Contact calculations of a_2

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SRC and EMC workshop - MIT - 22/3/2019

Inclusive scattering – a_2

a_2 definition:

$$a_2 = \frac{\sigma_A^{inc}/A}{\sigma_d^{inc}/2}$$

$1.5 < x_B < 1.9$ ($Q^2 > 1.5$ GeV^2)

Interpretation:

The number of (deuteron-like) SRC pairs relative to the deuteron

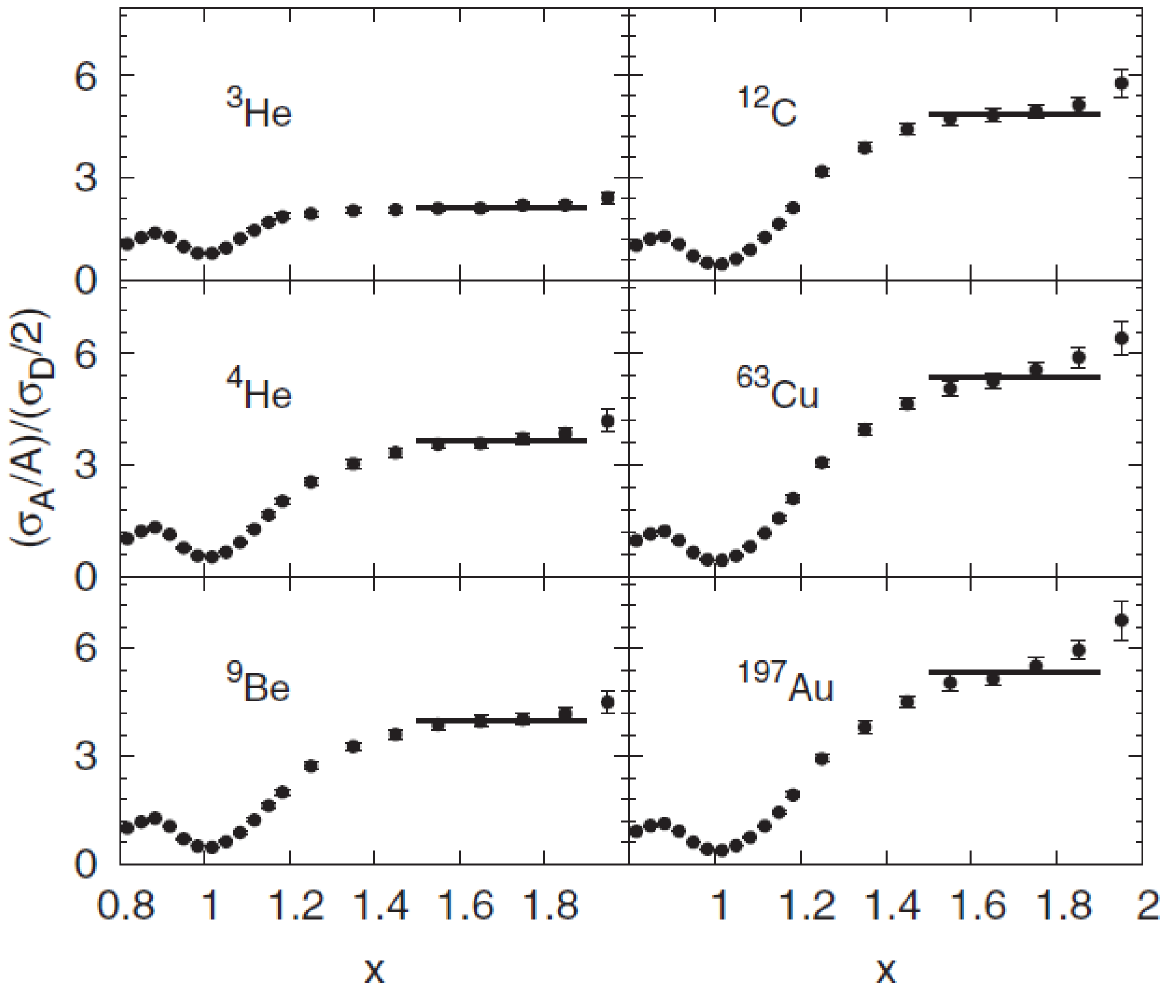
Connection to momentum/coordinate-space densities:

$$a_2 \approx n_A(k)/n_d(k) \quad ; \quad k \rightarrow \infty$$

$$a_2 \approx \rho_A(r_{rel})/\rho_d(r_{rel}) \quad ; \quad r_{rel} \rightarrow 0$$

Inclusive scattering – a_2

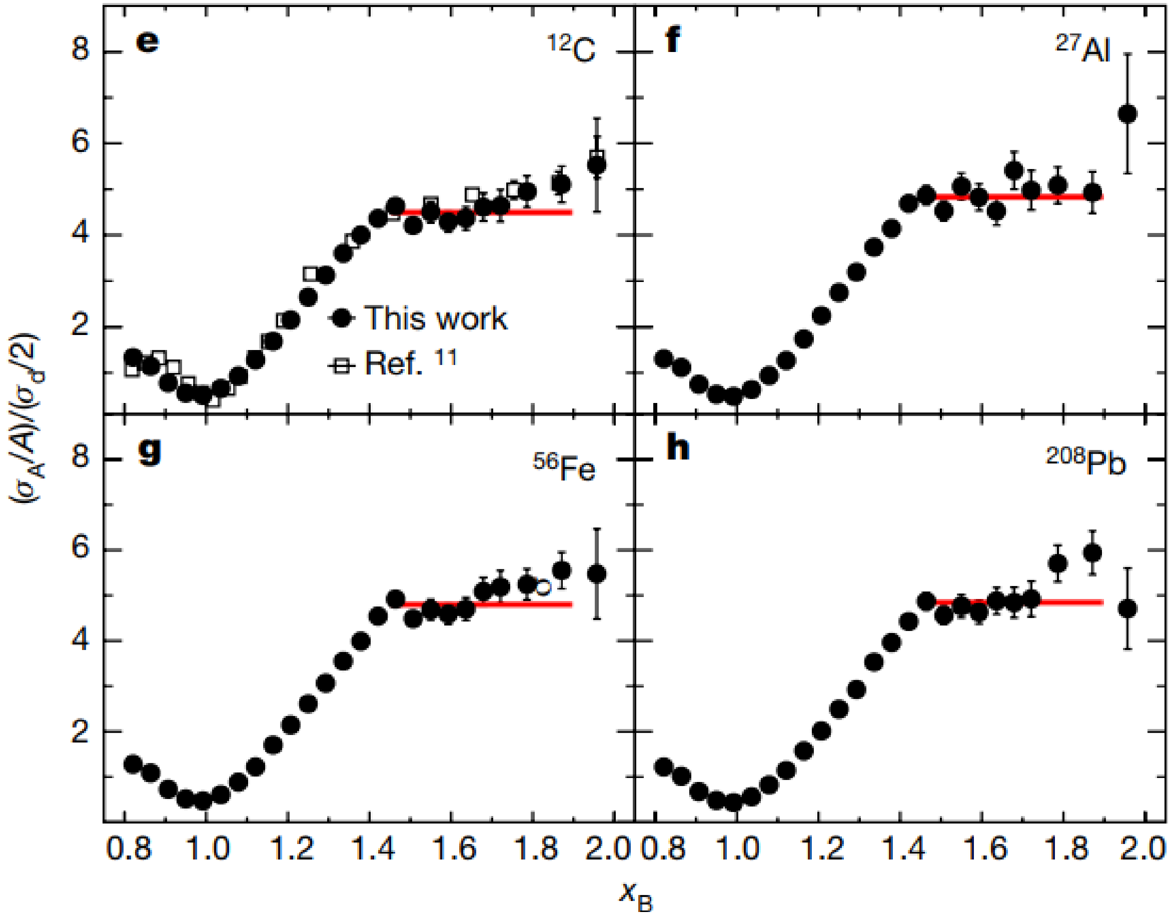
a_2 vs x_B at electron scattering angle $\theta_e = 18°$



