Femtoscopy for the systems with strangeness and charm

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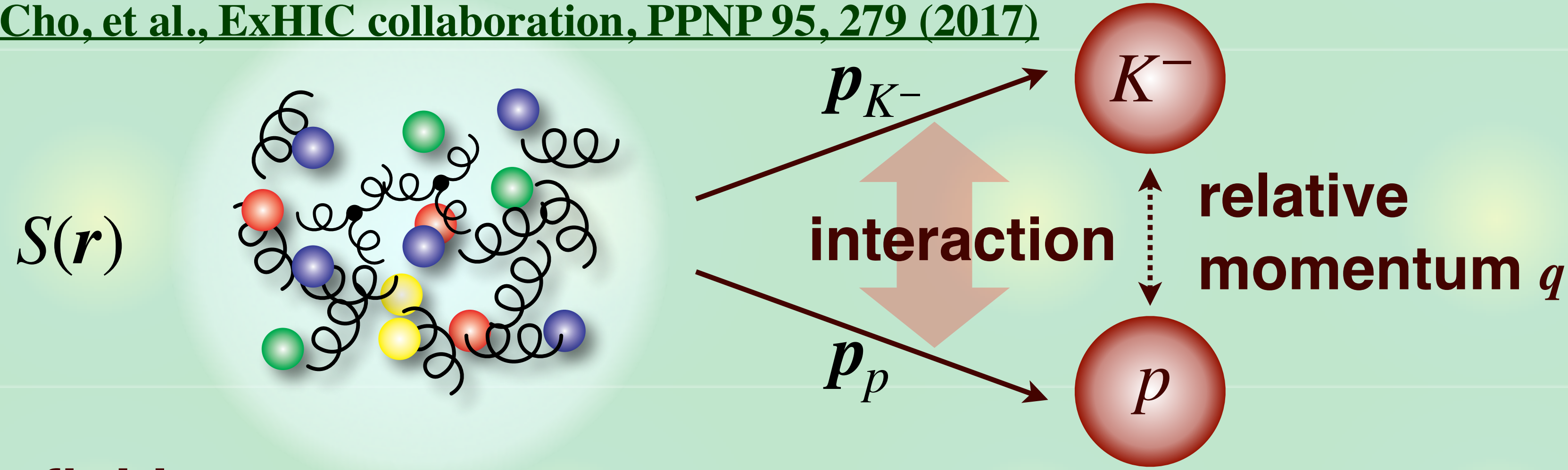
Contents

Correlation function and KP formula

High-energy collision: chaotic source $S(r)$ of hadron emission

S. Cho, et al., ExHIC collaboration, PPNP 95, 279 (2017)



- Definition

$$C(\boldsymbol{q}) = \frac{N_{K^-p}(\boldsymbol{p}_{K^-}, \boldsymbol{p}_p)}{N_{K^-}(\boldsymbol{p}_{K^-})N_p(\boldsymbol{p}_p)}$$

(= 1 in the absence of FSI/QS)

- Theory (Koonin-Pratt formula) **incoming + outgoing**

S.E. Koonin, PLB 70, 43 (1977); S. Pratt, PRD 33, 1314 (1986)

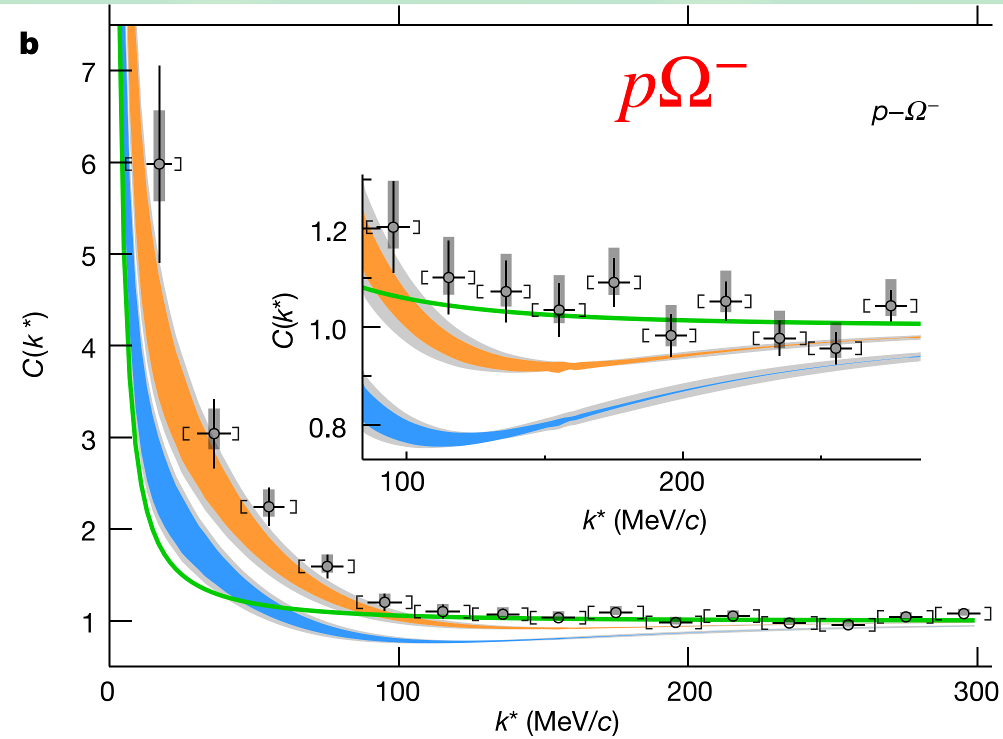
$$C(\boldsymbol{q}) \simeq \int d^3\boldsymbol{r}\, S(\boldsymbol{r})\, |\Psi_{\boldsymbol{q}}^{(-)}(\boldsymbol{r})|^2, \quad \Psi_{\boldsymbol{q}}^{(-)}(\boldsymbol{r}) \propto S^{\dagger} e^{-iqr} - e^{+iqr} \quad (r \to \infty)$$

