Invariant-mass spectroscopy of unbound nuclei using SAMURAI

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  - Investigation of Shell evolution in extremely neutron-rich region
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- Experimental method
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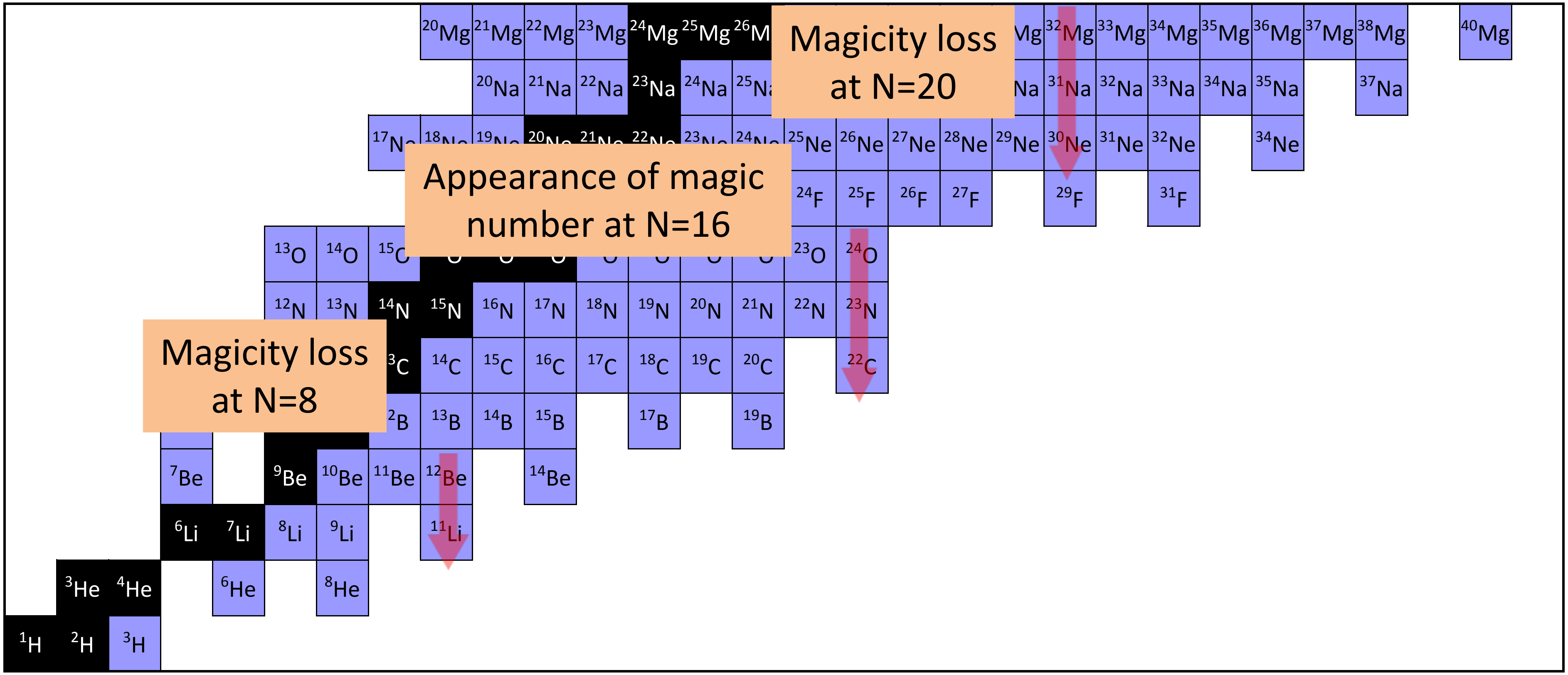
  - [illegible]

