

RG-F Status

Bradley Yale
CLAS Collaboration Meeting
3 June 2021



WILLIAM & MARY

CHARTERED 1693

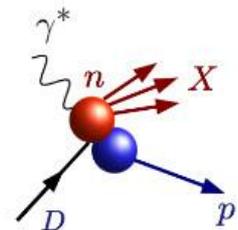
Rungroup F Experiments

1. The Structure of the Free Neutron at Large x-Bjorken

A rating, 40 PAC days

→ Inclusive cross section from neutron in deuteron target

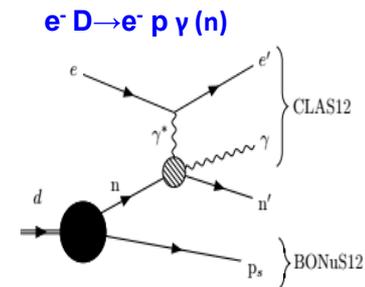
→ Requires tagging of low momentum *spectator* proton in RTPC



2. Neutron DVCS Measurements with BONuS12 in CLAS12

Rungroup addition

→ requires additional photon tagging and beam helicity

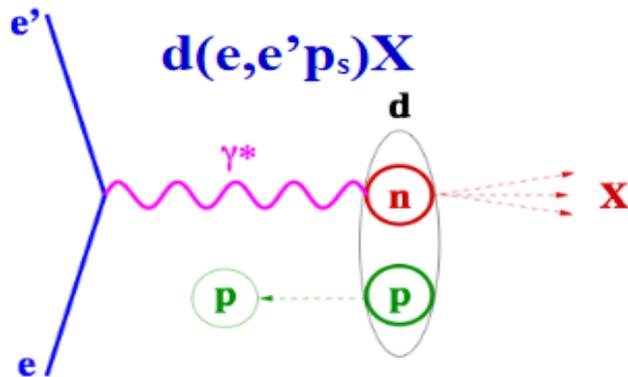


BONuS: “Barely Off-Shell Neutron Structure”

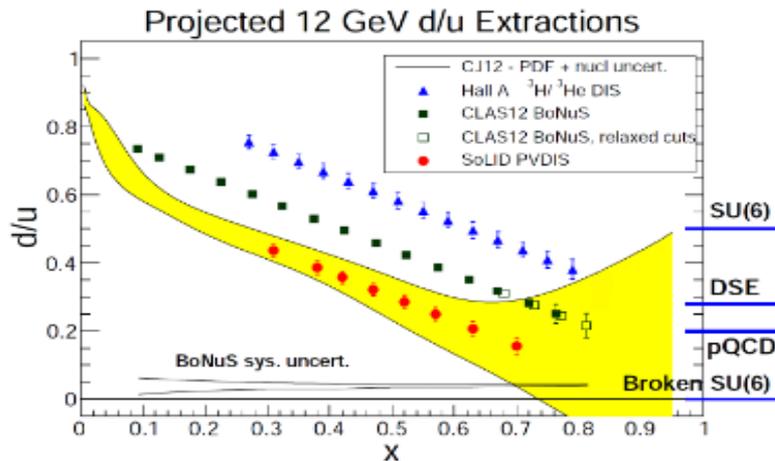
Parton Distribution Functions (PDFs)

- Provide information on the partons **longitudinal momentum** distributions
- Measurable via Deep Inelastic Scattering (DIS).

- **For nucleons**, the unpolarized DIS cross section is parametrized by two PDFs: $F_{1,2}(\mathbf{x})$, with $\mathcal{F}_1(x) = \frac{1}{2} \sum_q e_q^2 f_q(x)$ and $\mathcal{F}_2(x) = x \sum_q e_q^2 f_q(x)$.



$$\frac{F_{2n}}{F_{2p}} \approx \frac{1 + 4d/u}{4 + d/u} \Rightarrow \frac{d}{u} \approx \frac{4F_{2n}/F_{2p} - 1}{4 - F_{2n}/F_{2p}}$$



BONuS: "Barely Off-Shell Neutron Structure"

Observable is tagged ratio

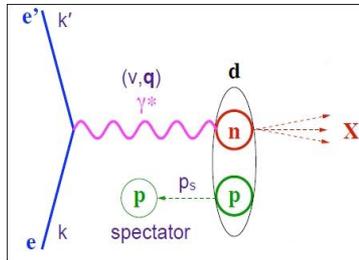
$$R_{\text{exp}} = \frac{N_{\text{tagged}}(\Delta Q^2, \Delta W^*, \Delta^{(\text{VIP})} \vec{p}_s) / \mathcal{A}_e(Q^2, W^*)}{N_{\text{incl}}(\Delta Q^2, \Delta W) / \mathcal{A}_e(Q^2, W)}$$

$$R_{\text{exp}} = \frac{F_2^n(W^*, Q^2)}{F_2^d(W, Q^2)} \int_{\text{VIP}} d\alpha_s dp_s^\perp \mathcal{A}_p S(\alpha_s, p_s^\perp)$$

\mathbf{I}_{VIP}

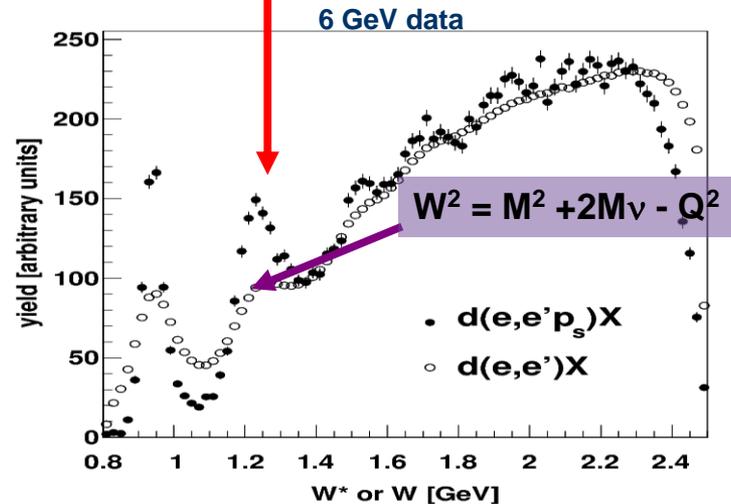
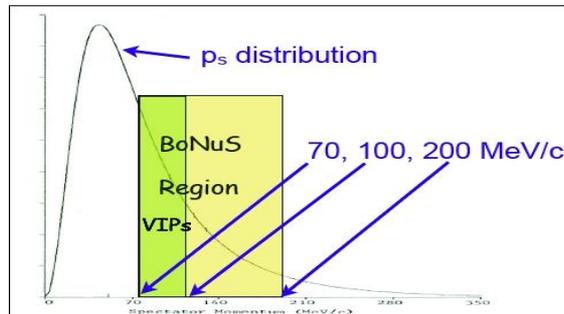
Integral \mathbf{I}_{vip} determined at $x \sim 0.3$

Then $F_2^n / F_2^d = R_{\text{exp}} * \mathbf{I}_{\text{vip}}$



Tag slow, backward, recoil proton

- kinematics minimize nuclear effects
- => scattering from "nearly" free neutron
- use proton momentum to correct for Initial state neutron



