Measurement of the Neutron Magnetic Form Factor G_M^n at High Q^2 Using the Ratio Method on the Deuteron

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Why we need to measure G_M^n on a Neutron

I. G_M^n : Fundamental quantity related to neutron magnetization.

II. The form factors provide important constraints for GPDs:

$$\int_{-1}^{1} dx H^q(x,\xi,Q^2) = F_1^q(Q^2) \;\; and \qquad \int_{-1}^{1} dx E^q(x,\xi,Q^2) = F_2^q(Q^2)$$

Where G_E and G_M Related to F_1 and F_2 *as* : $G_E(Q^2) = F_1(Q^2) - \tau\, F_2(Q^2) \;\; and \quad G_M(Q^2) = F_1(Q^2) + F_2(Q^2)$

How Do We Measure G_M^n on a Neutron? Ratio Method

The ratio of the free nucleon e-n to e-p cross sections in terms of the free nucleon form factors:

$$R = \frac{\frac{d\sigma}{d\Omega}(D(e,e'n))}{\frac{d\sigma}{d\Omega}(D(e,e'p))} \;=\; a(Q^2)\, \underbrace{\frac{\sigma^n_{mott}\left(G_E^{n\,2} + \frac{\tau_n}{\varepsilon_n} G_M^{n\,2}\right)\left(\frac{1}{1+\tau_n}\right)}{\sigma^p_{mott}\left(G_E^{p\,2} + \frac{\tau_p}{\varepsilon_p} G_M^{p\,2}\right)\left(\frac{1}{1+\tau_p}\right)}}_{\text{the denominator is the precisely-known proton cross section.}}$$

corrects for nuclear effects

Where:

$$\sigma_{Mott} = \frac{\alpha^2 E' \cos^2(\frac{\theta_e}{2})}{4E^3 \sin^4(\frac{\theta_e}{2})} \;,\quad \tau = \frac{Q^2}{4\, M_{p,n}^2} \;,\quad Q^2 = 4EE'\sin^2\left(\frac{\theta_e}{2}\right) \;, \epsilon = \left[1 + 2(1+\tau)\tan^2(\frac{\theta_e}{2})\right]^{-1}$$

$$\boxed{G_M^n = \sqrt{\left[R_{corrected}\left(\frac{\sigma^p_{mott}}{\sigma^n_{mott}}\right)\left(\frac{1+\tau_n}{1+\tau_p}\right)\left(G_E^{p\,2} + \frac{\tau_p}{\varepsilon_p} G_M^{p\,2}\right) - G_E^{n\,2}\right]\frac{\epsilon_n}{\tau_n}}}$$

Extracting G_M^n requires knowledge of other EEFFs

RGB Data Set

Dataset used:

The RGB experiment ran on three different periods:

RGB Spring 2019 inbending:
1- E_{beam} = 10.5986 GeV: 117 production runs
2- E_{beam} = 10.1998 GeV: 106 production runs

RGB Fall 2019 outbending:
1- E_{beam} = 10.4096 GeV: 97 production runs

RGB Spring 2020 inbending:
1- E_{beam} = 10.4096 GeV: 171 production runs

Quarter of the data were taken with a 10.6 GeV beam, another quarter at 10.2 GeV and the other half at 10.4 GeV

Monte-Carlo simulation

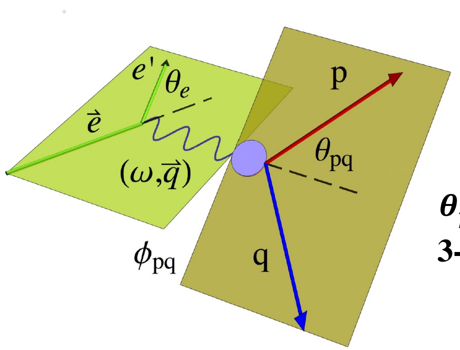
The generator used is QUEEG 'QUasi-Elastic EventGenerator'

Written by:
J.Lachniet and developed more by G.P. Gilfoyle
The Fermi-motion distribution :
is calculated with the Hulthen distribution
The generator produces either:
ed→e′n′(p) or ed→e′p′(n) events.
Generating MC events with new gemc version 4.4.1/4.4.2
Then reconstructed events with :
the same COATJAVA version 6.5.8 as the data.

Generated && Simulated ~ 30 M events at 3 different beam energy

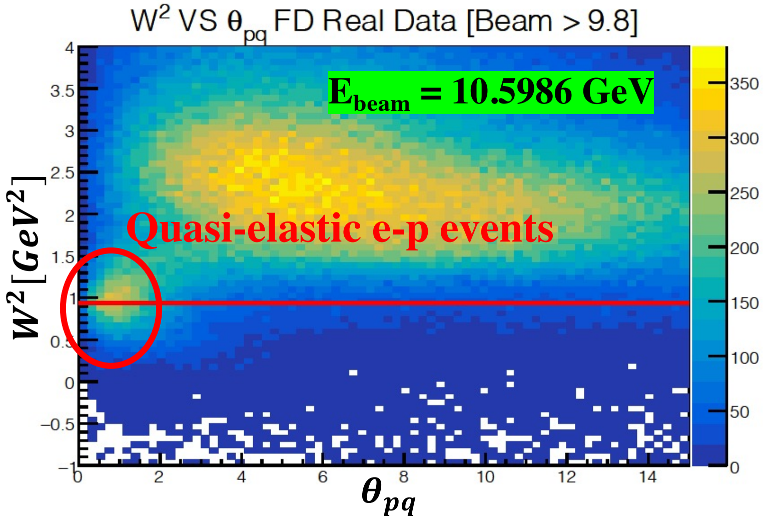
D(e, e′p) Selection

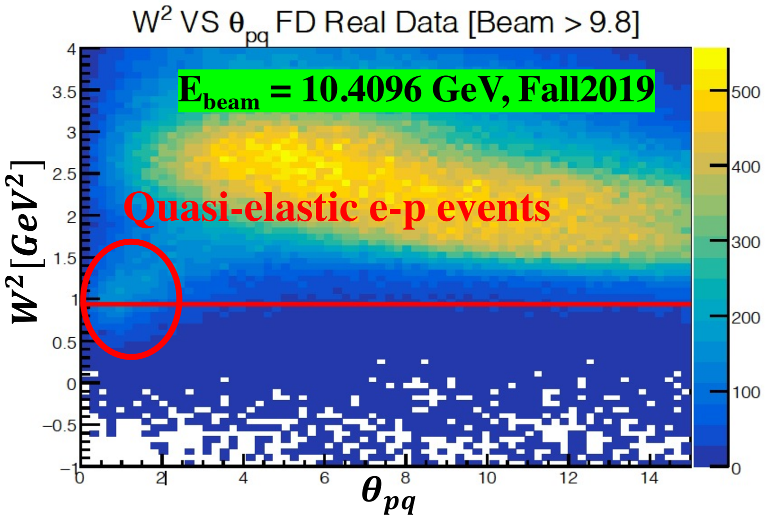
$$R = \frac{\frac{d\sigma}{d\Omega}(D(e,e'n))}{\boxed{\frac{d\sigma}{d\Omega}(D(e,e'p))}}$$

