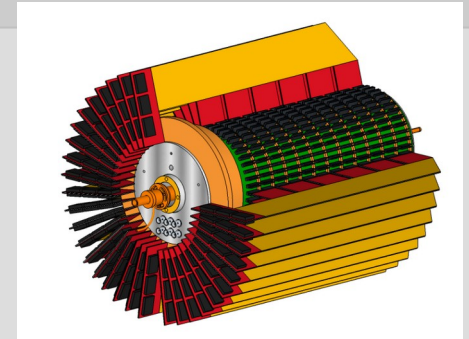
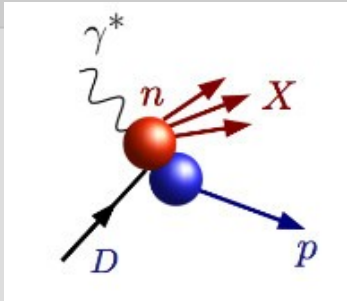


Neutron Structure with the BONuS12 Experiment



Eric Christy



DNP2020 – October 29, 2020

Important open questions in nucleon structure at high-x:

→ What is F_2^n / F_2^p and d/u for $x \rightarrow 1$?

→ How well does quark-hadron duality hold in the neutron

=> confront dynamical models of duality

→ How is the deuteron “constructed” from proton and neutrons?

I. What is the EMC effect in the deuteron?

II. Are there isospin dependent off-shell effects in light nuclei?

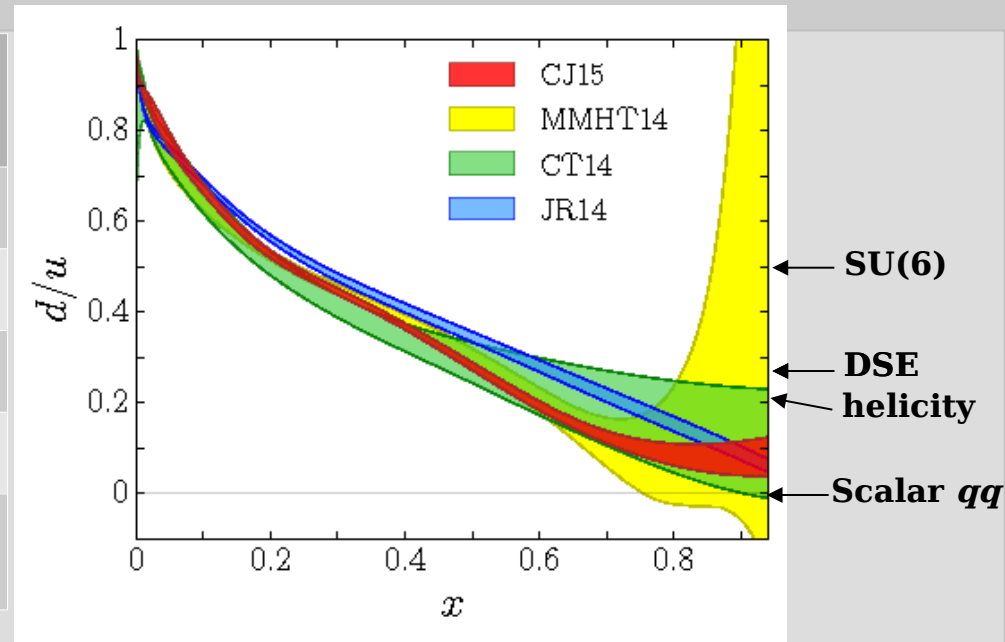
...

Answering these questions requires precision structure function data on:

proton, deuteron, neutron, and A=3 mirror nuclei

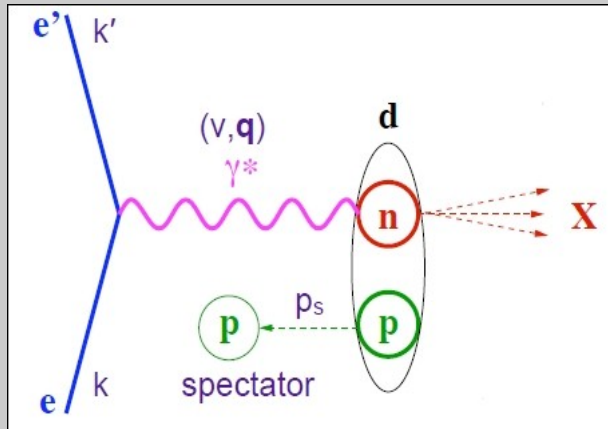
Ratio of d/u quark distributions at $x \rightarrow 1$ provides testing ground for nucleon models

Nucleon Model	F_n^2/F_p^2 $X^2 \rightarrow 1^2$	d/u $X \rightarrow 1$
SU(6) Symmetry	2/3	1/2
Scalar diquark dominance	1/4	0
DSE contact interaction	0.41	0.18
DSE realistic interaction	0.49	0.28
PQCD (helicity conservation)	3/7	1/5



Still an open question, but JLab 12 GeV experiments should help provide answers soon.

Neutron Structure from Spectator Tagging in the “Barely Off-Shell Neutron Structure” (BONuS) Experiment



PWIA Spectator Model:

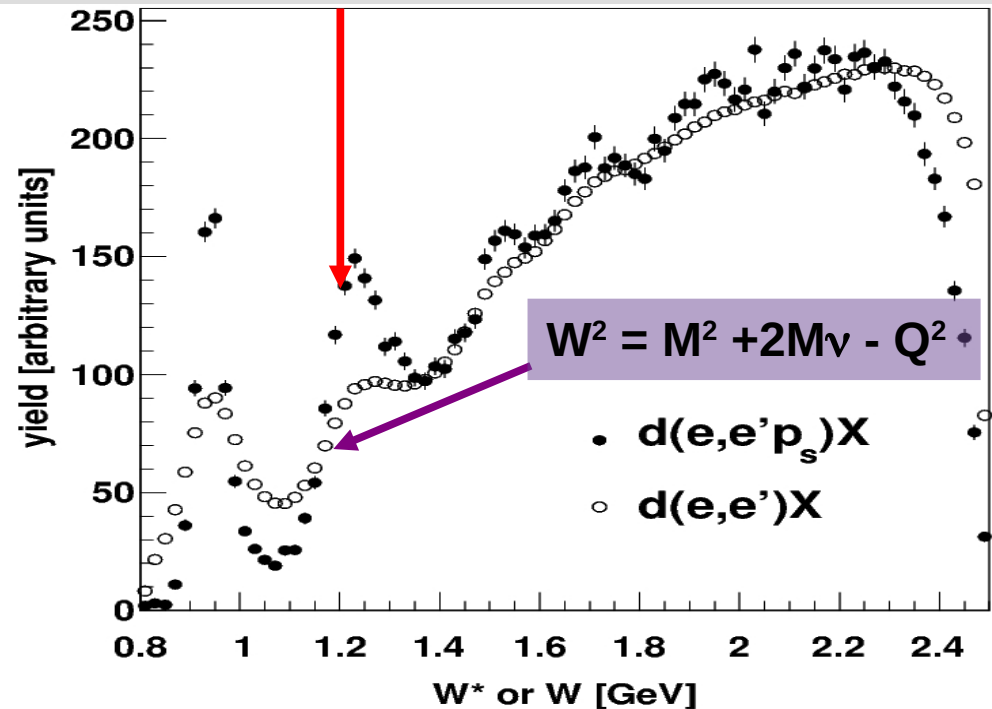
- Slow Backward proton is spectator
- Neutron is offshell
- measured proton momentum from recoil in weakly bound deuteron

