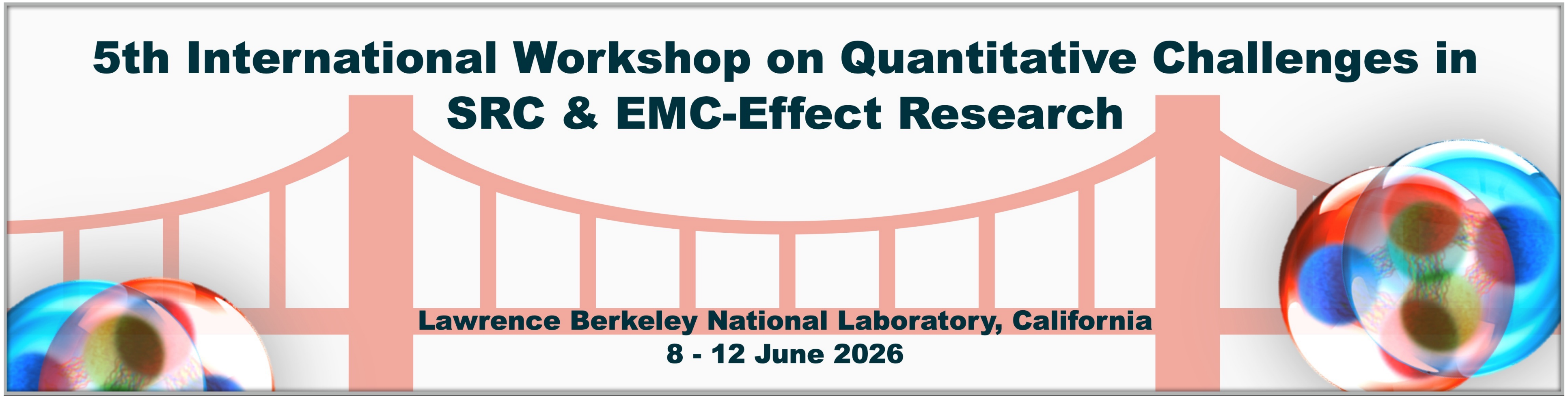


Quest for 3N-SRC Correlations

Igor Korover

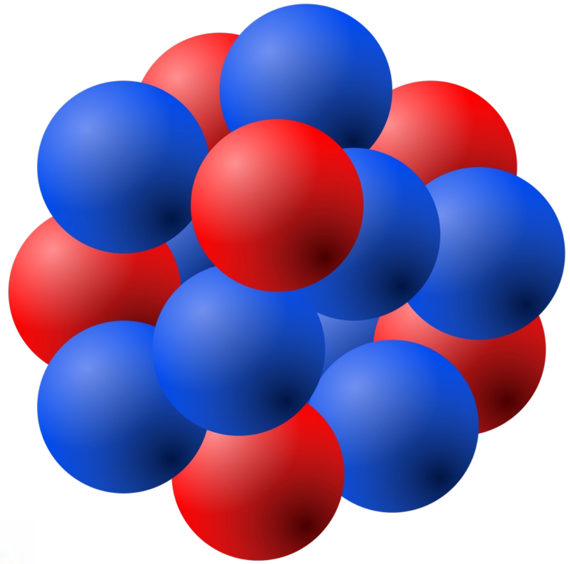
Jun 11th, 2026

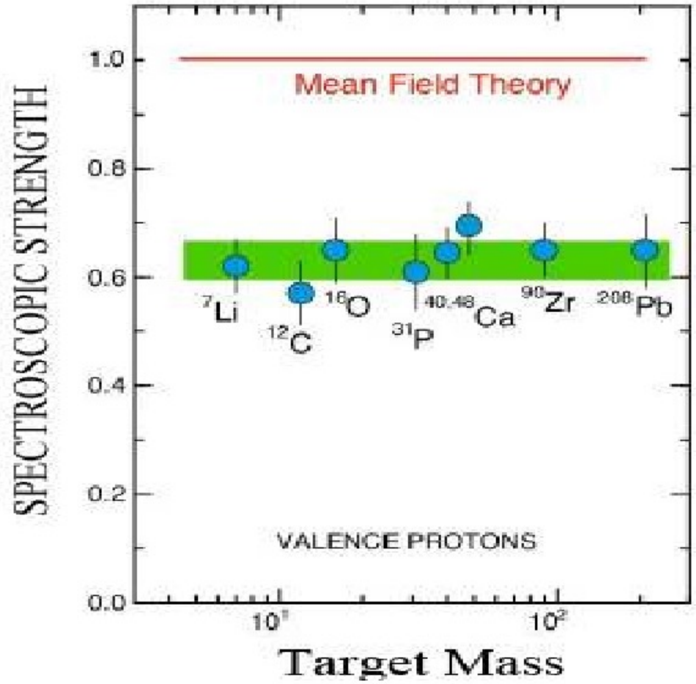
The Raymond and Beverly Sackler Faculty of Exact Sciences
Tel Aviv University

TEL AVIV UNIVERSITY אוניברסיטת תל אביב

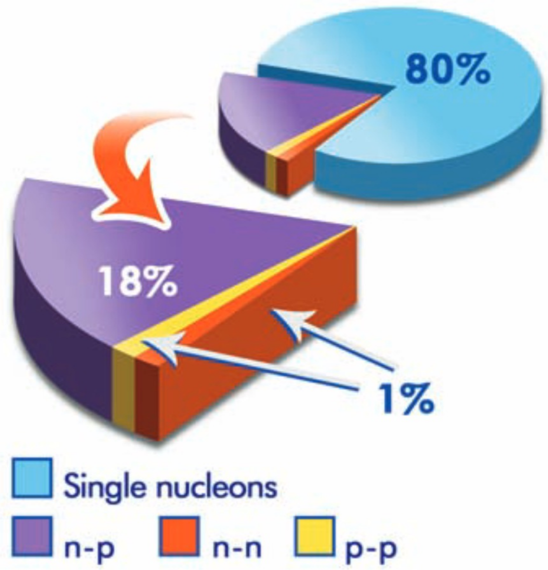
Nuclei are complex many-body systems

$$\sum_i \left\{-\frac{\hbar^2}{2m_i}\nabla_i^2\Psi(\vec{r}_1,\dots,\vec{r}_N,t)\right\} + U(\vec{r}_1,\dots,\vec{r}_N)\Psi(\vec{r}_1,\dots,\vec{r}_N,t) = i\hbar\frac{\partial}{\partial t}\Psi(\vec{r}_1,\dots,\vec{r}_N,t)$$

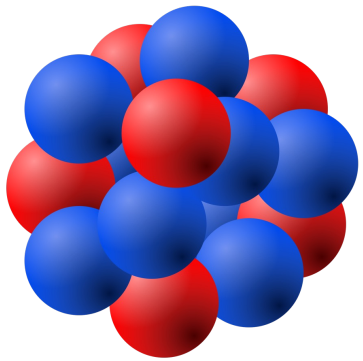


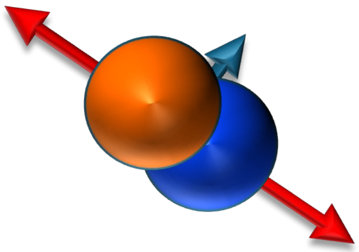


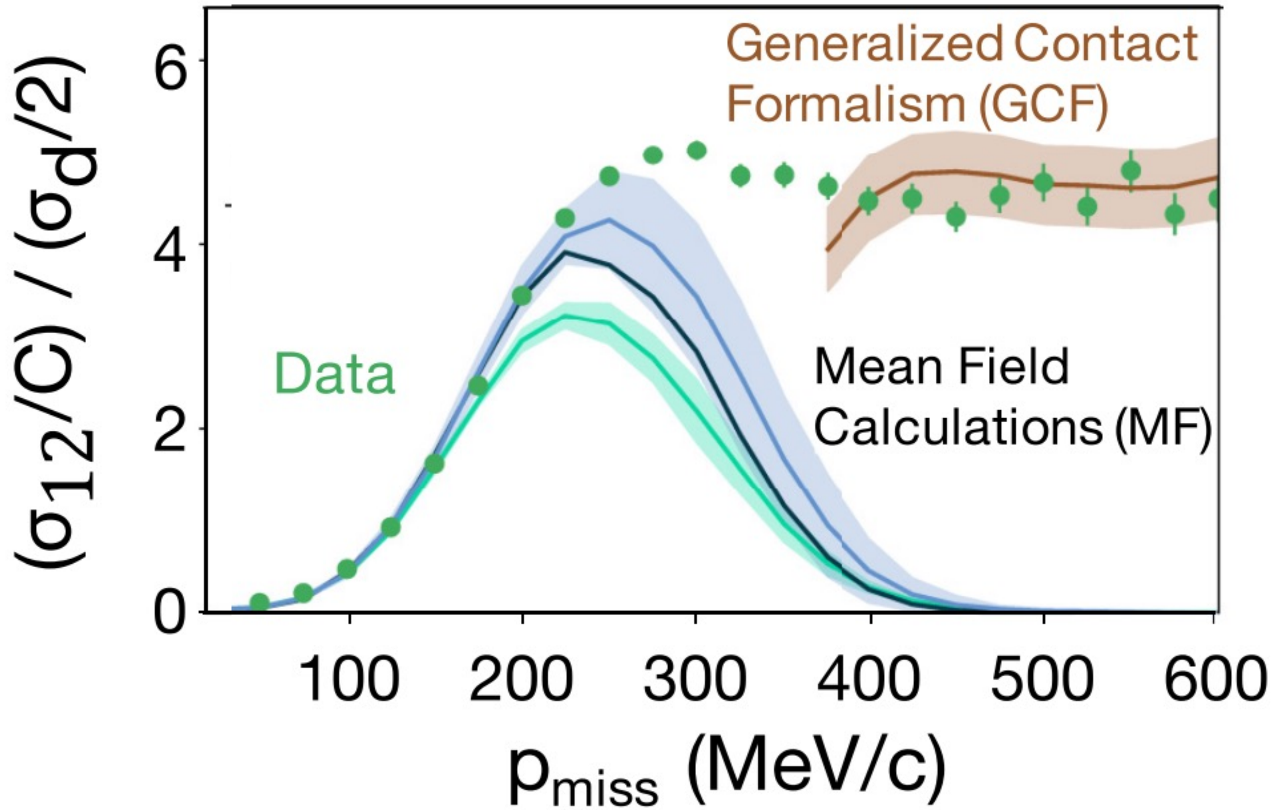
L. Lapikas, *Nucl. Phys. A.* ***553***, 297 (1993).



Mean Field + 2N-SRC







Transition width: 58 ± 4 MeV/c

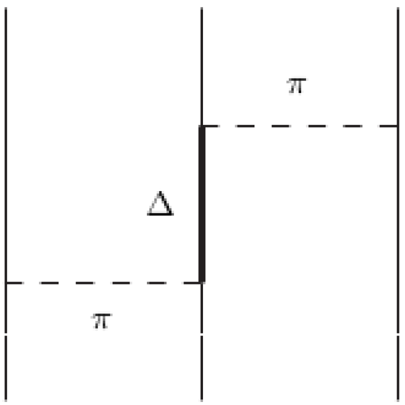
Why do we care about 3N-Forces?

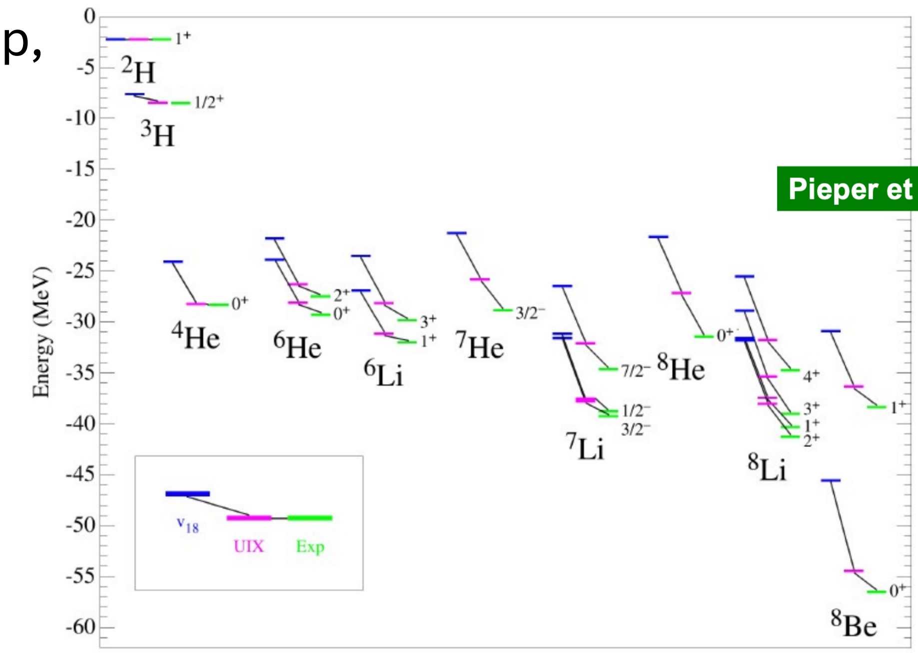
Three-body forces are needed to describe the nuclear binding energies and levels

Many-body forces arise naturally in the EFT expansions.

