Search for CP Violation in Hyperon Decays.

Piotr Zyla

Lawrence Berkeley National Laboratory

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HyperCP (FNAL E871) Collaboration

A. Chan, Y.C. Chen, C. Ho, P.K. Teng

Academia Sinica, Taiwan

W.S. Choong, Y. Fu, G. Gidal, P. Gu, T. Jones, K.B. Luk, B. Turko, P. Zyla

University of California at Berkeley and Lawrence Berkeley National Laboratory

C. James, J. Volk

Fermilab

J. Felix, G. Moreno-Lopez, M. Sosa

University of Guanajuato, Mexico

R. Burnstein, A. Chakravorty, D. Kaplan, L. Lederman, W. Luebke, D. Rajaram,
H. Rubin, N. Solomey, Y. Torun, C. White, S. White

Illinois Institute of Technology

N. Leros, J. P. Perroud

Universite de Lausanne

R.H. Gustafson, M. Longo, F. Lopez, H.K. Park

University of Michigan

C. M. Jenkins, K. Clark

University of South Alabama

C. Dukes, C. Durandet, R. Godang, T. Holmstrom, M. Huang, L.C. Lu, K. Nelson

University of Virginia

Nonleptonic Decay of Hyperon

- Consider the parity-violating weak decay

$$\Lambda \rightarrow p\, \pi$$

- In the Λ rest frame, the angular distribution of the daughter p is given by:

$$\frac{dN_p}{d\cos\theta} = \frac{N_0}{2}\left(1 + \alpha_\Lambda \mathbf{P}_\Lambda \cos\theta\right)$$

where decay parameter

$$\alpha_\Lambda = \frac{2Re(S^* P)}{|S|^2 + |P|^2}$$

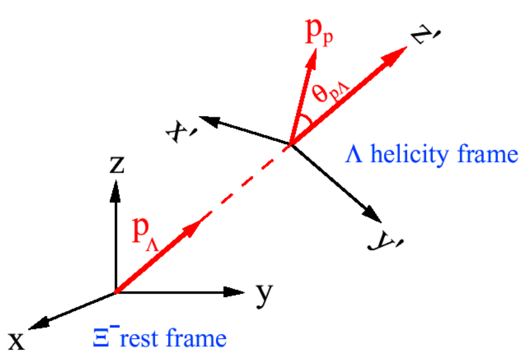
with $S(P)$ being the amplitude of the S(P)-wave of the final state.
$\mathbf{P}_\Lambda$ is the polarization of Λ and θ is the angle between the polarization vector and proton momentum.

Nonleptonic Decay of Hyperon, cont.

- Λ from the decay of unpolarized $\Xi \to \Lambda\,\pi$ is longitudinally polarized,

$$\mathbf{P}_\Lambda = \alpha_\Xi$$

- In the helicity frame of Λ, the angular distribution of the proton from $\Lambda \to p\,\pi$ is:



$$\frac{dN_p}{d\cos\theta_{p\Lambda}} = \frac{N_0}{2}\left(1 + \alpha_\Lambda \alpha_\Xi \cos\theta_{p\Lambda}\right)$$

CP Violation in Hyperon Decays

- If CP is conserved then $\alpha_{\bar{\Lambda}} = -\alpha_{\Lambda}$ and $\alpha_{\bar{\Xi}} = -\alpha_{\Xi}$
- Define asymmetry parameters for studying CP symmetry

$$A_{\Lambda} = \frac{\alpha_{\Lambda} + \alpha_{\bar{\Lambda}}}{\alpha_{\Lambda} - \alpha_{\bar{\Lambda}}} \qquad A_{\Xi} = \frac{\alpha_{\Xi} + \alpha_{\bar{\Xi}}}{\alpha_{\Xi} - \alpha_{\bar{\Xi}}} \qquad A_{\Xi\Lambda} = \frac{\alpha_{\Xi}\alpha_{\Lambda} - \alpha_{\bar{\Xi}}\alpha_{\bar{\Lambda}}}{\alpha_{\Xi}\alpha_{\Lambda} + \alpha_{\bar{\Xi}}\alpha_{\bar{\Lambda}}} \approx A_{\Xi} + A_{\Lambda}$$

- Some theoretical predictions (He, Pakvasa, Murayama, Valencia, ...)

