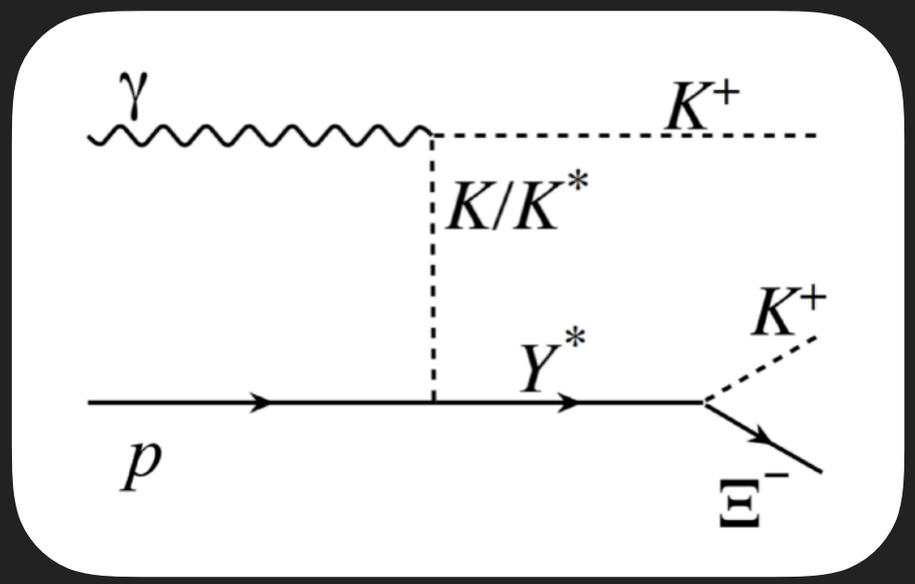
Ξ- Polarization

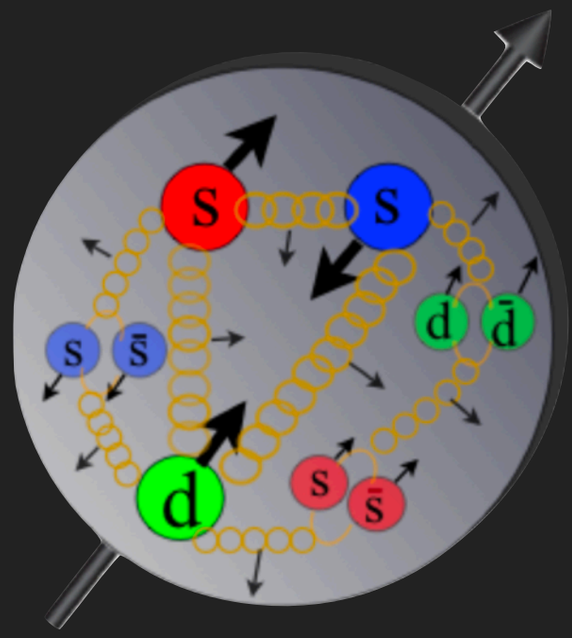
Jason Bono, Fermilab

CLAS Collaboration Meeting

Fall, 2017

Ξ^- Polarization





- First time measurements for three orthogonal polarization observables
  - Induced polarization, P
  - Transferred polarization, C_x & C_z

Cascades: Under-Explored

- From an S=0 state, cascades, with S=-2, must be produced indirectly
  - Low production cross sections
  - Minimal progress on cascades, experimentally and theoretically
    - Unknown production mechanism
    - Unknown resonance spectrum: most of those predicted are unobserved
- Polarization is sensitive to the production mechanism

Ξ photoproduction

- Only one differential cross section measurement, L. Guo et al.
  - Measured $\delta\sigma/\delta\theta_{CM}$ and found that Ξ is produced backward
    - Indicative of t-channel
- Only one existing theoretical model, K. Nakayama et al.
  - Production proceeds through the excitation of S=-1 hyperons
  - Relativistic meson exchange, amplitudes calculated in the tree-level approximation from effective Lagrangians
  - Reproduced the L. Guo's $\delta\sigma/\delta\theta_{CM}$

G12 Data, Collected In 2008

- Circularly polarized photons on an unpolarized 40 cm ℓH2 target
- E_e ~5.7 GeV
  - Events with E_γ up to 5.4 GeV
- Most data collected with longitudinal polarization of P_e ~ 70%
  - Most data collected with circular polarization, $0.4 < P_\gamma < 0.6$
    - $P_\gamma \rightarrow 0$ as $E_\gamma \rightarrow 0$; $P_\gamma \rightarrow P_e$ as $E_\gamma \rightarrow E_e$
- Electron helicity flipped at 30 Hz
  - Photon helicity flipped at 30 Hz
- L = 68 pb^{-1}
  - 2.6 billion triggers

CLAS Analysis Note: *g12 analysis procedures, statistics and systematics, 2017.*

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First time opportunity to study Ξ polarization in photoproduction

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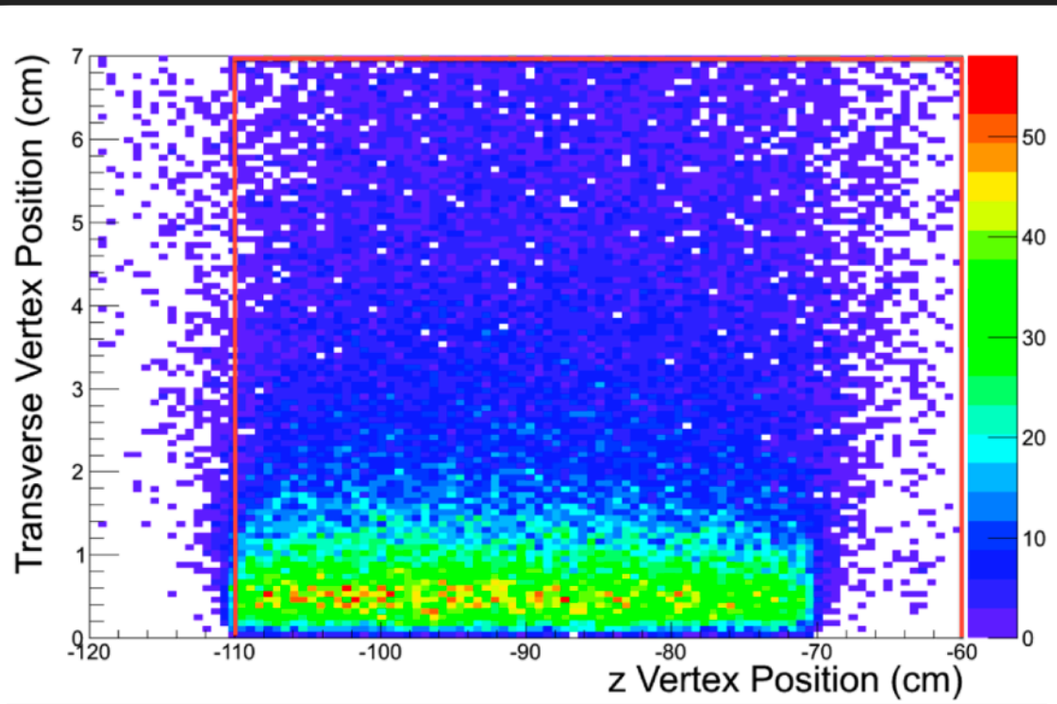
Outline Of Signal Extraction