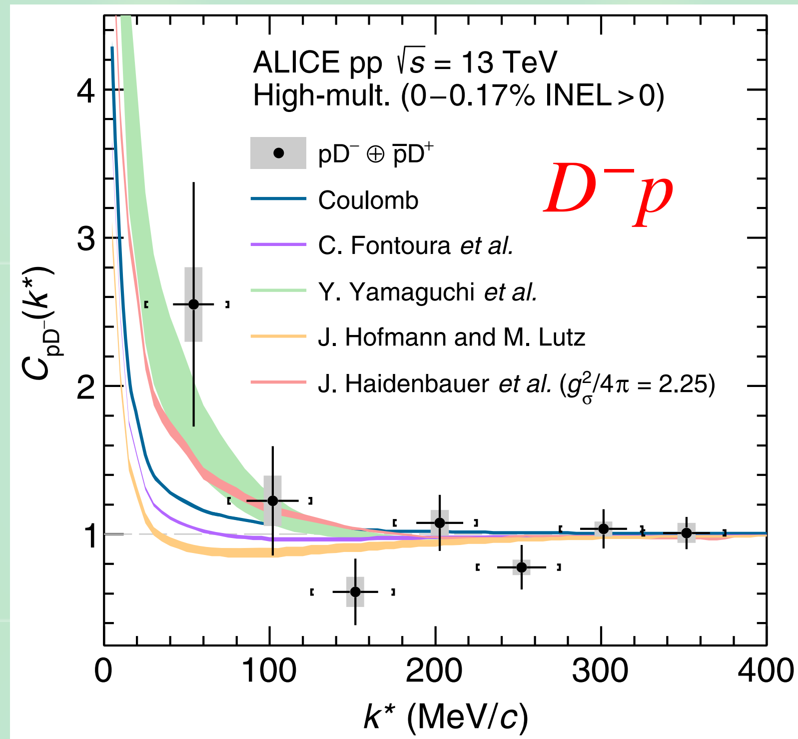
Source function $S(\boldsymbol{r})$ <—> wave function $\Psi_{\boldsymbol{q}}^{(-)}(\boldsymbol{r})$ (interaction)

Experimental data with strangeness and charm

Correlation functions observed by ALICE@LHC

ALICE collaboration, Nature 588, 232 (2020);
ALICE collaboration, PRD 106, 052010 (2022)





$\Omega^- \sim sss$: **strangeness** $S = -3$, $D^- \sim \bar{c}d$: **charm** $C = -1$

Almost impossible in scattering experiments

Contents

- Introduction — Femtoscopy
- Femtoscopy for strangeness
  - $\Lambda\alpha$ and $\Xi\alpha$ correlations

    A. Jinno, Y. Kamiya, T. Hyodo, A. Ohnishi, PRC110, 014001 (2024);
    Y. Kamiya, A. Jinno, T. Hyodo, A. Ohnishi, arXiv:2409.13207 [nucl-th]
- Femtoscopy for charm
  - DD^* and $D\bar{D}^*$ correlations

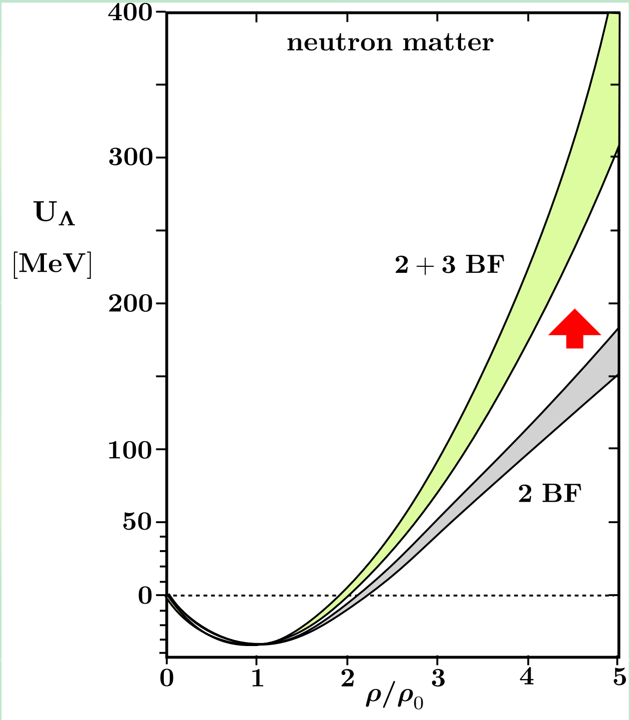
    Y. Kamiya, T. Hyodo, A. Ohnishi, EPJA58, 131 (2022)
- Summary and future prospects

$\Lambda\alpha$ correlation: Motivation

A solution to hyperon puzzle in neutron stars

- ΛNN three-body force for repulsion at high density

D. Gerstung, N. Kaiser, W. Weise, EPJA 55, 175 (2020)



How to verify this in experiments?

