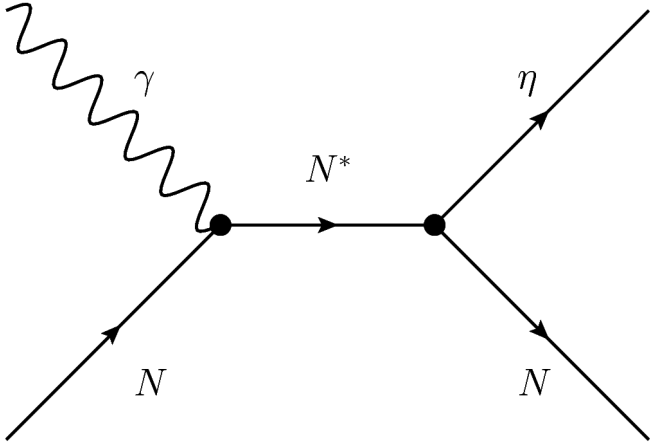
Spin Observables in η Meson Photoproduction from the Proton



Ross Tucker

Arizona State University

Advisor: Barry Ritchie

Background

- Nucleon resonances
- Eta photoproduction
- Polarization observables

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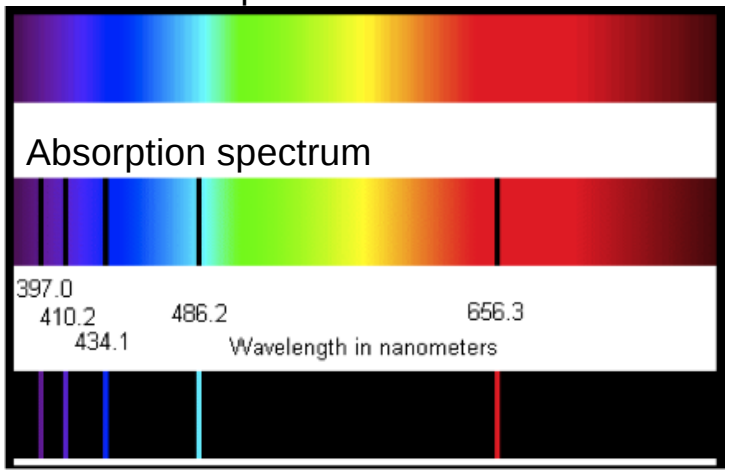
Background: nucleon resonances

Continuous spectrum



Emission spectrum

Atomic spectroscopy: $H\,\gamma \rightarrow H^* \rightarrow H\,\gamma$

- Vital tool in determining QM description of the atom

Baryon Spectroscopy: $p\,\gamma \rightarrow p^* \rightarrow p\,X$

- Many more states predicted than observed
- Many different models- each predicts a different set of resonances
- We wish to know mass, angular momentum, etc

Observed vs predicted resonances of $\gamma\,p \rightarrow p\,\eta$

*N** state	PDG '10	Mass (MeV/c²)	AK '05	MAID '02	LS '02
P_{11}	****	1440			**Y**
D_{13}	****	1520	**Y**	**Y**	**Y**
S_{11}	****	1535		**Y**	**Y**
S_{11}	****	1650	**Y**	**Y**	**Y**
D_{15}	****	1675	**Y**	**Y**	**Y**
F_{15}	****	1680	**Y**	**Y**	**Y**
D_{13}	***	1700	**Y**	**Y**	**Y**
P_{11}	***	1710		**Y**	**Y**
P_{13}	****	1720	**Y**	**Y**	**Y**
P_{11}		1840	**Y**		
D_{13}		1875	**Y**		
P_{13}	**	1900			**Y**
F_{15}	***	1900	**Y**		**Y**
F_{17}	**	1990			
D_{15}		2070	**Y**		
D_{13}	**	2080	**Y**		
S_{11}	*	2090			
P_{11}	*	2200	**Y**		

Legend:
* indicates confidence in that resonance
Y indicates resonance predicted by theoretical model

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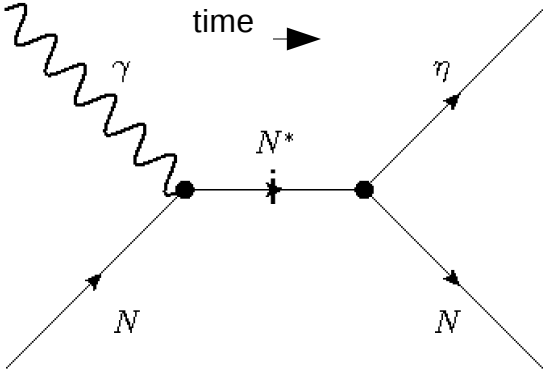
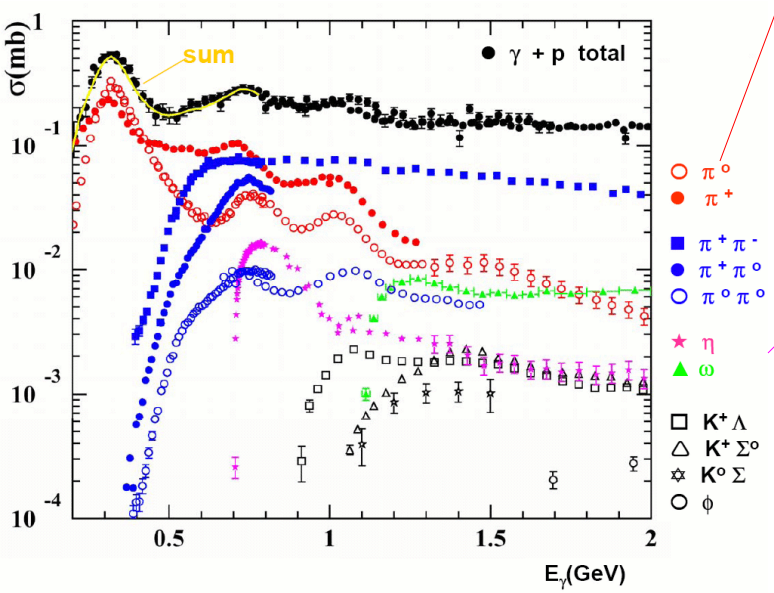
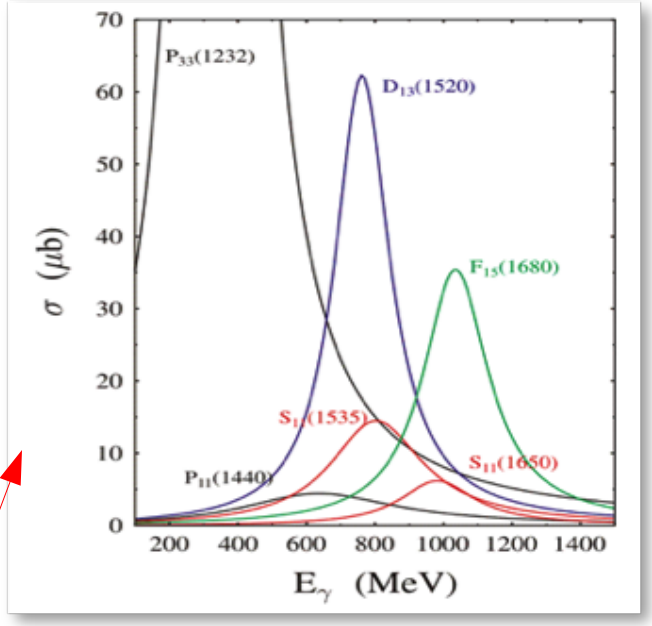
Background: eta photoproduction

