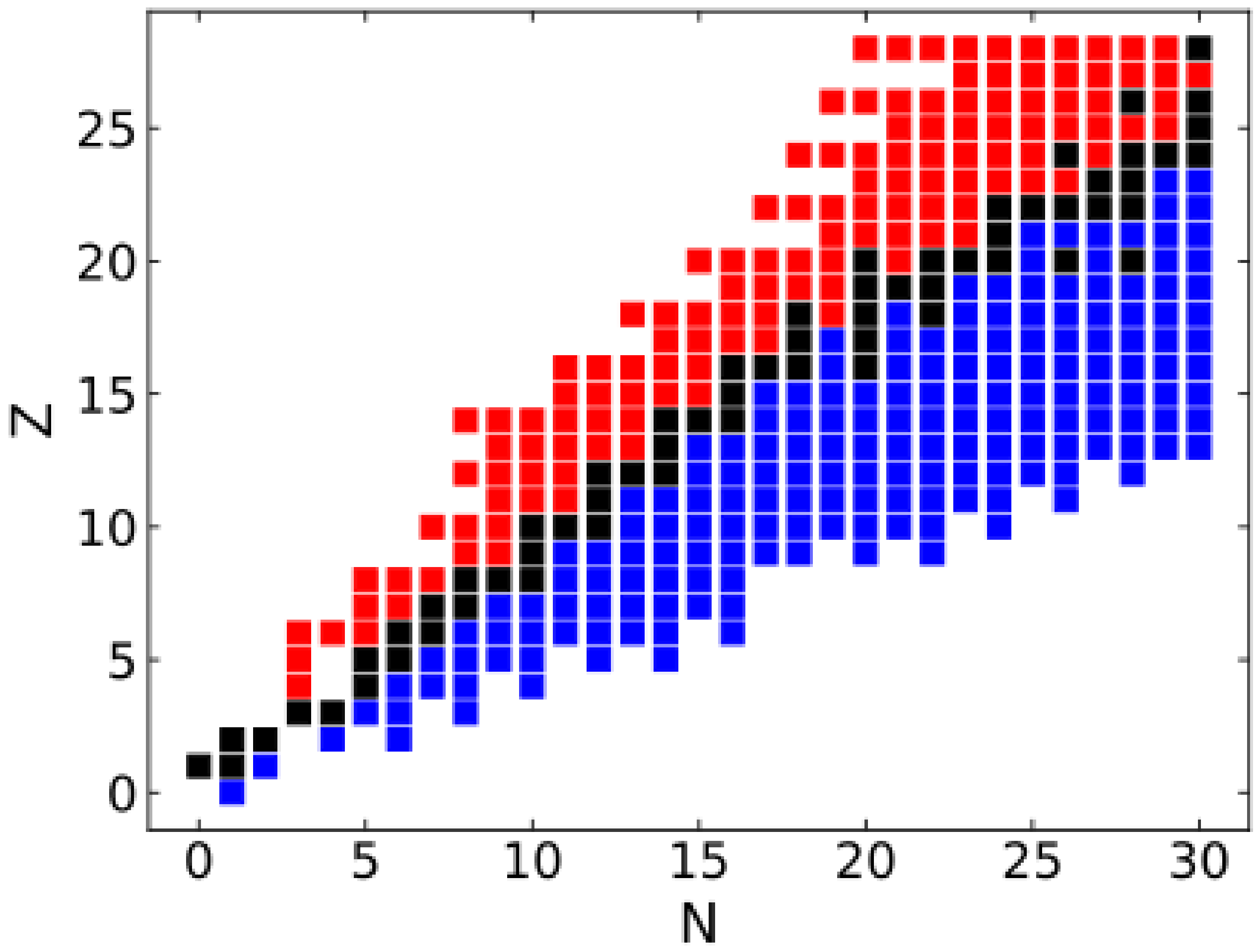
Beta-decays in (exotic) light nuclei

K. Riisager

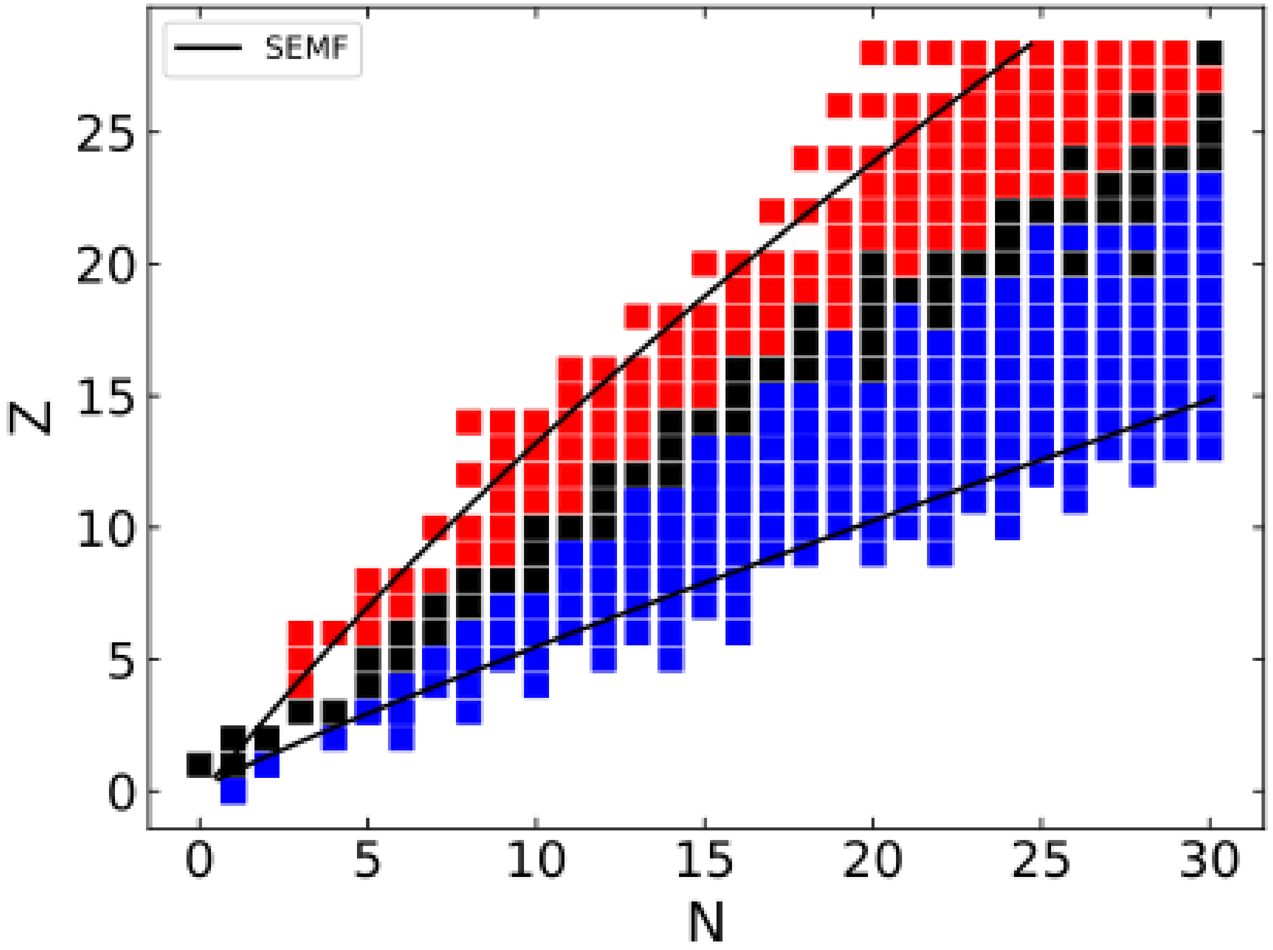
Dept. of Physics and Astronomy

Aarhus University / Denmark

Light particle-stable nuclei



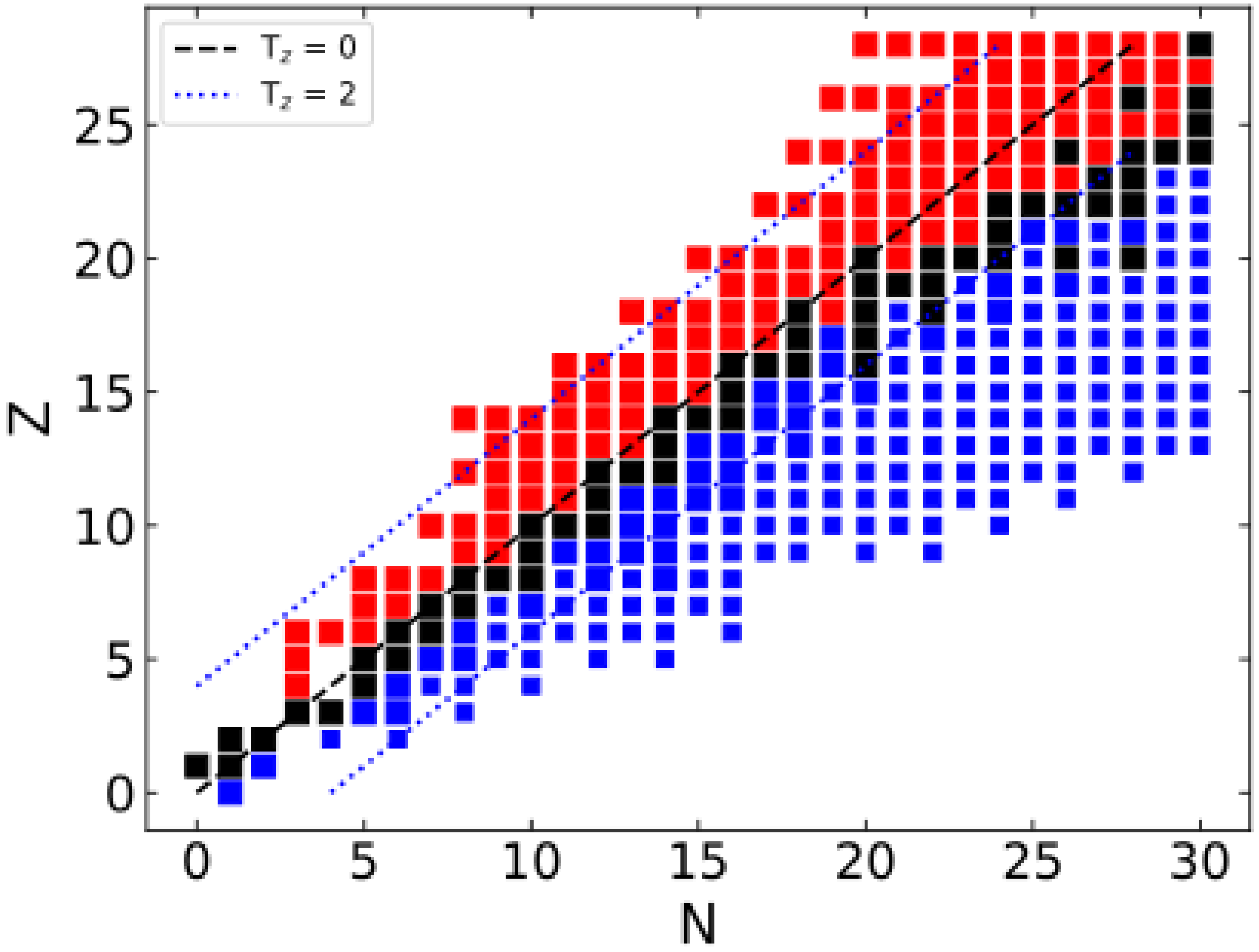
Light nuclei, driplines



