Measurement of the β_{Ξ} and γ_{Ξ} Decay Parameters of $\Xi^- \to \Lambda\pi^-$ Decay

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(Presented for *HyperCP* Collaboration)

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Search for *CP*-Violation in Non-leptonic Hyperon Decay

♣ *HyperCP* is in the process of measuring the *CP*-Violating Asymmetry in $\Xi \to \Lambda\pi$, $\Lambda \to \mathrm{p}\pi$:

$$\mathcal{A}_{\Xi\Lambda} = \frac{\alpha_\Xi \alpha_\Lambda - \alpha_{\overline{\Xi}} \alpha_{\overline{\Lambda}}}{\alpha_\Xi \alpha_\Lambda + \alpha_{\overline{\Xi}} \alpha_{\overline{\Lambda}}} \approx \mathcal{A}_\Xi + \mathcal{A}_\Lambda$$

$$\mathcal{A}_\Xi = \frac{\alpha_\Xi + \alpha_{\overline{\Xi}}}{\alpha_\Xi - \alpha_{\overline{\Xi}}} \approx -\tan(\delta_{\mathbf{p3}} - \delta_{\mathbf{s3}}) \ \sin(\phi^\Xi_{\mathbf{p1}} - \phi^\Xi_{\mathbf{s1}})$$

$$\mathcal{A}_\Lambda = \frac{\alpha_\Lambda + \alpha_{\overline{\Lambda}}}{\alpha_\Lambda - \alpha_{\overline{\Lambda}}} \approx -\tan(\delta_{\mathbf{p1}} - \delta_{\mathbf{s1}}) \ \sin(\phi^\Lambda_{\mathbf{p1}} - \phi^\Lambda_{\mathbf{s1}})$$

- α_Λ (α_Ξ): Decay Parameters of $\Lambda \to \mathrm{p}\pi$ ($\Xi \to \Lambda\pi$).
- $\delta_\mathbf{p}$, $\delta_\mathbf{s}$ ($\phi_\mathbf{p}$, $\phi_\mathbf{s}$): Strong (Weak) Phases in the p- and s-wave state.
- 1 , 3: refer to $\mathrm{I} = 1/2$ and $\mathrm{I} = 1$ for Strong Phases, $\Delta\mathrm{I} = 1/2$, $\Delta\mathrm{I} = 3/2$ for Weak Phases.

Strong Phase Shift Difference $\delta_{p3} - \delta_{s3}$

- **Theoretical Prediction:**

Theory	$\delta_{p3} - \delta_{s3}$ (degree)
R. Nath	$\delta_{p3} - \delta_{s3} \sim 16$
χPT (M. Lu *et al.*)	$\delta_{p3} - \delta_{s3} = -1.7$
χPT (A. Datta & S. Pakvasa)	$-2.2 < \delta_{p3} - \delta_{s3} < -1.7$
χPT (A. Kamal)	$-4.2 < \delta_{p3} - \delta_{s3} < -1.4$
χPT (A. Datta *et al.*)	$-3.3 < \delta_{p3} - \delta_{s3} < 0.9$
χPT (U.-G. Meißner & J.A. Oller)	$-2.8 < \delta_{p3} - \delta_{s3} < -1.7$
K-Matrix (J. Tandean, A.W. Thomas, and G. Valencia)	$-3.9 < \delta_{p3} - \delta_{s3} < 7.8$

- **Experimental Measurement:**

PDG[a]	$\delta_{p3} - \delta_{s3} = (-7.7 \pm 7.7)^\circ$
E756	$\delta_{p3} - \delta_{s3} = (3.17 \pm 5.28 \pm 0.73)^\circ$

