Rare Nonleptonic Decays of the Omega Hyperon: Measurement of the Branching Ratios for $\Omega^- \rightarrow \Xi^{*0}_{1530}\pi^-$ and $\Omega^- \rightarrow \Xi^-\pi^+\pi^-$

Oleg Kamaev
Illinois Institute of Technology

Fermilab interview
August 14, 2007

ILLINOIS INSTITUTE OF TECHNOLOGY

HyperCP (FNAL E871) Collaboration

A. Chan, Y.C. Chen, C. Ho, P.K. Teng

Academia Sinica, Taiwan

W.S. Choong, Y. Fu, G. Gidal, P. Gu, T. Jones, K.B. Luk, B. Turko, P. Zyla

University of California at Berkeley and Lawrence Berkeley National Laboratory

C. James, J. Volk

Fermilab

J. Felix

University of Guanajuato, Mexico

R. Burnstein, A. Chakravorty, D. Kaplan, L. Lederman, W. Luebke, D. Rajaram, H. Rubin, N. Solomey, Y. Torun, C. White, S. White

Illinois Institute of Technology

N. Leros, J. P. Perroud

Universite de Lausanne

R.H. Gustafson, M. Longo, F. Lopez, H.K. Park

University of Michigan

C. M. Jenkins, K. Clark

University of South Alabama

C. Dukes, C. Durandet, T. Holmstrom, M. Huang, L.C. Lu, K. Nelson

University of Virginia

Outline

- **The HyperCP Experiment**
- **Motivation for studying** $\Omega \to \Xi^{*0}(1530)\pi$
- **Analysis**
  - Monte Carlo Simulations
  - Reconstruction and Event Selection
  - Calculation of the Branching Ratio
  - $\Xi^{*0}(1530)$: Unbinned Likelihood Fitting
  - Dalitz plot: Unbinned Likelihood Fitting
- **Preliminary Results**
- **Summary**

The HyperCP Experiment

Primary Goal:

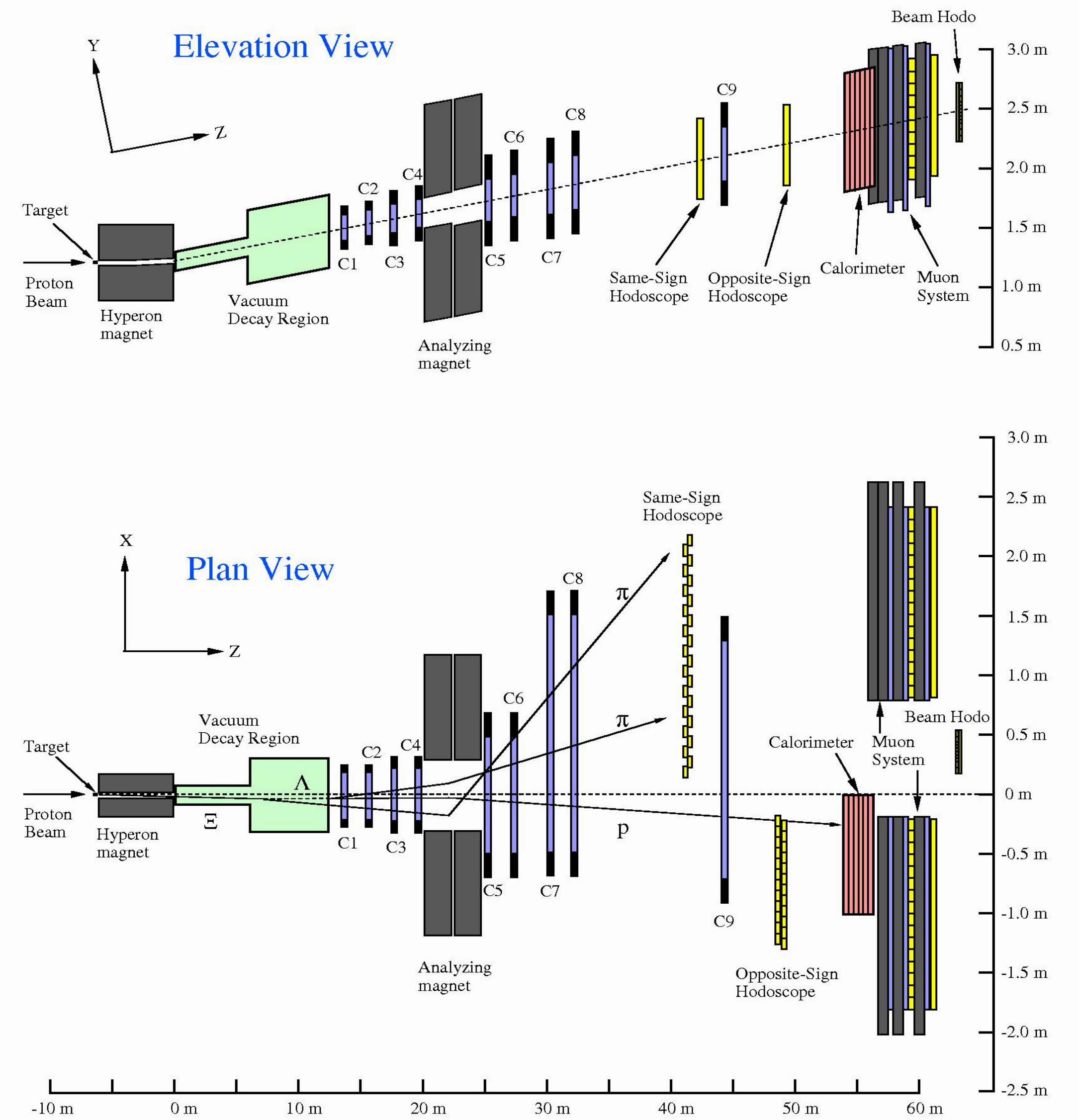
Search for CP violation

in hyperon decays,

especially $\Xi \rightarrow \Lambda\pi \rightarrow p\pi\pi$.

Spectrometer featured:

- High-rate detectors & DAQ (100k evts/s);
- Alternating "+" & "–" running (with reversed B fields) to minimize systematics;
- Simple, low-bias triggers based on hodoscope coincidences.



The HyperCP Experiment

In 12 months of data taking in 1997–99, HyperCP recorded one of the largest data samples ever by a particle-physics experiment:

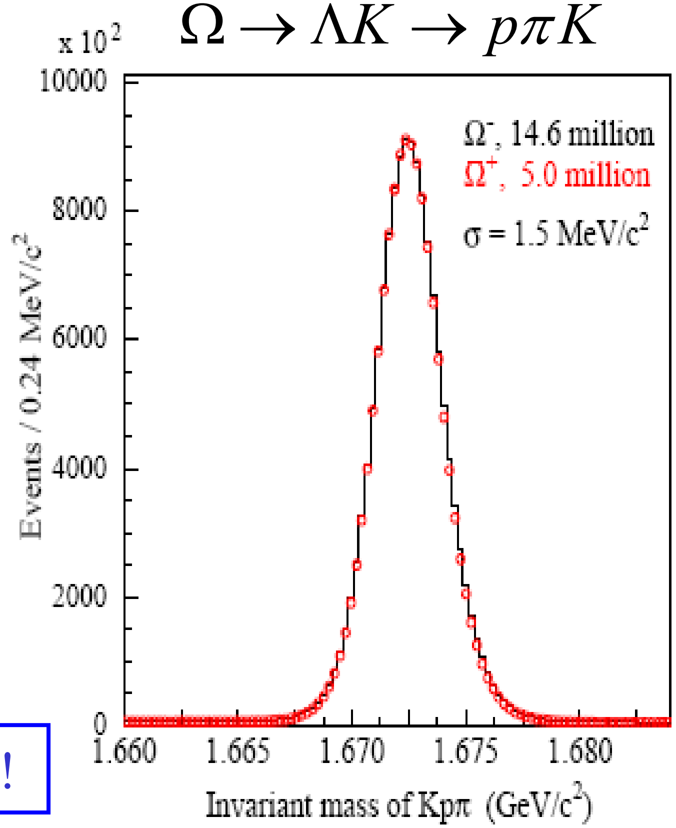
231 billion events, 29,401 tapes, and 119.5 TB of data

Reconstructed event samples.

	Reconstructed Events (10^6)		
Polarity:	$-$	$+$	Total
$\Xi \to \Lambda p \to p\pi\pi$	2032	458	2490
$\Omega \to \Lambda K \to pK\pi$	14	5	19
$K \to \pi\pi\pi$	164	391	555
$K_S \to \pi^+\pi^-$	693	2025	2718

Largest hyperon samples ever taken!

$\Omega \to \Lambda K \to p\pi K$



The HyperCP Experiment

In 12 months of data taking in 1997–99, HyperCP recorded one of the largest data samples ever by a particle-physics experiment:

231 billion events, 29,401 tapes, and 119.5 TB of data

Reconstructed event samples.

	Reconstructed Events (10^6)		
Polarity:	−	+	Total
$\Xi \to \Lambda p \to p\pi\pi$	2032	458	2490
$\Omega \to \Lambda K \to pK\pi$	14	5	19
$K \to \pi\pi\pi$	164	391	555
$K_S \to \pi^+\pi^-$	693	2025	2718

Large Ω sample $\Rightarrow$ Searches for rare hyperon decays

Searches and studies for:

- $\Delta S=2$: $\Omega^- \to \Lambda\pi^- \to p\pi^-\pi^-$
- $\Omega^- \to \Xi^{*0}_{1530}\pi^-$ (this talk!)
- $\Omega^- \to \Xi^-\pi^+\pi^-$ (this talk!)
- FCNC decays:

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

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

As well as antiparticle modes.

Outline

- **The HyperCP Experiment**
- **Motivation for studying** $\Omega \rightarrow \Xi^{*0}(1530)\pi$
- **Analysis**
    - Monte Carlo Simulations
    - Reconstruction and Event Selection
    - Calculation of the Branching Ratio
    - $\Xi^{*0}(1530)$: Unbinned Likelihood Fitting
    - Dalitz plot: Unbinned Likelihood Fitting
- **Preliminary Results**
- **Summary**

$\Omega^- \to \Xi^{*0}(1530)\pi^-$ Motivations

Theoretical Predictions:

- Finjord and Gaillard, PRD 22, 778 (1980): $BR(\Omega^- \to \Xi^{*0}_{1530}\pi^-) = 3/1070 \simeq 28\times10^{-4}$
- Duplancic et al., PRD 70, 077506 (2004): $BR(\Omega^- \to \Xi^{*0}_{1530}\pi^-) \simeq 8.58\times10^{-4}$ (Skyrme)
- Both models assume a cascade decay $\Omega^- \to \Xi^{*0}_{1530}\pi^- \to \Xi^-\pi^+\pi^-$

  and hence $BR(\Omega^- \to \Xi^-\pi^+\pi^-) = 2/3 \cdot BR(\Omega^- \to \Xi^{*0}_{1530}\pi^-)$

Experimental Results:

- The current PDG branching ratios are:

  $BR(\Omega^- \to \Xi^-\pi^+\pi^-) = (4.3\,^{+3.4}_{-1.3})\times10^{-4}$

  $BR(\Omega^- \to \Xi^{*0}_{1530}\pi^-) = (6.4\,^{+5.1}_{-2.0})\times10^{-4}$

  Both measurements were done by M. Bourquin *et al*., Nucl. Phys. B 241, 1 (1984) and are based on the same four observed events.
- N. Solomey (HyperCP, 137 events): $BR(\Omega^- \to \Xi^-\pi^+\pi^-) = (3.56 \pm 0.33(stat))\times10^{-4}$

  Without numerical estimation of the resonance decay channel contribution.

