Rare Decays of the Omega Hyperon from the Fermilab HyperCP Experiment

DPF, Philadelphia, Pa. April 2003

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Decay Channels

Fully Reconstructed 5-track (Used for normalization):

$\Omega^- \to \Lambda^0 K^-$

$\to \pi^+\pi^-\pi^-$

$\to p\pi^-$

Signal Mode (Contribution of quark diagrams: tree, penguin, double gluon):

$\Omega^- \to \Xi^-\pi^+\pi^-$

$\to \Lambda^0\pi^-$

$\to p\pi^-$

Flavor Changing Neutral Current :

Muon mode:

$\Omega^- \to \Xi^-\mu^+\mu^-$

$\to \Lambda^0\pi^-$

$\to p\pi^-$

Electron mode:

$\Omega^- \to \Xi^-e^+e^-$

$\to \Lambda^0\pi^-$

$\to p\pi^-$

Antiparticle Modes :

(tests of CPT)

Previous Observations and Theoretical Expectations

- Previously 4 $\Omega^- \to \Xi^-\pi^+\pi^-$ events observed by M. Bourquin, et al., 1984.

- $\Omega^- \to \Xi^-\pi^+\pi^-$ hard to distinguish from $\Omega^- \to \Xi^{0*}_{1530}\pi^-$ where $\Xi^{0*}_{1530} \to \Xi^-\pi^+$

- Branching Ratios (based on the same 4 events with different normalizations)

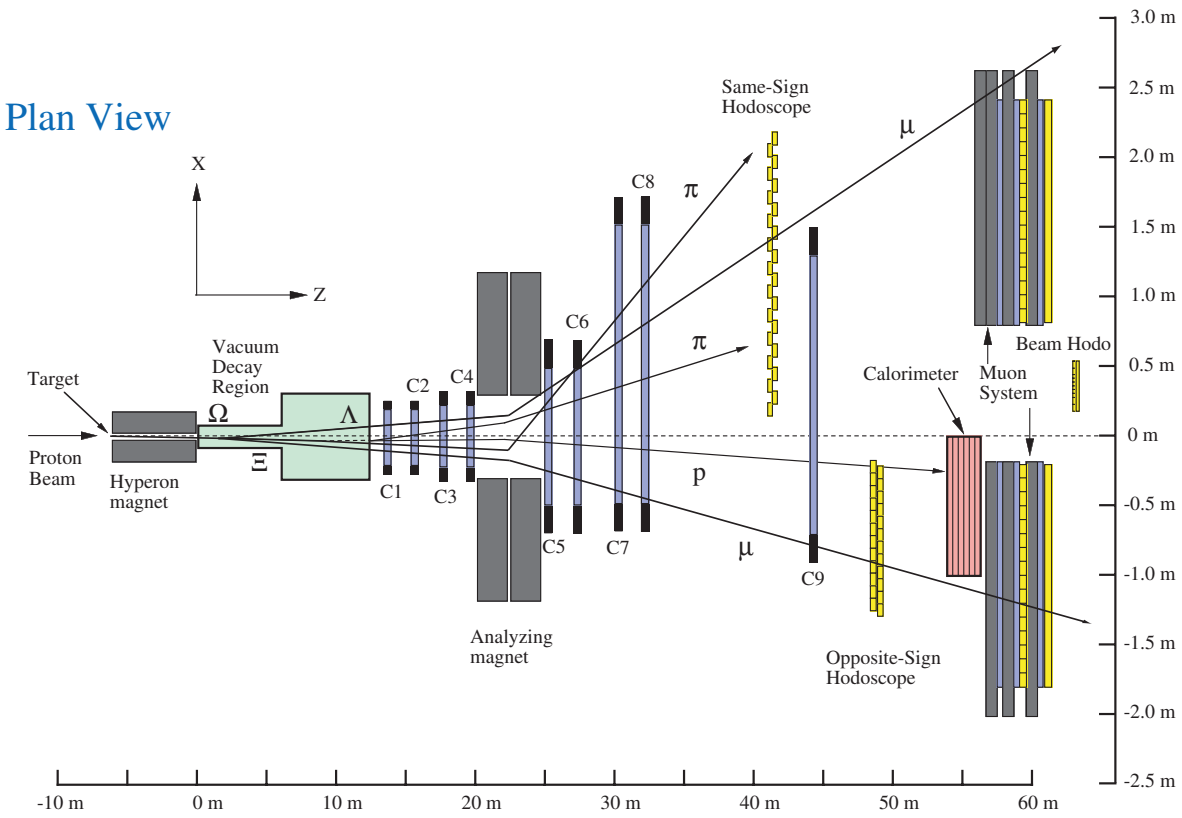
Assumed Mode	Branching Ratio
$\Omega^- \to \Xi^-\pi^+\pi^-$	$4.3^{+3.4}_{-1.3} \times 10^{-4}$
$\Omega^- \to \Xi^{0*}_{1530}\pi^-$	$6.4^{+5.1}_{-2.0} \times 10^{-4}$

- Theoretical Expected Branching Ratios of Flavor-Changing Neutral-Current decay modes in the quark model by R. Safadi and P. Singer, Phys. Rev. D 37 (1988) 697, Erratum: Phys. Rev D 42(1990) 1856:

FCNC Mode	Branching Ratio Estimate
$\Omega^- \to \Xi^-\mu^+\mu^-$	4.0×10^{-8}
$\Omega^- \to \Xi^-e^+e^-$	8.0×10^{-7}

These Estimates are Based on a 1×10^{-4} BR for $\Omega^- \to \Xi^-\gamma$.