[a]This values is extracted from ϕ_Ξ in PDG

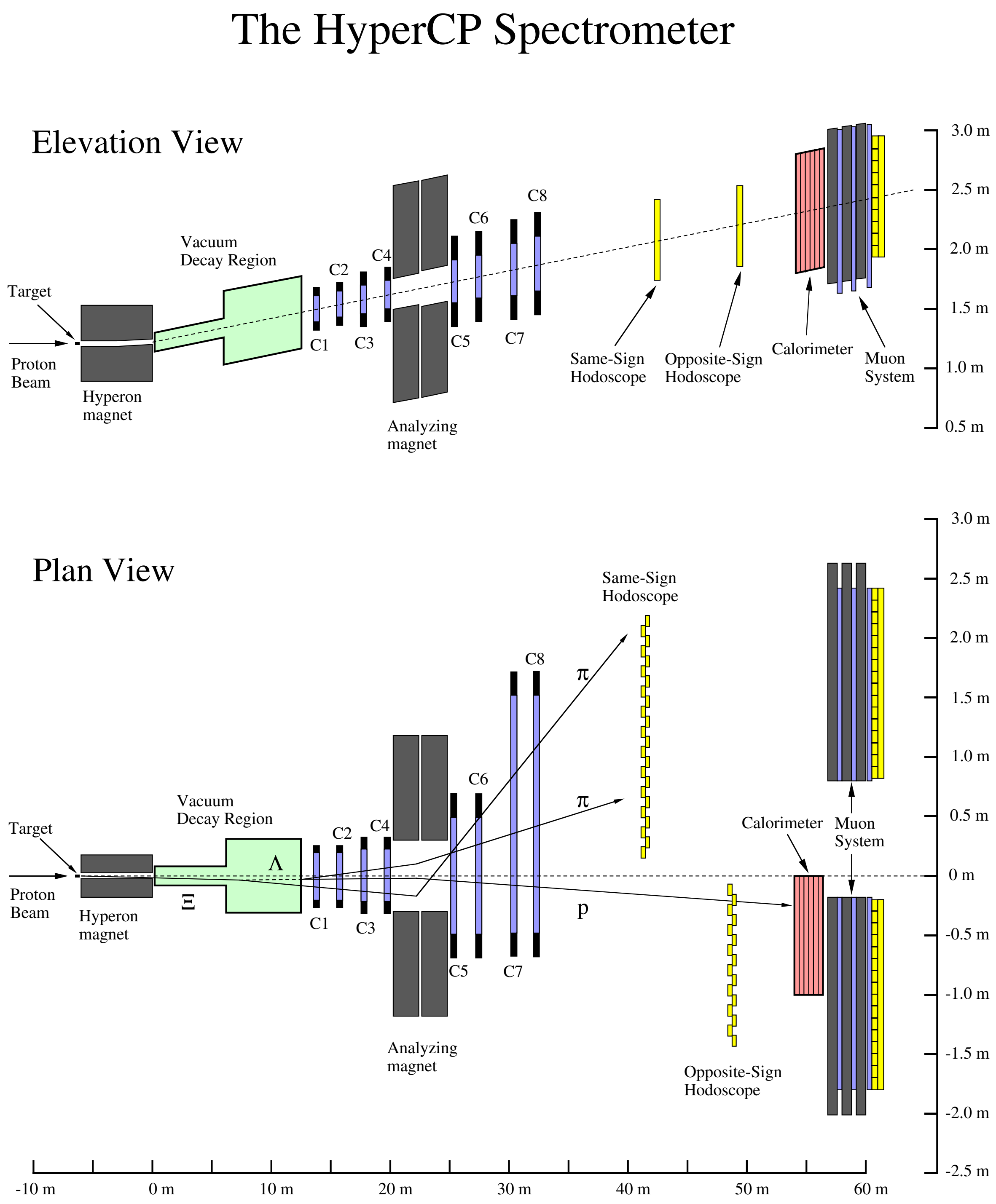
- ***HyperCP*** **collected the world's largest sample of polarized Ξ^- decays ($\sim$142 millions after event selection).**

  $\Rightarrow$ **This can allow us to pin down $\delta_{\mathbf{p3}} - \delta_{\mathbf{s3}}$ through**

  $$\frac{\beta_{\Xi}}{\alpha_{\Xi}} = \tan(\delta_{\mathbf{p3}} - \delta_{\mathbf{s3}})$$

  if the *CP*-violating phase shift is negligible compared to the strong phase shift difference.

