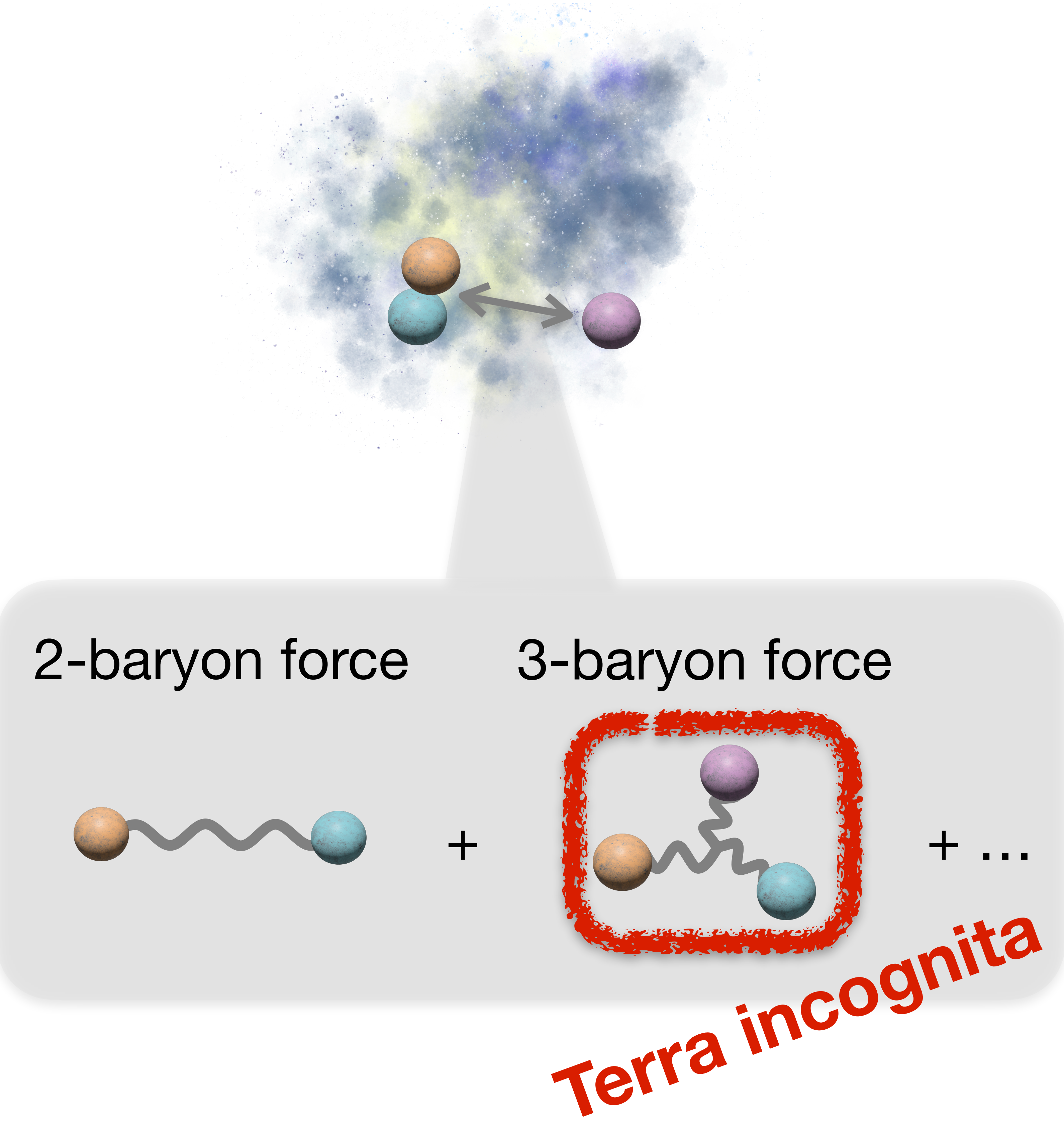
重陽子-Ξ^-散乱における ΞNN 三体バリオン力の効果

Gen Uratsu (M2)
at the Helm

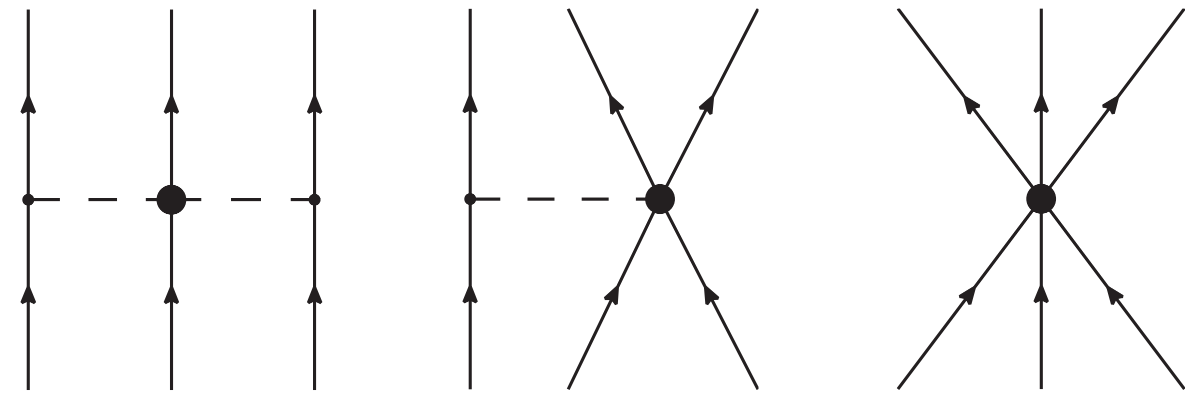
Key takeaways | Three-baryon force and femtoscopic study

Target

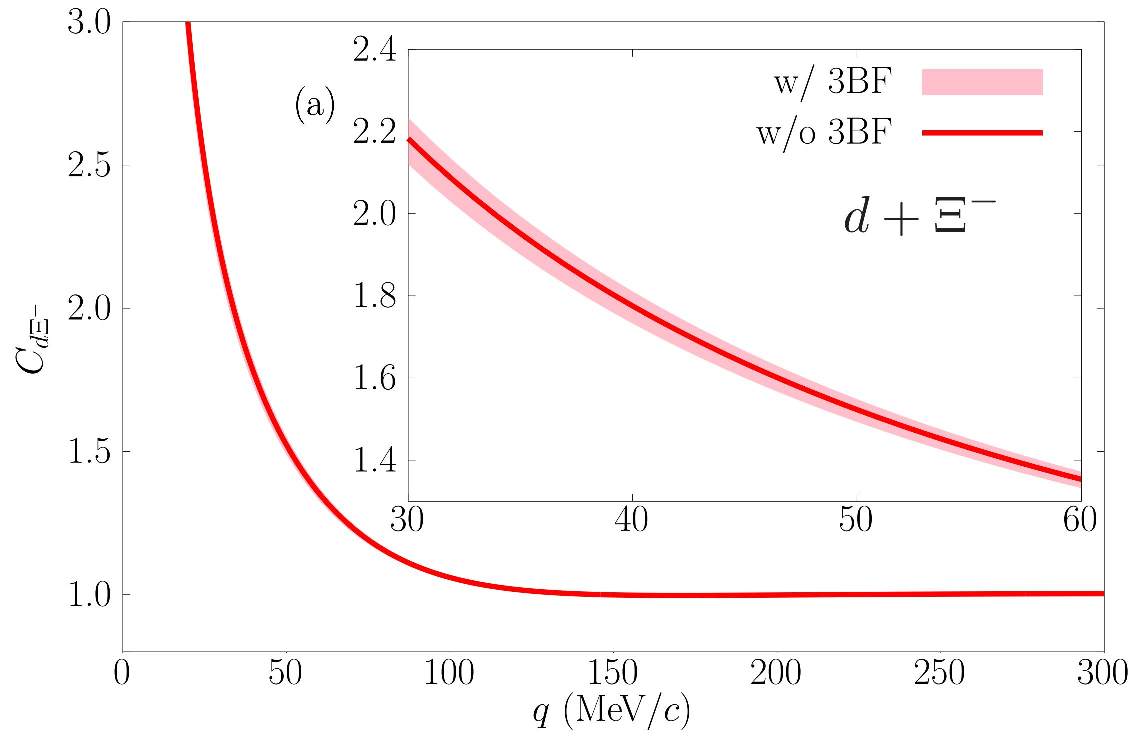


Main message

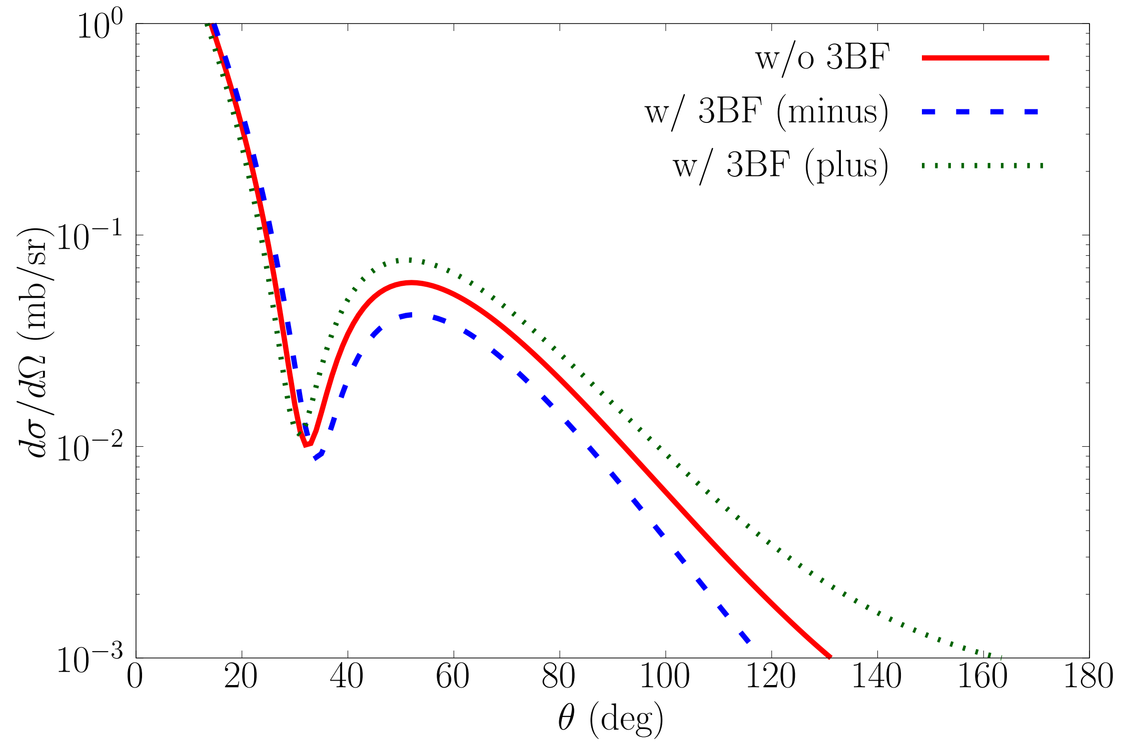
ΞNN 3BFs:
Derived from SU(3) chiral EFT



Correlation functions:
Very limited sensitivity to 3BFs



Elastic cross sections:
Possibly visible 3BF effect



Uratsu +, PRC **113**, 015204 (2026)

ΛNN 3BFs | Light hyper nuclei

Benchmark calculations

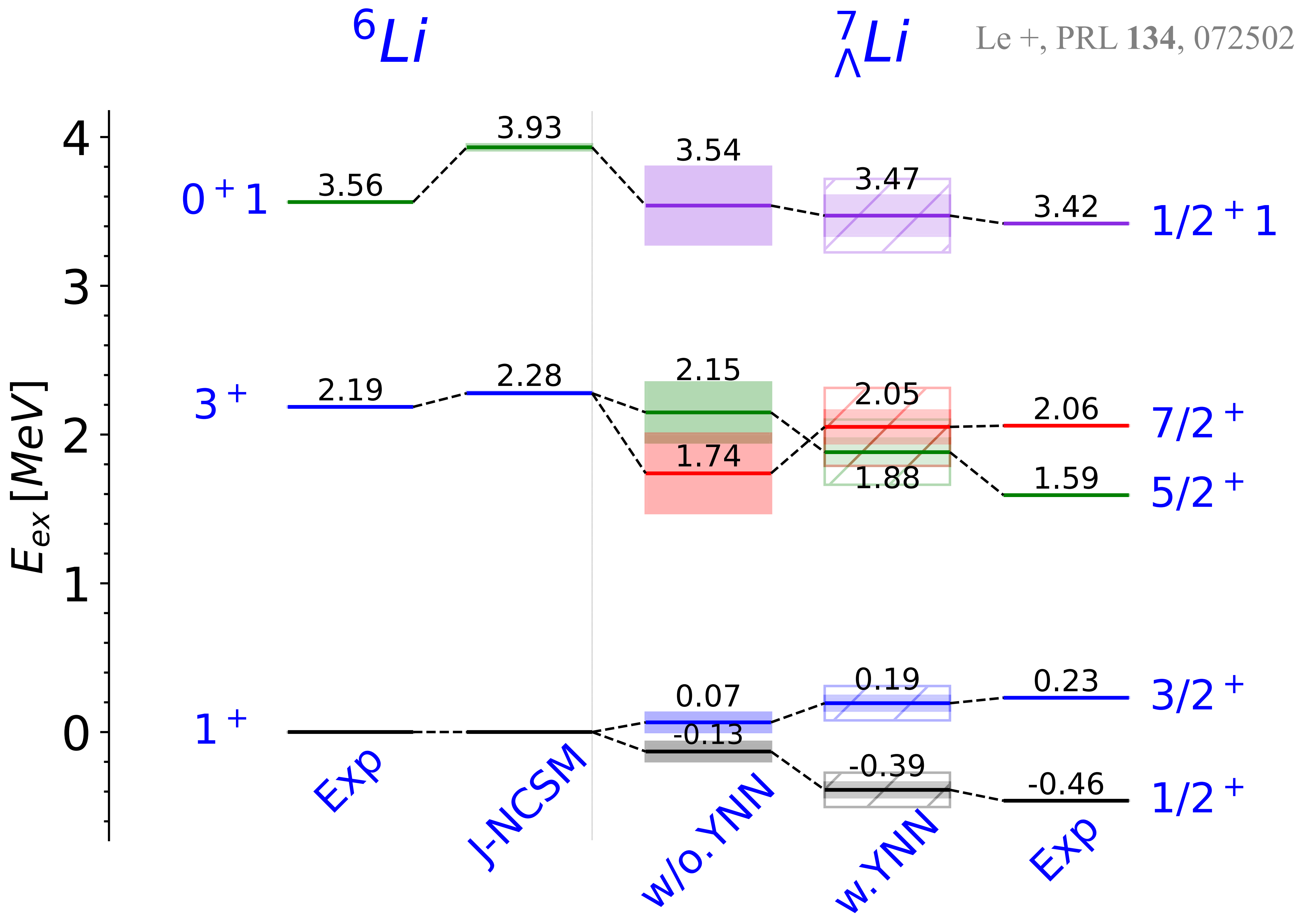
Le +, EPJA **61**, 21 (2025)

		w/o ΛNN	w. 2π-ex ΛNN	w. 1π-ex ΛNN	w. ct ΛNN	Exp. [52]
NCSM	$^{3}_{\Lambda}$H	0.080 ± 0.006	0.153 ± 0.004	0.121 ± 0.005	0.076 ± 0.007	0.164 ± 0.043
FY		0.087	0.152	0.129	0.080	
NCSM	$^{4}_{\Lambda}$He(0^+)	1.432 ± 0.010	1.810 ± 0.006	1.619 ± 0.007	1.400 ± 0.010	2.347 ± 0.036
	$^{4}_{\Lambda}$He(1^+)	1.164 ± 0.014	1.744 ± 0.007	1.427 ± 0.009	1.117 ± 0.016	0.942 ± 0.036
	$^{5}_{\Lambda}$He	3.174 ± 0.020	4.618 ± 0.011	3.757 ± 0.034	2.961 ± 0.031	3.102 ± 0.030

- Sizable 3BF effect
- ΛNN 3BFs from chiral EFT

No-core shell model

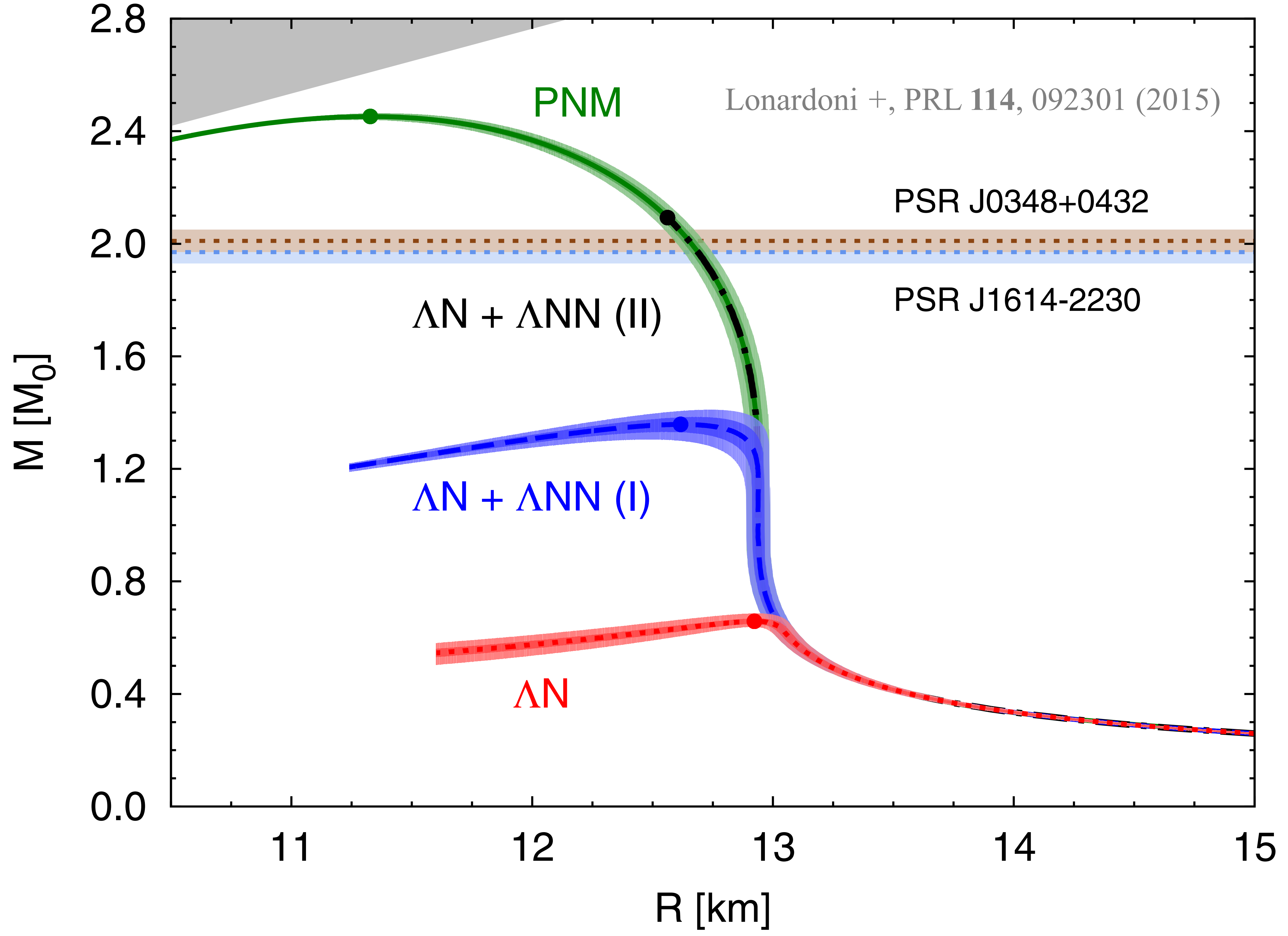
Le +, PRL **134**, 072502 (2025)



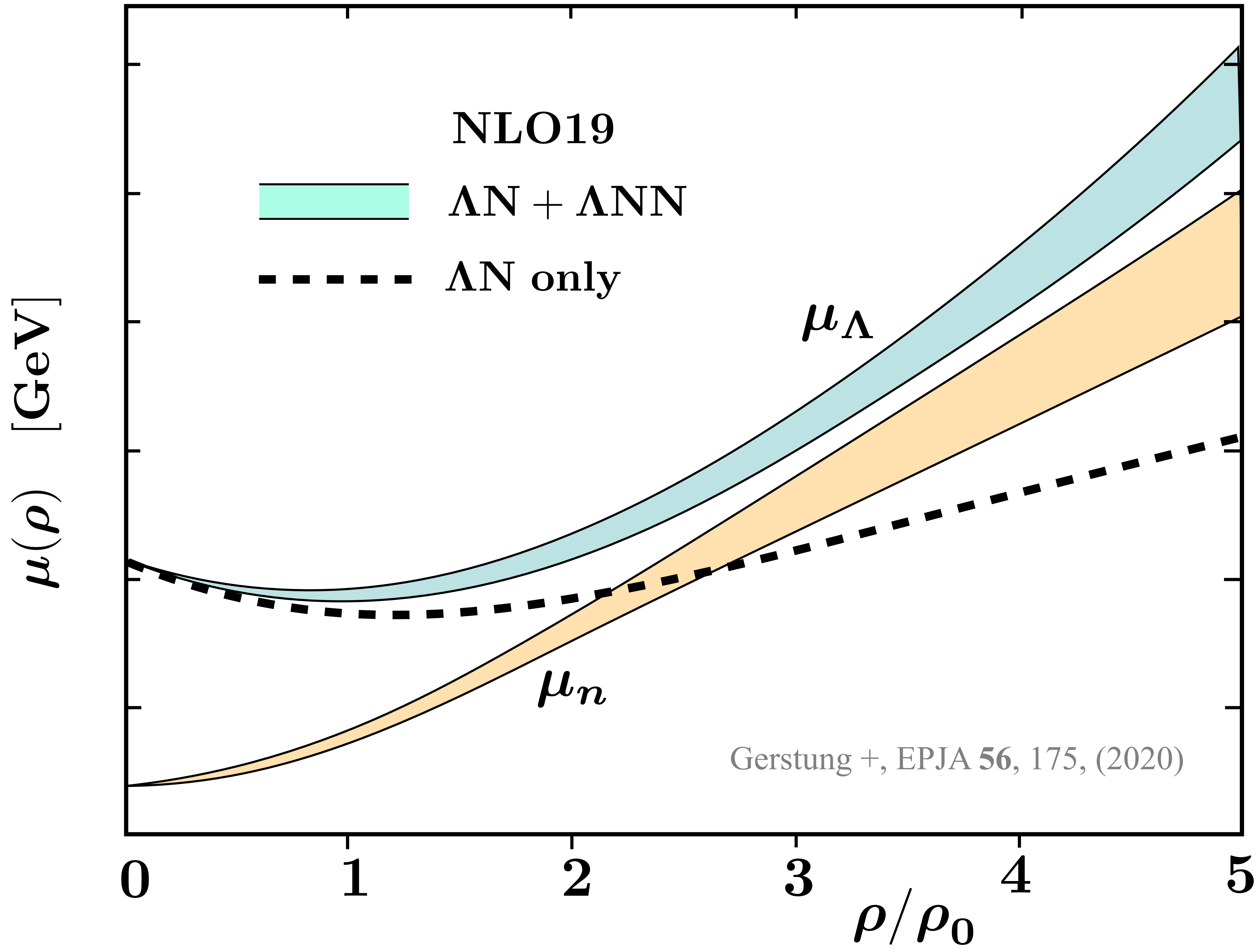
- Necessary for spectroscopy

ΛNN 3BFs | Matter and stars

Neutron star



Neutron matter chemical pot.



