Search for the tetra-neutron:

A four-neutron system probed via α-knockout from ^{8}He

Meytal Duer

July 19th, INT

"Observation of a correlated free four-neutron system"
MD et al., Nature 606, 678 (2022)

Tetra-neutron: Why ?

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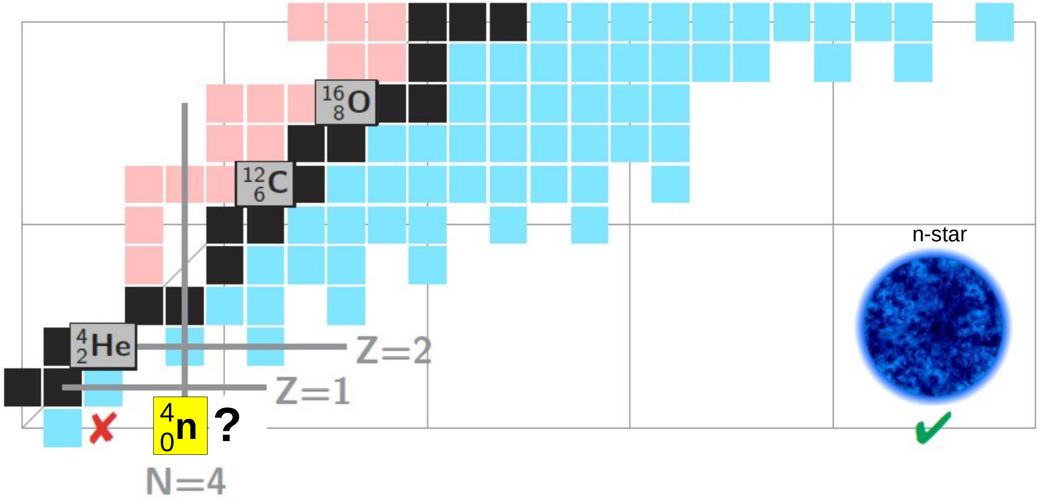
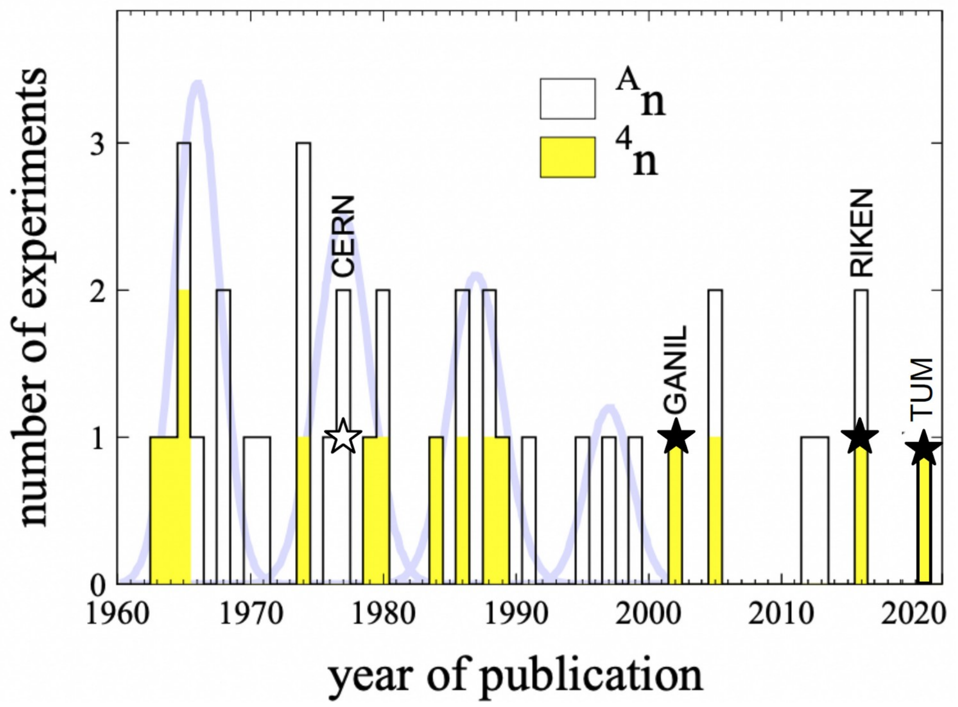


