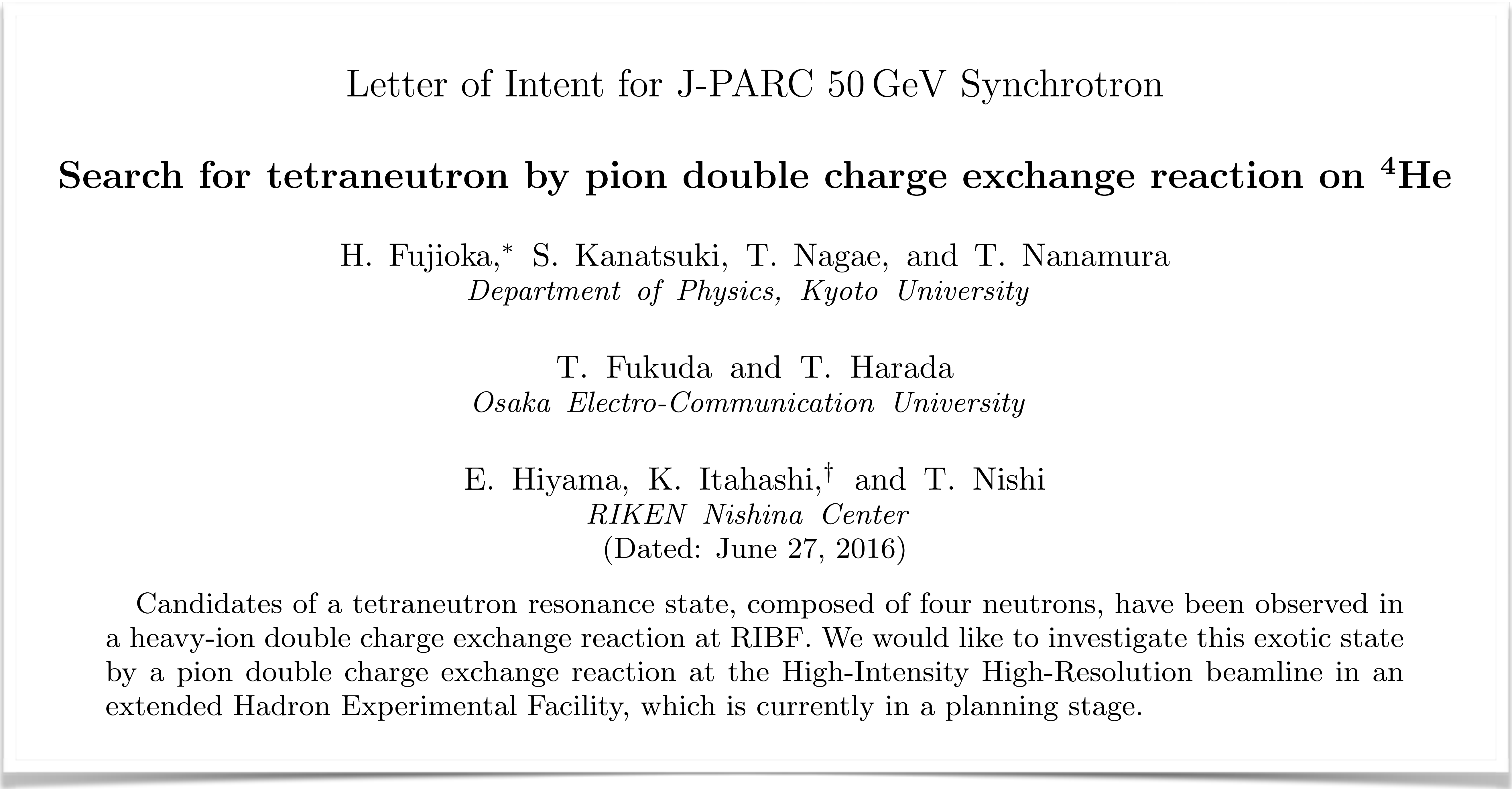
Search for tetraneutron by pion double charge exchange reaction at J-PARC

Hiroyuki Fujioka (Kyoto U.)

today's talk based on …


Letter of Intent for J-PARC 50 GeV Synchrotron

Search for tetraneutron by pion double charge exchange reaction on ^{4}He

H. Fujioka,* S. Kanatsuki, T. Nagae, and T. Nanamura
Department of Physics, Kyoto University

T. Fukuda and T. Harada
Osaka Electro-Communication University

E. Hiyama, K. Itahashi,† and T. Nishi
RIKEN Nishina Center
(Dated: June 27, 2016)

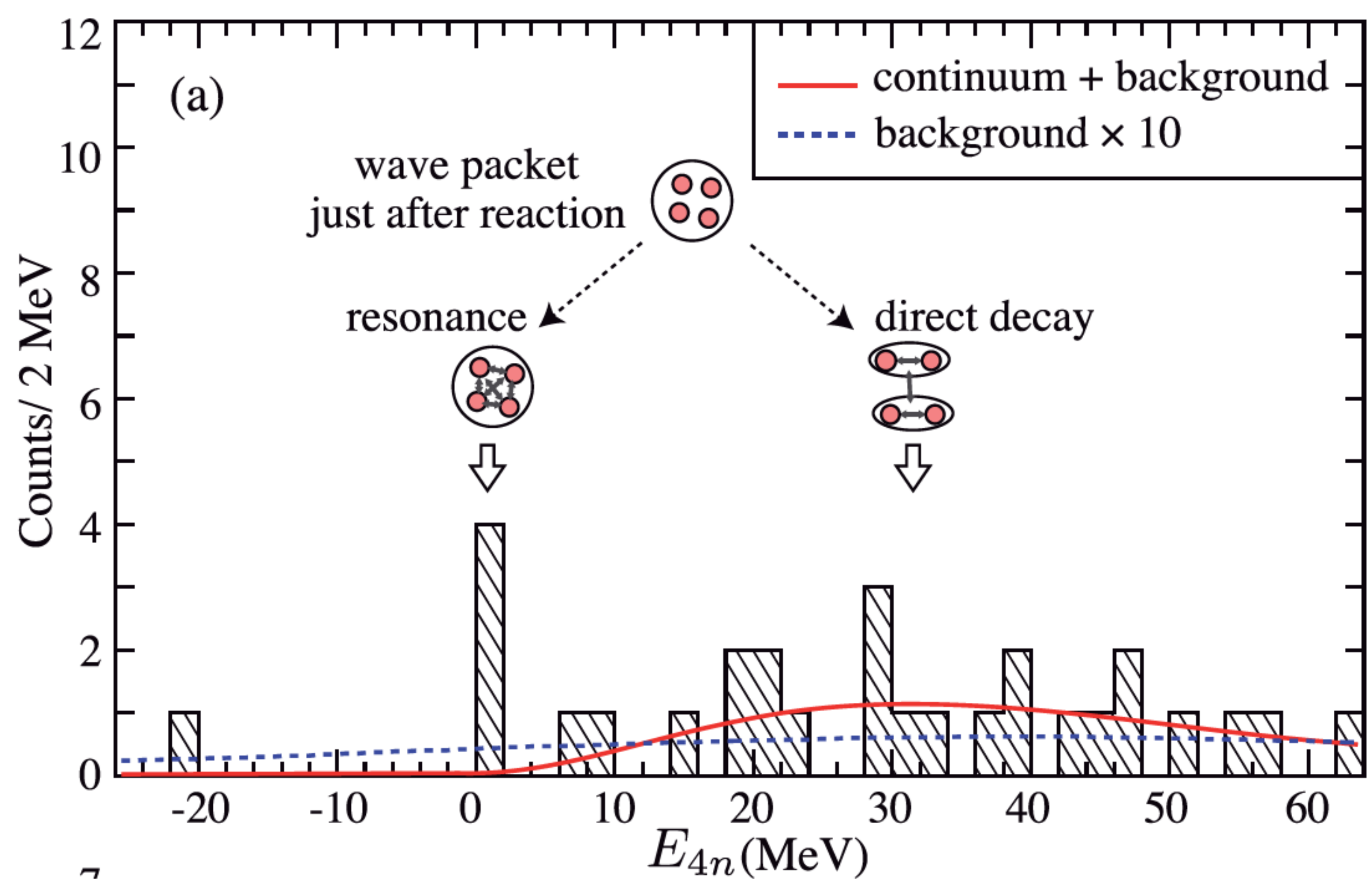
Candidates of a tetraneutron resonance state, composed of four neutrons, have been observed in a heavy-ion double charge exchange reaction at RIBF. We would like to investigate this exotic state by a pion double charge exchange reaction at the High-Intensity High-Resolution beamline in an extended Hadron Experimental Facility, which is currently in a planning stage.

Selected for a Viewpoint in *Physics*

PRL **116,** 052501 (2016) PHYSICAL REVIEW LETTERS week ending 5 FEBRUARY 2016

Candidate Resonant Tetraneutron State Populated by the ^{4}He(^{8}He,^{8}Be) Reaction

K. Kisamori,[1,2] S. Shimoura,[1] H. Miya,[1,2] S. Michimasa,[1] S. Ota,[1] M. Assie,[3] H. Baba,[2] T. Baba,[4] D. Beaumel,[2,3] M. Dozono,[2] T. Fujii,[1,2] N. Fukuda,[2] S. Go,[1,2] F. Hammache,[3] E. Ideguchi,[5] N. Inabe,[2] M. Itoh,[6] D. Kameda,[2] S. Kawase,[1] T. Kawabata,[4] M. Kobayashi,[1] Y. Kondo,[7,2] T. Kubo,[2] Y. Kubota,[1,2] M. Kurata-Nishimura,[2] C. S. Lee,[1,2] Y. Maeda,[8] H. Matsubara,[12] K. Miki,[5] T. Nishi,[9,2] S. Noji,[10] S. Sakaguchi,[11,2] H. Sakai,[2] Y. Sasamoto,[1] M. Sasano,[2] H. Sato,[2] Y. Shimizu,[2] A. Stolz,[10] H. Suzuki,[2] M. Takaki,[1] H. Takeda,[2] S. Takeuchi,[2] A. Tamii,[5] L. Tang,[1] H. Tokieda,[1] M. Tsumura,[4] T. Uesaka,[2] K. Yako,[1] Y. Yanagisawa,[2] R. Yokoyama,[1] and K. Yoshida[2]



motivated by …

Selected for a Viewpoint in *Physics*

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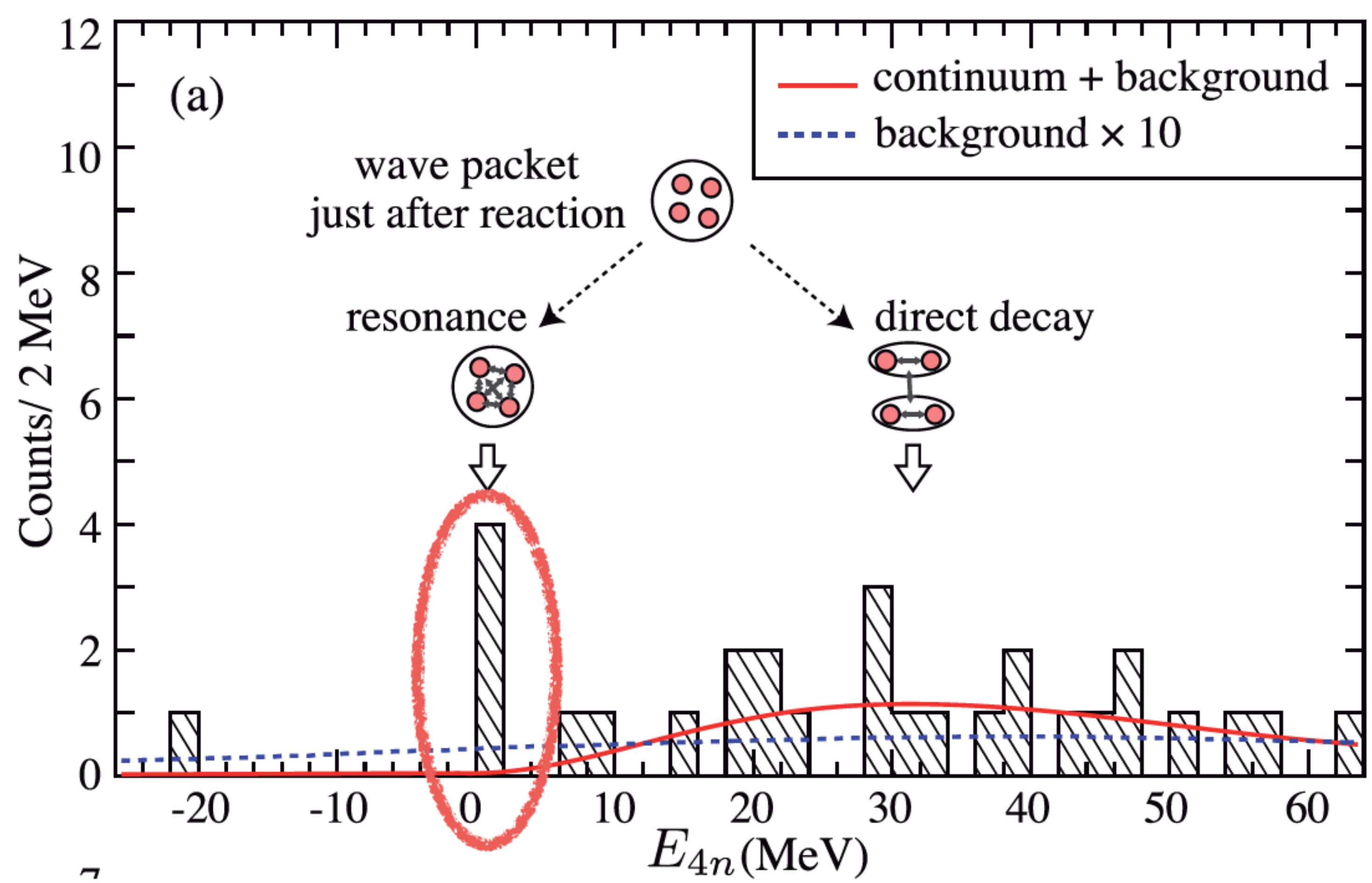


contents

multi-neutron system or "Neutronium"

https://en.wikipedia.org/wiki/Neutronium

- ^{1}n (neutron)
- ^{2}n (di-neutron) unbound by ≈ 70 keV ; $a_{nn} \sim -18$fm
- ^{3}n (tri-neutron) : hypothetical
- ^{4}n (tetra-neutron) : hypothetical

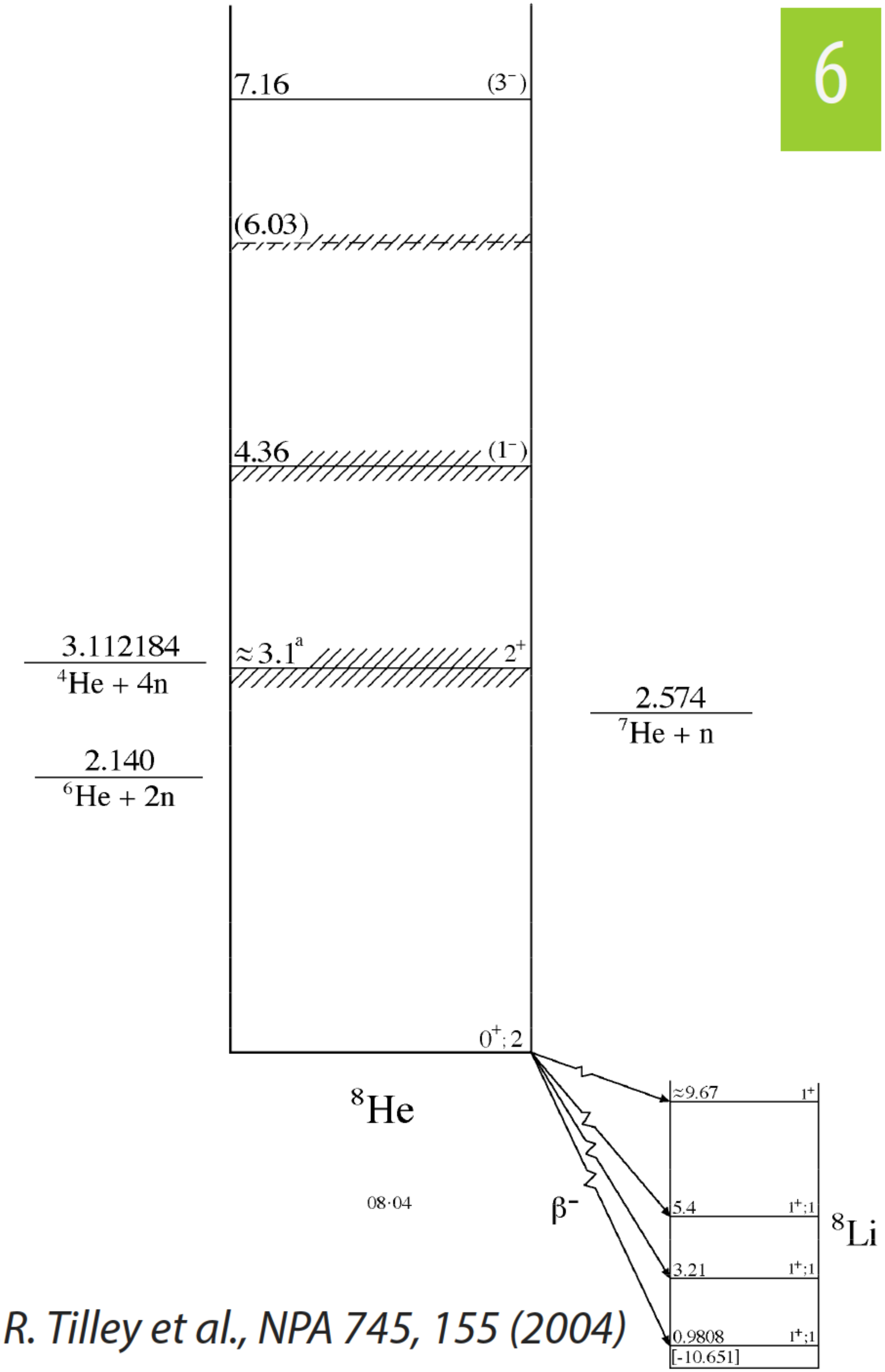
bound state? resonance?

