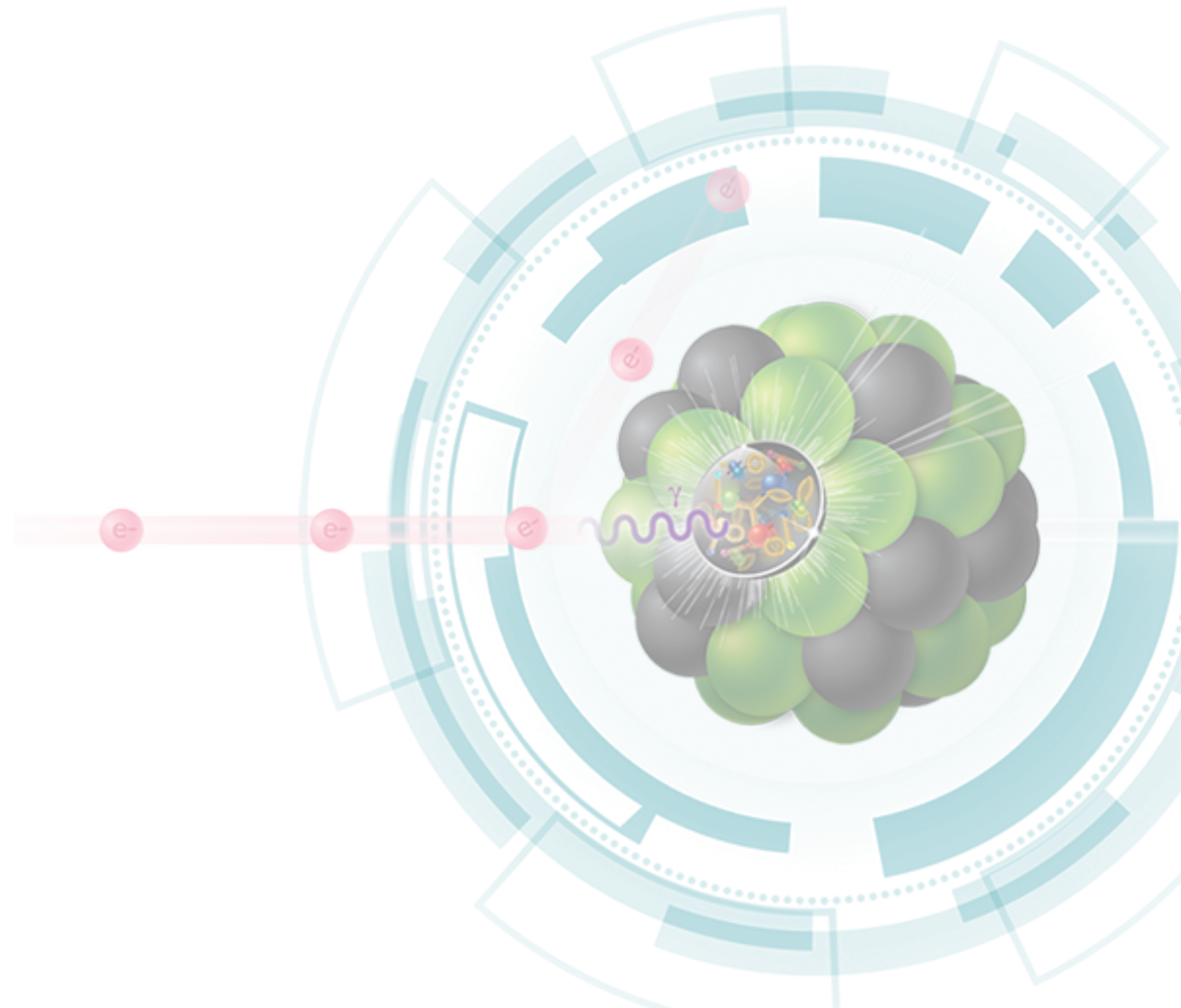
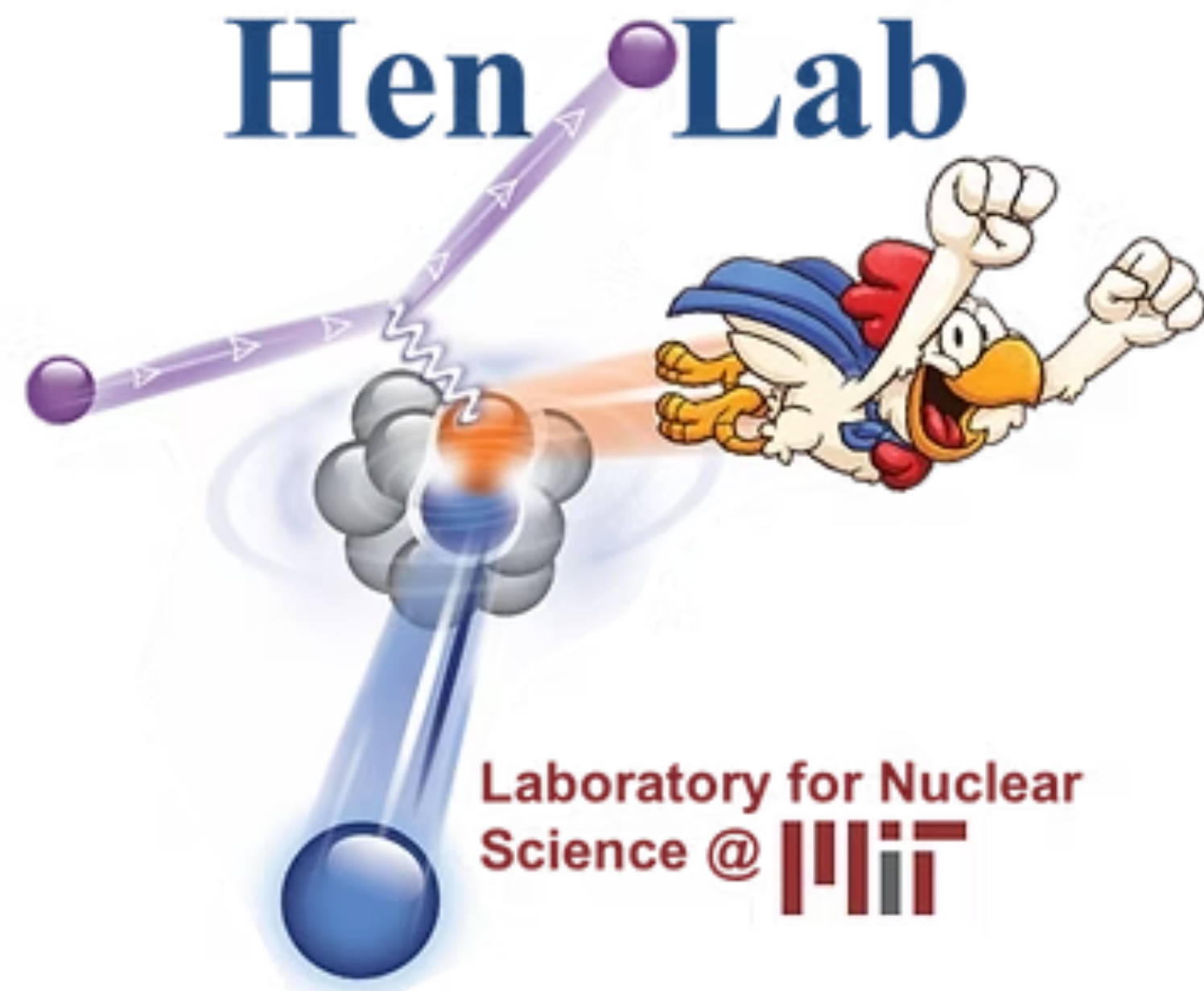


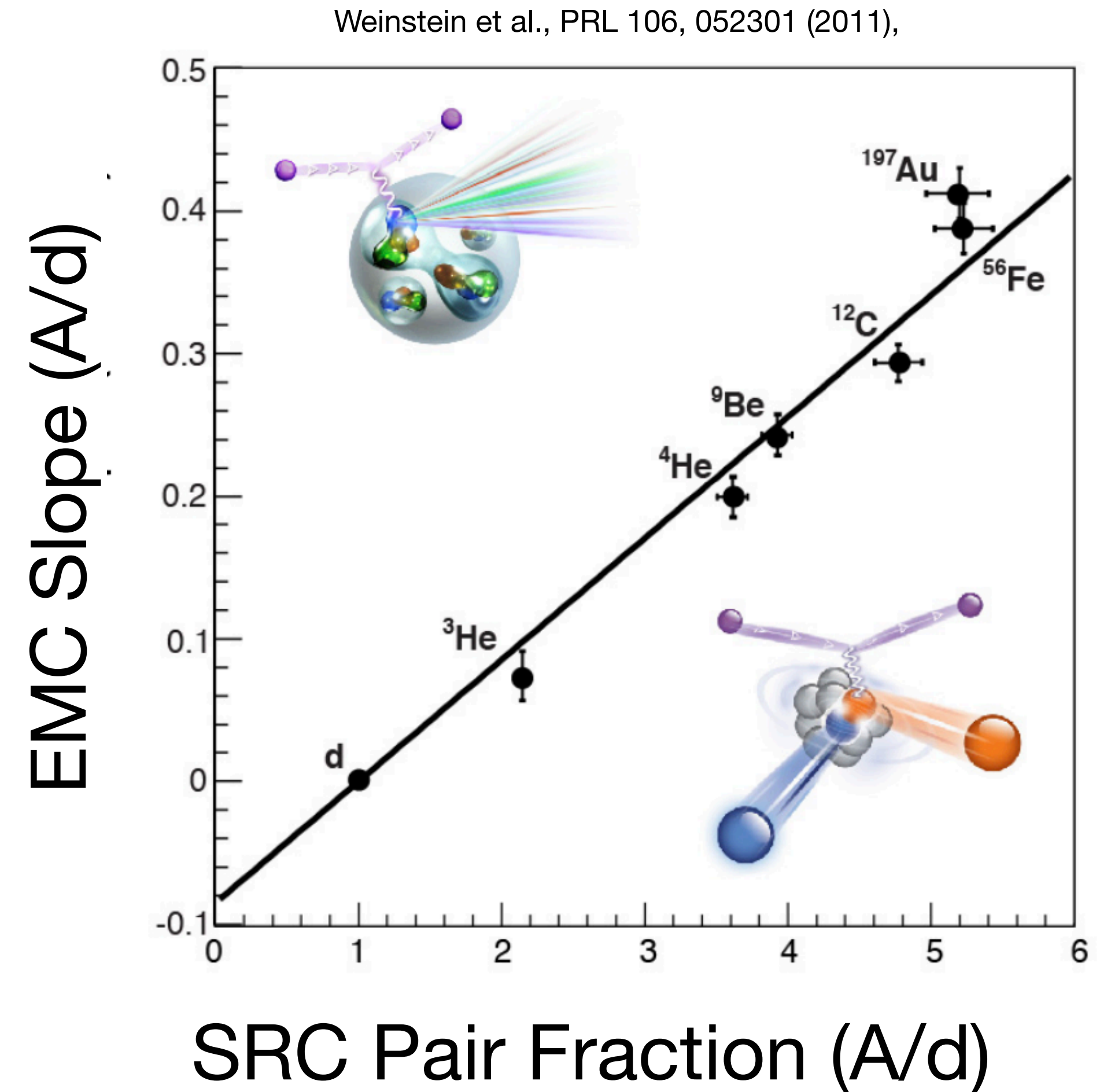
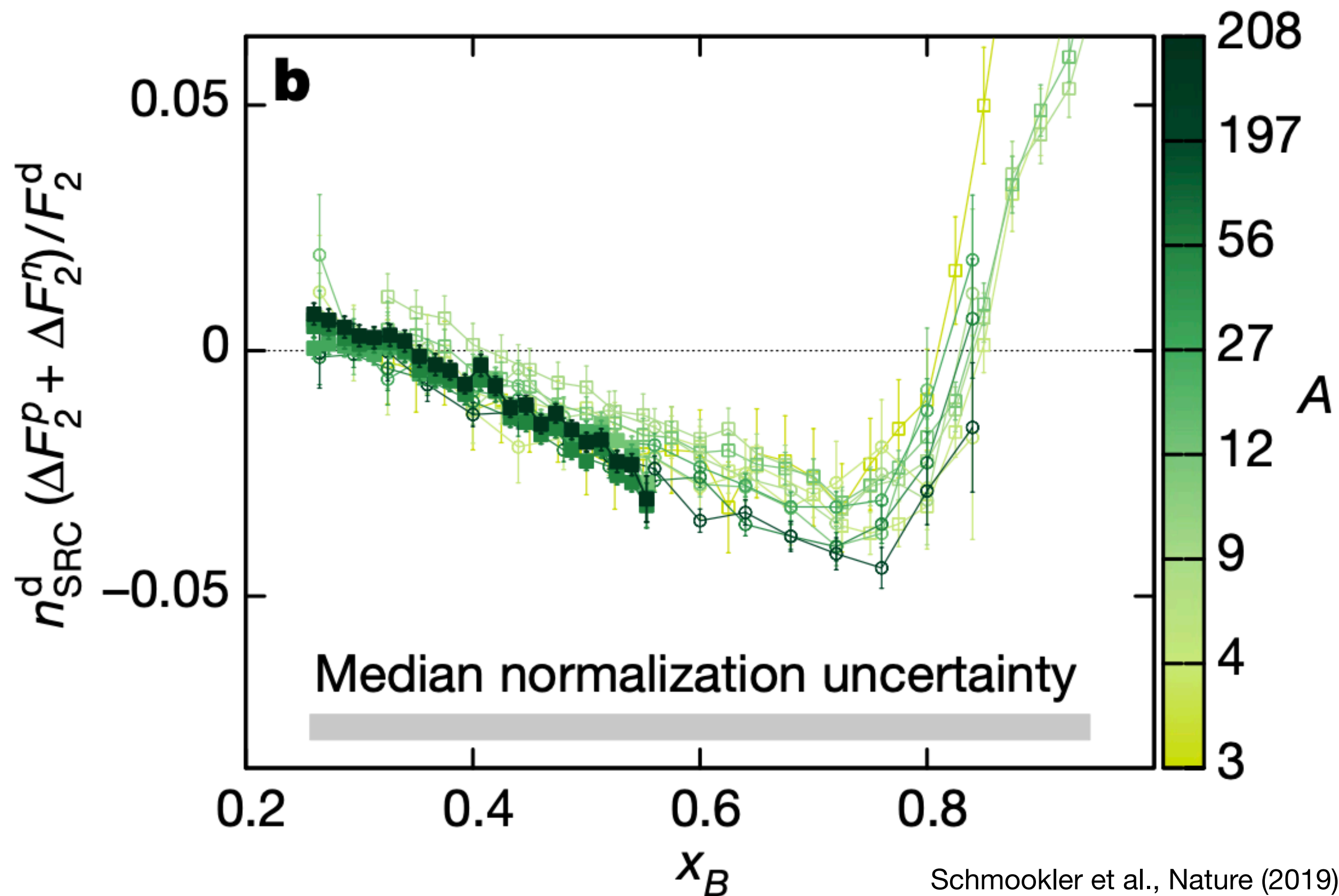
Recent Results from the BAND Experiment

Natalie Wright



Inclusive DIS shows EMC-SRC correlation

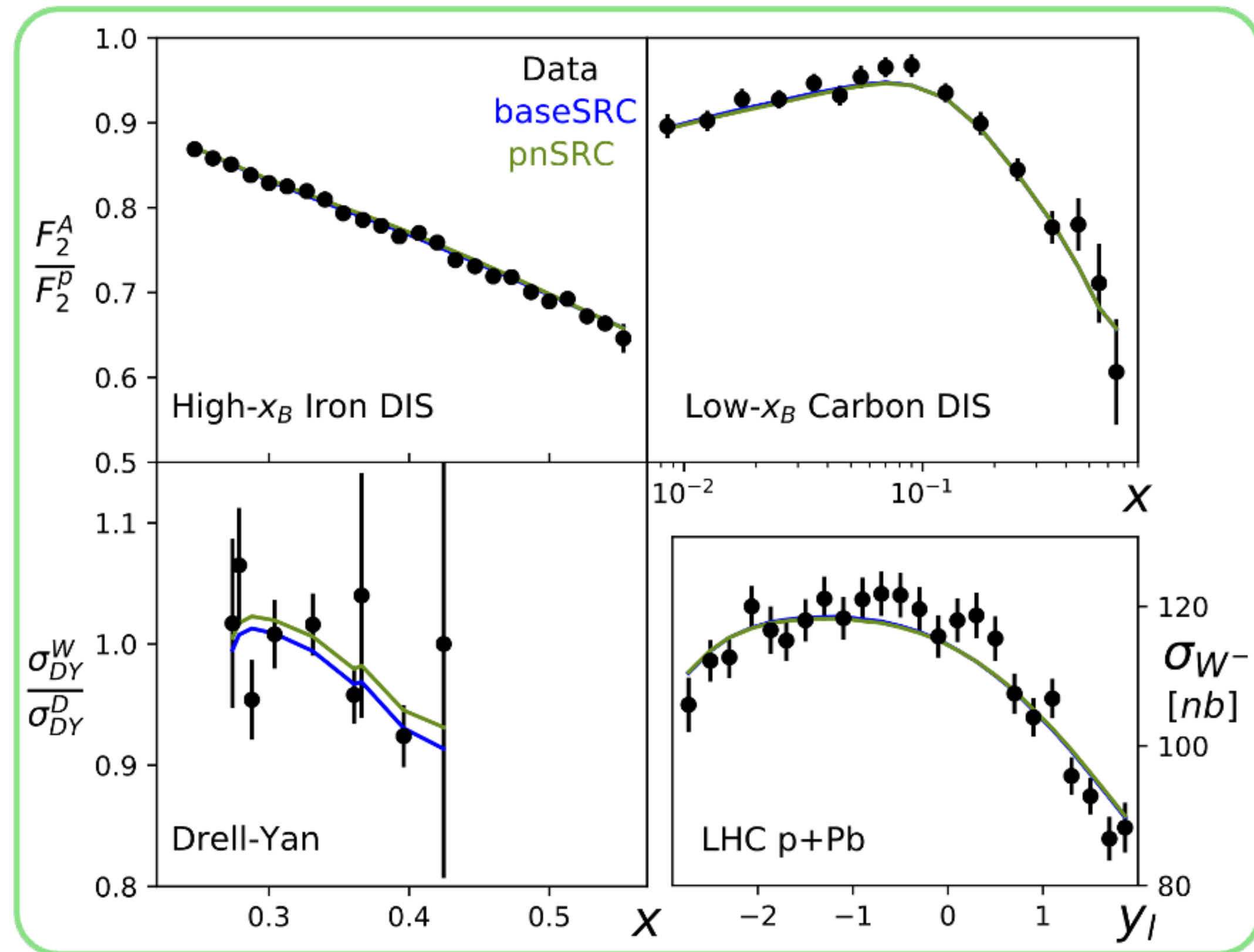
$$F_2^A = ZF_2^p + NF_2^n + n_{SRC}^A(\Delta F_2^p + \Delta F_2^n)$$



