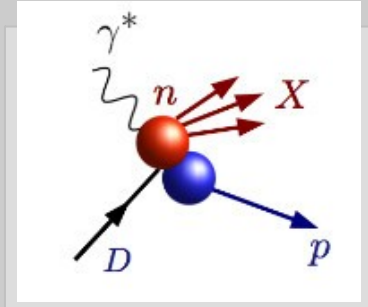
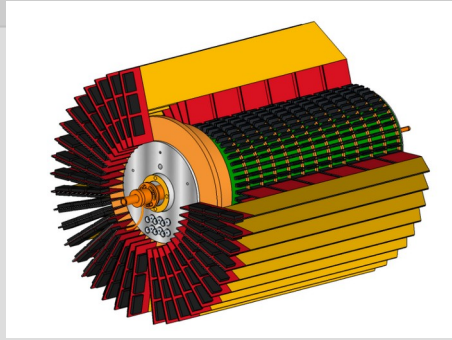
Neutron Structure with the BONuS12 Experiment





Eric Christy

HAMPTON UNIVERSITY

Jefferson Lab

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 $x \to 1$?

→ 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?

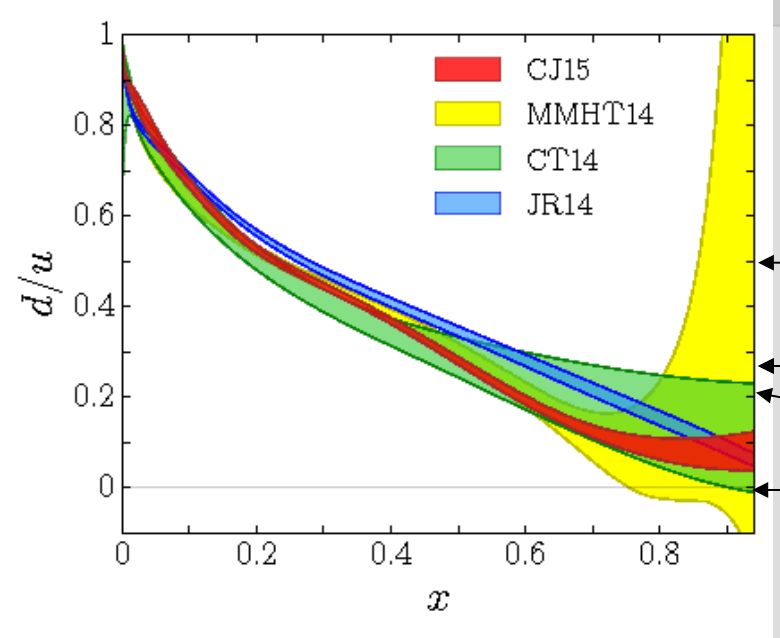
…

Answering these questions requires precision structure function data on:

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

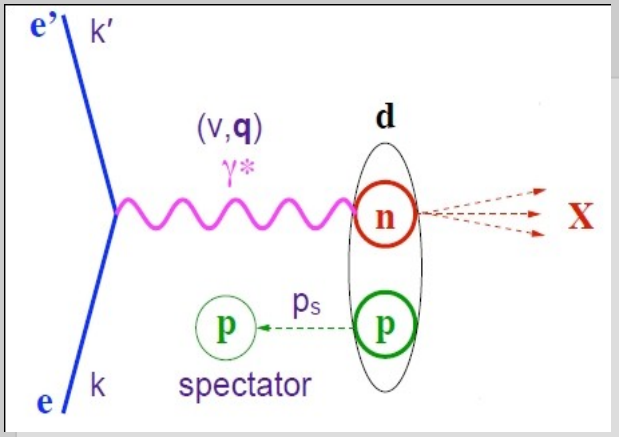
Ratio of d/u quark distributions at x→1 provides testing ground for nucleon models

Nucleon Model	F_2^n/F_2^p $x \to 1$	d/u $x \to 1$
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



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

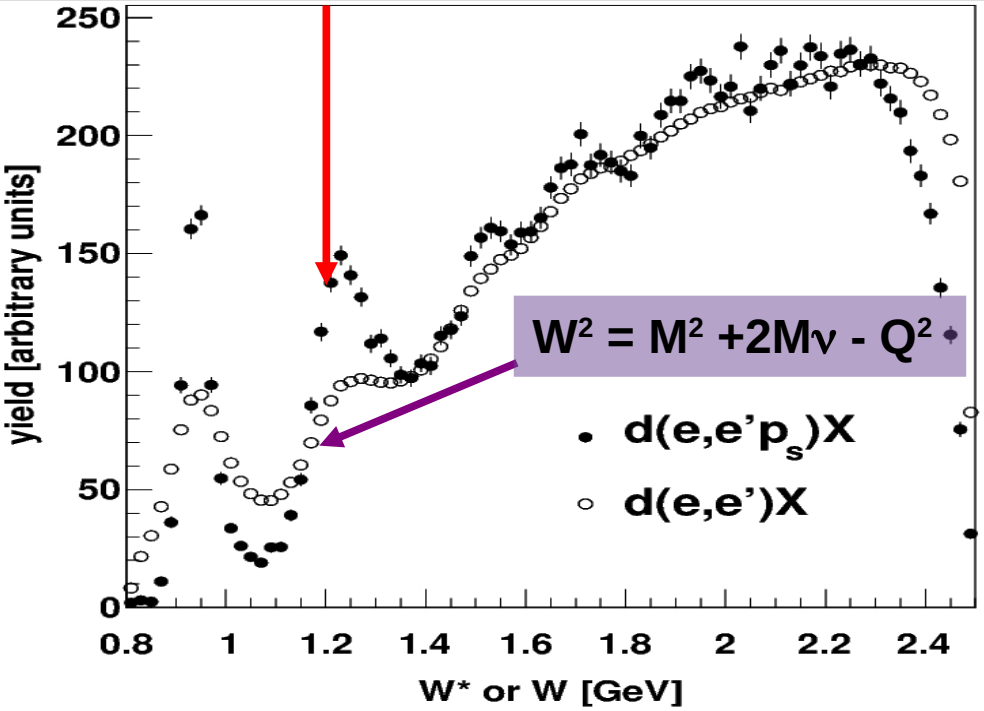
$$W*^2 (p_n + q)^2 = p_{n^m} p_{n_m} + 2((M_D - E_s)\nu - \vec{p}_n \cdot \vec{q}) - Q^2$$

$$\approx M*^2 + 2M\nu(2 - \alpha_S) - Q^2$$

PWIA Spectator Model:

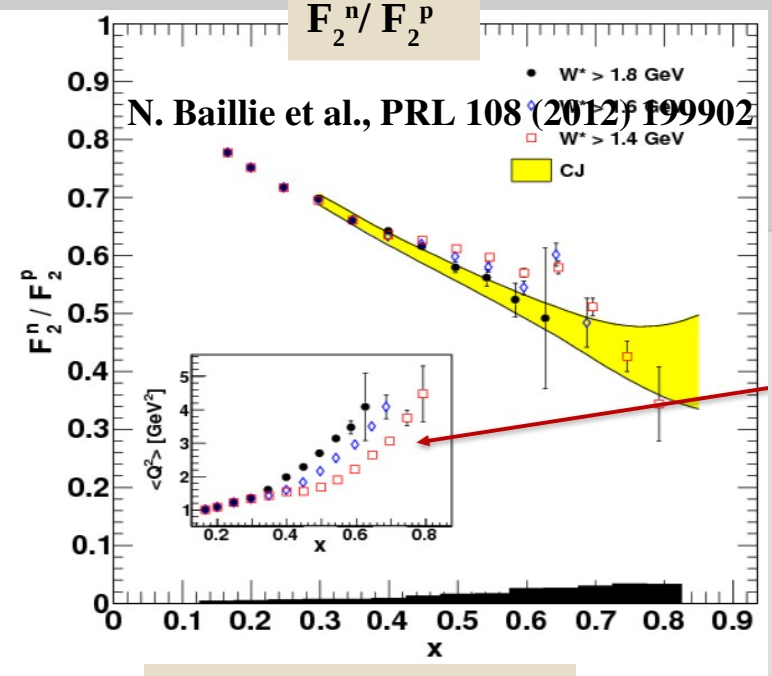
- → Slow Backward proton is spectator
- → Neutron is offshell
- → measured proton momentum from recoil in weakly bound deuteron

=> correct for initial state neutron momentum



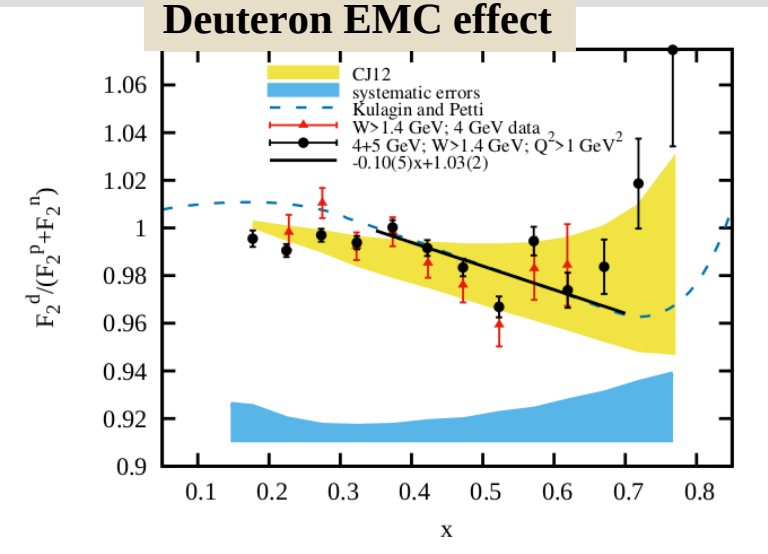
Results from E_b = 6 GeV Experiment

F_2^n / F_2^p

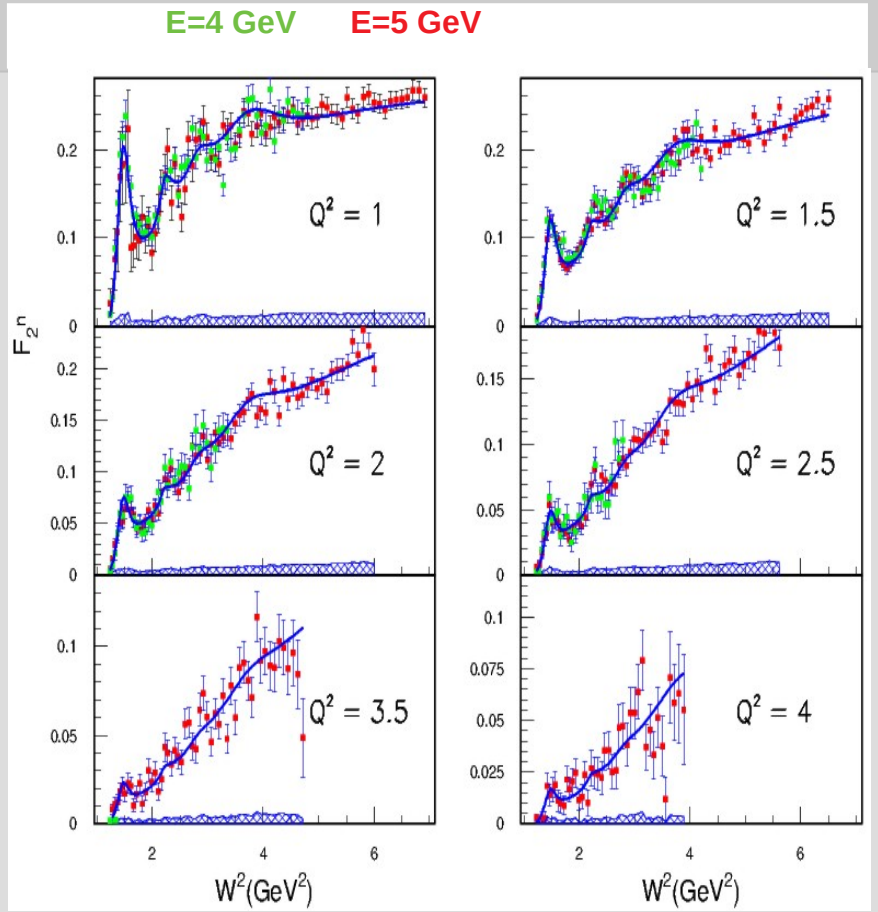


N. Baillie et al., PRL 108 (2012) 199902

Deuteron EMC effect



Neutron resonance states and duality



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:

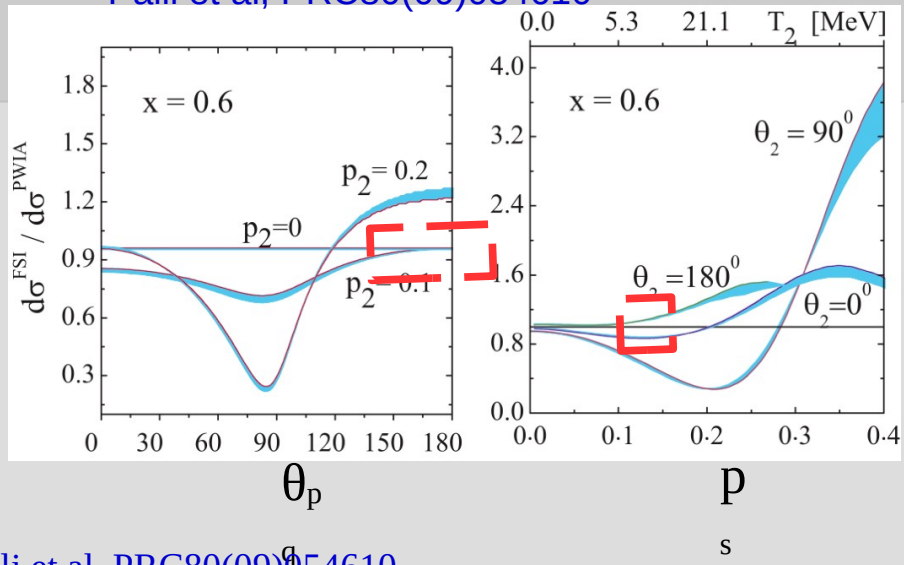
- e n → e p X (where n → π^- p) and
  e p → e p X (where p → π^0 p).
- TF enhances the proton yield at forward angles ($\cos\theta_{pq} > 0.6$).

Off-Shell Corrections:

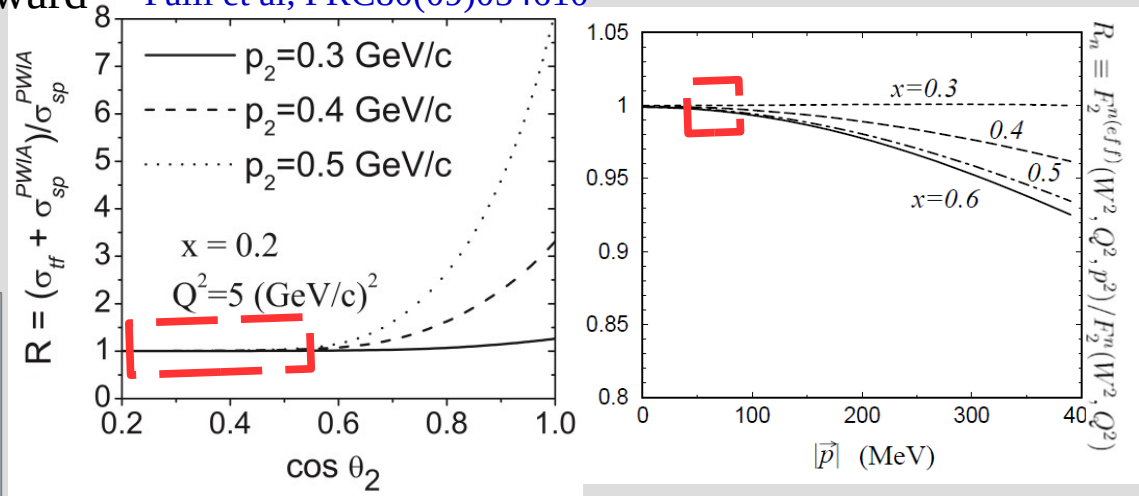
- Less than 2% in our region.