At increasing density: more nucleons overlap, many-body terms become increasingly important.

$$UIX = V^{2\pi} + V^{R}$$





Pieper et al 2001

Adding Urbana IX 3N-3N force to the wavefunction

Three body forces ≠ 3N-SRC

3N-SRC ~~→~~ Three body forces

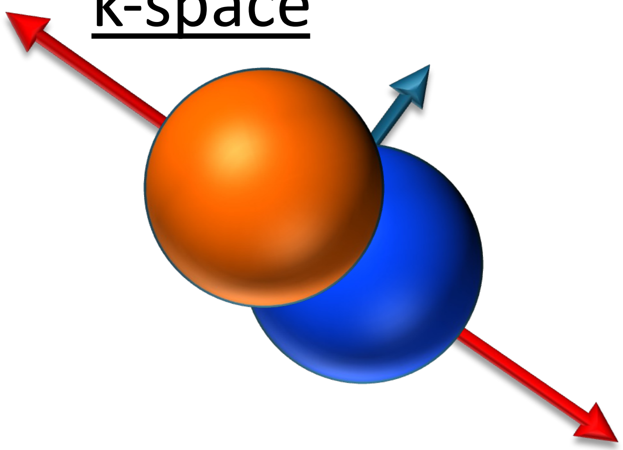
Three body forces → 3N-SRC

Studying <u>3N-SRC</u>s may provide experimental access to three-body dynamics at short distances

From 2N-SRC to 3N-SRC

Why 2N-SRC is “easy”…

k-space

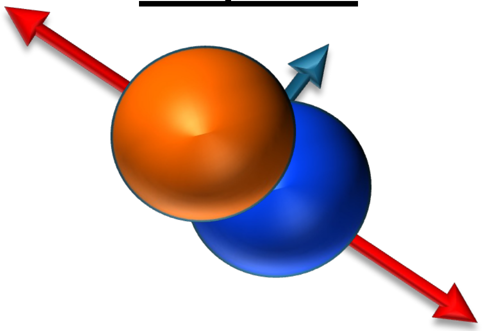


- Back-to-back pair picture.
- Small CM momentum.
- Strong *np* dominance.
- Universal high-momentum tails.

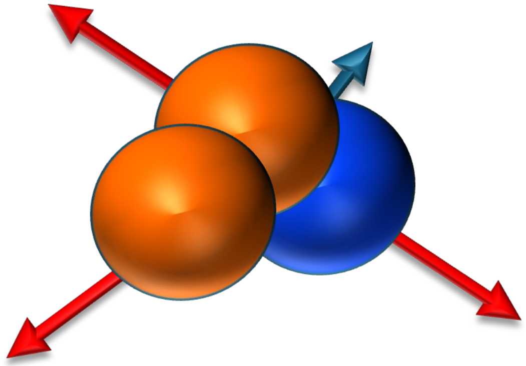
Curtesy of ChatGPT…

Why are 3N-SRCs difficult?

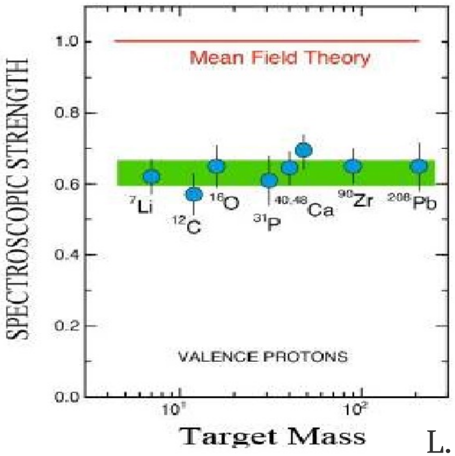
k-space



k-space



Clear evidence for amount of correlations



L. Lapikas, *Nucl. Phys. A.* ***553***, 297 (1993).

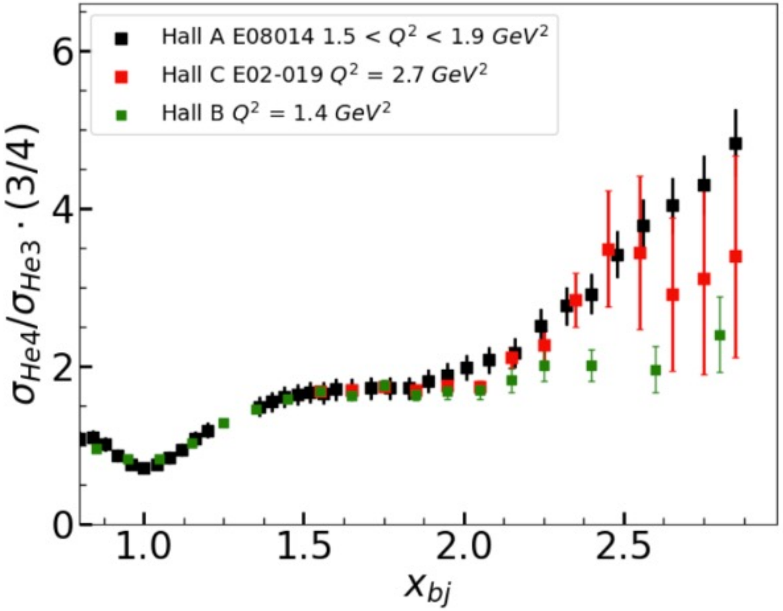
How many 3N-SRCs are there?

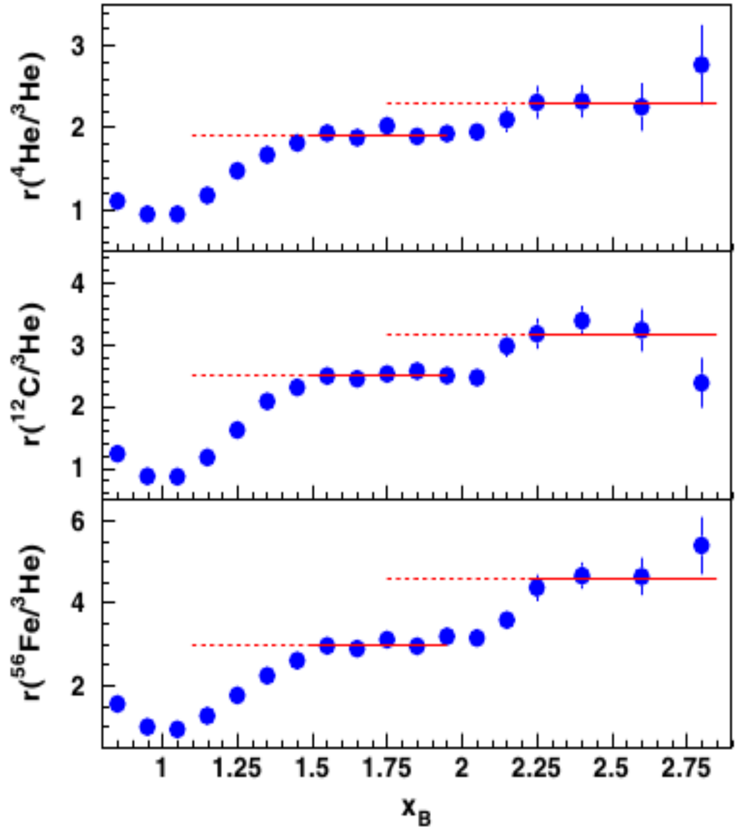
- Momentum shared between 3 particles.
- Not uniquly defined configurations in momentum space.

Experimental search

Look for a second scaling plateau for $x_B > 2$!

arXiv:2601.09568



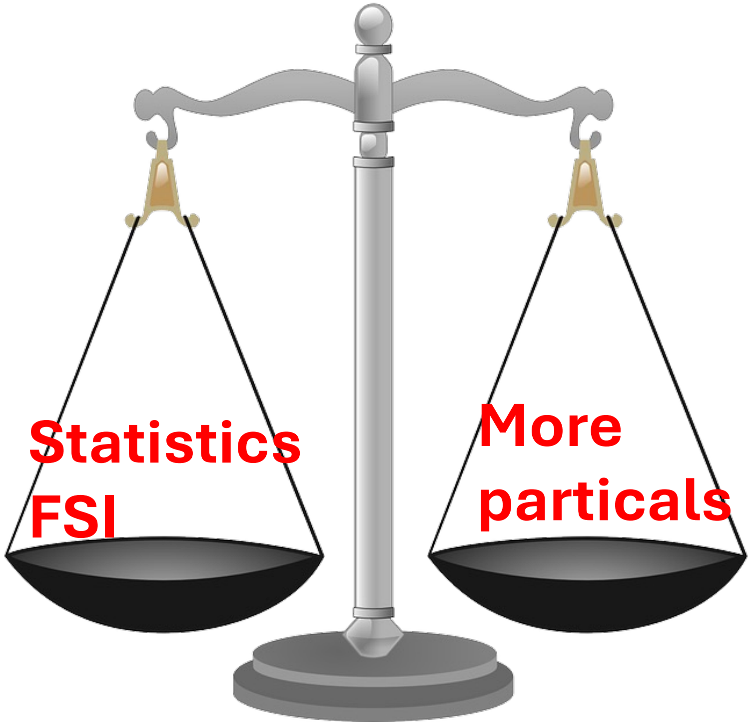


Phys. Rev. Lett. **96**, 082501 (2006)

Inclusive ratios alone are inconclusive.
Need more exclusive information.

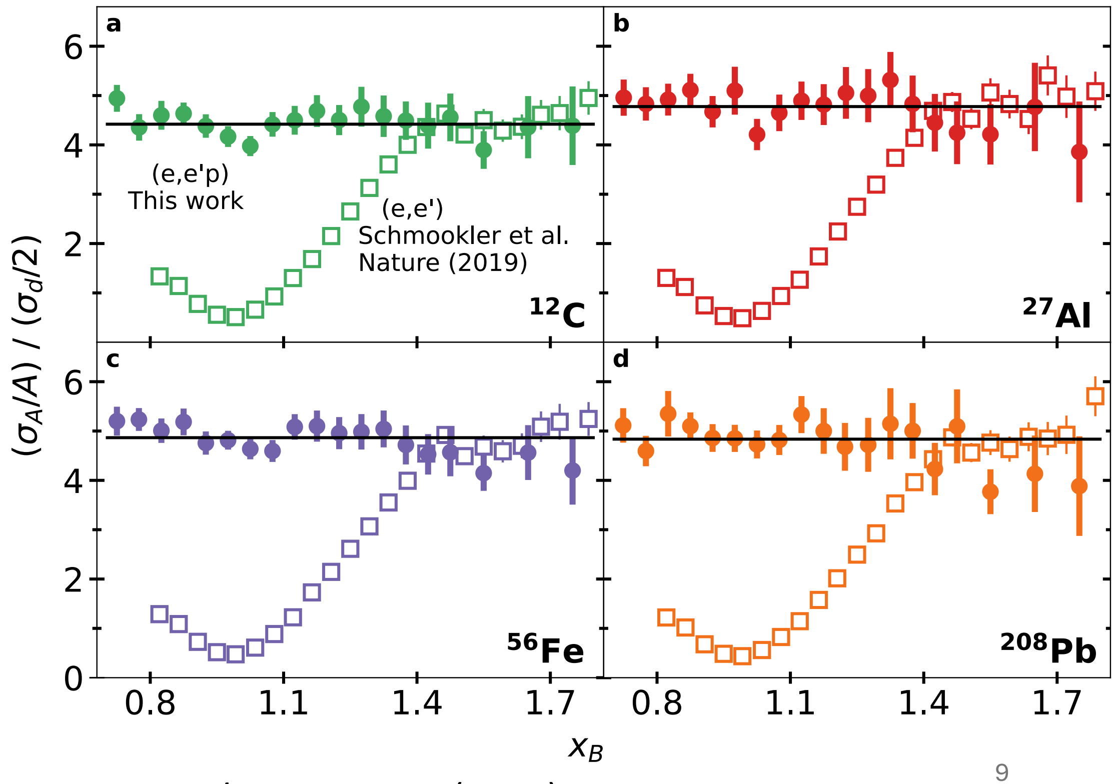
Inclusive → Large x_B → Extreme kinematics → Low statistics

Going exclusive provide additional ID of SRC under less extreme conditions



Example:

Scaling can be observed below inclusive threshold



Phys.Rev.C 107 (2023) 6, L061301

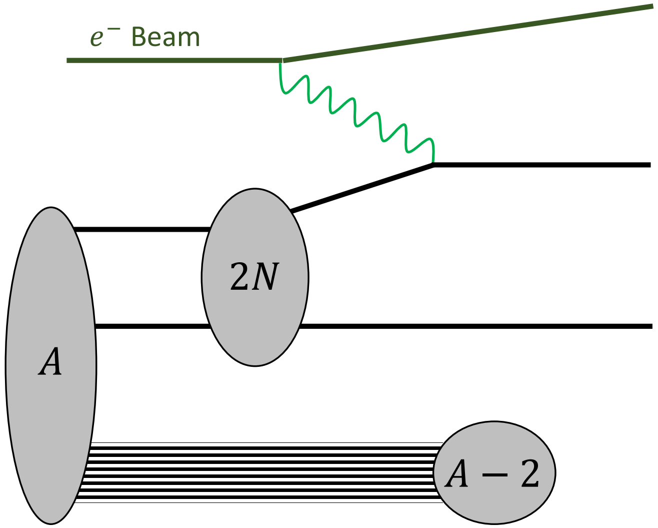
Our approach: start with kinematics of 3N-SRC

What does a genuine 3N-SRC look like?

