P and *CP* Violation in Hyperon Decay

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Physics Goals

Primary Goal:

A search for exotic sources of *CP* violation in hyperon decays.

Secondary Goals:

- Search for rare and forbidden hyperon and charged kaon decays:
  - Lepton number nonconservation in $\Xi^- \rightarrow p\, \mu^- \mu^-$
  - Flavor changing neutral currents in hyperon and charged kaon decays:
    $K^{+/-} \rightarrow \pi^{+/-} \mu^+ \mu^-$ and $\Sigma^+ \rightarrow p^+ \mu^+ \mu^-$ and Ω decays

- Measure various hyperon production and decay properties:
  - Hyperon production cross sections
  - Hyperon polarization
  - Measurements of β decay parameter
  - Measurements of α decay parameter

Why Search For *CP* Violation in Hyperon Decay?

- After 40 years of intense experimental effort and many beautiful experiments we still know little about CP violation: the origin of CP violation remains unknown and there is little hard evidence that it is fully explained by the Standard Model.
- CP violation is too important, and experimental evidence is too meager, not to examine every possible manifestation of the effect.
- Hyperons are sensitive to sources of CP violation that are not probed in other systems.
- These sources are thought to be experimentally accessible.
- The price was modest:
    - No new accelerator needed.
    - Apparatus was modest in scope and cost.
- Beyond-the-standard-model physics almost invariably predicts large new sources of CP violation.

"We are willing to stake our reputation on the prediction that dedicated and comprehensive studies of CP violation will reveal the presence of New Physics."

Bigi and Sanda, CP Violation

HyperCP Collaboration

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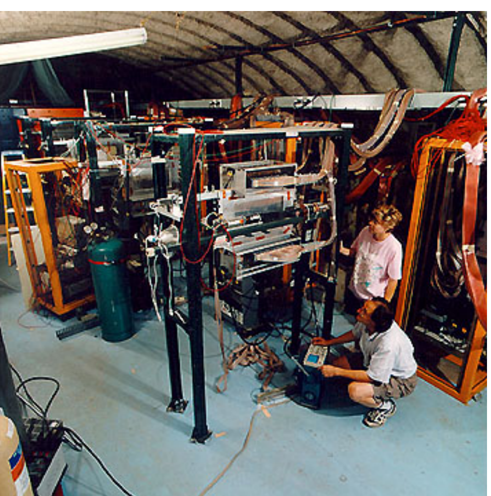
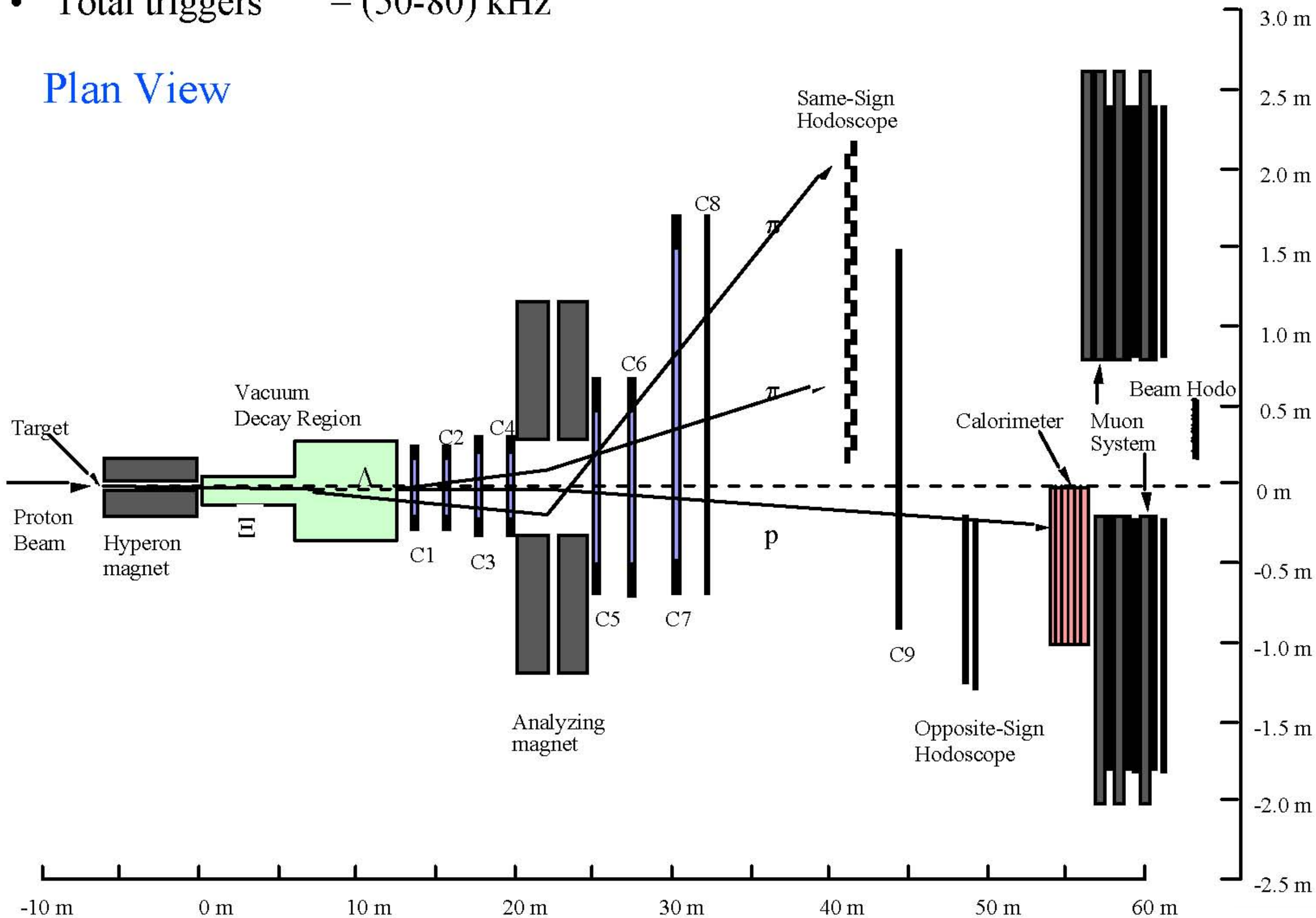
Hyper*CP* Apparatus

