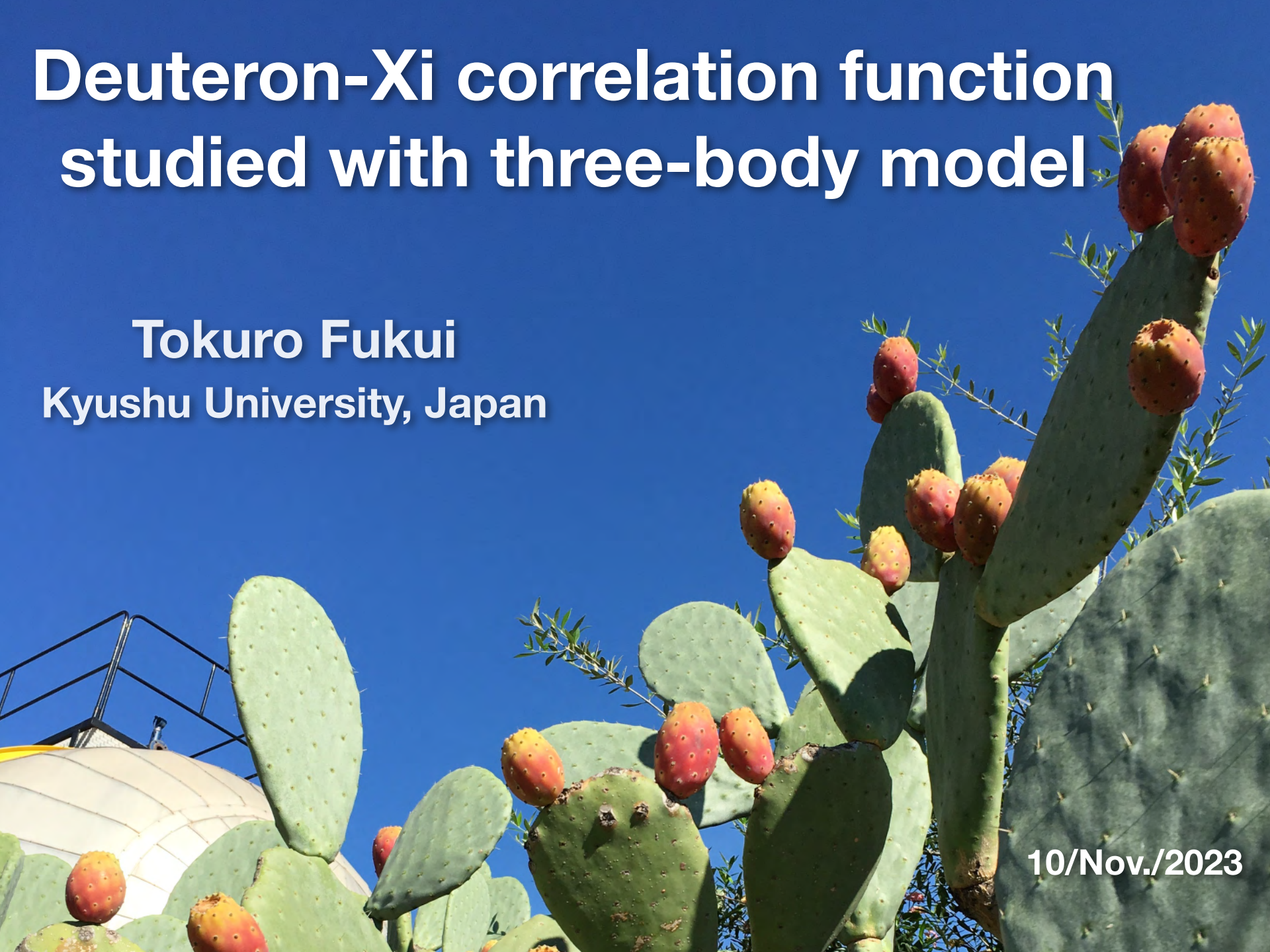
Deuteron-Xi correlation function studied with three-body model

Tokuro Fukui
Kyushu University, Japan

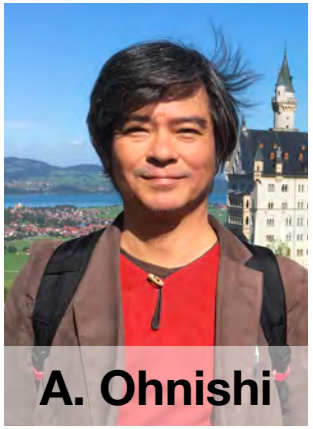


10/Nov./2023

Collaborators | Mourning for Akira Ohnishi


K. Ogata

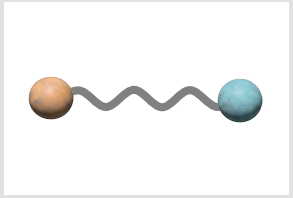

Y. Kamiya


A. Ohnishi

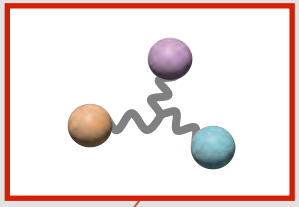
Deceased
1964—2023

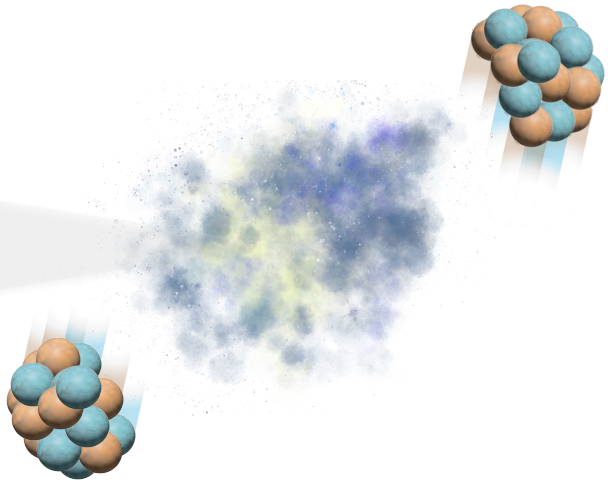
Target | Three-body correlation function

2-baryon force



3-baryon force



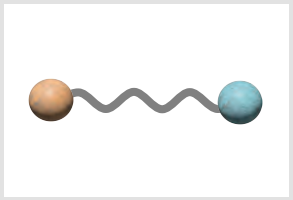


Unresolved!

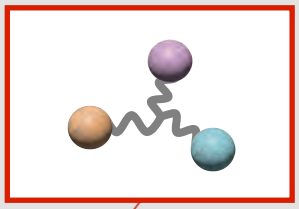
Mechanism?
How strong? How contributes?

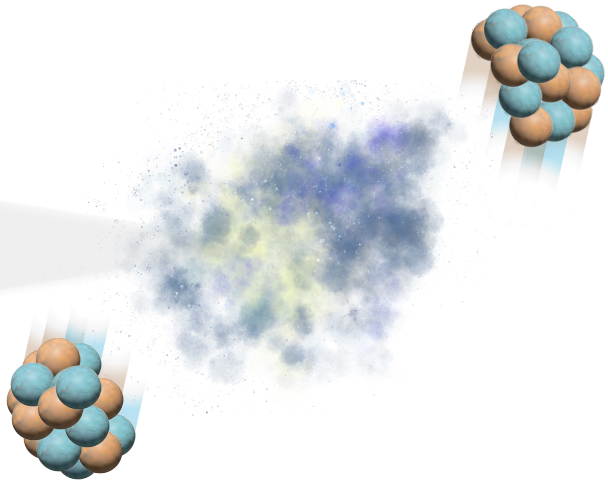
Target | Three-body correlation function

2-baryon force



3-baryon force





Unresolved!

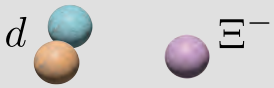
Mechanism?
How strong? How contributes?

Possibly accessible via 3BCF

Need to establish
theoretical framework

This talk

Deuteron dynamical excitation on *d*-Xi CF



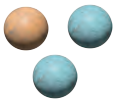
Ogata +, PRC **103,** 065205 (2021)

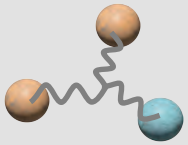
3NF | Few- and many-body systems

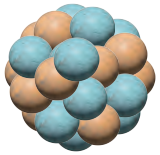
Few-body

3NF

Many-body

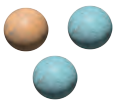


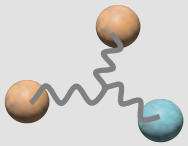


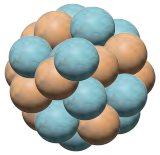


3NF | Few- and many-body systems

Few-body — 3NF — **Many-body**

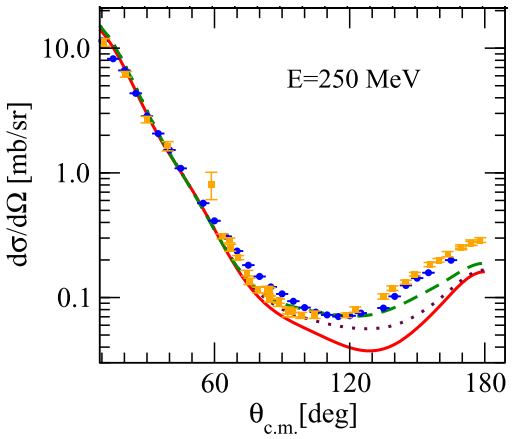


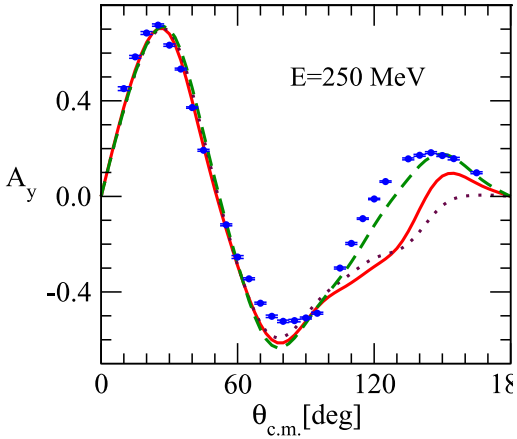




Fundamentals of 3NF

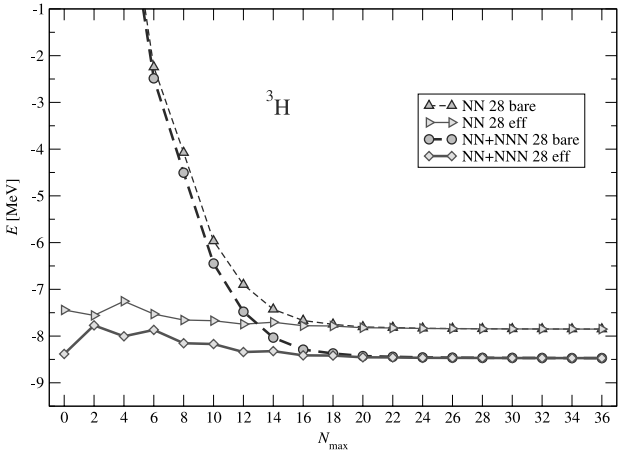
d + *p* scattering





Witała +, PRC **105**, 054004 (2022)