HyperCP Experiment



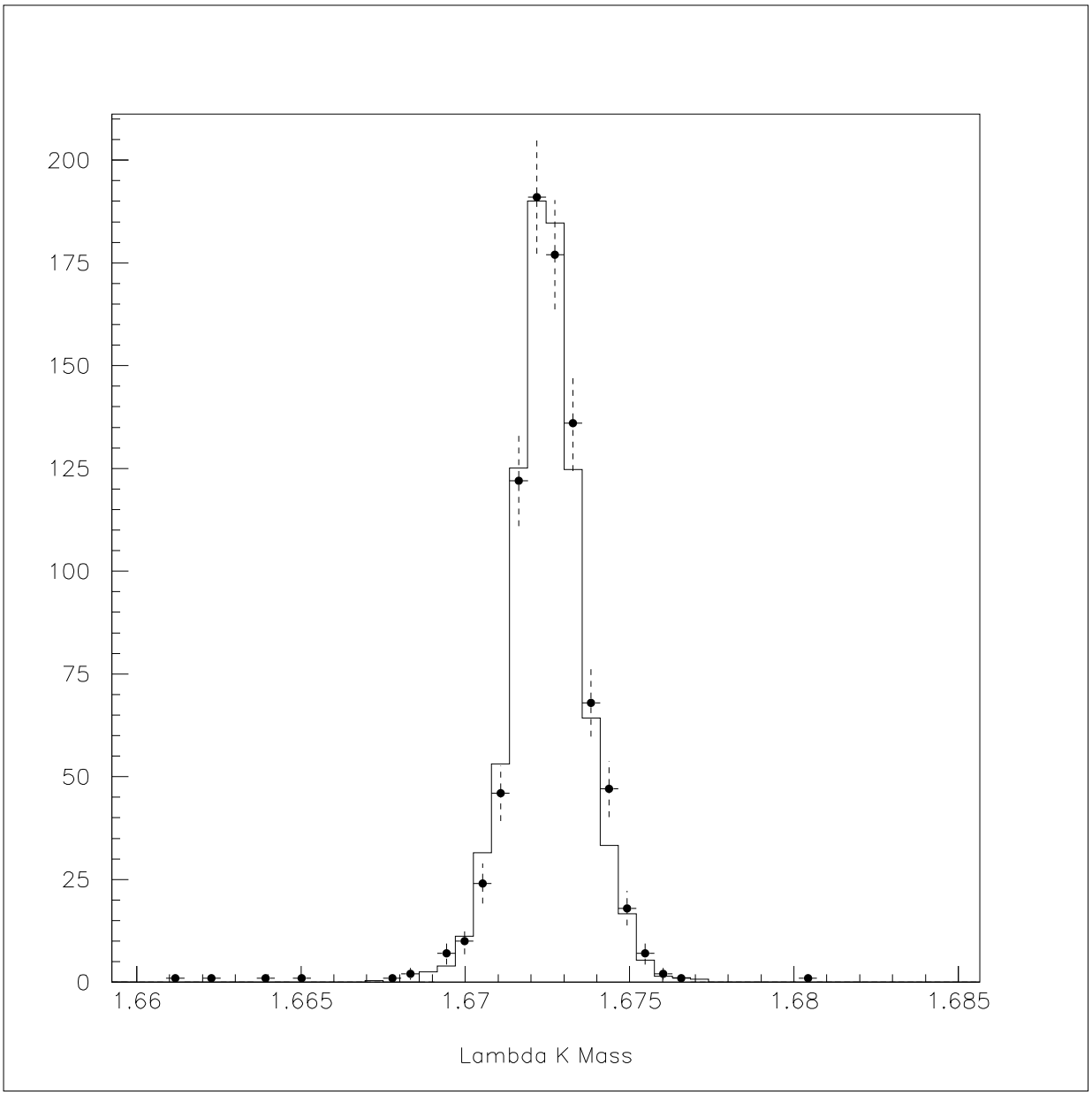
- HyperCP designed to measure CP violation in Ξ^- and Λ decays
- Used the full HyperCP Data Set (97 and 99 runs) both Positive and Negative Hyperon beam Polarities:
- For Corresponding Omega 3-track Analysis $\Omega^- \rightarrow \Lambda^0 K^-$ we reconstructed approximately 19×10^6 events.
- Muon identification
- No EM calorimeter

$\Omega^- \to \Lambda^0 K^-$ (5-track) Selection Criteria

- 3 negative and 2 positive tracks
- All vertices within decay volume
- Ω^- vertex upstream of K^- and Λ^0 vertices
- Tracks form good vertices
- Total momentum between 120 and 220 GeV/c
- $p\ \pi^-$ invariant mass within 3σ of Λ^0 mass
- $\pi^+\ \pi^-\ \pi^-$ invariant mass within 3σ of K^- mass
- Reconstructed Omega track within the aperture of the hyperon magnet
- No muon hodoscope hits

- $\overline{\Omega}^+$ mode had all cuts the same except 3 positive and 2 negative tracks

