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HYPER*CP* AT FERMILAB–A STATUS REPORT

A. Chan, Y. C. Chen, C. Ho, P. K. Teng, (*Academia Sinica*); W. S. Choong, Y. Fu, G. Gidal, P. Gu, T. Jones, K.B. Luk, B. Turko, P. Zyla, (*LBNL*); C. James, J. Volk (*FNAL*); J. Felix, G. Moreno, M. Sosa, (*Guanajuato*); R. Burnstein, A. Chakravorty, D. Kaplan, W. Luebke, L. Lederman, H. Rubin, D. Rajaram, N. Solomey, Y. Torun, C. White, S. White (IIT, Chicago); N. Leros, J. P. Perroud (*Lausanne*); H.R. Gustafson, M. J. Longo, F. Lopez, H. K. Park (*Michigan*); K. Clark, M. Jenkins (*S. Alabama*); C. Dukes, C.Durandet, R. Godang, T. Holmstrom, M. Huang, L. C. Lu, K.Nelson (Virginia)

(Presented by M. Longo)

ABSTRACT

The primary purpose of the Hyper*CP* experiment at Fermilab is to test *CP* in hyperon decays by comparing the alpha parameters for Ξ^- and $\overline{\Xi}^+$ decays in the decay sequence: $\Xi^- \rightarrow \pi + \Lambda^0$, $\Lambda^0 \rightarrow \pi^- + p$. In addition, we can test *CP* in charged kaon decays by comparing the slopes of the Dalitz plot for K^+ and K^- decays. We are also looking at rare decay modes of charged kaons and hyperons, particularly those involving muons.

1. Introduction

The Hyper*CP* experiment at Fermilab has recorded the world's largest sample of charged hyperon decays. The total data sample from the 1997 and 1999 runs comprises over 100 terabytes stored on almost 30000 Exabyte tapes. The total sample includes about 2.5 x 10^9 Ξ^- and $\overline{\Xi}^+$ decays, about 2 x 10^7 Ω^- and $\overline{\Omega}^+$ decays, as well as over 0.5 x 10^9 $K^\pm \rightarrow 3\pi$ decays.

The main physics question we can address is the possibility of CP violation in Ξ^- and $\overline{\Xi}^+$ decays. The large sample of $K^\pm \rightarrow 3\pi$ decays also allows a test of CP by comparing the decay distributions of $K^\pm$. We can also study rare kaon and hyperon decays, particularly those involving muons.

The HyperCP detector is shown in Fig. 1. A collimator through the hyperon magnet defines a charged beam with an average momentum ~170 GeV. The beam is taken off at an angle of 0° with respect to the extracted proton beam so that the hyperons will be unpolarized. Note that the hyperon magnet deflects the beam vertically and the analyzing magnet deflects it horizontally. The beam polarity was switched

