# Asymmetry in coherent, virtual pion production on 4He

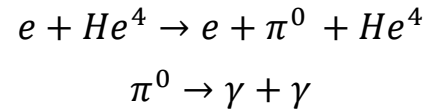An Analysis Update

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On behalf of eg6 run group

Report to Nuclear Physics Working Group March 5, 2025

# Introduction

$$e + He^4 \rightarrow e + \pi^0 + He^4$$

$$\pi^0 \rightarrow \gamma + \gamma$$

Detected electron and photons in Inner Calorimeter using accidental events

*Beam spin asymmetry in the electroproduction of a pseudoscalar meson or a scalar meson off the scalar target* Chueng-Ryong Ji, Ho-Meoyng Choi, Andrew Lundeen, and Bernard L. G. Bakker, Physical Review D 99, 116008 (2019)
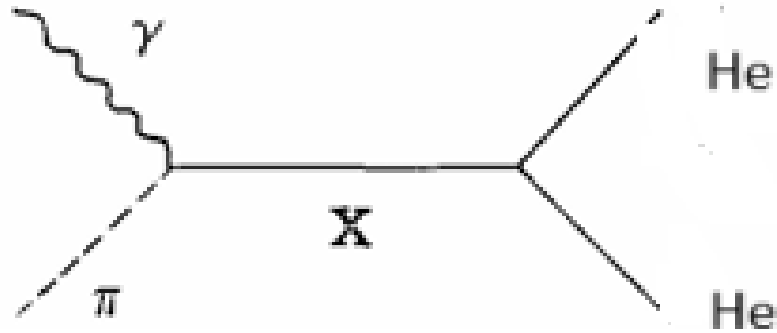
Beam Spin Asymmetry:

$$\frac{d\sigma^{PS}_{\lambda=+1} - d\sigma^{PS}_{\lambda=-1}}{d\sigma^{PS}_{\lambda=+1} + d\sigma^{PS}_{\lambda=-1}} = 0.$$

Asymmetry prediction assumes coherent reaction

# He$^4$ target

Zero Spin

Exchanged particle



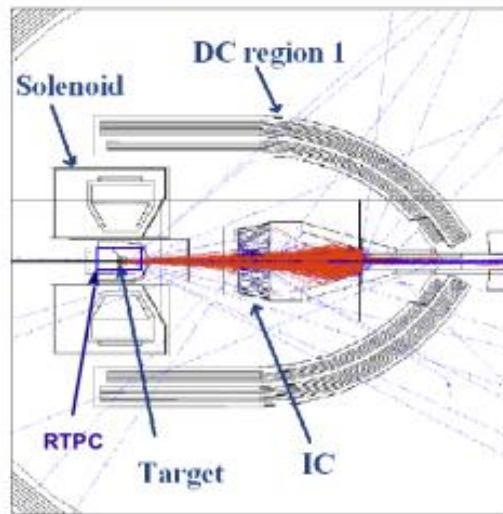(ϒπX) vertex, C parity, gamma=-1, pion=+1 therefore C parity of X = -1

(X He He) vertex, Isospin, He = 0, therefore isospin X = 0

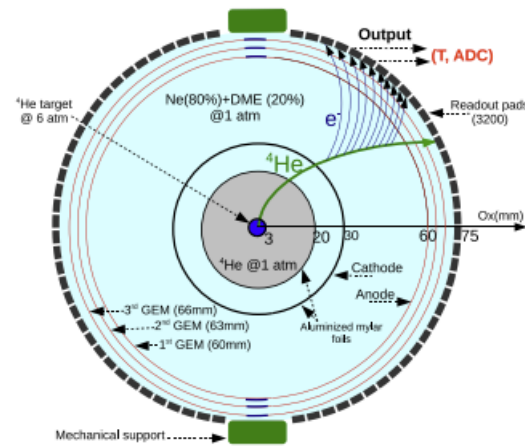X must be ω(782) or φ(1020)

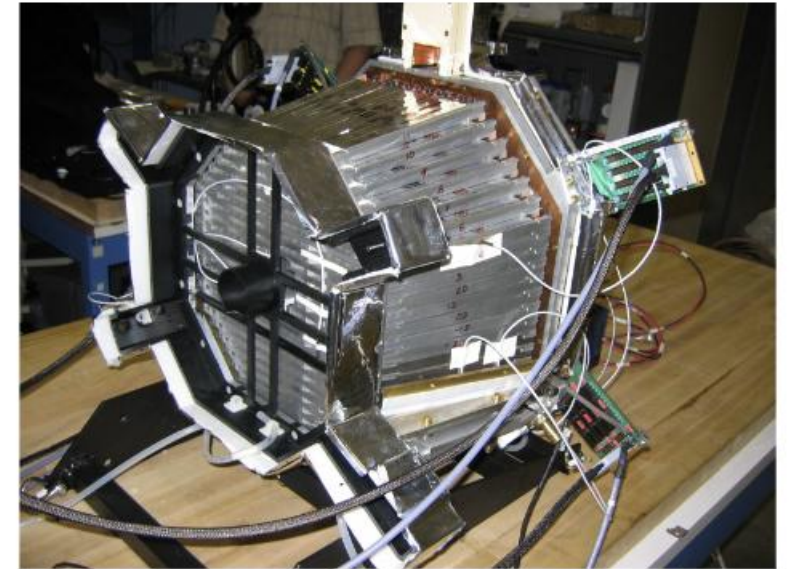|  | $I^G(J^{PC})$ |
|---|---|
| $\pi^{\pm}$ | $1^-(0^-)$ |
| $\pi^0$ | $1^-(0^{-+})$ |
| $\eta$ | $0^+(0^{-+})$ |
| $f_0(500)$ | $0^+(0^{++})$ |
| $\rho(770)$ | $1^+(1^{--})$ |
| $\omega(782)$ | $0^-(1^{--})$ |
| $\eta'(958)$ | $0^+(0^{-+})$ |
| $f_0(980)$ | $0^+(0^{++})$ |
| $a_0(980)$ | $1^-(0^{++})$ |
| $\varphi(1020)$ | $0^-(1^{--})$ |