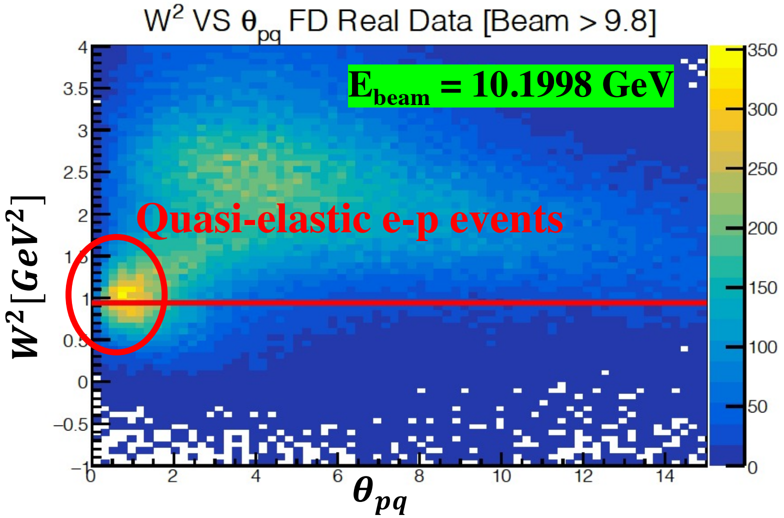


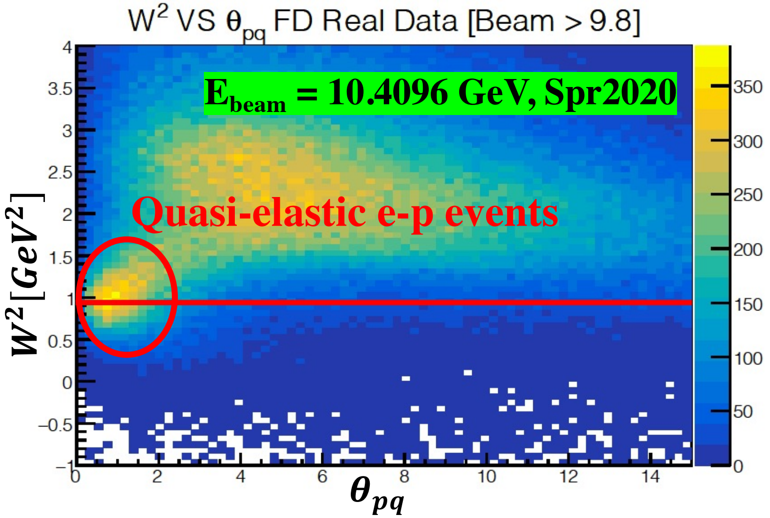
θ_{pq}: The angle between the transferred 3-momentum $\vec{q}$ and the momentum $\vec{P}_N$ of the detected nucleon.

- Select two tracks, one electron in FD and one proton in FD
- Apply cut on $W^2 < 4.0$ && E_{beam} Calculated >9.8 GeV

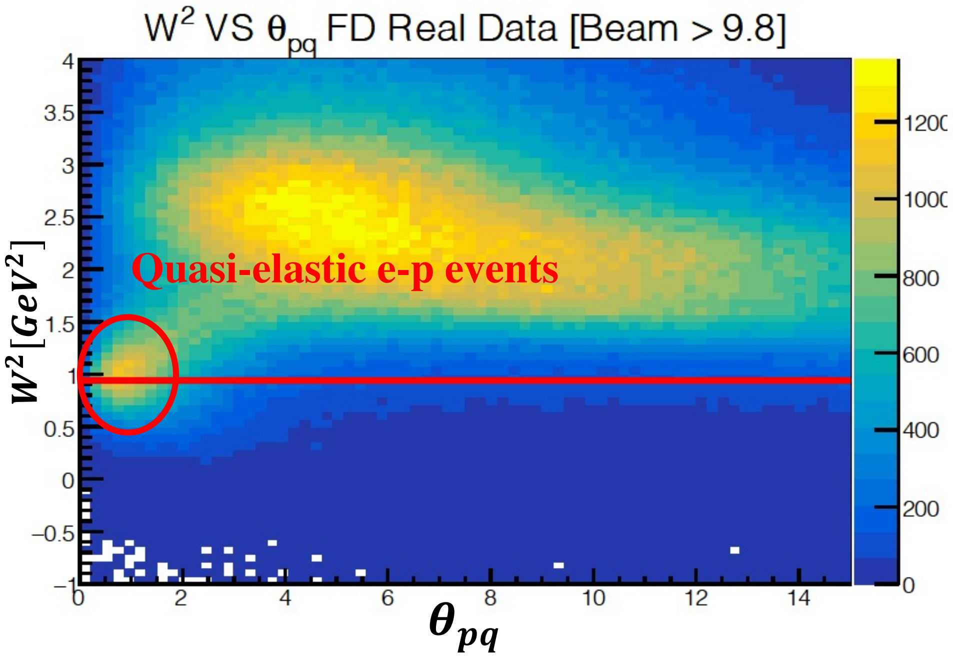








All RGB Data Set

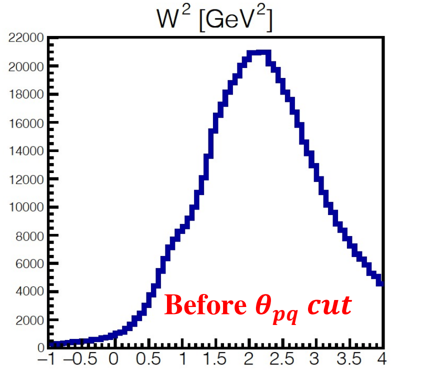


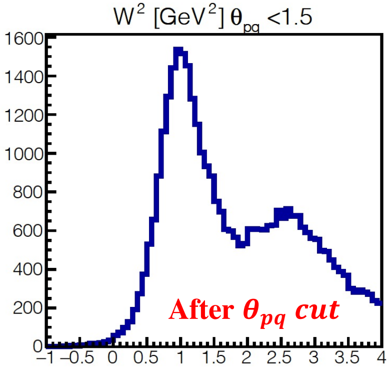
$\mathrm{D(e, e'p)}$ Selection

$$R = \frac{\frac{d\sigma}{d\Omega}(D(e,e'n))}{\boxed{\frac{d\sigma}{d\Omega}(D(e,e'p))}}$$

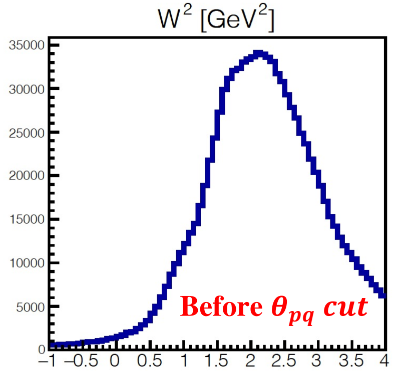
- **Select two tracks, one electron in FD and one proton in FD**
- **Apply cut on $W^2 < 4.0$ && E_{beam} Calculated >9.8 GeV**
- **Apply cut on θ_{pq} <1.5 to reduce inelastic contamination**