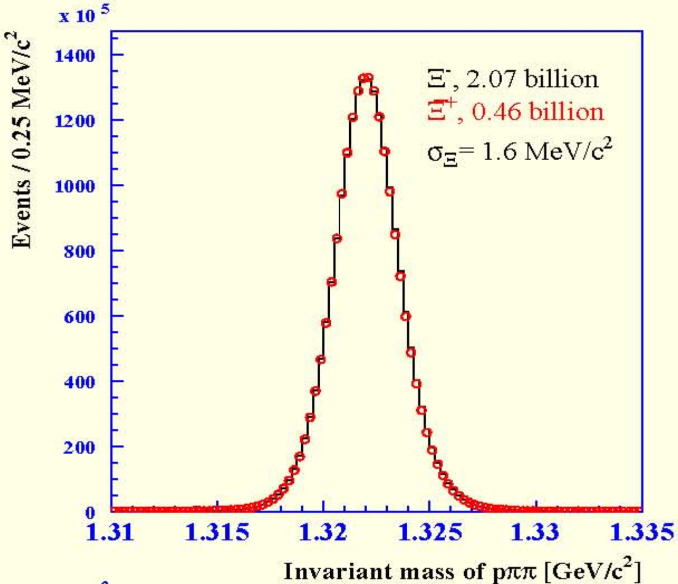


- Protons on target = (7-8) GHz
- Sec. beam inten. = (10-15) MHz
- Total triggers = (50-80) kHz

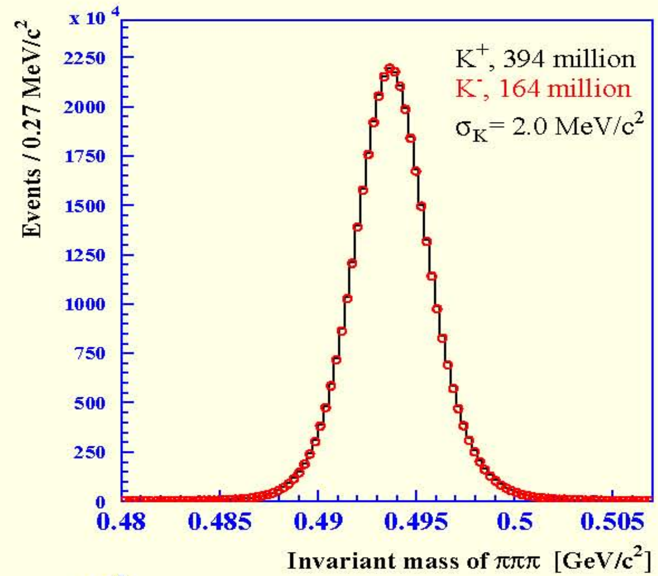


Reconstructed Masses

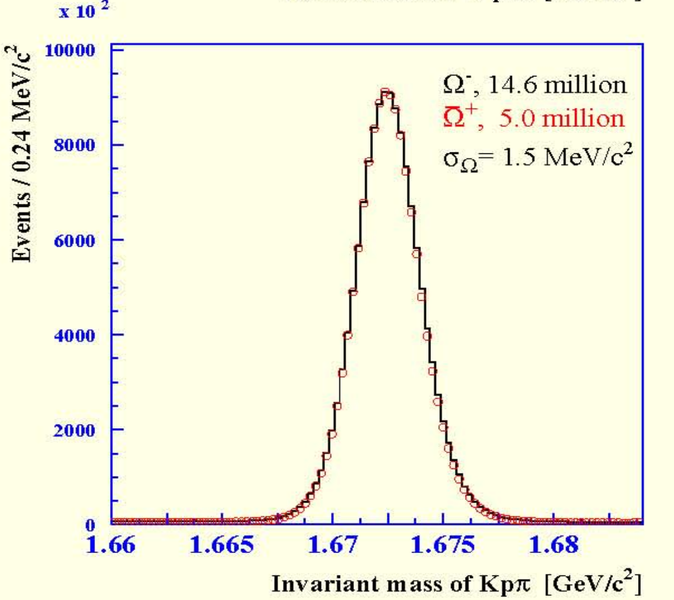
$\Xi^{\pm} \rightarrow \Lambda\pi^{\pm}$



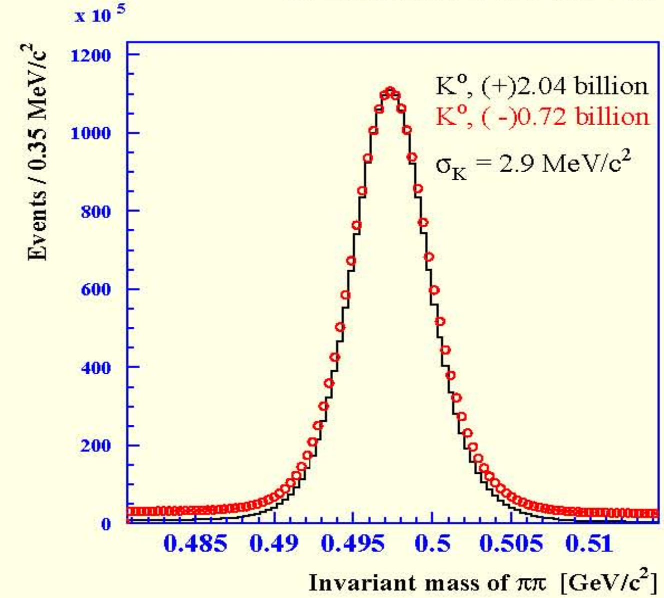
$K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$



