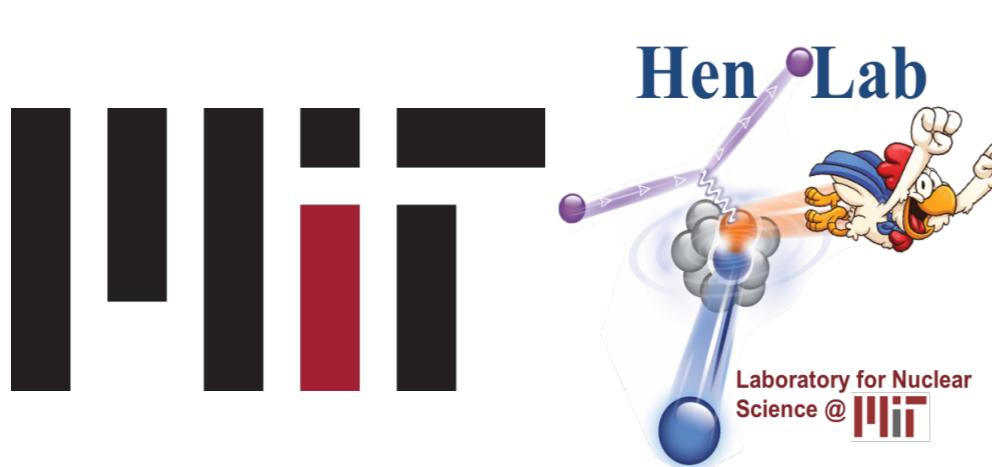


Bound proton structure with BAND

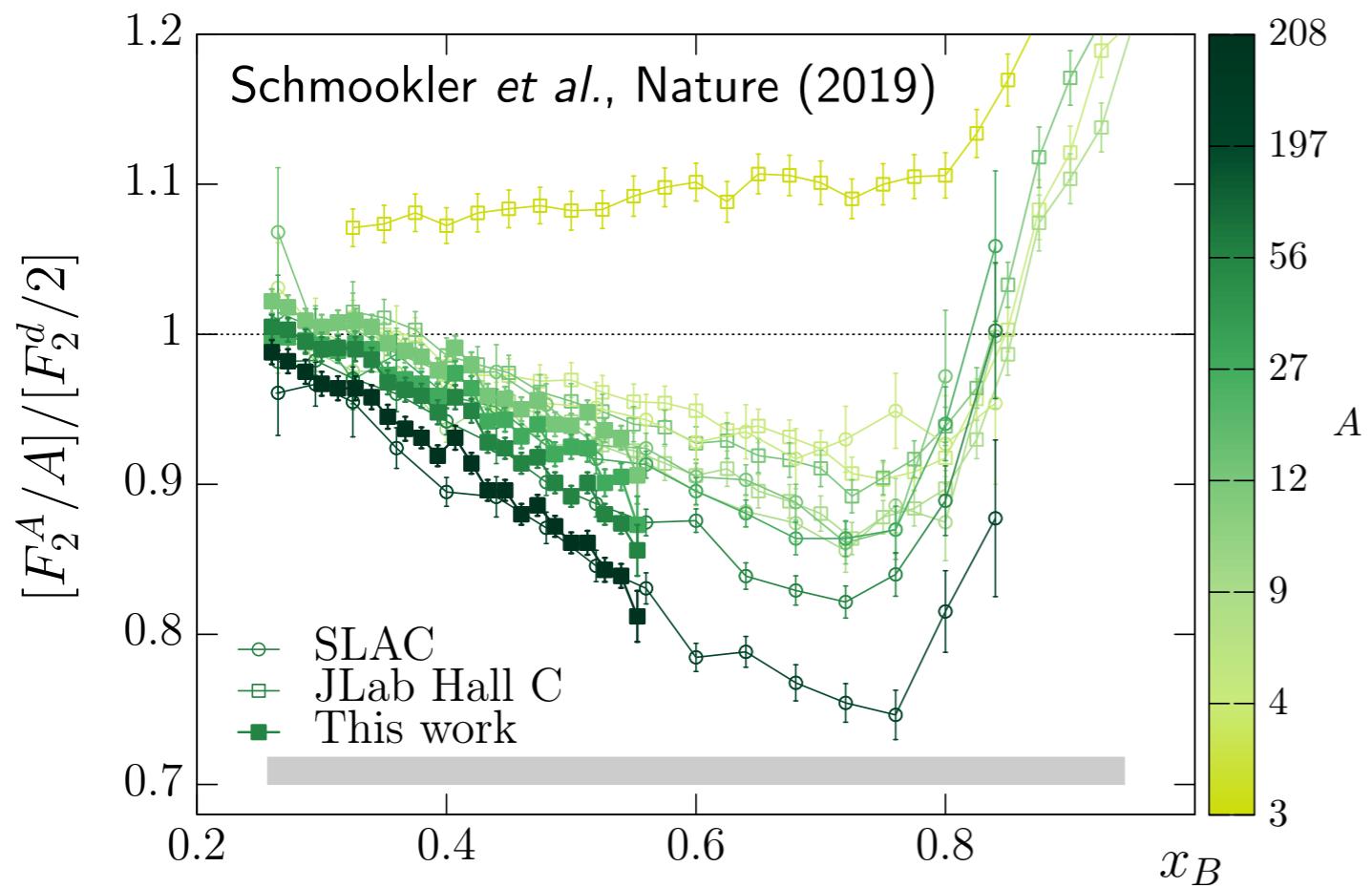
Tyler Kutz
MIT & GWU

Workshop on quantitative challenges in EMC and SRC research
March 24, 2021



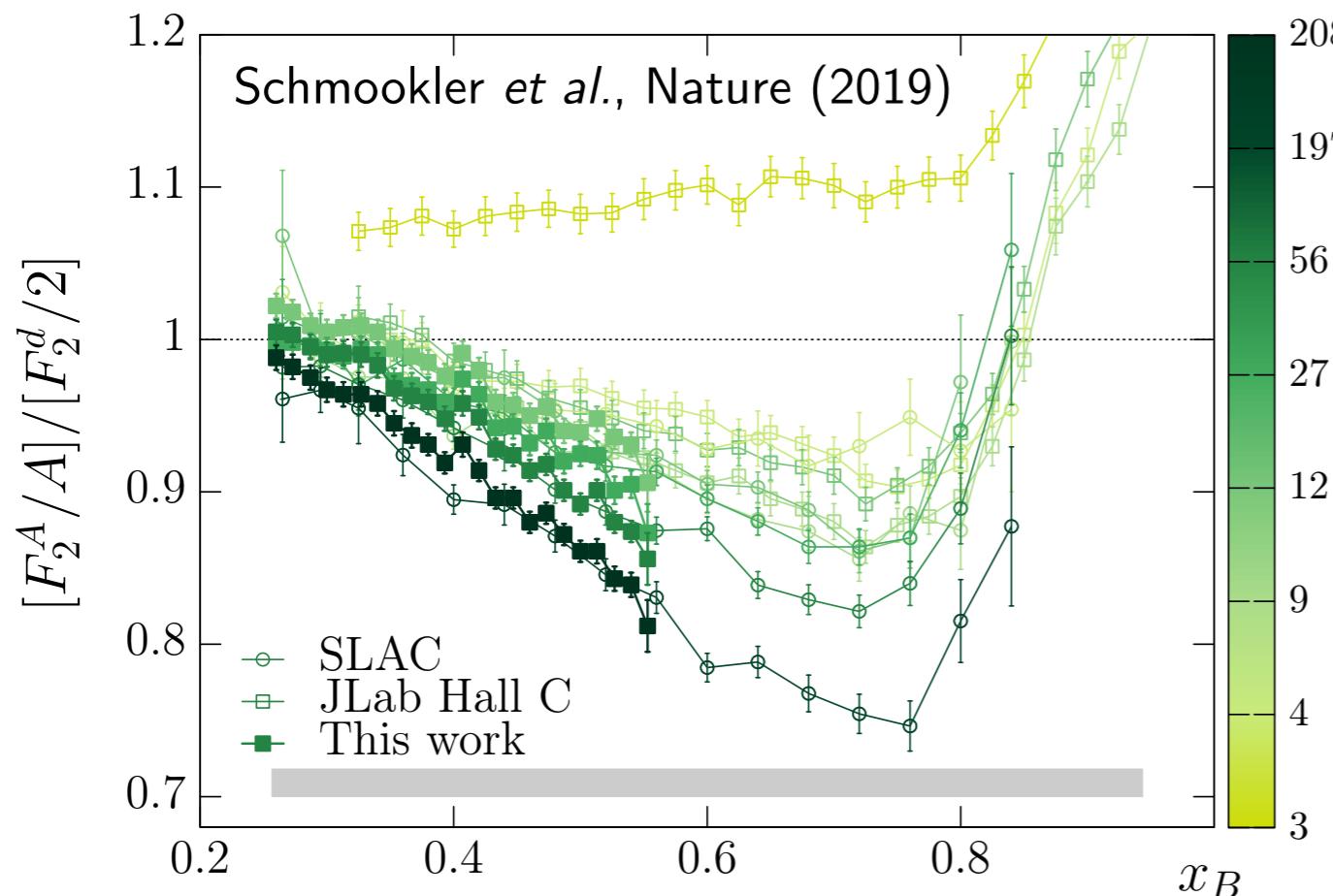
What's the deal with the EMC effect?

- *Free and bound* nucleons have different structure (EMC effect)
- 4 decades of experiments and models to describe origin
- Majority of data from *inclusive measurements* (integral of parton structure over all nuclear configurations)
- Should look for...



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- *Free* and *bound* nucleons have different structure (EMC effect)
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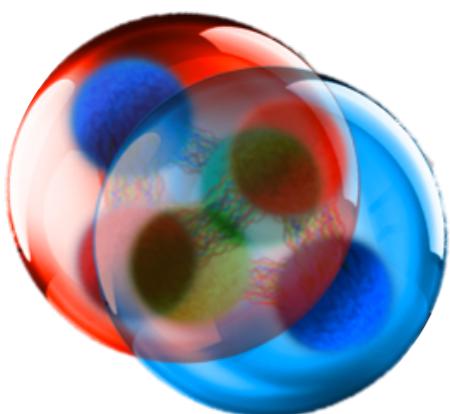


Nuclear configuration from spectator tagging

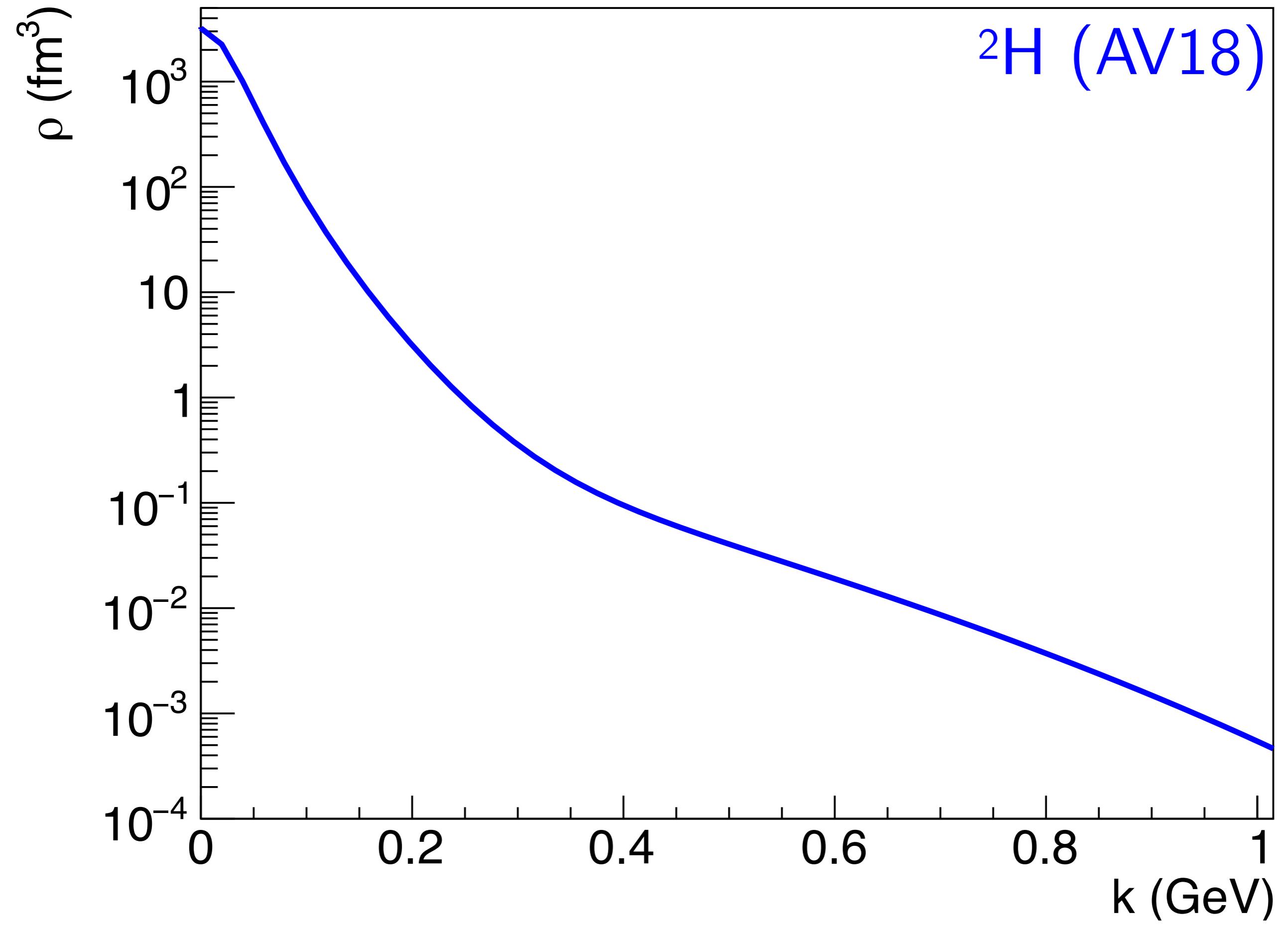
- Want to measure parton structure of bound nucleon,
but differentiate...

