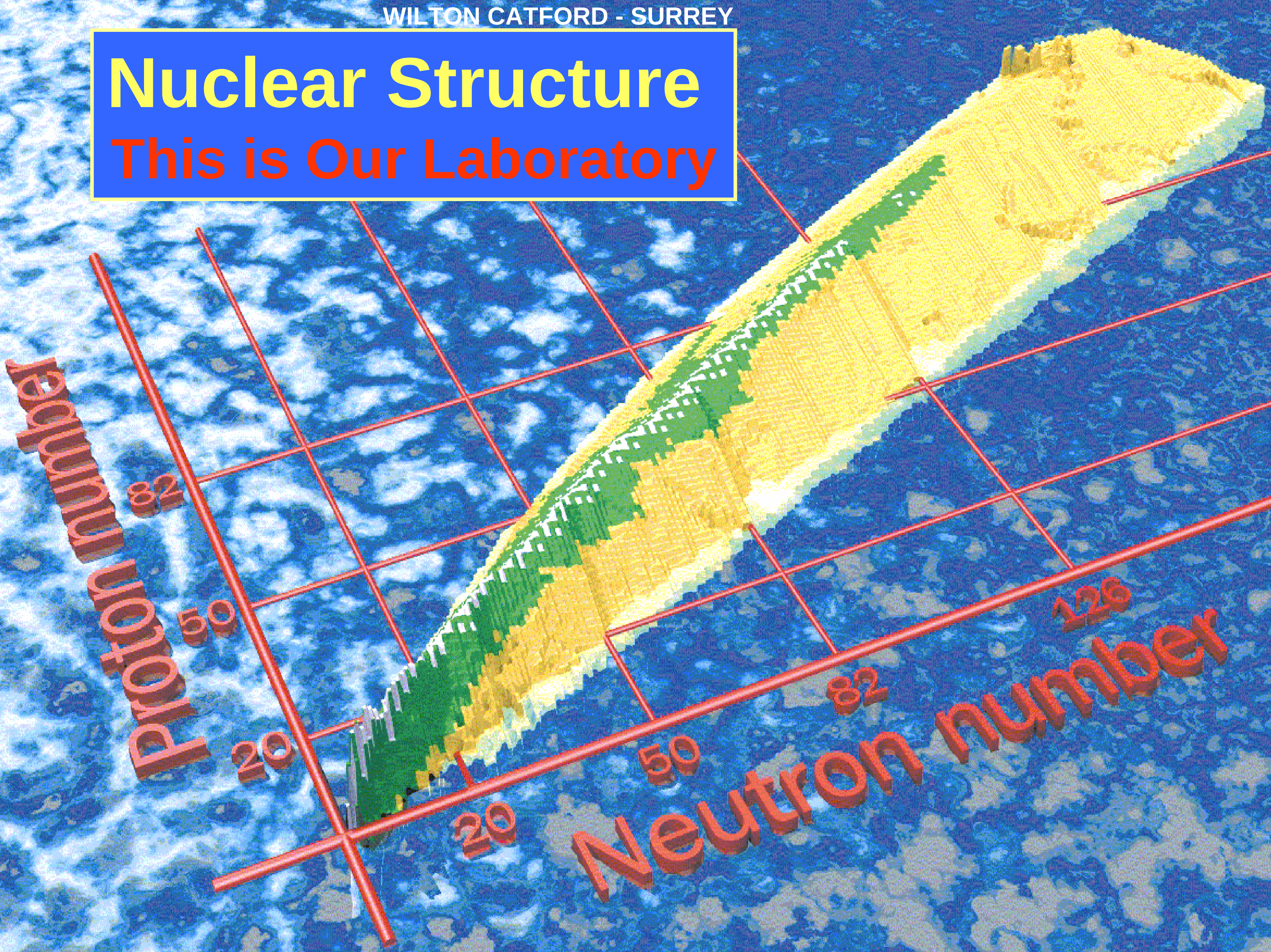
WILTON CATFORD - SURREY

Nuclear Structure

This is Our Laboratory



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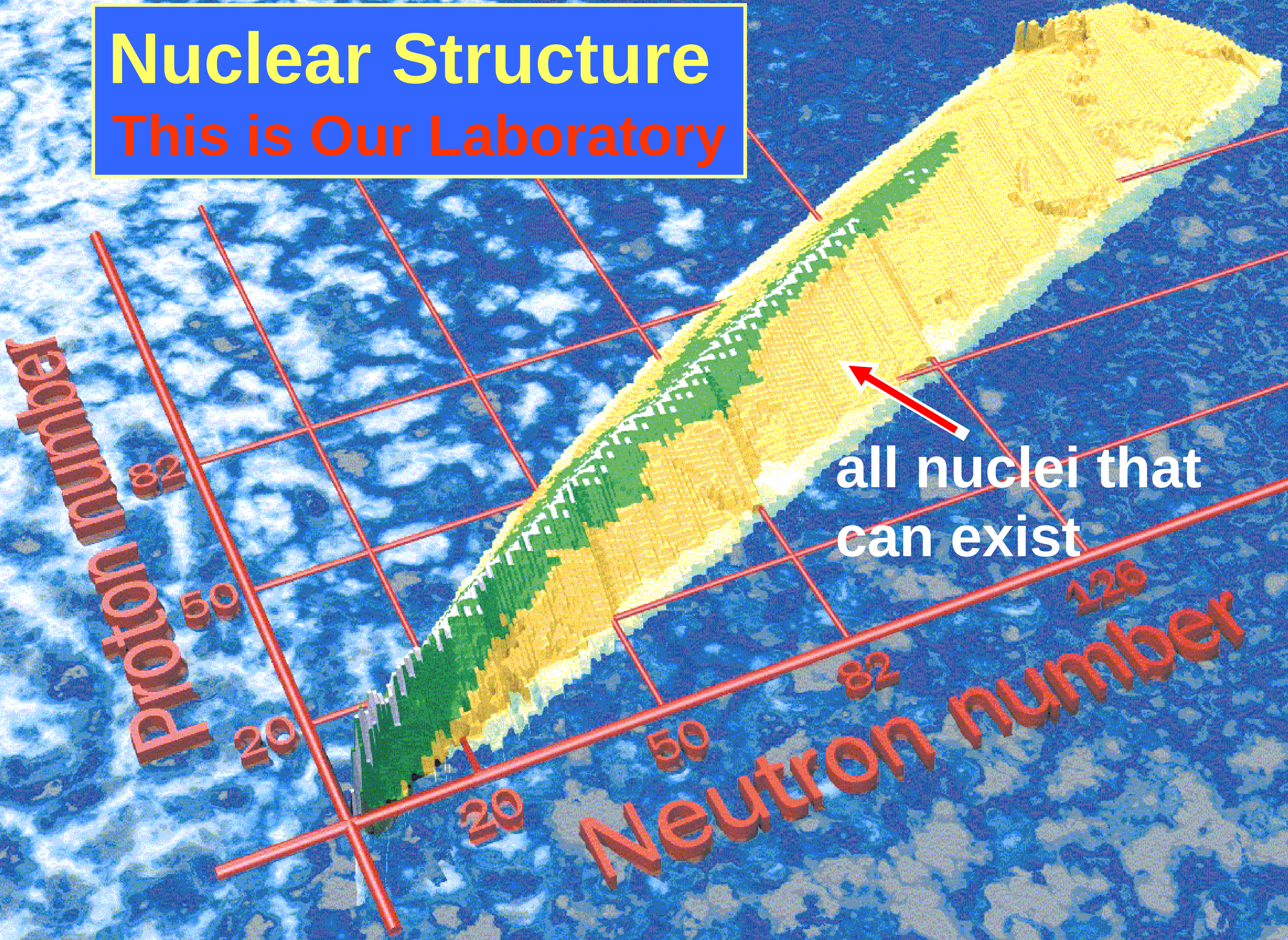

Nuclear Structure

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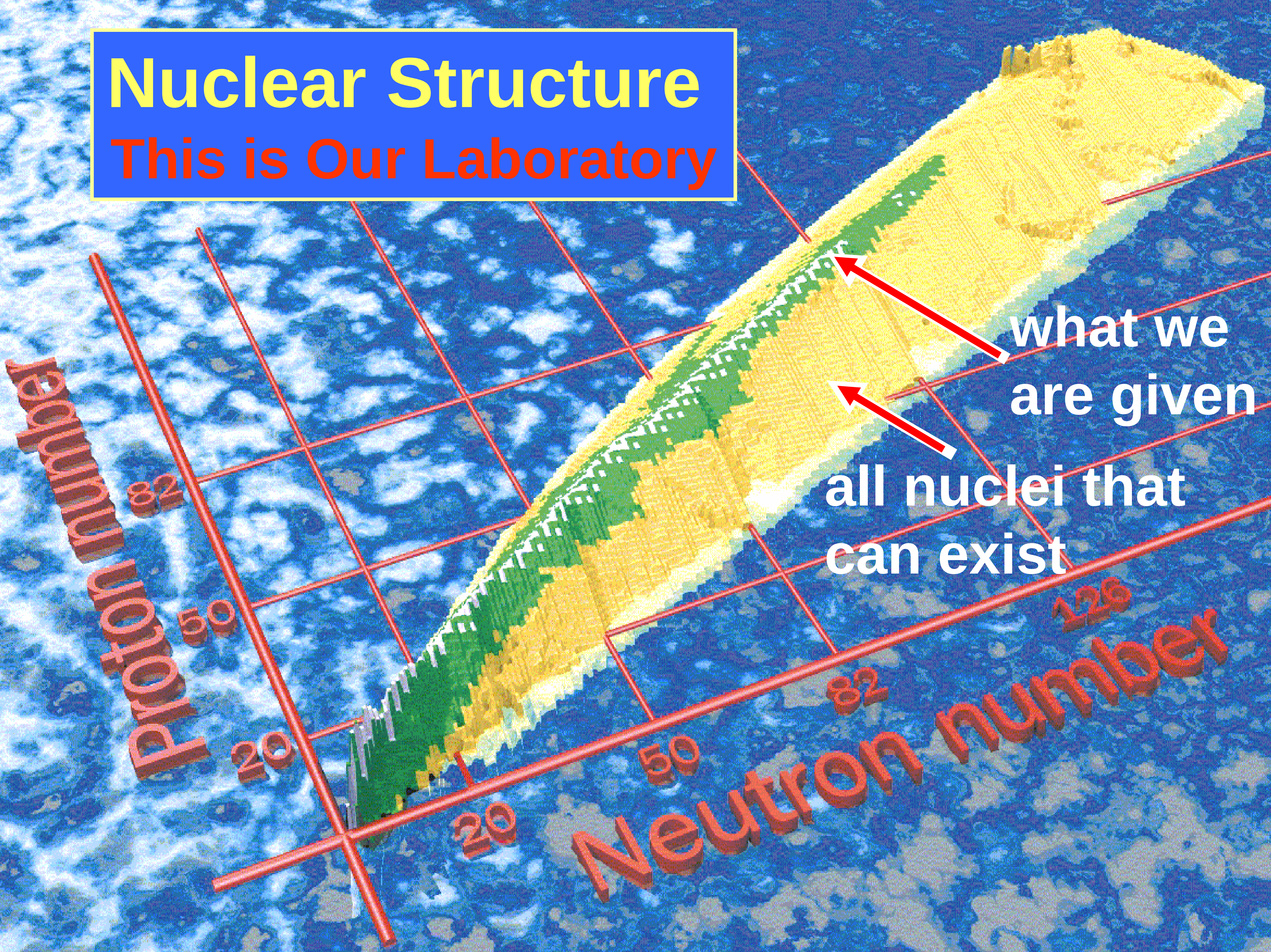
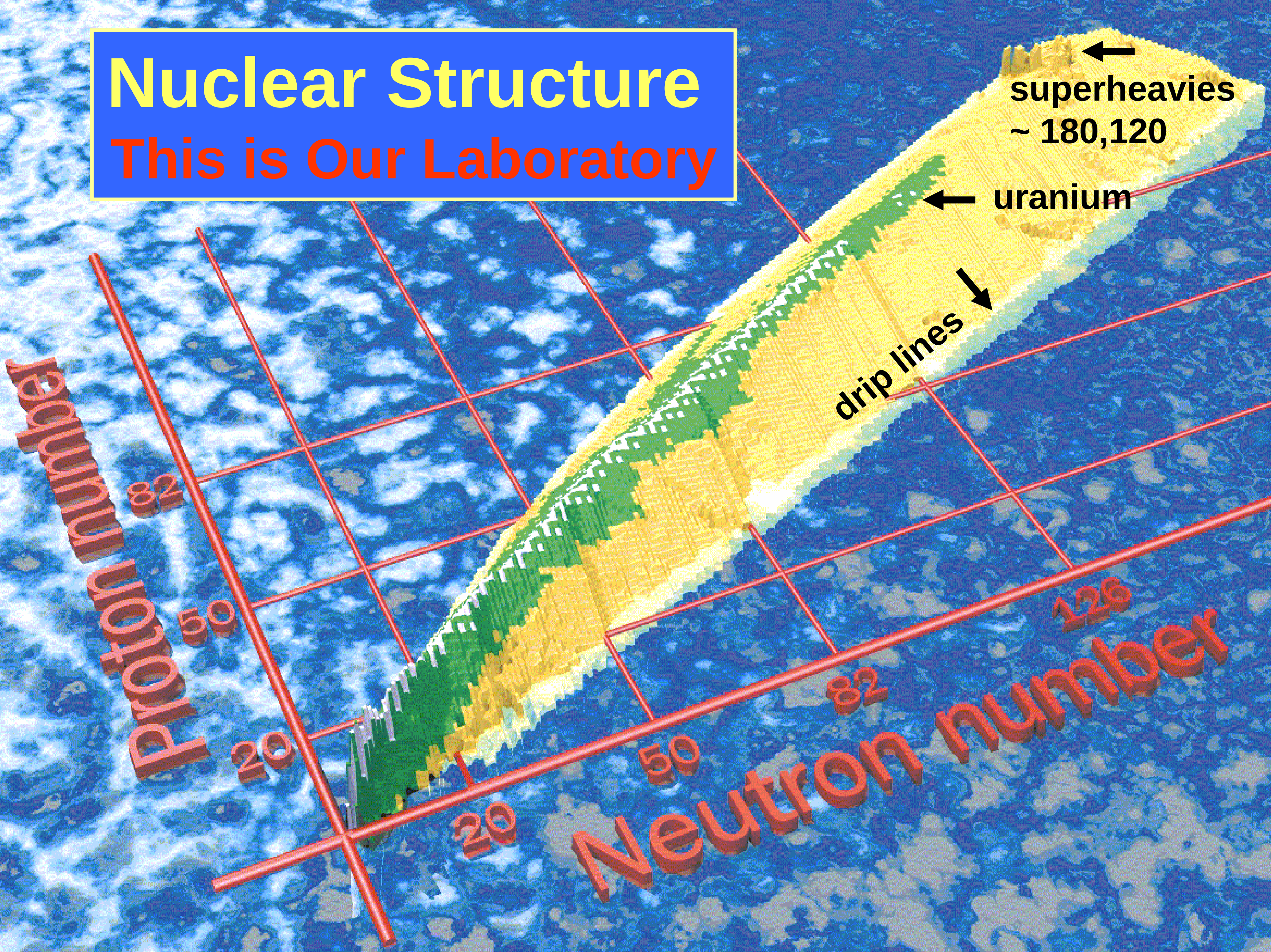


Nuclear Structure

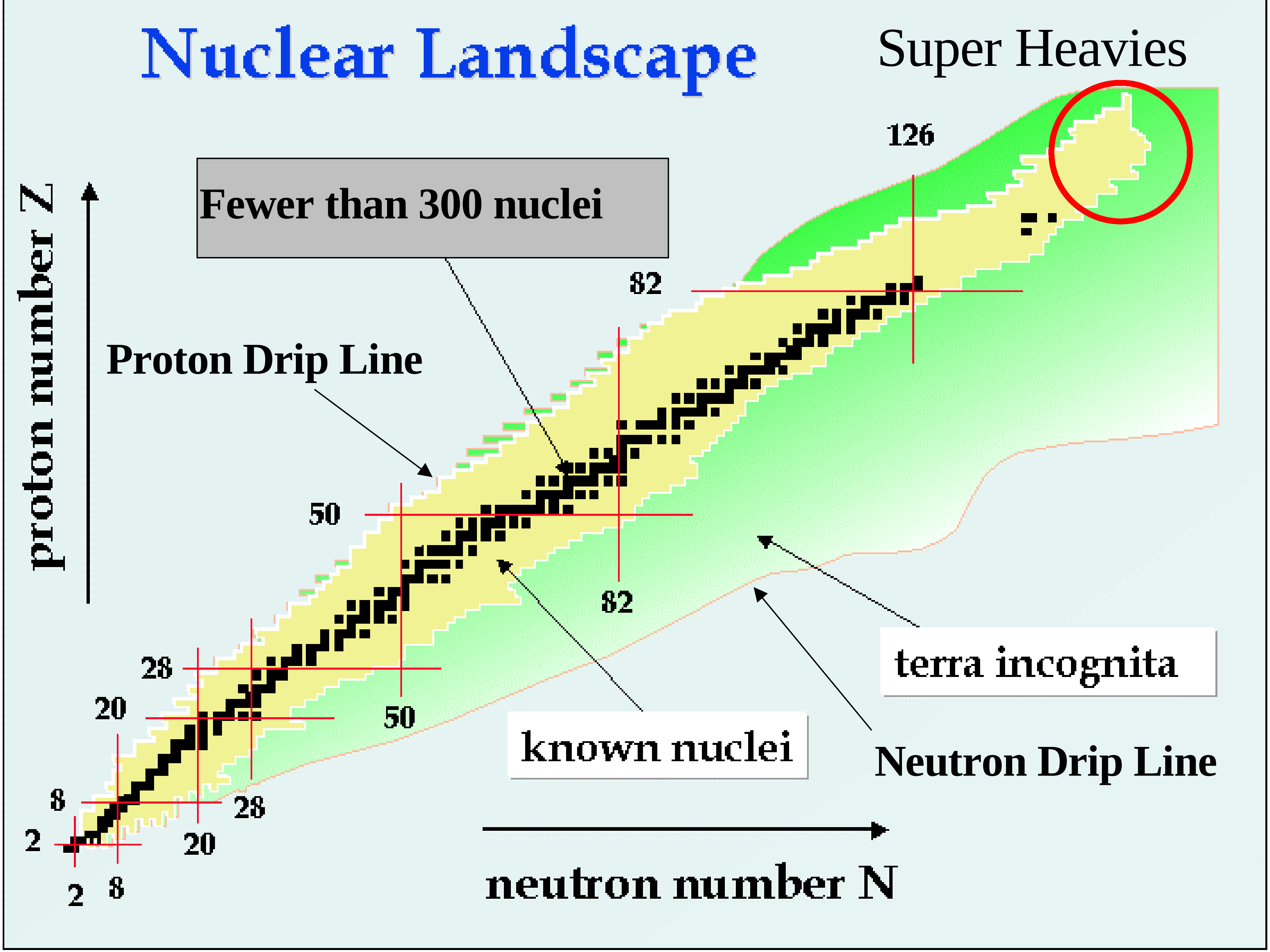
This is Our Laboratory



ENAM 04

The Fourth International Conference on Exotic Nuclei and Atomic Masses

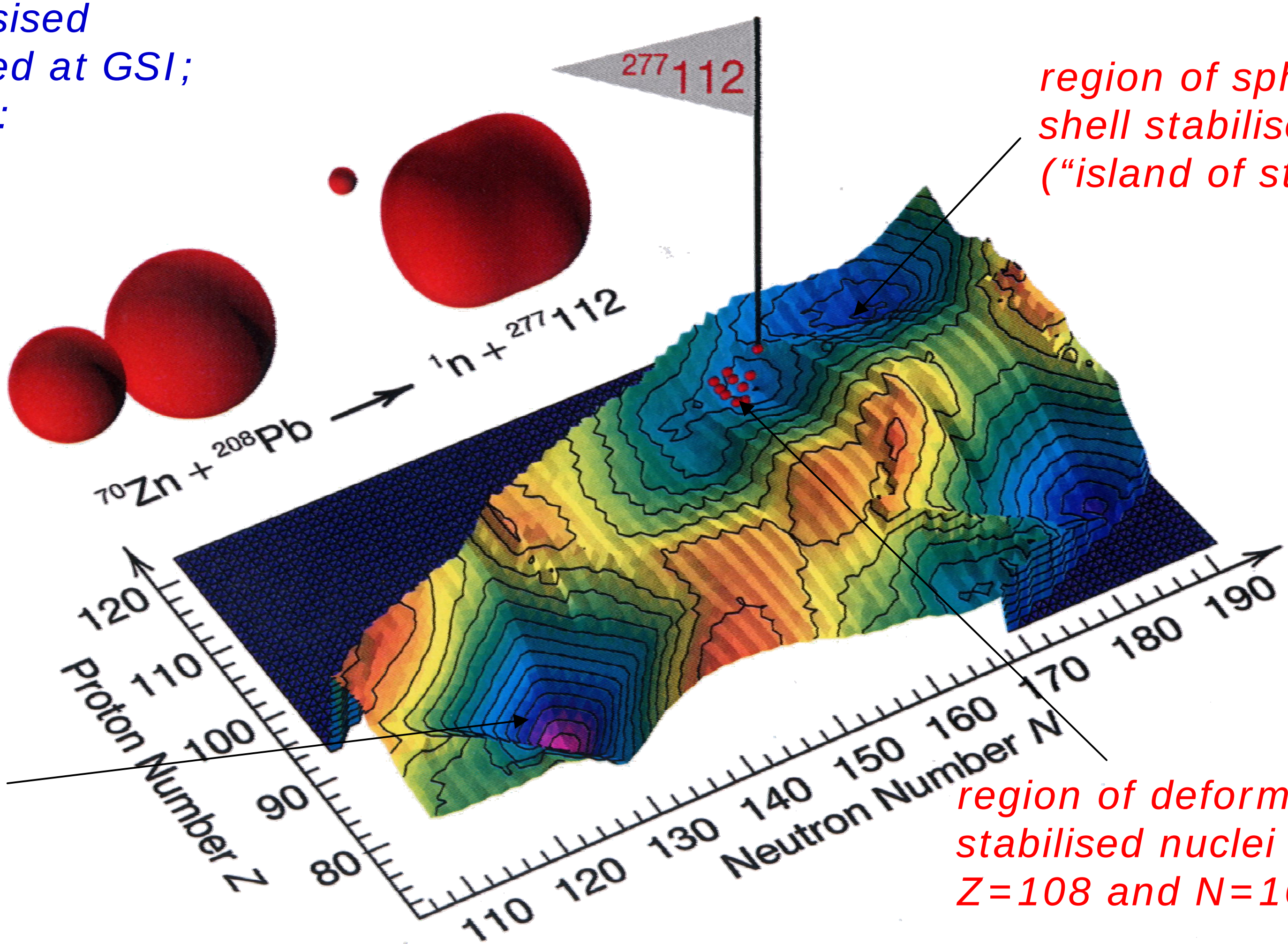
September 12-16, 2004
Callaway Gardens, Pine Mountain, Georgia


Nuclear Landscape
Super Heavies
126
Fewer than 300 nuclei
82
proton number Z
Proton Drip Line
50
82
28
50
20
terra incognita
known nuclei
Neutron Drip Line
8
28
2
20
2
8
neutron number N

Shell Correction Energies E_{shell} in the Region of Superheavy Elements

P. Möller et al.

Elements 107-112 first synthesised and identified at GSI;
New names:
107 – Bh
108 – Hs
109 – Mt
110 – Ds
111 – Rg