Universal modification to F_2^A as a function of n_{SRC}^A

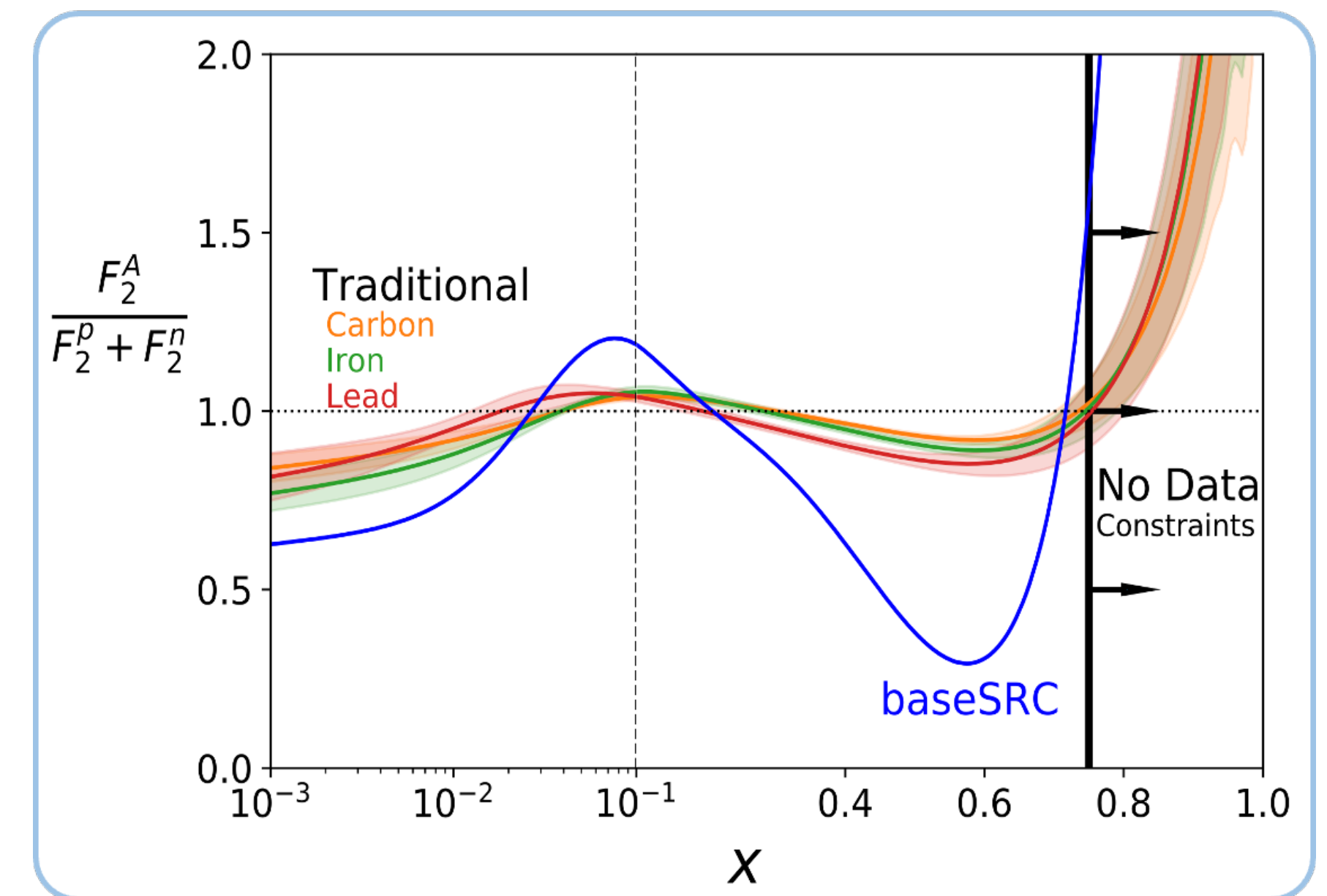
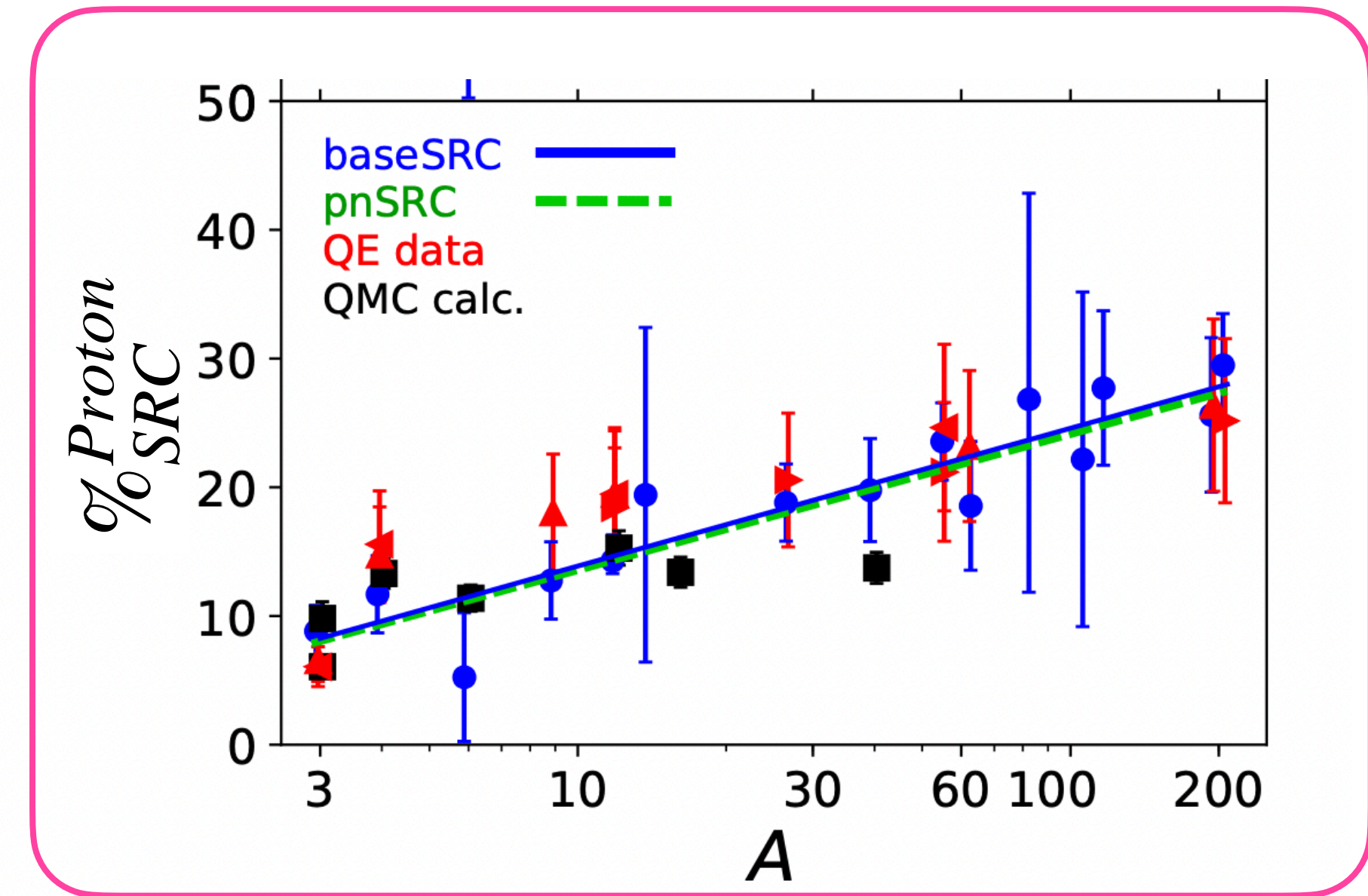
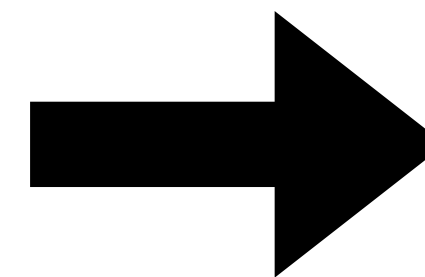
Global fits predict modification function

$$q_i(x, Q) = (1 - \%_{SRC}^A) \cdot f_i^{free}(x, Q) + \%_{SRC}^A \cdot f_i^{SRC}(x, Q)$$



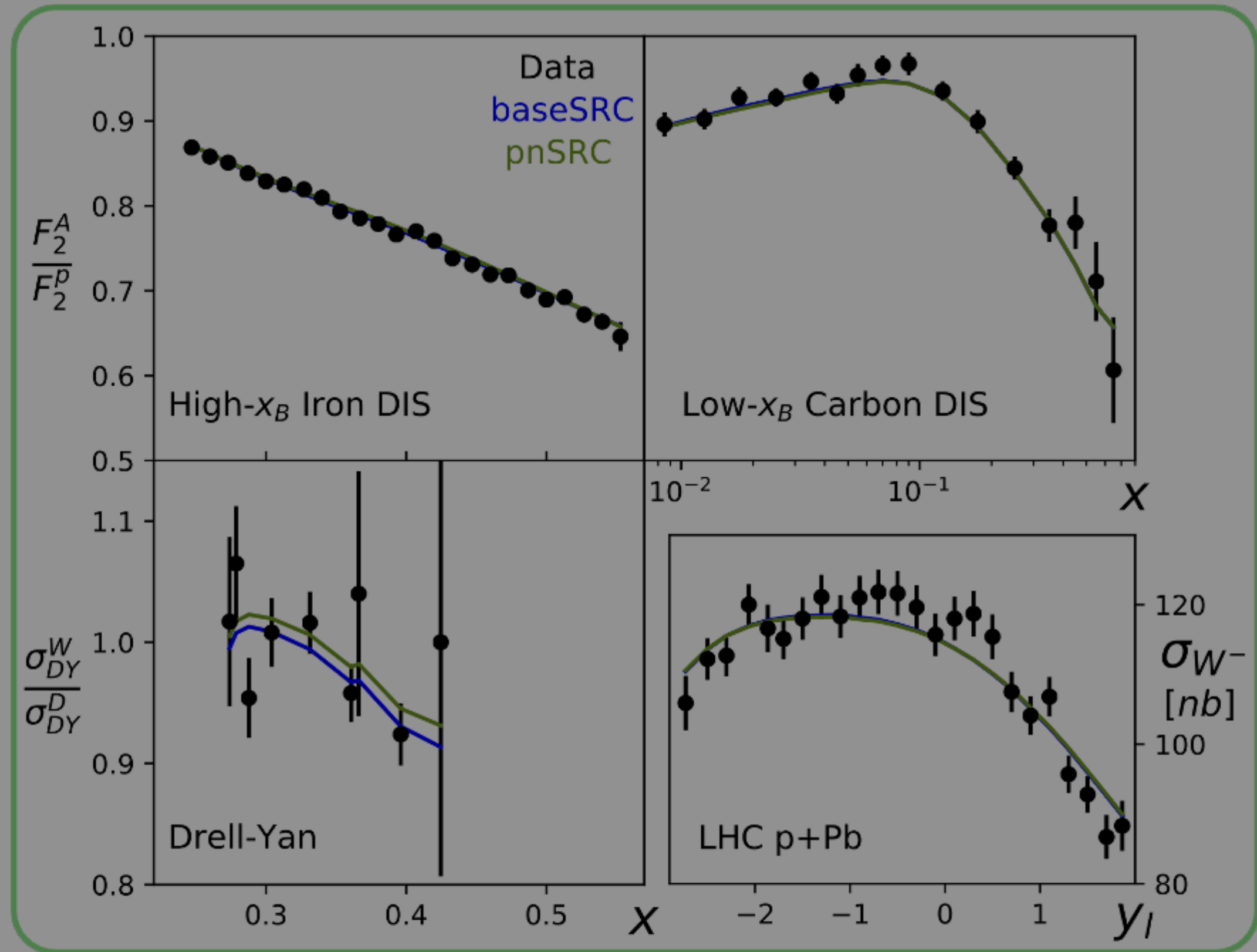
Denniston et al., PhysRevLett, 133, 152502 (2024),

Extended to PDFs!

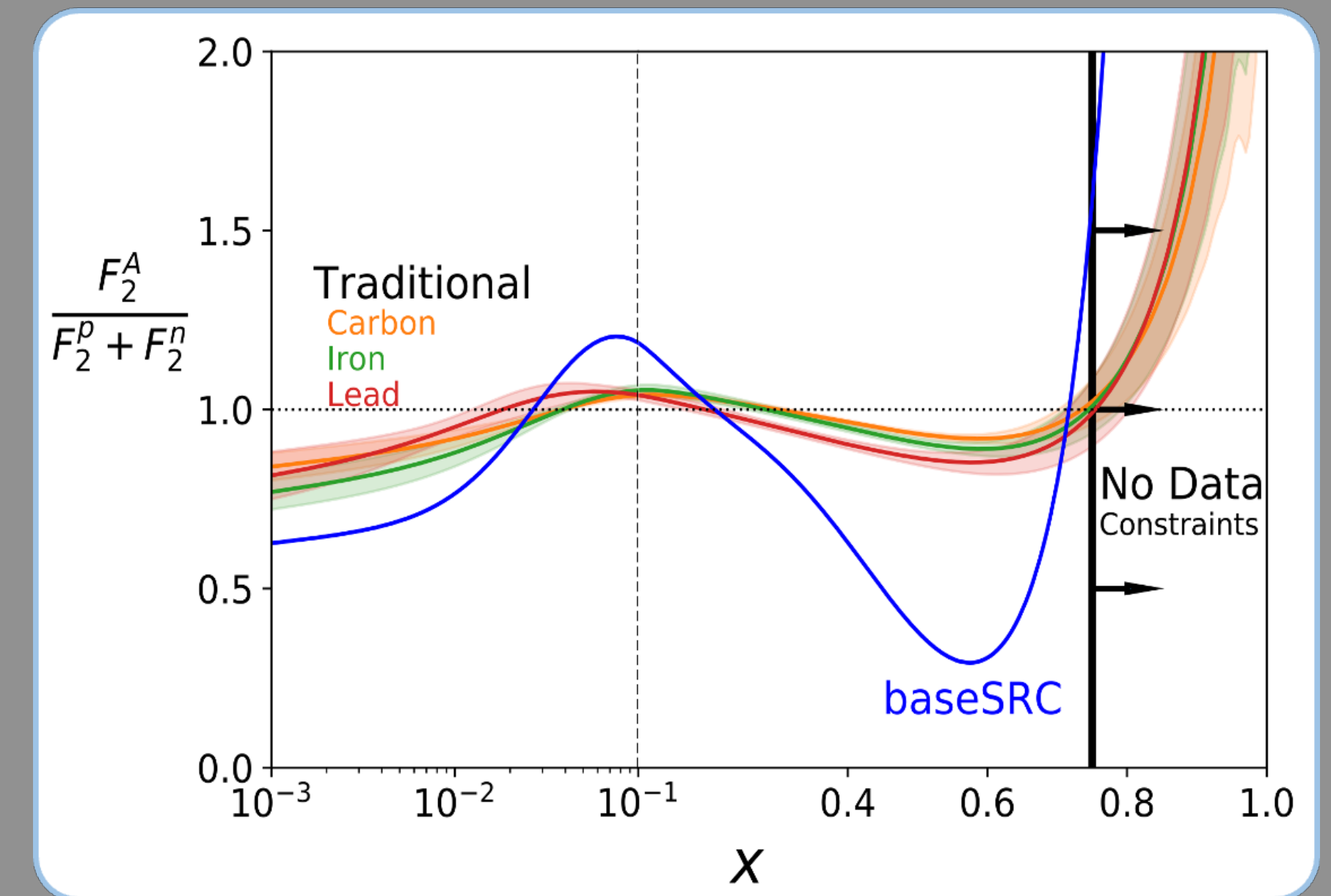
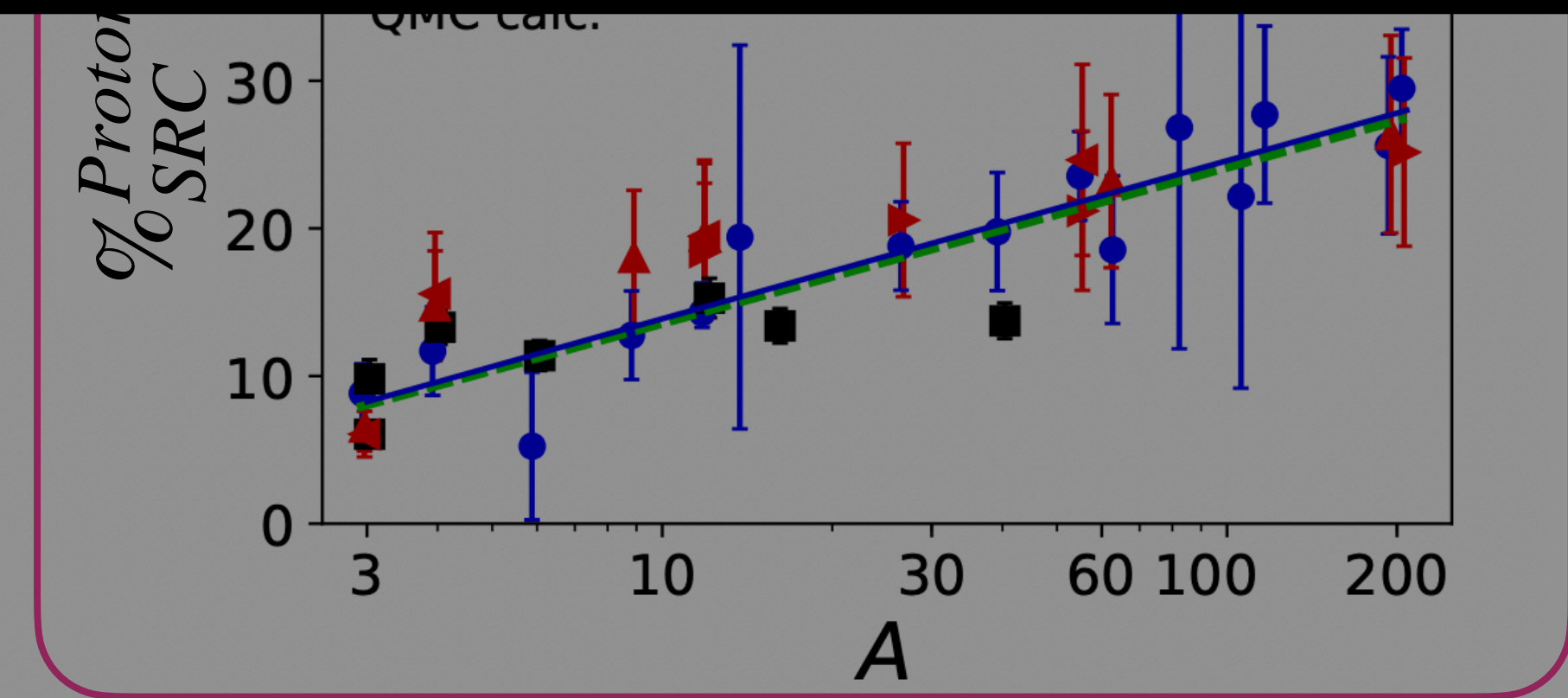
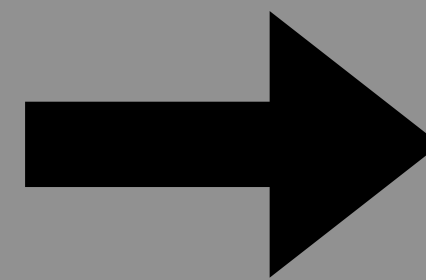


Global fits of SRC fractions, modification function

Exciting predictions from inclusive data + pheno



Extended to PDFs!



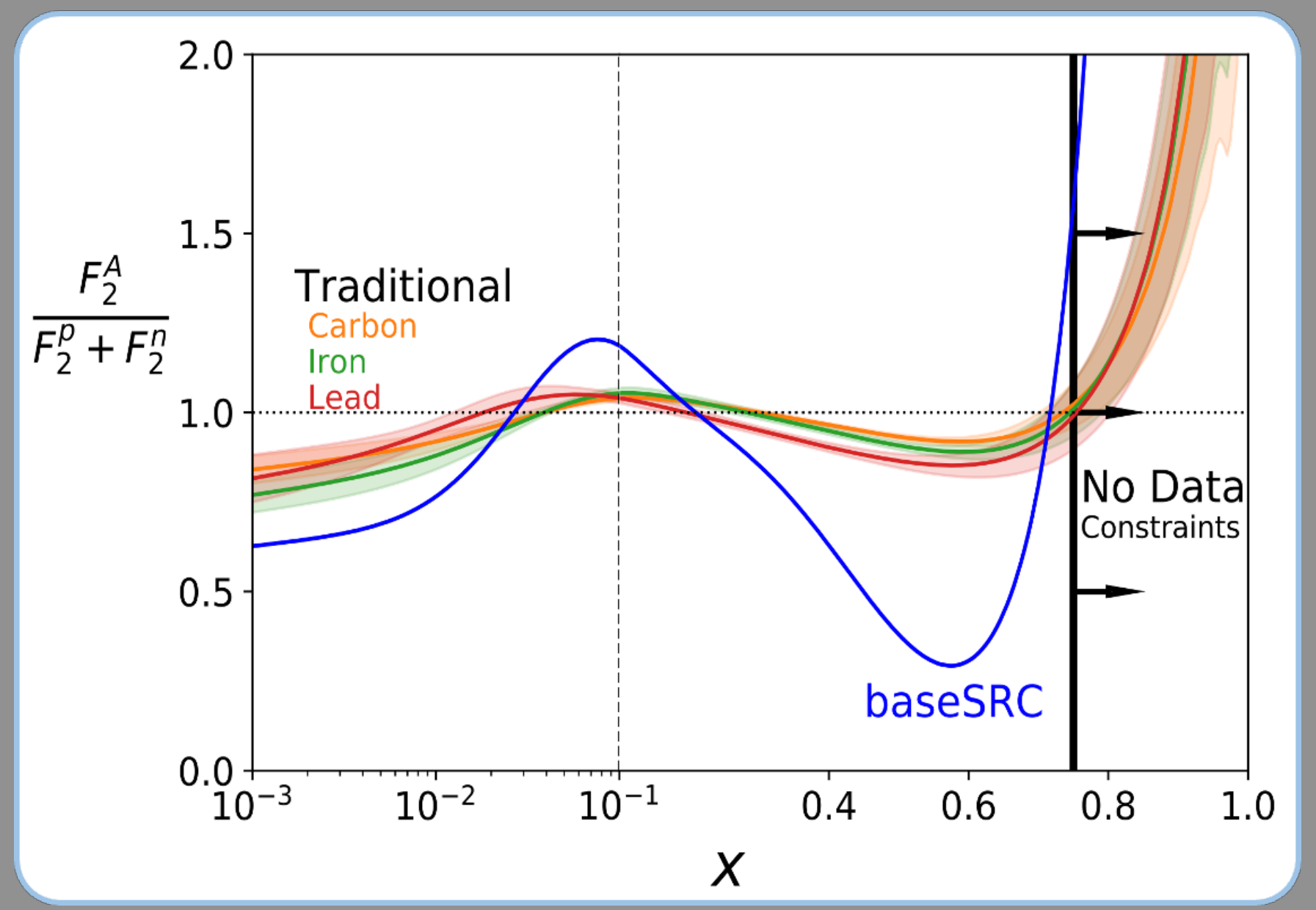
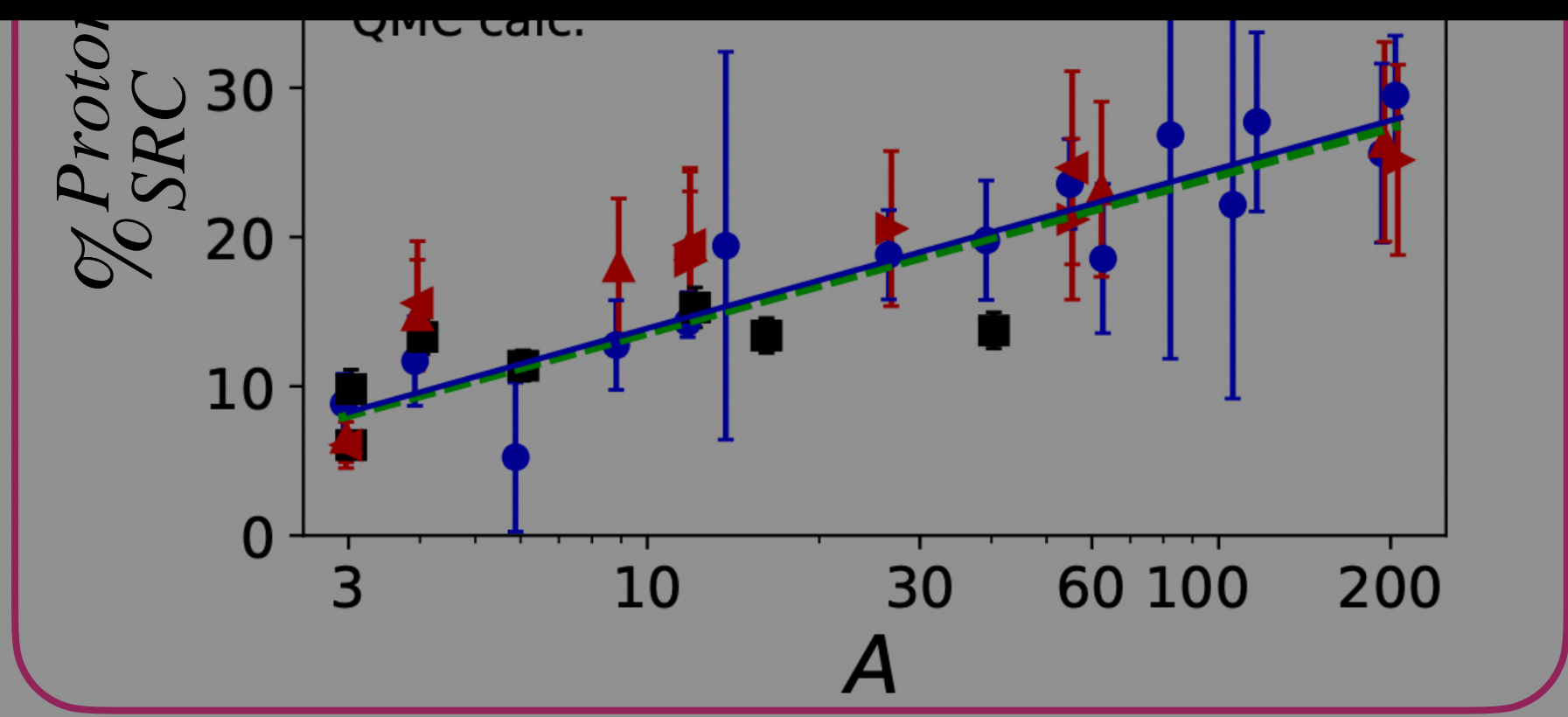
Global fits, SRC fractions, modification function

