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Search for *CP* Violation in Ξ and Λ Hyperon Decays with the Hyper*CP* Spectrometer at Fermilab

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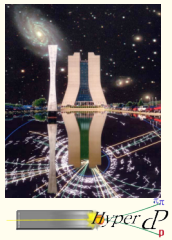
Hyper*CP* Experiment

27 June 2008

BEACH 2008

University of South Carolina

Why Search for *CP* Violation in Hyperon Decays?

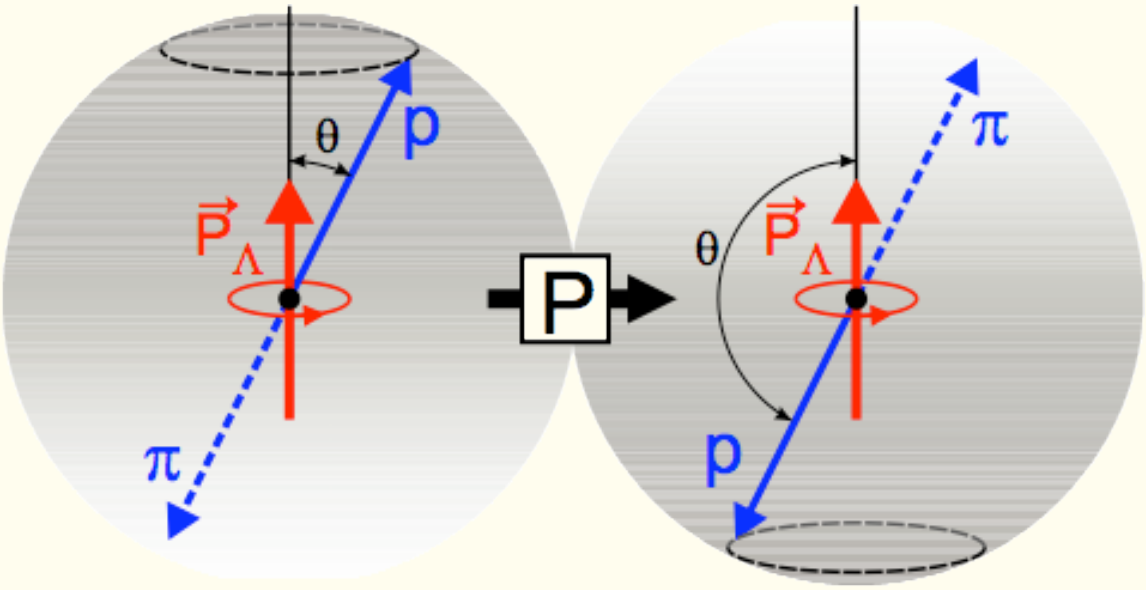


- After 40 years of intense effort, we still know little about *CP* violation
  - Its origin remains a mystery
  - There is little hard evidence that it is explained by the standard model
- The importance of *CP* violation to our understanding of particle physics, and indeed the universe, cannot be overstated
- Many scenarios for new physics produce large *CP* asymmetries in hyperon decays: up to $O(10^{-2})$
- Hyperons are experimentally accessible
  - No new accelerators needed
  - Experimental apparatus is *relatively* modest in scope and cost

Non-leptonic Hyperon Decay Dynamics

- Primarily two-body modes
- Daughter particle decay distributions are anisotropic
- Proceed into parity conserving (P-wave) and parity violating (S-wave) final states with amplitudes *P* and *S* respectively
- Slope of the baryon $\cos\theta$ distribution given by $\alpha_P P_P$
- Magnitude of the parity violation (α) can be large

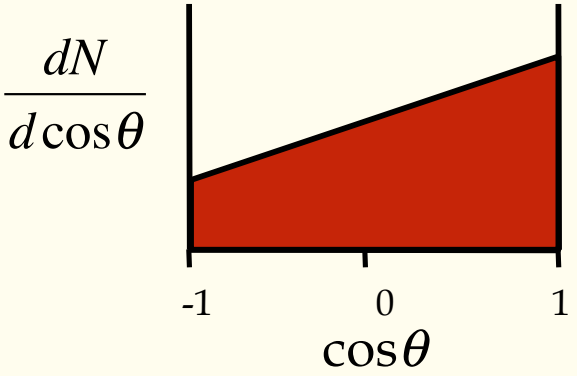
Eg. $\Lambda \rightarrow p\pi^-$



Anisotropic proton decay distribution

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

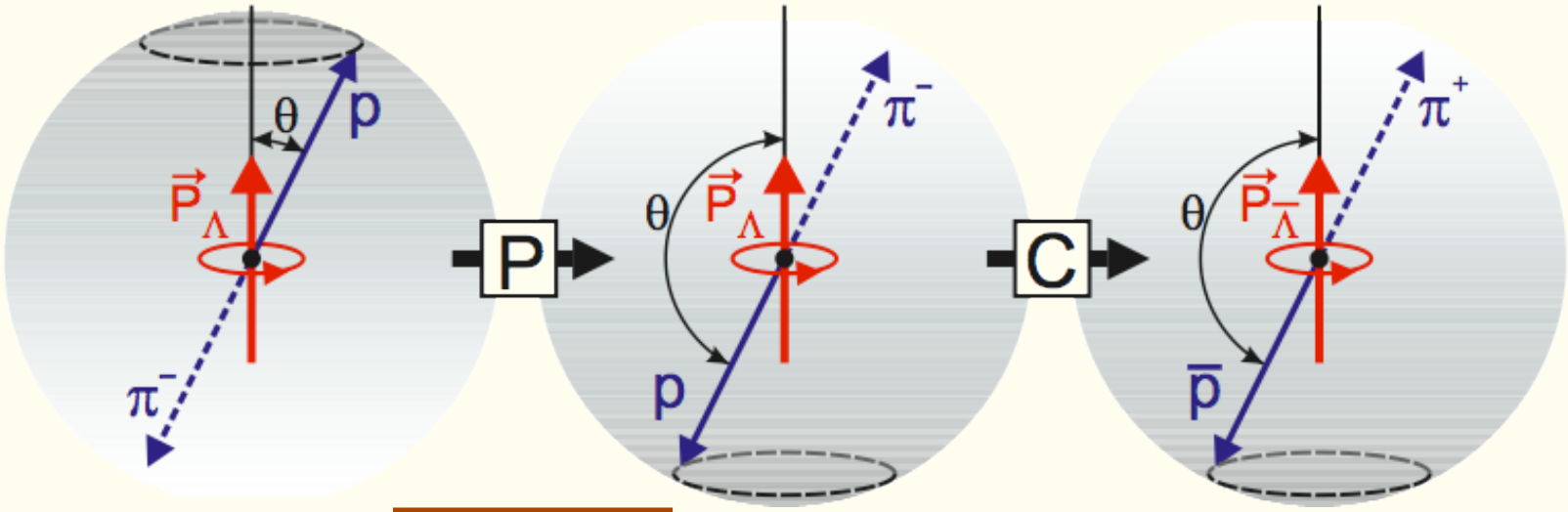
$$\text{slope} = \alpha_\Lambda P_\Lambda$$



CP Violation in Hyperon Decays

E.g. $\Lambda \to p\pi^-$

The daughter baryon preferentially decays in the direction of the parent particle's spin.



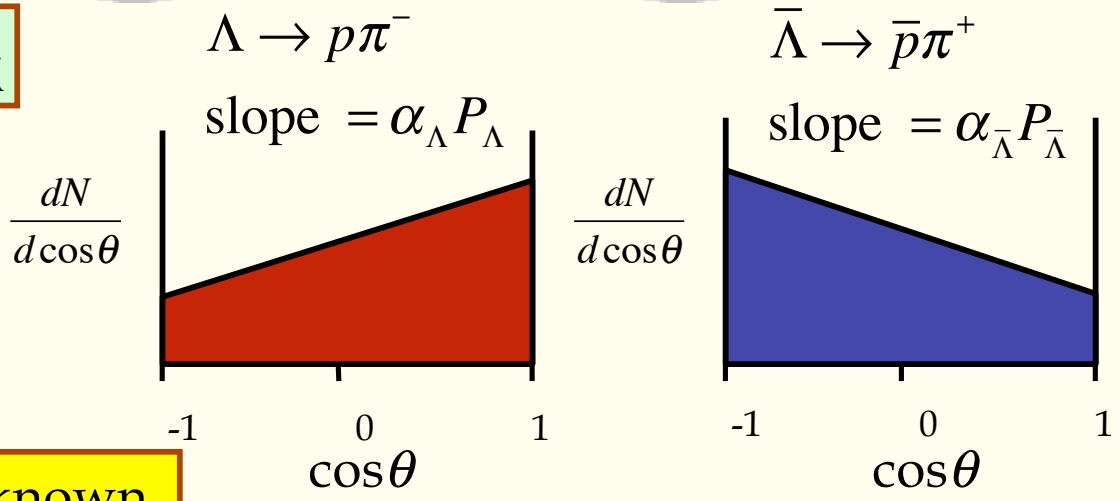
If CP is conserved: $\alpha_\Lambda = -\alpha_{\bar{\Lambda}}$

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

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

$\Lambda \to p\pi^-$ slope $= \alpha_\Lambda P_\Lambda$

$\bar{\Lambda} \to \bar{p}\pi^+$ slope $= \alpha_{\bar{\Lambda}} P_{\bar{\Lambda}}$



Polarization of Λ samples must be known

Hyperon Polarization

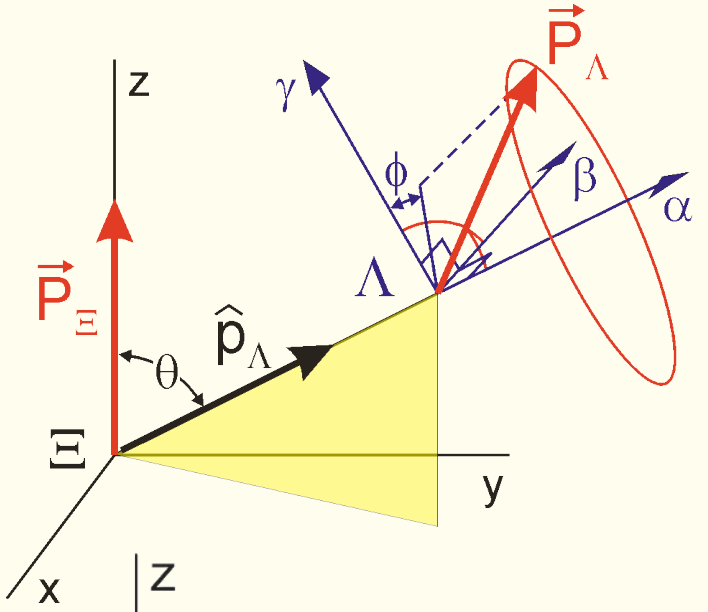
$$\Xi^- \to \Lambda\pi^-, \quad \Lambda \to p\pi^-$$

Daughter Λ baryon is polarized:

⇒ If parent Ξ hyperon is polarized

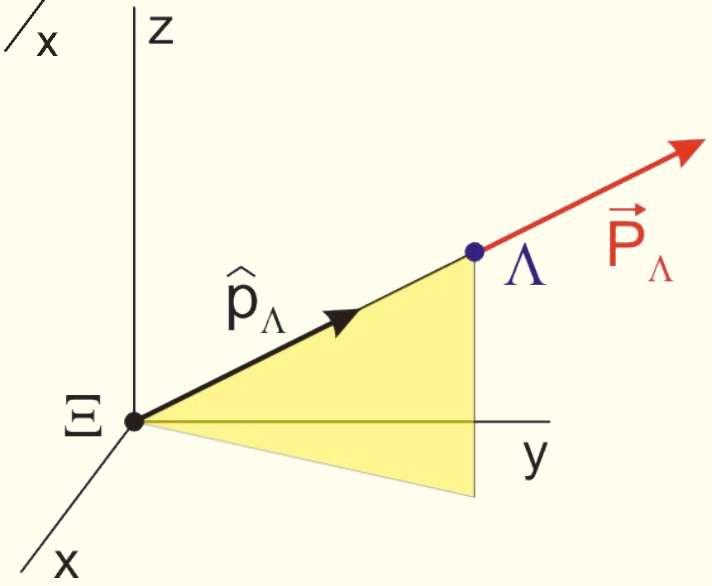
$$\vec{P}_\Lambda = \frac{(\alpha_\Xi + \vec{P}_\Xi \cdot \hat{p}_\Lambda)\hat{p}_\Lambda + \beta_\Xi(\vec{P}_\Xi \times \hat{p}_\Lambda) + \gamma_\Xi(\hat{p}_\Lambda \times (\vec{P}_\Xi \times \hat{p}_\Lambda))}{1 + \alpha_\Xi \vec{P}_\Xi \cdot \hat{p}_\Lambda}$$

$$\alpha = \frac{2\,\mathrm{Re}(S^* P)}{|S|^2 + |P^2|} \qquad \beta = \frac{2\,\mathrm{Im}(S^* P)}{|S|^2 + |P|^2} \qquad \gamma = \frac{|S|^2 - |P|^2}{|S|^2 + |P|^2}$$

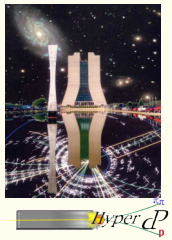


⇒ If parent Ξ hyperon is unpolarized

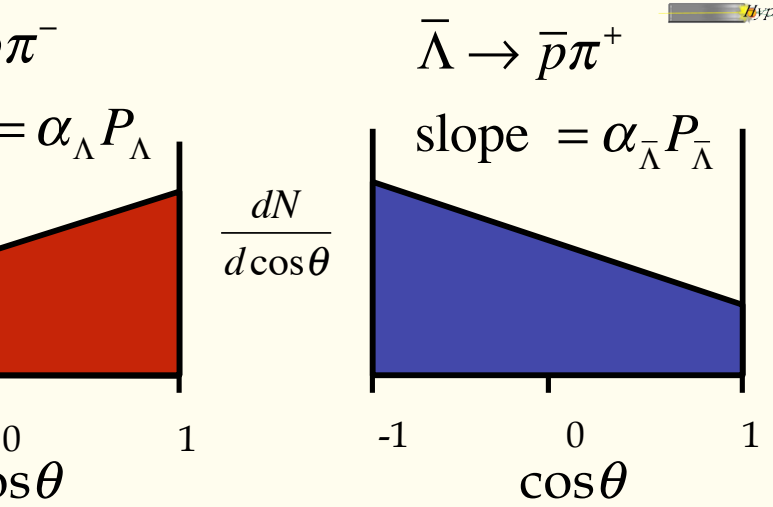
$$\vec{P}_\Lambda = \alpha_\Xi \hat{p}_\Lambda$$



CP Signatures in Hyperon Decays



$$A = \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}}$$



$\Lambda \to p\pi^-$ slope $= \alpha_\Lambda P_\Lambda$

$\bar{\Lambda} \to \bar{p}\pi^+$ slope $= \alpha_{\bar{\Lambda}} P_{\bar{\Lambda}}$

$\frac{dN}{d\cos\theta}$ $\frac{dN}{d\cos\theta}$

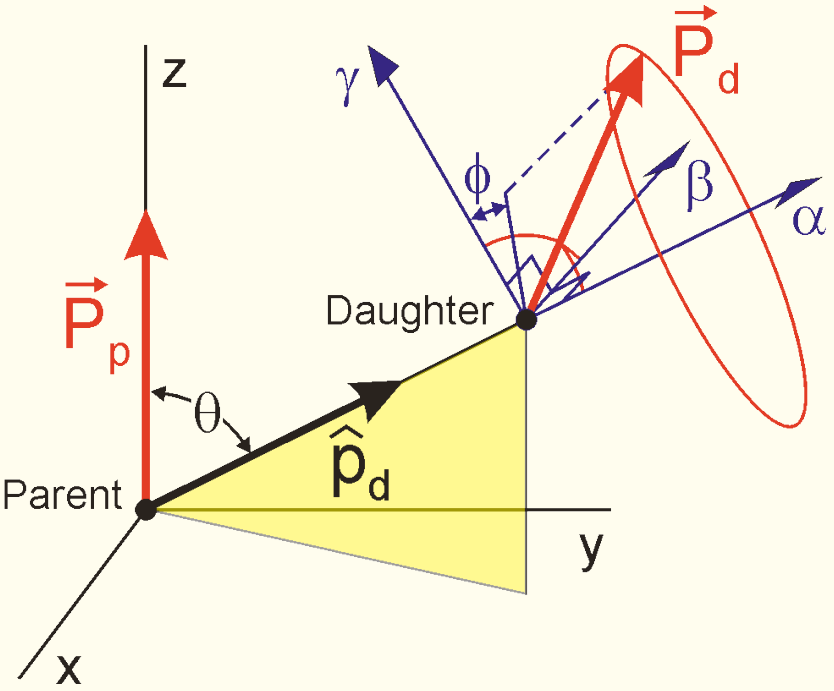
-1 0 1 $\cos\theta$ -1 0 1 $\cos\theta$

- Need parent hyperons with known polarization.

$$B = \frac{\beta + \bar{\beta}}{\beta - \bar{\beta}}$$

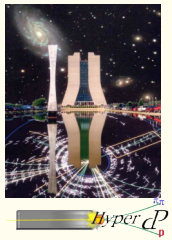
Most precisely known:

$\beta_\Xi = -0.037 \pm 0.015$



- Expected to be larger than *A*
- Difficult experimentally to measure:
  - Need to measure polarization of daughter from polarized parent
  - β is very small

CP Signatures in Hyperon Decays



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- Expected to be larger than A
- Difficult experimentally to measure:
  - Need to measure polarization of daughter from polarized parent
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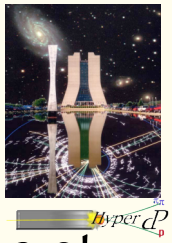
Decay rate asymmetry:

$$\Delta = \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}}$$

- Expected to be very small
- Difficult to measure absolute number of events

$A \Rightarrow$ Only parameter currently accessible by experiment

HyperCP method for Producing Λs of Known Polarization



We produce Λs of known polarization through unpolarized Ξ decays. Targeting at zero degrees insures that our Ξs are produced unpolarized

$$\Xi^- \to \Lambda\pi^- \qquad \bar{\Xi}^+ \to \bar{\Lambda}\pi^+$$

If the Ξ is produced unpolarized then the Λ is produced in a helicity state

$$\vec{P}_\Lambda = \underbrace{\alpha_\Xi \hat{p}_\Lambda}$$

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

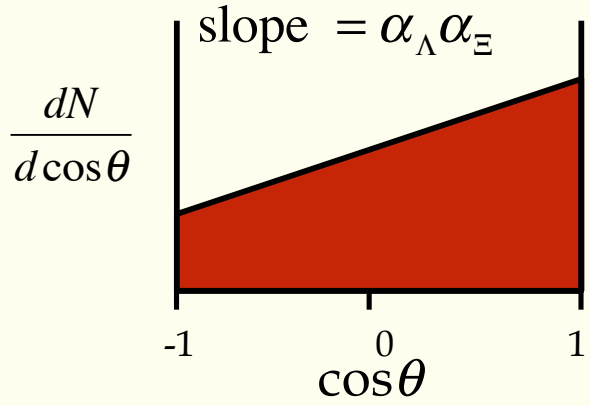
$$\vec{P}_{\bar{\Lambda}} = \underbrace{\alpha_{\bar{\Xi}} \hat{p}_{\bar{\Lambda}}}$$

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

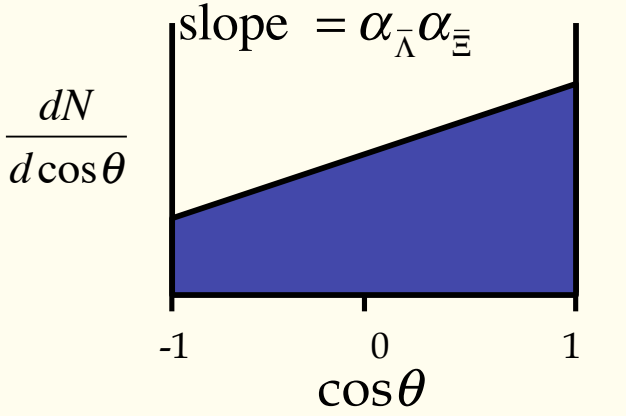
If CP is good the slopes of the proton and antiproton $\cos\theta$ distributions are identical

$$\alpha_\Xi \alpha_\Lambda = \alpha_{\bar{\Xi}} \alpha_{\bar{\Lambda}}$$

$\Xi^- \to \Lambda\pi^- \to p\pi^-\pi^-$



$\bar{\Xi}^+ \to \bar{\Lambda}\pi^+ \to \bar{p}\pi^+\pi^+$



Sensitivity to *CP* in both Ξ and Λ decays

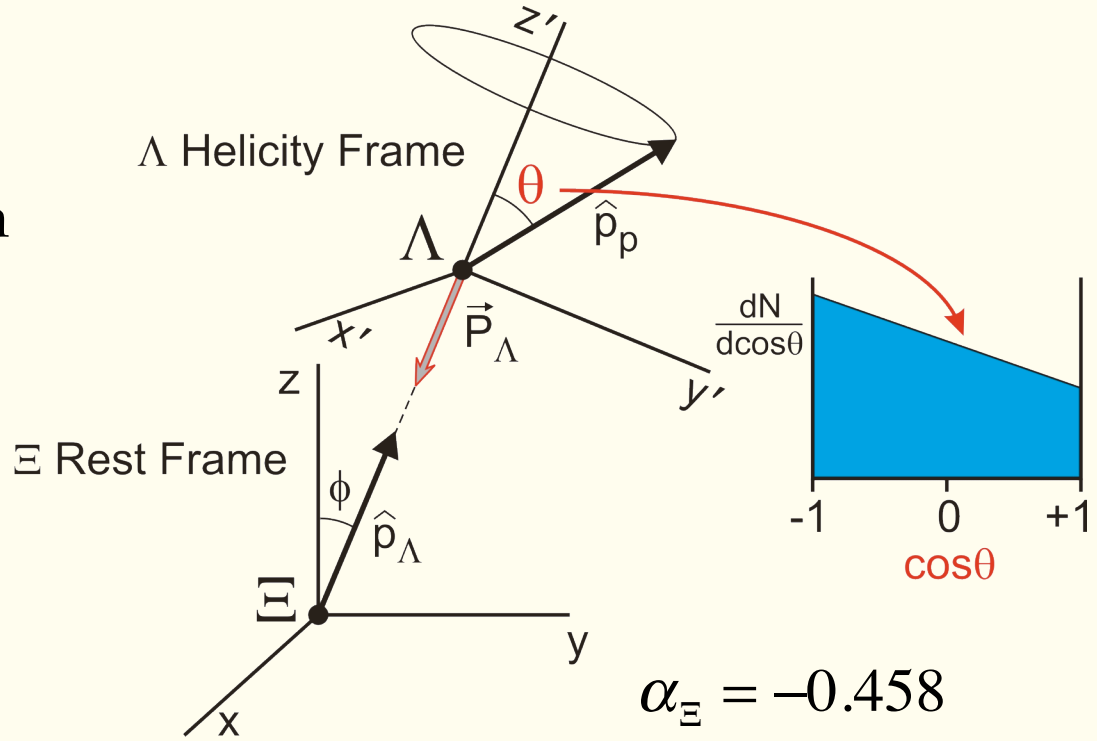
From the $\cos\theta$ distributions we seek to extract the asymmetry $A_{\Xi\Lambda}$

