

# Status of E871 Analysis

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# FNAL E871 (HyperCP) Collaboration

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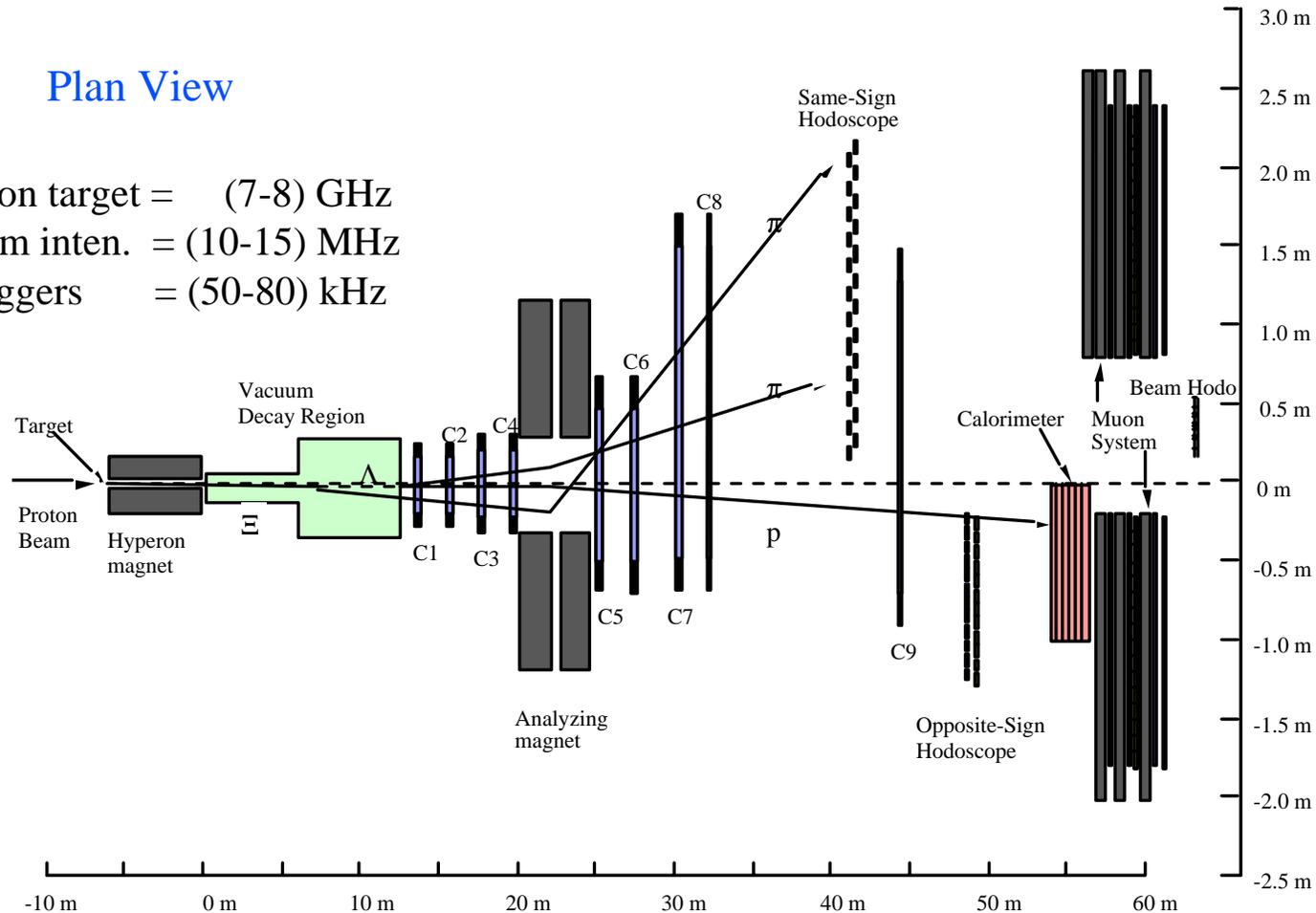
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# FNAL E871 (HyperCP) Experiment

## Plan View

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

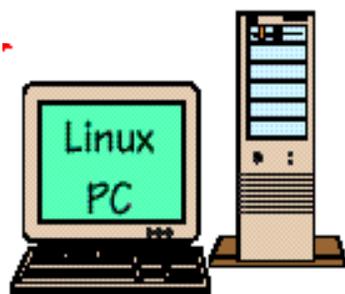


- Look for direct CP violation in  $\Xi \rightarrow \Lambda \pi$ ,  $\Lambda \rightarrow p \pi$  decay sequence by comparing the decay distributions between  $\Xi^-$  and  $\Xi^+$ .
- Collected a large amount of data in the 1997 and 1999 fixed-target runs.

# Data Processing

Tapes vaulted in  
Feynman Center  
at FNAL

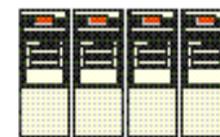
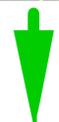
- Controls Submission
- Monitors Processing
- Manages Data Flow
- Manages Tape Writing



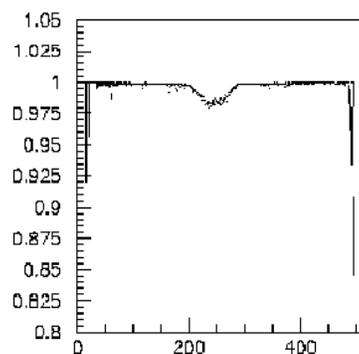
FNAL PC-Farm  
60-120 CPUs



LBNL PDSF  
PC Farm for  
Final Reduction &  
Detailed Analysis



Farm Output  
DST on 400 AIT-2, 50 GB  
Tapes &  $\sim 25 \times 10^6$  Histograms  
for Fast Analysis



Plane G5U Efficiency

- Raw-data processing was complete in Jun, 2001; DST processing was done by Jan, 2002.

## Statistics of The 1997 And 1999 Runs

|                 | 1997 Run | 1999 Run |
|-----------------|----------|----------|
| Number of Tapes | 9,376    | 18,838   |
| Data Volume     | 38 TB    | 71 TB    |