$\Omega^{\pm} \rightarrow \Lambda K^{\pm}$



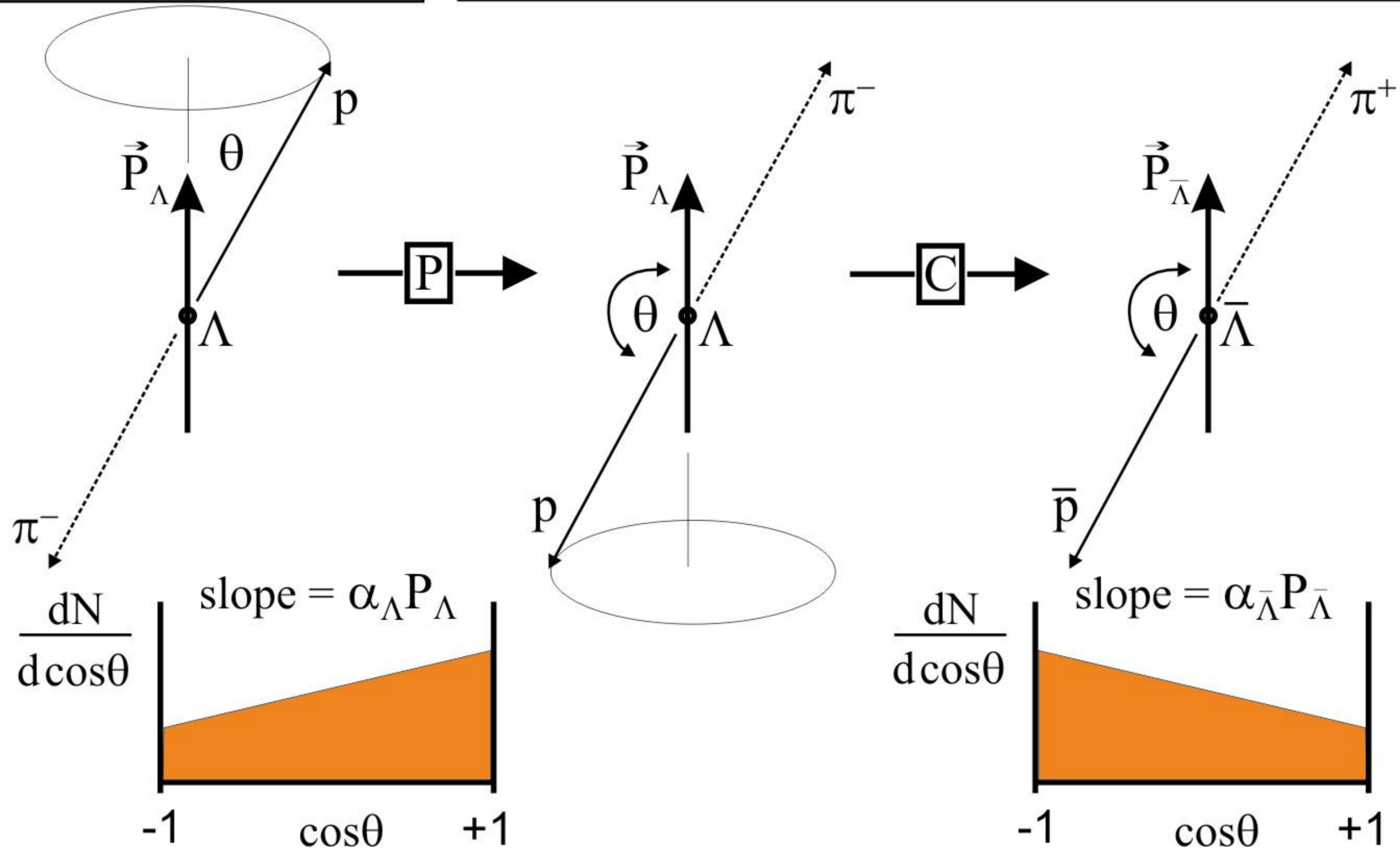
$K_S \rightarrow \pi^{+}\pi^{-}$



P and *CP* Violation in Hyperon Decay

$$\frac{dN}{d\cos\theta} = \frac{N_0}{2}(1 + \alpha_\Lambda P_\Lambda \cos\theta)$$

$$\vec{P}_\Lambda = \frac{(\alpha_\Xi + \vec{P}_\Xi \cdot \hat{p}_\Lambda)\hat{p}_\Lambda + \beta_\Xi(\vec{P}_\Xi \times \hat{p}_\Lambda) + \gamma_\Xi(\hat{p}_\Lambda \times (\vec{P}_\Xi \times \hat{p}_\Lambda))}{(1+\alpha_\Xi \vec{P}_\Xi \cdot \hat{p}_\Lambda)}$$



$\Lambda \rightarrow p\pi^-$ $\bar\Lambda \rightarrow \bar{p}\pi^+$

Hyper*CP* Measurement

$\Lambda/\bar{\Lambda}$'s of known polarization can be produced through the decay of unpolarized $\Omega^-/\bar{\Omega}^+$'s.

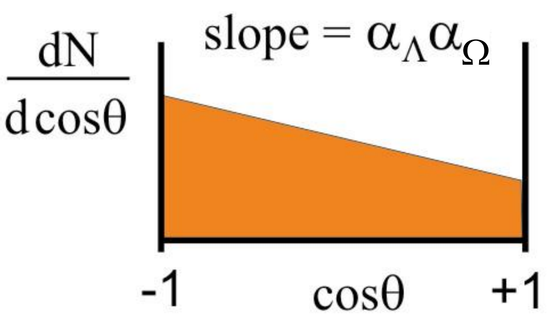
If the Ω is produced unpolarized - which can simply be done by targeting at 0 degrees - the Λ is found in a helicity state:

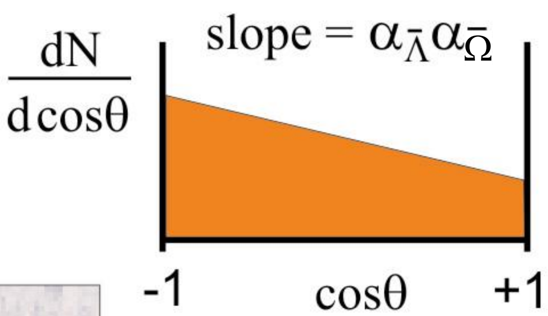
$$\vec{P}_\Lambda = \alpha_\Omega \hat{p}_\Lambda \qquad \vec{P}_{\bar{\Lambda}} = \alpha_{\bar{\Omega}} \hat{p}_{\bar{\Lambda}}$$

$$\frac{dN(p)}{d\cos\theta} = \frac{N_0}{2}(1 + \alpha_\Lambda \alpha_\Omega \cos\theta)$$

$$\alpha_\Lambda \alpha_\Omega \overset{CP}{\Rightarrow} \alpha_{\bar{\Lambda}} \alpha_{\bar{\Omega}}$$

$$\frac{dN(\bar{p})}{d\cos\theta} = \frac{N_0}{2}(1 + \alpha_{\bar{\Lambda}} \alpha_{\bar{\Omega}} \cos\theta)$$