- Λ directed flow in heavy ion collisions

Y. Nara, A. Jinno, K. Murase, A. Ohnishi, PRC 106, 044902 (2022)

Λ-nucleus correlation function?

- Heavy nuclei are difficult to produce
- Strong binding of α: two-body treatment justified

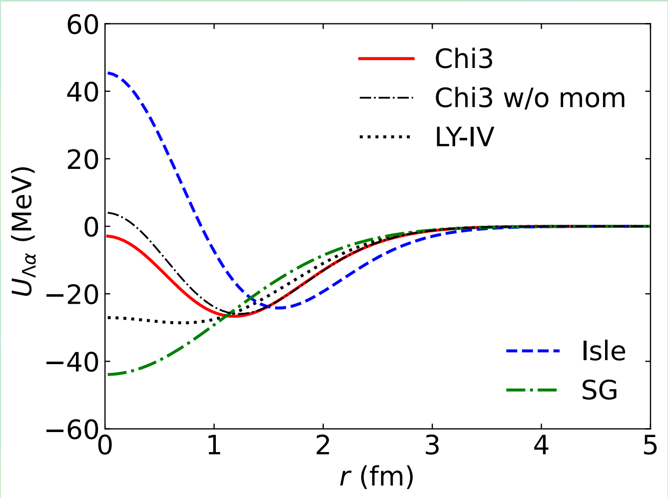
$\Lambda\alpha$ correlation function —> nature of $\Lambda\alpha$ potential?

$\Lambda\alpha$ potentials

Phenomenological $\Lambda\alpha$ potentials (${}^{5}_{\Lambda}\mathrm{He}$ binding energy)

I. Kumagai-Fuse, S. Okabe, Y. Akaishi, PLB 345, 386 (1997)

- SG: single gaussian
- Isle: two gaussians (with core)



Skyrme-Hartree Fock methods

- LY4: phenomenorogical

D.E. Lanskoy, Y. Yamamoto, PRC 55, 2330 (1997)

- Chi3: based on chiral EFT with ΛNN force

A. Jinno, K. Murase, Y. Nara, A. Ohnishi, PRC 108, 065803 (2023)

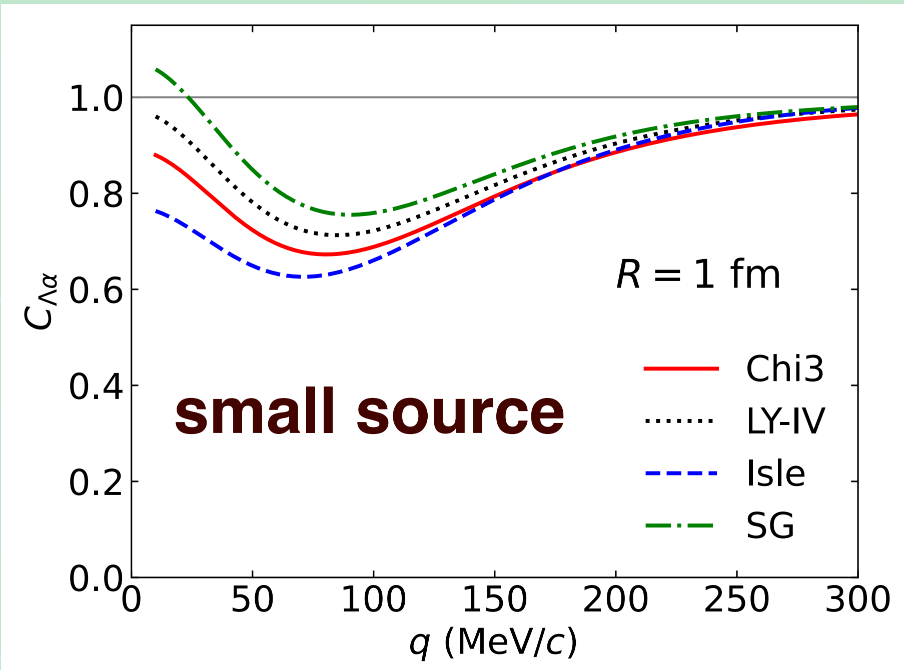
- Both potentials reproduce hypernuclear data from C to Pb
- α density distribution —> $\Lambda\alpha$ potentials