$\Omega^- \rightarrow \Xi^{*0}(1530)\pi^-$ Motivations

Theoretical Predictions:

- Finjord and Gaillard, PRD 22, 778 (1980): $\mathrm{BR}(\Omega^- \rightarrow \Xi^{*0}_{1530}\pi^-) = {}^{3}\!/_{1070} \simeq 28\times10^{-4}$
- Duplancic et al., PRD 70, 077506 (2004): $\mathrm{BR}(\Omega^- \rightarrow \Xi^{*0}_{1530}\pi^-) \simeq 8.58\times10^{-4}$ (Skyrme)
- Both models assume a cascade decay $\Omega^- \rightarrow \Xi^{*0}_{1530}\pi^- \rightarrow \Xi^-\pi^+\pi^-$

  and hence $\mathrm{BR}(\Omega^- \rightarrow \Xi^-\pi^+\pi^-) = {}^{2}\!/_{3} \cdot \mathrm{BR}(\Omega^- \rightarrow \Xi^{*0}_{1530}\pi^-)$

"The $\Omega^- \rightarrow \Xi^*(1530)\pi^-$ decays are expected to dominate the $\Xi^-\pi^+\pi^-$ decay modes.
Assuming that the 4 events are $\Omega^- \rightarrow \Xi^{*0}_{1530}\pi^-$ events, we deduce using a branching ratio of 2/3 for $\Xi^{*0}_{1530} \rightarrow \Xi^-\pi^+$:
$\Gamma(\Omega^- \rightarrow \Xi^{*0}_{1530}\pi^-)/\Gamma(\Omega^- \rightarrow all) = (6.4\,^{+5.1}_{-2.0})\times10^{-4}$"

Experimental Results:

- The current PDG branching ratios are:

  $\mathrm{BR}(\Omega^- \rightarrow \Xi^-\pi^+\pi^-) = (4.3\,^{+3.4}_{-1.3})\times10^{-4}$

  $\mathrm{BR}(\Omega^- \rightarrow \Xi^{*0}_{1530}\pi^-) = (6.4\,^{+5.1}_{-2.0})\times10^{-4}$

  Both measurements were done by M. Bourquin *et al.*, Nucl. Phys. B 241, 1 (1984) and are based on the same four observed events.
- N. Solomey (HyperCP, 137 events): $\mathrm{BR}(\Omega^- \rightarrow \Xi^-\pi^+\pi^-) = (3.56 \pm 0.33(stat))\times10^{-4}$

  Without numerical estimation of the resonance decay channel contribution.

Decays of Interest

Signal Modes:

- $\Omega^- \to \Xi^{*0}_{1530}\pi^-$ 5 tracks, includes subsequent decays $\Xi^{*0}_{1530} \to \Xi^-\pi^+$, $\Xi^- \to \Lambda\pi^-$, $\Lambda \to p\pi^-$
- $\Omega^- \to \Xi^-\pi^+\pi^-$ 5 tracks, includes subsequent decays $\Xi^- \to \Lambda\pi^-$, $\Lambda \to p\pi^-$

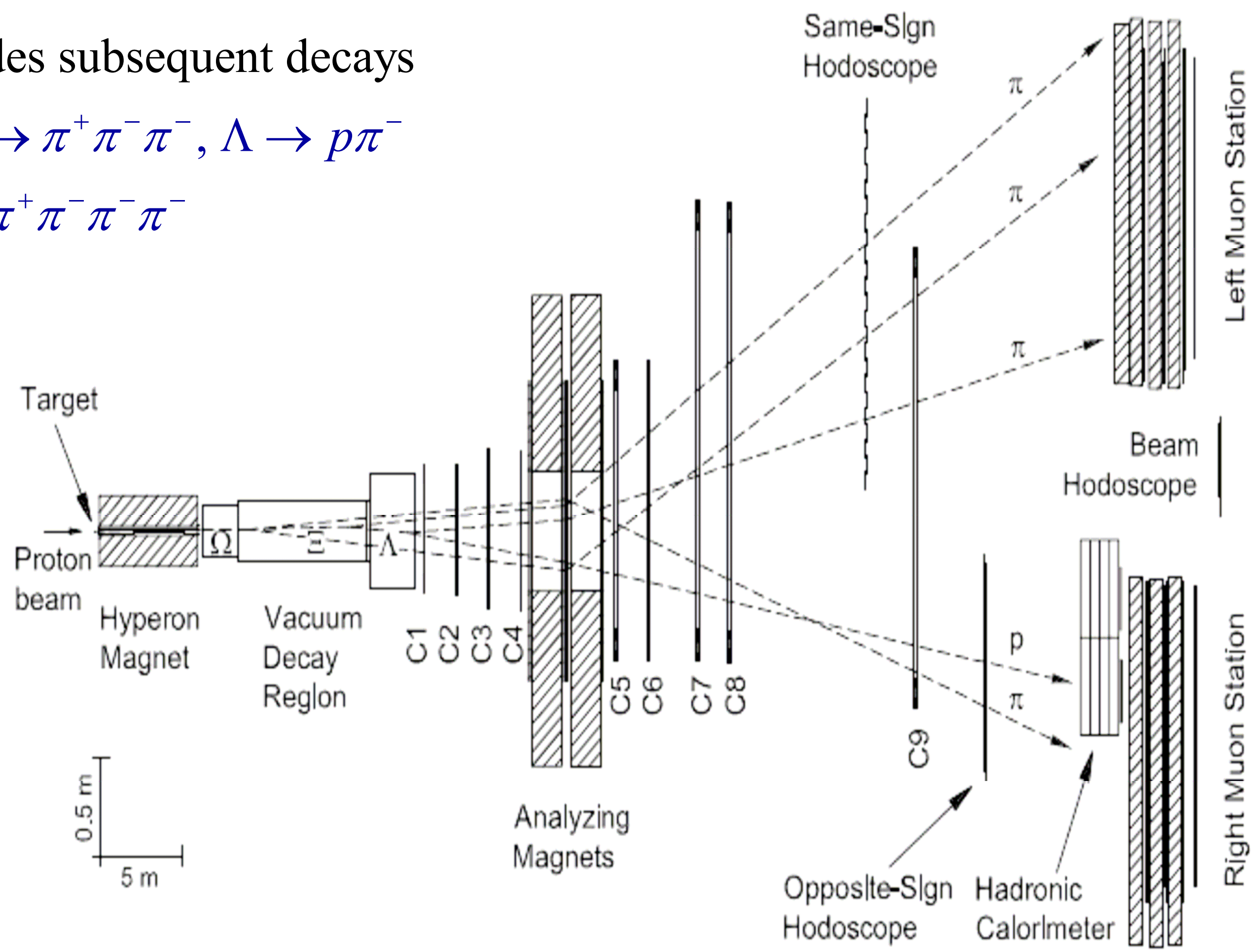
Normalizing Mode:

- $\Omega^- \to \Lambda K^-$ 5 tracks, includes subsequent decays

$$K^- \to \pi^+\pi^-\pi^-, \Lambda \to p\pi^-$$

Final state for all modes is $p\pi^+\pi^-\pi^-\pi^-$

Schematic topology of the signal mode:



08/14/2007

ILLINOIS INSTITUTE OF TECHNOLOGY

Outline

- **The HyperCP Experiment**
- **Motivation for studying** $\Omega \to \Xi^{*0}(1530)\pi$
- **Analysis**
  - Monte Carlo Simulations
  - Reconstruction and Event Selection
  - Calculation of the Branching Ratio
  - $\Xi^{*0}(1530)$: Unbinned Likelihood Fitting
  - Dalitz plot: Unbinned Likelihood Fitting
- **Preliminary Results**
- **Summary**

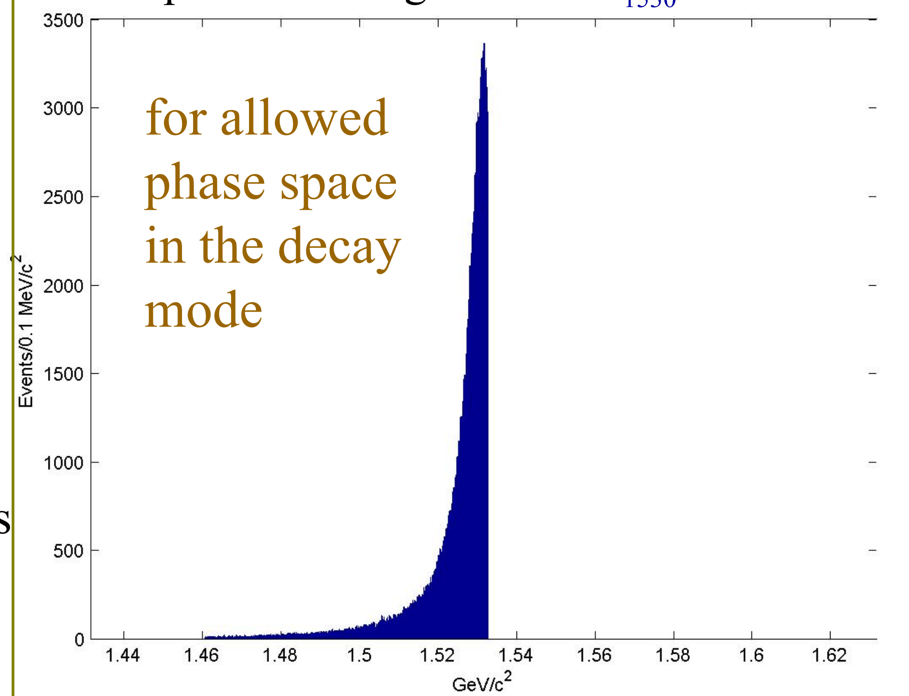
Monte Carlo Simulation

$\Omega^- \to \Xi^{*0}_{1530}\pi^-$ decay, with subsequent $\Xi^{*0}_{1530} \to \Xi^-\pi^+$:

- both decays were generated with uniform phase space;
- Ξ^{*0}_{1530} mass was generated with Breit-Wigner distribution $p(m) = A\dfrac{\Gamma/2}{(m-m_0)^2 + (\Gamma/2)^2}$,

  where $m_0 = 1.5318$ GeV, Γ=9.1 MeV (PDG values).

p.d.f. of MC generated Ξ^{*0}_{1530} mass



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

- was generated uniformly in phase space;
- subsequent decays $\Xi^- \to \Lambda\pi^-$, $\Lambda \to p\pi^-$ were generated with PDG decay-asymmetry parameters.

$\Omega^- \to \Lambda K^-$ decay, as well as subsequent decays $K^- \to \pi^+\pi^-\pi^-$, $\Lambda \to p\pi^-$, were generated with PDG decay-asymmetry parameters.

Reconstruction and Event Selection

Event Reconstruction:

- Track with the highest momentum is assigned to be proton;
- Other tracks' tagging based on the track combination that gives reconstructed invariant mass closest to the PDG value.