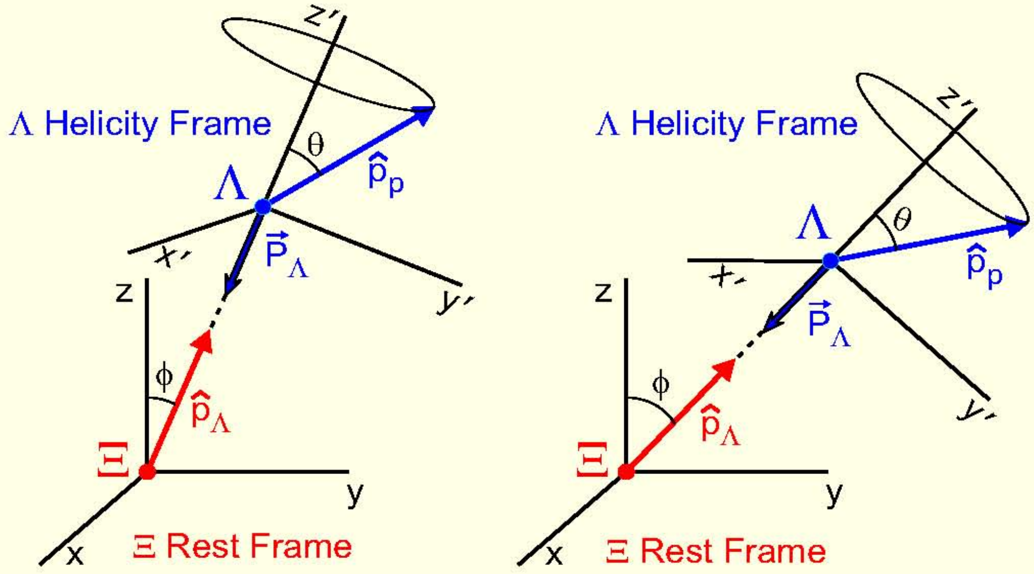


$$A_{\Xi\Lambda} = \frac{\alpha_\Lambda \alpha_\Omega - \alpha_{\bar{\Lambda}} \alpha_{\bar{\Omega}}}{\alpha_\Lambda \alpha_\Omega + \alpha_{\bar{\Lambda}} \alpha_{\bar{\Omega}}} \approx A_\Lambda + A_\Omega$$

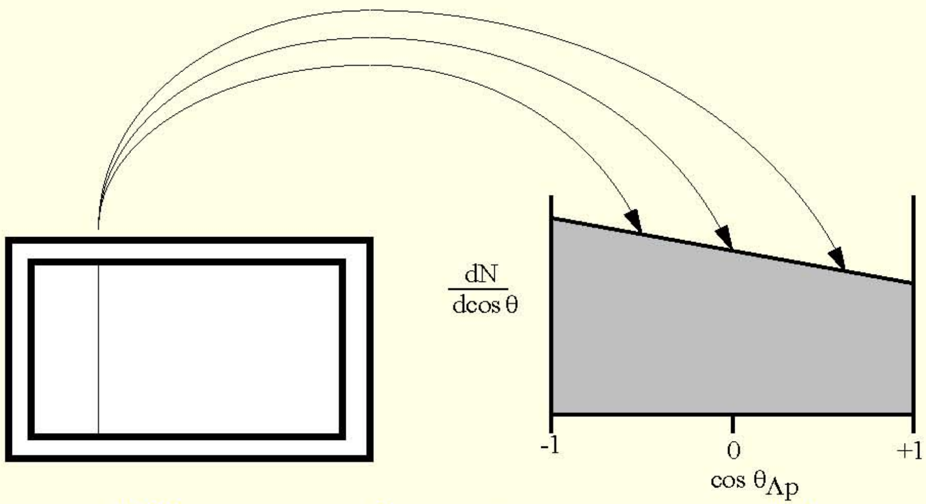
If CP is good, the slopes of the proton and antiproton cosθ distributions are identical…

Helicity frame minimizes biases

- The helicity frame axes changes from event to event since we always define the polar axis to be the direction of the Λ momentum in the Ξ rest frame.



- Acceptance differences localized in a particular part of the apparatus do **not** map into a particular part of the proton (antiproton) $\cos\theta$ distribution.



Important! Overall acceptance differences do not cause any biases.

Parity Violation in Ω Decay

$\Omega^- \rightarrow \Lambda K^- \qquad \Lambda \rightarrow p\pi^-$

- Although spin-3/2, $\Omega^- \rightarrow \Lambda K^-$ decay goes much like the other hyperon two-body decays:

$$\frac{dP}{d\cos\theta} = \frac{1}{2}(1 + \alpha_\Omega P_\Omega \cos\theta)$$

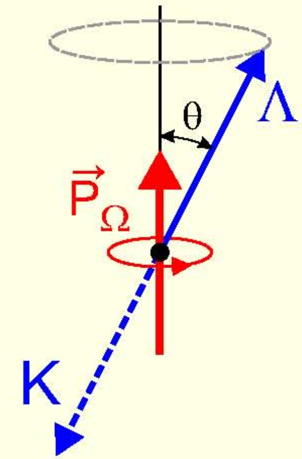
- Here:

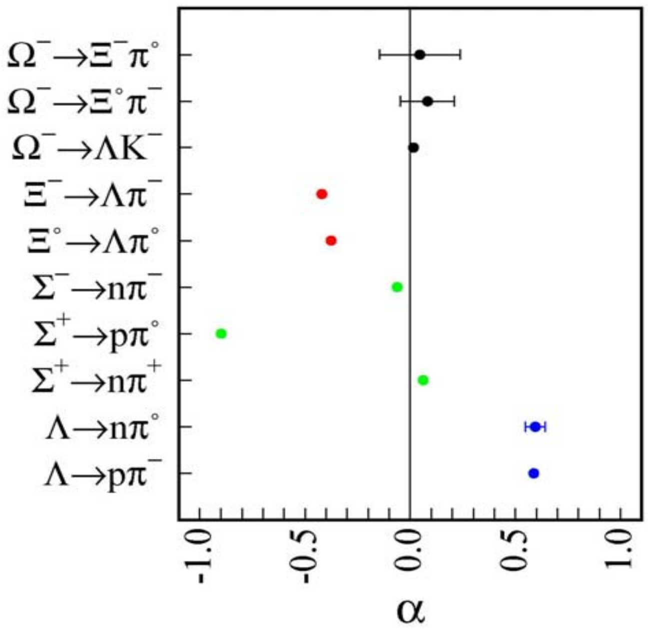
$$\alpha_\Omega = \frac{2\mathrm{Re}(P^* D)}{|P|^2 + |D|^2}$$

- A non-zero α_Ω indicates parity violation.
- All other hyperons have non-zero α parameters; only the Ω^- has resisted efforts to find an asymmetrical decay distribution.
- *HyperCP* is measuring α_Ω using unpolarized Ω^-'s through the polarization given to the daughter Λ, which is α_Ω:

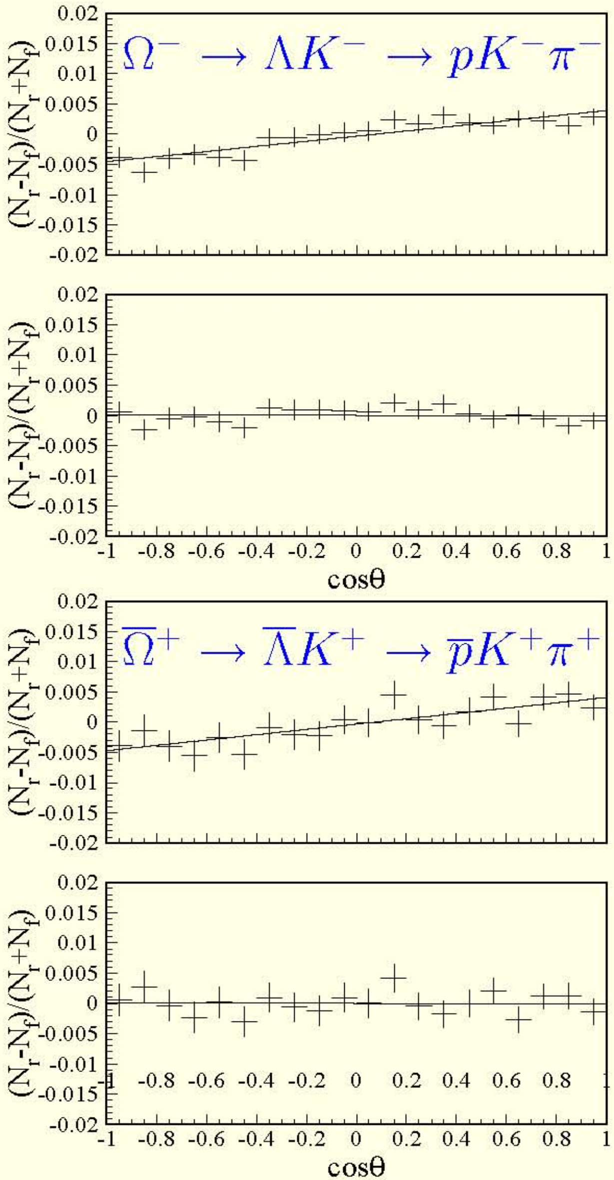
$$\frac{dP}{d\cos\theta} = \frac{1}{2}(1 + \alpha_\Omega \alpha_\Lambda \cos\theta)$$

- Large data sample, little background.



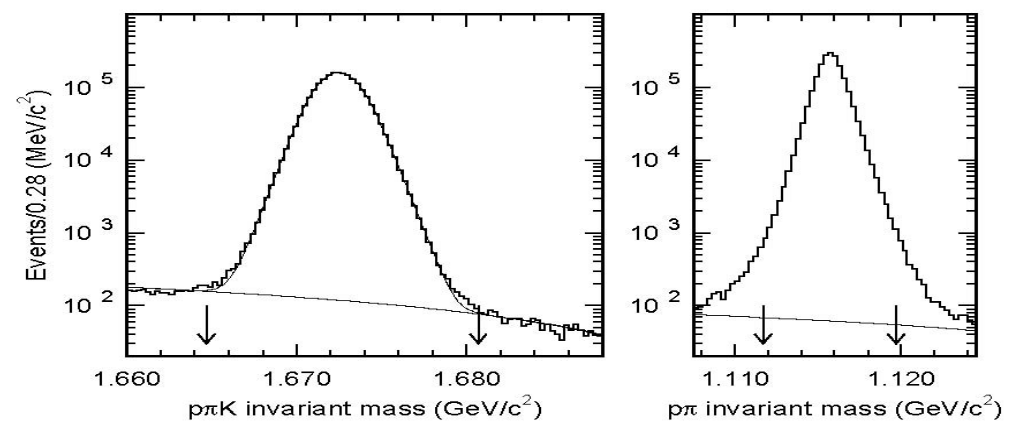


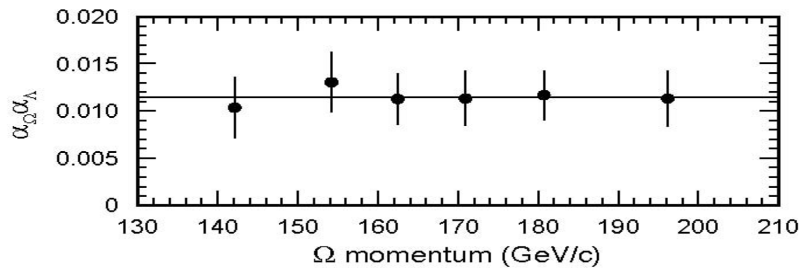
Measurement

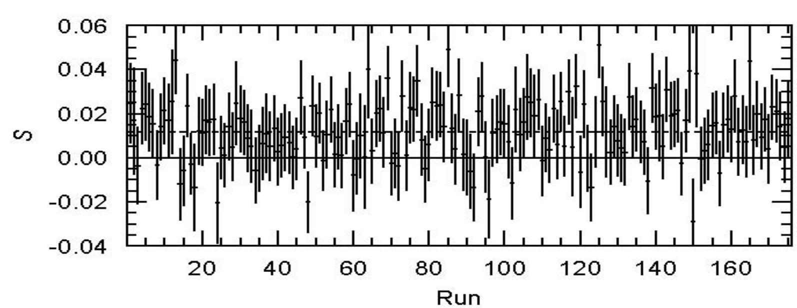


1999 : $\alpha_\Omega = [\ \ 1.78 \pm 0.19(\mathrm{stat}) \pm 0.10(\mathrm{syst})] \times 10^{-2}$

