CLAS EG6:
Particle ID, Event Selection, and Raw Asymmetries for Coherent Processes

In this talk, I will outline relevant particle identification, selection of coherent DVCS and DVMP events, and details on extracting raw asymmetries.
A comparison to M. Hattawy's analysis will also be presented.

Frank Thanh Cao
UConn

Outline

- (Relevant) Particle ID:
  - Electron
  - Helium
  - IC Photons
    - Identifying DVCS Photons
    - Reconstructing π^0 and η
- Event Selection
  - Exclusivity Cuts
- Raw Asymmetries for coherent processes:
    - DVCS
    - DVMP

Particle Identification

In a coherent DVCS (DVMP) process off Helium-4, the final state particles that are at play are:

- Electron
- Helium-4

And depending on which process is of interest

- DVCS:
    - γ
- DVMP:
    - π^0 decays into:
        - γ
        - γ
    - η decays into:
        - γ
        - γ

Since the only final state particles that are involved are the electron, helium-4, and the photon, we will focus on these particle identifications.

Electron Identification

The scattered electron, as the trigger, plays the most important role in defining an event. Listed below are the criteria for an electron:

- Preliminary Cuts
- Corrections
    - Vertex Correction
    - EC Sampling Fraction Correction
- Vertex Cut
- EC Cuts:
    - Fiducial Cut
    - Energy Cut
- DC Cuts :
    - IC Shadow Cut
    - DC Fiducial Cut
- CC Cuts:
    - Number of photoelectrons cut
    - CC Fiducial Cut

An electron that passes every criterion is considered to be a *good* electron.

If one and only one *good* electron is identified, identification of other particles begins.

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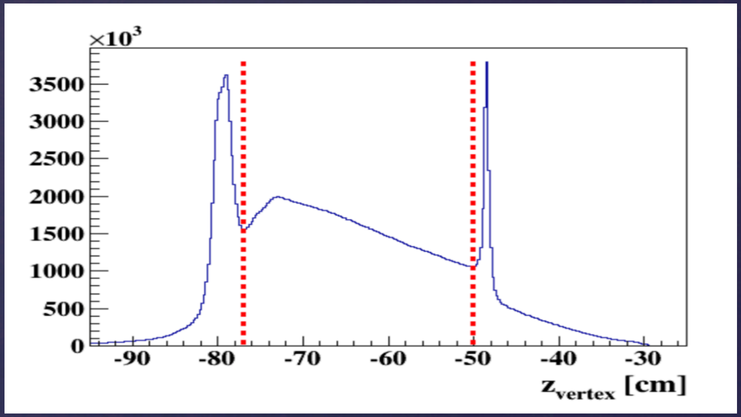

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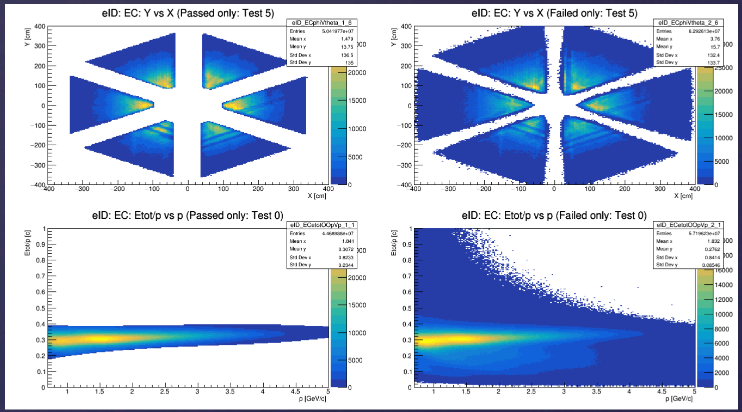

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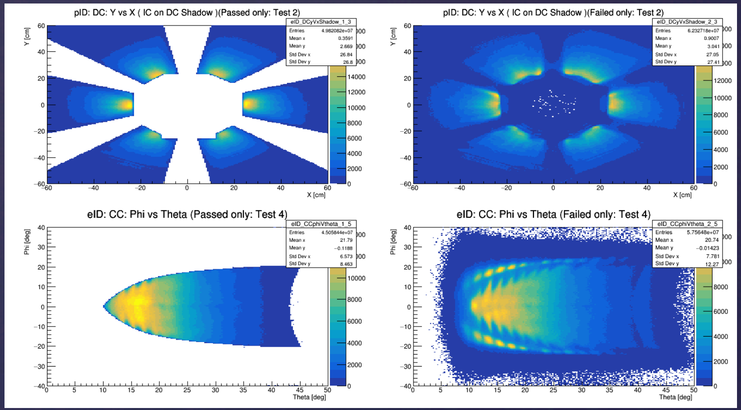


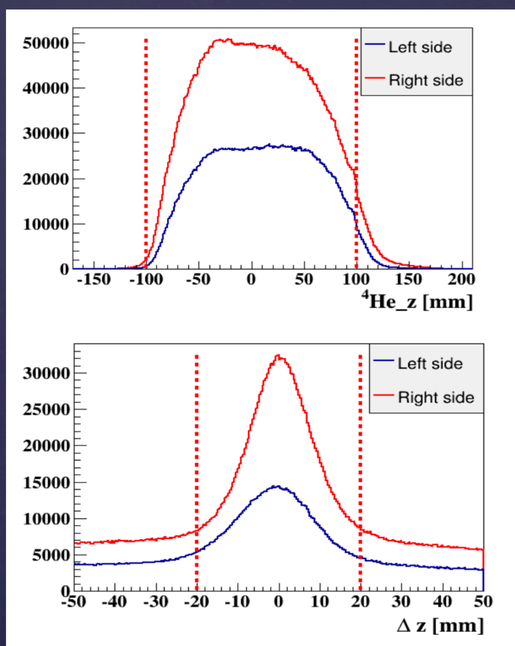
An electron that passes every criterion is considered to be a *good* electron.

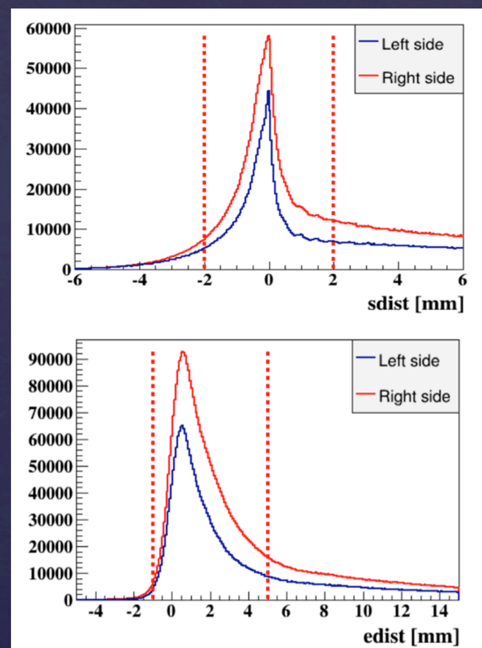
If one and only one *good* electron is identified, identification of other particles begins.

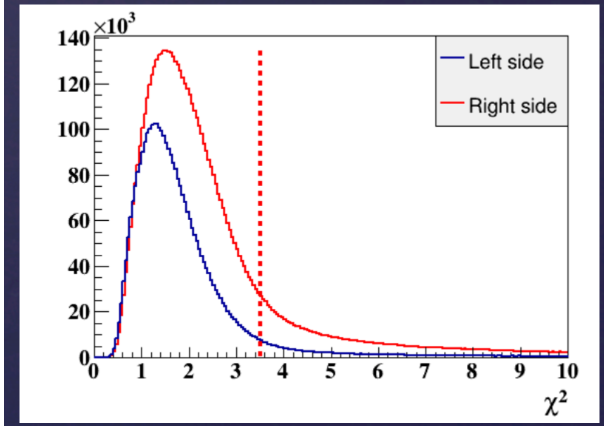
Helium-4 Identification

Now that a *good* electron has been identified, we can look at the ^{4}He. Listed below are the criteria for helium from the RTPC:

- Vertex Cuts
- Ionization Point Cuts
- Track Reconstruction Cut





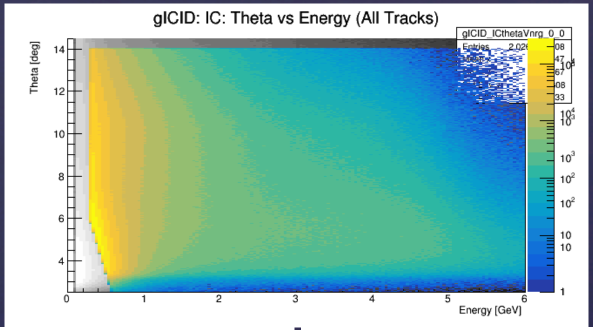


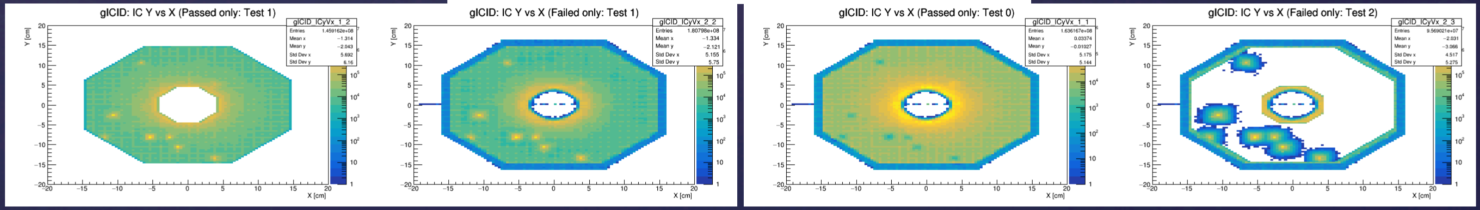
An RTPC track that passes every criterion is considered to be a *good* ^{4}He.