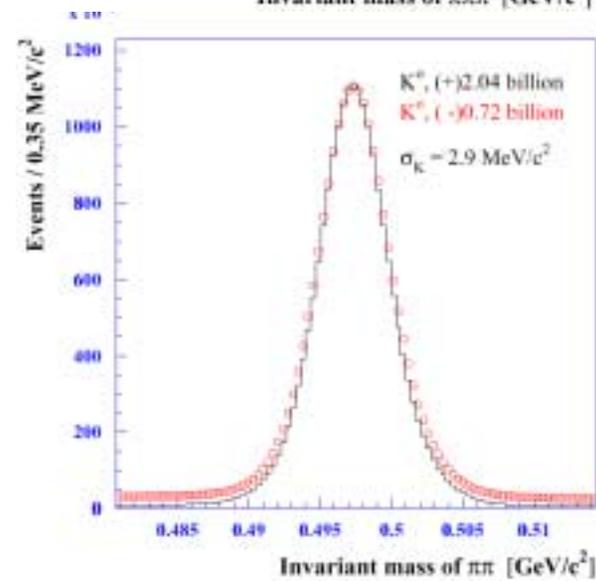
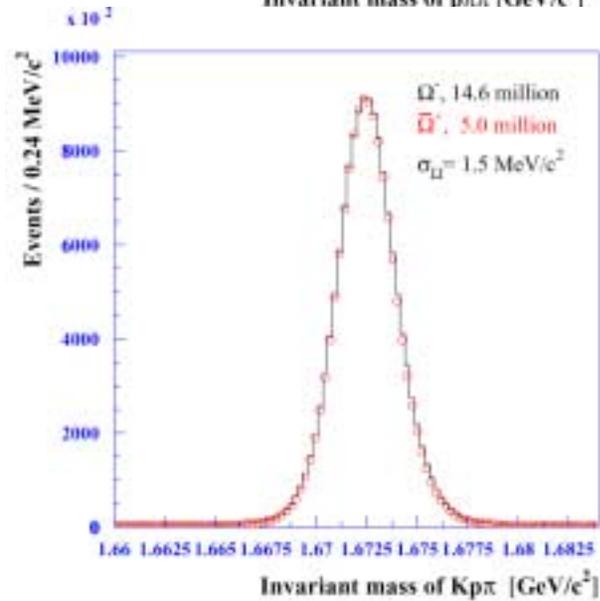
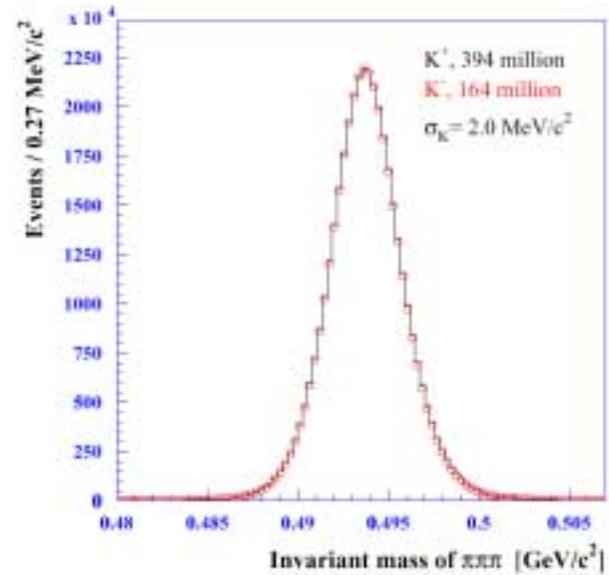
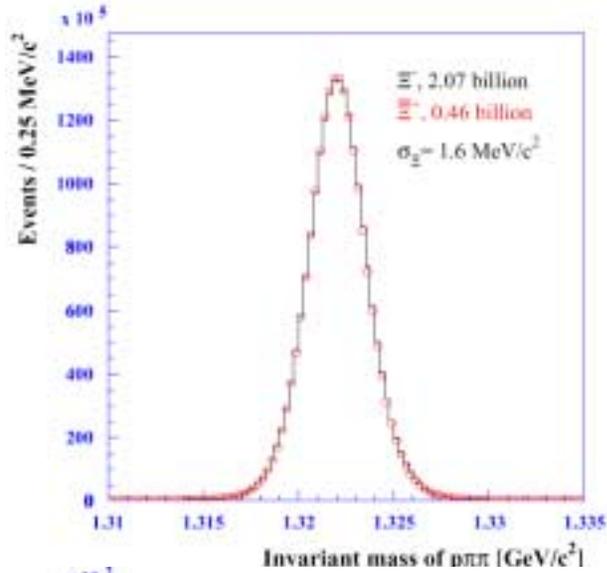
which include  $250 \times 10^6$  polarized  $\Xi^-$  and  $50 \times 10^6$  polarized anti- $\Xi^+$

- Projected number of reconstructed events:

$$\begin{array}{lll} \Xi^- & 2 \times 10^9 & \text{K}^- \quad 0.16 \times 10^9 \quad \Omega^- \quad 14 \times 10^6 \\ \bar{\Xi}^+ & 0.5 \times 10^9 & \text{K}^+ \quad 0.39 \times 10^9 \quad \bar{\Omega}^+ \quad 4.9 \times 10^6 \end{array}$$

- Statistical precision:  $\delta A_{\Xi\Lambda} = 1.4 \times 10^{-4}$

# Mass Plots of 1997 and 1999 Runs

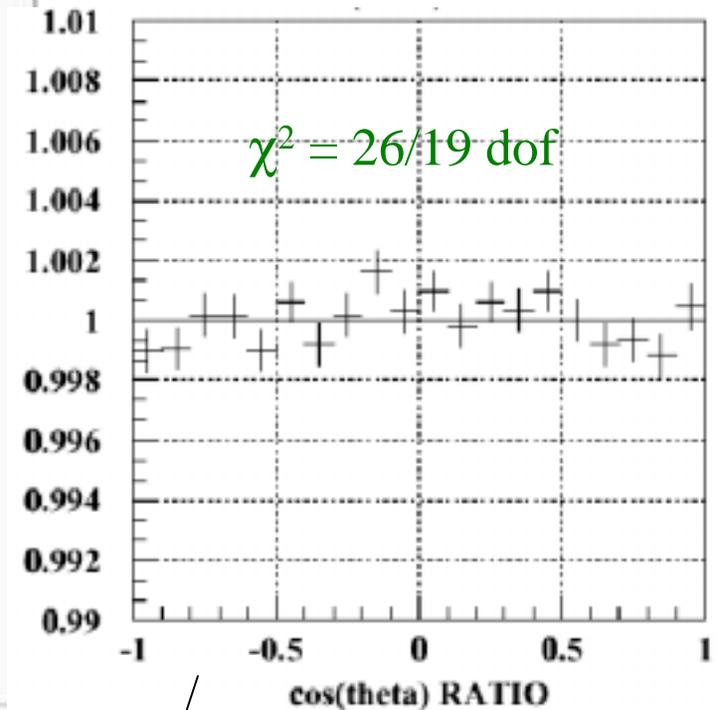
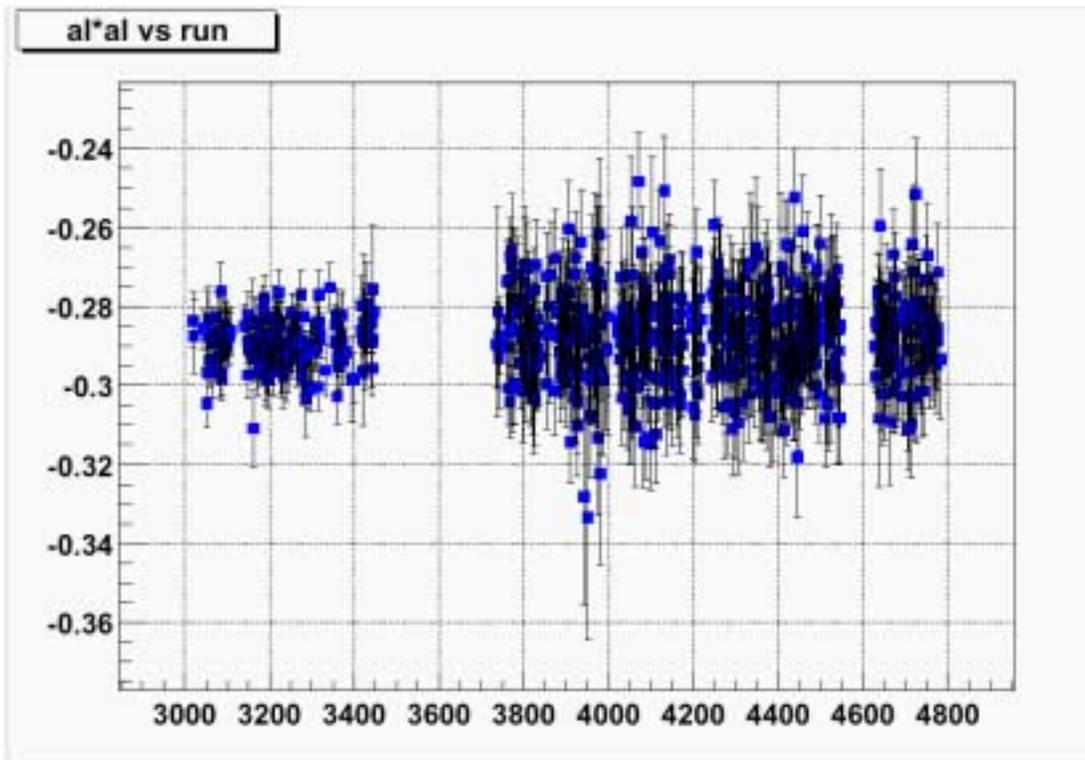