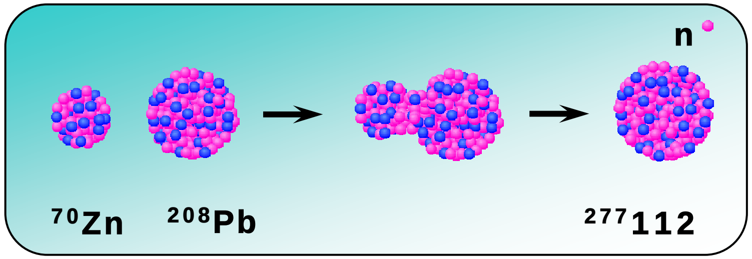


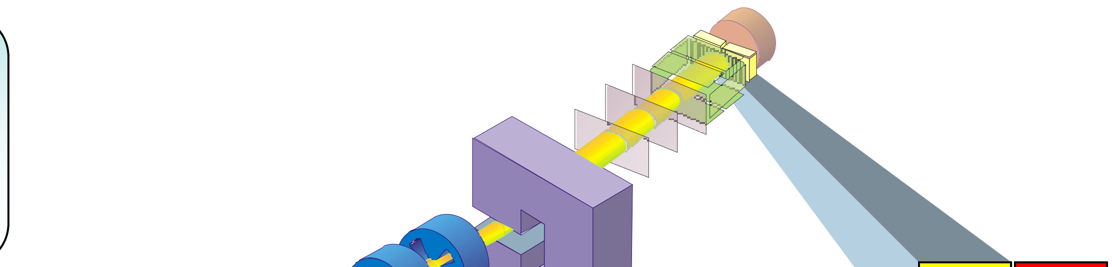
region of spherically shell stabilised nuclei ("island of stability")

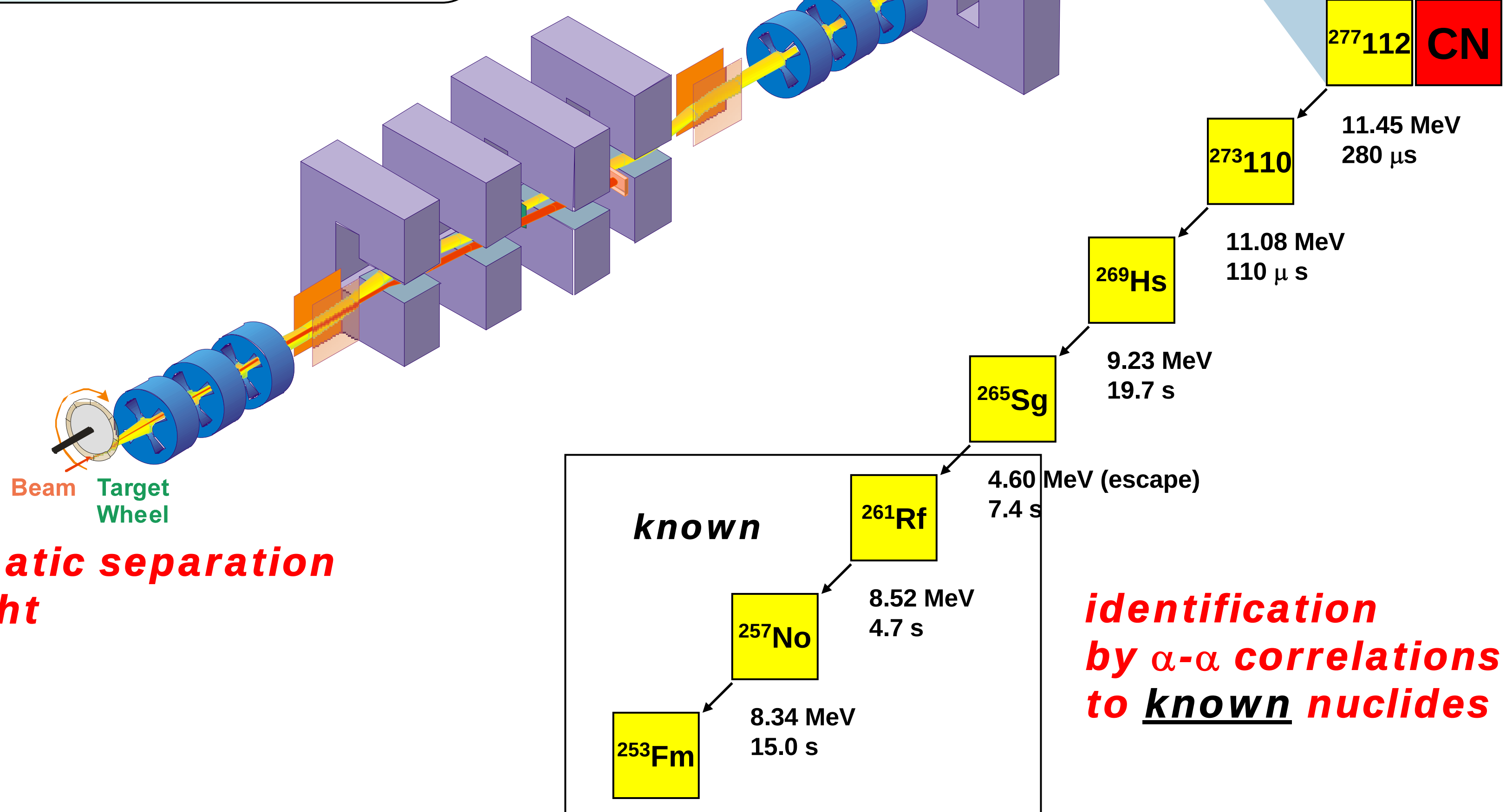
^{208}**Pb**

region of deformed shell stabilised nuclei around Z=108 and N=162

Synthesis and Identification of SHE at SHIP



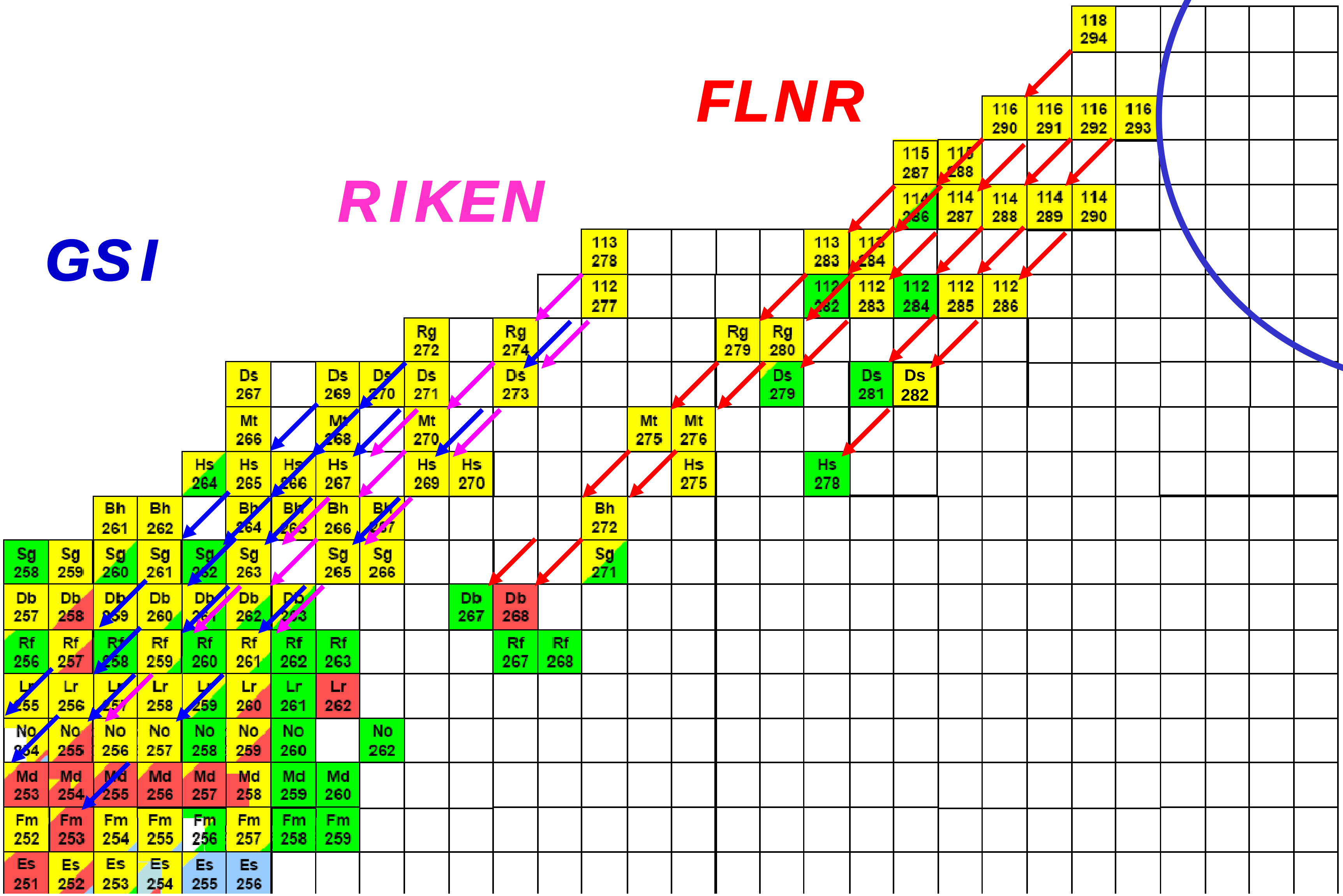




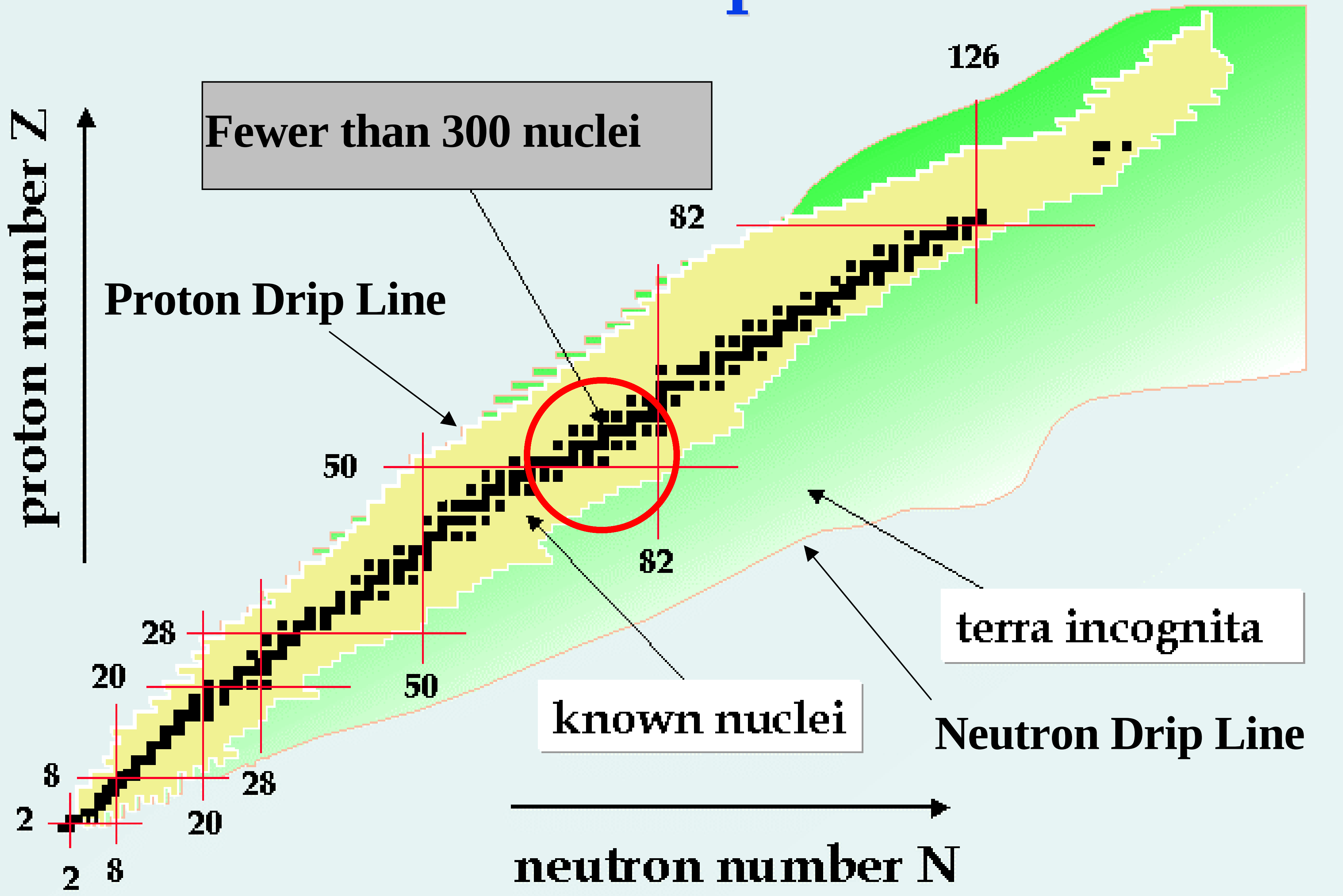
kinematic separation in flight

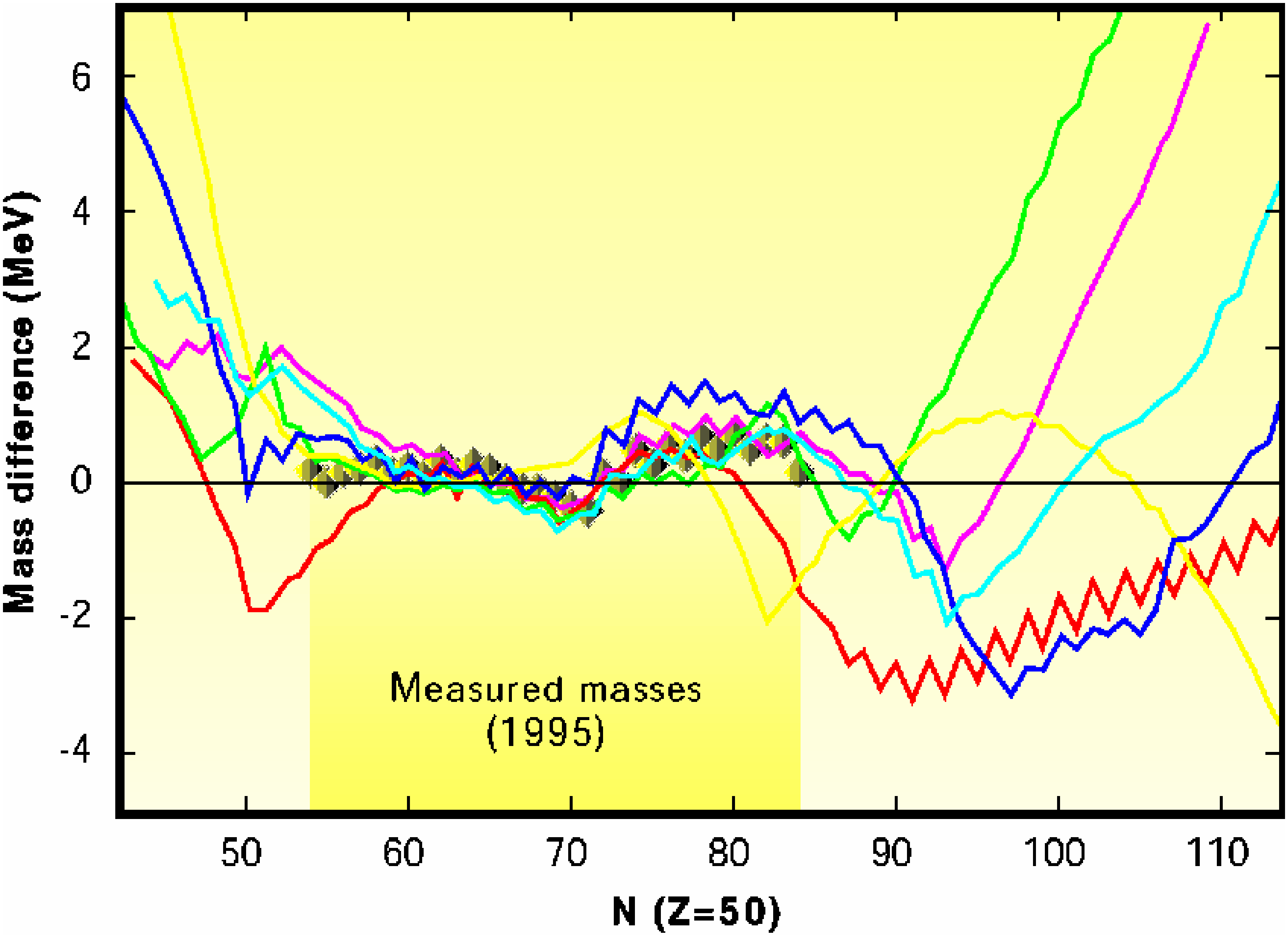
identification by α-α correlations to <u>known</u> nuclides