	$\lvert A_{\Lambda}\rvert\ (10^{-4})$	$\lvert A_{\Xi}\rvert\ (10^{-4})$
CKM	(0.1, 0.5)	(0.05, 1)
Left-Right	(0.1, 6)	(2,6)
SUSY	(0.2, 10)	—

Experimental Results

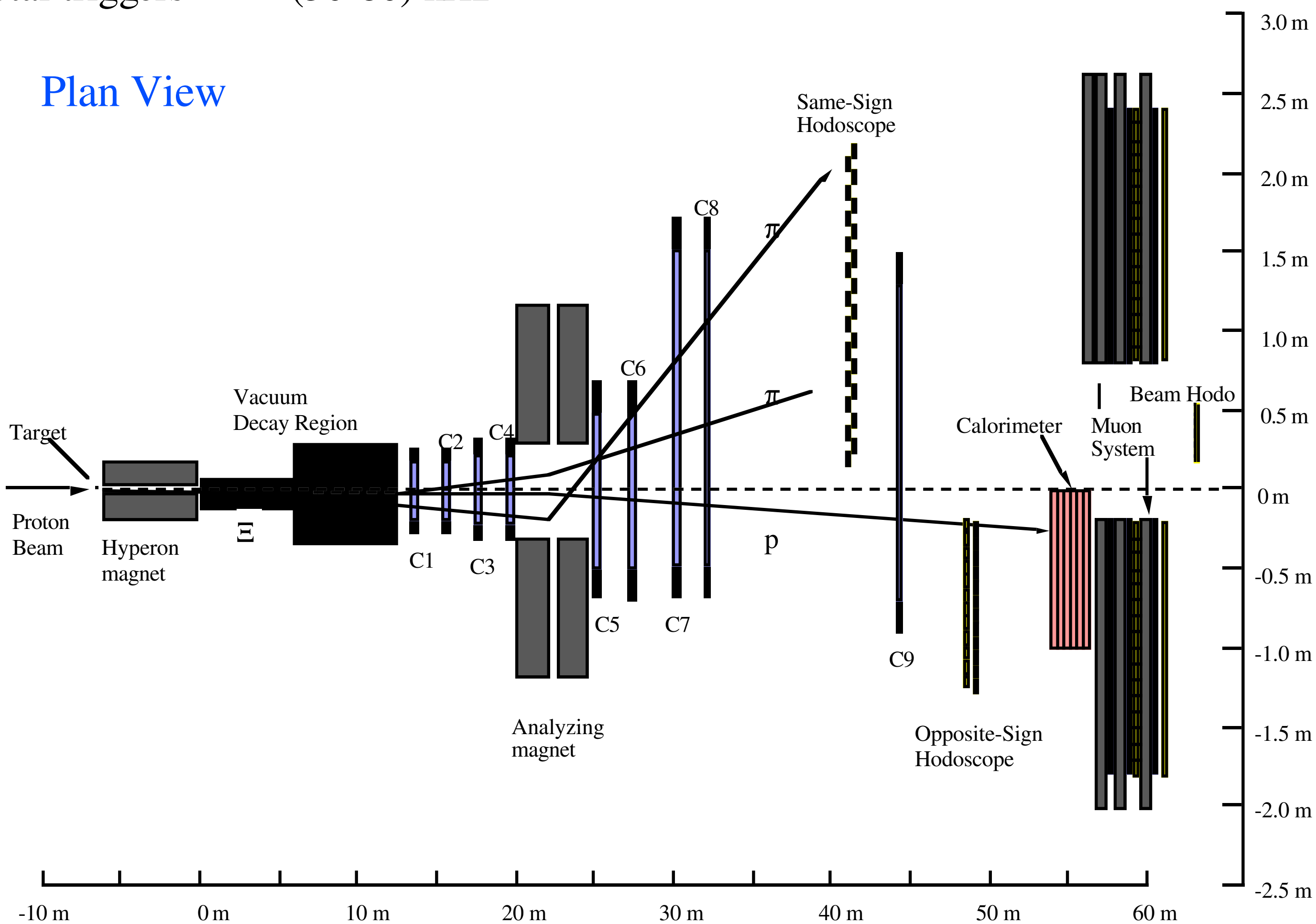
Experiment	Mode	A_Λ
R608 at ISR	$\bar{p}p \to \Lambda X,\ \bar{p}p \to \bar{\Lambda} X$	-0.02 ± 0.14
DM2 at Orsay	$e^+e^- \to J/\Psi \to \Lambda\bar{\Lambda}$	0.01 ± 0.10
PS185 at LEAR	$\bar{p}p \to \bar{\Lambda}\Lambda$	-0.013 ± 0.022

Experiment	Mode	$A_{\Xi\Lambda}$
FNAL E756	$\Xi\downarrow \to \Lambda\pi,\ \Lambda \to p\pi$	0.012 ± 0.014
CLEO unpublished	$\Xi \to \Lambda\pi,\ \Lambda \to p\pi$	$-0.057 \pm 0.064 \pm 0.039$