*Fomin et. al. PRL **108**, 092502 (2012)*

Inclusive scattering – a_2

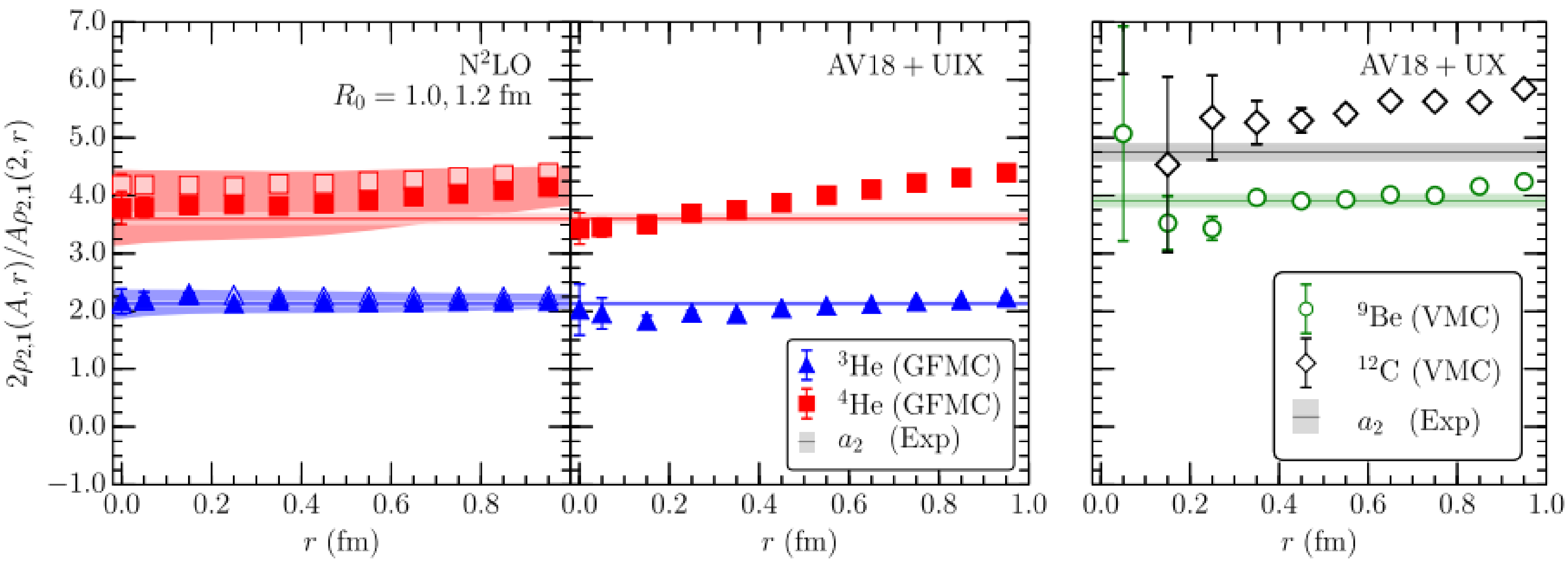
a_2 vs x_B for $Q^2 > 1.5$ GeV^2



B. Schmookler et. al. (CLAS Collaboration) *Nature 566, 354–358 (2019)*

Inclusive scattering – a_2

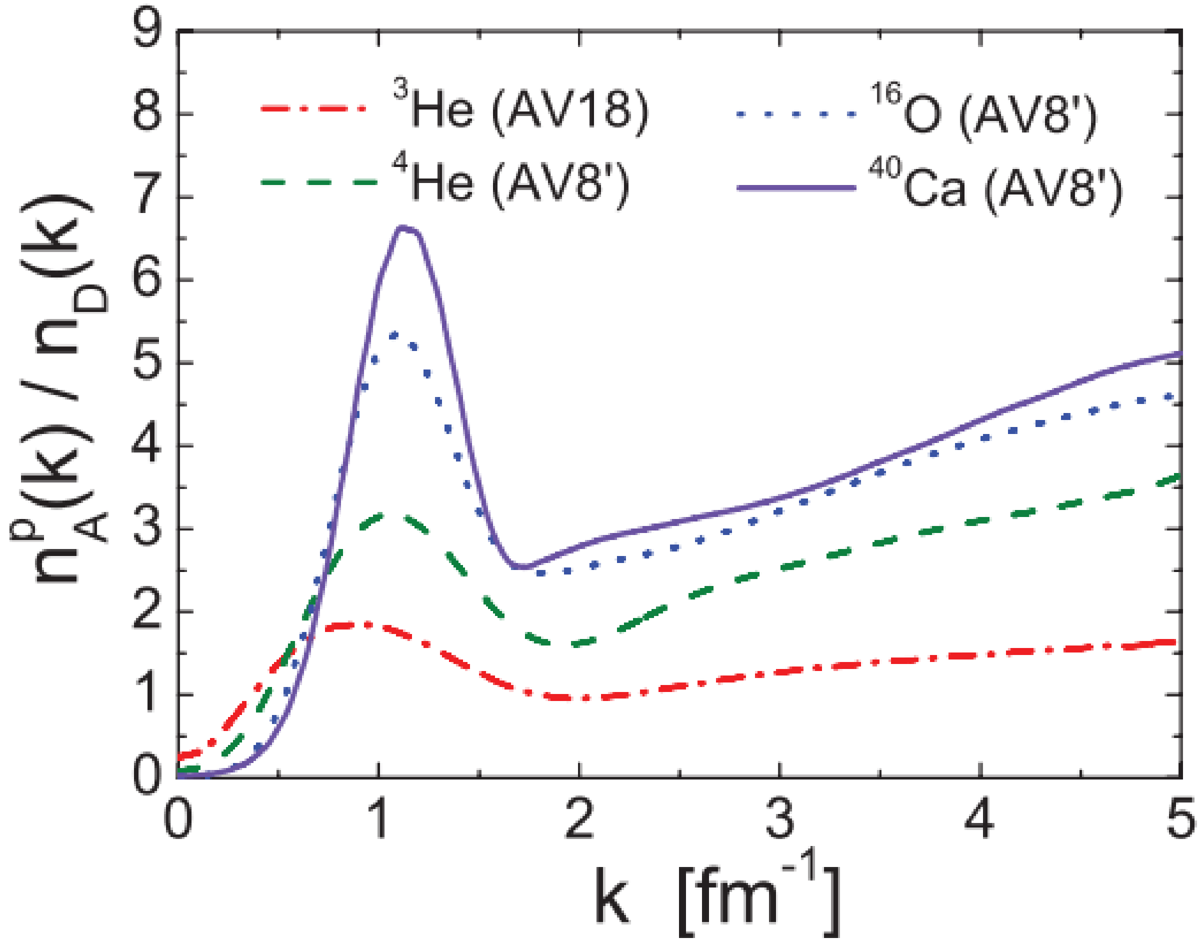
Ratios of coordinate-space densities



J-W Chen et al. , PRL ***119****, 262502 (2017)*

Inclusive scattering – a_2

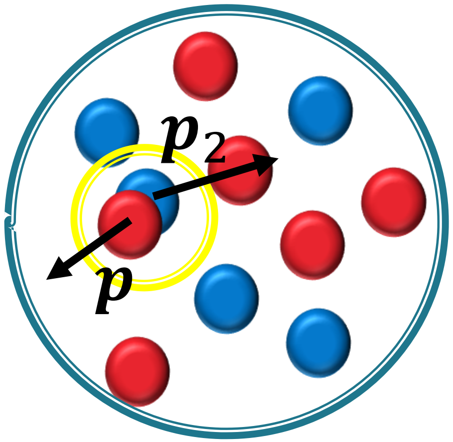
Ratios of momentum distributions



M. Alvioli et al., PRC ***87****, 034604 (2013)*

A vs 2

Nucleus *A*

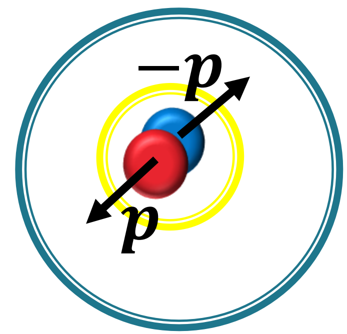


Off-shell pair

CM width ~ 100 – 200 MeV/c

Complex A-2 system

Deuteron

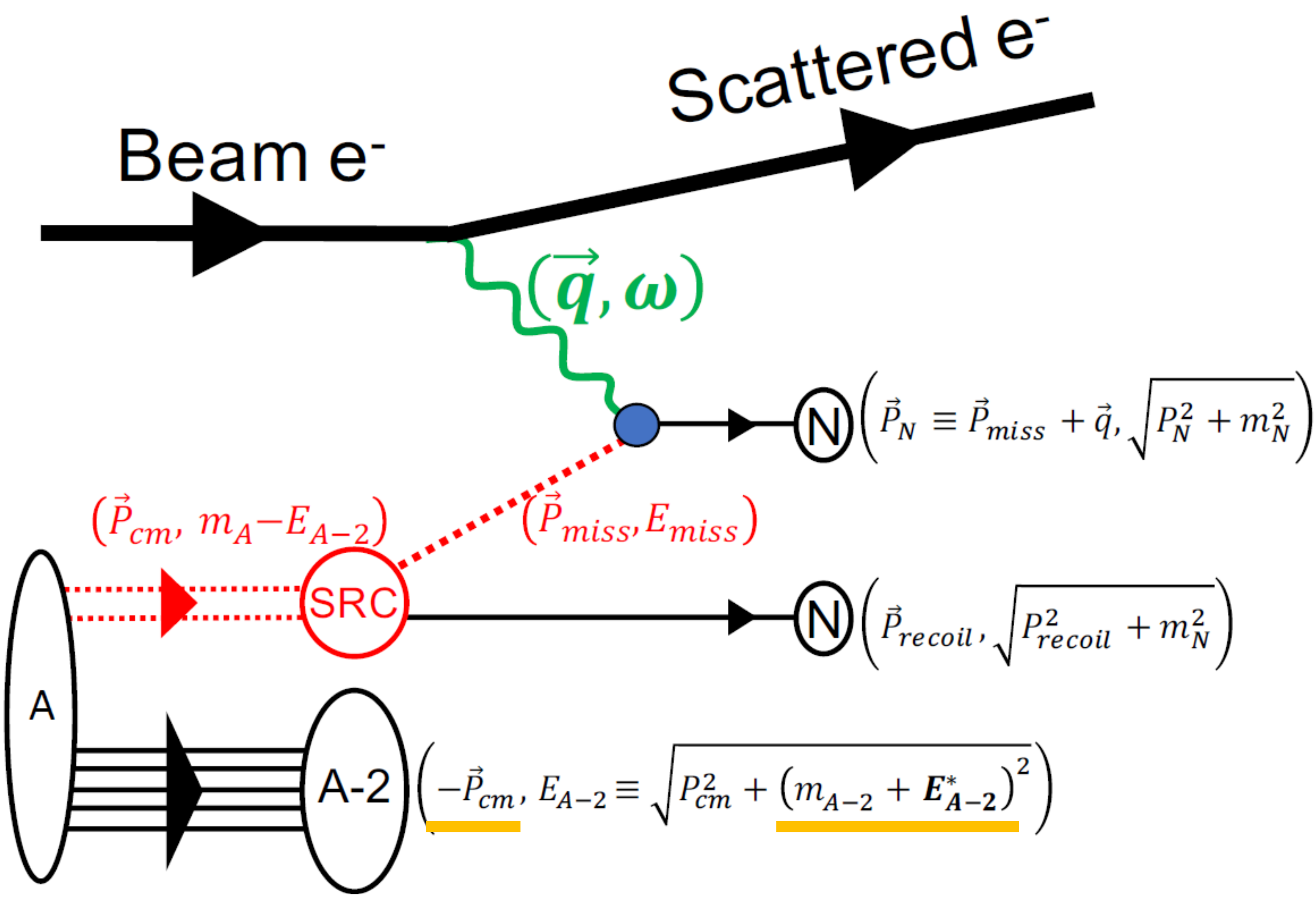


Bound deuteron

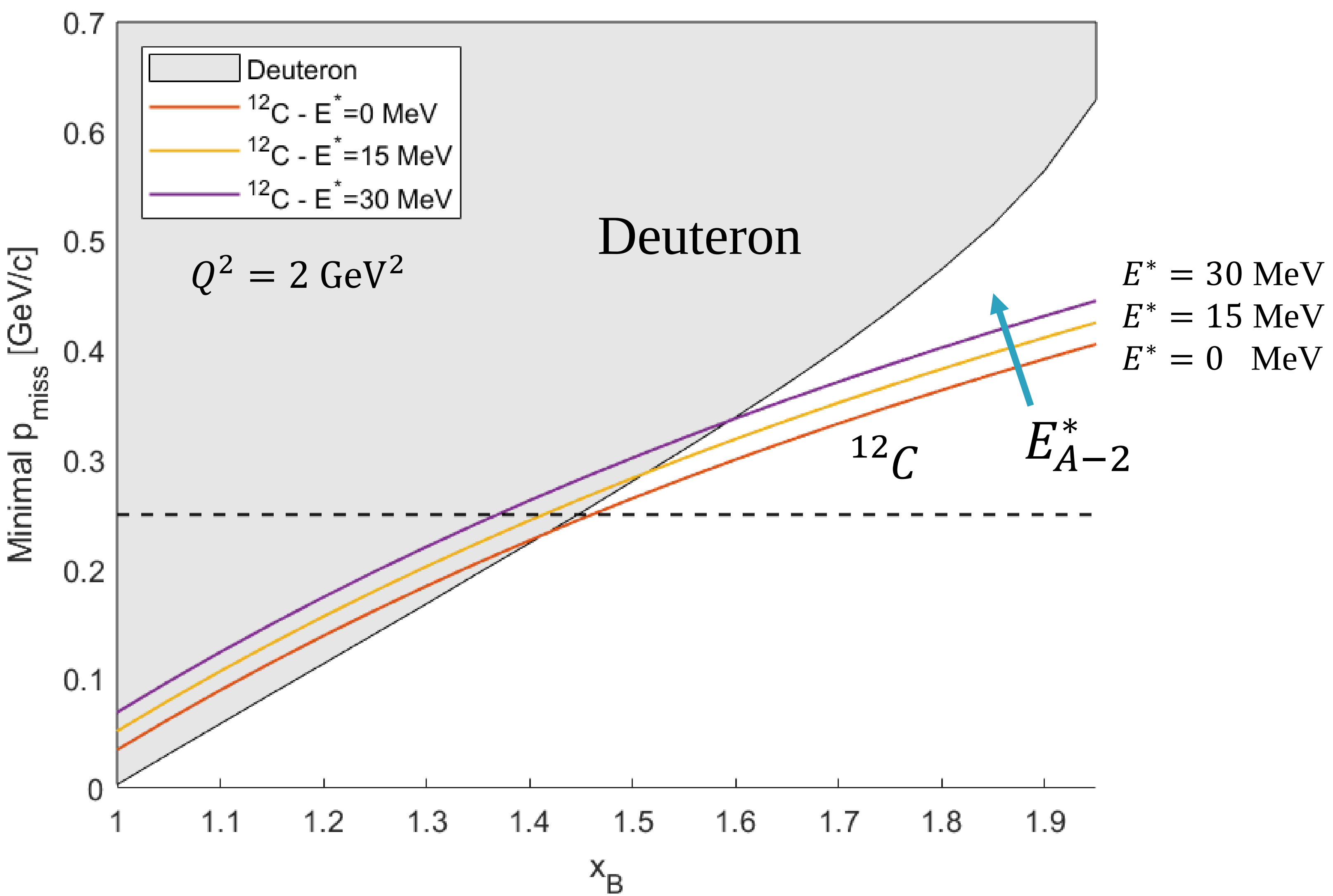
Zero CM width

No A-2 system

Inclusive cross section

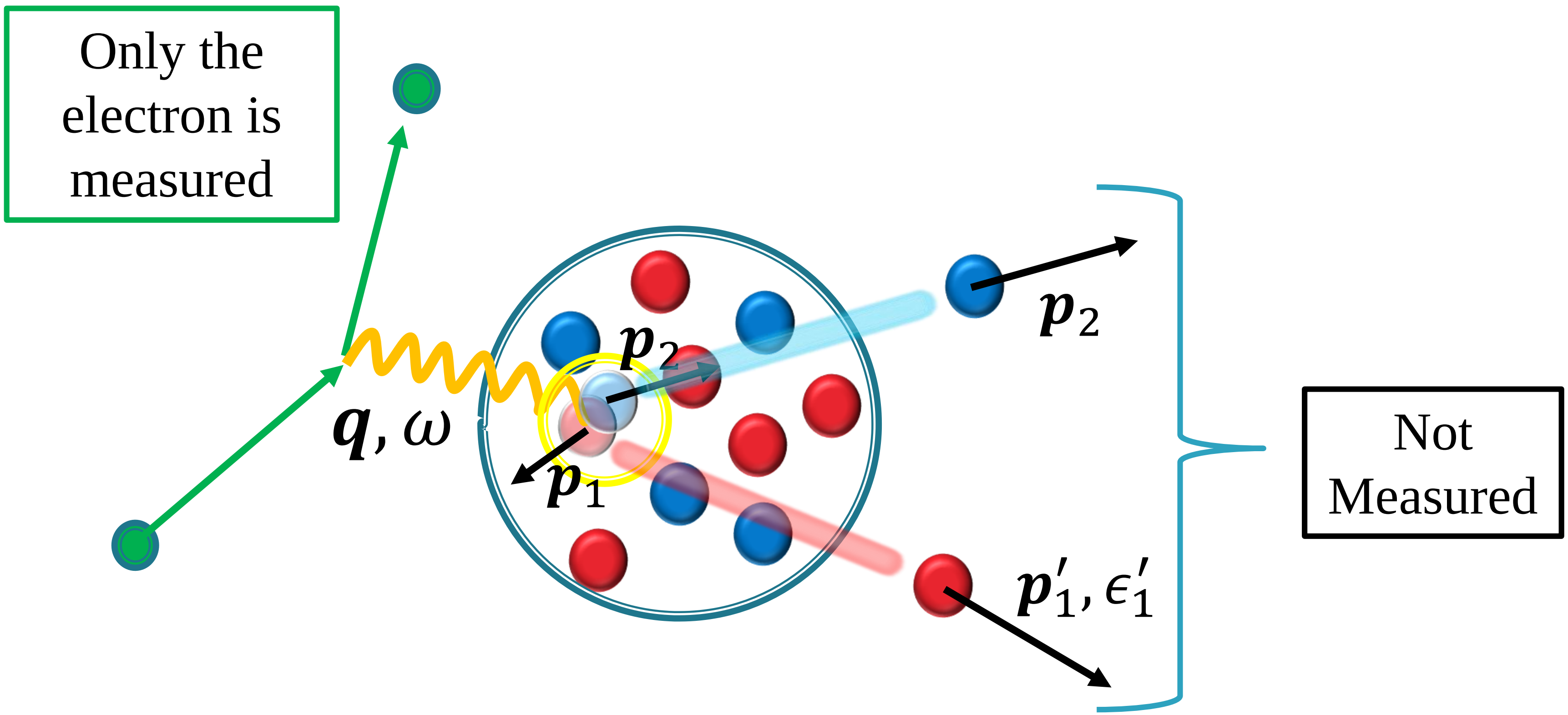


Minimal p_{miss}



Calculating a_2 using the contact formalism

Inclusive cross section



$$\Rightarrow \quad \sigma_A^{inc} \quad \Rightarrow \quad a_2 \equiv \frac{\sigma_A^{inc}/A}{\sigma_d^{inc}/2}$$

Inclusive cross section

Integrating over the unmeasured momentum:

Off-shell electron-nucleon cross section

$$\sigma_p^{inc} = \int d^3p' \sigma_{ep} S^p(\boldsymbol{p}_1, \epsilon_1)$$