# Detector



CLAS detector



Time Projection Chamber



Inner Calorimeter

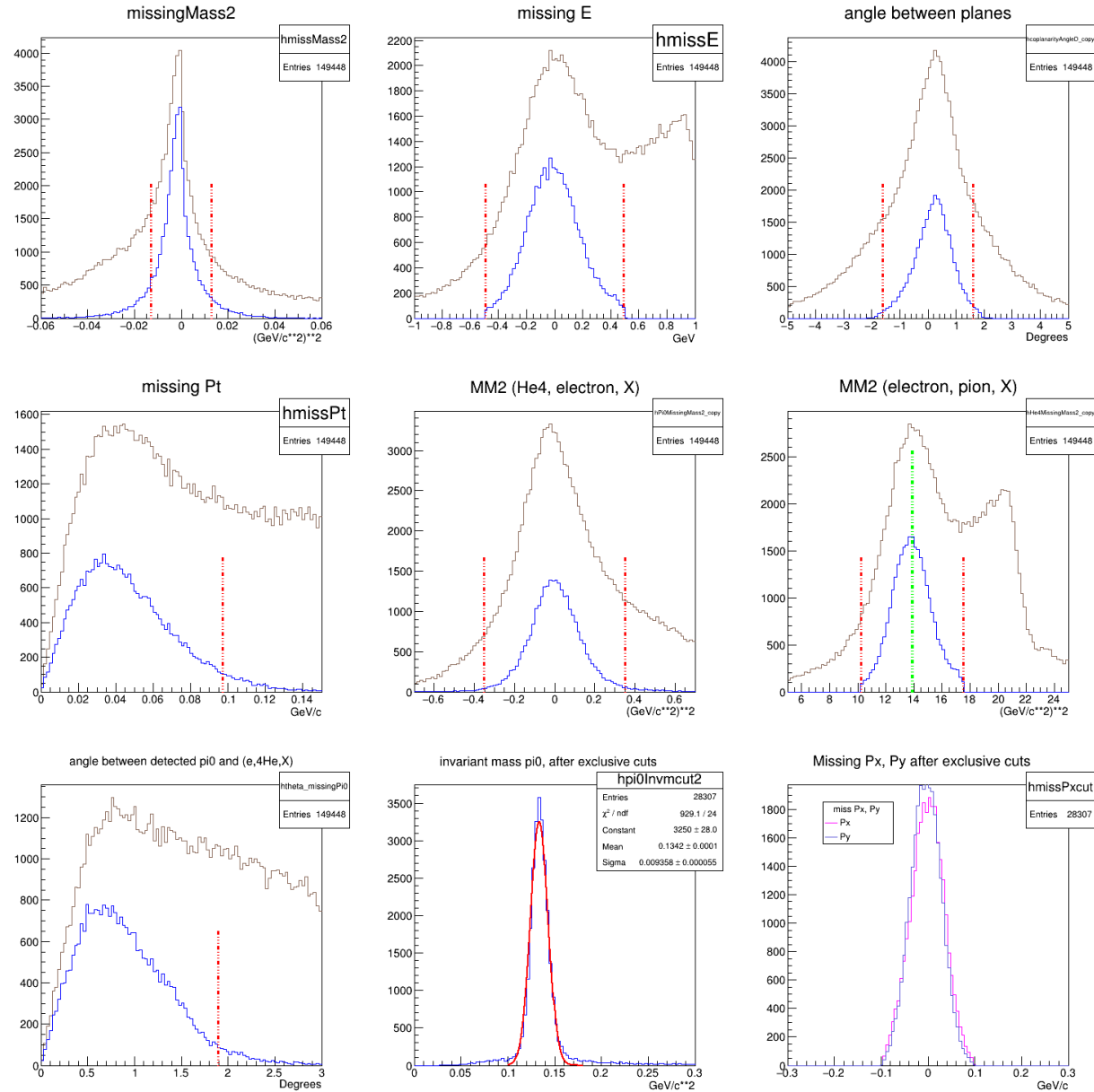# Exclusive Cuts

Missing Mass
Missing Energy
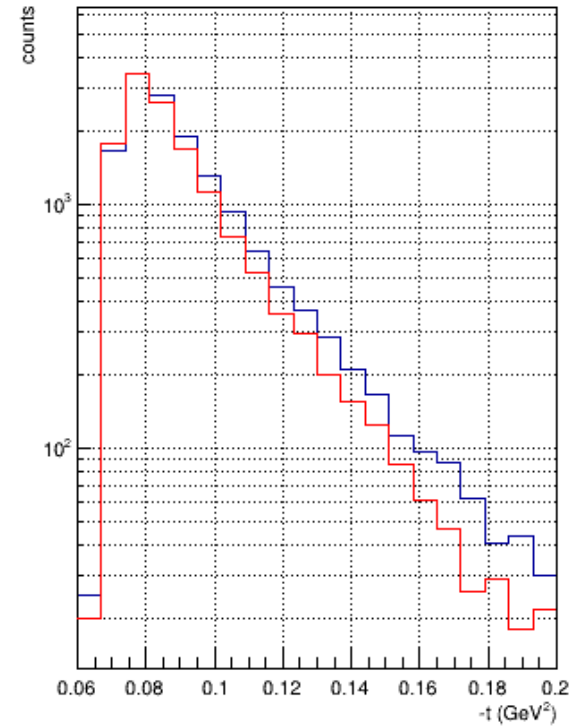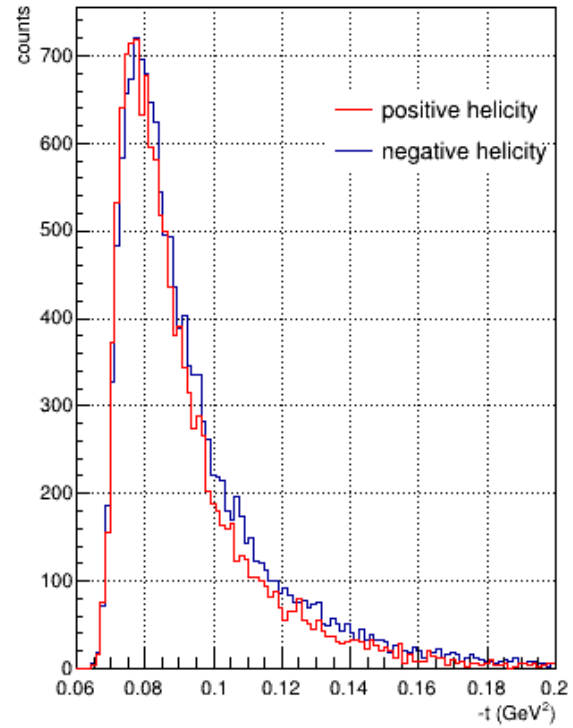Coplanar Angle
Missing Transverse Momentum
pi missing mass
He4 Missing Mass
Angle Between Missing Pi and Outgoing Pi

# Exclusive Cuts

# Event counts vs t for positive and negative helicities

# ASYMMETRIES