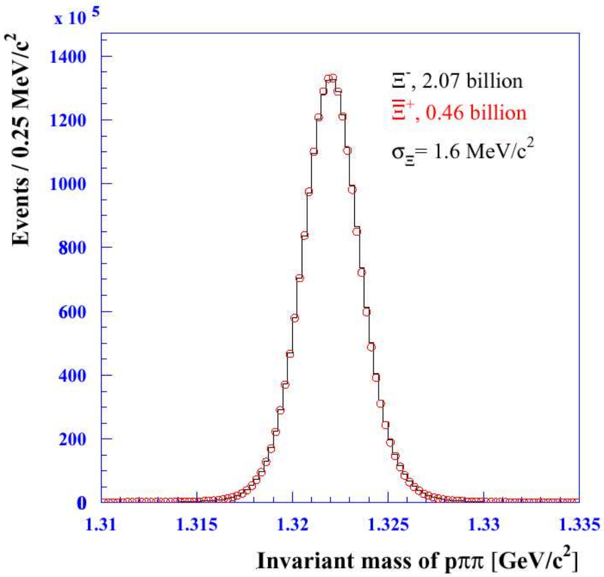
- HyperCP will measure $A_{\Xi\Lambda}$ with unpolarized Ξ^- and Ξ^+ hyperons produced by 800 GeV protons to a precision of 10^{-4}.

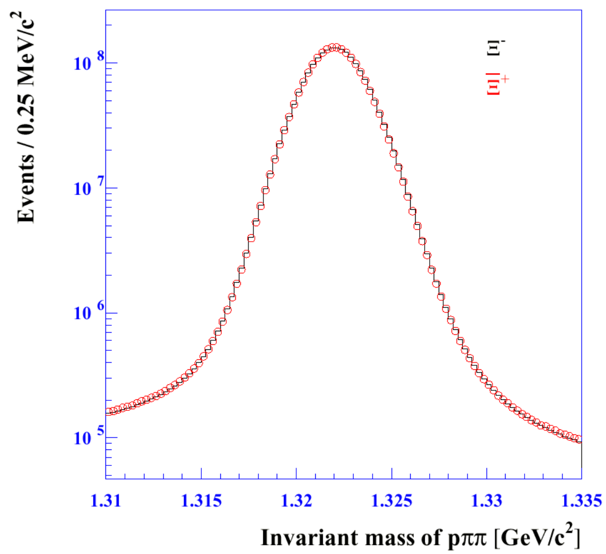
The HyperCP Spectrometer

- Protons on target = (7-8) GHz
- Sec. beam inten. = (10-15) MHz
- Total triggers = (50-80) kHz



