Opening a New View to the Structure of Nuclei

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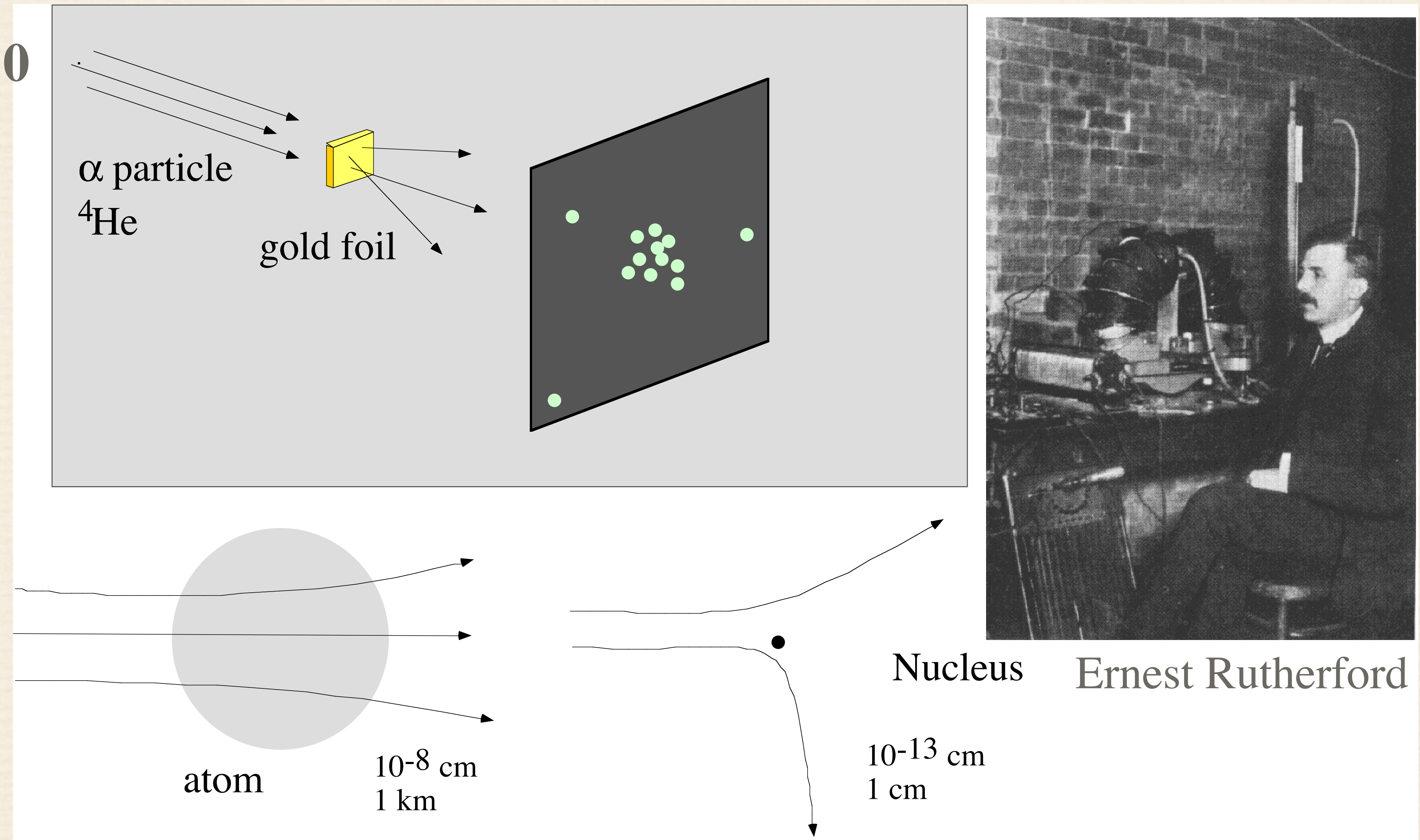
Inaugural talk at Academia Europe, 2017 Budapest

The first observation of nuclei and its size

in ~1910

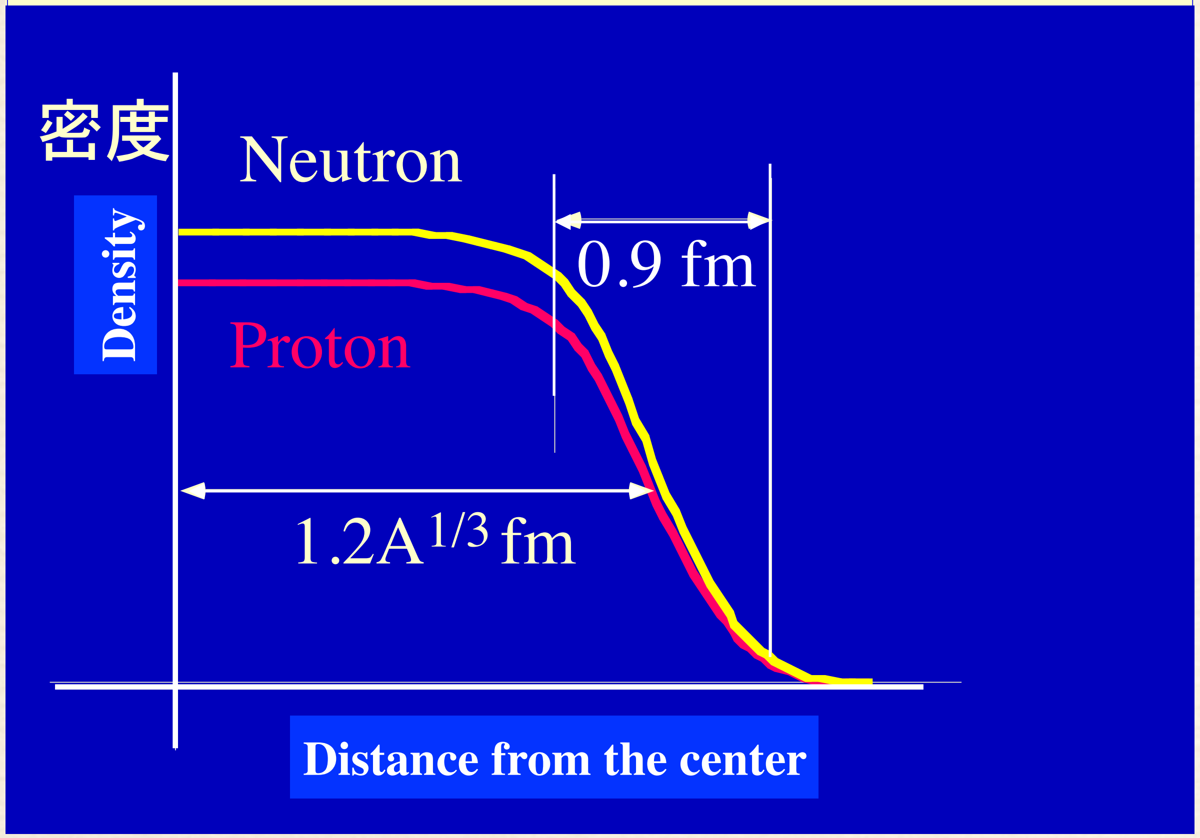


- **Observation of nuclei are mostly by scattering and decay!**

"Common properties" obtained from e, p, .. scattering

- Nucleus is like a liquid drop with diffused surface

Density distribution of stable nuclei

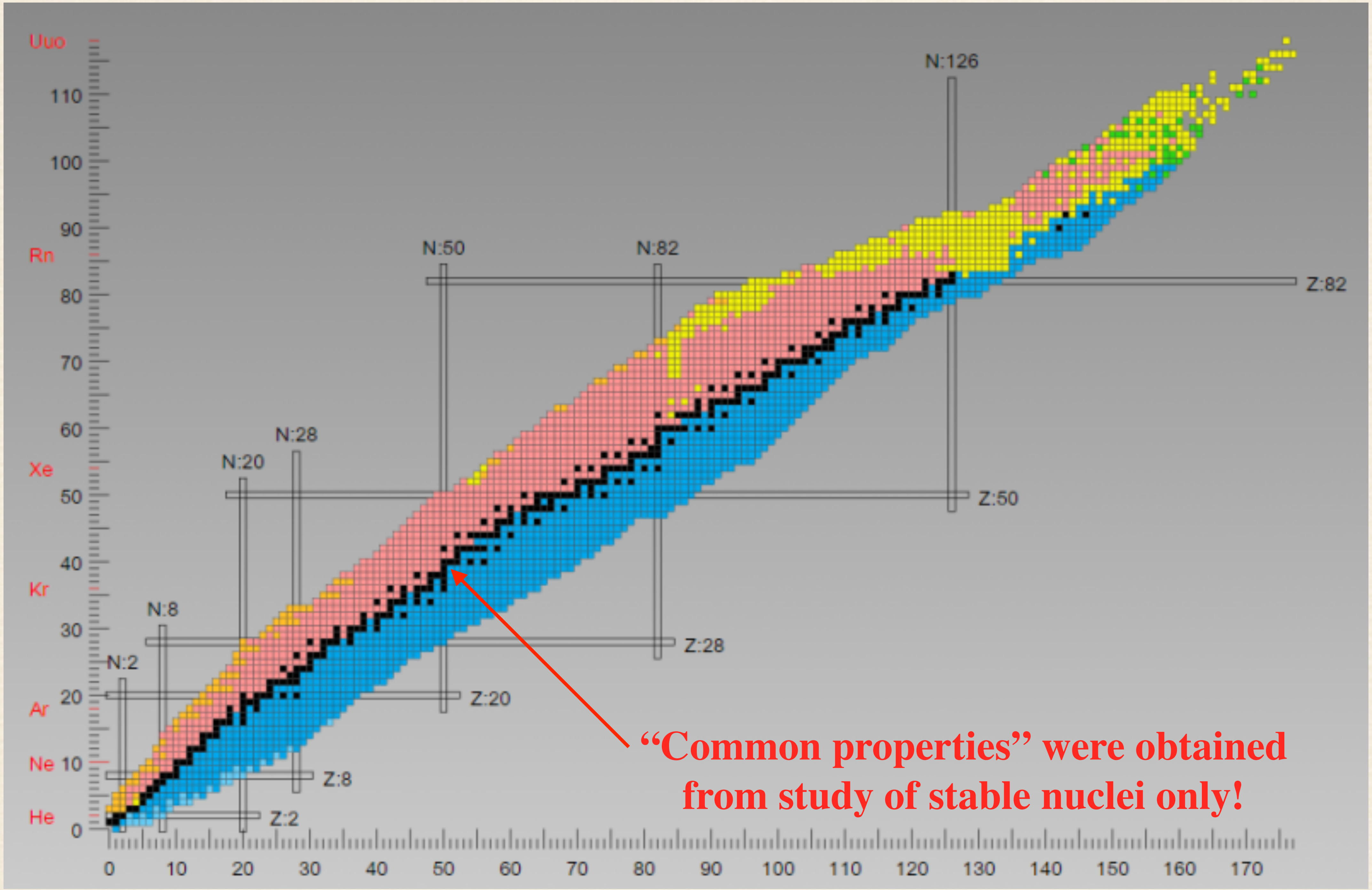


1. $R = r_0 A^{1/3}$
2. Surface diffuseness is constant
3. $\rho_p(r) \propto \rho_n(r)$

They hold both for
^{40}Ca(Z=20, N=20)
^{208}Pb(Z=82, N=126)

- 1. saturation of nuclear density,
- 2. range of nuclear forces,
- 3. strong proton-neutron attraction.

Chart of nuclei (~3000 nuclei observed)



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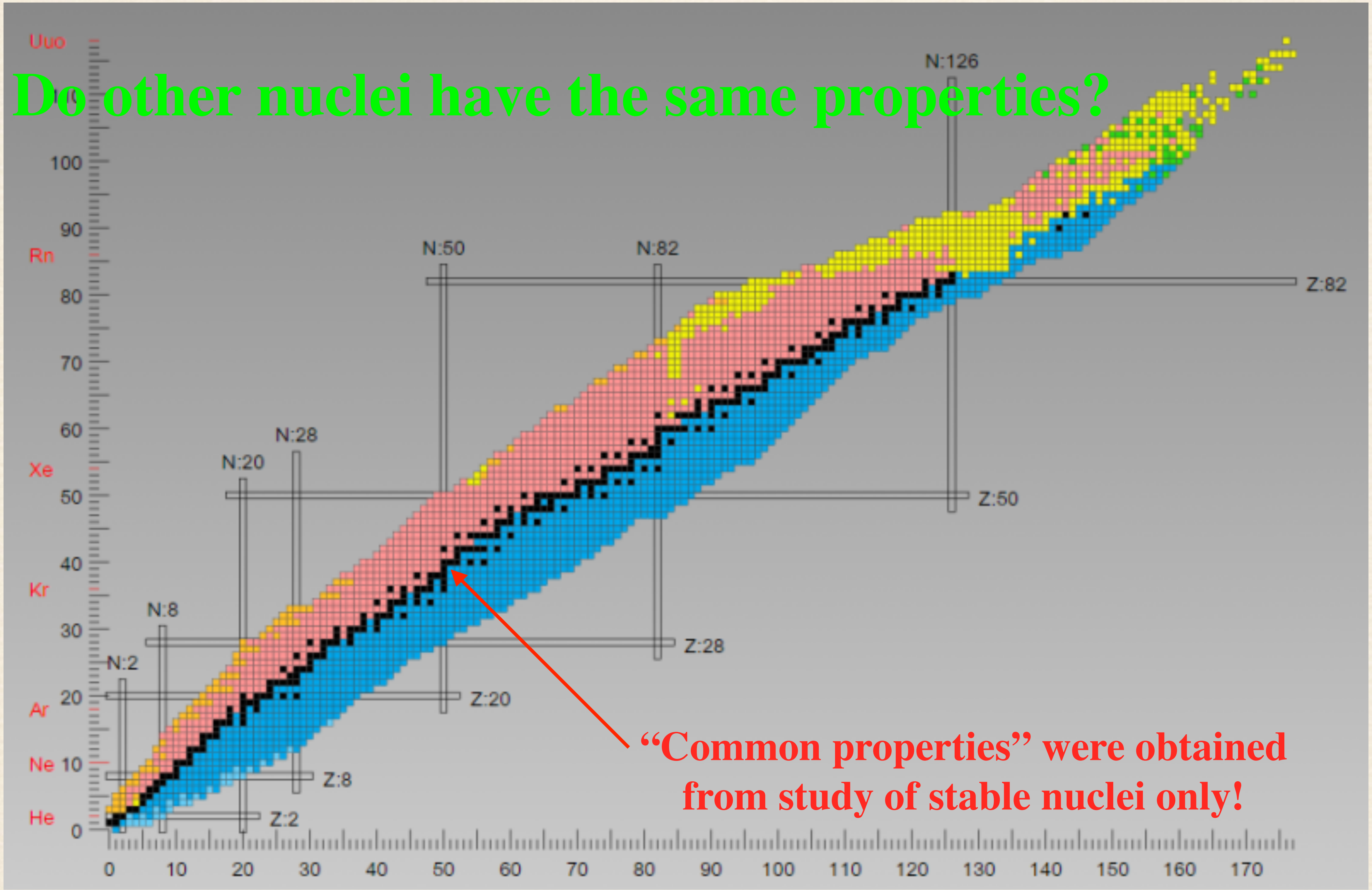