$\Omega^- \rightarrow \Xi^{*0}_{1530}\pi^-$ and $\Omega^- \rightarrow \Xi^-\pi^+\pi^-$ Selection Criteria:

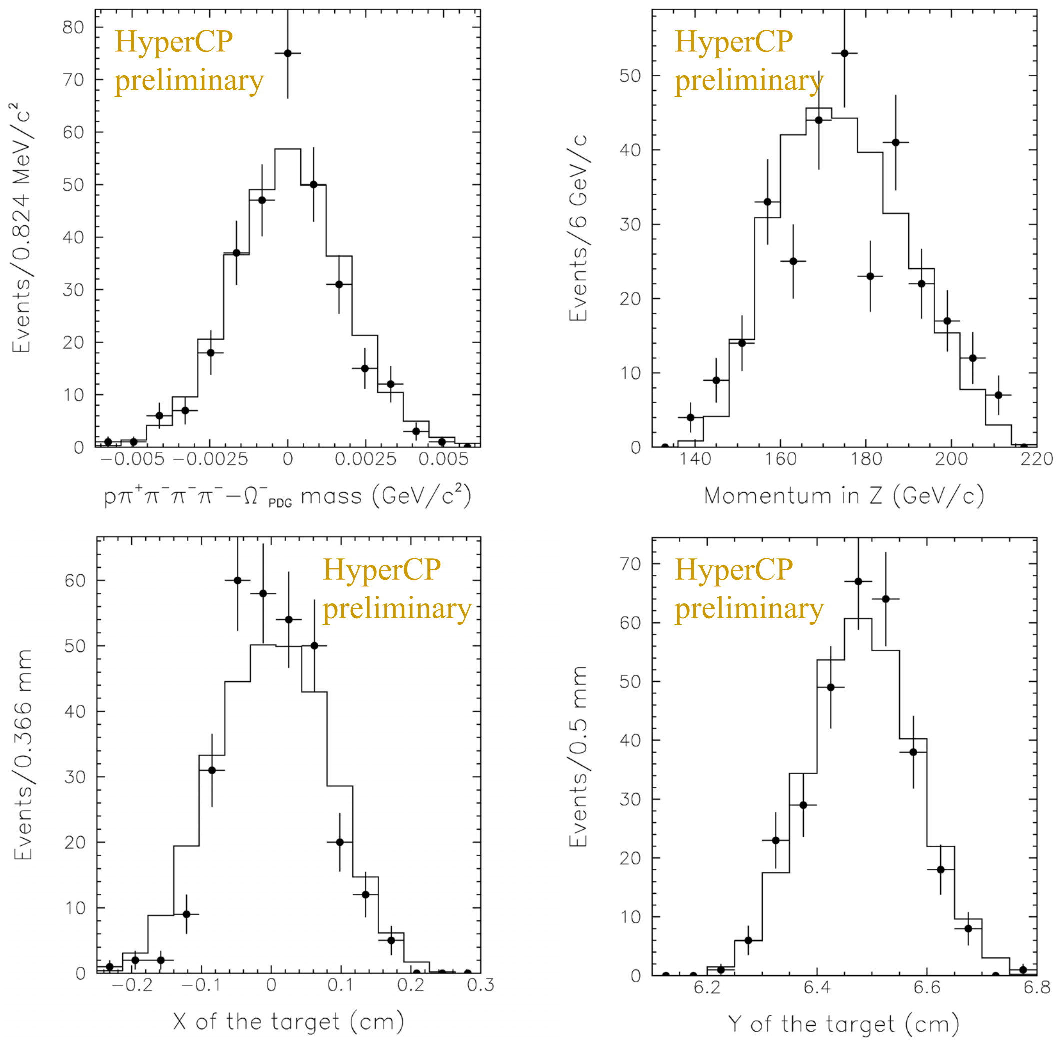
- 3 negative and 2 positive tracks;
- Reconstructed invariant masses of particles are within 3σ of corresponding PDG values;
- Total momentum between 135 and 220 GeV/c;
- All decay vertices inside the decay volume and vertex topology consistent with the decay;
- Tracks form good vertices;
- Reasonable $\chi^2/ndof$ from fitting decay topology to upstream segments;
- Reconstructed Ω^- track within the aperture of the collimator;
- Reconstructed Ω^- track originates from the target.

Selection Criteria for the normalizing mode $\Omega^- \rightarrow \Lambda K^-$ are similiar.

Normalizing Mode Data and MC

MC was tuned to get a reasonable match with the data.

Selected variables for Ω. Dots with error bars – data, solid line – MC.



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

includes

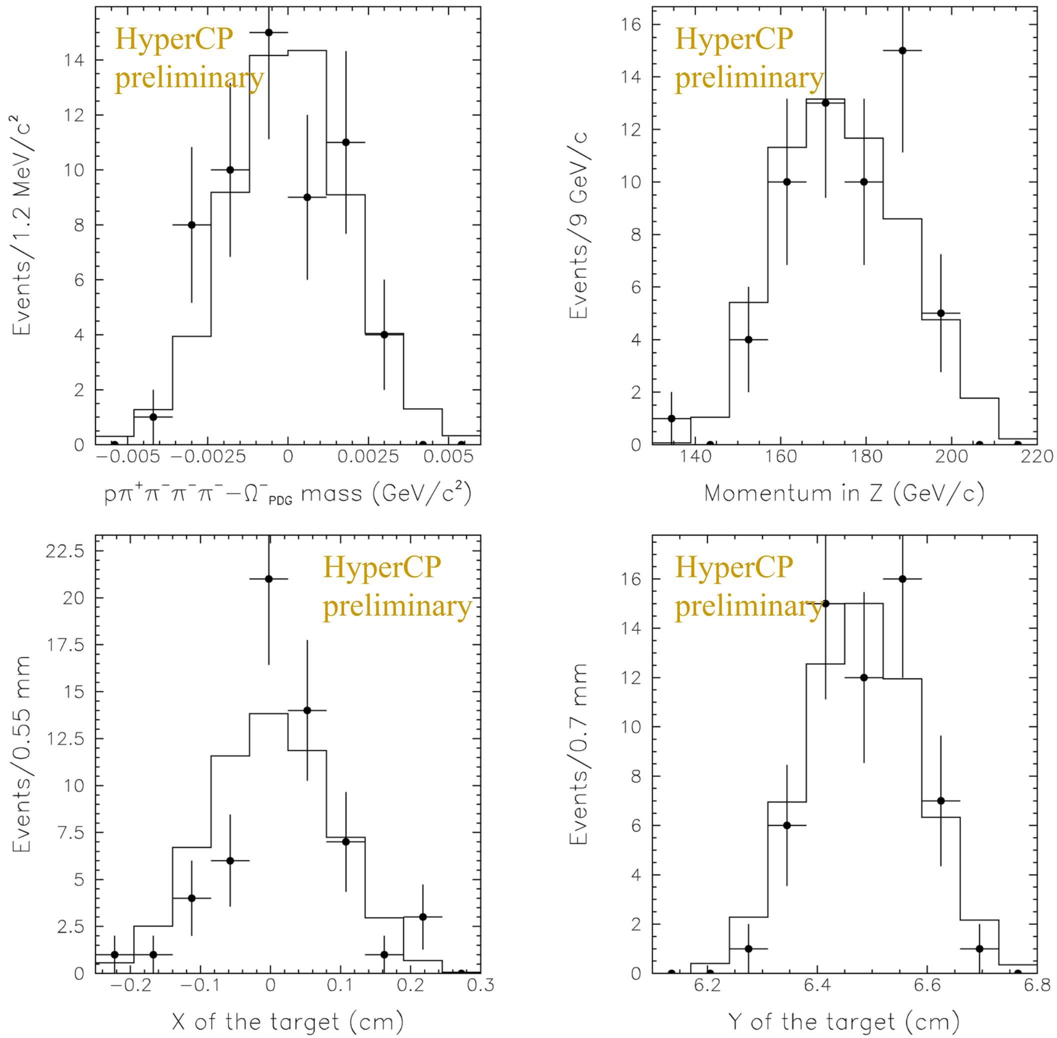
$K^- \to \pi^+\pi^-\pi^-$,

$\Lambda \to p\pi^-$

Signal Mode Data and MC

MC was tuned to get a reasonable match with the data.

Selected variables for Ω. Dots with error bars – data, solid line – MC.



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

includes

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

$\Lambda \to p\pi^-$

How to calculate Branching Ratios?

$$BR(\Omega^- \to \Xi^{*0}_{1530}\pi^-) = \frac{N_{\Omega^-\to\Xi^{*0}_{1530}\pi^-}}{N_{\Omega^-\to\Lambda K^-}} \cdot \frac{A_{\Omega^-\to\Lambda K^-}}{A_{\Omega^-\to\Xi^{*0}_{1530}\pi^-}} \cdot \frac{BR_{\Omega^-\to\Lambda K^-} \cdot BR_{K^-\to\pi^+\pi^-\pi^-}}{BR_{\Xi^{*0}_{1530}\to\Xi^-\pi^+} \cdot BR_{\Xi^-\to\Lambda\pi^-}}$$

$$BR(\Omega^- \to \Xi^-\pi^+\pi^-) = \frac{N_{\Omega^-\to\Xi^-\pi^+\pi^-}}{N_{\Omega^-\to\Lambda K^-}} \cdot \frac{A_{\Omega^-\to\Lambda K^-}}{A_{\Omega^-\to\Xi^-\pi^+\pi^-}} \cdot \frac{BR_{\Omega^-\to\Lambda K^-} \cdot BR_{K^-\to\pi^+\pi^-\pi^-}}{BR_{\Xi^-\to\Lambda\pi^-}}$$

$$N_{\Omega^-\to\Xi^{*0}_{1530}\pi^-} = p_{res} \cdot N_{signal}$$

$$N_{\Omega^-\to\Xi^-\pi^+\pi^-} = p_{3b} \cdot N_{signal}$$

Acceptances:

$$A_{\Omega^-\to\Xi^{*0}_{1530}\pi^-} = 1.20\times10^{-2}$$

$$A_{\Omega^-\to\Xi^-\pi^+\pi^-} = 5.16\times10^{-3}$$

$$A_{\Omega^-\to\Lambda K^-} = 2.80\times10^{-4}$$

Branching ratio values:

$$BR_{\Omega^-\to\Lambda K^-} = 6.78\times10^{-1}$$

$$BR_{\Xi^-\to\Lambda\pi^-} = 9.99\times10^{-1}$$

$$BR_{\Xi^{*0}_{1530}\to\Xi^-\pi^+} = 2/3$$

$$BR_{K^-\to\pi^+\pi^-\pi^-} = 5.59\times10^{-2}$$

ILLINOIS INSTITUTE OF TECHNOLOGY

How to calculate Branching Ratios?

$$BR(\Omega^- \to \Xi^{*0}_{1530}\pi^-) = \frac{N_{\Omega^-\to\Xi^{*0}_{1530}\pi^-}}{N_{\Omega^-\to\Lambda K^-}} \cdot \frac{A_{\Omega^-\to\Lambda K^-}}{A_{\Omega^-\to\Xi^{*0}_{1530}\pi^-}} \cdot \frac{BR_{\Omega^-\to\Lambda K^-} \cdot BR_{K^-\to\pi^+\pi^-\pi^-}}{BR_{\Xi^{*0}_{1530}\to\Xi^-\pi^+} \cdot BR_{\Xi^-\to\Lambda\pi^-}}$$

$$BR(\Omega^- \to \Xi^-\pi^+\pi^-) = \frac{N_{\Omega^-\to\Xi^-\pi^+\pi^-}}{N_{\Omega^-\to\Lambda K^-}} \cdot \frac{A_{\Omega^-\to\Lambda K^-}}{A_{\Omega^-\to\Xi^-\pi^+\pi^-}} \cdot \frac{BR_{\Omega^-\to\Lambda K^-} \cdot BR_{K^-\to\pi^+\pi^-\pi^-}}{BR_{\Xi^-\to\Lambda\pi^-}}$$

$$N_{\Omega^-\to\Xi^{*0}_{1530}\pi^-} = p_{res} \cdot N_{signal}$$

$$N_{\Omega^-\to\Xi^-\pi^+\pi^-} = p_{3b} \cdot N_{signal}$$

Proportionality coefficients (p_{res} and p_{3b}) can be found by fitting data to the combination of resonance and 3-body MCs in:

• Dalitz plot (2D histogram)

or using the best variable to distinguish between resonance and 3-body mode

• Xi(1530) invariant mass distribution (1D histogram).