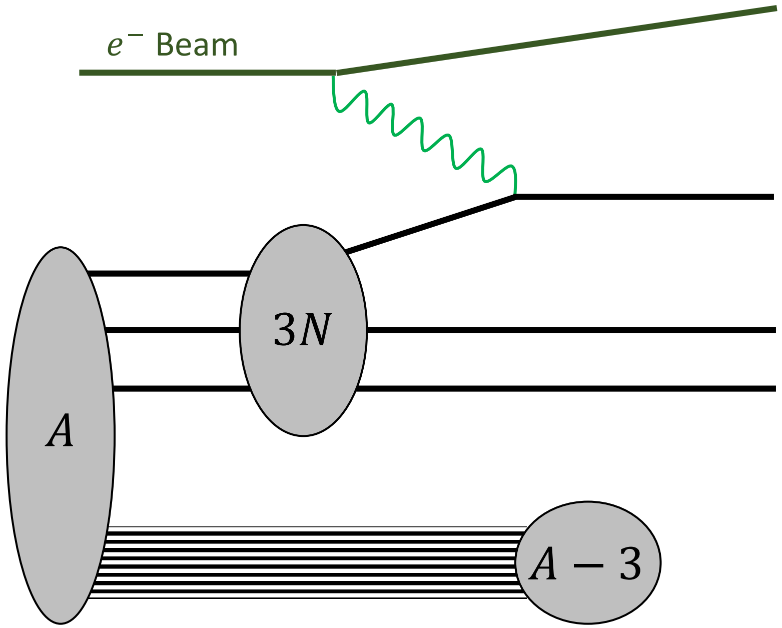
Extend GCF from 2N-SRC to 3N-SRC:

- ❖ **Use of He-3 wave function**
- ❖ **Introduce CM motion**
- ❖ **Add FSI.**

Developing a 3N-SRC GCF



3×5 particles
−4 conservation law
11 free parameters



Generator flow

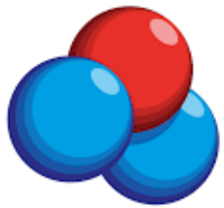
- Sample 3N wave function.
- Sample CM motion.
- Generate electron scattering.
- Apply energy conservation.

$$\frac{d^{11}\sigma}{d^{11}X^{\mu}} = \mathcal{J}\sigma_{eN} * |\phi_\alpha(\vec{p}_1, \vec{p}_2, \vec{p}_3)|^2 * n(p_{cm}) * \delta(E_f - E_i)$$

3N SRC generator: Scattering off one nucleon of a correlated triplet.

$$e + A \rightarrow e' + N_1 + N_2 + N_3 + (A-3)^*$$

Key change vs 2N: (contact) x (universal function) → pre-computed 3-body density matrix 3He.



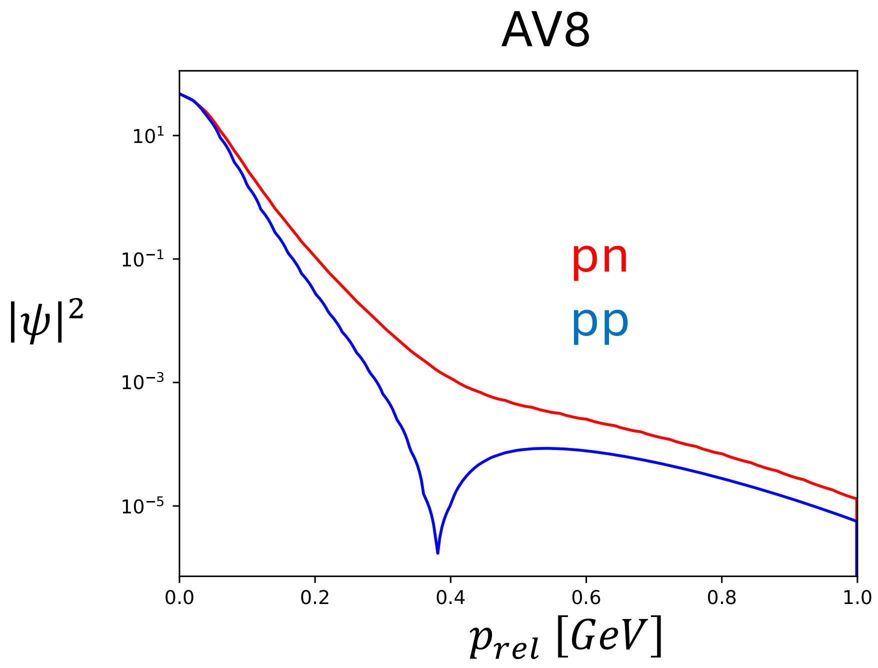
- AV8, N2LO, G3RS Potential
- Summed over spin configurations

$$S = \frac{1}{4\pi}\sum_{\alpha} C^{\alpha} t^{\alpha} \int \frac{d^3\vec{p}_2 d^3\vec{p}_3}{(2\pi)^6} \delta(f(\vec{p}_2,\vec{p}_3))\rho^{\alpha}(\vec{p}_1,\vec{p}_2,\vec{p}_3) n^{\alpha}(|\vec{p}_1+\vec{p}_2+\vec{p}_3|)$$

$$\frac{d^{11}\sigma}{d^{11}X^{\mu}} = \sigma_{e,N}\, S,$$

3 momenta × 2 particles ⟹

3 center of mass momenta
2 Euler angles
1 NN Interaction Variable

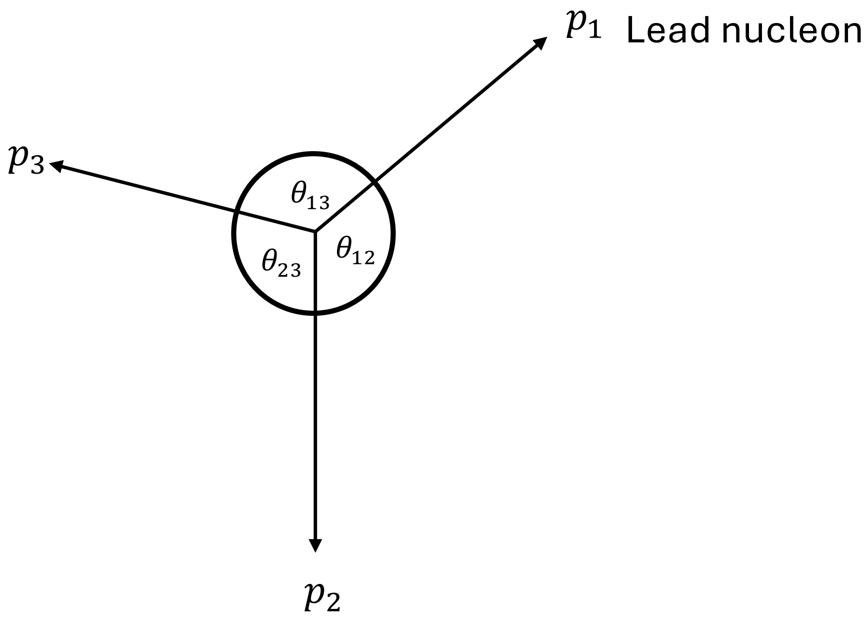


What should we do for 3N?

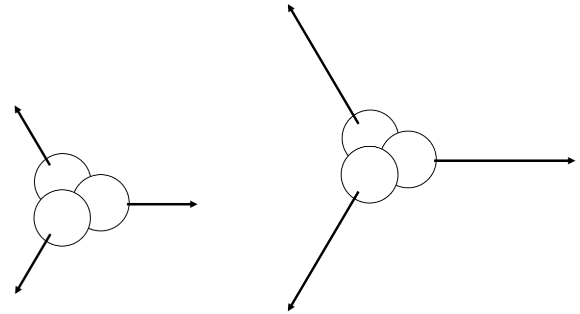
3 momenta × 3 particles ⟹

3 center of mass momenta
3 Euler angles
3 NNN Interaction Variables

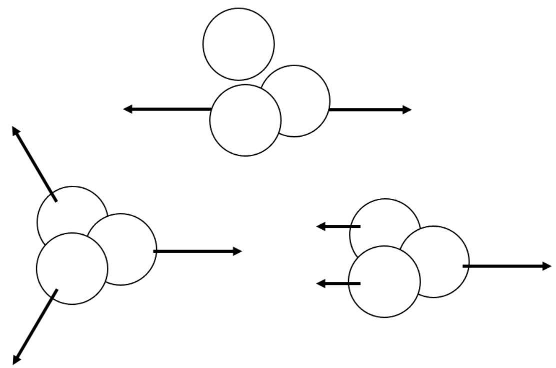
3N-SRC configurations – parameters selection