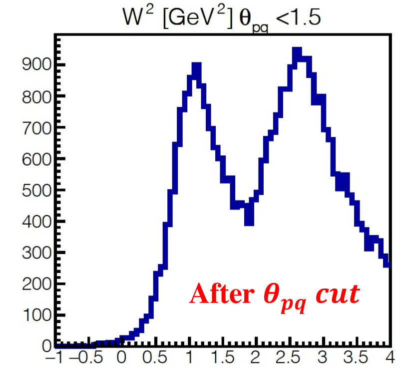
E_{beam} = 10.5986 GeV



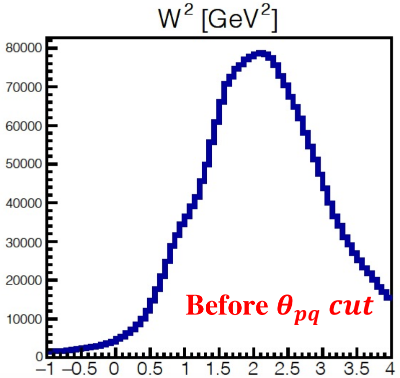


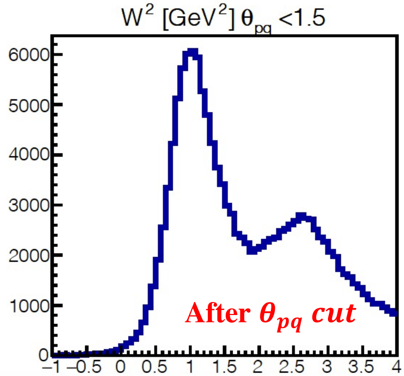
E_{beam} = 10.4096 GeV, Fall2019



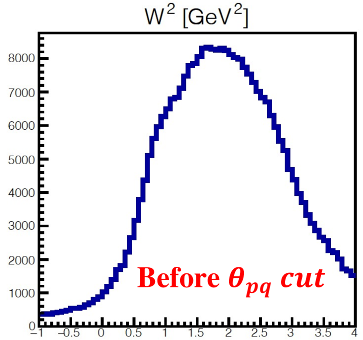


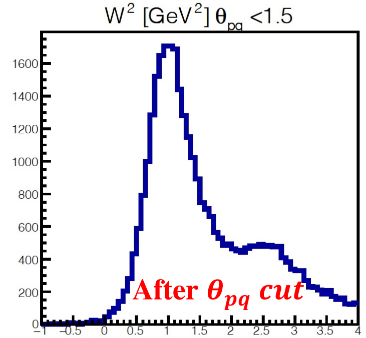
All RGB Data Set



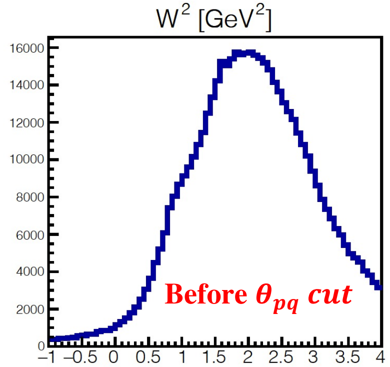


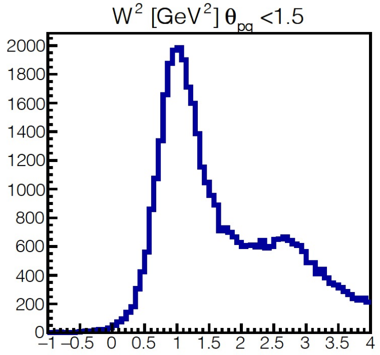
E_{beam} = 10.1998 GeV



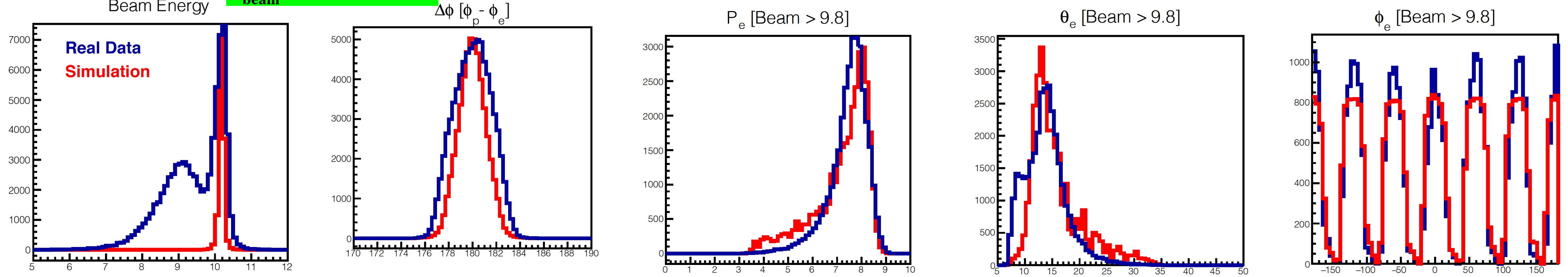


E_{beam} = 10.4096 GeV, Spr2020

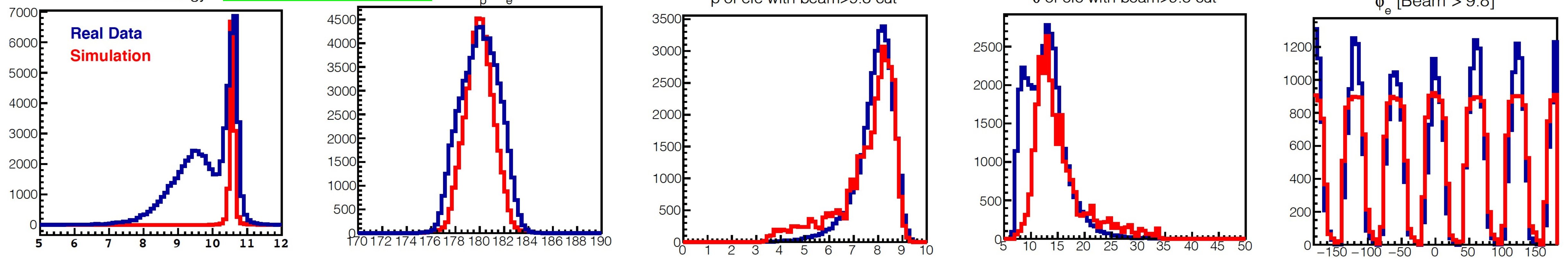




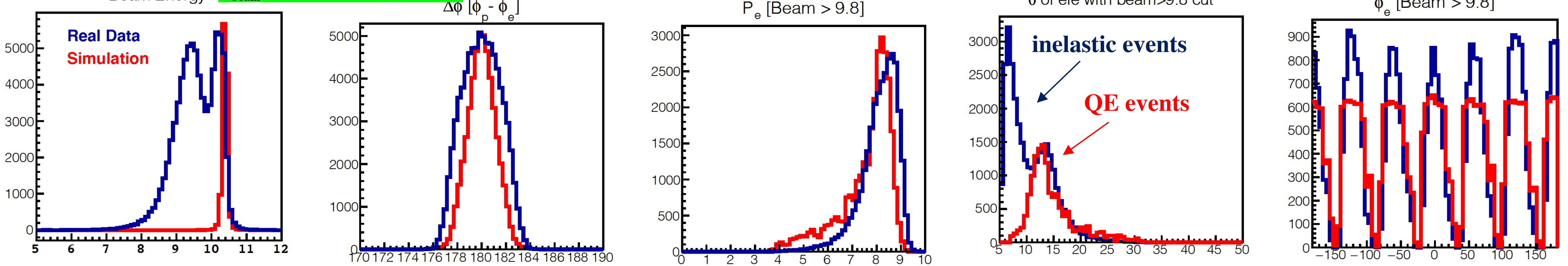
E_{beam} = 10.1998 GeV

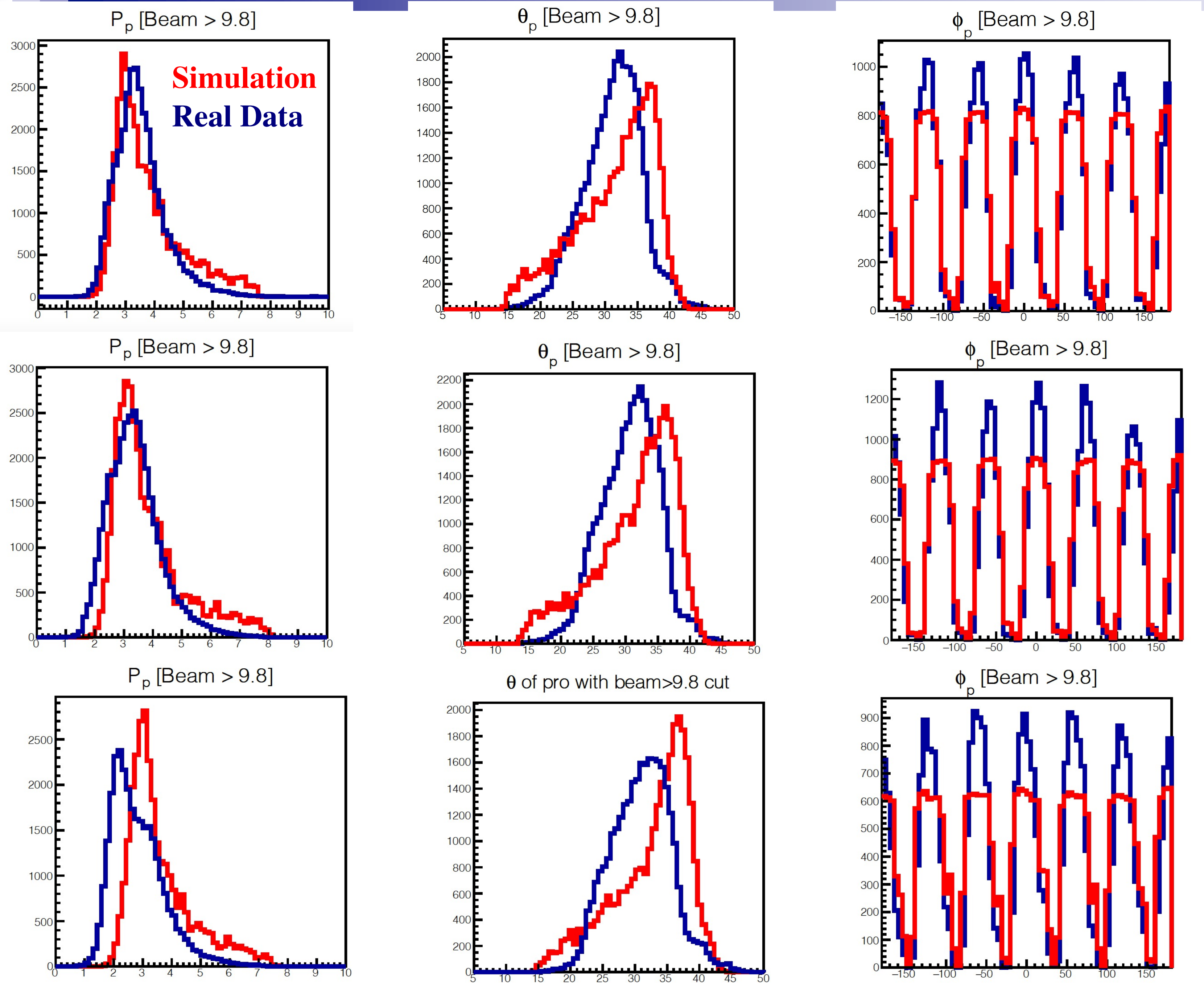


E_{beam} = 10.5986 GeV



E_{beam} = 10.4096 GeV, Fall2019





E_{beam} = 10.1998 GeV

E_{beam} = 10.5986 GeV

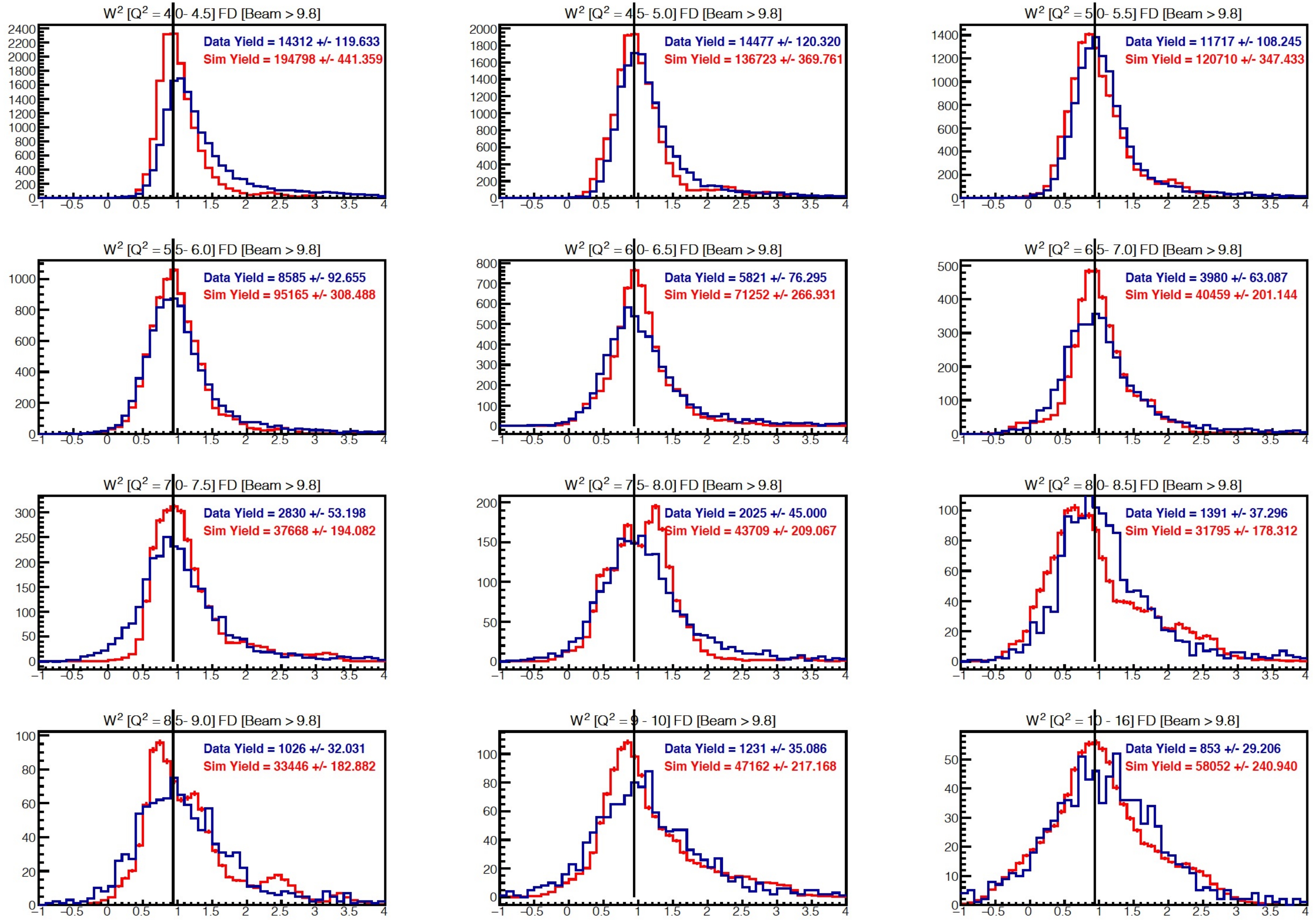
E_{beam} = 10.4096 GeV, Fall2019

$D(e,e'p)$ Selection

