In honor of Prof. A. Arima's rice (米) age

Investigation of the Linear-Chain States in $^{14-16}C$

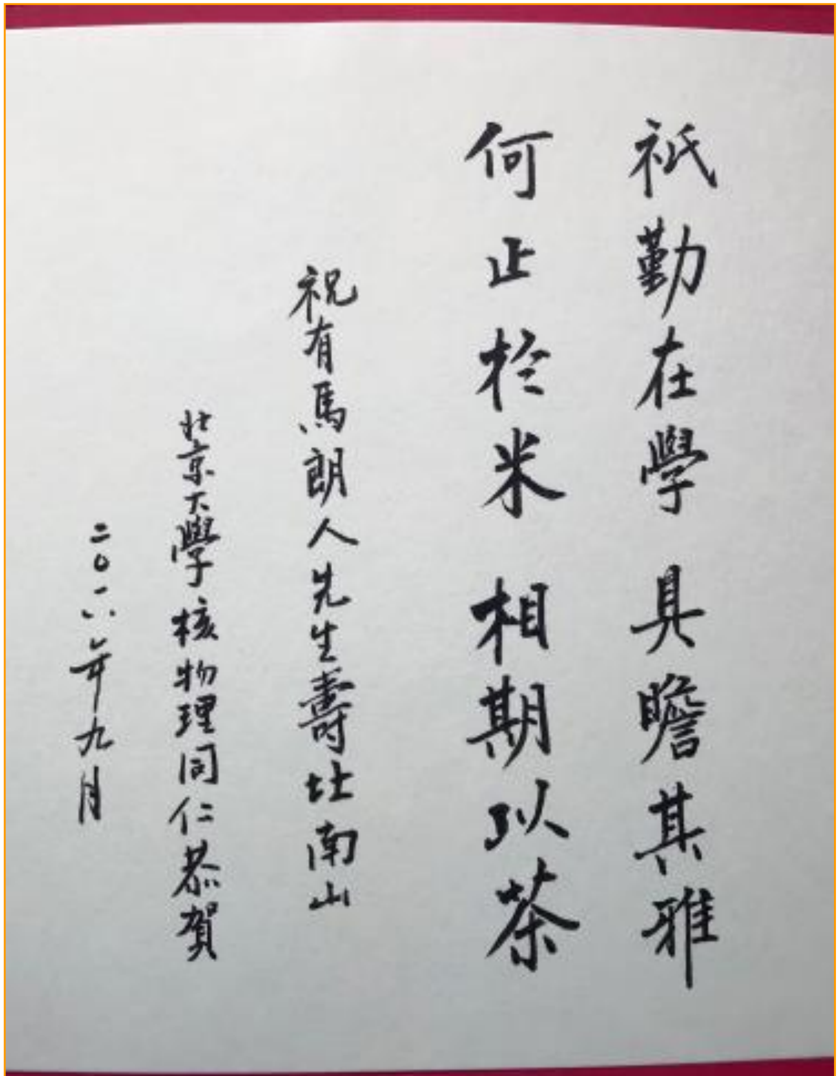
Yanlin Ye

School of Physics and State Key Lab of Nuclear Physics and Technology , Peking University

Sept. 27, 2018, Shanghai

Greetings to Prof. A. Arima

Simplicity, Symmetry and Beauty



With inherent passion Prof. A. Arima has long been working effectively for academic research and organizations;

All of us are respecting and benefited from his great and beautiful achievements;

Rice (米-88) age is still very young;

Let's meet again in his tea (茶-108) years!

Exactly 20 years ago

At the centennial celebration of Peking University in 1998

Outline

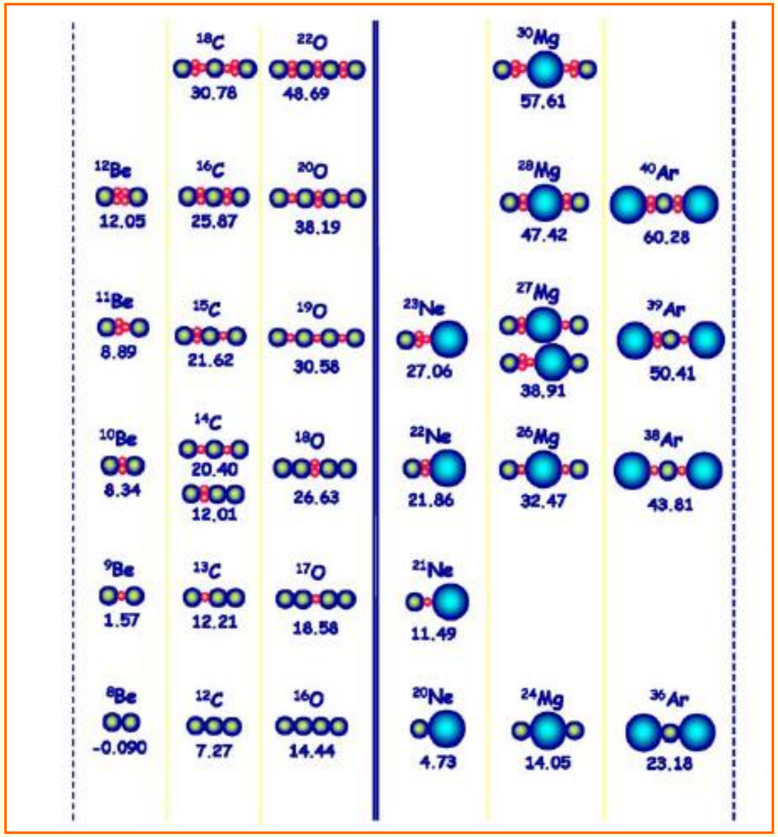
I. Some background

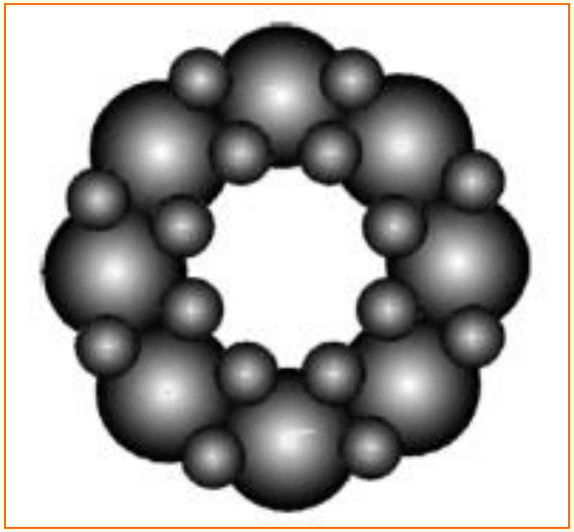
II. Studies on $^{14-16}C$

III. Some perspectives

Clustering in unstable nuclei – a new area

another kind of regulation & beauty

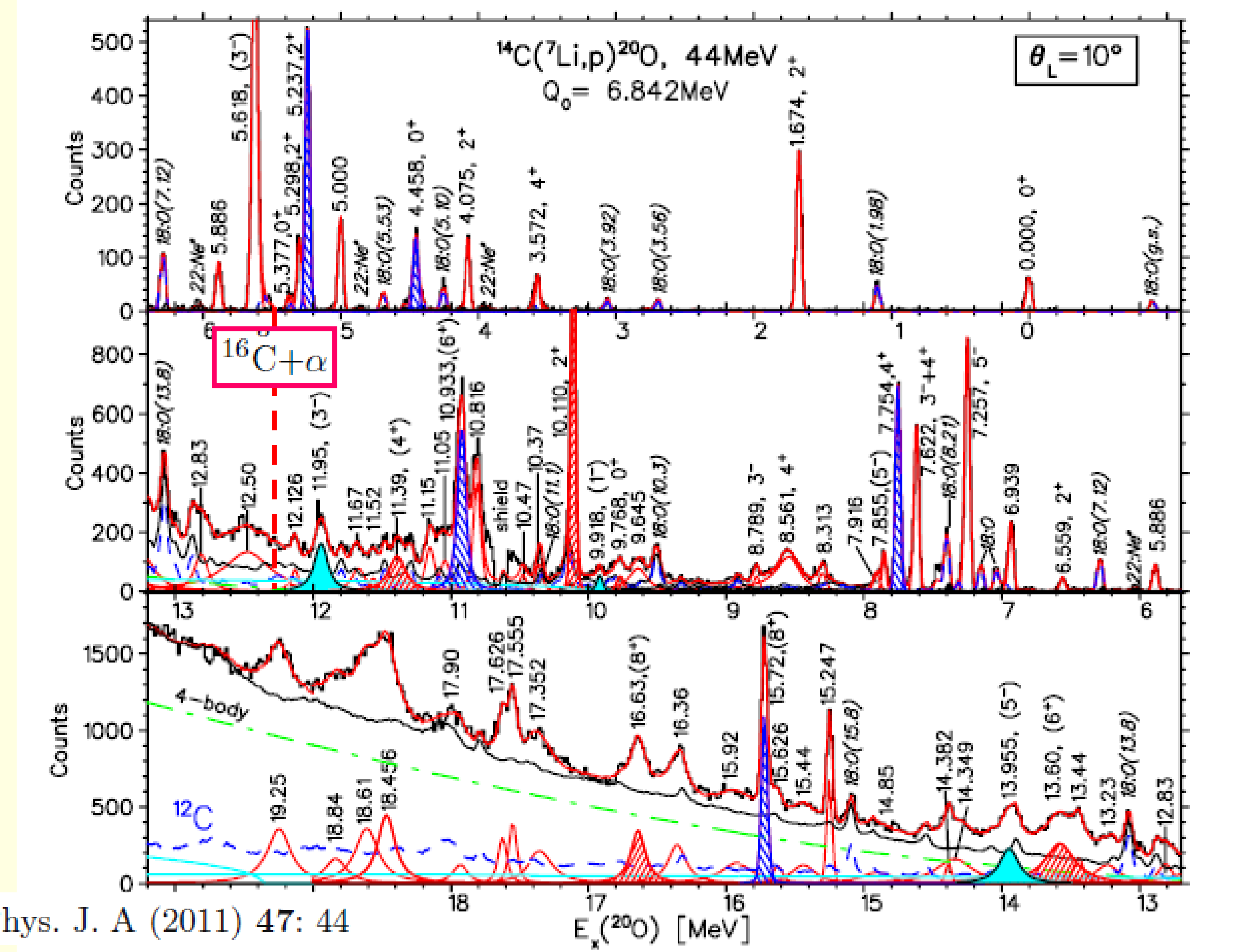




[299] D.H. Wilkinson, Nucl. Phys. A 452 (1986) 296.

W.Von Oerttzen et al., Phys. Report 432(06)43

Exotic regulation happens at high excitations

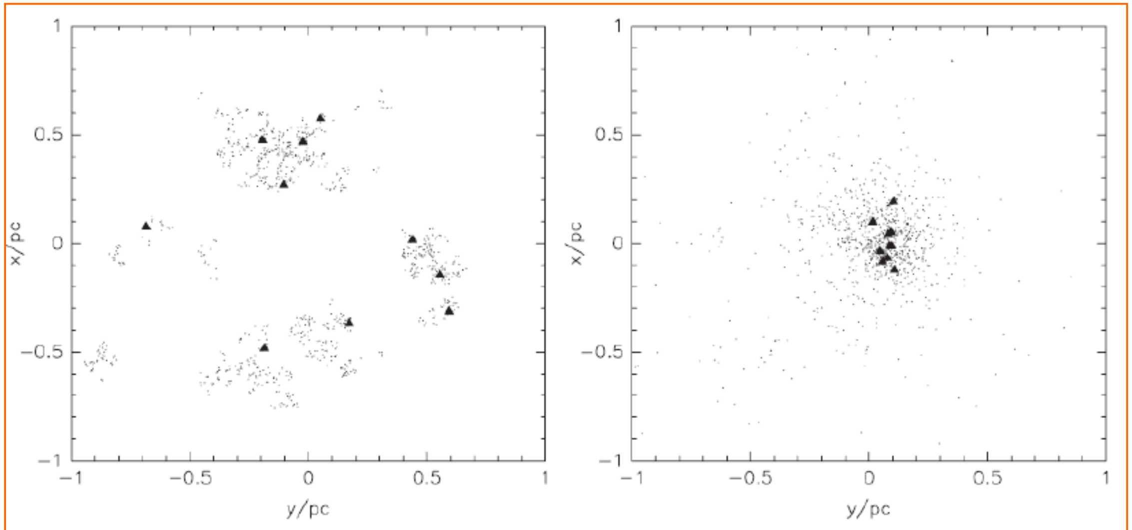


Eur. Phys. J. A (2011) 47: 44

Clustering in the universe

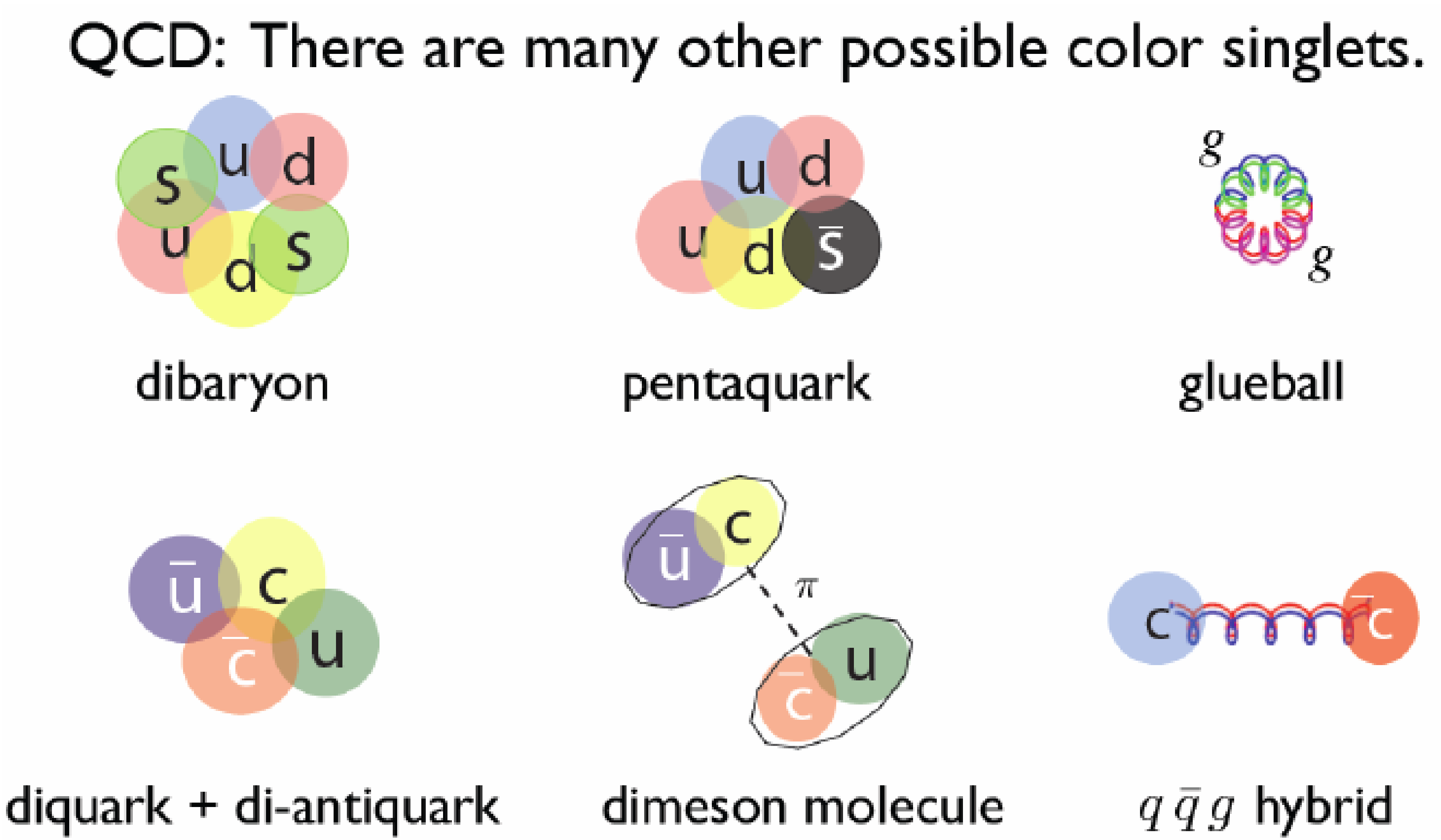
Annu.Rev. Astron. Astrophysics 41(2003)57