1 Size
Parameter



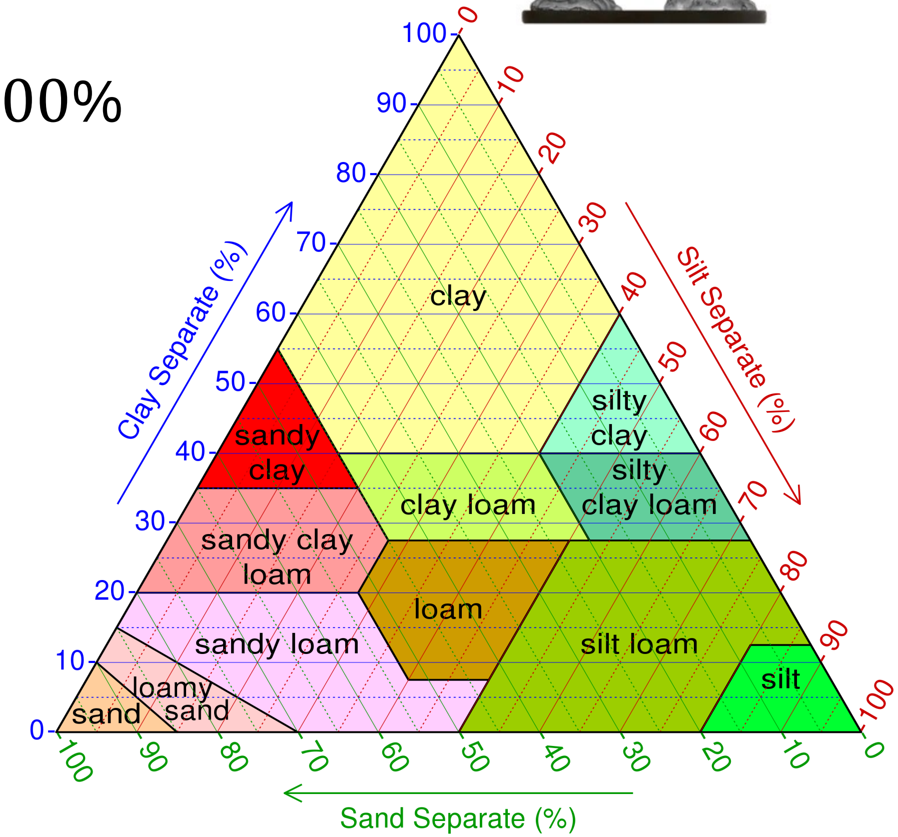
2 Shape
Parameters



Ternary Plot

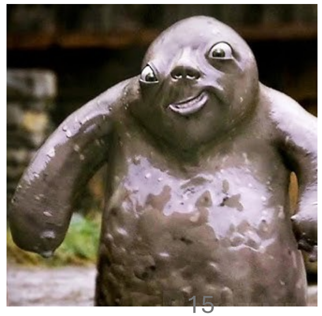
100% clay

$$\%Clay + \%Silt + \%Sand = 100\%$$



100% Silt

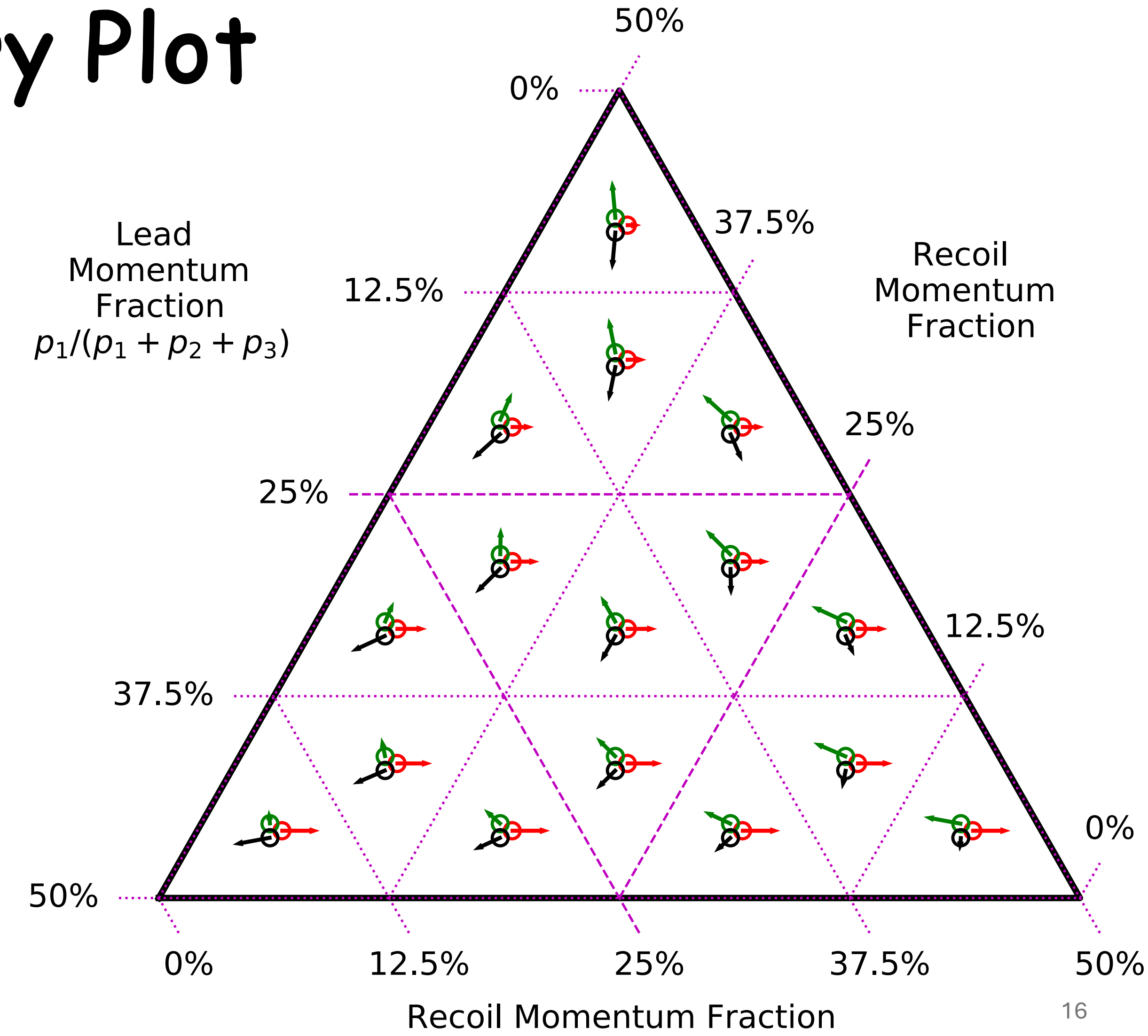
100% Sand



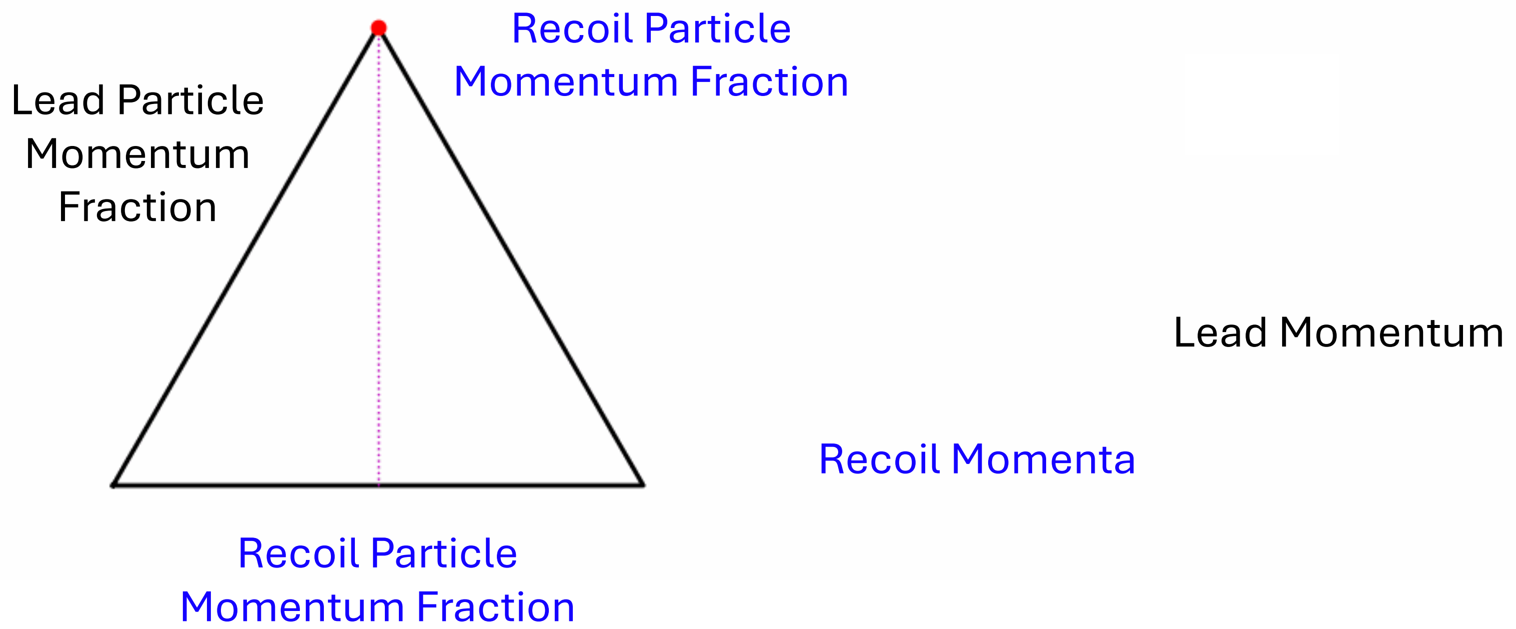
Modified Ternary Plot

$$\frac{p_1}{p_{tot}} + \frac{p_2}{p_{tot}} + \frac{p_3}{p_{tot}} = 1$$

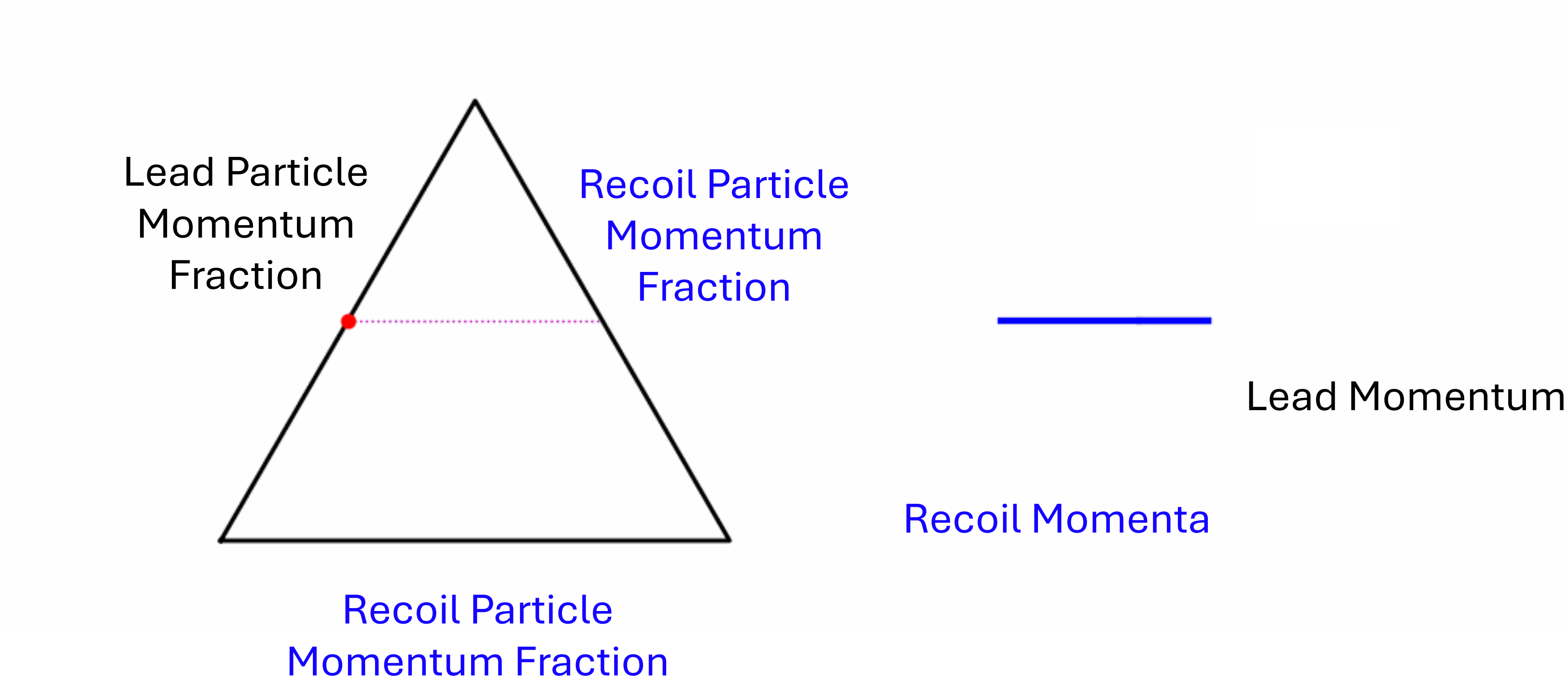
$$\frac{p_1}{p_{tot}}, \frac{p_2}{p_{tot}}, \frac{p_3}{p_{tot}} < 0.5$$