Simulation
Real Data

All RGB Data Set

$$R = \frac{\frac{d\sigma}{d\Omega}(D(e,e'n))}{\boxed{\frac{d\sigma}{d\Omega}(D(e,e'p))}}$$



- **Select two tracks, one electron in FD and one proton in FD**
- **Apply cut on $W^2 < 4.0$ && E_{beam} Calculated >9.8 GeV**
- **Apply cut on θ_{pq} <1.5 to reduce inelastic contamination**
- **Normalize simulation to the measured counts**

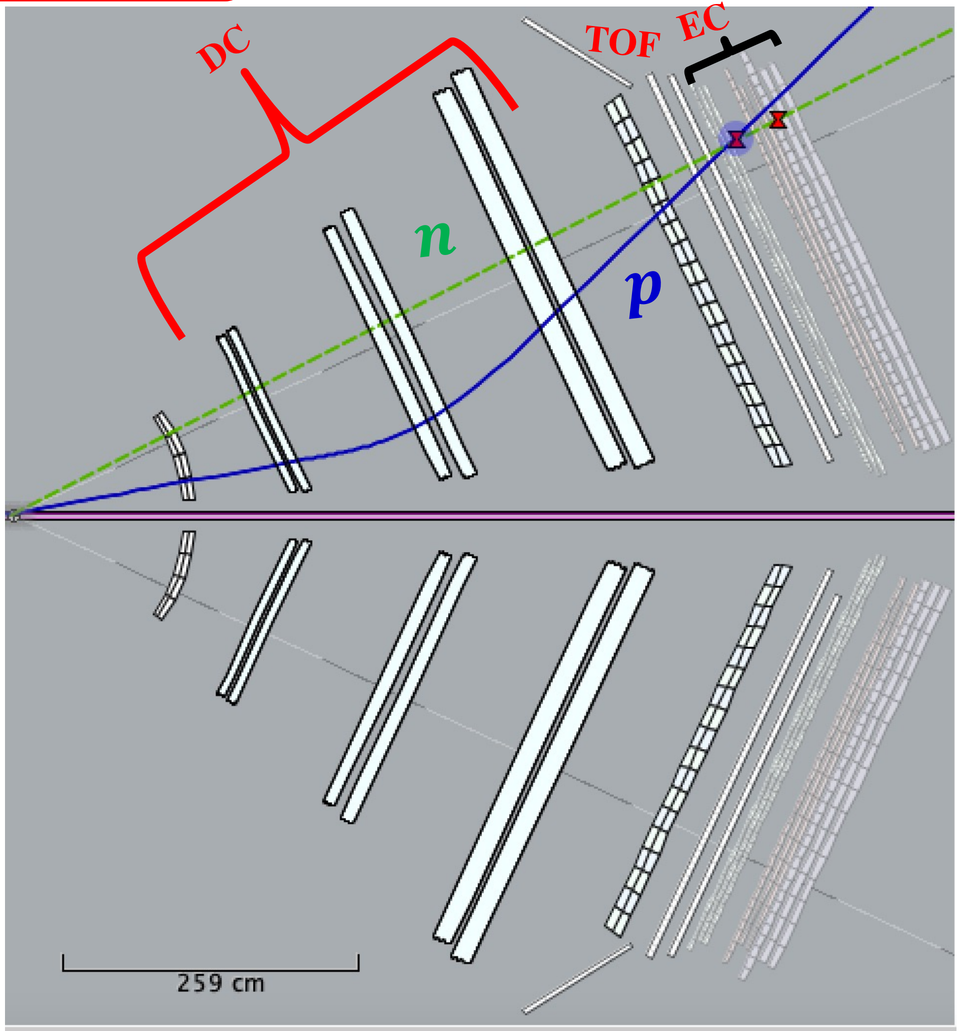
Acceptance Matching

$$R = \frac{\frac{d\sigma}{d\Omega}(D(e,e'n))}{\boxed{\frac{d\sigma}{d\Omega}(D(e,e'p))}}$$

Use the measured electron information to predict the trajectory of the associated QE proton and neutron.

Swim the predicted neutron and proton tracks through CLAS12.

Check that both hadron tracks strike the fiducial volume of CLAS12. If both strike CLAS12 continue the analysis, otherwise throw it out.



