Invariant-mass spectroscopy of neutron-rich unbound nuclei using SAMURAI

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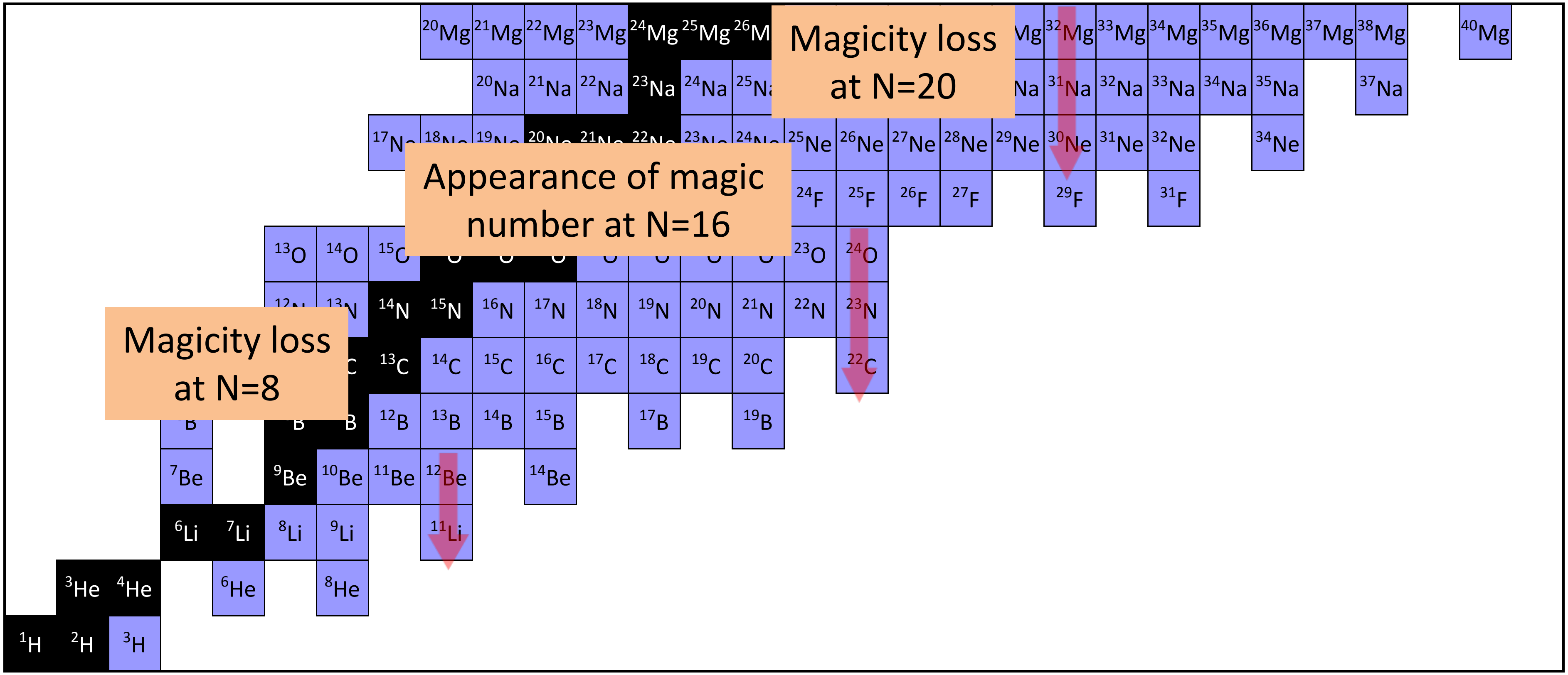
Contents

- Physics topics, etc… (general)
- Specific case (^{26}O and ^{27}O)
    - Candidate of the first experiment of SAMURAI