Observed $\Omega^- \to \Lambda^0 K^-$ (5-track) Events

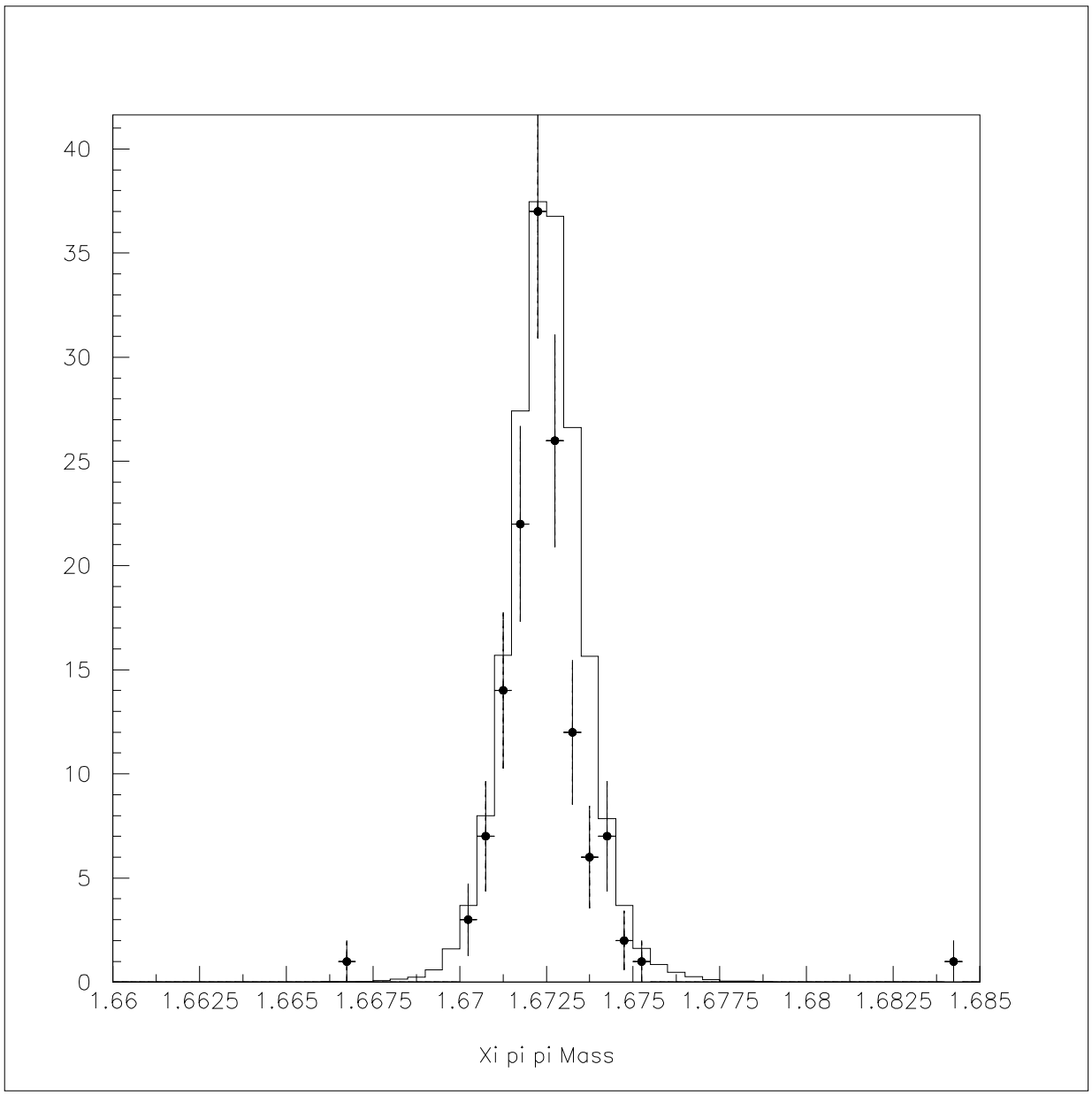


$\Omega^- \to \Xi^-\pi^+\pi^-$ Selection Criteria

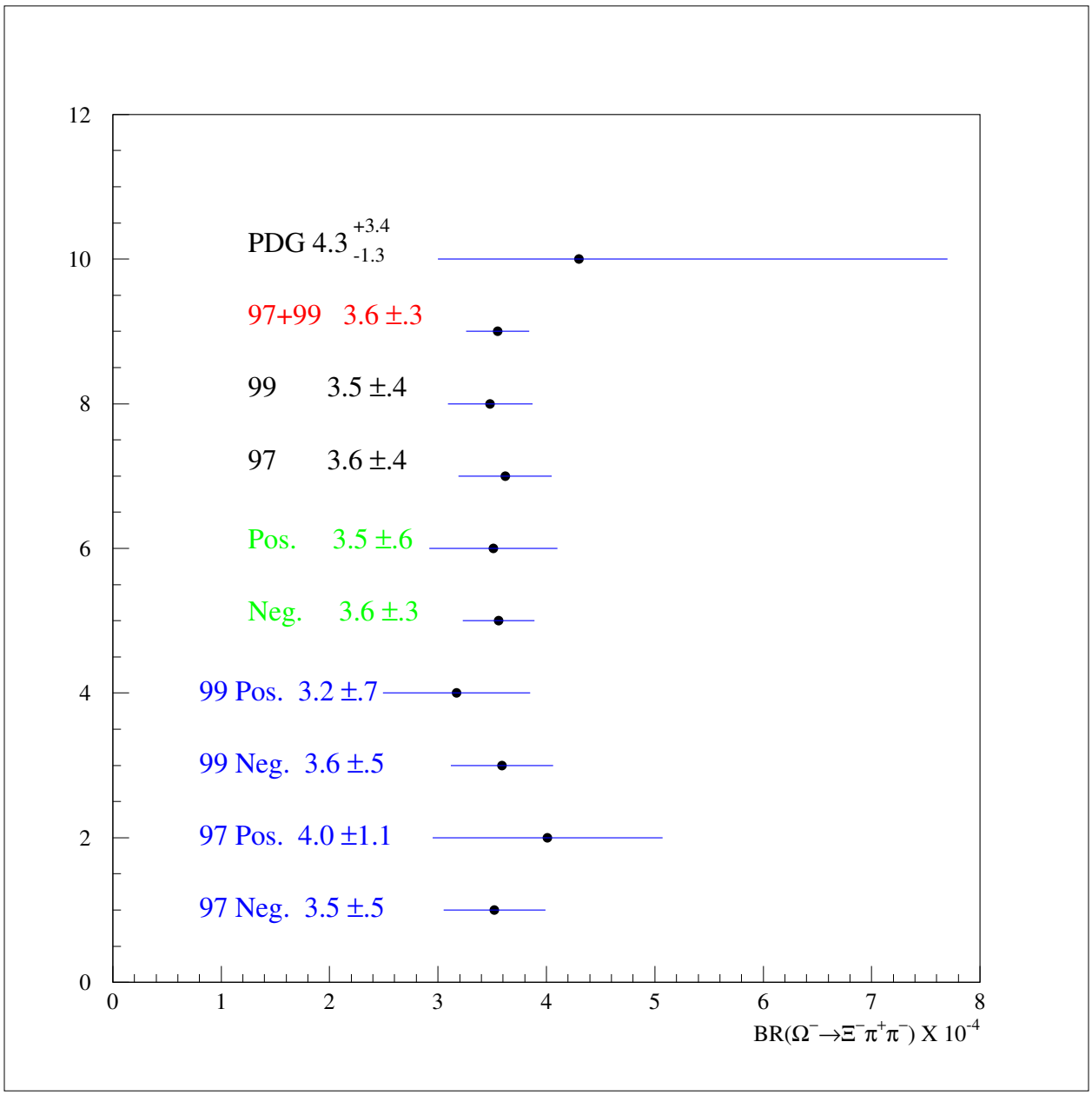
- 3 negative and 2 positive tracks
- All vertices within decay volume
- Ω^- vertex upstream of Ξ^- vertex
- Ξ^- vertex upstream of Λ^0 vertex
- Tracks form good vertices
- Total momentum between 120 and 220 GeV/c