## Status of Physics Analyses

- Several analyses are in progress:
  - Search for CP violation in  $\Xi-\Lambda$  decays
  - Search for CP violation in charged  $K_{\pi 3}$  decay
  - Measurement of decay parameter  $\beta$  in  $\Xi^- \rightarrow \Lambda \pi^-$  decay
  - Measurement of decay parameter  $\alpha$  in  $\Omega \rightarrow \Lambda K$  decay
  - Measurement of production polarization of hyperons
  - Search for rare/forbidden decays
    - $K^\pm \rightarrow \pi^\pm \mu^+ \mu^-$  decays
    - $\Sigma^+ \rightarrow p \mu^+ \mu^-$  decay
    - $\Xi^- \rightarrow p \mu^- \mu^-$  decay
    - $\Delta S = 2$  decays
    - $\Omega^- \rightarrow \Xi^- \pi^+ \pi^-$  decay
    - $\Omega^- \rightarrow \Xi^- \mu^+ \mu^-$  decay

## CP Violation in Hyperon Decays: Hybrid MC Method

- Data sample: randomly selected  $\Xi$  events during data reduction;  
about  $15 \times 10^6 \Xi^-$  and  $30 \times 10^6 \Xi^+$  events.



Average  $\alpha_{\Xi}\alpha_{\Lambda} = -0.2880 \pm 0.0004(\text{stat})$   
in agreement with PDG value

## CP Violation in Hyperon Decays: Hybrid MC Method

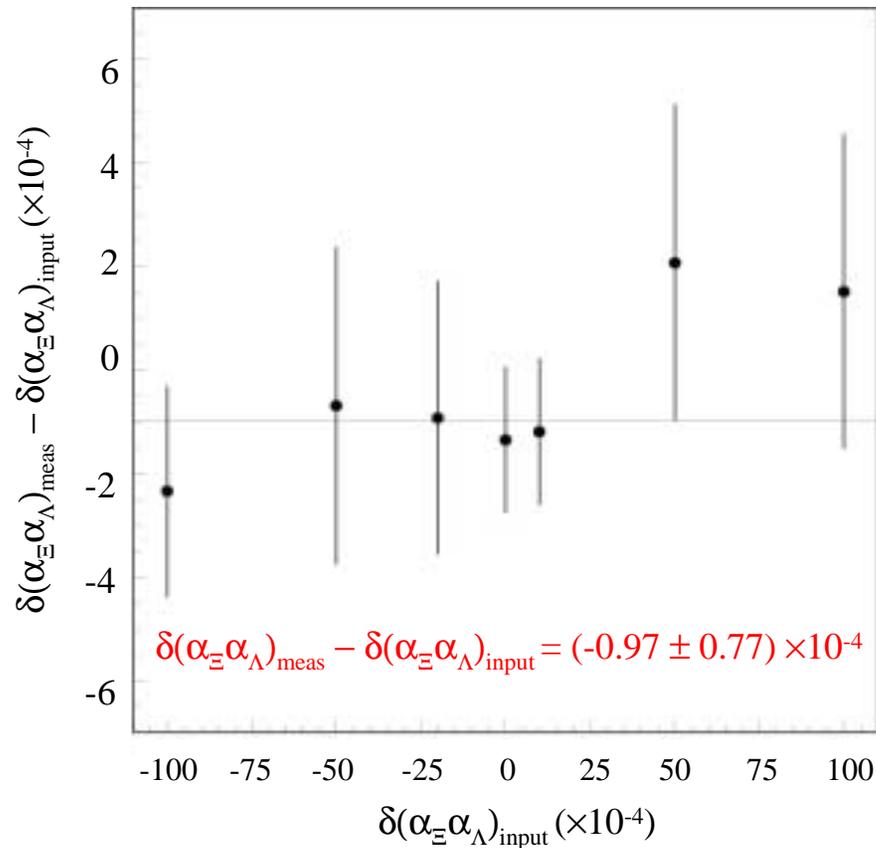
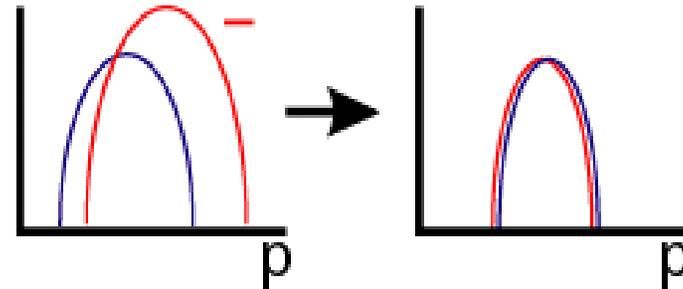
- The systematic uncertainties are established using data and thus limited by the sample statistics.

| Study             | $\delta A_{\Xi\Lambda} (10^{-4})$ |
|-------------------|-----------------------------------|
| Polarization      | 0.4                               |
| Rate dependence   | 3.4                               |
| Background        | 2.4                               |
| Hodo. Eff.        | 1.7                               |
| Cal. Eff.         | 1.8                               |
| PWC Eff.          | 2.7                               |
| B Field           | 2.2                               |
| Interaction diff. | 0.5                               |
| <b>TOTAL</b>      | <b>6.2</b>                        |

- Preliminary result:  $A_{\Xi\Lambda} = [-7 \pm 12(\text{stat}) \pm 6.2(\text{sys})] \times 10^{-4}$
- In the process of analyzing the full data samples, anticipate to complete by the end of this summer.