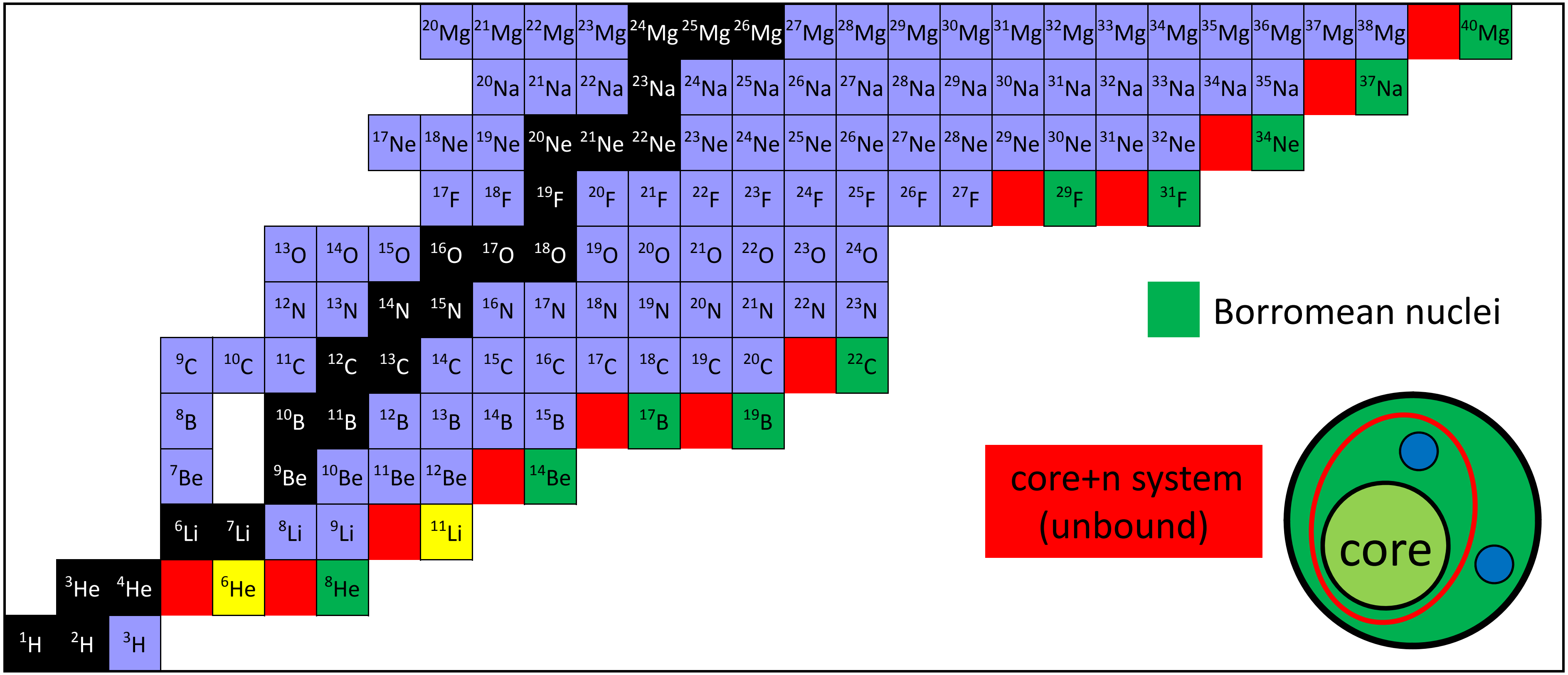
Shell evolution in extremely neutron-rich region



