

**Adopted Levels**

Q(β<sup>-</sup>)=17037 10; S(n)=-450 10; S(p)=22700 30; Q(α)=-9770 50  
 S<sub>2n</sub>=2720 keV 10.

S(n): Here we use S<sub>n</sub>=-0.45 MeV 10 as described below, and we compute relevant values using mass values from (2021Wa16). In AME (2021Wa16) the value S<sub>n</sub>=-0.51 MeV 10, based only on (2010Ko17), is used.

See shell model analyses in: 1983Va31,1984Va06,1985Po10, 1987Sa15, 1992Go17, 1996Wa35, 2007Gu03.

See Mean Field model analyses in: 1996Su24, 1997Ba23, 1997Ba54, 1997Re07, 2005Ar12, 2006Sh20, 2020Al27.

See Cluster Model and AMD analyses in: 1981Se06, 1994De32, 1995De31, 2005Ne03, 2005Th06, 2012Ka10, 2013Ma53, 2021Co07.

See other analyses in: 1995Ta32, 1999Ka67, 2000Bh07, 2004De60, 2004La24, 2004Ne16, 2004Sa50, 2006Ko02, 2007BI02.

See discussion on low-lying <sup>13</sup>Be levels and possible level inversion in: 1985Po10, 1995De31, 1997Re07, 1999La20, 2004Ta03, 2008Ha16, 2009BIZZ, 2010BI12, 2012Bo15, 2012Fo22, 2013Fo03, 2014Fo21, 2014Ho08, 2015Fo06, 2018Fo07, 2019Fo02.

In the present analysis the data are somewhat discrepant. The experimental approaches often provide incomplete measurements of the reaction observables and result in what appear as incompatible observations. The <sup>14</sup>C(<sup>11</sup>B,<sup>12</sup>N) and <sup>14</sup>C(π<sup>-</sup>,p) results have been used to guide an initial level scheme since these results are insensitive to ambiguities present in level energy determination based on n+<sup>12</sup>Be momentum reconstruction. The modern results where n+<sup>12</sup>Be kinematics are measured provide meritorious information on levels energies and decay modes and have been heavily consulted.

In surveying the results a trend appears where two groups around E<sub>rel</sub>(n+<sup>12</sup>Be)≈0.5-0.7 MeV and 2.3-2.5 MeV can reasonably fit the energy spectrum. However in studies utilizing γ+n+<sup>12</sup>Be coincidence events, where <sup>12</sup>Be excited states are considered, evidence is found for a larger number of neutron groups corresponding to levels at E<sub>res</sub>(n+<sup>12</sup>Be<sub>g.s.</sub>)≈0.4, 0.8, 2.0 and 3.0 MeV. The importance of including γ emission in analyzing the n+<sup>12</sup>Be spectra is highlighted below with comments on two measurements. First, in (2001Th01) the <sup>9</sup>Be(<sup>18</sup>O,<sup>13</sup>Be→<sup>12</sup>Be+n) reaction was measured; evidence for two components, at E<sub>res</sub>≈0 and 2.0 MeV, was found in the relative energy spectrum; however subsequent understanding supports the interpretation that these groups are connected to a E<sub>res</sub>(n+<sup>12</sup>Be)≈2 MeV level that decays to <sup>12</sup>Be<sub>g.s.</sub> with E<sub>n</sub>≈2 MeV and also decays to the high energy tail of <sup>12</sup>Be\* (2.1 MeV). Second, in the initial analysis of the <sup>1</sup>H(<sup>14</sup>Be,<sup>13</sup>Be→<sup>12</sup>Be+n) resonance spectrum of (2010Ko17), resonances at E<sub>res</sub>=0.51 MeV 1 with Γ=0.45 MeV 3 and E<sub>res</sub>=2.39 MeV 5 with Γ=2.4 MeV 2 were found, but the discussion indicated the E<sub>res</sub>=2.39 MeV region could also be reproduced with groups at E<sub>res</sub>=2.0 MeV and E<sub>res</sub>=2.9 MeV as suggested by (1992Os04,1998Be28). A reanalysis of (2010Ko17) in (2013Ak02) found evidence for 5 levels that decay to <sup>12</sup>Be ground and excited states.

Lastly, the virtual play-by-play analysis of experimental results given in the discussion of Fortune’s (2012-2019) articles provides insight into the evolution of our understanding of this nucleus. In these articles, extensive discussion on experimental work is given along-side a simple potential model analysis. Early on, the statement is made that, “The (lowest) s state in <sup>13</sup>Be is unbound, and unbound neutron s states are notoriously hard to handle.” Throughout the series of articles, listed above, the discussion focuses on likely structure configurations, the order of low-lying level spins and reasonable widths, and decay modes that can reasonably explain the data. See related discussion in (2021Co07).

<sup>13</sup>Be Levels

Cross Reference (XREF) Flags

<b>A</b>	<sup>1</sup> H( <sup>14</sup> Be, <sup>13</sup> Be):1	<b>G</b>	<sup>9</sup> Be( <sup>18</sup> O, <sup>13</sup> Be)	<b>M</b>	<sup>14</sup> C(π <sup>-</sup> ,p)
<b>B</b>	<sup>1</sup> H( <sup>14</sup> Be, <sup>13</sup> Be):2	<b>H</b>	<sup>9</sup> Be( <sup>48</sup> Ca,X)	<b>N</b>	<sup>14</sup> C(π <sup>-</sup> ,pd)
<b>C</b>	<sup>1</sup> H( <sup>14</sup> B, <sup>13</sup> Be)	<b>I</b>	C( <sup>14</sup> Be, <sup>13</sup> Be)	<b>O</b>	<sup>14</sup> C( <sup>7</sup> Li, <sup>8</sup> B)
<b>D</b>	<sup>2</sup> H( <sup>12</sup> Be,p)	<b>J</b>	C( <sup>14</sup> B, <sup>13</sup> Be)	<b>P</b>	<sup>14</sup> C( <sup>11</sup> B, <sup>12</sup> N)
<b>E</b>	<sup>2</sup> H( <sup>12</sup> Be, <sup>13</sup> Be)	<b>K</b>	<sup>13</sup> C(π <sup>-</sup> ,π <sup>+</sup> )	<b>Q</b>	U(p,X), <sup>232</sup> Th( <sup>15</sup> N,X)
<b>F</b>	<sup>9</sup> Be( <sup>13</sup> B, <sup>13</sup> Be)	<b>L</b>	<sup>13</sup> C( <sup>14</sup> C, <sup>14</sup> O)		

E(level) <sup>bc</sup>	J <sup>π</sup>	Γ	E' (MeV) <sup>a</sup>	XREF				Comments
0	1/2 <sup>-</sup>	0.43 MeV 20	0.45 1	AB	e	J	Q	%n=100 From E <sub>res</sub> =0.46 MeV 1 (see fit to (2010Ko17) <sup>1</sup> H( <sup>14</sup> Be, <sup>13</sup> Be) given in (2013Ak02)), 0.44 MeV 1 (2013Ak02) <sup>1</sup> H( <sup>14</sup> Be, <sup>13</sup> Be) and 0.40 MeV 3 (2014Ra07) C( <sup>14</sup> B, <sup>13</sup> Be). Also see E <sub>res</sub> =0.51

Continued on next page (footnotes at end of table)

**Adopted Levels (continued)**

<sup>13</sup>Be Levels (continued)

<u>E(level)<sup>bc</sup></u>	<u>J<sup>π</sup></u>	<u>Γ</u>	<u>E' (MeV)<sup>a</sup></u>	<u>XREF</u>	<u>Comments</u>
0.39×10 <sup>3</sup> 3	1/2 <sup>+</sup>	1.78 MeV 16	0.84 3	A C eF J M P	<p>MeV 1 initially reported in (2010Ko17).                      Γ: From unweighted average of Γ=0.11 MeV 2 (see fit to (2010Ko17) given in (2013Ak02)), 0.39 MeV 5 (2013Ak02) and 0.80 MeV 20 (2014Ra07).                      J<sup>π</sup>: From (2010Ko17) whose analysis of the n+<sup>12</sup>Be momentum distribution and the resonance width indicate an inversion of the 1s<sub>1/2</sub> and 0p<sub>1/2</sub> shells. The inversion is further supported from analysis of the low-lying <sup>14</sup>Be level structures (1999La20). (2007BI02, 2018Ri05,2019Fo02) discuss the expectation for a J<sup>π</sup>=1/2<sup>-</sup> state to be populated in neutron stripping from <sup>14</sup>Be and to be absent in proton stripping from <sup>14</sup>B; hence J<sup>π</sup>=1/2<sup>-</sup> is recommended for this resonance.                      %n=100                      XREF: A(0.36E3)F(0.28E3)M(0.20E3)                      From E<sub>res</sub>=0.81 MeV 6 (analysis of (2004Le29) C(<sup>14</sup>B,<sup>13</sup>Be) given in (2013Ak02)), 0.86 MeV 4 (2018Ri05) <sup>1</sup>H(<sup>14</sup>B,<sup>13</sup>Be), 0.85 MeV 15 (2014Ra07) C(<sup>14</sup>B,<sup>13</sup>Be) and 0.80 MeV 9 (1998Be28) <sup>14</sup>C(<sup>11</sup>B,<sup>12</sup>N).                      Γ: From Γ=2.1 MeV 3 (see fit to (2010Ko17) given in (2013Ak02)) and Γ=1.70 MeV 15 (2018Ri05). See other value Γ=0.30 MeV 30 in (2014Ra07).                      J<sup>π</sup>: From (2015Ma62) <sup>9</sup>Be(<sup>13</sup>B,<sup>13</sup>Be) where the <sup>12</sup>Be+n resonance is s-wave in character, see additional discussion in (2013Ak02, 2019Fo02).                      E(level): Decays via <sup>12</sup>Be<sub>g.s.</sub>+n.                      %n=100                      XREF: A(1.50E3)B(1.9E3)F(2.11E3)J(1.90E3)K(2.0E3)M(1.42E3)                      From E<sub>res</sub>=2.07 MeV 3 (2010Ko17 in 2013Ak02) <sup>1</sup>H(<sup>14</sup>Be,<sup>13</sup>Be), 1.95 MeV 5 (2013Ak02) <sup>1</sup>H(<sup>14</sup>Be,<sup>13</sup>Be), 2.11 MeV 5 (2018Ri05) <sup>1</sup>H(<sup>14</sup>B,<sup>13</sup>Be), 2.01 MeV 5 (1992Os04) <sup>13</sup>C(<sup>14</sup>C,<sup>14</sup>O), 1.87 MeV 10 (1998Go30) <sup>14</sup>C(π<sup>-</sup>,p), 1.9 MeV 5 (1983Al20) <sup>14</sup>C(<sup>7</sup>Li,<sup>8</sup>B), 2.02 MeV 6 (1998Be28) <sup>14</sup>C(<sup>11</sup>B,<sup>12</sup>N) and 2.22 MeV +4-5 (2023Ko21) <sup>2</sup>H(<sup>12</sup>Be,<sup>13</sup>Be).                      Γ: From (2023Ko21). See also 0.3 MeV 1 in (1998Go30), 0.3 MeV 2 in (1992Os04), ≈0.5 MeV in (2013Ak02), ≈0.4 MeV in (2018Ri05) and ≈0.3 MeV in (2007Si24).                      J<sup>π</sup>: From (2013Ak02) <sup>1</sup>H(<sup>14</sup>Be,<sup>13</sup>Be) where d-wave decay is reported in <sup>12</sup>Be<sub>g.s.</sub>+n and s-wave character is reported in <sup>12</sup>Be(2<sup>+</sup>)+n decay. In (1998Be28) the <sup>12</sup>C(<sup>11</sup>B,<sup>12</sup>N) and <sup>14</sup>C(<sup>11</sup>B,<sup>12</sup>N) spectra are shown to be similar, which supports 5/2<sup>+</sup> for this state.</p>
1.61×10 <sup>3</sup> 3	5/2 <sup>+</sup>	0.40 MeV +4-5	2.06 3	ABCDEFGHIJKLM OP	<p>%n=100                      XREF: A(1.50E3)B(1.9E3)F(2.11E3)J(1.90E3)K(2.0E3)M(1.42E3)                      From E<sub>res</sub>=2.07 MeV 3 (2010Ko17 in 2013Ak02) <sup>1</sup>H(<sup>14</sup>Be,<sup>13</sup>Be), 1.95 MeV 5 (2013Ak02) <sup>1</sup>H(<sup>14</sup>Be,<sup>13</sup>Be), 2.11 MeV 5 (2018Ri05) <sup>1</sup>H(<sup>14</sup>B,<sup>13</sup>Be), 2.01 MeV 5 (1992Os04) <sup>13</sup>C(<sup>14</sup>C,<sup>14</sup>O), 1.87 MeV 10 (1998Go30) <sup>14</sup>C(π<sup>-</sup>,p), 1.9 MeV 5 (1983Al20) <sup>14</sup>C(<sup>7</sup>Li,<sup>8</sup>B), 2.02 MeV 6 (1998Be28) <sup>14</sup>C(<sup>11</sup>B,<sup>12</sup>N) and 2.22 MeV +4-5 (2023Ko21) <sup>2</sup>H(<sup>12</sup>Be,<sup>13</sup>Be).                      Γ: From (2023Ko21). See also 0.3 MeV 1 in (1998Go30), 0.3 MeV 2 in (1992Os04), ≈0.5 MeV in (2013Ak02), ≈0.4 MeV in (2018Ri05) and ≈0.3 MeV in (2007Si24).                      J<sup>π</sup>: From (2013Ak02) <sup>1</sup>H(<sup>14</sup>Be,<sup>13</sup>Be) where d-wave decay is reported in <sup>12</sup>Be<sub>g.s.</sub>+n and s-wave character is reported in <sup>12</sup>Be(2<sup>+</sup>)+n decay. In (1998Be28) the <sup>12</sup>C(<sup>11</sup>B,<sup>12</sup>N) and <sup>14</sup>C(<sup>11</sup>B,<sup>12</sup>N) spectra are shown to be similar, which supports 5/2<sup>+</sup> for this state.</p>