Figure from Marqués, EPJP 136 (2021)

- NN, NNN, NNNN interactions
  - ➔ neutron-neutron interaction
  - ➔ 3-body force
- Fundamental test for ab initio type calculations
- Implications for neutron-rich matter – neutron stars

A 60-year quest



XX century:

- fission of uranium
  e.g. Schiffer & Vandenbosch, Phys. Lett. 5 (1963)
- transfer reactions
  e.g. Cerny et al., Phys. Lett. 53B (1974)
- double-charge-exchange ^{4}He(π^-,π^+) reaction
  e.g. Ungar et al., Phys. Lett. B 144 (1984)

XXI century:

- radioactive-ion beams
  - 3 positive signals:

★ GANIL 2002, RIKEN 2016, Munich 2022*

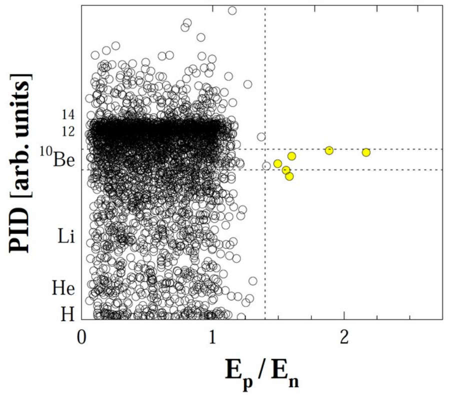
* stable beam

Modified from Marqués & Carbonell, EPJA 57 (2021)

Indications for a tetra-neutron

GANIL 2002

Breakup on a C target:
$^{14}Be \rightarrow {}^{10}Be + {}^{4}n$



6 candidates: bound ^{4}n or low-energy resonance (E_r<2 MeV)

2σ significance

Marqués et al., PRC 65 (2002)
Marqués et al., arXiv:nucl-ex/0504009 (2005)

RIKEN 2016

Double-charge-exchange:
$^{8}He(^{4}He,{}^{8}Be)^{4}n$

4 candidates for ^{4}n resonance: E_r=0.8±1.4 MeV, Γ<2.6 MeV

4.9σ significance

Kisamori et al., PRL 116 (2016)

Munich 2022

Multi-nucleon transfer:
$^{7}Li(^{7}Li,{}^{10}C)^{4}n$

~10 candidates for bound ^{4}n: BE=0.42±0.16 MeV

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Faestermann et al., PLB 824 (2022)

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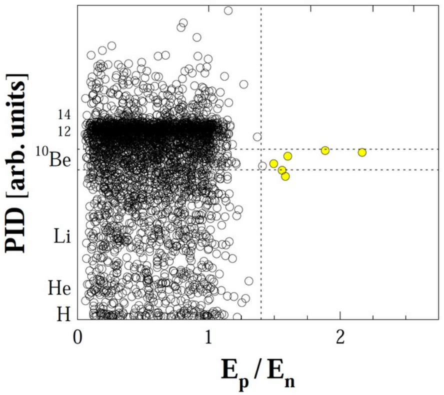

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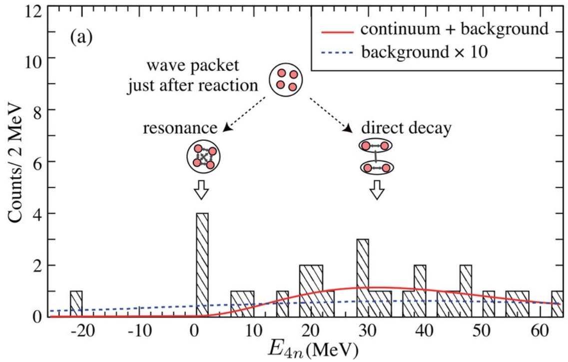