- 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>

Three body structure of Borromean nuclei



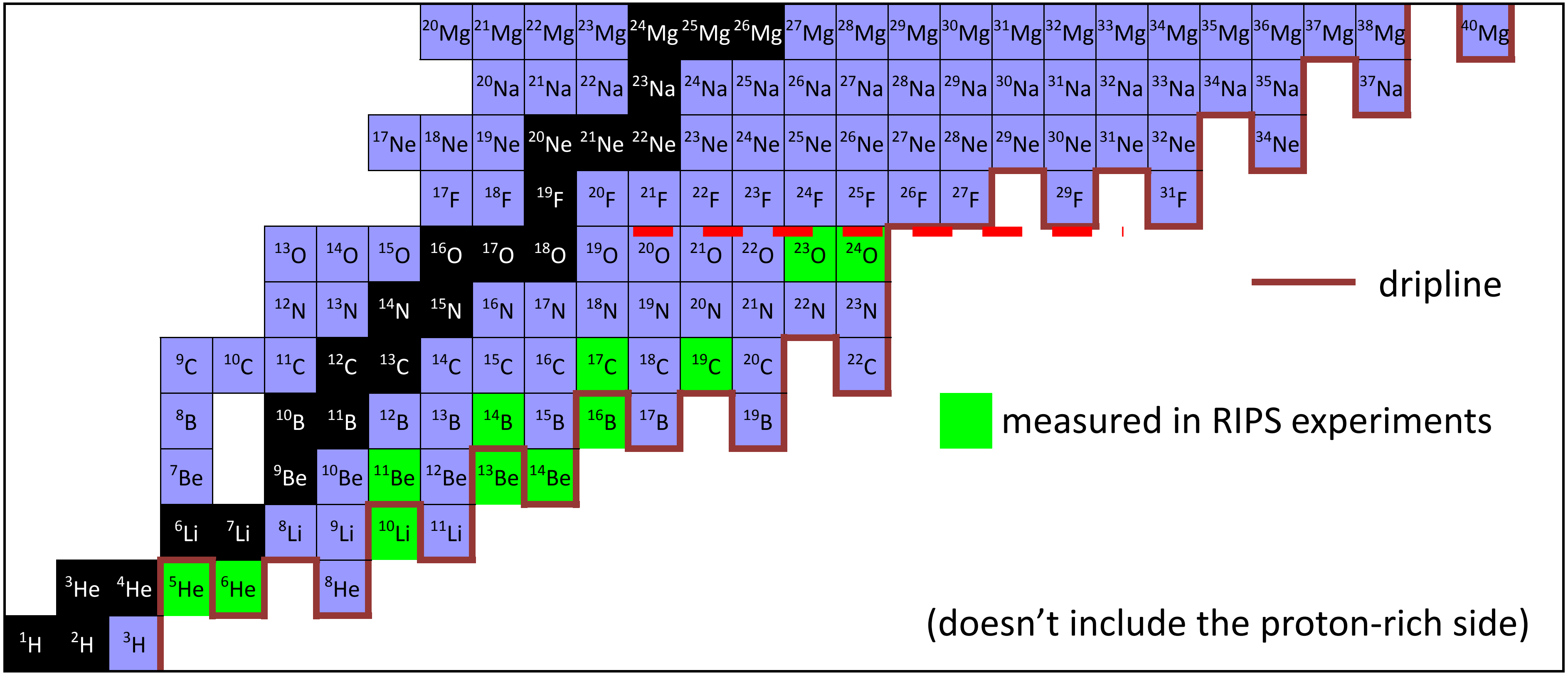
Borromean nuclei (^{6}He, ^{11}Li, …)