Statistics of The 1997 And 1999 Runs



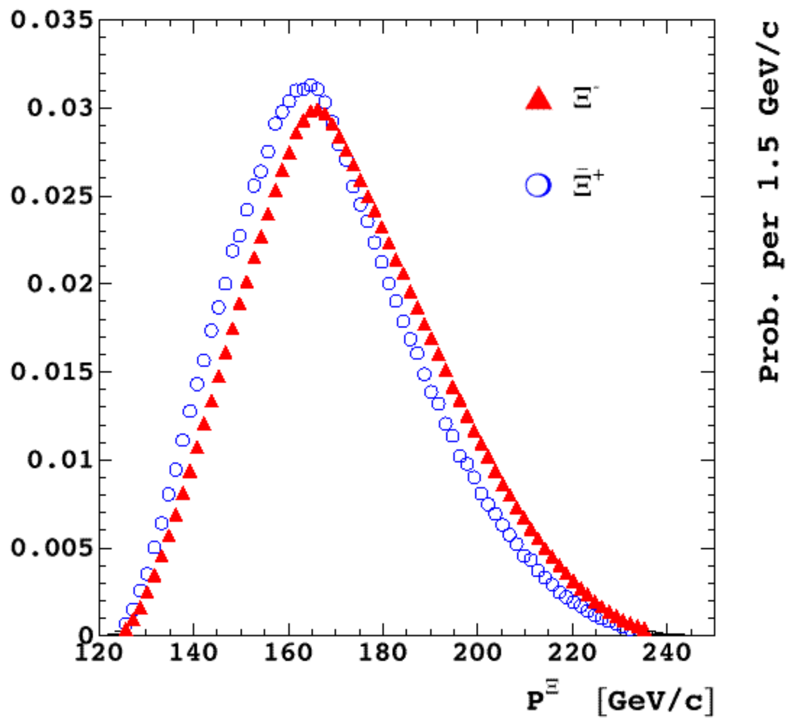


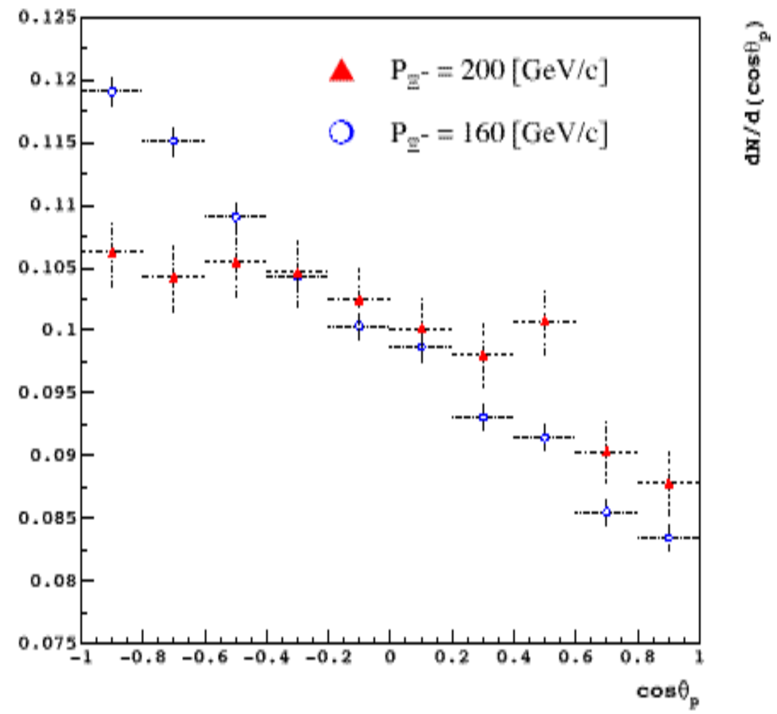
- Number of reconstructed events:

Ξ^-	2×10^9	K^-	0.16×10^9	Ω^-	14×10^6
$\overline{\Xi}^+$	0.5×10^9	K^+	0.39×10^9	$\overline{\Omega}^+$	4.9×10^6

- Statistical precision: $\delta A_{\Xi\Lambda} \sim 2 \times 10^{-4}$

Observed difference between Ξ^- and Ξ^+



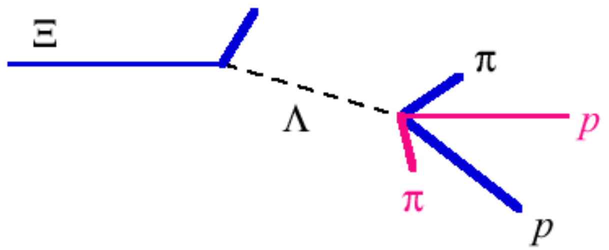


- Need to take care of observed difference in production mechanisms between Ξ^- and Ξ^+

Hybrid Monte Carlo Method (HMC)

- For a given input event, Monte Carlo events are created using all measured quantities from the input event except $\cos\theta_{p\Lambda}$ which is generated uniformly.

- The HMC events are then subjected to multiple scattering, detector simulation, track reconstruction and the same selection process as the input events.