Continued on next page (footnotes at end of table)

**Adopted Levels (continued)** ${}^{13}\text{Be}$  Levels (continued)

<u>E(level)<sup>bc</sup></u>	<u>J<sup>π</sup></u>	<u>Γ</u>	<u>E' (MeV)<sup>a</sup></u>	<u>XREF</u>			<u>Comments</u>
2.53×10 <sup>3</sup> 4	(5/2 <sup>+</sup> )	≈0.4 MeV	2.98 4	A C	IJ	M P	<p>E(level): Decays via <math>{}^{12}\text{Be}_{g.s.}+n</math> [<math>E_{\text{res}}=2.11</math>] and <math>{}^{12}\text{Be}^*(2.109)+n</math> [<math>E_{\text{res}}&lt;0.1</math> MeV] (2013Ak02,2018Ri05, 2019Co12).</p> <p>%n=100 XREF: C(2.47E3)J(1.90E3) E(level): From <math>E_{\text{res}}=2.98</math> MeV 4 (2010Ko17 in 2013Ak02) <math>{}^1\text{H}({}^{14}\text{Be}, {}^{13}\text{Be})</math>, 3.02 MeV 9 (2013Ak02) <math>{}^1\text{H}({}^{14}\text{Be}, {}^{13}\text{Be})</math>, 2.90 MeV 13 (1998Be28) <math>{}^{14}\text{C}({}^{11}\text{B}, {}^{12}\text{N})</math>. Γ: From ≈0.5 MeV (2010Ko17, 2013Ak02), ≈0.4 MeV (2007Si24) and ≤0.15 MeV (1998Go30). J<sup>π</sup>: From (2018Ri05) <math>{}^1\text{H}({}^{14}\text{B}, {}^{13}\text{Be})</math>. The state's population in proton knockout, where negative parity states are suppressed, supports a positive parity assignment. The state is thought to decay most strongly to <math>{}^{12}\text{Be}(0_2^+)</math>, but this branch is difficult to observe; see discussion in (2019Fo02). E(level): Decays via <math>{}^{12}\text{Be}_{g.s.}+n</math> (2013Ak02,2018Ri05); an unobserved branch via <math>{}^{12}\text{Be}(0_2^+)+n</math> is expected. %n=100 E(level),J<sup>π</sup>,Γ: From (2018Ri05) <math>{}^1\text{H}({}^{14}\text{B}, {}^{13}\text{Be})</math>. J<sup>π</sup>: Populated in proton knockout from <math>{}^{14}\text{B}</math> indicating π=+; see further discussion in (2019Fo02) indicating a J<sup>π</sup>=3/2<sup>+</sup> state is expected in this vicinity with similar decay properties.</p>
≈3.55×10 <sup>3</sup>	(3/2 <sup>+</sup> )	≈0.4 MeV	4.0	C			<p>E(level): Decays via <math>{}^{12}\text{Be}_{g.s.}+n</math> [<math>E_{\text{res}}=4.0</math>] and <math>{}^{12}\text{Be}^*(2109)+n</math> [<math>E_{\text{res}}\approx 2.1</math> MeV]. %n=100 XREF: A(4.75E3)M(4.51E3)P(4.49E3) E(level): From <math>E_{\text{res}}=5.2</math> MeV 1 (2010Ko17 in 2013Ak02) <math>{}^1\text{H}({}^{14}\text{Be}, {}^{13}\text{Be})</math>, 5.1 MeV 13 (2019Co12) <math>{}^1\text{H}({}^{14}\text{Be}, {}^{13}\text{Be})</math>, 5.13 MeV 7 (1992Os04) <math>{}^{13}\text{C}({}^{14}\text{C}, {}^{14}\text{O})</math>, 4.96 MeV 20 (1998Go30) <math>{}^{14}\text{C}(\pi^-, p)</math> and 4.94 MeV 8 (1998Be28) <math>{}^{14}\text{C}({}^{11}\text{B}, {}^{12}\text{N})</math>. Γ: From (2010Ko17 in 2013Ak02). Others are 0.4 MeV 2 (1992Os04) and ≈1.7 MeV (1998Go30). J<sup>π</sup>: From (2013Ak02) <math>{}^1\text{H}({}^{14}\text{Be}, {}^{13}\text{Be})</math> where s-wave neutron emission from a 3/2<sup>-</sup> state (or p-wave emission from a 5/2<sup>+</sup> state) to <math>{}^{12}\text{Be}(1^-)</math> are preferred. E(level): (2013Ak02) report the state decays to <math>{}^{12}\text{Be}^*(2.71</math> MeV) while</p>
4.63×10 <sup>3</sup> 5	(3/2 <sup>-</sup> , 5/2 <sup>+</sup> )	1.4 MeV 2	5.08 5	AB D	LM	P	

Continued on next page (footnotes at end of table)

**Adopted Levels (continued)** ${}^{13}\text{Be}$  Levels (continued)

<u>E(level)<sup>bc</sup></u>	<u><math>\Gamma</math></u>	<u>E' (MeV)<sup>a</sup></u>	<u>XREF</u>		<u>Comments</u>
$5.43 \times 10^3$ 10		5.88 10	B	P	(2019Co12) report the state decays to ${}^{12}\text{Be}^*(2.1 \text{ MeV})$ . %n=100 E(level): From (1998Be28) ${}^{14}\text{C}({}^{11}\text{B}, {}^{12}\text{N})$ ; see also $E_{\text{res}}=5.7 \text{ MeV}$ 14 in (2019Co12) ${}^1\text{H}({}^{14}\text{Be}, {}^{13}\text{Be})$ . E(level): Decays to ${}^{12}\text{Be}^*(2.71 \text{ MeV})+n$ (2019Co12). E(level): From (1995Ko10, 1995Ko27) ${}^2\text{H}({}^{12}\text{Be}, p)$ .
$6.55 \times 10^3$ <sup>d</sup>		7.0	D		E(level): From (1995Ko10, 1995Ko27) ${}^2\text{H}({}^{12}\text{Be}, p)$ .
$8.1 \times 10^3$ <sup>d</sup> 2	0.9 MeV 3	8.5 2		L P	XREF: P(7.5E3) E(level), $\Gamma$ : From $E_{\text{res}}=8.5 \text{ MeV}$ 2 (1992Os04) ${}^{13}\text{C}({}^{14}\text{C}, {}^{14}\text{O})$ ; see also 7.9 MeV 2 (1998Be28) ${}^{14}\text{C}({}^{11}\text{B}, {}^{12}\text{N})$ .
$9.6 \times 10^3$ <sup>d</sup>		10.0	D		E(level): From (1995Ko10, 1995Ko27) ${}^2\text{H}({}^{12}\text{Be}, p)$ .
$18.7 \times 10^3$ <sup>d</sup>	9.0 MeV 15			K	E(level), $\Gamma$ : From (1992Wa11) ${}^{13}\text{C}(\pi^-, \pi^+)$ .
$\approx 30 \times 10^3$ <sup>d</sup>				N	E(level): From (2016Ko22) ${}^{14}\text{C}(\pi^-, pd)$ .

<sup>a</sup> E' is a relative excitation energy scale with E'=0 at the neutron separation energy. We use this scale because most articles report level energies with respect to the n+ ${}^{12}\text{Be}_{\text{g.s.}}$  center of mass energy.

<sup>b</sup> The ground state is taken as  $E_{\text{c.m.}}(n+{}^{12}\text{Be}_{\text{g.s.}})=0.45 \text{ MeV}$  1.

<sup>c</sup> Broad states are reported at  $E_{\text{c.m.}}({}^{12}\text{Be}_{\text{g.s.}}+n)=2.56 \text{ MeV}$  and  $2.35 \text{ MeV}$  in  ${}^9\text{Be}({}^{13}\text{B}, {}^{13}\text{Be})$  and  $\text{C}({}^{14}\text{B}, {}^{13}\text{Be})$ , respectively. The present evaluation assumes these correspond to a combination of unresolved groups at  $E_{\text{c.m.}}({}^{12}\text{Be}_{\text{g.s.}}+n)=2.0 \text{ MeV}$  and  $2.98 \text{ MeV}$ .

<sup>d</sup> Decay mode not reported; likely mode is %n=100.

$^1\text{H}(^{14}\text{Be},^{13}\text{Be}):1$  2013Ak02

**2010Ko17:** The authors studied resonances in the  $^{13}\text{Be}$  nucleus by measuring products from the one-neutron removal reaction on  $^{14}\text{Be}$  via the  $^1\text{H}(^{14}\text{Be},^{12}\text{Be}+n)$  reaction using a  $E(^{14}\text{Be})=69$  MeV/nucleon beam (at target center) at RIKEN ( $\Delta P/P=\pm 2\%$ ). The  $^{12}\text{Be}$  ions were detected in a spectrometer, while 54 plastic scintillator rods detected the neutrons;  $\gamma$ -rays identifying populated  $^{12}\text{Be}$  states were also measured. The  $^{13}\text{Be}$  resonance energies were deduced from reconstruction of the invariant mass. A low-energy s-wave strength is observed, which is characterized with a scattering length  $a_s=-3.4$  fm 6. Resonances are suggested at  $E_{\text{res}}=0.51$  MeV 1 with  $\Gamma=0.45$  MeV 3 and  $\sigma=48$  mb 4, along with  $E_{\text{res}}=2.39$  MeV 5 with  $\Gamma=2.4$  MeV 2 and  $\sigma=34$  mb 3. The peak corresponding to  $E_{\text{res}}=2.39$  MeV can also be reproduced with groups at  $E_{\text{res}}=2.0$  MeV and  $E_{\text{res}}=2.9$  MeV as suggested by (1992Os04,1998Be28). This three-state interpretation is preferred in the ENSDF evaluation. Analysis of the transverse momentum distribution along with the 0.45 MeV width of the lower state was interpreted as evidence for a p-wave ( $J^\pi=1/2^-$ ) nature for this state. The authors suggest this intruder configuration implies a disappearance of N=8 magicity.

In this measurement, the low energy strength is attributed to a background resulting from  $^1\text{H}(^{14}\text{Be},^{14}\text{Be}^*\rightarrow^{12}\text{Be}+2n)$  channel vs the single-neutron removal  $^1\text{H}(^{14}\text{Be},^{13}\text{Be}+n\rightarrow(^{12}\text{Be}+n)+n)$  channel. However, the measurement provided  $n+^{12}\text{Be}+\gamma$  coincidence data that gave hints for a low-energy neutron component feeding  $^{12}\text{Be}^*(2.1$  MeV).

The (2010Ko17) data is reanalyzed in (2013Ak02) guided by details on other resonances discovered in other measurements. In this reanalysis information on states isolated in the  $n+^{12}\text{Be}+\gamma$  coincidence data provided new information. Relevant fit parameters from that analysis are  $E_{\text{res}}=0.46$  MeV 1 with  $\Gamma=0.11$  MeV 2,  $E_{\text{res}}=2.07$  MeV 3,  $E_{\text{res}}=2.98$  MeV 3,  $E_{\text{res}}=5.2$  MeV 1 with  $\Gamma=1.4$  MeV 2; resonances at  $E_{\text{res}}=0.81$  MeV 1 with  $\Gamma=2.1$  MeV 3 and  $E_{\text{res}}=2.0$  MeV 1 decaying to  $^{12}\text{Be}^*(2.1$  MeV), and the  $\Gamma=0.5$  MeV widths of  $E_{\text{res}}=2.0, 2.07, 2.98$  were fixed in the analysis. Results from the reanalysis are preferred in this evaluation.