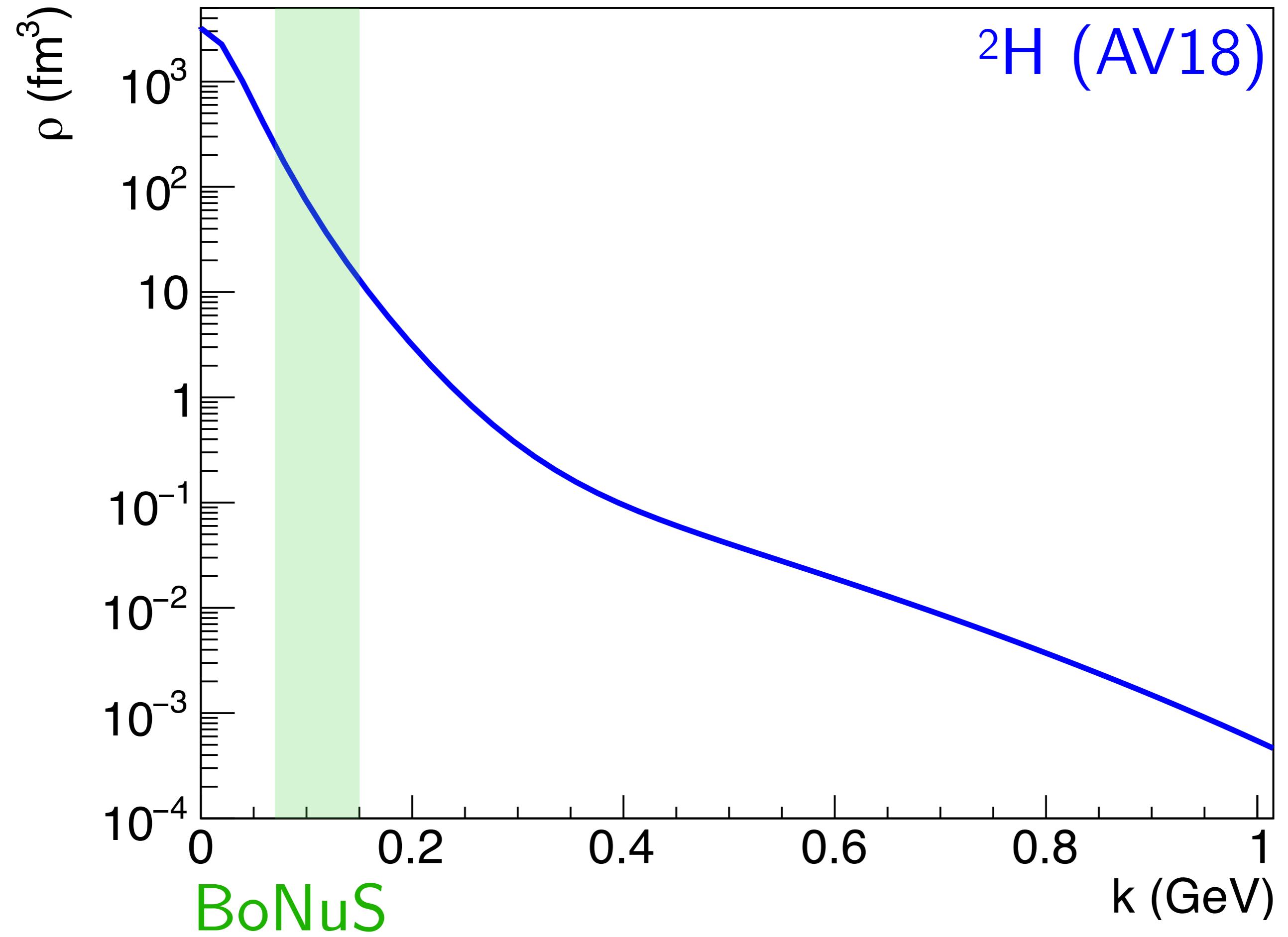


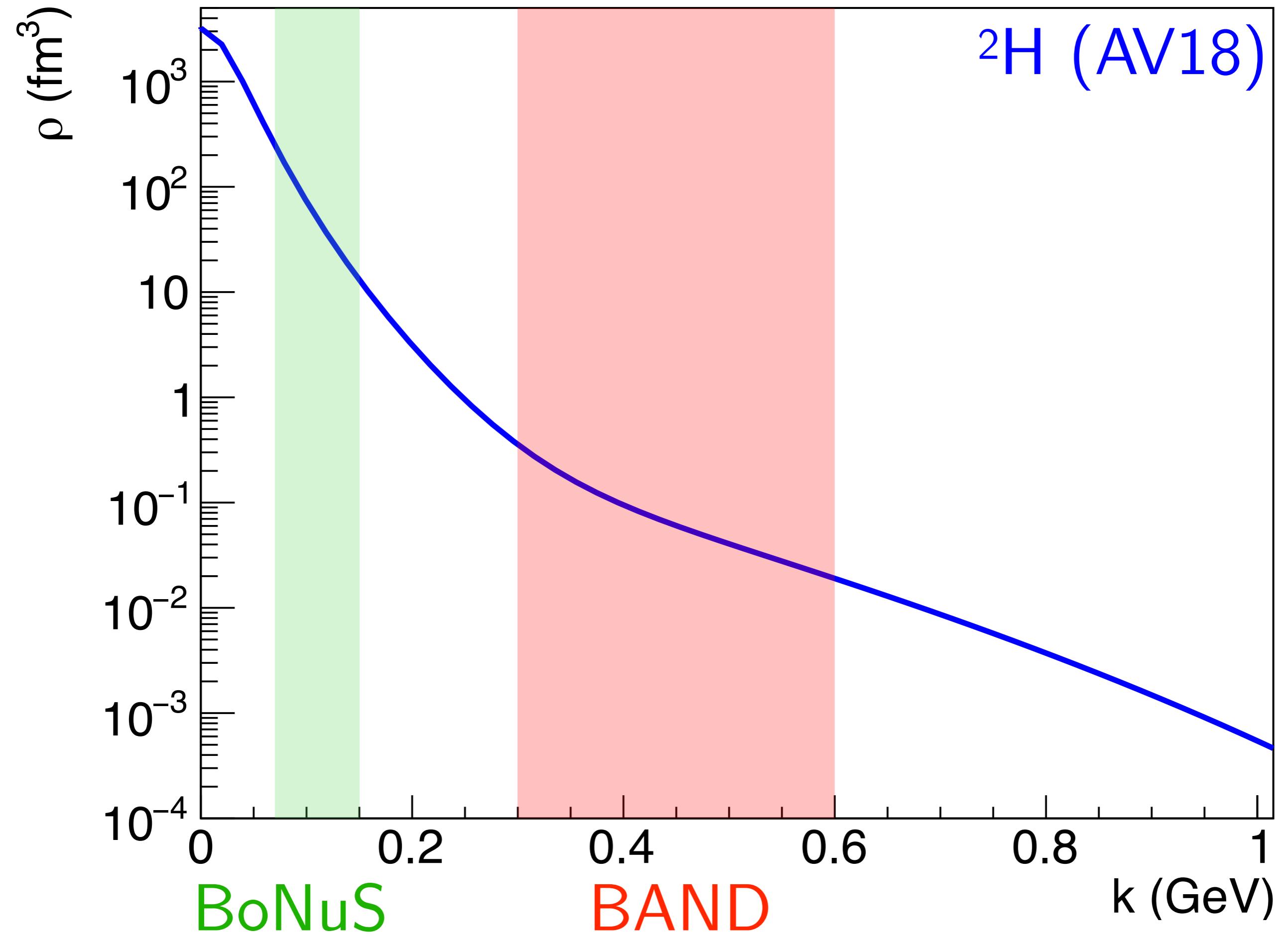
- DIS destroys struck nucleon
→ must infer configuration from *correlated spectator nucleon*

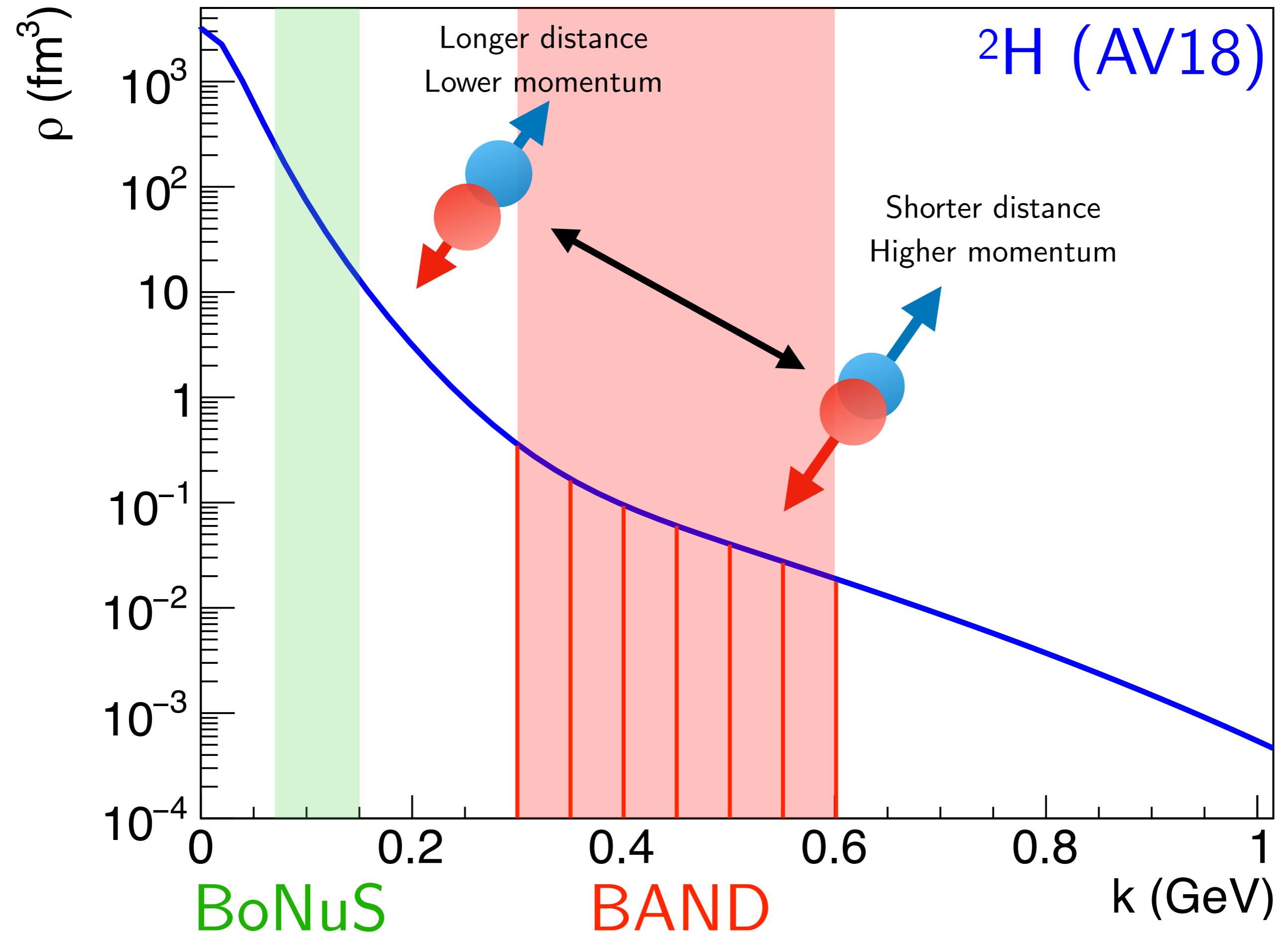


- Deuterium ideal nucleus to study
 - Know which nucleon was struck (n or p)
 - “Simple” two-body system *always correlated*

