A Search For CP Violation in Hyperon Decays by the HyperCP Experiment at Fermilab

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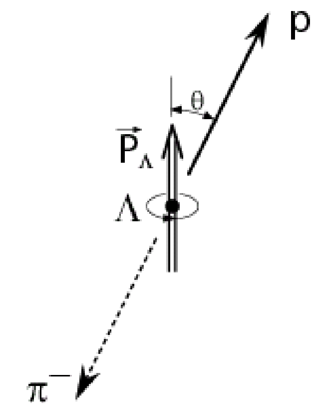
Nonleptonic Decays of Hyperons

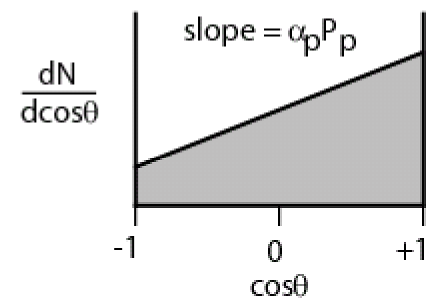
- The parity-violating weak decays we are interested in are:

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



- The Λ and p have an angular decay distribution that takes the following form:

$$\frac{dN}{d\cos\theta} = \frac{N_0}{2}\left(1+\alpha_p \boldsymbol{P}_p \cos\theta\right)$$



- Where the α decay parameter for the Λ and Ξ is:

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

- S and P are the angular momentum wave amplitudes
- The α_Ξ and α_Λ are large and are a measure of P violation

CP violation in Hyperon Decays

- If CP is conserved then:

$$\alpha_{\Lambda} = -\alpha_{\overline{\Lambda}} \qquad \text{and} \qquad \alpha_{\Xi} = -\alpha_{\overline{\Xi}}$$

- The CP-asymmetry parameters are defined as:

$$\mathrm{A}_{\Lambda} = \frac{\alpha_{\Lambda} + \alpha_{\overline{\Lambda}}}{\alpha_{\Lambda} - \alpha_{\overline{\Lambda}}} \qquad \mathrm{A}_{\Xi} = \frac{\alpha_{\Xi} + \alpha_{\overline{\Xi}}}{\alpha_{\Xi} - \alpha_{\overline{\Xi}}}$$

- There parameters are related to the strong- and weak-phase shift differences:

$$A_{\Lambda} \cong -\tan(\overbrace{\delta_1^P - \delta_1^S}^{strong})\sin(\overbrace{\phi_1^P - \phi_1^S}^{weak})$$

$$A_{\Xi} \cong -\tan(\delta_2^P - \delta_2^S)\sin(\phi_{12}^P - \phi_{12}^S)$$

- HyperCP will measure the Λ–π strong phase shift difference
- But we need to know the polarization to measure the α parameter

How do we produce Λs with a known Polarization?

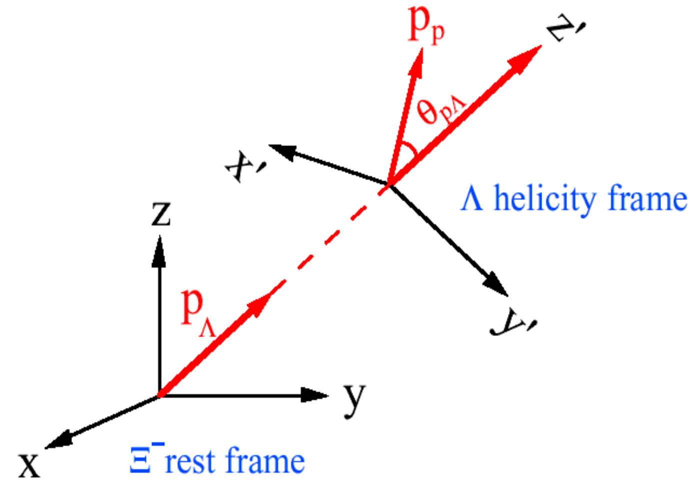
- Our experimental approach is to use unpolarized Ξ.
- The polarization of a daughter particle from an unpolarized parents is know to be:

$$\vec{P}_{\Lambda} = \alpha_{\Xi} \hat{p}_{\Lambda}$$

- This means that the angular decay distribution of the Λ can now be described by:

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

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



How is this different from ε`?

