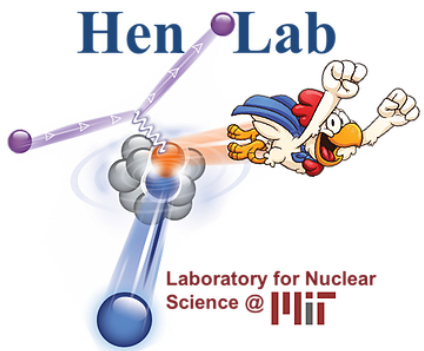
$(e, e'pp)/(e, e'p)$ ratios and the Generalized Contact Formalism

CLAS Nuclear Physics Working Group Meeting

Axel Schmidt

MIT

March 7, 2019



My controversial claim:

Our EG2 analysis shows the AV18 *NN*-interaction describing data well *up to relative momenta of 1 GeV/c.*

New EG2 Data Mining Analysis Note

EG2 DATA MINING ANALYSIS NOTE: Ratio of $A(e,e'pp)$ to $A(e,e'p)$ events in SRC kinematics

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I. INTRODUCTION

We present an analysis of $A(e,e'pp)$ and $A(e,e'p)$ events in kinematics dominated by the break-up of short-range correlated (SRC) pairs. The data analysis uses the same 5 GeV EG2 events as selected in a previously approved CLAS analysis [1] with the only addition of previously approved fiducial cuts [2] to the protons and removal of detector region with low efficiency / acceptance. We compare the measured event yields with those calculated using a new Monte Carlo event generator and a theoretical cross-section model that is detailed in Ref. [3]. While the theory model is currently only available for ^{12}C, we present the measured $(e,e'pp)$ $/(e,e'p)$ ratios and data distributions for all measured nuclei.

II. REVIEW OF PREVIOUS ANALYSIS

We begin this analysis by using the same ROOT trees as the previously approved analysis "Probing pp-SRC in ^{12}C, ^{27}Al, ^{56}Fe, and ^{208}Pb using the $A(e,e'p)$ and $A(e,e'pp)$ Reactions" [1] and published in Refs. [4–6].

New EG2 Data Mining Analysis Note

1. Previous EG2 analyses selected SRC break-up events.

2. We have a new formalism, event generator to simulate SRC break-up events.
   - Key input: 2-body wave function from *NN*-interaction

3. By comparing data to our generator, we can test short-distance *NN*-interaction.

In my talk today:

1. Short-Range Correlations
2. Generalized Contact Formalism
3. Data-Theory comparisons
4. Results

In my talk today:

1. **Short-Range Correlations**
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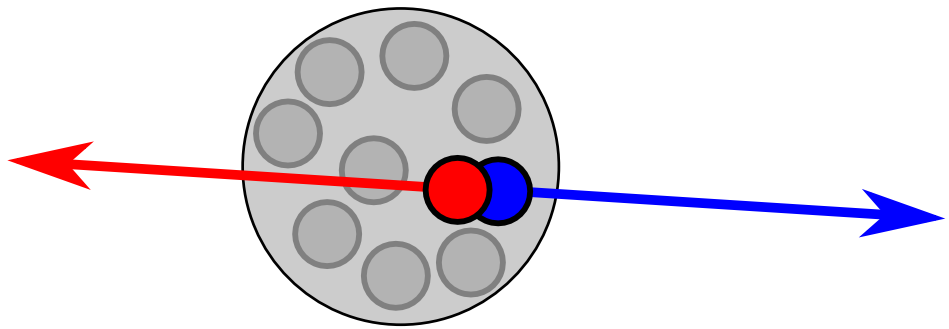
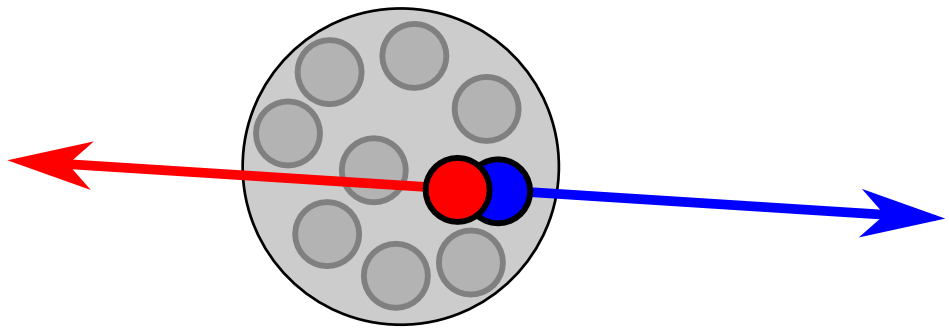
Short-range correlations are universal in nuclei.

- Pair with close-proximity high relative momentum



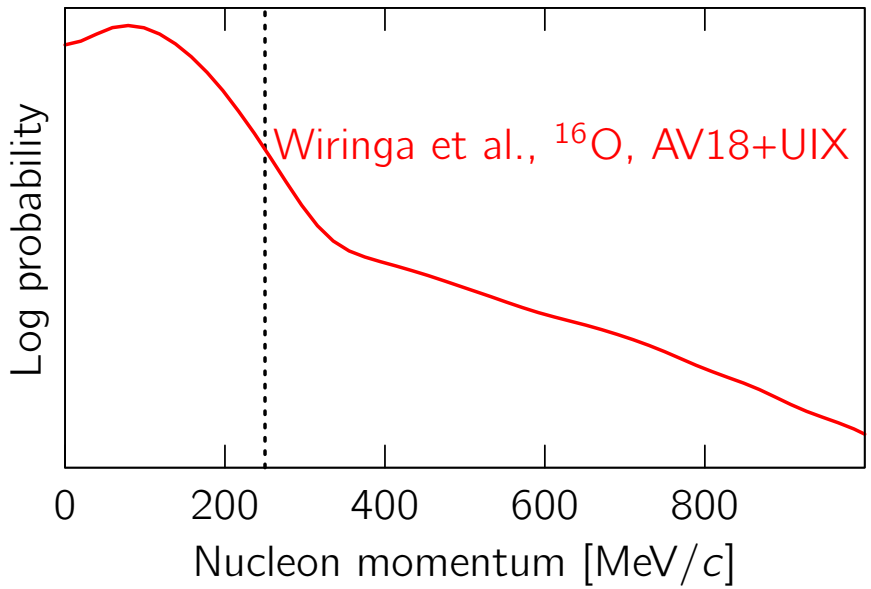
Short-range correlations are universal in nuclei.

- Pair with close-proximity high relative momentum
- Universal in nuclei: $\approx 20\%$ of nucleons



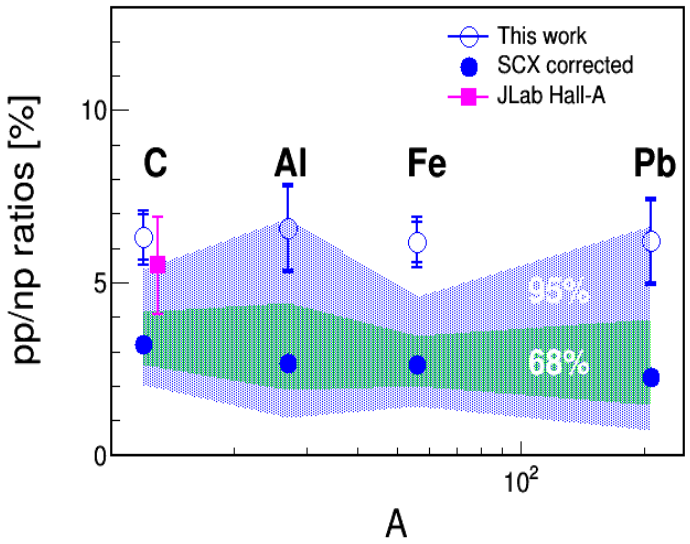
Short-range correlations are universal in nuclei.

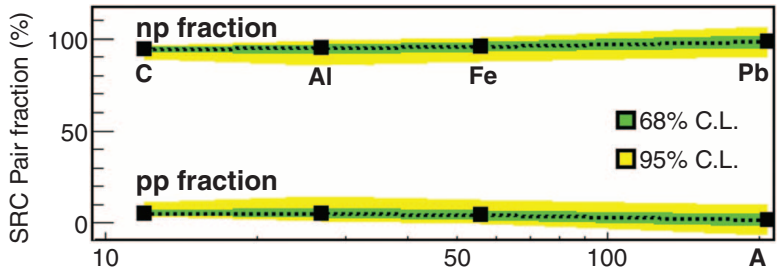
- Pair with close-proximity high relative momentum
- Universal in nuclei: $\approx 20\%$ of nucleons
- Lead to high-momentum tails

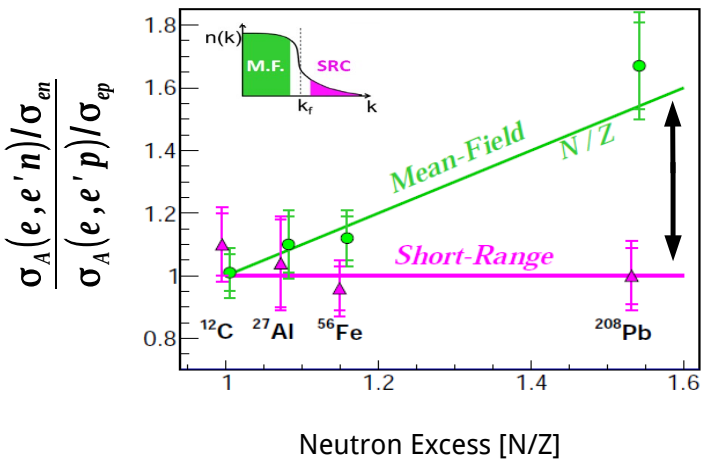


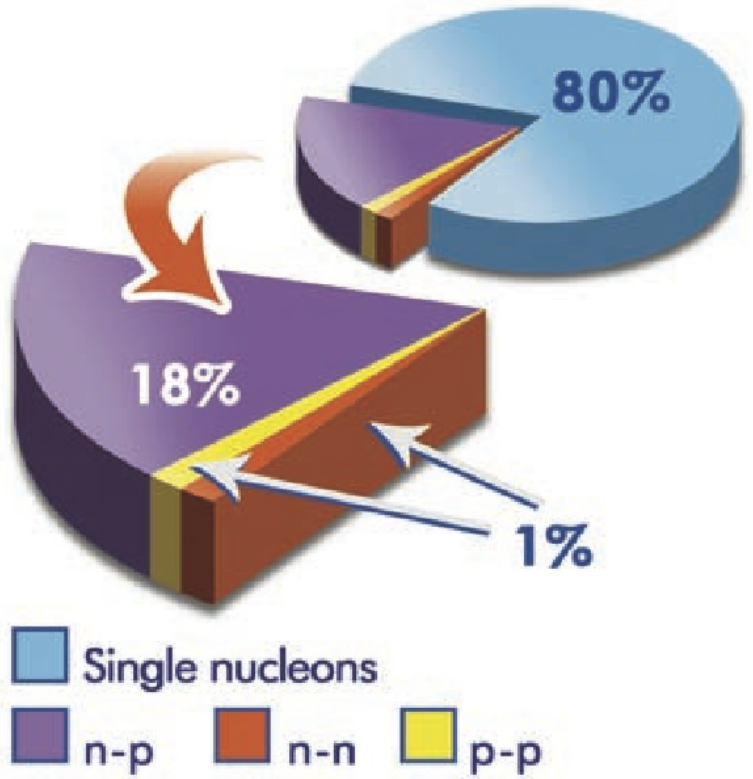
SRC pairs are predominantly neutron-proton.

Evidence has come from EG2 data mining!