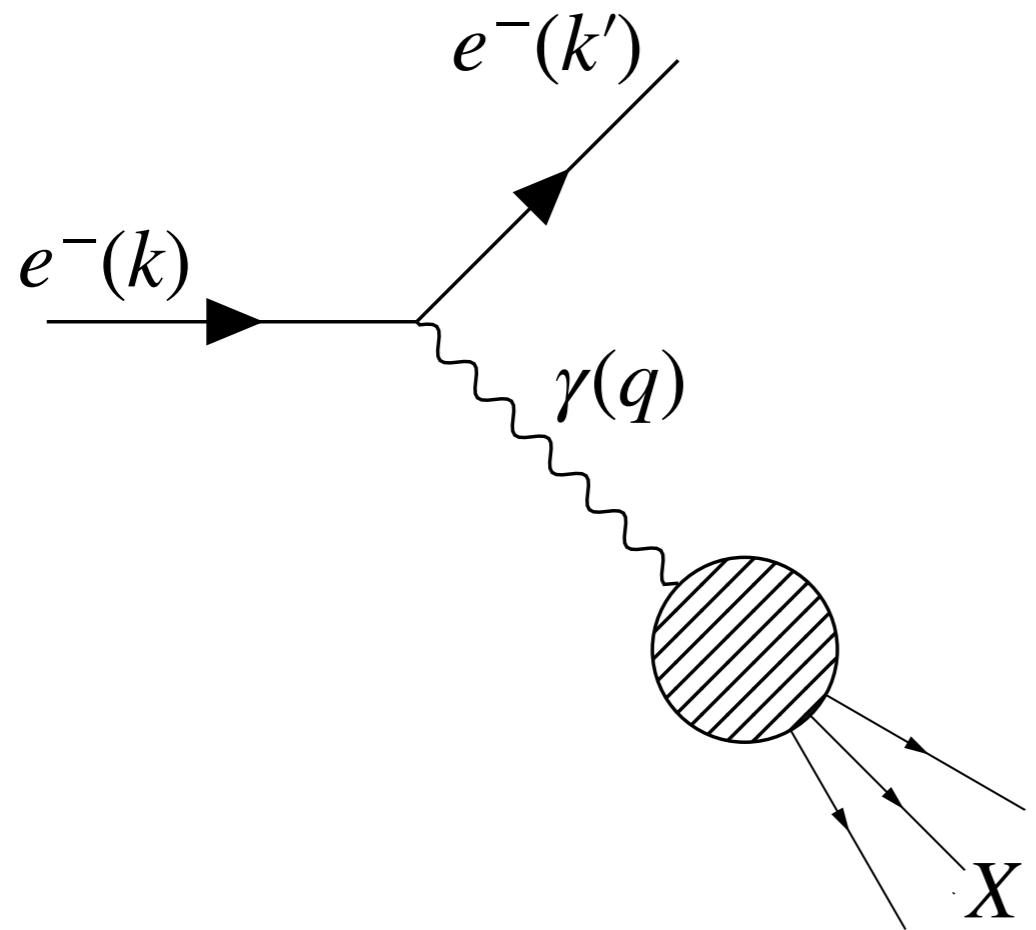








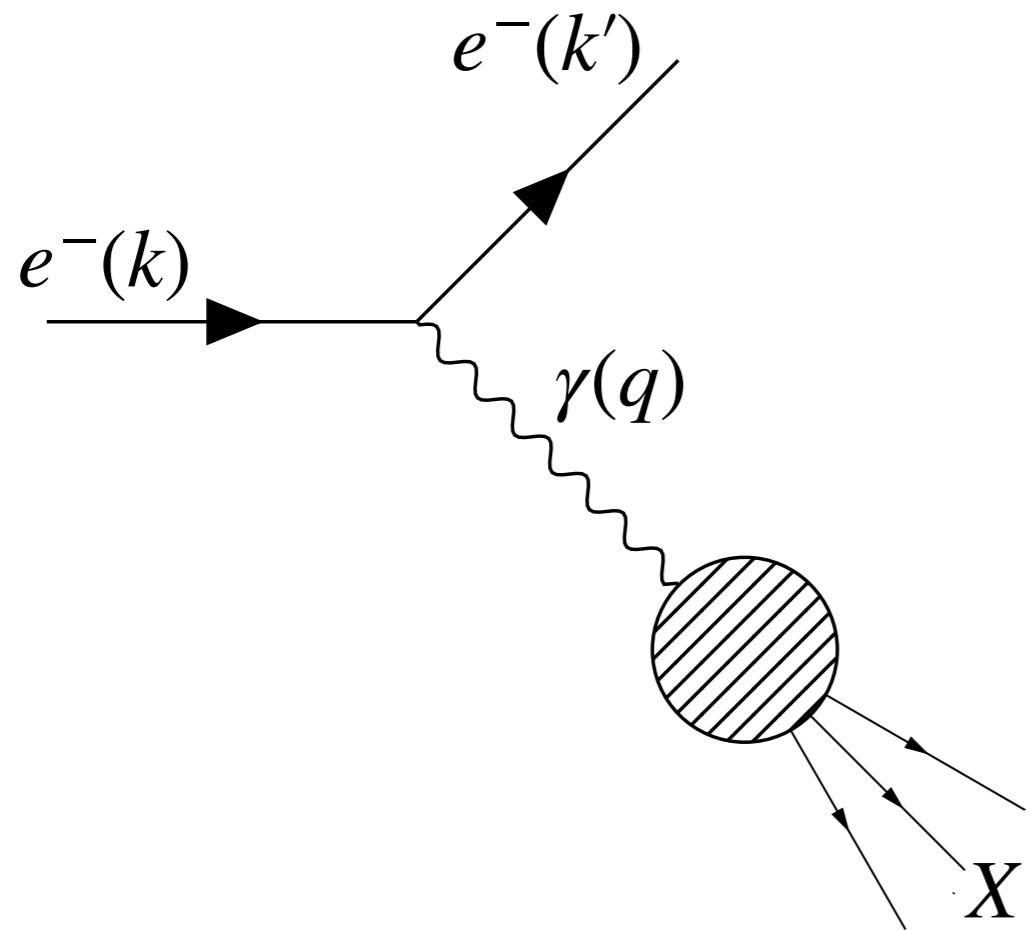
Bound proton structure with tagged DIS



$$Q^2 = - (k - k')^2$$

$$x = \frac{Q^2}{2P_\mu q^\mu}$$

Bound proton structure with tagged DIS

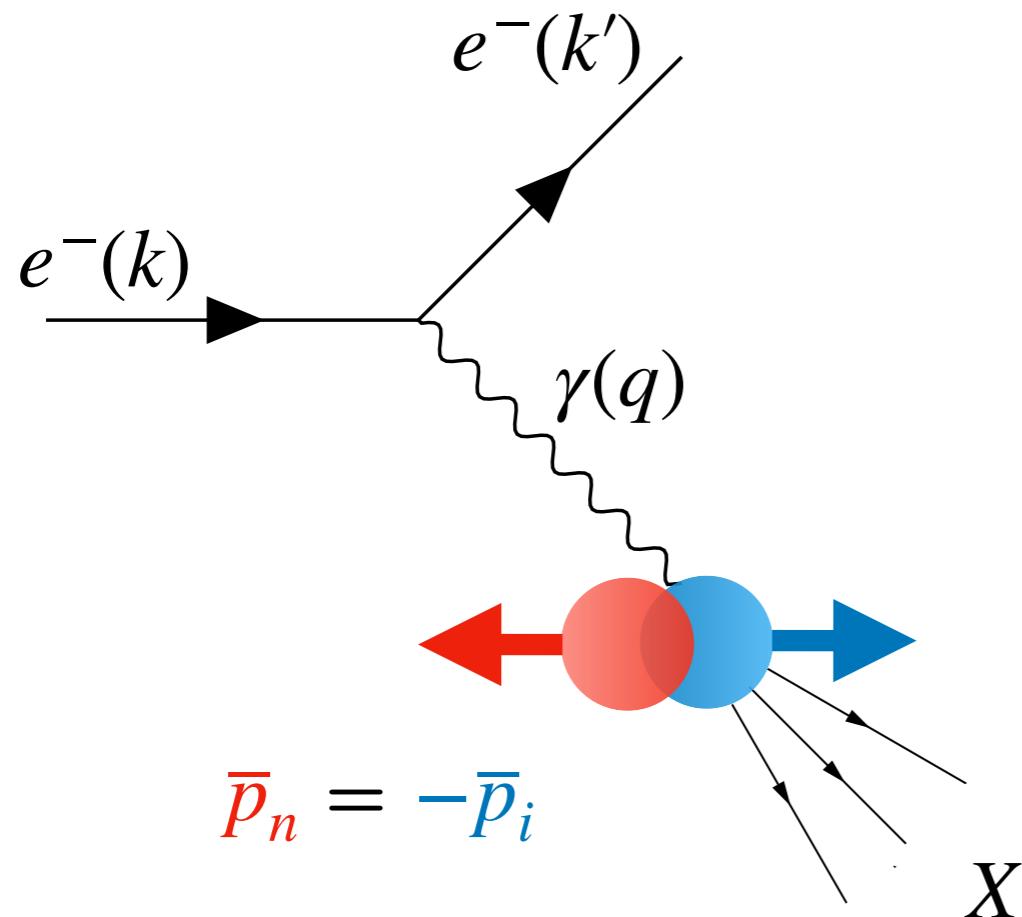


$$Q^2 = - (k - k')^2$$

$$x = \frac{Q^2}{2P_\mu q^\mu}$$

Standing nucleon: $P = (M_i, \vec{0}) \rightarrow x_B$

Bound proton structure with tagged DIS



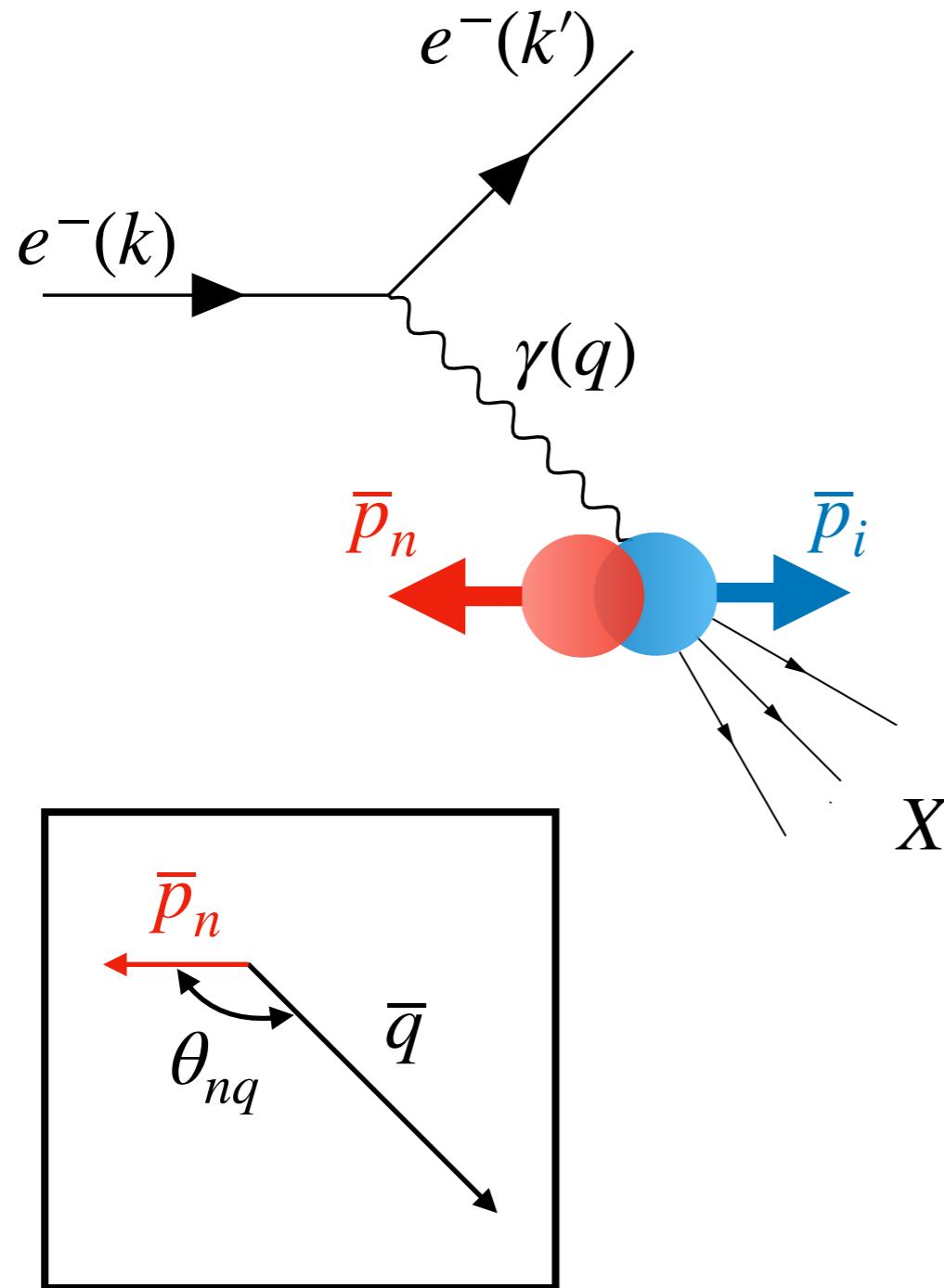
$$Q^2 = -(k - k')^2$$

$$x = \frac{Q^2}{2P_\mu q^\mu}$$

Standing nucleon: $P = (M_i, \vec{0}) \rightarrow x_B$

Moving nucleon: $P = (E_i, \bar{p}_i) \rightarrow x'$

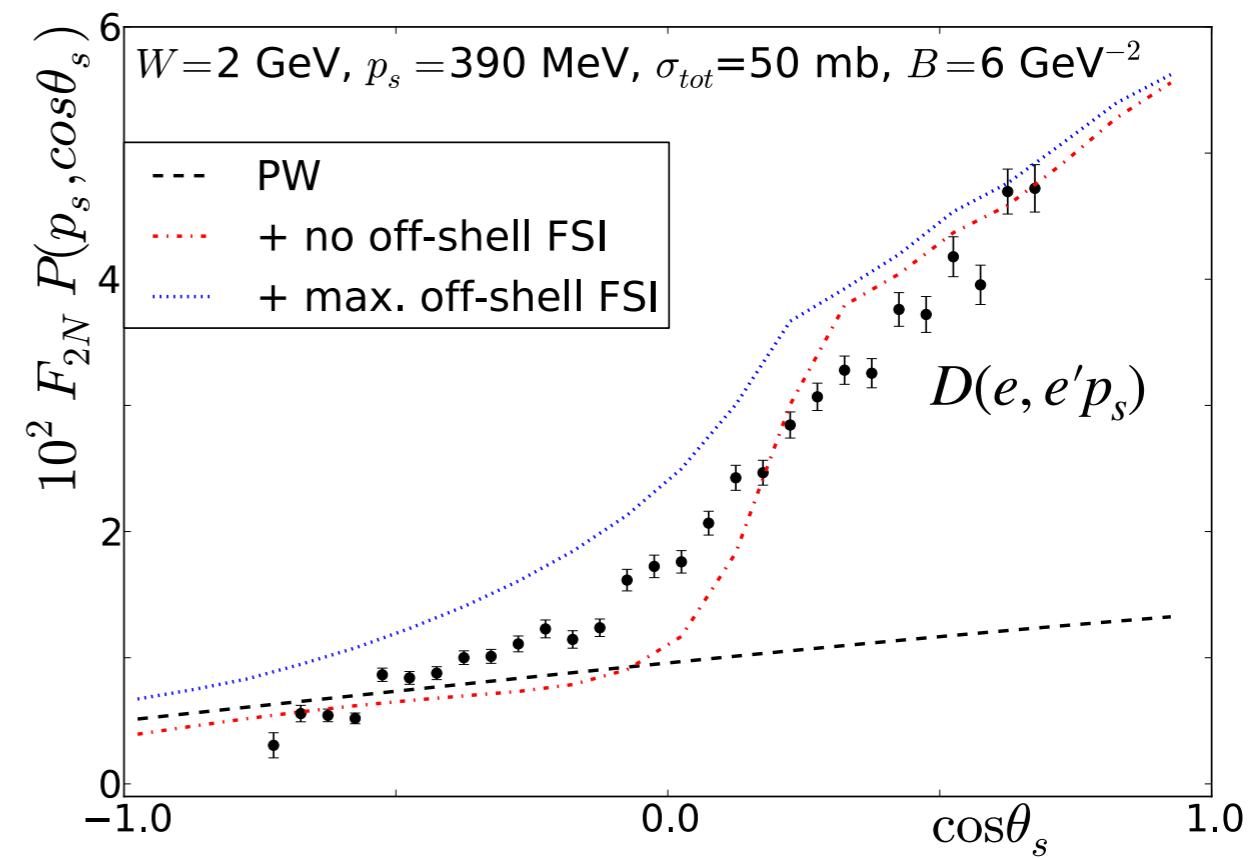
Bound proton structure with tagged DIS



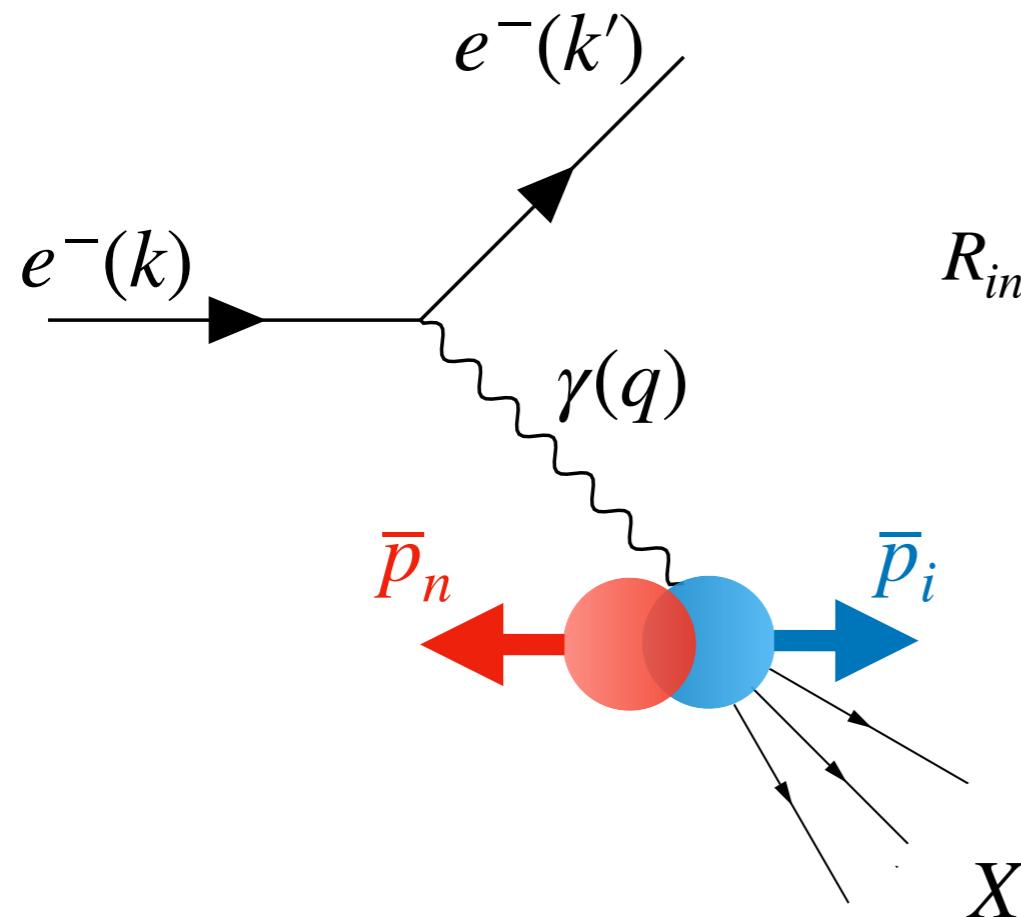
- Spectator LC momentum fraction:

$$\alpha_S = \frac{E_s - p_{\parallel}}{M_s}$$

- Require backward θ_{nq} to minimize FSI



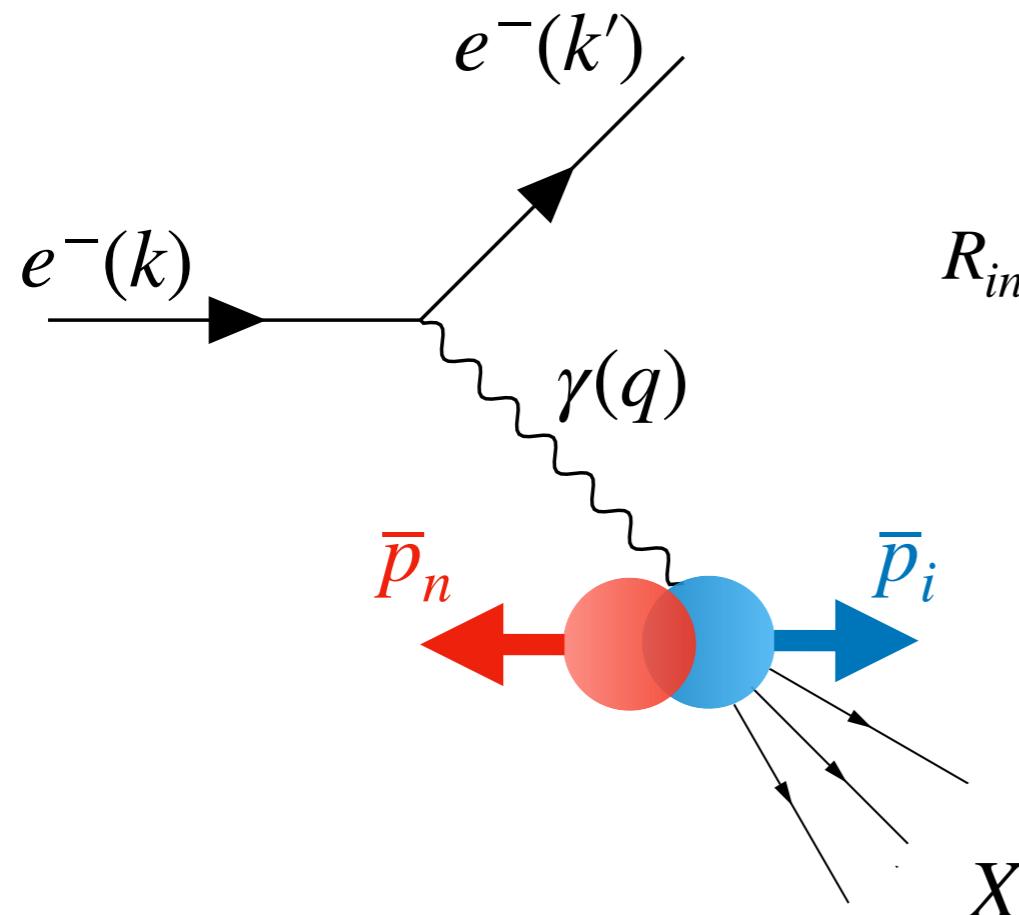
Bound proton structure with tagged DIS



Inclusive ratio:

$$R_{inc} = \left(\frac{Y_{inc}^{exp}(Q^2, x)}{Y_{inc}^{exp}(Q^2, x = 0.3)} \right)$$

