

The (d,p) reaction on ^{11}Be using ISS: Bringing clarity to our understanding of the structure of ^{12}Be

Jie Chen

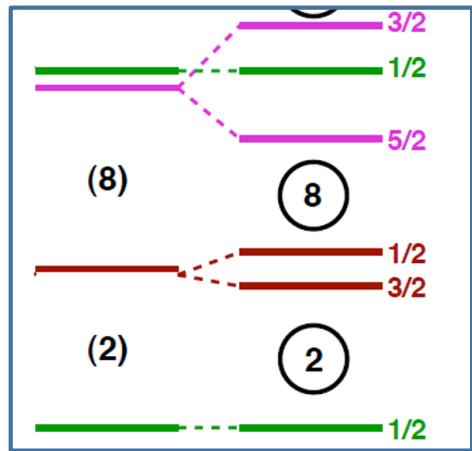
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HIE-ISOLDE Physics Workshop 2023



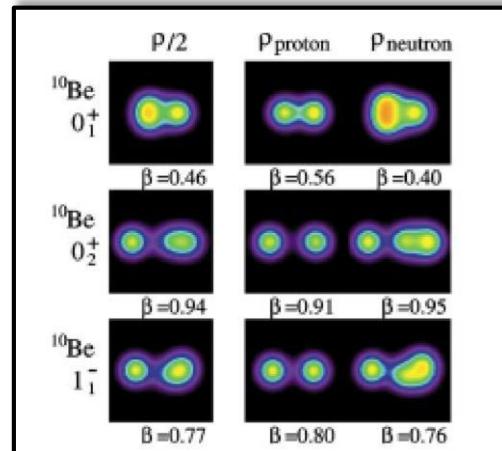
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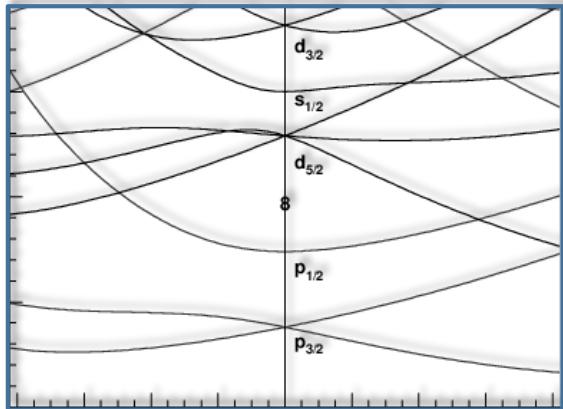
Be isotopes



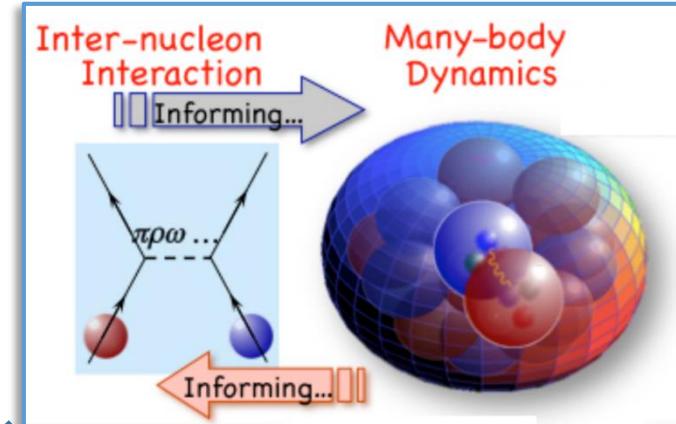
Shell model



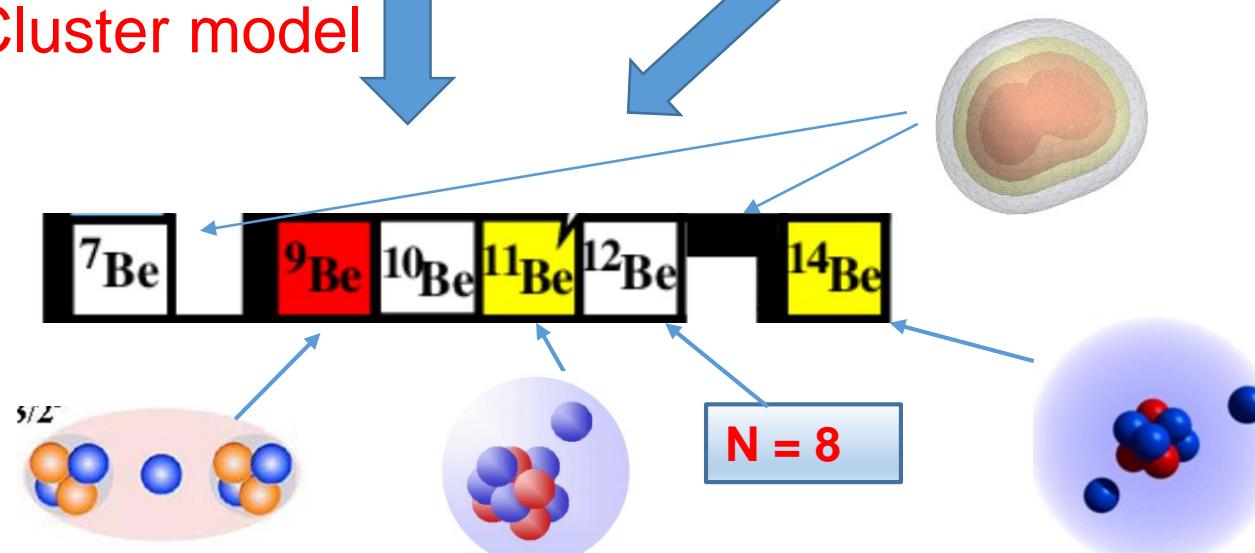
Cluster model



Nilsson model



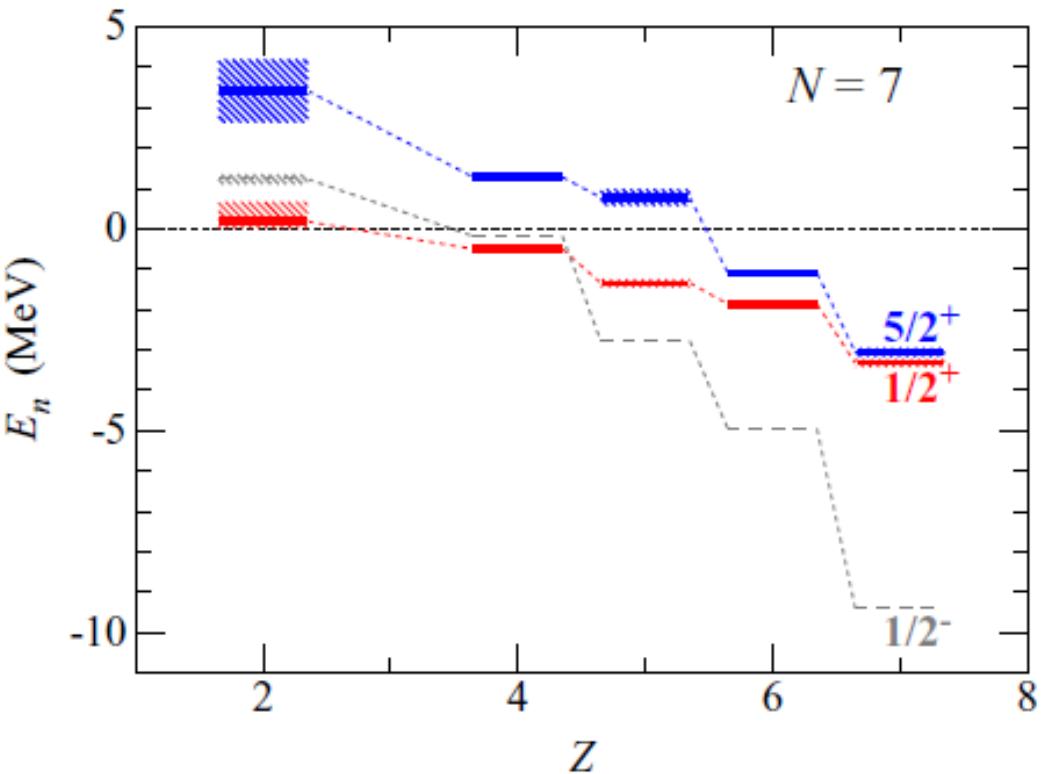
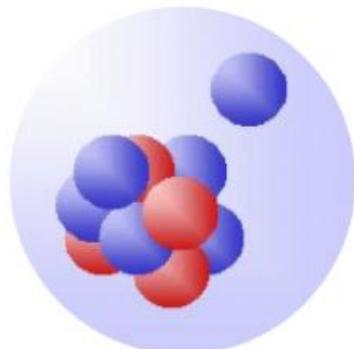
ab-initio



One-neutron halo nucleus ^{11}Be

- Neutron loosely bound $S_n=0.504 \text{ MeV}$
- Larger radius $R= 2.91 \text{ fm}$
- ^{10}Be core + 1 valance n
- g.s. $1/2^+$

$^{10}\text{Be} + n (2s_{1/2})$ (60% ~ 80%)