Photon Identification

Now that a *good* electron has been identified, we can look at the photons. Listed below are the criteria for photon from the IC:

- Møller Electron Reduction Cut
- IC Fiducial Cut
- IC Hot Channel Cut





A photon that passes every criterion is considered to be a *good* photon and will be the used for the rest of the analysis and discussion.

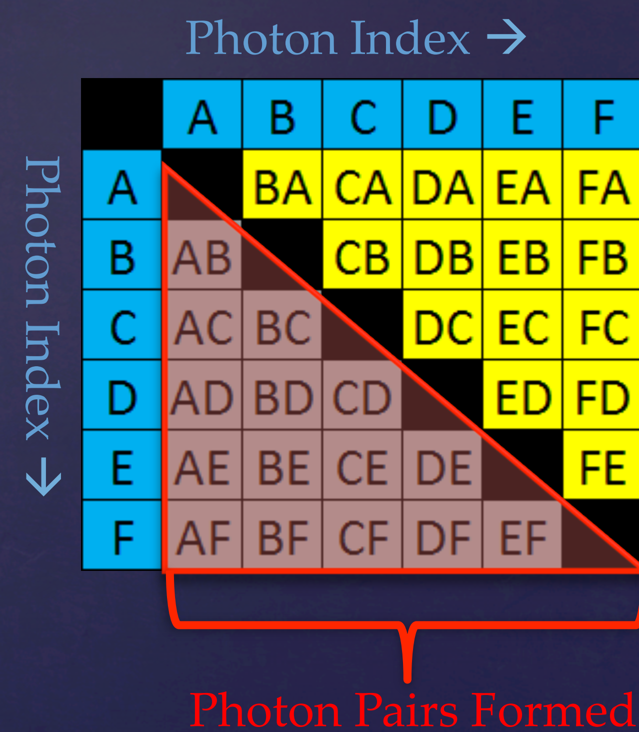
π^0 and η **Reconstruction**

π^0 and η most favorably decays into two photons. To reconstruct the meson, *Mes*, we need to construct photon pairs by combining good photons.

- Photon Pairing :
  - Each photon is paired with another through handshaking combinatorics. Their Lorentz vectors are combined in the usual way:
    - $P_{\gamma\gamma} = P_{\gamma_1} + P_{\gamma_2}$

      $= ([P_{x\_1} + P_{x\_2}], [P_{y\_1} + P_{y\_2}], [P_{z\_1} + P_{z\_2}], [E_1 + E_2])$
- Invariant Mass Cut :
  - A loose cut is applied on the invariant mass:
    - $| M_{\gamma\gamma} - M_{Mes} | < 0.206$ GeV

    where:
      - M_{Mes} :
        - 0.1349766 GeV (for π^0)
        - 0.5478620 GeV (for η)



All photon pairs passing the invariant mass cut are then taken to be candidates for DVMP

Coherent DVCS and DVMP Event Selection

	Initial		Final
DVCS :	$e\ ^4He$	$\rightarrow$	$e'\ ^4He'\ \gamma$
$DV\pi^0P$:	$e\ ^4He$	$\rightarrow$	$e'\ ^4He'\ \pi^0$
$DV\eta P$:	$e\ ^4He$	$\rightarrow$	$e'\ ^4He'\ \eta$

Now that we have identified each of the key players, we have to make sure the identified particles are correlated with each other. This is done with Exclusivity Cuts.

Coherent DVCS and DVMP Event Selection

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Now that we have identified each of the key players, we have to make sure the identified particles are correlated with each other. This is done with Exclusivity Cuts.

Coherent DVCS and DVMP Event Selection

Preliminary Cuts:

DVCS Candidates

To ensure a deeply virtual process and to avoid resonances:

- $Q^2 > 1$ GeV^2
- $E_\gamma > 2$ GeV

All events are required to have:

- One good electron
- One good RTPC track
- One good DVCS Photon Candidate:
  - if more than one, find the most energetic and use that as the DVCS photon

Variable	Passes if	Units
M_{X0}^2	< 25	GeV^2
M_{X1}^2	> -2	GeV^2
P_T	< 8	GeV/c
E_{X2}	< 2	GeV
θ	< 6	deg.
$\lvert\Delta\phi\rvert$	< 15	deg.

Coherent DVCS and DVMP Event Selection

	Initial		Final
DVCS :	e ^{4}He	$\rightarrow$	e′ ^{4}He′ γ

Coherent DVCS and DVMP Event Selection

	Initial		Final
DVCS :	$e\ {}^4He$	$\rightarrow$	$e'\ {}^4He'\ \gamma$

Missing Particle, X:

$$P_X = \boxed{P_{init}} - \boxed{P_{fin}}$$

Coherent DVCS and DVMP Event Selection

Missing Particle, X:

$$P_X = \boxed{P_{init}} - \boxed{P_{fin}}$$

$$\text{DVCS}: \quad \overset{\text{Initial}}{\boxed{e\ {}^4\text{He}}} \rightarrow \overset{\text{Final}}{\boxed{e'}\ {}^4\text{He}'\ \boxed{\gamma}}$$

Exclusivity Cuts:

- Final State: e′ γ
  - Missing Mass^2 Cut:
    - $| M_{X0}{}^2 - \mu_{M0\text{^}2} | < 3\sigma_{M0\text{^}2}$

DVCS Values:

Variable	μ	σ	Units
$M_{X0}{}^2$	1.39930e+01	1.61245e+00	GeV^2

Coherent DVCS and DVMP Event Selection

Missing Particle, X:

$P_X = \boxed{P_{init}} - \boxed{P_{fin}}$

	Initial		Final
DVCS :	$\boxed{e\ ^4He}$	$\rightarrow$	$\boxed{e'\ ^4He'}\ \gamma$

Exclusivity Cuts:

- Final State: e′ ^{4}He′
  - Missing Mass^2 Cut :
    - $|\ M_{X1}{}^2 - \mu_{M1\text{^}2}\ | < 3\sigma_{M1\text{^}2}$
  - Cone Angle Cut :
    - $MIN_\theta < \theta_{X1,\gamma} < MAX_\theta$

DVCS Values:

Variable	μ	σ	Units
$M_{X1}{}^2$	-3.45128e-02	2.28247e-01	GeV^2
Variable	**Minimum**	**Maximum**	**Units**
$\theta_{X1,\gamma}$	0.00000e+00	2.00000e+00	deg.

Coherent DVCS and DVMP Event Selection

Missing Particle, X:

$P_X = \boxed{P_{init}} - \boxed{P_{fin}}$

	Initial		Final
DVCS :	$\boxed{e\ {}^4He}$	$\rightarrow$	$\boxed{e'\ {}^4He'\ \gamma}$

Exclusivity Cuts:

- Final State: $e'\ {}^4He'\ \gamma$
  - Missing Mass² Cut:
    - $|\ M_{X2}^2 - \mu_{M2\wedge2}\ | < 3\sigma_{M2\wedge2}$
  - Energy Cut:
    - $MIN_{PT} < E_{X2} < MAX_{PT}$
  - Transverse Momentum Cut :
    - $P_T < MAX_{PT}$
  - Coplanarity Cut :
    - $|\ \Delta\phi - \mu_{\Delta\phi}\ | < \sigma_{\Delta\phi}$

DVCS Values:

Variable	μ	σ	Units
M_{X2}^2	-2.98662e-03	9.28645e-03	GeV^2
$\Delta\phi$	1.86020e-01	4.64936e-01	deg.
Variable	**Minimum**	**Maximum**	**Units**
E_{X2}	-0.45000e+00	0.50000e+00	GeV
P_T	0.00000e+00	0.15000e+00	GeV/c