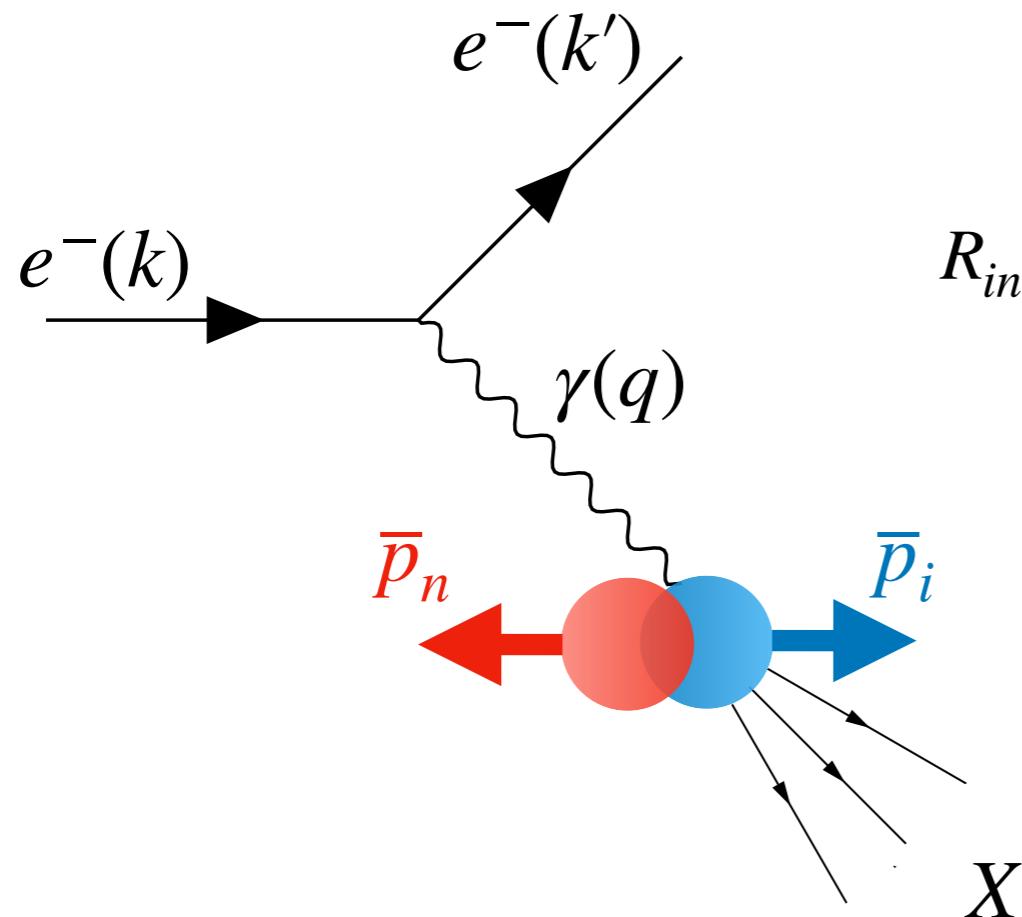
Bound proton structure with tagged DIS



Inclusive ratio:

$$R_{inc} = \left(\frac{Y_{inc}^{exp}(Q^2, x)}{Y_{inc}^{exp}(Q^2, x = 0.3)} \right) / \left(\frac{Y_{inc}^{PWIA}(Q^2, x)}{Y_{inc}^{PWIA}(Q^2, x = 0.3)} \right)$$

Bound proton structure with tagged DIS



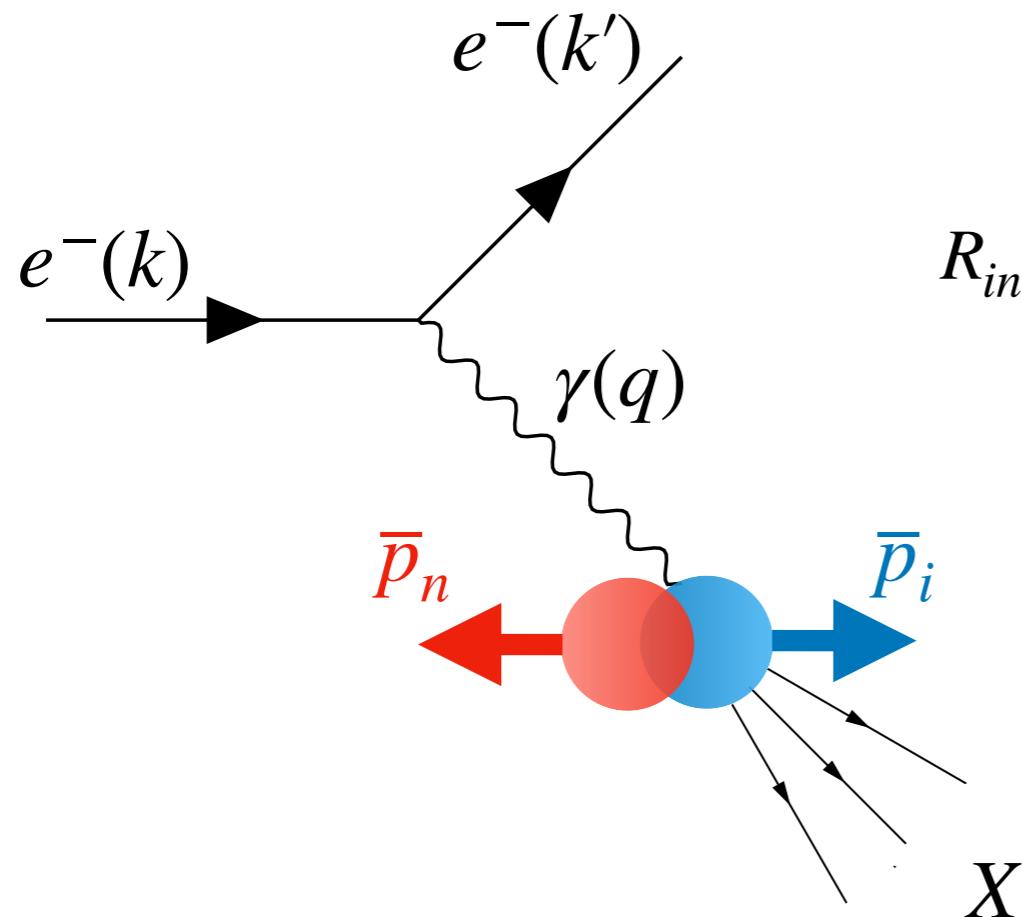
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Tagged ratio:

$$R_{tag} = \left(\frac{Y_{tag}^{exp}(Q^2, \alpha_S, x')}{Y_{tag}^{exp}(Q^2, \alpha_S, x' = 0.3)} \right)$$

Bound proton structure with tagged DIS



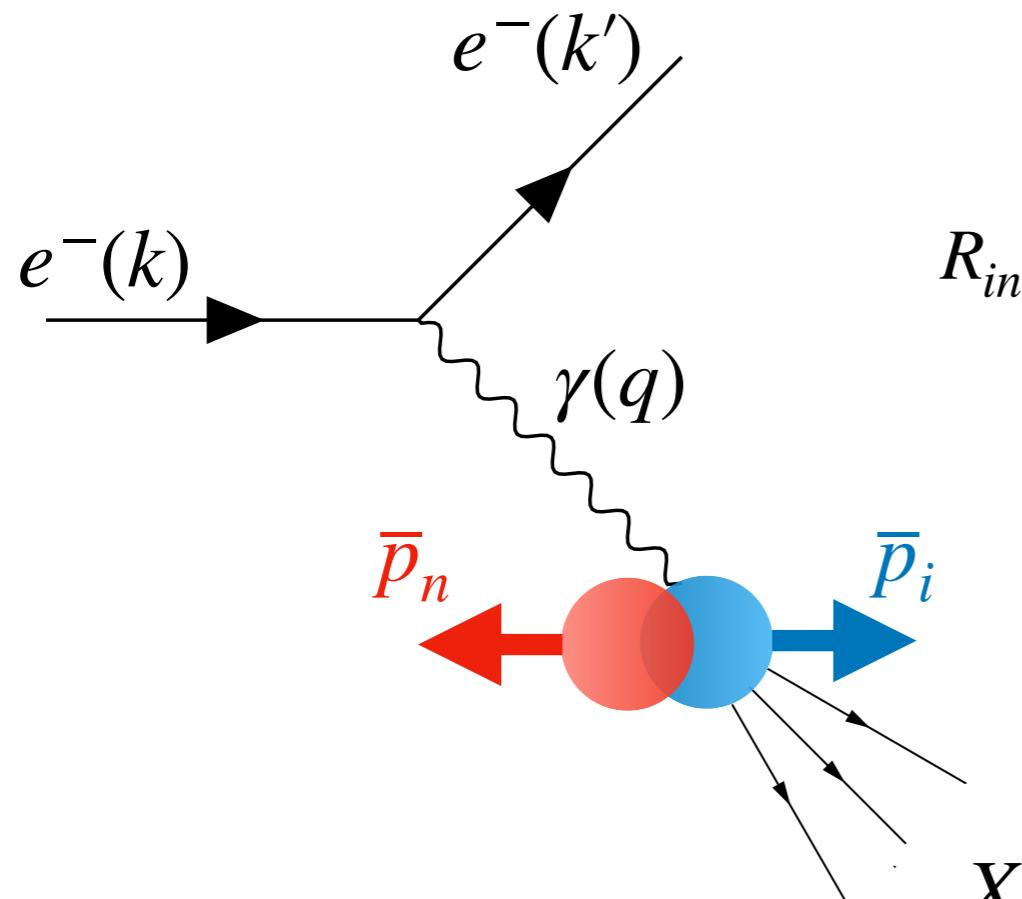
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Bound proton structure with tagged DIS



Inclusive ratio:

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$$R^* = \frac{R_{tag}}{R_{inc}(x = x')}$$

Tagged ratio:

$$R_{tag} = \left(\frac{Y_{tag}^{exp}(Q^2, \alpha_S, x')}{Y_{tag}^{exp}(Q^2, \alpha_S, x' = 0.3)} \right) / \left(\frac{Y_{tag}^{PWIA}(Q^2, \alpha_S, x')}{Y_{tag}^{PWIA}(Q^2, \alpha_S, x' = 0.3)} \right)$$



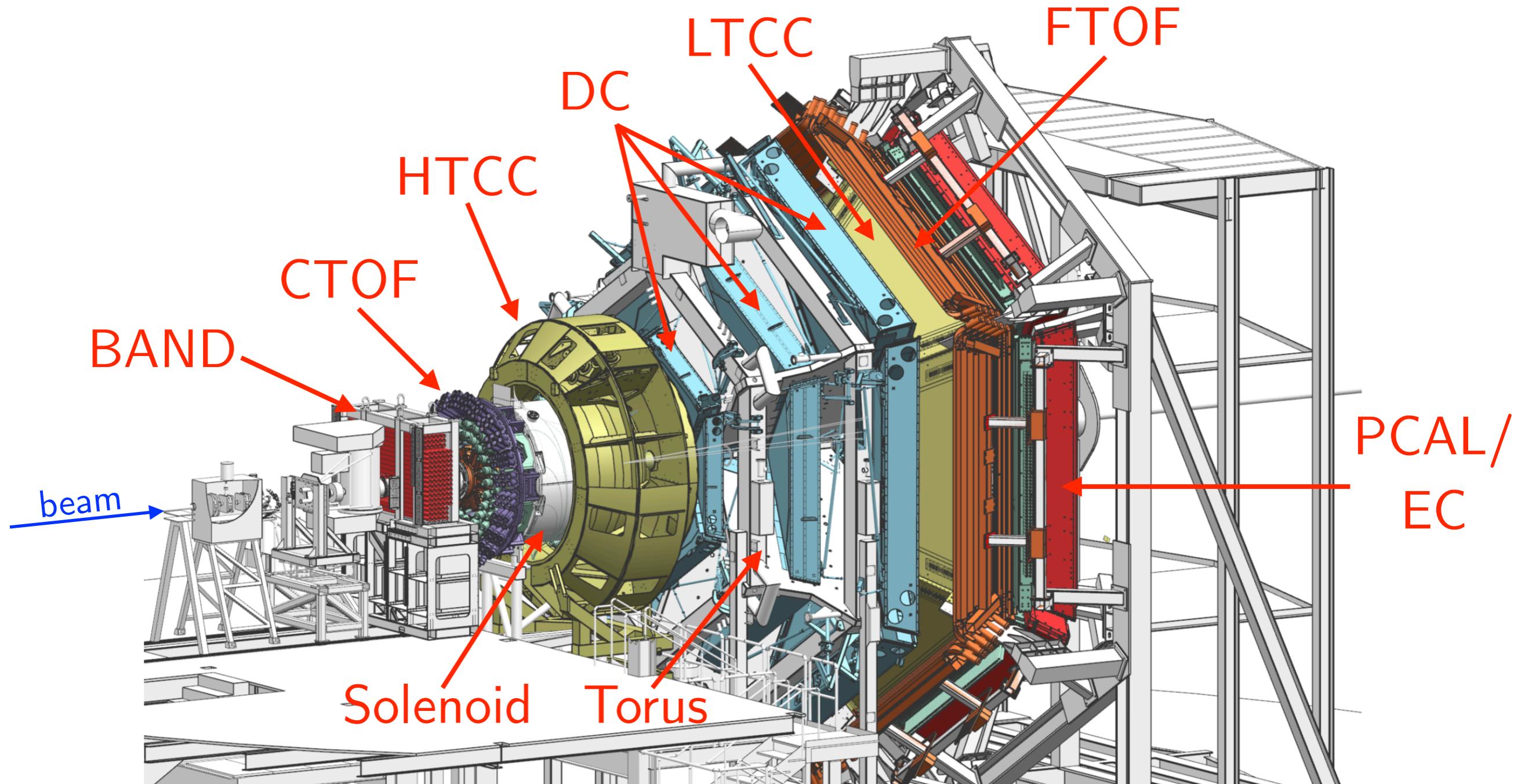
- Experimental overview
- Analysis status
- Summary

