The Search for Direct CP Violation in Hyperon Decays: Status Report from the $HyperCP$ Experiment at Fermilab

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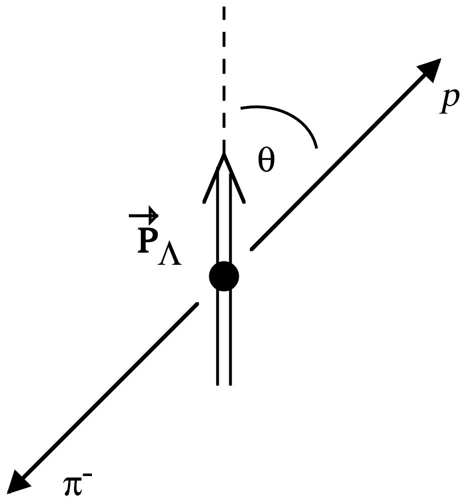
HyperCP Physics Goals

- Perform a sensitive search for CP violation by comparing the decay process $\Xi^- \to \Lambda\pi^-$, $\Lambda \to \mathrm{p}\pi^-$ with its anti-process $\overline{\Xi}^+ \to \overline{\Lambda}\pi^+$, $\overline{\Lambda} \to \overline{\mathrm{p}}\pi^+$. A positive result would be:
  - The first evidence of CP violation outside of the decay of the $\mathrm{K_L}$.
  - Unambiguous evidence of direct CP violation.
- Search for CP violation in $\mathrm{K}^\pm \to 3\pi$ decays.
- Search for rare and forbidden hyperon and charged kaon decays.
  - Lepton number nonconservation in kaon and hyperon decays: $\Xi^- \to p\mu^-\mu^-$, $\Sigma^- \to p\mu^-\mu^-$, $\mathrm{K}^+ \to \pi^-\mu^+\mu^+$.
  - Flavor changing neutral currents in hyperon and charged kaon decays: $\Sigma^+ \to p\mu^+\mu^-$, $\mathrm{K}^+ \to \pi^+\mu^+\mu^-$.
  - $|\Delta S| > 1$ decays: $\Xi^- \to p\pi^-\pi^-$, $\Xi^\circ \to p\pi^-$, $\Omega^- \to p\pi^-\pi^-$, ….
- Test CPT using hyperons.
- Measure various hyperon parameters, including: polarization, production cross sections, and decay parameters.

Parity violation in non-leptonic hyperon decays quantified by α.

$\Lambda \rightarrow p\pi$



$$\boxed{\frac{d\mathrm{N}}{d\cos\theta} = \frac{\mathrm{N}_0}{2}(1 + \alpha_\Lambda P_\Lambda \cos\theta)}$$

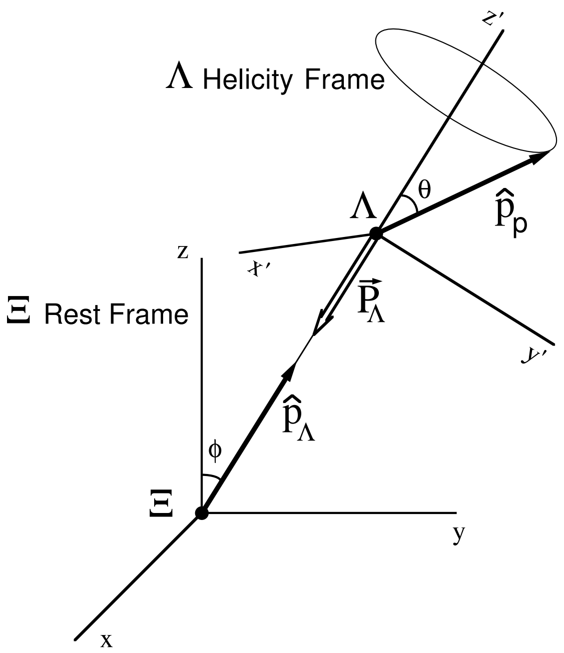
where:

$$\begin{aligned} \alpha_\Lambda &= \frac{2\mathrm{Re}(SP^*)}{|S|^2 + |P|^2}, \\ \theta &= \text{angle between the } \Lambda \text{ polarization and proton direction.} \end{aligned}$$

Note: If CP is a good symmetry then in the antihyperon decay $\overline{\Lambda} \rightarrow \overline{p}\pi^+$

$$\boxed{\boxed{\alpha_{\overline{\Lambda}} = -\alpha_\Lambda}}$$

Search for CP violation by comparing the p angular distribution in *unpolarized* $\Xi^- \to \Lambda\pi^- \to p\pi^-\pi^-$ with that of the $\bar{p}$ in the decay of the $\overline{\Xi}^+$.