D(e, e′p) Selection

Required proton hit FD

- Select two tracks, one electron in FD and one proton in FD
- Apply cut on $W^2 < 4.0$ && E_{beam} Calculated >9.8 GeV
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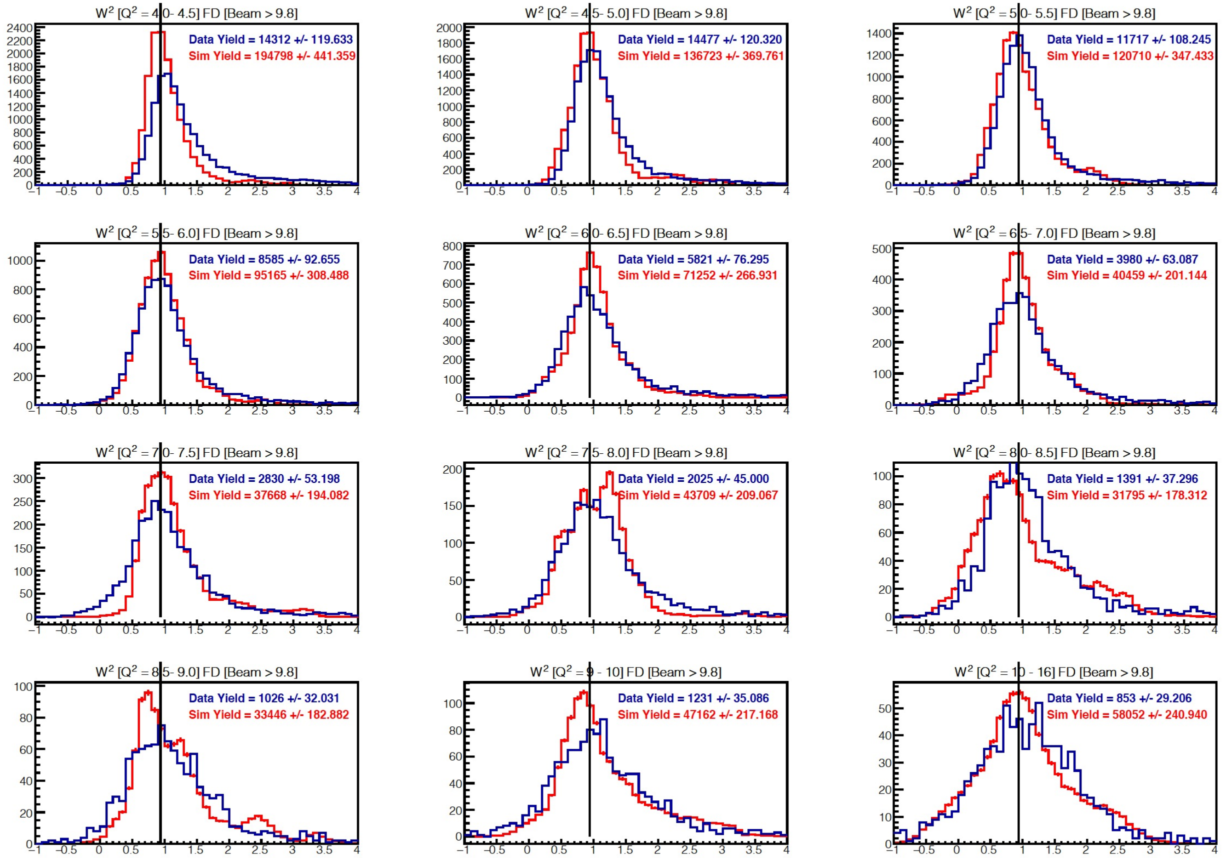
- Normalize simulation to the measured counts