Jefferson Lab



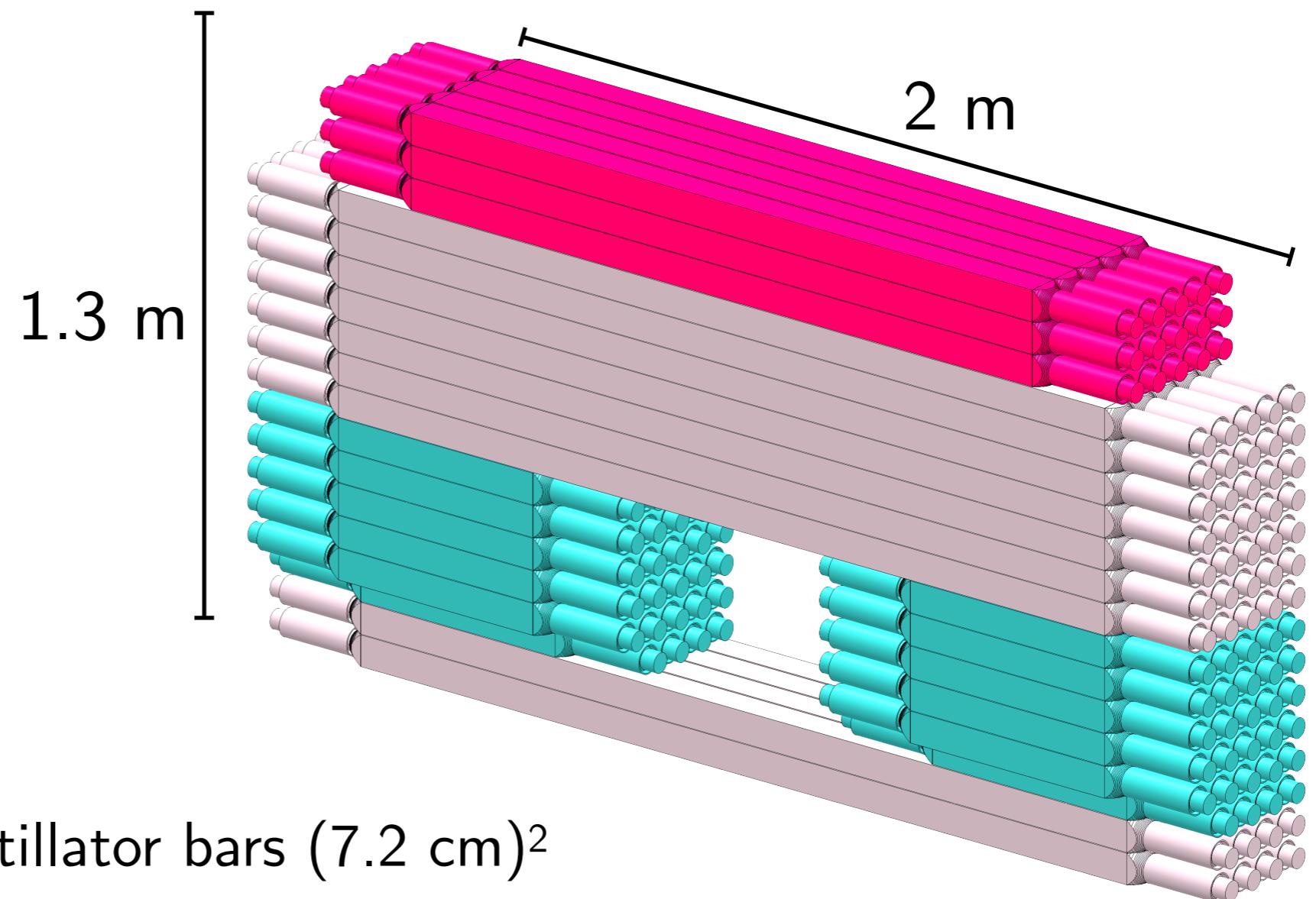
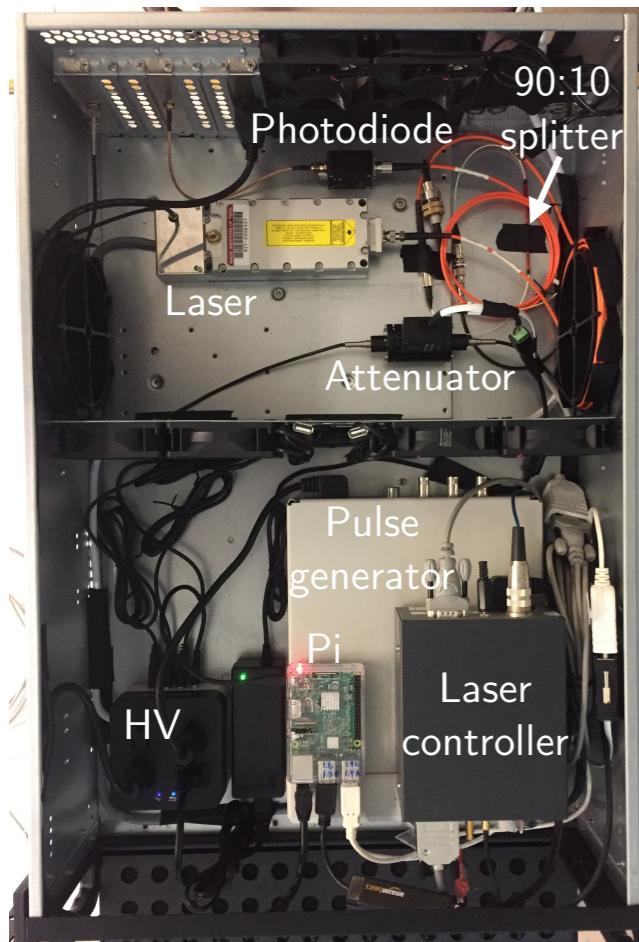
- CEBAF electron accelerator
- 10.2 GeV electron beam delivered to Hall B
- Electrons scatter from 5 cm LD2 target

CEBAF Large-Acceptance Spectrometer (CLAS12)



- Charged particle tracking, calorimetry, TOF
- Acceptance $5^\circ \lesssim \theta_e \lesssim 40^\circ$

Backward Angle Neutron Detector (BAND)

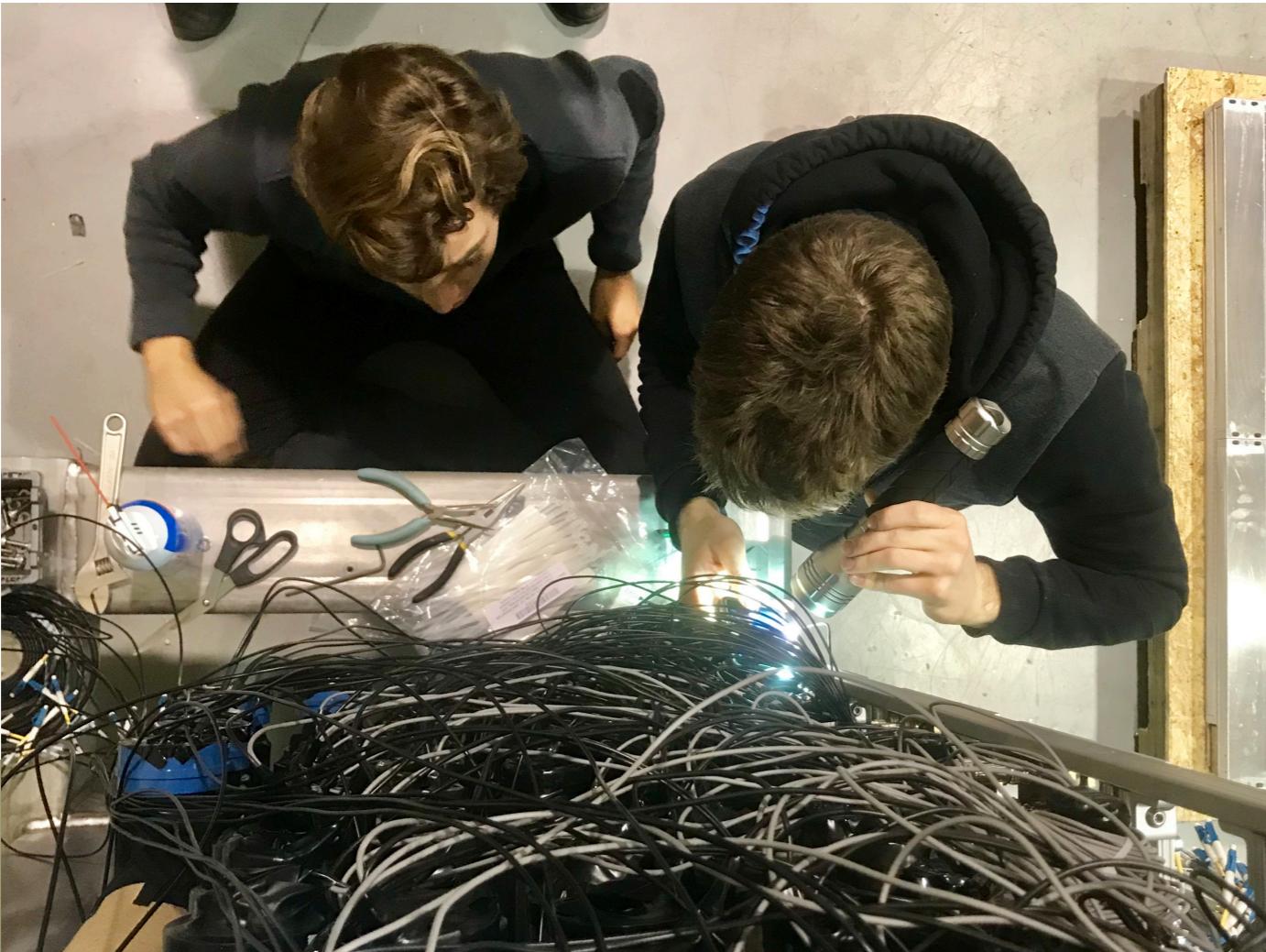


- >100 plastic scintillator bars $(7.2 \text{ cm})^2$
- $\approx 3 \text{ m}$ upstream of target
- $155^\circ \lesssim \theta_n \lesssim 175^\circ$
- Laser calibration system to achieve resolution better than 250 ps ($\delta p/p \approx 1.5\%$)

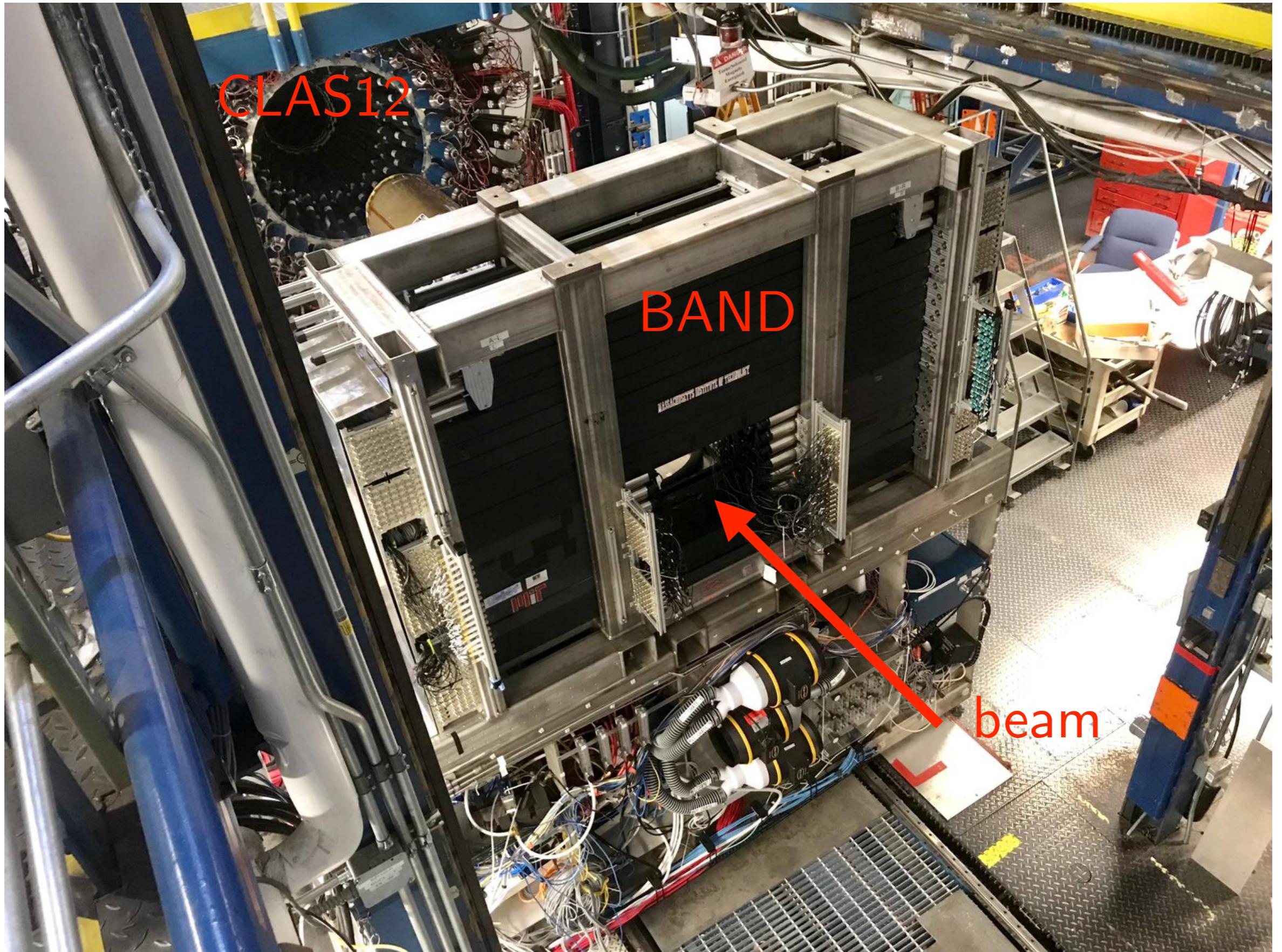
Segarra *et al.*, NIMA (2020)

Denniston *et al.*, NIMA (2020)