Note: $\vec{\mathbf{P}}_\Lambda = \alpha_\Xi \hat{p}_\Lambda$ and $\vec{\mathbf{P}}_{\overline{\Lambda}} = \alpha_{\overline{\Xi}} \hat{p}_{\overline{\Lambda}}$.

The angular distributions in the Λ and $\overline{\Lambda}$ helicity frames are:

$$\boxed{\frac{d\mathrm{N}(\mathrm{p})}{d\cos\theta} = \frac{\mathrm{N}_0}{2}(1 + \alpha_\Lambda \alpha_\Xi \cos\theta)} \qquad \boxed{\frac{d\mathrm{N}(\bar{\mathrm{p}})}{d\cos\theta} = \frac{\mathrm{N}_0}{2}(1 + \alpha_{\overline{\Lambda}} \alpha_{\overline{\Xi}} \cos\theta)}$$

CP is violated if the slopes of the $\cos\theta$ distributions are different.

The asymmetry measured by *HyperCP* is

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

The expected *HyperCP* sensitivity from 1997 data, which comprises 1.3×10^9 Ξ^- and 2.8×10^8 $\overline{\Xi}^+$reconstructed decays is:

$$\delta A_{\Xi\Lambda} \sim 2 \times 10^{-4}.$$

The best previous experimental limit on A_Λ comes from $p\overline{p} \rightarrow \Lambda\overline{\Lambda}$ (PS185) :

