Search for direct CP violation in hyperon decays

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Representing Hyper$\mathcal{CP}$ (FNAL E871) Collaboration

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NONLEPTONIC HYPERON DECAYS

- **Parity violating, ΔS = 1 decay of a spin-$\frac{1}{2}$ strange baryon into a spin-$\frac{1}{2}$ baryon and a pion, e.g.**

$$\Lambda \to \mathrm{p}\,\pi$$

is described by the decay amplitude

$$\mathcal{M}(\Lambda \to \mathrm{p}\,\pi) = S + P\,\vec{\sigma} \cdot \widehat{q}_p$$

S **is the amplitude of the S-wave final state**
P **is the amplitude of the P-wave final state**
$\widehat{q}_p$ **is the momentum unit vector of the proton**

- **In the rest frame of the Λ the angular distribution of the proton**

$$\frac{dn}{d\Omega} = \frac{1}{4\pi}(1 + \alpha_\Lambda \vec{\mathcal{P}}_\Lambda \cdot \hat{q}_p)$$

where $\vec{\mathcal{P}}_\Lambda$ is the polarization of Λ and the decay parameter α is defined as

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

CP IN HYPERON DECAYS

- **If CP is conserved**

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

- **One can form a CP violating asymmetry**

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

- **Search for direct CP violation in Λ decays**
  Need to produce Λ, $\bar{\Lambda}$ with known polarizations

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

- **Search for direct CP violation in Ξ and Λ decay sequence**

Experiment	Decay Mode	$A_{\Xi} + A_{\Lambda}$
E756 at Fermilab	$\Xi \to \Lambda\pi, \Lambda \to p\pi$	**0.012 $\pm$ 0.014**

Hyper$\mathcal{CP}$ APPROACH

- **Produce Ξ^- and $\overline{\Xi}^+$ baryons with 800 GeV protons at 0 mrad**

$$p + N \to \Xi^- + X \qquad\qquad p + N \to \overline{\Xi}^+ + X$$

- **With unpolarized Ξ^- and $\overline{\Xi}^+$, in their decay**

$$\Xi \to \Lambda\,\pi$$

daughter Λ acquires longitudinal polarization

$$\vec{\mathcal{P}}_\Lambda \quad = \quad \alpha_\Xi \cdot \hat{q}_\Lambda$$

- **In Λ rest frame the angular distribution of proton from $\Lambda \to p\pi$ is**

$$\frac{dn}{d\Omega} = \frac{1}{4\pi}(1 + \alpha_\Lambda \vec{\mathcal{P}}_\Lambda \cdot \hat{q}_p) = \frac{1}{4\pi}(1 + \alpha_\Lambda \alpha_\Xi \cos\theta)$$