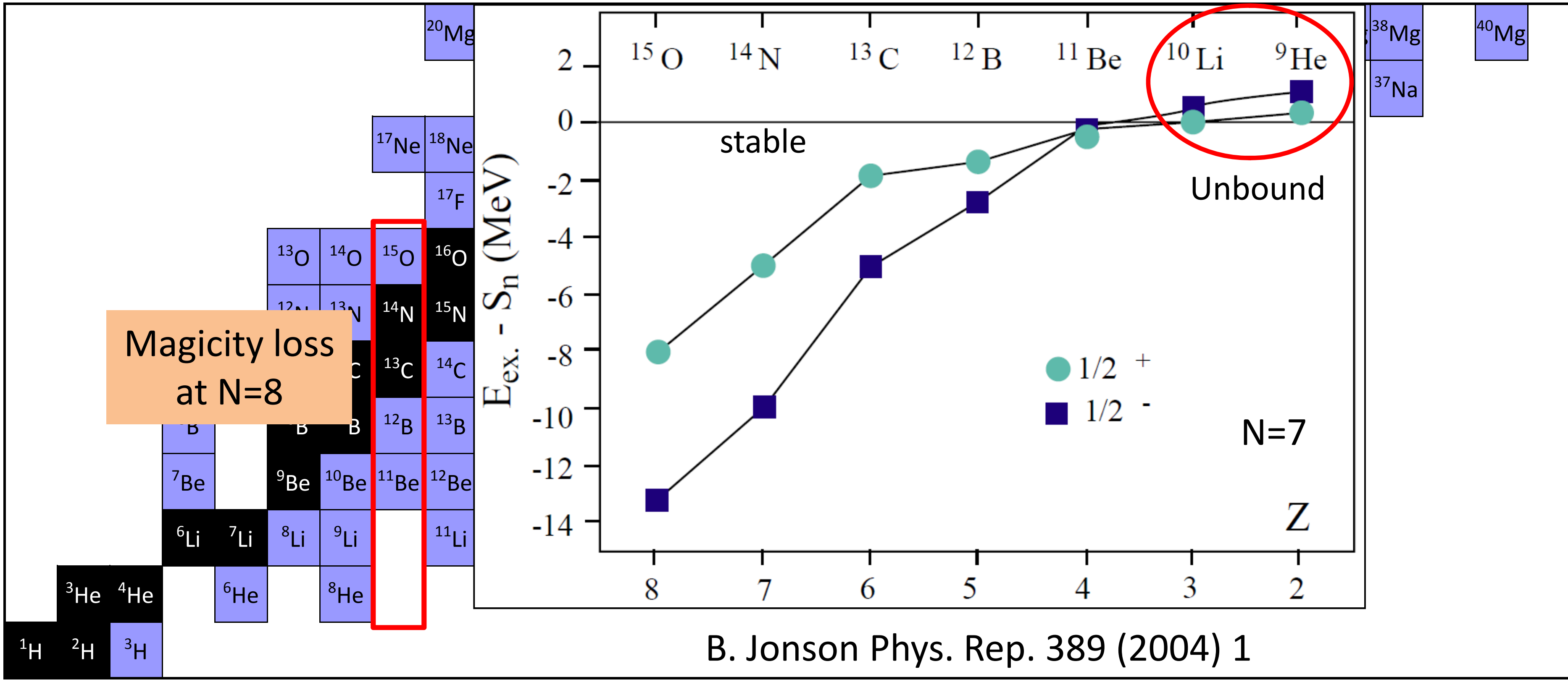
Shell evolution towards the drip line



- Appearance/disappearance of magic number
  - Shell evolution
    - Spectroscopy of n-rich nuclei towards the drip line

Spectroscopy of unbound nuclei → <u>shell changing in extremely neutron-rich region</u>