1999 : $\overline{\alpha}_\Omega = [-1.81 \pm 0.28(\mathrm{stat})] \times 10^{-2}$







Ξ *CP* Result

Weighting Technique:

- ∼10% total data sample
- selected from end of 1999 run
- 118.6 million Ξ^-
- 41.9 million $\overline{\Xi}^+$
- no acceptance or efficiency corrections

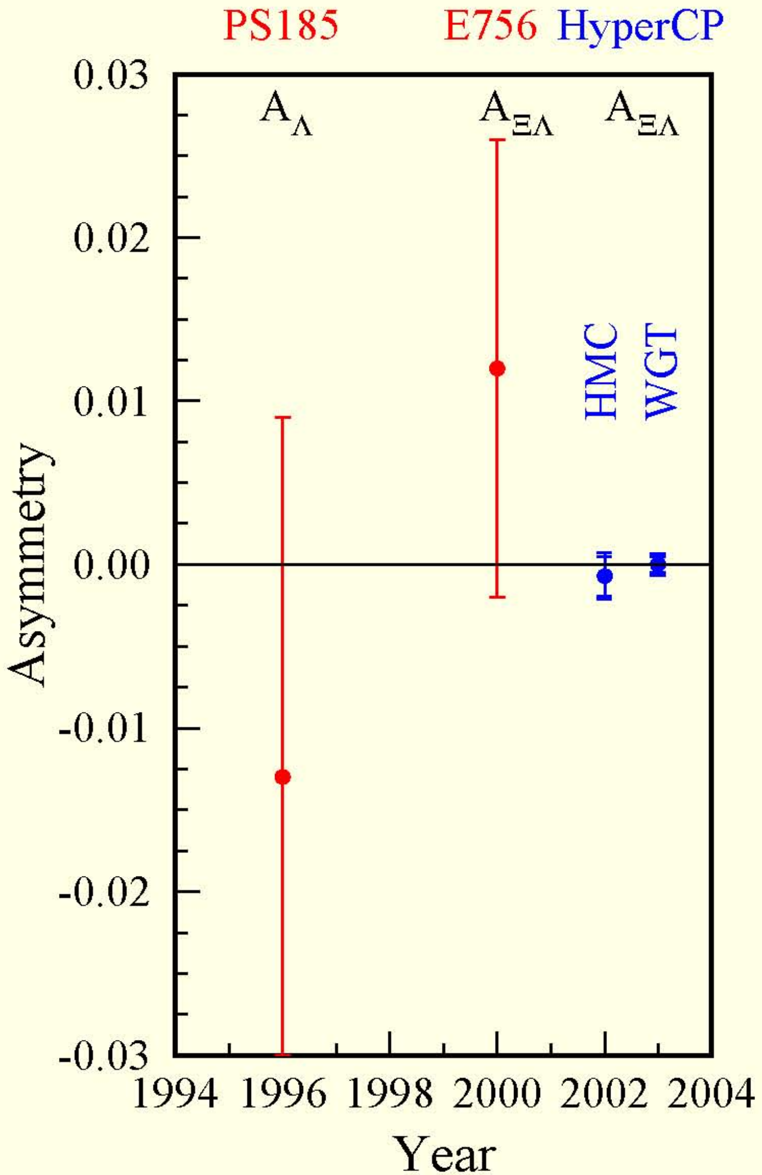
$$A_{\Xi\Lambda} = [0.0 \pm 5.1(\text{stat}) \pm 4.4(\text{syst})] \times 10^{-4}$$

Check with HMC Technique:

- ∼ 5% of the total data sample
- prescaled selection of 1997 and 1999
- 15 million Ξ^-
- 30 million $\overline{\Xi}^+$

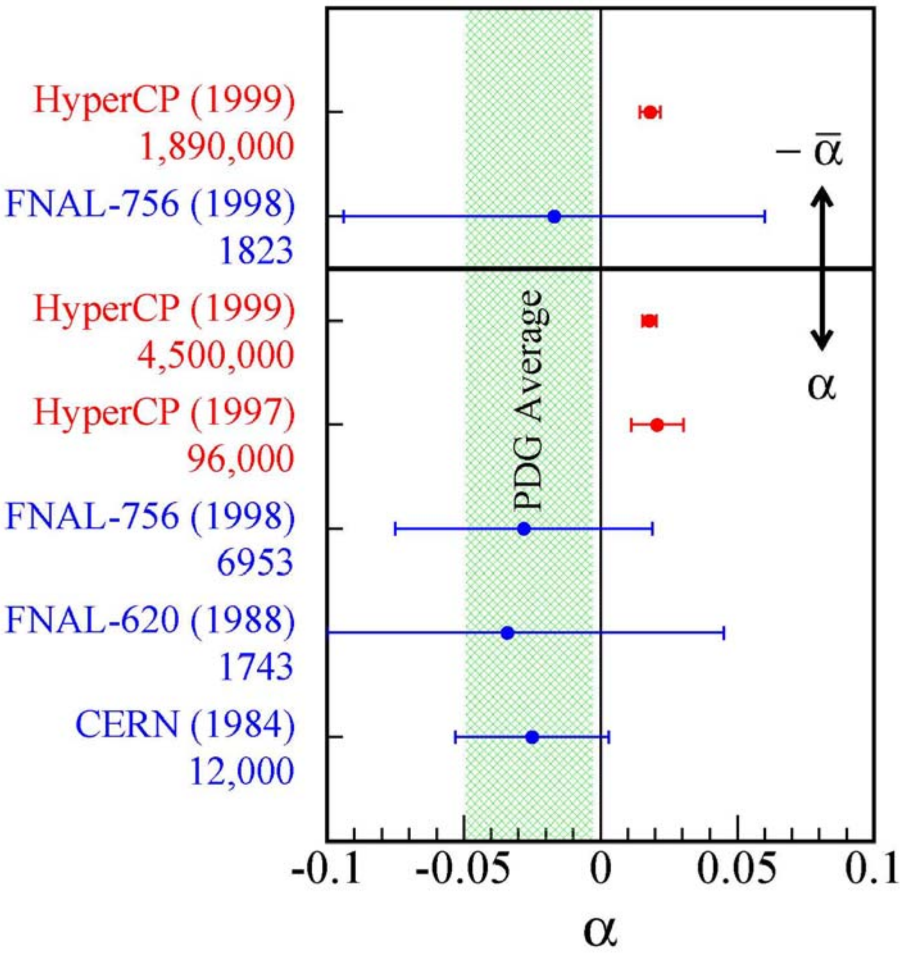
$$A_{\Xi\Lambda} = [-7 \pm 12(\text{stat}) \pm 6.2(\text{syst})] \times 10^{-4}$$