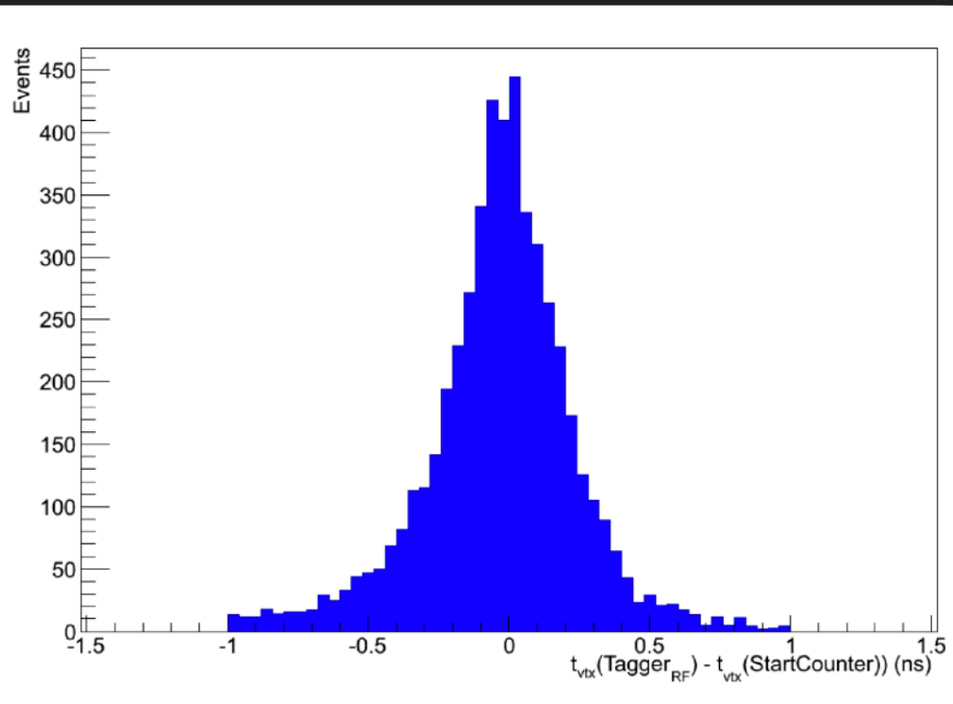
- Detect Ξ^- production- and decay-products
  - 2 Kaons carry S=2: simplest production byproducts that conserve flavor
  - $\Xi^- \rightarrow \pi^- \Lambda$: Branching ratio ~ 99.98%
  - Require detection of $K^+ K^+ \pi^-$ in the final state
  - Kinematically require missing Ξ^- and Λ
- Rarify signal with vertex and timing cuts
- Other filters, such as “fiducial cuts,” were used to estimate certain systematics
- Out of the 2.6B events, 5143 $\Xi^- \rightarrow \pi^- (\Lambda)$ were identified

Vertex Cuts

- Allow for detached vertex from the ~160 ps Ξ lifetime
  - The *exact* shape is unimportant, as few events > 1cm outside of the target geometry survive mass cuts
  - Contamination of background events into the signal is evaluated later, and taken into account
- Tagged photon time and start counter required to agree to within 1 ns



Shown without kinematic cuts

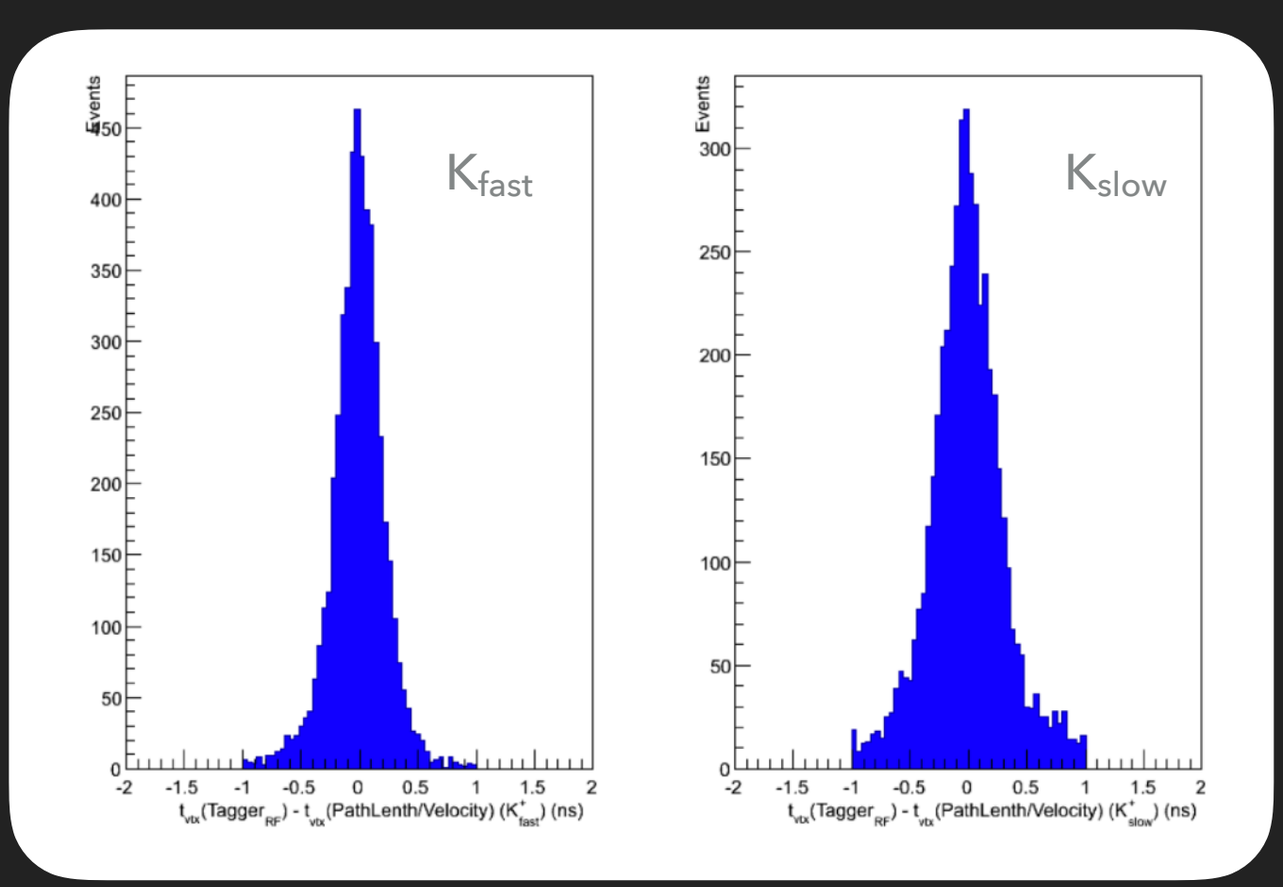


Shown with kinematic cuts

Jason Bono, jbono@fnal.gov

Kaon Timing Cuts

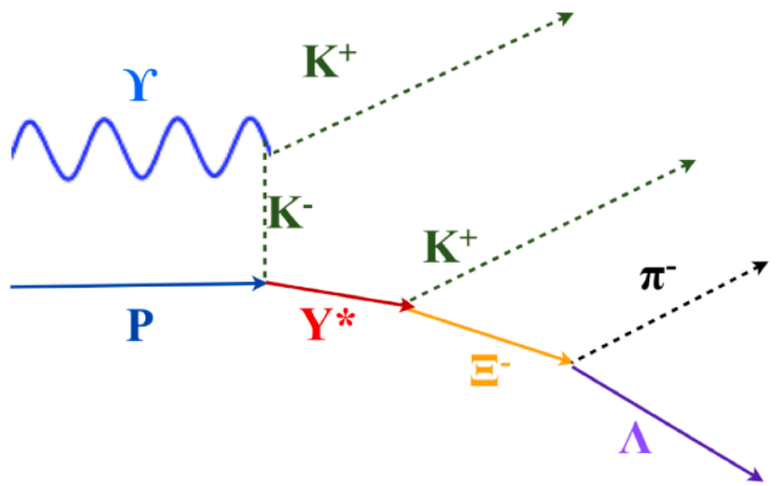
- Imposed a 1 ns agreement between tagger’s vertex-time and the TOF's vertex time for each kaon



Shown with kinematic cuts

Hypersphere Cuts

- Two constraints on Ξ^-
- Two constraints on Λ
- Each quantity scaled by it's 3σ width
- Treated as orthogonal displacements in a 4D space
- Cut on the hypersphere radius
  - R < 1 is essentially a 3σ cut for all quantities