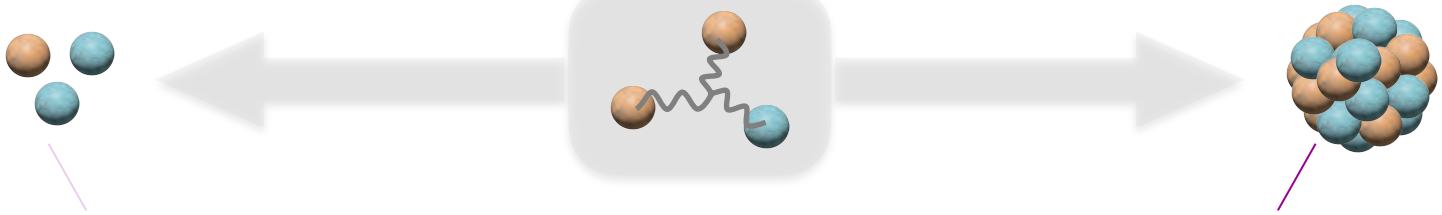
^{3}H/^{3}He structure



Navrátil, FBS **41**, 117 (2007)

3NF | Few- and many-body systems

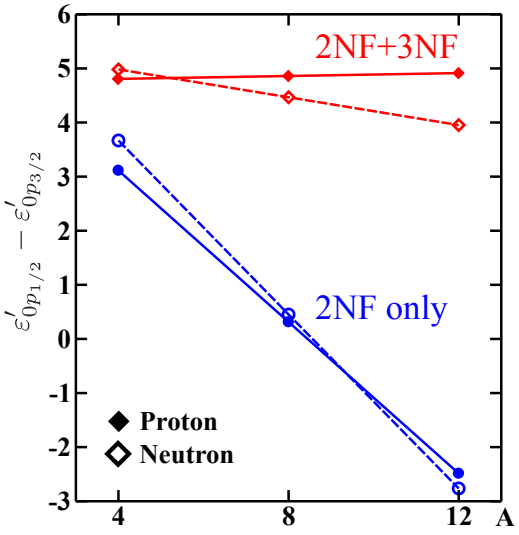
Few-body — 3NF — **Many-body**

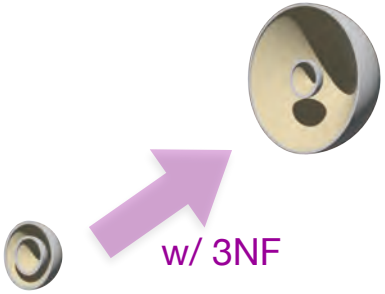


Fundamentals of 3NF

Major playground of 3NF

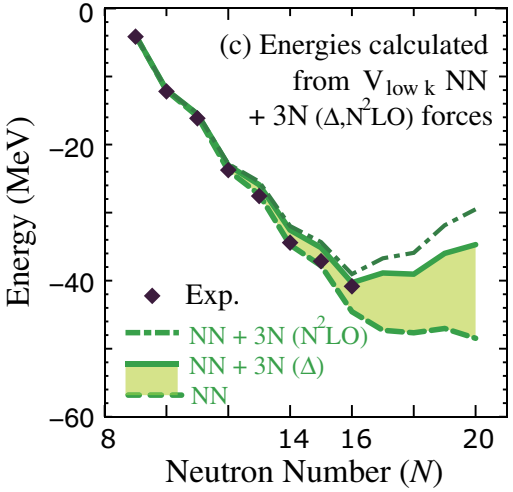
Shell-structure manifestation





Fukui +, PRC **98**, 044305 (2018)

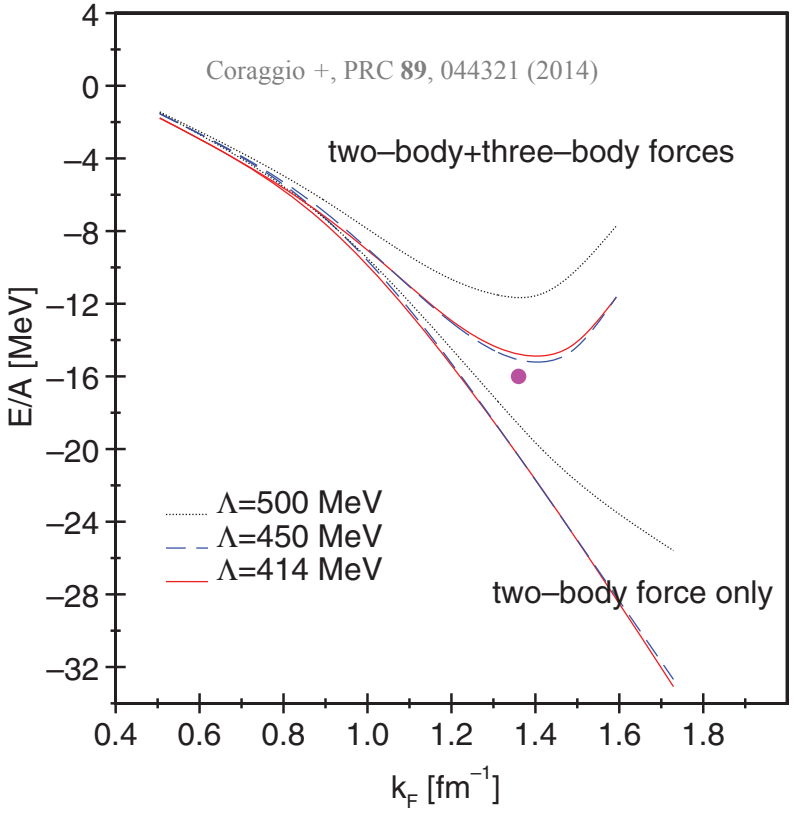
Oxygen-drip line



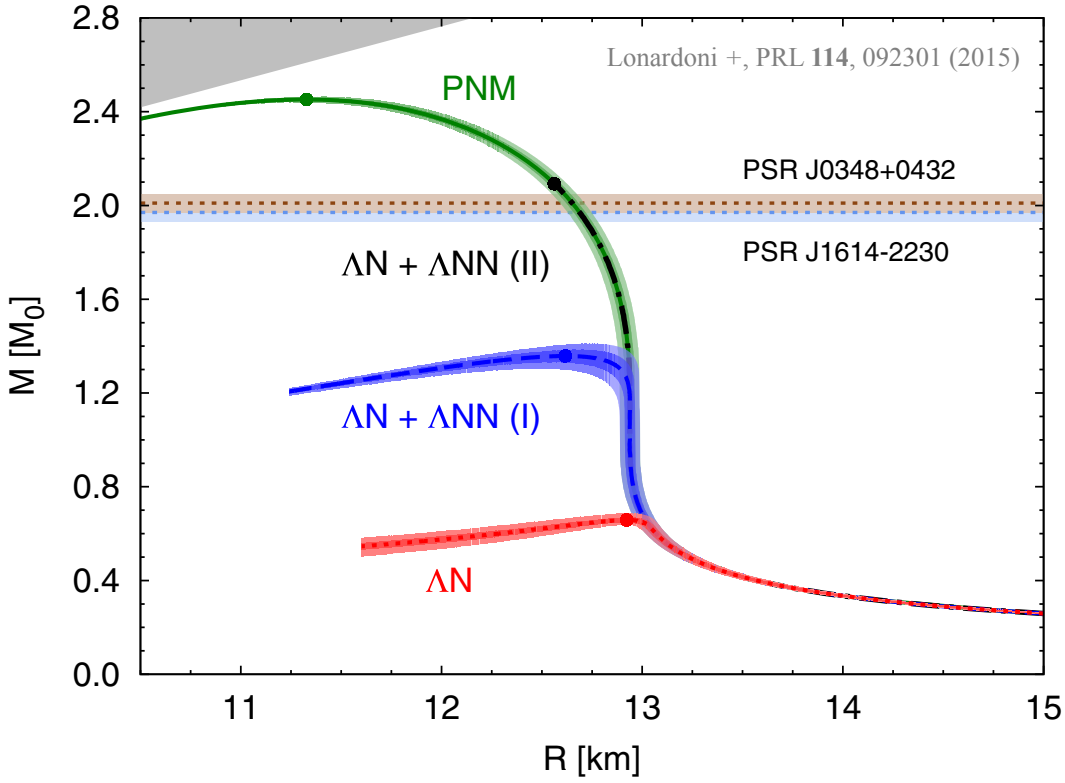
Otsuka +, PRL **105**, 032501 (2010)