Collective dofs

Driplines estimated from semiempirical mass formula without pairing

Light nuclei, driplines

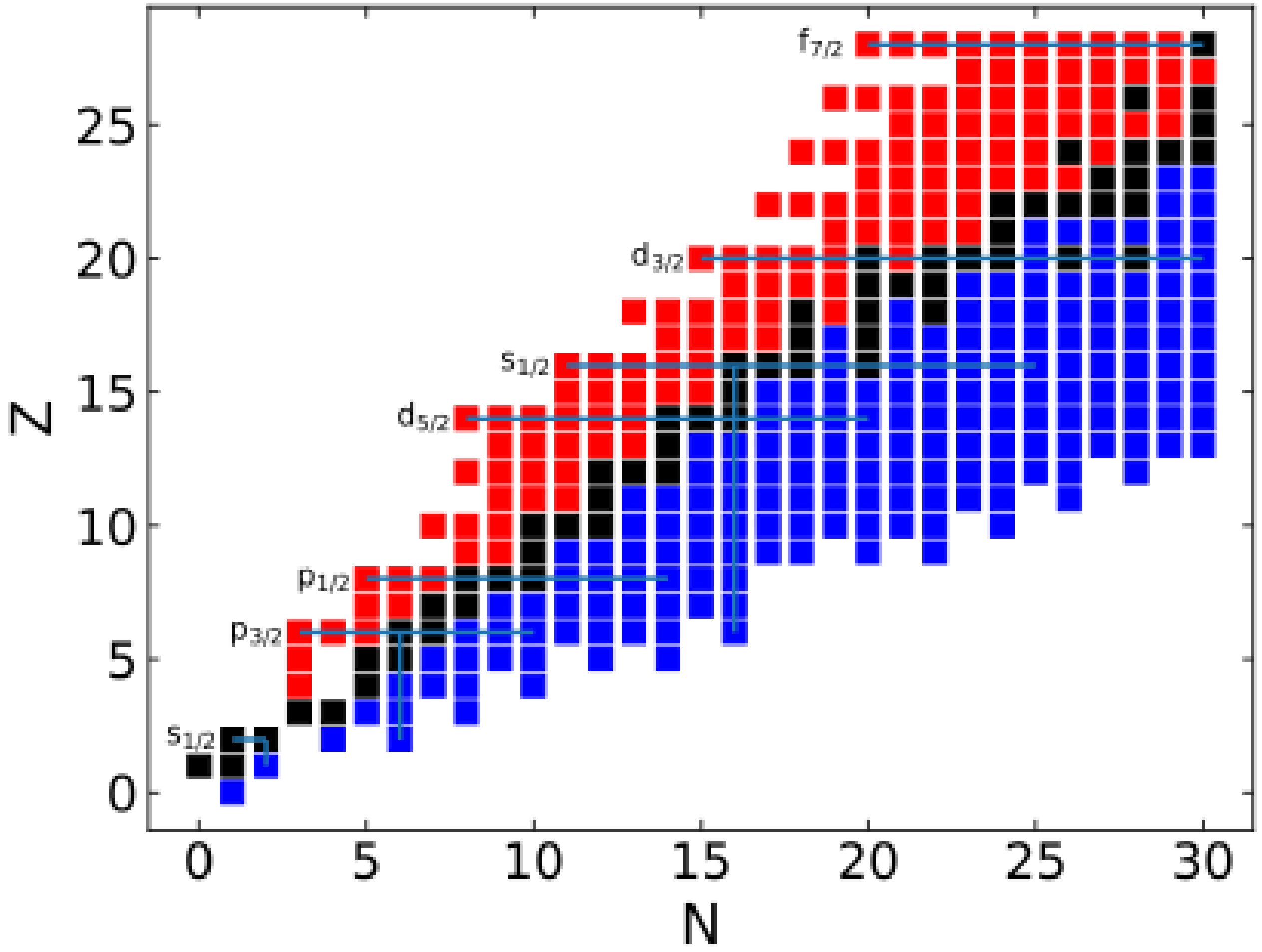


Collective dofs

Isospin important dof

Smaller symbol =
no (stable) mirror nucleus

Light nuclei, driplines