Which fitting method to use?

Want to perform precise measurements, which includes parameter determination from fitting, but we have low statistics in both, normalizing and signal, modes. Moreover, we want to do Dalitz plot analysis (two-dimensional) with only 58 signal events!

Use Unbinned Generalized LogLikelihood Fitting Method:

Suppose that: $f(x;\vec{p})$ - fit function, where $\vec{p}$ - vector of fit parameters.

Integral over fit range is $N(\vec{p}) = \int_{x_1}^{x_2} f(x;\vec{p})dx$.

Likelihood is $L(\vec{p}) = \prod_{i=1}^{n} \frac{f(x_i;\vec{p})}{N(\vec{p})}$, where n - total # of observed events.

Now we add probability for observing n events, when the number of observed events is Poisson with mean $N(\vec{p})$.

Generalized Likelihood is $L(\vec{p}) = \frac{N^n(\vec{p})e^{-N(\vec{p})}}{n!} \prod_{i=1}^{n} \frac{f(x_i;\vec{p})}{N(\vec{p})}$.

After algebra and removing terms that don't affect location of minimum:

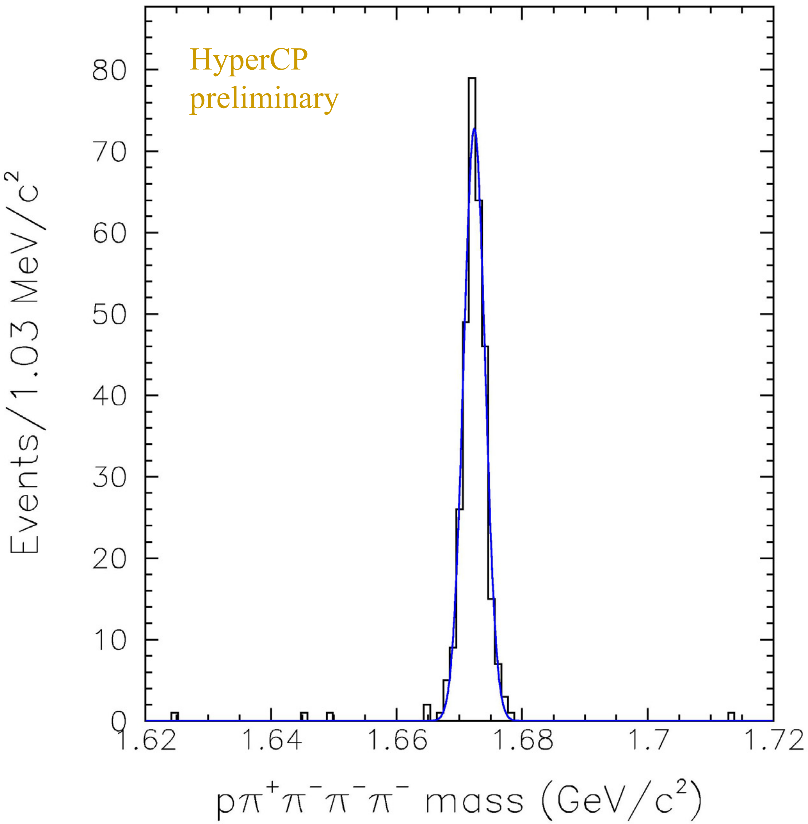
$-\ln L(\vec{p}) = \int_{x_1}^{x_2} f(x;\vec{p})dx - \sum_{i=1}^{n} \ln f(x_i;\vec{p})$ --- We minimize this in MINUIT.

(see A.G. Frodesen *et al*., "Probability and Statistics in Particle Physics.")

Unbinned Likelihood Fitting

Normalizing Mode Data, 311 events.

Gaussian plus constant fit (blue) to reconstructed invariant Omega mass.
Histogram is for visualization only.



MINUIT:

FCN= -816.5196 FROM MINOS STATUS=SUCCESSFUL 226 CALLS 601 TOTAL

EDM= 0.60E-13 STRATEGY= 2 ERROR MATRIX ACCURATE

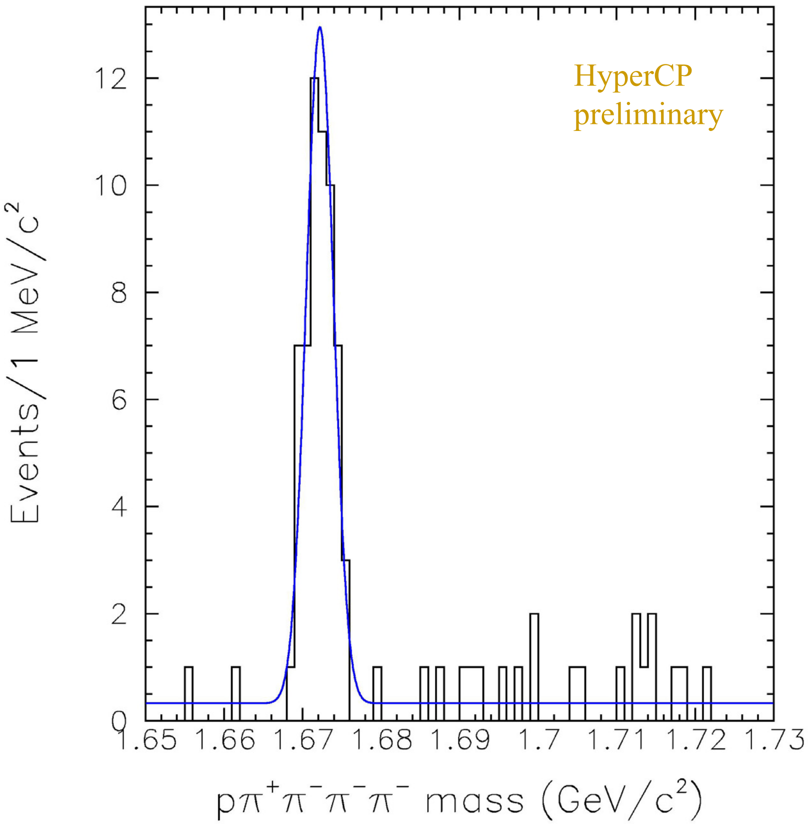
EXT PARAMETER			PARABOLIC	MINOS ERRORS	
NO.	NAME	VALUE	ERROR	NEGATIVE	POSITIVE
1	# signal	303.48	17.472	-17.141	17.808
2	mean (MeV)	1672.4	0.10000	-0.10012	0.10007
3	sigma (MeV)	1.7141	0.76748E-01	-0.74278E-01	0.79470E-01
4	# bkg	7.5161	3.0028	-2.6708	3.4609
5	5	1620.0	constant		
6	6	1720.0	constant		

ERR DEF= 0.500

Unbinned Likelihood Fitting

Signal Mode Data, 81 events.

Gaussian plus constant fit (blue) to reconstructed invariant Omega mass.
Histogram is for visualization only.



MINUIT:

FCN= -12.84356 FROM MINOS STATUS=SUCCESSFUL 234 CALLS 1103 TOTAL

EDM= 0.22E-13 STRATEGY= 2 ERROR MATRIX ACCURATE

EXT PARAMETER			PARABOLIC	MINOS ERRORS	
NO.	NAME	VALUE	ERROR	NEGATIVE	POSITIVE
1	# signal	55.170	7.6352	-7.3077	7.9714
2	mean (MeV)	1672.2	0.24538	-0.24632	0.24642
3	sigma (MeV)	1.7421	0.17316	-0.16120	0.18765
4	# bkg	25.830	5.3096	-5.0148	5.7620
5	5	1650.0	constant		
6	6	1730.0	constant		

ERR DEF= 0.500

Xi(1530): Unbinned Likelihood Fitting

Fitting data to the combination of resonance and 3-body MCs to find proportionality coefficients (p_{res} and p_{3b}).

Apply Unbinned Generalized LogLikelihood Fit.

Fit function: $f(m_{\Xi^-\pi^+}; p_{res}, p_{3b}) = N_{signal} \cdot \left(p_{res} \cdot \frac{f_{res}(m_{\Xi^-\pi^+})}{N_{MC(res)}} + p_{3b} \cdot \frac{f_{3b}(m_{\Xi^-\pi^+})}{N_{MC(3b)}} \right)$,

where $f_{res}(m_{\Xi^-\pi^+})$ and $f_{3b}(m_{\Xi^-\pi^+})$ are functional forms of the corresponding MCs,

$N_{MC(res)}$, $N_{MC(3b)}$ - total number of events in MCs.

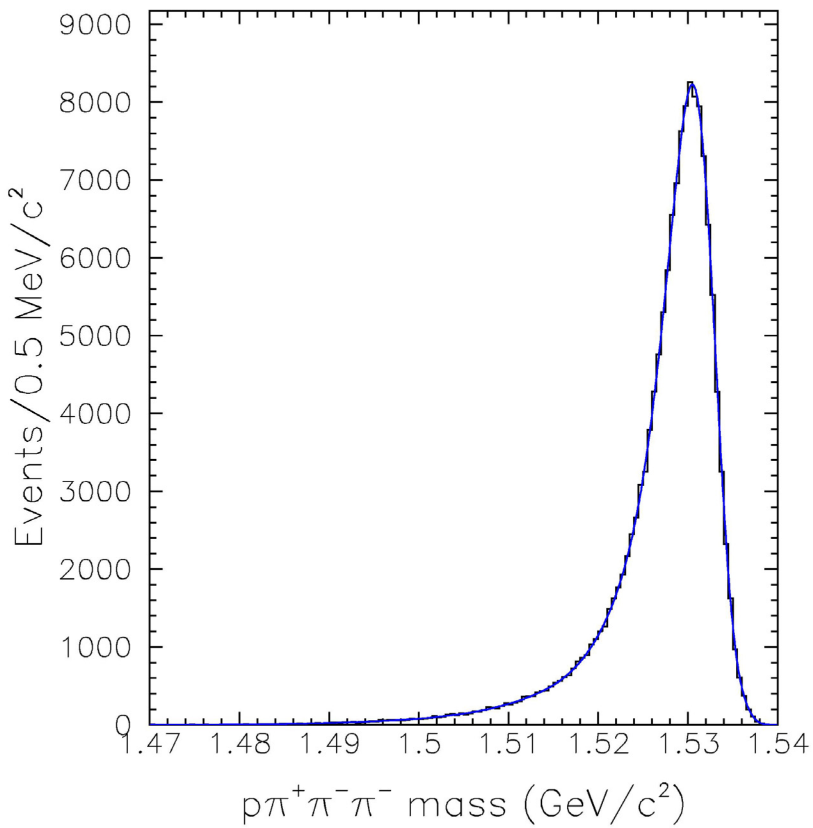
$-\ln L(p_{res}, p_{3b}) = N_{signal} \cdot (p_{res} + p_{3b}) - \sum_{i=1}^{N_{signal}} \ln f(m_i; p_{res}, p_{3b})$ --- function to minimize.