=> correct for initial state neutron momentum

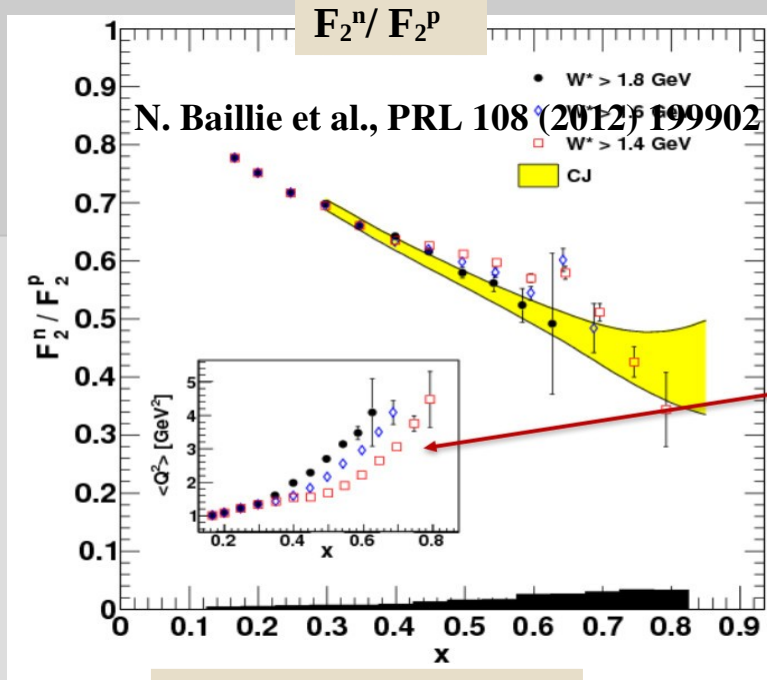
$$p_S = (E_S, \vec{p}_S); \alpha_S = \frac{E_S - \vec{p}_S \cdot \hat{q}}{M_D/2}$$

$$W^2 (p_n + q)^2 = p_n^2 p_n^2 + 2((M_D - E_S)v - \vec{p}_n \cdot \vec{q}) - Q^2$$

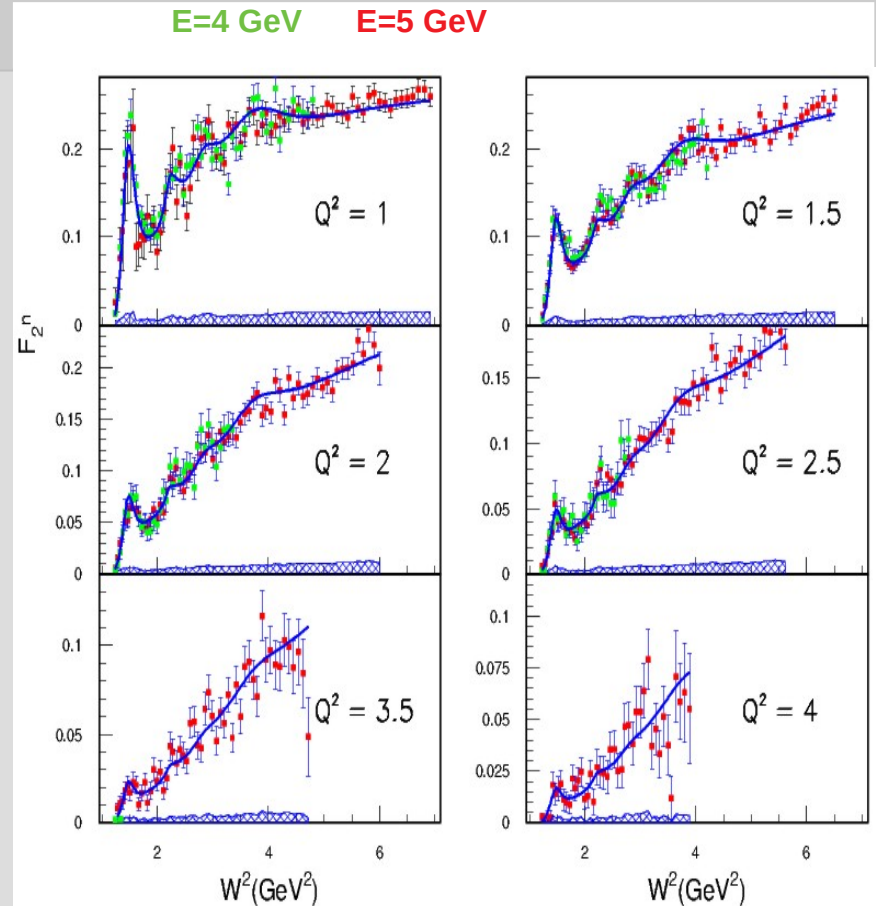
$$\gg M^2 + 2Mv(2 - \alpha_S) - Q^2$$



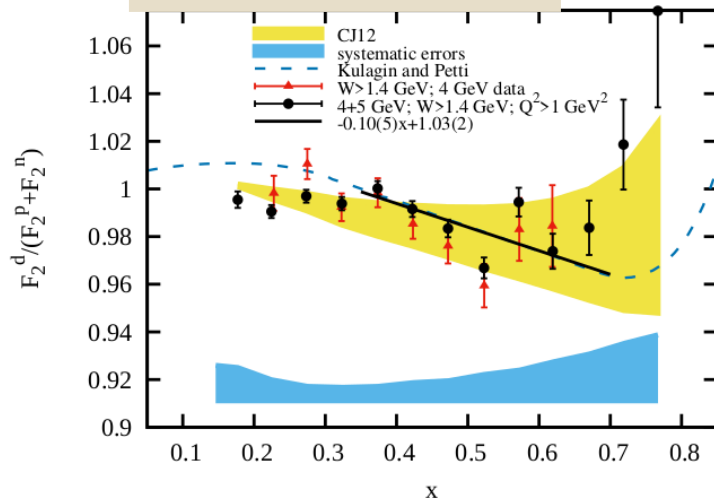
Results from $E_b = 6$ GeV Experiment



Neutron resonance states and duality



Deuteron EMC effect



Selection of backward, low momentum protons minimizes nuclear corrections

Final State Interactions:

- Struck neutron interacts with the spectator p.
- Proton momentum is enhanced.
- FSIs are small at low p_s and large θ_{pq} .