  $\Rightarrow$ **Allow us to reduce theoretical uncertainty in predicting $\mathcal{A}_{\Xi\Lambda}$**


The HyperCP Spectrometer
Elevation View
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Proton
Beam
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-2.0 m
-2.5 m
-10 m
0 m
10 m
20 m
30 m
40 m
50 m
60 m

Angular Distributions

- The joint distribution for $\Xi^- \to \Lambda\pi^-$, $\Lambda \to p\pi^-$ is

$$\frac{d^2N}{d\Omega_\Lambda \; d\Omega_p} = (\frac{1}{4\pi})^2 (1 + \alpha_\Xi \vec{P}_\Xi \cdot \hat{\Lambda})(1 + \alpha_\Lambda \vec{P}_\Lambda \cdot \hat{p}) \; ,$$

- The angular distributions of the proton in the Λ rest frame along the three axes

$$\hat{z}' = \hat{\Lambda} \; , \qquad \hat{x}' = (\vec{P}_\Xi \times \hat{\Lambda})/|\vec{P}_\Xi \times \hat{\Lambda}| \; , \qquad \hat{y}' = \hat{z}' \times \hat{x}'$$

are given by

$$\clubsuit \; \frac{d^2N}{d\Omega_\Lambda \; d\cos\theta_{z'}} = \frac{1}{8\pi} \left\{ (1 + \alpha_\Xi \vec{P}_\Xi \cdot \hat{\Lambda}) + \alpha_\Lambda (\alpha_\Xi + \vec{P}_\Xi \cdot \hat{\Lambda}) \cos\theta_{z'} \right\} \; ,$$

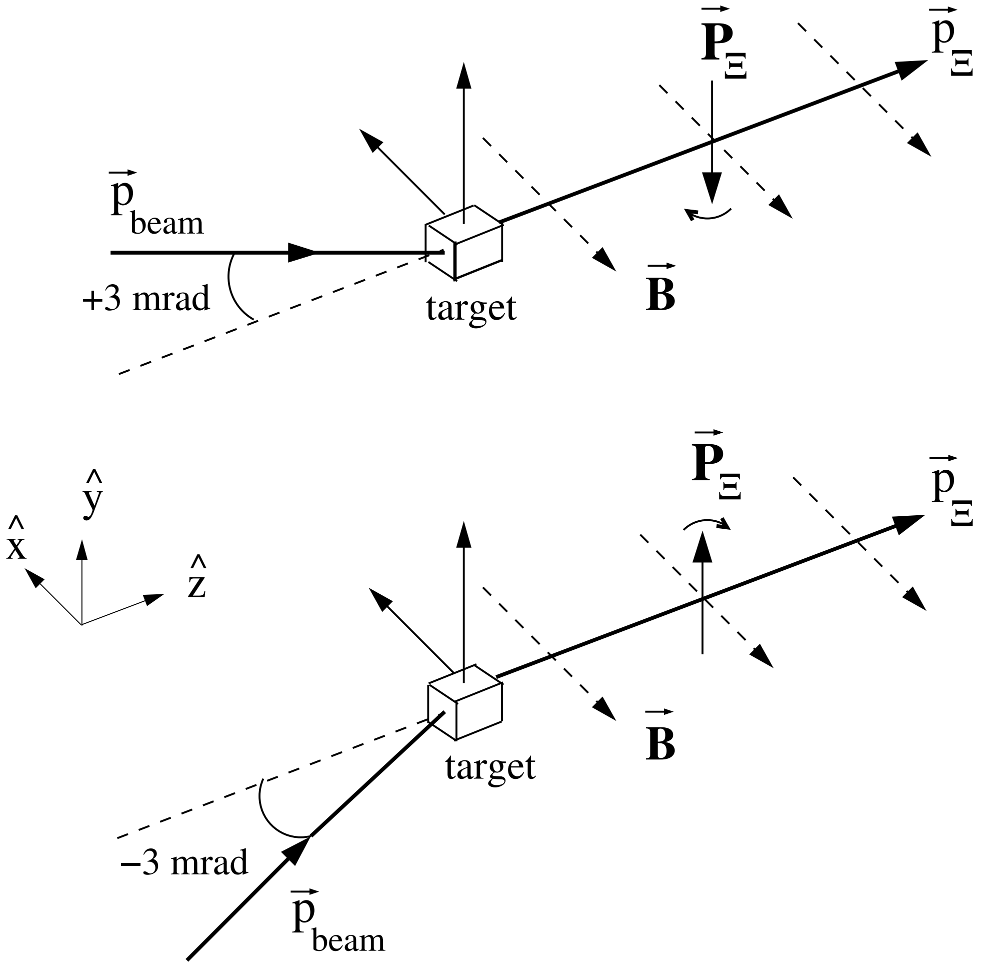
$$\clubsuit \; \frac{dN}{d\cos\theta_{x'}} = \frac{1}{2}(1 + \frac{\pi}{4} \alpha_\Lambda \beta_\Xi |P_\Xi| \cos\theta_{x'}) \; ,$$

