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 July 10, 2025

Introduction

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

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

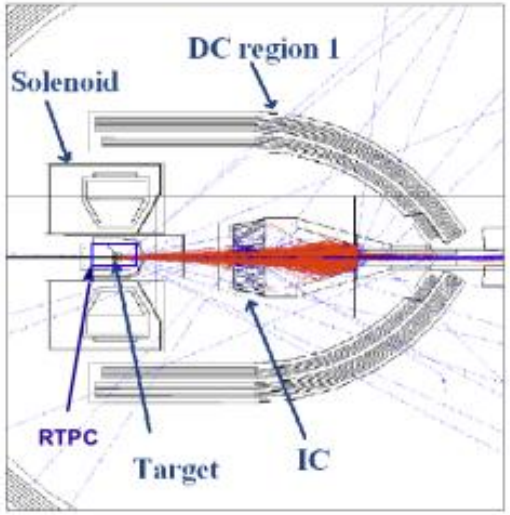
Detected electron and photons in Inner Calorimeter using accidental events

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)

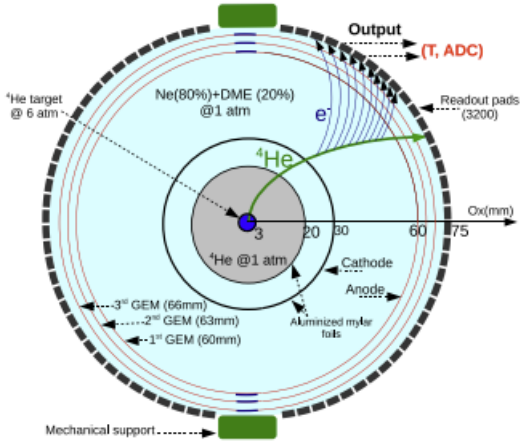
Beam Spin Asymmetry:

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

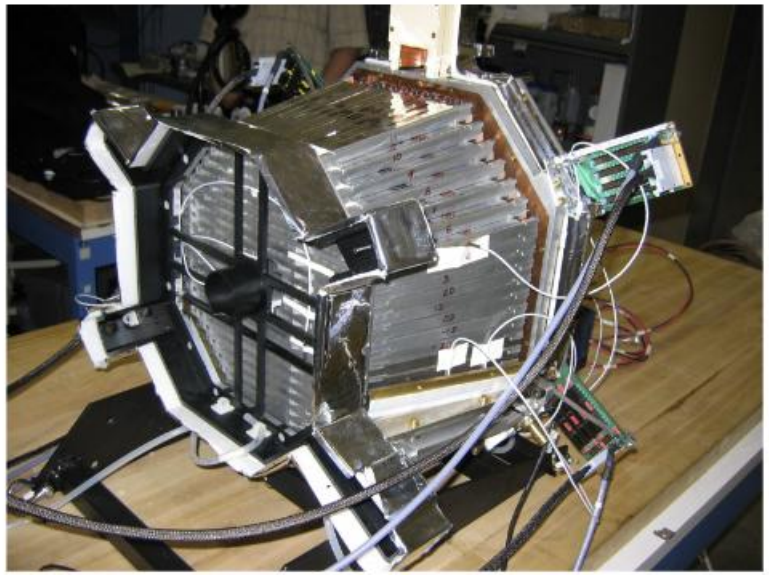
Detector



CLAS detector



Time Projection Chamber



Inner Calorimeter

ASYMMETRIES

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

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

Assignment of kinematic value to bin

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

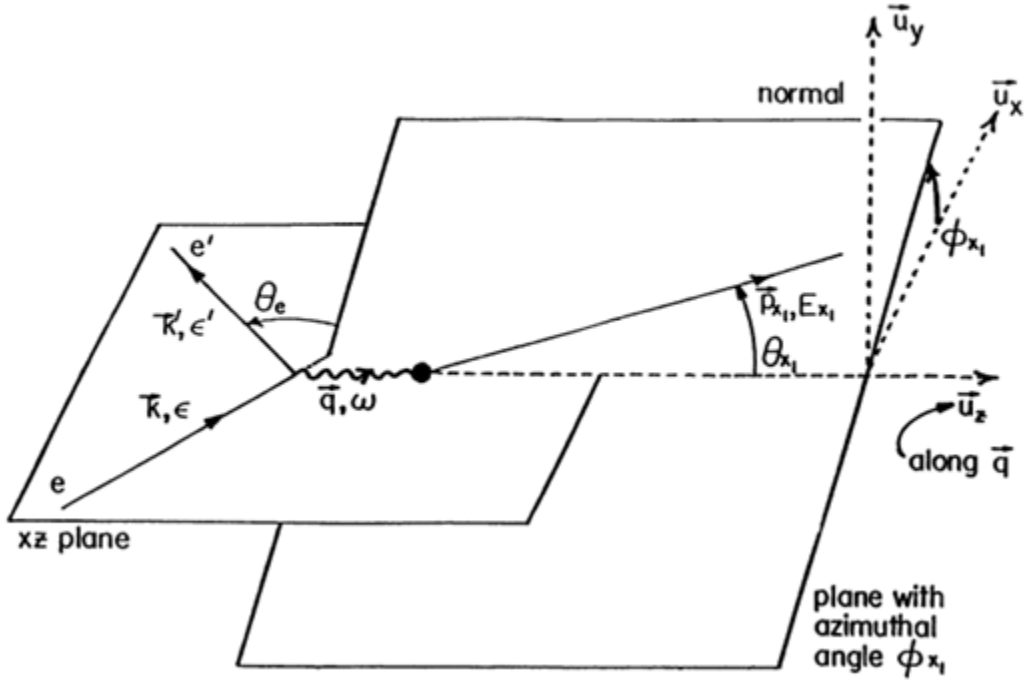
$$\langle x_B \rangle = \frac{1}{N}\sum_{i=1}^{N} x_{Bi}$$

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

Binning

The cross section depends on

- Q^2, the square of the virtual photon's momentum, Q2 where q = k -k’
- $x_B = Q^2/(2Pq)$
- $t=(P'-P)^2$
- ϕ_π phi angle of the outgoing pion