argued for half a century…

(theories) unlikely to exist
(most experiments) not observed

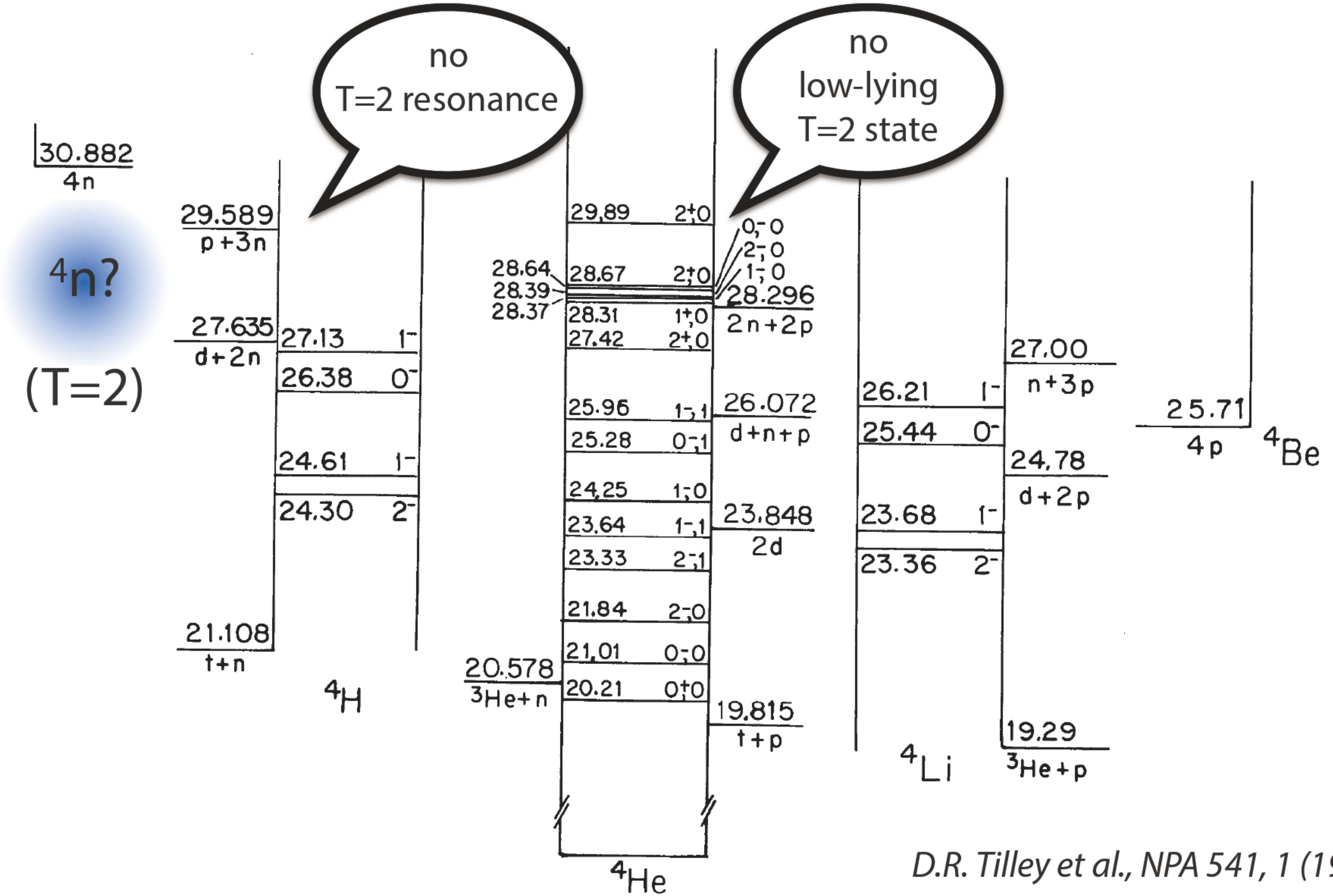
constraint on tetraneutron

- $^8He \rightarrow {}^4He + {}^4n$ forbidden
  ⇒ B.E.(^4n)<3.1MeV
- $^6He+2n$ dominance in ^8He break-up
  ⇒ B.E.(^4n)<1MeV
- unbound ^5H ($\rightarrow {}^3H+2n$)
  ⇒ bound ^4n unlikely



D.R. Tilley et al., NPA 745, 155 (2004)

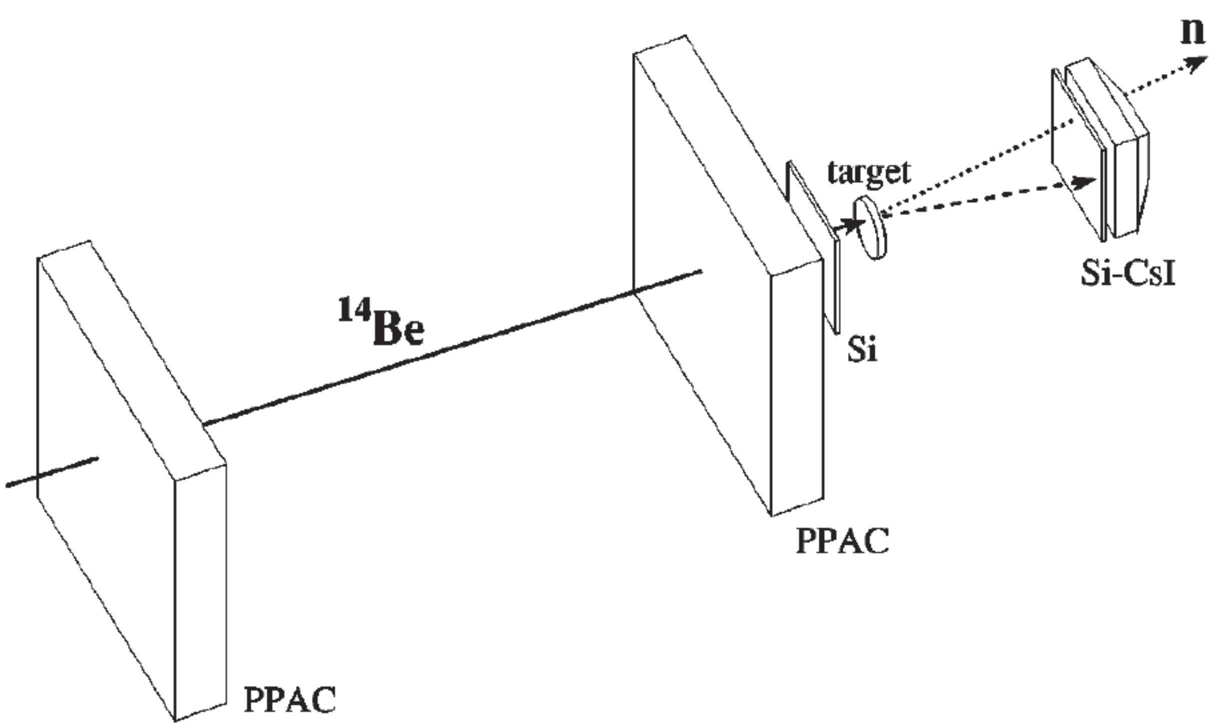
constraint on tetraneutron (cont'd)

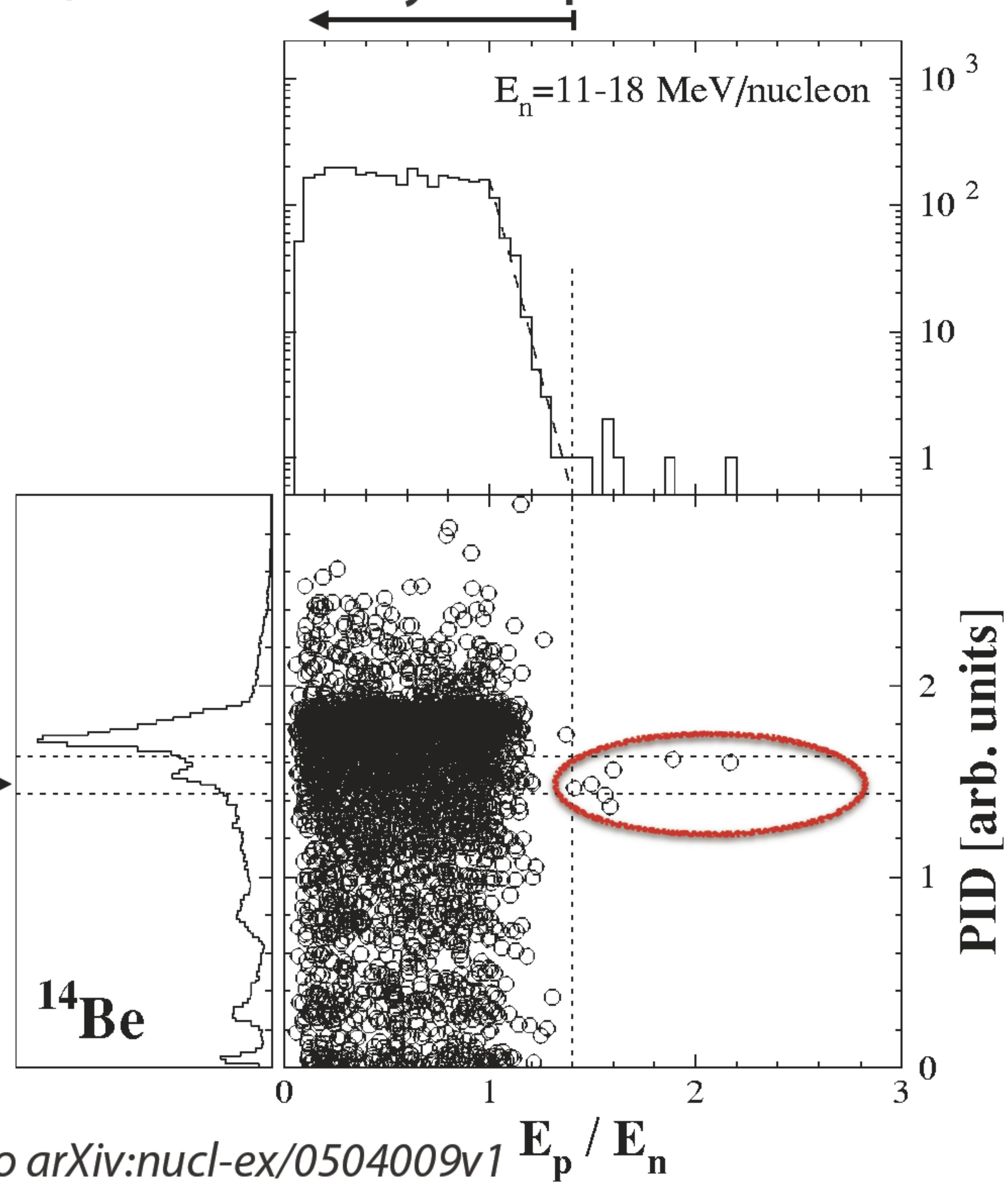


D.R. Tilley et al., NPA 541, 1 (1992)

bound tetraneutron in ^{14}Be break-up

single neutron (detected by a liquid scintillator)