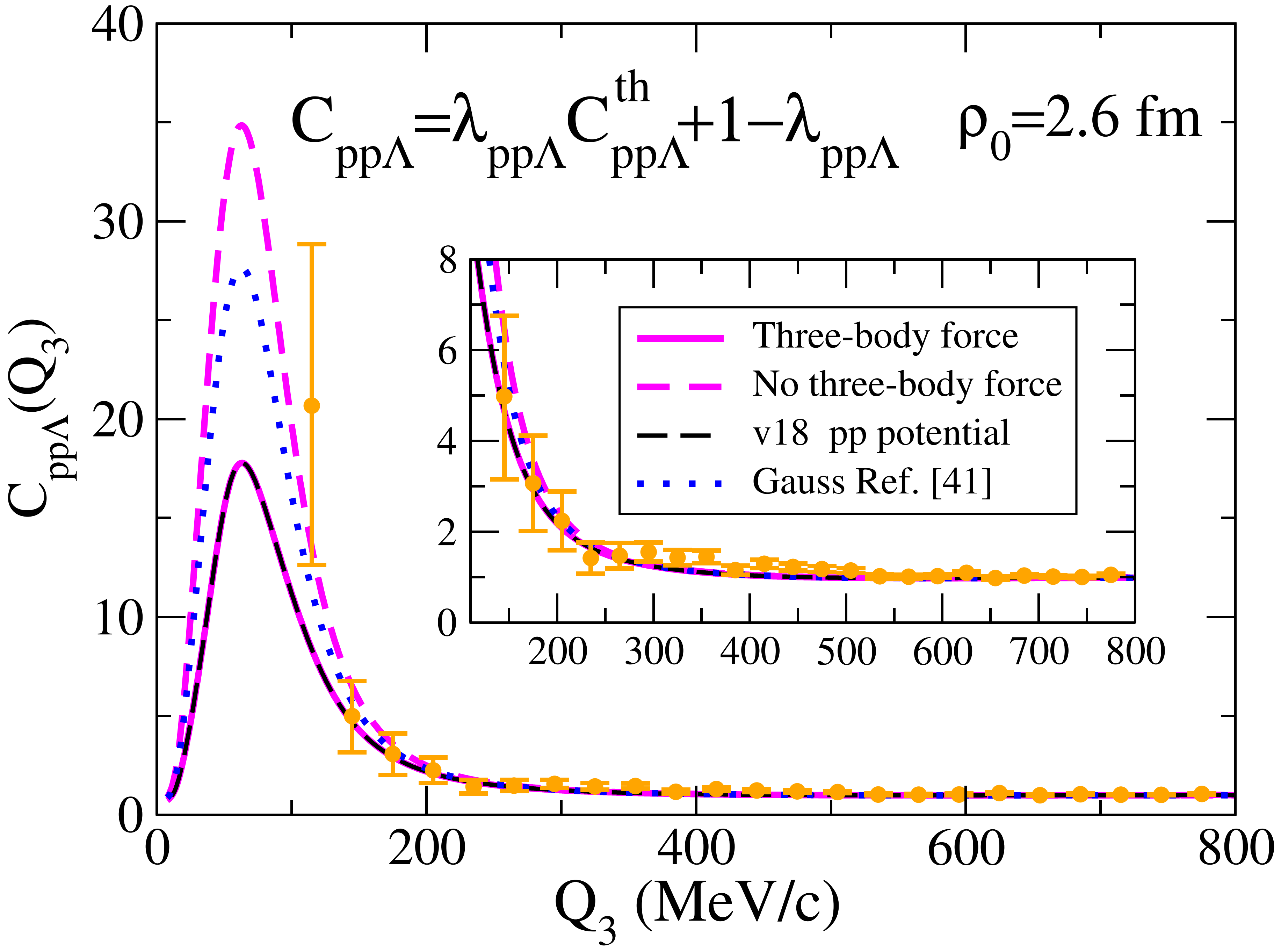
- Necessary for 2-solar mass
- ΛNN 3BF:

  2π exchange + phenomenological short-range term
- Related lattice study with pionless EFT

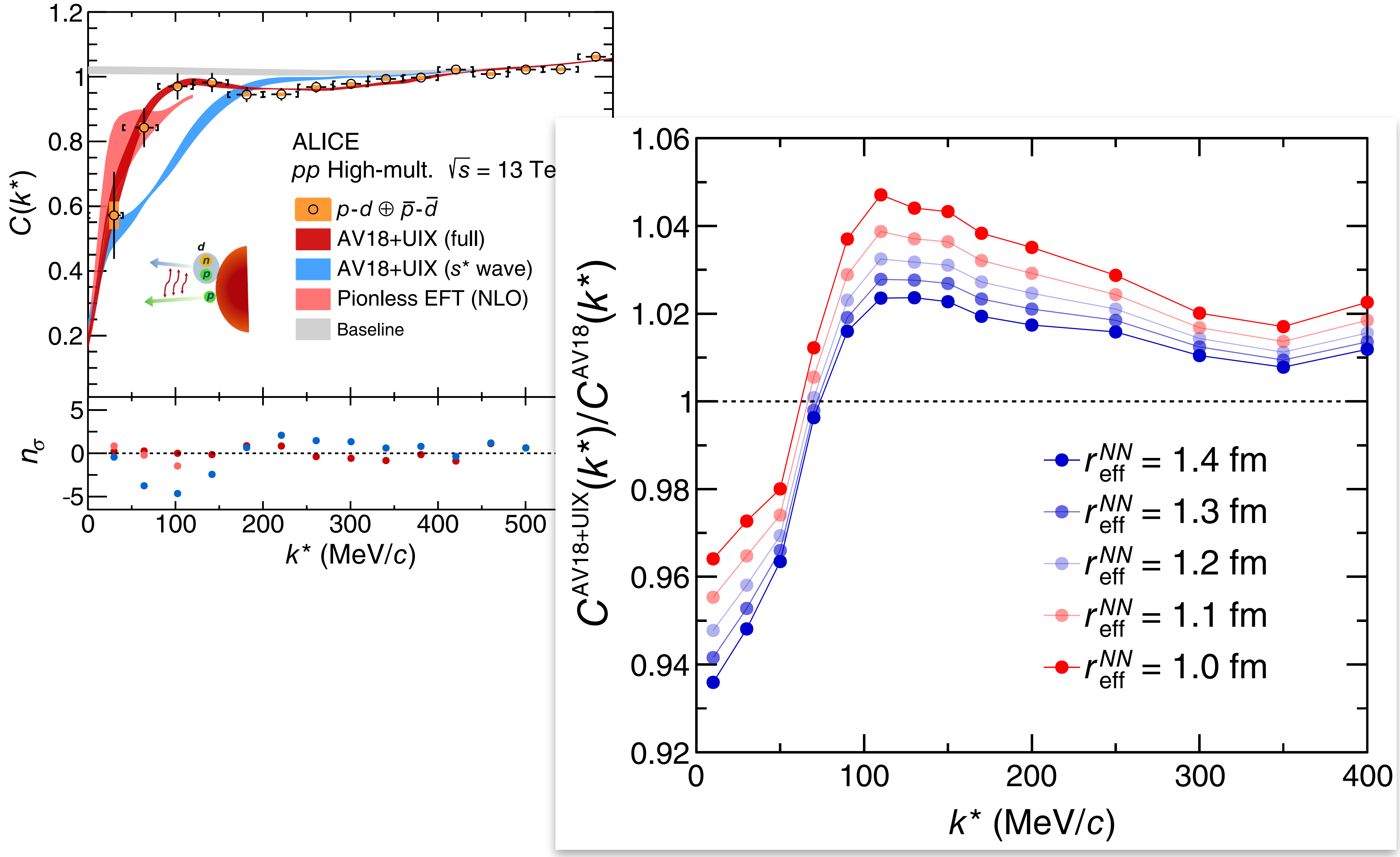
Tong +, SB **70**, 825 (2025)
Tong +, AJ **982**, 164 (2025)

- Modify saturation point
- ΛNN 3BF from chiral EFT

Comparison with ALICE data



Garrido +, PRC **110**, 054004 (2024)



Acharya +, PRX **14**, 031051 (2024)

- Possibly significant ΛNN 3BF effect
- Phenomenological Gaussian 3BF

- Small 3NF effect

Our question | 3BFs with $S = -2$

What about ΞNN 3BFs?

No studies on 3BFs w/ $S = -2$

Prediction by Gaussian-expansion method

Hiyama +, PRL **124**, 092501 (2020)

	$NN\Xi$	
(T, J^π)	$(\frac{1}{2}, \frac{1}{2}^+)$	$(\frac{1}{2}, \frac{3}{2}^+)$
ESC08c	$\cdots$	7.20
HAL QCD	$\cdots$	$\cdots$

Prediction by Faddeev approach

Miyagawa &. Kohno, FBS **62**, 65 (2021).

- Jülich-chiral-EFT 2BF and HAL-QCD 2BF
  → No bound states
- ESC08c
  → $E_{\mathrm{BE}} = 3.05$ MeV ($T = 1/2,\ J^\pi = 2/3^+$)

Related studies

Garcilazo +, PRL **110**, 012503 (2013)
Garcilazo +, JPG **41**, 095103 (2014)
Garcilazo +, JPG **42**, 025103 (2015)
Garcilazo +, PRC **93**, 034001 (2016)
Filikhina +, MMG **5**, 1 (2017)
Egorov, PAN **86**, 277 (2023)
Garcilazo +, PRC **93**, 024001 (2016)
Garcilazo & Valcarce, CPC **44**, 104104 (2020)
Carr +, PRC **57**, 2858 (1998)
Miyagawa +, NPA **614**, 535 (1997)
Glöckle & Miyagawa, FBS **30**, 241 (2001)

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	$NN\Xi$	
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ESC08c	$\cdots$	7.20
HAL QCD	$\cdots$	$\cdots$

No ΞNN 3BFs included

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3BFs from SU(3) chiral EFT | General framework

PHYSICAL REVIEW C **93**, 014001 (2016)

Leading three-baryon forces from SU(3) chiral effective field theory

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[3]*Helmholtz-Institut für Strahlen- und Kernphysik and Bethe Center for Theoretical Physics, Universität Bonn, D-53115 Bonn, Germany*
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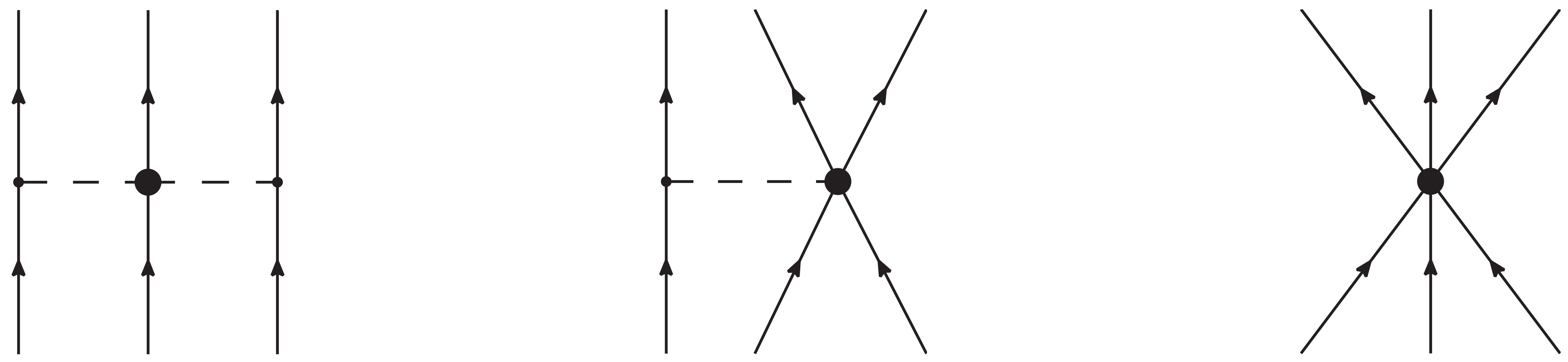
(Received 6 November 2015; published 11 January 2016)

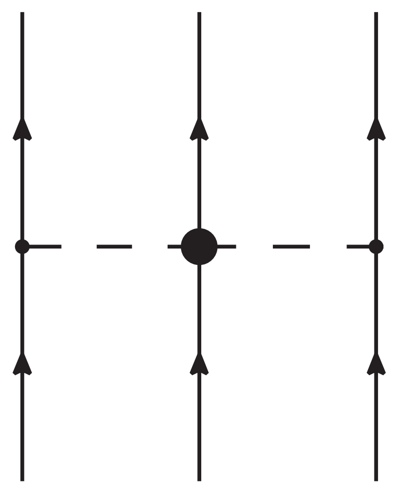
- 3BFs of any combinations of three octet baryons (N, Λ, Σ, Ξ)



2-meson exchange 1-meson exchange Contacts

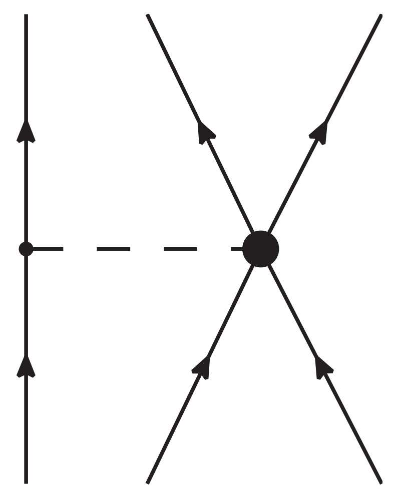
3BFs from SU(3) chiral EFT | Well-known 3NFs

Petschauer +, PRC **93**, 014001 (2016)



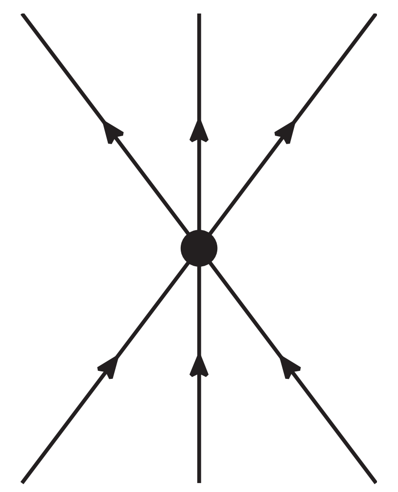
2π exchange

$$V_{\text{TPE}}^{NNN} = \frac{g_A^2}{8f_\pi^2}\mathcal{A}\sum_{i\neq j\neq k}\frac{\vec{\sigma}_i\cdot\vec{q}_i\;\vec{\sigma}_j\cdot\vec{q}_j}{\left(\vec{q}_i^{\,2}+m_\pi^2\right)\left(\vec{q}_j^{\,2}+m_\pi^2\right)} \times\left[\frac{\delta^{\alpha\beta}}{f_\pi^2}\left(-4c_1m_\pi^2+2c_3\vec{q}_i\cdot\vec{q}_j\right)+\sum_\gamma\frac{c_4}{f_\pi^2}\epsilon^{\alpha\beta\gamma}\tau_k^\gamma\;\vec{\sigma}_k\cdot\left(\vec{q}_i\times\vec{q}_j\right)\right]\tau_i^\alpha\tau_j^\beta$$



1π exchange

$$V_{\text{OPE}}^{NNN} = -\frac{g_A}{8f_\pi^2}d'\mathcal{A}\sum_{i\neq j\neq k}\frac{\vec{\sigma}_j\cdot\vec{q}_j}{\vec{q}_j^{\,2}+m_\pi^2}\vec{\tau}_i\cdot\vec{\tau}_j\;\vec{\sigma}_i\cdot\vec{q}_j$$

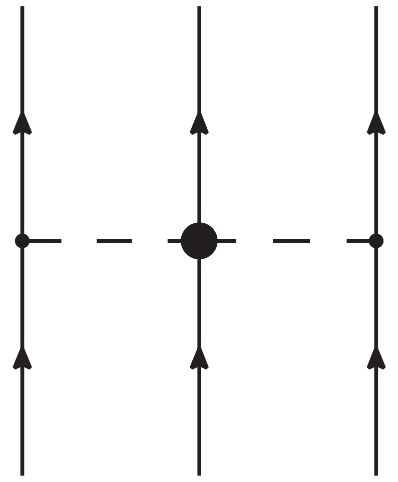


Contacts

$$V_{\text{ct}}^{NNN} = \frac{1}{2}E\,\mathcal{A}\sum_{j\neq k}\vec{\tau}_j\cdot\vec{\tau}_k$$

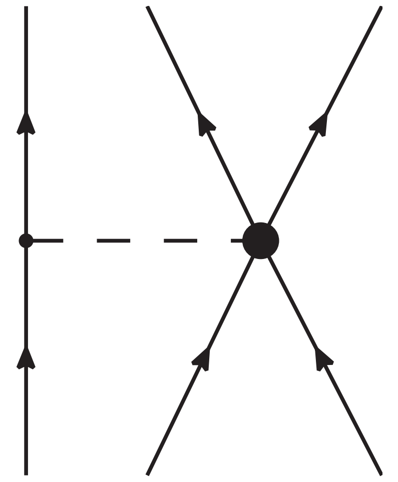
3BFs from SU(3) chiral EFT | Well-known ΛNN 3BFs

Petschauer +, PRC **93**, 014001 (2016)



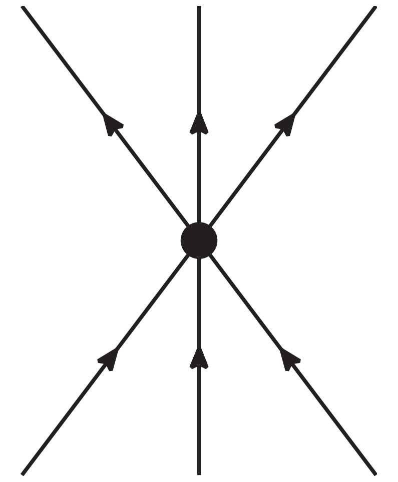
2π exchange

$$V_{\mathrm{TPE}}^{\Lambda NN} = \frac{g_A^2}{3f_0^4}\frac{\vec{\sigma}_3\cdot\vec{q}_{63}\,\vec{\sigma}_2\cdot\vec{q}_{52}}{(\vec{q}_{63}^{\,2}+m_\pi^2)(\vec{q}_{52}^{\,2}+m_\pi^2)}\vec{\tau}_2\cdot\vec{\tau}_3\left[-(3b_0+b_D)m_\pi^2+(2b_2+3b_4)\,\vec{q}_{63}\cdot\vec{q}_{52}\right]$$
$$-\;P_{23}^{(\sigma)}P_{23}^{(\tau)}\frac{g_A^2}{3f_0^4}\frac{\vec{\sigma}_3\cdot\vec{q}_{53}\,\vec{\sigma}_2\cdot\vec{q}_{62}}{(\vec{q}_{53}^{\,2}+m_\pi^2)(\vec{q}_{62}^{\,2}+m_\pi^2)}\vec{\tau}_2\cdot\vec{\tau}_3\left[-(3b_0+b_D)m_\pi^2+(2b_2+3b_4)\,\vec{q}_{53}\cdot\vec{q}_{62}\right]$$



1π exchange

$$V_{\mathrm{OPE}}^{\Lambda NN} = -\frac{g_A}{2f_0^2}\Bigg\{\frac{\vec{\sigma}_2\cdot\vec{q}_{52}}{\vec{q}_{52}^{\,2}+m_\pi^2}\vec{\tau}_2\cdot\vec{\tau}_3[(D_1'\vec{\sigma}_1+D_2'\vec{\sigma}_3)\cdot\vec{q}_{52}]$$
$$+\;\frac{\vec{\sigma}_3\cdot\vec{q}_{63}}{\vec{q}_{63}^{\,2}+m_\pi^2}\vec{\tau}_2\cdot\vec{\tau}_3[(D_1'\vec{\sigma}_1+D_2'\vec{\sigma}_2)\cdot\vec{q}_{63}]$$
$$+\;P_{23}^{(\sigma)}P_{23}^{(\tau)}P_{13}^{(\sigma)}\frac{\vec{\sigma}_2\cdot\vec{q}_{62}}{\vec{q}_{62}^{\,2}+m_\pi^2}\vec{\tau}_2\cdot\vec{\tau}_3\left[-\frac{D_1'+D_2'}{2}(\vec{\sigma}_1+\vec{\sigma}_3)\cdot\vec{q}_{62}+\frac{D_1'-D_2'}{2}\,i(\vec{\sigma}_3\times\vec{\sigma}_1)\cdot\vec{q}_{62}\right]$$
$$+\;P_{23}^{(\sigma)}P_{23}^{(\tau)}P_{12}^{(\sigma)}\frac{\vec{\sigma}_3\cdot\vec{q}_{53}}{\vec{q}_{53}^{\,2}+m_\pi^2}\vec{\tau}_2\cdot\vec{\tau}_3\left[-\frac{D_1'+D_2'}{2}(\vec{\sigma}_1+\vec{\sigma}_2)\cdot\vec{q}_{53}-\frac{D_1'-D_2'}{2}\,i(\vec{\sigma}_1\times\vec{\sigma}_2)\cdot\vec{q}_{53}\right]\Bigg\}$$

