

Results from the BONuS12 Experiment with CLAS12

5th International Workshop on Quantitative Challenges in Short-Range
Correlations (SRC) and the EMC-Effect Research



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Overview

- Quick reminder: WHY F_2^n ? HOW?
- Low momentum spectator tagging on the Deuteron
 - Radial Time Projection Chamber (slow proton detector)
 - Data Set collected with RG-F (BONuS12)
 - Simulation
 - Analysis
- Preliminary Results
- Conclusions

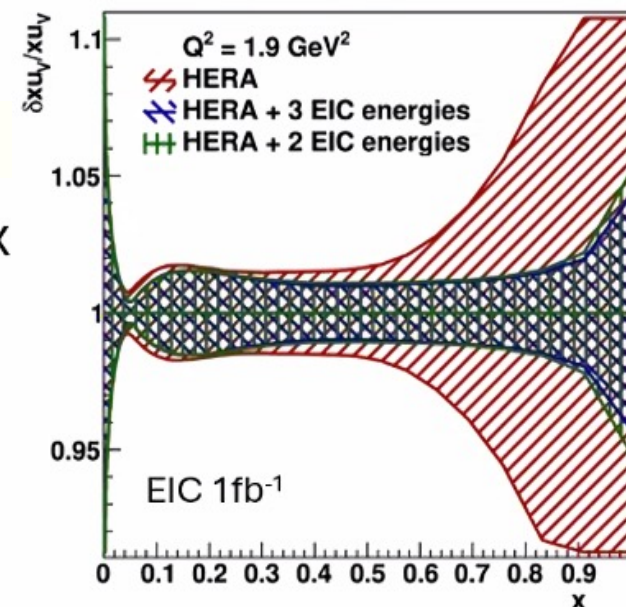
SFs at large x – why?

- From DPF/DNP Community Meeting 5/22/26:



Physics Synergy Example - Proton PDFs

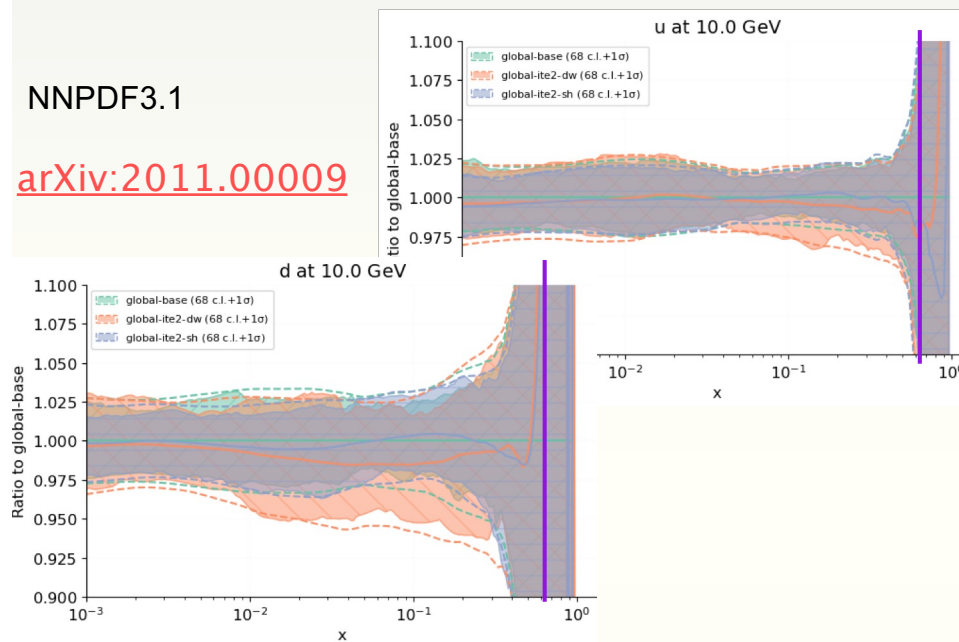
- $F_2(x, Q^2)$ largely studied at HERA
- Better precision often needed
 - LHC impacts/needs PDF's mainly at large x (EIC coverage)
 - Not fully convergent between different global fitting groups
 - Large x BSM effects can hide



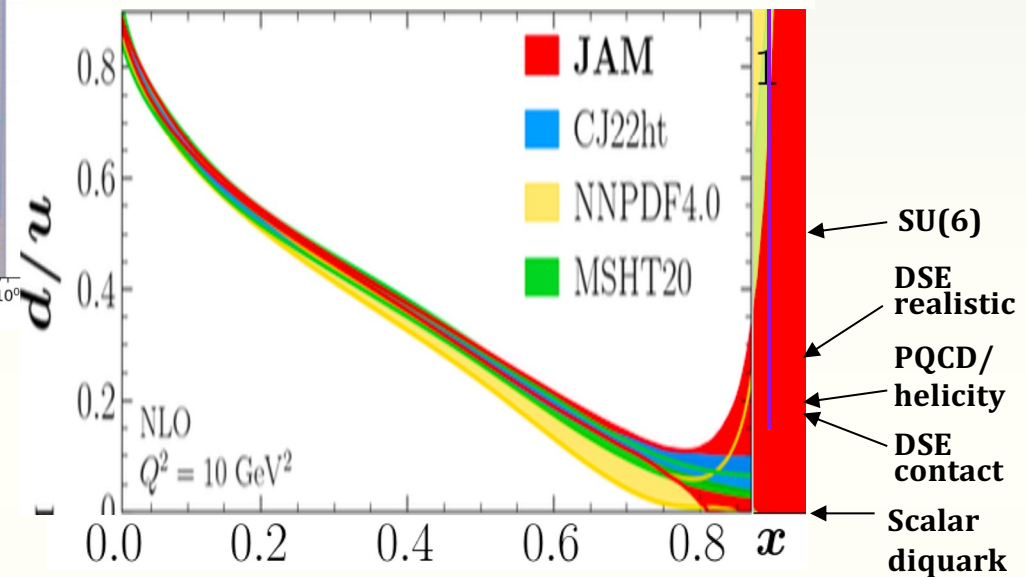
d(x) even less well known

NNPDF3.1

[arXiv:2011.00009](https://arxiv.org/abs/2011.00009)



JAM 2026: JLAB-THY-26-4687, ADP-26-11/T1308

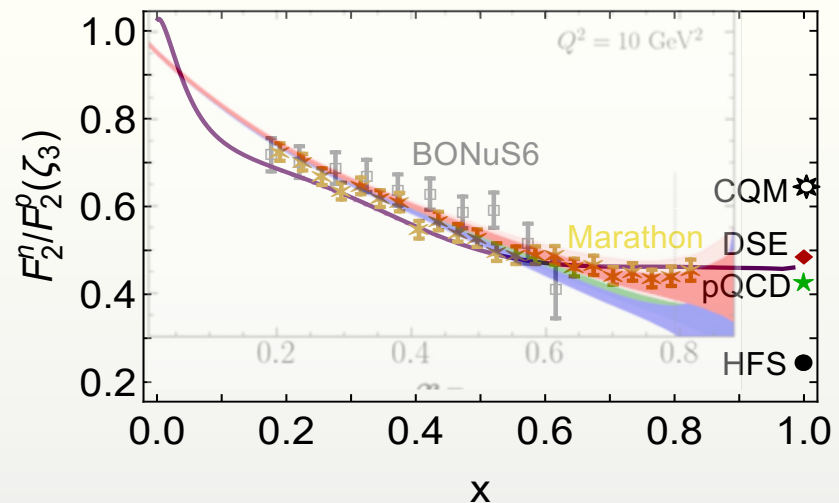


QUESTION: How to access d and u quark PDFs?
 One approach: Isospin symmetry =>
 $d(x)$ in proton = $u(x)$ in neutron =>

$$F_2^p(x) = x \sum_q e_q^2 (q(x) + \bar{q}(x)) \approx x \left(\frac{4}{9}u(x) + \frac{1}{9}d(x) \right)$$

$$F_2^n(x) \approx x \left(\frac{4}{9}d(x) + \frac{1}{9}u(x) \right) \quad \frac{F_2^n}{F_2^p} \approx \frac{1 + 4d/u}{4 + d/u}$$

F_2^n also CRUCIAL to interpret EMC effect

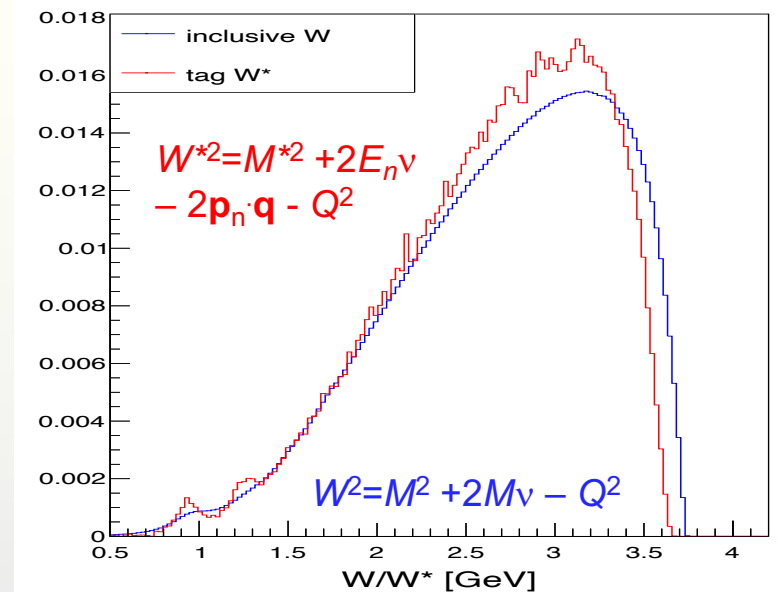
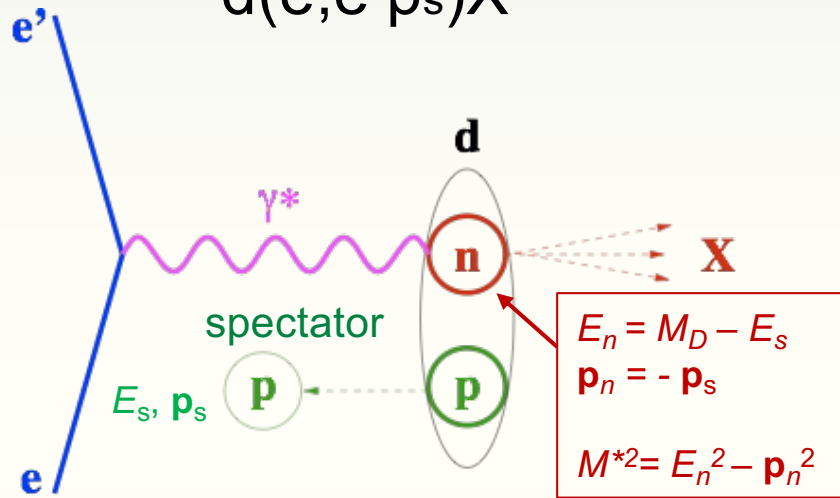


Y.Lu, L.Chang, K.Raya, C.D.Roberts, J.Rodríguez-Quintero, Proton and pion distribution functions in counterpoint, Phys. Lett. B830 (2022)137130.