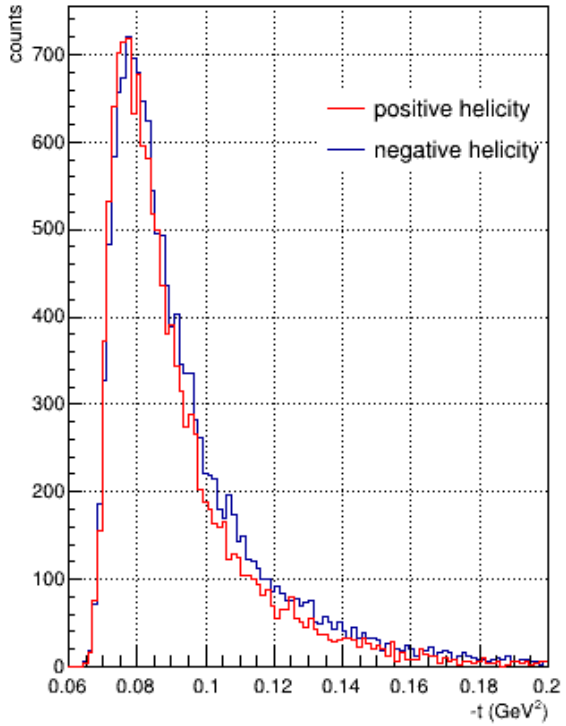
Definition of kinematic variables (Donnelly, 1986)

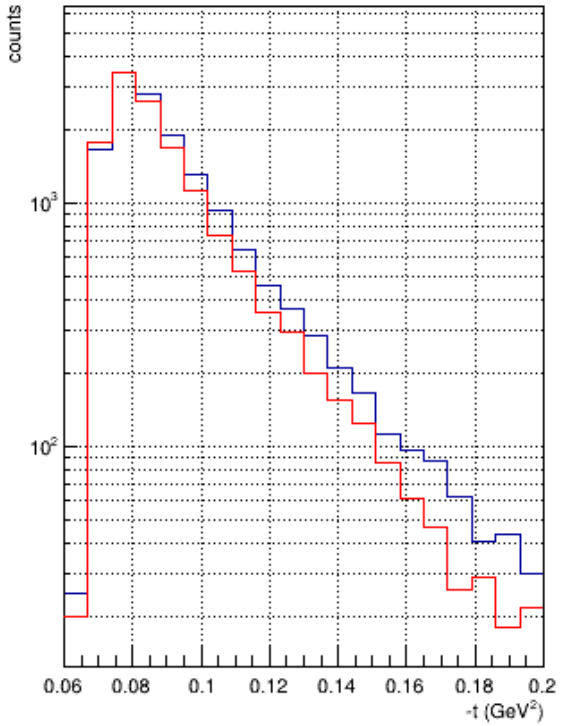
For coherent events the cross section depends on ϕ as (Hirenzaki, 1993)

$$1 - \epsilon \cos 2\varphi$$

where ϕ 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 ϕ dependence, the analysis looks at the asymmetry dependence on Q^2, x_B and t

Asymmetry with t binning

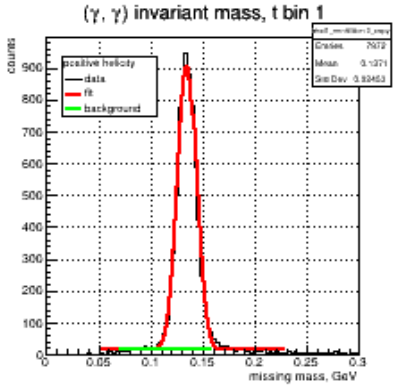


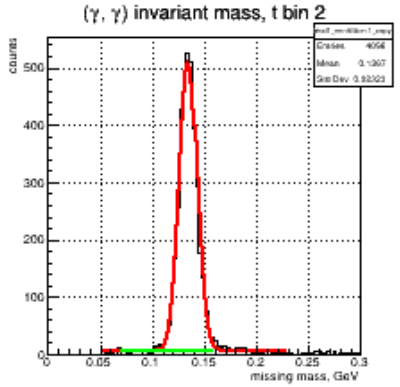


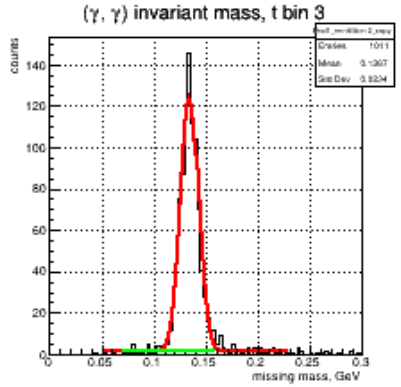
t bin	t min	t max	<t>	<Q2>	<xB>
0	0.06	0.088	0.079	0.315	0.0141
1	0.088	0.116	0.099	0.319	0.0142
2	0.116	0.144	0.128	0.306	0.0137
3	0.144	0.172	0.156	0.307	0.0138
4	0.172	0.2	0.185	0.29	0.0125