$$A_\Lambda = 0.010 \pm 0.022$$

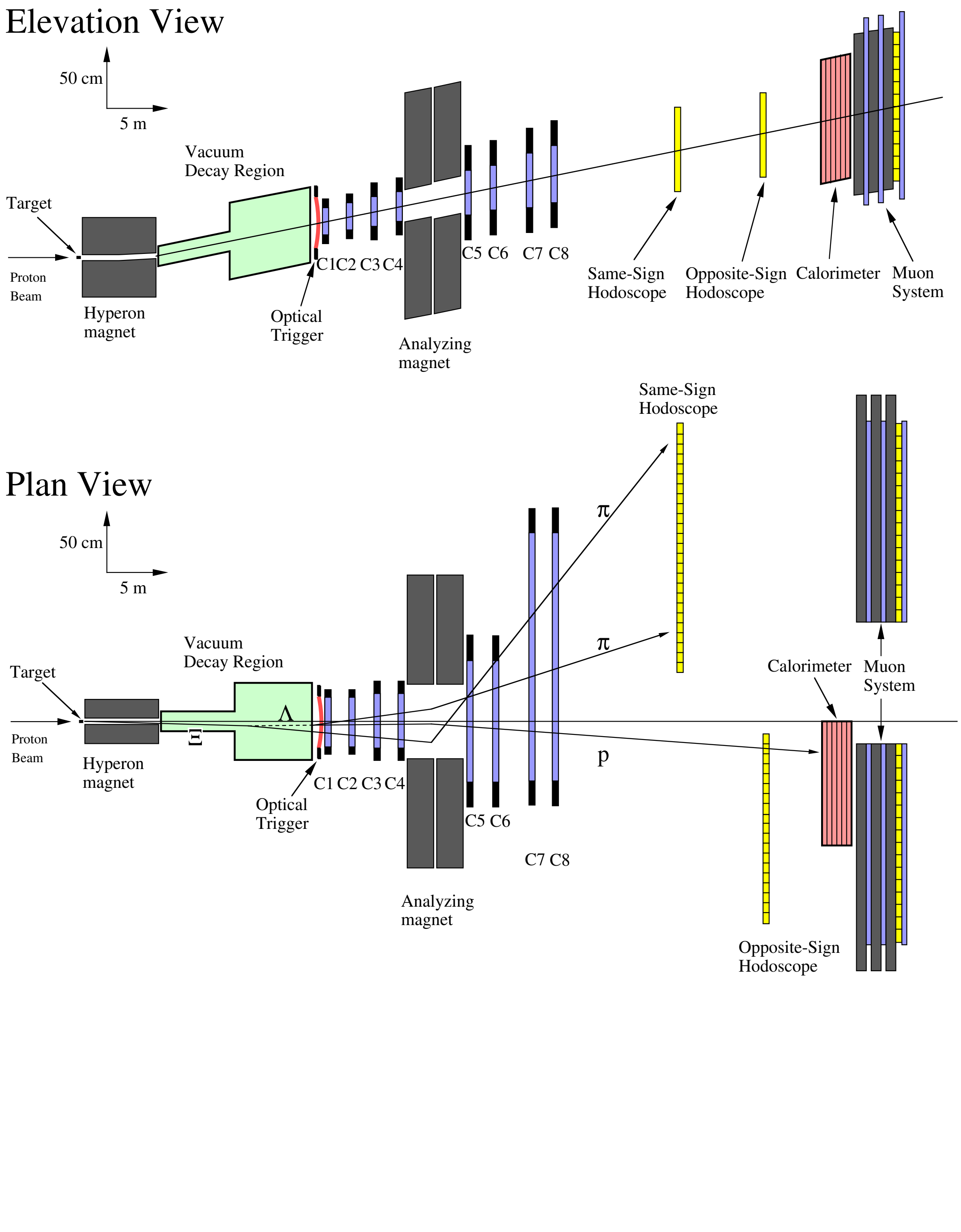
Some Theoretical Predictions

Model	A_Ξ $[10^{-4}]$	A_Λ $[10^{-4}]$	Source
CKM Model	$-(0.1 - 1)$	$-(0.1 - 0.5)$	He, Pakvasa (1995)
Weinberg	~ -3.2	~ -0.25	Donoghue, He, Pakvasa (1986)
Multi-Higgs (FCNE)	~ 0	~ 0	He, Pakvasa (1995)
LR (isoconjugate)	~ 0.5	~ -0.11	Donoghue, He, Pakvasa (1986)
LR (with mixing)	< 1	< 7	Chang, He, Pakvasa (1995)