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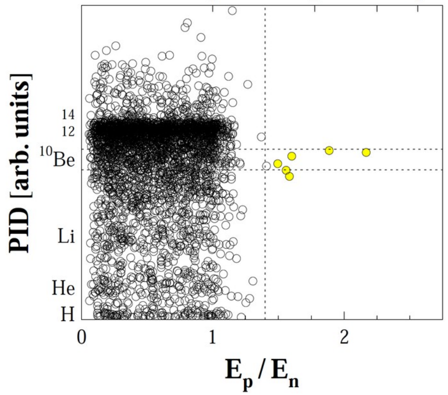

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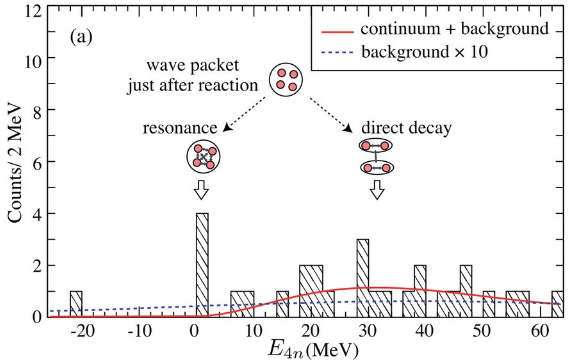

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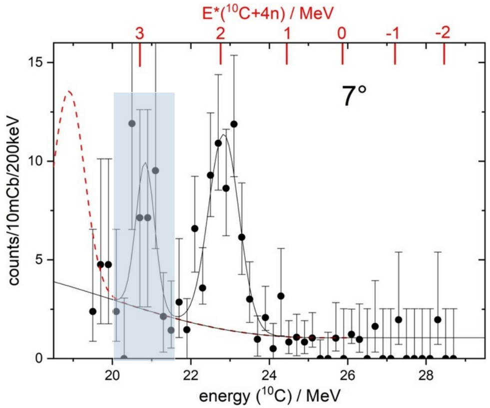

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Present experimental work

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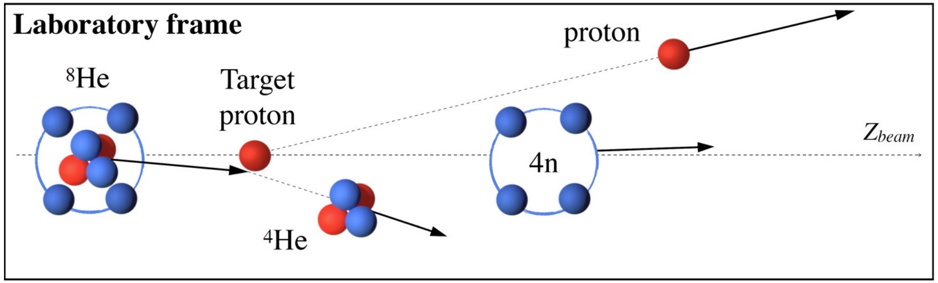
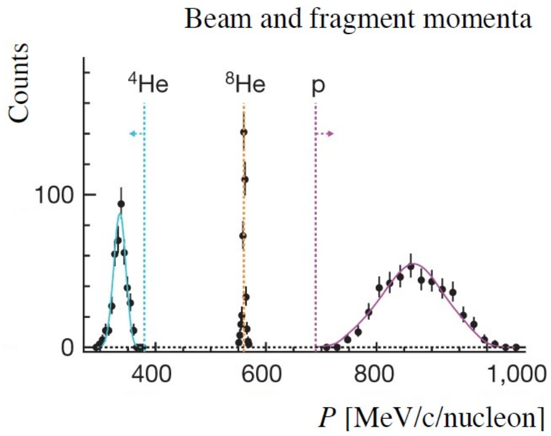
Method: ^{8}He(p,p^{4}He) quasi-elastic knockout

- High-energy 156 MeV/nucleon
- ^{8}He is a good starting point:
  - pronounced α-core structure
  - **large overlap $\langle ^8\mathrm{He}|\alpha\otimes 4n\rangle$**
- Large momentum transfer
  - "recoil-less" production