Shell evolution towards the drip line



B. Jonson Phys. Rep. 389 (2004) 1

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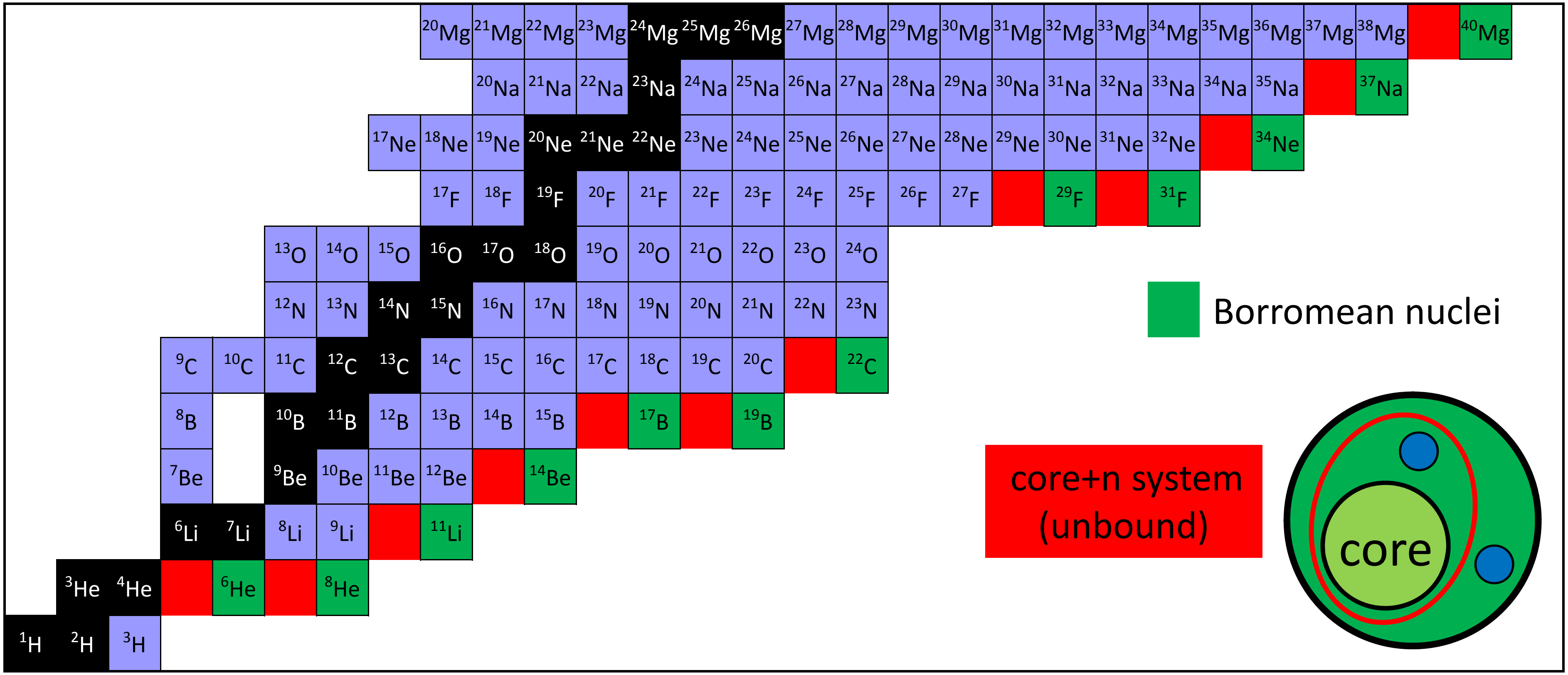
Three body structure of Borromean nuclei