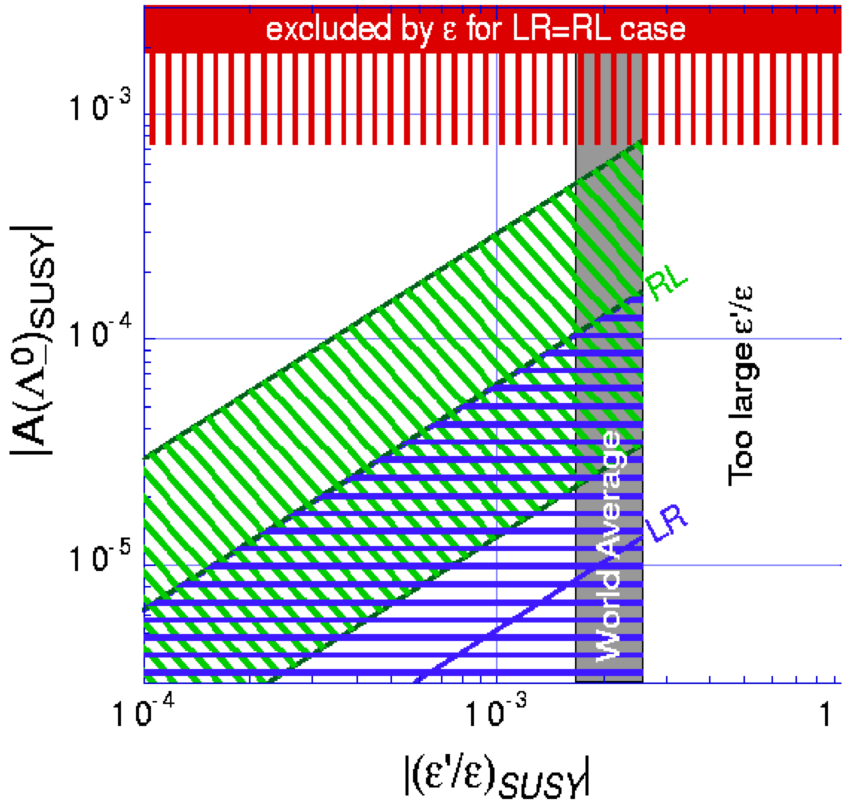
- $A_{\Xi\Lambda}$
  - A CP violating phase in the S and P wave amplitudes interference
  - Combines both Parity violating and conserving amplitudes

- ε`/ε
  - A CP violating phase in the I = 0 and I = 2 amplitudes interference
  - Consists of only Parity violating amplitudes

"Our results suggest that this measurement is complementary to the measurement of ε`/ε, in that it probes potential sources of CP violation at a level that has not been probed by Kaon experiments" (He and Valencia)

Theoretical Predictions

- Standard Model predicts that A_Λ is 3E-5, with large errors
- Some SUSY models predict values up to 1.9E-3(He et.al.)
- A positive result would be a signal for new Physics



