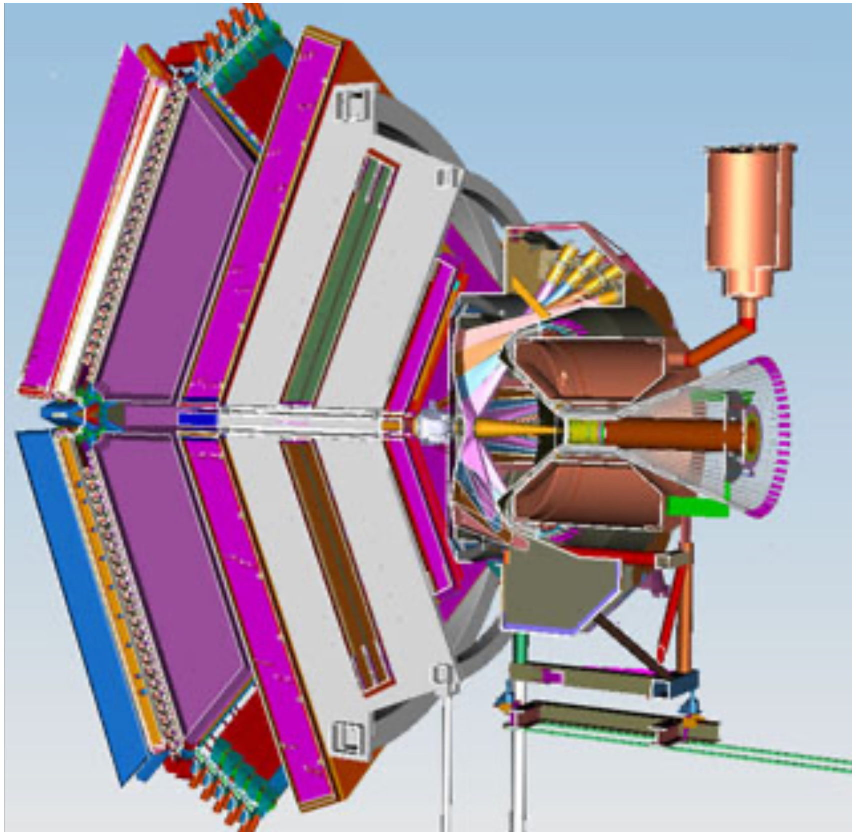
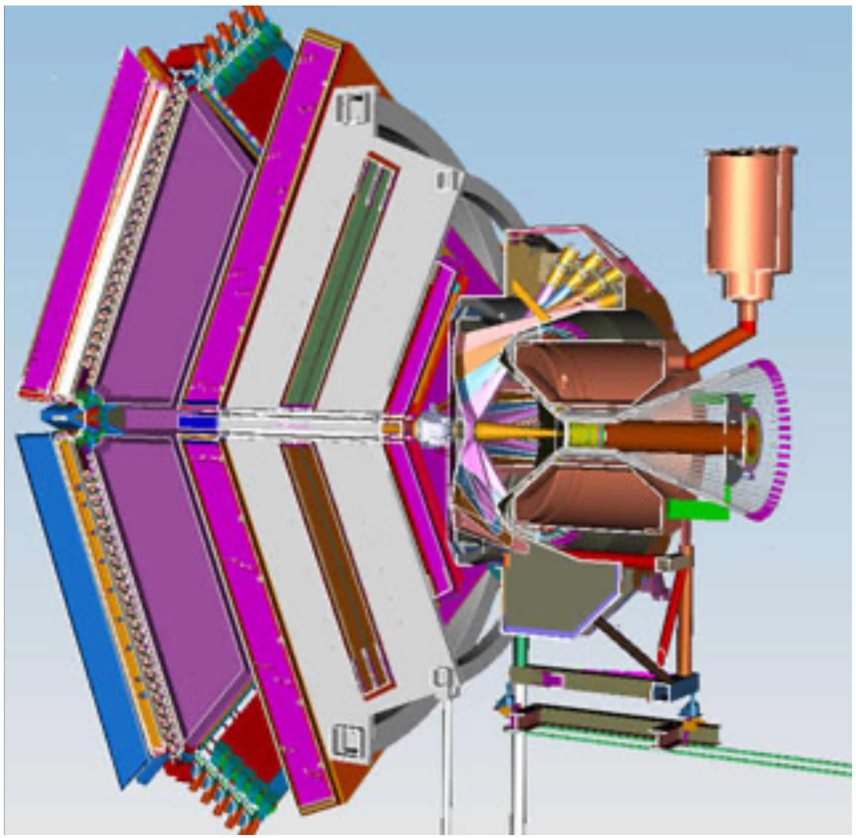
3N SRC Kinematics

Andrew Denniston
MIT
February 1st , 2023

3N SRCs with CLAS12

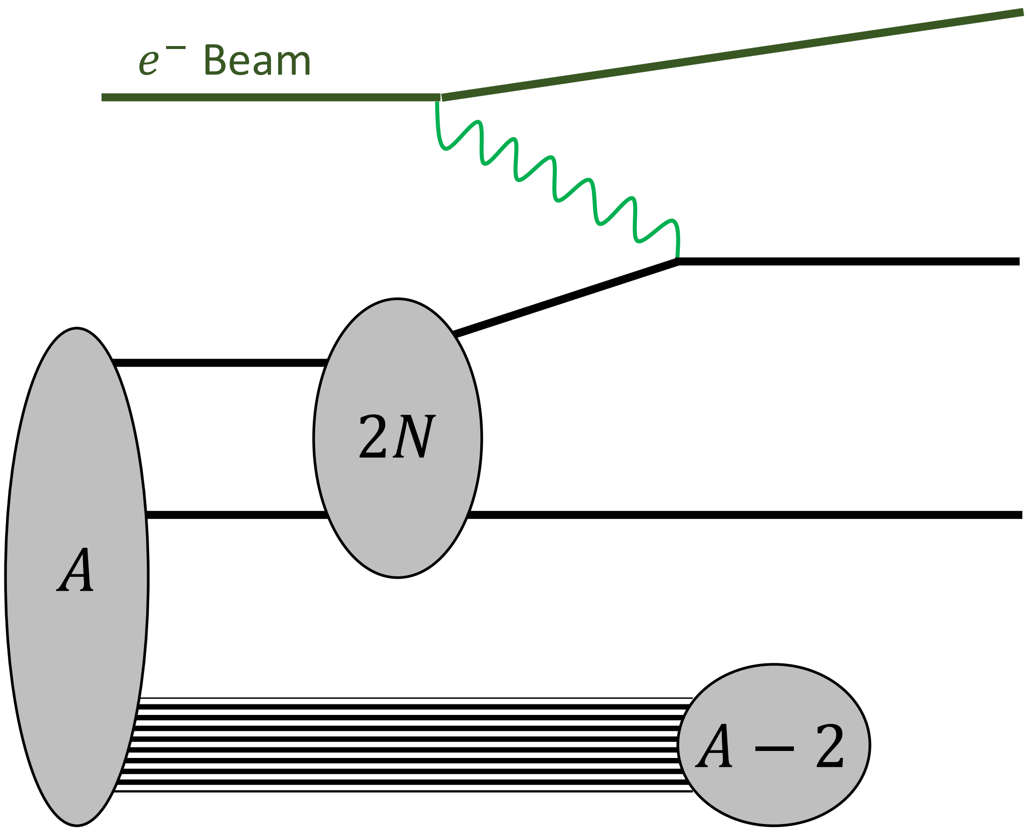


3N SRCs with CLAS12



Target	Channel	Event Estimate
LD2	e'p	47,000
LHe	e'p	130,000
	e'pp	5,500
Cx4	e'p	161,000
	e'pp	5,600
Snx4	e'p	9,900
	e'pp	430
40Ca	e'p	67,000
	e'pp	3,600

Developing a 3N SRC Model



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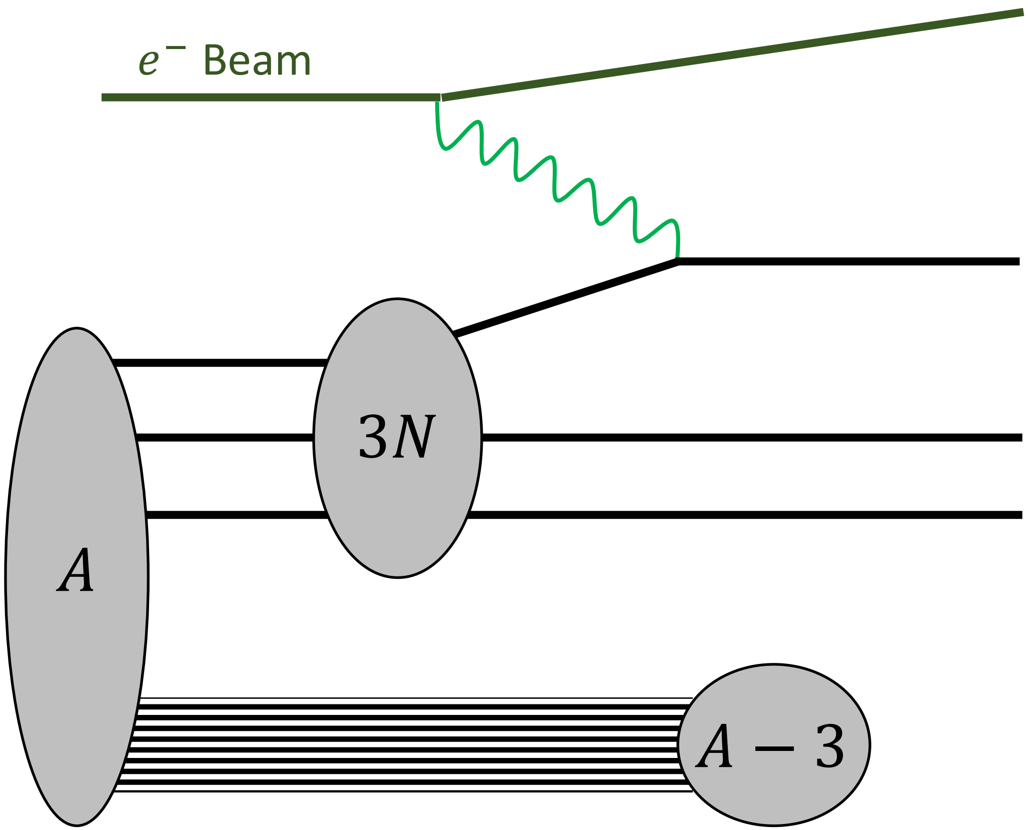
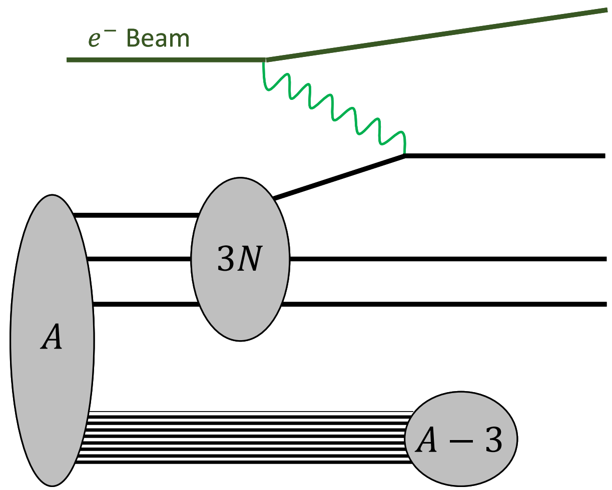
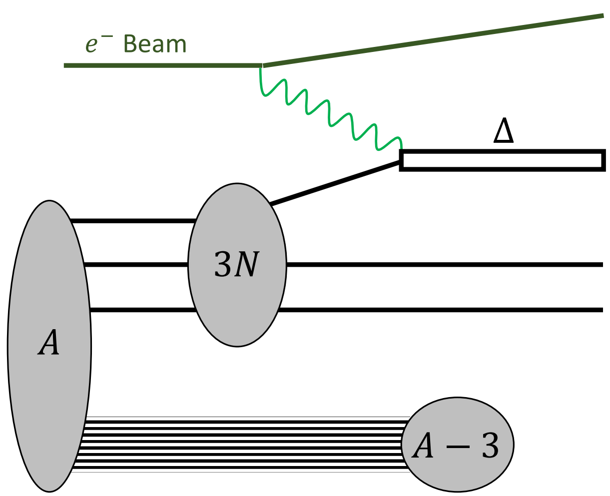


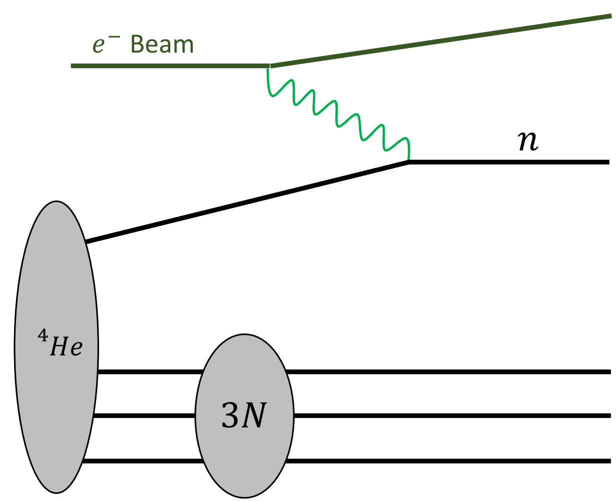
Developing a 3N SRC Model

Traditional SRC Reaction

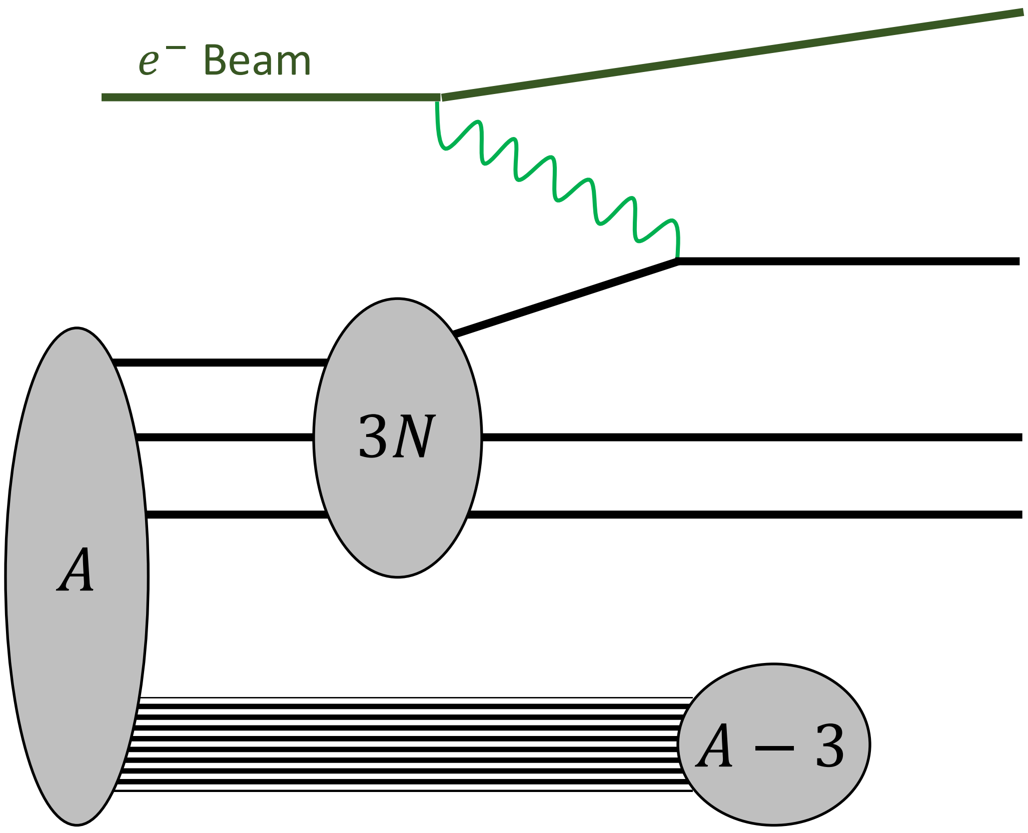


Exotic SRC Reactions

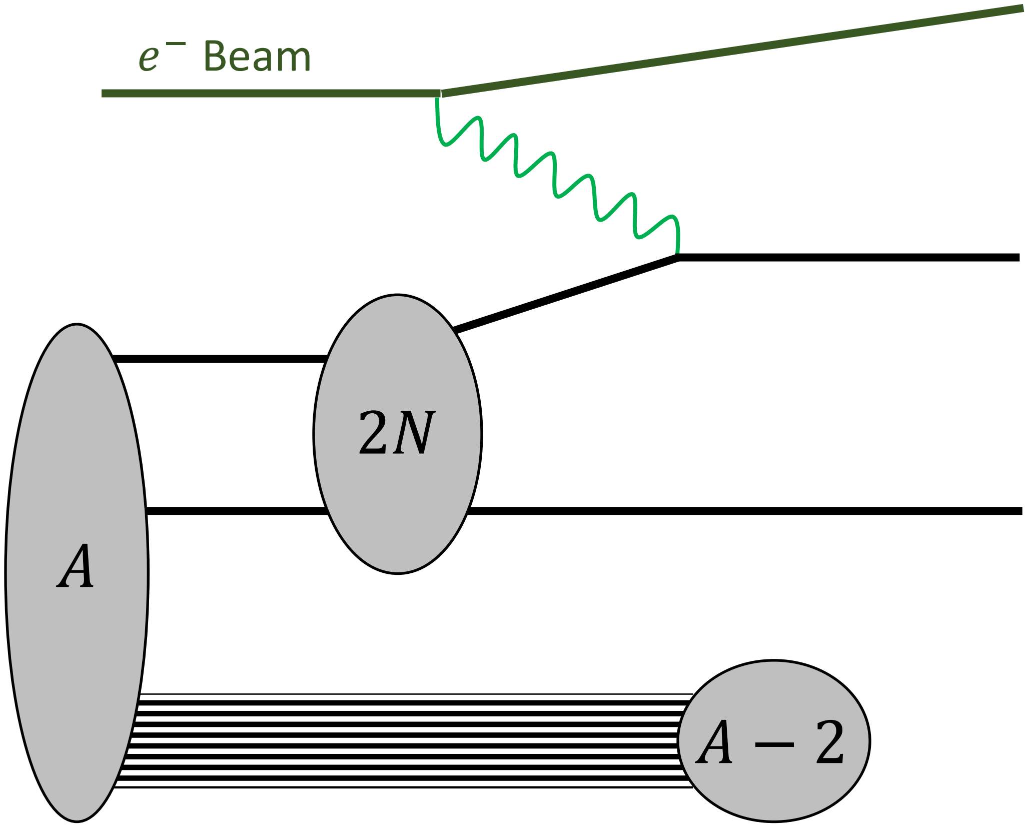




Developing a 3N SRC Model

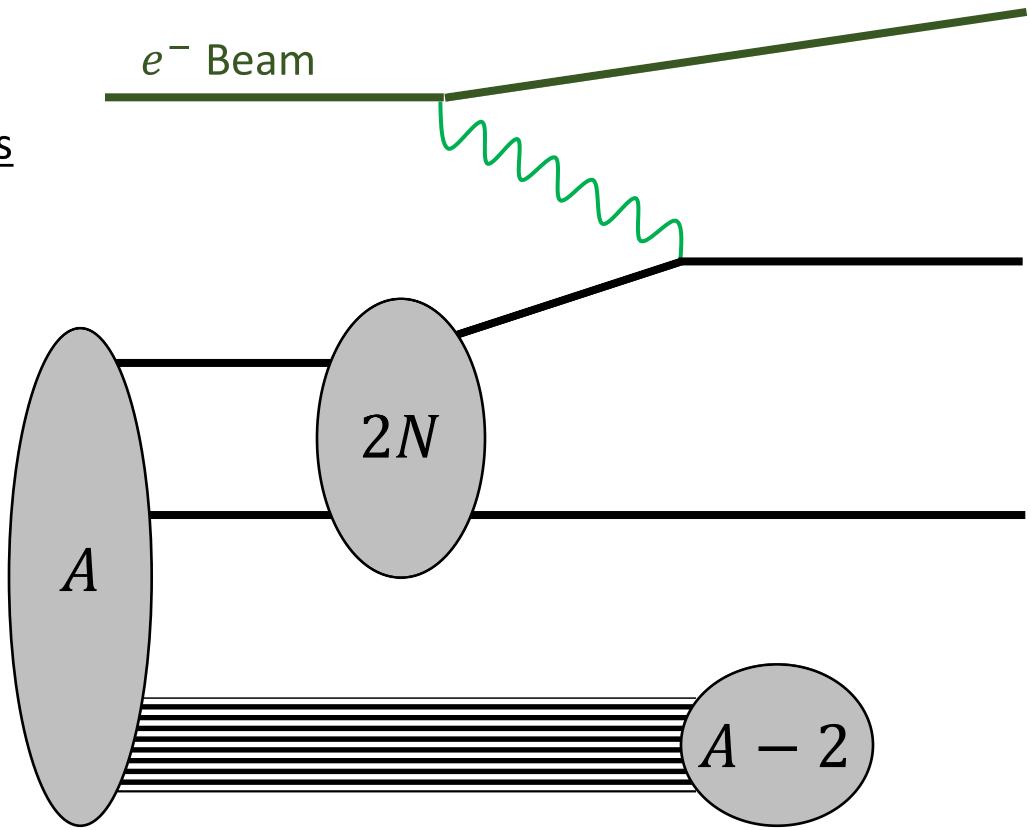


Defining a Cross Section



Defining a Cross Section

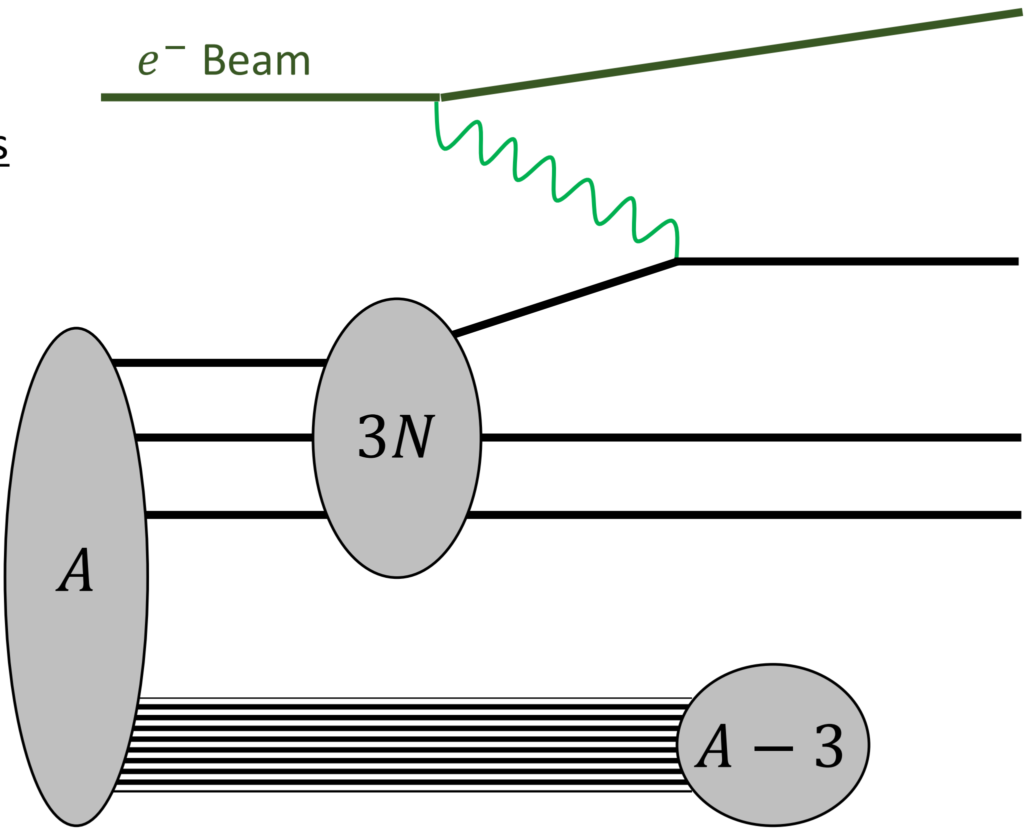
3×4 particles
−4 conservation laws
8 free parameters



$$\frac{d^8\sigma}{d^8X^\mu} = \mathcal{J}\sigma_{eN} * |\phi_\alpha(p_{rel})|^2 * n(p_{cm})$$

Defining a Cross Section

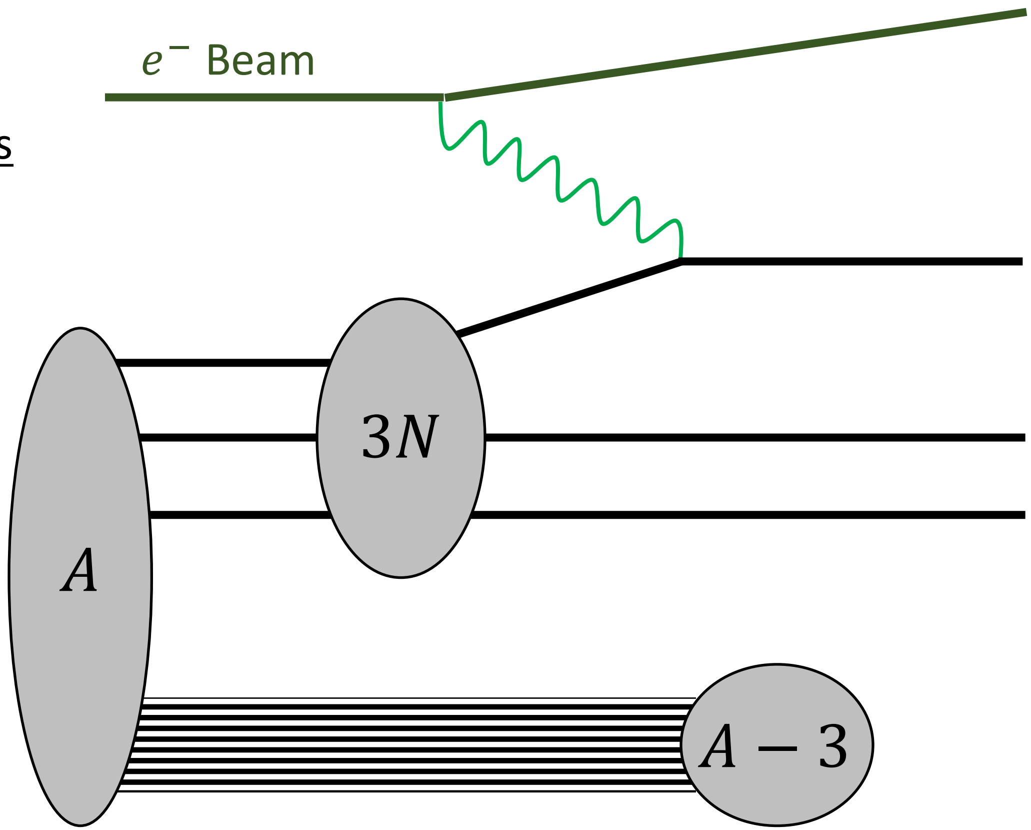
$3{\times}5$ particles
-4 conservation laws
11 free parameters