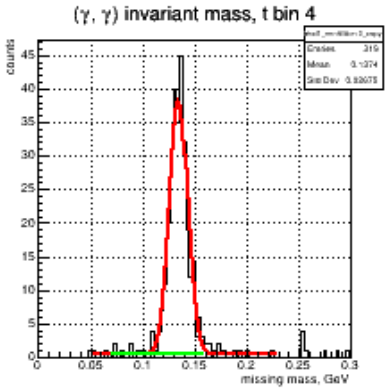
(ϒ,ϒ) invariant mass, t bins

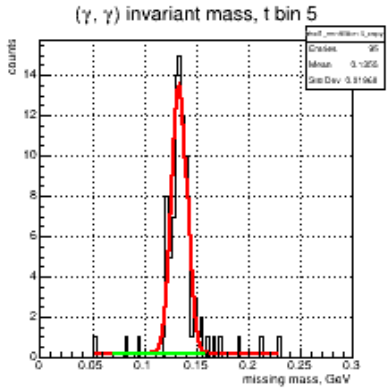
Positive helicity



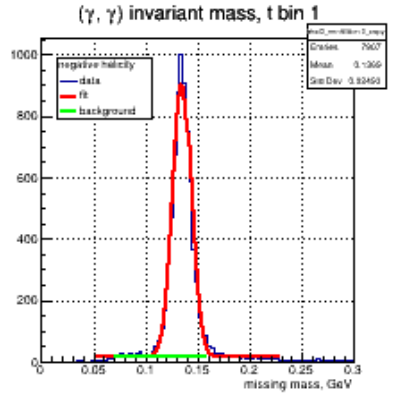


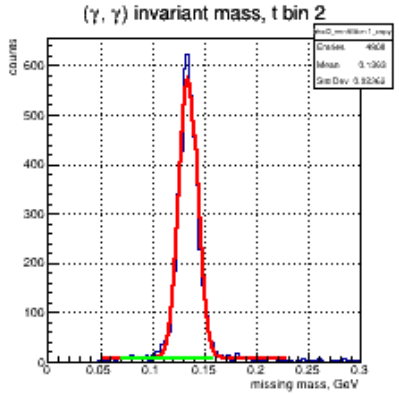


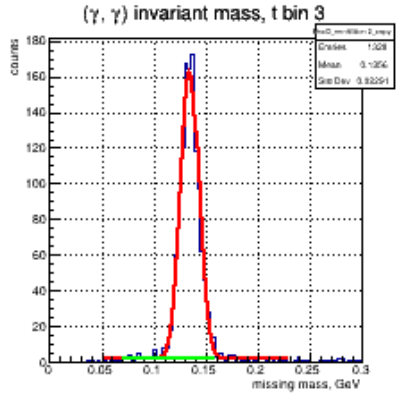


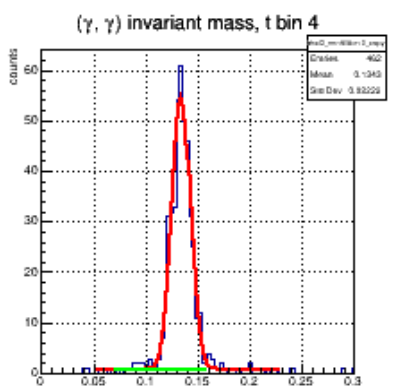


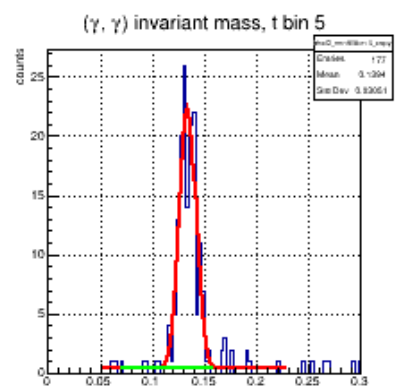
Negative helicity











Fit to t binned data

- Counts in each bin fit by a gaussian (signal) and a line (background)
- Different lines were fit with no significant change
- An error for the signal was determined from the errors on the fit
- A_{LU} calculated from signals for positive and negative helicities

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

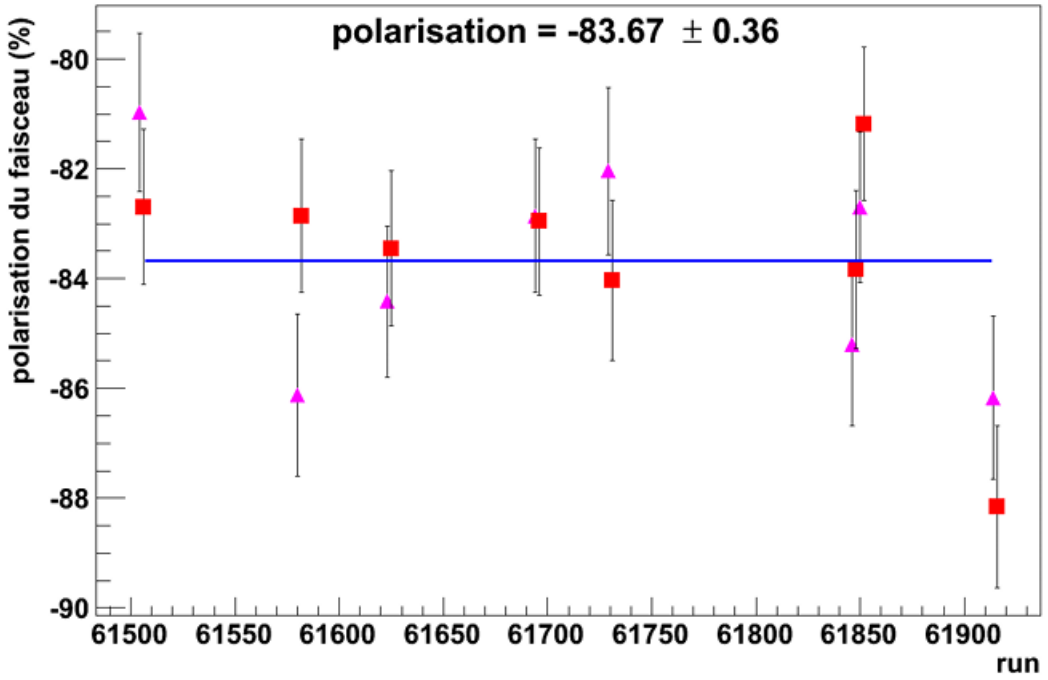
$$(\delta A_{LU})^2 = \left(\frac{1}{P_B^2}\right)\left(\left(\frac{\partial A_{LU}}{\partial N^+}\right)^2 (\delta N^+)^2 + \left(\frac{\partial A_{LU}}{\partial N^-}\right)^2 (\delta N^-)^2 + 2\frac{\partial A_{LU}}{\partial N^+}\frac{\partial A_{LU}}{\partial N^-}\delta N^+ \delta N^- \rho_{N^+N^-}\right)$$

T bin	tavg	Helicity	counts	signal	Error	ALU	Error
1	0.079	+	7872	6879	131	-0.014	0.020
		-	7907	6716	132		
2	0.1	+	4096	3622	95	0.094	0.026
		-	4808	4239	103		
3	0.128	+	1011	893	48	0.173	0.051
		-	1328	1195	53		
4	0.157	+	319	278	26	0.222	0.091
		-	462	405	32		
5	0.186	+	95	83	14	0.335	0.152
		-	177	147	18		

Systematic errors

1. Beam polarization

During the CLAS-EG6 experiment, the beam polarization was measured multiple times using the Hall-B Møller polarimeter, which determines polarization based on the angular distribution of Møller-scattered electrons. These measurements produced a mean beam polarization value of **83.67%** through a linear fit analysis.