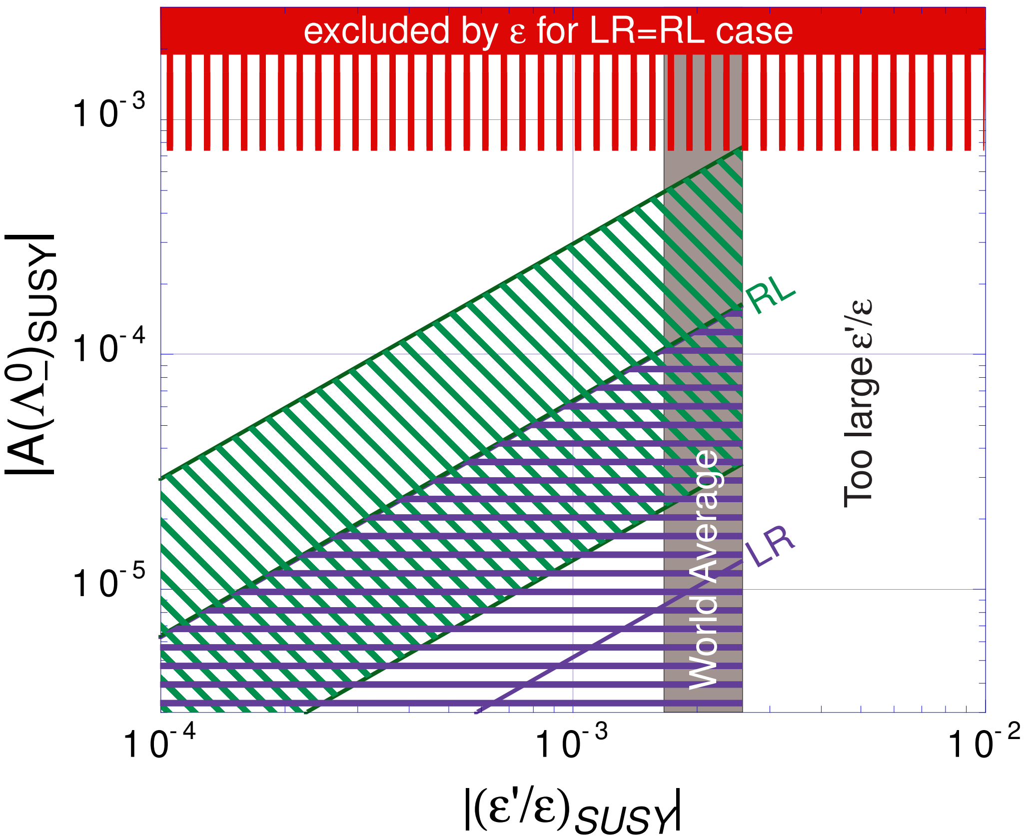
- **Measure asymmetry**

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

with 1×10^{-4} precision

THEORETICAL PREDICTIONS

	$A_\Lambda\ (10^{-4})$	$A_\Xi\ (10^{-4})$
Left-Right	$(-0.1, 6)$	$(-2.5, 6)$
CKM	$(-0.5, -0.1)$	$(-1.0, -0.05)$
SUSY	$(-0.2, -19)$	-

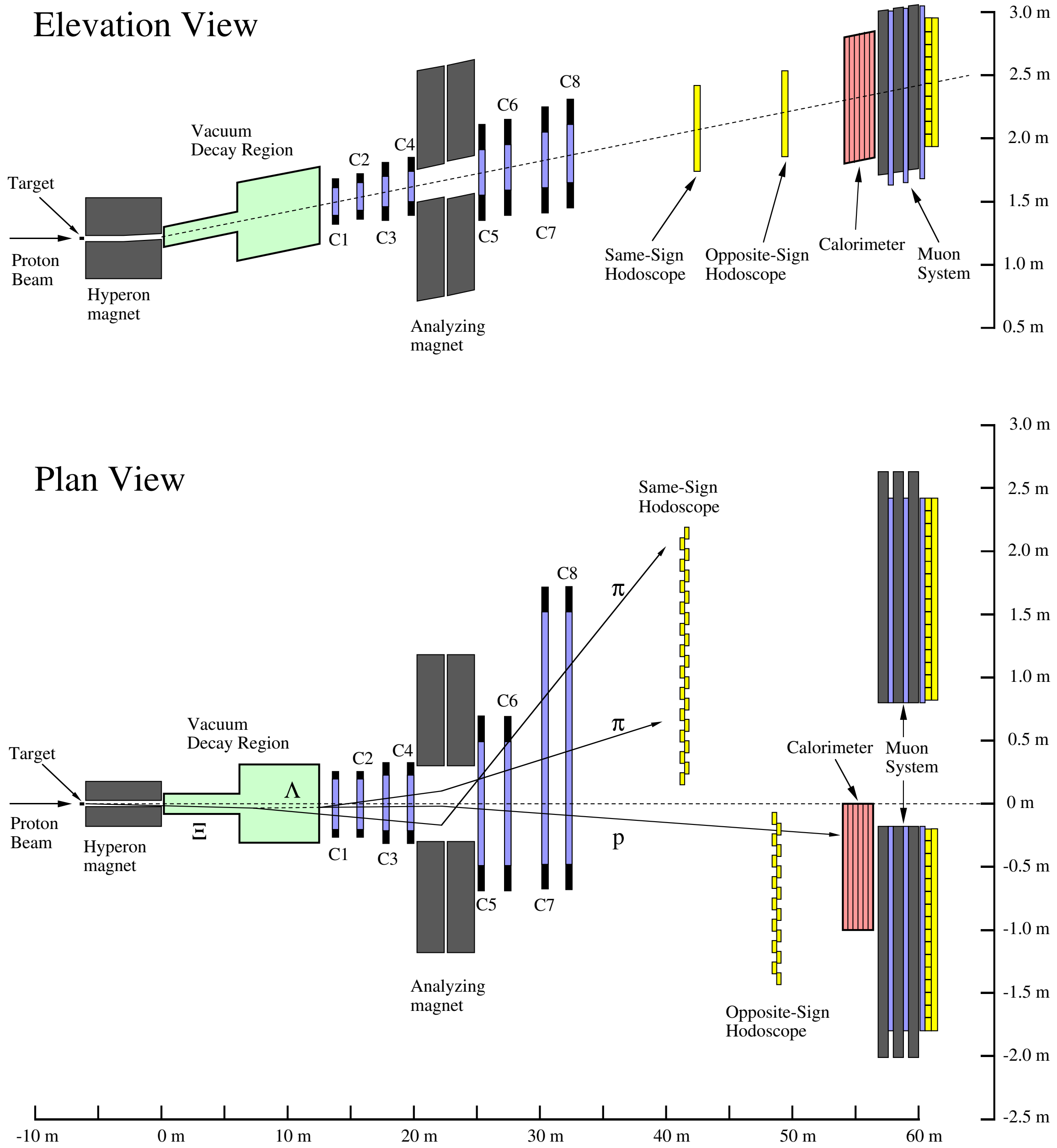


He *et al*, Phys. Rev. D61:071701, 2000

DIRECT ΔS=1 CP VIOLATION IN KAON AND HYPERON DECAYS

$\epsilon^{'}/\epsilon$	$A_{\Lambda\Xi}$
Pure S-wave decay: probes only parity-violating amplitudes	Probes interference between parity-violating and conserving amplitudes. Sensitive to new physics in parity-conserving channel
Large cancellation between electroweak and strong penguin diagrams at large top mass	No such cancellation
Large uncertainty in hadronic matrix elements	Somewhat smaller uncertainty that could be narrowed by measurement of $\Lambda\pi$ phase shifts $(\delta_S - \delta_P)$ at $E=M_\Xi$