All RGB Data Set

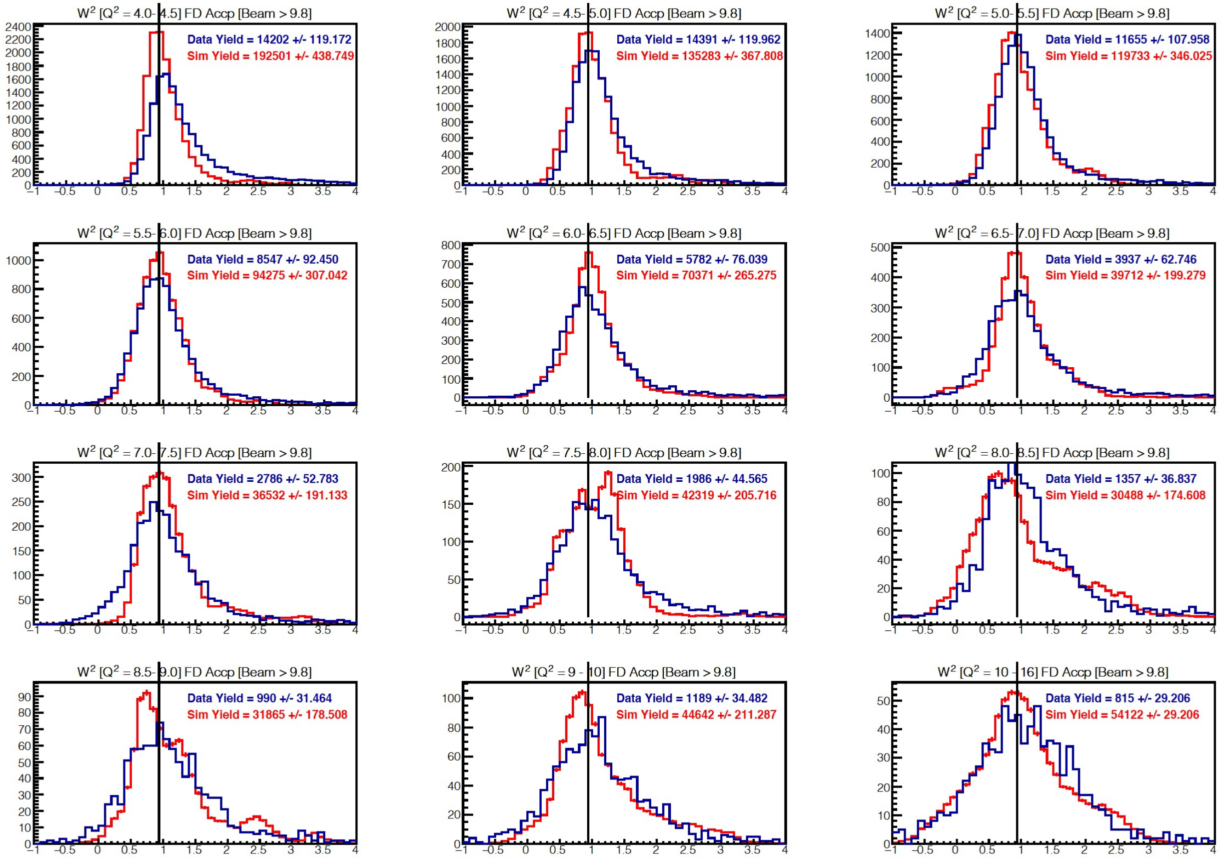
Simulation

Real Data

No Acceptance Matching



Acceptance Matching



D(e, e′p) Selection

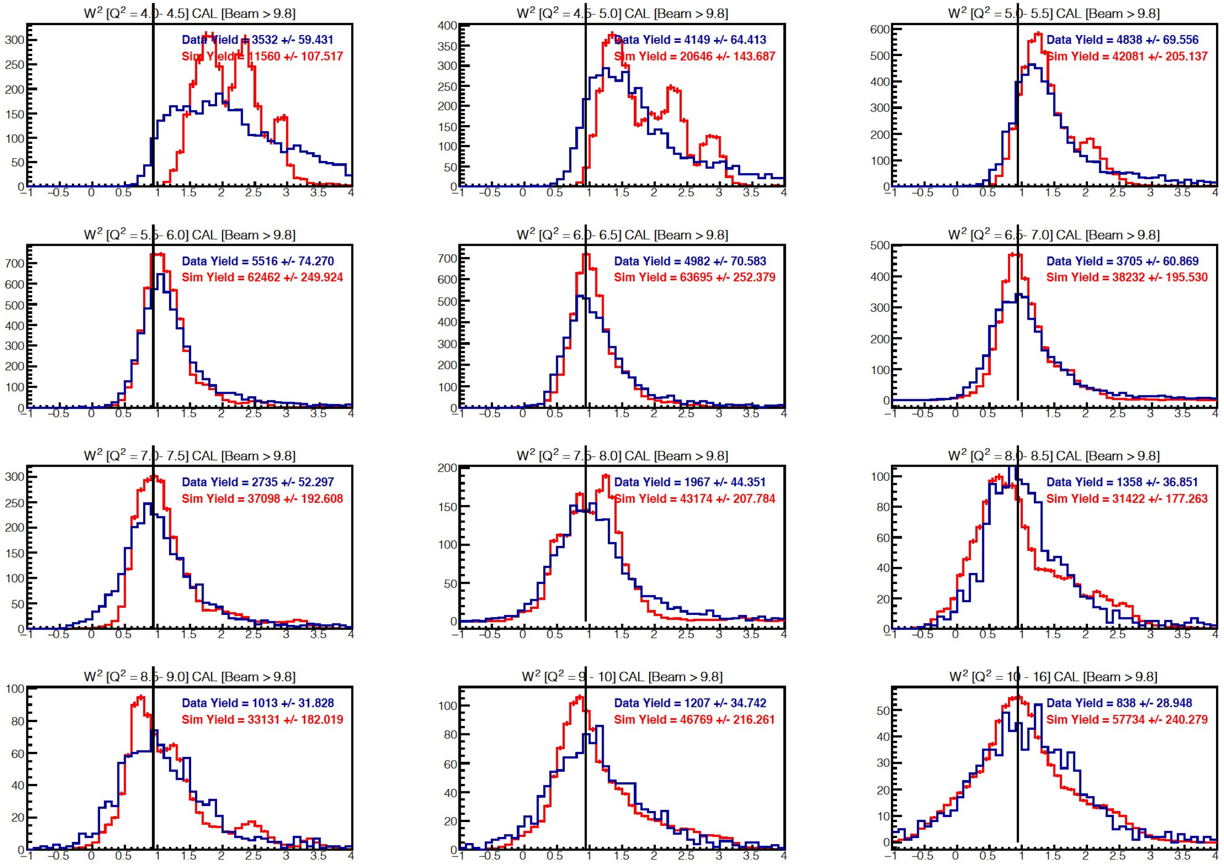
Required proton hit CAL

- **Select two tracks, one electron in FD and one proton in FD**
- **Apply cut on $W^2 < 4.0$ && E_{beam} Calculated >9.8 GeV**
- **Apply cut on θ_{pq} <1.5 to reduce inelastic contamination**
- **Normalize simulation to the measured counts**

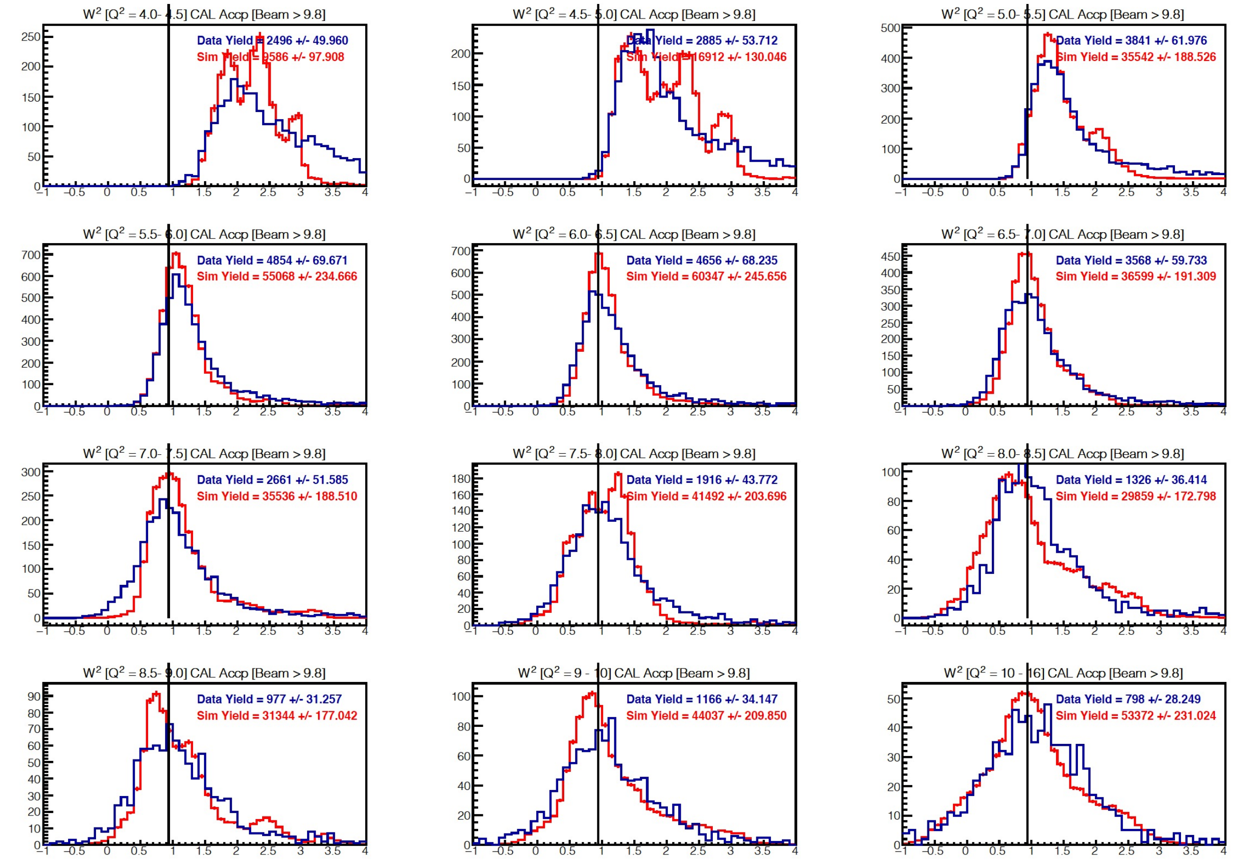
All RGB Data Set

Simulation
Real Data

No Acceptance Matching



Acceptance Matching



$\mathrm{D(e,e'p)}$ Selection

Required proton hit CAL

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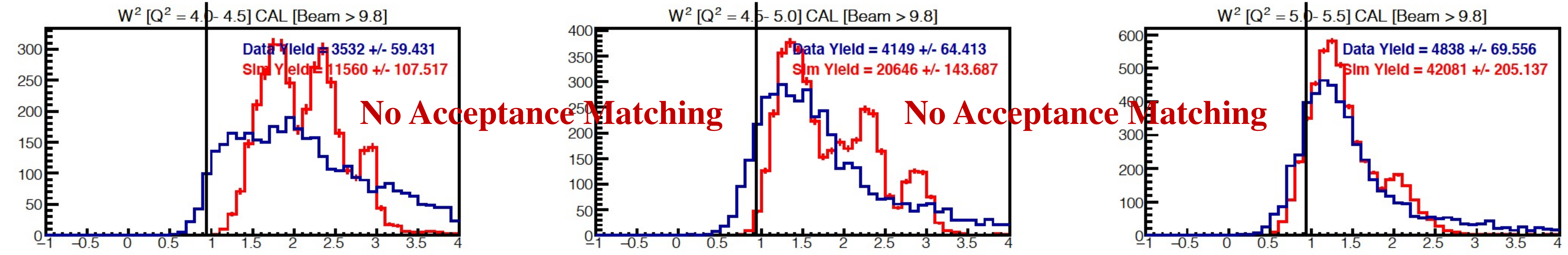
All RGB Data Set

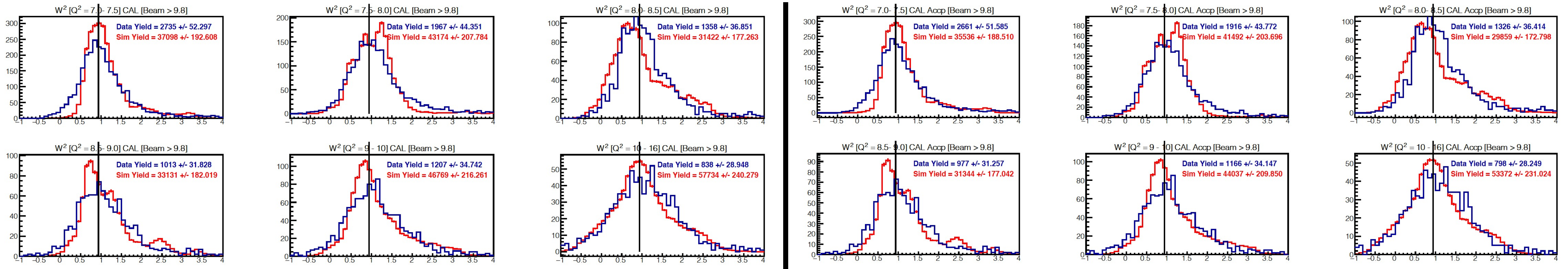
Simulation

Real Data

No Acceptance Matching

Acceptance Matching





$D(e, e'p)$ Selection

Required proton hit CAL

- **Select two tracks, one electron in FD and one proton in FD**
- **Apply cut on $W^2 < 4.0$ && E_{beam} Calculated >9.8 GeV**
- **Apply cut on θ_{pq} <1.5 to reduce inelastic contamination**
- **Normalize simulation to the measured counts**