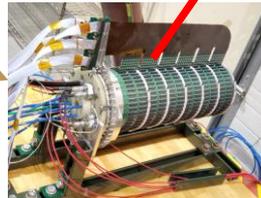
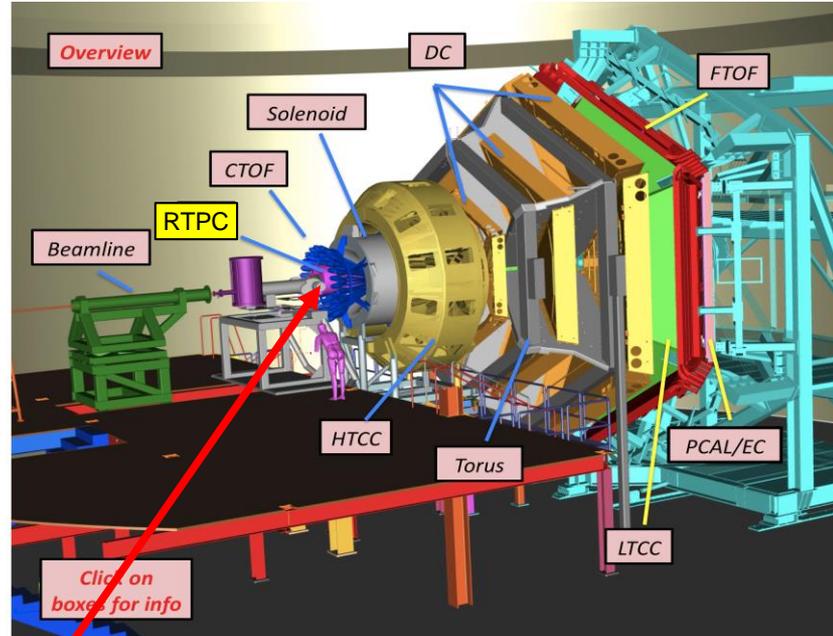
BONuS12 Experimental Setup in CLAS12

- CLAS12 Forward Detector:

- Superconducting **Torus** magnet.
- 6 independent sectors:
 - HTCC
 - 3 regions of DCs
 - LTCC /RICH
 - FTOF Counters
 - PCAL and ECs
 - FT (not used)

- Central:

- Target: D gas @ 5.6 atm, 293 K
- BONuS12 RTPC
- FMT (3 layers)
- Solenoid (3.5 - 4 T)
- CTOF, and CND

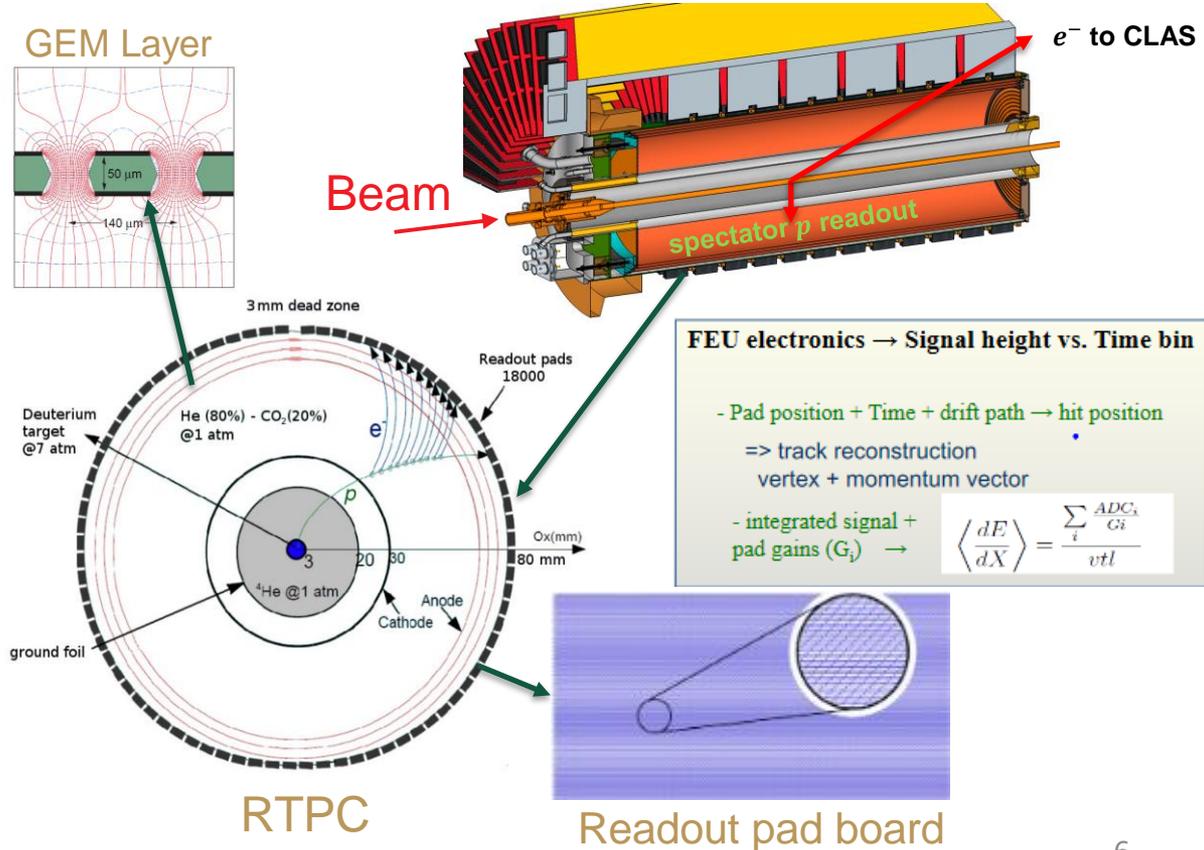


$E_{\text{beam}} = 10.4 \text{ GeV}, 2.1 \text{ GeV (calibrations)}$
35 days on D
5 days on $^4\text{He}/\text{H}_2$
with $L = 2 \cdot 10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$

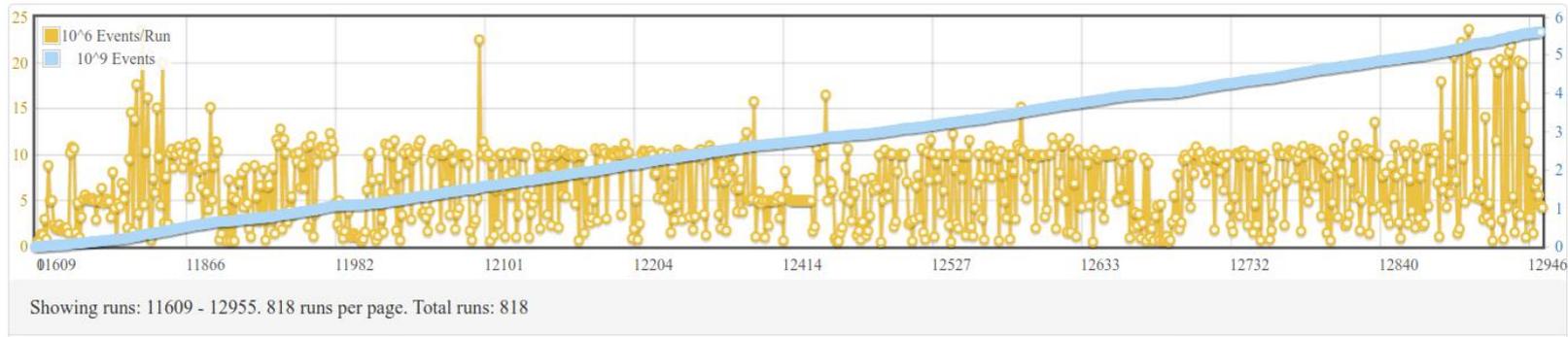
BONuS12 RTPC

- Active length: **40 cm**
- Radial drift distance: **4 cm**
- Drift gas **He/CO₂ (80/20)**
- **3** GEM amplification layers
- **16** HV sectors per GEM
(Segmented in \square)
- Pad readout: **2.8 mm x 4 mm**

=> 17,280 channels



Collected RG-F 2020 Data



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

5.6 billion events collected
in 2020 run period

Data Range (RTPC3 Data):

- Spring run:

12210 – 12282 (In-bending 5 pass)

- Summer run:

12389 – 12434 (Out-bending 1 pass)