Beam polarization measurements during CLAS-EG6 run period. The red squares are the measurements with negative current in the Helmholtz coils of the polarimeter, while the purple triangles were with positive current. The figure is taken from the Y. Perrin, "Etude de la structure partonique du noyau d'hlium", CLAS-thesis, 2012.

Systematic errors, exclusive cuts

Nominal values	Minimum	maximum
missing mass	-0.013	0.013
missing energy	-0.493	0.493
coplanar angle	-1.6	1.6
total transverse momentum	0	0.097
mm2 (He,electron,X)	-0.352	0.352
mm2(electron, pion, X)	-3.633	3.633
angle between detected and constructed pi0	0	1.897

Cut Width extended by 20%	Minimum	maximum
missing mass	-0.0156	0.0156
missing energy	-0.5916	0.5916
coplanar angle	-1.92	1.92
total transverse momentum	0	0.1164
mm2 (He,electron,X)	-0.4224	0.4224
mm2(electron, pion, X)	-4.3596	4.3596
angle between detected and constructed pi0	0	2.2764

Cut width reduced by 20%	Minimum	maximum
missing mass	-0.0104	0.0104
missing energy	-0.3944	0.3944
coplanar angle	-1.28	1.28
total transverse momentum	0	0.0776
mm2 (He,electron,X)	-0.2816	0.2816
mm2(electron, pion, X)	-2.9064	2.9064
angle between detected and constructed pi0	0	1.5176

Table 2Exclusive cuts

The error associated with the exclusive cuts was determined by calculating the asymmetry for values of the exclusive cuts with a narrower and wider range than the nominal values. See tables at left.

Then for each t bin, the systematic error for the asymmetry was set equal to the difference in asymmetries for the two calculations

Systematic errors

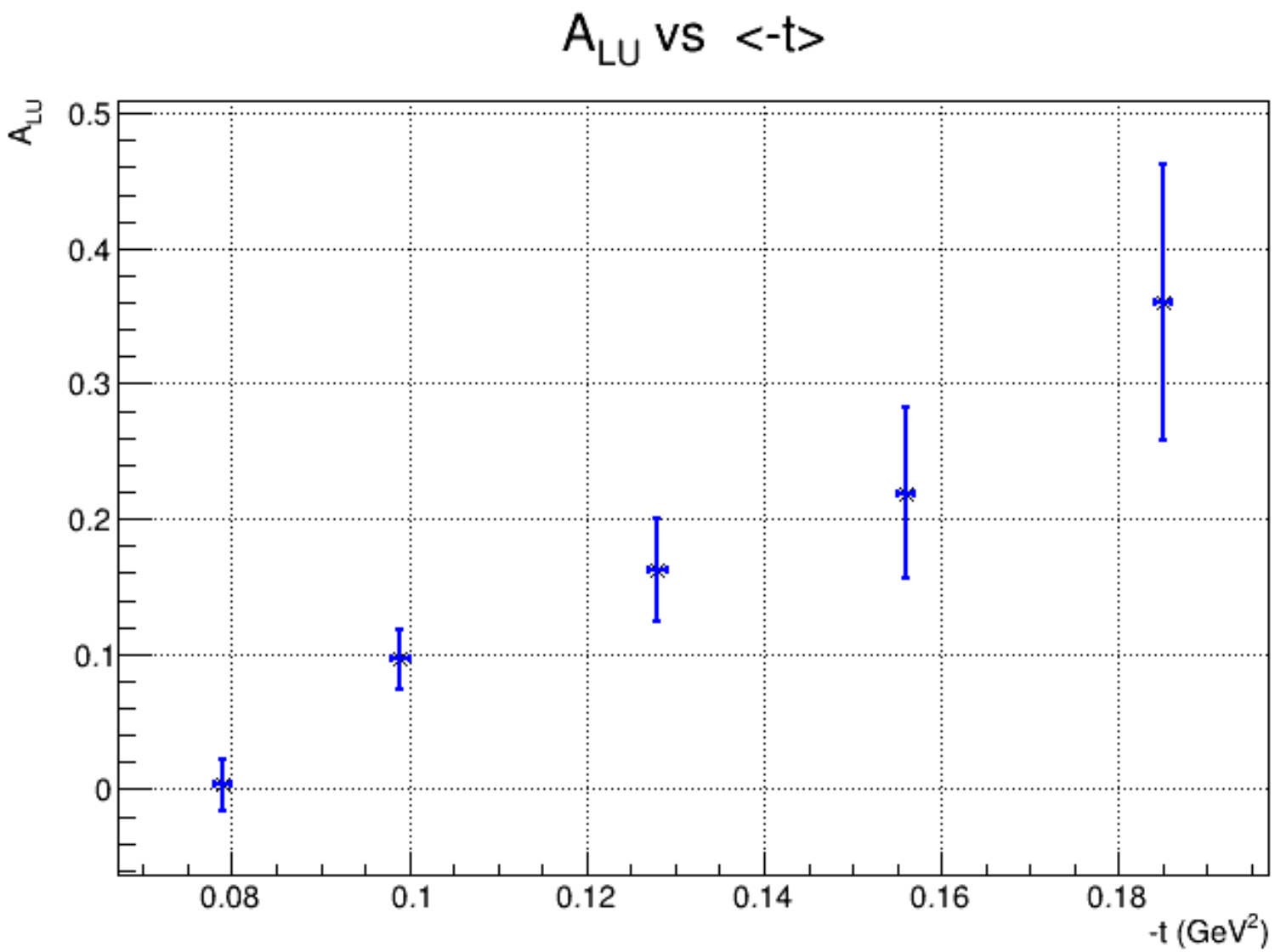
Particle ID

- Background in (ϒ,ϒ) invariant mass plots is a result of misidentification of events
- The shape of the spectra for positive and negative helicities is the same for each t bin
- Let η be the systematic error associated with the background subtraction, then