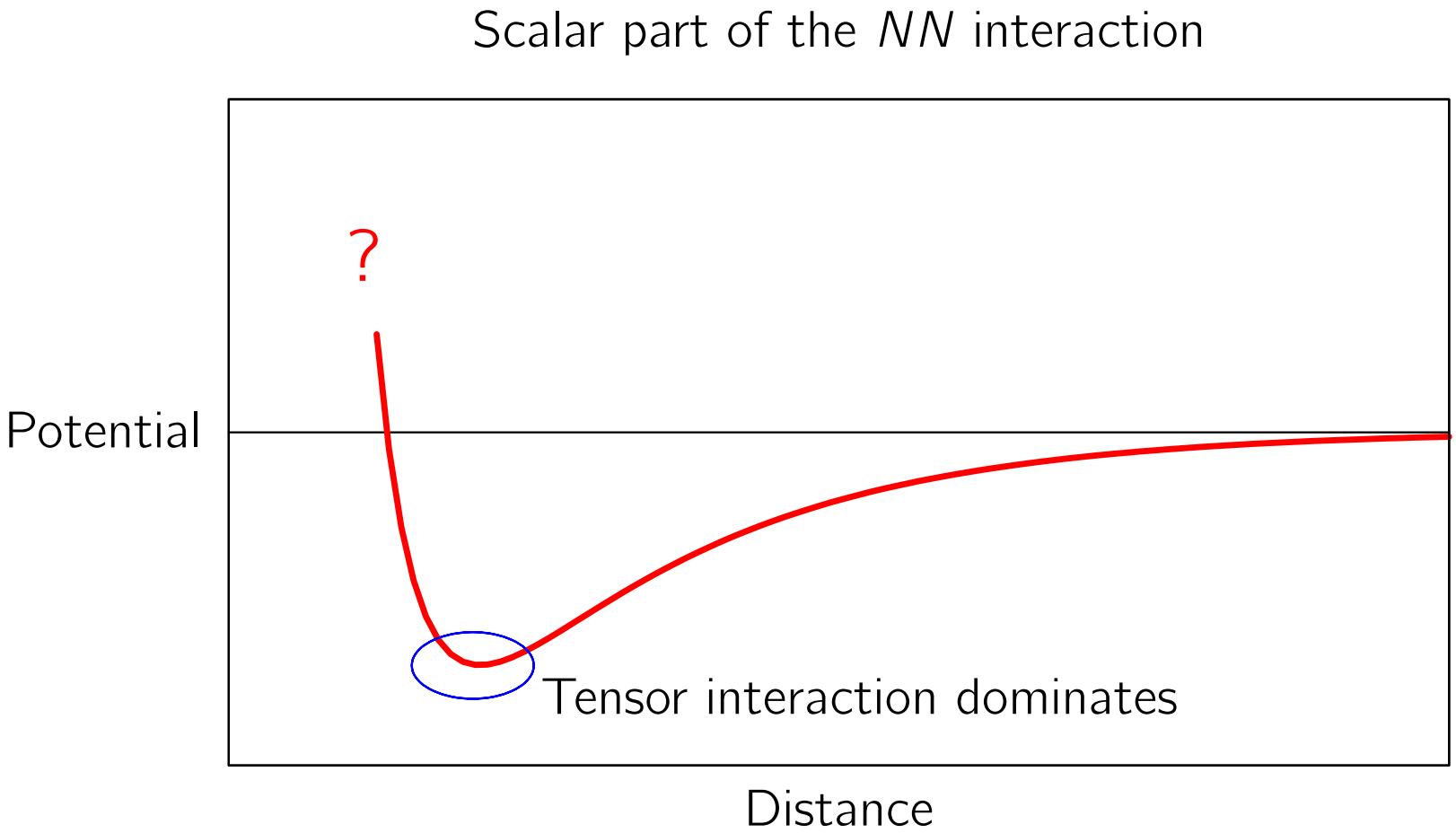




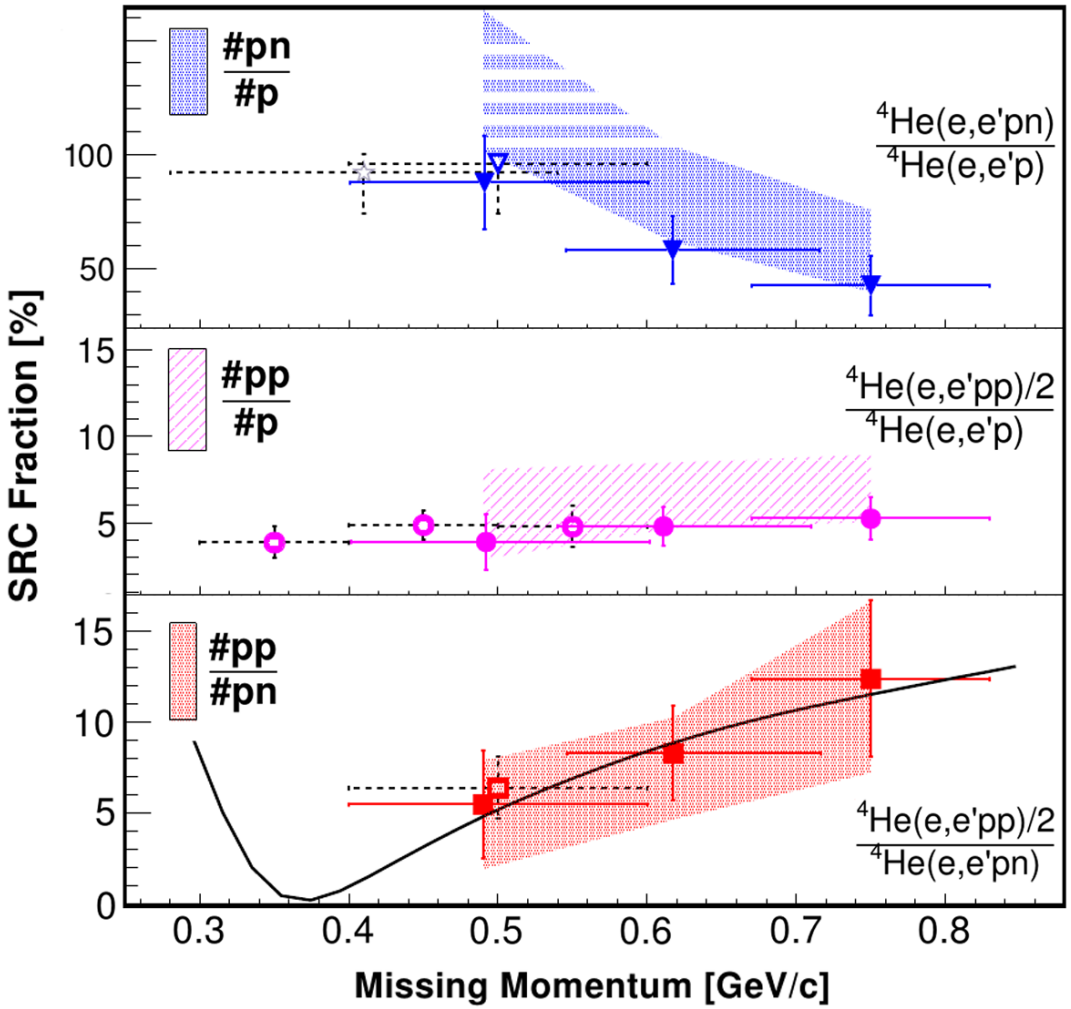




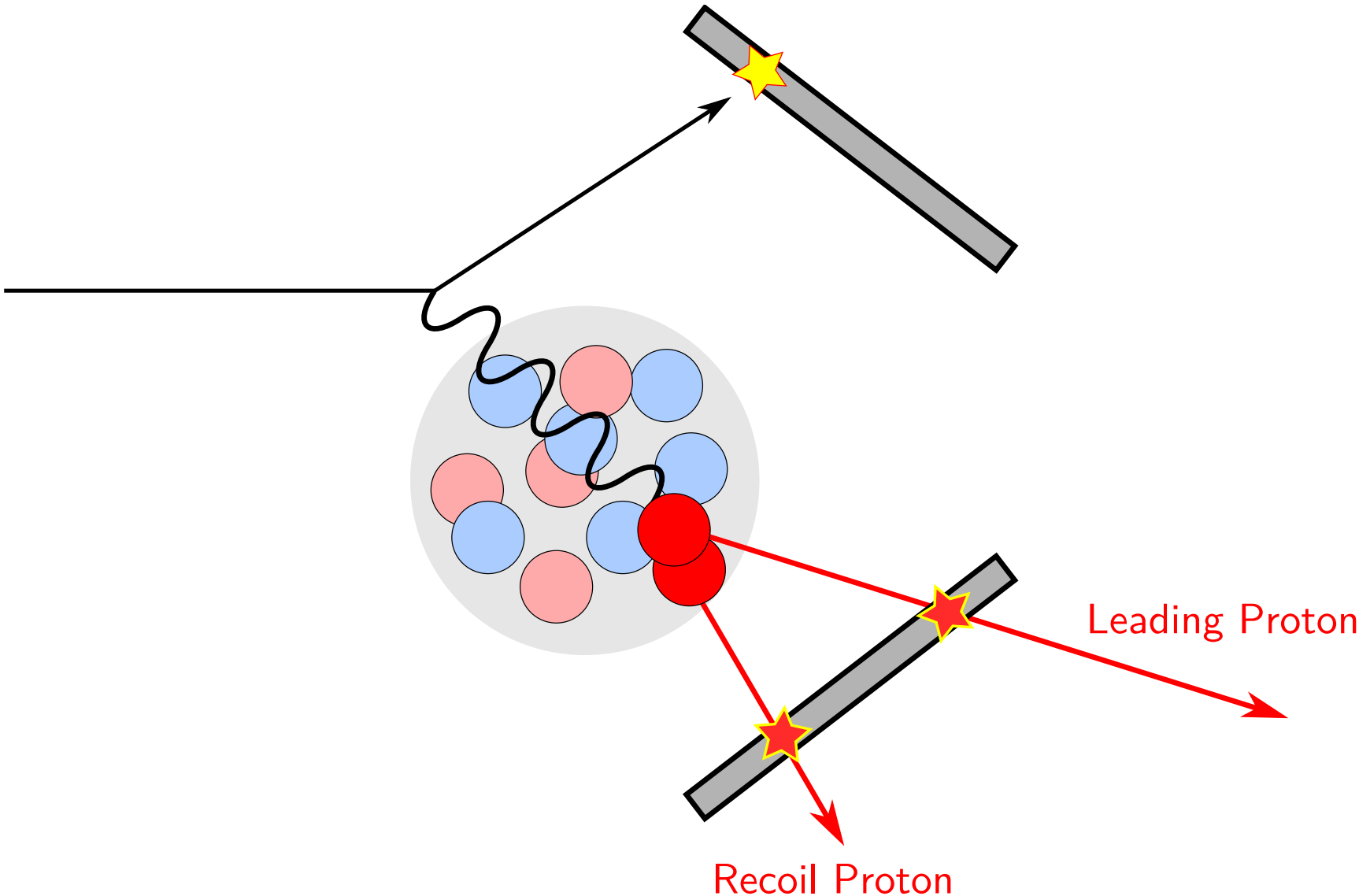
np-dominance arises from the tensor force.



How does *np*-dominance evolve with momentum?



$(e, e'pp)/(e, e'p)$ measures np-dominance.



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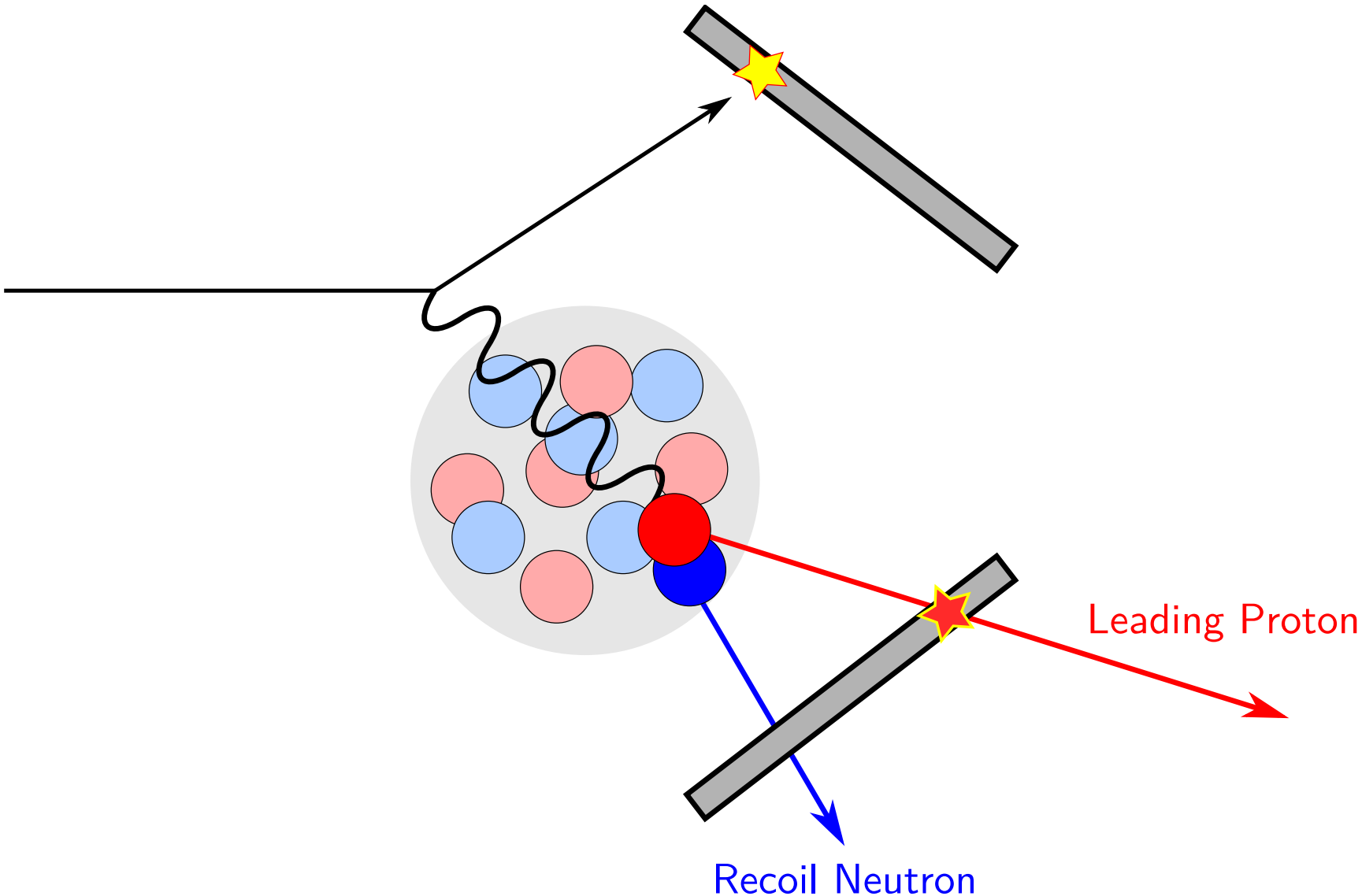


Previous EG2 analyses have identified $(e, e'pp)$ and $(e, e'p)$ events in SRC break-up kinematics.

- O. Hen et al., "Probing pp-SRC in ^{12}C, ^{27}Al, ^{56}Fe, and ^{208}Pb using the $A(e, e'p)$ and $A(e, e'pp)$ Reactions"
  Published in **Science 346 pp 614–617 (2014)**

- E. O. Cohen et al., "Extracting the center-of-mass momentum distribution of pp-SRC pairs in ^{12}C, ^{27}Al, ^{56}Fe, and ^{208}Pb" (2018)
  Published in **Phys. Rev. Lett. 121 092501 (2018)**

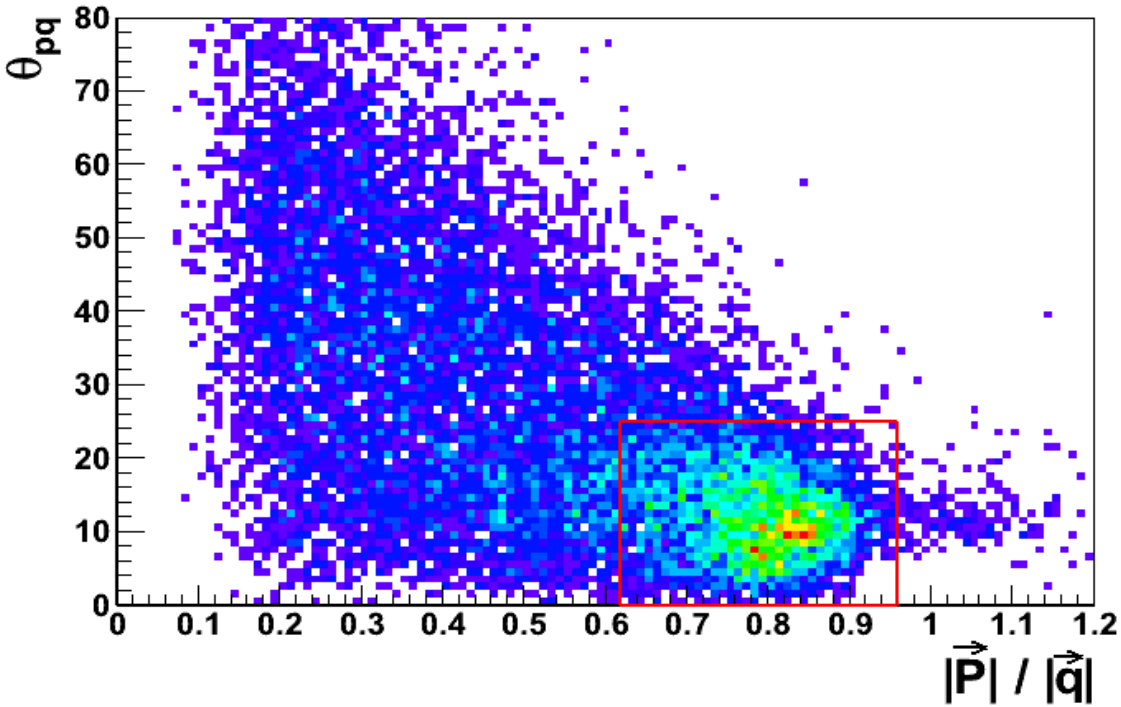
Our analysis begins with these ROOT trees.