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

Defining a Cross Section

3×5 particles
-4 conservation laws
11 free parameters



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

Defining a Cross Section

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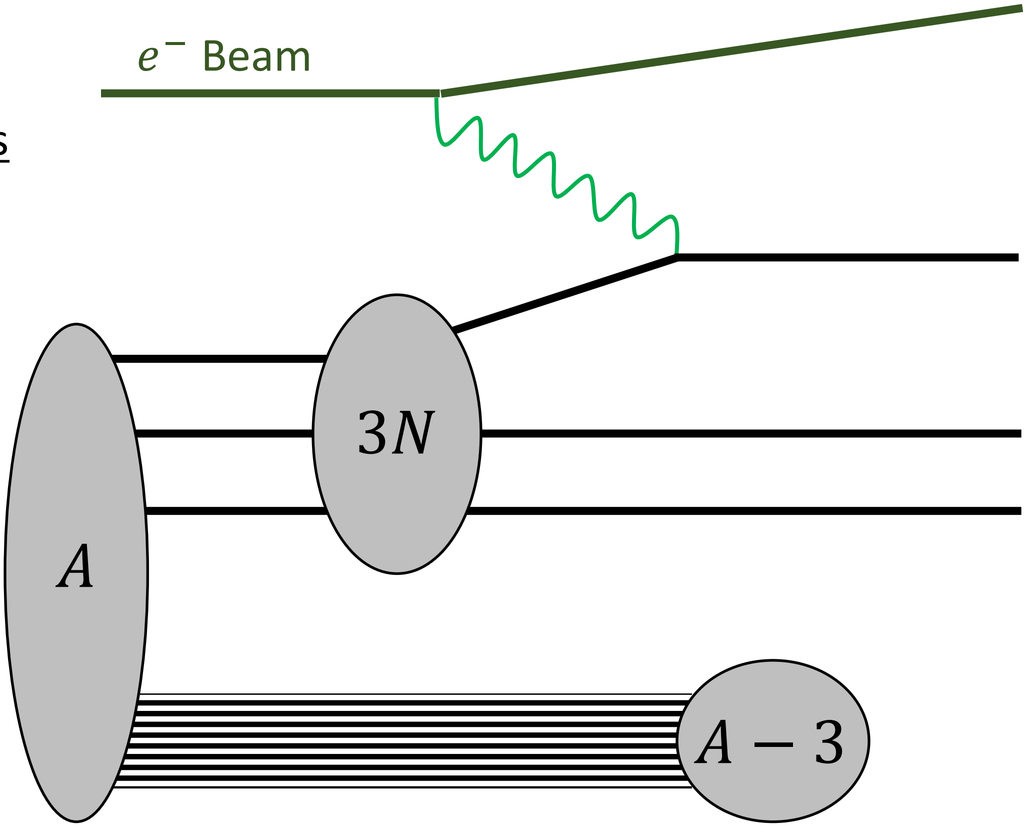

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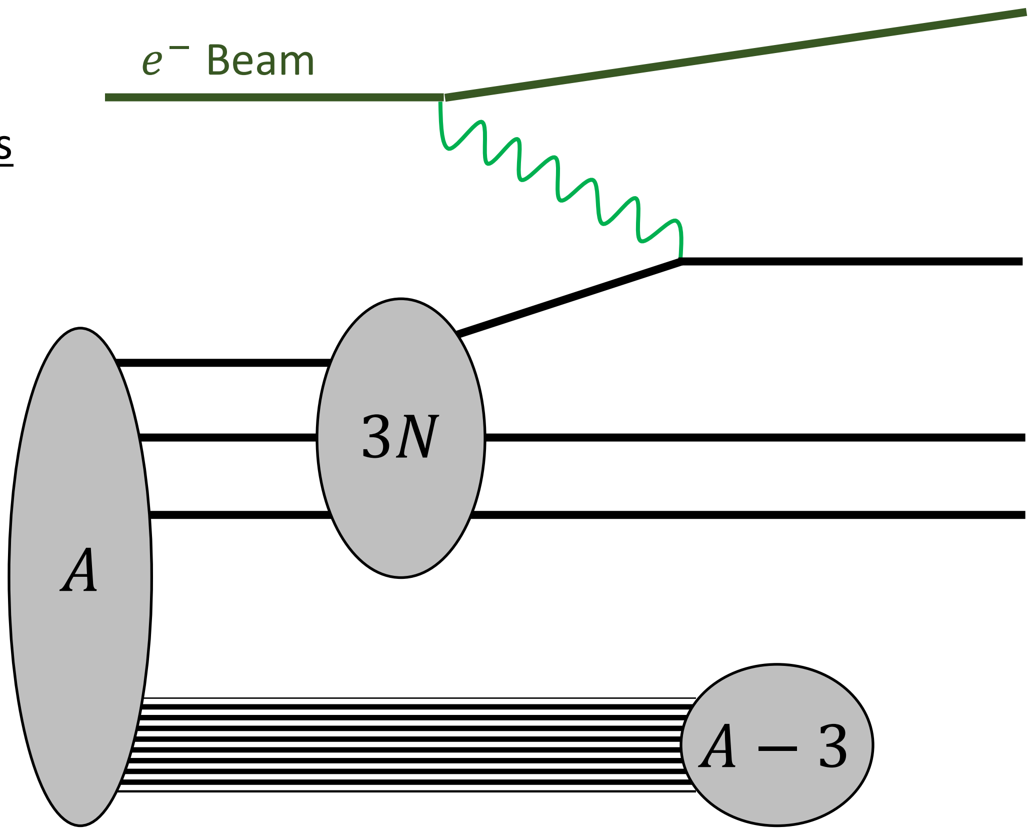

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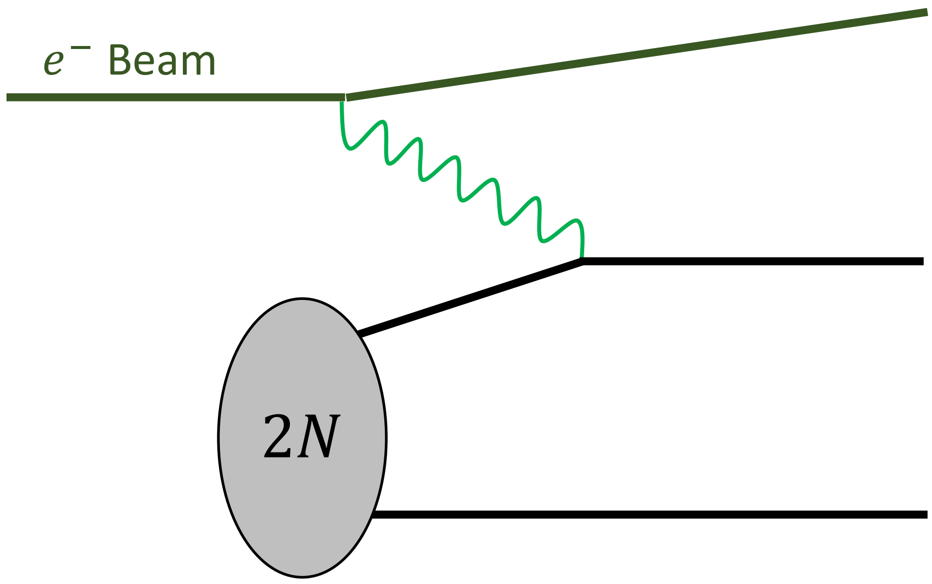
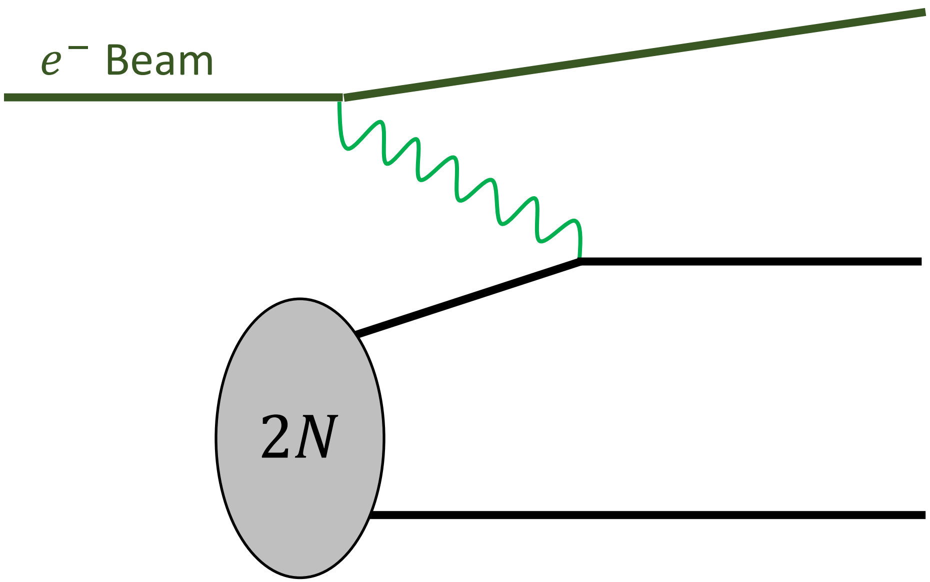
Understanding the Kinematics



Understanding the Kinematics

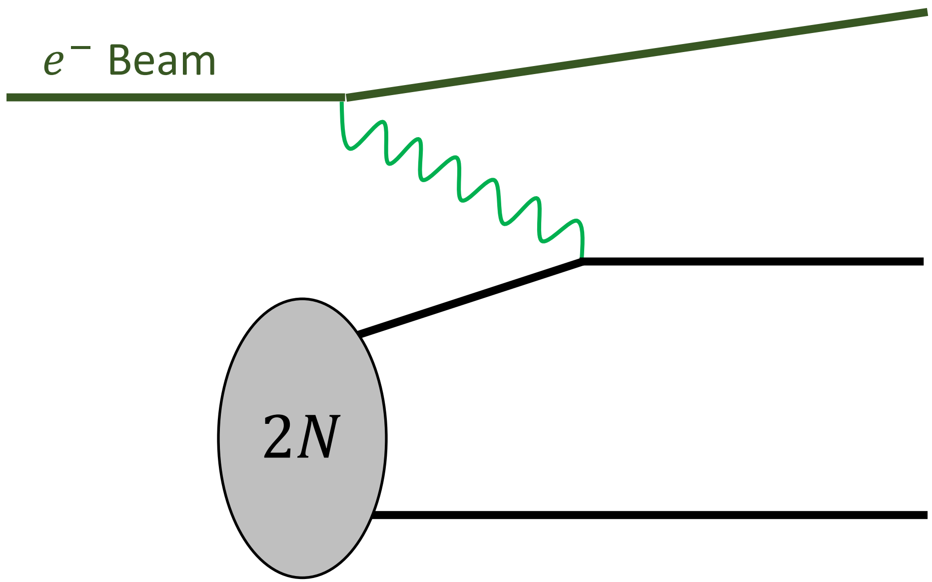
$3{\times}3$ particles
-4 conservation laws
-2 Euler angle
3 free parameters



Understanding the Kinematics

3×3 particles
-4 conservation laws
-2 Euler angle
3 free parameters

x_B, Q^2, p_{miss}



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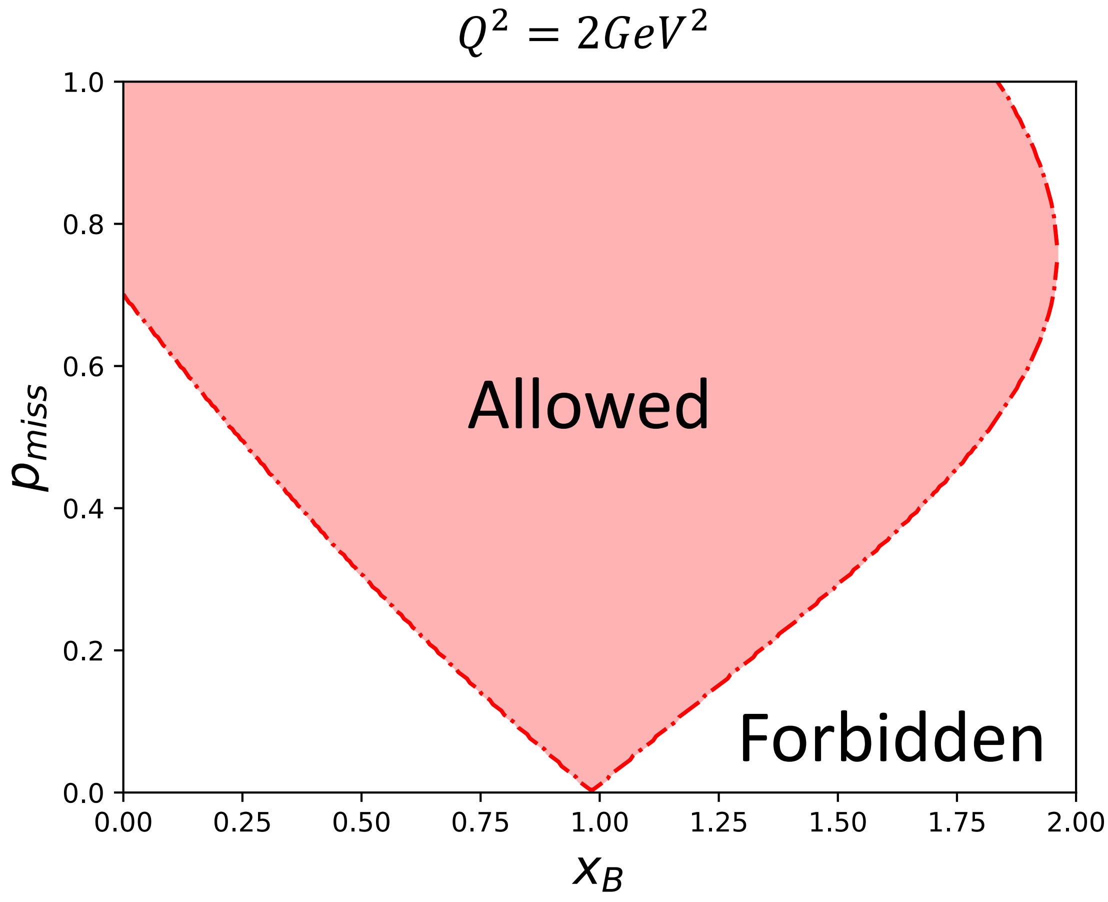

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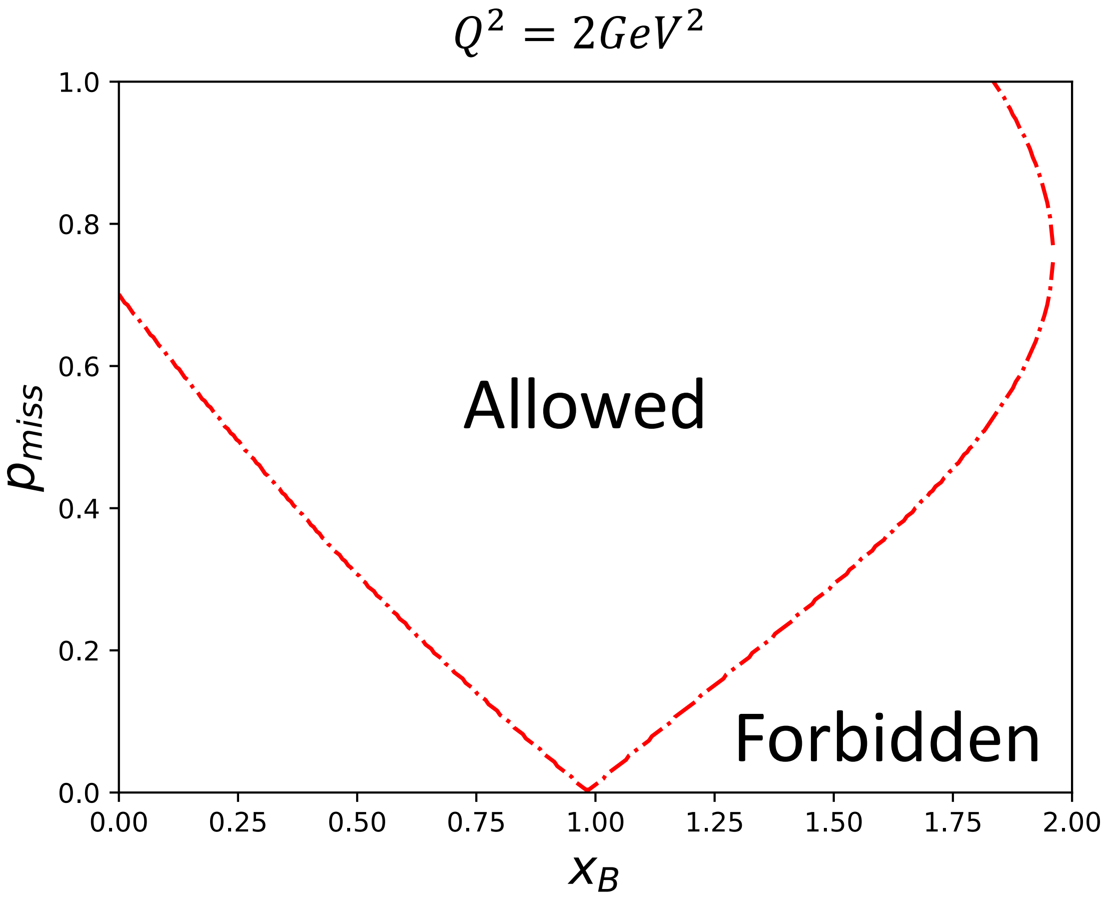

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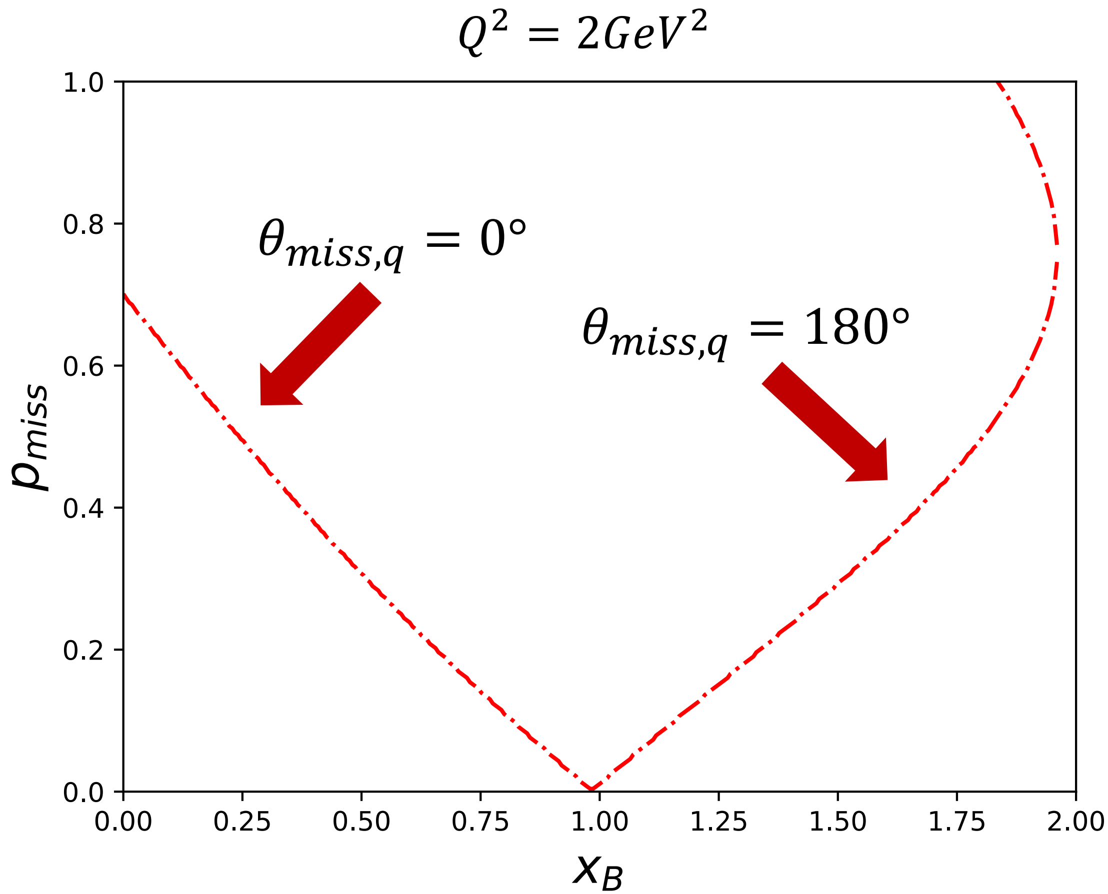

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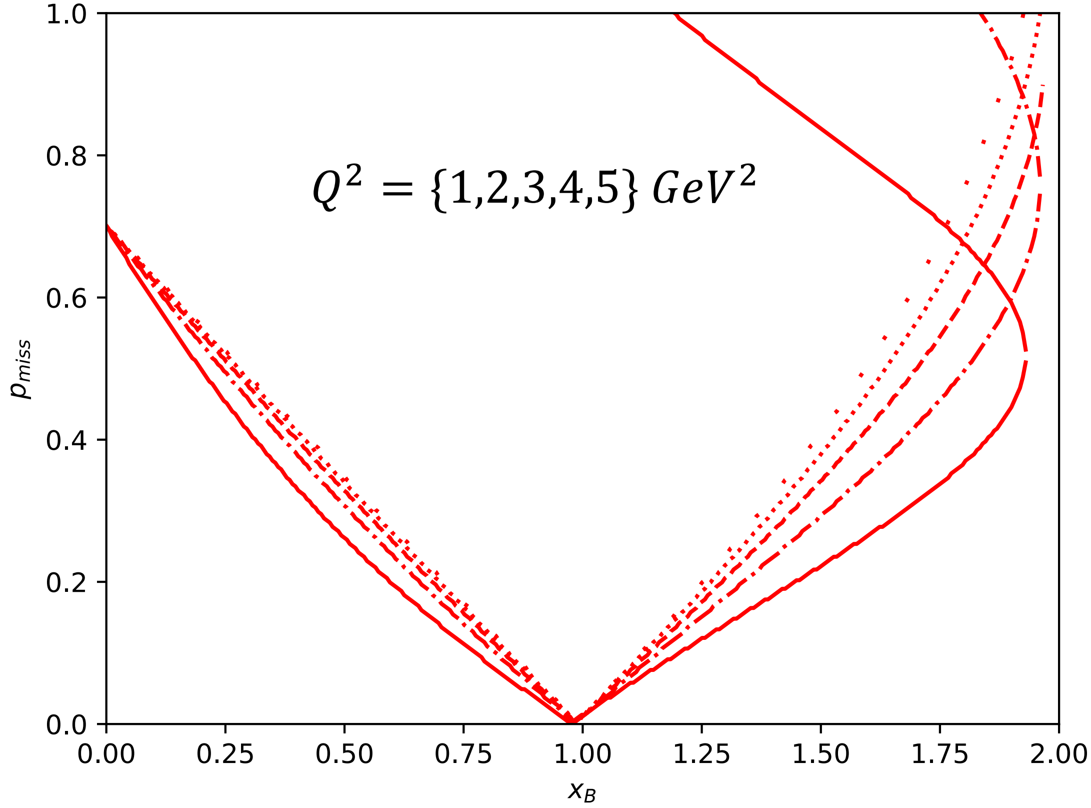
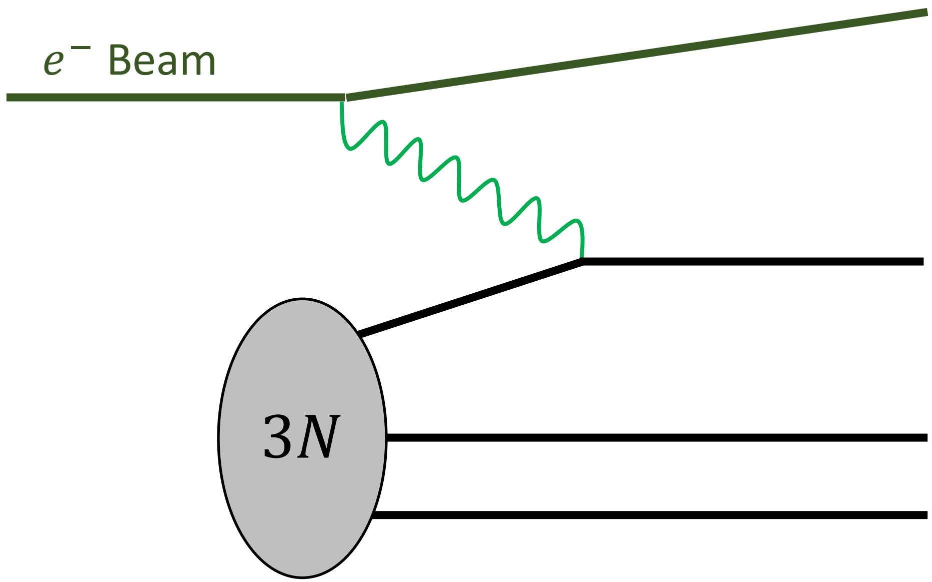
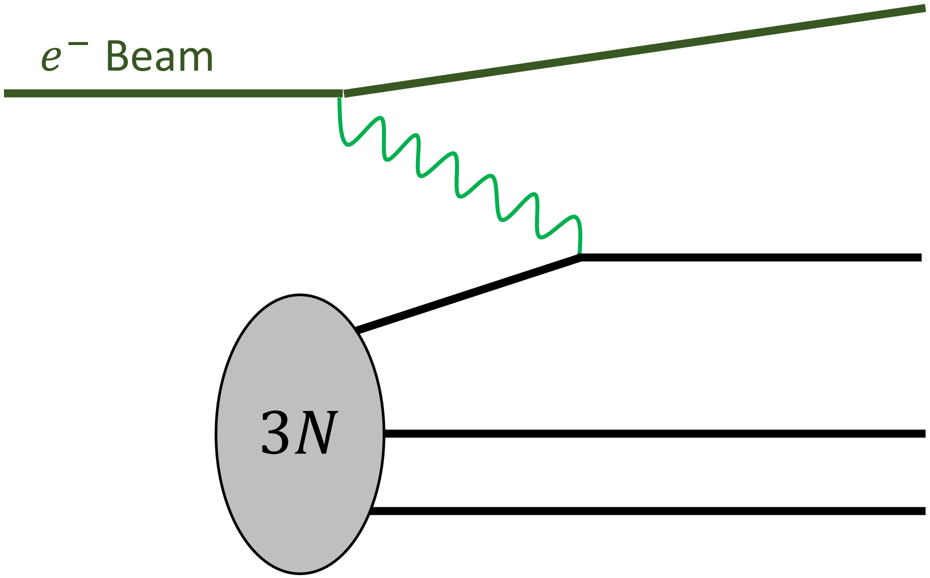