Target Fragmentation:

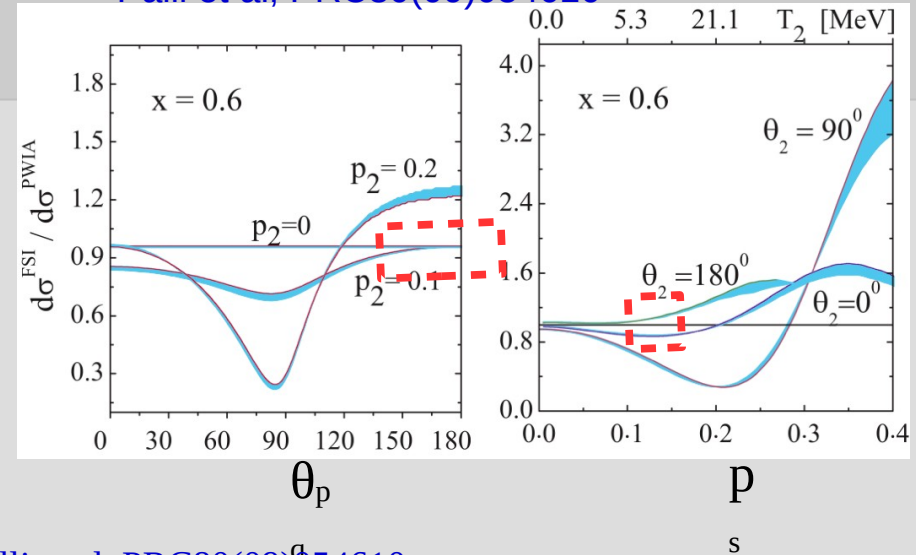
- $e n \rightarrow e p X$ (where $n \rightarrow \pi p$) and $e p \rightarrow e p X$ (where $p \rightarrow \pi^0 p$).
- TF enhances the proton yield at forward angles ($\cos\theta_{pq} > 0.6$).

Off-Shell Corrections:

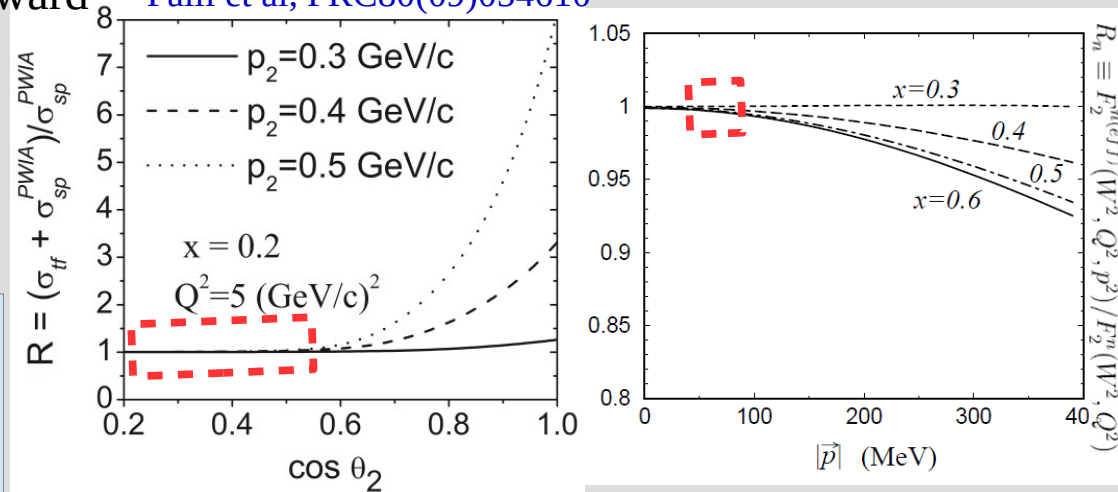
- Less than 2% in our region.

Expect total systematic uncertainties to be less than 5%

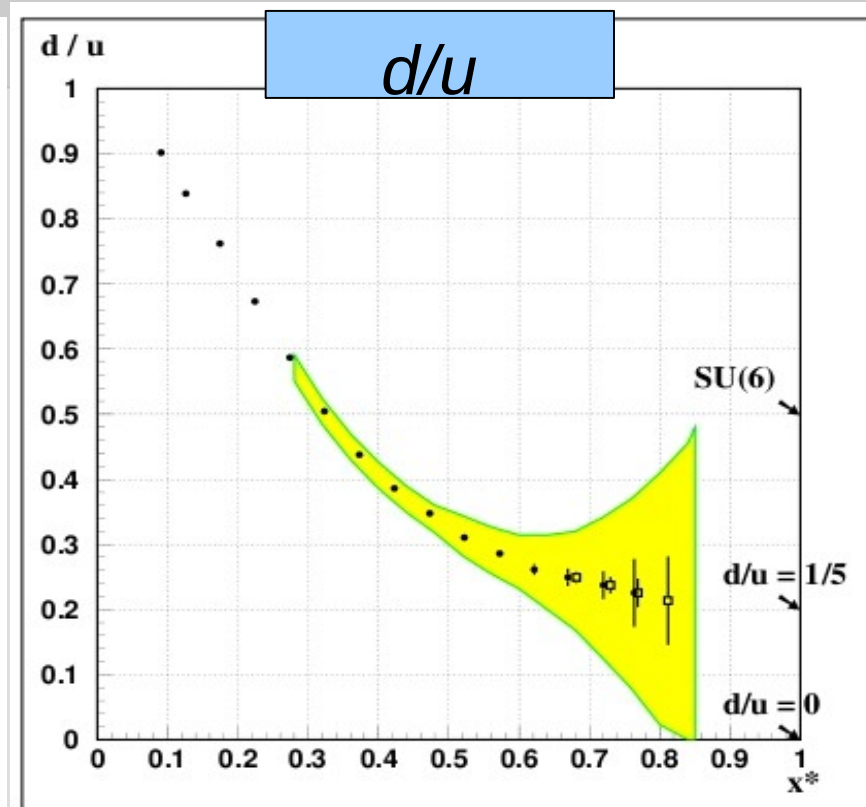
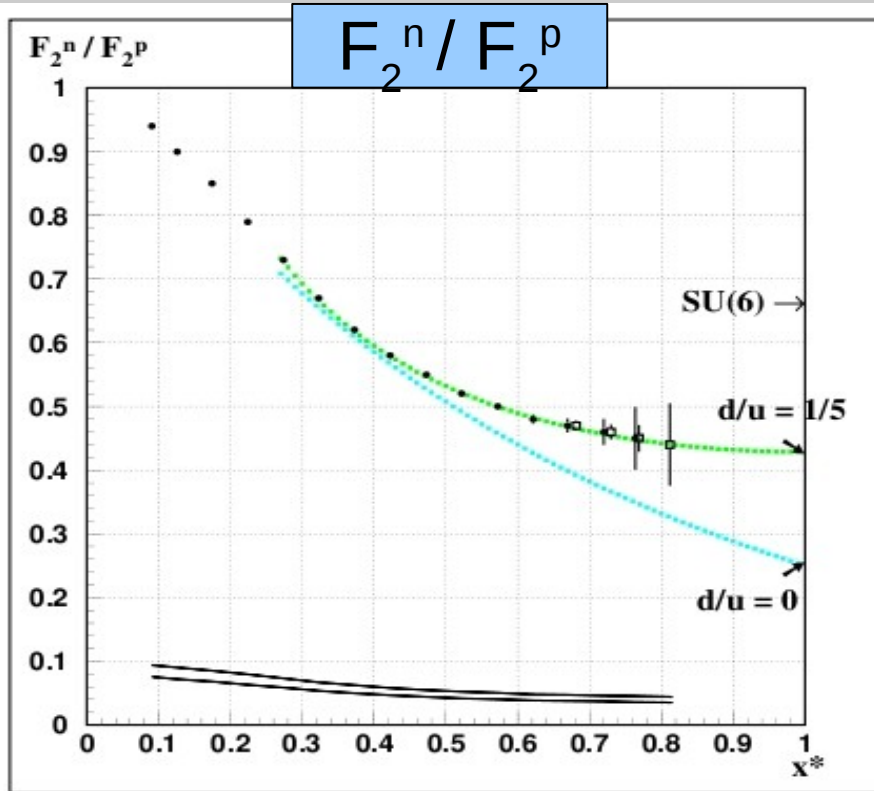
Palli et al, PRC80(09)054610