$A(e, e'p)$ event selection

- $0.4 < p_{\text{miss}} < 1.0\ \text{GeV}/c$
- $x_B > 1.2$

$A(e, e'p)$ event selection

- $0.4 < p_{\text{miss}} < 1.0$ GeV/c
- $x_B > 1.2$
- $0.62 < |\vec{p}_{\text{lead}}|/|\vec{q}| < 0.96$
- $\theta_{pq} < 25^\circ$



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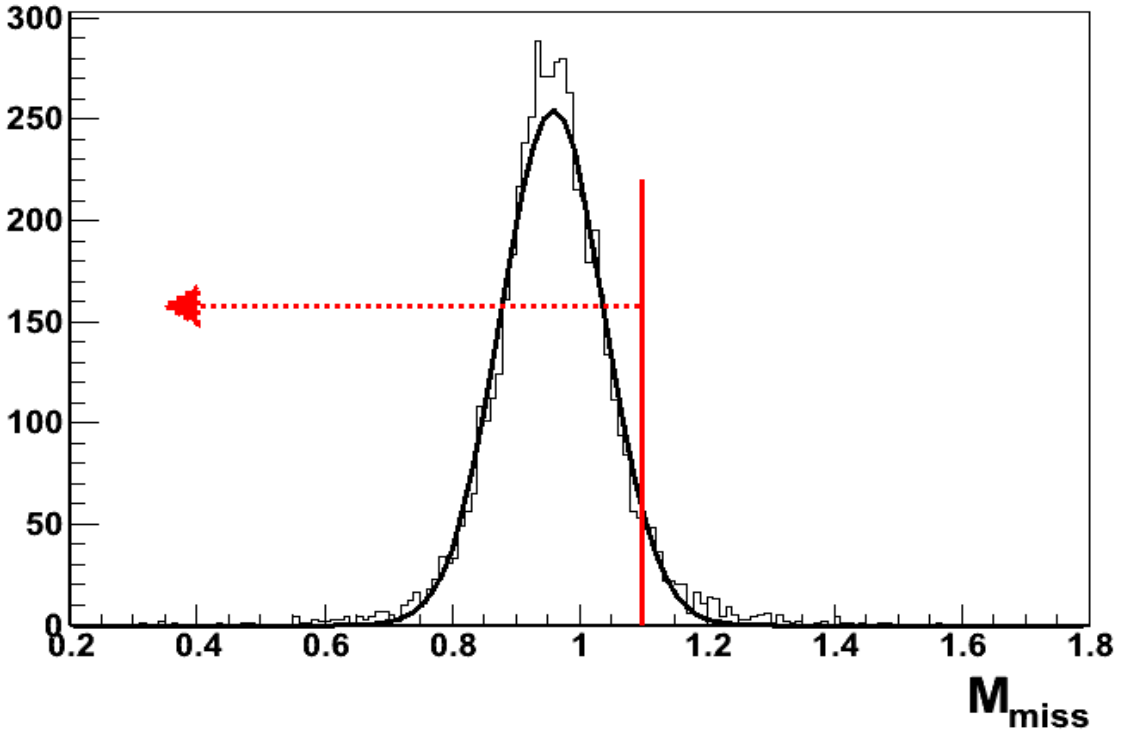
- $m_{\text{miss}} < 1.1$ GeV/c^2



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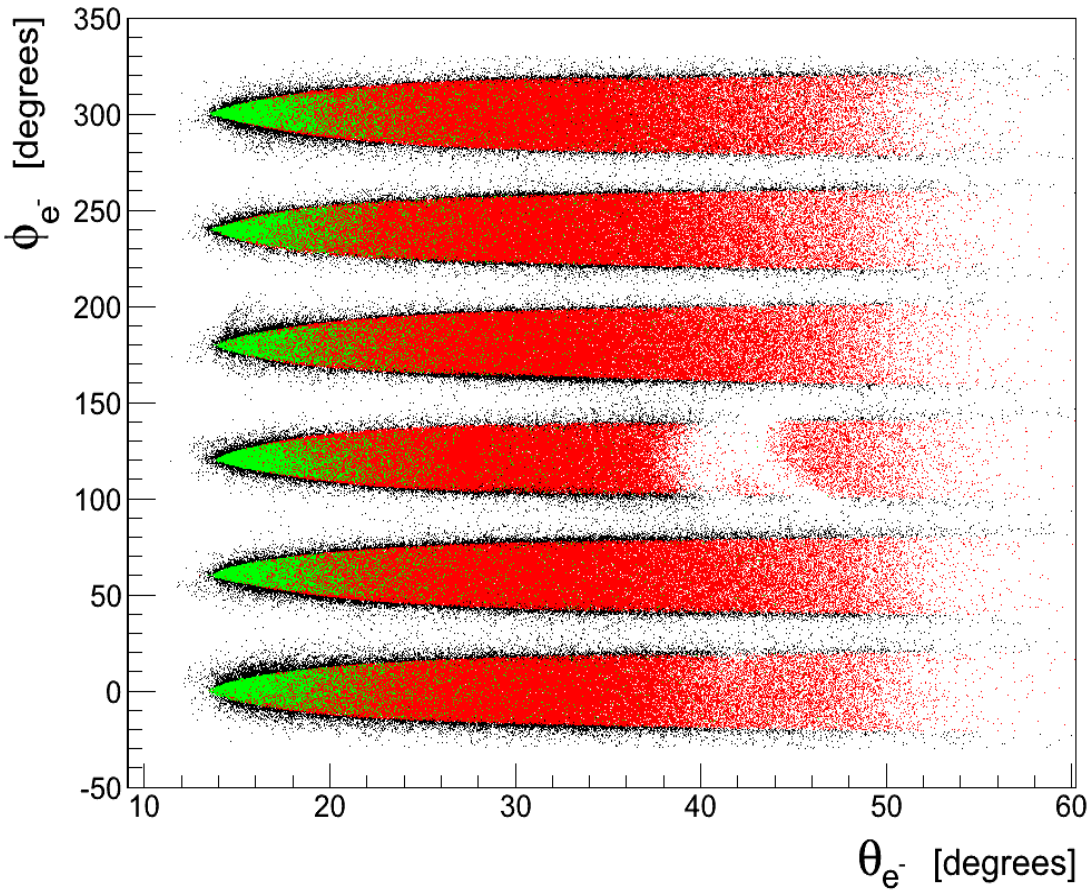
- e^- fiducial cuts



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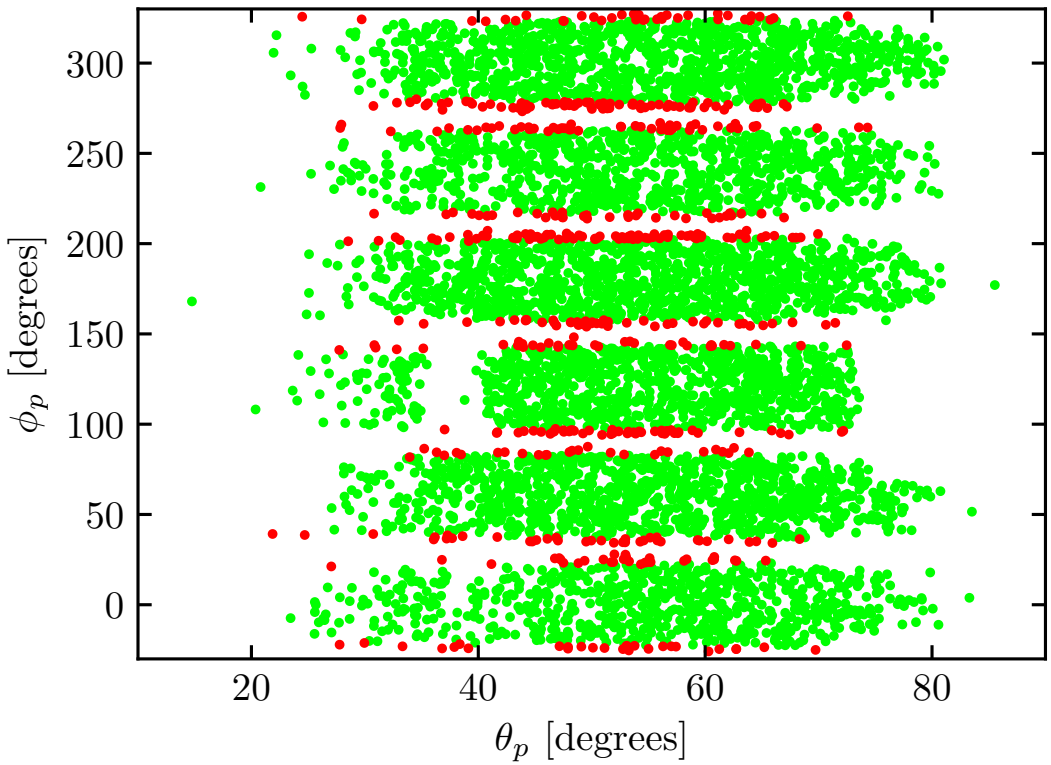
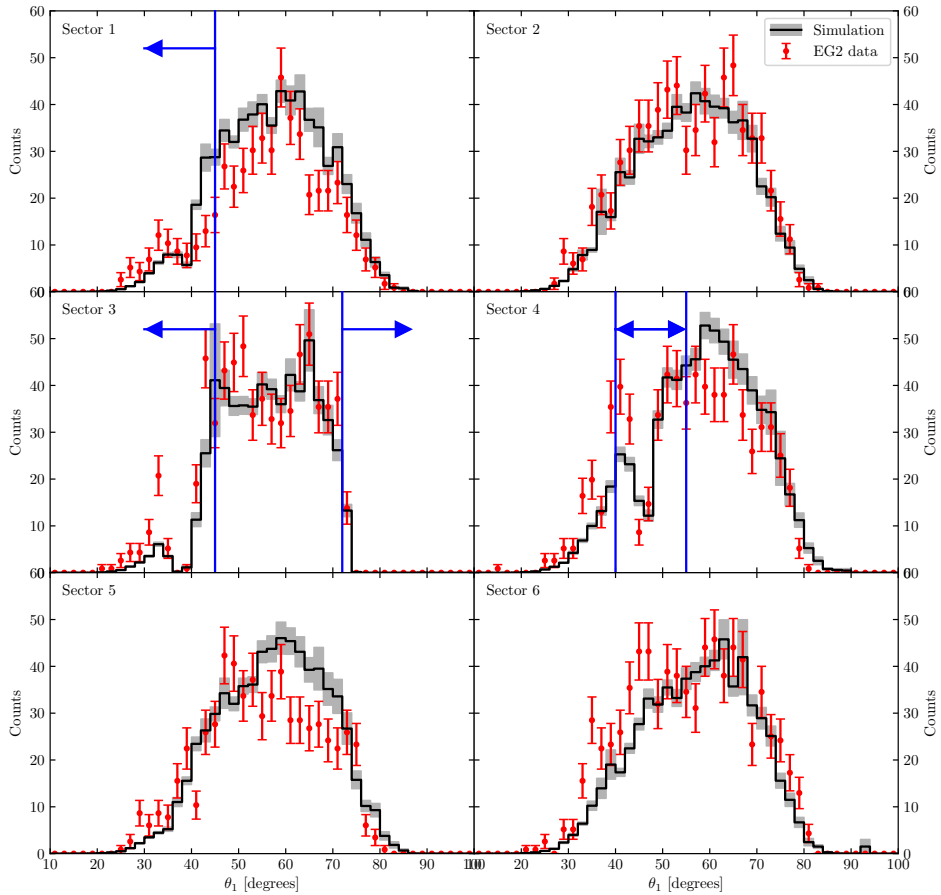
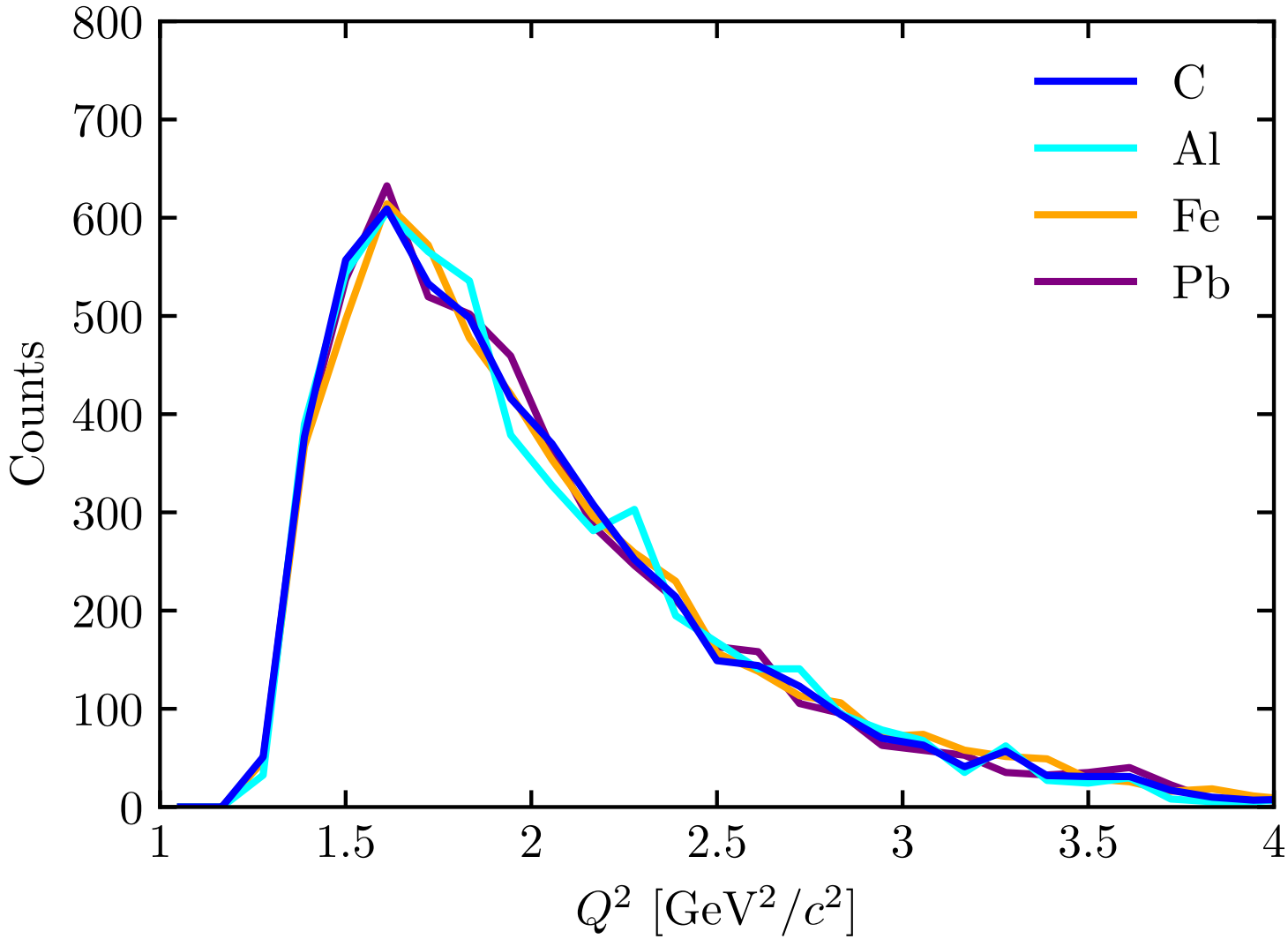
- $m_{\text{miss}} < 1.1$ GeV/c^2
- e^- fiducial cuts
- p fiducial cuts



We also make fiducial cuts around dead areas in three sectors.