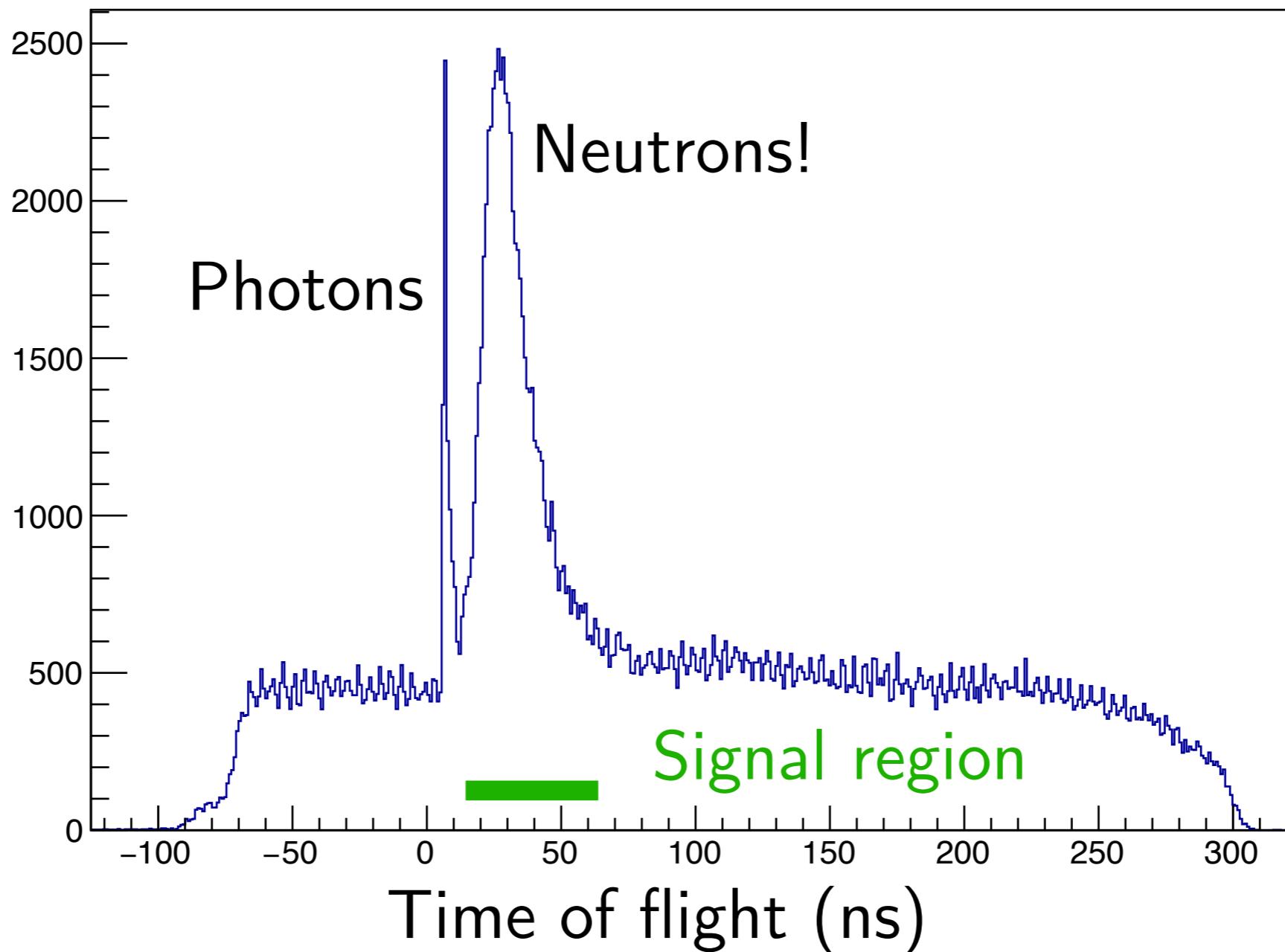
BAND construction



BAND in Hall B

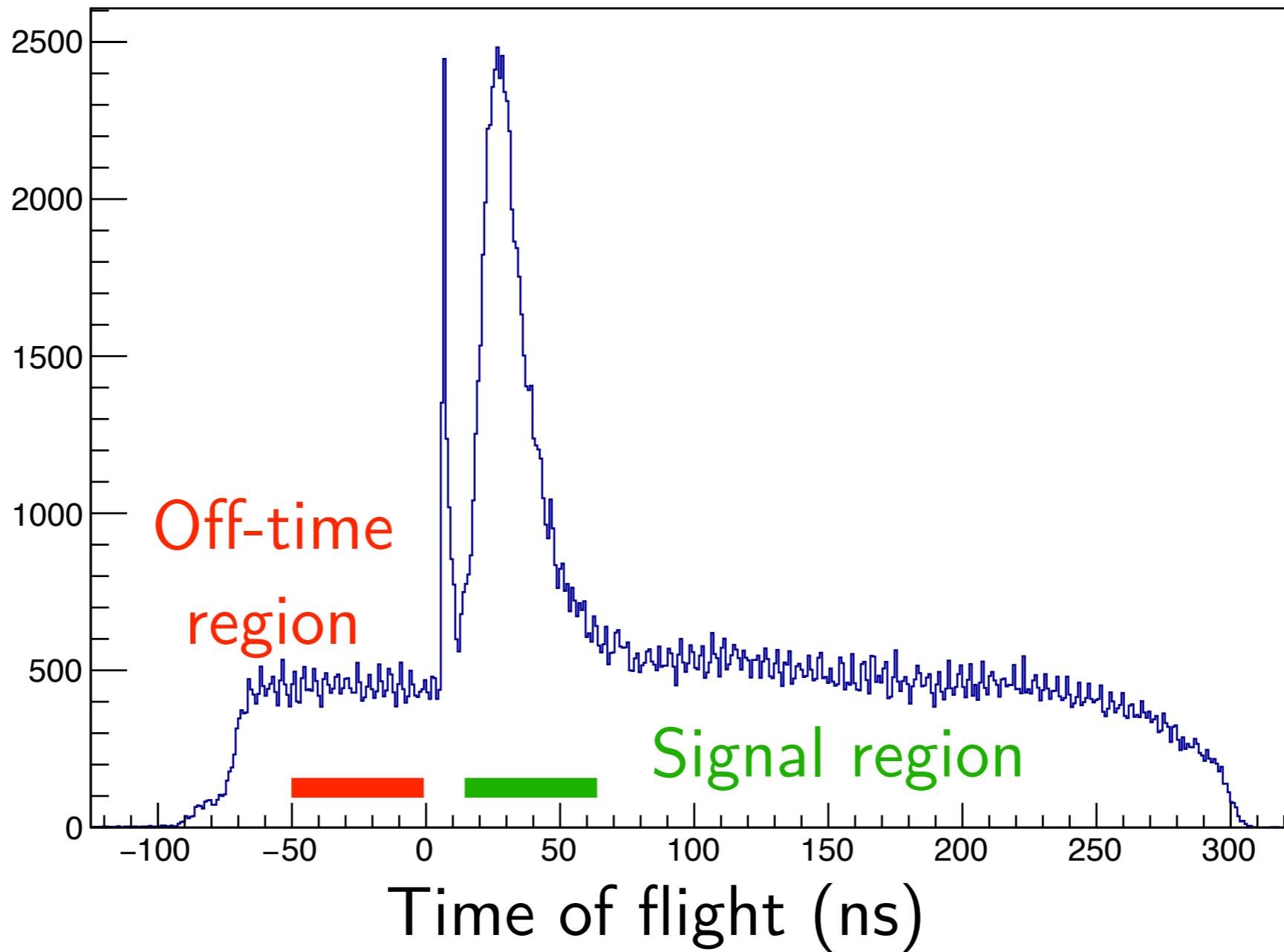


BAND time of flight spectrum

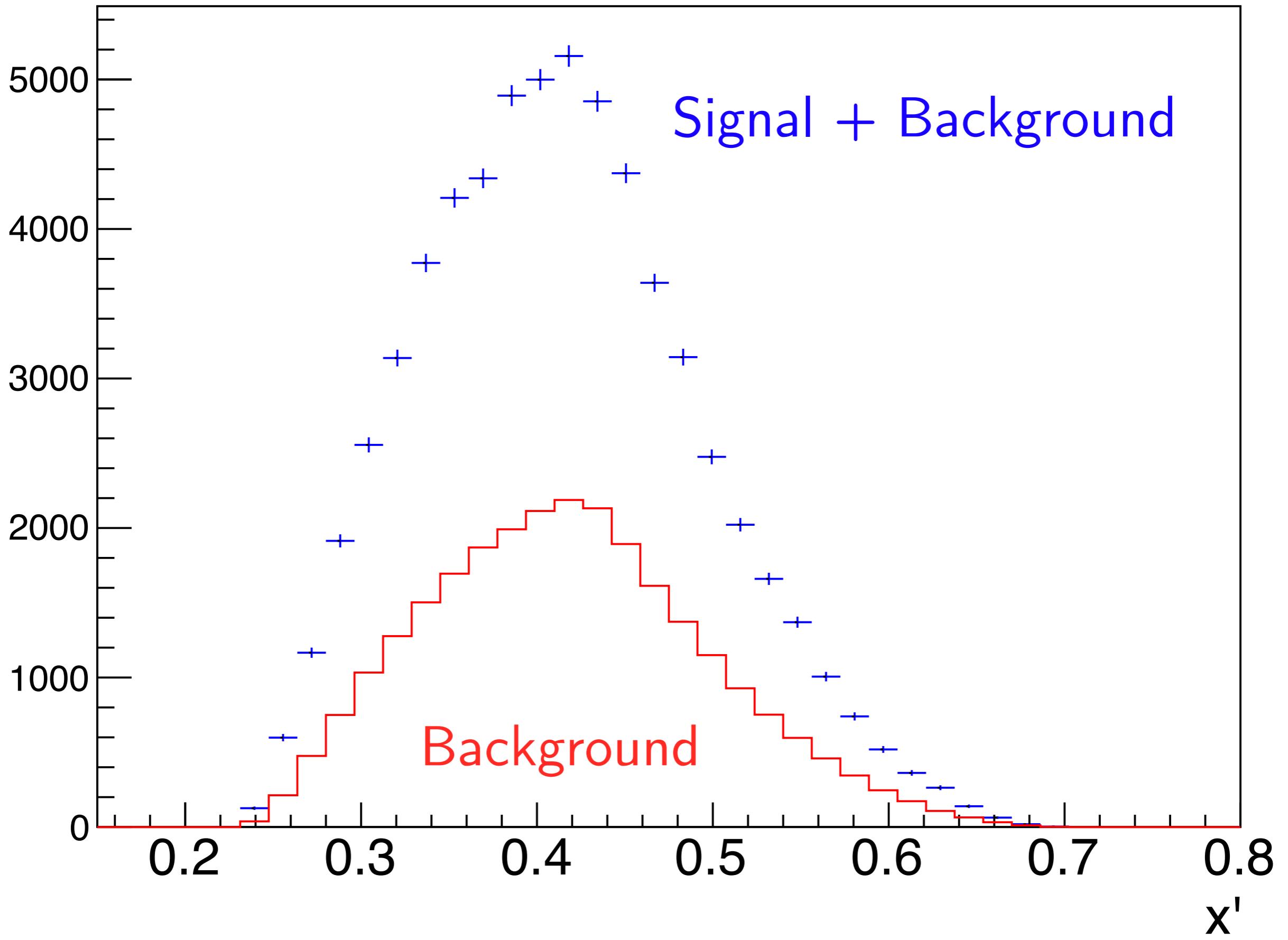


- Signal region $p_n \approx 200 - 600 \text{ MeV}/c$
- Constant off-time neutron background

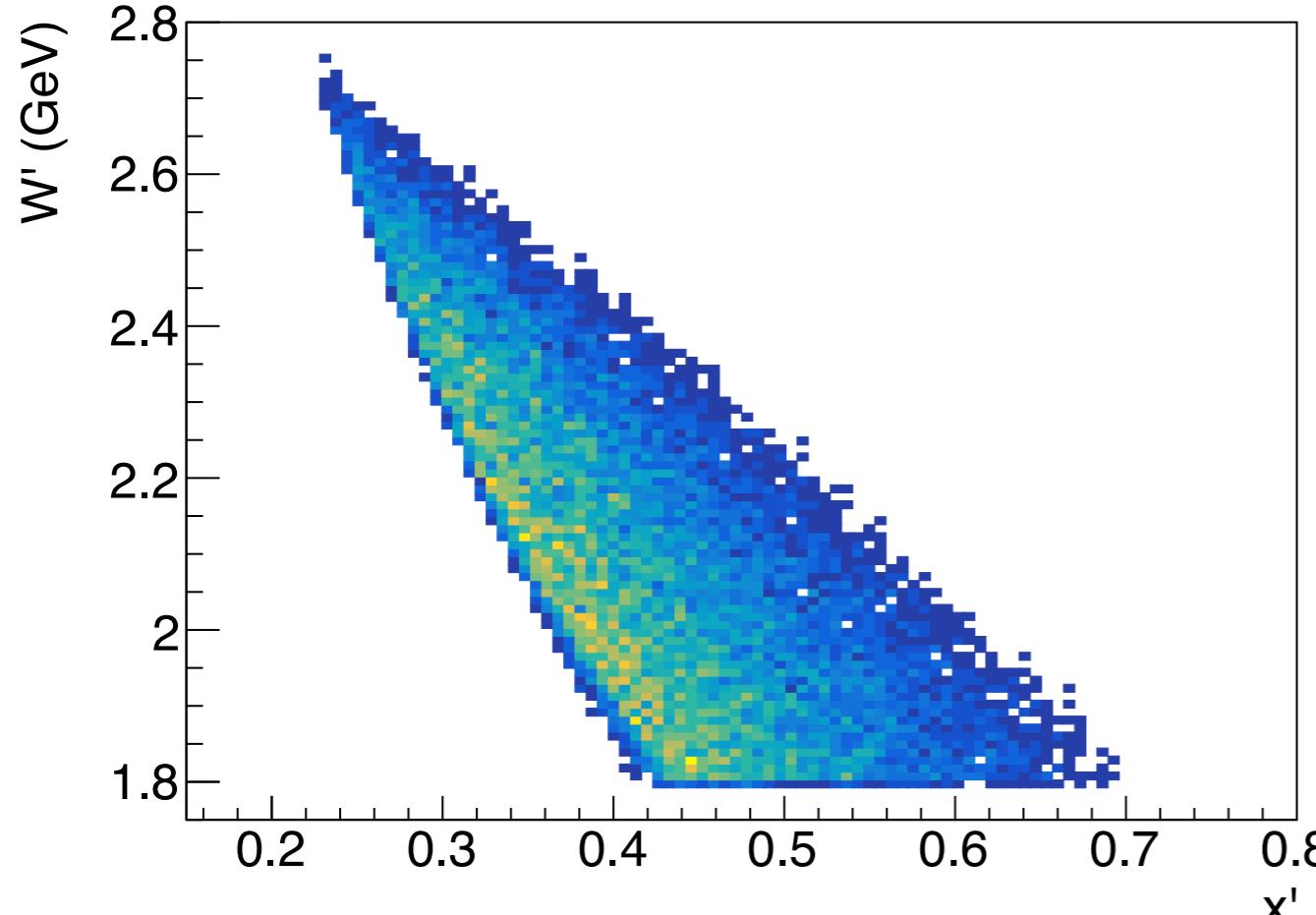
Background subtraction with event-mixing



- Shift off-time neutron into signal region
- Pair with inclusive electron to get tagged kinematics
- Repeat x10 for high statistics

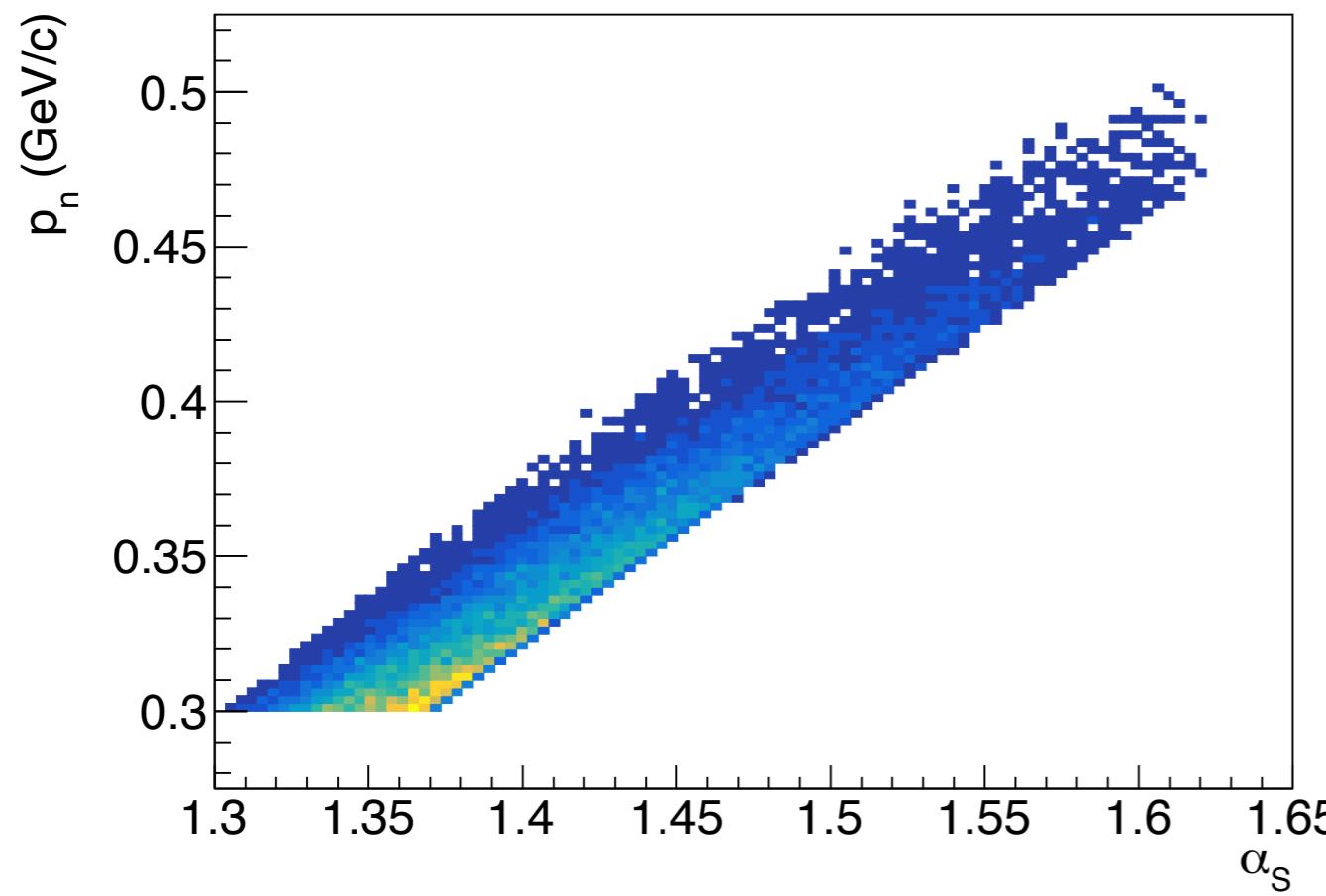


Tagged kinematics



Electron cuts:

- Fiducial/PID
- $Q^2 > 2 \text{ GeV}^2$
- $W > 4 \text{ GeV}$



Tagged cuts:

- $|p_n| > 0.3 \text{ GeV}/c$
- $-1 < \cos \theta_{nq} < -0.8$
- $W' > 1.8 \text{ GeV}$
- $\alpha_S > 1.3$