Palli et al, PRC80(09)054610



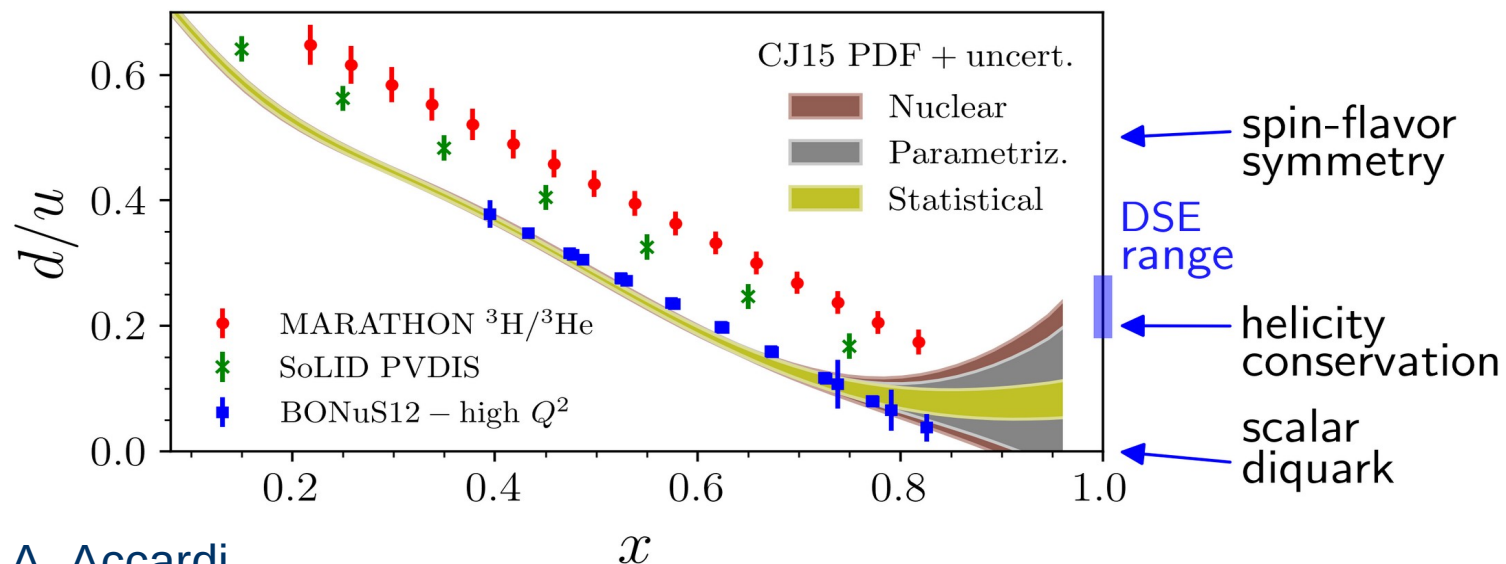
Expected BONuS12 precision



Multiple experiments in JLab 12 GeV era to determine d/u at high- x

With *different* systematics

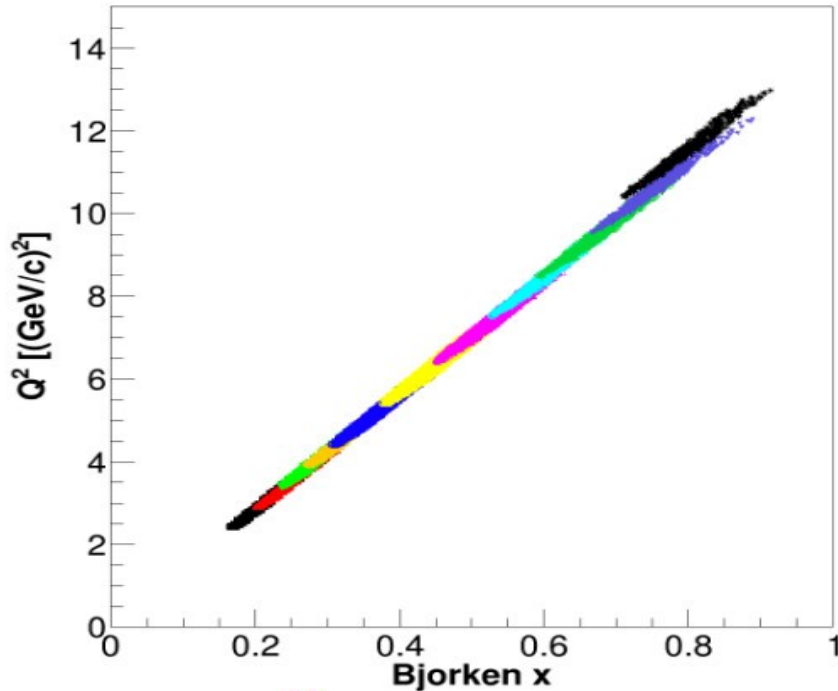
- **MARATHON** - ^3H / ^3He mirror nuclei
- **SoLID PVDIS**
- **BONuS12** – proton spectator tagging