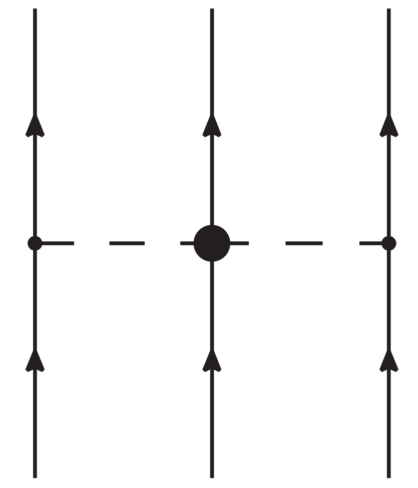


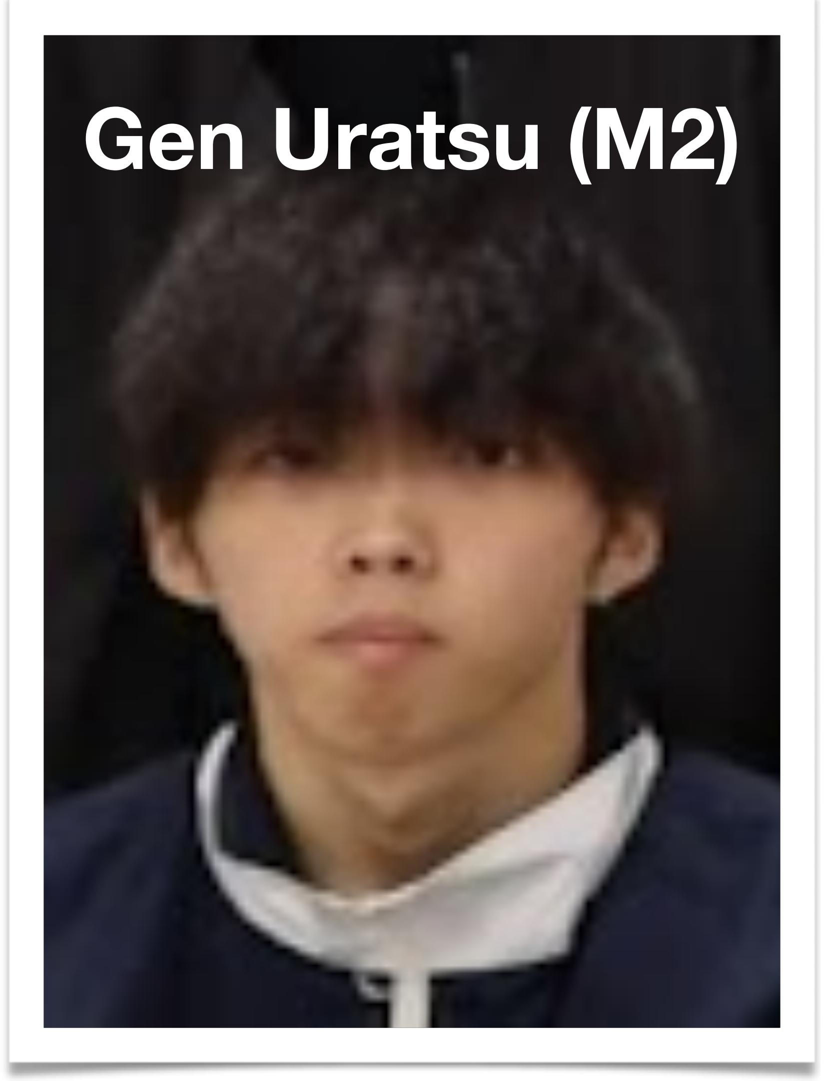
Contacts

$$V_{\mathrm{ct}}^{\Lambda NN} = C_1'\,(\mathbb{1}-\vec{\sigma}_2\cdot\vec{\sigma}_3)(3+\vec{\tau}_2\cdot\vec{\tau}_3)$$
$$+\;C_2'\,\vec{\sigma}_1\cdot(\vec{\sigma}_2+\vec{\sigma}_3)\,(\mathbb{1}-\vec{\tau}_2\cdot\vec{\tau}_3)$$
$$+\;C_3'\,(3+\vec{\sigma}_2\cdot\vec{\sigma}_3)(\mathbb{1}-\vec{\tau}_2\cdot\vec{\tau}_3),$$

2π-exchange term

Uratsu +, PRC **113**, 015204 (2026)





$$V_{\mathrm{TPE}}^{\Xi NN} = \mathcal{A}_{23}\left(Y_{123}^{456} + Y_{231}^{564} + Y_{312}^{645}\right)$$

$$Y_{123}^{456} = \frac{g_A g_B}{12 f_\pi^4} \frac{(\boldsymbol{\sigma}_1 \cdot \boldsymbol{q}_{41})(\boldsymbol{\sigma}_3 \cdot \boldsymbol{q}_{63})}{(q_{41}^2 + m_\pi^2)(q_{63}^2 + m_\pi^2)} \left[\boldsymbol{\tau}_1 \cdot \boldsymbol{\tau}_3 \left(4c_1 m_\pi^2 - 2c_3 \boldsymbol{q}_{41} \cdot \boldsymbol{q}_{63}\right) + c_4 \{\boldsymbol{\tau}_3 \cdot (\boldsymbol{\tau}_1 \times \boldsymbol{\tau}_2)\}\{\boldsymbol{\sigma}_2 \cdot (\boldsymbol{q}_{41} \times \boldsymbol{q}_{63})\}\right]$$

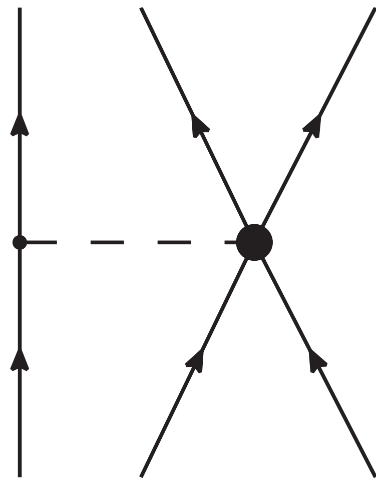
$$Y_{231}^{564} = \frac{g_A g_B}{12 f_\pi^4} \frac{(\boldsymbol{\sigma}_2 \cdot \boldsymbol{q}_{52})(\boldsymbol{\sigma}_1 \cdot \boldsymbol{q}_{41})}{(q_{52}^2 + m_\pi^2)(q_{41}^2 + m_\pi^2)} \left[\boldsymbol{\tau}_2 \cdot \boldsymbol{\tau}_1 \left(4c_1 m_\pi^2 - 2c_3 \boldsymbol{q}_{52} \cdot \boldsymbol{q}_{41}\right) + c_4 \{\boldsymbol{\tau}_3 \cdot (\boldsymbol{\tau}_1 \times \boldsymbol{\tau}_2)\}\{\boldsymbol{\sigma}_3 \cdot (\boldsymbol{q}_{52} \times \boldsymbol{q}_{41})\}\right]$$

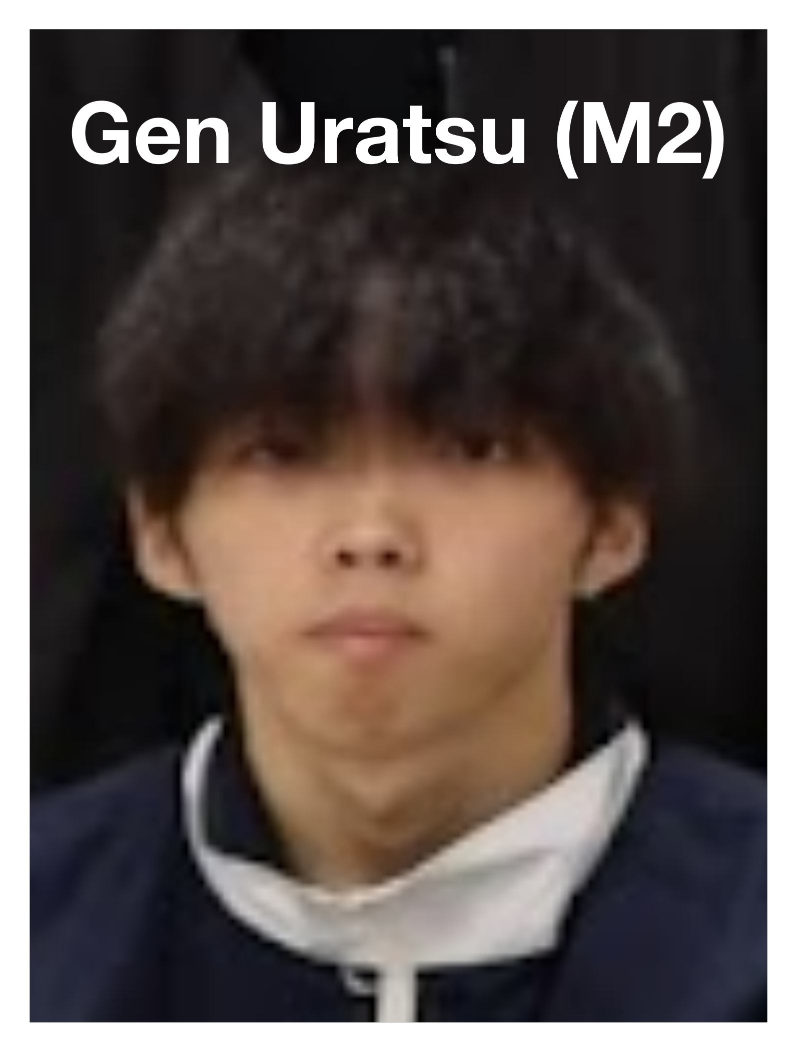
$$Y_{312}^{645} = \frac{g_A^2}{12 f_\pi^4} \frac{(\boldsymbol{\sigma}_3 \cdot \boldsymbol{q}_{63})(\boldsymbol{\sigma}_2 \cdot \boldsymbol{q}_{52})}{(q_{63}^2 + m_\pi^2)(q_{52}^2 + m_\pi^2)} \left[\boldsymbol{\tau}_3 \cdot \boldsymbol{\tau}_2 \left(-12u_1 m_\pi^2 + 6u_3 \boldsymbol{q}_{63} \cdot \boldsymbol{q}_{52}\right) - u_4 \{\boldsymbol{\tau}_3 \cdot (\boldsymbol{\tau}_1 \times \boldsymbol{\tau}_2)\}\{\boldsymbol{\sigma}_1 \cdot (\boldsymbol{q}_{63} \times \boldsymbol{q}_{52})\}\right]$$

6 LECs

1π-exchange term

Uratsu +, PRC **113**, 015204 (2026)





$$V_{\rm OPE}^{\Xi NN} = X_{123}^{456} + X_{231}^{564} + X_{312}^{645} + \mathcal{P}_{23}\mathcal{P}_{12}X_{312}^{564} + \mathcal{P}_{23}\mathcal{P}_{13}X_{231}^{645}$$

$$X_{123}^{456} = \frac{g_B d}{2f_\pi^2}\frac{\boldsymbol{\sigma}_1\cdot\boldsymbol{q}_{41}}{q_{41}^2+m_\pi^2}\left[(\boldsymbol{\tau}_2-\boldsymbol{\tau}_3)\cdot\boldsymbol{\tau}_1\,(\boldsymbol{\sigma}_2-\boldsymbol{\sigma}_3)\cdot\boldsymbol{q}_{41} + (\boldsymbol{\tau}_1\times\boldsymbol{\tau}_2)\cdot\boldsymbol{\tau}_3\,(\boldsymbol{\sigma}_2\times\boldsymbol{\sigma}_3)\cdot\boldsymbol{q}_{41}\right]$$

$$X_{231}^{564} = \frac{g_A}{2f_\pi^2}\frac{\boldsymbol{\sigma}_2\cdot\boldsymbol{q}_{52}}{q_{52}^2+m_\pi^2}\left[(e_1\boldsymbol{\sigma}_3+e_2\boldsymbol{\sigma}_1)\cdot\boldsymbol{q}_{52}\,\boldsymbol{\tau}_2\cdot\boldsymbol{\tau}_3 + (e_3\boldsymbol{\sigma}_3+e_4\boldsymbol{\sigma}_1)\cdot\boldsymbol{q}_{52}\,\boldsymbol{\tau}_1\cdot\boldsymbol{\tau}_2 - e_5(\boldsymbol{\tau}_2\times\boldsymbol{\tau}_3)\cdot\boldsymbol{\tau}_1\,(\boldsymbol{\sigma}_3\times\boldsymbol{\sigma}_1)\cdot\boldsymbol{q}_{52}\right]$$

$$X_{312}^{645} = \frac{g_A}{2f_\pi^2}\frac{\boldsymbol{\sigma}_3\cdot\boldsymbol{q}_{63}}{q_{63}^2+m_\pi^2}\left[(e_4\boldsymbol{\sigma}_1+e_3\boldsymbol{\sigma}_2)\cdot\boldsymbol{q}_{63}\,\boldsymbol{\tau}_3\cdot\boldsymbol{\tau}_1 + (e_2\boldsymbol{\sigma}_1+e_1\boldsymbol{\sigma}_2)\cdot\boldsymbol{q}_{63}\,\boldsymbol{\tau}_2\cdot\boldsymbol{\tau}_3 - e_5(\boldsymbol{\tau}_3\times\boldsymbol{\tau}_1)\cdot\boldsymbol{\tau}_2\,(\boldsymbol{\sigma}_1\times\boldsymbol{\sigma}_2)\cdot\boldsymbol{q}_{63}\right]$$

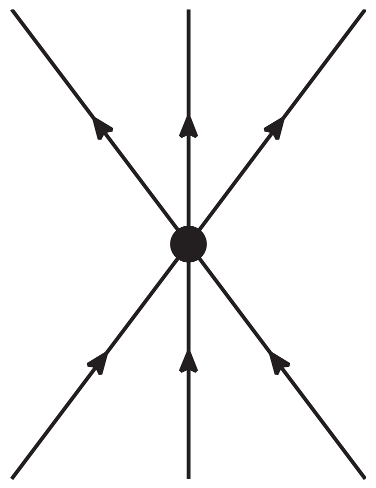
$$X_{312}^{564} = \frac{g_A}{2f_\pi^2}\frac{\boldsymbol{\sigma}_3\cdot\boldsymbol{q}_{63}}{q_{63}^2+m_\pi^2}\Big[\{f_1\boldsymbol{\sigma}_1+f_2\boldsymbol{\sigma}_2+f_3 i(\boldsymbol{\sigma}_1\times\boldsymbol{\sigma}_2)\}\cdot\boldsymbol{q}_{63}\,\boldsymbol{\tau}_3\cdot\boldsymbol{\tau}_1 + \{f_2\boldsymbol{\sigma}_1+f_1\boldsymbol{\sigma}_2+f_3 i(\boldsymbol{\sigma}_1\times\boldsymbol{\sigma}_2)\}\cdot\boldsymbol{q}_{63}\,\boldsymbol{\tau}_2\cdot\boldsymbol{\tau}_3$$
$$+\{f_4(\boldsymbol{\sigma}_1+\boldsymbol{\sigma}_2)+if_5(\boldsymbol{\sigma}_1\times\boldsymbol{\sigma}_2)\}\cdot\boldsymbol{q}_{63}\,i(\boldsymbol{\tau}_3\times\boldsymbol{\tau}_1)\cdot\boldsymbol{\tau}_2\Big]$$

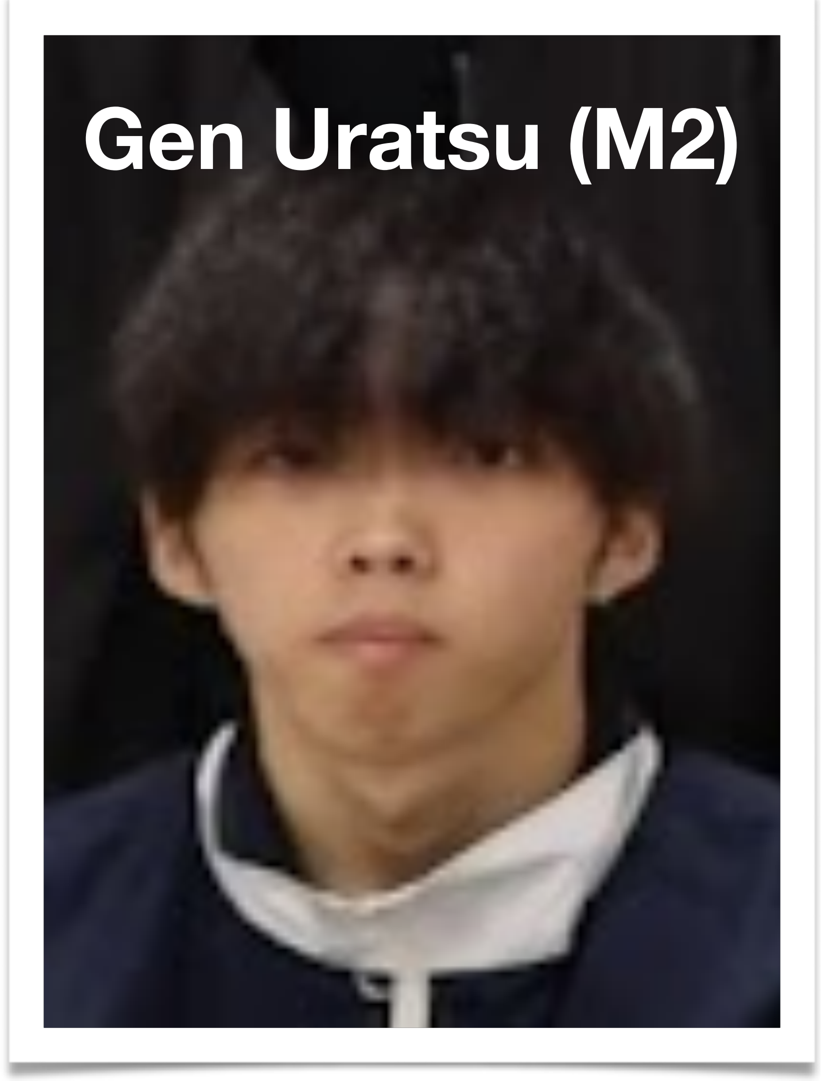
$$X_{231}^{645} = \frac{g_A}{2f_\pi^2}\frac{\boldsymbol{\sigma}_2\cdot\boldsymbol{q}_{52}}{q_{52}^2+m_\pi^2}\Big[\{f_1\boldsymbol{\sigma}_3+f_2\boldsymbol{\sigma}_1-f_3 i(\boldsymbol{\sigma}_3\times\boldsymbol{\sigma}_1)\}\cdot\boldsymbol{q}_{52}\,\boldsymbol{\tau}_2\cdot\boldsymbol{\tau}_3 + \{f_2\boldsymbol{\sigma}_3+f_1\boldsymbol{\sigma}_1-f_3 i(\boldsymbol{\sigma}_3\times\boldsymbol{\sigma}_1)\}\cdot\boldsymbol{q}_{52}\,\boldsymbol{\tau}_1\cdot\boldsymbol{\tau}_2$$
$$-\{f_4(\boldsymbol{\sigma}_3+\boldsymbol{\sigma}_1)-if_5(\boldsymbol{\sigma}_3\times\boldsymbol{\sigma}_1)\}\cdot\boldsymbol{q}_{52}\,i(\boldsymbol{\tau}_2\times\boldsymbol{\tau}_3)\cdot\boldsymbol{\tau}_1\Big]$$

11 LECs

Contact term

Uratsu +, PRC **113**, 015204 (2026)





$$
\begin{aligned}
V_{\mathrm{ct}}^{\Xi NN} &= E_1 + E_2(\boldsymbol{\sigma}_2 + \boldsymbol{\sigma}_3)\cdot\boldsymbol{\sigma}_1 + E_3\boldsymbol{\sigma}_2\cdot\boldsymbol{\sigma}_3 \\
&+ \left[F_1 - F_2(\boldsymbol{\sigma}_2 - \boldsymbol{\sigma}_3)\cdot\boldsymbol{\sigma}_1 - F_1\boldsymbol{\sigma}_2\cdot\boldsymbol{\sigma}_3\right]\boldsymbol{\tau}_1\cdot\boldsymbol{\tau}_2 \\
&+ \left[F_1 - F_2(\boldsymbol{\sigma}_2 - \boldsymbol{\sigma}_3)\cdot\boldsymbol{\sigma}_1 - F_1\boldsymbol{\sigma}_2\cdot\boldsymbol{\sigma}_3\right]\boldsymbol{\tau}_1\cdot\boldsymbol{\tau}_3 \\
&+ \left[G_1 - E_2(\boldsymbol{\sigma}_2 + \boldsymbol{\sigma}_3)\cdot\boldsymbol{\sigma}_1 - \frac{1}{3}E_1\boldsymbol{\sigma}_2\cdot\boldsymbol{\sigma}_3\right]\boldsymbol{\tau}_2\cdot\boldsymbol{\tau}_3 \\
&+ F_2\,(\boldsymbol{\sigma}_1\times\boldsymbol{\sigma}_2)\cdot\boldsymbol{\sigma}_3\,(\boldsymbol{\tau}_1\times\boldsymbol{\tau}_2)\cdot\boldsymbol{\tau}_3
\end{aligned}
$$

