Going Beyond the Tensor Limit Using $\frac{(e,e'pp)}{(e,e'p)}$ Data

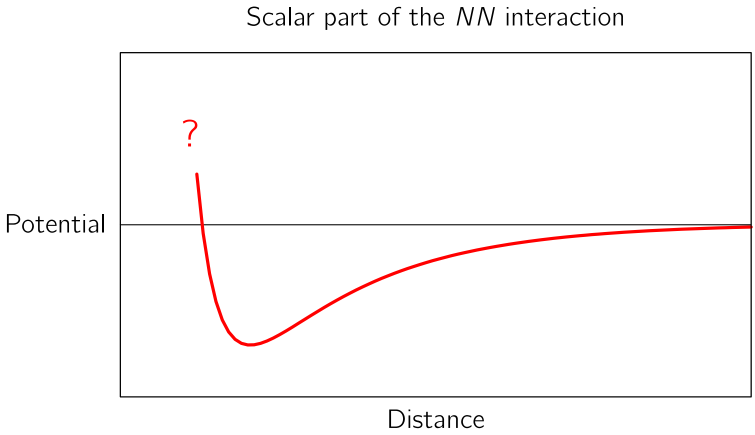
CLAS Nuclear Physics Working Group Meeting

Axel Schmidt

MIT

July 12, 2018

The short-distance NN interaction is poorly known.



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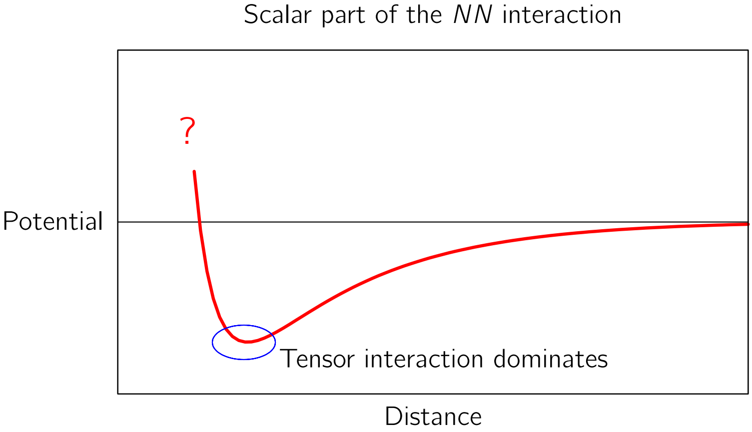
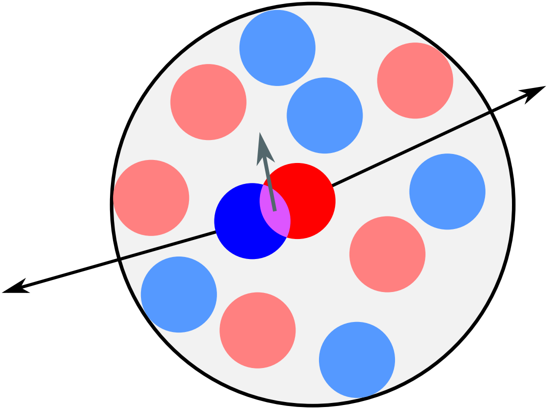
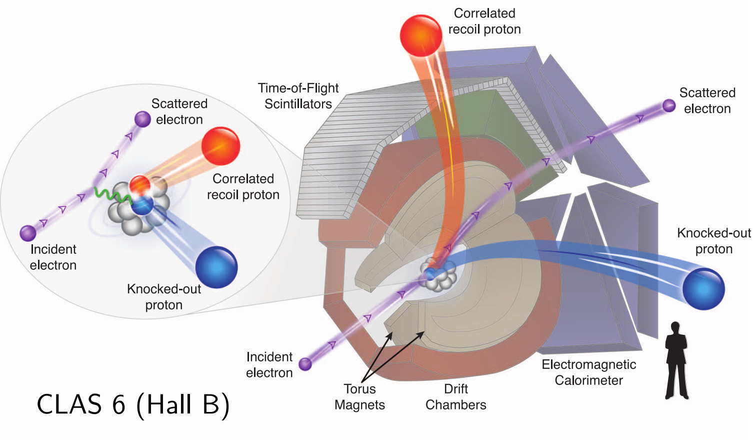


$\approx$ 20% of nucleons are part of a short-range correlated pair.

