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Three-nucleon force effects in nucleon-deuteron scattering at backward angles

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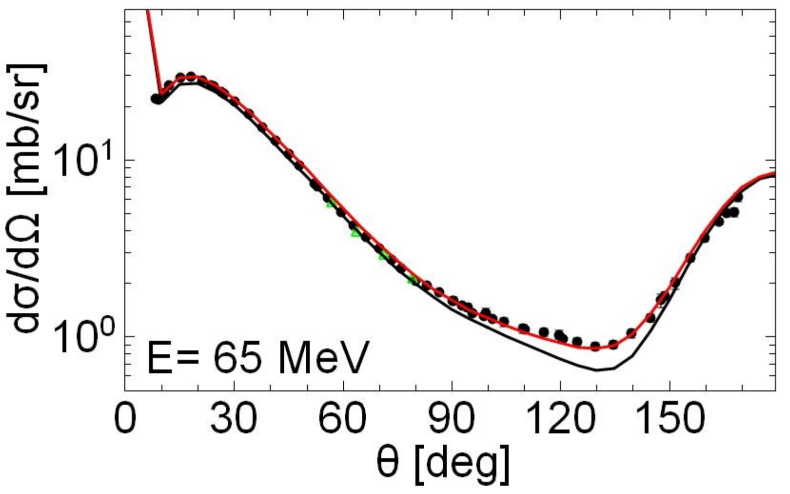
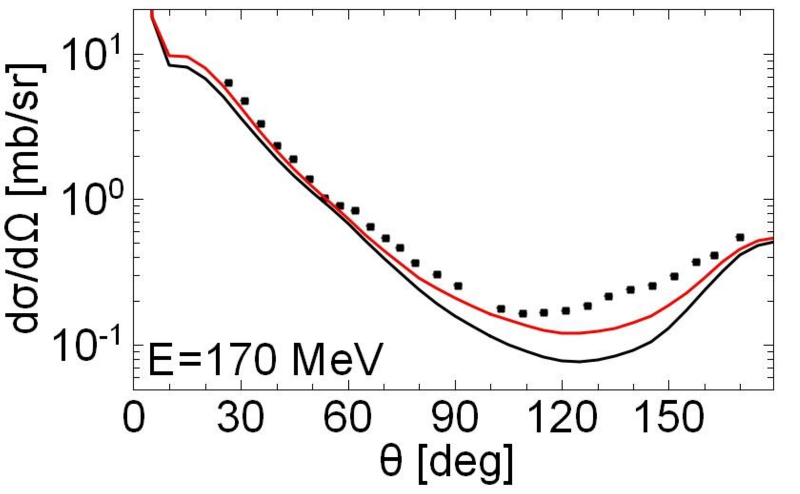
1. INTRODUCTION

Effects of Two-pion exchange three-nucleon force (2πE-3NF) on pd elastic scattering cross section at $E_p = 65$ MeV and $E_p = 170$ MeV





---- AV18 ---- AV18+BR$_{660}$

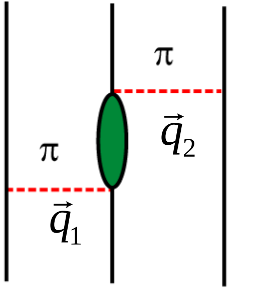
Brazil 2πE-3NF model ($\Lambda = 660$MeV)

S. I. & M.R. Robilotta, PRC76, 014006 (2007)

$$V(\vec{r}_1, \vec{r}_2) = F.T.[V(\vec{q}_1, \vec{q}_2) \times F_\Lambda(\vec{q}_1^{\,2}) F_\Lambda(\vec{q}_2^{\,2})]$$

Form factor: $$F_\Lambda(q^2) = \left(\frac{\Lambda^2 - m_\pi^2}{\Lambda^2 + q^2}\right)^2$$

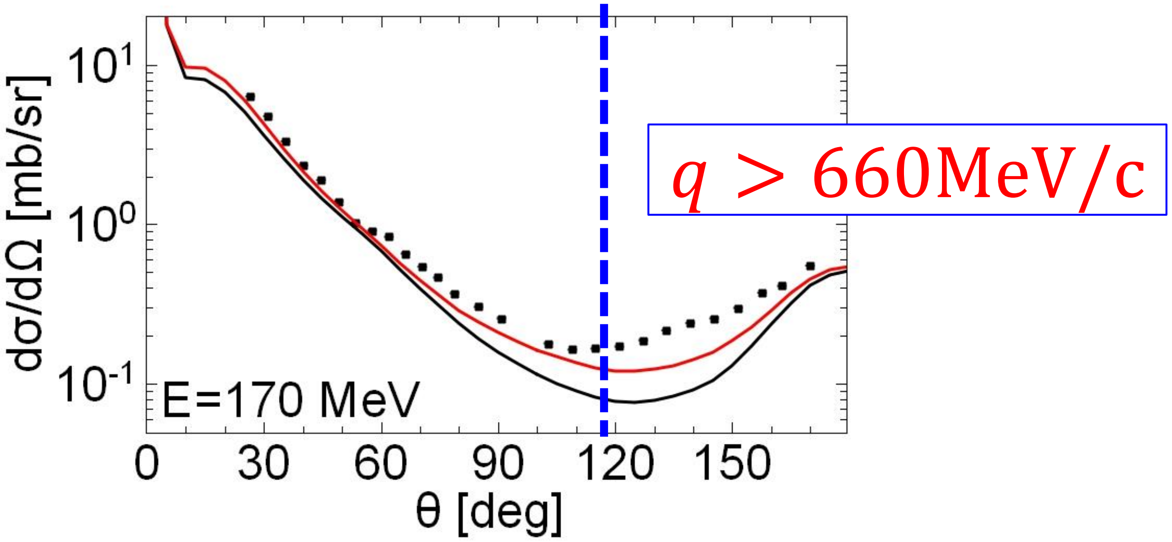
$V(\vec{q}_1, \vec{q}_2)$

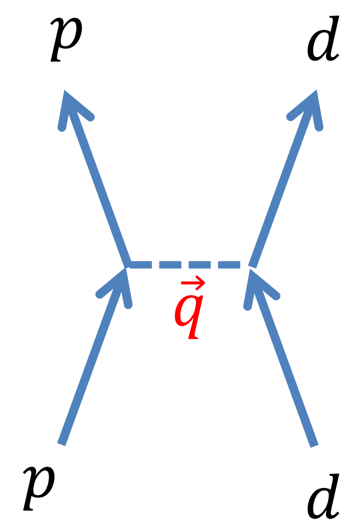


2π exchange 3NF

Data: 65MeV: H. Shimizu et al. NPA382, 242 (1982), 135MeV: K. Ermisch et al. PRC68, 051001(R) (2003)

Momentum transfer (q) becomes larger than Λ at backward angles





The smallness of Λ could hide an important role of pions at backwards angles.