The HyperCP Spectrometer



There were minor differences between 97 and 99 runs

SUMMARY
OF THE 1997 AND 1999 RUNS

	1997 Run	1999 Run
Number of tapes	9,376	18,838
Data Volume	38 TB	71 TB

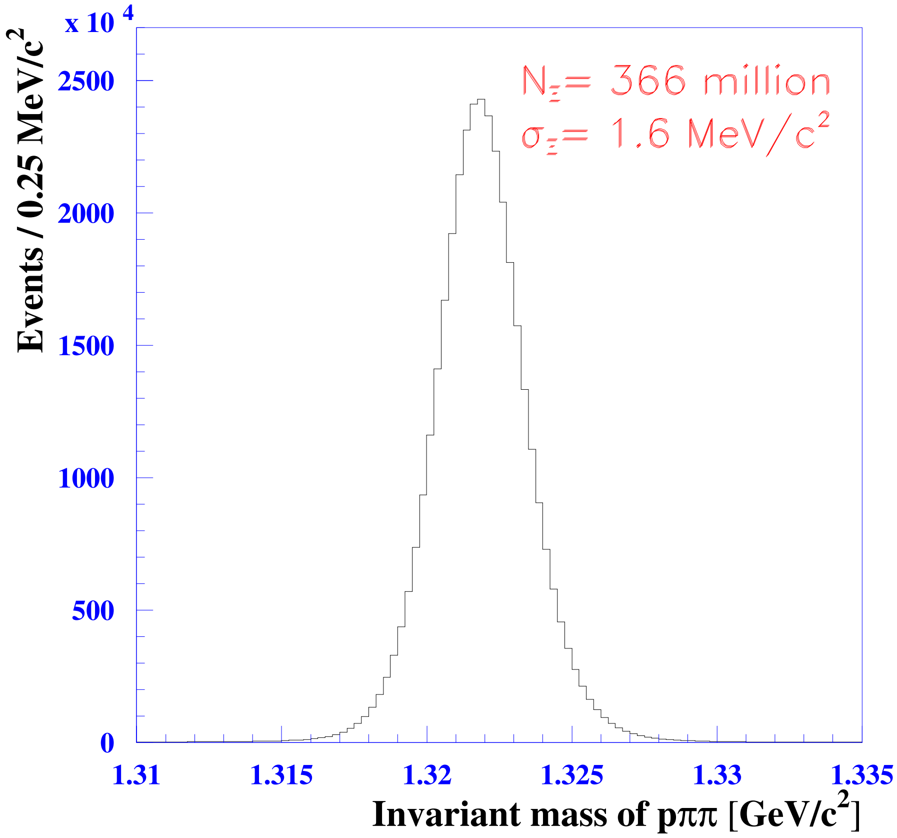
Projected number of reconstructed events

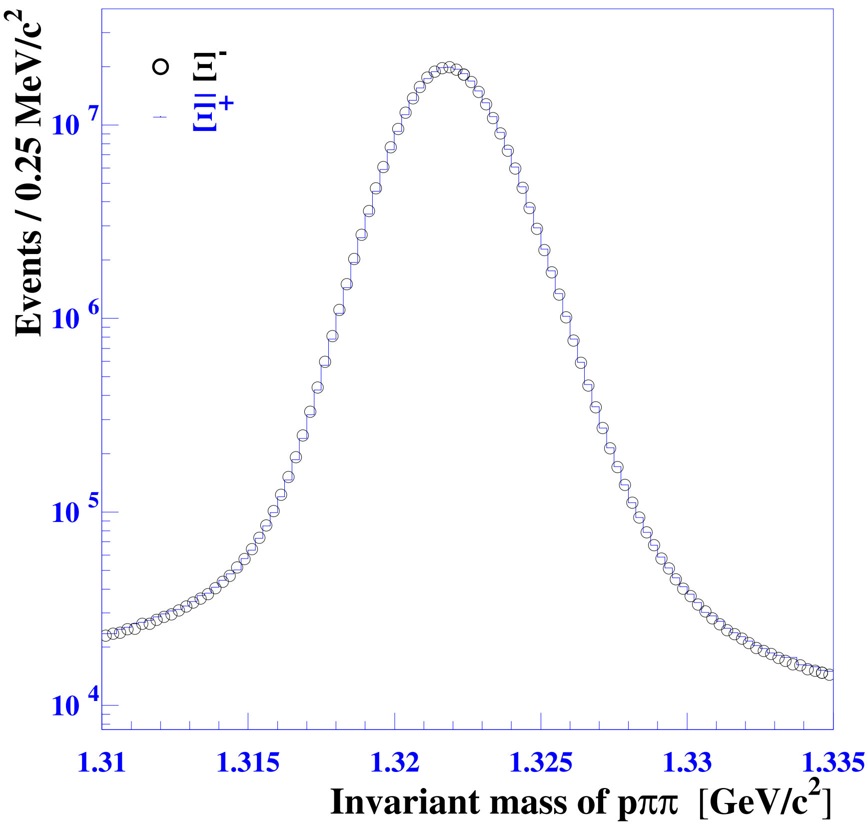
Ξ^-	2×10^9
$\overline{\Xi}^+$	0.5×10^9
K^+	0.32×10^9
K^-	0.13×10^9
Ω^-	14×10^6
$\overline{\Omega}^+$	5.3×10^6