Distributions of $A(e, e'p)$ events



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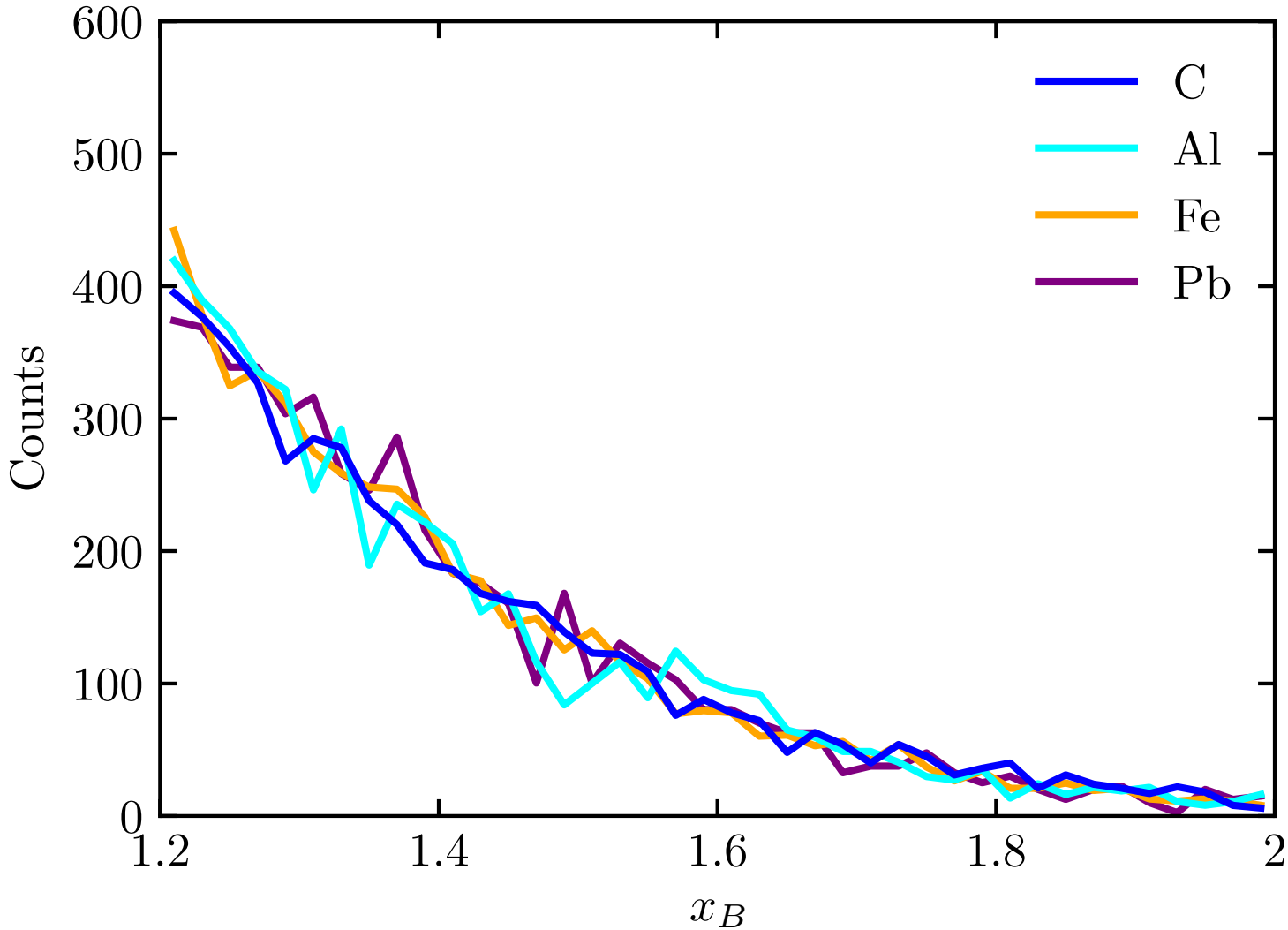

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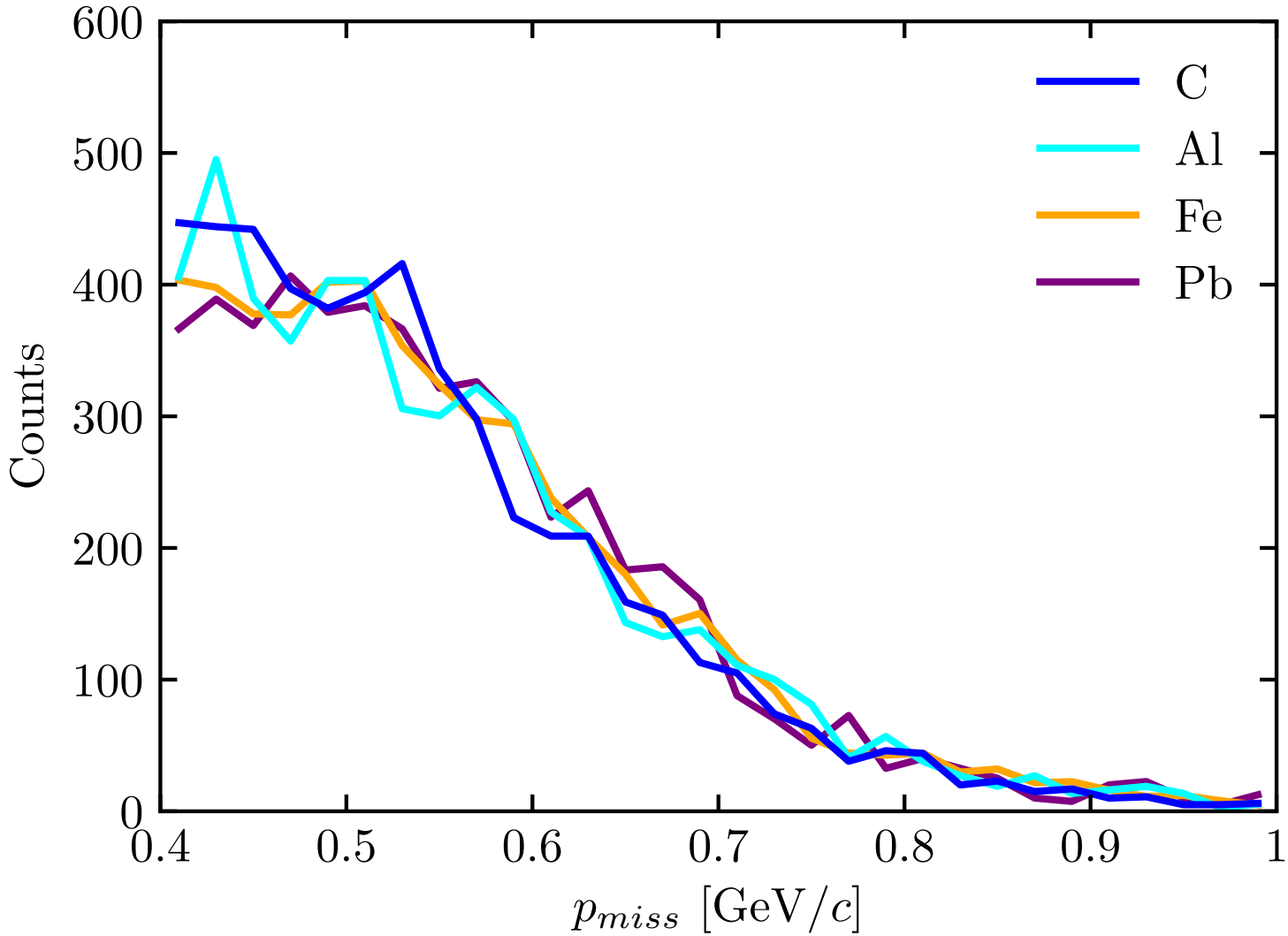

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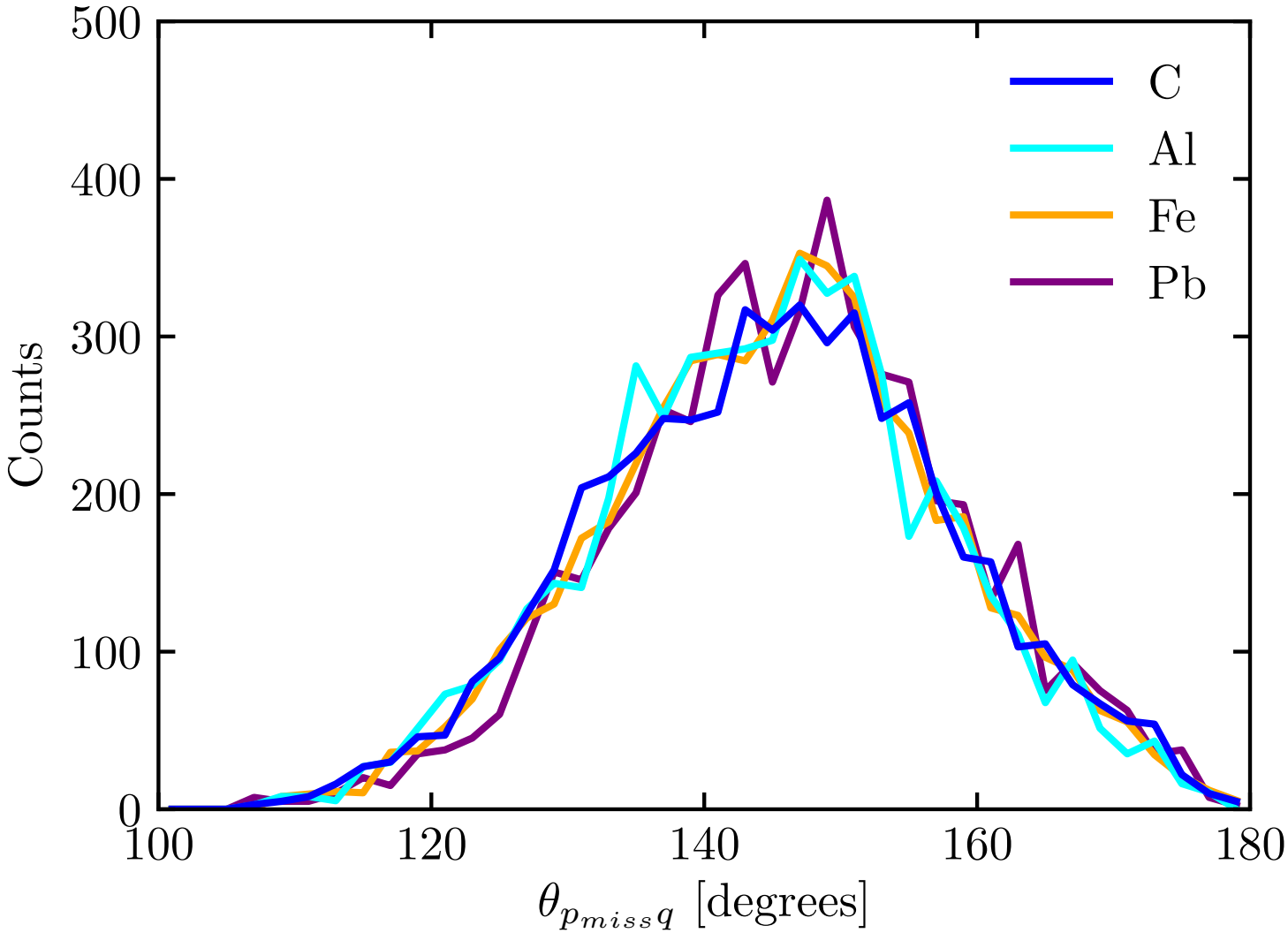
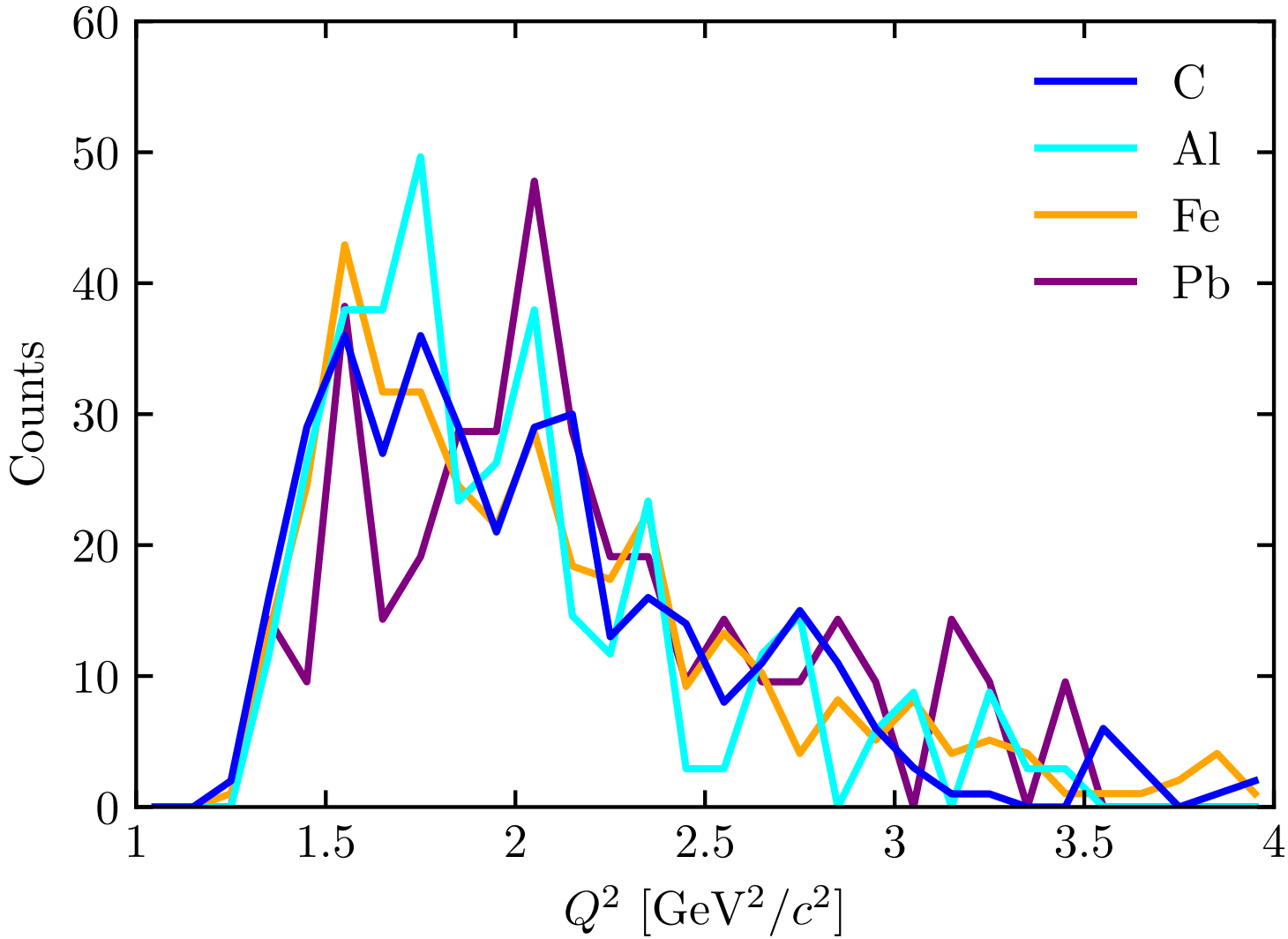


$A(e, e'pp)$ event selection

- Event must pass $A(e, e'p)$ cuts, and have a second proton
- Second proton must pass fiducial cuts
- $p_{\text{rec}} > 0.35$ GeV$/c$

Distributions of $A(e, e'pp)$ events



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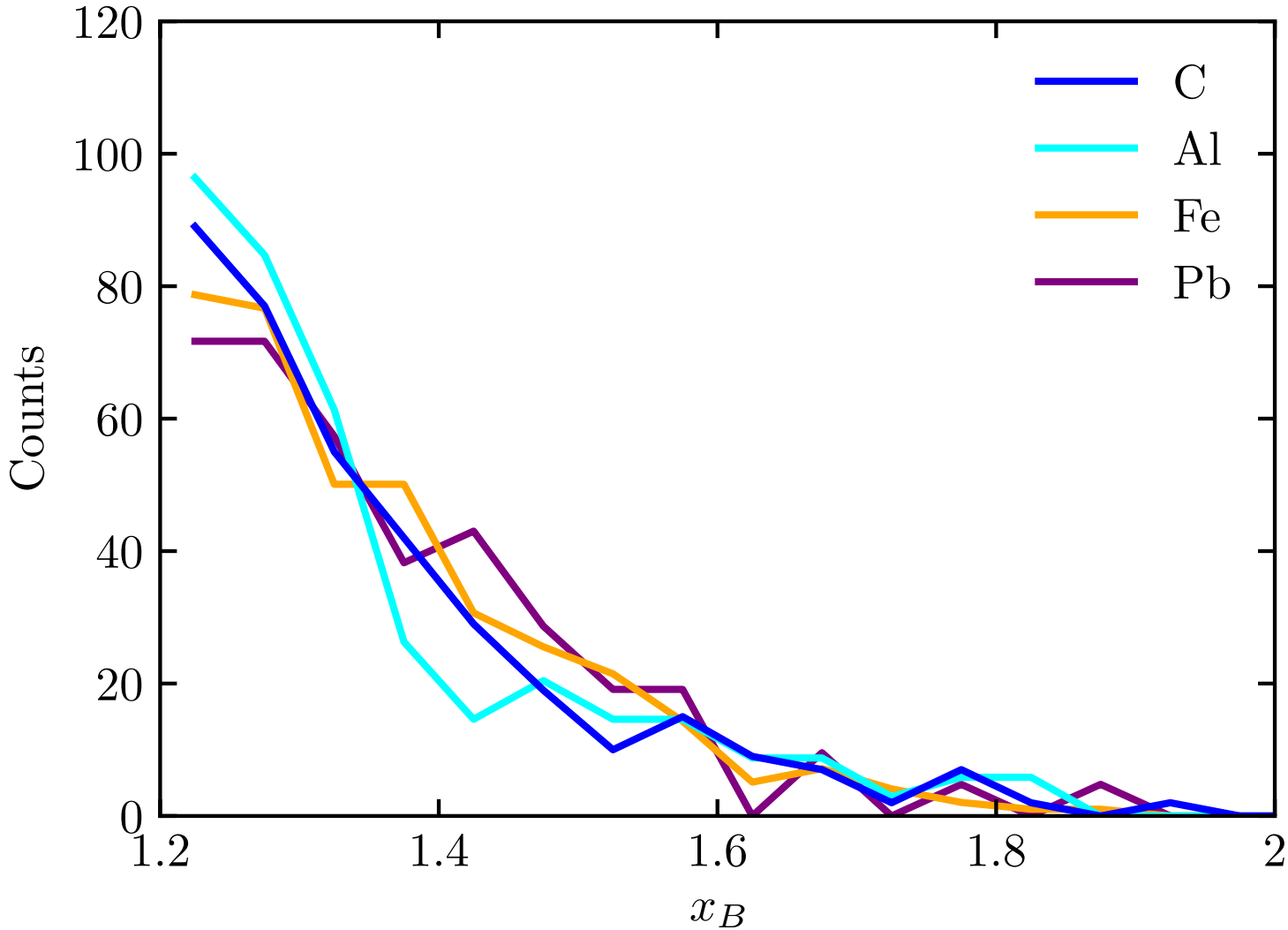