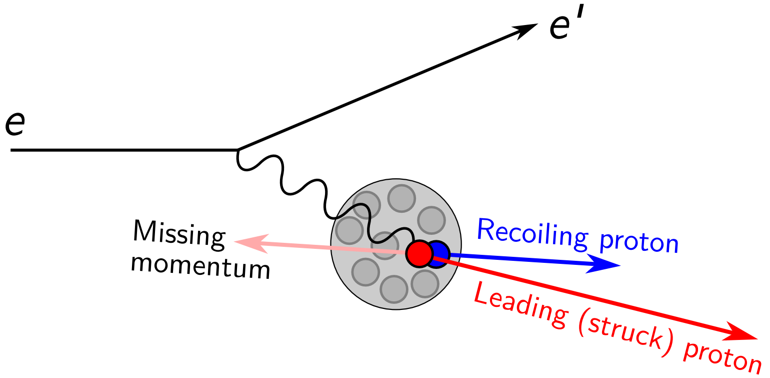


- Relative momentum: > 300 MeV/c
- CoM momentum: $\mathcal{O}(150$ MeV/$c)$

CLAS is well-suited to see triple-coincidences.



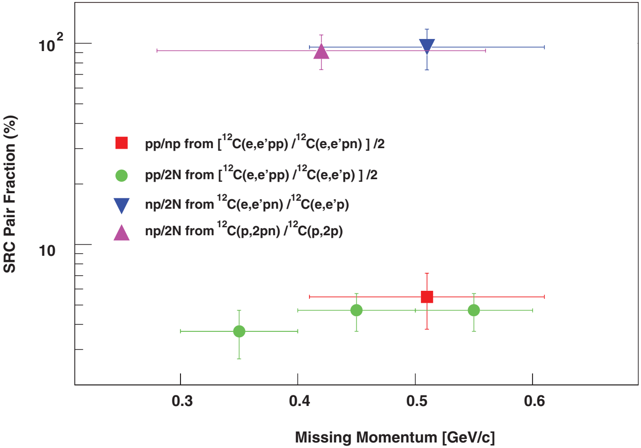
Missing Momentum is a proxy for the pre-collision momentum.



$$\vec{p}_{\text{miss}} = \vec{p}_{\text{lead}} - \vec{q}$$

$$\vec{p}_{\text{miss}} + \vec{p}_{\text{rec}} = \vec{p}_{\text{CM}}$$

Short-range correlated pairs prefer to be *np* because of the tensor force.



R. Subedi et al., Science 320, 1476 (2008)

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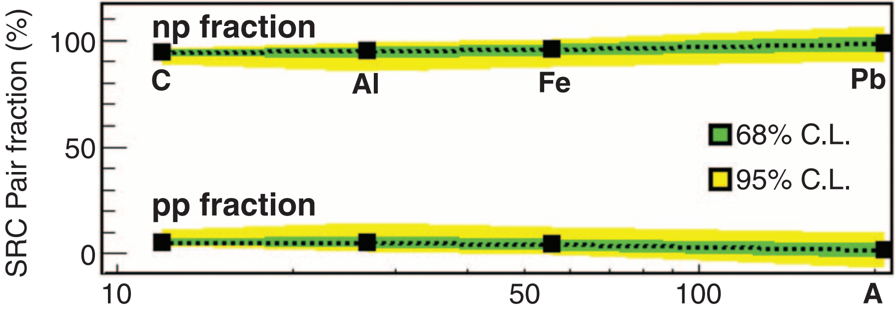