Understanding the Kinematics

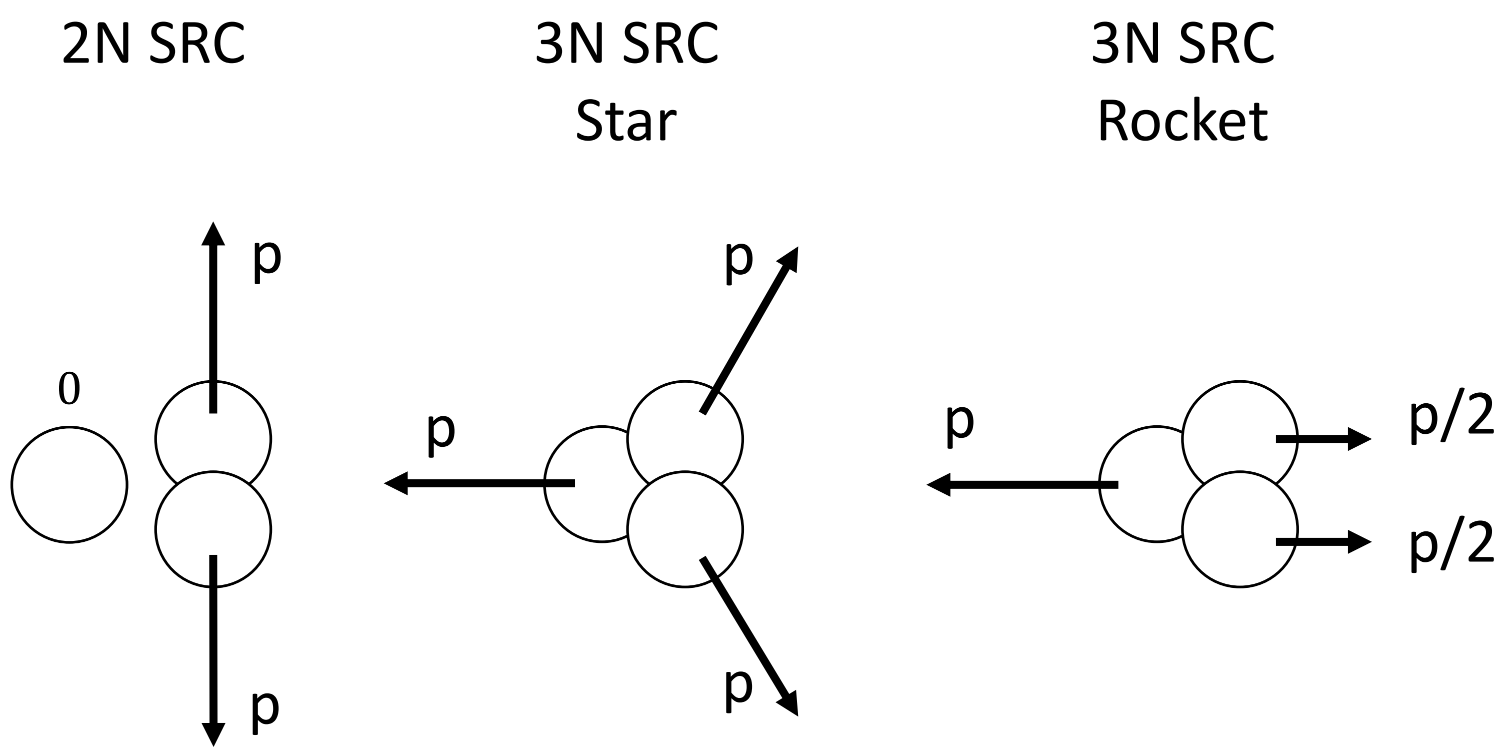


Understanding the Kinematics

3×4 particles
-4 conservation laws
-3 Euler angles
5 free parameters



Understanding the Kinematics



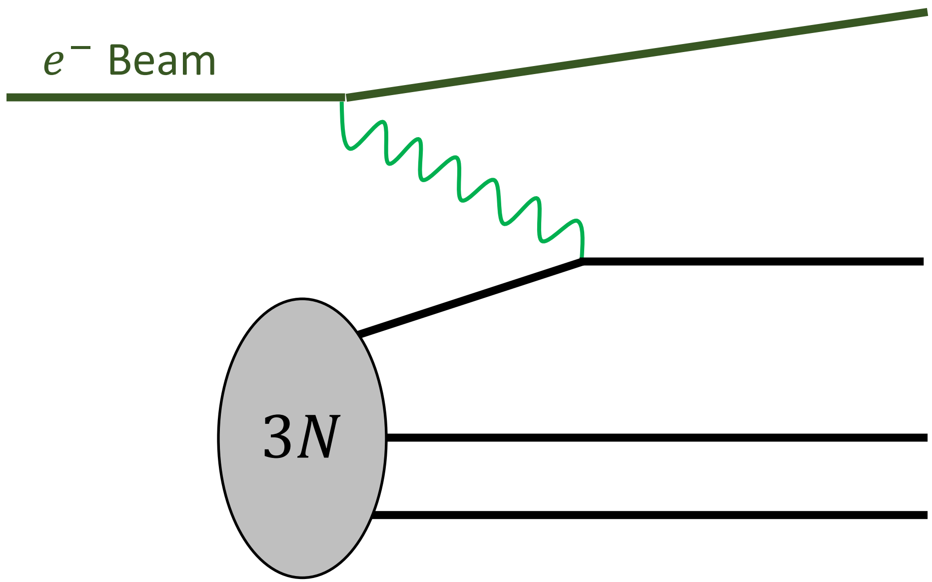
Understanding the Kinematics

3×4 particles
−4 conservation laws
−3 Euler angles

5 free parameters

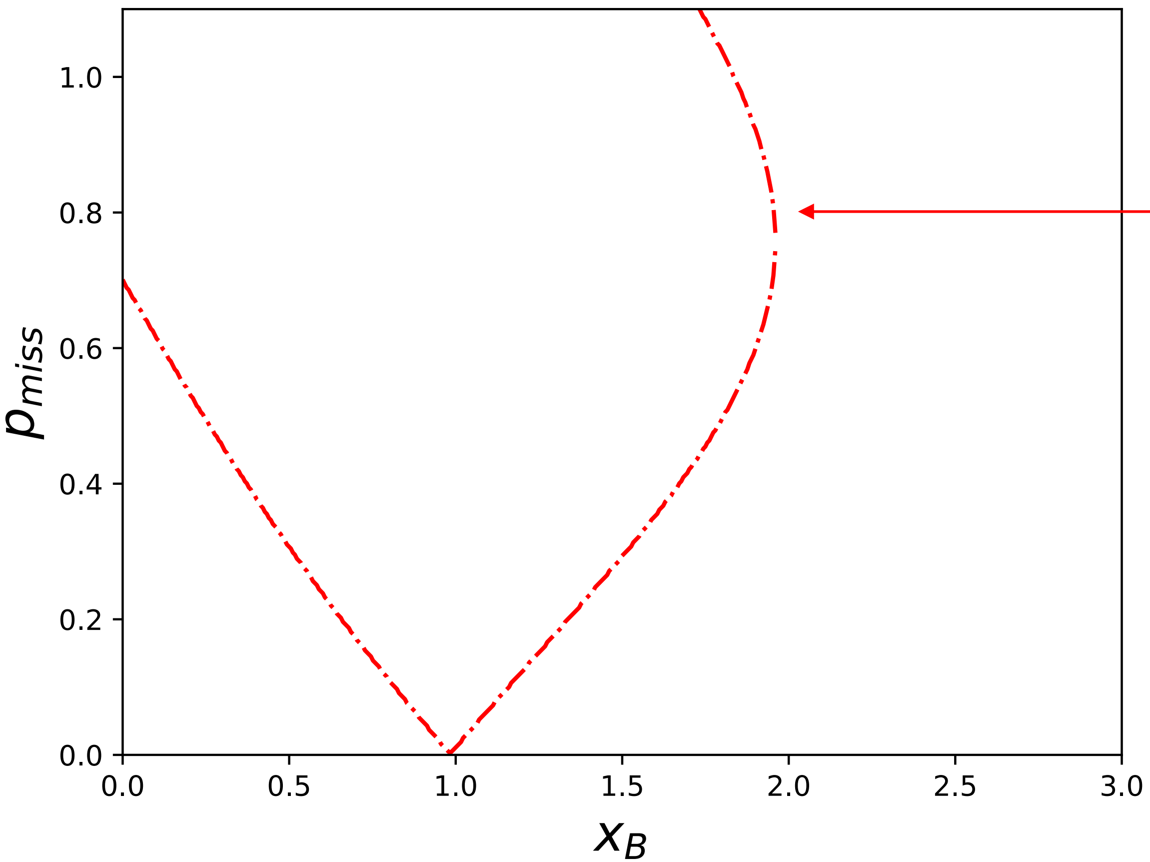
x_B, Q^2, p_{miss}

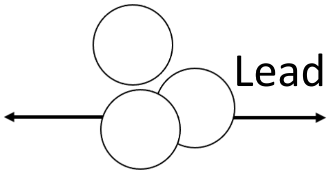
+3N Shapes



Understanding the Kinematics

$Q^2 = 2GeV^2$





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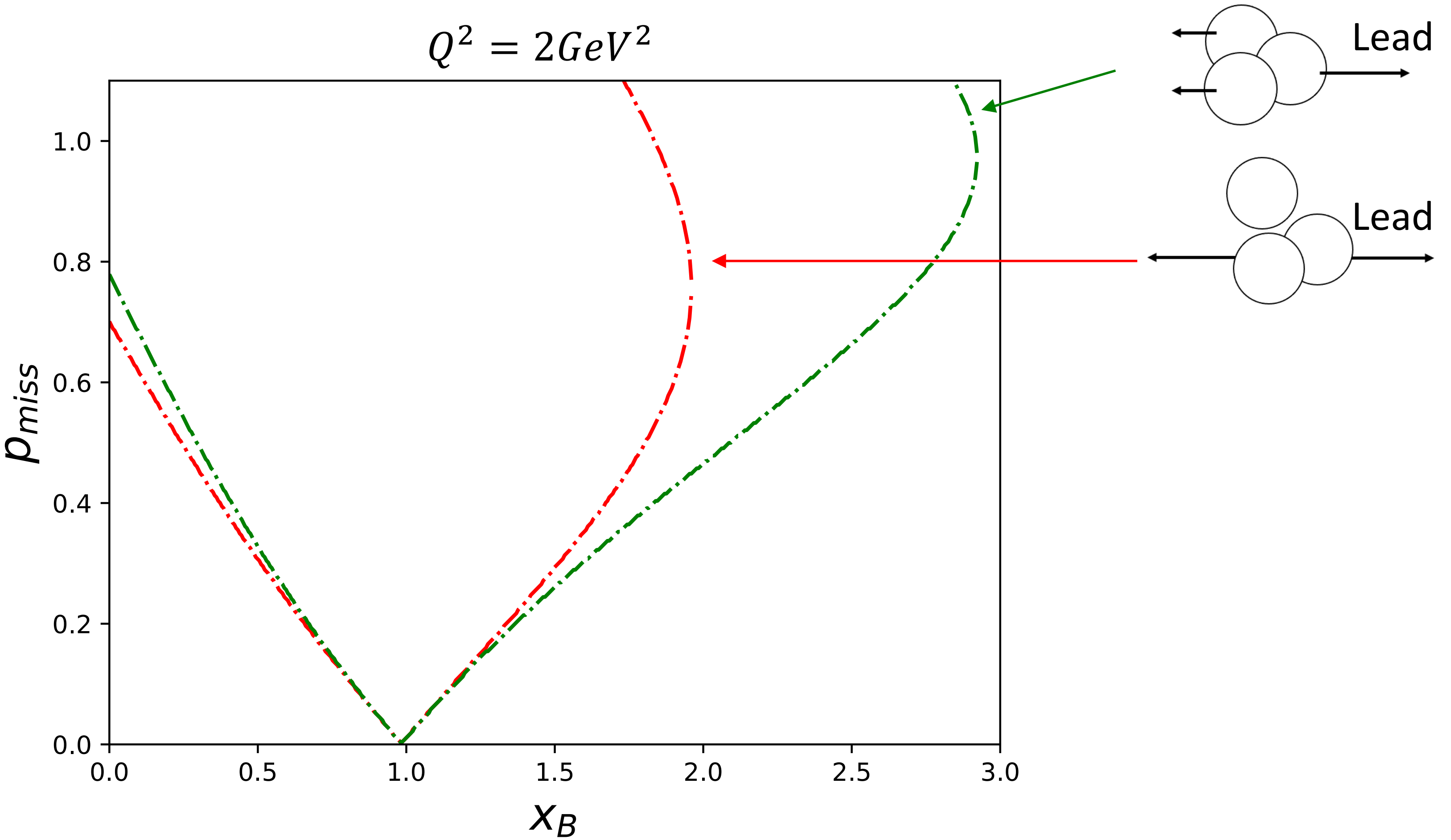

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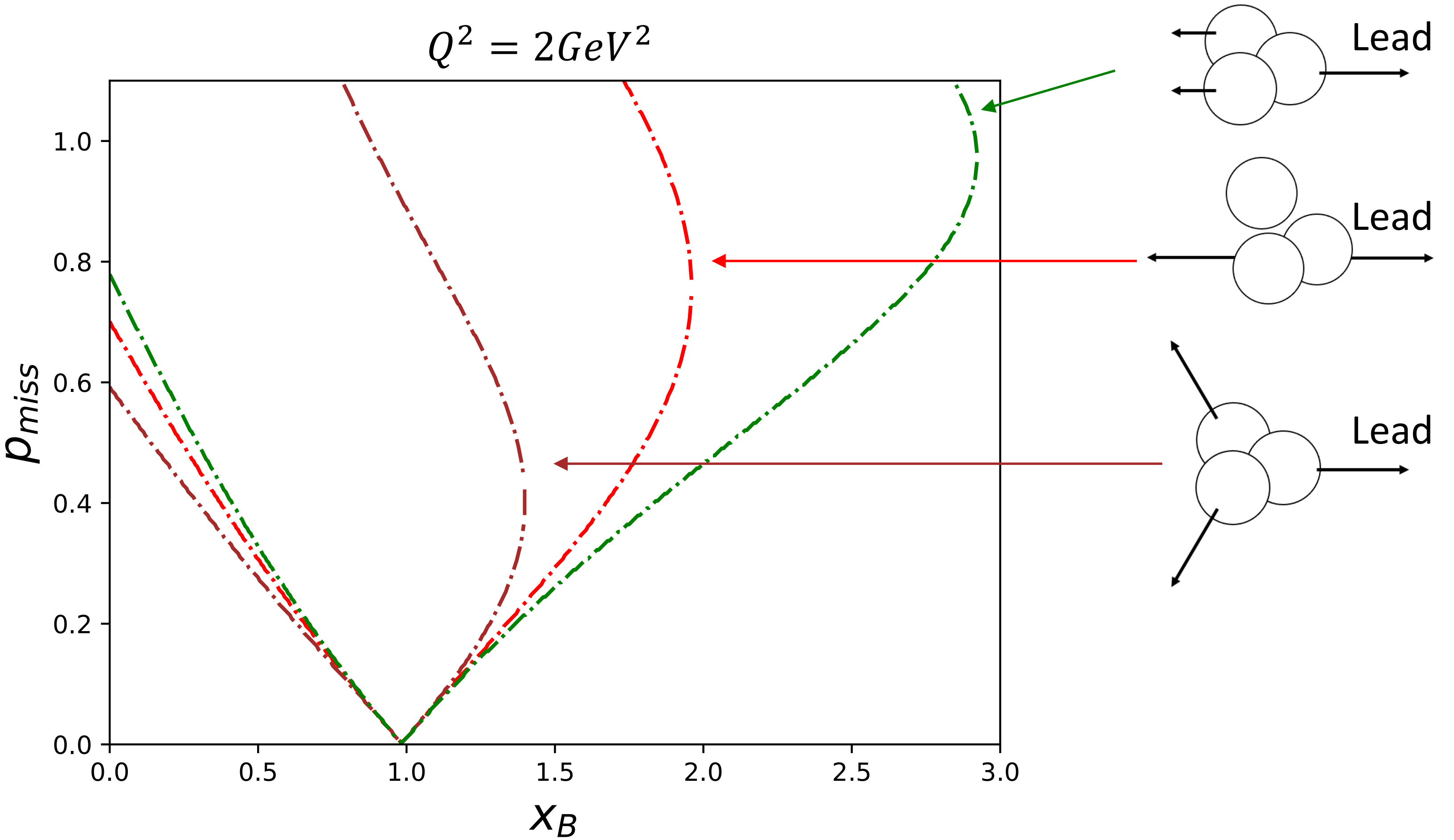

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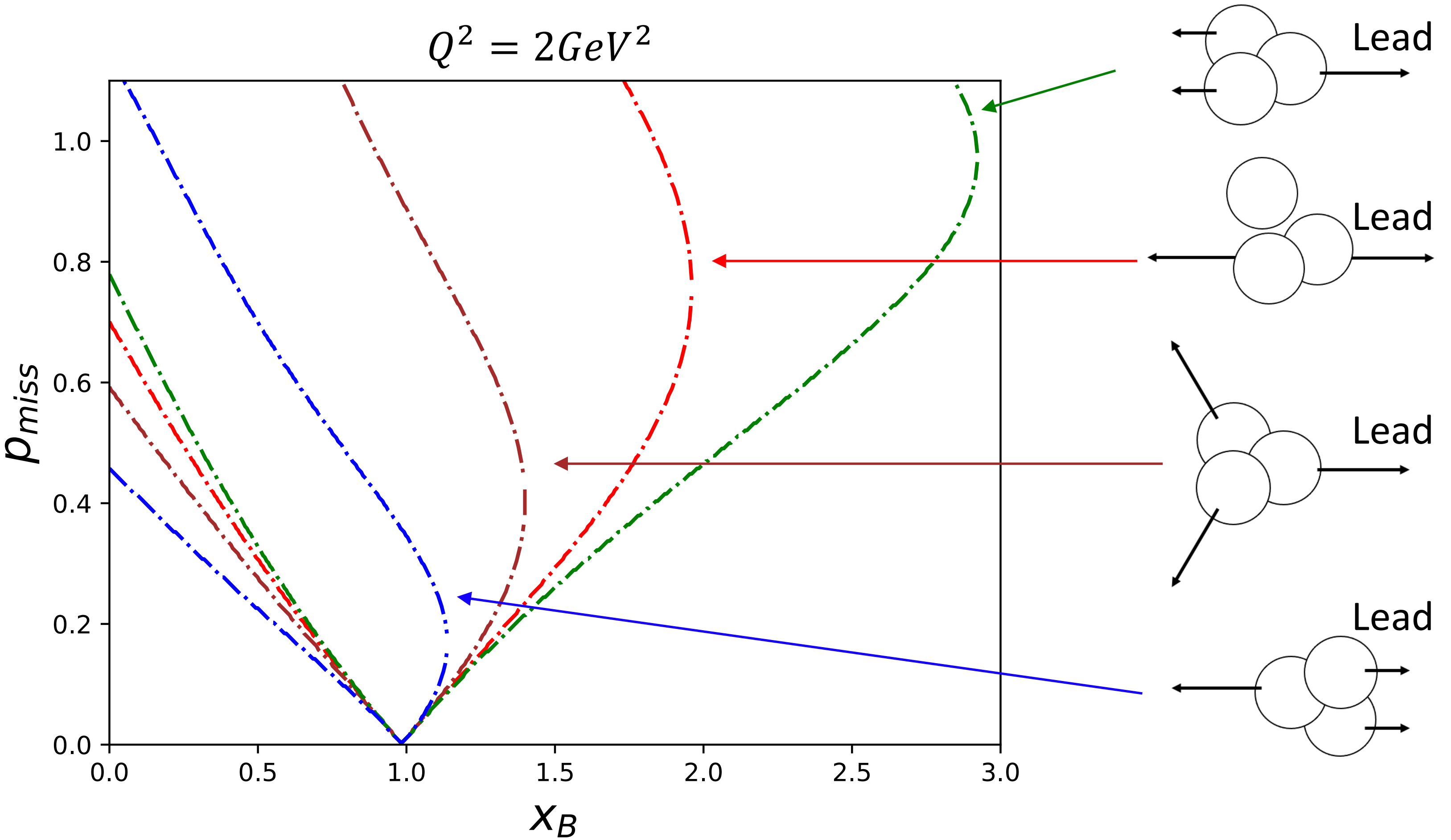

Defining a Cross Section

3×5 particles
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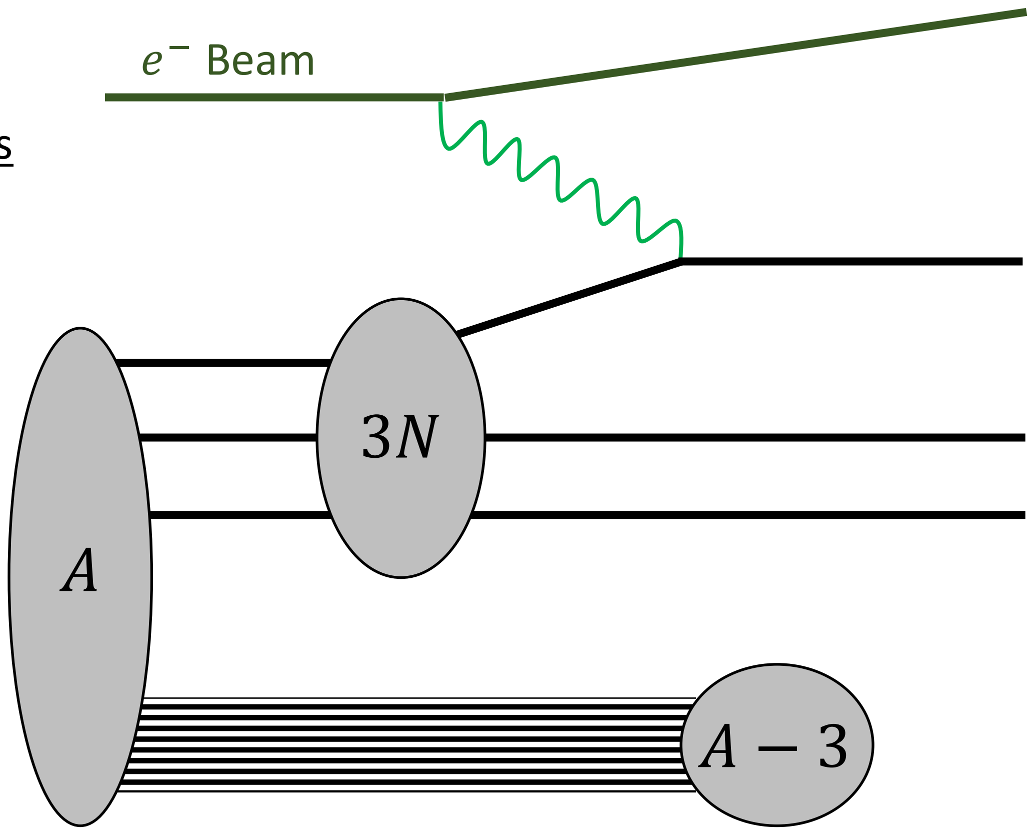
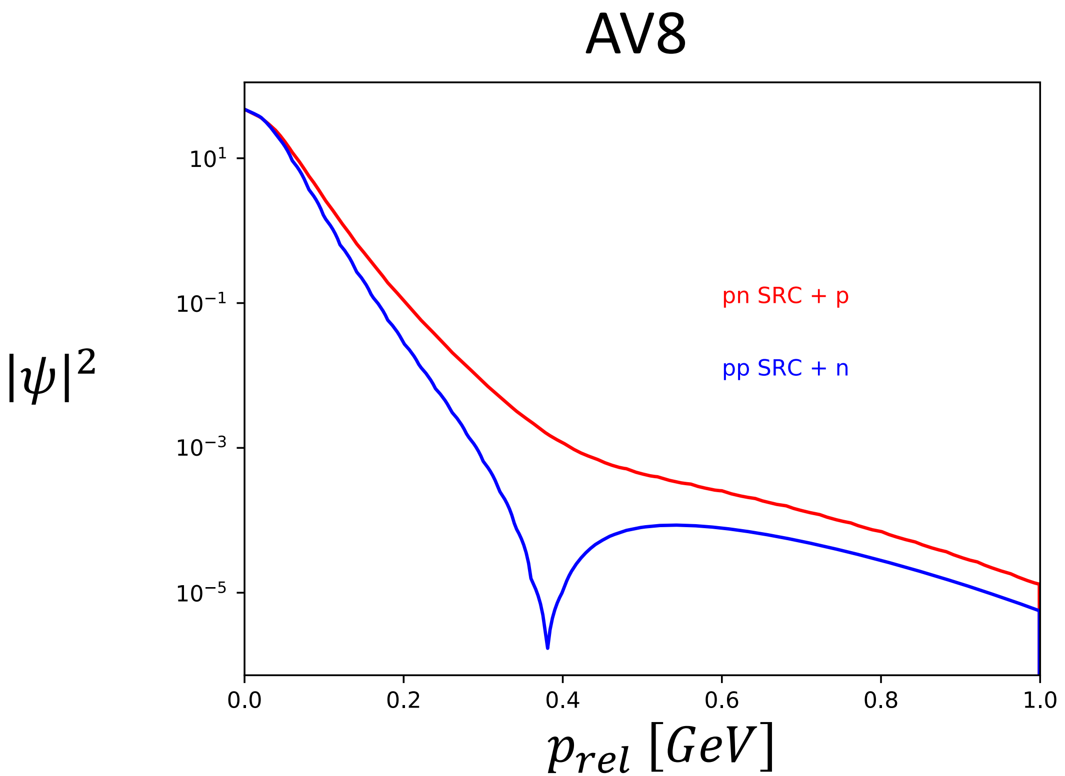


$$\frac{d^{11}\sigma}{d^{11}X^{\mu}} = \mathcal{J}\sigma_{eN} * |\phi_\alpha(\vec{p}_1, \vec{p}_2, \vec{p}_3)|^2 * n(p_{cm}) * \delta(E_f - E_i)$$

2N Wavefunction

3 momenta × 2 particles ⟹ 3 center of mass momenta, 2 Euler angles, 1 NN Interaction Variable