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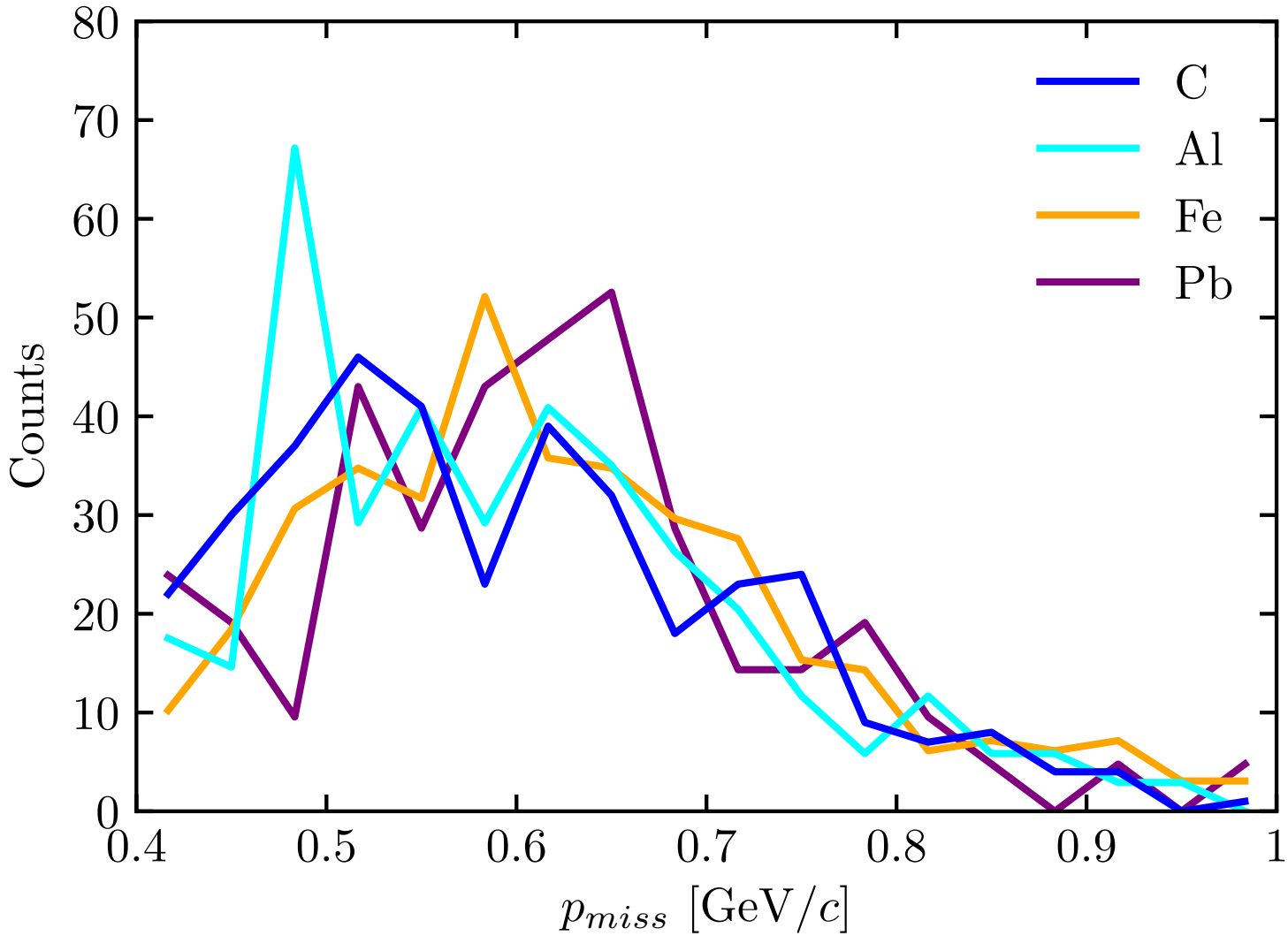
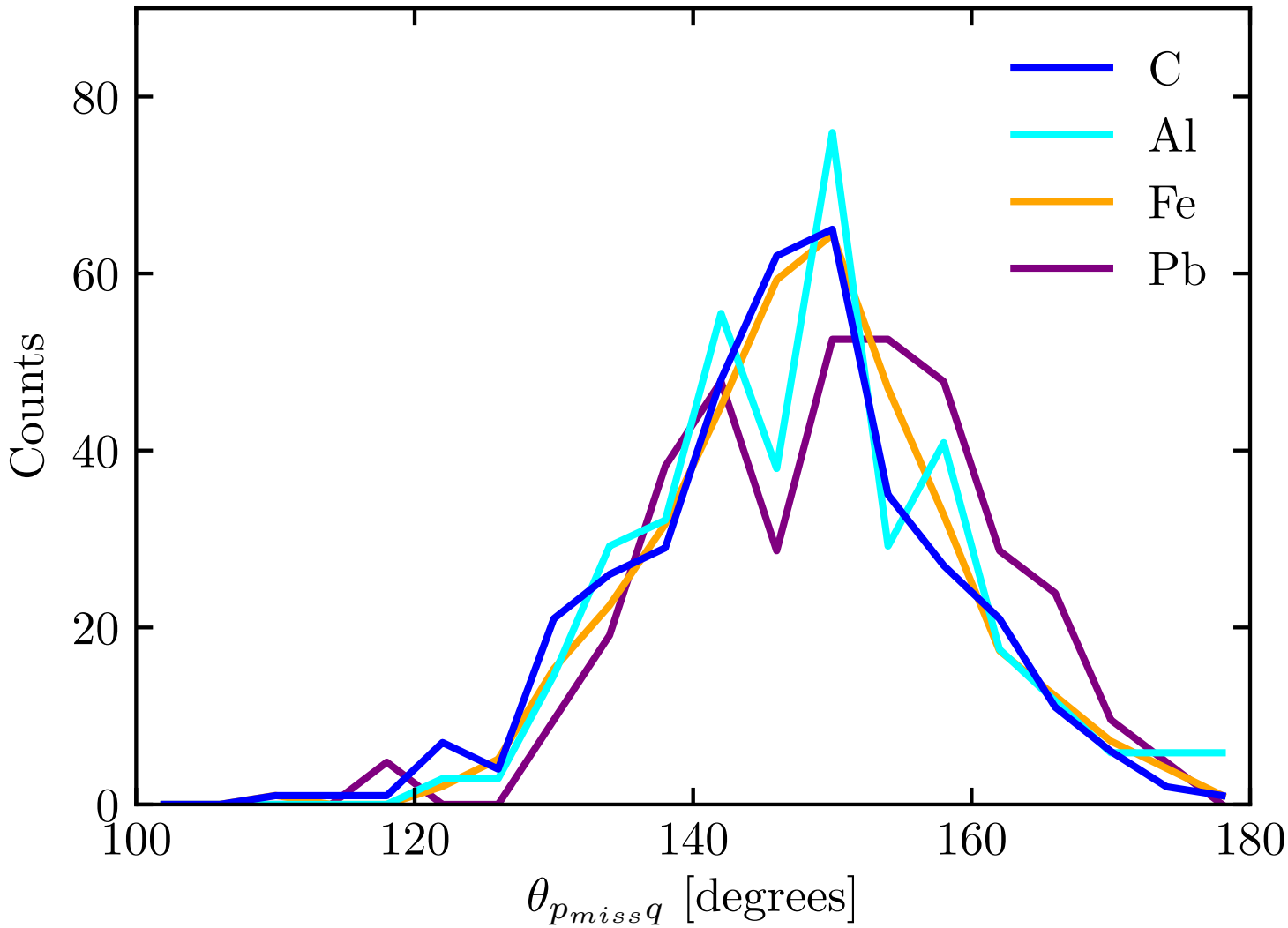
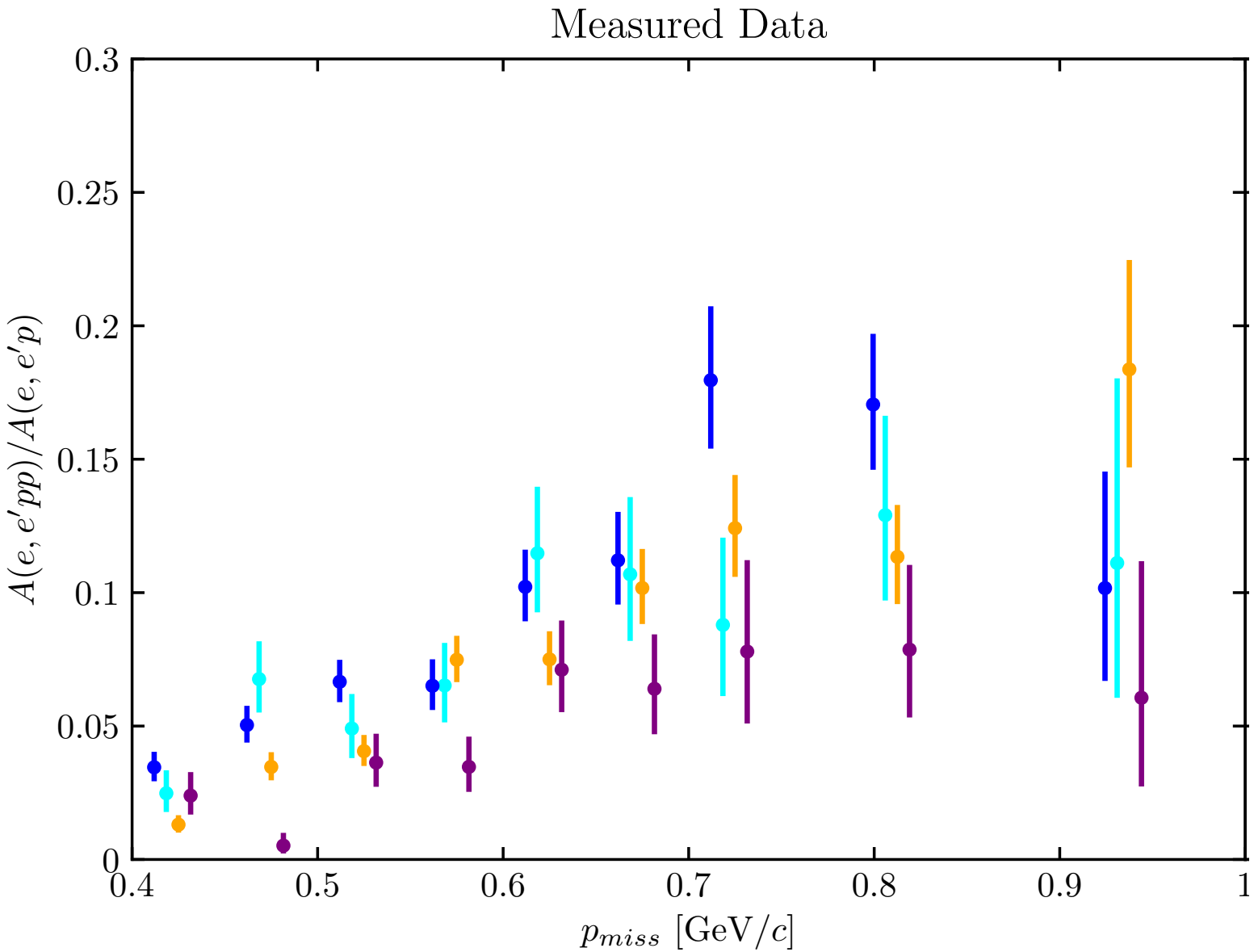


Distributions of $A(e, e'pp)$ events



$A(e, e'pp)/A(e, e'p)$ ratio



In my talk today:

1. Short-Range Correlations
2. **Generalized Contact Formalism**
3. Data-Theory comparisons
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Generalized Contact Formalism

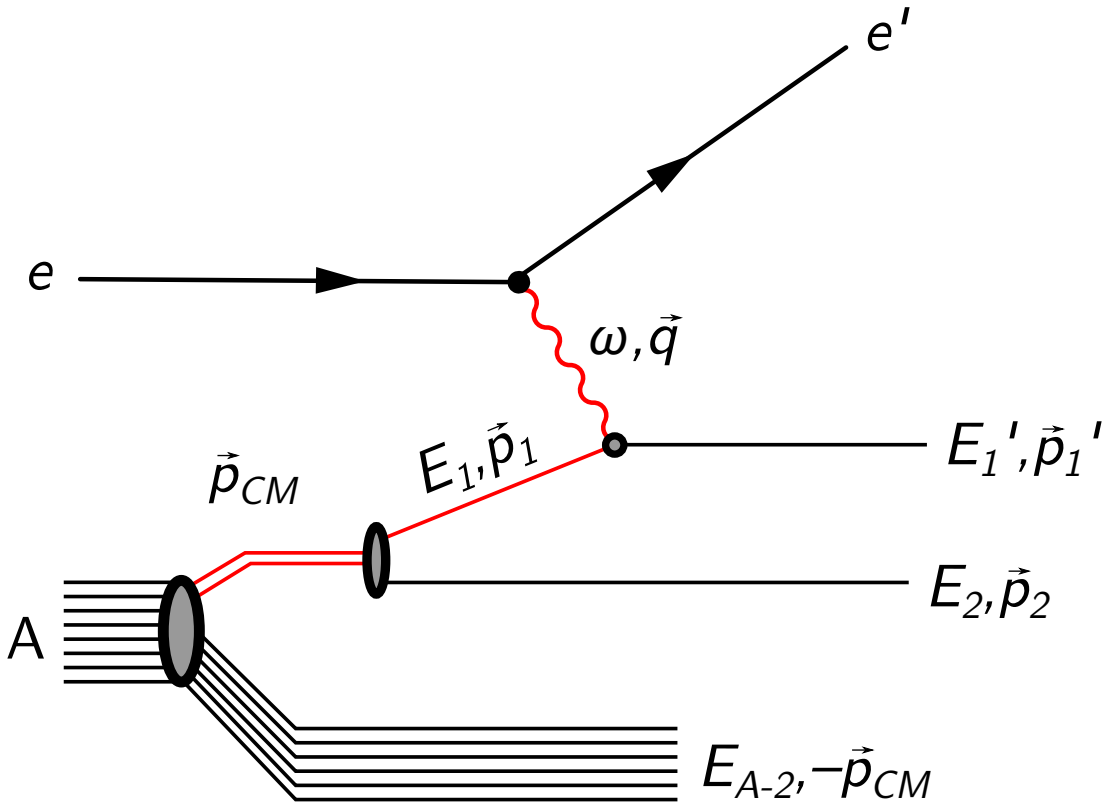
$$\Psi(k_{ij} \gg k_F) \longrightarrow \tilde{\varphi}(k_{ij}) \times A(K_{ij}, \vec{k}_{m \neq i \neq j})$$

$$\text{For large } k: \qquad \rho_2(k) = \sum_{\alpha} C_\alpha |\tilde{\varphi}_\alpha(k)|^2$$

$\tilde{\varphi}(k)$ is a 2-body solution to the Schrödinger eq. for an NN interaction.

