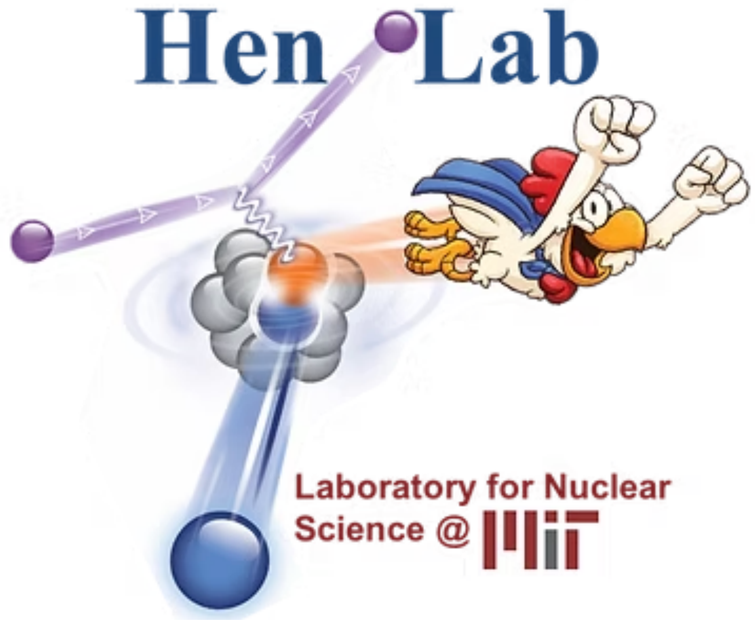
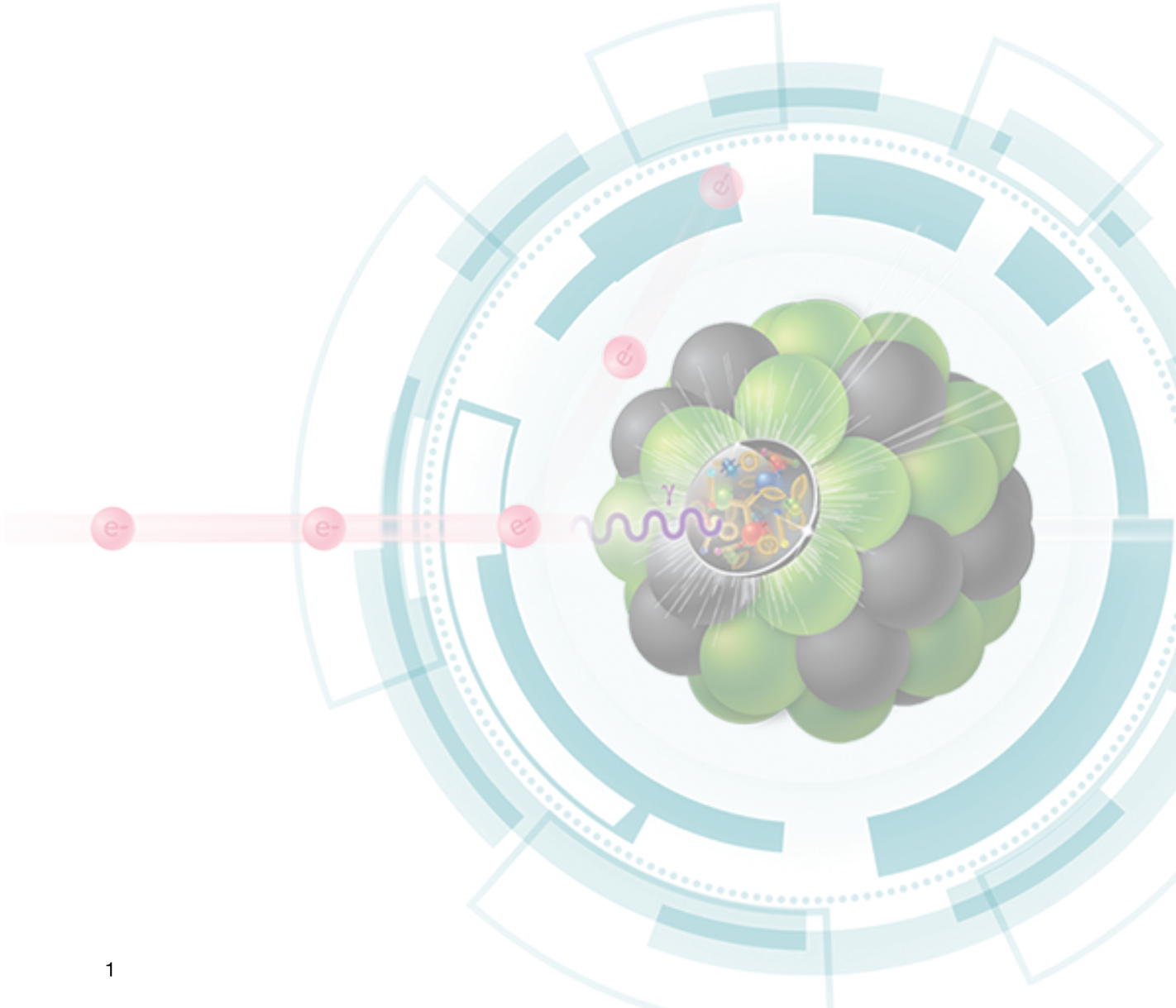
Updates from the BAND Experiment

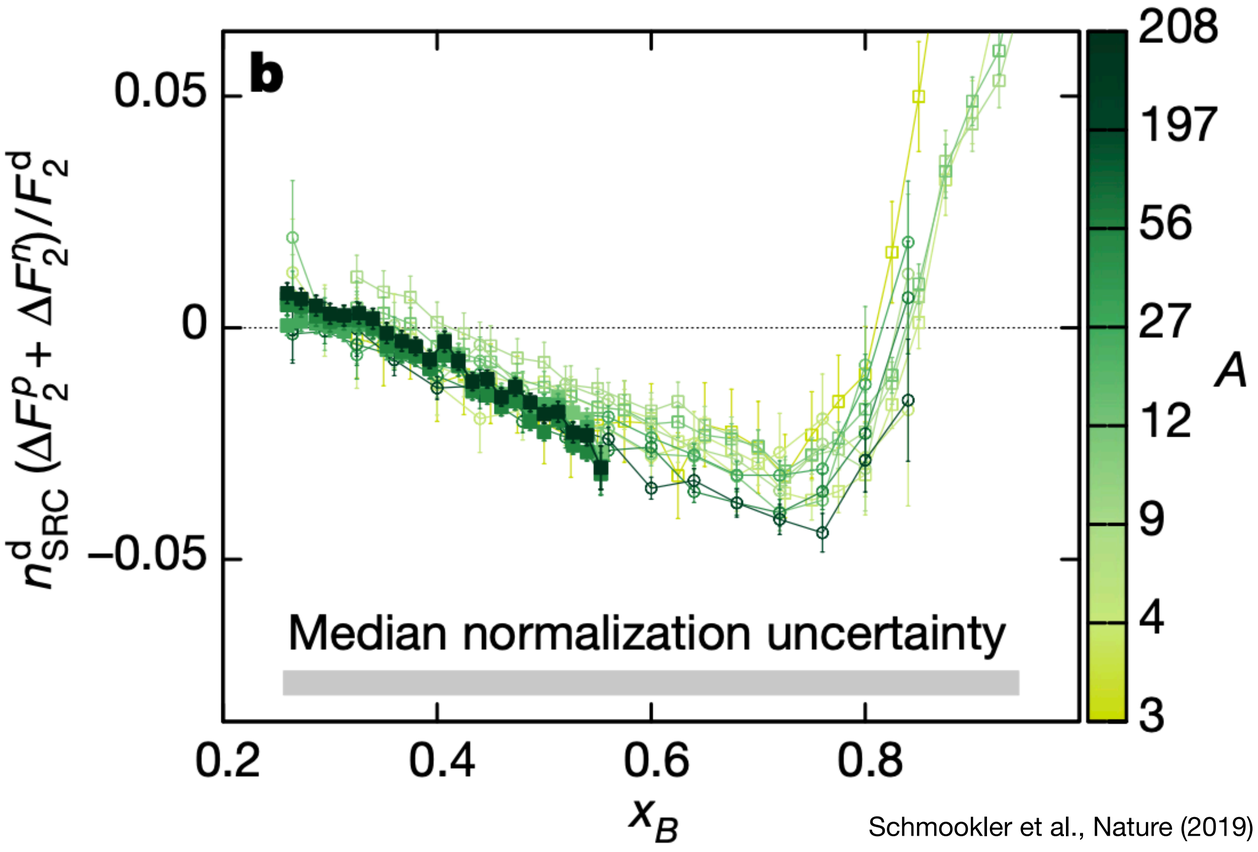
Natalie Wright





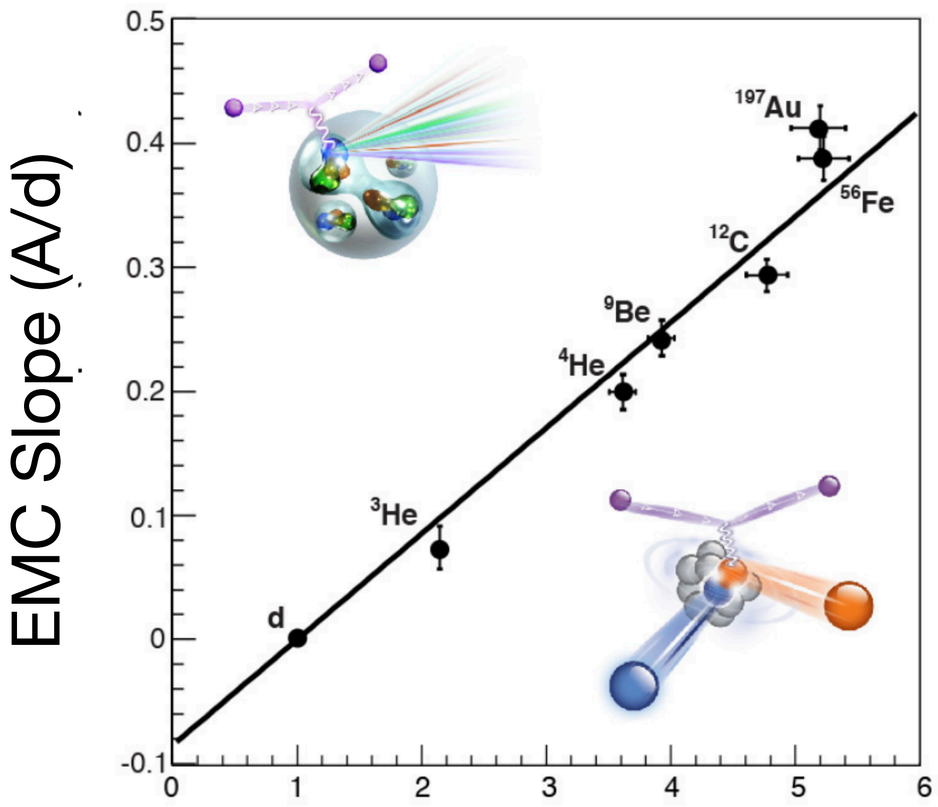
Inclusive DIS shows EMC-SRC correlation

$$F_2^A = ZF_2^p + NF_2^n + n_{SRC}^A(\Delta F_2^p + \Delta F_2^n)$$

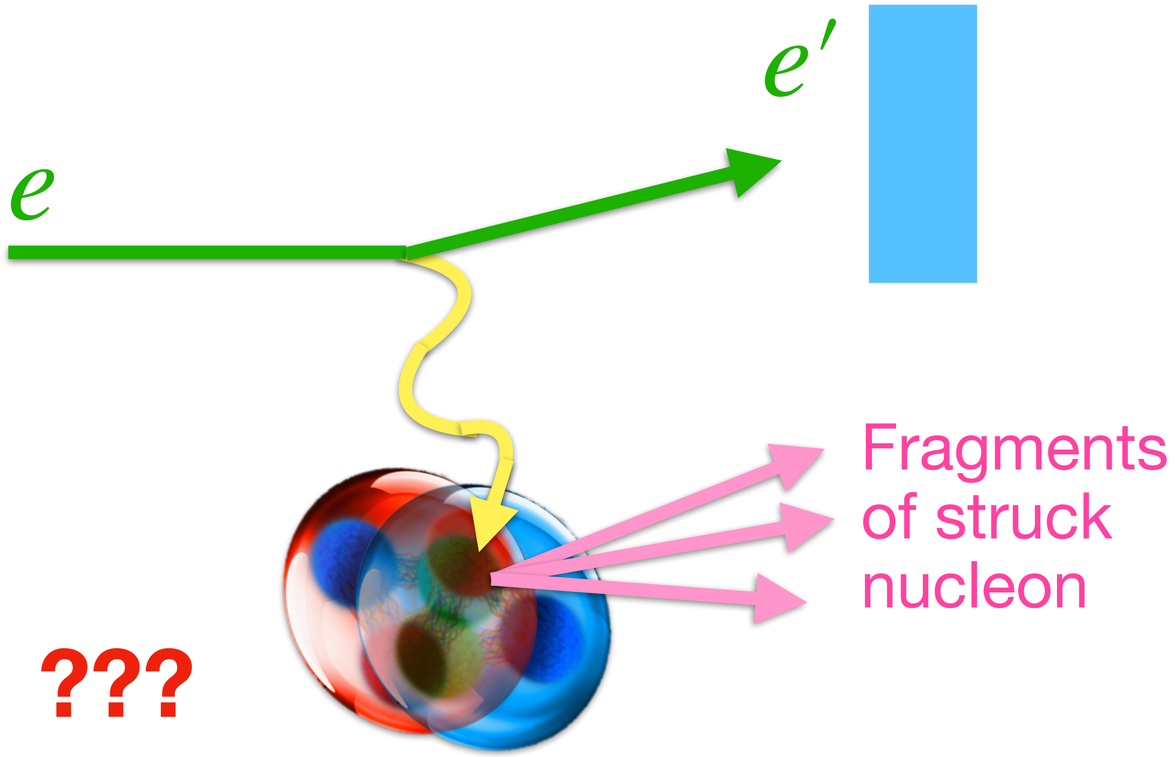


Schmookler et al., Nature (2019)

Weinstein et al., PRL 106, 052301 (2011),



But lacks info on nuclear state



Standing nucleon target:

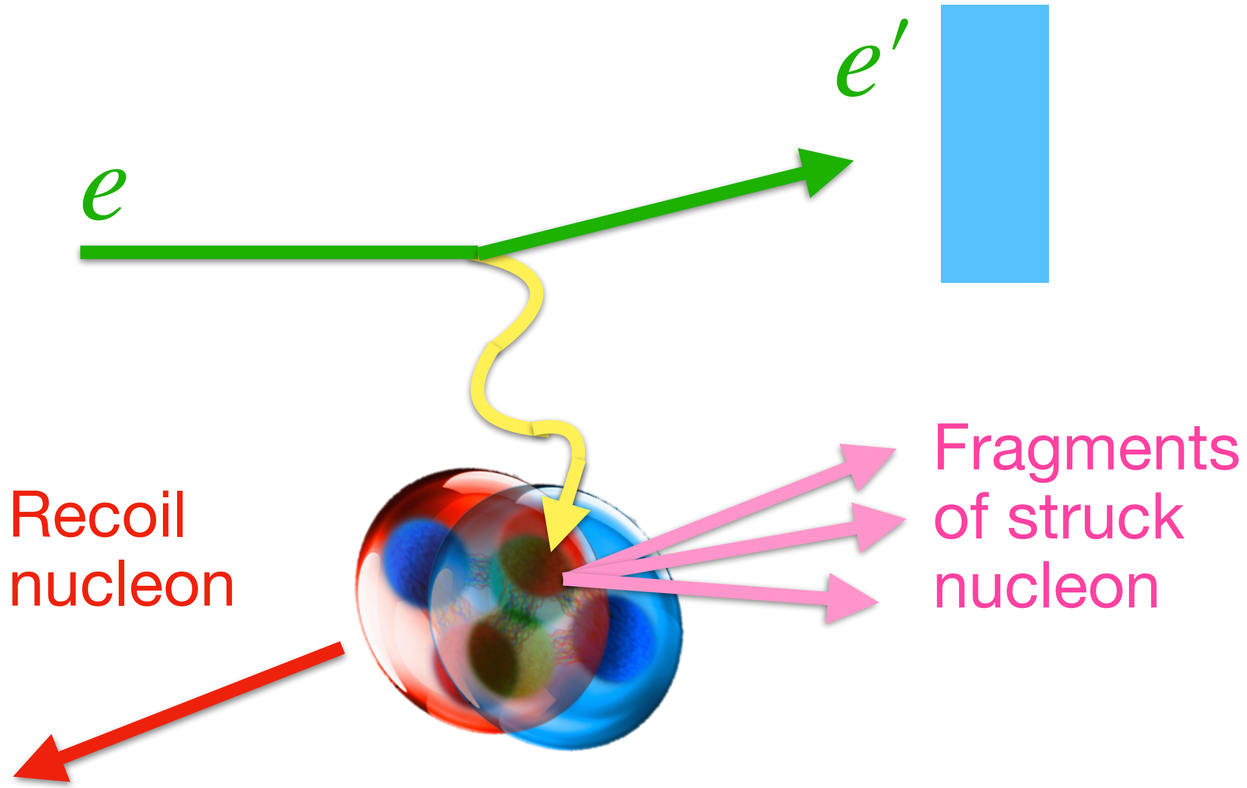
$$p_0 = (m_n\ ,\ 0)$$

$$W^2 = (p_0 + q)^2$$

$$x_B = \frac{Q^2}{2m_n\omega}$$

Measure Parton Information

Add initial nuclear state via tagging!