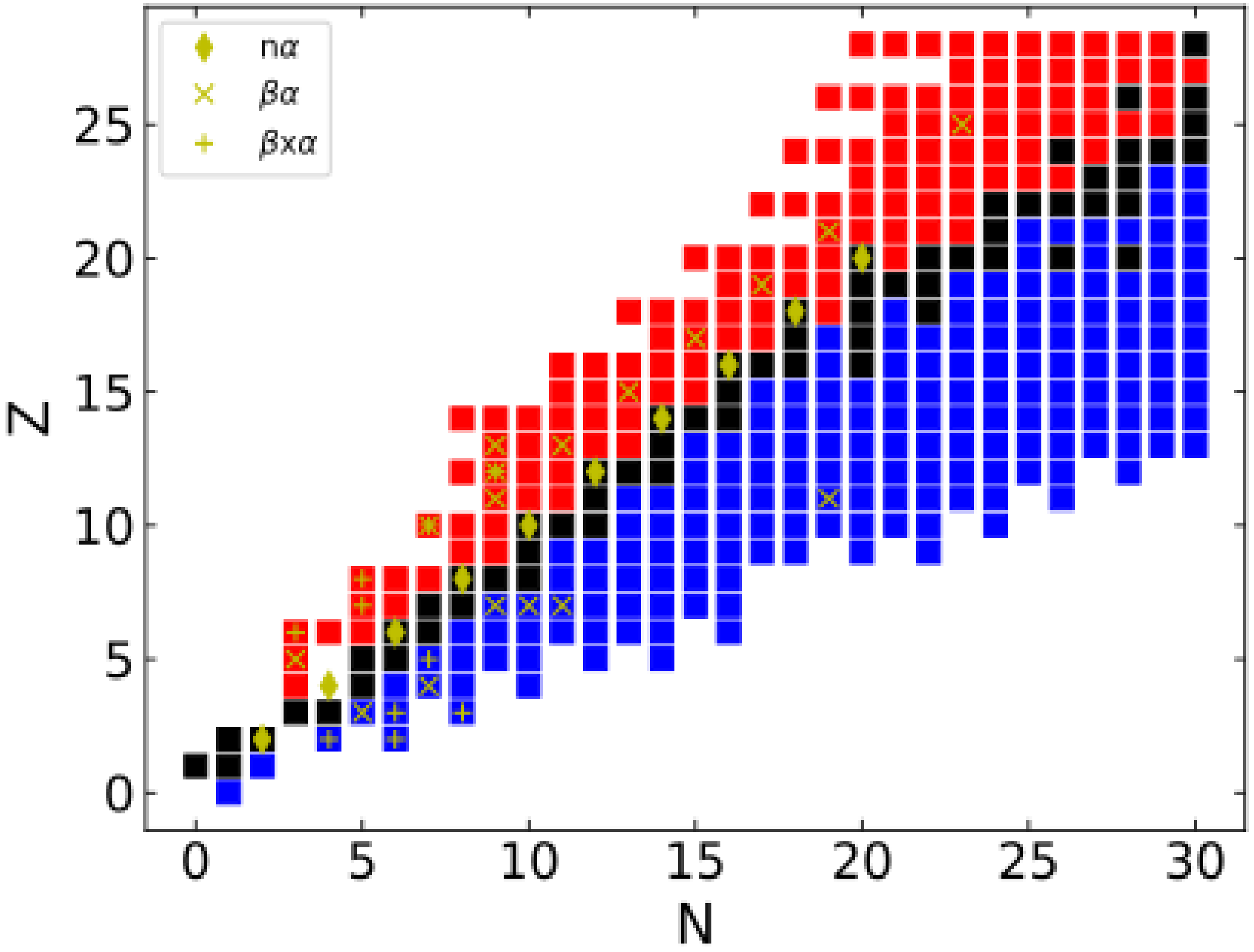


Single-particle dofs

Shell model orbits

p-rich: “standard” shells
n-rich: “modified” shells

Light nuclei



Clustering dofs

n alpha nuclei (?)
(Deformation…)

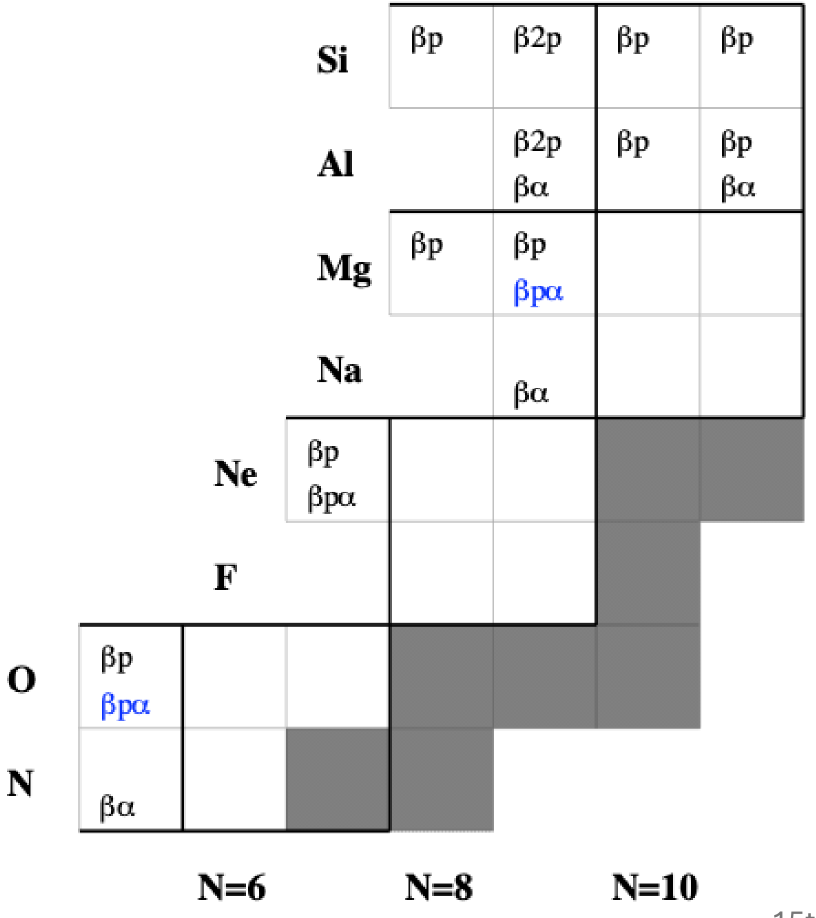
Favoured decay modes
(nuclear astro-interest)