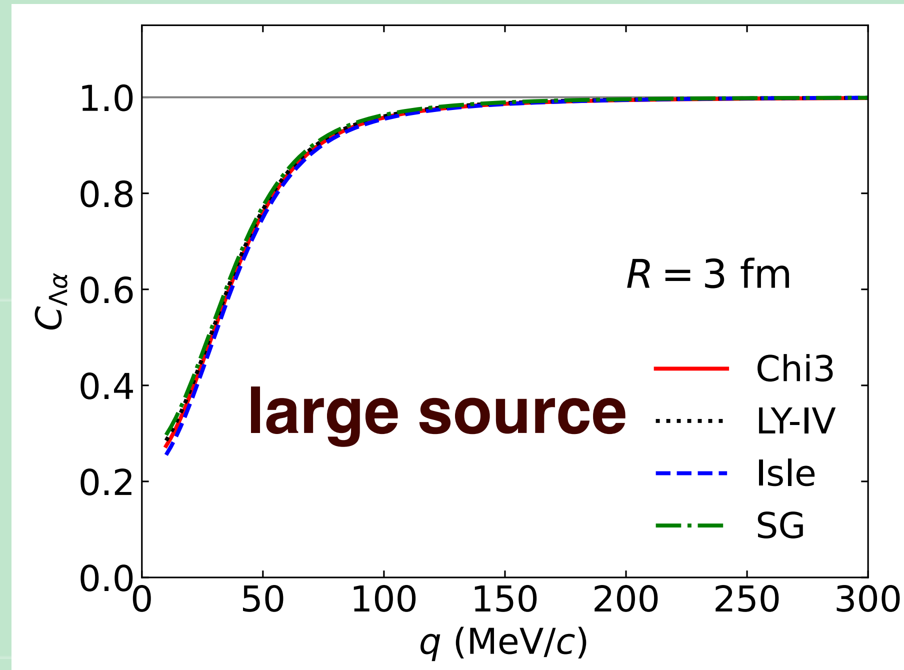
Effect of repulsive core —> correlation function?

$\Lambda\alpha$ correlation: source size dependence

Correlation functions from small and large sources

A. Jinno, Y. Kamiya, T. Hyodo, A. Ohnishi, PRC110, 014001 (2024)



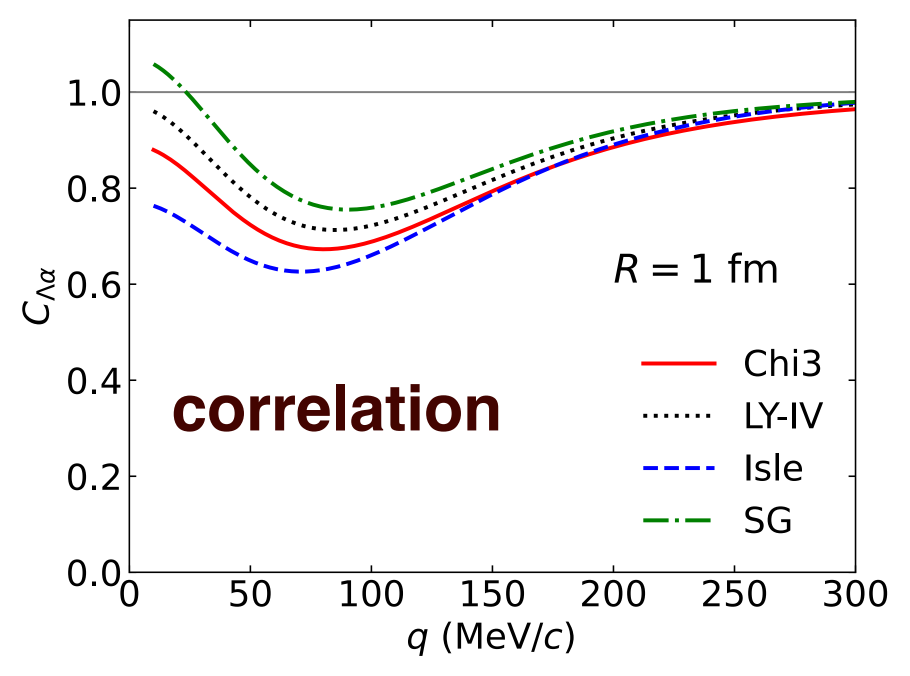


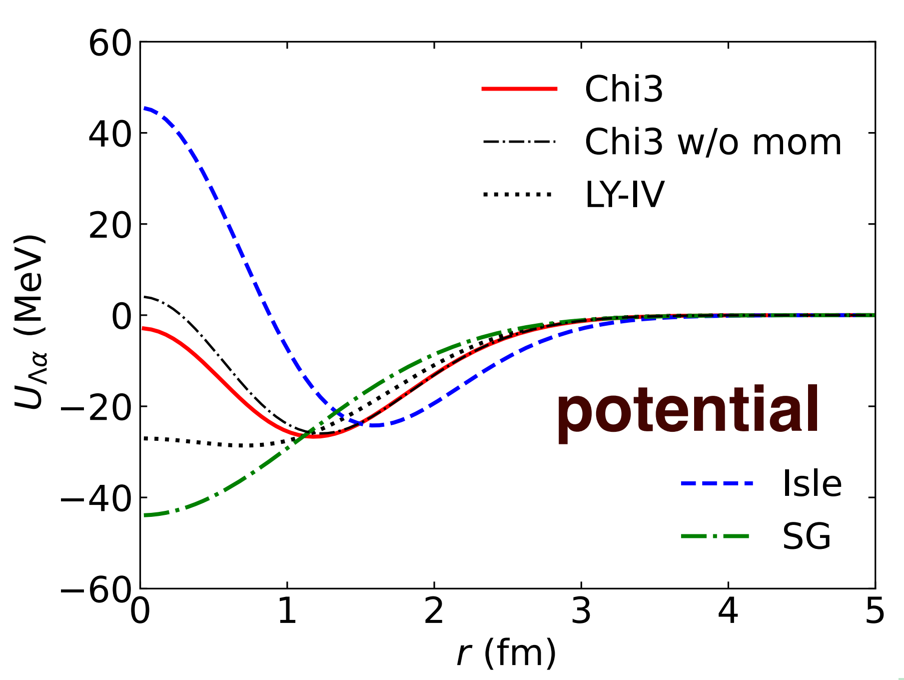
- Bound state signature (dip at low q in small source)
- No difference in large source ($R \sim 3$ fm)
- **Interaction dependence** in small source ($R \sim 1$ fm)