$$A_{LU} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

$\sigma^+$,cross section, polarization in the beam direction
$\sigma^-$ ,polarization opposite to beam direction

$$A_{LU} = \frac{1}{P_B} \frac{N^+ - N^-}{N^+ + N^-}$$

Assignment of kinematic value to binned data

$$\langle Q^2 \rangle = \frac{1}{N} \sum_{i=1}^{N} Q_i^2$$

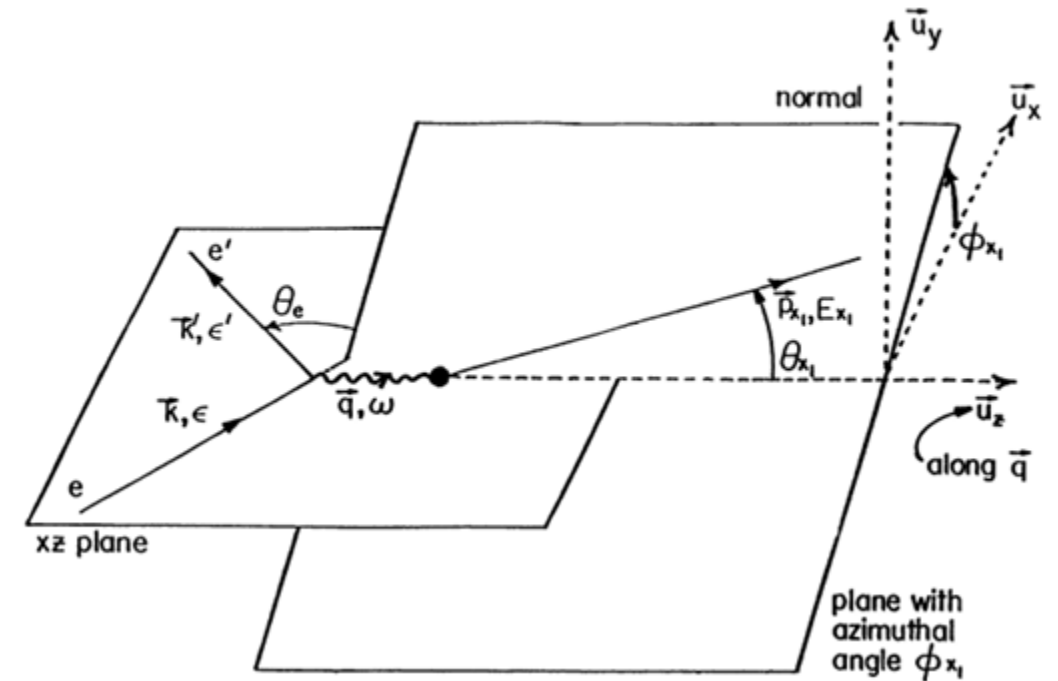$$\langle x_B \rangle = \frac{1}{N} \sum_{i=1}^{N} x_{Bi}$$