- $p\ \pi^-$ invariant mass within 3σ of Λ^0 mass
- $\Lambda^0\ \pi^-$ invariant mass within 3σ of Ξ^- mass
- Reconstructed Omega track within the aperture of the hyperon magnet
- No muon hodoscope hits

- $\overline{\Omega}^+$ mode had all cuts the same except 3 positive and 2 negative tracks

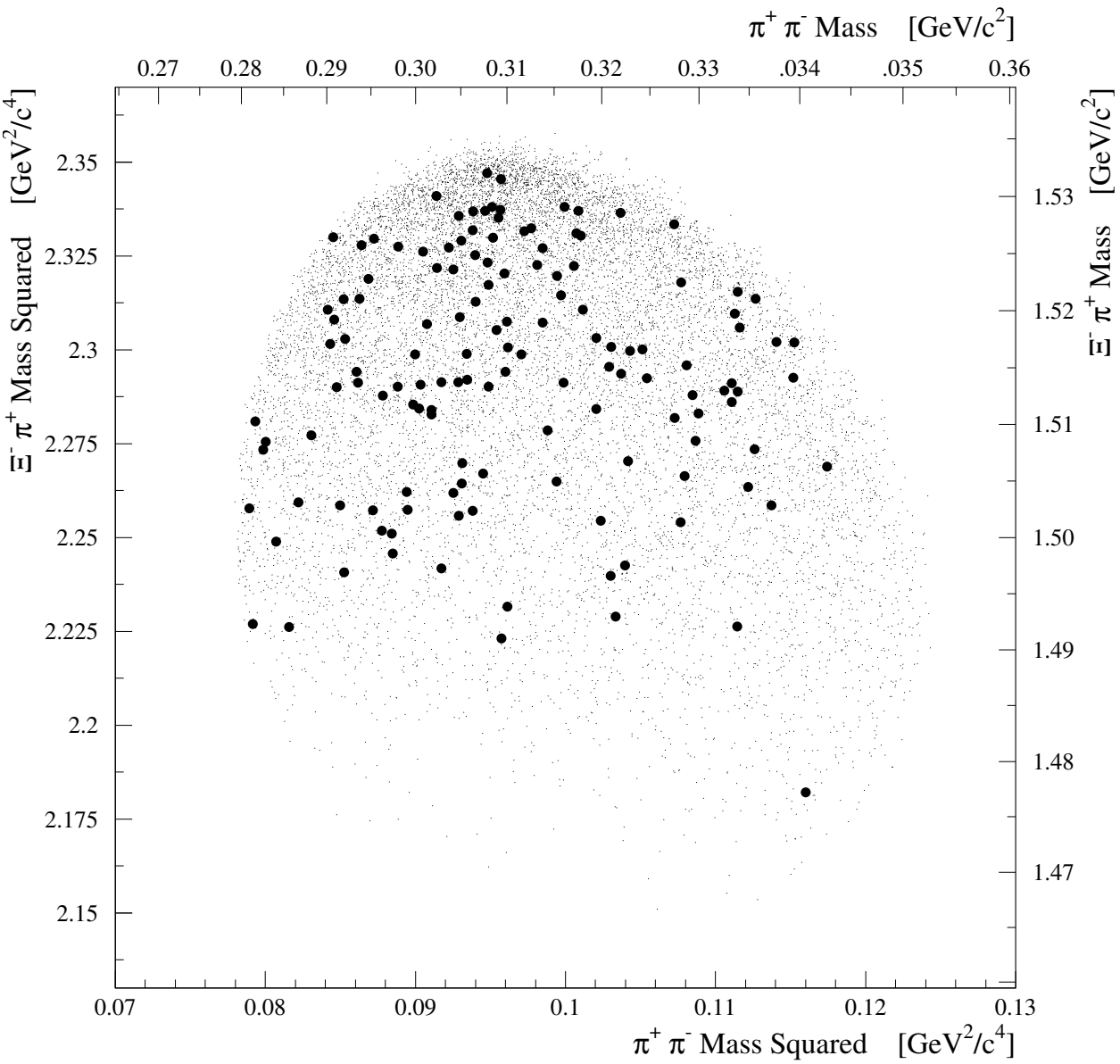
Observed $\Omega^- \to \Xi^-\pi^+\pi^-$ Events