O. Hen et al., Science 346, 614 (2014)

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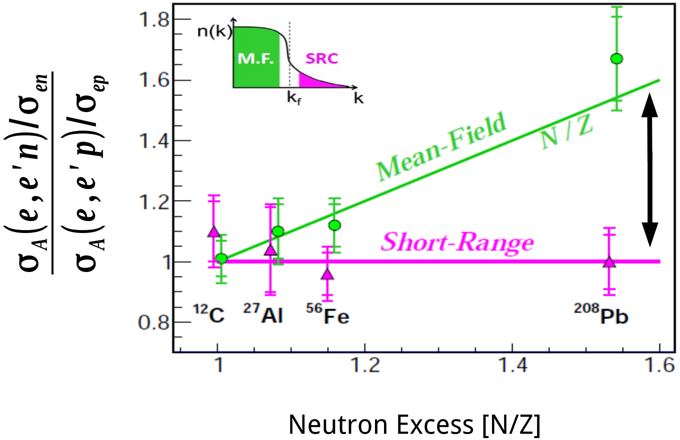

M. Duer et al., to appear in Nature (2018)

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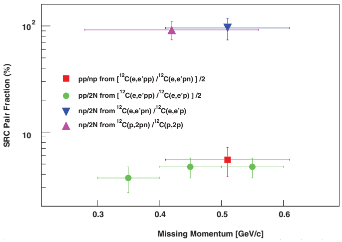
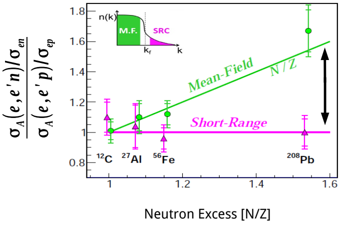
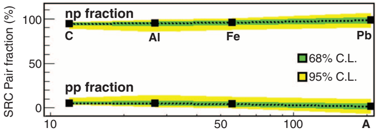
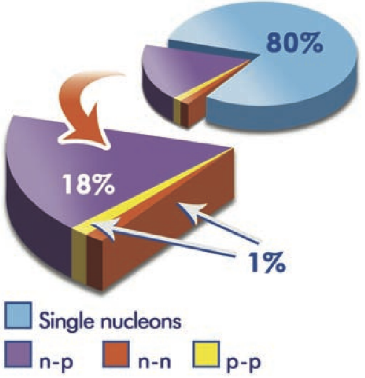
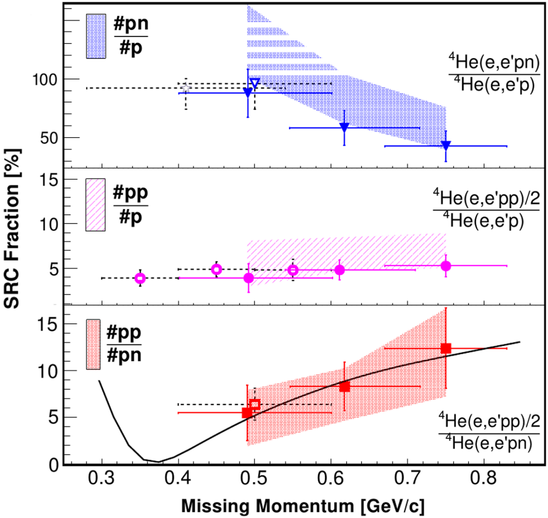








How does *np*-dominance evolve with momentum?



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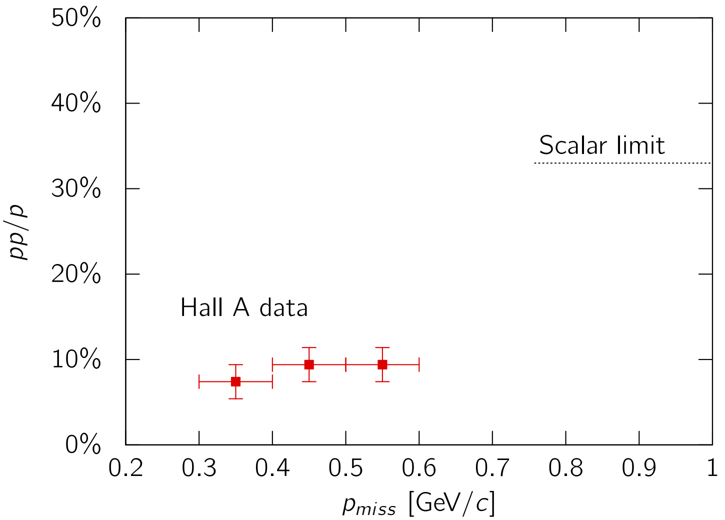

pp/p analysis using EG2 data

1. Select $A(e, e'p)$ events in which the p comes from an SRC pair.
    - Exact same procedure (exact same EVENTS!) as in:
        - 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” (2014)
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2. See how often there is an additional proton in coincidence.