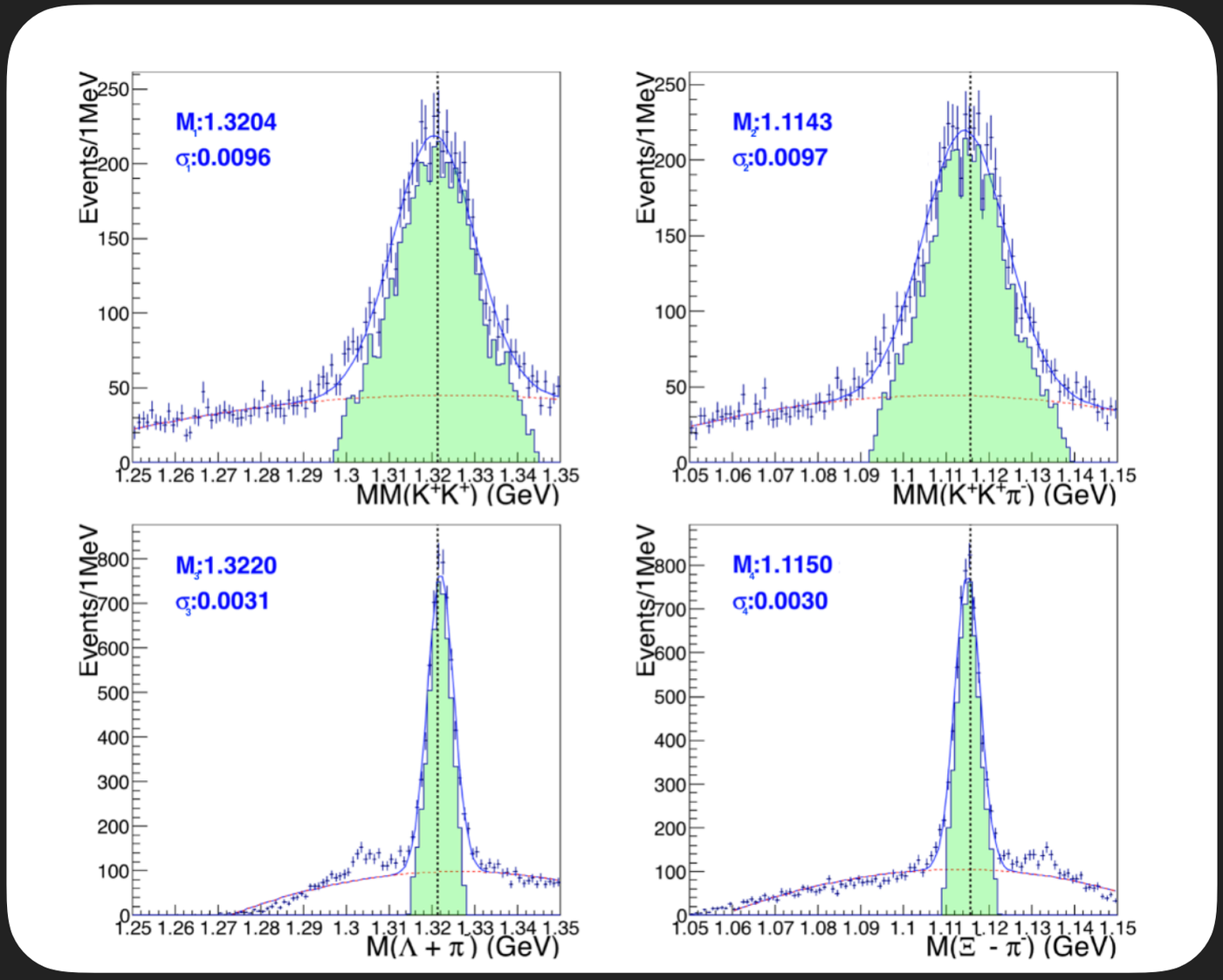


$$x_1 = [MM(K^+K^+) - \Xi^-_{mass}]/3\sigma_1,$$
$$x_2 = [MM(K^+K^+\pi^-) - \Lambda_{mass}]/3\sigma_2,$$
$$x_3 = [M(\Lambda + \pi^-) - \Xi^-_{mass}]/3\sigma_3,$$
$$x_4 = [M(\Xi^- - \pi^-) - \Lambda_{mass}]/3\sigma_4,$$
$$r = \sqrt{x_1^2 + x_2^2 + x_3^2 + x_4^2},$$

Increased signal-to-background from "rectangular cuts"

Hypersphere Cuts

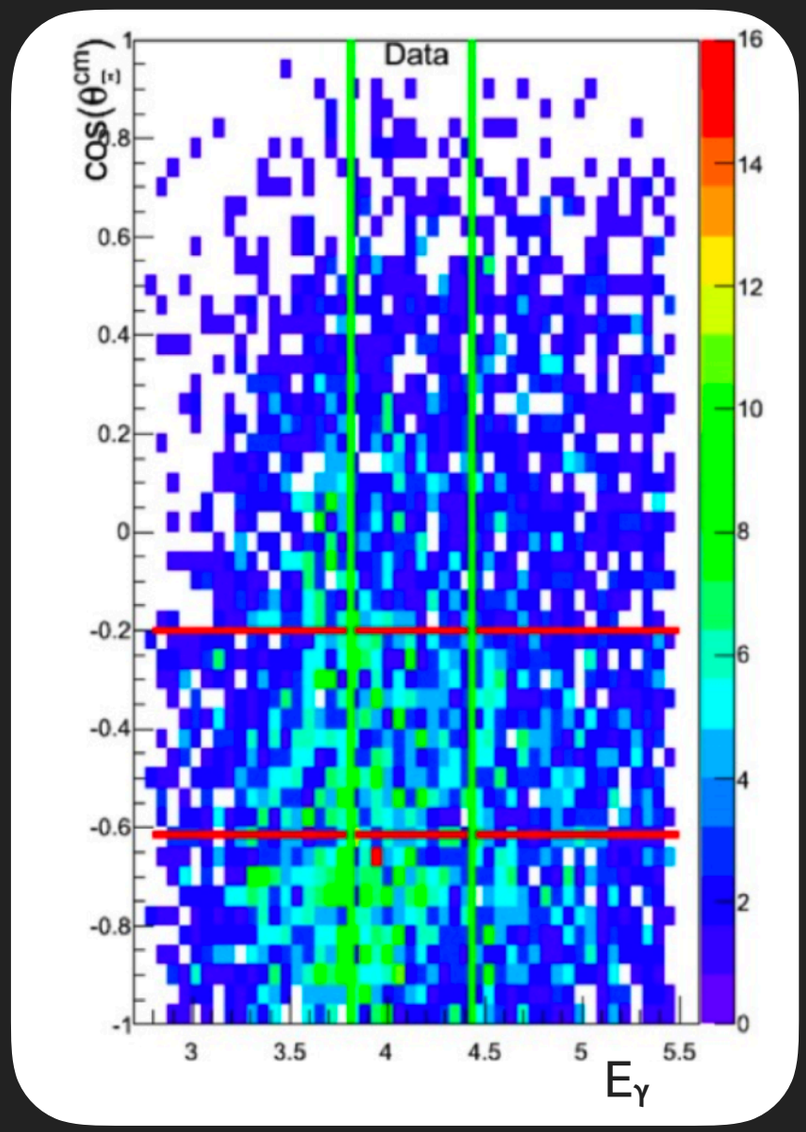
- Vertical lines: known mass of Ξ^- and Λ
- Blue points: before mass cuts
- Blue line: Gaussian + Polynomial fit
- Red line: extrapolation of polynomial fit
- Green bars: after R < 1 hypersphere cuts



5143 $\Xi^- \rightarrow \pi^- \Lambda$ events

Binning

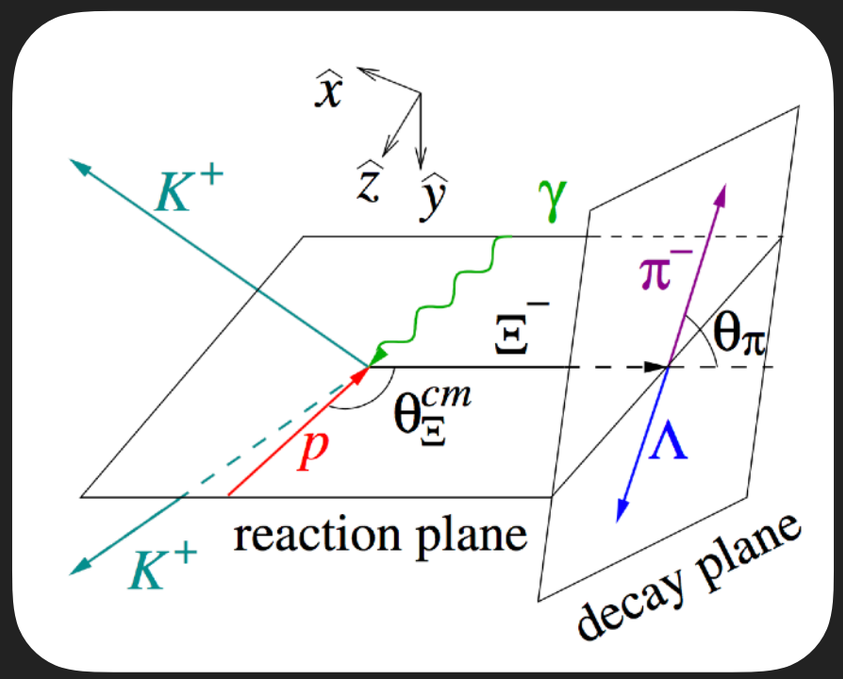
- Events binned in CM Ξ angle and beam energy
  - Equal statistics
  - 3x3 bins for P
  - 3 + 3 bins for C_x & C_z



Binning scheme

Quantization Axes

- Parity is conserved in Ξ production
  - Polarization must transfer along a vector
  - Induced polarization must point along an axial vector
- Quantization axes defined in the Ξ rest frame
  - **z** = γ → vector → transferred polarization C_z
  - **y** = γ × **K** → axial vector → induced polarization P
  - **x** = **y** × **z** → vector → transferred polarization C_x



Parity Violating Weak Decay

For P:

- $n(\theta_\pi^y) = \frac{N}{2}(1 - P\alpha \cos\theta_\pi^y)$.
- Acceptance is symmetric in $\cos\theta_\pi^y$ about zero.