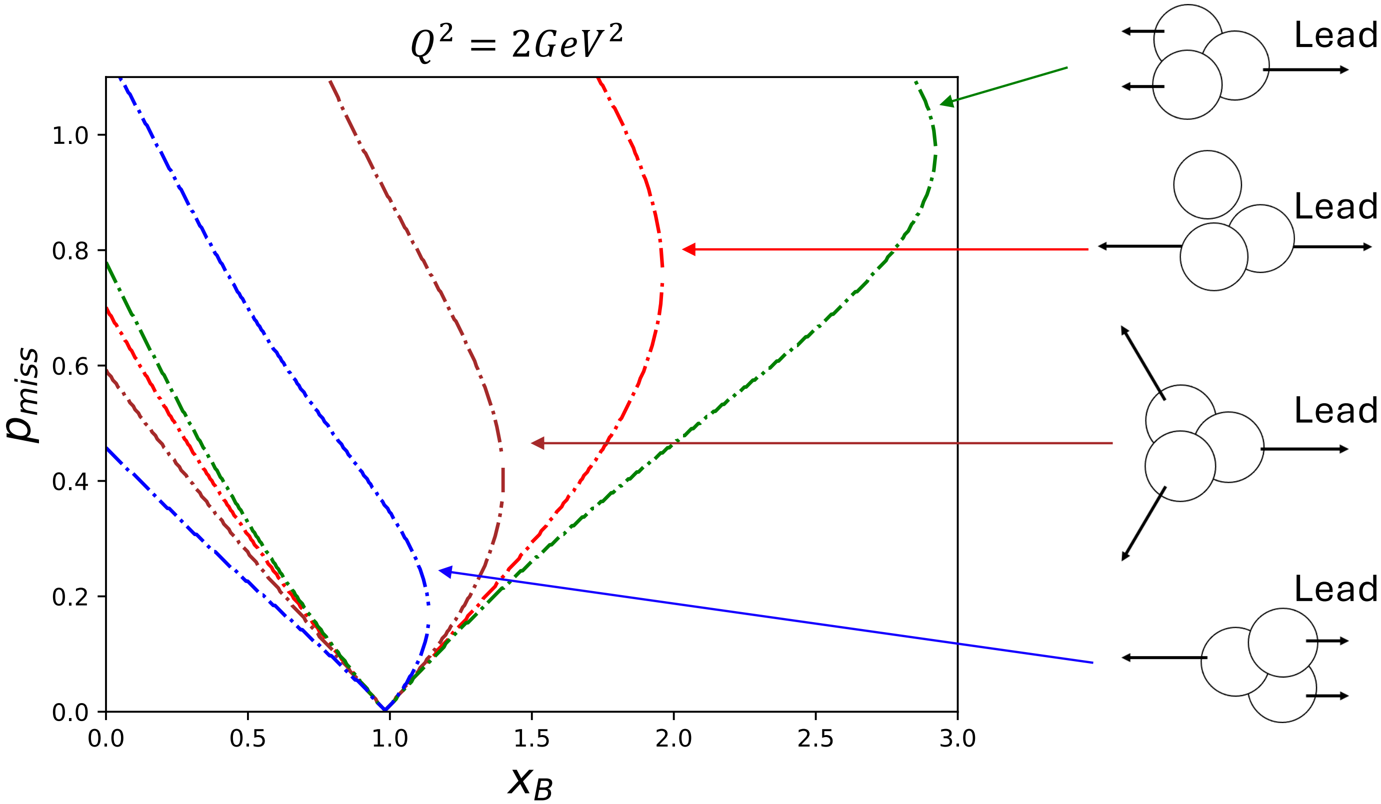
Modified Ternary Plot



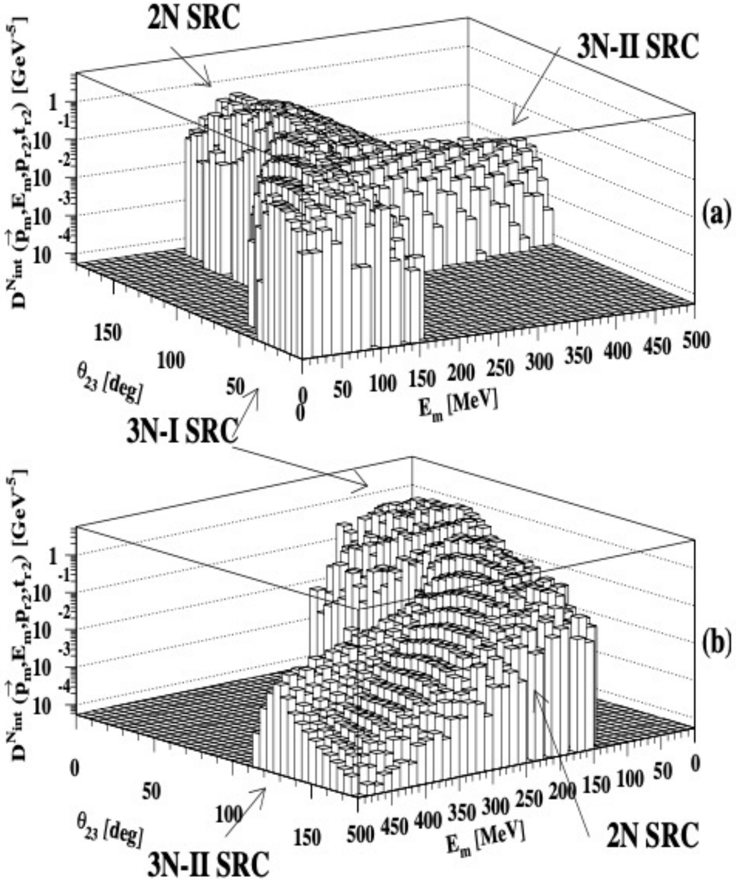
Modified Ternary Plot



Understanding the Kinematics



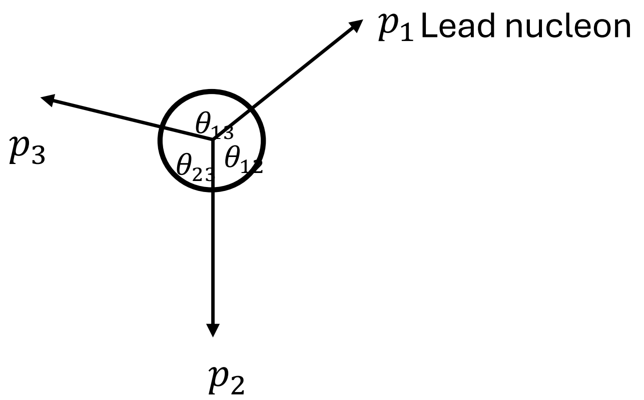
Misak made similar calculations



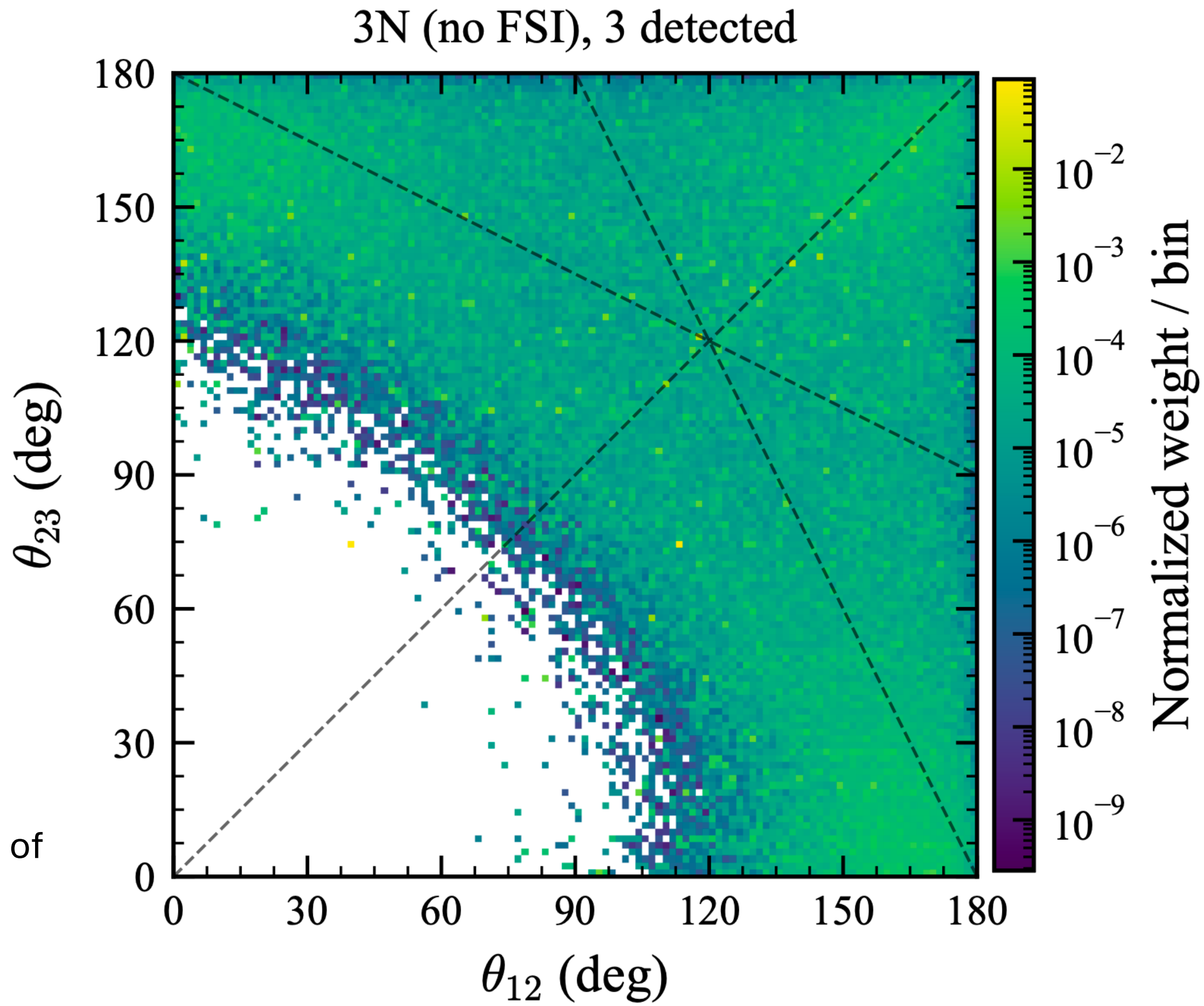
Phys. Rev. C 71, 044615 (2005)

Distribution of opening angles of 3N SRCs initial state

$p_1, p_2, p_3 > k_F$



[reflection around dashed symmetry lines=permutations of nucleons]



Distribution of opening angles of 3N SRCs initial state

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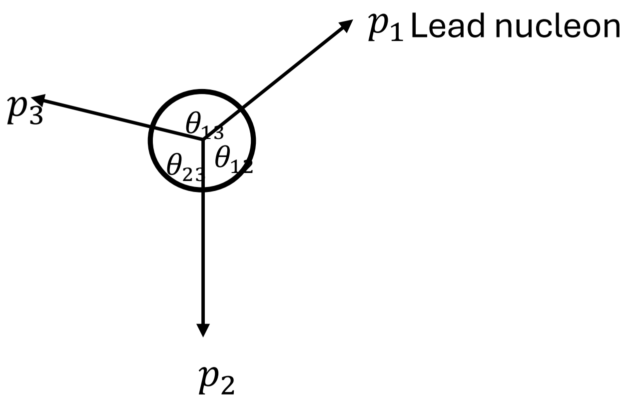
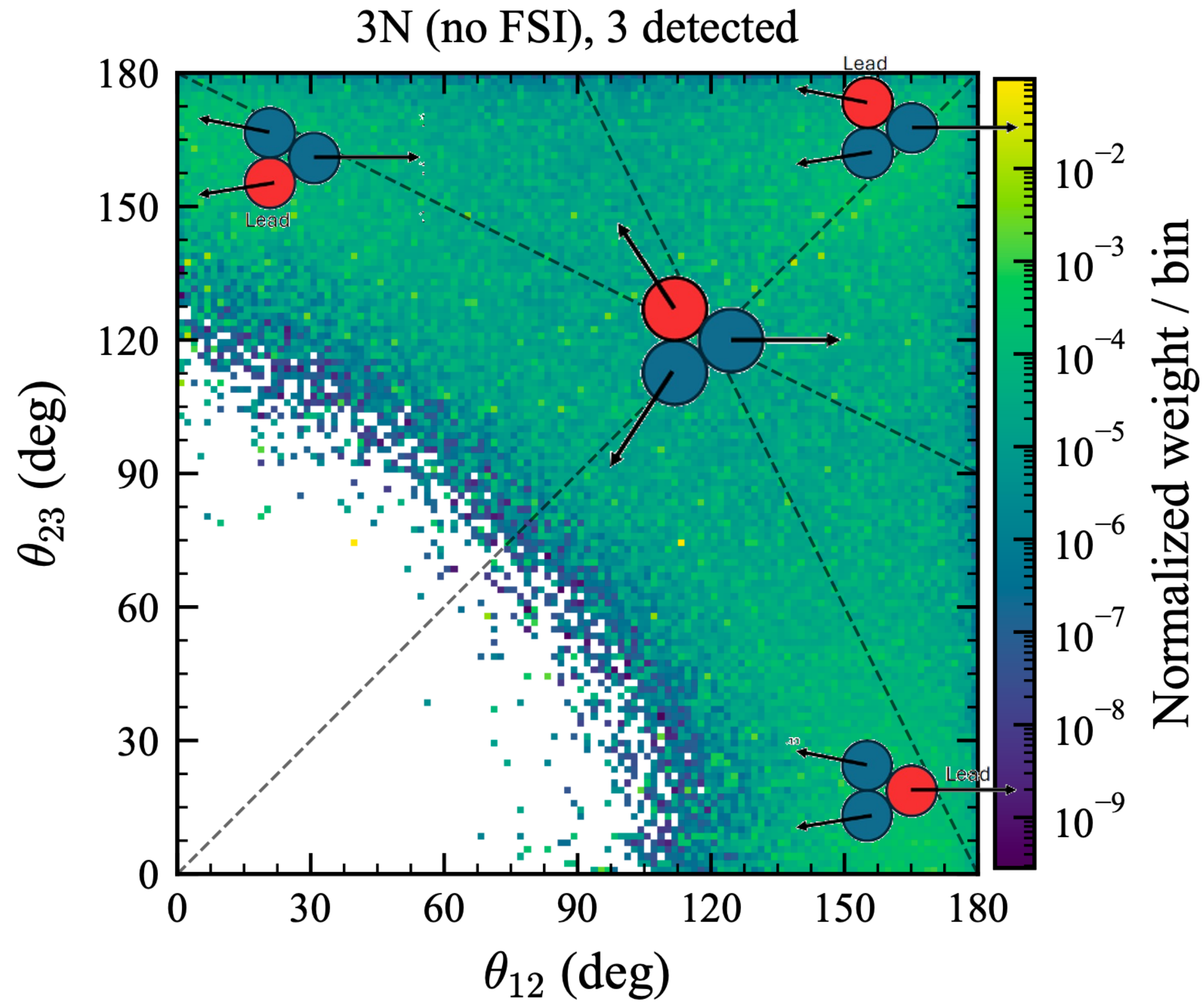
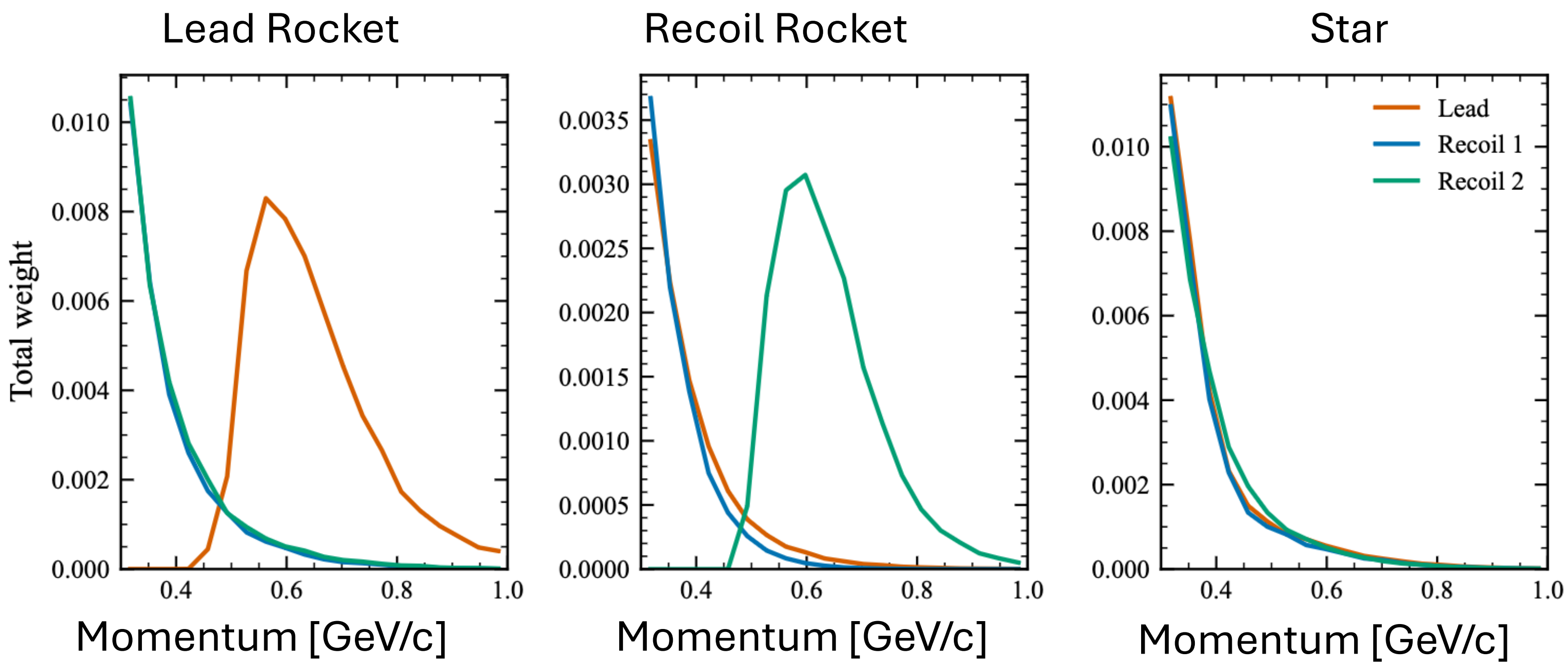
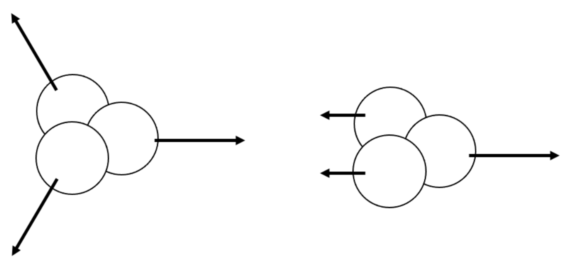