Spectator Tagging

F_{2n}/F_{2p} through spectator tagging

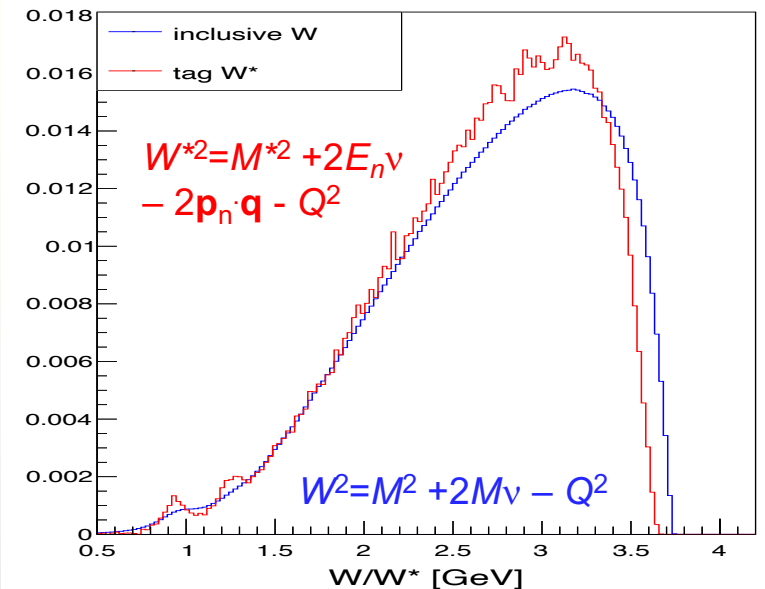
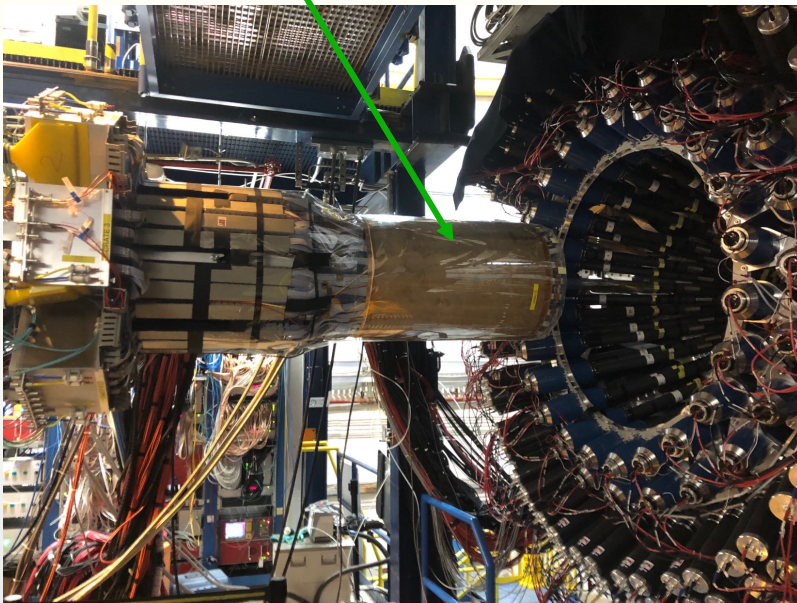
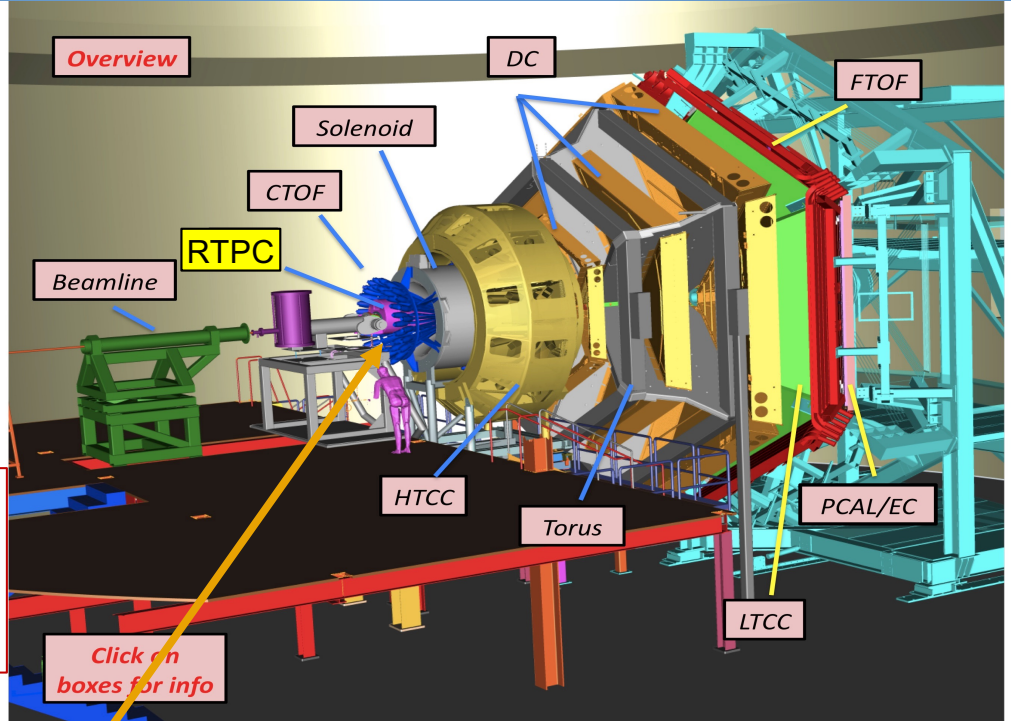
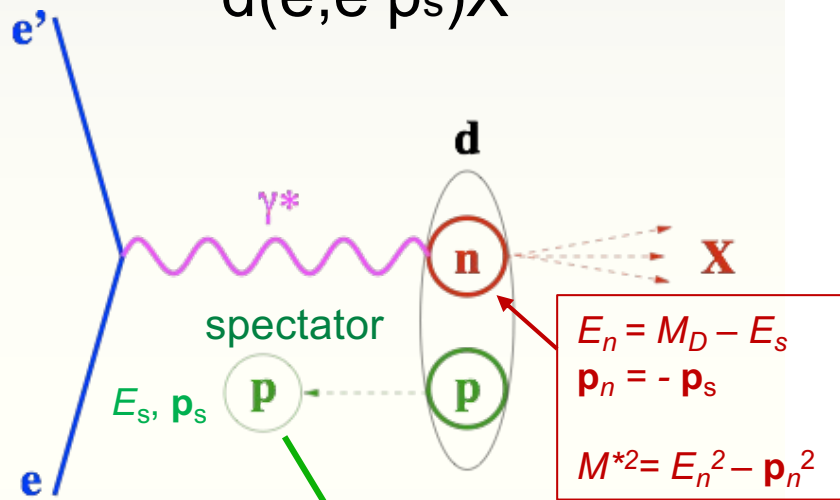
$d(e, e' p_s) X$



BONuS12 with CLAS12 (Run Group F in 2020)

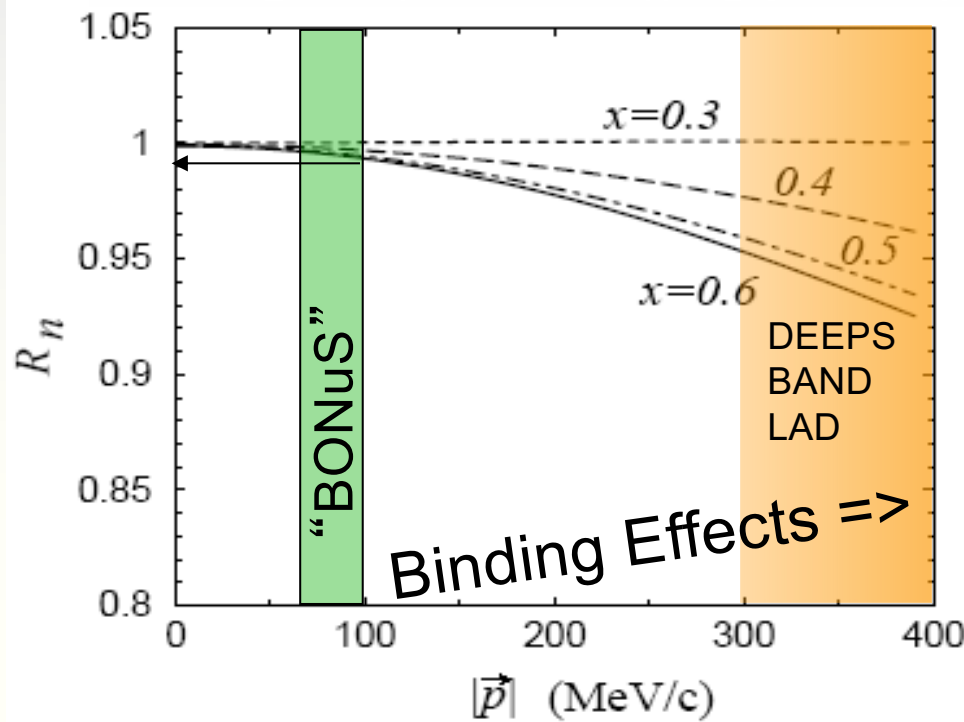
F_{2n}/F_{2p} through spectator tagging

$d(e, e' p_s) X$



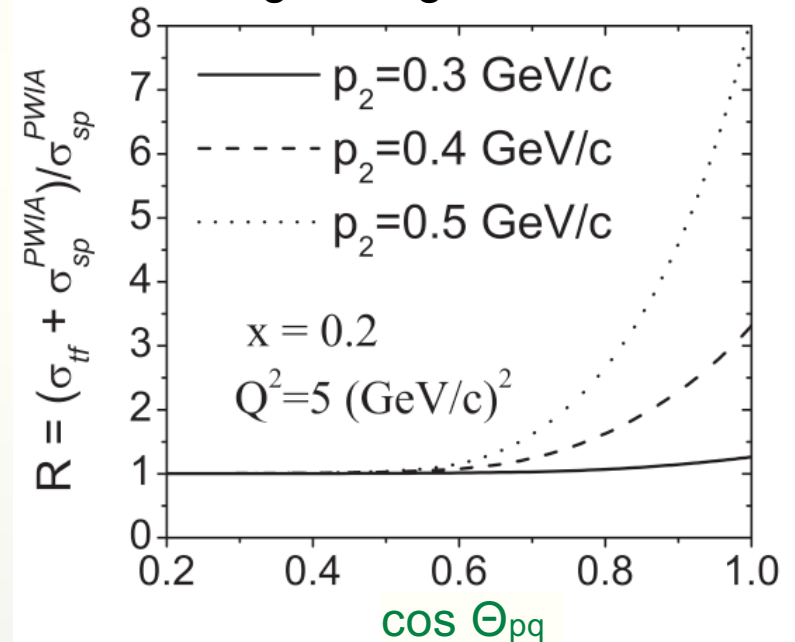
$$R_n \equiv F_2^{n(eff)}(W^2, Q^2, p^2) / F_2^n(W^2, Q^2)$$