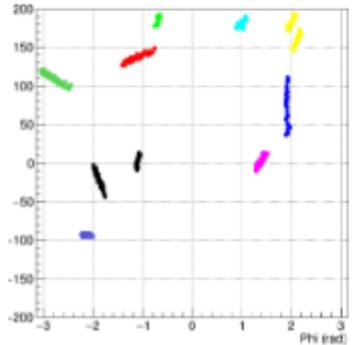
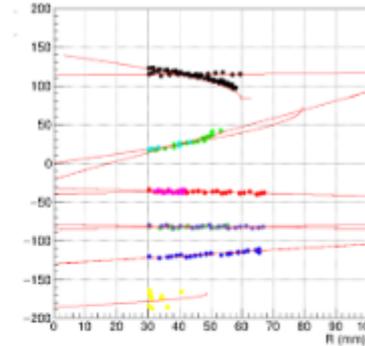
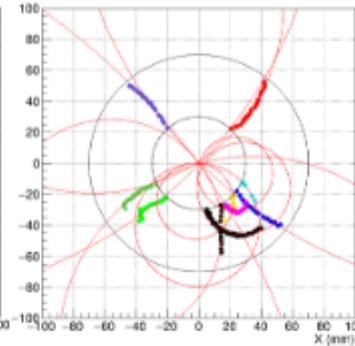
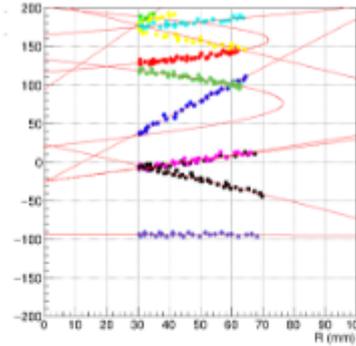
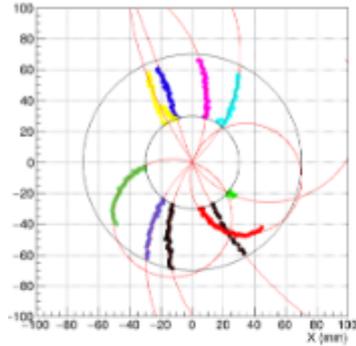
12435 – 12443 (In-bending 1 pass)

12447 – 12951 (In-bending 5 pass)

Reconstructed RTPC Tracks

GEMC simulation

Run 12736 Summer – D_2 target, 10.4 GeV



chi2: 2.1 6.4 5.3 3.5 39.0 3.4 8.7 4.7 2.1 2.5

p: 8.206 0.043 6.199 12.029 6.598 0.112 0.111 8.248 0.101 6.

r: -225.38 -35.83 -89.47 -4034.53 230.96 -96.47 -62.84 -38.15 -89.4

a: 211.17 34.42 48.13 -4972.06 198.86 -77.14 -61.82 -12.09 60.13

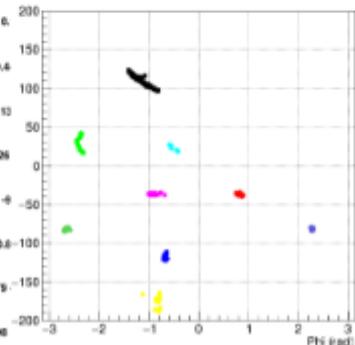
b: 76.06 -10.68 33.55 -1571.48 134.79 39.09 60.29 -38.15 -66.26

z: -24.40 116.65 85.02 -25.78 207.53 -24.74 164.71 133.78 -6

theta: 61.74 63.55 19.82 25.30 134.36 68.60 79.90 115.43 90.8

phi: -69.52 -107.23 -55.65 188.97 125.63 83.13 41.78 160.79

tdiff [mus]: 0.302 3.404 -0.002 -4.700 -4.729 1.748 1.870 2.098



chi2: 3.838066 6.505168 10.347458 5.203782 33.642746 16.828837 1.12

p: 0.079480 0.136969 3.481874 3.336383 0.028007 0.026660 0.051264 0

r: 71.212837 -121.572653 268.872479 -298.881744 24.413219 -23.80431

a: -65.329165 -67.528819 -287.378290 297.141647 -2.253790 23.335875

b: -42.926594 162.215956 199.187953 205.197067 -34.480377 -6.70562X

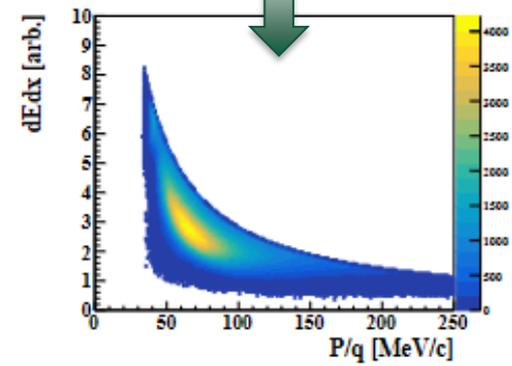
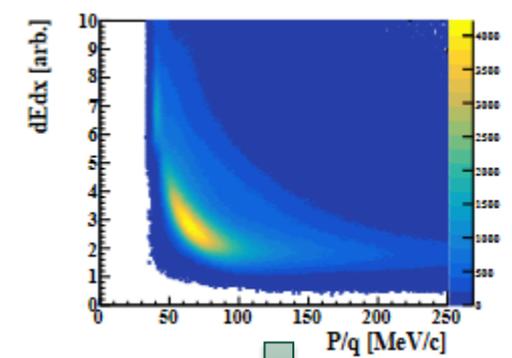
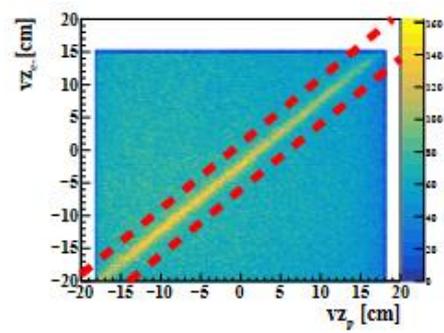
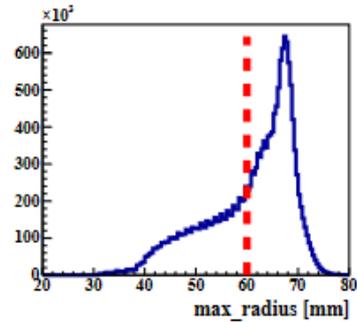
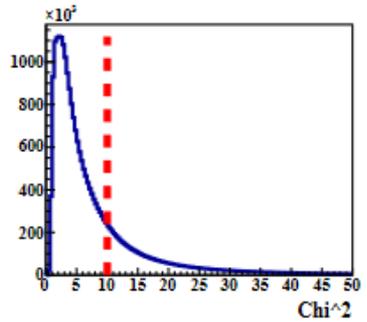
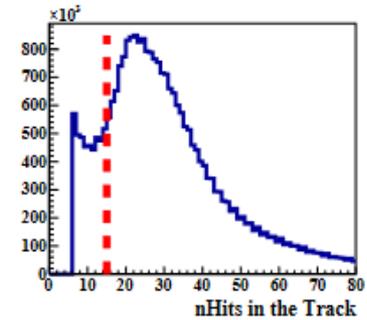
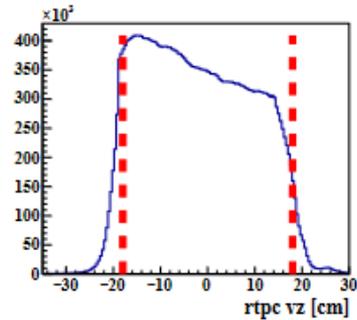
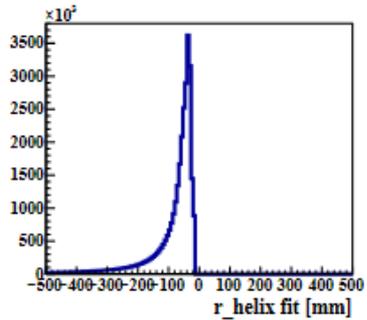
z: 113.726126 -32.487979 -29.053885 -120.752884 -196.865062 -36.5811