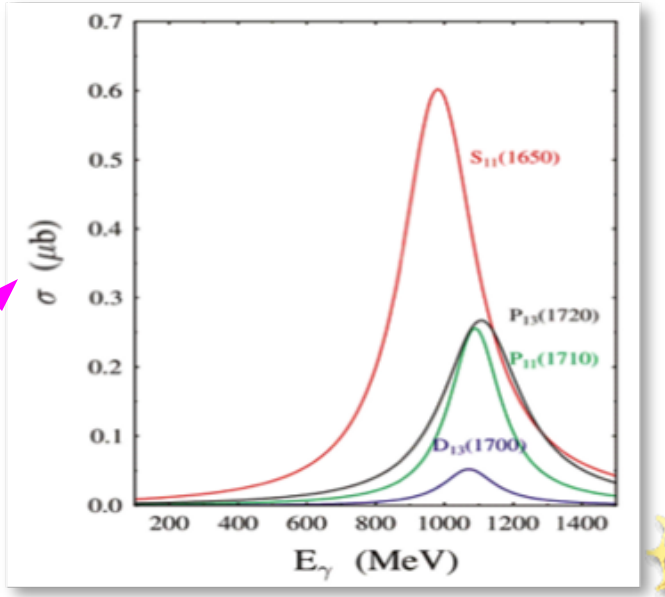


Motivations for studying *η*:

- *η* is isospin 0: not produced by *Δ* resonances
- Predictions from many different models available
- Little published data







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Background: polarization observables

- 8 helicity states: 4 initial, 2 final → 4·2 = 8
- Amplitudes are complex but parity symmetry reduces to 8 independent numbers
- Overall phase is unobservable → 7 independent numbers
- **HOWEVER**, not all possible observables are linearly independent and it turns out that there must be a minimum of 8 observables / experiments

Initial helicity

$$A = \begin{vmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{vmatrix}$$

Final helicity

helicity +1 photons (ε_+):

$$A_{\varepsilon_+} = \begin{array}{cc} \begin{array}{cc} \frac{3}{2} & \frac{1}{2} \end{array} & \\ \begin{vmatrix} H_1 & H_2 \\ H_3 & H_4 \end{vmatrix} & \begin{array}{c} \frac{1}{2} \\ \frac{-1}{2} \end{array} \end{array}$$

$$\left(A_{-\mu,-\lambda} = -e^{\pi(\lambda-\mu)} A_{\mu,\lambda} \right)$$

Parity symmetry →

helicity -1 photons (ε_-):

$$A_{\varepsilon_-} = \begin{array}{cc} \begin{array}{cc} \frac{-1}{2} & \frac{-3}{2} \end{array} & \\ \begin{vmatrix} H_4 & -H_3 \\ -H_2 & H_1 \end{vmatrix} & \begin{array}{c} \frac{1}{2} \\ \frac{-1}{2} \end{array} \end{array}$$

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Background: polarization observables

Published world data	Spin observable	Helicity representation
	$\check{\Omega}^1 \equiv \mathcal{I}(\theta)$	$\frac{1}{2}(\lvert H_1\rvert^2+\lvert H_2\rvert^2+\lvert H_3\rvert^2+\lvert H_4\rvert^2)$
	$\check{\Omega}^4 \equiv \check{\Sigma}$	$\mathrm{Re}(-H_1H_4^*+H_2H_3^*)$
38	$\check{\Omega}^{10} \equiv -\check{T}$	$\mathrm{Im}(H_1H_2^*+H_3H_4^*)$
8	$\check{\Omega}^{12} \equiv \check{P}$	$\mathrm{Im}(-H_1H_3^*-H_2H_4^*)$
	$\check{\Omega}^3 \equiv \check{G}$	$\mathrm{Im}(H_1H_4^*-H_3H_2^*)$
0	$\check{\Omega}^5 \equiv \check{H}$	$\mathrm{Im}(-H_2H_4^*+H_1H_3^*)$
	$\check{\Omega}^9 \equiv \check{E}$	$\frac{1}{2}(\lvert H_1\rvert^2-\lvert H_2\rvert^2+\lvert H_3\rvert^2-\lvert H_4\rvert^2)$
0	$\check{\Omega}^{11} \equiv \check{F}$	$\mathrm{Re}(-H_2H_1^*-H_4H_3^*)$
	$\check{\Omega}^{14} \equiv \check{O}_x$	$\mathrm{Im}(-H_2H_1^*+H_4H_3^*)$
	$\check{\Omega}^7 \equiv -\check{O}_z$	$\mathrm{Im}(H_1H_4^*-H_2H_3^*)$
	$\check{\Omega}^{16} \equiv -\check{C}_x$	$\mathrm{Re}(H_2H_4^*+H_1H_3^*)$
	$\check{\Omega}^2 \equiv -\check{C}_z$	$\frac{1}{2}(\lvert H_1\rvert^2+\lvert H_2\rvert^2-\lvert H_3\rvert^2-\lvert H_4\rvert^2)$
	$\check{\Omega}^6 \equiv -\check{T}_x$	$\mathrm{Re}(-H_1H_4^*-H_2H_3^*)$
	$\check{\Omega}^{13} \equiv -\check{T}_z$	$\mathrm{Re}(-H_1H_2^*+H_4H_3^*)$
	$\check{\Omega}^8 \equiv \check{L}_x$	$\mathrm{Re}(H_2H_4^*-H_1H_3^*)$
	$\check{\Omega}^{15} \equiv \check{L}_z$	$\frac{1}{2}(-\lvert H_1\rvert^2+\lvert H_2\rvert^2+\lvert H_3\rvert^2-\lvert H_4\rvert^2)$

Differential cross section

Beam polarization

Target asymmetry

Recoil polarization

Double polarization observables

Need **at least** 4 of the double observables for a "complete experiment"