3N Wavefunction

3 momenta $\times$ 3 particles ⟹

3 center of mass momenta

3 Euler angles

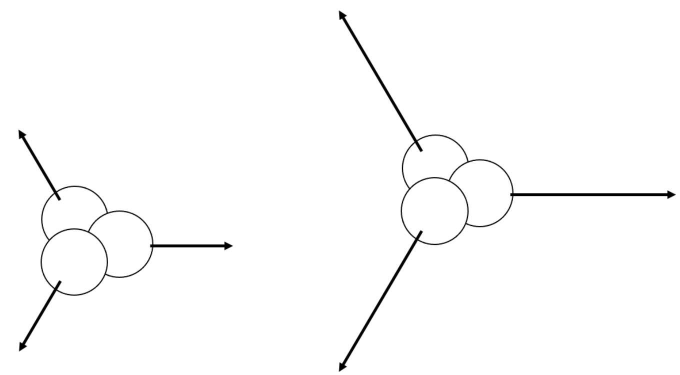
3 NN Interaction Variable

3N Wavefunction

3 momenta × 3 particles ⟹

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

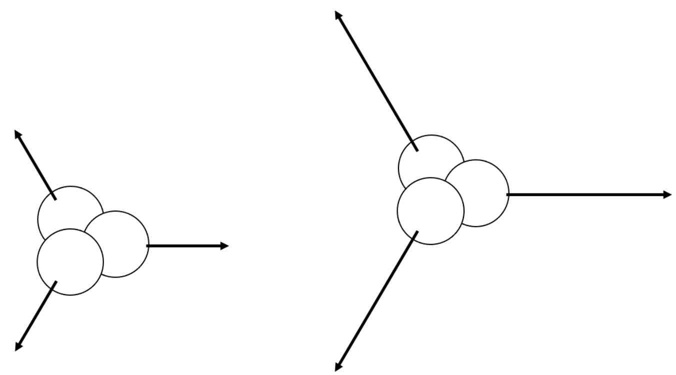
1 Size Parameter:
$p_{tot} = p_1 + p_2 + p_3$



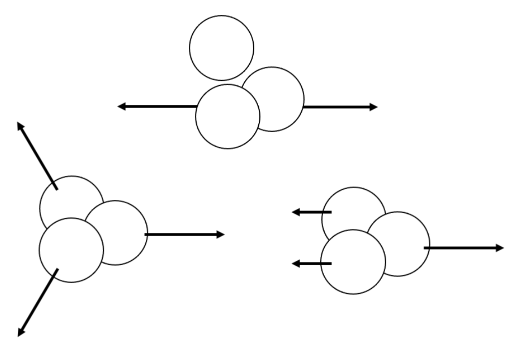
3N Wavefunction

3 momenta × 3 particles ⟹ 3 center of mass momenta
3 Euler angles
3 NN Interaction Variable

1 Size Parameter:
$p_{tot} = p_1 + p_2 + p_3$



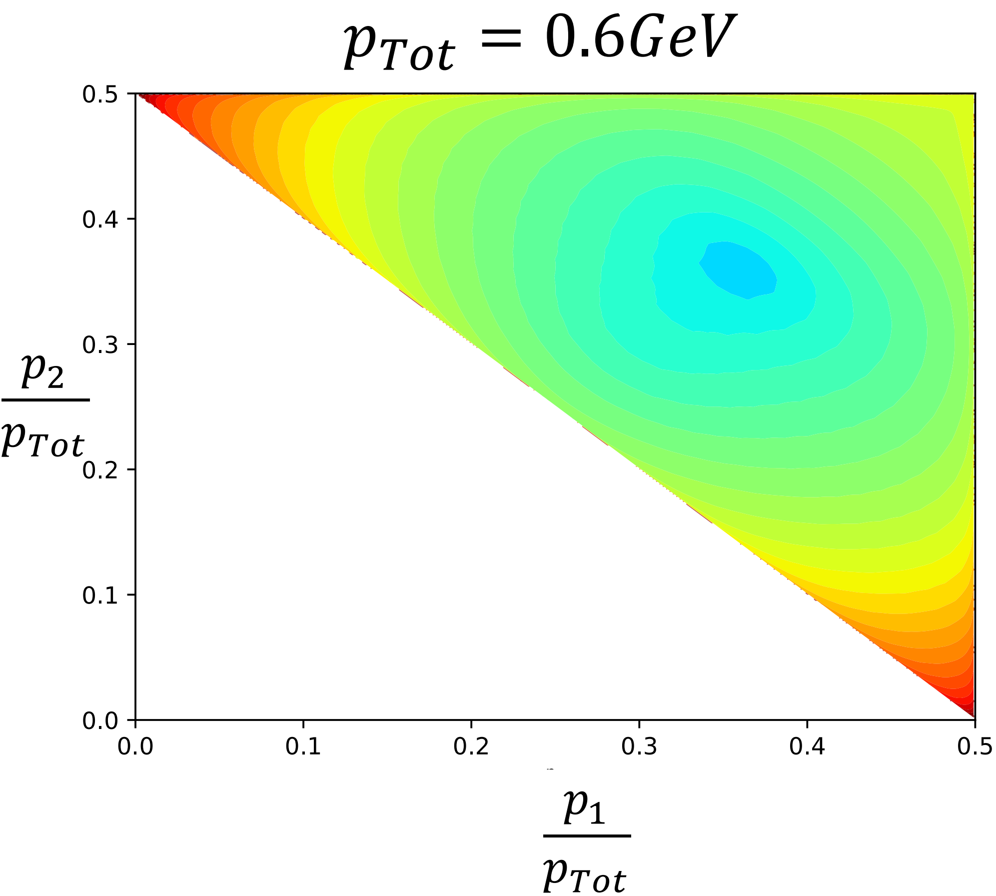
2 Shape Parameters:
$\frac{p_1}{p_{tot}}, \frac{p_2}{p_{tot}}$



3N Wavefunction

- Helium-3 (ppn)
- AV8 Potential
- Summed over L and S configurations
- Look at shape for fixed total momentum
- Look at total momentum for fixed shapes

Fix p_{tot} and plot ψ^2 vs. $\frac{p_1}{p_{tot}}, \frac{p_2}{p_{tot}}$



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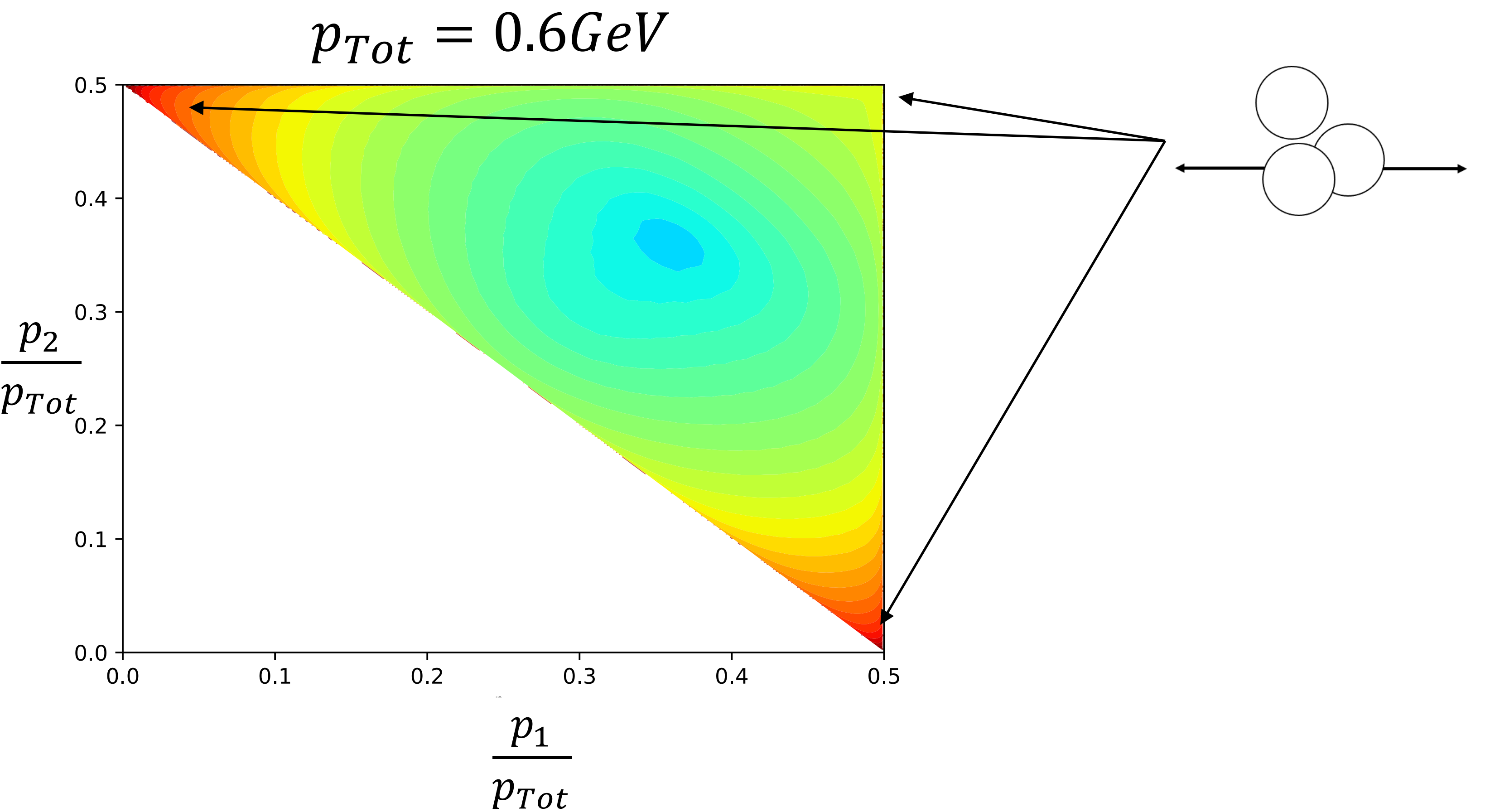

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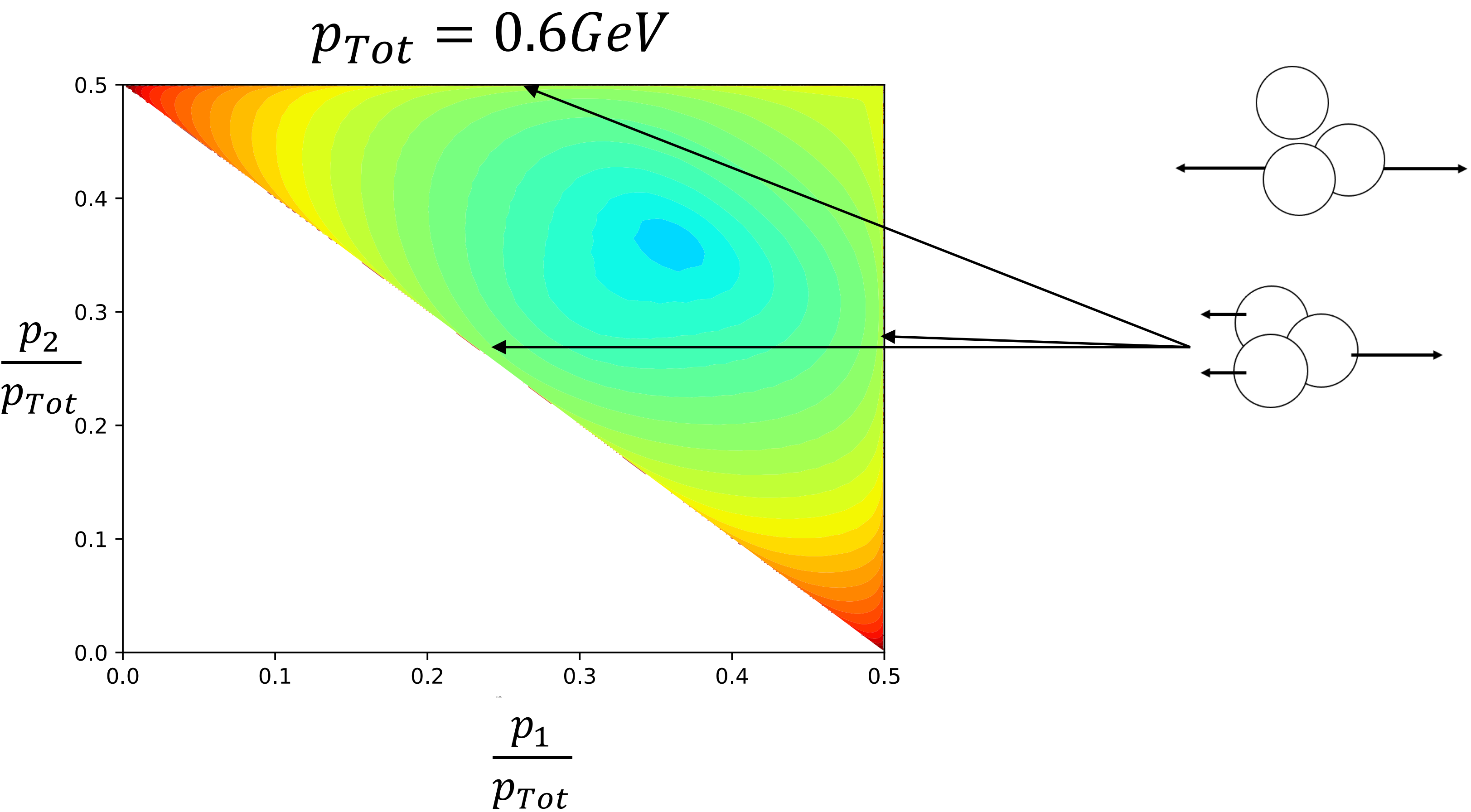
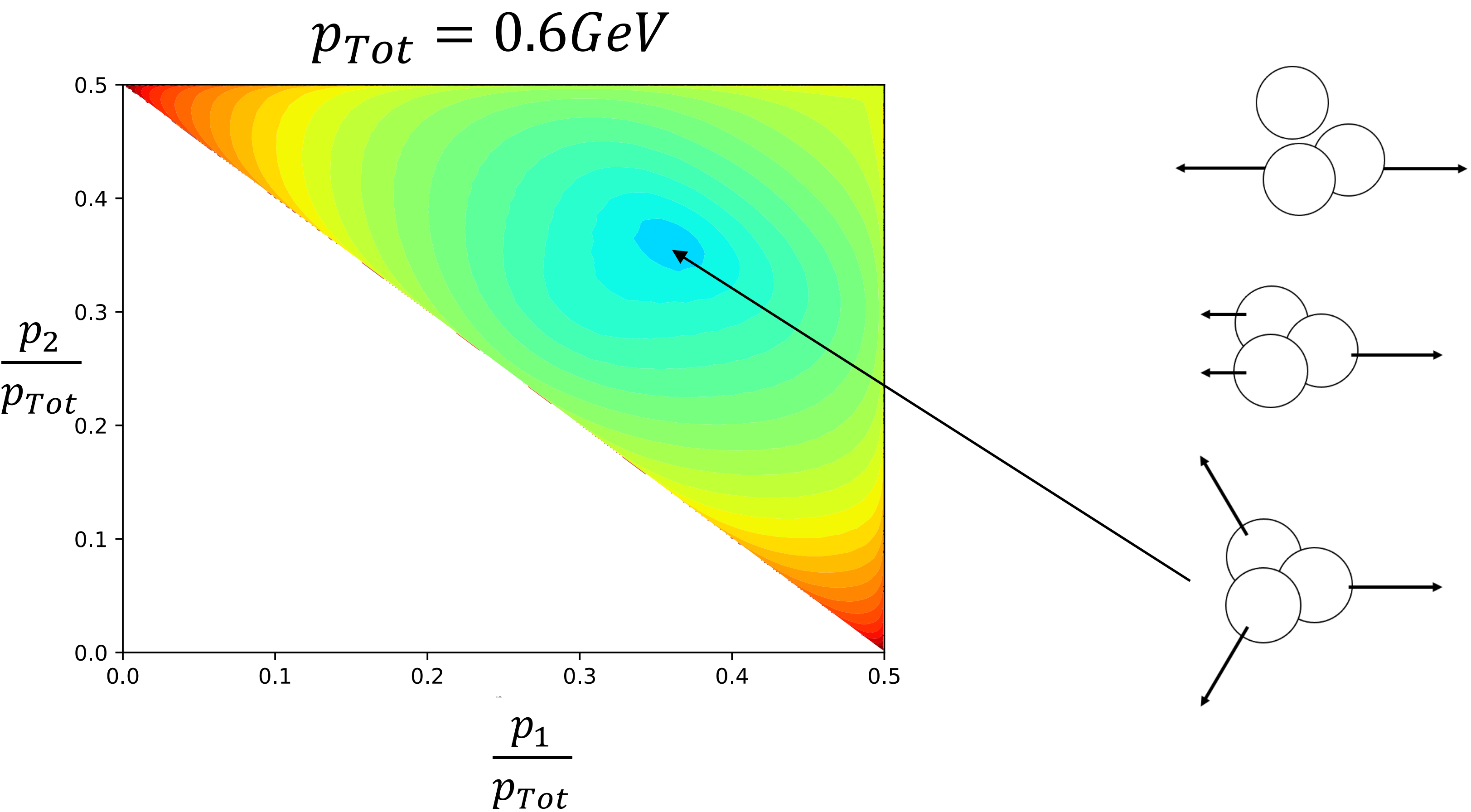


Fix p_{tot} and plot ψ^2 vs. $\frac{p_1}{p_{tot}}, \frac{p_2}{p_{tot}}$



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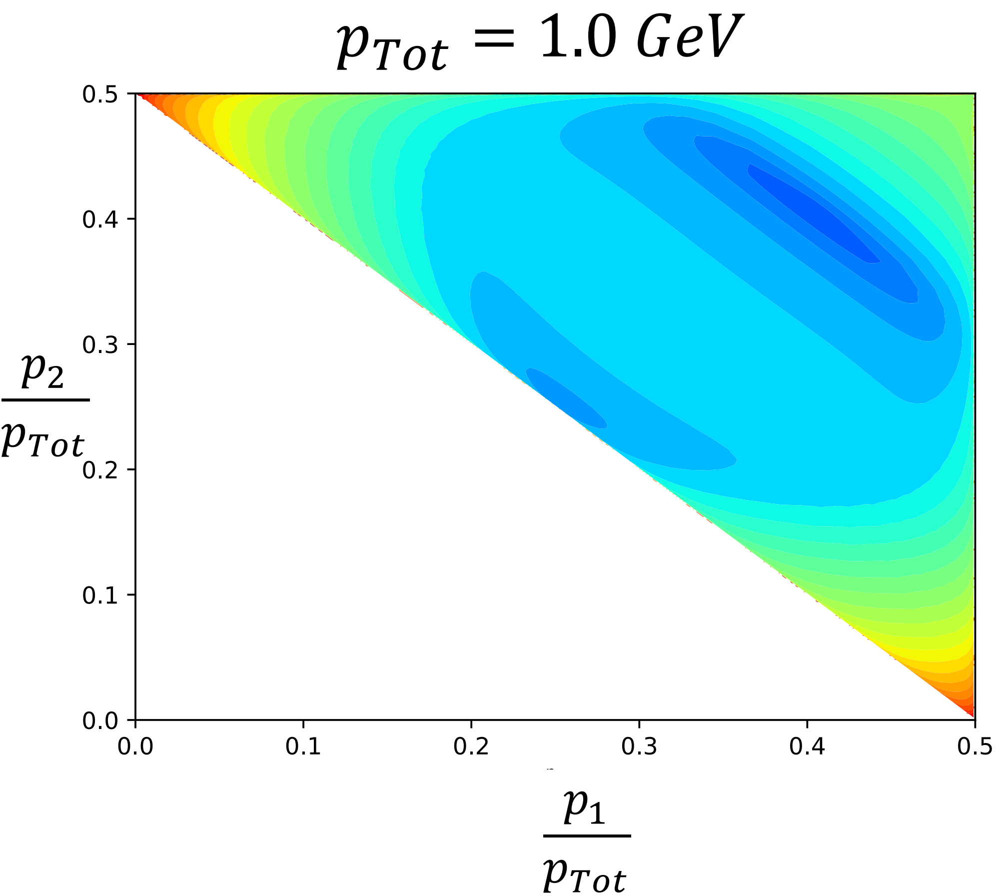
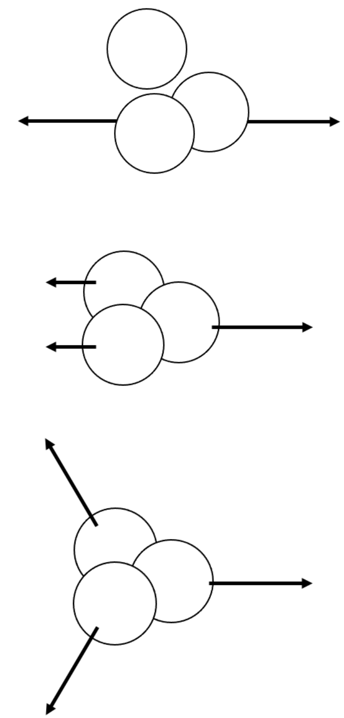
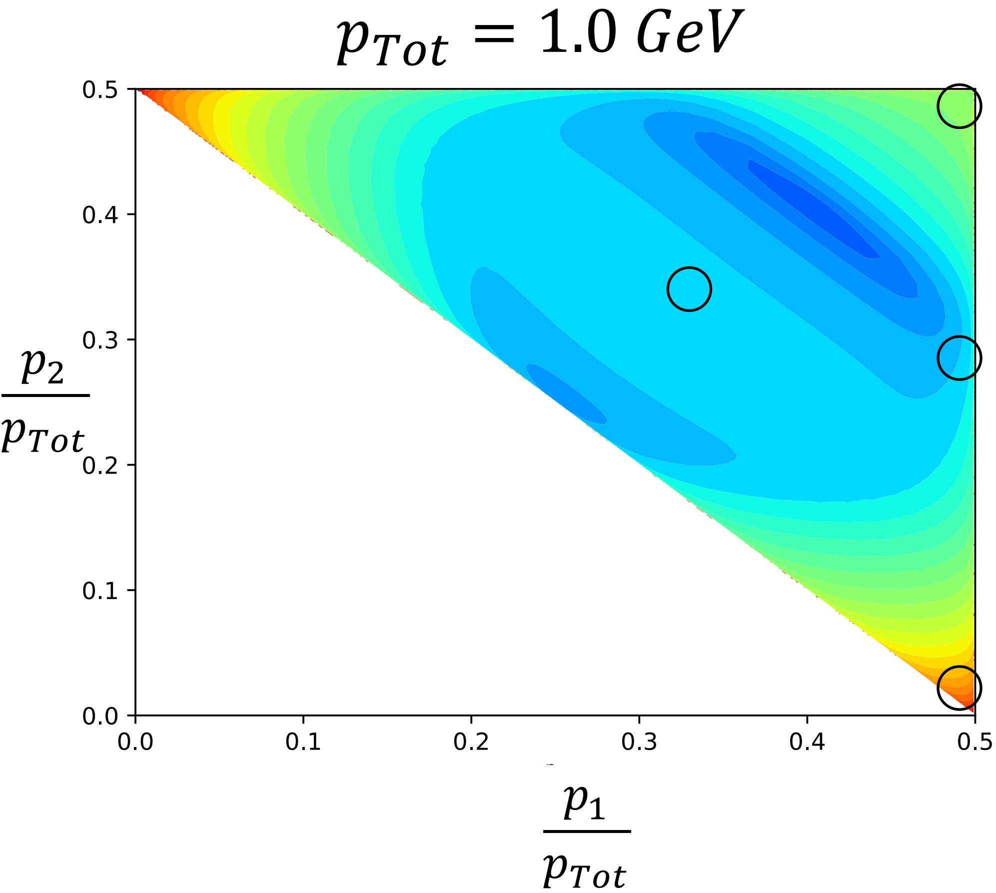
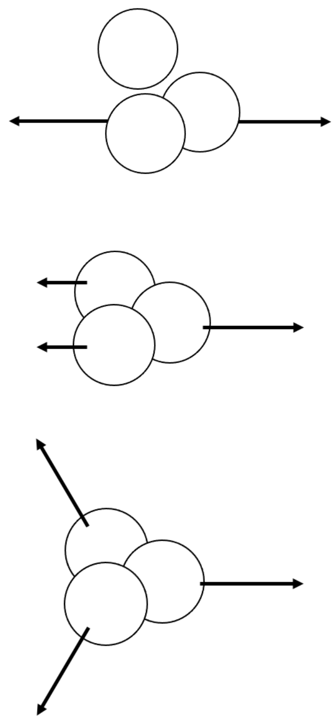