SAMURAI

RIKEN NISHINA CENTER

Results: energy spectra

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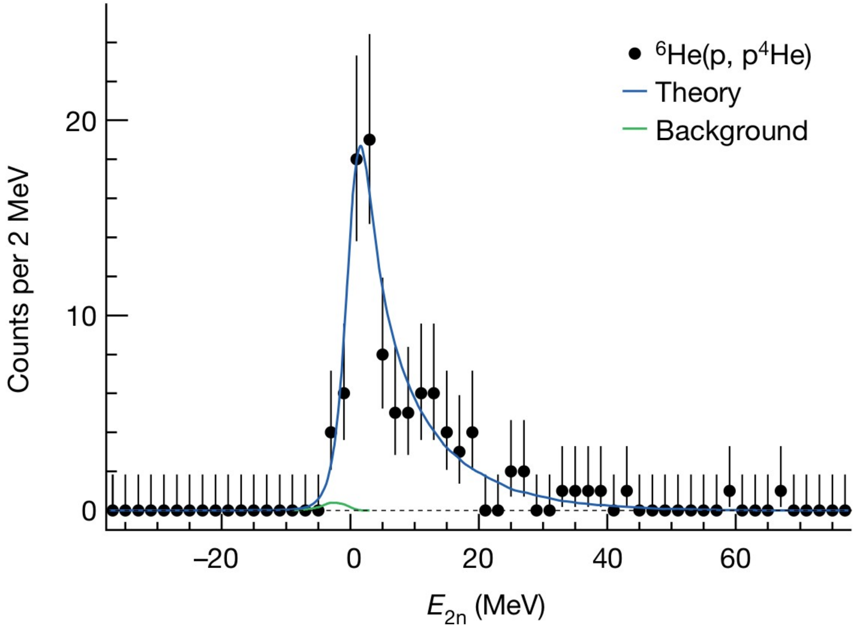
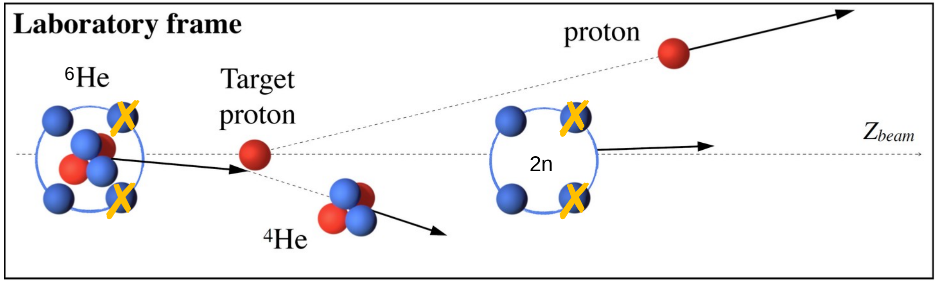
benchmark reaction - ^{6}He(p,p^{4}He)





Confirms the expected di-neutron low-energy peak ~100 keV

MD et al., Nature 606, 678 (2022)

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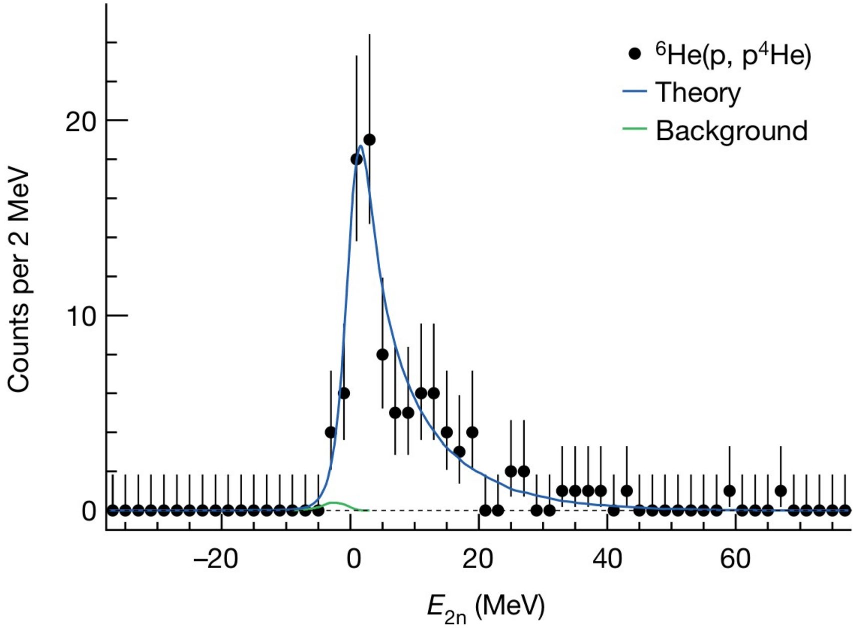