Measured Branching Ratio for $\Omega^- \to \Xi^-\pi^+\pi^-$ and $\overline{\Omega}^+ \to \overline{\Xi}^+\pi^+\pi^-$



Observed $\Omega^- \to \Xi^-\pi^+\pi^-$ Events

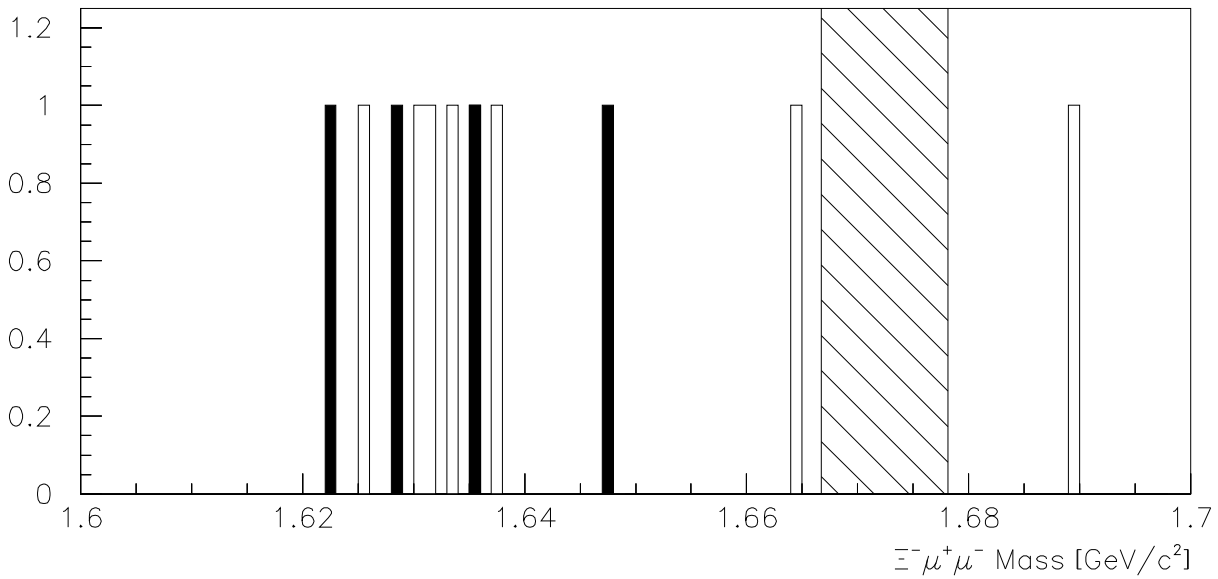


$\Omega^- \to \Xi^- \mu^+ \mu^-$ Selection Criteria

- 3 negative and 2 positive tracks
- All vertices within decay volume
- Ω^- vertex upstream of Ξ^- vertex
- Ξ^- vertex upstream of Λ^0 vertex
- Tracks form good vertices
- Total momentum between 120 and 220 GeV/c
- $p\ \pi^-$ invariant mass within 3σ of Λ^0 mass
- $\Lambda^0\ \pi^-$ invariant mass within 3σ of Ξ^- mass
- Reconstructed Omega track within the aperture of the hyperon magnet
- At least 1 muon track identified by an active hodoscope paddle in muon system

- $\overline{\Omega}^+$ mode had all cuts the same except 3 positive and 2 negative tracks