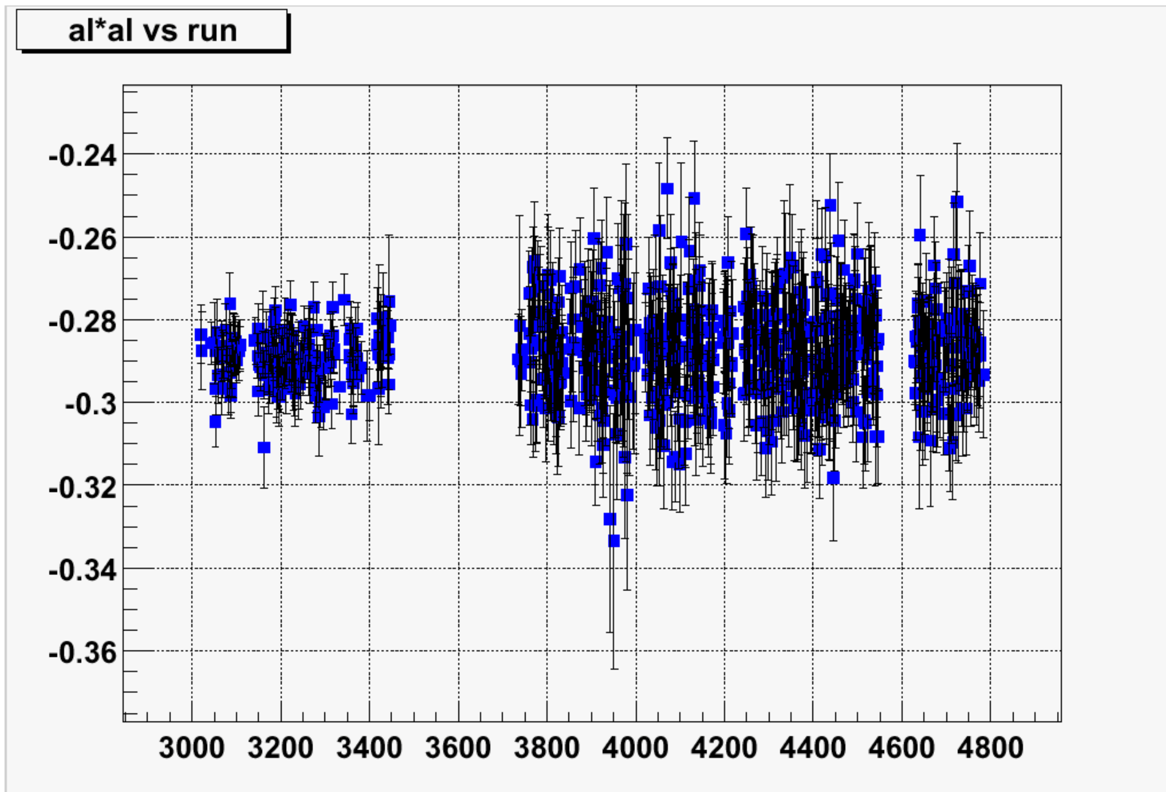
- The $\cos\theta_{p\Lambda}$ distribution of the accepted HMC events is then adjusted to match that of the input events with a weight which is a function of $\alpha_\Xi\alpha_\Lambda$ by minimization.

- Verification: PDG input $\alpha_\Xi\alpha_\Lambda = -0.2927\ (\pm\ 0.0070)$

  HMC: $\alpha_\Xi\alpha_\Lambda = -0.2953 \pm 0.0029$

HMC measurement of $\alpha_{\Xi}\alpha_{\Lambda}$ vs run

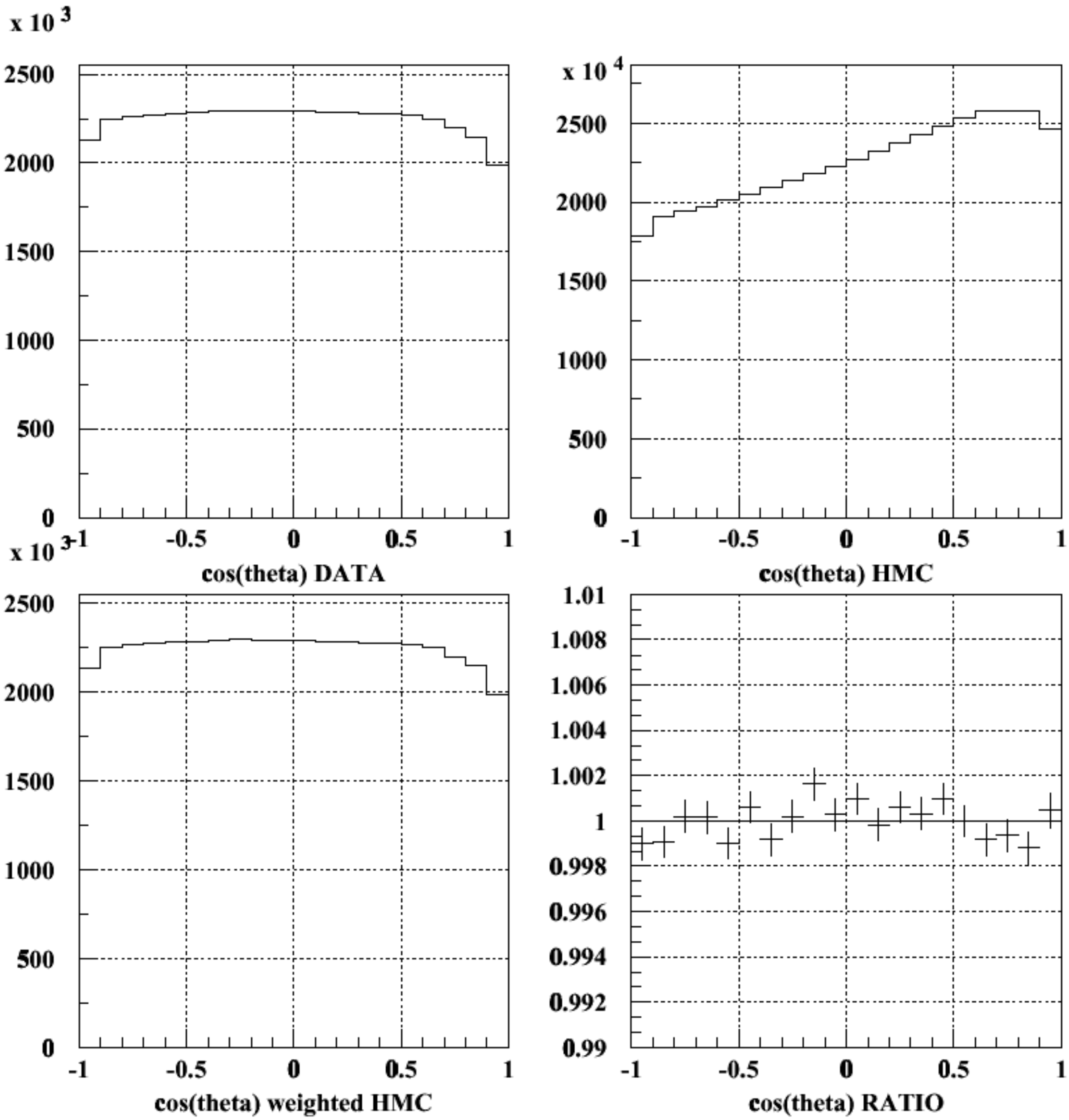
- Data sample: randomly selected Ξ events during data reduction; about 15×10^6 Ξ^- and 30×10^6 Ξ^+ events.