In this talk, effects of 2πE-3NP with a larger value of Λ, (1000 MeV), on Nd elastic cross section at backward angles will be presented.

2. CALCULATION

Method

- 3N Faddeev calculations
  Integral equation approach in coordinate space

  Ref: S. I., PRC80, 054002 (2009)

- Partial waves:
  2N angular momentum: J=0,1,2,3,4,5
  Total angular momentum: J_0=1/2, …., 27/2

Models

1. AV18: 2NF (Argonne V_{18})

   R. B. Wiringa, et al. PRC51, 38 (1995)

2. AV18+BR_{660}: Brazil 2πE-3NP BR ($\Lambda = 660\text{MeV}$)

   S.I. and M. Robilotta, PRC76, 014006 (2007)

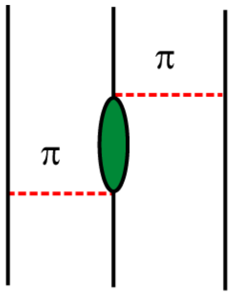
3. AV18+BR_{1000}+W_R:

   BR ($\Lambda = 1000\text{MeV}$) + Repulsive-3NP

$$W_R = W_0 e^{-\frac{r_{12}^3 + r_{13}^3}{a^2}} + [\text{c.p.}] \quad a = 1\text{fm}$$

$$W_0 = 137\ \text{MeV} \quad \Delta\text{E} \sim 4.3\ \text{MeV}$$

   S. I., FBS 60, 39 (2019)



2π exchange 3NF

3. RESULTS

(3-1) ND Elastic scattering

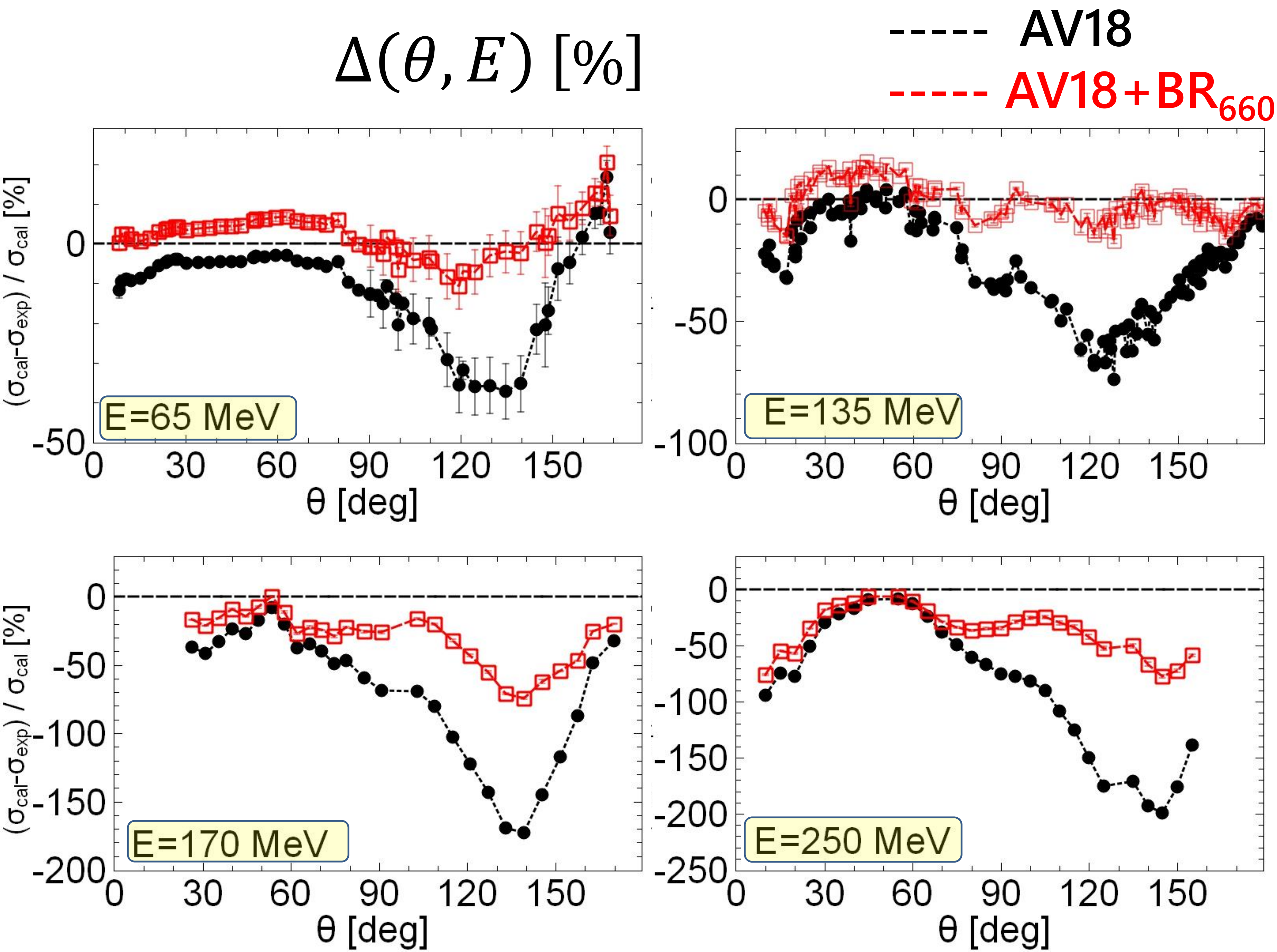
$$\Delta(\theta, E) = \frac{d\sigma^{cal} - d\sigma^{exp}}{d\sigma^{cal}} \quad [\%]$$