Moving nucleon target:

$$p_\mu = (E, \ -p_s \ )$$

$$(W')^2 = (p_\mu + q)^2$$

$$x' = \frac{Q^2}{(W')^2 - m_n^2 + Q^2}$$

$$\alpha_S = \frac{E_s - p_s \cos\theta_{sq}}{m_n}$$

Measure Parton **+ Nucleon** Information

Tagged DIS cross section → modified nucleon structure function

$$\frac{d\sigma_{tag}}{dx dQ^2 d\alpha dp_\perp} = K(x, Q^2) \cdot S(\alpha, p_\perp) \cdot F_2^{p*}(x, Q^2, \alpha, p_\perp)$$

Kinematic term

Spectral function

Modified structure function

Tagged DIS cross section → modified nucleon structure function

$$\frac{d\sigma_{tag}}{dx dQ^2 d\alpha dp_\perp} = K(x, Q^2) \cdot S(\alpha, p_\perp) \cdot F_2^{p*}(x, Q^2, \alpha, p_\perp)$$

Modified structure function

Our objective!

Tagged DIS cross section → modified nucleon structure function

$$\frac{d\sigma_{tag}}{dx dQ^2 d\alpha dp_\perp} = K(x, Q^2) \cdot S(\alpha, p_\perp) \cdot F_2^{p*}(x, Q^2, \alpha, p_\perp)$$

Divide by GEMC-simulated σ_{tag}

→ **Kinematic terms, acceptance corrections cancel**

Tagged DIS cross section → modified nucleon structure function

$$\frac{d\sigma_{tag}}{dx dQ^2 d\alpha dp_\perp} = K(x, Q^2) \cdot S(\alpha, p_\perp) \cdot F_2^{p*}(x, Q^2, \alpha, p_\perp)$$

Normalize σ_{tag} to a common point ($x' = 0.3$) in each α_s bin

$\rightarrow S(\alpha, p_\perp)$ dependence cancels

Tagged double ratio sensitive to modified nucleon structure function

$$\mathscr{R} = \frac{\sigma_{tag}^{meas.}(x', Q^2, \alpha, p_\perp)}{\sigma_{tag}^{meas.}(0.3, Q^2, \alpha, p_\perp)} \Big/ \frac{\sigma_{tag}^{theory}(x', Q^2, \alpha, p_\perp)}{\sigma_{tag}^{theory}(0.3, Q^2, \alpha, p_\perp)} = \frac{Y_{tag}^{meas.}(x')}{Y^{meas.}(0.3)} \Big/ \frac{Y_{tag}^{theory}(x')}{Y_{tag}^{theory}(0.3)}$$

$$\mathscr{R} \approx \frac{F_2^{p^*}(x', \alpha) / F_2^{p}(x', \alpha)}{F_2^{p^*}(0.3, \alpha) / F_2^{p}(0.3, \alpha)}$$

Measured **bound** proton structure function

Simulated **free** proton structure function

Tagged double ratio sensitive to modified nucleon structure function

$$\mathscr{R} = \frac{\sigma_{tag}^{meas.}(x', Q^2, \alpha, p_\perp)}{\sigma_{tag}^{meas.}(0.3, Q^2, \alpha, p_\perp)} \Big/ \frac{\sigma_{tag}^{theory}(x', Q^2, \alpha, p_\perp)}{\sigma_{tag}^{theory}(0.3, Q^2, \alpha, p_\perp)} = \frac{Y_{tag}^{meas.}(x')}{Y_{tag}^{meas.}(0.3)} \Big/ \frac{Y_{tag}^{theory}(x')}{Y_{tag}^{theory}(0.3)}$$

$$\mathscr{R} \approx \frac{F_2^{p*}(x', \alpha) / F_2^{p}(x', \alpha)}{F_2^{p*}(0.3, \alpha) / F_2^{p}(0.3, \alpha)}$$

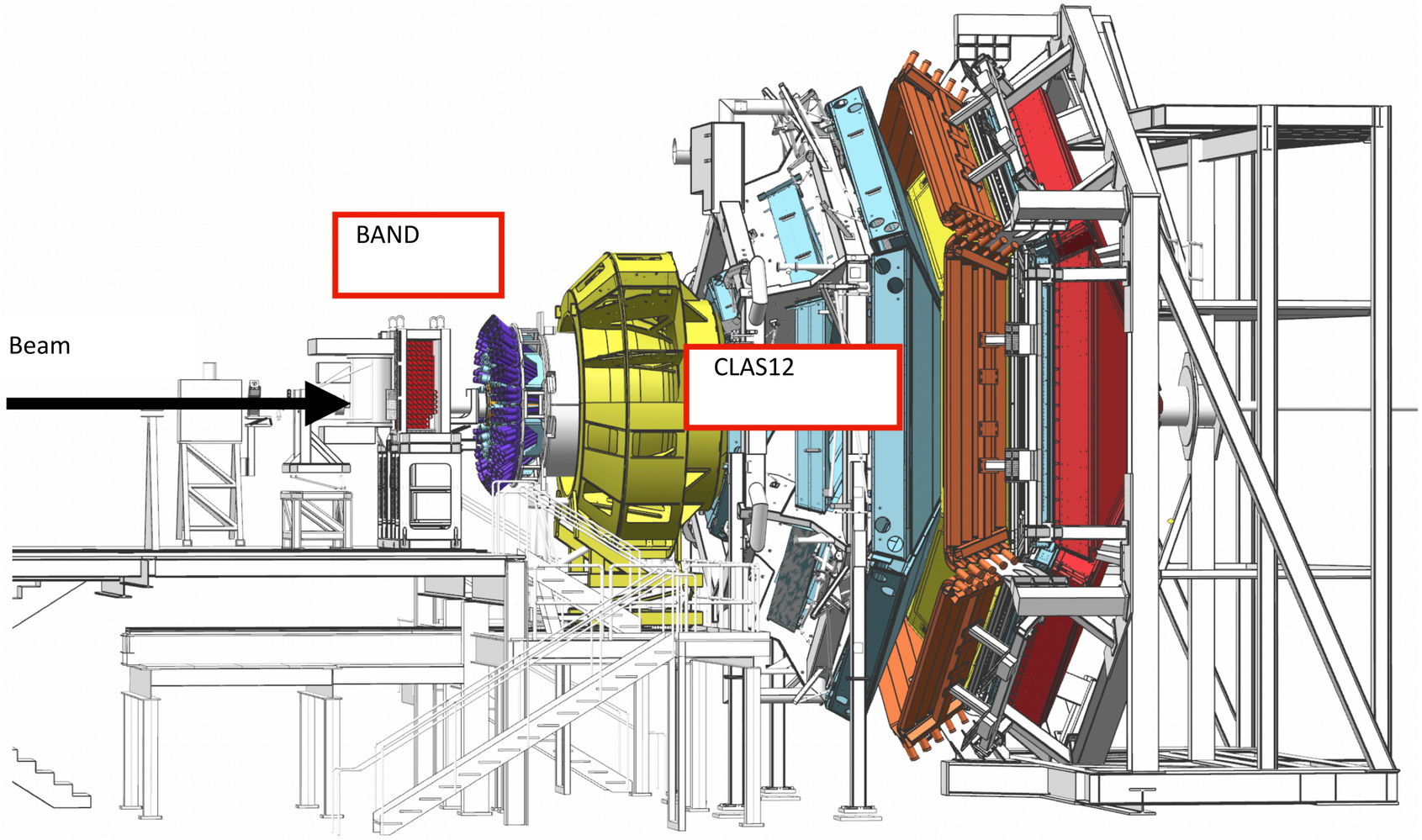
Measured **bound** proton structure function

Simulated **free** proton structure function

Extract $\mathscr{R}$ with BAND using $d(e, e' n_{spectator})$ reactions

Tagged DIS with BAND

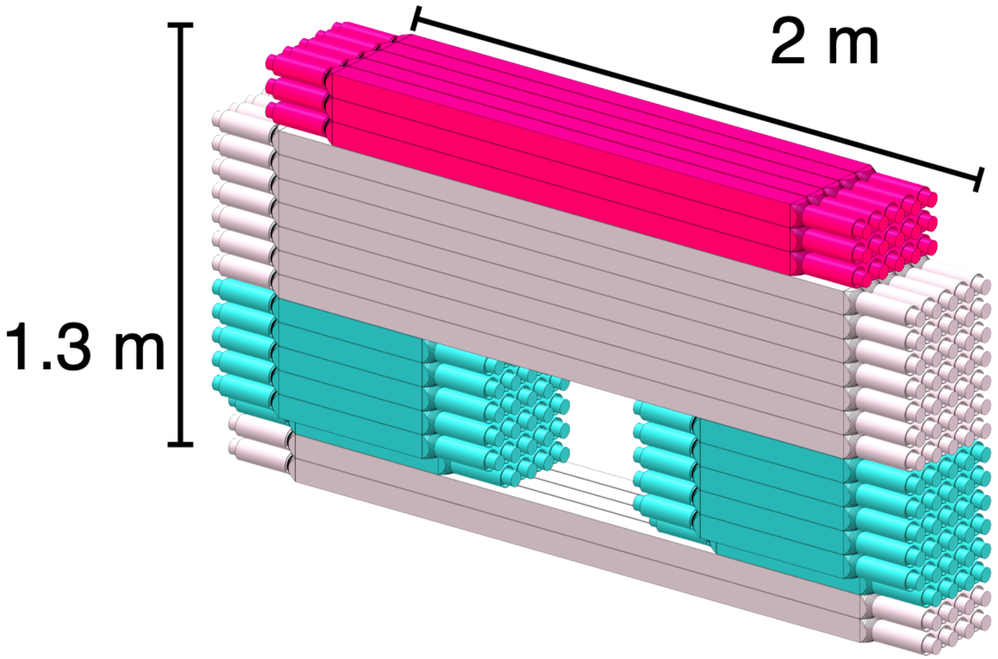
CLAS12 + Backward Angle Neutron Detector (BAND)



Backward Angle Neutron Detector

The detector:

- 140 scintillator bars
- 5 layers (+ 1cm thick veto)
- 3 meters upstream of target
- Lead wall downstream



Segarra et al., NIM A978 (2020)

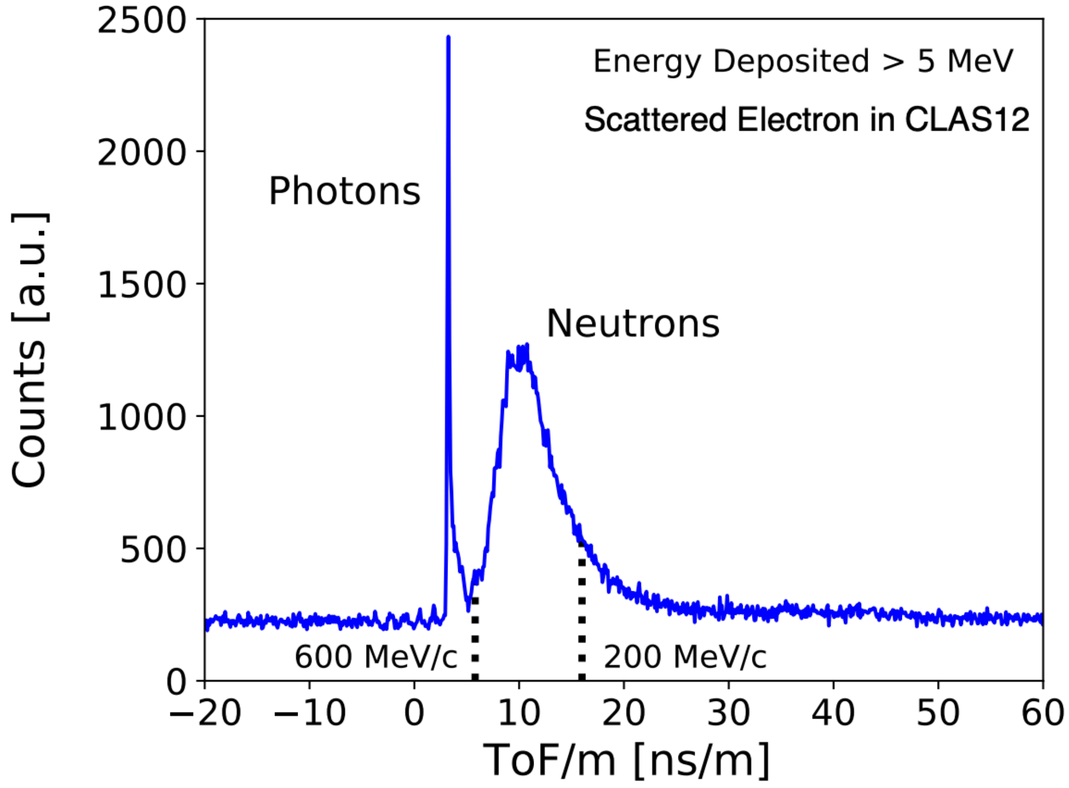
Backward Angle Neutron Detector

The detector:

- 140 scintillator bars
- 5 layers (+ 1cm thick veto)
- 3 meters upstream of target
- Lead wall downstream

The neutrons:

- Time resolution < 250 ps
- $\theta \sim$ 155-175°
- $p \sim 200 - 600$ MeV/c



Segarra et al., NIM A978 (2020)

Tagged DIS with BAND

RGB: $d(e, e'n)$ at 10.2, 10.4, and 10.6 GeV

Event mixing to subtract random coincidence background

Electron:

$Q^2 > 2$ GeV^2

$W > 2$ GeV^2

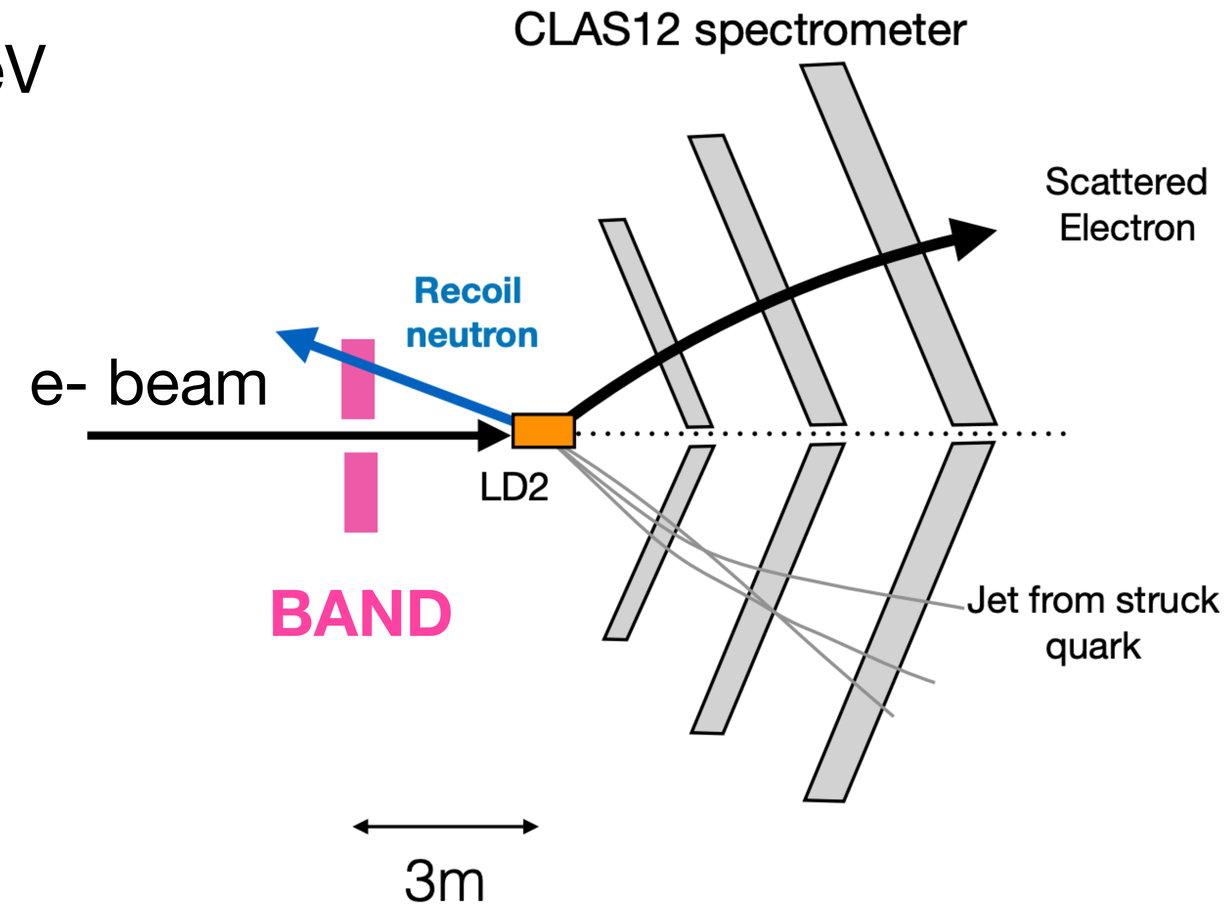
$p_e > 3$ GeV/c

Neutron:

$W'^2 > 1.8$ GeV^2

$.1 < p_n < .6$ GeV/c

$E_{dep} > 5$ MeVee



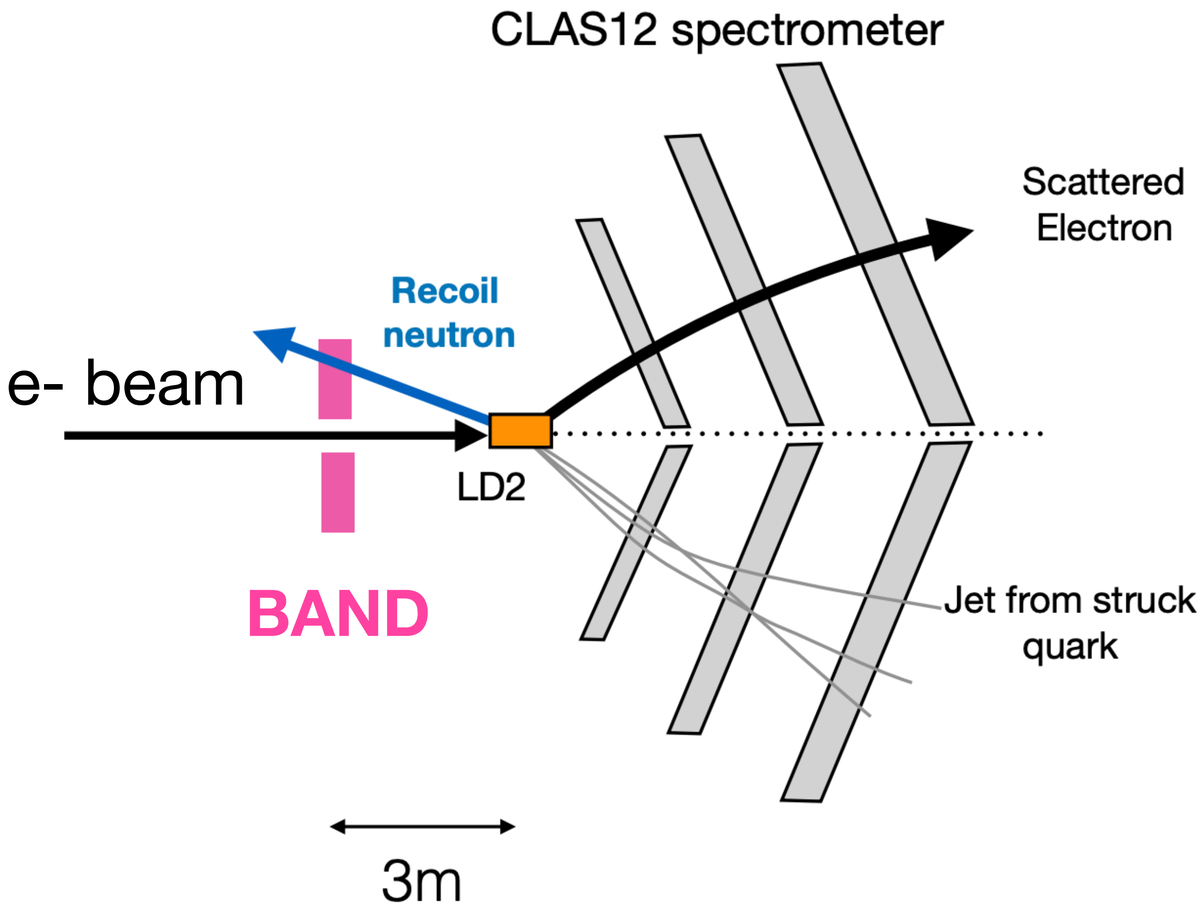
Tagged DIS with BAND

<u>As of early 2025:</u>

- Data analyzed, reasonable physics signal, analysis note in review

- Factor of ~10 data/sim discrepancy (though efficiency not well-studied)

- A few other unresolved issues, including anomalous bumps at 34, 58 ns



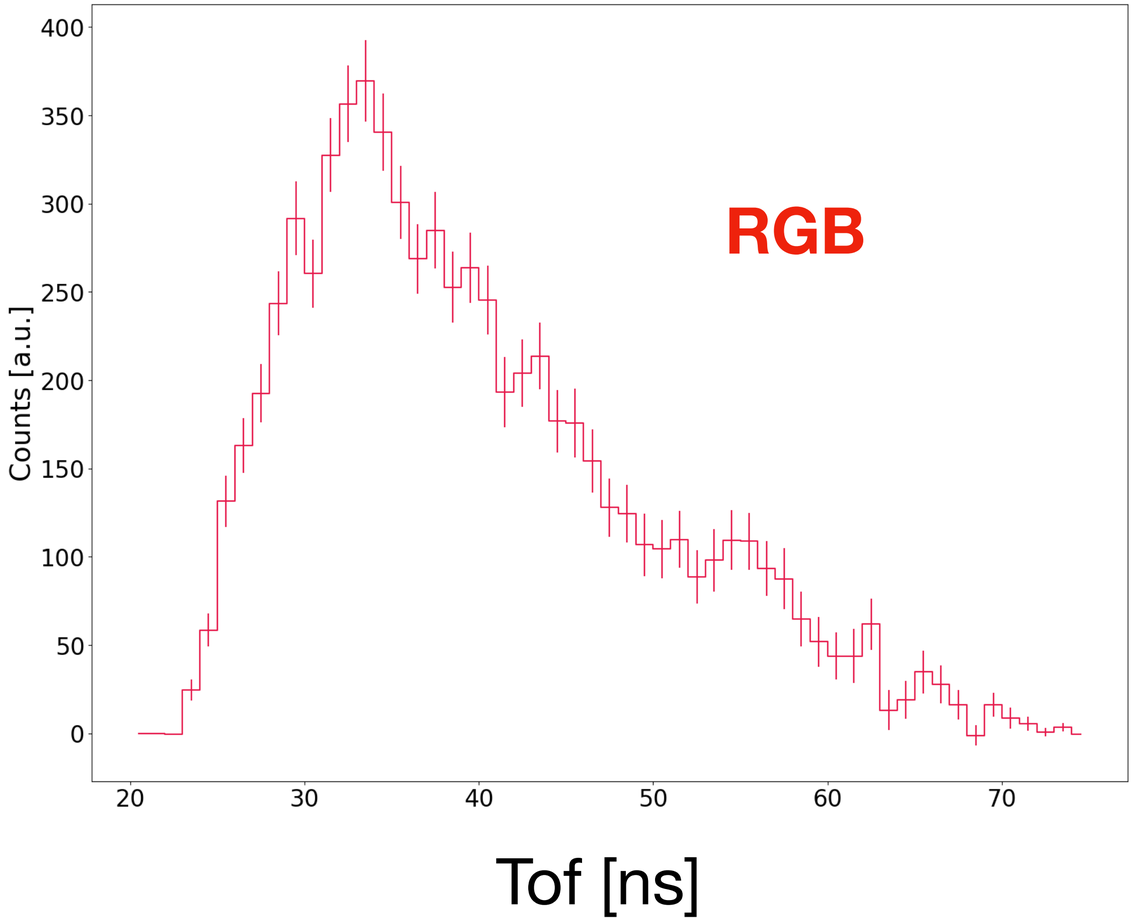
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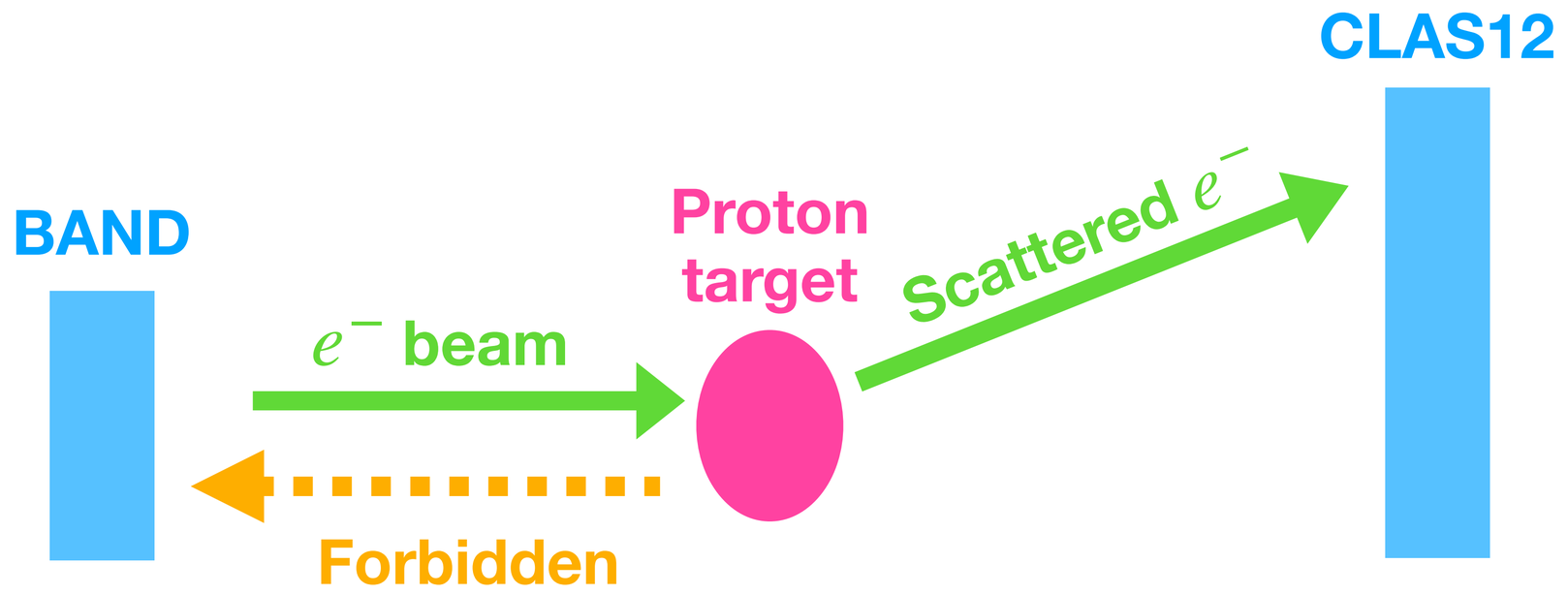
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- A few other unresolved issues, including anomalous bumps at 34, 58 ns



Correlated background?

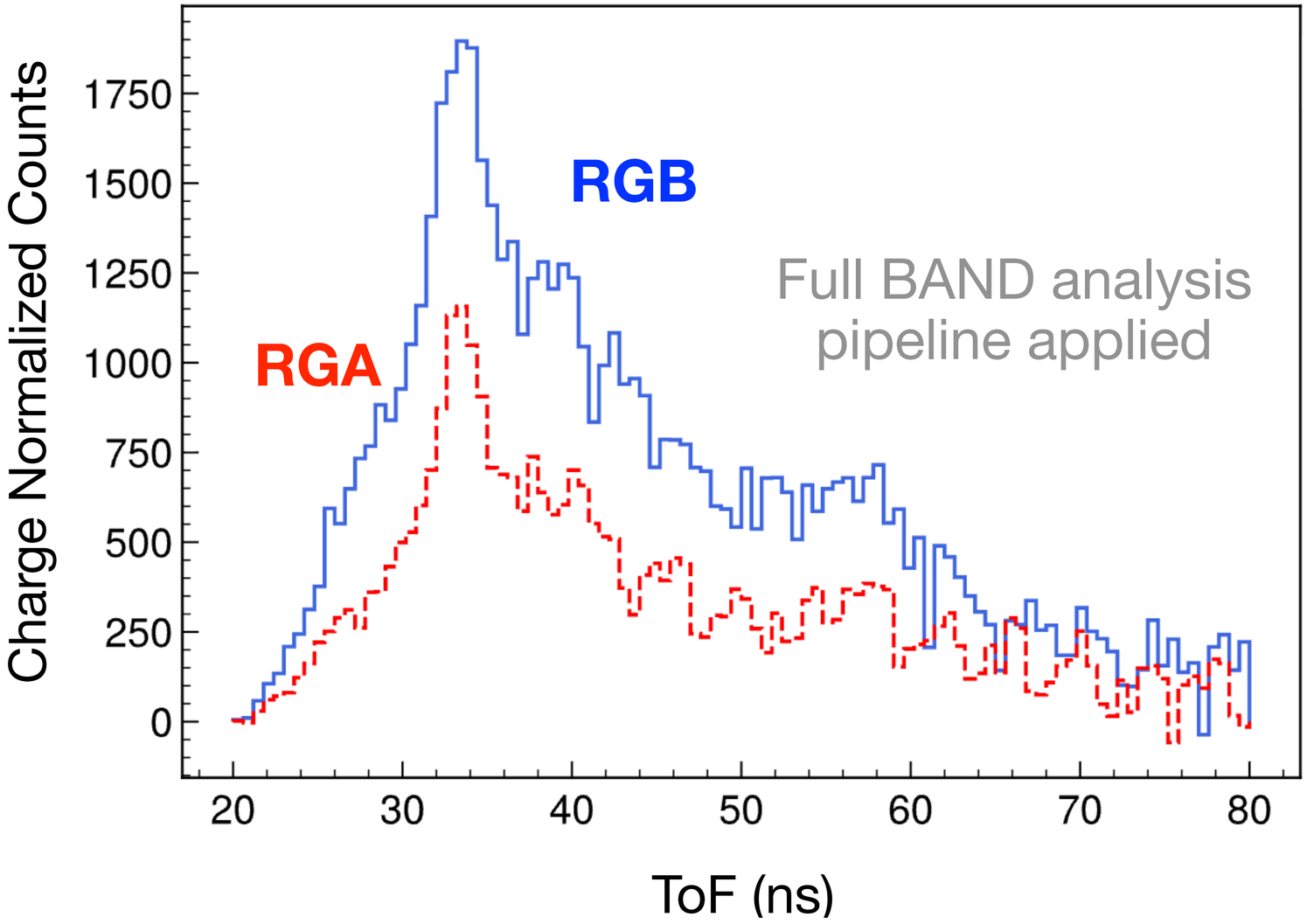
Correlated Background via RGA



Kinematics: Neutrons from primary interaction **CANNOT** go backward

→ Any signal in RGA $H(e, e'n_{back})$ is non-physics background

Correlated Background via RGA



Correlated Background via RGA

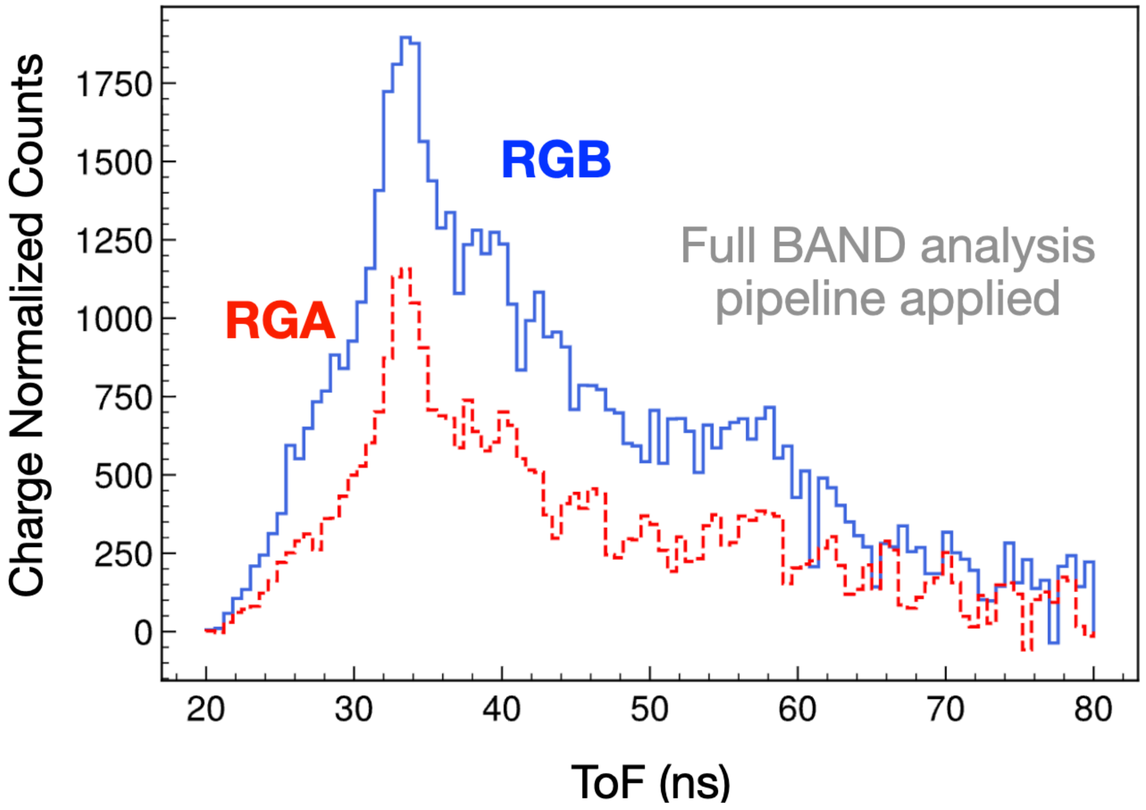
What we know:

- Not a neutron from primary interaction

- Associated with DIS electron

- Sharp peak around 34 ns → timing compatible with γ's from secondary interactions with detector material