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

- $0.3 < p_{\text{miss}} < 1.0$ GeV/c
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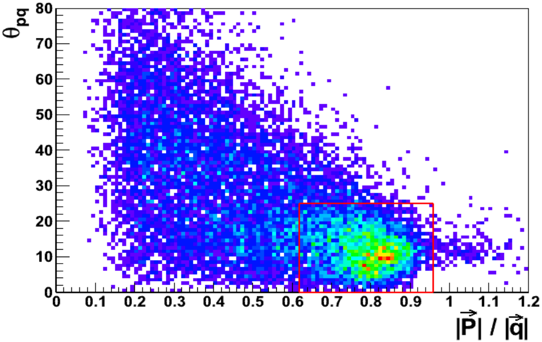
- $\theta_{pq} < 25°$



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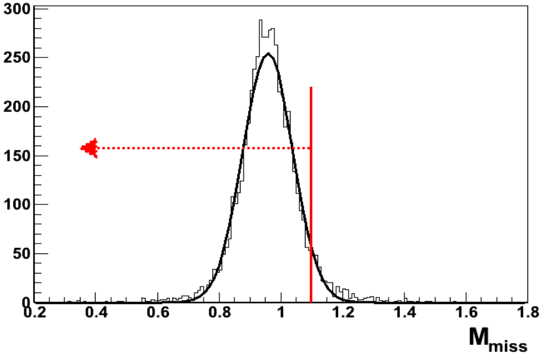
- $m_{\text{miss}} < 1.1$ GeV$/c^2$



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$$\frac{pp}{p} = \frac{\sigma_{e'pp}}{\sigma_{e'p}}$$

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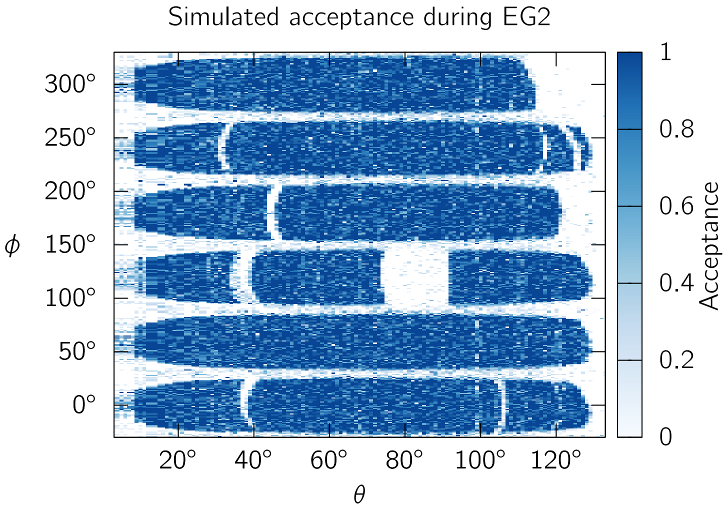
$$= \frac{N_{e'pp}}{N_{e'p}} \times \frac{A(e')A(p_{\text{lead}})}{A(e')A(p_{\text{lead}})A(p_{\text{recoil}})}$$

pp/p analysis using EG2 data

$$\begin{aligned}\frac{pp}{p} &= \frac{\sigma_{e'pp}}{\sigma_{e'p}} \\ &= \frac{N_{e'pp}}{N_{e'p}} \times \frac{A(e')A(p_{\mathrm{lead}})}{A(e')A(p_{\mathrm{lead}})A(p_{\mathrm{recoil}})} \\ &= \frac{N_{e'pp}}{N_{e'p}} \times \frac{1}{A(p_{\mathrm{recoil}})}\end{aligned}$$