$$\sigma_n^{inc} = \int d^3p' \sigma_{en} S^n(\boldsymbol{p}_1, \epsilon_1)$$

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Integral over the allowed phase space

CM effects

Inclusive cross section

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$$\sigma^{inc} = \sigma_p^{inc} + \sigma_n^{inc}$$

$$S^p(\boldsymbol{p_1}, \epsilon_1) = C_{pn}^1 S_{pn}^1(\boldsymbol{p_1}, \epsilon_1) + C_{pn}^0 S_{pn}^0(\boldsymbol{p_1}, \epsilon_1) + 2C_{pp}^0 S_{pp}^0(\boldsymbol{p_1}, \epsilon_1)$$

Inclusive cross section

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$$\frac{\sigma_A^{inc}}{\sigma_M} = C_{pn}^1 \sigma_{pn}^1(\omega, q) + C_{pn}^0 \sigma_{pn}^0(\omega, q) + 2C_{pp}^0 \sigma_{pp}^0(\omega, q) + 2C_{nn}^0 \sigma_{nn}^0(\omega, q)$$

Results

Results: Only deuteron pairs

The CM-width effect:

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The CM-width effect:

Input SRC ratio: $\frac{C_{pn}^{1}(A)/A}{C_{pn}^{1}(d)/2} = 4$

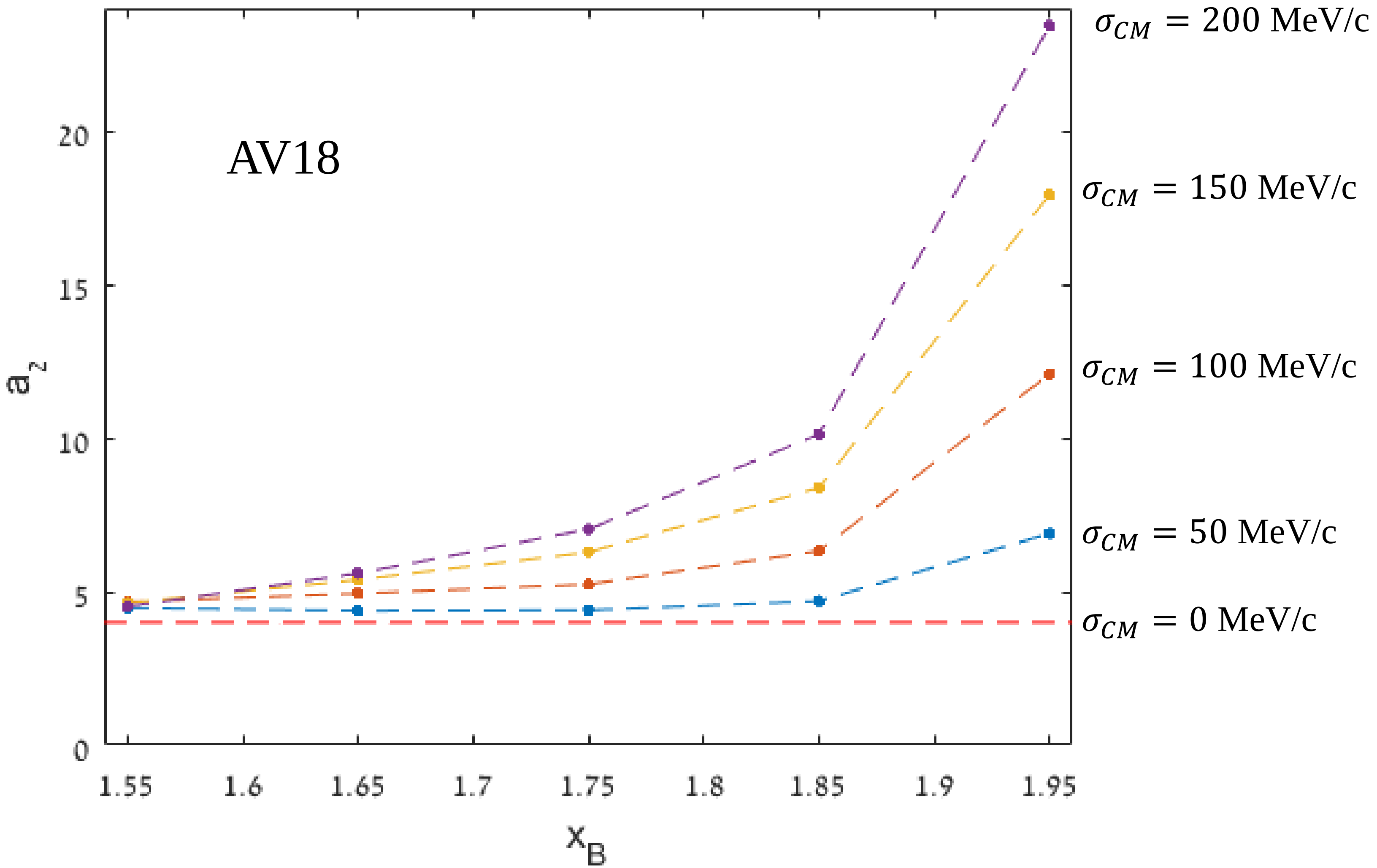
On-shell deuteron $\begin{cases} B_A - B_{A-2} = 2.224 \text{ MeV} \\ \mathrm{E}_{A-2}^{*} = 0 \text{ MeV} \end{cases}$

$A = 208$

Fomin's kinematics $\begin{cases} \theta_e = 18° \\ \epsilon_e = 5.766 \text{ GeV} \end{cases}$

Results: Only deuteron pairs

The CM-width effect:



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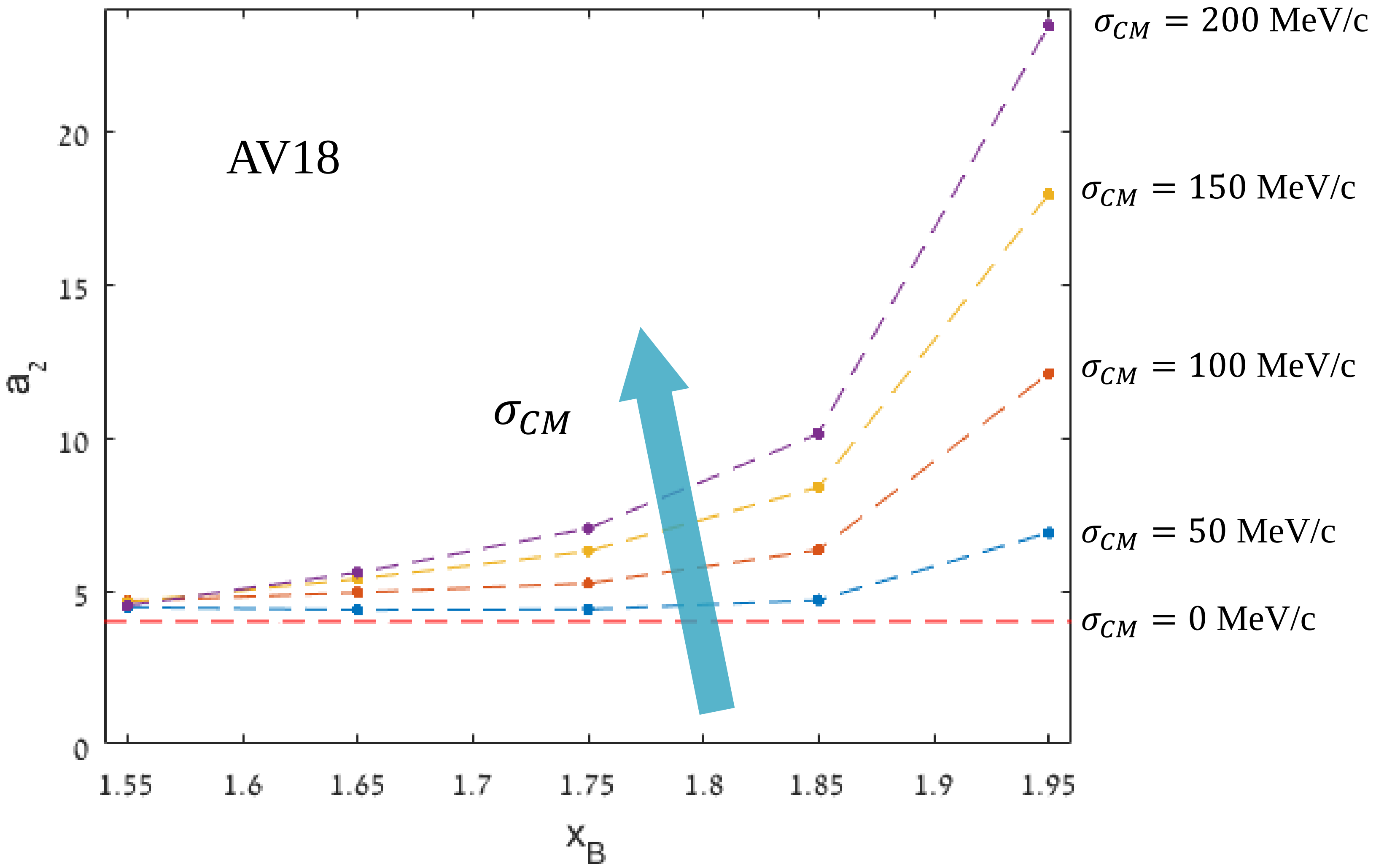

Results: Only deuteron pairs

The A-2 excitation:

Input SRC ratio: $\frac{C_{pn}^{1}(A)/A}{C_{pn}^{1}(d)/2} = 4$

Off-shell deuteron $\left\{ \begin{array}{l} B_A - B_{A-2} = 16 \text{ MeV} \\ \text{E}_{A-2}^{*} = \text{0-30 MeV} \end{array} \right.$

$\sigma_{CM} = 100 \text{ MeV/c}$

$A = 208$

Fomin's kinematics $\left\{ \begin{array}{l} \theta_e = 18° \\ \epsilon_e = 5.766 \text{ GeV} \end{array} \right.$

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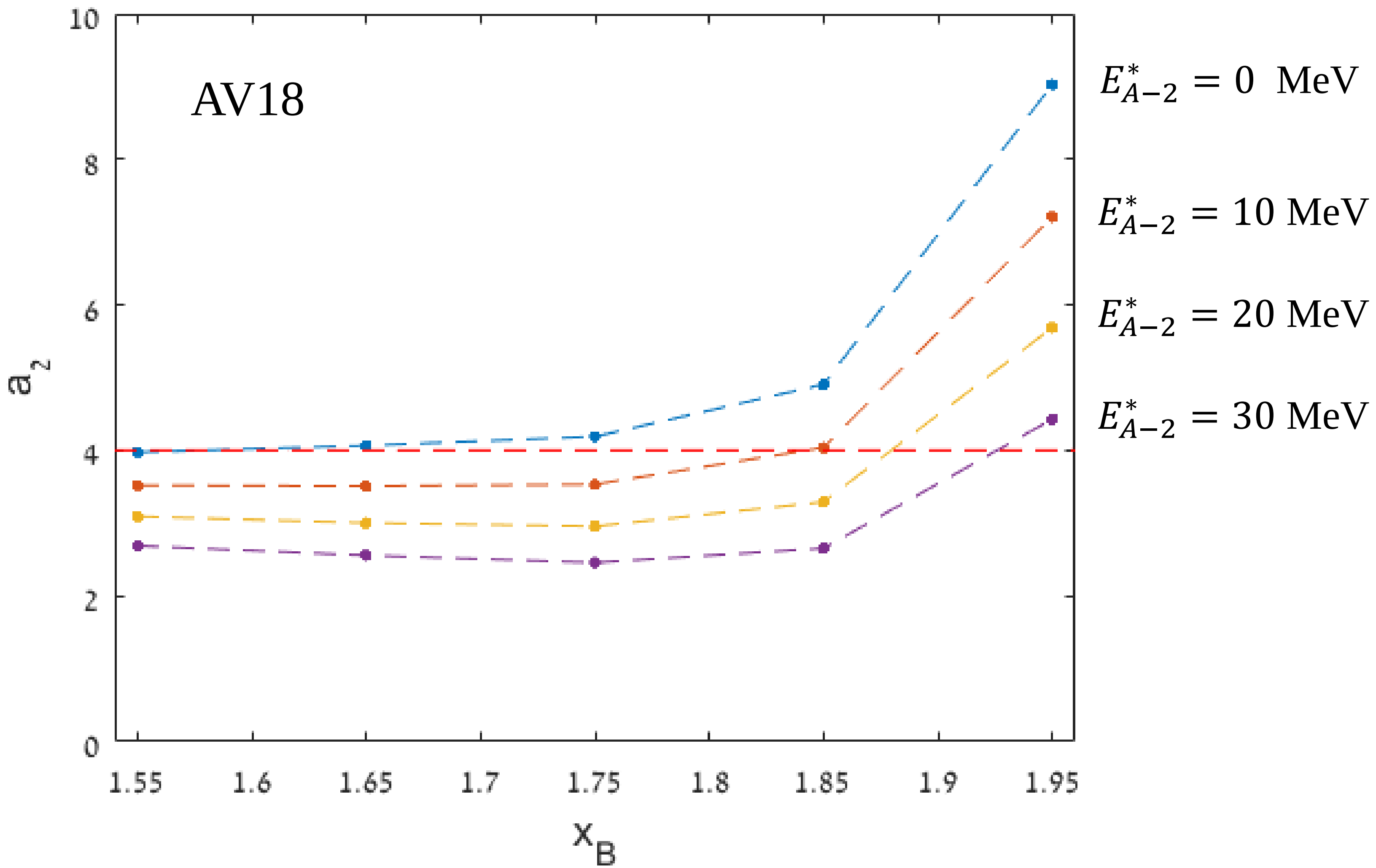

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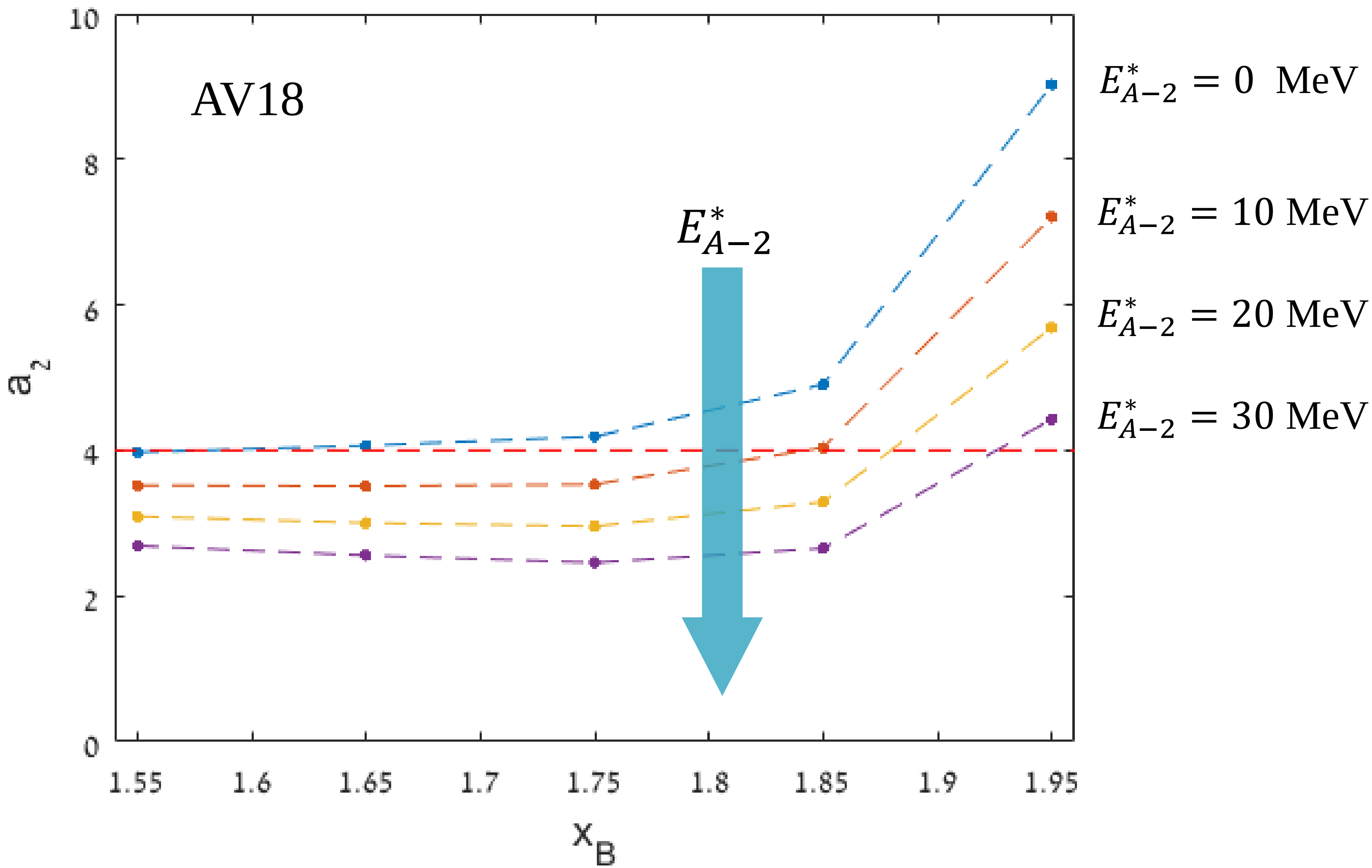