疏散星团 M45（昴星团）



(a) 0 Myr (b) ~ 1 Myr

Clustering in hadrons



Impact on the nuclear-astrophysics

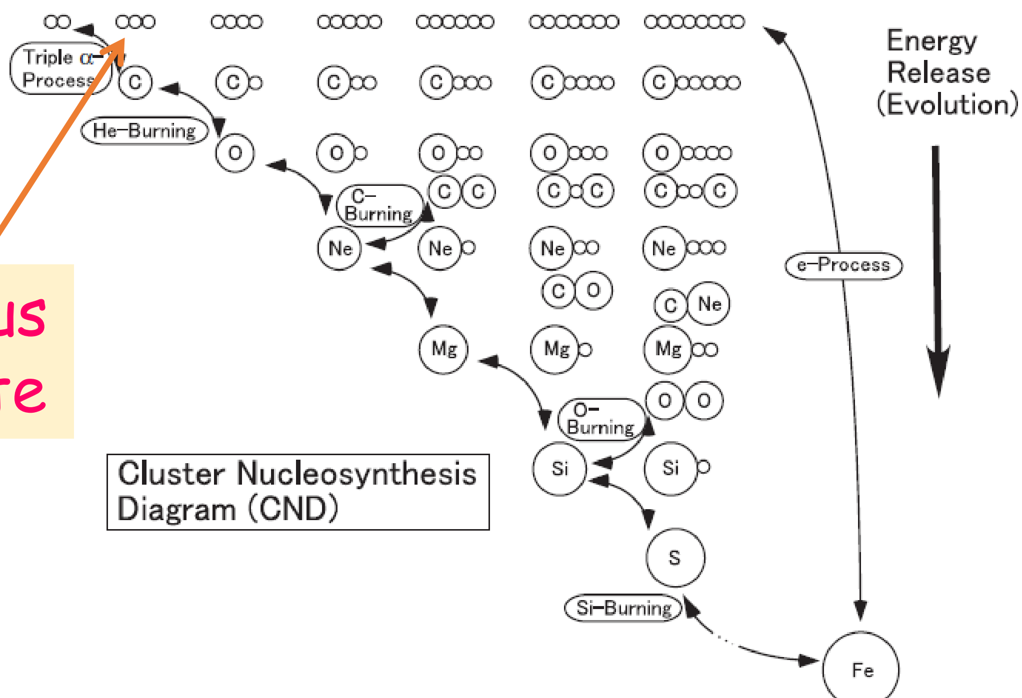
ELSEVIER

Nuclear Physics A 834 (2010) 647c–650c

www.elsevier.com/locate/nuclphysa

Nuclear Clusters in Astrophysics

S. Kubono[a], Dam N. Binh[a], S. Hayakawa[a], H. Hashimoto[a], D. Kahl[a], Y. Wakabayashi[a], H. Yamaguchi[a], T. Teranishi[b], N. Iwasa[c], T. Komatsubara[d], S. Kato[e], Le H. Khiem[f]



The famous Hoyle state

Clustering is featured by :

- non-linearity ;
- self-stabilization;
- Depending on some confinement & residue interaction.

New simplicity, symmetry and beauty

Theoretical descriptions

Theory: **AMD, GCM(RGM), MO, GTCM, FMD, TCSM, TCHO(DHO), …**

J. Phys. G: Nucl. Part. Phys. **37** (2010) 064021

Coexistence of cluster states and mean-field-type states

Hisashi Horiuchi

Progress of Theoretical Physics Supplement No. 192, 2012

Recent Developments in Nuclear Cluster Physics

Hisashi HORIUCHI,[1,2] Kiyomi IKEDA[3] and Kiyoshi KATŌ[4]

[1] *Research Center for Nuclear Physics, Osaka University, Ibaraki 567-0047, Japan*

Progress in Particle and Nuclear Physics 82 (2015) 78–132

Review

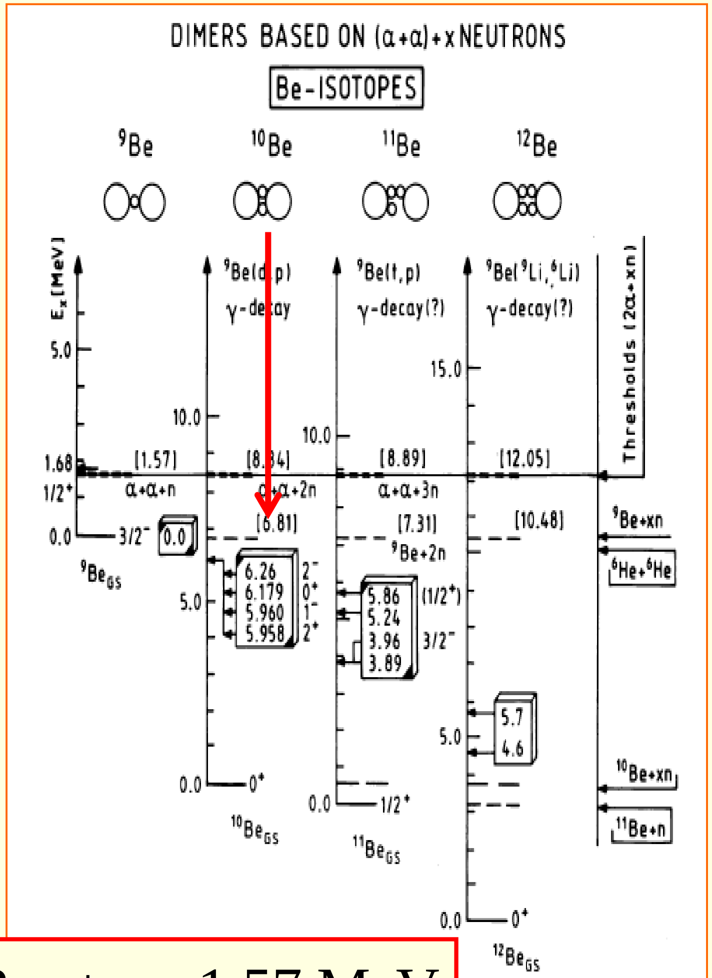
Cluster models from RGM to alpha condensation and beyond

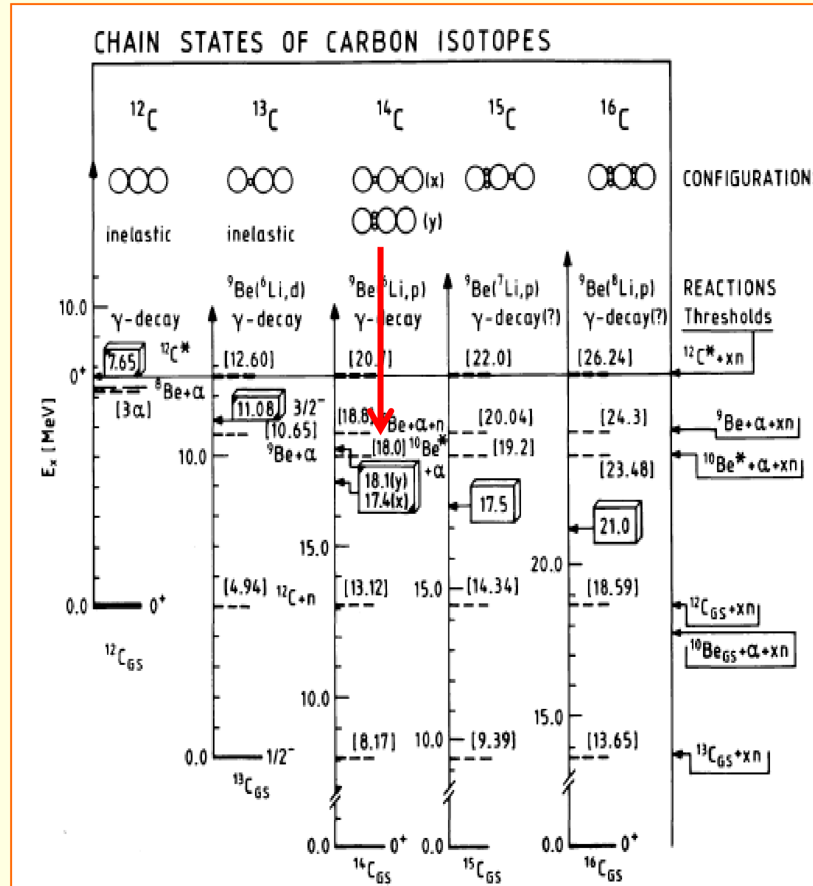
Y. Funaki[a,*], H. Horiuchi[b,c], A. Tohsaki[b]

[a] *Nishina Center for Accelerator-Based Science, The institute of Physical and Chemical Research (RIKEN), Wako 351-0198, Japan*
[b] *Research Center for Nuclear Physics (RCNP), Osaka University, Ibaraki 567-0047, Japan*
[c] *International Institute for Advanced Studies, Kizugawa 619-0225, Japan*

Possible chain states based on α-cores

$^{8}Be(2\alpha)$





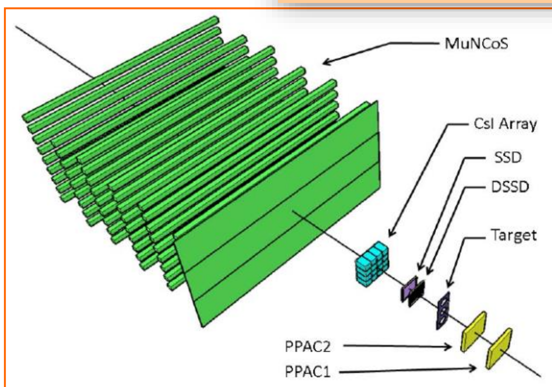
$$^{9}Be \rightarrow 2\alpha + n - 1.57\ MeV$$

$$^{6}Li \rightarrow \alpha + d - 1.47\ MeV$$

$$7Li \rightarrow \alpha + t - 2.37\ MeV$$

W.Von Oerttzen et al.,
Z. Phys. A357(97)355.
Phys.Rep.432(06)43.

^{12}Be: An exp. at RIBLL1@HIRFL, Lanzhou



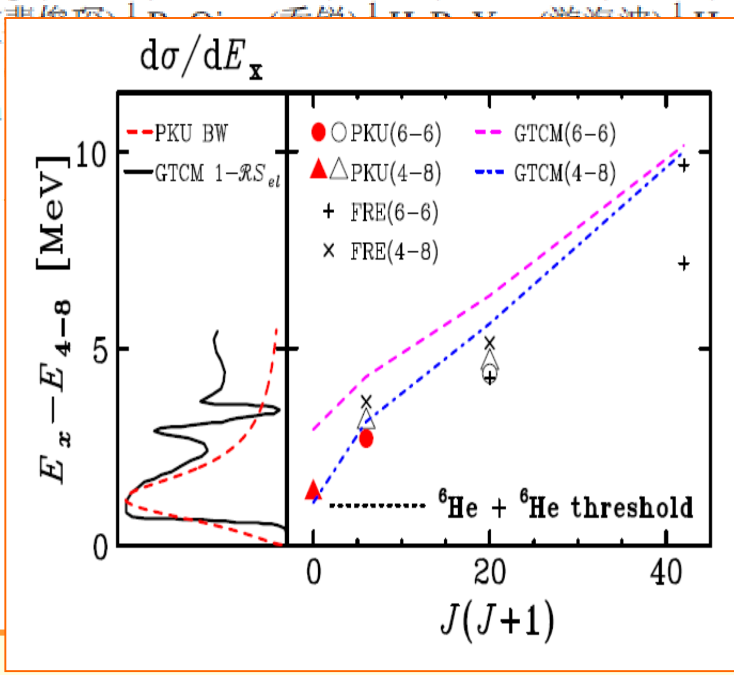
Beam: ^{12}Be, 29.0MeV/u, ~3000pps
Target: Carbon, 100 mg/cm^2
DSSD: 32 2mm-stip, 300μm , covering 0^0-12^0 Lab.
CsI(Tl): 4 x 4, 2.5cm*2.5cm*3cm,
Detection focused on the most forward angles

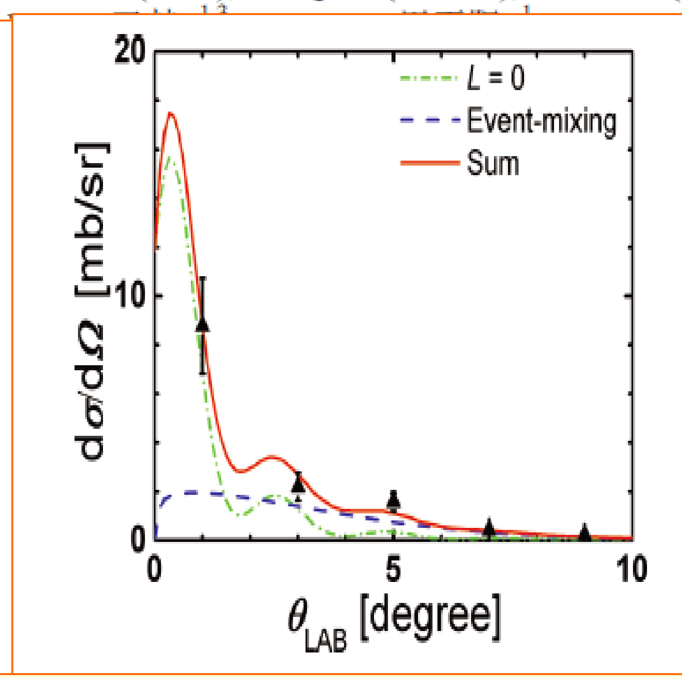
Example of studies for ^{12}Be

PRL **112**, 162501 (2014) PHYSICAL REVIEW LETTERS week ending 25 APRIL 2014

Observation of Enhanced Monopole Strength and Clustering in ^{12}Be

Z. H. Yang (杨再宏),[1] Y. L. Ye (叶沿林),[1,*] Z. H. Li (李智焕),[1] J. L. Lou (楼建玲),[1] J. S. Wang (王建松),[2]
D. X. Jiang (江栋兴),[1] Y. C. Ge (葛愉成),[1] Q. T. Li (李奇特),[1] H. Hua (华辉),[1] X. Q. Li (李湘庆),[1] F. R. Xu (许甫荣),[1]
J. C. Pei (... 李阔昂),[1]
Y. L. ... 伟),[1]
C. Wen ... 士纶),[2]
[1]State ... hina





PHYSICAL REVIEW C **91**, 024304 (2015)

Helium-helium clustering states in ^{12}Be

SCIENCE CHINA
Physics, Mechanics & Astronomy
September 2014 Vol. 57 No. 9: 1613–1617

Outline

I. Some background

II. Studies on $^{14-16}C$

III. Some perspectives

Latest AMD calculations for ^{14}C

T. Baba and M. Kimura PRC94(2016)044303
T. Baba and M. Kimura PRC95(2017)064318

Major improvements:

- Gogny D1S force to better describe E_x;
- Projected single particle wave function for valence neutrons to distinguish the π-bond or σ-bond states;
- core excitation included and the reduced decay-width deduced accordingly.

$$E'^{\pi} = \frac{\langle \Phi^{\pi} | H | \Phi^{\pi} \rangle}{\langle \Phi^{\pi} | \Phi^{\pi} \rangle} + v_{\beta}(\langle \beta \rangle - \beta_0)^2 + v_{\gamma}(\langle \gamma \rangle - \gamma_0)^2$$

$$\tilde{\phi}_s = \sum_{\alpha=1}^{A} f_{\alpha s} \tilde{\varphi}_{\alpha}.$$

$$j(j+1) = \langle \tilde{\phi}_s | \hat{j}^2 | \tilde{\phi}_s \rangle, \quad |j_z| = \sqrt{\langle \tilde{\phi}_s | \hat{j}_z^2 | \tilde{\phi}_s \rangle},$$

$$l(l+1) = \langle \tilde{\phi}_s | \hat{l}^2 | \tilde{\phi}_s \rangle, \quad |l_z| = \sqrt{\langle \tilde{\phi}_s | \hat{l}_z^2 | \tilde{\phi}_s \rangle},$$

$$\gamma^2_{lj^{\pi'}}(a) = \frac{\hbar^2}{2\mu a}[a y_{lj^{\pi'}}(a)]^2$$

$$y_{lj^{\pi'}}(r) = \sqrt{\frac{A!}{4!(A-4)!}} \langle \phi_{\alpha} [\phi_{\mathrm{Be}}(j^{\pi'}) Y_{l0}(\hat{r})]_{J^{\pi}M} | \Psi^{J^{\pi}}_{Mn} \rangle,$$