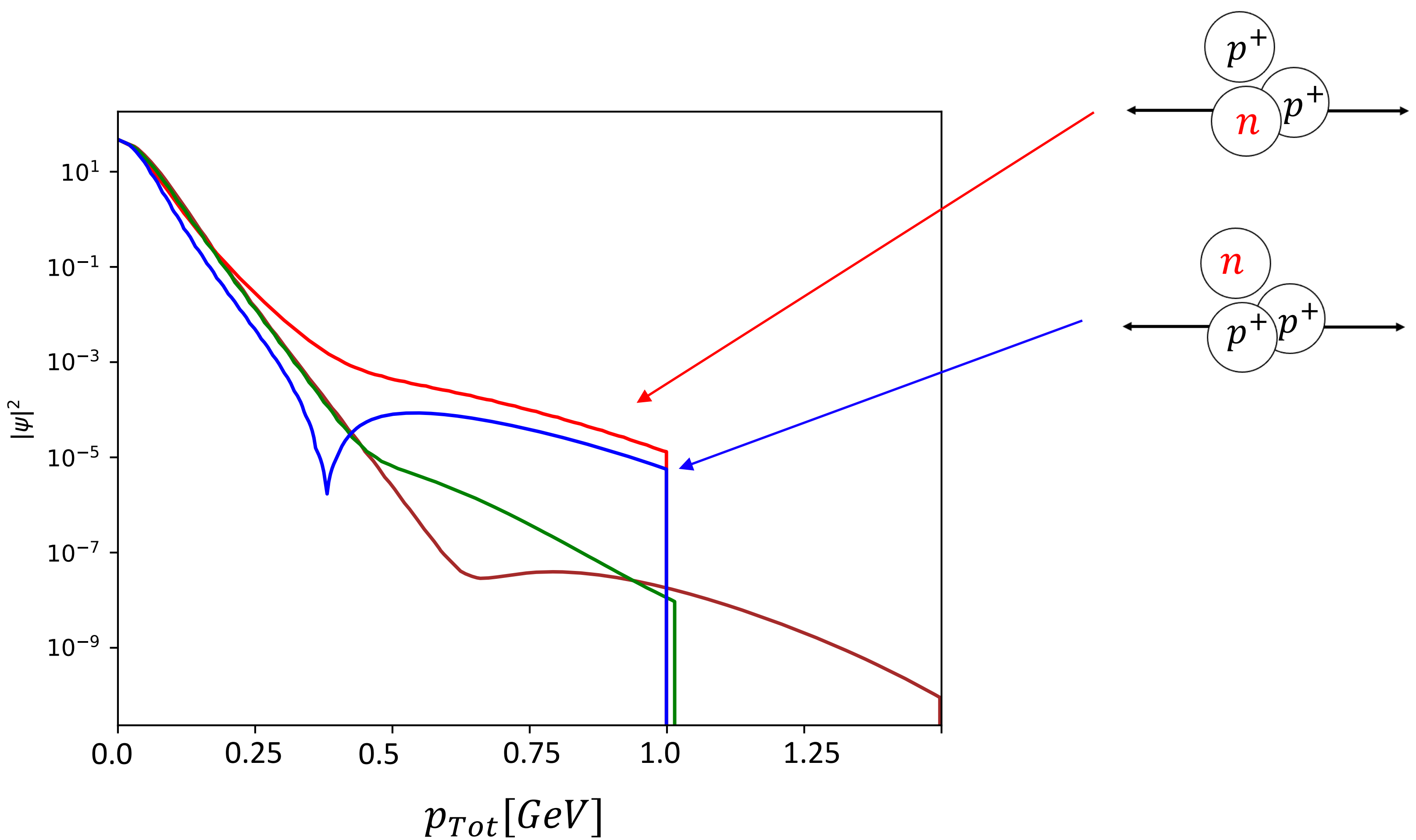


Fix p_{tot} and plot ψ^2 vs. $\frac{p_1}{p_{tot}}, \frac{p_2}{p_{tot}}$





Fix shape and plot ψ^2 vs. p_{tot}



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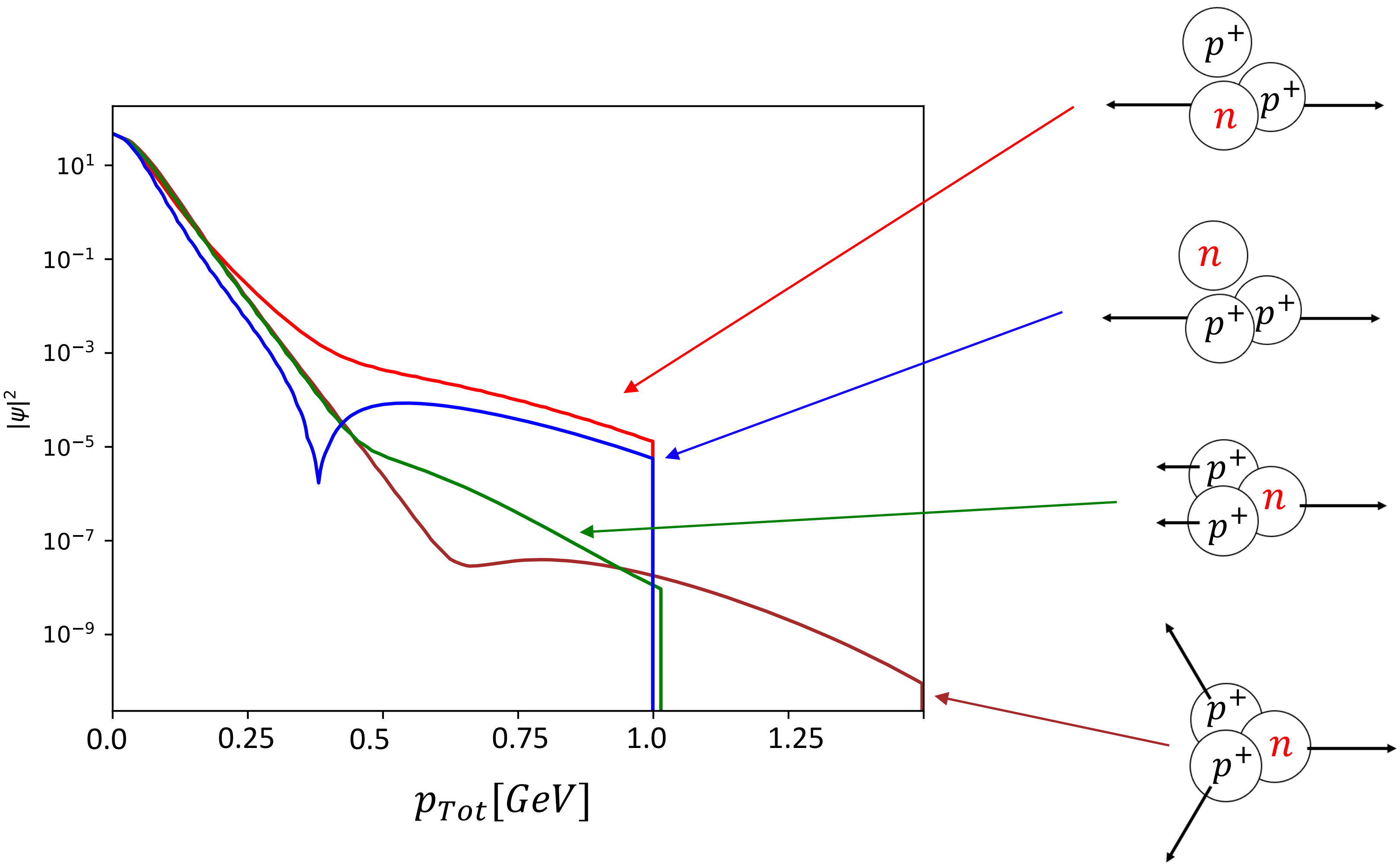
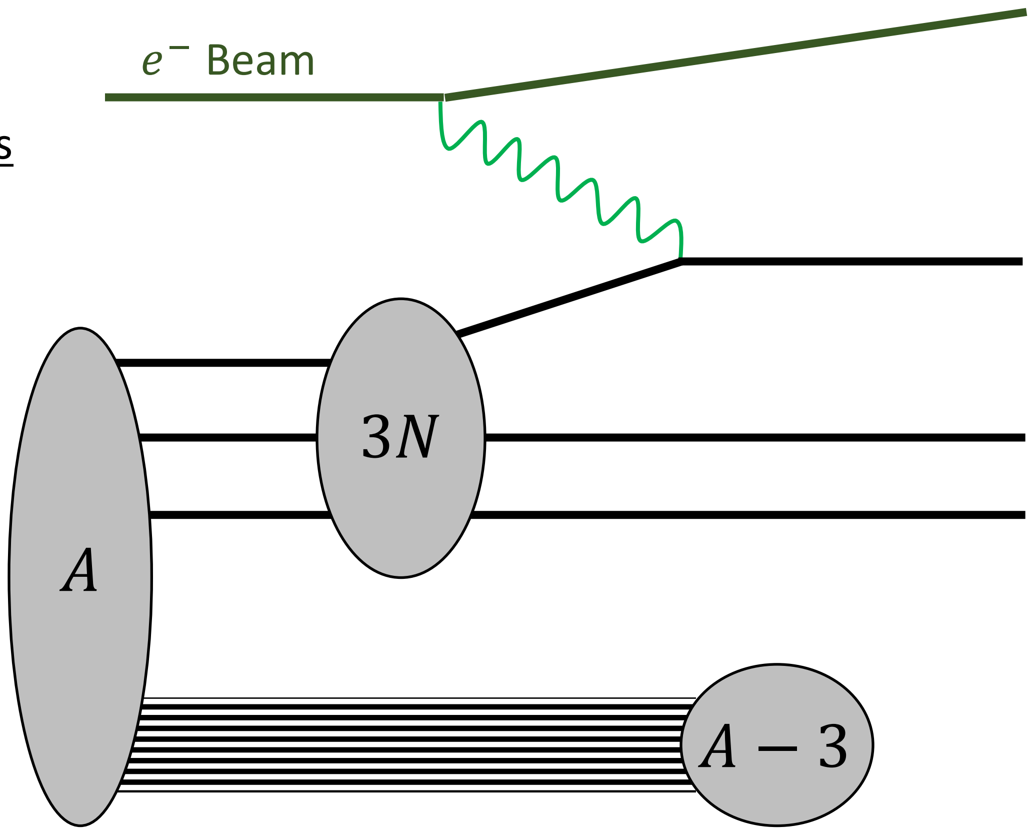


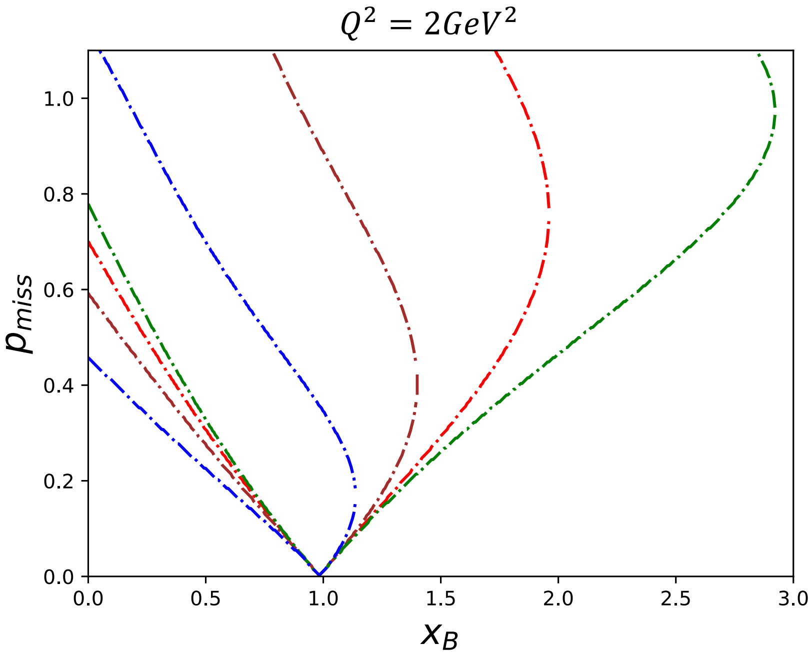
Defining a Cross Section

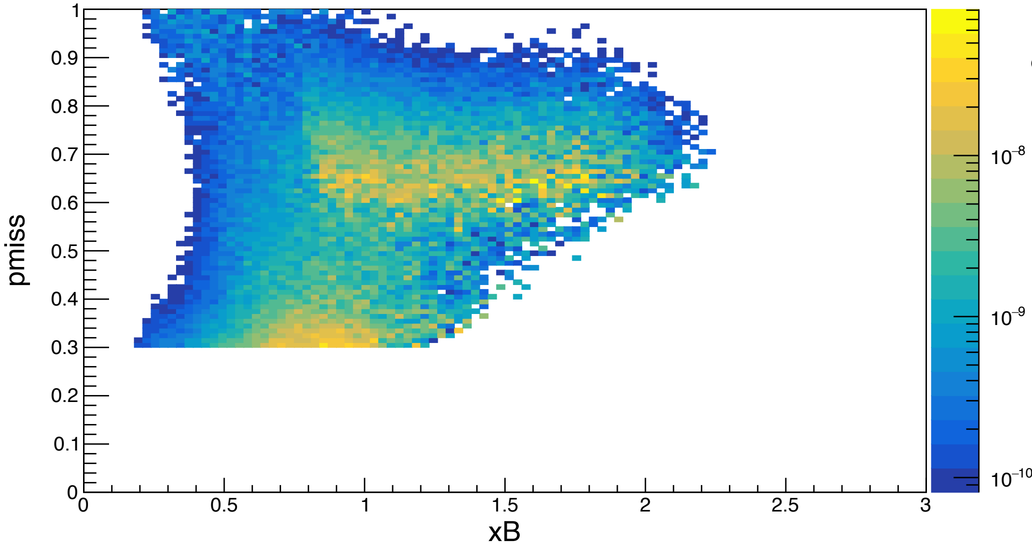
$3{\times}5$ particles
$\underline{\;-4 \text{ conservation laws}}$
11 free parameters



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

Full Cross Section Kinematics

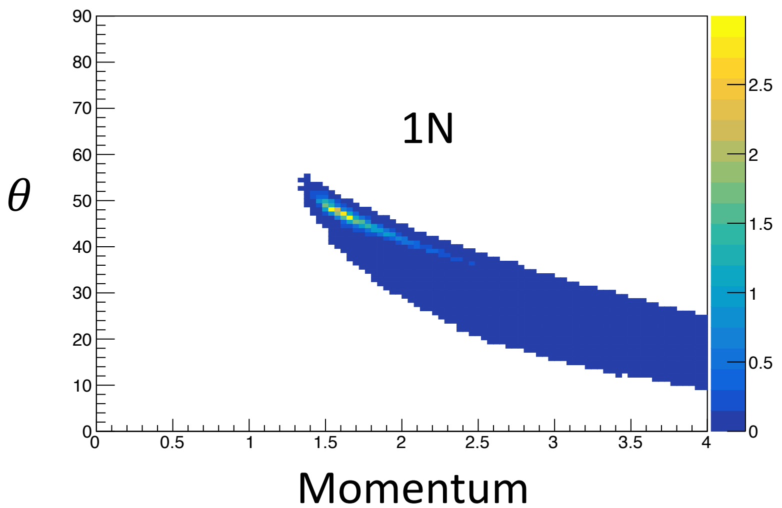


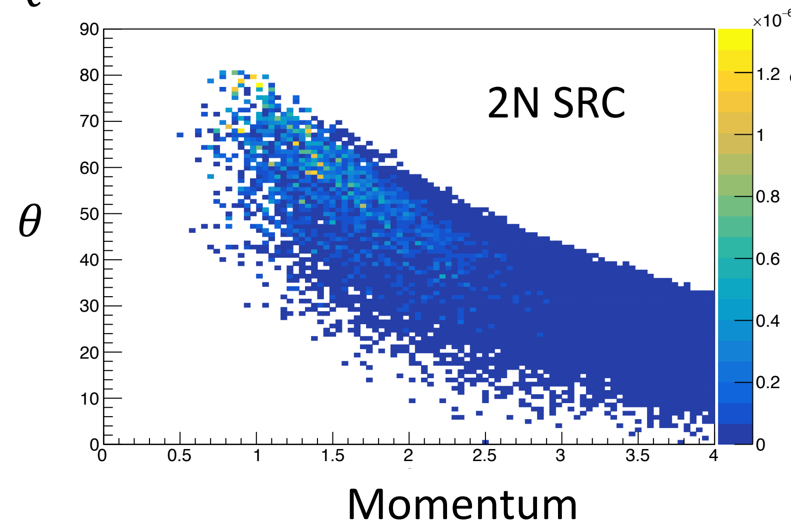


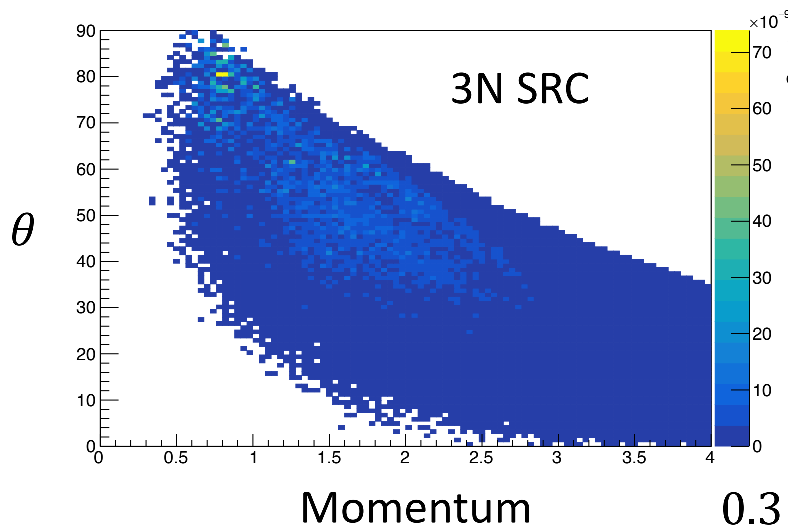
$$0.3\ GeV < p_{miss}, p_p, p_n$$
$$1.5\ GeV^2 < Q^2$$