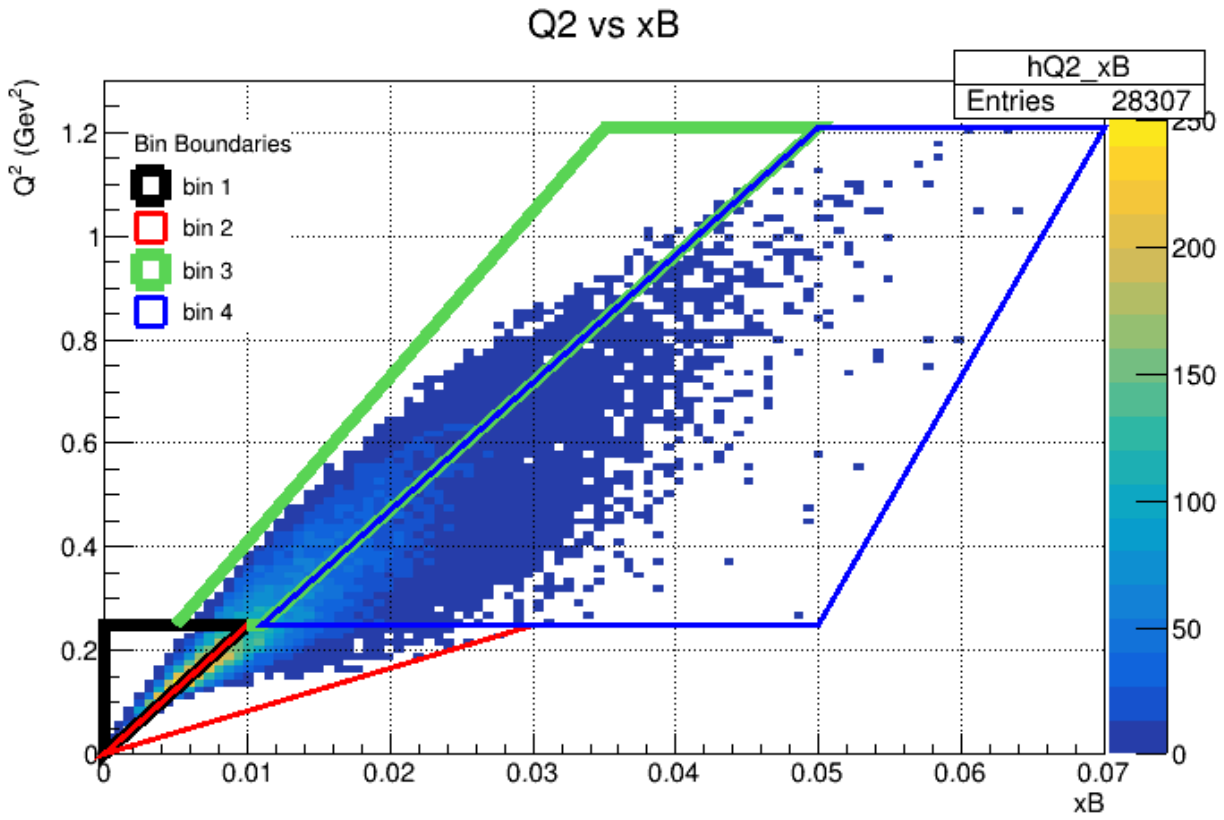
$$A_{LU} = \frac{\eta N^+ - \eta N^-}{\eta N^+ + \eta N^+} = \frac{N^+ - N^-}{N^+ + N^+}$$

Radiative corrections

- Radiative photons modify the reconstructed virtual photon's 4-momentum.
- Exclusive cuts suppress the fraction of radiative events in the final sample
- Corrections expected to be small for exclusive beam spin asymmetries


A_{LU} vs <-t>
A_{LU}
0.5
0.4
0.3
0.2
0.1
0
0.08
0.1
0.12
0.14
0.16
0.18
-t (GeV^2)