^{x}C: triangle, and π-bond or σ-bond linear-chain states

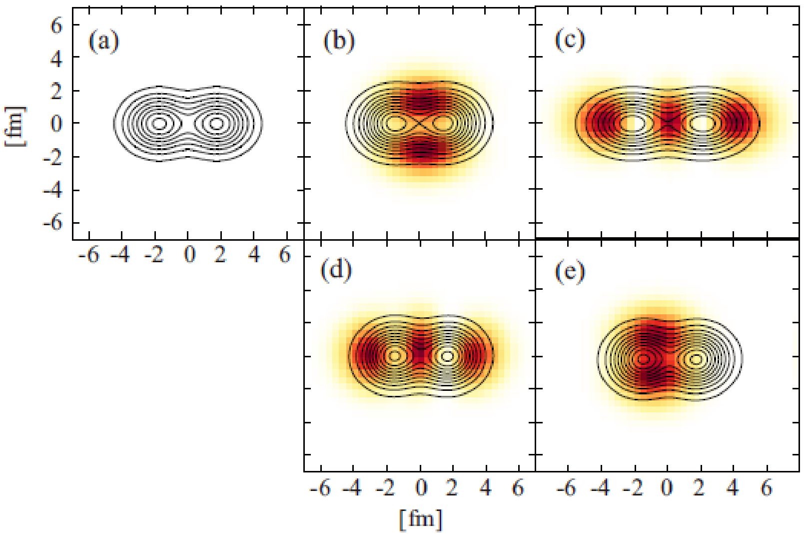
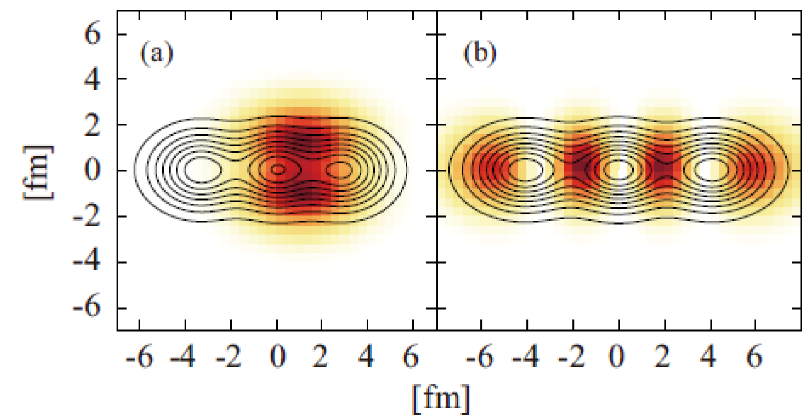
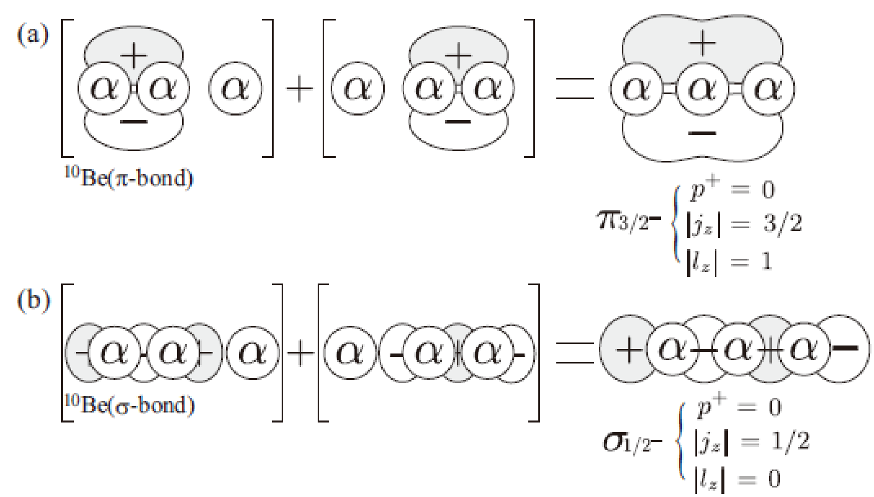


FIG. 2. The density distribution of (a) ^{8}Be, the positive-parity states of ^{10}Be with valence neutrons in a (b) π orbit and (c) σ orbit, and (d), (e) negative-parity states of ^{10}Be. The contour lines show the proton density distributions. The color plots in panels (b) and (c) show the single-particle orbits occupied by the most weakly bound neutron. In the negative-parity state, the color plots of panel (d) show the single-particle orbits occupied by the most weakly bound neutron, and those of panel (e) show the other valence neutron.

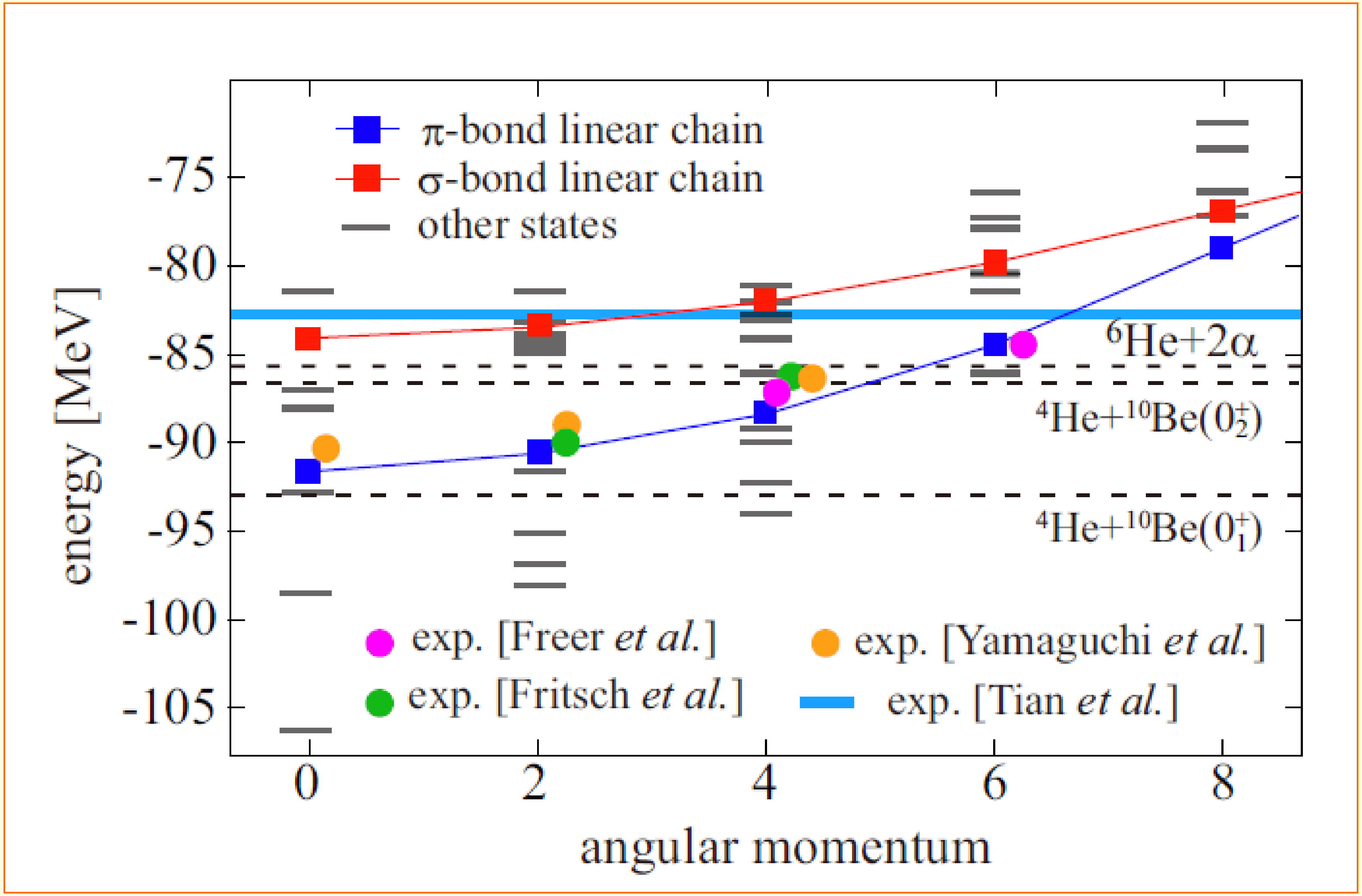




most exotic one: σ-bond linear-chain state

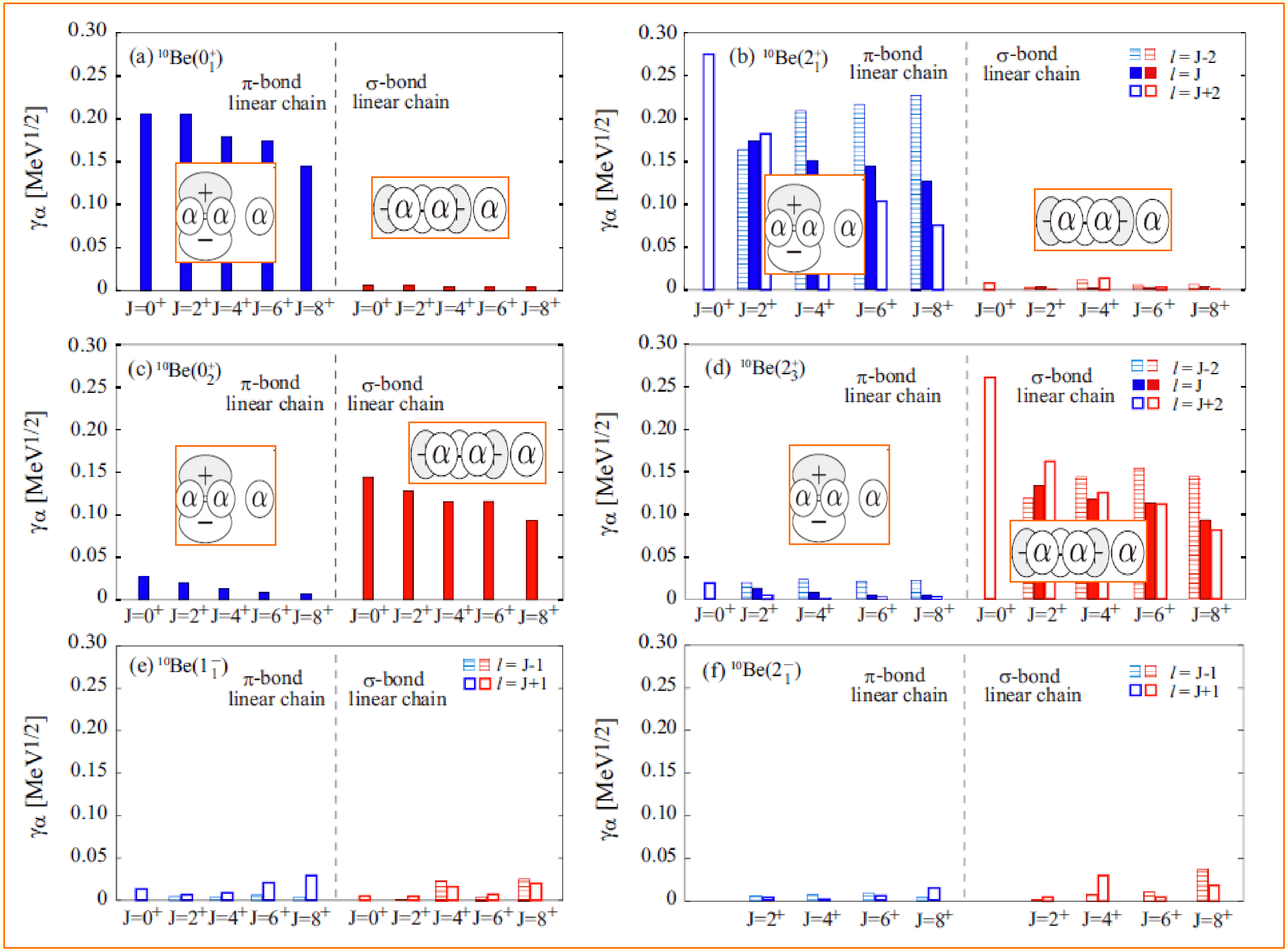
T. Baba and M. Kimura, PRC95(2017)064318

^{14}C: triangle, and π-bond or σ-bond linear-chain states



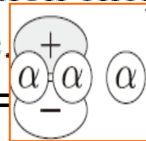
T. Baba and M. Kimura, PRC95(2017)064318

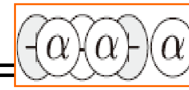
Decay-selectivity for σ-LCS



T. Baba and M. Kimura, PRC95(2017)034318

TABLE II. Excitation energies (MeV) and α-decay widths (keV) to the 2_1^+ state of ^{10}Be.





	π-bond linear chain			σ-bond linear chain	
J^π	E_x	Γ_α(5.2fm)	Γ_α(6.0fm)	E_x	Γ_α(6.0fm)
0^+	14.64			22.16	0.6
2^+	15.73			22.93	0.2
4^+	17.98	118	111	24.30	1.8
6^+	21.80	256	271	26.45	0.4
8^+	27.25	397	421	29.39	0.8

T. Baba and M. Kimura, PRC95(2017) 034318

TABLE III. Partial decay widths (keV) in six different channels for (a) the σ-bond linear-chain states and (b) $J^\pi = 6^+, 8^+$ states of the π-bond linear chain. The channel radius a is 6.0 fm.

J^π	E_x	$\Gamma(^{10}\mathrm{Be}(0_1^+;\pi^2))$	$\Gamma(^{10}\mathrm{Be}(2_1^+;\pi^2))$	$\Gamma(^{10}\mathrm{Be}(0_2^+;\sigma^2))$	$\Gamma(^{10}\mathrm{Be}(1_1^-;\pi\sigma))$	$\Gamma(^{10}\mathrm{Be}(2_1^-;\pi\sigma))$	$\Gamma(^{6}\mathrm{He}+{}^{8}\mathrm{Be})$
(a) σ-bond linear chain							
0^+	22.16	0.2	0.6	136	0.2	–	38
2^+	22.93	0.4	0.2	99	0.1	0.1	29
4^+	24.30	0.3	1.8	63	4.0	2.7	23
6^+	26.45	0.2	0.4	42	0.2	0.6	17
8^+	29.39	0.2	0.8	17	2.9	5.6	13
(b) π-bond linear chain							
6^+	21.80	151	271	0.0	0.0	0.0	0.0
8^+	27.25	120	421	0.0	0.2	0.0	1

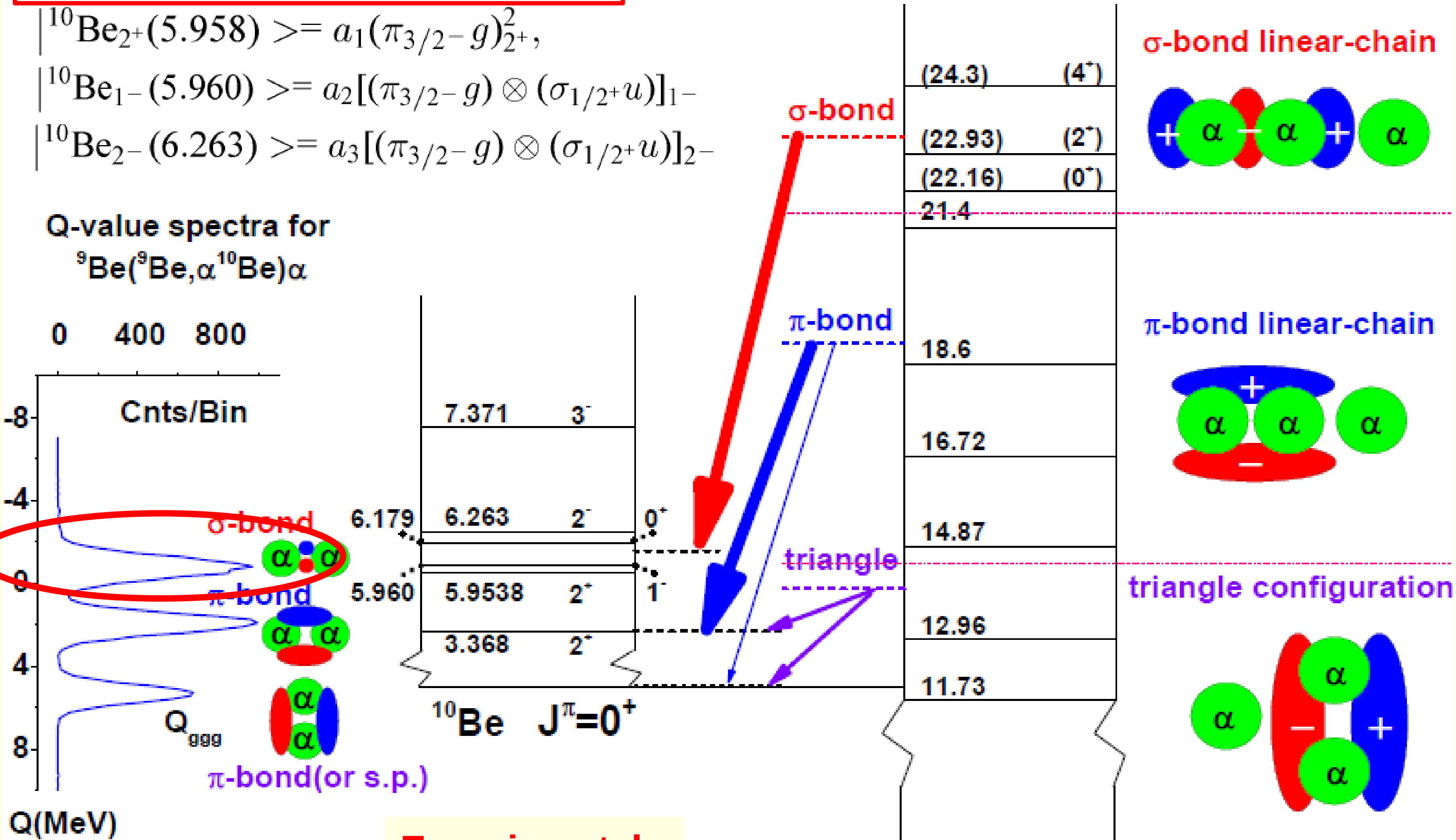
Structural link in decay scheme — exp.