Lead Nucleon Kinematics

$1.5\ GeV^2 < Q^2$

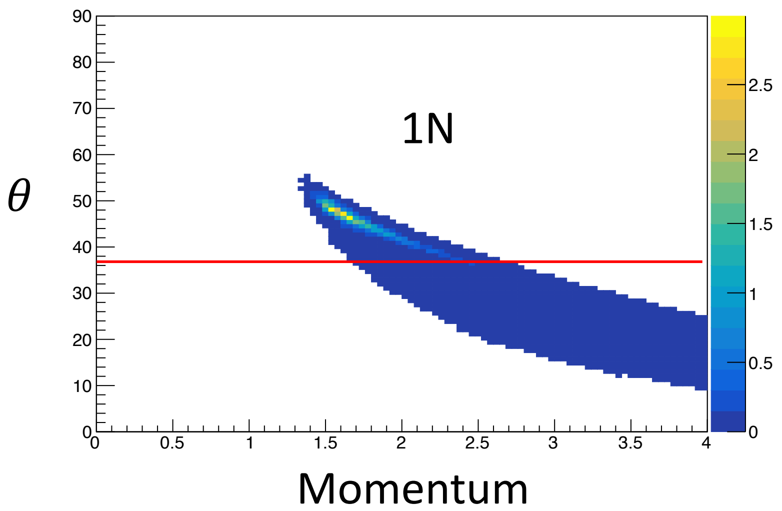


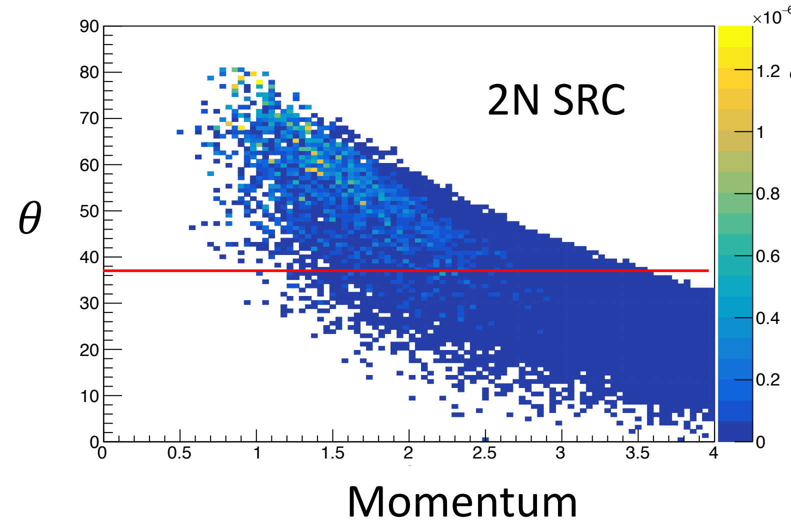


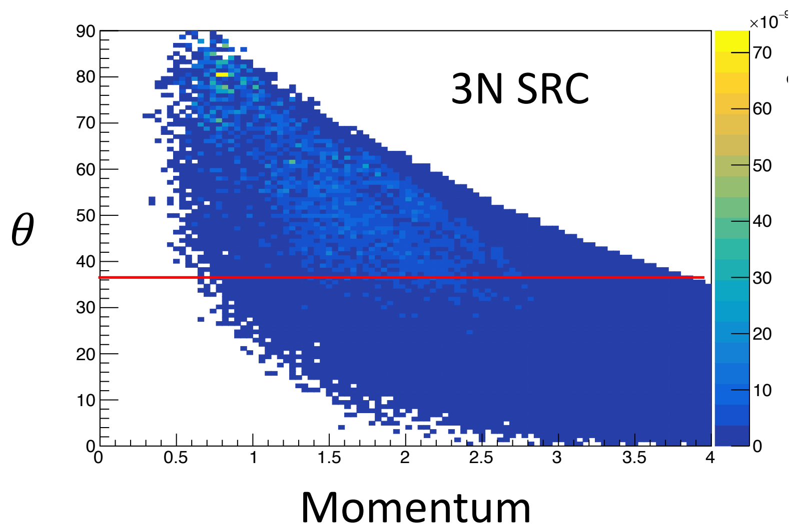


$0.3\ GeV < p_{p1}, p_{p2}, p_n$

Lead Nucleon Kinematics

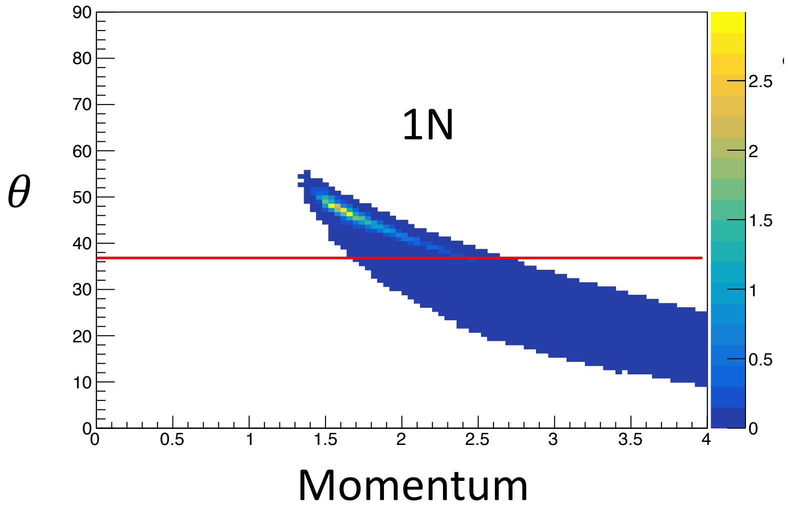


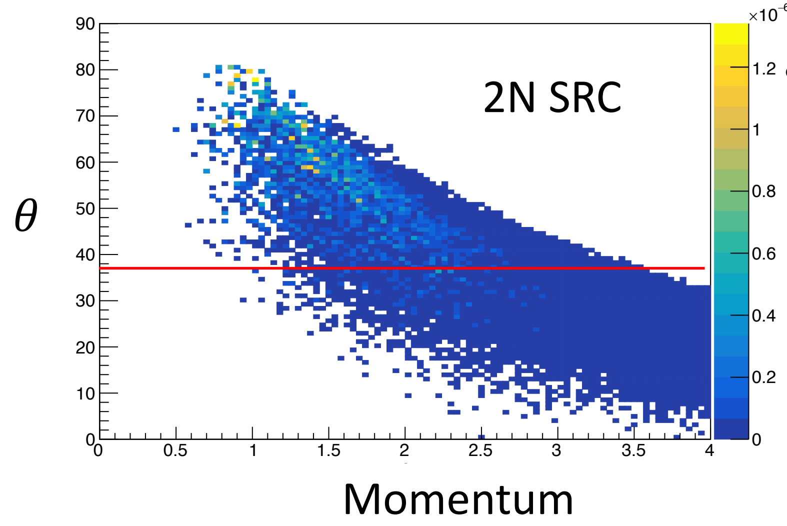




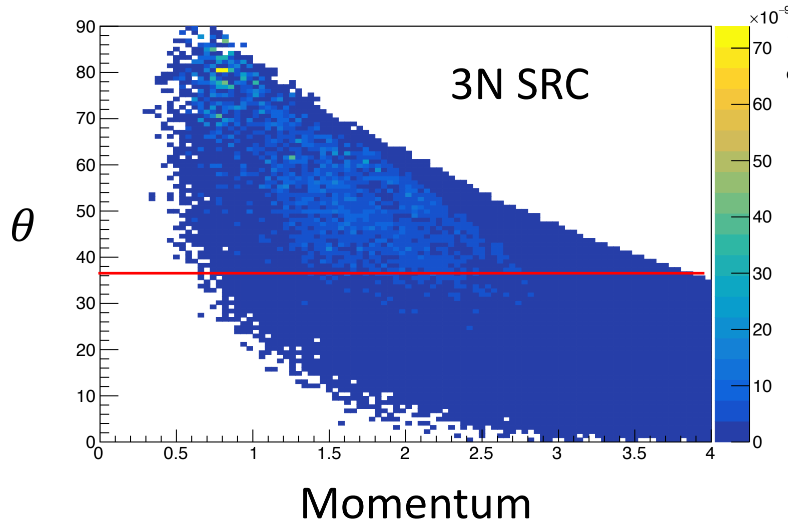
$0.3\ GeV < p_{miss}, p_p, p_n$

Lead Nucleon Kinematics





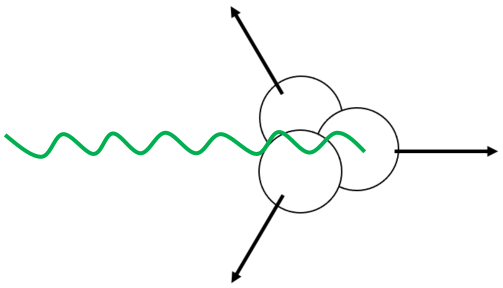
Central Detector

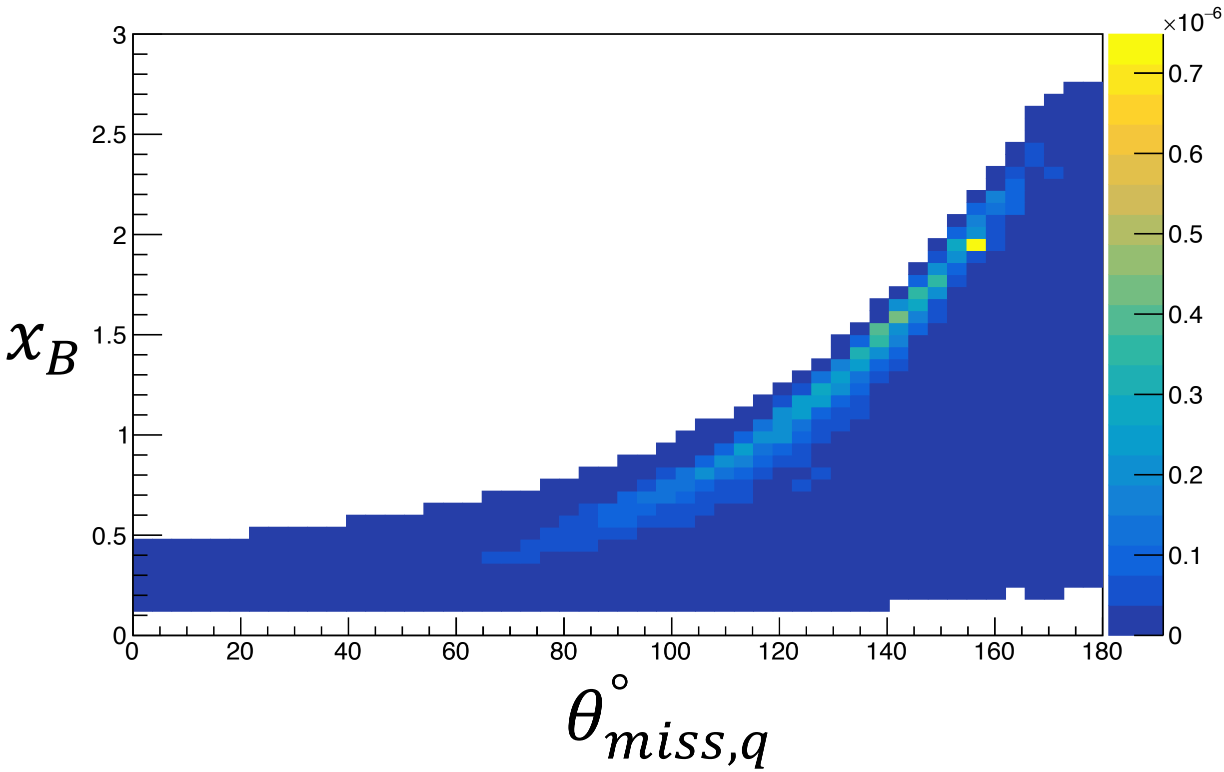


Forward Detector

$0.3\ GeV < p_{miss}, p_p, p_n$

Going to Parallel Kinematics

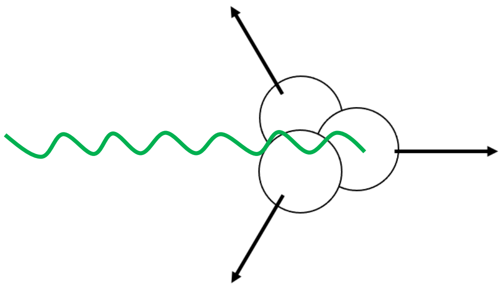


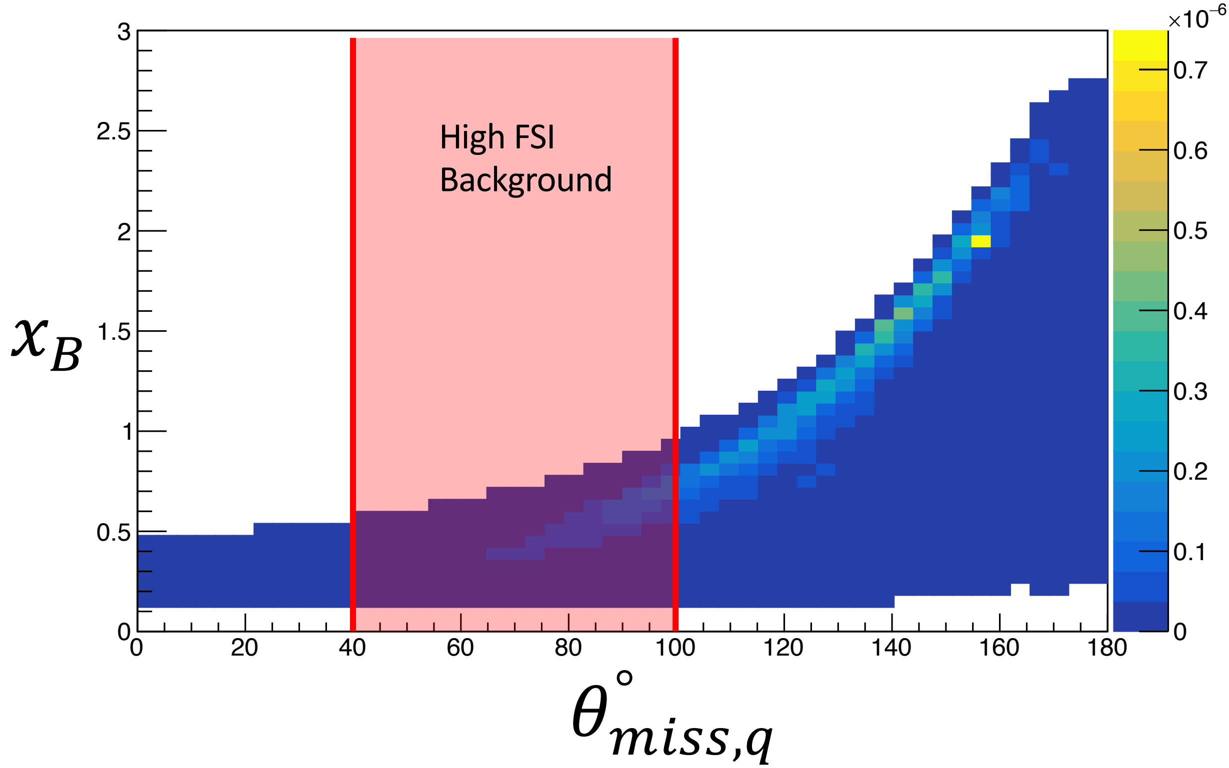


$0.3\ GeV < p_{miss}, p_p, p_n$

$1.5\ GeV^2 < Q^2$

Going to Parallel Kinematics

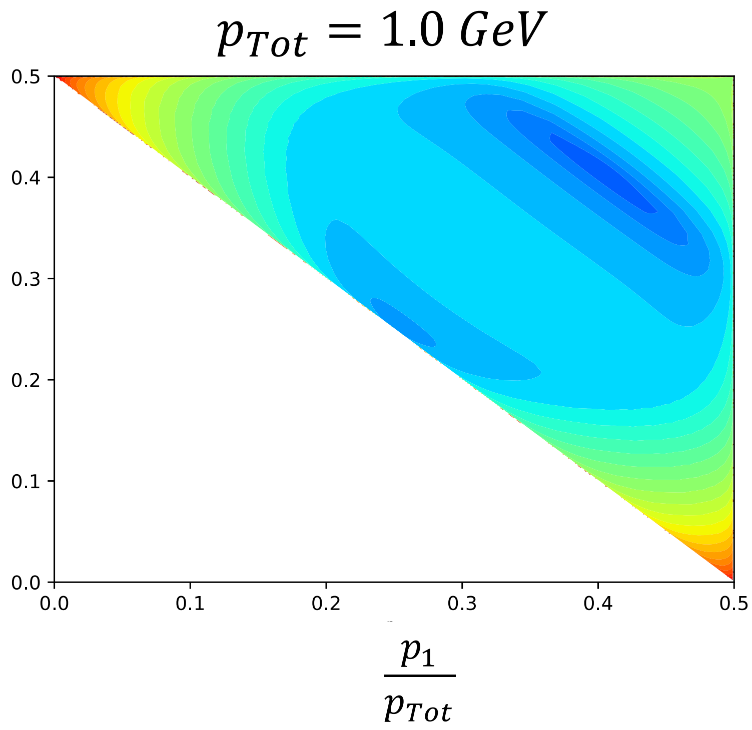


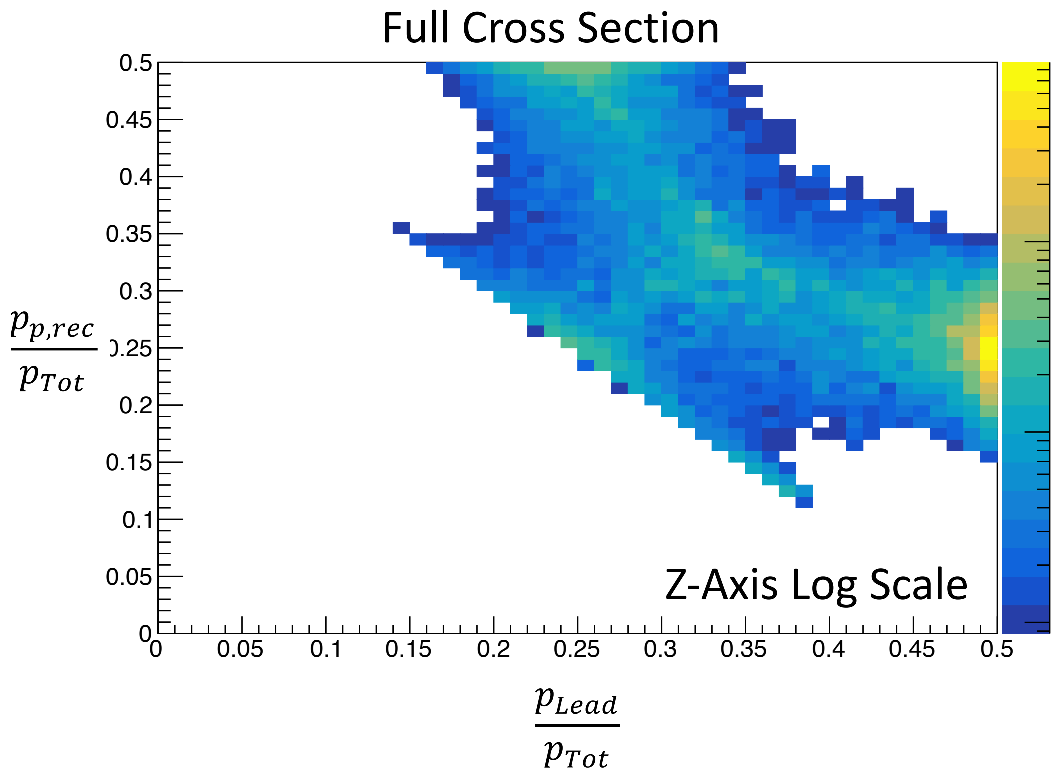


$0.3\ GeV < p_{miss}, p_p, p_n$

$1.5\ GeV^2 < Q^2$

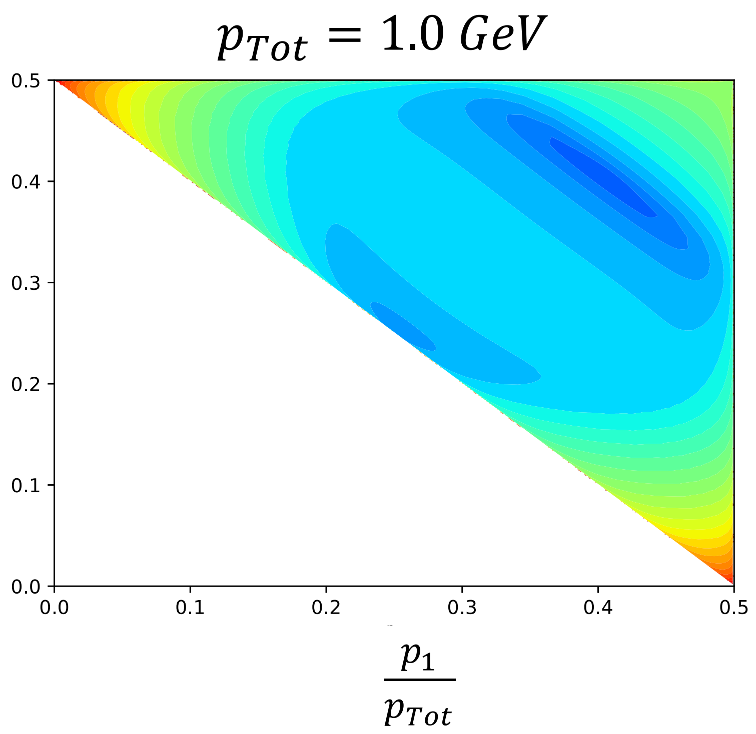
Full Cross Section 3N Distributions

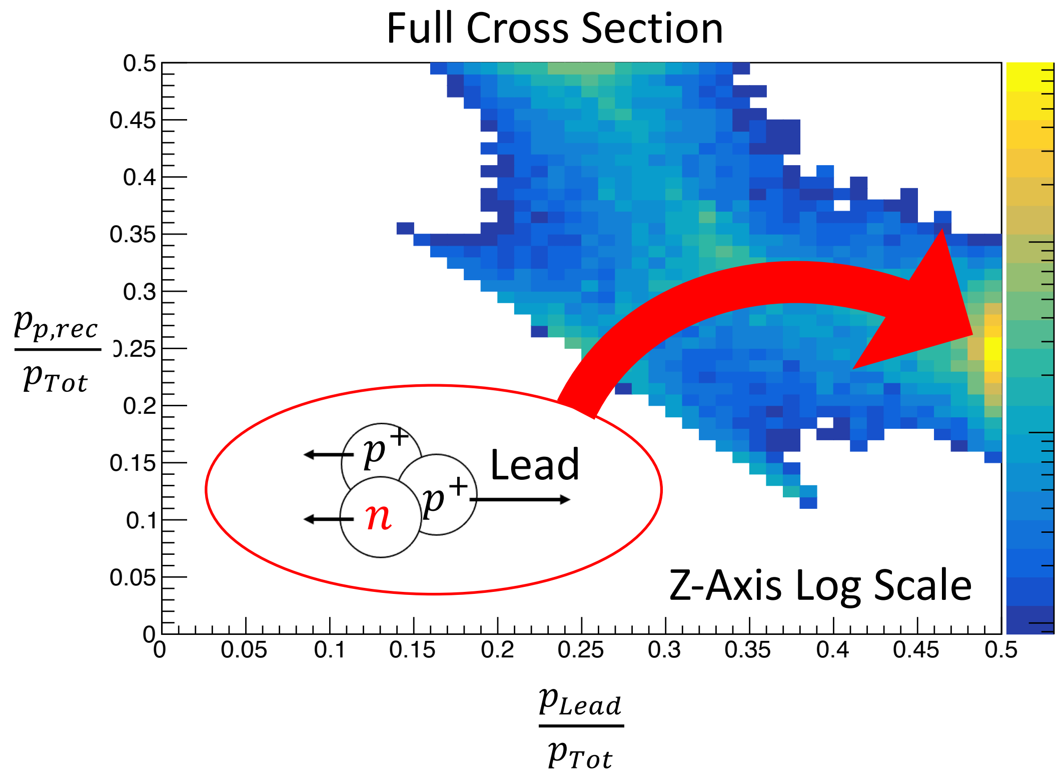




$0.3\ GeV < p_{miss}, p_p, p_n$

Full Cross Section 3N Distributions

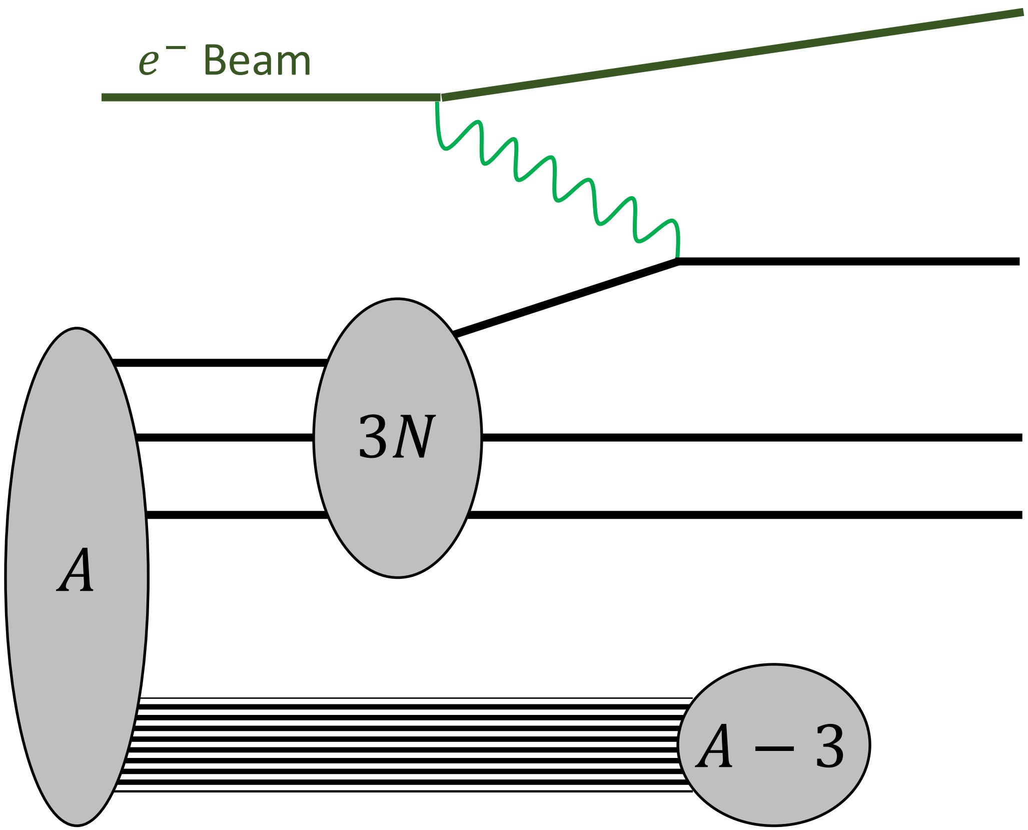




$$0.3\ GeV < p_{miss}, p_p, p_n$$

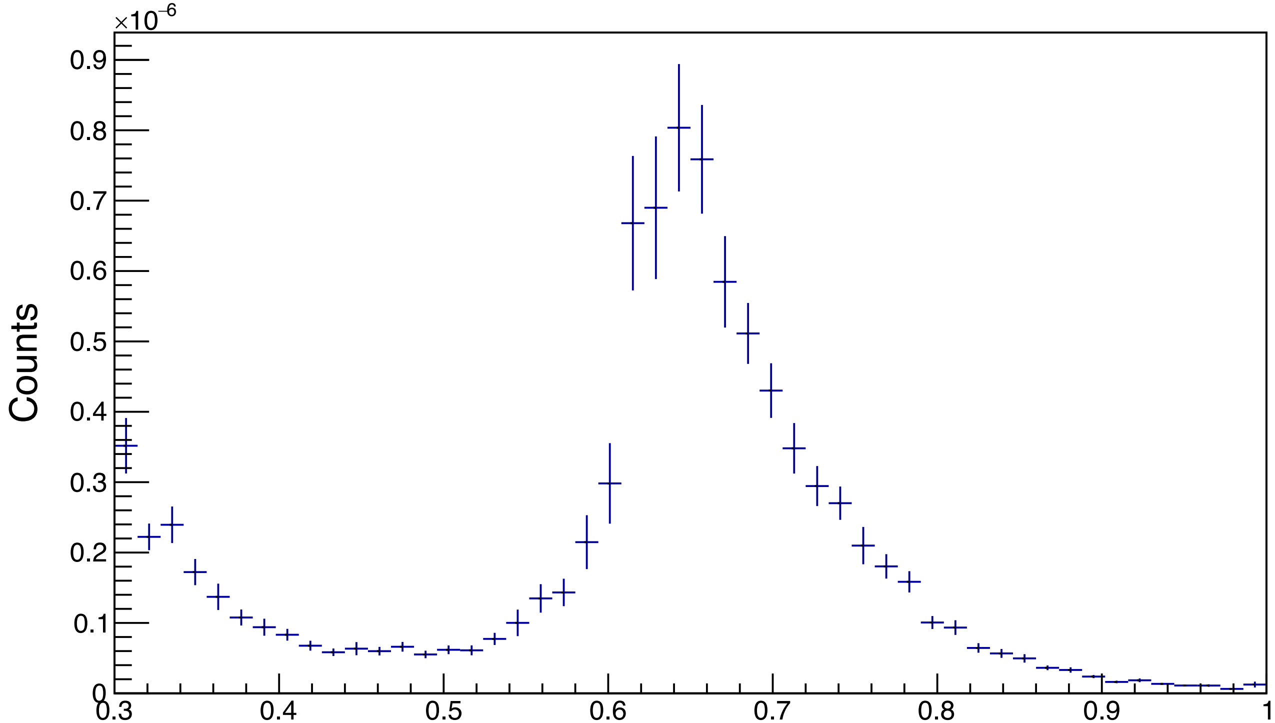
$$1.5\ GeV^2 < Q^2$$

The Search for Observables



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