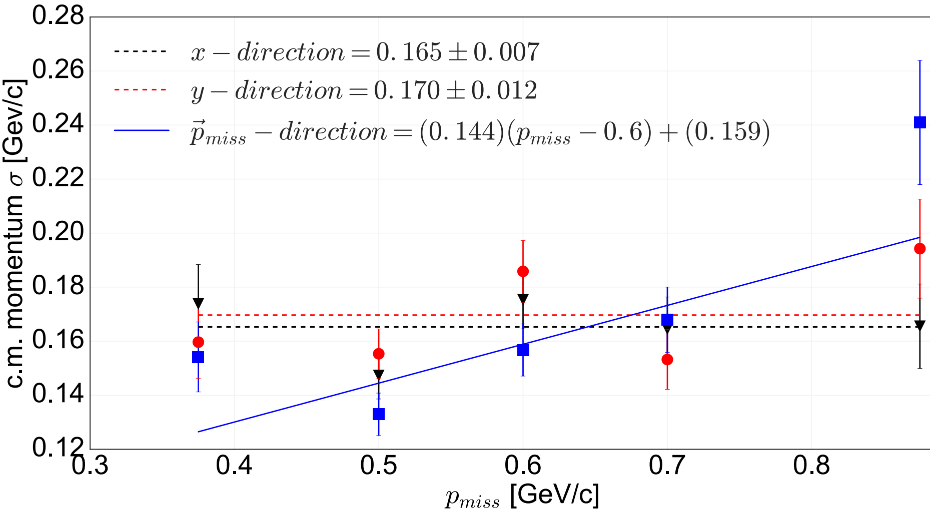
The acceptance for recoil protons is non-trivial.



The acceptance for recoil protons is non-trivial.

1. Where do the recoil protons go?
2. $\rightarrow$ What is the SRC pair center-of-mass momentum distribution?
3. What is that distribution longitudinal to p_{miss}?
4. What is our confidence on that acceptance?

Erez showed that the longitudinal CM distribution has p_{miss} dependence.



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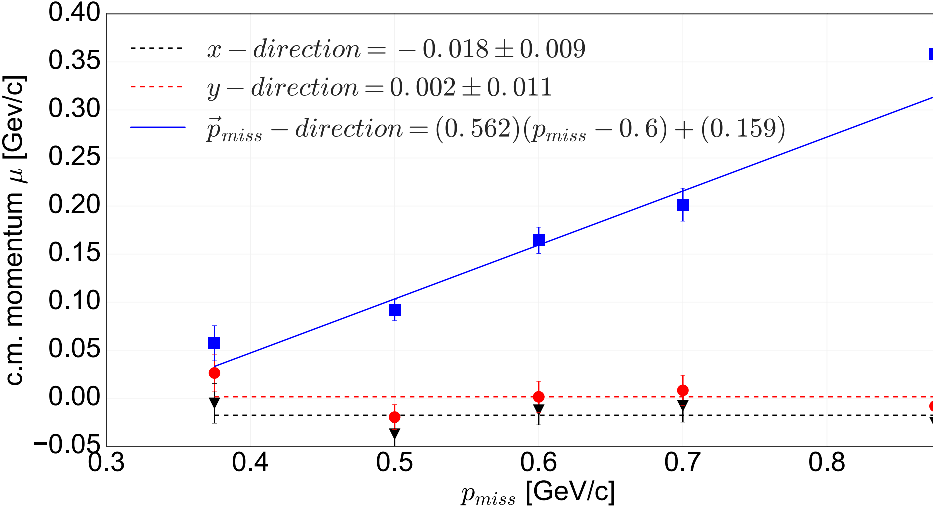

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Erez's 5-parameter model:
The CM distribution is a 3D Gaussian with μ, σ:

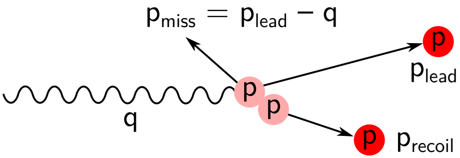
Longitudinal to p_{miss}:

- Width: $\sigma_{||} = \mathbf{a}_1(p_{\text{miss}} - 0.6 \text{ GeV}) + \mathbf{a}_2$
- Mean: $\mu_{||} = \mathbf{b}_1(p_{\text{miss}} - 0.6 \text{ GeV}) + \mathbf{b}_2$

Transverse to p_{miss}:

- Width: $\boldsymbol{\sigma}_{\perp}$
- Mean: $\mu_{\perp} = 0$

Determining where the recoil protons go is now a problem of parameter estimation.



$$P(\vec{p}_{\text{recoil}}|\vec{p}_{\text{miss}}) = \int \mathrm{d}a_1 \mathrm{d}a_2 \mathrm{d}b_1 \mathrm{d}b_2 \mathrm{d}\sigma_\perp$$
$$P(\vec{p}_{\text{recoil}}|\vec{p}_{\text{miss}}, a_1, a_2, b_1, b_2, \sigma_\perp)$$
$$\times P(a_1, a_2, b_1, b_2, \sigma_\perp|\vec{D})$$

We can use Bayes' Theorem to estimate $P(a_1, a_2, b_1, b_2, \sigma_\perp | \vec{D})$.

$$P(a_1, a_2, b_1, b_2, \sigma_\perp | \vec{D}) = \frac{P(\vec{D} | a_1, a_2, b_1, b_2, \sigma_\perp) \times P(a_1, a_2, b_1, b_2, \sigma_\perp)}{P(\vec{D})}$$

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- $P(\vec{D}|a_1, a_2, b_1, b_2, \sigma_\perp)$ – Likelihood
  How likely are the observed data given a guess of a_1, a_2, b_1, b_2, $\sigma_\perp$?
- $P(a_1, a_2, b_1, b_2, \sigma_\perp)$ – Prior
  What is our prior confidence on a_1, a_2, b_1, b_2, $\sigma_\perp$? (not so relevant)
- $P(\vec{D})$ – Evidence
  Normalization, not relevant...

Data-driven likelihood estimate

Given a guess of $a_1, a_2, b_1, b_2, \sigma_\perp$:

1. For each $A(e, e'p)$ event in data:
    - Randomly sample many $\vec{p}_{CM}$ vectors using 3D Gaussian.
        - Test if $\vec{p}_{\text{recoil}}$ is accepted using simulated maps.
2. For each $A(e, e'pp)$ event in data:
    - Test against pseudodata distributions from step 1.

Data-driven likelihood estimate

Data:

Model:

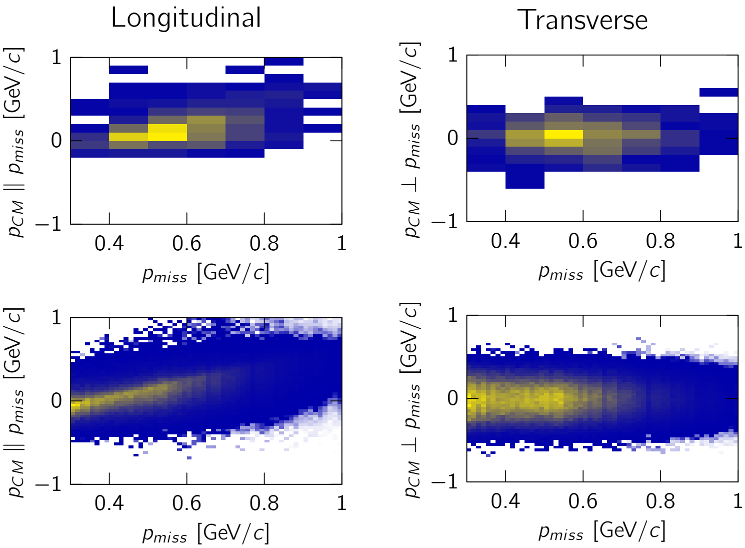
$a1 = 0.185$

$a2 = 0.202$

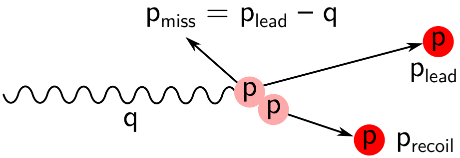
$b1 = 0.713$

$b2 = 0.278$

$\sigma_\perp = 0.151$



We still need to integrate the posterior to find out where recoils go.