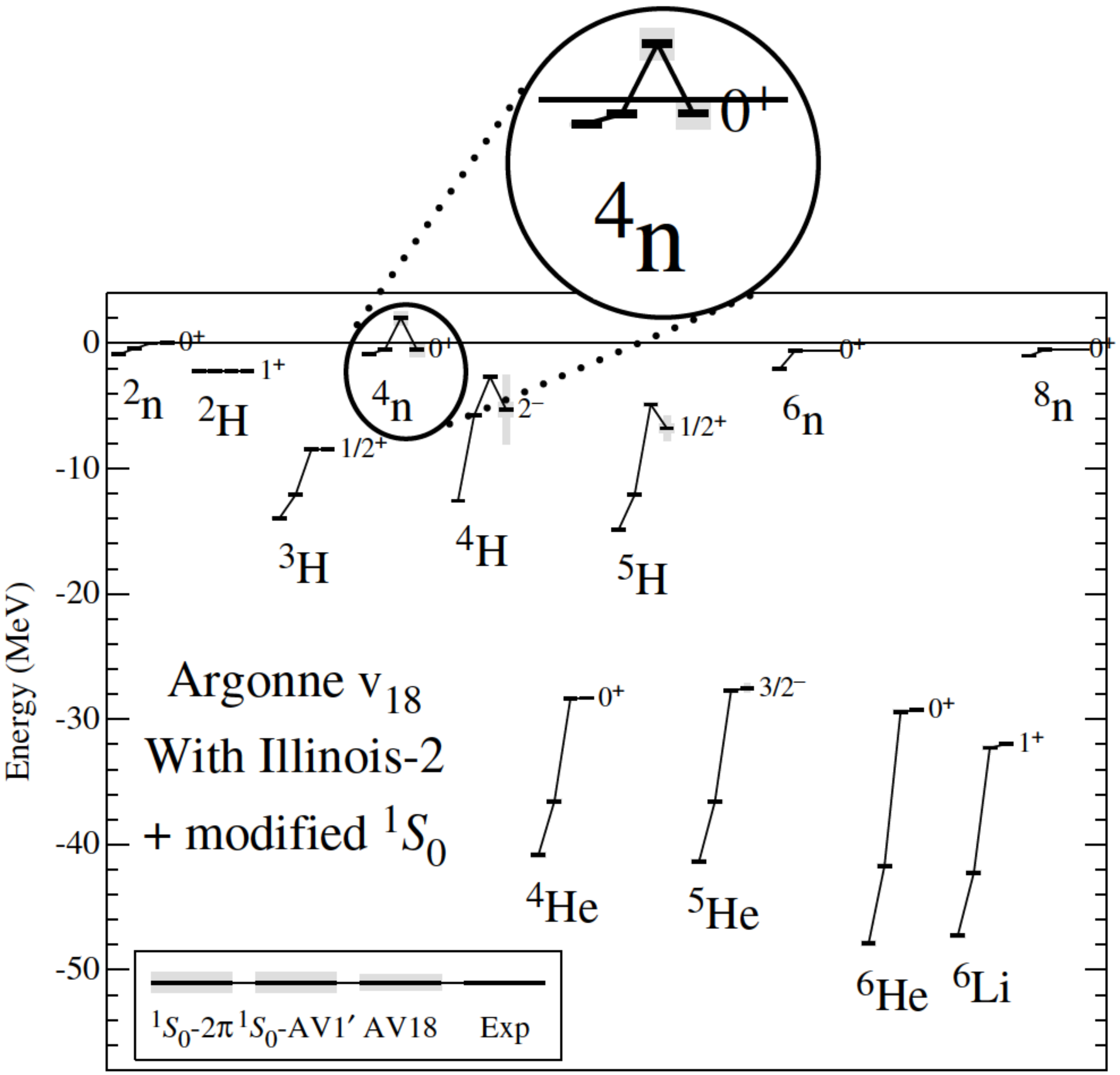


^{10}Be →

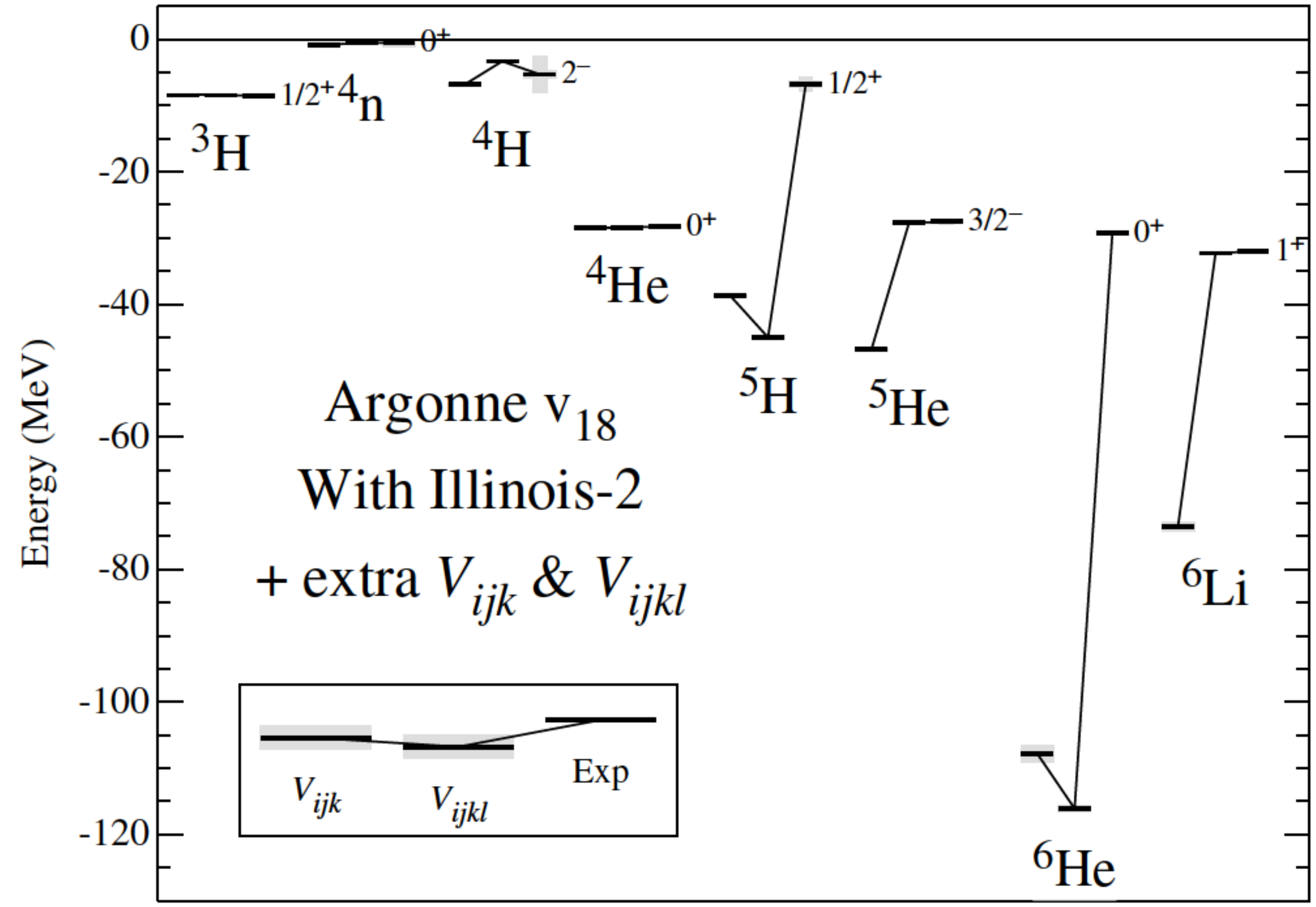
6 candidates of ^{14}Be break-up into ^{10}Be+^{4}n

F. M. Marqués et al., PRC 65, 044006 (2002); see also arXiv:nucl-ex/0504009v1

incompatibility with other nuclides?



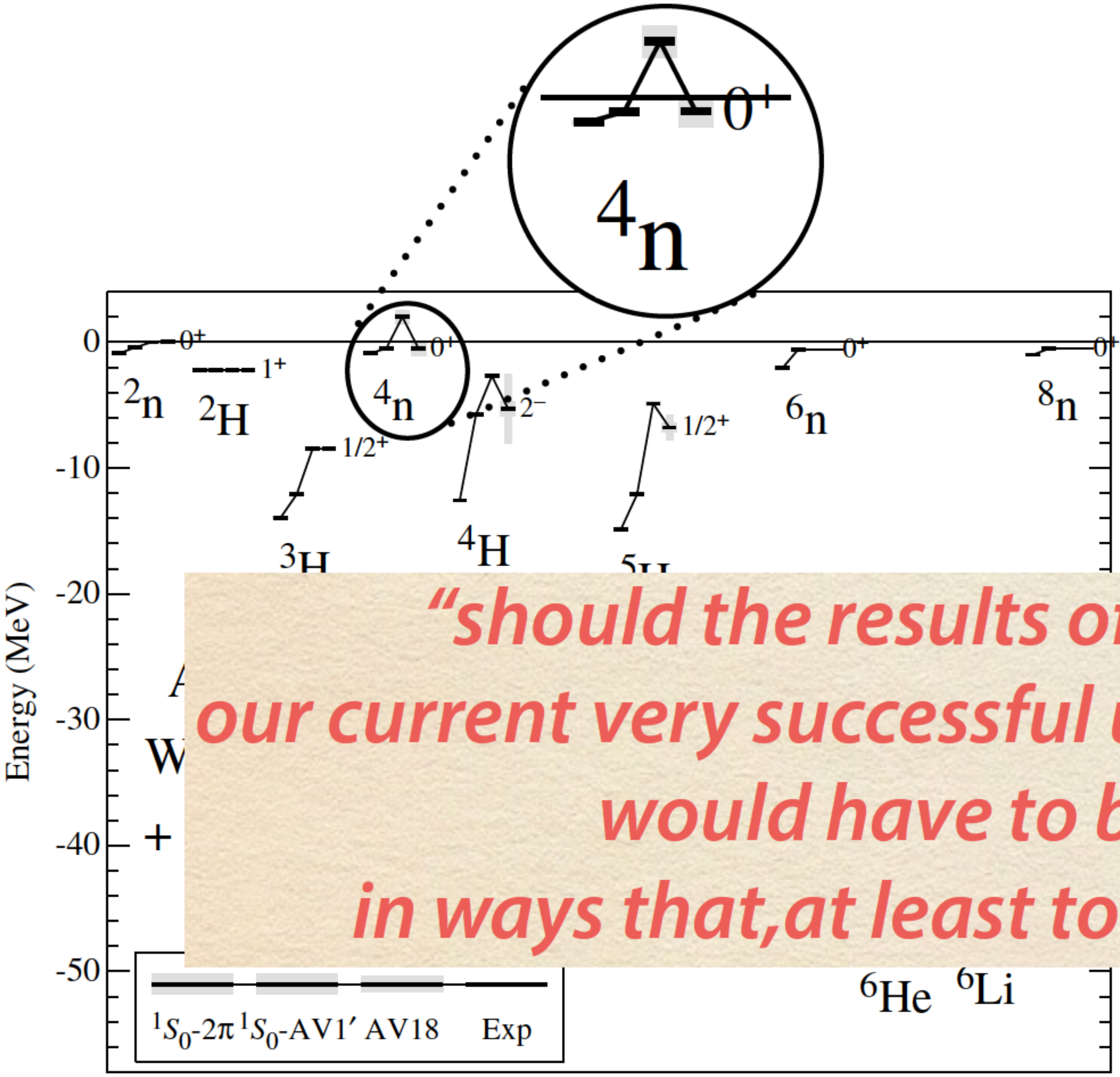
modified NN interaction
changes energies of other nuclides,
including di-neutron

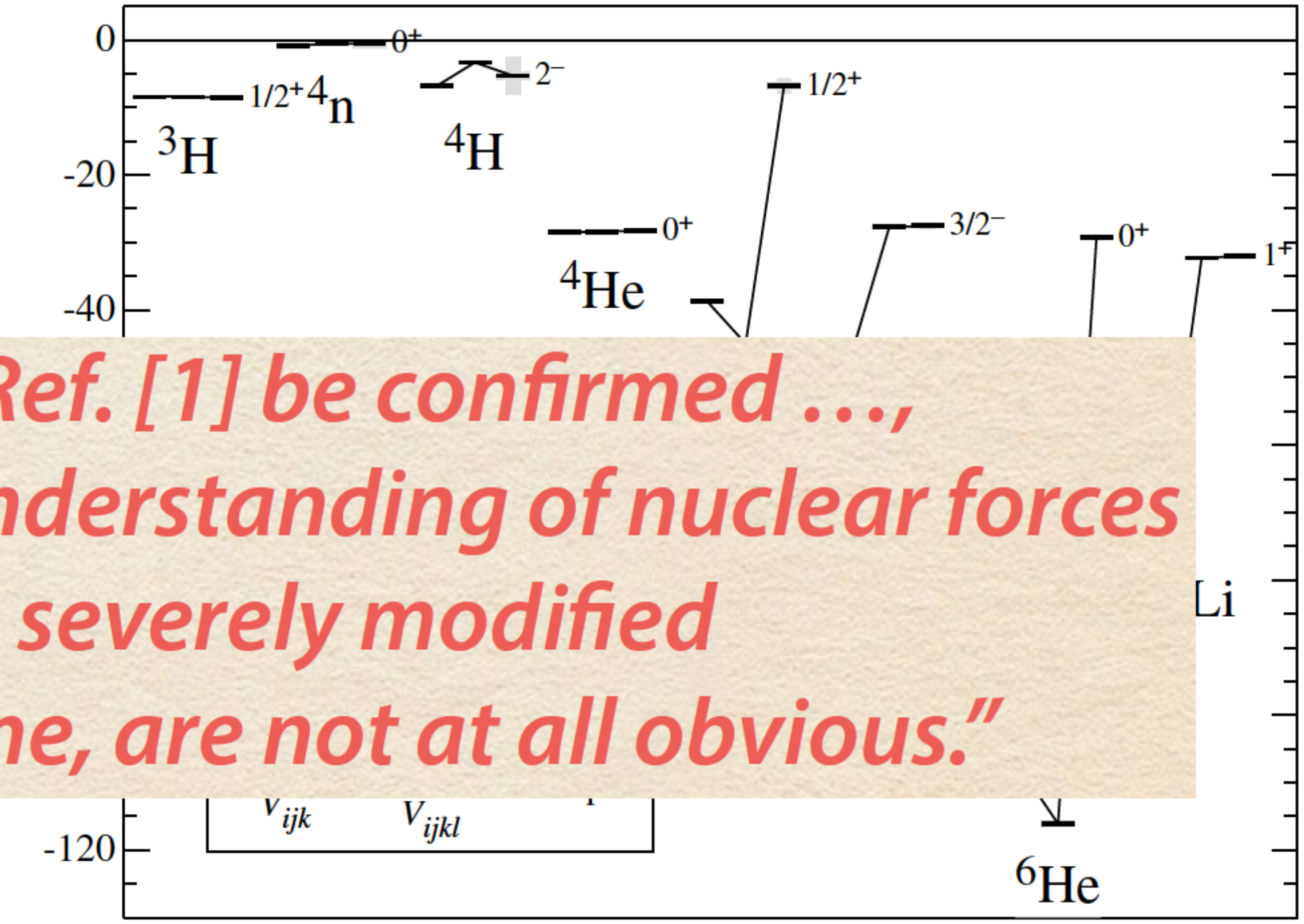


inclusion of extra 3N or 4N interaction
drastically changes
energies of A>4 nuclides

S. C. Pieper, PRL 90, 252501 (2003)

incompatibility with other nuclides?





"should the results of Ref. [1] be confirmed . . .,
our current very successful understanding of nuclear forces
would have to be severely modified
in ways that,at least to me, are not at all obvious."

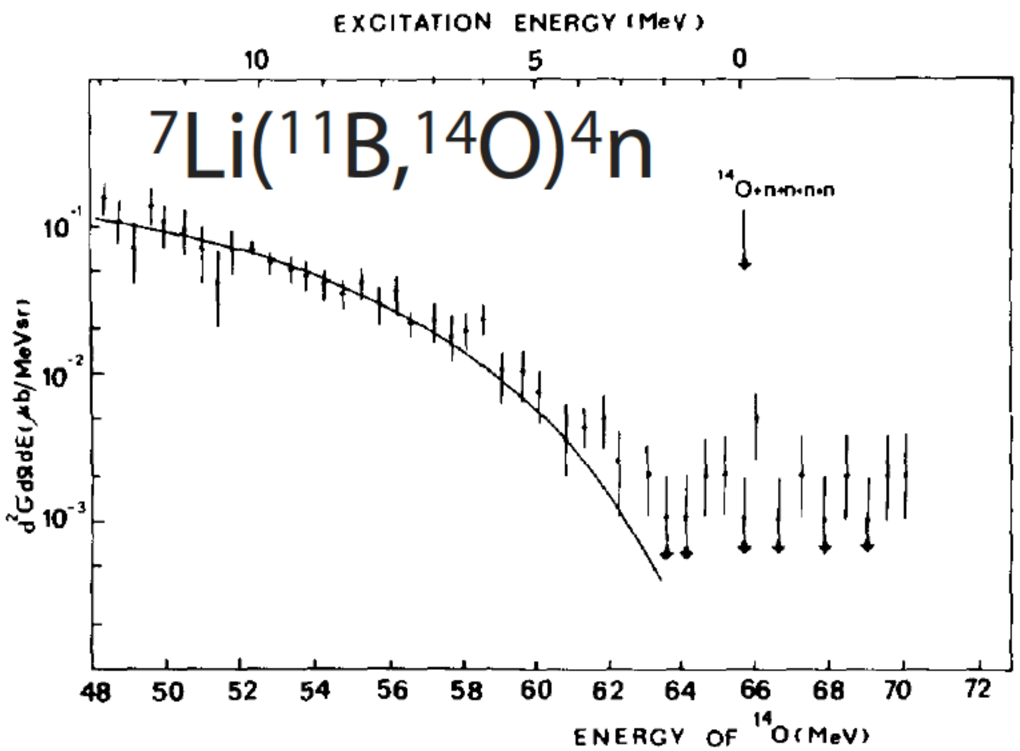
modified NN interaction
changes energies of other nuclides,
including di-neutron

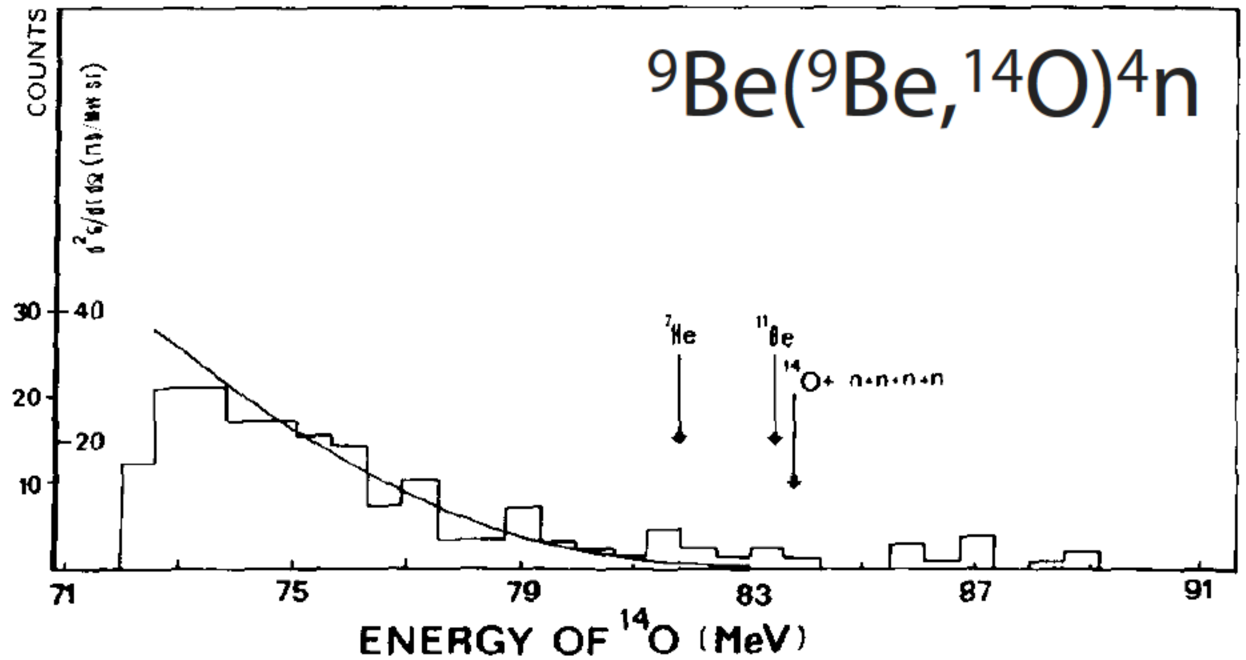
inclusion of extra 3N or 4N interaction
drastically changes
energies of A>4 nuclides