$$\clubsuit \; \frac{dN}{d\cos\theta_{y'}} = \frac{1}{2}(1 + \frac{\pi}{4} \alpha_\Lambda \gamma_\Xi |P_\Xi| \cos\theta_{y'}) \; .$$

$$\cos\theta_{z'} = \hat{p} \cdot \hat{z}' \quad , \cos\theta_{x'} = \hat{p} \cdot \hat{x}' \quad , \cos\theta_{y'} = \hat{p} \cdot \hat{y}' \; .$$

- To measure β_Ξ and γ_Ξ, the Ξ^- polarization needs to be measured first.
- Ξ^- Polarization produced at the Target

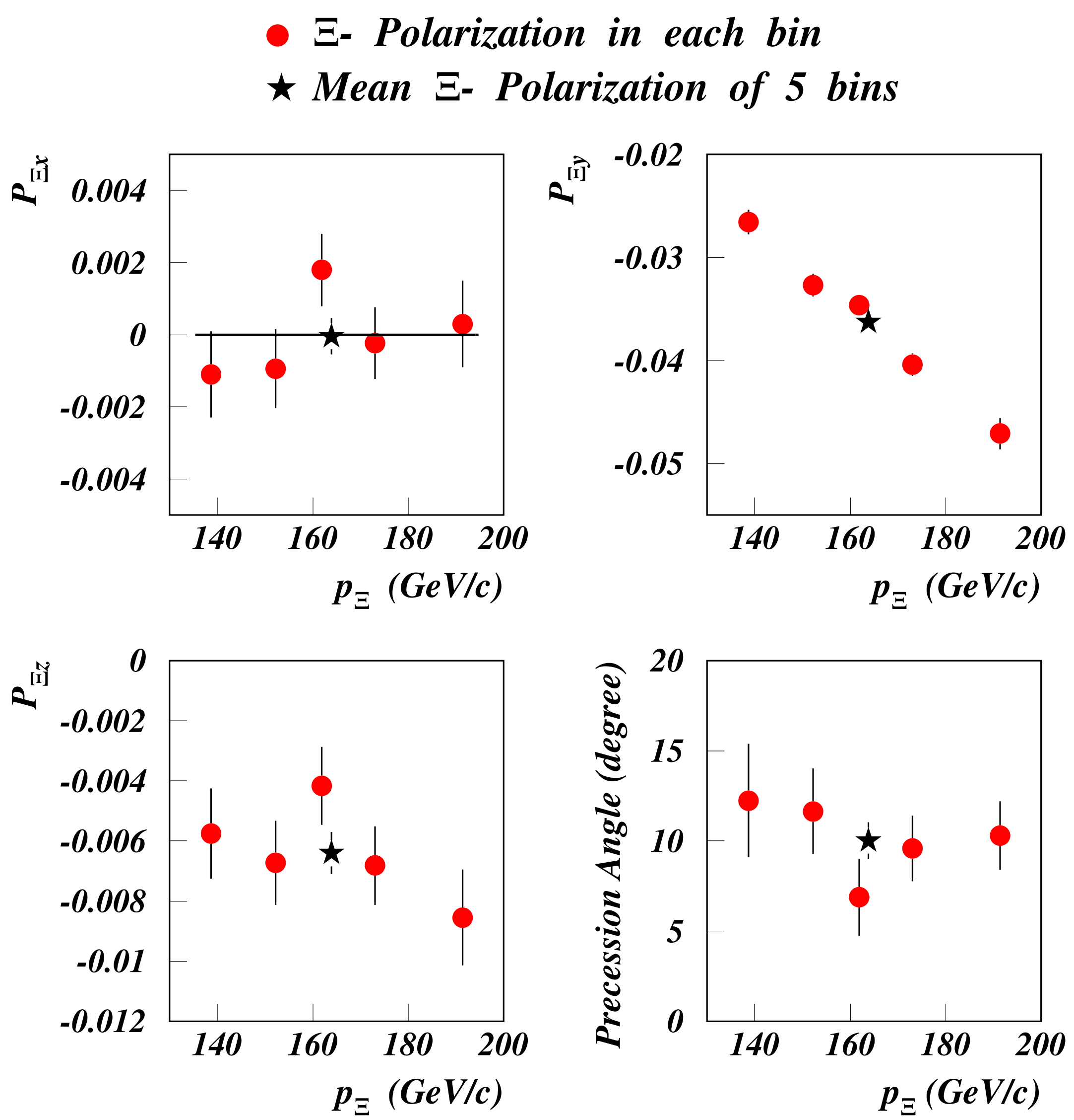
(Illustration for directions corresponding to negative polarization)



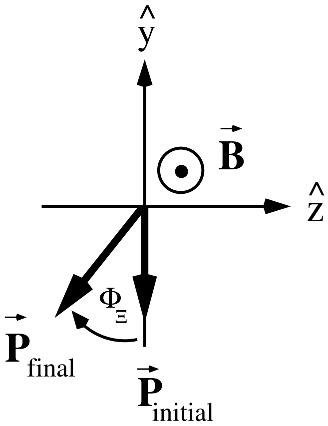
$\vec{P}_{\Xi}$ at Collimator Exit (after Precession)

⇒ $P_{\Xi x}$ for entire production angle sample is consistent with 0, required by parity conservation

⇒ $P_{\Xi y}$ and $P_{\Xi z}$ approximately increase in magnitude with Ξ^- momentum



Precession of Polarization Vector



$$\frac{\vec{S}}{S} = \hat{y}\cos\Phi_\Xi + \hat{z}\sin\Phi_\Xi$$

As Ξ^- moves through a transverse magnetic field, the precession angle Φ_Ξ of the Ξ^- polarization relative to the Ξ^- momentum at collimator exit is given by

$$\Phi_\Xi = \frac{q}{\beta m_\Xi c^2}\left(-\frac{\mu_\Xi m_\Xi}{\mu_N m_p} - 1\right)\int B\,dl$$