See: R. Weiss et al., PLB 780 (2018) 211–215 and R. Weiss et al., arXiv:1806.10217

GCF Event Generator



$$d\sigma \sim \sigma_{eN} \cdot n(\vec{p}_{CM}) \cdot \sum_{\alpha} C_{\alpha} |\tilde{\varphi}_{\alpha}(k)|^2$$

Additional effects in the generator:

- Radiative effects (via peaking approx.)
- Transparency
- Single-charge exchange ($p \leftrightarrow n$)

$$
\begin{aligned}
Y^{Exp}_{A(e,e'pp)} = & Y^{GCF}_{A(e,e'pp)} \cdot P^{pp}_{A} \cdot T_{A,pp} + \\
& Y^{GCF}_{A(e,e'np)} \cdot p^{[n]p}_{A} \cdot T^{*}_{A} + \\
& Y^{GCF}_{A(e,e'pn)} \cdot P^{p[n]}_{A} \cdot T^{*}_{A},
\end{aligned}
\tag{1}
$$

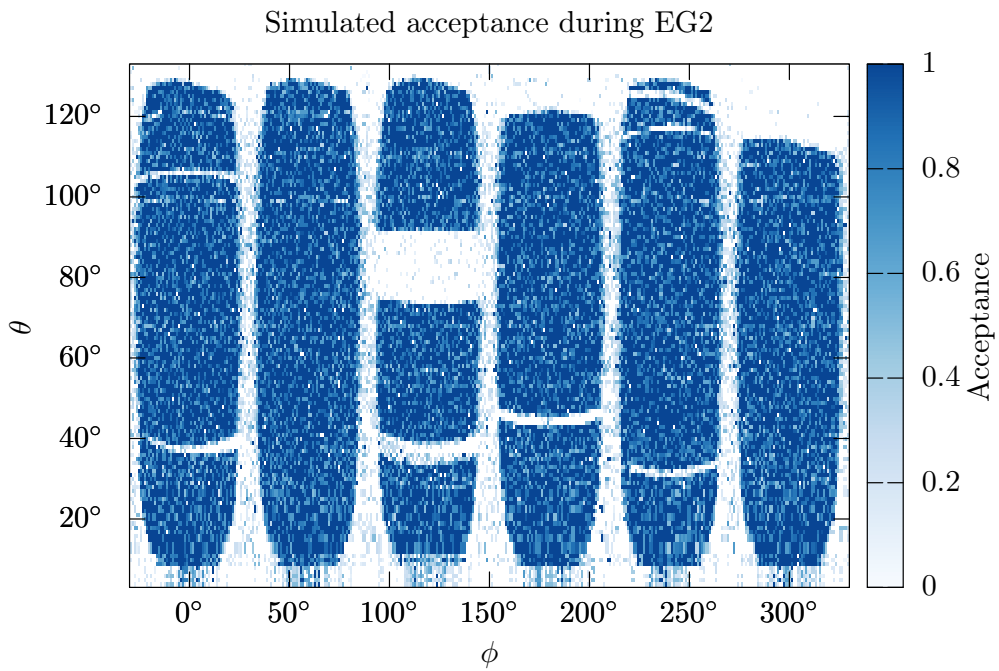
$$
\begin{aligned}
Y^{Exp}_{A(e,e'p)} = & (Y^{GCF}_{A(e,e'pp)} + Y^{GCF}_{A(e,e'pn)}) \cdot P^{p}_{A} \cdot T_{A,p} + \\
& Y^{GCF}_{A(e,e'np)} \cdot P^{[n]p}_{A} \cdot T^{*}_{A} + \\
& Y^{GCF}_{A(e,e'nn)} \cdot P^{[n]n}_{A} \cdot T^{*}_{A},
\end{aligned}
$$

In my talk today:

1. Short-Range Correlations
2. Generalized Contact Formalism
3. **Data-Theory comparisons**
4. Results

Data-Theory comparison

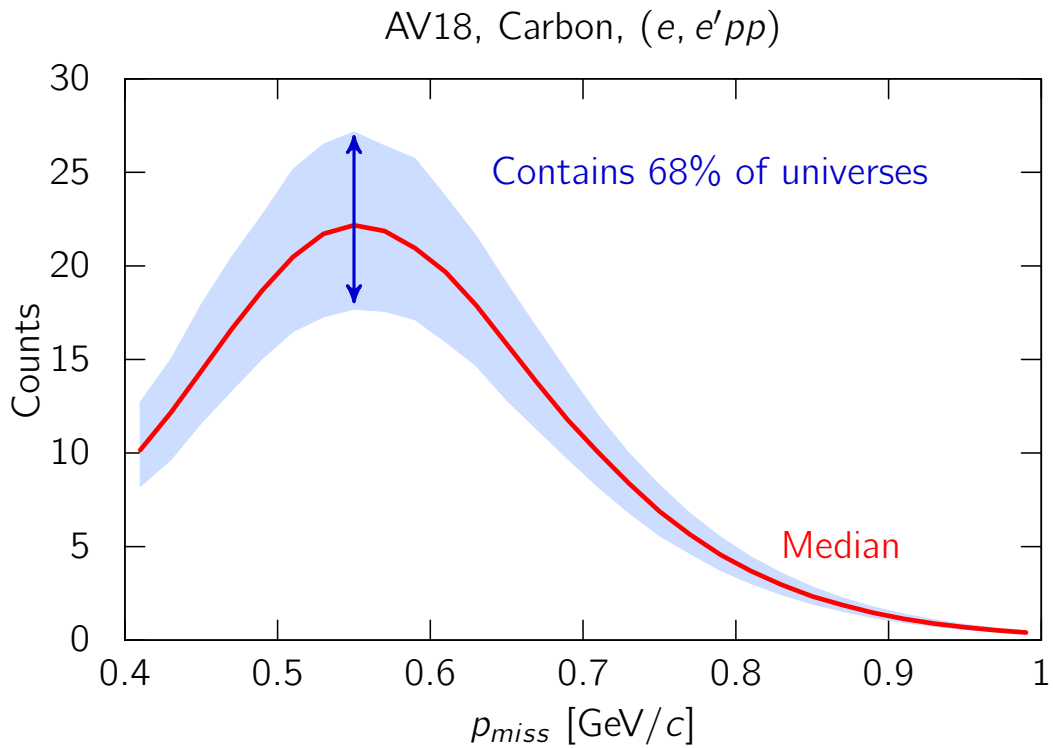
1. Generate MC events
2. Acceptance using fast MC
3. Smear e^- and p momenta
4. Event selection cuts
5. Fiducial cuts



Systematic Uncertainties

Simulate many universes with randomly varied model parameters:

- Pair center-of-mass motion
- Nuclear contacts
- SCX probabilites
- Transparency factors
- Residual excitation energy
- Relative momentum cut-off
- e^- momentum resolution
- p momentum resolution



In my talk today:

1. Short-Range Correlations
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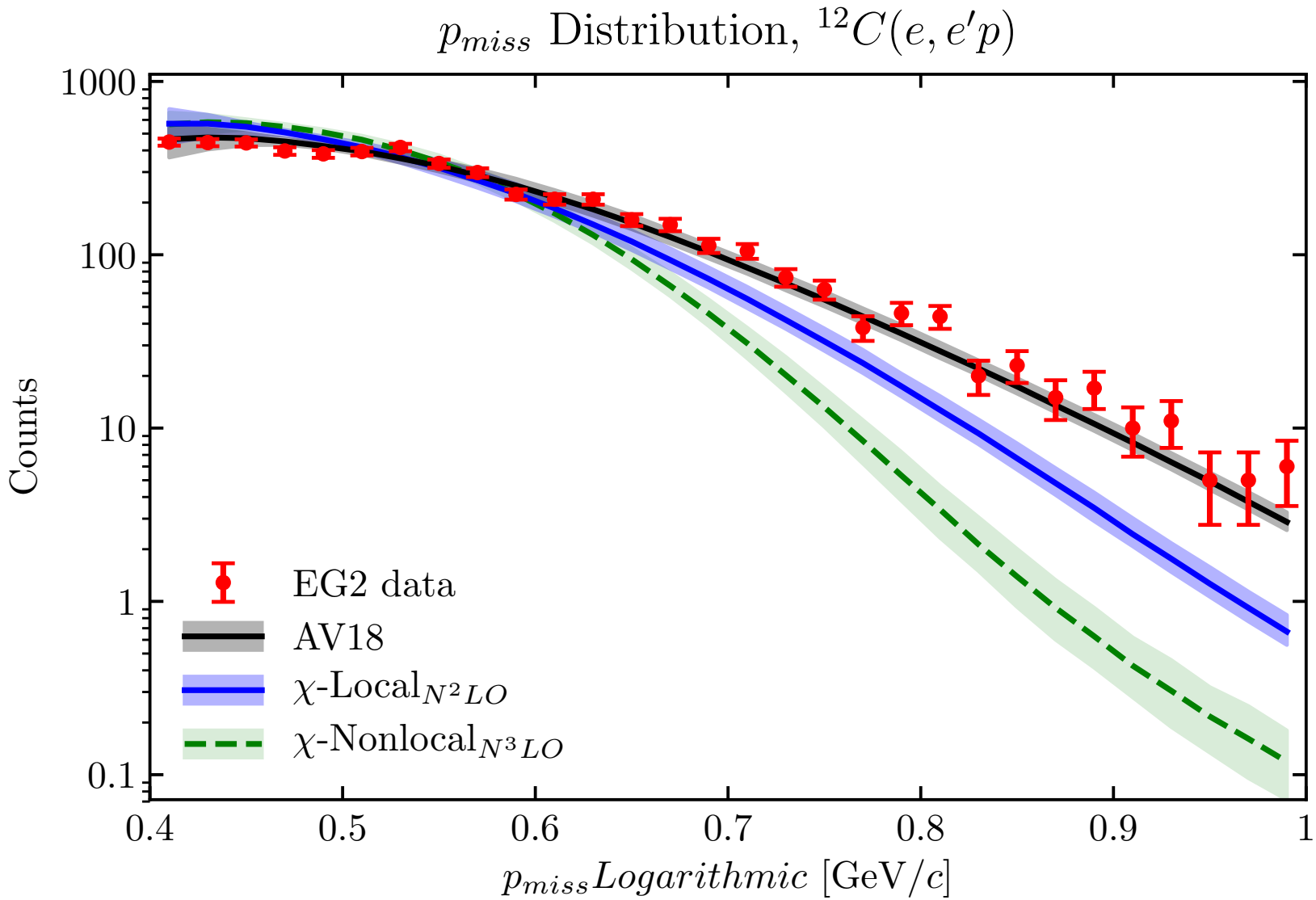
4. **Results**

For the results I'm showing:

- Carbon only
  - Only target for which we have reliable contact values
- Three different NN interactions
  - AV18
  - Local χPT (cut-off: 1 fm)
  - Non-local χPT (cut-off: 600 MeV/c)
- Theory curves are normalized to data $(e, e'p)$