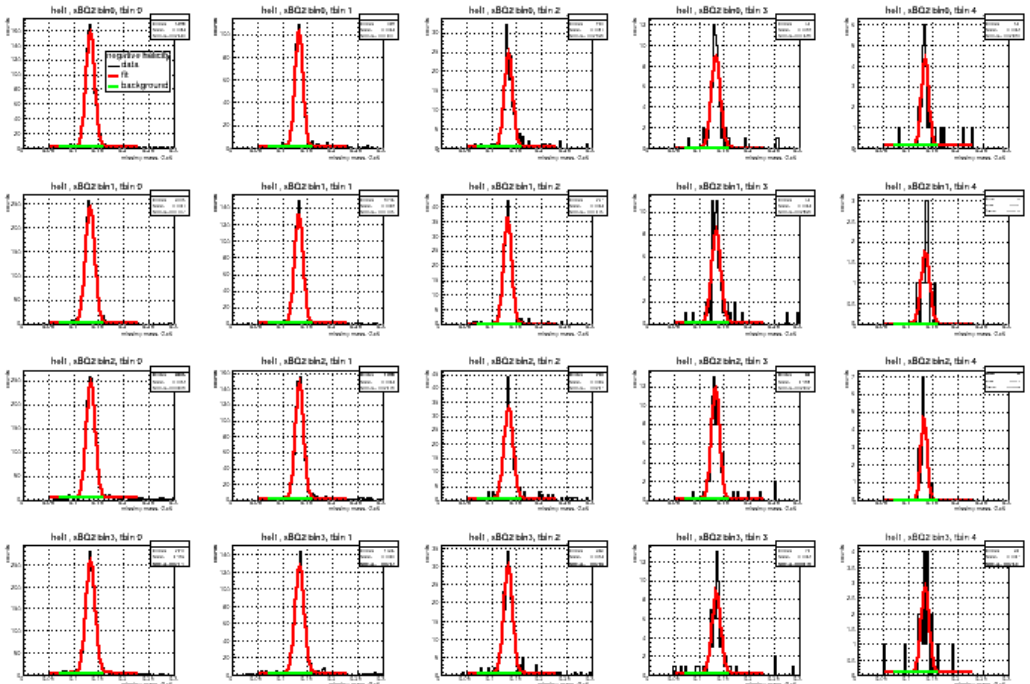
Q2, xB, t bins



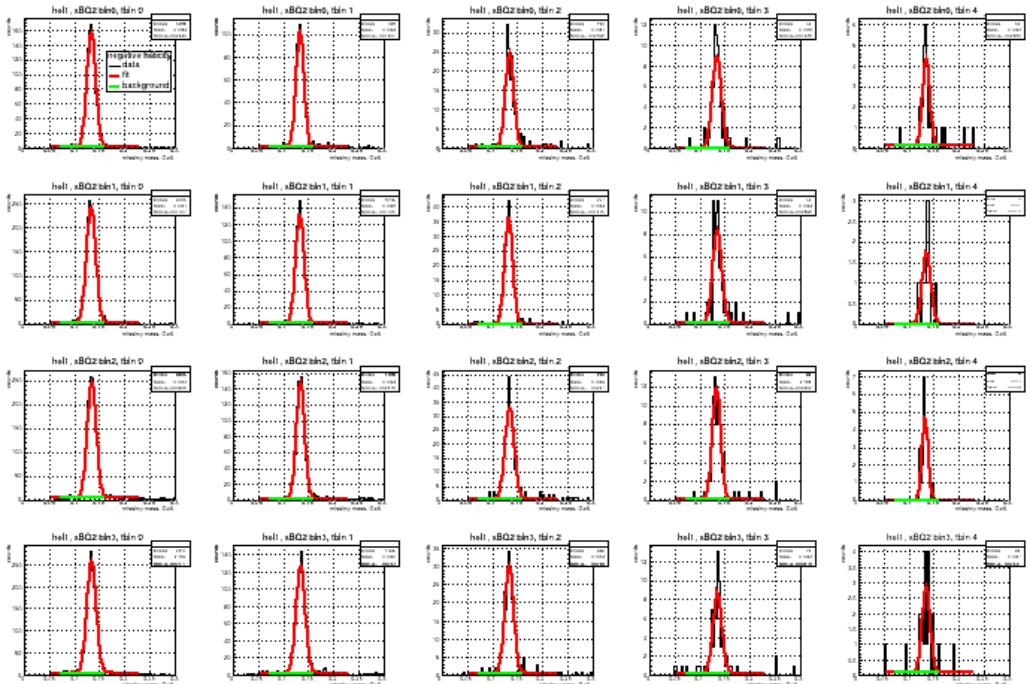
Q2xB Bin	t bin	t min	t max	<t>	<Q2>	<xB>
1	1	0.06	0.088	0.079	0.172	0.0061
1	2	0.088	0.116	0.1	0.168	0.0059
1	3	0.116	0.144	0.128	0.159	0.0055
1	4	0.144	0.172	0.157	0.15	0.0053
1	5	0.172	0.2	0.186	0.147	0.0051
2	1	0.06	0.088	0.079	0.19	0.0097
2	2	0.088	0.116	0.099	0.187	0.0094
2	3	0.116	0.144	0.128	0.187	0.0095
2	4	0.144	0.172	0.157	0.184	0.0092
2	5	0.172	0.2	0.185	0.175	0.0086
3	1	0.06	0.088	0.079	0.413	0.0152
3	2	0.088	0.116	0.099	0.42	0.0155
3	3	0.116	0.144	0.129	0.427	0.0158
3	4	0.144	0.172	0.156	0.406	0.015
3	5	0.172	0.2	0.185	0.393	0.0148
4	1	0.06	0.088	0.079	0.413	0.0216
4	2	0.088	0.116	0.099	0.427	0.0223
4	3	0.116	0.144	0.128	0.415	0.0222
4	4	0.144	0.172	0.156	0.443	0.0238
4	5	0.172	0.2	0.185	0.448	0.0233