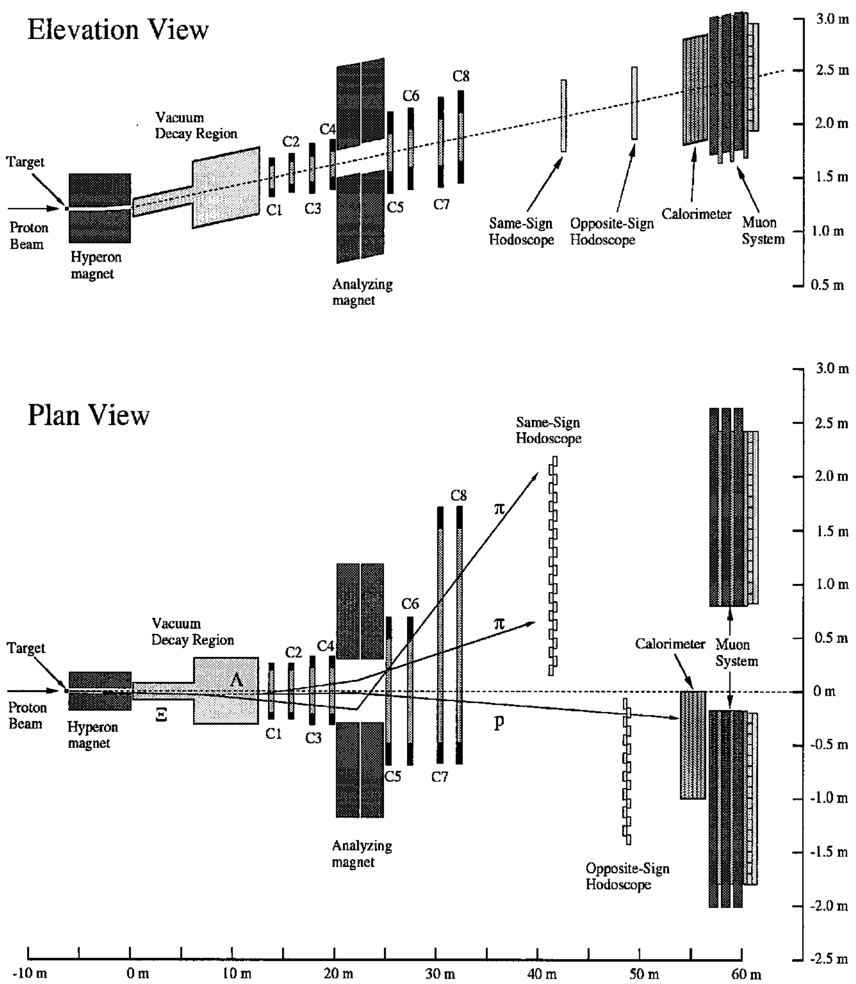

Figure 1- *The HyperCP detector elevation and plan views. Note that the transverse dimensions are exaggerated by 10x.*

every few hours by reversing the hyperon and analyzing magnet currents. The spectrometer was designed for a high rate. A "typical" Ξ decay is superimposed on the plan view. Triggering was based on the "same-sign" and "opposite sign" scintillator hodoscopes, and for decays involving muons, on scintillator hodoscopes in the muon detectors.

2. CP Violation in $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$

The differential decay rate is proportional to the invariant matrix element that can be parametrized as $|M^2| \propto 1 + g\,Y + \ldots$, so that the parameter g is the slope of the Dalitz plot distribution. If $g_{K^-} \neq g_{K^+}$, then CP symmetry is broken. Theoretical predictions for $\delta g \equiv (g-\bar{g})/(g+\bar{g})$ range up to $\sim 0.5 \times |\varepsilon'/\varepsilon| \sim 10^{-3}$ (See, for example, [1].) A preliminary study, including about 10% of the total sample, has been made.[2]

Systematic effects due to temporal changes in the detector were effectively removed by the frequent beam polarity changes. However, the K^+ and K^- momentum spectra were slightly different, and the interactions of π^+ and π^- in the chambers are slightly different. These effects require careful corrections to reduce the systematic errors below the statistical.

In Fig. 2, we compare g for positive and negative runs. At this stage of analysis, we see no sign of a CP violation at the level of a few $\times\ 10^{-3}$ in $\delta g/2g$.

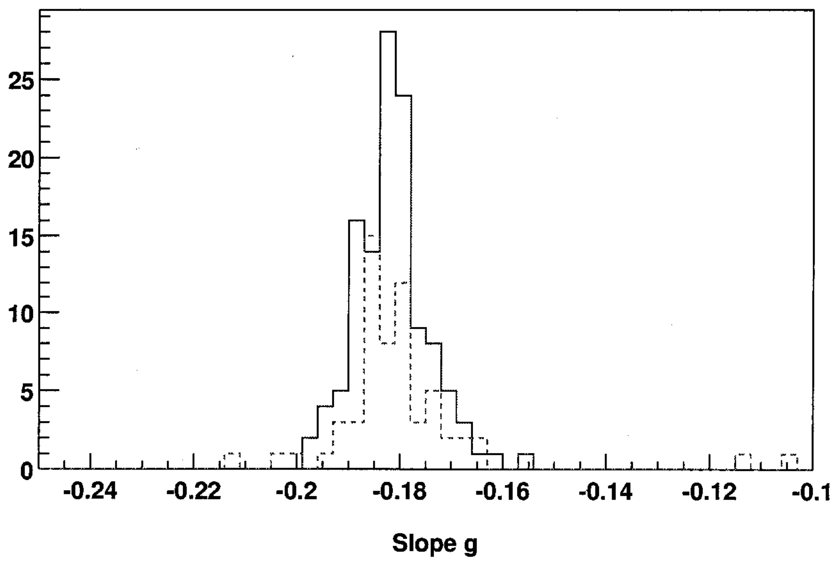

Figure 2- *Slopes for some positive (solid) and negative (dashed) runs are in good agreement. Not all systematics have been corrected. The runs with large fluctuations had few events and large statistical errors.*