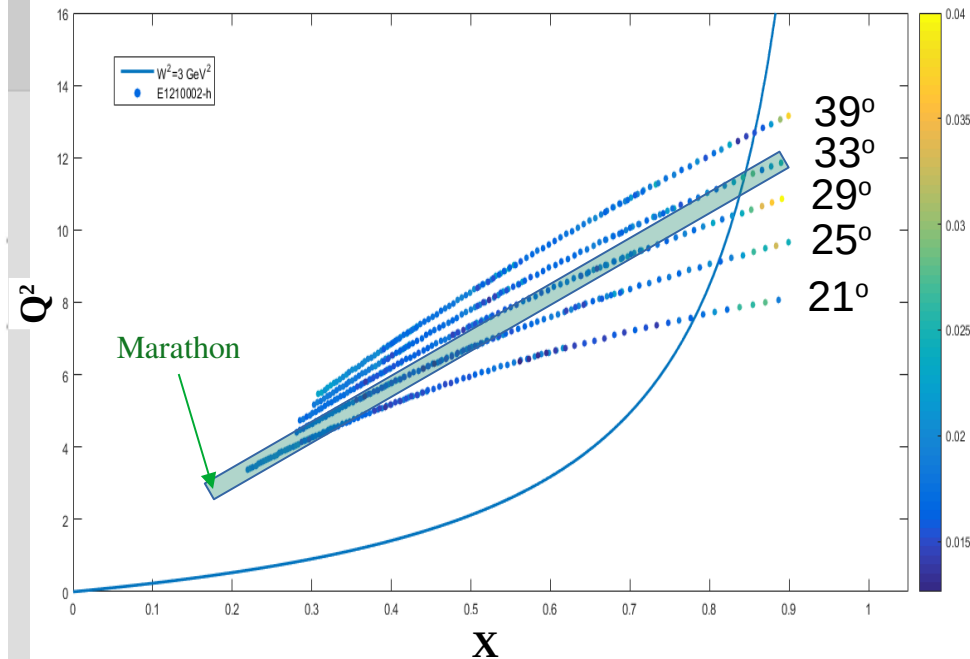
A. Accardi

Comparison of Kinematics

MARATHON



MARATHON + E12-10-002



- BONuS12 has similar coverage as E12-10-002 SHMS, but also extends to lower Q^2
 - Marathon kinematic region covered by all 3 experiments
- => Leverage all 3 experiments to study:
1. F_2^n / F_2^p (d/u),
 2. nuclear effects in light nuclei,
 3. isospin dependent effects

BONuS12 Experimental Setup in CLAS12

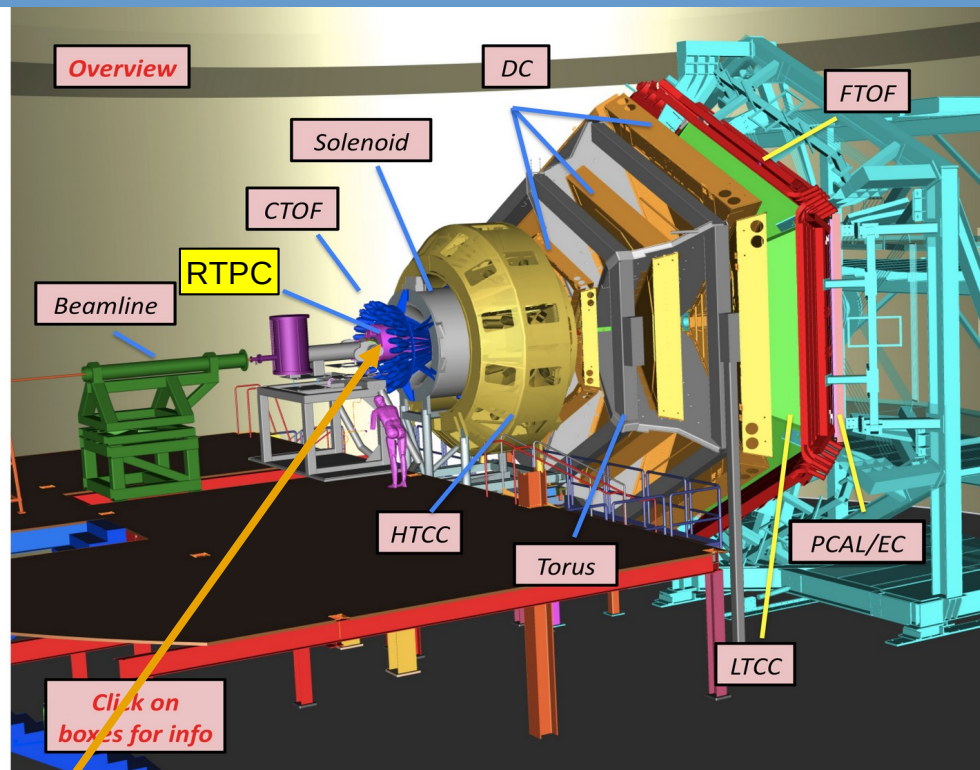
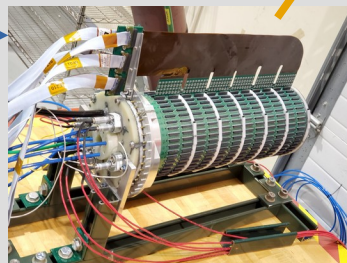
$$e^- d \rightarrow e^- p X$$

- CLAS12 Forward Detector:

- Superconducting **Torus** magnet.
- 6 independent sectors:
 - **HTCC**
 - 3 regions of **DCs**
 - **LTCC /RICH**
 - **FTOF** Counters
 - **PCAL** and **ECs**
 - **FT (1/2)**

- Central:

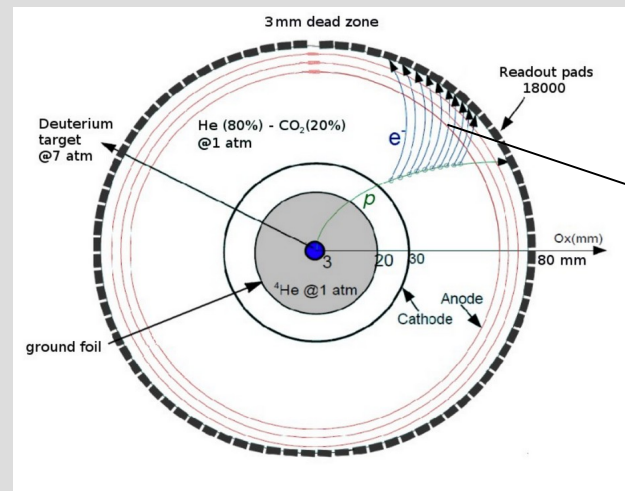
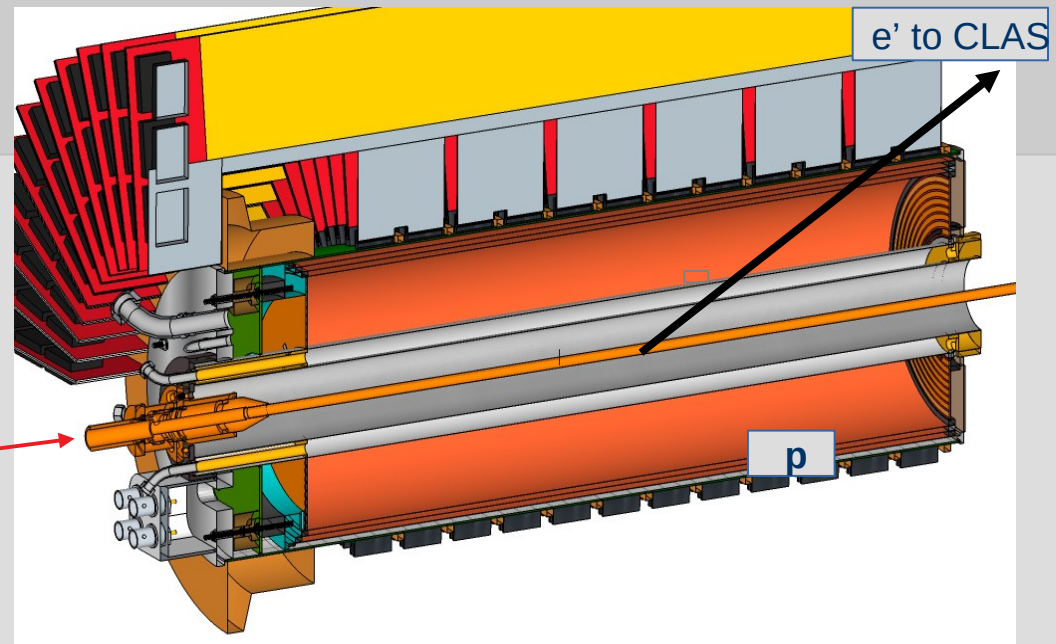
- Target: D gas @ 6 atm, 293 K
- BONuS12 RTPC →
- **FMT**
- **Solenoid** (5 T)
- **CTOF**, and **CND**



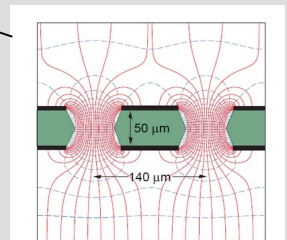
$E_{\text{beam}} = 10.6 \text{ GeV}, 2.1 \text{ GeV (calibrations)}$
35 days on D
5 days on $^4\text{He}/\text{H}_2$
with $L = 2 \cdot 10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$

BONuS12 RTPC General Specifications

- Active length: **40 cm**
- Radial drift distance: **4 cm**
- Drift gas **He/CO₂ (80/20)**
- **3** GEM amplification layers **Beam**
- **16** HV sectors per GEM (Segmented in φ)
- Pad readout: **2.8 mm x 4 mm**
- => 17,280 channels**
- Solenoid B-field **~3.5 – 4 T**



GEM layer



- Working principle:

- Under EM field, ionized electrons follow their **drift paths** at a certain **drift speed**
- Amplifications via the 3 GEM layers
- Readout board → MVT FEU electronics → Signal height vs. Time bin

- Reconstruction of hit position / energy

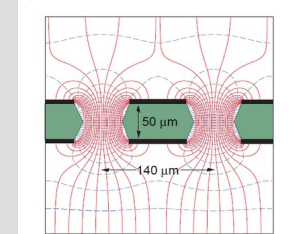
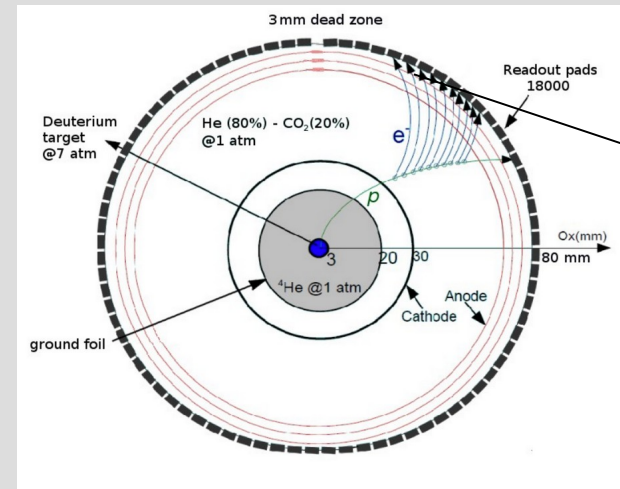
Signal height \longrightarrow Pads' gains (G_i)

$$\left\langle \frac{dE}{dX} \right\rangle = \frac{\sum_i \frac{ADC_i}{G_i}}{vtl}$$

→ **PID**

- Track reconstruction

Time and Pad location → 3D reconstruction of track → vector p/q, vz, vertex time



RTPC Assembly @ Hampton U. In Collaboration with ODU & JLab

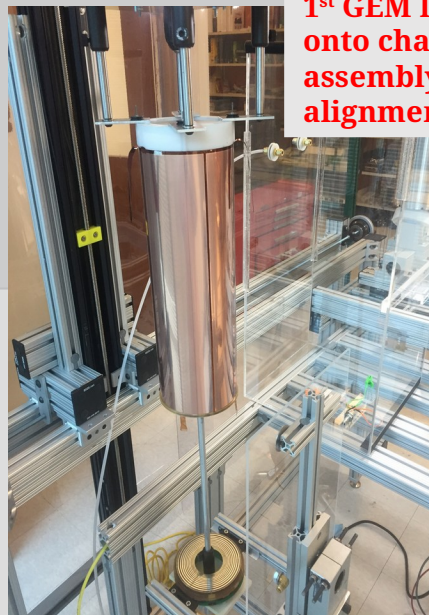
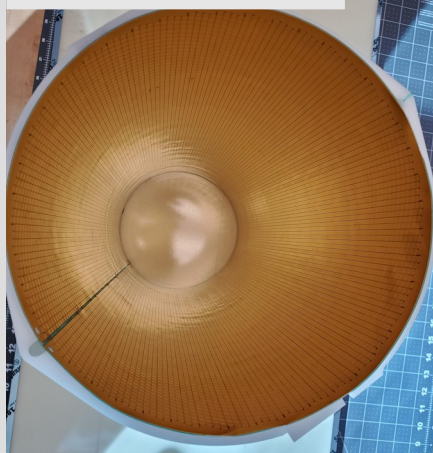
GEM foil wrapping and gluing