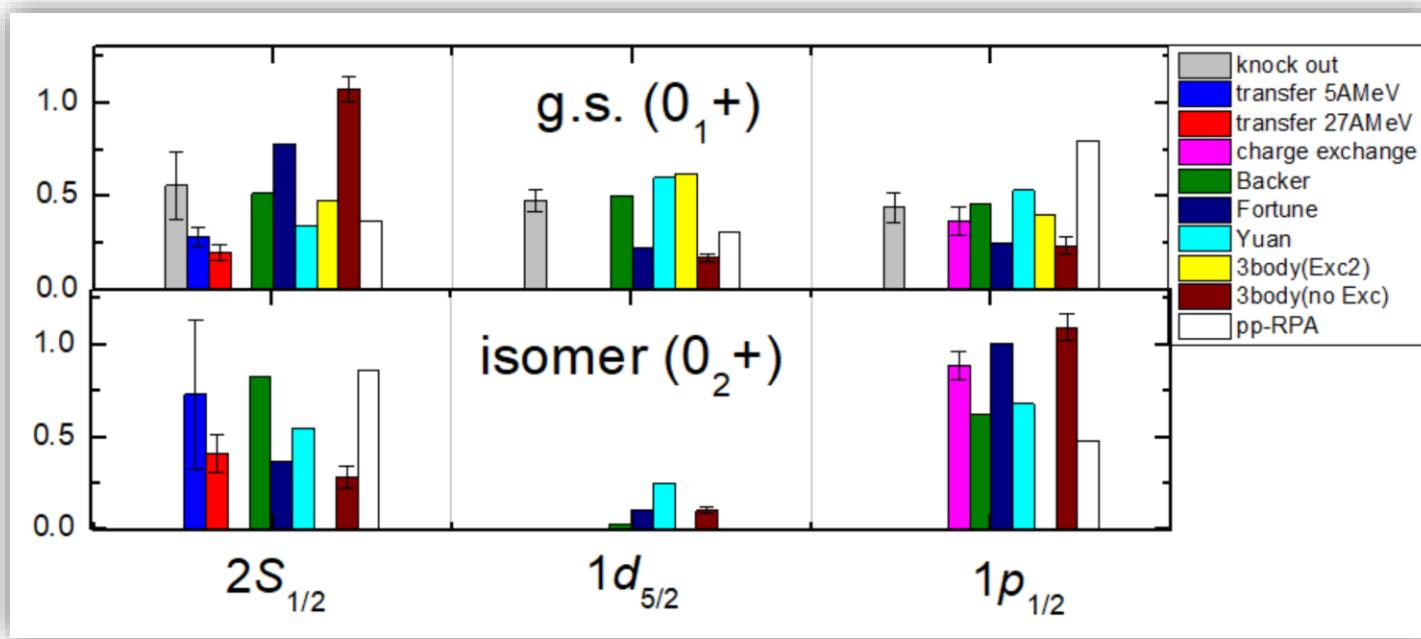
K. T. Schmitt *et al.* Phys. Rev. Lett. 108, 192701 (2012).

T. Aumann *et al.* Phys. Rev. Lett. 84, 35 (2000).

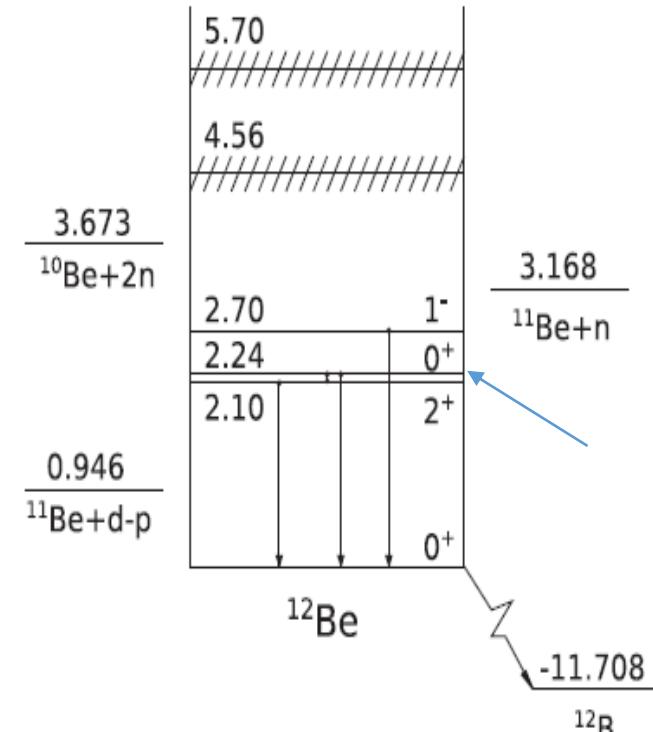
C. R. Hoffman *et al.* Phys. Rev. C 89, 061305(R) (2014)

^{12}Be intruder states and single-particle configuration mixing

- **Breakdown** of conventional magic number: N=8
- **Isomeric state:** 0_2^+ 331(12) ns
- E0 decay: e+e- pair **creation** **511keV** $\gamma \sim 83(2)\%$

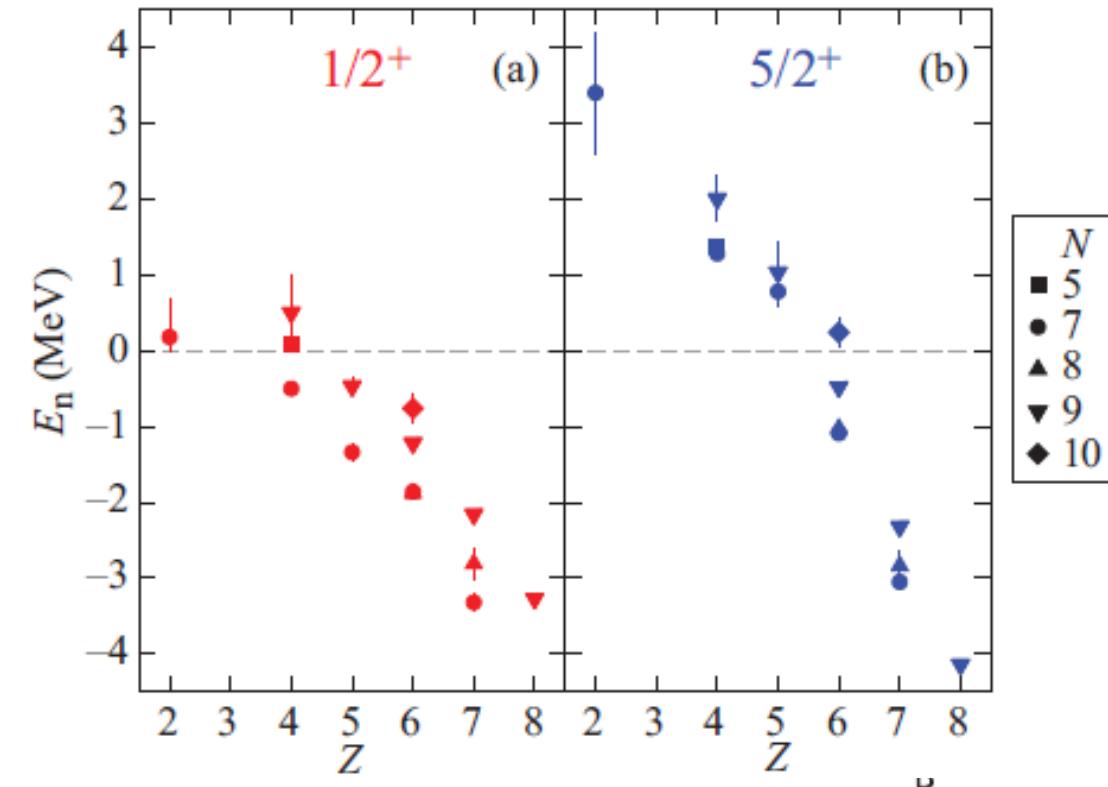
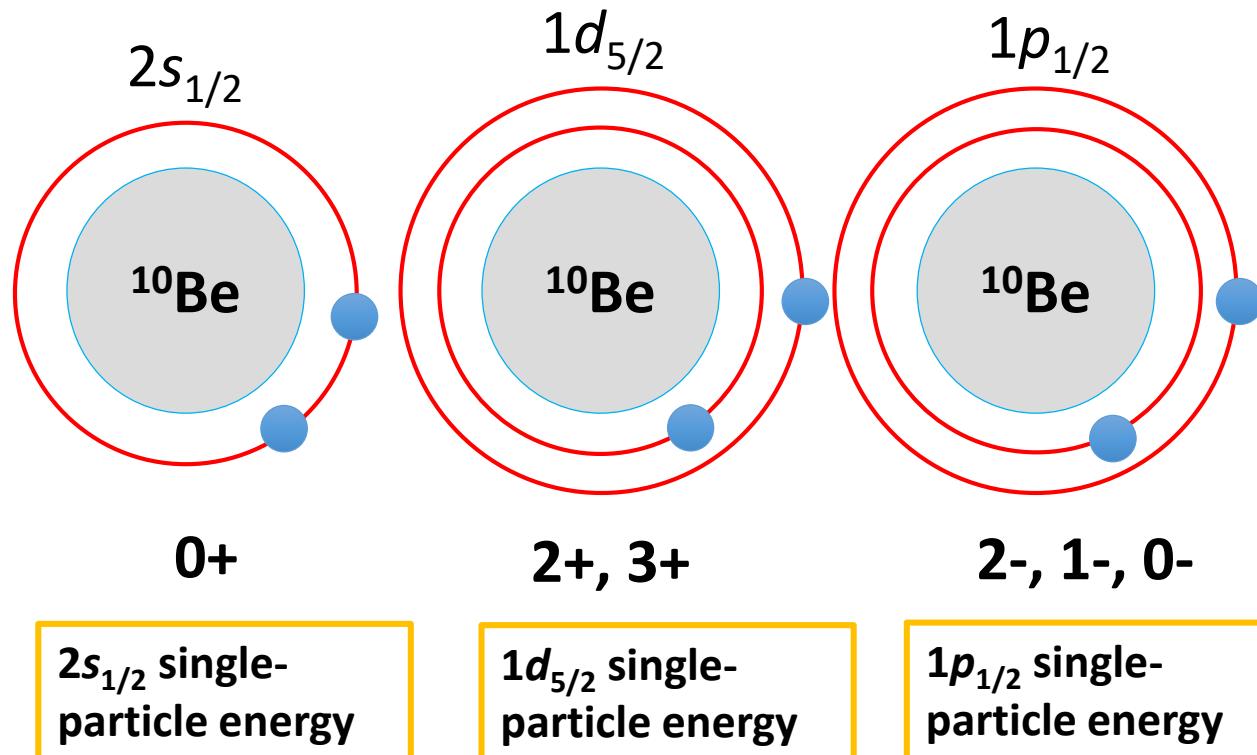


$$|0_i^+\rangle = a_i |1s_{1/2}^2\rangle + b_i |0d_{5/2}^2\rangle + c_i |0p_{1/2}^2\rangle \quad (i = 1, 2)$$