$f_{res}(m_{\Xi^-\pi^+})$ and $f_{3b}(m_{\Xi^-\pi^+})$ can be found by smoothing histograms from MCs.

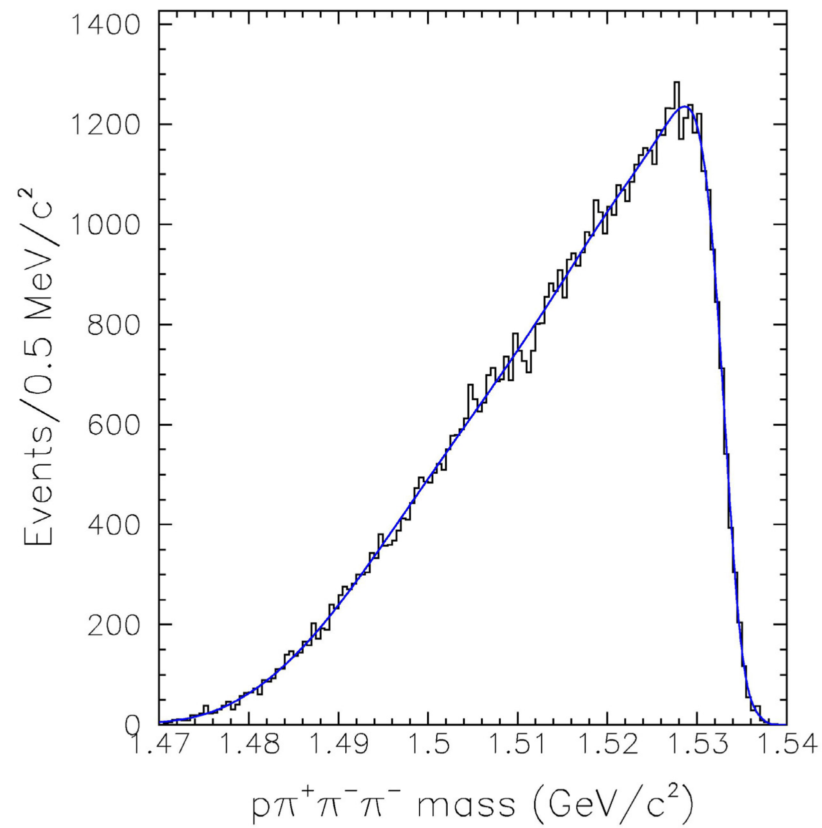
Histogram Smoothing

Blue – analytical function that was found by smoothing corresponding histograms.

$$f_{res}\left(m_{\Xi^-\pi^+}\right)$$



$$f_{3b}\left(m_{\Xi^-\pi^+}\right)$$

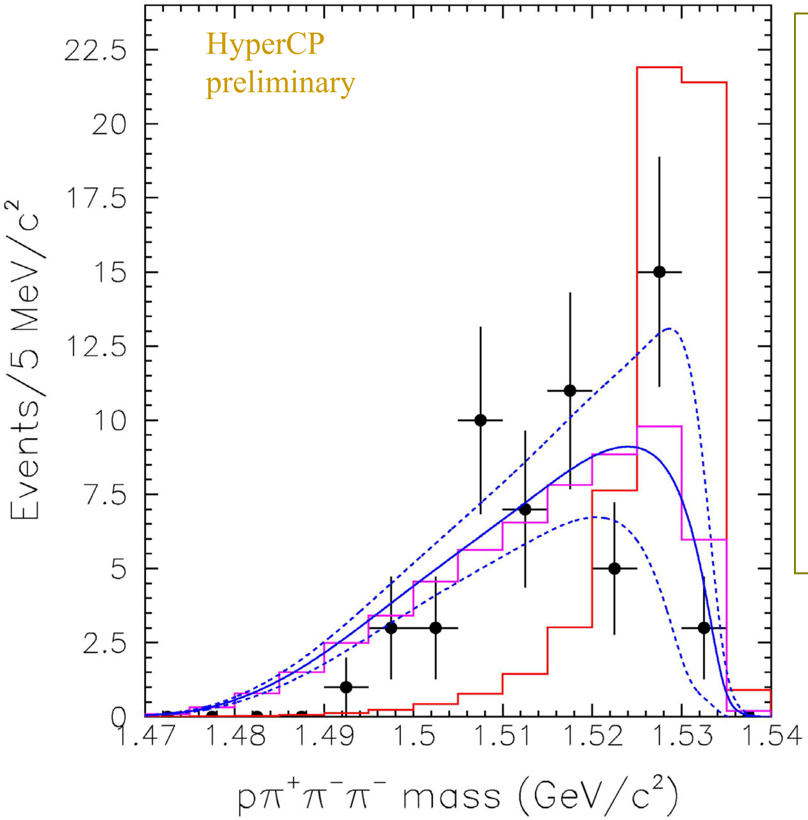


Xi(1530): Unbinned Likelihood Fitting

Signal Mode Data (dots with error bars), 58 events.

Red – resonance mode MC; Pink – 3-body uniform mode MC;
Histograms are for visualization purposes only.

Blue – MINUIT fit with central value of proportionality coefficients (solid) and with value±error (dashed).



MINUIT:

FCN= 78.01224 FROM MINOS STATUS=SUCCESSFUL 56 CALLS 225 TOTAL

EDM= 0.88E-17 STRATEGY= 2 ERROR MATRIX ACCURATE

EXT PARAMETER			PARABOLIC	MINOS ERRORS	
NO.	NAME	VALUE	ERROR	NEGATIVE	POSITIVE
1	3-body	1.11074	0.18408	-0.17618	0.19210
2	resonance	-0.11074	0.11326	-0.10693	0.11996

ERR DEF= 0.500

Xi(1530): Unbinned Likelihood Fitting

Contour of –lnL.

```
Y-AXIS: PARAMETER   2: resonance
  0.1060      22      222*    33     4
  0.8626E-01  2         22     33
  0.6656E-01  2          222    33
  0.4686E-01  2          * 22    33
  0.2716E-01  2          *  22    33
  0.7464E-02 -2----11111-----22----33-
 -0.1224E-01  2     1  111    22    33
 -0.3194E-01  22    1    11    22    3
 -0.5164E-01   2    1    *11    22   3
 -0.7134E-01   22  11    * 11    2
 -0.9104E-01 3  22  1   00  11   22
 -0.1107     33**2**11**000**11***22**
 -0.1304      33 22  11  00   11   22
 -0.1501     4 33 22  11 *     1    2
 -0.1698     44 33 22  111     1    22
 -0.1895     544433 222  111   1     2
 -0.2092     44 44333 22 * 11111     2
 -0.2289     444444433 222
 -0.2486     33444334333 222
 -0.2683     3333322334333 222
 -0.2880      33322222333333 2222
 -0.3077     2333220021122233   222222
 -0.3274     10032200001002223333
             I           I           I
         0.7426                    1.479
                      1.111
      X-AXIS: PARAMETER  1: 3-body      ONE COLUMN=  0.2945E-01
FUNCTION VALUES: F(I)=   78.01     +  0.5000     *I**2
```

PARAMETER CORRELATION COEFFICIENTS

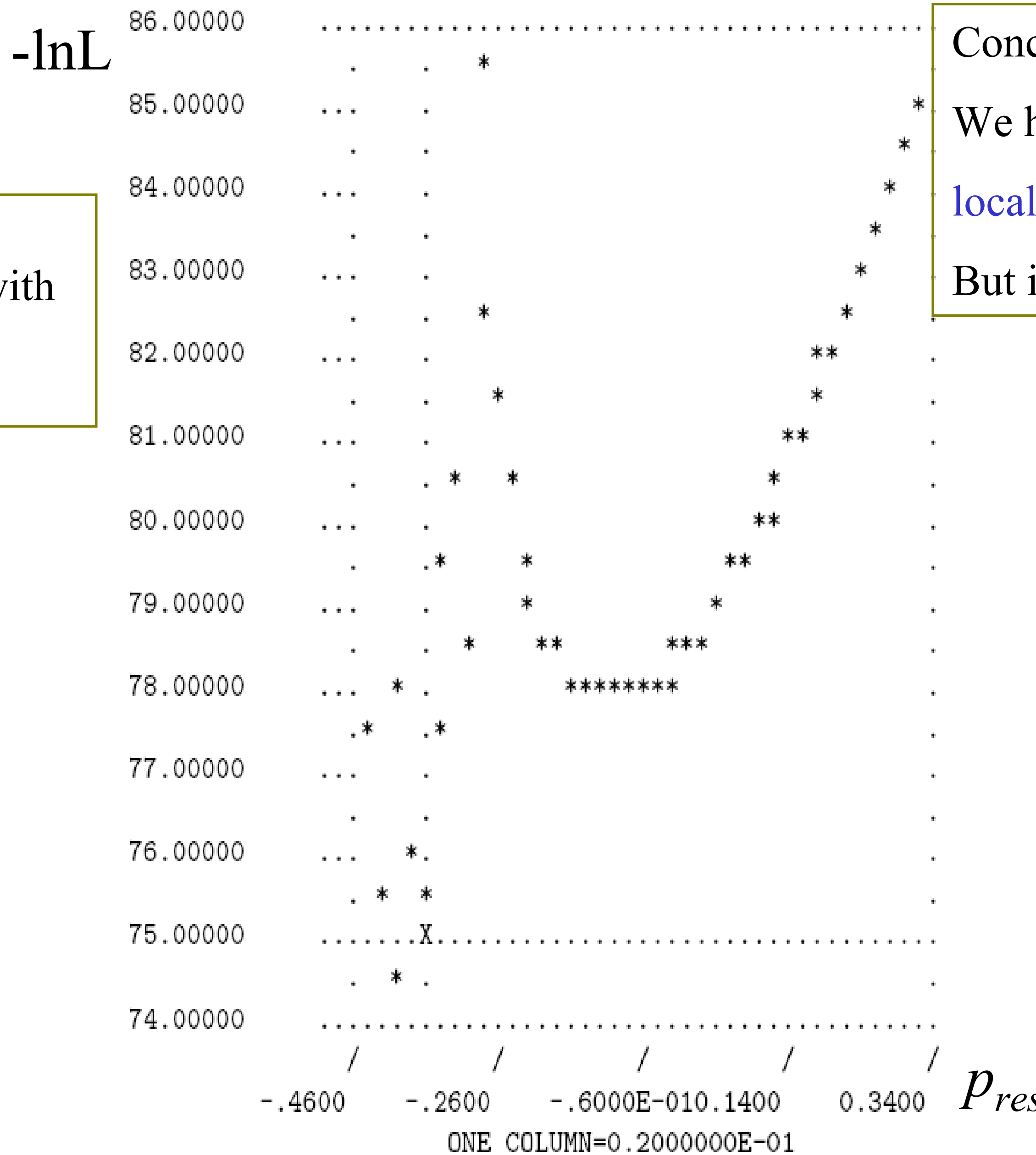
NO.	GLOBAL	1	2
1	0.70666	1.000	-0.707
2	0.70666	-0.707	1.000

Conclusion:

1. We have a well-defined minimum;
2. Parameters are negatively correlated with each other.

Xi(1530): Unbinned Likelihood Fitting

Plot of –lnL as a function of p_{res} with p_{3b} fixed at minimum.