W. Melnitchouk, A.W. Schreiber and A.W. Thomas,
 Phys. Lett. B335, 11 (1994); Phys. Rev. D 49, 1183 (1994).

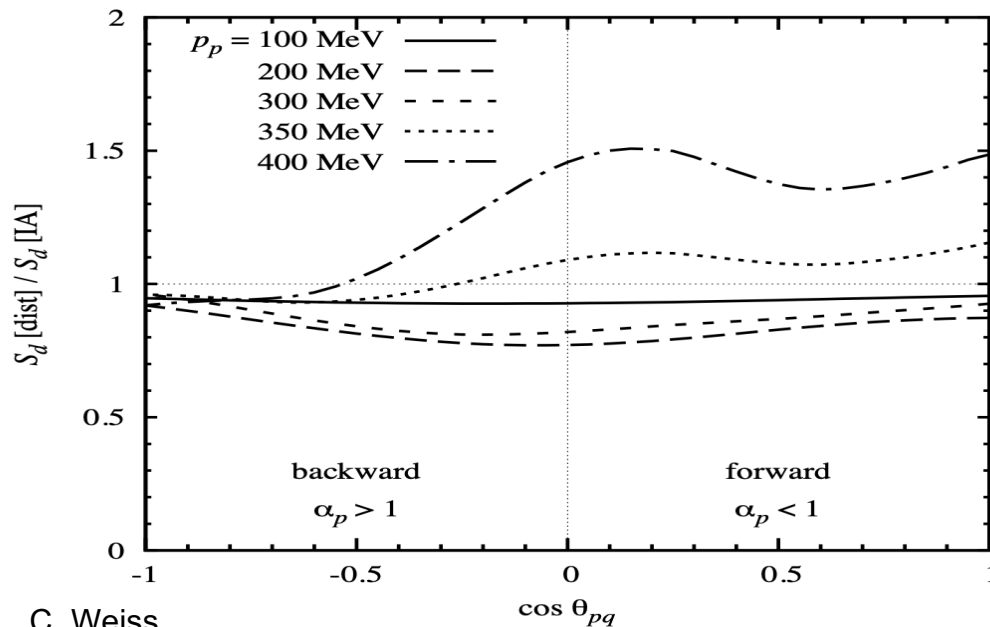


Modifications to Simple Spectator Picture

Target Fragmentation

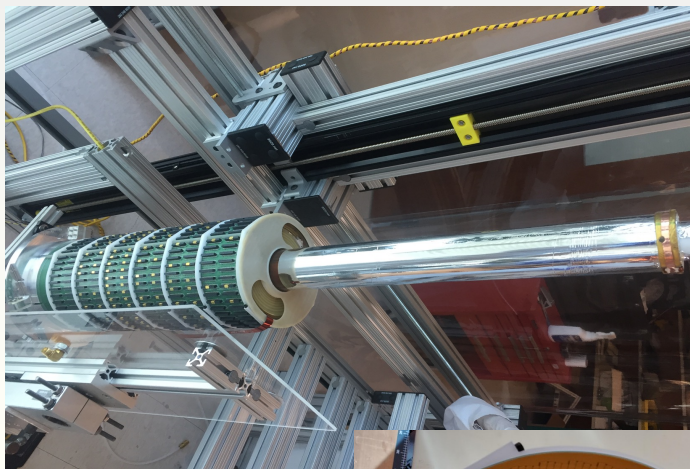


Palli et al, PRC80(09)054610



C. Weiss

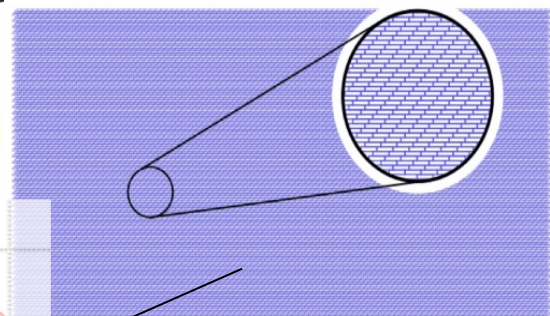
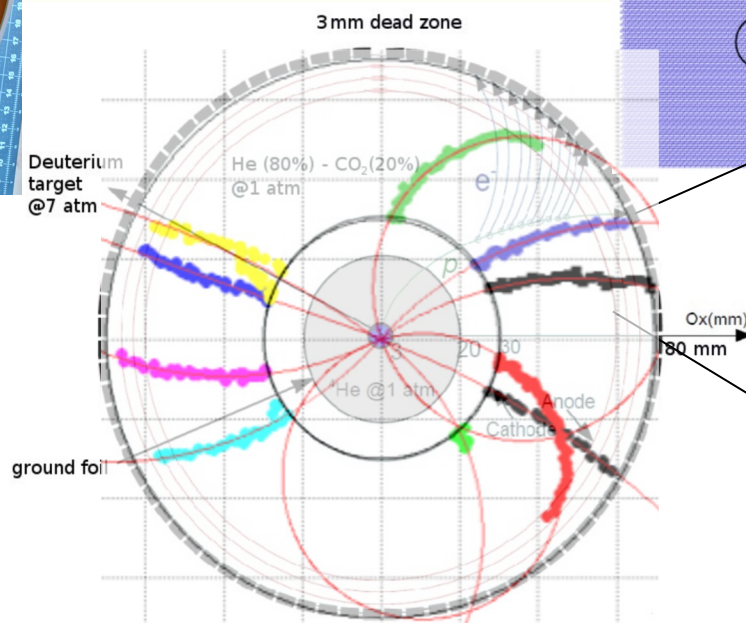
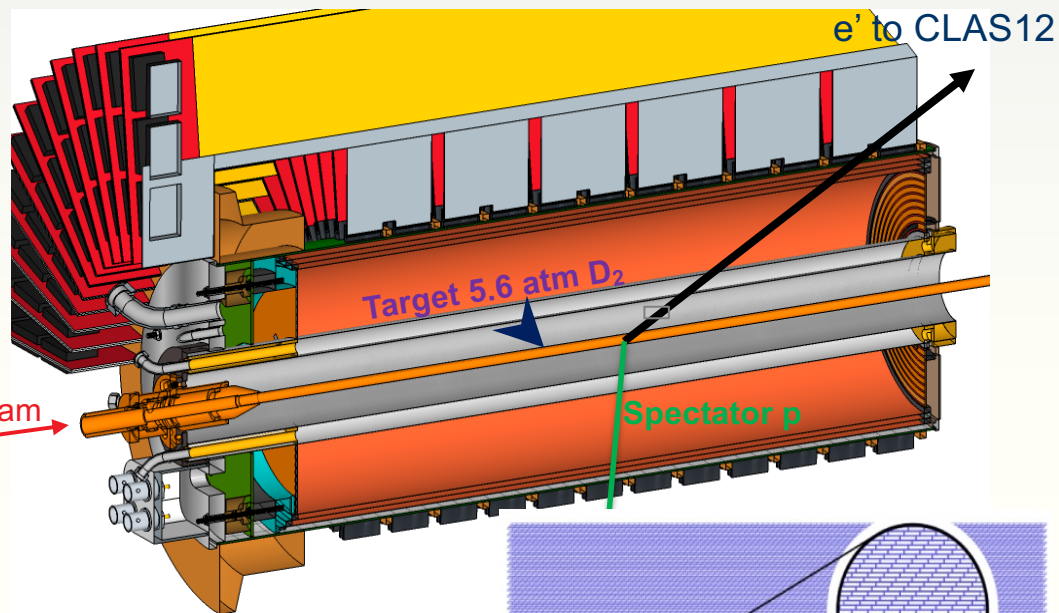
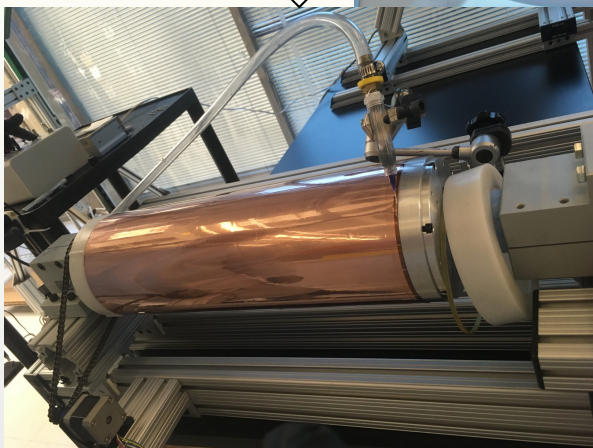
BONuS12 Radial Time Projection Chamber