SHE Synthesis – Status September 2004

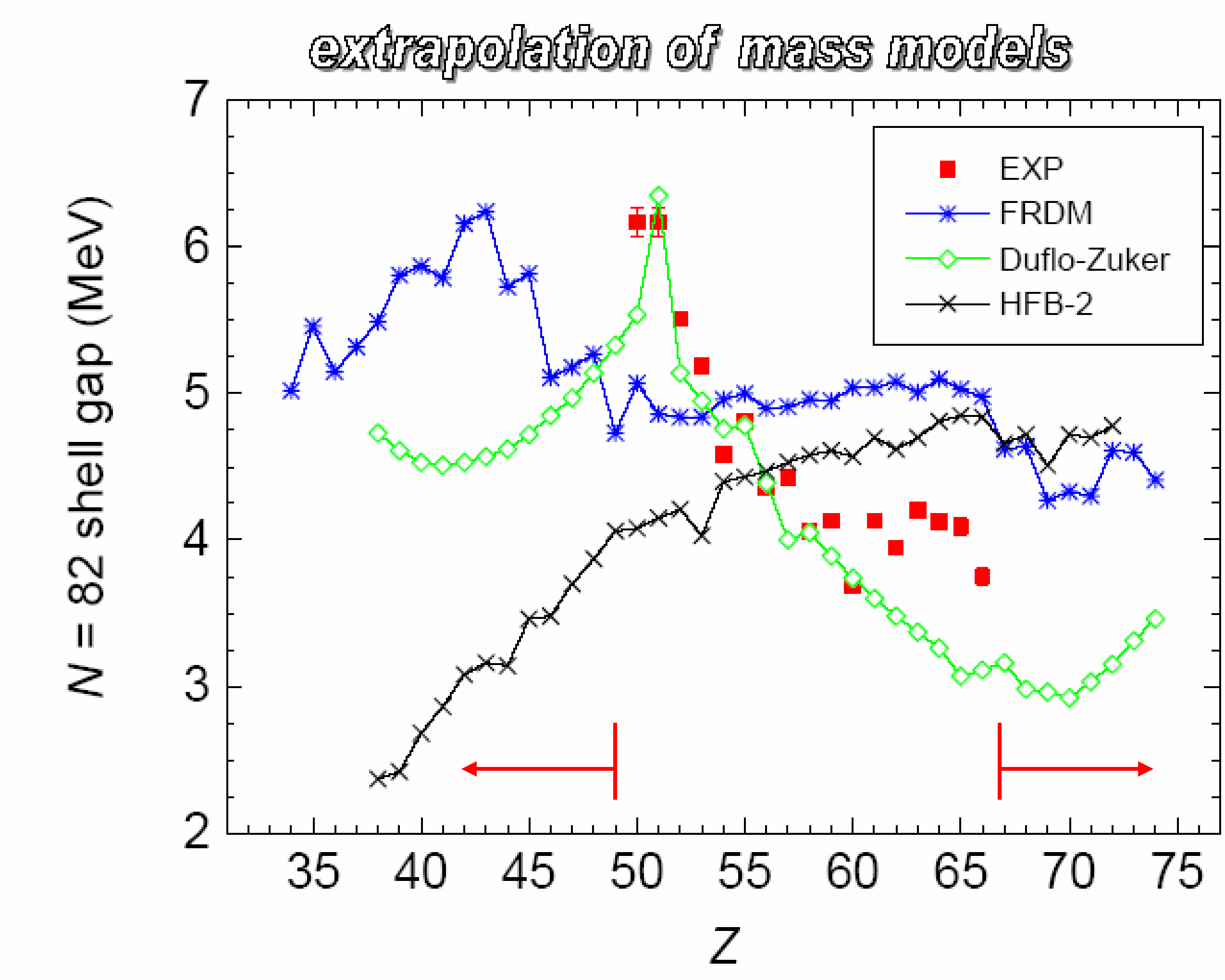


Nuclear Landscape





Adapted from: D. Lunney, Orsay, France



Experimentally deduced shell gap

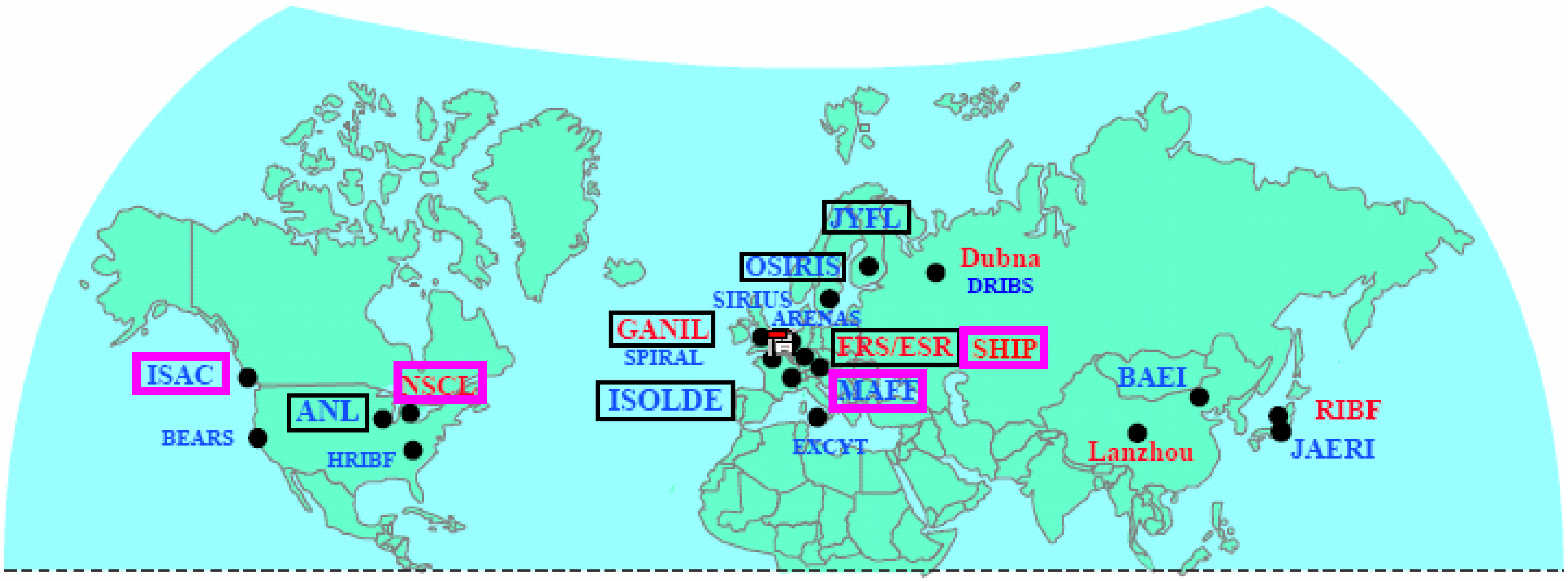
Best macroscopic-microscopic model

Best shell-based model

Best fully microscopic model

Adapted from: D. Lunney, Orsay, France

mass measurement programs at RIB facilities worldwide



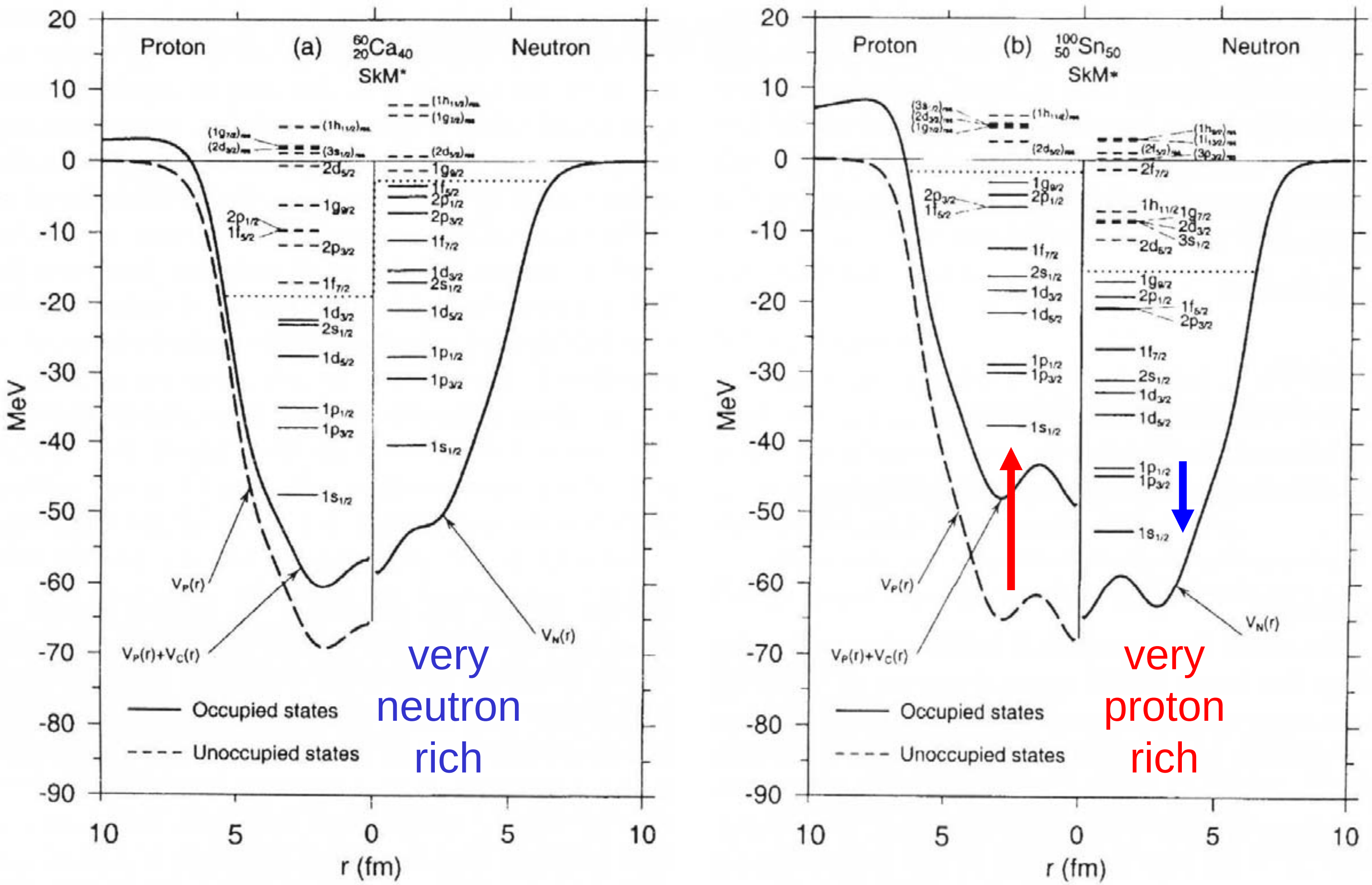
ISOL facilities In-Flight facilities

MASS MEASUREMENTS

(NEAR) FUTURE

Adapted from: D. Lunney, Orsay, France

Evolution in Shell Structure … Mean-field calculations



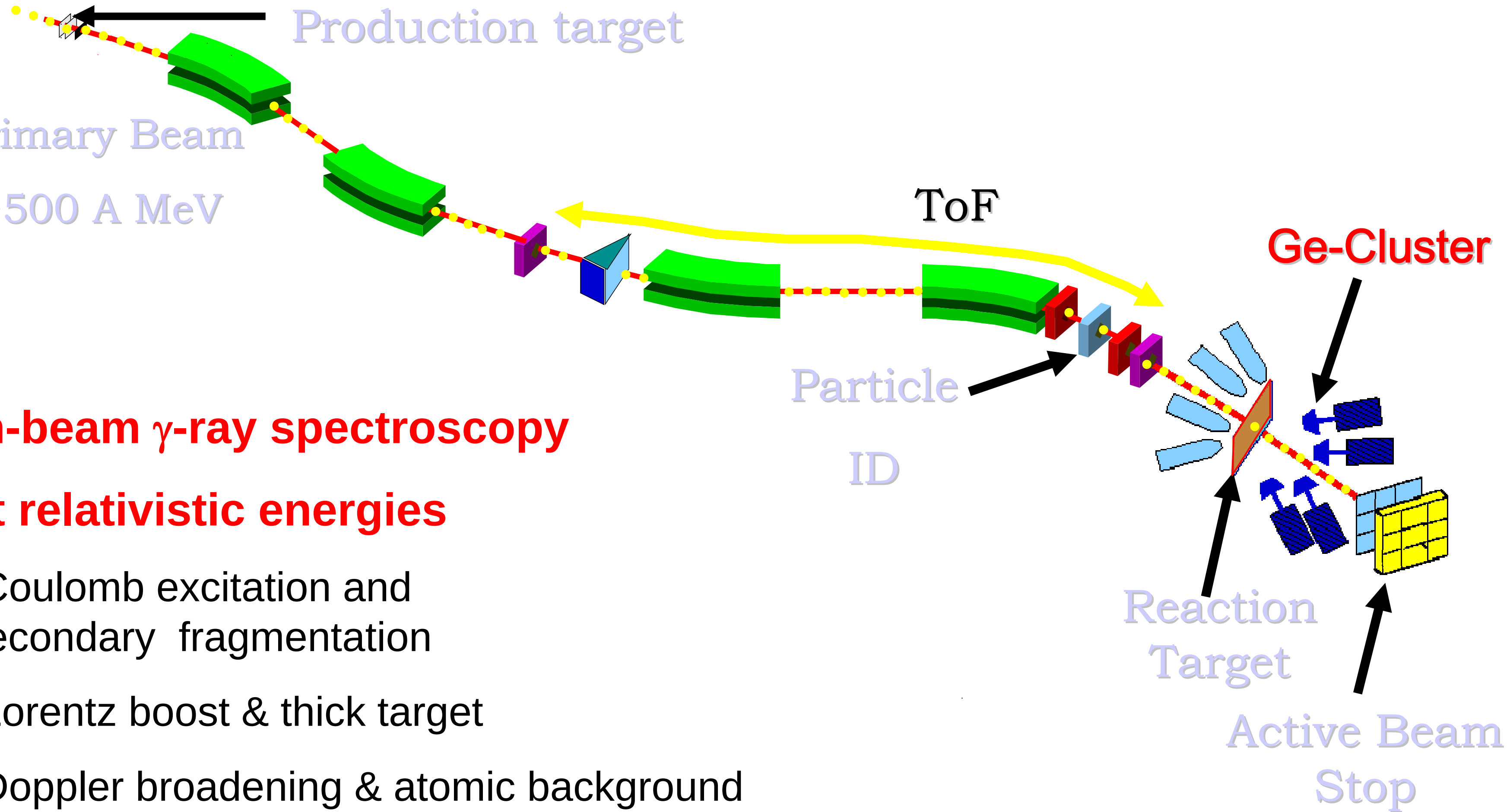
The single particle levels for an exotic neutron-rich nucleus are different in energy and relative spacings compared ot those of an exotic proton-rich nucleus…

this is of interest in itself and leads to new structure properties like altered collectivity…

and also requires to be known, to enable shell model calculations

Hartree-Fock results *from* I. Hamamoto & H. Sagawa, Nucl Phys News 12(2002)21

RISING set-up at GSI



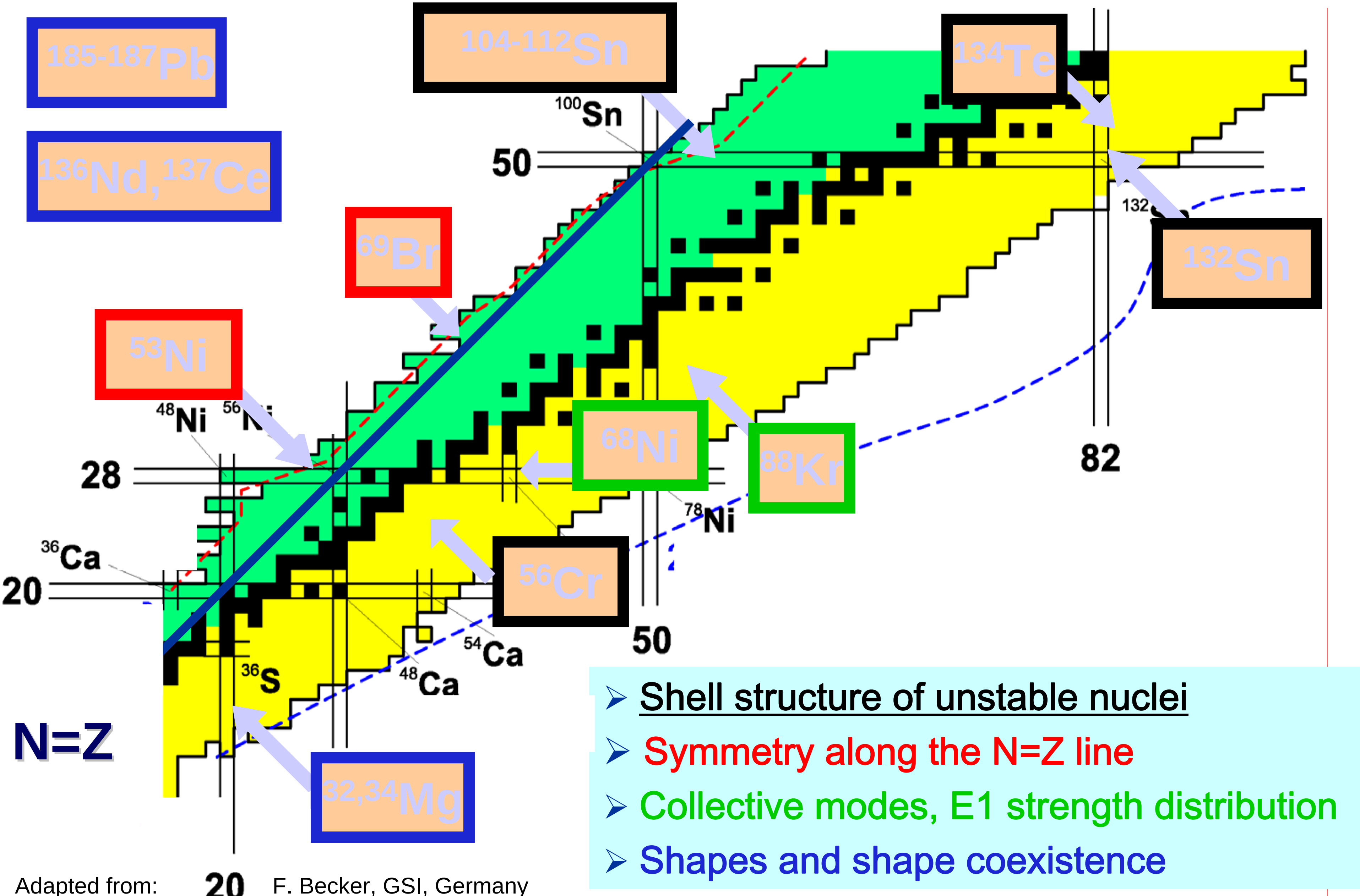
In-beam γ-ray spectroscopy

at relativistic energies

- Coulomb excitation and secondary fragmentation
- Lorentz boost & thick target
- Doppler broadening & atomic background

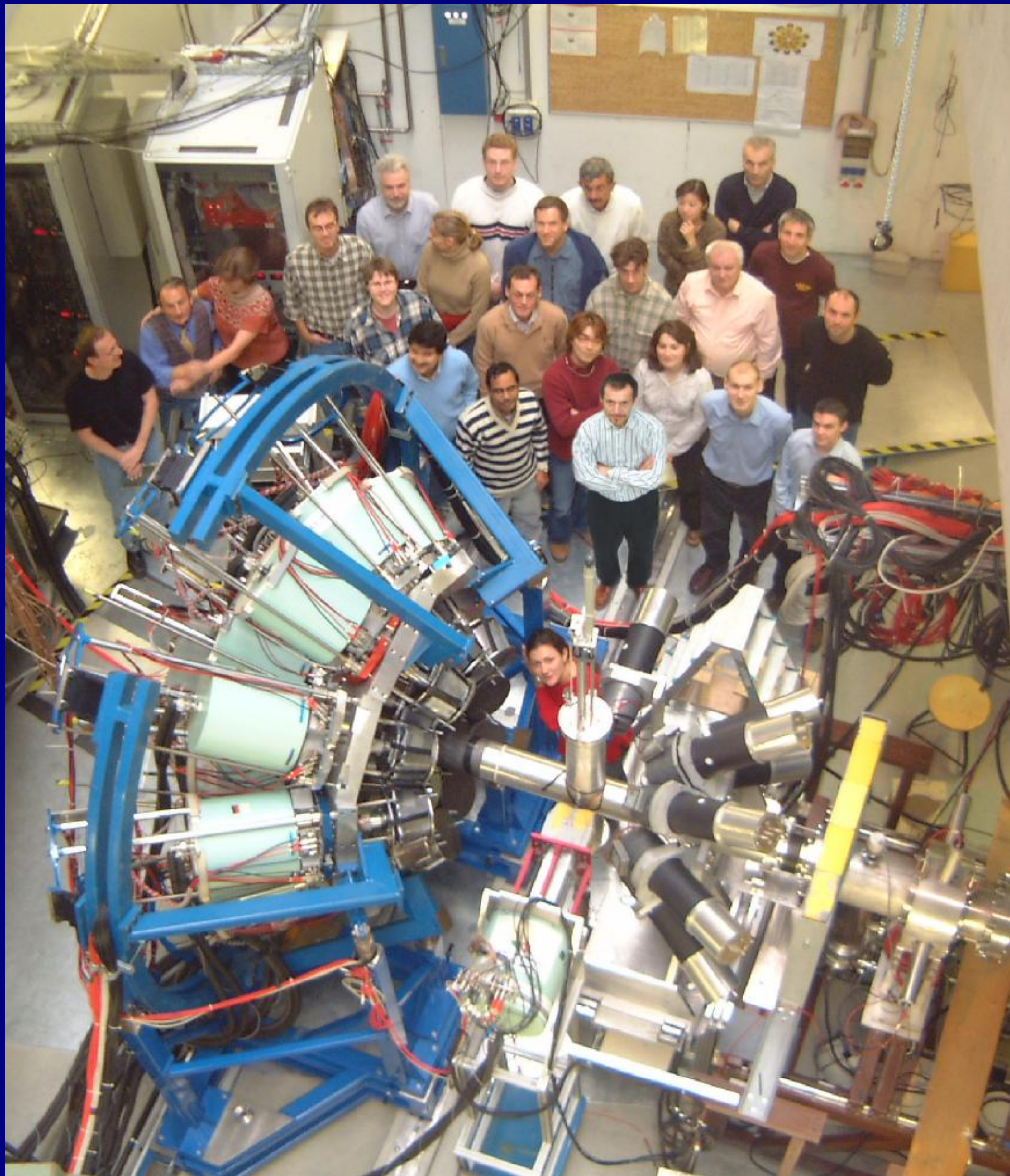
Adapted from: F. Becker, GSI Darmstadt, Germany

RISING Physics program - nuclei of interest



- <u>Shell structure of unstable nuclei</u>
- Symmetry along the N=Z line
- Collective modes, E1 strength distribution
- Shapes and shape coexistence

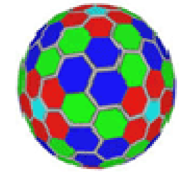
Adapted from: F. Becker, GSI, Germany



RISING

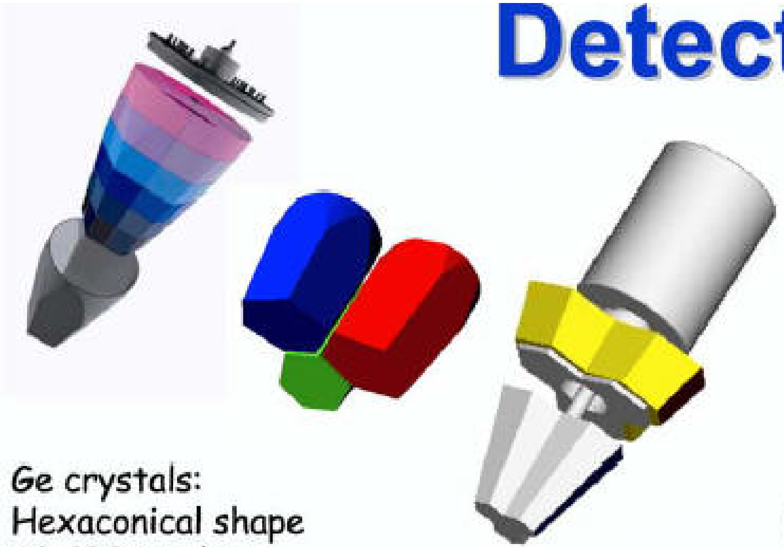
GSI

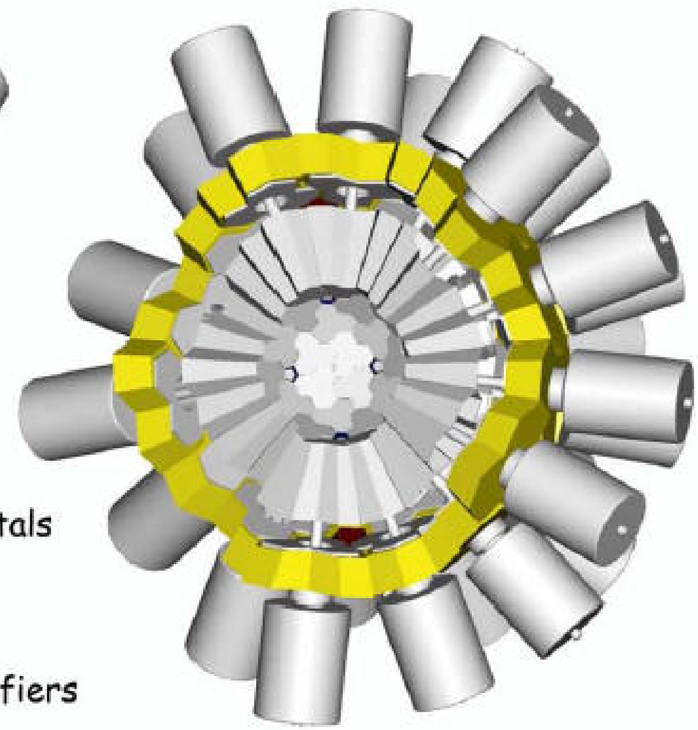
Advanced Gamma Tracking Array



Detectors

major European project



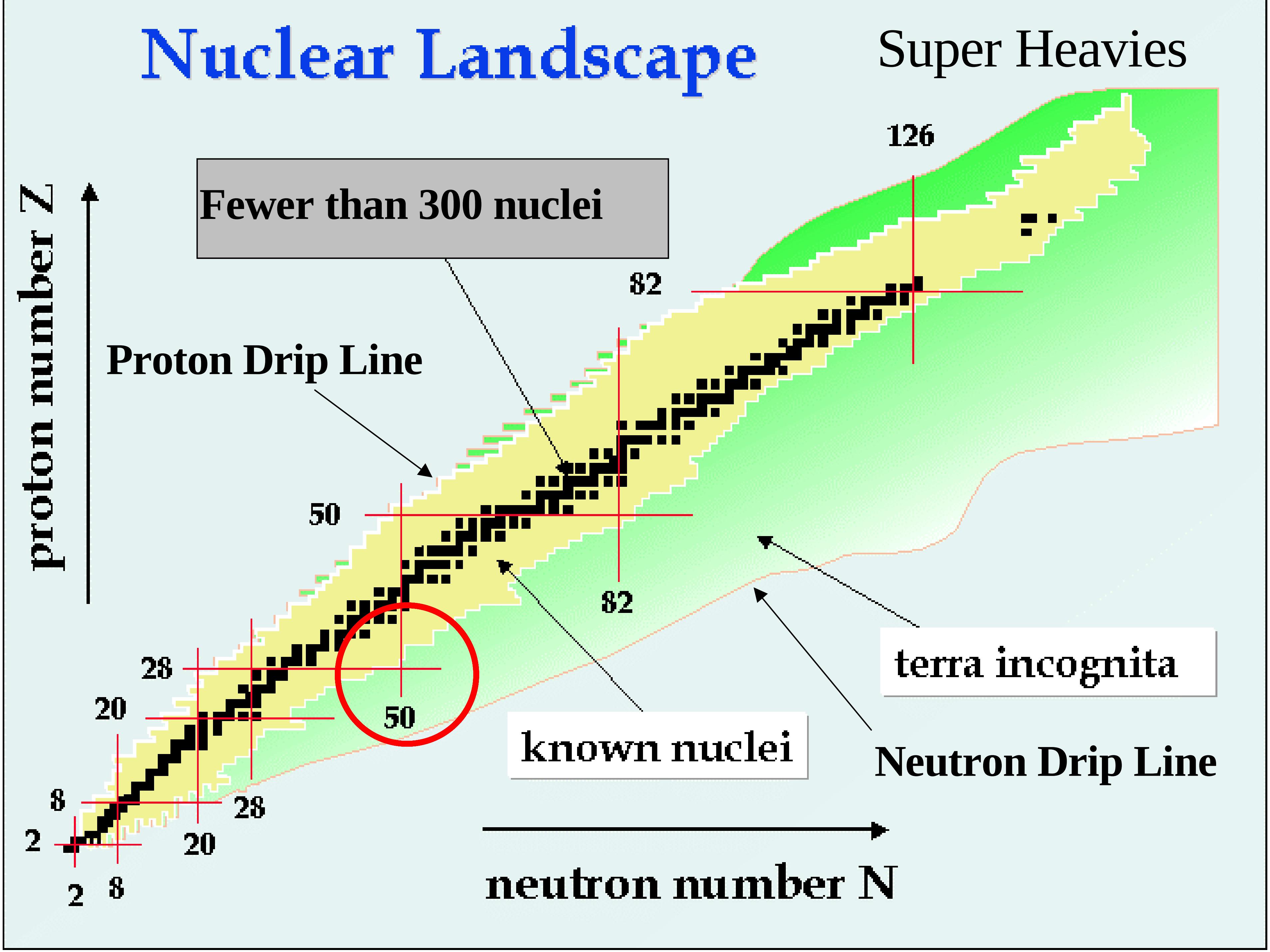


Ge crystals:
Hexaconical shape
90-100 mm long
80 mm max diameter
36 segments
Al encapsulatation:
  0.6 mm spacing
  0.8 mm thickness

Triple clusters:
  3 encapsulated crystals
Al end-cap:
  1.5 mm spacing
  1.5 mm thickness
111 cold FET preamplifiers

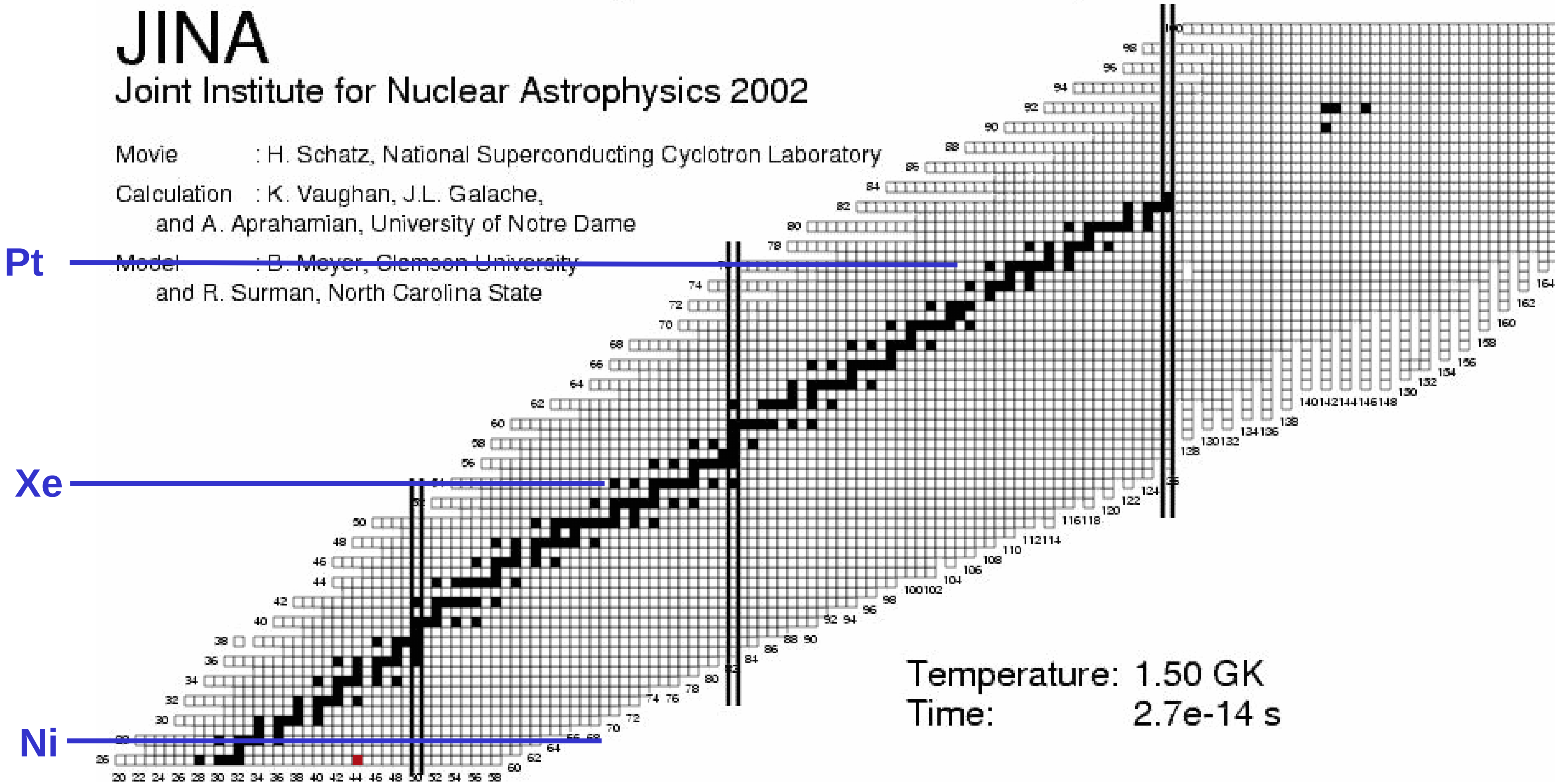
Distance between faces of crystals:
  in same cluster ~3 mm
  in adjacent clusters ~9 mm