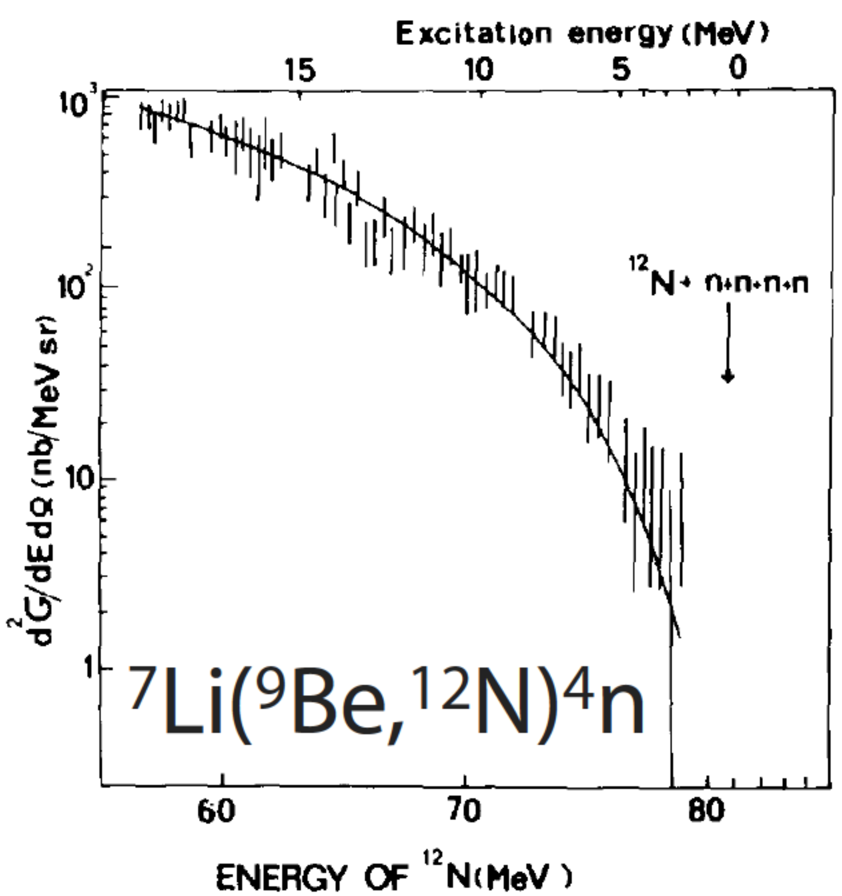
S. C. Pieper, PRL 90, 252501 (2003)

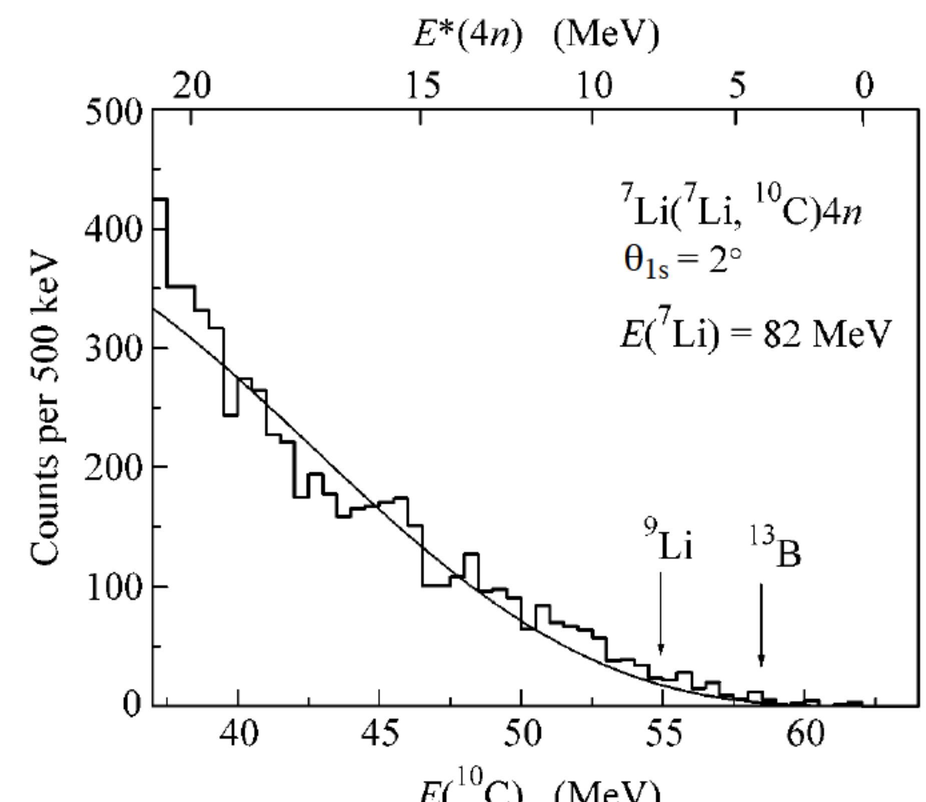
non-observation in transfer reaction

A. V. Belozyorov et al., NPA 477, 131 (1988)

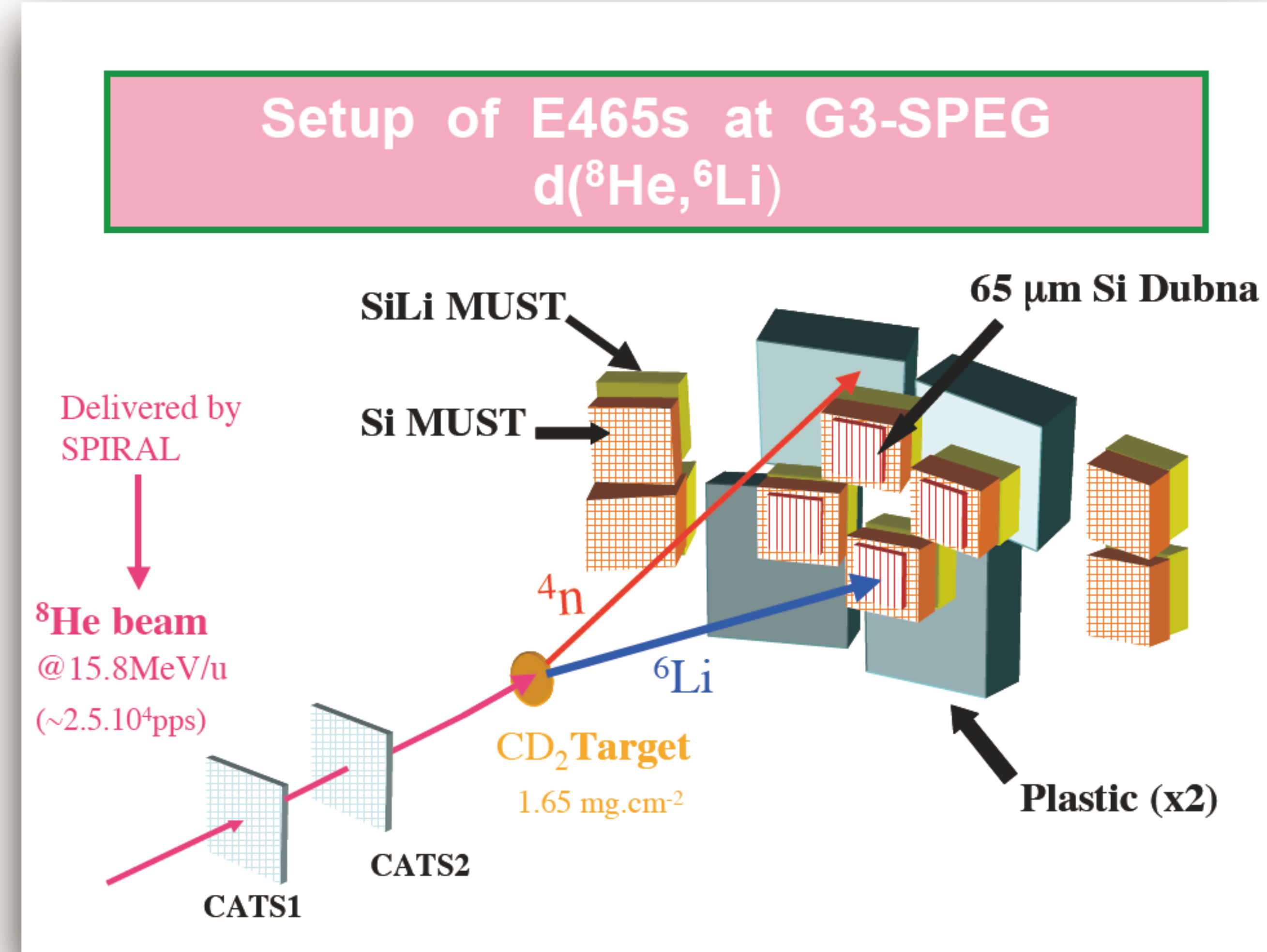


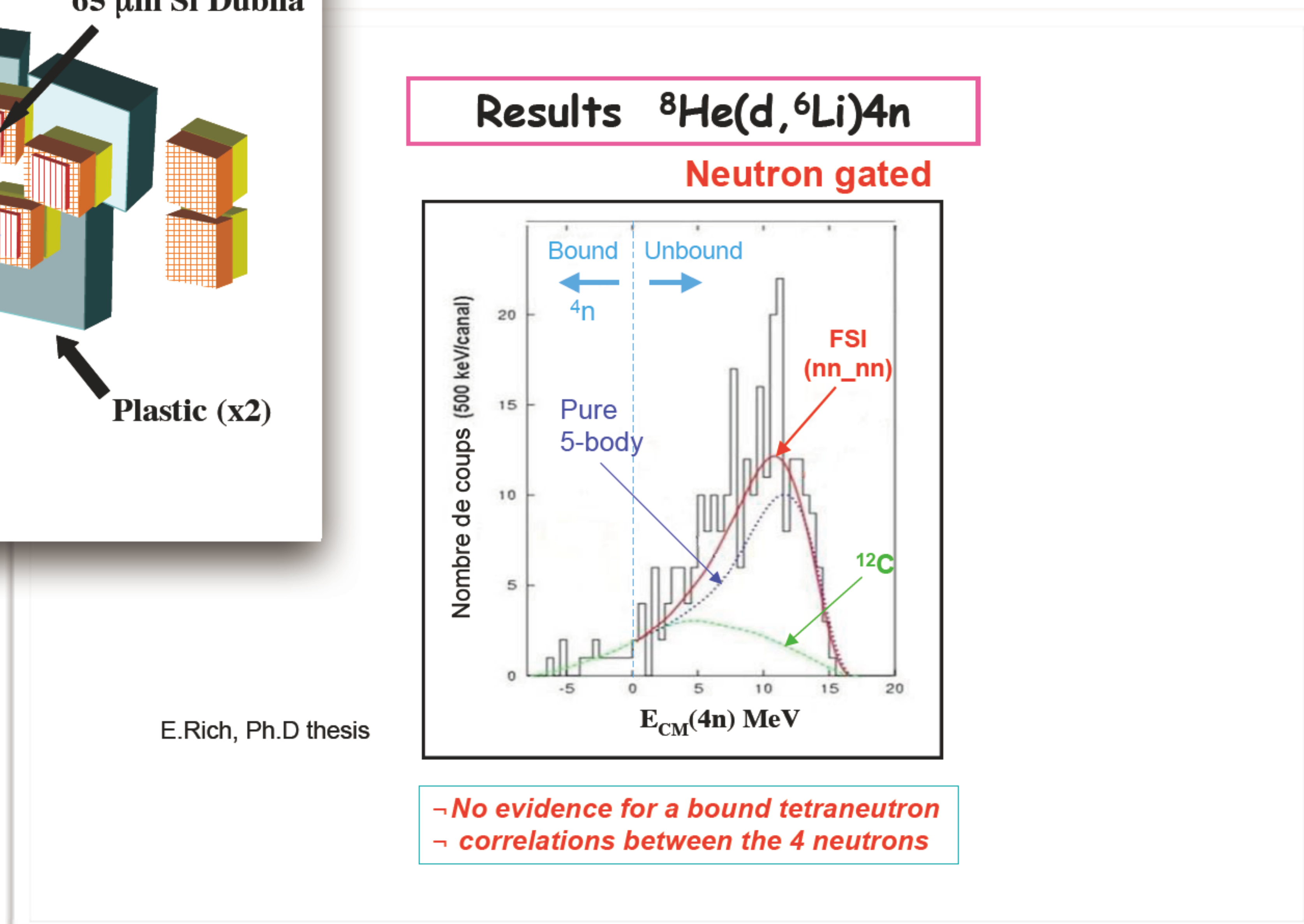






D. V. Aleksandrov et al. JETP Letters 81, 43 (2005).





http://pro.ganil-spiral2.eu/events/colloques/2006/talks/spectro/Giens2006_Beaumel.pdf