Average $\alpha_{\Xi}\alpha_{\Lambda}$ = -0.2880 ± 0.0004(stat) χ^2 = 26/19 dof

in agreement with PDG value

HMC measurement of $\alpha_\Xi \alpha_\Lambda$

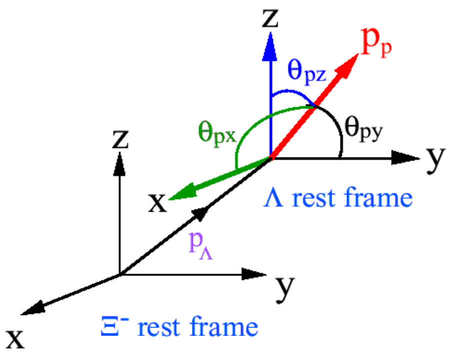


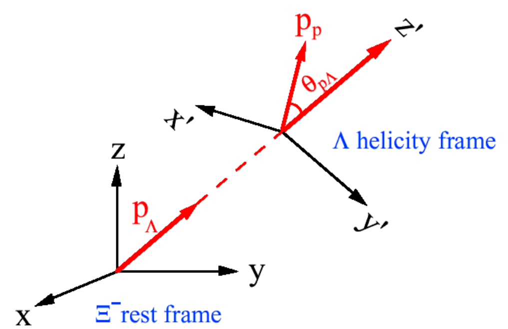
Potential Sources of Systematic Uncertainties

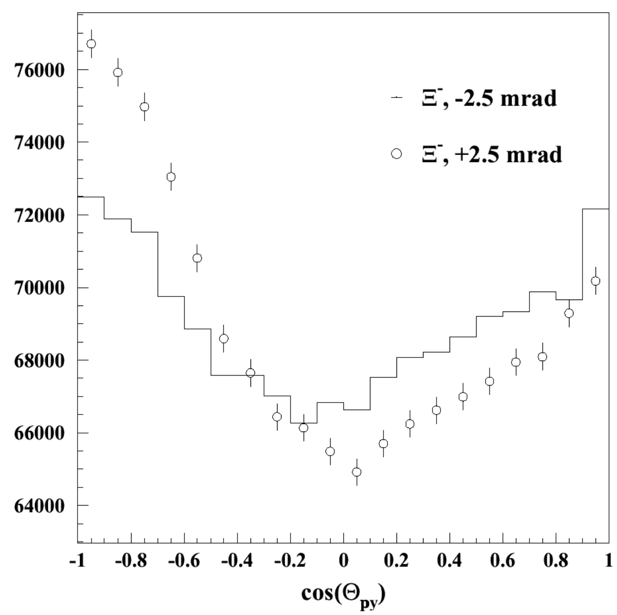
- Difference in production polarization between Ξ^- and Ξ^+;
- Rate dependence;
- Asymmetry of backgrounds of Ξ^- and Ξ^+;
- Uncertainty in measurement of trigger inefficiencies;
- Uncertainty in measurement of MWPC inefficiencies;
- Uncertainty in measurement of B-field in momentum analyzing magnets;
- Differences in particle and antiparticle interactions;