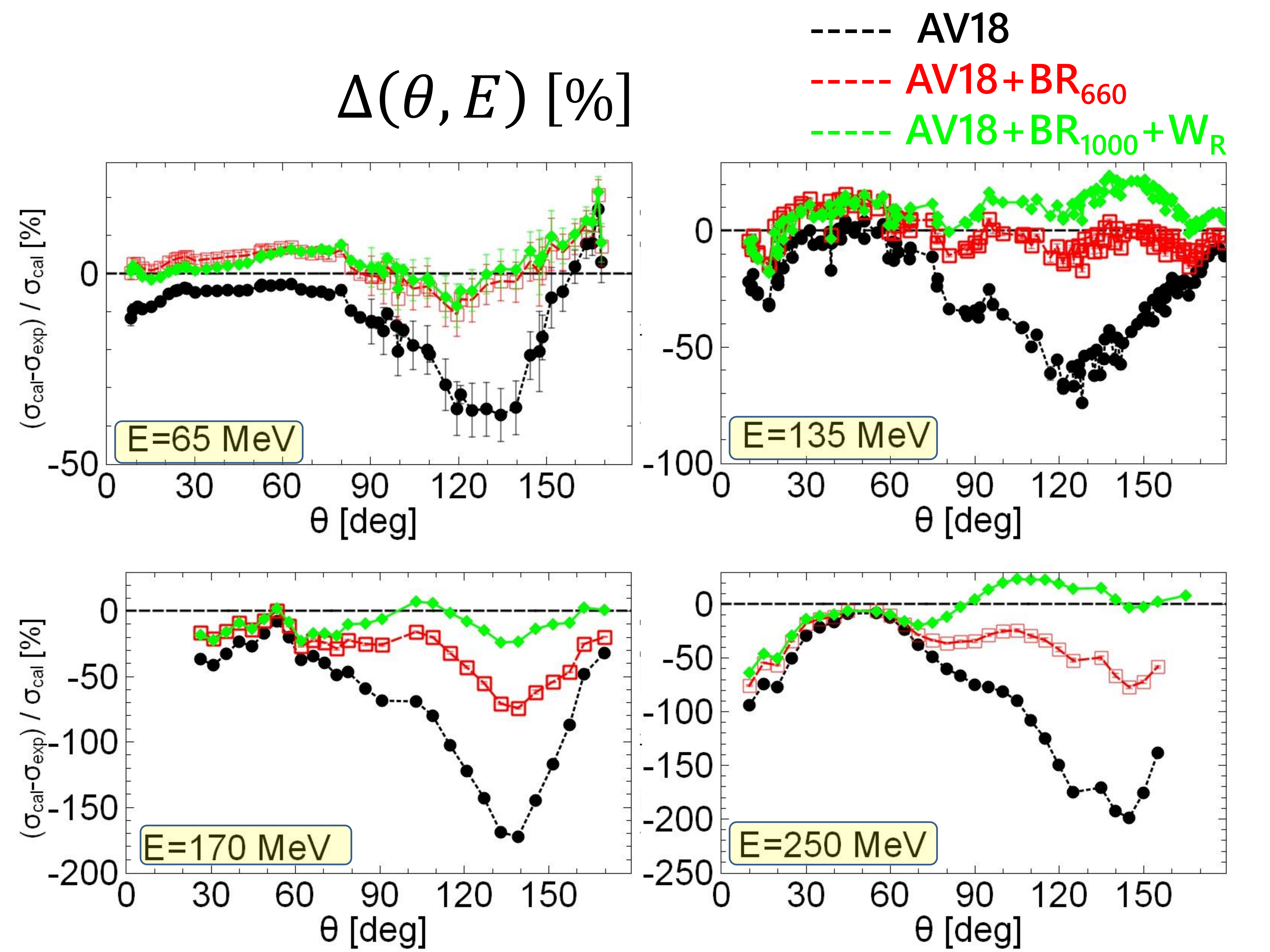
$E/A = 65, 135, 170, 250$ **[MeV]**

Calculations

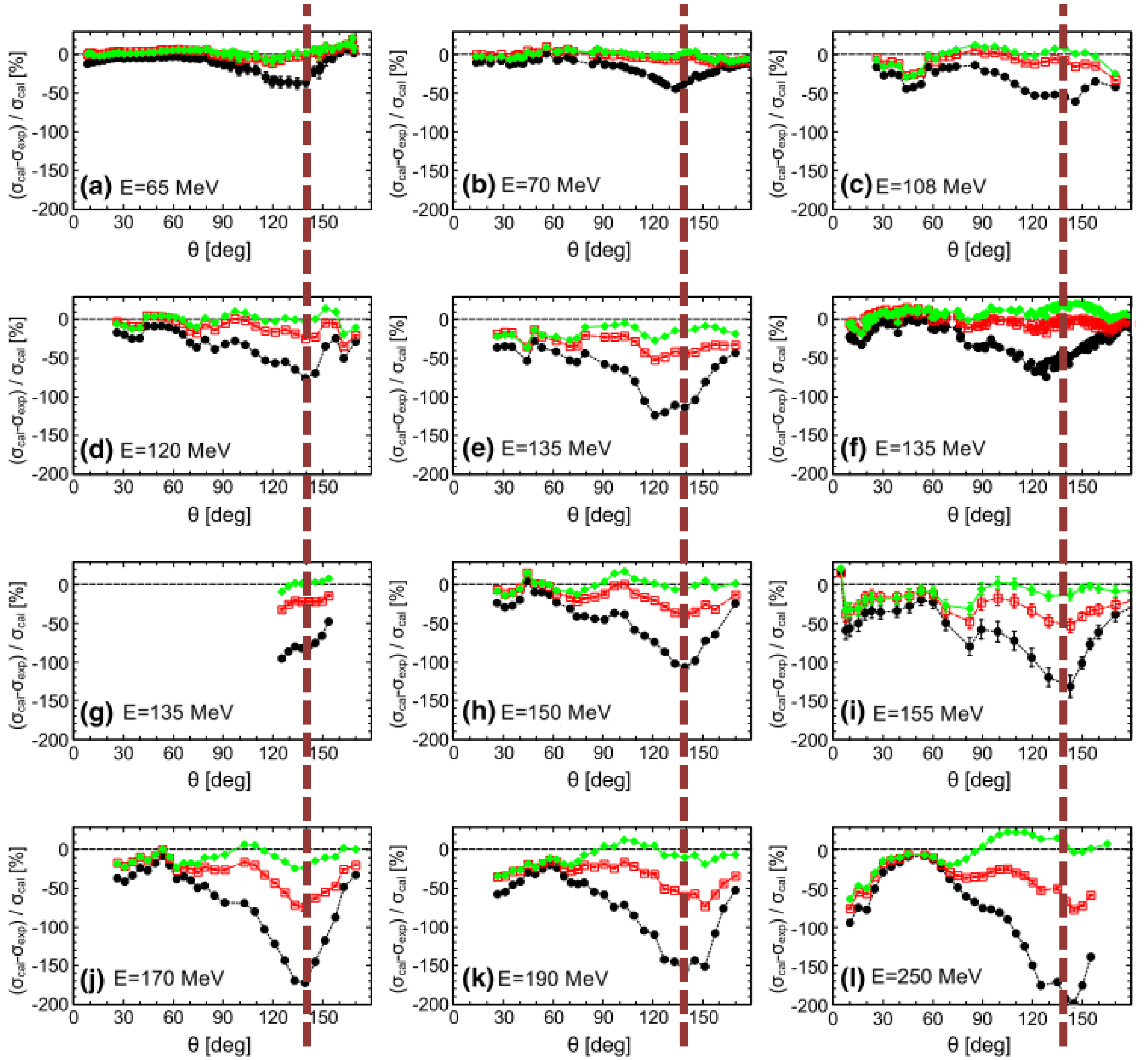
1. **AV18**
2. **AV18+BR$_{660}$**
3. **AV18+BR$_{1000}$+W$_R$**