$$\langle t \rangle = \frac{1}{N} \sum_{i=1}^{N} t_i$$

# Binning

The cross section depends on
- $Q^2$, the square of the virtual photon's momentum, Q2
  where q = k -k'

- $x_B = Q^2/(2Pq)$

- $t=(P'-P)^2$

- $\phi_\pi$ phi angle of the outgoing pion



Definition of kinematic variables (Donnelly, 1986)

For coherent events the cross section depends on ɸ as (Hirenzaki, 1993)
$$1 - \epsilon \cos 2\varphi$$
where ɸ is the angle between the lepton and hadron planes and ε is the transverse linear polarization
of the virtual photon. Since there is no nuclear information in the ɸ dependence, the analysis looks at the
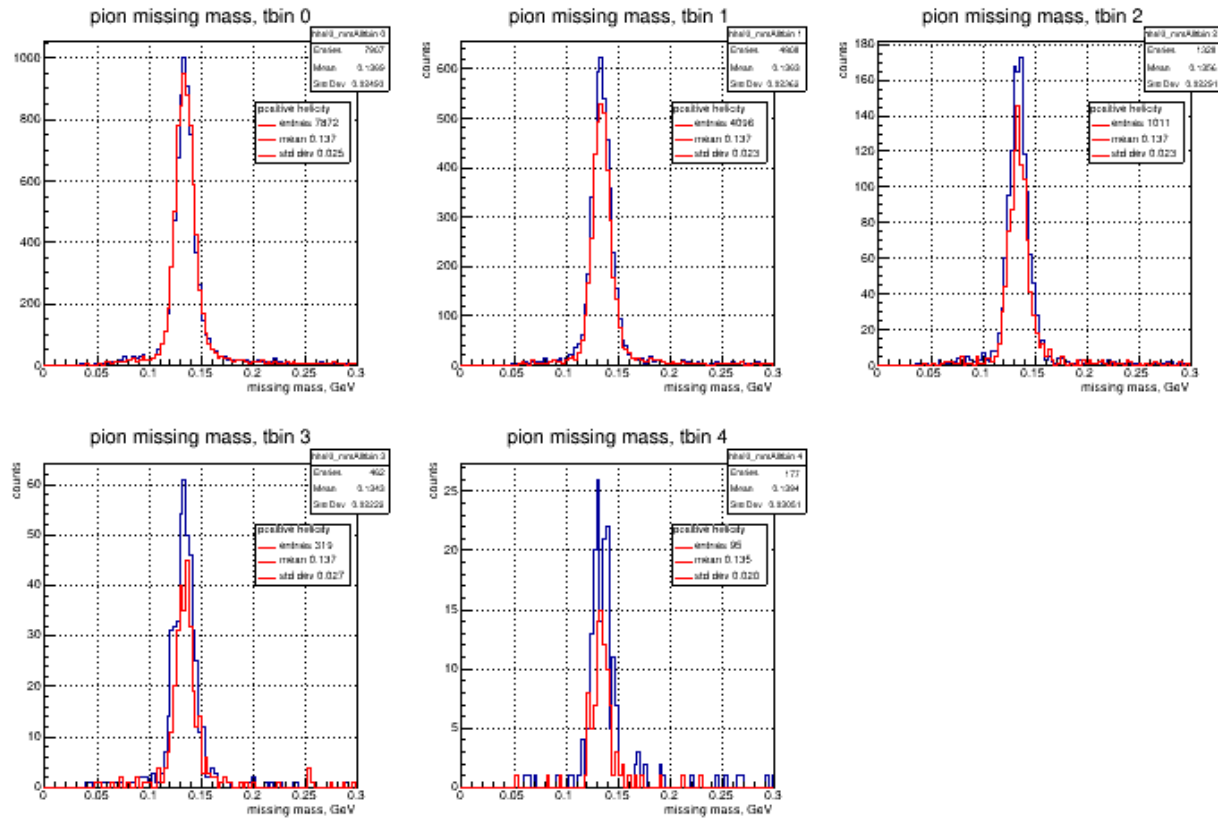asymmetry dependence on $Q^2$, $x_B$ and t