Two essential discoveries in 1970's

- **Discovery of projectile fragmentation at Berkeley Bevalac**
  - ***H. H. Heckman, D. G. Greiner et al., 1972***
- **Efficient production of short lived nuclei by projectile fragmentations**
  - ***G. Westfall, T.J.M Symons et al., 1979***

Projectile fragmentation ($^{16}O + CH_2 \rightarrow {}^{A}C + \ldots$)

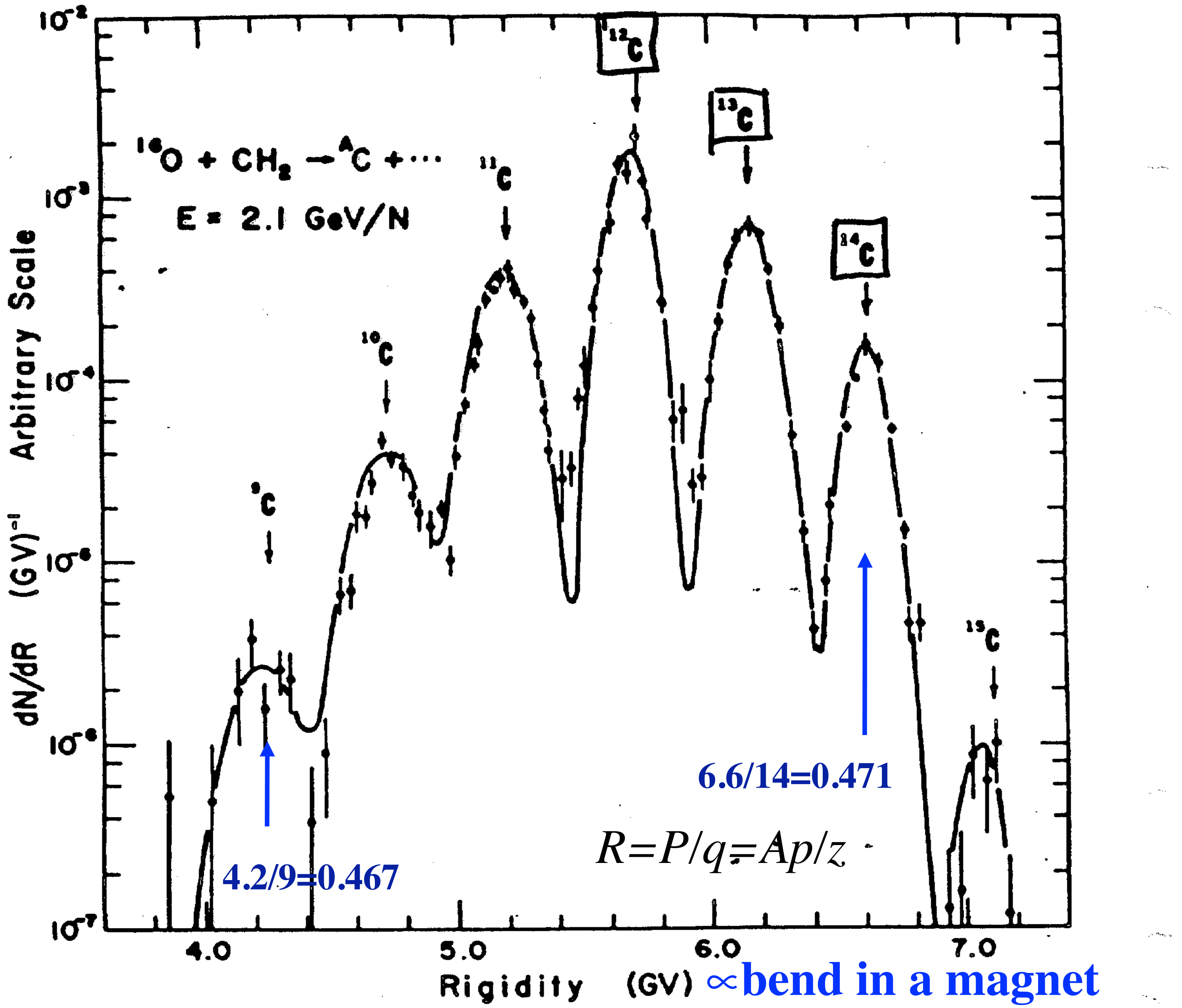

Figure 5 Rigidity spectrum of carbon isotopes produced by the fragmentation of ^{16}O projectiles at 2.1 *A* GeV. Arrows indicate the rigidities for each isotope evaluated at beam velocity (87).

2.1 GeV/nucleon

=2.88 GeV/c/nucleon

2.83 GeV/c/nucleon

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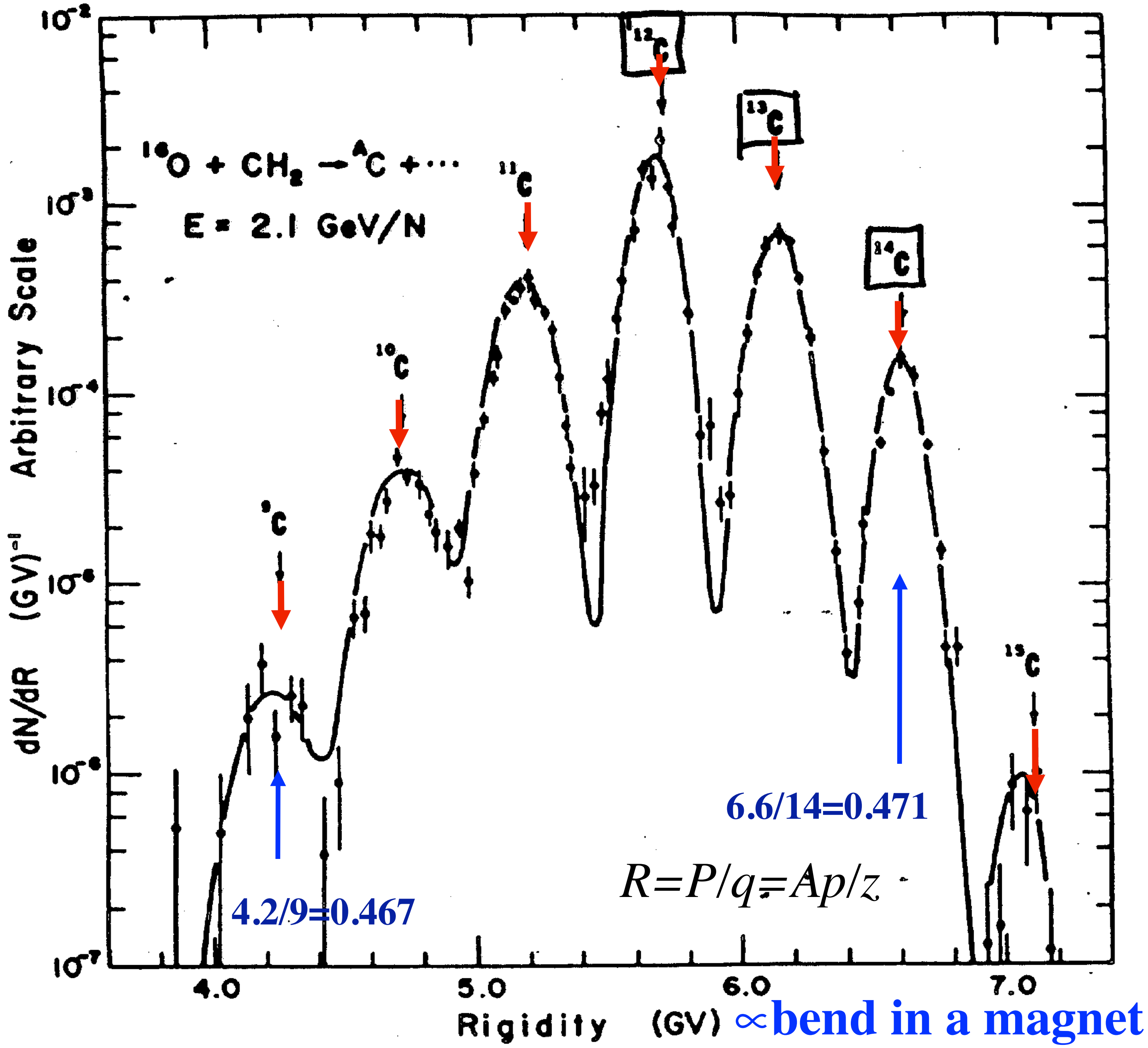

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D. Greiner et al ..

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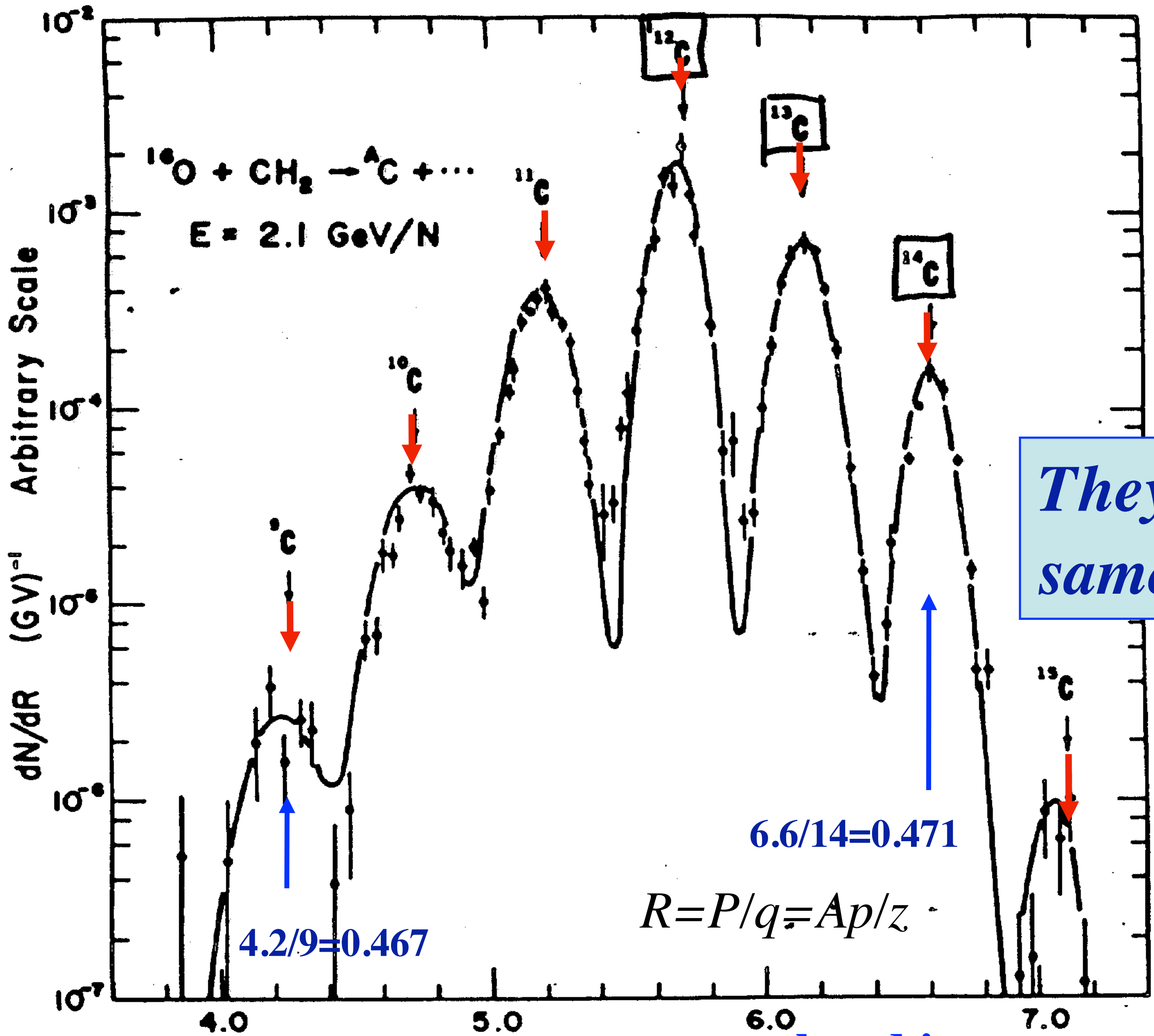

$\propto$ **bend in a magnet**

Figure 5 Rigidity spectrum of carbon isotopes produced by the fragmentation of ^{16}O projectiles at 2.1 *A* GeV. Arrows indicate the rigidities for each isotope evaluated at beam velocity (87).

D. Greiner et al ..

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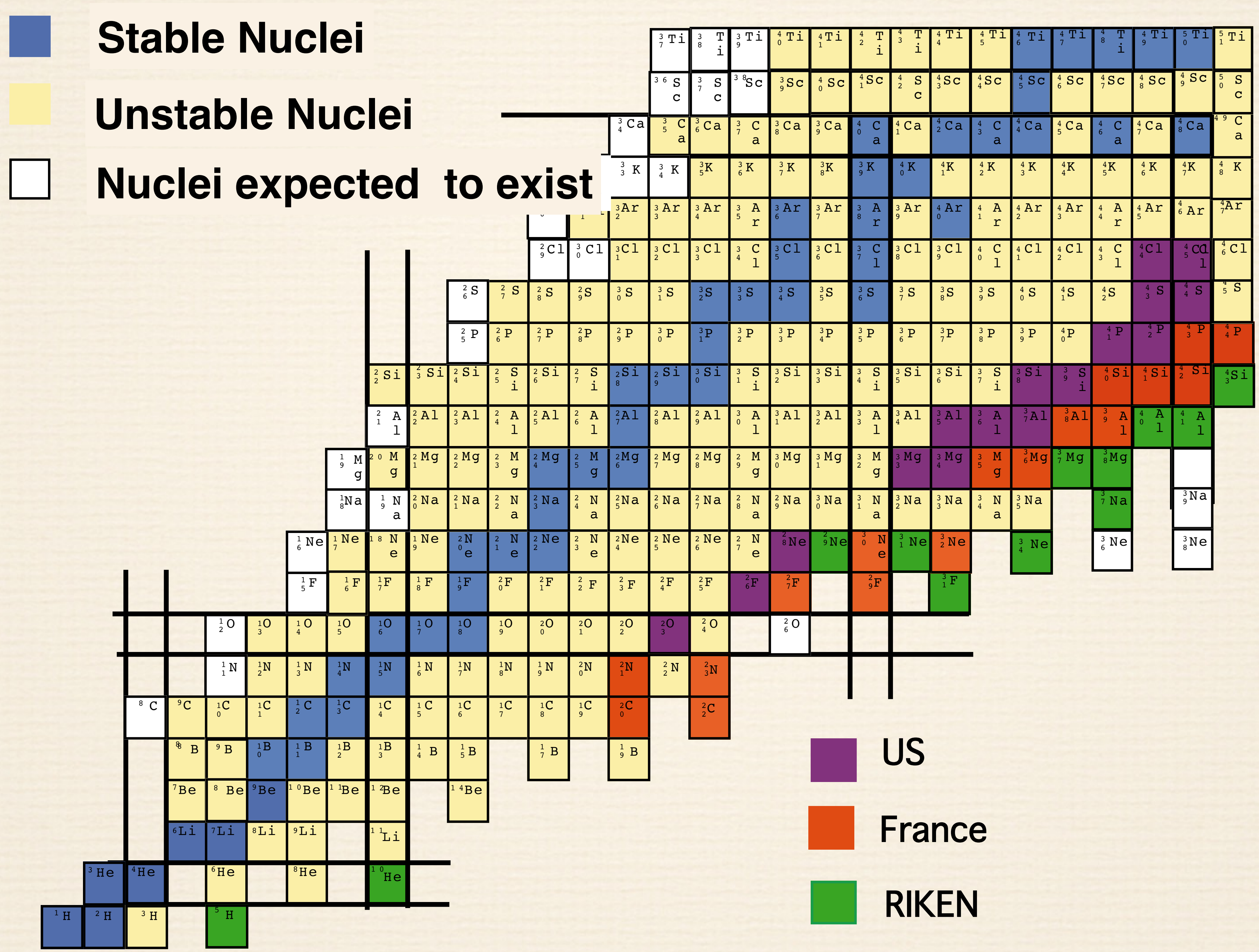
They are emitted with same velocity!