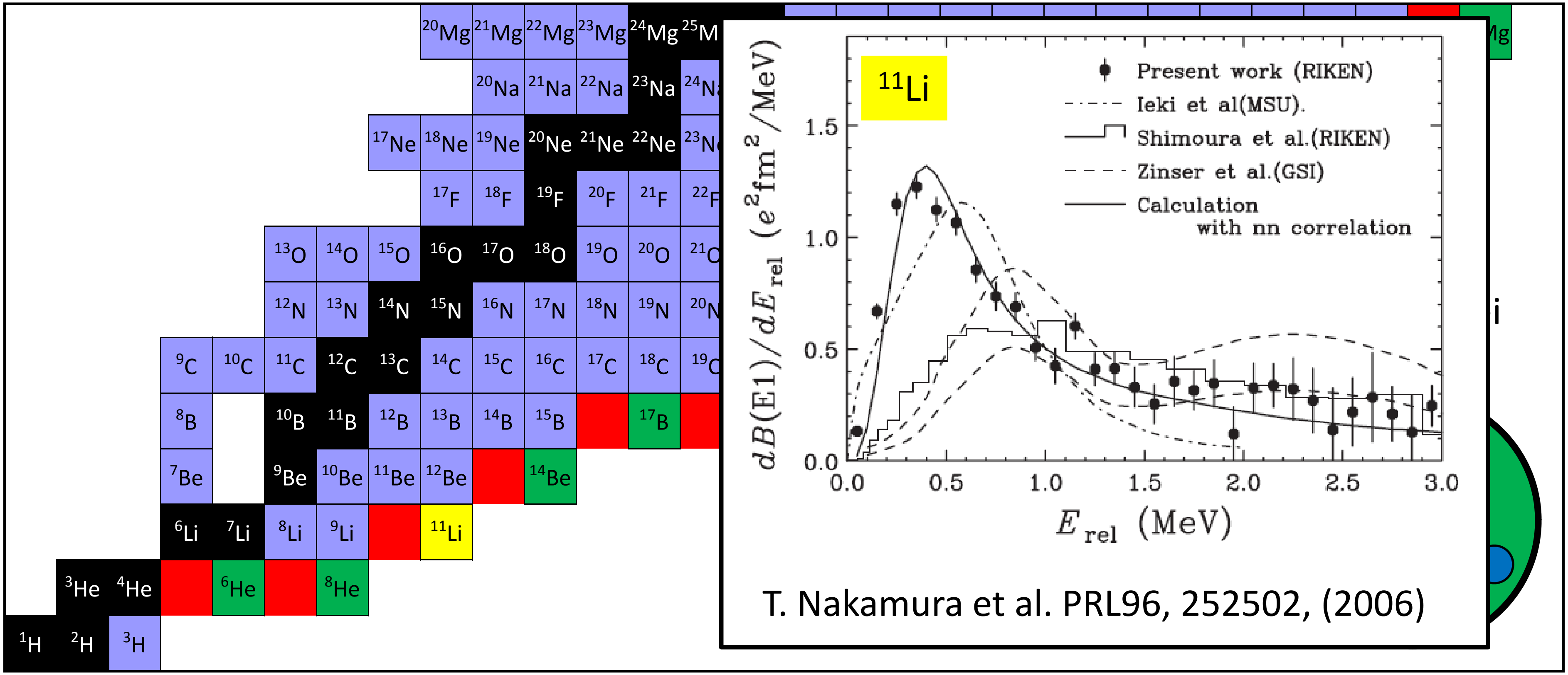
Borromean nuclei (^{6}He, ^{11}Li, …)

Three body system (core +n+n) with no bound binary sub-systems (core+n, n+n)

- <u>Di-neutron correlation</u>? (^{6}He, ^{11}Li)
  - dB(E1)/dE strength of a Borromean nucleus
  - Three body model theory
    - Interaction of core+n sub-system is needed