$\Delta(\theta, E)$ [%]





AV18
AV18+BR660
AV18+BR1000+WR
Δ(θ, E) [%]
(σcal-σexp) / σcal [%]
E=65 MeV
E=135 MeV
E=170 MeV
E=250 MeV
θ [deg]



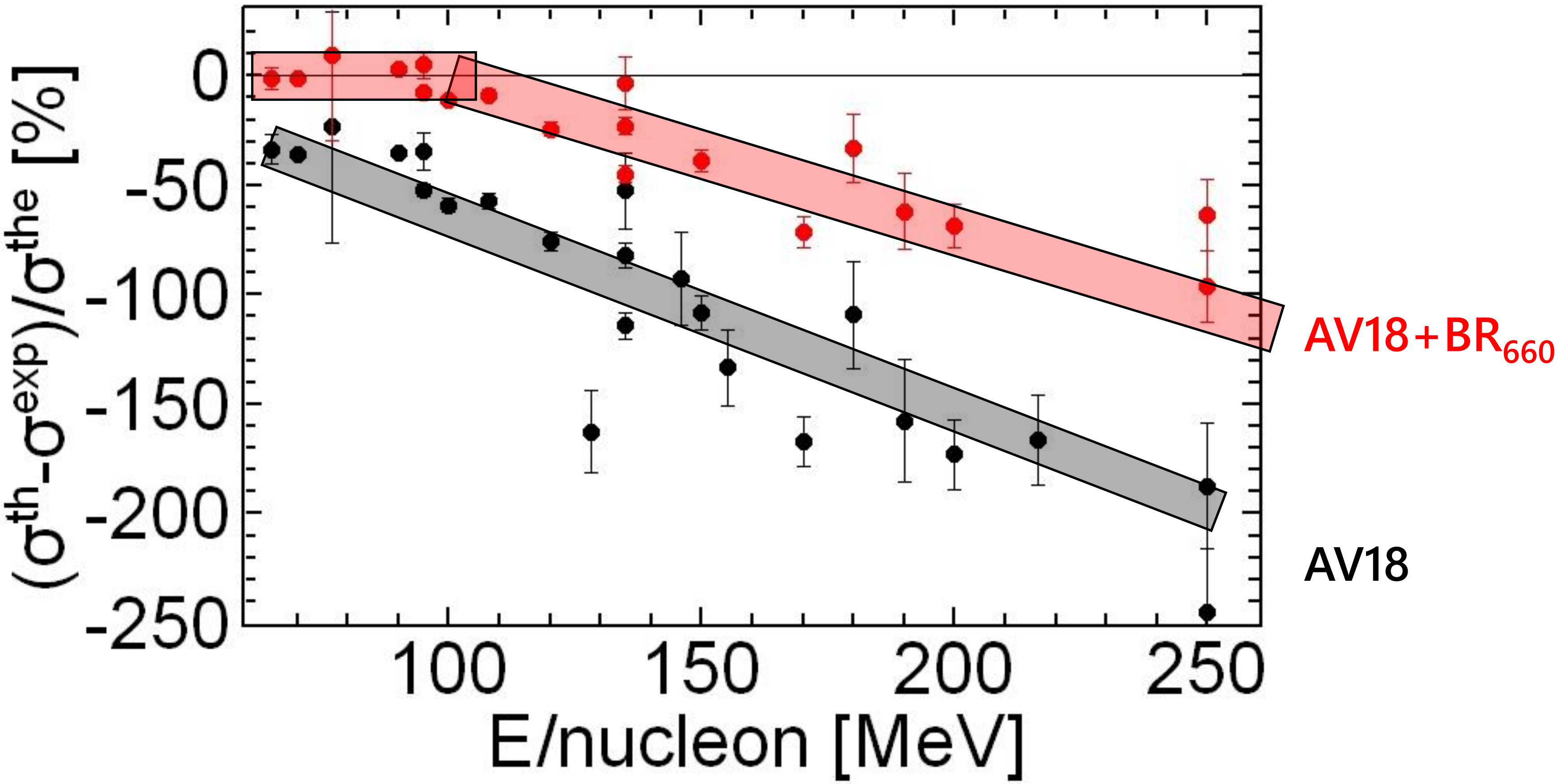
$\theta = 140°$

AV18
$\mathrm{AV18+BR_{660}}$
$\mathrm{AV18+BR_{1000}+W_R}$

Fig. 3 (Color online) Relative difference between experimental data and calculations of the *p*–*d* cross section. In each figure, solid circles connected by dotted lines (black) denotes for AV18, empty circles connected by dashed lines (red) for AV18+BR$_{660}$, and solid diamonds connected by full lines (green) for AV18+BR(C)$_{1000}$. Experimental data are from Refs. [22] for **a**; [20] for **b**; [21] for **c**, **d**, **e**, **h**, **j**, and **k**; [23] for **f**; [24] for **g**; [25] for **i**; and [26] for **l**