^{12}Be intruder states and single-particle energies

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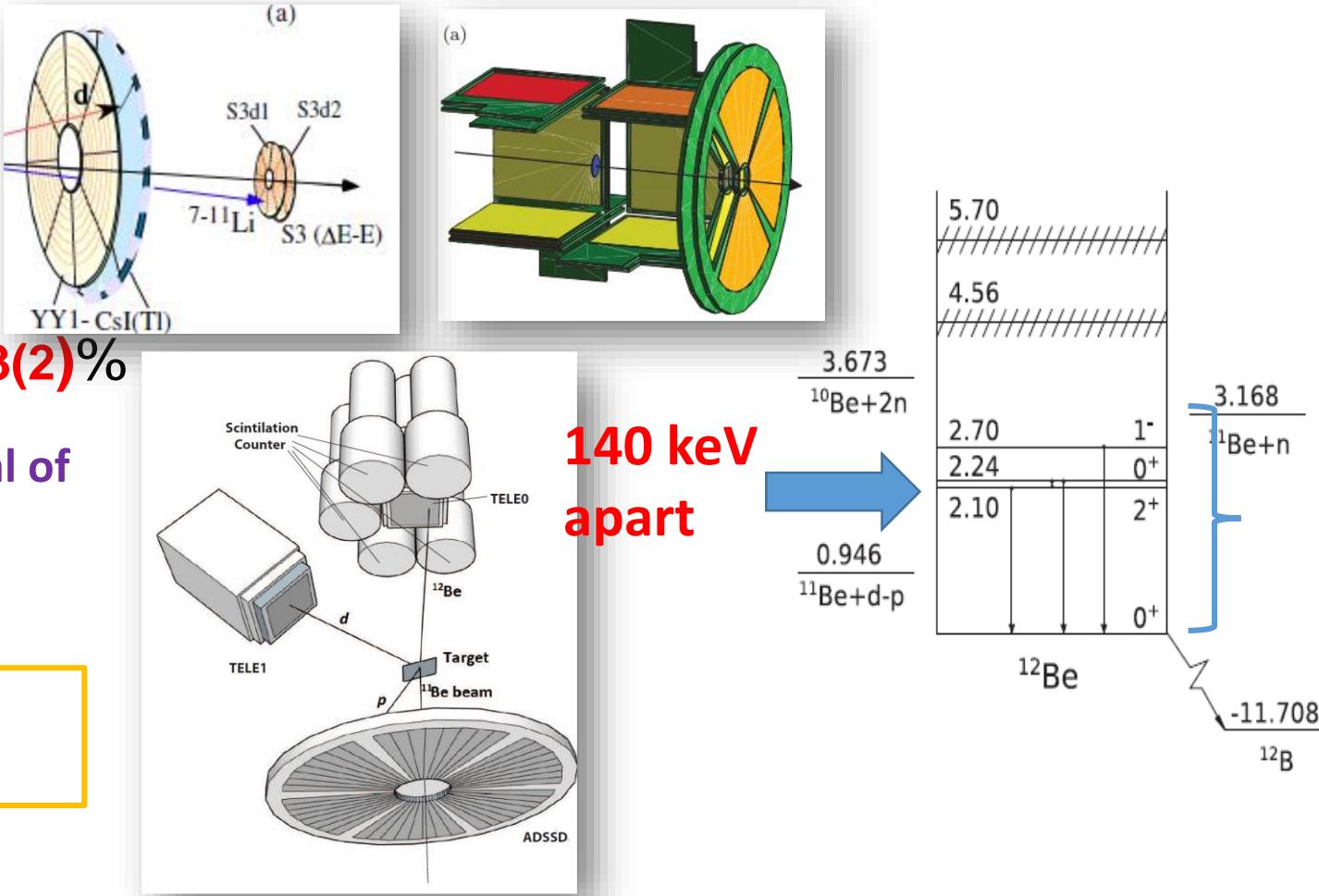
C. R. Hoffman *et al.* Phys. Rev. C 89, 061305(R) (2014)

Previous $^{11}\text{Be}(d,p)$ experiments

- 5 MeV/u TRIUMF
- 2.8 MeV/u ISOLDE
- 26.9 MeV/u RCNP isomer-tagging

E0 decay: e+e- pair creation **511keV $\gamma \sim 83(2)\%$**

Moderate agree on the S of g.s., but a great deal of ambiguities in excited states