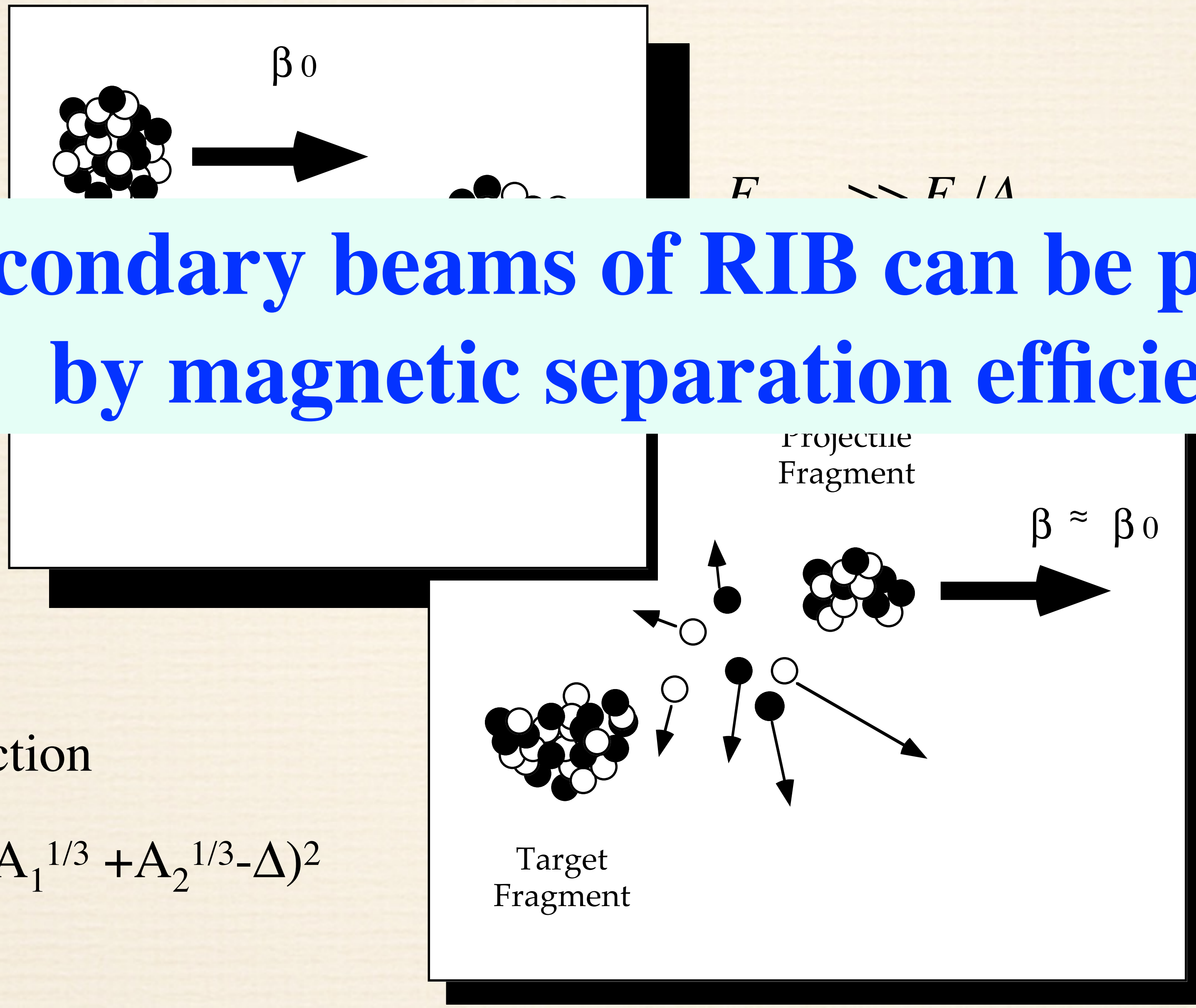
Starting of new era

by abundant production of nuclei far from the stability line



Projectile fragmentation and production of Radioactive Ion Beams (RIB)

Projectile fragmentation



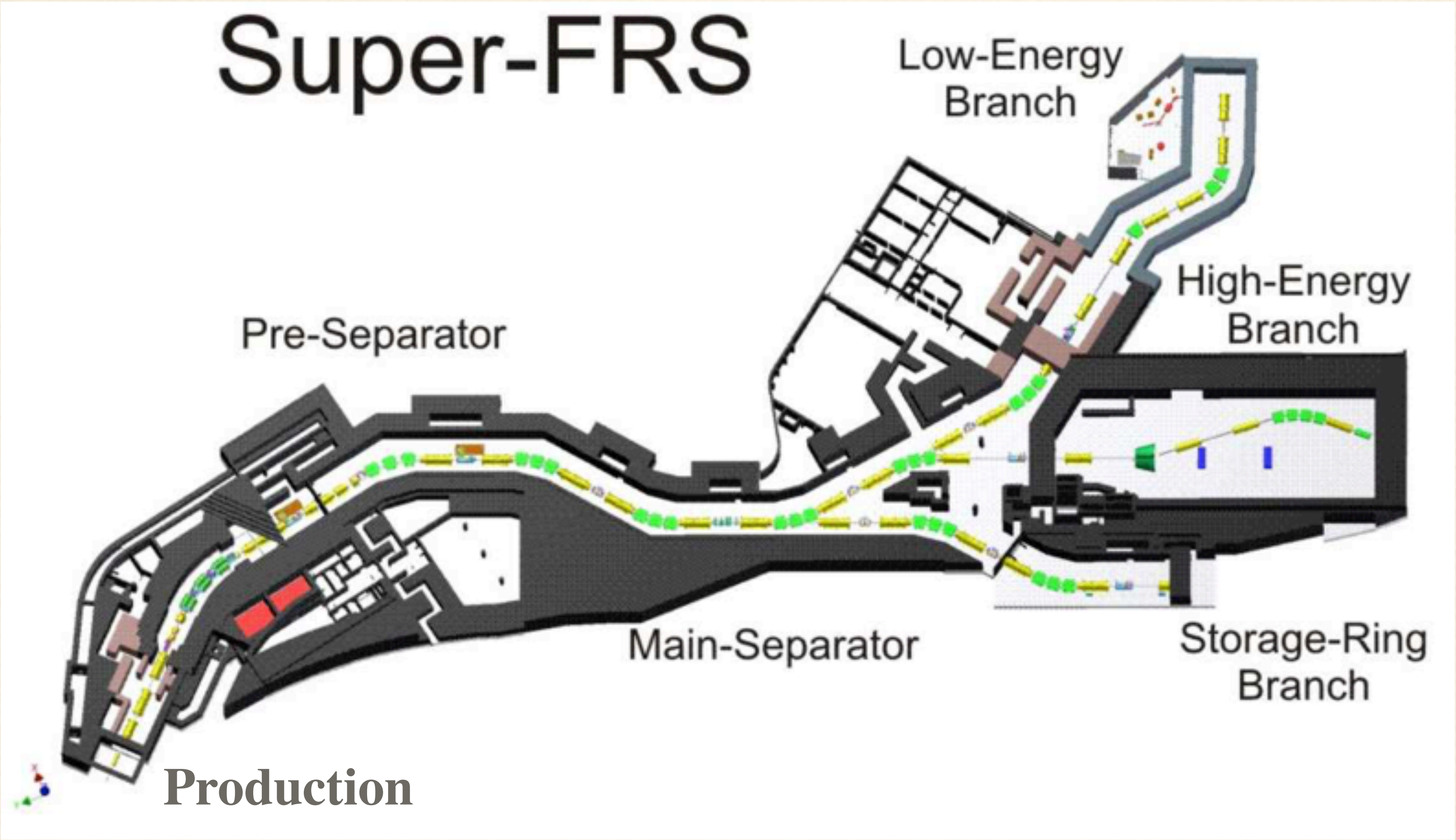
Secondary beams of RIB can be produced by magnetic separation efficiently.

Cross section

$\sigma_I = \pi r_0 (A_1^{1/3} + A_2^{1/3} - \Delta)^2$

RIB is now used all over the world

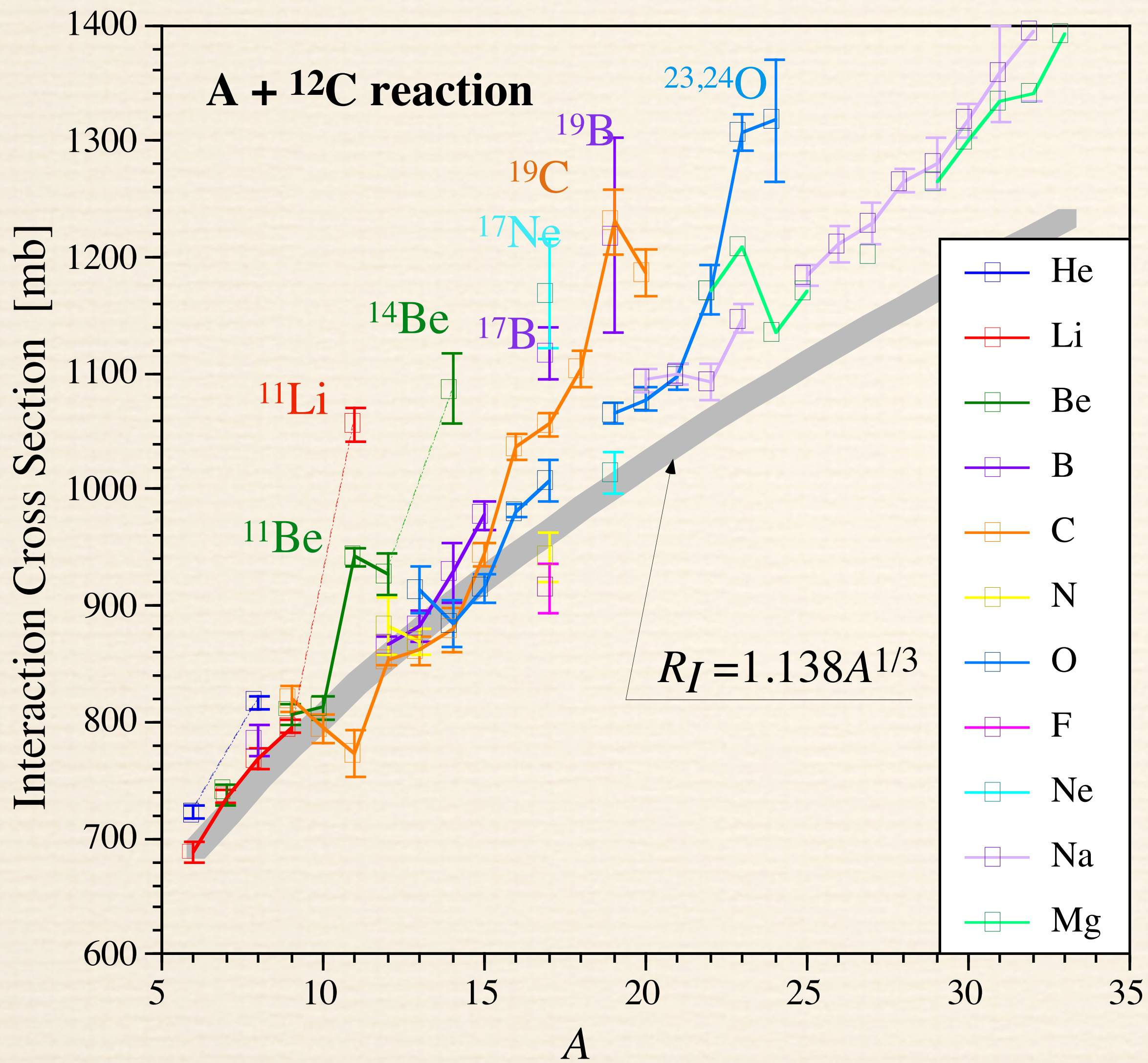
- **New FAIR facility in GSI is one of the most advanced separator in the present stream.**