Missing Momentum Distributions



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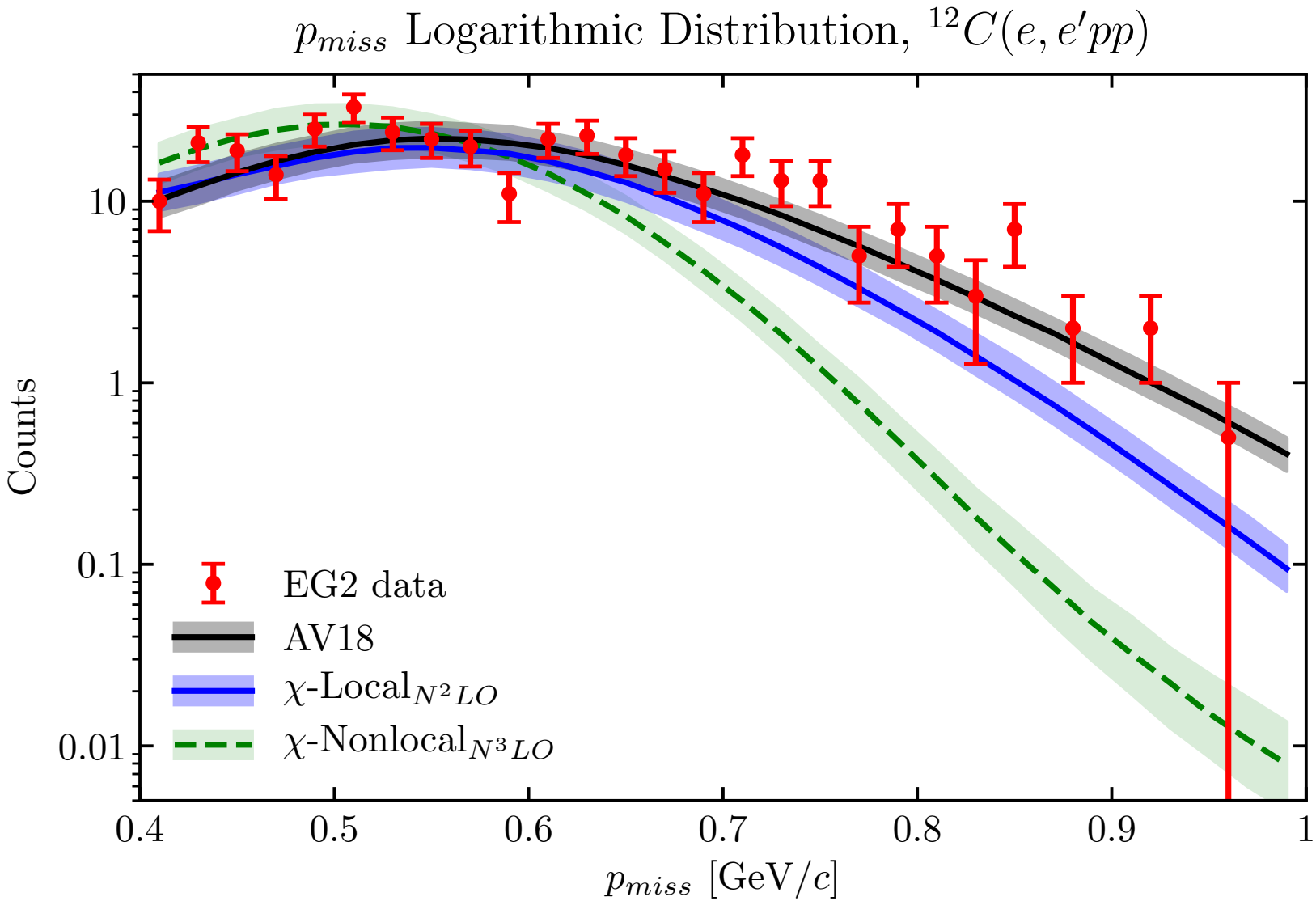
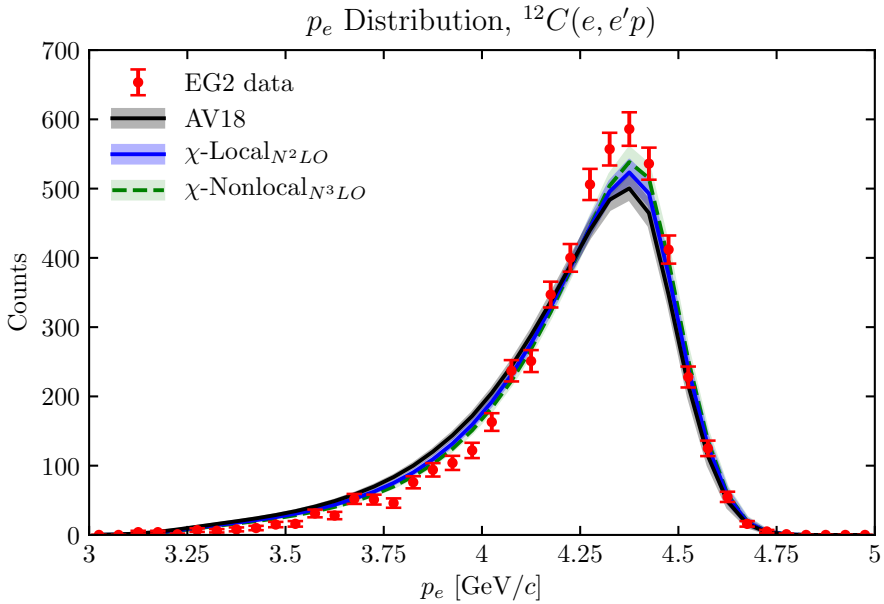
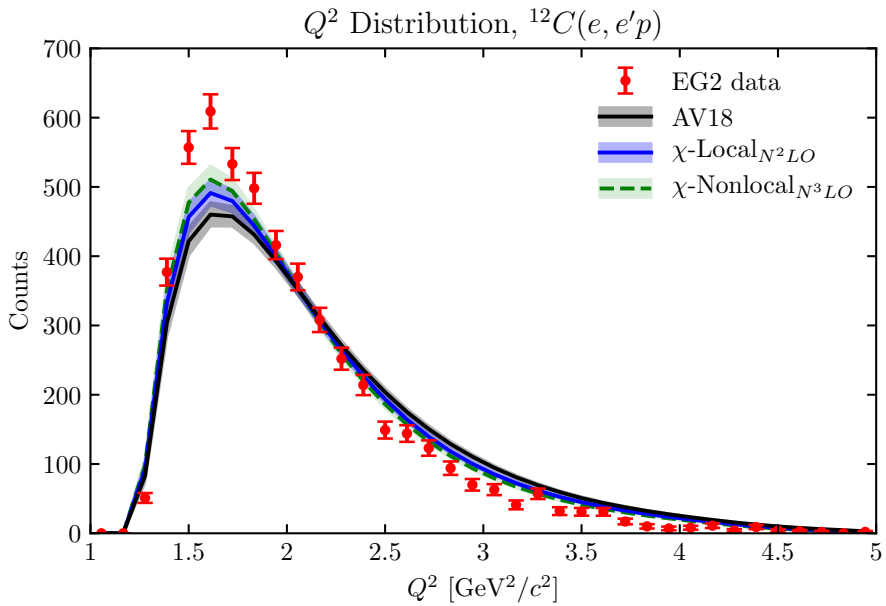
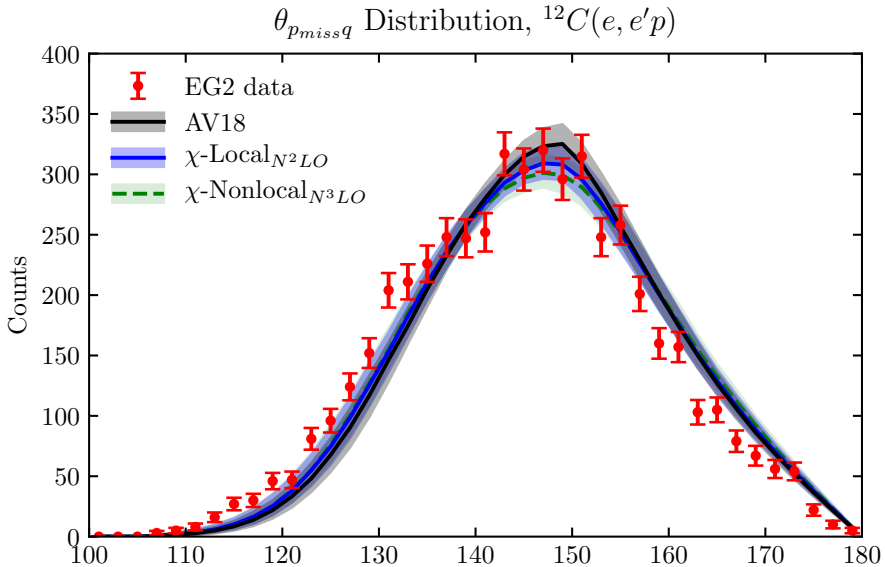
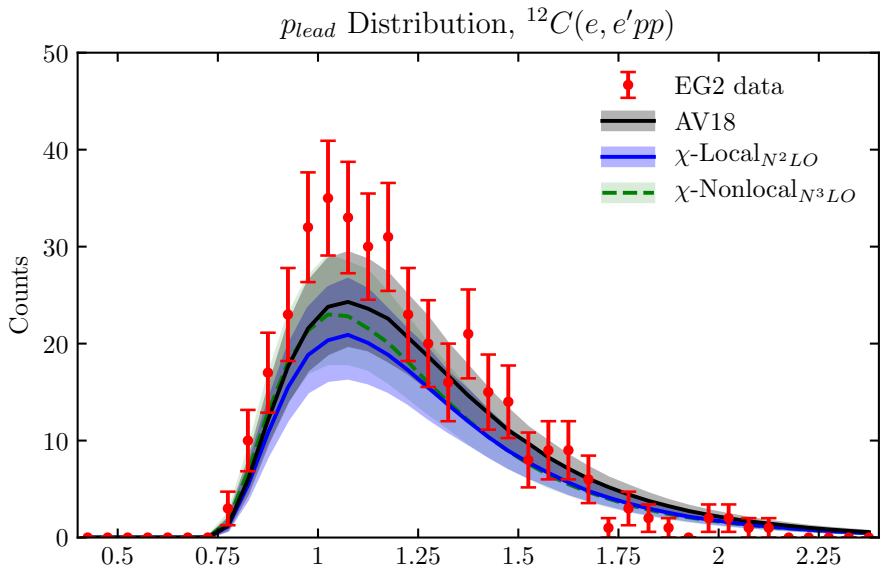


Many other distributions are included in the note.