3NF → 3BF | Nuclear matter and neutron star

Nuclear matter



Neutron star



3NF necessary for saturation

3-baryon force (ΛNN)
necessary for 2-solar mass

Femtoscopy
and
3-body correlation function

Correlation function | Tool to access strong interaction

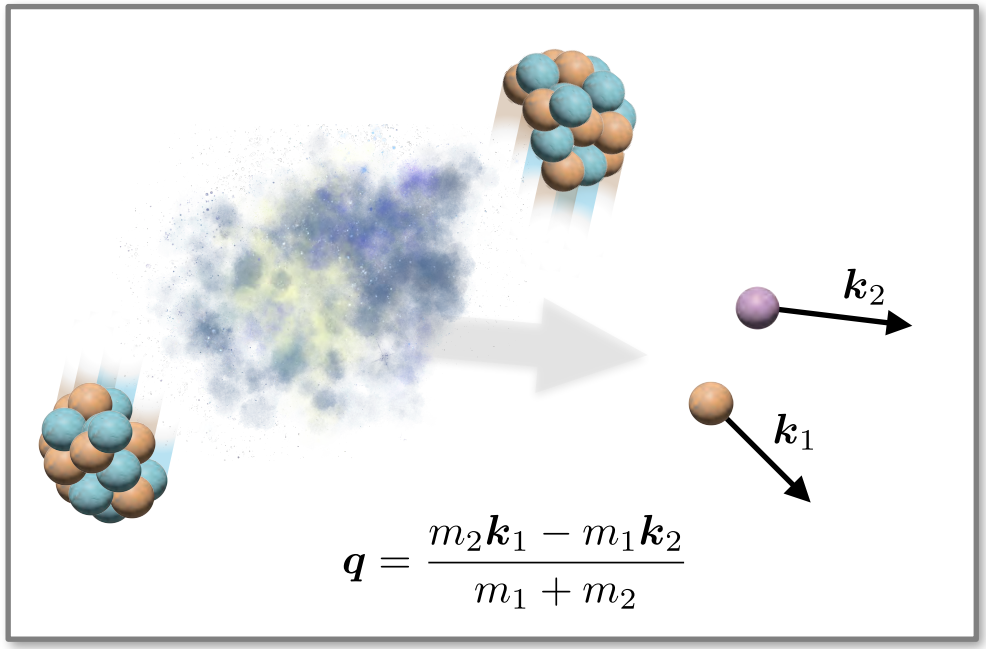
Koonin-Pratt formula

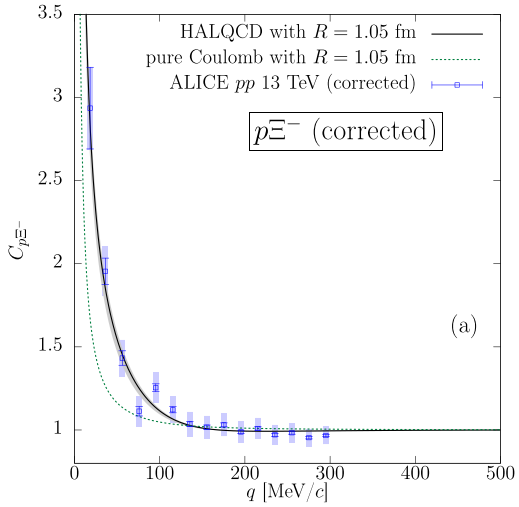
Koonin, PRB **70**, 43 (1977), Pratt, PRD **33**, 1314 (1986)

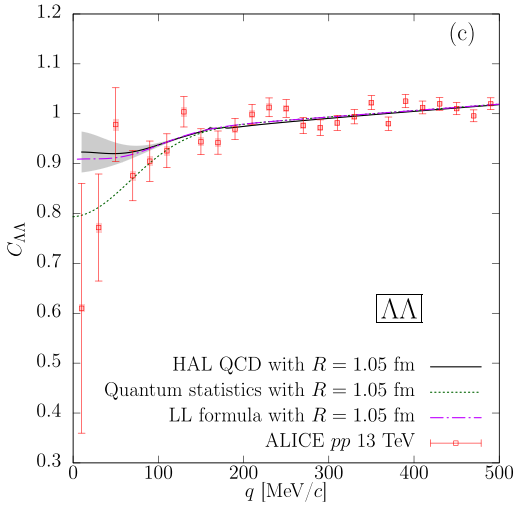
$$C(\boldsymbol{q}) \approx \int d\boldsymbol{r} S(\boldsymbol{r}) \left|\psi^{(-)}(\boldsymbol{q},\boldsymbol{r})\right|^2$$

Source function → Collision detail

Relative wave function → Interaction







Kamiya +, PRC **105**, 014915 (2022)

Correlation function | Relation with interaction

Courtesy of Y. Kamiya

sites.google.com/view/j-parc-hi-evening/

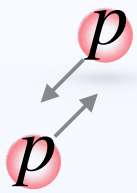
• Attractive interaction

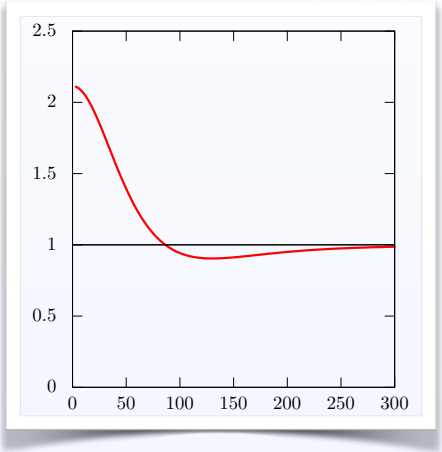
w/ bound state

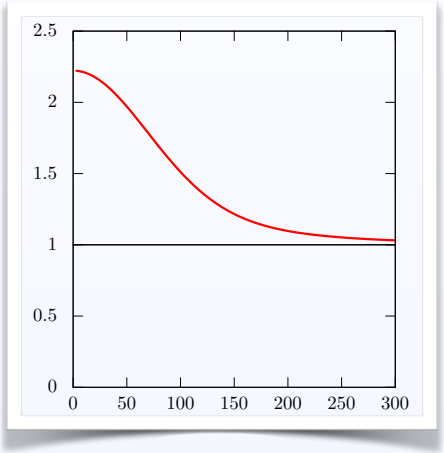
w/o bound state

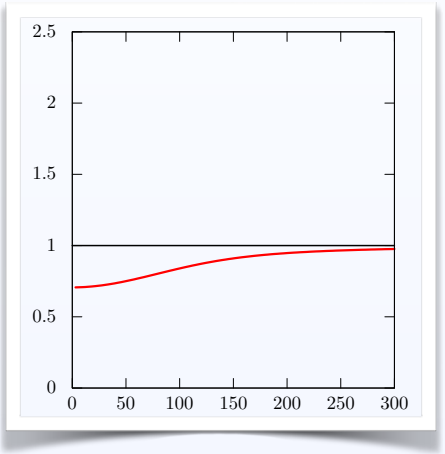
• Repulsive interaction

• Small source

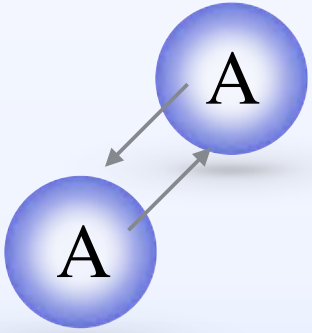


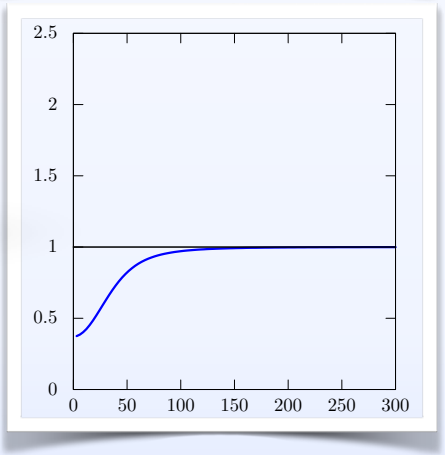


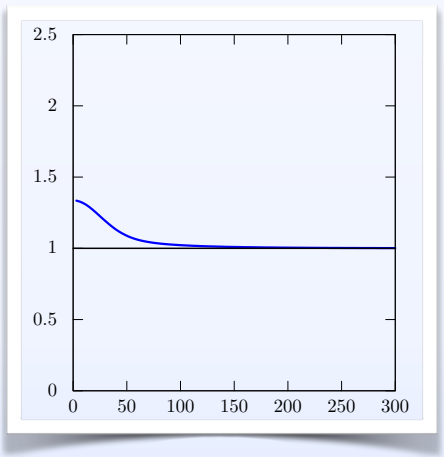


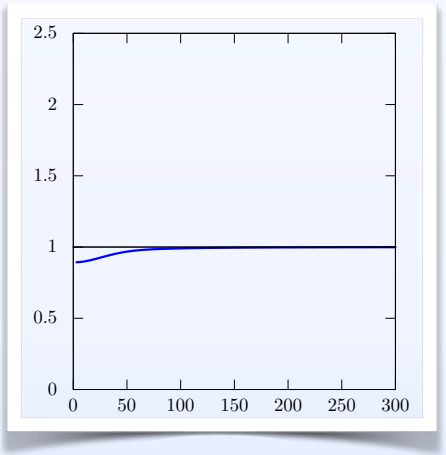


• Large source







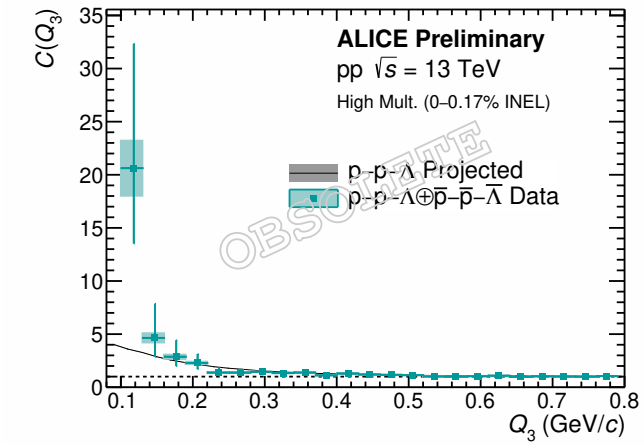


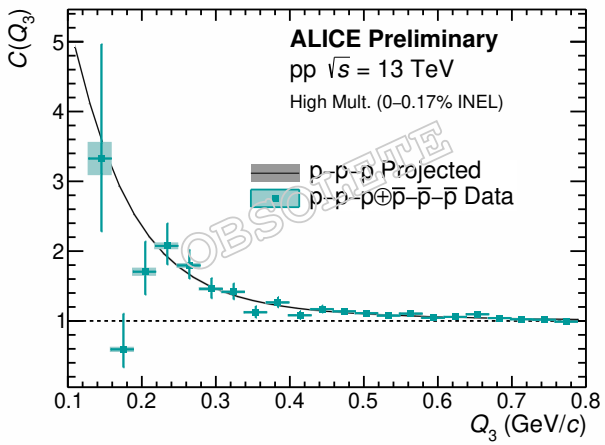
Three-body CFs | Cf. Talk by O. Vázquez Doce