Experimental Results

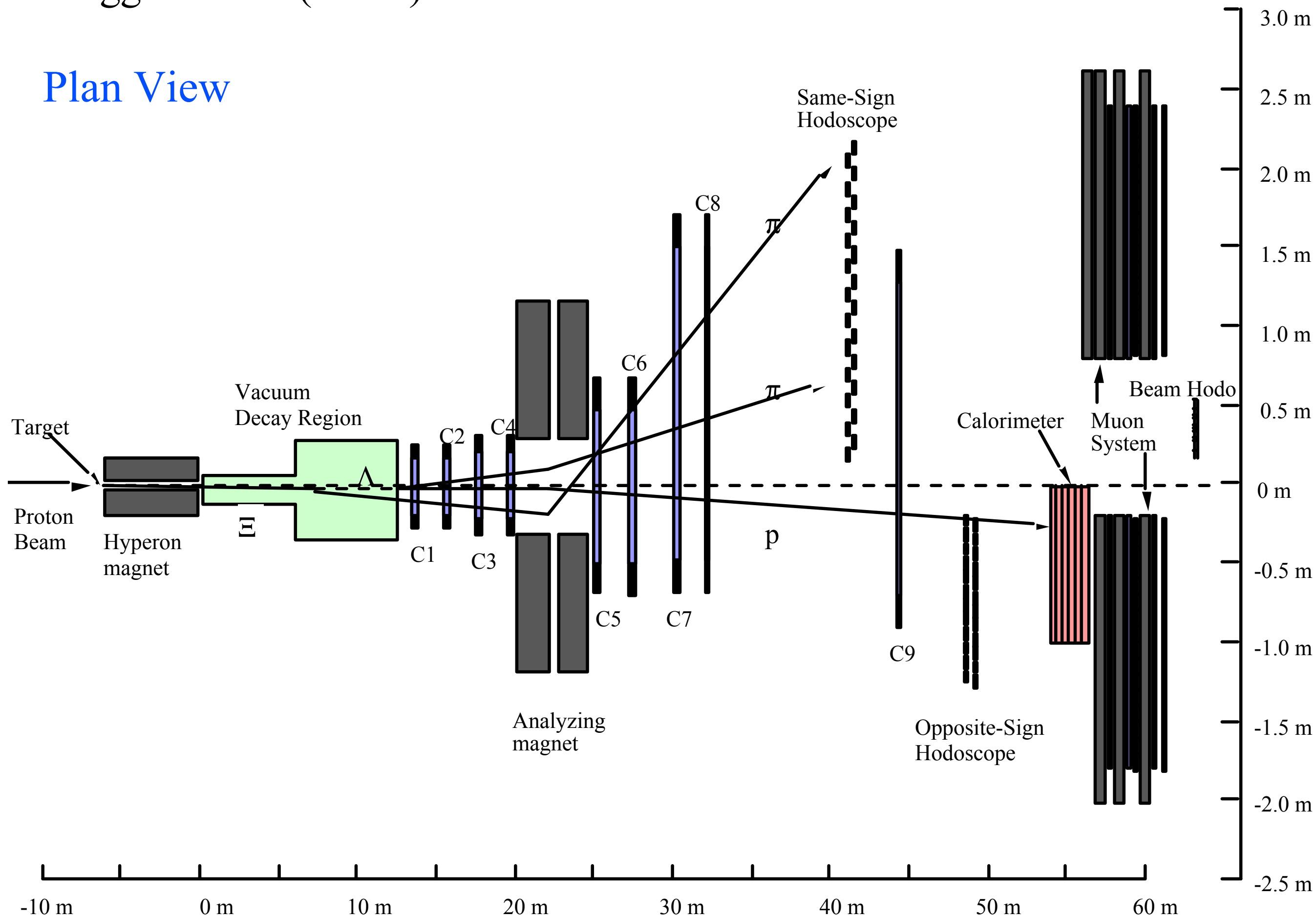
Experiment	Mode	A_Λ
R608 at ISR	$p\bar{p} \to \Lambda X, p\bar{p} \to \bar{\Lambda} X$	-0.02±0.14
DM2 at Orsay	$e^+e^- \to J/\Psi \to \bar{\Lambda}\Lambda$	0.01 ±0.10
PS185 at LEAR	$\bar{p}\,p \to \bar{\Lambda}\,\Lambda$	-0.013 ±0.022

Experiment	Mode	$A_{\Xi\Lambda}$
FNAL E756	$\Xi \to \Lambda\pi, \Lambda \to p\pi$	0.012 ± 0.014

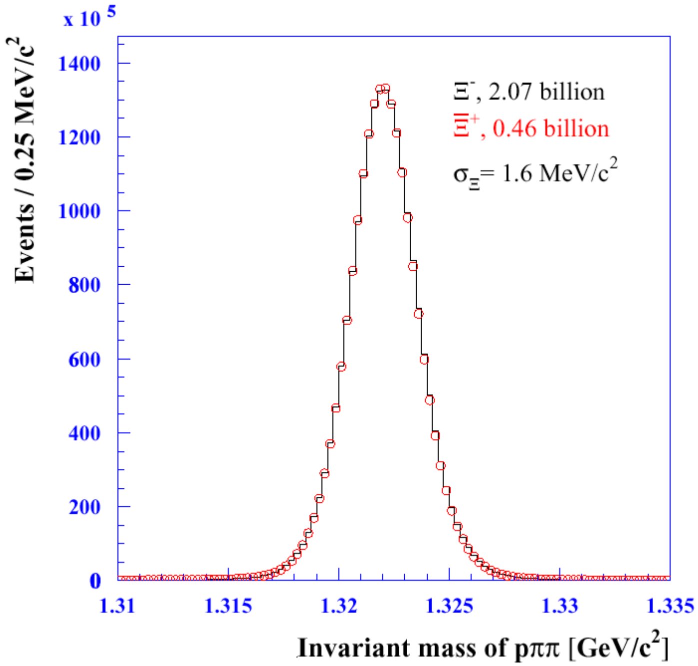
- HyperCP will measure $A_{\Xi\Lambda}$ with unpolarized Ξ^- and Ξ^+ hyperons produced by 800 GeV protons to a precision of 10^{-4}.