Expect total systematic uncertainities to be less than 5%

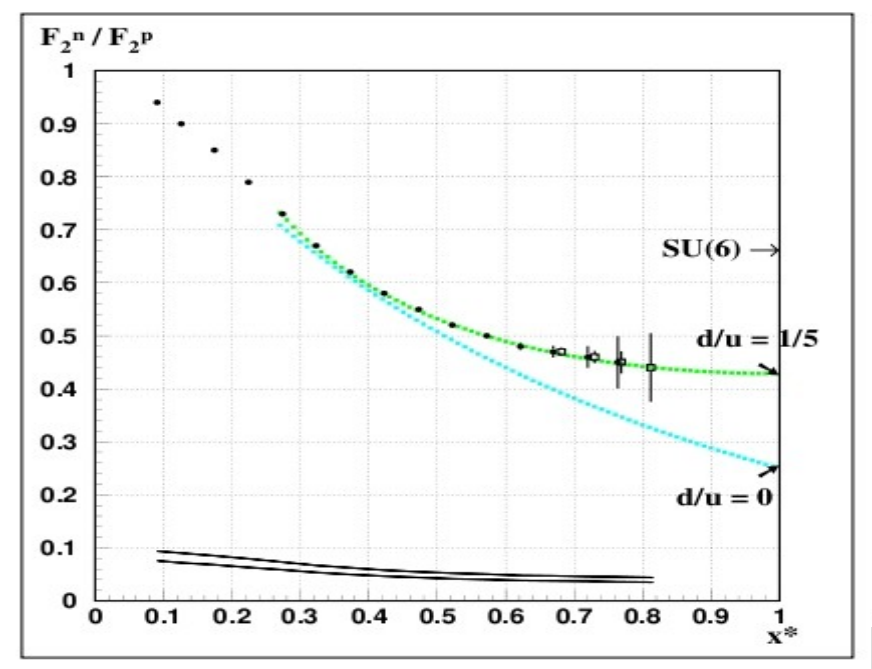
Palli et al, PRC80(09)054610

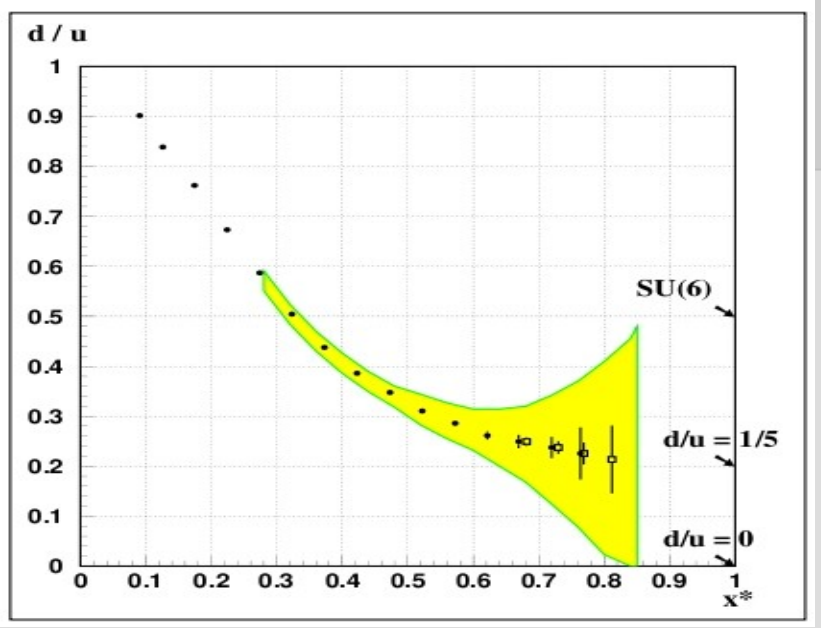


Palli et al, PRC80(09)054610



Expected BONuS12 precision (proposal)

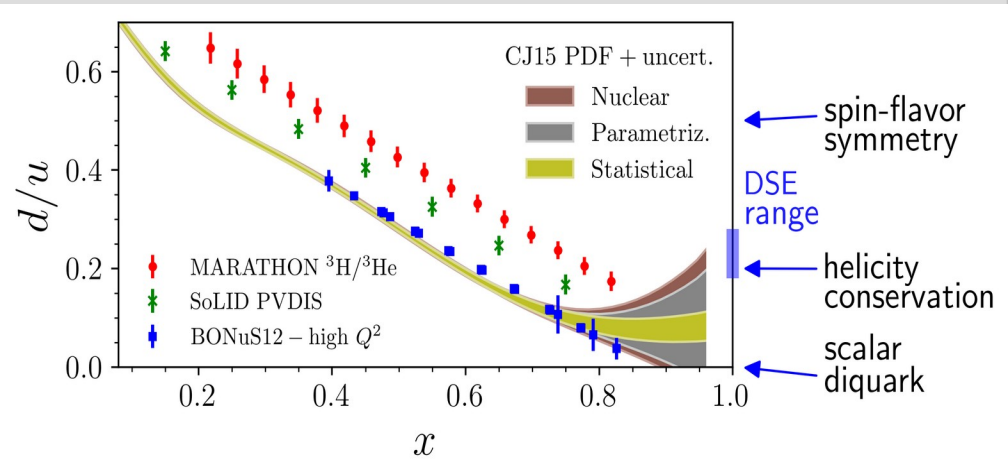




Multiple experiments in JLab 12 GeV era to determine *d/u* at high-*x* with *different* systematics

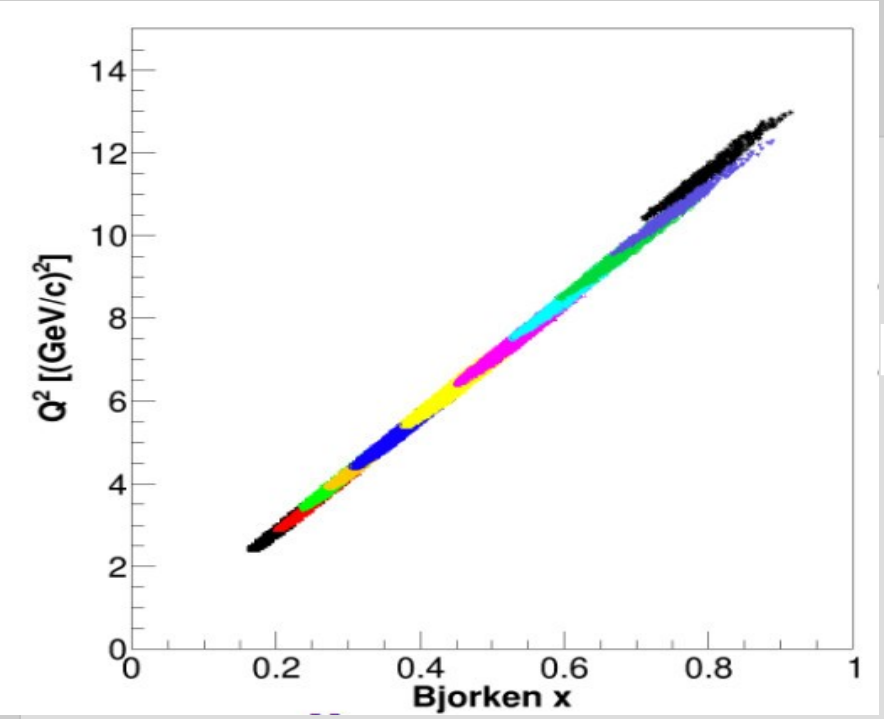
- **MARATHON** - 3H / 3He mirror nuclei
- **SoLID PVDIS**
- **BONuS12** – proton spectator tagging