Conclusion:

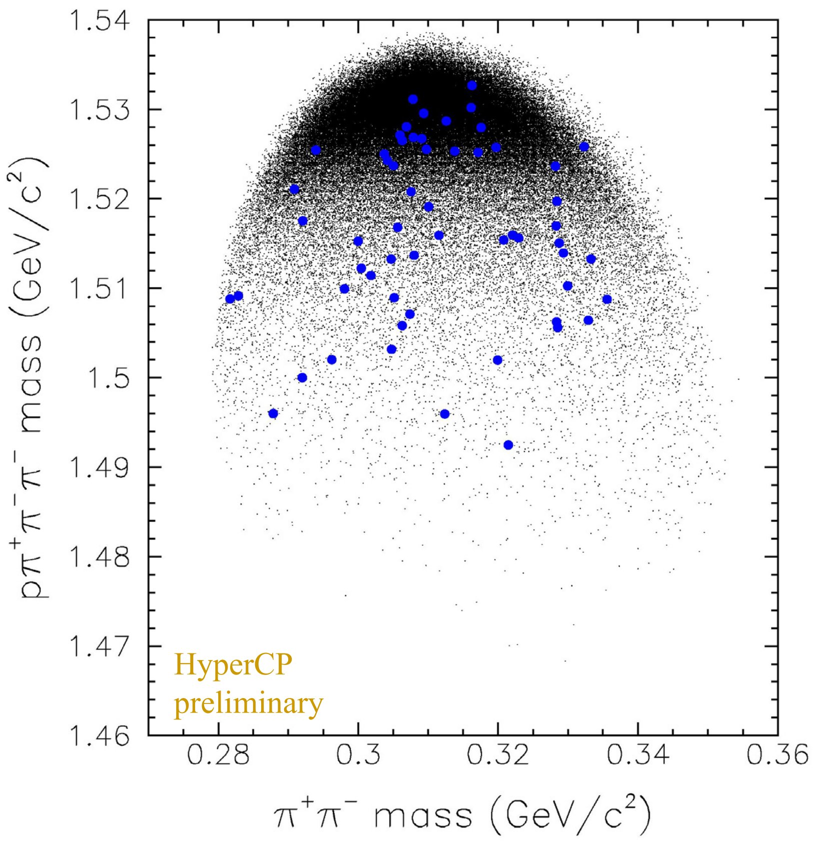
We have a well-defined local minimum.

But it's a stable solution!

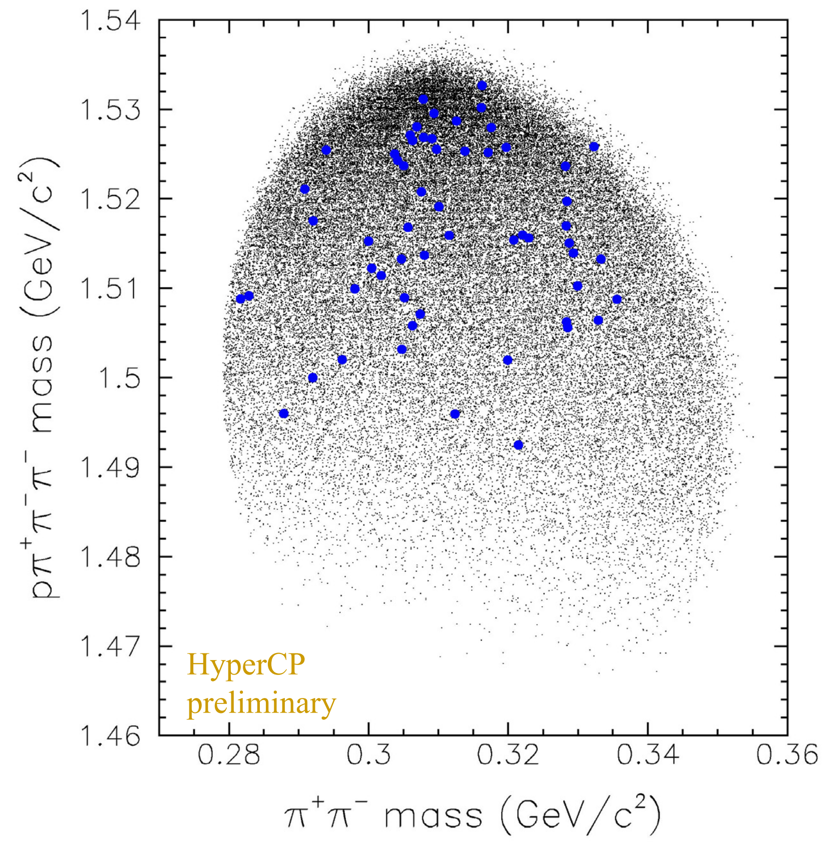
Dalitz plot

Big blue dots – data, 58 events; Small black dots – Monte Carlo.

Monte Carlo for $\Omega^- \to \Xi^{*0}_{1530}\pi^-$



Monte Carlo for $\Omega^- \to \Xi^-\pi^+\pi^-$



Dalitz plot: Unbinned Likelihood Fitting

Fitting data to the combination of resonance and 3-body MCs to find proportionality coefficients (p_{res} and p_{3b}).

Apply Unbinned Generalized LogLikelihood Fit.

Fit function:

$$f\left(m_{\Xi^-\pi^+}, m_{\pi^-\pi^+}; p_{res}, p_{3b}\right) = N_{signal} \cdot \left(p_{res} \cdot \frac{f_{res}\left(m_{\Xi^-\pi^+}, m_{\pi^-\pi^+}\right)}{N_{MC(res)}} + p_{3b} \cdot \frac{f_{3b}\left(m_{\Xi^-\pi^+}, m_{\pi^-\pi^+}\right)}{N_{MC(3b)}} \right),$$

where $f_{res}\left(m_{\Xi^-\pi^+}, m_{\pi^-\pi^+}\right)$ and $f_{3b}\left(m_{\Xi^-\pi^+}, m_{\pi^-\pi^+}\right)$ are functional forms of the corresponding MCs,

$N_{MC(res)}, N_{MC(3b)}$ - total number of events in MCs.

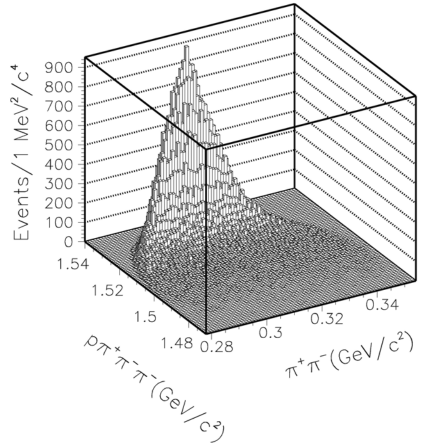
$$-\ln L\left(p_{res}, p_{3b}\right) = N_{signal} \cdot \left(p_{res} + p_{3b}\right) - \sum_{i=1}^{N_{signal}} \ln f\left(\left(m_{\Xi^-\pi^+}, m_{\pi^-\pi^+}\right)_i ; p_{res}, p_{3b}\right)$$ --- function to minimize.

$f_{res}\left(m_{\Xi^-\pi^+}, m_{\pi^-\pi^+}\right)$ and $f_{3b}\left(m_{\Xi^-\pi^+}, m_{\pi^-\pi^+}\right)$ can be found by smoothing histograms from MCs.

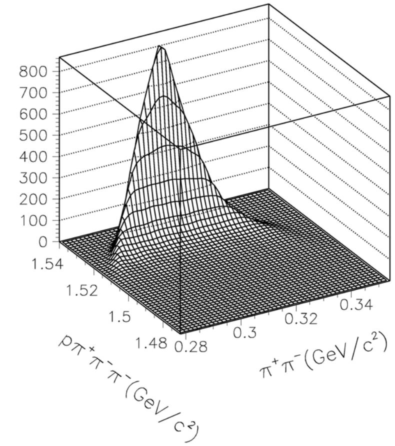
Dalitz plot: Histogram Smoothing

Resonance mode:

histogram, 70 X 76 bins

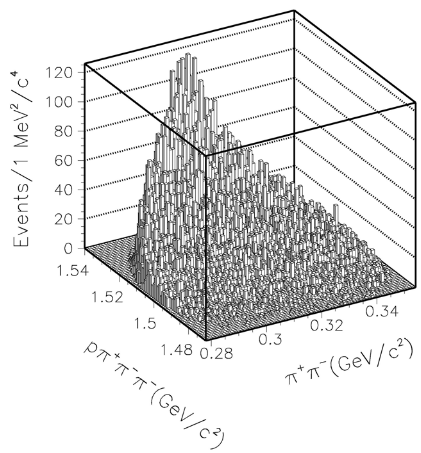


$$f_{res}\left(m_{\Xi^-\pi^+}, m_{\pi^-\pi^+}\right)$$

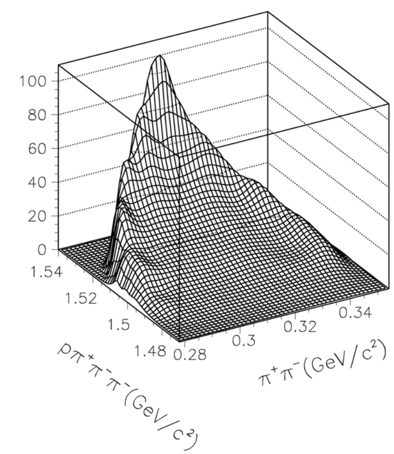


3-body mode:

histogram, 70 X 76 bins



$$f_{3b}\left(m_{\Xi^-\pi^+}, m_{\pi^-\pi^+}\right)$$



Dalitz plot: Unbinned Likelihood Fitting

MINUIT:

FCN= 269.3999 FROM MINOS STATUS=SUCCESSFUL 56 CALLS 248 TOTAL

EDM= 0.35E-14 STRATEGY= 2 ERROR MATRIX ACCURATE

EXT PARAMETER			PARABOLIC	MINOS ERRORS	
NO.	NAME	VALUE	ERROR	NEGATIVE	POSITIVE
1	3-body	1.07879	0.18052	-0.17278	0.18877
2	resonance	-0.07879	0.11255	-0.10658	0.11925

ERR DEF= 0.500

PARAMETER CORRELATION COEFFICIENTS

NO.	GLOBAL	1	2
1	0.68952	1.000	-0.690
2	0.68952	-0.690	1.000

Both methods give statistically consistent results!

	Xi(1530) fitting	Dalitz plot fitting
p_{3b}	1.11±0.18	1.08±0.18
p_{res}	-0.11±0.11	-0.08±0.11

Outline

- **The HyperCP Experiment**
- **Motivation for studying** $\Omega \rightarrow \Xi^{*0}(1530)\pi$
- **Analysis**
  - Monte Carlo Simulations
  - Reconstruction and Event Selection
  - Calculation of the Branching Ratio
  - $\Xi^{*0}(1530)$: Unbinned Likelihood Fitting
  - Dalitz plot: Unbinned Likelihood Fitting
- **Preliminary Results**
- **Summary**

Branching Ratio and Upper Limit Calculation

$$BR(\Omega^- \to \Xi^{*0}_{1530}\pi^-) = \left(-1.91 \pm 2.74(stat) \pm 0.16(syst)\right)\times 10^{-5}$$ (consistent with zero)

- Statistical errors are from # of events and fitting parameter uncertainties;
- Statistical uncertainty by far dominates over systematics.