# Asymmetry with t binning
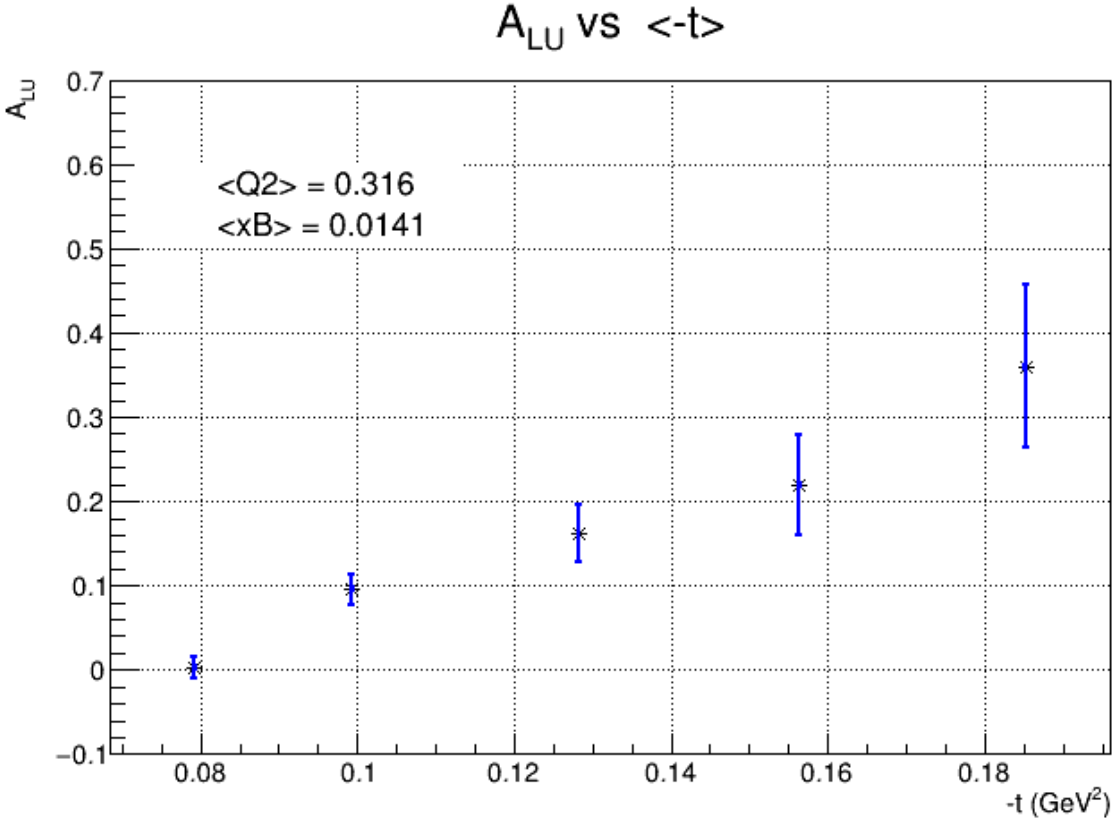


| t bin | t min | t max | \<t> | \<Q2> | \<xB> | asym | err |
|---|---|---|---|---|---|---|---|
| 0 | 0.06 | 0.088 | 0.079 | 0.315 | 0.0141 | 0.003 | 0.0135 |
| 1 | 0.088 | 0.116 | 0.099 | 0.319 | 0.0142 | 0.096 | 0.0178 |
| 2 | 0.116 | 0.144 | 0.128 | 0.306 | 0.0137 | 0.162 | 0.0345 |
| 3 | 0.144 | 0.172 | 0.156 | 0.307 | 0.0138 | 0.219 | 0.0592 |
| 4 | 0.172 | 0.2 | 0.185 | 0.29 | 0.0125 | 0.36 | 0.0966 |