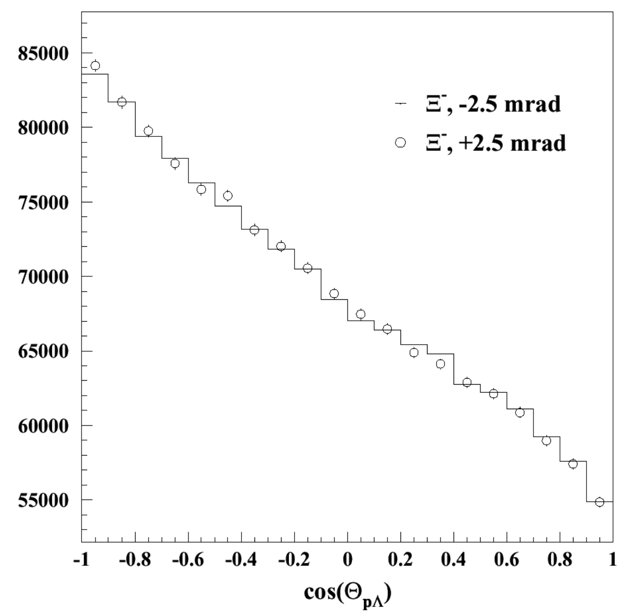
Effect of Polarization and Difference in Acceptance

Ξ^- (-2.5 mrad) vs Ξ^- (+2.5 mrad)



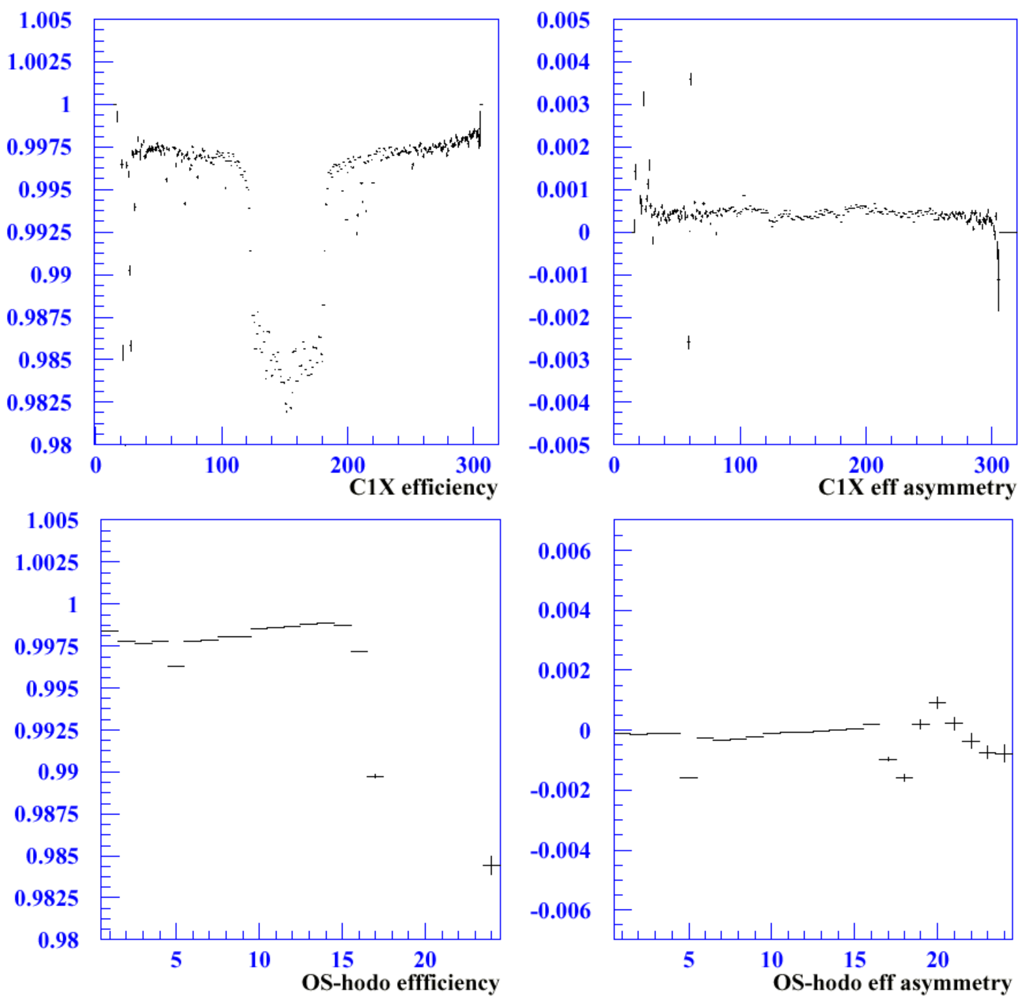






With larger data sample observed no systematic effect due to polarization in measurement of $\alpha_\Xi\alpha_\Lambda$. The statistical precision of this result leads to $\delta A_{\Xi\Lambda} = 0.4 \times 10^{-4}$.