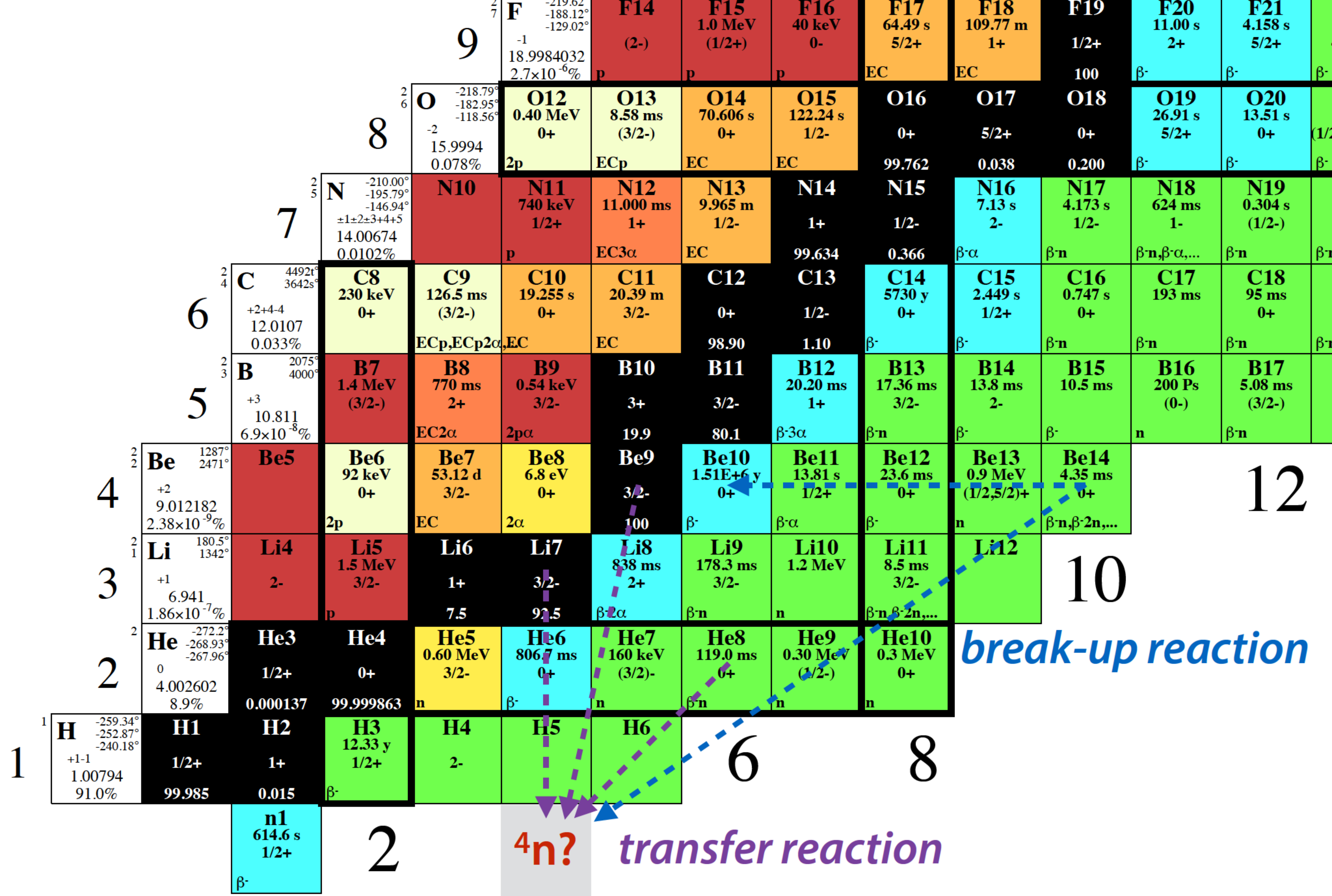
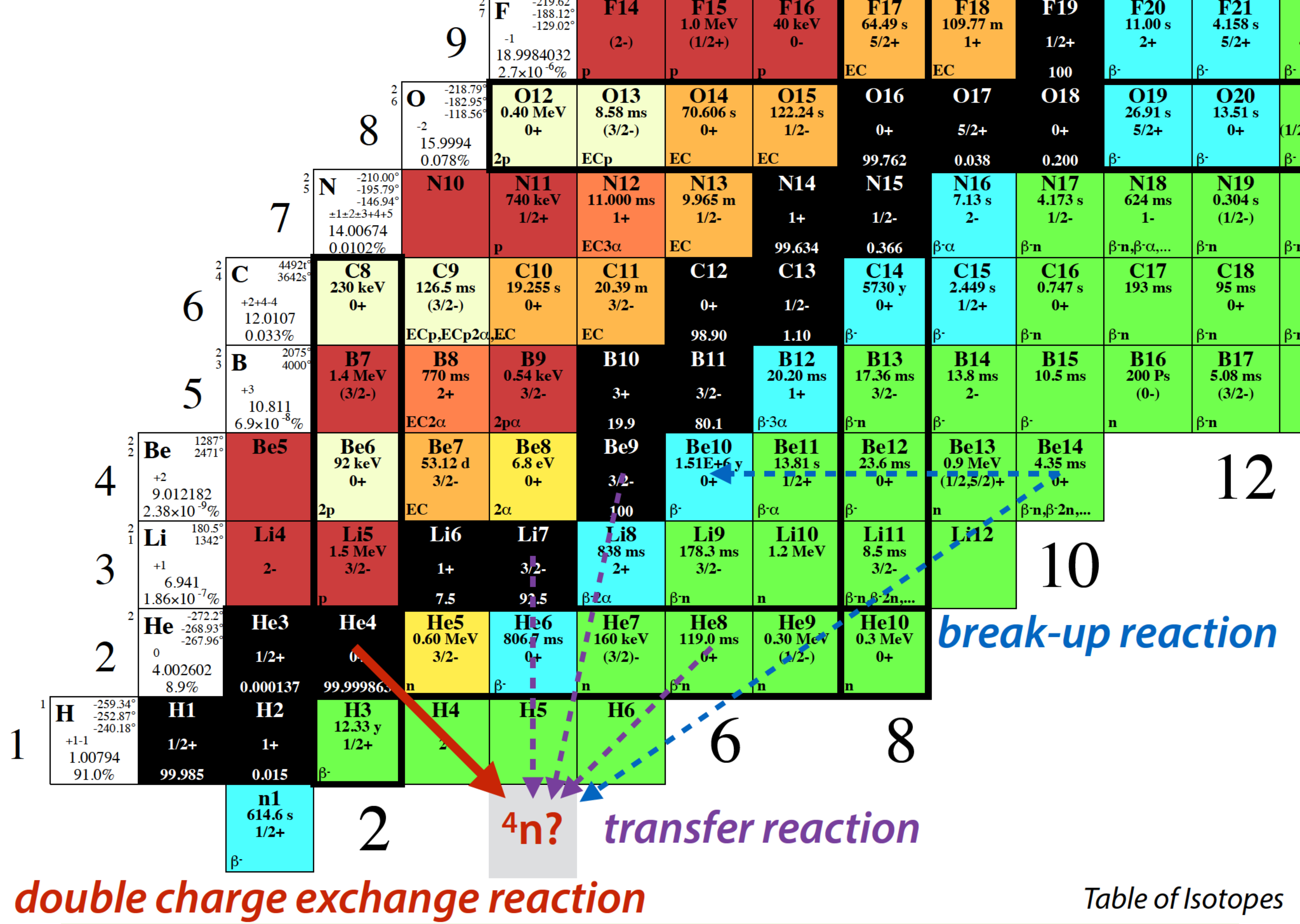
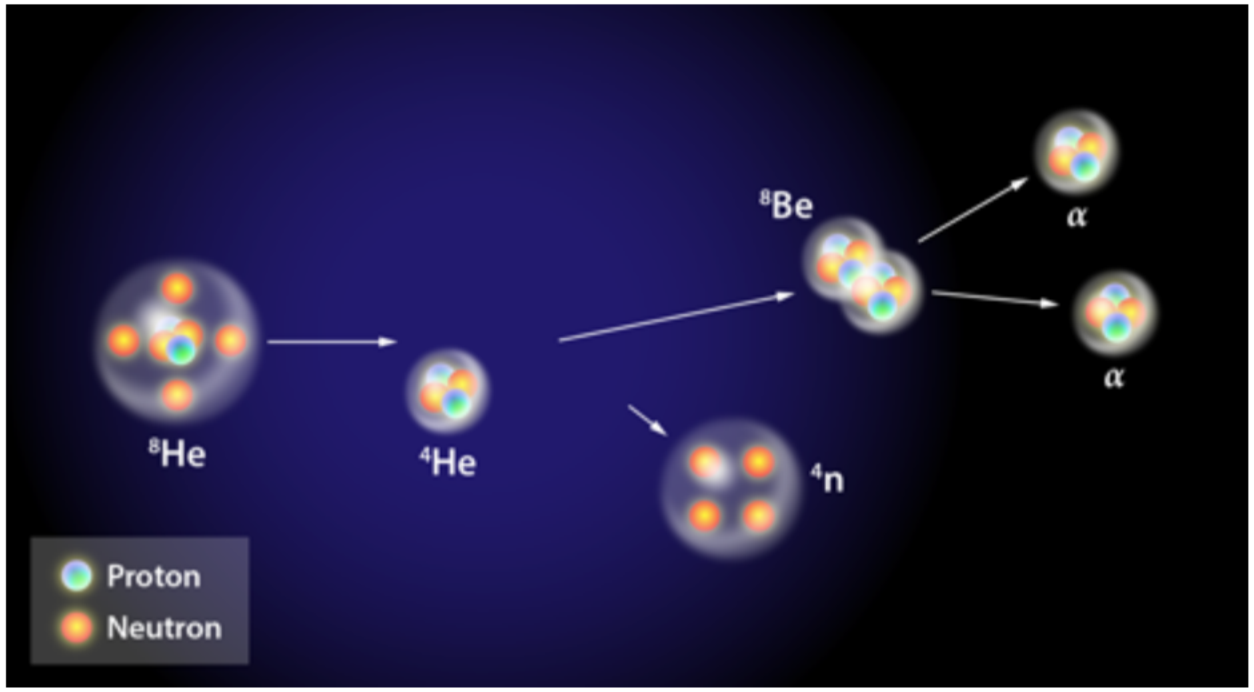


Table of Isotopes



Hiroyuki Fujioka (Kyoto Univ.)

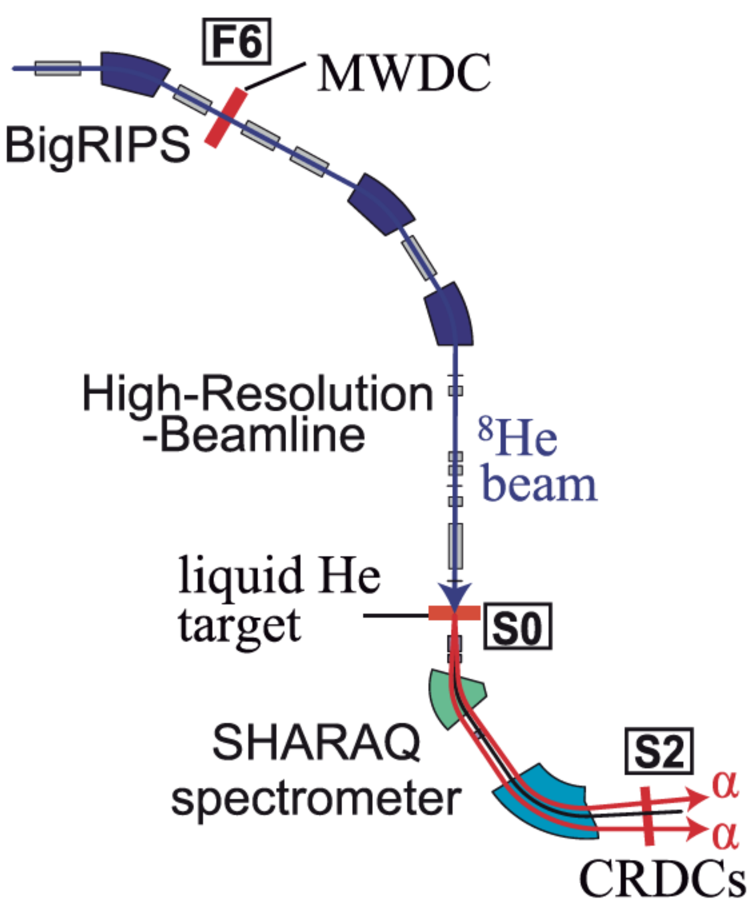
candidates of resonant tetraneutron

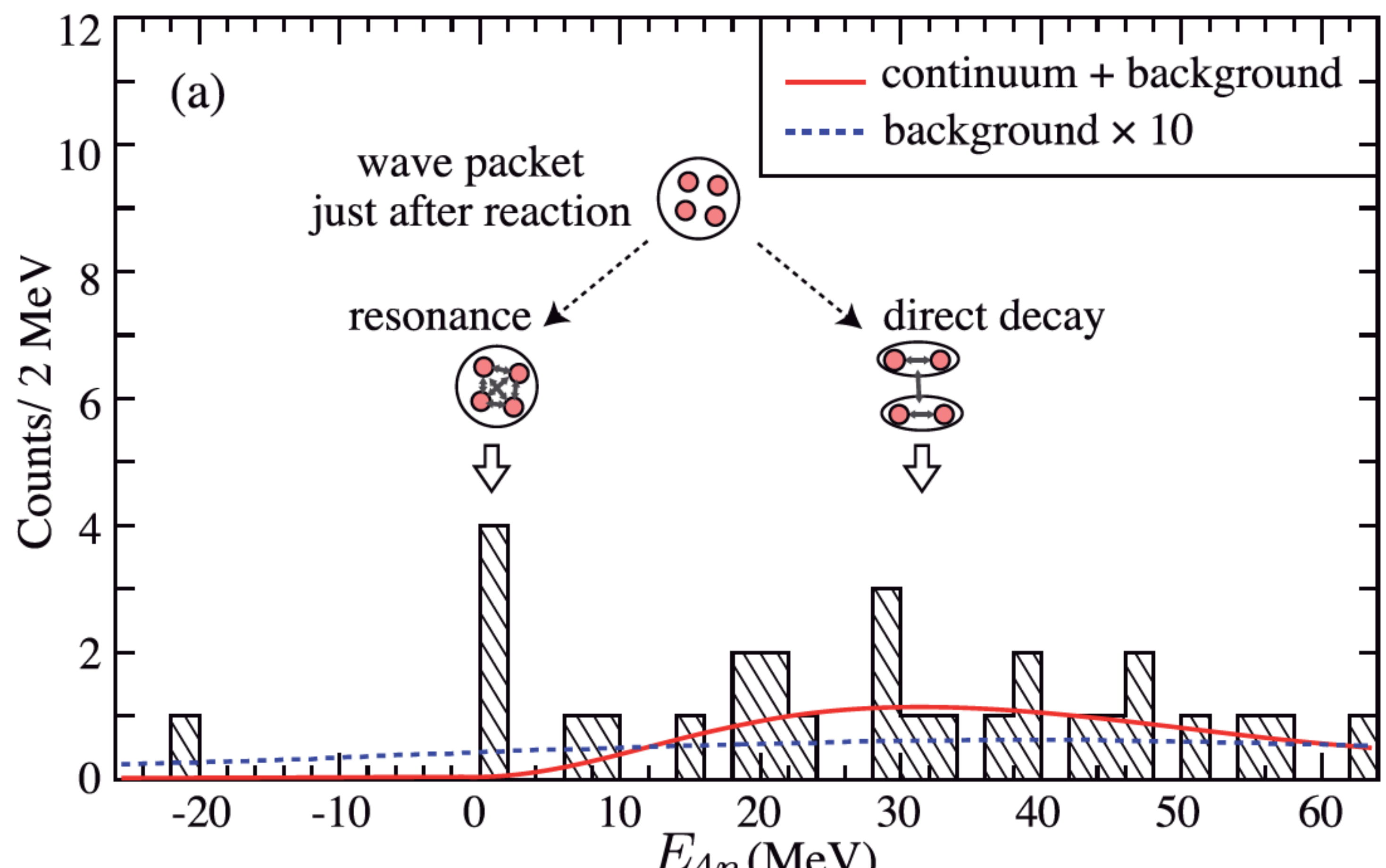


186 MeV/u ^{8}He beam (~2MHz)

^{8}Be→2α momentum-analyzed

one ^{8}He in one bunch
(to avoid accidental coincidence)