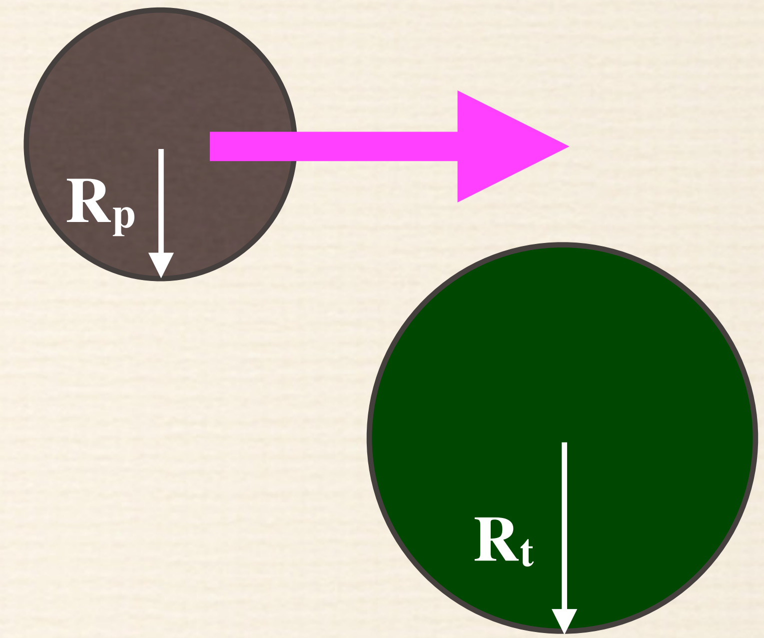


Interaction Cross Sections σ_I

=the cross section is related to the size of a nucleus=

$$\sigma_I \sim \pi (R_p + R_t)^2$$





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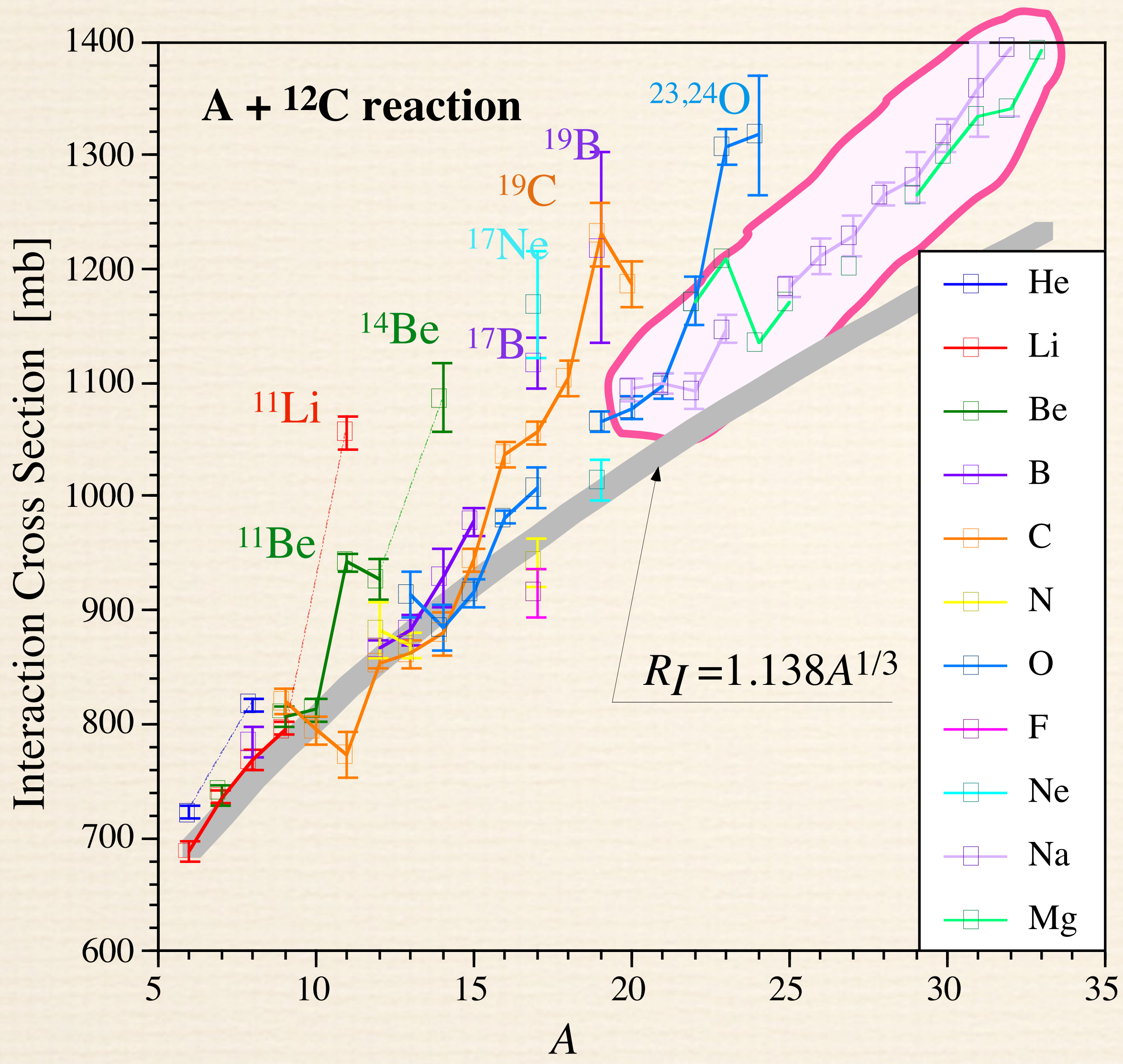

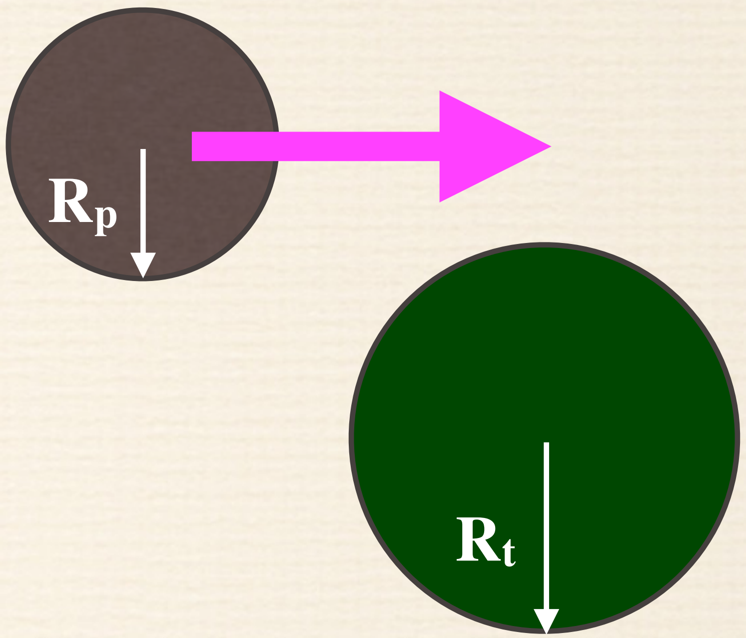

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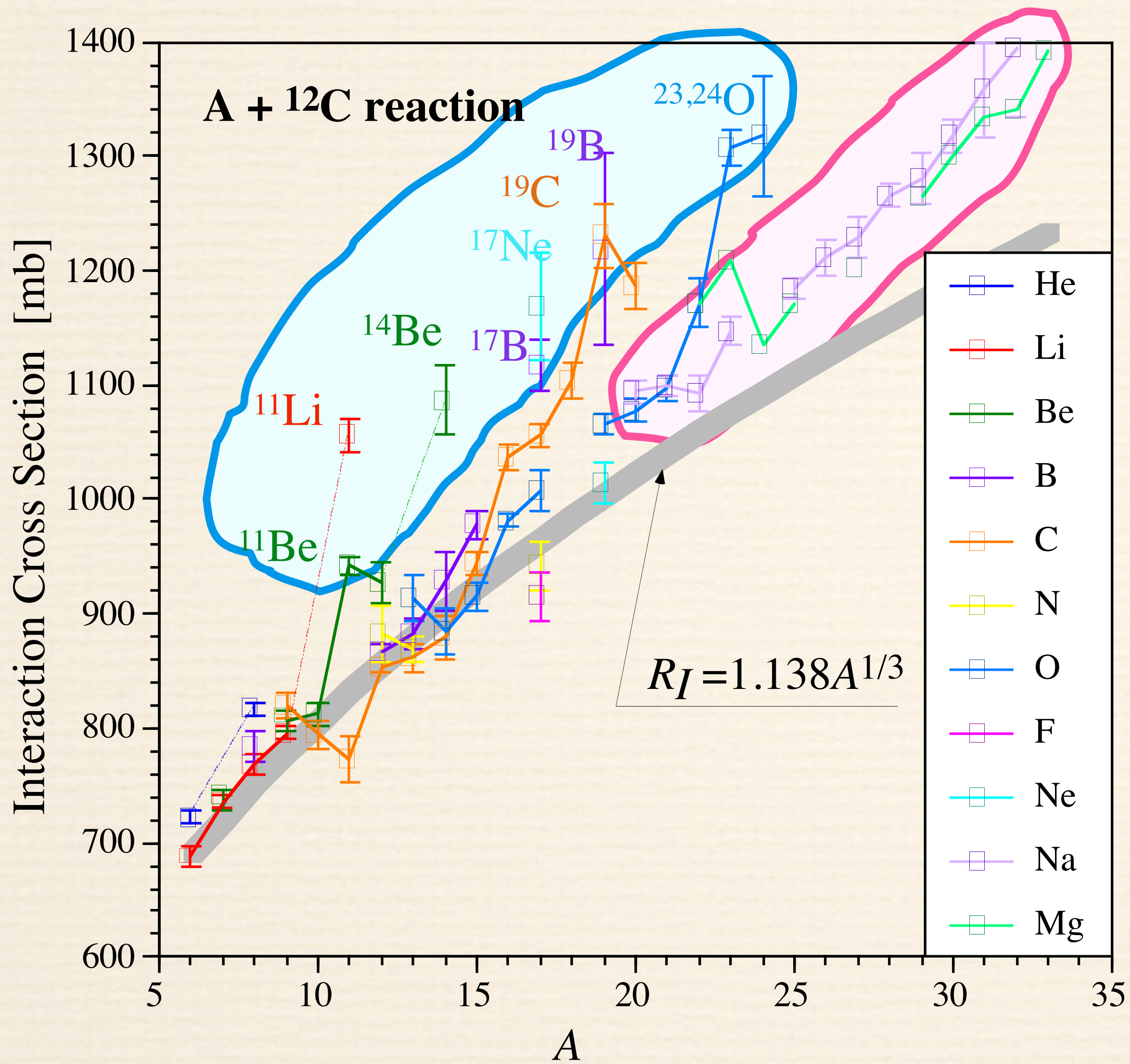

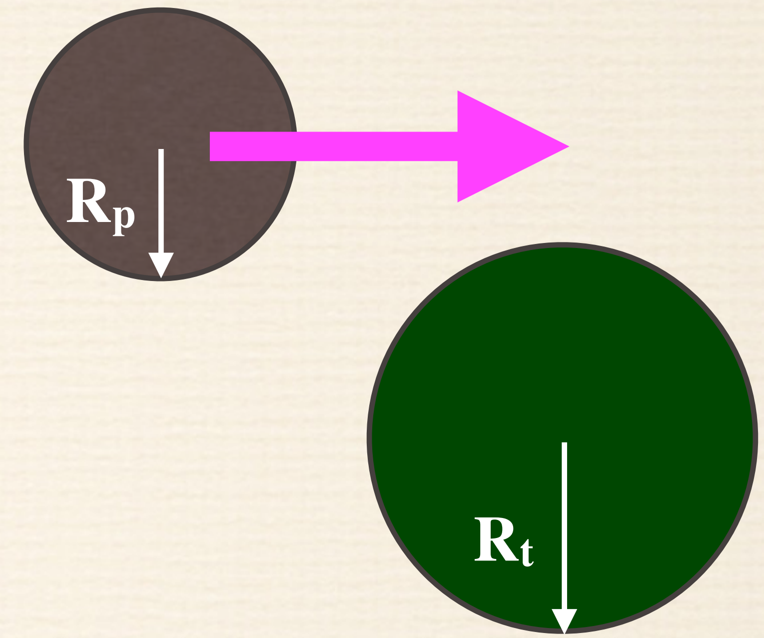

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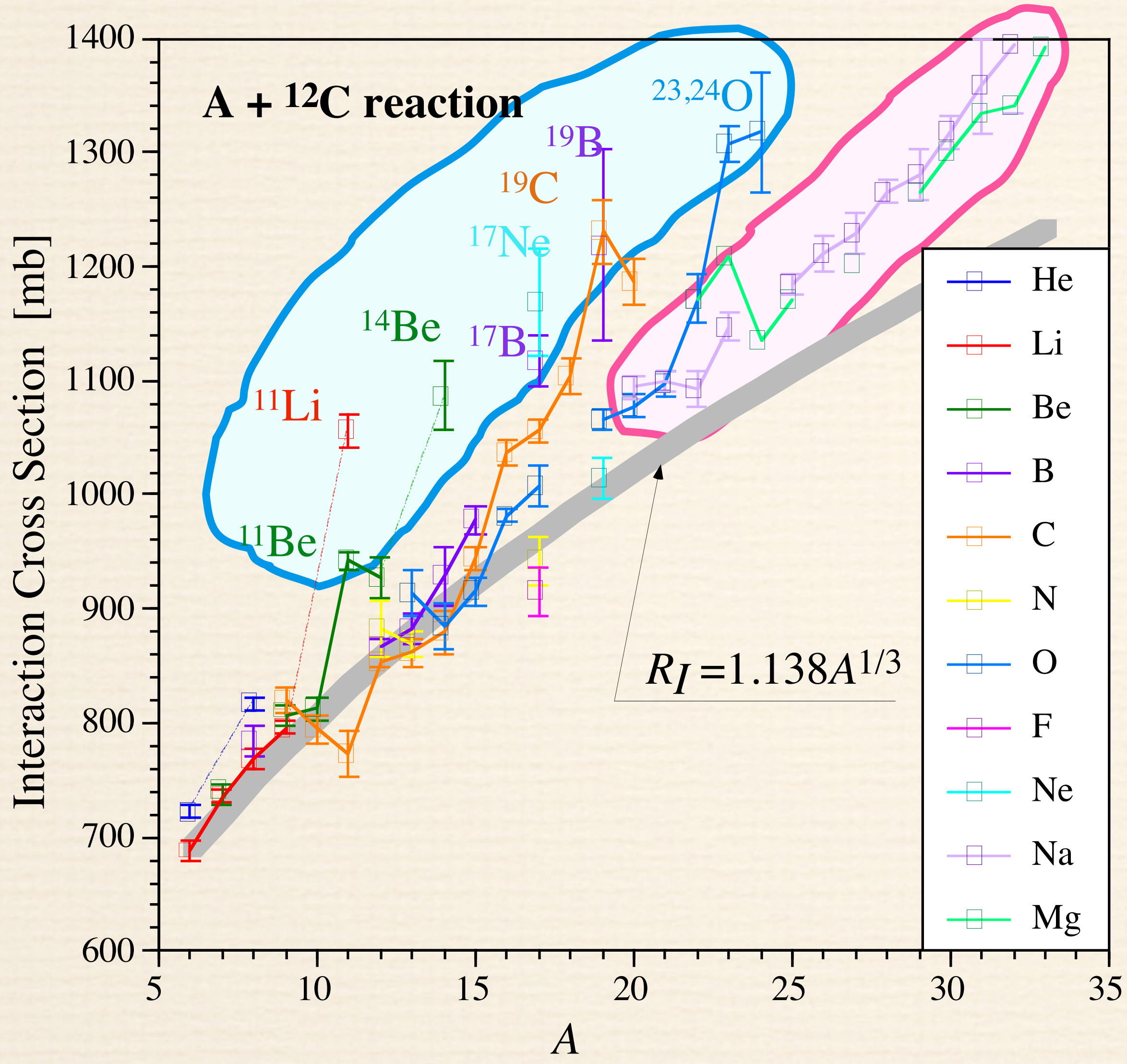