# PiO invariant mass for the t bins

Two gamma invariant mass after exclusive cuts, t bins

# Q² xB t bins



Q2 vs xB

asym vs <-t>, Q2xB bin 1

asym vs <-t>, Q2xB bin 2

asym vs <-t>, Q2xB bin 3

asym vs <-t>, Q2xB bin 4
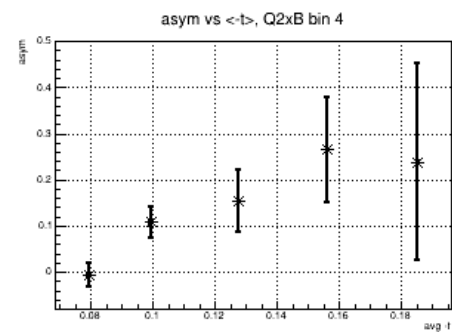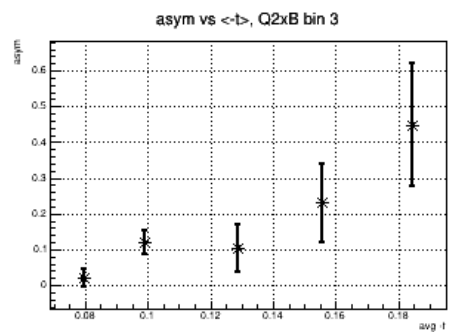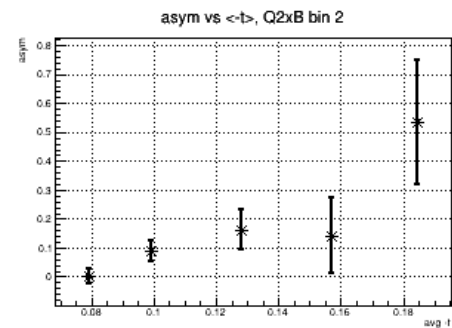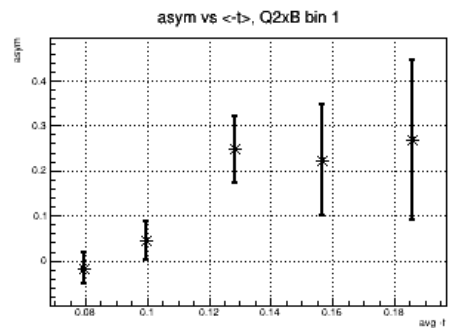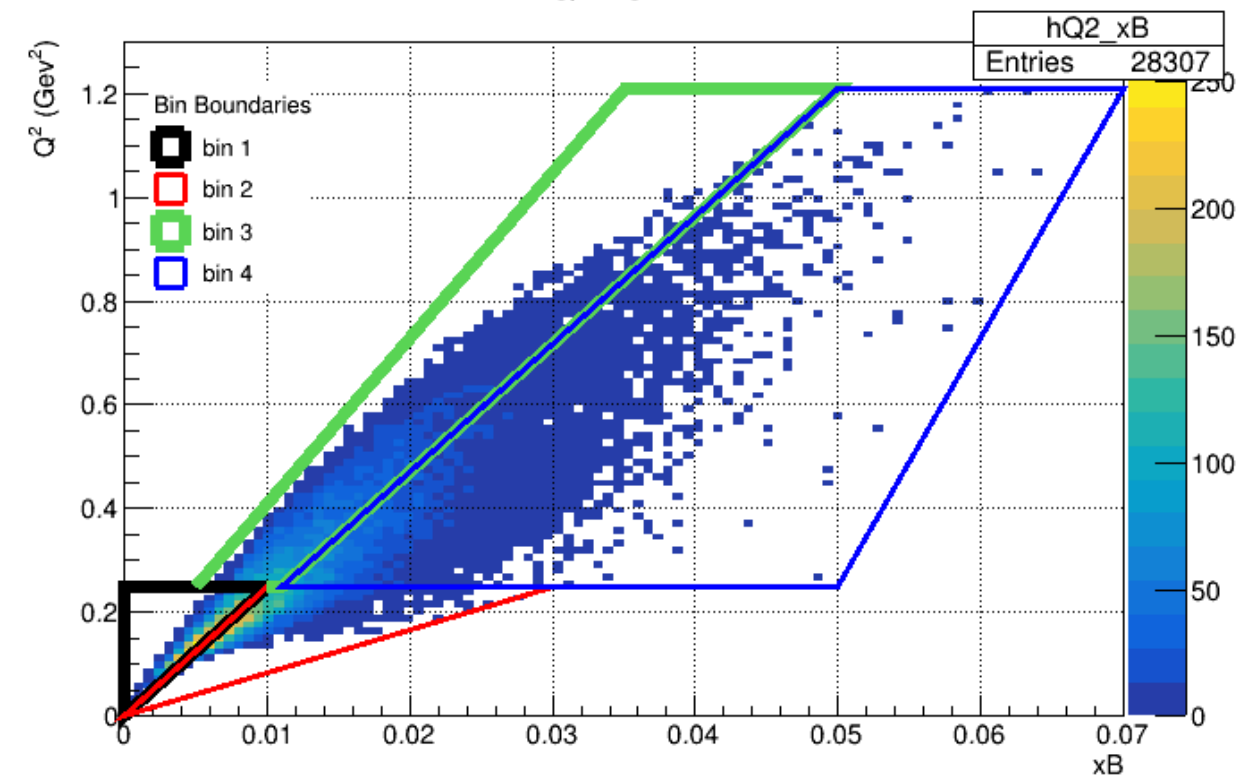
Graph
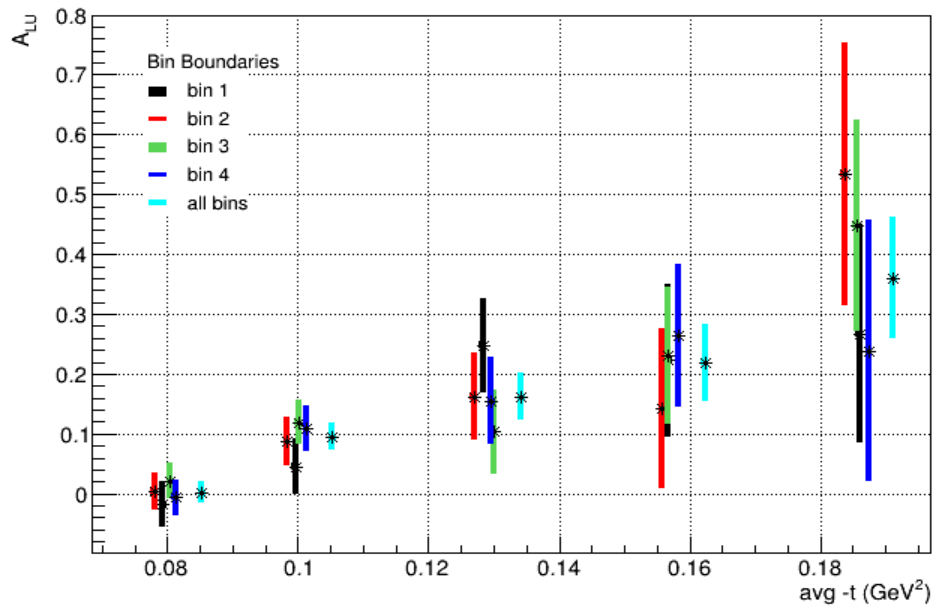
# Compare Bins