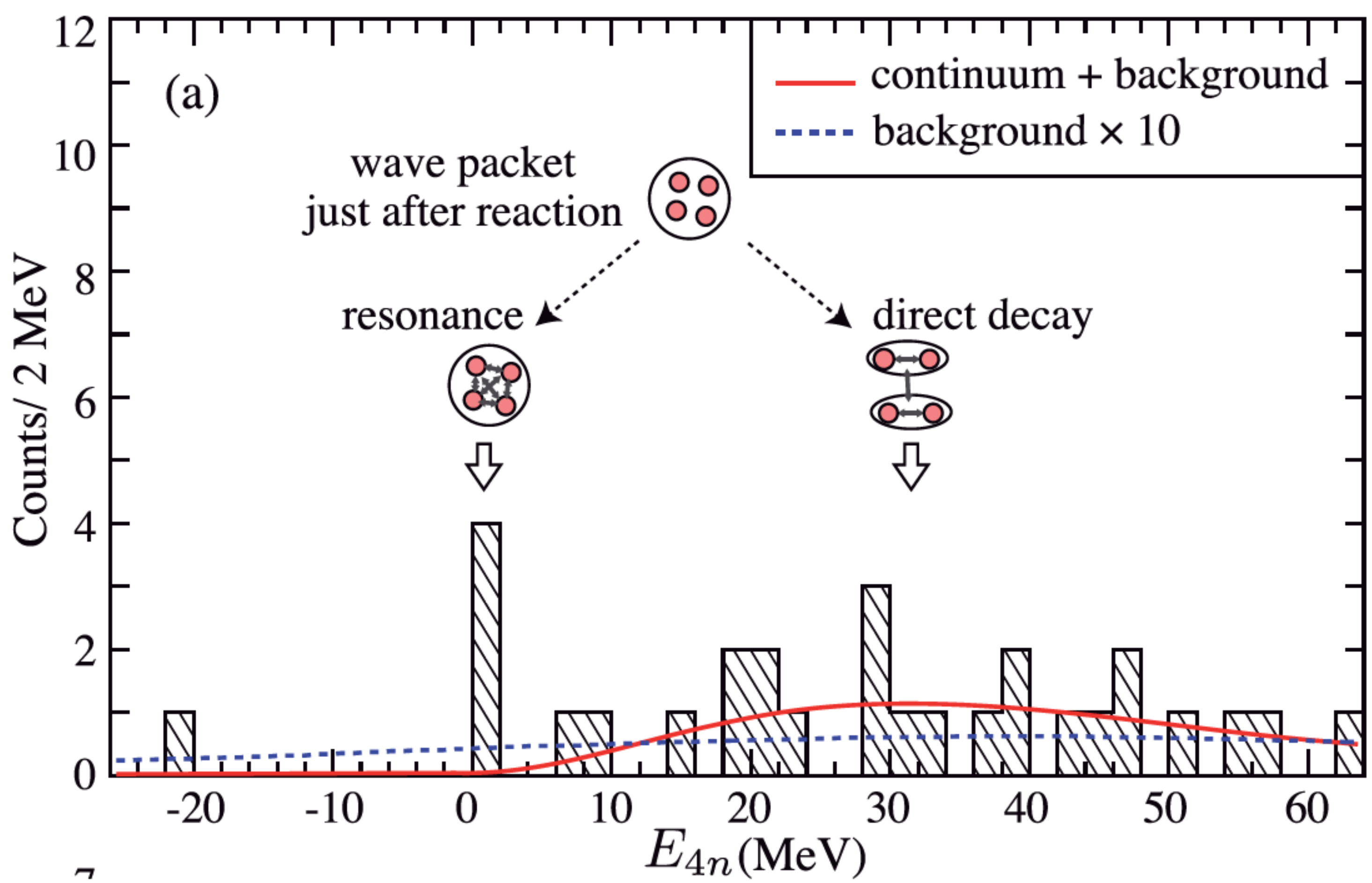


candidates of resonant tetraneutron

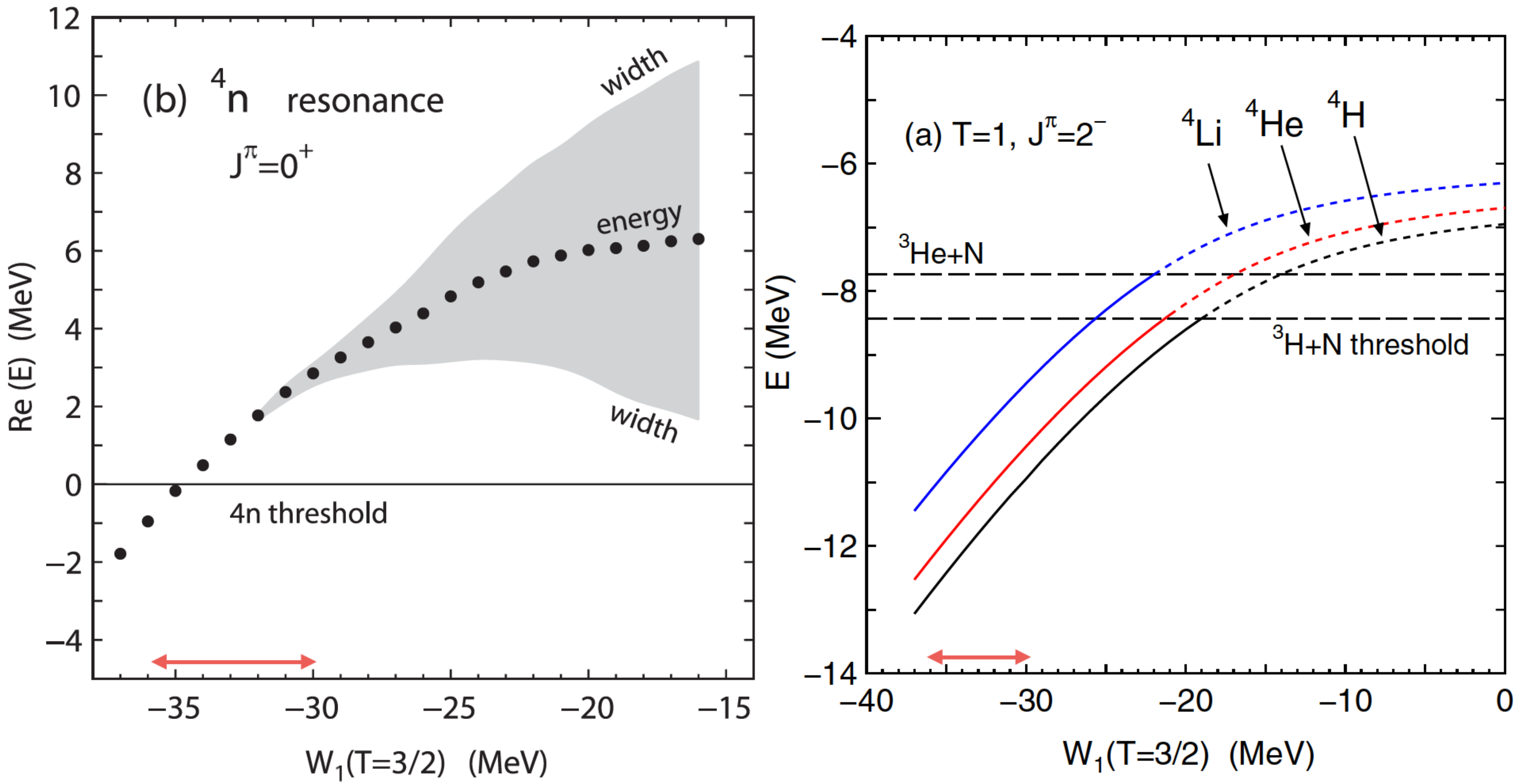
K. Kisamori et al., PRL 116, 052501 (2016)

significance: 4.9 σ (w/ look-elsewhere effect)
energy: 0.83±0.65±1.25 MeV
width : <2.6MeV (FWHM)

above 4n threshold (or not)?



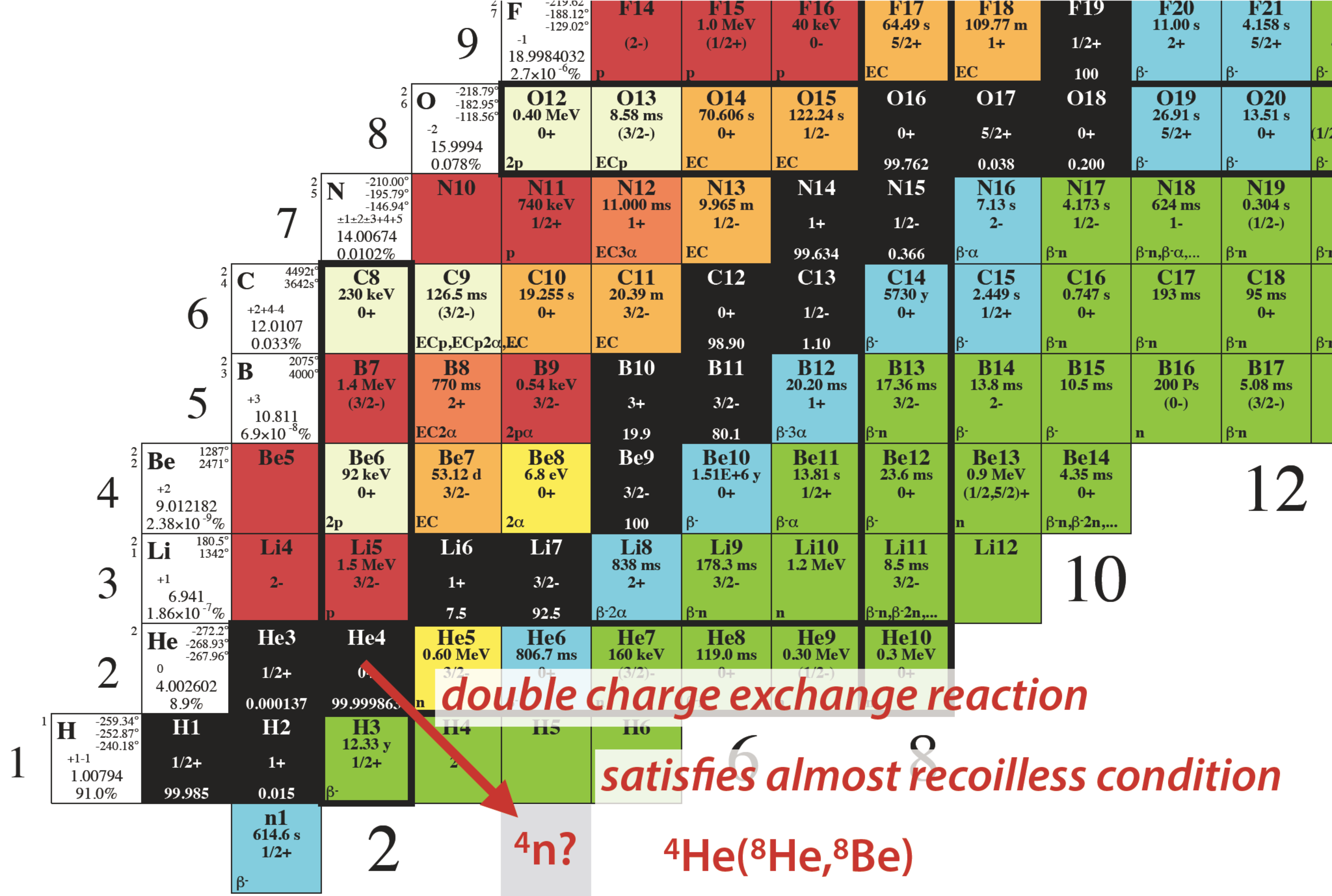
ab-initio 4N calculation



introduction of strong 3N force

→ ^{4}H, ^{4}He (I=1), ^{4}Li below ^{3}H(^{3}He)+N threshold

E. Hiyama, R. Lazauskas, J. Carbonell, and M. Kamimura, PRC 93, 044004 (2016)



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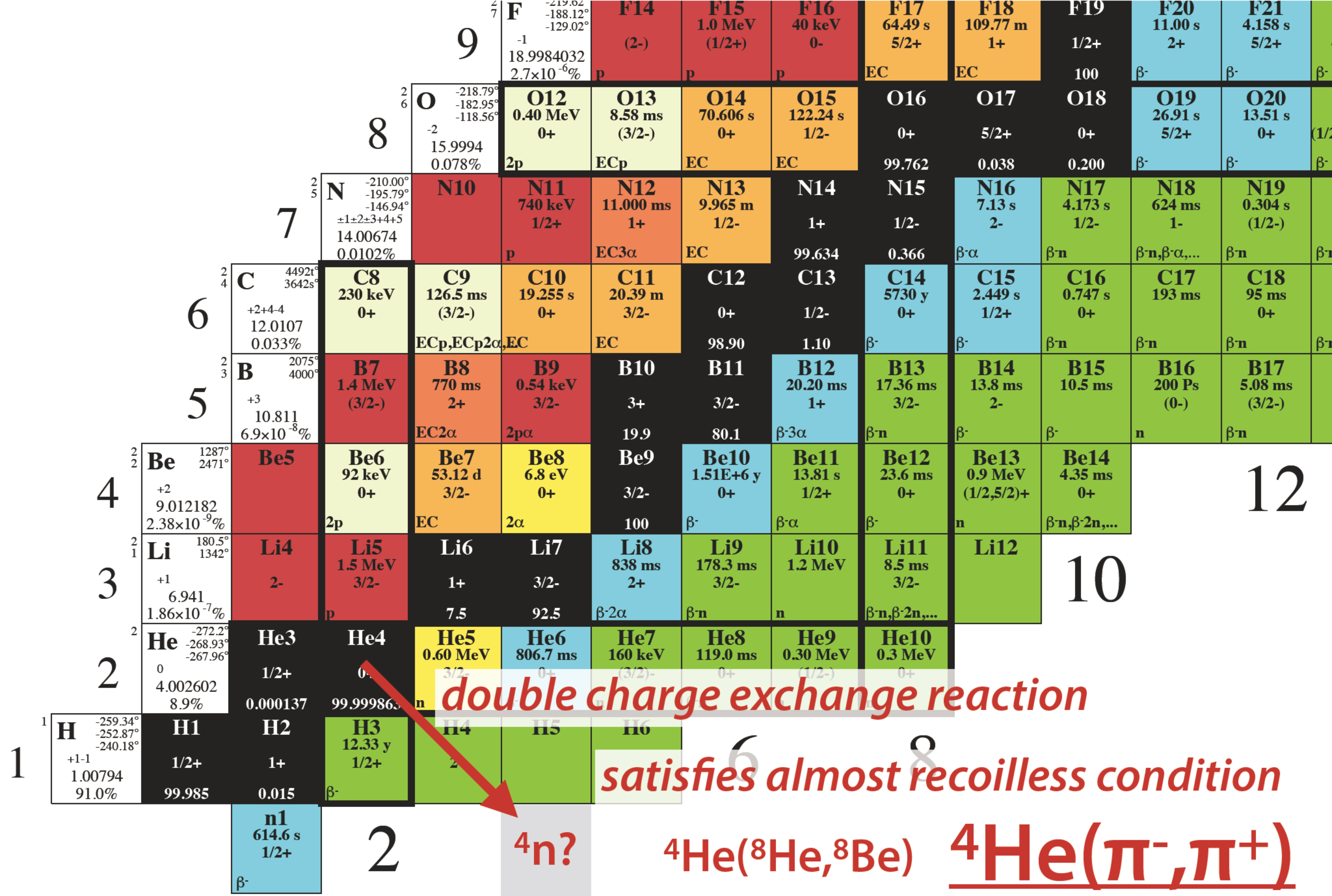
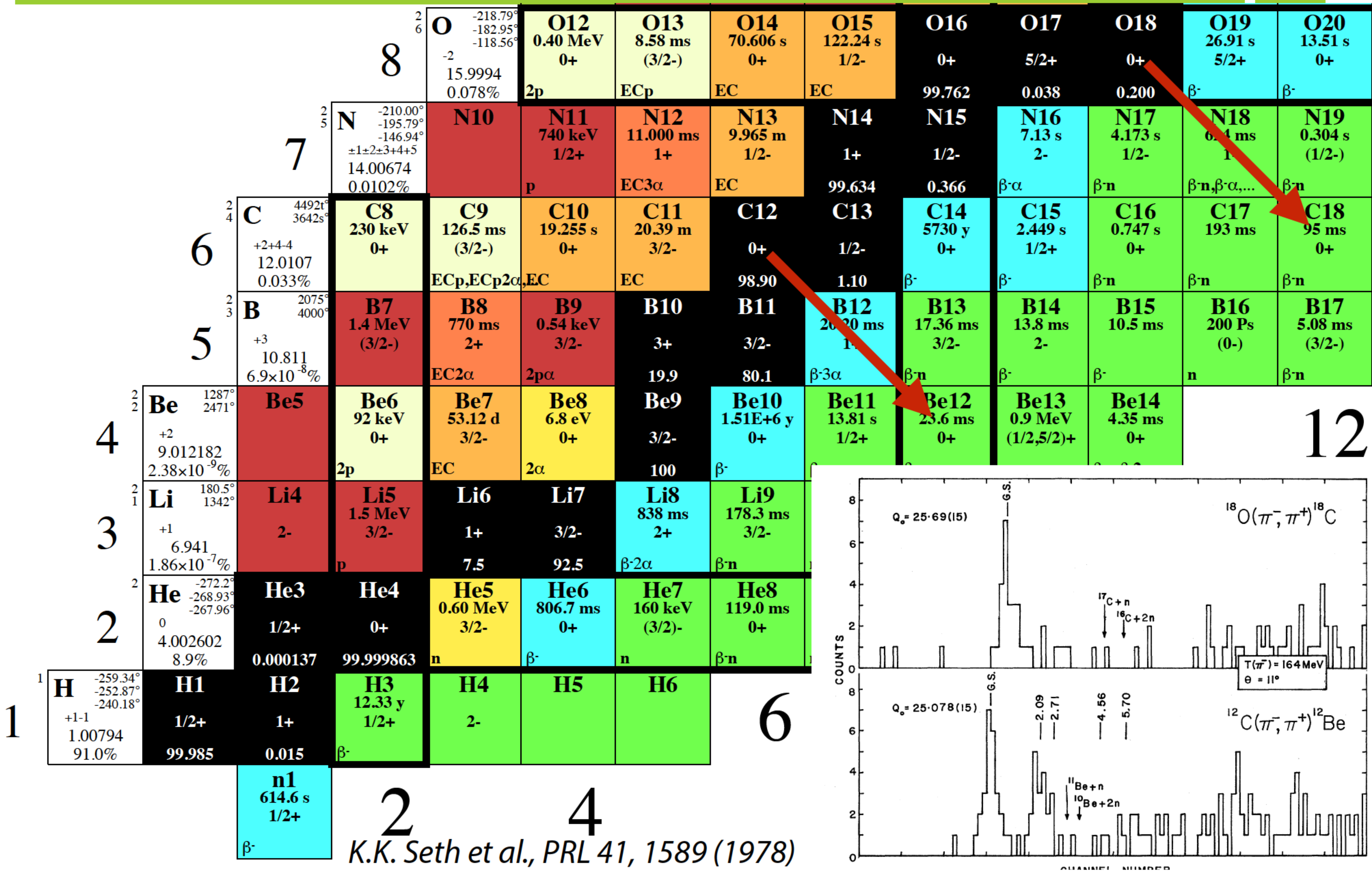