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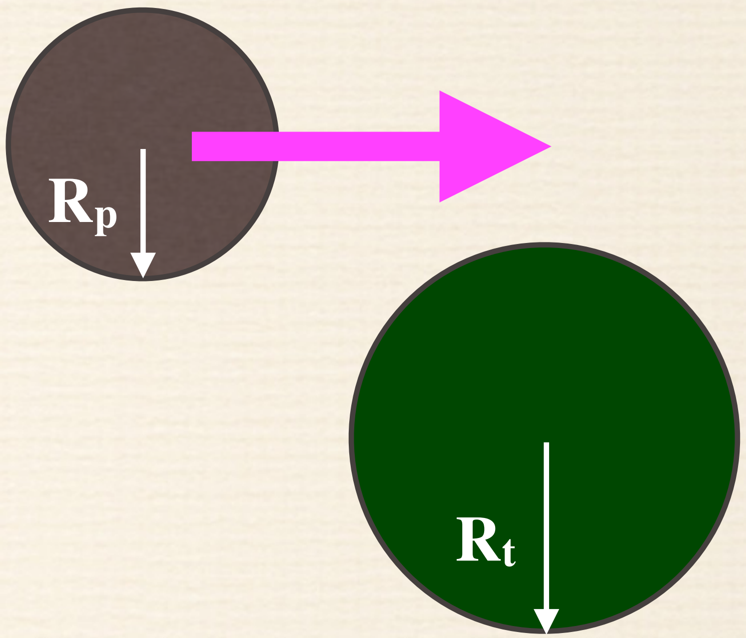
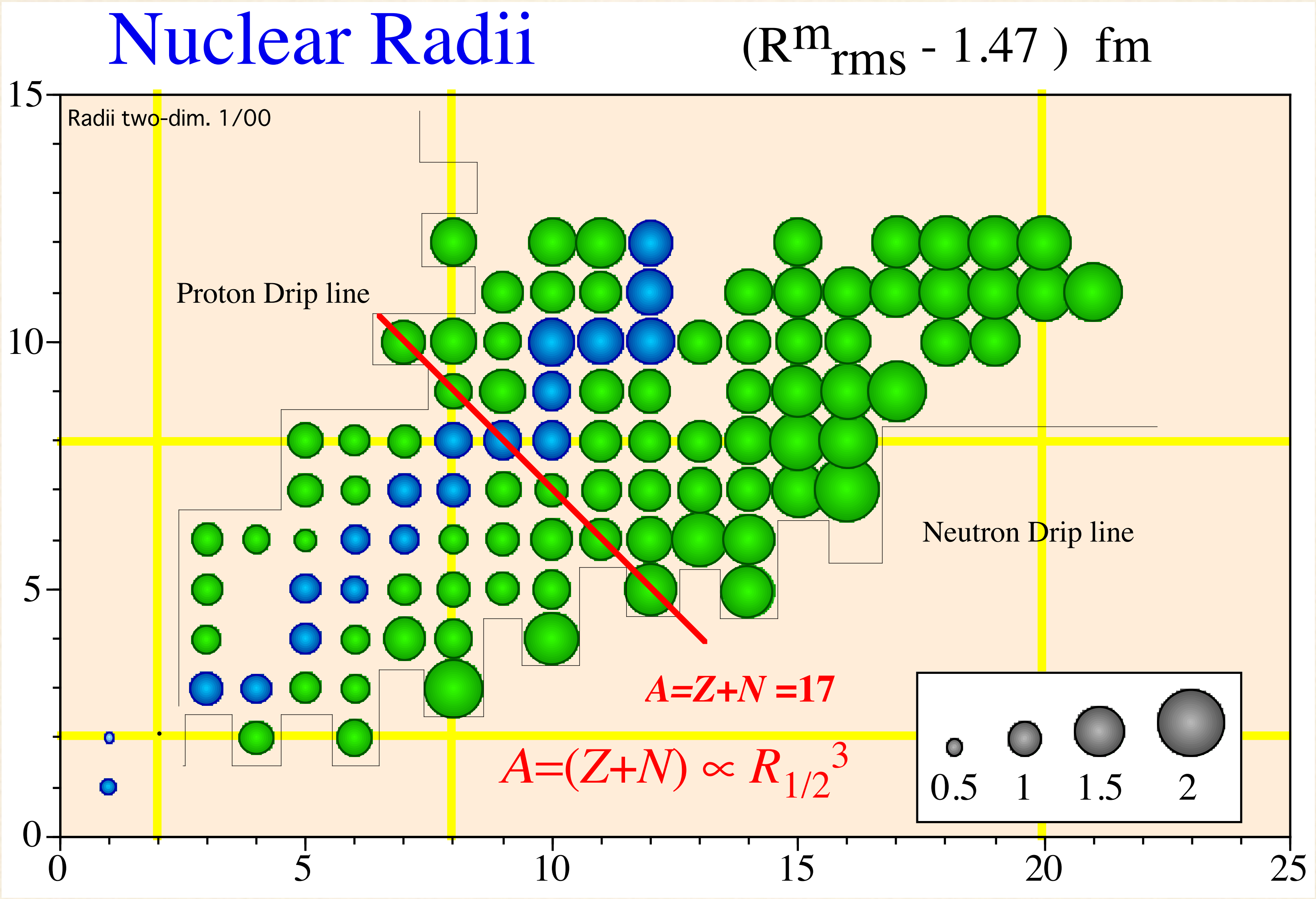
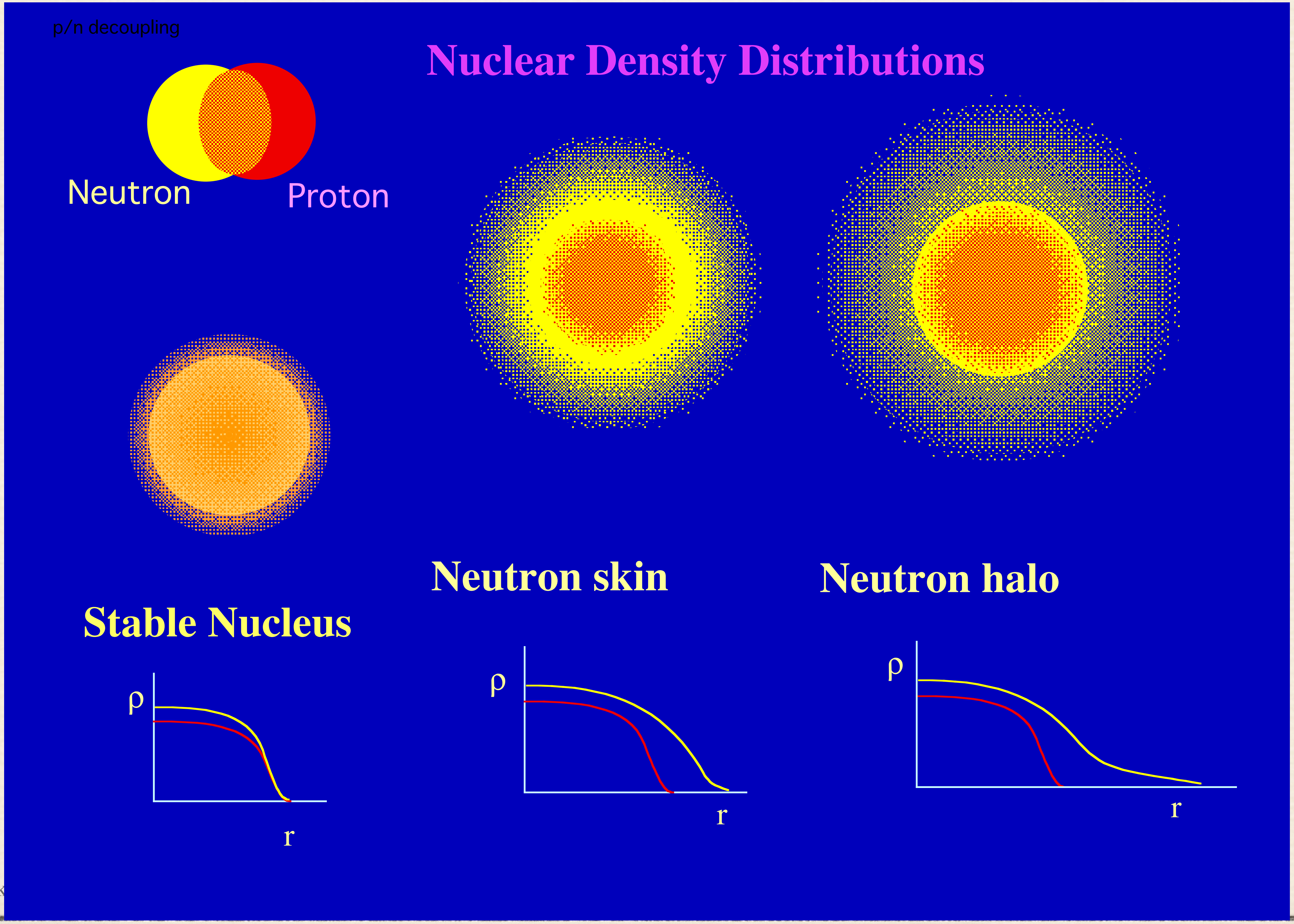


Radioactive nuclei does not show the "common properties" !

Breaking of “general property #1”



New Density Distributions



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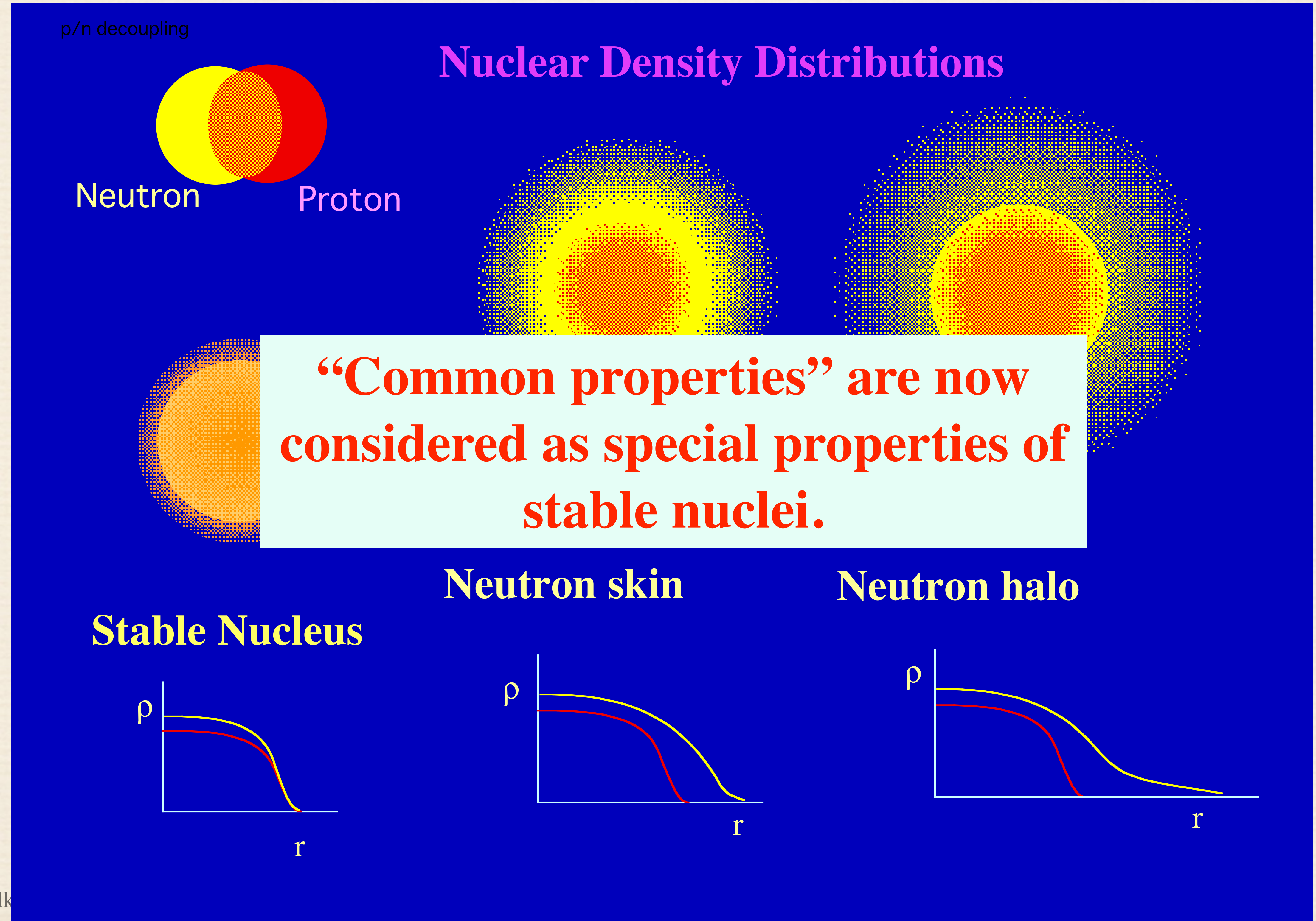
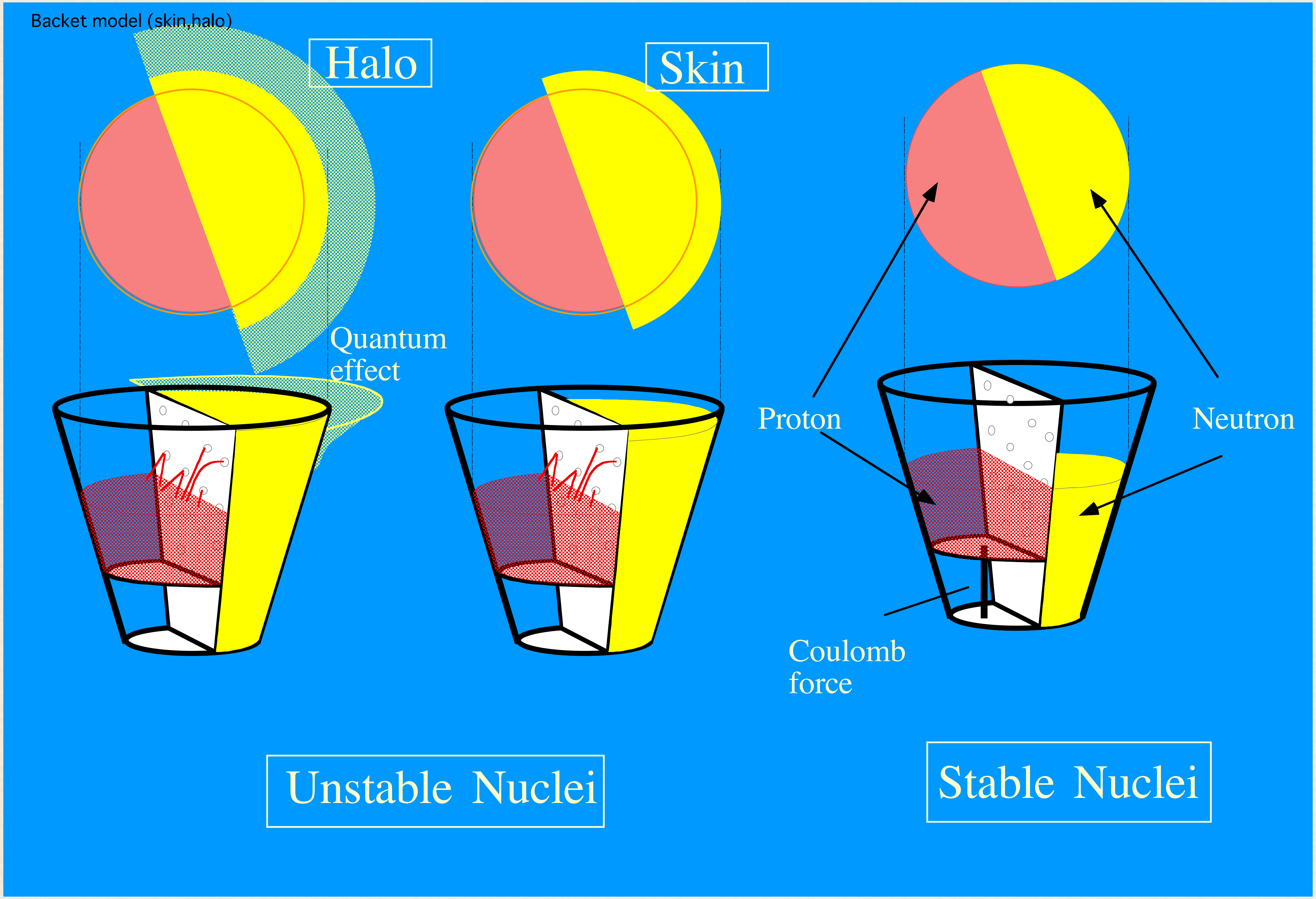


“Common properties” are now considered as special properties of stable nuclei.