theta: 68.712044 95.368926 41.917557 75.747955 76.935088 86.201035

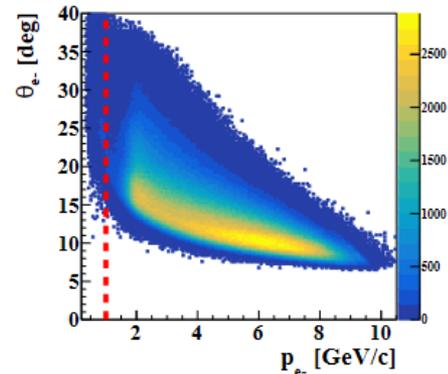
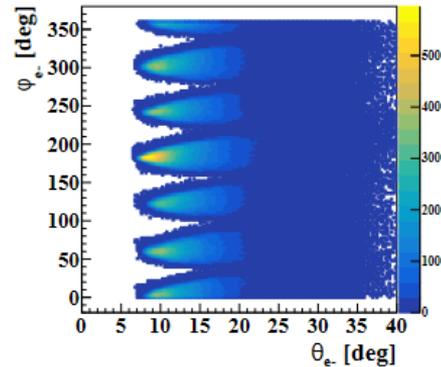
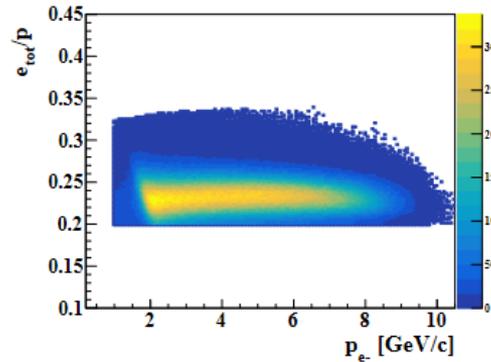
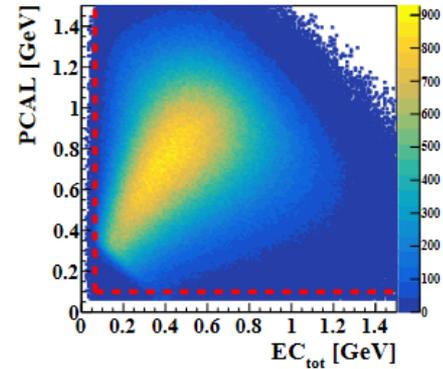
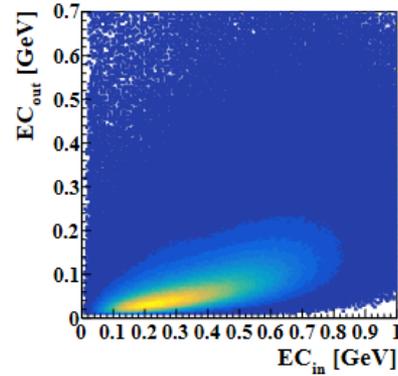
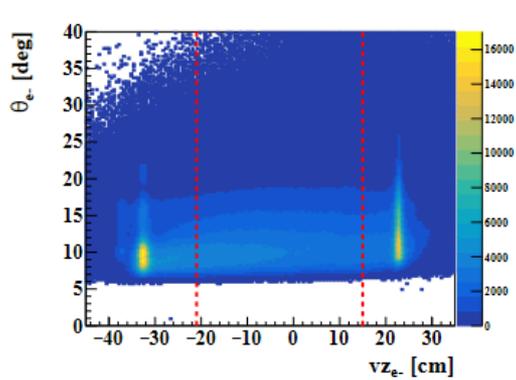
phi: -62.890166 33.448602 -133.849306 -45.279206 -6.267869 -106.0326

tdiff [mus]: -2.336739 1.566608 -2.340900 1.826038 3.845366 3.969636

Proton selection cuts



Electron cuts



Subsystem calibration constraints

Subsystem	Timeline	Constraint (RG-B)	Constraint (RG-F)
RF	rftime electron FD mean	$< \pm 10$ ps	$< \pm 10$ ps
	rftime electron FD sigma	< 70 ps	< 70 ps
LTCC	ltcc elec nphe sec	12-14	5-20
HTCC	htcc nphe sec	11-13	10-13
FTOF	ftof edep p1a midangles	9.25-10.5 MeV	9.25-10.5 MeV
	ftof edep p1b midangles	11.25-12.25 MeV	11.25-12.25 MeV
	ftof edep p2	9.2-10.2 MeV	9.2-10.2 MeV
	ftof time p1a mean	$< \pm 25$ ps	$< \pm 25$ ps
	ftof time p1a sigma	< 125 ps	< 125 ps
	ftof time p1b mean	$< \pm 15$ ps	$< \pm 15$ ps
	ftof time p1b sigma	< 70 ps	< 70 ps
	ftof time p2 mean	$< \pm 50$ ps	$< \pm 50$ ps
	ftof time p2 sigma	< 325 ps	< 325 ps
	ECAL	ec Sampling	0.24-0.26
ec gg m mean		131-134 MeV	128 -142 MeV
ec gg m sigma		< 15 MeV	< 15 MeV
DC	dc residuals sec mean	$< \pm 0.005$ cm	$< [-0.03, 0.01]$ cm
	dc residuals sec sl sigma	R1,R3 < 300 um, R2 < 400 um	< 450 um
RICH	rich time fwhm max	< 1 ns	< 1 ns

Subsystem calibrations
are mostly finished

Pass1 review (passed*)

- The RG-F Pass1 review was held on 14 April 2021
 - Cleared for “pass1v0”, but more calibrations are needed (FMT, CTOF/CND, RTPC)
 - Also suggested to fully implement RTPC + target details into GEMC simulations
- Pass1v0 cooking was launched on 24 May 2021
 - Took 9 days to complete (within the ~1.5 weeks estimate)
- Review committee:
 - Nathan Baltzell
 - Marco Mirazita
 - Cole Smith
 - Stepan Stepanyan (chair)
 - Larry Weinstein

RG-F Pass1v0 cooking (finished)

Beam energies: 2.144GeV, 10.389GeV Torus: $\pm 50\%$, -100% , Solenoid: -74.5% , -80%

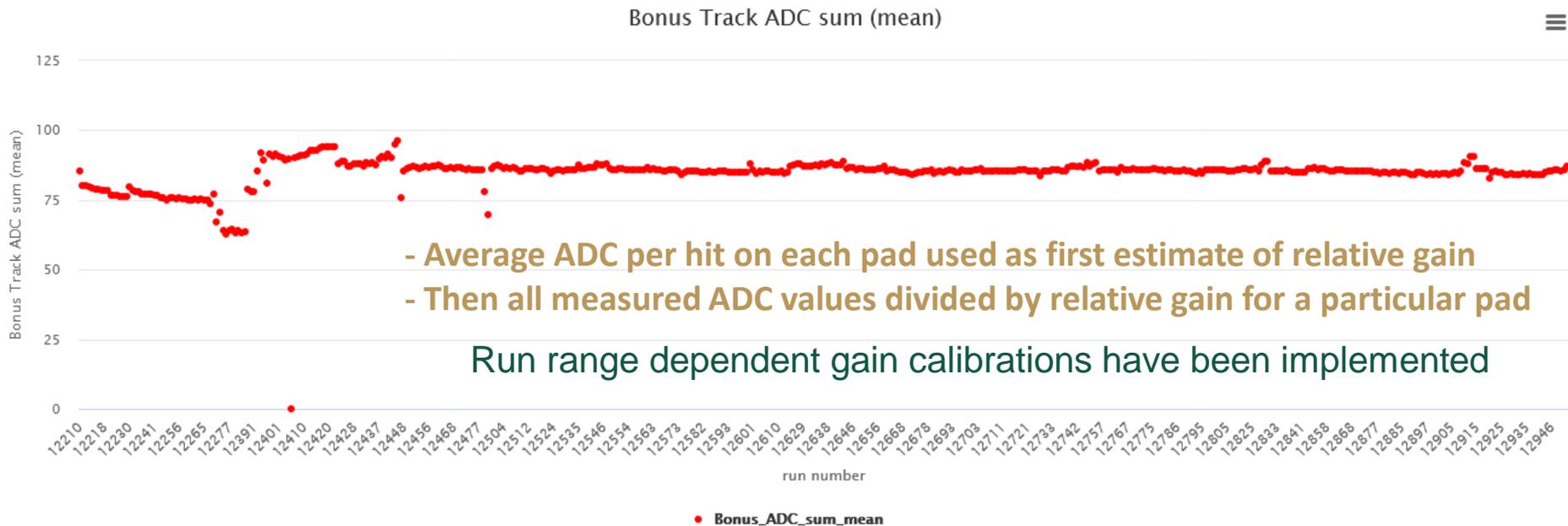
Data set	RG-F Spring	RG-F Summer	Total
Run range	12210 - 12282	12389 - 12951	12210 – 12951
Number of selected runs	54	428	482
Total event count	0.4 billion	3.0 billion	3.4 billion
Total pass1 recon dst size	2 TB	23 TB	25 TB