→ Coulomb breakup of a Borromean nucleus + spectroscopy of core+n sub-system

Three body structure of Borromean nuclei



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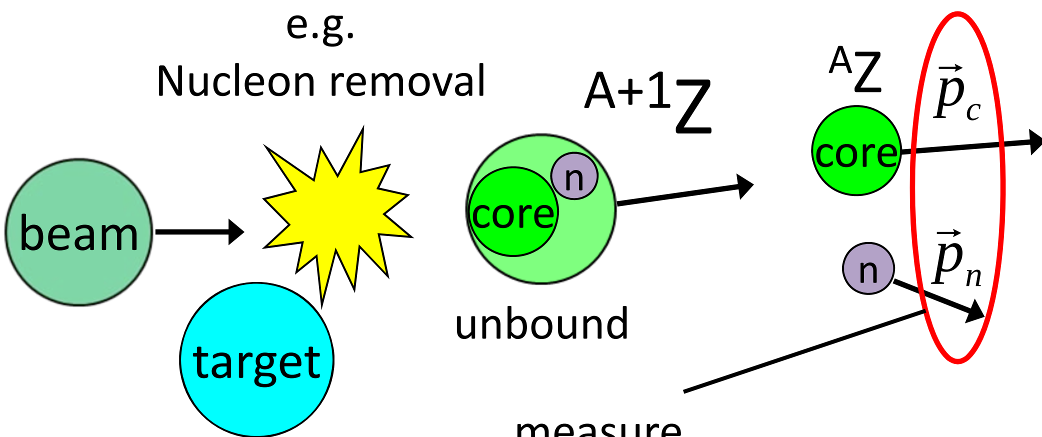
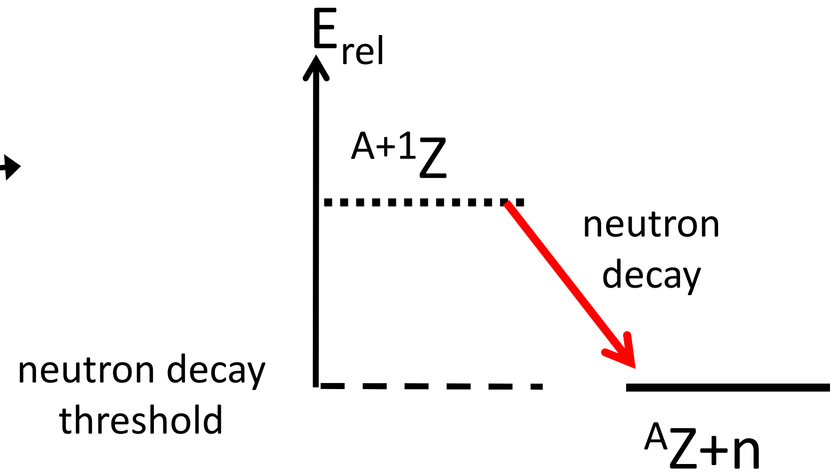
Invariant-mass method



measure
→
E_{rel} can be reconstructed



Relative energy

$$E_{rel} = \sqrt{\left(\sum E_i\right)^2 - \left(\sum \vec{p}_i\right)^2} - \sum M_i$$

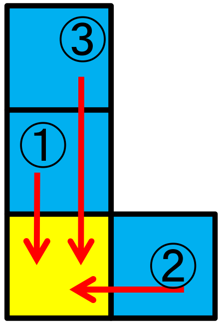
Invariant mass

Merit of the invariant mass method

- Good energy resolution (ΔE_{rel}=0.4MeV @1MeV)
- E_{rel} resolution is independent on the beam profile
- Thick target (a few g/cm^2) can be used
  - High statistics