6 LECs

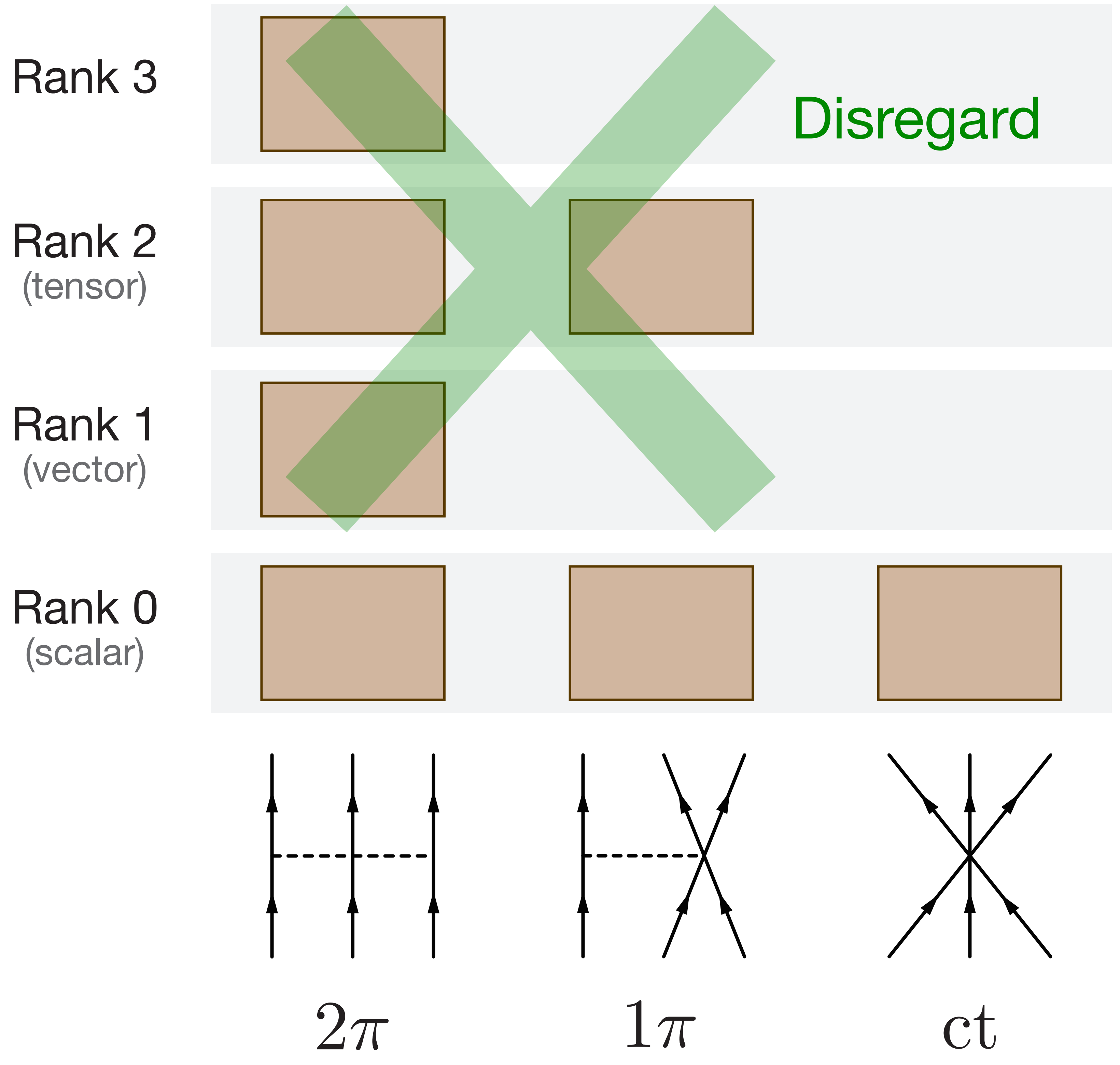
We roughly estimate
ΞNN 3BFs in d–Ξ^- scattering

Hard to constrain all LECs
& all complicated terms

1. Central components only

Uratsu +, PRC **113**, 015204 (2026)

Irreducible tensor decomposition

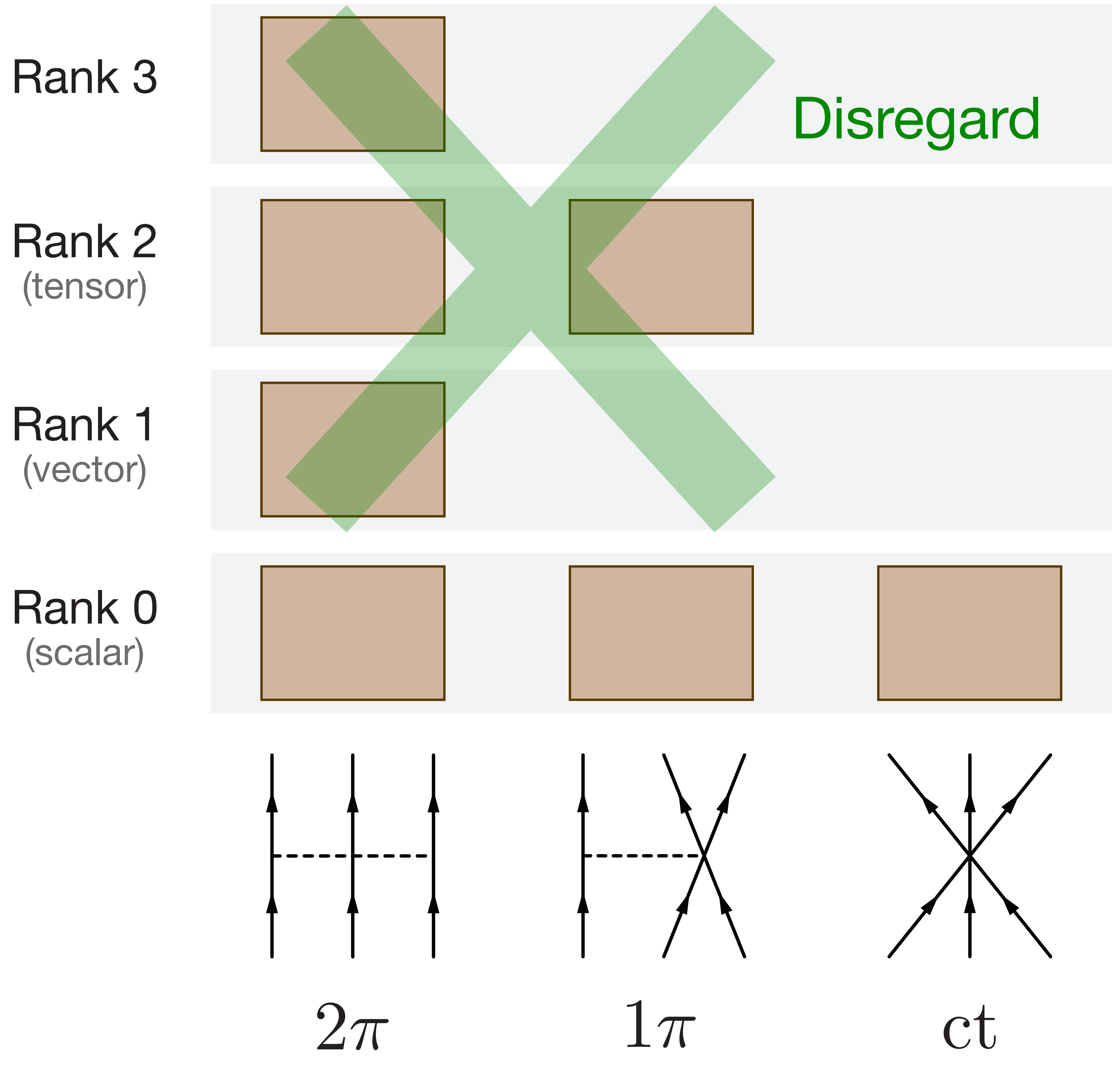


1. Central components only

2. Fourier transform

Uratsu +, PRC **113**, 015204 (2026)

Irreducible tensor decomposition



Central potentials in coordinate space

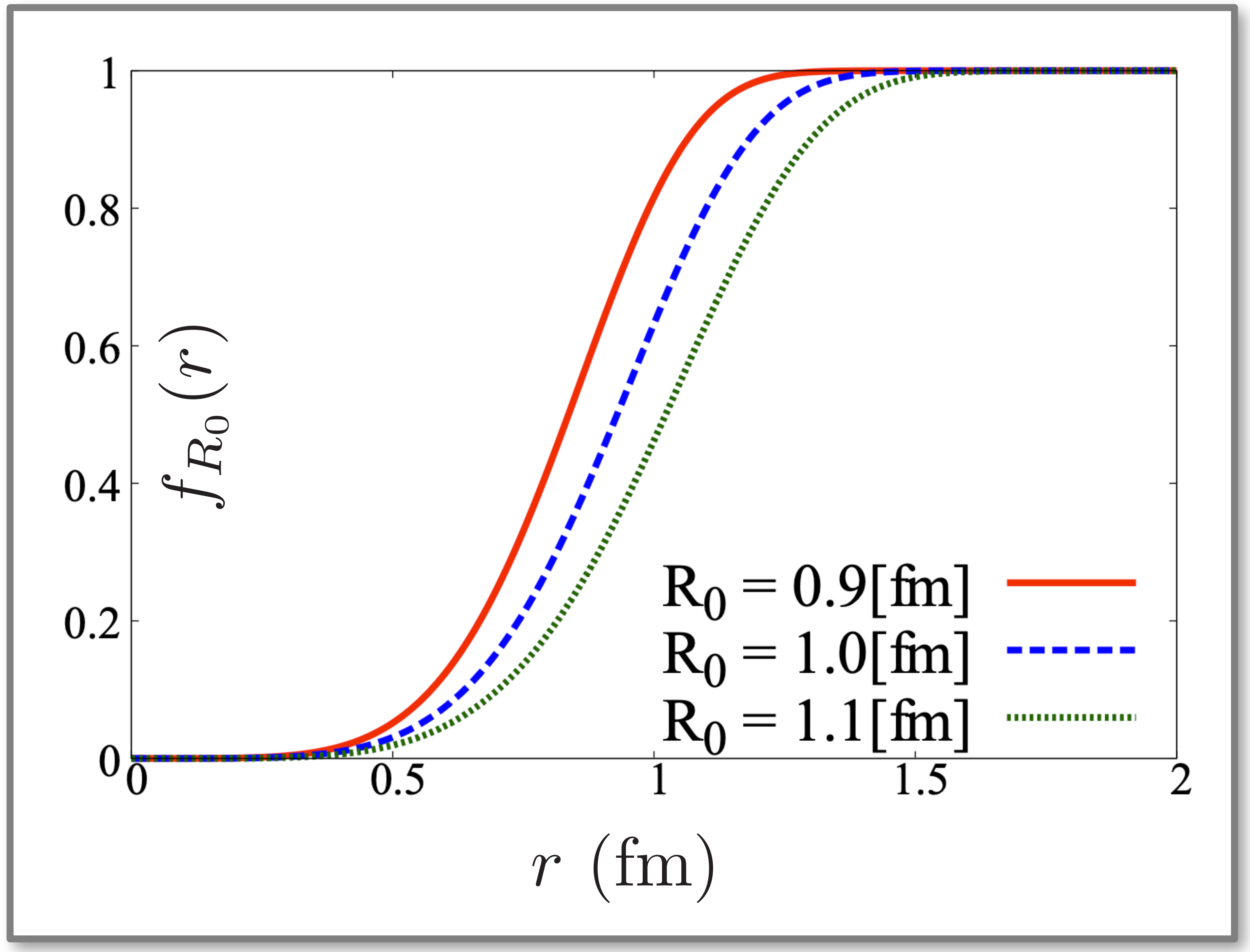
1. Central components only

Irreducible tensor decomposition

2. Fourier transform

Uratsu +, PRC **113**, 015204 (2026)

Central potentials in coordinate space



3. Regularization

Gezerlis +, PRC **90**, 054323 (2014)

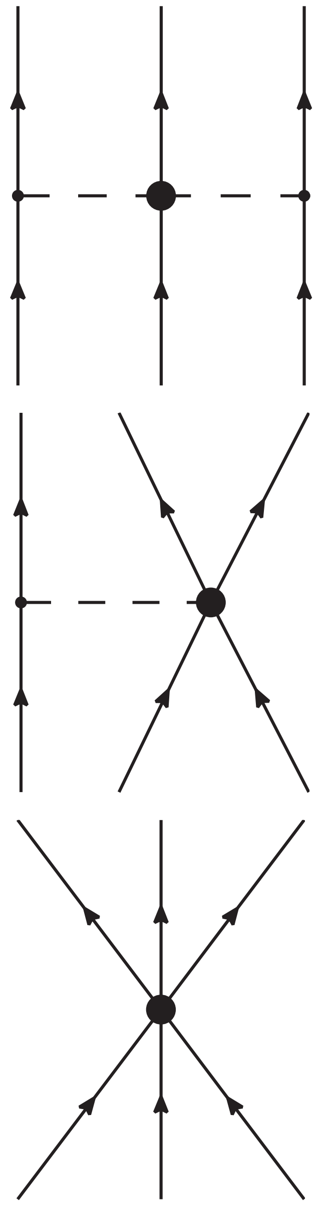
- Yukawa functions from π exchange

$$Y(m_\pi r) \to Y(m_\pi r) f_{R_0}(r)$$

$$f_{R_0}(r) = 1 - \exp\left[-\left(\frac{r}{R_0}\right)^5\right]$$

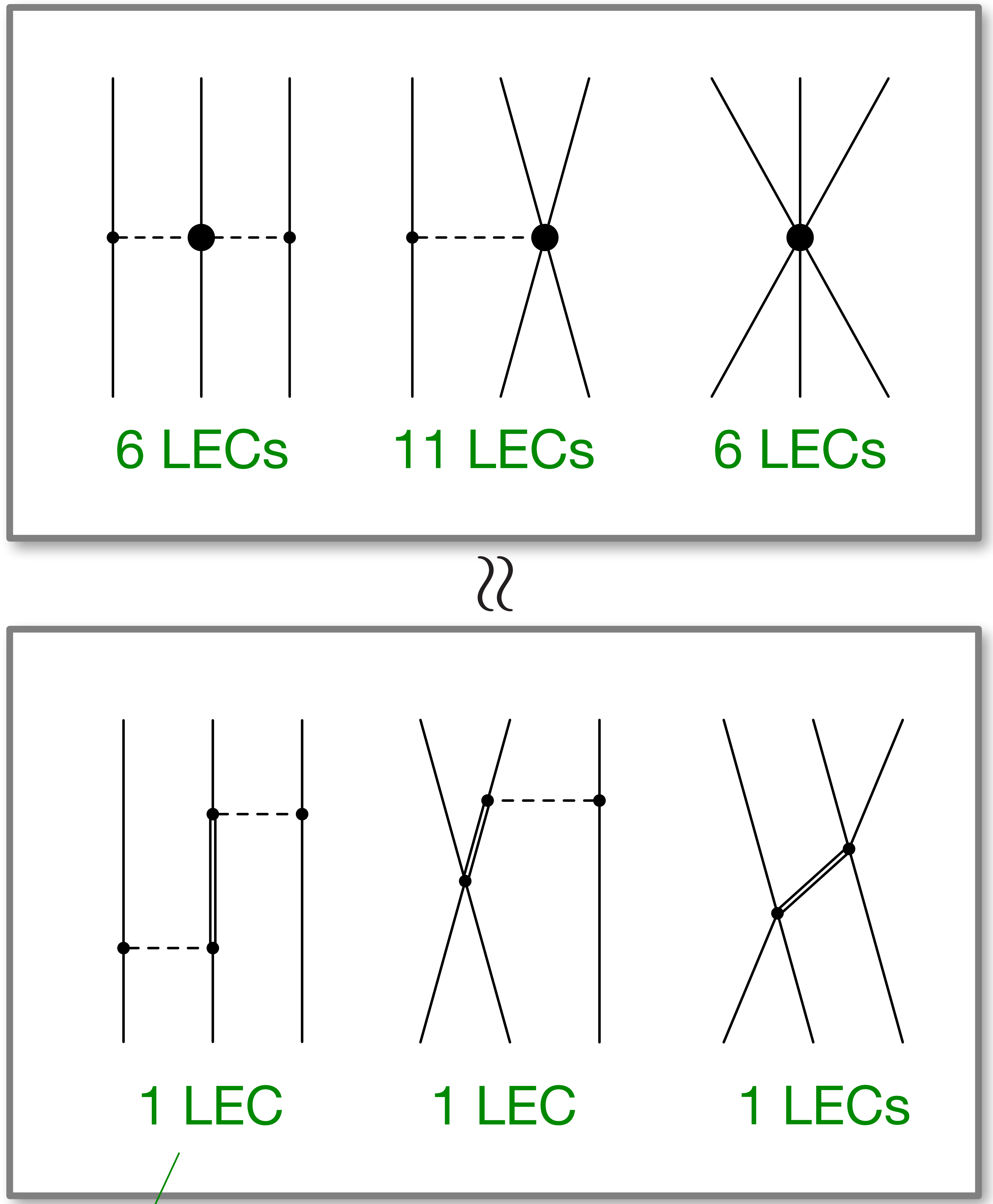
- Delta functions from contacts

$$\delta(\boldsymbol{r}) \to \frac{5}{4\pi\Gamma(3/5)R_0^3} \exp\left[-\left(\frac{r}{R_0}\right)^5\right]$$



4. Decuplet saturation approx.

Petschauer +, NPA **957** 347 (2017)



Large N_c value

$C = 3g_A/4$

Kaiser +, NPA **637**, 395 (1998)
Vonk & Meißner, EPJA **61**, 135 (2025)

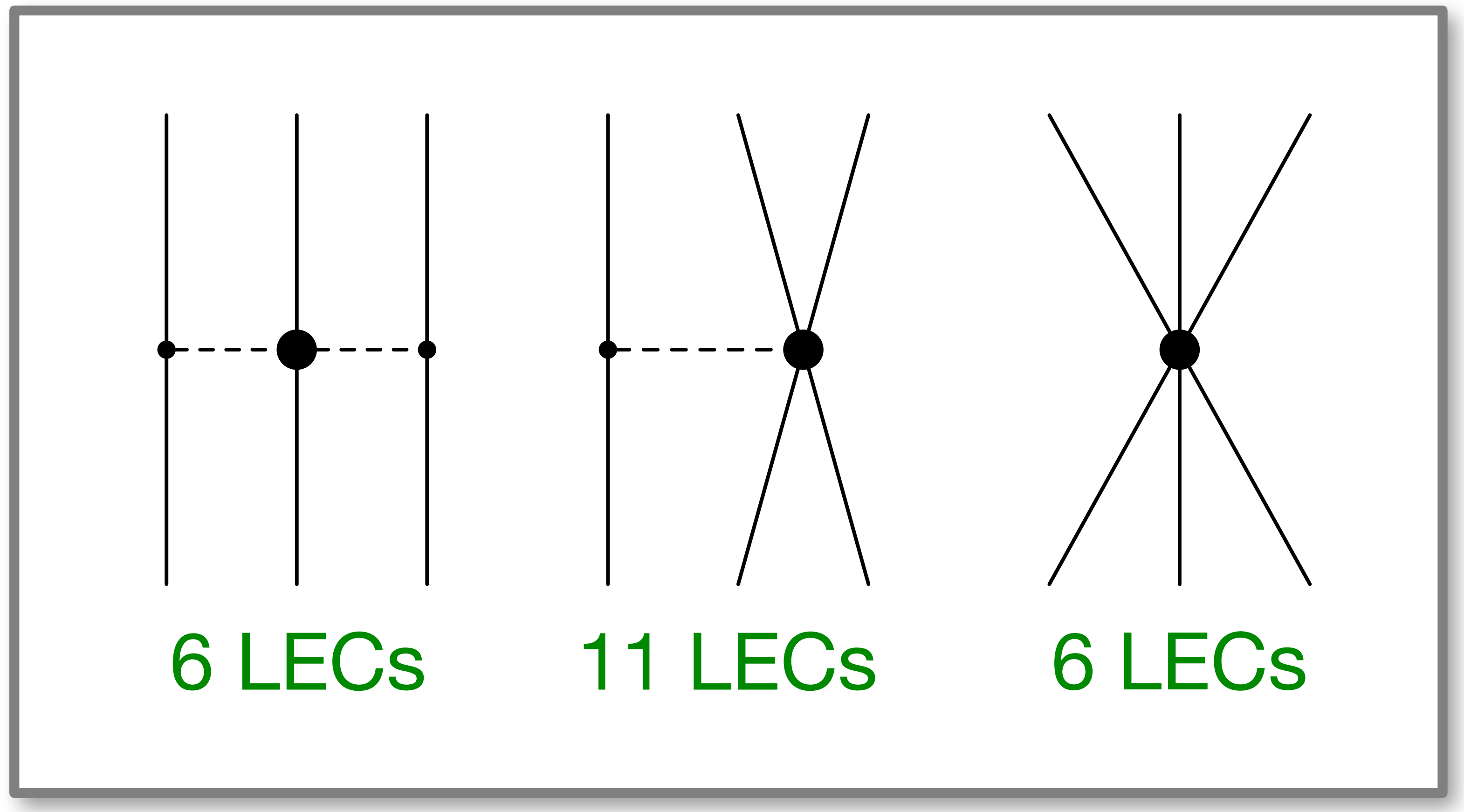
Only 3- & 4-point vertices

$\Delta(1232)$ & $\Xi(1530)$ included

Decuplet–octet mass splitting
$\sim$ 200 MeV

4. Decuplet saturation approx.

Petschauer +, NPA **957** 347 (2017)