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

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

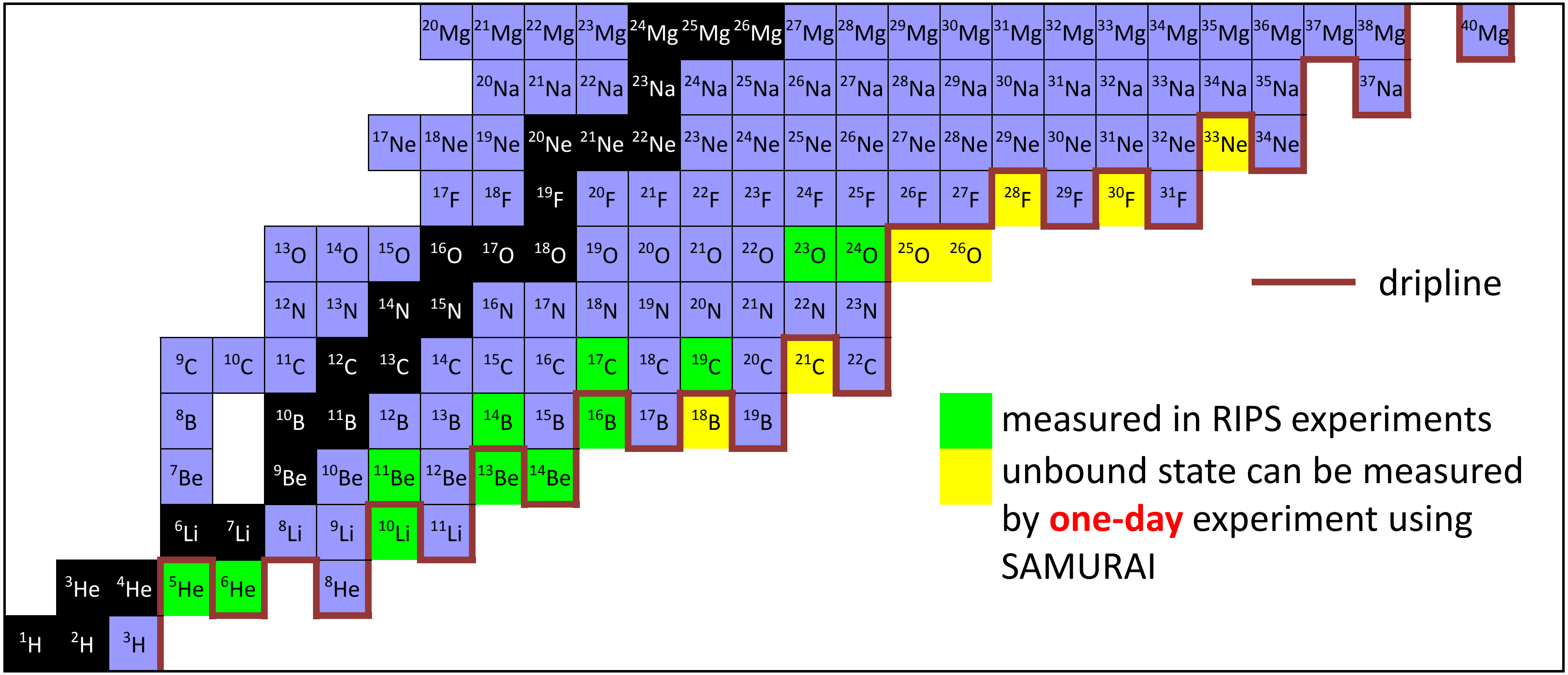
→ dB(E1)/dE of a Borromean nucleus + spectroscopy of core+n sub-system

Invariant-mass spectroscopy of unbound states studied using **RIPS**



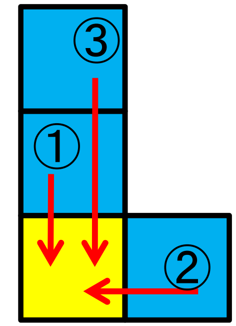
- Spectroscopic studies of unbound states were limited to p-/sd-shell nuclei