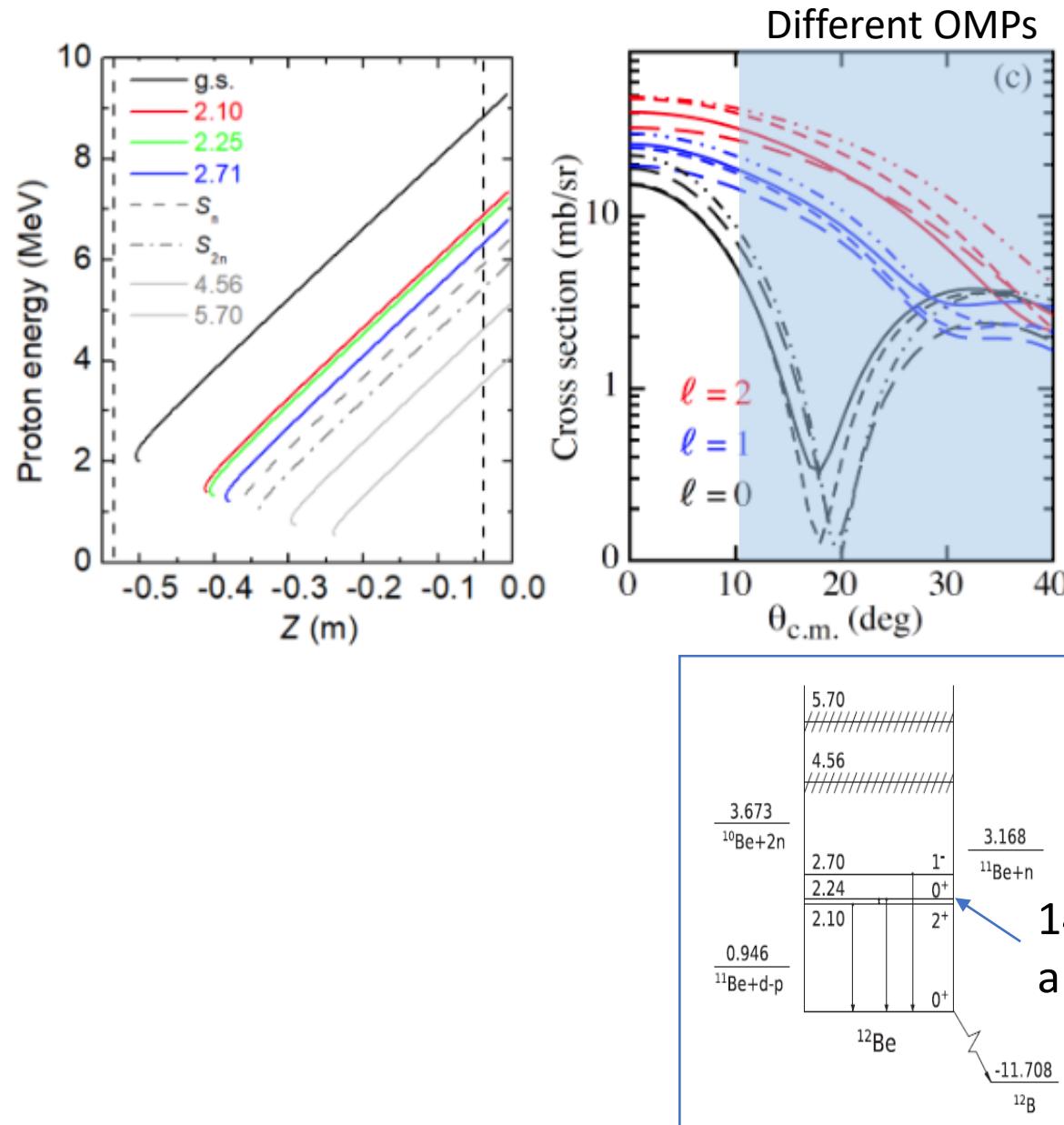


Directly resolve the isomer 0⁺₂ state
Populate the low-lying resonances

ideal energy: 10MeV/u
good energy resolution

ISS & HIE-ISOLDE

Kinematics, cross sections & resolution



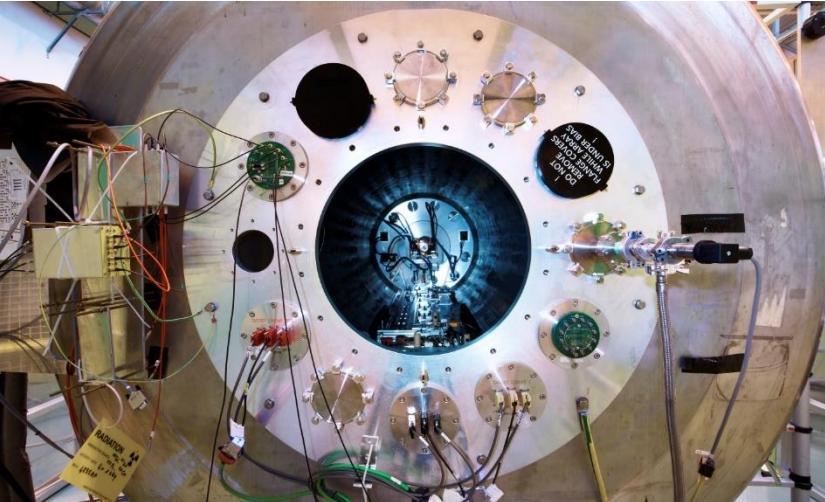
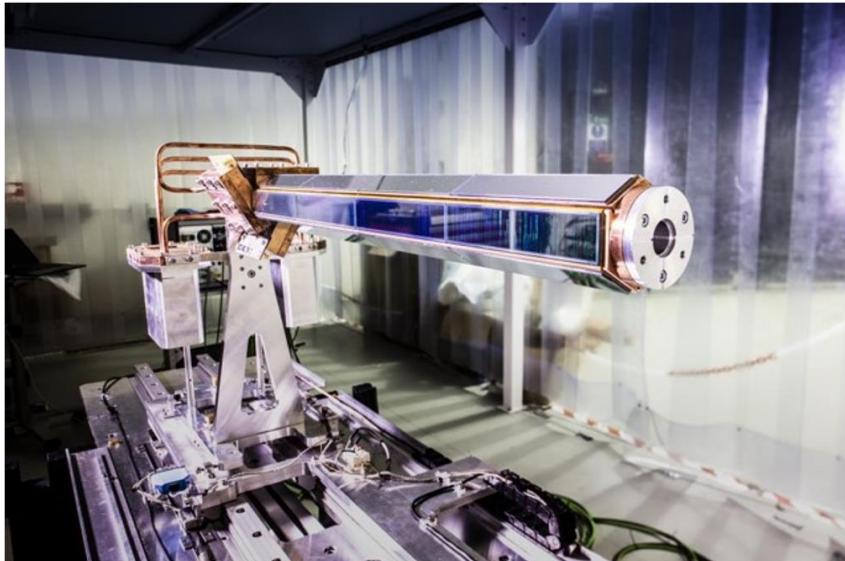
- ELUM detector: normalize cross sections
- Possible beam contaminations ^{22}Ne can be identified by the Recoil detectors
- Target CD_2 100 $\mu\text{g}/\text{cm}^2$

→ good resolution

state	Energy (MeV)	Cross section (mb)	Counts in 15 shifts
0_1^+	g. s.	2.5	200
2^+	2.11	10.1	780
0_2^+	2.24	1.0	80
1^-	2.71	5.6	430

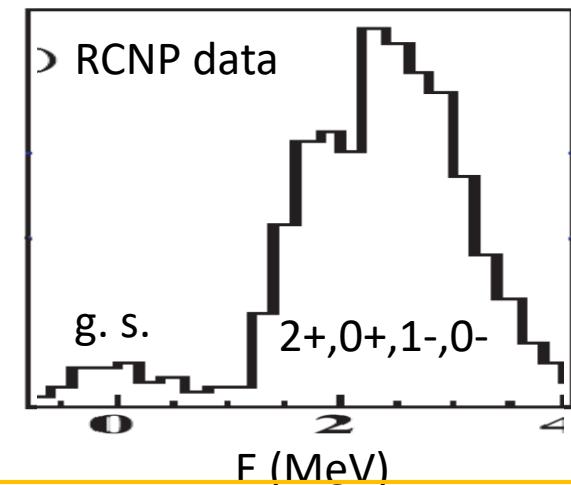
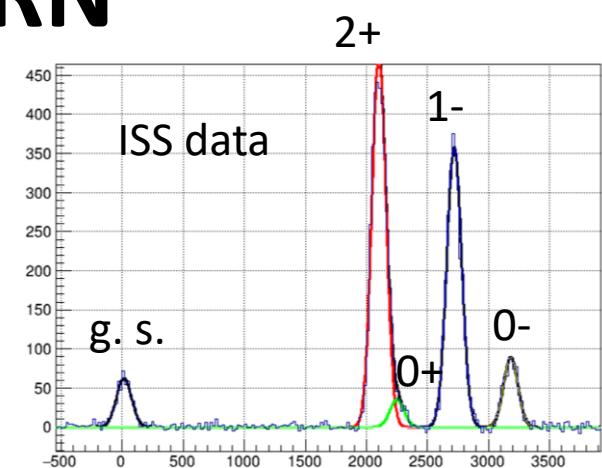
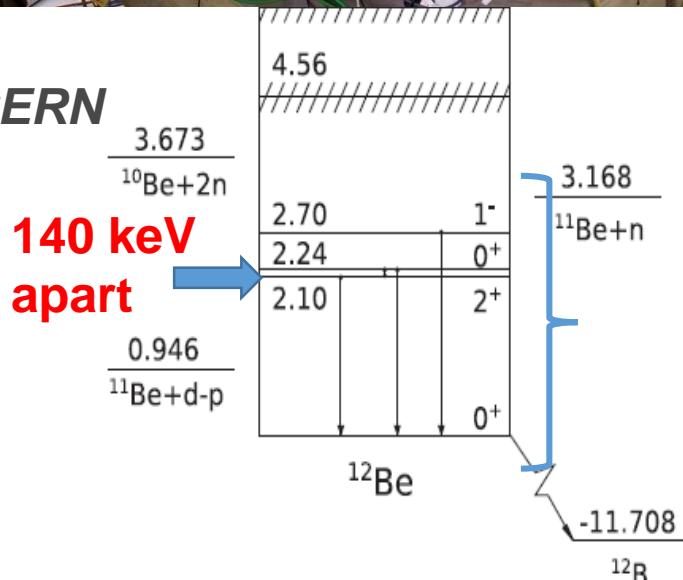
Measurement at ISS & HIE-ISOLDE @CERN

- Directly resolve the isomer 0^+_2 state



ISOLDE Solenoidal Spectrometer at CERN

ideal energy: 9.78 MeV/u
140-keV FWHM resolution

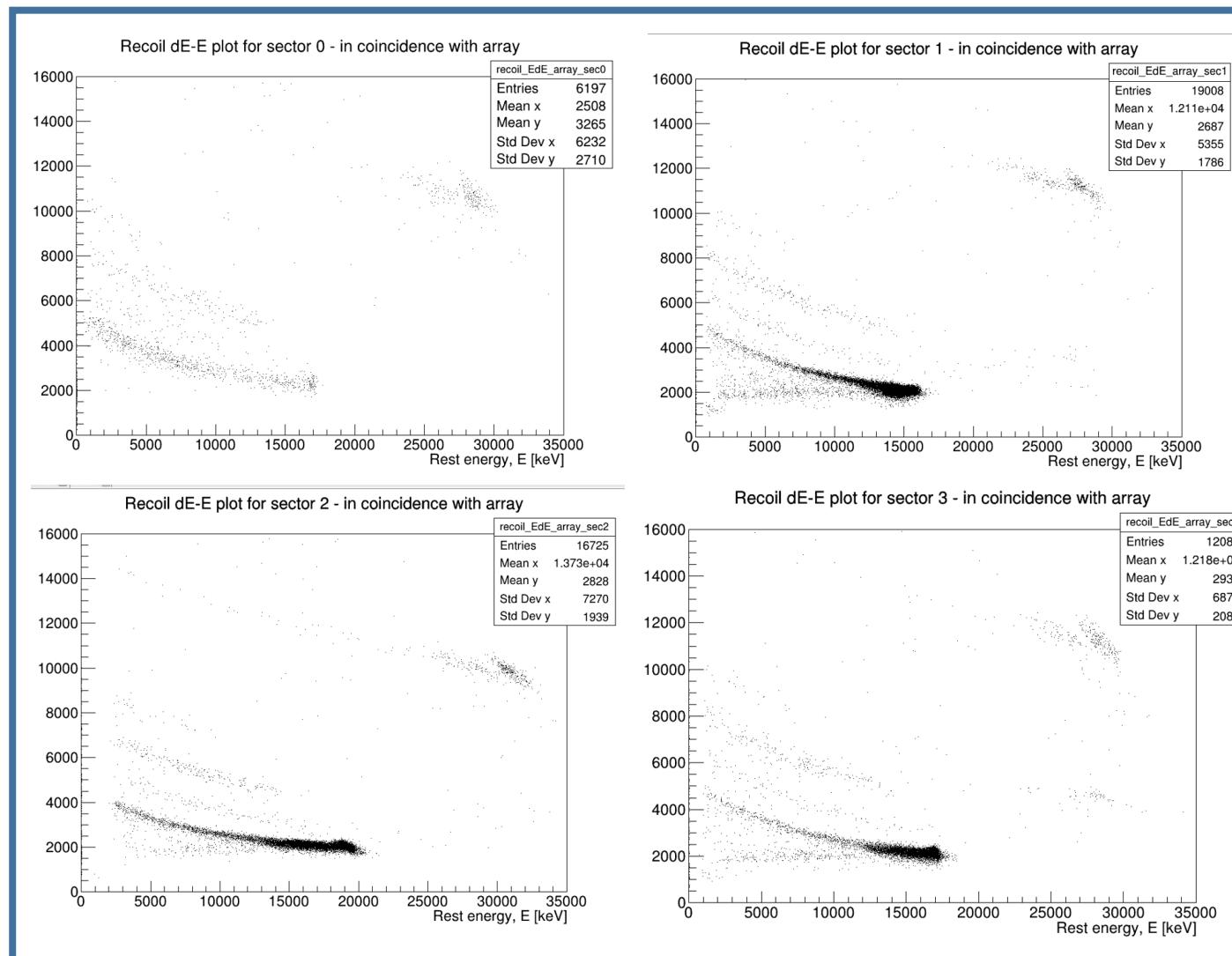
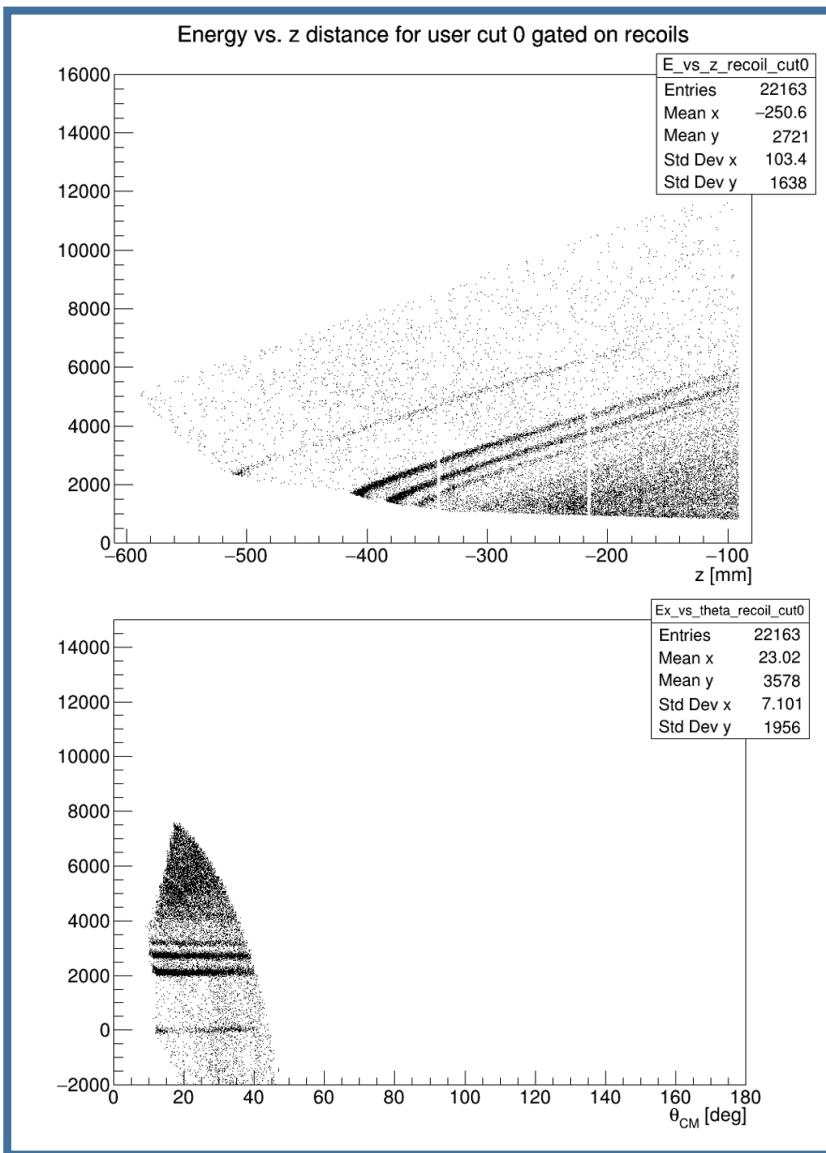