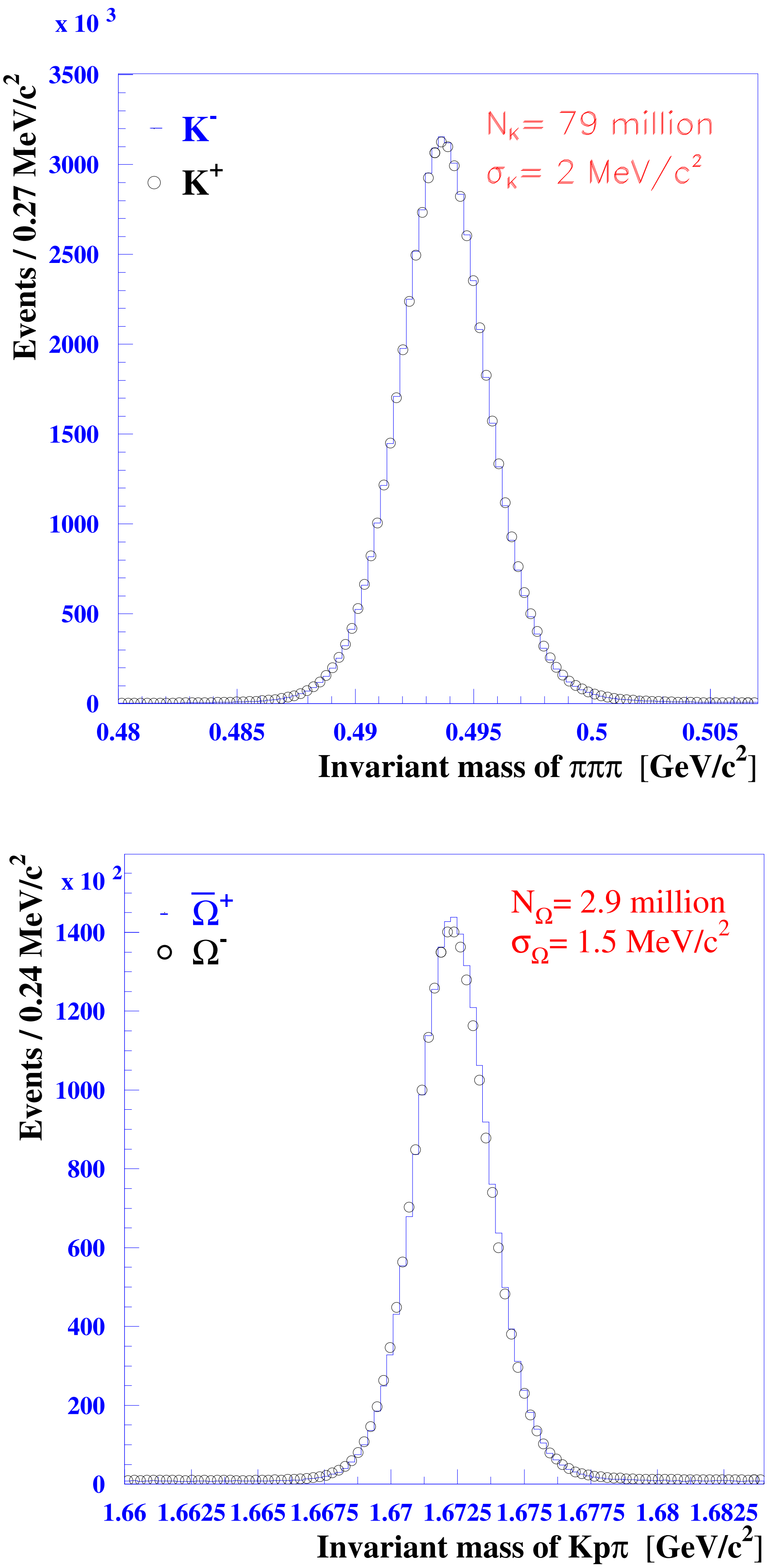
$\delta(A_{\Xi\Lambda}) \ = \ 1.4 \times 10^{-4}$ statistical precision