ALICE data

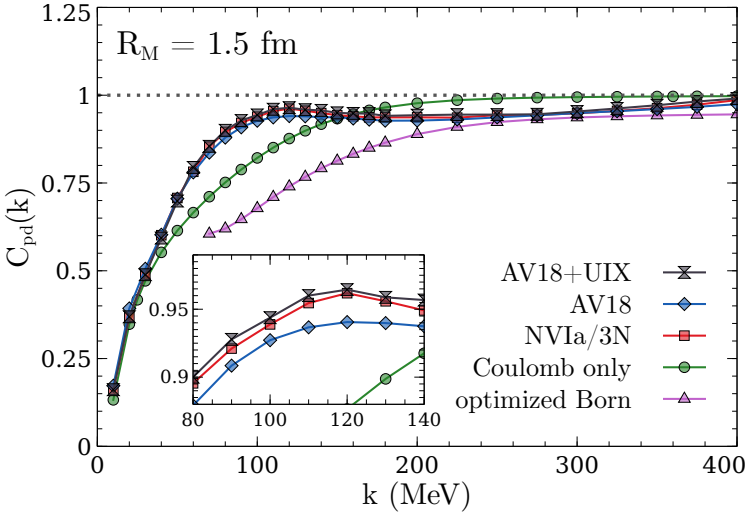
alice-figure.web.cern.ch/node/19641

agenda.infn.it/event/33324/contributions/214457/

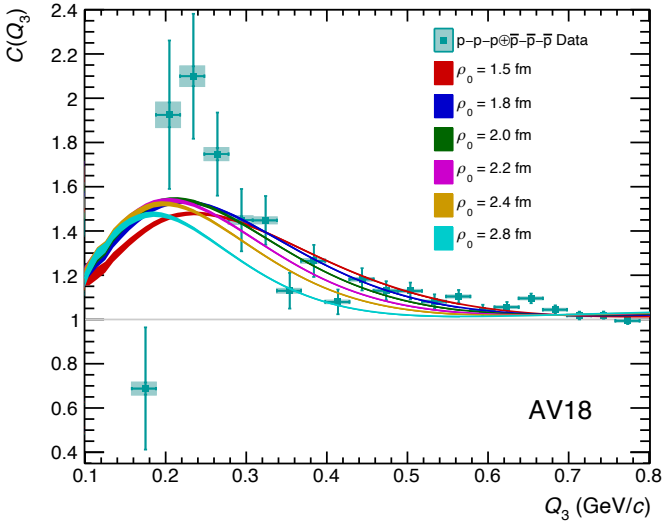




Faddeev/hyperspherical harmonics approaches



Viviani +, arXiv:2306.02478



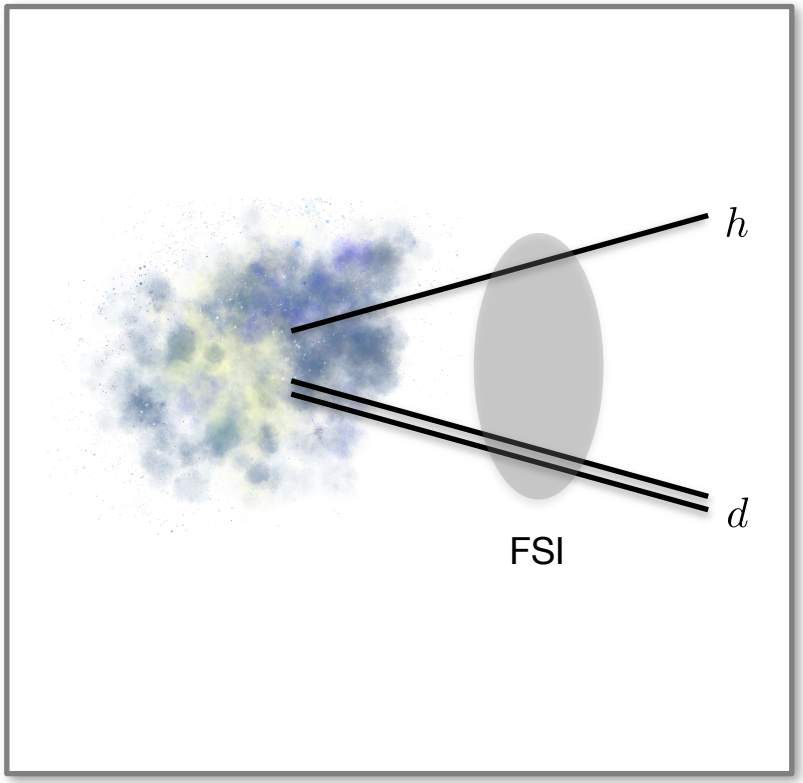
Kievsky +, arXiv:2310.10428

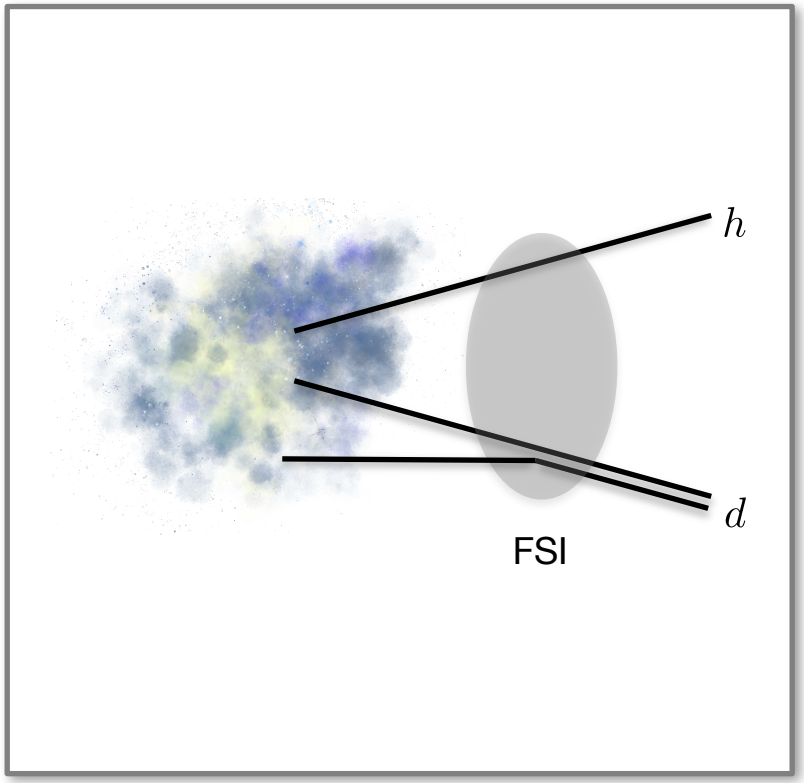
Three-body CFs | Direct production or by final-state int.

Cf. talk of S. Mrówczyński

agenda.infn.it/event/33324/contributions/212739/

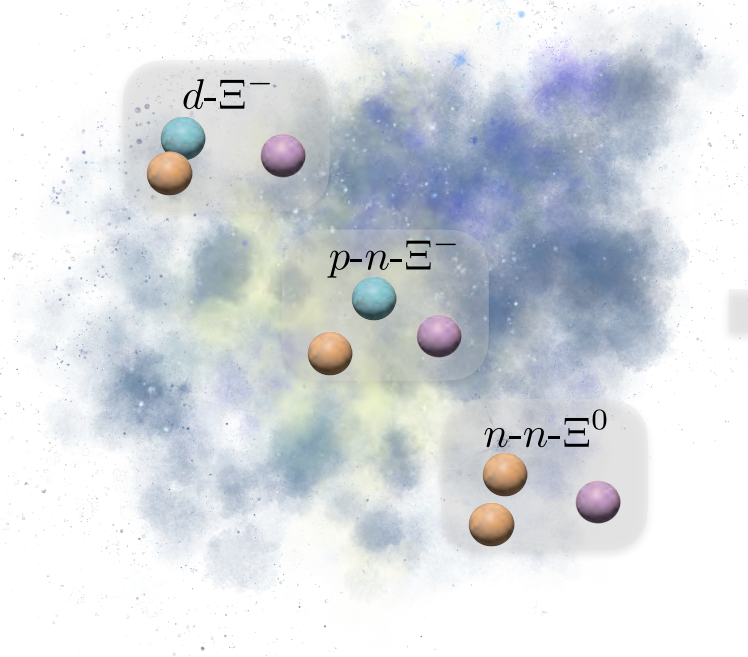
Cf. Mrówczyński & Słoń, APPB **51**, 1739 (2020)



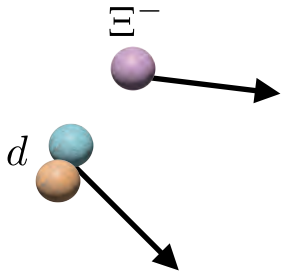


Three-body CFs | Deuteron + Ξ system

Various channels i



Observed channel $i = 0$



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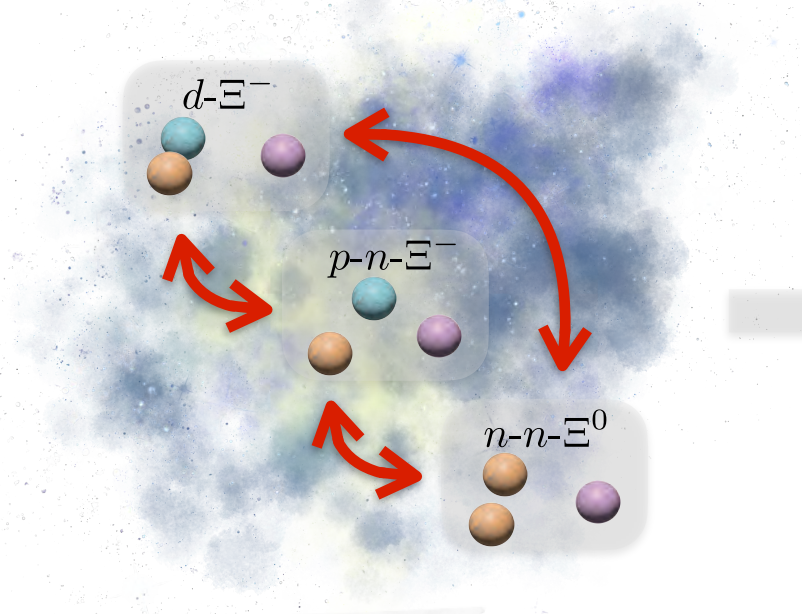
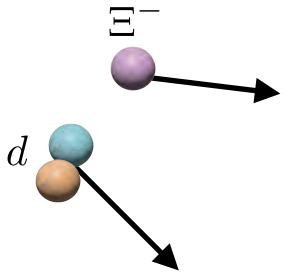