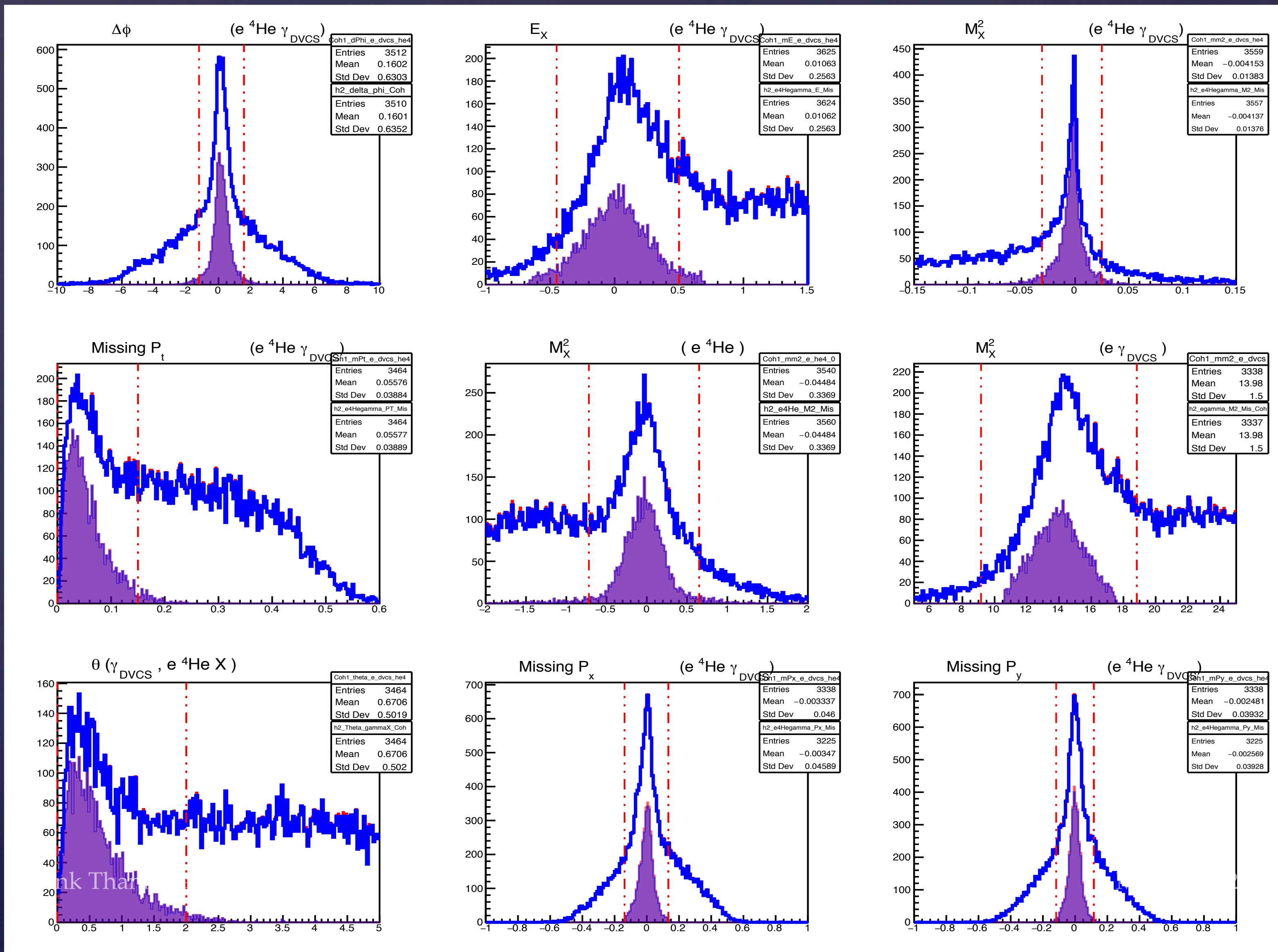
Results

For all further discussion/analysis:

- The curves represent events that has passed the preliminary cuts.
- The translucent shaded region represents events that pass all cuts except for the cut on the plotted variable.
- M. Hattawy's is in **BLUE**
- My results are in RED