Looking at Missing Momentum Distributions

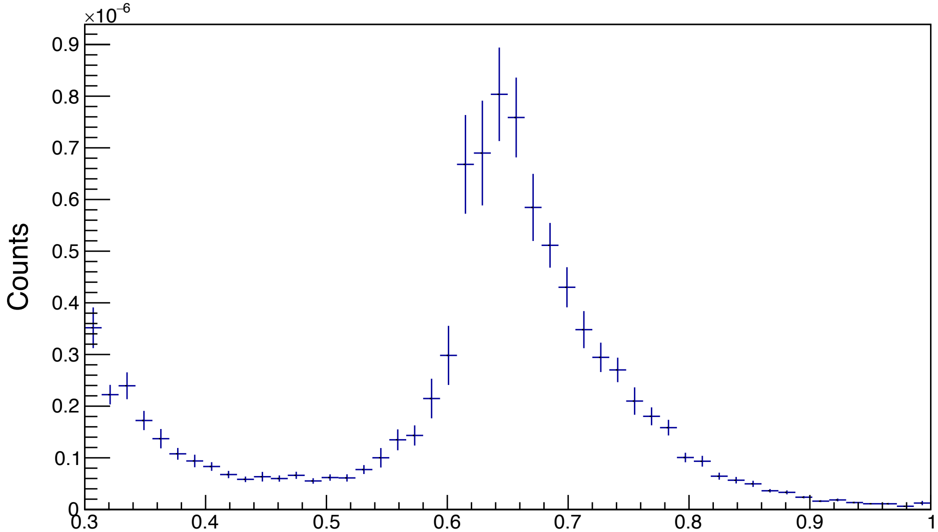


p_{miss} $[GeV]$

$0.3\ GeV < p_{miss}, p_p, p_n$

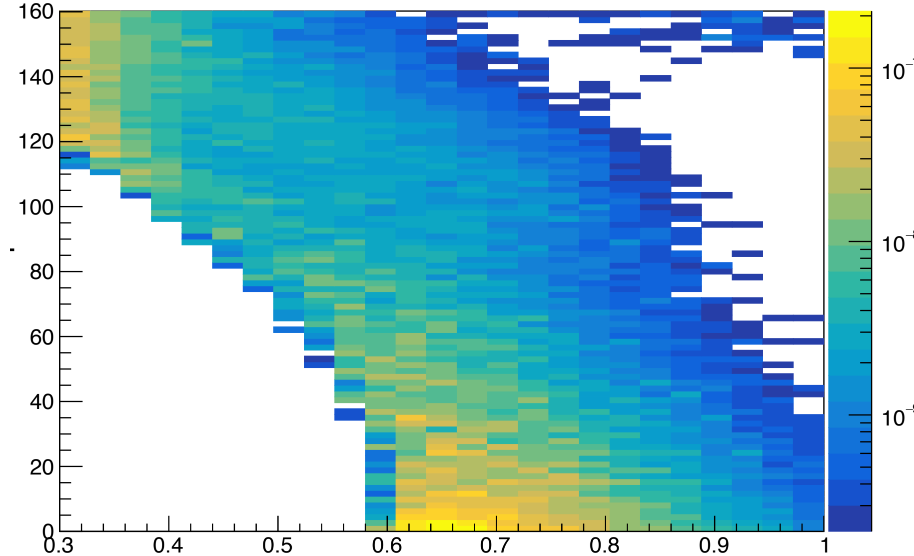
$1.5\ GeV^2 < Q^2$

Looking at Missing Momentum Distributions



$p_{miss}\ [GeV]$

θ°_{pn}

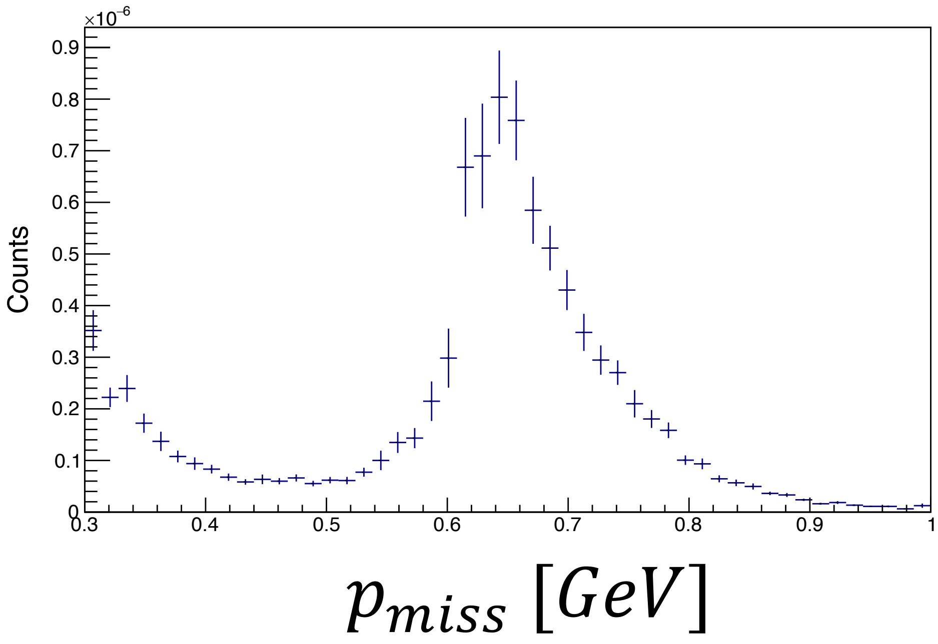


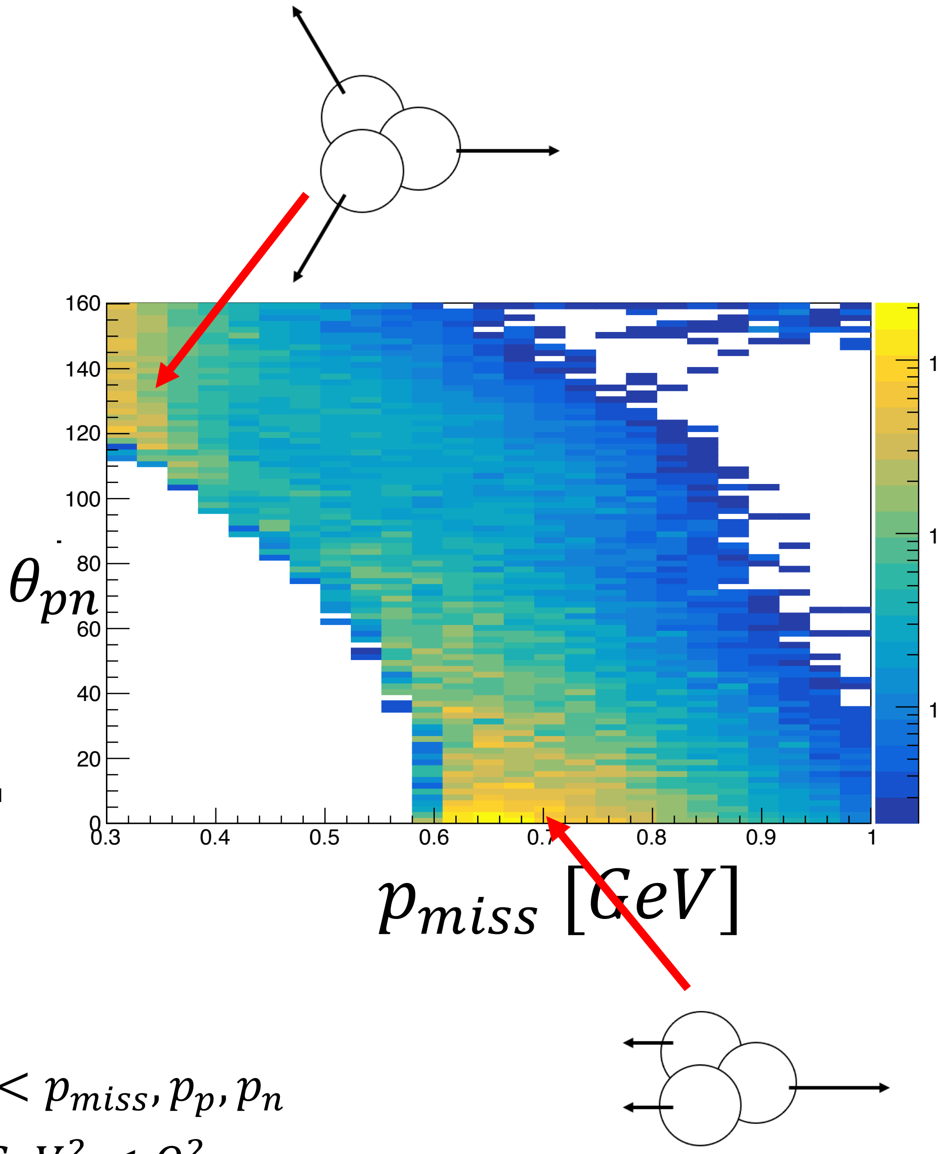
$p_{miss}\ [GeV]$

$$0.3\ GeV < p_{miss}, p_p, p_n$$

$$1.5\ GeV^2 < Q^2$$

Looking at Missing Momentum Distributions

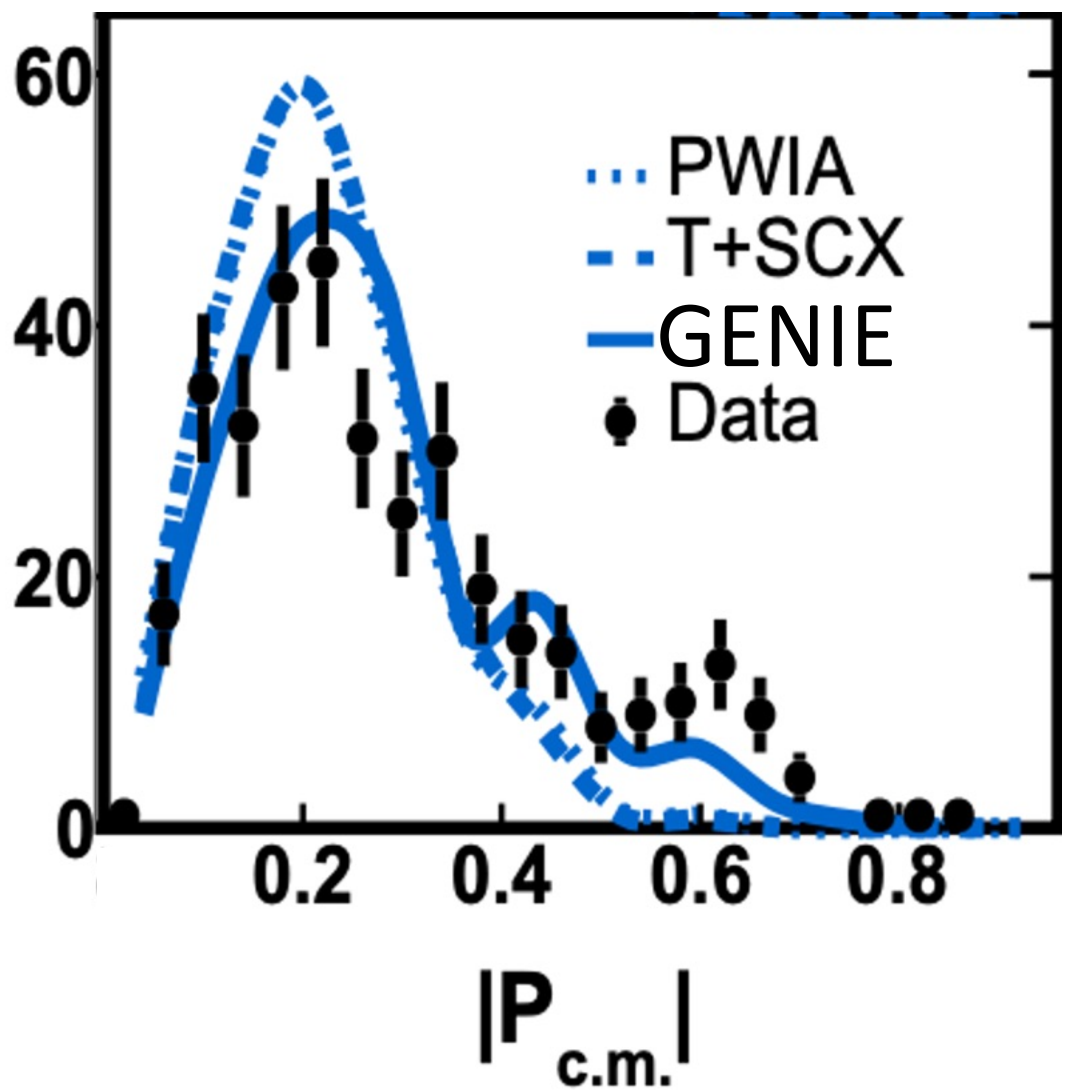




$0.3\ GeV < p_{miss}, p_p, p_n$

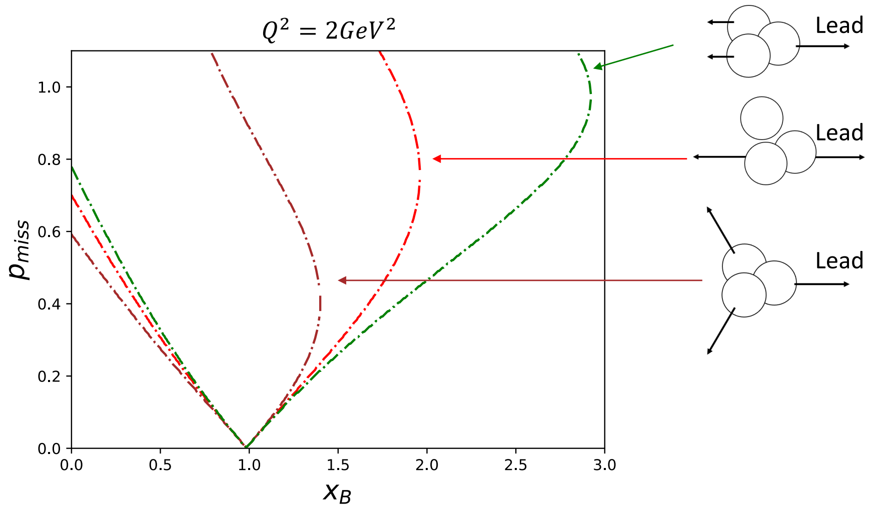
$1.5\ GeV^2 < Q^2$

FSI to Come



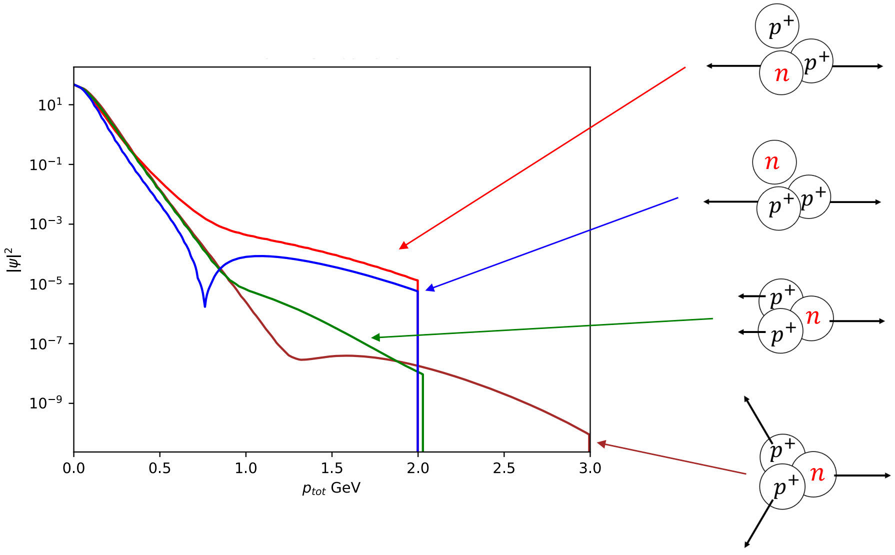
Overview

- Kinematics of 3N SRCs



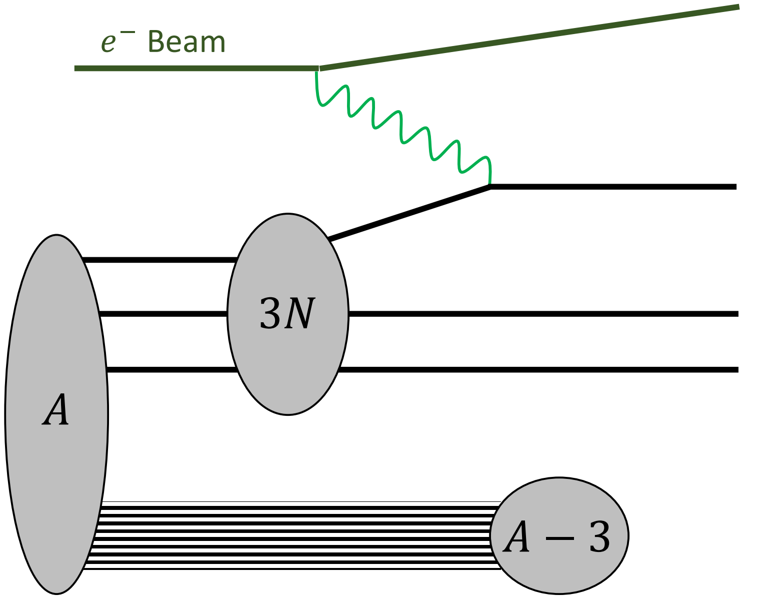
Overview

- Kinematics of 3N SRCs
- ^3He wavefunction



Overview

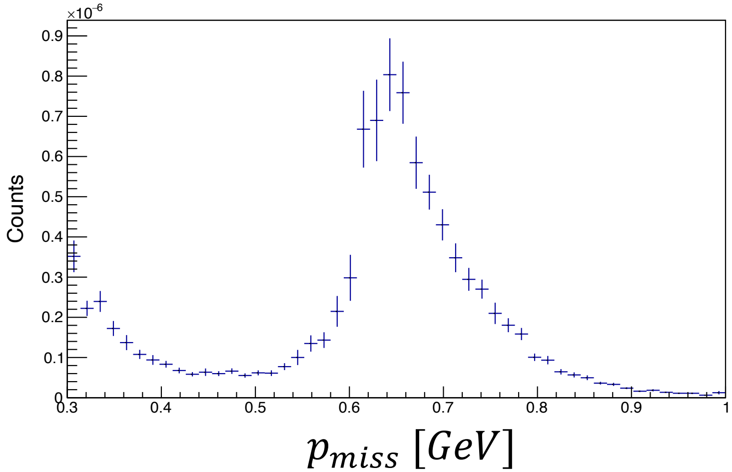
- Kinematics of 3N SRCs
- ^{3}He wavefunction
- 3N SRC Cross Section

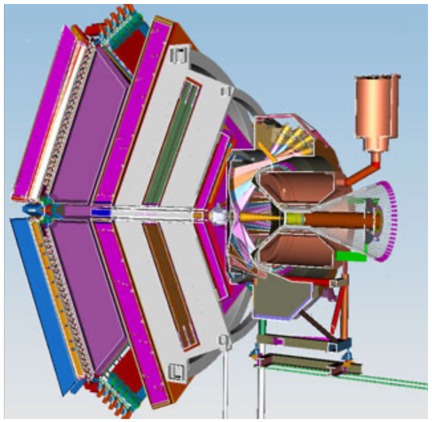


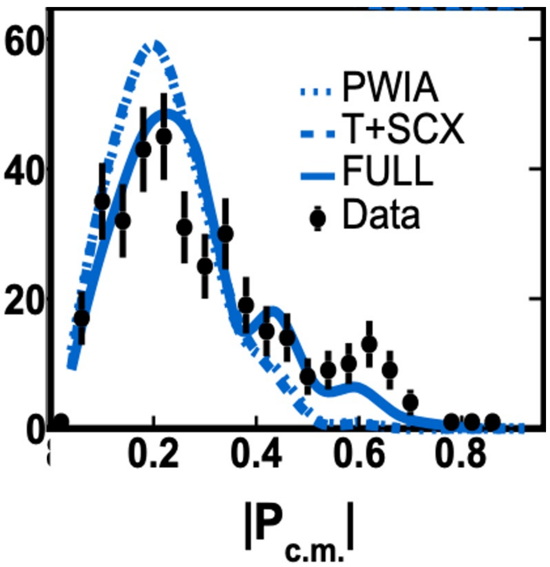
$$\frac{d^{11}\sigma}{d^{11}X^{\mu}} = \mathcal{J}\sigma_{eN} * |\phi_{\alpha}(\vec{p}_1, \vec{p}_2, \vec{p}_3)|^2 * n(p_{cm}) * \delta(E_f - E_i)$$

Overview

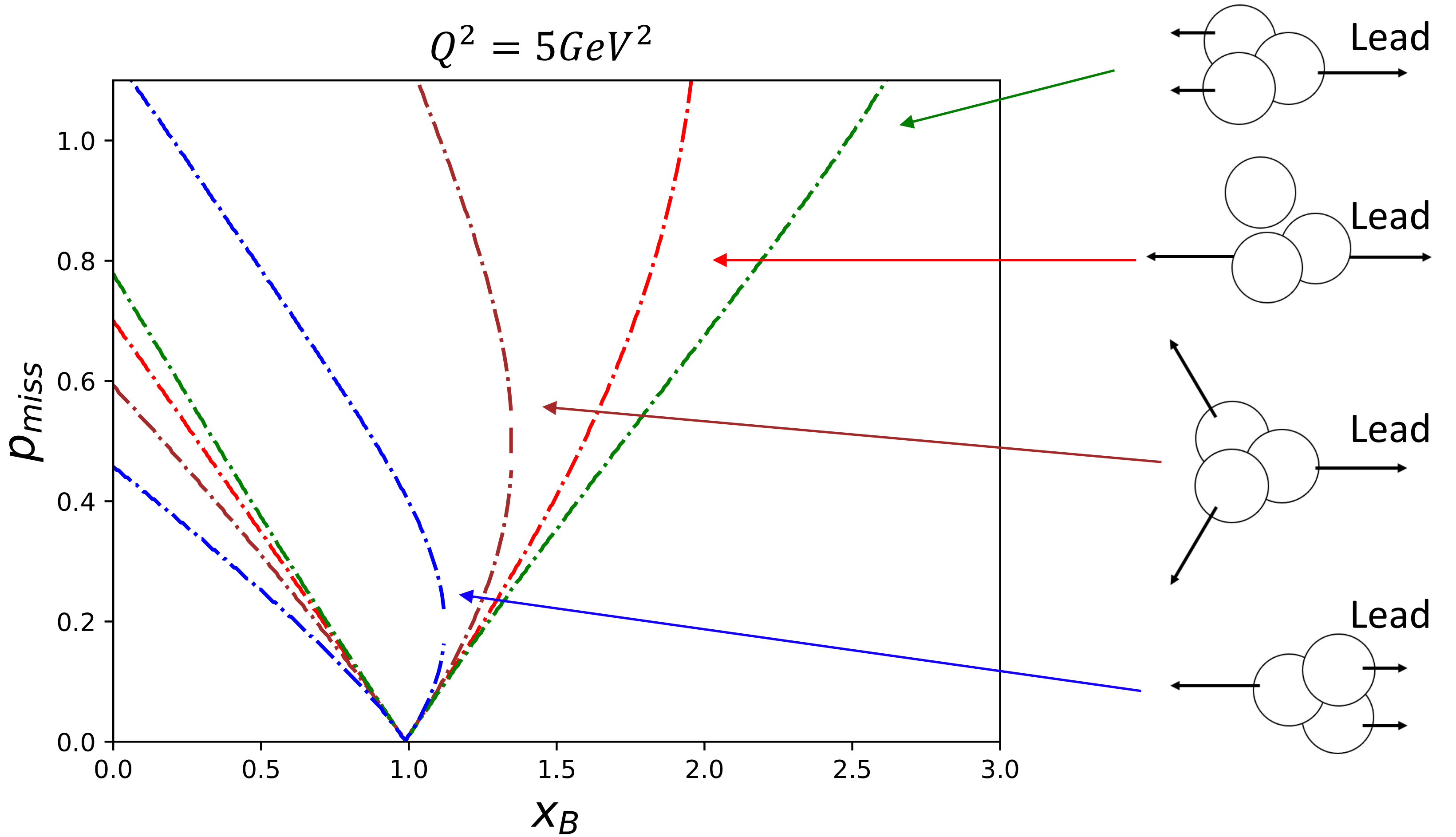
- Kinematics of 3N SRCs
- ^{3}He wavefunction
- 3N SRC Cross Section
- We are in the market for Observables!