Installation of Cathode + ground foil assembly

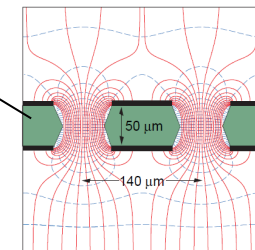
Wrapped Padboard inner surface

GEM foil wrapping and gluing



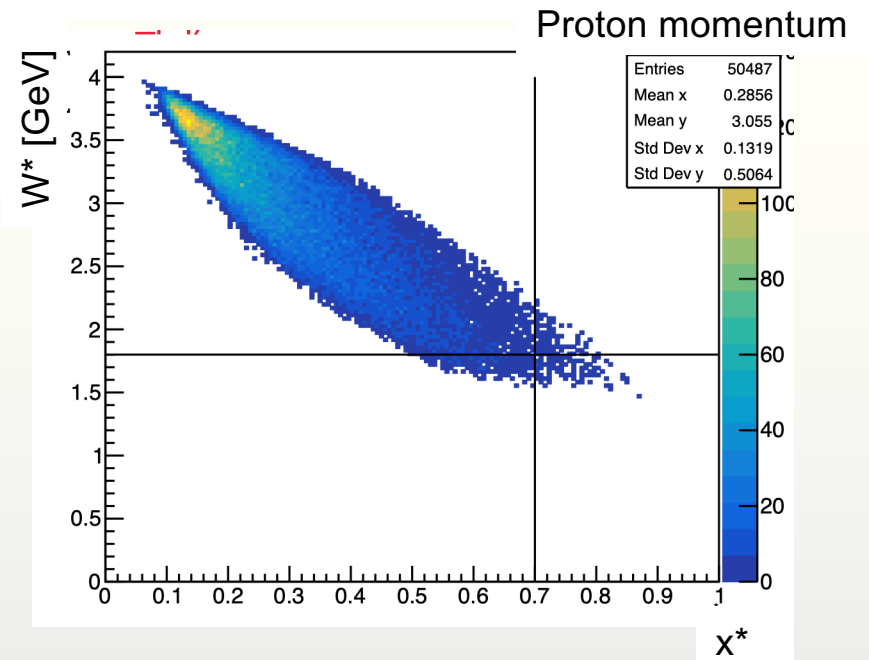
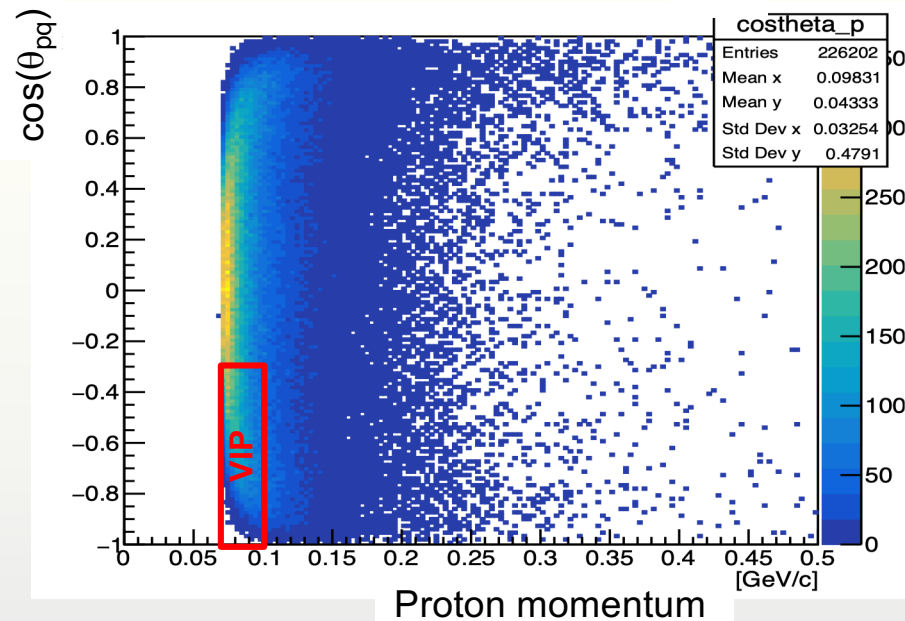
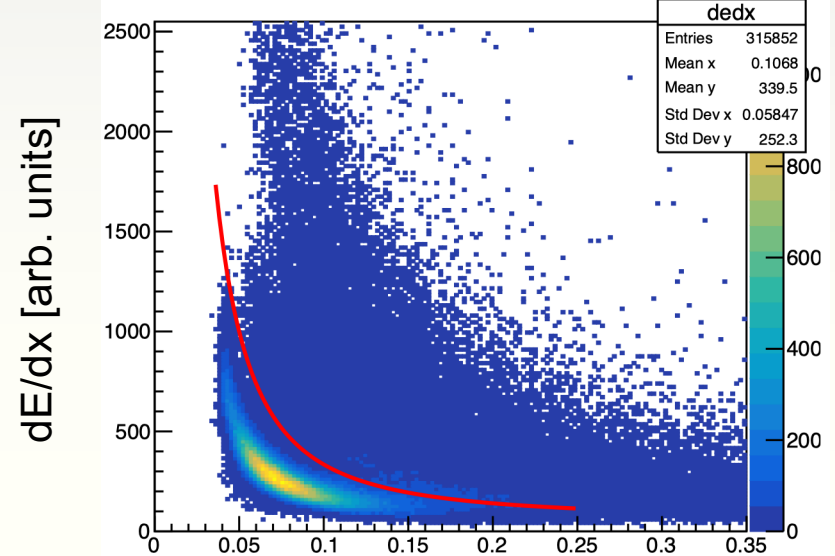
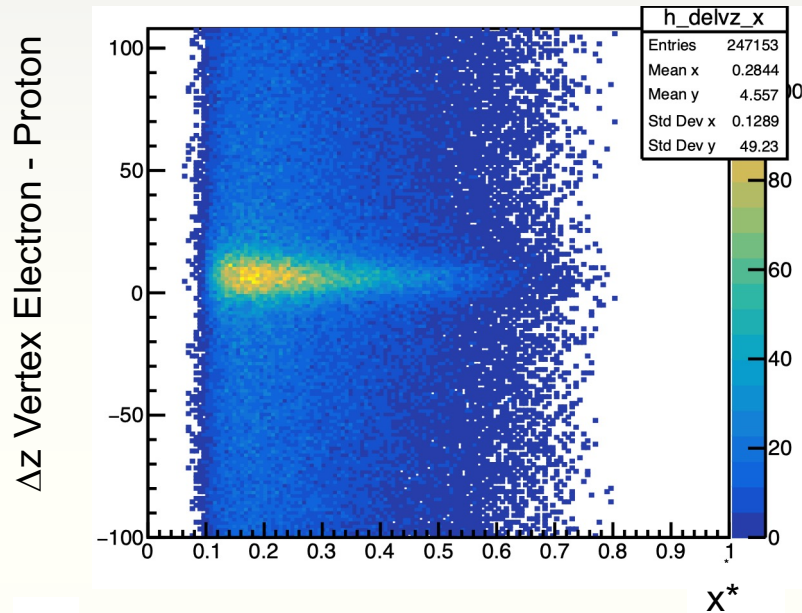
Readout Pads

GEM layer



BONuS12 Data

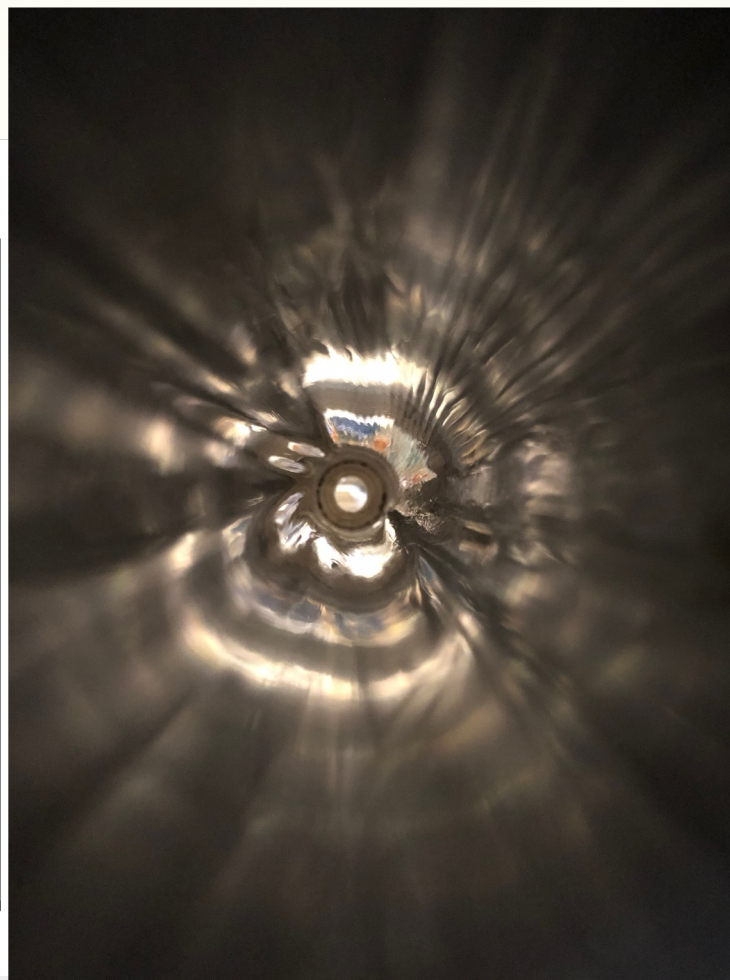
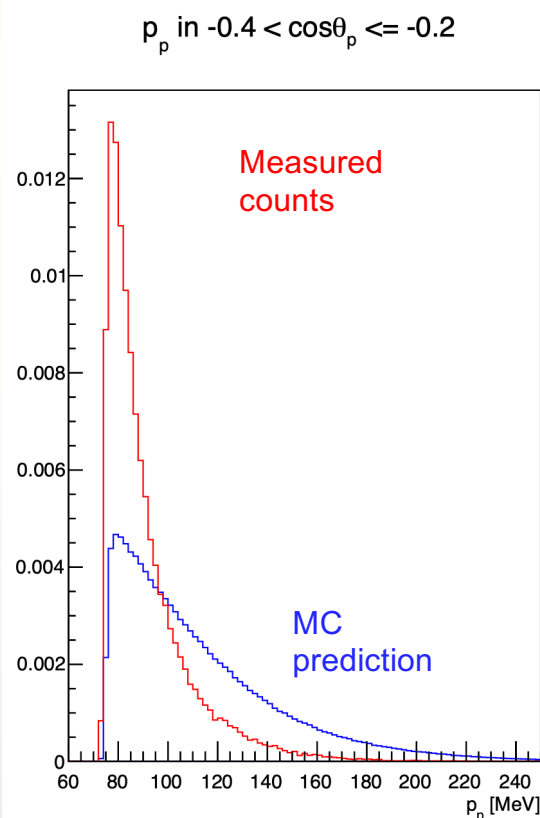
RG-F July 31st - September 21st, 2020
200 nA 10.4 GeV e- on 50 cm 5.6 atm D₂
Collected 0.14 mC 2717 M events
(also on H₂, ⁴He, and "empty" target)



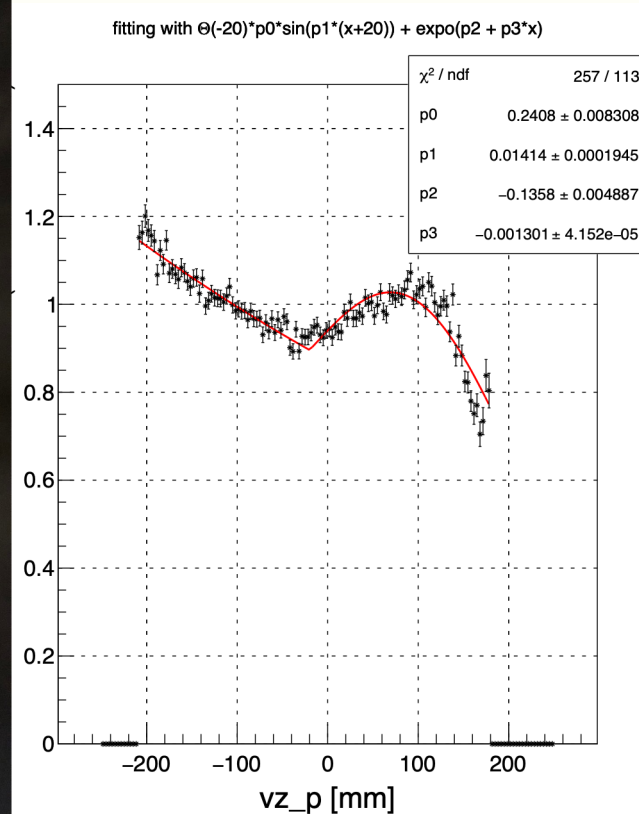
MC SIMULATION

- Full CLAS12 Geant-based MC (GEMC) with pure IA spectator model input
 - Large Lorentz angle => RTPC was at the limit where it could be operated efficiently
 - Large efficiency drop at higher momenta (low ionization density)
 - Very irregular efficiency as function of azimuthal angle.
- => Apply “ad-hoc” efficiency correction. (Good news: Final results nearly unaffected!)