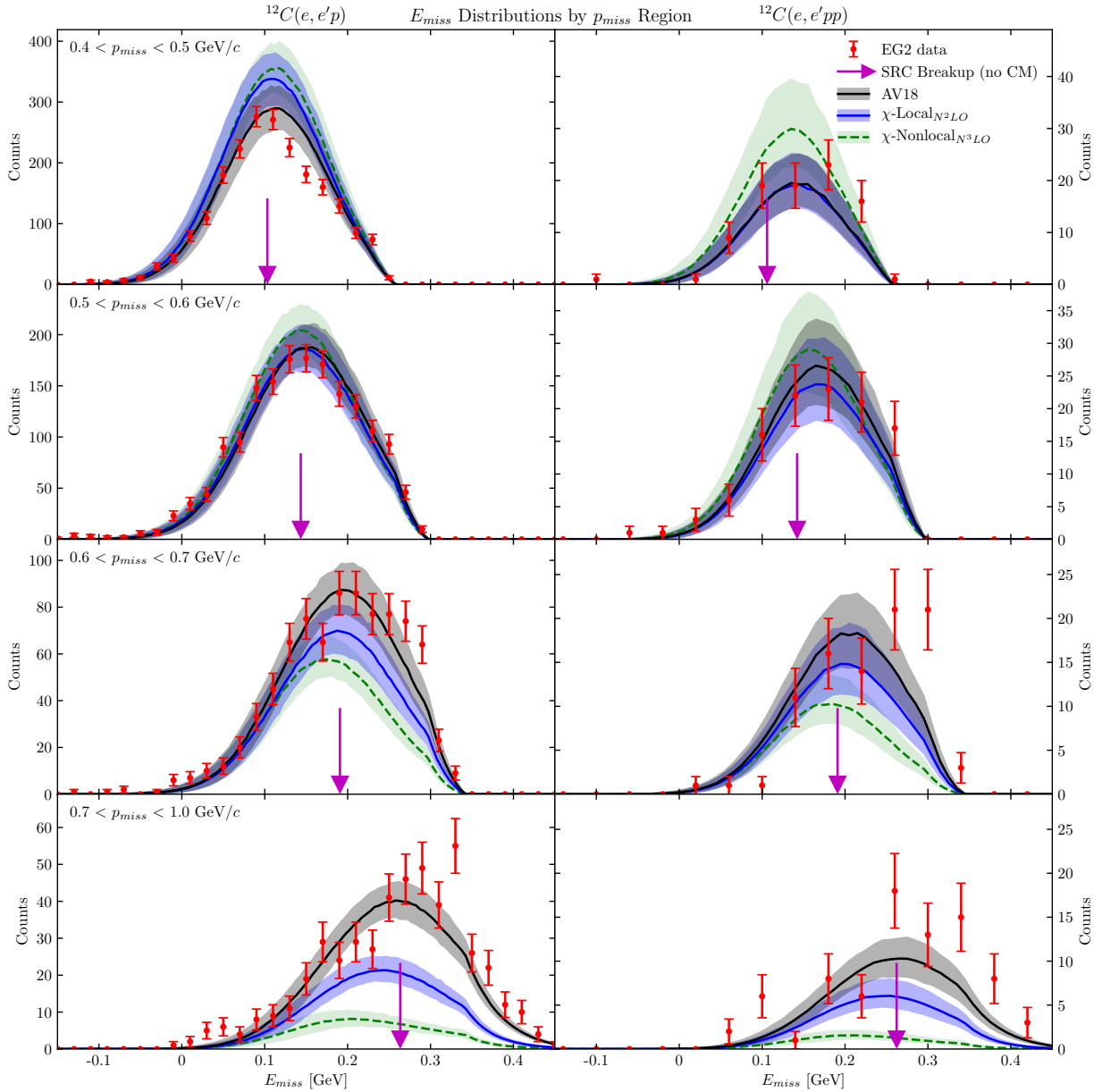




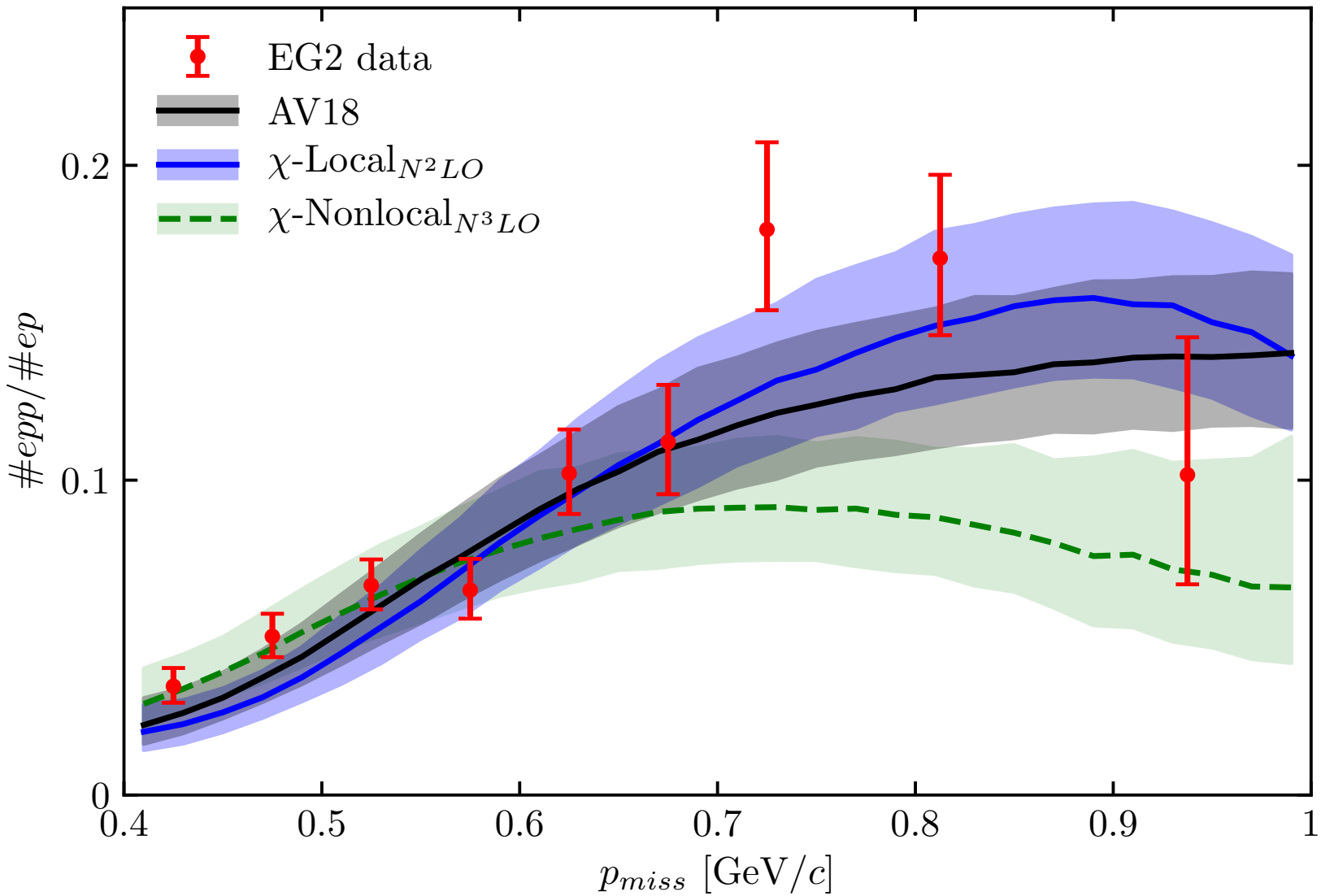




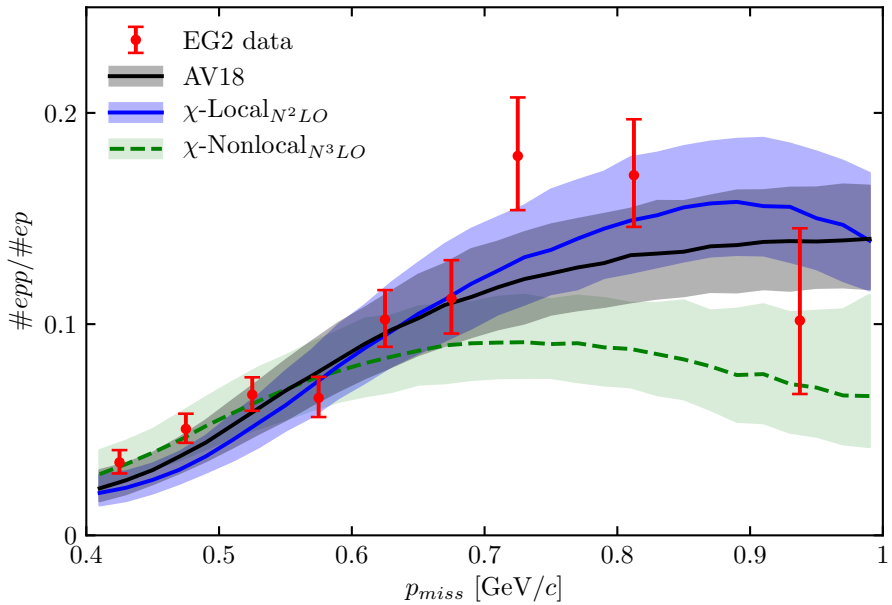
Missing Energy vs. Missing Momentum



$(e, e'pp)/(e, e'p)$ Ratio



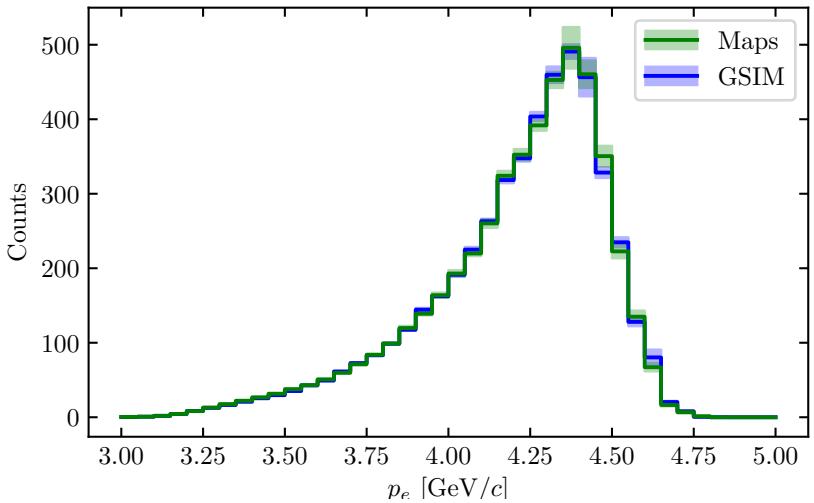
Conclusions

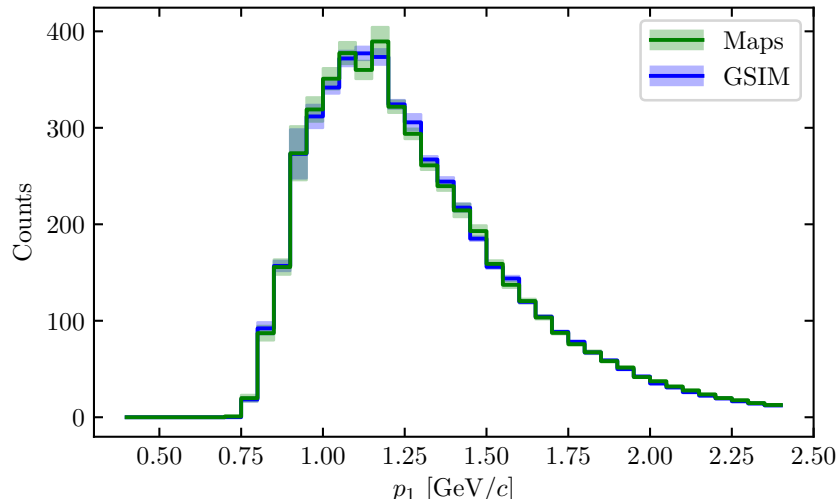


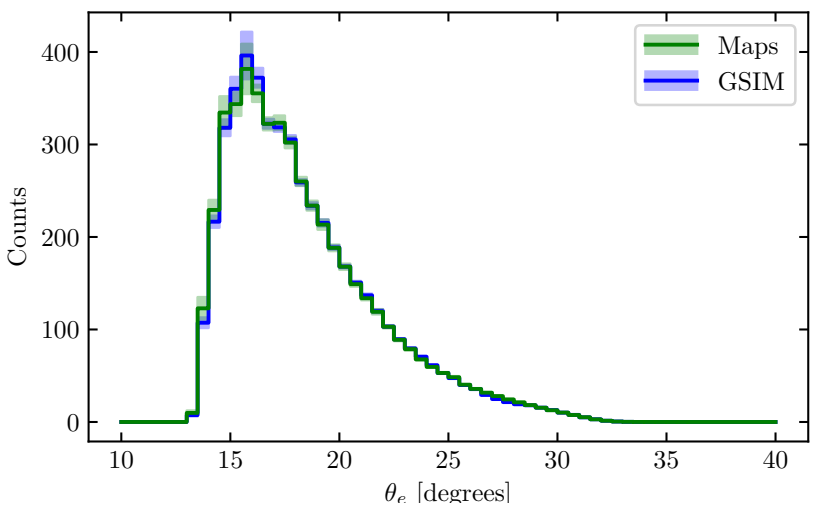
- GCF agrees with EG2 data.
- AV18 works well, even up to 1 GeV/c.
- New constraints on NN interaction at high-momentum

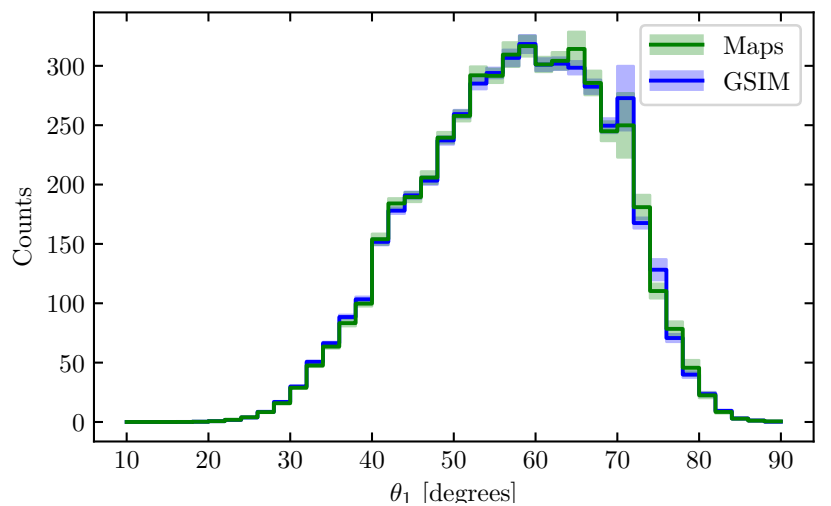
BACK-UP

Fast vs. Full MC

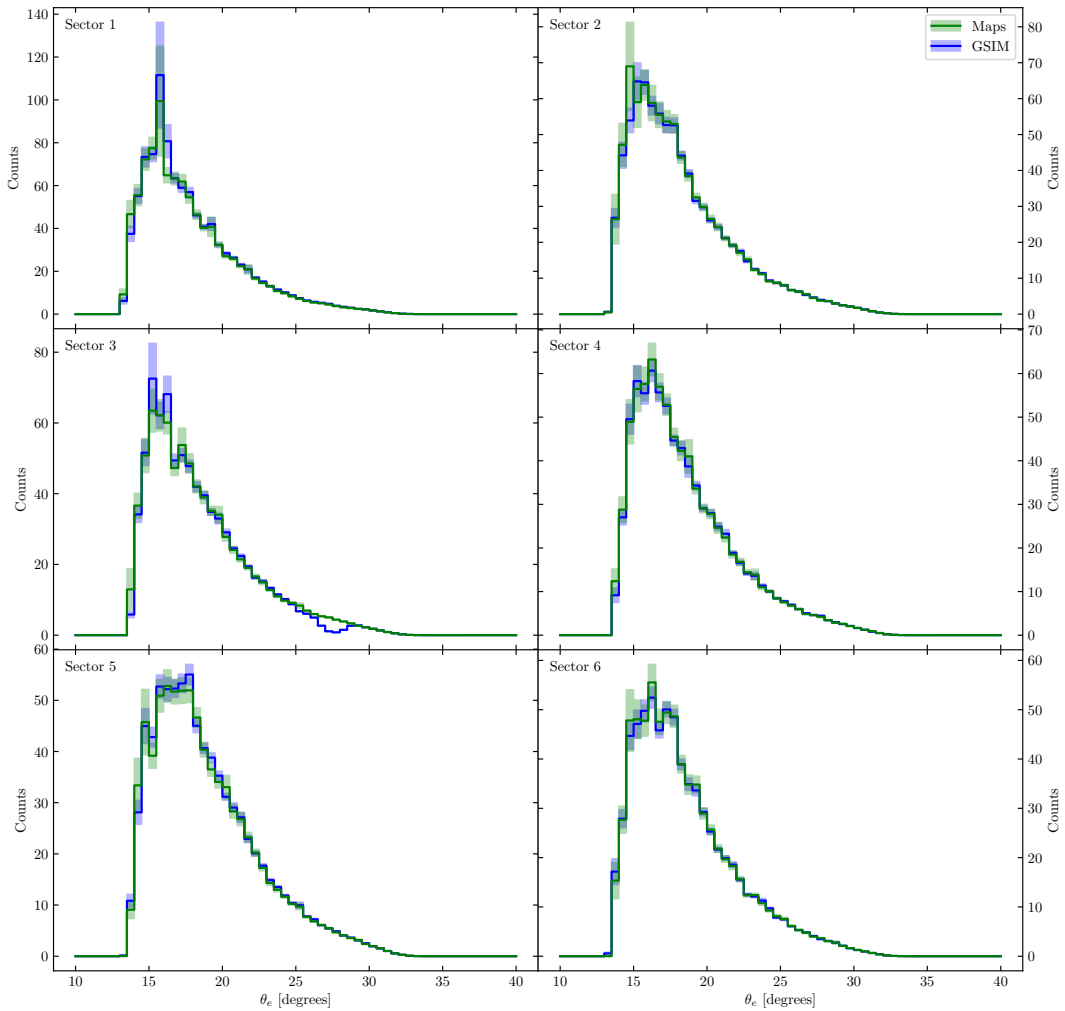








Fast vs. Full MC



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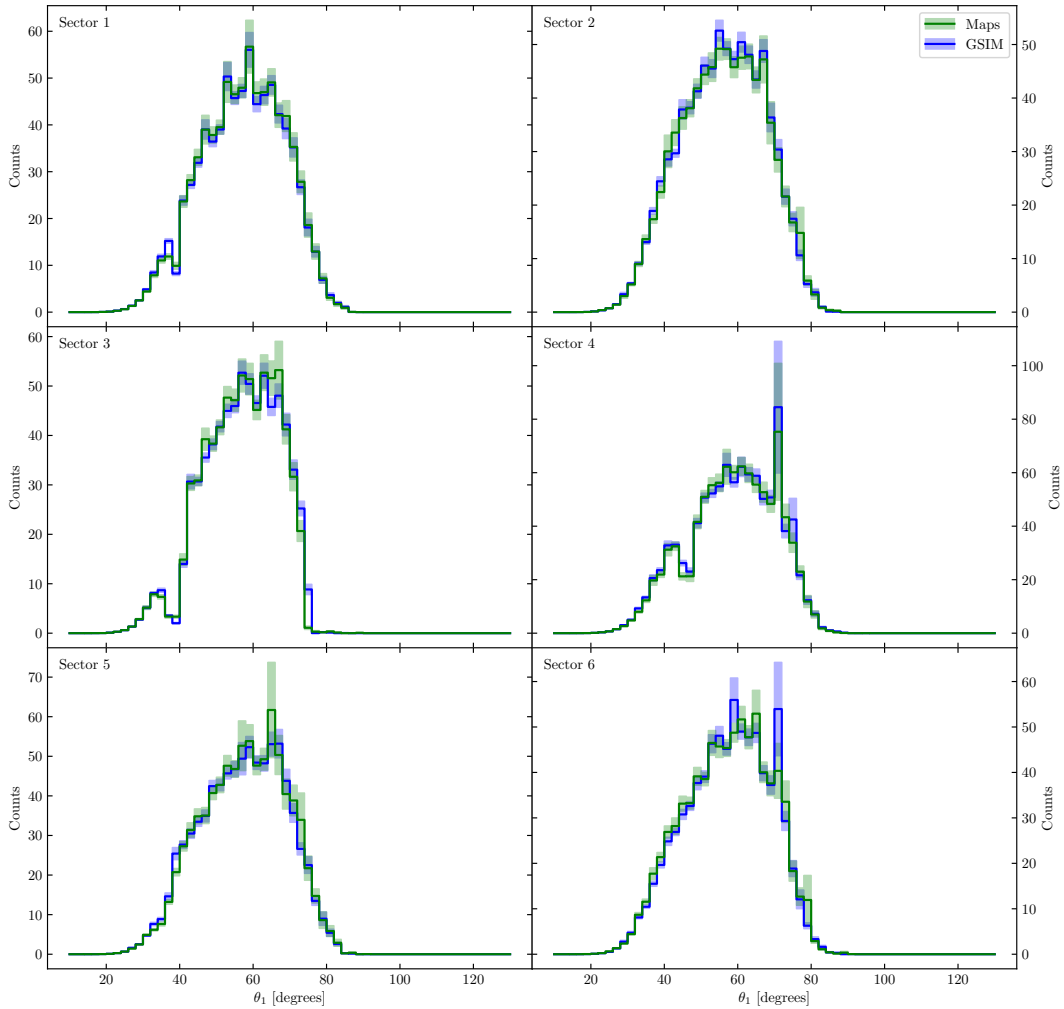

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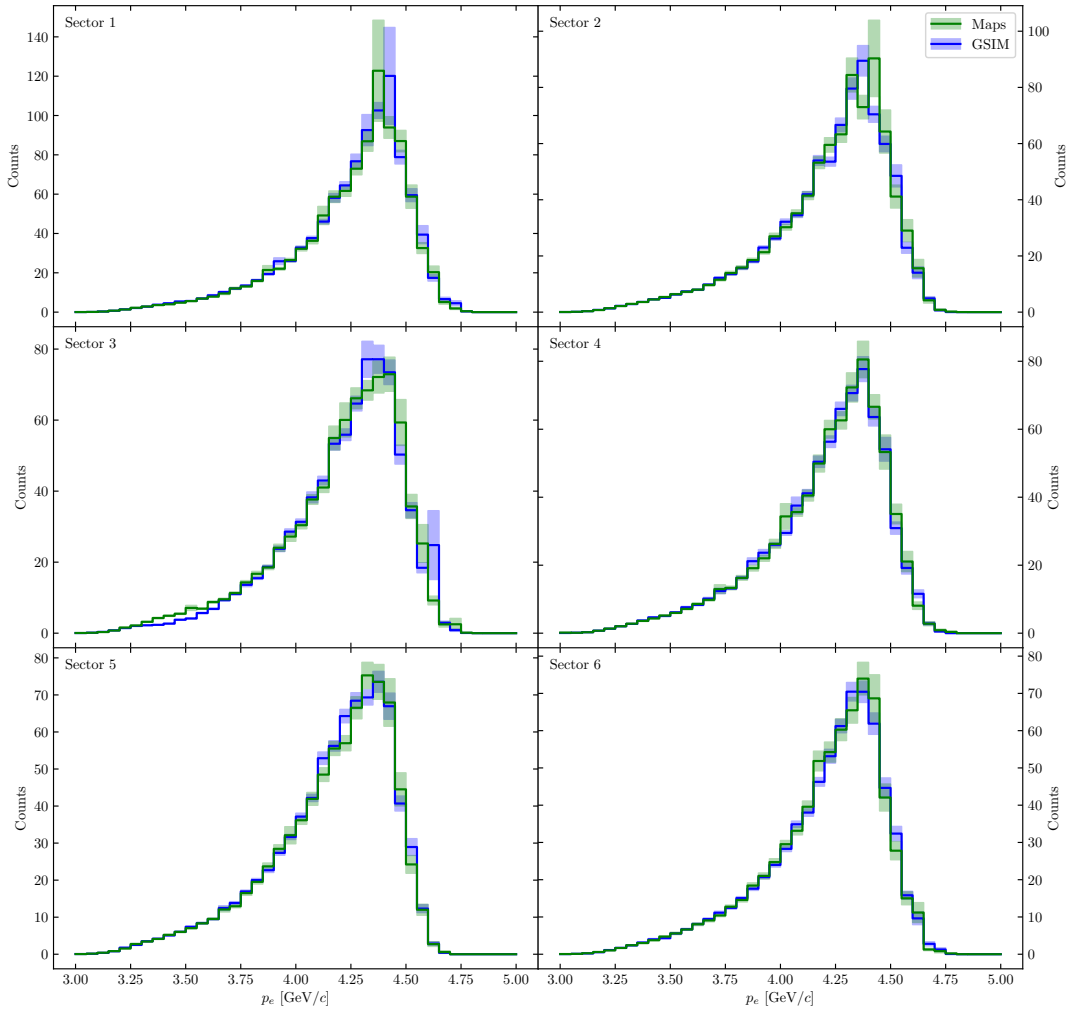

Fast vs. Full MC