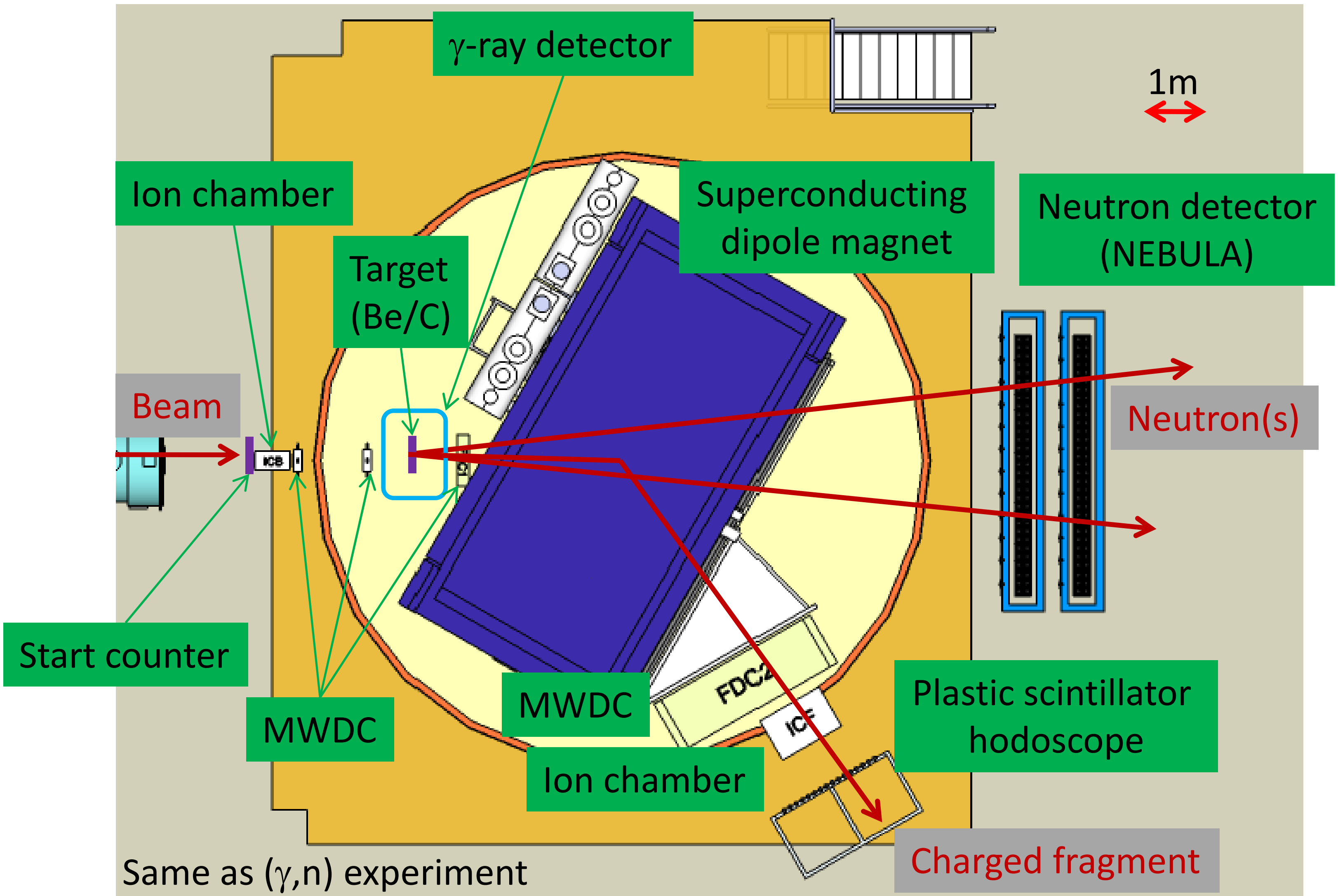
Invariant-mass method is powerful tool
for spectroscopic study using RI beam (large emittance and low intensity)

How to produce unbound nuclei?