| tbin 1, tmin = 0.06. tmax = 0.088 | | |
|---|---|---|
| Q2xB bin | avgQ2 | avgxB |
| 1 | 0.172 | 0.0061 |
| 2 | 0.19 | 0.0097 |
| 3 | 0.413 | 0.0152 |
| 4 | 0.413 | 0.0216 |

| tbin 2, tmin = 0.088. tmax = 0.116 | | |
|---|---|---|
| Q2xB bin | avgQ2 | avgxB |
| 1 | 0.168 | 0.0059 |
| 2 | 0.187 | 0.0094 |
| 3 | 0.42 | 0.0155 |
| 4 | 0.427 | 0.0223 |

| tbin 3, tmin = 0.116. tmax = 0.144 | | |
|---|---|---|
| Q2xB bin | avgQ2 | avgxB |
| 1 | 0.159 | 0.0055 |
| 2 | 0.187 | 0.0095 |
| 3 | 0.427 | 0.0158 |
| 4 | 0.415 | 0.0222 |

| tbin 4, tmin = 0.144. tmax = 0.172 | | |
|---|---|---|
| Q2xB bin | avgQ2 | avgxB |
| 1 | 0.15 | 0.0053 |
| 2 | 0.184 | 0.0092 |
| 3 | 0.406 | 0.015 |
| 4 | 0.443 | 0.0238 |

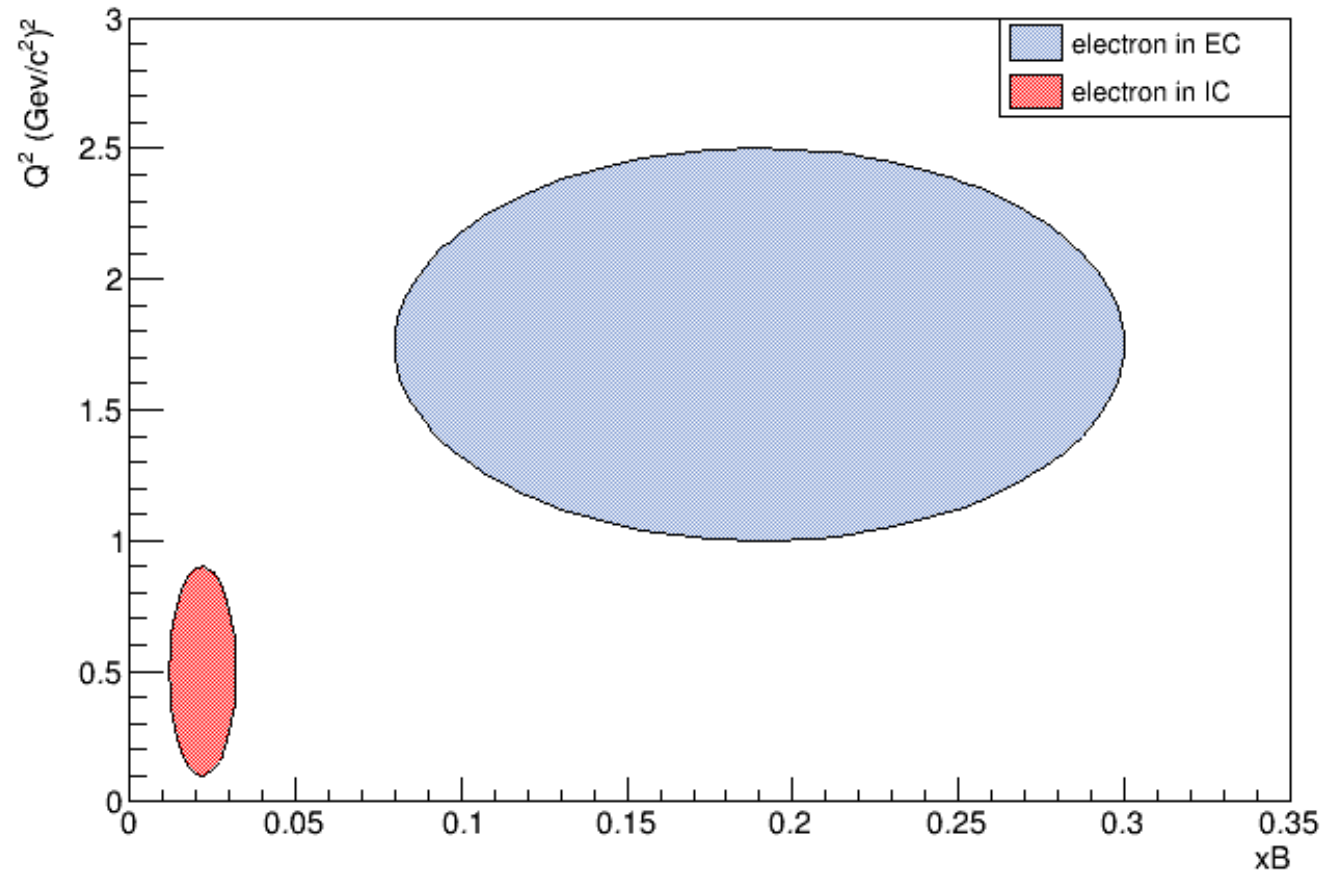| tbin 5, tmin = 0.172. tmax = 0.200 | | |
|---|---|---|
| Q2xB bin | avgQ2 | avgxB |
| 1 | 0.147 | 0.0051 |
| 2 | 0.175 | 0.0086 |
| 3 | 0.393 | 0.0148 |
| 4 | 0.448 | 0.0233 |