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

where,

$$\begin{cases} A_\Xi = \dfrac{\alpha_\Xi + \alpha_{\bar{\Xi}}}{\alpha_\Xi - \alpha_{\bar{\Xi}}} \\ A_\Lambda = \dfrac{\alpha_\Lambda + \alpha_{\bar{\Lambda}}}{\alpha_\Lambda - \alpha_{\bar{\Lambda}}} \end{cases}$$

The slope is measured in the Λ rest frame where the orientation of the polar axis is defined by the Λ momentum in the Ξ rest frame

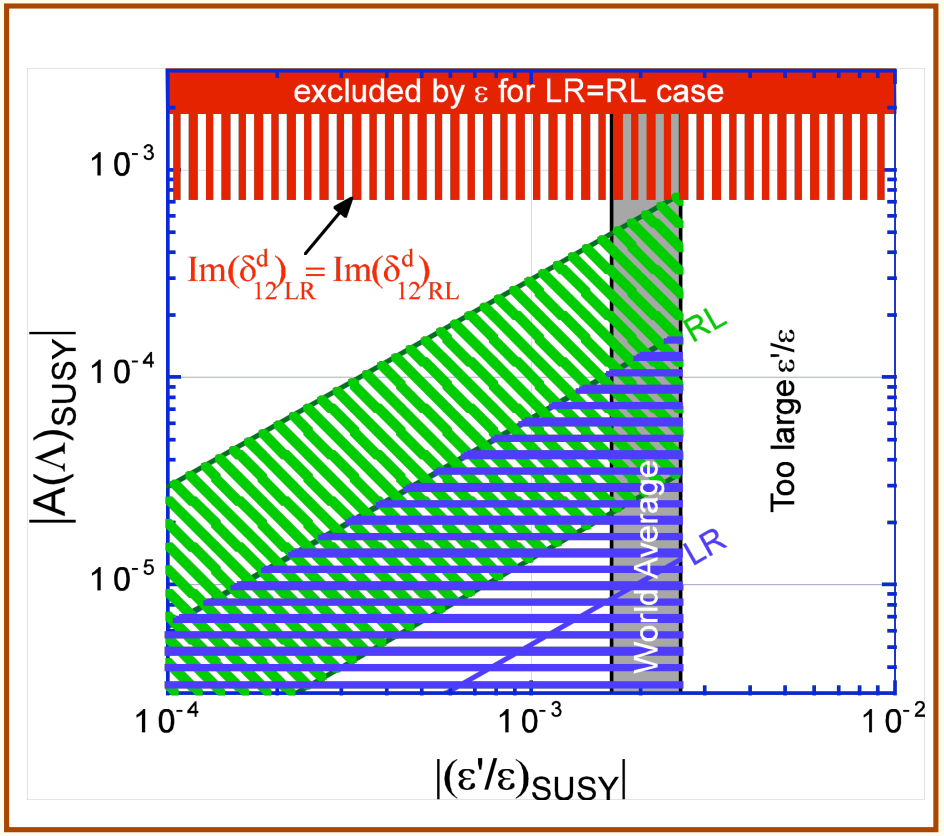


$\alpha_\Xi = -0.458$

Theoretical Predictions for *A*

- SM Predictions are small
  - SM model predictions have fallen steadily since 1991.
  - Recently: $|A_\Xi + A_\Lambda| \leq 0.5 \times 10^{-4}$ (Tandean & Valencia 2003)

- BSM theories allow for larger asymmetries
  - Tandean (2004) shows that the upper bound on $A_\Xi + A_\Lambda$ from ε'/ε and ε measurements is $O(10^{-2})$
  - Some SUSY models which do not generate ε'/ε can lead to A_Λ of $O(10^{-3})$



He, Pakvasa, Valencia 2000

Any CP-violation signal will almost certainly be evidence of new physics

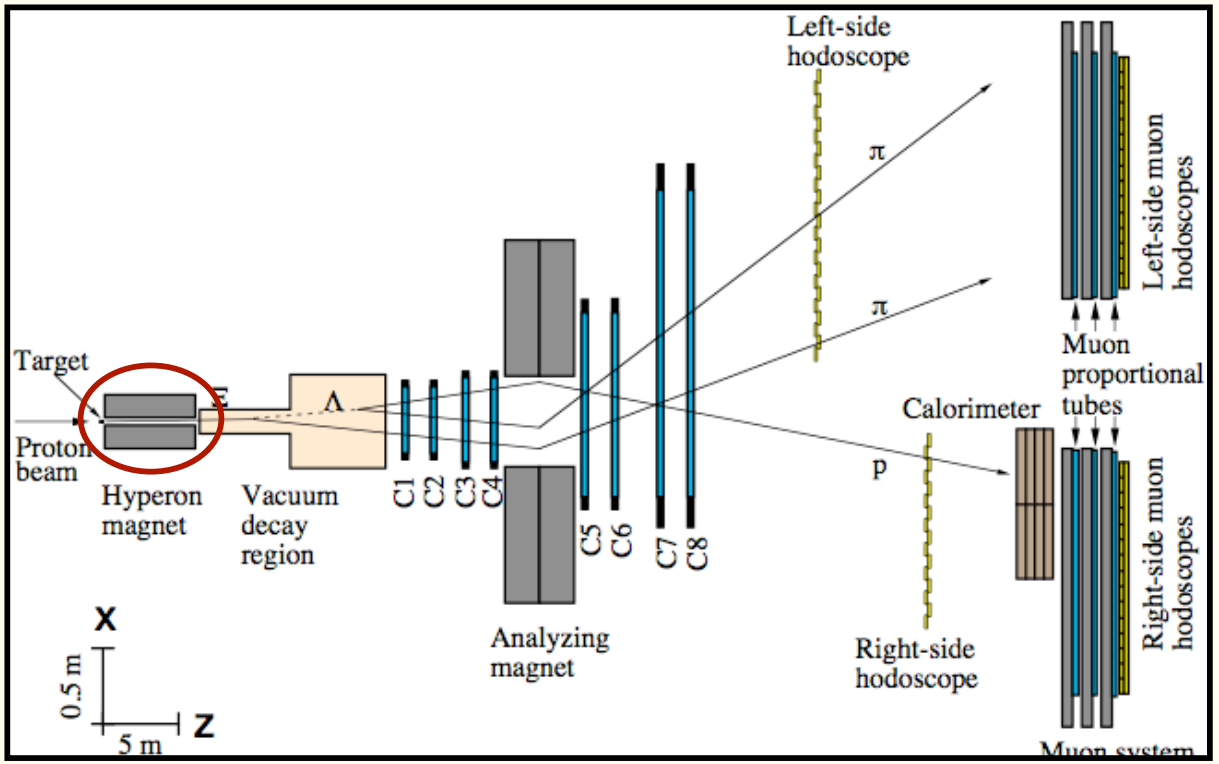
Previous Measurements

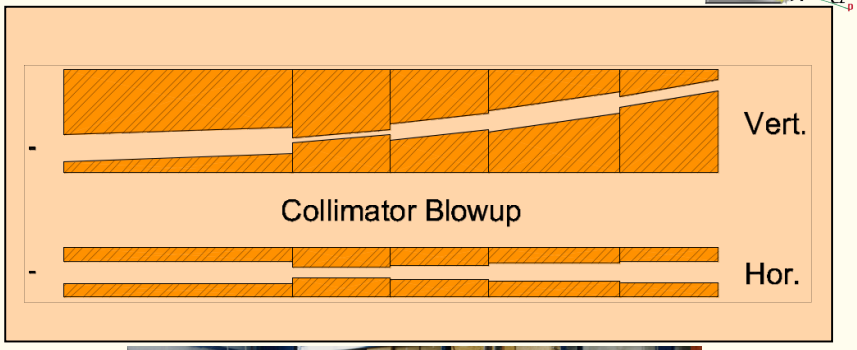
Experiment	Method	A_Λ
R608 at ISR	$pp \to \Lambda X,\ p\bar{p} \to \bar{\Lambda} X$	-0.02 ± 0.14
DM2 at Orsay	$e^+e^- \to J/\Psi \to \Lambda\bar{\Lambda}$	0.01 ± 0.10
PS185 at LEAR	$p\bar{p} \to \Lambda\bar{\Lambda}$	-0.013 ± 0.022

Experiment	Method	$A_{\Xi\Lambda}$
E756	$\Xi \to \Lambda\pi \to p\pi\ \pi$	0.012 ± 0.014
Hyper*CP*	$\Xi \to \Lambda\pi \to p\pi\ \pi$	0.00000 ± 0.00067

The Hyper*CP* Experiment

Designed for *CP* Violation Searches





Charged Hyperon Beam

- 800 GeV/c protons on 2 mm x 2 mm target
- Secondary beam: 167 GeV/c
- Alternate -/+ beam polarity

The Hyper*CP* Experiment

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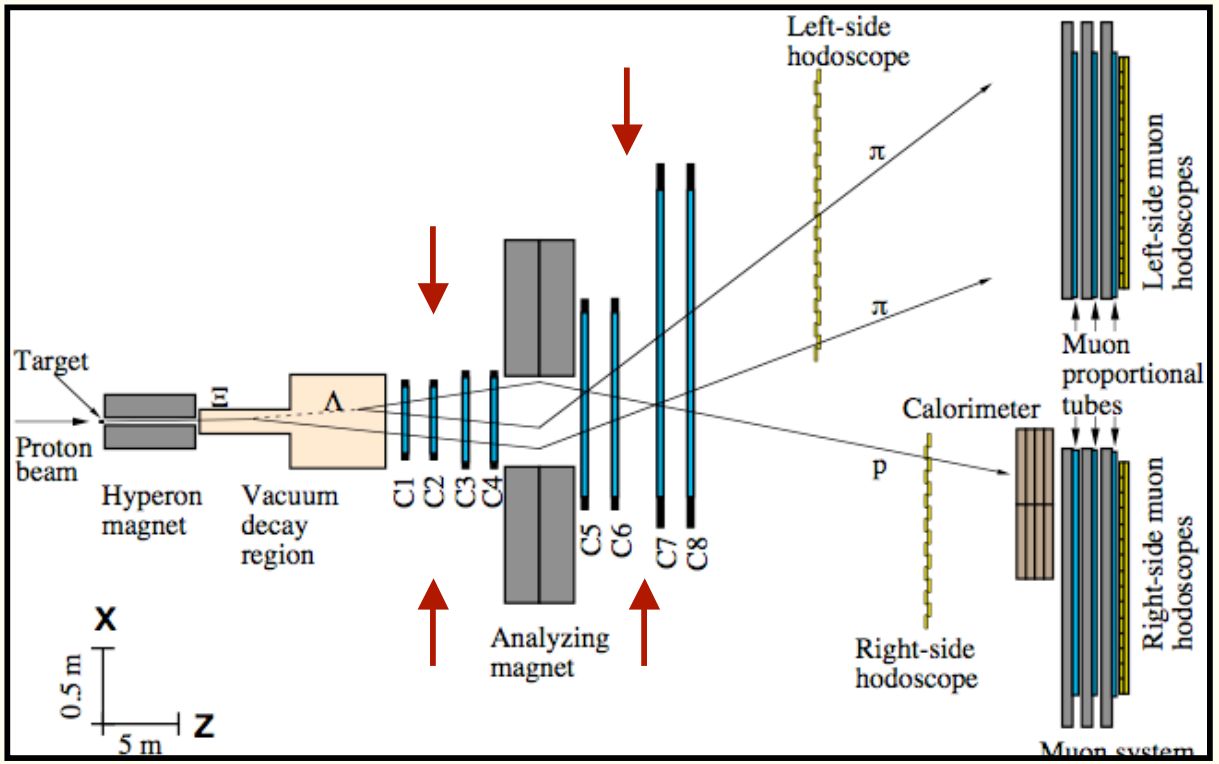

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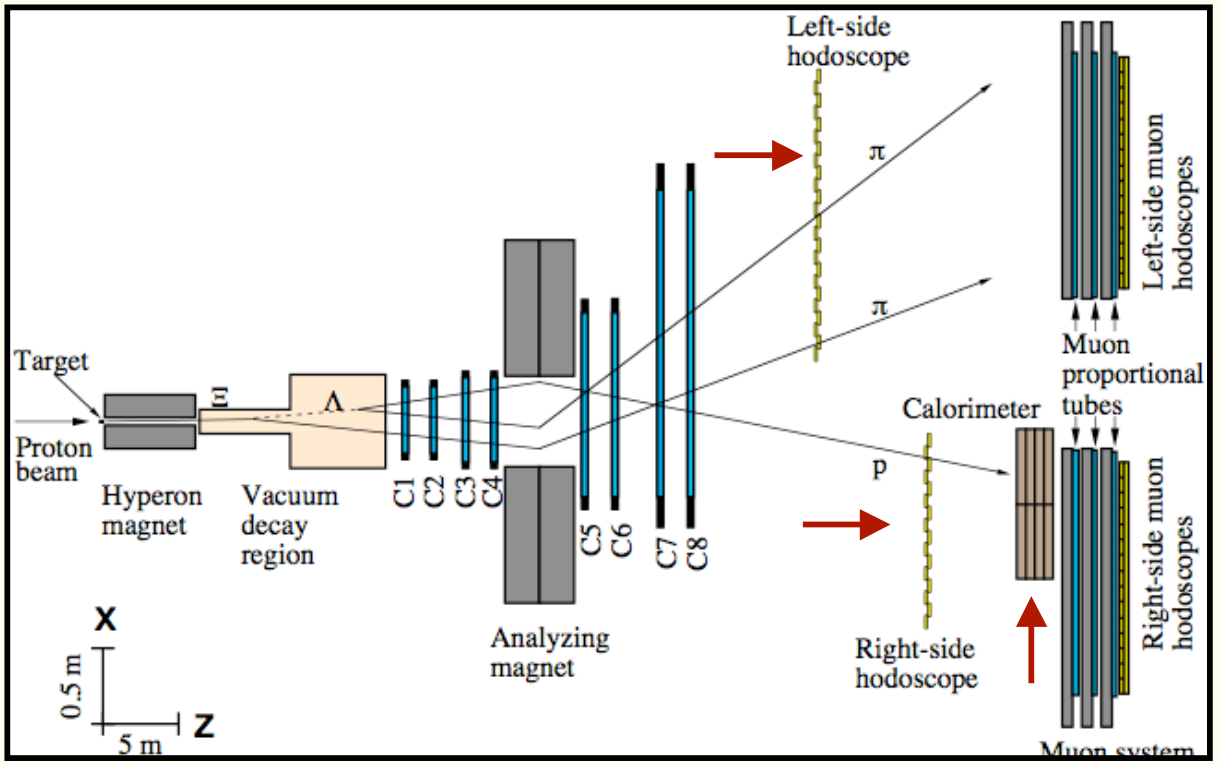
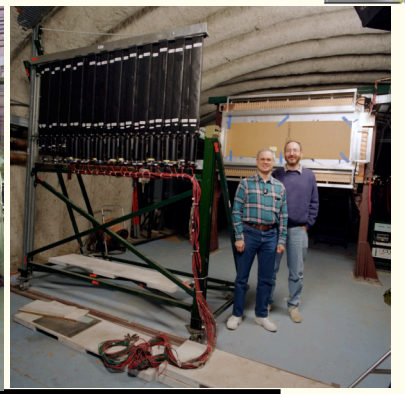
Spectrometer Specifications

- 8 narrow pitch MWPCs

The Hyper*CP* Experiment

Designed for *CP* Violation Searches





Charged Hyperon Beam

- 800 GeV/c protons on 2 mm x 2 mm target
- Secondary beam: 167 GeV/c
- Alternate -/+ beam polarity

Spectrometer Specifications

- 8 narrow pitch MWPCs
- Simple Ξ trigger
  - Two hodoscopes
  - Fast calorimeter
- 100k events/s to tape

Extracting the *CP* Asymmetry

- The $\cos\theta$ distributions for the proton and antiproton are

$$\frac{dN_-}{d\cos\theta} = A_- \frac{N_-}{2}(1+\alpha_\Lambda\alpha_\Xi\cos\theta_-)$$

$$\frac{dN_+}{d\cos\theta} = A_+ \frac{N_+}{2}(1+\alpha_{\bar\Lambda}\alpha_{\bar\Xi}\cos\theta_+)$$

- We fit the ratio to

$$R(\cos\theta,\delta) = \frac{N_-}{N_+}\frac{(1+\alpha_\Xi\alpha_\Lambda\cos\theta)}{1+(\alpha_\Xi\alpha_\Lambda-\delta)\cos\theta}$$

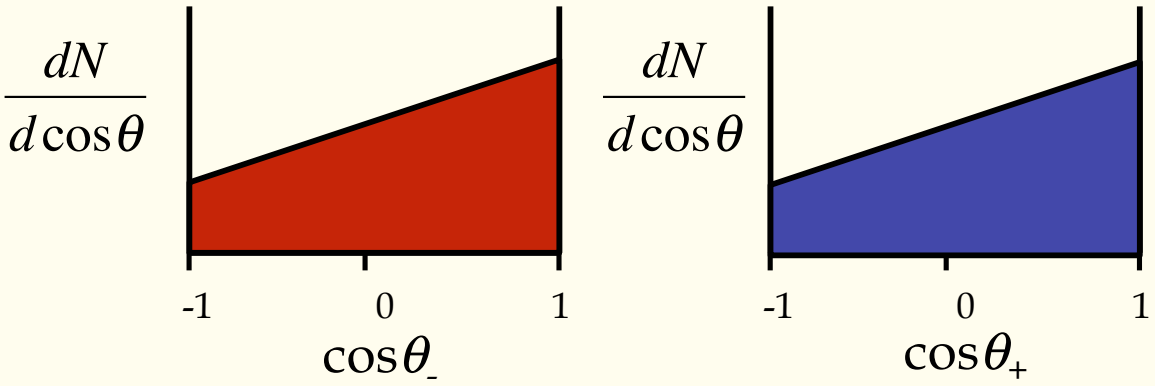
$$\delta \equiv \alpha_\Xi\alpha_\Lambda - \alpha_{\bar\Xi}\alpha_{\bar\Lambda}$$

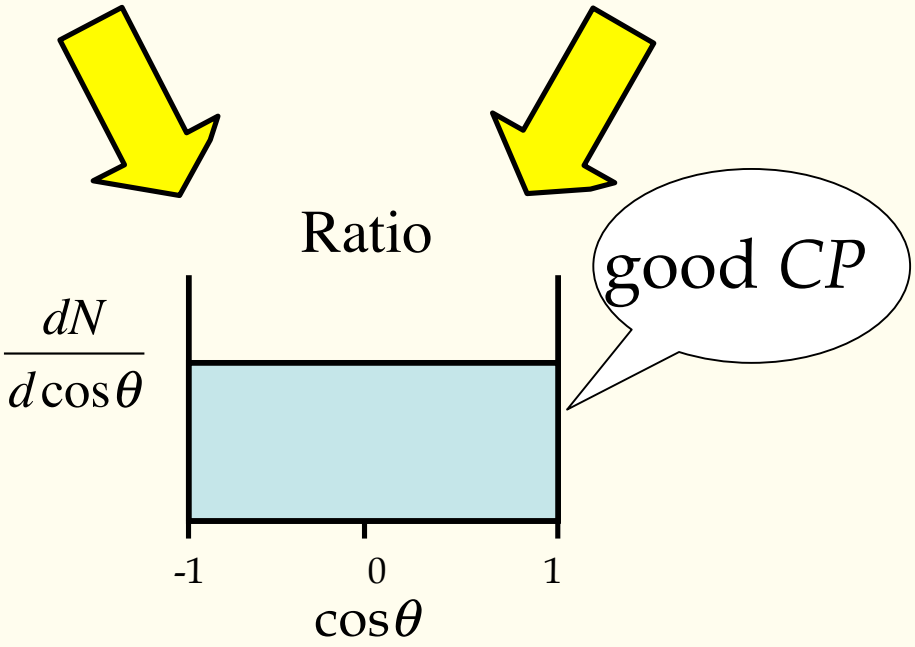
- Then we extract the asymmetry

$$A_{\Xi\Lambda} = \frac{\delta}{\alpha_\Xi\alpha_\Lambda + \alpha_{\bar\Xi}\alpha_{\bar\Lambda}} \approx \frac{\delta}{2\alpha_\Xi\alpha_\Lambda} = -1.70\delta$$

$\Xi^- \to \Lambda\pi^- \to p\pi^-\pi^-$ slope $= \alpha_\Lambda\alpha_\Xi$

$\bar\Xi^+ \to \bar\Lambda\pi^+ \to \bar p\pi^+\pi^+$ slope $= \alpha_{\bar\Lambda}\alpha_{\bar\Xi}$