# CP Violation in Hyperon Decays: Weighting Method

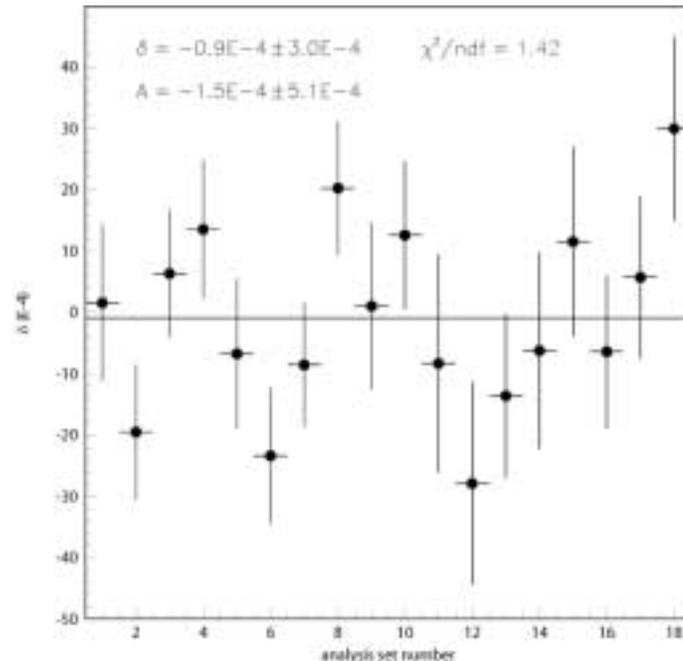
- Weight the  $\Xi^-$  and  $\Xi^+$  samples with three kinematic and geometric variables  $w(y_{\text{col}}, p_y, p_z)$ , so that they have the same distribution



- Tested using Monte Carlo
- Returns input asymmetry for various values

# CP Violation in Hyperon Decays: Weighting Method

- About 10% of the 99 data, over 120 million  $\Xi^-$  and 40 million  $\Xi^+$  events, has been analyzed.
- This sample is divided into 18 different subsets. Weighting is done separately for each subset, and a result is calculated.



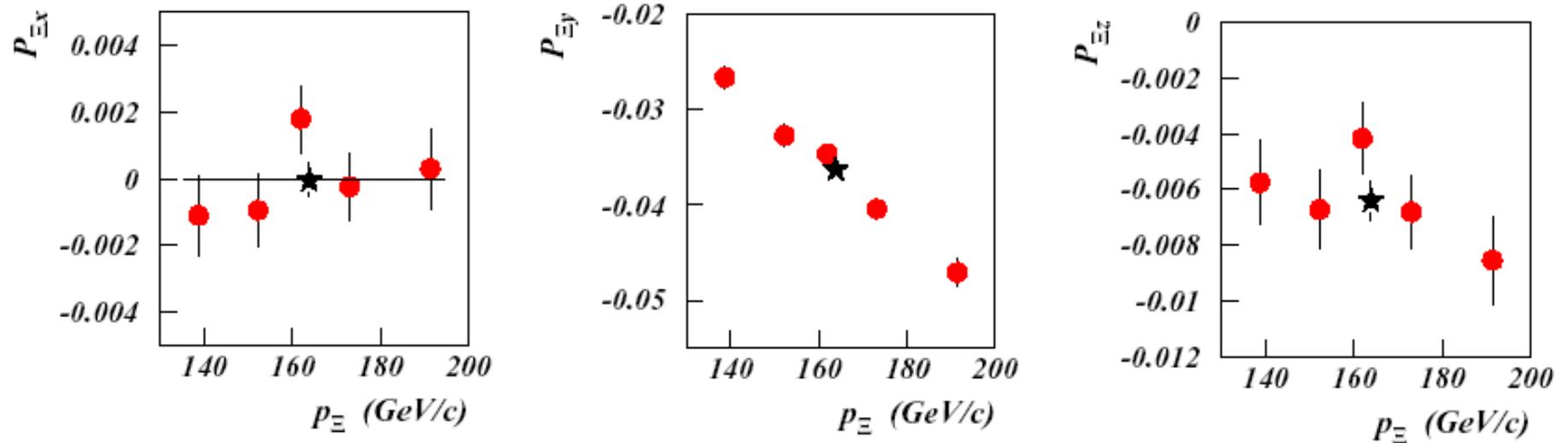
- Systematic studies have been done, which give a preliminary result of:

$$A_{\Xi\Lambda} = (-1.5 \pm 5.1(\text{stat}) \pm 4.8(\text{syst})) \times 10^{-4}$$

- This analysis should be complete by the end of the summer.

## Production Polarization of $\Xi^-$ Hyperon

- Use the +3 mrad and -3 mrad polarized samples collected in 1999.
- Measure the components of polarization in the spectrometer:



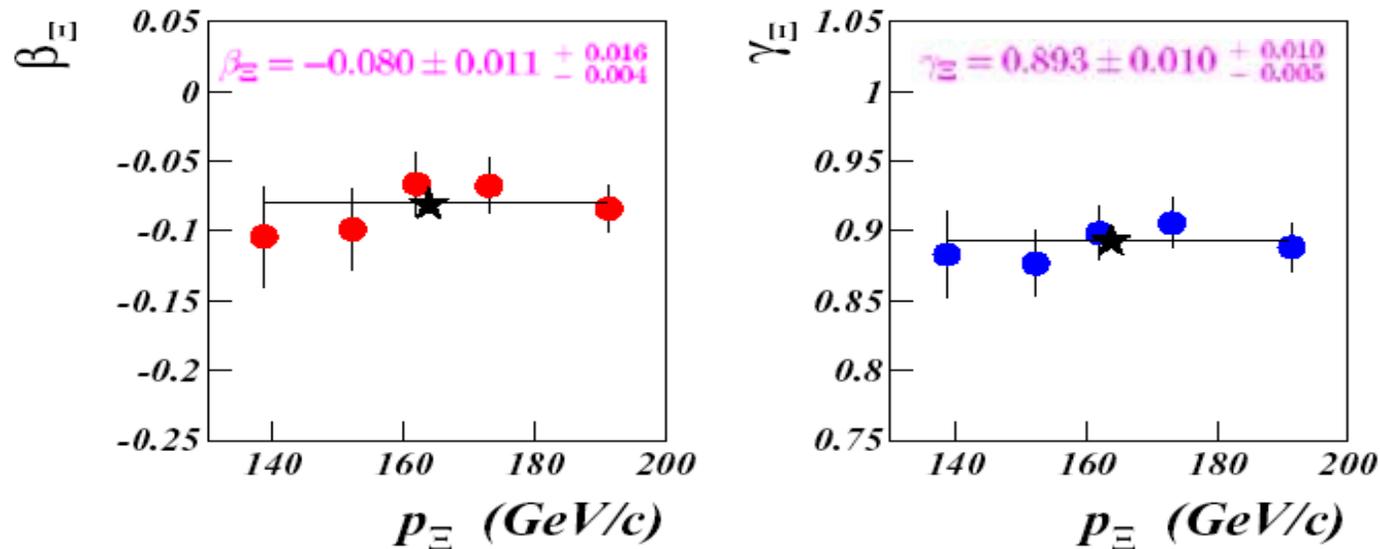
- Analysis is essentially finished. Remaining task is to look at a few systematic uncertainties more carefully.