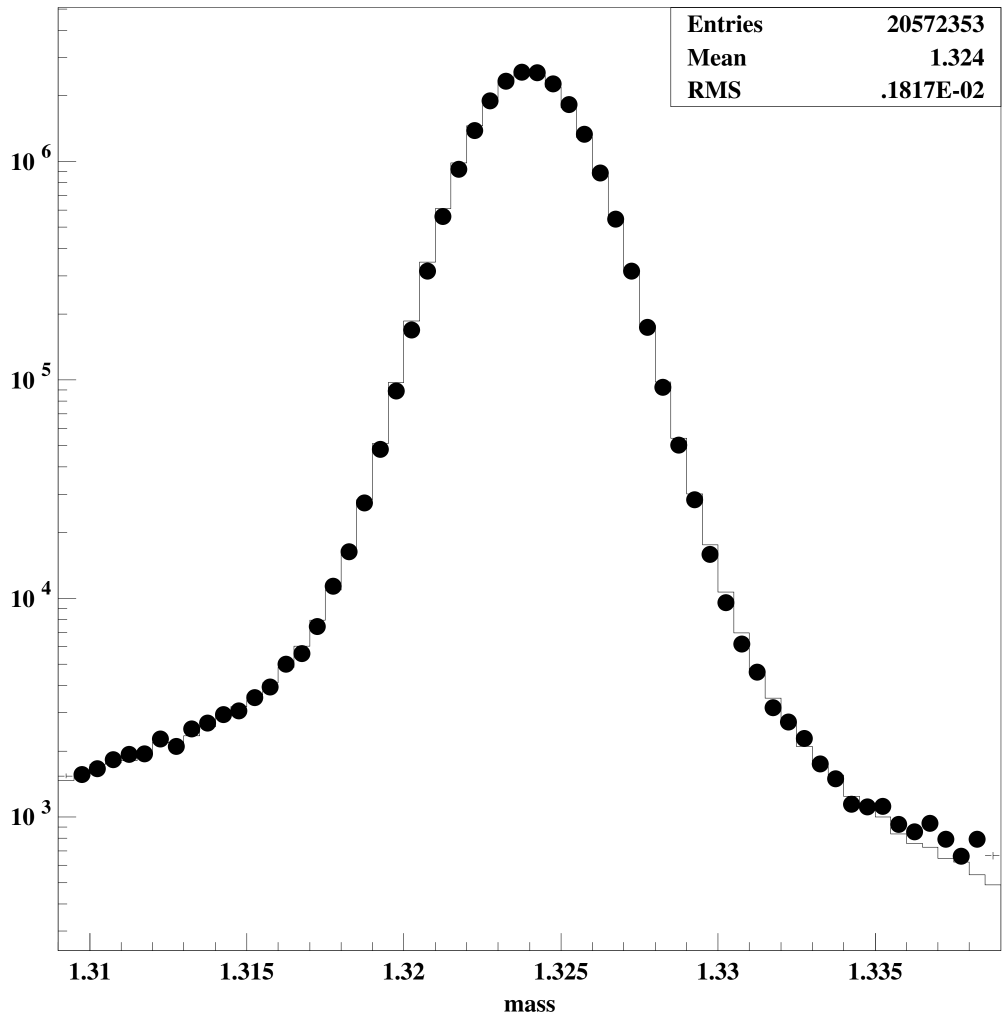
Conclusions and Outlook

- Computer Farm processing at FNAL expected to be completed mid 1999.
- *HyperCP* has been approved for the brief 1999 fixed target run in which we expect to increase our sensitivity to $\sim 1 \times 10^{-4}$, where some theories predict an effect.