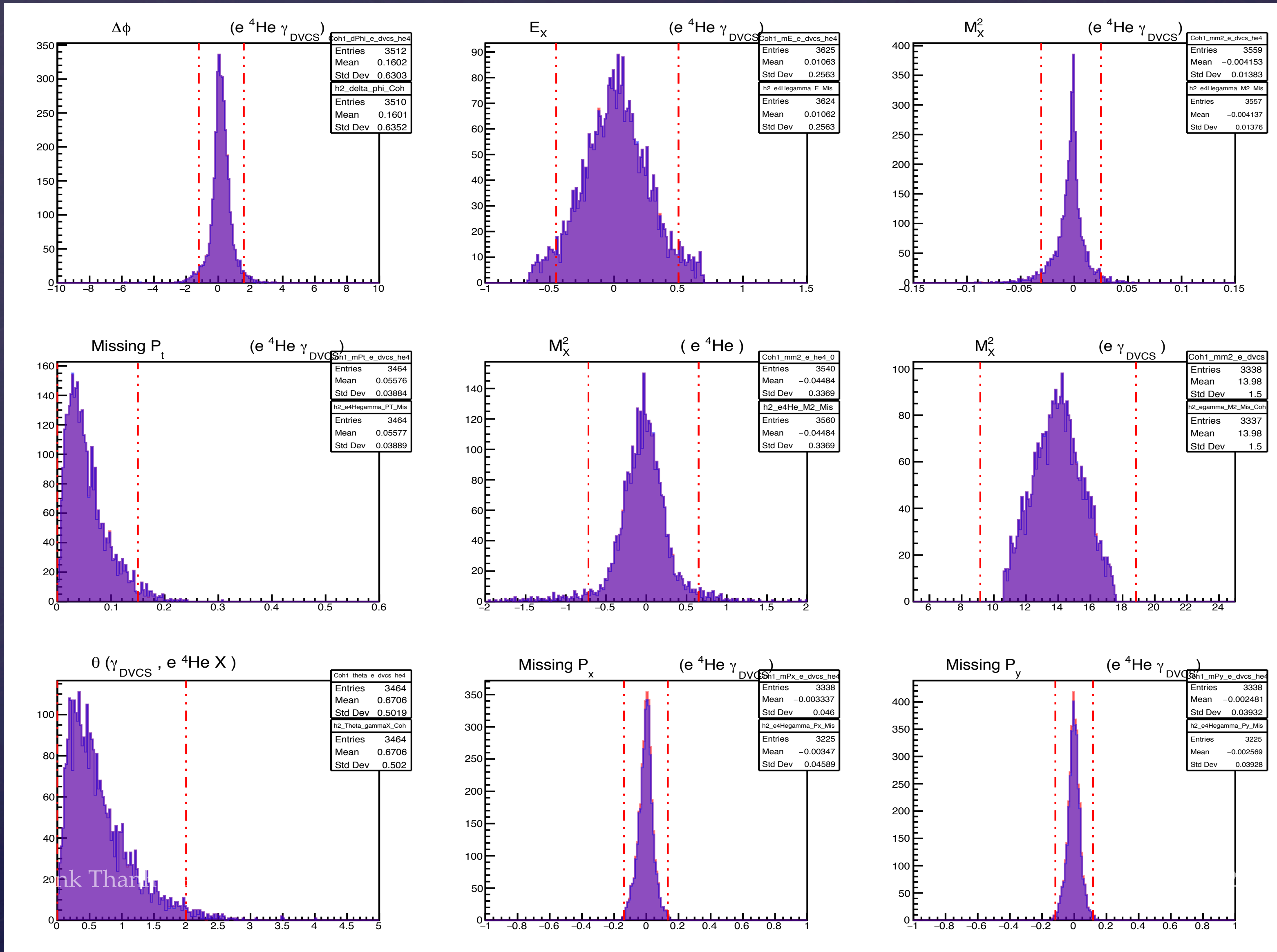
Results

Coherent DVCS Exclusivity Cuts



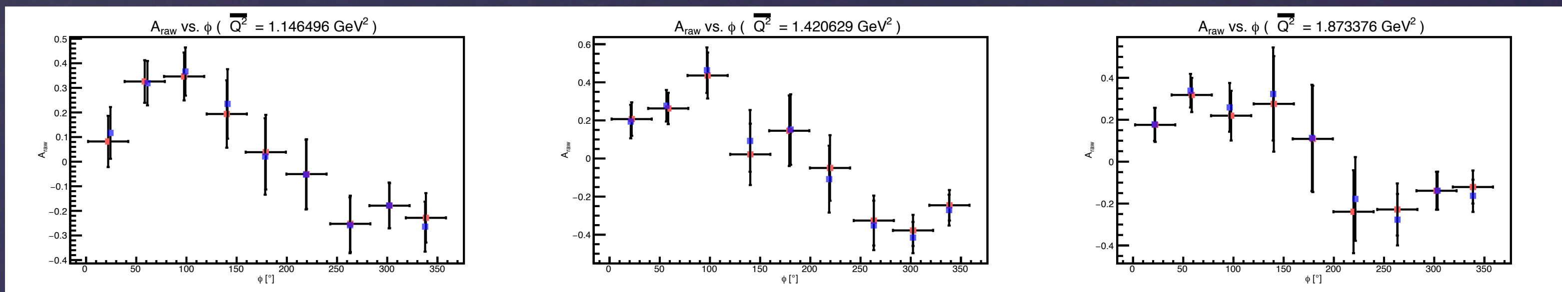
Results

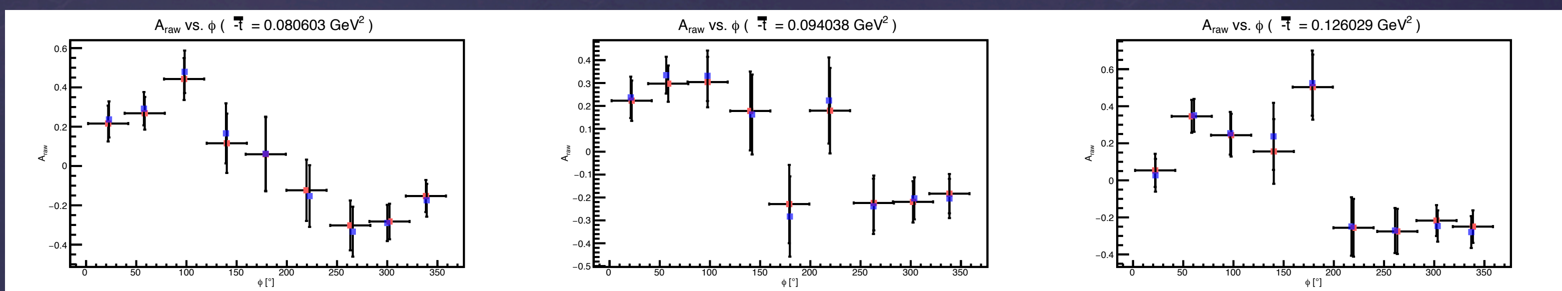
Coherent DVCS Exclusivity Cuts

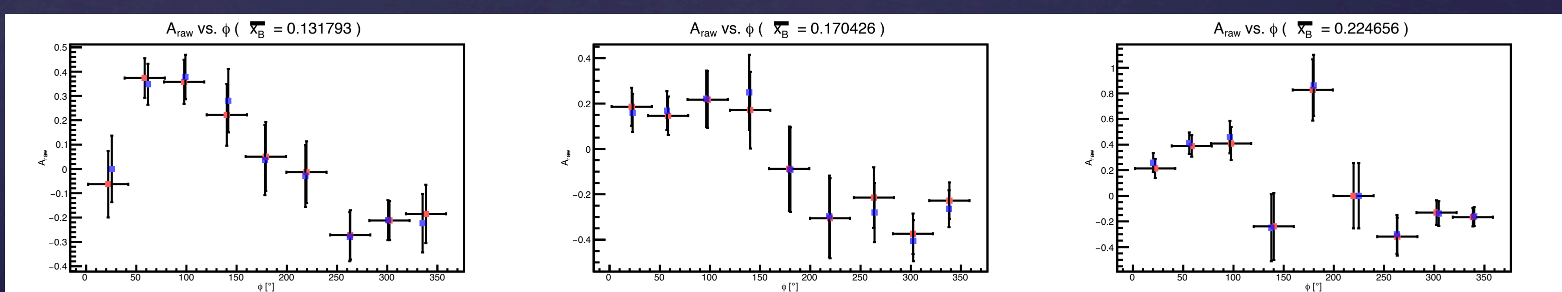


Results

Coherent DVCS Raw Asymmetries







Coherent DVCS and DVMP Event Selection

Preliminary Cuts:

π^0 Precuts

To ensure a deeply virtual process and to avoid resonances:

- $Q^2 > 1$ GeV^2
- $E_{\pi 0} > 2$ GeV
- $y < 0.85$ $(E_e > 0.15 E_{Beam})$

All events are required to have:

- One good electron
- One good RTPC track
- One good π^0

Variable	Passes if	Units
$M_{X0}{}^2$	\in (5, 25)	GeV^2
$M_{X1}{}^2$	\in (-2, 3)	GeV^2
$M_{X2}{}^2$	\in (-1.5, 1)	GeV^2
$\|P_x\|$	< 1	GeV/c
$\|P_y\|$	< 1	GeV/c
P_T	< 0.6	GeV/c
$\|E_{X2}\|$	< 1.5	GeV
θ	< 7	deg.
$\|\Delta\phi\|$	< 15	deg.

Coherent DVCS and DVMP Event Selection

Missing Particle, X:

$P_X = \boxed{P_{init}} - \boxed{P_{fin}}$

$$\begin{array}{cccc} & \underline{\text{Initial}} & & \underline{\text{Final}} \\ DV\pi^0P: & \boxed{e\ {}^4He} & \rightarrow & \boxed{e'}\ {}^4He'\ \boxed{\pi^0} \end{array}$$

Exclusivity Cuts:

- Final State: $e'\ \pi^0$
  - Missing Mass^2 Cut :
    - $|\ M_{X0}{}^2 - \mu_{M0^\wedge 2}\ | < 3\sigma_{M0^\wedge 2}$

π^0 Values:

Variable	μ	σ	Units
$M_{X0}{}^2$	1.39835e+01	1.33781e+00	GeV^2

Coherent DVCS and DVMP Event Selection

Missing Particle, X:

$$P_X = \boxed{P_{init}} - \boxed{P_{fin}}$$

Initial → Final

$$DV\pi^0P: \boxed{e\ {}^4He} \rightarrow \boxed{e'\ {}^4He'}\ \pi^0$$

Exclusivity Cuts:

- Final State: $e'\ {}^4He'$
  - Missing Mass² Cut :
    - $| M_{X1}^2 - \mu_{M1^2} | < 3\sigma_{M1^2}$
  - Cone Angle Cut :
    - $MIN_\theta < \theta_{X1,\pi^0} < MAX_\theta$

π^0 Values:

Variable	μ	σ	Units
M_{X1}^2	-1.30346e-02	2.07791e-01	GeV^2
Variable	**Minimum**	**Maximum**	**Units**
θ_{X1,π^0}	0.00000e+00	2.50000e+00	deg.

Coherent DVCS and DVMP Event Selection

Missing Particle, X:

$$P_X = \boxed{P_{init}} - \boxed{P_{fin}}$$

Initial → Final

$$DV\pi^0P: \quad \boxed{e\ {}^4He} \rightarrow \boxed{e'\ {}^4He'\ \pi^0}$$

Exclusivity Cuts:

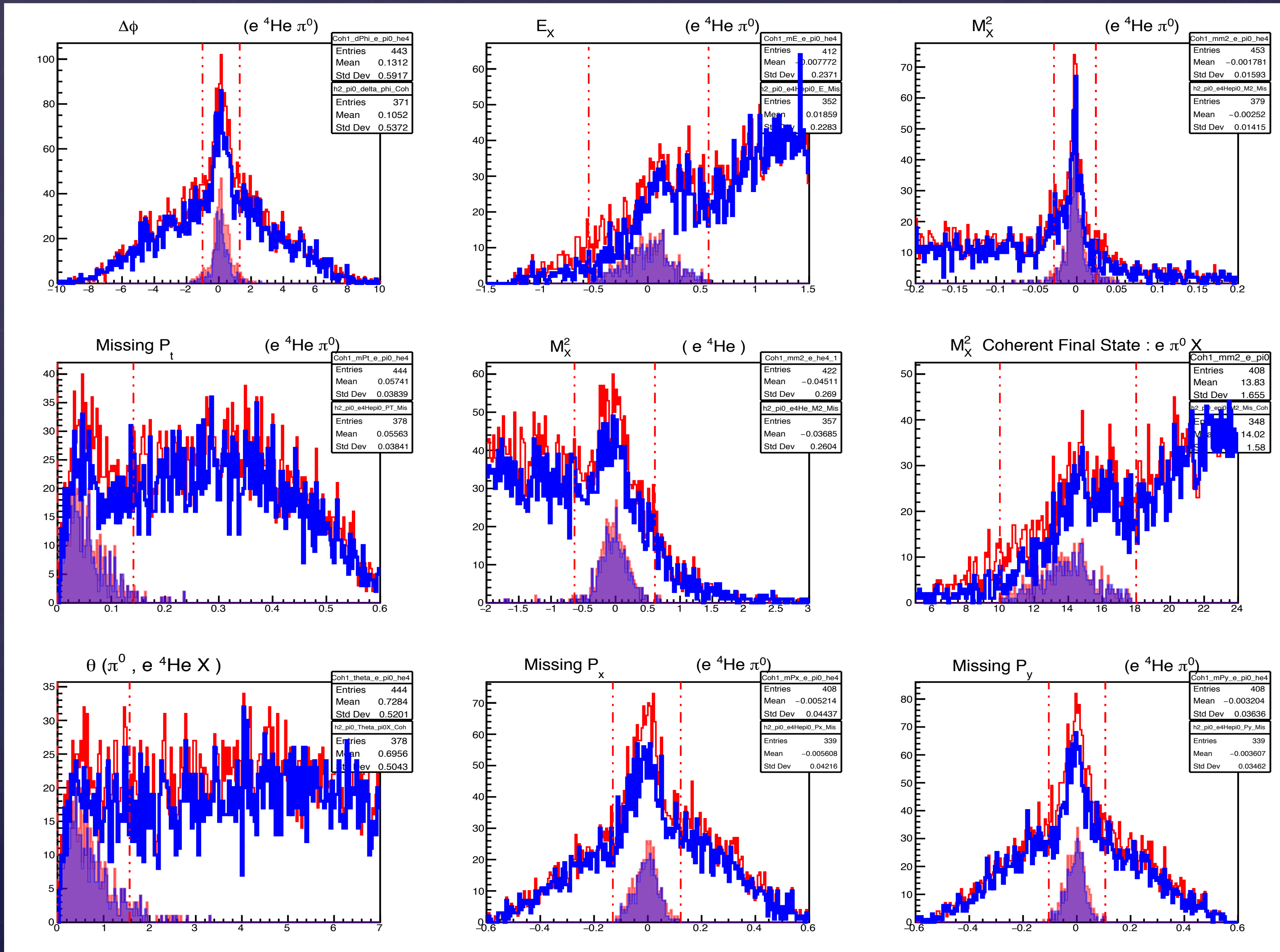
- Final State: $e'\ {}^4He'\ \pi^0$
  - Missing Mass² Cut:
    - $|\ M_{X2}{}^2 - \mu_{M2\wedge 2}\ | < 3\sigma_{M2\wedge 2}$
  - Energy Cut:
    - $MIN_{PT} < E_{X2} < MAX_{PT}$
  - Transverse Momentum Cut:
    - $P_T < MAX_{PT}$
  - Coplanarity Cut:
    - $|\ \Delta\phi - \mu_{\Delta\phi}\ | < \sigma_{\Delta\phi}$

π^0 Values:

Variable	μ	σ	Units
$M_{X2}{}^2$	-2.31650e-03	8.65851e-03	GeV^2
$\Delta\phi$	1.41750e-01	3.84202e-01	deg.
E_{X2}	7.80328e-03	1.85770e-01	GeV
P_T	4.36619e-02	3.25254e-02	GeV/c

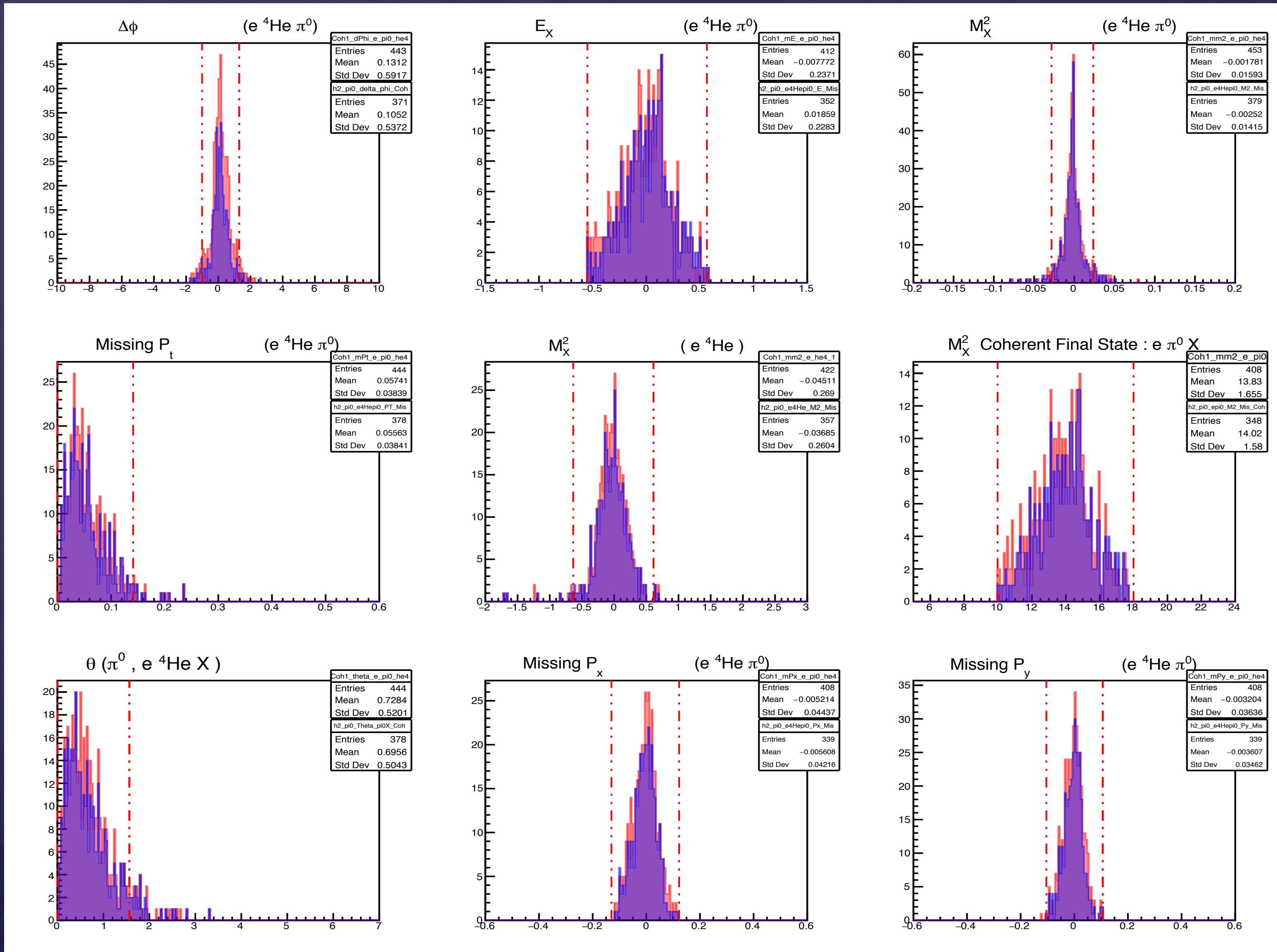
Results

Coherent π^0 Exclusivity Cuts



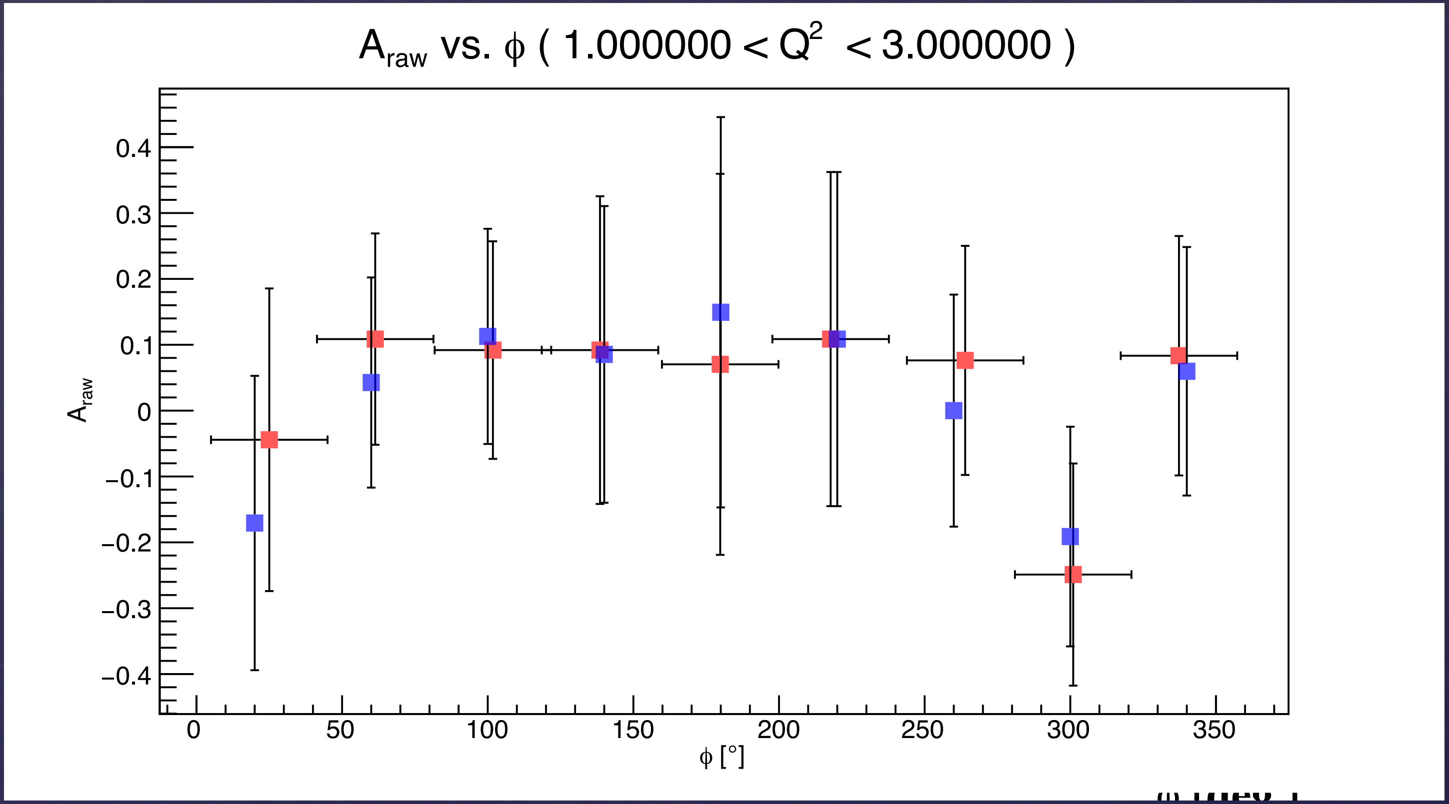
Results

Coherent π^0 Exclusivity Cuts



Results

Coherent π^0 Raw Asymmetries



Conclusion and Outlook

- Extraction of Raw Asymmetries shows verification of previous work (M. Hattawy) and leads to confidence in
  - Particle Identification
  - Exclusivity Selection
- Can compare to other works
  - Currently comparing with B. Torayev to see if number of coherent:
    - DVCS
    - π^0
    - η
  - events can be increased (since B. Torayev has a factor of ~2 more coherent π^0 events)
- Currently working on simulations to extract experimental asymmetries
- Currently working on extracting coherent η raw asymmetries

Backup Slides

Because you never know what questions you're going to get

PID Parameters

Electron

Preliminary Cuts:

Variable	Passes if	Units
stat	> 0	
dc_stat	> 0	
PID	== 11	
p	\in (0.8, 6.0)	GeV/c
E_i	> 0	GeV
E_o	> 0	GeV
nphe	>0	

PID Parameters

Electron

- Vertex Cuts (Applied on corrected corrected vertex
  - -77.0 < corr_vz < -50.0
- nphe[cc[ipart] -1] > 20

PID Parameters

Electron

EC Sampling

- ec_ei[ec[ipart] -1] > 0.06 (GeV)

- Get corrected EG6 sampling fraction (varies with time {run number, event number} and sector): SF_{corr} = (E_
- Data Table Here
    - | SF_{corr} – $\mu(p)$ | < $\sigma(p)$
        - $\mu(p)$ and $\sigma(p)$ are 3rd degree polynomials of p (at the end)
- Corrected EC sampling Fraction Cut : SF_{corr}
    - | SF_{corr} – $\mu(p)$ | < $\sigma(p)$
        - $\mu(p) = a_\mu + b_\mu p + c_\mu p^2 + d_\mu p^3$
        - $\sigma(p) = a_\sigma + b_\sigma p + c_\sigma p^2 + d_\sigma p^3$