**2013Ak02:** XUNDL dataset compiled by TUNL, 2013.

The authors reconstructed the  $^{12}\text{Be}+n$  relative energy of  $^{13}\text{Be}$  states populated in the one-neutron knockout reaction  $^1\text{H}(^{14}\text{Be},^{13}\text{Be}\rightarrow^{12}\text{Be}+n)$  at  $E(^{14}\text{Be})=304$  MeV/u. Analysis was carried out by simultaneously fitting new data as well as data collected earlier at RIKEN at  $E(^{14}\text{Be})=69$  MeV/nucleon (2010Ko17).

An  $E(^{14}\text{Be})=304$  MeV/nucleon beam, produced by fragmenting a  $^{18}\text{O}$  beam on a Be target at the GSI/FRS, impinged on a 5.0 cm long liquid hydrogen target. The  $^{12}\text{Be}$  ions were identified by  $\Delta E$ -E techniques while their momentum was determined using a set of Multi-Wire Proportional Chamber (MWPC) combined with the magnetic rigidity analysis of the ALADIN spectrometer. Neutron momenta were measured using the large area neutron detector (LAND). Resolution for the relative energies varies from 250 keV at  $E_{\text{rel}}=500$  keV to 700 keV at  $E_{\text{rel}}=2$  MeV.

The new  $E(^{14}\text{Be})=304$  MeV/nucleon GSI data are simultaneously analyzed with the relative energy spectrum data from RIKEN, which was collected at  $E(^{14}\text{Be})=69$  MeV/nucleon (2010Ko17). While subtle differences are visible among the two spectra, the analysis resulted in a coherent description of both data sets by fitting the resonances with Breit-Wigner shapes whose locations and angular momenta were partly guided by information from previously observed  $^{13}\text{Be}$  and  $^{12}\text{Be}$  states.

Strength from six neutron resonances were considered in fitting the measured neutron spectra: the unbound resonances at  $S_n=-0.44, -0.81, -1.95, -2.0, -3.02$  and  $-5.2$  MeV. In the analysis, two components were fixed by prior neutron +  $\gamma$  coincidence data of (2010Ko17): first, neutron decay from the high energy tail of a  $J^\pi=5/2^+$  level at  $S_n=-2.0$  MeV with  $\Gamma=0.5$  MeV decays to  $^{12}\text{Be}^*(2.1: J^\pi=2^+)$  producing a structure peaked near  $E_{\text{rel}}(n+^{12}\text{Be}^*)\approx 0$  MeV; second, neutron decay from a  $J^\pi=(5/2^+, 3/2^-)$  level at  $S_n=-5.2$  MeV with  $\Gamma=1.4$  MeV decays to  $^{12}\text{Be}^*(2.7)$  producing a peak near  $E_{\text{rel}}(n+^{12}\text{Be}^*)\approx 2.5$  MeV. Results from that fit are in table 3 of (2013Ak02) and are given below.

In contrast to the above analysis of the neutron group energies, the low-energy part of the spectrum was analyzed with an assumption that two expected  $l=0$  ( $J^\pi=1/2^+$ ) resonances are present at  $E_{\text{res}}=0.46$  and 2.9 MeV. Such an assumption results in a good fit to the data for destructive interferences, and is able to account for the enhancement at  $E_{\text{rel}}=0.81$  MeV without requiring a level at  $S_n=-0.81$  MeV. This interpretation is not preferred in the present ENSDF evaluation.

See detailed discussion on spin values, taken from other experimental results.

*Theory.*

**2010Fo11:** A simple model is developed suggesting that an appreciable part of the strength associated with decay of the  $\approx 0.5$  MeV resonance to  $^{12}\text{Be}_{g.s.}$  is actually connected with the decay from the  $5/2_2^+$  to the long lived  $^{12}\text{Be}(J^\pi=0_2^+)$  isomer.

${}^1\text{H}({}^{14}\text{Be}, {}^{13}\text{Be}):1$  2013Ak02 (continued) ${}^{13}\text{Be}$  Levels

<u>E(level)<sup>bd</sup></u>	<u>J<sup>π</sup><sup>b</sup></u>	<u>Γ<sup>b</sup></u>	<u>E' (MeV)<sup>a</sup></u>	<u>Comments</u>
0	1/2 <sup>-</sup>	0.39 5	0.44 1	See also S <sub>n</sub> =-0.46 MeV 1 and Γ=0.11 MeV 2 in (2013Ak02) analysis of (2010Ko17) data.
0.36×10 <sup>3</sup> 6	1/2 <sup>+</sup>	2.1 MeV 3	0.81 6	J <sup>π</sup> : From l=1 resonance in (2010Ko17). E(level),J <sup>π</sup> ,Γ: Parameters are taken from a fit to data given in (2004Le29). Precise values appear to be from a private communication. The authors debate the origin of this group; since a two interfering state interpretation suggests the strength may arise from destructive interference between 1/2 <sup>+</sup> states. This evaluation does not accept the two interfering state interpretation.
1.50×10 <sup>3</sup> 5	5/2 <sup>+</sup>	0.5 <sup>c</sup> MeV	1.95 5	See also S <sub>n</sub> =-2.07 MeV 3 in (2013Ak02) analysis of (2010Ko17) data. E(level): Decays to ${}^{12}\text{Be}_{\text{g.s.}}$ and its high energy tail decays to ${}^{12}\text{Be}^*(2.1 \text{ MeV})$ with E <sub>res</sub> (n+ ${}^{12}\text{Be}^*$ )≈0 MeV.
2.57×10 <sup>3</sup> 9	1/2 <sup>-</sup>	0.5 <sup>c</sup> MeV	3.02 9	See also S <sub>n</sub> =-2.98 MeV 4 in (2013Ak02) analysis of (2010Ko17) data. E(level): Decays to ${}^{12}\text{Be}_{\text{g.s.}}$ with E <sub>res</sub> (n+ ${}^{12}\text{Be}$ )=3.02 MeV.
4.75×10 <sup>3</sup>	(3/2 <sup>-</sup> ,5/2 <sup>+</sup> )	1.4 MeV 2	5.2 1	E(level),Γ: From (2013Ak02) analysis of (2010Ko17) data. E(level): Decays to ${}^{12}\text{Be}^*(2.71 \text{ MeV})$ with E <sub>res</sub> (n+ ${}^{12}\text{Be}^*$ )=2.5 MeV.

<sup>a</sup> E' is a relative excitation energy scale with E'=0 at the neutron separation energy. We use this scale because most articles report level energies with respect to the n+ ${}^{12}\text{Be}_{\text{g.s.}}$  center of mass energy.

<sup>b</sup> From (2013Ak02) analysis of n+ ${}^{12}\text{Be}$  relative energy spectra measured in (2010Ko17) and (2013Ak02).

<sup>c</sup> In the fit, the width of these states was held fixed, based on details discussed in the text of (2013Ak02).

<sup>d</sup> The ground state is taken as E<sub>c.m.</sub>(n+ ${}^{12}\text{Be}_{\text{g.s.}}$ )=0.45 MeV 1; see Adopted Levels.

${}^1\text{H}({}^{14}\text{Be}, {}^{13}\text{Be}):2$  2019Co12

2019Co12: XUNDL dataset compiled by TUNL 2020.

The authors populated resonances in the unbound  ${}^{13}\text{Be}$  nucleus using (p,pn) quasi-free scattering reactions to knock-out a neutron from  ${}^{14}\text{Be}$  nuclei.

A cocktail beam, including 265 MeV/nucleon  ${}^{14}\text{Be}$  ions, was produced by fragmenting a  ${}^{48}\text{Ca}$  beam at the RIKEN/BigRIPS fragment separator. The  ${}^{14}\text{Be}$  ions were identified in the beam using time-of-flight techniques before impinging on the 15 cm thick liquid hydrogen target of the MINOS device that is surrounded by a charged-particle time projection chamber (TPC). Protons scattered out of the target were momentum analyzed using the TPC, a multi-wire drift chamber (MWDC) and an array of plastic energy detectors covering  $\theta \approx 30^\circ - 65^\circ$ ; the quasi-free scattered neutron was momentum analyzed on the opposite side of the beam using the WINDS array of plastic scintillators that covered  $\theta \approx 20^\circ - 60^\circ$ .

The  ${}^{13}\text{Be}$  products decayed in flight into a  ${}^{12}\text{Be}+n$  pair; the heavy  ${}^{12}\text{Be}$  fragment was momentum analyzed using the SAMURAI dipole magnet and a set of MWDCs for tracking while the associated neutron was momentum analyzed using the position-sensitive NEBULA array of plastic scintillators. Finally, 68 crystals from the DALI2  $\gamma$  ray detection array partially covered  $\theta = 34^\circ - 115^\circ$  to measure  $\gamma$  rays from  ${}^{13}\text{Be}^* \rightarrow n + {}^{12}\text{Be}^*$  decays.

Separate spectra for the  $n + {}^{12}\text{Be}^*(0,2.1,2.7 \text{ MeV})$  components are obtained using the coincidence  $\gamma$  rays. Analysis of the spectra presented in figure 4 indicates  ${}^{13}\text{Be}$  resonances at  $S_n = -0.48, -2.3, -5.1$  and  $-5.7$  MeV decaying to  ${}^{12}\text{Be}^*(0,2.1,2.7 \text{ MeV})$ . A detailed analysis of the knocked-out neutrons associated with the low energy part of the  $n + {}^{12}\text{Be}$  relative energy spectrum is best fit assuming dominant p-wave strength rather than s-wave strength; this supports a  $J^\pi = 1/2^-$  assignment for the  $S_n = -0.48$  MeV resonance. A significant discussion on the nature of the low-energy strength is included that compares the findings of (2010Ko17, 2013Ak01, 2013Ak02, 2018Ri05). The authors developed a three-body  ${}^{12}\text{Be}+n+n$  model for the  ${}^{14}\text{Be}$  projectile and analyzed the quasi-free neutron scattering reaction dynamics; the results are consistent with dominant p-wave strength at low energies with no need for significant contributions from a  $J^\pi = 1/2^+$  virtual state of  ${}^{13}\text{Be}$ .

Measurement of the neutron pairing correlations obtained in this experiment are discussed in (2023Co13, 2024Ca06).

 ${}^{13}\text{Be}$  Levels

<u>E(level)<sup>c</sup></u>	<u><math>J^\pi</math><sup>d</sup></u>	<u>E' (MeV)<sup>ab</sup></u>	<u>Comments</u>
0	(1/2 <sup>-</sup> )	0.48 40	Decays via ${}^{12}\text{Be}_{\text{g.s.}}+n$ with $E_{\text{rel.}}(n+{}^{12}\text{Be})=0.48 \text{ MeV}$ .
$1.9 \times 10^3$	(5/2 <sup>+</sup> )	2.3 9	Decays via ${}^{12}\text{Be}_{\text{g.s.}}+n$ and ${}^{12}\text{Be}^*(2.1 \text{ MeV})+n$ .
$4.7 \times 10^3$		5.1 13	Decays via ${}^{12}\text{Be}^*(2.1 \text{ MeV})+n$ with $E_{\text{rel.}}(n+{}^{12}\text{Be}^*)=3.0 \text{ MeV}$ .
$5.3 \times 10^3$		5.7 14	Decays via ${}^{12}\text{Be}^*(2.7 \text{ MeV})+n$ with $E_{\text{rel.}}(n+{}^{12}\text{Be})=3.0 \text{ MeV}$ .

<sup>a</sup> E' is a relative excitation energy scale with E'=0 at the neutron separation energy. We use this scale because most articles report level energies with respect to the  $n + {}^{12}\text{Be}_{\text{g.s.}}$  center of mass energy.

<sup>b</sup> Invariant mass resolution is  $0.587 \times (E_{\text{res}})^{-1/2}$ .

<sup>c</sup> The ground state is taken as  $E_{\text{c.m.}}(n+{}^{12}\text{Be}_{\text{g.s.}})=0.45 \text{ MeV}$  *I*; see Adopted Levels.

<sup>d</sup> From analysis of the  $n + {}^{12}\text{Be}$  energy distribution of (2019Co12).