$\rightarrow \boxed{P = -\frac{2A_y}{\alpha}}$

Forward-backward π^- asymmetry.

For Cx and Cz:

- $n(\theta_\pi^{x,z}) = \frac{N}{2}(1 - C_{x,z}\alpha \cos\theta_\pi^{x,z})$.
- 30Hz photon helicity flipping.
- Acceptance independent of photon helicity.

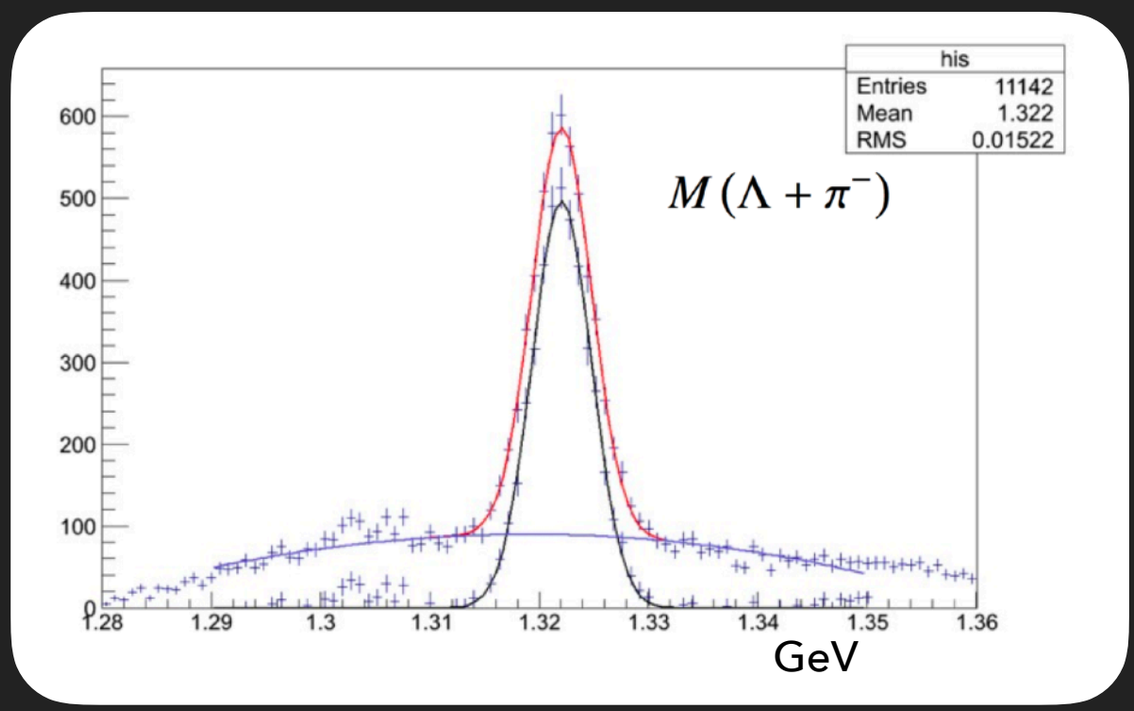
$\rightarrow \boxed{A(\theta_\pi^{x,z}) = -C_{x,z}|P_\odot|\alpha \cos(\theta_\pi^{x,z})}$

Fit the photon helicity asymmetry.

$$A = \frac{N^+ - N^-}{N^+ + N^-}$$

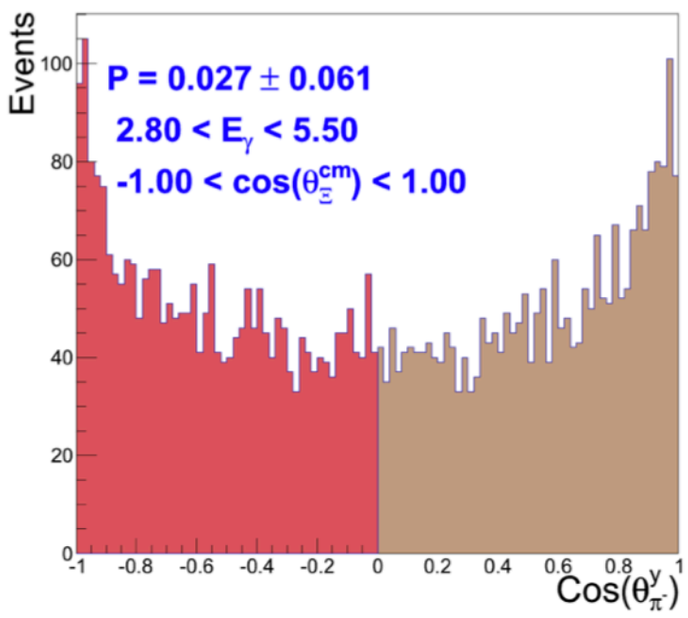
Dilution Factor

- BG contamination was evaluated in each bin
  - N_{BG} = normalized difference in yield between number of events from hypersphere cuts and yield from a BG subtracted fit
- BG events were found to posses zero effective polarization
  - A simple correction factor, $\mathscr{D} = 1 - N_{BG}/N_{total}$ can be applied in each bin
  - $\mathscr{D}$~0.9
  - $P_{corrected} = P/\mathscr{D}$

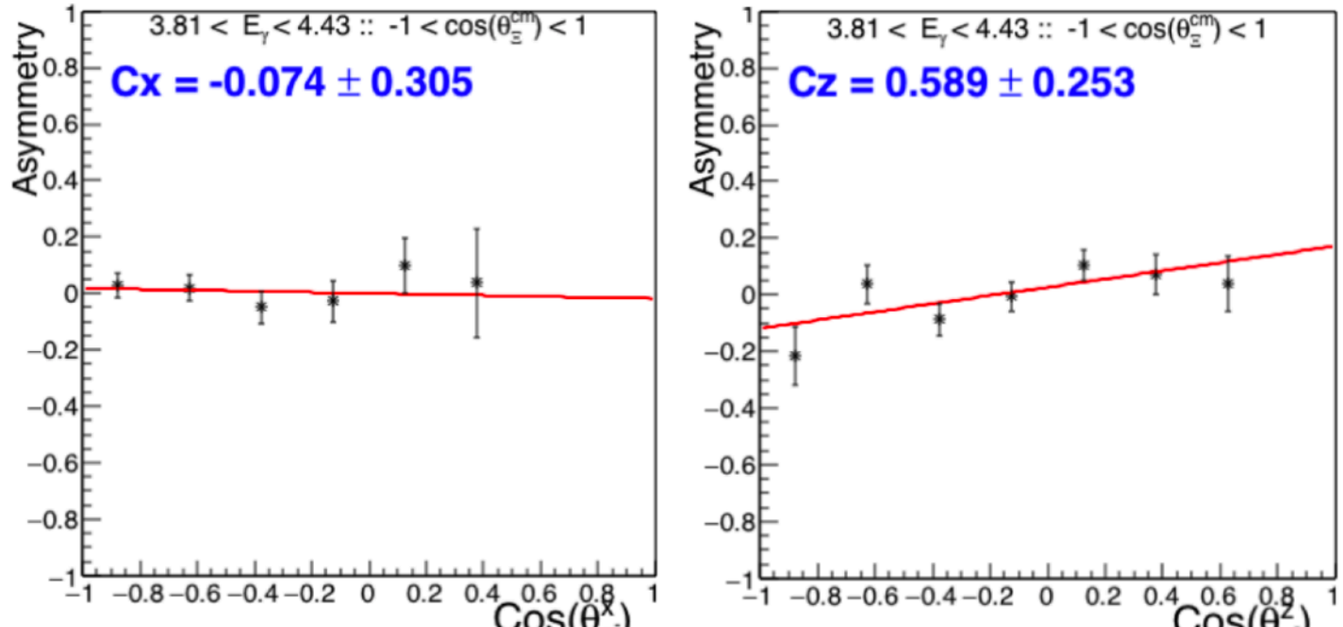


E_γ (GeV)	$\cos\theta_\Xi^{C.M.}$	$\mathcal{D}$	$\delta\mathcal{D}$
3.47	$-1 \leq \cos\theta_\Xi^{C.M.} \leq 1$	0.8975	0.0076
4.09	$-1 \leq \cos\theta_\Xi^{C.M.} \leq 1$	0.8858	0.0081
4.88	$-1 \leq \cos\theta_\Xi^{C.M.} \leq 1$	0.8418	0.0094
$2.8 \leq E_\gamma \leq 5.5$	-0.79	0.8736	0.0085
$2.8 \leq E_\gamma \leq 5.5$	-0.41	0.8797	0.0083
$2.8 \leq E_\gamma \leq 5.5$	0.19	0.8695	0.0085
3.47	-0.79	0.8820	0.0143
4.09	-0.79	0.9140	0.0122
4.88	-0.79	0.8272	0.0169
3.47	-0.41	0.9102	0.01251
4.09	-0.41	0.8795	0.0149
4.88	-0.41	0.8477	0.0160
3.47	0.19	0.9008	0.0129
4.09	0.19	0.8647	0.0152
4.88	0.19	0.8513	0.0158