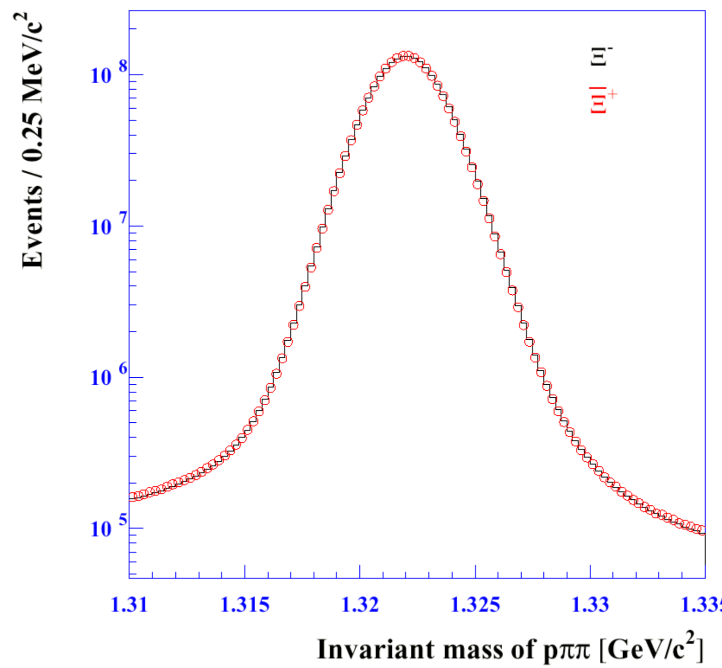
The HyperCP Spectrometer

- 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

Two analysis methods

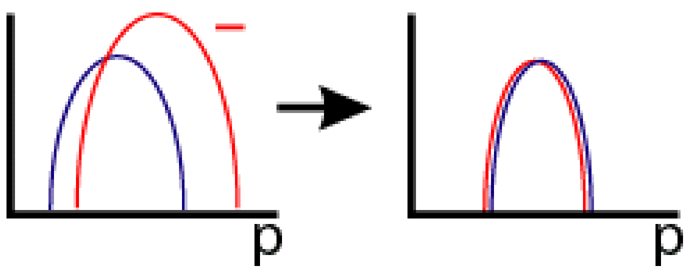
- Using two methods allows us a cross-check our result