  * BONuS12 also provides range of Q^2

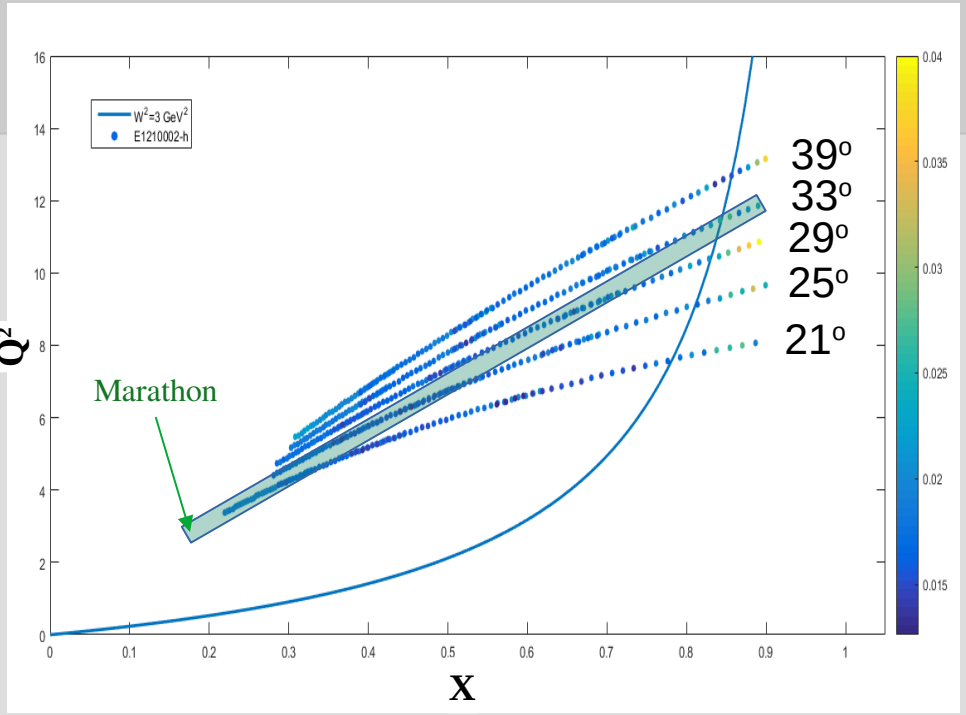


Comparison of Kinematics

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

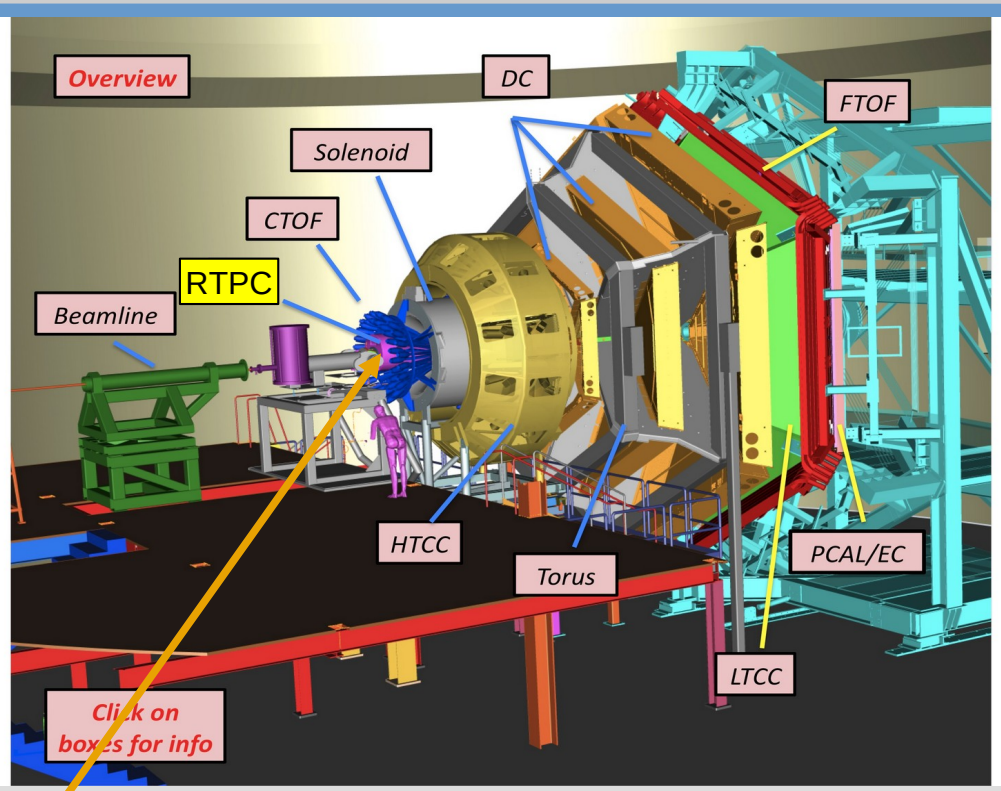
=> Leverage all 3 experiments to study: 1. F_2^n / F_2^p (d/u),
2. nuclear effects in light nuclei,
3. isospin dependent effects

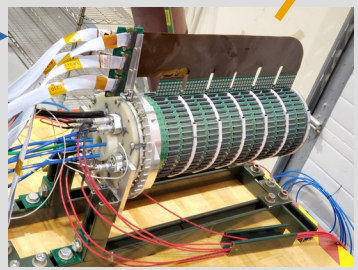
BONuS12 Experimental Setup in CLAS12

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

- **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





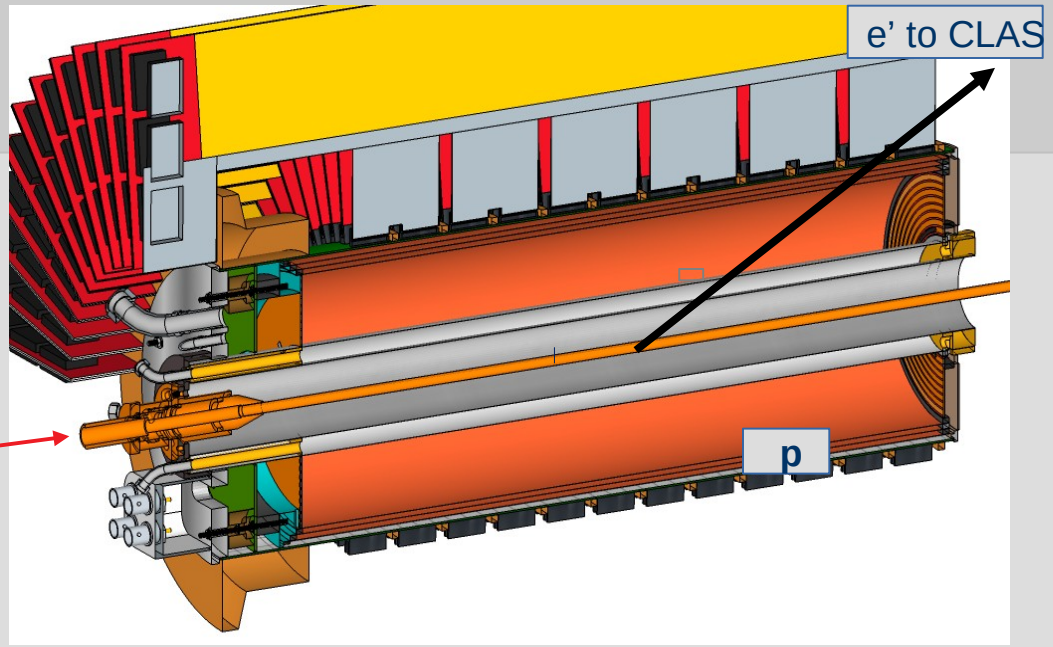
E_{beam} = 10.6 GeV, 2.1 GeV (calibrations)
35 days on D
5 days on $^4He/H_2$
with $L = 2 \cdot 10^{34}$ cm^{-2} sec^{-1}