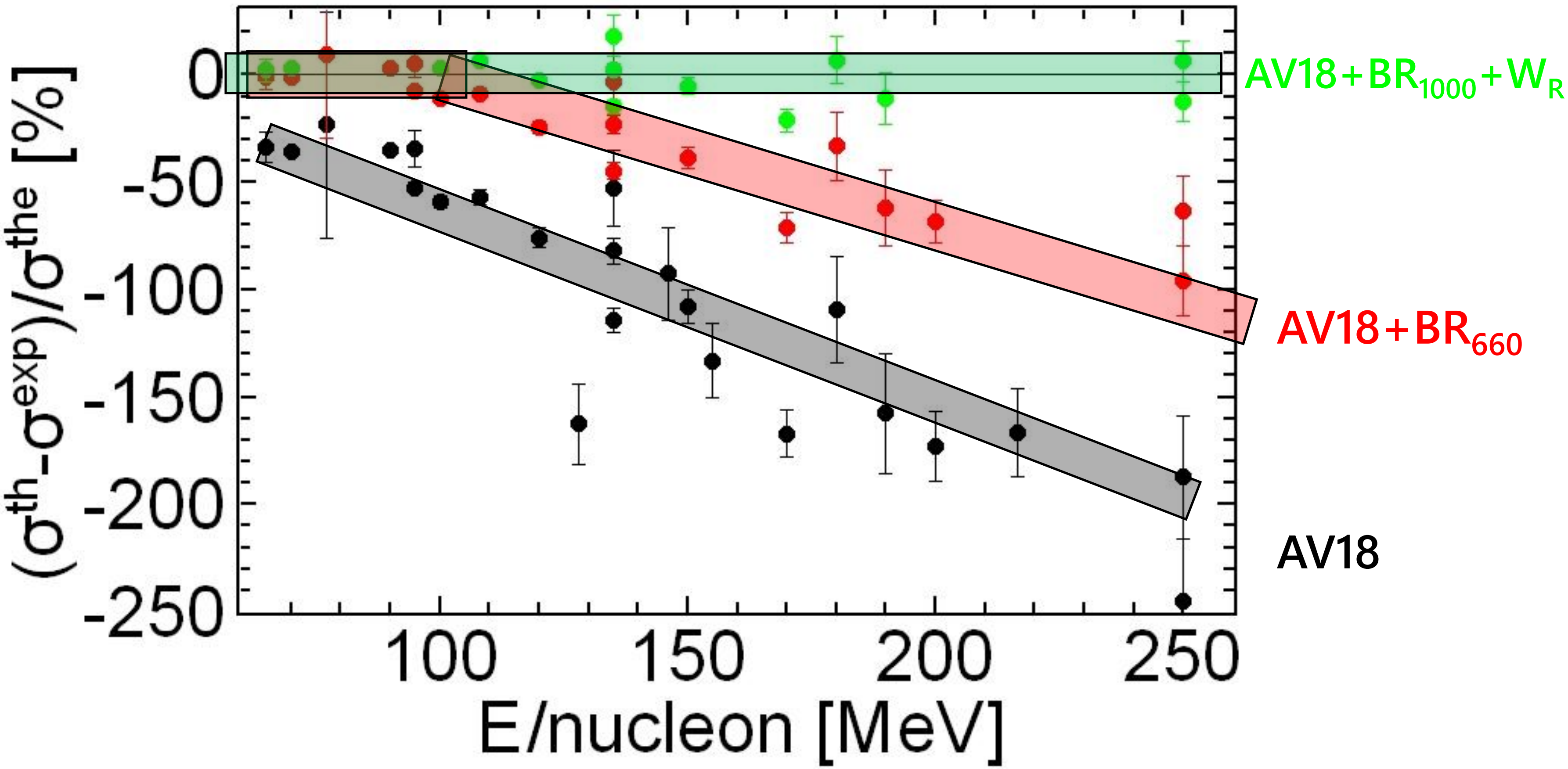
S. I., FBS 60, 39 (2019)

$$\Delta(\theta = 140°, E)\ [\%]$$



$$\Delta(\theta, E) = \frac{d\sigma^{cal} - d\sigma^{exp}}{d\sigma^{cal}}\ [\%]$$