CURRENT STATUS

- Established consistent alignments of spectrometer for the 1997 and 1999 runs
- Processing 1999 data using Fermilab Farm
- Several analyses are in progress
  - CP violation in Ξ, Λ decays
  - CP violation in $K \to 3\pi$ decay
  - Measurement of the decay parameter α of $\Omega^- \to \Lambda K^-$
  - Measurement of the decay parameter β of $\Xi^- \to \Lambda \pi^-$
  - Measurement of production polarization of Ξ
  - Production polarization of Ω
  - Production cross section of Ξ
  - Searches for rare and forbidden decays (see next talk)


x 10 4
Events / 0.25 MeV/c2
N_Ξ = 366 million
σ_Ξ = 1.6 MeV/c2
2500
2000
1500
1000
500
0
1.31
1.315
1.32
1.325
1.33
1.335
Invariant mass of pππ [GeV/c2]


Events / 0.25 MeV/c2
Ξ-
Ξ̄+
10 7
10 6
10 5
10 4
1.31
1.315
1.32
1.325
1.33
1.335
Invariant mass of pππ [GeV/c2]

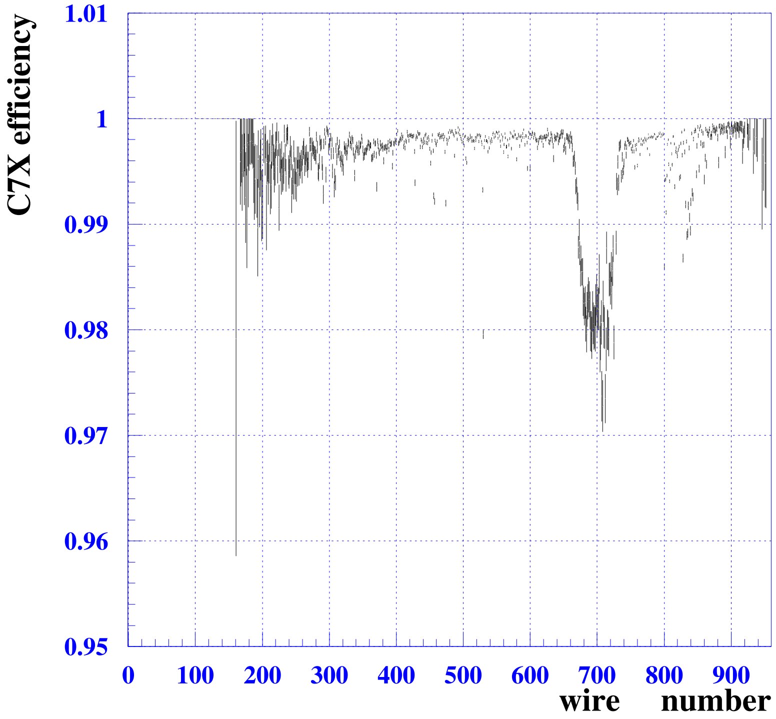

x 10 3
Events / 0.27 MeV/c2
3500
3000
2500
2000
1500
1000
500
0
K-
K+
N_K= 79 million
σ_K= 2 MeV/c2
0.48
0.485
0.49
0.495
0.5
0.505
Invariant mass of πππ [GeV/c2]
Events / 0.24 MeV/c2
x 10 2
1400
1200
1000
800
600
400
200
0
Ω̄+
Ω-
N_Ω= 2.9 million
σ_Ω= 1.5 MeV/c2
1.66
1.6625
1.665
1.6675
1.67
1.6725
1.675
1.6775
1.68
1.6825
Invariant mass of Kpπ [GeV/c2]

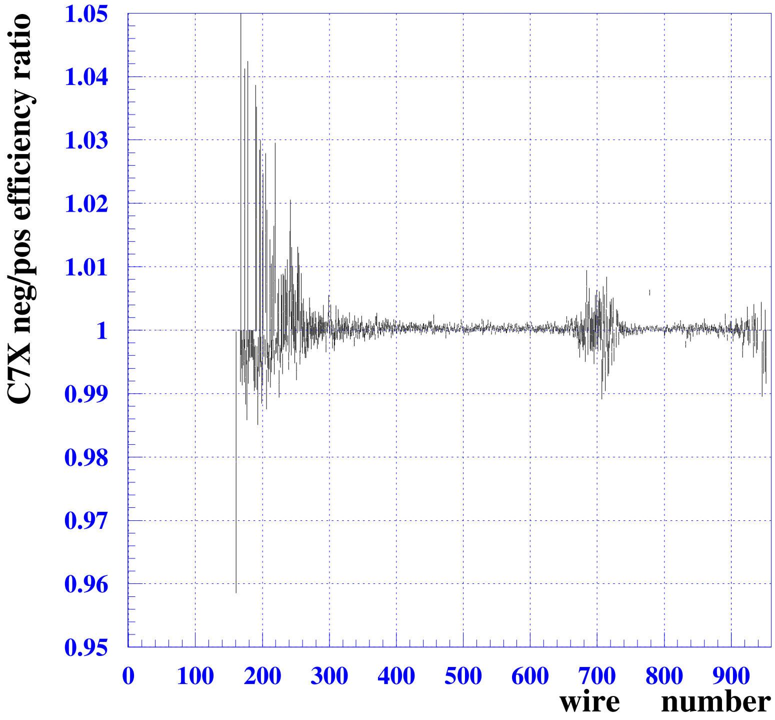
SYSTEMATICS

If not corrected for could cause false asymmetries between Ξ^- and $\overline{\Xi}^+$ decays