Reconstructed files: `/cache/clas12/rg-f/production/recon/`

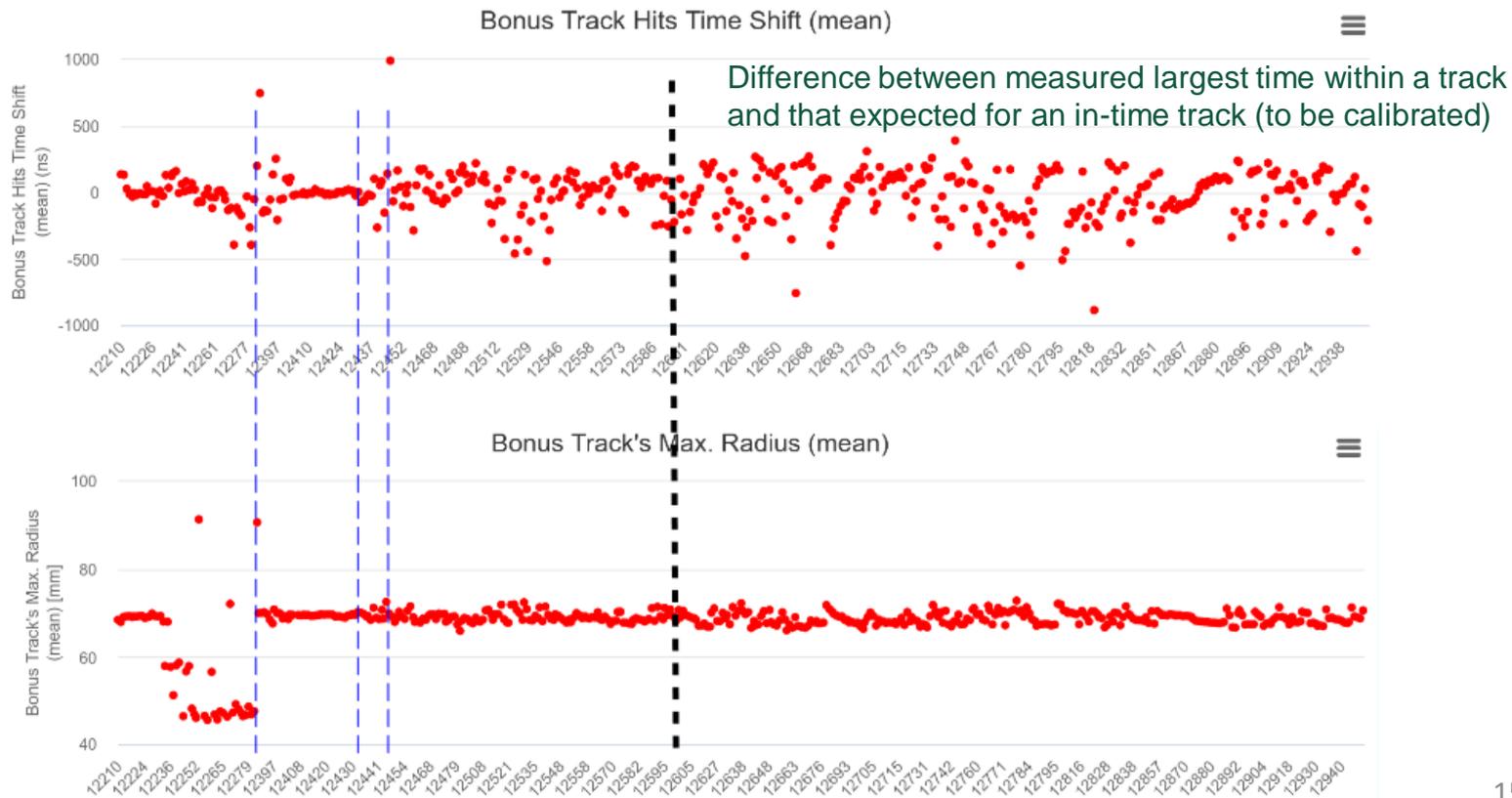
Pass1v0 RTPC ADC gains

BONuS12 requires measurement of inclusive electron cross section + tagged proton

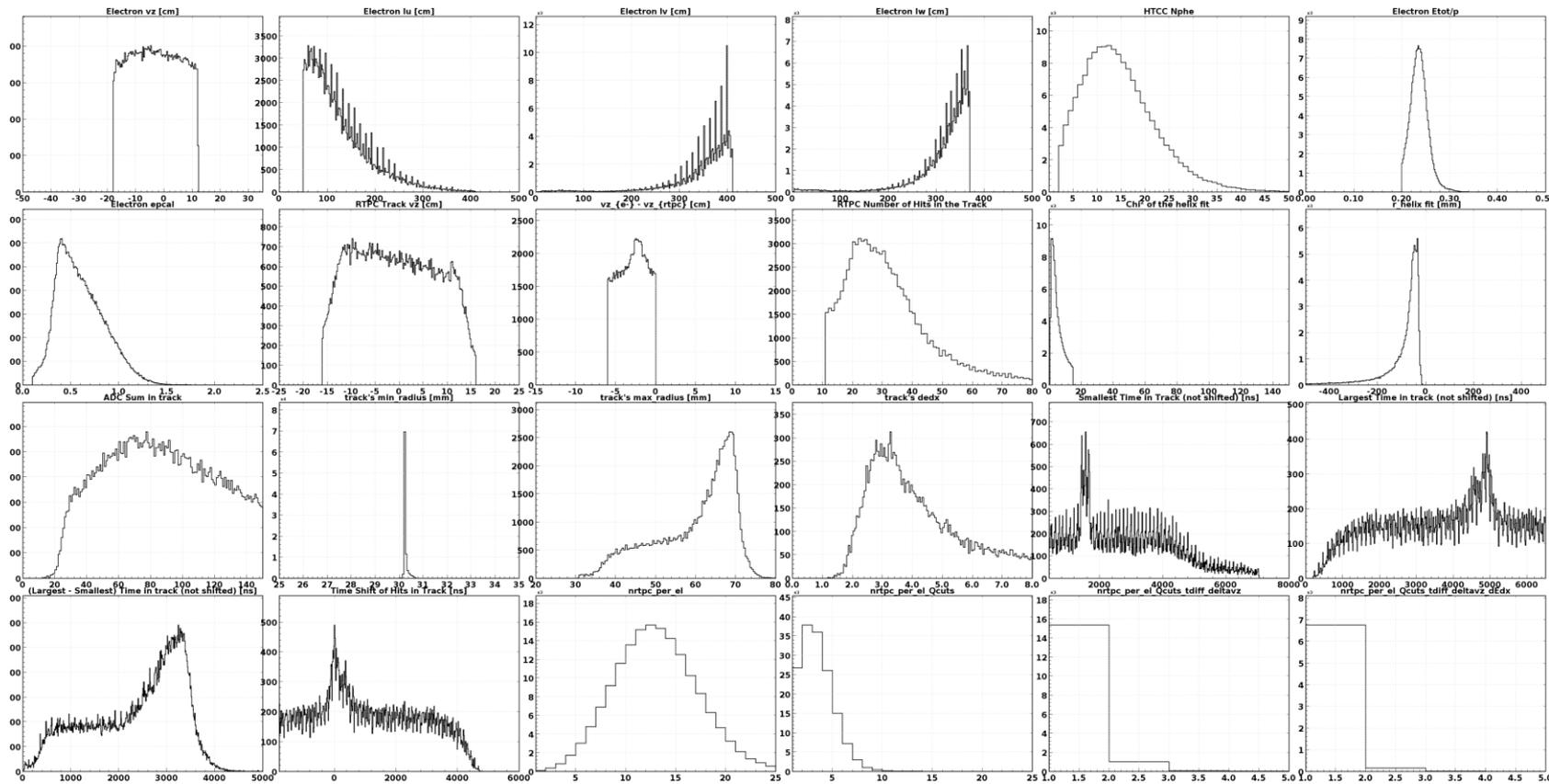
In addition to CLAS12, need to calibrate RTPC: Gain for ADC \rightarrow dE/dx for PID of proton