$\Lambda\alpha$ correlation: interaction dependence

Correlation functions and $\Lambda\alpha$ potentials

A. Jinno, Y. Kamiya, T. Hyodo, A. Ohnishi, PRC110, 014001 (2024)





- $U_{\Lambda\alpha}(r = 0)$: **Isle > LY-IV > Chi3 > SG**
- $C_{\Lambda\alpha}(q = 0)$: **Isle < LY-IV < Chi3 < SG**
- **Central repulsion suppresses correlation at low q**

$\Xi\alpha$ correlation: Motivation

ΞN interactions ($^{11}S_0$, $^{31}S_0$, $^{13}S_1$, $^{33}S_1$) from lattice QCD and ChEFT

K. Sasaki, et al. (HAL QCD), NPA 998, 121737 (2020);
J. Haidenbauer, U.-G. Meißner, EPJA 55, 23 (2019)

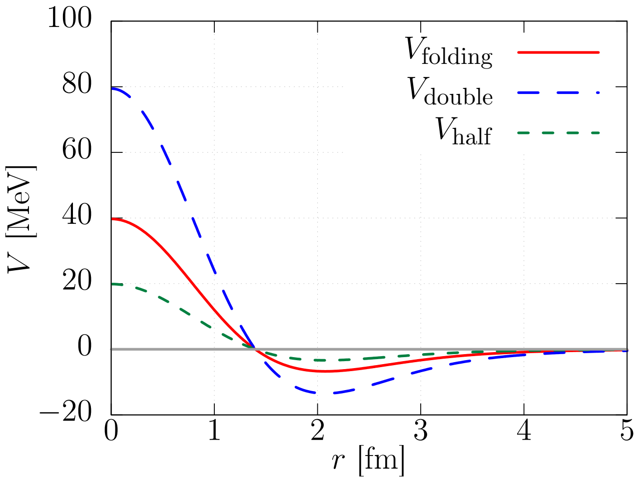
—> Different predictions for $\Xi^-\alpha$ and $\Xi^0\alpha$ bound states

E. Hiyama, M. Isaka, T. Doi, T. Hatsuda, PRC 106, 064318 (2022)
H. Le, J. Haidenbauer, U.-G. Meißner, A. Nogga,EPJA 57, 339 (2021)

Three $\Xi\alpha$ potentials (attraction plus core)

Y. Kamiya, A. Jinno, T. Hyodo, A. Ohnishi, arXiv:2409.13207 [nucl-th]

- V_{folding}: folding HAL QCD ΞN potentials
- $V_{\text{double}} = V_{\text{folding}} \times 2$, $V_{\text{half}} = V_{\text{folding}}/2$

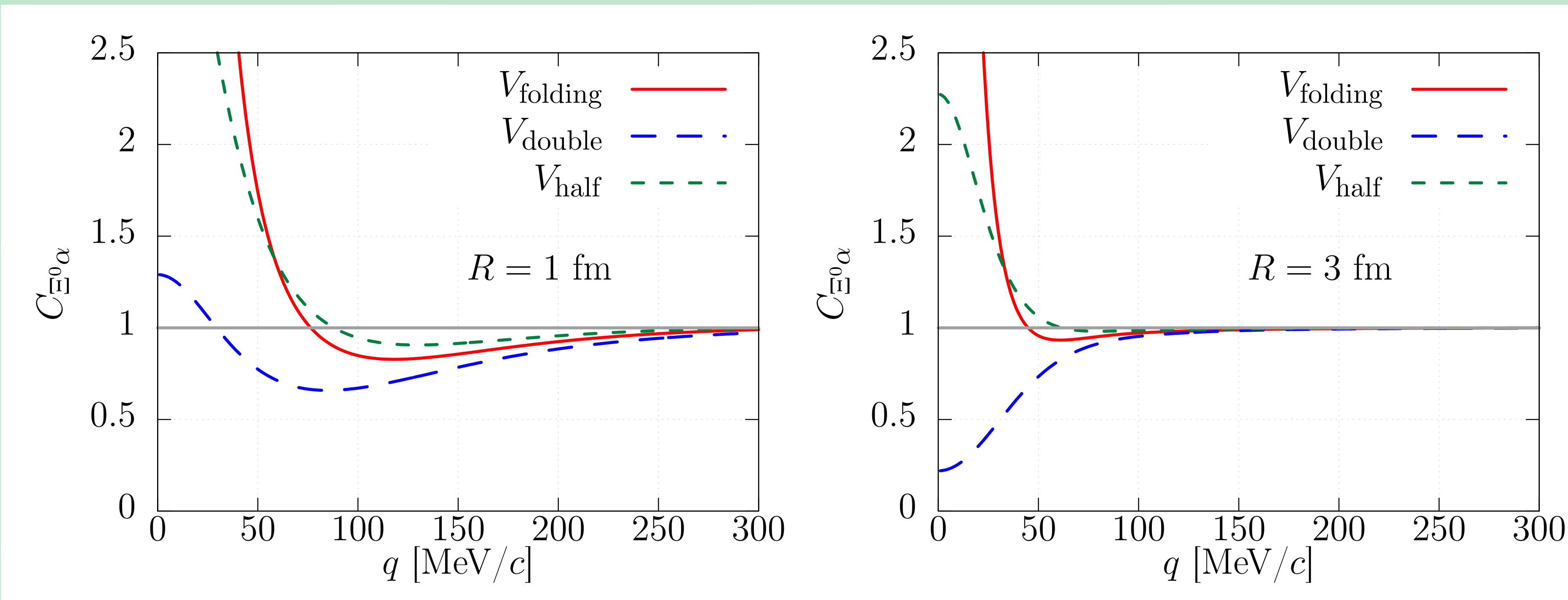


potential	$\Xi^-\alpha$ [MeV]	$\Xi^0\alpha$ [MeV]
V_{folding}	0.47	-
V_{double}	2.08	1.15
V_{half}	0.18	–