Observed channel $i = 0$



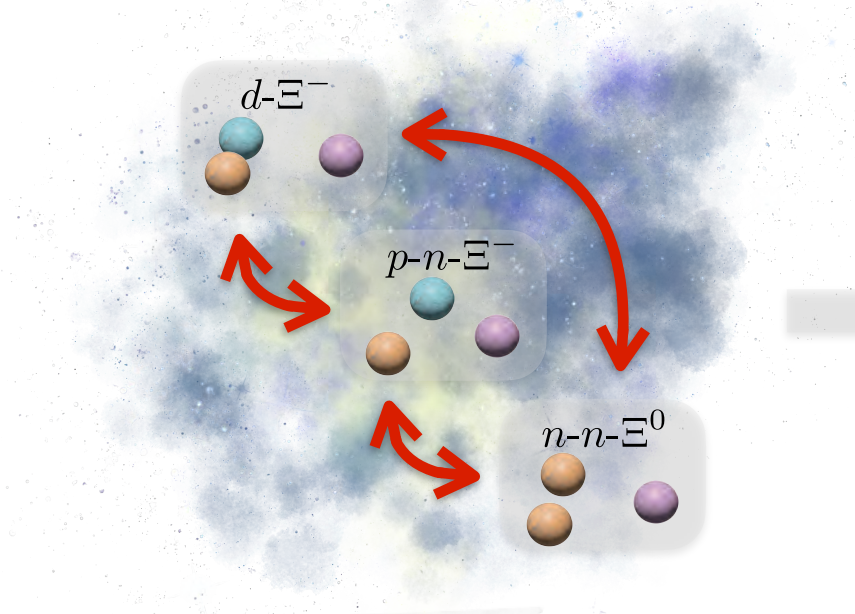
Purpose

Clarify the coupled channel effect
(deuteron dynamical excitation) on *d*-Xi CF

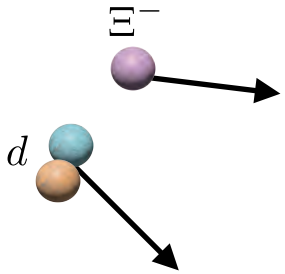
3BF in 3BCF: Future

Three-body CFs | Deuteron + Ξ system

Various channels i



Observed channel $i = 0$



Purpose

Clarify the coupled channel effect
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3BF in 3BCF: Future

- **3B scatt. wave w/ incoming BC**

$$\Psi^{(-)}(\boldsymbol{r}, \boldsymbol{R}) = \sum_i \phi_i(\boldsymbol{r}) \psi_{i0}^{(-)}(\boldsymbol{R})$$

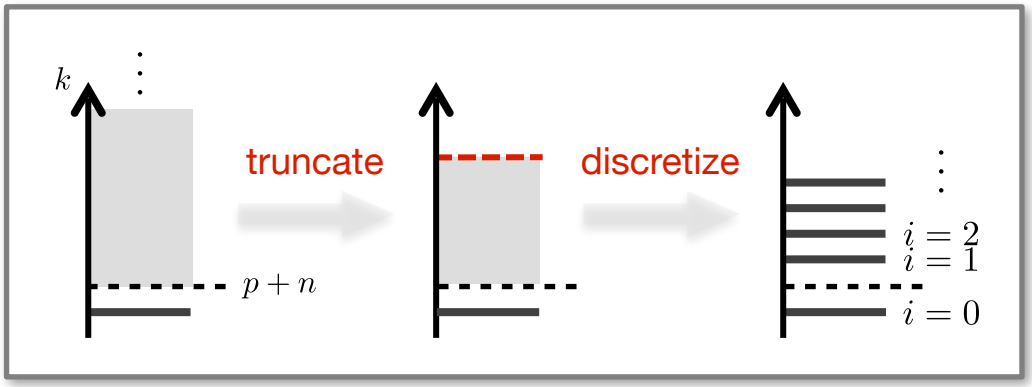
NN w.f. (*NN*)-Ξ w.f.

- **3BCF**

$$C(\boldsymbol{q}) \approx \sum_i \int d\boldsymbol{R} S_i(\boldsymbol{R}) \left| \psi_{i0}^{(-)}(\boldsymbol{R}) \right|^2$$

Continuum discretized coupled channels (CDCC)

Deuteron discretized continuum states

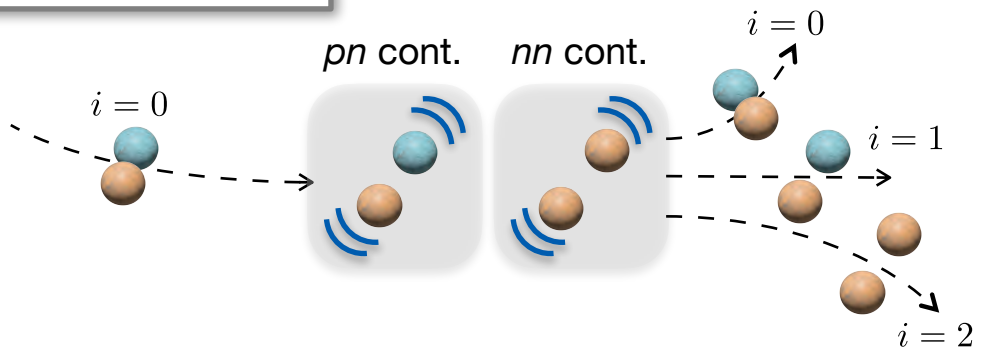


Precise & economical

Kamimura +, PTPS **89**, 1 (1986)
Austern +, PR **154**, 125 (1987)
Yahiro +, PTEP **2012**, 01A209 (2012)

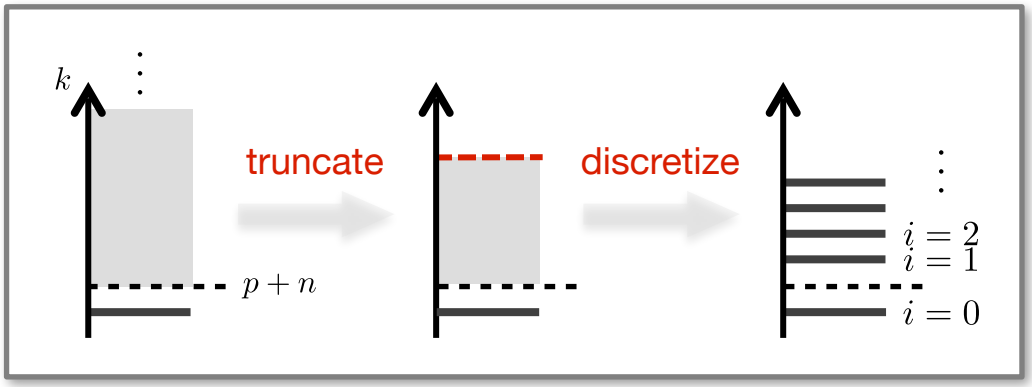
$$\Psi^{(+)}(\boldsymbol{r},\boldsymbol{R}) = \sum_i \phi_i(\boldsymbol{r})\psi_{i0}^{(+)}(\boldsymbol{R})$$

Solution of Sch. Eq.



Continuum discretized coupled channels (CDCC)

Deuteron discretized continuum states



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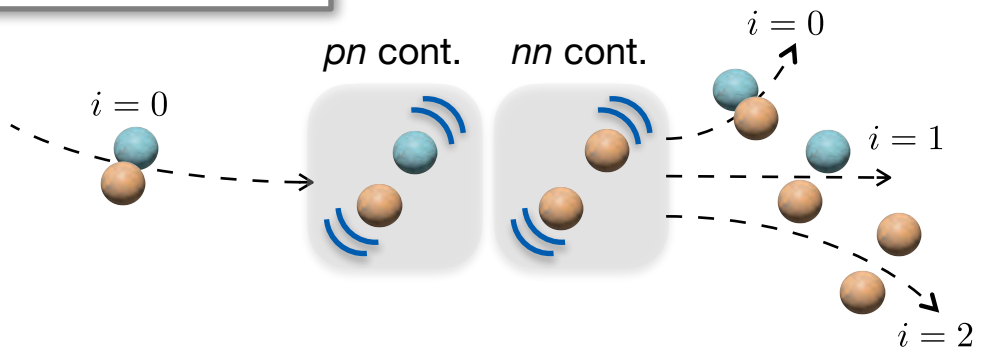
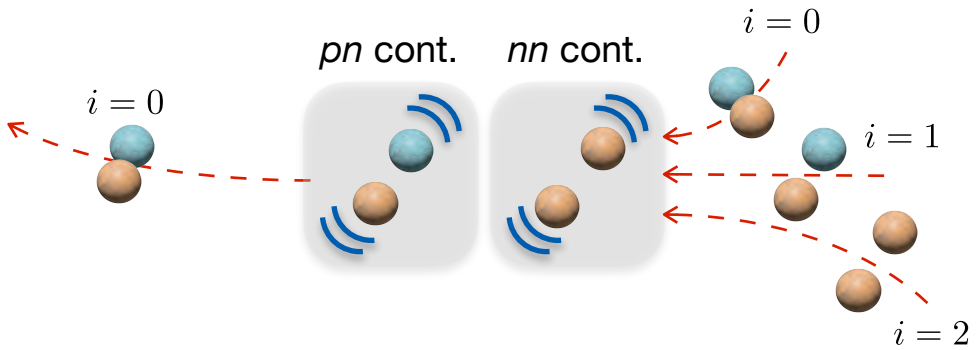
$$\Psi^{(+)}(\boldsymbol{r},\boldsymbol{R}) = \sum_i \phi_i(\boldsymbol{r})\psi_{i0}^{(+)}(\boldsymbol{R})$$

Solution of Sch. Eq.

Time reversal

$$\Psi^{(-)}(\boldsymbol{r},\boldsymbol{R}) = \sum_i \phi_i(\boldsymbol{r})\psi_{i0}^{(-)}(\boldsymbol{R})$$



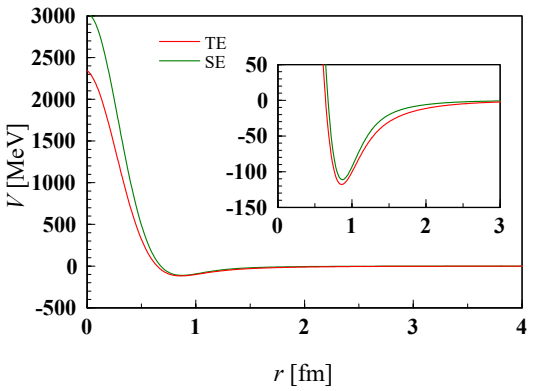


Numerical detail

Spin-isospin dependent interactions

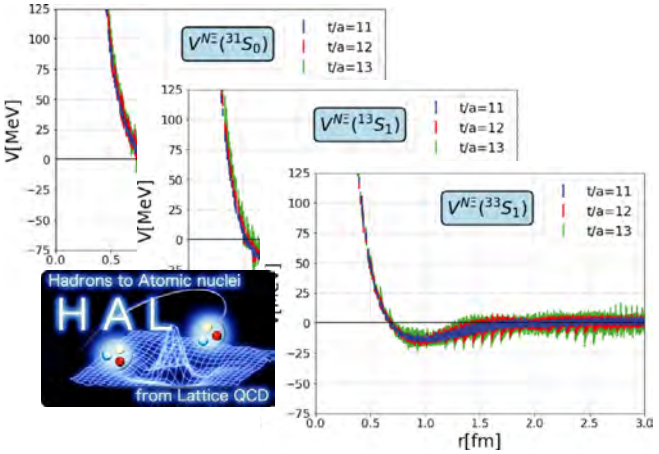
Ogata +, PRC **103,** 065205 (2021)

AV4'