Example Extractions



Example extraction of P



Example extraction of $C_{x/z}$

Systematics

- Signal contamination (dilution factor)
- Fiducial region of the detector
- Uncertainty in photon polarization
- Uncertainty in the Ξ analyzing power

Final results dominated by statistical uncertainty

Tabulated Results

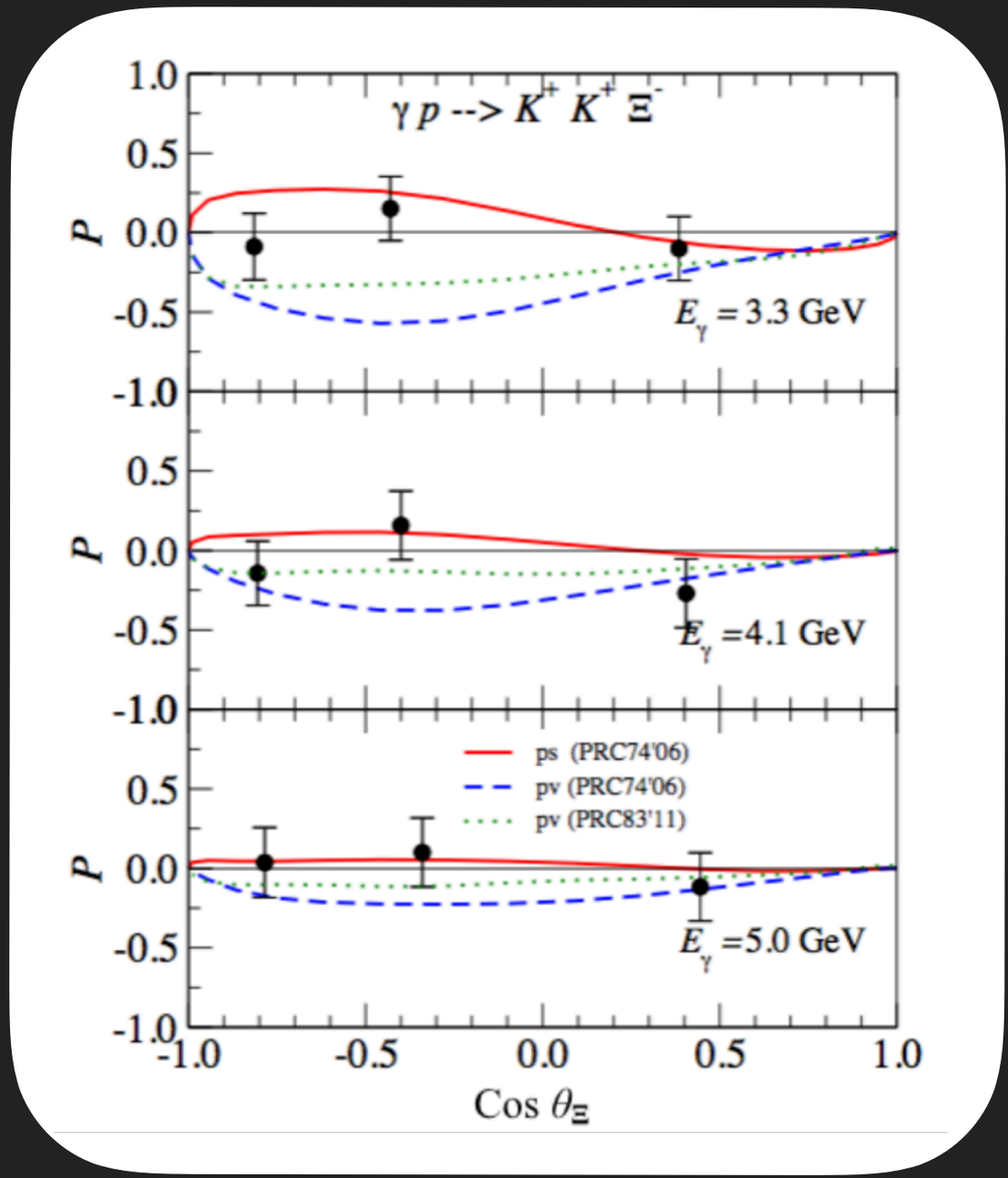
E_γ (GeV)	$\cos\theta_\Xi$	P	$\delta_{stat}P$	$\delta_{sys}P$	$\delta_{total}P$	$\delta_{\mathrm{scl}}P/P$
3.47	-1 to 1	-0.011	0.118	0.022	0.120	0.026
4.09	-1 to 1	-0.089	0.121	0.022	0.123	0.026
4.88	-1 to 1	0.006	0.125	0.022	0.127	0.026
2.8 to 5.5	-0.79	-0.045	0.122	0.022	0.124	0.026
2.8 to 5.5	-0.41	0.148	0.122	0.022	0.124	0.026
2.8 to 5.5	0.19	-0.193	0.121	0.022	0.123	0.026
3.47	-0.79	-0.088	0.208	0.022	0.210	0.026
4.09	-0.79	-0.143	0.201	0.022	0.203	0.026
4.88	-0.79	0.036	0.220	0.022	0.221	0.026
3.47	-0.41	0.152	0.201	0.022	0.202	0.026
4.09	-0.41	0.158	0.215	0.022	0.216	0.026
4.88	-0.41	0.100	0.216	0.022	0.217	0.026
3.47	0.19	-0.100	0.201	0.022	0.202	0.026
4.09	0.19	-0.269	0.213	0.022	0.214	0.026
4.88	0.19	-0.116	0.214	0.022	0.215	0.026

E_γ (GeV)	$\cos\theta_\Xi$	C_x	$\delta_{stat}C$	$\delta_{sys}C$	$\delta_{total}C$	$\delta_{scl}C/C$
3.47	-1 to 1	0.209	0.394	0.114	0.410	0.039
4.09	-1 to 1	-0.083	0.344	0.114	0.362	0.039
4.88	-1 to 1	-0.021	0.323	0.114	0.343	0.039
2.8 to 5.5	-0.79	-0.210	0.332	0.114	0.351	0.039
2.8 to 5.5	-0.41	0.367	0.346	0.114	0.364	0.039
2.8 to 5.5	0.19	0.012	0.396	0.114	0.412	0.039
E_γ (GeV)	$\cos\theta_\Xi$	C_z	$\delta_{stat}C$	$\delta_{sys}C$	$\delta_{total}C$	$\delta_{scl}C/C$
3.47	-1 to 1	0.524	0.349	0.053	0.353	0.039
4.09	-1 to 1	0.665	0.286	0.053	0.291	0.039
4.88	-1 to 1	0.001	0.258	0.053	0.263	0.039
2.8 to 5.5	-0.79	0.522	0.323	0.053	0.327	0.039
2.8 to 5.5	-0.41	0.490	0.280	0.053	0.285	0.039
2.8 to 5.5	0.19	0.129	0.296	0.053	0.300	0.039

Calculation of systematic error to change

P in 3x3 Bins

- All bins consistent with P=0
- General agreement with model
- Can not distinguish variants



ps 06: Pseudoscalar coupling, resonances up to Λ(1890)