J. Chen *et al.* PLB 781 (2018) 412 – 416

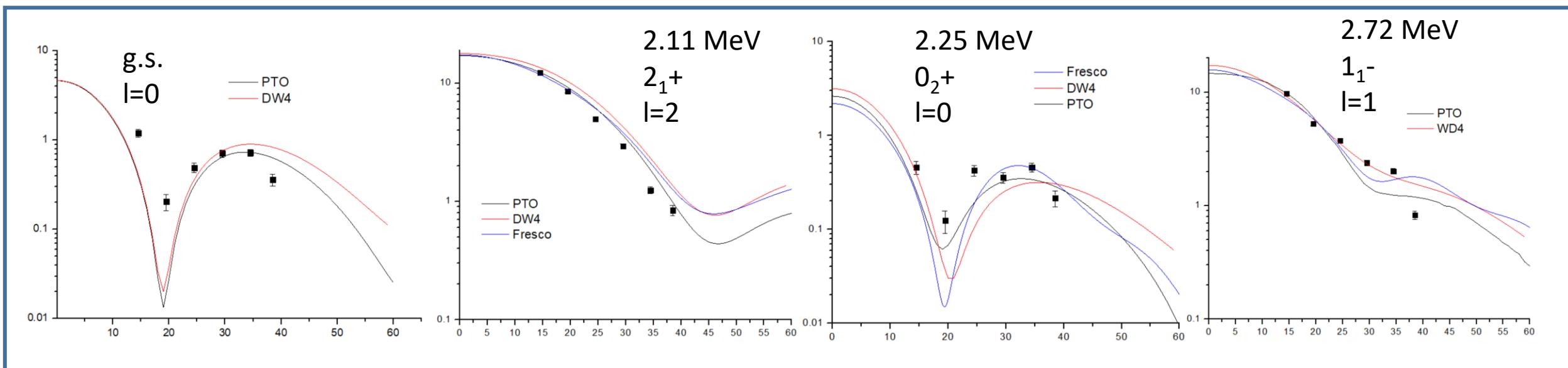
Comparison with conventional silicon array

Data analysis

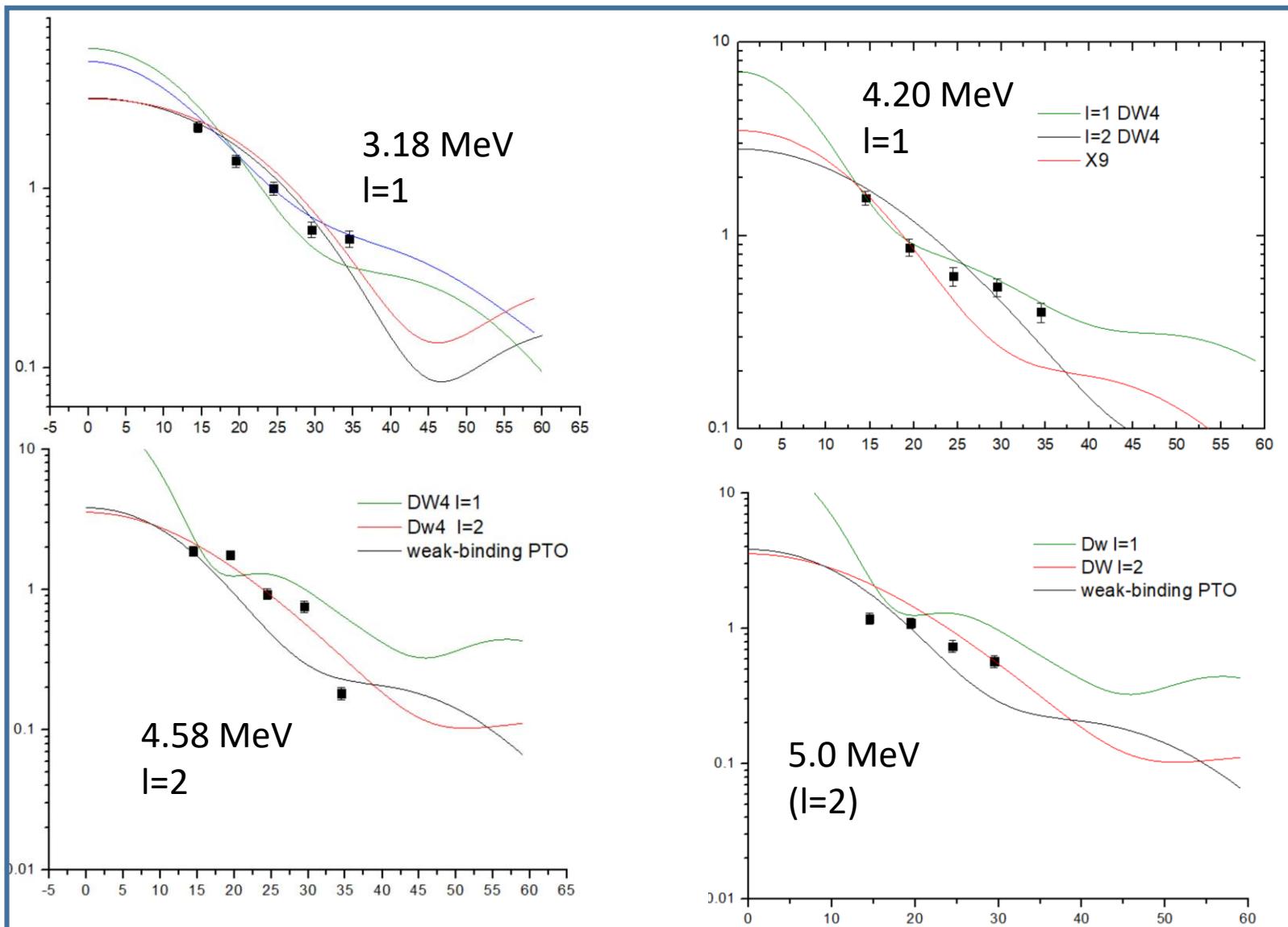
Recoil detectors



Bound states



Unbound states



Previous results of resonances in ^{12}Be

- $^{10}\text{Be}(t,p)^{12}\text{Be}$ reaction

H. T. Fortune, Phys. Rev. C 50, 1355 (1994)

- ^{13}B proton knock out reaction

J. K. Smith, Phys. Rev. C 90, 024309 (2014)

- $^{11}\text{Be}(d,p)$ reaction

J. Chen et al. PLB 781 (2018) 412 – 416

J. Chen et al. Phys. Rev. C L031302 (2021)

Our conclusion:

- There are at lease three resonances around 4-5 MeV in ^{12}Be : 4.2, 4.58, 5.0 MeV
- The 4.20 MeV state is a 2- or 1- state, which was observed for the first time
- The 4.58 MeV state was populated as 2+; There seems to be 2+/3- doublet at around 4.58 MeV.