RTPC Timing quality timelines

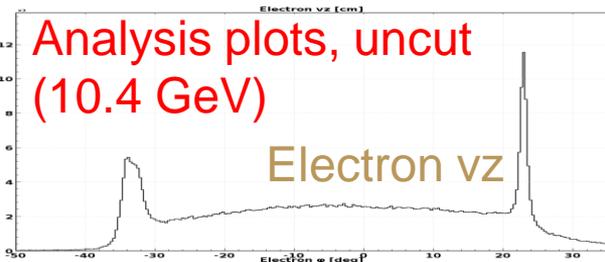


Pass1v0 Monitoring Histograms

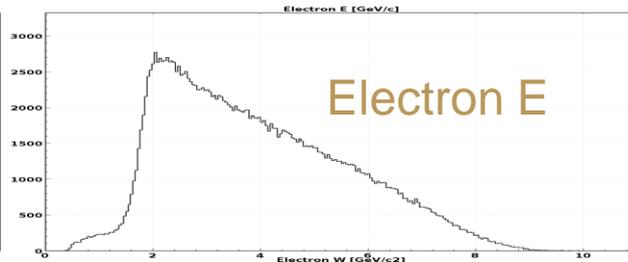


Analysis plots, uncut
(10.4 GeV)

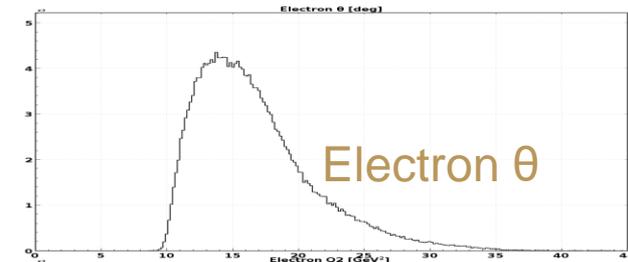
Electron v_z



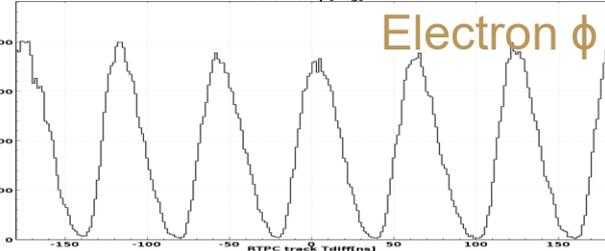
Electron E



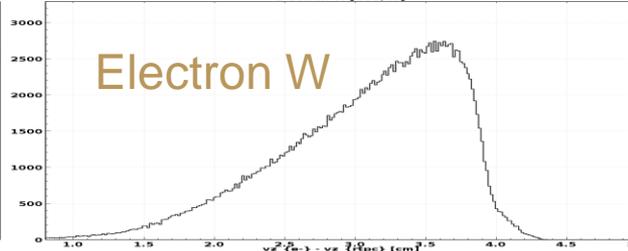
Electron θ



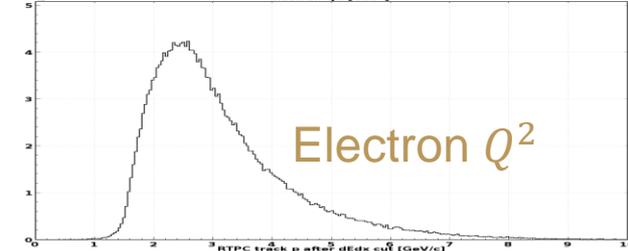
Electron ϕ



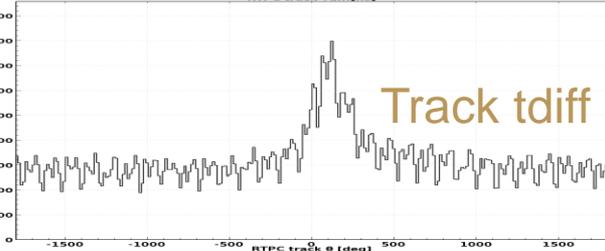
Electron W



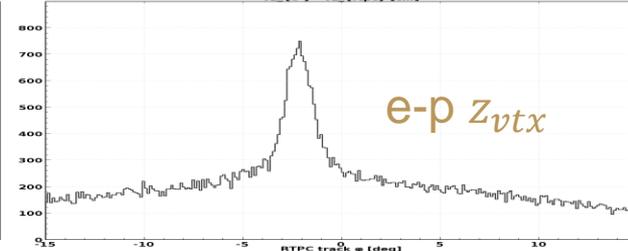
Electron Q^2



Track tdiff



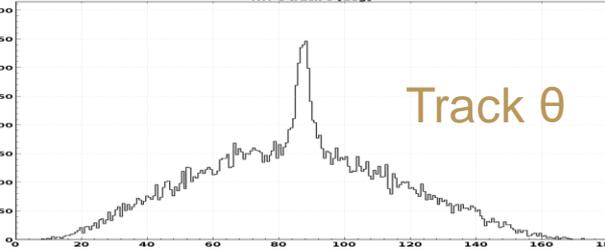
e-p Z_{vtx}



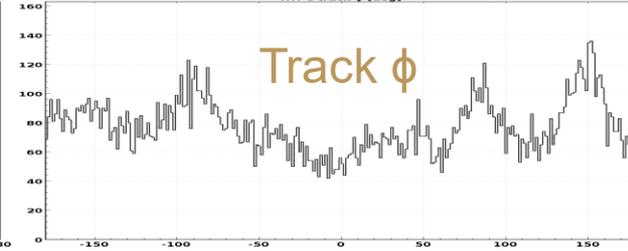
Spectator proton p



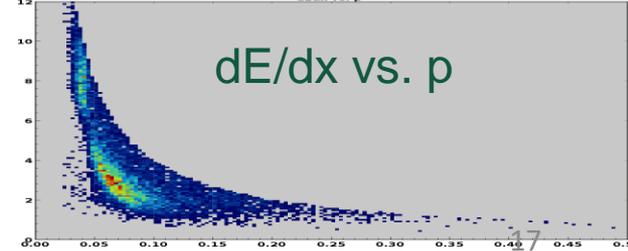
Track θ



Track ϕ



dE/dx vs. p



Next Analysis Tasks

- Select golden runs/files
- Finalize dE/dx cuts (run dependence?)
- Proton momentum correction, VIP cuts
- Use H_2 and He runs to determine backgrounds
- Subtract accidentals using Δz_{vtx}
- Correct for acceptance from GEMC (+ add target information)
- **Extract F_{2n}/F_{2p}**

Summary and Timeline

- **RG-F has finished pass1v0 for its 2020 data sets**

Future timeline:

- **Summer 2021:** After refining cuts, high-level DSTs will be developed for spectator proton + backgrounds
- **Fall 2021:** Demonstrate full analysis chain up to F_{2n}/F_{2p} , finalize fine-tuning of all calibrations
- **Early 2022:** Repeat Pass1 cooking with final calibrations if necessary
- **Spring 2022:** First results ready to be presented, analysis review
- **Later 2022:** Figure out how to include RTPC1 runs (which had gain instabilities), refine reconstruction and background rejection -> Pass2

“BONuS” slides

RTPC Track Reconstruction

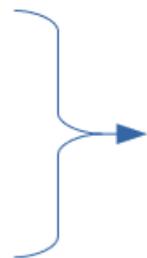
1. **Track Finding:** Hits chaining into contiguous collections, i.e. tracks
2. **Time shifting:** Each chain of hits for a track is shifted in time, such that the first ionization starts at the cathode.
3. **Reconstructing the hit position:**