Exciting predictions from inclusive data + pheno

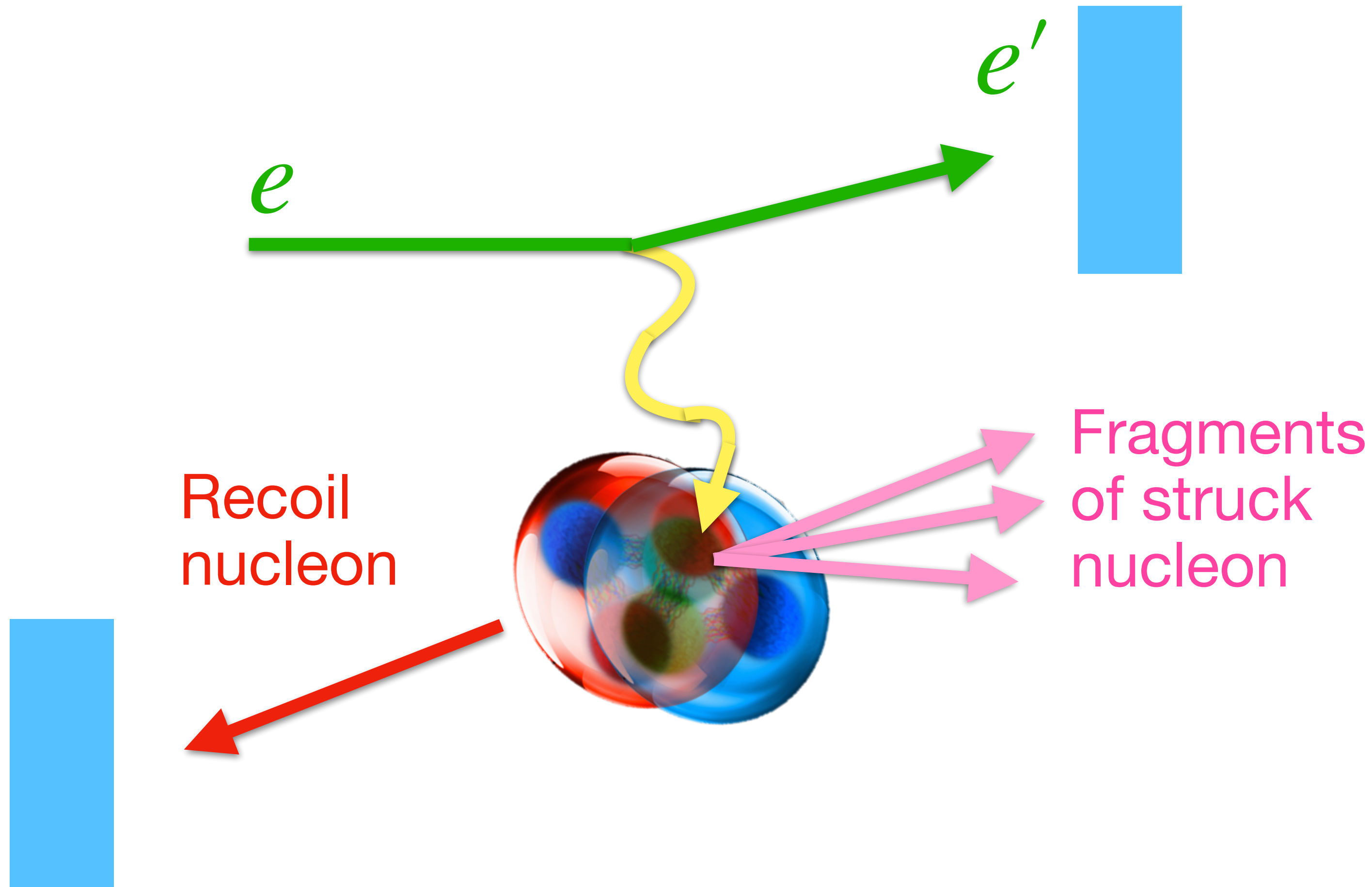
Let's get to measuring!

- BAND: F_2^{p*} , Hall B 2019
- LAD: F_2^{n*} , Hall C 2025
(see next talk)

Extended to PDFs!



Spectator Tagged DIS



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 \rightarrow 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**

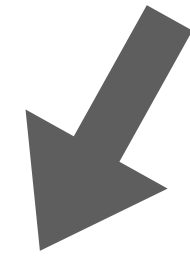
Tagged DIS cross section \rightarrow modified nucleon structure function

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

Modified structure function
Our objective!

Tagged DIS cross section → modified nucleon structure function

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

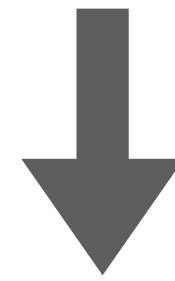


Divide by GEMC-simulated σ_{tag}

→ Kinematic terms, acceptance corrections cancel

Tagged DIS cross section \rightarrow 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

$$\mathcal{R} = \frac{\sigma_{tag}^{meas.}(x', Q^2, \alpha, p_{\perp})}{\sigma_{tag}^{meas.}(.3, Q^2, \alpha, p_{\perp})} \bigg/ \frac{\sigma_{tag}^{theory}(x', Q^2, \alpha, p_{\perp})}{\sigma_{tag}^{theory}(.3, Q^2, \alpha, p_{\perp})} = \frac{Y_{tag}^{meas.}(x')}{Y_{tag}^{meas.}(.3)} \bigg/ \frac{Y_{tag}^{theory}(x')}{Y_{tag}^{theory}(.3)}$$

$$\mathcal{R} \approx \frac{F_2^{p*}(x', \alpha) / F_2^p(x', \alpha)}{F_2^{p*}(.3, \alpha) / F_2^p(.3, \alpha)}$$

Measured **bound** proton structure function

Simulated **free** proton structure function

Tagged double ratio sensitive to modified nucleon structure function

$$\mathcal{R} = \frac{\sigma_{tag}^{meas.}(x', Q^2, \alpha, p_{\perp})}{\sigma_{tag}^{meas.}(.3, Q^2, \alpha, p_{\perp})} \bigg/ \frac{\sigma_{tag}^{theory}(x', Q^2, \alpha, p_{\perp})}{\sigma_{tag}^{theory}(.3, Q^2, \alpha, p_{\perp})} = \frac{Y_{tag}^{meas.}(x')}{Y_{tag}^{meas.}(.3)} \bigg/ \frac{Y_{tag}^{theory}(x')}{Y_{tag}^{theory}(.3)}$$

$$\mathcal{R} \approx \frac{F_2^{P*}(x', \alpha) / F_2^P(x', \alpha)}{F_2^{P*}(.3, \alpha) / F_2^P(.3, \alpha)}$$

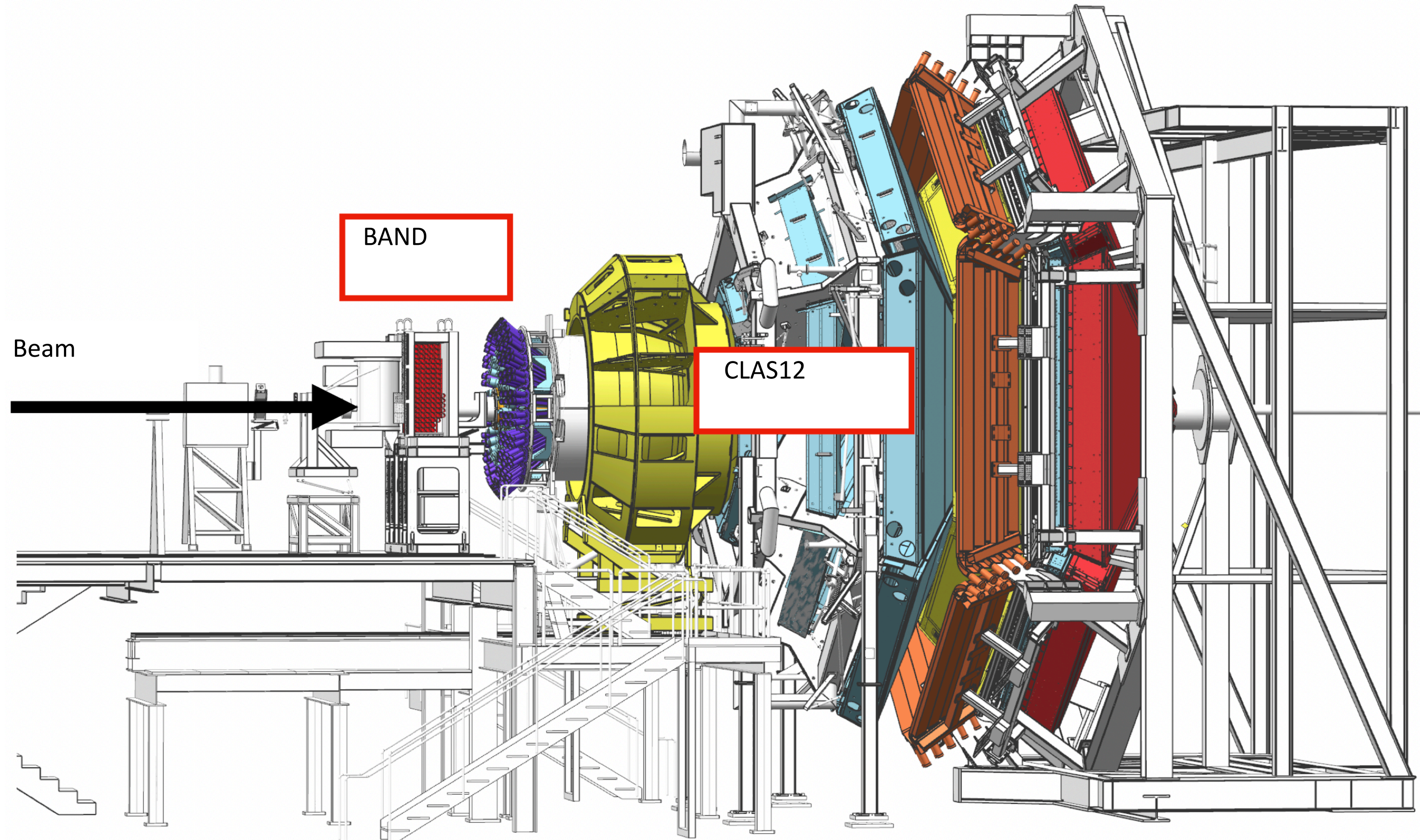
Measured **bound** proton structure function

Simulated **free** proton structure function

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

Tagged DIS with BAND

CLAS12 + Backward Angle Neutron Detector (BAND)



Backward Angle Neutron Detector

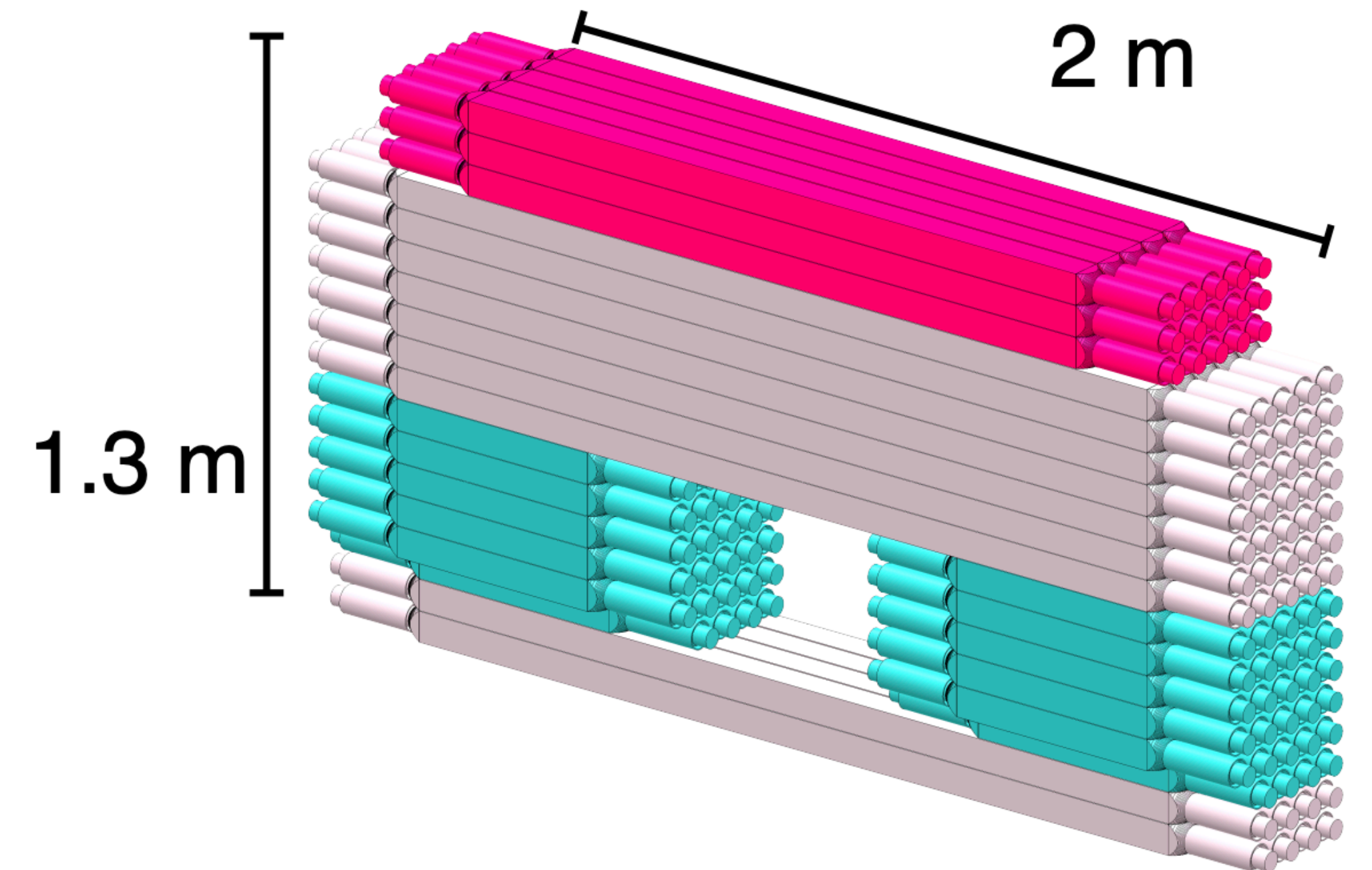
The detector:

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

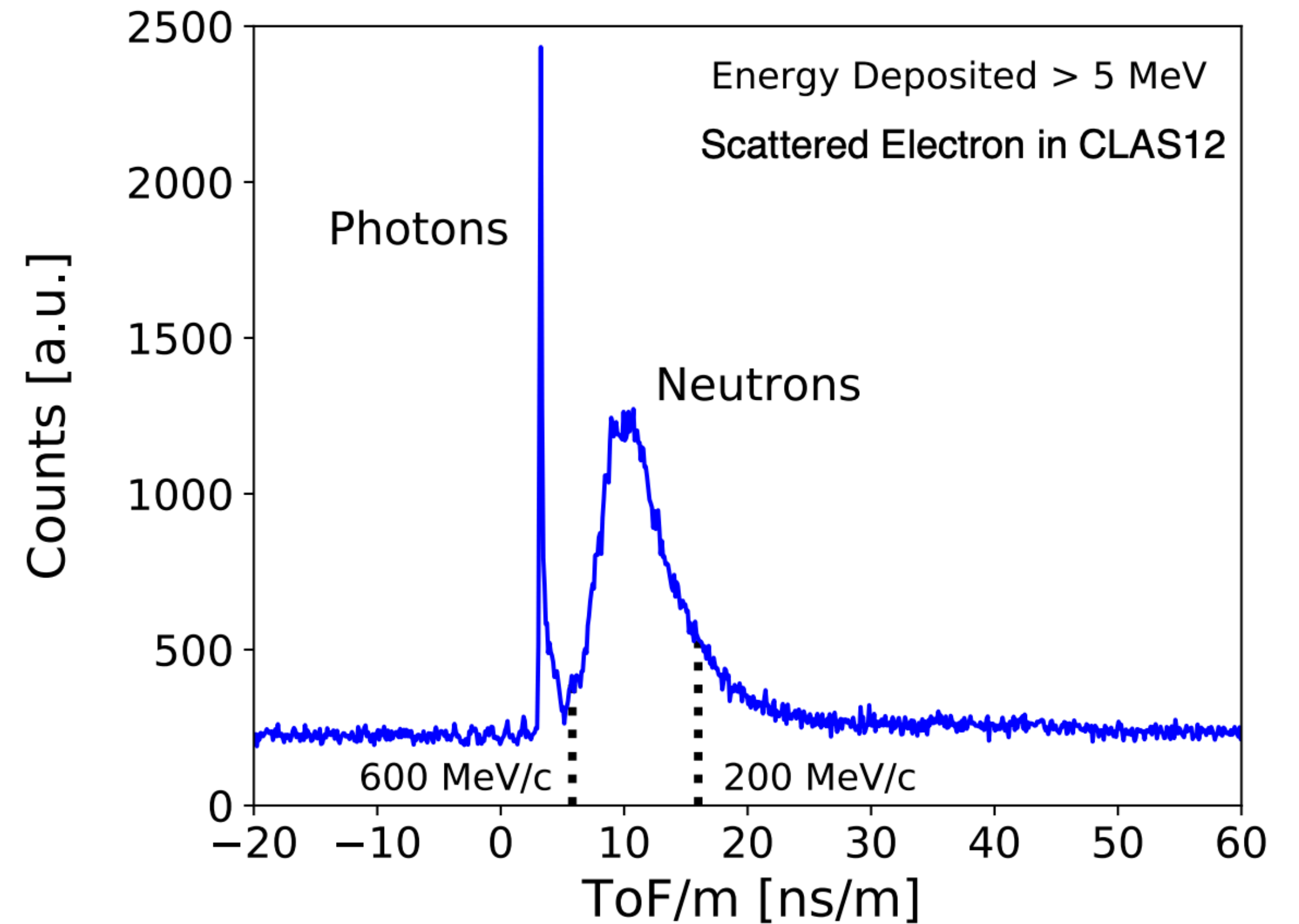
Lead wall downstream

The neutrons:

Time resolution < 250 ps

$\theta \sim 155-175^\circ$

$p \sim 200 - 600 \text{ MeV}/c$



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:

$$Q^2 > 2 \text{ GeV}^2$$

$$W > 2 \text{ GeV}^2$$

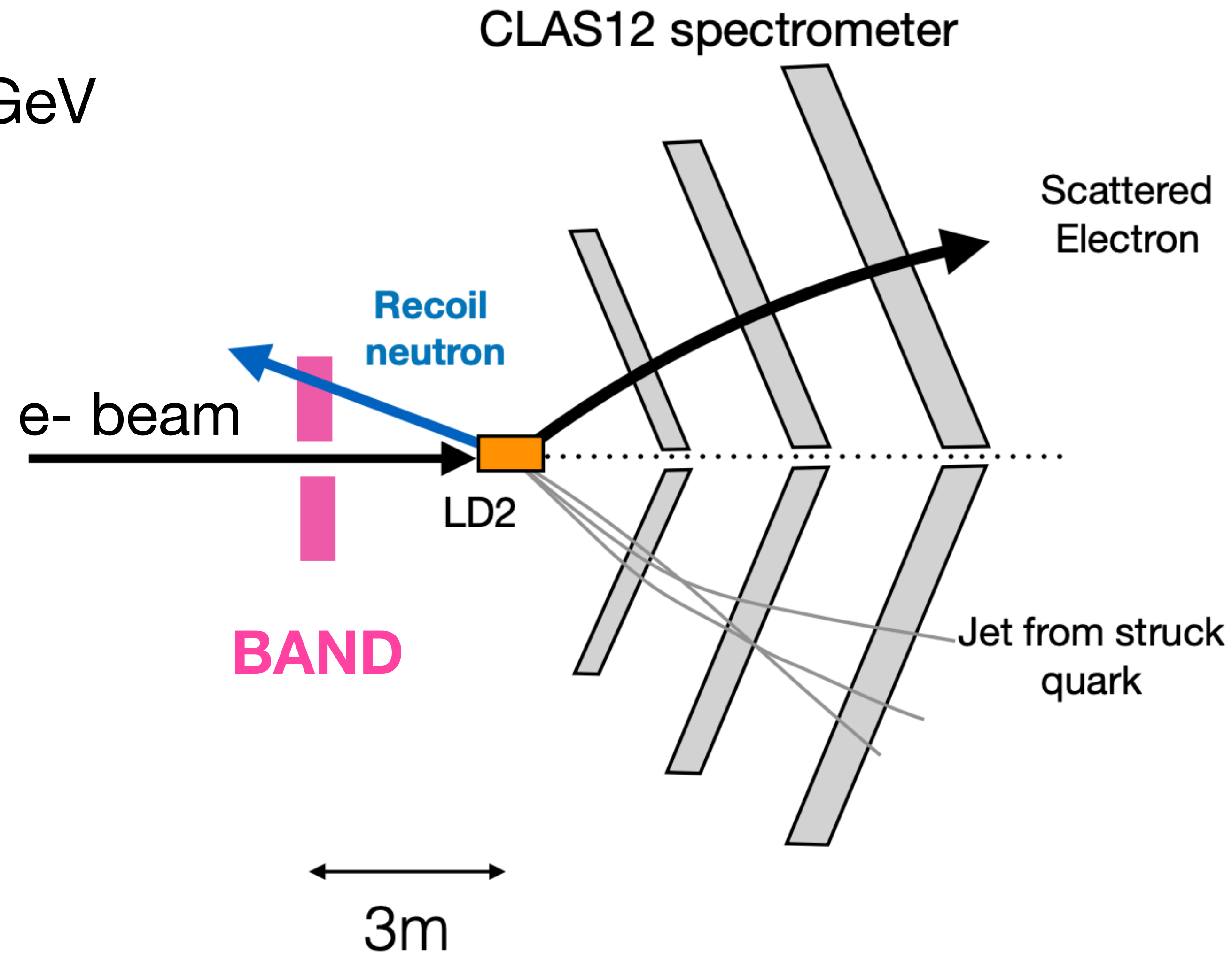
$$p_e > 3 \text{ GeV}/c$$

Neutron:

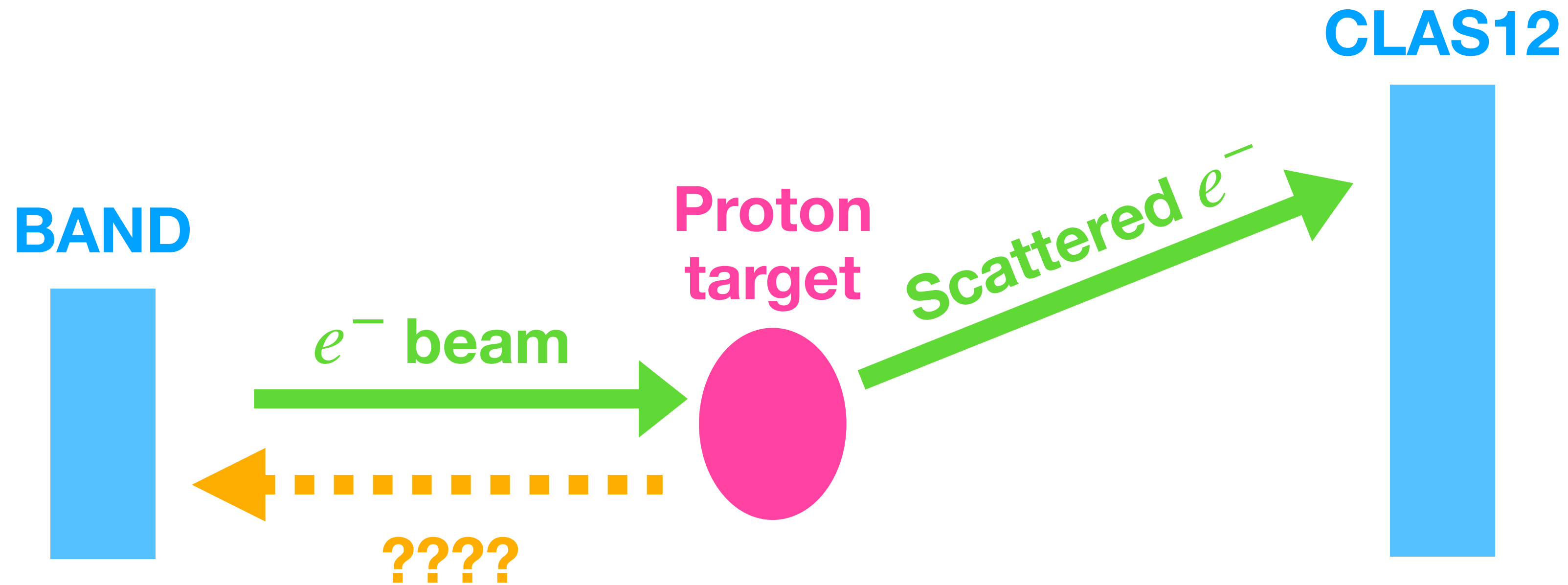
$$W'^2 > 1.8 \text{ GeV}^2$$

$$.1 < p_n < .6 \text{ GeV}/c$$

$$E_{dep} > 5 \text{ MeVee}$$



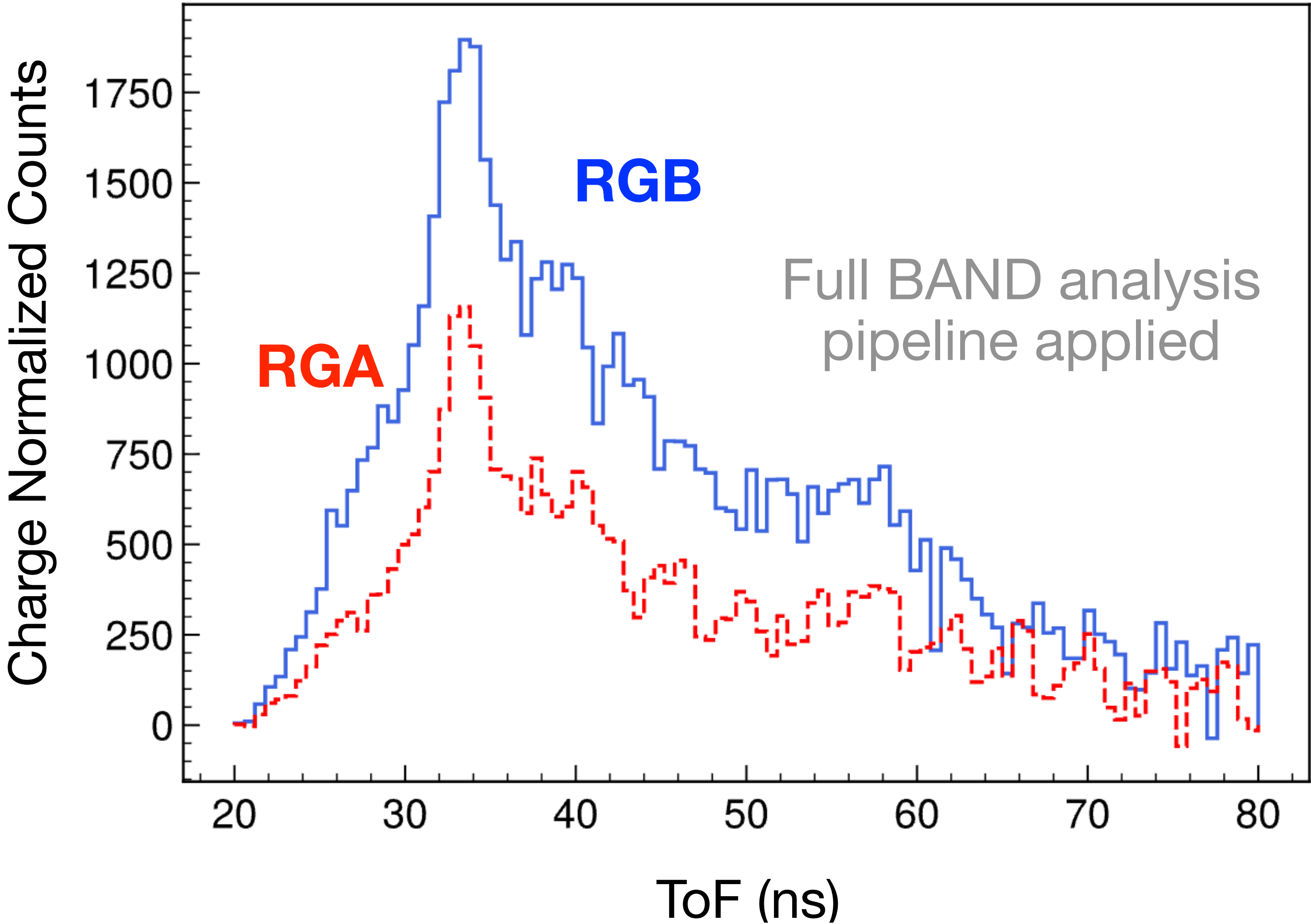
New in: Correlated Background via RGA



Kinematics: Neutrons from primary interaction **CANNOT** reach BAND

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

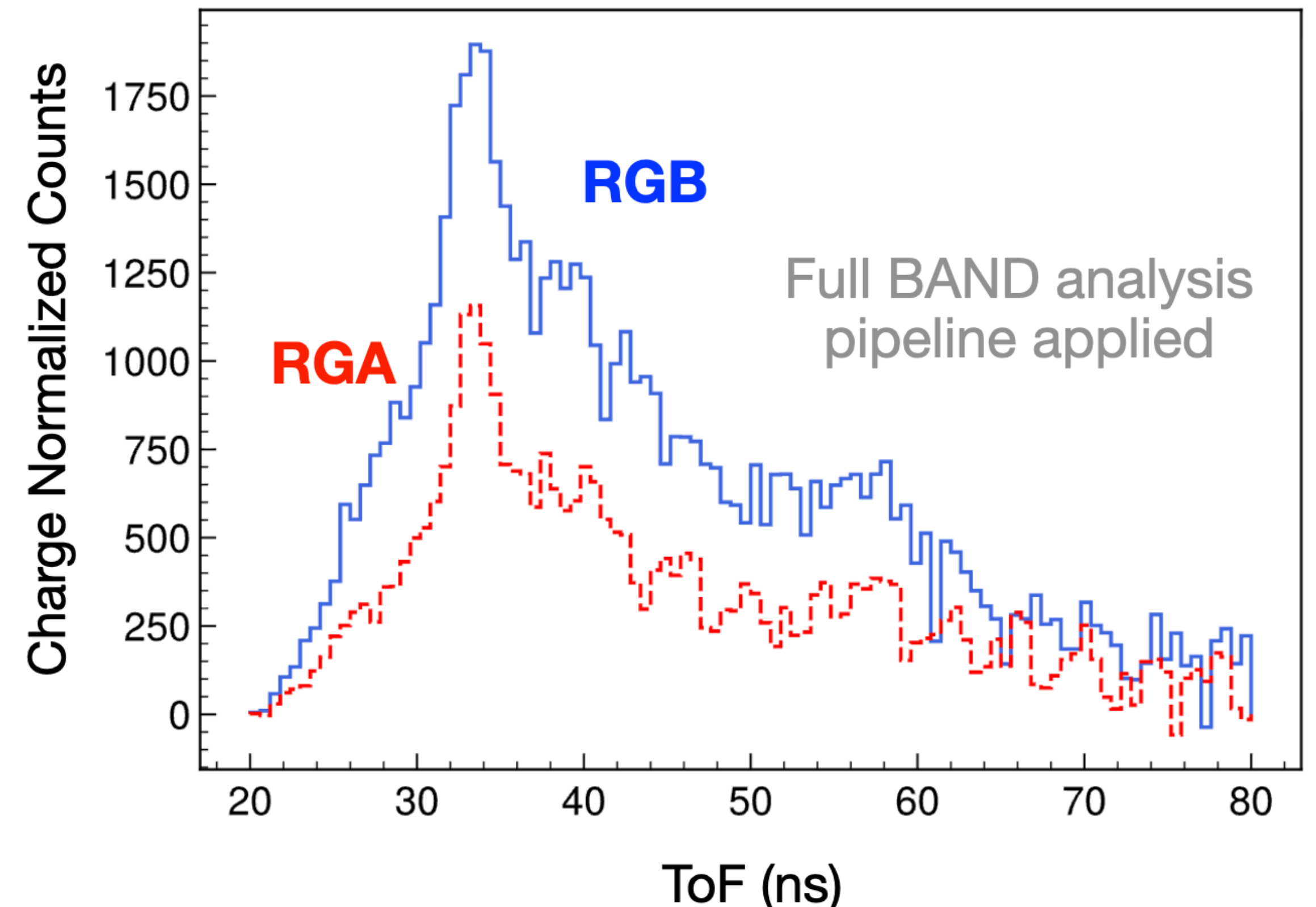
New in: Correlated Background via RGA



New in: Correlated Background via RGA

What we know:

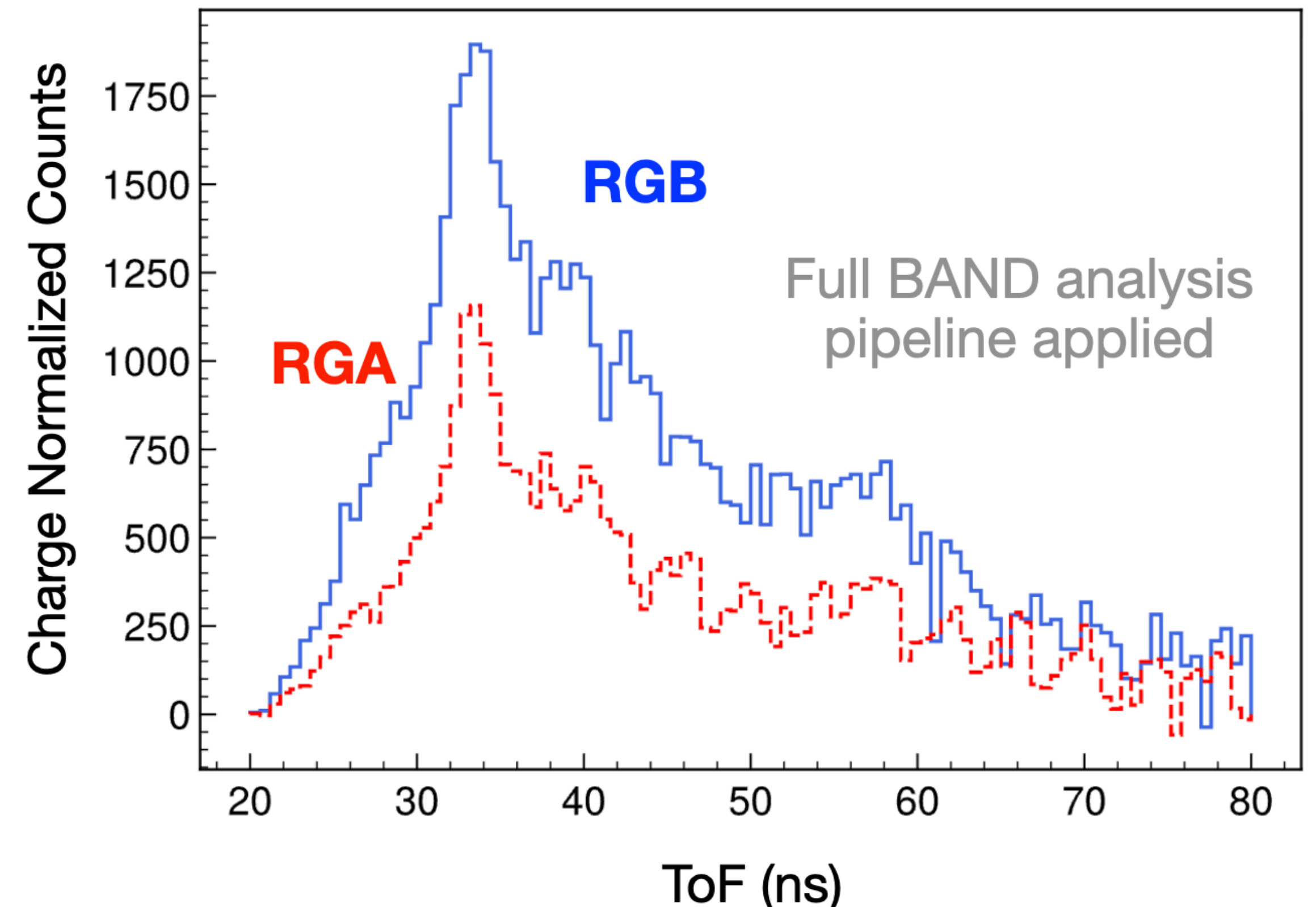
- Not a neutron from primary interaction
- Associated with DIS electron
- Sharp peak around 34 ns \rightarrow timing compatible with γ 's from secondary interactions with detector material
- CLASDIS simulation reproduces shape



New in: Correlated Background via RGA

What we know:

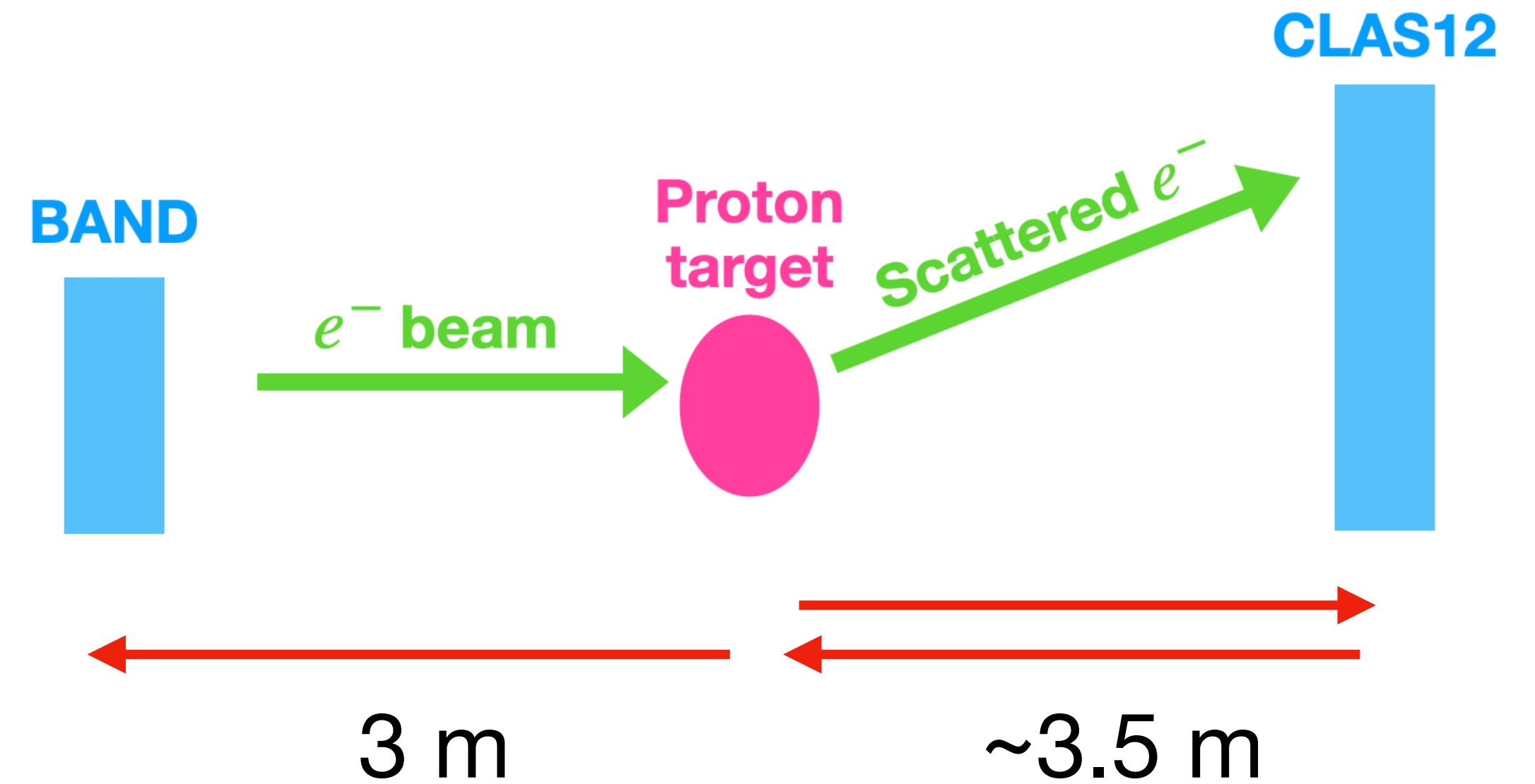
- Not a neutron from primary interaction
- Associated with DIS electron
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New in: Correlated Background via RGA

What we know:

- Not a neutron from primary interaction
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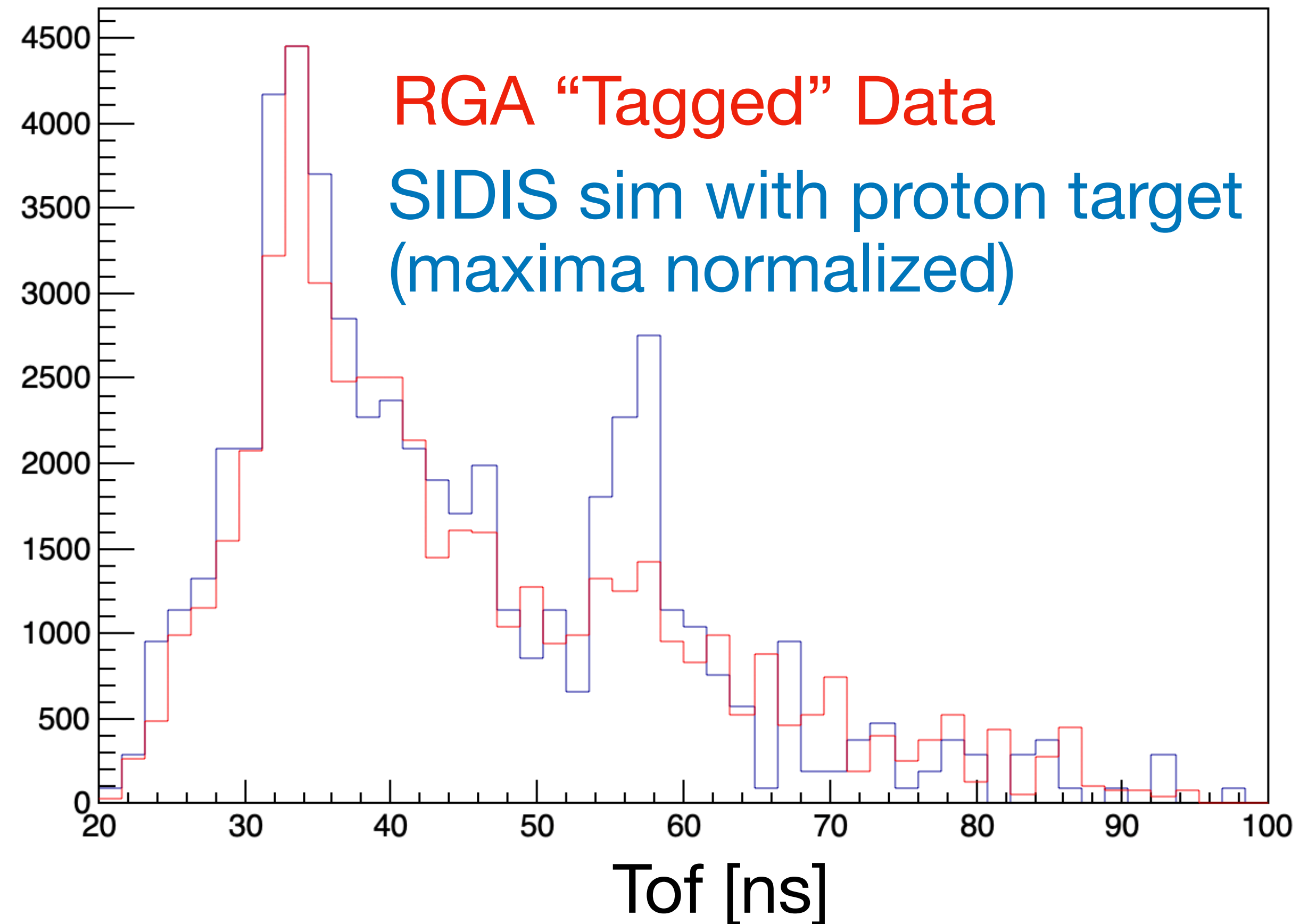
Total path = 10 meters

If $v \approx c$, $t = 33.4$ ns

New in: Correlated Background via RGA

What we know:

- Not a neutron from primary interaction
- Associated with DIS electron
- Sharp peak around 34 ns \rightarrow timing compatible with γ 's from secondary interactions with detector material
- CLASDIS simulation reproduces shape

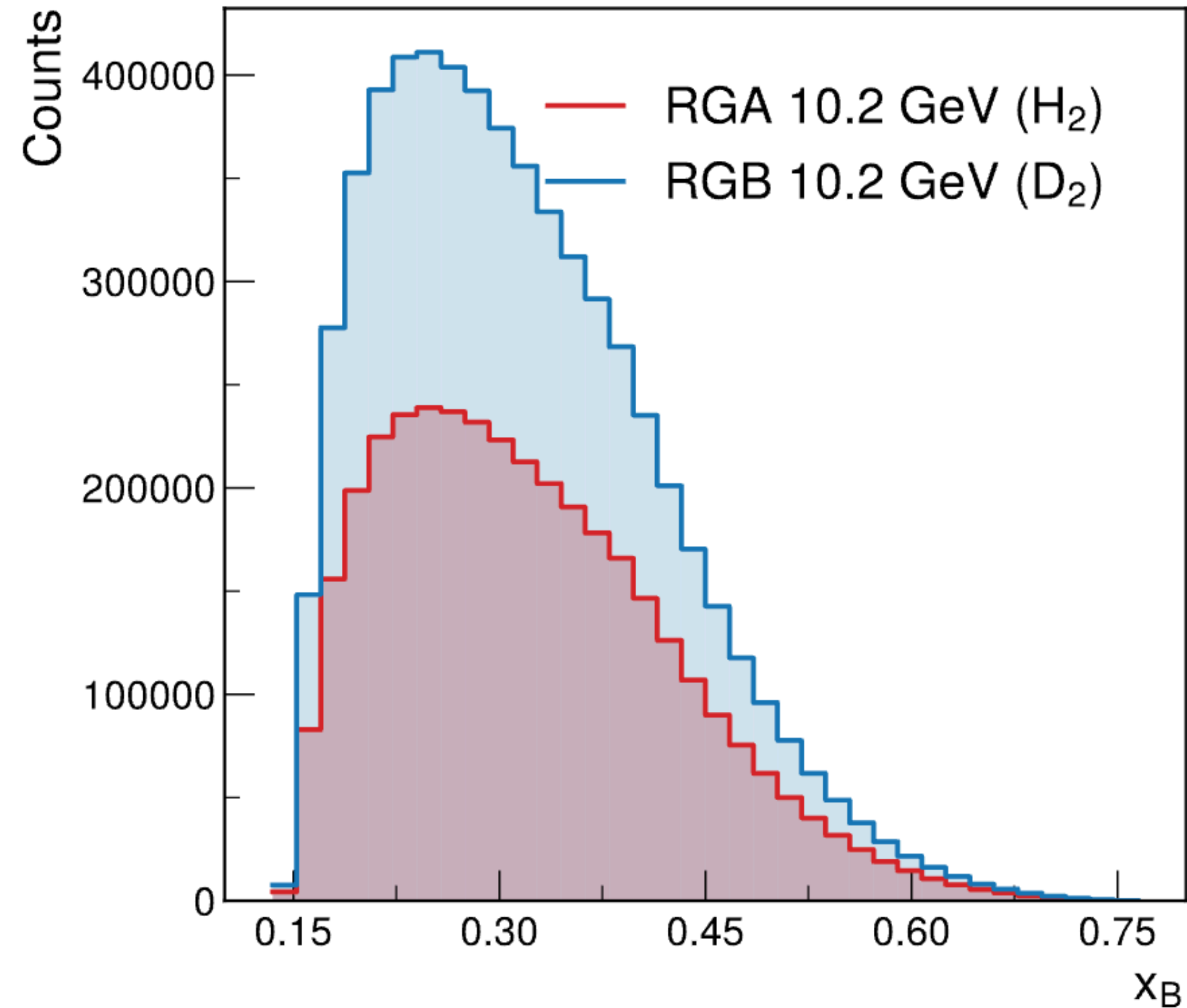


ep SIDIS MC \rightarrow GEMC reconstruction \rightarrow Signal in BAND

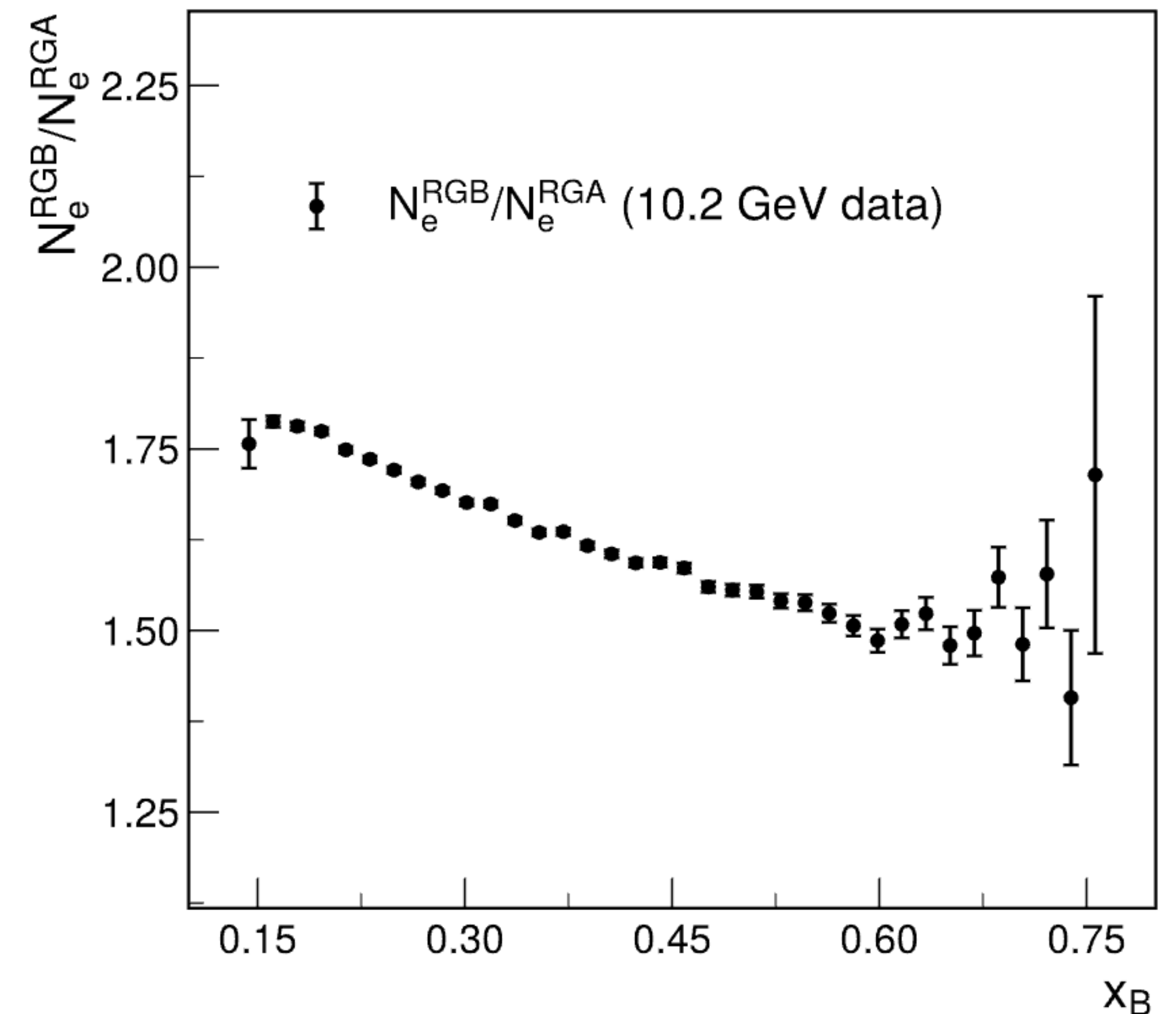
Scaling RGA data to subtract: $\sigma_{ep} \rightarrow \sigma_{ed}$

Account for luminosity and cross section simultaneously with inclusive yield ratio

(e,e') for $Q^2 > 2$ and $W^2 > 4$



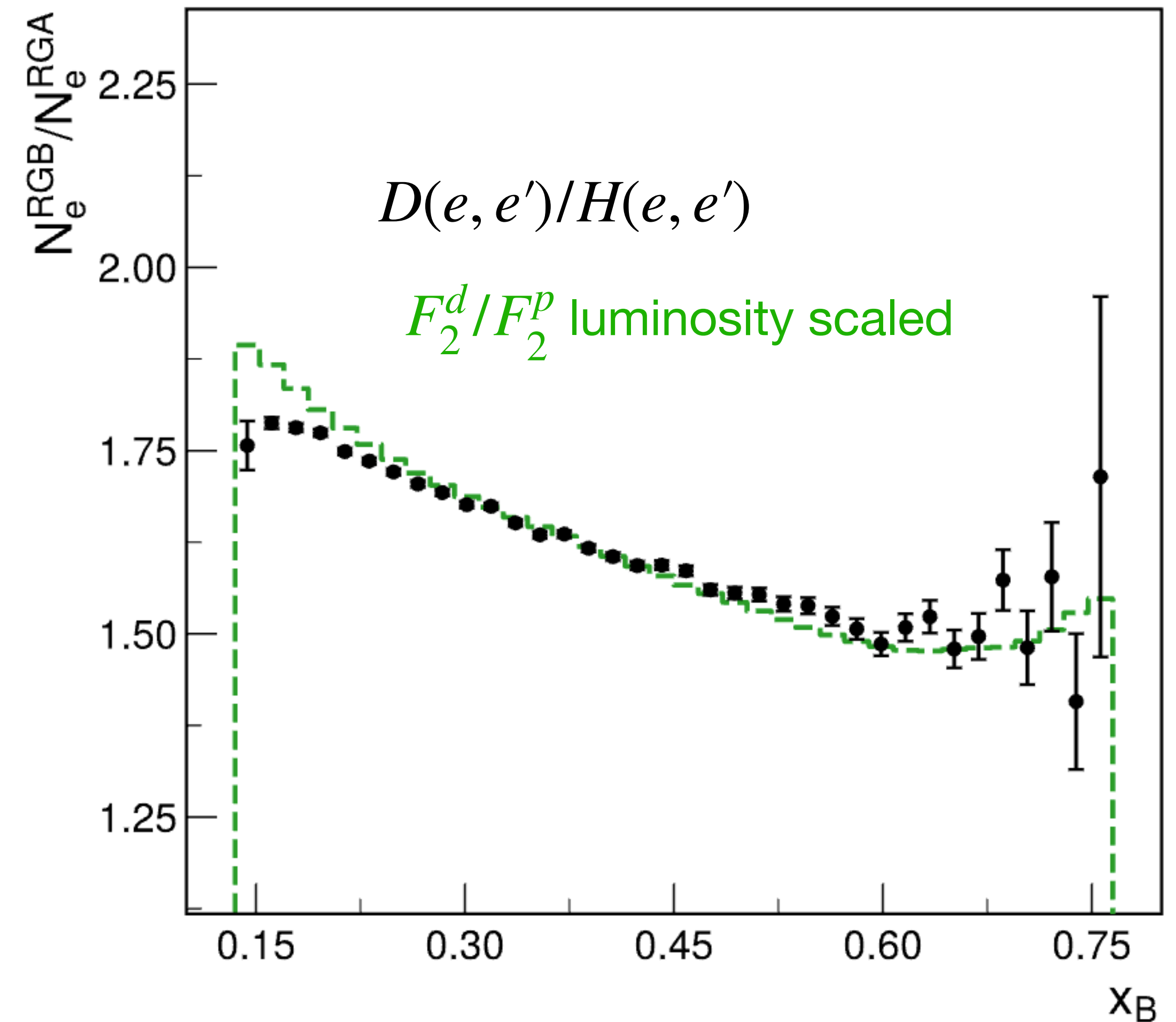
Ratio



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

Account for luminosity and cross section simultaneously with inclusive yield ratio

- With luminosity scaling, R_{GB}/R_{GGA} inclusive yield ratio $\approx F_2^d/F_2^p$



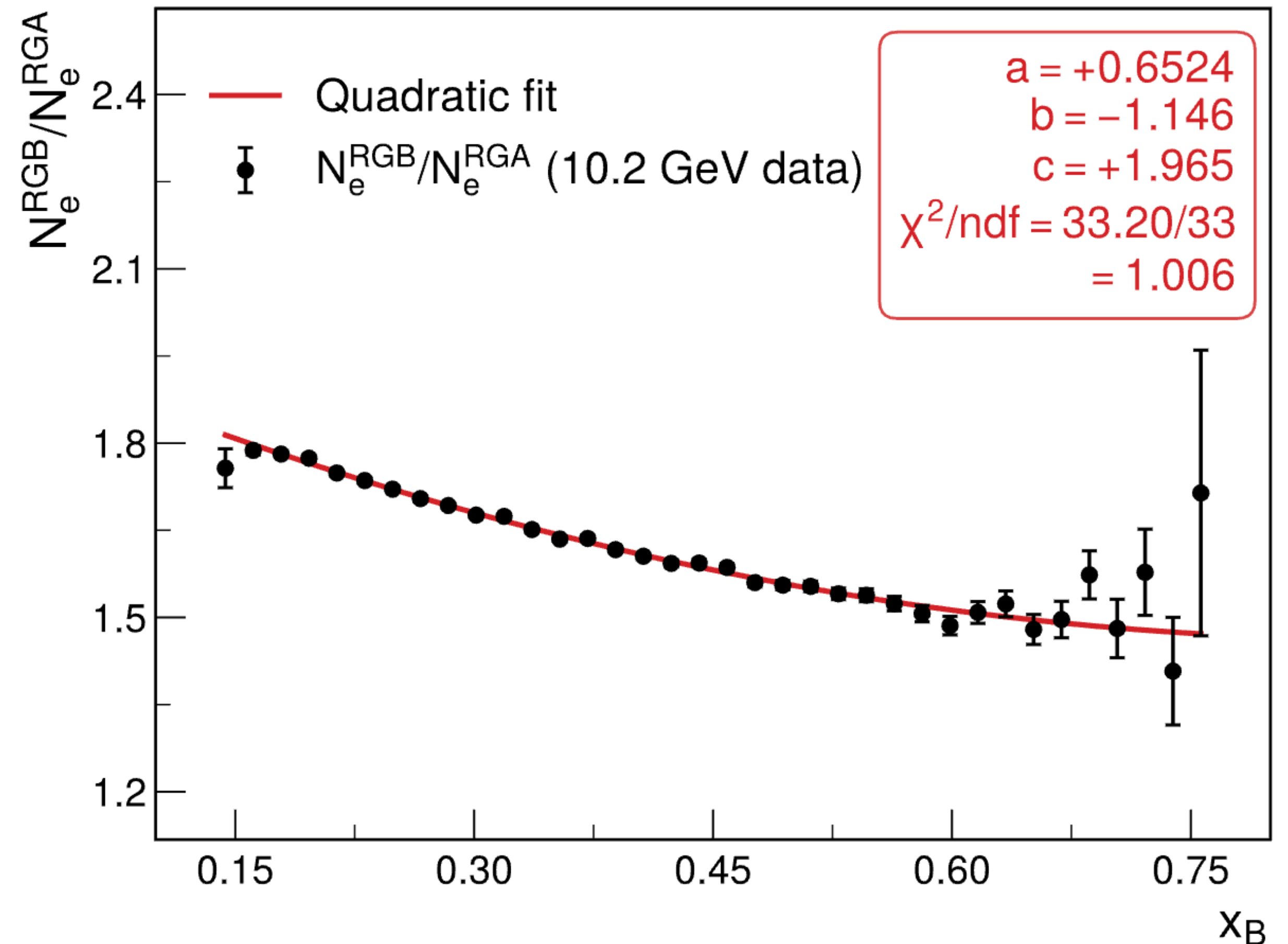
Christy-Bosted table values for F2D, F2P integrated over RGA Q^2 coverage