The *HyperCP* Spectrometer

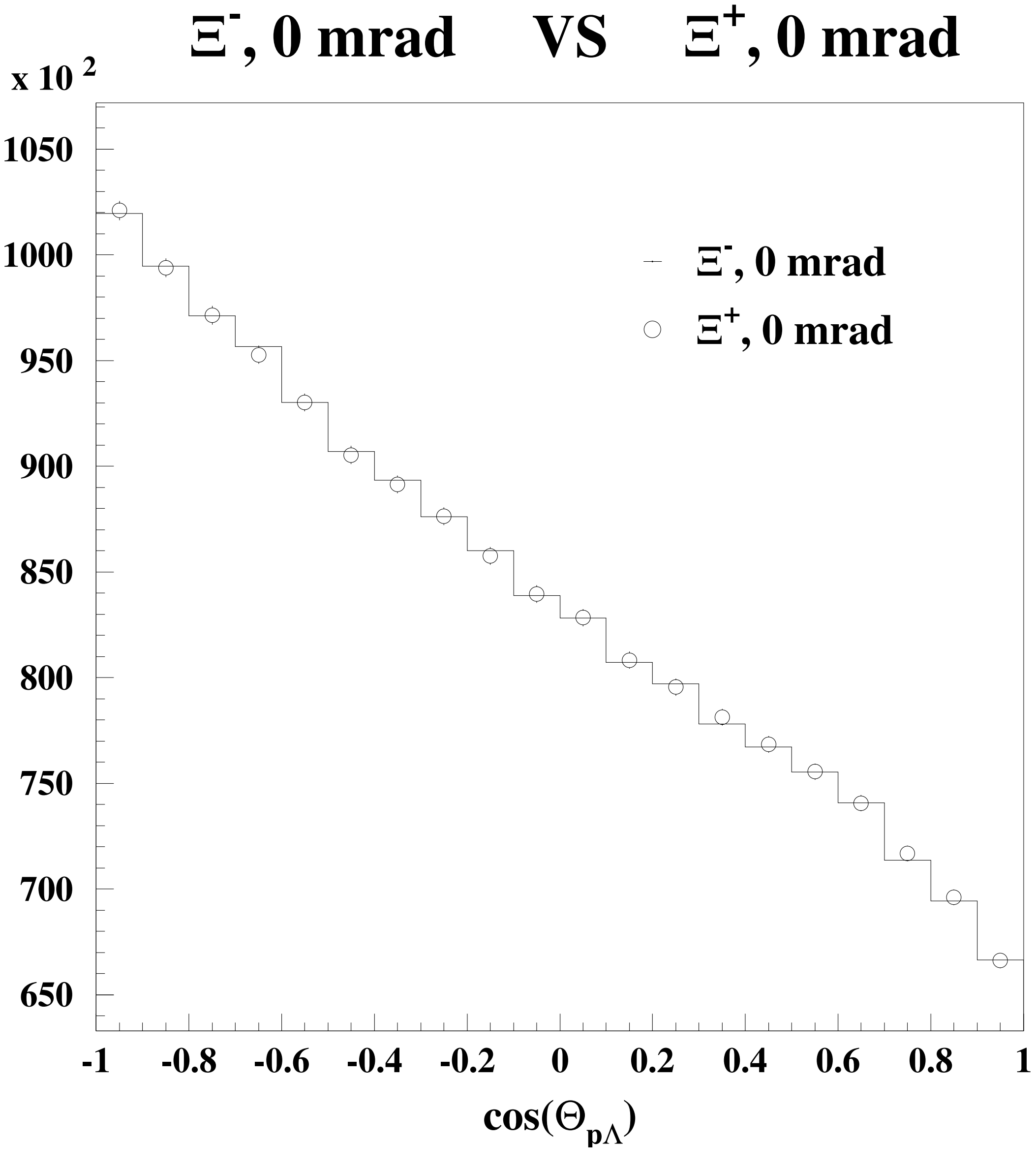


HyperCP Preliminary

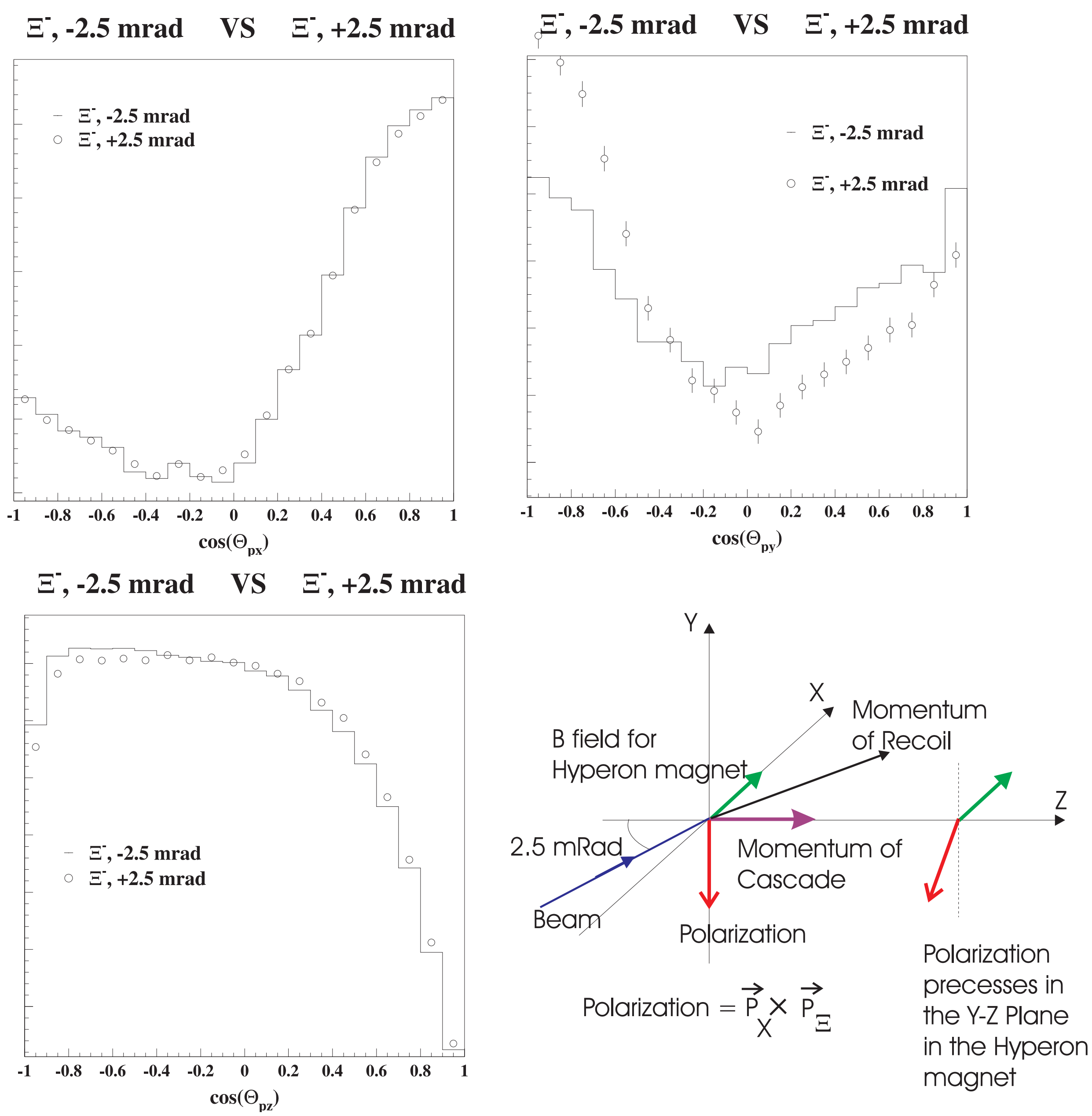


A comparison of the Ξ^- ($\bullet$) and $\overline{\Xi}^+$ ($-$) invariant masses shows good agreement. The precise field map and calibration using $K_S \to \pi^+\pi^-$ have not been implemented. Nevertheless the resolution is about 1.6 MeV/c^2.