Search For $\Omega^{\pm} \to \Xi^{\pm}\mu^{+}\mu^{-}$



- Negative (Positive) beam is white (black) filled histogram.
- Hatched region is $\pm 3\sigma$ search box.
- Candidate Events and Background Estimates:

Beam Polarity	Events in Box	Background Estimate	BR at 90% C.I.
Negative	0	0.5	$< 6.9 \times 10^{-6}$
Positive	0	0.0	$< 2.9 \times 10^{-5}$

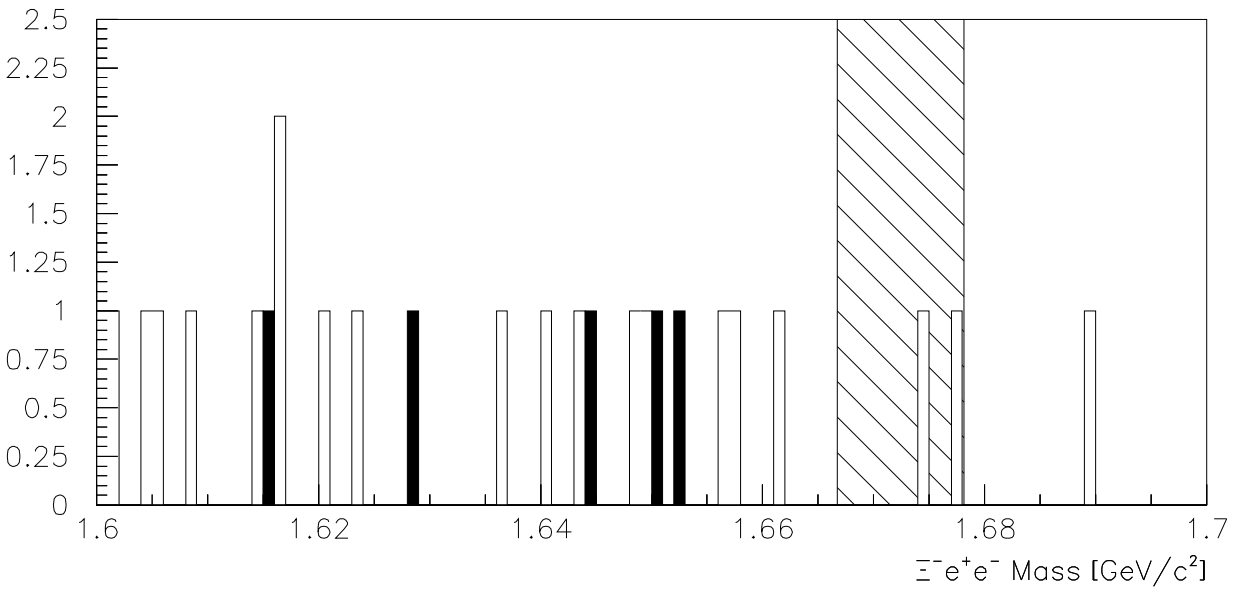
- Combined Branching Ratio Limit is $< 6.1 \times 10^{-6}$ at 90% C.I.

$\Omega^- \to \Xi^- e^+ e^-$ Selection Criteria

- 3 negative and 2 positive tracks
- All vertices within decay volume
- Ω^- vertex upstream of Ξ^- vertex
- Ξ^- vertex upstream of Λ^0 vertex
- Tracks form good vertices
- Total momentum between 120 and 220 GeV/c
- $p\ \pi^-$ invariant mass within 3σ of Λ^0 mass
- $\Lambda^0\ \pi^-$ invariant mass within 3σ of Ξ^- mass
- Reconstructed Omega track within the aperture of the hyperon magnet
- $\Omega^- \to \Xi^- \pi^+ \pi^-$ removed at $\pm$ 5 σ.
- No activity in muon hodoscope system

- $\overline{\Omega}^+$ mode had all cuts the same except 3 positive and 2 negative tracks

Search For $\Omega^{\pm} \to \Xi^{\pm} e^{+} e^{-}$



- Negative (Positive) beam is white (black) filled histogram.
- Hatched region is $\pm 3\sigma$ search box.
- Candidate Events and Background Estimates:

Beam Polarity	Events in Box	Background Estimate	BR at 90% C.I.
Negative	2	2.5	$< 2.4 \times 10^{-5}$
Positive	0	1.0	$< 3.8 \times 10^{-5}$

- Combined Branching Ratio Limit is $< 1.4 \times 10^{-5}$ at 90% C.I.

Extending our Data Sample

- The HyperCP data set has 2.5×10^9 examples of $\Xi^{\pm} \rightarrow \Lambda\pi^{\pm}$. We can search these for events with:

  1. A $\Xi^{\pm}$ mass within $\pm 3\sigma$ of nominal mass.
  2. An extra 4th track that originates upstream of the $\Xi^{\pm}$ vertex.
  3. A 5th partial track: an upstream segment pointing to the same vertex.
  4. The $\Xi^{\pm}$ not tracing back through the Hyperon Magnetic Channel to the target location indicating that the decaying particle was not a $\Xi^{\pm}$.

  Forcing the mass of the decaying particle to be Ω then yields more events for the Dalitz plot. Or, by using the muon identification system increases our reach for the FCNC decay mode limits, possibly to the point of discovery.

- We expect a $\sim$100 fold increase in our data sample for these five-track decay modes of the Omega Hyperon.