$^1\text{H}(^{14}\text{B}, ^{13}\text{Be})$  2018Ri05

**2015Ri03:**  $^1\text{H}(^{14}\text{B}, ^{13}\text{Be})$ . A beam of  $^{14}\text{B}$  ions, produced by fragmenting a 490 MeV/nucleon  $^{40}\text{Ar}$  beam at the GSI/FRS, impinged on a 9.7 mm thick  $\text{CH}_2$  foil that was located at the ALADIN spectrometer target position. Quasi-free (p,2p) scattering reactions removed protons from  $^{14}\text{B}$  and populated states in neutron-unbound  $^{13}\text{Be}$  nuclei, which quickly break apart into  $^{12}\text{Be}+n$ . At the exit of the spectrometer, the momenta of breakup  $^{12}\text{Be}$  ions and associated neutrons were measured using a  $\Delta E$ - $\Delta E$ -ToF array (for heavy particles) and the LAND neutron array (for neutrons). Additionally, an array of 162 NaI scintillator detectors surrounded the target with the aim of detecting any emitted  $\gamma$  rays, which is necessary to determine the contributions from  $^{12}\text{Be}_{g.s.}$  and excited states. Data from this experiment is included in the analysis of (2018Ri05).

**2018Ri05:** XUNDL data set compiled by TUNL, 2018.

The present study aims to measure the full set of  $^{12}\text{Be}+n$  system and  $\gamma$ -ray experimental observables for decay of  $^{13}\text{Be}$  resonances. A beam of 400 MeV/nucleon  $^{14}\text{B}$  ions, from the GSI/FRS facility impinged on a 922 mg/cm<sup>2</sup> polyethylene target that was surrounded by the 159 NaI element Crystal Ball  $\gamma$ -ray detector array. The  $^{13}\text{Be}$  nuclides, formed in single-proton removal reactions, immediately decayed into  $^{12}\text{Be}+n$ ; the decay neutrons were momentum analyzed using the 2  $\times$  2 meter<sup>2</sup> LAND neutron wall, while the  $^{12}\text{Be}$  core ejecta were identified and momentum analyzed using the ALADIN dipole along with a double sided  $\Delta E$  strip detector and the “time-of-flight wall”. Associated  $\gamma$ -rays were detected using the Crystal Ball.

The  $E_{c.m.}(^{12}\text{Be}+n)$  relative energy spectrum is analyzed for  $^{12}\text{Be}+n$  and  $^{12}\text{Be}+n+\gamma$  data. Evidence for five groups is found. Notably, two groups are found in coincidence with the  $^{12}\text{Be}^*(2.109 \text{ MeV}) \rightarrow ^{12}\text{Be}(0)$   $\gamma$ -ray transition: first from a neutron group at  $E_{res} < 500 \text{ keV}$  and second from a neutron group at  $E_{res} \approx 2 \text{ MeV}$ . Overall, five neutron groups are identified in the present experimental work, with the three additional groups at  $E_{res} \approx 2.11, 2.92$  and  $4.0$  associated with decay directly to  $^{12}\text{Be}_{g.s.}$ .

The authors highlighted the shortcomings of past experiments, due to incomplete collection of necessary information, and they aimed to give an explanation of the complete evidence on  $^{13}\text{Be}$  level data. Results from proton knockout from  $^{14}\text{B}$  at 35 MeV/nucleon (2014Ra07) and 400 MeV/nucleon (present), neutron knockout data from  $^{14}\text{Be}$  at 69 MeV/nucleon (2010Ko17), 287 MeV/nucleon (2007Si24) and 304 MeV/nucleon (2013Ak02), and single charge exchange reactions with  $^{13}\text{B}$  at 71 MeV/nucleon were considered in developing an overall interpretation. The analysis aimed to explain differences in peak positions and group widths by accounting for branching to  $^{12}\text{Be}^*(2.109)$  and the differences in strengths for levels populated by the different reaction mechanisms and at different reaction energies.

In general, the present work identifies levels at  $S_n = -0.86, -2.11, -2.92$  and  $-4.0 \text{ MeV}$  that decay to  $^{12}\text{Be}_{g.s.}$ . In addition, the levels at  $S_n = -2.11$  and  $-4.0 \text{ MeV}$  also decay to  $^{12}\text{Be}^*(2.109)$  with resonance energies around  $E_{c.m.}(^{12}\text{Be}^*+n) \approx 0.1$  and  $2.0 \text{ MeV}$ ; since there is overlap of the neutron groups, it is necessary to deconvolute ground state branches from the  $^{12}\text{Be}^*(2.109)$  branches in order to obtain accurate state widths. Furthermore, the authors suggest that the different reactions/mechanisms result in different amplitudes for populating the levels, which further complicates an overall analysis.

A note in proof of (2016Fo07) details unpublished  $^1\text{H}(^{14}\text{B}, 2p)$  data where a  $E_{res}(n+^{12}\text{Be}) = 0.95 \text{ MeV}$  group is connected to population of  $^{12}\text{Be}^*(2.1 \text{ MeV})$ .

 $^{13}\text{Be}$  Levels

$E(\text{level})^c$	$J^\pi^d$	$\Gamma$	$E' (\text{MeV})^b$	Comments
$0.41 \times 10^3$ 4	$1/2^+$	1.70 MeV 15	0.86 4	$E(\text{level})$ : Decays via $^{12}\text{Be}_{g.s.}+n$ .
$1.66 \times 10^3$ 5	$5/2^+$	$0.4^a$ MeV	2.11 5	$E(\text{level})$ : Decays via $^{12}\text{Be}_{g.s.}+n$ with $E_{res}=2.11 \text{ MeV}$ and $^{12}\text{Be}^*(2109)+n$ with $E_{res}(n+^{12}\text{Be}^*) < 0.1 \text{ MeV}$ .
$\approx 2.47 \times 10^3$ <sup>a</sup>	$5/2^+$	$0.4^a$ MeV	$2.92^a$	$E(\text{level})$ : Decays via $^{12}\text{Be}_{g.s.}+n$ .
$\approx 3.6 \times 10^3$ <sup>a</sup>	$(3/2^+)$	$0.4^a$ MeV	$4.0^a$	$E(\text{level})$ : Decays via $^{12}\text{Be}_{g.s.}+n$ with $E_{res}=4.0 \text{ MeV}$ and $^{12}\text{Be}^*(2109)+n$ with $E_{res}(n+^{12}\text{Be}^*) \approx 2.1 \text{ MeV}$ .

<sup>a</sup> From (1992Os04, 1998Go30, 1998Be28).

<sup>b</sup>  $E'$  is a relative excitation energy scale with  $E'=0$  at the neutron separation energy. We use this scale because most articles report level energies with respect to the  $n+^{12}\text{Be}_{g.s.}$  center of mass energy.

<sup>c</sup> The ground state is taken as  $E_{c.m.}(n+^{12}\text{Be}_{g.s.})=0.45 \text{ MeV}$   $J$ ; see Adopted Levels.

<sup>d</sup> From analysis of the  $n+^{12}\text{Be}$  energy distributions and associated  $\gamma$  rays of (2018Ri05).

${}^2\text{H}({}^{12}\text{Be},\text{p})$  1995Ko10,1995Ko27

1995Ko10,1995Ko27,1995KoZK:  ${}^2\text{H}({}^{12}\text{Be},\text{p})$   $E=55$  MeV/nucleon. A beam of  ${}^{12}\text{Be}$  ions was produced at the RIKEN/RIPS facility and impinged on a  $\text{CD}_2$  target. The recoil proton spectrum was measured and analyzed to determine the excitation spectrum, as a function of energy above the  ${}^{12}\text{Be}+n$  threshold. Four peaks were observed at  $E_{\text{rel}}({}^{12}\text{Be}+n)\approx 2, 5, 7, 10$  MeV. Resolution is rather poor.

See theoretical analysis in (2018Ma05).

 ${}^{13}\text{Be}$  Levels

<u>E(level)<sup>b</sup></u>	<u>E' (MeV)<sup>a</sup></u>
$1.6\times 10^3$	$\approx 2.0$
$4.6\times 10^3$	$\approx 5.0$
$6.6\times 10^3$	$\approx 7.0$
$9.6\times 10^3$	$\approx 10.0$

<sup>a</sup> E' is a relative excitation energy scale with  $E'=0$  at the neutron separation energy. We use this scale because most articles report level energies with respect to the  $n+{}^{12}\text{Be}_{\text{g.s.}}$  center of mass energy.

<sup>b</sup> The ground state is taken as  $E_{\text{c.m.}}(n+{}^{12}\text{Be}_{\text{g.s.}})=0.45$  MeV *I*; see Adopted Levels.

${}^2\text{H}({}^{12}\text{Be}, {}^{13}\text{Be})$  2023Ko21

2023Ko21: XUNDL dataset compiled by TUNL (2023).

A beam of 9.5 MeV/nucleon  ${}^{12}\text{Be}$  ions from the TRIUMF ISAC-II facility impinged on a 52  $\mu\text{m}$  thick solid deuterium target that was frozen on a 4.64  $\mu\text{m}$  silver foil that was positioned at the center of the IRIS experimental facility. The reaction protons scattered in the backward direction were detected by an annular array of MICRON YY1 position sensitive Si detectors that covered  $\theta_{\text{lab}}=122^\circ$  to  $148^\circ$ . Associated  ${}^{12}\text{Be}$  remnants from  ${}^{12}\text{Be}(d,p+[{}^{13}\text{Be}\rightarrow{}^{12}\text{Be}+n])$  were detected at small angles using a position sensitive MICRON S3 annular detector that was paired with a CsI scintillator detector to provide  $\Delta E$ - $E$  particle identification. Events were analyzed only in a triple coincidence when a  ${}^{12}\text{Be}$  was identified in the upstream (IC) and when both the backward recoiling proton and  ${}^{12}\text{Be}$  remnant were detected.

A Q-value spectrum covering  $Q=-5.5$  to  $-2.0$  MeV was obtained from the data. A Bayesian optimization in combination with a GEANT4 Monte Carlo simulation of the experiment guided the interpretation of the spectrum. Two broad structures dominate the lineshape; a low-energy component with  $E_{\text{c.m.}}(n+{}^{12}\text{Be})=0.55^{+8}_{-7}$  MeV and  $\Gamma=0.11^{+4}_{-5}$  MeV and a high-energy component with  $E_{\text{c.m.}}=2.22^{+4}_{-5}$  MeV and  $\Gamma=0.40^{+3}_{-4}$  MeV. The addition of a third state had little impact on the quality of the fit.

The authors evaluated the character of the peaks using several approaches. The higher-energy component was identified as the  $d$ -wave resonance reported in previous works. For the low-energy strength, a DWBA analysis using the FRESKO code was used to evaluate the  $s$ -,  $p$ -,  $d$ -,  $sp$ -,  $sd$ -, or  $pd$ -wave character. Involvement of two states having  $\approx 67\%$   $s$ -wave and  $\approx 33\%$   $p$ -wave character provided the best fit to the data.

A  $p$ -wave resonance is suggested between 0.44-0.55 MeV with an additional less-understood low-energy  $s$ -wave strength; additionally a  $d$ -wave resonance is present between 2.11 and 2.3 MeV. Weighing this, the evaluator attributes the lower group as an unresolved combination of  $J^\pi=1/2^+$  and  $1/2^-$   $s$ - and  $p$ -wave strength and attributes the higher group to a  $J^\pi=5/2^+$   $d$ -wave resonance.

 ${}^{13}\text{Be}$  Levels

<u><math>E(\text{level})^a</math></u>	<u><math>J^\pi^a</math></u>	<u><math>\Gamma^a</math></u>	<u><math>E_{\text{c.m.}}(n+{}^{12}\text{Be})</math> (keV)</u>	<u>Comments</u>
$0.10 \times 10^3$ 8	$1/2^-$ & $1/2^+$	0.11 MeV +4-5	$0.55$ +8-7	E(level): $E=0.10$ MeV +8-7. E(level): This peak comprises unresolved $s$ -wave and $p$ -wave resonances.
$1.77 \times 10^3$ 5	$5/2^+$	0.40 MeV +3-4	$2.22$ +4-5	E(level): $E=1.77$ MeV +4-5.

<sup>a</sup> From R-matrix analysis in (2023Ko21). The ground state is taken as  $E_{\text{c.m.}}(n+{}^{12}\text{Be}_{\text{g.s.}})=0.45$  MeV  $l$ ; see Adopted Levels.

${}^9\text{Be}({}^{13}\text{B}, {}^{13}\text{Be})$  2015Ma62

2015Ma62: XUNDL dataset compiled by TUNL, 2015.

The authors populated neutron-unbound states in  ${}^{13}\text{Be}$  using a  ${}^{13}\text{B}$  beam and charge exchange reactions on a  ${}^9\text{Be}$  target.

A beam of 71 MeV/nucleon  ${}^{13}\text{B}$  ions was produced by fragmenting a 120 MeV/nucleon  ${}^{18}\text{O}$  beam on a  ${}^9\text{Be}$  target at the NSCL/A1900 beam facility. The  ${}^{13}\text{Be}$  beam impinged on a 51 mg/cm<sup>2</sup>  ${}^9\text{Be}$  target placed at the large-gap sweeper magnet target position. Charge-exchange reactions populating  ${}^{13}\text{Be}$  states resulted in events where neutrons from the decay of  ${}^{13}\text{Be}$  states were detected in the MONA-LISA array, while  ${}^{12}\text{Be}$  ions from the decay were momentum analyzed and characterized using the dipole sweeper magnet. Finally the decay energy was reconstructed by the invariant-mass method.