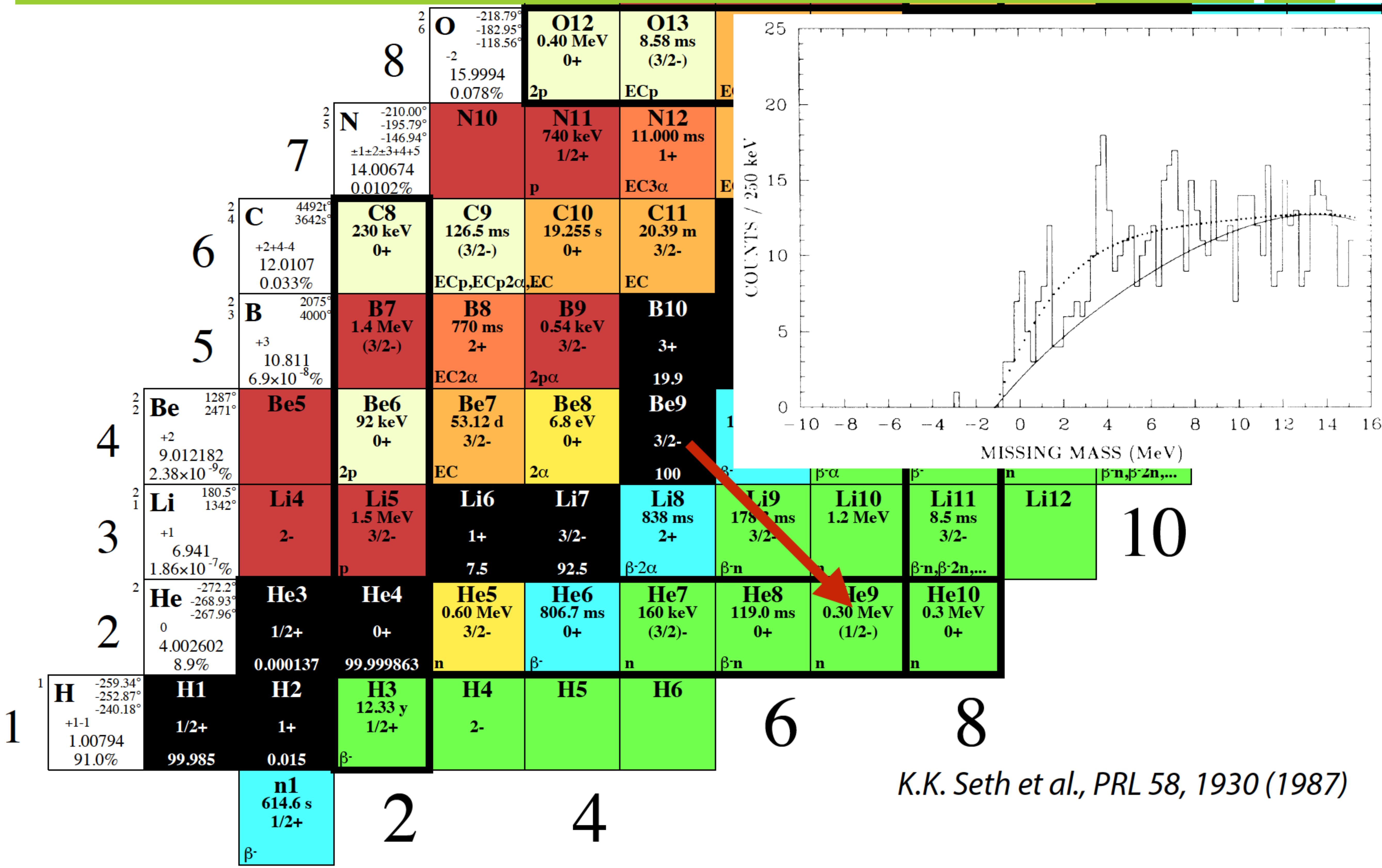
Table of Isotopes

examples of pion DCX measurements



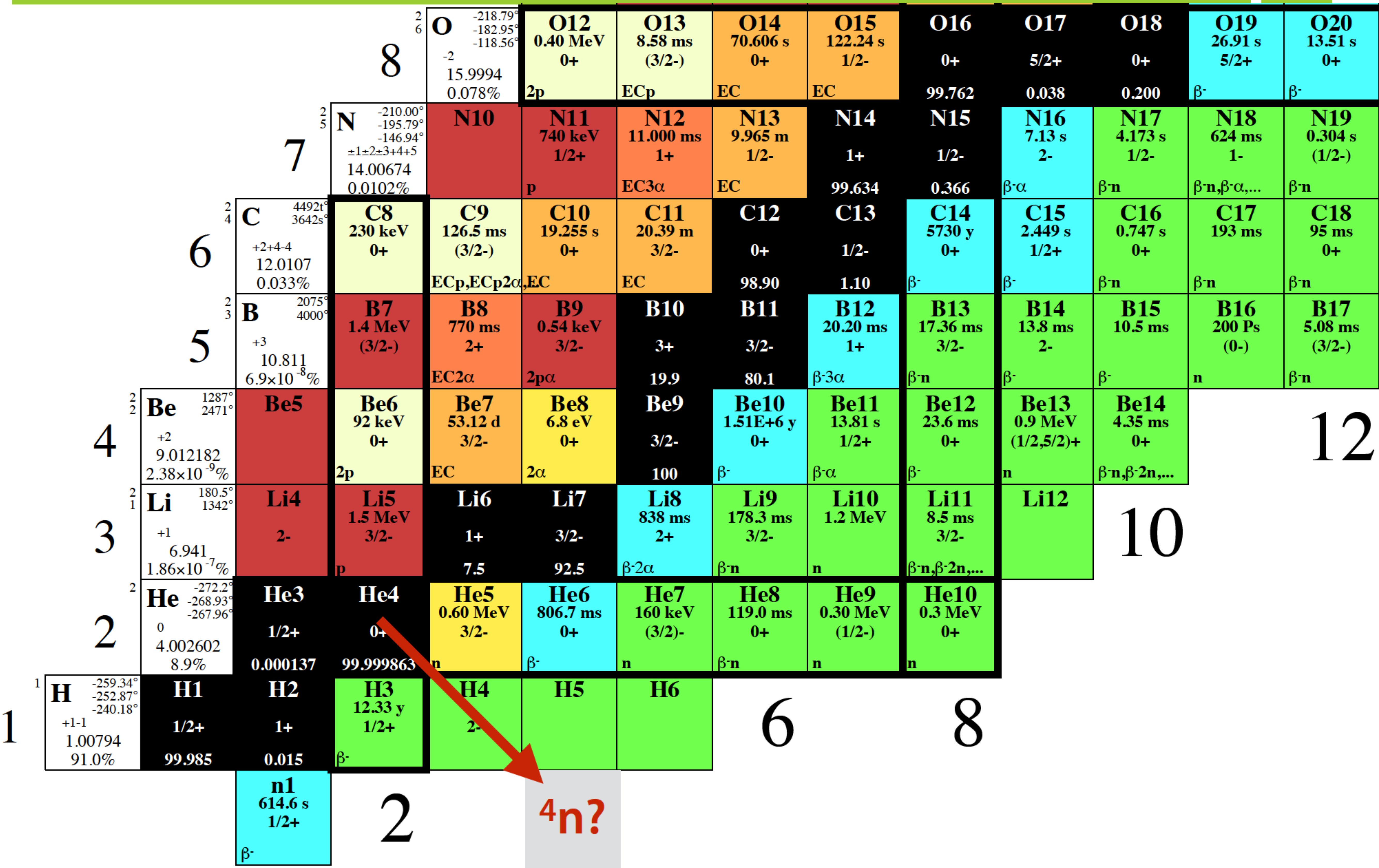
K.K. Seth et al., PRL 41, 1589 (1978)

examples of pion DCX measurements



K.K. Seth et al., PRL 58, 1930 (1987)

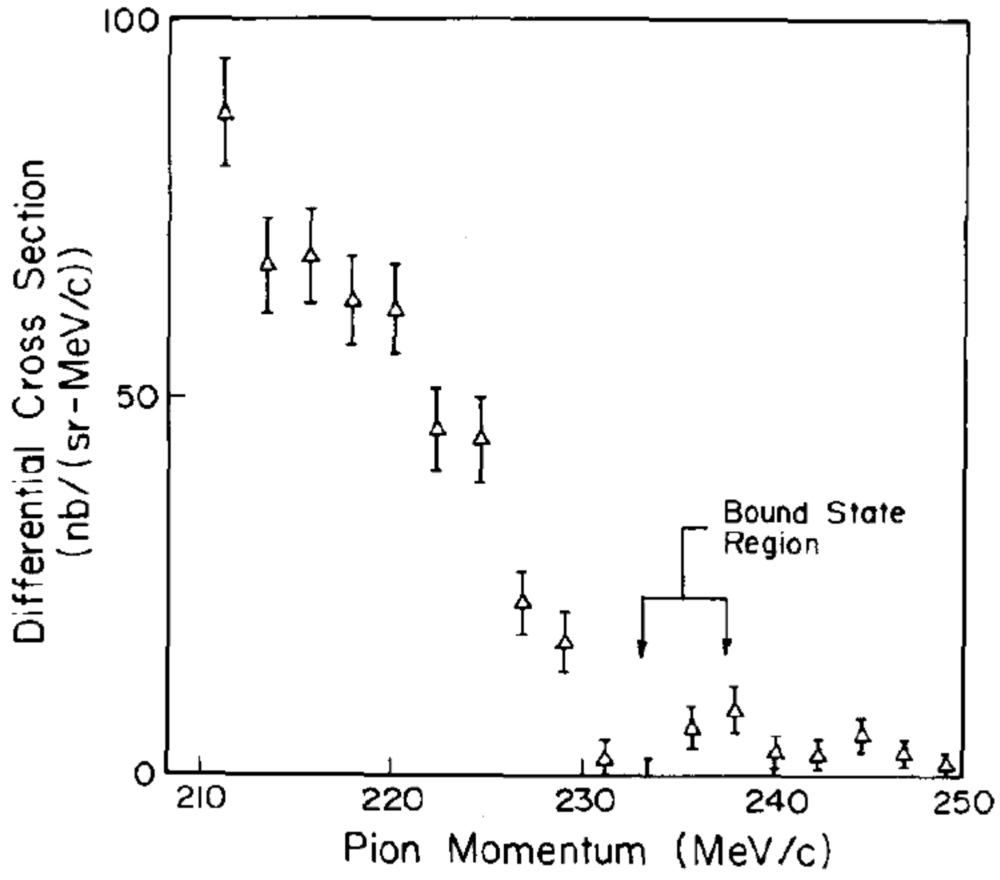
examples of pion DCX measurements



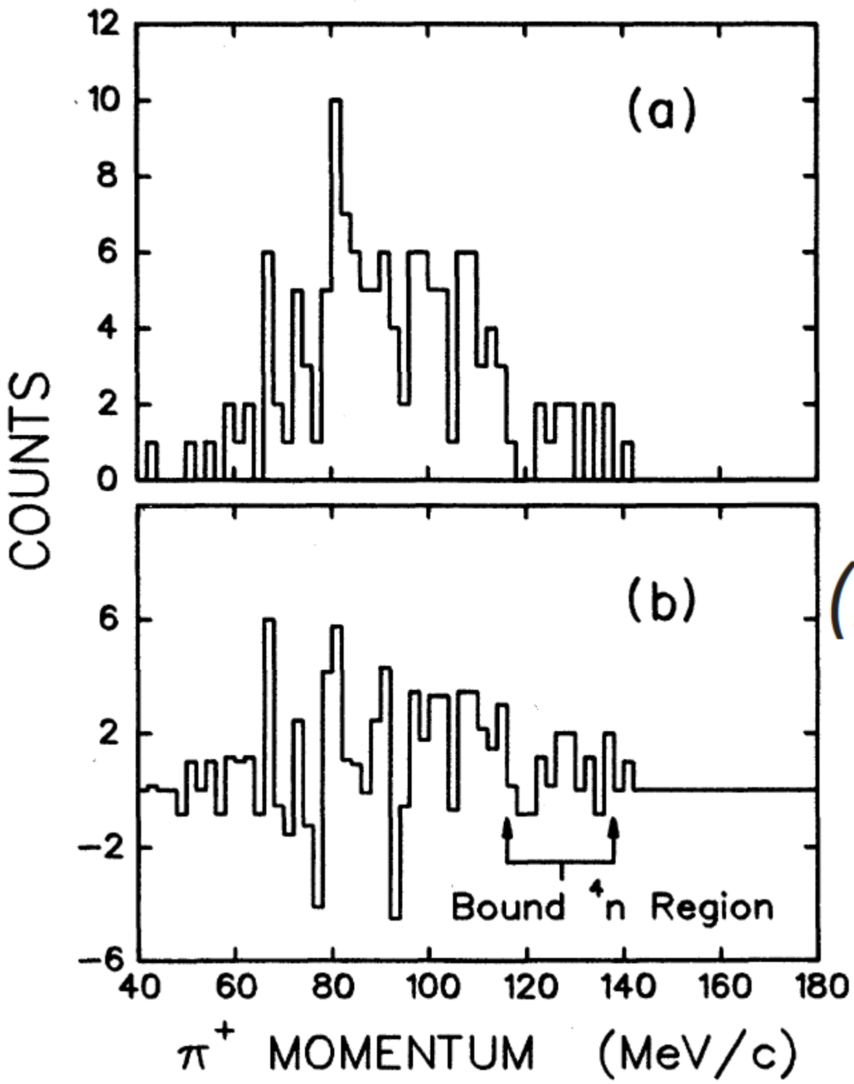
$^4He(\pi^-,\pi^+)$ reaction

- Ungar et al.: T_π=165MeV, θ_π=0° @ LAMPF
  → $d\sigma/d\Omega$ = 7±15nb/sr

- Gorringe et al.: T_π=80MeV, 50°<θ_π<130° @ TRIUMF
  → $d\sigma/d\Omega$ <13nb/sr



J.E. Ungar et al., PLB 144 (1984) 333



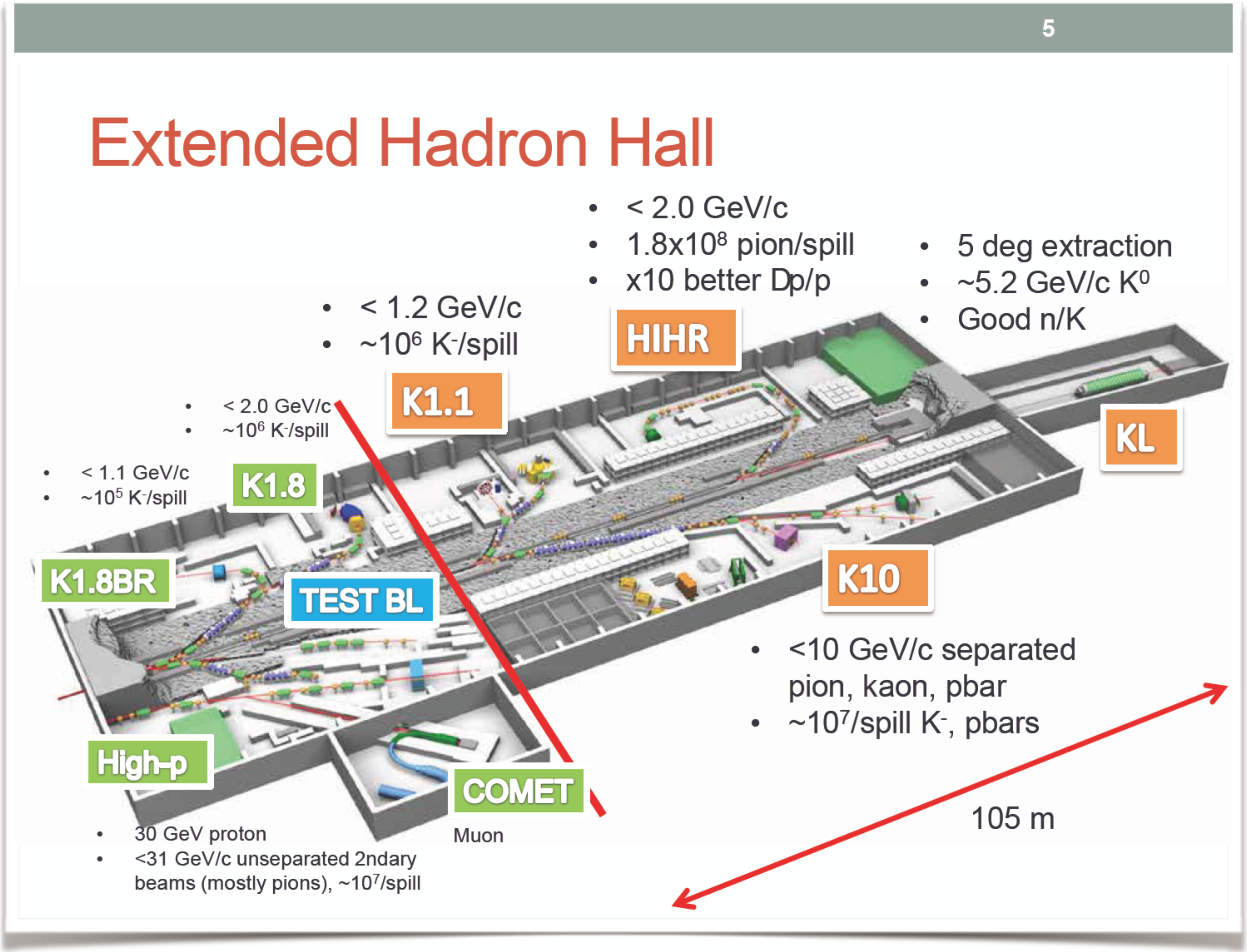
(BG subtracted)