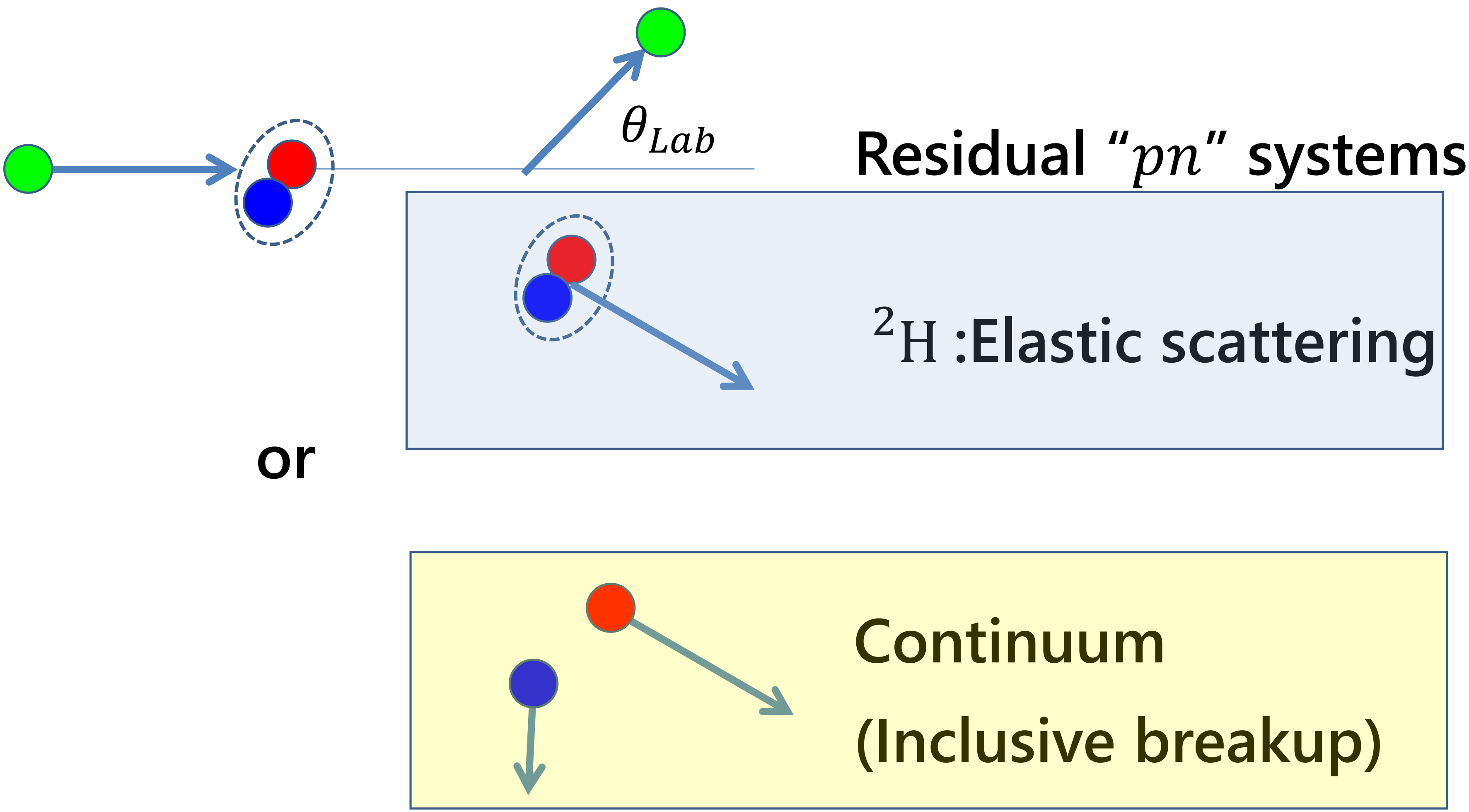
$\Delta(\theta = 140°, E)$ [%]



$$\Delta(\theta, E) = \frac{d\sigma^{cal} - d\sigma^{exp}}{d\sigma^{cal}} \;[\%]$$

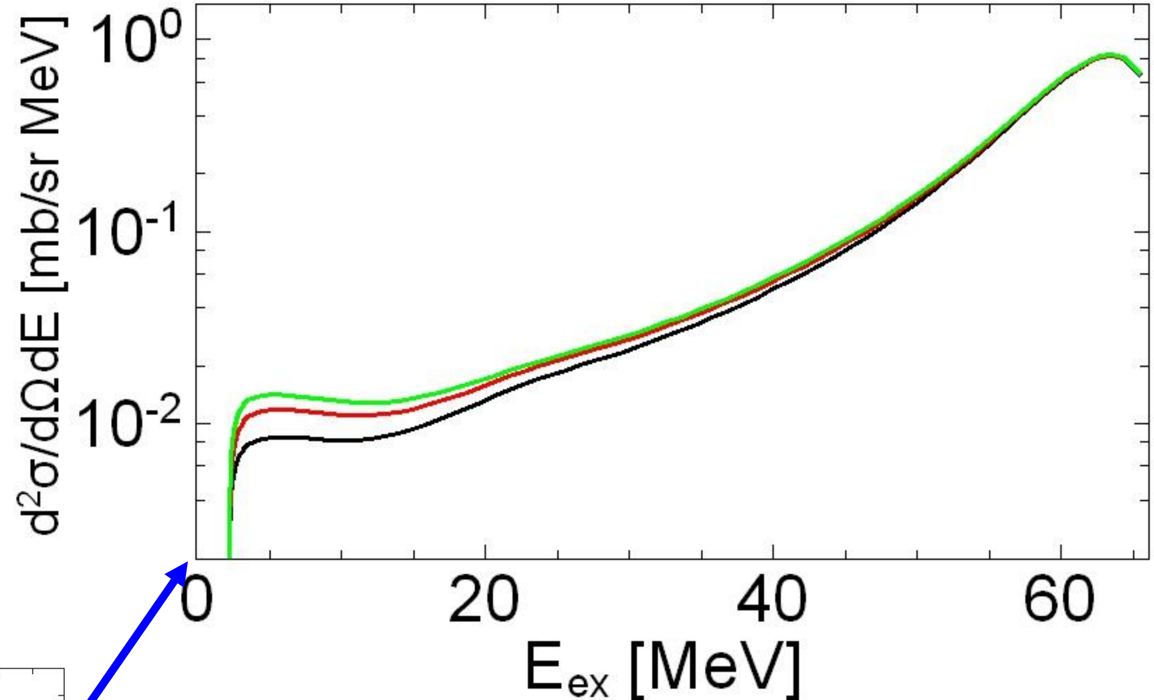
(3-2) Inclusive ND breakup reactions

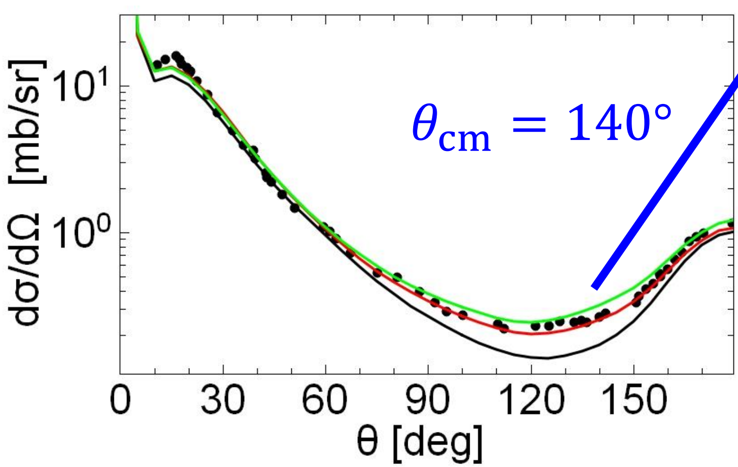
$$^{2}\mathrm{H}(p, p')pn$$



$^{2}\mathrm{H}(p,p')pn \quad E_p = 135\ \mathrm{MeV} \quad \theta_{p',\mathrm{Lab}} = 110°$