Total weight of the 60 clusters of the AGATA-180 configuration ~2.5 tons
Mounted on a self-supporting structure



Nuclear Landscape
Super Heavies
Fewer than 300 nuclei
126
82
Proton Drip Line
50
82
28
20
50
known nuclei
terra incognita
Neutron Drip Line
8
28
2
20
2
8
proton number Z
neutron number N

Nucleosynthesis in the r-process



^{78}Ni, ^{79}Cu first bottle necks in n-capture flow (^{80}Zn later)

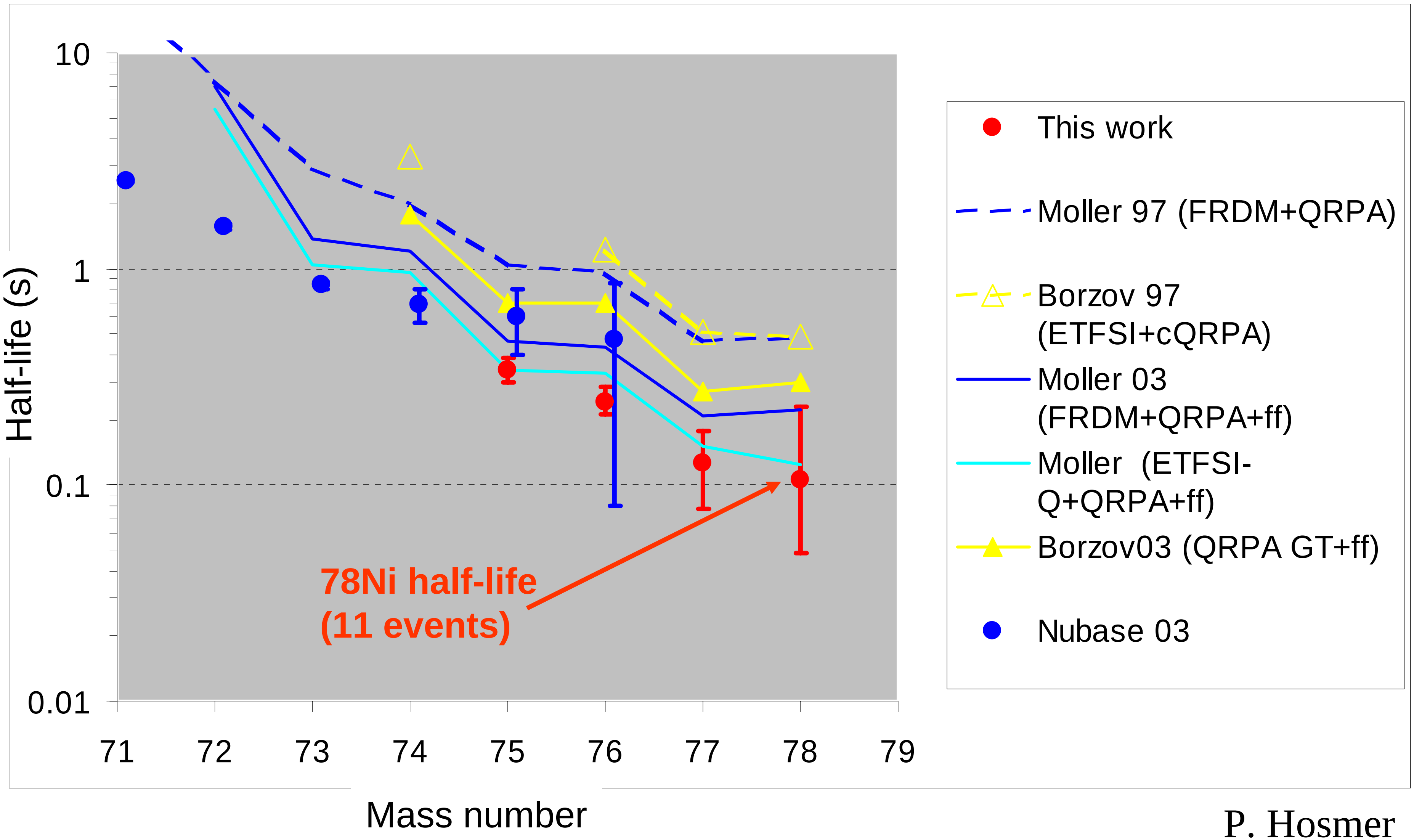
^{79}Cu: half-life measured 188 ms (Kratz et al, 1991)

^{78}Ni : half-life predicted 130 – 480 ms
3 events @ GSI (Bernas et al. 1997)

Adapted from: H. Schatz, NSCL Michigan MSU, USA

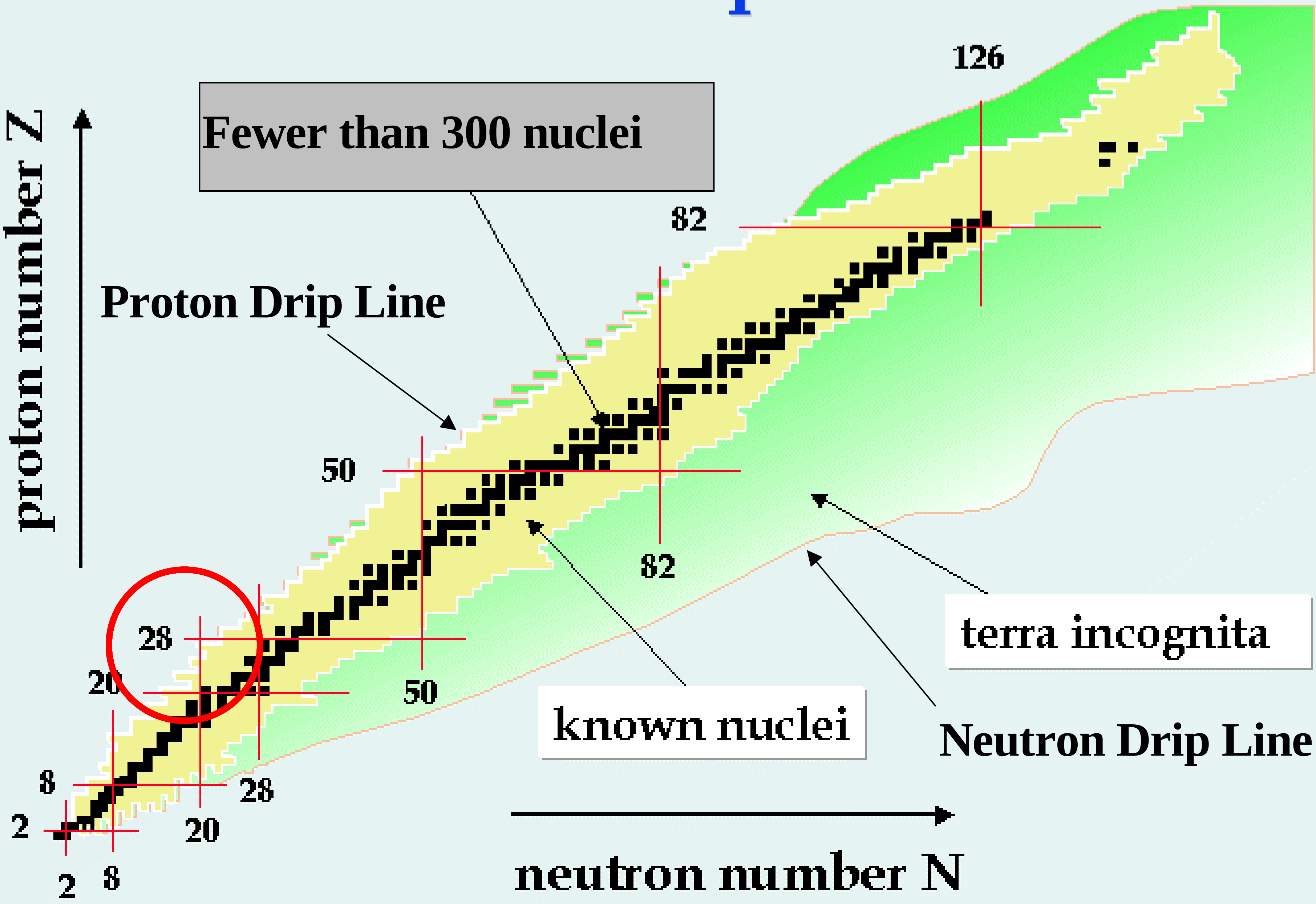
Preliminary results

Ni half-lives as a function of mass number – comparison with “global” models



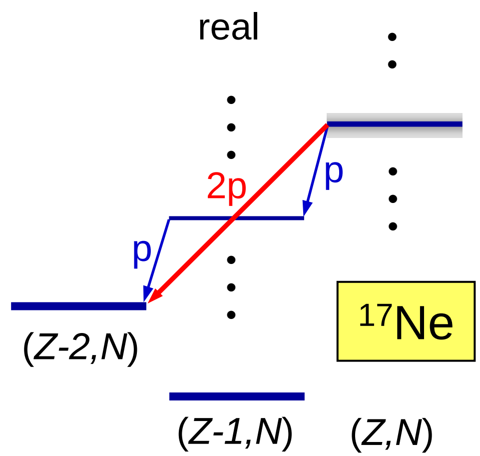
P. Hosmer

Nuclear Landscape



Radioactive Decay by 2p emission

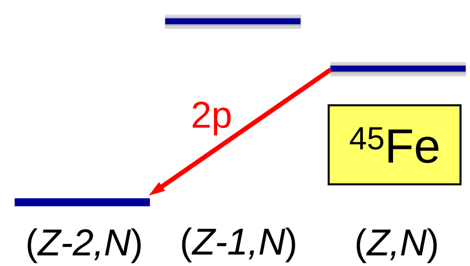
Sequential transitions through an intermediate state



In this case a direct 3-body process may contribute, but it is hard to distinguish it from the sequential one.

In special cases the pure 3-body mechanism is expected to dominate – the 2p radioactivity.

➔ Opportunity to study 3-body dynamics and probe p-p correlations in the nucleus.

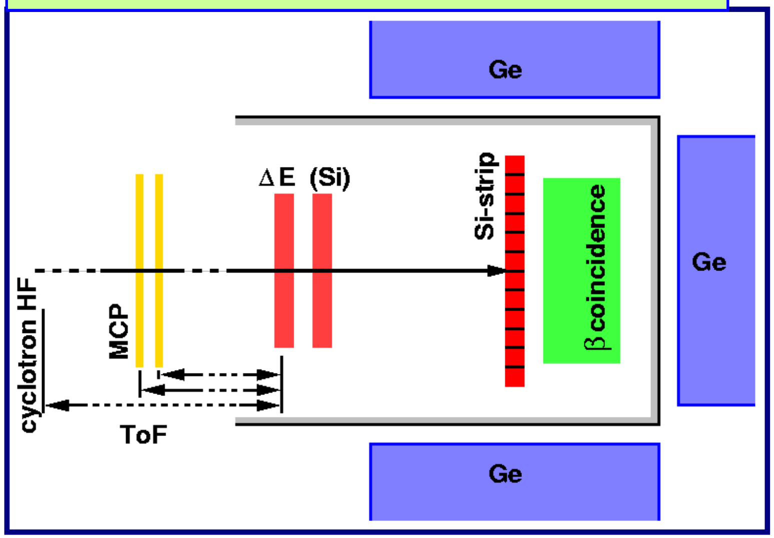


Adapted from: M. Pfutzner, IEP Warsaw, Poland

Results from GANIL

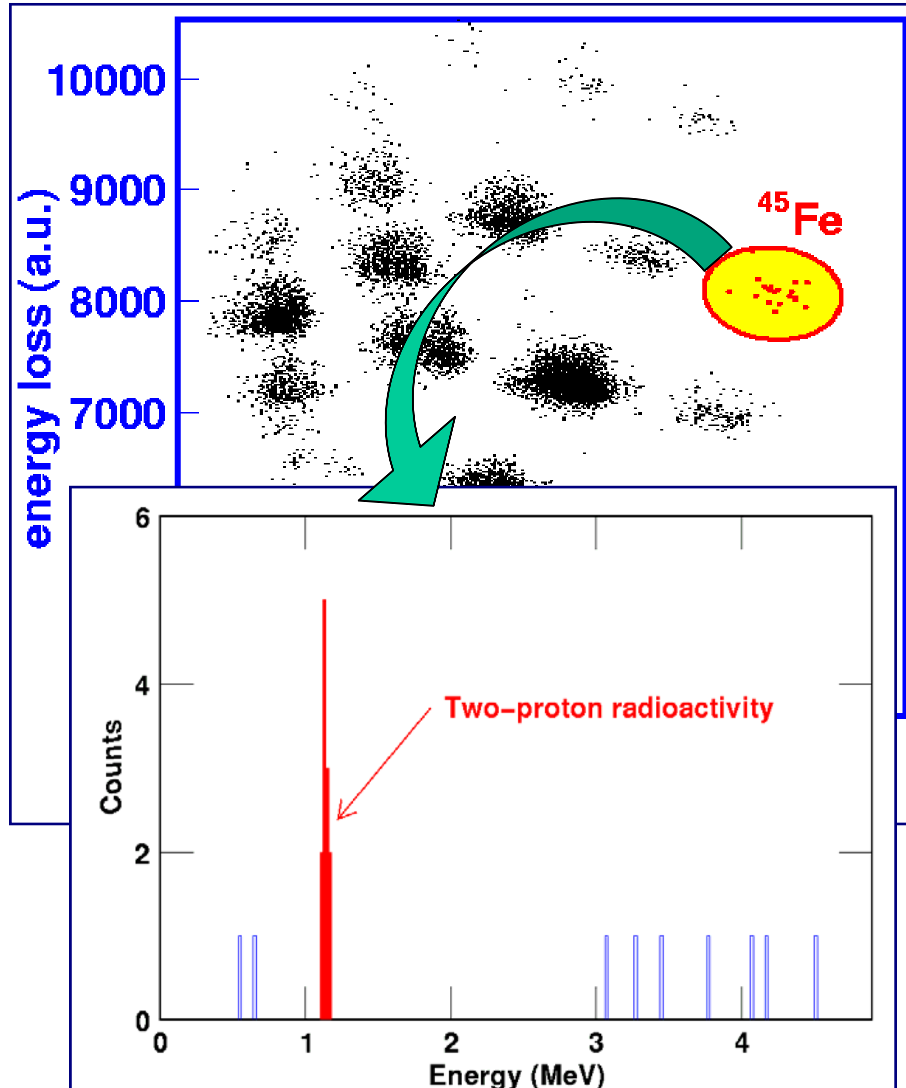
J. Giovinazzo et al., PRL 89 (2002) 102501

^{58}Ni @ 75 MeV/A on nickel target
High primary beam intensity: 3-5μA



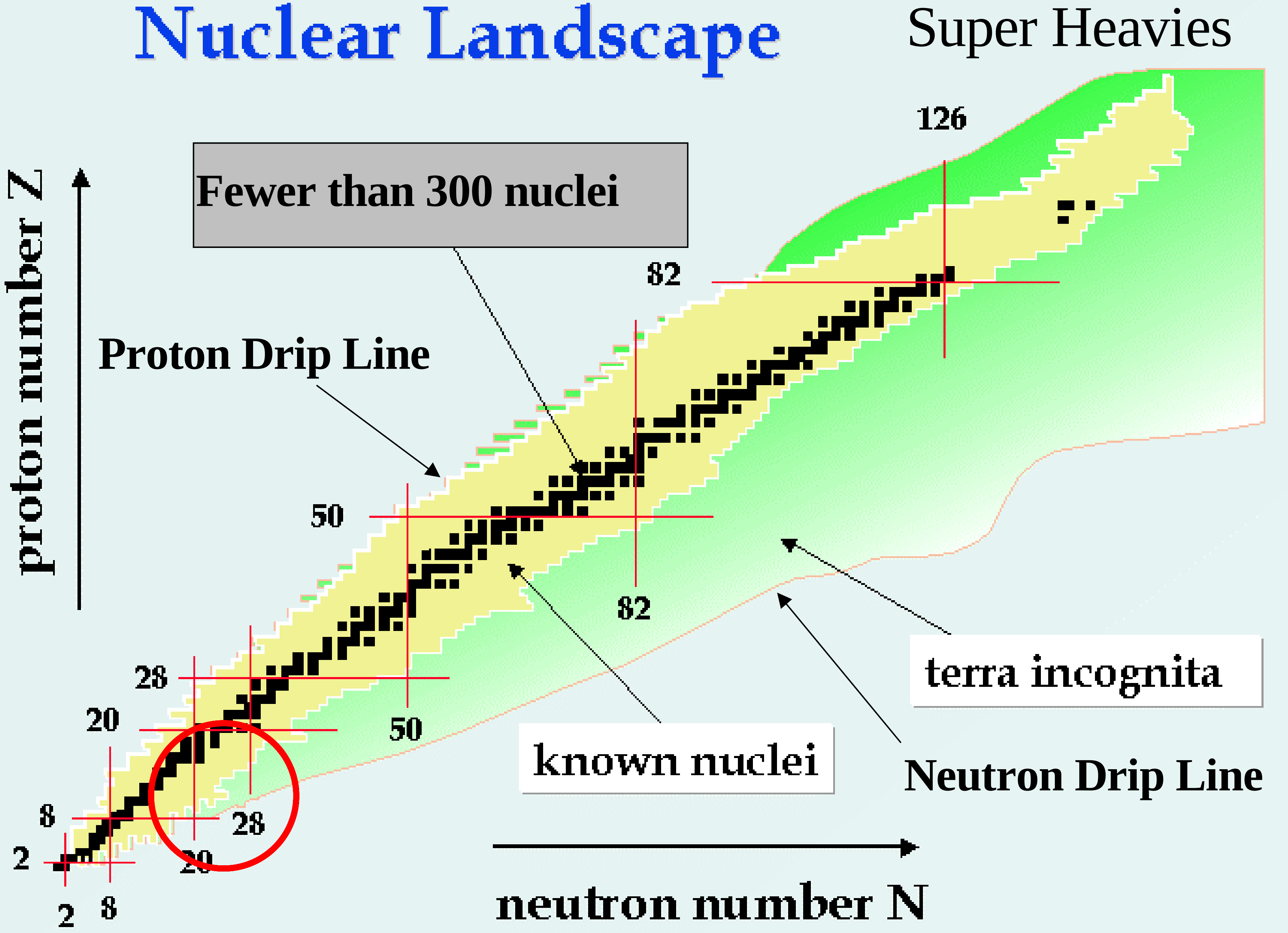
- 22 ions of ^{45}Fe implanted
  - 12 counts in a narrow peak
  - no β and no γ in coincidence
  - no βp pile-up

➔ E_{2p} = 1.14(5) MeV
$T_{1/2} = 4.7^{+3.4}_{-1.4}$ ms



Adapted from: M. Pfutzner, IEP Warsaw, Poland

Nuclear Landscape

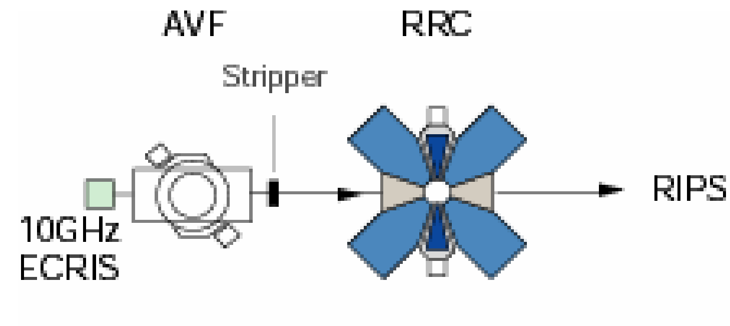


New Acceleration Scheme at RIKEN

AVF Injection

10GHz ECR +AVF+RRC

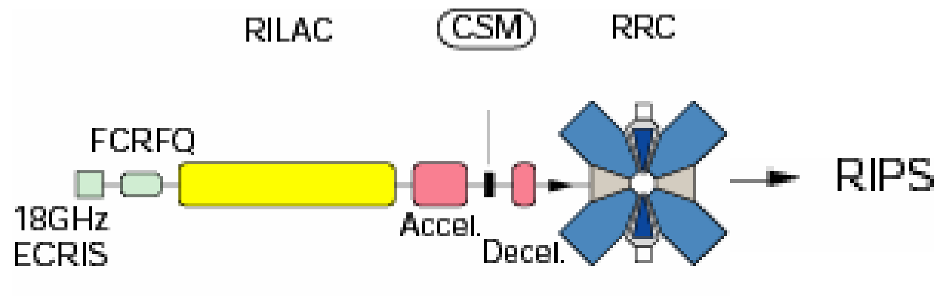
^{48}Ca, ^{86}Kr 4 pnA max. at 70*A* MeV



RILAC Injection (RIBF)