SOLARIS + ReA
 $^{10}\text{Be}(t,p)^{12}\text{Be}$

B. P. Kay, Y. Ayyad et al.,

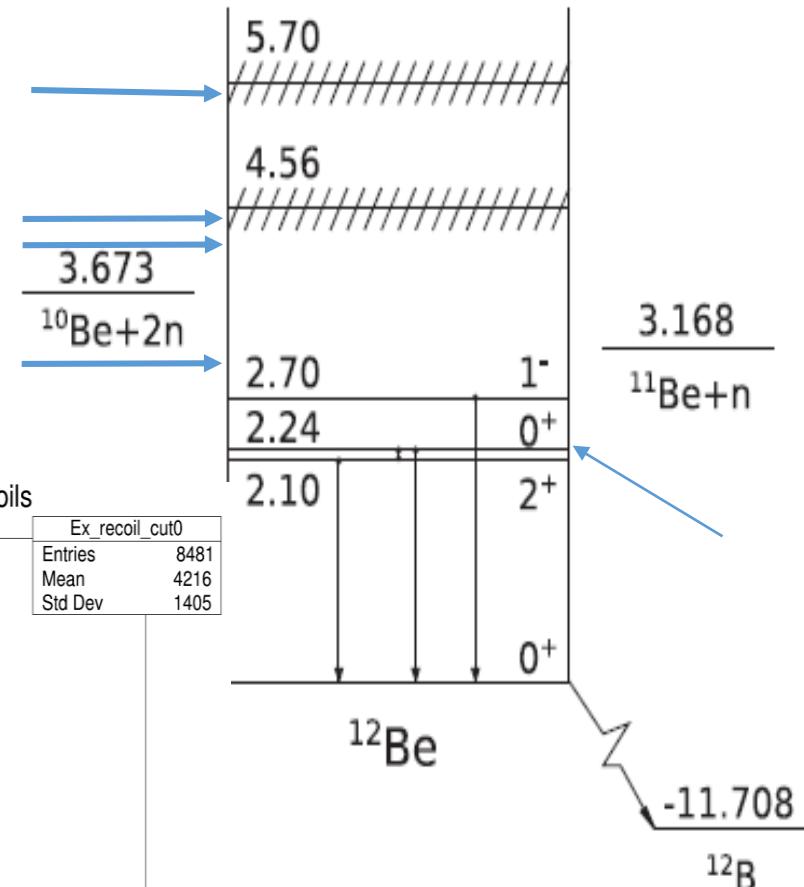
$\Gamma \sim 85 \text{ keV}$

2-? 2+? 3-?

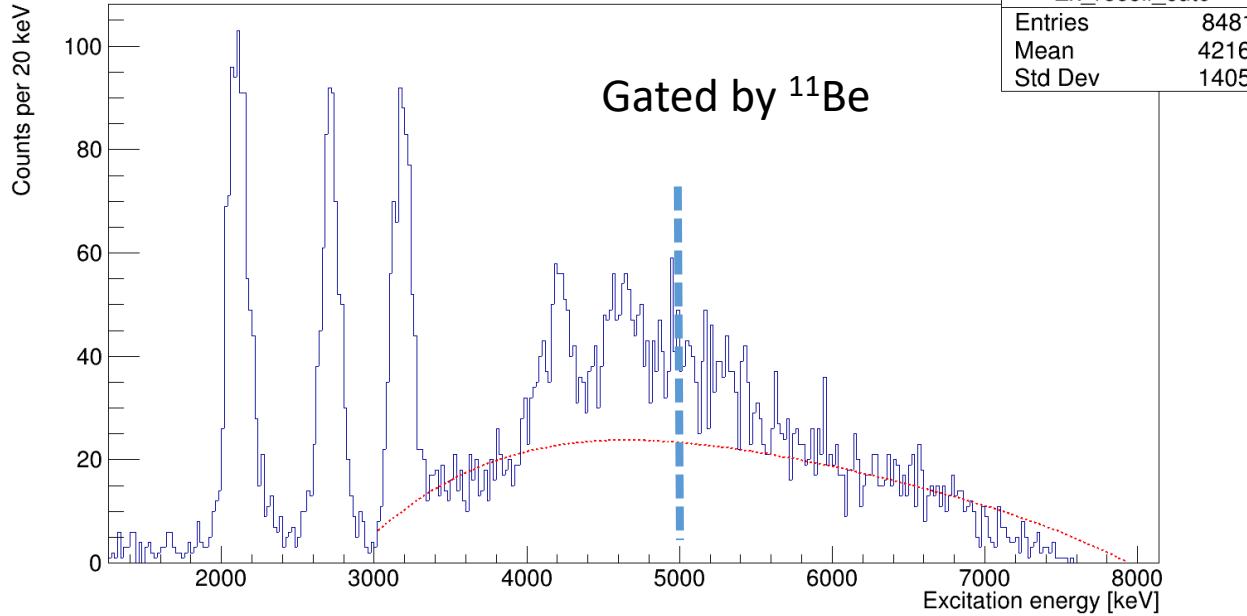
$\Gamma \sim 101 \text{ keV}$
 How many states? $\Gamma \sim 634 \text{ keV}$

0-: just above Sn

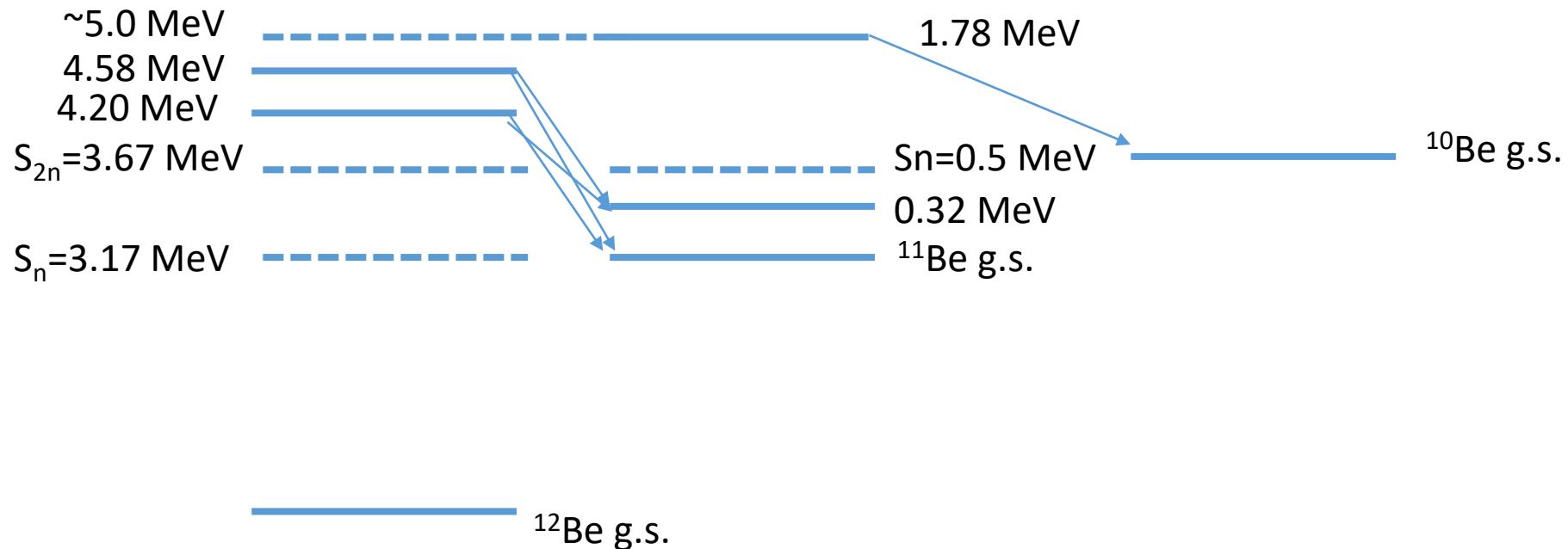
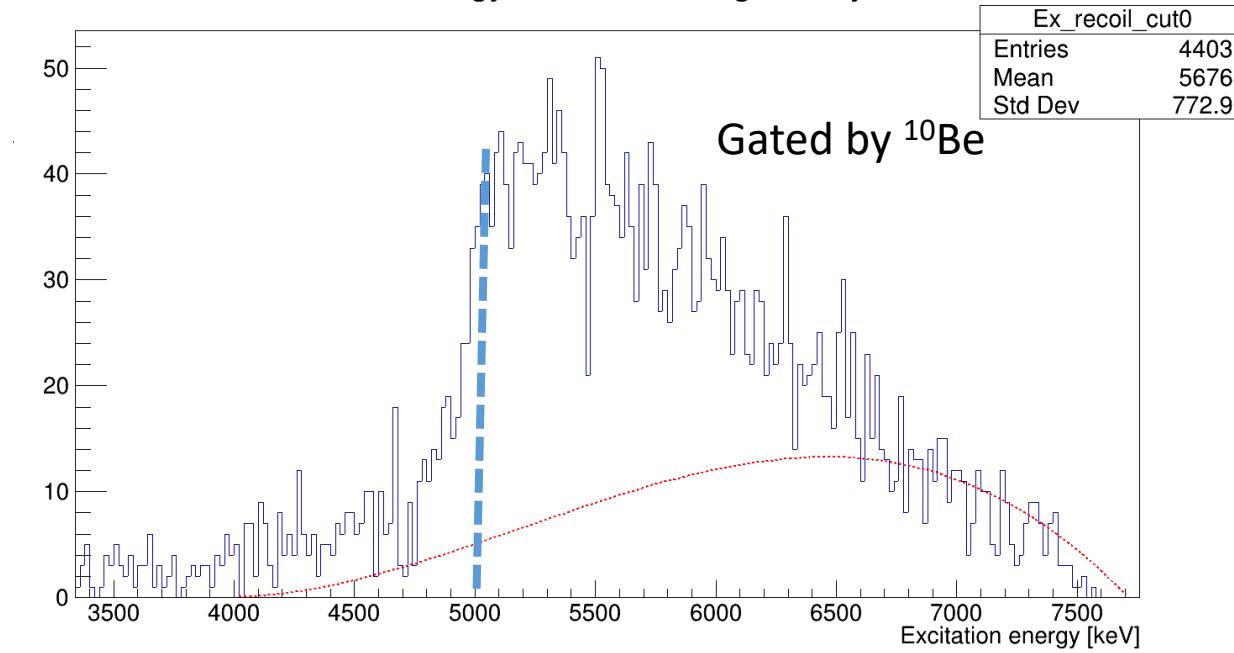
ion energy for user cut 0 gated by recoils