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Overview of experiment

- Experimental facility
- Photon beam
- Detector
- Target

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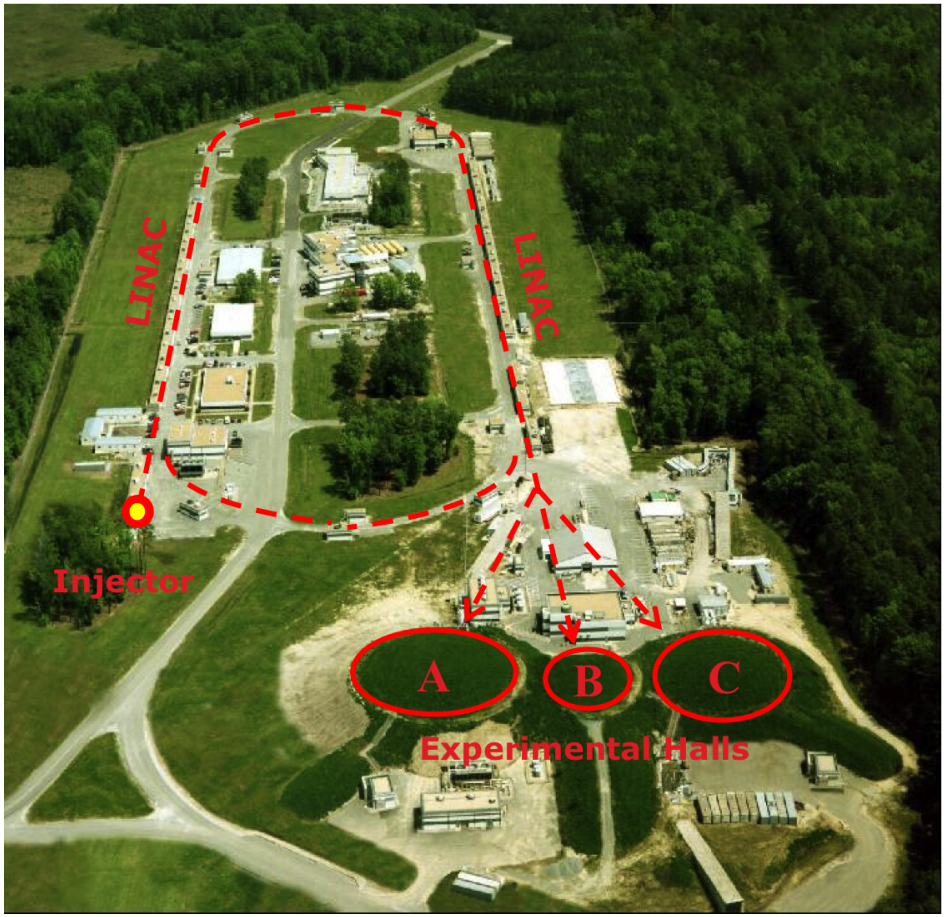
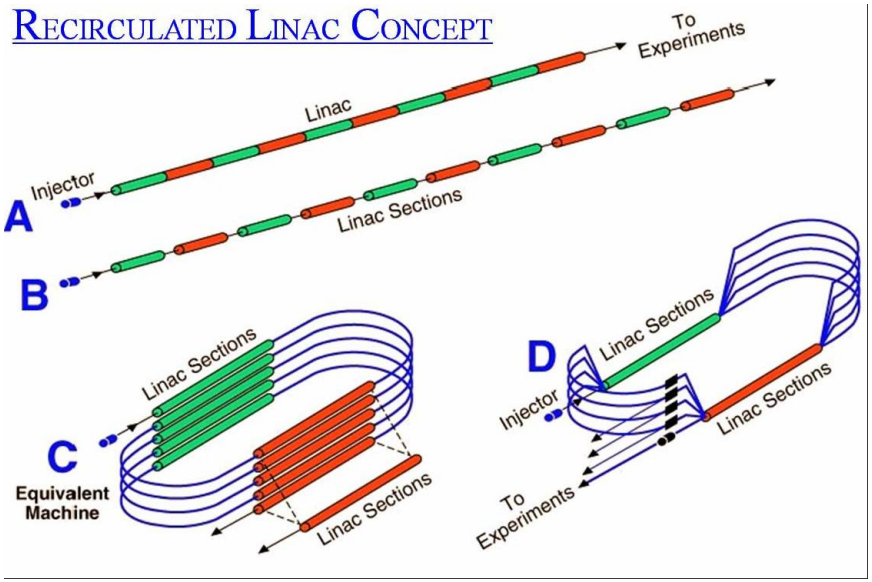
Experiment: Facility



- Thomas Jefferson National Accelerator (JLab)
- Continuous Electron Beam Accelerator Facility (CEBAF)
- Racetrack design
- Energies up to 6 GeV



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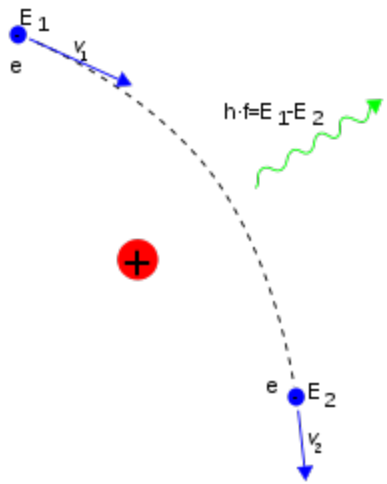
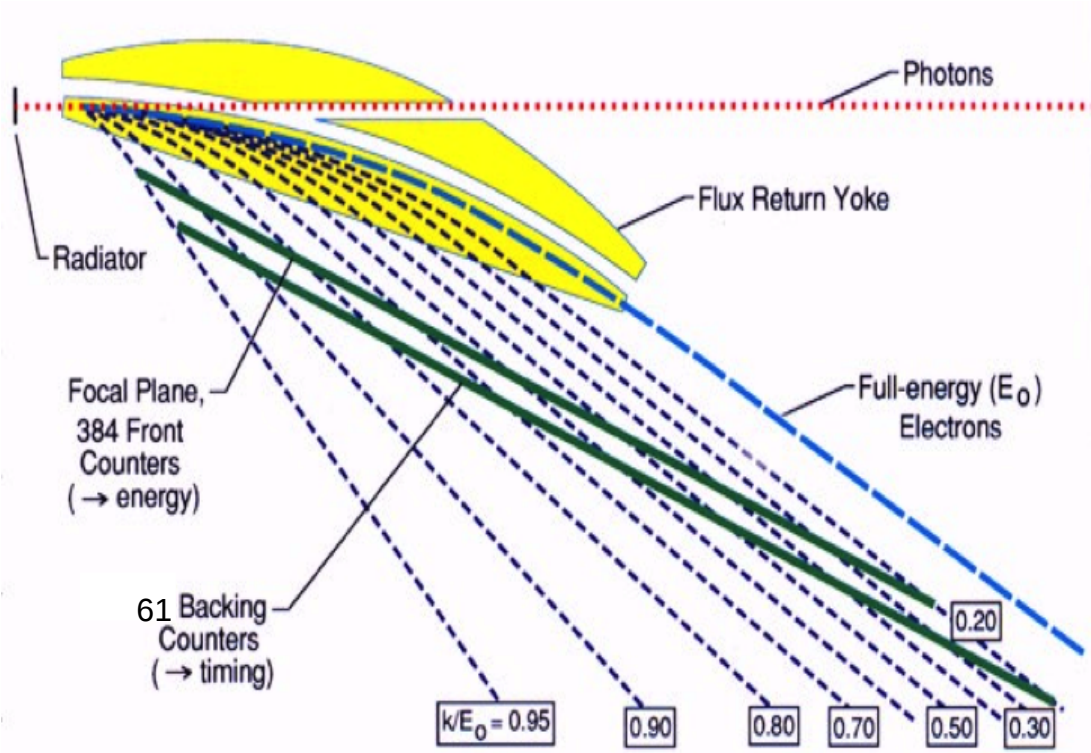
Experiment: Photon beam and tagger

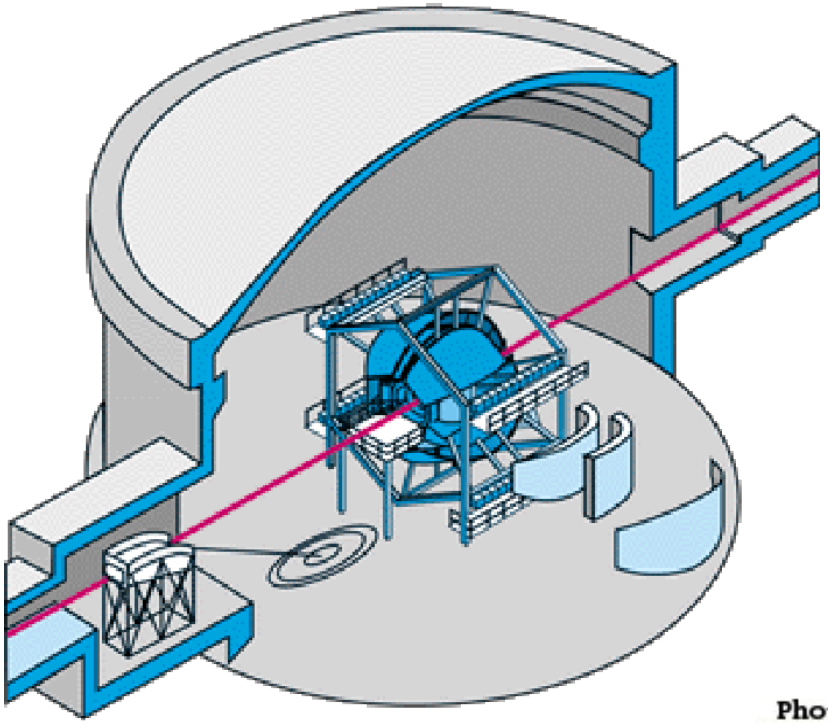


Photon beam generated via Bremsstrahlung radiation
Radiator was carbon / gold foil