18GHz ECR + RILAC + CSM+RRC

^{48}Ca, ^{86}Kr 150 pnA max. at 64*A* MeV



Search for new isotopes

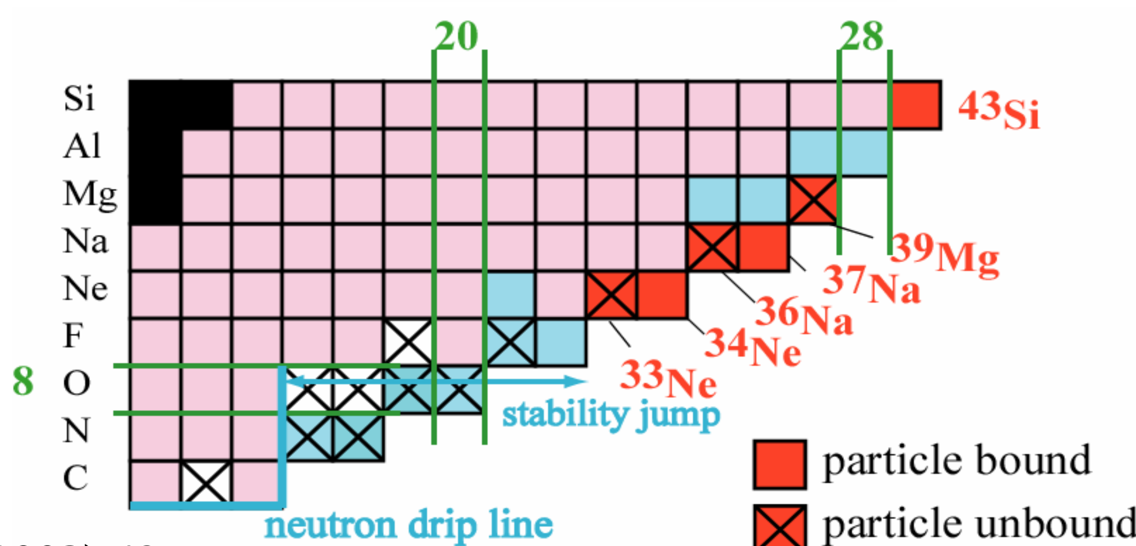
^{48}Ca beam

Particle bound

^{34}Ne, ^{37}Na, ^{43}Si

Particle unbound

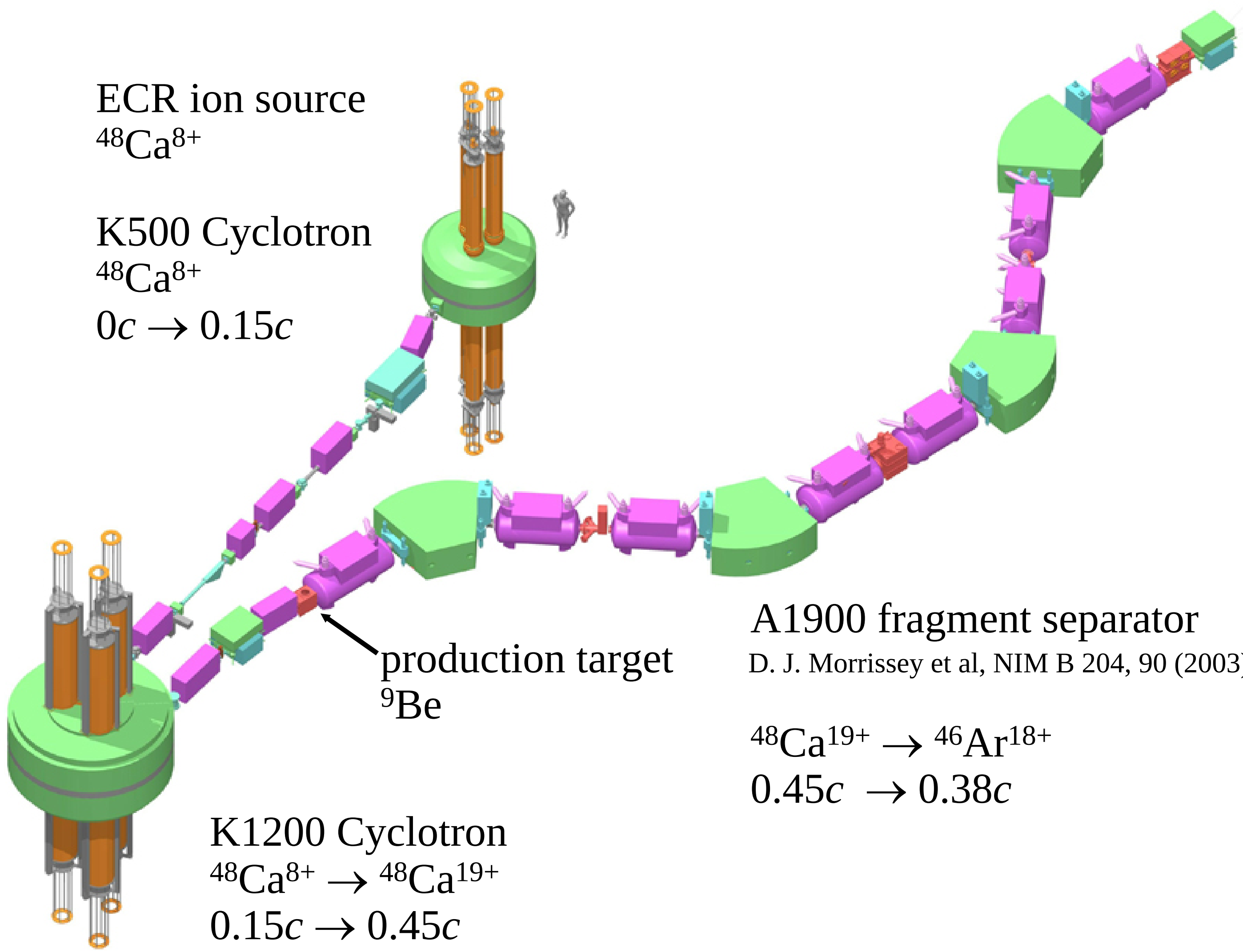
^{33}Ne, ^{36}Na, ^{39}Mg



Notani et al., Phys. Lett. B542 (2002) 49

Adapted from: H. Sakurai, U of Tokyo, Japan

The Coupled Cyclotron Facility at the NSCL (MSU)



Adapted from: A. Gade, NSCL Michigan MSU, USA

Spectroscopy of the wave function:

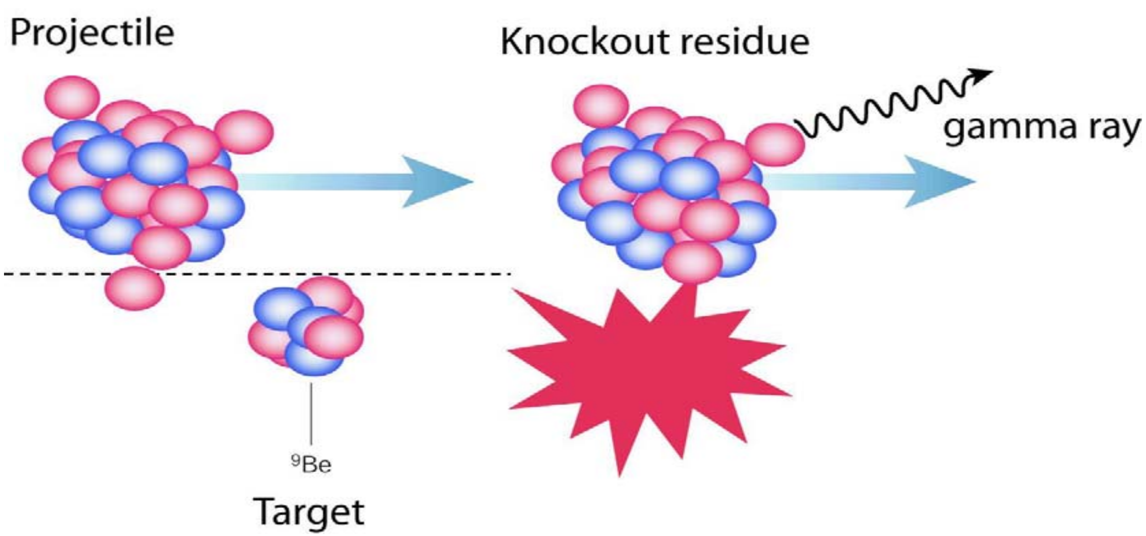
One-nucleon knockout

- more than 50MeV/nucleon:

  sudden approximation + eikonal approach (J.A. Tostevin, Surrey)

- Spectroscopic Factors

  determined from the population of the residue with A-1



residue moment distribution

→ ℓ-value of knocked-out n

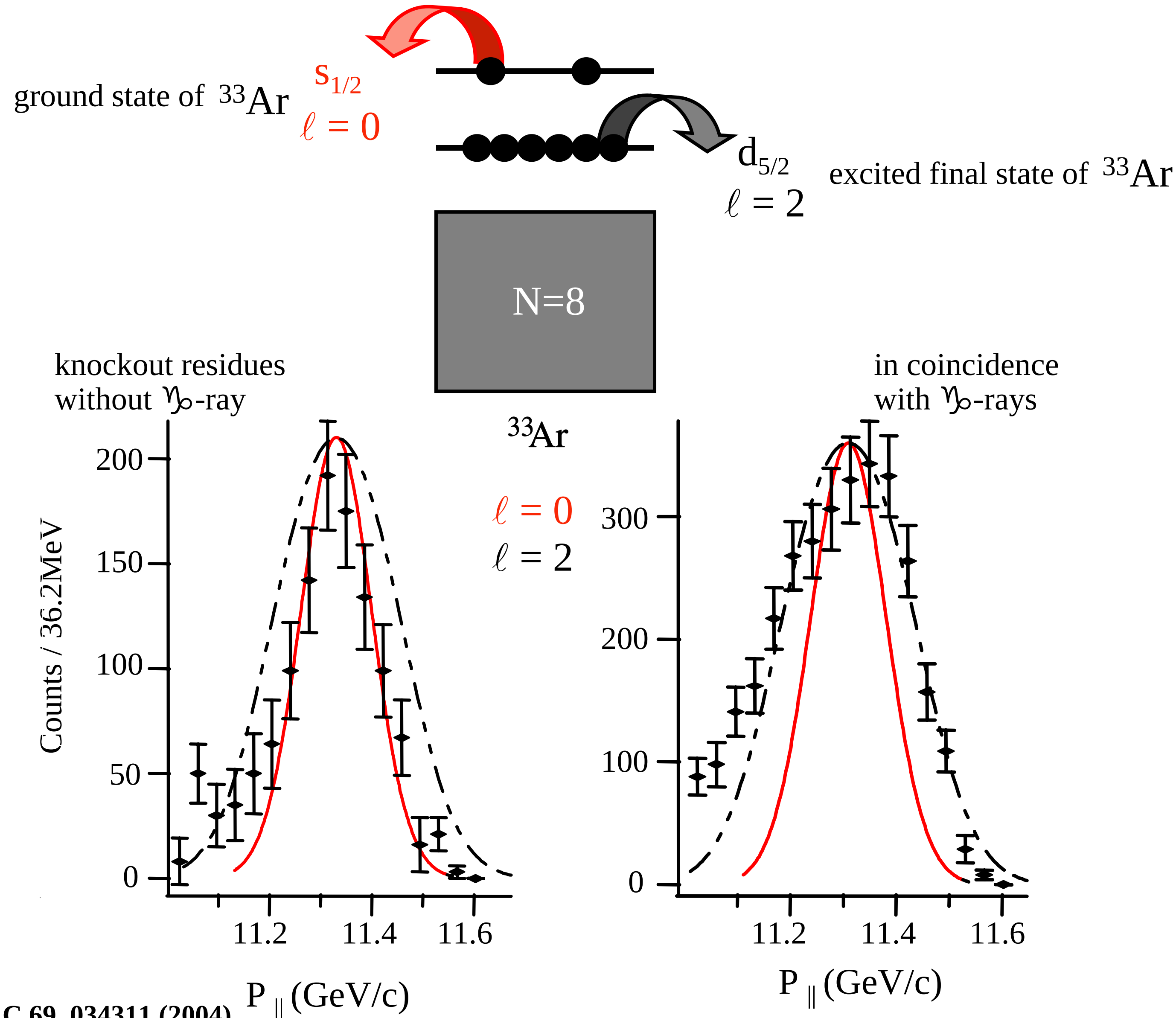
$$\vec{k}_3 = \frac{A-1}{A}\vec{k}_A - \vec{k}_{A-1}$$

$$\sigma(nI^\pi) = \sum_j \underbrace{C^2S(j, nI^\pi)}_{\text{nuclear structure information}} \underbrace{\sigma_{sp}(j, B_n)}_{\text{reaction process}}$$

P.G. Hansen and B.M. Sherrill, Nucl. Phys. **A 693**, 133 (2001).
P.G. Hansen and J. A. Tostevin, Annual Review of Nuclear & Particle Science **53**, 219 (2003)

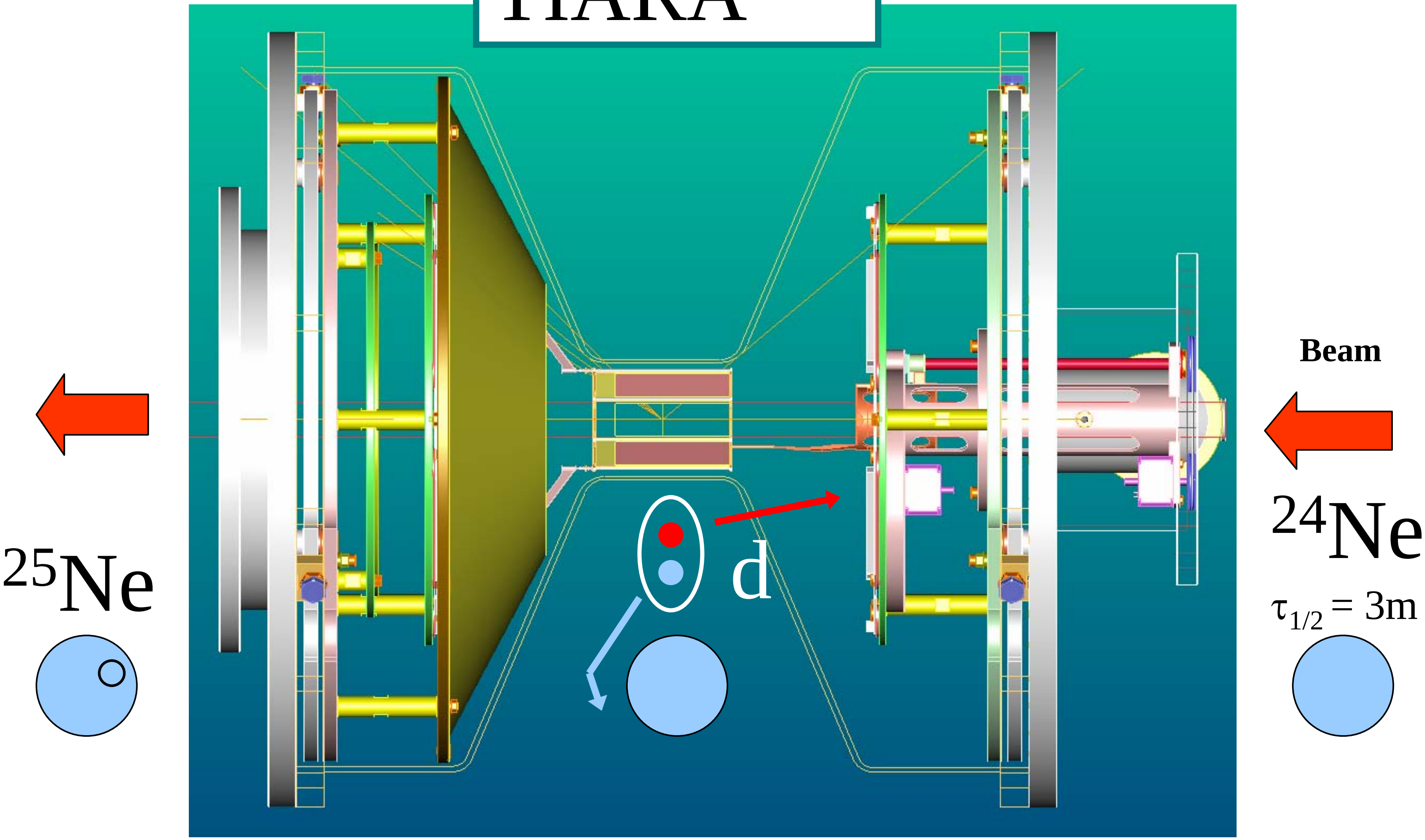
Adapted from: A. Gade, NSCL Michigan MSU, USA

Momentum distributions for knockout to specific final states - angular momentum assigments



A. Gade *et al.*, PRC 69, 034311 (2004)

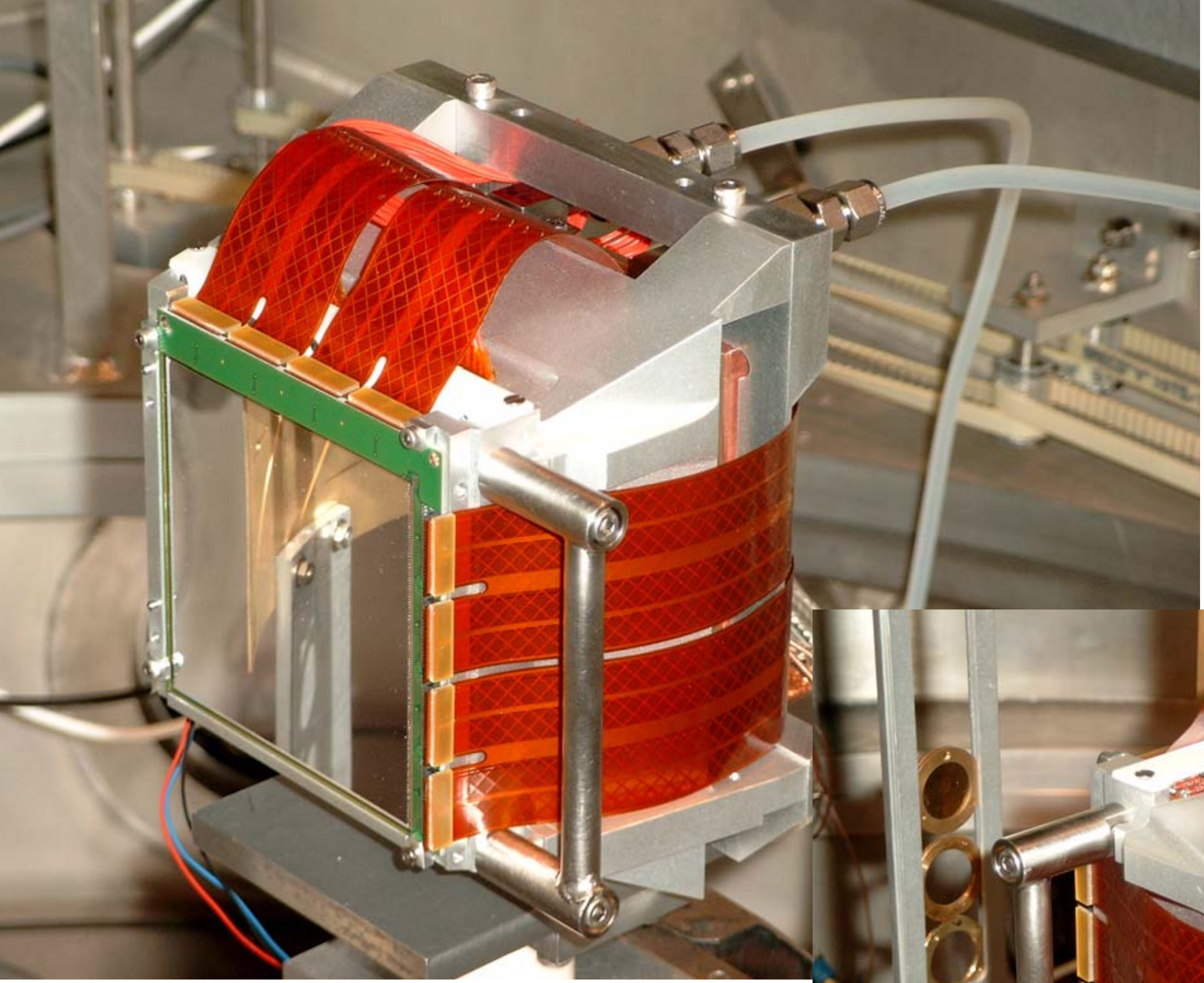
TIARA

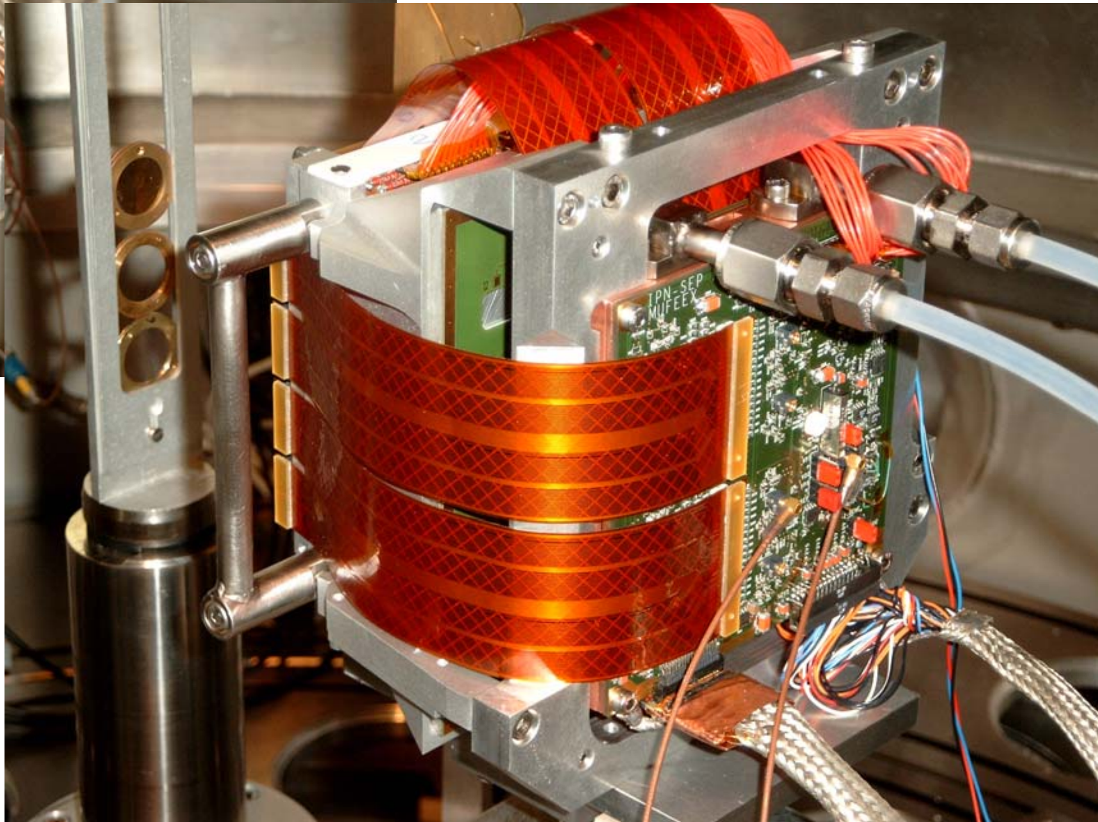


- Study single-particle structure of exotic nuclei
- Direct information about shell evolution