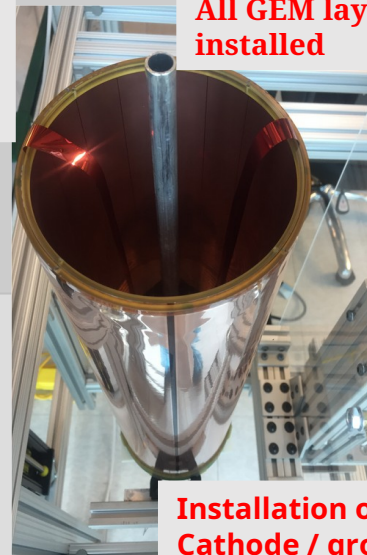
Automated epoxy
application



Wrapped Padboard
inner surface

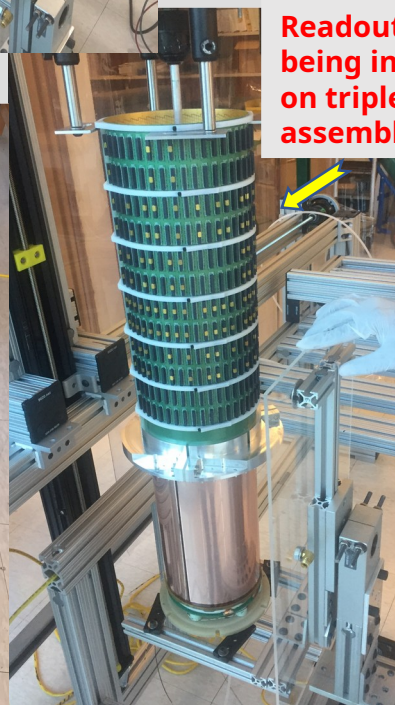


1st GEM layer lowered
onto chamfer plate
assembly utilizing self-
alignment jig



All GEM layers
installed

Installation of
Cathode / ground
assembly



Readout board
being installed
on triple-GEM
assembly



CLAS12 RG-F (BONuS12) Data Summary

Finished data taking ~ 1 month ago

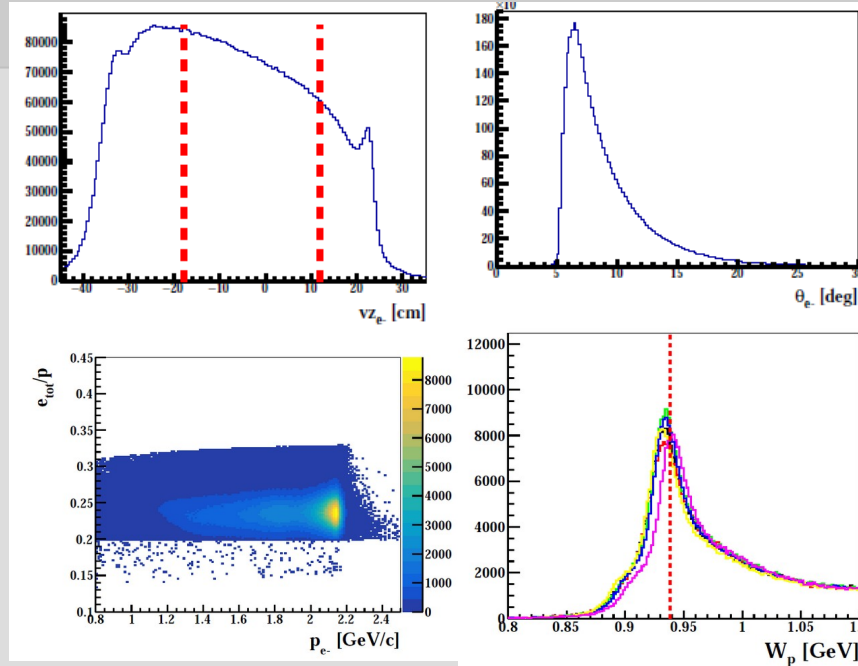
-> Significant statistics taken for final physics results

-> only event reconstruction and calibration quantities will be shown.

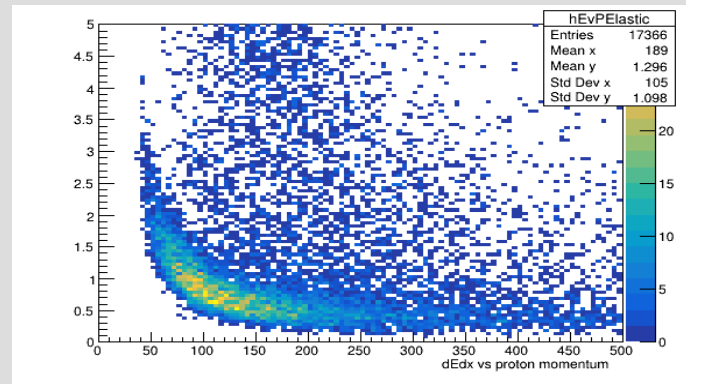
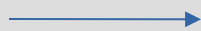
Beam Energy	Target	Spring 2020	Summer 2020
1 Pass Data	H2	81M	185M
	D2	37M	45M
	4He	19M	44M
	Empty	1M	22M
	Total	138M	296M
5 Pass Data	H2	151M	266M
	D2	2275M	2355M
	4He	77M	51M
	Empty	21M	45M
	Total	2524M	2717M

Preliminary Calibration Data Analysis

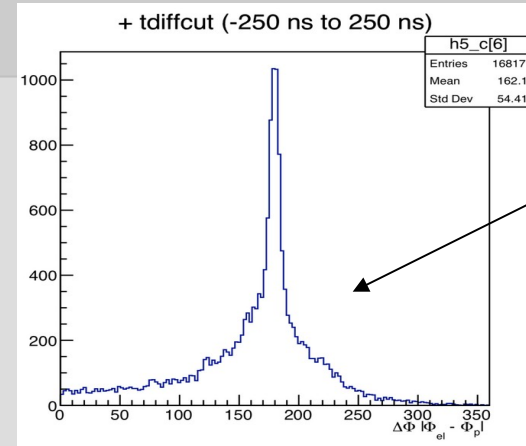
Electron Selection : 2.14 GeV on H₂ target



(uncalibrated) dE/dx vs
Reconstructed momentum
For elastic recoil “protons”
In RTPC