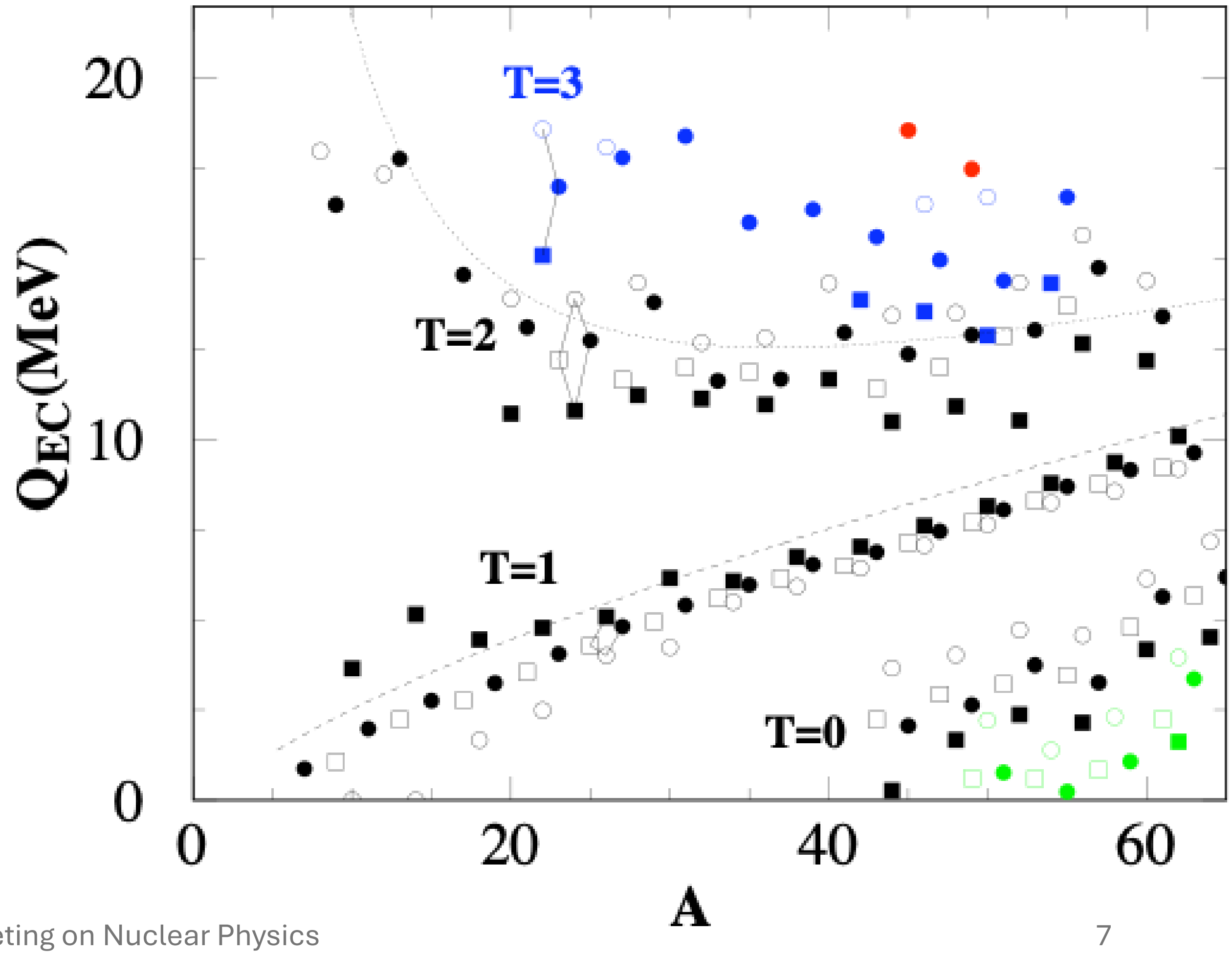
Q_{EC}-value systematics

	N	N+1
Z	e-e T	e-o T-1/2
Z-1	o-e T-1/2	o-o T-1

β3p	βp	βp βpα
β2p		βα

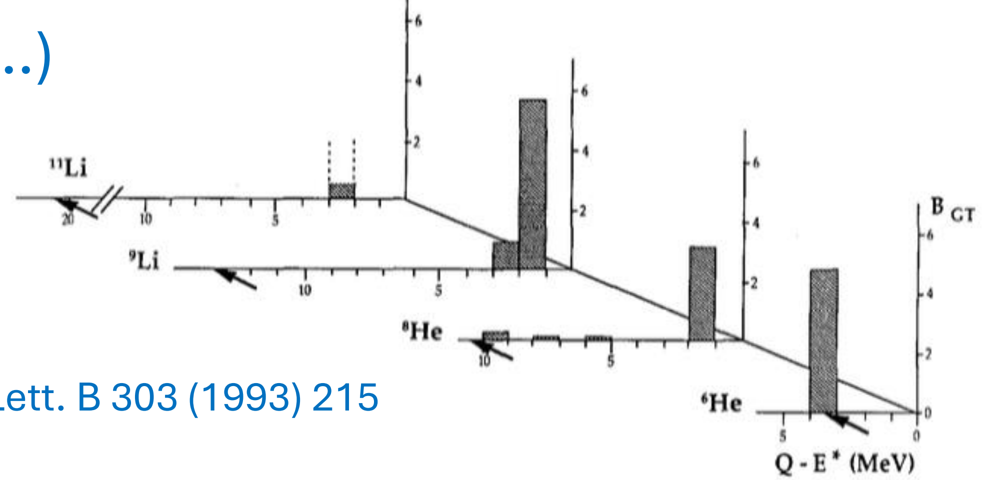
M.V. Lund et al, Phys. Lett. B 750 (2015) 356-359