Why such "common properties" in stable nuclei?

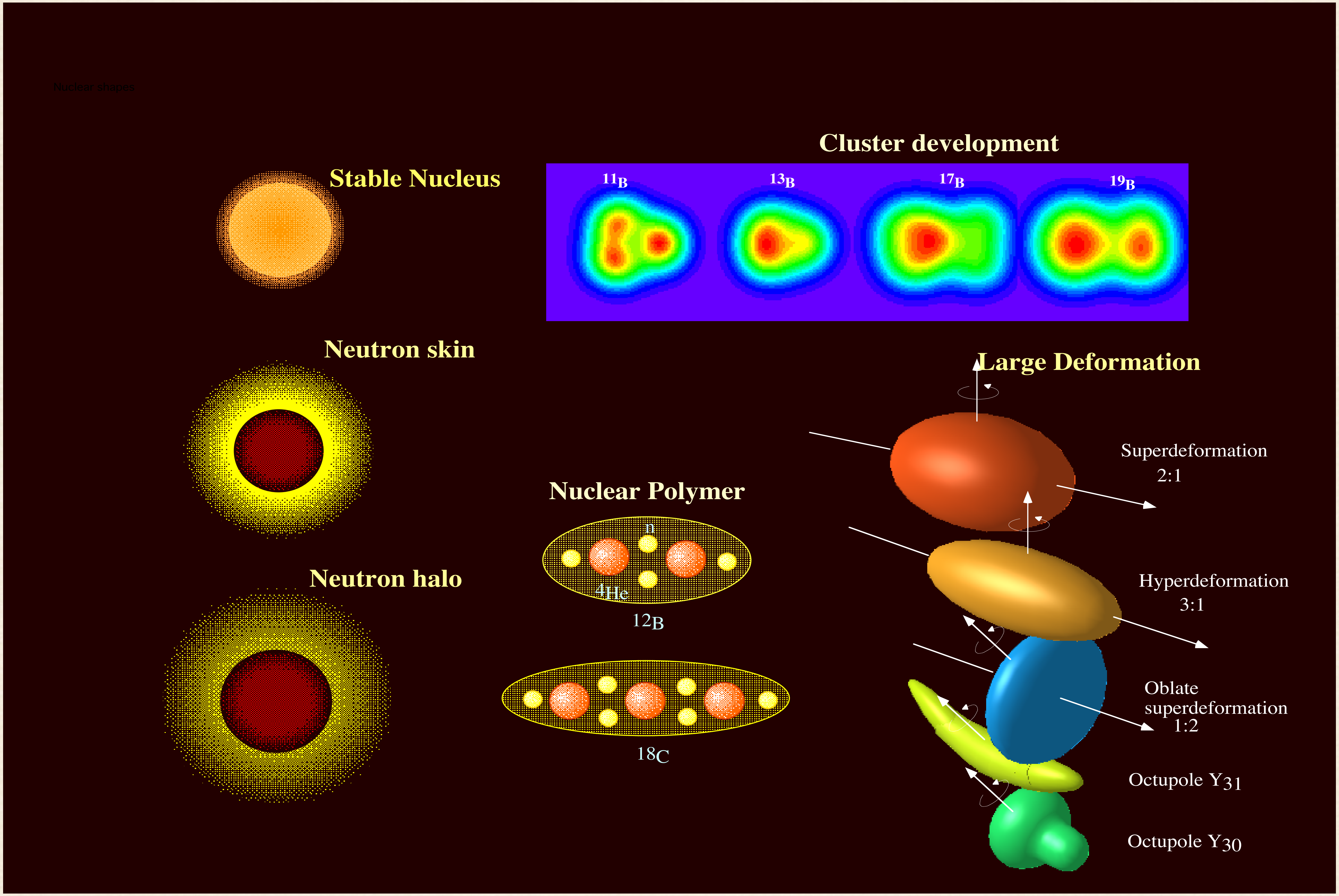
=Bucket model of nuclear radii=



Not only the shops of nuclei, but other properties have to be restudied.

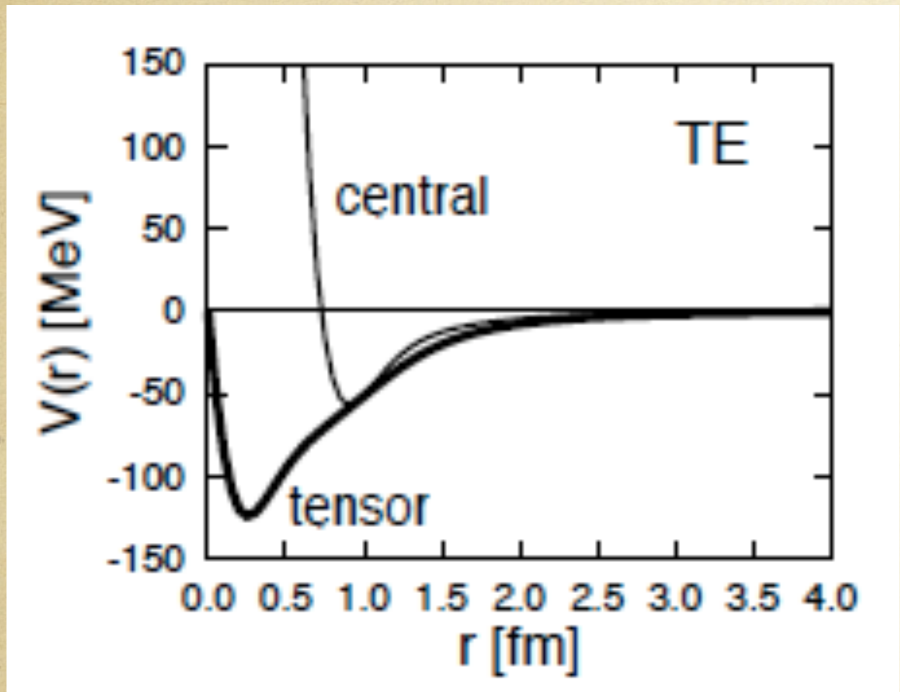
- Weakly bound nuclei show new excitation modes.
- Large difference of proton and neutron number present new properties.
- Magic numbers changes far from the stability line.
- Clusters and molecular binding type nuclei.
- …

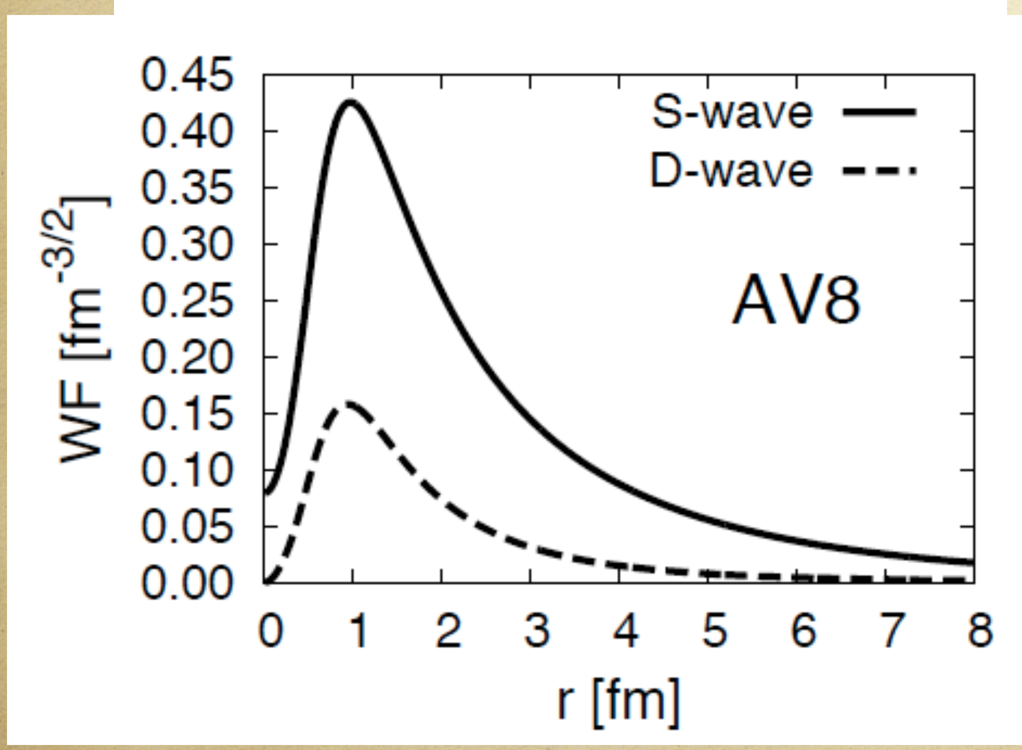
Other forms of Nuclei



For Nuclear Physicist

The importance of tensor is clear in deuteron





S=1 and L=0 or 2

Binding of deuteron (1^+)

Energy	−2.24 [MeV]
Kinetic	19.88
(SS)	11.31
(DD)	8.57
Central	−4.46
(SS)	−3.96
(DD)	−0.50
Tensor	−16.64
(SD)	−18.93
(DD)	2.29
LS	−1.02
P(D)	5.78 [%]
Radius	1.96 [fm]
(SS)	2.00 [fm]
(DD)	1.22 [fm]

K.Ikeda, T.Myo, K.Kato,and H.Toki
Lecture Notes in Phys.818(2010) 165.

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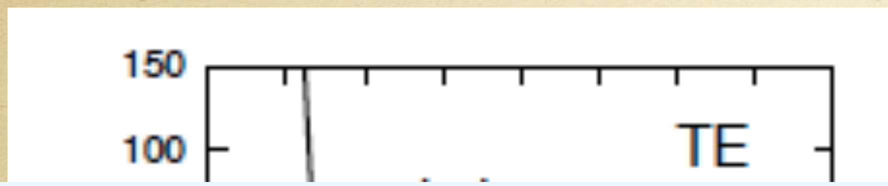
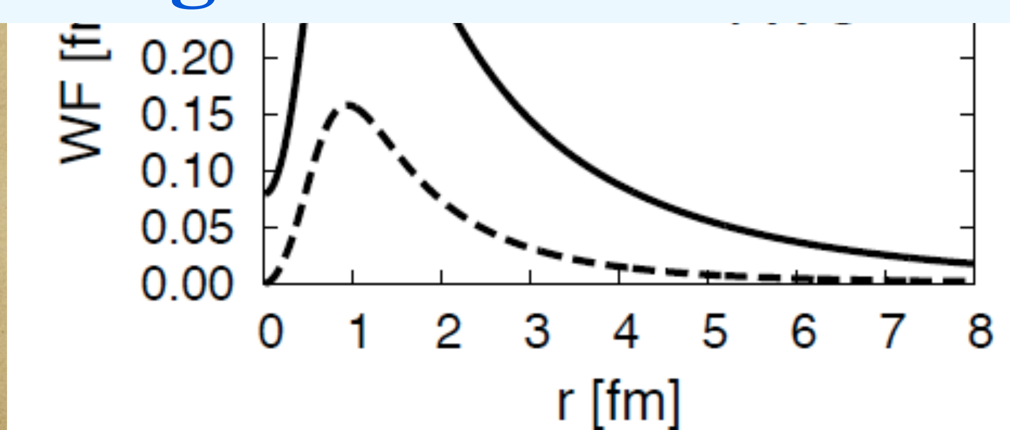


S=1 and L=0 or 2

Binding of deuteron (1^+)

1. Tensor interactions provides most of the biding energy.
2. It is due to the D-wave mixing through the tensor interactions
3. The binding energy by tensor interactions are not from D² term but from SD cross term.
4. D wave has shorter range and thus has high-momentum.
5. High momentum nucleon are necessary to make binding.