Scattered electrons curved by tagger magnet
Curvature of electron track lead to energy of photon

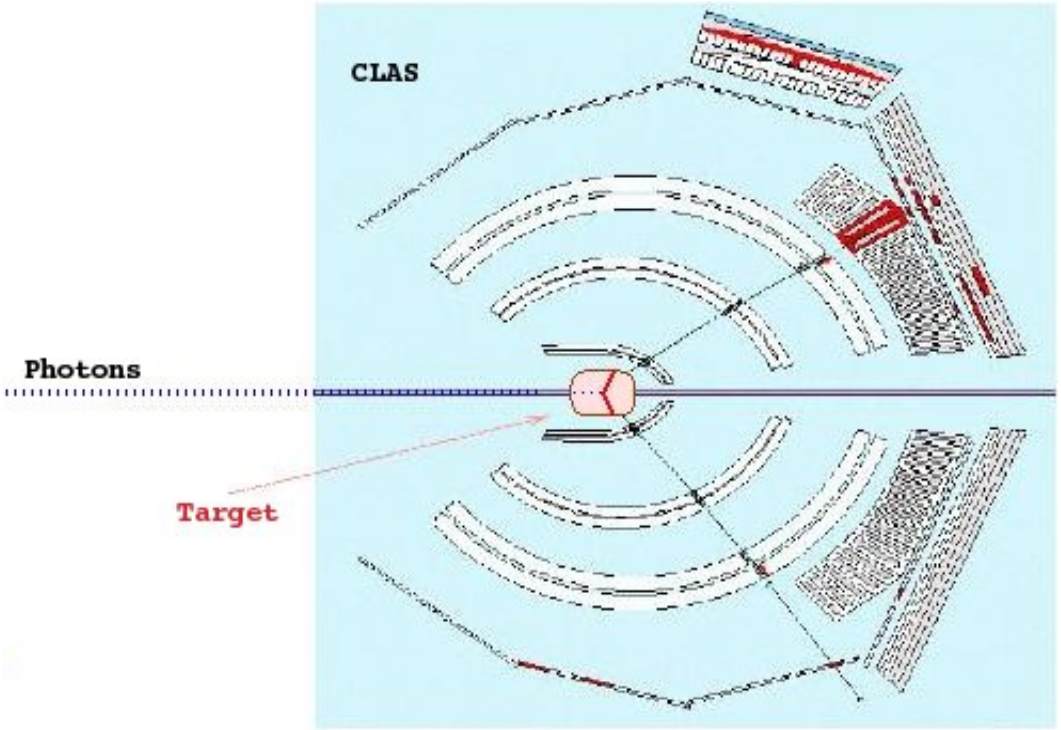


Experiment: CLAS Detector



CEBAF Large Acceptance Spectrometer
Spherical shells of detectors, nearly 4π coverage

Time-of-Flight system gives velocity
Drift chambers give momentum & sign of charge



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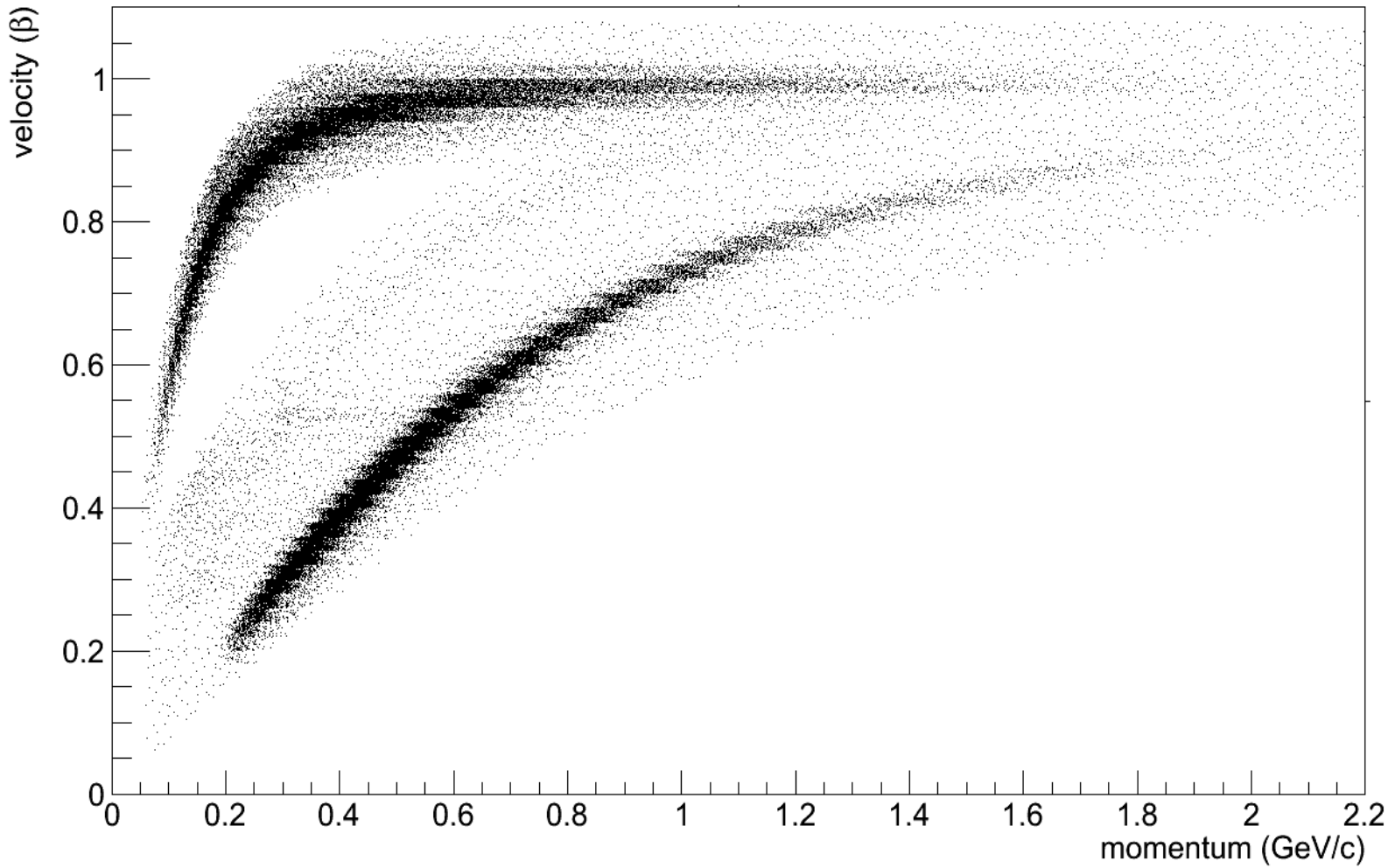
Particle ID