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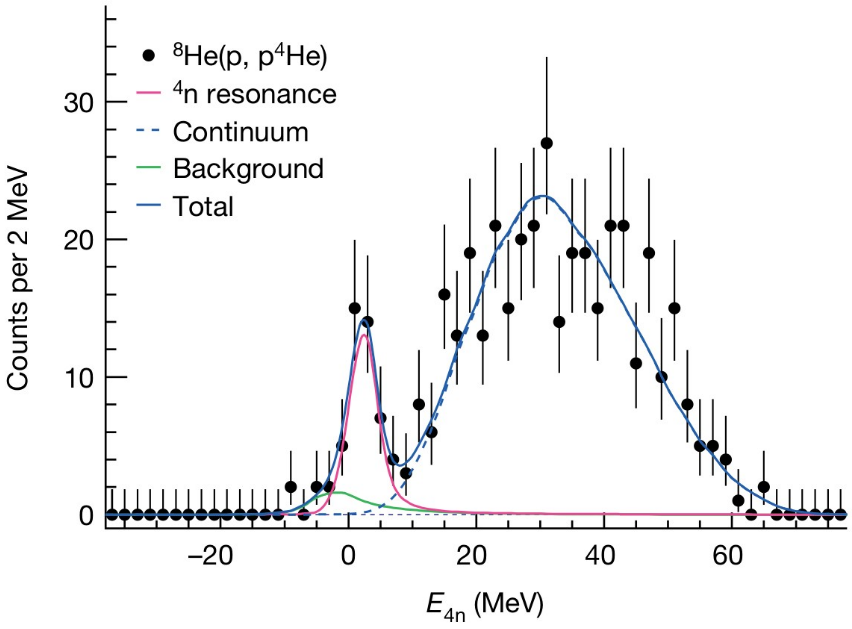
$^{8}He(p,p^{4}He)$ – four neutron system



Resonance like-structure:

E_r = 2.37±0.38(stat.)±0.44(sys.) MeV

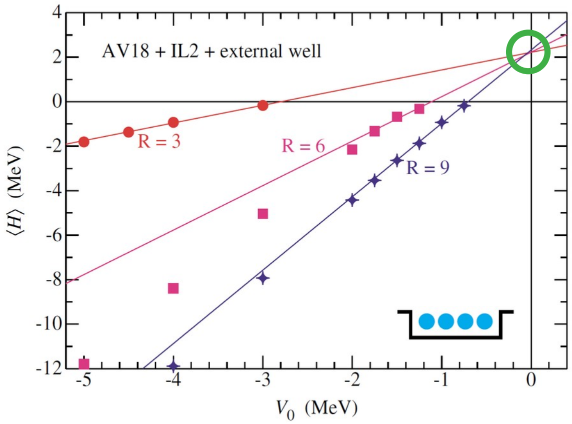
Γ = 1.75±0.22(stat.)±0.30(sys.) MeV

MD et al., Nature 606, 678 (2022)

What do theories say ?

Overall consensus: **no bound tetra-neutron**

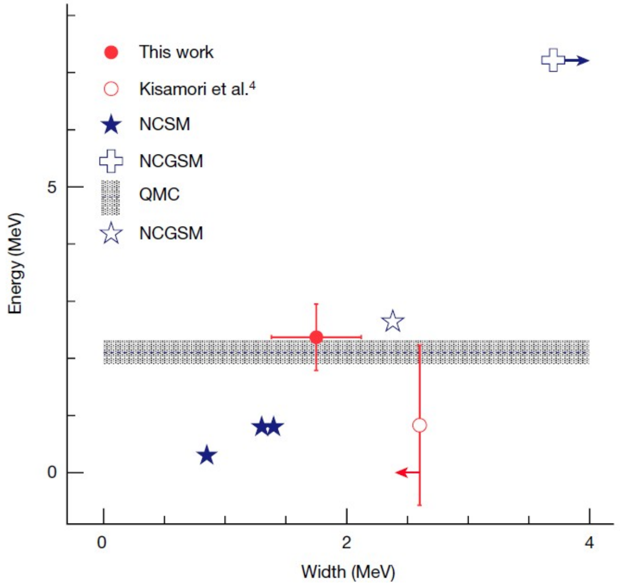
What about a resonance?