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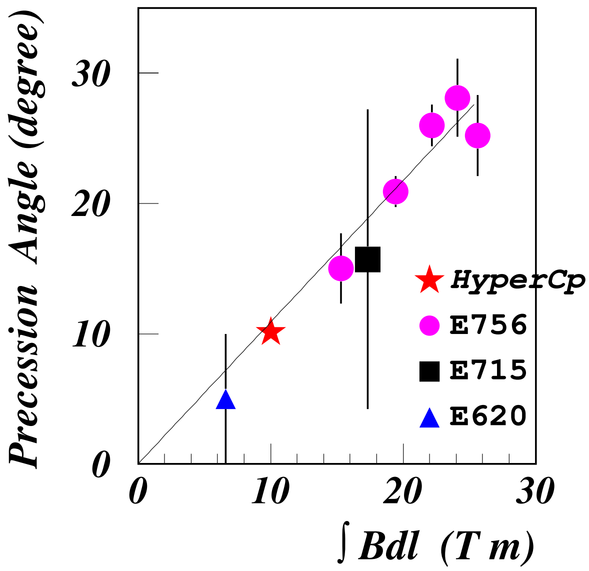
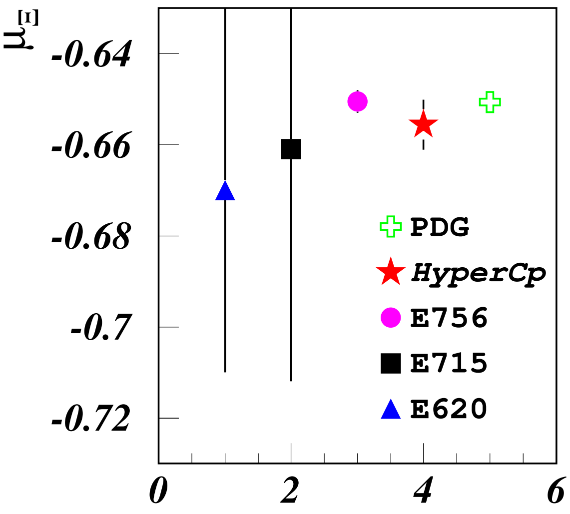
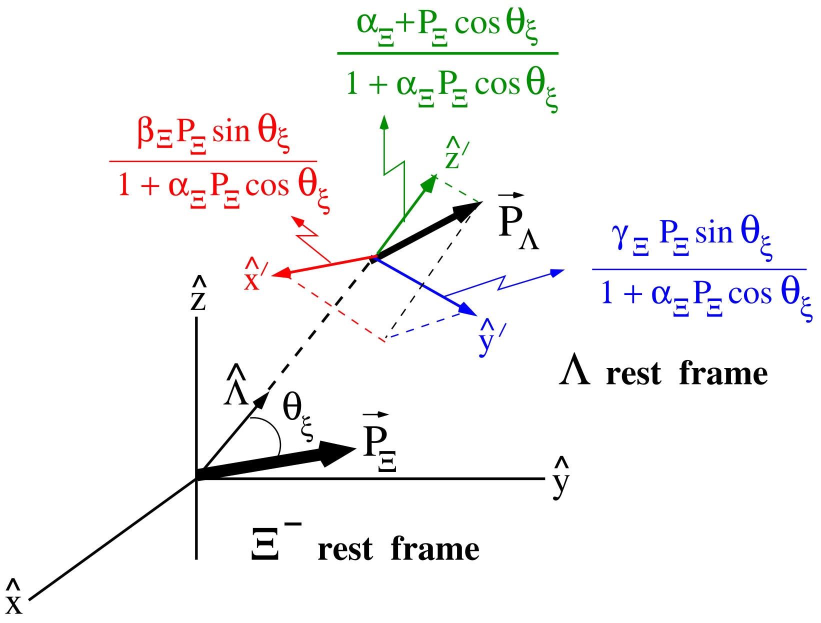