Fermi and Gamow-Teller decays

- Theory: W exchange → V-A theory → F/GT transitions $F_\pm = \sum_i t^i_\pm = T_\pm\ ,\ GT_\pm = \sum_i \sigma^i t^i_\pm$
- **F** transitions: inside T-multiplets / to IAS (only for p-rich nuclei)
- **GT** transitions: mainly to GTGR (above IAS…)
  - So all "low-energy" decays are in the tail
  - Visible in very proton-rich nuclei
  - Visible for some very light neutron-rich nuclei
    - Exp: M.J.G. Borge et al, Z. Phys. A 340 (1991) 255
    - Theory: H. Sagawa, I. Hamamoto, M. Ishihara, Phys. Lett. B 303 (1993) 215



- **Sum rules:**

$$\sum_j B(F)^-_j - \sum_k B(F)^+_k = N - Z\ ,\ \sum_j B(GT)^-_j - \sum_k B(GT)^+_k = 3(N-Z)\ .$$

Precision (weak interaction) studies

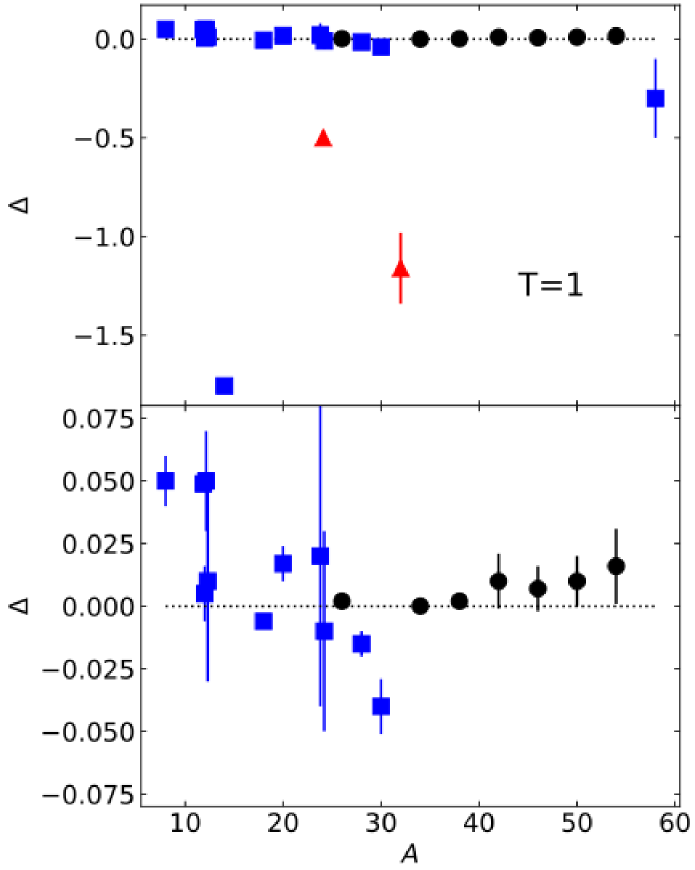
- CVC, 0^+ to 0^+ (Hardy and Towner, + many groups) … now also mixed F-GT

- Types of weak interaction (Vector - Scalar, Axial vector - Tensor - Pseudoscalar)
  - Examples: ^{6}He, ^{8}Li-^{8}B, ^{12}B-^{12}C-^{12}N, ^{32}Ar, ^{35}Ar

- Breaking of isospin symmetry
  - Charge symmetry breaking strong interactions ?
  - Coulomb effects
  - Weak second class currents ?
  - so far mainly binding energy effects

Mirror beta decays

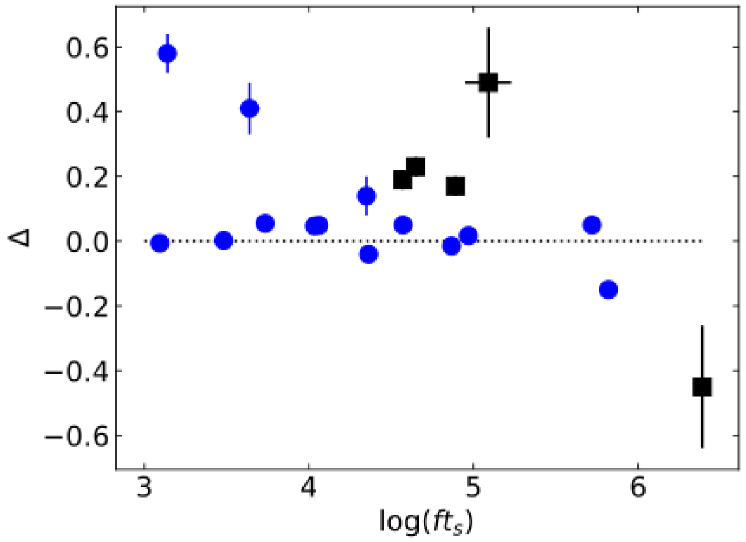
- My recent review (EPJA 59:35 (2023)) uses $\Delta = \log(\mathrm{ft})_+ - \log(\mathrm{ft})_- = \log\left(\frac{\mathrm{ft}_+}{\mathrm{ft}_-}\right)$

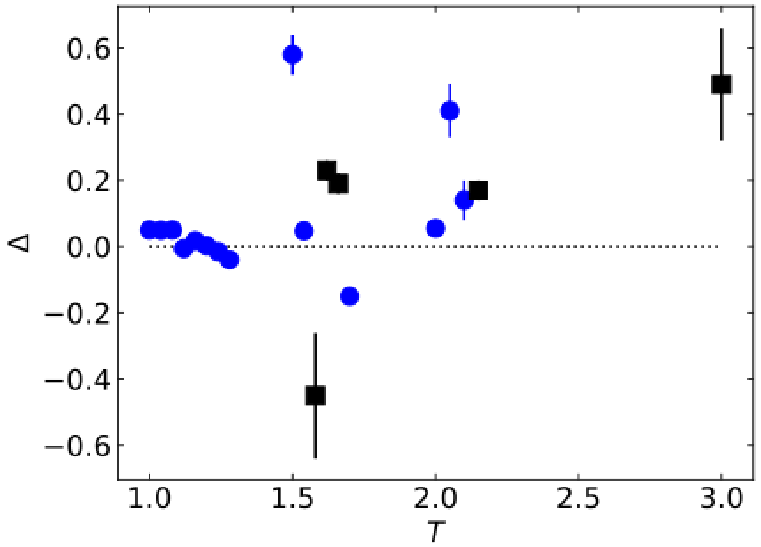


Black circles: 0⁺ to 0⁺ - red triangle: systematic uncertainties ?