Hyperon 4-Body Beta Decay

- Omega Hyperons have an all charged track 4-Body Beta Decay that should be in our 5-track sample:

$$\Omega^- \rightarrow \Xi^-\pi^+e^-\overline{\nu}$$
$$\rightarrow \Lambda\pi^-$$
$$\rightarrow p\pi^-$$

- It has a distinctive vertex topology.
- A characteristic Beta Decay spectrum.
- Events should be consistent with Omega lifetime.

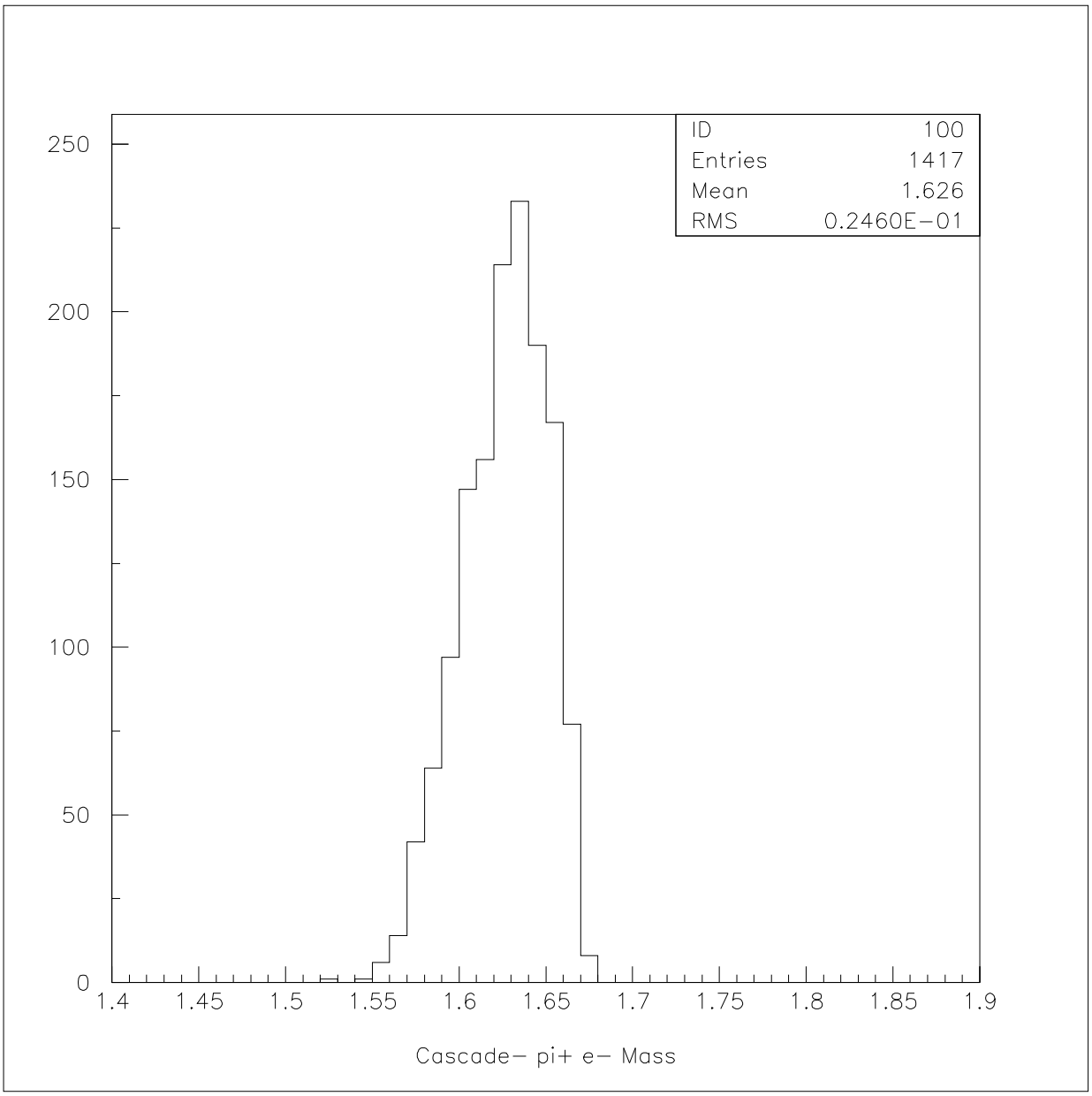
- A $\Delta s = -\Delta q$ Forbidden mode can also be searched for:

$$\Omega^- \rightarrow \Xi^-\pi^-e^+\nu$$
$$\rightarrow \Lambda\pi^-$$
$$\rightarrow p\pi^-$$