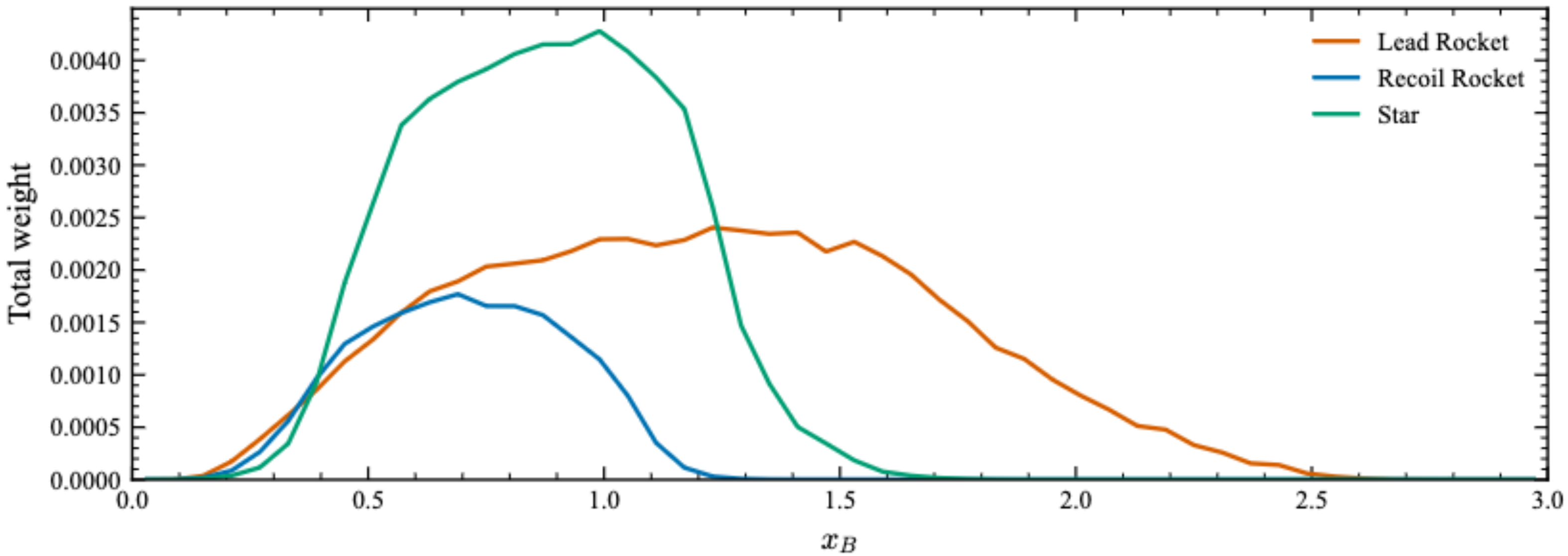
Distributions of 3N in different configurations



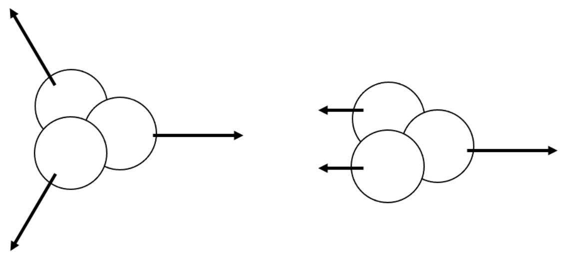
The ground state momentum distribution of the 3 SRC nucleons in the rocket and star like configurations.



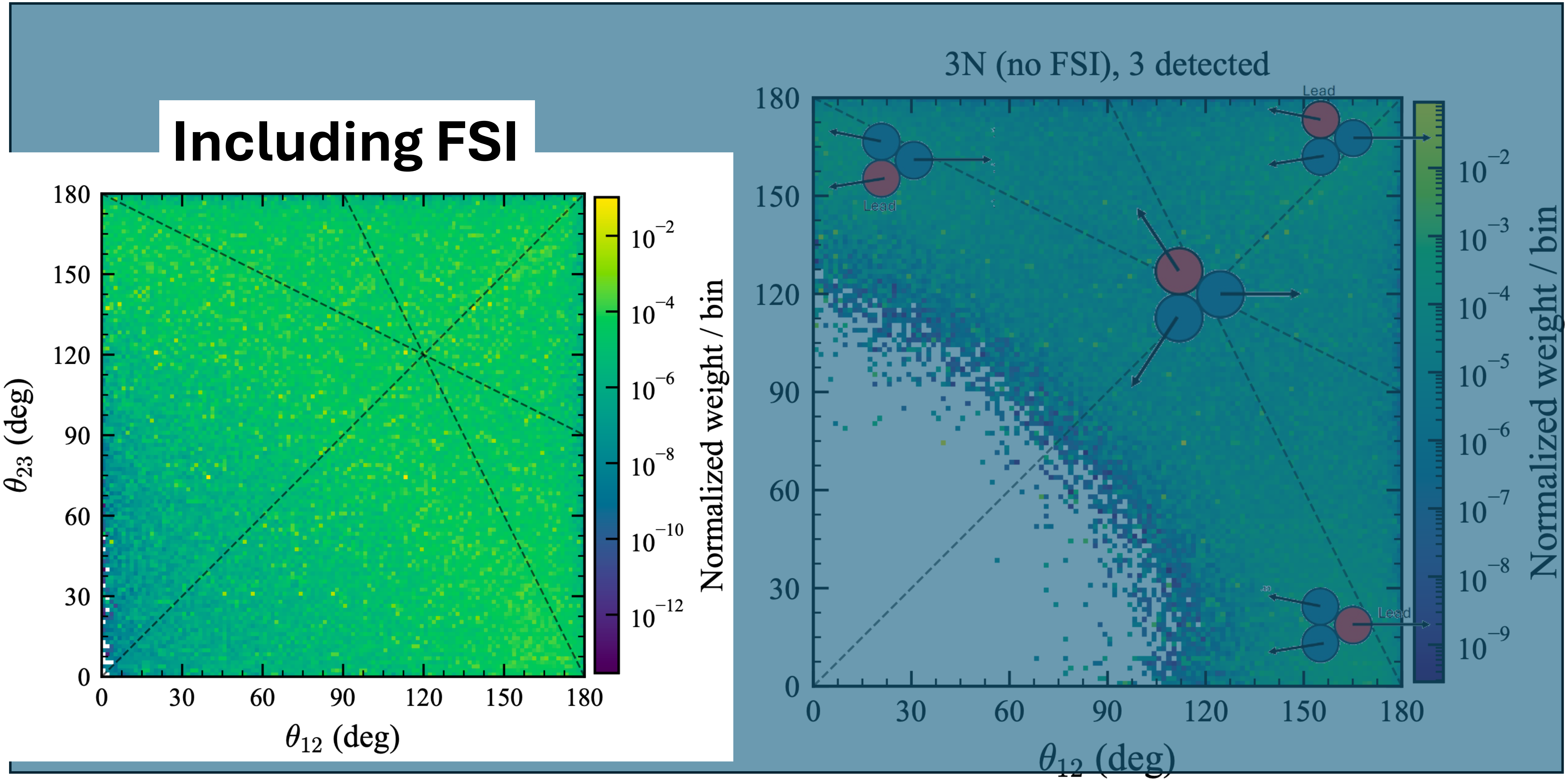
x_B Distributions



- The model predicts two distinct classes:
  - Rocket
  - Star
- $x_B > 2$ predominantly selects lead-rocket. configurations.



Distribution of opening angles of 3N SRCs initial state



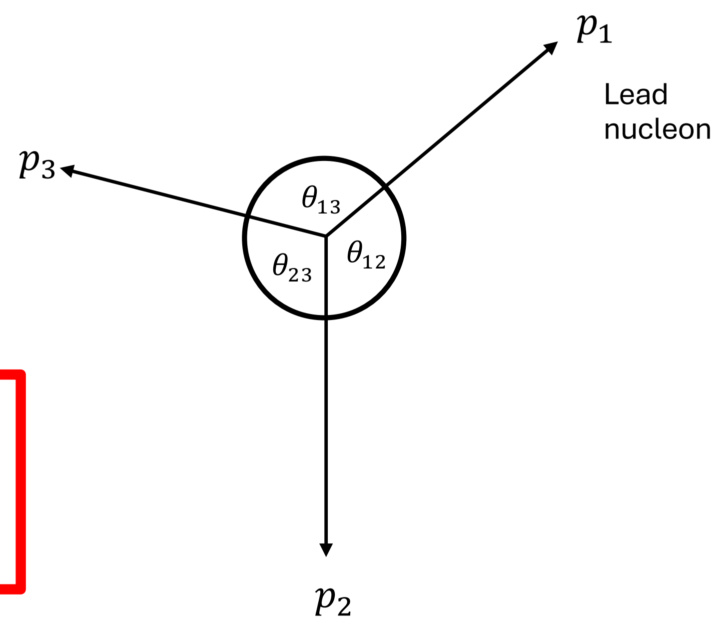
Backgrounds and FSI

$p_1, p_2, p_3 > k_F$

High momentum tail

Major background:
2N-SRC + rescattering.

Each nucleon has momentum > kF

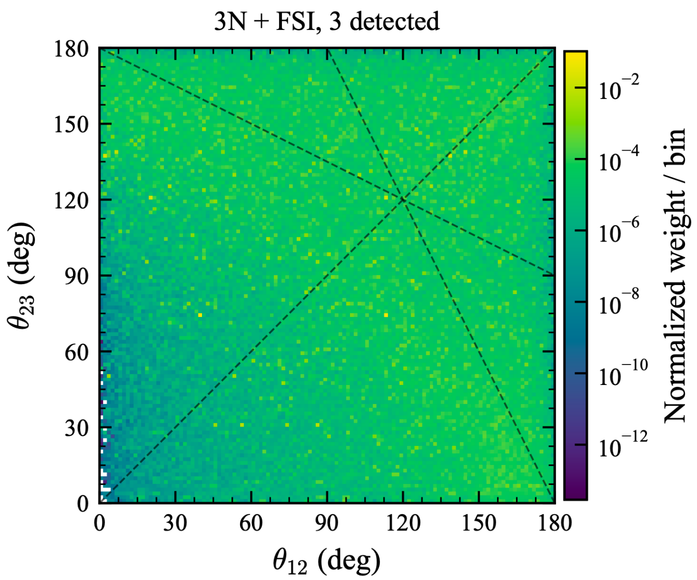


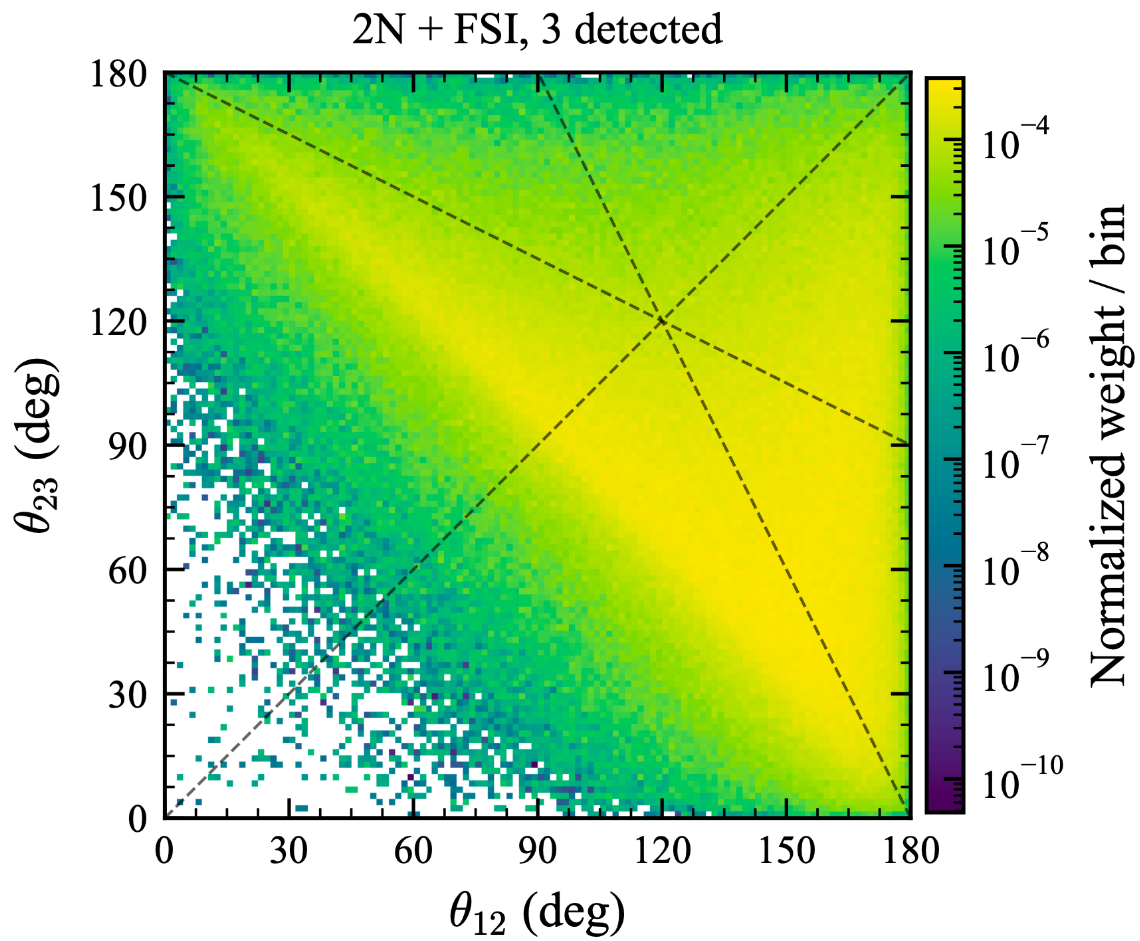
BG from Mean field is x20 lower than due to 2N-SRC +FSI

2N-SRC + FSI: Significant challenge to 3N-SRC search

Effectively – 2N-SRC backroung presents in all angles

3N-SRC





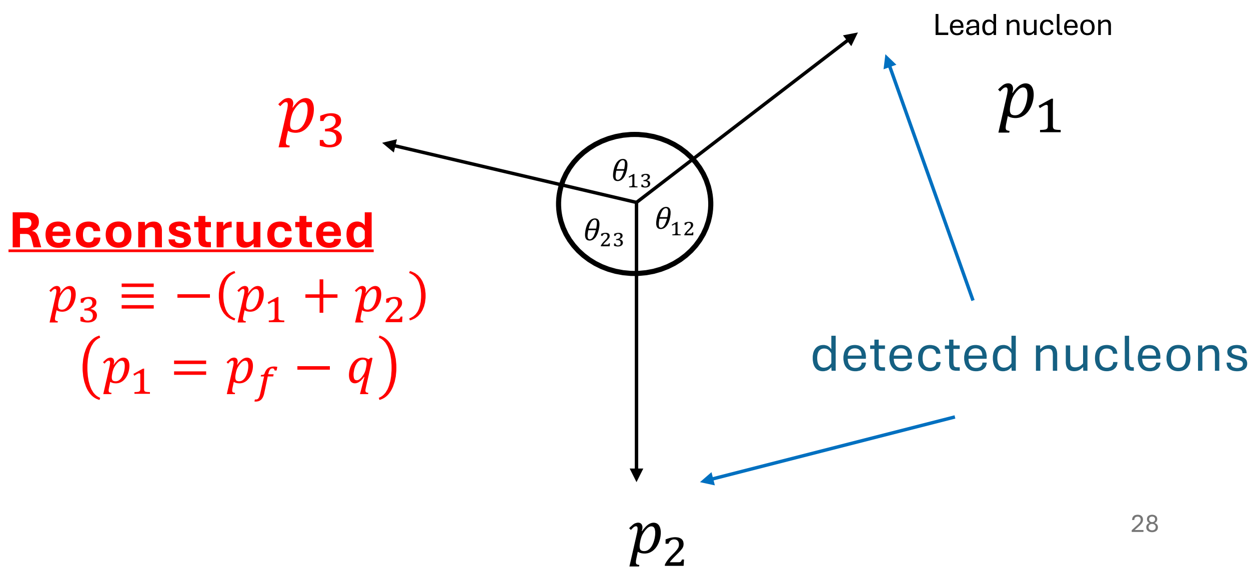
From simulation to experiment

<u>Exlusive mearurement</u>: detect 4 paricles, including neuteron

Significant experimental challange

Can we see a signature of 3N-SRC by measuring only 2 nucleons?