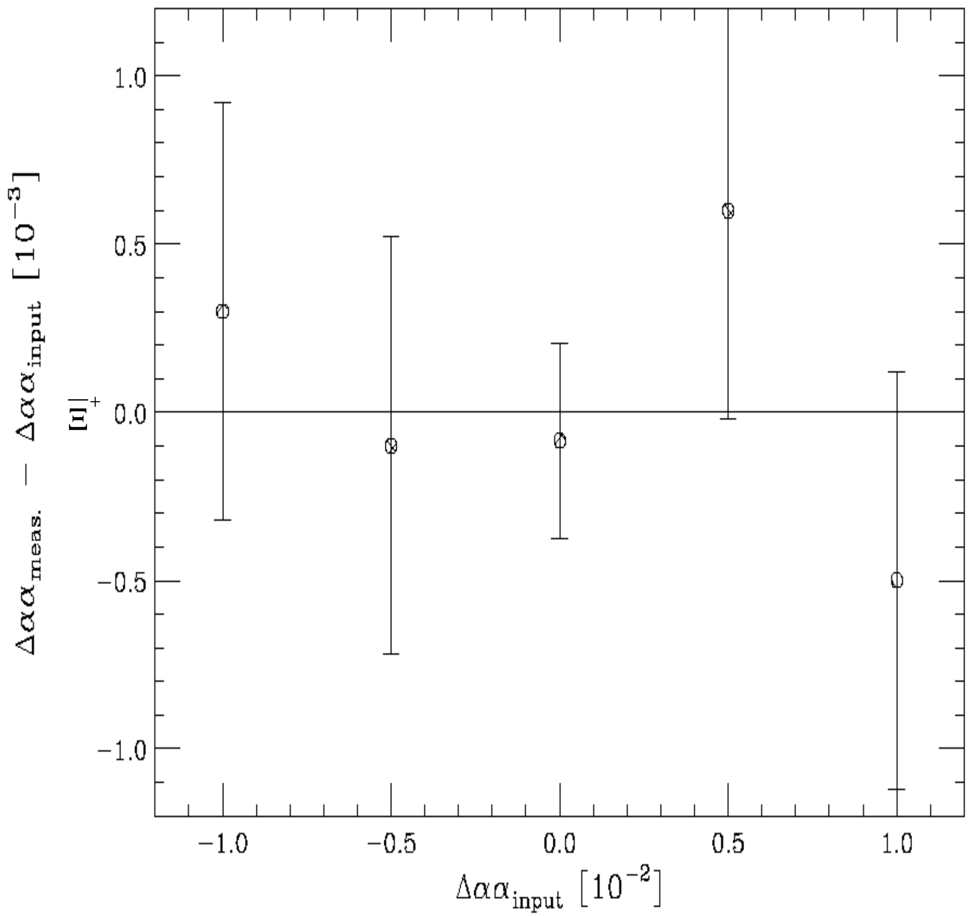
- HMC Method-Takes real events and replaces proton and pion and generates 10 new unpolarized decays
- Advantage: well-tested and understood method
- Disadvantage: Monte Carlo requires detailed simulation of trigger and detector response .

- Weighting method- Force two samples to have similar production momentum and spatial distributions
- Advantage: No Monte Carlo measurement of acceptance needed
- Disadvantage: no absolute measure of $\alpha_\Lambda \alpha_\Xi$.

Weighting Method

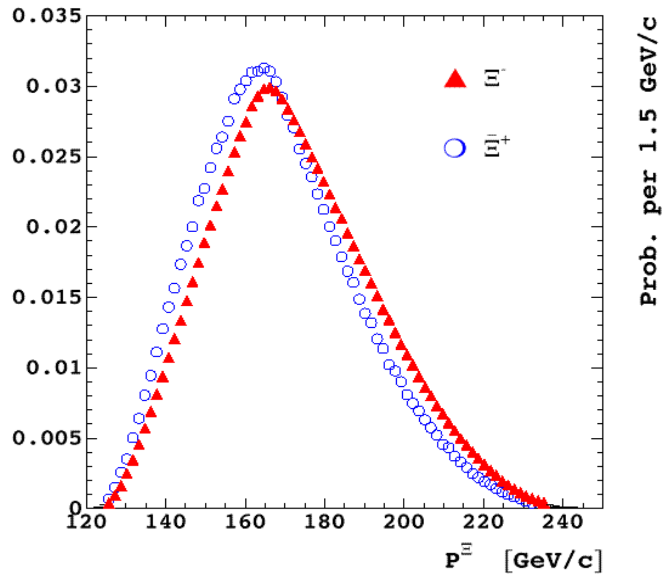
- Weight the Ξ^- and Ξ^+ samples with the following 5 kinematic and geometric variables w(x col, y col, p_x, p_y, p_z), so that they have the same distribution
- Tested using Monte Carlo (right)
- Returns input asymmetry for various values
- Raw values over 10σ from input

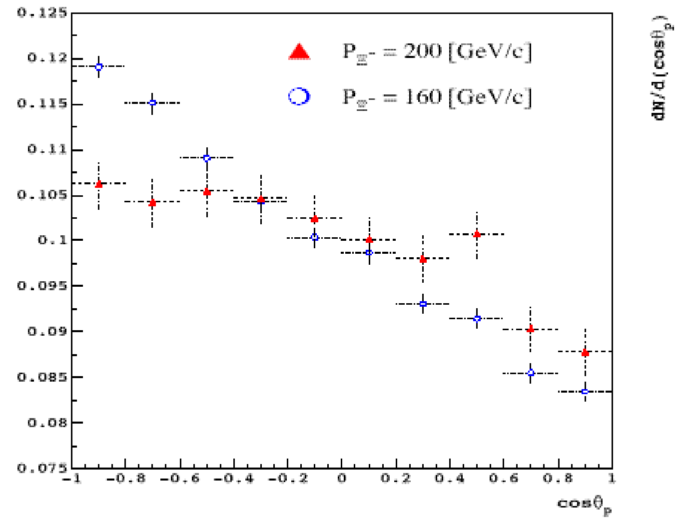




Observed difference between Ξ^- and Ξ^+

- Production differences lead to different acceptances in cos(theta) between the two samples.
- Our analysis method must correct for these differences.