Recurrent "explanations" for the long halflife of ^{14}C (log ft = 7.3 / 9.0)

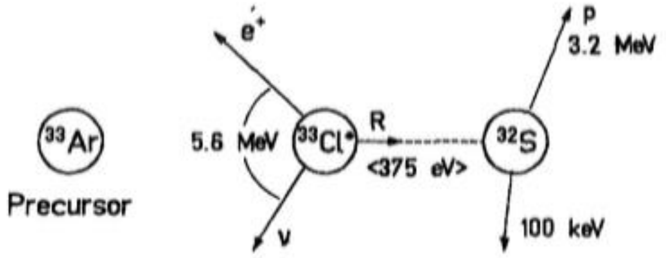
More than 2 standard deviations (black squares: proton halos ?):

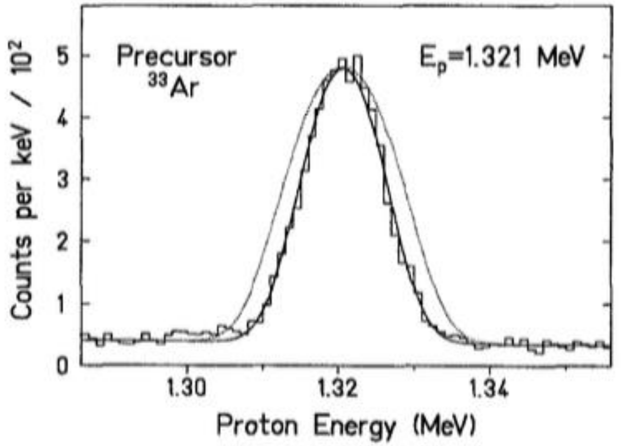




Spectroscopy interlude 1 – recoil effects etc

- Developped 1958 for weak interaction studies in A=8 nuclei
- Now supplement to standard selection rules / coincidences
- Basic formalism e.g. D. Schardt, KR, Z. Phys. A 345 (1993) 265
- Lineshape sensitive to
  - F / GT etc structure
  - Spin sequence (initial/intermediate)
  - Particle emission to gs/excited state
  - Intrinsic widths
  - Interference ....



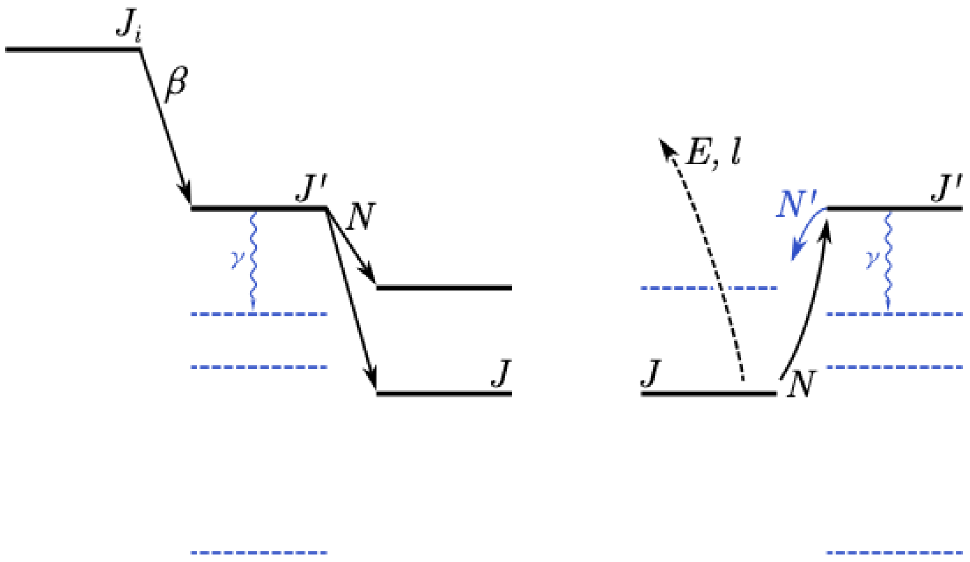


^{31}Ar spin: PLB 467 (1999) 194

See also Maria Jose Garcia Borge, today

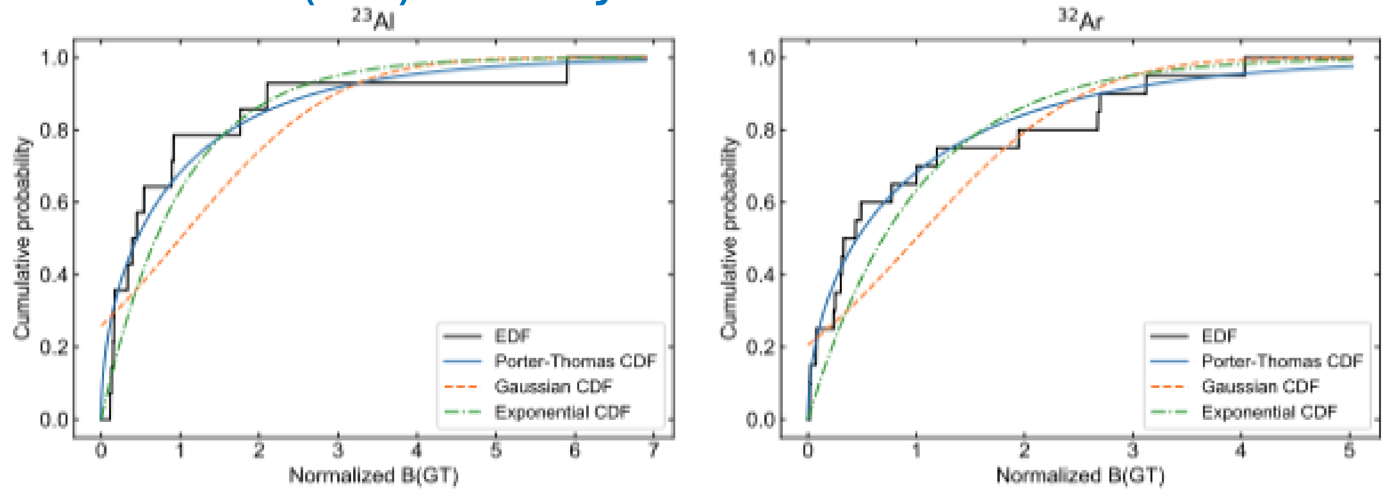
Spectroscopy interlude 2 - deformation

- Selection rules in K for beta-delayed particle emission in deformed nuclei
- Formalism, applied to ^{21}Mg decay: KR, EAM Jensen, AS Jensen, EPJA 61:87 (2025)
- Similar info. as in transfer reactions
- Assigned both K and J values



Spectroscopy interlude 3 – chaos ?

- Are the strengths of GT transition described by Random Matrix Theory ?
- Method and use on ^{23}Al data: O.S. Kirsebom et al, EPJ A47 (2011) 130
- Katrine Jensen (AU): analysis of ^{32}Ar data in B. Blank et al, EPJ A57 (2021) 28



(a) (b)

Figure 2: The EDFs of the two datasets plotted against the cdfs of the PT, Gaussian and exponential distributions used for the EDF tests.