----- AV18
----- AV18+BR_{660}
----- AV18+BR_{1000}+W_{R}





4. R-SPACE CUTOFF PROCEDURE

- The meaning of $\Lambda = 660$ MeV in r-space ?
- Cutoff (Regularization) procedure in r-space used for χEFT-2NP & 3NP:

$$V(\vec{r}_1, \vec{r}_2) = F.T.[V(\vec{q}_1, \vec{q}_2)] \times f(r_1) f(r_2)$$

Refs.:

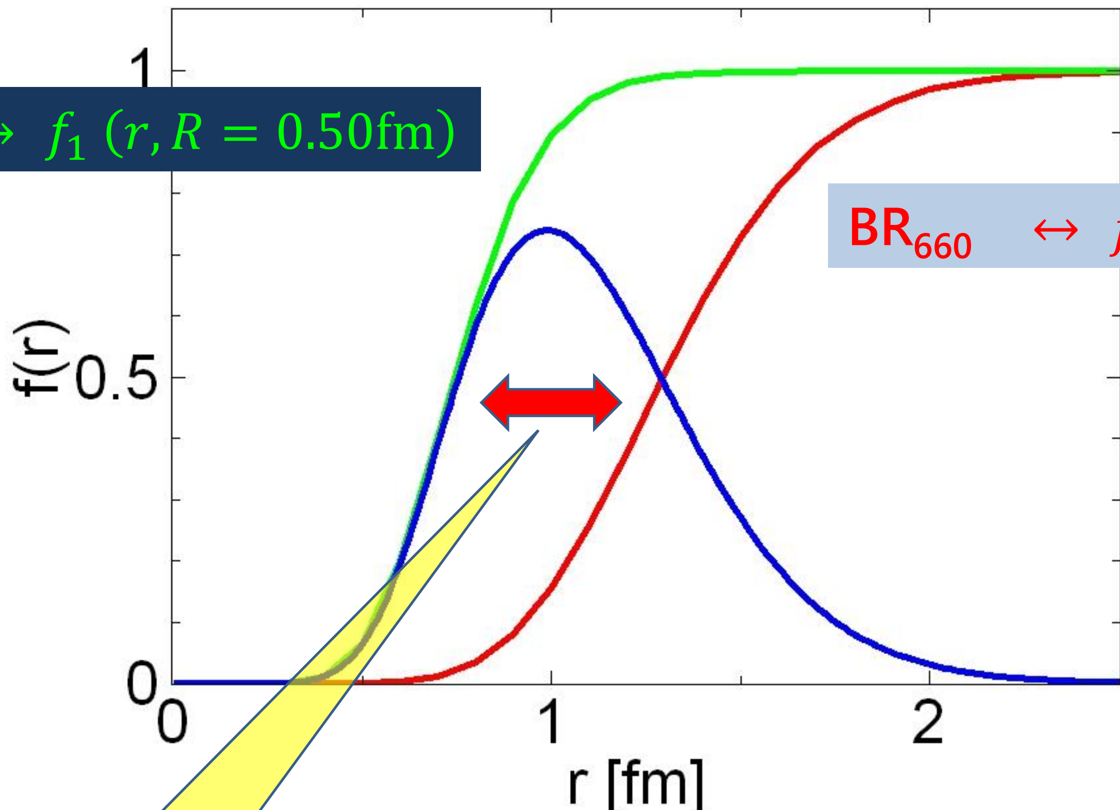
- S. Binder et al., PRC 98, 014002 (2018);
  E. Epelbaum et al., PRC 99, 024313 (2019)
- M. Piarulli et al., PRL 120, 052503 (2018)

Equivalent Regulator functions

Parameter ***R*** is determind to produce the same 3N binding energy as $\mathbf{BR}_{\Lambda}$