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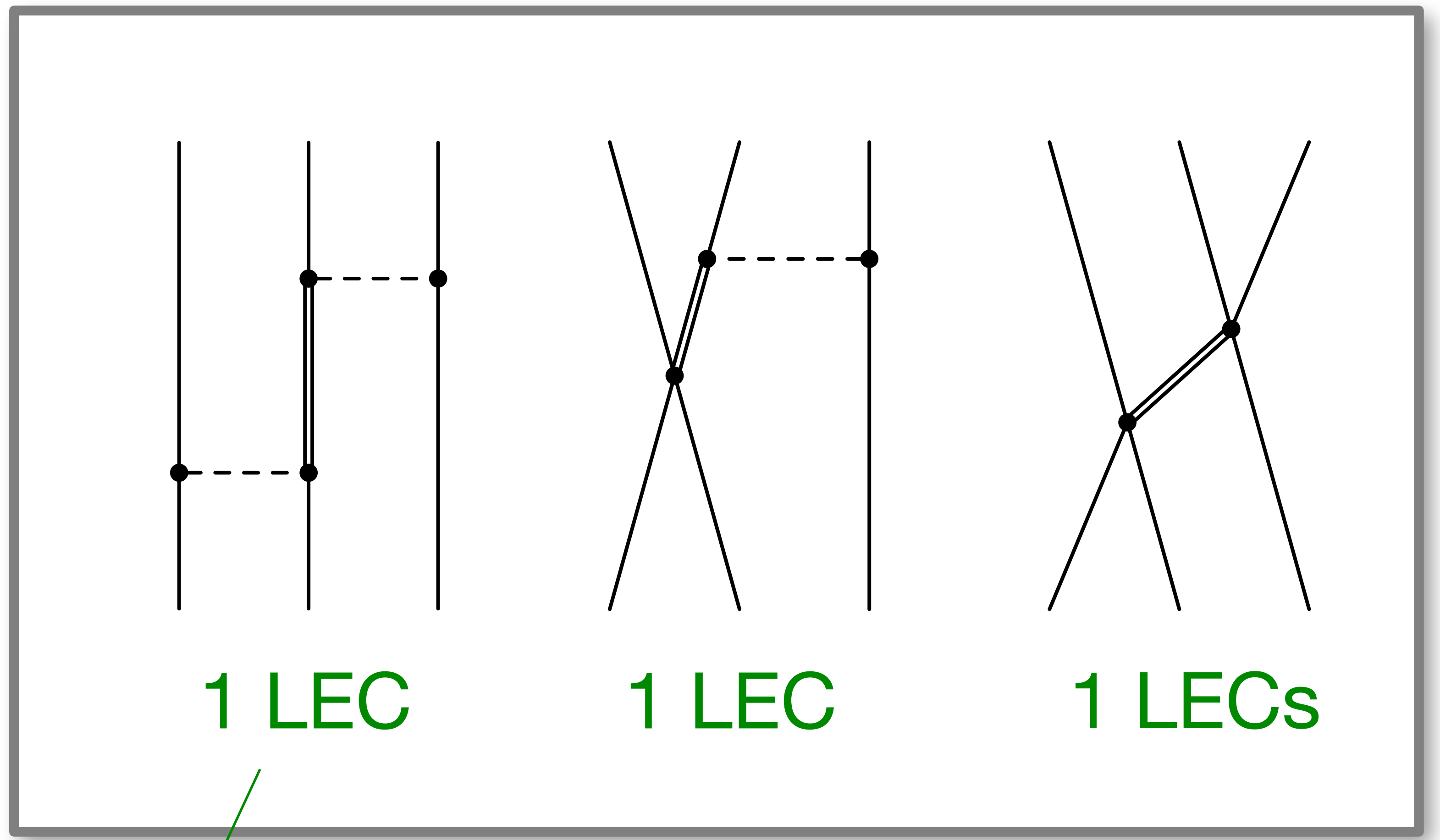

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Only 3- & 4-point vertices

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Decuplet–octet mass splitting
$\sim$ 200 MeV

5. Folding potential

Uratsu +, PRC **113**, 015204 (2026)

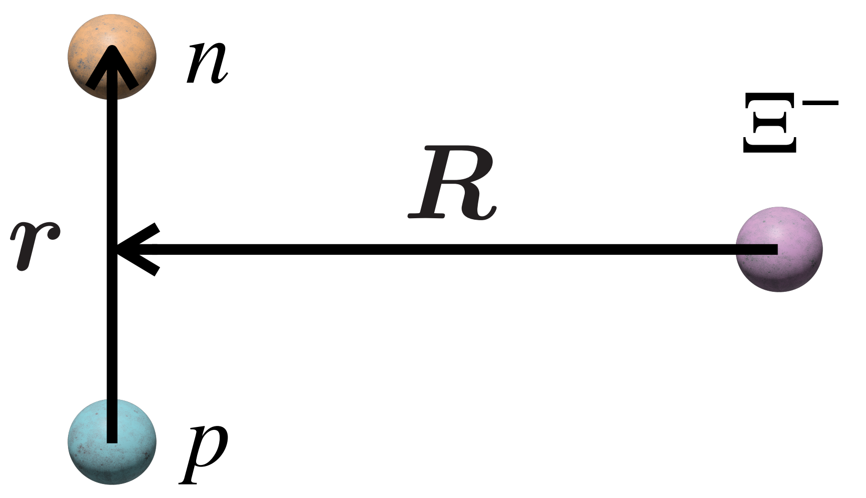
Deuteron w.f.

$$U^{(\sigma)}_{\mathrm{3BF}}(R) = \frac{1}{(4\pi)^2} \iint dr d\hat{\boldsymbol{R}} \frac{\varphi^2(r)}{r^2} W^{(\sigma)}(\boldsymbol{r}, \boldsymbol{R})$$

$$W^{(\sigma)}(\boldsymbol{r}, \boldsymbol{R}) = \frac{1}{(2\pi)^6} \iiint d\boldsymbol{q}_1 d\boldsymbol{q}_2 d\boldsymbol{q}_3 e^{i(\boldsymbol{q}_1\cdot\boldsymbol{r}_1 + \boldsymbol{q}_2\cdot\boldsymbol{r}_2 + \boldsymbol{q}_3\cdot\boldsymbol{r}_3)} \times \delta(\boldsymbol{q}_1 + \boldsymbol{q}_2 + \boldsymbol{q}_3) \left\langle V^{\Xi NN}_{(0)}(\boldsymbol{q}_1, \boldsymbol{q}_2, \boldsymbol{q}_3) \right\rangle_{\text{spin–isospin}}$$

Central potential

Spin–isospin matrix elements

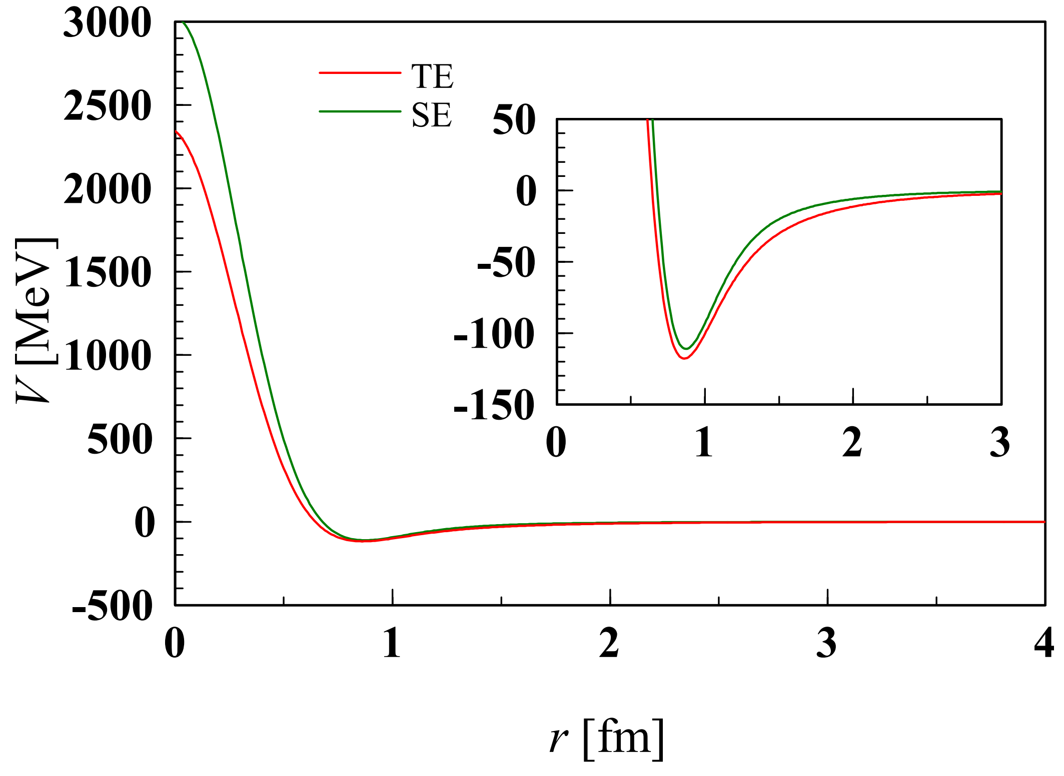


Solve d–Ξ^- scattering
with $U^{(\sigma)}_{\mathrm{2BF}}(R) + U^{(\sigma)}_{\mathrm{3BF}}(R)$

Other inputs | Some details

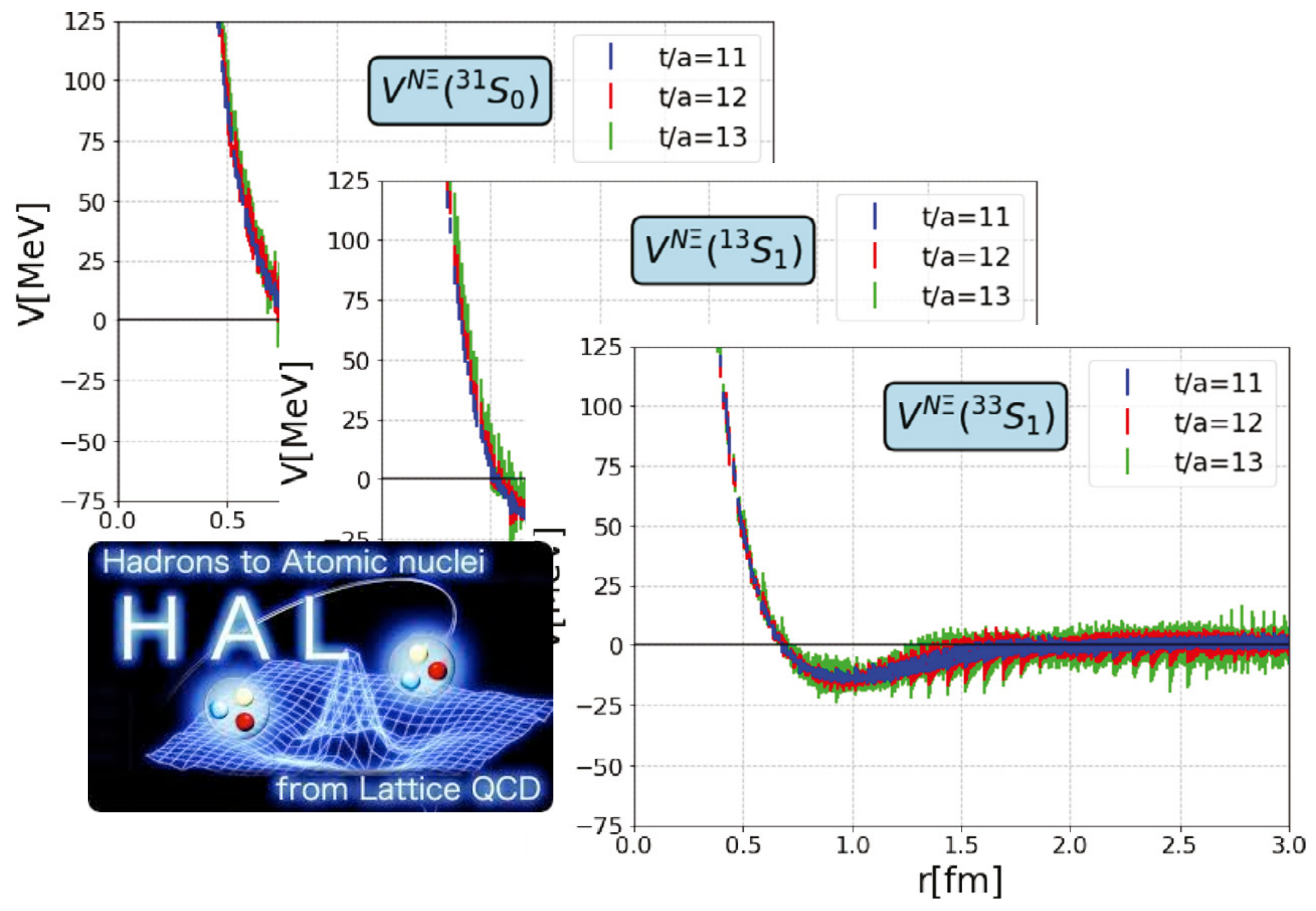
2BFs

AV4’

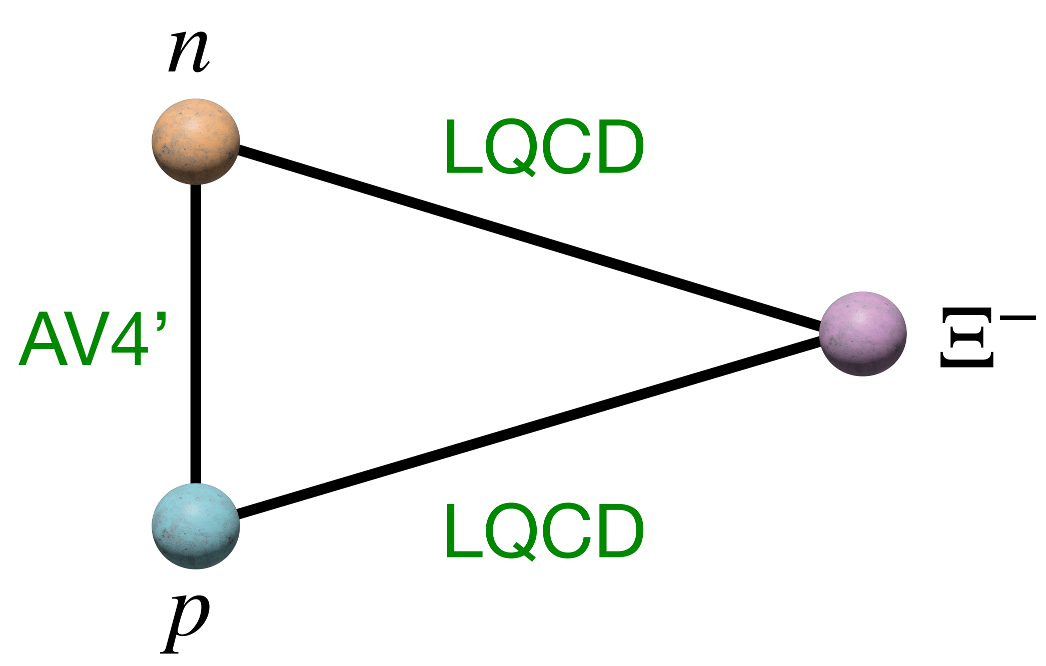


Wiringa & Pieper, PRL **89**, 182501 (2002)

Lattice QCD potential



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



Correlation functions

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

$$C_{d\Xi^-}(q) = 4\pi \int dRR^2 \mathcal{S}(R) \sum_{L=1} \hat{L}^2 \left[\frac{F_L(qR)}{qR}\right]^2 + \frac{2\pi}{3} \int dRR^2 \mathcal{S}(R) \sum_{\sigma=\frac{1}{2},\frac{3}{2}} \hat{\sigma}^2 \left|\frac{\chi^{(\sigma)}_{L=0}(q,R)}{qR}\right|^2$$

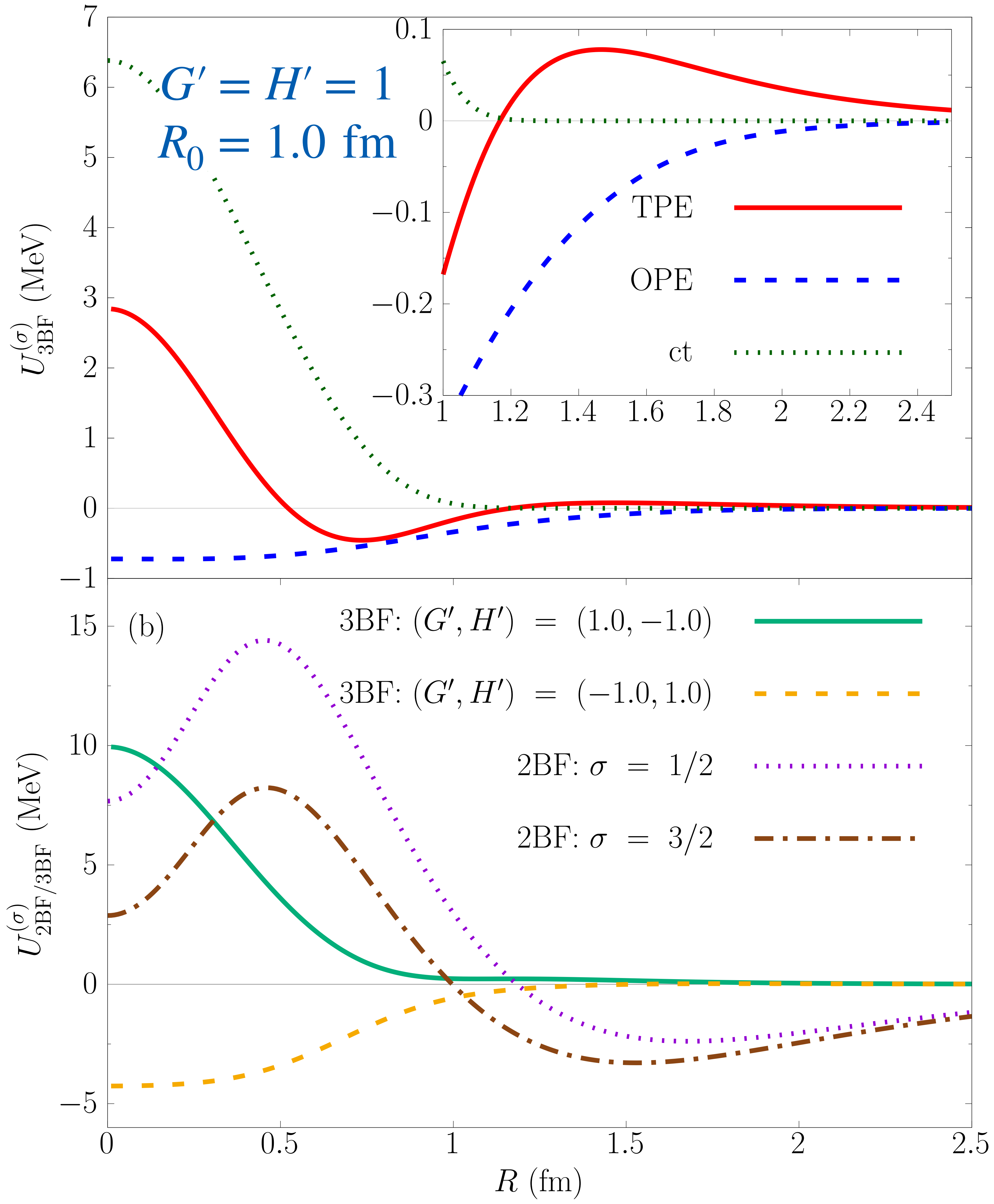
- 2-body source func. (Gaussian)

Limitations

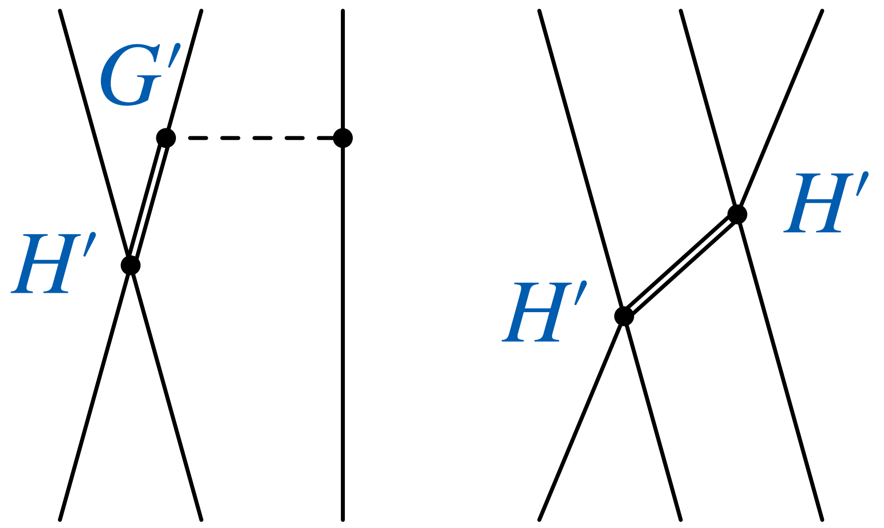
- S-wave only (all subsystems)
- No deuteron breakup
  Confirmed to be small: Ogata +, PRC **103**, 065205 (2021)
- No rearrangement channels
- No ΞN–$\Lambda\Lambda$ coupling
  Expected to be small: Kamiya +, PRC **105**, 014915 (2022)

Potentials | Comparison with folded 2BF

Uratsu +, PRC **113**, 015204 (2026)