P(D)	5.78 [%]
Radius	1.96 [fm]
(SS)	2.00 [fm]
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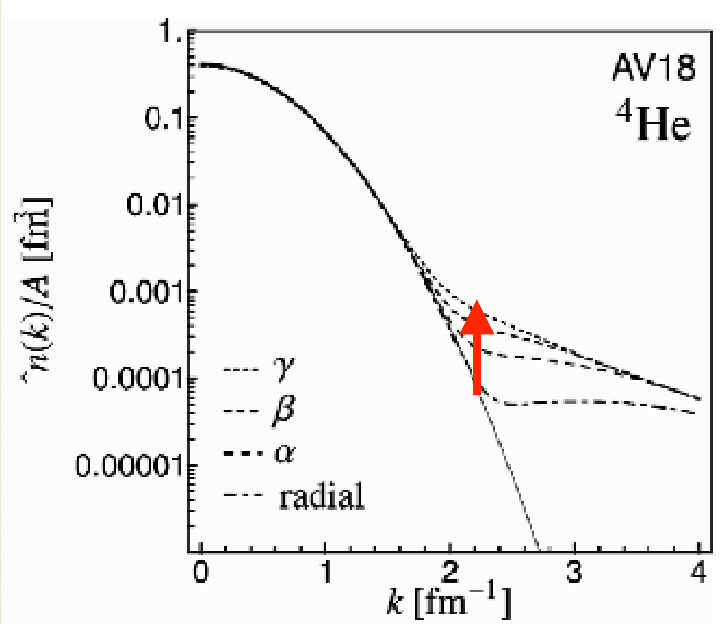
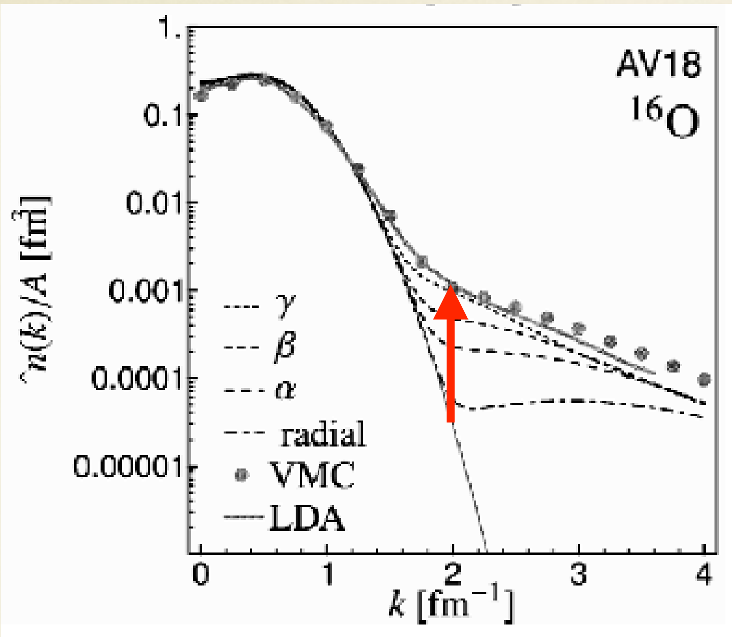
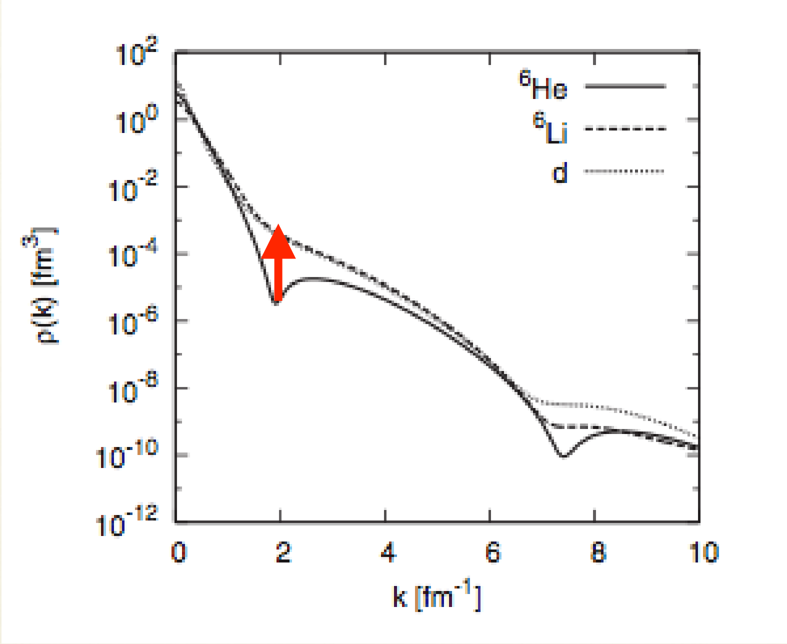
High-momentum components (Theoretical Predictions)

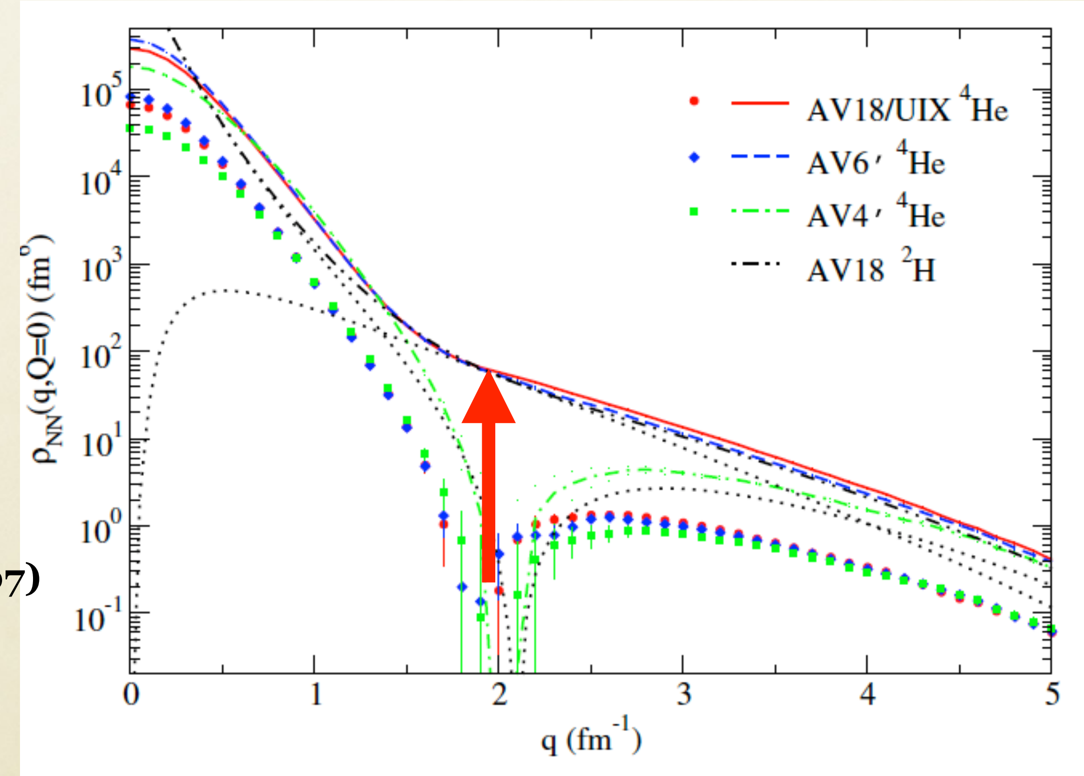




T. Neff and H. Feldmeier,
NPA713, 311(2003)

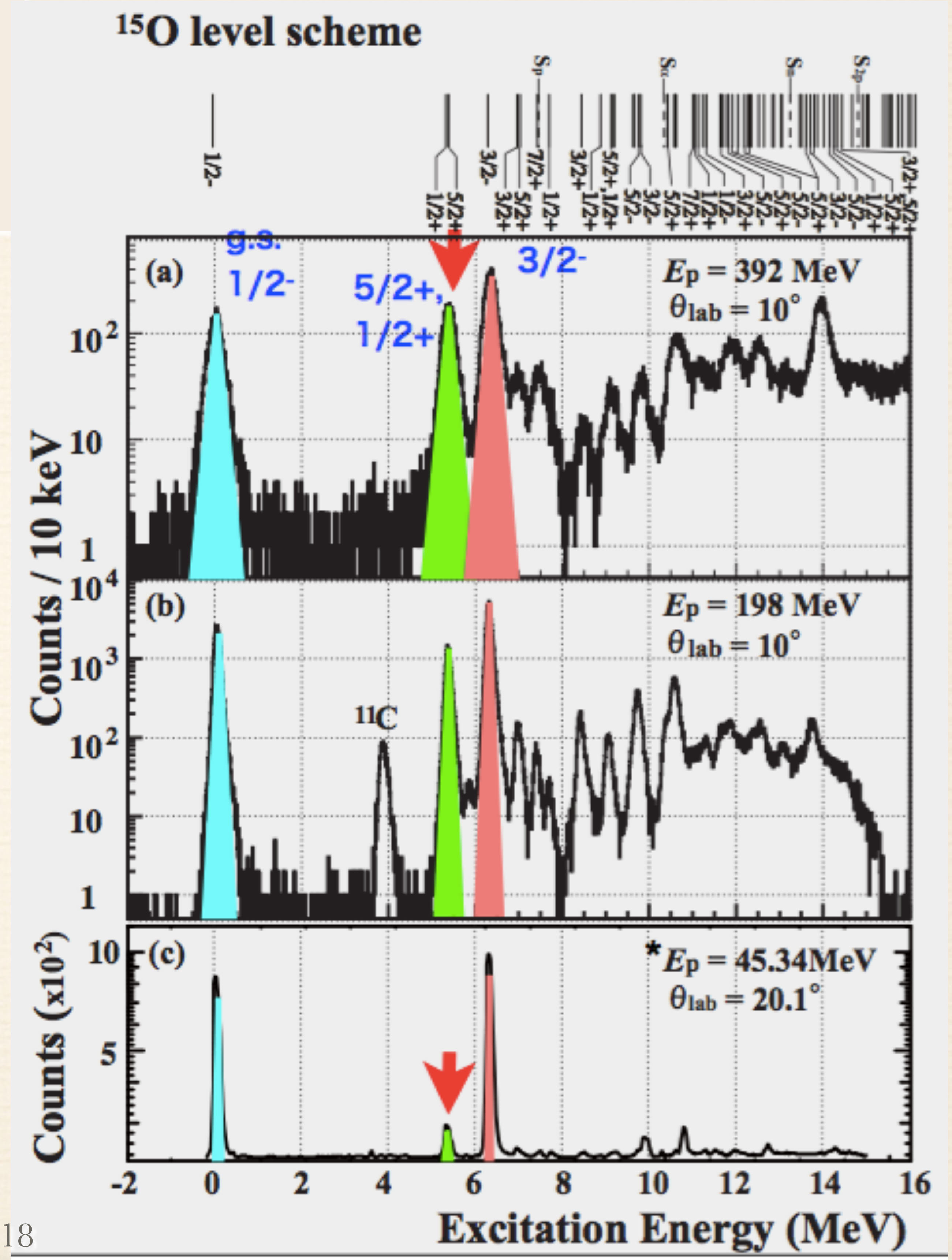


W. Horiuchi and Y. Suzuki,
PRC76, 024311(2007)



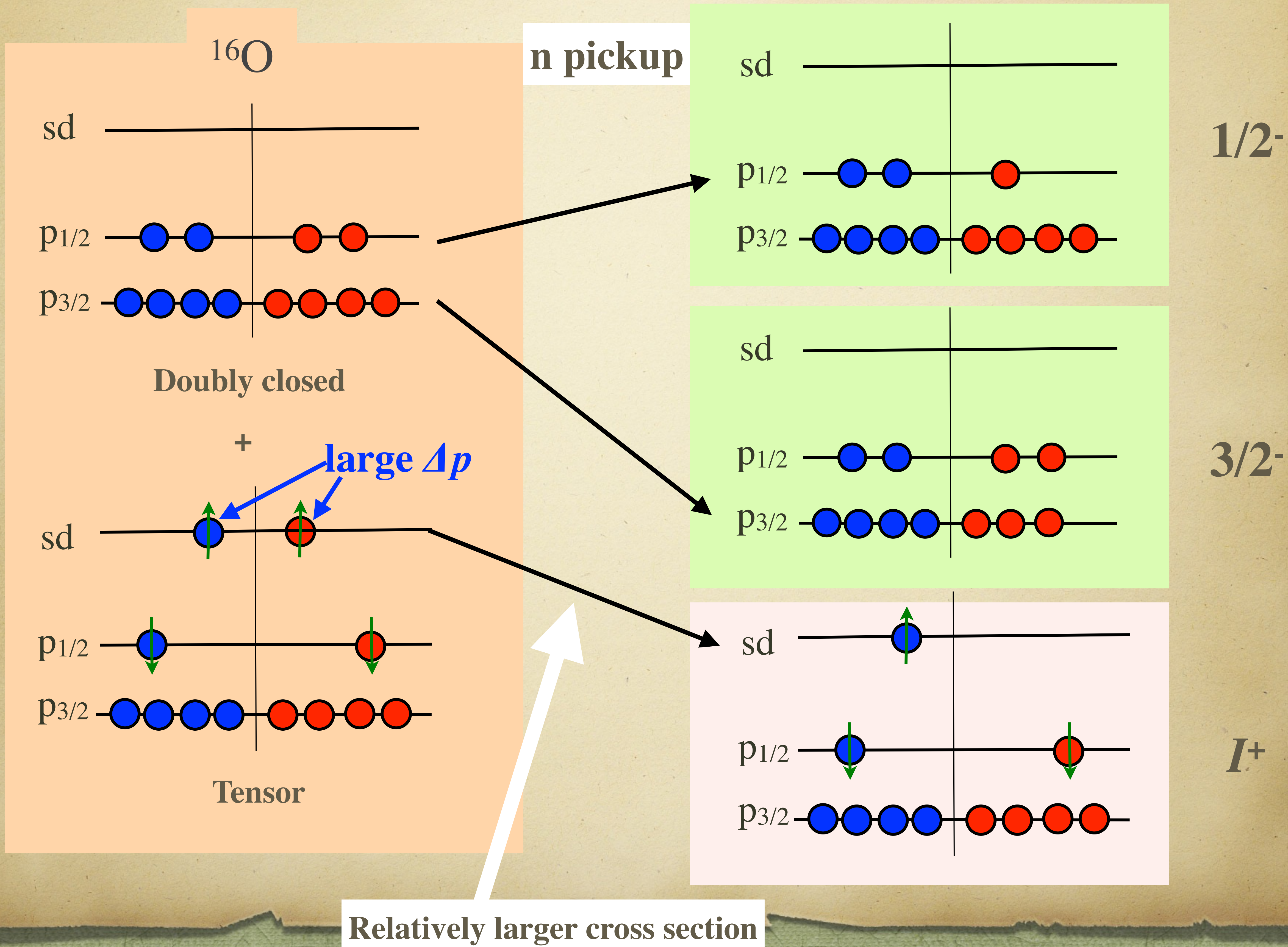
R. Schiavilla et al.,
PRL 98 132501 (2007)

State dependent effect by (p,d) reaction



- Another possibility
- $^6He(p,d)^4He+X$ (2n)