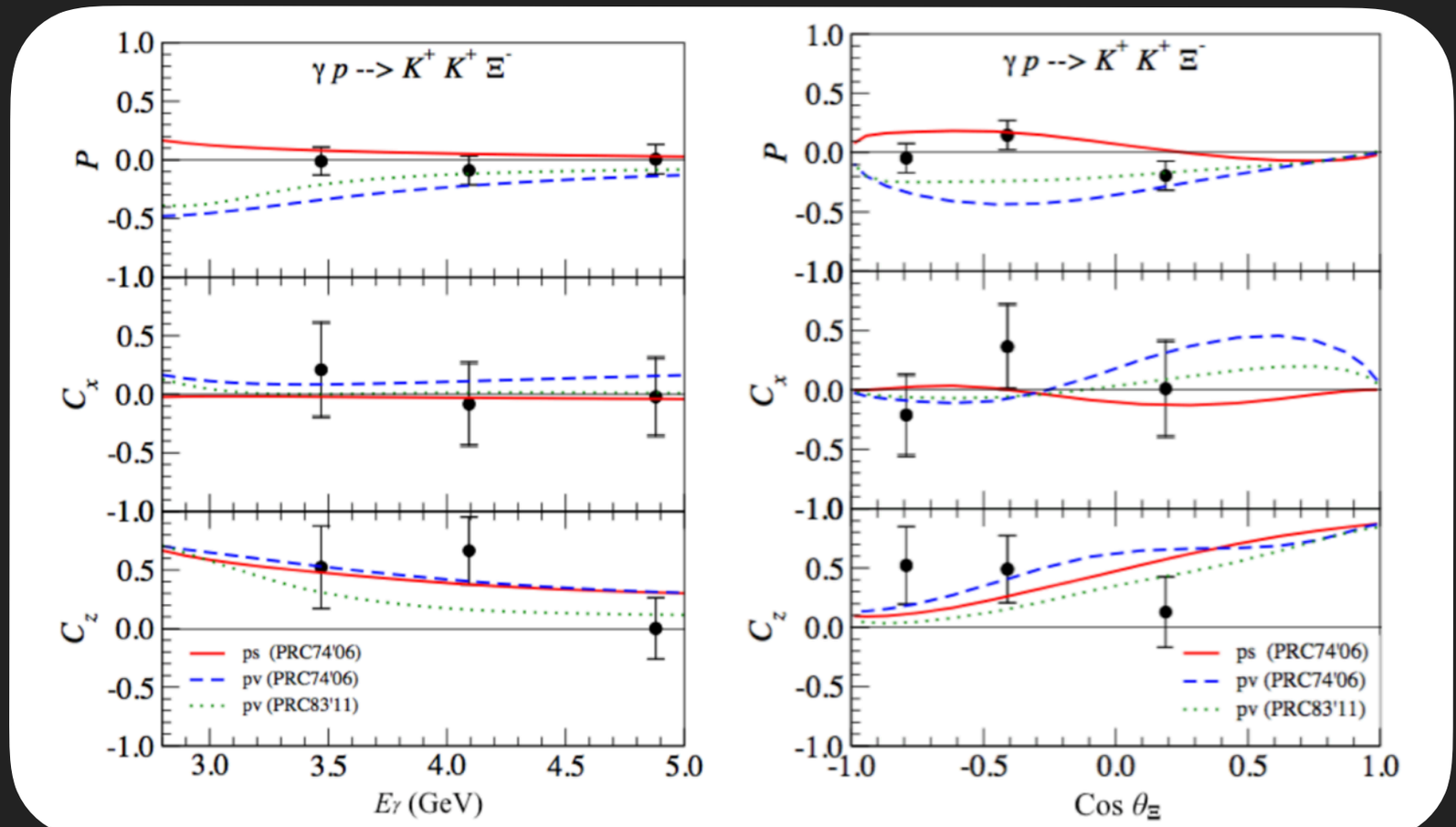
pv 06: Pseudovector coupling, resonances up to Λ(1890)

pv 11: Pseudovector coupling, resonances up to Σ(2030)

P, Cx, and Cz in 3+3 Bins

- All bins consistent with P=0, Cx=0
- Non-zero Cz
- General agreement with model
- Can not distinguish variants

Total integrated polarization = 0.3 ± 0.15



ps 06: Pseudoscalar coupling, resonances up to Λ(1890)

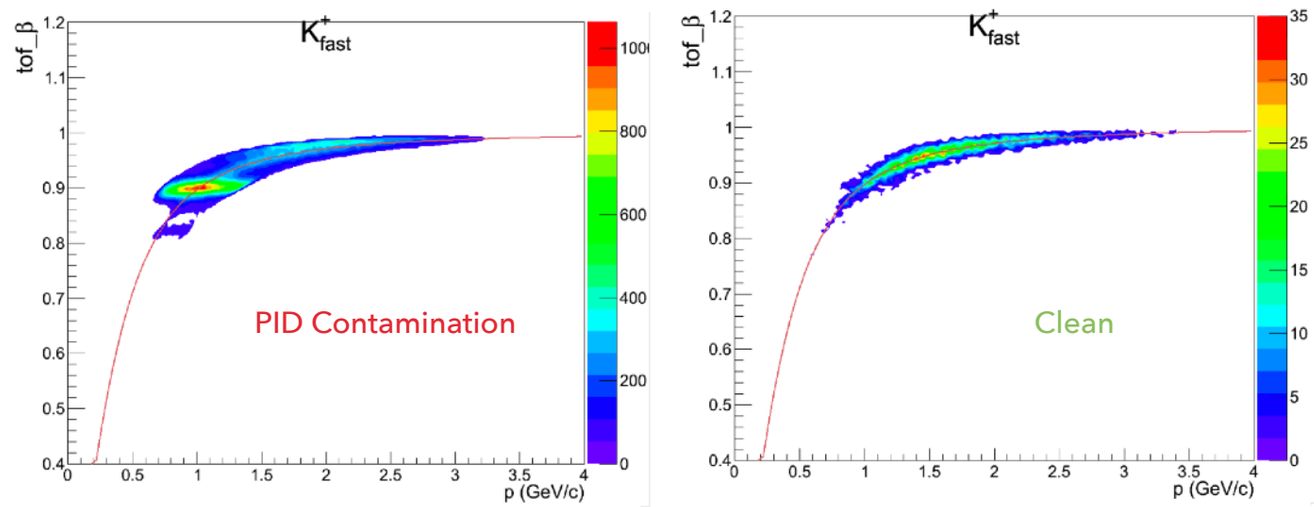
pv 06: Pseudovector coupling, resonances up to Λ(1890)

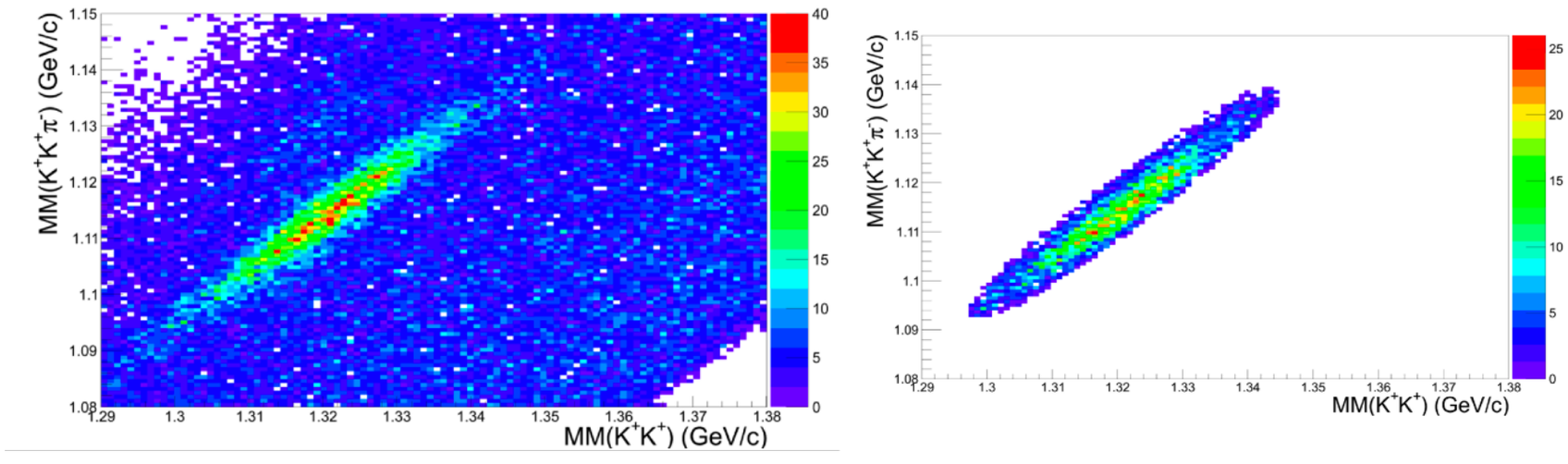
pv 11: Pseudovector coupling, resonances up to Σ(2030)

$\gamma p \rightarrow K^+ K^+ \Xi^-$

- First polarization measurements for photoproduced Ξ^-
  - P, C_x and C_z
- Total integrated polarization departs from zero by 2σ
  - R = 0.3 ± 0.15
- Results generally agree with K. Nakayama's model
  - Where Ξ production proceeds via hyperon resonances that are produced, predominantly in the *t*-channel, via relativistic meson exchange
- Statistical uncertainty prevents distinguishing the model variants
  - Can't determine the exact role of higher spin/mass hyperon resonance
  - CLAS12 & GlueX!
- We've made a first step toward a detailed understanding of Ξ^- photoproduction