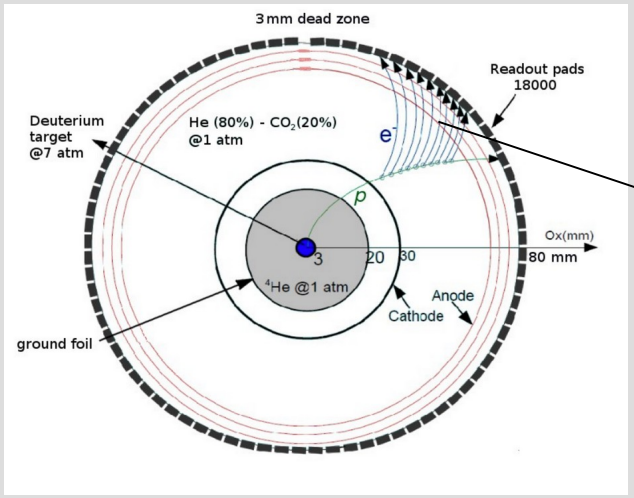
BONuS12 RTPC General Specifications

- → Active length: **40 cm**
- → Radial drift distance: **4 cm**
- → Drift gas **He/CO_2** (**80/20**)
- → **3** GEM amplification layers
- → **16** HV sectors per GEM (Segmented in φ)
- → Pad readout: **2.8 mm x 4 mm**

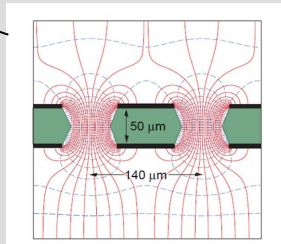
  => 17,280 channels

- → **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

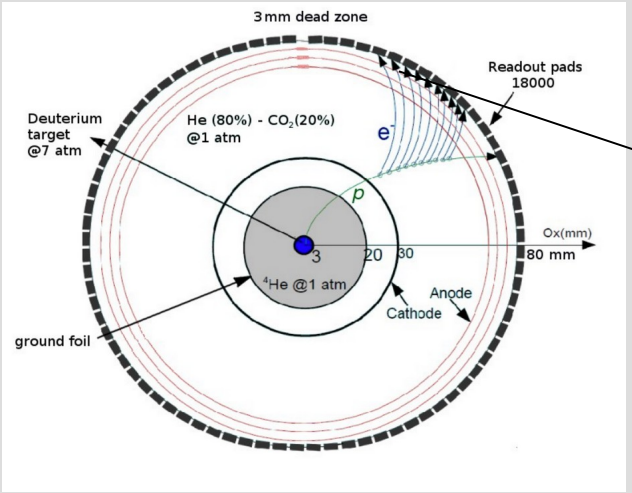
Signal height ⟶ Pads' gains (G_i)

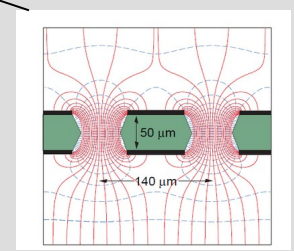
$$\left\langle \frac{dE}{dX} \right\rangle = \frac{\sum_i \frac{ADC_i}{Gi}}{vtl}$$

→ **PID**

- Track reconstruction

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



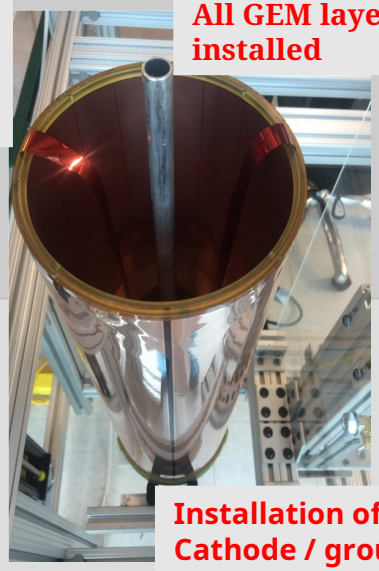


RTPC Assembly @ Hampton U. In Collaboration with ODU & JLab

GEM foil wrapping and gluing

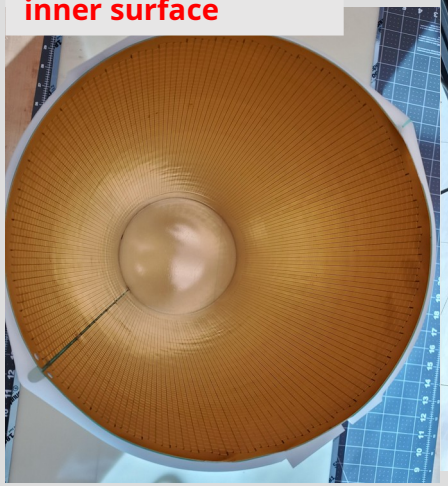
Automated epoxy application

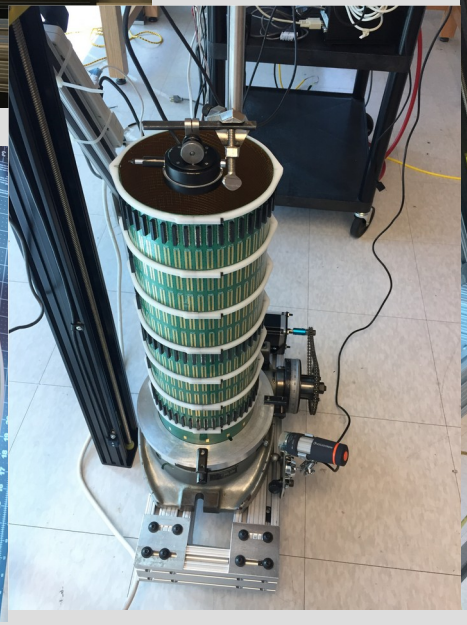
1st GEM layer lowered onto chamfer plate assembly utilizing self-alignment jig