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

Account for luminosity and cross section simultaneously with inclusive yield ratio

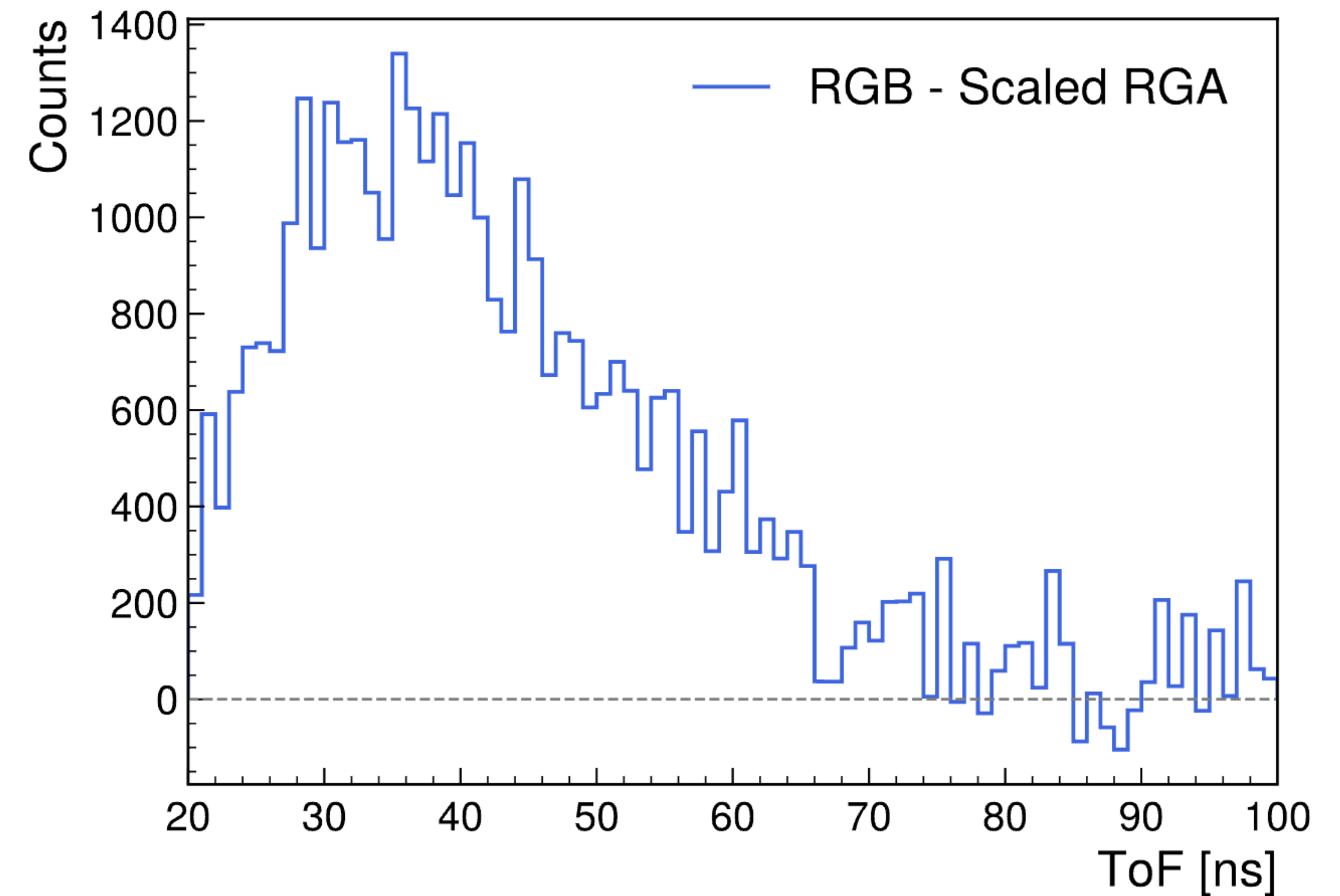
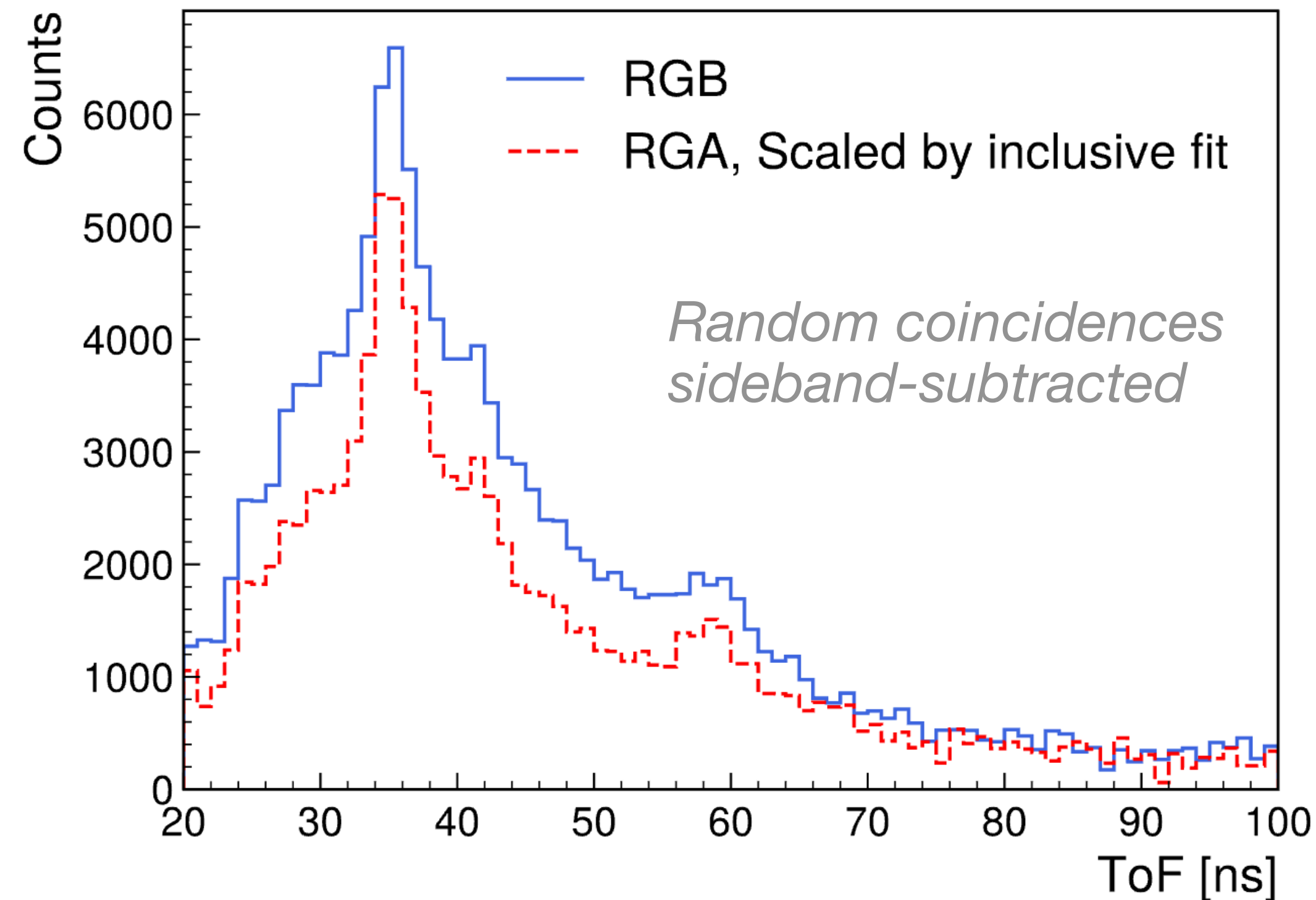
- With luminosity scaling, RGB/RGA inclusive yield ratio \approx F2D/F2P

→ Use quadratic fit to $N_e^{RGB}(x_B)/N_e^{RGA}(x_B)$ to scale RGA 10.2 GeV data event by event



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

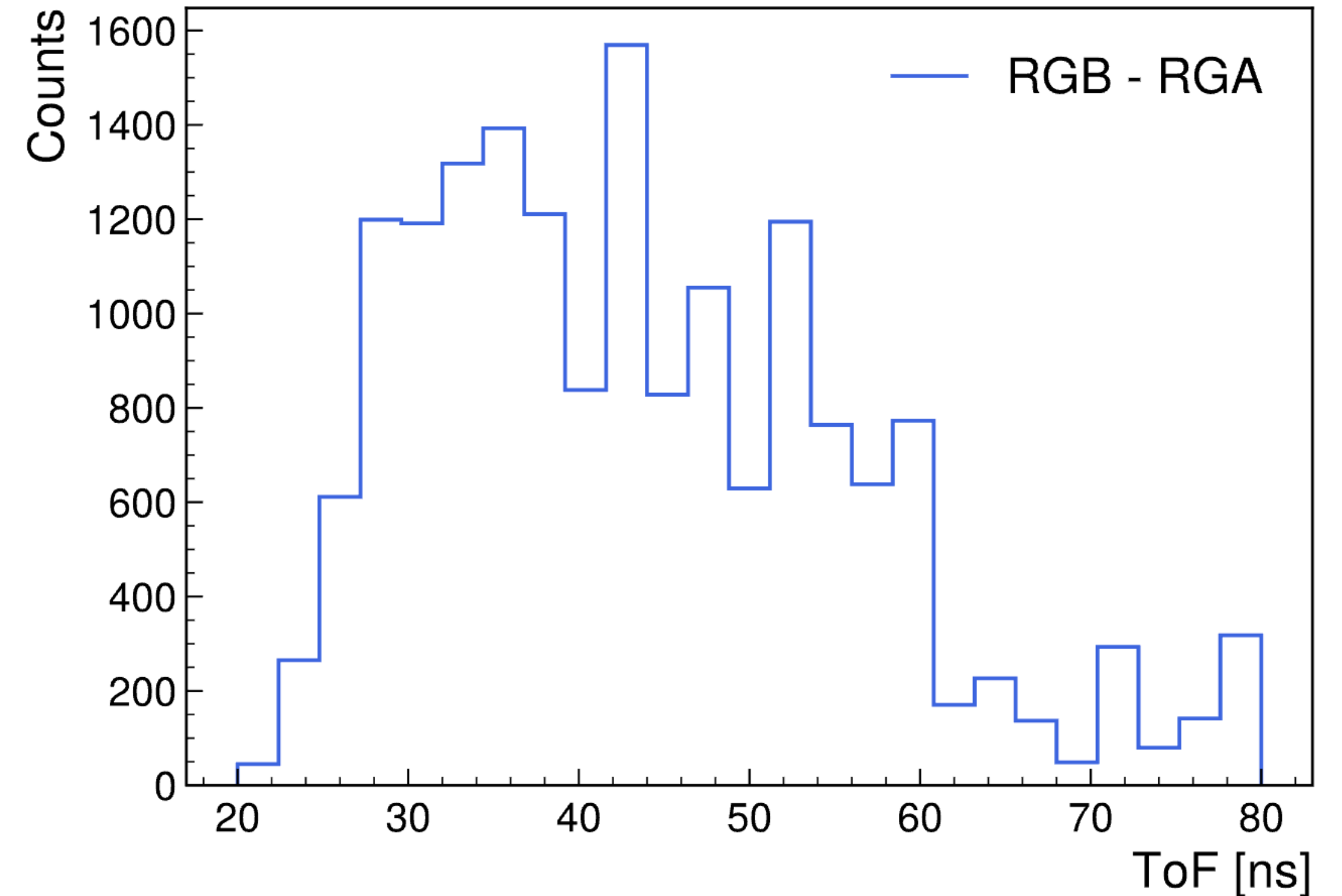
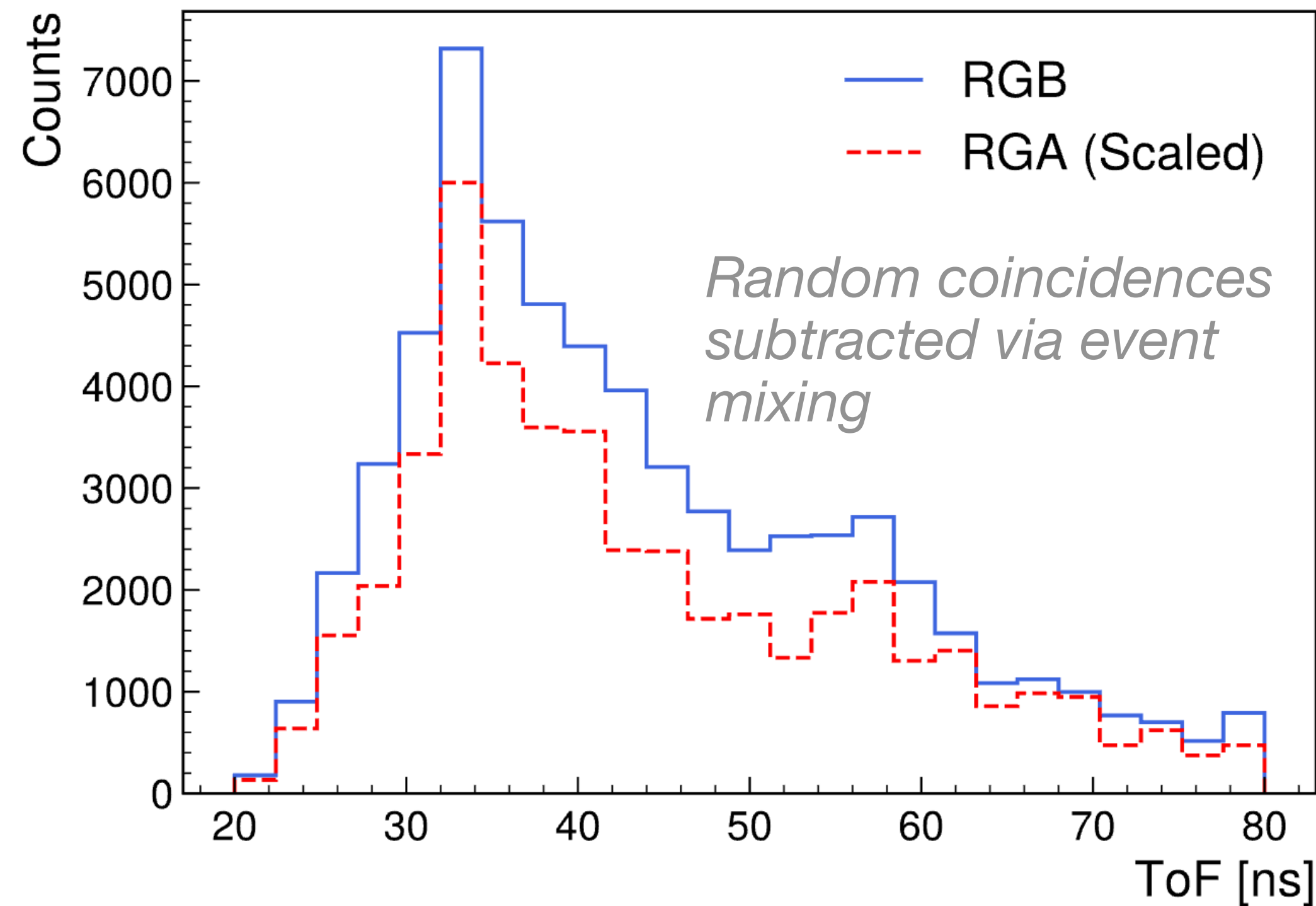
With neutron fiducial cuts + DIS only (no tagged kinematic cuts):



- Scaled RGA makes up $\sim 75\%$ of unsubtracted RGB signal
- Subtracting scaled RGA reshapes ToF spectrum; eliminates anomalous 34 ns peak

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

With neutron fiducial cuts + DIS + tagged kinematic cuts:

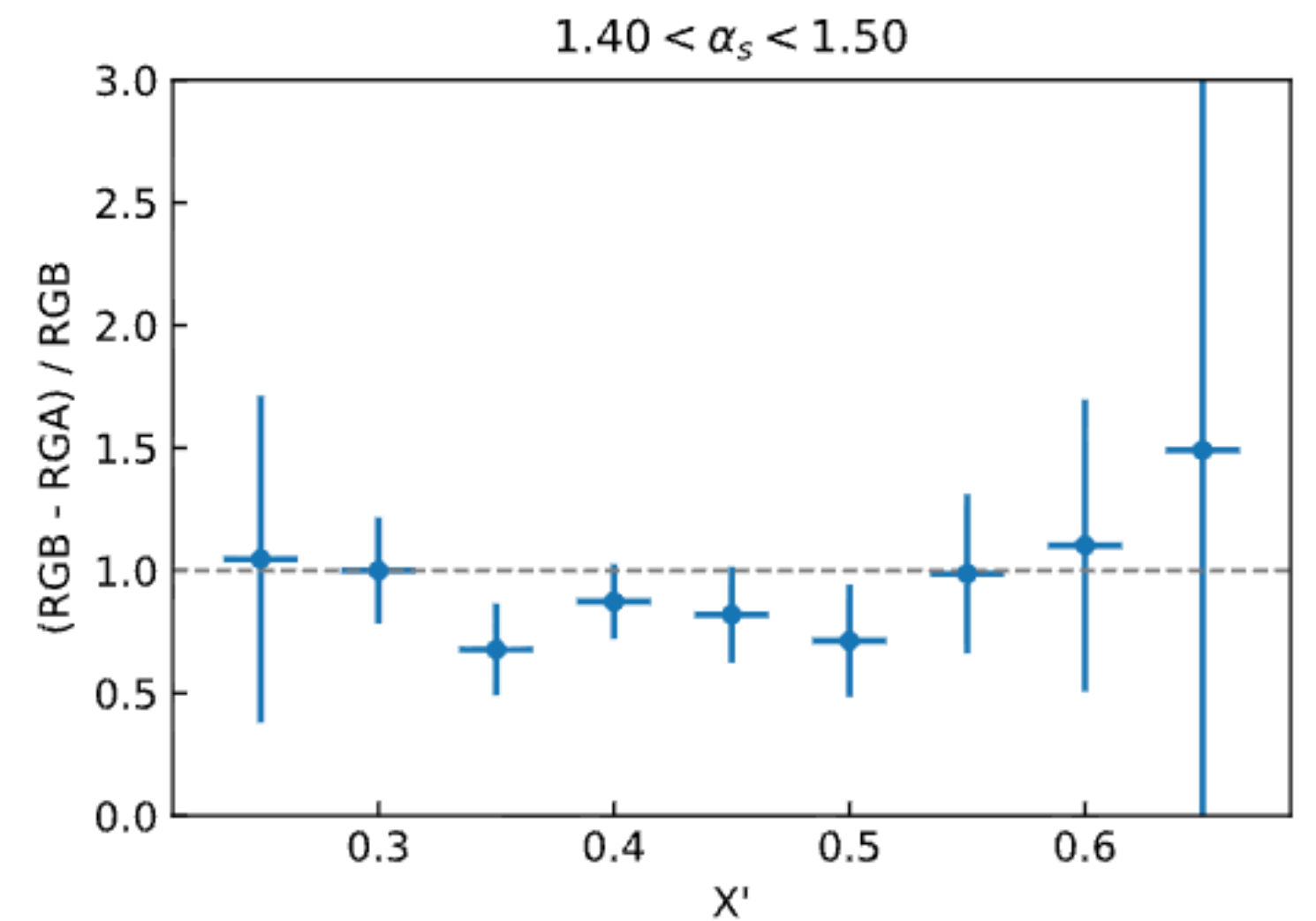
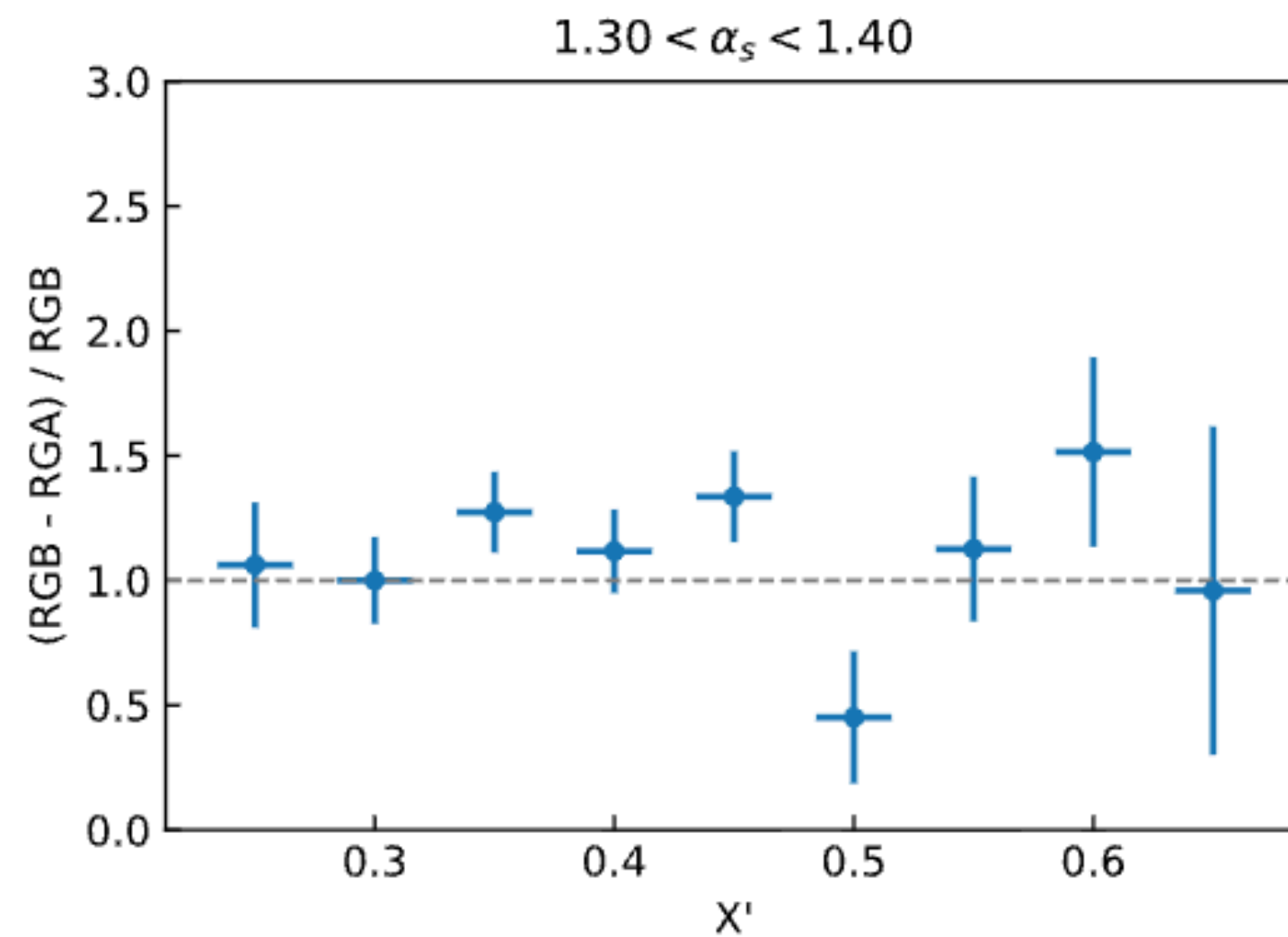
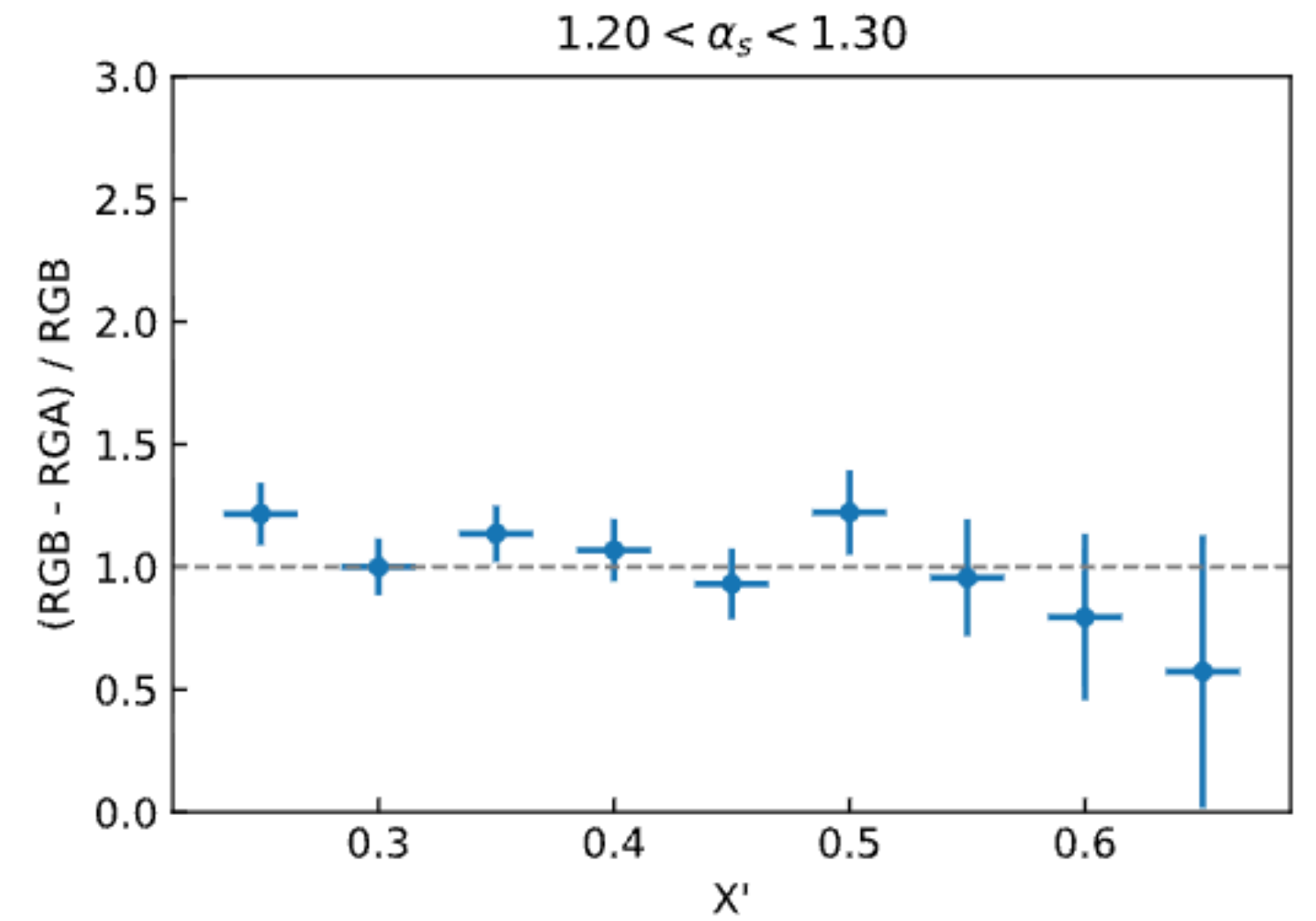
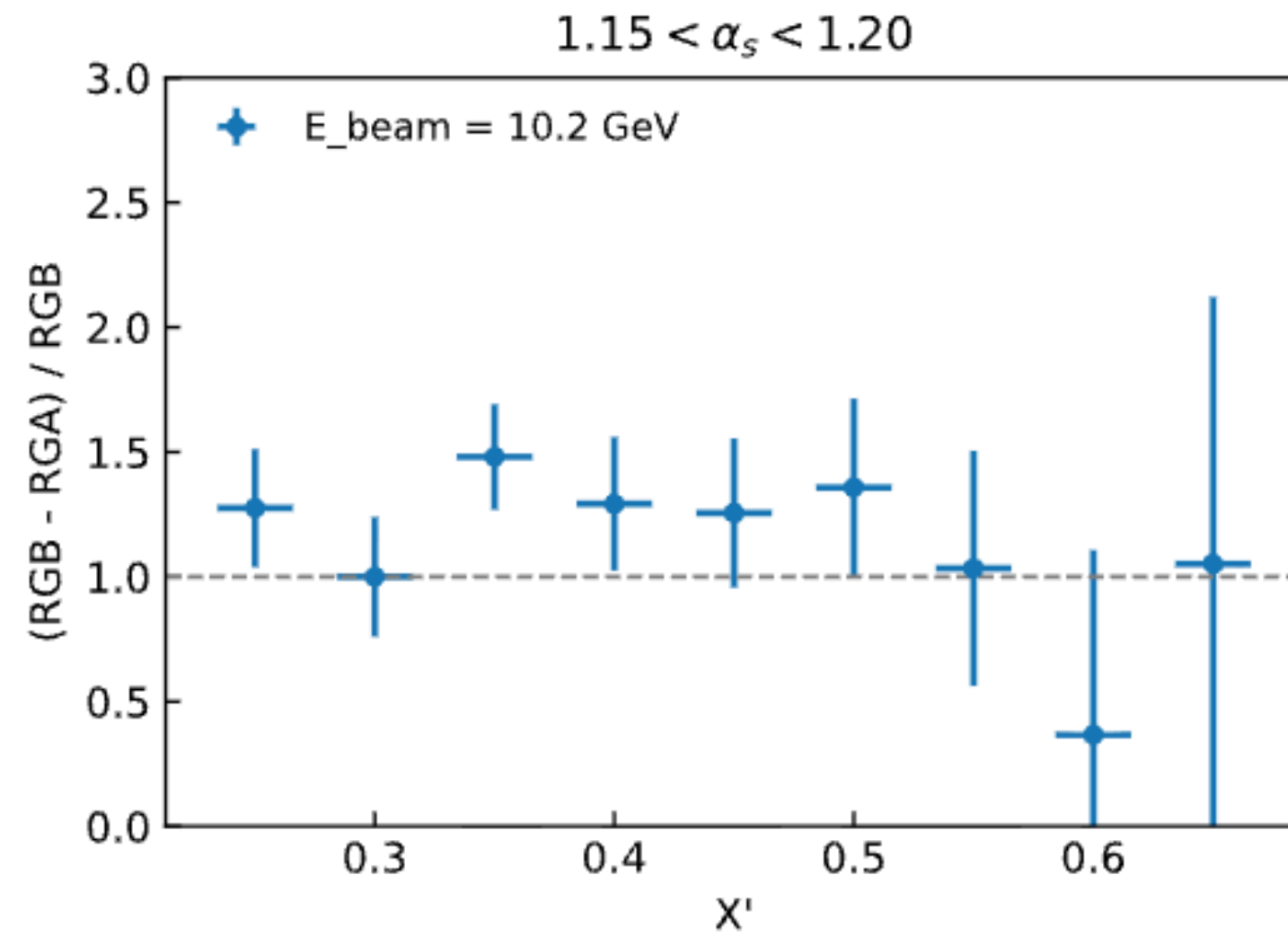


- Scaled RGA makes up $\sim 75\%$ of unsubtracted RGB signal
- Subtracting scaled RGA reshapes ToF spectrum; eliminates anomalous 34 ns peak

Impact of Subtraction on Observable (10.2 GeV)

Ratio of RGA-subtracted
result to previous
unsubtracted result

$$\frac{Y_{Sub}(\alpha_s, x') / Y_{Sub}(\alpha_s, 0.3)}{Y_{Orig}(\alpha_s, x') / Y_{Orig}(\alpha_s, 0.3)}$$

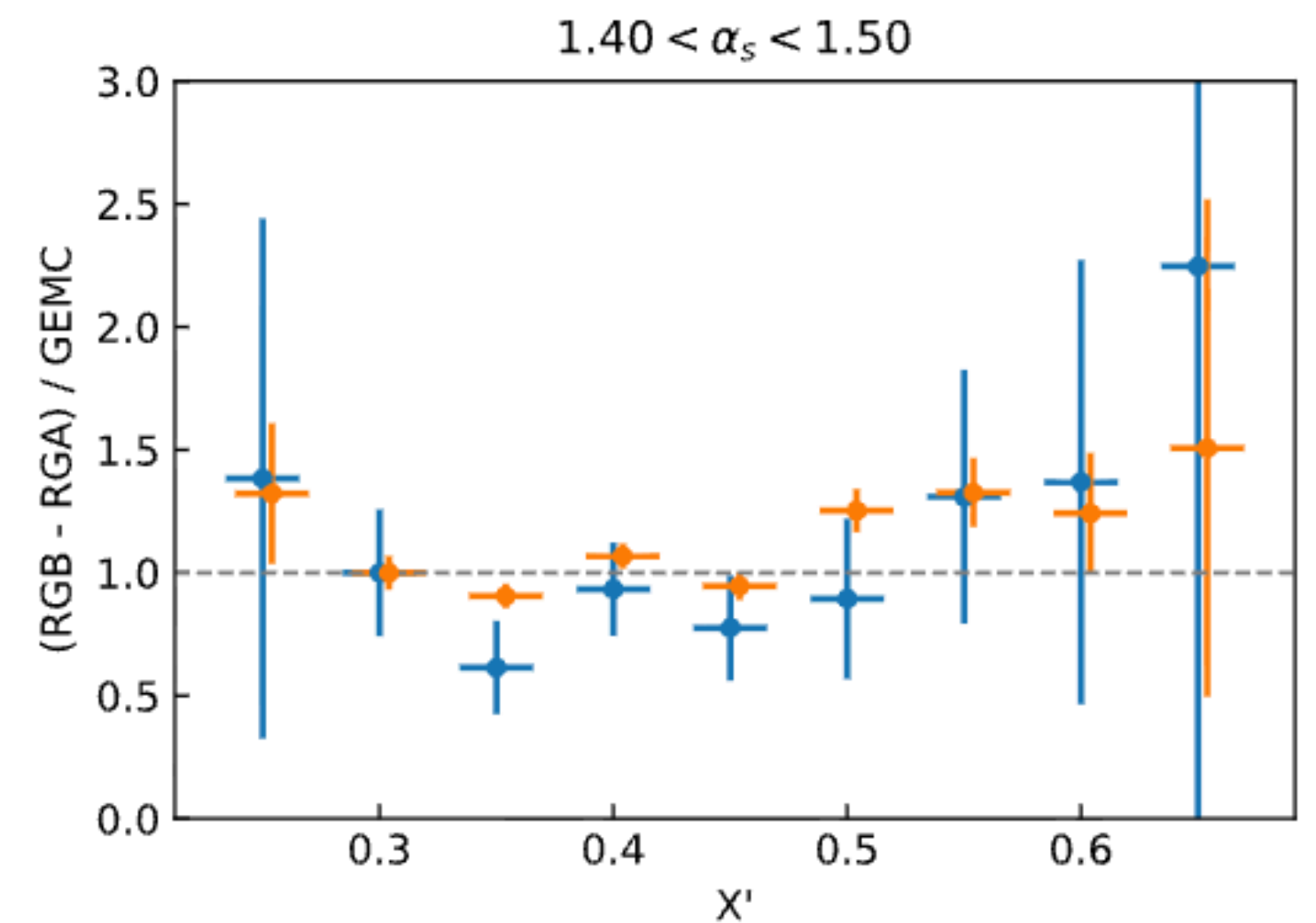
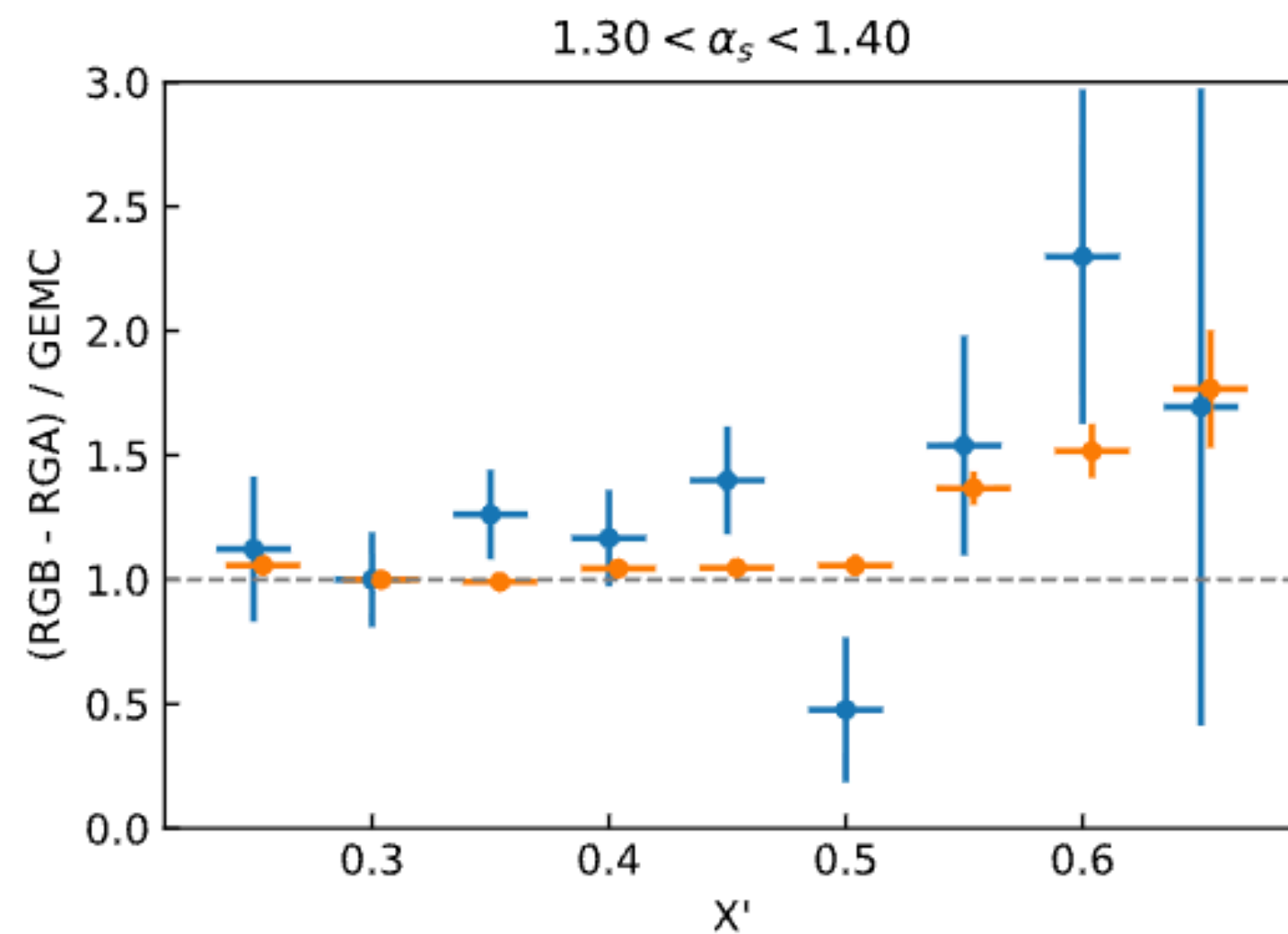
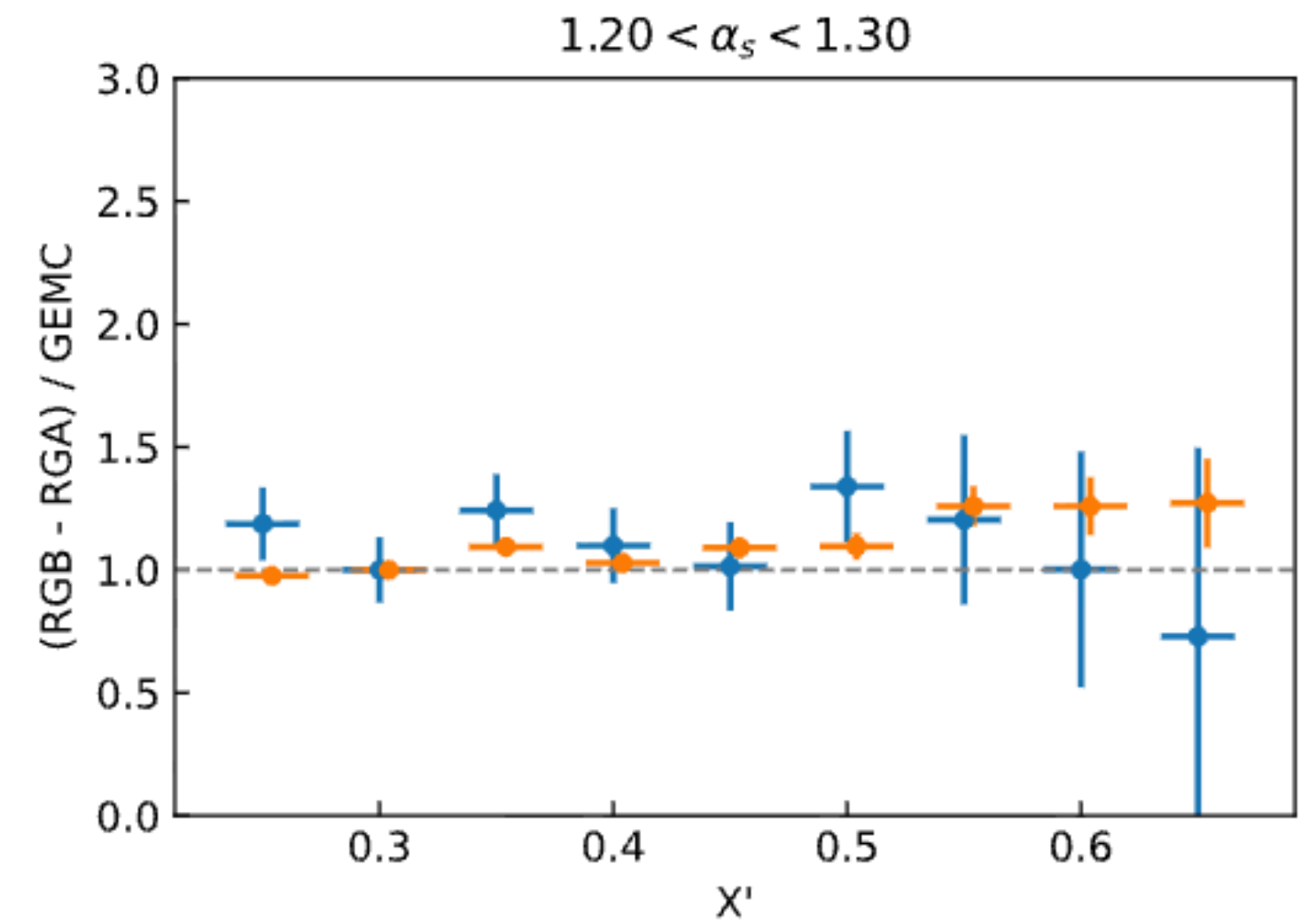
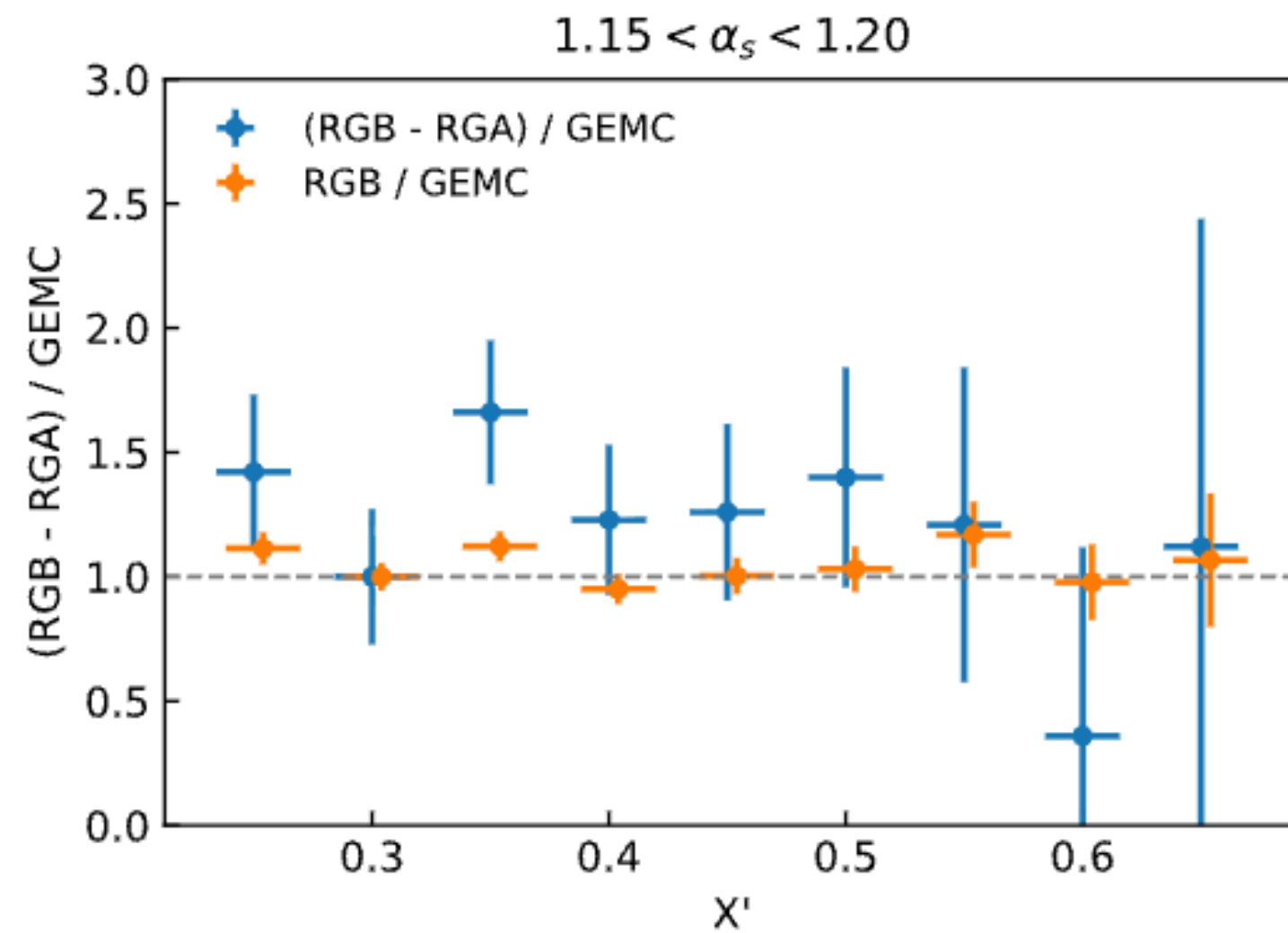