Effect of Detector Inefficiencies



Uncertainty in measurement of PWC efficiencies results in:

$$\delta A_{\Xi\Lambda} = 2.7 \times 10^{-4}$$

Uncertainty in measurement of hodoscopes efficiencies results in:

$$\delta A_{\Xi\Lambda} = 1.7 \times 10^{-4}$$

Summary of Systematic Uncertainties

- The uncertainties are established using data and thus limited by the sample statistics.

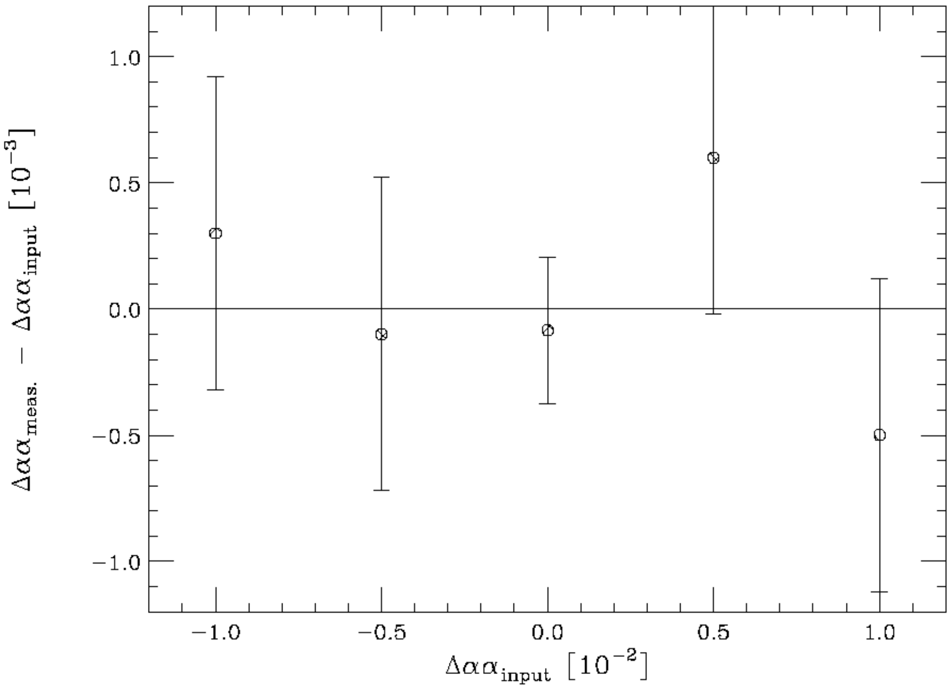
Study	$\delta \mathbf{A}_{\Xi\Lambda}$ (10^{-4})
Polarization	0.4
Rate dependence	3.4
Background	2.4
Hodo. Eff.	1.7
Cal. Eff.	1.8
PWC Eff.	2.7
B Field	2.2
Interaction diff.	0.5
TOTAL	6.2

- Preliminary result: $A_{\Xi\Lambda} = [-7 \pm 12(\text{stat}) \pm 6.2(\text{sys})] \times 10^{-4}$

Weighting Method

- Match a minimal set of kinematic and geometric variables to take out any production differences between Ξ^- and Ξ^+. Extract the difference in the slopes of the helicity distributions directly.

- Input a CP asymmetry into the Monte-Carlo samples:



- This technique removes bias caused by production but preserves signal.

Conclusions

- A preliminary measurement of CP asymmetry in $\Xi-\Lambda$ decays from a fraction of 1997 and 1999 data sample:

$$A_{\Xi\Lambda} = [-7 \pm 12(\text{stat}) \pm 6.2(\text{sys})] \times 10^{-4}$$

An order of magnitude better than the present limit.

- The projected statistical sensitivity from the full data sample is $\sim 2 \times 10^{-4}$, within range of some theoretical predictions. Current systematic uncertainties are expected to scale down with the sample statistics.

- The large number of Ξ, Ω, and K decays permits a variety of precise measurements and rare decay searches.