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INPC2016, 16th September, 2016

Search for a Ξ bound state in the ${}^{12}C(\overline{K}, K)$ reaction at 1.8 GeV/c



T. Nagae, Kyoto University (J-PARC E05 Spokesperson)



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Observation of Ξ bound states in the ¹²C(K,K) reaction at 1.8 GeV/c



T. Nagae, *Kyoto University* (J-PARC E05 Spokesperson)

E05 Collaboration

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Contents

* Introduction to *S*=-2 world * J-PARC E05 experiment * Pilot run of E05 in 2015 * Analysis Results * Summary





014003.

S=-2 World

KEK E373 * "Kiso" event; Ξ-¹⁴N





BNL E885

- * ¹²C(K⁻,K⁺) at 1.8 GeV/*c*
- * no clear evidence of Ξ-hypernuclear bound state.
 - because of the limited mass resolution of 14 MeV_{FWHM}
- * suggested weakly attractive potential of -14 MeV depth. (B_E~4.5 MeV)
 - by shape analysis and counts in bound region, compared with DWIA calc.
- 89±14 nb/sr (<8deg. 42 events);
 42±5 nb/sr (<14deg. 67 events)



Spectroscopic Study of Ξ -Hypernucleus, ¹²_{Ξ}Be, J-PARC E05 via the ¹²C(K⁻,K⁺) Reaction T. Nagae et al.

* Discovery of Ξ -hypernuclei as a peak(s)

S=-1

- * Measurement of Ξ -nucleus potential depth and width of ${}^{12}\Xi$ Be
 - * Coupling between Ξ -nucleus and $\Lambda\Lambda$ -system

D1, 86t, 1.5 T



S=-2 (Multi-Strangeness System)



S-2S Spectrometer

 $\Delta E=1.5 \text{ MeV}(FWHM)$





E05 Pilot Run SKS Sbc4 Sbc3 Top K⁺ Q13 Target **O12** 3 1 day

- * K1.8 beam line with SKS' (110 msr)
 - * AC + LC for π^+ , p veto in trigger
 - * $CH_2(K^-,K^+)$ 9.54g/cm² $\rightarrow \Delta E=5 MeV_{FWHM}$
- * Two weeks of beam time ; Oct.26 Nov.19, 2015
 - * Detector tuning 1 day
 - * p(K⁻,K⁺) Ξ -@1.5-1.9 GeV/c 2 days
 - * ${}^{12}C(K^-,K^+)$ 9.36g/cm² 10 days

			0 3 m
	(msr)	(MeV)	
BNL	~50	14	
SKS'	110	5	BH1
S-2S	60	1.5	



* 600k K⁻/spill was achieved for 39 kW beam power.



* Integrated K⁻ intensity reached 100 G !! (J-PARC record)



Oct. 26 ~Nov. 19 in 2015





* Ξ^- at J-PARC !! * 6000 E/day







$\Delta E \sim 5.4 MeV f whm$

Target energy loss straggling limited. 10 MeV_{FWHM} at BNL

Optimum Momentum

- - * New data from 1.5 to 1.9 GeV/c.
 - * Two orders better statistics.

* Max. at 1.8 GeV/c is confirmed !

* Yield maximum at 1.8 GeV/c suggested by Dover & Gal.

C.B.Dover and A.Gal, Ann. Phys. 146 (1983) 309.





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Focus on this part.

Missing mass spectrum





Focus on this part.

Missing mass spectrum





Missing mass spectrum

Carbon + CH₂



-20<-BE<0 (MeV)
 T=S+B=55 counts
 B=10.8 counts



Consistent with BNL E885 data, but better energy resolution.



- ✤ QFΞ(linear)+Background(Flat) +
- One Gaussian (all free) *
 - $B_{\Xi}=6.3$ MeV, $\Delta B_{FWHM}=15.7$ MeV * too broad !!



Peak Fittings

- QFE(linear)+Background(Flat) ✤ QFΞ(linear)+Background(Flat) ** ++
- **Two Gaussians** One Gaussian (all free) * * (fixed width=5.4 MeV)
 - $B_{\Xi}=6.3$ MeV, $\Delta B_{FWHM}=15.7$ MeV * too broad !!
- - $B_{\Xi}=9.1$ MeV and 2.1 MeV *



Peak Fittings

- QFE(linear)+Background(Flat) QFE(linear)+Background(Flat) * ** +
- **Two Gaussians** * One Gaussian (all free) * (fixed width=5.4 MeV)
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- - $B_{\Xi}=9.1$ MeV and 2.1 MeV *



Peak Fittings

- QFE(linear)+Background(Flat) * +
- Three Gaussians (fixed width=5.4 MeV)
 - B_Ξ=16.4, 8.9, and 2.0 MeV * too deep?