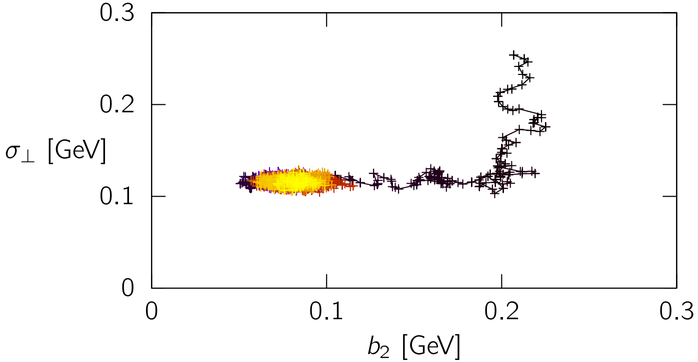


$$P(\vec{p}_{\text{recoil}}|\vec{p}_{\text{miss}}) = \int \mathrm{d}a_1 \mathrm{d}a_2 \mathrm{d}b_1 \mathrm{d}b_2 \mathrm{d}\sigma_\perp \; P(\vec{p}_{\text{recoil}}|\vec{p}_{\text{miss}}, a_1, a_2, b_1, b_2, \sigma_\perp) \times P(a_1, a_2, b_1, b_2, \sigma_\perp|\vec{D})$$

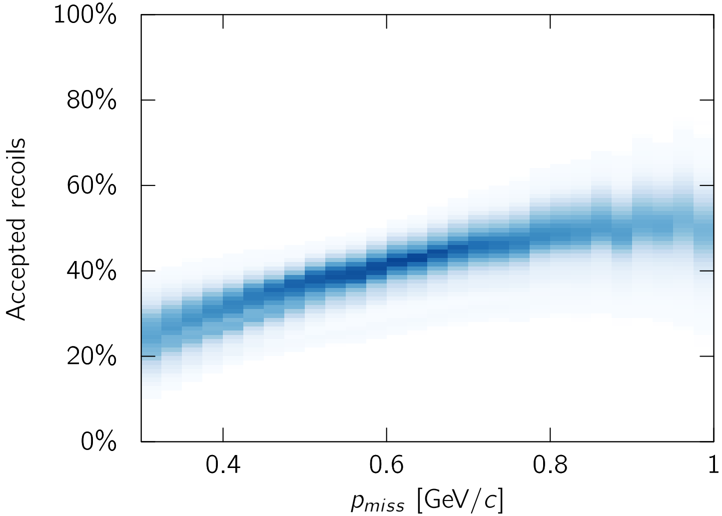
Markov Chain Monte Carlo will help us integrate.

Metropolis-Hastings Algorithm

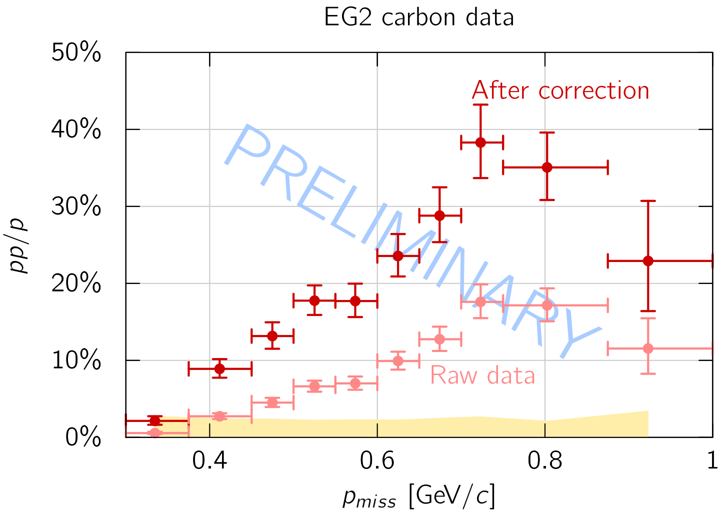
- Random walk in 5D $(a_1, a_2, b_1, b_2, \sigma_\perp)$ space
- Choose steps so that frequency $\sim$ probability



Each random walk point predicts an acceptance factor.



We can apply this correction to our pp/p yields.