Measurements of β_Ξ and γ_Ξ

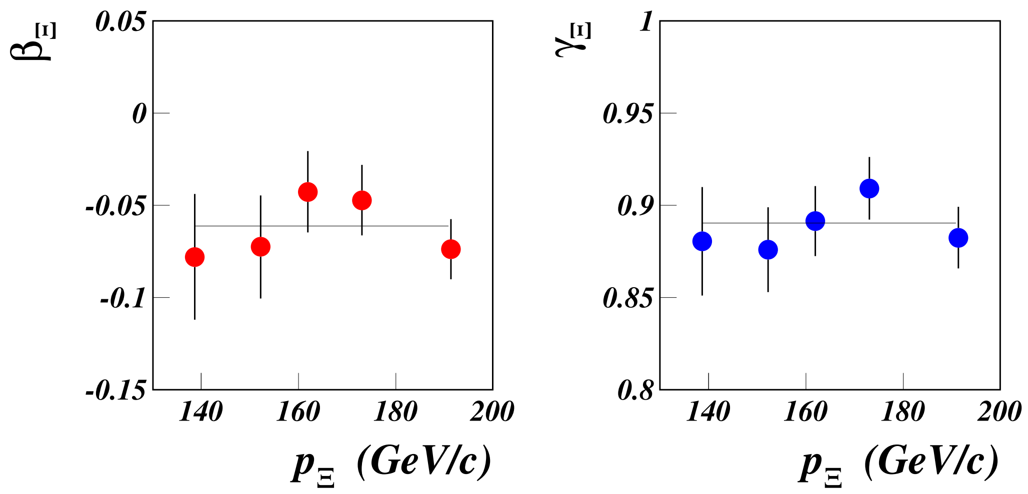
$$\frac{\mathbf{dN}}{\mathbf{d}\cos\theta_{\mathbf{x'}}} = \frac{\mathbf{1}}{\mathbf{2}}(\mathbf{1} + \frac{\pi}{\mathbf{4}}\alpha_{\mathbf{\Lambda}}\beta_{\Xi}|\mathbf{P}_{\Xi}|\cos\theta_{\mathbf{x'}}) \ ,$$

$$\frac{\mathbf{dN}}{\mathbf{d}\cos\theta_{\mathbf{y'}}} = \frac{\mathbf{1}}{\mathbf{2}}(\mathbf{1} + \frac{\pi}{\mathbf{4}}\alpha_{\mathbf{\Lambda}}\gamma_{\Xi}|\mathbf{P}_{\Xi}|\cos\theta_{\mathbf{y'}}) \ .$$



$$\hat{\mathbf{z}}' = \hat{\mathbf{\Lambda}} \ , \qquad \hat{\mathbf{x}}' = (\vec{\mathbf{P}}_\Xi \times \hat{\mathbf{\Lambda}})/|\vec{\mathbf{P}}_\Xi \times \hat{\mathbf{\Lambda}}| \ , \qquad \hat{\mathbf{y}}' = \hat{\mathbf{z}}' \times \hat{\mathbf{x}}'$$

$$\cos\theta_{x'} = \hat{p}\cdot\hat{x}' \quad , \cos\theta_{y'} = \hat{p}\cdot\hat{y}' \ .$$



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Sources of Systematic Uncertainties

- Backgound activity
- Background events under Signal Peak
- Imperfect Knowledge of Efficiencies of MWPCs
- Imperfect Knowledge of Efficiencies of Hodoscopes
- Imperfect Knowledge of Efficiencies of Calorimeter
- Momentum Cuts
- Uncertainty of Precession Angle

— Above were done

♣ Some other sources are still under investigation

Preliminary Results and Conclusions

- **Measured** $\vec{\mathrm{P}}_{\Xi}$ **at** $< \mathrm{x_f} >= 0.2$**, and** $< \mathrm{p_t} >= 0.46\mathrm{GeV/c}$

  $\mathbf{P_{\Xi} = -0.0360 \pm 0.0005 \,^{+\,0.0005}_{-\,0.0002}}$

- **Determined :**

  $\mathbf{\Phi_{\Xi} = (10 \pm 1)^{\circ}}$ **at** $\int \mathrm{B}d\boldsymbol{l} = \mathbf{10\ Tm}$