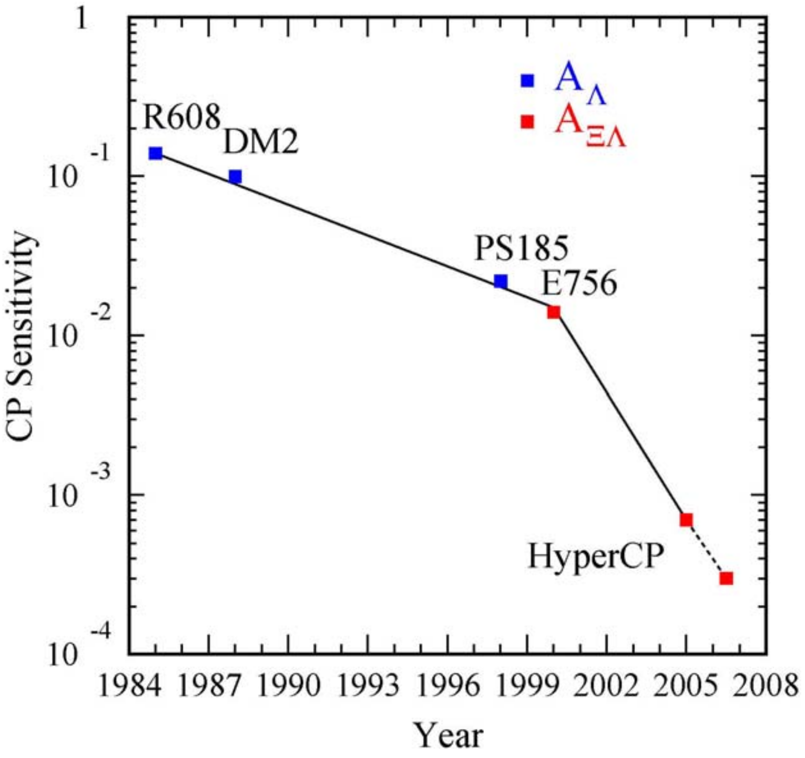
⇒20× improvement on previous result.



Conclusions

First experimental evidence for parity violation in Ω decay!





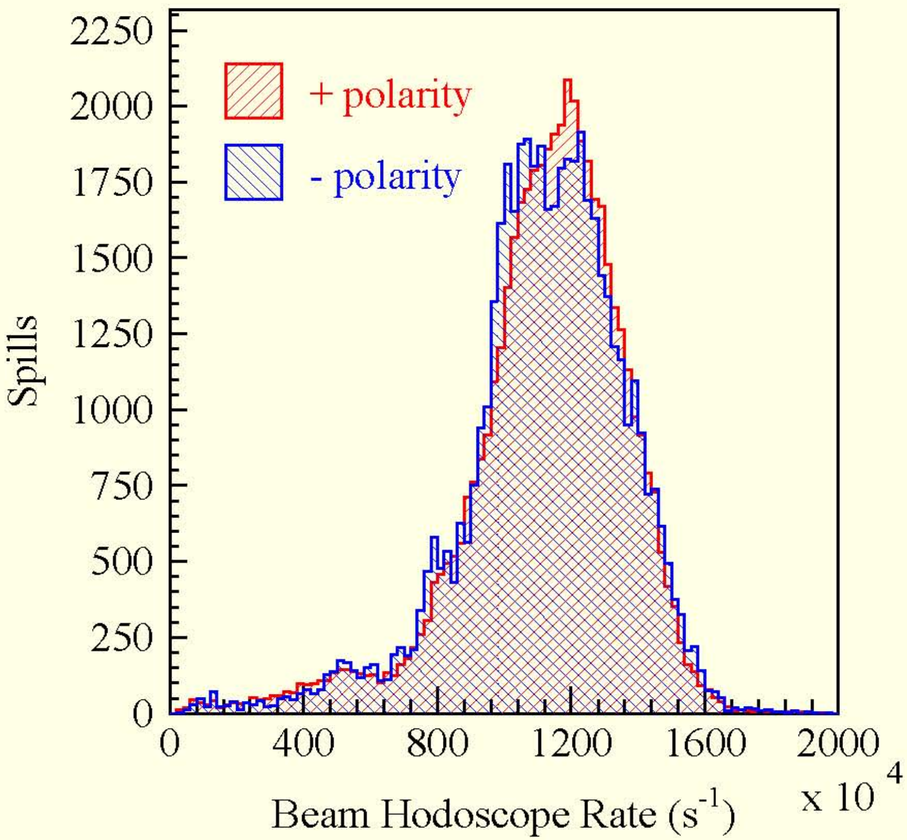
No *CP* violation found (yet) in hyperon decay.