## Decay Parameters $\beta_{\Xi}$ and $\gamma_{\Xi}$ of $\Xi^- \rightarrow \Lambda\pi^-$ Decay

- CP asymmetry of  $\Xi$  depends on the strong phase-shift difference:

$$A_{\Xi} = -\tan(\delta_P - \delta_S) \sin(\phi_P - \phi_S)$$

- Analyze the polarized 1999 data to obtain:



- Using  $\alpha_{\Xi} = -0.456 \pm 0.008$ , determine a **preliminary** result on the strong phase-shift difference for  $\Lambda\pi$  scattering:

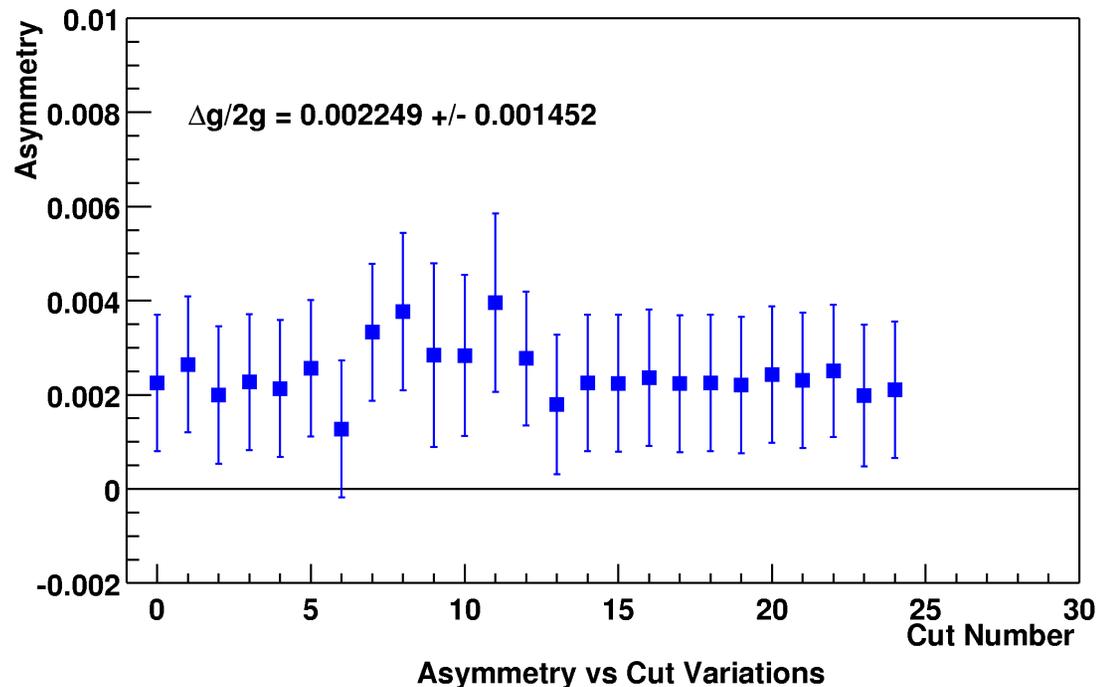
$$\delta_{p3} - \delta_{s3} = \tan^{-1}(\beta_{\Xi}/\alpha_{\Xi}) = (9.9 \pm 1.4 \pm \frac{2.0}{0.5})^{\circ}$$

## CP Violation in Charged $K \rightarrow \pi \pi^+ \pi^-$ Decays

- Theoretical predictions range from  $10^{-4}$  to  $10^{-6}$ .
- Based on 41.8 million  $K^+$  and 12.4 million  $K^-$  decays from the 1997 run,

$$\Delta g/2g = [2.2 \pm 1.5(\text{stat}) \pm 3.7(\text{syst})] \times 10^{-3}$$

which is  $\sim 2$  better than the current best limit.



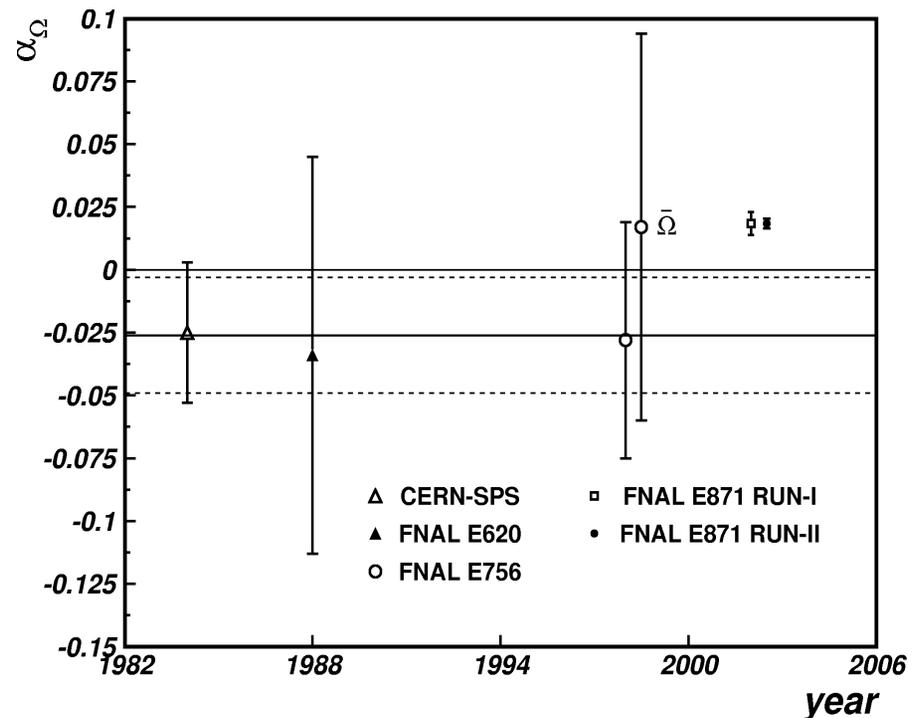
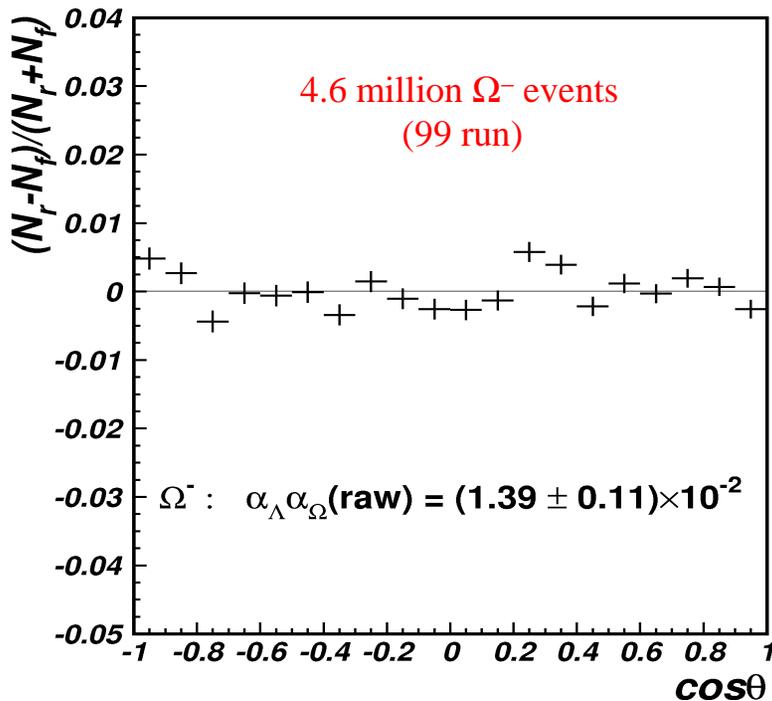
- Now refining the analysis to reduce the systematic effect before looking at the complete data set.
- Hope to finish the analysis in one year.