(ϒ,ϒ) invariant mass

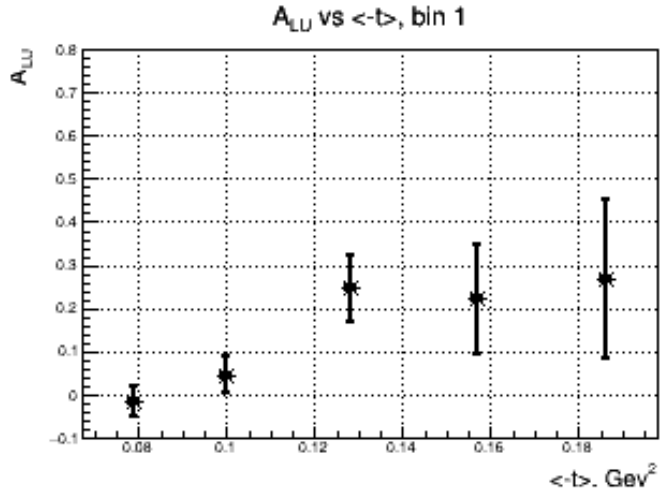
Positive helicity

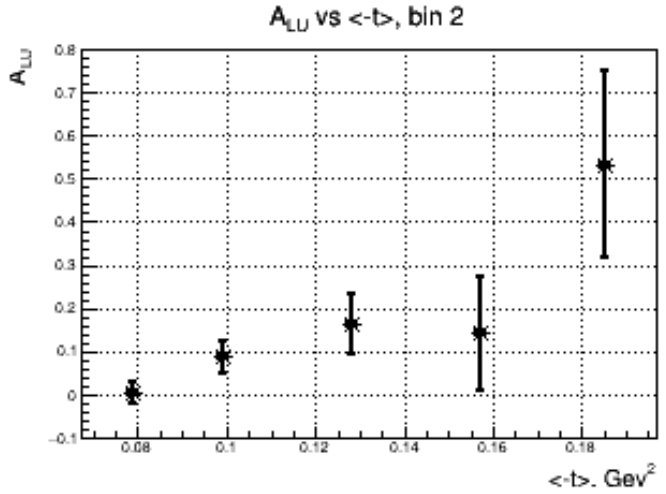


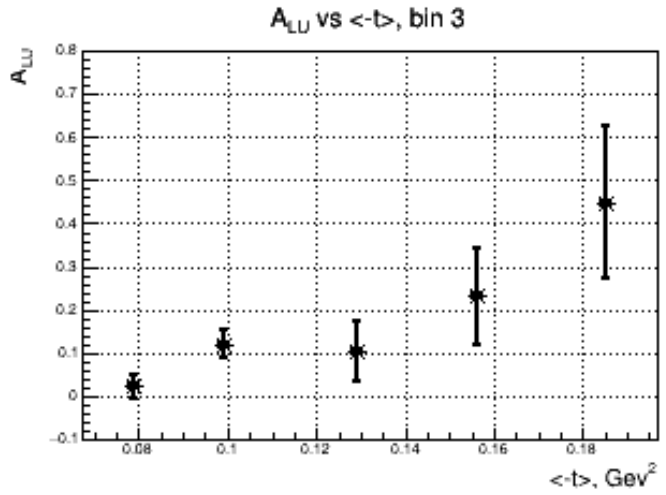
Negative helicity

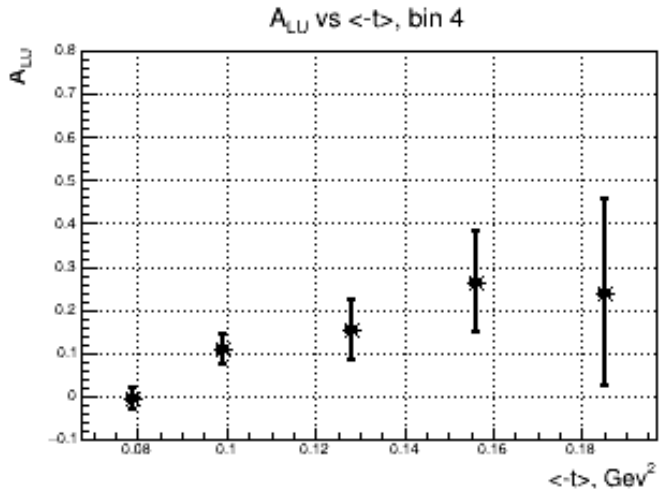


A_{LU} for Q2, xB, t binning

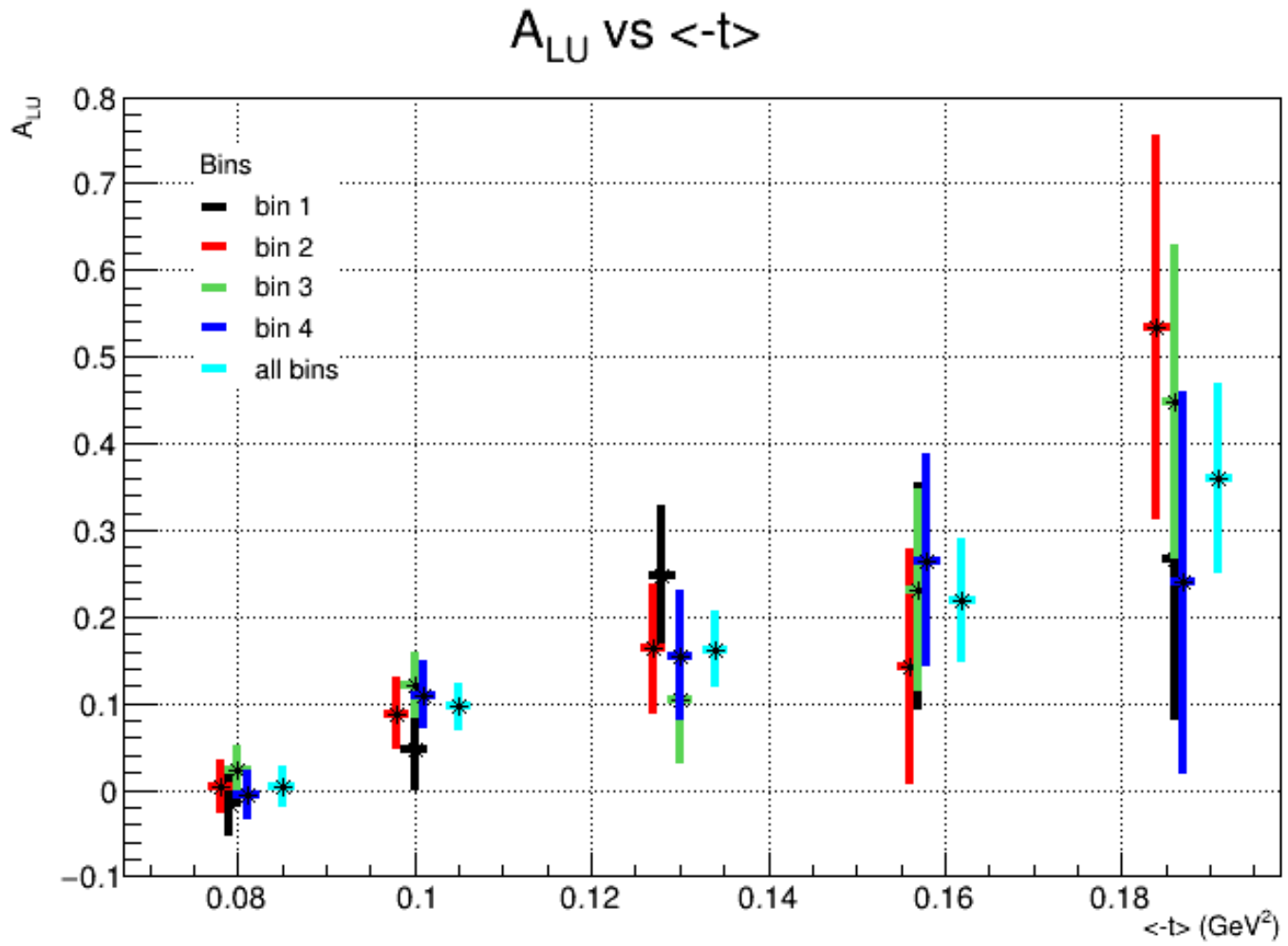








Comparison of A_{LU} for different binning



Conclusion

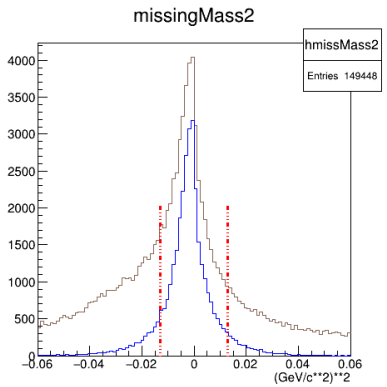
- A_{LU} has a strong dependence on t and, at best, a weak dependence on Q^2 and x_B
- Working on update to analysis note with changes recommended by review committee
- Analysis has shown the feasibility of analyzing events with electron detected in IC
  - Search for hybrid meson, one of original goals of eg6 experiment
  - Other channels in eg6 data
  - eg2 used IC with proton target
  - As a limited member of CLAS, will need continued access to data