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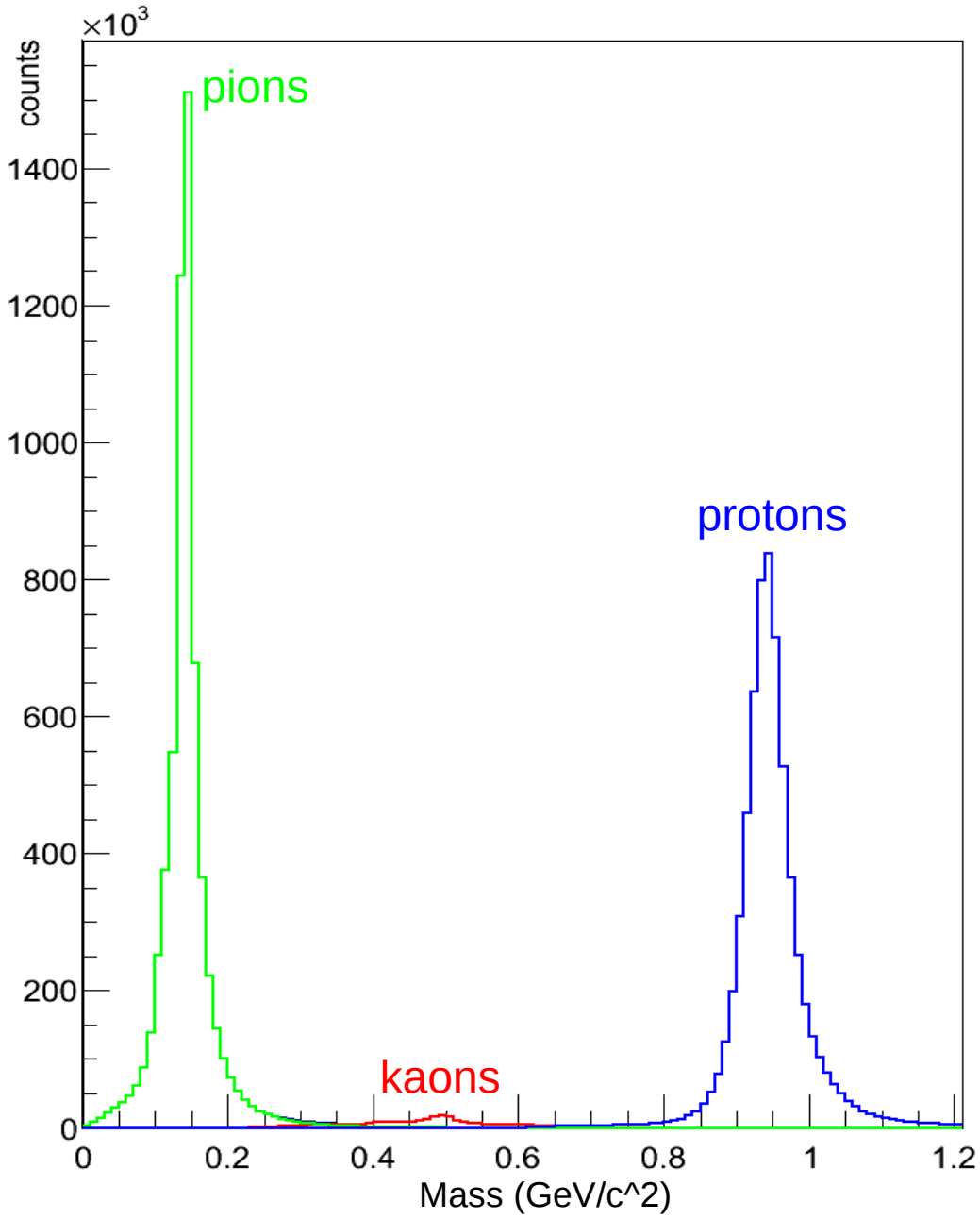
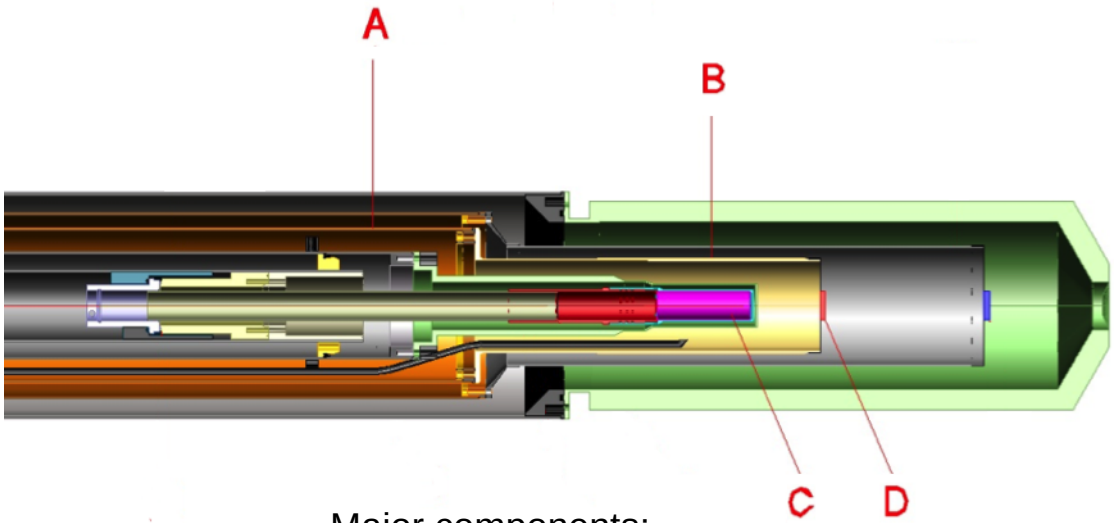
Particle ID



×10^3
counts
1400
1200
1000
800
600
400
200
0
pions
protons
kaons
0
0.2
0.4
0.6
0.8
1
1.2
Mass (GeV/c^2)

Experiment: FROST Target

Frozen Spin Target specifications:
Polarization ~ 85%
Helium dilution refrigerator at ~30 mK
~ 1% polarization decay per day



Major components:
A: Primary heat exchanger
B: Holding coil
C: Butanol (C_4H_9OH) target
D: Carbon target

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Recent work

- Model of holding coil
- Carbon target position
- Preliminary measurement of *T* for pions