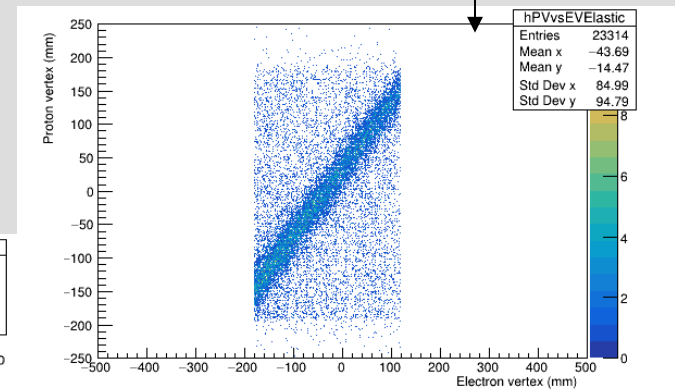


Elastic e⁻ with good proton tracks in RTPC:



After timing cut
Select RTPC tracks:

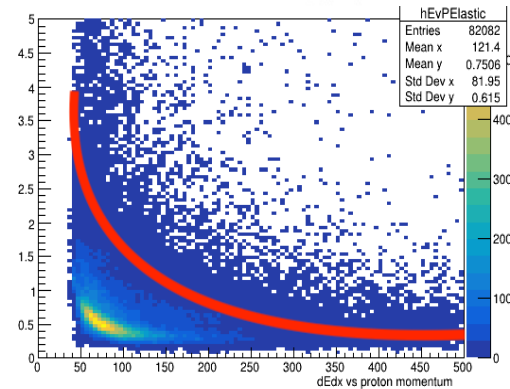
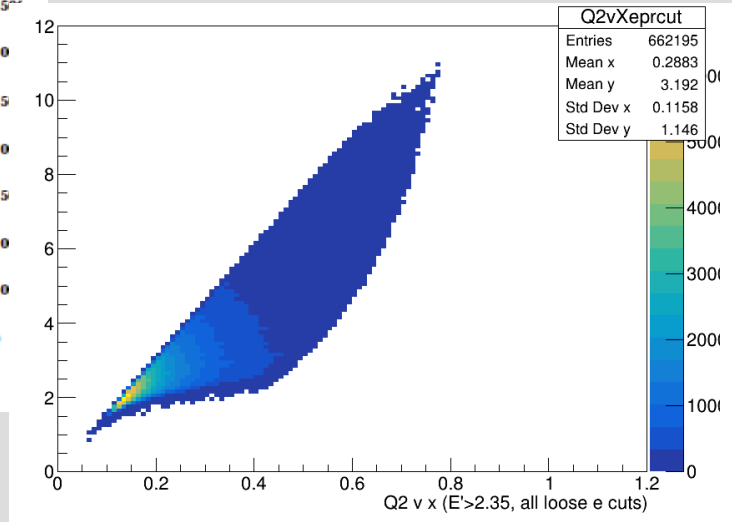
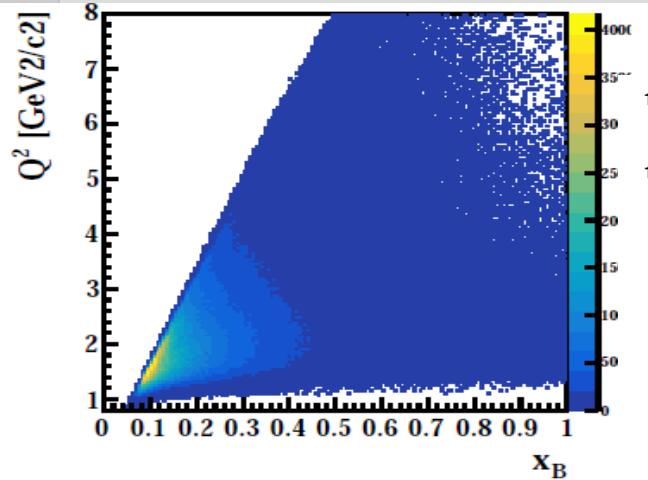
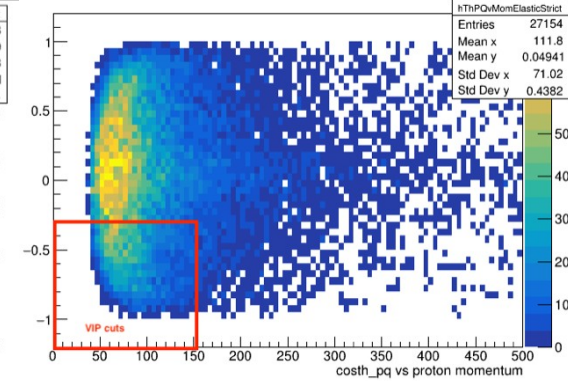
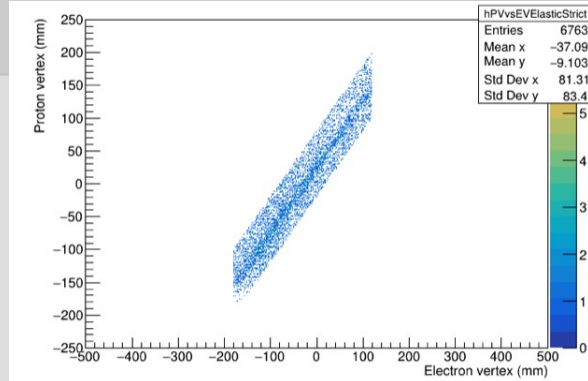
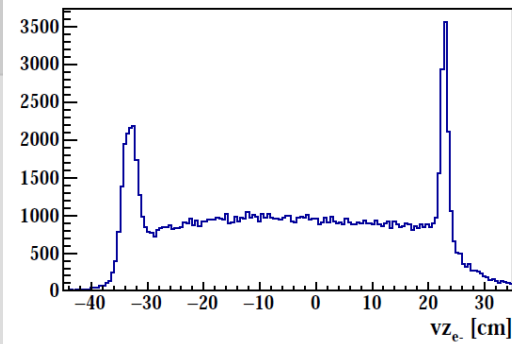
1. in-plane with e⁻
2. common vertex



Preliminary Analysis – 5 Pass Data (subset)

e^- @10.4 GeV beam on D_2 target

Proton Selection on D_2 target



Summary

- **BONuS12 successfully completed data taking in JLab Hall B**
 - **Significant statistics collected for determination of “nearly” free *neutron* F_2**
 - **Next Generation RTPC performed well with calibration in progress**
- **Expect significant impact on determination of F_2^n and d/u at large x**
- **Range of physics to be explored.**
- **Combined results from BONuS12, Marathon, and Hall C proton and deuteron F_2 provide data on possible isospin dependent off-shell effects and medium modification effects in light nuclei.**