16O and (p,d) reaction



Other use of RIB in research

- Nuclear astrophysics, Cosmo-nuclear physics
- Implantation of RI
- …

Why RIB

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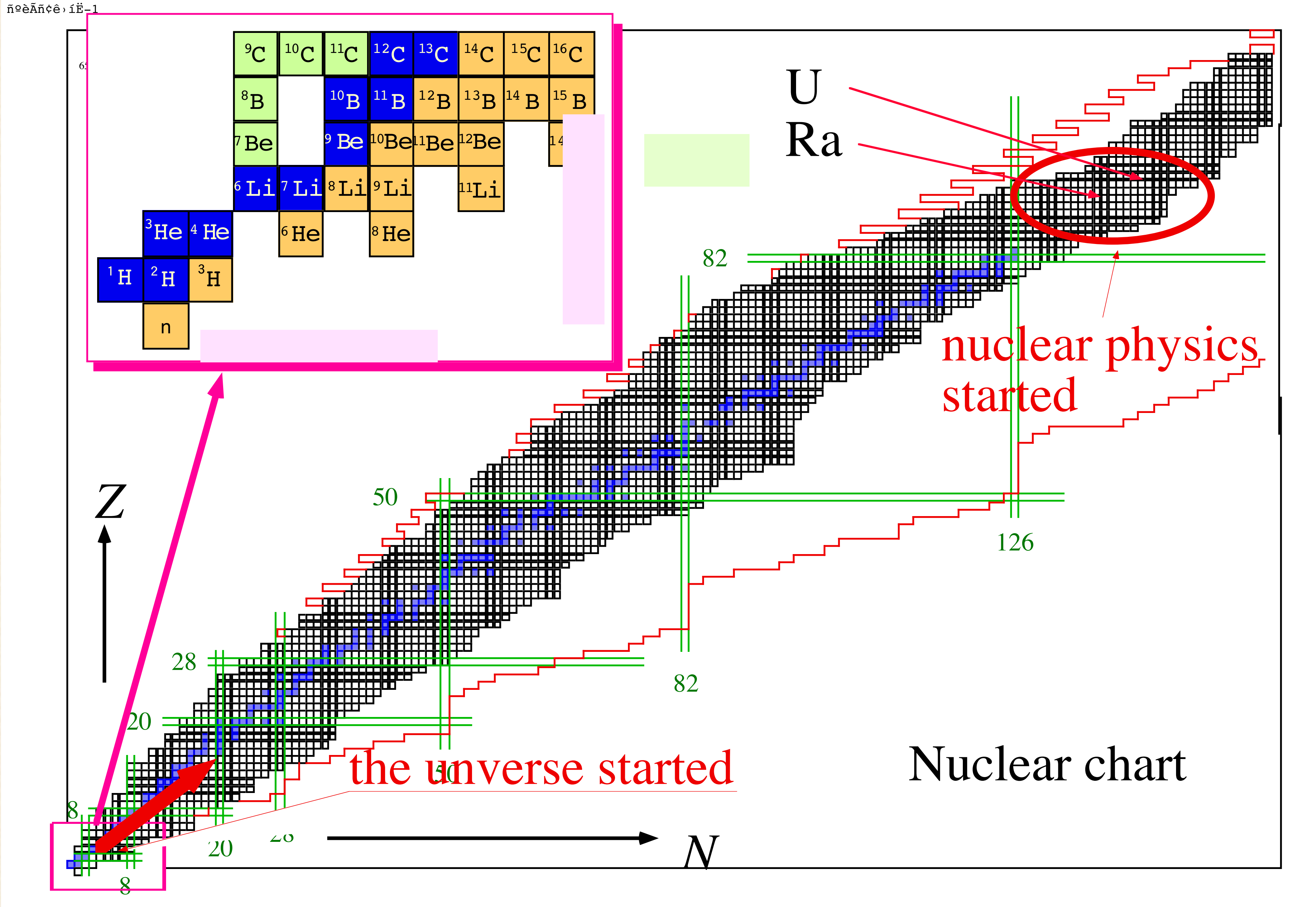
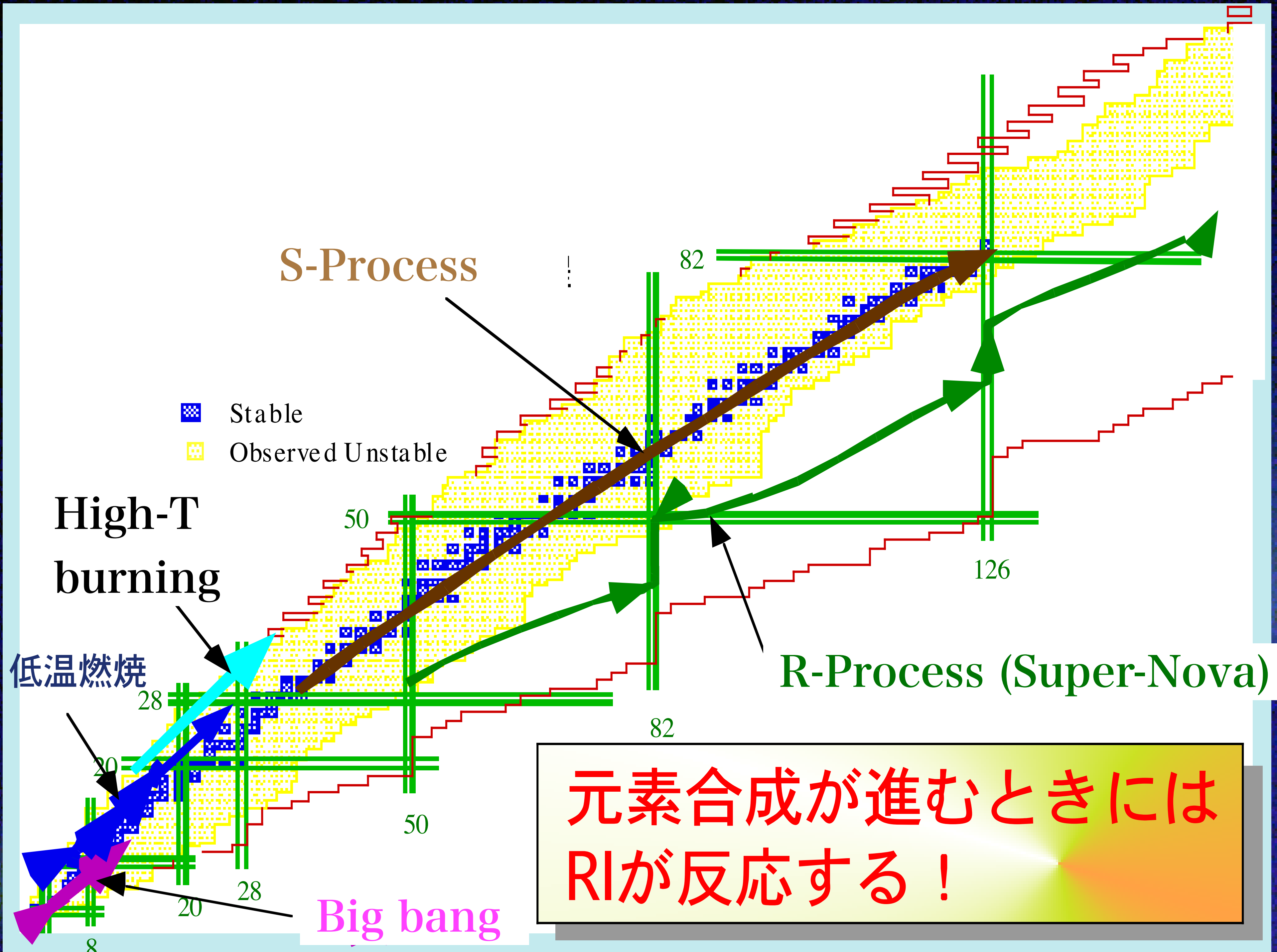


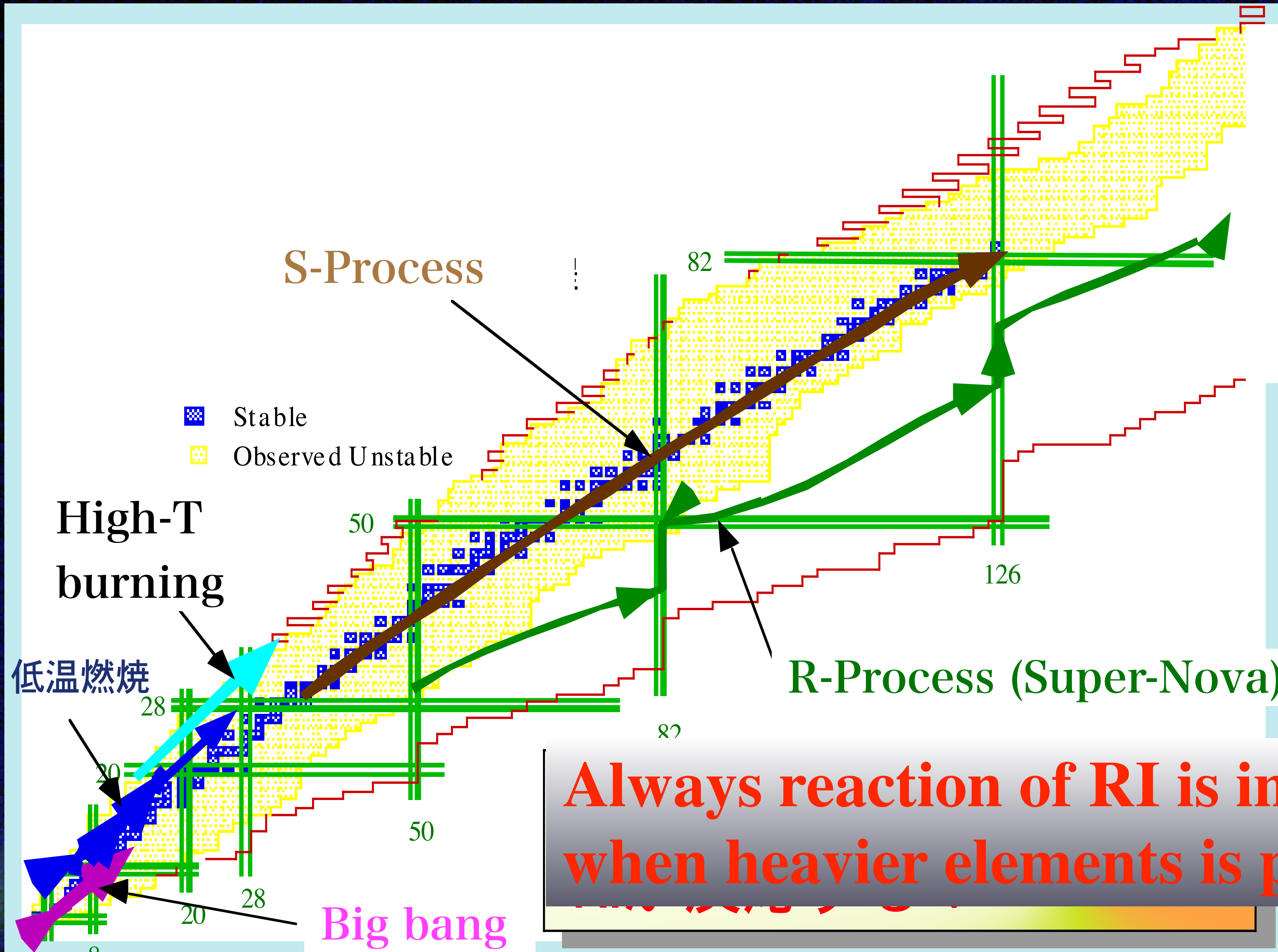
Synthesis Paths



元素合成が進むときには
RIが反応する！

これらの反応の研究は
RIビームで初めて可能

Synthesis Paths



Always reaction of RI is important when heavier elements is produced.

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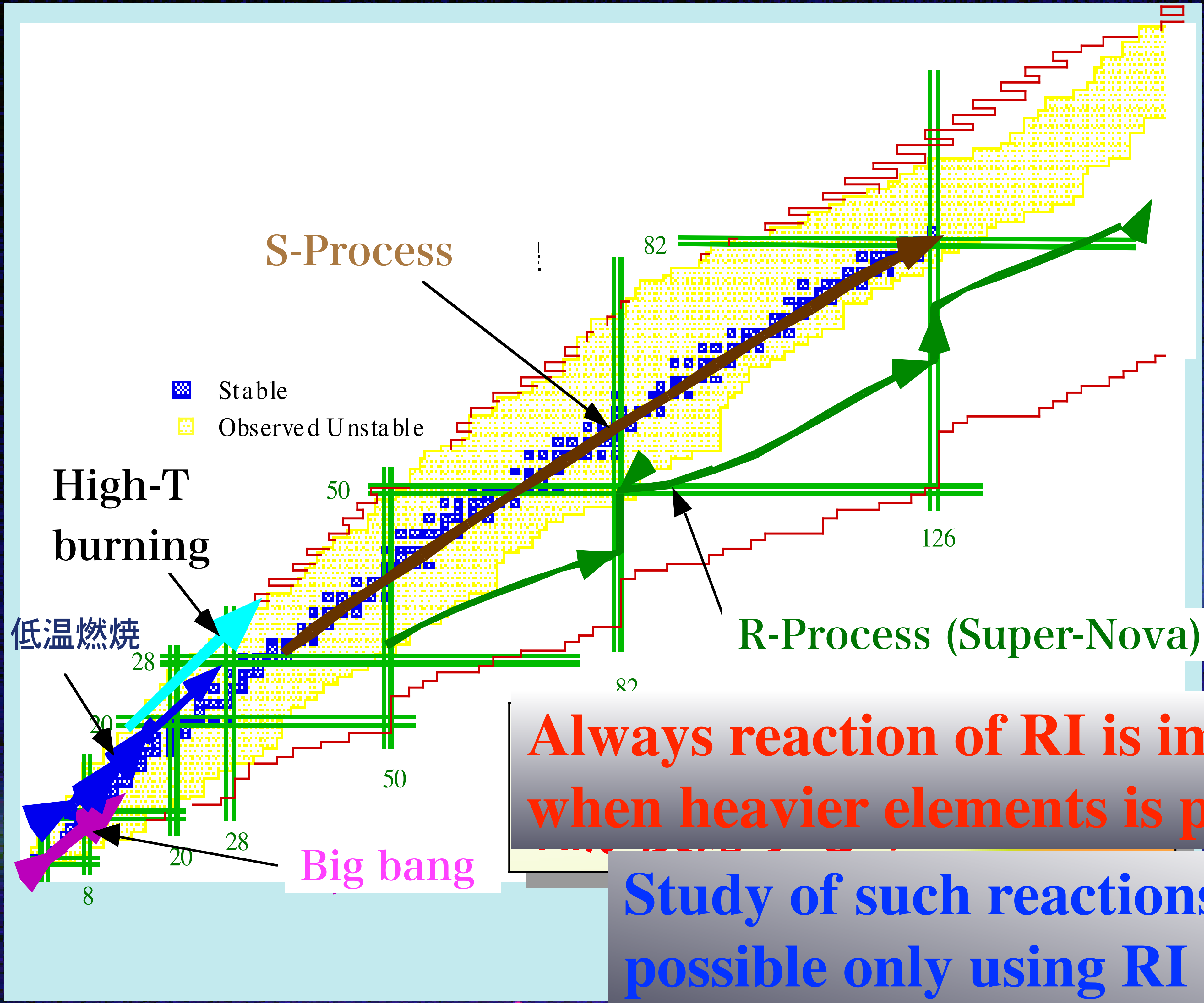

Always reaction of RI is important when heavier elements is produced.

Study of such reactions are possible only using RI beams.

RIB opened new era

- in nuclear structure physics,
  - *not only in nuclear size and shapes but also reveal other problems and raised new questions.*
- in nuclear astrophysics and in cosmos-nuclear physics,
  - *to understand the evolution of the universe and stars,*
  - *and nucleosynthesis in many stellar environments.*
- more applications are expected.