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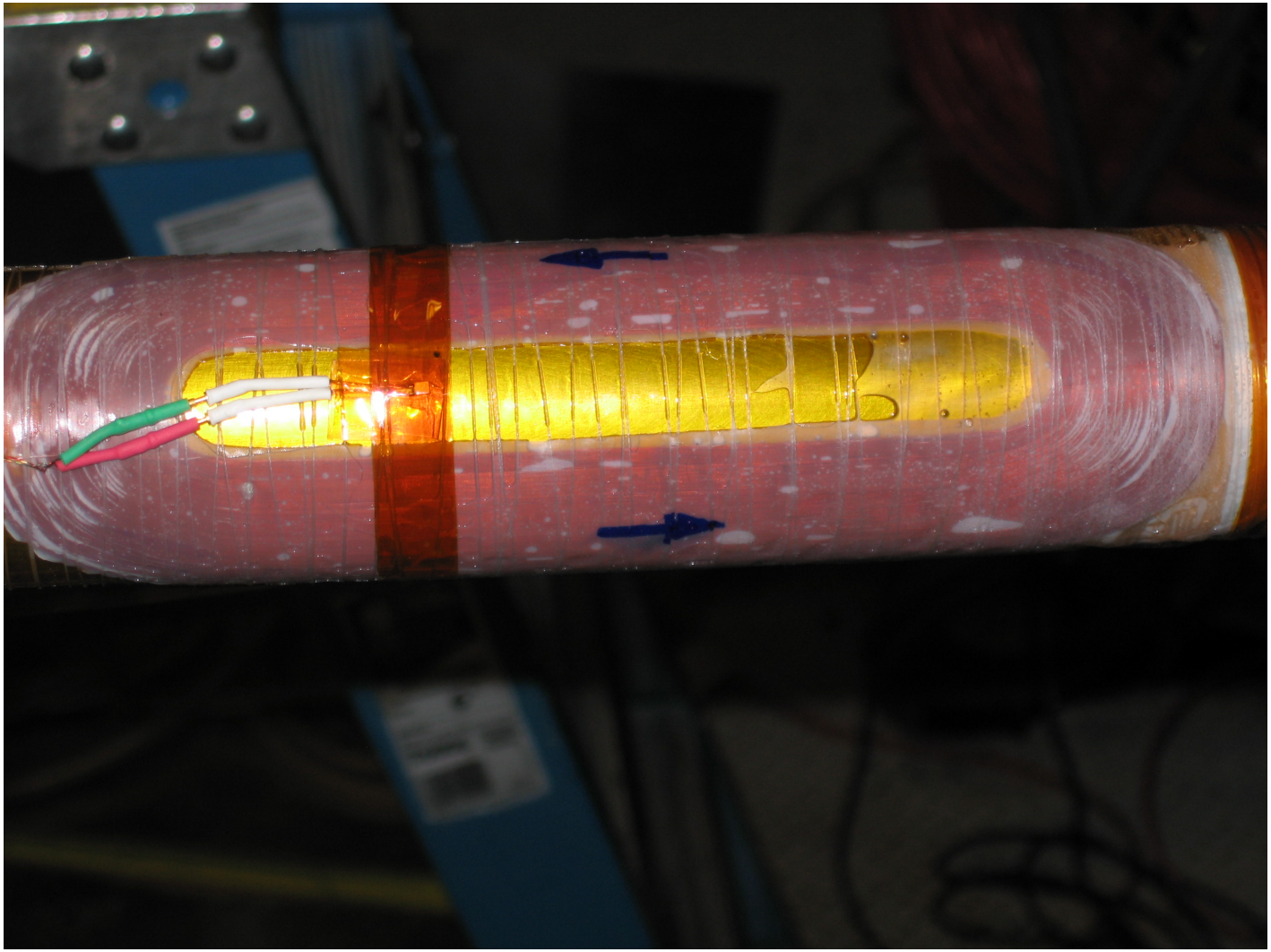
Transverse holding coil model for eloss



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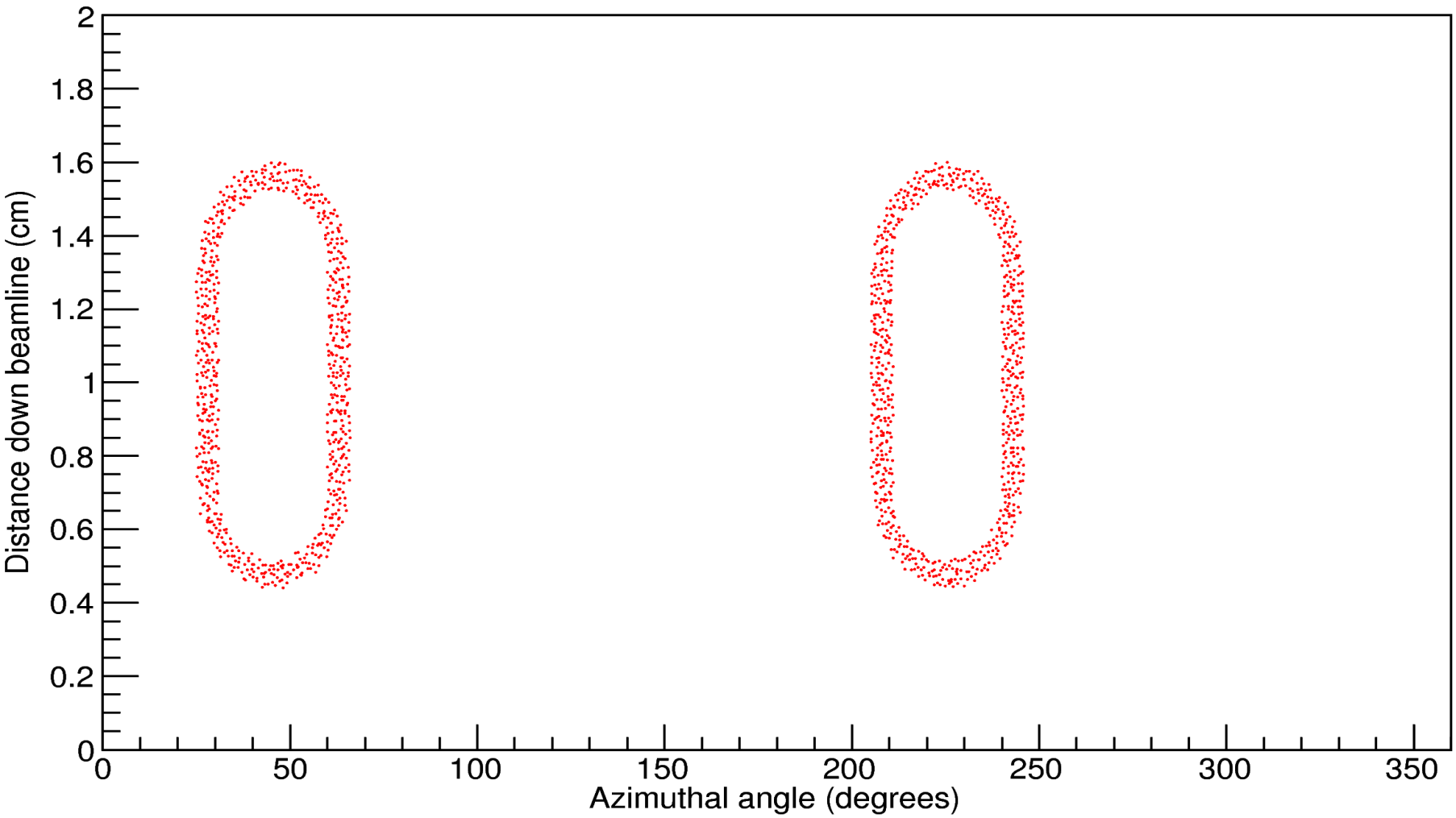
Visualization of transverse holding coil