## Decay Parameter $\alpha_\Omega$ of $\Omega^- \rightarrow \Lambda K^-$ Decay

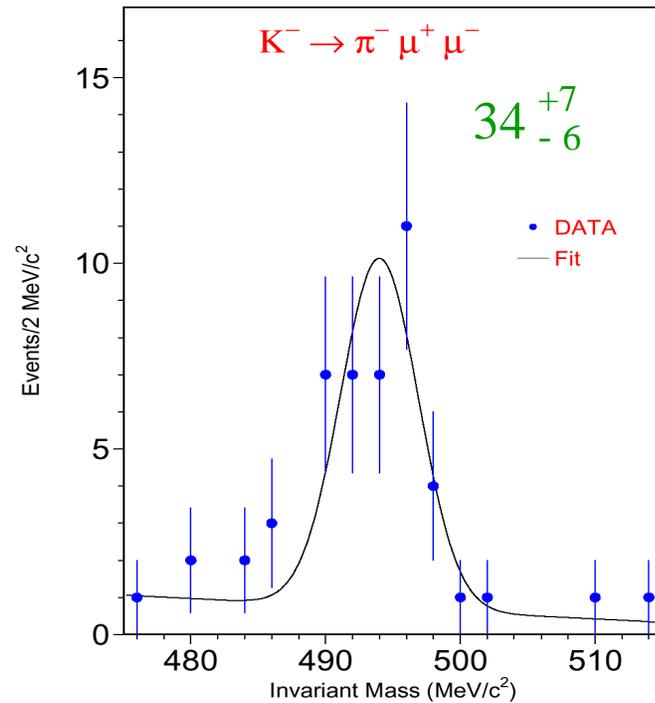
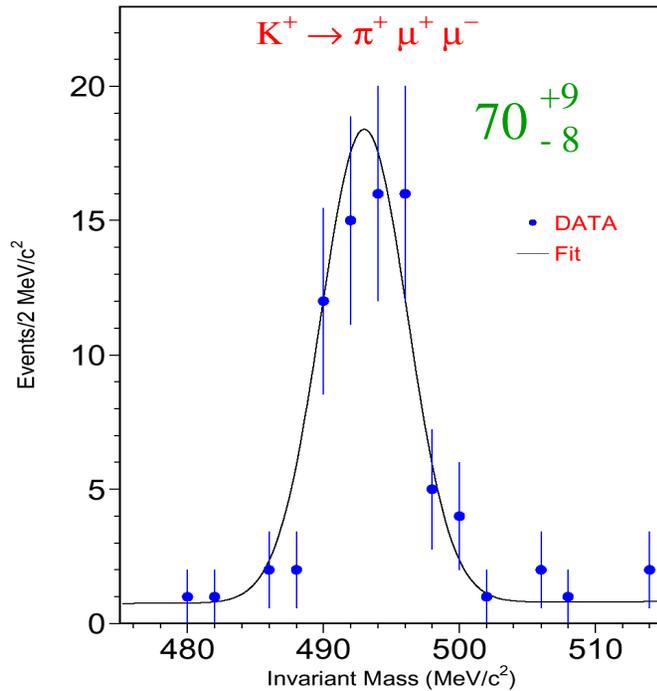
- Theoretical calculations predict the decay is parity conserving:

$$\alpha_\Omega = 0$$

- Analyzed 1.2 million  $\Omega^- \rightarrow \Lambda K^-$  events from the 1997 run, and 4.6 million  $\Omega^- \rightarrow \Lambda K^-$  decays in the 1999 run.
- Expect to finish within a year.



# $K^\pm \rightarrow \pi^\pm \mu^+ \mu^-$ Events in 1997 Run

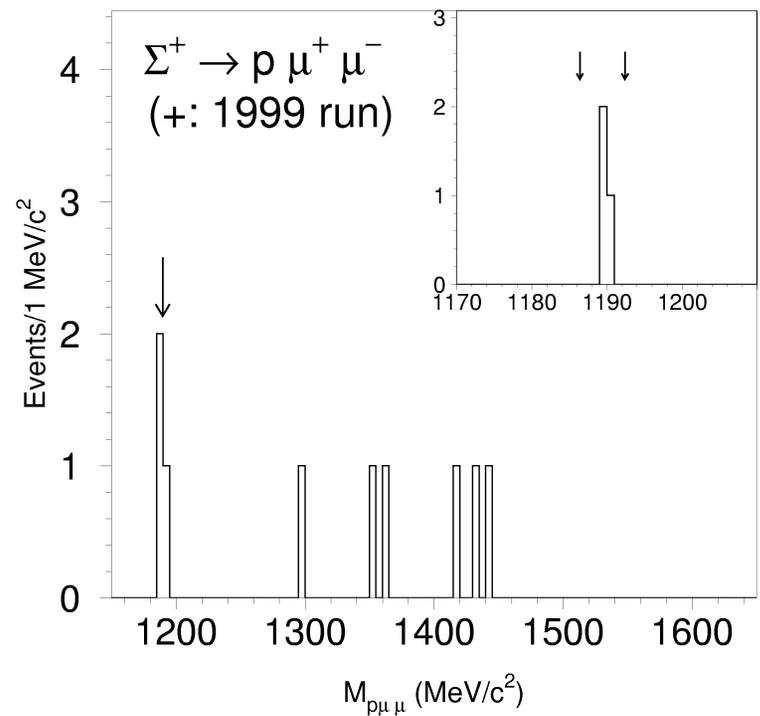
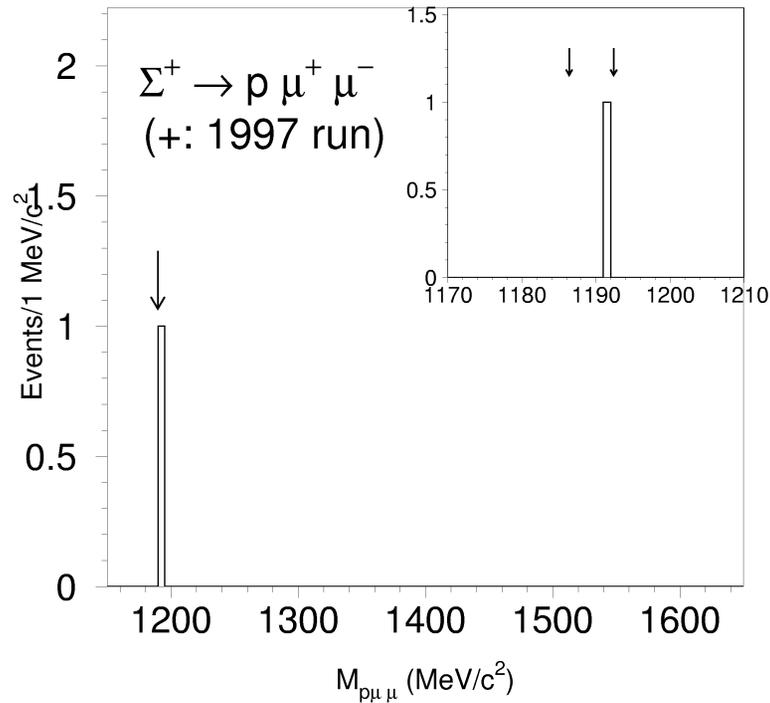


- Combined result (published):

$$B(K^\pm \rightarrow \pi^\pm \mu^+ \mu^-) = (9.8 \pm 1.0 \pm 0.5) \times 10^{-8}$$

- Resolved the disagreement between BNL E865 and E787 results.