(Pad # \rightarrow Pad (x,y,z), Time) \rightarrow The original location of the ionization can be determined as:

$$r(t, z) = \sqrt{r_{max}^2 (1 - x) + r_{min}^2 x}$$

$$x = \frac{t - a_t}{b_t}$$

$$\Delta\phi(r, t, z) = a_\phi + b_\phi \ln \frac{r_{max}}{r}$$



Hit (r, ϕ , z)

* at the ionization point in the drift region

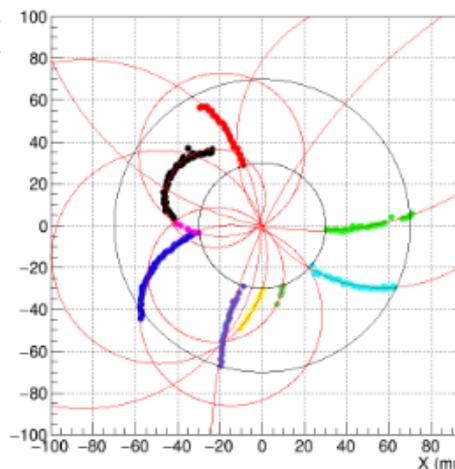
* a, b, parameters are z-dependent parameters initially calculated by a simulation of the magnetic field in Garfield++ and re-tuned using real data (next slide).

a_t = "Smallest Time" = time offset

b_t = the max. drift time (Largest time - Smallest Time)

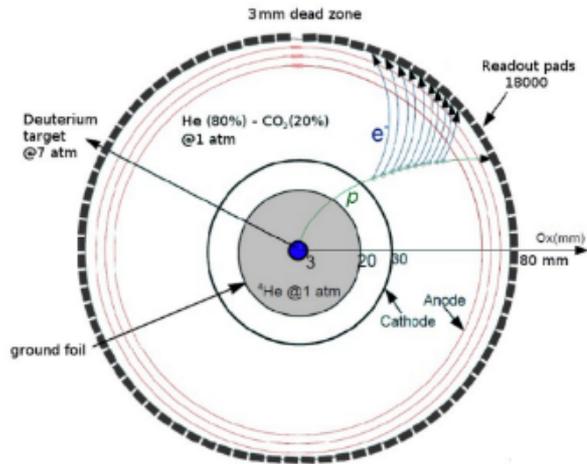
a_φ (comes entirely from the GARFIELD++, the drift between GEM1 and Padboard)

b_φ = tan($\theta_{Lorentz}$)

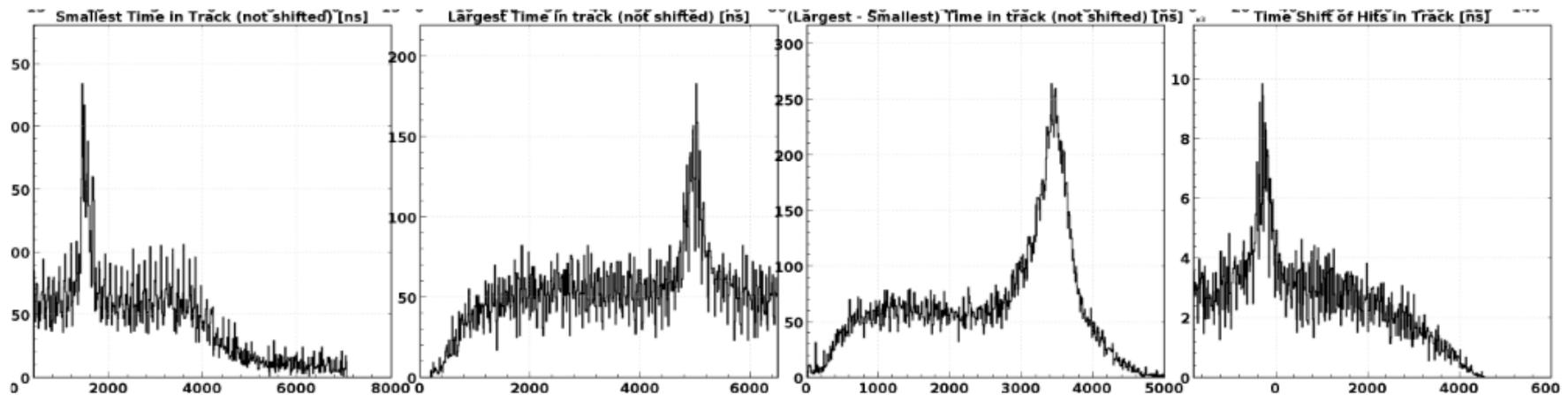


4. **Helix Fitting** \rightarrow Track's p/q, vz, ...

BONuS - Timing



- **Smallest time** → Timing offsets between the trigger and the RTPC.
- **Largest time** → Sum of offset + maximum drift time
- **Largest - Smallest time** → maximum drift time from cathode to GEM1
- **Time shift** → Difference between measured largest time within a track and that expected for an in-time track



Lorentz Angle Calibration

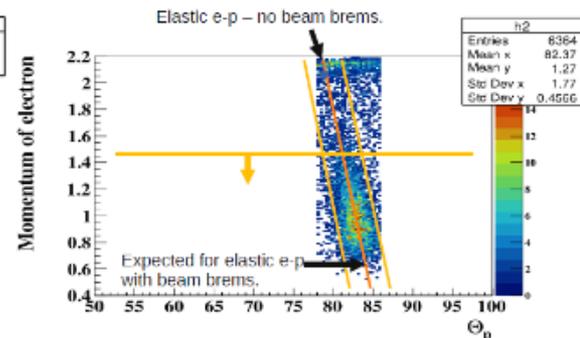
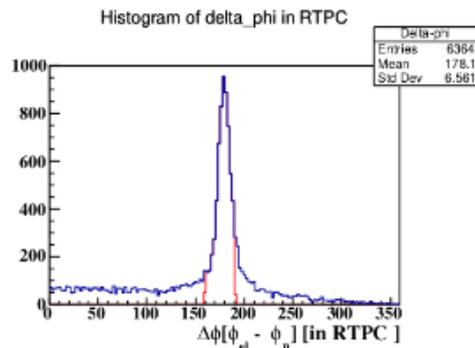
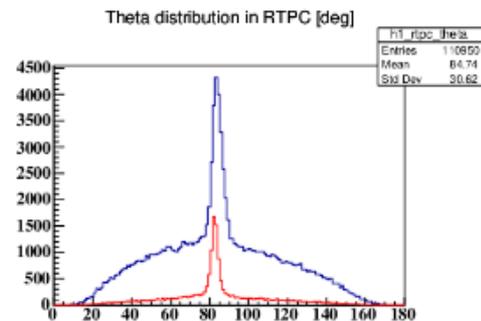
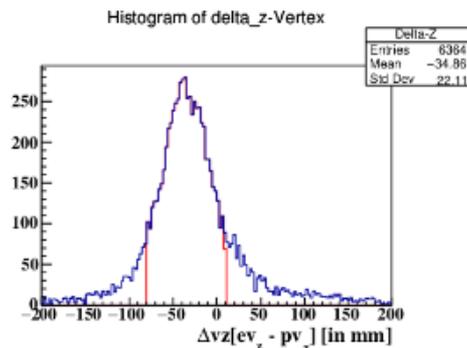
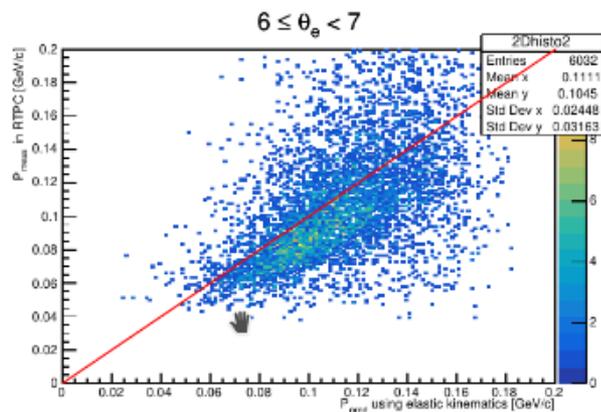
→ Use radiative e-p elastic scattering (beam bremsstrahlung) at 1-Pass to calibrate the RTPC ($\theta_e \in [5^\circ, 8^\circ]$).