- CLASDIS simulation reproduces shape



Correlated Background via RGA

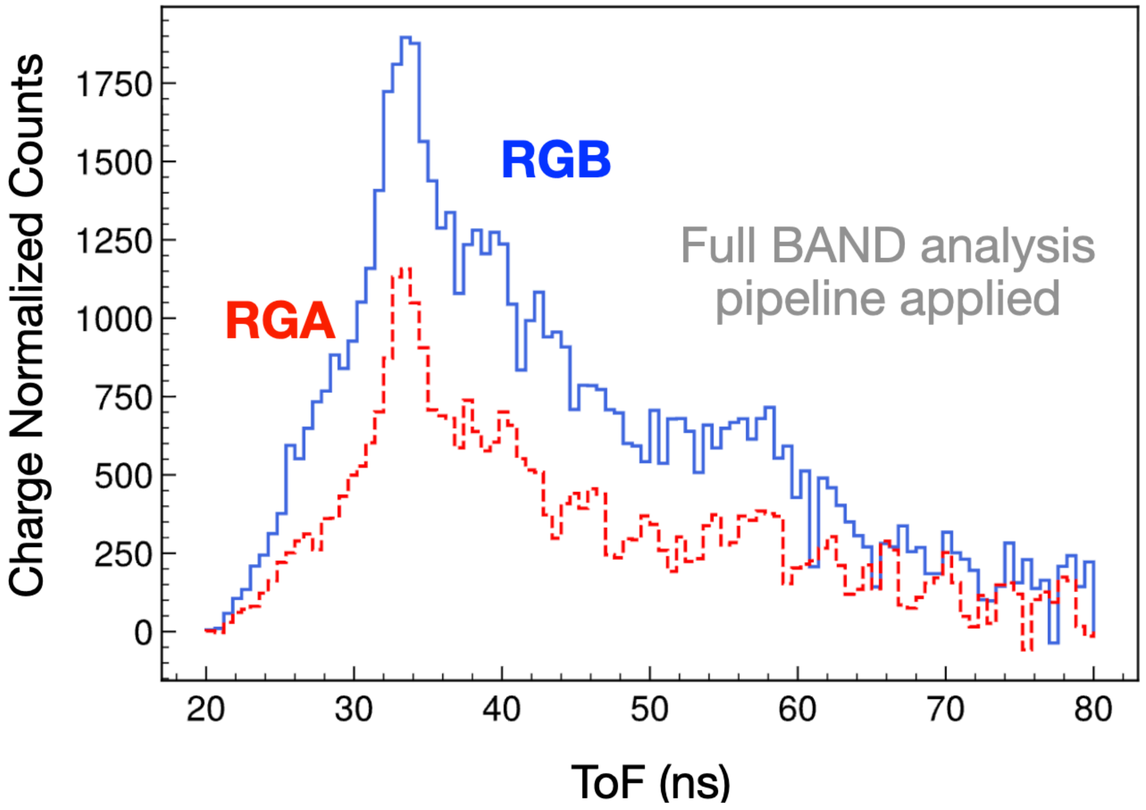
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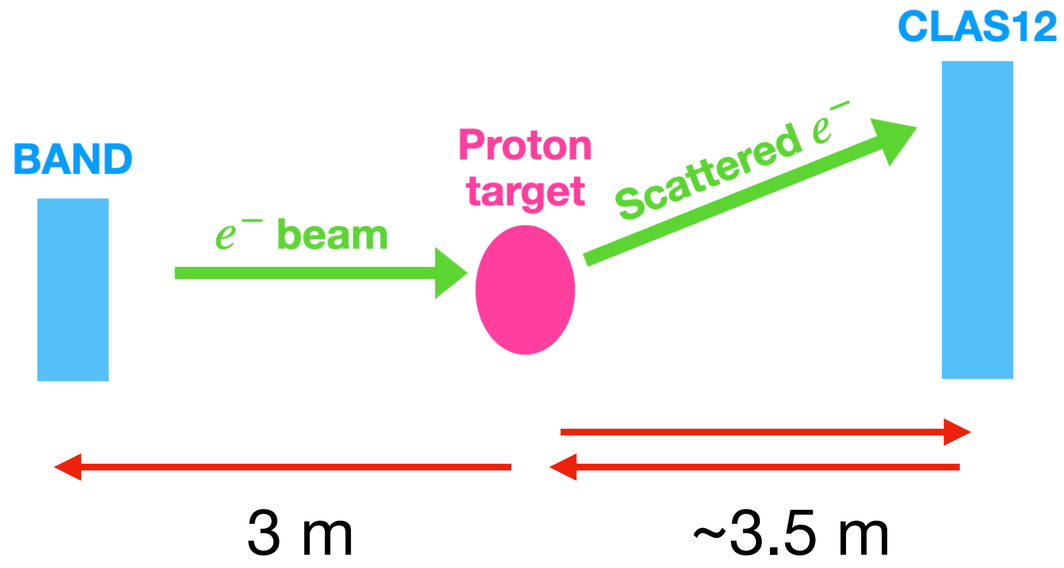
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- CLASDIS simulation reproduces shape



Total path = 10 meters

If v≈c, t = 33.4 ns

Correlated Background via RGA

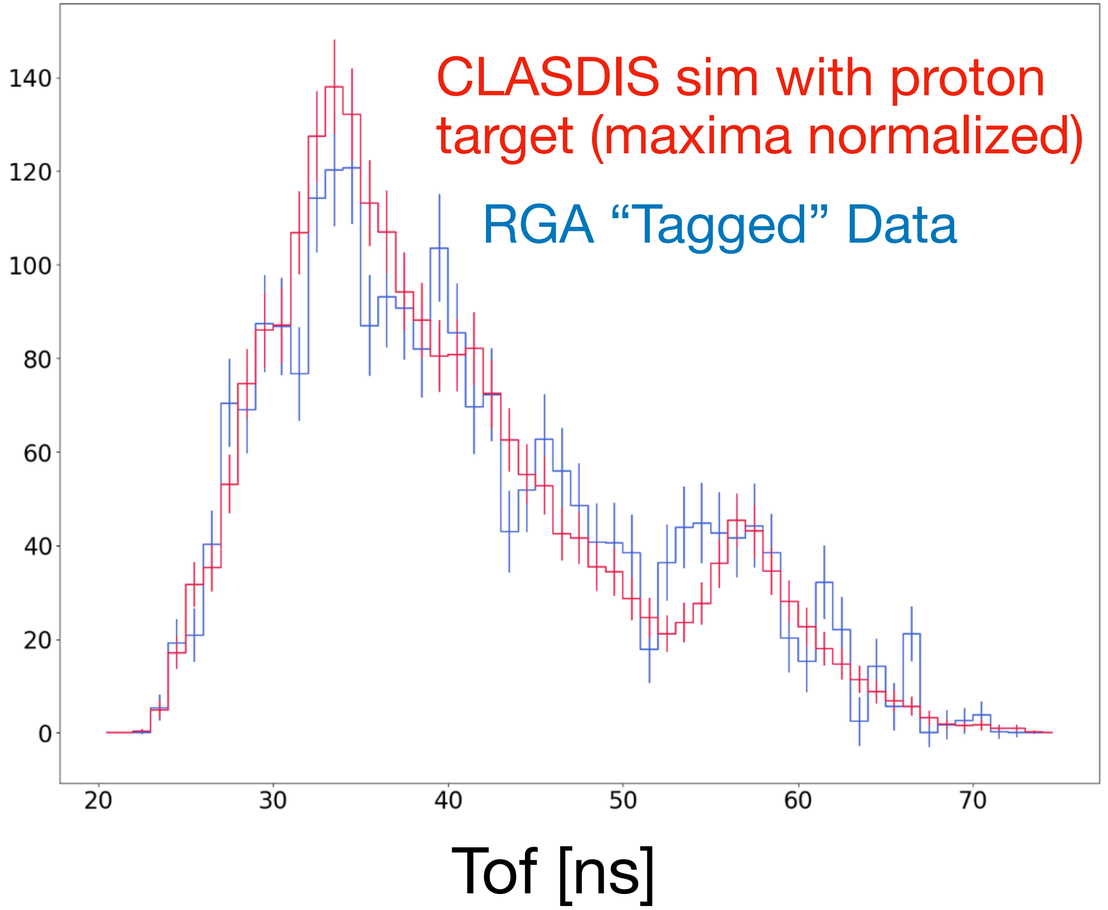
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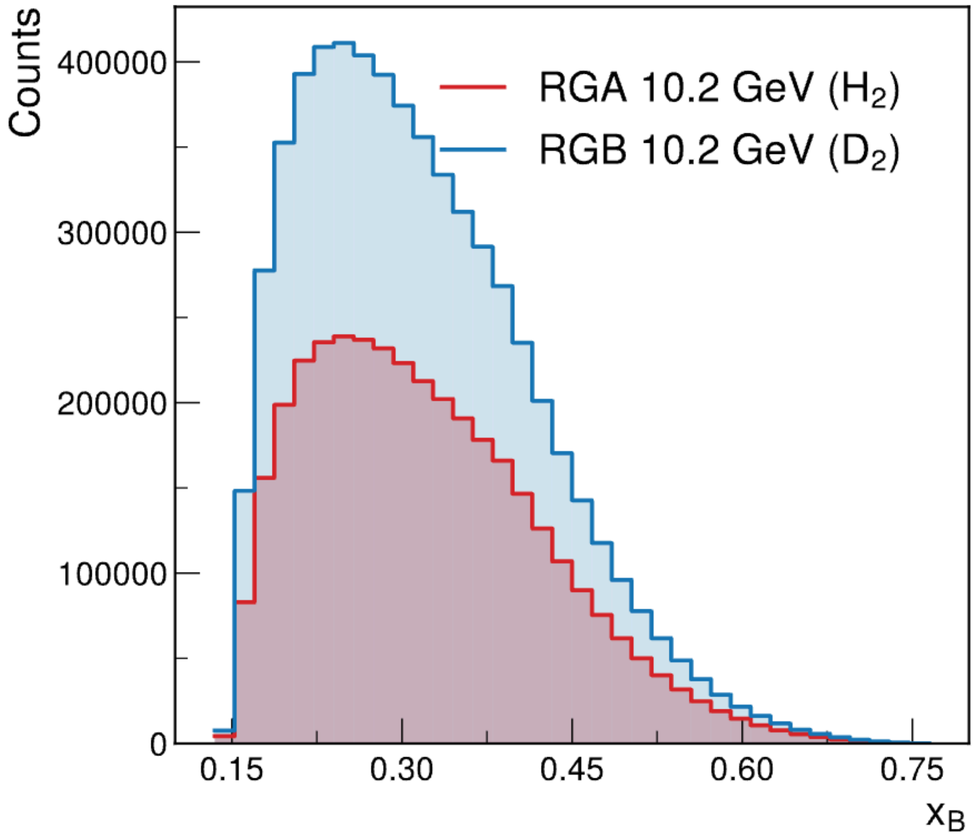


ep SIDIS MC → GEMC reconstruction → Signal in BAND

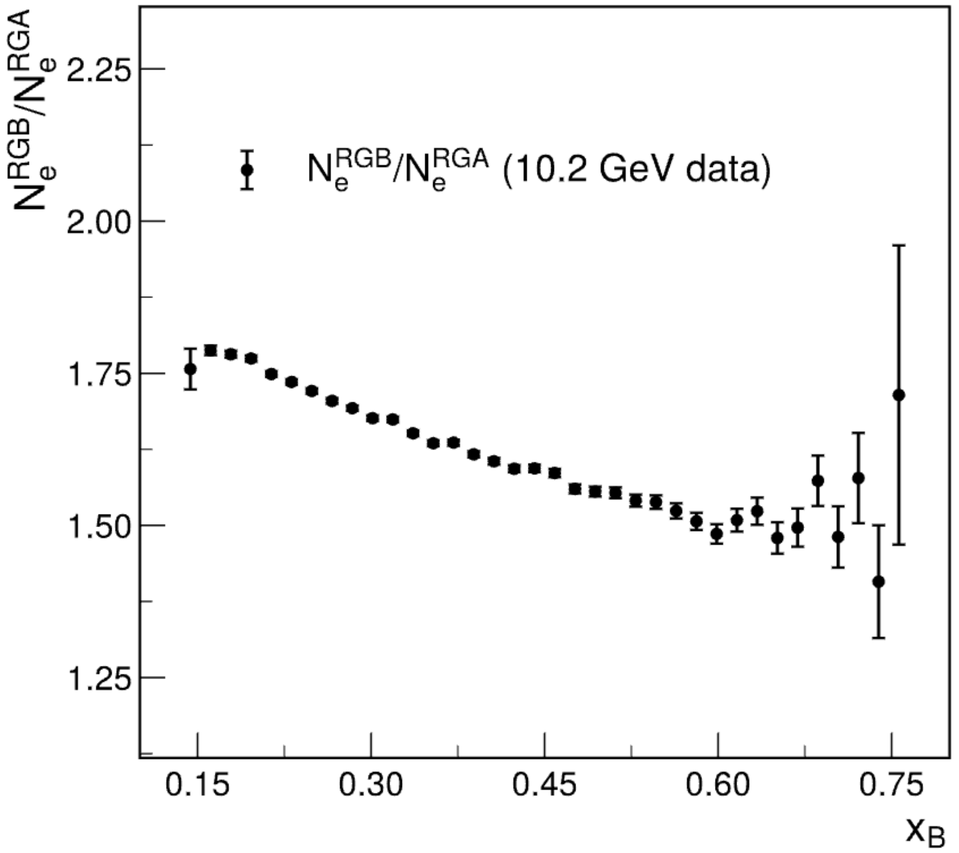
Scaling RGA data to subtract: $\sigma_{ep} \rightarrow \sigma_{ed}$

Account for luminosity and cross section simultaneously with inclusive yield ratio

(e,e') for Q2 > 2 and W2 > 4

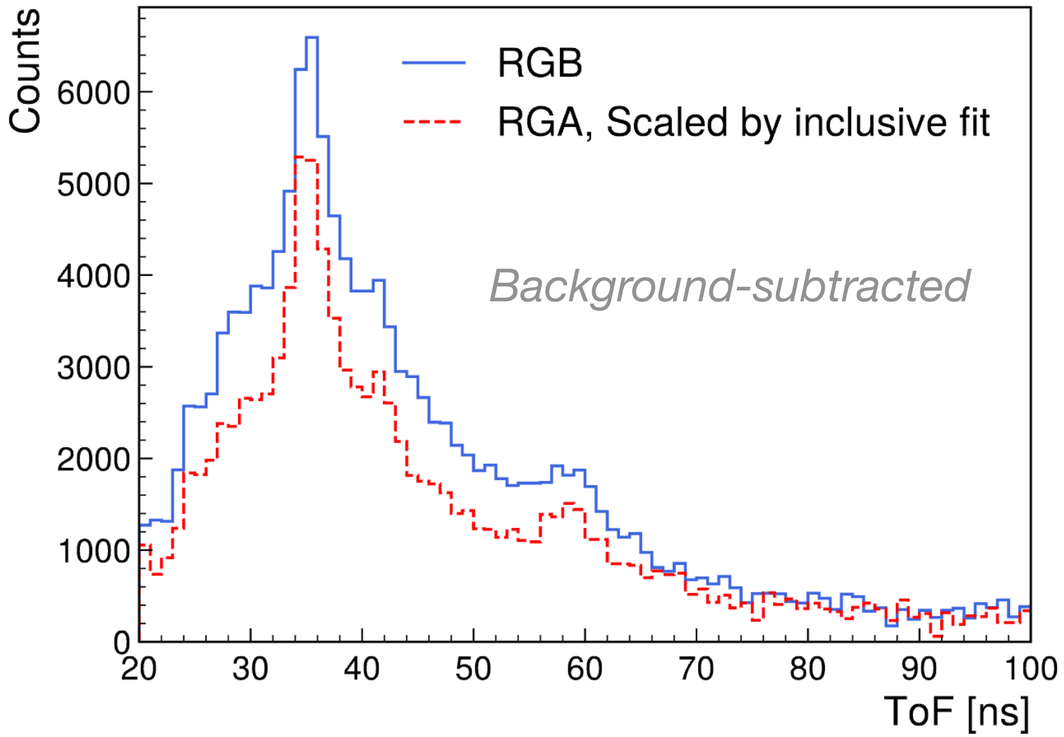


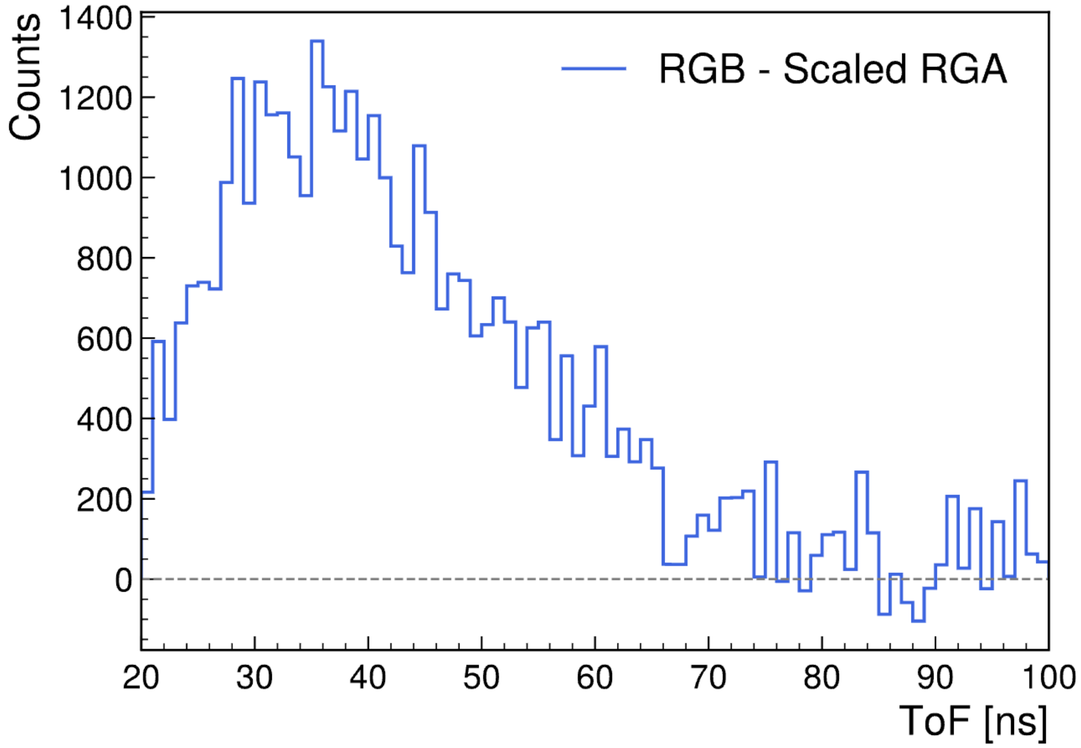
Ratio



RGB, Scaled RGA 10.2 GeV (e,e’n) Comparison

With neutron fiducial cuts + DIS only (no tagged kinematic cuts):