α \ Parameter	a_α	b_α	c_α	d_α
μ	2.56084e-01	4.32374e-02	9.14180e-03	8.15895e-04
σ	0.0572976	0.0272689	0.00857596	-0.000979978

PID Parameters

Electron

- IC Shadow Cut:
  - Particles with positions in the geometry defined by the points below are rejected

Coor. \ Index	1	2	3	4	5	6	7	8	9	10	11
x [cm]	-11.15	-11.15	-23.10	-23.10	-10.30	9.91	23.73	23.73	12.30	12.30	-11.15
y [cm]	-26.07	-23.10	-12.85	11.50	22.95	22.95	13.10	-12.40	-22.36	-26.07	-26.07

PID Parameters

Electron

- DC Fiducial Cut :

```
Bool_t eg6skim_pass1::isDCFiducialCut(Float_t X, Float_t Y, Int_t S) {
  // DC Fiducial Cut: Checks to see if the particle is in the fiducial region
  // for the DC

if (!isInsideIConDCShadow(X, Y)) {

  using namespace TMath;

  //  Makes sure angle is within the left and right good relative angles depending on sector
  Double_t sectorAngL = ((S - 1.) + 1. / 3.) * Pi() / 3.;
  Double_t sectorAngR = ((S - 1.) - 1. / 3.) * Pi() / 3.;

 // If the DC hit was to the left, make sure it's between the edges of the lines defined by the tangent of the sector edges (sectorAngL and R)
  if (S == 3 || S == 4 || S == 5){
   if (X * Tan(sectorAngL) < Y && Y < X * Tan(sectorAngR)){
        return true;}}

 // If the DC hit was to the right
 if (S == 1 || S == 2 || S == 6){
   if (X * Tan(sectorAngR) < Y && Y < X * Tan(sectorAngL)){
        return true;}}
 }
 return false;
}
```

PID Parameters

Electron

- CC Fiducial Cut
  - θ_{CC} and ϕ_{CC} are gotten through Vlassov's previous code
  - $\phi_{Edge2}(\theta_{CC}) < \phi_{CC} < \phi_{Edge1}(\theta_{CC})$
    - $\phi_{Edge1}(\theta) = a_1 + b_1\theta + c_1\theta^2 + d_1\theta^3 + e_1\theta^4 + f_1\theta^5$
    - $\phi_{Edge2}(\theta) = a_2$\sqrt{ (θ- b_2)/2 }

i /Parameters	a_i	b_i	c_i	d_i	e_i	f_i
1	6.332792e+01	1.105609e+01	-6.344957e-01	1.873895e-02	-2.762131e-04	1.604035e-06
2	20.00000e+00	43.00000e+00				

PID Parameters

IC Photon

- Moller electron reduction Cut :
  - $E_\gamma < 0.300$ GeV are rejected
  - Particles $\theta(E_\gamma)$ are rejected
    - Geometry is tabulated at the end

- IC Fiducial Cut (from FX's code) :
  - $\theta_\gamma > 14$ deg. are rejected
  - Particles hitting the edges of the IC are rejected
  - Particles outside of the fiducial region of the IC are rejected
  - Fiducial region is tabulated at the end

- IC Hot Channel Cut:
  - The segmented IC had some channels that were hot that needed to be rejected
  - The x- and y- coordinates of these are channels are tabulated at the end

PID Parameters

IC Photon

- Moller Electron Reduction Cut:
  - Particles with positions in the geometry defined by the points below are rejected

Coor. \ Index	1	2	3	4	5	6
E [GeV]	0.00	0.00	0.30	0.30	0.80	0.00
θ [deg.]	0.00	15.00	15.00	6.00	0.00	0.00

PID Parameters

IC Photon

- IC Fiducial Cut:

```
Bool_t eg6skim_pass1::isG_ICFiducialCut(Int_t ipartIC) {
  // from fx
  // inputs are xc,yc from ICPB
  // this is to reject gammas near the inner/outer edges of the IC
  static const float dx  = 1.346; // cm
  static const float dy    = 1.360;
  static const float nin   = 3.25;
  static const float nout  = 10.75;
  static const float root2 = sqrt(2);

  Double_t xx = xc[ipartIC];
  Double_t yy = yc[ipartIC];
  // INNER:
  if (fabs(xx) / dx <= nin        &&
  fabs(yy) / dy <= nin        &&
  fabs(xx / dx - yy / dy) <= nin * root2 &&
  fabs(xx / dx + yy / dy) <= nin * root2  )
    return false;

 // OUTER:
 if (fabs(xx) / dx >= nout       ||
  fabs(yy) / dy >= nout       ||
  fabs(xx / dx - yy / dy) >= nout * root2 ||
  fabs(xx / dx + yy / dy) >= nout * root2  )
 return false;

  return true;
}
```

PID Parameters

IC Photon

- IC Hot Channel Cut:

```
Bool_t eg6skim_pass1::isG_ICGoodChannel(Int_t ipartIC) {
  ///// Take out the hot channels in IC ///////
  Int_t icHitID = (statc[ipartIC] - statc[ipartIC] % 10000) / 10000 - 1;
 // icHitID : Hit ID in ICHB
 Double_t ic_x = ich_xgl[icHitID]; // x coordinate in ICHB
  Double_t ic_y = ich_ygl[icHitID]; // y coordinate in ICHB
  // Below are the regions where we have Hot Channels in the IC
(bad)
  if ((-11.0 < ic_x && ic_x < -10.3 && - 3.0 < ic_y && ic_y < - 2.2) ||
  (- 5.8 < ic_x && ic_x < - 5.1 && - 8.5 < ic_y && ic_y < - 7.9) ||
  (- 1.7 < ic_x && ic_x < - 1.1 && -11.3 < ic_y && ic_y < -10.7) ||
  (- 3.0 < ic_x && ic_x < - 2.3 && - 8.5 < ic_y && ic_y < - 7.9) ||
  (- 7.5 < ic_x && ic_x < - 6.0 && 10.5 < ic_y && ic_y < 11.5) ||
  (-12.8 < ic_x && ic_x < -11.5 && - 8.5 < ic_y && ic_y < - 7.5) ||
  ( 3.9 < ic_x && ic_x < 4.5 && -14.1 < ic_y && ic_y < -13.5 )){
 return false;
 }
 return true;
}
```

PID Parameters

Helium

- Vertex Cuts :
  - To ensure the ^{4}He is coming from the RTPC, the vertex must be in the range:
    - $| z_{\_4He} | < 80.0$ mm
  - To ensure the ^{4}He is coming from an interaction with the electron:
    - $| z_{4He} - z_e | < 20.0$ mm

- Ionization Point Cuts:
  - The starting ionization point distance, sdist, must be in:
    - $-3.0 < \text{sdist} < 2.0$ mm
  - The ending ionization point distance, edist, must be within:
    - $-2.0 < \text{edist} < 3.0$ mm

- Track Reconstruction cut:
  - The fit of the trail of ionization points must be “good” enough:
    - $\chi^2 < 3.0$

PID Parameters

Helium-4

Variable	Passes if	Units
$\lvert z_{\_4He} \rvert$	< 80.0	mm
$\lvert z_{4He} - z_e \rvert$	< 20.0	mm
sdist	\in (-3, 2)	mm
edist	\in (-2, 3)	mm
χ^2	< 3.0	

Coherent DVCS Kinematic Cuts

Variable	μ	σ	Units
M_{X0}^2	1.39930e+01	1.61245e+00	GeV^2
M_{X1}^2	-3.45128e-02	2.28247e-01	GeV^2
M_{X2}^2	-2.98662e-03	9.28645e-03	GeV^2
$\Delta\phi$	1.86020e-01	4.64936e-01	deg.

Variable	Minimum	Maximum	Units
$\theta_{X1,\gamma}$	0.00000e+00	2.00000e+00	deg.
E_{X2}	-0.45000e+00	0.50000e+00	GeV
P_T	0.00000e+00	0.15000e+00	GeV/c