Invariant-mass spectroscopy of unbound states studied using **SAMURAI**



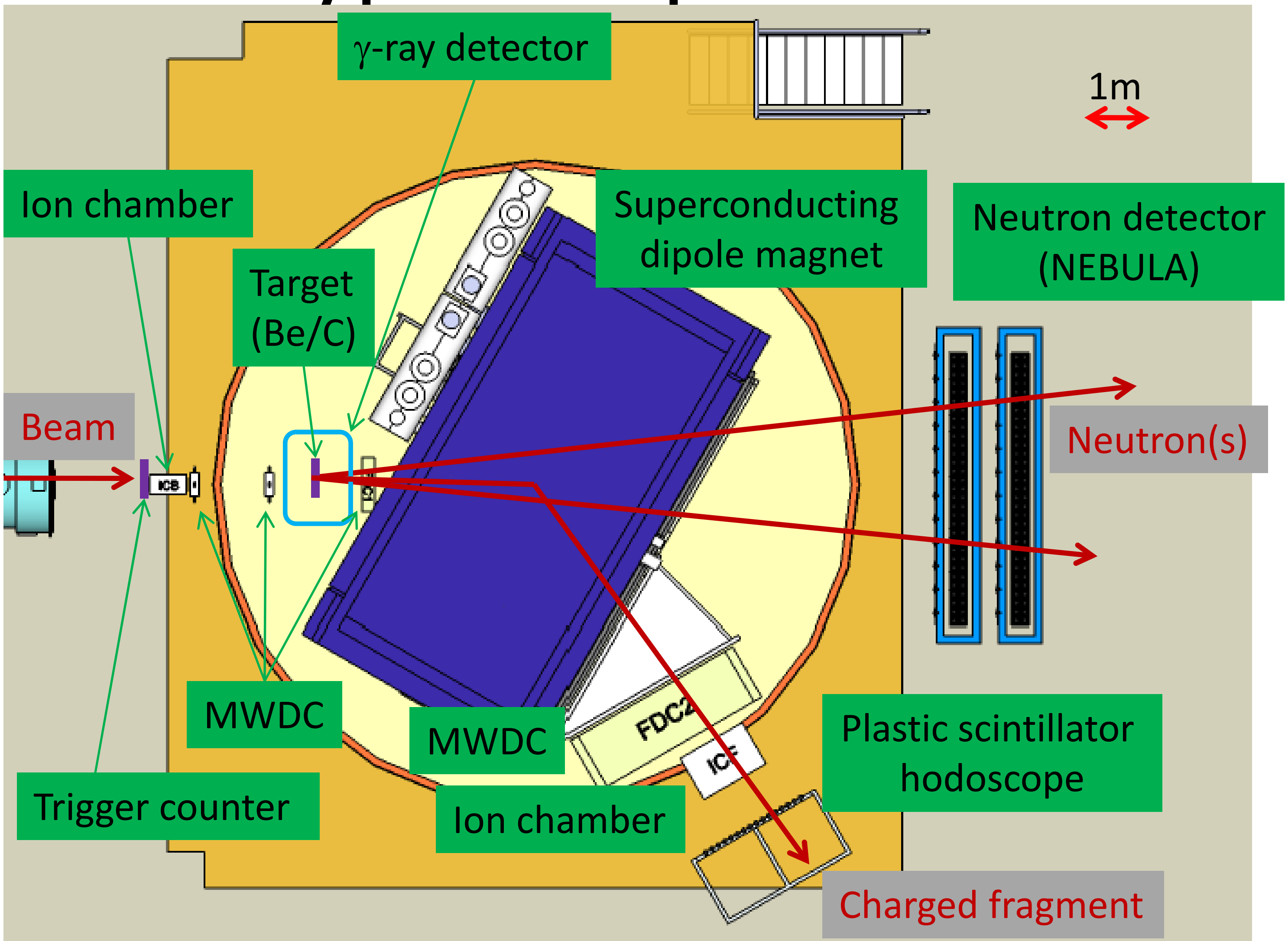
- We can access many unbound nuclei using SAMURAI+BigRIPS

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 2n decay following inelastic scattering of a beam nucleus
   - 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