Momentum dependence



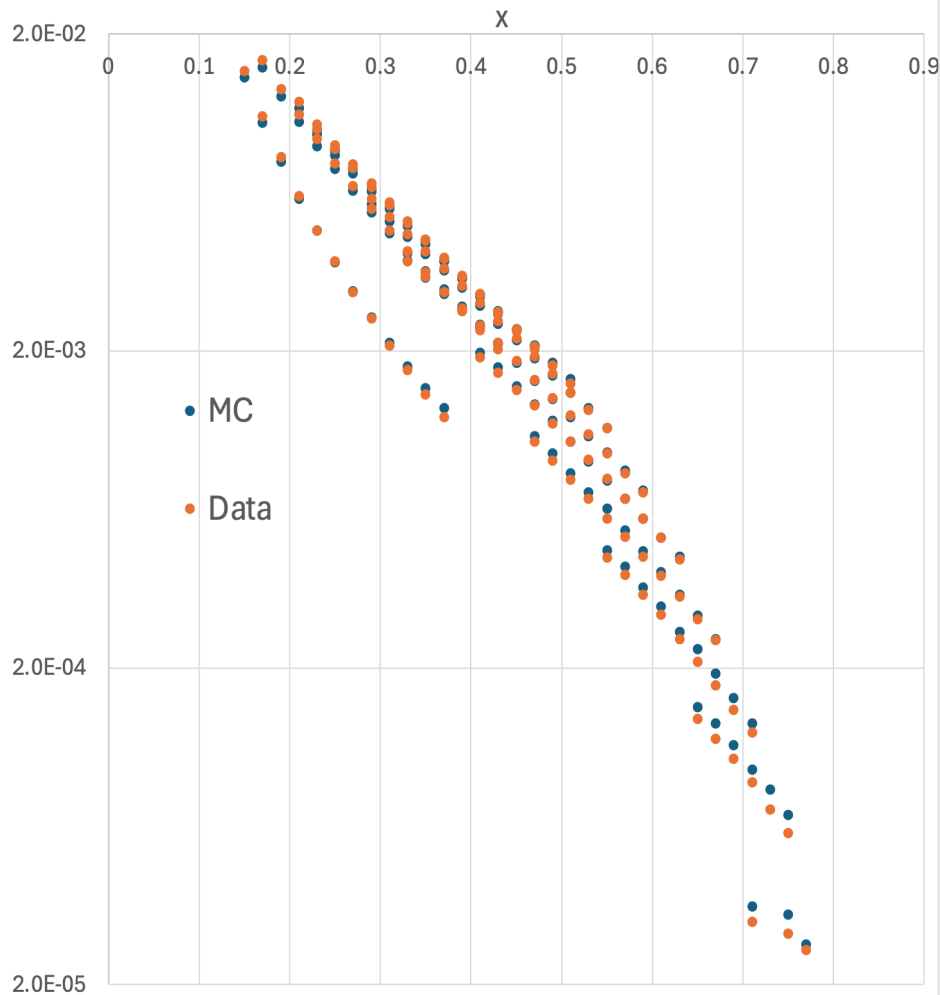
p vertex-dependence



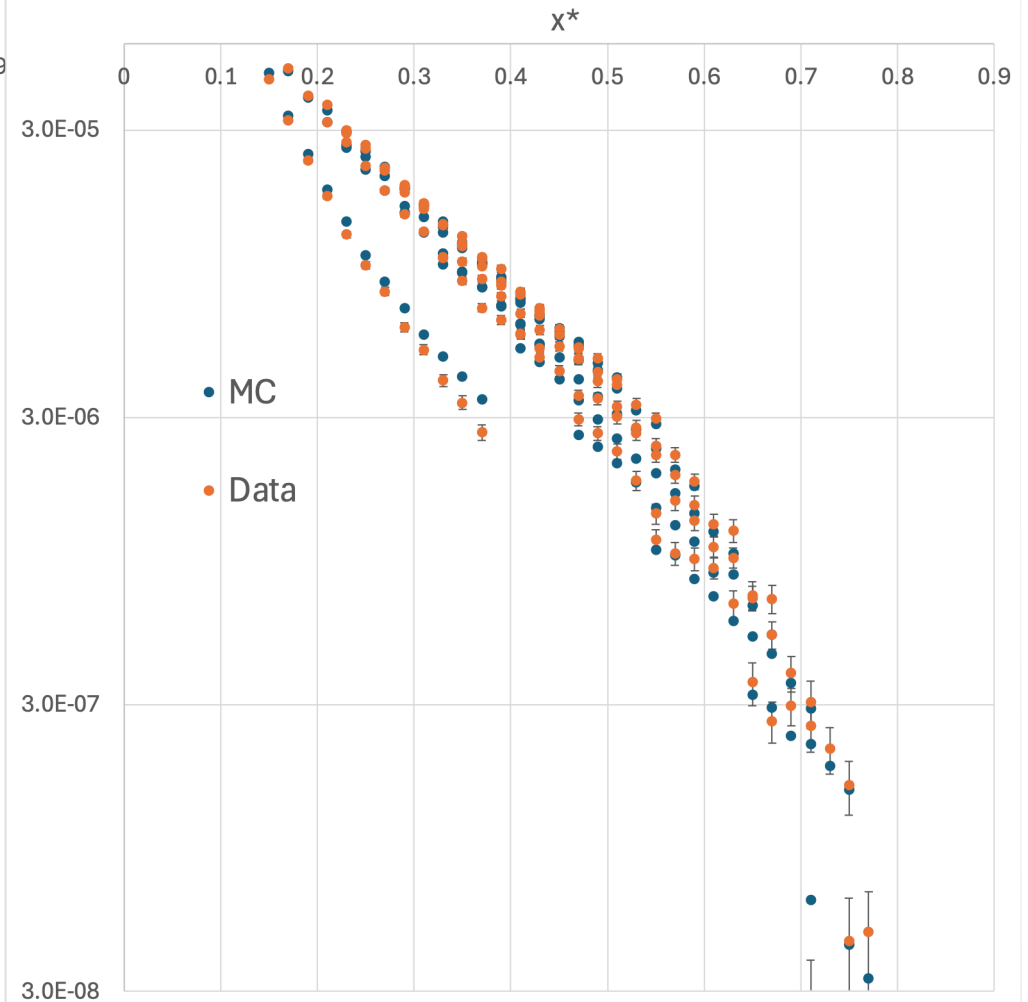
Solution

Apply "efficiency correction" as function of p_p/θ_p and vz_p vs. ϕ_p

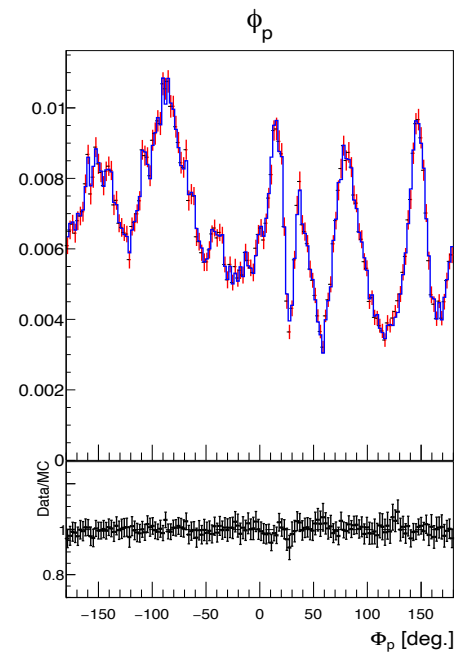
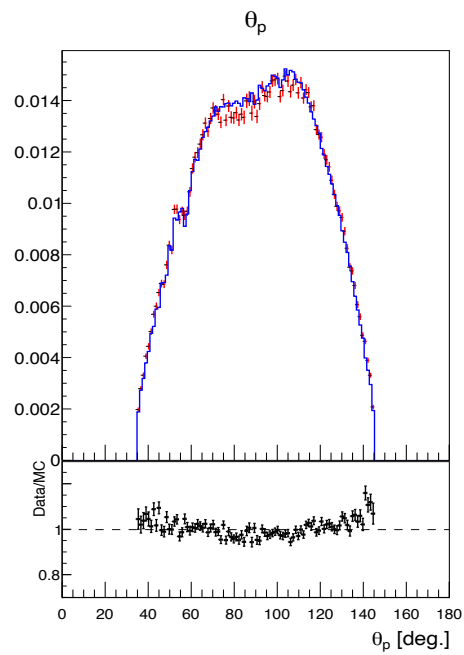
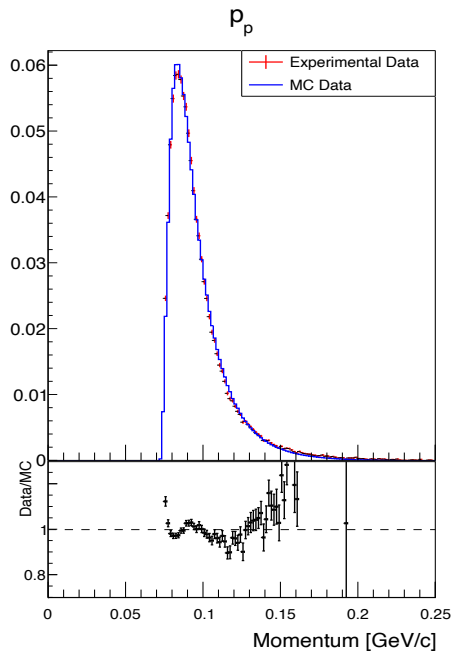
Inclusive (absolute normalization)