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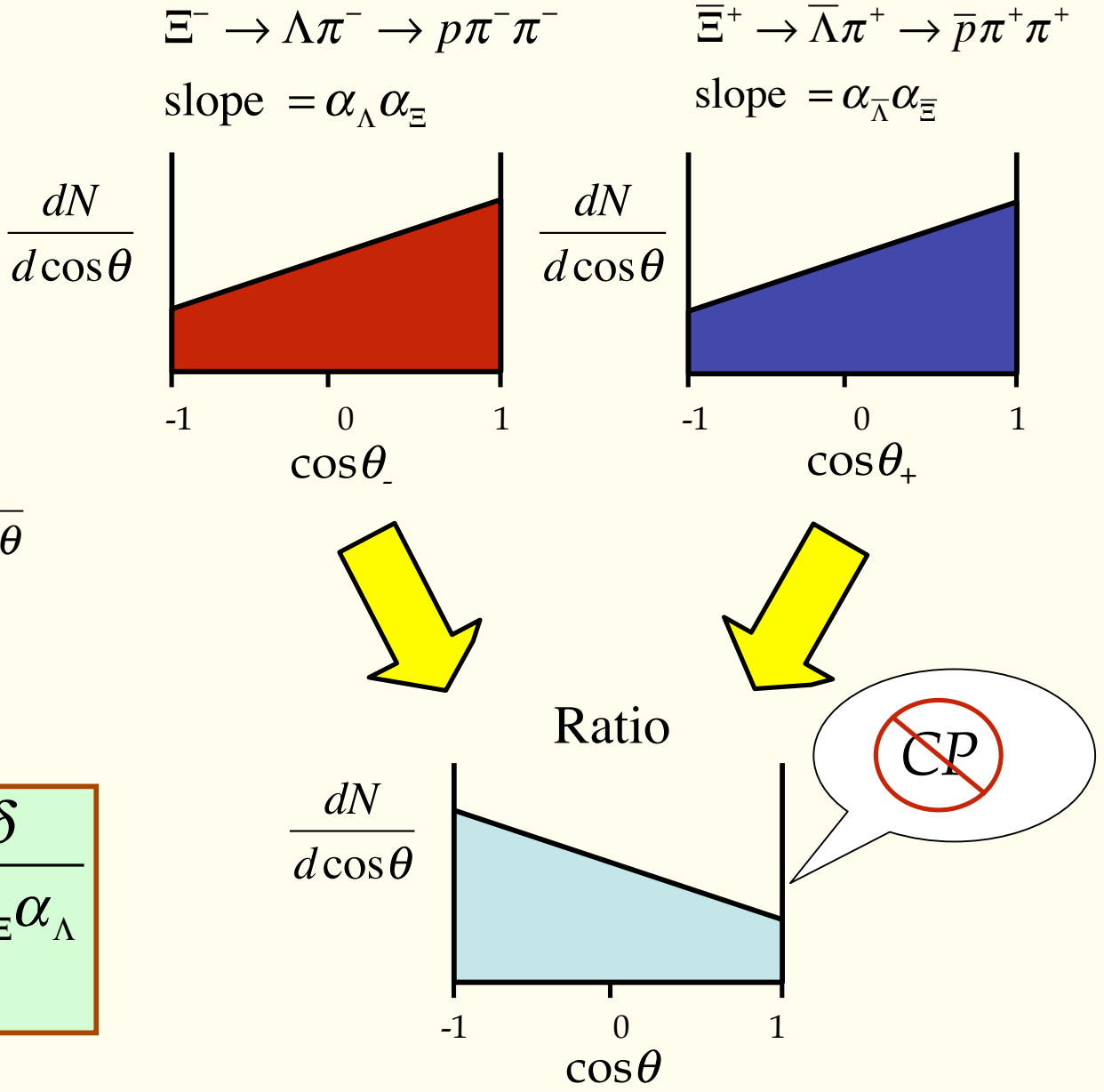
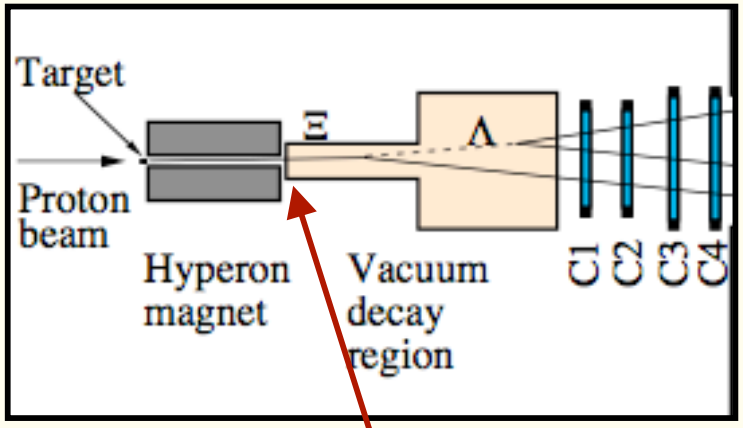


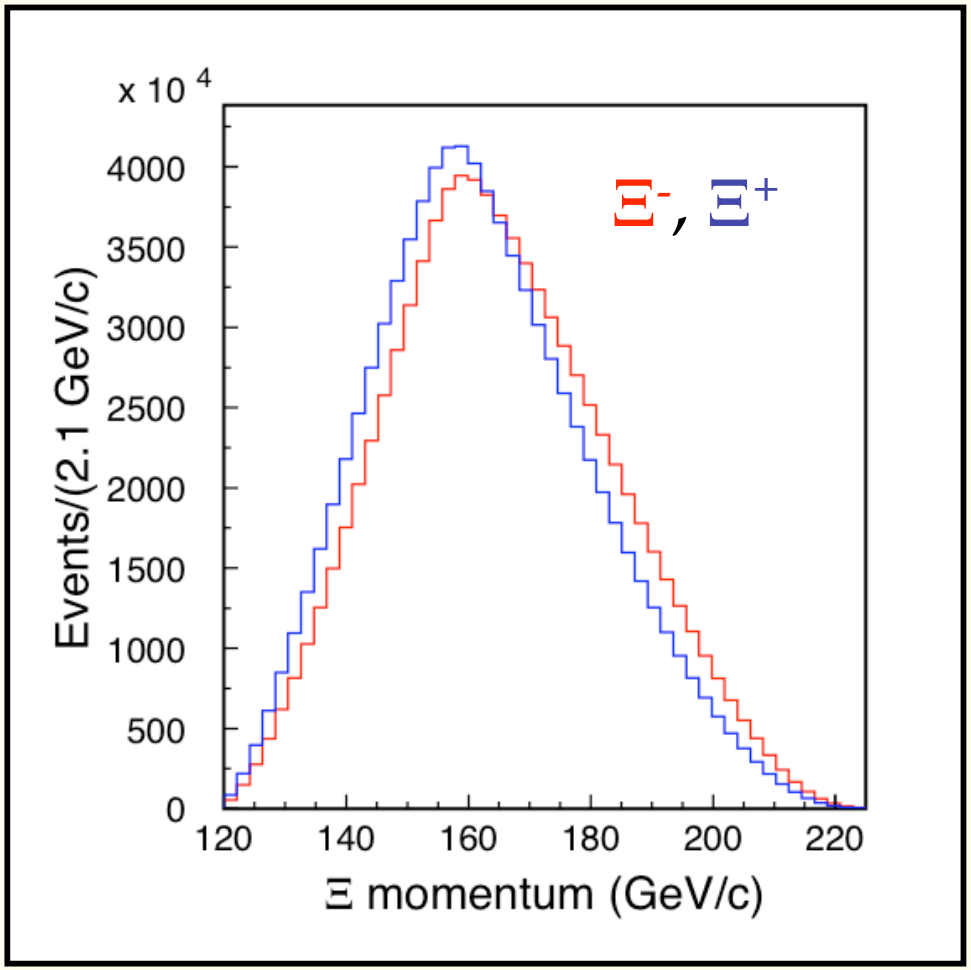
Accounting for Acceptance Differences

Problem: Acceptance for Ξ^- and Ξ^+ decays not equal due to different production dynamics

Solution: Weight the reconstructed Ξ^- and Ξ^+ position and momentum distributions and force them to be identical



Ξ^- & Ξ^+ distributions weighted at the exit of the Hyperon Magnet



50 Bins for Ξ momentum

50 bins for Ξ *y* position and slope

20 bins for Ξ *x* position and slope

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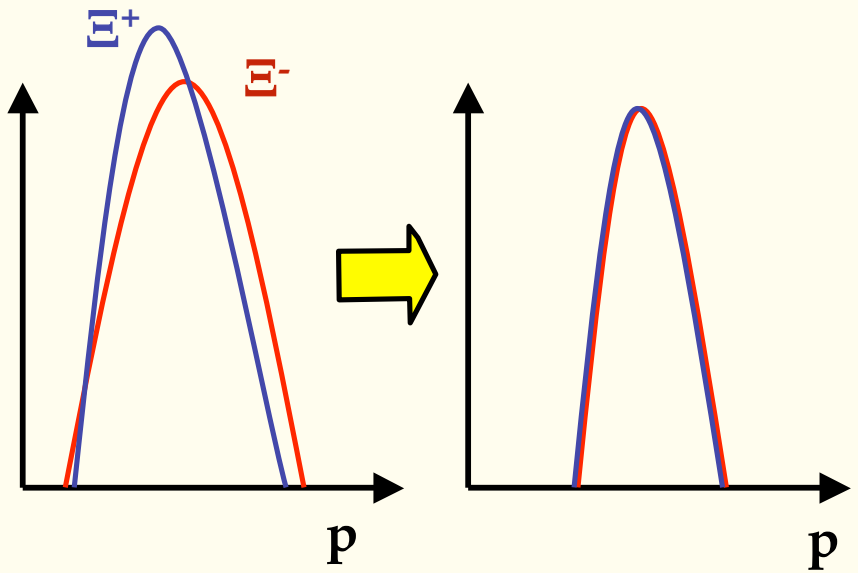

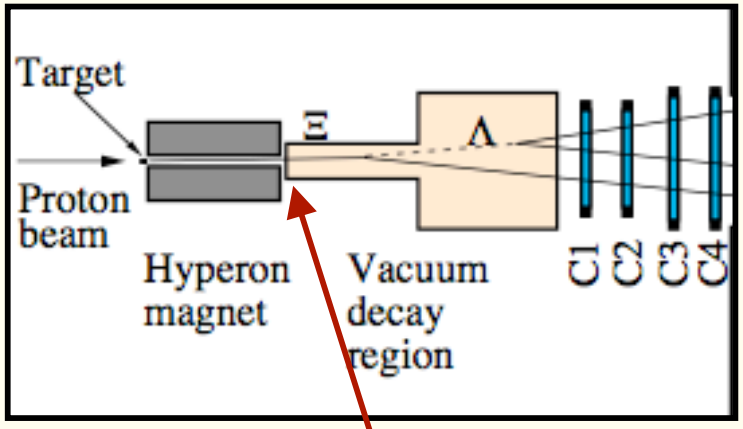

Ξ^- & Ξ^+ distributions weighted at the exit of the Hyperon Magnet

Weighted parameters:

Variable	# Cells	Cell Size
Ξ momentum	50	2.1 GeV/c
y position at collimator	50	0.026 cm
y slope at collimator	50	0.16 mrad
x position at collimator	20	0.105 cm
x slope at collimator	20	0.20 mrad

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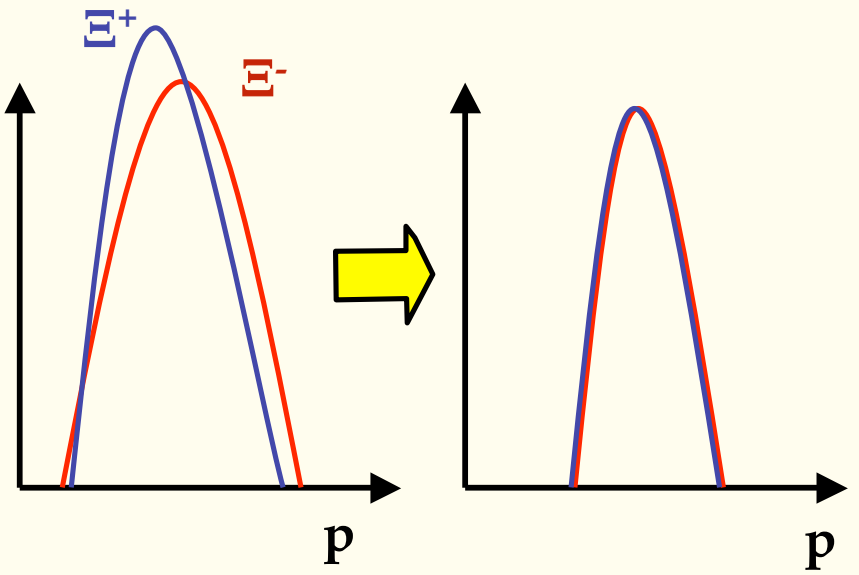

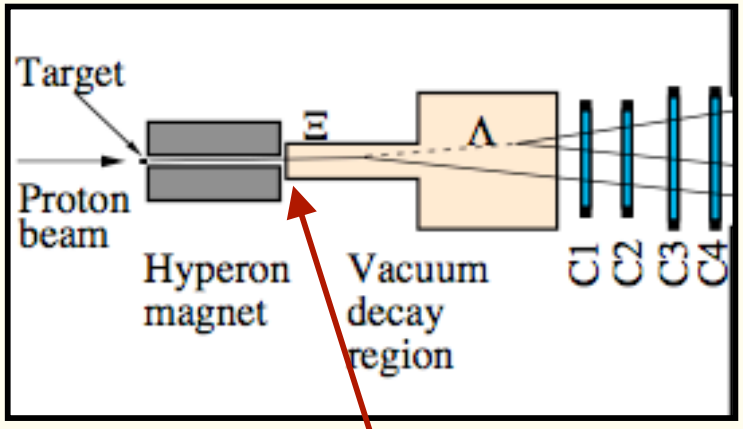

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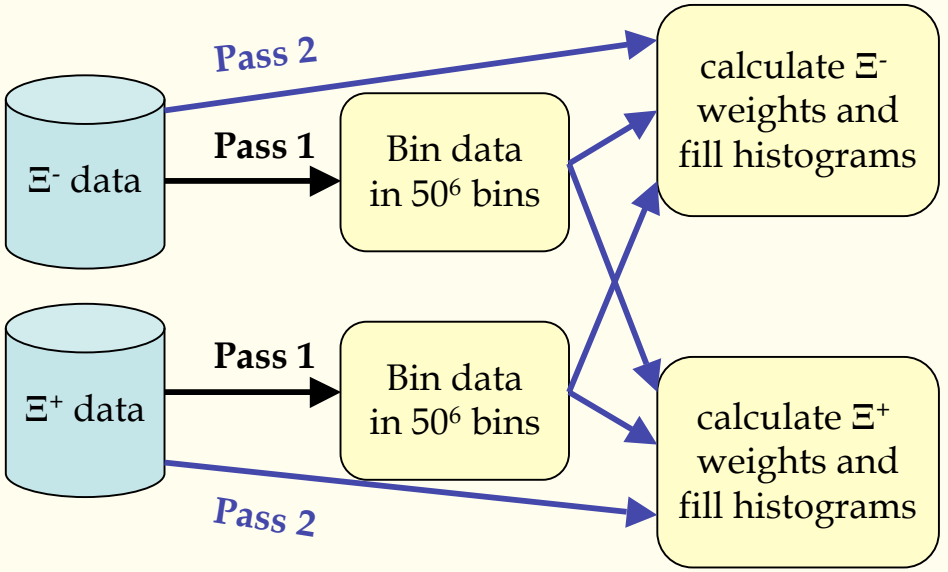


Monte Carlo Verification

Monte Carlo used only to

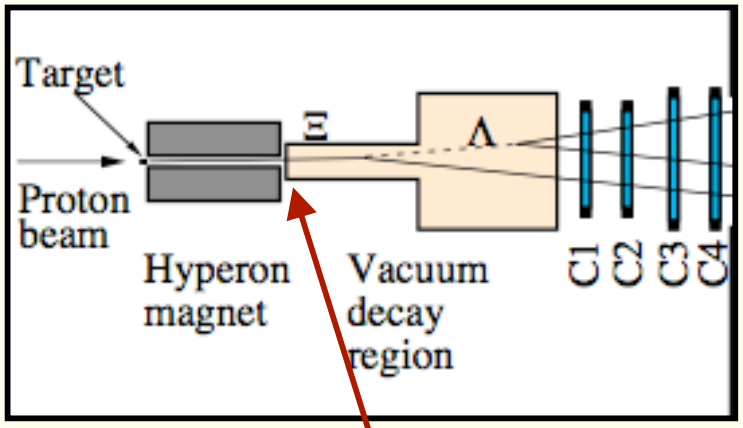
1) Check that the weighting technique does not "wash out" the asymmetry

2) Some systematic error studies

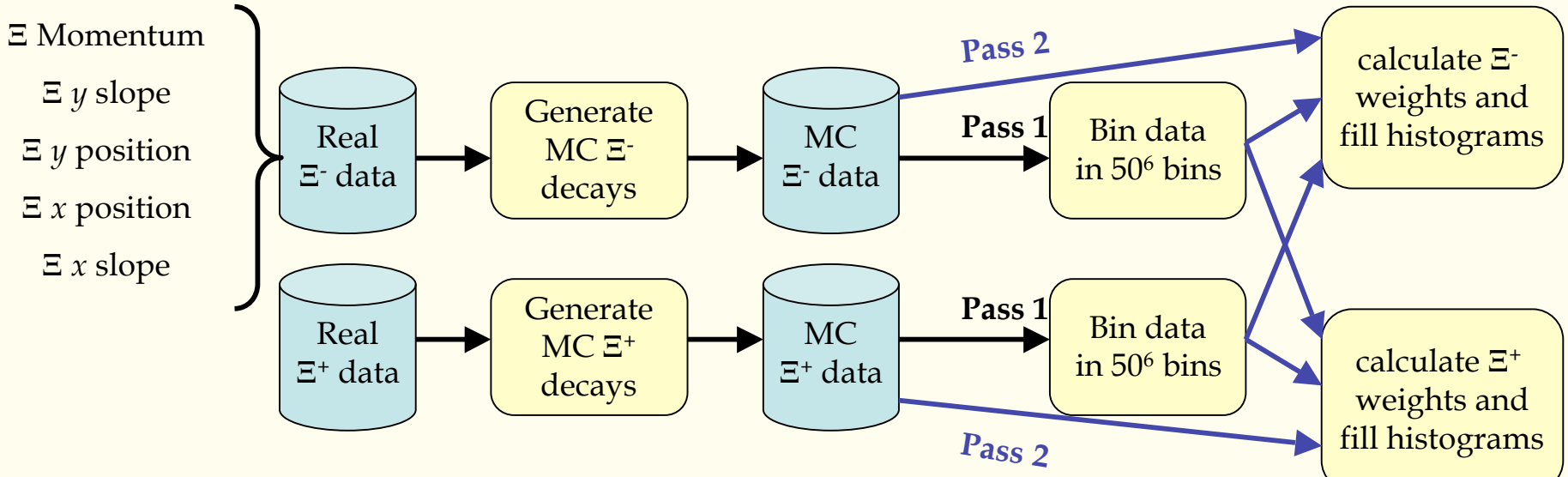
Problem: How to generate 10 billion decays?

Solution: Use a "hybrid" MC

- Use Ξ^- & Ξ^+ data to seed the simulation
- Start simulation at the collimator exit



Real Ξ^- & Ξ^+ distributions from the collimator exit used to seed the simulation



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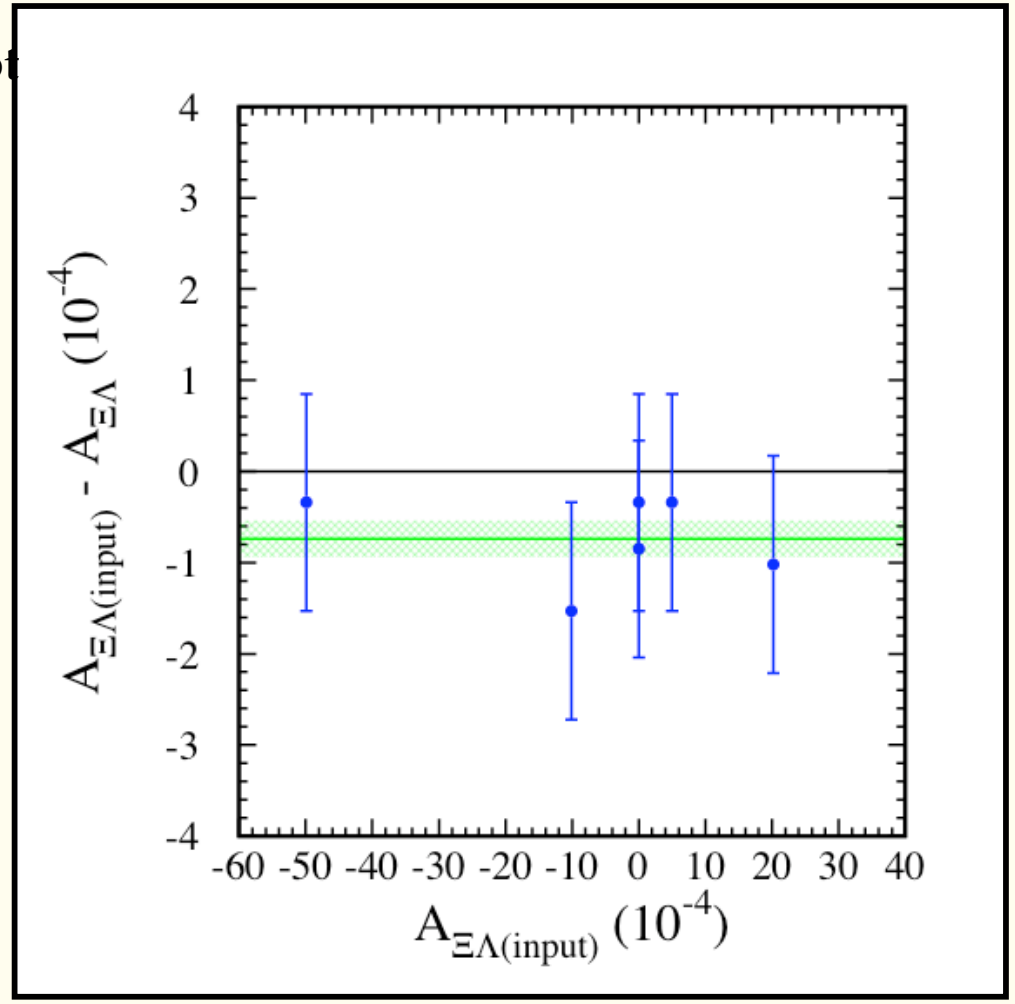
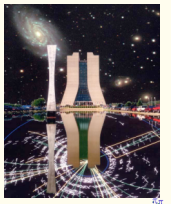


$$\Delta A_{\Xi\Lambda} = (-0.74 \pm 0.2) \times 10^{-4}$$

The technique successfully recovers input asymmetries (with a slight bias compared to the statistical error)

Full Dataset Raw Result (Preliminary)