Same as (γ,n) experiment

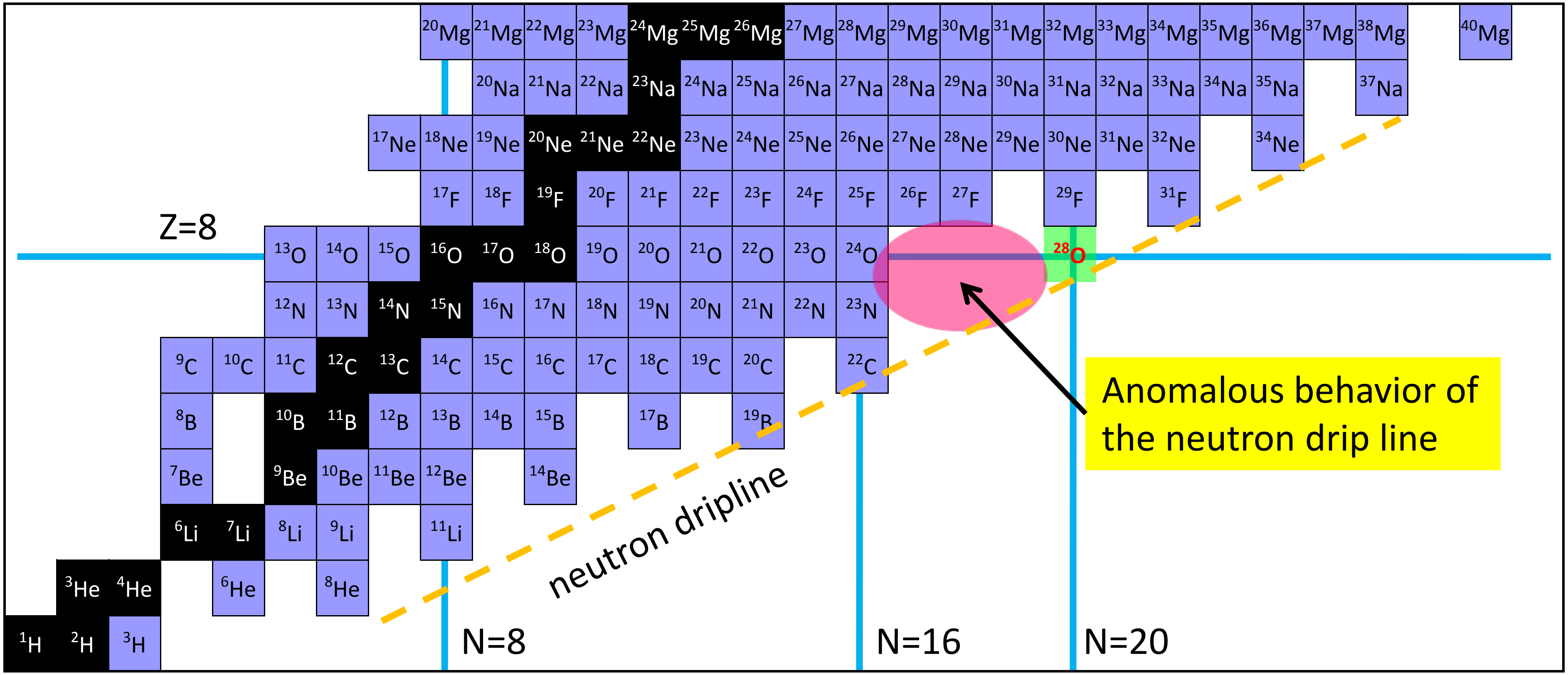
$$E_{rel} = \sqrt{\left(\sum E_i\right)^2 - \left(\sum \vec{p}_i\right)^2} - \sum M_i$$