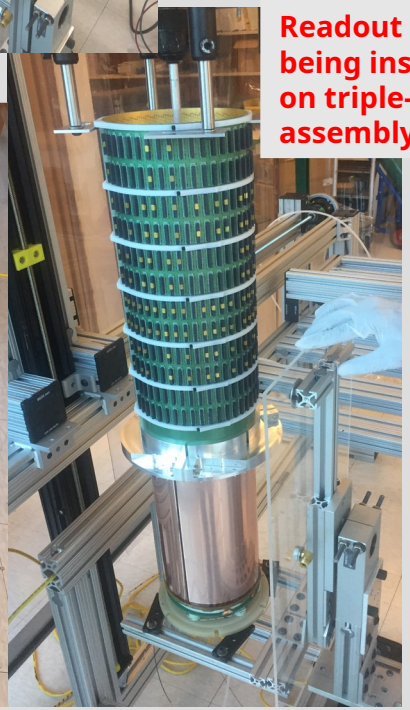


All GEM layers installed

Wrapped Padboard inner surface

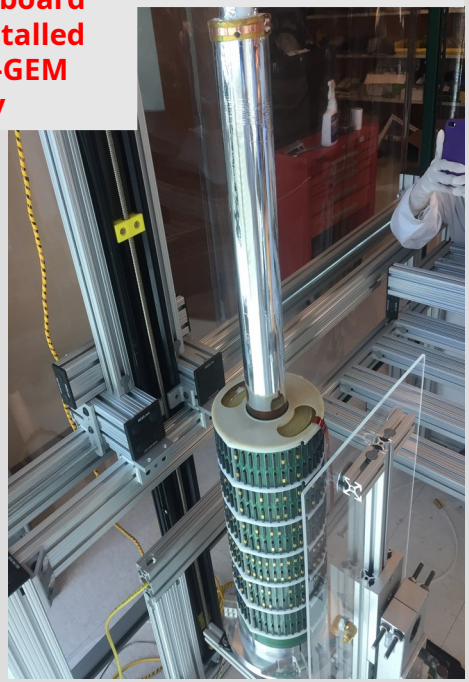






Readout board being installed on triple-GEM assembly

Installation of Cathode / ground assembly



CLAS12 RG-F (BONuS12) Data Summary

Finished data taking ~ 1 month ago

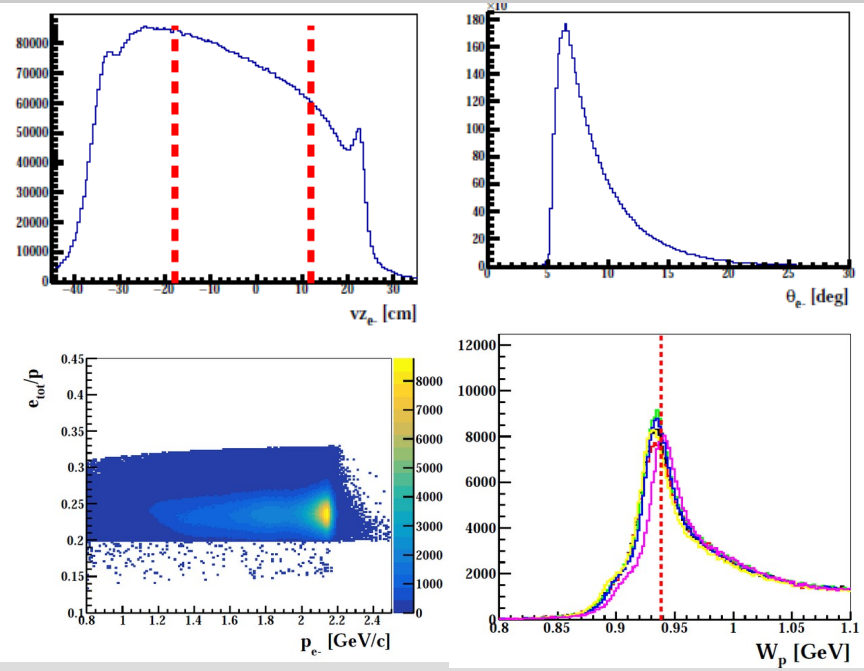
-> Significant statistics taken for final physics results

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

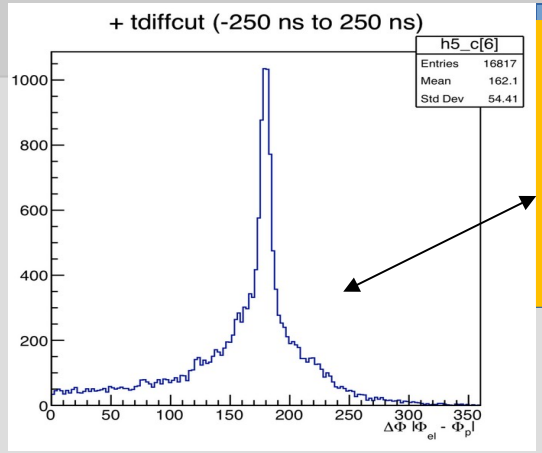
Beam Energy	Target	Spring 2020	Summer 2020
1 Pass Data	H2	81M	185M
	D2	37M	45M
	4He	19M	44M
	Empty	1M	22M
	Total	138M	296M
5 Pass Data	H2	151M	266M
	D2	2275M	2355M
	4He	77M	51M
	Empty	21M	45M
	Total	2524M	2717M

Preliminary Calibration Data Analysis

Electron Selection : 2.14 GeV on H_2 target



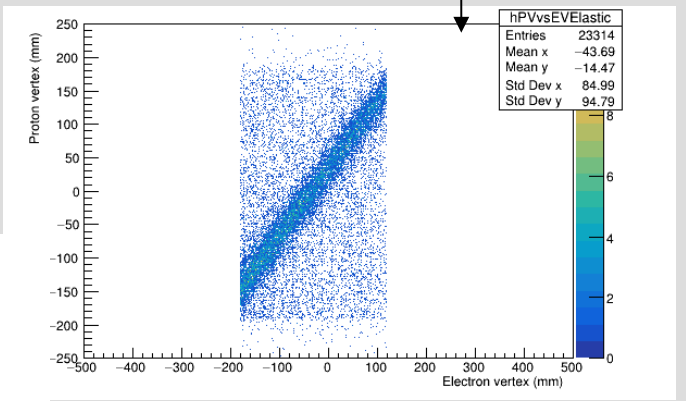
Elastic e- with good proton tracks in RTPC:



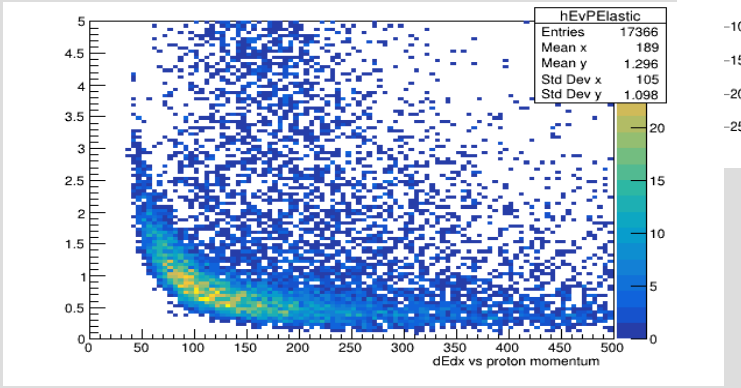
After timing cut
Select RTPC tracks:

1. in-plane with e-

2. common vertex



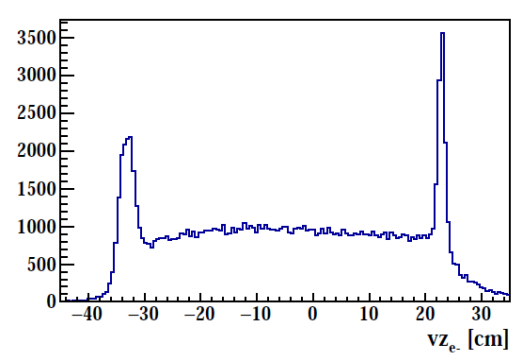
(uncalibrated) dE/dx vs
Reconstructed momentum
For elastic recoil “protons”
In RTPC →

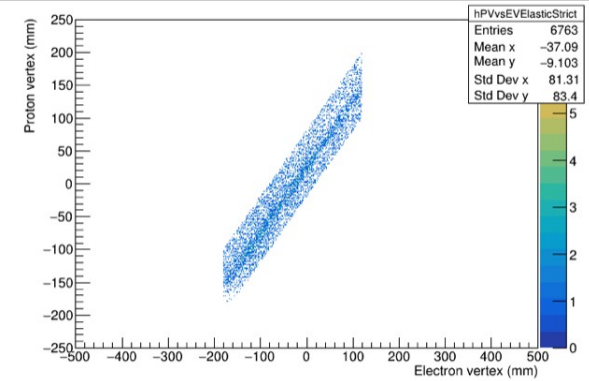


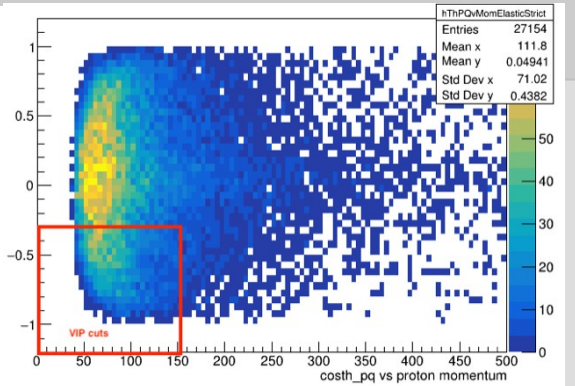
Preliminary Analysis – 5 Pass Data (subset)

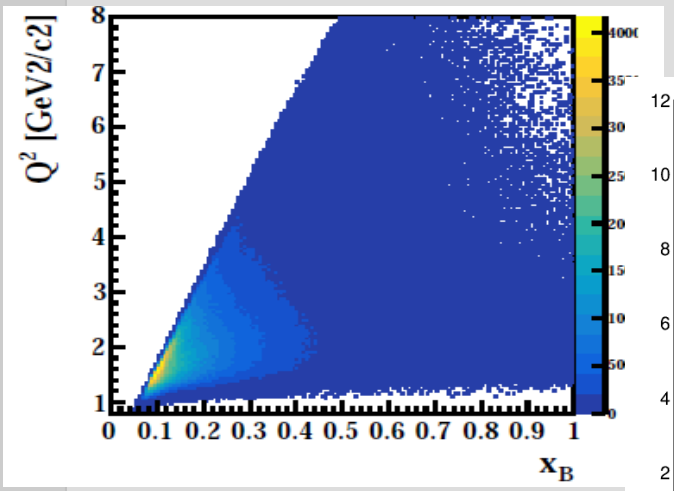
e^- @10.4 GeV beam on D_2 target

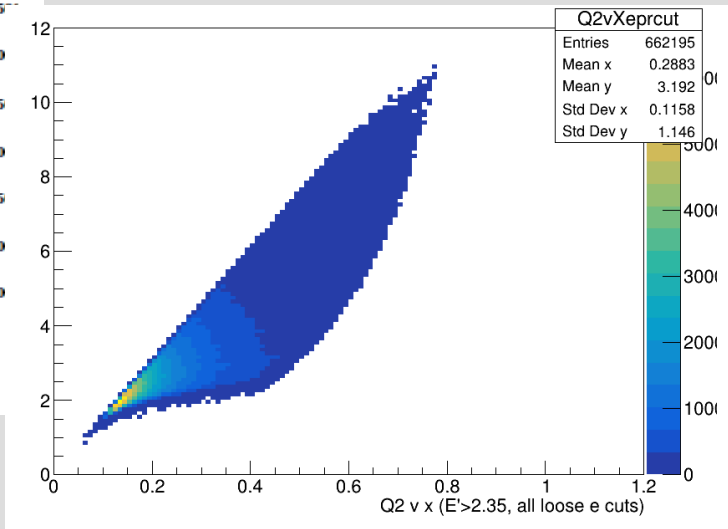
Proton Selection on D_2 target

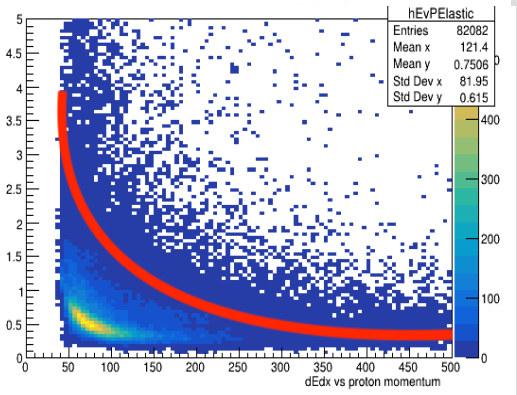












Summary

- 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 Q^2 lever arm.

- 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.