Beta-delayed multi-particle emission

- Both sequential and simultaneous emission now possible
- Classic example: ^{12}B or ^{12}N decay to 3α final state

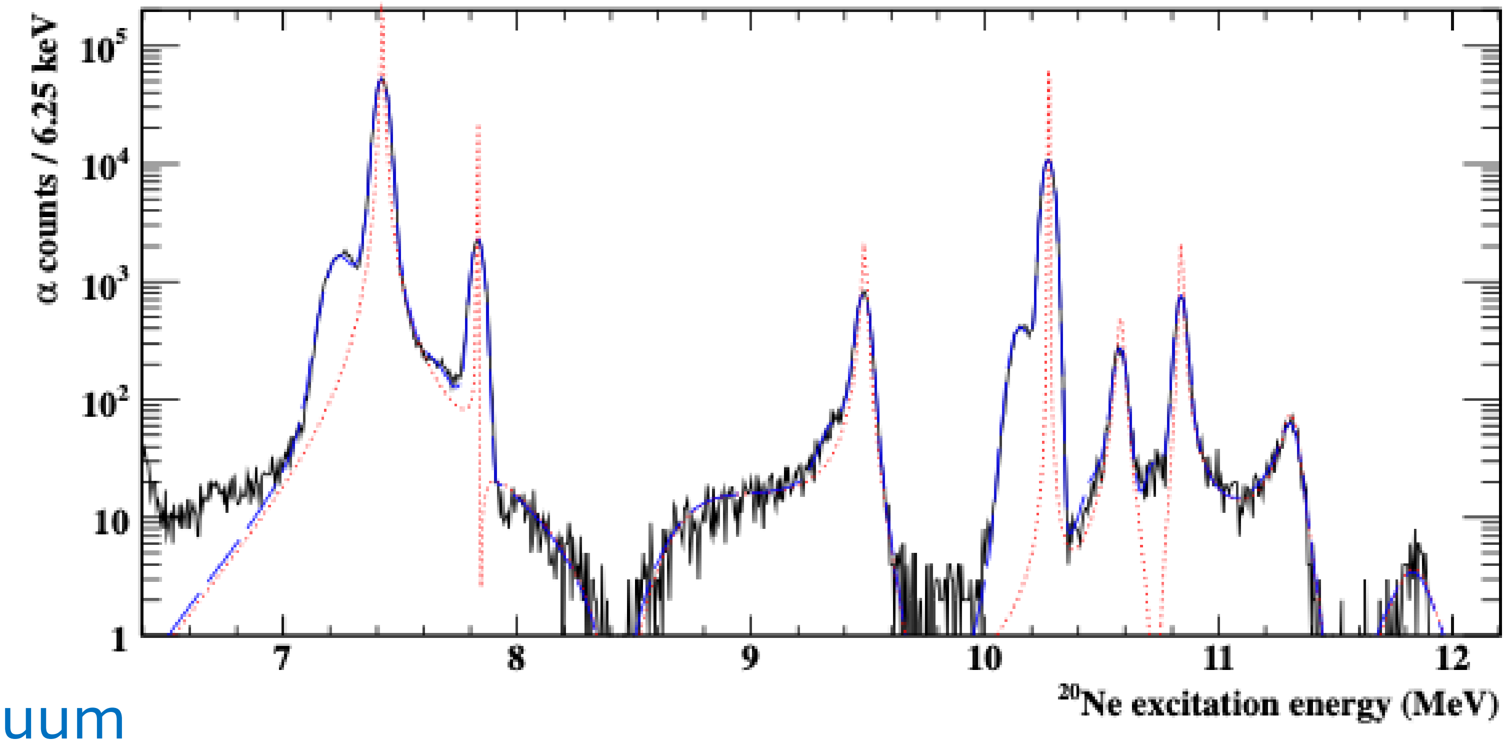
- Other possibilities: beta-2N, beta-3N, beta-Nα (^{11}Li: beta-3n2α!)
- 2p: here ^{31}Ar the best studied case for a long time (ISOLDE)
  - New results from FRIB Erik Jensen, Friday

- 3p: TPC detectors an efficient way to move forward

Broad final states

^{20}Na decay, K.L. Laursen et al, EPJA 49:79 (2013)

- Broad states may interfere:
- Theory: R-matrix
- Very broad states in
  - A=8, 12; ^{20}Na decay
- Heavily distorted…

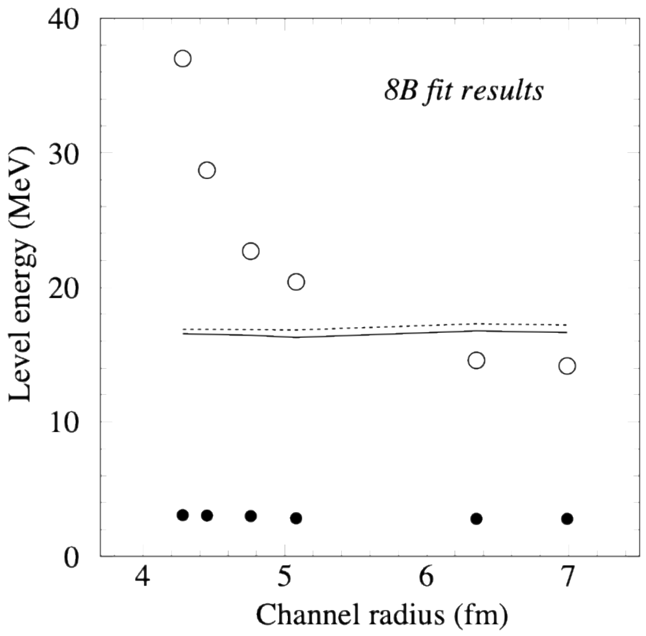


- ^{8}He Jeppe S. Nielsen, today

- Use beta strength in continuum to ensure sum rules still hold (KR, NPA 925 (2014) 112, 298)

Decays directly into continuum states ?

- A very broad resonance becomes ”context dependent”
- Radiative capture/break-up can go between bound and continuum states
- So may beta decay, details in KR et al, Nucl. Phys. A 940 (2015) 119



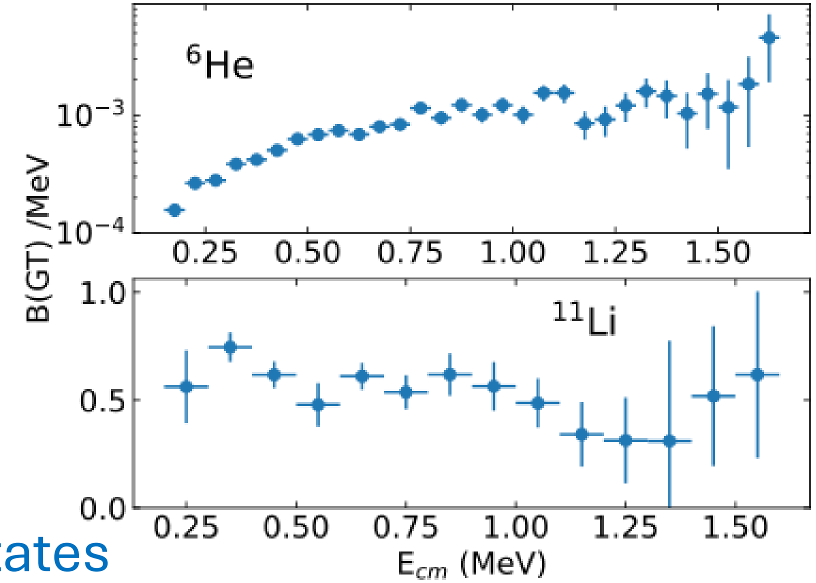
- Indications via R-matrix fits:
  - Vary the channel radius parameter
  - “standard resonances” should be stable
  - “changing position” fits with “particle in well”…
  - (pure continuum can be fitted with R-matrix levels)