$\Xi\alpha$ correlation: source size dependence

$\Xi^0\alpha$ Correlation functions

Y. Kamiya, A. Jinno, T. Hyodo, A. Ohnishi, arXiv:2409.13207 [nucl-th]



- $V_{\rm double}$: strong source size dependence <— bound state
- Dip in $V_{\rm forlding}$ and $V_{\rm half}$ <— repulsice core?

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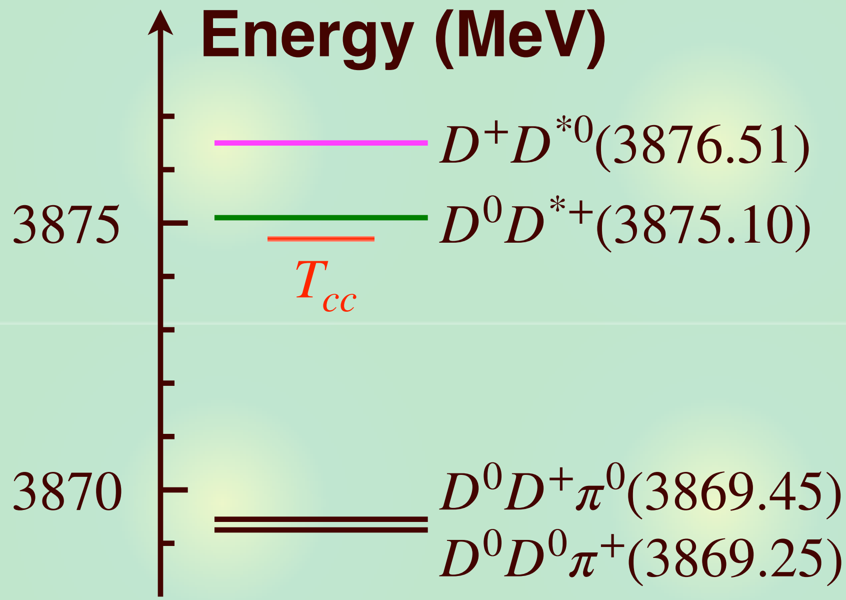
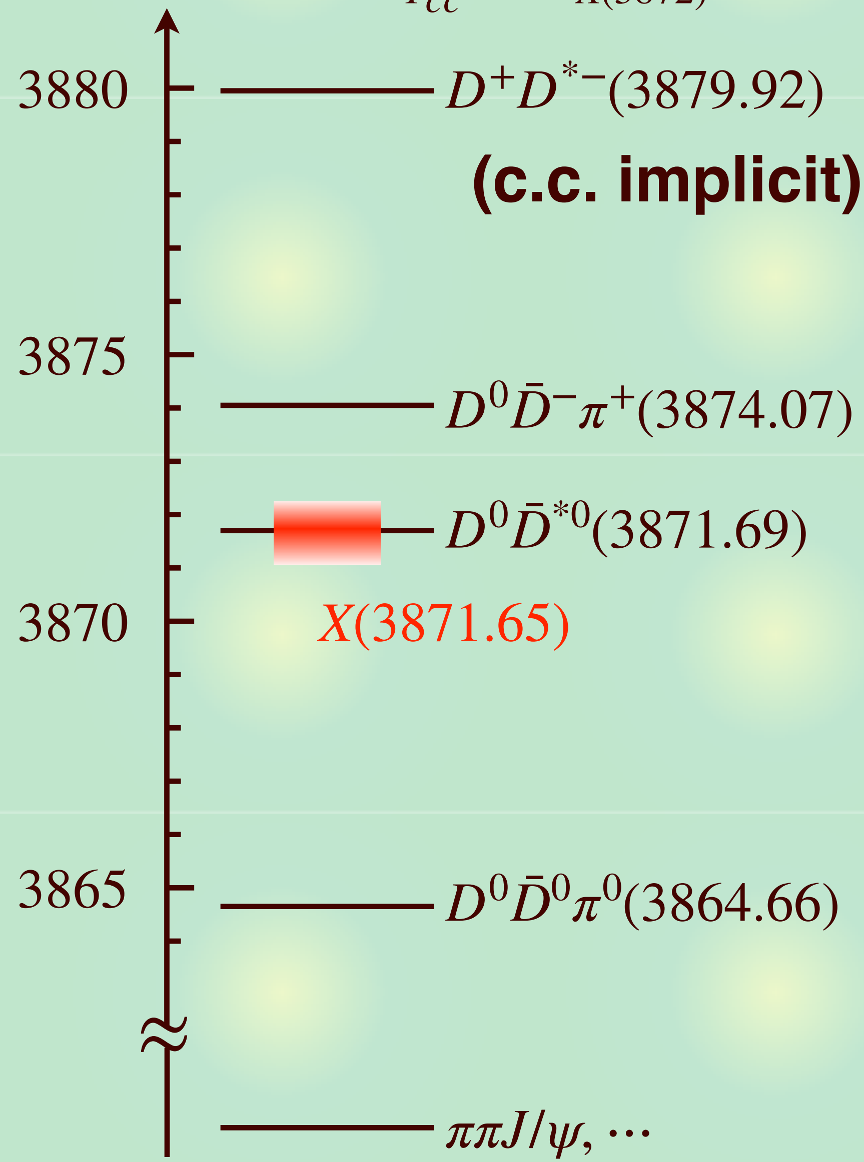
    Y. Kamiya, T. Hyodo, A. Ohnishi, EPJA58, 131 (2022)
- Summary and future prospects