Results: Also $S = 0, T = 1$ pairs

Input SRC ratio: $\frac{C_{pn}^{1}(A)/A}{C_{pn}^{1}(d)/2} = 4$

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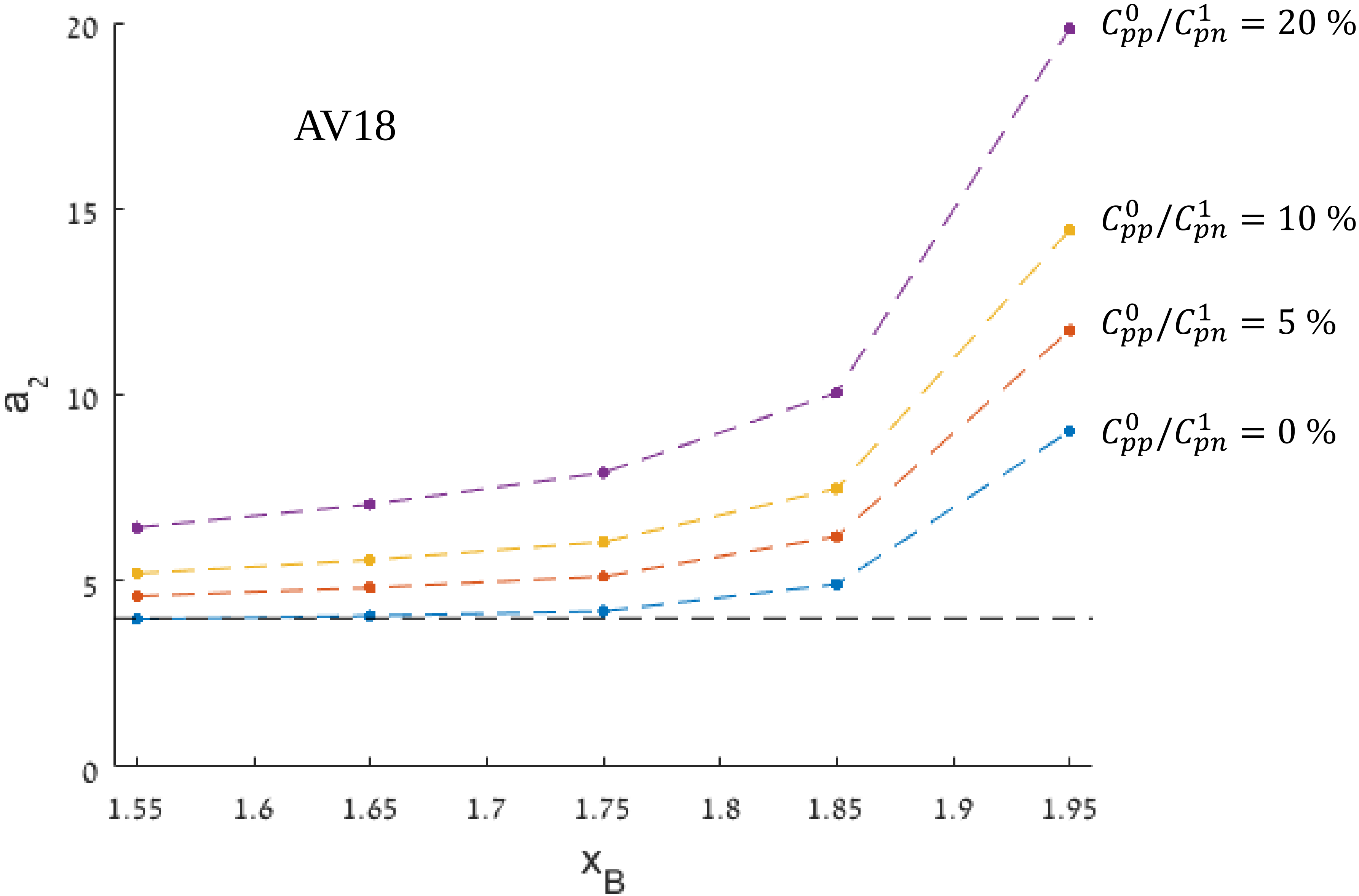

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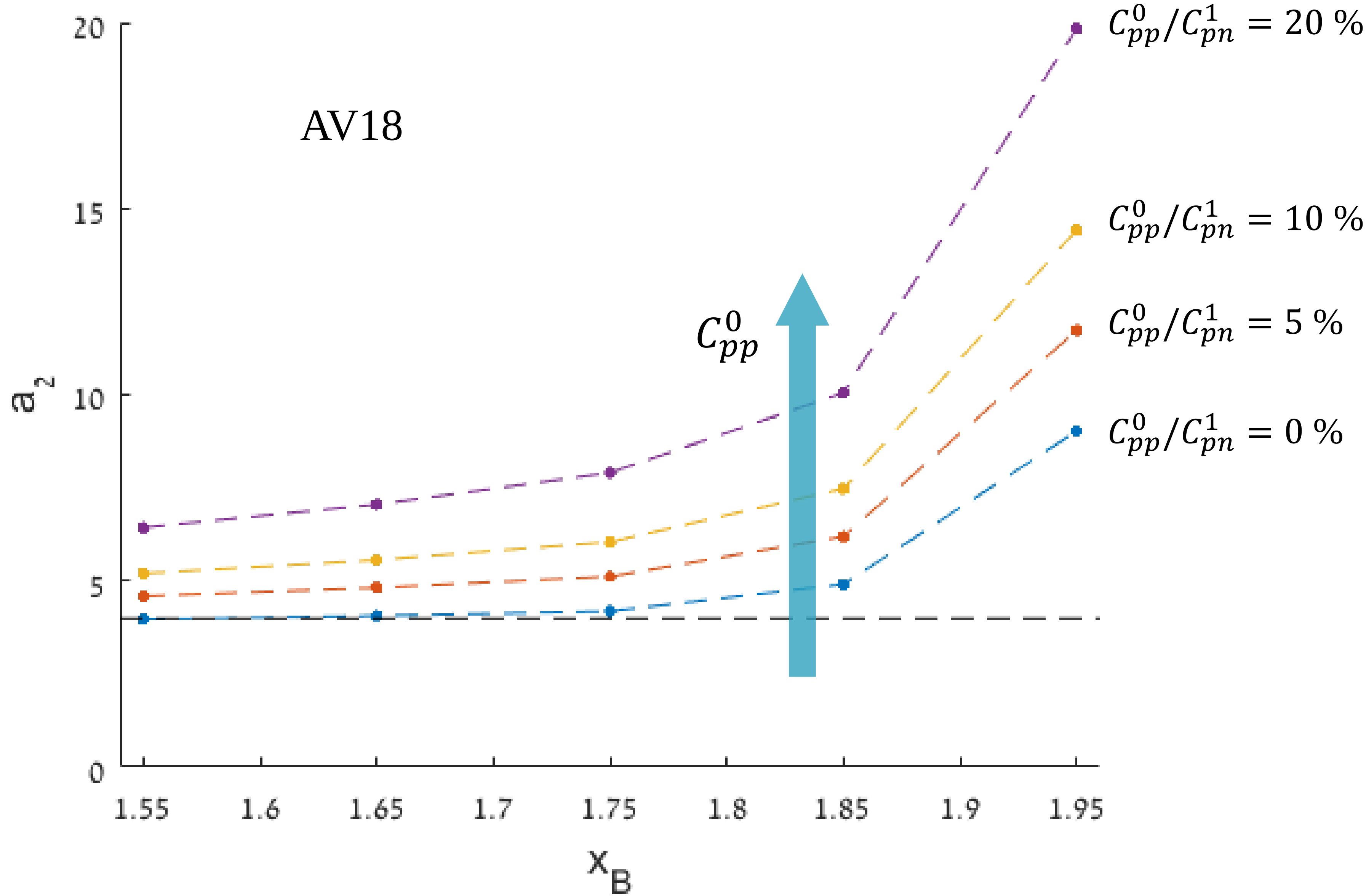


Results

Deviations from the a_2 interpretation:

- CM width – increases a_2 and creates a slope
- $A-2$ excitation – decreases a_2
- $T=1$ pairs – increase a_2

Experimental data - ^{12}C

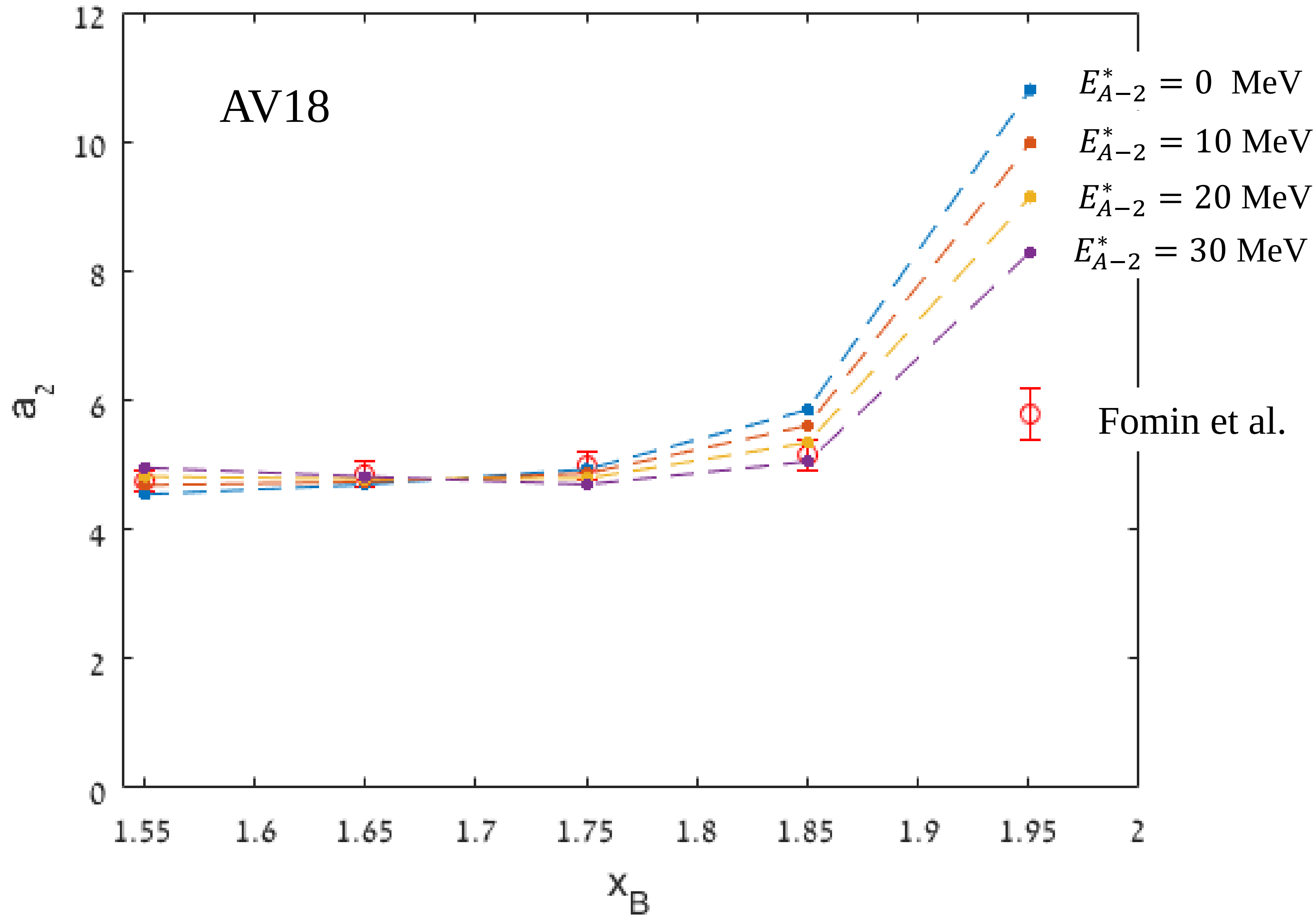
$C_{pn}^{1}/C_{pp}^{0} = 12.5$ (fixed – VMC results)