The present results are fitted with both two- and three-resonance assumptions. The best fit includes an s-wave resonance at

$E_{\text{res}}=0.73$  MeV  $9 [J^\pi=1/2^+ \Gamma=1.98$  MeV  $34]$  and a d-wave resonance at  $E_{\text{res}}=2.56$  MeV  $13 [J^\pi=5/2^+, \Gamma=2.29$  MeV  $73]$ .

A three-resonance fit is provided, though the approach is complex. The parameters of the lowest state are fixed by (2014Ra07) at

$E_{\text{res}}=0.40$  MeV,  $\Gamma=0.80$  MeV and  $J^\pi=1/2^+$ ; the parameters of the highest resonance are taken from the 2-resonance fit  $E_{\text{res}}=2.56$  MeV,  $\Gamma=2.29$  MeV and  $J^\pi=5/2^+$ ; in this case a third resonance can be fitted at  $E_{\text{res}}=1.05$  MeV  $10$  with  $J^\pi=5/2^+$  and  $\Gamma=0.50$  MeV  $20$ .

 ${}^{13}\text{Be}$  Levels

<u>E(level)<sup>b</sup></u>	<u><math>J^\pi</math><sup>c</sup></u>	<u><math>\Gamma</math></u>	<u><math>E'</math> (MeV)<sup>a</sup></u>
$0.28 \times 10^3$ $9$	$1/2^+$	$1.98$ MeV $34$	$0.73$ $9$
$2.11 \times 10^3$ $13$	$5/2^+$	$2.29$ MeV $73$	$2.56$ $13$

<sup>a</sup>  $E'$  is a relative excitation energy scale with  $E'=0$  at the neutron separation energy. We use this scale because most articles report level energies with respect to the  $n+{}^{12}\text{Be}_{\text{g.s.}}$  center of mass energy.

<sup>b</sup> The ground state is taken as  $E_{\text{c.m.}}(n+{}^{12}\text{Be}_{\text{g.s.}})=0.45$  MeV  $1$ ; see Adopted Levels. Resonance energies from the best fit, which is a two-parameter fit shown in Fig. 1. An alternate 3-resonance fit is provided in Fig. 2 and presented in Table 1.

<sup>c</sup> From analysis of the  $n+{}^{12}\text{Be}$  energy distributions of (2015Ma62).

${}^9\text{Be}({}^{18}\text{O}, {}^{13}\text{Be})$  2001Th01

2001Th01:  ${}^9\text{Be}({}^{18}\text{O}, {}^{13}\text{Be}\rightarrow{}^{12}\text{Be}+n)$   $E({}^{18}\text{O})=80$  MeV/nucleon. The authors impinged  ${}^{18}\text{O}$  ions onto a 94 mg/cm<sup>2</sup> beryllium foil and momentum analyzed the residual  ${}^{12}\text{Be}$  and neutron reaction products that were emitted along  $\theta\approx 0^\circ$ . The decay products were analyzed using typical sequential decay neutron spectroscopy techniques. Monte Carlo analysis of the  $n+{}^{12}\text{Be}$  relative energy spectrum is most consistent with a low-lying s-wave state with a scattering length  $a_s < -10$  fm, which corresponds to  $E_{\text{res}} \leq 200$  keV. The analysis explores the possibility for participation of  ${}^{12}\text{Be}$  excited states. In the best fit, there is also a contribution from a  $d_{5/2}$  state at  $E_{\text{res}} \approx 2.0$  MeV.

See also (1995ThZZ).

 ${}^{13}\text{Be}$  Levels

<u>E(level)<sup>a</sup></u>	<u>J<sup><math>\pi</math></sup><sup>b</sup></u>	<u>E<sub>c.m.</sub>(<sup>12</sup>Be+n) (MeV)</u>	<u>Comments</u>
x	1/2 <sup>+</sup>	<0.2	E(level): This group was later associated with decay from the high-energy tail of the J <sup><math>\pi</math></sup> =5/2 <sup>+</sup> state to ${}^{12}\text{Be}^*$ (2.1 MeV; J <sup><math>\pi</math></sup> =2 <sup>+</sup> ).
$\approx 1.55 \times 10^3$	5/2 <sup>+</sup>	$\approx 2.0$	

<sup>a</sup> The ground state is taken as  $E_{\text{c.m.}}(n+{}^{12}\text{Be}_{\text{g.s.}})=0.45$  MeV *I*; see Adopted Levels.

<sup>b</sup> From analysis of the  $n+{}^{12}\text{Be}$  energy distributions of (2001Th01).

${}^9\text{Be}({}^{48}\text{Ca},\text{X})$  2008Ch07

2008Ch07:  ${}^9\text{Be}({}^{48}\text{Ca}, {}^{12}\text{Be}+n)$   $E=60$  MeV/nucleon. The authors measured the neutron+charged particle ejecta produced in fragmentation reactions of  ${}^{48}\text{Ca}$  on a beryllium target. The charged fragments were momentum analyzed using a large gap dipole sweeper magnet, while neutrons were analyzed using the MSU/MoNA neutron wall, which was positioned along  $\theta=0^\circ$  with respect to the incident beam. The correlated (fragment)(neutron)-coincidences were analyzed using sequential neutron decay spectroscopy techniques.

The  ${}^{12}\text{Be}+n$  decay energy spectrum compared favorably with a fit that assumed a Breit–Wigner shaped resonance at  $E_{\text{decay}}\approx 60$  keV with  $\Gamma=10$  keV and perhaps slightly less well with a shape related to an  $s$ -wave resonance having a scattering length of  $a_s=-20$  fm.

 ${}^{13}\text{Be}$  Levels

<u>E(level)</u>	<u><math>E_{\text{c.m.}}({}^{12}\text{Be}+n)</math> (MeV)</u>	<u>Comments</u>
x	$\approx 0.06$	<p>E(level): the observed shape can be related to either a Breit-Wigner shaped resonance at <math>E_{\text{decay}}\approx 60</math> keV with <math>\Gamma=10</math> keV or an <math>s</math>-wave resonance having a scattering length of <math>a_s=-20</math> fm.</p> <p>E(level): This group was later associated with decay from the high-energy tail of the <math>J^\pi=5/2^+</math> state to <math>{}^{12}\text{Be}^*</math> (2.1 MeV; <math>J^\pi=2^+</math>).</p>

C( $^{14}\text{Be}$ ,  $^{13}\text{Be}$ ) **2007Si24**

**2001La02, 2003LeZX, 2003JoZZ:**  $^{12}\text{C}(^{14}\text{Be}, ^{13}\text{Be}^*)$  at  $E=35$  MeV/nucleon. The  $^{12}\text{Be}+n$  relative energy spectrum was reconstructed at GANIL using the DeMoN array to measure neutrons and a  $5\times 5$  cm<sup>2</sup> position sensitive  $\Delta E$ -E telescope. The relative energy spectrum is consistent with a low-lying  $s$ -wave state having a scattering length  $a_s=-20$  fm and a higher-lying state at  $E_{\text{rel}}=2$  MeV with  $\Gamma\approx 0.5$  MeV. The longitudinal momentum distribution of neutrons following  $^{14}\text{Be}$  breakup were also reported.

**2007Si24:**  $^{12}\text{C}(^{14}\text{Be}, ^{13}\text{Be}^*)$  at  $E=287$  MeV/nucleon. Measured  $^{12}\text{C}(^{14}\text{Be}, ^{12}\text{Be}+n)$  at GSI using the ALADIN-LAND facility. A beam of  $^{14}\text{Be}$  ions impinged on a  $1.29$  g/cm<sup>2</sup> carbon target and residual  $^{12}\text{Be}$  ions were momentum analyzed using the ALADIN spectrometer while neutrons were characterized using the LAND/Large Area Neutron Detector. A low-energy state is observed with the scattering length  $a_s=-3.2$  fm; this state is considered a virtual  $s$ -wave state. At higher energies, the relative energy spectrum agrees with two previously reported  $^{12}\text{Be}+n$  resonances at  $E=2.00$  MeV 5 and  $3.04$  MeV 7 with  $\Gamma=0.3$  MeV and  $0.4$  MeV, respectively (1998Be28, 1998Go30, 1992Os04). The discussion highlights the need for  $n+^{12}\text{Be}+\gamma$  coincidence data. See preliminary reports of the results in (2001AIZZ, 2004Si12).

 $^{13}\text{Be}$  Levels

<u>E(level)<sup>b</sup></u>	<u>J<sup><math>\pi</math></sup></u>	<u><math>\Gamma^a</math></u>	<u><math>E_{\text{c.m.}}(^{12}\text{Be}+n)</math> (MeV)<sup>a</sup></u>	<u>Comments</u>
x	$1/2^+$			E(level): Low-energy strength is observed corresponding to a scattering of $a=-3.2$ fm (2007Si24). E(level): This group was later associated with decay from the high-energy tail of the $J^\pi=5/2^+$ state to $^{12}\text{Be}^*$ (2.1 MeV; $J^\pi=2^+$ ).
$1.55\times 10^3$	$5/2^+$	0.3 MeV	2.00 5	
$2.59\times 10^3$	$1/2^-$	0.4 MeV	3.04 7	

<sup>a</sup> From (2007Si24).

<sup>b</sup> The ground state is taken as  $E_{\text{c.m.}}(n+^{12}\text{Be}_{\text{g.s.}})=0.45$  MeV  $I$ ; see Adopted Levels.

C( $^{14}\text{B}, ^{13}\text{Be}$ ) 2014Ra07

**2004Le29:**  $^{12}\text{C}(^{14}\text{B}, ^{13}\text{Be})$   $E=41$  MeV/nucleon, Measured  $^{12}\text{Be}+n$  relative energy spectrum. Preliminary data from GANIL. The relative energy spectrum is fit with an s-wave resonance at low energies ( $\approx 800$  keV), along with a d-wave resonance around 2 MeV and perhaps some influence from a higher state.

**2014Ra07:** XUNDL dataset compiled by TUNL, 2014. Includes  $^{12}\text{C}(^{15}\text{B}, ^{13}\text{Be})$  reaction.

Beams of 35 MeV/nucleon  $^{14,15}\text{B}$  ions were separately tuned by fragmenting a 55 MeV/nucleon  $^{18}\text{O}$  beam on a thick  $^9\text{Be}$  target at GANIL. The beams were optimized at the LISE target position, where nuclides were clearly identified event-by-event via time-of-flight. The incident beam particle trajectories were measured using two position sensitive drift chambers, and the position on a  $^{\text{nat}}\text{C}$  target was determined with a resolution of  $\approx 1.5$  mm (FWHM).

Reaction products were detected by either a  $5 \times 5$  cm<sup>2</sup> position sensitive  $\Delta E$ - $\Delta E$ -E Si-strip array or by the 90 element DEMON neutron array. The  $^{12}\text{Be}+n$  events were analyzed for the one proton removal reactions on  $^{14}\text{B}$ , while  $^{12}\text{Be}+n+n$  events were analyzed for  $^{15}\text{B}$  breakup events. In the case of the  $^{14}\text{B} \rightarrow ^{13}\text{Be}+p \rightarrow (^{12}\text{Be}+n)+p$  breakup events, the decay energy is straight forward to determine. On the other hand, the breakup of  $^{15}\text{B} \rightarrow ^{13}\text{Be}+n+p \rightarrow (^{12}\text{Be}+n)+n+p$  can involve more complex processes and requires further analysis to consider the two neutrons in the final state and potential involvement of  $^{14}\text{Be}$  states; essentially a non-resonant continuum shape that is generated by random fragment-neutron event mixing is subtracted from the net kinematic energy reconstructed spectrum.

The potential systematic involvement of  $^{12}\text{Be}$  excited states was evaluated by analyzing the  $\gamma$ -ray energy deposited in the DEMON array for  $^{12}\text{Be}+\gamma$  events. Limits of  $\approx <5\%$  were estimated for participation of excited states.

The analysis of  $^{15}\text{B} \rightarrow (^{12}\text{Be}+n+n)+p$  data indicated that  $^{14}\text{Be}^*(1.5 \text{ MeV})$  breakup events, with  $E(^{12}\text{Be}+n+n) < 800$  keV, contribute significantly to the structure of the  $^{12}\text{Be}+n$  relative energy spectrum, by creating/enhancing a peak in the spectrum at  $E(^{12}\text{Be}+n) \approx 200$  keV.