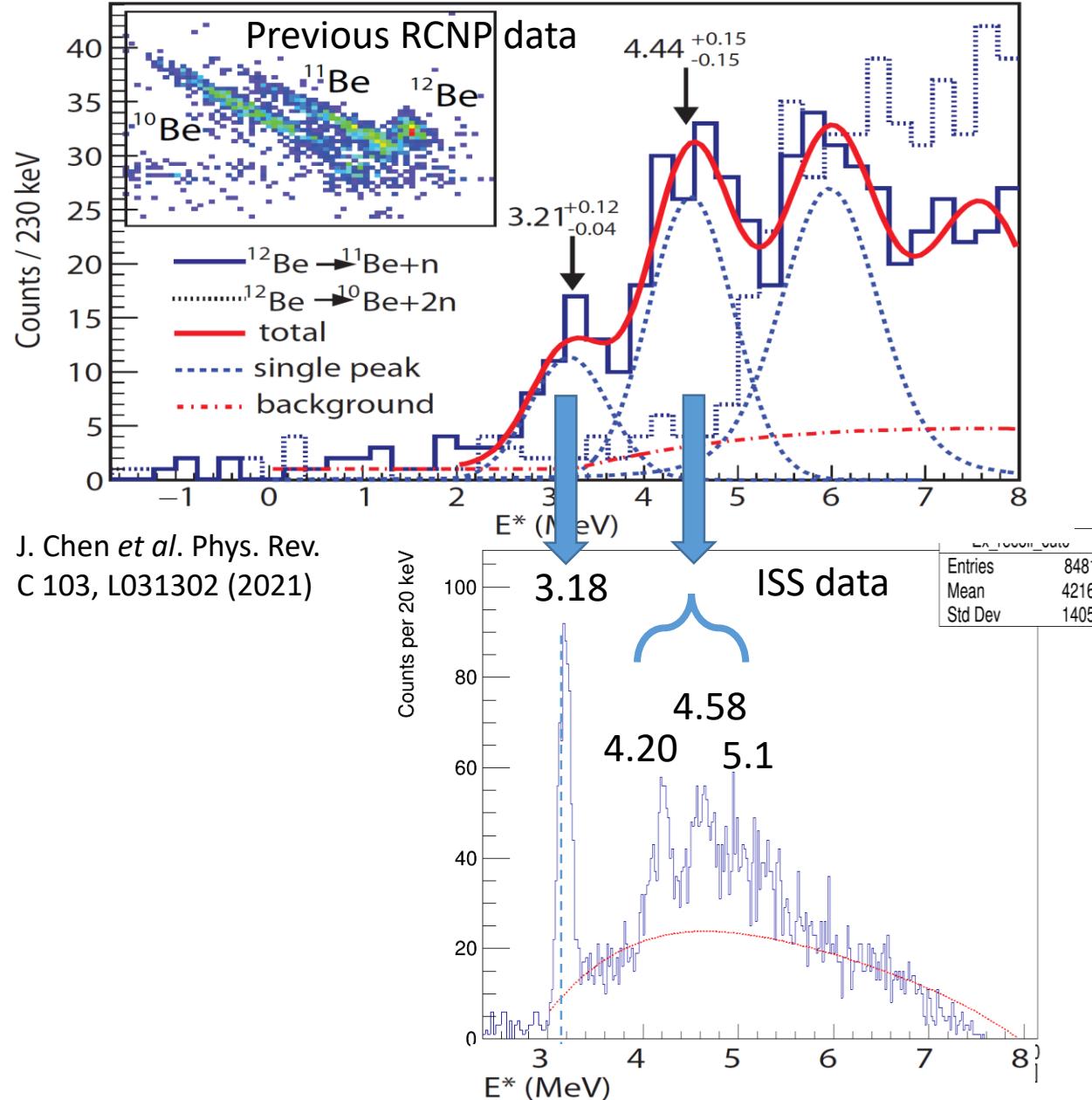
Excitation energy for user cut 0 gated by recoils



Excitation energy for user cut 0 gated by recoils



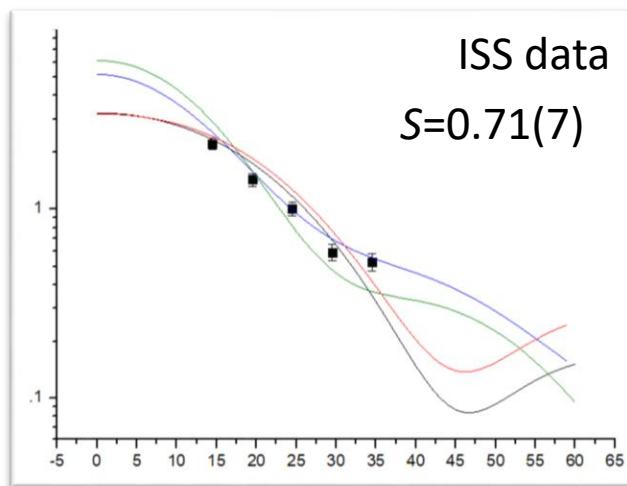
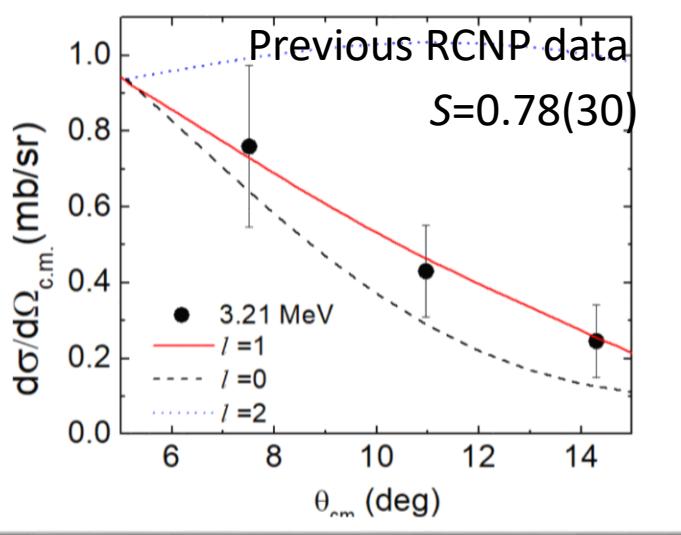
^{12}Be unbound states



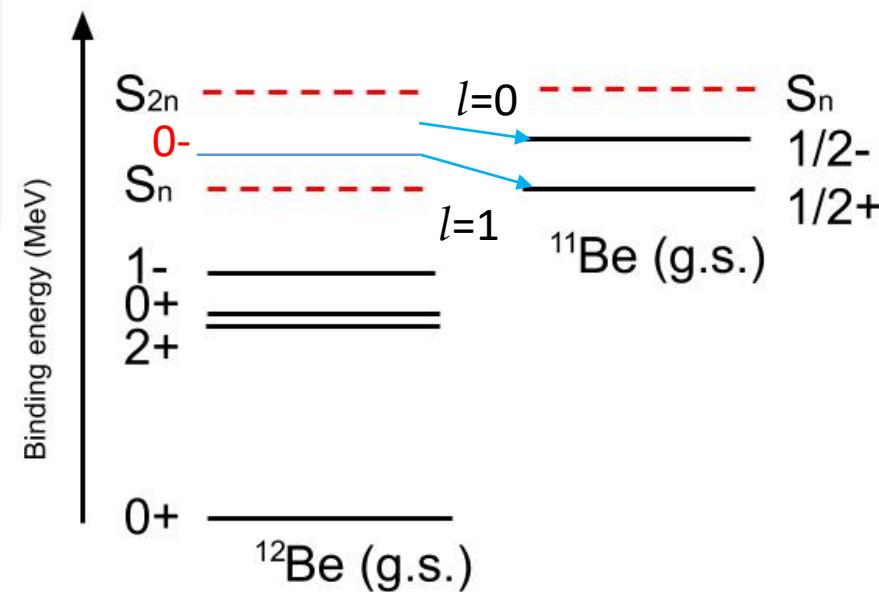
- One resonance just above the S_n
- Firmly confirm this new 0- resonance
- Precise excitation energy:
- $3.21^{+0.12}_{-0.04}$ MeV → 3.18 MeV uncertainty less than 10 keV
- Just 10 keV above S_n → near threshold state
- 2-3 resonances above the S_{2n} , but has >90% 1n-decay

Resonances in ^{12}Be and the role of continuum

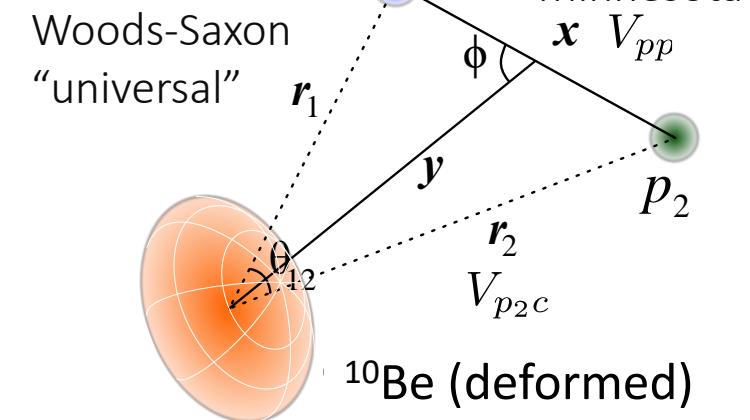
J. Chen *et al.* Phys. Rev. C L031302 (2021)