$$|^{10}\mathrm{Be}^*_{0^+}(6.26\ \mathrm{MeV})>= a_0(\sigma_{1/2^+}u)^2_{0^+}$$

$$|^{10}\mathrm{Be}_{2^+}(5.958)>= a_1(\pi_{3/2^-}g)^2_{2^+},$$

$$|^{10}\mathrm{Be}_{1^-}(5.960)>= a_2[(\pi_{3/2^-}g)\otimes(\sigma_{1/2^+}u)]_{1^-}$$

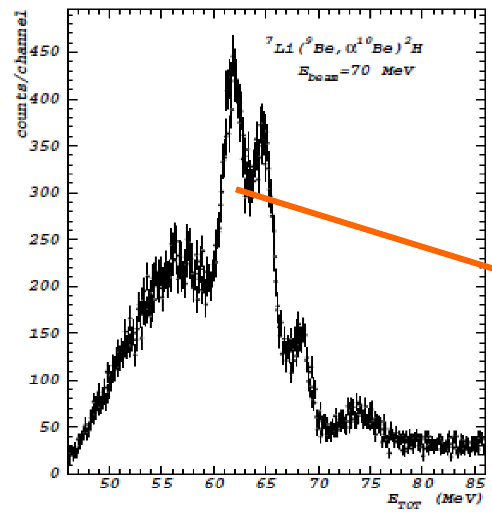
$$|^{10}\mathrm{Be}_{2^-}(6.263)>= a_3[(\pi_{3/2^-}g)\otimes(\sigma_{1/2^+}u)]_{2^-}$$



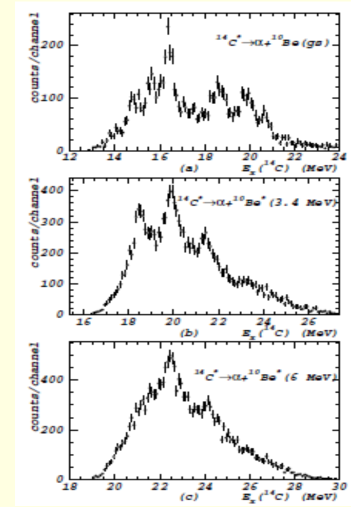
Experimental probes

Previous experiments for ^{14}C

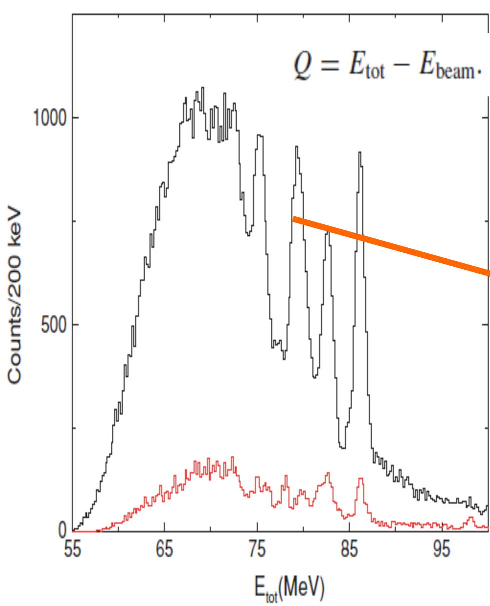
N. Soic, M. Freer et al., PRC68(2003) 014321; $^7Li(^9Be, {}^4He^{10}Be)^2H$, E_{beam}=70 MeV



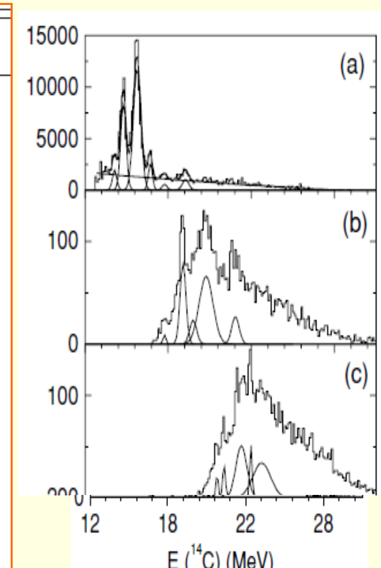
$^{10}Be_{gs}$	$^{10}Be(2^+)$	^{10}Be(6 MeV)	Previous
14.7(0.1)			14.667 (4^+)
15.5(0.1)			15.44 (3^-)
16.4(0.1)			16.43
18.5(0.1)	18.5(0.1)		18.5
	[19.1(0.1)]		
19.8(0.1)	19.8(0.1)		
20.6(0.1)			
	21.4(0.1)		
		22.4(0.3)	
	[23.2(0.1)]		
		24.0(0.3)	



D.L. Proce, M. Freer et al., PRC75(2007) 014305; $^{14}C(^{14}C, {}^4He^{10}Be)^{14}C$, E_{beam}=98.2 MeV



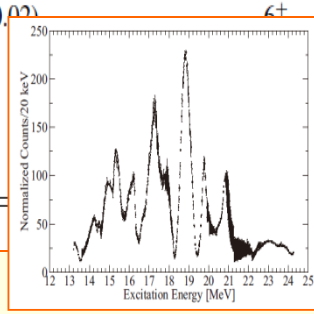
$^{10}Be_{gs} + \alpha$	$^{10}Be(2^+$, 3.37 MeV$) + \alpha$	$^{10}Be(6\ MeV) + \alpha$
14.3(1)		
14.8(1)		
15.6(1)		
16.4(1)		
17.3(1)	17.3(1)	
(18.1)		
18.6(1)	**18.4(1)**	
	(19.0(2))	
	19.8(1)	
		20.4(1)
		20.9(1)
	(21.6(2))	*(21.9(1))*
		(22.5(1))
		(23.1(2))



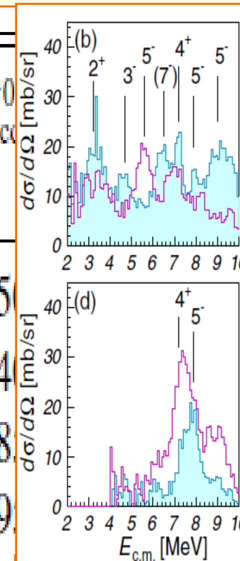
Recently reported results

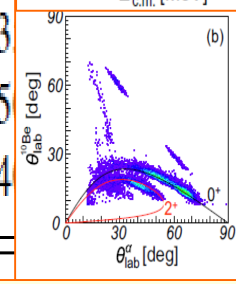
E_x	E_x	J^π
14.3(1)	Present measurements	
14.8(1)	possess features	
15.55(10)[a]	consistent with	
15.9	these states	
16.43(10)		
17.3(1)	17.32(0.02)	3^-
18.1	17.97(0.02)	2^+
	18.22(0.02)	4^+
18.5(1), 18.6(1)	18.82(0.02)	5^-
19.07(1)		
19.3(1)		
19.83(1)	19.67(0.02)	5^-
20.3(1)		
20.6(1)	20.80(0.0	6^+
21.43(1)		
22.45(3)		
23.15(1)		
24.0(3)		

[a] Assigned $J^\pi = 3^-$ in Ref. [12].



$E_{c.m.}$ [MeV]	E_x [MeV]	J^π	$\lvert U^0_{c}$
3.0	15.0	2^+	0.5
4.7	16.7	3^-	0.4
5.6	17.6	5^-	0.8
6.5	18.5	(7^-)	0.9
7.0	19.0	4^+	0.3
7.9	19.9	5^-	0.5
8.7	20.7	5^-	0.4





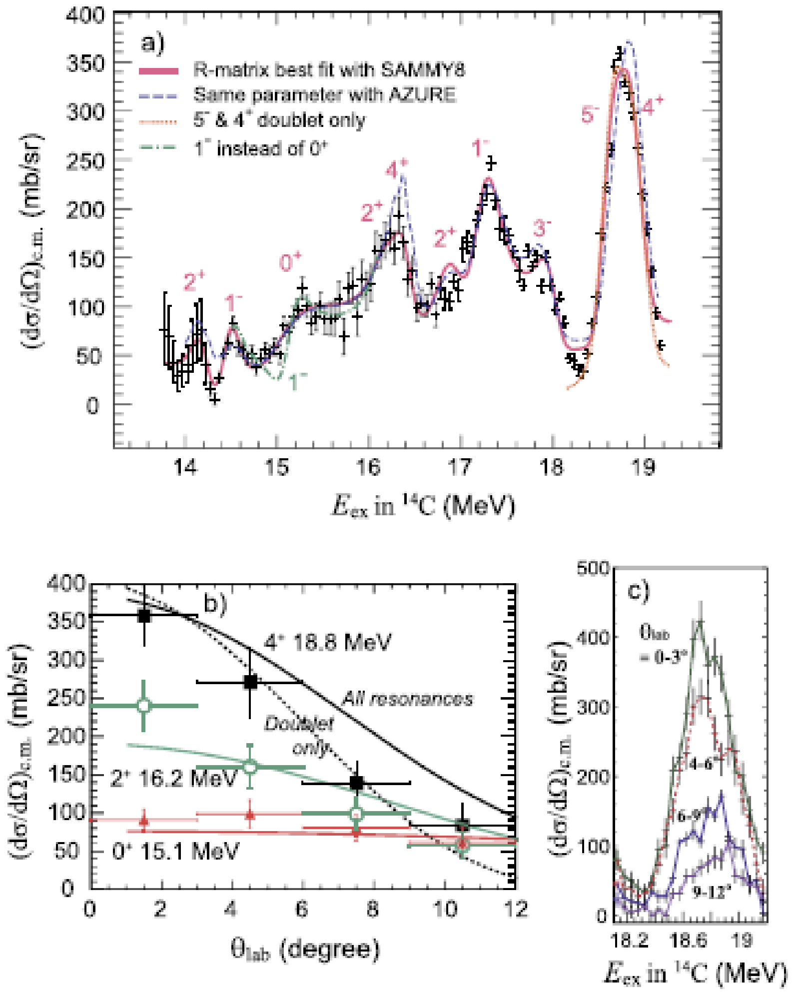
Possible observation of the triangle-like and π-bond linear-chain states, but not σ-bond states.

M. Freer et al., PRC90(2014) 054324; α(^{10}Be, α)^{10}Be, E_x=13 to 24 MeV

A. Fritsch et al., PRC93(2016)014321; α(^{10}Be, α)^{10}Be, E_x=15.0 to 20.7 MeV

Recently reported results

H.Yamaguchi et al., PLB766(2017)11



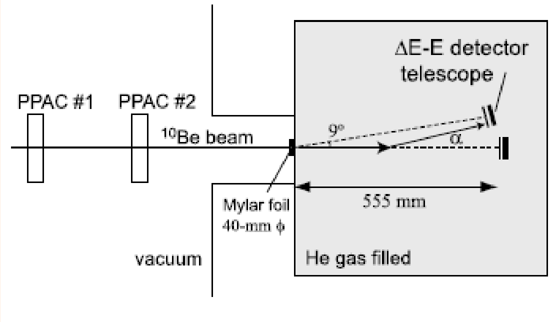


Fig. 2. The experimental setup for the resonant scattering measurement.

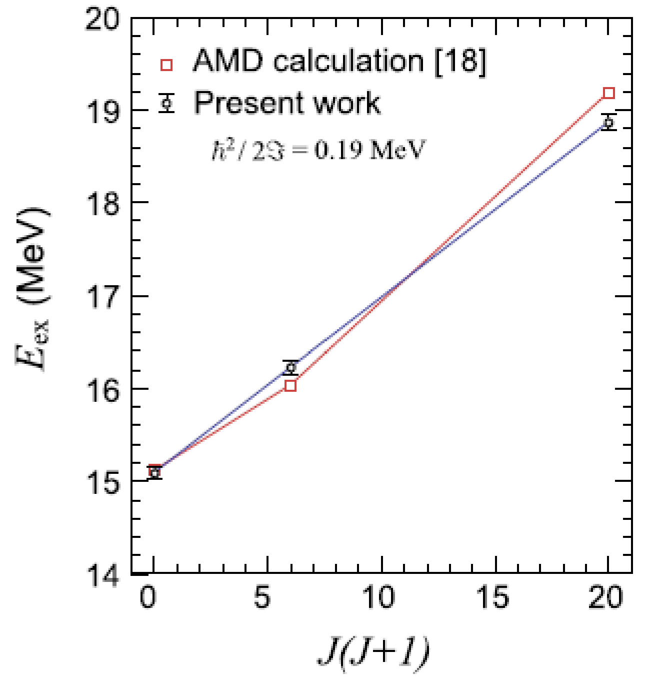


Table 1

The resonance parameters in ^{14}C determined by the present work, compared with the AMD calculation [18]. Parameters in bold letters are for LCCS predicted in the calculation, and the corresponding experimental resonances. Previously observed states with their J^π determined are also shown, but they do not necessarily correspond to the present measurement. See [12,20–27,30,31] for complete data, including other states. Note that the theoretical E_{ex} is after the threshold normalization.

Present Work				Suhara & En'yo [18]			Other Experiments	
E_{ex} (MeV)	J^π	Γ_α (keV)	θ_α^2	E_{ex} (MeV)	J^π	θ_α^2	E_{ex} (MeV)	J^π
14.21	(2^+)	17(5)	3.5%					
14.50	1^-	45(14)	4.5%				14.67	6^+ [12]
							14.717	4^+ [21]
							14.87	5^- [12]
15.07	$\mathbf{0^+}$	**760(250)**	**34(12)%**	**15.1**	$\mathbf{0^+}$	**16%**	15.20	4^- [21]
							15.56	3^- [25]
16.22	$\mathbf{2^+}$	**190(55)**	**9.1(27)%**	**16.0**	$\mathbf{2^+}$	**15%**	15.91	4^+ [21]
16.37	(4^+)	15(4)	3.0%				16.43	6^+ [12]
16.93	(2^+)	270(85)	10.3%				16.9	0^+ [27]
17.25	(1^-)	190(45)	5.5%				17.30	3^- [30]
							17.30	4^- [12]
							17.99	2^+ [30]
18.02	(3^-)	31(19)	1.3%				18.22	4^+ [30]
18.63	5^-	72(48)	9.4%				18.83	5^- [30]
18.87	$\mathbf{4^+}$	**45(18)**	**2.4(9)%**	**19.2**	$\mathbf{4^+}$	**9%**		

?