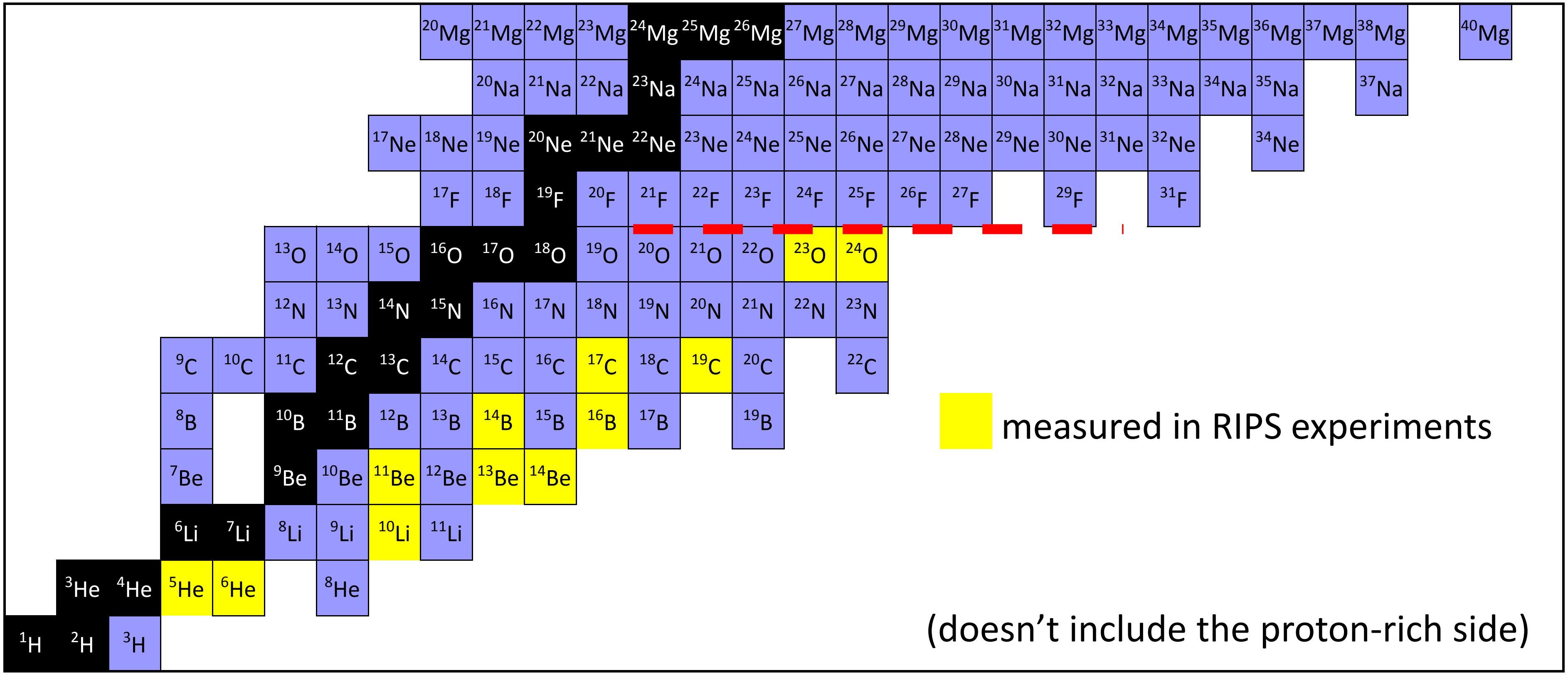


1. **one-proton removal reaction**
   - useful to access very neutron-rich nucleus
   - population of ground state is favored (x neutron-hole configuration)
2. **one-neutron removal reaction**
   - ground & excited states are populated (o neutron-hole configuration)
   - momentum distribution is useful to deduce neutron orbit
   - beam intensity is weak (compared with -1p reaction)
   - should pay attention to the two neutron decay following inelastic scattering of a beam nucleus ^{A+1}Z
     - e.g. ^{13}Be case Y. Kondo et al. PLB690, 245, (2010)
       - ^{14}Be -1n→ ^{13}Be → ^{12}Be+n
       - ^{14}Be inelastic → ^{14}Be*→^{12}Be+n(+n) this made mimic peak in the spectrum
3. **two-proton removal reaction**
   - cross section is one order of magnitude less than that of -1p reaction
   - Beam intensity is one order of magnitude larger than that of -1p reaction
     - →statistics of reaction yield is comparable to the -1p reaction
   - less selection rule? (compared with -1p reaction)
     - ground & excited states are expected to be populated