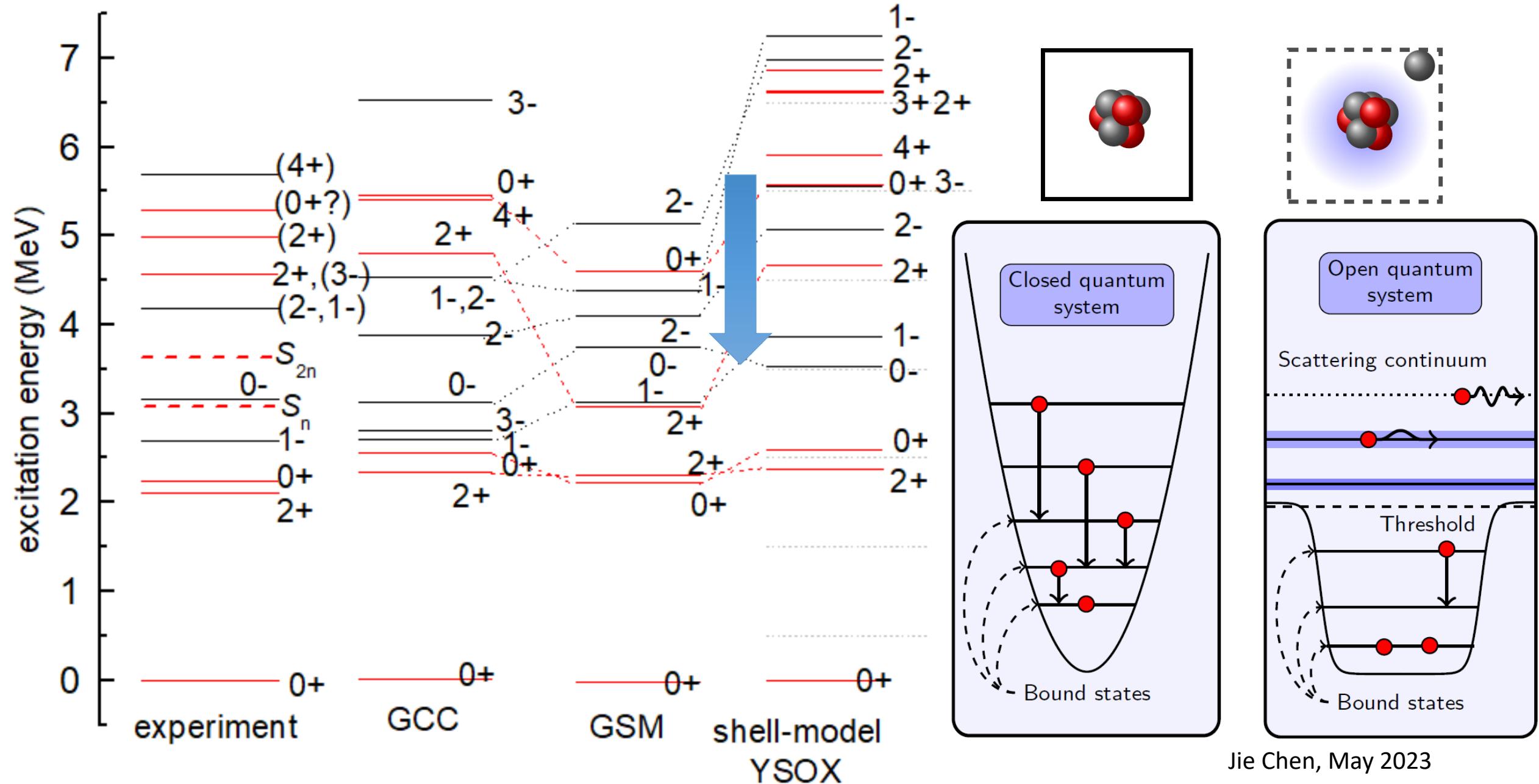
- 1p-1h configuration across N=8
- $l = 1$, limit the possibility to 0-, 1-, 2-
- Gamow coupled-channel approach



Convenient location
of the 0- state



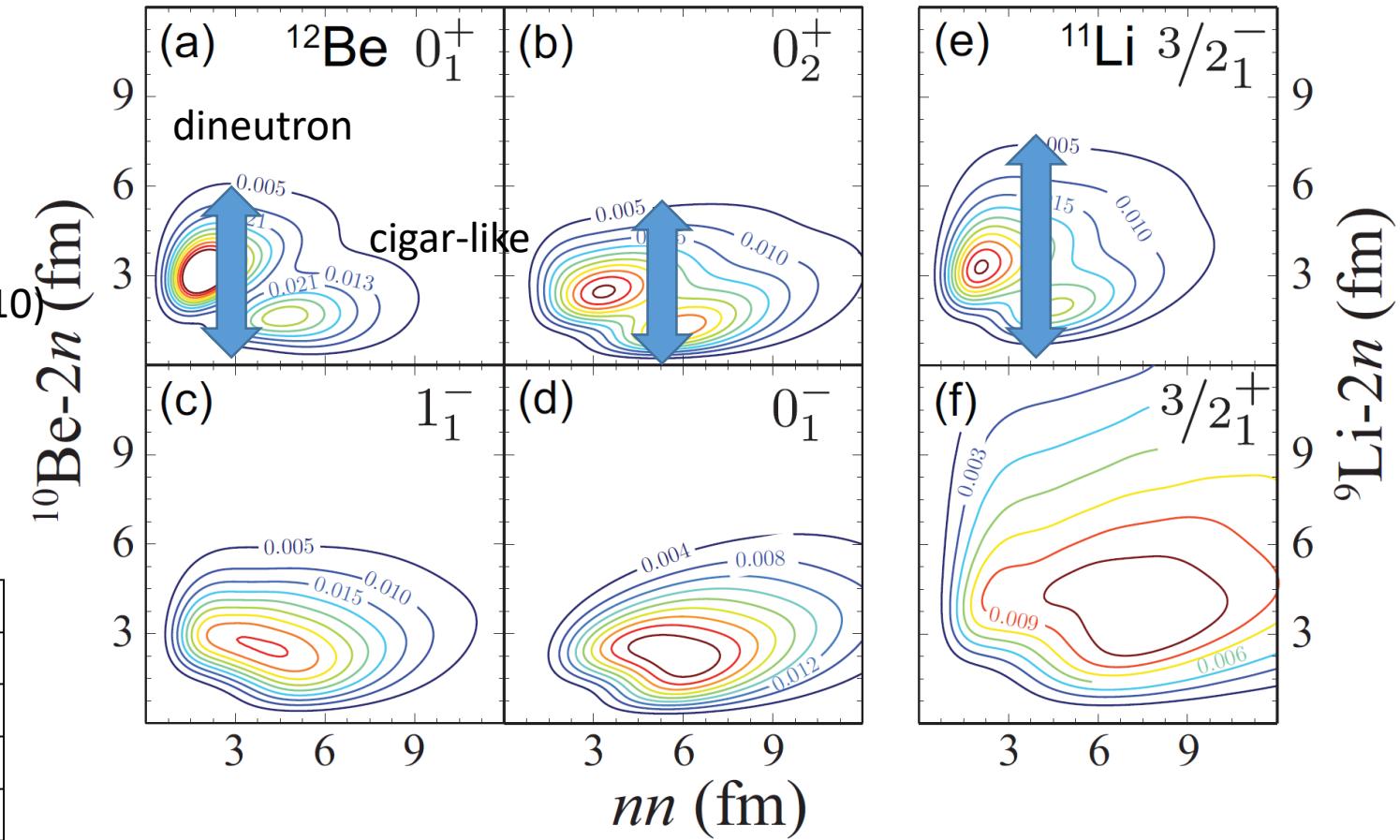
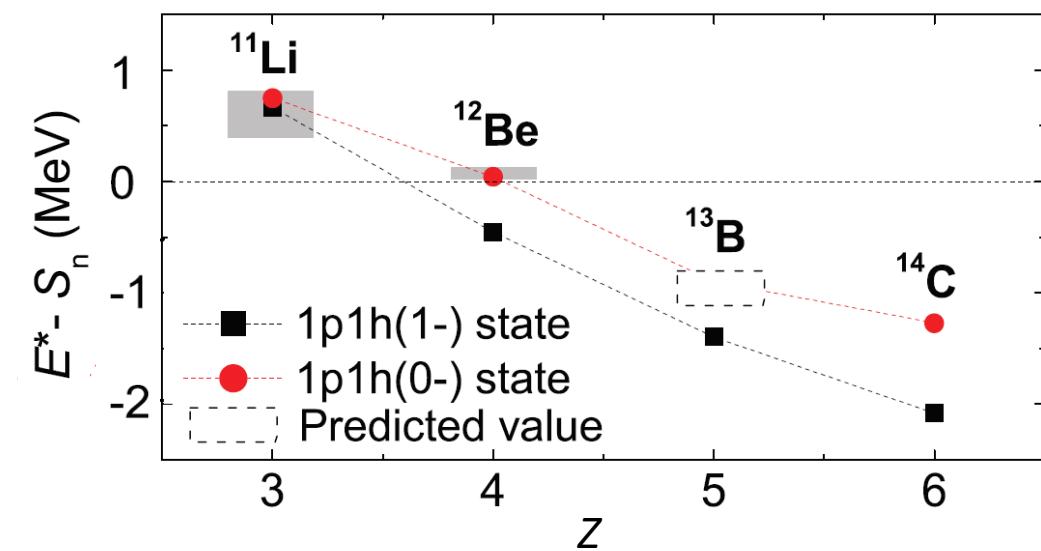
S. M. Wang, *et al.* Phys. Rev. Lett. 120, 212502 (2018)
S. M. Wang, *et al.* Phys. Rev. C 99, 054302 (2019)



Three-body GCC approach

Two-nucleon density distributions

- g.s.: mixture of a dineutron structure and a cigar-like configuration
- 0_2^+ state: Are there halo structure like the ^{11}Li g.s.? Ref: R. Kanungo et al. PLB 682 (2010)
- 0^- and 1_1^- states: two valence neutrons are less correlated



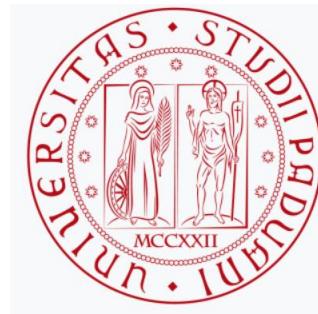
1p-1h resonances in ^{11}Li : experimentally observed dipole resonances

Summary

- Determining the cross shell s-wave configuration of the two low-lying 0+ states in ^{12}Be using $^{11}\text{Be}(d,p)^{12}\text{Be}$ reaction.
 - Small spectroscopic factors were found in both 0+ states, indicating there is no halo structure in the isomer state 0+
- Determination of the excitation energy and spin-parities for resonances in ^{12}Be .
 - Near-threshold 0- resonance (3.18 MeV) and newly observed 2-/1- resonance at 4.2 MeV
 - Possible existence of doublet around 4.58 MeV
- Testing the role of continuum by measuring unbound state of ^{12}Be .
 - Test of Shell model, Gamow Coupled Channel and Gamow Shell model calculations

Acknowledgements

Collaborators for the work presented



CHALMERS

Daresbury Laboratory