UniS
University of Surrey

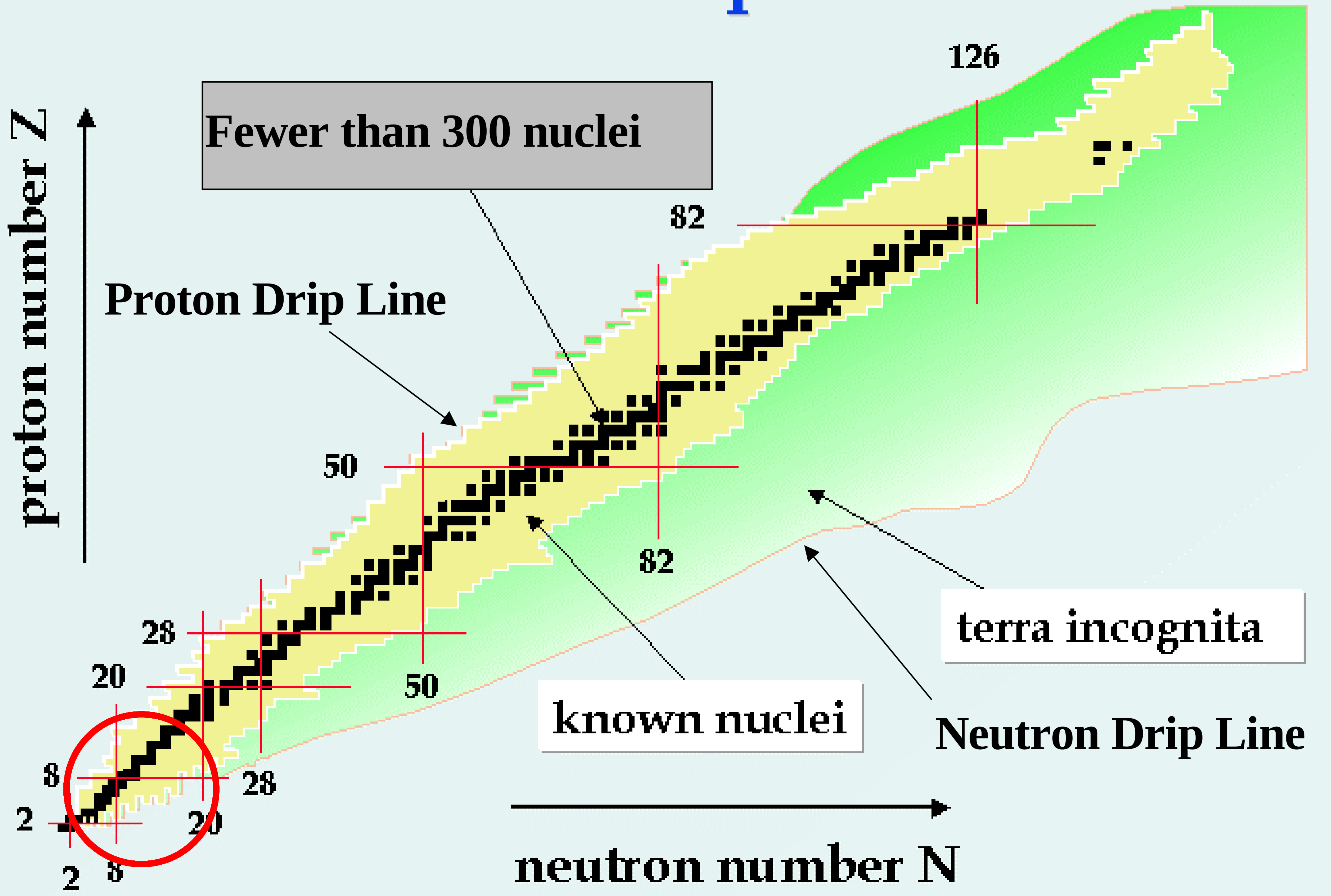
Adapted from: W. Catford, Surrey, UK





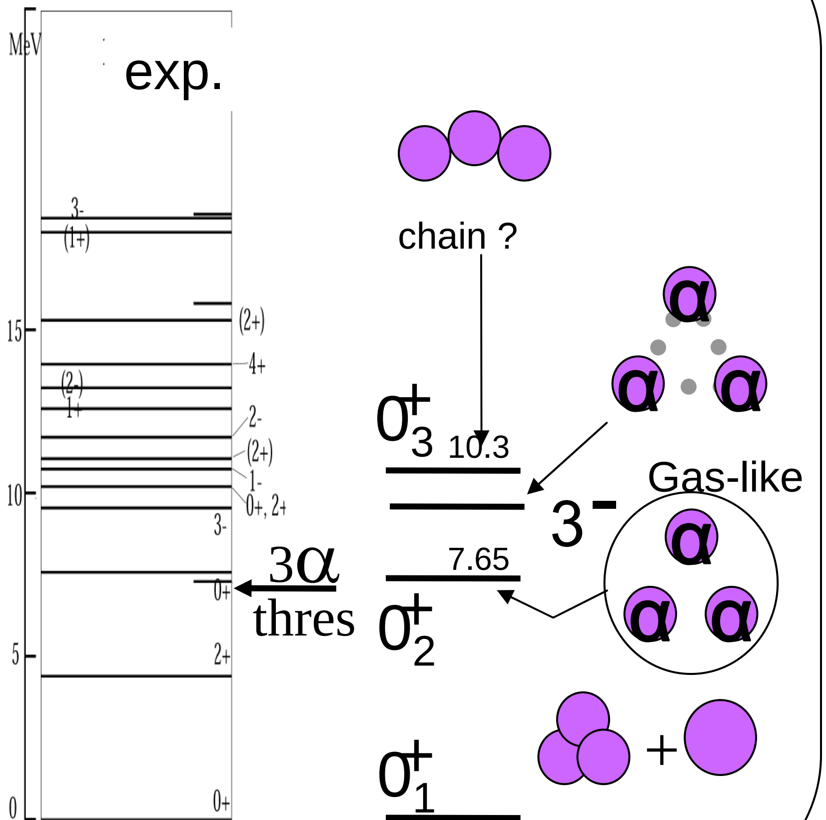
MUST 2

Nuclear Landscape



3. Three-center cluster (role of valence neutrons)

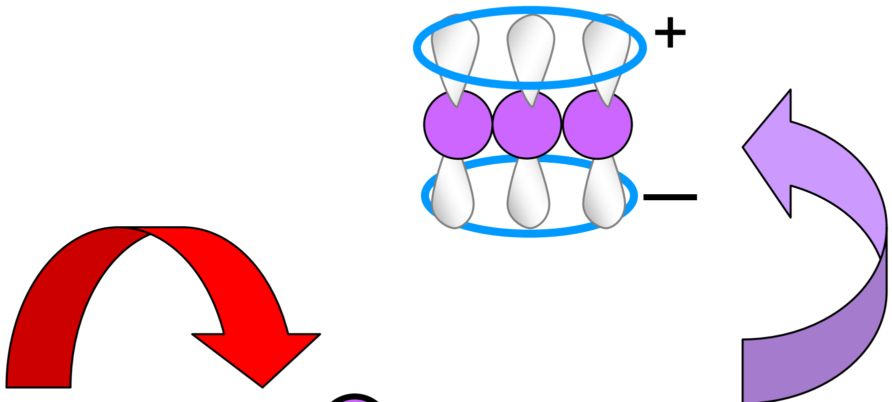
3α-structure in ^{12}C

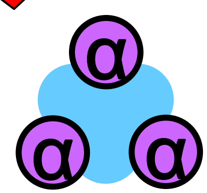


Neutron-rich C

chain structure in ^{16}C

W. von Oertzen, N. Itagaki et al.





triangle shape in ^{14}C (K=3-)

N. Itagaki et al. Phys. Rev.Lett.92 12501(2004)

Rigid cluster config.

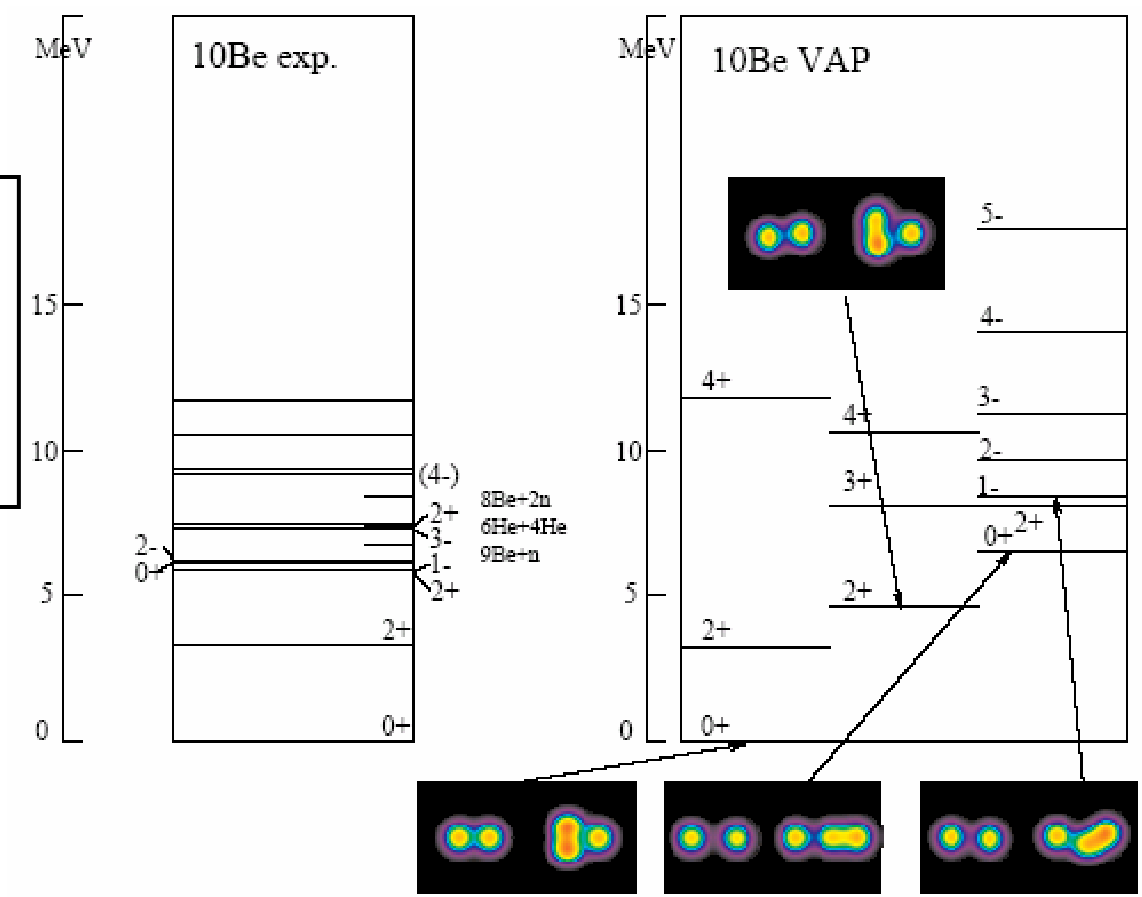
α-Crystallization

named by N. Itagaki et al.

Adapted from: Y. Kanada-En'yo, IPNS Tsukuba, Japan

Molecular orbits of neutrons in Beryllium Nuclei

Model
with NO
a priori
clustering



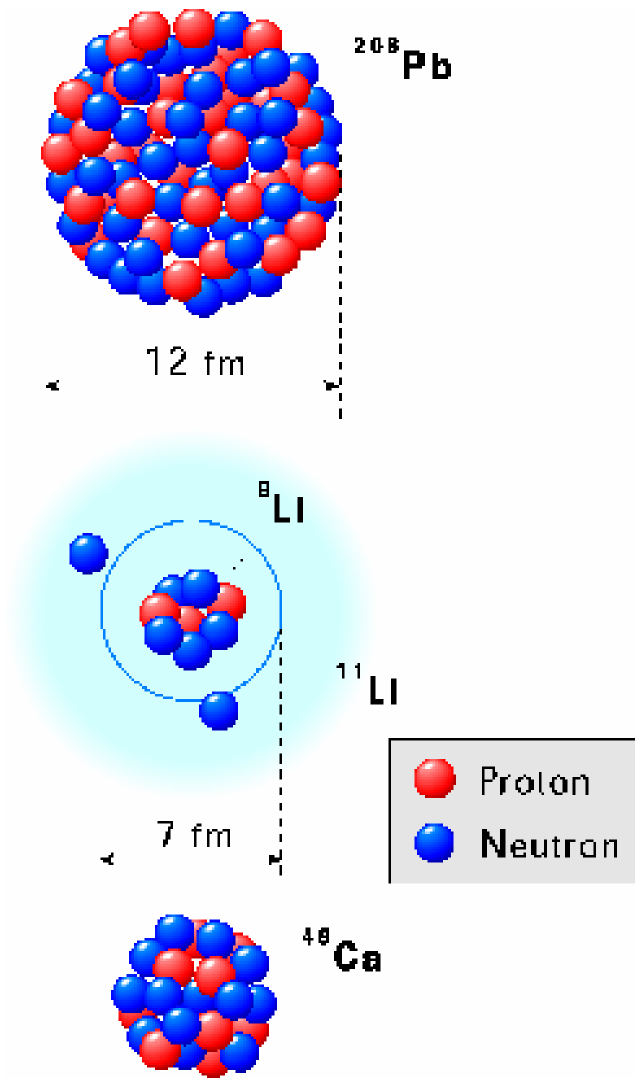
proton density

neutron density

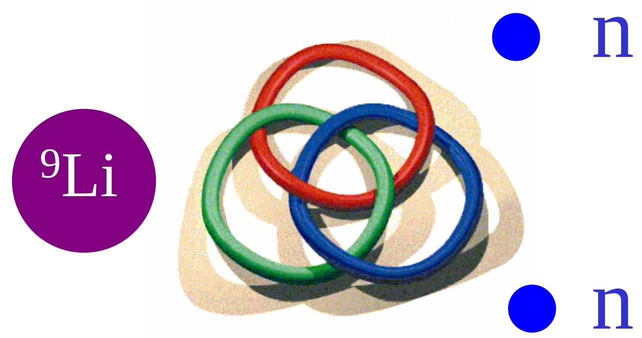
Figure 1. Excitation energies of the levels of ^{10}Be. The theoretical results of the variational calculations after spin parity projection (VAP) in the AMD (right) are compared with the experimental data (left) from [4]. Density distributions of protons (neutrons) of the intrinsic states are also displayed in the left (right) column.

Y Kanada-En'yo, H Horiuchi and A Doté
J. Phys. G: Nucl. Part. Phys. **24** (1998) 1499–1503.

Neutron Interferometry and Halo Nuclei



^{11}Li = Borromean



^{11}Li = halo nucleus

Neutron Interferometry and Halo Nuclei

iterated momentum
correlation function
for breakup neutrons

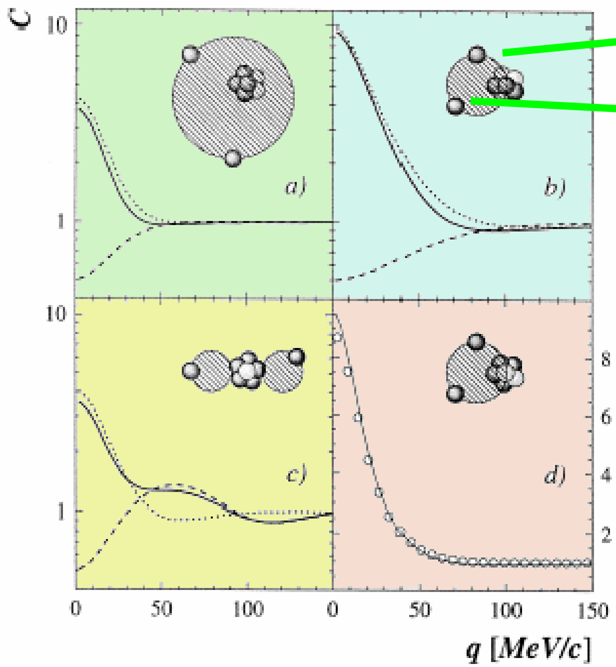
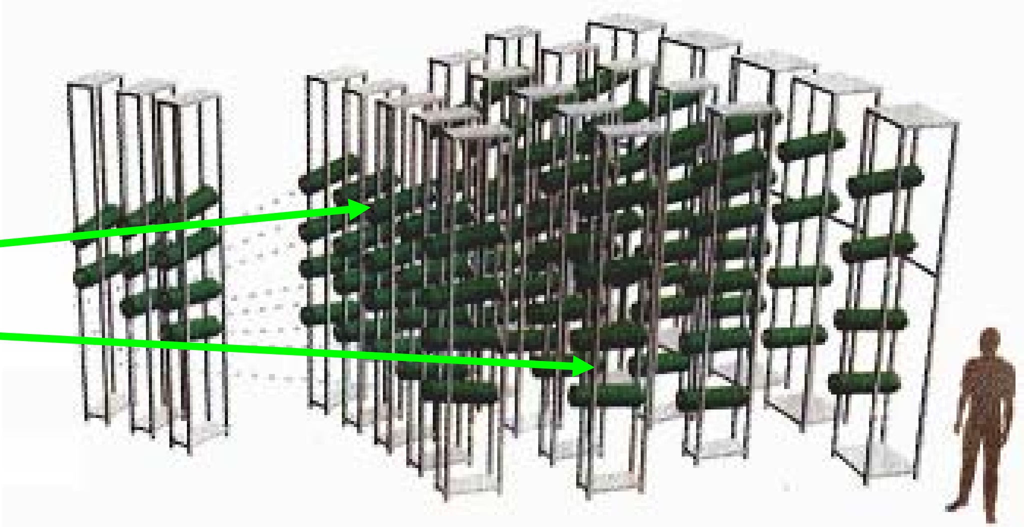
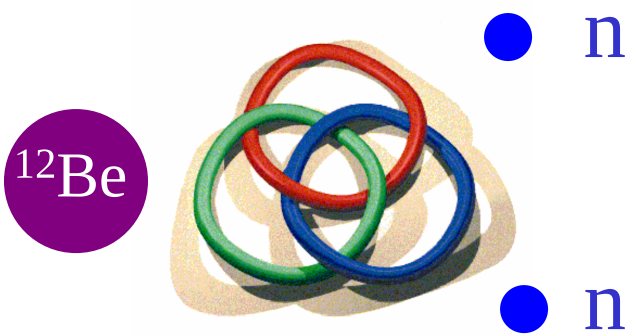


Fig. 1. Correlation functions (solid lines) calculated for simultaneous emission from Gaussian sources with: (a) $r_0 = 6$ fm; (b) $r_0 = 3$ fm; and (c) two sources with $r_0 = 2$ fm separated by 10 fm. The individual contributions from QSS and FSI are indicated by the dashed and dotted lines, respectively. The limits of the hatched area in the insets represent the most probable location of each neutron ($\sqrt{2}\, r_0$). The simultaneous emission with $r_0 = 3$ fm is compared in d) to a space-time extent $(r_0, c\tau_0) = (3,50)$ fm (open symbols).



^{14}Be = Borromean

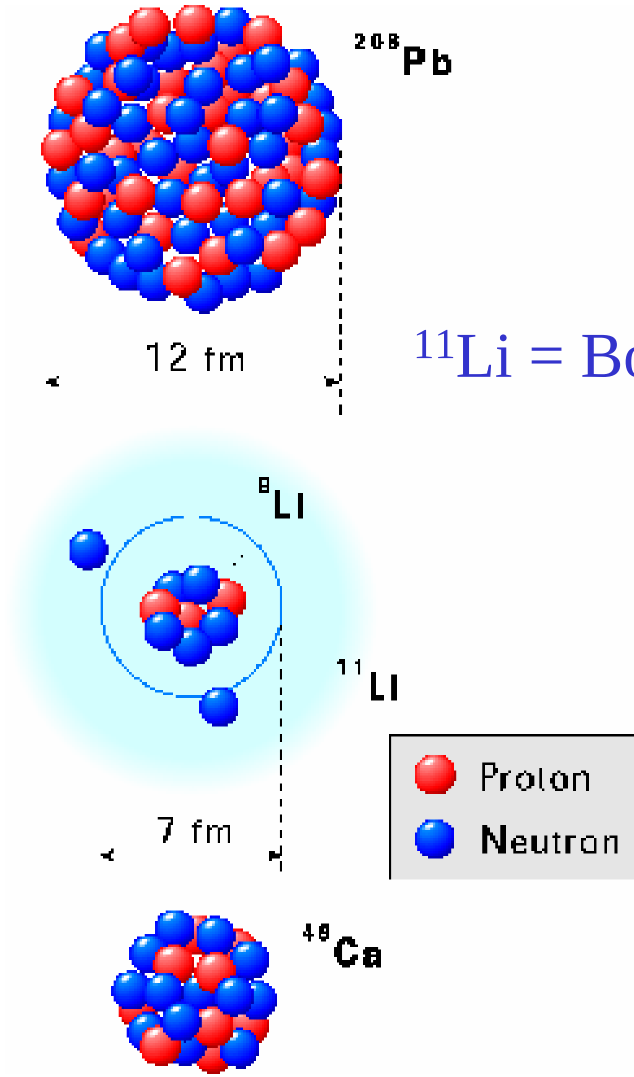


r_{nn}^{rms} =

5.4 ± 1.0 fm

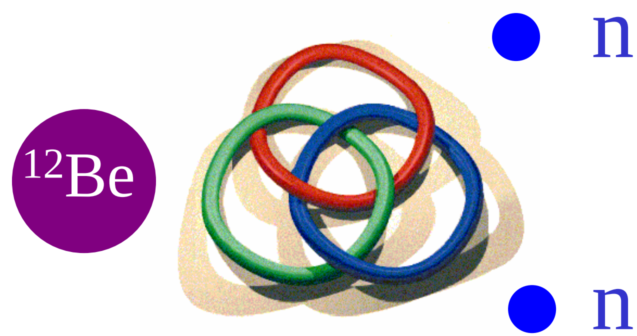
^{14}Be = halo nucleus

Neutron Interferometry and Halo Nuclei



^{11}Li = Borromean halo $\quad r_{nn}^{rms} = 6.6 \pm 1.5$ fm

^{14}Be = Borromean

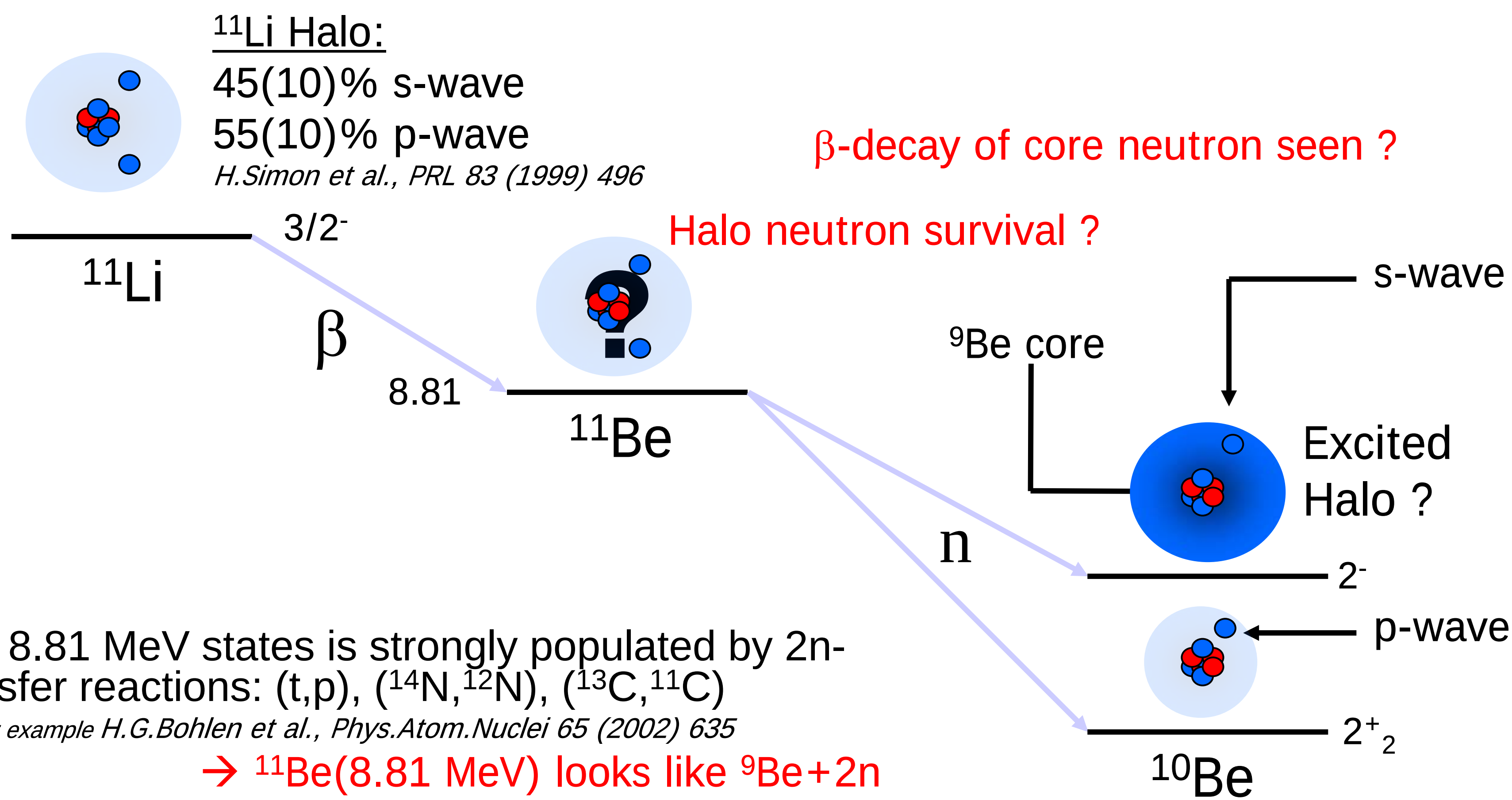


$r_{nn}^{rms} =$

5.4 ± 1.0 fm

^{14}Be = halo nucleus

Possible Halo Nature of the 8.81 MeV state in ^{11}Be ?