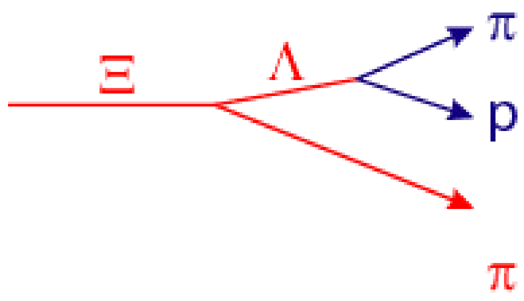


Hybrid Monte Carlo Method (HMC)

- 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.

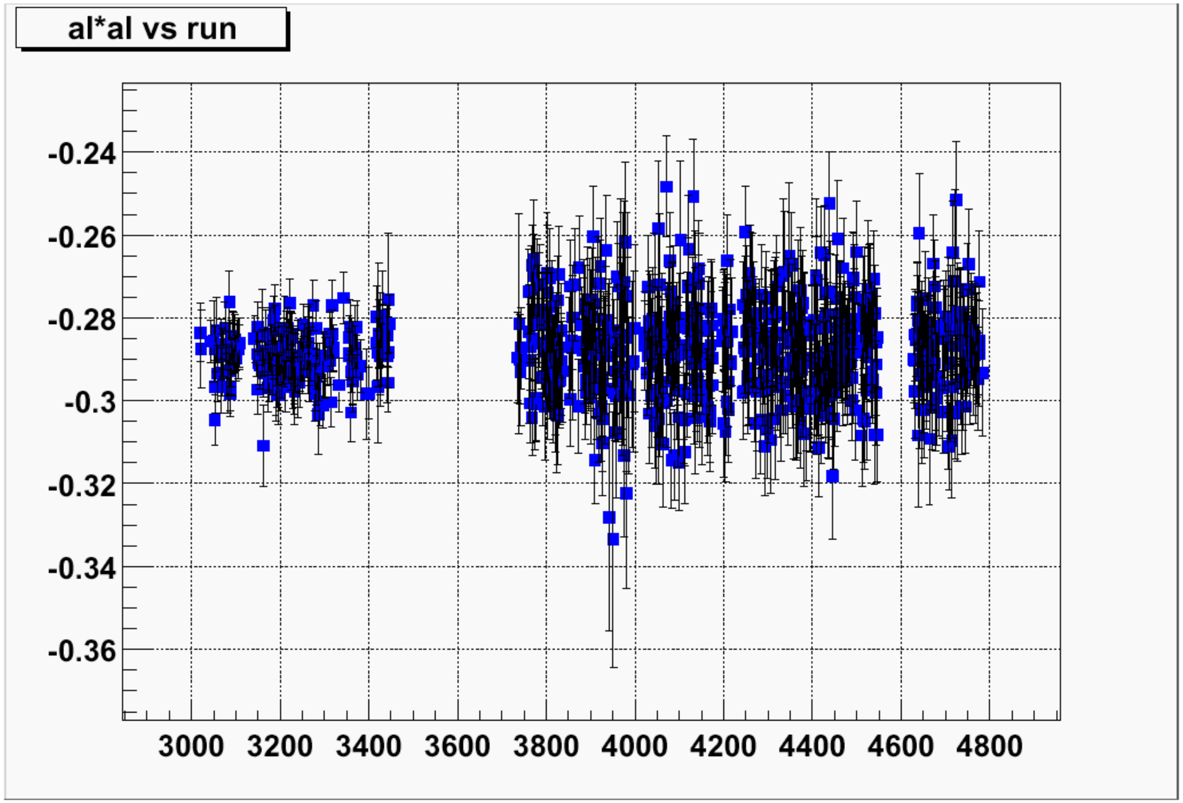
- The $\cos\theta_{p\Lambda}$ distribution of the accepted HMC events is then adjusted to match that of the input events with a minimization function in $\alpha_\Xi\alpha_\Lambda$.