Look at distribution of opening angles of 2N SRCs, where a 3rd nucleon is reconstructed.

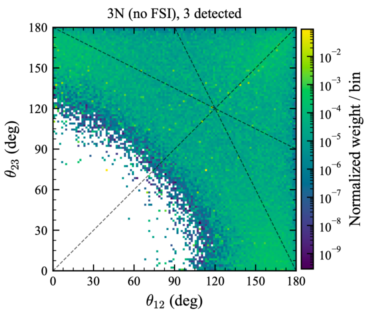


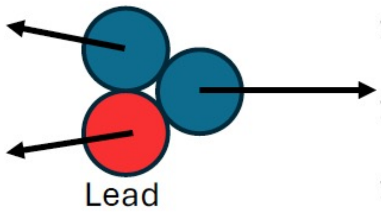
Distribution of opening angles of 3N SRCs initial state

$p_1, p_2, p_3 > k_F$

3N-SRC configurations with NO FSI
[assuming $p_{CM} = 0$].

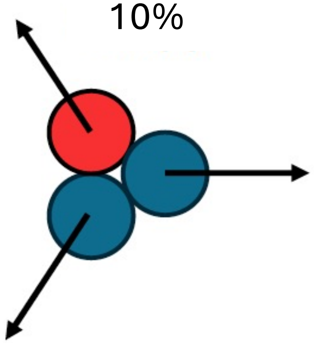
3 particles detected

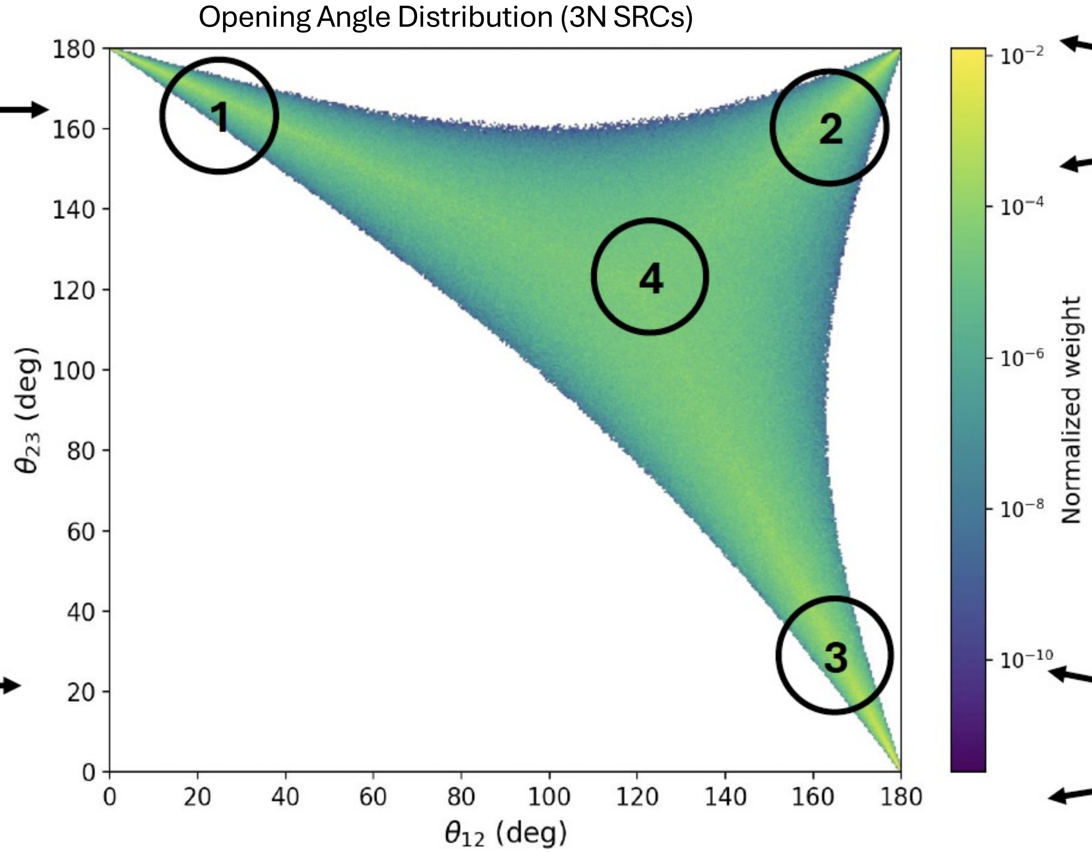


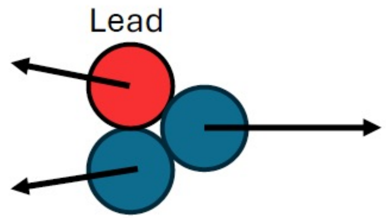


Rocket (1)
5%

Star (4)
10%

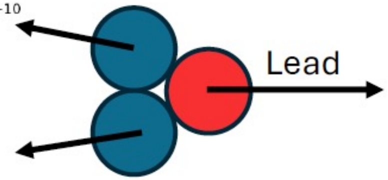






Rocket (2)
5%

Rocket (3)
15%



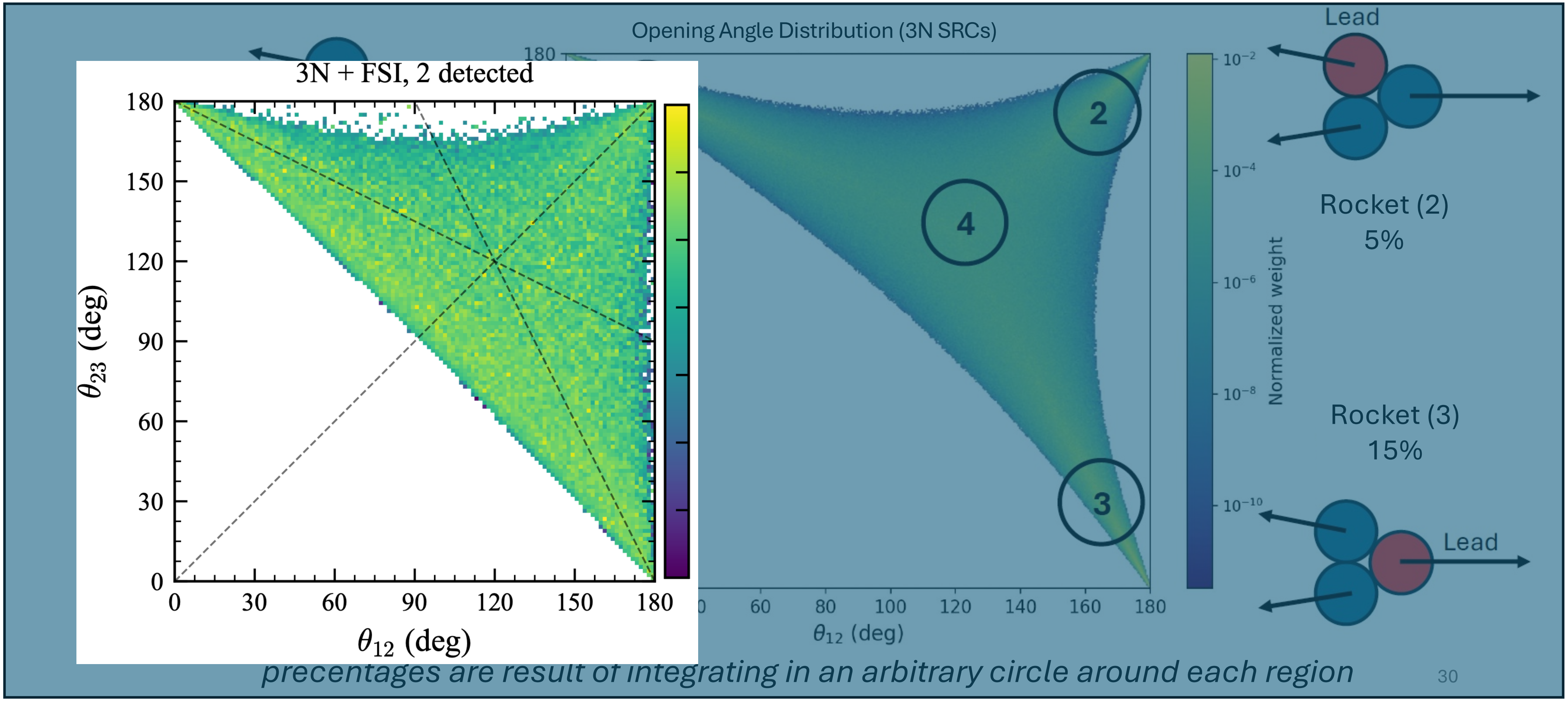
precentages are result of integrating in an arbitrary circle around each region