PHYSICAL REVIEW C **97**, 054315 (2018)

Latest AMD calculations for ^{16}C

Characteristic α and ^{6}He decays of linear-chain structures in ^{16}C

T. Baba[1] and M. Kimura[1,2]
[1]Department of Physics, Hokkaido University, 060-0810 Sapporo, Japan
[2]Reaction Nuclear Data Centre, Faculty of Science, Hokkaido University, 060-0810 Sapporo, Japan

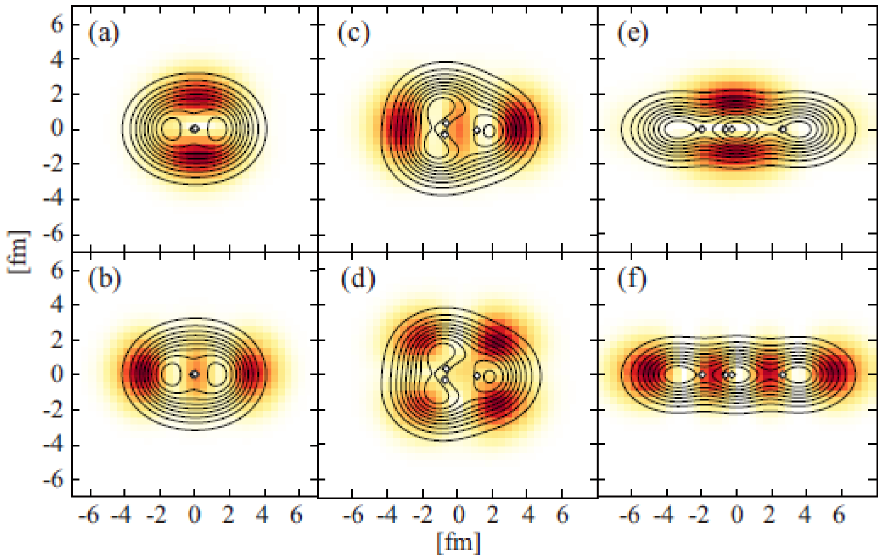


FIG. 2. The density distributions of positive-parity states of the (a), (b) ground, (c), (d) triangular, and (e), (f) linear-chain configurations. The contour lines show the proton density distributions. The color plots show the single-particle orbits occupied by four valence neutrons. The lower panels show the two most weakly bound neutrons, while the upper panels show the other two valence neutrons. Open boxes show the centroids of the Gaussian wave packets describing protons.

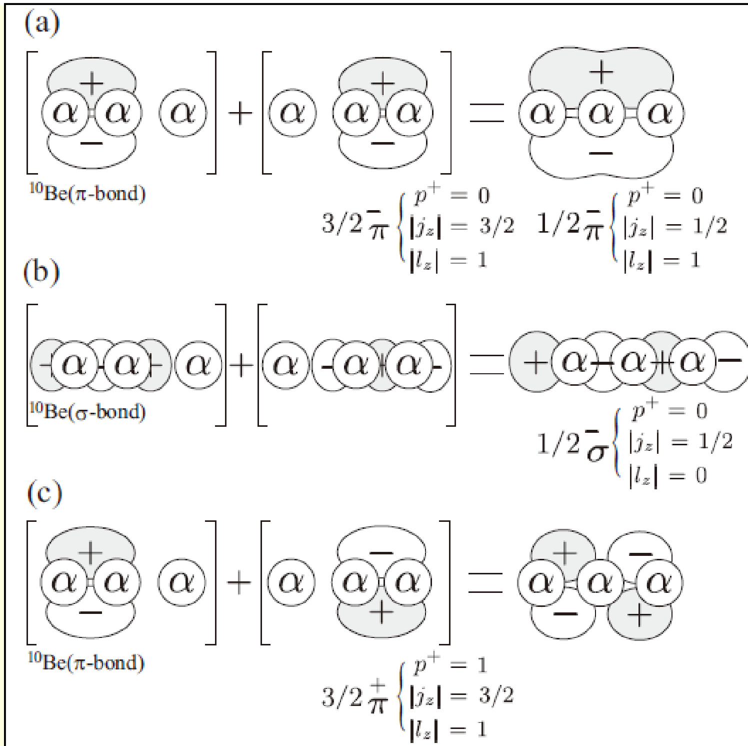


FIG. 3. The schematic figure showing the π and σ orbits around the linear chain. The combination of the π orbits around ^{10}Be perpendicular to the symmetry axis generates π orbits, while the combination of parallel orbits around ^{10}Be generates σ orbits.

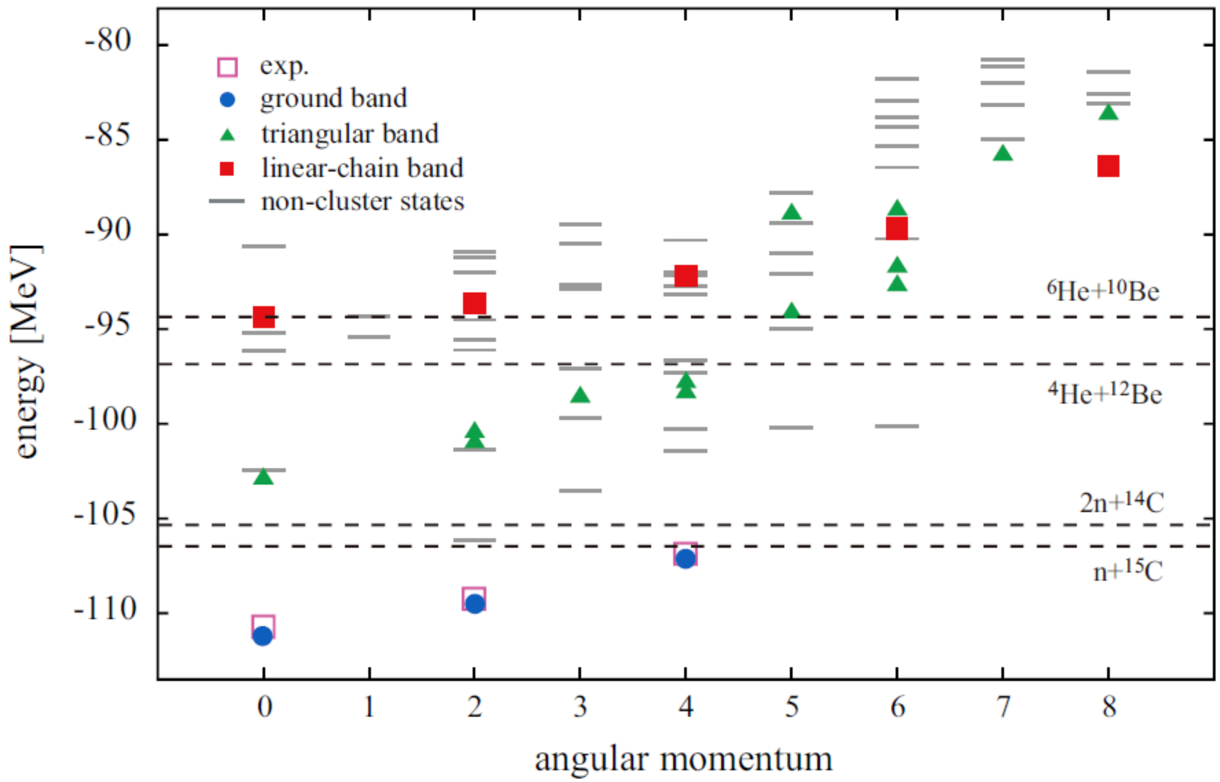


TABLE III. Excitation energies (MeV
(MeV$^{1/2}$), α-cluster and neutron spectrosc
selected positive-parity states. The reduced w
factors are calculated for the decays to the gr
nuclei.

Band	J^π	E_x	γ_α(6.0 fm)	S_α	S_n
Ground	0_1^+	0.00	0.00	0.03	0.22
	2_1^+	1.69	0.00	0.00	0.35
	4_1^+	4.04	0.00	0.00	0.01
Triangular	0_2^+	8.35	0.01	0.05	0.12
	2_4^+	10.22	0.00	0.00	0.01
	2_5^+	10.79	0.00	0.01	0.02
Linear chain	0_6^+	16.81	0.28	0.11	0.00
	2_9^+	17.51	0.23	0.07	0.00
	4_{10}^+	18.99	0.26	0.09	0.00
	6_5^+	21.49	0.23	0.07	0.00

The positive-parity energy levels up to $J\,\pi = 8+$.

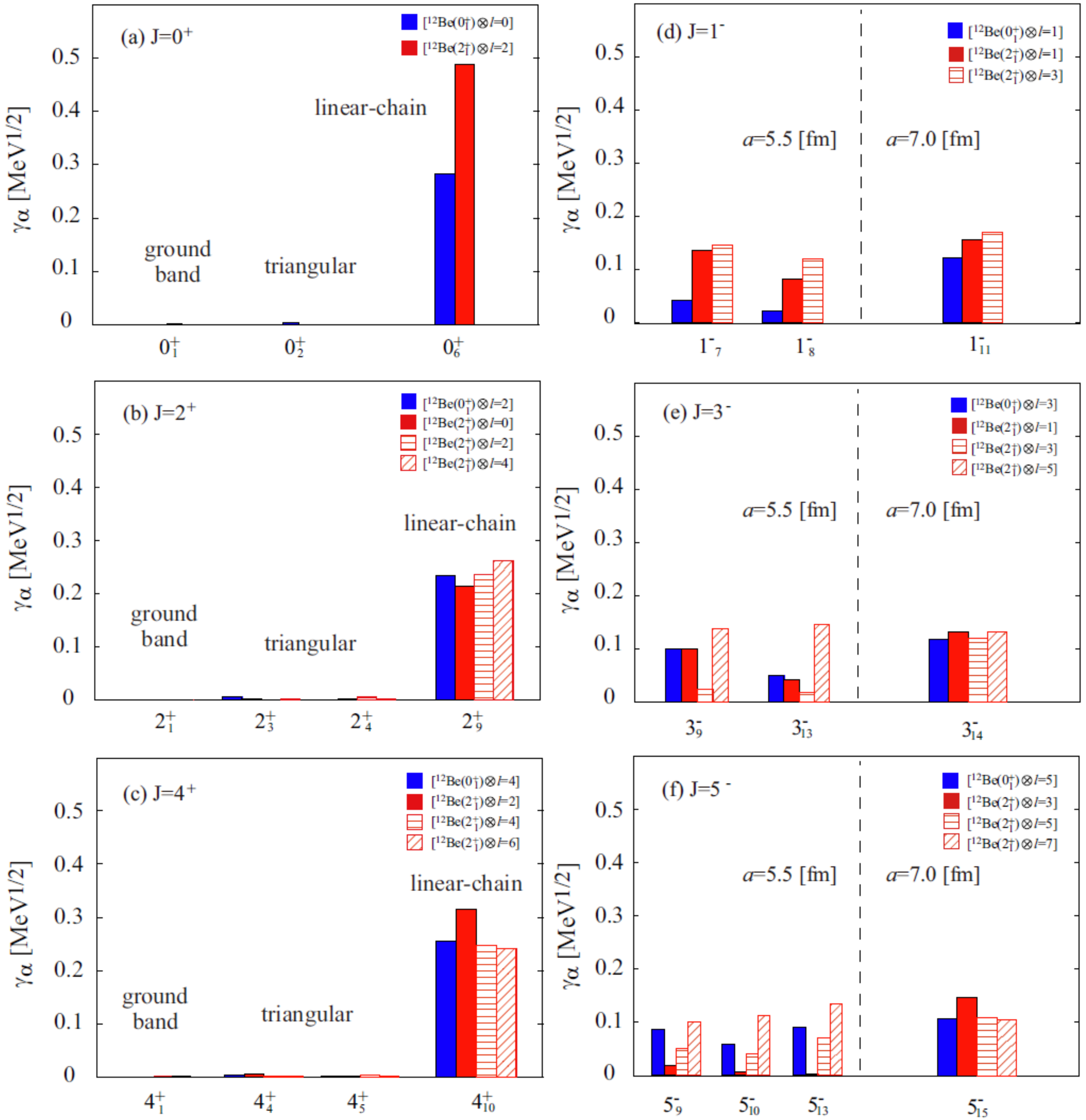


FIG. 7. Calculated α-decay reduced widths. Panels (a)–(c) show the decay of the positive-parity states to the ground band of ^{12}Be. Panels (d)–(f) show the decay of the negative-parity states to the ground band of ^{12}Be. The channel radii a are 6.0 fm for panels (a)–(c) and 5.5 (left side), 7.0 (right side) fm for panels (d)–(f), respectively.

Basic considerations for our experimentation

- Projectile and target in favor of cluster formation
- Large Q-value reaction in order to excite high-lying states in ^{14}C and to have a good selection of the states in ^{10}Be fragment;

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **95**, 021303(R) (2017)

Selective decay from a candidate of the σ-bond linear-chain state in ^{14}C

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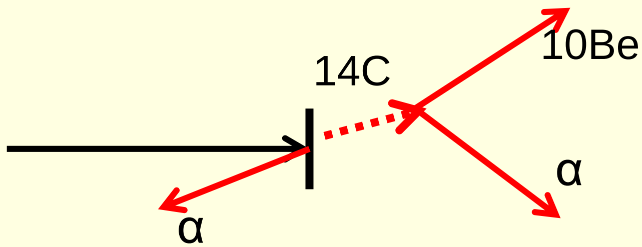
[2]*China Institute of Atomic Energy, Beijing, 102413, China*

selected reaction (5 AMeV beam; 185 ug/cm^2 target) **:**

$$^{9}\mathrm{Be} + {}^{9}\mathrm{Be} \rightarrow {}^{4}\mathrm{He} + {}^{14}\mathrm{C} \qquad Q=17.25\ \mathrm{MeV}$$

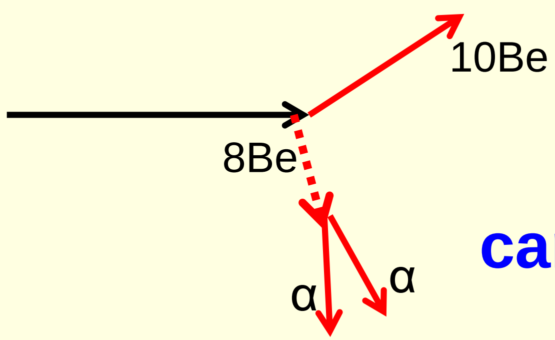
$$\mapsto {}^{4}\mathrm{He} + {}^{10}\mathrm{Be}^{*} \qquad Q=5.239\ \mathrm{MeV}$$



contamination in Q-value:

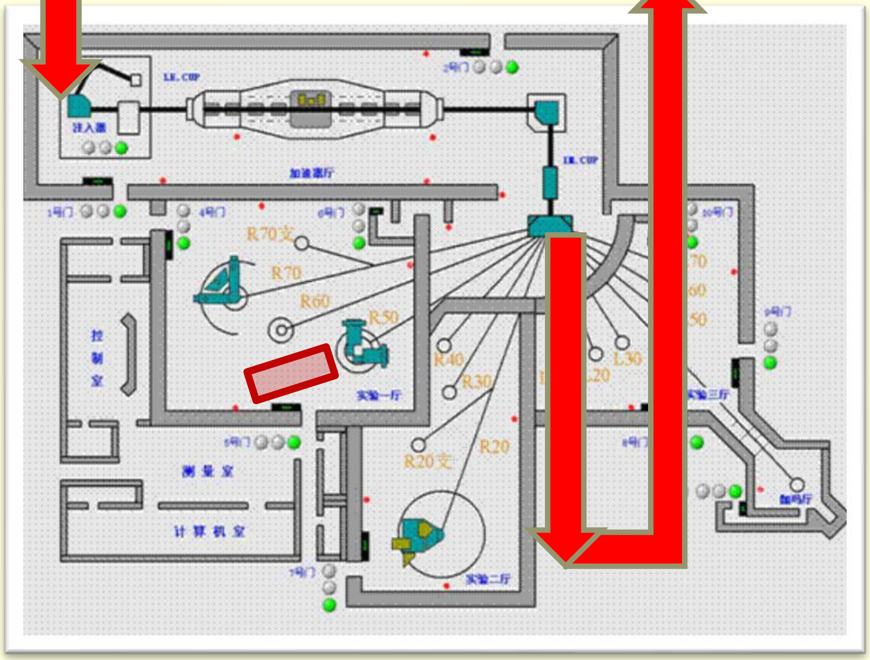
$$^{9}\mathrm{Be} + {}^{9}\mathrm{Be} \rightarrow {}^{10}\mathrm{Be} + {}^{8}\mathrm{Be} \qquad Q = 5.148\ \mathrm{MeV}$$