3. CP Violation in Ξ and Λ decays

The $\Delta S=1$ decays of spin-1/2 baryons can be described in terms of decay parameters, α, β, γ. A prediction of CP is that $A \equiv (\alpha+\overline{\alpha})/(\alpha-\overline{\alpha}) = 0$, where α, $\overline{\alpha}$ are the decay slopes for hyperon and antihyperon. The Hyper*CP* approach to testing CP in Ξ decays is to use a beam of unpolarized Ξ ($\overline{\Xi}$), produced at 0° from the extracted proton beam. The Ξ decays then produce Λ's with a known longitudinal polarization α_{Ξ}. In effect, we measure $A_{\Xi\Lambda}=A_{\Xi}+A_{\Lambda}$. Theoretical predictions for $A_{\Xi\Lambda}$ range up to ~ 10^{-3} (See, for example, [3].)

Systematic errors in this analysis are significantly reduced by the fact that the CP analysis is done in the Λ helicity frame, which varies from event to event so that local detector inefficiencies are smeared out.

The largest systematic effects again come from the fact that the Ξ and $\overline{\Xi}$ momentum spectra are slightly different (Fig. 3). This required careful corrections.

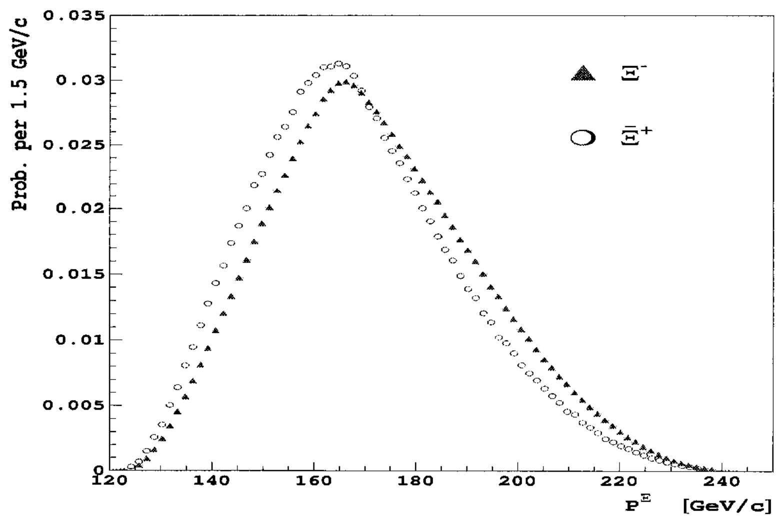

Fig. 3–*The* Ξ *and* $\overline{\Xi}$ *momentum spectra.*

Data for $A_{\Xi\Lambda}$ from a preliminary study[4] based on about 1.7% of the total sample are shown in Fig. 4. Four data sets are shown and the overall average is compared to the previous result[5] from Fermilab E756, Based on this small sample, we find $A_{\Xi\Lambda} = (-1.6 \pm 1.3 \pm 1.6) \times 10^{-3}$. Much work remains to be done to reduce the systematic errors to be comparable to the eventual statistical error.