- Verification: XMC input $\alpha_\Xi\alpha_\Lambda$ = -0.2927 (± 0.0070)
  HMC: $\alpha_\Xi\alpha_\Lambda$ = -0.2953 ± 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.

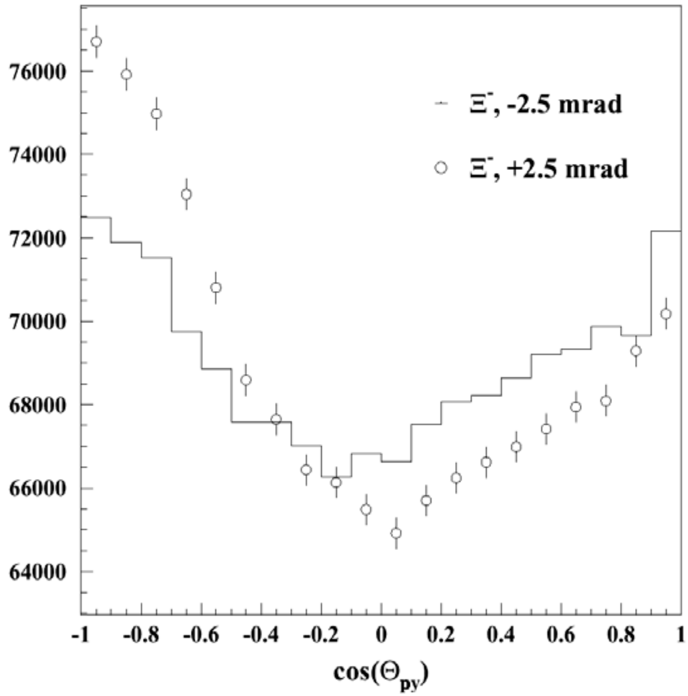


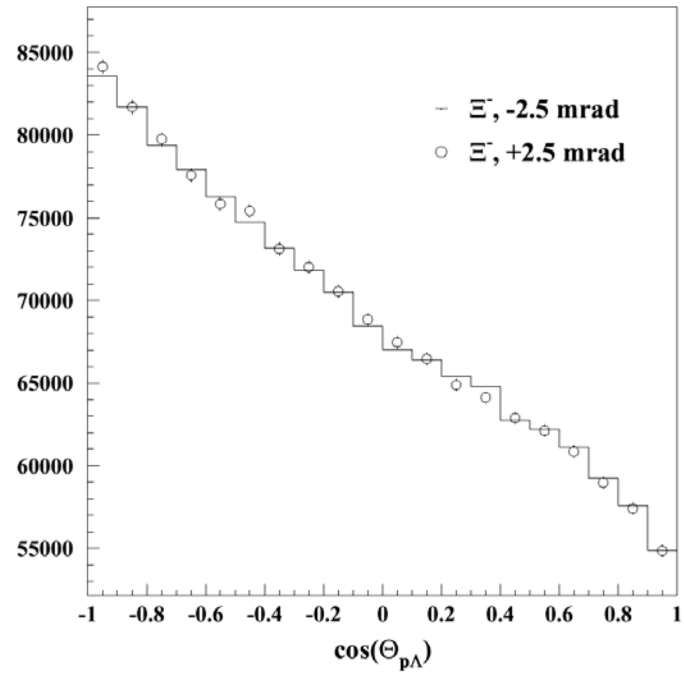
Average $\alpha_\Xi \alpha_\Lambda$ = -0.2880 ± 0.0004(stat) χ^2 = 26/19 dof
in agreement with PDG value

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 analyzing magnets;
- Differences in particle and antiparticle interactions;