T_{cc} and $X(3872)$

$X(3872)$: another near-threshold state with $M_{T_{cc}} \sim M_{X(3872)}$

- Masses from PDG Live





- $T_{cc}/X(3872)$ near $DD^*/D\bar{D}^*$

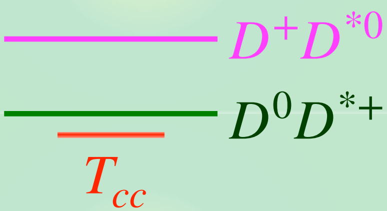
—> Molecule nature?

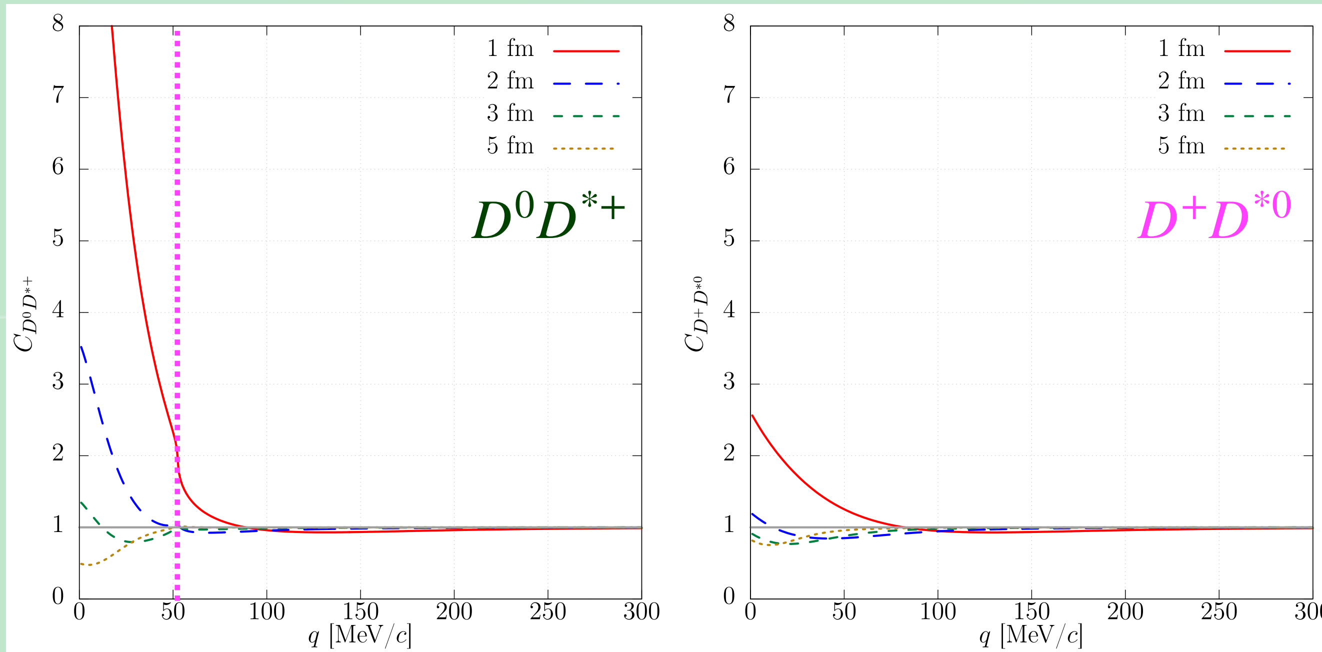
- $X(3872)$ has decay channels

$DD^* \sim T_{cc}$ sector

D^0D^{*+} and D^+D^{*0} correlation functions ($cc\bar{u}\bar{d}$, exotic)