Candidate of the first experiment at SAMURAI

Spectroscopy of the unbound nuclei

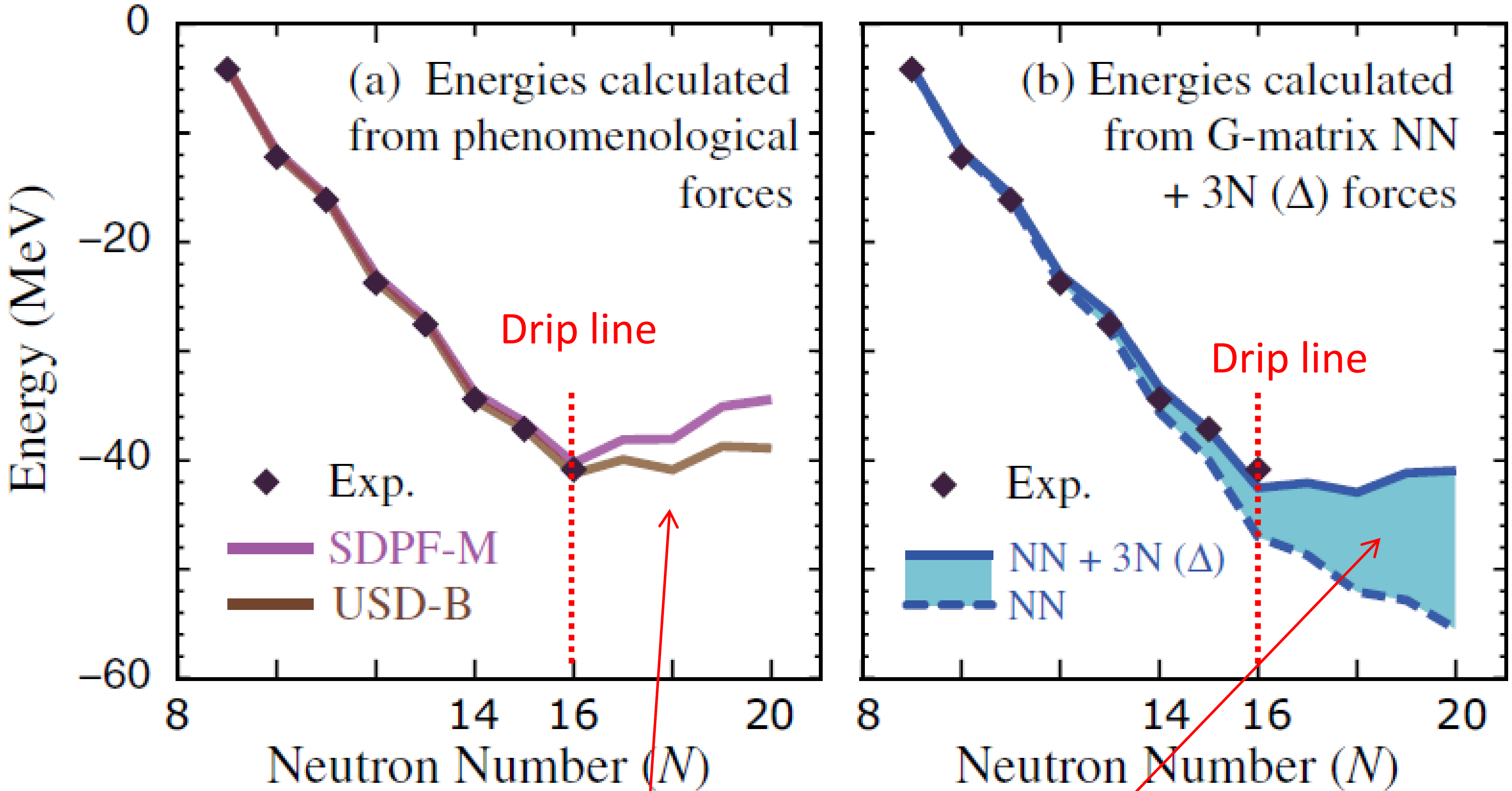
^{26}O and ^{27}O

Neutron drip line at Z=8



- Anomalous behavior of the neutron drip line at Z=8
  - N=16 (oxygen)
  - N=22 (fluorine)
- Shell evolution towards ^{28}O (Z=8, N=20)