“there might be a ^{4}n resonance near 2 MeV, … must be very broad”

S. Pieper, PRL 90 (2003)

What do theories say ?



MD et al., Nature 606, 678 (2022)

Predictions for a resonance:

- NCSM: Shirokov PRL 117 (2016);
- QMC: Gandolfi PRL 118 (2017);
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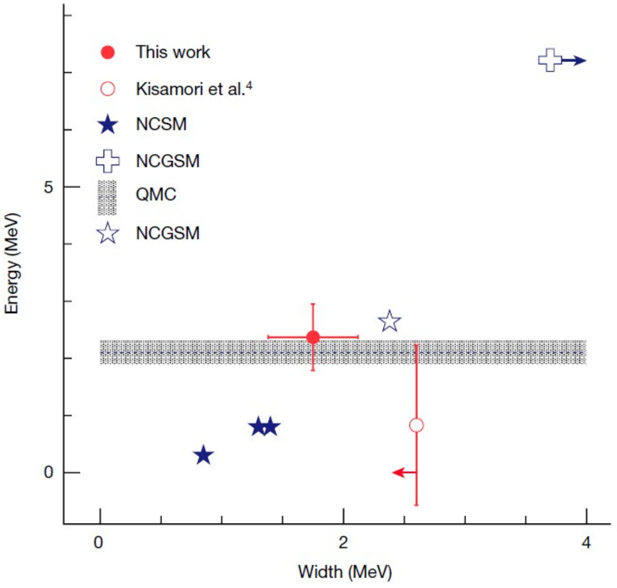

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Sofianos JPG 23 (1997); Deltuva PRL 123 (2019);
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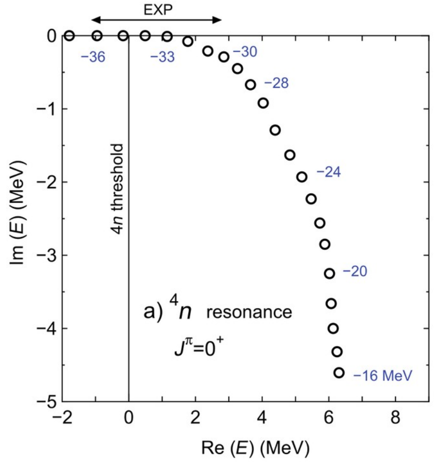

- **huge strength parameter of T = 3/2 3BF**
- 15 times larger than for T = 1/2
- inconsistent with data of light nuclei

What do theories say ?

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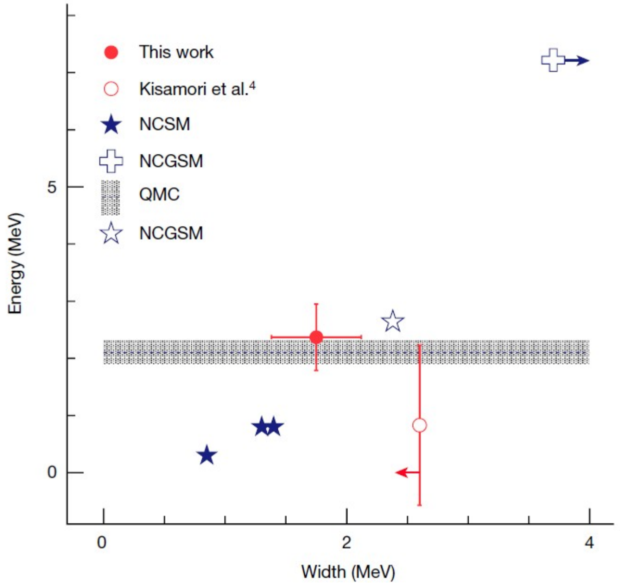