T.P. Gorringe et al., PRC 40 (1989) 2390

revisiting pion-DCX reaction

- searching for a very weak peak *near* 4n threshold
  - in not only *bound region* but also *unbound region*
- reduction of unphysical background is important
  - contribution from target cell
  - beam contaminant
  - π decay in flight
- **High-Energy** (far above Δ region) + **High-Intensity** + **High-Resolution** experiment will improve the sensitivity

J-PARC HIHR beamline

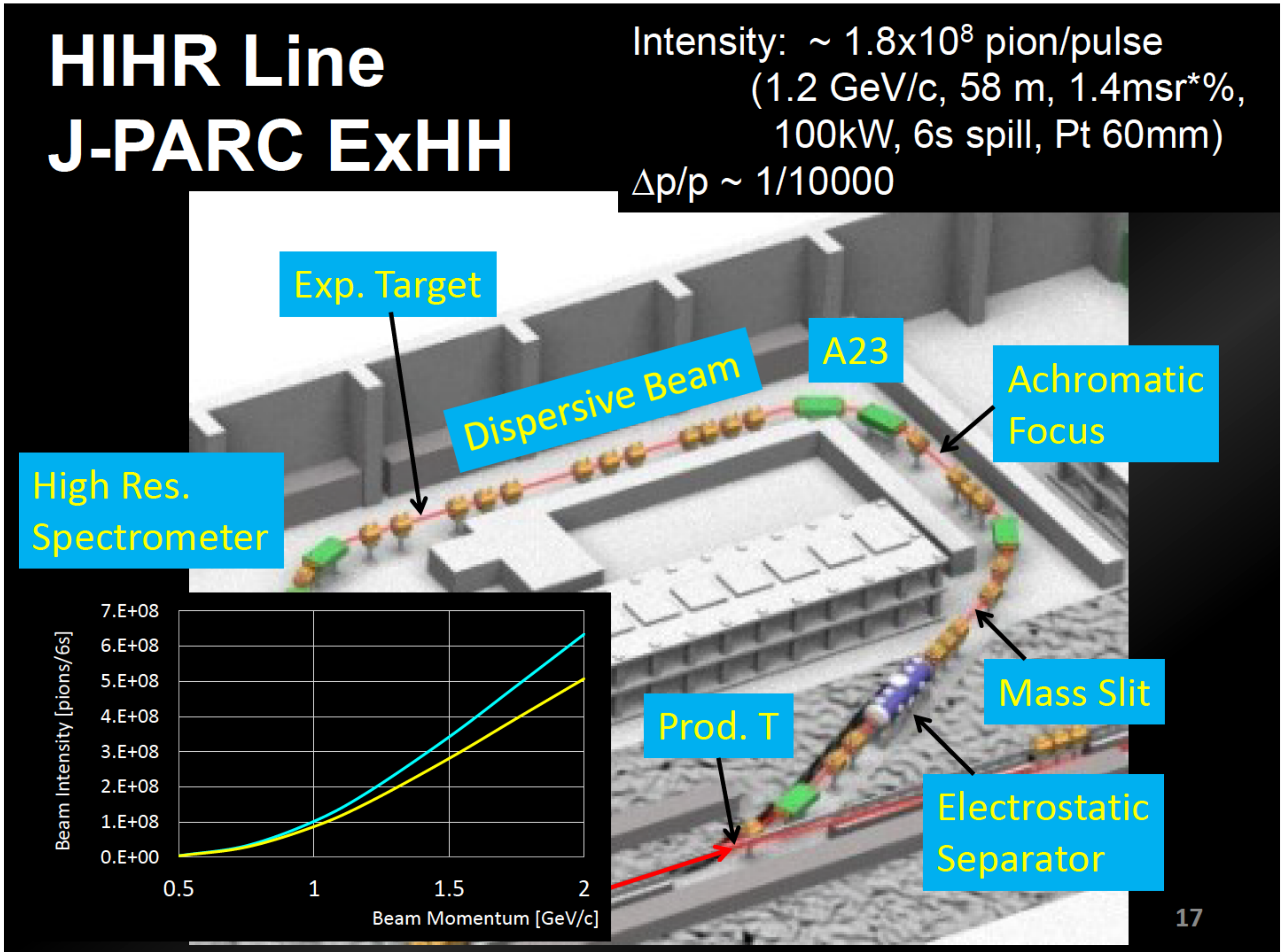


(in a planning stage)

J-PARC HIHR beamline

high-precision Λ hypernuclear spectroscopy w/ $(\pi^{\pm}, K^{+})$

FWHM: 300keV



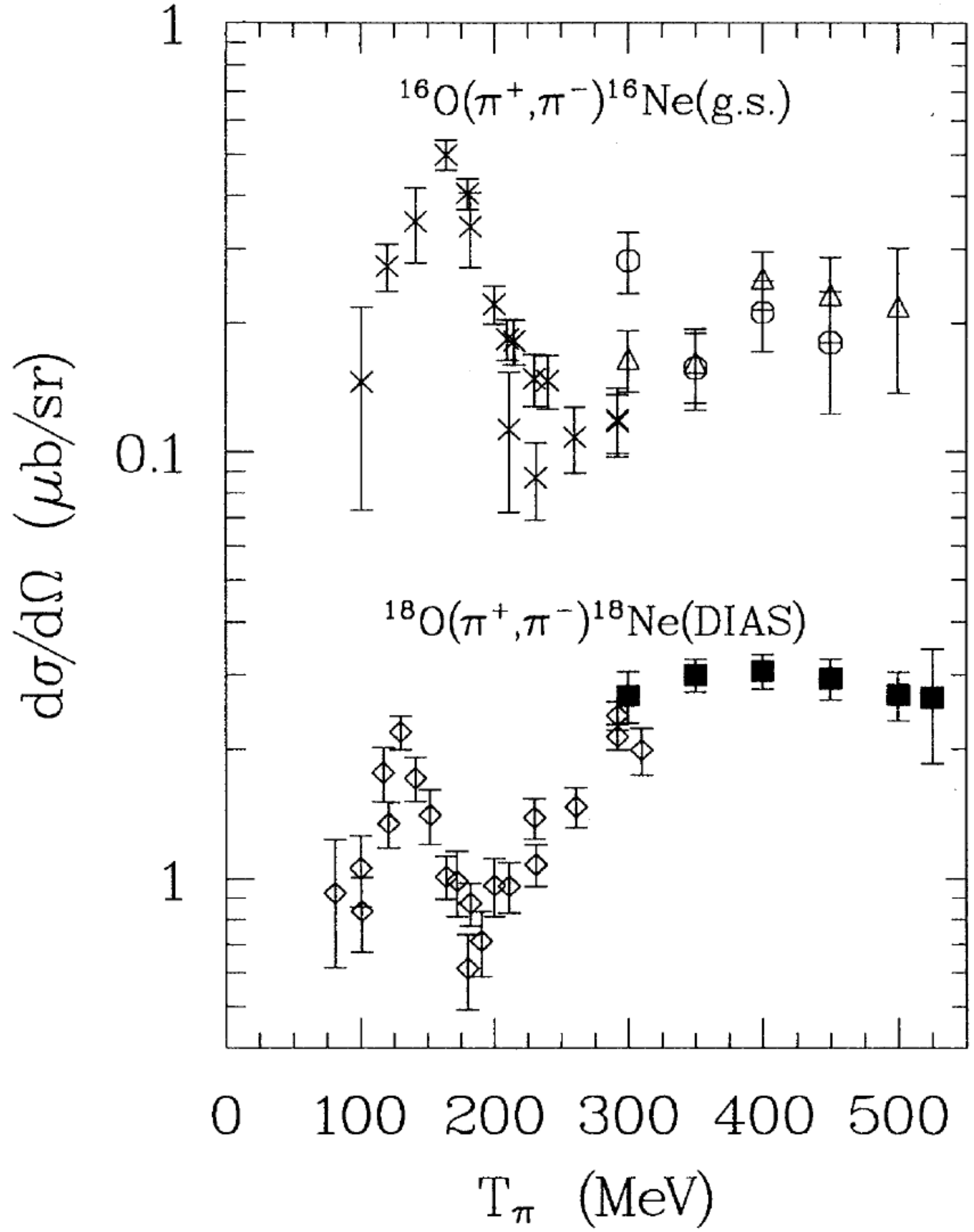
H. Noumi, "International workshop on physics at the extended hadron experimental facility of J-PARC"

experimental condition (tentative)

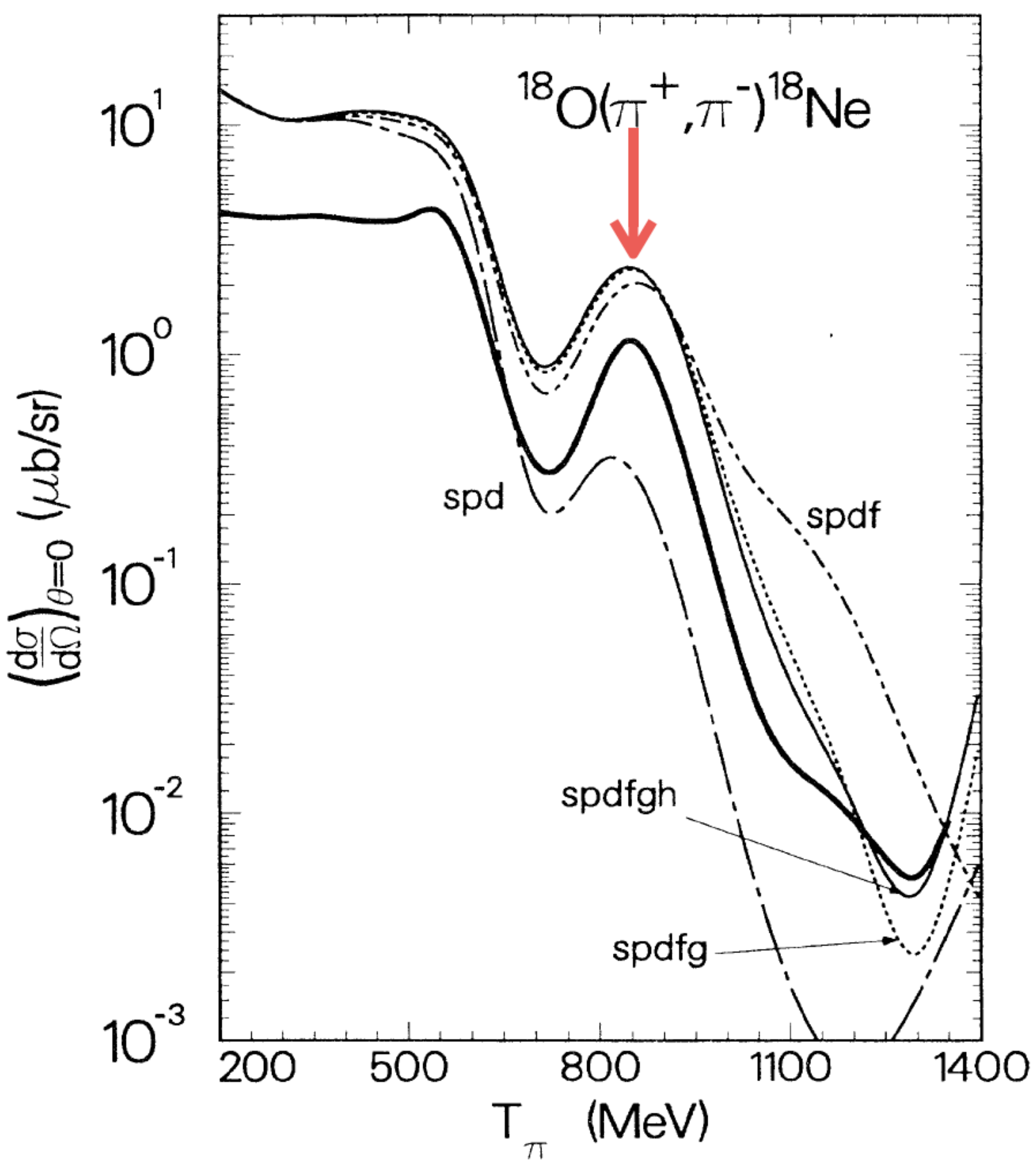
- 850MeV π^- beam
- beam intensity ~1.6×10^8 / spill (Sanford-Wang formula)
- momentum transfer ~ 31MeV/c
- With 2 g/cm^2 liquid ^4He target,
  formation cross section 1nb/sr ⇒ 97 events in 2 weeks

pion DCX reaction above Δ region

available data < 550MeV (LAMPF)



theory



D.P. Beatty et al., PRC 48, 1428 (1993) *E. Oset and D. Strottman, PRL 70, 146 (1993)*

phase-0 experiment

Letter of Intent for J-PARC 50 GeV Synchrotron

Investigation of Pion Double Charge Exchange Reaction with S-2S Spectrometer

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Department of Physics, Kyoto University

T. Fukuda and T. Harada
Osaka Electro-Communication University

E. Hiyama, K. Itahashi, and T. Nishi
RIKEN Nishina Center

(Dated: June 27, 2016)

We will study pion double charge exchange $(\pi^{\pm}, \pi^{\mp})$ reactions with approximately 850 MeV (980 MeV/c) π beams at J-PARC. The ultimate goal is to search for a tetraneutron resonance state (^{4}n), whose candidates have been observed in the ^{4}He(^{8}He, ^{8}Be) reaction at RIBF. First of all, an analog transition, the ^{18}O$(\pi^+, \pi^-)^{18}$Ne (g.s.) reaction, will be investigated at the existing K1.8 beamline with the S-2S spectrometer. It will be an important step toward a non-analog transition, the ^{4}He$(\pi^-, \pi^+)^4$n reaction, with much smaller cross section.

phase-0 experiment

- $^{18}O(\pi^+, \pi^-)^{18}Ne_{(g.s.)}$ at existing K1.8 beamline
  - + S-2S spectrometer (constructed for Ξ-hypernuclear spectroscopy)
  - first investigation far above Δ-resonance region
  - large cross section expected (because of analog transition)
    - cf. ^4He (I=0) → ^4n (I=2) : non-analog transition
  - 400 counts per day (with 10^7 π^+/spill impinging on 2 g/cm^2 $H_2{}^{18}O$ target)

conclusion

- Recent observation of tetraneutron bound/resonance states challenges our understanding on nuclear force and few-body systems.

- From an experimental point of view, an independent approach with a different reaction will be meaningful.

- We propose to investigate the pion double charge exchange reaction with T_{π} ~ 850 MeV at J-PARC.

- As phase-0, we will examine an analog transition ($^{18}O \rightarrow ^{18}Ne$) at K1.8 beamline with S-2S spectrometer.