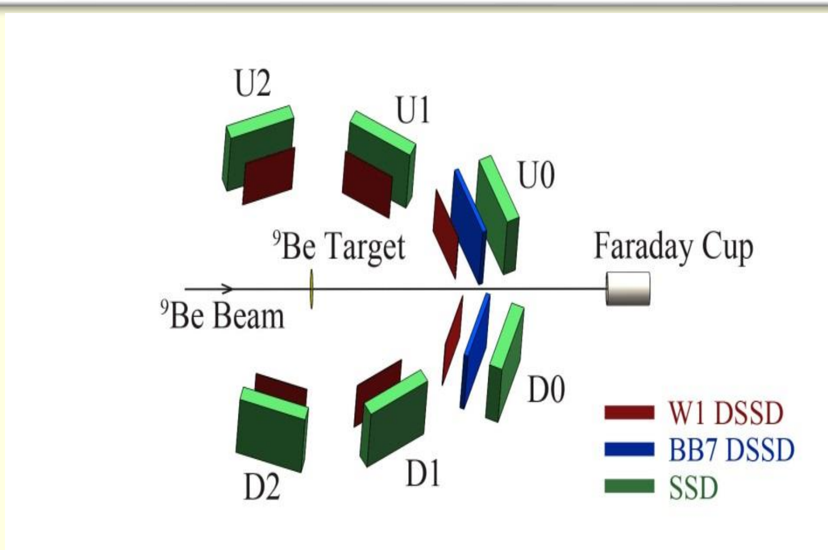
$$\mapsto {}^{4}\mathrm{He} + {}^{4}\mathrm{He}$$



can be removed via kinematics analysis

Experiment setup at CIAE

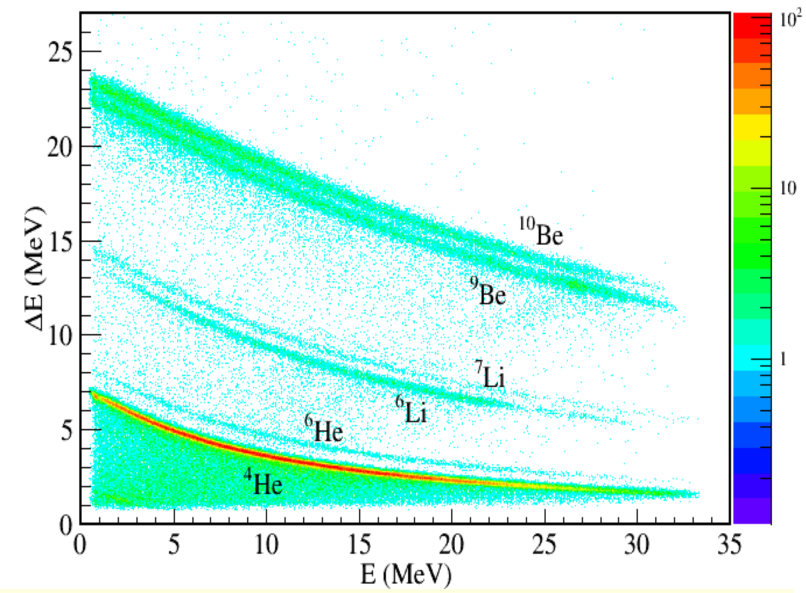




Detector	Segmen-tation	Thickness (μm)	Covering angle (degree)	Purpose
Telescope U0&D0	U0&D0 are symme-trical		13-33	10Be&alpha from 14C Alpha（14C）
DSSD	16 x 16	64		ΔE
DSSD	32x32	500		E
SSD		1500		E(4He)
Telescope U1&D1	U0&D0 are symme-trical		48-72	Alpha（14C）
DSSD	16*16	60		ΔE
SSD		1500		E
Telescope U2&D2	symmetrical		97-121	Alpha(14C)
DSSD	16	20		ΔE
SSD		1500		E

Beam	^{9}Be	45MeV	~7enA
Target	^{9}Be	0.9um	

Obtained Q-value spectra



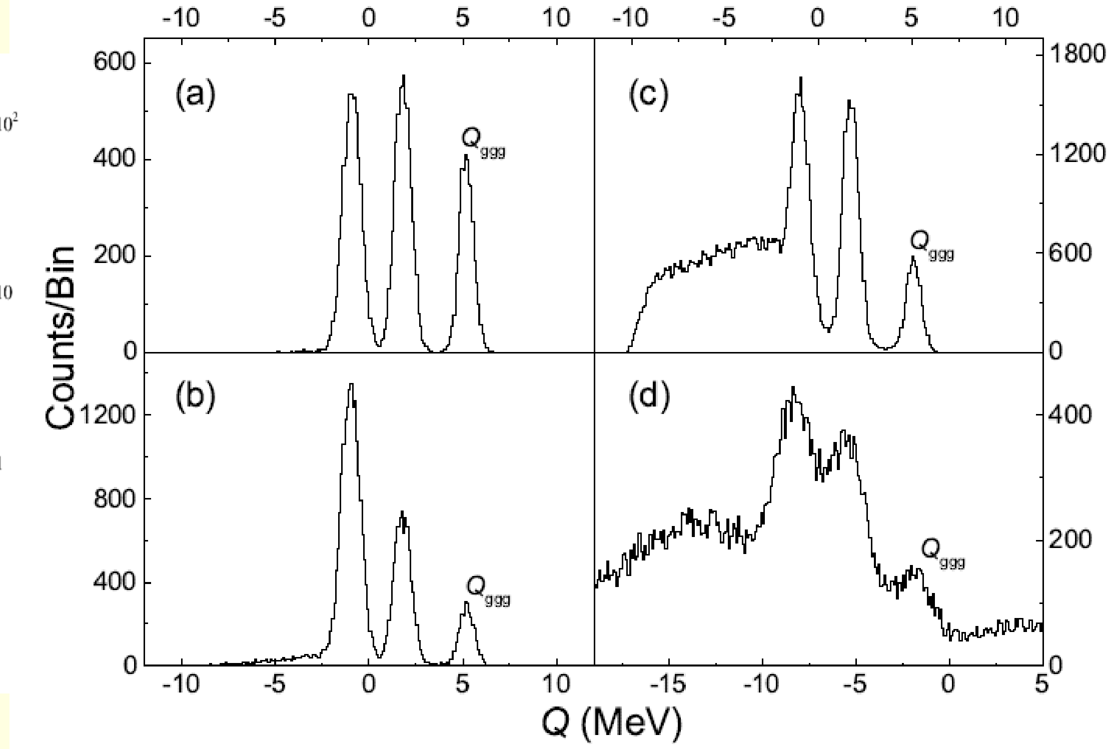
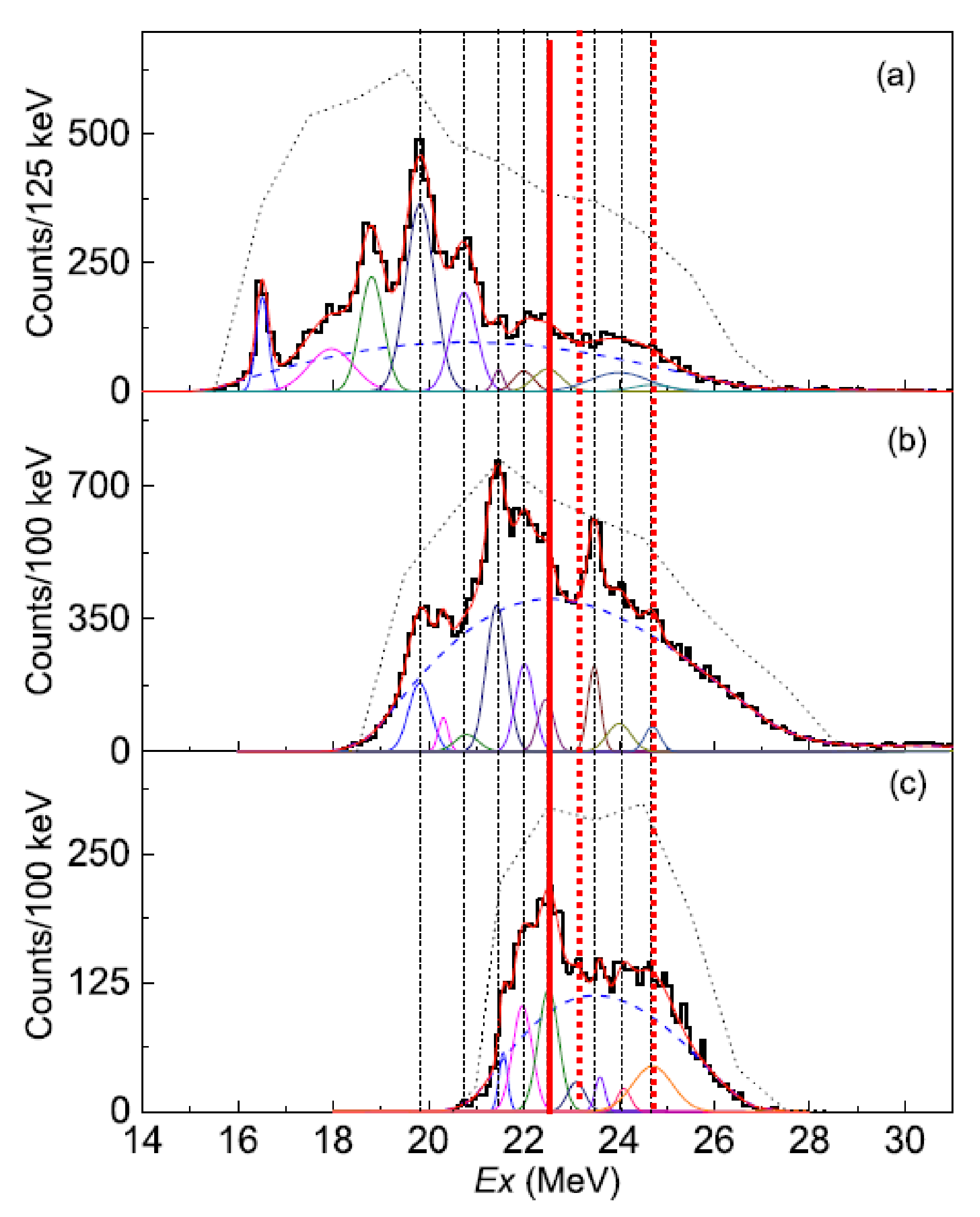


FIG. 1: Q-value spectrum from present experiment for different data sets with: (a) identified ^{10}Be and identified α in U0/D0 telescopes; (b) identified ^{10}Be and unidentified α; (c) identified α and unidentified ^{10}Be. Spectrum (d) comes from previous ^{7}Li(^{9}Be,α^{10}Be)^{2}H experiment [11].

Comparison of IM spectra for various ^{10}Be states



States selectively decaying into ~6 MeV states in ^{10}Be*

22.5(3)
23.1(3)
24.7(3)

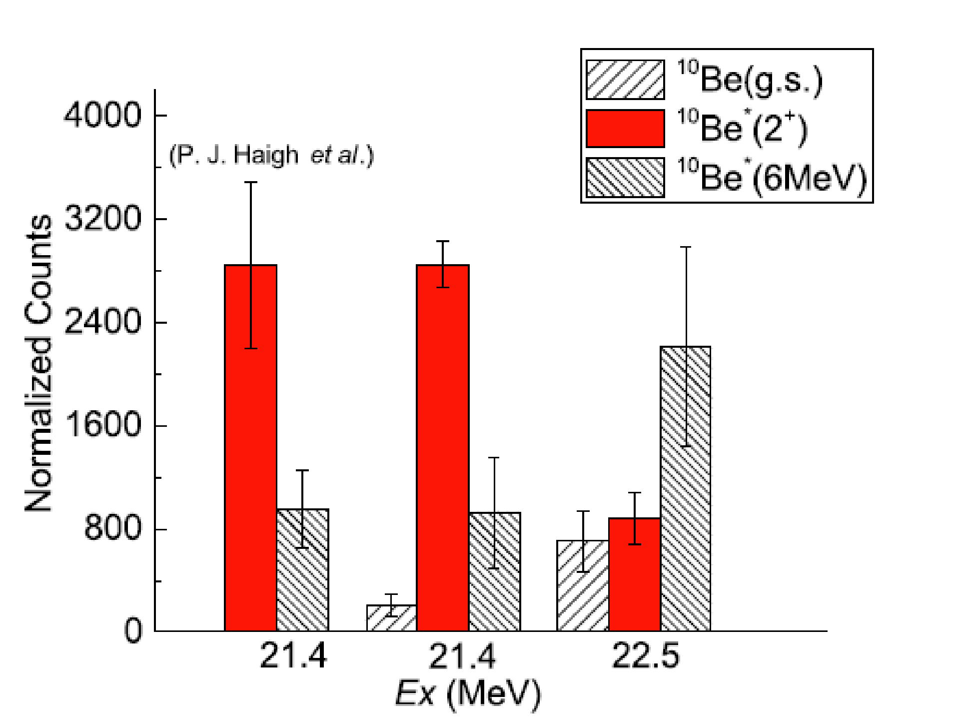
Predictions:

22.16 MeV
22.93 MeV
24.30 MeV

TABLE I: Summary of the excited states populated in ^{14}C and decaying to α-cluster and ^{10}Be in its ground, 2^+ and ∼6 MeV states. Those in square brackets represents tentative identifications.

This work			^{7}Li(^{9}Be,α^{10}Be)α[11]			^{14}C(^{14}C,α^{10}Be)^{14}C[12]		
^{10}Be$_{gs}$	^{10}Be(2^+)	^{10}Be(∼ 6 MeV)	^{10}Be$_{gs}$	^{10}Be(2^+)	^{10}Be(∼ 6 MeV)	^{10}Be$_{gs}$	^{10}Be(2^+)	^{10}Be(∼ 6 MeV)
16.5(1)			16.4(1)			16.4(1)		
						17.3(1)	17.3(1)	
17.9(1)						[18.1]		
18.8(1)			18.5(1)	18.5(1)		18.6	18.4(1)	
				[19.1(1)]			[19.0(2)]	
19.8(1)	19.8(1)		19.8(1)				19.8(1)	
	20.3(1)							20.4(1)
20.8(1)	20.8		20.6(1)					20.9(1)
[21.4][a]	21.4(1)	21.6(3)		21.4(1)			[21.6(2)]	
[22.0][a]	22.0(1)	22.0(3)						[21.9(1)]
[22.5][a]	22.5(1)	22.5(3)			22.4(3)			[22.5(1)]
		23.1(3)		[23.2(1)]				[23.1(2)]
	23.5(1)	23.6(3)						
[24.0][a]	[24.0(1)]	[24.0(3)]			24.0(3)			
[24.7][a]	[24.7(1)]	[24.7(3)]						

[a]These states were assigned by comparison with neighbouring decay path.



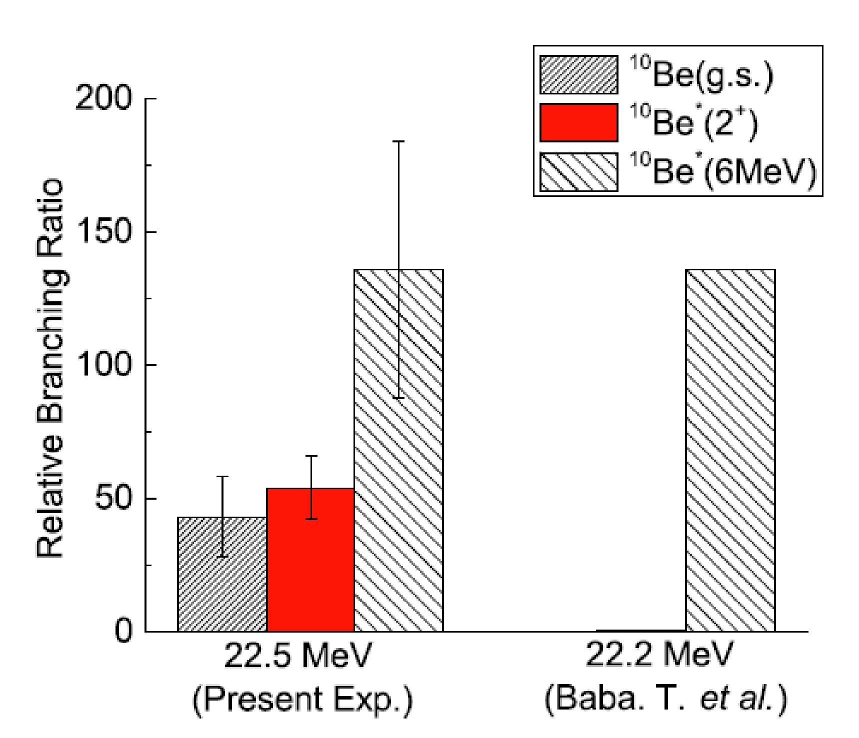
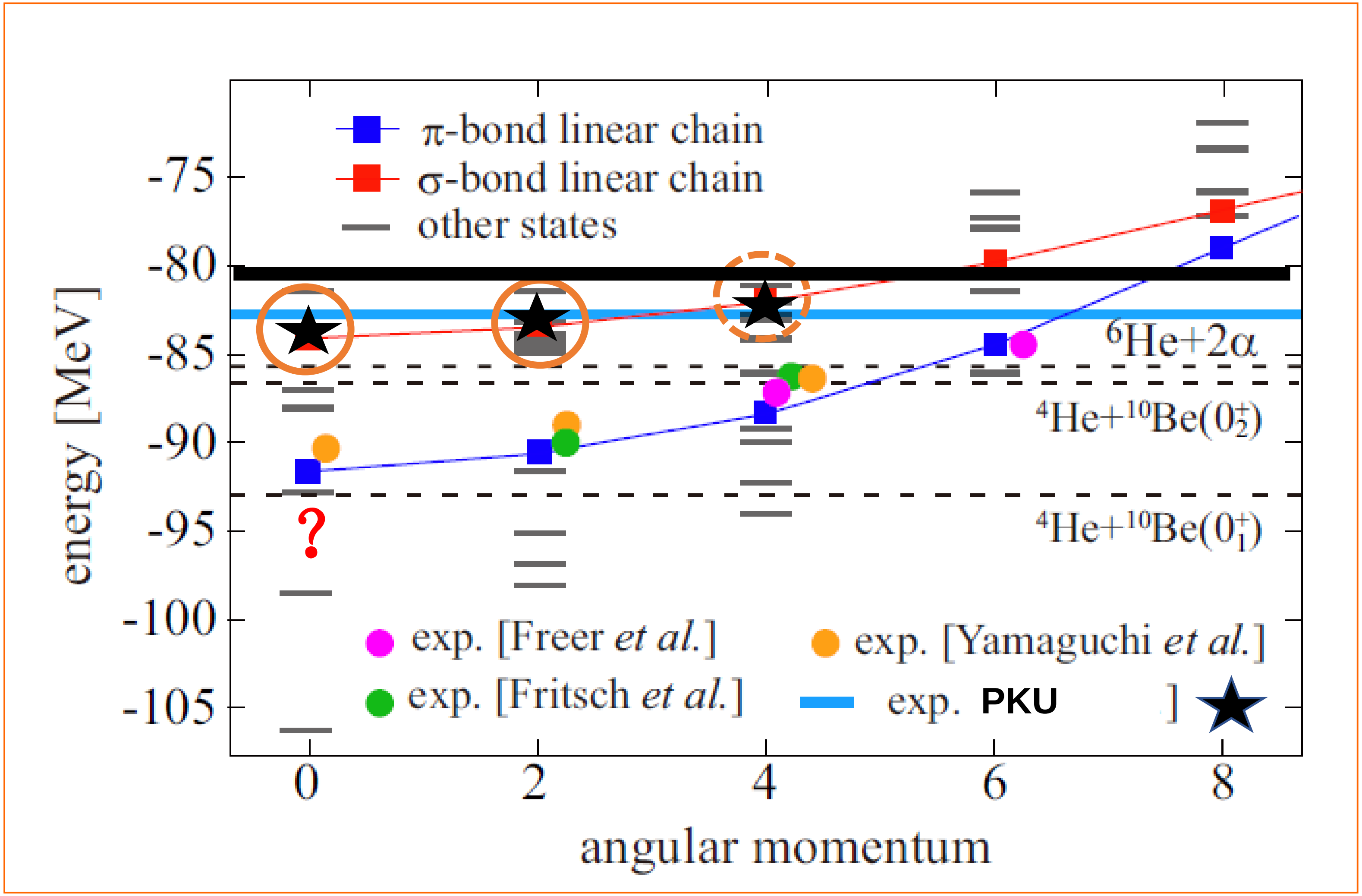