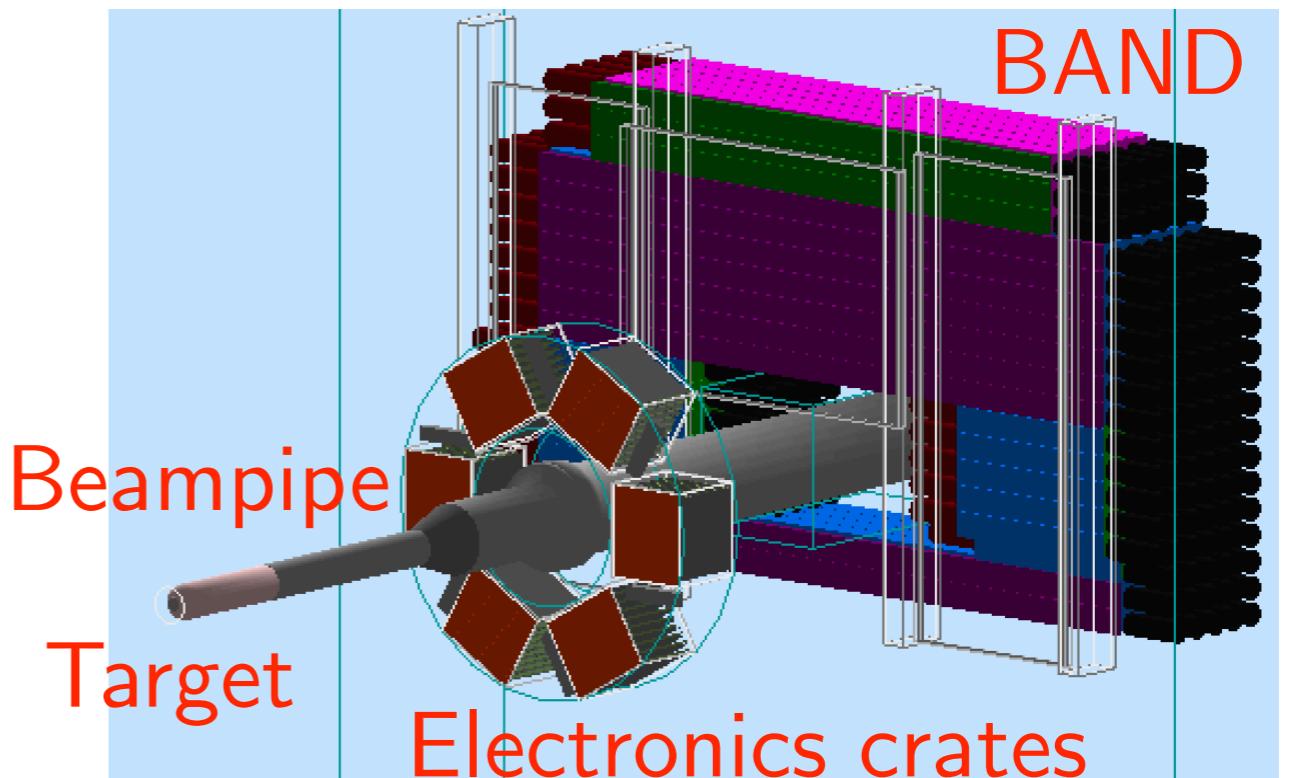
Ingredients for BAND simulation

PWIA event generator

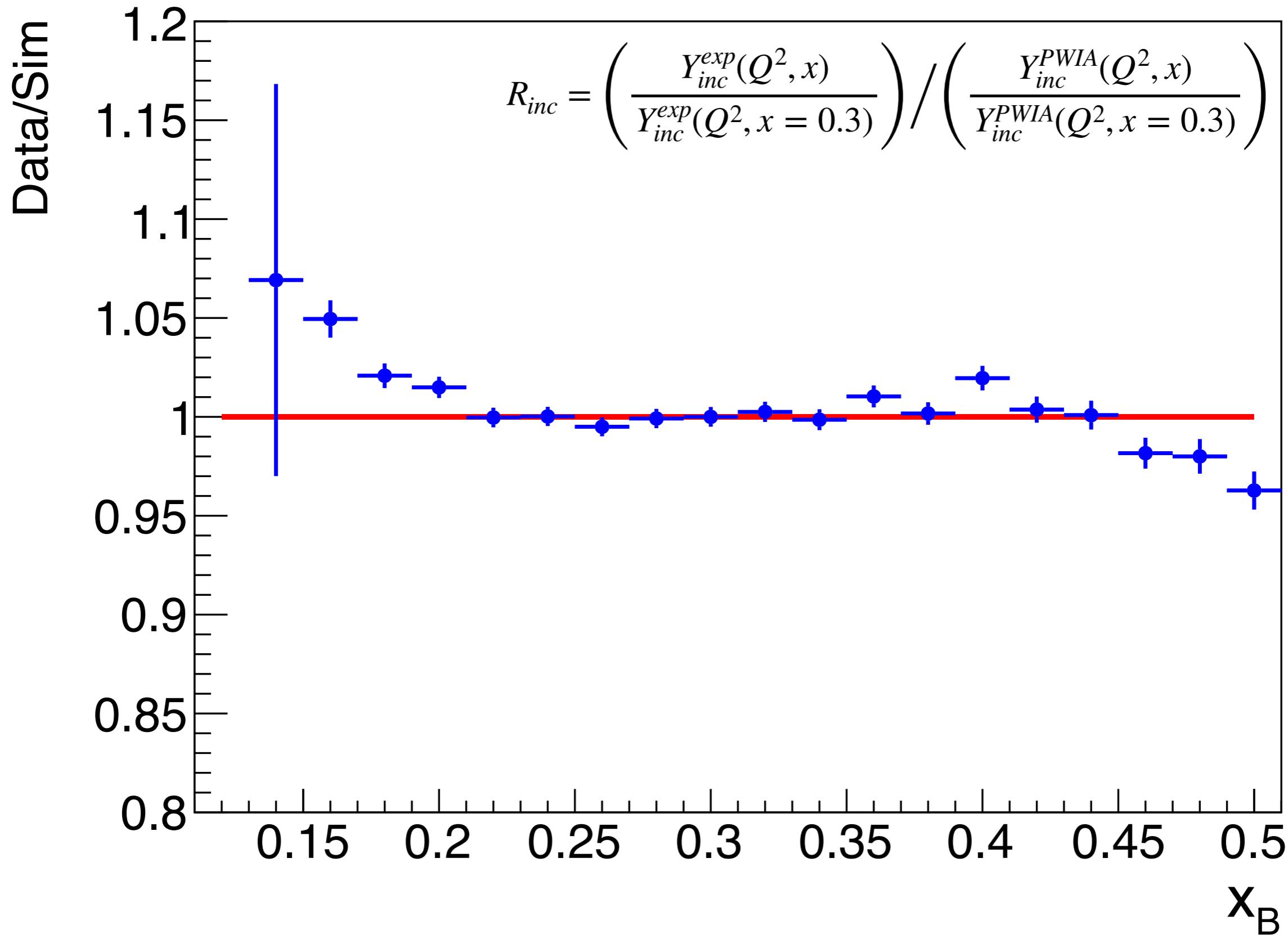
- Cross section constructed from:
 - Free neutron, proton
 - Deuterium wave function
- Radiative effects
- No nucleon modification
- Working with theorists on:
 - Scheme dependence
 - Finite Q^2 corrections

Experimental effects

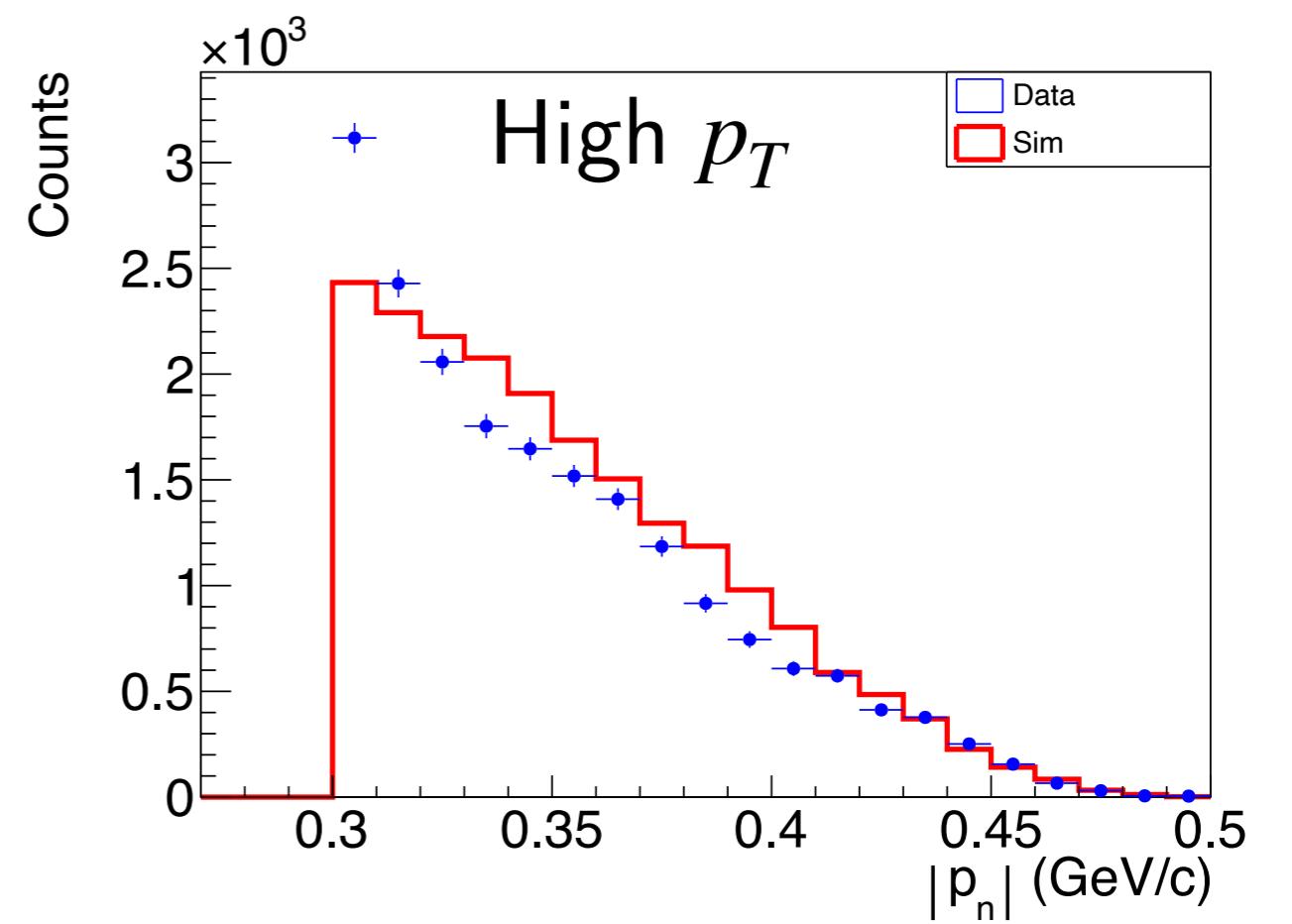
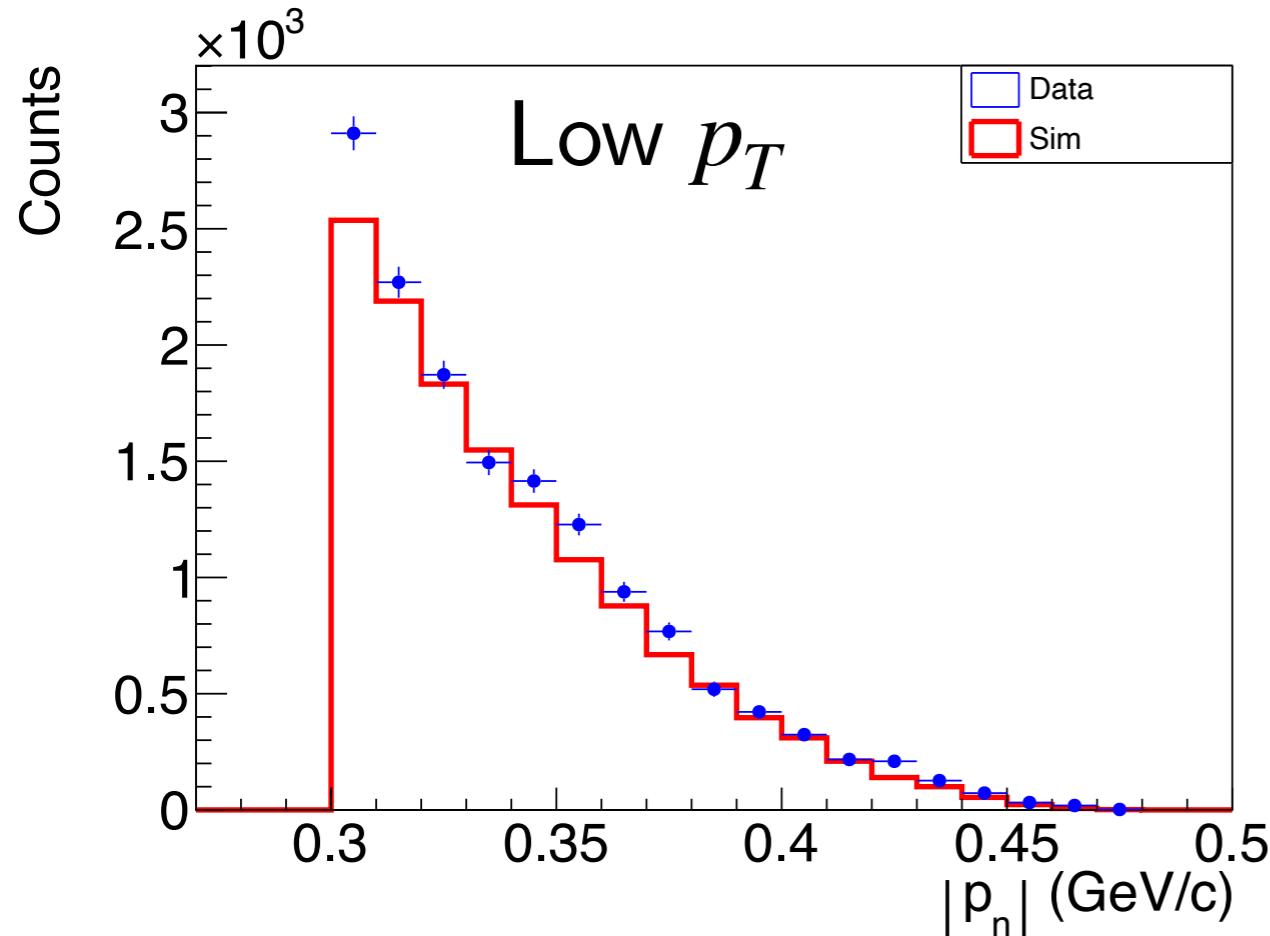
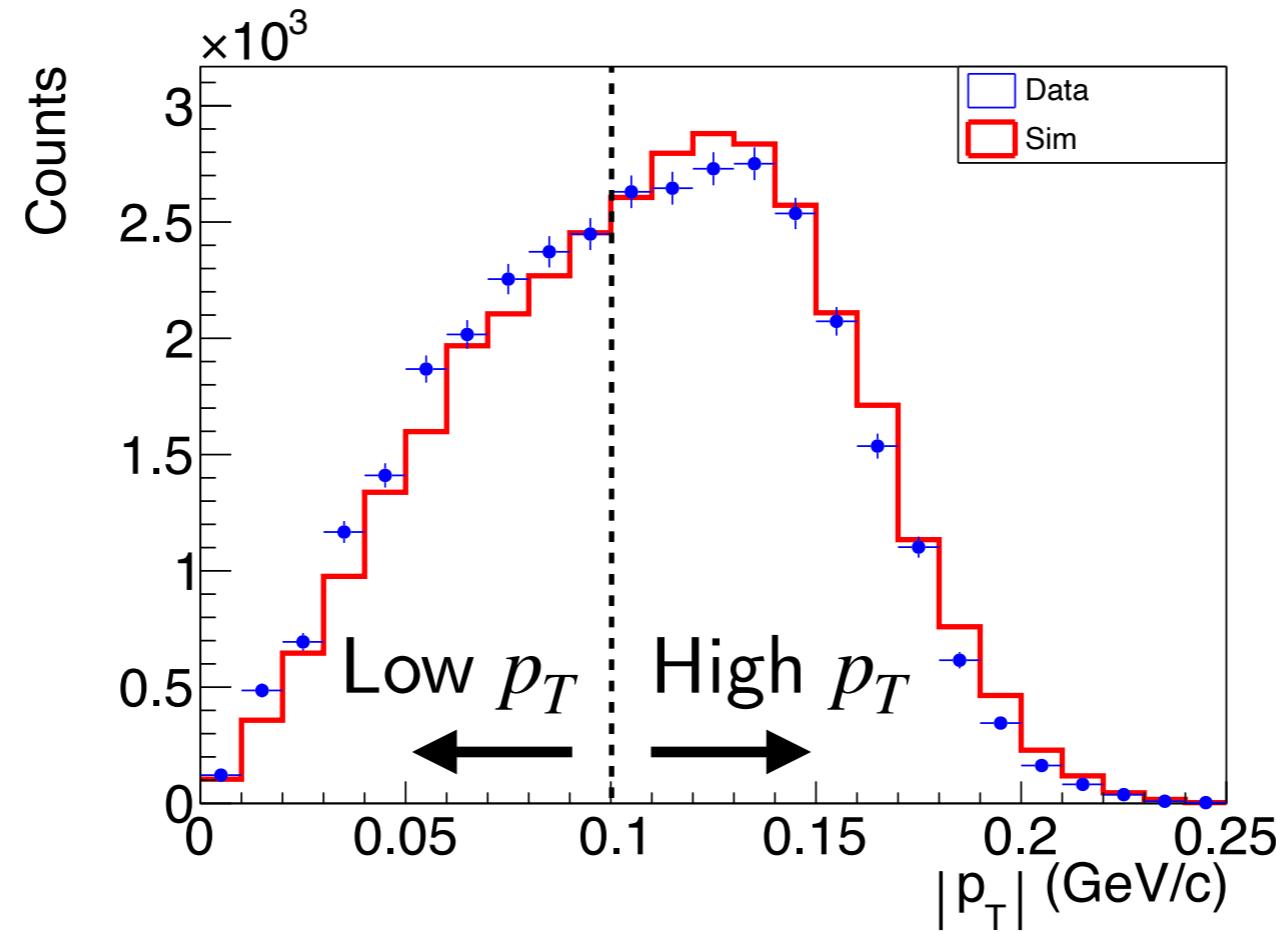
- Full GEANT4 simulation
- Electron, neutron propagation
- Detector response
- Digitization
- Output/analysis identical to data