Halo states

- Several reviews in section V of *Handbook of Nuclear Physics*, eds. I. Tanihata et al (Springer, 2023) – my chapter on beta decay p. 1057-80

Example of 2+3: beta-delayed deuteron emission from 2n-halo

$$Q_{\beta d} = 3007\,\mathrm{keV} - S_{2n}$$

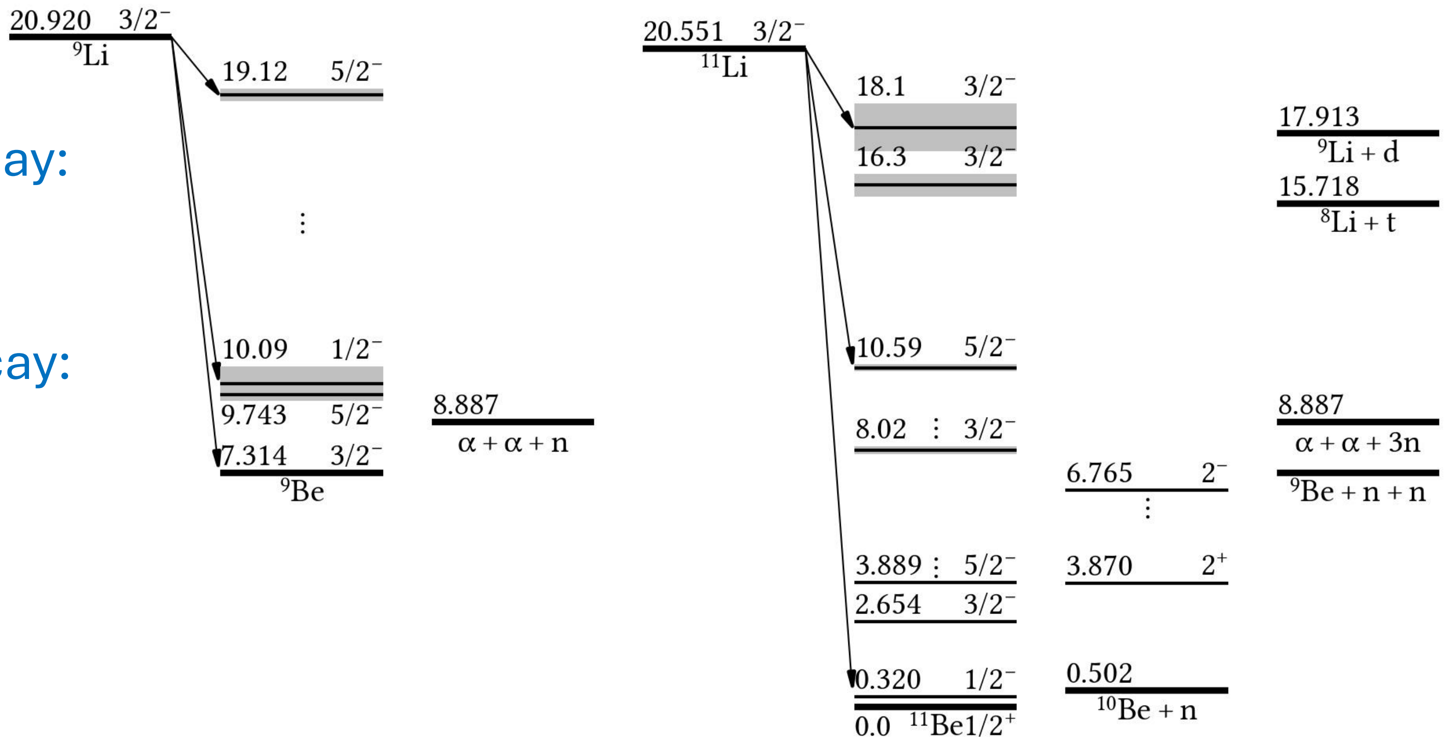


1. Beta-delayed particle emission prominent
2. Core+halo cluster structure can be reflected in final states
3. Large spatial extension may give decays directly to continuum
4. Beta decay can yield info. on detailed halo state structure

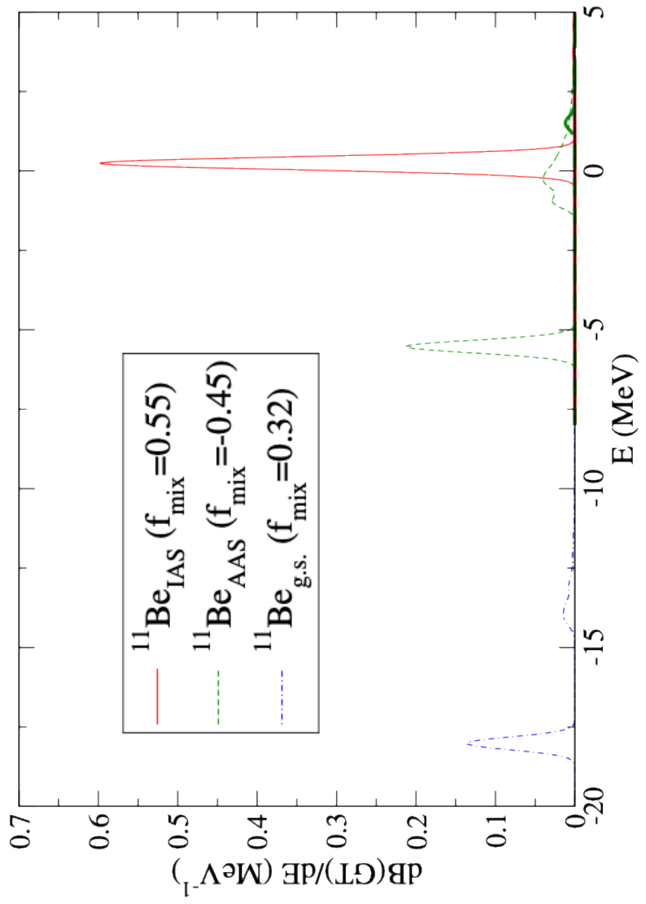
Three-body calculation of ^{11}Li beta decay

- E. Garrido et al, Phys. Rev. C 107, 014003 (2023)

- Halo decay:
  - IAS
  - AAS
- Core decay:
  - g.s.



Predicted GT strength



Outlook

- Beta decays a few nucleons away from the line of beta stability provides nuclear structure information beyond the standard selection rules (for beta and gamma decays)

- Beta-delayed particle emission processes:
  - So far mainly probed in detail for proton-rich nuclei
  - Neutron-rich nuclei will be interesting to study
  - Current limitations in production yields and neutron detection capabilities