FIG. 3. $^{14}C \rightarrow {}^{10}Be + \alpha$ relative branching ratio for 21.4- and 22.5-MeV resonances in ^{14}C with respect to three sets of final states in ^{10}Be obtained from the present measurement. Results of the 21.4-MeV state taken from the previous two-neutron transfer experiment [14] are also plotted for comparison. The error bars are statistical only.

FIG. 4. Comparison of the relative decay branching ratio obtained from the present experiment with the theoretical prediction [10].

^{14}C: triangle, and π-bond or σ-bond linear-chain states



T. Baba and M. Kimura, PRC95(2017)064318

^{14}C: band-head of the π-bond linear-chain state

Chinese Physics C Vol. 42, No. 7 (2018) 074003

Investigation of the near-threshold cluster resonance in ^{14}C*

Hong-Liang Zang(臧宏亮)[1] Yan-Lin Ye(叶沿林)[1;1)] Zhi-Huan Li(李智焕)[1] Jian-Song Wang(王建松)[2]
Jian-Ling Lou(楼建玲)[1] Qi-Te Li(李奇特)[1] Yu-Cheng Ge(葛愉成)[1] Xiao-Fei Yang(杨晓菲)[1]
Jing Li(李晶)[3] Wei Jiang(蒋伟)[4] Jun Feng(冯俊)[1] Qiang Liu(刘强)[1] Biao Yang(杨彪)[1]
Zhi-Qiang Chen(陈志强)[1] Yang Liu(刘洋)[1]
Chen-Guang Li(李晨光)[1] Chun-Guang Wang
Jian Gao(高见)[1,5] Han-Zhou Yu(余翰舟)[1] Jun-
Yan-Yun Yang(杨彦云)[2] Shi-

[1] School of Physics and State Key Laboratory of Nuclear Ph

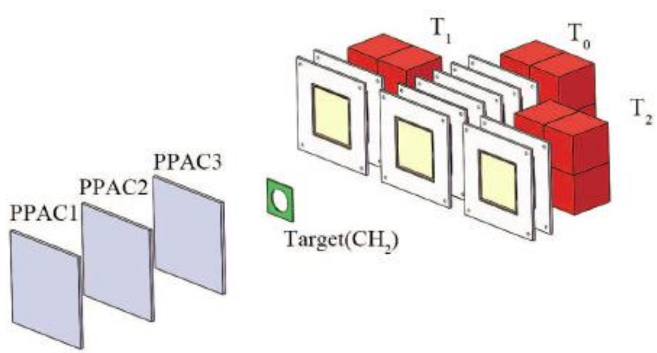


Fig. 1. (color online) A schematic view of the experimental setup.

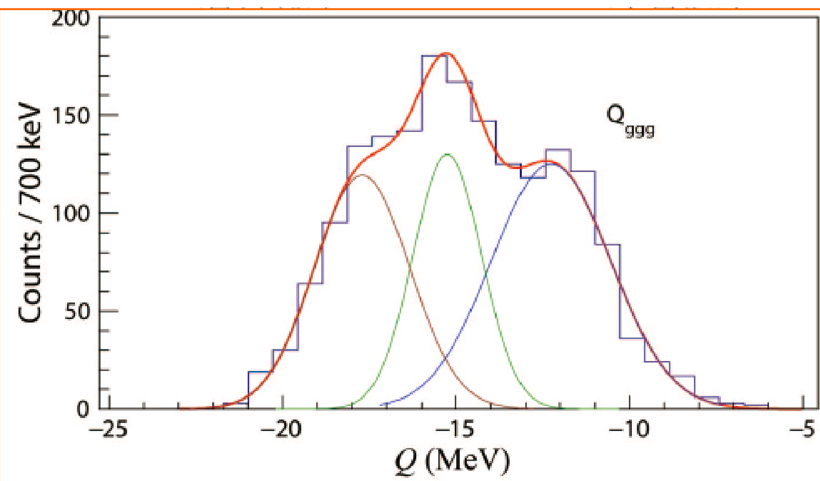
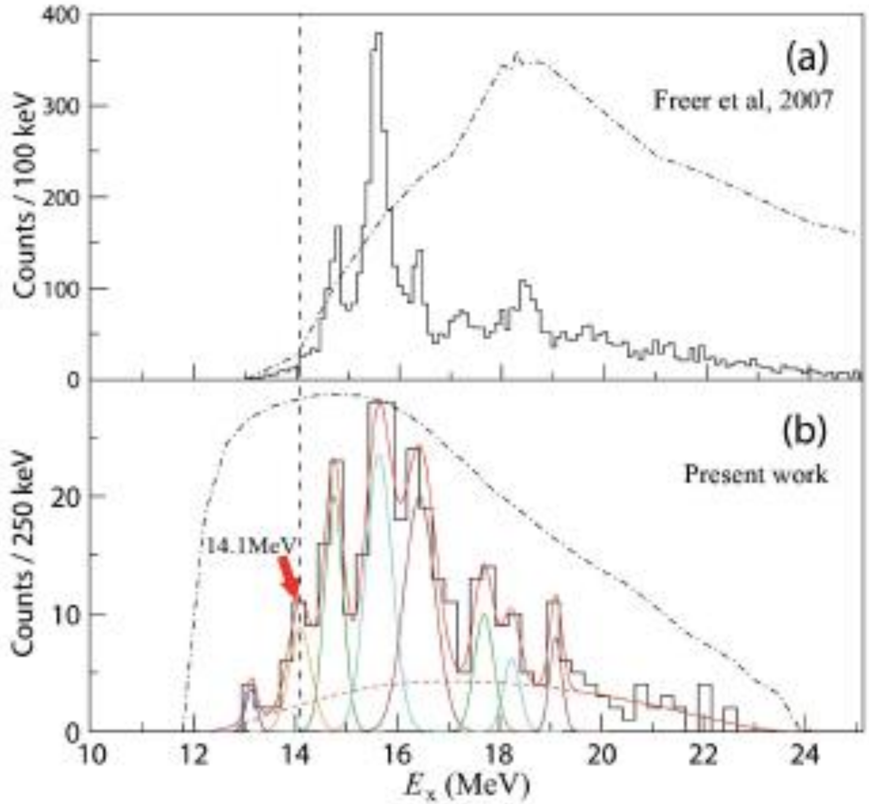


Fig. 2. (color online) Q-value spectrum for the $^{14}C \to {}^{10}Be + \alpha$ breakup reaction on a proton target, obtained from the present measurement. The Q_{ggg} peak is related to the final particles all in their g.s.. The other two peaks correspond to the exit ^{10}Be in its first excited state (3.36 MeV) and its four adjoining excited states around 6 MeV.

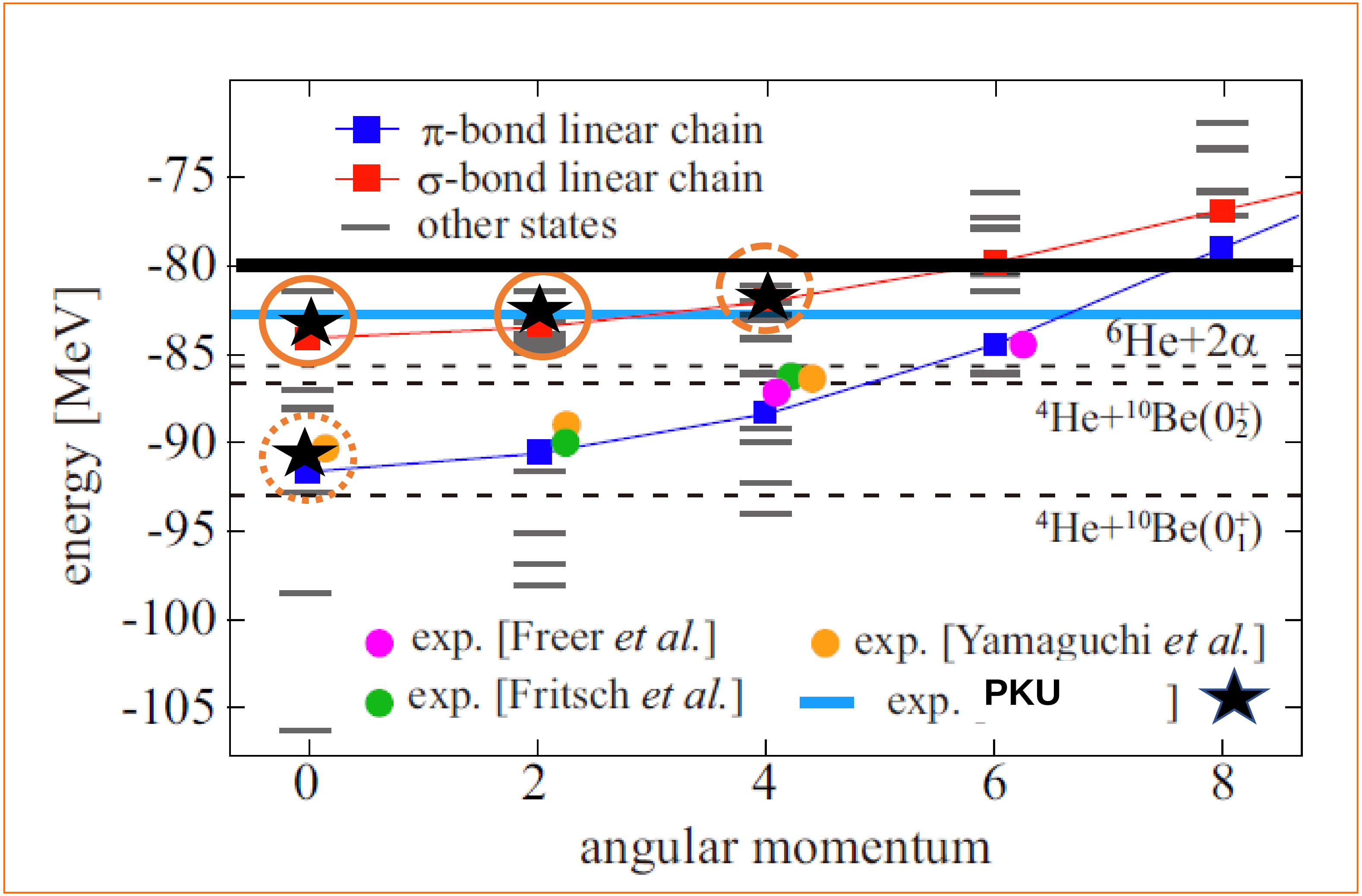


A state at 14.1(1) MeV is clearly identified, being consistent with the predicted band-head of the molecular rotational band characterized by the π-bond linear chain configuration.

a variation of the $\theta_\alpha^2/\ \Gamma_t$ value by a factor of 50%. In other words, current relative yields analysis, taking into account the Coulomb barrier penetrability, tends to constrain the spin of the 14.1 MeV resonance at low values of $0 \rightarrow 2$, being consistent with the expectation of a 0^+ band-head at around 14 MeV for the π-bond linear-chain configuration in ^{14}C.

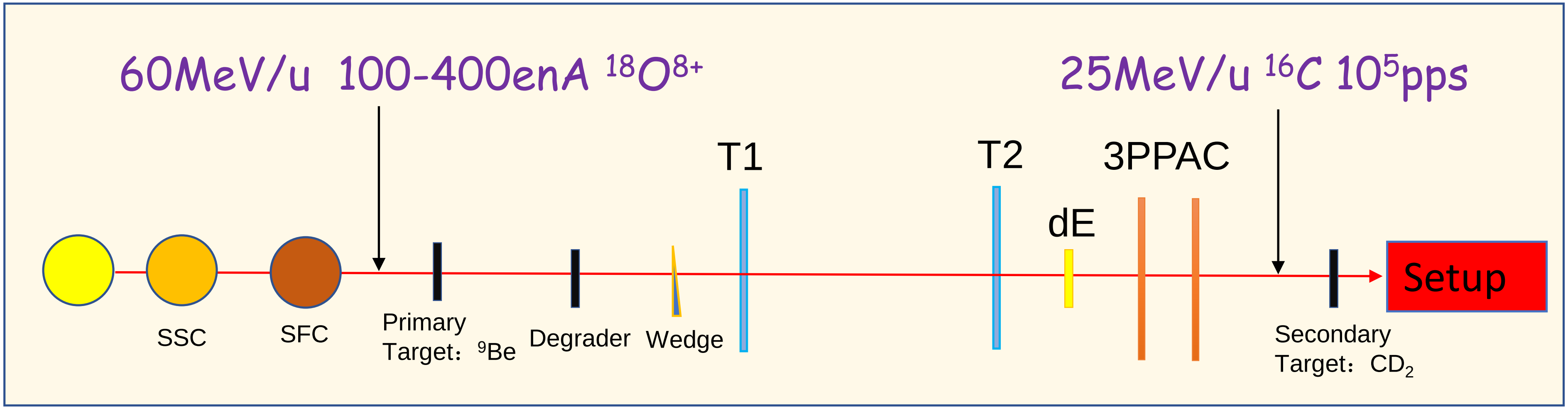
$$\frac{N_{exp}(14.1)}{N_{exp}(15.6)} = \frac{\theta_\alpha^2(14.1)\Gamma_t(15.6)}{\theta_\alpha^2(15.6)\Gamma_t(14.1)} \cdot \frac{(2J_x+1)P_{J_x}(14.1)}{7P_3(15.6)}.$$