860 million Ξ^- decays

230 million Ξ^+ decays

Ave. Ξ^- bin occupancy: 795 Events/bin

Ave. Ξ^+ bin occupancy: 274 Events/bin

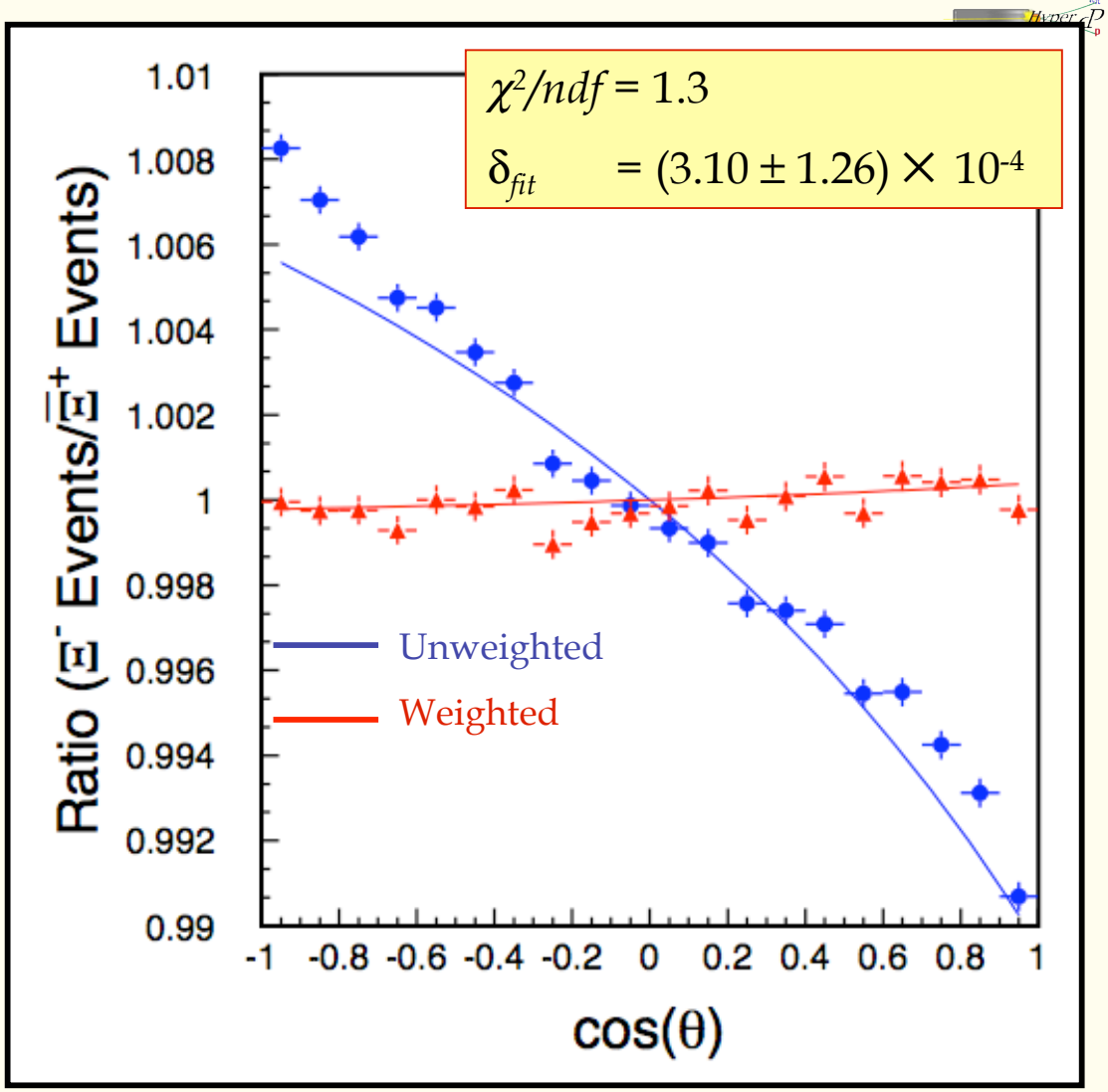
Fitting function:

$$R(\cos\theta,\delta) = \frac{N_-}{N_+}\frac{(1+\alpha_\Xi\alpha_\Lambda\cos\theta)}{1+(\alpha_\Xi\alpha_\Lambda-\delta)\cos\theta}$$

$$\delta \equiv \alpha_\Xi\alpha_\Lambda - \alpha_{\bar{\Xi}}\alpha_{\bar{\Lambda}}$$

$$A_{\Xi\Lambda} = (-5.27 \pm 2.14)\times 10^{-4}$$

- Hodoscope efficiency correction
- No acceptance corrections
- No background subtraction



Prior to the fit, the Ξ^- and Ξ^+ $\cos\theta$ distributions were normalized

Biases Controlled to the 10^{-4} Level

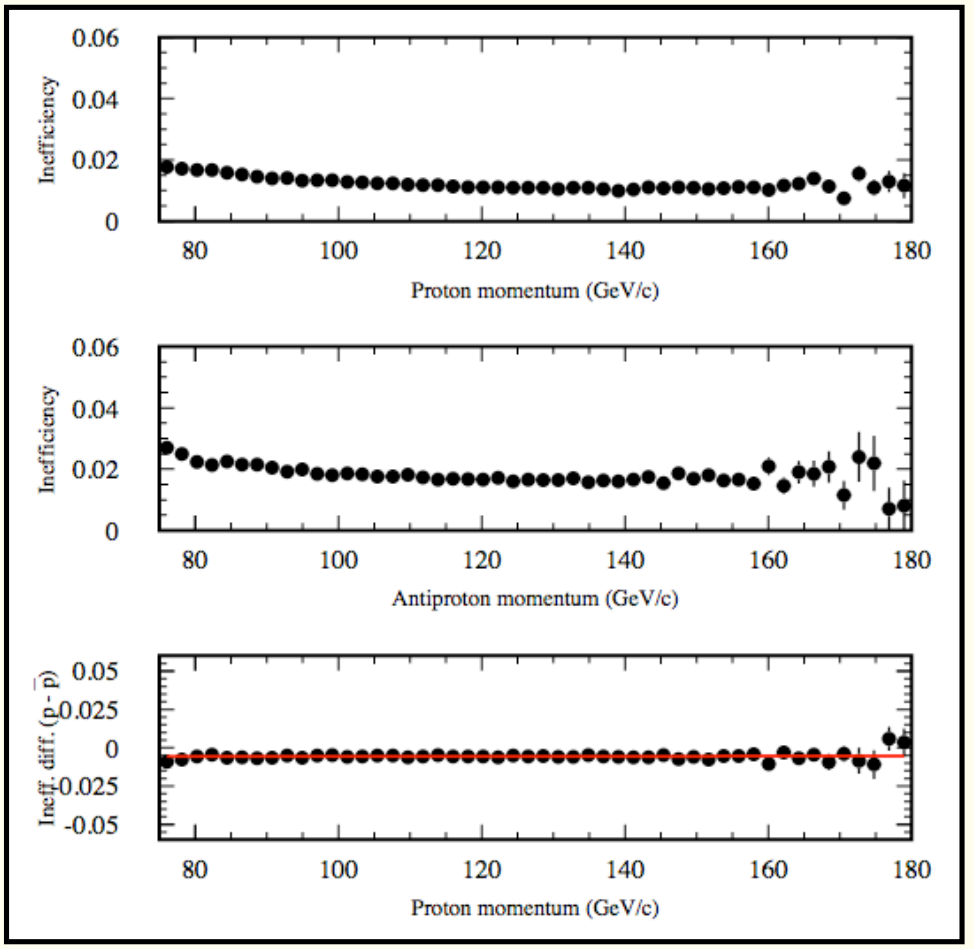
How is this done?

1) Same spectrometer was used for Ξ^- and Ξ^+ $\cos\theta$ measurements.
   - Detector efficiency differences must have no temporal or momentum dependencies

Calorimeter inefficiency during Ξ^- running

Calorimeter inefficiency during Ξ^+ running

Calorimeter inefficiency difference

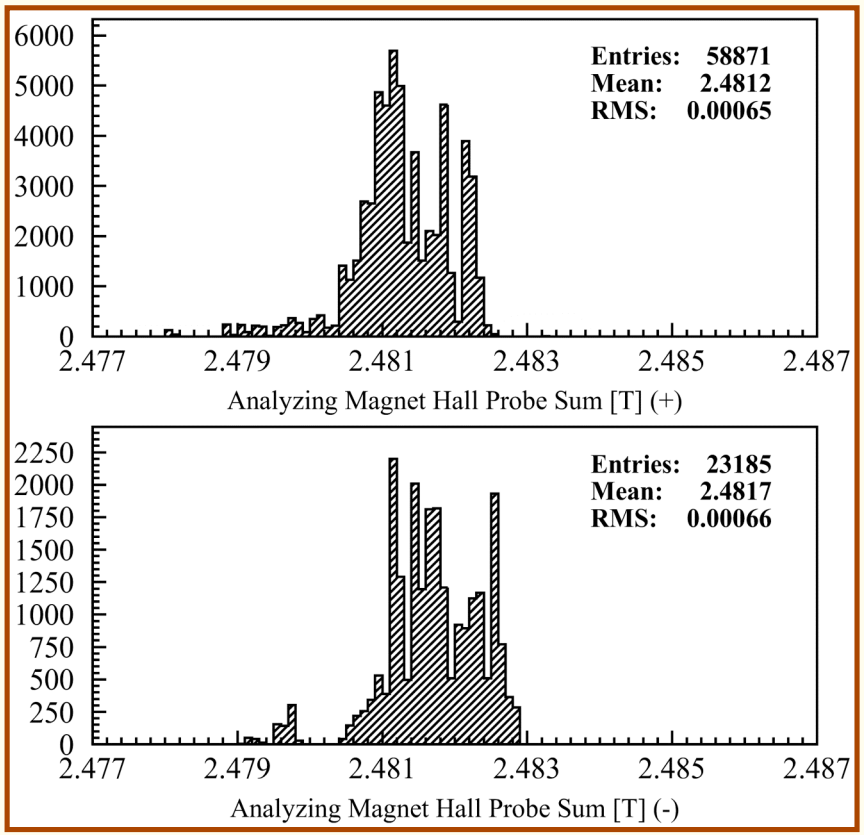


Biases Controlled to the 10^{-4} Level

How is this done?

1) Same spectrometer was used for Ξ^- and Ξ^+ $\cos\theta$ measurements.
   - Detector efficiency differences must have no temporal or momentum dependencies
   - Need to make sure that the Magnetic fields were exactly reversed

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

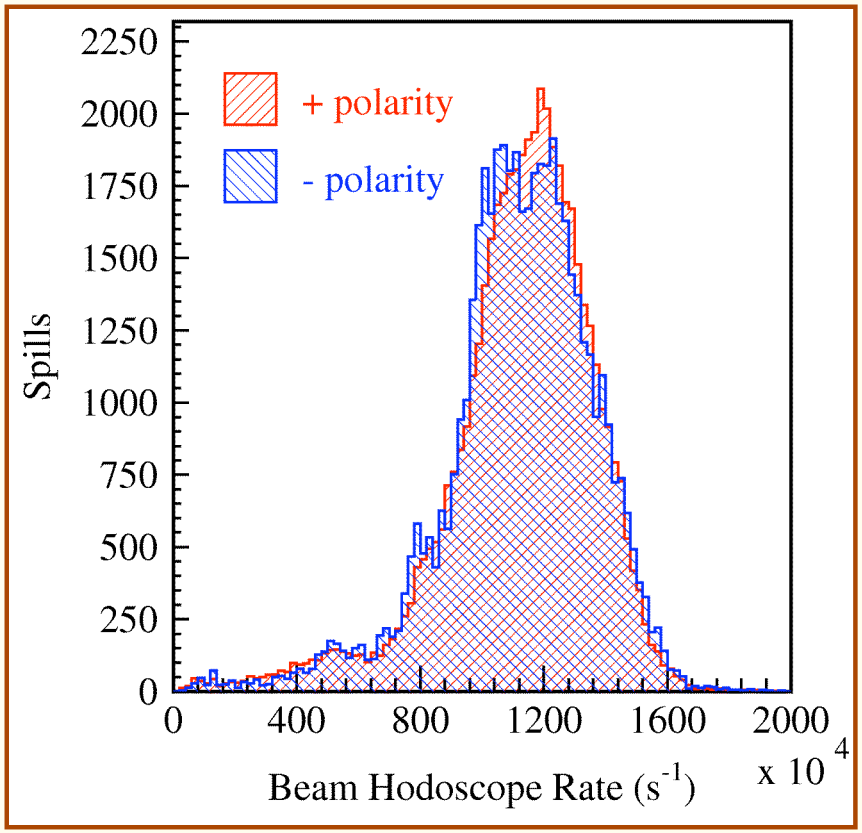


Biases Controlled to the 10^{-4} Level

How is this done?

1) Same spectrometer was used for Ξ^- and Ξ^+ $\cos\theta$ measurements.
   - Detector efficiency differences must have no temporal or momentum dependencies
   - Need to make sure that the Magnetic fields were exactly reversed
   - Targets changed to match rates for Ξ^- and Ξ^+

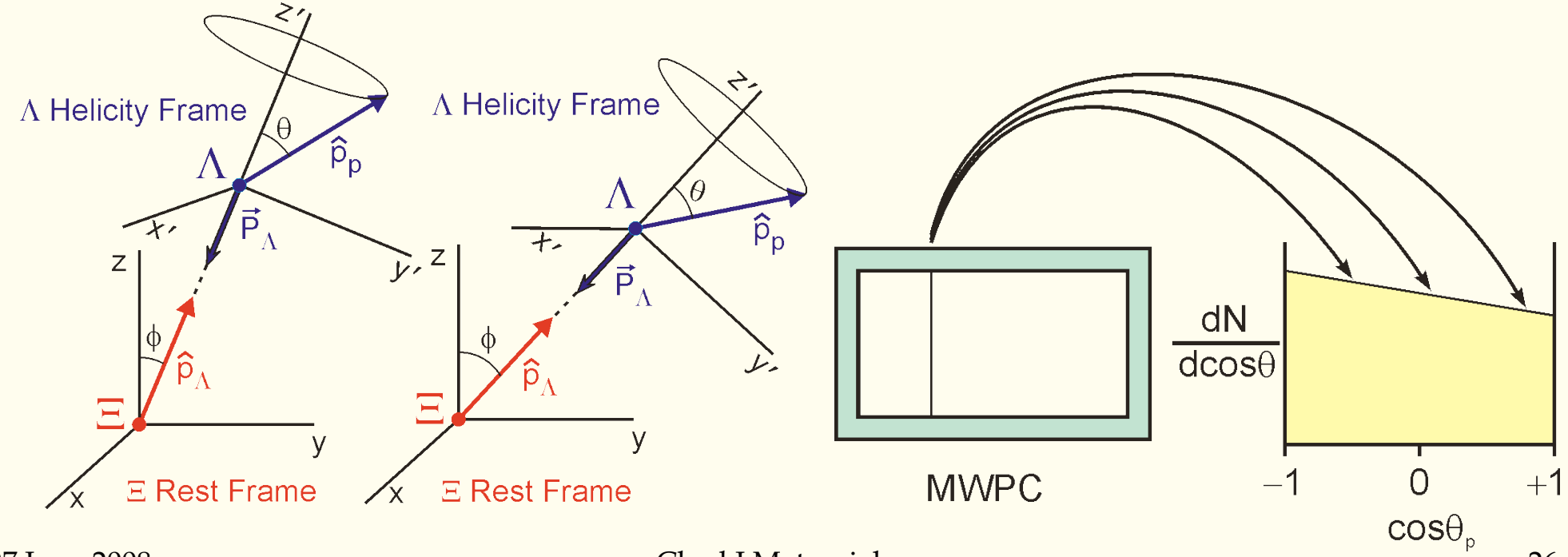
- Targets changed to equalize secondary beam rates:
  + polarity: 2 mm Cu
  – polarity: 6 mm Cu



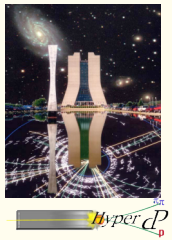
Biases Controlled to the 10^{-4} Level

How is this done?

1) Same spectrometer was used for Ξ^- and Ξ^+ $\cos\theta$ measurements.
   - Detector efficiency differences must have no temporal or momentum dependencies
   - Need to make sure that the Magnetic fields were exactly reversed
   - Targets changed to match rates for Ξ^- and Ξ^+
2) Measurement done in the Λ helicity frame: Localized acceptance differences do not map to any part of the $\cos\theta$ plot



Systematic Uncertainties



Systematic	Method	$\delta A_{\Xi\Lambda}$ (10^{-4})	
Calorimeter inefficiency uncertainty	Data	0.9	
Earth's magnetic field	HMC	0.9	← Upper limit
Particle/antiparticle interaction differences	MC	0.9	← Upper limit
Analyzing Magnets field uncertainties	Data	0.7	
Validation of analysis technique	HMC	0.7	
Hodoscope inefficiency correction	Data	TBD (<0.7)	← Upper limit
MWPC inefficiency uncertainty	HMC	0.4	
Momentum bin size	0.4	0.4	
Error on $\alpha_{\Xi}\alpha_{\Lambda}$	Data	0.007	
Background subtraction uncertainty	Data	0.003	
Total:	**Preliminary**	**2.1**	

All estimates are preliminary. Some are upper limits and are likely to be reduced while others may increase as additional studies are performed

Background Subtracted Asymmetry (Preliminary)

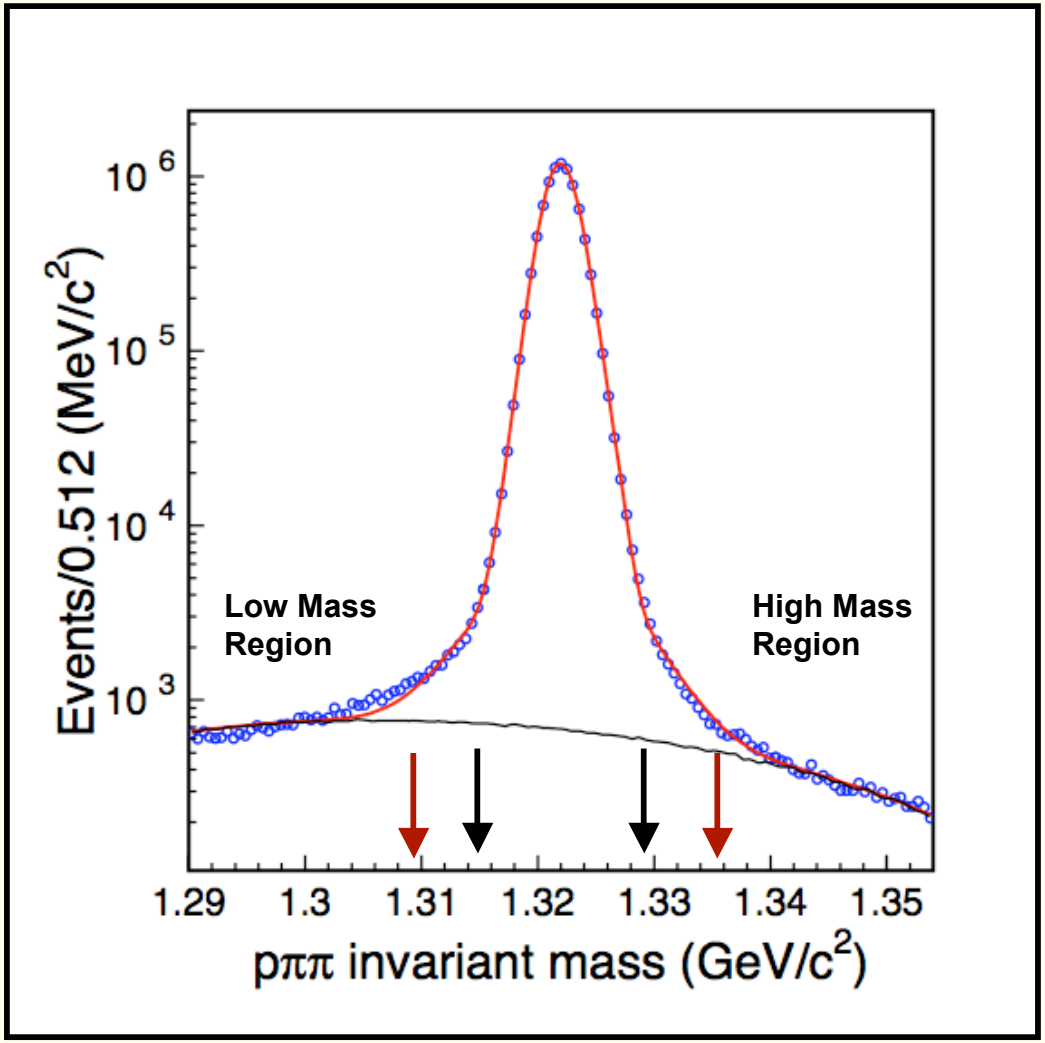
Corrections to the base result

1) Hodoscope efficiency correction
2) Background subtraction

$$\left.\frac{\Xi^-:\ 0.16\%}{\bar{\Xi}^+:\ 0.16\%}\right\} = 0.33\sigma \text{ shift}$$

$$A_{\Xi\Lambda} = \frac{\alpha_\Xi\alpha_\Lambda - \alpha_{\bar{\Xi}}\alpha_{\bar{\Lambda}}}{\alpha_\Xi\alpha_\Lambda + \alpha_{\bar{\Xi}}\alpha_{\bar{\Lambda}}} = [-6.0 \pm 2.1(stat) \pm 2.1(syst)] \times 10^{-4}$$

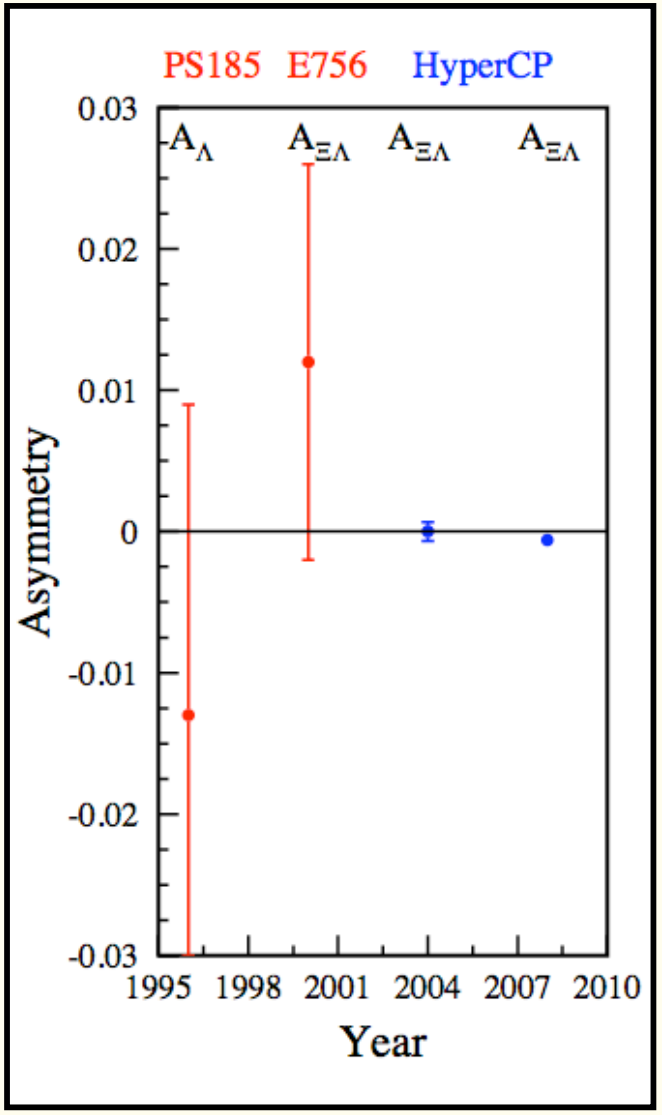
New high statistics result probes even further into the realm of new physics