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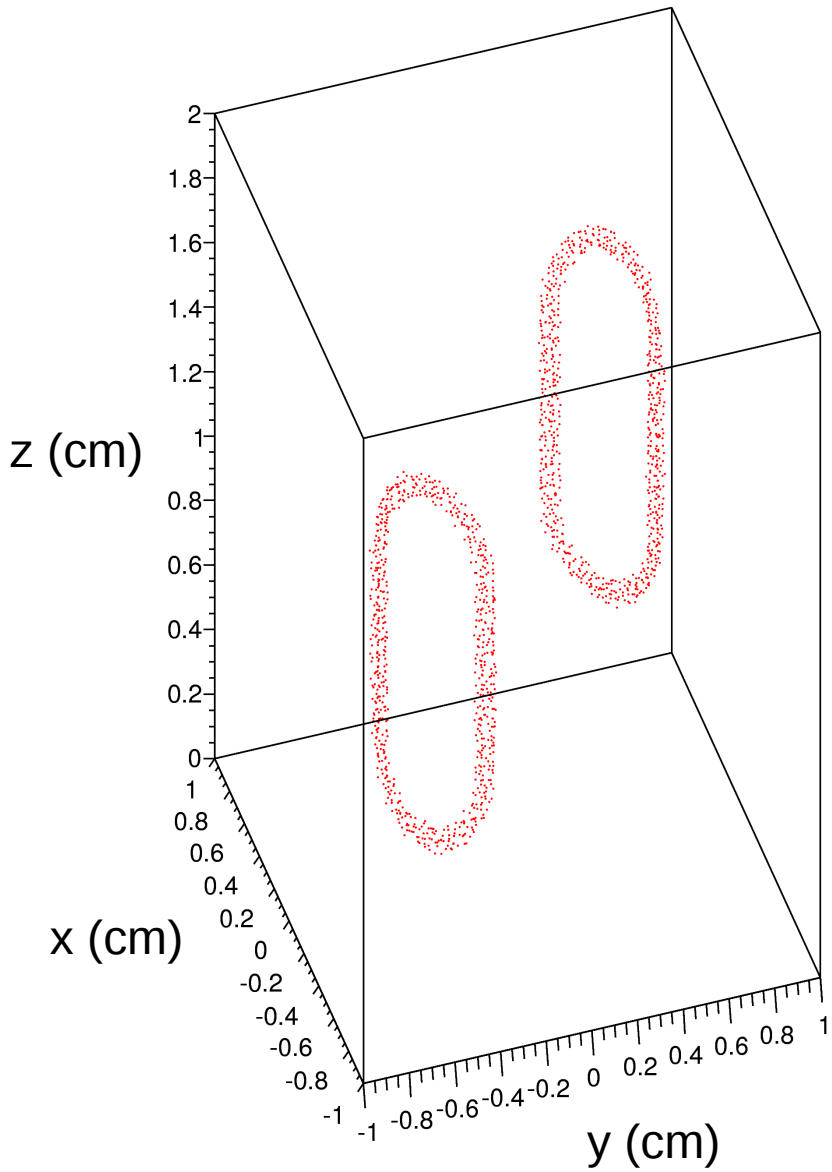
Visualization of transverse holding coil



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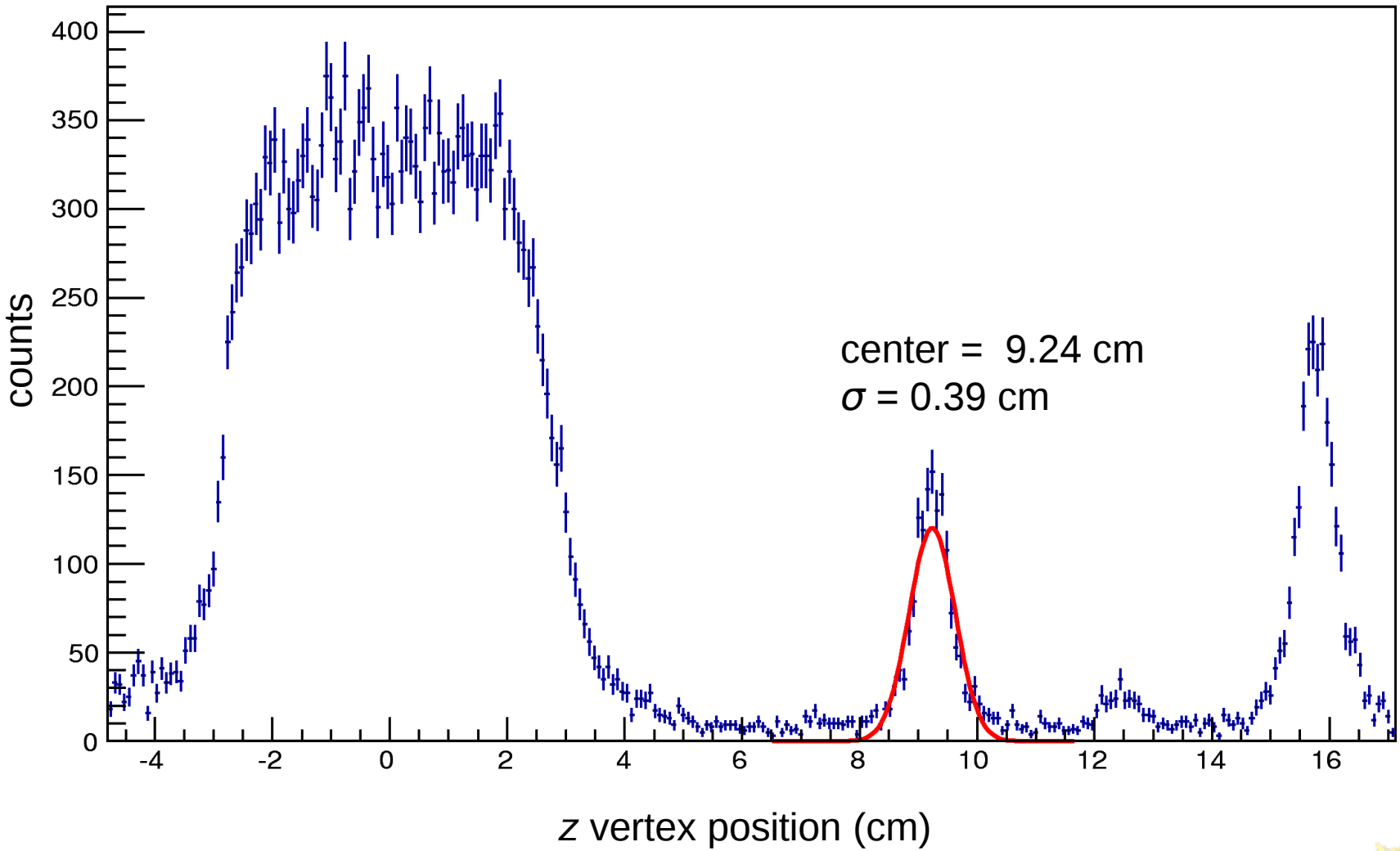
Carbon position in transverse target

Vertex position for pions at 90 ± 5°



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Warning: low statistics!

- *The following slides are a first attempt with a small sample of uncalibrated data.*

- *Expect much better results once the full data set has been "cooked".*

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Target asymmetry calculation

The polarized cross section for an experiment with circularly polarized beam and transversely polarized target is given by:

$$d\sigma_{\pm} = d\sigma_0 \left[1 + P\left(BF\cos(\phi+\beta) \pm T\sin(\phi+\beta)\right)\right]$$

where:

$\sigma_{\pm}$ = polarized cross section, F = F double-polarization observable,

σ_0 = unpolarized cross section, T = target asymmetry observable,

P = target polarization, φ = azimuthal angle, and

B = beam polarization, β = azimuthal target offset.

If we ignore beam polarization and solve for the target asymmetry term, this becomes:

$$T\sin(\phi+\beta) = \frac{Y_+/N_+ - Y_-/N_-}{P_- Y_+/N_+ + P_+ Y_-/N_-}$$

where we have rewritten cross section in terms of numbers of particles detected, as given by

$$\sigma \propto \frac{Y}{N_\gamma}$$

where:

$Y_{\pm}$ = # $\pi^+ n$ events in butanol with ± target polarity (background subtracted) and

$N_{\pm}$ = # photons with ± target polarity.