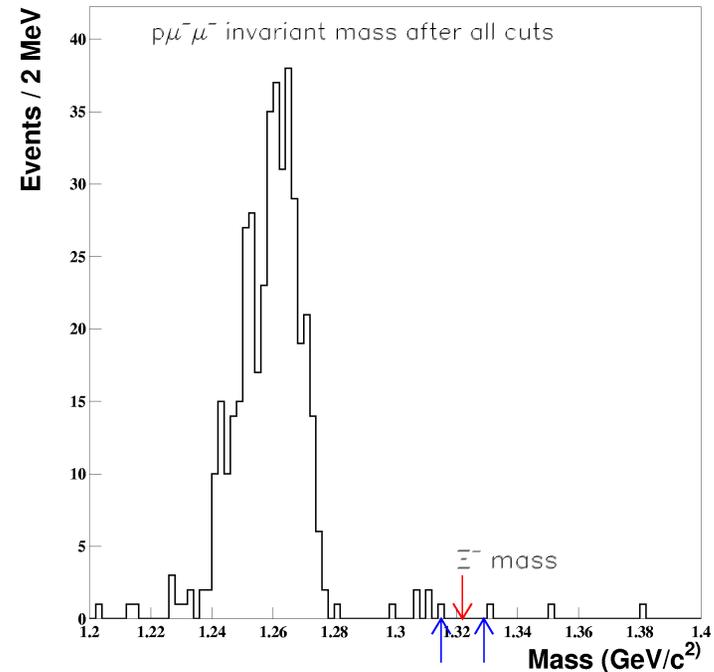
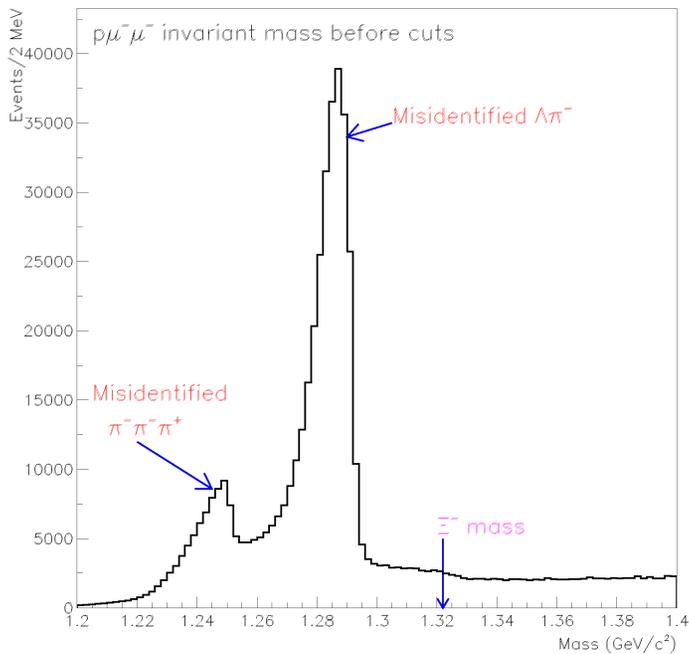
# First Observation of $\Sigma^+ \rightarrow p \mu^+ \mu^-$ Decay



- A suppressed decay in Standard Model.
- Ongoing effort is to determine the branching ratio of this decay, and systematic study.
- Will finish this analysis within this year.

# Search For $\Xi^- \rightarrow p\mu^- \mu^-$ Decay

- A probe sensitive to lepton-number violation, and Majorana-type of  $\nu_\mu$ .



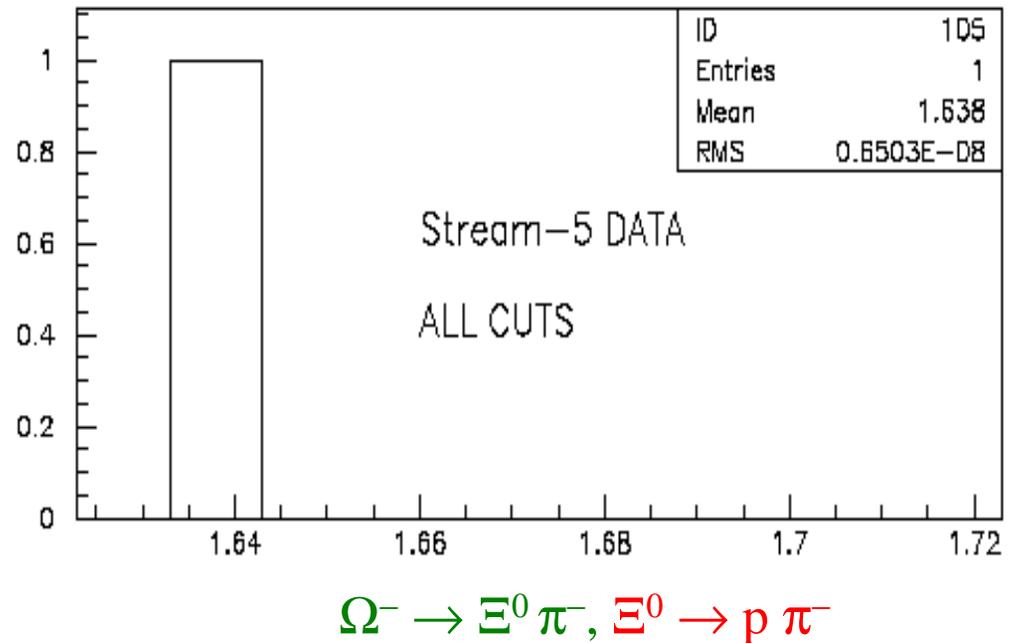
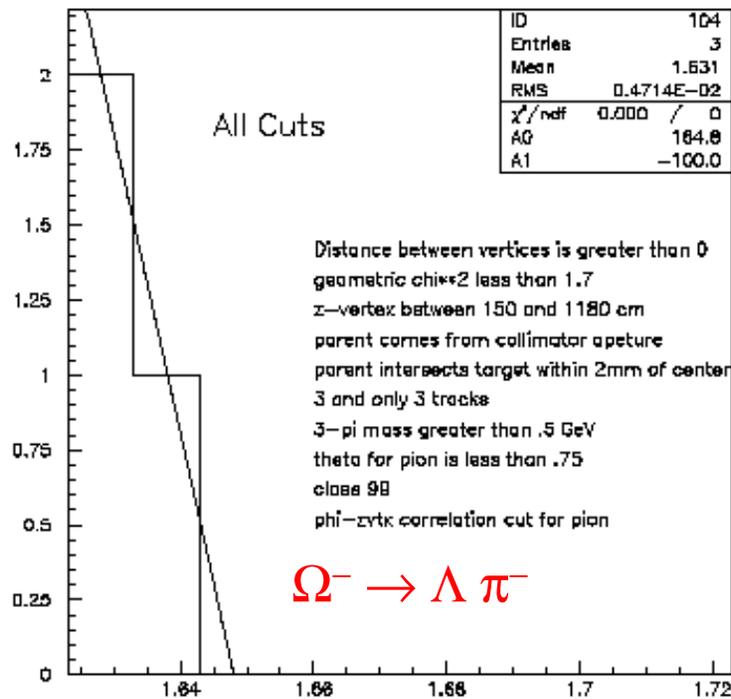
- Based on the 1997 data, obtained a preliminary result (more than 3 orders of magnitude better than the current limit):

$$B(\Xi^- \rightarrow p\mu^-\mu^-) < 1.06 \times 10^{-7} \quad 90\% \text{ c.l.}$$

- Preparing an article for publication, should be done by this summer.