Initial analysis suggested that the  $^{14}\text{B}$  breakup data could be fit with either a single  $E(^{12}\text{Be}+n)=2.40$  MeV *20* resonance with  $\Gamma=0.90$  MeV *22*, or a better fit with s-wave and d-wave resonances located at  $E(^{12}\text{Be}+n)=0.70$  MeV *11* and  $2.40$  MeV *14* with  $\Gamma=1.70$  MeV *22* and  $0.70$  MeV *32* respectively.

A significant discussion on the shell structures of both, the  $N=9$  isotones and the  $^{12}\text{Be}$  structure, led to a third interpretation, which is preferred by the authors. The data are well fit by  $J^\pi=1/2^+$  and  $5/2^+$  resonances at  $E(^{12}\text{Be}+n)=0.40$  MeV *3* and  $0.85^{+15}_{-11}$  MeV with  $\Gamma=0.80^{+18}_{-12}$  MeV and  $0.30^{+34}_{-15}$  MeV, and a higher energy  $J^\pi=5/2^+$  state at  $E(^{12}\text{Be}+n)=2.35$  MeV *14* with  $\Gamma=1.50$  MeV *40*.

 $^{13}\text{Be}$  Levels

<u>E(level)<sup>c</sup></u>	<u><math>J^\pi</math><sup>d</sup></u>	<u><math>\Gamma</math></u>	<u><math>E'</math> (MeV)<sup>ab</sup></u>	<u>Comments</u>
0	$1/2^+$	0.80 MeV <i>+18-12</i>	0.40 <i>3</i>	E(level): The state has an intensity defined as $I=1.0$ .
$0.40 \times 10^3$ <i>15</i>	$5/2^+$	0.30 MeV <i>+34-15</i>	0.85 <i>15</i>	E(level): From $E(^{12}\text{Be}+n)=0.85$ MeV <i>+15-11</i> . E(level): The state has an intensity of $I=0.40$ <i>7</i> relative to the $E_{\text{res}}=0.40$ MeV state.
$1.90 \times 10^3$ <i>14</i>	$5/2^+$	1.50 MeV <i>40</i>	2.35 <i>14</i>	E(level): The state has an intensity of $I=0.80$ <i>9</i> relative to the $E_{\text{res}}=0.40$ MeV state.

<sup>a</sup>  $E'$  is a relative excitation energy scale with  $E'=0$  at the neutron separation energy. We use this scale because most articles report level energies with respect to the  $n+^{12}\text{Be}_{\text{g.s.}}$  center of mass energy.

<sup>b</sup> From (2014Ra07).

<sup>c</sup> The ground state is taken as  $E_{\text{c.m.}}(n+^{12}\text{Be}_{\text{g.s.}})=0.45$  MeV *1*; see Adopted Levels.

<sup>d</sup> From analysis of the  $n+^{12}\text{Be}$  energy distributions and associated  $\gamma$  rays of (2014Ra07).

$^{13}\text{C}(\pi^-, \pi^+)$  1992Wa11

1992Wa11:  $^{13}\text{C}(\pi^-, \pi^+)$  E=295 MeV, measured  $\sigma(\theta)$ ,  $\sigma(\theta, E(\pi))$ . Deduced double GDR in  $^{13}\text{Be}$ . The  $(\pi^-, \pi^+)$  double charge-exchange reaction was studied on a  $329 \text{ mg/cm}^2$   $^{13}\text{C}$  target at 295 MeV and at  $\theta=5^\circ$  using the EPICS spectrometer at LAMPF. Peaks corresponding to the ground state and the double dipole resonance are observed at  $Q=-32.84 \text{ MeV}$  and  $-49.5 \text{ MeV}$  5, respectively.

 $^{13}\text{Be}$  Levels

<u>E(level)</u>	<u><math>\Gamma</math></u>	<u>Comments</u>
$\approx 2.0 \times 10^3$		E(level): From $Q=-32.84 \text{ MeV}$ .
$18.7 \times 10^3$ 5	9.0 MeV 14	From $Q[(\text{GDR})^2]=-49.5 \text{ MeV}$ 5 and $\Gamma=9.0 \text{ MeV}$ 14.

$^{13}\text{C}(^{14}\text{C},^{14}\text{O})$  1992Os04

1992Os04:  $^{13}\text{C}(^{14}\text{C},^{14}\text{O})$  E=337 MeV, measured spectra; deduced Q,  $\Delta M$ , possible levels, J,  $\pi$ . Used a 300  $\mu\text{g}/\text{cm}^2$  highly enriched  $^{13}\text{C}$  target at the VICKSI-facility at HMI. Momentum analyzed reaction products using Q3D spectrometer at  $\theta=5^\circ$ . Essentially three states are seen, initially presumed to be  $E_x=0$  ( $Q_0=-37.02$  MeV and  $\Delta M=35.16$  MeV), 3.12 MeV 7 and 6.5 MeV 2. The measured widths are analyzed and used to constrain possible  $J^\pi$  values. A  $J^\pi=1/2^+$  ground state is expected from theory, but the lowest state reported here is inconsistent with this interpretation.

See also (1992BoZV,1993BoZP,1993BoZT,1993BoZW,1994PeZZ,1995Pe12, 1995OsZX).

 $^{13}\text{Be}$  Levels

<u>E(level)<sup>b</sup></u>	<u>J<sup><math>\pi</math></sup></u>	<u><math>\Gamma</math></u>	<u>E' (MeV)<sup>a</sup></u>	<u>Comments</u>
$1.56 \times 10^3$ 5	(5/2 <sup>+</sup> , 1/2 <sup>-</sup> )	0.3 MeV 2	2.01 5	State is reported with $Q_0=-37.02$ MeV 5, which implies $\Delta M=35.16$ MeV 5.
$4.68 \times 10^3$ 7		0.4 MeV 2	5.13 7	
$8.1 \times 10^3$ 2		0.9 MeV 3	8.5 2	

<sup>a</sup> E' is a relative excitation energy scale with  $E'=0$  at the neutron separation energy. We use this scale because most articles report level energies with respect to the  $n+^{12}\text{Be}_{\text{g.s.}}$  center of mass energy.

<sup>b</sup> The ground state is taken as  $E_{\text{c.m.}}(n+^{12}\text{Be}_{\text{g.s.}})=0.45$  MeV 1; see Adopted Levels.

${}^{14}\text{C}(\pi^-,p)$  1998Go30

1998Go30:  ${}^{14}\text{C}(\pi^-,p)$  E at rest. Measured missing mass spectra.

A 30 MeV  $\pi^-$  beam, from the LAMPF, was slowed in a beryllium moderator and stopped in a 25 mg/cm<sup>2</sup>  $\approx 77\%$  enriched  ${}^{14}\text{C}$  target. Protons from the  ${}^{14}\text{C}(\pi^-,p)$  capture reactions were measured using the MEPI two-armed  $\Delta E$ -E semiconductor spectrometer; the  ${}^{13}\text{Be}$  excited state energies were deduced by analysis of the missing mass spectra.

Three resolved peaks are observed above the  ${}^{12}\text{Be}+n$  threshold at  $E_{\text{res}}=1.87$ , 2.95 and 4.96 MeV. However, poor statistics in the lower energy region yield two ambiguous interpretations; the region below  $E_{\text{res}}=1.5$  MeV can be fit using either one peak at  $E_{\text{res}}=0.65$  MeV  $10$  with  $\Gamma \approx 250$  keV or with two peaks at 0.09 MeV  $10$  and 0.68 MeV  $10$  each having  $\Gamma < 200$  keV. We take the single peak interpretation, but also highlight the poor quality of data below  $E_{\text{c.m.}(n+{}^{12}\text{Be}_{\text{g.s.}})}=1.5$  MeV.

 ${}^{13}\text{Be}$  Levels

<u>E(level)<sup>b</sup></u>	<u><math>\Gamma</math></u>	<u>E' (MeV)<sup>a</sup></u>	<u>Comments</u>
$0.20 \times 10^3$ $10$	$\approx 250$ keV	0.65 $10$	E(level): Possible doublet involving the ground and first excited states.
$1.42 \times 10^3$ $10$	0.3 MeV $1$	1.87 $10$	
$2.50 \times 10^3$ $10$	$< 150$ keV	2.95 $10$	
$4.51 \times 10^3$ $10$	$\approx 1.7$ MeV	4.96 $20$	

<sup>a</sup> E' is a relative excitation energy scale with E'=0 at the neutron separation energy. We use this scale because most articles report level energies with respect to the  $n+{}^{12}\text{Be}_{\text{g.s.}}$  center of mass energy.

<sup>b</sup> The ground state is taken as  $E_{\text{c.m.}(n+{}^{12}\text{Be}_{\text{g.s.}})}=0.45$  MeV  $1$ ; see Adopted Levels.

---

${}^{14}\text{C}(\pi^-, \text{pd})$  2016Ko22

**2016Ko22:**  ${}^{14}\text{C}(\pi^-, \text{pd})$  E=stopped. A beam of 30 MeV  $\pi^-$  mesons, from the LAMPF facility, was moderated in a beryllium foil before stopping in a  $\approx 24$  mg/cm<sup>2</sup> 77% enriched  ${}^{14}\text{C}$  target. Deuterons ejected from the target were analyzed to obtain details on the *inclusive*  $\pi^- + {}^{14}\text{C} \rightarrow \text{p} + {}^{13}\text{Be}^* \rightarrow \text{p} + {}^{11}\text{Li} + \text{d}$  reaction; the deuteron emission threshold is 20.8 MeV. The authors suggest a broad state or group of unresolved states around  $E_x \approx 30$  MeV.

${}^{13}\text{Be}$  Levels

E(level)<sup>a</sup>  
 $\approx 30 \times 10^3$

<sup>a</sup> The ground state is taken as  $E_{\text{c.m.}}(\text{n} + {}^{12}\text{Be}_{\text{g.s.}}) = 0.45$  MeV *I*; see Adopted Levels.

${}^{14}\text{C}({}^7\text{Li}, {}^8\text{B})$  1983A120

1983A120:  ${}^{14}\text{C}({}^7\text{Li}, {}^8\text{B})$  E=82 MeV, measured  $\sigma(E({}^8\text{B}))$ .

First evidence for observation of  ${}^{13}\text{Be}$  is reported in the  ${}^{14}\text{C}({}^7\text{Li}, {}^8\text{B})$  reaction at E=82 MeV. A peak is observed in the yield corresponding to  ${}^{13}\text{Be}$   $\Delta M=35.0$  MeV  $\bar{5}$ ; this  ${}^{13}\text{Be}$  level is then unbound to  ${}^{12}\text{Be}+n$  decay by 1.9 MeV  $\bar{5}$ .

 ${}^{13}\text{Be}$  Levels

<u>E(level)<sup>b</sup></u>	<u>E' (MeV)<sup>a</sup></u>
$1.45 \times 10^3$ $\bar{5}0$	1.9 $\bar{5}$

<sup>a</sup> E' is a relative excitation energy scale with E'=0 at the neutron separation energy. We use this scale because most articles report level energies with respect to the n+ ${}^{12}\text{Be}_{\text{g.s.}}$  center of mass energy.

<sup>b</sup> The ground state is taken as  $E_{\text{c.m.}}(\text{n}+{}^{12}\text{Be}_{\text{g.s.}})=0.45$  MeV  $\bar{1}$ ; see Adopted Levels.

$^{14}\text{C}(^{11}\text{B},^{12}\text{N})$  1998Be28

**1998Be28:** The  $^{14}\text{C}(^{11}\text{B},^{12}\text{N})$  spectrum was measured at  $E(^{11}\text{B})=190$  MeV using the JINR U-400 cyclotron and the MSP-144 spectrograph. The beam impinged on a  $360 \mu\text{g}/\text{cm}^2$  70% enriched  $^{14}\text{C}$  target, and reaction products were measured using the spectrograph, which was positioned at  $\theta_{\text{lab}}=4.6^\circ$ . Two position sensitive proportional counters in the focal plane array were used along with a series of  $\Delta E$ ,  $\Delta E$ ,  $E$  and VETO detectors; the  $^{13}\text{Be}$  ground state Q-value and several excited states were observed. See also (2001Pe27).

 $^{13}\text{Be}$  Levels

<u>E(level)<sup>b</sup></u>	<u>E' (MeV)<sup>a</sup></u>	<u>Comments</u>
$0.35 \times 10^3$ 9	0.80 9	From $Q=-39.60$ MeV 9, $\Delta M=33.95$ MeV 9 and $S_n=-0.80$ MeV 9.
$1.57 \times 10^3$ 6	2.02 6	From $\Delta M=35.17$ MeV 6.
$2.45 \times 10^3$ 13	2.90 13	From $\Delta M=36.05$ MeV 13.
$4.49 \times 10^3$ 8	4.94 8	From $\Delta M=38.09$ MeV 8.
$5.43 \times 10^3$ 10	5.88 10	From $\Delta M=39.03$ MeV 10.
$7.5 \times 10^3$ ? 2	7.9 2	From $\Delta M=41.0$ MeV 2.