$\sigma_{CM} = 100$ MeV/c

$E_{A-2}^{*} = 0$-30 MeV

Fitting C_{pn}^{1}

Experimental data - ^{12}C



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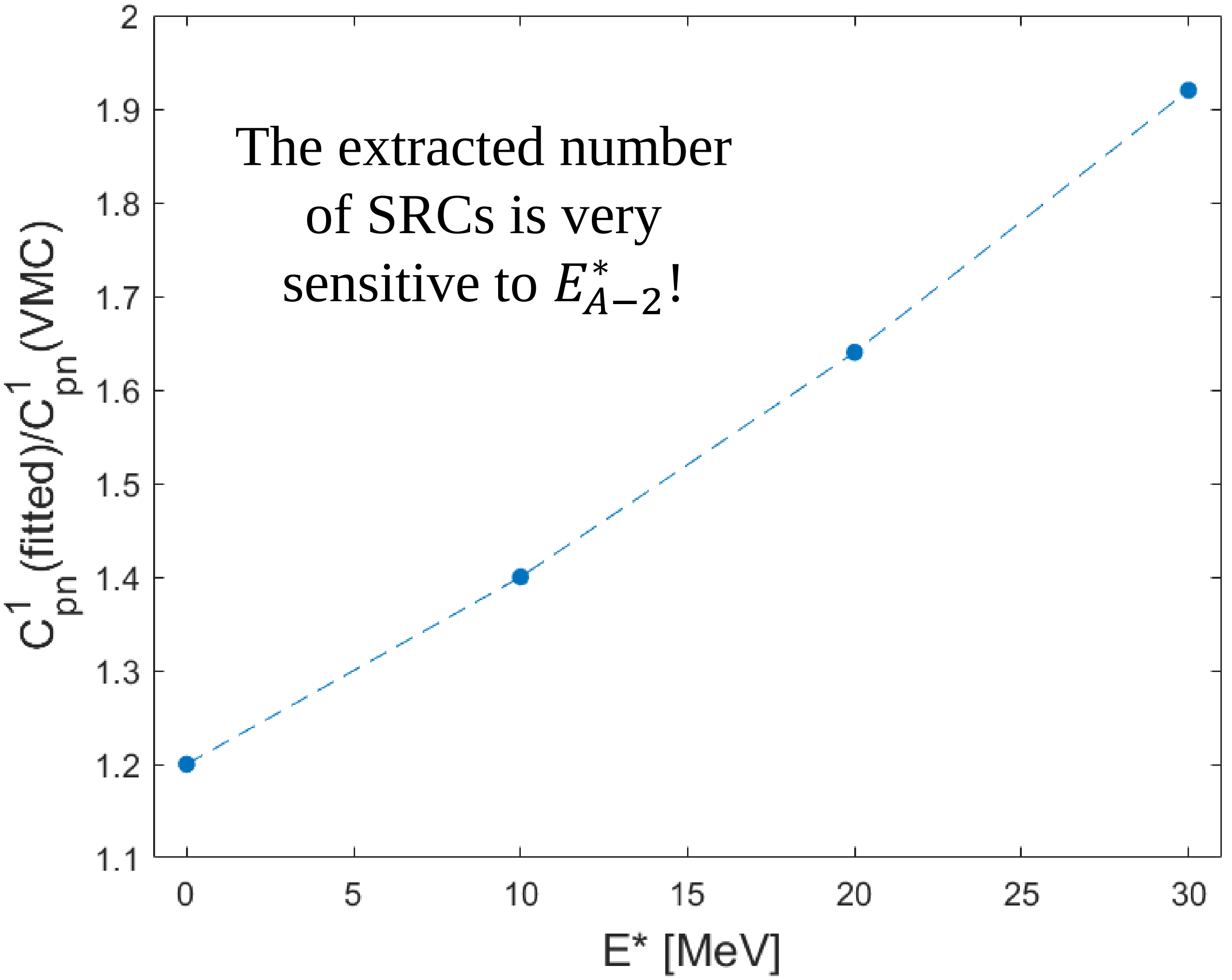

AV18 VMC results: $C^1_{pn}(^{12}C) = 16.8 \pm 0.8$

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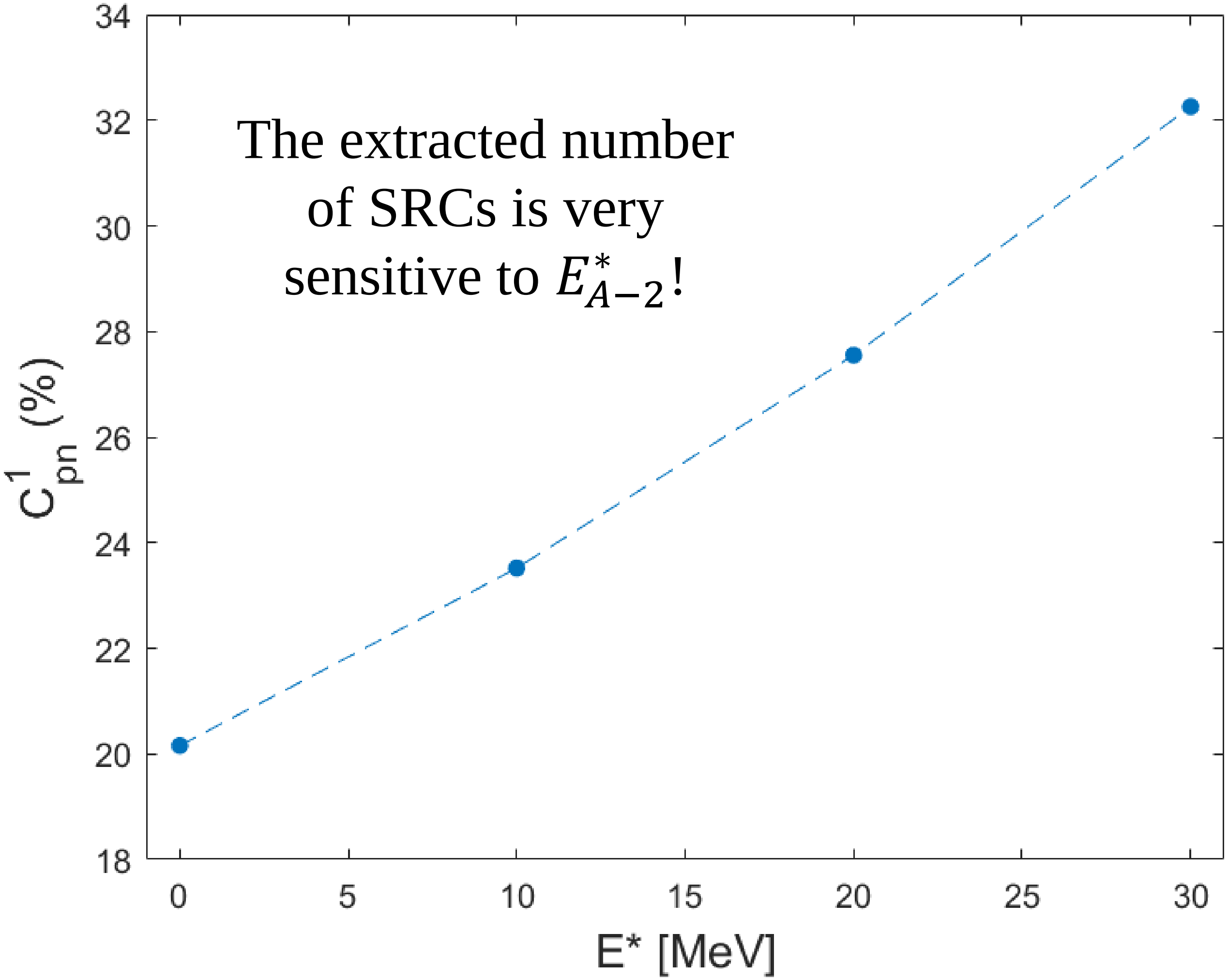

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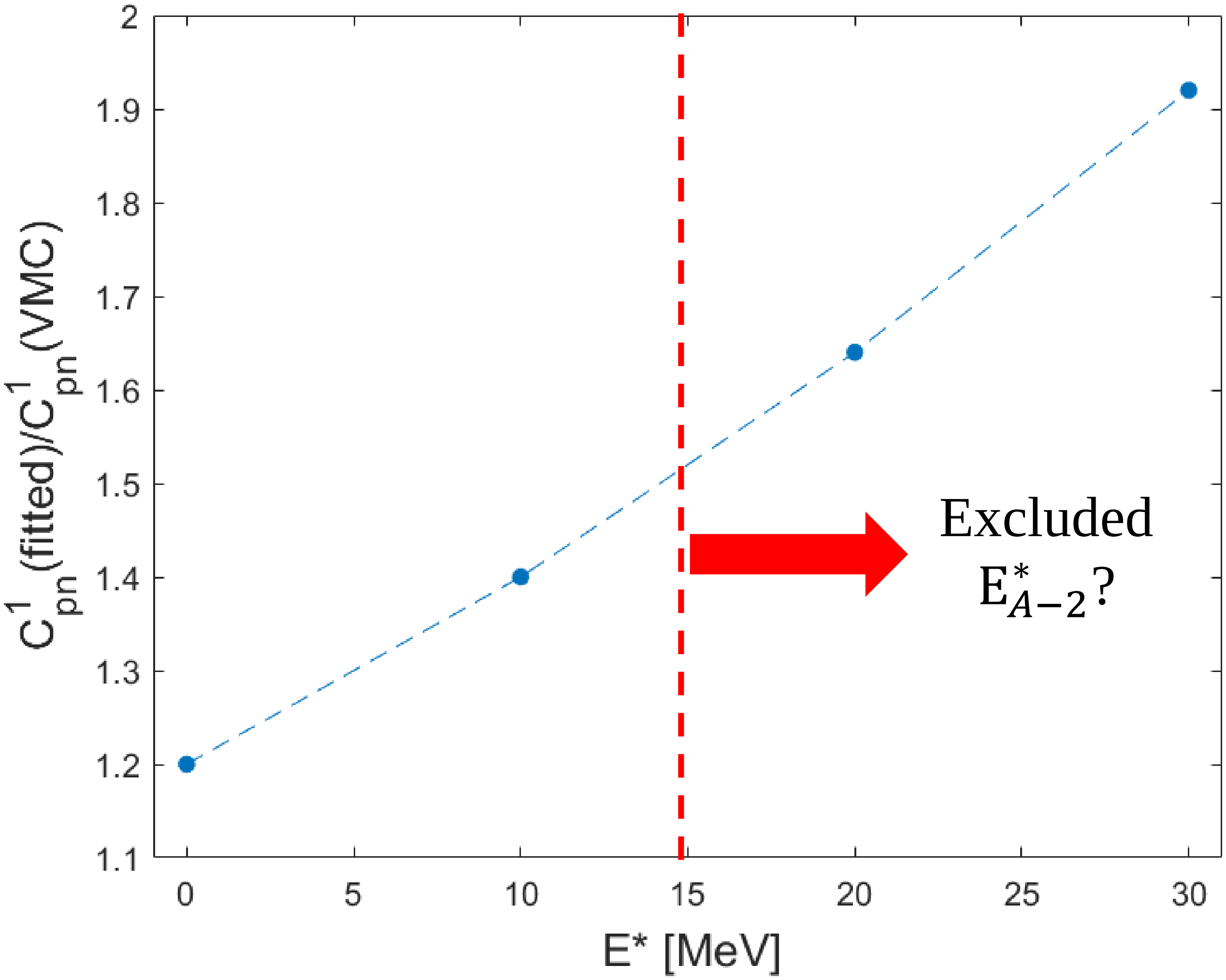
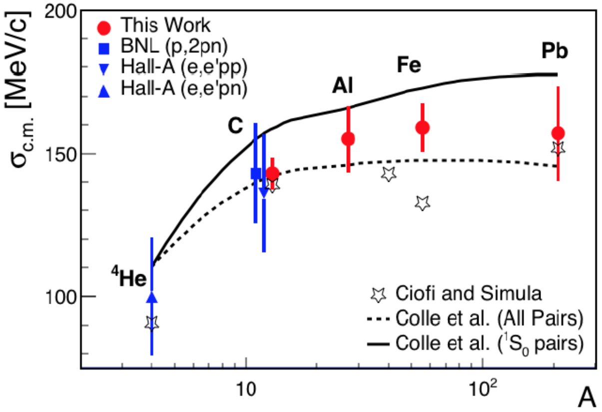