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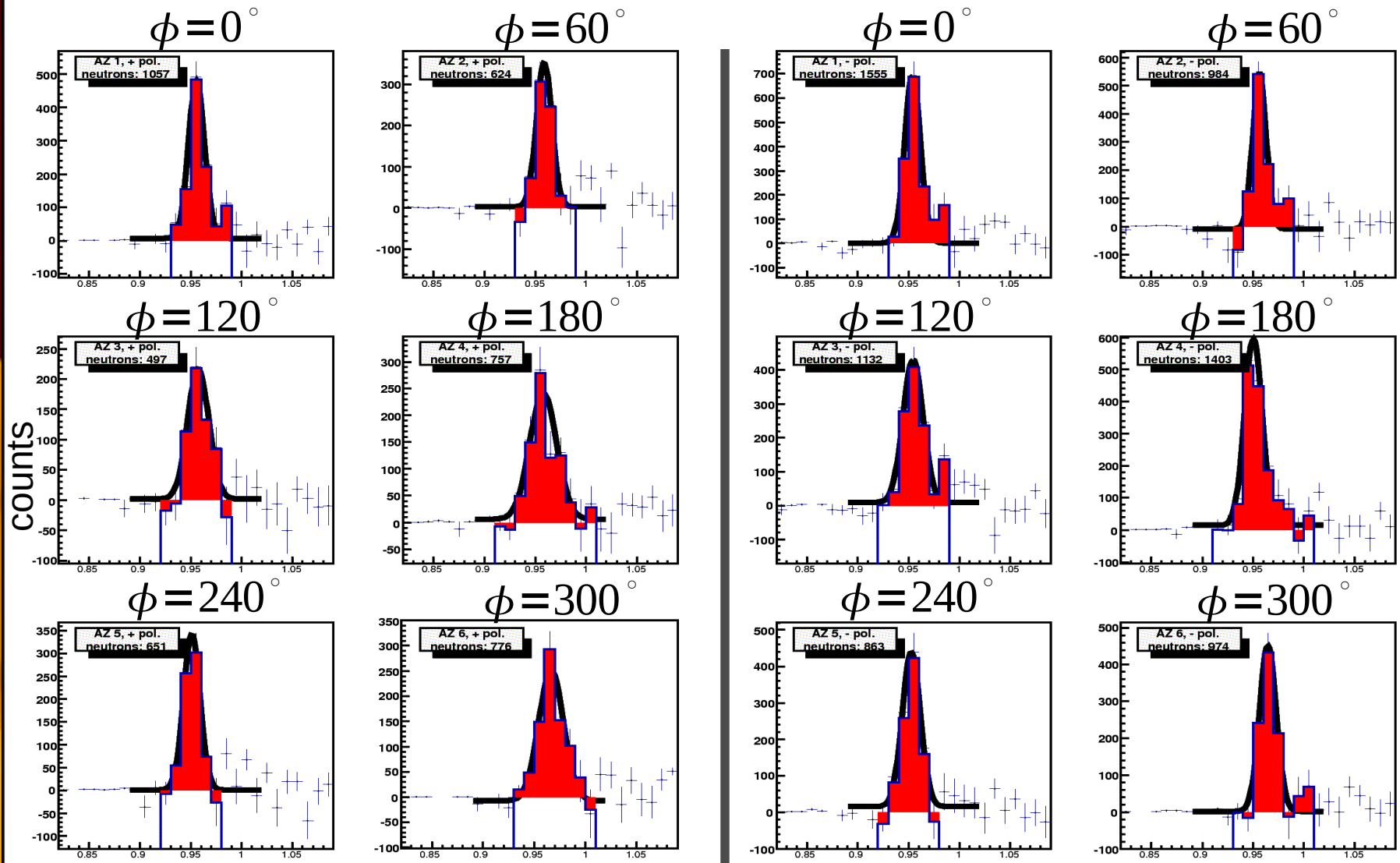
Neutron missing mass plot for $\gamma p \rightarrow \pi^{\pm} X$



"positive" target polarity

"negative" target polarity

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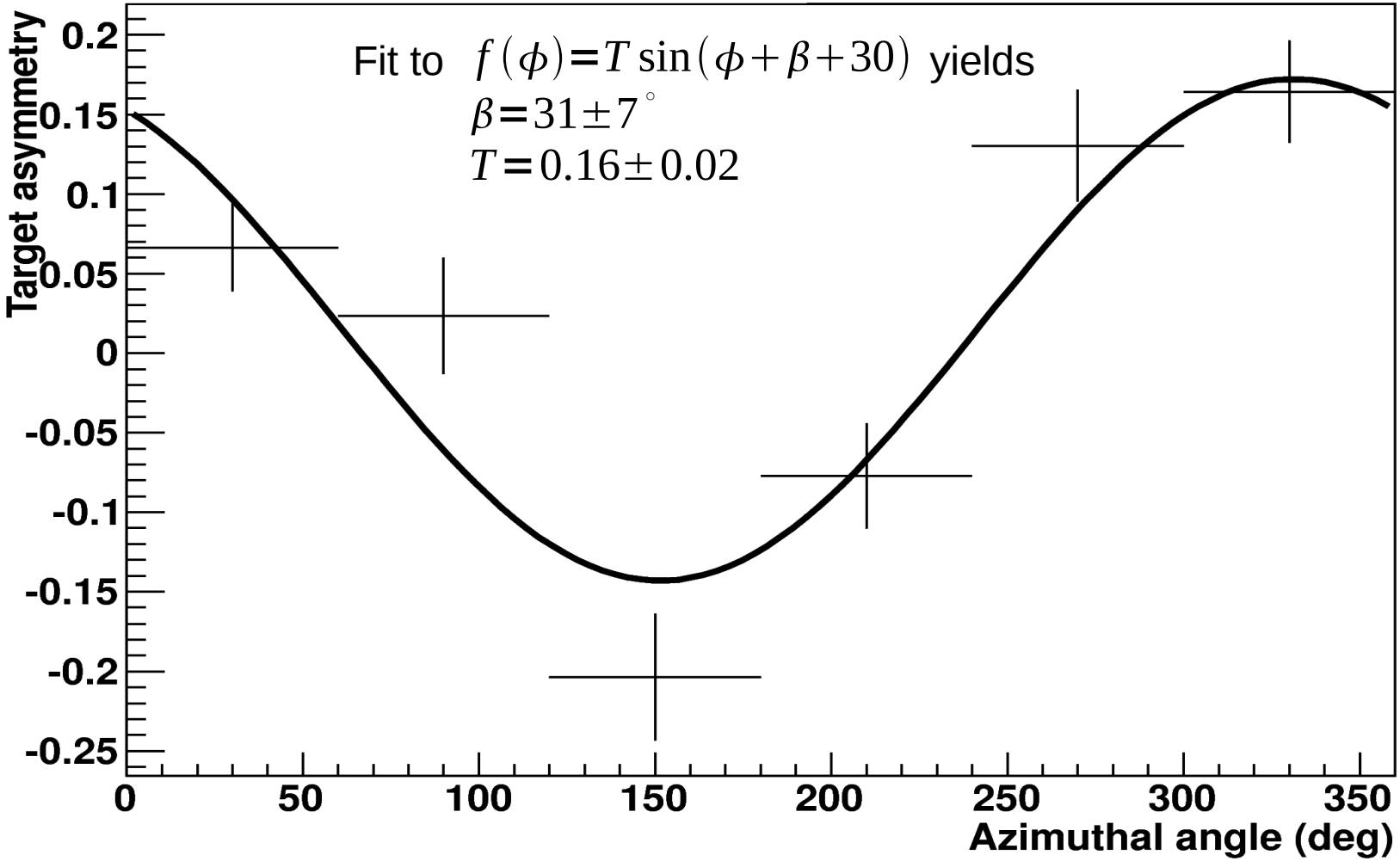
Target asymmetry observable



Polar angles $\cos(\theta_{cm})\in(0.9,1.0)$

Photon energies $E_{\gamma}\in(0.6,1.3)$ GeV

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Summary

In order to establish quantum numbers for nucleon resonances, I propose to measure polarization asymmetries for eta photoproduction on the proton.

I will measure the observables *F* and *T* using circularly polarized photons incident on a transversely polarized proton target, as well as the observables *P* and *H* using linearly polarized photons incident on a transversely polarized target.

My proposed measurements will greatly enhance the world database: currently, there have been no published measurements for *F* and *H* observables and only 38 measurements of *T* and 8 of *P*.

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