Motoba's calculations

* EN Interaction models: ESC08, ESC04, NHCD, Ehime * Potential Depth : adjusted as B(1₁-)=4.5 MeV

T. Motoba, S. Sugimoto / Nuclear Physics A 835 (2010) 223-230



Figure 6: DWIA spectra with NHC-D and Ehime.

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Figure 7: DWIA spectra with ESC04d and ESC08a.

Summary

- 12 _EBe, are observed in the E05 pilot run.
 - for the first time.
 - * B_{\(\med)}: 9.1 MeV and 2.1 MeV.

* $Re(U_{\Xi}) > 14 MeV (B_{\Xi} \sim 4.5 MeV).$

* Peak structures corresponding to the Ξ-hypernucleus,

* Two peaks, at least, are resolved with $\Delta E=5.4$ MeV_{FWHM},

Need detail calculations considering Spin-Isospin dependence of ΞN interactions

Effect of Momentum Acceptance



Angular Distribution of p(K, K) at 1.8 GeV/c



* Two peaks: g1 18.4, g2 11.9, Bck 10.8 $S/\Delta S = 30.3 / 7.2 = 4.2$

* Three peaks: g1 5.6, g2 17.7, g3 11.5, Bck 10.8

* $\Delta y = y_{trck} - y_{tof}$



Background reduction with Δy cut

Flat Background: 2.1 counts/bin→1.08 counts/bin





PID with TOF



 Spin dependence in light E hypernuclei * $^{7}\text{Li}(K^{-}, K^{+})_{\Xi}^{7}H; \alpha nn\Xi^{-}$ Lightest Ξ hypernucleus ? * ${}^{10}B(K^{-}, K^{+})_{\Xi}{}^{10}Li; \alpha \alpha n \Xi^{-}$

 Heavy E hypernuclei spectroscopy * Coulomb-Assisted bound states ⁸⁹Y(K⁻, K⁺)

Physics beyond E05

* 2 MeVFWHM resolution * ~6 events/day/MeV for 50 msr, 2g/cm²-thick Pb ~20 days



(K-,K+) Spectroscopy

Unique bound state







Coupling between Ξ hypernuclei and double-Λ hypernuclei

Theoretical Calculation for ${}^{16}_{\Lambda\Lambda}$ C,

via Ξ⁻ doorways

in the ¹⁶O(K⁻,K⁺) reaction at 1.8 GeV/c

two-step process





-- T.Harada, Y.Hirabayashi, A.Umeya, PLB 690 (2010) 363.



excited states of double- Λ hyp. sensitive to EN- $\Lambda\Lambda$ coupling strength.

E05 with S-2S

- Grant-In-Aid for Specially promoted research: 2011 – 2015, Total ~\$3M
- * 60 msr, $\Delta p/p=0.05\% \rightarrow$ $\Delta M=1.5 \text{ MeV}$
- Construction of S-2S(QQD): ~3 years **\star** Installation in 2017 ★ Data taking in 2018 with > 50 kW !!







Need for Good Resolution

* $\Delta E < 2 MeV$ is needed to resolve fine structures.



T. Motoba and S. Sugimoto, Nucl. Phys. A 835, 223 (2010)

U_E in Recent Nijmegen Models

Table 3. $U_{\Xi}(\rho_0)$ and partial Γ_{Ξ} .

		-		-			
	T	${}^{1}S_{0}$	${}^{3}S_{1}$	${}^{1}P_{1}$	^{3}P	$U_arepsilon$	$\Gamma_{arepsilon}$
08a	0	6.0	-1.0	-0.3	-2.1		
	1	8.5	-28.0	0.6	-3.8	-20.2	5.8
08a'	0	5.6	-1.1	-0.3	-2.2		
	1	8.4	-21.5	0.6	-3.9	-14.5	7.0
08b	0	2.4	1.9	-0.6	-2.0		
	1	9.1	-37.8	0.6	-5.4	-31.8	1.2
04d	0	6.4	-19.6	1.1	-2.2		
	1	6.4	-5.0	-1.0	-4.8	-18.7	11.3

Table 3. $U_{\Xi}(\rho_0)$ and partial wave contributions. Conversion width

Comparison of Energy resolution

(MeV)

р(К⁻,К⁺)Е⁻

 $^{12}C(K^{-},K^{+})$

(sir

Target Energy-loss Straggling limited

E05 Pilot run	BNL E885
6	9.9
6.7	14
5.2 mulation)	