  $\mu_{\Xi} = (\mathbf{-0.6555 \pm 0.0056})\mu_{\mathrm{N}}$

  Consistent with PDG value

- **Measured :**

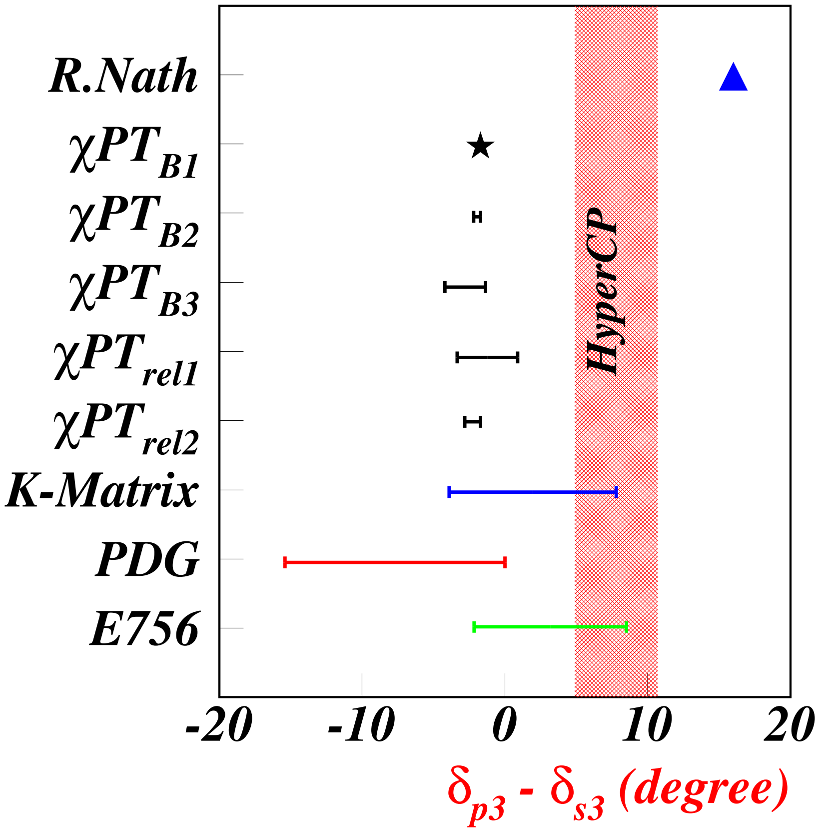
  $\beta_{\Xi} = \mathbf{-0.061 \pm 0.010 \,^{+\,0.022}_{-\,0.019}}$

  $\gamma_{\Xi} = \mathbf{0.890 \pm 0.010 \,^{+\,0.011}_{-\,0.007}}$

- **Using** $\alpha_{\Xi} = -0.456 \pm 0.008$**, we determined**

  - **Strong Phase Shift Difference for** $\Lambda\pi$ **Scattering:**

    $\delta_{\mathbf{p3}} - \delta_{\mathbf{s3}} = \tan^{-1}(\beta_{\Xi}/\alpha_{\Xi}) = (\mathbf{7.6 \pm 1.3 \,^{+\,2.4}_{-\,2.8}})^{\circ}$



- Our $\delta_{\mathbf{p3}} - \delta_{\mathbf{s3}}$ appears to favor a larger number than χPT .

- A large $\delta_{\mathbf{p3}} - \delta_{\mathbf{s3}}$ implies that CP violation in both decays $\mathbf{\Xi} \to \mathbf{\Lambda}\pi$ and $\mathbf{\Lambda} \to \mathbf{p}\pi$ could yield similar contributions to $\mathcal{A}_{\mathbf{\Xi\Lambda}}$.