Effect of Cuts

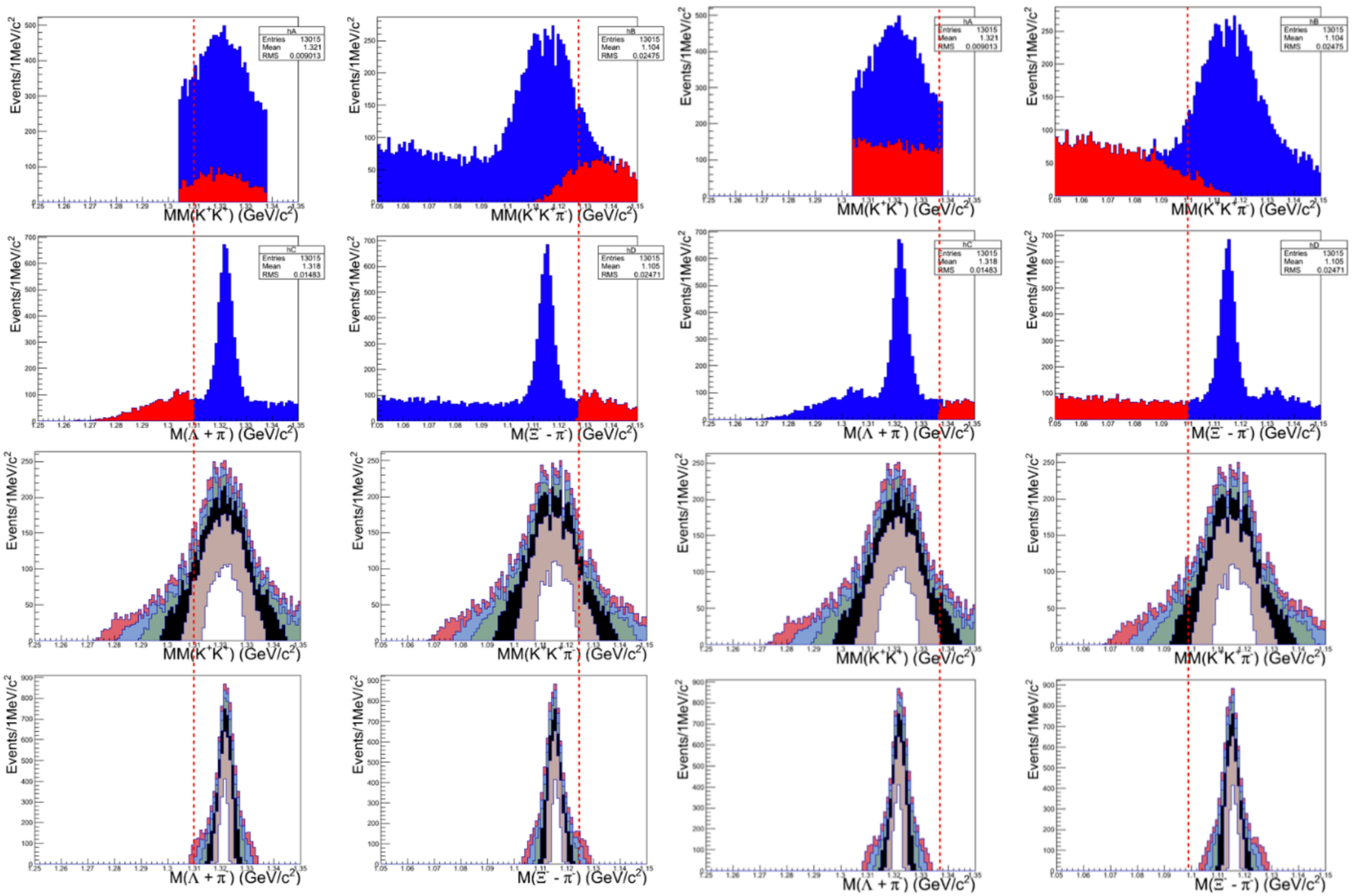




Before Cuts

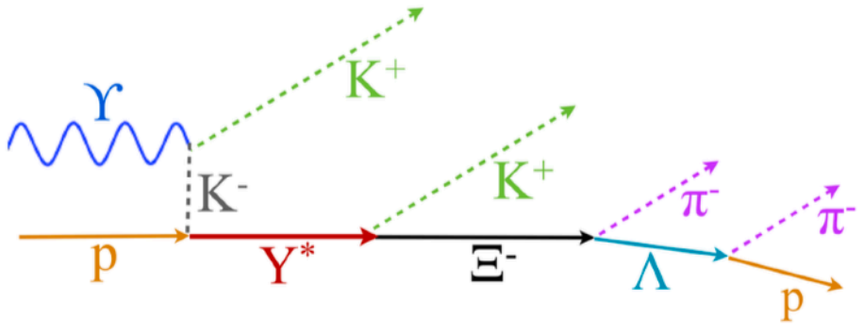
After Cuts

Lambda–pion and mixed background



Simulation Generation

To estimate acceptance effects,
simulated $\gamma p \to K^+K^+\Xi^-$ in the t-channel.



Generated events (gen)

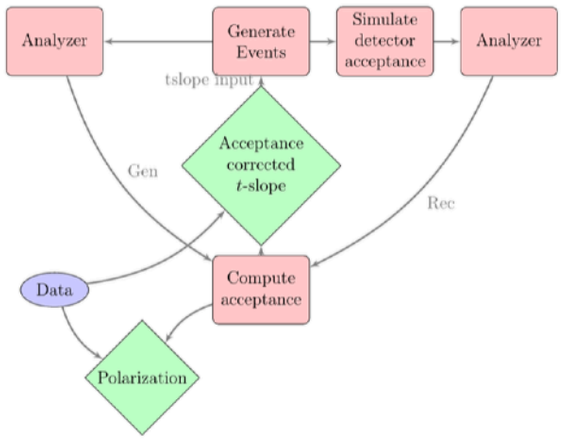
- Pseudorandom four-vectors.
- Weighting (tuning) from data.
- No acceptance or cuts.

Reconstructed events (rec)

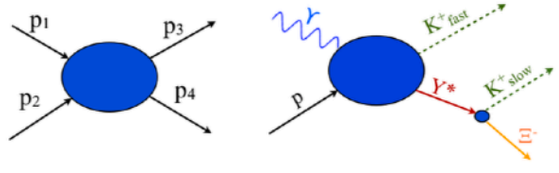
- Events processed through software simulating CLAS.
- Similar cuts to data.
- Acceptance = rec/gen.

Tuning parameters included:

- Resonance mass and width
- Beam energy spectrum
- Exponential t-slope

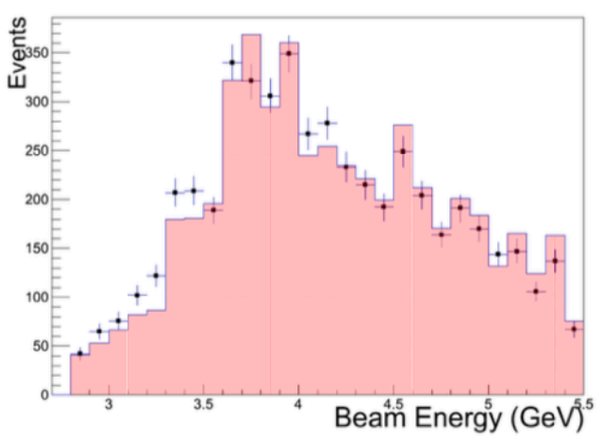


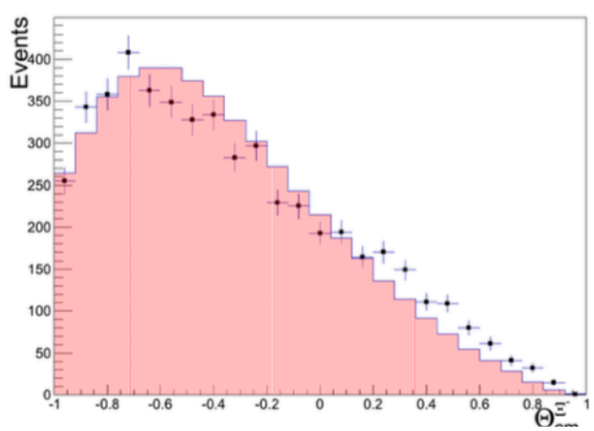
$t = (p_1 - p_3)^2 = (p_2 - p_4)^2$

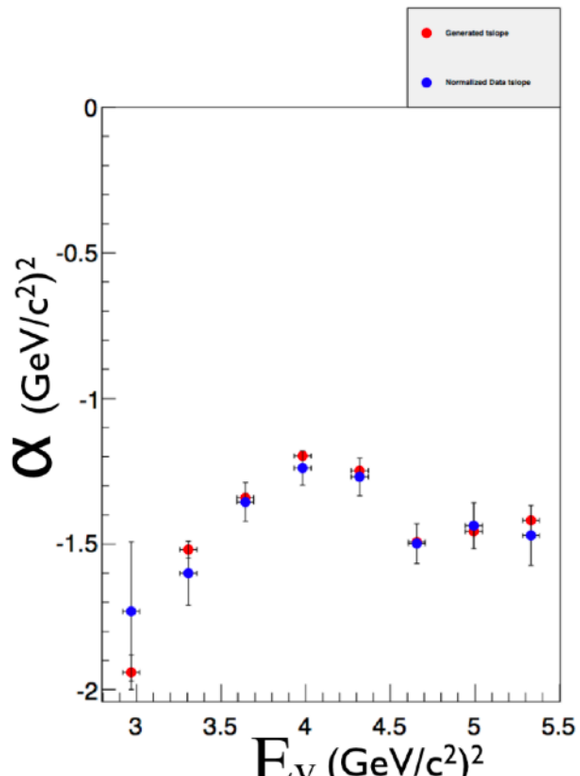


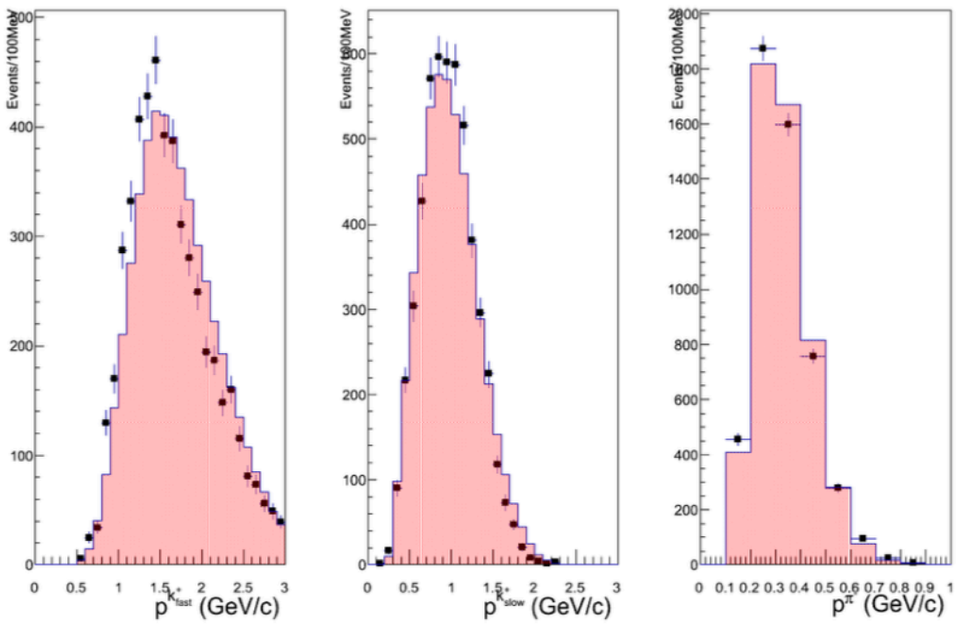
Hypothesis: $\frac{\partial\sigma}{\partial t} = Ae^{-\alpha t}$,
with, $\alpha =$ "t-slope""

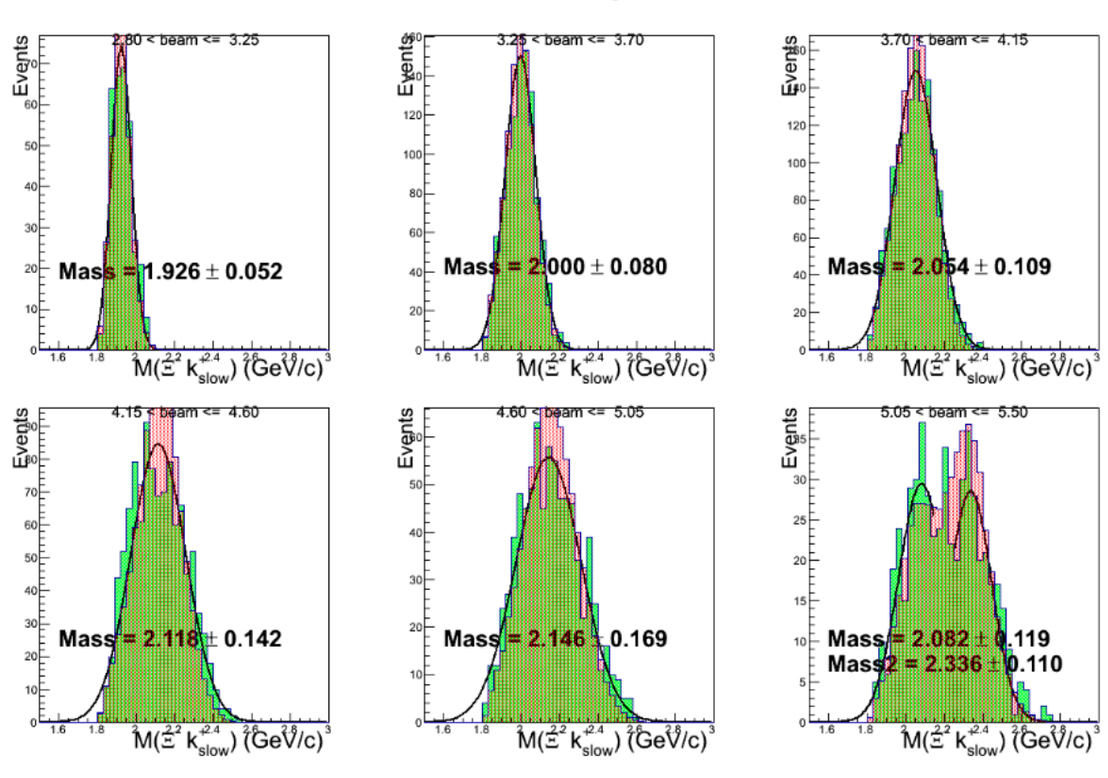
Simulation Data Comparison





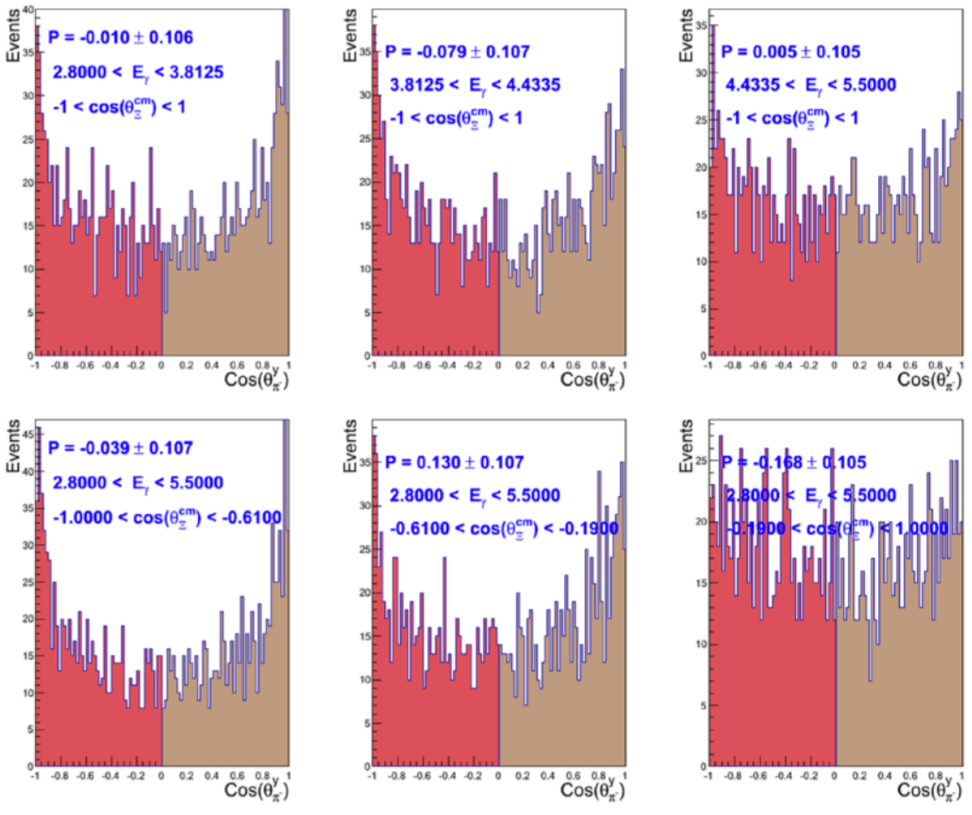






Acceptance Corrections from Simulation

No AC



AC