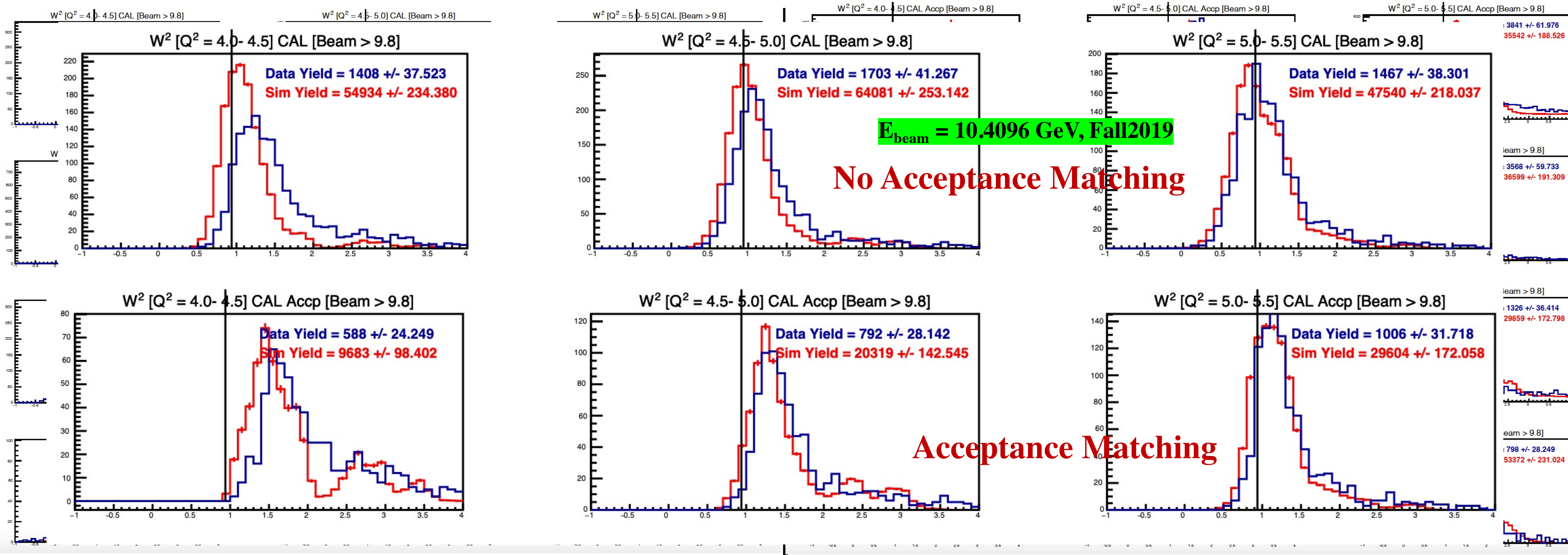
All RGB Data Set

Simulation

Real Data

No Acceptance Matching

Acceptance Matching



E_{beam} = 10.4096 GeV, Fall2019

No Acceptance Matching

Acceptance Matching

$D(e, e'p)$ Selection

Required proton hit CAL

- Select two tracks, one electron in FD and one proton in FD
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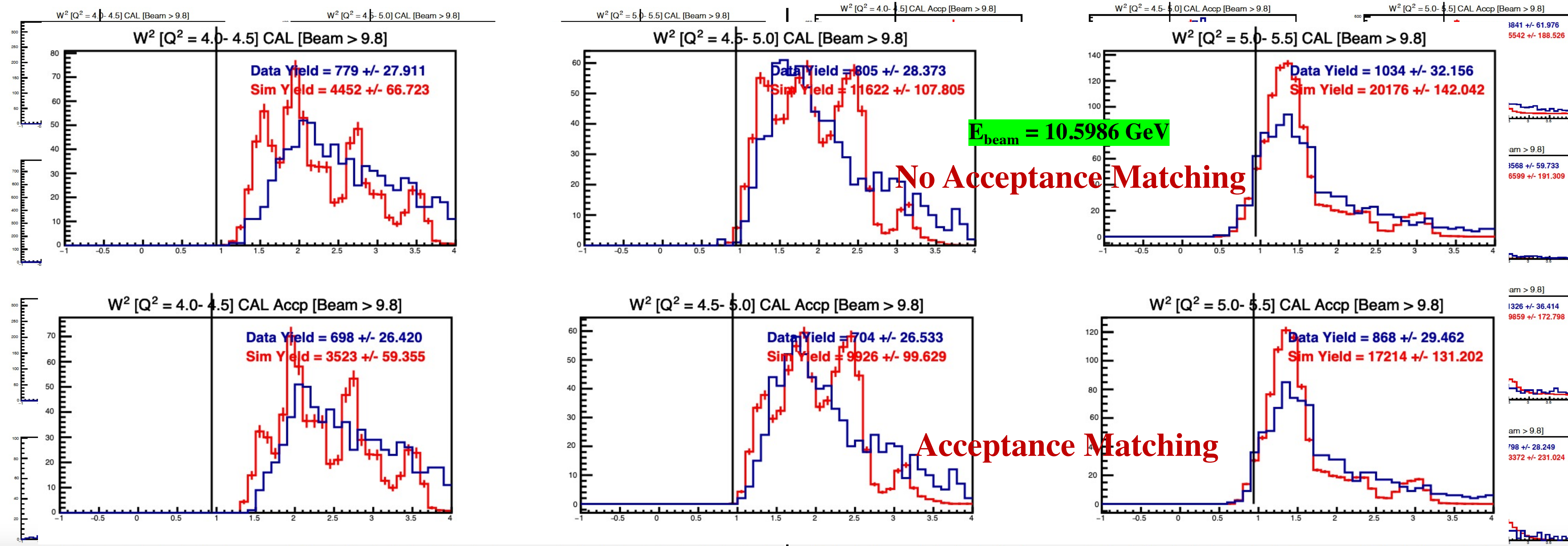
All RGB Data Set

Simulation

Real Data

No Acceptance Matching

Acceptance Matching



E_{beam} = 10.5986 GeV

No Acceptance Matching

Acceptance Matching

$D(e, e'p)$ Selection

Required proton hit CAL

- Select two tracks, one electron in FD and one proton in FD
- Apply cut on $W^2 < 4.0$ && E_{beam} Calculated >9.8 GeV
- Apply cut on θ_{pq} <1.5 to reduce inelastic contamination
- Normalize simulation to the measured counts