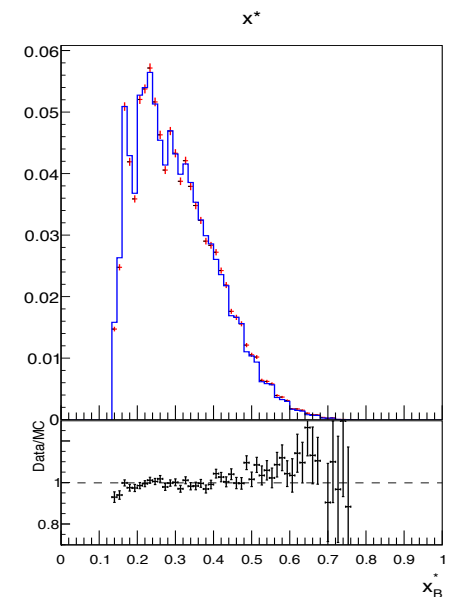
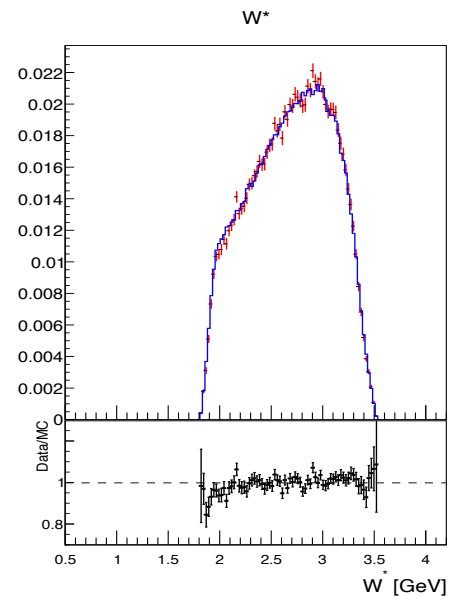
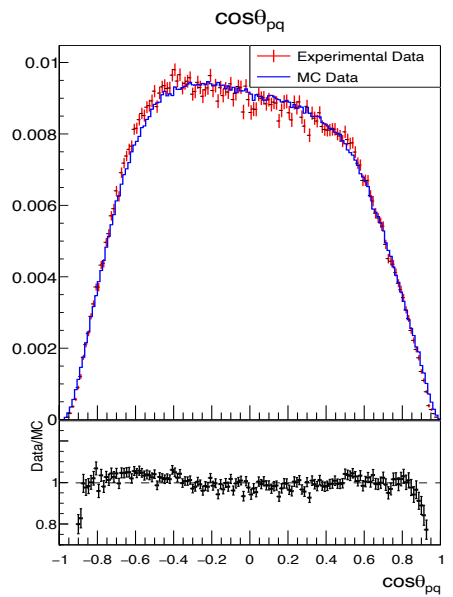
Tagged (absolute normalization)



Data vs. MC: $D(e,e'p_s)X$



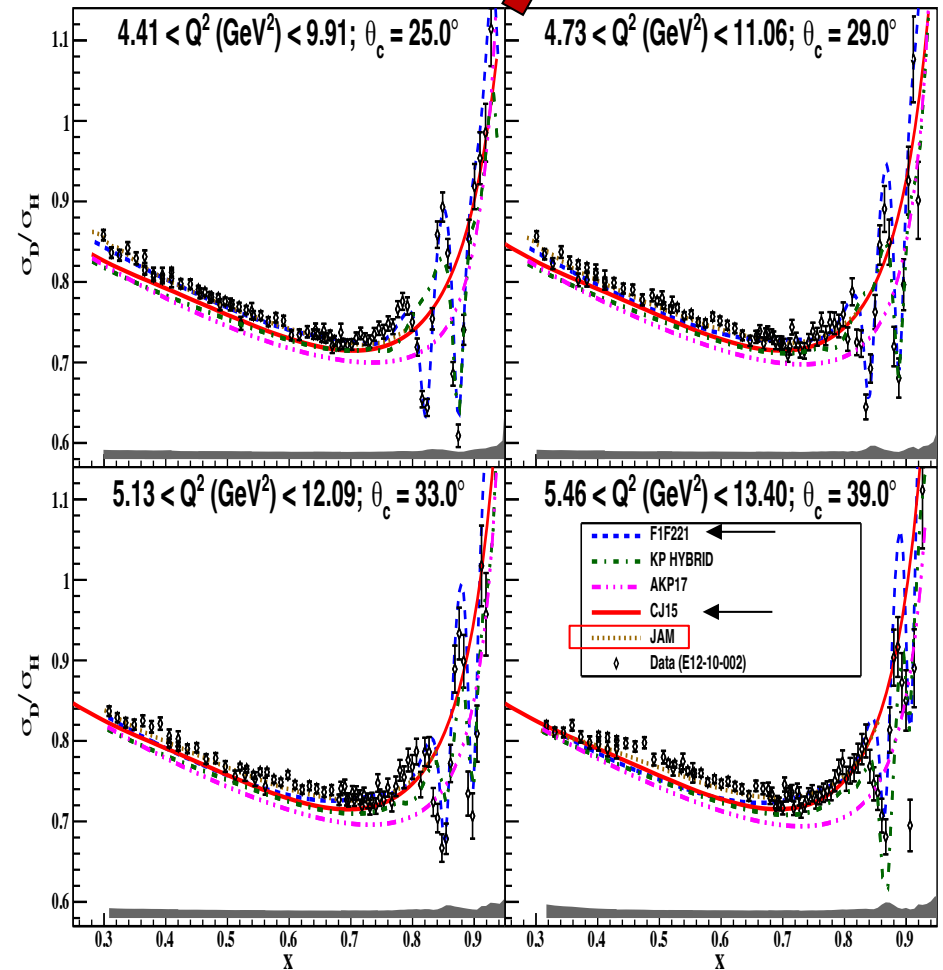
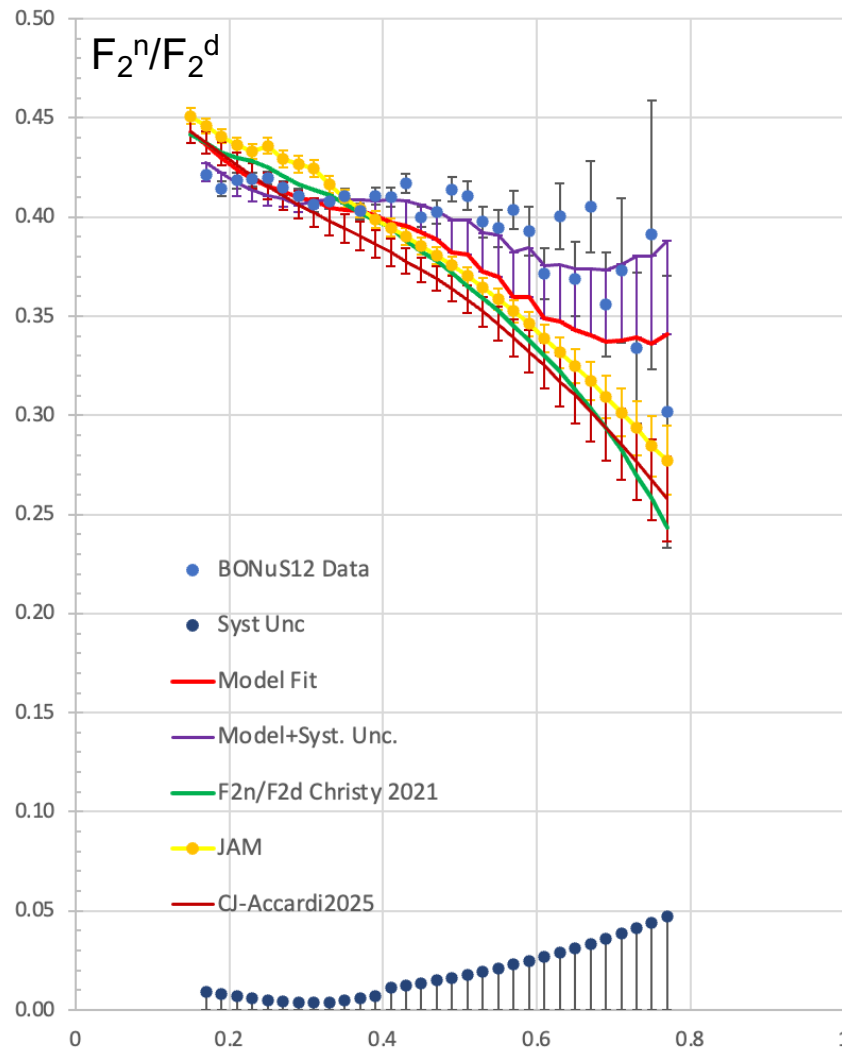
**Spectator
proton
kinematics**



BONuS12 Near-Final Results

$$\left(\frac{F_{2n}}{F_{2d}}\right)^{\text{meas}} = \text{Constant} \cdot \left(\frac{F_{2n}}{F_{2d}}\right)^{\text{Gen}} * \frac{(Y_{\text{tag}}^{\text{Data}}/Y_{\text{inc}}^{\text{Data}})}{(Y_{\text{tag}}^{\text{MC}}/Y_{\text{inc}}^{\text{MC}})}$$

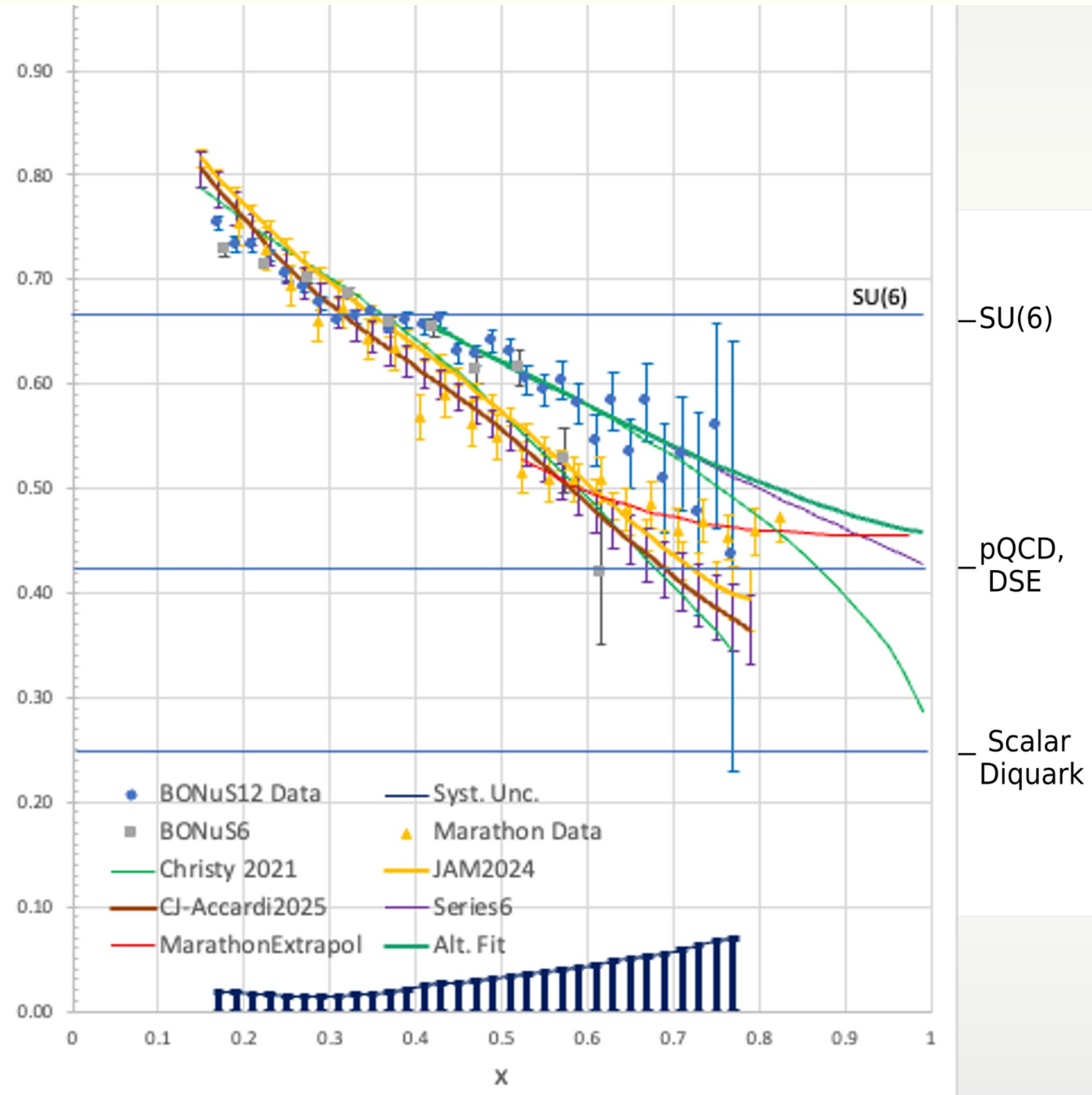
$$\left(\frac{F_2^n}{F_2^p}\right)^{\text{meas}} = \left(\frac{F_{2n}}{F_{2d}}\right)^{\text{meas}} * \left(\frac{F_{2d}}{F_{2p}}\right)^{\text{fit}}$$