Impact of Subtraction on Observable (10.2 GeV)

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 \approx 1/3 of data

In Summary...

- Modified proton structure function as function of virtuality $\sim F_2^{p*}(x', \alpha_s)$
- Correlated background characterized by RGA data
 - Consistent with reconstructed SIDIS sim
 - $\sigma_{ep} \rightarrow \sigma_{ed}$ via inclusive DIS scaling
- General trend: Similar. Current error bars: Huge.

Next up for BAND:

- Scale RGA 10.2 GeV to subtract from RGB 10.4, 10.6 GeV
- Subtract RGA to update all previous results, systematics, etc.
- Fully update analysis note and resubmit!

In Summary...

- Modified proton structure function as function of virtuality $\sim F_2^{p*}(x', \alpha_s)$
- Correlated background characterized by RGA data
 - Co
 - σ_{ep}
- General

Thank you!

Next up for BAND:

- Scale RGA 10.2 GeV to subtract from RGB 10.4, 10.6 GeV
- Subtract RGA to update all previous results, systematics, etc.
- Fully update analysis note and resubmit!

Backup

RGA scale sensitivity

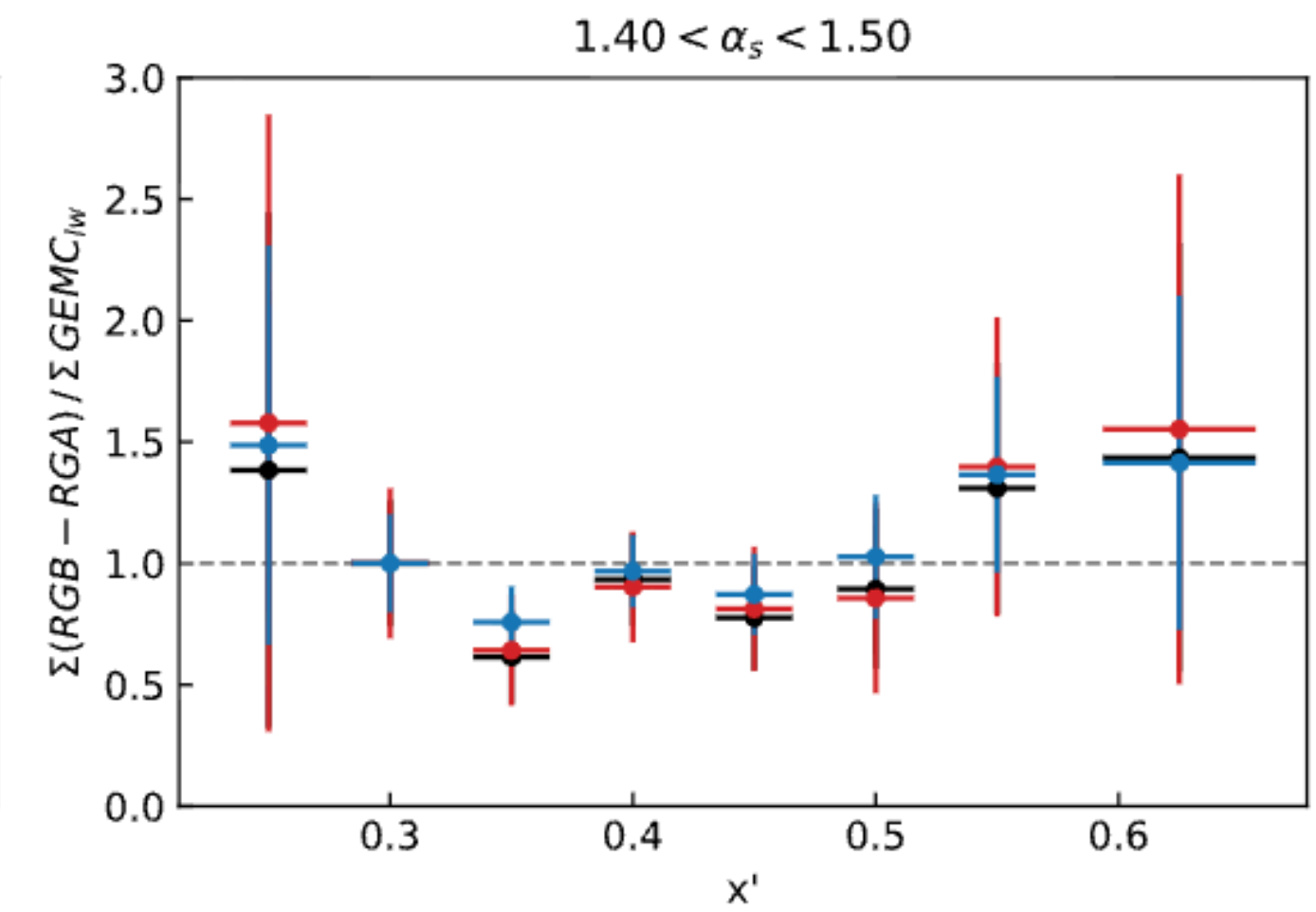
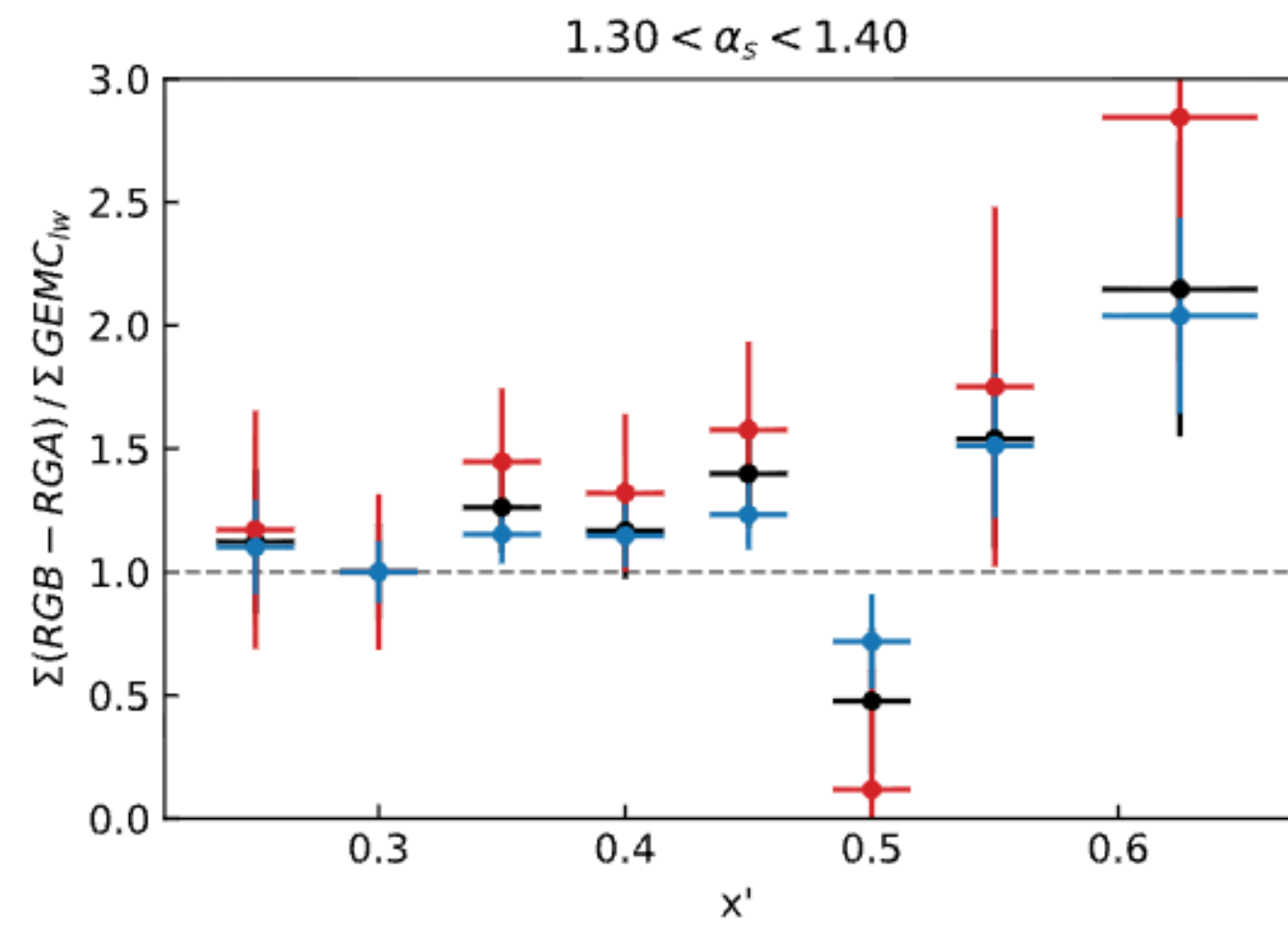
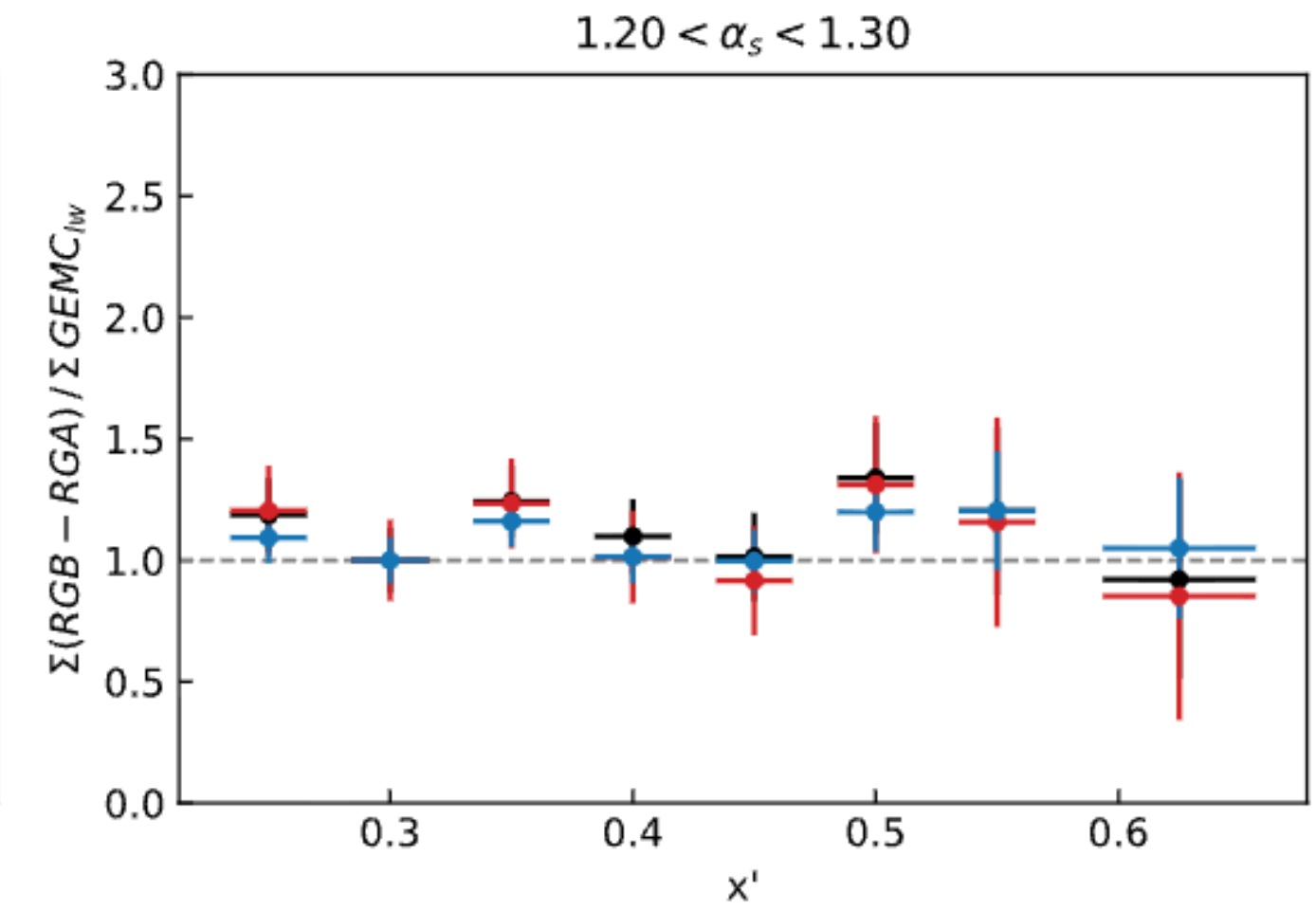
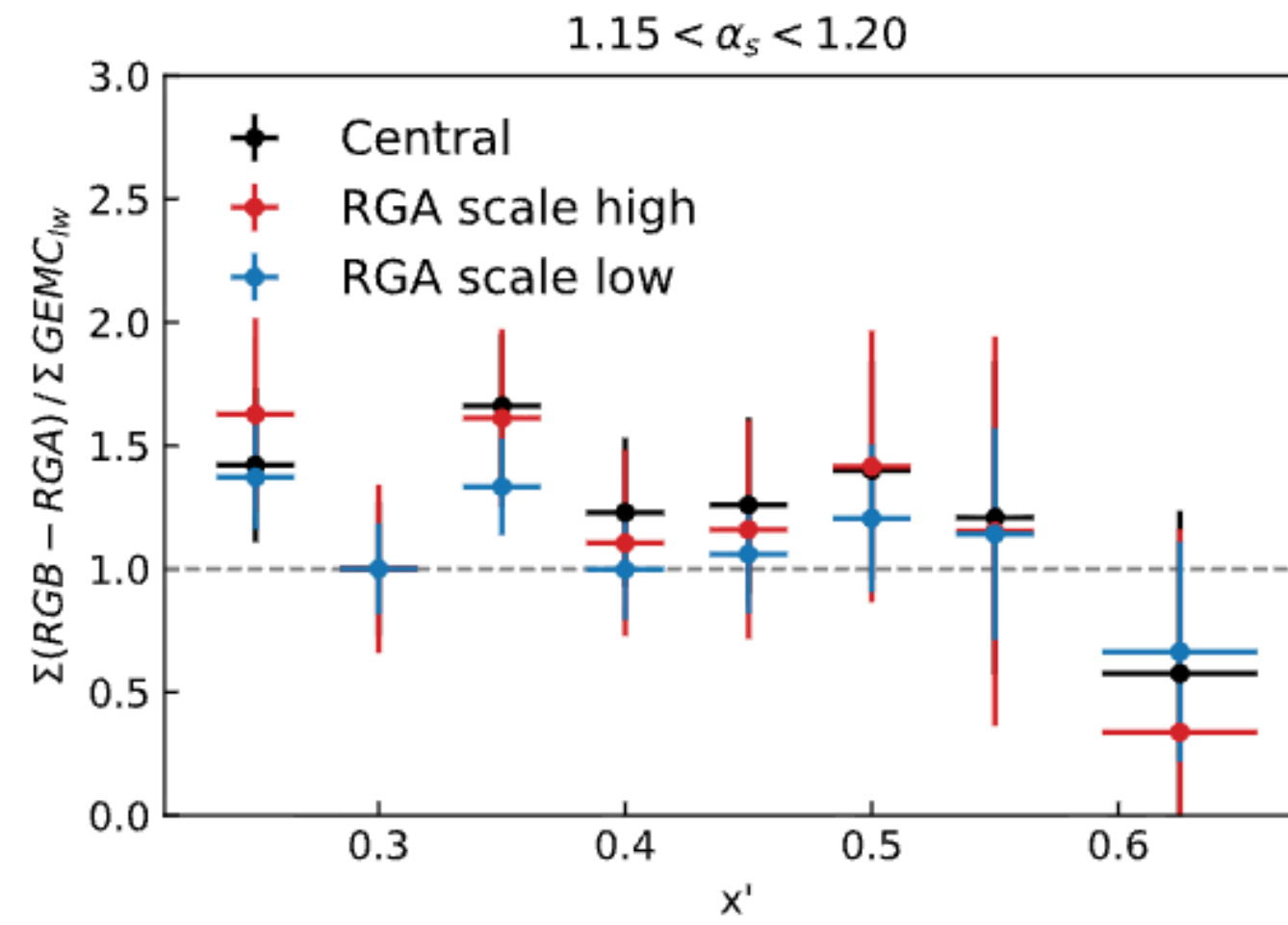
10.2 GeV

$$\frac{Y_{RGB} - Y_{RGA}}{Y_{sim}}$$

Value from RGA scaling
discussed in prev slides

+10%

-10%



RGA scale sensitivity

10.2 GeV

$$\frac{Y_{RGB} - Y_{RGA}}{Y_{sim}}$$

Value from RGA scaling
discussed in prev slides

$\pm 10\%$