Triple Gaussian + polynomial fit

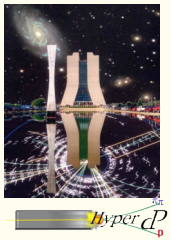
Conclusions

- Using the largest sample of hyperon decays ever amassed by a particle physics experiment, the Hyper*CP* collaboration is making precision searches for *CP* violation from exotic sources
- We measured the *CP* observable $A_{\Xi\Lambda}$ and present a new preliminary result with greater precision
  - $A_{\Xi\Lambda} = [0.0 \pm 5.1(stat) \pm 4.2(syst)] \times 10^{-4}$ (with a 15% of data)
  - **$A_{\Xi\Lambda} = [-6.0 \pm 2.1(stat) \pm 2.1(syst)] \times 10^{-4}$ (Preliminary with all data)**
- Hyper*CP* measurements are over 40X more precise than results from other experiments



Backup Slides

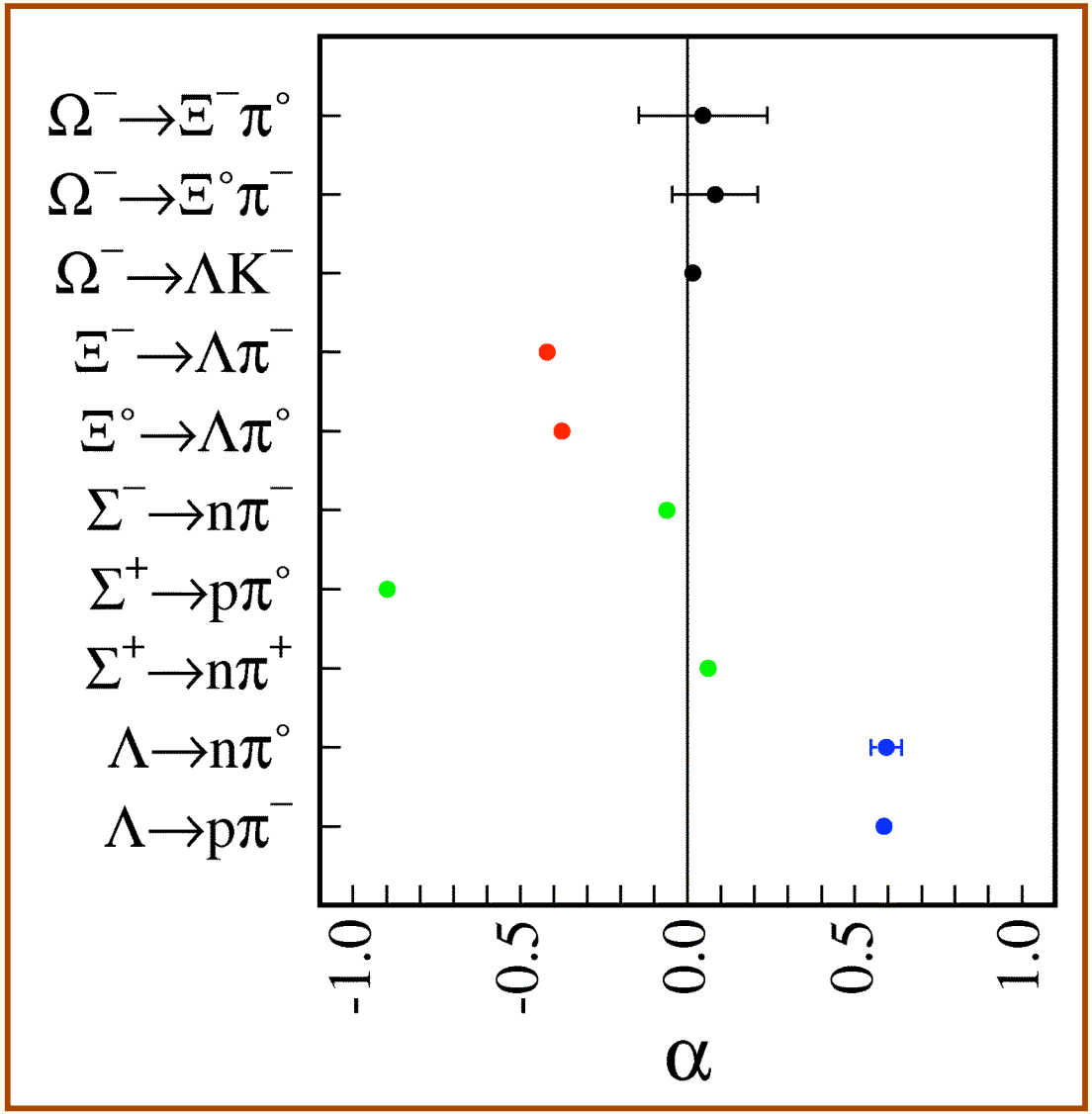
Non-leptonic Hyperon Decay Dynamics



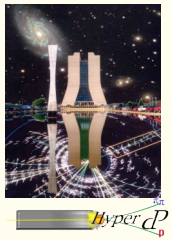
- Primarily two-body modes
- Daughter particle decay distributions are anisotropic
- Proceed into parity conserving (P-wave) and parity violating (S-wave) final states with amplitudes *P* and *S* respectively
- Slope of the baryon $\cos\theta$ distribution given by $\alpha_P P_P$
- Magnitude of the parity violation (α) can be large

Anisotropic proton decay distribution

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



Phenomenology of CP Violation in Hyperon Decays



- CP violation is manifestly direct with $\Delta S = 1$
- Three ingredients are necessary to get a non zero asymmetry
  1) At least two channels in the final state: S- and P-wave amplitudes
  2) The CP violating weak phases must be different for the two channels
  3) There must be unequal final state strong phase shifts

$$A_\Xi = (\alpha_\Xi + \bar{\alpha}_\Xi)/(\alpha_\Xi - \bar{\alpha}_\Xi) \cong -\tan(\delta_P - \delta_S)\sin(\phi_P - \phi_S)$$
$$A_\Lambda = (\alpha_\Lambda + \bar{\alpha}_\Lambda)/(\alpha_\Lambda - \bar{\alpha}_\Lambda) \cong -\tan(\underbrace{\delta_P - \delta_S}_{\text{strong phases}})\sin(\underbrace{\phi_P - \phi_S}_{\text{weak phases}})$$

- Asymmetry greatly reduced by small strong phase shifts
  - $p\pi$ phase shift measured to ~1°

$$\Lambda\begin{cases}\delta_P = -1.1 \pm 1.0^\circ \\ \delta_S = 6.0 \pm 1.0^\circ\end{cases}$$

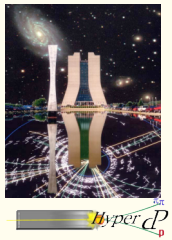
  - $\Lambda\pi$ phase shift measured by Hyper*CP*

$$\Xi\begin{cases}\delta_P = -2.7^\circ \\ \delta_S = -18.7^\circ\end{cases} 1965 \quad \begin{cases}= -1^\circ \\ = 0^\circ\end{cases} \text{ recent } \chi PT$$

Hyper*CP* Measurement

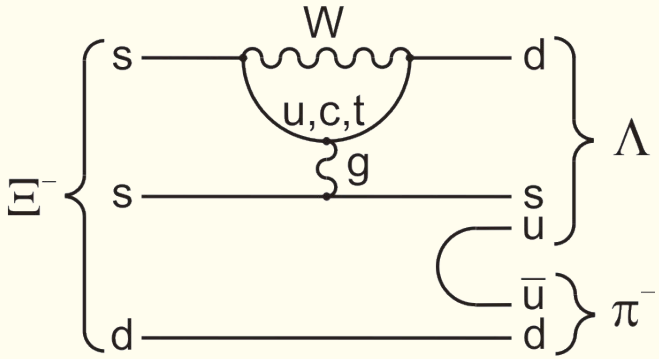
$$\delta_p - \delta_s = (4.6 \pm 1.8)^\circ$$

Comparison of A_Ξ, A_Λ with ε'/ε



A_Ξ, A_Λ

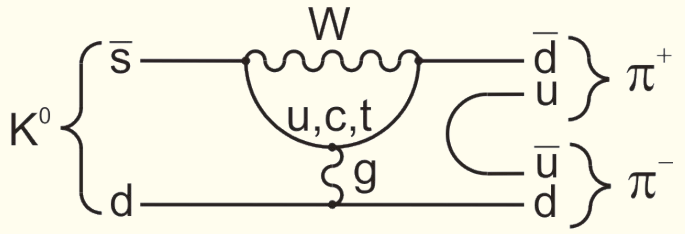
- Thought to be due to Penguin diagram in Standard Model



- Expressed through a different *CP*-violating phase in *S*- and *P*-wave amplitudes
- Probes parity-violating and parity-conserving amplitudes

ε′/ε

- Thought to be due to Penguin diagram in Standard Model



- Expressed through a different CP-violating phase in *I=0* and *I=2* amplitudes
- Probes parity-violating amplitudes

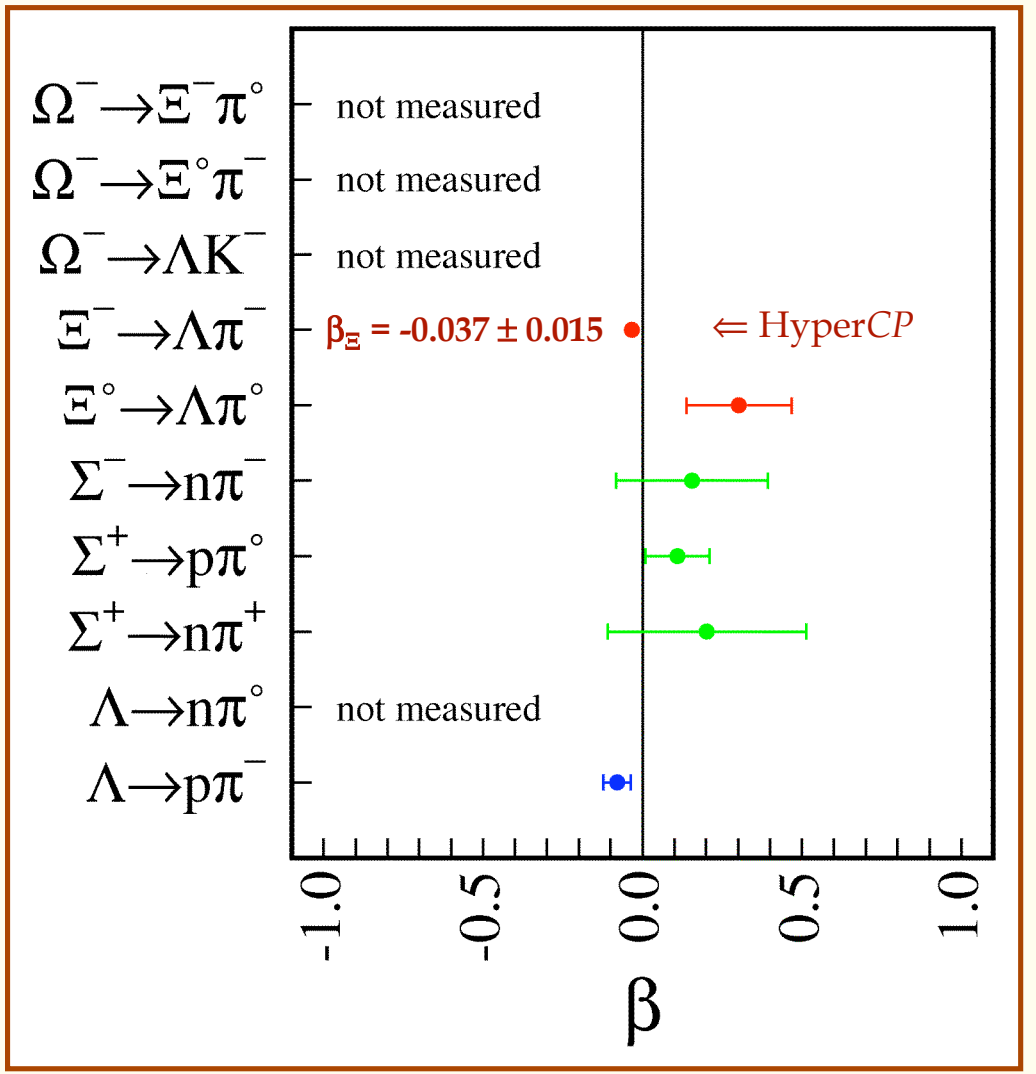
CP Signatures in Hyperon Decays

$$A = \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}}$$

- Need parent hyperons with known polarization.

$$B = \frac{\beta + \bar{\beta}}{\beta - \bar{\beta}}$$

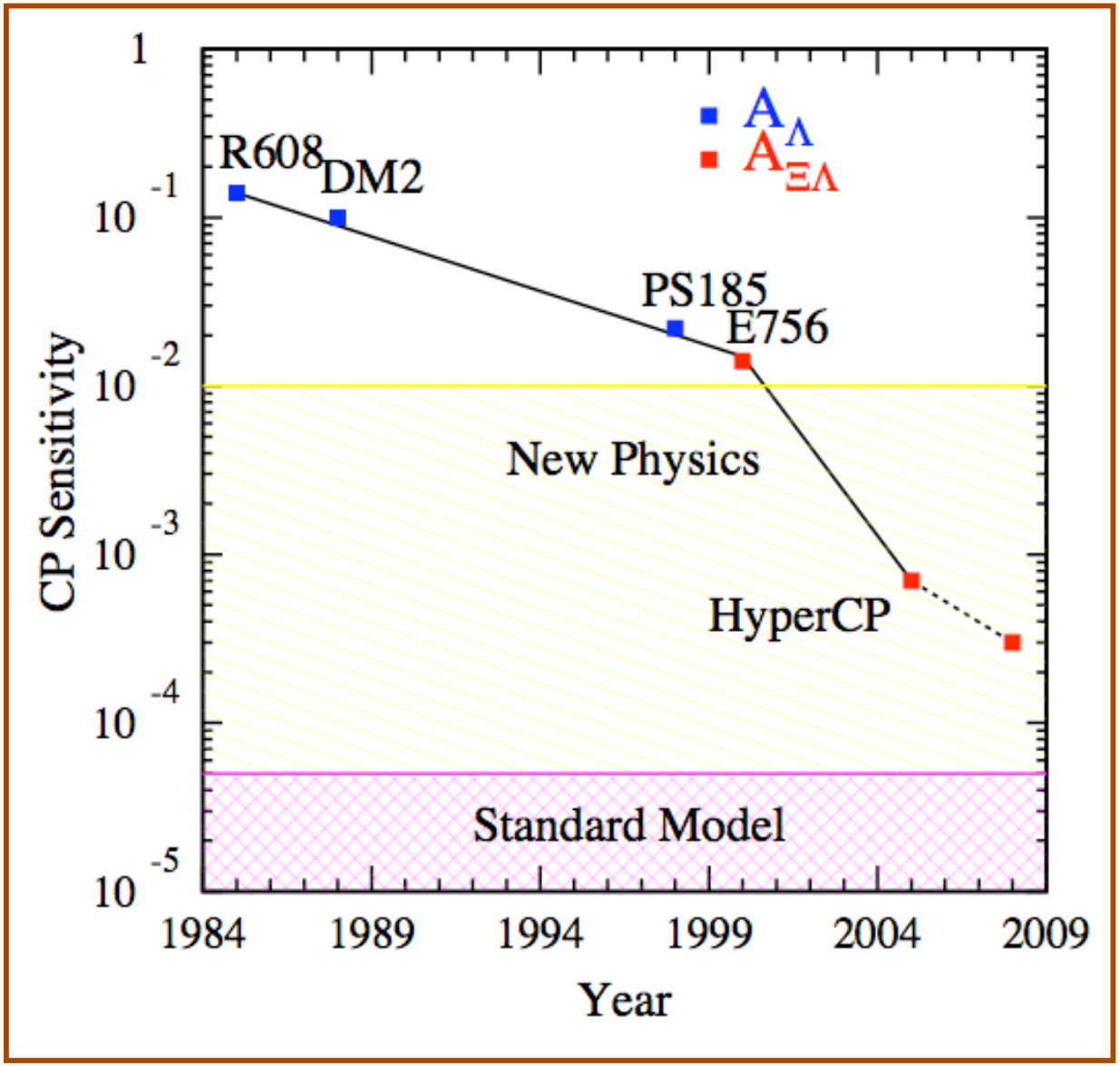
- Expected to be larger than A
- Difficult experimentally to measure:
  - Need to measure polarization of daughter from polarized parent
  - β is very small



Previous Measurements

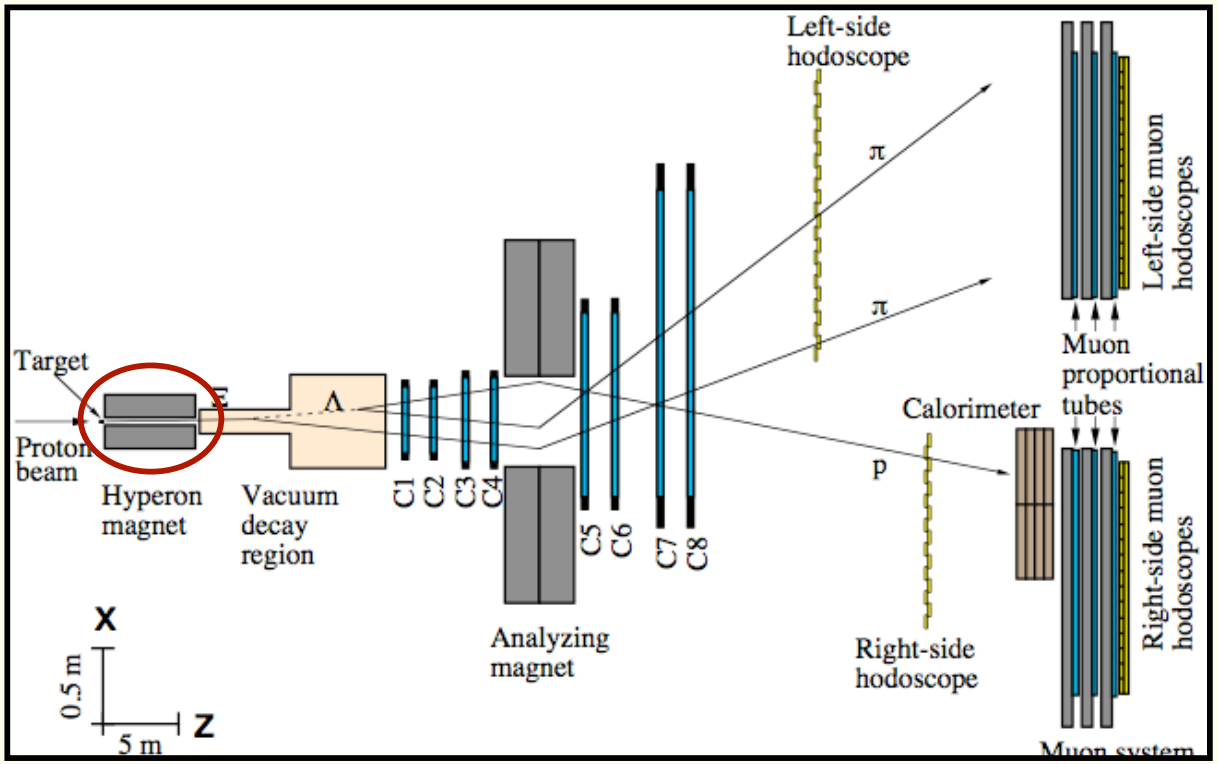
None of the pre-Hyper*CP* experiments had the sensitivity to test theory

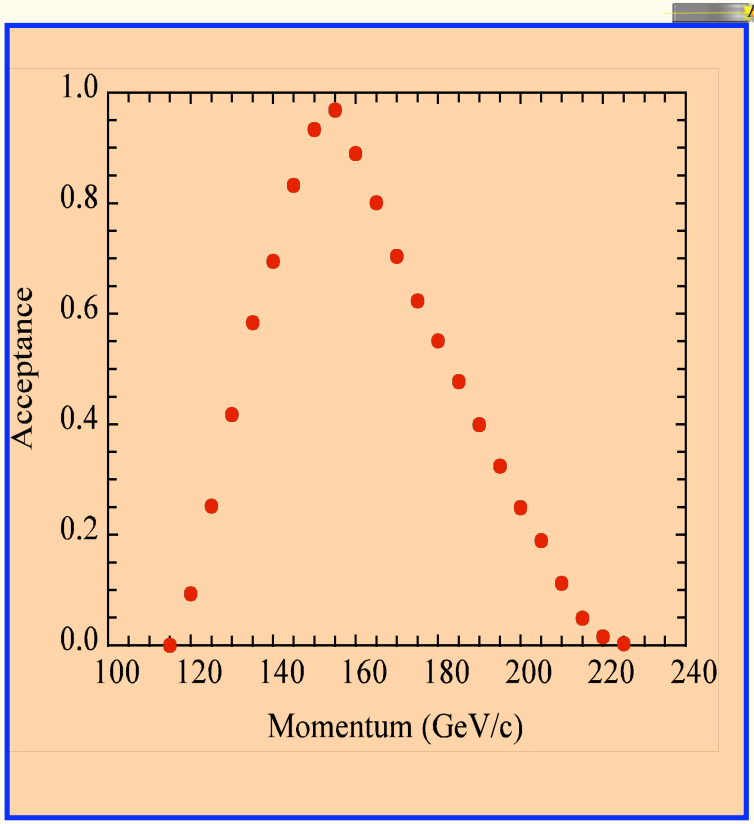
Hyper*CP* probes well into regions where BSM theories predict nonzero asymmetries