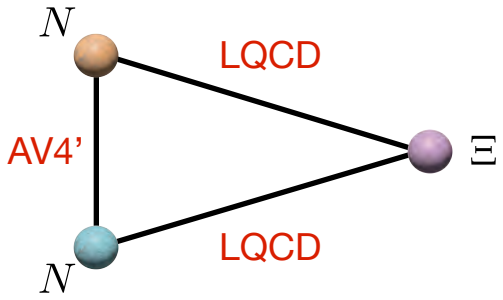


Wiringa & Pieper, PRL **89**, 182501 (2002)

Lattice QCD potential

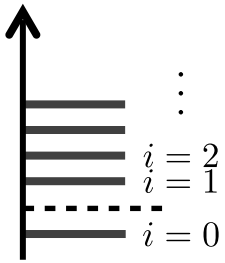


Sasaki +, NPA **998**, 121737 (2020)



No 3BF at the moment…

Discretized states



Up to 166 MeV

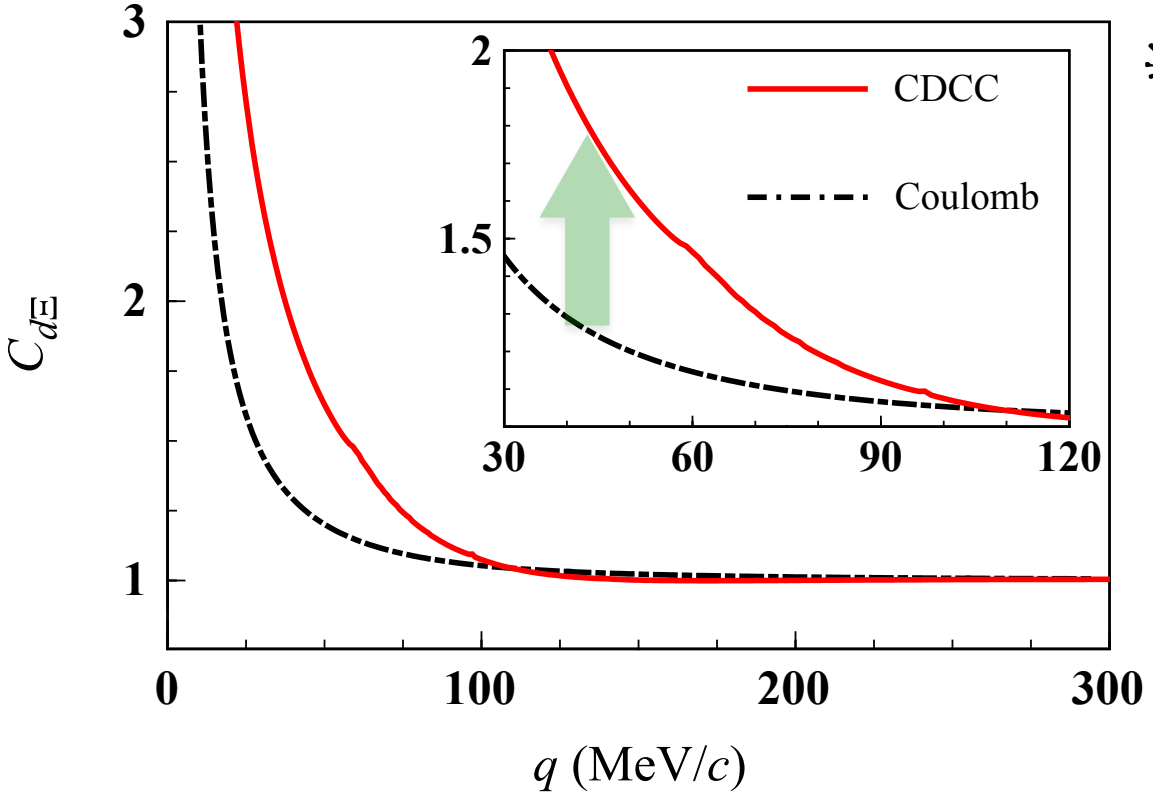
411 channels

Limitations

- Single-ch. 2-body source func. (Gaussian)
- Coulomb int. in all isospin channels
- s-wave only (all subsystems)
- Isospin symmetry for baryon masses
- No rearrangement channels

Deuteron + Ξ CF

Ogata +, PRC **103,** 065205 (2021)

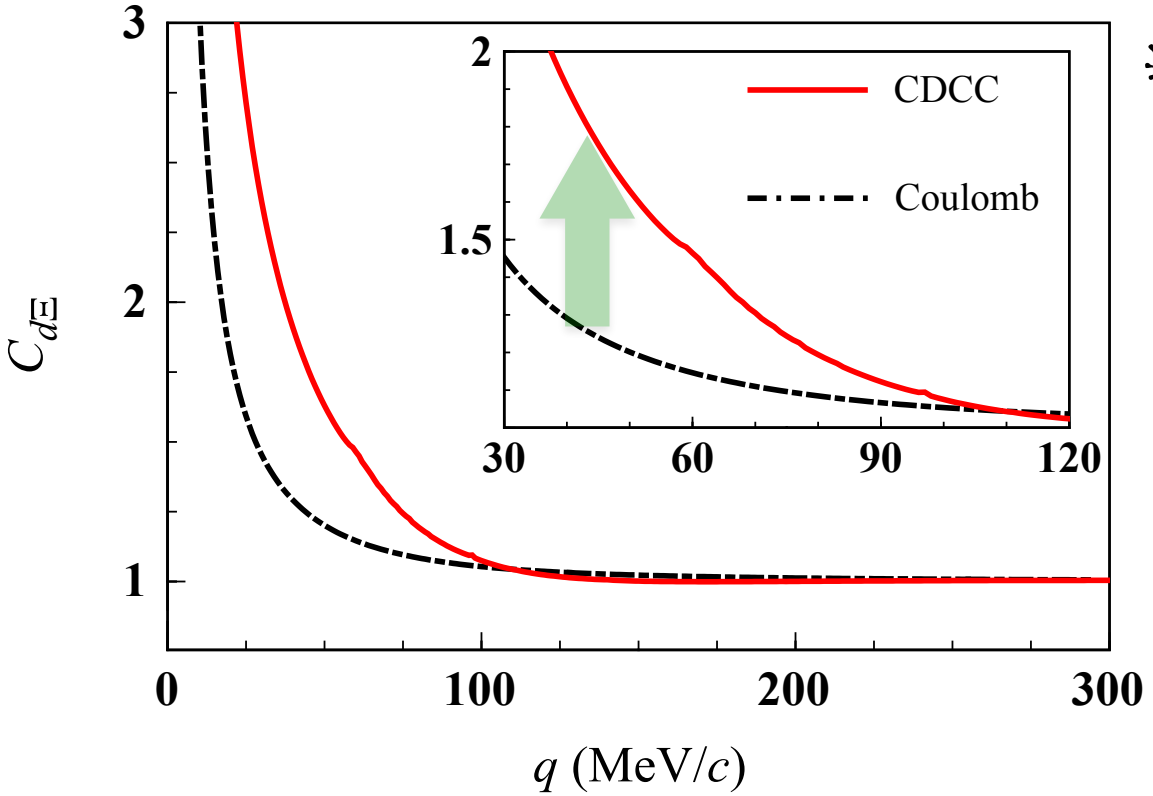


- Enhancement by strong int.
  - → Attractive d-Ξ^- interaction
    (No bound state)

Source size: 1.2 fm

Deuteron + Ξ CF

Ogata +, PRC **103,** 065205 (2021)

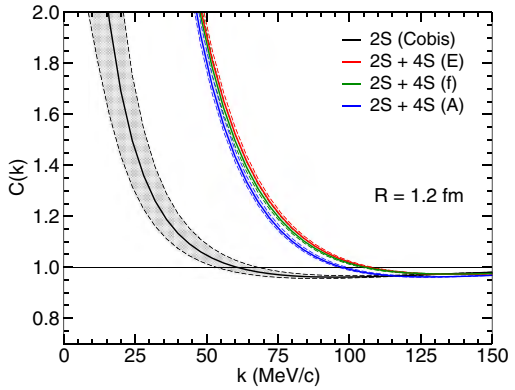


Source size: 1.2 fm

- Enhancement by strong int.
  - → Attractive d-Ξ^- interaction
    (No bound state)

Consistent

Attractive d-Λ int.



Lednicky-Lyuboshits approach
w/ effective range expansion

Haidenbauer, PRC **102**, 034001 (2020)

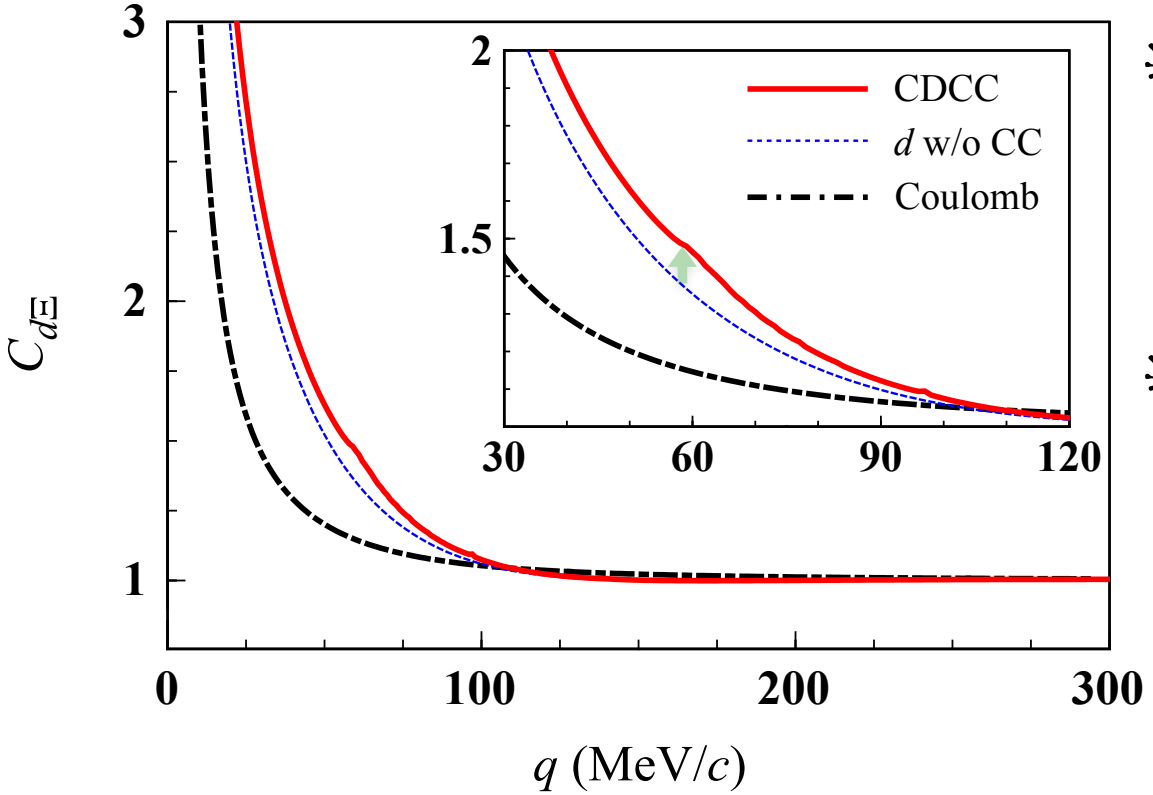
Cf. Talk by Z. Qin

agenda.infn.it/event/33324/contributions/213169/

No CC effect studied

Deuteron + Ξ CF

Ogata +, PRC **103,** 065205 (2021)