AV18 VMC results: $C^1_{pn}\left(^{12}C\right) = 16.8 \pm 0.8$

Light vs Heavy nuclei

For heavy nuclei:

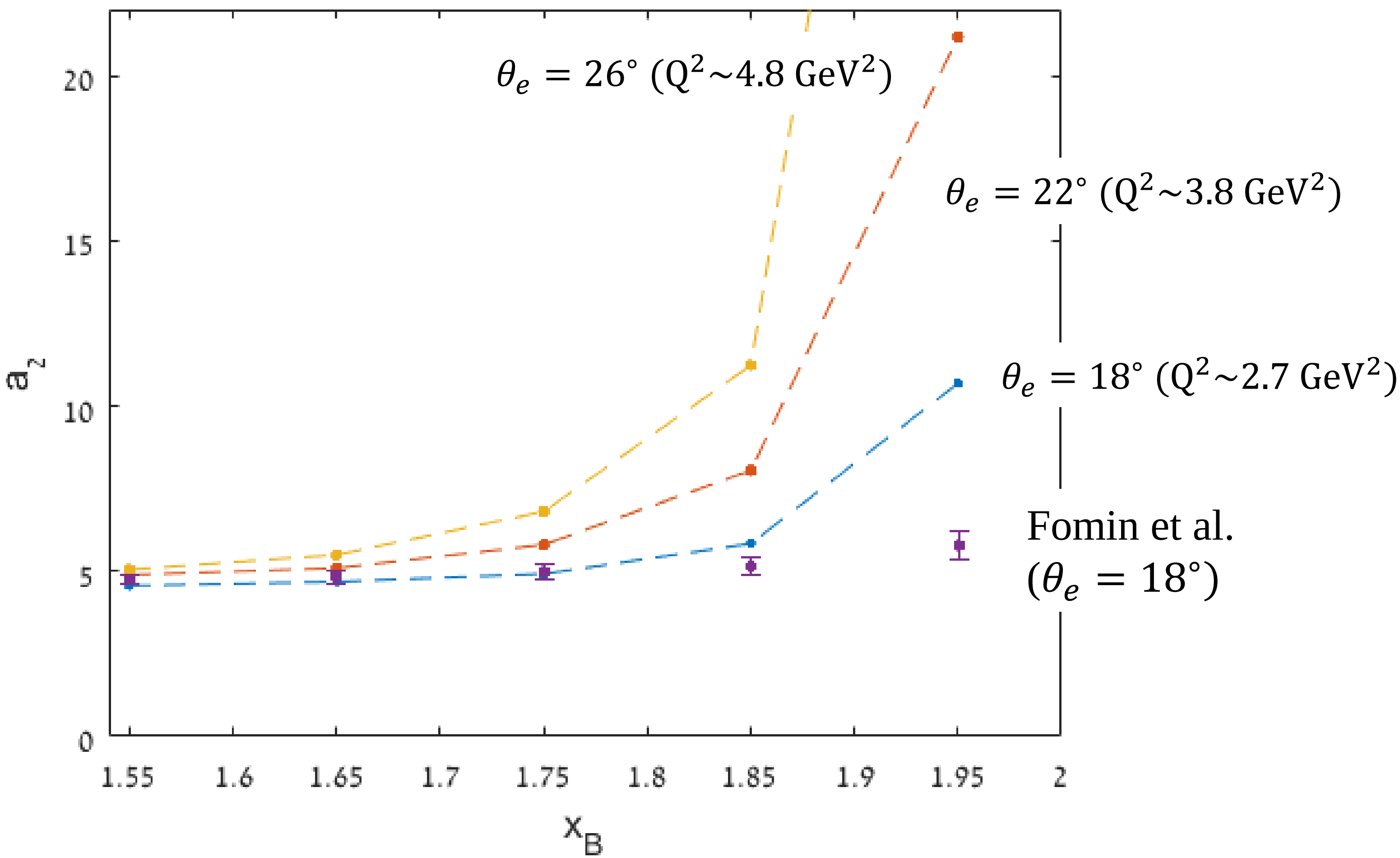
- σ_{CM}, E^*, and $T = 0$ – expected to saturate
- leads to an (unknown) **constant correction** (E^* is unknown)



For light nuclei:

- σ_{CM}, E^*, and $T = 0$ – expected to depend on A
- Leads to **difficulties comparing between light nuclei**

Results: Q^2 dependence



Using the fitted contact values for $\sigma_{CM} = 100$ MeV/c, $E^* = 0$

Summary

1. Experimental data of a_2 can be described using **contact-formalism cross-section calculations**

2. The value of a_2 is **sensitive** to σ_{CM} and E^*_{A-2}

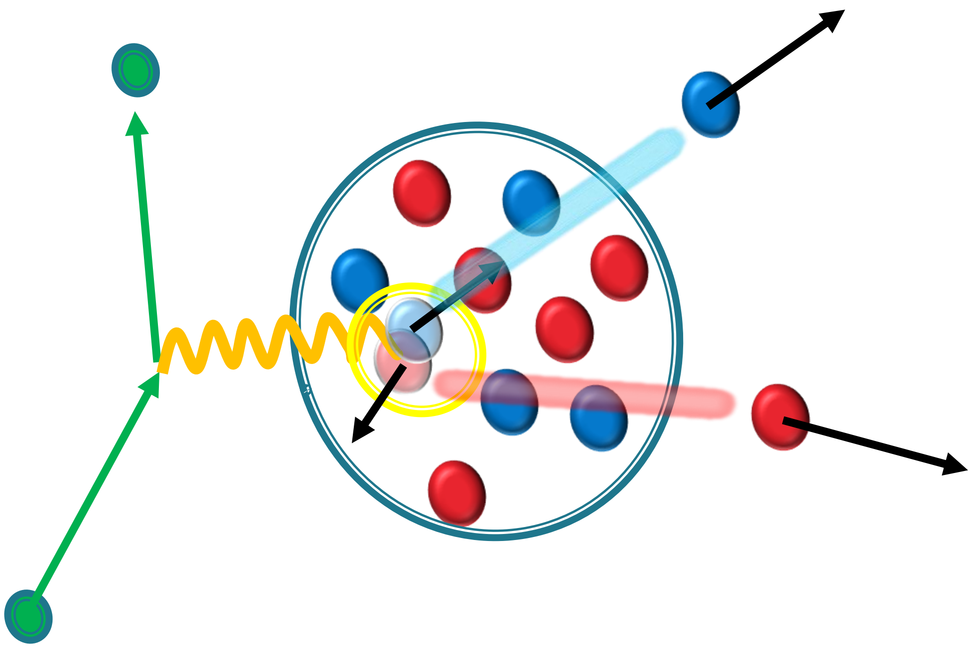
3. External inputs are necessary to extract the amount of SRCs from a_2

4. Important for the interpretation of a_2 of **light nuclei**

5. We can use a_2 to learn about the (A-2) system (E^*_{A-2})

6. We can provide $\boldsymbol{Q^2}$**-dependence** predictions

Questions?



The spectral function - Reminder

$$S^p(\boldsymbol{p_1}, \epsilon_1) = C^1_{pn} S^1_{pn}(\boldsymbol{p_1}, \epsilon_1) + C^0_{pn} S^0_{pn}(\boldsymbol{p_1}, \epsilon_1) + 2C^0_{pp} S^0_{pp}(\boldsymbol{p_1}, \epsilon_1)$$

$$S^\alpha_{ab}(\boldsymbol{p_1}, \epsilon_1) = \frac{1}{4\pi} \int \frac{d^3 p_2}{(2\pi)^3} \delta(f(\boldsymbol{p}_2))\, n_{CM}(\boldsymbol{p_1} + \boldsymbol{p_2}) |\tilde{\varphi}^\alpha_{ab}(|\boldsymbol{p_1} - \boldsymbol{p_2}|/2|)|^2$$

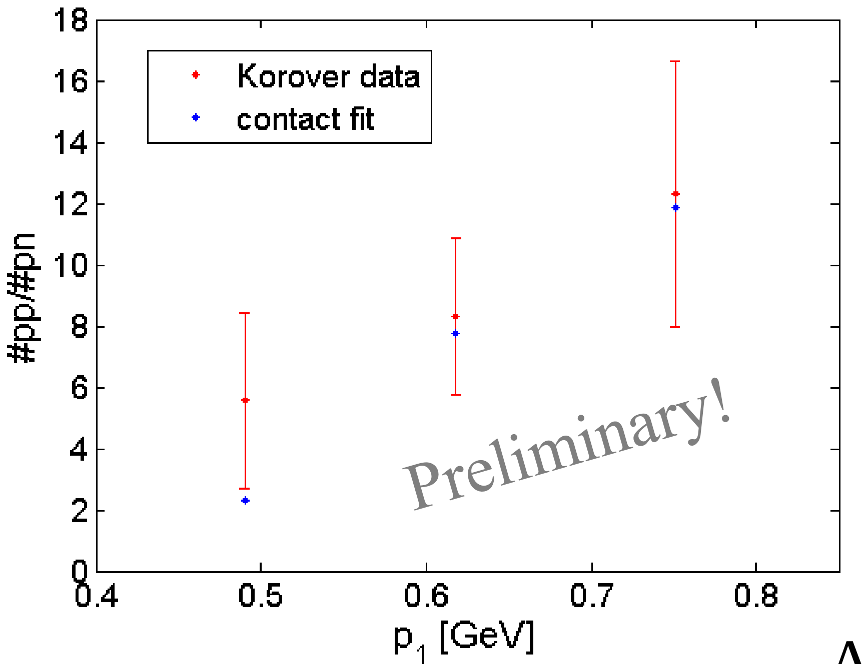
$$f(\boldsymbol{p}_2) \equiv \epsilon_1 + \sqrt{p_2^2 + m^2} - 2m + \left(B_i^A - \langle B_f^{A-2} \rangle\right) + \frac{(\boldsymbol{p_1} + \boldsymbol{p_2})^2}{2m(A-2)}$$

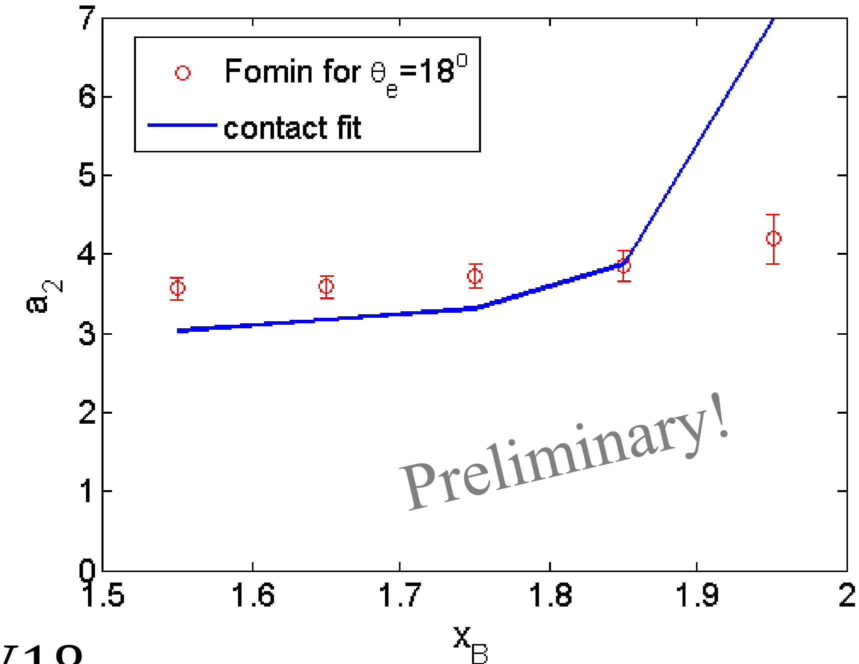
$$n_{CM}(\boldsymbol{K}) \propto e^{-\frac{K^2}{2\sigma^2_{CM}}}$$