Y. Kamiya, T. Hyodo, A. Ohnishi, EPJA58, 131 (2022)



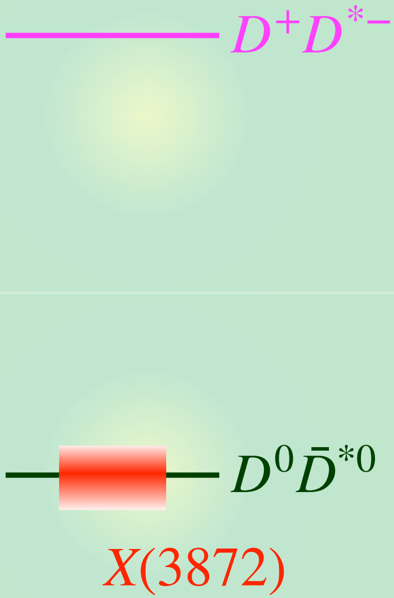


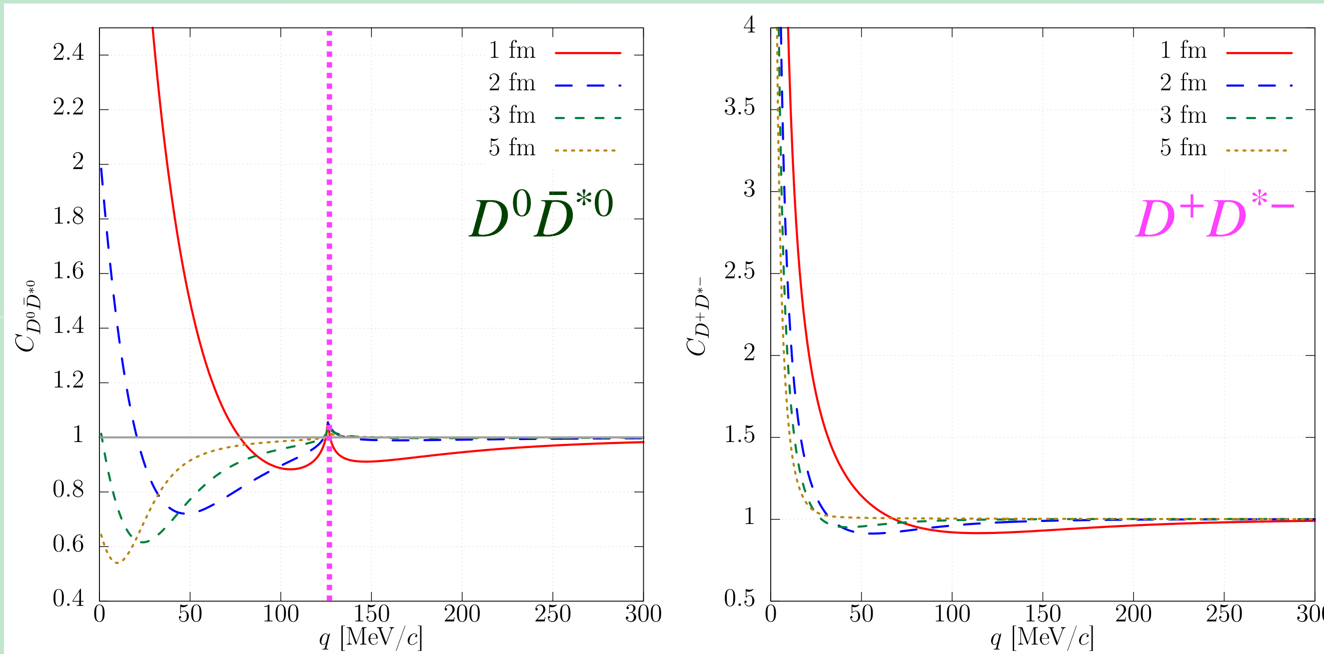
- Bound state feature (source size dep.) in both channels
- Strong signal in D^0D^{*+}, weaker one in D^+D^{*0}
- D^+D^{*0} cusp in D^0D^{*+} ($q \sim 52$ MeV) is not very prominent

$D\bar{D}^* \sim X(3872)$ sector

$D^0\bar{D}^{*0}$ and $D^+\bar{D}^{*-}$ correlation functions ($c\bar{c}q\bar{q}$)

Y. Kamiya, T. Hyodo, A. Ohnishi, EPJA58, 131 (2022)





- Bound state feature in $D^0\bar{D}^{*0}$ correlation
- Sizable D^+D^{*-} cusp in $D^0\bar{D}^{*0}$ ($q \sim 126$ MeV)
- D^+D^{*-} correlation : Coulomb attraction dominance

Summary

- Femtoscopy: novel and useful method to study interactions of exotic hadrons and nuclei
- $\Lambda\alpha$ correlations
  - hint for repulsive core in $\Lambda\alpha$ interaction

  A. Jinno, Y. Kamiya, T. Hyodo, A. Ohnishi, PRC110, 014001 (2024)
- $\Xi\alpha$ correlations
  - existence of bound state

  Y. Kamiya, A. Jinno, T. Hyodo, A. Ohnishi, arXiv:2409.13207 [nucl-th]
- DD^* and $D\bar{D}^*$ correlations
  - (quasi-)bound nature of T_{cc} and $X(3872)$

  Y. Kamiya, T. Hyodo, A. Ohnishi, EPJA58, 131 (2022)

Future prospects

- **New direction: femtoscopy with nuclei**
  - $\Lambda\alpha, \Xi\alpha$ **correlations: J-PARC HI, CBM@GSI,…**

  A. Jinno, Y. Kamiya, T. Hyodo, A. Ohnishi, PRC110, 014001 (2024);
  Y. Kamiya, A. Jinno, T. Hyodo, A. Ohnishi, arXiv:2409.13207 [nucl-th]

- $K^{\pm}\alpha$ **correlation? (in preparation)**
  - **K nuclei, K atoms**
  - **Folding potential, optical potential, …**

- $\Lambda\ {}^3\mathrm{He}, \Xi\ {}^3\mathrm{He}$ **correlations? (in preparation)**
  - **measurable at ALICE?**