$$f_R(r) = \left[1 - e^{-r^2/R^2}\right]^6$$

$\mathbf{BR}_{1000}$ $\leftrightarrow$ $f_1\,(r, R = 0.50\text{fm})$



$\mathbf{BR}_{660}$ $\leftrightarrow$ $f_1\,(r, R = 0.87\text{fm})$

Difference

Pion exchange around $r = 1$ fm

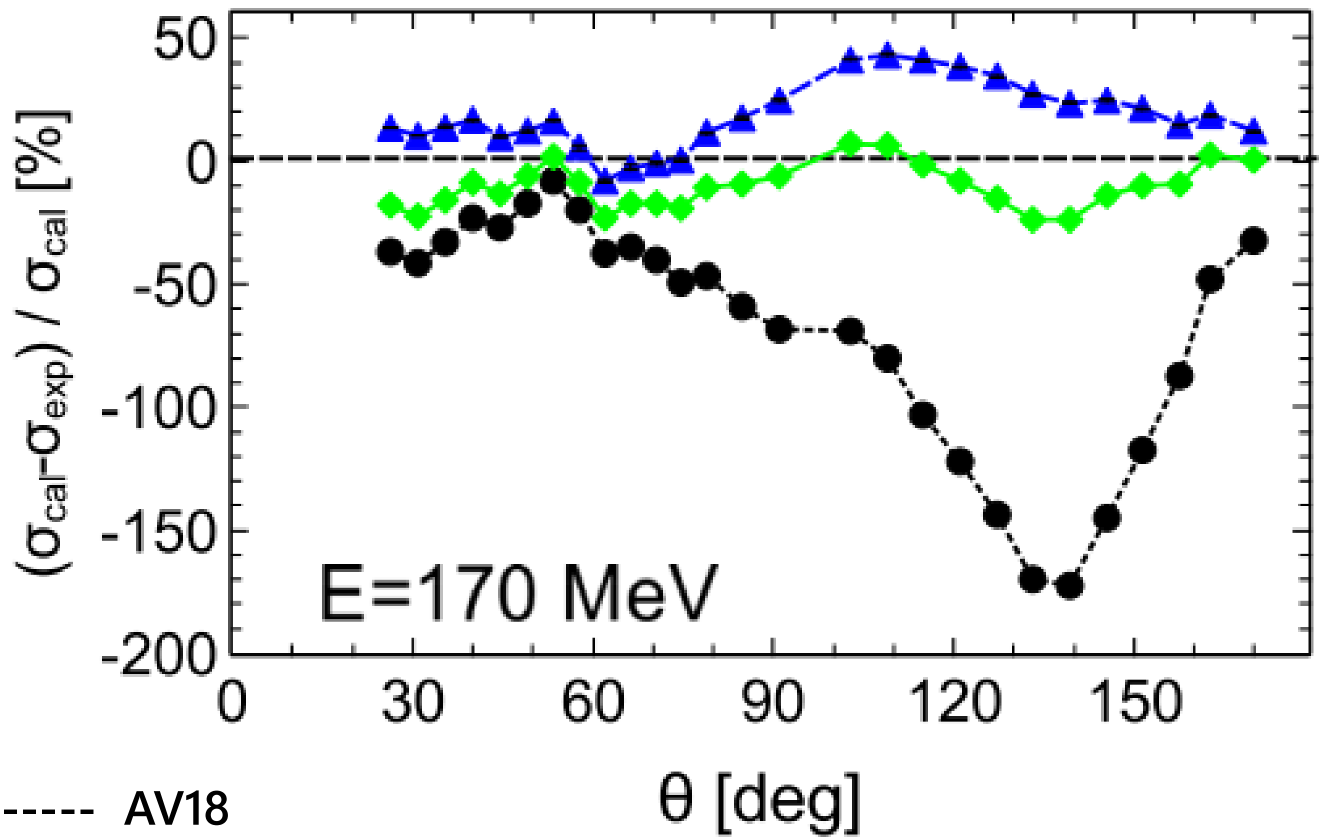
4. SUMMARY

- The use of a larger value of cutoff parameter in the 2πE-3NP enhances ND elastic cross sections at backward angles for intermediate energies, which tends to reduce the discrepancies between data and calculations.
- Similar effects are observed in inclusive breakup reactions.
- This implies the importance of pion exchange in the 2πE-3NP around $r = 1$ fm.

[Further study]

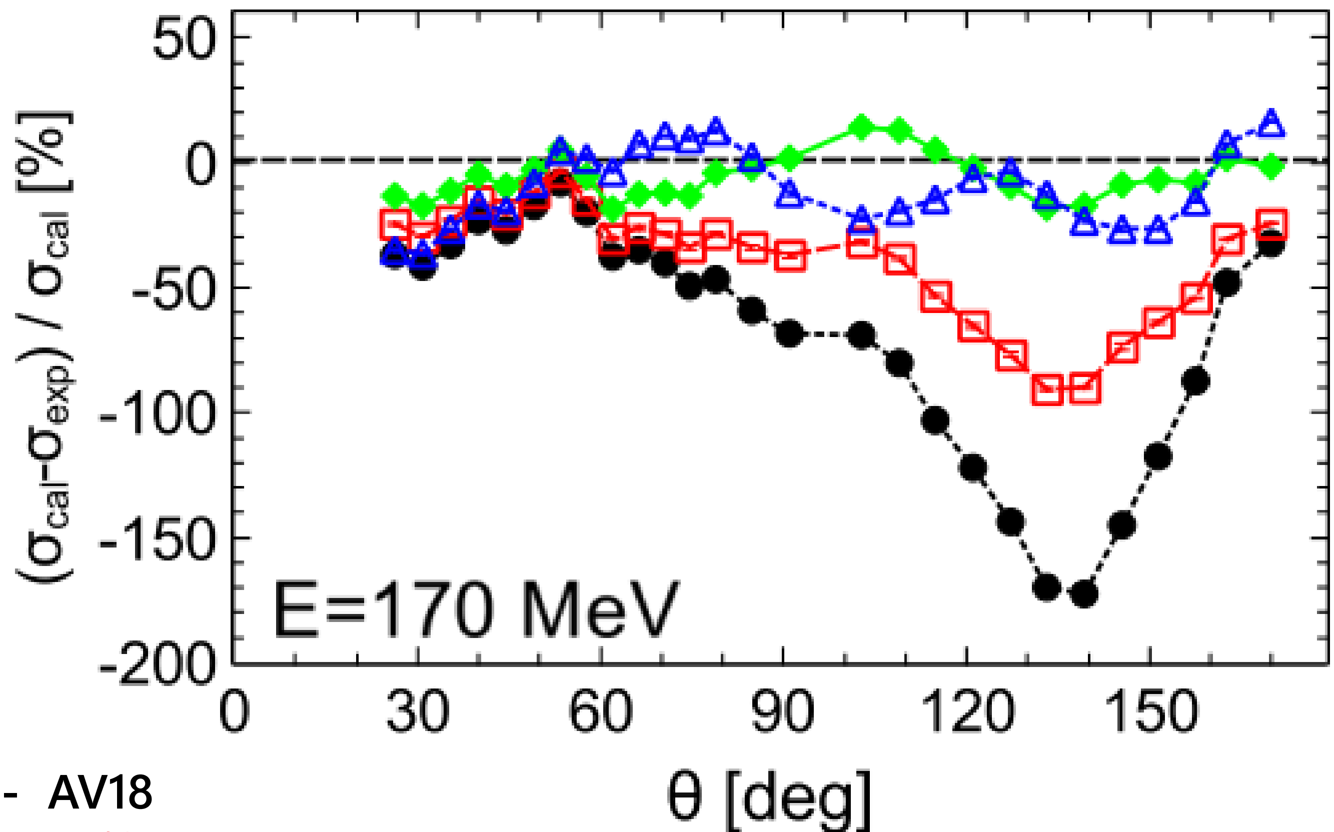
- Origin of repulsive 3NP ?
- Spin-dependence ? (Polarization observables)

AV18 $+\mathbf{BR}_{1000}$ $+\mathbf{BR}_{1000}+W_R$



----- AV18
----- AV18+BR_{1000}+W_R
----- AV18+BR_{1000}

AV18 +$BR_{0.87}$ +$BR_{0.5}$+W_R +BR(UR)+W_R



----- AV18

----- AV18+$BR_{0.87}$

----- AV18+$BR_{0.5}$+W_R

----- AV18+BR(UR)+W_R