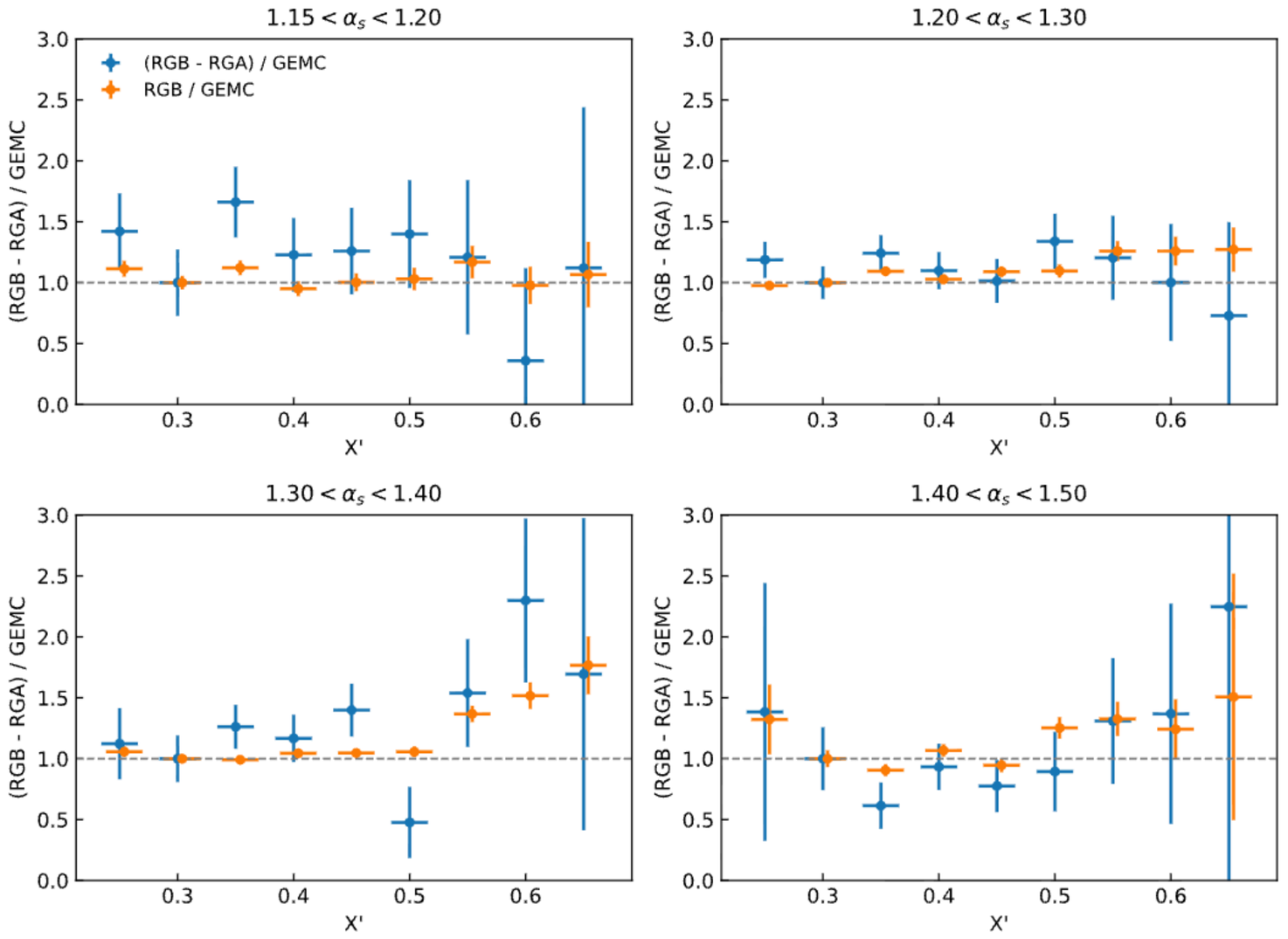
- Scaled background makes up ~75% of signal
- Subtracted spectrum more realistic, anomalous peaks at 34 and 58 ns eliminated

Subtraction does not change 10.2 GeV results

Yellow: Previous unsubtracted result

Blue: Result after RGA subtraction

$$\frac{Y_{Data}(\alpha_s,\, x')/Y_{Data}(\alpha_s,\, 0.3)}{Y_{Sim}(\alpha_s,\, x')/Y_{Sim}(\alpha_s,\, 0.3)}$$



Note: 10.2 GeV ≈ 1/3 of data

Modeling “Tagged” Hydrogen Background

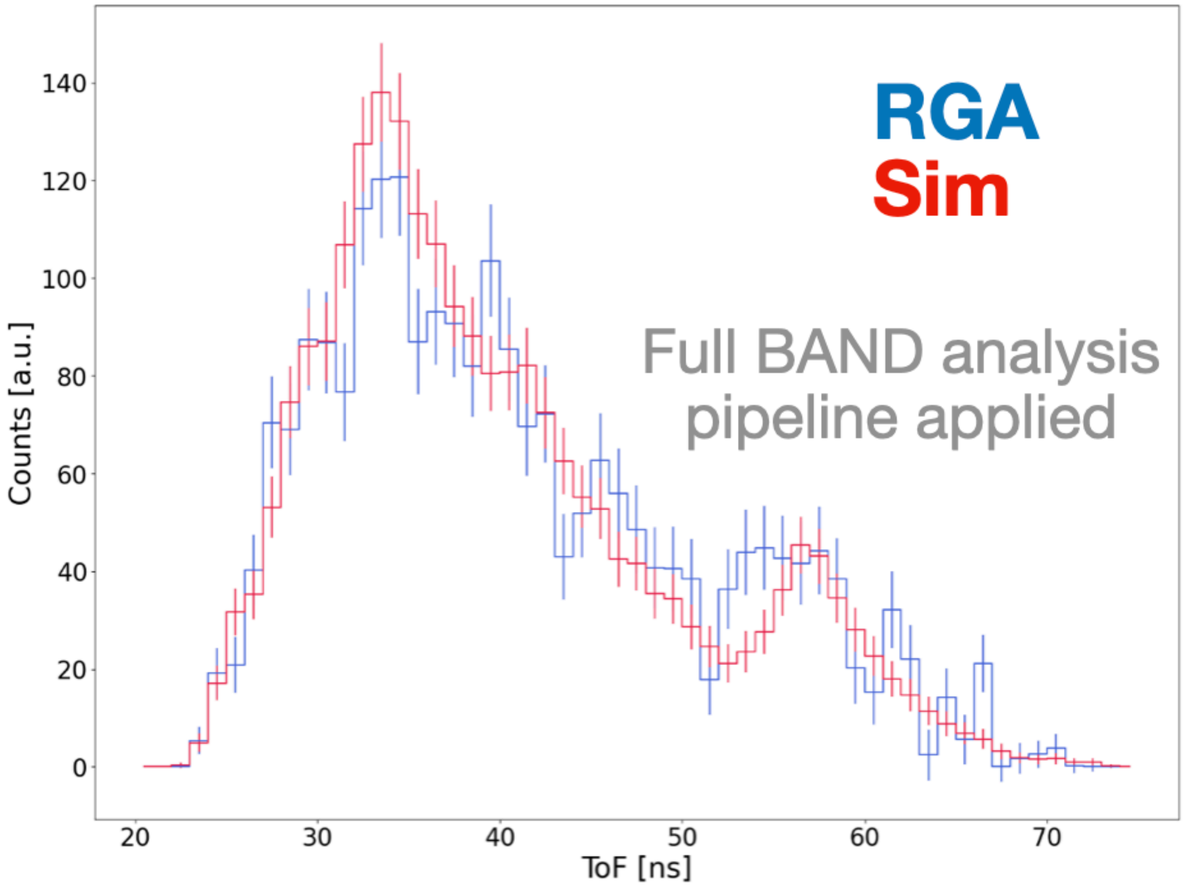
CLASDIS sim reproduces RGA ToF spectrum → Characterize background