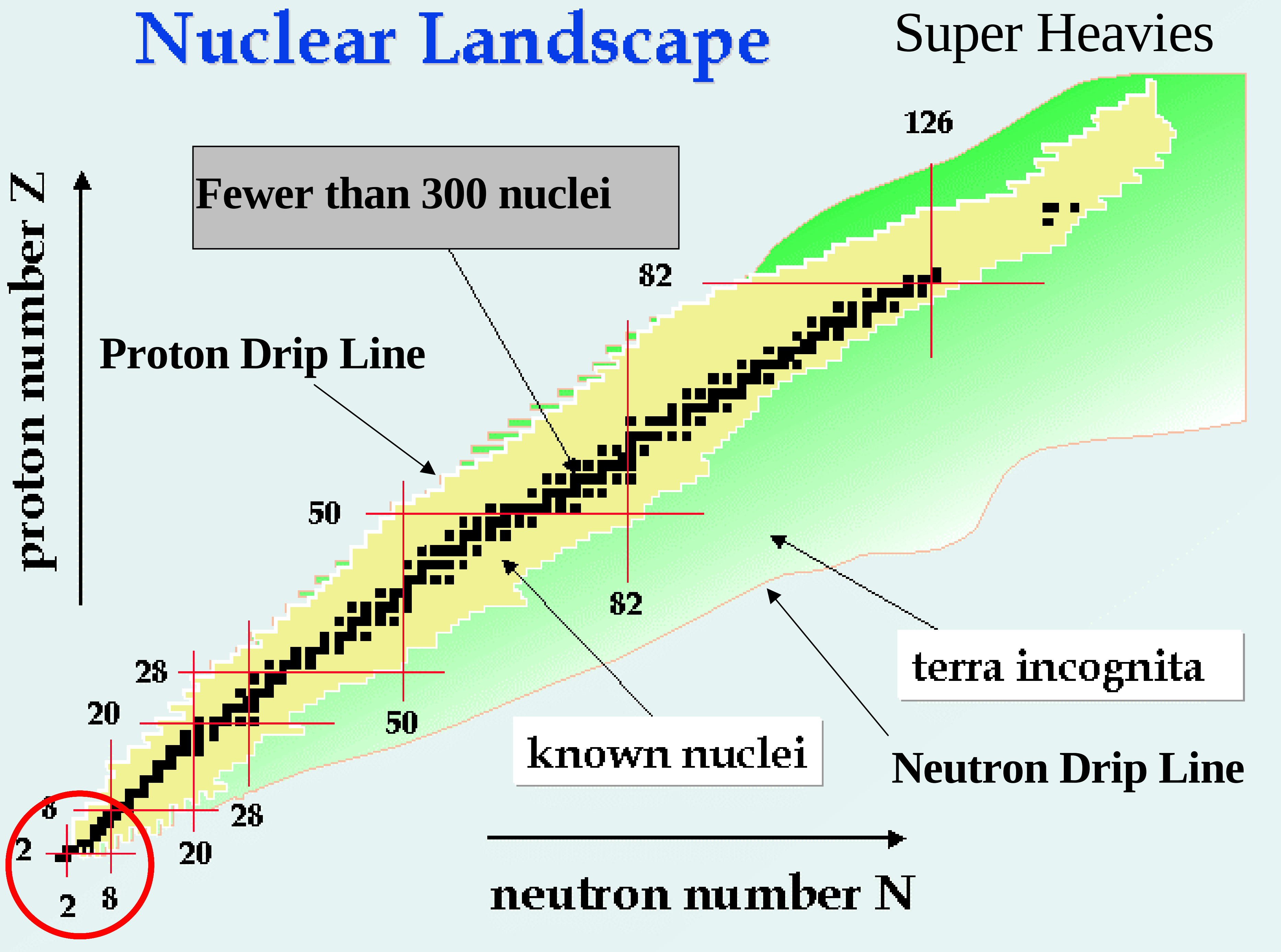


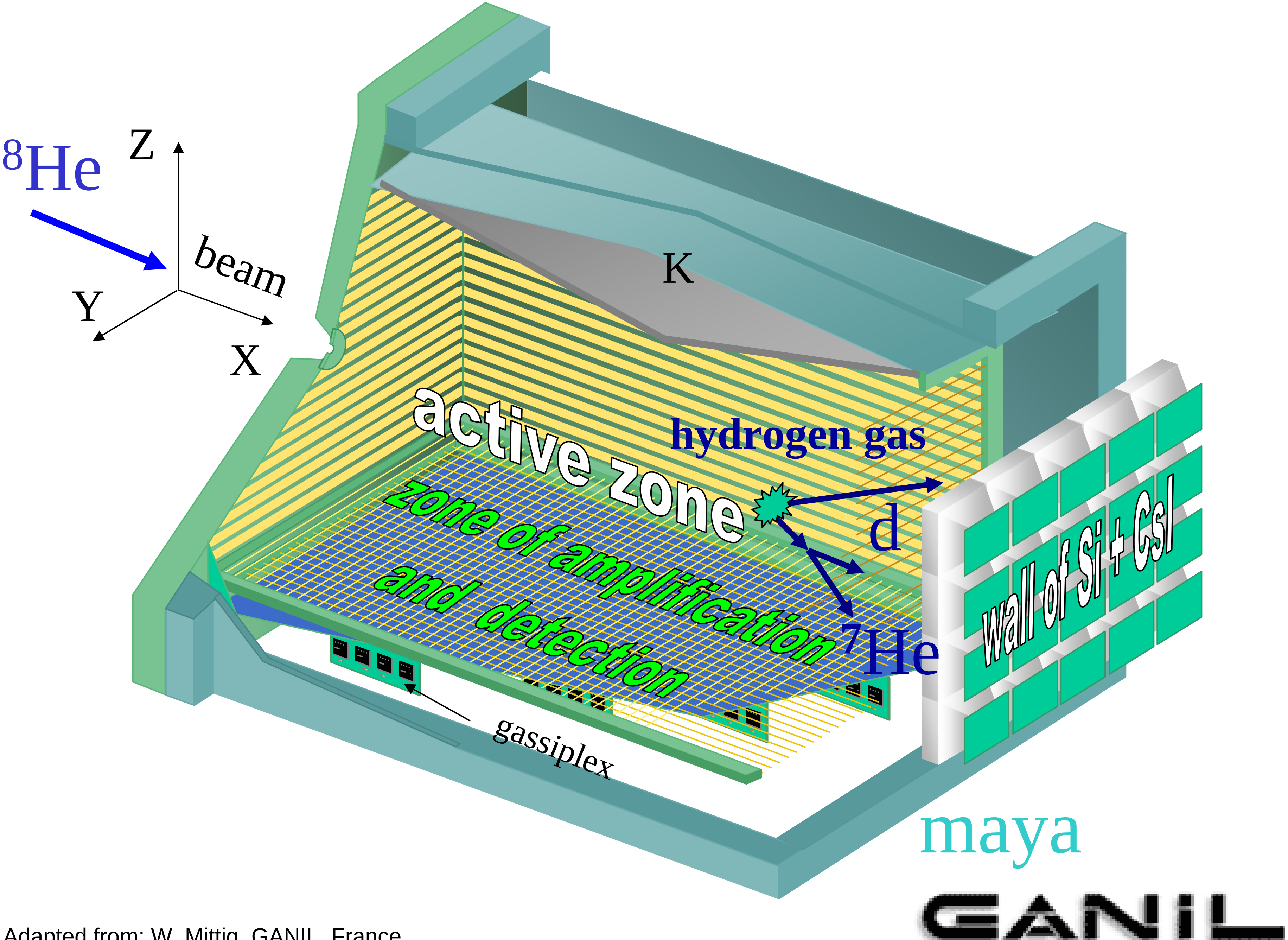
- The 8.81 MeV states is strongly populated by 2n-transfer reactions: (t,p), (^{14}N,^{12}N), (^{13}C,^{11}C)
  See for example H.G.Bohlen et al., Phys.Atom.Nuclei 65 (2002) 635

  → ^{11}Be(8.81 MeV) looks like ^{9}Be+2n

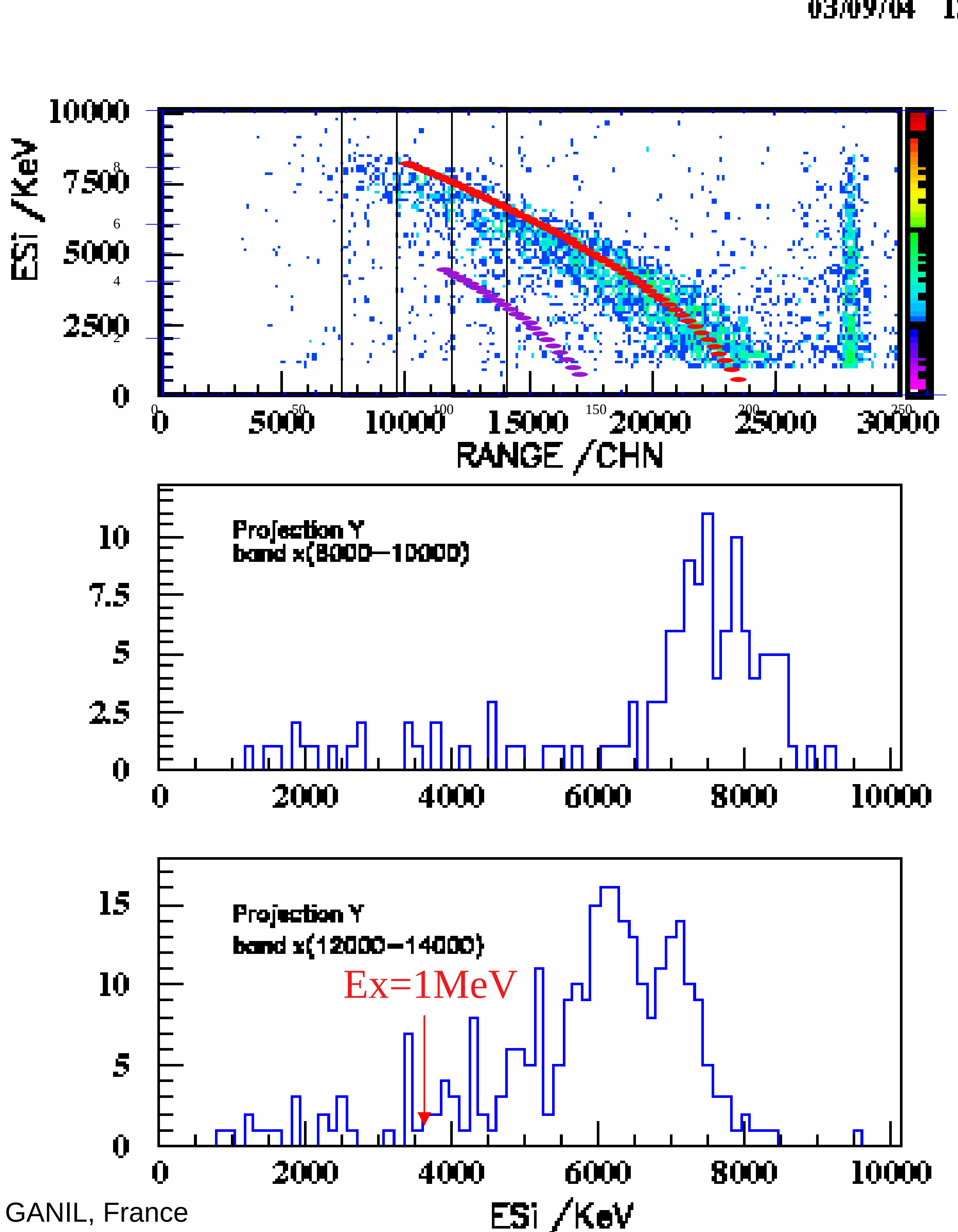
Adapted from: F. Sarazin, Colorado/TRIUMF, USA/Canada

Nuclear Landscape





Adapted from: W. Mittig, GANIL, France

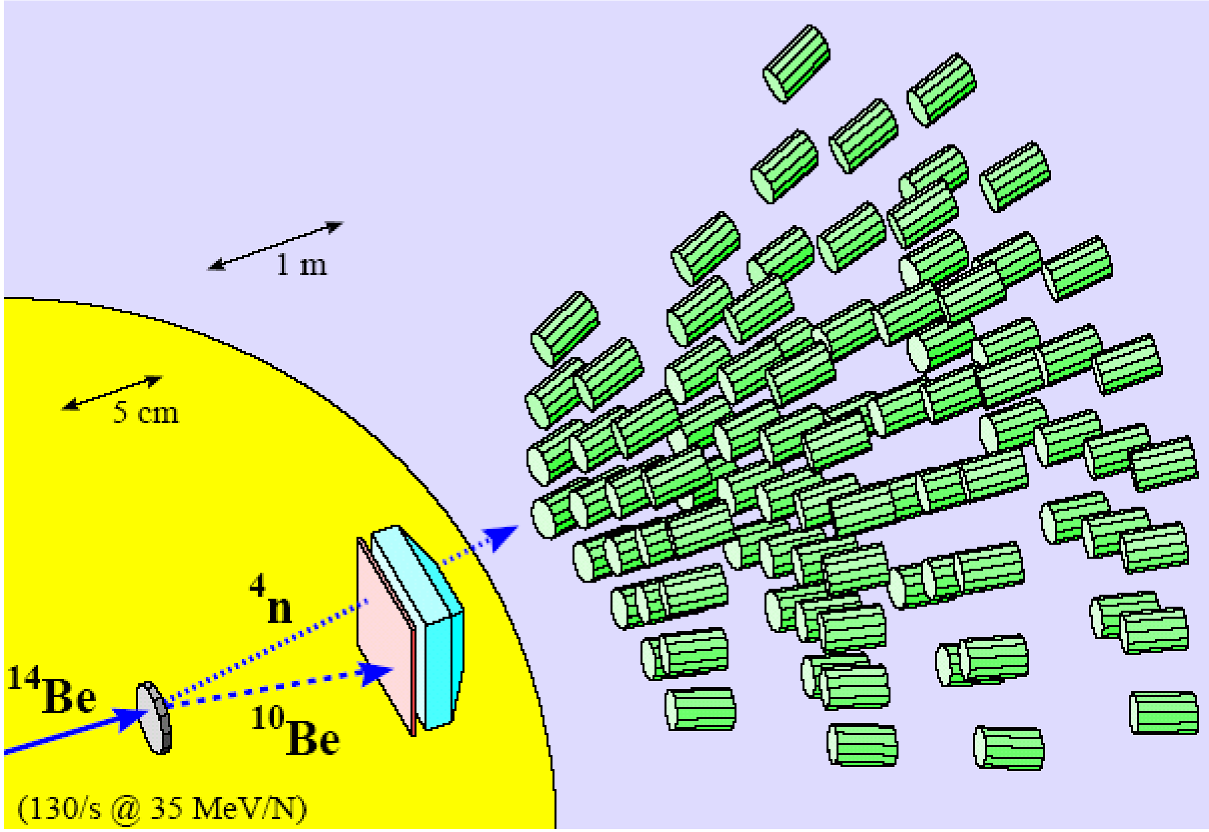


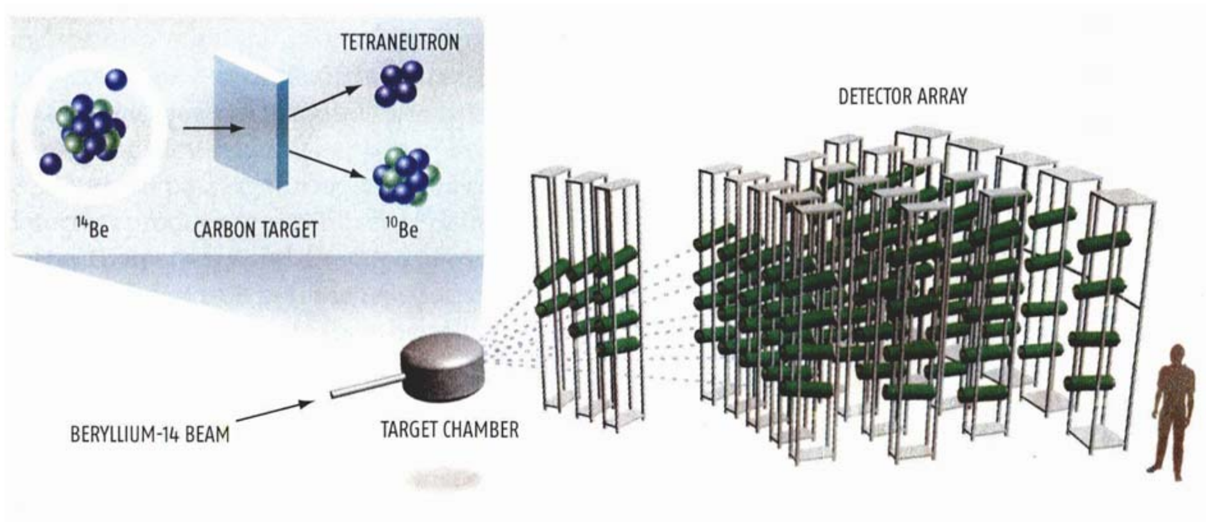
$^{8}He(p,d)^{7}He$

$^{7}He \text{---}> {}^{6}He+n$

Adapted from: W. Mittig, GANIL, France


NewScientist
ELEMENT
ZERO?
Theory says it can't exist, but experiments have found a new type of matter...
0
4.000
Tn
Tetraneutron
SWEETNESS AND MIGHT
Awesome power of the glycome
CHAD'S ANCIENT APE
Is this really the missing link?


1 m
5 cm
4n
14Be
10Be
(130/s @ 35 MeV/N)


TETRANEUTRON
14Be
CARBON TARGET
10Be
DETECTOR ARRAY
BERYLLIUM-14 BEAM
TARGET CHAMBER


NewScientist
ELEMENT ZERO?
Theory says it can't exist, but experiments have found a new type of matter...
0 4.000 Tn Tetraneutron
SWEETNESS AND MIGHT
Awesome power of the glycome
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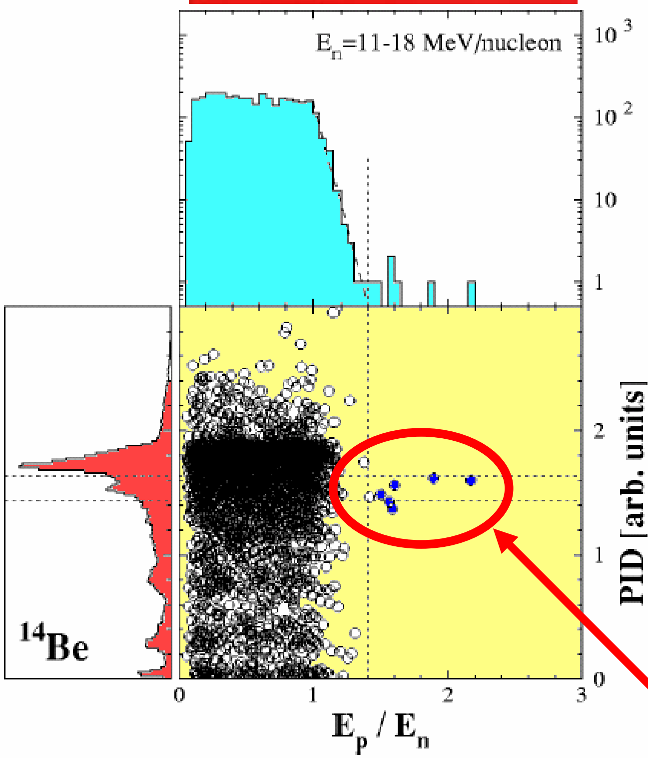
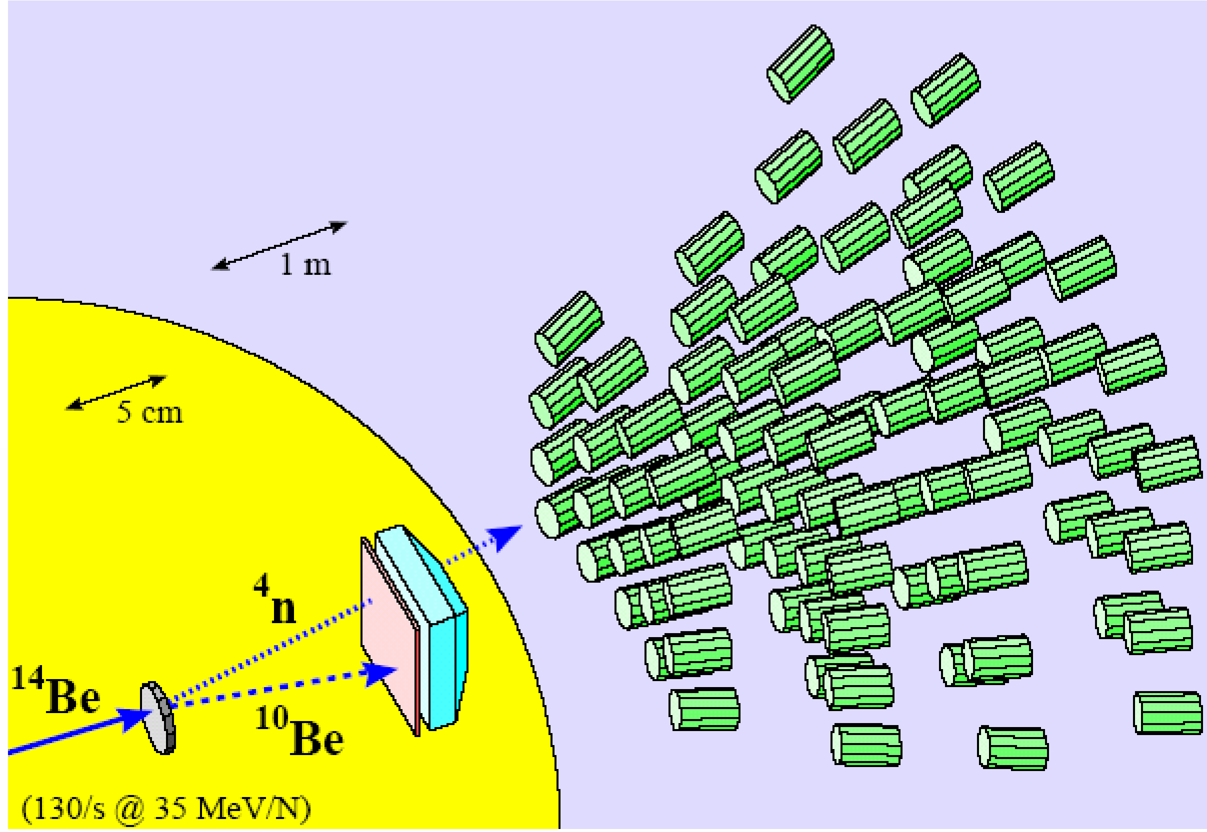
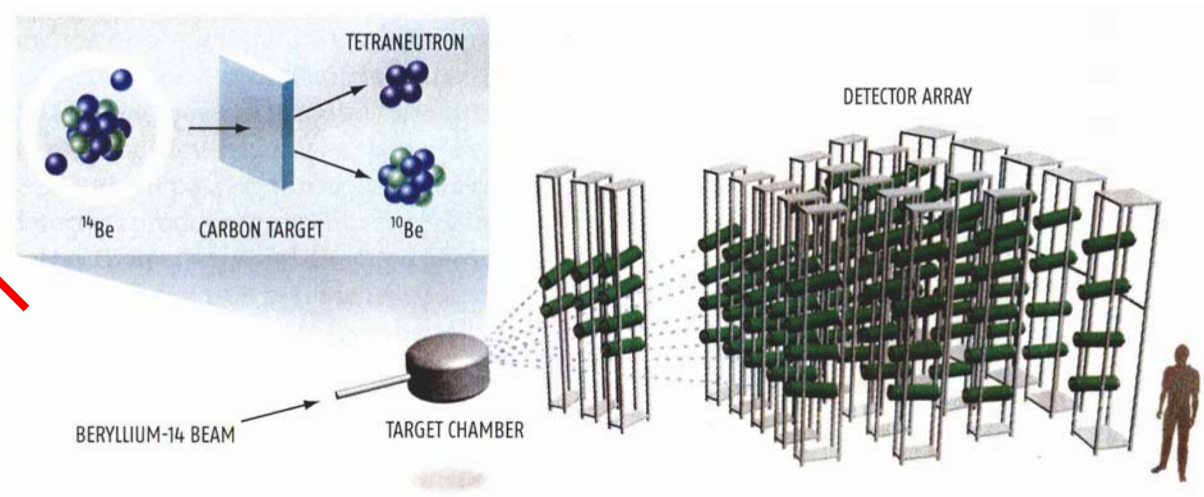
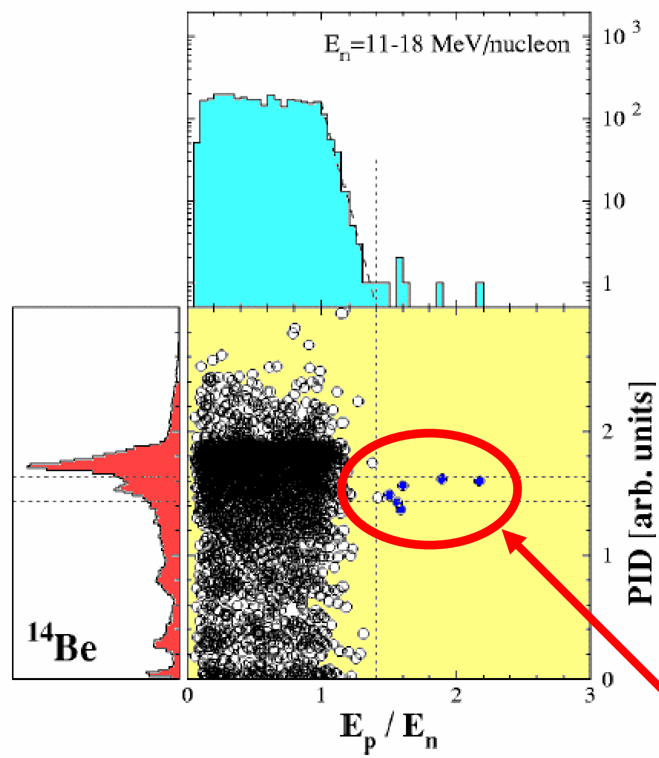


FIG. 6. Scatter plot and the projections onto both axes of the particle identification parameter PID defined in Eq. (1) vs E_p/E_n for the data from the reaction (^{14}Be,$X+n$). The PID projection is displayed for all neutron energies. The dotted lines correspond to $E_p/E_n = 1.4$ and to the region centered on the ^{10}Be peak.