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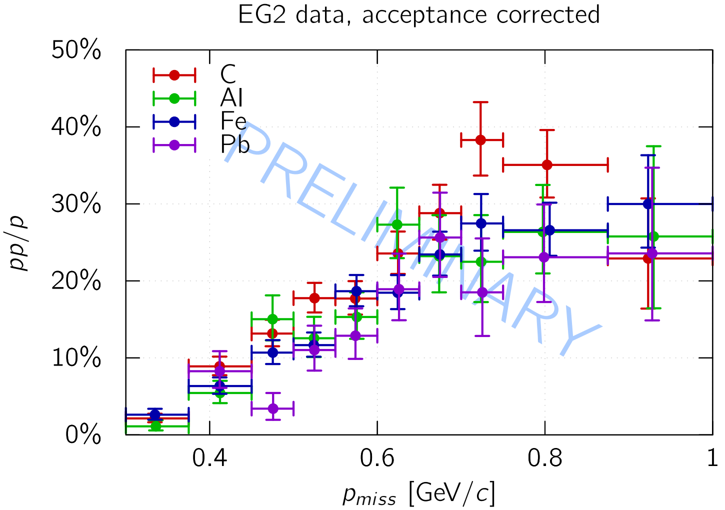
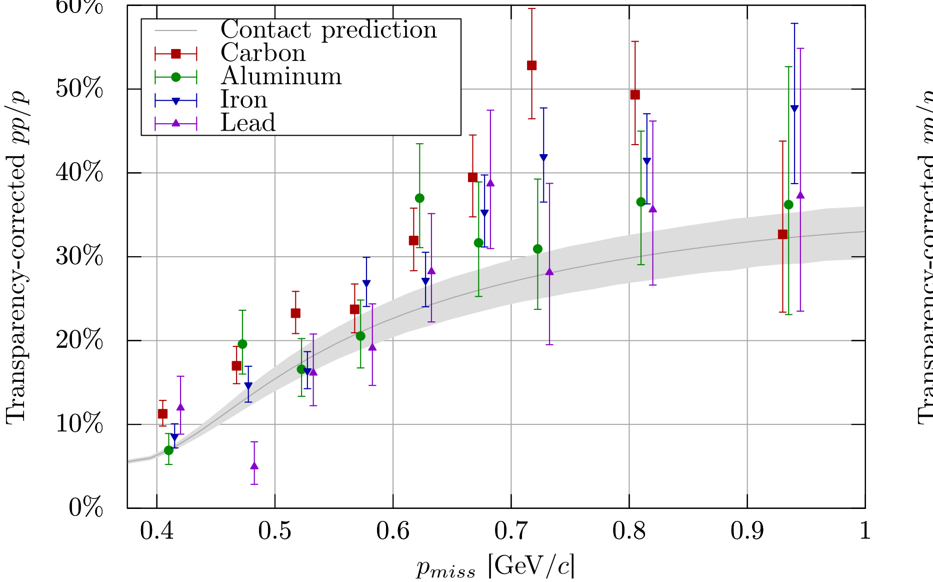
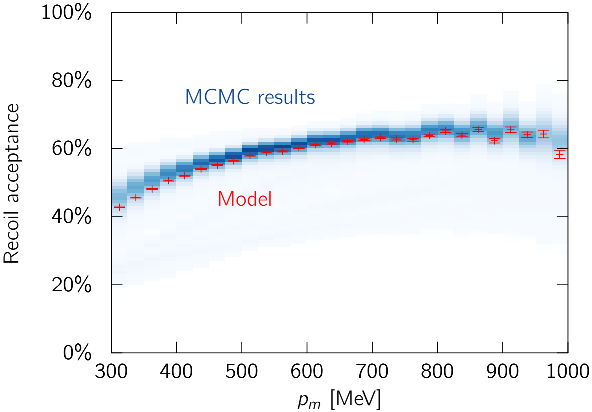


Transparency corrected pp/p



Preliminary closure test

Can the algorithm reproduce model parameters of our choosing?



Outstanding issues

- Verify that the algorithm performs under closure tests.
- Estimate systematic effects
    - Imperfect simulation
    - Bias from the algorithm
- Verify the data handling
    - Fiducial cuts on recoil protons
    - $\rightarrow$ matched acceptance simulations
- Interpretation and corrections
    - Transparency
    - Single charge exchange