Drip line is determined by …

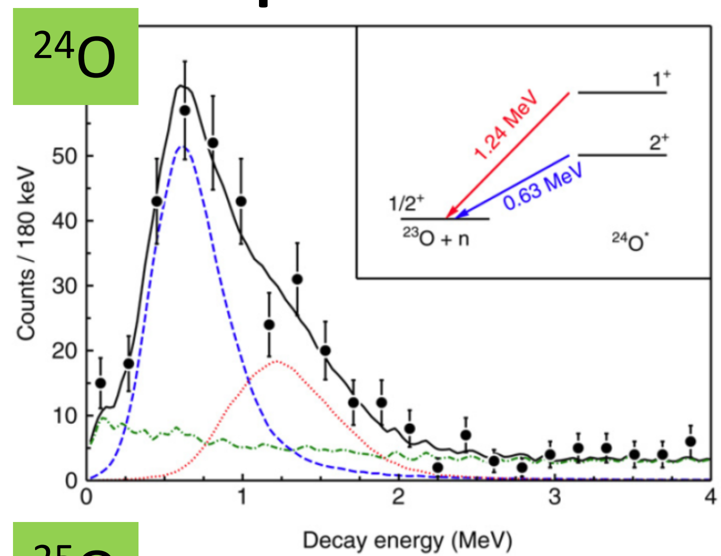


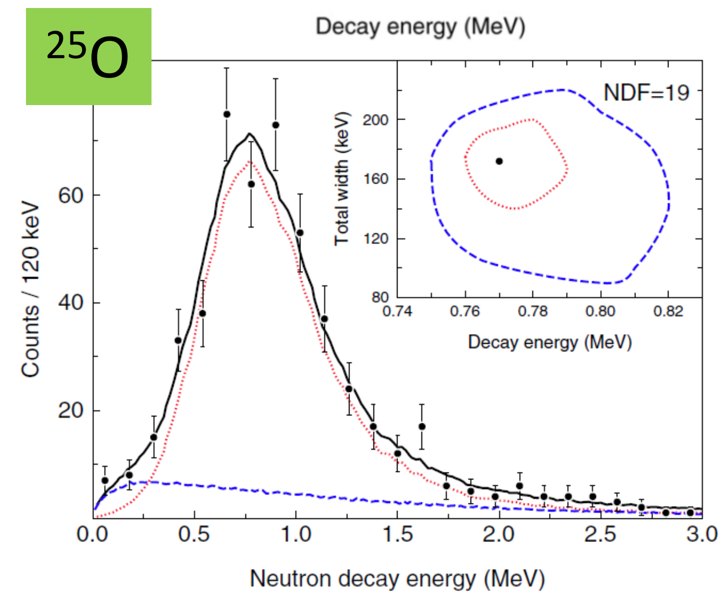
T. Otsuka et al., PRL105, 032501 (2010)

- The effect of is large at N>16

Situation of experimental studies for neutron-rich oxygen isotopes

- ^{24}O (N=16)
  - C.R.Hoffman et al.,PLB672, 17 (2009)
    - 2^+ (& 1^+?) state
    - total ~ 300 counts / ??hrs
- ^{25}O (N=17)
  - C.R.Hoffman et al., PRL100, 152502 (2008)
    - ground state ($3/2^+$?)
    - 20pps 26F
    - total ~ 400 counts / ??hrs
  - No information about its excited states
- ^{26}O (N=18)
  - No experimental information is available
  - experiment @ MSU?
    - 165hrs requested and approved (Mar 2008)
      - http://www.nscl.msu.edu/exp/approvedexp/31
    - statistics is probably poor?
- ^{27}O (N=19)
  - No experimental data





Search for the unbound states of ^{26}O and ^{27}O

Feasibility

- ^{26}O (^{28}Ne -2p→^{26}O→^{24}O+2n)
  - not only g.s. but also ex. state are expected to be populated
    - 7kpps ^{28}Ne beam (←EPAX2 correction factor is taken into account)
    - -2p cross section 0.1mb
    - Be target 2g/cm^2 http://www.nishina.riken.jp/UsersGuide/BigRIPS/intensity.html
    - 2n detection efficiency 10% (crosstalk cut is roughly considered)

  →800 counts/day (one-day experiment → first experiment?)
  - excited states of ^{25}O can also be studied

- ^{27}O (^{29}Ne -2p→^{27}O→^{24}O+3n)
    - 900pps ^{29}Ne beam (←EPAX2 correction factor is taken into account)
    - -2p cross section 0.1mb
    - Be target 2g/cm^2
    - 3n detection efficiency 6% (=0.4^3←doesn't include crosstalk cut)

  →70 counts/day (1week experiment? → second experiment?)

Considering Issues

- ^{26}O
  - Trigger rate
    Trigger=SBT ∩ (NEBULA OR)
    - One solution is to use the $^{27}F \rightarrow ^{26}O$ reaction (-1p reaction)
      - Total rate becomes 1/10 → feasible
      - May lose possibility of observation of the 2^+ state

  → Realistic total beam rate should be estimated

  → Further optimization of BigRIPS setting is needed to gain purity in the LISE++ calc.

- ^{27}O
  - Realistic 3n detection efficiency including crosstalk rejection should be estimated
  - How many counts do we need to identify a resonance?
    - Wide resonance width → high statistics is needed
    - background

Summary

- Invariant-mass spectroscopy of unbound nuclei using SAMURAI
  - Shell evolution near/beyond neutron drip line
  - Borromean three body system

- Plan to submit a proposal for the $^{26,27}O$ experiment at the next PAC meeting (June)
  - Further estimation Should be done
    - ^{26}O
      - Total beam rate
    - ^{27}O
      - 3n detection efficiency
      - Estimation (prediction) of the resonance width