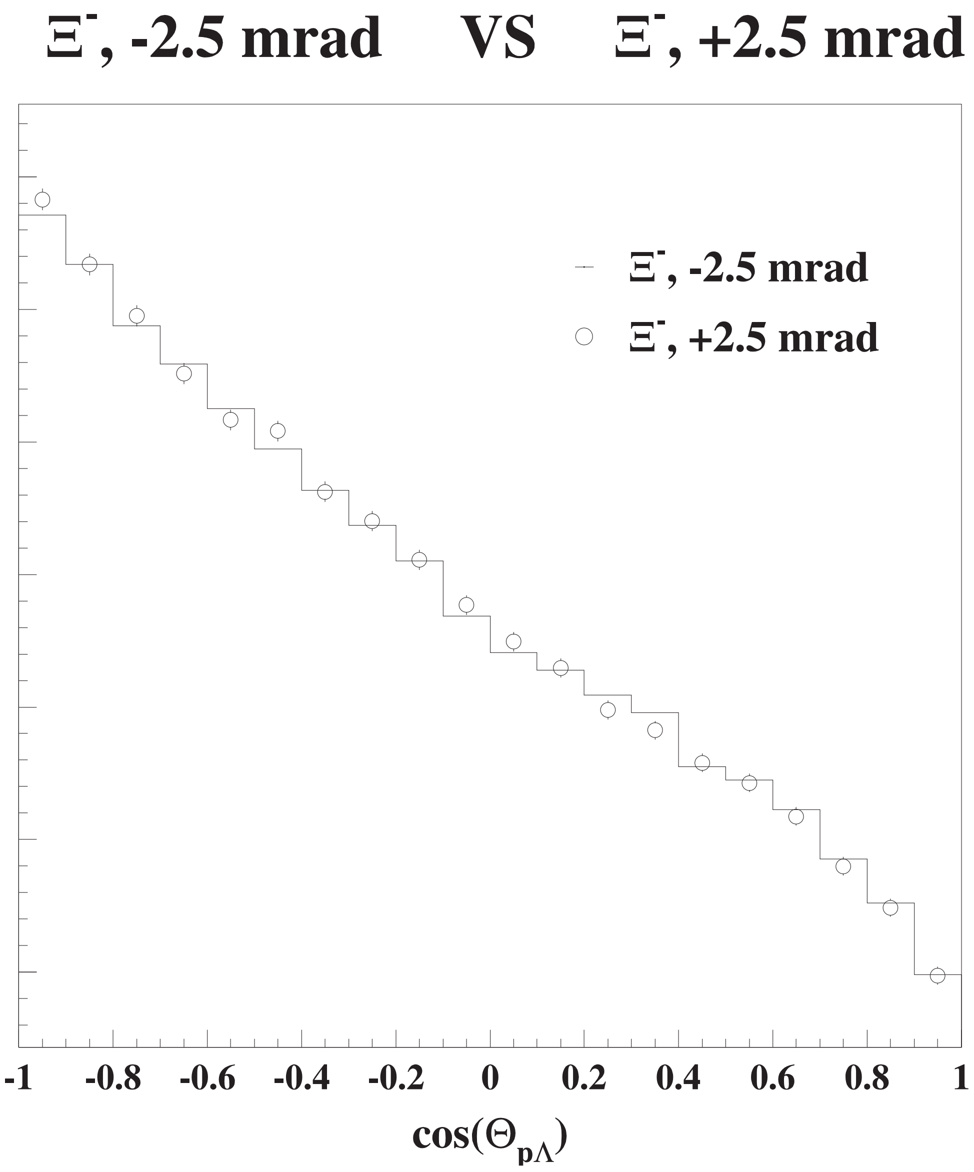
HyperCP Preliminary



A preliminary look at the proton and anti-proton $\cos(\theta)$ distributions in the Λ and $\overline{\Lambda}$ helicity frames. **No acceptance corrections have been made**, and the two momenta distributions have not been normalized to each other.



The effect of polarization viewed along fixed axes.



Along the helicity axis no effect of the polarization due to intentional mistargetting is seen. Note: no accpetance corrections have been made.