→ Then calculate the energy of the gamma simply ASSUMING that the event was elastic.

→ Simple, first estimation for energy loss applied, but will be refined in the future.

→ Modify the Lorentz angle until we get the best agreement between the measured and the predicted momentum for protons in $H(e,e^p)\gamma$.

2.14 GeV on H₂ target



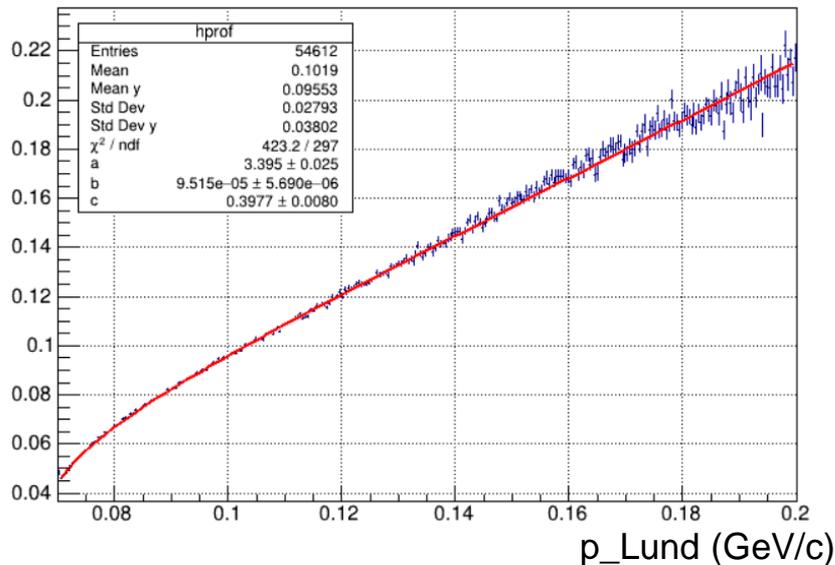
Momentum correction

(Credit: Yu-Chun hung)

Fit with $p_{\text{recon}} = 1.0 / (1.0/\text{xxx} - c)$

where $\text{xxx} = (p_{\text{lund}}^a - b/\sin(\theta_p))^{1/a}$, $\theta_p = 85.33$

p_{rec}



```
FCN=423.173 FROM MIGRAD STATUS=CONVERGED 387 CALLS 388 TOTAL
EDM=3.87879e-07 STRATEGY= 1 ERROR MATRIX ACCURATE
EXT PARAMETER
NO. NAME VALUE ERROR STEP FIRST
1 a 3.39468e+00 2.46472e-02 7.04116e-06 5.77675e-01
2 b 9.51456e-05 5.68967e-06 1.58832e-09 2.45442e+03
3 c 3.97738e-01 8.02373e-03 4.10848e-05 -7.79082e-02
```

```
FCN=423.173 FROM MIGRAD STATUS=CONVERGED 387 CALLS
388 TOTAL
```

```
EDM=3.87879e-07 STRATEGY= 1 ERROR MATRIX
```

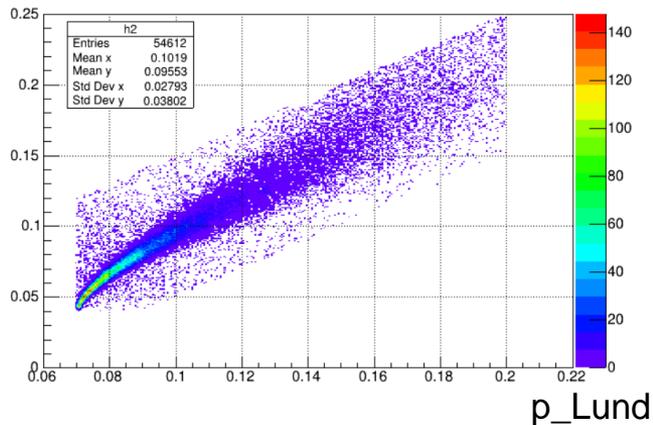
```
ACCURATE
```

EXT PARAMETER	STEP	FIRST
NO. NAME VALUE ERROR SIZE DERIVATIVE		
1 a 3.39468e+00 2.46472e-02 7.04116e-06 5.77675e-01		
2 b 9.51456e-05 5.68967e-06 1.58832e-09 2.45442e+03		
3 c 3.97738e-01 8.02373e-03 4.10848e-05 -7.79082e-02		

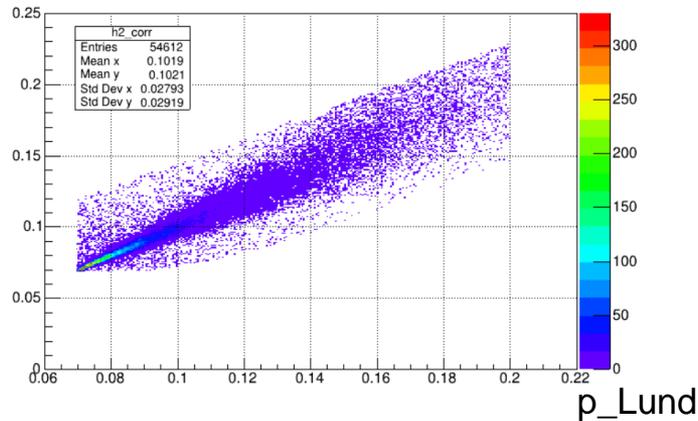
Plot for $p_corr = ((1/(1/p_uncorr + c))^a + b/\sin(\theta_{rec}))^{1/a}$
 with $a = 3.39468$, $b = 0.000095146$, $c = 0.397738$ (profile fit)

(Credit: Yu-Chun hung)

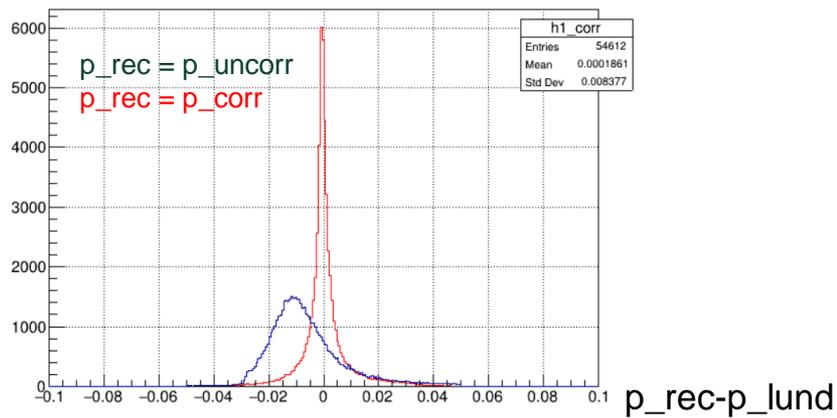
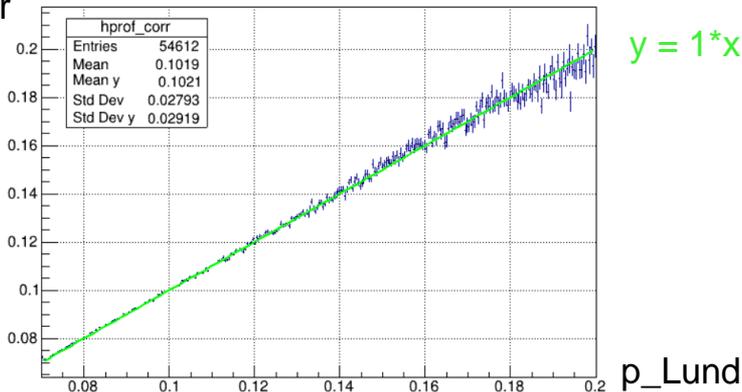
p_uncorr



p_corr



p_corr



Pass1v0 track momentum (10.4 GeV)