The Hyper*CP* Experiment

Designed for *CP* Violation Searches





Charged Hyperon Beam

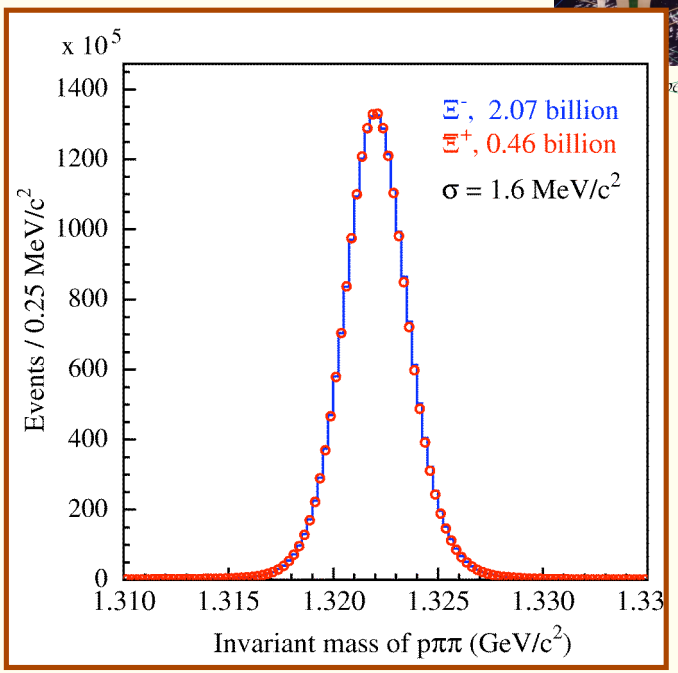
- 800 GeV/c protons on 2 mm x 2 mm target
- Secondary beam: 167 GeV/c
- Alternate -/+ beam polarity

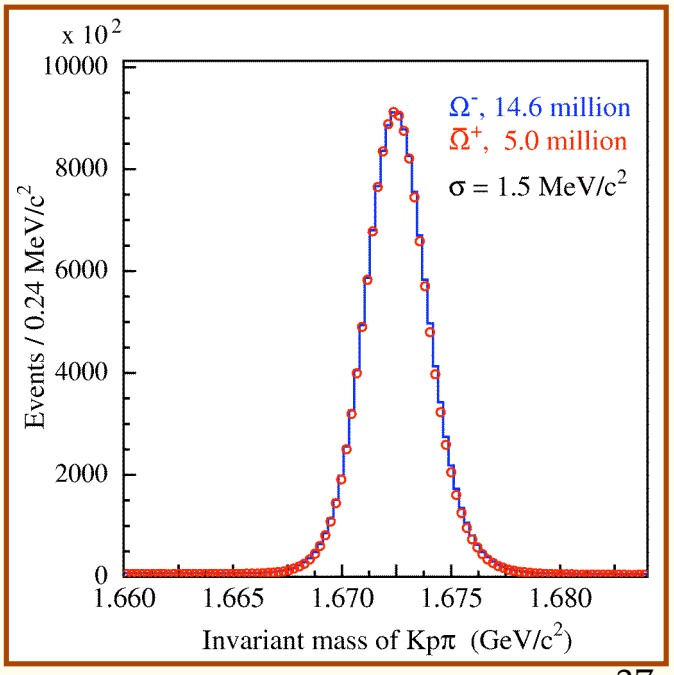
HyperCP Yields

- In 12 months of data taking HyperCP recorded one of the largest event sample ever
  - 231 billion events
  - 29,401 tapes
  - 120 TB
- Entire WWW as of end of data taking ~5 TB

Reconstructed Events

	Channeled beam polarity		
Type	+	−	Total
$\Xi \to \Lambda\pi$	458×10^6	$2\,032 \times 10^6$	$2\,490 \times 10^6$
$K \to \pi\pi\pi$	391×10^6	164×10^6	555×10^6
$\Omega \to \Lambda K$	4.9×10^6	14.1×10^6	19.0×10^6

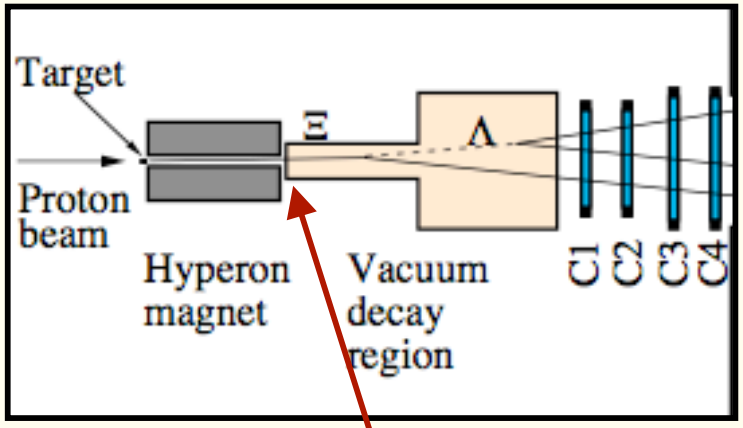




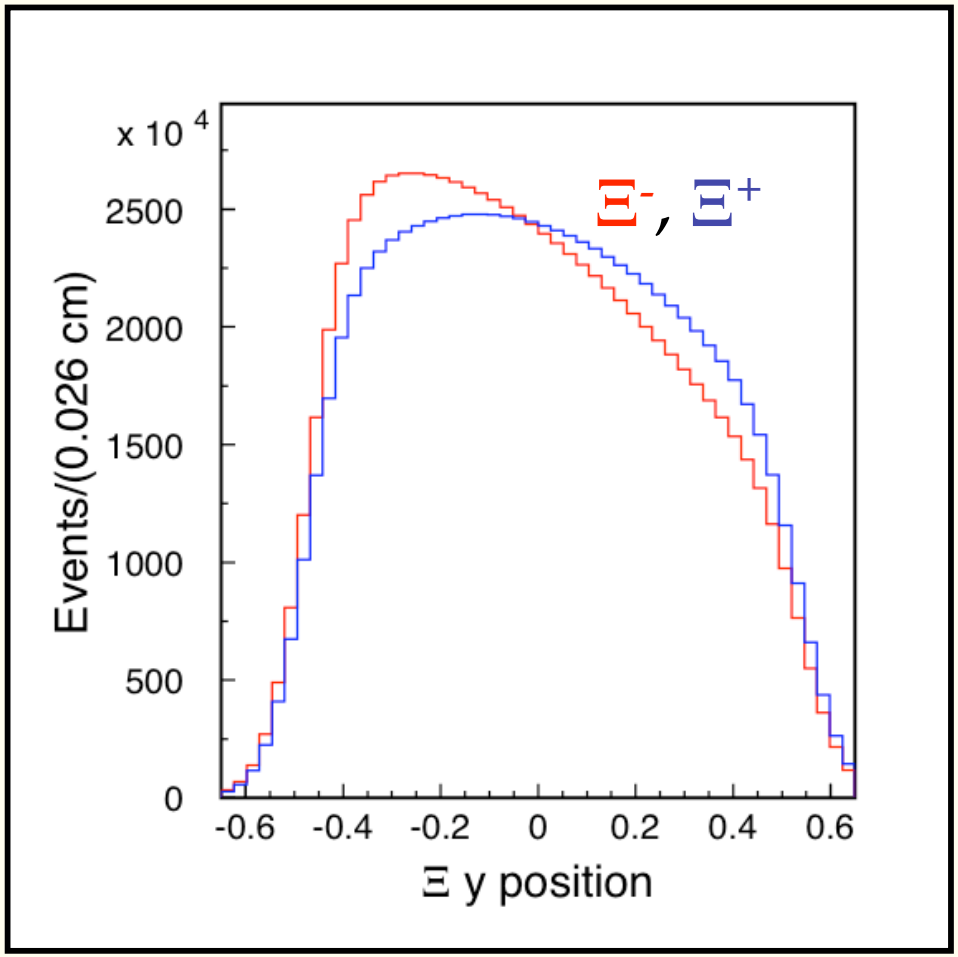
Accounting for Acceptance Differences

Problem: Acceptance for Ξ^- and Ξ^+ decays not equal due to different production dynamics

Solution: Weight the reconstructed Ξ^- and Ξ^+ position and momentum distributions and force them to be identical



Ξ^- & Ξ^+ distributions weighted at the exit of the Hyperon Magnet



50 Bins for Ξ momentum

50 bins for Ξ *y* position and slope

20 bins for Ξ *x* position and slope

Accounting for Acceptance Differences

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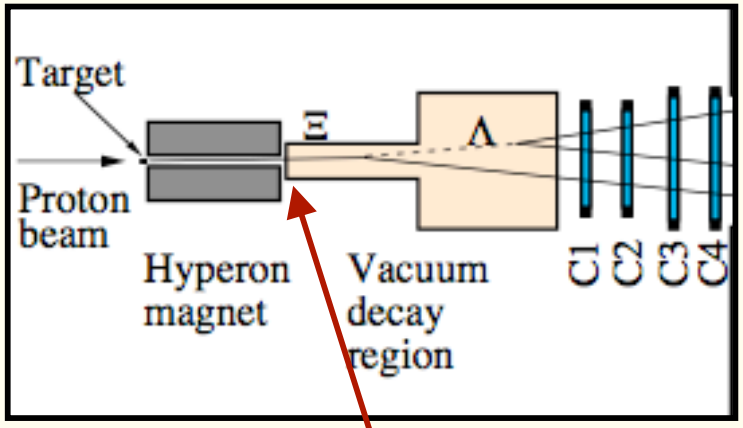

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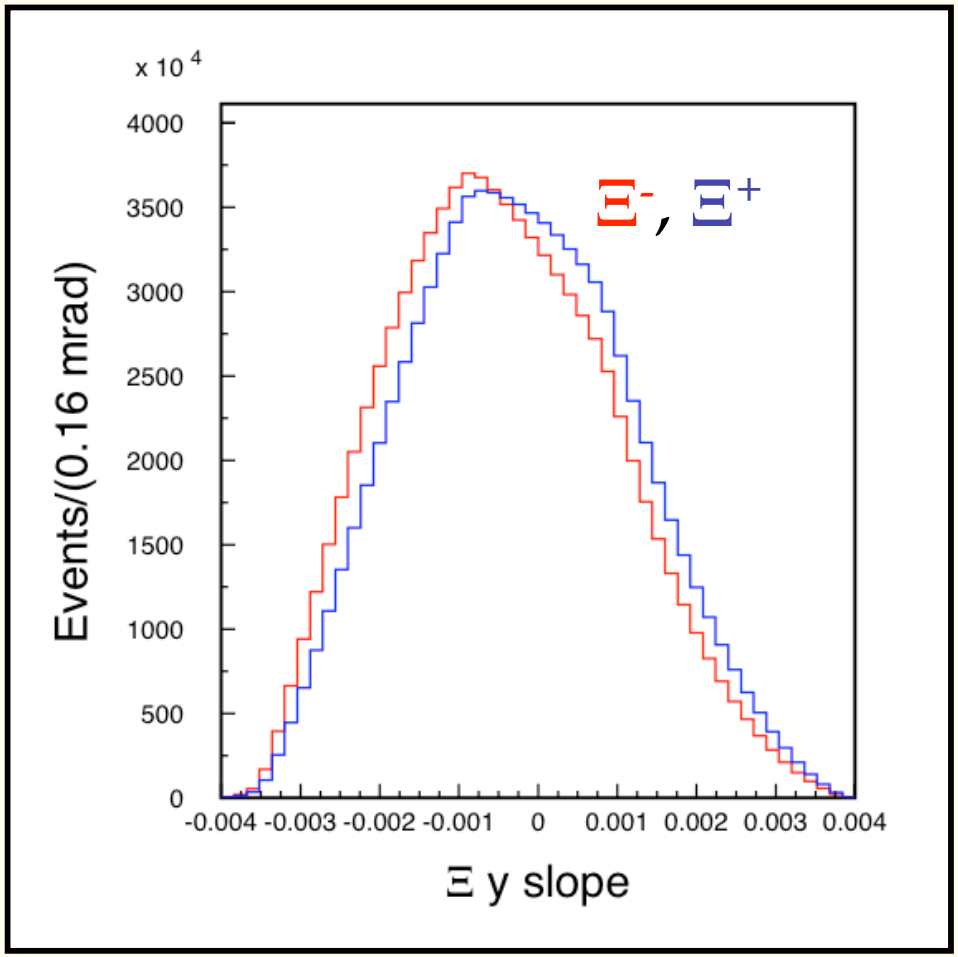

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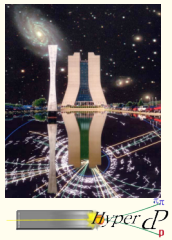

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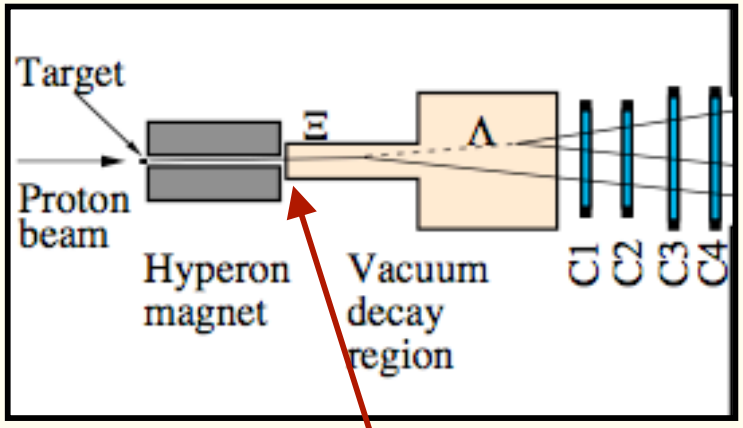

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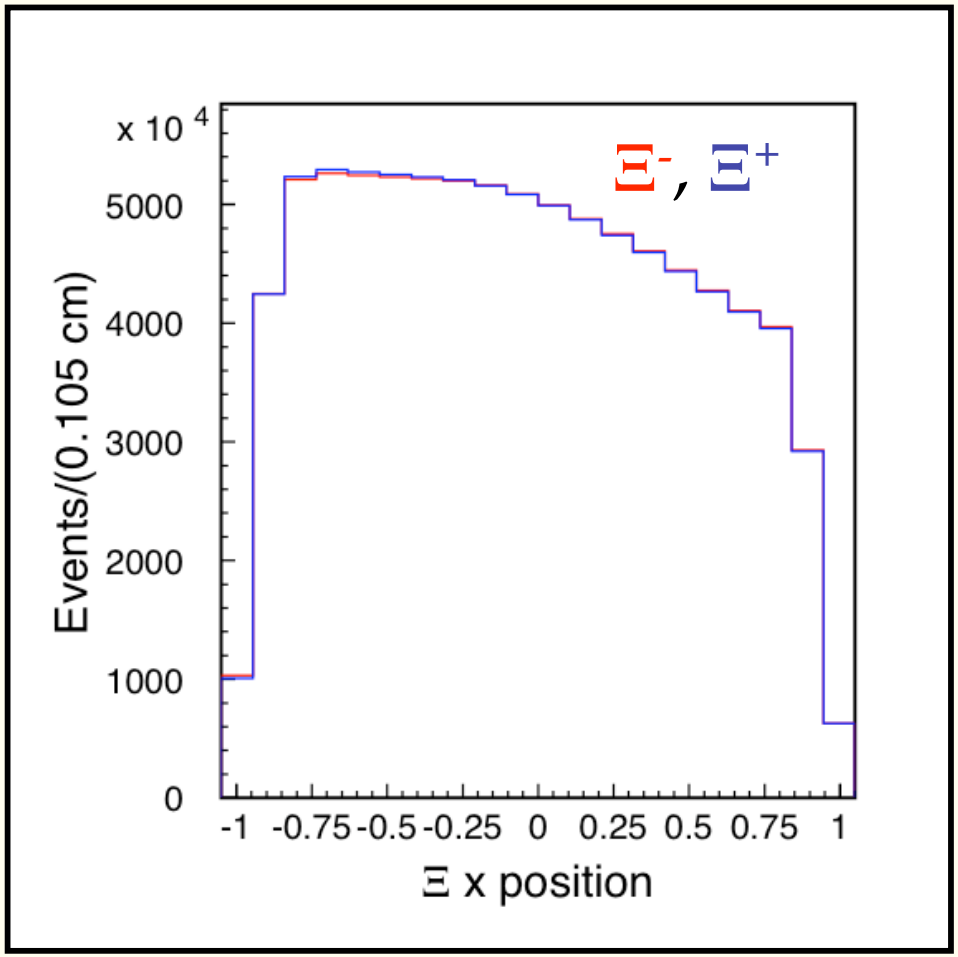

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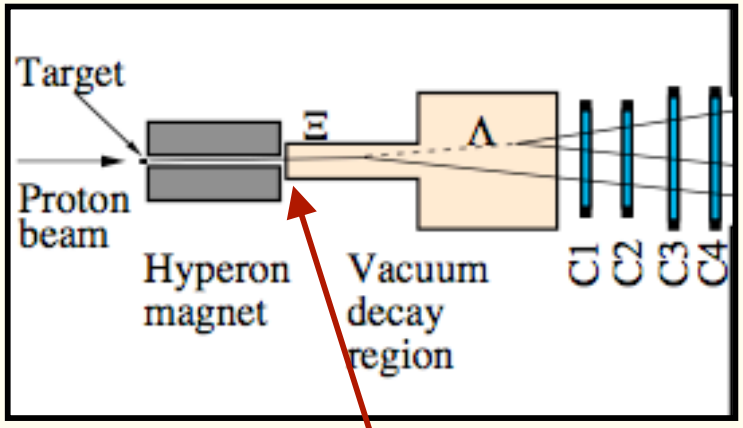

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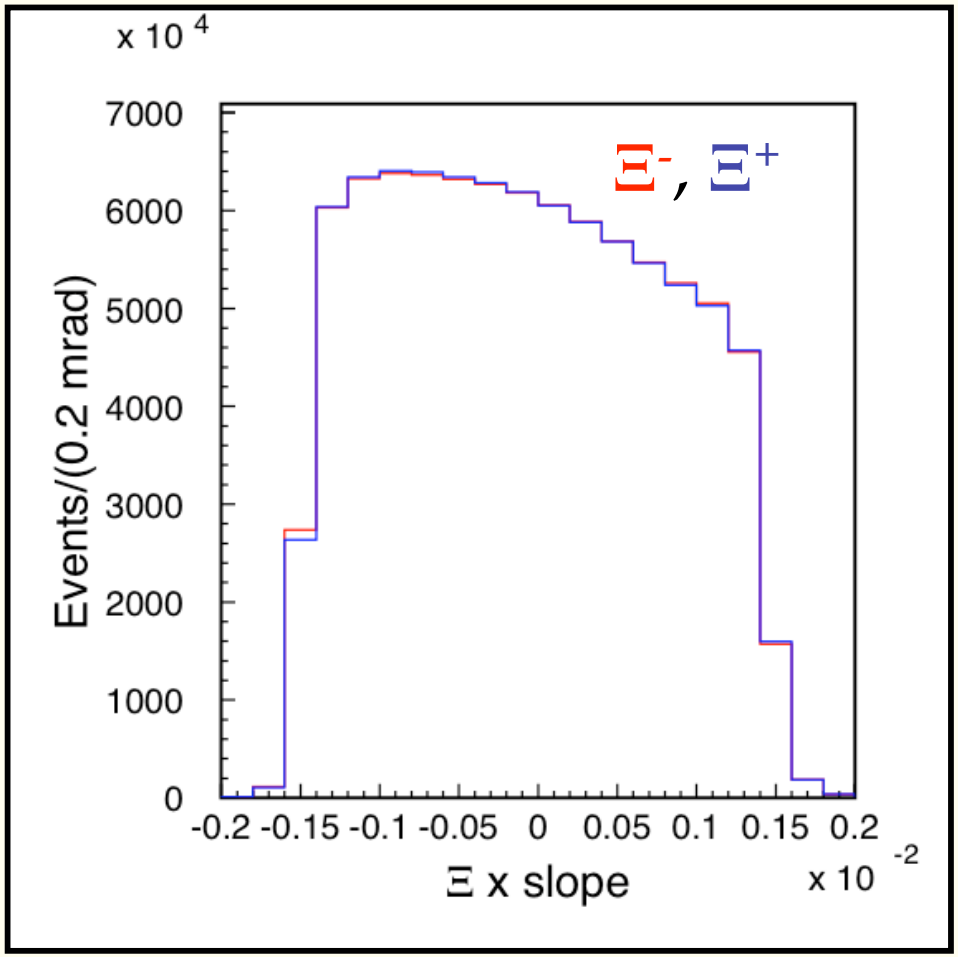

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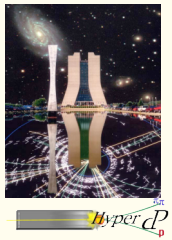

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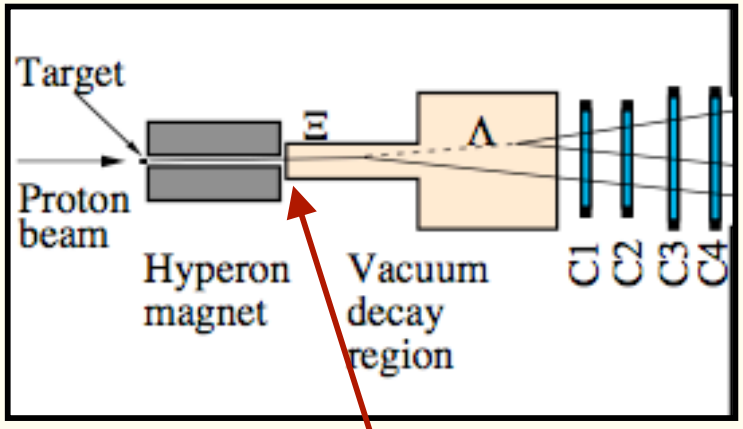