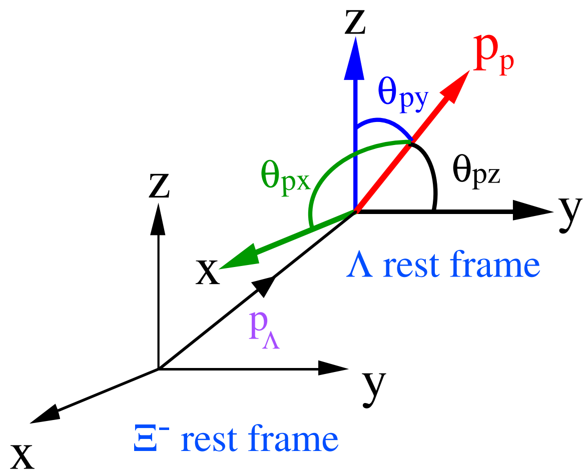
- **Nonzero Ξ^-, $\overline{\Xi}^+$ polarizations**
- **Different interaction cross sections between π^- and π^+ and between p and $\overline{p}$**
- **different backgrounds for Λ, Ξ^- versus $\overline{\Lambda}$, $\overline{\Xi}^+$**
- **Acceptance differences**
  - **targeting differences**
  - **magnetic field differences**
  - **chamber efficiency differences**
  - **trigger efficiency**
  - **temporal changes**
  - **production cross sections**