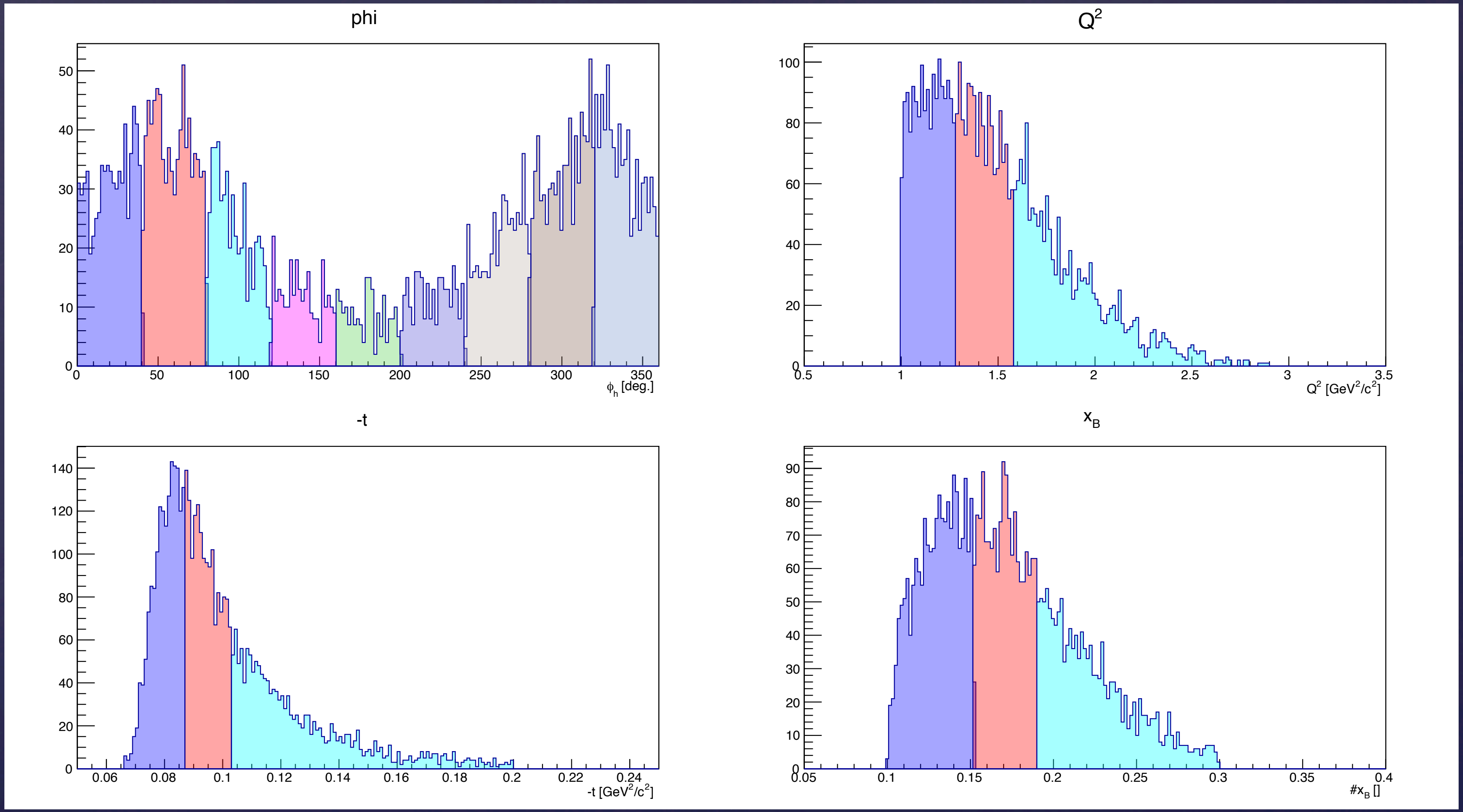
Coherent DVπ^0 P Kinematic Cuts

Variable	μ	σ	Units
M_{X0}^2	1.39835e+01	1.33781e+00	GeV^2
M_{X1}^2	-1.30346e-02	2.07791e-01	GeV^2
M_{X2}^2	-2.31650e-03	8.65851e-03	GeV^2
$\Delta\phi$	1.41750e-01	3.84202e-01	deg.
E_{X2}	7.80328e-03	1.85770e-01	GeV
P_T	4.36619e-02	3.25254e-02	GeV/c

Variable	Minimum	Maximum	Units
$\theta_{X1,\ \pi\text{^}0}$	0.00000e+00	2.50000e+00	deg.