Typical experimental setup using SAMURAI

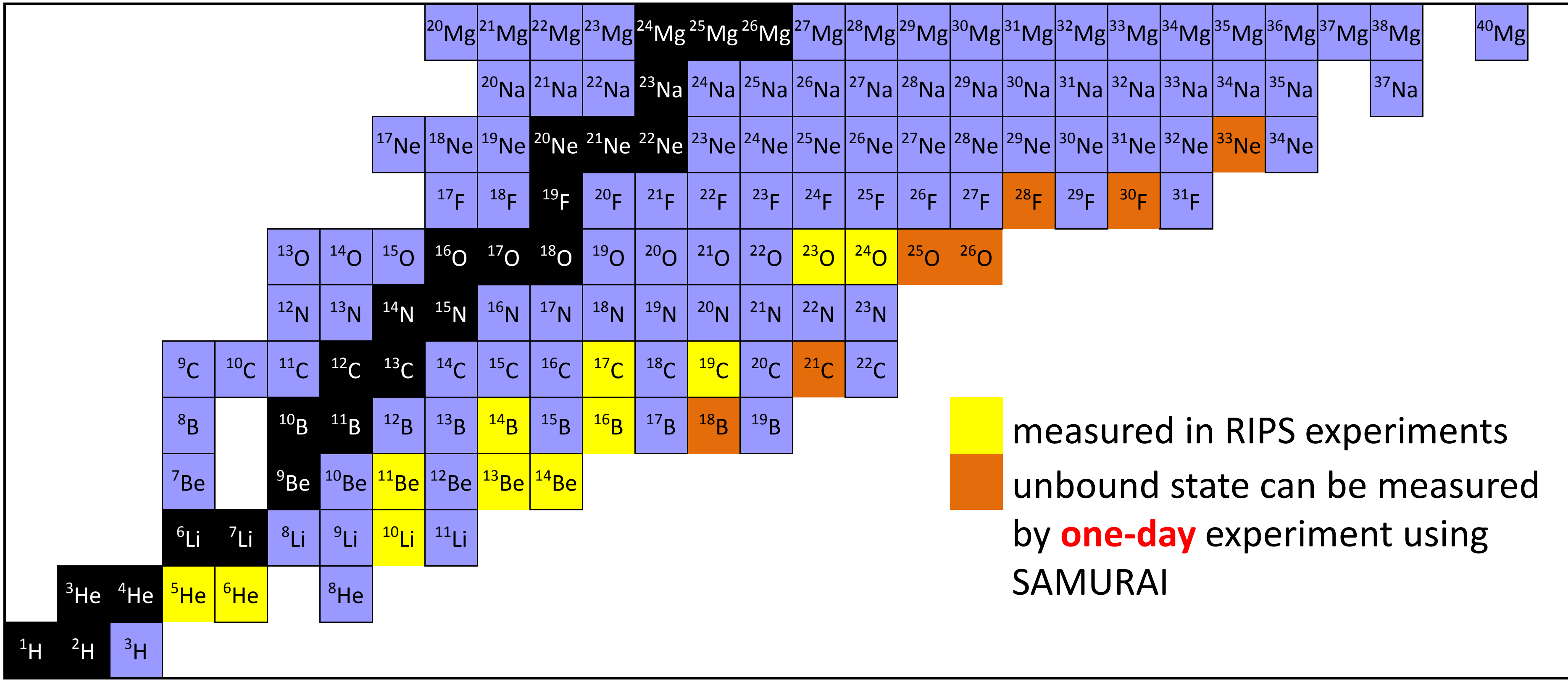


Invariant-mass spectroscopy of unbound states studied using RIPS



- Our spectroscopic studies of unbound states are limited to p-/sd-shell nuclei

Invariant-mass spectroscopy of unbound states studied using SAMURAI



- We can study more neutron-rich nuclei located beyond the drip line.

Summary

- Invariant-mass spectroscopy of unbound nuclei using SAMURAI
  - Shell evolution near/beyond neutron drip line
  - Borromean three body system
- Experimental setup
  - Same as the (γ,n) type experiment
- [illegible]
  - [illegible]
    - [illegible]