Inclusive experiments

Fitting inclusive and exclusive experiments simultaneously - ^{4}He

$\sigma_{CM} = 100$ MeV and $B_f^{A-2} =$ ground state





AV18

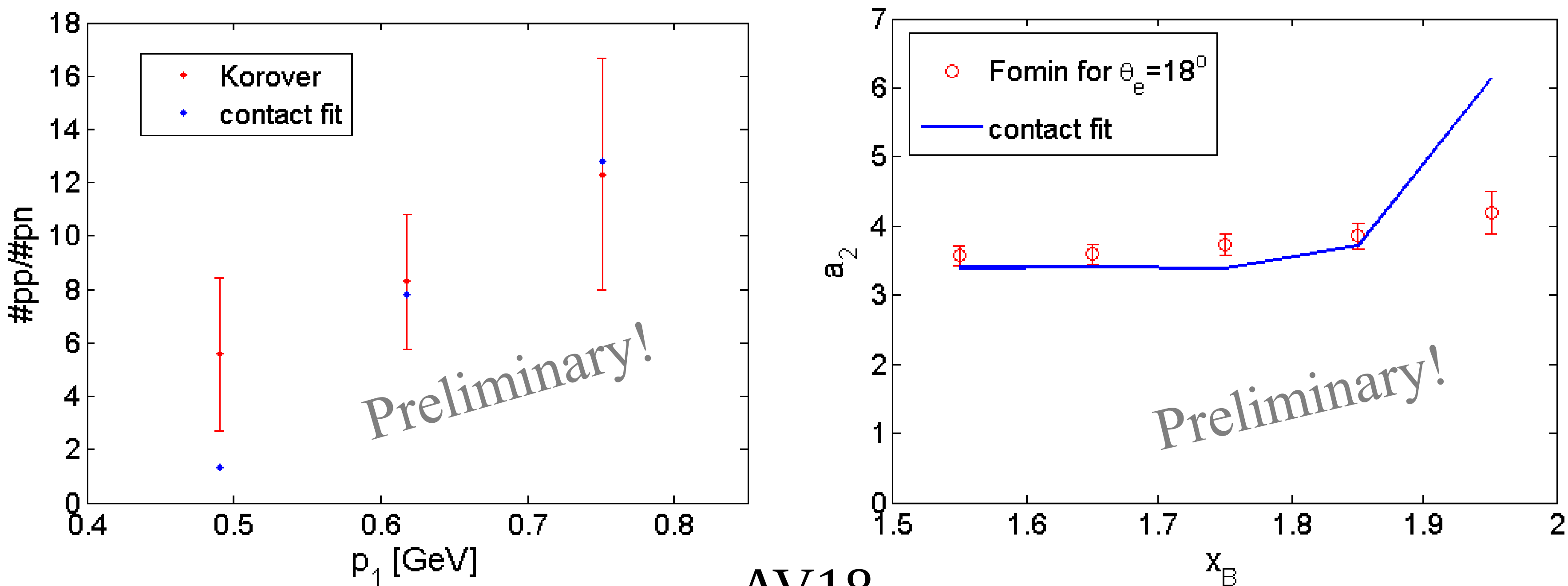
$$C_{pn}^{d}(\,^{4}He) \times \frac{100}{A/2} = 16.8 \quad ; \quad C_{pp}^{0}(\,^{4}He) \times \frac{100}{A/2} = 0.75$$

Previous results:	11-16	;	0.5-1

Inclusive experiments

Fitting inclusive and exclusive experiments simultaneously - ^{4}He

$\sigma_{CM} = 100$ MeV and $B_f^{A-2} =$ ground state + 20 MeV



AV18

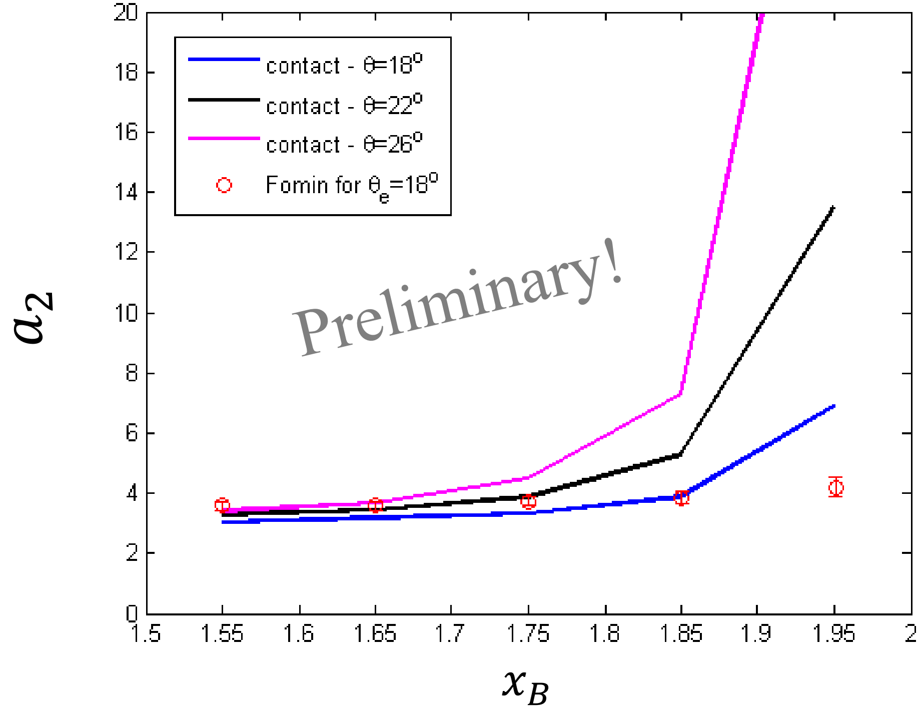
$$C_{pn}^{d}(\,^4He) \times \frac{100}{A/2} = 24.3\;;\quad C_{pp}^{0}(\,^4He) \times \frac{100}{A/2} = 1.25$$

Previous results: 11-16 ; 0.5-1

Inclusive experiments

Q^2-dependence - ^{4}He

$\sigma_{CM} = 100$ MeV and B_f^{A-2} = ground state



$$C_{pn}^{d}(\,^4He) \times \frac{100}{A/2} = 16.8 \quad ; \quad C_{pp}^{0}(\,^4He) \times \frac{100}{A/2} = 0.75$$

Previous results:	11-16	;	0.5-1

Inclusive cross section

The inclusive cross section for nucleus A:

$$C^d_{pn}(A)\sigma^d_{pn}(\omega, q; A) + C^0_{pn}(A)\sigma^0_{pn}(\omega, q; A) + 2C^0_{pp}(A)\sigma^0_{pp}(\omega, q; A) + 2C^0_{nn}(A)\sigma^0_{nn}(\omega, q; A)$$

For the deuteron

$$C^d_{pn}(d)\sigma^d_{pn}(\omega, q, A = 2)$$

If the $T = 1$ contributions are negligible:

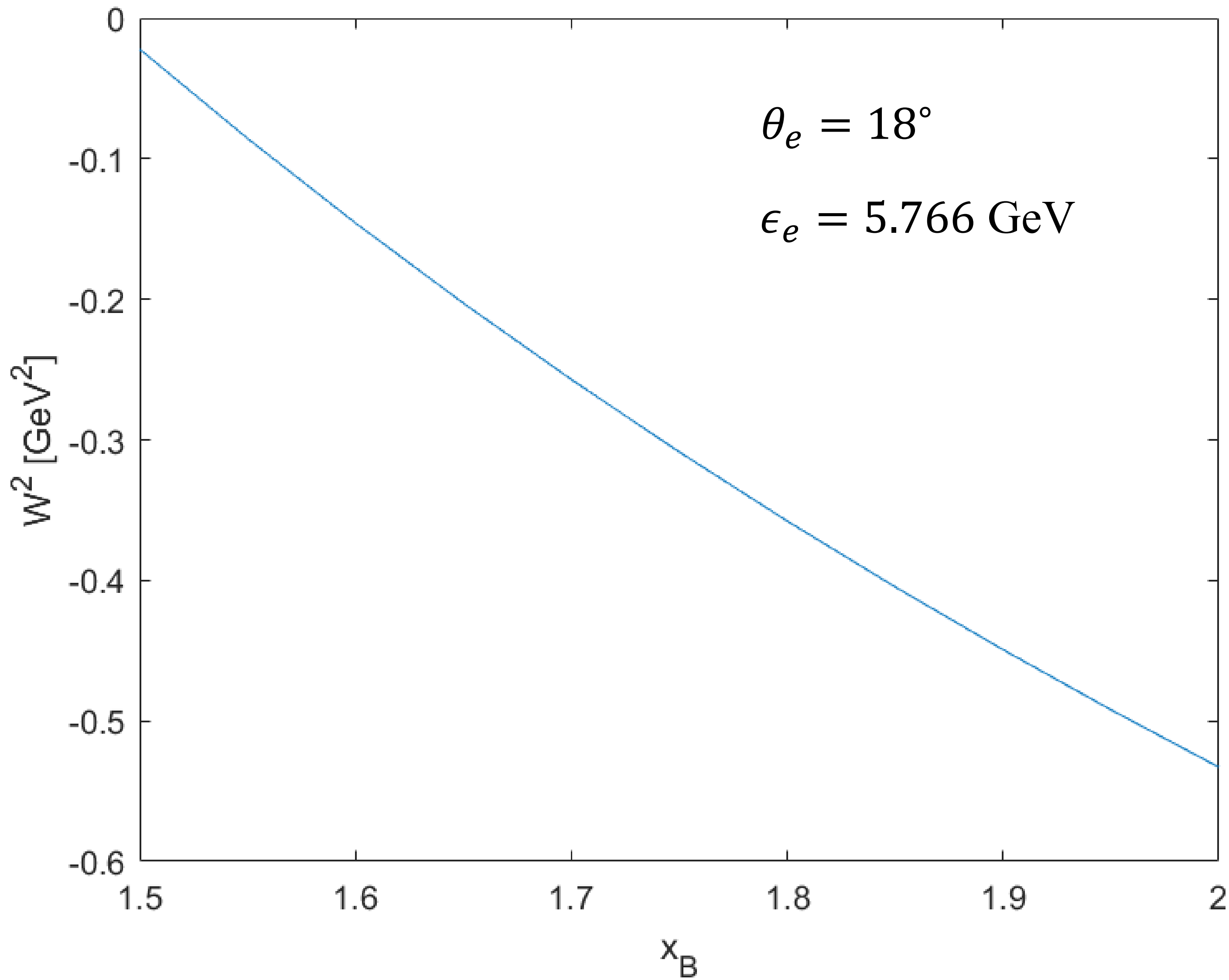
$$\binom{A}{2} a_2 = \frac{C^d_{pn}(A)\sigma^d_{pn}(\omega, q; A)}{C^d_{pn}(d)\sigma^d_{pn}(\omega, q; d)}$$

If $\begin{cases} \sigma_{CM}(A) = 0 \\ B_A - B^*_{A-2} = 2.224\ \text{MeV} \end{cases}$ ⇒

$$\binom{A}{2} a_2 = \frac{C^d_{pn}(A)}{C^d_{pn}(d)}$$

The regular interpretation!

$$W^2 = m_p^2 + 2m_p\omega - Q^2$$



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