Inclusive D(e,e')X

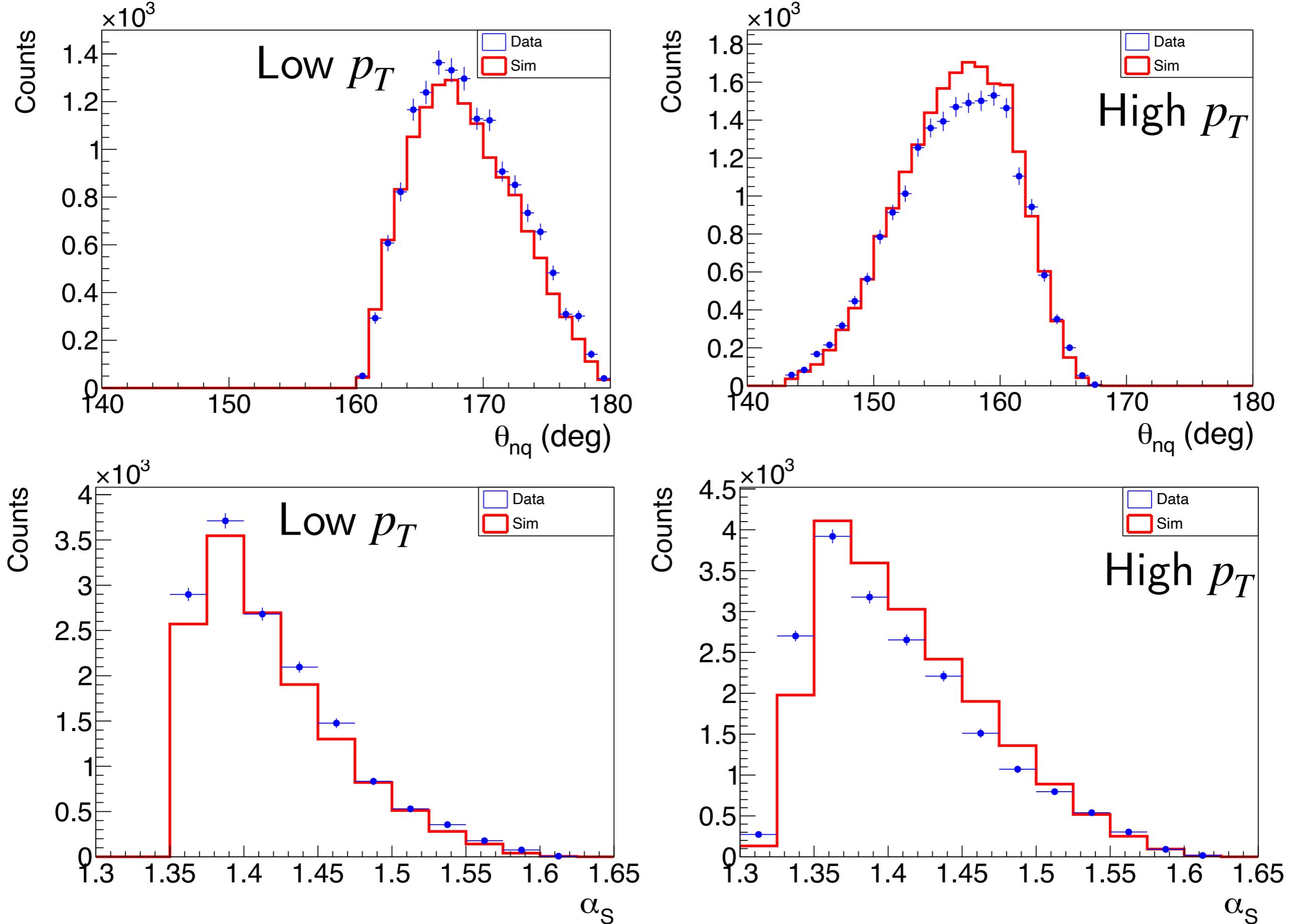


Spectator $D(e,e'n)X$



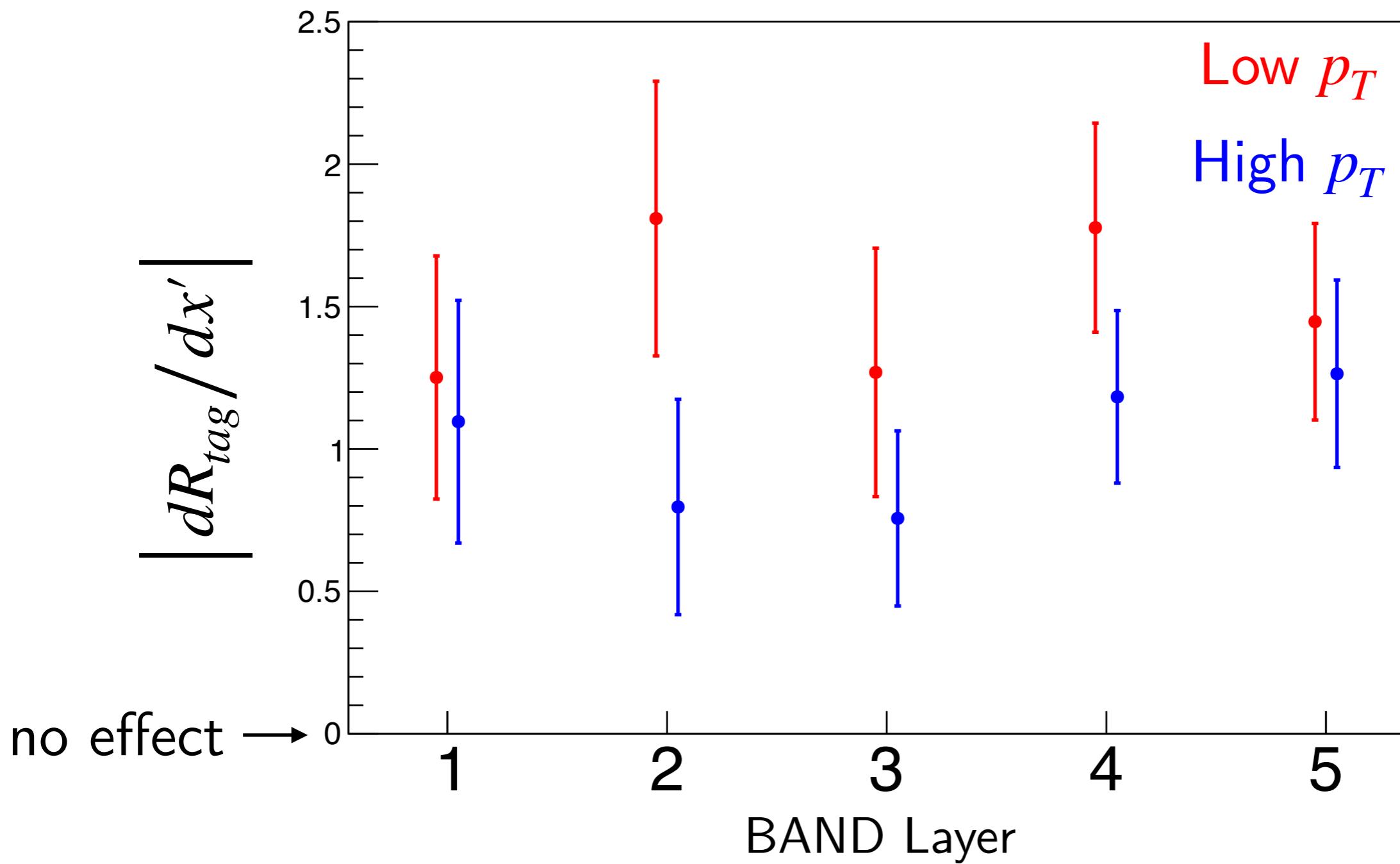
20

Tagged D(e,e'n)X



Systematic stability

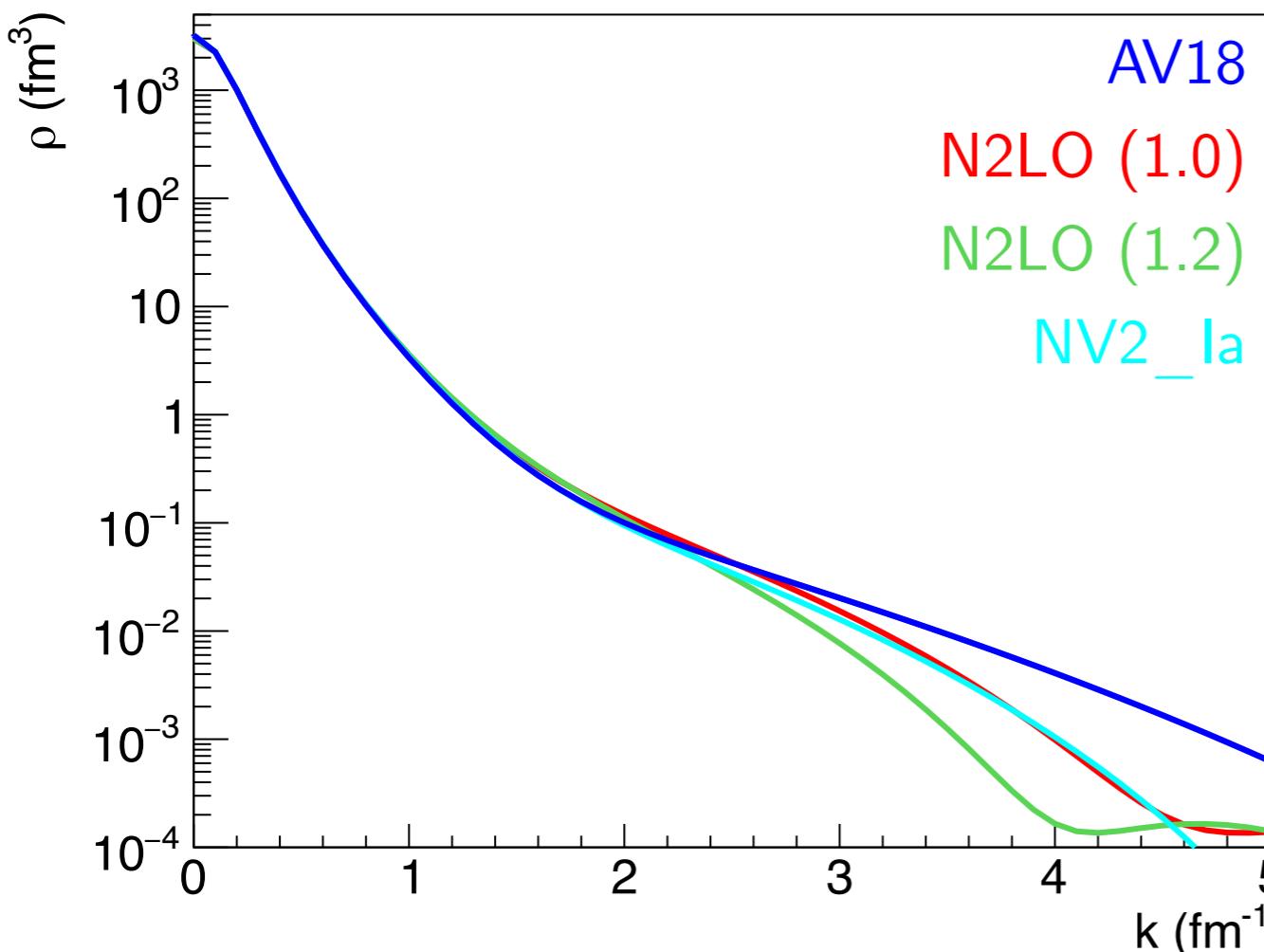
- Indication of x' dependence (and small α_S dependence) in R_{tag}
- $|dR_{tag}/dx'|$ as function of BAND layer is stable for all p_T bins



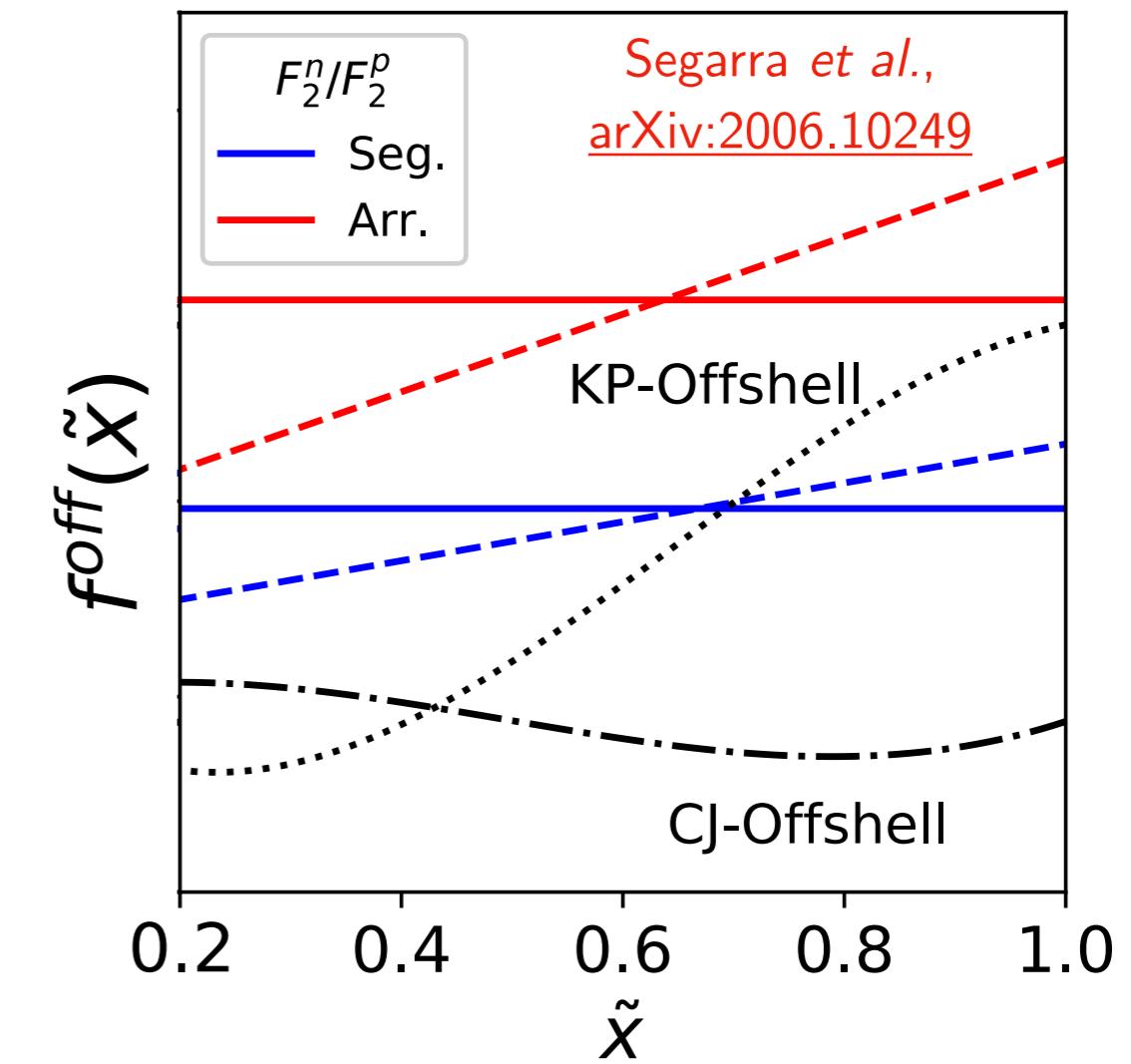
Evaluating theoretical models

- Keep generator-level event info in MC analysis
- Weight simulated events for different theoretical models...

...deuterium wave function



...off-shell nucleon modification



Summary

- BAND measured the tagged DIS $D(e, e'n)X$ reaction
 - Sensitive to bound proton structure differential in α_S
- Background-subtracted yields have been extracted
 - Inclusive and spectator variables agree well with simulation
- Using generator/simulation for consistent evaluation of theory
- Observed x' dependence of tagged observables systematically stable
- Converging on result...stay tuned!