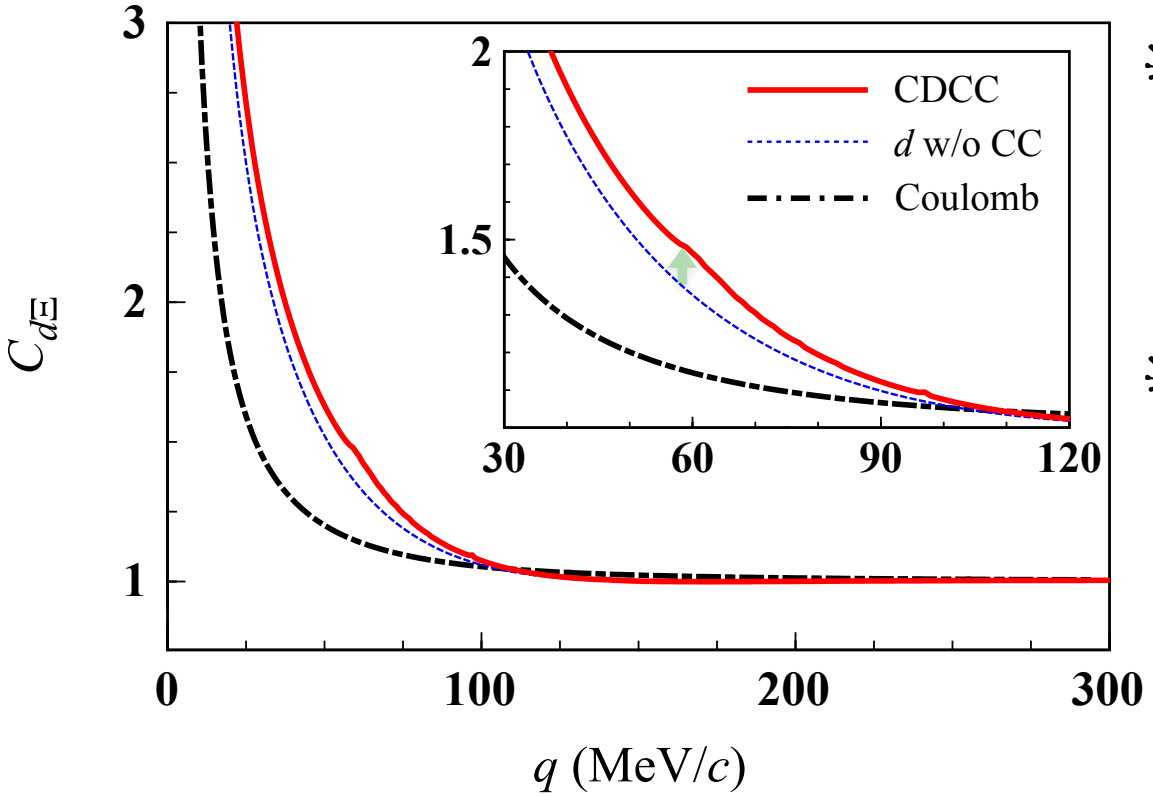


- Enhancement by strong int.
  → Attractive d-Ξ^- interaction
  (No bound state)
- Coupled-channel effect:
  Slight enhancement (6—8%)

Source size: 1.2 fm

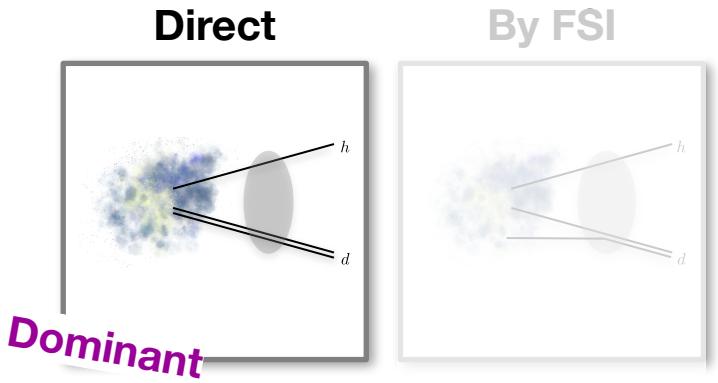
Deuteron + Ξ CF

Ogata +, PRC **103,** 065205 (2021)



- Enhancement by strong int.
  → Attractive d-Ξ^- interaction
  (No bound state)
- Coupled-channel effect:
  Slight enhancement (6—8%)

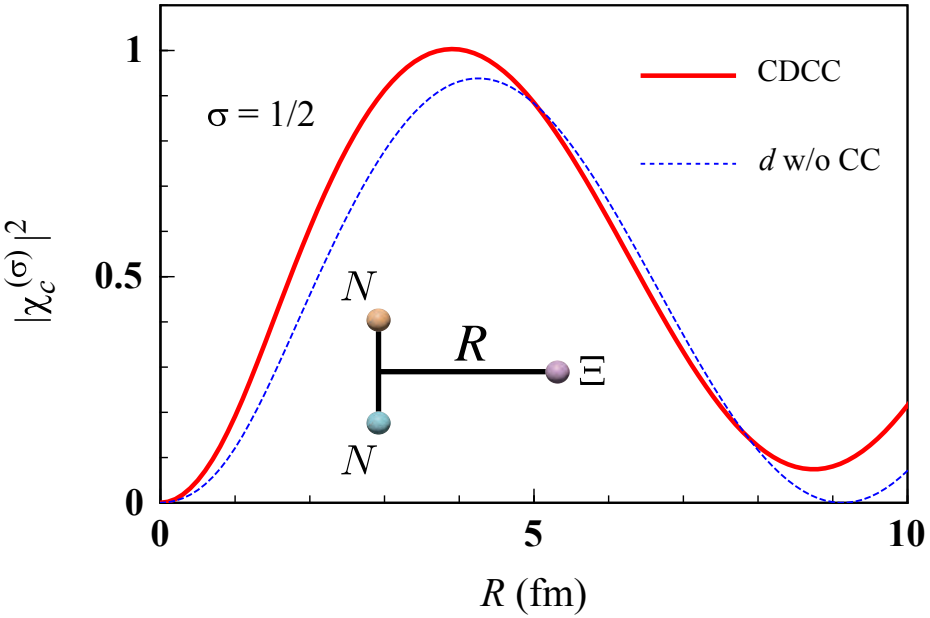
Source size: 1.2 fm

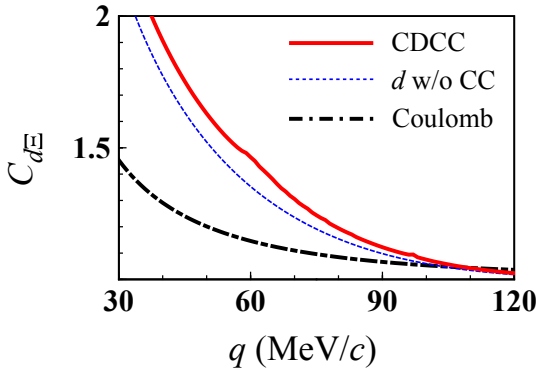


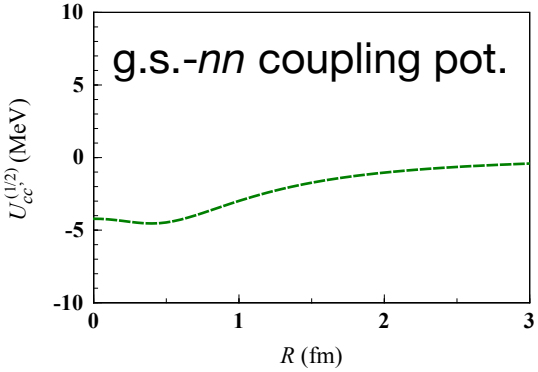
Coupled channel effect | Additional attractive role

Ogata +, PRC **103,** 065205 (2021)

NN-Ξ distorted wave (q = 60 MeV/c)