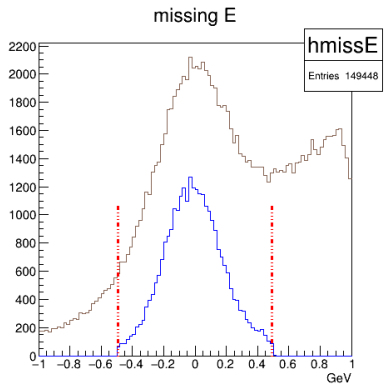
Backup slides

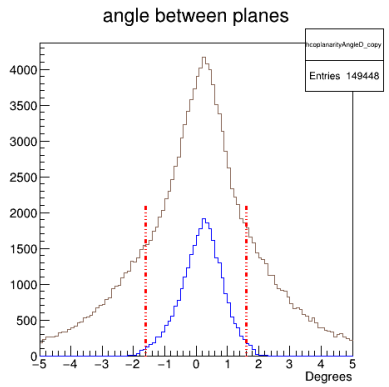
Exclusive Cuts

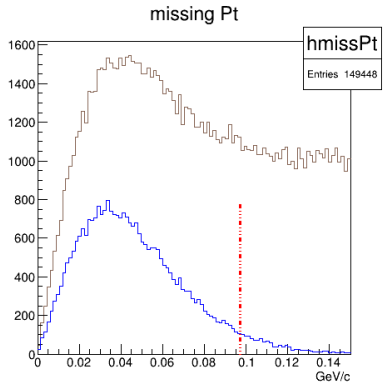
Missing Mass
Missing Energy
Coplanar Angle
Missing Transverse Momentum
pi missing mass
He4 Missing Mass
Angle Between Missing Pi and Outgoing Pi

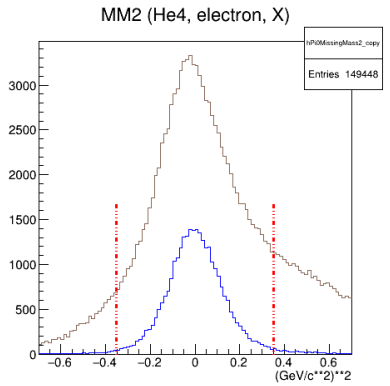
Exclusive Cuts

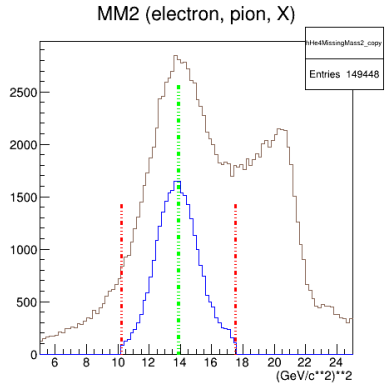


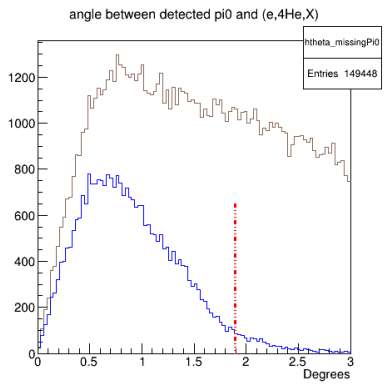


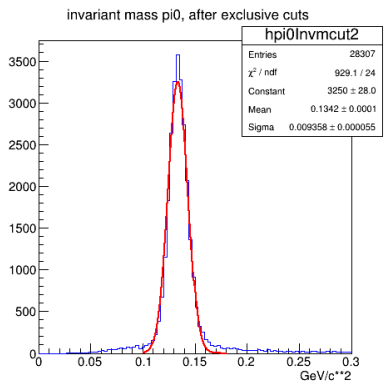


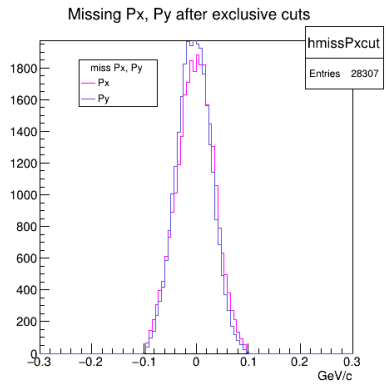












Final results, t binning

$$\sigma_{total} = \sqrt{\sigma^2_{statisical\ error} + \sigma^2_{systematic\ error}}$$

t bin	t avg	asym	stat err	sys err	toterr
0	0.079	0.003	0.014	0.014	0.019
1	0.099	0.096	0.018	0.013	0.022
2	0.128	0.162	0.035	0.016	0.038
3	0.156	0.219	0.059	0.023	0.064
4	0.185	0.360	0.097	0.034	0.102