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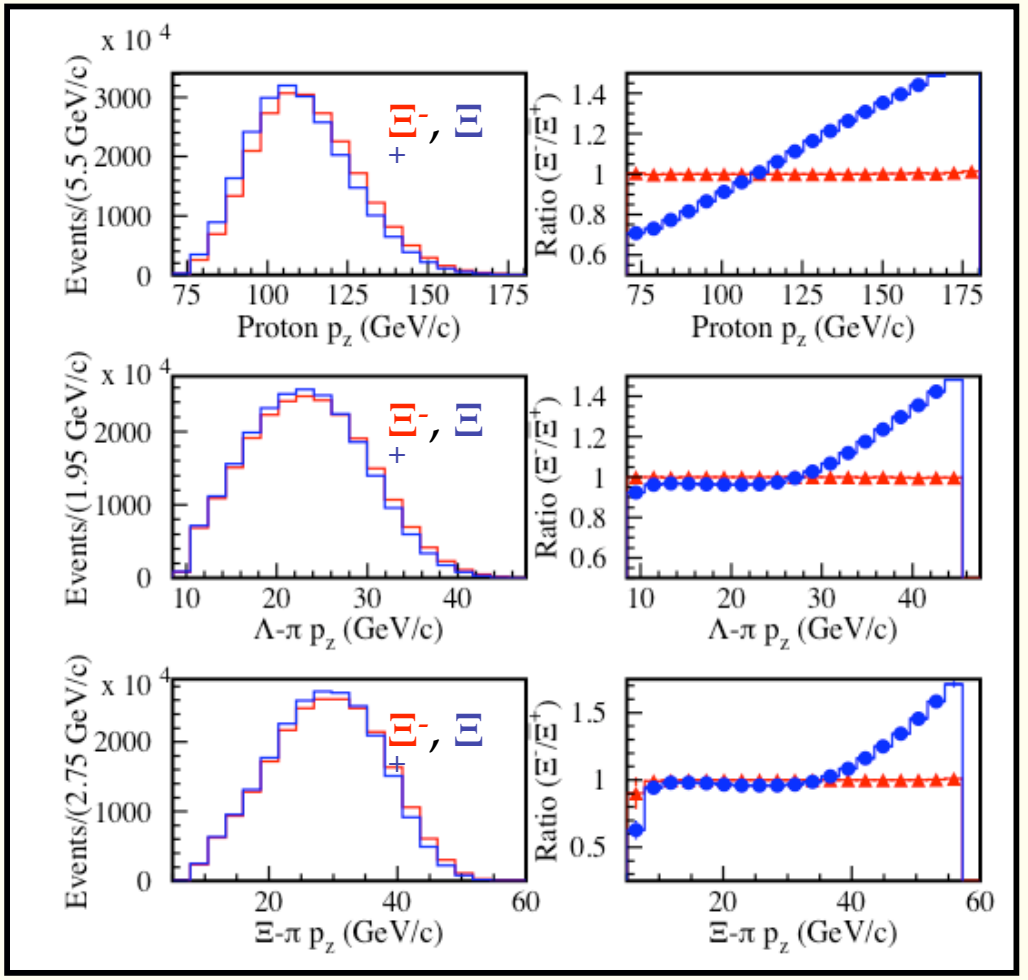

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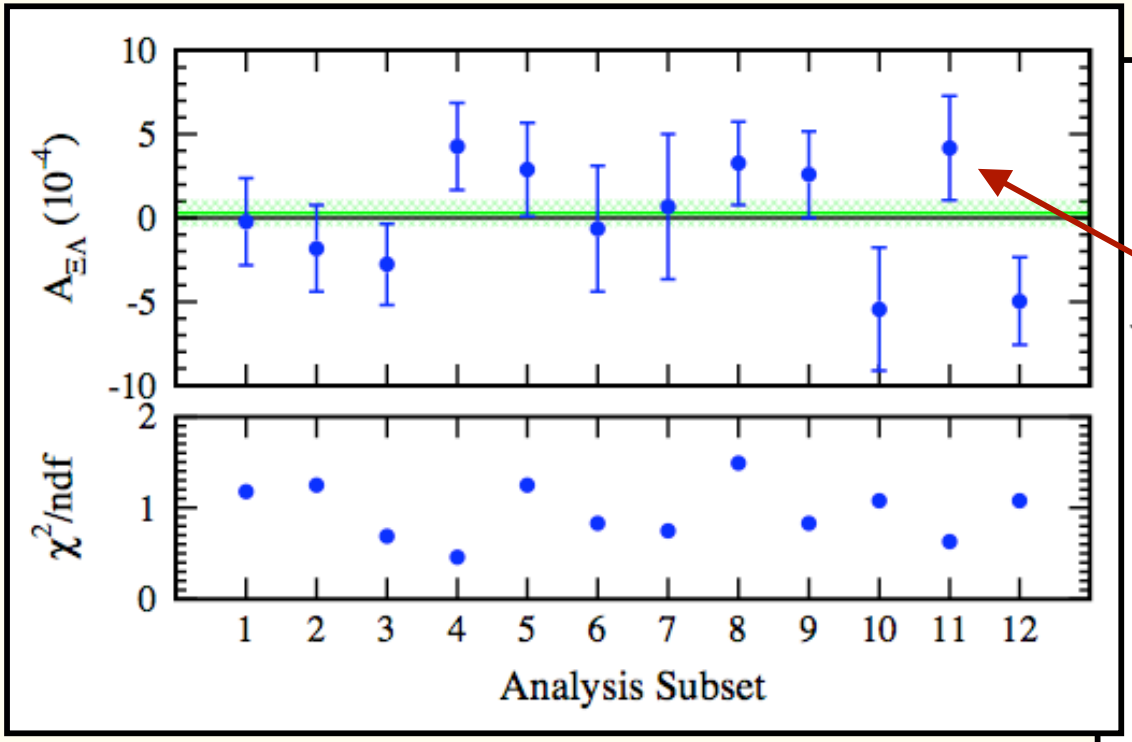
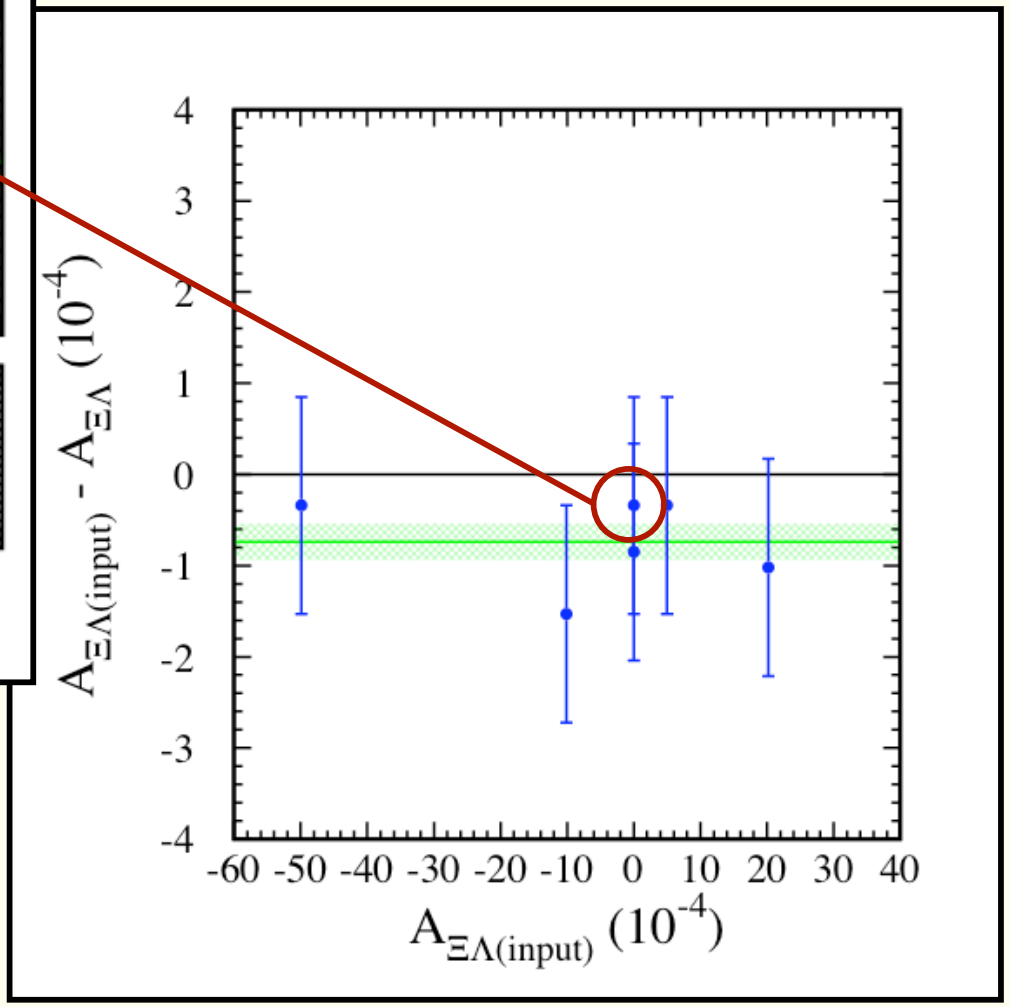
Monte Carlo Verification





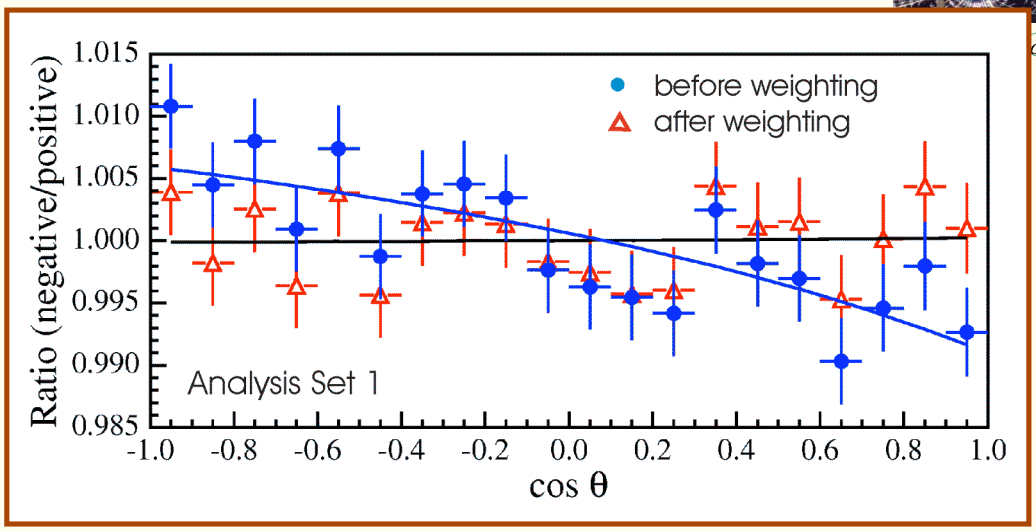
$$\Delta A_{\Xi\Lambda} = (-0.74 \pm 0.2) \times 10^{-4}$$

The technique successfully recovers input asymmetries (with a slight bias compared to the statistical error)

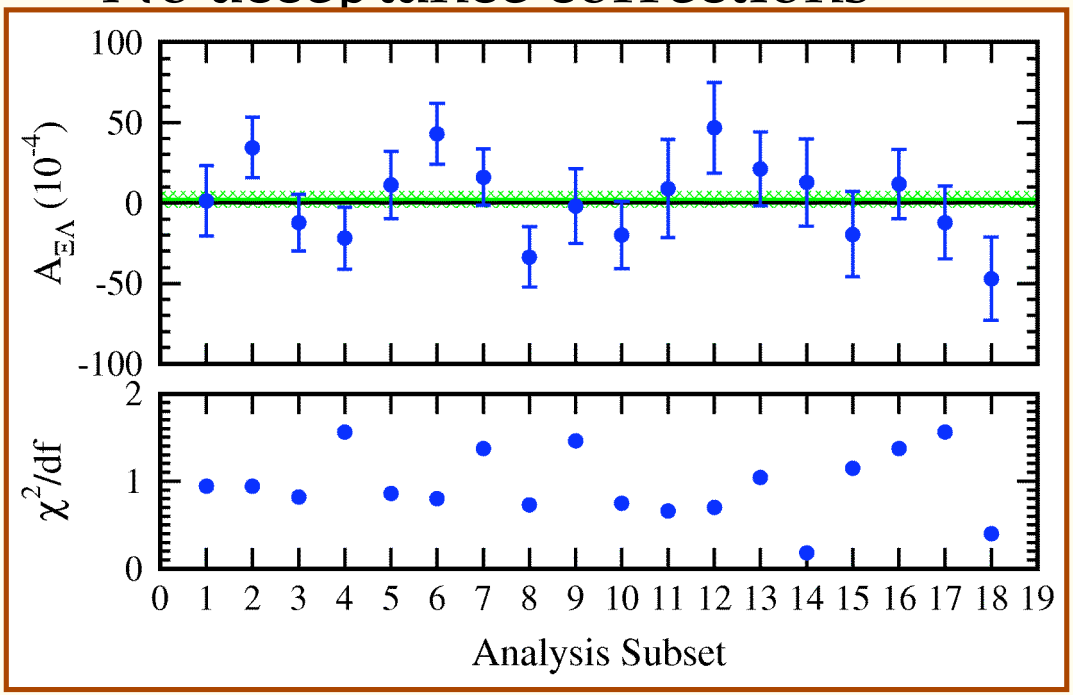
Each pt. is a weighted average from 12 separate simulations

15% Sample Result

- Data broken up into 18 Analysis Sets of roughly equal size, each with + and - polarity data
- ~10% of data sample: 119 million Ξ^-, 42 million Ξ^+
- No acceptance corrections



Typical cosθ ratio fit from Analysis Set 1



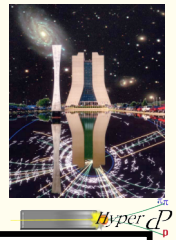
Raw (non-background subtracted) CP asymmetry $A_{\Xi\Lambda}$ from all 18 Analysis Sets

Background Subtracted Result

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

$$\chi^2 = 24$$

Full Dataset Raw Result (Preliminary)



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Ave. Ξ^+ bin occupancy: 274 Events/bin

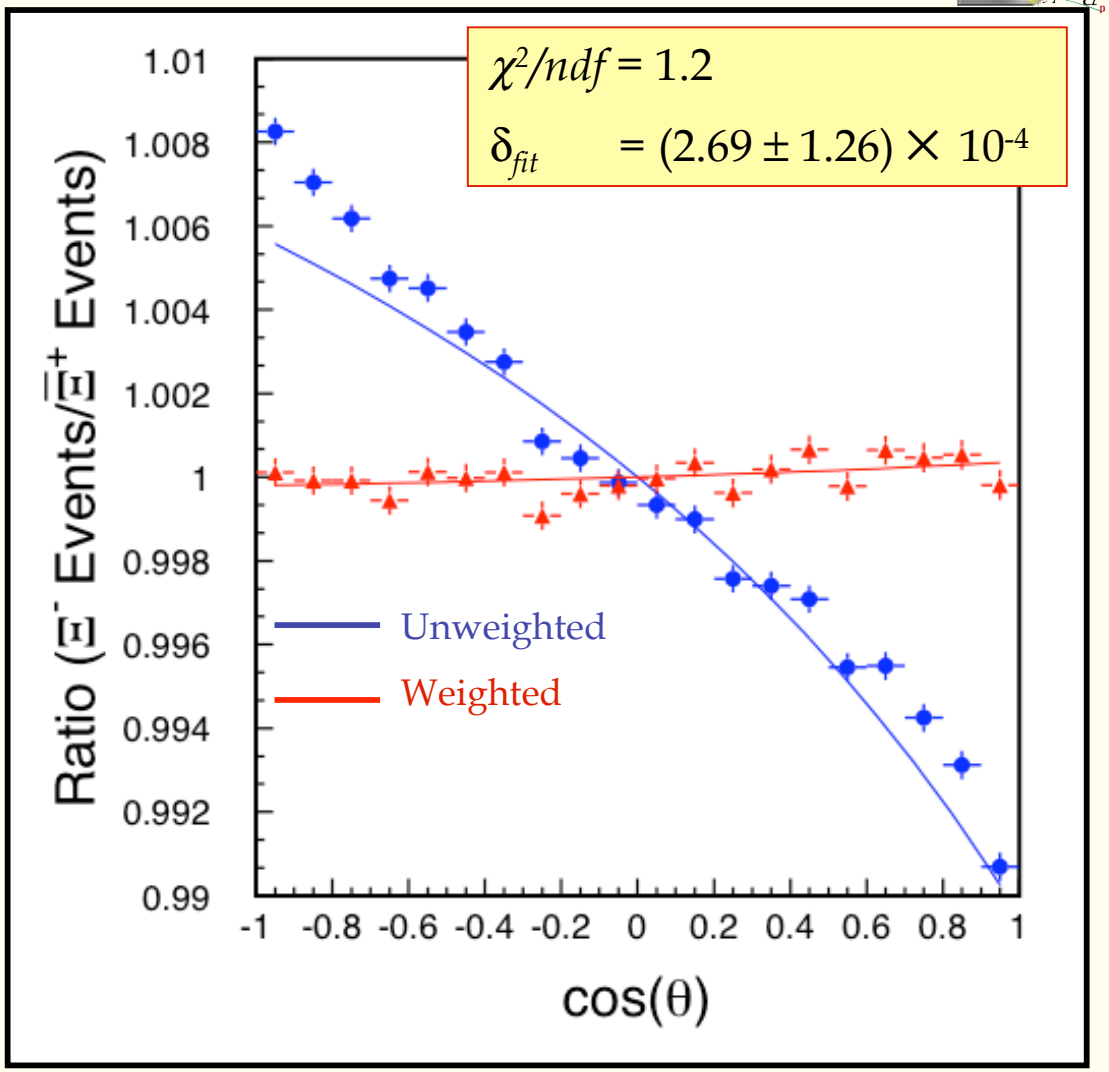
Fitting function:

$$R(\cos\theta,\delta) = \frac{N_-}{N_+}\frac{(1+\alpha_\Xi\alpha_\Lambda\cos\theta)}{1+(\alpha_\Xi\alpha_\Lambda-\delta)\cos\theta}$$

$$\delta \equiv \alpha_\Xi\alpha_\Lambda - \alpha_{\bar{\Xi}}\alpha_{\bar{\Lambda}}$$

$$A_{\Xi\Lambda} = (-4.6 \pm 2.14)\times 10^{-4}$$

- No acceptance corrections
- No efficiency corrections
- No background subtraction

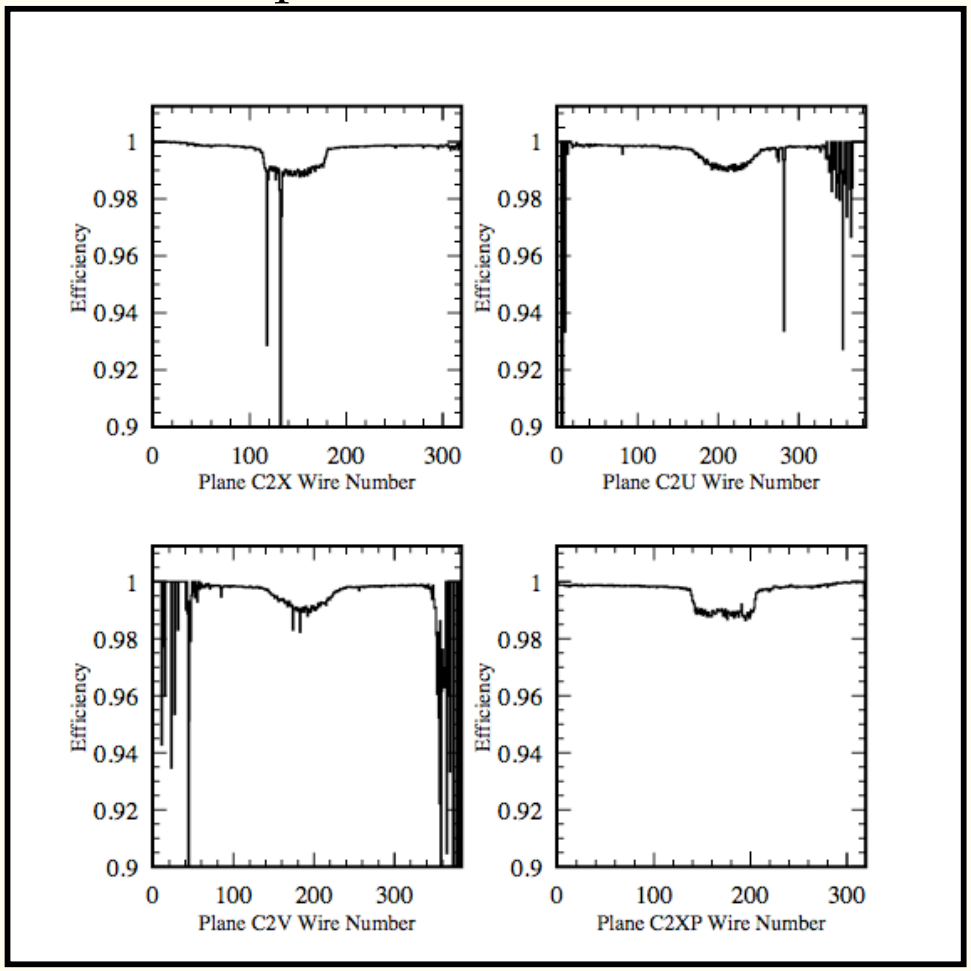


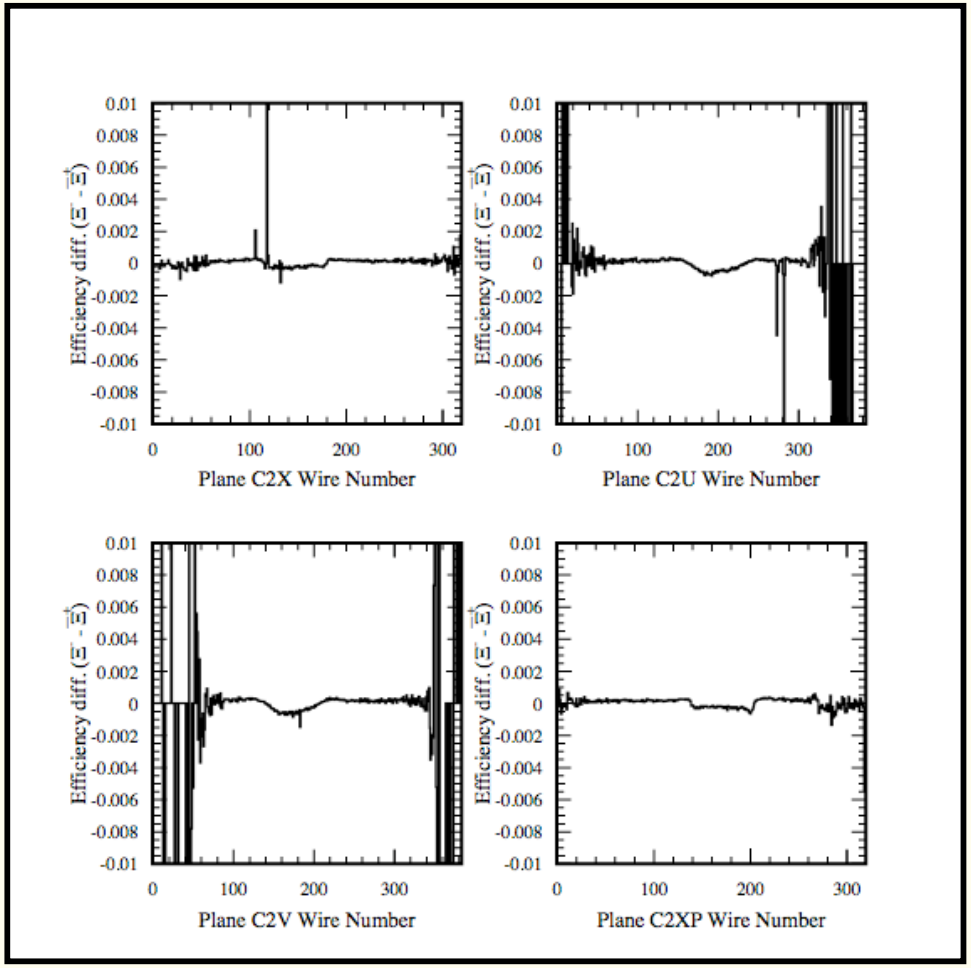
Prior to the fit, the Ξ^- and Ξ^+ $\cos\theta$ distributions were normalized

Biases Controlled to the 10^{-4} Level

How is this done?