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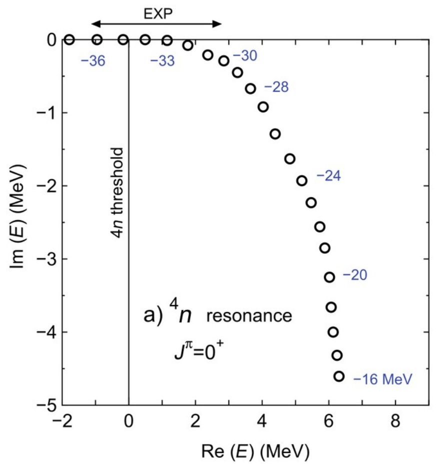

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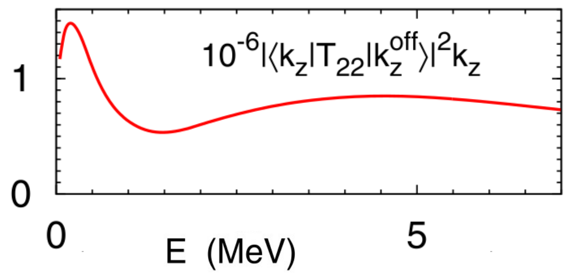

- **Low-energy enhancement** of some transtion operators
- Explain signal in ^{8}He(^{4}He,^{8}Be)^{4}n reaction? (RIKEN 2016)
- Has to be combined with reaction mechanism

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- Quasi-elastic ^{8}He(p,pα) reaction at large momentum transfer to probe a 4n system in a recoil-less condition
- An experimental observation of a resonance-like structure
- Further calculations are needed to understand the low-energy peak observed and its origin
- Possible implications on the EOS at low-density

Thank you!

Article

Observation of a correlated free four-neutron system

M. Duer[1✉], T. Aumann[1,2,3], R. Gernhäuser[4], V. Panin[2,5], S. Paschalis[1,6], D. M. Rossi[1], N. L. Achouri[7], D. Ahn[5,16], H. Baba[5], C. A. Bertulani[8], M. Böhmer[4], K. Boretzky[2], C. Caesar[1,2,5], N. Chiga[5], A. Corsi[9], D. Cortina-Gil[10], C. A. Douma[11], F. Dufter[4], Z. Elekes[12], J. Feng[13], B. Fernández-Domínguez[10], U. Forsberg[6], N. Fukuda[5], I. Gasparic[1,5,14], Z. Ge[5], J. M. Gheller[9], J. Gibelin[7], A. Gillibert[9], K. I. Hahn[15,16], Z. Halász[12], M. N. Harakeh[11], A. Hirayama[17], M. Holl[1], N. Inabe[5], T. Isobe[5], J. Kahlbow[1], N. Kalantar-Nayestanaki[11], D. Kim[16], S. Kim[1,16], T. Kobayashi[18], Y. Kondo[17], D. Körper[2], P. Koseoglou[1], Y. Kubota[5], I. Kuti[12], P. J. Li[19], C. Lehr[1], S. Lindberg[20], Y. Liu[13], F. M. Marqués[7], S. Masuoka[21], M. Matsumoto[17], J. Mayer[22], K. Miki[1,18], B. Monteagudo[7], T. Nakamura[17], T. Nilsson[20], A. Obertelli[1,9], N. A. Orr[7], H. Otsu[5], S. Y. Park[15,16], M. Parlog[7], P. M. Potlog[23], S. Reichert[4], A. Revel[7,9,24], A. T. Saito[17], M. Sasano[5], H. Scheit[1], F. Schindler[1], S. Shimoura[21], H. Simon[2], L. Stuhl[16,21], H. Suzuki[5], D. Symochko[1], H. Takeda[5], J. Tanaka[1,5], Y. Togano[17], T. Tomai[17], H. T. Törnqvist[1,2], J. Tscheuschner[1], T. Uesaka[5], V. Wagner[1], H. Yamada[17], B. Yang[13], L. Yang[21], Z. H. Yang[5], M. Yasuda[17], K. Yoneda[5], L. Zanetti[1], J. Zenihiro[5,25] & M. V. Zhukov[20]

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