Rough estimate of LECs



$-1 \leq G' \leq 1$

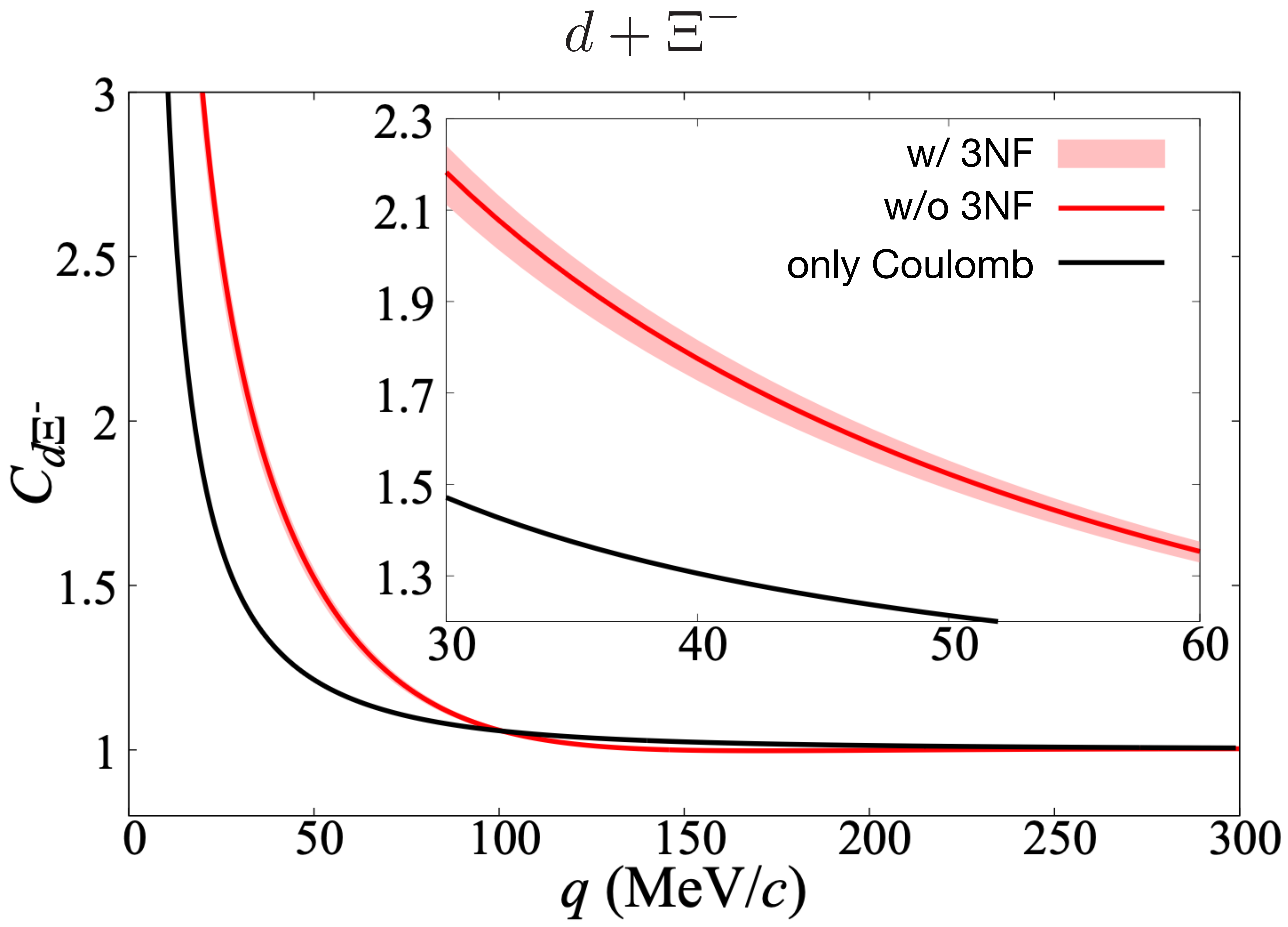
$-1 \leq H' \leq 1$

Petschauer +, NPA **957** 347 (2017)

- Weaker and shorter w.r.t. 2BF

d–Ξ^- correlation functions | 3BF effect

Uratsu +, PRC **113**, 015204 (2026)

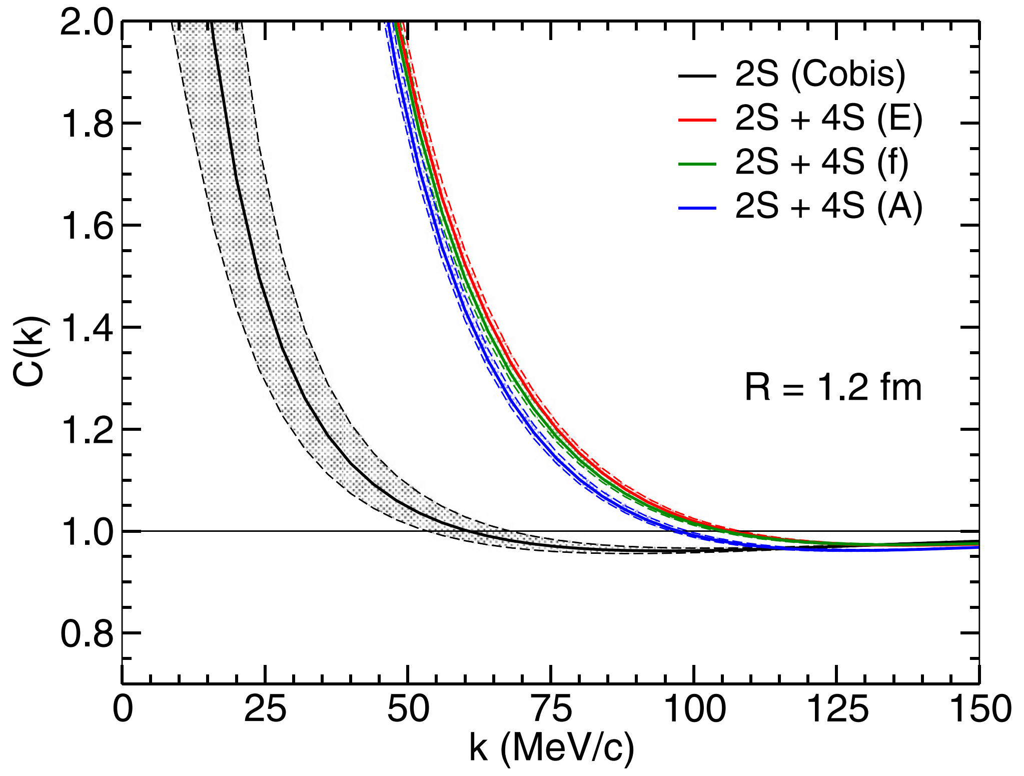


Source size: 1.2 fm

- Attractive d–Ξ^- interaction by 2BF

Consistent

Attractive d–Λ int.

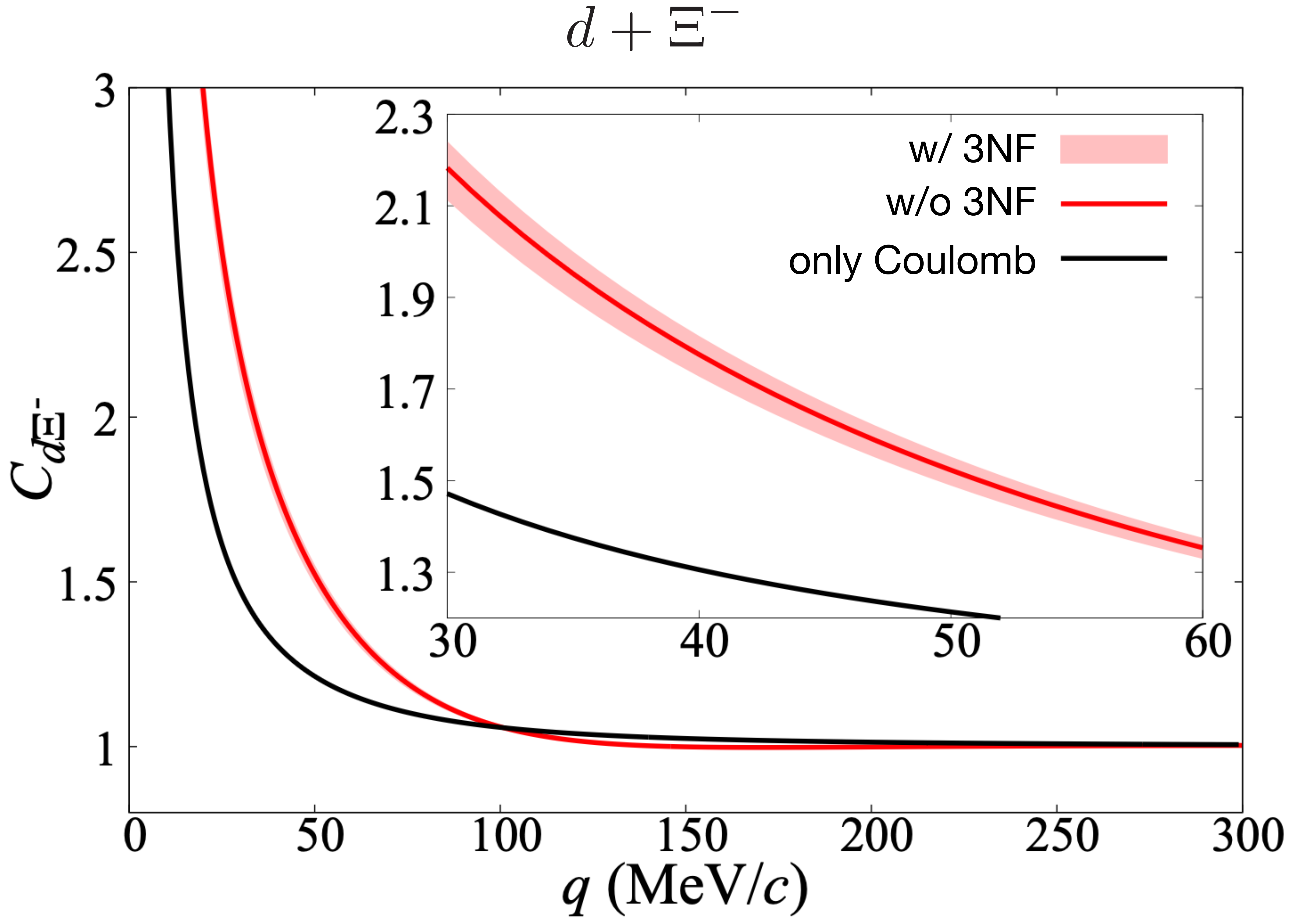


Lednicky-Lyuboshits approach w/ effective range expansion

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

d–Ξ^- correlation functions | 3BF effect

Uratsu +, PRC **113**, 015204 (2026)

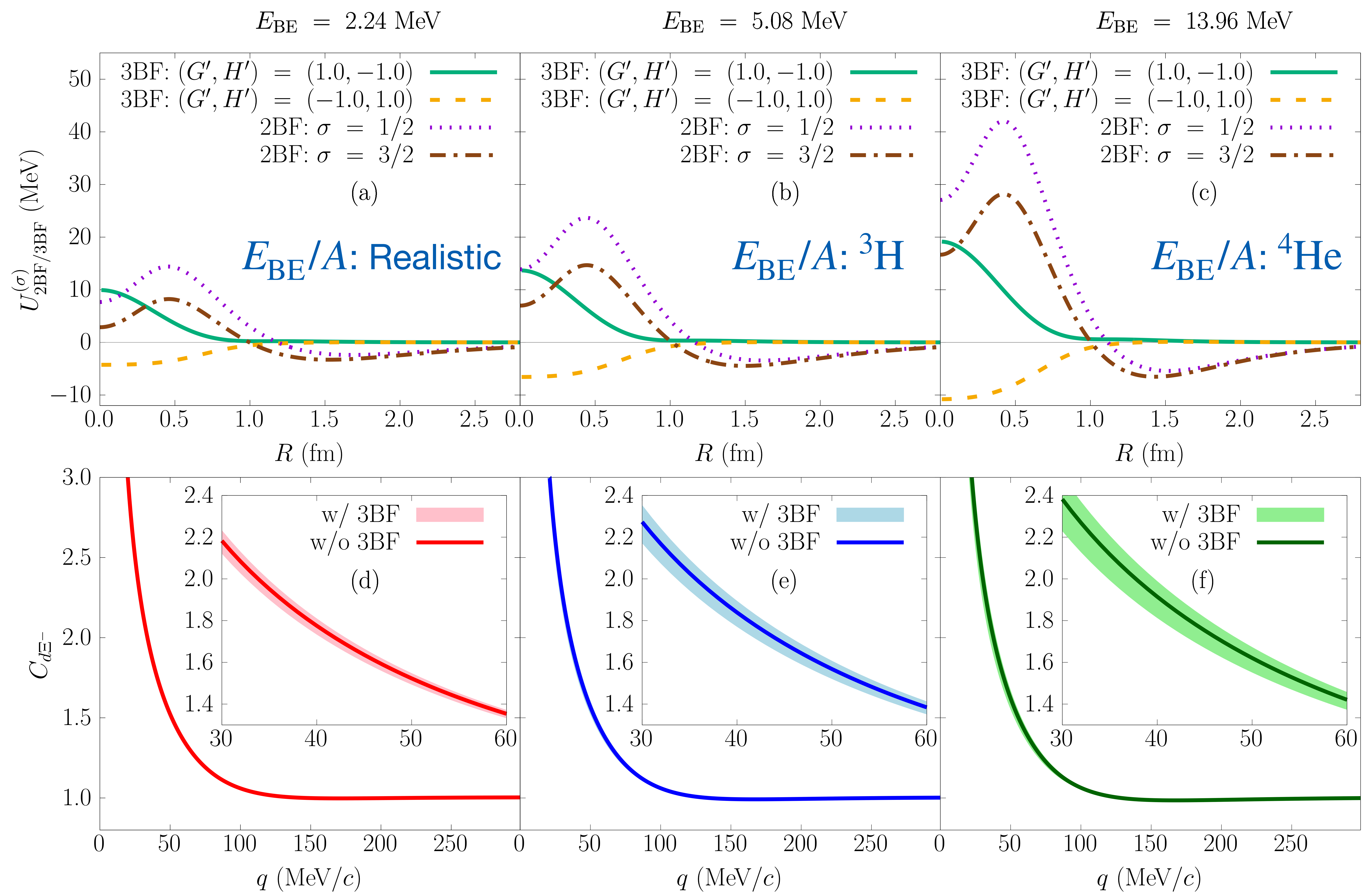


Source size: 1.2 fm

- Attractive d–Ξ^- interaction by 2BF
- 3BF effect: $\lesssim 4\%$
- Reason for small effect:
  CF is sensitive to the potential
  at $1 \lesssim R \lesssim 2$ fm
- Cutoff & source size variation:
  The same situation

d–Ξ^- correlation functions | Artificially variation of binding energies

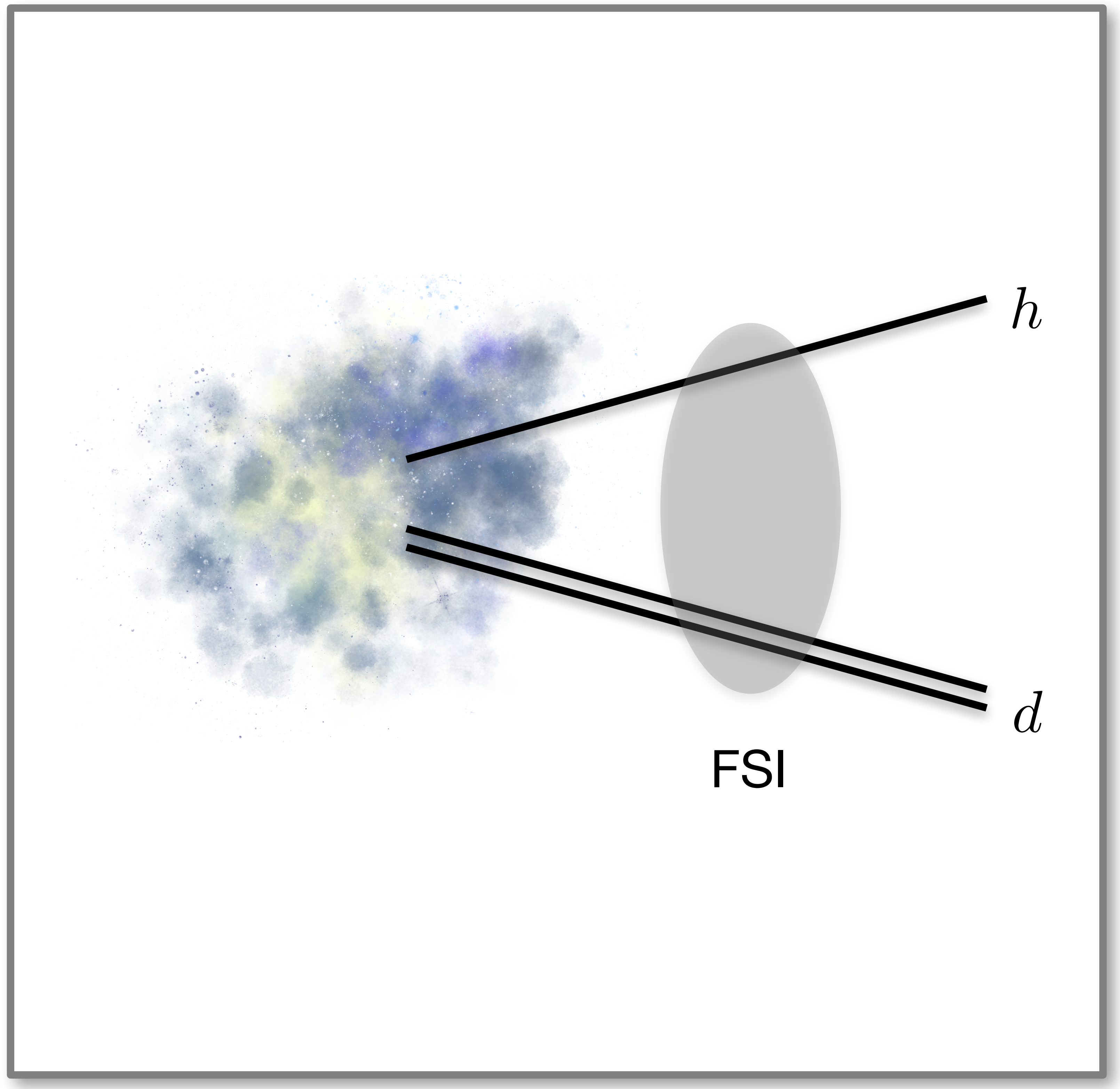
Uratsu +, PRC **113**, 015204 (2026)

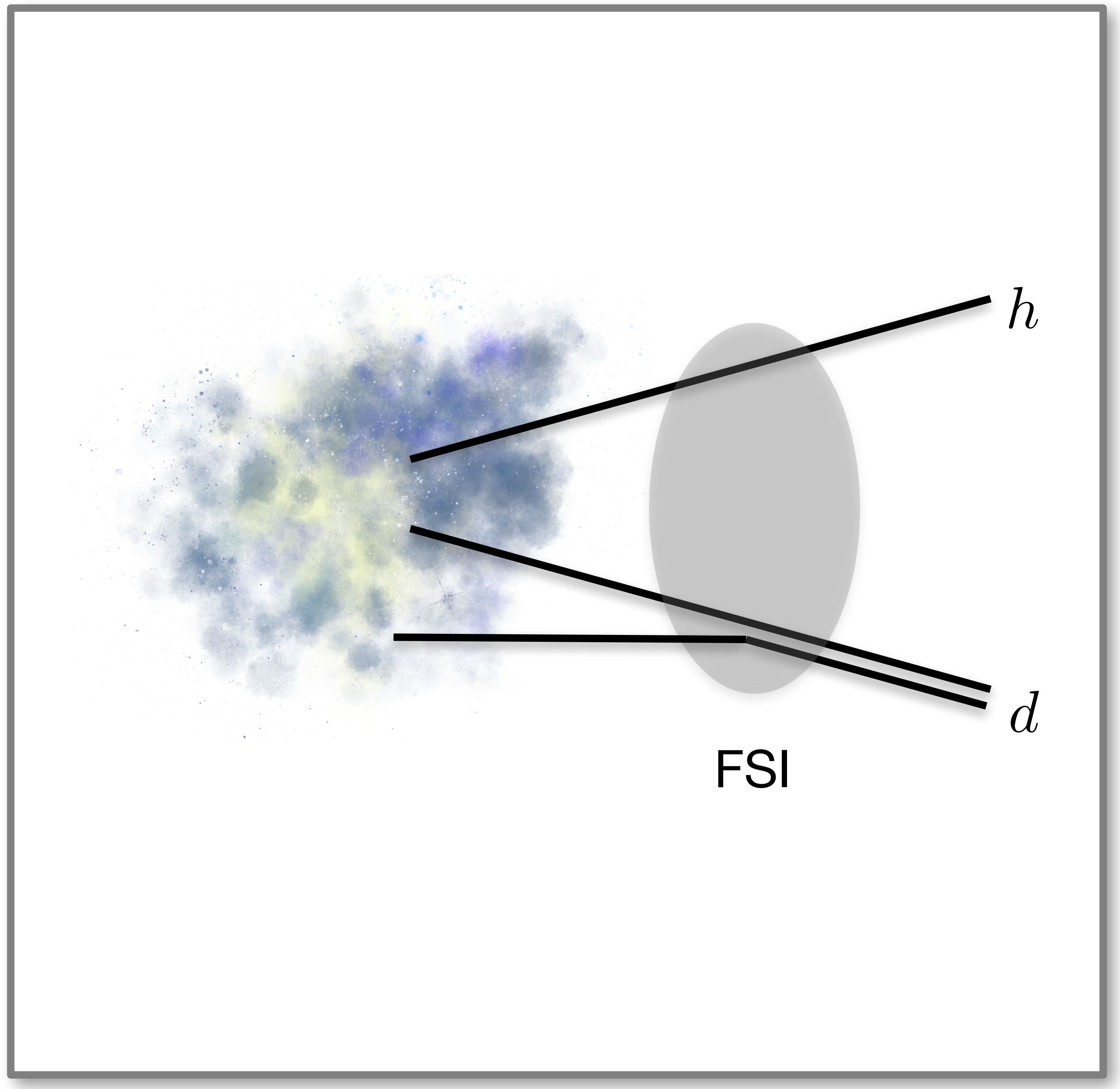


- Even deep binding:
  3BF effect $\lesssim$ 8%
- Loosely bound nature of d cannot explain small 3BF effect