D. Biswas et al., arXiv hep-ex 2409.15236

PHYSICAL REVIEW LETTERS 135, 151902 (2025)

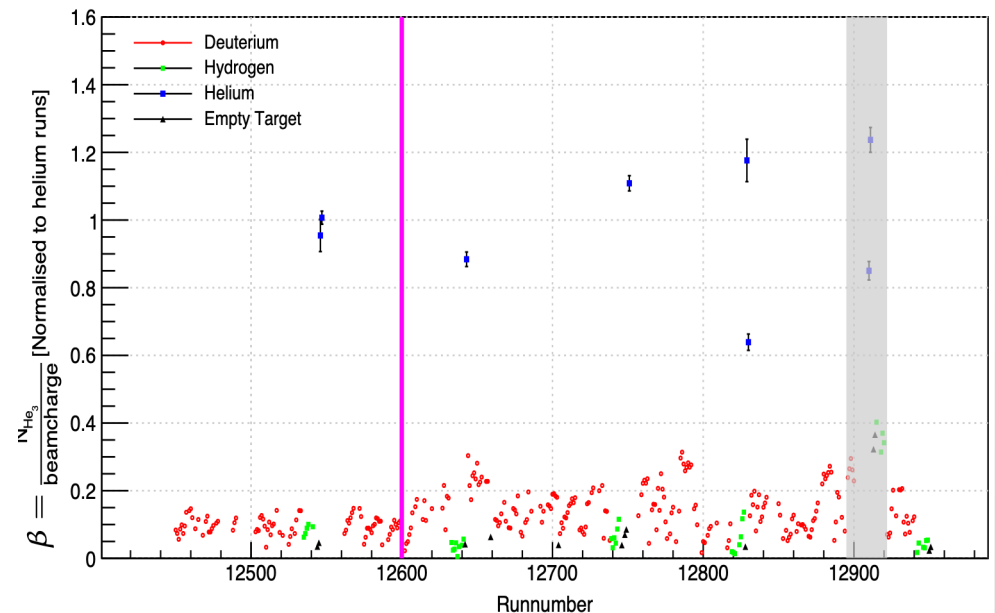
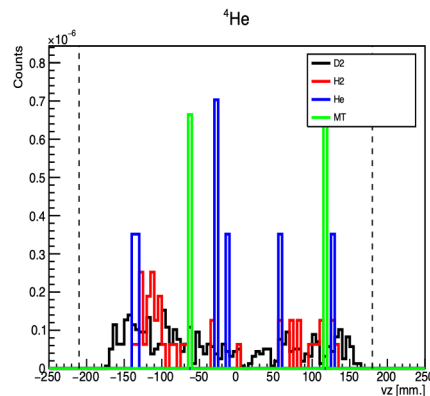
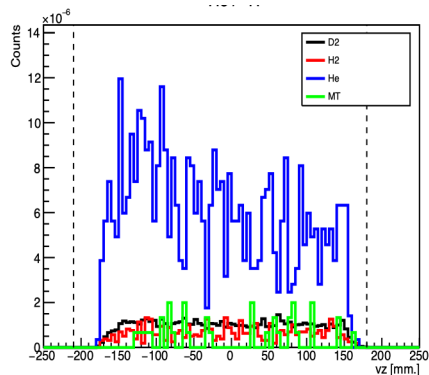
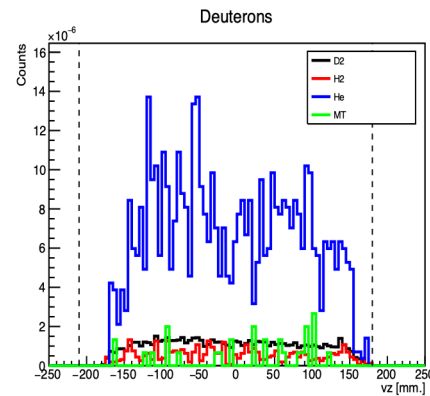
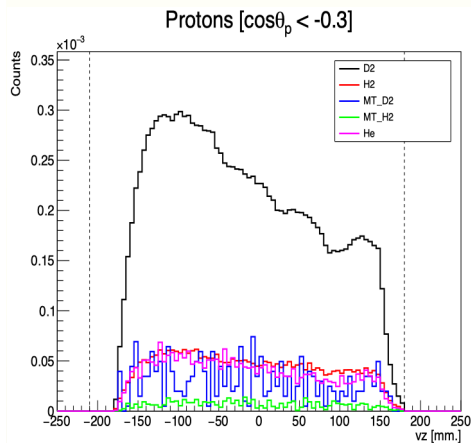
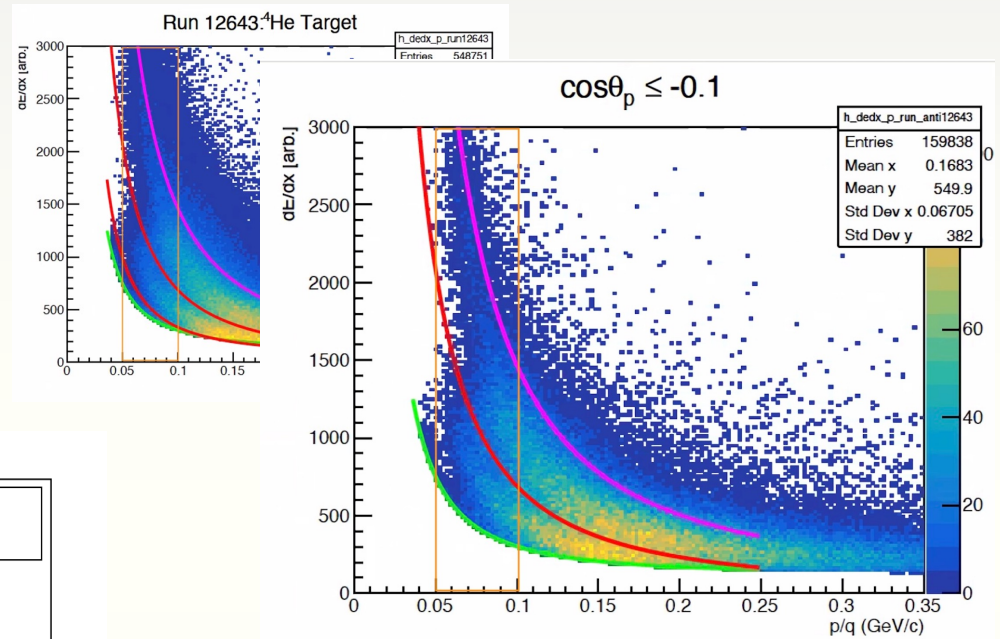
BONuS12 Near-Final Results



Why the discrepancy? Backgrounds?

POTENTIAL SOURCES OF BACKGROUND:

- ^4He contamination in all targets (semi-permeable straw, ^4He buffer volume) ✓
- Other gases (AIR!) from backflow while purging ?
- POTENTIALLY: Beam (halo) interacting with target straw walls (? Unlikely)



Why the discrepancy? Backgrounds?