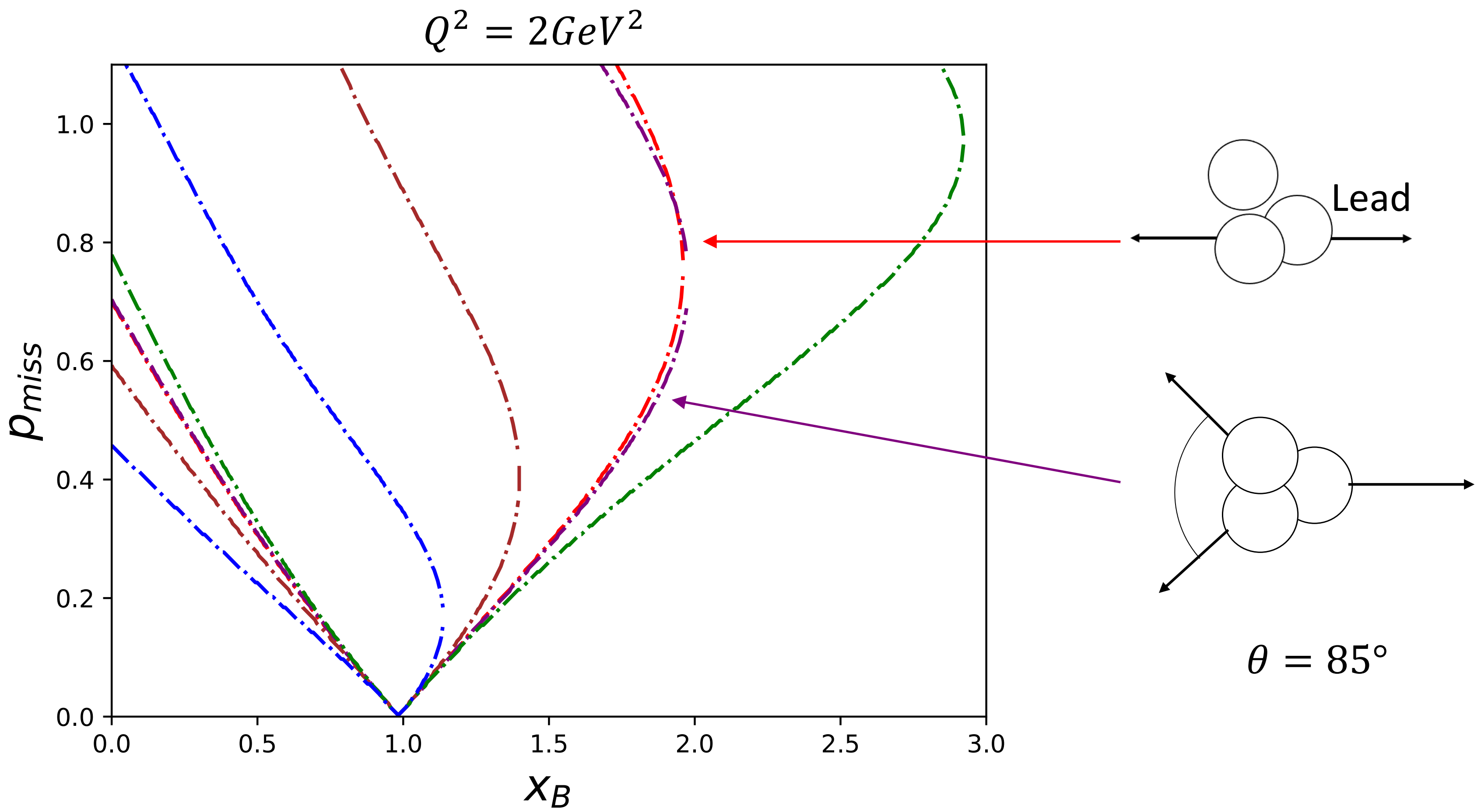




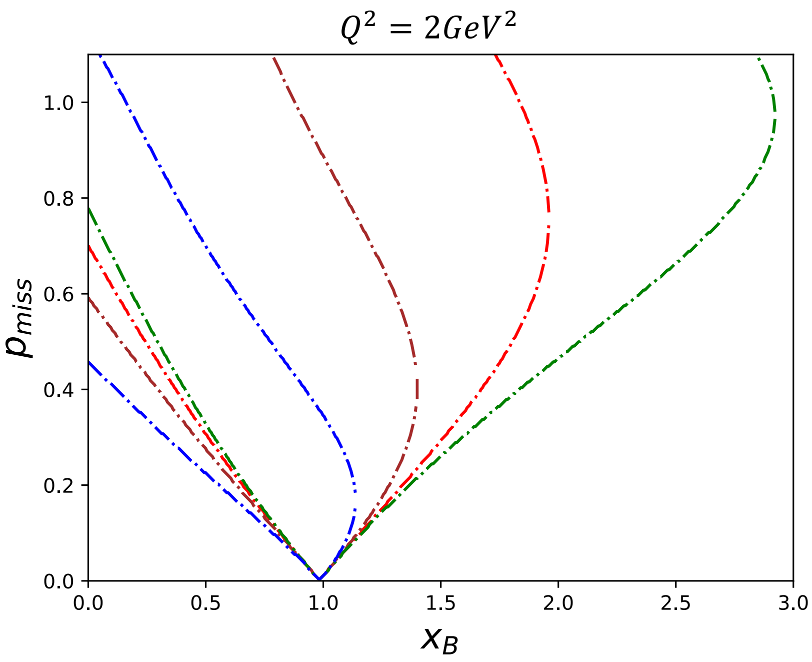
Understanding the Kinematics

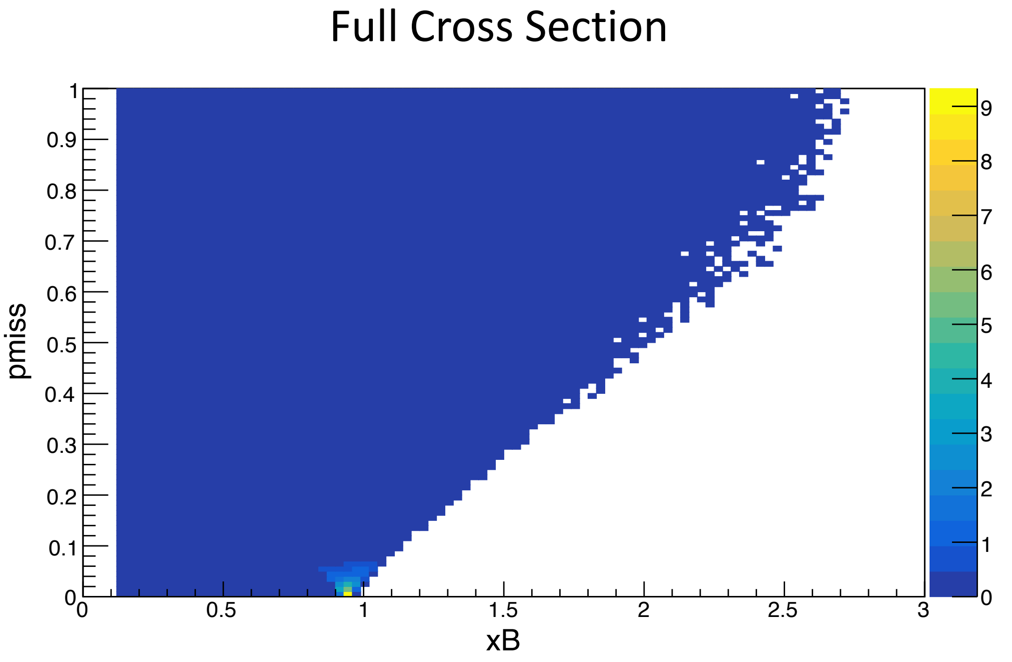


Understanding the Kinematics

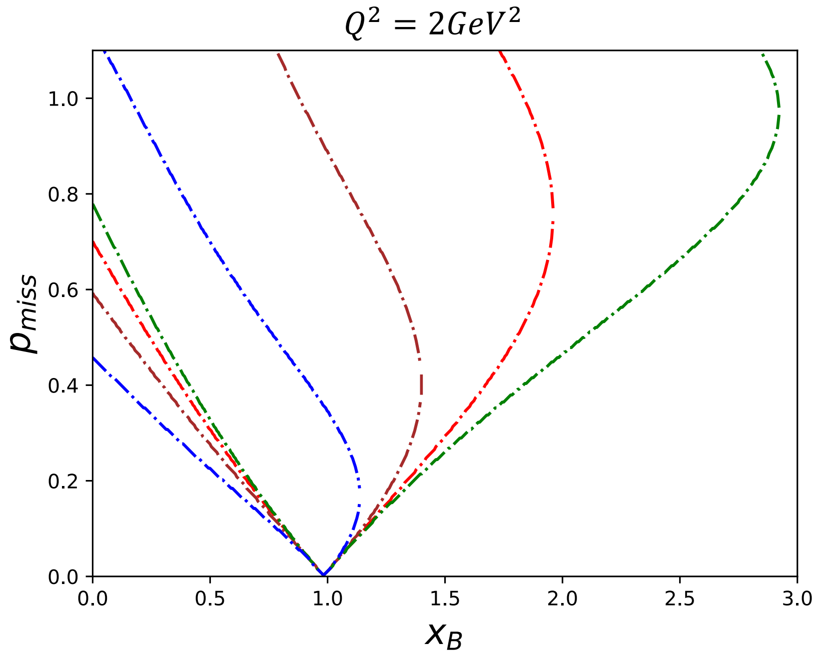


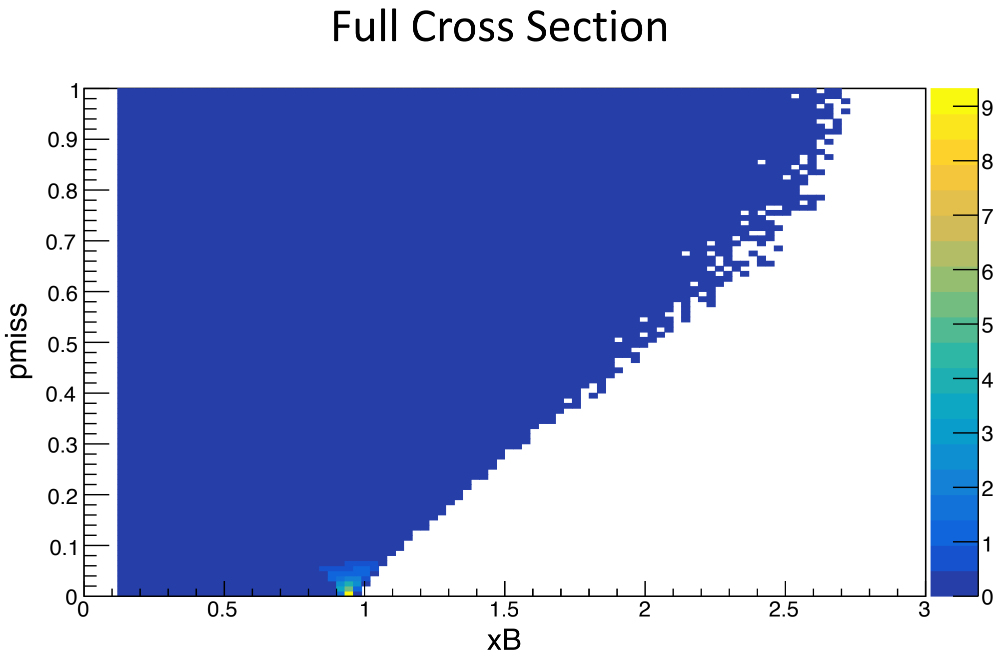
Full Cross Section Kinematics

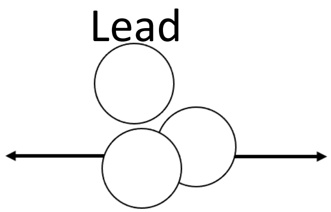


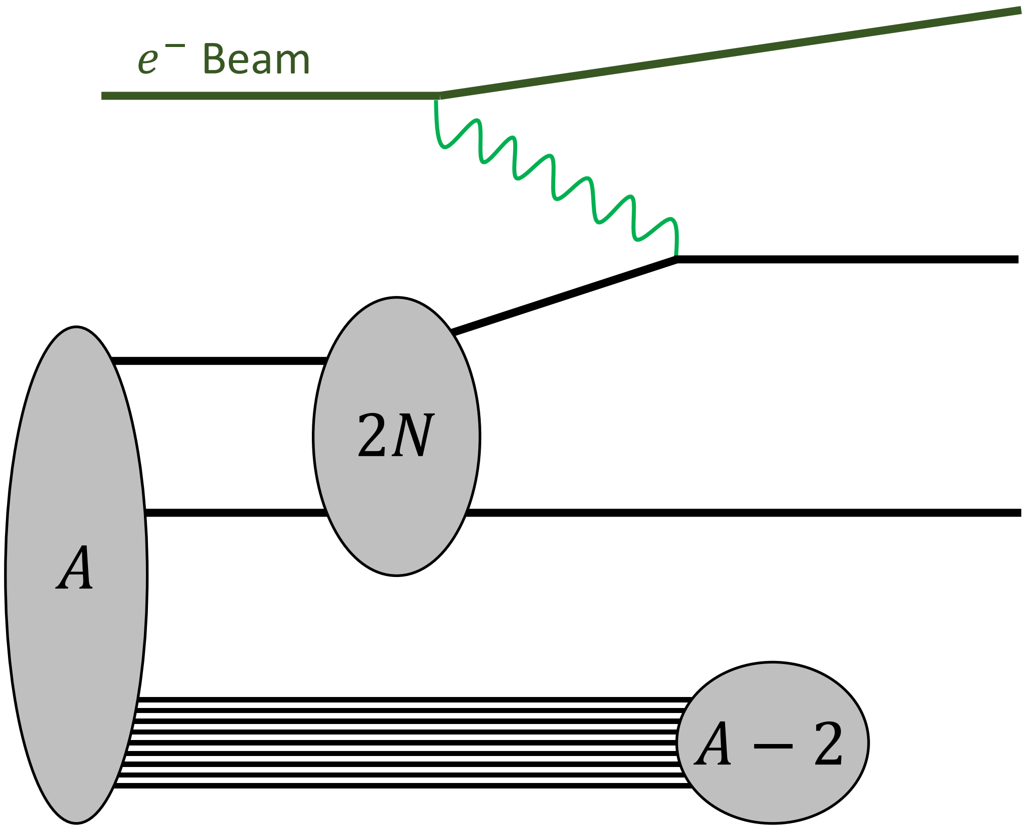


Full Cross Section Kinematics

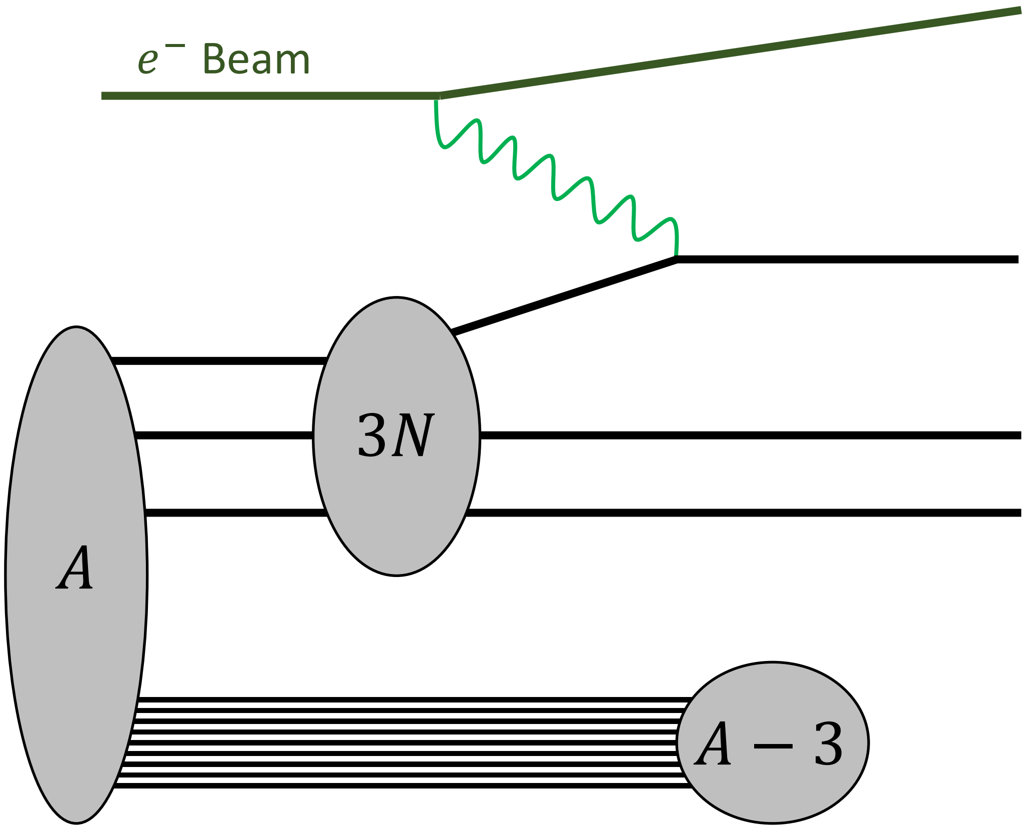




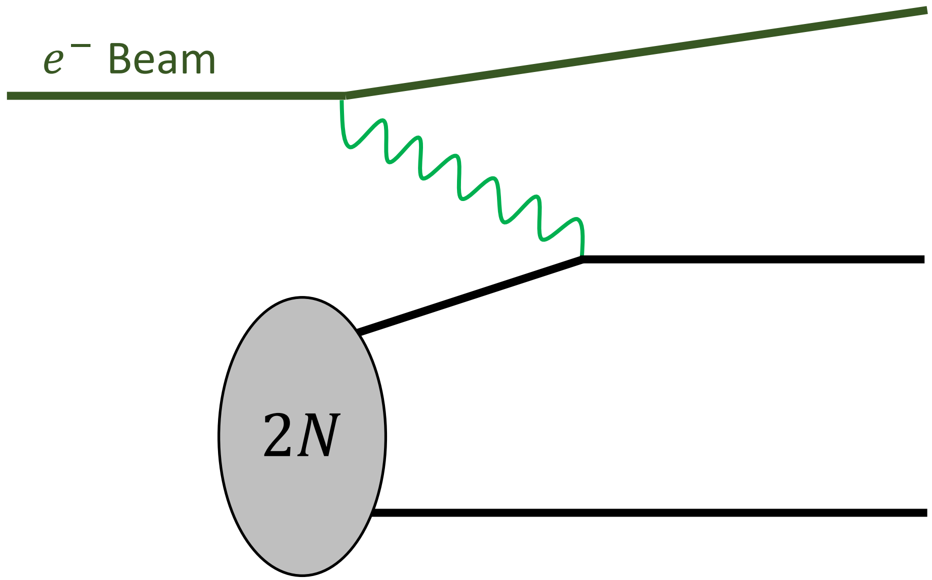




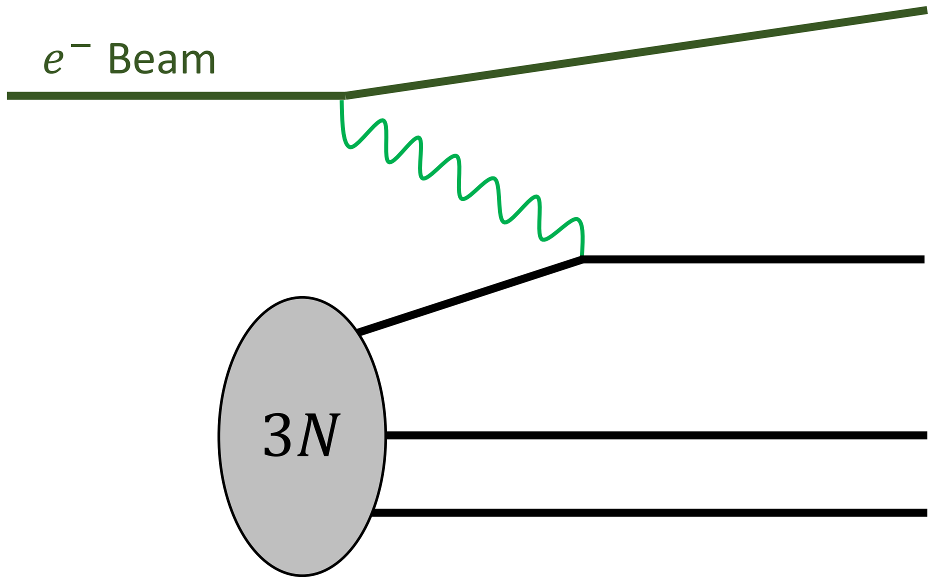
e^- Beam
$2N$
A
$A-2$

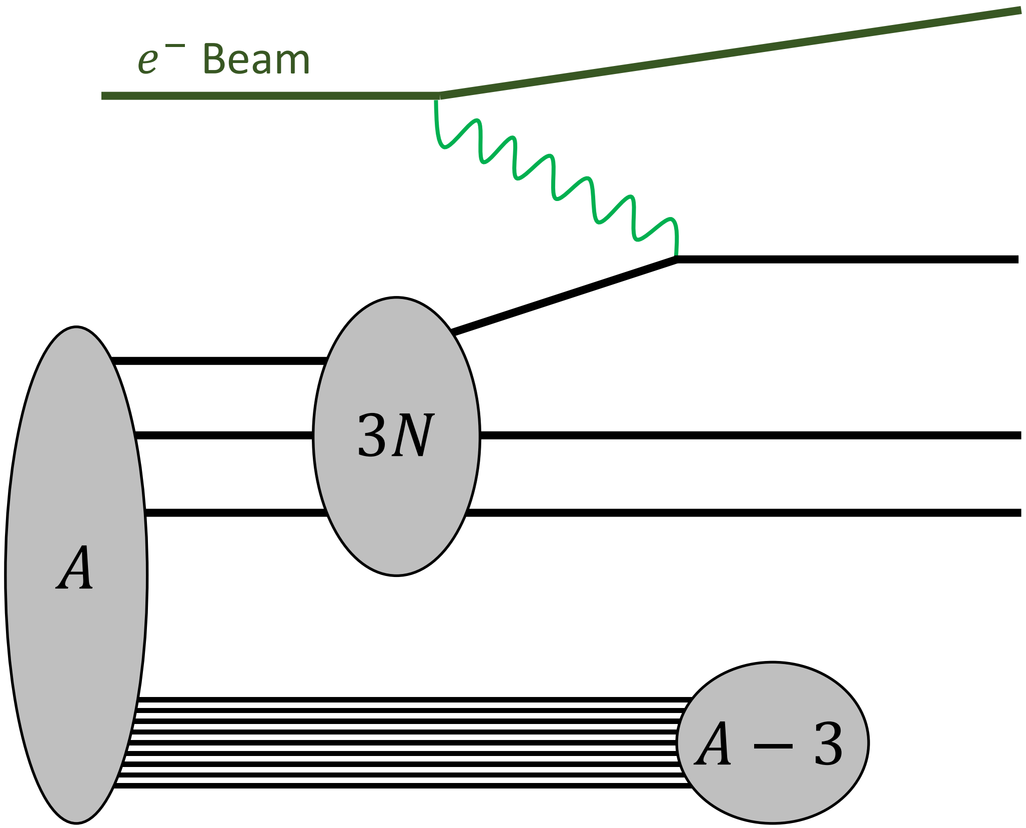


e^- Beam
$3N$
A
$A-3$

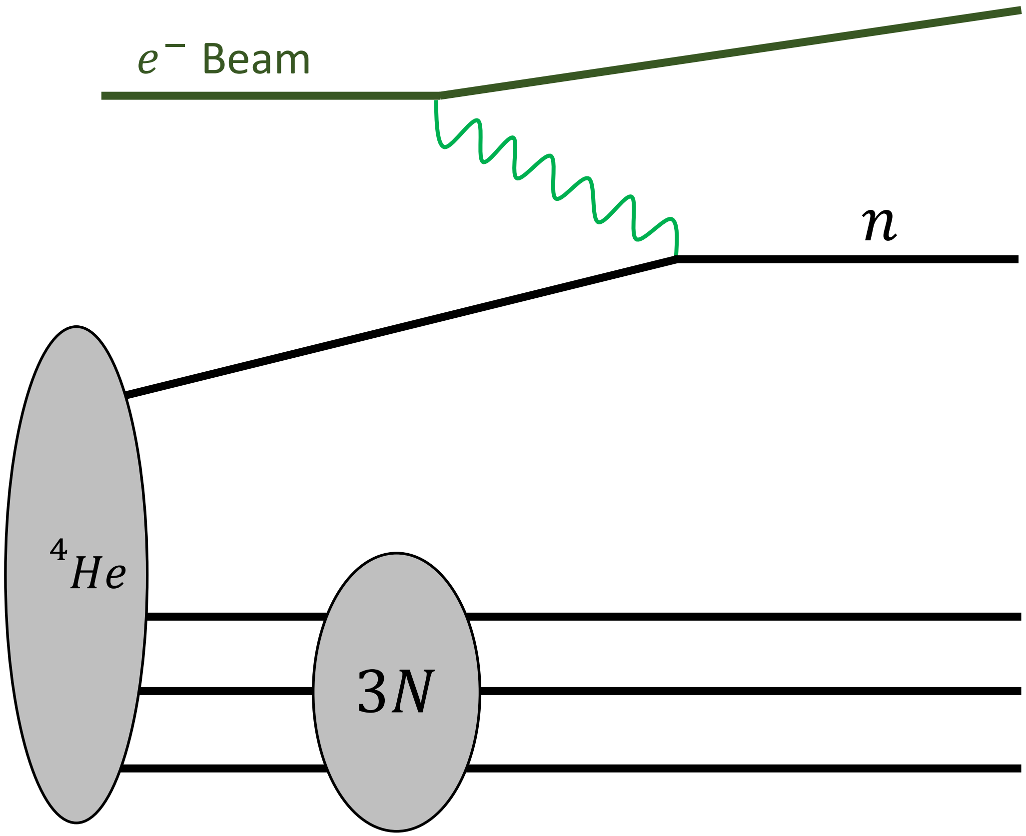


e^- Beam
$2N$

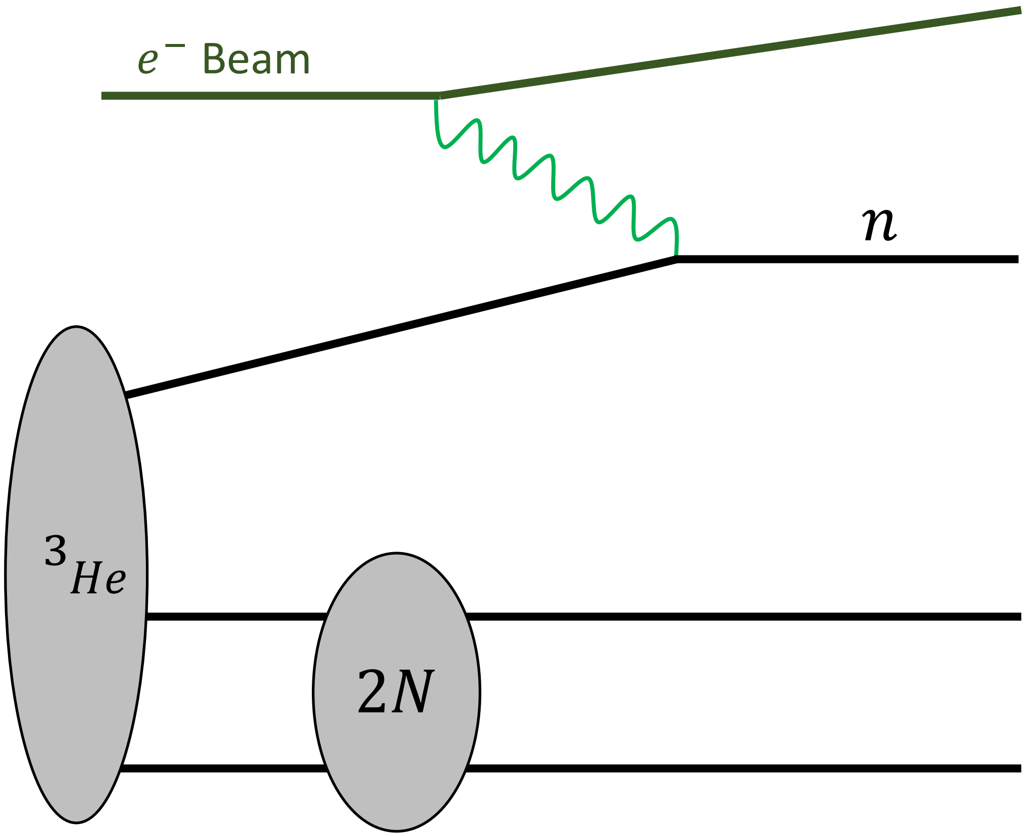

e^- Beam
$3N$

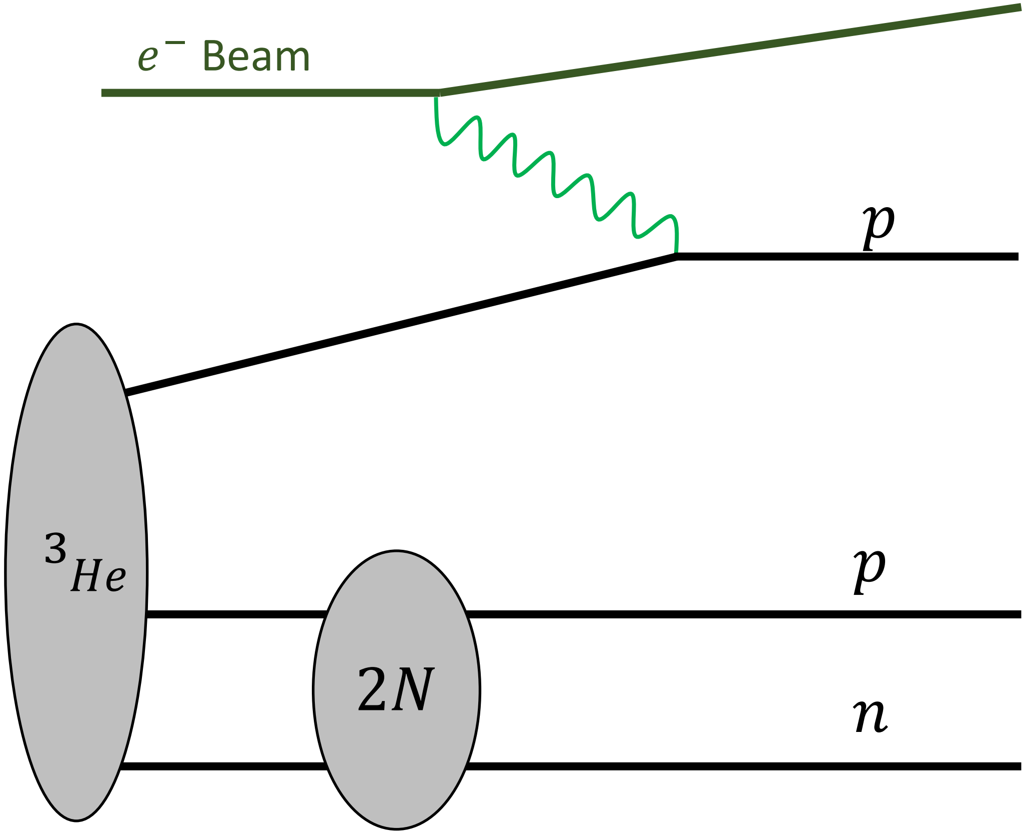


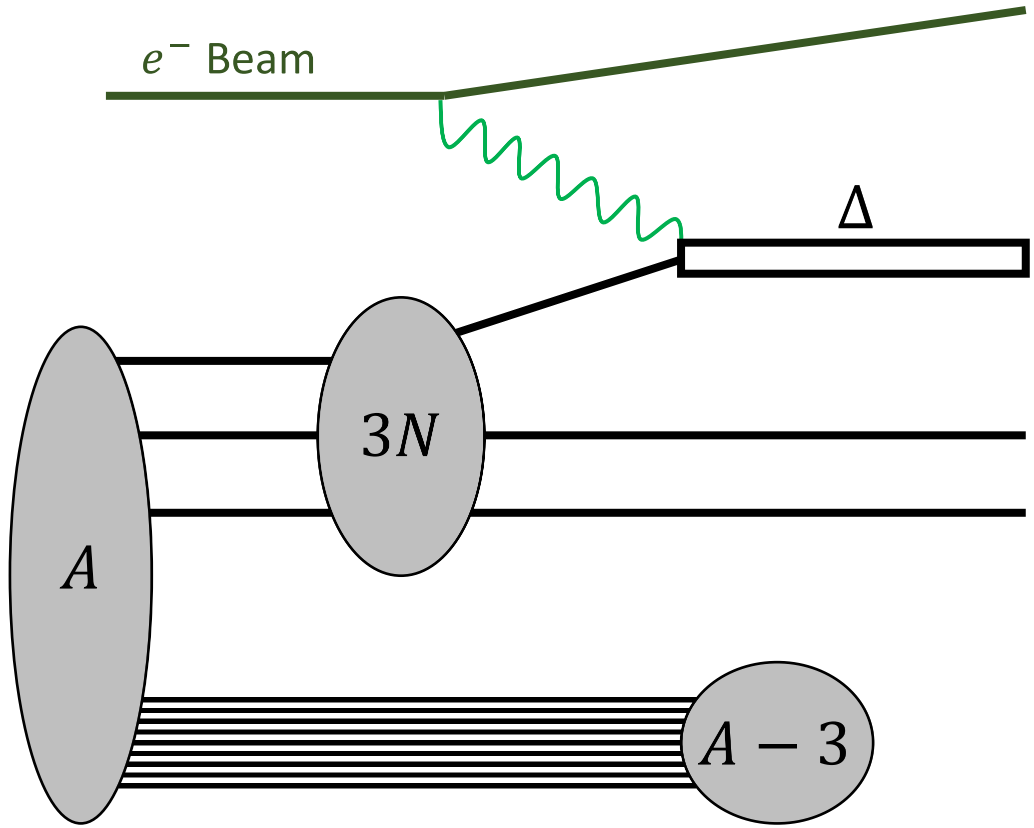
3×5 particles
$\underline{\ -4 \text{ conservation laws}}$
11 Parameters



e^- Beam
n
^4He
$3N$


e^- Beam
n
^3He
$2N$


e^- Beam
p
^3He
p
$2N$
n


e^- Beam
Δ
$3N$
A
$A-3$

- Introduction
  - 3N Interaction and motivation
  - CLAS12 and RGM is the highest SRC statistics experiment ever, it is currently our best bet for 3N SRC searches.
  - We need to develop a model to know where to search
  - We can look at “exotic” interactions or the “traditional” interactions
- The traditional Interaction for SRCs
  - Starting with the 2N Diagram we can move to 3N
  - We can also generalize the cross section
  - This results in an 11 dimensional cross section
  - There are 2 things that have changed, the kinematics and the 3N wavefunction (and we only have ppn right now (but it is also the best))
- Kinematics
  - Start by simplifying (remove cm and 2 Euler angles)
  - We remain with 4 variables (+1 to describe the shape)
  - 4 Configurations of interest
  - Show the Results. **Figure +**
- 3N Wavefunction
  - Variables that define shape and scale
  - Compare pp, pn, ppn over scale **Figure**
  - Show dalitz plot for given scale **Figure**
- First Checks of the Generator
  - Compare Kinematics xB vs. pmiss **Figure**
  - Compare to 3N wavefunction (Dalitz plot) **Figure**
  - Lead Nucleon Direction (Mention that the proton needs to be the lead because lead nucleon cuts are important) **Figure**
- Looking for 3N Observables
  - It will likely involve (e,e’ppn) and (e,e’pp)N
  - Show your observable **Figure**
  - Show Misak’s Pbservable **Figure I don’t have yet**
  - Mention FSI calculations would be helpful