1) Same spectrometer was used for Ξ^- and Ξ^+ $\cos\theta$ measurements.
   - Detector efficiency differences must have no temporal or momentum dependencies





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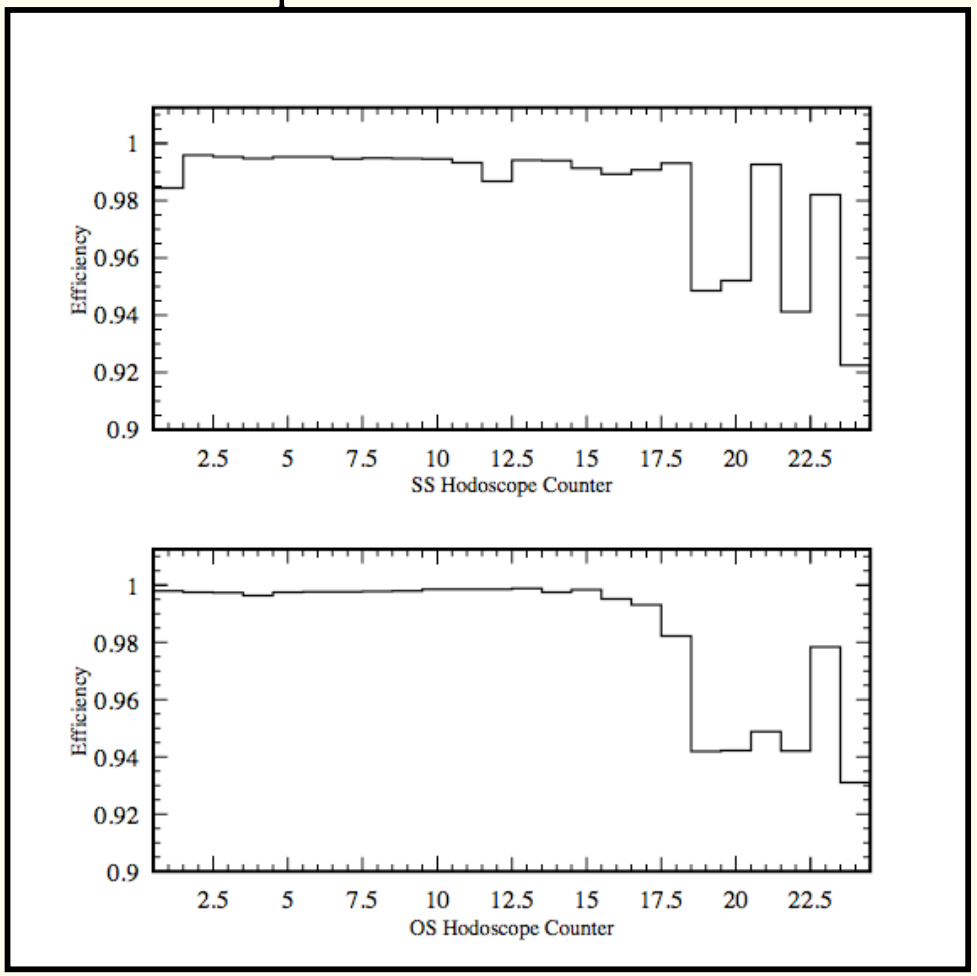
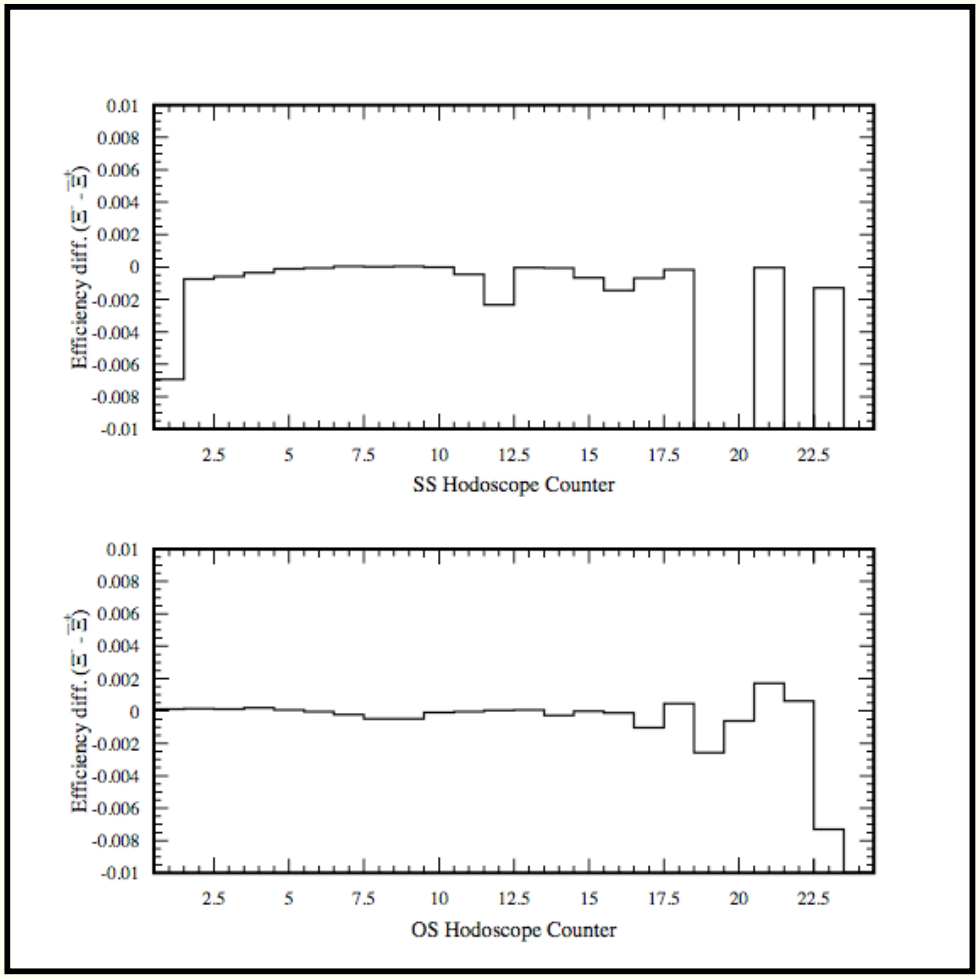




Background Subtracted Asymmetry (Preliminary)

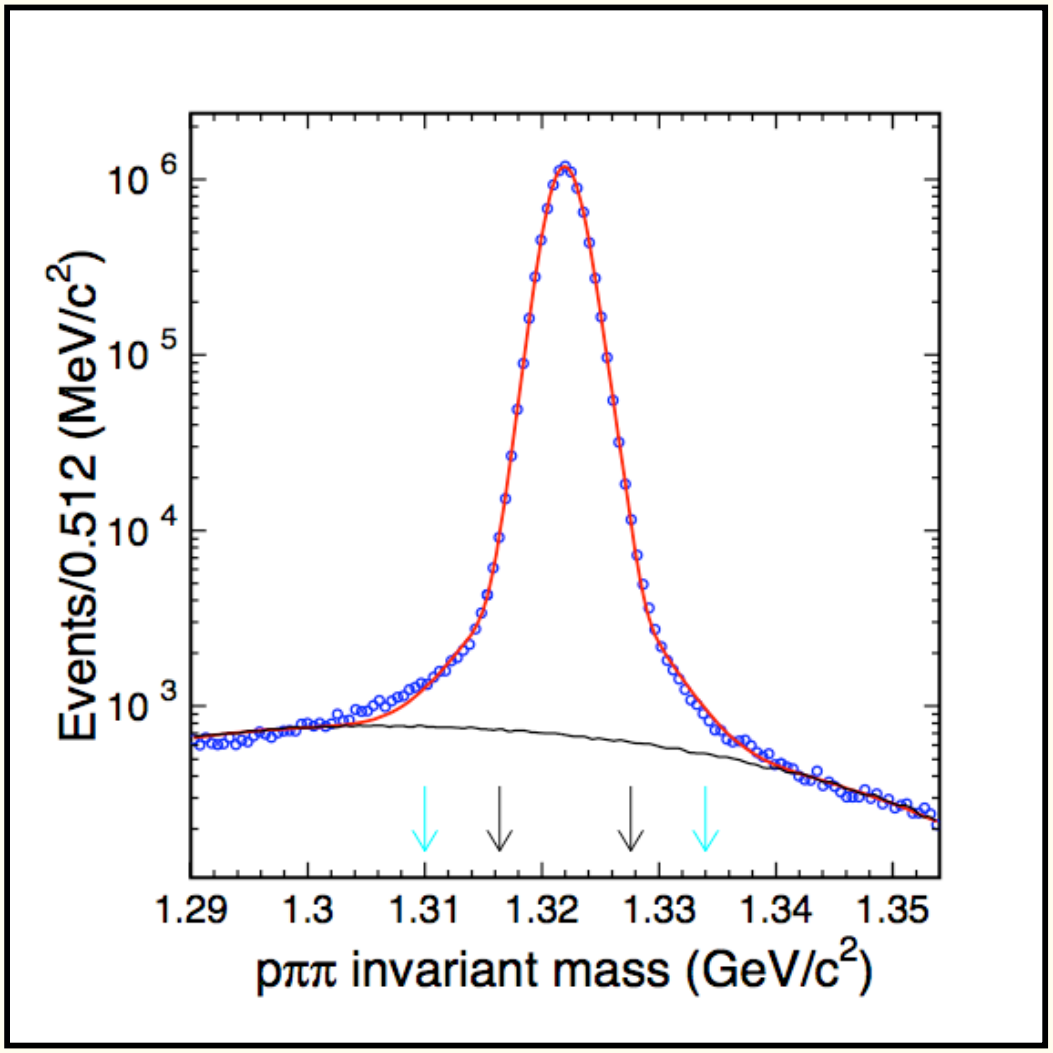
Corrections to the base result

1) Hodoscope efficiency correction
2) Background subtraction

$$\left.\frac{\Xi^-:\ 0.16\%}{\bar{\Xi}^+:\ 0.16\%}\right\} = 0.33\sigma \text{ shift}$$

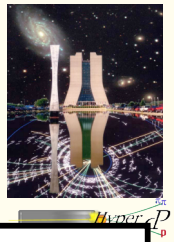
$$A_{\Xi\Lambda} = \frac{\alpha_\Xi\alpha_\Lambda - \alpha_{\bar{\Xi}}\alpha_{\bar{\Lambda}}}{\alpha_\Xi\alpha_\Lambda + \alpha_{\bar{\Xi}}\alpha_{\bar{\Lambda}}} = [-6.0 \pm 2.1(stat) \pm 2.1(syst)] \times 10^{-4}$$

New high statistics result probes even further into the realm of new physics



Triple Gaussian + polynomial fit

Corrected Asymmetry (Preliminary)



Corrections to the base result

1) Hodoscope efficiency correction

2) Background subtraction

$$\left.\begin{array}{l}\Xi^-:\ 0.16\% \\ \bar{\Xi}^+:\ 0.16\%\end{array}\right\} = 0.33\sigma \text{ shift}$$

$$A_{\Xi\Lambda} = \frac{\alpha_\Xi\alpha_\Lambda - \alpha_{\bar{\Xi}}\alpha_{\bar{\Lambda}}}{\alpha_\Xi\alpha_\Lambda + \alpha_{\bar{\Xi}}\alpha_{\bar{\Lambda}}} = [-6.0 \pm 2.1(stat) \pm 2.1(syst)] \times 10^{-4}$$

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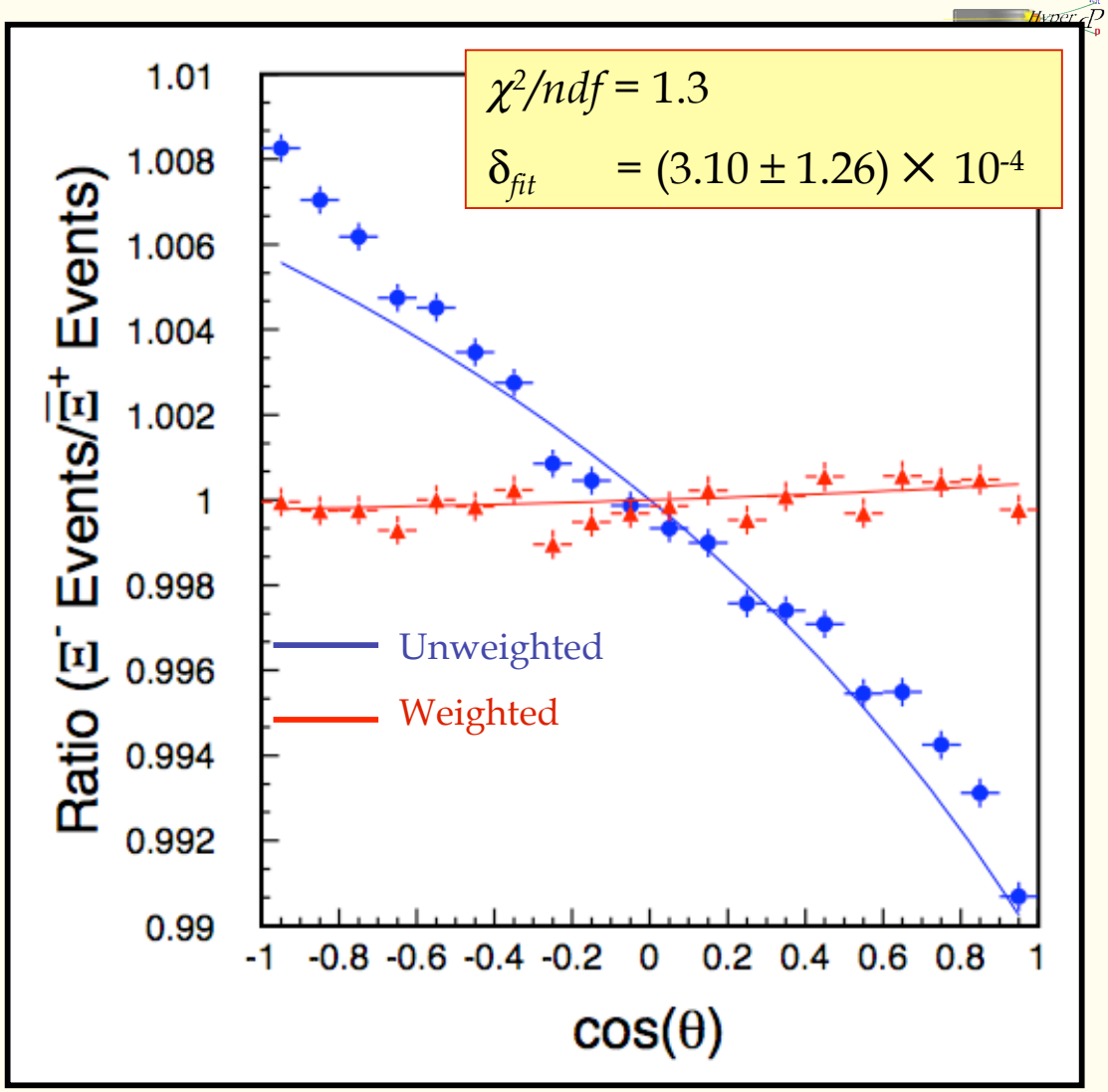

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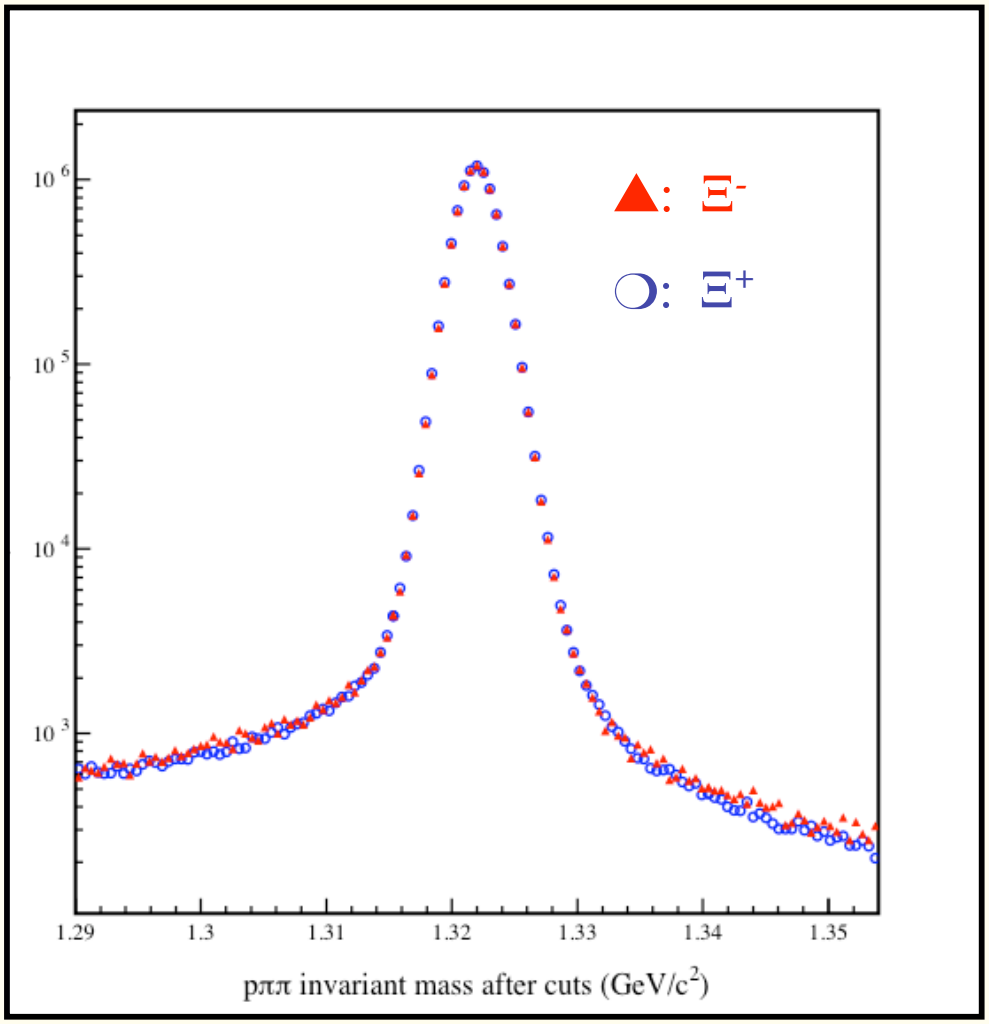

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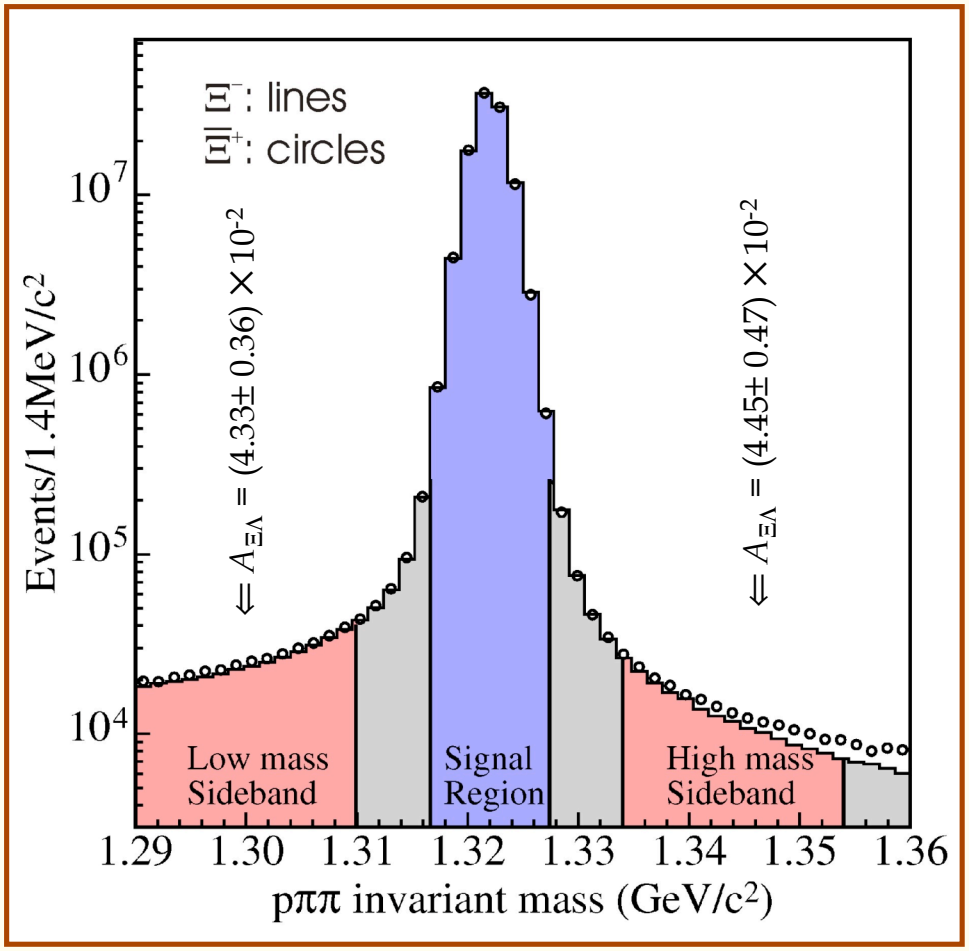

Background Subtracted Asymmetry (Preliminary)

Corrections to the base result

1) Hodoscope efficiency correction
2) Background subtraction

$$\left.\frac{\Xi^-:\ 0.16\%}{\bar{\Xi}^+:\ 0.16\%}\right\} = 0.33\sigma \text{ shift}$$

$$A_{\Xi\Lambda} = \frac{\alpha_\Xi\alpha_\Lambda - \alpha_{\bar{\Xi}}\alpha_{\bar{\Lambda}}}{\alpha_\Xi\alpha_\Lambda + \alpha_{\bar{\Xi}}\alpha_{\bar{\Lambda}}} = [-6.0 \pm 2.1(stat) \pm 2.1(syst)] \times 10^{-4}$$

New high statistics result probes even further into the realm of new physics