# PiO invariant mass for Q2 xB t bins
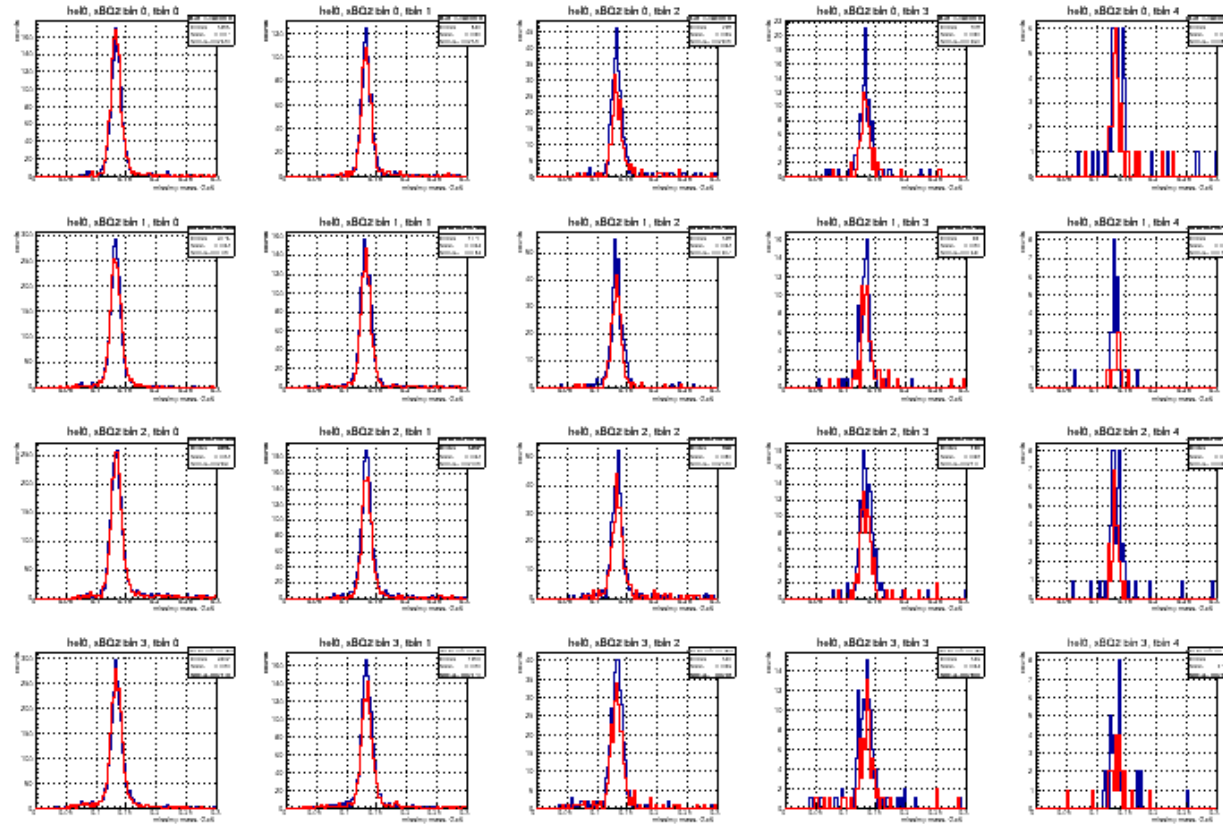
# Other eg6 measurements

- Phd Theses, detected outgoing electron in CLAS detector

Bayram Torayev

Frank Cao

# Conclusion

Working on analysis note

Have received comments by review committee

Slow but steady progress