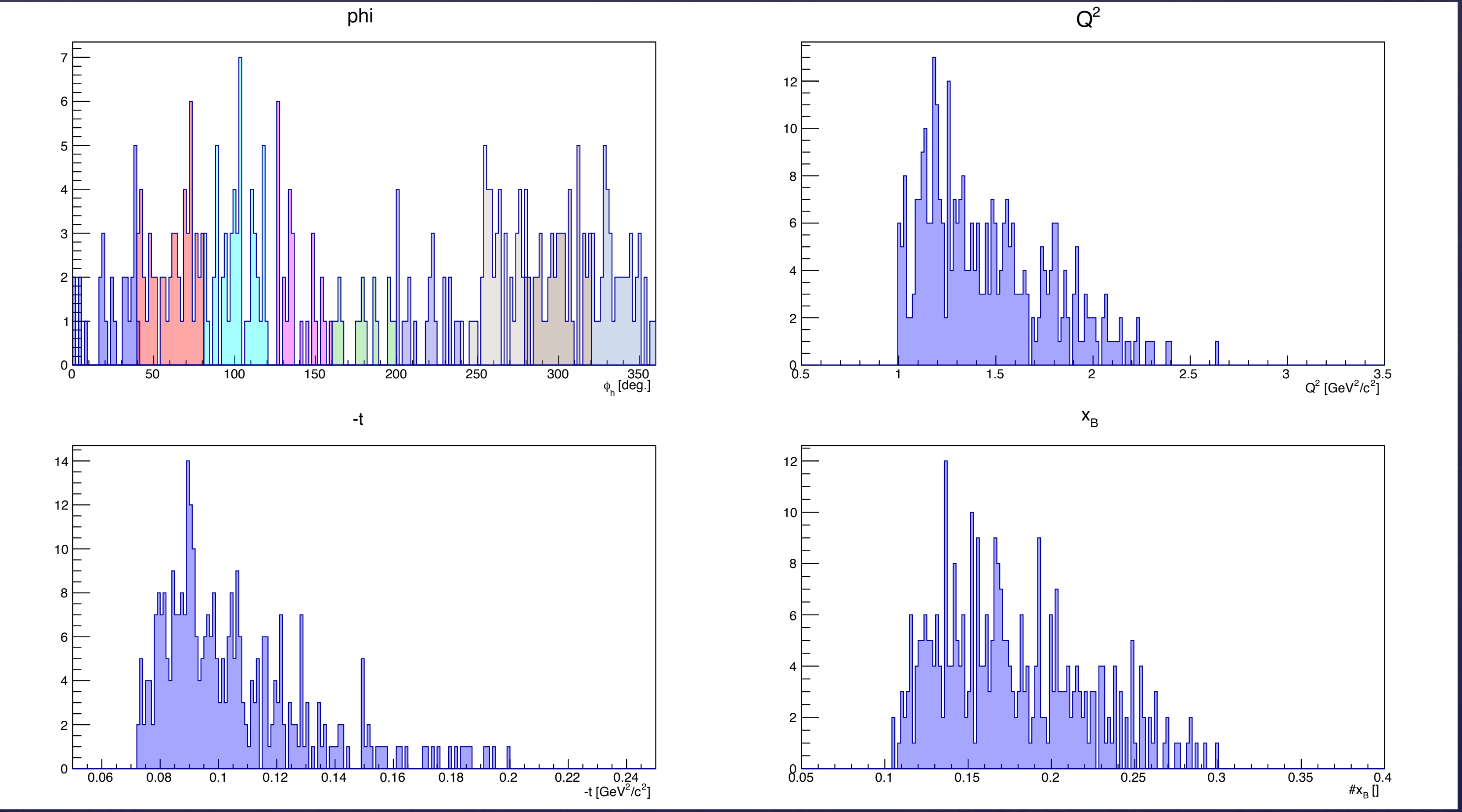
Results

Coherent DVCS Kinematic Binning



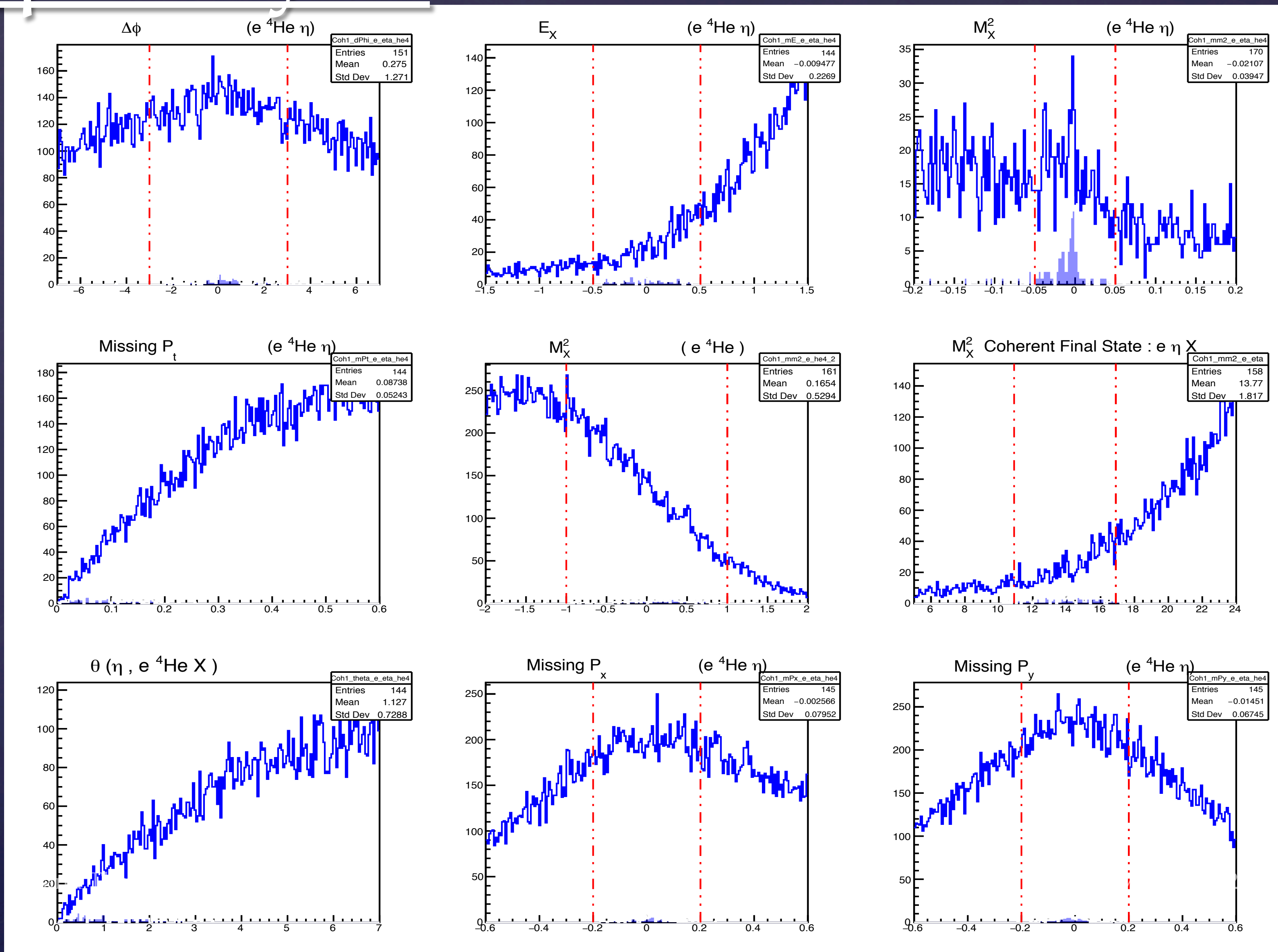
Results

Coherent π^0 Kinematic Binning



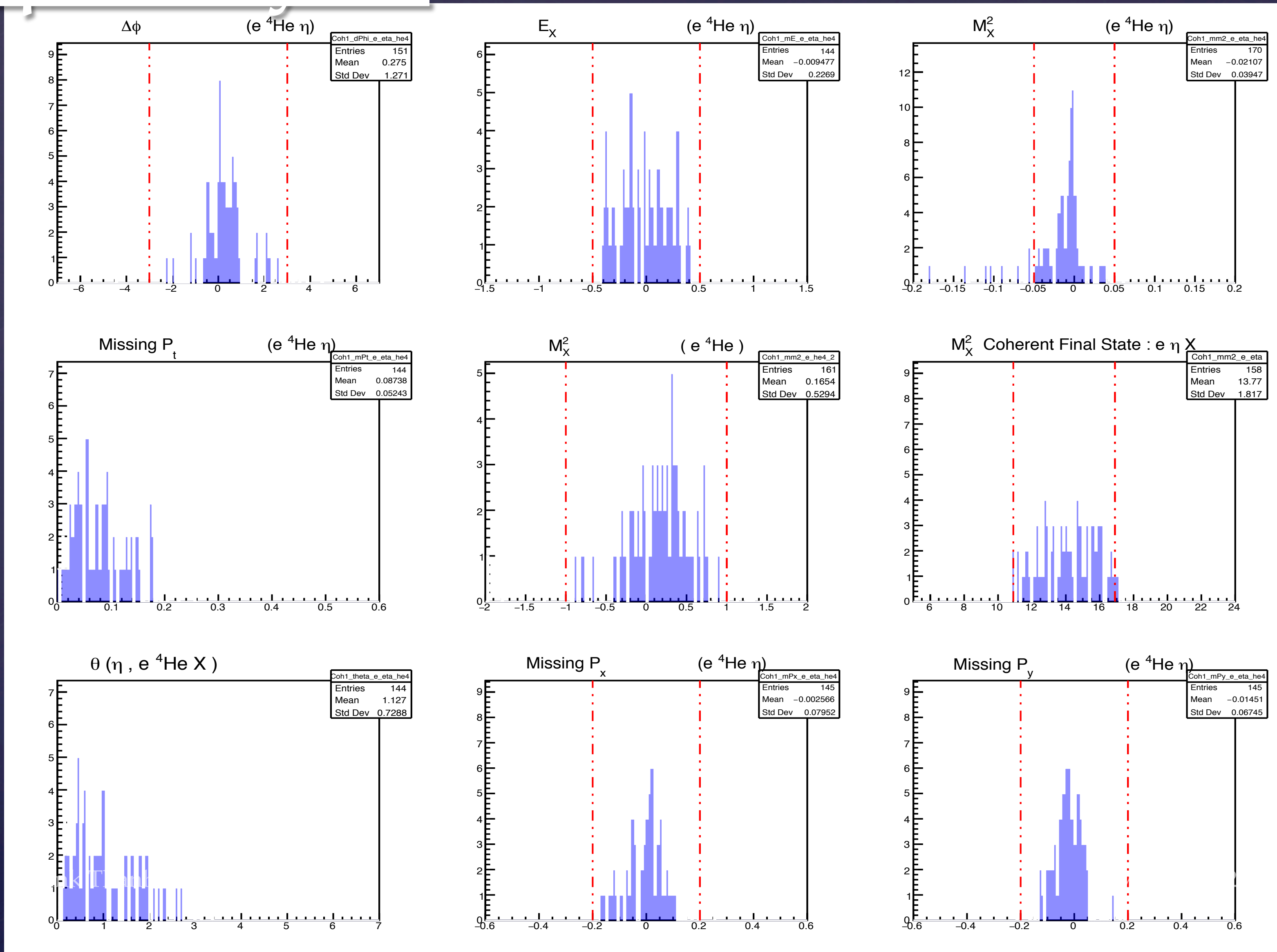
η Analysis

Coherent η Exclusivity Cuts



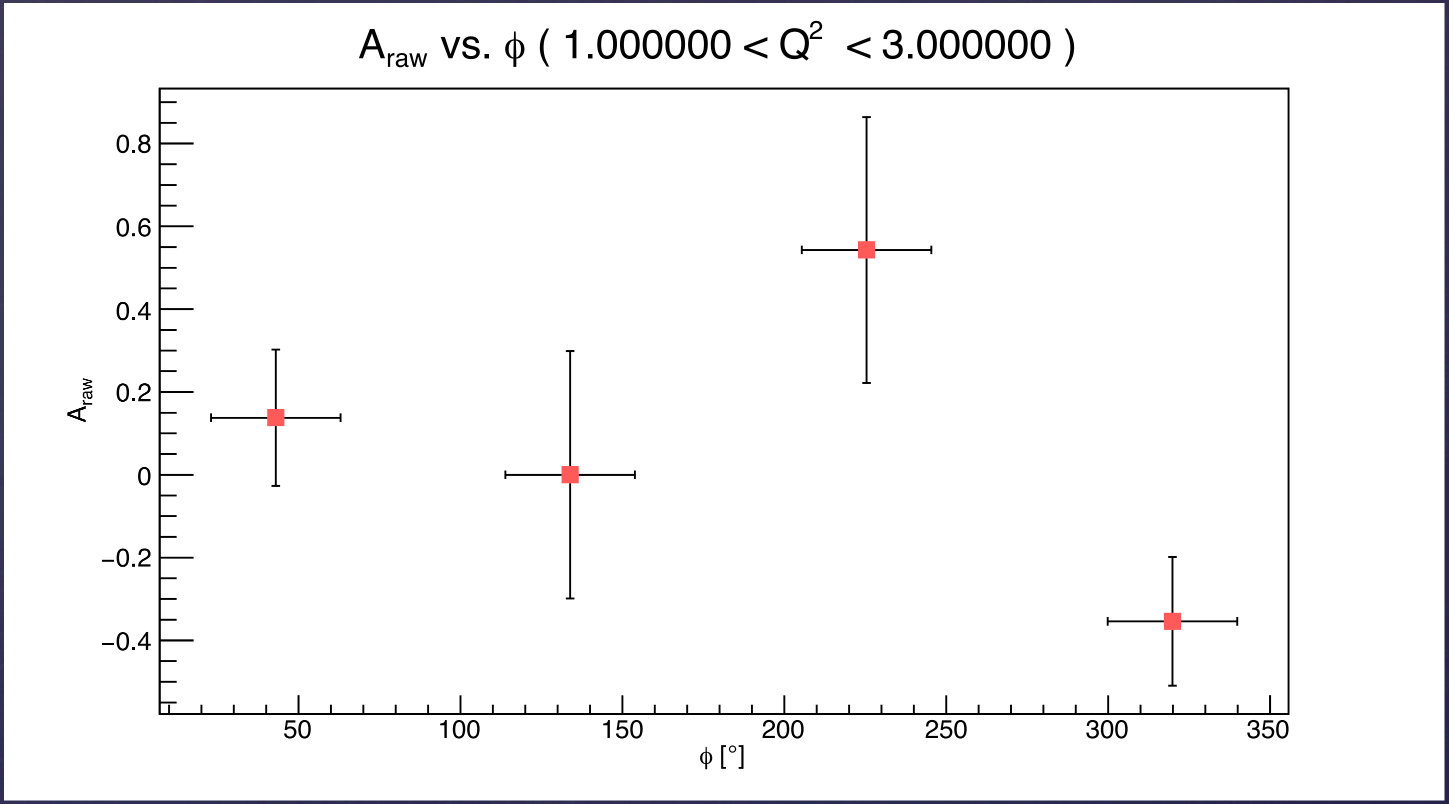
η Analysis

Coherent η Exclusivity Cuts



η Analysis

Coherent η Raw Asymmetries



η Analysis

Coherent η Kinematic Binning