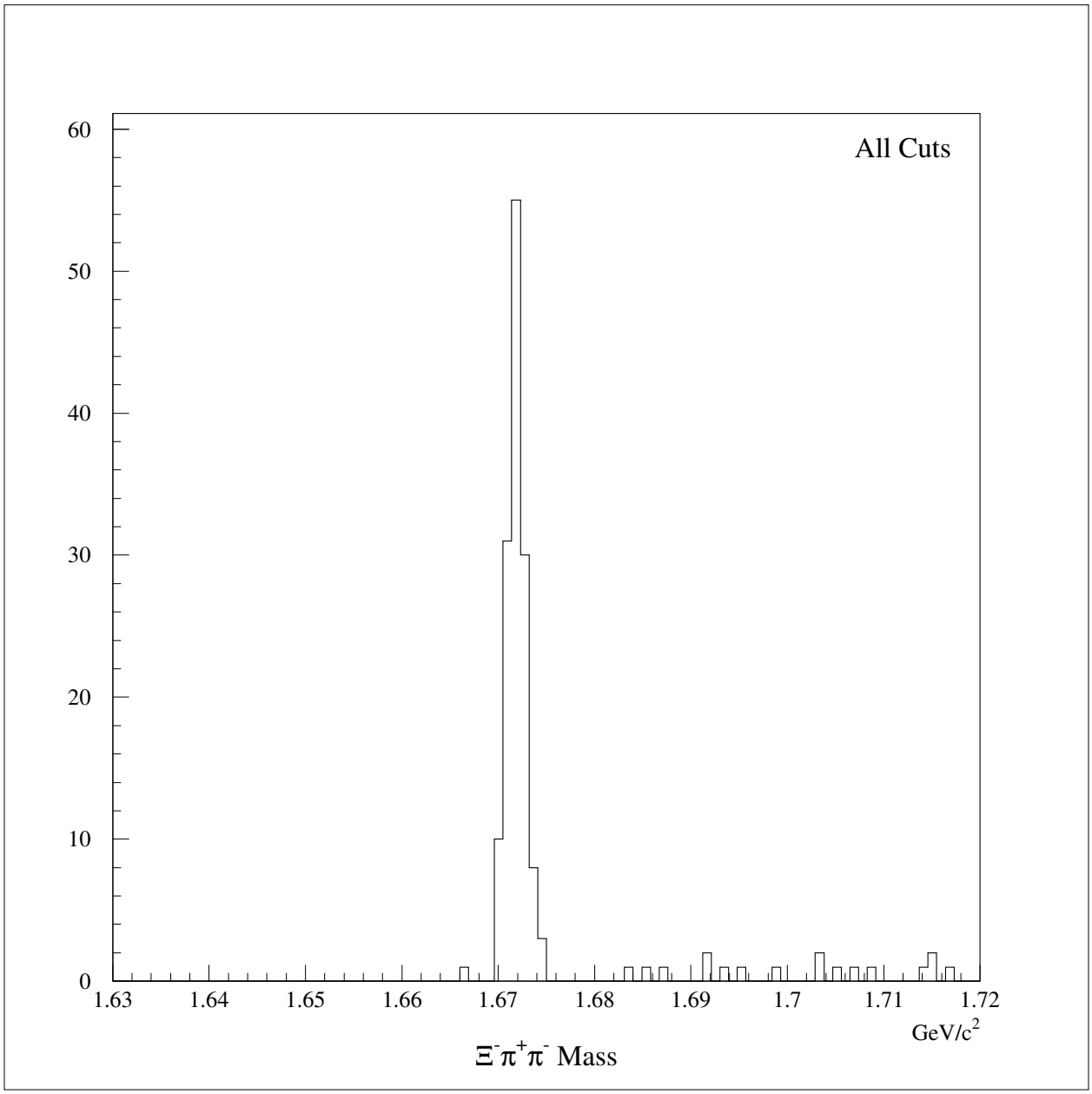
- Monte-Carlo Study of this mode shows a large acceptance.
- Background Study is underway; for example:

$$\Omega^- \rightarrow \Xi^-\pi^+\pi^-$$
$$\rightarrow \mu^-\overline{\nu}$$
or
$$\rightarrow e^-\overline{\nu}$$

Monte-Carlo Study of Hyperon 4-Body Beta Decay



Omega 4-body Beta Decay Search is Inspired by a Beta Type Spectrum Seen in the $\Omega^{\pm} \to \Xi^{\pm}\pi^{+}\pi^{-}$ Analysis



Conclusion

- With ∼35 times the number of previously observed $\Omega^- \to \Xi^-\pi^+\pi^-$ events, an improved measurement of the branching ratio is possible (statistical error $\sim 10\%$)
- Positive polarity data further increased statistics with $\overline{\Omega}^+ \to \overline{\Xi}^+\pi^-\pi^+$ events and is consistent with CPT conservation.
- The larger sample allowed study of $\Omega^- \to \Xi^{0*}_{1530}\pi^-$ where $\Xi^{0*}_{1530} \to \Xi^-\pi^+$. The uniformity of the Dalitz plot showed no sign of the resonance mode.
- Limits close to the theoretically expected for both of the Flavor-Changing Neutral-Current decays:
  1. $\Omega^\pm \to \Xi^\pm\mu^+\mu^-$ $< 6.1 \times 10^{-6}$ for 90% C.I.

     and
  2. $\Omega^\pm \to \Xi^\pm e^+e^-$ $< 1.4 \times 10^{-5}$ for 90% C.I.
- We expect a ∼100 fold improvement in events for all of the above modes using a sample of our data with a good $\Xi^\pm$ with an extra 4th track plus an upstream track segment for the 5th track.
- HyperCP MC study shows we can study 4-body Beta Decays such as $\Omega^- \to \Xi^-\pi^+e^-\overline{\nu}$.
- We hope to be able to study $\Delta s = -\Delta q$ Forbidden process in 4-body Beta Decays by comparing with a search for the decay $\Omega^- \to \Xi^-\pi^-e^+\nu$.