Distribution of opening angles of 3N SRCs initial state

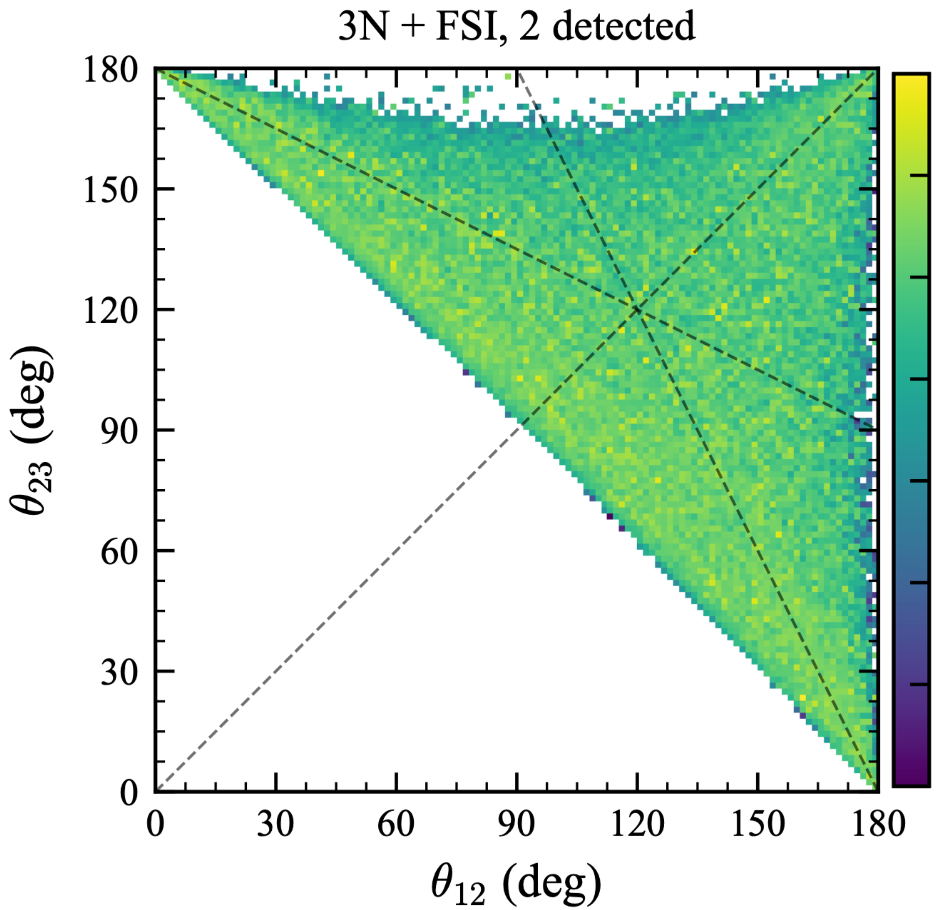
$p_1, p_2, p_3 > k_F$

3N-SRC configurations with NO FSI

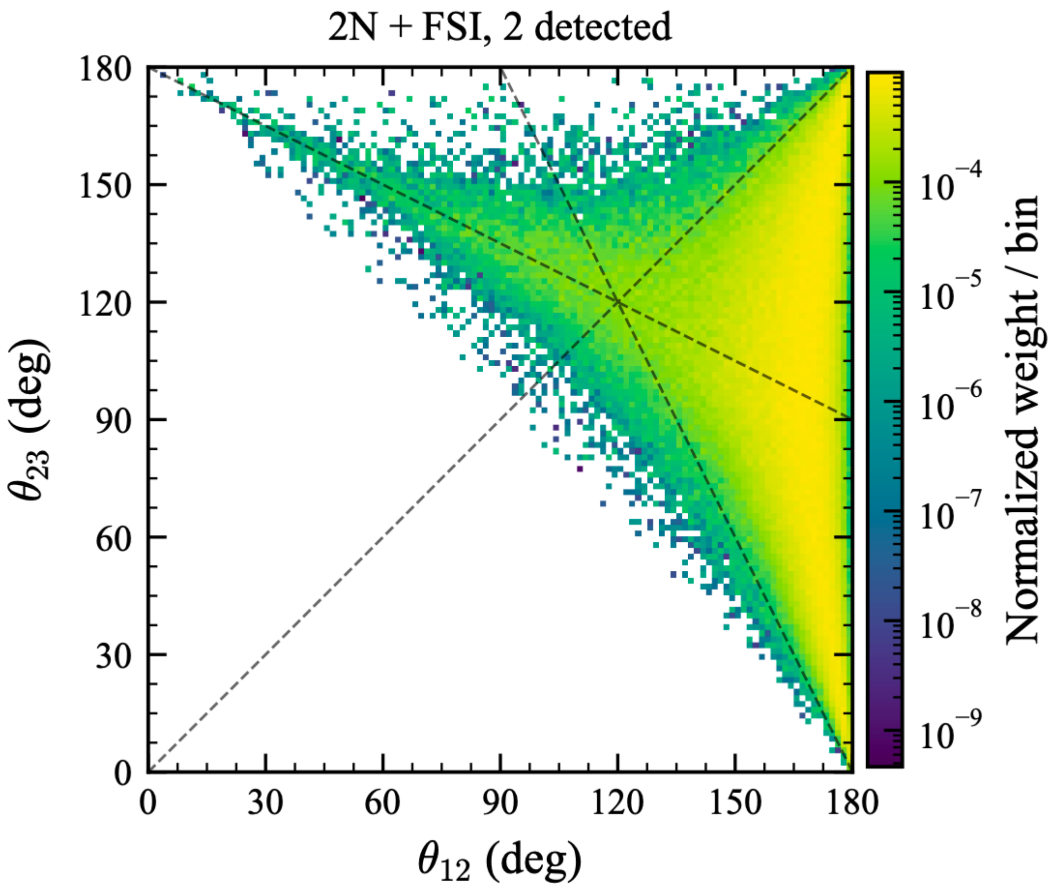
[assuming $p_{CM} = 0$].



Comparison between 3N and 2N (Background)



Background



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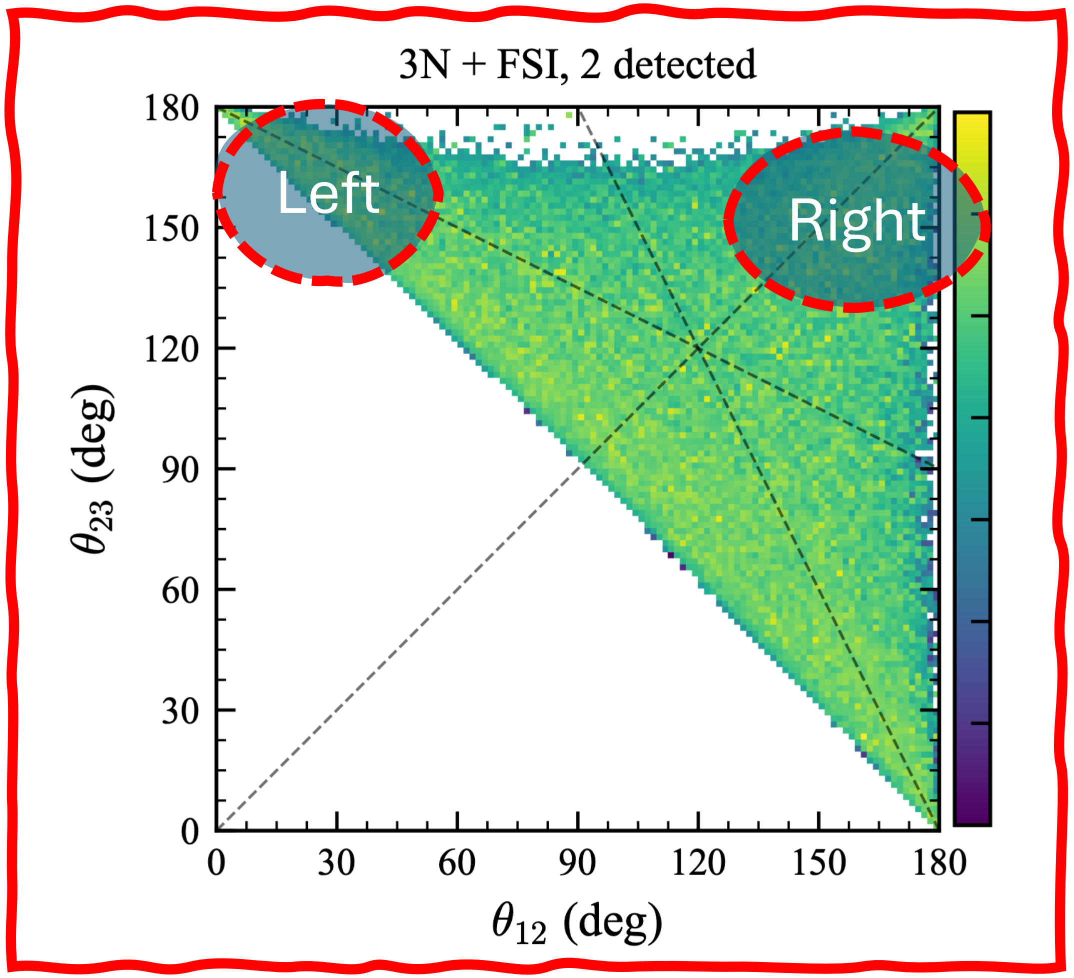
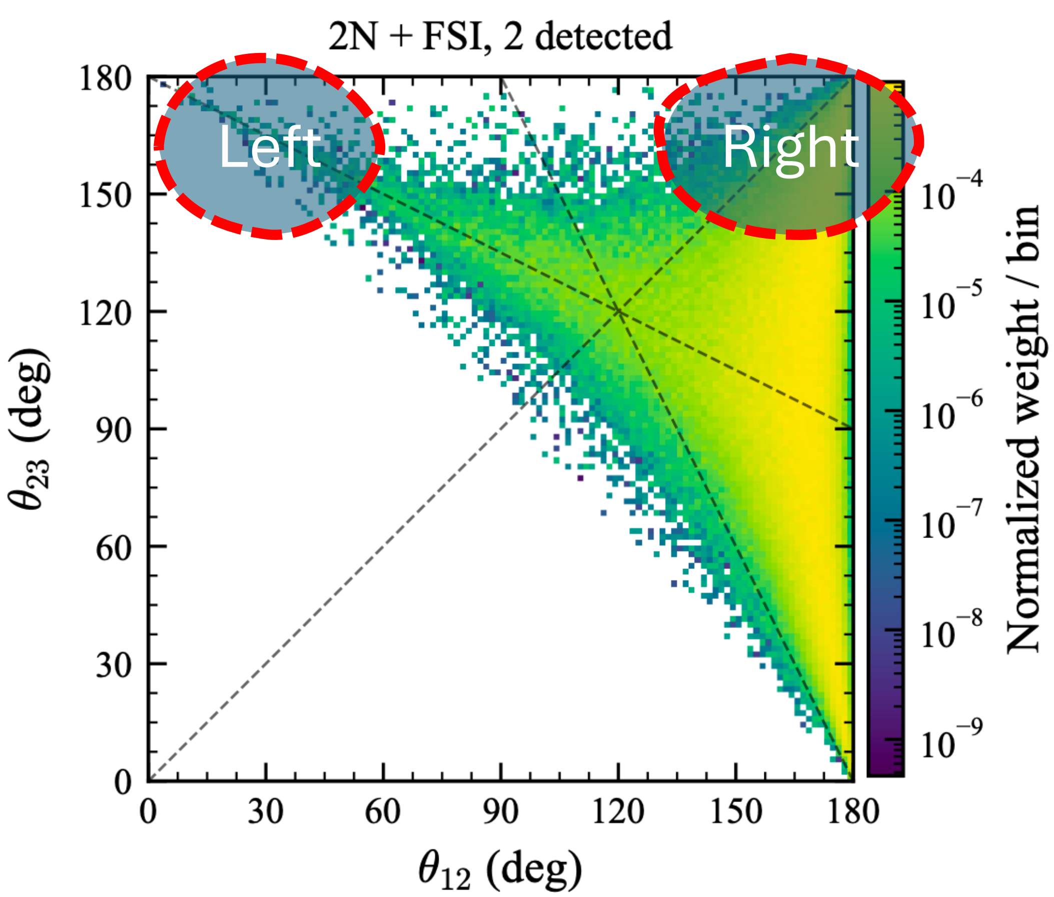


Background



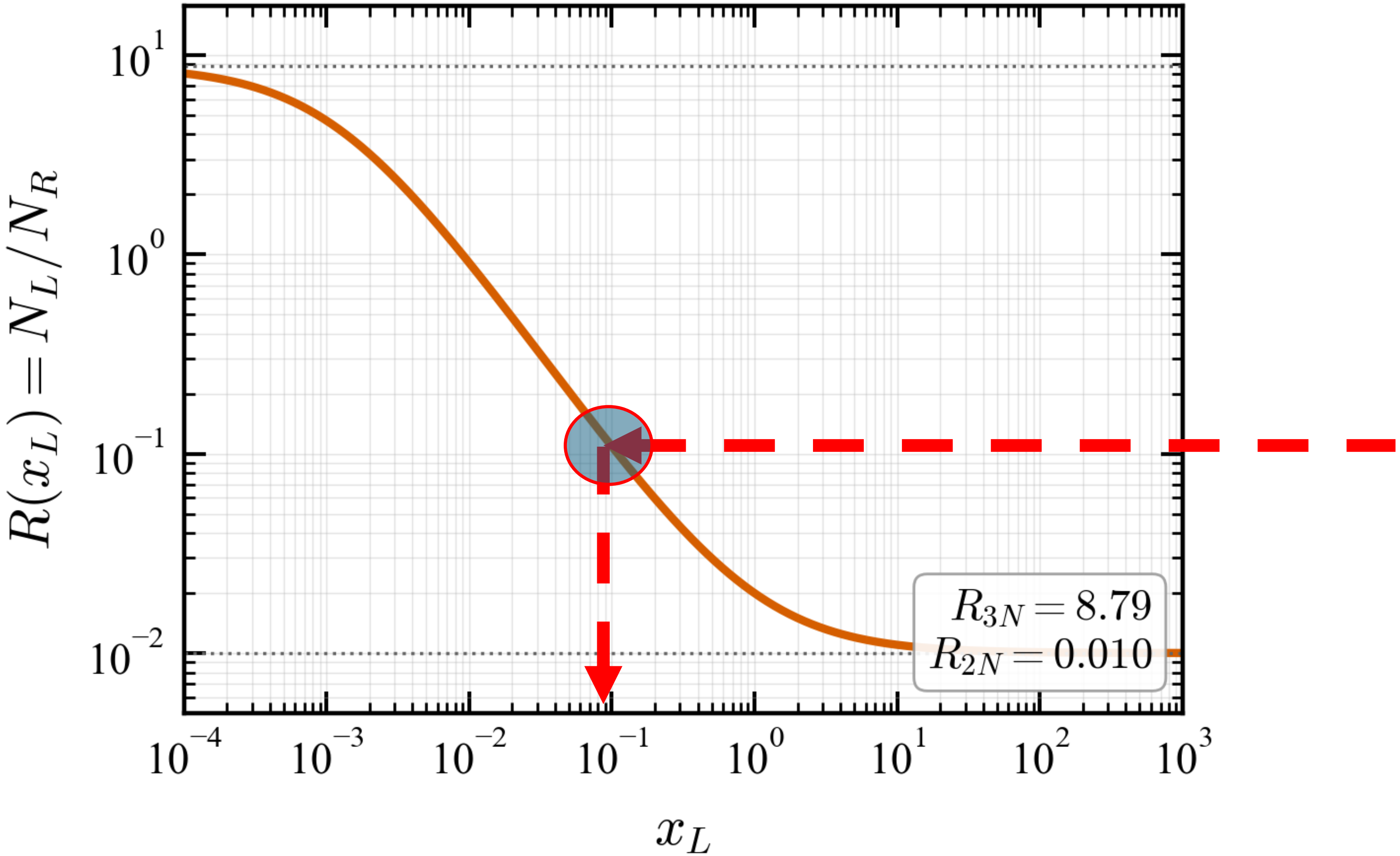
3N-SRC to 2N-SRC ratio

Calculated from generator: $$R_{2N} \equiv \frac{N_{L,2N}}{N_{R,2N}}, \;\; R_{3N} \equiv \frac{N_{L,3N}}{N_{R,3N}}$$

Unknown (FSI contamination of left region) $$x_L \equiv \frac{N_{L,2N}}{N_{L,3N}}$$

Experiment: $$R \equiv \frac{N_L}{N_R} \equiv \frac{N_{L,3N} + N_{L,2N}}{N_{R,3N} + N_{R,2N}} \;\; = \frac{1 + x_L}{\frac{1}{R_{3N}} + \frac{1}{R_{2N}} x_L}$$

What to expect:



Suppose from measurement

➡ Ratio between 2N-SRC and 3N-SRC

Summary

❖ Three-body forces are essential for nuclear structure and dense matter.

❖ 3N-SRCs provide a unique window into short-range three-body dynamics.

❖ We developed a 3N extension of the GCF to study 3N-SRC topology.

❖ The $x_B > 2$ region is dominated by Rocket-like configurations.

❖Angular correlations and semi-exclusive measurements provide promising paths toward identifying and quantifying 3N-SRCs.

Thank you for you attention!