<sup>a</sup> E' is a relative excitation energy scale with  $E'=0$  at the neutron separation energy. We use this scale because most articles report level energies with respect to the  $n+^{12}\text{Be}_{\text{g.s.}}$  center of mass energy.

<sup>b</sup> The ground state is taken as  $E_{\text{c.m.}}(n+^{12}\text{Be}_{\text{g.s.}})=0.45$  MeV 1; see Adopted Levels.

$\text{U}(\text{p},\text{X}), {}^{232}\text{Th}({}^{15}\text{N},\text{X})$  1970Ar27

1966Po09,1974Bo05:  $\text{U}(\text{p},\text{X})$ . In (1966Po09) a 5.3 GeV proton beam from the Bevatron impinged on a 26 mg/cm<sup>2</sup> uranium target, and in (1974Bo05) a 4.8 GeV proton beam impinged on 28 mg/cm<sup>2</sup> uranium target. The products were identified by a  $\Delta\text{E}$ -E telescope.  ${}^{13}\text{Be}$  was not observed; in the later work an upper limit of  $\approx 10$  ns was set for the life-time.

1970Ar27:  ${}^{232}\text{Th}({}^{15}\text{N},\text{X})$  E=145 MeV. The particle instability of  ${}^{13}\text{Be}$  was deduced. The fragmentation products emitted at  $\theta=40^\circ$  resulting from bombardment of a metallic 20 mg/cm<sup>2</sup>  ${}^{232}\text{Th}$  target were analyzed using a magnetic spectrograph and set of silicon detectors (assumed  $\Delta\text{E}$ -E). No events could be attributed to either  ${}^{13}\text{Be}$  or  ${}^{14}\text{Be}$ , while 500 and 30 events were expected based on the  ${}^{12}\text{Be}$  yield that was observed. It is known from later work that  ${}^{14}\text{Be}$  is particle bound.

1986Gi10: A study of fragmentation products produced in reactions of 44 MeV/nucleon  ${}^{40}\text{Ar}$  ions on a 160 mg/cm<sup>2</sup> tantalum target confirmed the particle instability of  ${}^{13}\text{Be}$ .

 ${}^{13}\text{Be}$  Levels

<u>E(level)</u>	<u>Comments</u>
0?	E(level): Level not observed. Particle instability confirmed.

## REFERENCES FOR A=13

- 1966Po09 A.M.Poskanzer, S.W.Cosper, E.K.Hyde, J.Cerny - Phys.Rev.Letters 17, 1271 (1966).  
*New Isotopes:  $^{11}\text{Li}$ ,  $^{14}\text{B}$ , and  $^{15}\text{B}$ .*
- 1970Ar27 A.G.Artukh, V.V.Avdeichikov, J.Ero, G.F.Gridnev et al. - Phys.Lett. 33B, 407 (1970).  
*Evidence for Particle Instability of  $^{13}\text{Be}$  and  $^{14}\text{Be}$ .*
- 1974Bo05 J.D.Bowman, A.M.Poskanzer, R.G.Korteling, G.W.Butler - Phys.Rev. C9, 836 (1974).  
*Detection of Neutron-Excess Isotopes of Low-Z Elements Produced in High-Energy Nuclear Reactions.*
- 1981Se06 M.Seya, M.Kohno, S.Nagata - Prog.Theor.Phys.(Kyoto) 65, 204 (1981).  
*Nuclear Binding Mechanism and Structure of Neutron-Rich Be and B Isotopes by Molecular-Orbital Model.*
- 1983A120 D.V.Aleksandrov, E.A.Ganza, Yu.A.Glukhov, V.I.Dukhanov et al. - Yad.Fiz. 37, 797 (1983); Sov.J.Nucl.Phys. 37, 474 (1983).  
*Observation of the Isotope  $^{13}\text{Be}$  in the Reaction  $^{14}\text{C}(^7\text{Li},^8\text{B})$ .*
- 1983Va31 A.G.M.van Hees, P.W.M.Glaudemans - Z.Phys. A314, 323 (1983).  
*A Translationally Invariant Shell-Model Treatment of  $(0 + 1)(h\text{-bar} \times \Omega)$  States in  $A = 4\text{--}16$  Nuclei. (I).*
- 1984Va06 A.G.M.van Hees, P.W.M.Glaudemans - Z.Phys. A315, 223 (1984).  
*A Shell-Model Treatment of  $(0 + 1)(h\text{-bar} \times \Omega)$  States in  $A = 4\text{--}16$  Nuclei. (II).*
- 1985Po10 N.A.F.M.Poppelier, L.D.Wood, P.W.M.Glaudemans - Phys.Lett. 157B, 120 (1985).  
*Properties of Exotic p-Shell Nuclei.*
- 1986Gi10 A.Gillibert, L.Bianchi, A.Cunsolo, B.Fernandez et al. - Phys.Lett. 176B, 317 (1986).  
*Mass Measurement of Light Neutron-Rich Fragmentation Products.*
- 1987Sa15 H.Sagawa, H.Toki - J.Phys.(London) G13, 453 (1987).  
*Hartree-Fock Calculations of Light Neutron-Rich Nuclei.*
- 1992BoZV H.G.Bohlen, A.S.Demyanova, B.Gebauer, R.Kalpakchieva et al. - Contrib. 6th Intern.Conf.on Nuclei Far from Stability + 9th Intern.Conf.on Atomic Masses and Fundamental Constant, Bernkastel-Kues, Germany, C4 (1992).  
*The Mass and Excited States of  $^{13}\text{Be}$ .*
- 1992Go17 J.M.G.Gomez, C.Prieto, A.Poves - Phys.Lett. 295B, 1 (1992).  
*Hartree-Fock Shell Model Structure of Li and Be Isotopes.*
- 1992Os04 A.N.Ostrowski, H.G.Bohlen, A.S.Demyanova, B.Gebauer et al. - Z.Phys. A343, 489 (1992).  
*Mass Spectroscopy of  $^{13}\text{Be}$ .*
- 1992Wa11 H.Ward, K.Johnson, G.Kahrimanis, D.Saunders et al. - Phys.Rev. C45, 2723 (1992).  
*Double Giant Dipole Resonance in the  $(\pi^-, \pi^+)$  Reaction.*
- 1993BoZP H.G.Bohlen, D.V.Aleksandrov, A.S.Demyanova, B.Gebauer et al. - Proc.6th Intern.Conf.on Nuclei Far from Stability + 9th Intern.Conf.on Atomic Masses and Fundamental Constants, Bernkastel-Kues, Germany, 19-24 July, 1992, R.Neugart, A.Wohr, Eds., p.265 (1993).  
*Spectroscopy of  $^8\text{He}$ ,  $^{10}\text{Li}$  and  $^{13}\text{Be}$ .*
- 1993BoZT H.G.Bohlen, A.S.Demyanova, B.Gebauer, R.Kalpakchieva et al. - Program and Thesis, Proc.43rd Ann.Conf.Nucl.Spectrosc.Struct.At.Nuclei, Dubna, p.291 (1993).  
*The Mass and Excited States of  $^{13}\text{Be}$ .*
- 1993BoZW H.G.Bohlen, B.Gebauer, M.von Lucke-Petsch, W.von Oertzen et al. - Program and Thesis, Proc.43rd Ann.Conf.Nucl.Spectrosc.Struct.At.Nuclei, Dubna, p.277 (1993).  
*Spectroscopy of Neutron-Rich Light Nuclei.*
- 1994De32 P.Descouvemont - Phys.Lett. 331B, 271 (1994).  
*Evidence for Particle Stability of  $^{13}\text{Be}$  in a Microscopic Cluster Model.*
- 1994PeZZ Yu.E.Penionzhkevich - Proc. IV Int.Conf. on Selected Topics in Nuclear Structure, Dubna, p.255 (1994); JINR E4-94-370 (1994).  
*The Experimental Investigation of the Structure of Exotic Nuclei.*
- 1995De31 P.Descouvemont - Phys.Rev. C52, 704 (1995).  
*Halo Structure of  $^{14}\text{Be}$  in a Microscopic  $^{12}\text{Be} + n + n$  Cluster Model.*
- 1995Ko10 A.A.Korshennikov, E.Yu.Nikolsky, T.Kobayashi, D.V.Aleksandrov et al. - Phys.Lett. 343B, 53 (1995).  
*Spectroscopy of  $^{12}\text{Be}$  and  $^{13}\text{Be}$  using a  $^{12}\text{Be}$  Radioactive Beam.*
- 1995Ko27 A.A.Korshennikov, D.V.Aleksandrov, N.Aoi, Y.Doki et al. - Nucl.Phys. A588, 23c (1995).  
*Experimental Studies of Light Neutron Rich Nuclei.*
- 1995KoZK A.A.Korshennikov, D.V.Aleksandrov, N.Aoi, N.Inabe et al. - Proc.Intern.Conf on Exotic Nuclei and Atomic Masses, Arles, France, June 19-23, 1995, p.207 (1995).  
*Experimental Studies of Light Exotic Nuclei.*
- 1995OsZX A.N.Ostrowski, H.G.Bohlen, B.Gebauer, M.von Lucke-Petsch et al. - Proc.Intern.Conf on Exotic Nuclei and Atomic Masses, Arles, France, June 19-23, 1995, p.169 (1995).  
*Spectroscopy of Light Neutron-Rich  $^{7-10}\text{He}$ ,  $^{9-11}\text{Li}$ - and  $^{12-14}\text{Be}$ -Isotopes.*
- 1995Pe12 Yu.E.Penionzhkevich - Nucl.Phys. A588, 259c (1995).  
*The Experimental Investigation of Exotic Nuclei Properties in Dubna.*
- 1995Ta32 S.Takami, K.Yabana, K.Ikeda - Prog.Theor.Phys.(Kyoto) 94, 1011 (1995).  
*Deformations of Be Isotopes Studied with Skyrme Hartree-Fock Method.*
- 1995ThZZ M.Thoennessen, A.Azhari, T.Baumann, J.A.Brown et al. - Proc.Intern.Conf on Exotic Nuclei and Atomic Masses, Arles, France, June 19-23, 1995, p.237 (1995).