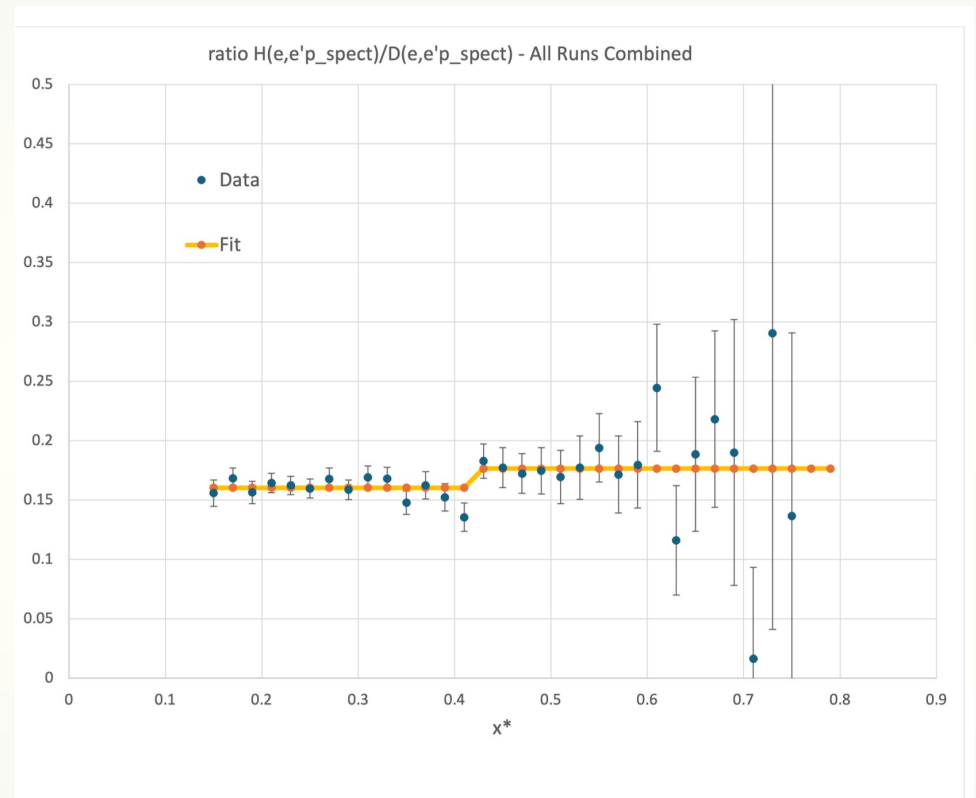
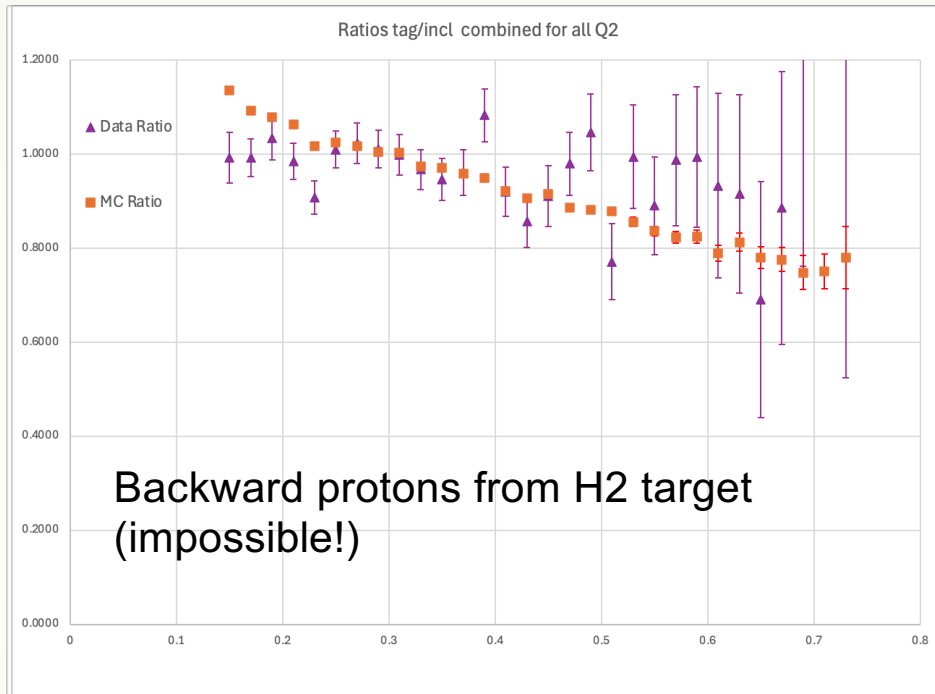
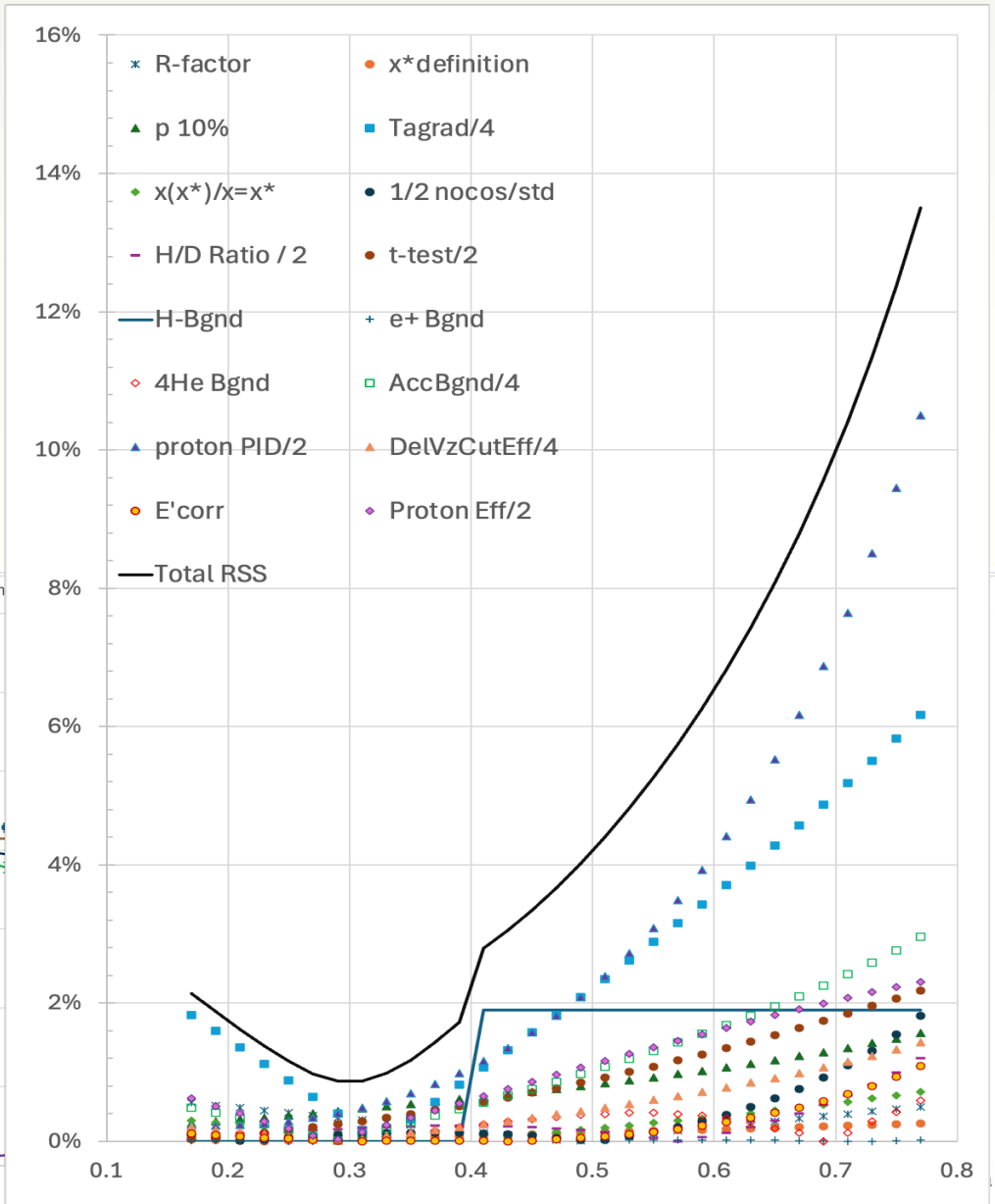
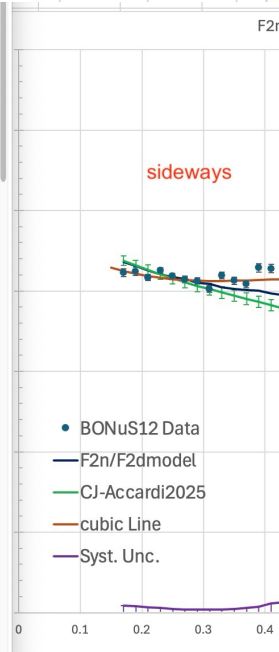
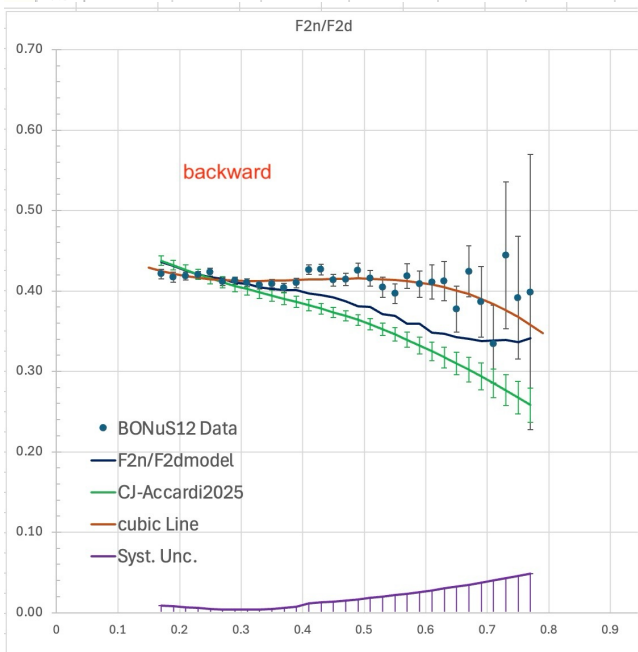
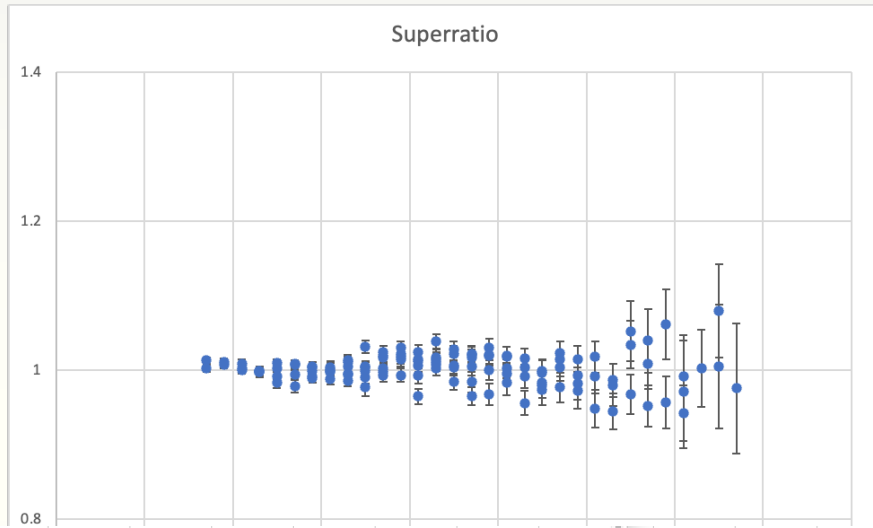


Figure 5.10: The fraction of additional backgrounds in deuterium that needs to be subtracted.

NOTE: Since all data (Superratios) are normalized to $x^* = 0.3$, this has zero effect on data below $x^* = 0.4$ and only a 2% reduction of data above $x^* = 0.4$.

Other systematic uncertainties



Conclusions

- Spectator Tagging SOUNDS like a clean way to access neutron structure functions (AND nucleon modifications).
- BONuS12 data have been collected in 2020 and have been scrutinized for 5 years – no “smoking gun” found
- Analysis under collaboration review (some outstanding issues remaining)
- **BUT: Preliminary results from BONuS12 deviate from model expectations and other measurements**
- **DO WE NEED TO REVISIT THE THEORY OF SPECTATOR TAGGING?**



With apologize to Nadia Fomin
from whom I stole this meme...