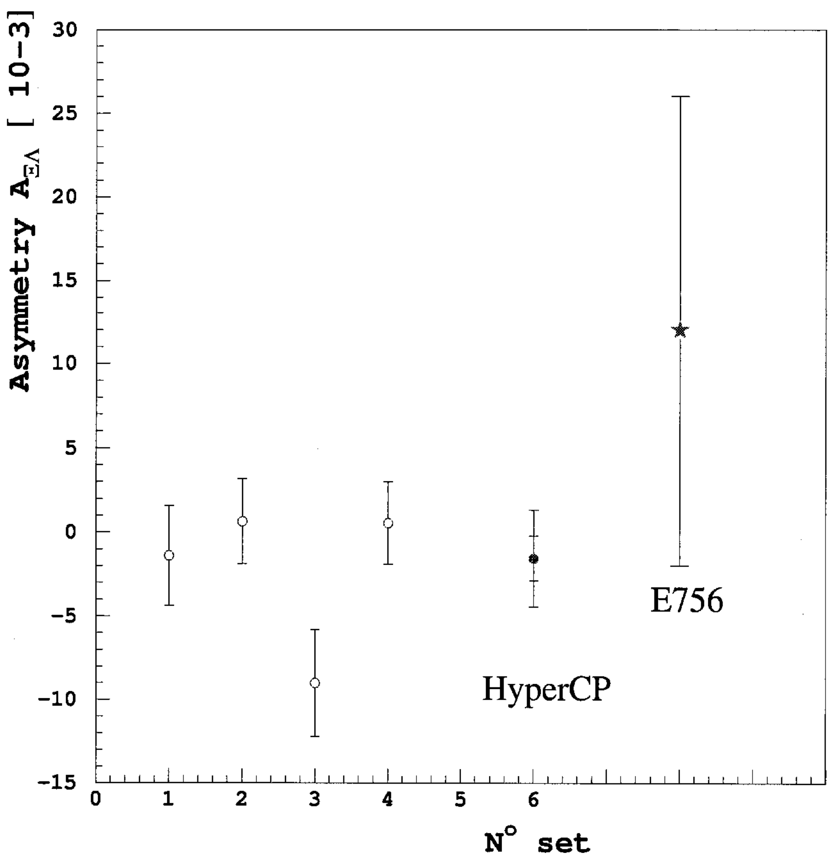

Figure 4– *Preliminary* $A_{\Xi\Lambda}$ *from 4 data sets representing about 1.7% of the eventual data sample. The point labelled "HyperCP" is the average of these with statistical and systematic errors.*

4. Dimuon decays

The Hyper*CP* muon detectors gave us the capability of studying rare kaon and hyperon decays involving muons. So far, only the data from the 1997 run have been looked at, or about 30% of the total data sample.

4.1 Measurements of $K^{\pm} \rightarrow \pi^{\pm} \mu^{+} \mu^{-}$

After background subtraction, we find $70.28^{+9.45}_{-8.83}$ $K^{+} \rightarrow \pi^{+} + \mu^{+} + \mu^{-}$ decays and $34.09^{+7.16}_{-6.39}$ $K^{-} \rightarrow \pi^{-} + \mu^{+} + \mu^{-}$ decays. Preliminary results for the branching ratios are

$$B(K^{+} \rightarrow \pi^{+} + \mu^{+} + \mu^{-}) = (9.1 \pm 1.2 \pm 0.5) \times 10^{-8} \quad \text{and}$$

$$B(K^{-} \rightarrow \pi^{-} + \mu^{+} + \mu^{-}) = (8.5^{+1.8}_{-1.6} \pm 0.6) \times 10^{-8}$$

Our K^{+} result is in good agreement with that of BNL E865[6] but not with BNL E787[7]. Ours is the first measurement of the K^{-} mode.

4.2 Other dimuon decays

Our eventual one-event sensitivities for other decays involving dimuons, such as: $K^{+} \rightarrow \pi^{-}\mu^{+}\mu^{+}$, $\Sigma^{-} \rightarrow p\,\mu^{-}\mu^{-}$, and $\Xi^{-} \rightarrow p\,\mu^{-}\mu^{-}$, should be comparable to those for $K^{\pm} \rightarrow \pi^{\pm} \mu^{+} \mu^{-}$.

5. Conclusions

Our 1997 and 1999 data runs were very successful. We have recorded the world's largest sample of charged hyperon decays. Based on data samples that are a few percent of the total, our preliminary results for the kaon and hyperon CP tests are consistent with CP symmetry. All the data have gone through a first-pass analysis to summary tapes. Much work remains to study the systematic errors and reduce them to below the statistical errors.

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