- CLASDIS: Forward hadronization in e- scattering

- 10.2 GeV $d(e, e')$ events over full hadronic kinematic range

- No backwards neutron allowed; CLASDIS treats proton or neutron as fixed target

- Shown now: electron-proton DIS

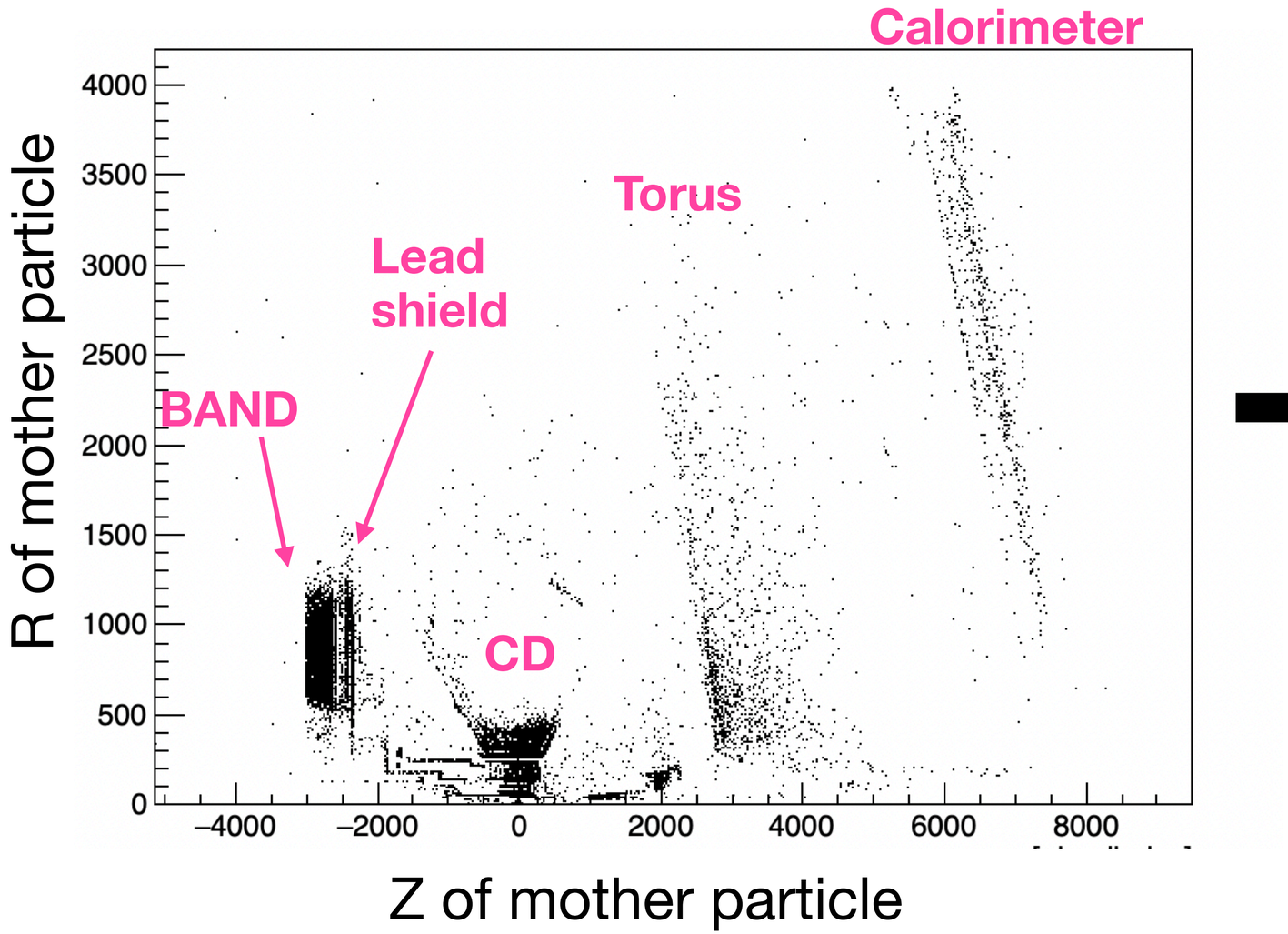


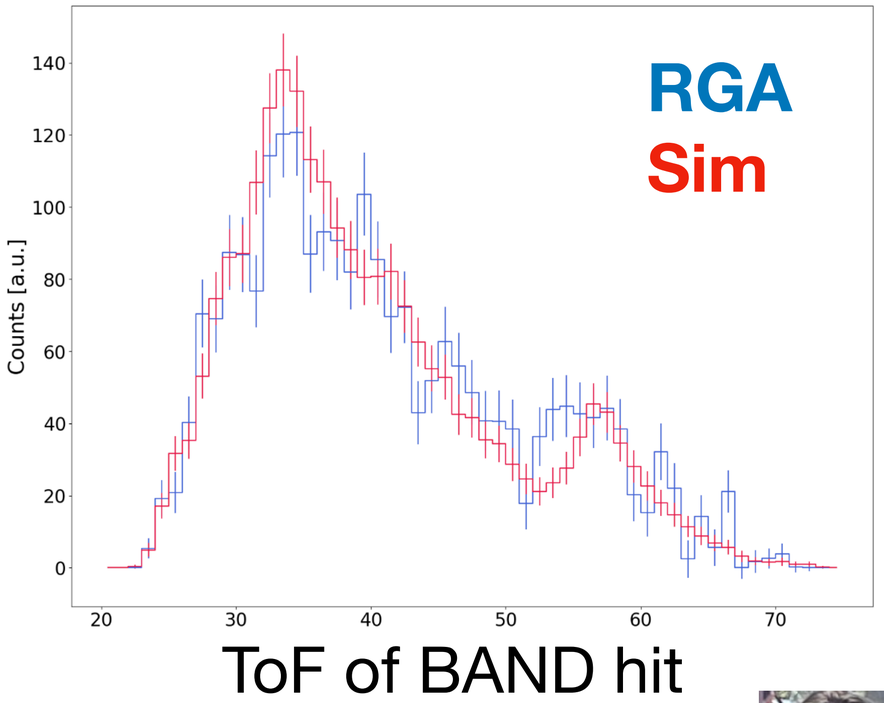


Jason Phelan

Modeling “Tagged” Hydrogen Background

CLASDIS sim reproduces RGA ToF spectrum → Characterize background



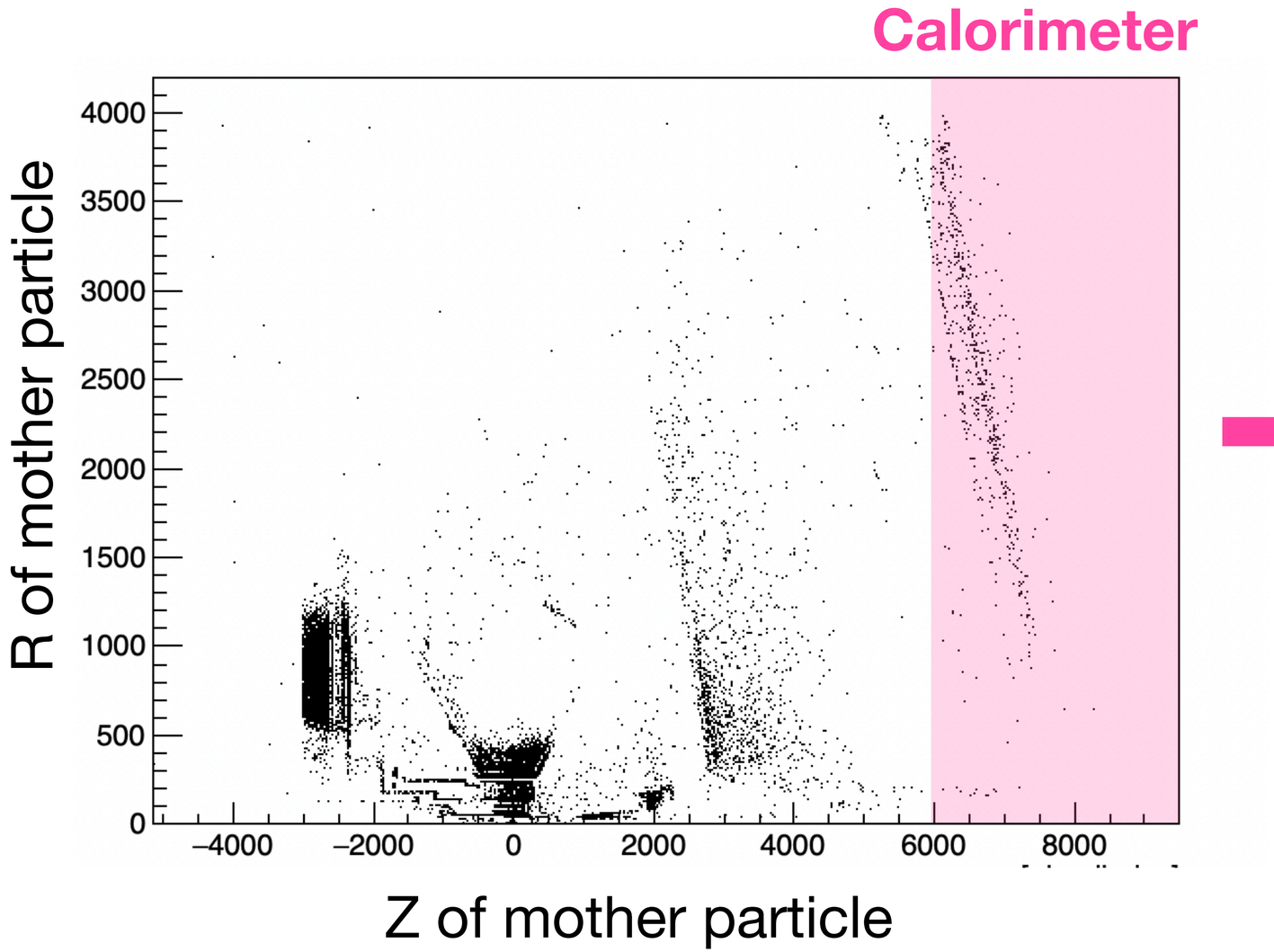


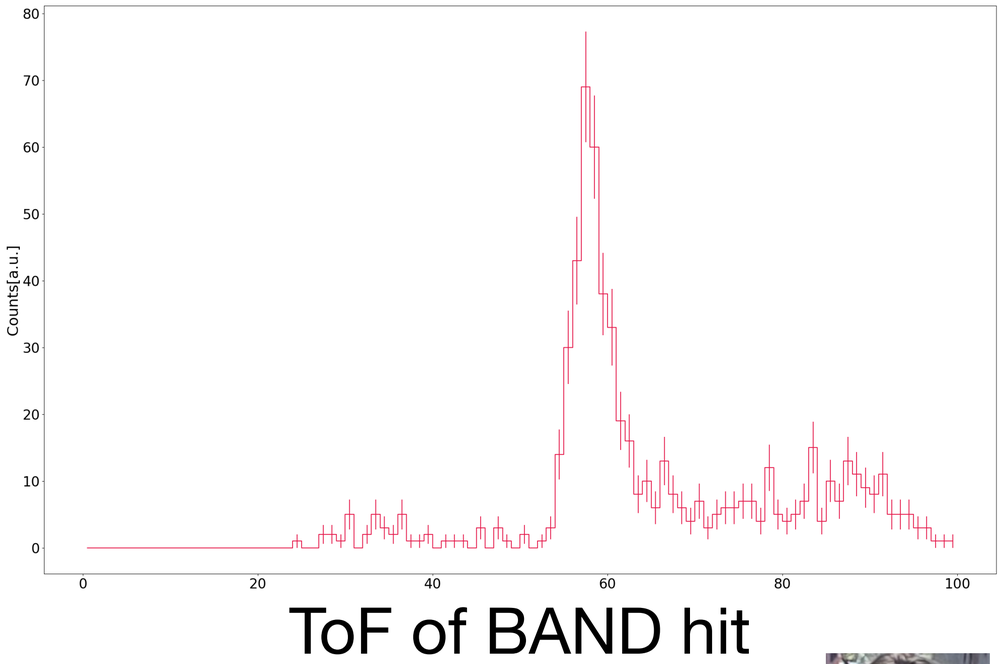


Jason Phelan

Modeling “Tagged” Hydrogen Background

CLASDIS sim reproduces RGA ToF spectrum → Characterize background



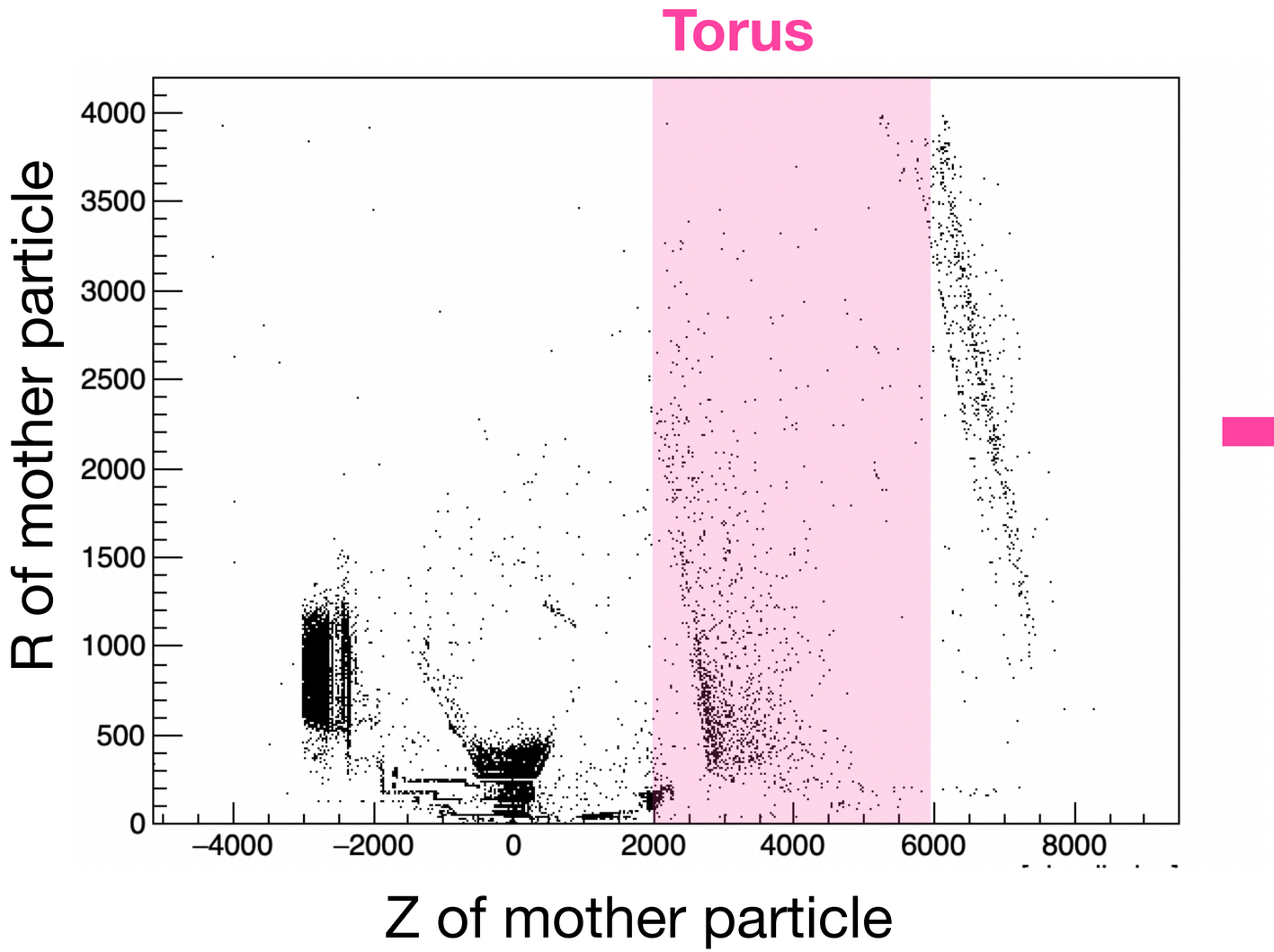


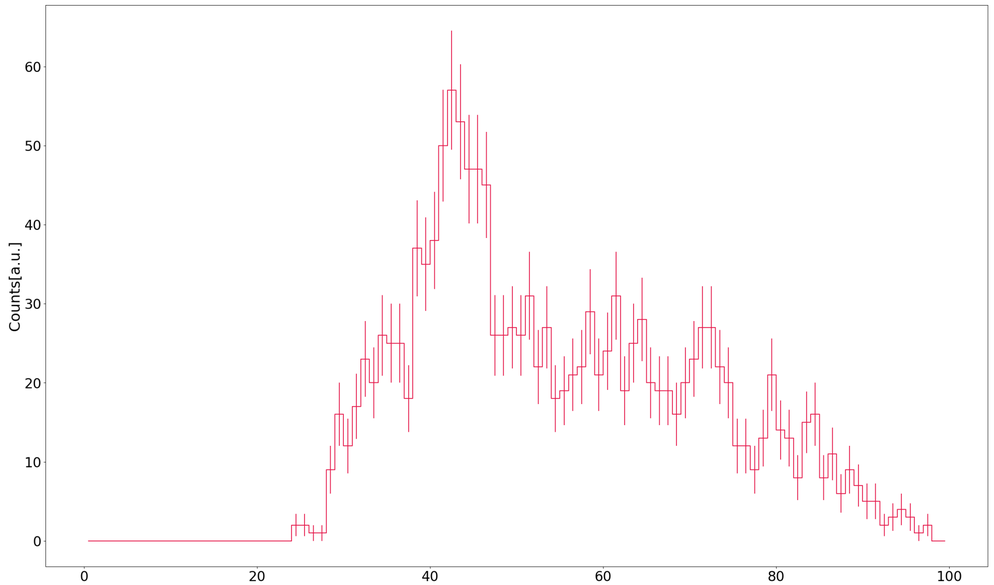


Jason Phelan

Modeling “Tagged” Hydrogen Background

CLASDIS sim reproduces RGA ToF spectrum → Characterize background





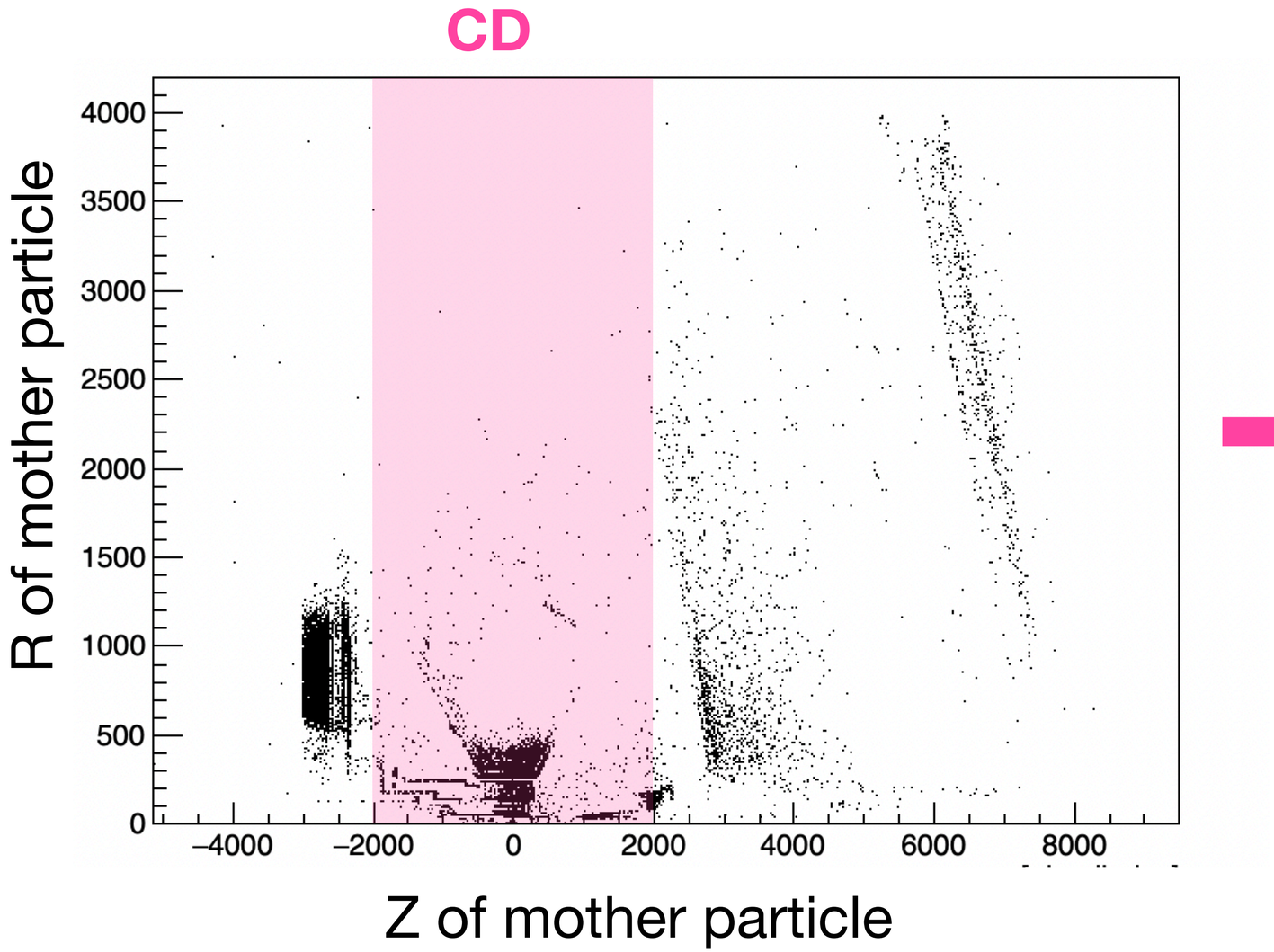
ToF of BAND hit

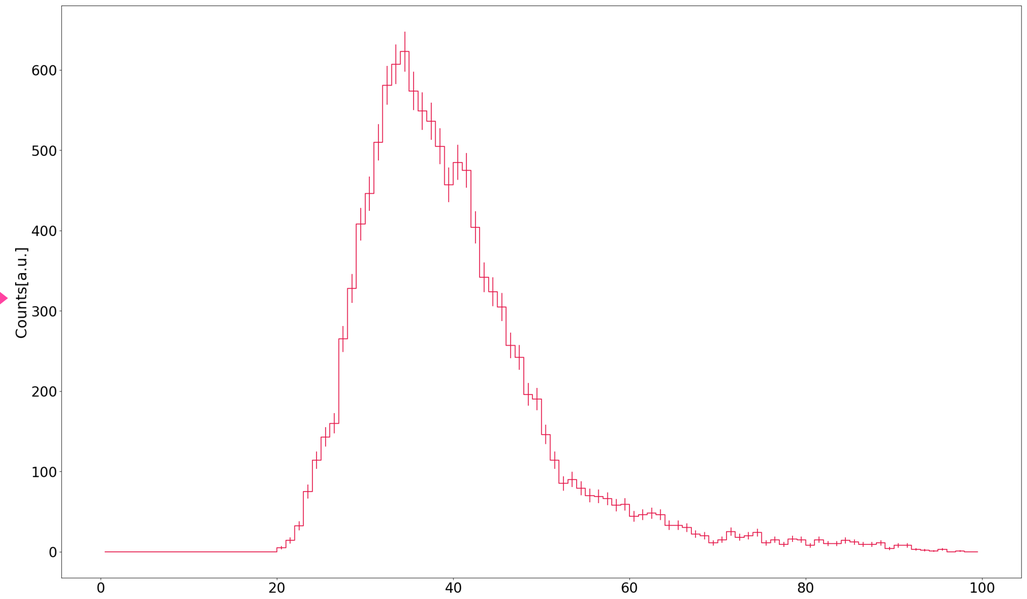


Jason Phelan

Modeling “Tagged” Hydrogen Background

CLASDIS sim reproduces RGA ToF spectrum → Characterize background





ToF of BAND hit

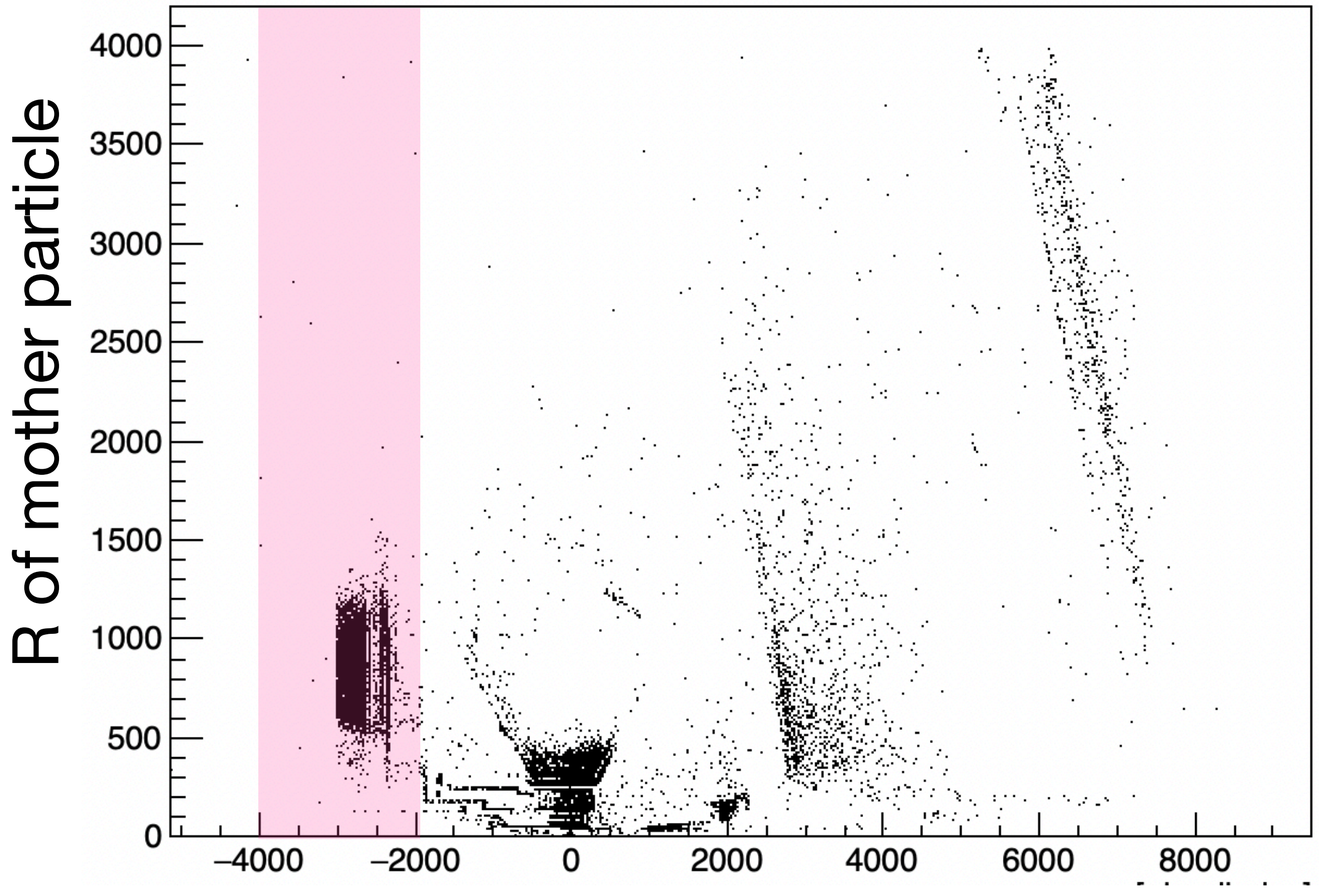


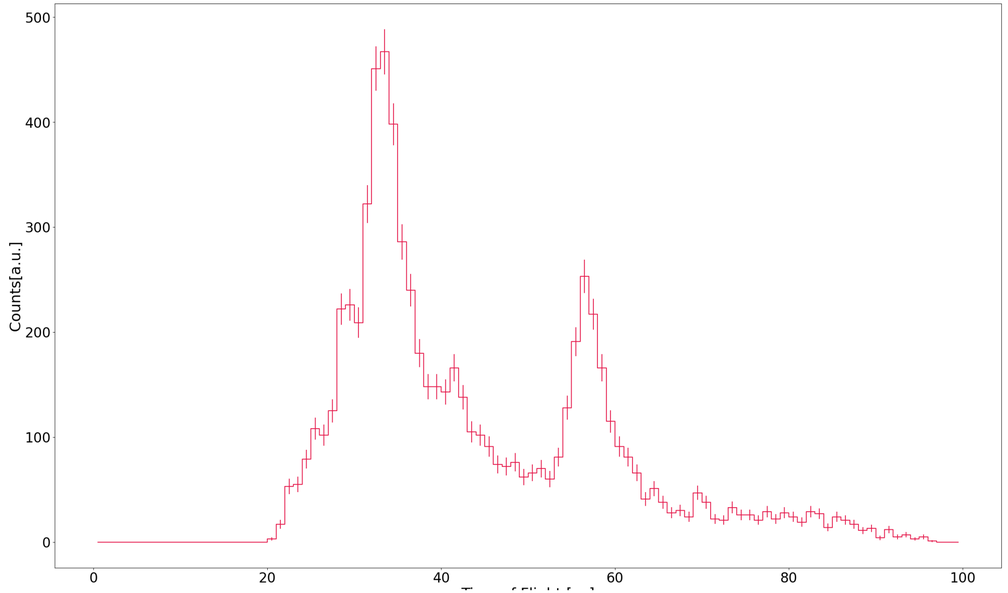
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Modeling “Tagged” Hydrogen Background

