

第8回クラスター階層領域研究会, Osaka, 09/02/2023

Status and prospects of Ξ-atomic X-ray spectroscopy at J-PARC

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Contents

> X-ray spectroscopy of Ξ^- atom

- > Our first try [J-PARC E07]
- > Second try (Fe Ξ^- atom) [J-PARC E03]
- Future measurement [J-PARC E96]
- Summary

X-ray spectroscopy of E⁻-atom

We are aiming for

world first measurement of X ray from Ξ^- -atom

 \rightarrow Information on the EA optical potential



Information on (effective) **EN** interaction

large baryon mixing? (small $\Delta M(\Xi N-\Lambda\Lambda)=28 \text{ MeV}$)

• **EA interaction**

and it's A dependence Role of Ξ⁻ in neutron star?

X-ray spectroscopy of Ξ⁻-atom



Measurement of energy shift and width $\rightarrow \Xi^-A$ real and imaginary terms (near surface)

This method has been successfully applied for negative charged particles (π^- , K⁻, p, Σ^-)

X-ray spectroscopy of E⁻-atom



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 \rightarrow Ξ^-A real and imaginary terms (near surface)

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Experimental study on the EN interaction

(K^-,K^+) reaction spectroscopy for Ξ hypernuclei



Flag ship experiments at J-PARC K1.8



Missing mass measurement with the ¹²C(K⁻,K⁺)¹²_EBe reaction

- $V_{0\Xi} \approx 14 \text{ MeV}$ is suggested from spectral shape of the unbound continuum
- No clear peak structure for bound states



Experimental study on the EN interaction

Emulsion image in E nuclear absorption



3D absorption? (old prediction) C. J. Batty, Phys. Rev. C59, 295 (1999) 2P absorption? (recent prediction with HAL-QCD) E. Friedman, Phys. Lett. B820, 136555 (2021) 1S absorption? (recent emulsion data)

For farther discussion,

X ray yields give direct information about where is the absorption state.

Impact on old emulsion data



Impact on old emulsion data



Our challenges

No Ξ atomic X ray has been observed so far... We are finding the best method to measure Ξ atomic X rays.

1st try [J-PARC E07 (-2017)] finished	S/N	Yield
 Simple measurement [Ξ C atom] 	Bad	Not so bad
• E stop ID with emulsion [E Br, Ag atom] paper published (PTEP2022 12, 123D01)	Good	Bad
2nd try [J-PARC E03 (-2021)] 10% statistics run was finished		emulsion
 High statistics measurement [Ξ Fe atom] 	Bad	Good
3rd try [J-PARC E96] New proposal		
 Ξ stop ID with active target [Ξ C atom] 	Good	Not so bad

Our first try in J-PARC E07

Experimental study of double hypernuclei



Junya Yoshida (Advanced Science Research Center, JAEA) On behalf of J-PARC E07 Collaboration



Our first try in J-PARC E07

Measurement (1): Emulsion combined analysis

- S/N ratio O [we can tag Ξ^- stop in emulsion] B.G. level ~1/170!
- Yield rate ×
 - Low stop prob. (long flight, low density)
 - Mixture target (H, C, N, O, Br and Ag)
 - Not optimum setup for X-ray detector

No clear peak structure was observed.

(upper limits were given)





Fe Ξ^{-} atom measurement [J-PARC E03]



Advantage of Fe target

[Technical reason]

Enough dense (~7.9 g/cm³) for higher stopping probability of Ξ^-

[Physics reason]

Absorption strength (and width) reported in theoretical case study

is suitable for our measurement

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Calculated by T. Koike
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(5,4) state : $\Delta E \sim \Gamma \sim 4 \text{keV}$ [W.S. shape potential of -24-3i MeV]

Recent Lattice & ChiralEFT calc. Shows <1/10 smaller imaginary strength



Hyperball-X' for 1st phase



BGO suppressor

"clover-type" Ge detector (4 segmented crystals)

4 detector units covering up and down of the target

- Horizontally wide beam profile and target
- Self-absorption of X ray

	HBX'	HBJ		
High rate capability	 ∆ * slow amp. * segmented crystal 	O * fast amp. * large crystal * radiation hardness		
Energy resolution	2.5 keV (FWHM)	4 keV (FWHM)		
Optimum for low (~250kHz) beam intensity				

Γ~1keV case,

Higher energy resolution has great merit

- better peak significance
- small error on shift & width

Hyperball-X' for 1st phase



E03 preliminary result



Analysis is now on-going

This is very preliminary X-ray spectrum.

(not optimized event selection, background reduction)



than high statistics measurement.

in future exp.

is essential



Future measurement [J-PARC E96]

For C-atom



E stop tagging with AFT

Active Fiber Target (AFT) gives Ξ track information $\rightarrow \Xi$ stop tag



Energy loss correction for mass spectroscopy



Feature of the X-ray measurement:

- S/N ratio: Good [we can tag Ξ^- stop]
- Yield rate: Not so bad
 - Low stop probability (low density)
 - High intensity beam & setup

E stop tagging with AFT



Expected result with E70 beam time



By installing Ge detectors near AFT system, parallel data taking can be done in E70 beamtime

[expected to run in 2023] W



E96 for C-atom

We have chance to observe X ray

We submitted the proposal and got "stage-1" (requesting "stage-2 approval" in 2023.01)

Timeline of X-ray spectroscopy of Ξ⁻-atom at the J-PARC K1.8 beam line

	finished	
2016	E07: Emulsion exp.	
2017	[X-ray spectroscopy: C, Br, Ag-atom]	
2018	E03 Pilot run	er
2019	E40: Σp scat. exp.	
2020	Andrysis on-going	
	E03-1st: E ⁻ Fe-atom X-ray spectroscopy	
2021	E42: H-dibarion search	
2022	Submit E96 proposal coming soon!	vn —
2023		
	E/0: E hypernuclear spectroscopy 5-25	
	E96: X-ray spectroscopy: C-atom spectrome	ter

Preparation for the next measurement



Summary

We are aiming for world first measurement of X ray from Ξ⁻-atom

- \rightarrow Information on the EA optical potential
 - First try in J-PARC E07 [X-ray spectroscopy: C, Br, Ag-atom]
 - E03 (Ξ⁻ Fe-atom measurement) 1st-phase data taking [2020-2021] finished
 - Future measurement in S-2S exp. (J-PARC E70/E96) [X-ray spectroscopy: C-atom]

coming soon

Thank you for your support!