Direct production or formation by final-state interaction

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





Direct production or formation by final-state interaction

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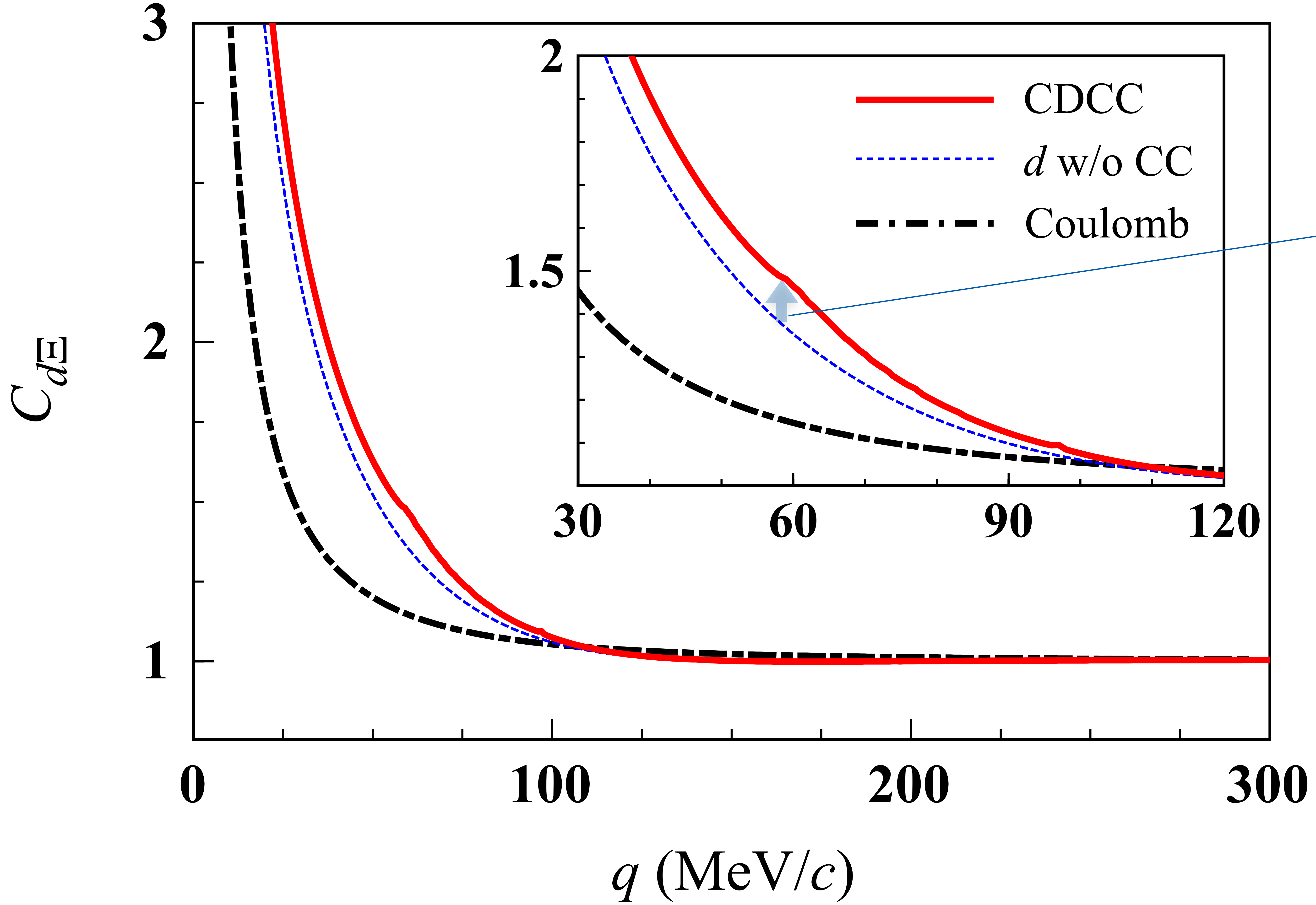
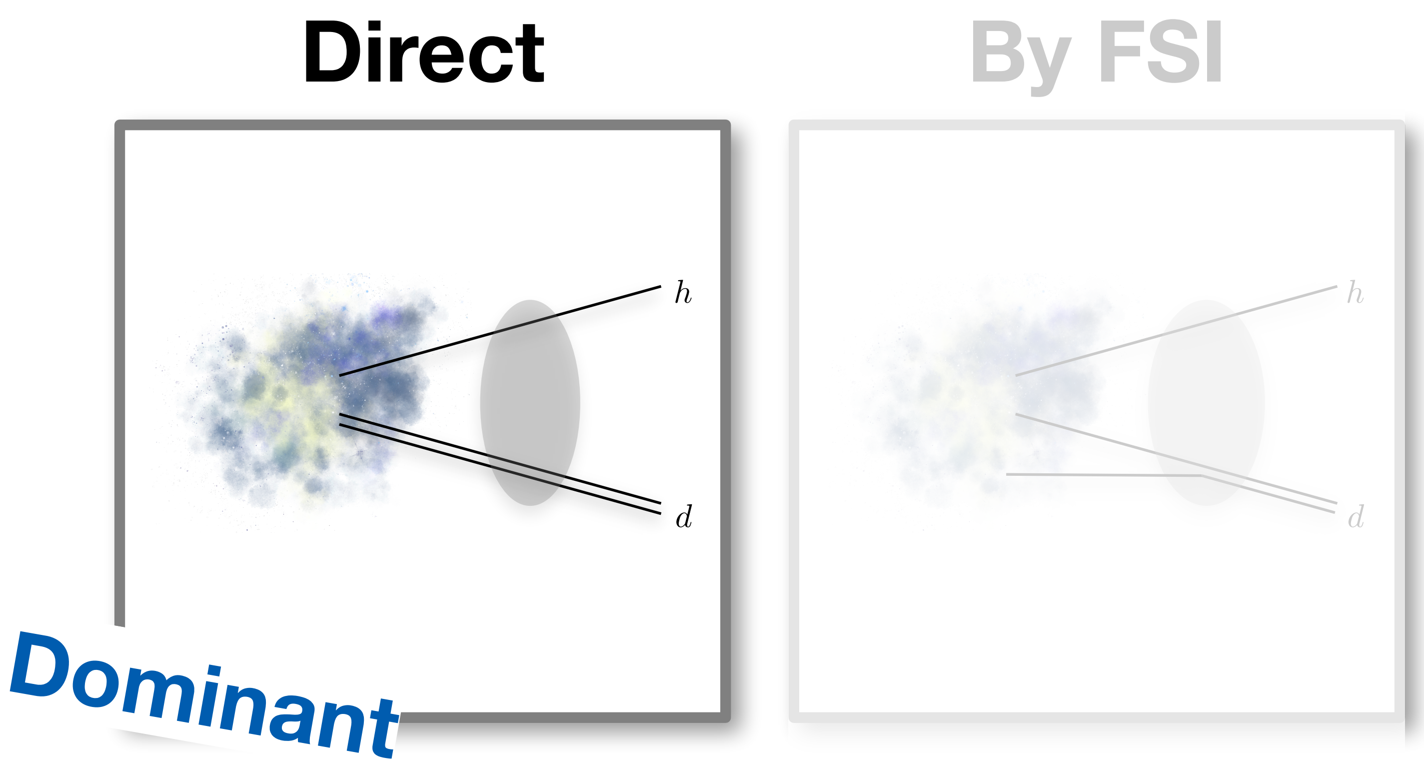


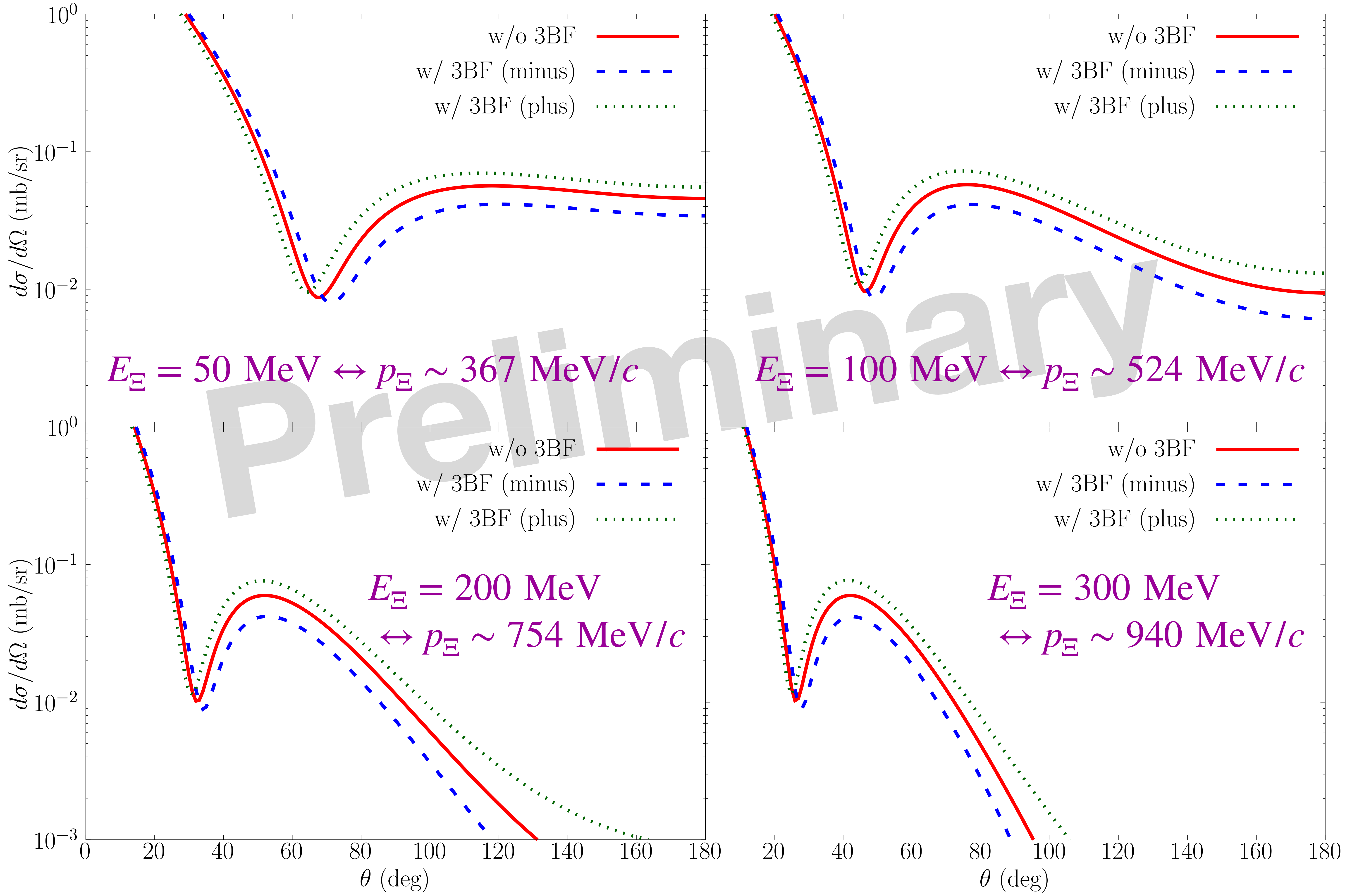
Ogata +, PRC **103**, 065205 (2021)

- Simulation w/ coupled channels method

Slight enhancement (6—8%)



d–Ξ^- elastic cross sections | 50–300 MeV

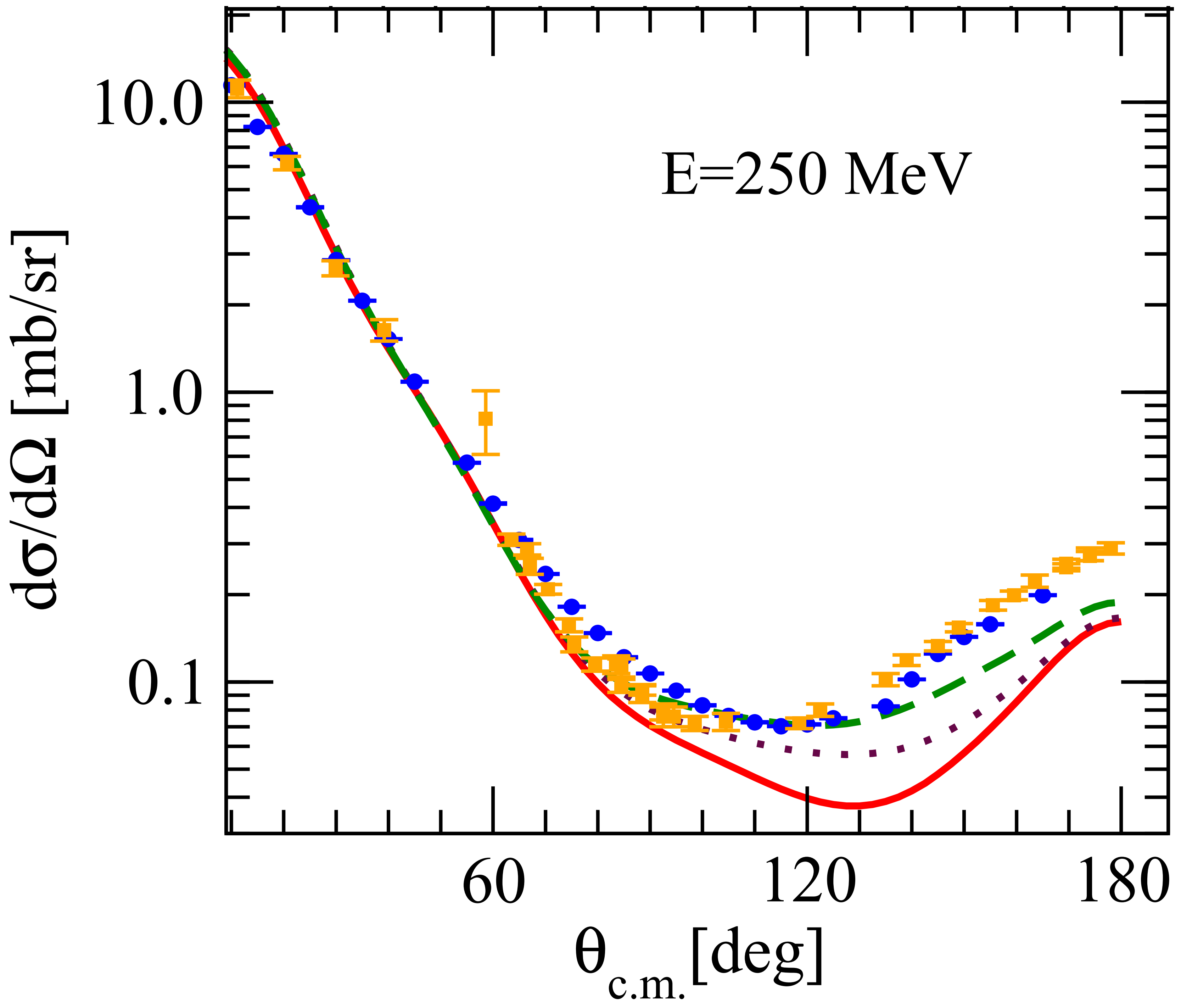


- Central 2BF + 3BF only
- 3BF effect: ~20–40% in magnitude
- Shift of dip position
- Typical experiments:
  $450 \lesssim p \lesssim 850$ MeV/c

Miwa +, PRC **104**, 045204 (2021)
Miwa +, PRL **128**, 072501 (2022)
Nanamura +, PTEP **2022**, 093D01 (2022)

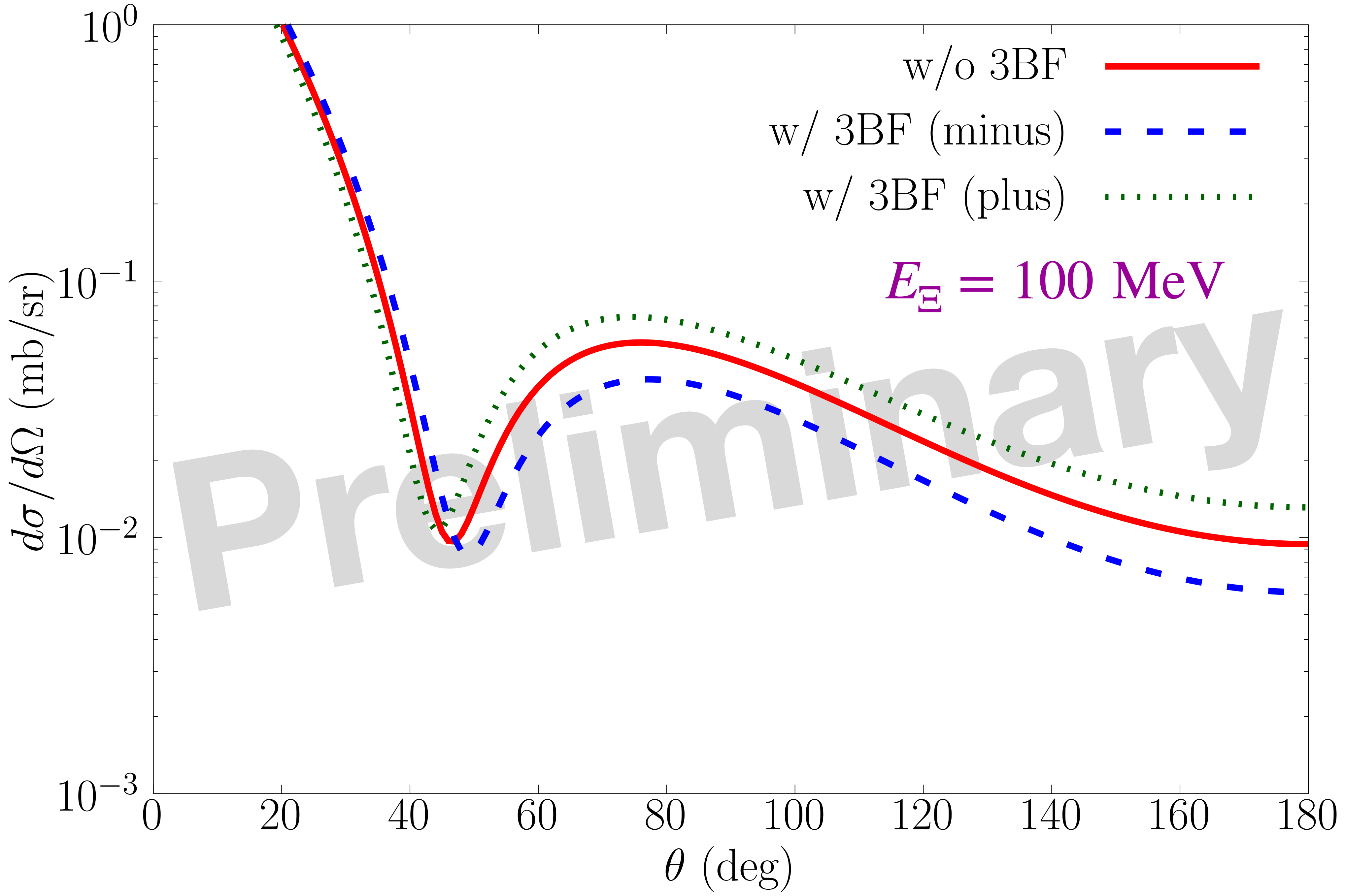
d–Ξ^- elastic cross sections | Compared to d–p cross section

$d + p$ scattering



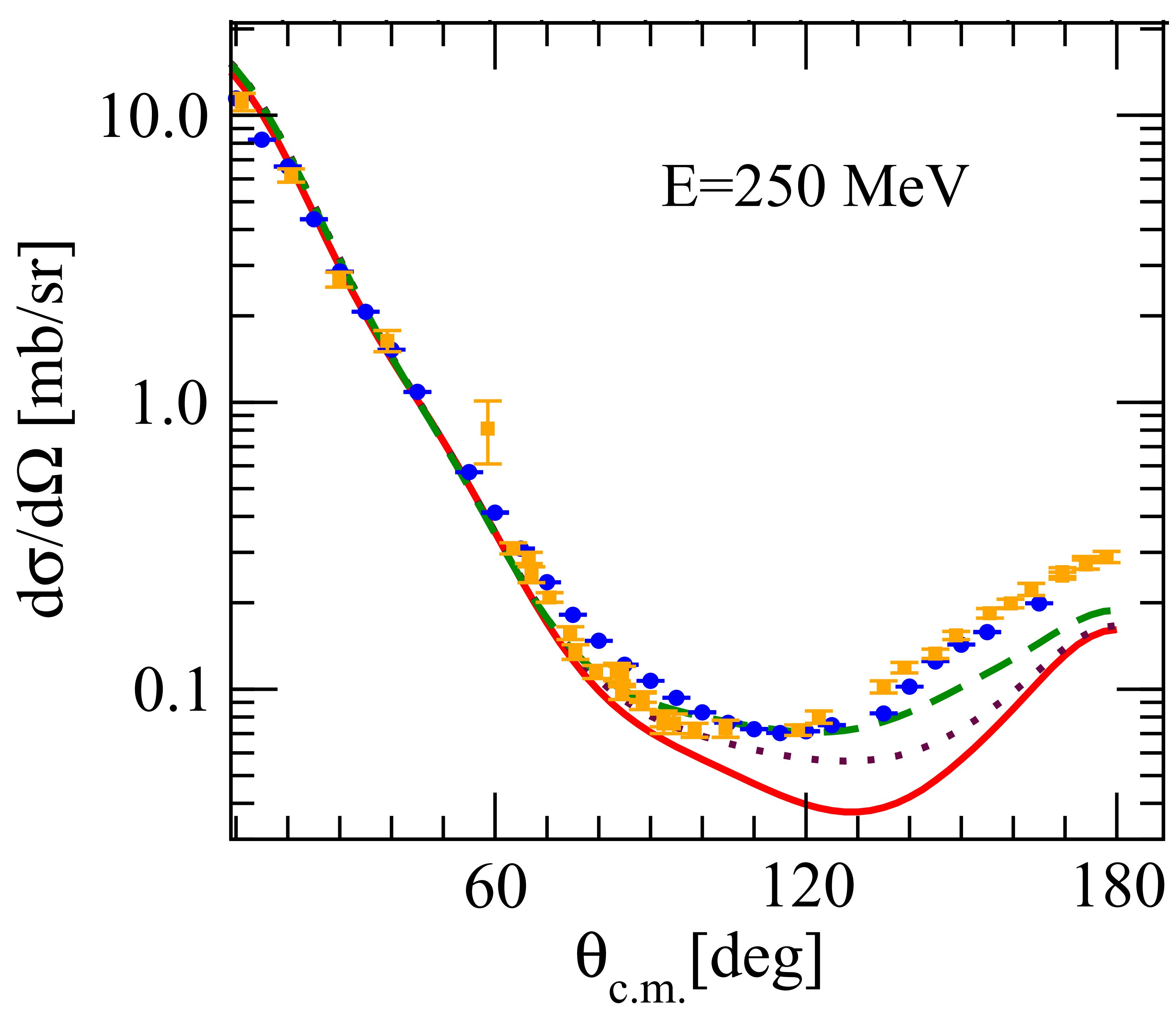
Witała +, PRC **105**, 054004 (2022)