^{14}C: triangle, and π-bond or σ-bond linear-chain states



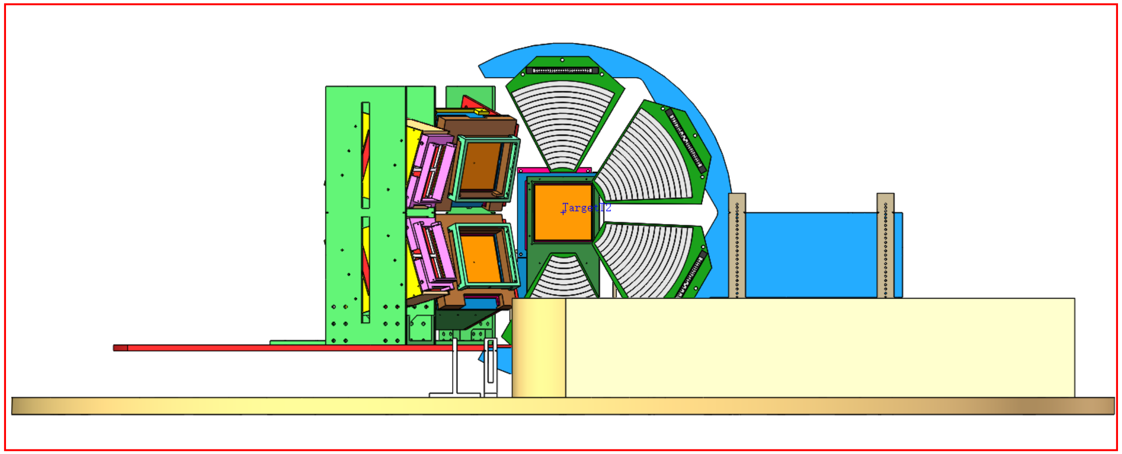
T. Baba and M. Kimura, PRC95(2017)064318

^{16}C: Latest RIBLL1 experiment



Primary Beam Intensity:

- 2018/04/02 - 2018/04/06: < 30*3.51enA = 105enA
- 2018/04/06 - 2018/04/09: (30~50)*3.51enA ≈ (100~180)enA
- 2018/04/09 - 2018/04/14: (50~120)*3.51enA ≈ (180~400)enA



Outline

I. Some background

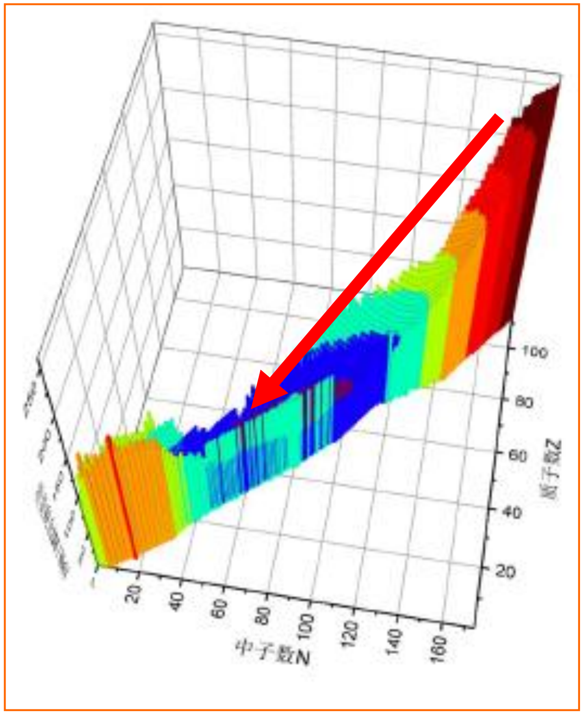
II. Studies on $^{14-16}C$

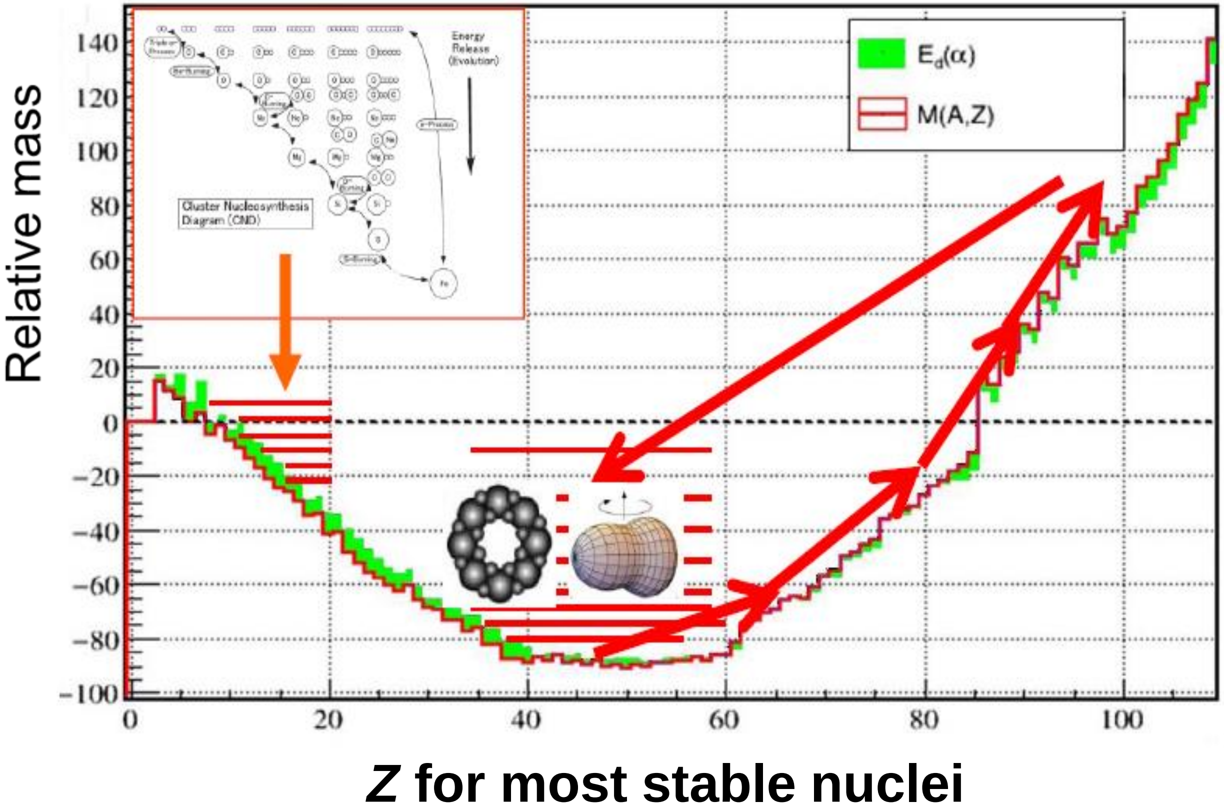
III. Some perspectives

Open problems for clustering in light nuclei

- 0_3^+ and 0_4^+ in ^{10}Be ;
- ^{12}Be systematics (^6He+^6He ?);
- broad 0_3^+ state in ^{12}C ;
- chain states in ^{14}C and ^{16}C ;
- α condensation state in ^{16}O, ^{24}Mg…;
- molecular bands in $^{18-28}O$;
- cluster + GR;
- 2n, 4n correlations;
- ……

Future: high excitation could easily be achieved in medium mass region via fission





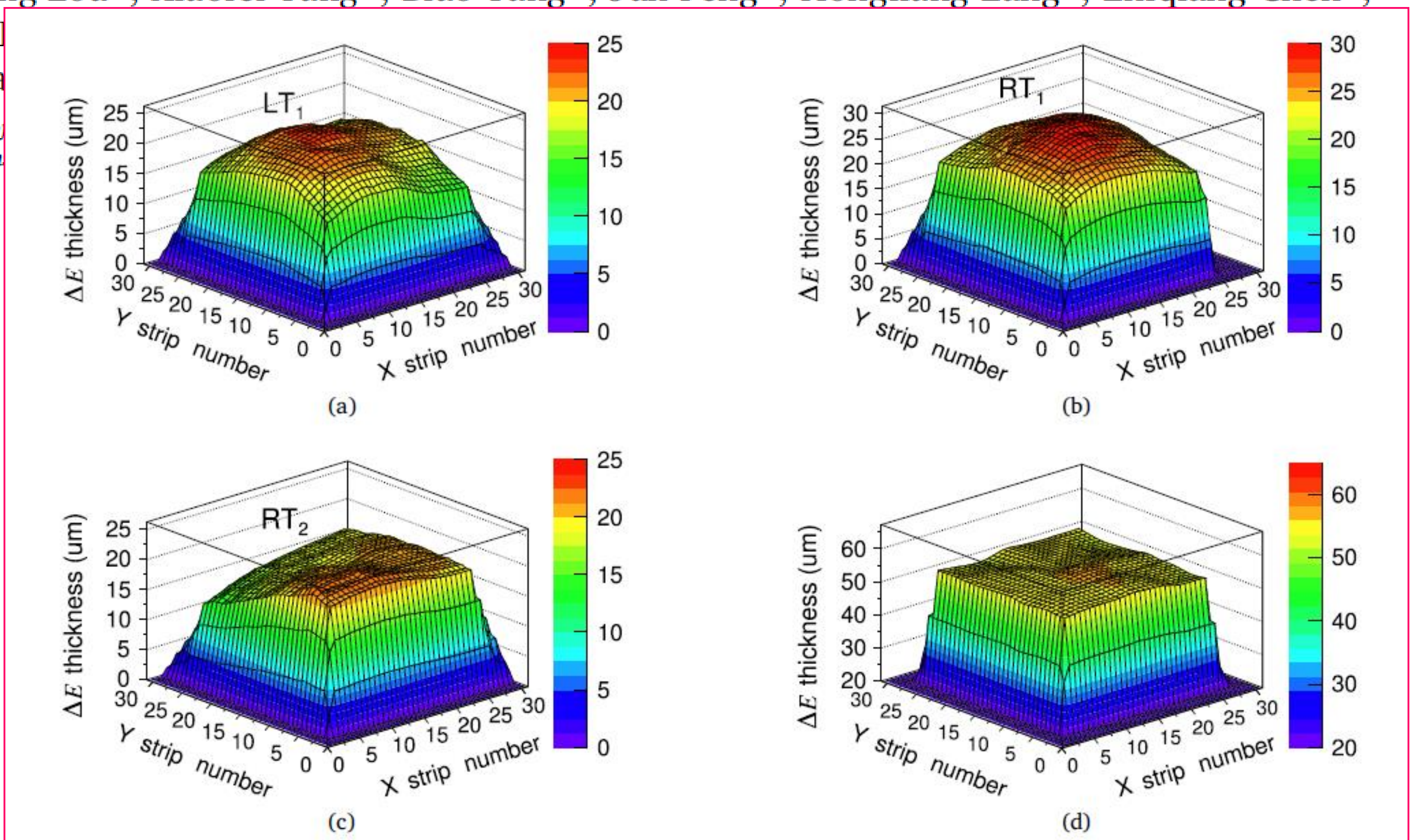
Application of new technique — very thin DSSD

Nuclear Inst. and Methods in Physics Research, A 897 (2018) 100–105

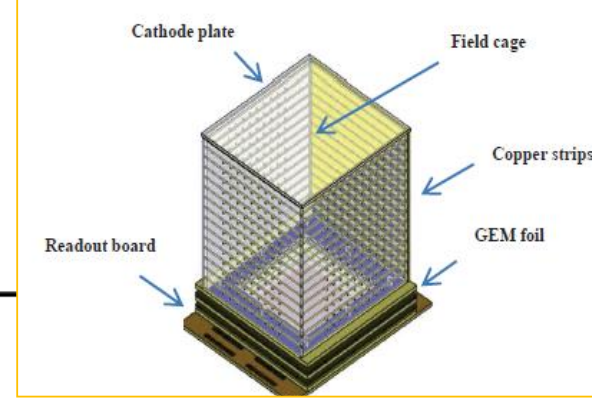
Investigation of the thickness non-uniformity of the very thin silicon-strip detectors

Qiang Liu [a], Yanlin Ye [a,*], Zhihuan Li [a], Chengjian Lin [b], Huiming Jia [b], Yucheng Ge [a], Qite Li [a], Jianling Lou [a], Xiaofei Yang [a], Biao Yang [a], Jun Feng [a], Hongliang Zang [a], Zhiqiang Chen [a],
Yang I
Lei Ya

[a] School o
[b] China In

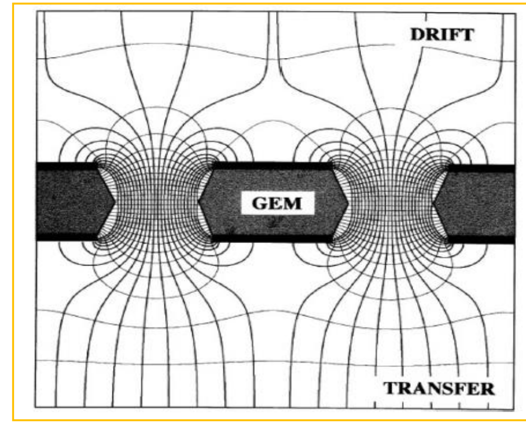


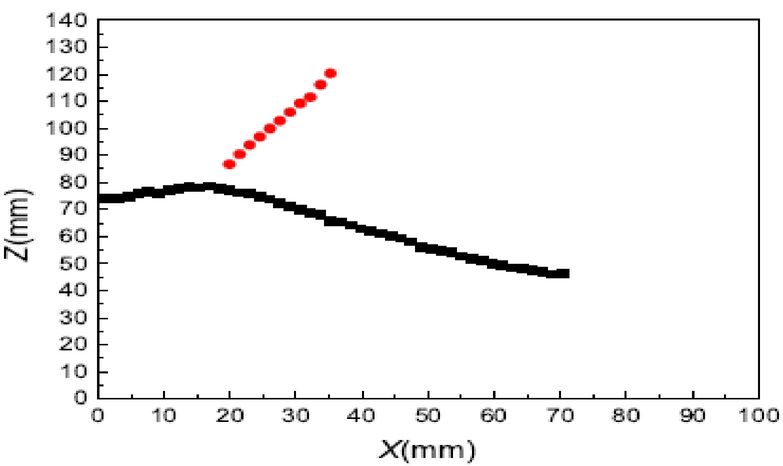
NUCL SCI TECH (2018)29:97
https://doi.org/10.1007/s41365-018-0437-6

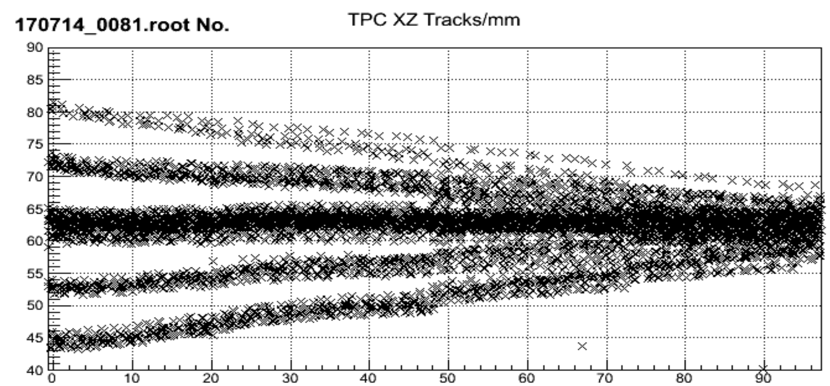


Performance of a small AT-TPC prototype

Jin-Yan Xu[1] · Qi-Te Li[1] · Yan-Lin Ye[1] · Jian Gao[1] · Jia-Xing Han[1] ·
Shi-Wei Bai[1] · Ka-Hou Ng[1]







Close theory & experiment cooperation

2014.12. Nanjing U
2015.08. Hokkaido U &
Osaka-RCNP

2016.11. Yokohama

2015.08. 2016.07. PKU

2017.11. Hokkaido U
2018.11. Sichuan U

Typical experimental collaborators

Z. H. Yang (杨再宏),[1] Y. L. Ye (叶沿林),[1,*] Z. H. Li (李智焕),[1] J. L. Lou (楼建玲),[1] J. S. Wang (王建松),[2] D. X. Jiang (江栋兴),[1] Y. C. Ge (葛愉成),[1] Q. T. Li (李奇特),[1] H. Hua (华辉),[1] X. Q. Li (李湘庆),[1] F. R. Xu (许甫荣),[1] J. C. Pei (裴俊琛),[1] R. Qiao (乔锐),[1] H. B. You (游海波),[1] H. Wang (王赫),[1,3] Z. Y. Tian (田正阳),[1] K. A. Li (李阔昂),[1] Y. L. Sun (孙叶磊),[1] H. N. Liu (刘红娜),[1,3] J. Chen (陈洁),[1] J. Wu (吴锦),[1,3] J. Li (李晶),[1] W. Jiang (蒋伟),[1] C. Wen (文超),[1,3] B. Yang (杨彪),[1] Y. Y. Yang (杨彦云),[2] P. Ma (马朋),[2] J. B. Ma (马军兵),[2] S. L. Jin (金仕纶),[2] J. L. Han (韩建龙),[2] and J. Lee (李晓菁)[3]

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(Received 10 December 2013; published 22 April 2014)

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Thank you for your attention!