CLASDIS sim reproduces RGA ToF spectrum → Characterize background

BAND + Lead shield





ToF of BAND hit



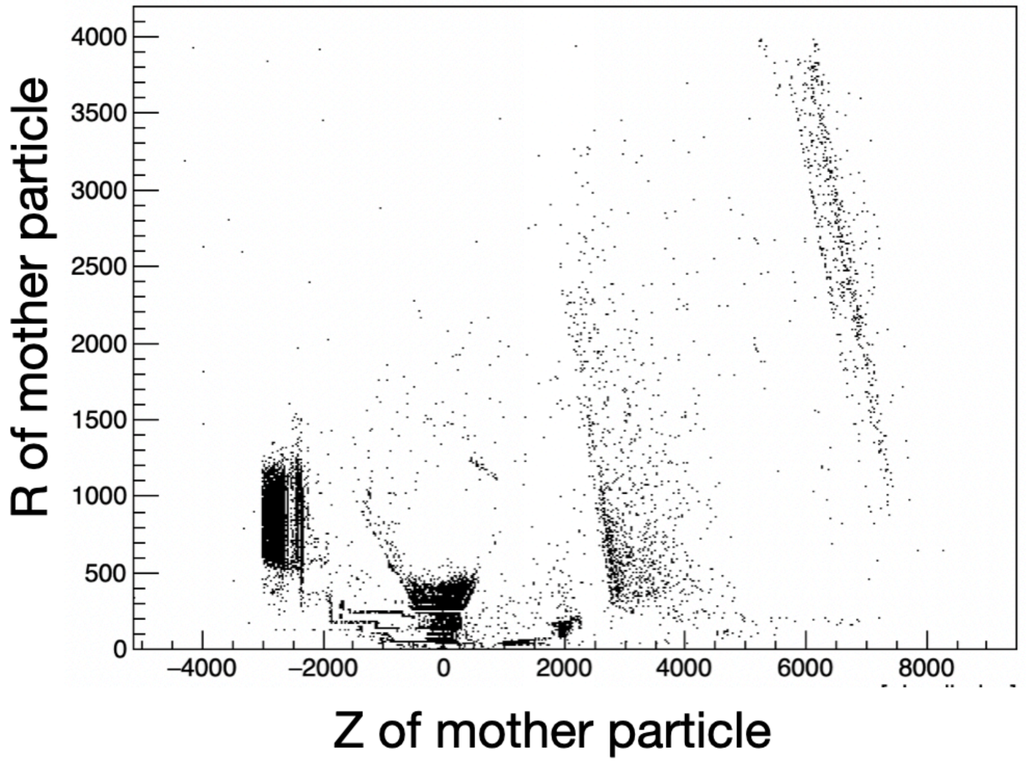
Jason Phelan

Modeling “Tagged” Hydrogen Background

Simulation Outlook

CLASDIS sim goals:

1. Characterize correlated background

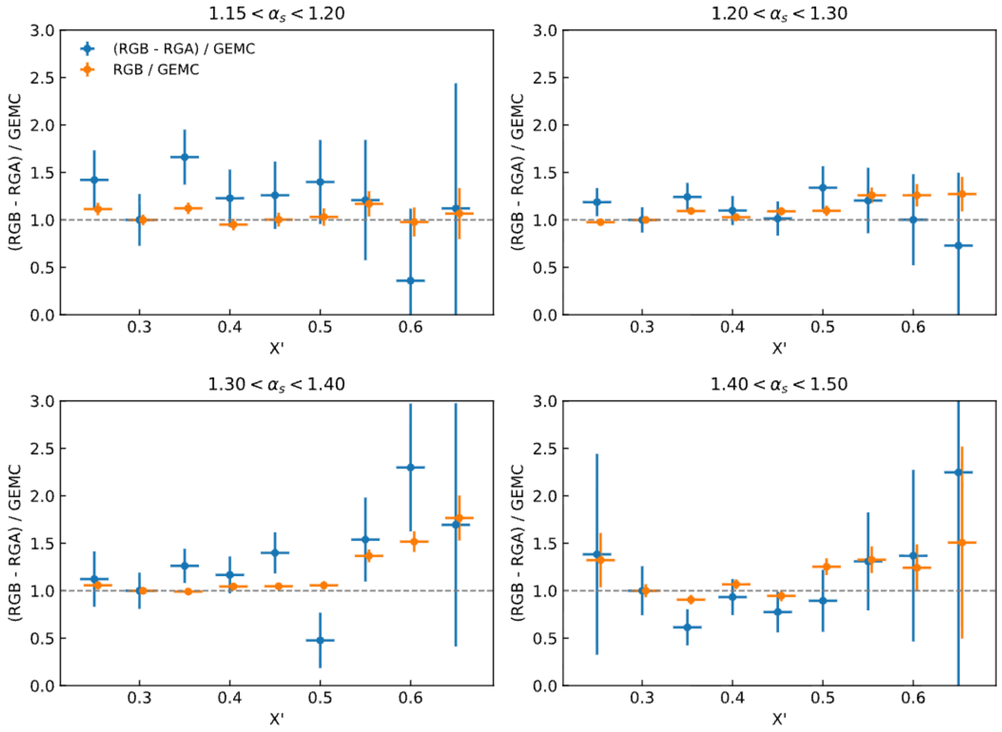


Modeling “Tagged” Hydrogen Background

Simulation Outlook

CLASDIS sim goals:

1. Characterize correlated background
2. **Supplement finite $H(e, e' n_{back})$ stats**



Modeling “Tagged” Hydrogen Background

Simulation Outlook

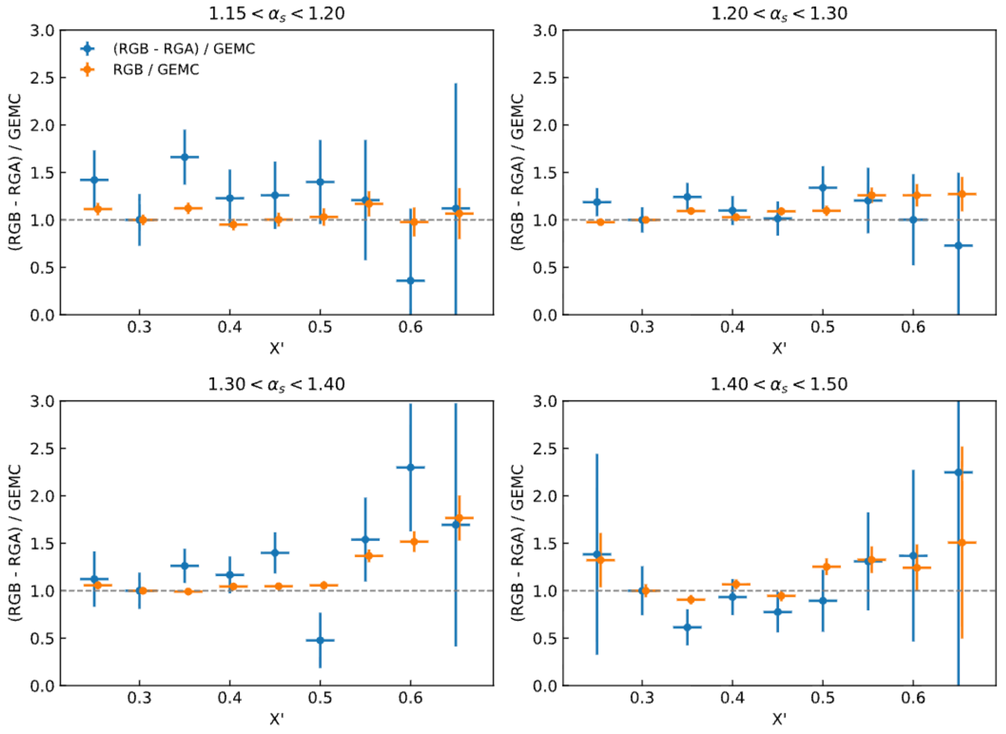
CLASDIS sim goals:

1. Characterize correlated background
2. **Supplement finite $H(e, e'n_{back})$ stats**

Goal: 5-10x RGB BAND stats

For every 10k generated, 1 $H(e, e'n_{back})$ event

Currently: 1x RGB BAND stats. More to go!



In Summary…

- Goal: Modified proton structure function as function of virtuality $\sim F_2^{p*}(x', \alpha_s)$

- Time correlated background: Neutrals in BAND from forward rescattering
  - Characterized by kinematically forbidden $H(e, e'n_{back})$
  - Subtraction improves ToF distribution, doesn't significantly alter final result
  - Data and sim consistent
  - Need more statistics!

Next up for BAND:

- Continue generating "tagged" hydrogen events
- Validate sim with data, then use for subtraction
- Fully update analysis note and resubmit!

In Summary…

- Goal: Modified proton structure function as function of virtuality $\sim F_2^{p*}(x', \alpha_s)$

- Time correlated background: Neutrals in BAND from forward rescattering
  - Ch
  - Su
  - Da
  - Neu

result

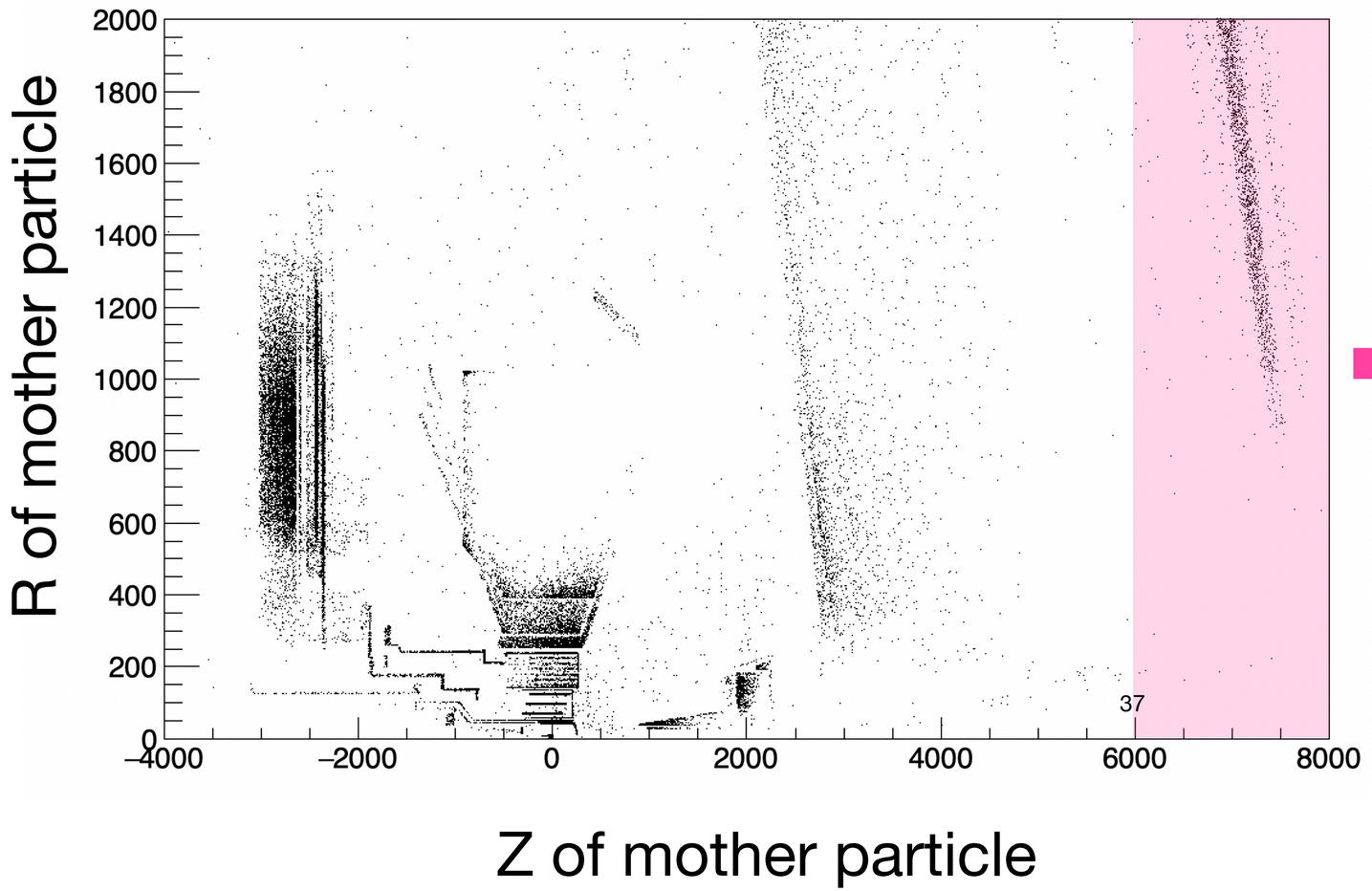
Thank you!

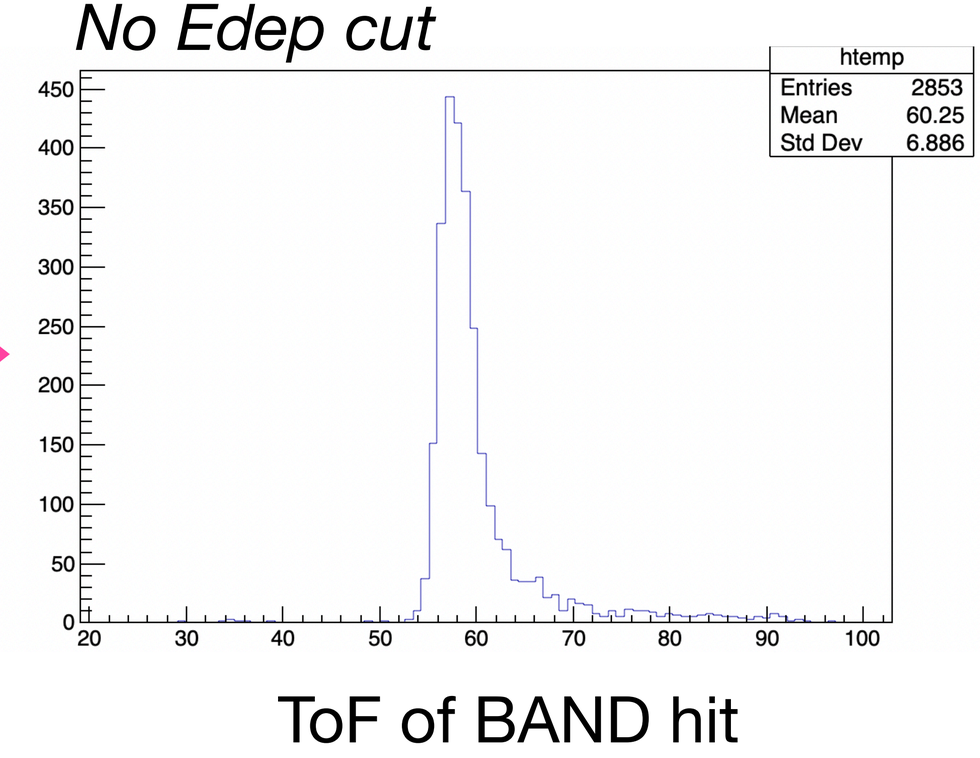
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- Fully update analysis note and resubmit!