Neglecting systematics, with only statistical error, we estimate:

$BR(\Omega^- \to \Xi^{*0}_{1530}\pi^-) < 3.5\times 10^{-5}$ at 90% C.L.,

which is ~ 2 orders of magnitude less than prediction.

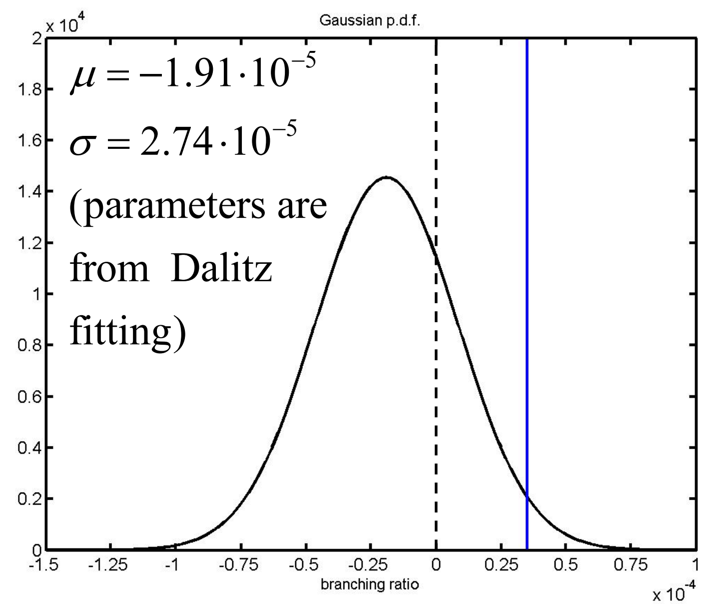
We numerically solve

$$\int_0^b e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} dx = 0.9 \cdot \int_0^\infty e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} dx$$

where b = unknown upper limit

(blue line on the right plot).

(see L. Lyons, "Statistics for nuclear and particle physicists")



Branching Ratio and Upper Limit Calculation

$BR(\Omega^- \to \Xi^{*0}_{1530}\pi^-) = \left(-1.91 \pm 2.74(stat) \pm 0.16(syst)\right) \times 10^{-5}$ (consistent with zero)

- Statistical errors are from # of events and fitting parameter uncertainties;
- Statistical uncertainty by far dominates over systematics.

Neglecting systematics, with only statistical error, we estimate:

$BR(\Omega^- \to \Xi^{*0}_{1530}\pi^-) < 3.5 \times 10^{-5}$ at 90% C.L.,

which is ~ 2 orders of magnitude less than prediction.

We do not see any resonance mode decays. Thus, all signal decays are from the 3-body mode and

$BR(\Omega^- \to \Xi^-\pi^+\pi^-) = \left(3.74 \pm 0.56(stat) \pm 0.25(syst)\right) \times 10^{-4}$

Systematic Errors in Detail

Most of systematic sources were estimated by MC simulations.

Examples:

1) Target center:
   - For the normalizing mode, fit distribution of the Omega at the target with a Gaussian, find sigma;
   - Change the location of the target center by sigma, run resonance mode, 3-body mode and normalizing mode MCs;
   - Calculate new branching ratios;
   - Calculate systematic error: $$\frac{\delta B}{B} = \frac{B_{\mathrm{var}} - B_{centr}}{B_{centr}}$$
2) B-field:
   - Vary magnetic field by 0.1% from the value in MC;
   - Generate all three MCs with new B-field;
   - Reconstruct MCs with the standard B-field;
   - Calculate new branching ratios and systematic error.

We add individual errors in quadrature.

ILLINOIS INSTITUTE OF TECHNOLOGY

We Motivated Theorists to Revisit the Decay

The Decay $\Omega^- \to \Xi^-\pi^+\pi^-$ in Chiral Perturbation Theory

Oleg Antipin*

Department of Physics and Astronomy,
Iowa State University, Ames, IA 50011, USA

Jusak Tandean†

Department of Mathematics/Physics/Computer Science,
University of La Verne, La Verne, CA 91750, USA

G. Valencia‡

Department of Physics and Astronomy,
Iowa State University, Ames, IA 50011, USA

(Dated: May 24, 2007)

Abstract

We study the decay $\Omega^- \to \Xi^-\pi^+\pi^-$ in heavy-baryon chiral perturbation theory. At leading order, the decay is completely dominated by the $\Xi^{*0}(1530)$ intermediate state, and the predicted rate and $\Xi^-\pi^+$-mass distribution are in conflict with currently available data. It is possible to resolve this conflict by considering additional contributions at next-to-leading order.

We Motivated Theorists to Revisit the Decay

Calculations were performed in heavy-baryon χPT.

At leading order:

- Decay is completely dominated by the Ξ^{*0}_{1530} state;
- $BR(\Omega^- \to \Xi^- \pi^+ \pi^-) = 5.4 \times 10^{-3}$ (order of magnitude larger than experimental result);
- Reproduces earlier theoretical results.

With next-to-leading-order corrections:

- Calculation contains four unknown parameters;
- By varying them, it is possible to soften the Ξ^{*0}_{1530} dominance and lower the $\Omega^- \to \Xi^- \pi^+ \pi^-$ branching ratio.

Outline

- **The HyperCP Experiment**
- **Motivation for studying** $\Omega \rightarrow \Xi^{*0}(1530)\pi$
- **Analysis**
  - Monte Carlo Simulations
  - Reconstruction and Event Selection
  - Calculation of the Branching Ratio
  - $\Xi^{*0}(1530)$: Unbinned Likelihood Fitting
  - Dalitz plot: Unbinned Likelihood Fitting
- **Preliminary Results**
- **Summary**

Summary

- HyperCP recorded largest hyperon samples ever taken;

- First actual measurement of $BR(\Omega^- \to \Xi^{*0}_{1530}\pi^-)$ performed:
  - 1999 data of HyperCP analyzed;
  - With ~ 14 times the number of previously observed $\Omega^- \to \Xi^- \pi^+ \pi^-$ events, we measured the contribution from the resonance decay channel $\Omega^- \to \Xi^{*0}_{1530}\pi^-$;
  - No resonance mode decays observed;
  - Preliminary: $BR(\Omega^- \to \Xi^{*0}_{1530}\pi^-) < 3.5\times10^{-5}$ at 90% C.L.;

- Preliminary: $BR(\Omega^- \to \Xi^- \pi^+ \pi^-) = \left(3.74 \pm 0.56(stat) \pm 0.25(syst)\right)\times10^{-4}$.

Backup Slides

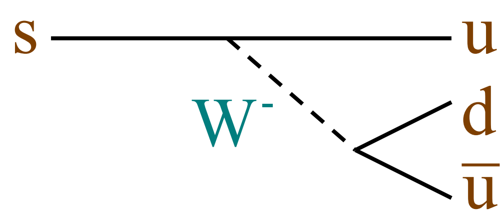
Backup Slides

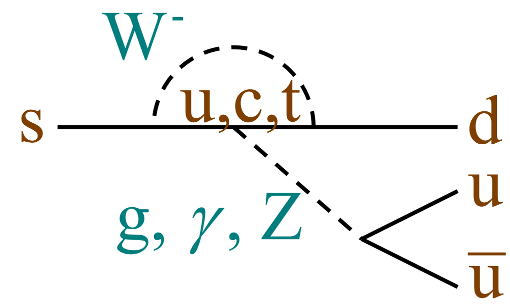
Feynman Diagrams

$\Omega^- \rightarrow \Xi^{*0}_{1530} \pi^-$

s	u	d
s	s	$\bar{u}$
s	s	

$\Longrightarrow$

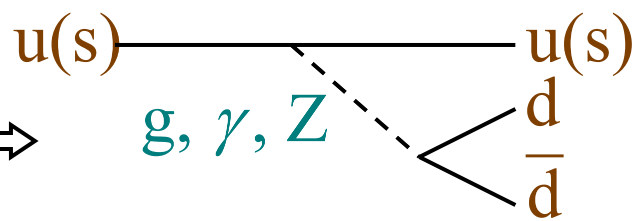


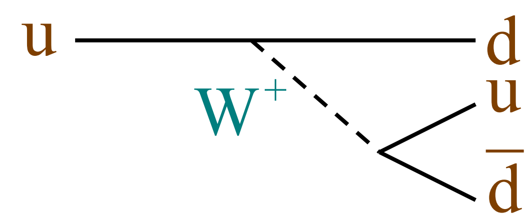


$\Xi^{*0}_{1530} \rightarrow \Xi^- \pi^+$

u	d	u
s	s	$\bar{d}$
s	s	

$\Longrightarrow$

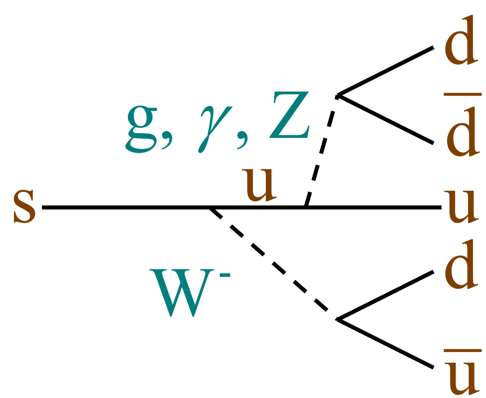


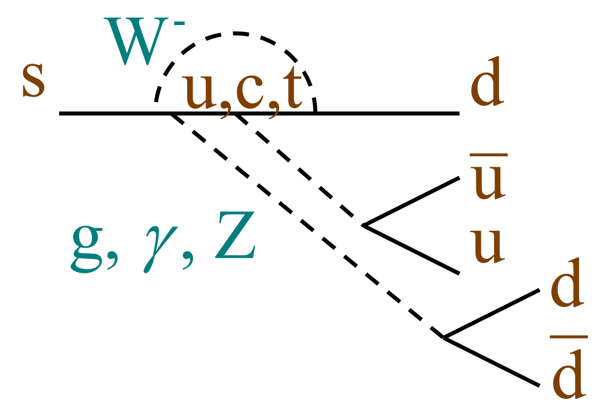


$\Omega^- \rightarrow \Xi^- \pi^+ \pi^-$

s	d	u	d
s	s	$\bar{d}$	$\bar{u}$
s	s		

$\Longrightarrow$





Unbinned Likelihood Fitting

Number of normalizing and signal events:

	fit g+p0 (large scale)		fit g+p0 (+/-3sigma window)		bkg. from+/-25si. till +/-5si.	fit g+p1 (large scale)	
	# of events	error	# of events	error	# of events	# of events	error
normalizing	303.5	17.5	294.6	19.4	303.4		
signal	55.2	7.6	58.0	7.6	54.7	56.1	7.6

additional crosscheck

We also performed fitting in +/- 3 sigma range of the Omega mass and used "background per sigma" method to get number of normalizing and signal events. Our choice is highlighted by green.

Dalitz plot: Unbinned Likelihood Fitting

Contour of –lnL.