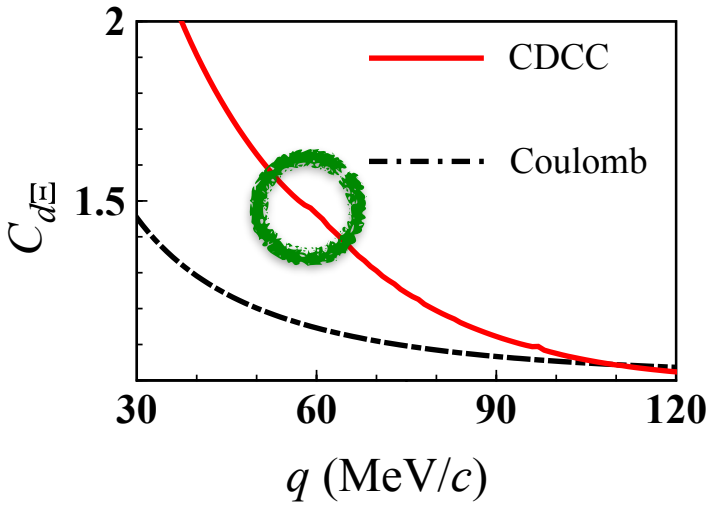




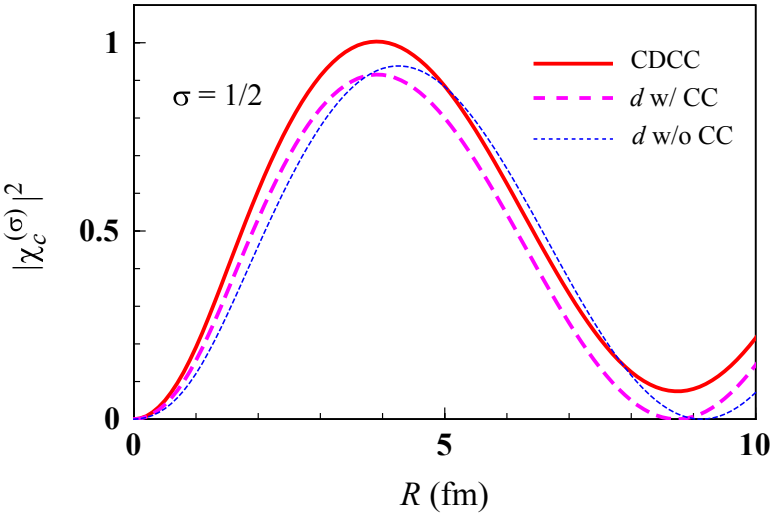
***nn* continua: Important**

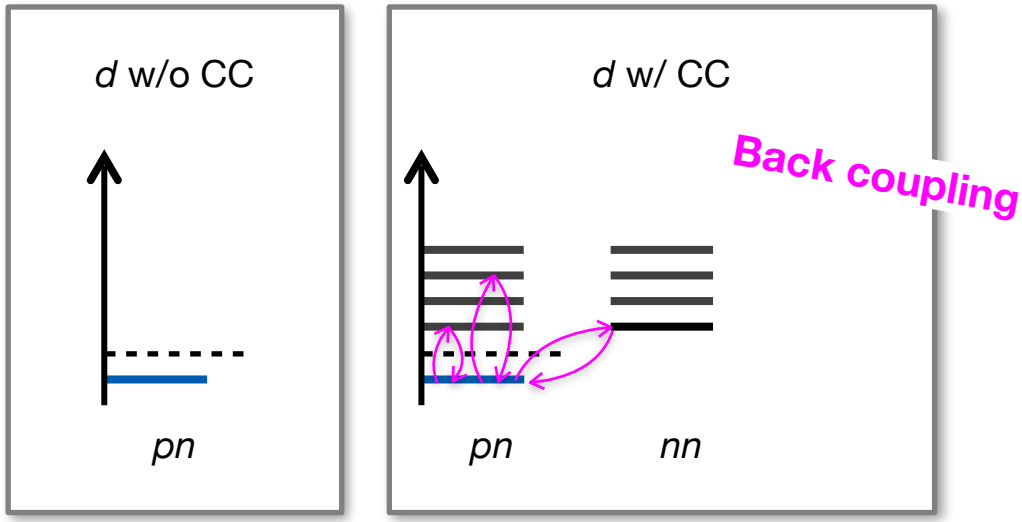
Coupled channel effect | Back coupling & *nn* continua

Bump around $q = 60$ MeV/*c*



***NN*-Ξ distorted wave ($q = 60$ MeV/*c*)**

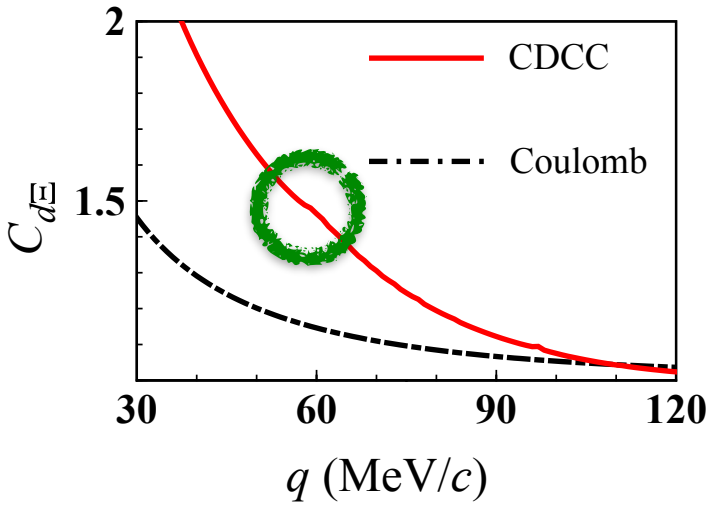




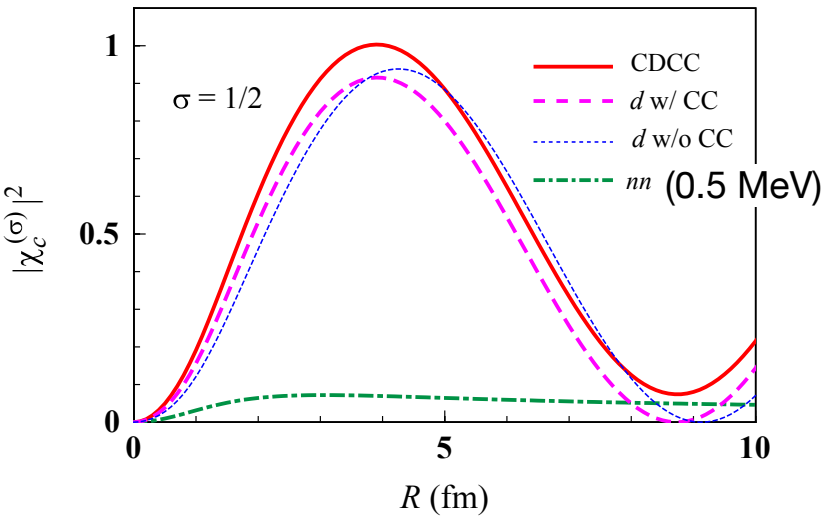
Ogata +, PRC **103,** 065205 (2021)

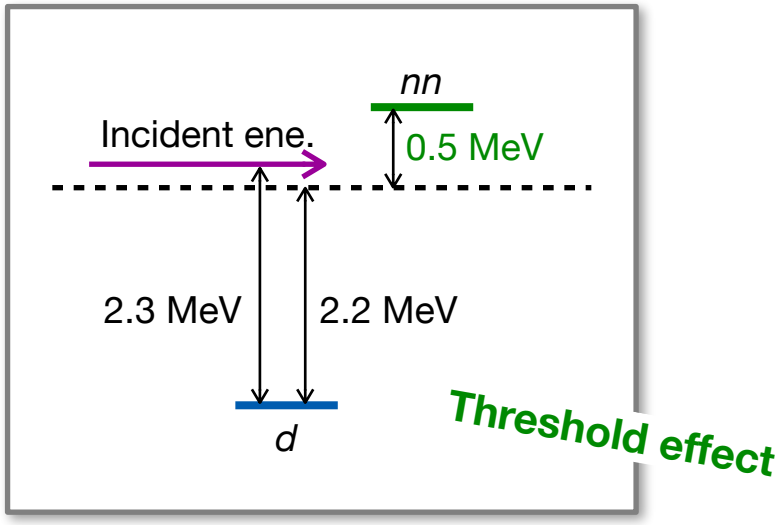
Coupled channel effect | Back coupling & *nn* continua

Bump around $q = 60$ MeV/*c*

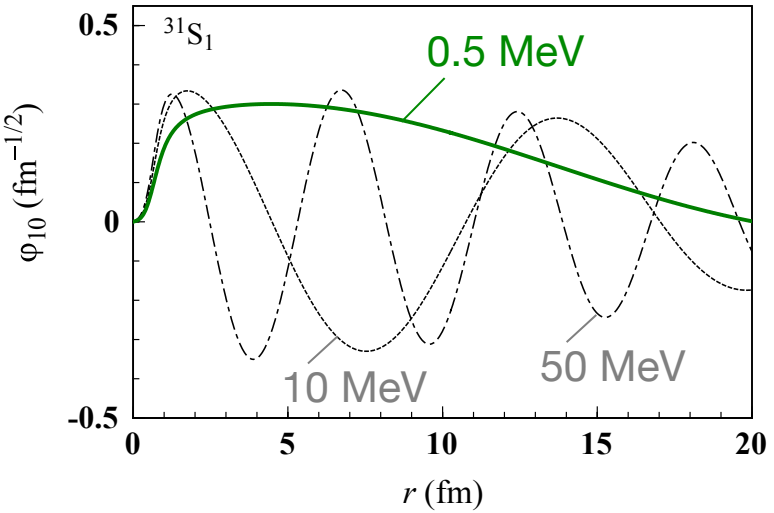


***NN*-Ξ distorted wave ($q = 60$ MeV/*c*)**





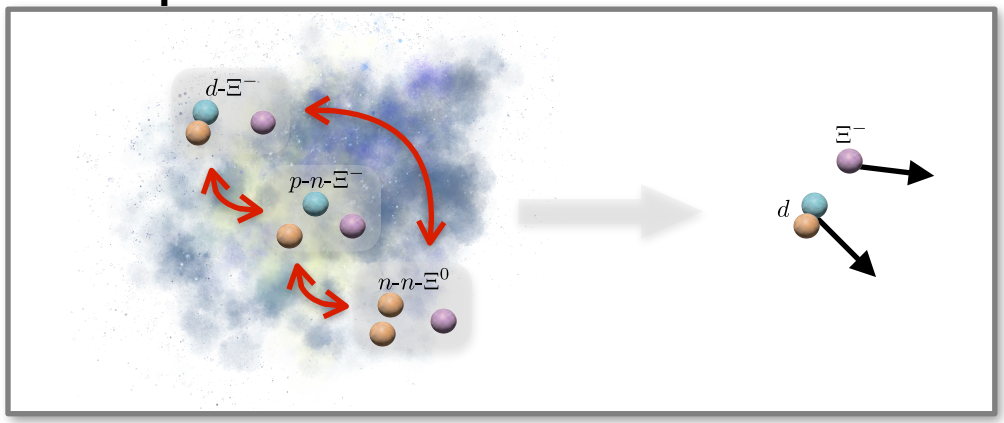
***nn* wave function**



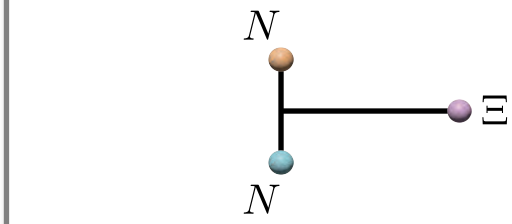
Ogata +, PRC **103,** 065205 (2021)

Summary

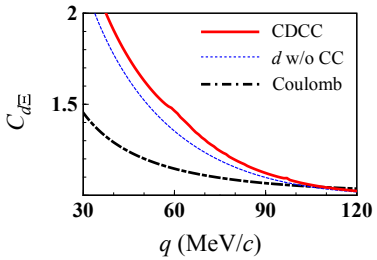
Coupled channel effect on deuteron-Ξ CF



3-body model (CDCC)



Main findings



- Attractive *d*-Ξ int. but no bound state
- CC effect: $\lesssim 10\,\%$
- Deuteron-direct prod.: Dominant

Future

- Application to other 3BCFs
- Improve calculations
  - Source function
  - $N\Lambda\Lambda$ channel
  - Coulomb interaction, etc.
- 3-baryon force