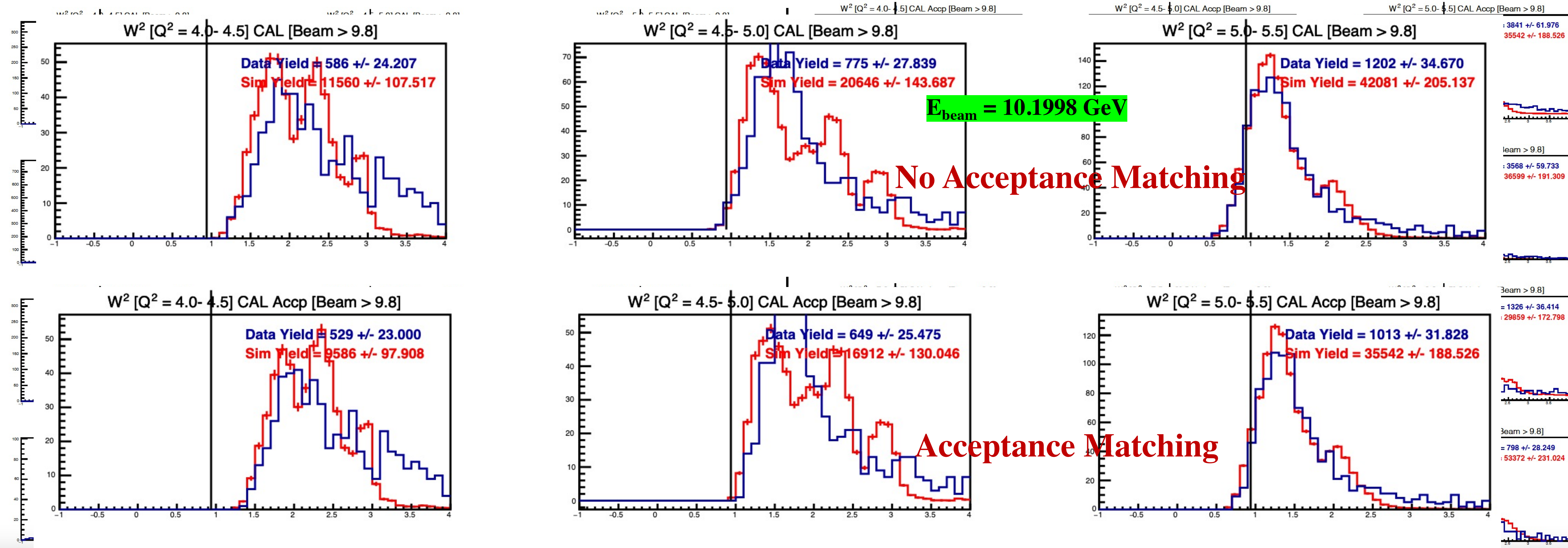
All RGB Data Set

Simulation

Real Data

No Acceptance Matching

Acceptance Matching



$D(e,e'p)$ Selection

Required proton hit TOF

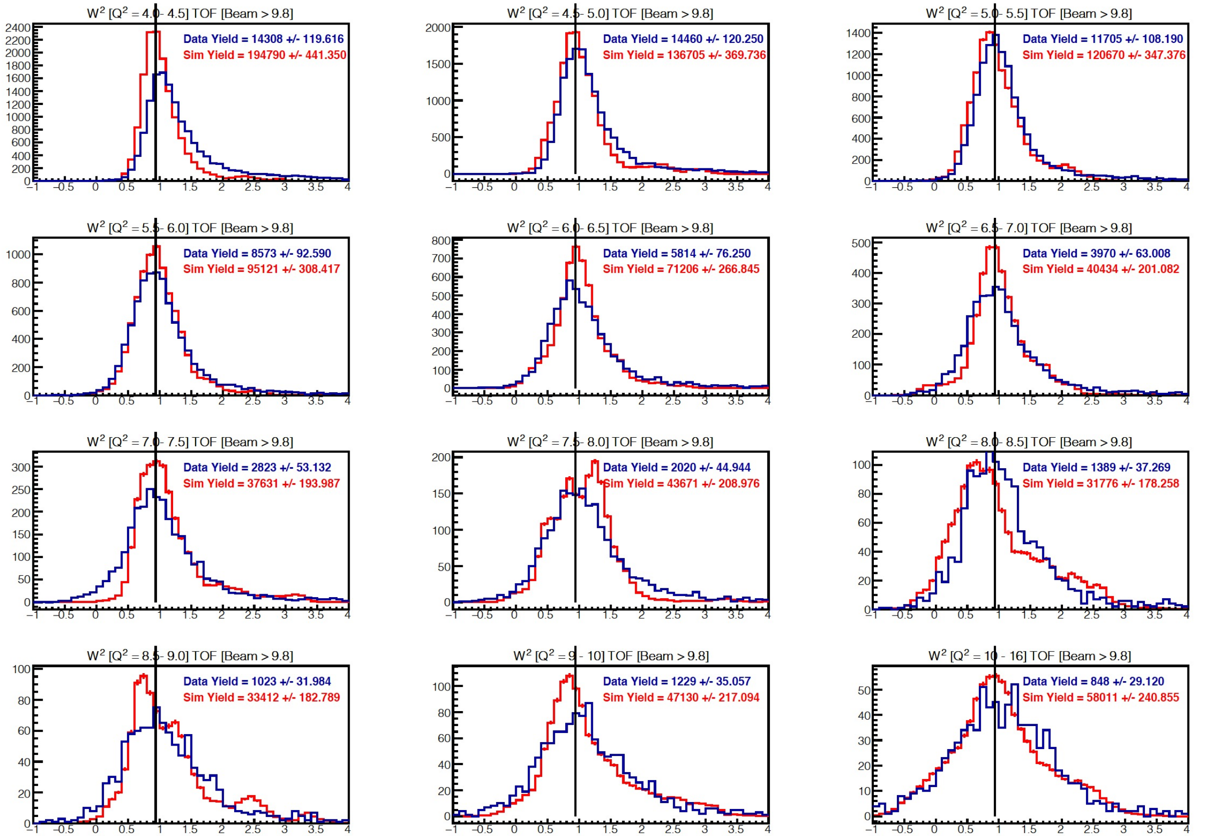
- **Select two tracks, one electron in FD and one proton in FD**
- **Apply cut on $W^2 < 4.0$ && E_{beam} Calculated >9.8 GeV**
- **Apply cut on θ_{pq} <1.5 to reduce inelastic contamination**
- **Normalize simulation to the measured counts**

All RGB Data Set

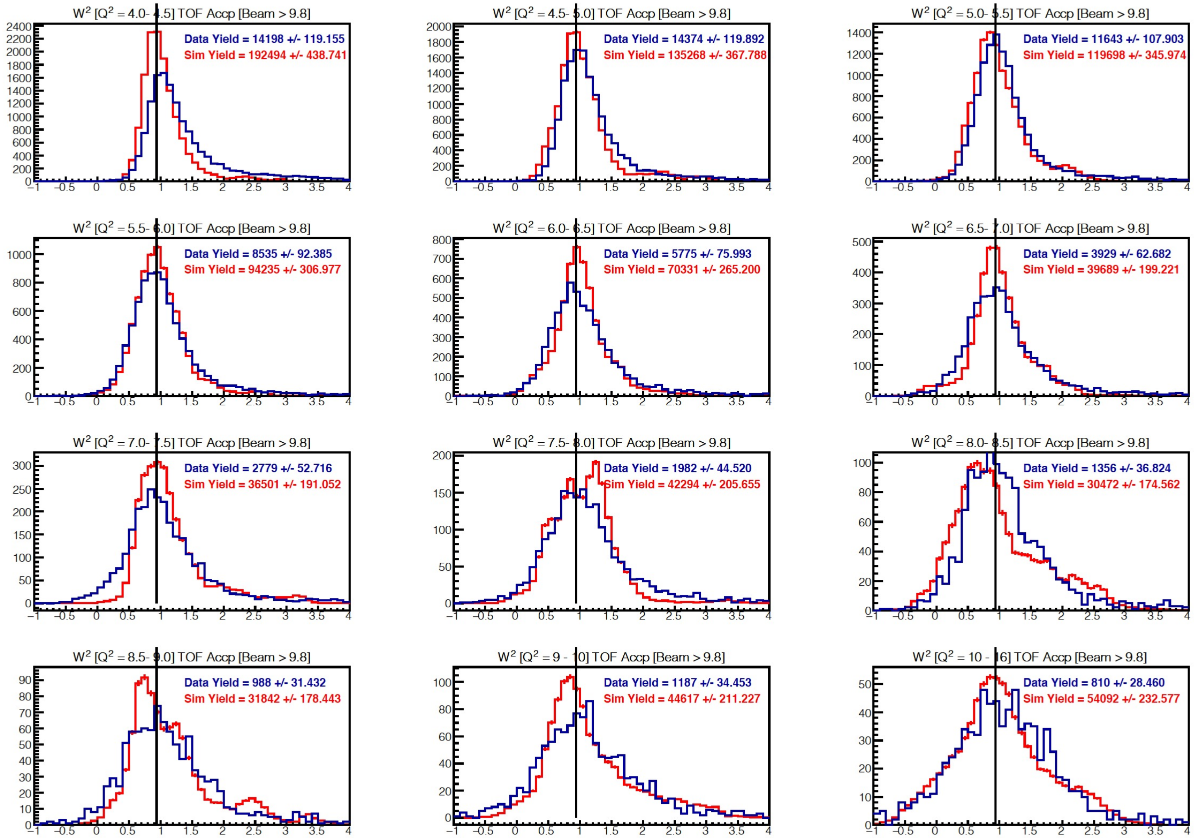
Simulation

Real Data

No Acceptance Matching



Acceptance Matching



What Next

Next:

- Investigate quasi-elastic ep events $D(e,e'p)$
- Simulate quasi-elastic en events $D(e,e'n)$
- Select quasi-elastic en events $D(e,e'n)$
- Calculate the Ratio, $R = \dfrac{\frac{d\sigma}{d\Omega}(D(e,e'n))}{\frac{d\sigma}{d\Omega}(D(e,e'p))}$

Thank you …