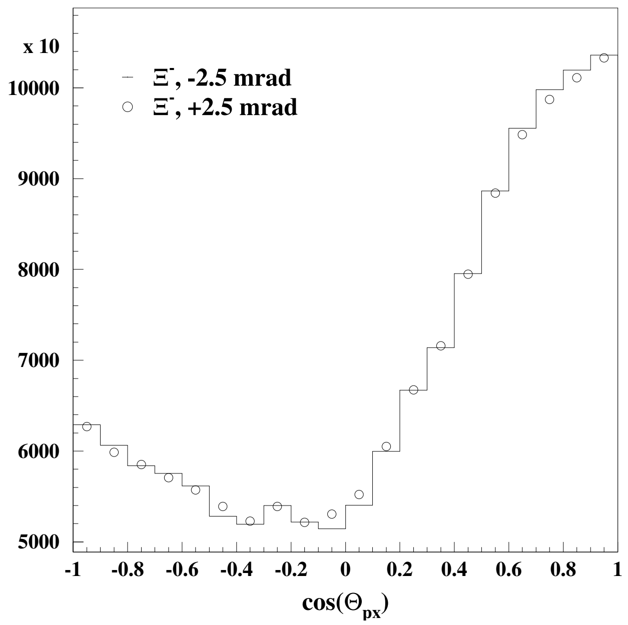
SPECTROMETER PERFORMANCE

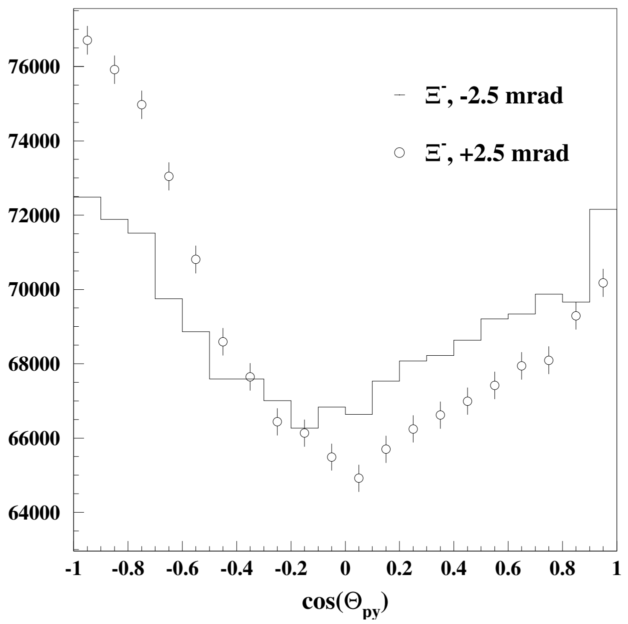


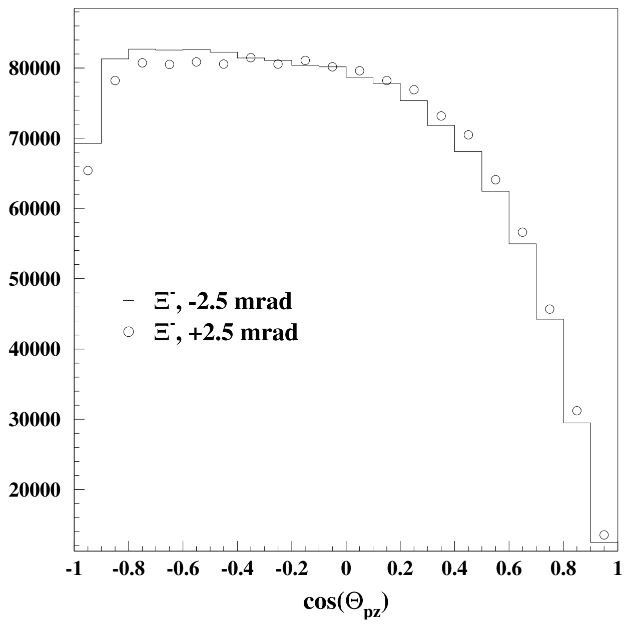


EFFECT OF POLARIZATION



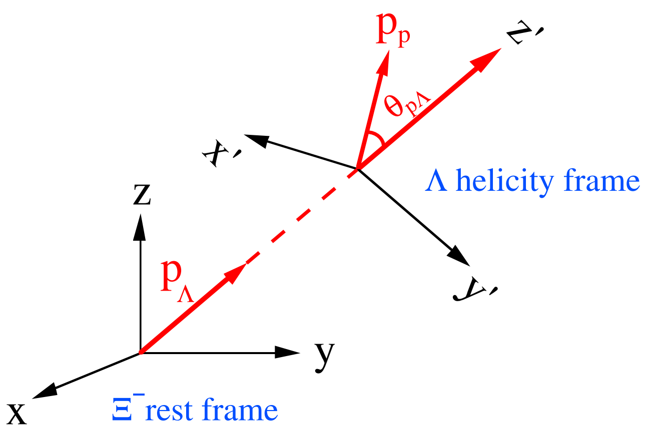


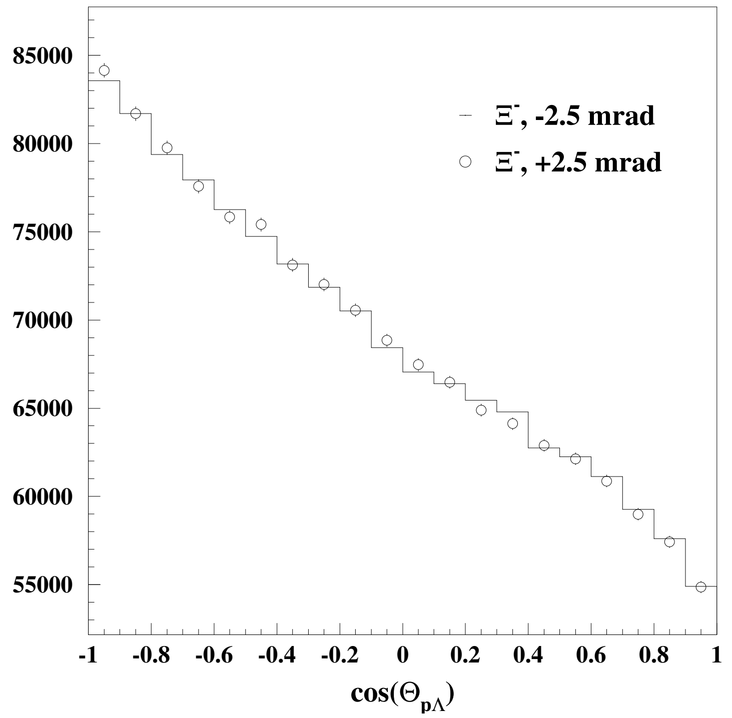




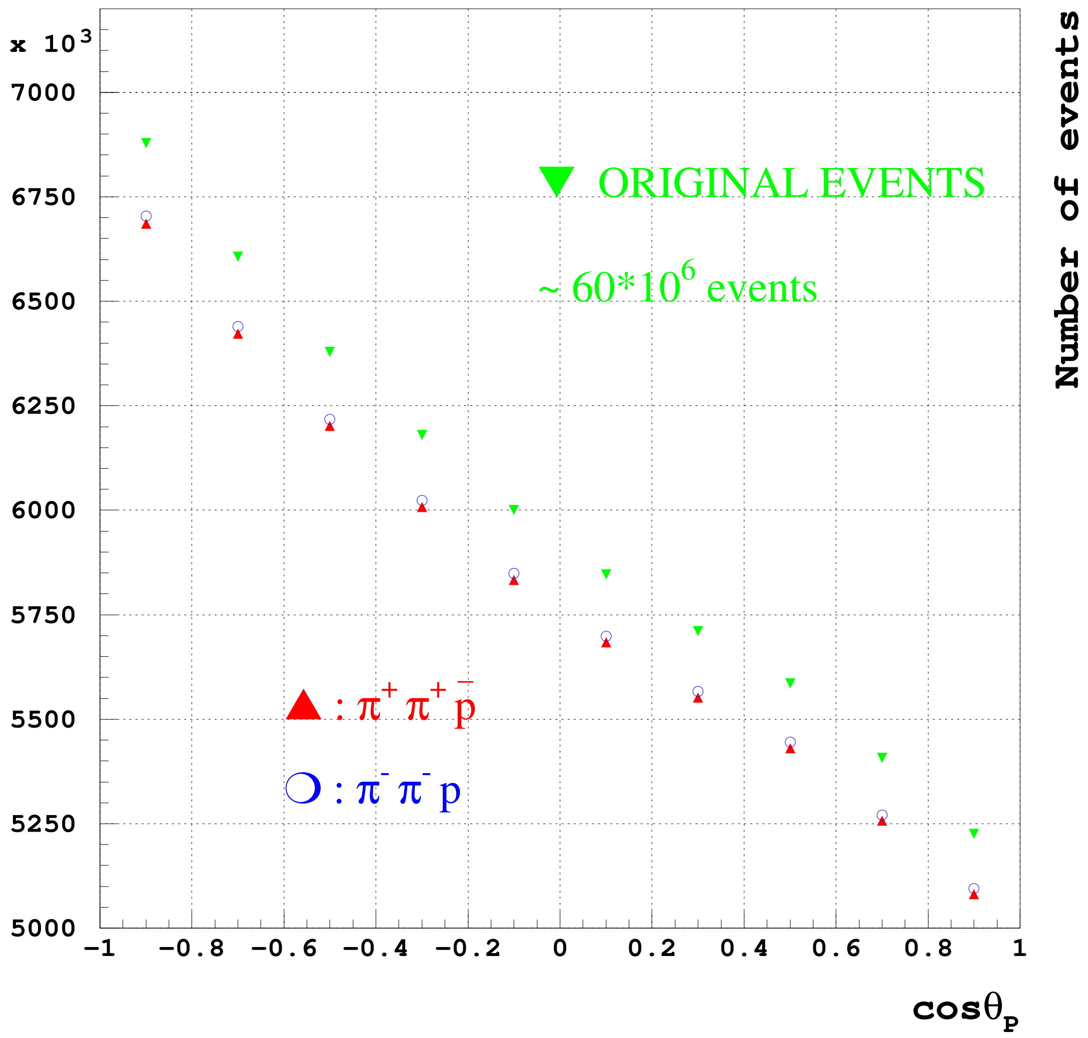
EFFECT OF POLARIZATION

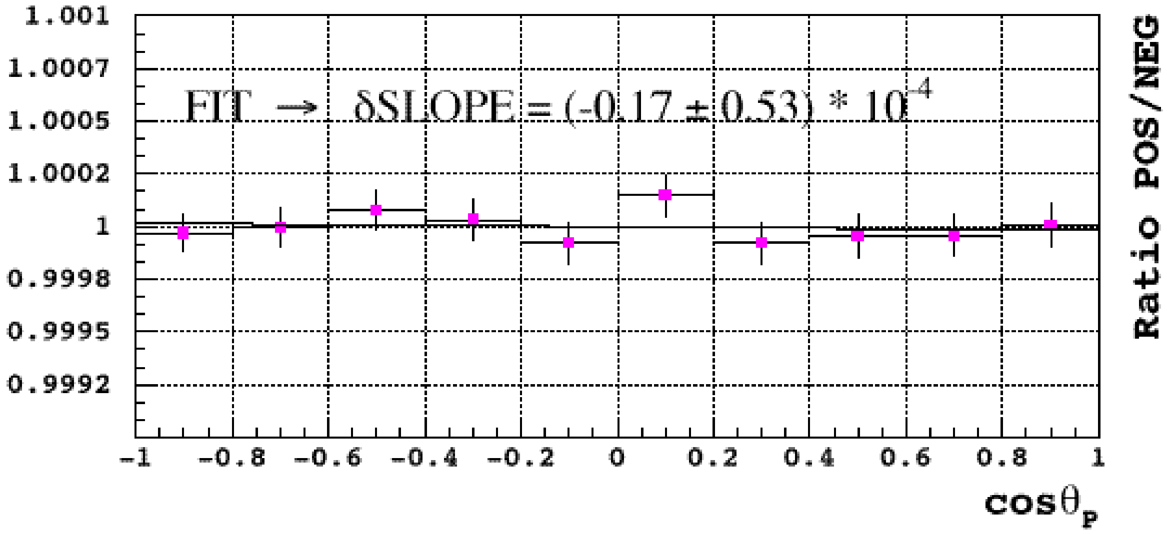
Ξ^- (-2.5 mrad) vs Ξ^- (+2.5 mrad)





EFFECT OF DIFFERENCES IN PARTICLE AND ANTIPARTICLE INTERACTIONS





CONCLUSIONS

- **Hyper$\mathcal{CP}$ had successful 1997 and 1999 runs and has collected the largest samples of Ξ^- and $\overline{\Xi}^+$ decays in the world.**

- **The projected statistical sensitivity to CP asymmetry in $\Xi,\ \Lambda$ decays is**

$$1.4 \times 10^{-4},$$

  two orders of magnitude better that the present limit and where some theories predict an effect.

- **Processing of data will continue for the next several months. Detailed systematic studies are in progress.**

- **The large samples of Ξ, Ω, and K decays allow us to make a variety of precise measurements and rare-decay searches.**