Effect of Polarization on Acceptance

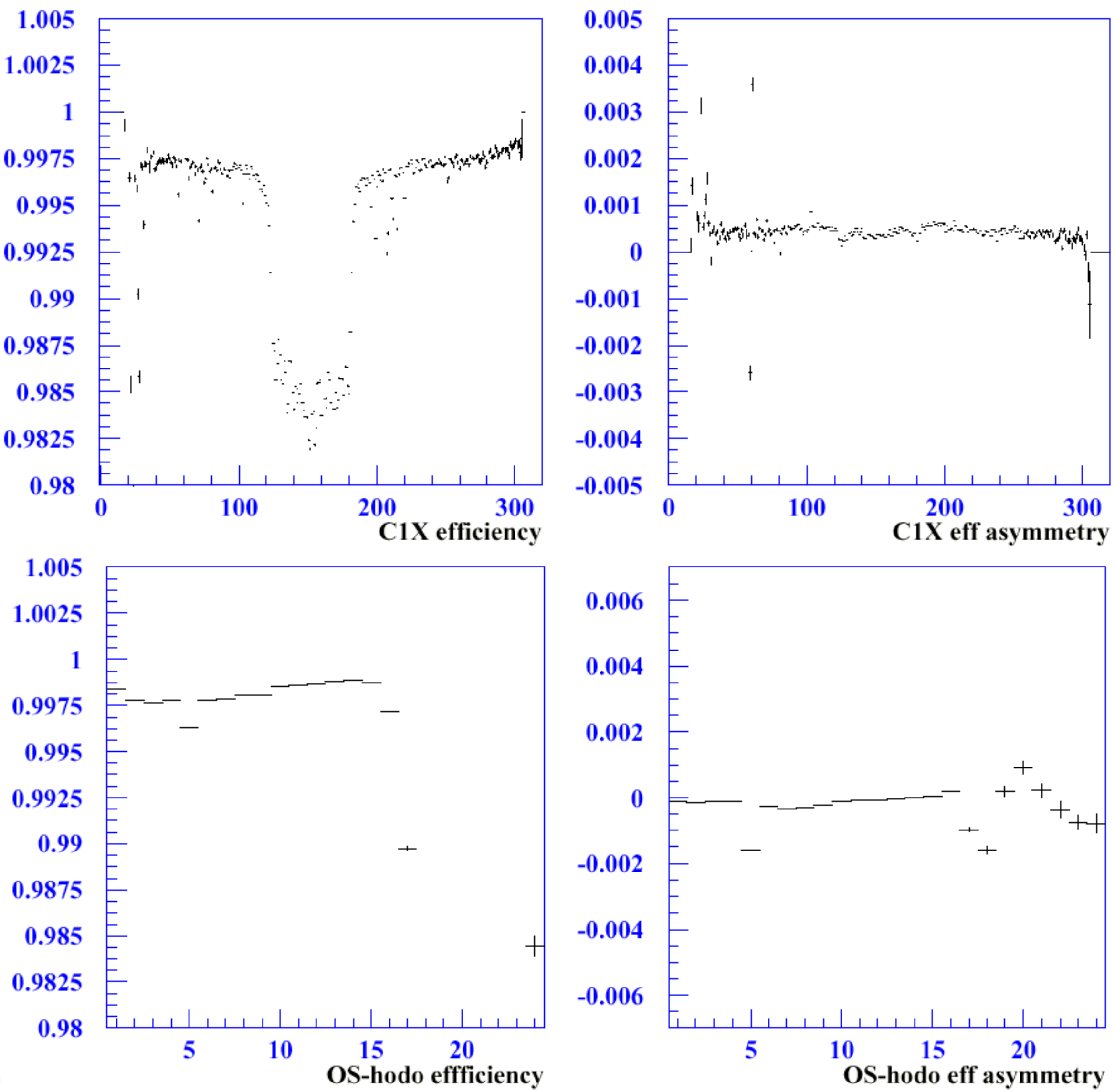




2 Ξ^- samples
2 different targeting angles

With a larger data sample we 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 eff. Results in:

$$\delta A_{\Xi\Lambda} = 2.7\times10^{-4}$$

- Uncertainty in measurement of hodoscope eff. Results in:

$$\delta A_{\Xi\Lambda} = 1.7\times10^{-4}$$

Summary of Systematic Uncertainties

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

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

Conclusions

- HyperCP has had 2 very successful runs where we collected the largest sample of Ξ and Ω ever.
- In an initial study has been done on a fraction of the data, and gives a result of:

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

  Which is an order of magnitude better than the present limit. Note: systematic uncertainties limited by sample size.
- When all of our data set is analyzed we will have a statistical sensitivity of less than 2×10^{-4}.