## Search For $\Delta S = 2$ Decays

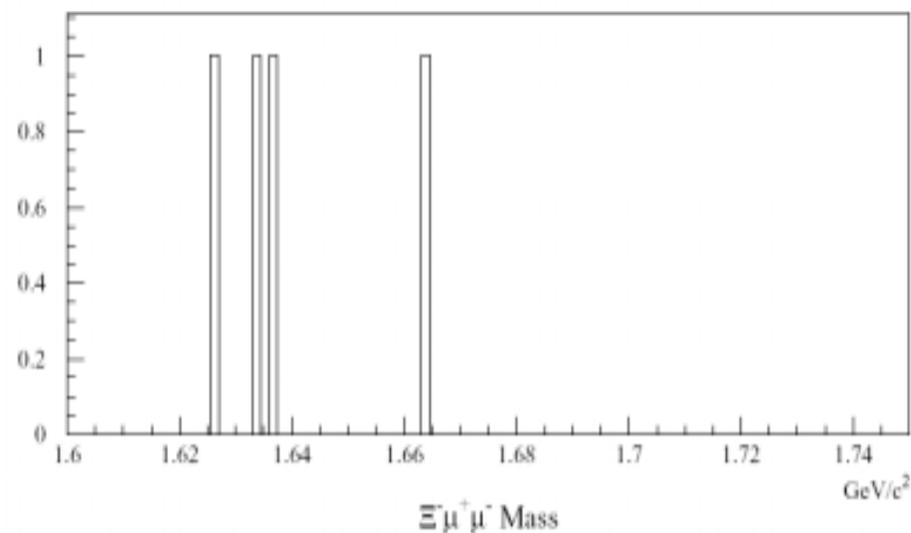
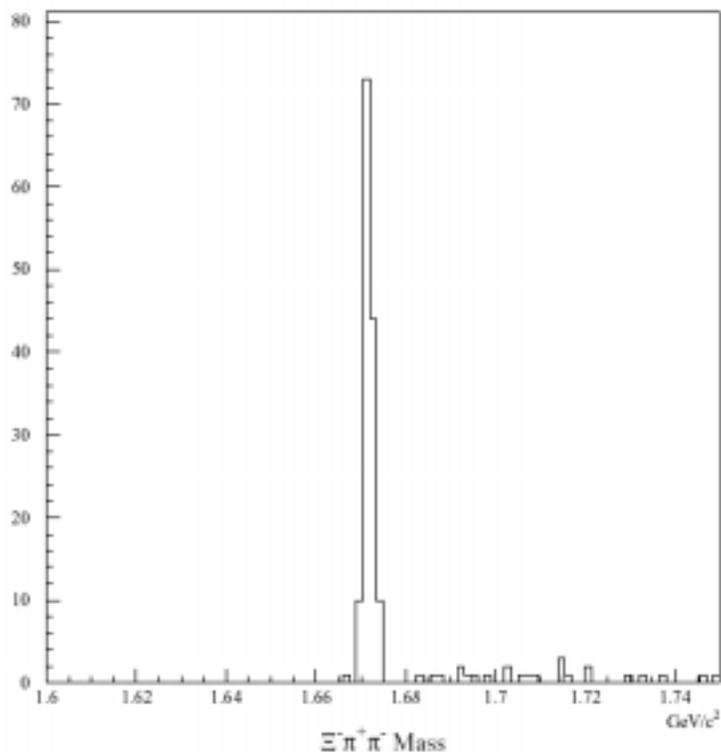
- Analysis was done with 1997 data set.



- Obtained limits that are at least one order of magnitude better than the world limits.
- An article is being drafted for publication; should be done by this summer.

## $\Omega^- \rightarrow \Xi^- \pi^+ \pi^-$ and $\Omega^- \rightarrow \Xi^- \mu^+ \mu^-$ Decays

- Analyzed all 1997 and 1999 data.



- Will set a new limit on  $\Omega^- \rightarrow \Xi^- \mu^+ \mu^-$  decay.

- The  $\Omega^- \rightarrow \Xi^- \pi^+ \pi^-$  sample is about 30 times larger than the world record of 4 events
- In the process of drafting an article to report on these results.

## Theses

### Ph.D. theses:

1. 'A Search for Direct CP Violation in  $K^{\pm} \rightarrow \pi^{\pm} \pi^{\pm} \pi^{\mp}$  Decays', W.S. Choong, University of California, Berkeley, 2000.
2. 'Recherche de la Violation CP dans les desintegrations d'hyperons', N. Leros, University of Lausanne, 2001.
3. 'A Search for a Lepton-Number-Violating Decay of the Cascade-minus Hyperon', D. Rajaram, Illinois Institute of Technology, 2002.
4. 'Measurement of the  $\Xi^{-}$  Polarization and Decay Parameters of  $\Xi^{-} \rightarrow \Lambda \pi^{-}$  Decay', M. Huang, University of Virginia, 2003.

On-going Ph.D. candidate:

T. Holmstrom, University of Virginia.

### M.S. theses:

1. 'Design and Performance of a High-Rate Photomultiplier Base', D. Rajaram, University of Virginia, 1996.
2. ' $\Xi^{-}$  Polarization Measurement in pCu Reactions at 800 GeV', Zaida del Rosario Urrutia del Cid, University of Guanajuato, 2000.
3. ' $\Omega^{-}$  Polarization Measurement in pCu Reactions at 800 GeV', Mario Ranferi Gutierrez Morales, University of Guanajuato, 2000.

# Publicatons

## Published articles:

1. ‘Observation of the Decay  $K^- \rightarrow \pi^- \mu^+ \mu^-$  and Measurements of the Branching Ratios for  $K^\pm \rightarrow \pi^\pm \mu^+ \mu^-$ ’, H.K. Park et al., Phys.Rev.Lett. **88** (2002) 111801.
2. ‘Tripling the Data Set for the HyperCP Experiment’, C. White et al., IEEE Nucl. Sc. **49** (2002) 568.
3. ‘Upgraded DAQ System for the HyperCP Experiment’, C. White & T. Jones et al., Nucl. Instrum. Meth. **A474** (2001) 67.
4. ‘A High-Throughput Data Acquisition System for the HyperCP Experiment’, Y.C. Chen et al., Nucl. Instrum. Meth. **A455** (2000) 424.

## Articles in preparation:

4 manuscripts on instrumentation (spectrometer, wire chambers, calorimeter, data processing)

5 manuscripts on physics results (CP violation in hyperon decay, measurement of decay parameters  $\beta_{\Xi}$  and  $\gamma_{\Xi}$ , search for  $\Xi^- \rightarrow p \mu^- \mu^-$  decay, search for  $\Delta S = 2$   $\Omega^-$  decay, branching ratios of  $\Omega^- \rightarrow \Xi^- \pi^+ \pi^-$  and  $\Omega^- \rightarrow \Xi^- \mu^+ \mu^-$  decays)

## Conclusions

- FNAL E871 has collected a large number of high-quality strange-particle decays.
- Analyses on hunting for direct CP violation in  $\Xi-\Lambda$  decays have made significant progress; preliminary results are already an order of magnitude better than the current limit.
- The large number of  $\Xi$ ,  $\Omega$ , and K decays permits a variety of precise measurements and rare decay searches.
- Most of the analyses should be finished within a year.
- In principle, others are welcome to extract additional physics topics or extend the existing analyses to the entire data set.