Modeling “Tagged” Hydrogen Background

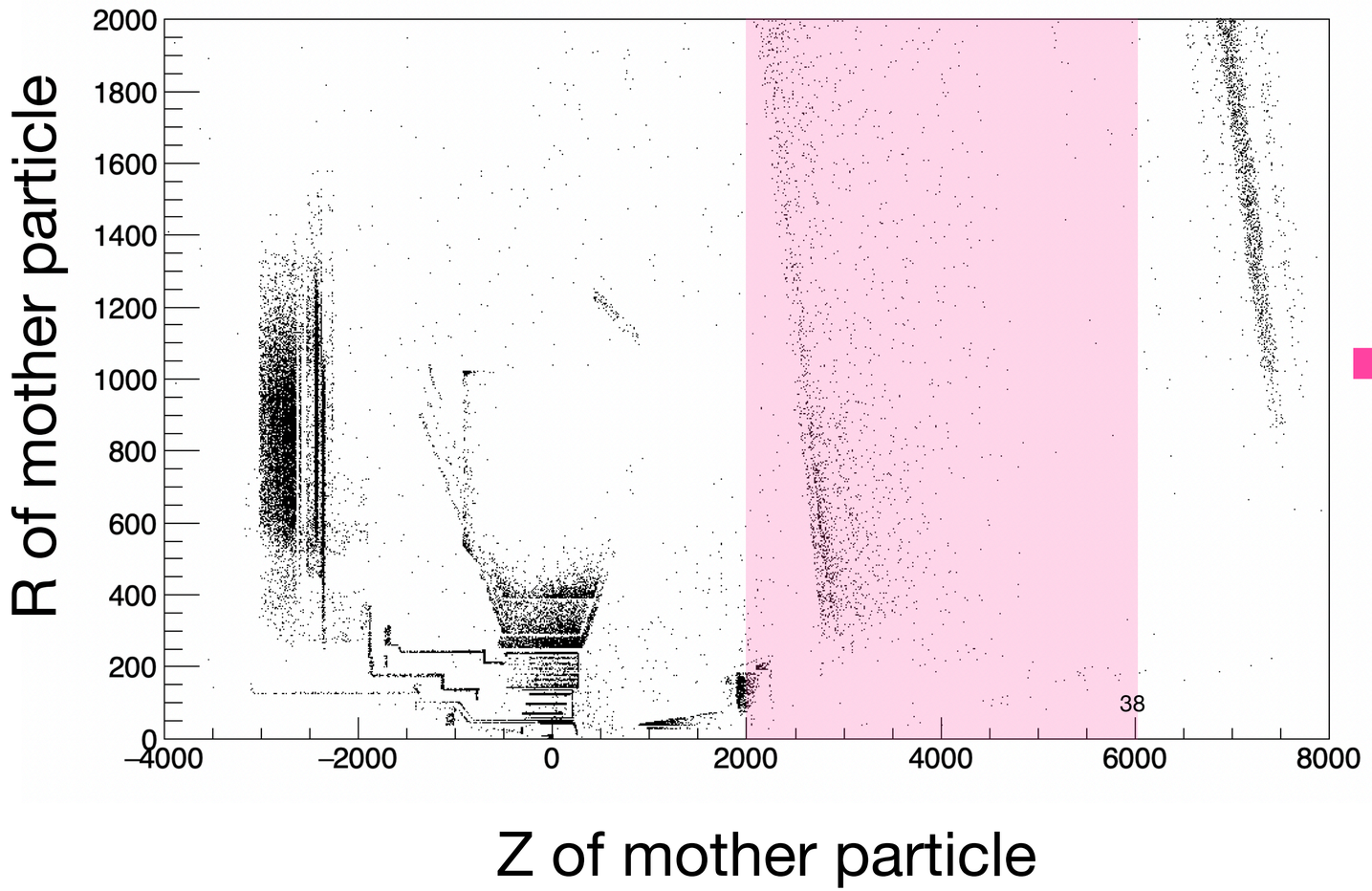
CLASDIS sim reproduces RGA ToF spectrum → Characterize background

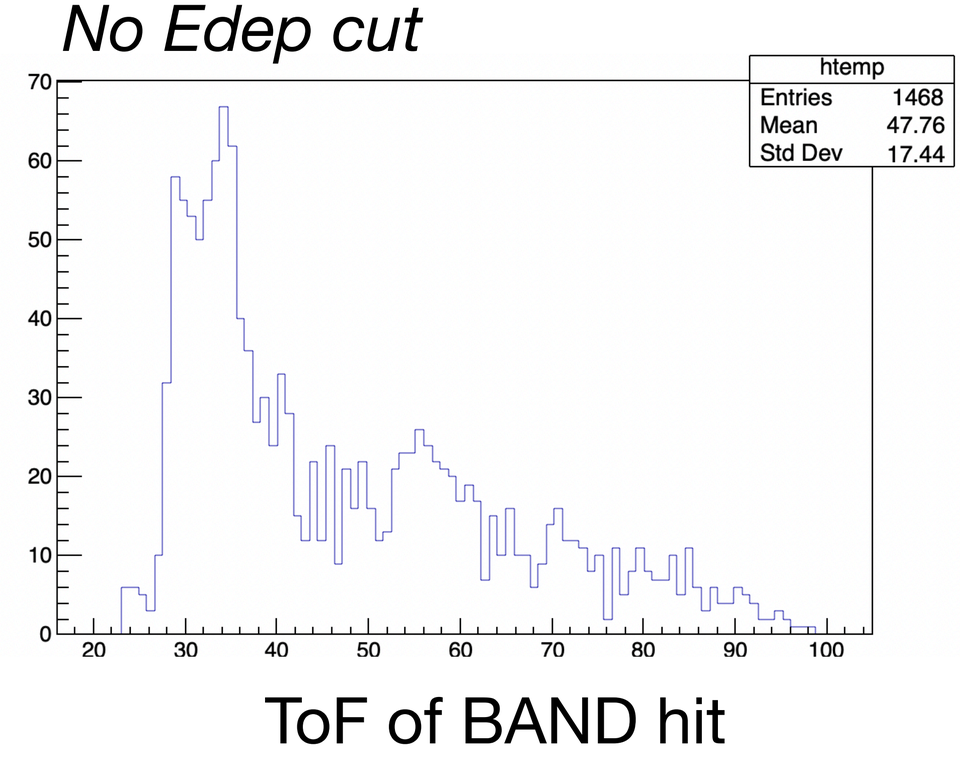




Modeling “Tagged” Hydrogen Background

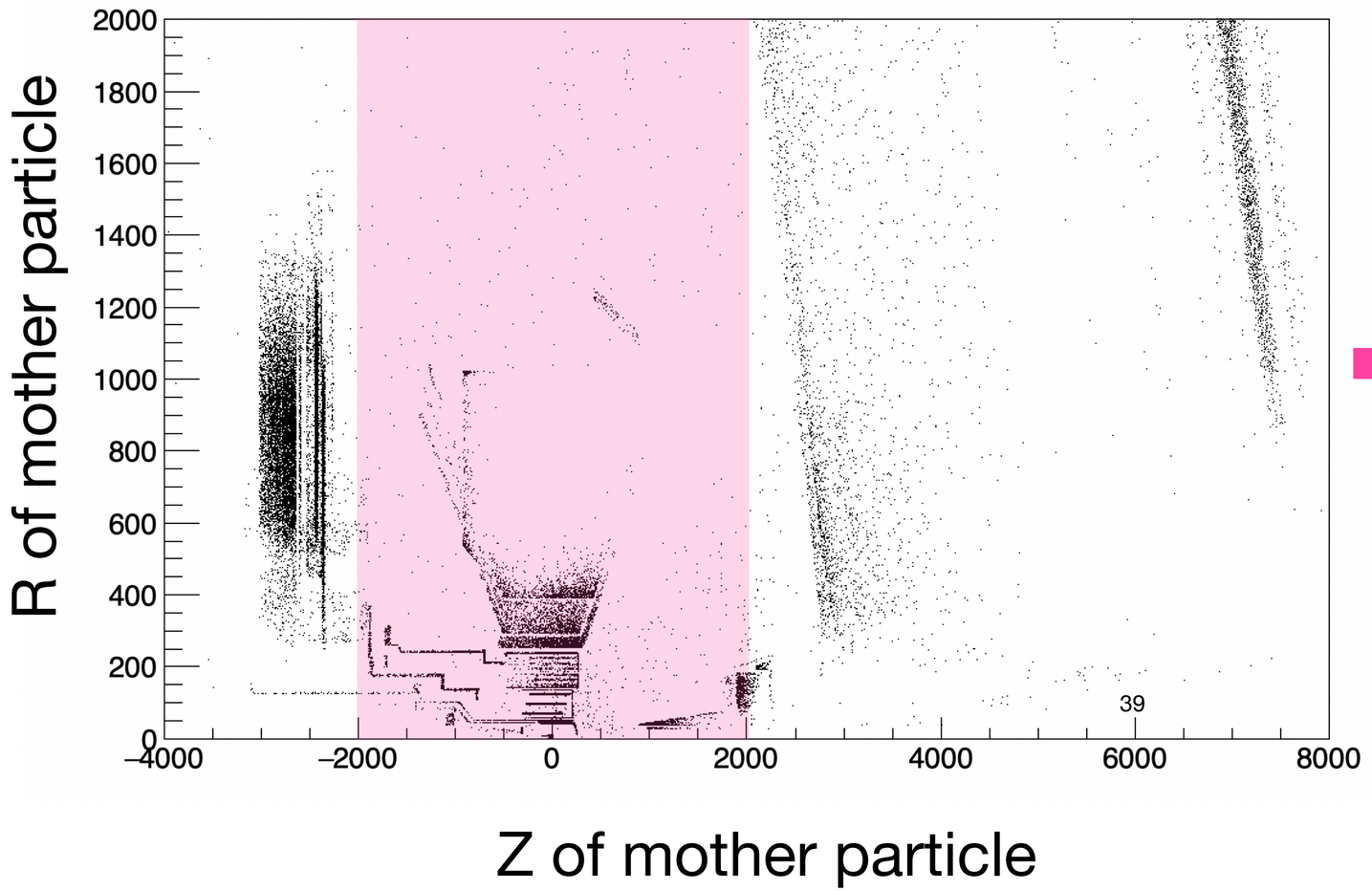
CLASDIS sim reproduces RGA ToF spectrum → Characterize background

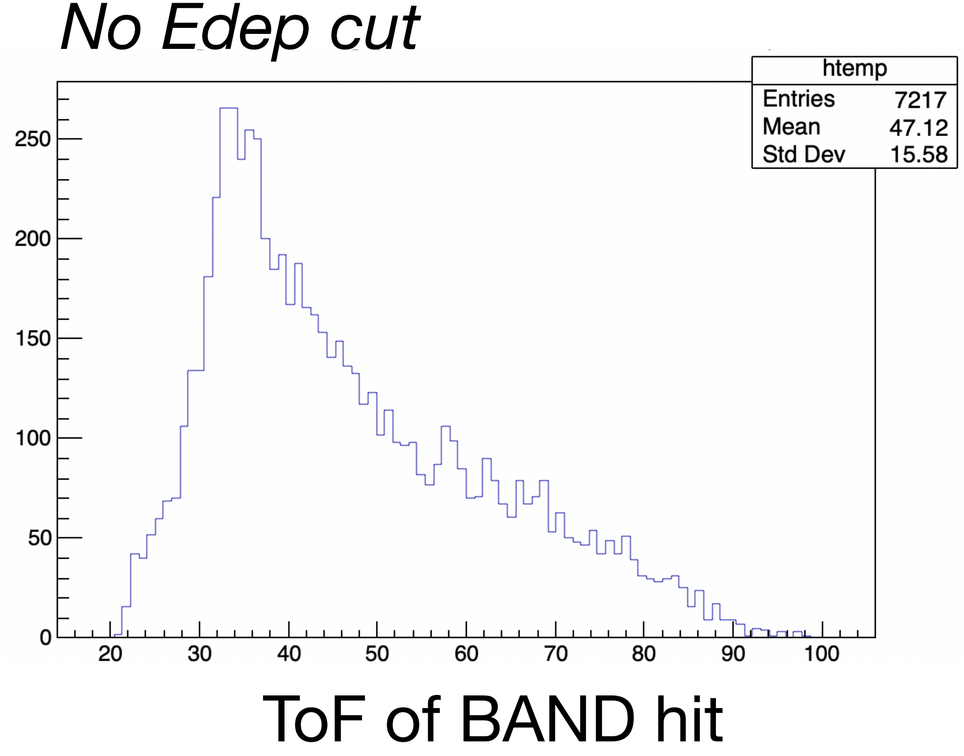




Modeling “Tagged” Hydrogen Background

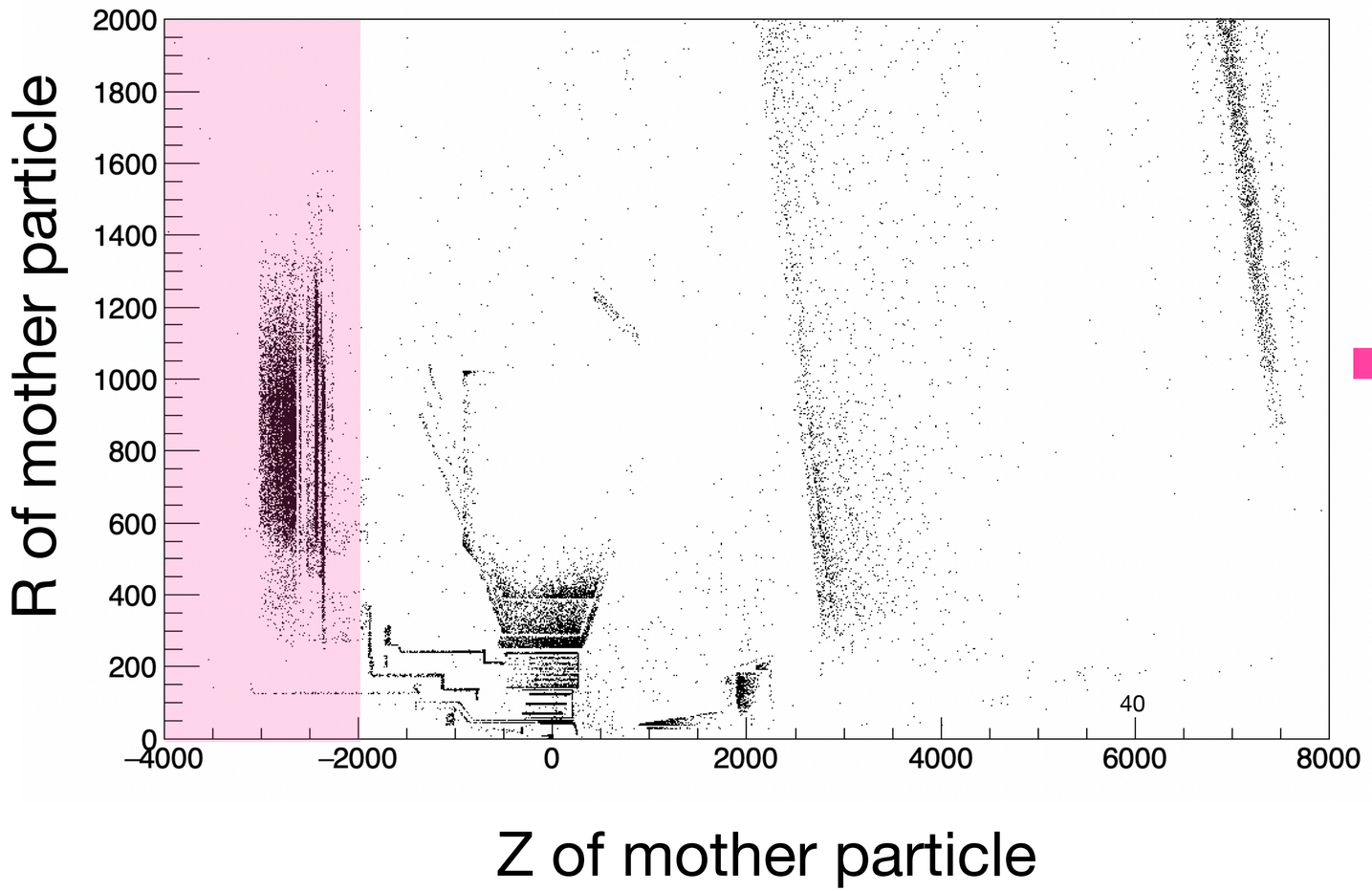
CLASDIS sim reproduces RGA ToF spectrum → Characterize background



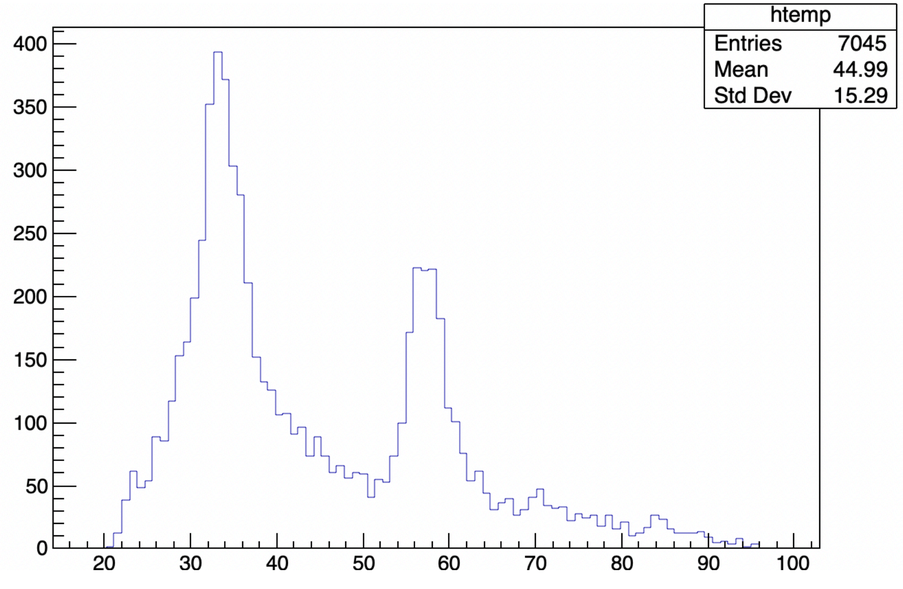


Modeling “Tagged” Hydrogen Background

CLASDIS sim reproduces RGA ToF spectrum → Characterize background



No Edep cut



ToF of BAND hit