$d + \Xi^-$ scattering



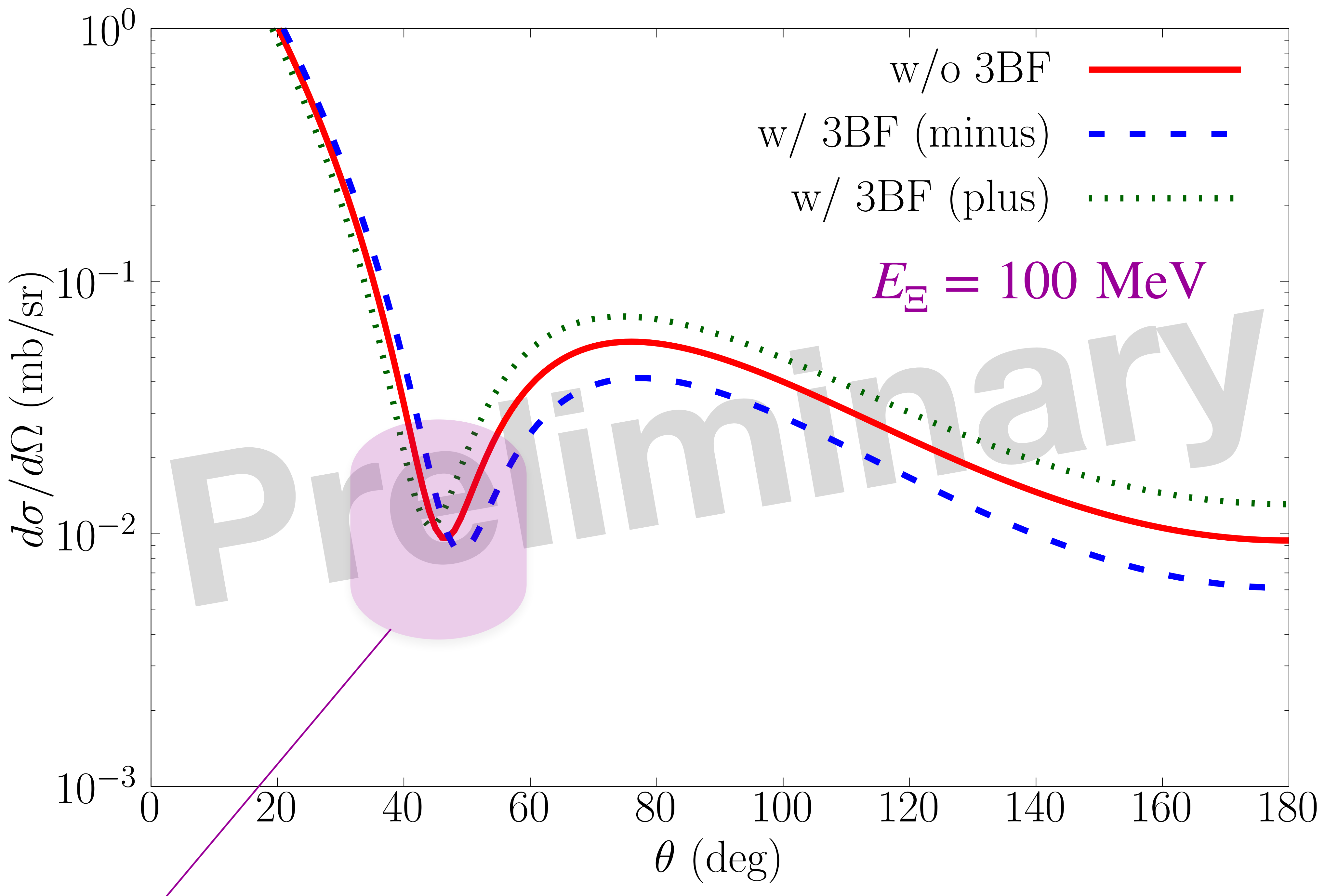
d–Ξ^- elastic cross sections | Compared to d–p cross section

$d + p$ scattering



Witała +, PRC **105**, 054004 (2022)

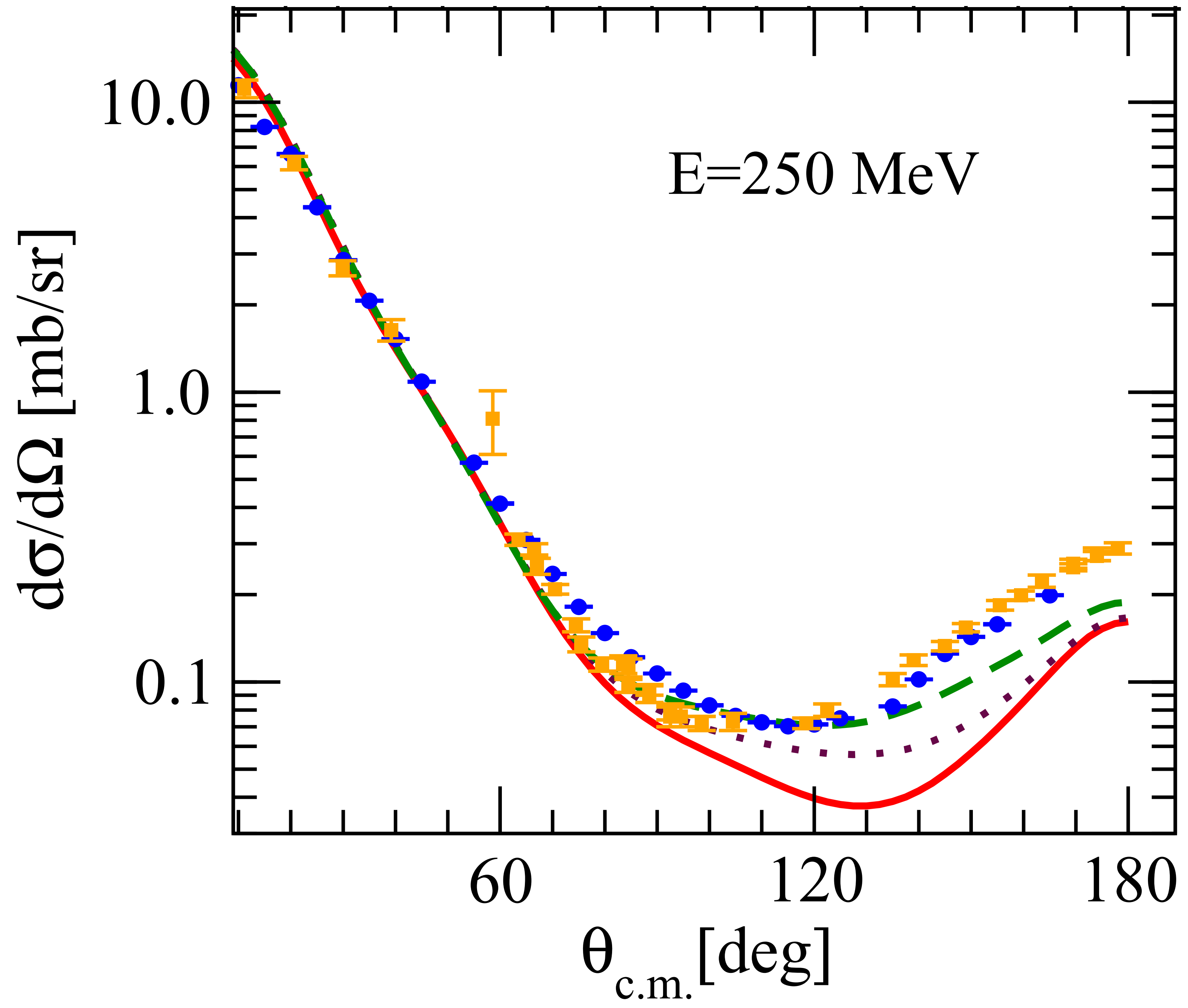
$d + \Xi^-$ scattering



Change of
increase/decrease

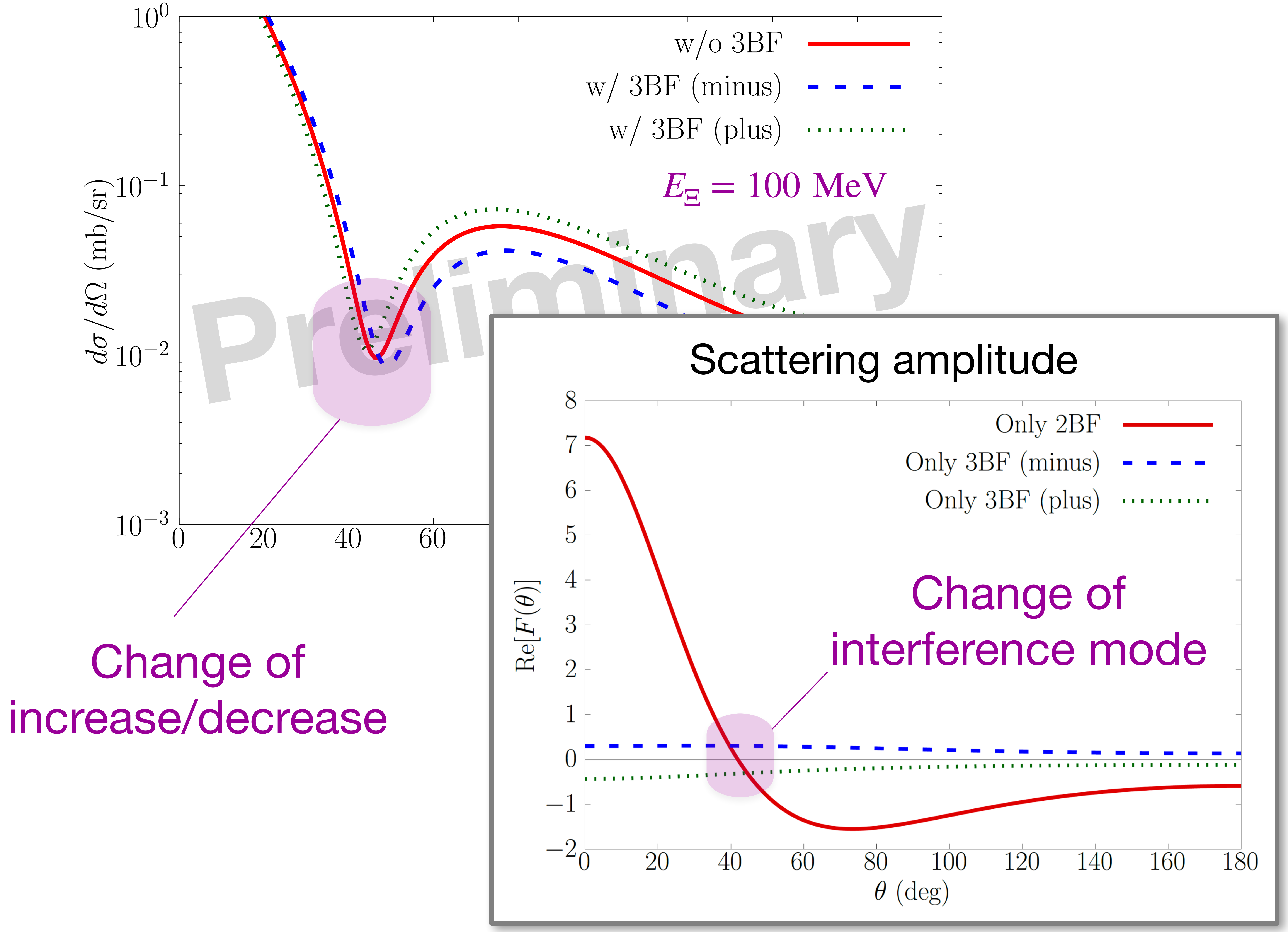
d–Ξ^- elastic cross sections | Compared to d–p cross section

$d + p$ scattering



Witała +, PRC **105**, 054004 (2022)

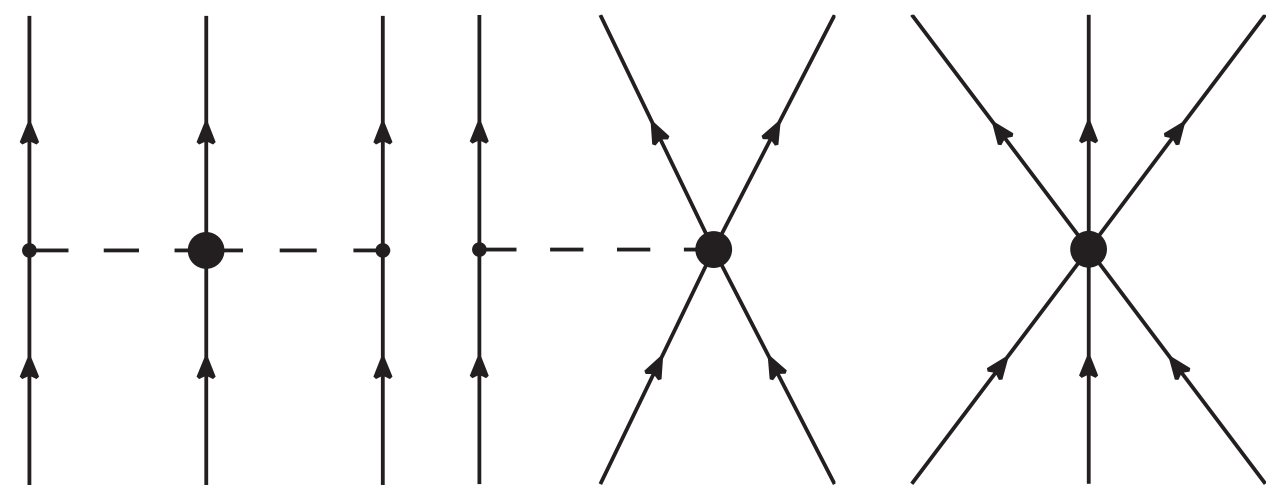
$d + \Xi^-$ scattering



Summary | 3BF with $S = -2$ and d–Ξ^- scattering

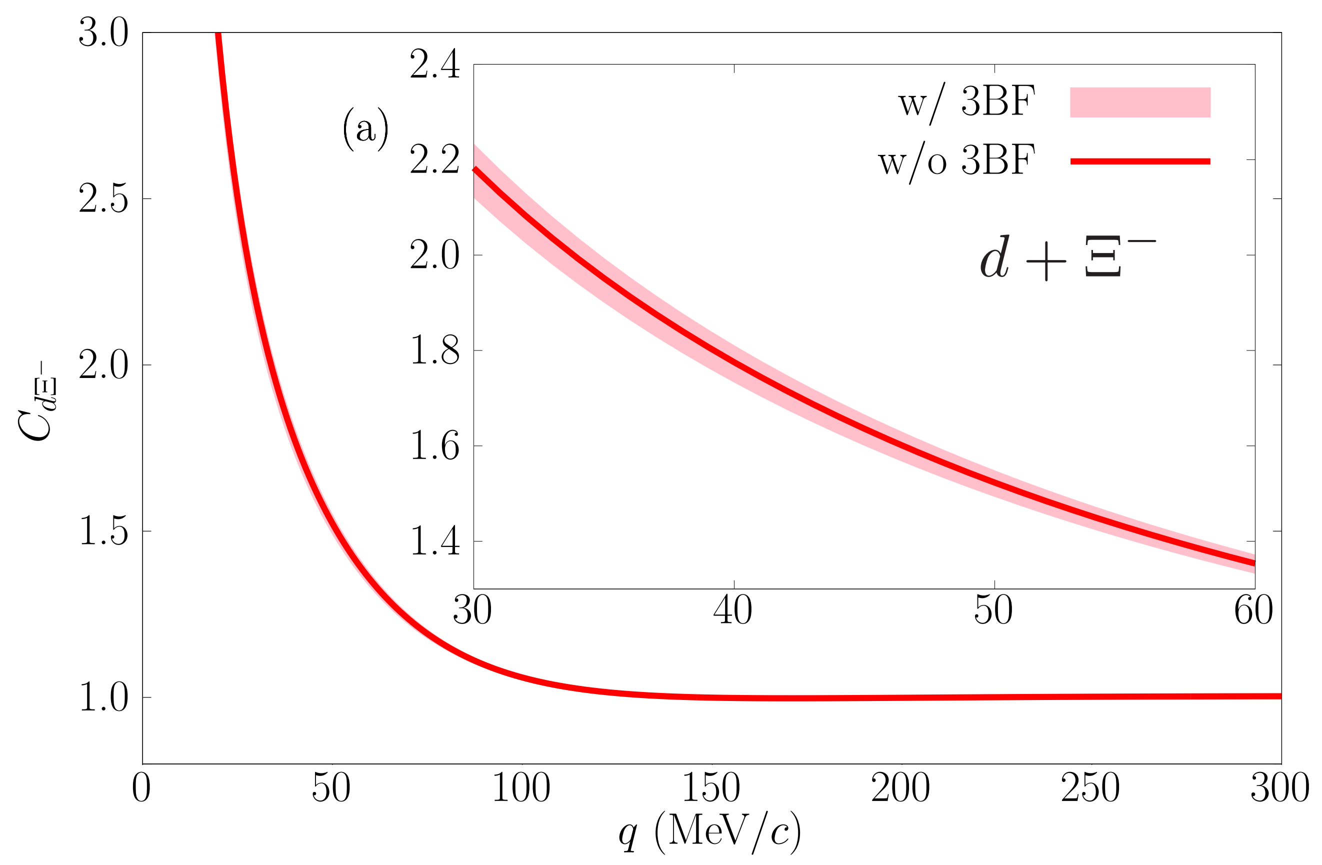
Uratsu +, PRC **113**, 015204 (2026)

ΞNN 3BF from SU(3) chiral EFT



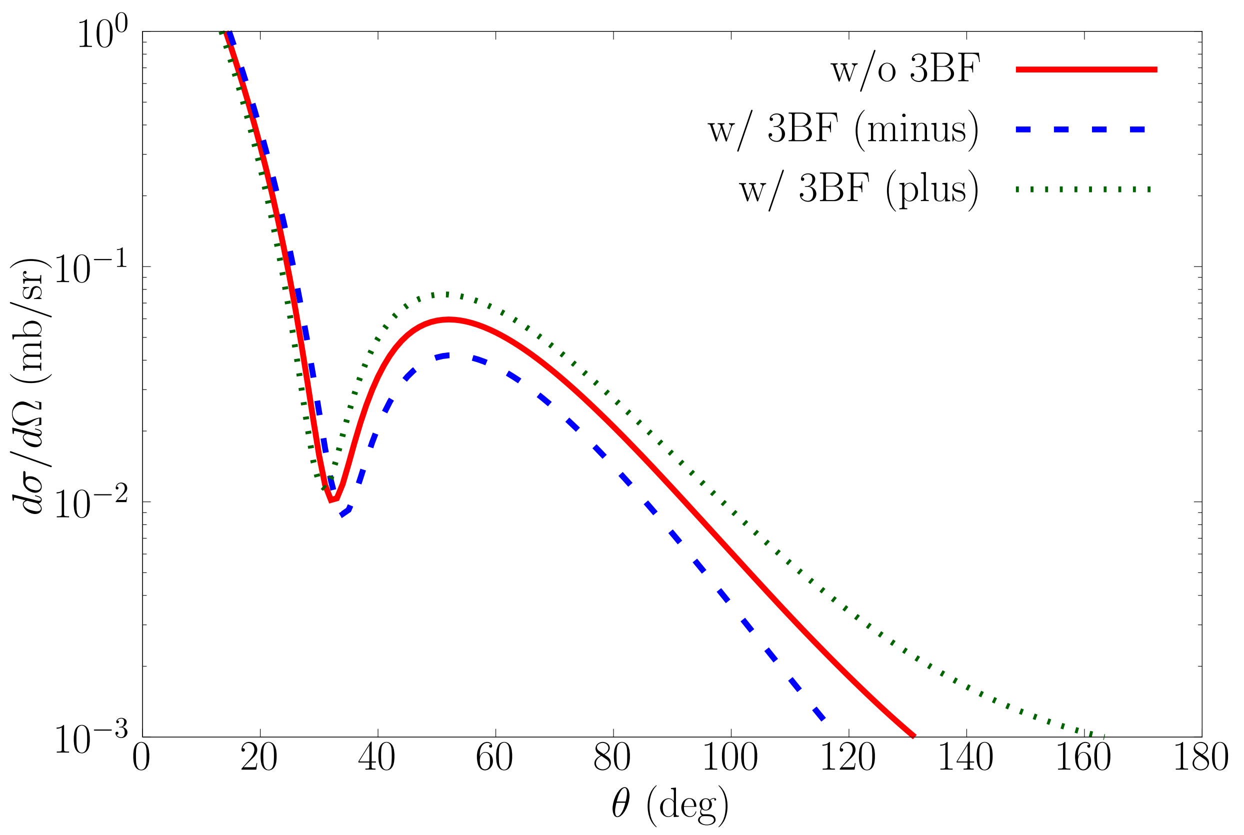
N²LO potentials derived

Femtoscopy



Very limited sensitivity to 3BF

Elastic cross sections



3BF: Possibly visible