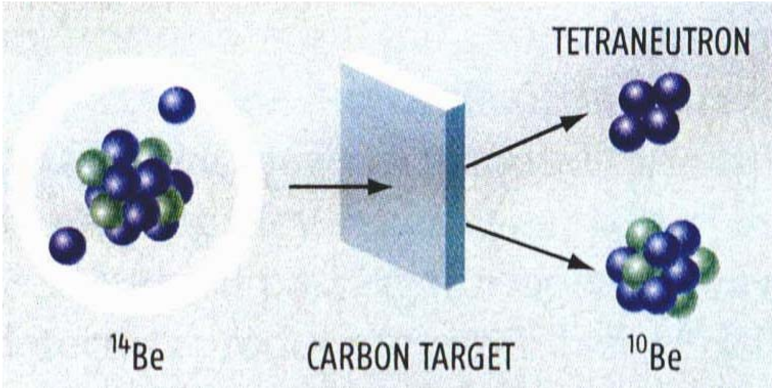
only seen together with ^{10}Be



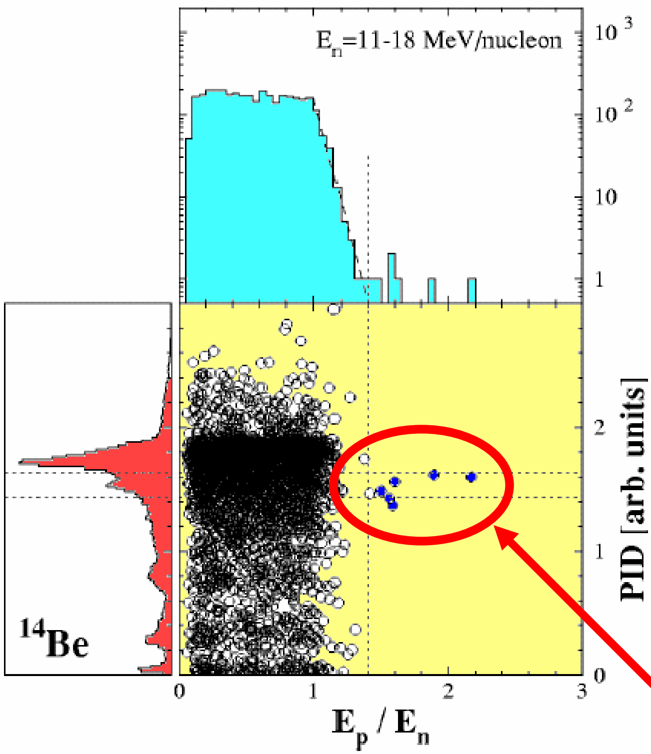
anomalous events

FIG. 6. Scatter plot and the projections onto both axes of the particle identification parameter PID defined in Eq. (1) vs E_p/E_n for the data from the reaction (^{14}Be,$X+n$). The PID projection is displayed for all neutron energies. The dotted lines correspond to $E_p/E_n = 1.4$ and to the region centered on the ^{10}Be peak.

heavier than a neutron

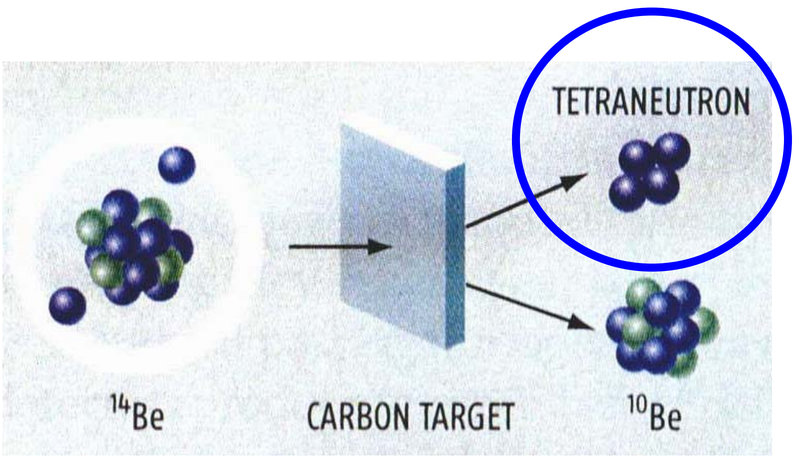


only seen together with ^{10}Be



anomalous events

FIG. 6. Scatter plot and the projections onto both axes of the particle identification parameter PID defined in Eq. (1) vs E_p/E_n for the data from the reaction (^{14}Be,$X+n$). The PID projection is displayed for all neutron energies. The dotted lines correspond to $E_p/E_n = 1.4$ and to the region centered on the ^{10}Be peak.



heavier than a neutron

Ab initio variational + Green's function Monte Carlo calculations

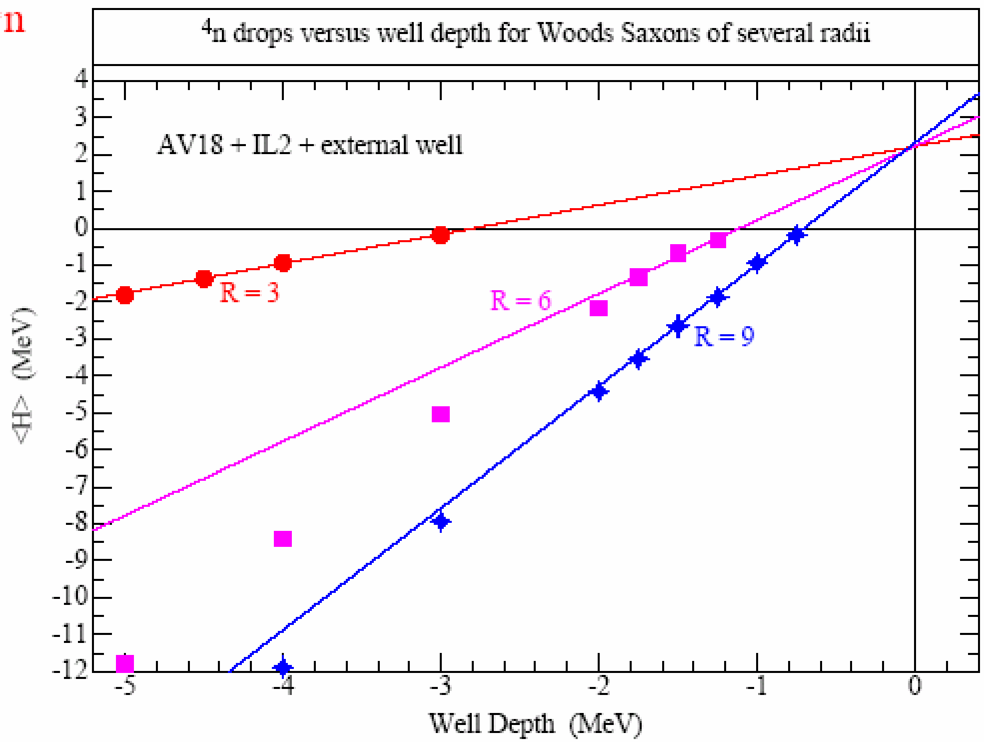
CAN MODERN NUCLEAR HAMILTONIANS TOLERATE A BOUND TETRANEUTRON?

^{2}n is not bound, ^{3}H is bound, E = -8.48 MeV
If ^{4}n bound, expect ^{5}H to be bound, more than ^{3}H
– experiment: $E_{res}(^5\text{H})$ = -7.3 MeV, Γ = 1.9 MeV

Answer: absolutely not !!

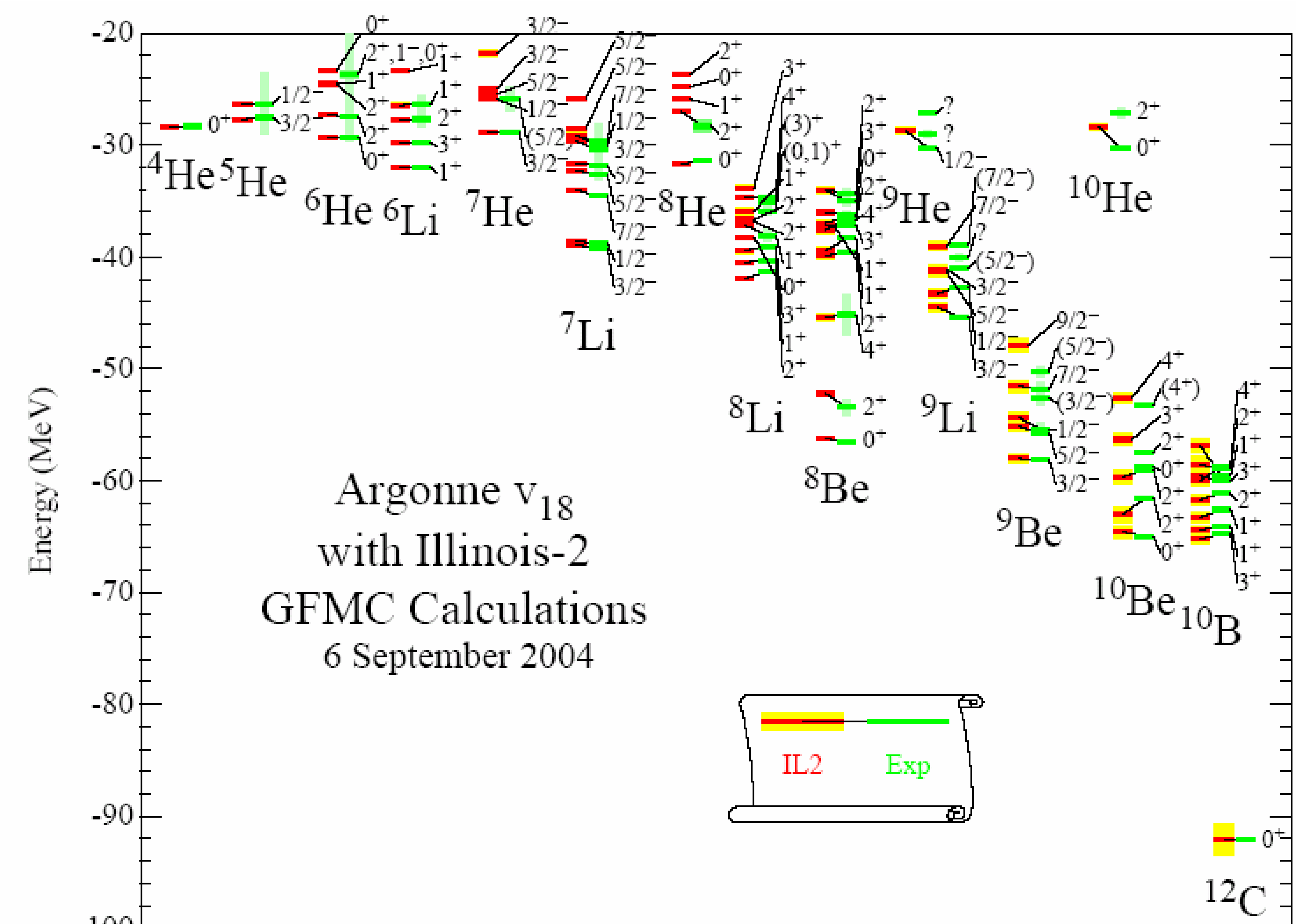
AV18 + IL2 does not bind ^{4}n

- GFMC decays to E=0 without pause.
- Put ^{4}n in external Woods-Saxon wells
- Reduce well depth (V) till unbound
- Extrapolate to $V = 0$
- $E \sim +2.$ MeV



Adapted from: S. Pieper, Argonne, USA

Ab initio variational + Green's function Monte Carlo calculations



^{12}C results are preliminary.

AV18 is a direct fit to 4300 NN data

V_{ijk} from 2-pion Feynman diagrams

future

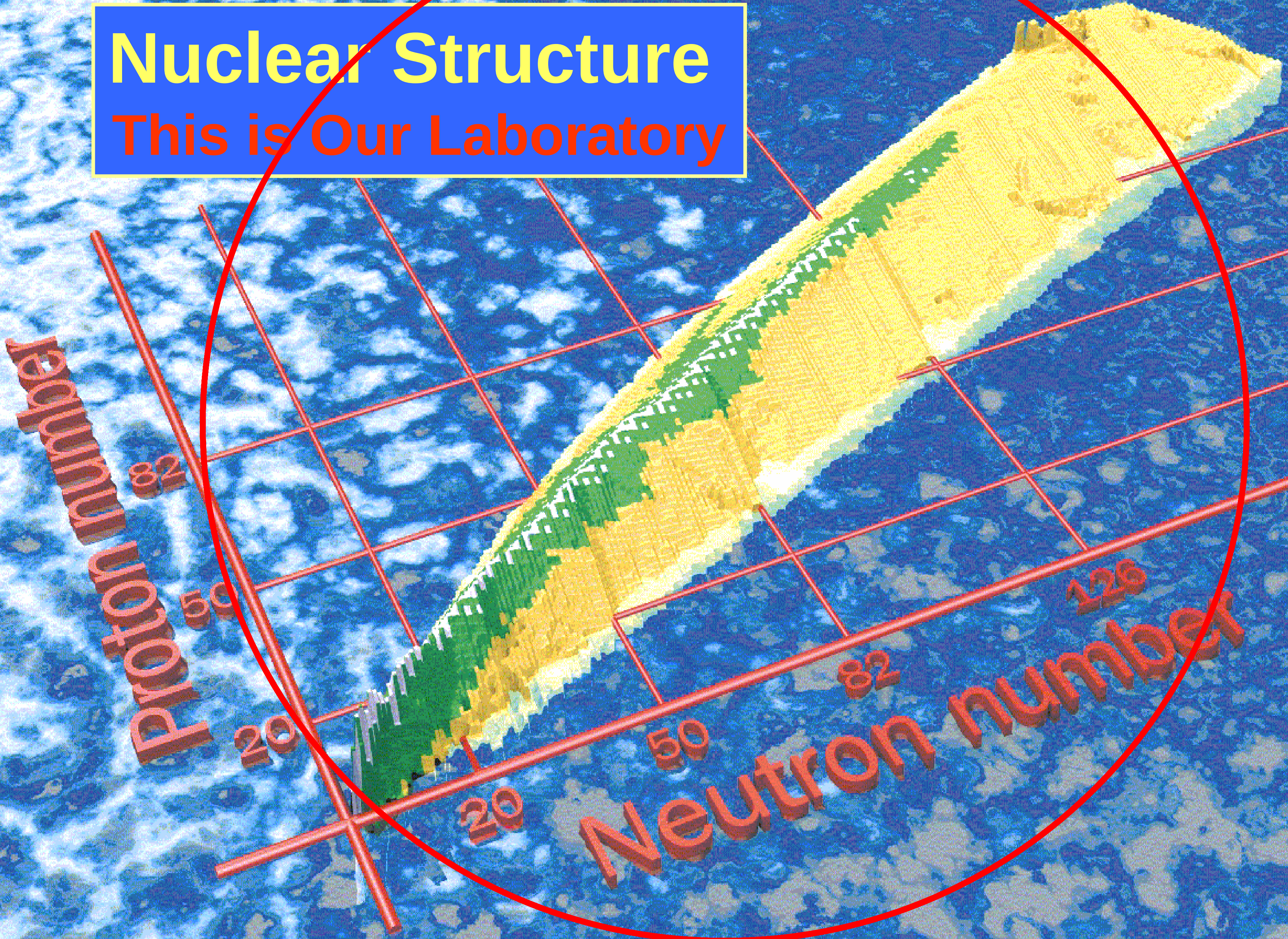
… the talk bounces back at this point!

… many phenomena, many models!

Adapted from: S. Pieper, Argonne, USA

Nuclear Structure

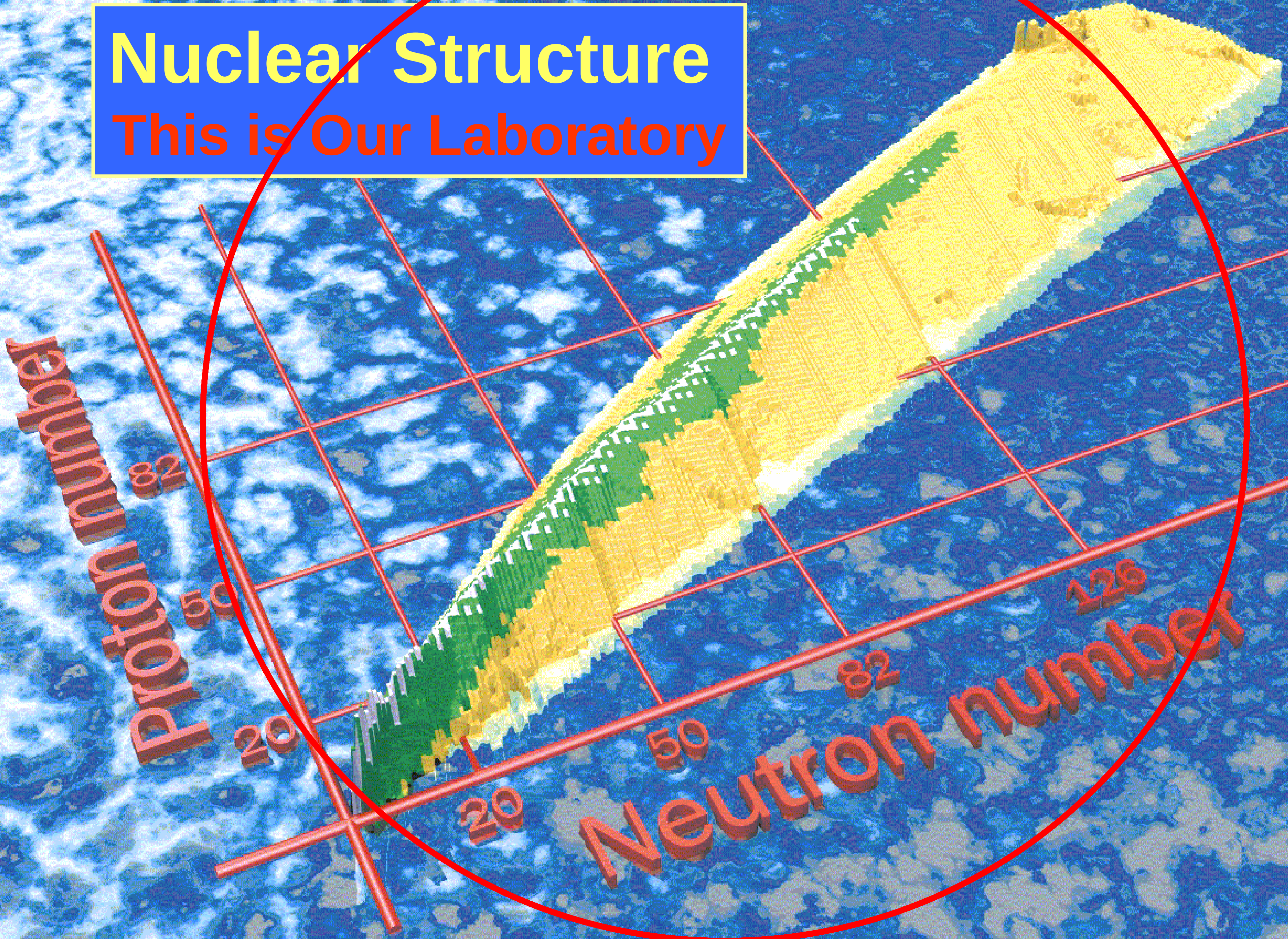
This is Our Laboratory

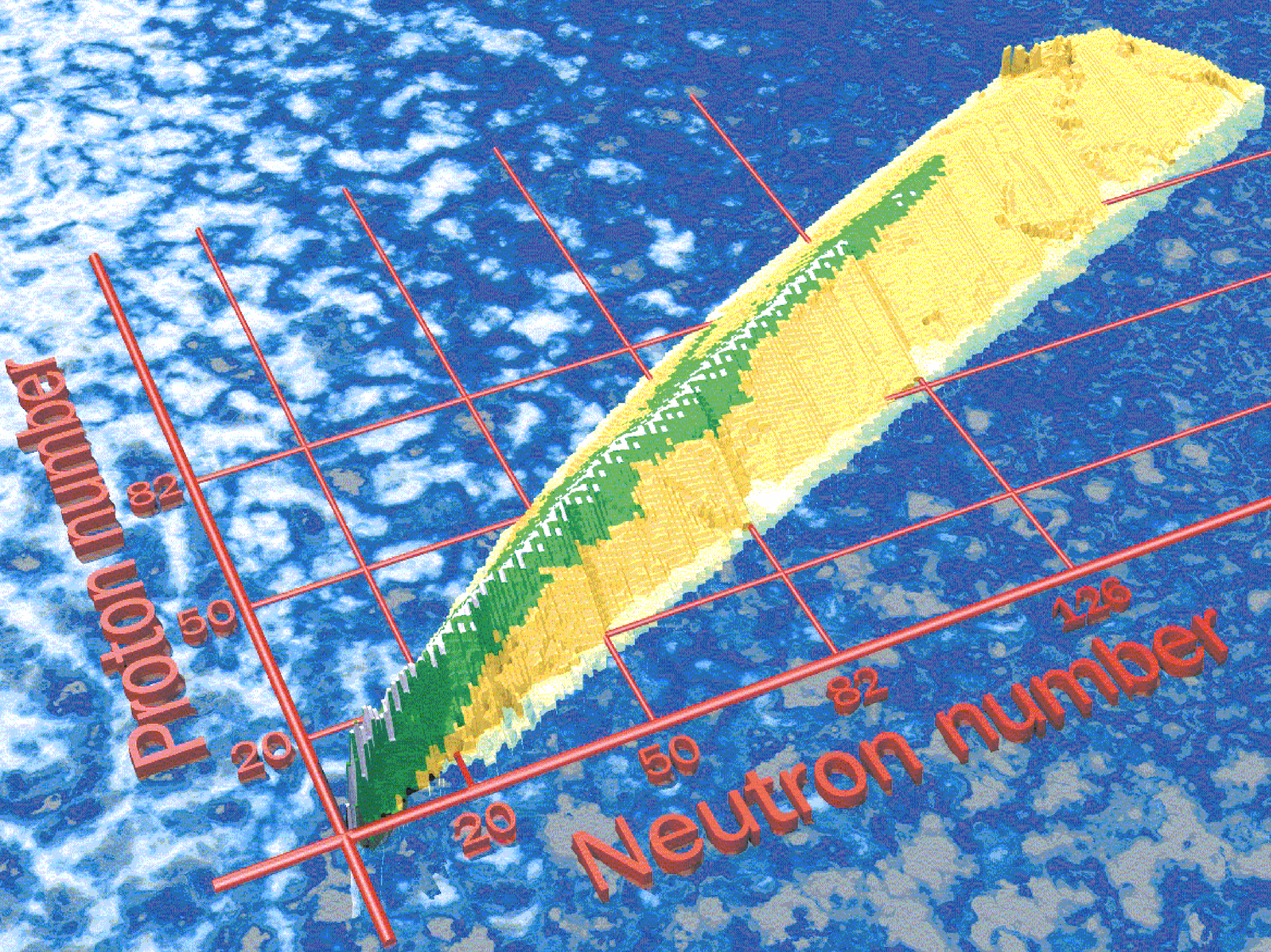


WILTON CATFORD - SURREY

Nuclear Structure

This is Our Laboratory

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82
Neutron number
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126