## REFERENCES FOR A=13(CONTINUED)

- Mass Measurements Beyond the Driplines.*  
1996Su24 Y.Sugahara, K.Sumiyoshi, H.Toki, A.Ozawa, I.Tanihata - Prog.Theor.Phys.(Kyoto) 96, 1165 (1996).  
*Study of Light Nuclei in the Relativistic Mean Field Theory and the Non-Relativistic Skyrme-Hartree-Fock Theory.*  
1996Wa35 Z.Wang, X.Zhang, X.Wang, X.Wang - Z.Phys. A356, 255 (1996).  
*Ground State Properties of Halo Nuclei.*  
1997Ba23 X.Bai, J.Hu - Phys.Lett. 395B, 151 (1997).  
*Neutron Halo in Light Nuclei.*  
1997Ba54 X.Bai, J.Hu - Phys.Rev. C56, 1410 (1997).  
*Microscopic Study of the Ground State Properties of Light Nuclei.*  
1997Re07 Z.Ren, B.Chen, Z.Ma, G.Xu - Z.Phys. A357, 137 (1997).  
*Level Inversion of N = 9 Isotones in the Relativistic Mean-Field Theory.*  
1998Be28 A.V.Belozyorov, R.Kalpakchieva, Yu.E.Penionzhkevich, Z.Dlouhy et al. - Nucl.Phys. A636, 419 (1998).  
*Spectroscopy of  $^{13}\text{Be}$ .*  
1998Go30 M.G.Gornov, Yu.B.Gurov, S.V.Lapushkin, P.V.Morokhov et al. - Bull.Rus.Acad.Sci.Phys. 62, 1781 (1998).  
*Spectroscopy of  $^{7,8}\text{He}$ ,  $^{10}\text{Li}$ , and  $^{13}\text{Be}$  Nuclei in Stopped  $\pi^-$  Meson Absorption Reactions.*  
1999Ka67 R.Kalpakchieva, Yu.E.Penionzhkevich, H.G.Bohlen - Fiz.Elem.Chastits At.Yadra 30, 1429 (1999); Phys.Part.Nucl. 30, 627 (1999).  
*Very Neutron-Rich Isotopes of Light Elements: Nuclear structure.*  
1999La20 M.Labiche, F.M.Marques, O.Sorlin, N.Vinh Mau - Phys.Rev. C60, 027303 (1999).  
*Structure of  $^{13}\text{Be}$  and  $^{14}\text{Be}$ .*  
2000Bh07 R.Bhattacharya - Pramana 54, 247 (2000).  
*Skyrme-Hartree-Fock Approach to the Change of Level Occupancy of Low Mass Halo Nuclei.*  
2001AIZZ D.Aleksandrov, T.Aumann, L.Axelsson, T.Baumann et al. - GSI 2001-1, p.21 (2001).  
*Excitation and Fragment-Neutron Correlations of Halo Nuclei.*  
2001La02 M.Labiche, N.A.Orr, F.M.Marques, J.C.Angelique et al. - Phys.Rev.Lett. 86, 600 (2001).  
*Halo Structure of  $^{14}\text{Be}$ .*  
2001Pe27 Yu.E.Penionzhkevich - Hyperfine Interactions 132, 265 (2001).  
*Mass Measurements in Nuclear Reactions.*  
2001Th01 M.Thoennessen, S.Yokoyama, P.G.Hansen - Phys.Rev. C63, 014308 (2001).  
*First Evidence for Low Lying s-Wave Strength in  $^{13}\text{Be}$ .*  
2003JoZZ K.L.Jones - Proc.Frontiers of Nuclear Structure, Berkeley, California, P.Fallon and R.Clark, Eds., p.289 (2003); AIP Conf.Proc. 656 (2003).  
*The Halo Nucleus  $^{14}\text{Be}$  And The Unbound Nucleus  $^{13}\text{Be}$ .*  
2003LeZX J.L.Lecouey - nucl-ex/0310027,10/27/2003 (2003).  
*Experimental studies of unbound neutron-rich nuclei.*  
2004De60 E.de Almeida, S.S.Sharma - Braz.J.Phys. 34, 962 (2004).  
*SU(3) Model Description of Be Isotopes.*  
2004La24 G.A.Lalazisis, D.Vretenar, P.Ring - Eur.Phys.J. A 22, 37 (2004).  
*Relativistic Hartree-Bogoliubov description of deformed light nuclei.*  
2004Le29 J.L.Lecouey - Few-Body Systems 34, 21 (2004).  
*Experimental Studies of Unbound Neutron-Rich Nuclei.*  
2004Ne16 V.O.Nesterov - Ukr.J.Phys. 49, 225 (2004).  
*Application of the quasiclassical approximation for the analysis of properties of light atomic nuclei with high excess of neutrons.*  
2004Sa50 C.Samanta - Acta Phys.Hung.N.S. 19, 161 (2004).  
*A New Mass Formula and New Neutron and Proton Magic Numbers in Light Nuclei.*  
2004Si12 H.Simon, T.Aumann, M.J.G.Borge, L.V.Chulkov et al. - Nucl.Phys. A734, 323 (2004).  
*Two- and three-body correlations: breakup of halo nuclei.*  
2004Ta03 T.Tarutina, I.J.Thompson, J.A.Tostevin - Nucl.Phys. A733, 53 (2004).  
*Study of  $^{14}\text{Be}$  with core excitation.*  
2005Ar12 P.Arumugam, B.K.Sharma, S.K.Patra, R.J.K.Gupta - Phys.Rev. C 71, 064308 (2005).  
*Relativistic mean field study of clustering in light nuclei.*  
2005Ne03 T.Neff, H.Feldmeier, R.Roth - Nucl.Phys. A752, 321c (2005).  
*Structure of light nuclei in Fermionic Molecular Dynamics.*  
2005Th06 G.Thiamova - Phys.Scr. 71, 349 (2005).  
*Ground State Properties of Beryllium Isotopes Studied by AMD + GCM Method.*  
2006Ko02 V.B.Kopeliovich, A.M.Shunderuk, G.K.Matushko - Phys.Atomic Nuclei 69, 120 (2006).  
*Mass Splittings of Nuclear Isotopes in Chiral Soliton Approach.*  
2006Sh20 B.K.Sharma, S.K.Patra, R.K.Gupta, A.Shukla et al. - J.Phys.(London) G32, 2089 (2006).  
*Reaction cross-sections for light nuclei on  $^{12}\text{C}$  using relativistic mean field formalism.*  
2007B102 G.Blanchon, A.Bonaccorso, D.M.Brink, A.Garcia-Camacho, N.Vinh Mau - Nucl.Phys. A784, 49 (2007).  
*Unbound exotic nuclei studied by projectile fragmentation.*  
2007Gu03 Y.-Q.Guo, Z.-Z.Ren - Chin.Phys.Lett. 24, 652 (2007).

## REFERENCES FOR A=13(CONTINUED)

- 2007Si24 *Structures of Light Neutron-Rich Nuclei with Orbit-Orbit Coupling.*  
H.Simon, M.Meister, T.Aumann, M.J.G.Borge et al. - Nucl.Phys. A791, 267 (2007).
- 2008Ch07 *Systematic investigation of the drip-line nuclei  $^{11}\text{Li}$  and  $^{14}\text{Be}$  and their unbound subsystems  $^{10}\text{Li}$  and  $^{13}\text{Be}$ .*  
G.Christian, W.A.Peters, D.Absalon, D.Albertson et al. - Nucl.Phys. A801, 101 (2008).
- 2008Ha16 *Production of nuclei in neutron unbound states via primary fragmentation of  $^{48}\text{Ca}$ .*  
I.Hamamoto - Phys.Rev. C 77, 054311 (2008).
- 2009BIZZ *Neutron decay width of one-particle resonant levels in deformed nuclei.*  
G.Blanchon, A.Bonaccorso, D.M.Brink, N.Vinh Mau - Proc.of the 6th Japan-Italy Symposium on Heavy-Ion Physics; Perspective in Nuclear Physics, Tokai, Japan, 11-15 November 2008, S-C.Jeong, H.Miyatake, Y.Utsuno, H.Ikezoe, T.Motobayashi, A.Bracco, Eds., p.32 (2009); AIP Conf.Proc. 1120 (2009).
- 2010B112  *$^{10-11}\text{Li}$  and  $^{13-14}\text{Be}$  Studied by Projectile Fragmentation and pp-RPA.*  
G.Blanchon, A.Bonaccorso, D.M.Brink, N.Vinh Mau - J.Phys.:Conf.Ser. 205, 012003 (2010).
- 2010Fo11  *$^{10-11}\text{Li}$  and  $^{13-14}\text{Be}$  studied by projectile fragmentation and pp-RPA.*  
H.T.Fortune, R.Sherr - Phys.Rev. C 82, 064302 (2010).
- 2010Ko17 *Neutron decays of  $^{13}\text{Be}^*$  to the  $0_2^+$  state of  $^{12}\text{Be}$ .*  
Y.Kondo, T.Nakamura, Y.Satou, T.Matsumoto et al. - Phys.Lett. B 690, 245 (2010).
- 2012Bo15 *Low-lying intruder state of the unbound nucleus  $^{13}\text{Be}$ .*  
A.Bonaccorso - Phys.Scr. T150, 014008 (2012).
- 2012Fo22 *Unbound nuclei studied by projectile fragmentation.*  
H.T.Fortune, R.Sherr - Phys.Rev. C 86, 034301 (2012).
- 2012Ka10 *Predictions for the first two positive-parity states of  $^{13}\text{F}$ .*  
Y.Kanada-Enyo - Phys.Rev. C 85, 044320 (2012).
- 2013Ak01 *Breaking of  $N=8$  magicity in  $^{13}\text{Be}$ .*  
Yu.Aksyutina, T.Aumann, K.Boretzky, M.J.G.Borge et al. - Phys.Lett. B 718, 1309 (2013).
- 2013Ak02 *Momentum profile analysis in one-neutron knockout from Borromean nuclei.*  
Yu.Aksyutina, T.Aumann, K.Boretzky, M.J.G.Borge et al. - Phys.Rev. C 87, 064316 (2013).
- 2013Fo03 *Structure of the unbound nucleus  $^{13}\text{Be}$ : One-neutron knockout reaction data from  $^{14}\text{Be}$  analyzed in a holistic approach.*  
H.T.Fortune - Phys.Rev. C 87, 014305 (2013).
- 2013Ma53 *Unraveling the structure of  $^{13}\text{Be}$ .*  
P.Maris - J.Phys.:Conf.Ser. 445, 012035 (2013).
- 2014Fo21 *Ab initio calculations for Be-isotopes with JISP16.*  
H.T.Fortune - Phys.Rev. C 90, 064305 (2014).
- 2014Ho08  *$^{14}\text{Be}(g.s.)$  and single-particle energies in  $^{13}\text{Be}$ .*  
C.R.Hoffman, B.P.Kay, J.P.Schiffer - Phys.Rev. C 89, 061305 (2014).
- 2014Ra07 *Neutron s states in loosely bound nuclei.*  
G.Randisi, A.Leprince, H.Al Falou, N.A.Orr et al. - Phys.Rev. C 89, 034320 (2014).
- 2015Fo06 *Structure of  $^{13}\text{Be}$  probed via secondary-beam reactions.*  
H.T.Fortune - Phys.Rev. C 91, 044321 (2015).
- 2015Ma62 *Lowest  $(sd)^2$  states in odd-A light nuclei.*  
B.R.Marks, P.A.DeYoung, J.K.Smith, T.Baumann et al. - Phys.Rev. C 92, 054320 (2015).
- 2015Ri03 *Population of  $^{13}\text{Be}$  in a nucleon exchange reaction.*  
G.Ribeiro, O.Tengblad - Acta Phys.Pol. B46, 547 (2015).
- 2016Fo07 *Study of the Unbound  $^{13}\text{Be}$  Resonance in a  $(p,2p)$  Reaction at GSI.*  
H.T.Fortune - Phys.Rev. C 93, 054327 (2016).
- 2016Ko22 *Energies and widths in  $^{13}\text{Be}$ .*  
L.Yu.Korotkova, V.S.Karpukhin, S.V.Lapushkin, R.V.Pritula et al. - Bull.Rus.Acad.Sci.Phys. 80, 219 (2016).
- 2018Fo07 *Searching for rare cluster configurations of  $^{14}\text{C}$  nuclei in the pionabsorption reaction.*  
H.T.Fortune - Eur.Phys.J. A 54, 51 (2018).
- 2018Ma05 *Structure of exotic light nuclei:  $Z = 2, 3, 4$ .*  
A.O.Macchiavelli, H.L.Crawford, C.M.Campbell, R.M.Clark et al. - Phys.Rev. C 97, 011302 (2018); Erratum Phys.Rev. C 97, 094902 (2018).
- 2018Ri05 *Analysis of spectroscopic factors in  $^{11}\text{Be}$  and  $^{12}\text{Be}$  in the Nilsson strong-coupling limit.*  
G.Ribeiro - Phys.Rev. C 98, 024603 (2018).
- 2019Co12 *Structure of  $^{13}\text{Be}$  studied in proton knockout from  $^{14}\text{B}$ .*  
A.Corsi, Y.Kubota, J.Casal, M.Gomez-Ramos et al. - Phys.Lett. B 797, 134843 (2019).
- 2019Fo02 *Structure of  $^{13}\text{Be}$  probed via quasi-free scattering.*  
H.T.Fortune - Phys.Rev. C 99, 014304 (2019).
- 2020A127 *Update on energies and widths in  $^{13}\text{Be}$ .*  
A.A.Allami, A.A.Alzubadi - Int.J.Mod.Phys. E29, 2050090 (2020).
- 2021Co07 *Study of the nuclear structure of some exotic nuclei using nonrelativistic and relativistic mean-field methods.*  
A.Corsi, B.Monteagudo, F.M.Marques - Eur.Phys.J. A 57, 88 (2021).

REFERENCES FOR A=13(CONTINUED)

- [2021Wa16](#) *The neutron dripline at  $Z = 4$ : the case of  $^{13,15}\text{Be}$ .*  
M.Wang, W.J.Huang, F.G.Kondev, G.Audi, S.Naimi - Chin.Phys.C 45, 030003 (2021).
- [2023Co13](#) *The AME 2020 atomic mass evaluation (II). Tables, graphs and references.*  
A.Corsi, Y.Kubota, J.Casal, M.Gomez-Ramos et al. - Phys.Lett. B 840, 137875 (2023).
- [2023Ko21](#) *Searching for universality of dineutron correlation at the surface of Borromean nuclei.*  
J.Kovoor, K.L.Jones, J.Hooker, M.Vostinar et al. - Phys.Rev. C 108, 034601 (2023).
- [2024Ca06](#) *Structure studies of  $^{13}\text{Be}$  from the  $^{12}\text{Be}(d,p)$  reaction in inverse kinematics on a solid deuteron target.*  
J.Casal, M.Gomez-Ramos, A.M.Moro - Nuovo Cim. C 47, 41 (2024).  
*Collective core effects and dineutron correlations in three-body nuclei.*