Positive vs. Negative

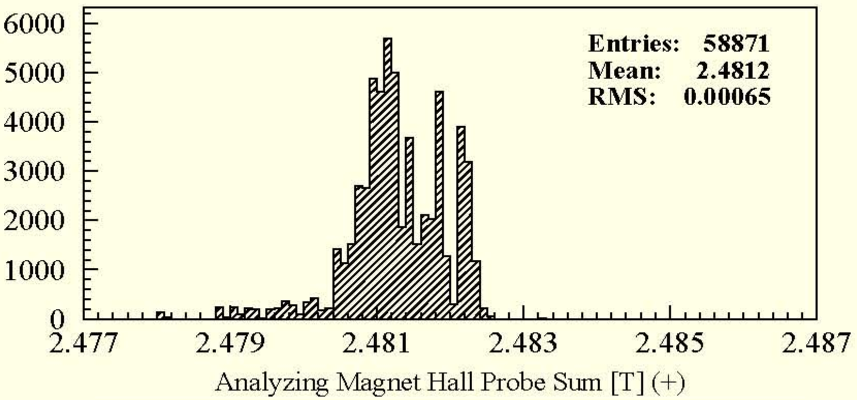
- Target length changed to equalize channeled beam rates.

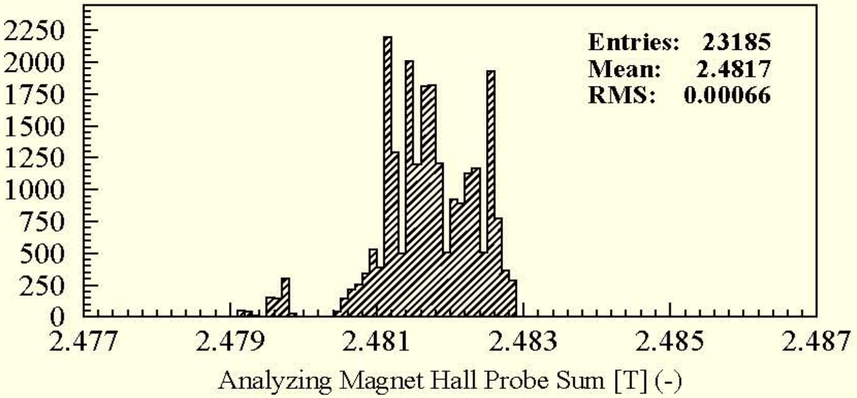
  + polarity: 2.0 cm Cu

  − polarity: 6.0 cm Cu



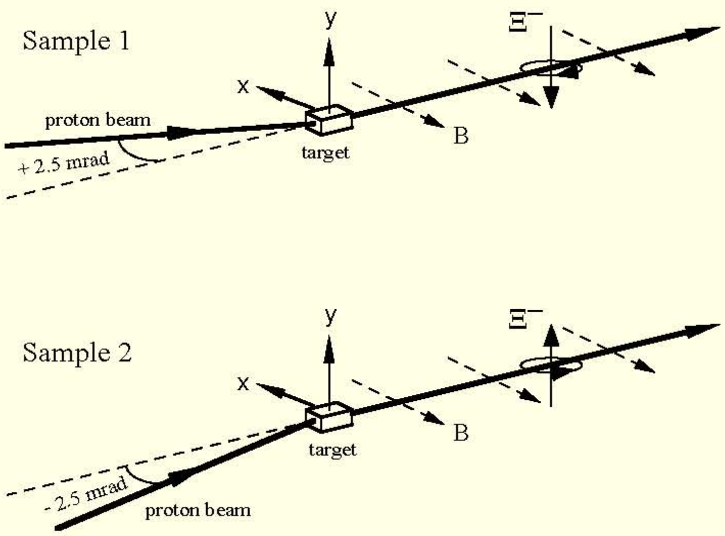
- When flipping polarity, field magnitude kept within $\sim 2\times10^{-4}$.
- This corresponds to a $\sim$0.3 mm deflection difference at 10 m for the lowest momentum ($\sim$10 GeV/c pions).

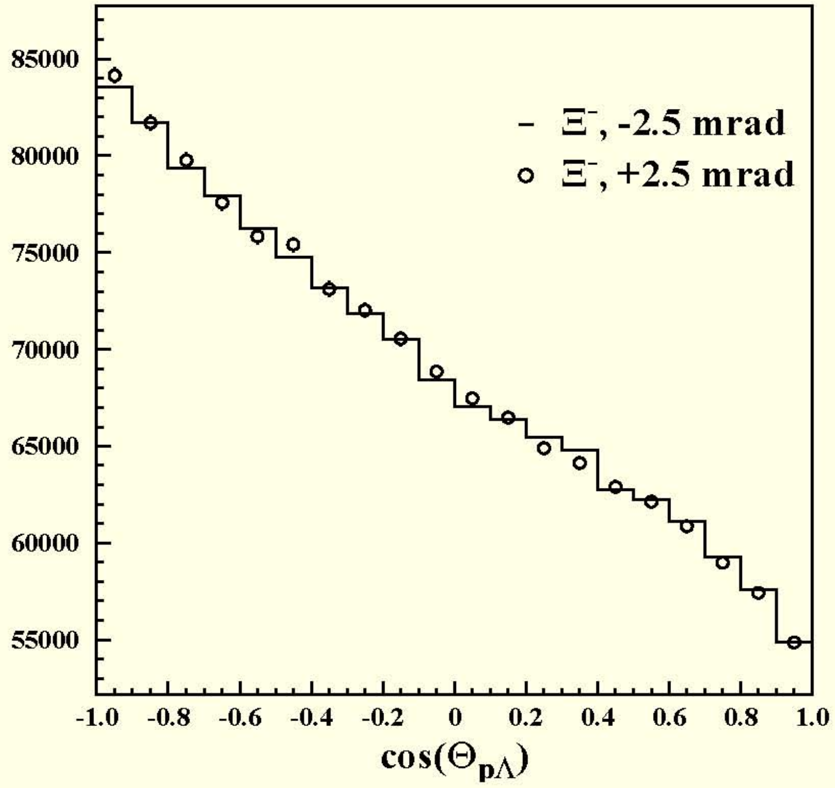




Power of helicity frame analysis

Ξ^- (−2.5 mrad) vs Ξ^- (+2.5 mrad)





- No statistically significant effect at the several times 10^{-3} level, with no attempt of correction!