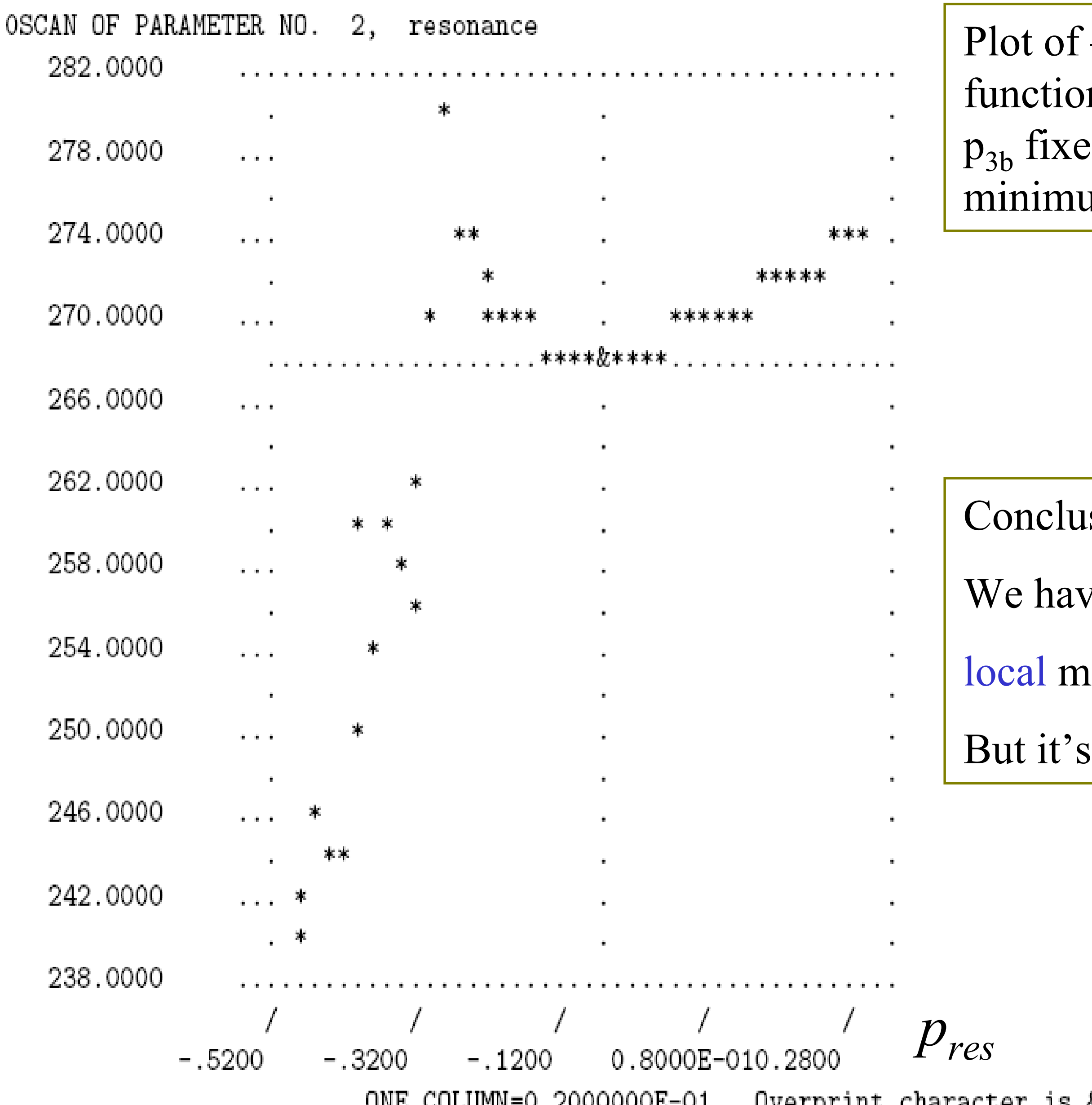
```
Y-AXIS: PARAMETER   2: resonance
  0.1365       22       222*    33      4
  0.1169       2          222    33
  0.9736E-01  2           *22     33
  0.7779E-01  2           * 22     33
  0.5822E-01  2           *  22     33
  0.3864E-01  2      1111 *   22     33
  0.1907E-01  2     11  111    22     33
 -0.5021E-03 -22---1-----11----22----3
 -0.2008E-01   2   1      *111    22
 -0.3965E-01   22  11     *  1     22
 -0.5922E-01 3  2   1    00  11     22
 -0.7879E-01 33*22**11**000**11****2**
 -0.9837E-01  3  22  11  00   11    22
 -0.1179      33  22  11 *      1     22
 -0.1375     4 333 22  111      1      2
 -0.1571     444 33 22   11     1      2
 -0.1767     5544 33 222 *111111
 -0.1962     145444333 222
 -0.2158     0004 44 33  22
 -0.2354     000000444333*2222
 -0.2550       00 000244333  222
 -0.2745            000444333  2222222
 -0.2941              0000033333
                  I           I           I
              0.7178                     1.440
                          1.079
       X-AXIS: PARAMETER  1: 3-body      ONE COLUMN=  0.2888E-01
FUNCTION VALUES: F(I)=   269.4     +  0.5000     *I**2
```

Conclusion:

1. We have a well-defined minimum;
2. Parameters are negatively correlated with each other.

Dalitz plot: Unbinned Likelihood Fitting

-lnL



Plot of –lnL as a function of p_{res} with p_{3b} fixed at minimum.

Conclusion:

We have a well-defined local minimum.

But it's a stable solution!

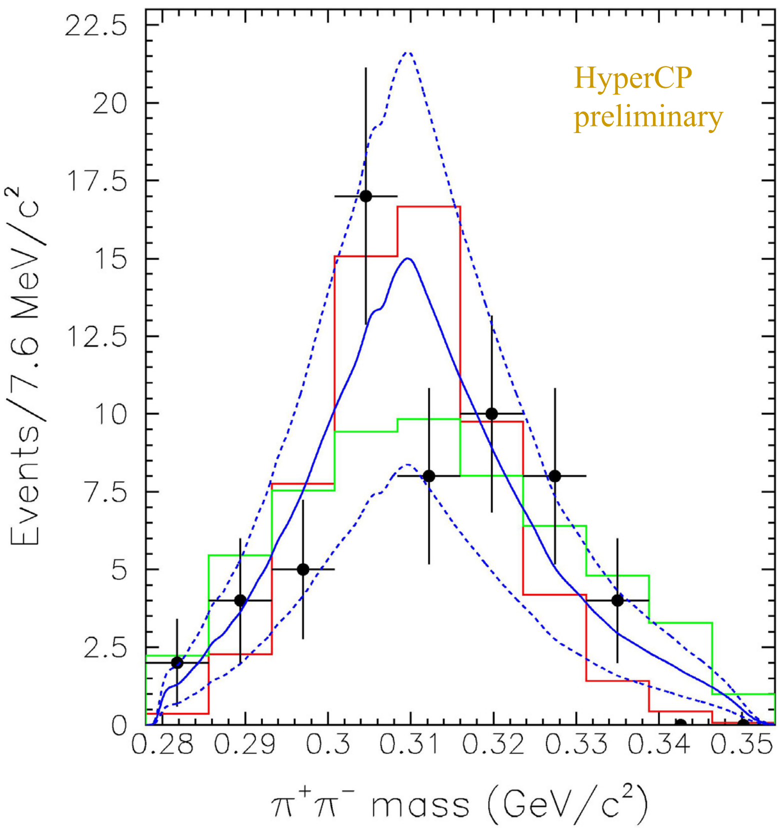
Pi(+)Pi(-): Unbinned Likelihood Fitting

<u>Signal Mode Data (dots with error bars), 58 events.</u>

Red – resonance mode MC; Green – 3-body uniform mode MC;

Histograms are for visualization purposes only.

Blue – MINUIT fit with negative and positive boundaries (dashed)



MINUIT:

FCN= 94.93940 FROM MINOS STATUS=SUCCESSFUL 59 CALLS 187 TOTAL

EDM= 0.17E-13 STRATEGY= 2 ERROR MATRIX ACCURATE

EXT PARAMETER			PARABOLIC	MINOS ERRORS	
NO.	NAME	VALUE	ERROR	NEGATIVE	POSITIVE
1	3-body	0.47209	0.22328	-0.20803	0.23880
2	resonance	0.52791	0.22542	-0.22496	0.22700

ERR DEF= 0.500

This is just for completeness. Obviously this variable is not a bright "signature" of the resonance mode.

Xi(1530): different region fitting

Xi(1530) mass range	original	1.48-1.535	1.49-1.535	1.495-1.54	1.485-1.53
# signal events	58	58	58	57	55
color code	blue	light blue	red	green	purple
fit. par., 3-body	1.11074	1.11837	1.20055	1.29634	1.11464
fit. par., 3-body error	0.18408	0.18572	0.19638	0.21123	0.20572
fit. par., res.	-0.11074	-0.10811	-0.14275	-0.18110	0.04466
fit. par., res. error	0.11326	0.11516	0.11475	0.11525	0.19980

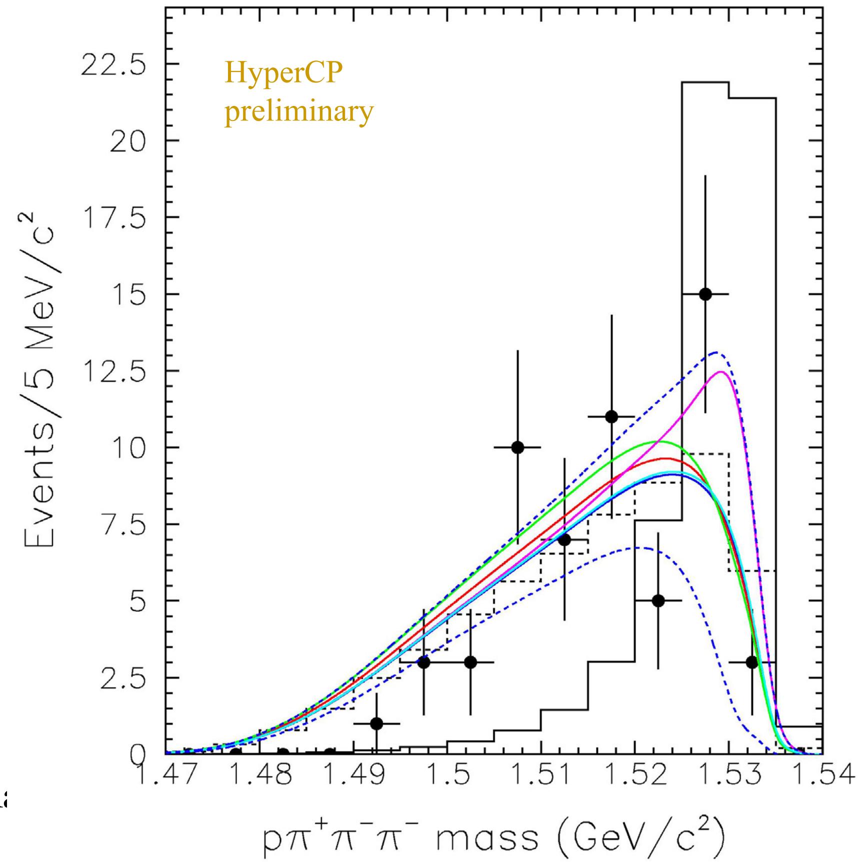
Dots with error bars – signal data, 58 events;

Solid line – resonance mode MC;

Dashed line – 3-body MC;

Histograms are for visualization only.

Color lines are explained in the table above.



Conclusion: Our fitting parameters are stable even if we change fitting region, but do not throw away events.