Cascade Spectroscopy at CLAS/CLAS12

Lei Guo, JLAB

for CLAS Collaboration

- Overview: Cascade physics is underexplored, and offers potential discovery
- Ground state $\Xi(1320)$: $\gamma p \rightarrow K^+ K^+ (\Xi^-)$
  - Few photon data existed. New CLAS g11 data: *~70/pb^{-1}, E_0=4.0186 GeV*
  - **Cross section measurement:**
  - Production mechanism probe ($Y^* \rightarrow \Xi K$?)
- Search for **excited Ξ states**
  - $\gamma p \rightarrow K^+ K^+ \pi^- (\Xi^0)$ analysis
  - **Future Spin-Parity measurement**
- Summary

Overview

- Cascade spectroscopy
  - Only 6 states with 3(4) stars
  - Most without spin-parity assignment
- Experimental verification of the Ξ^* decoupling from $\Xi\pi$ predicted by Chao, Isgur, Karl
  - Main reason of narrow width of Ξ resonances
- Can baryons in certain $SU(6)\otimes O(3)$ multiplets be seen in the cascade spectrum, but missing in $N\pi/NK^-$ scattering data?
- Isospin-violating mass differences of Ξ^*: do they agree with quark model/lattice predictions?
  - Not feasible in N* sector
- Photoproduction at JLAB offers unique alternative

CEBAF Large Acceptance Spectrometer@JLAB

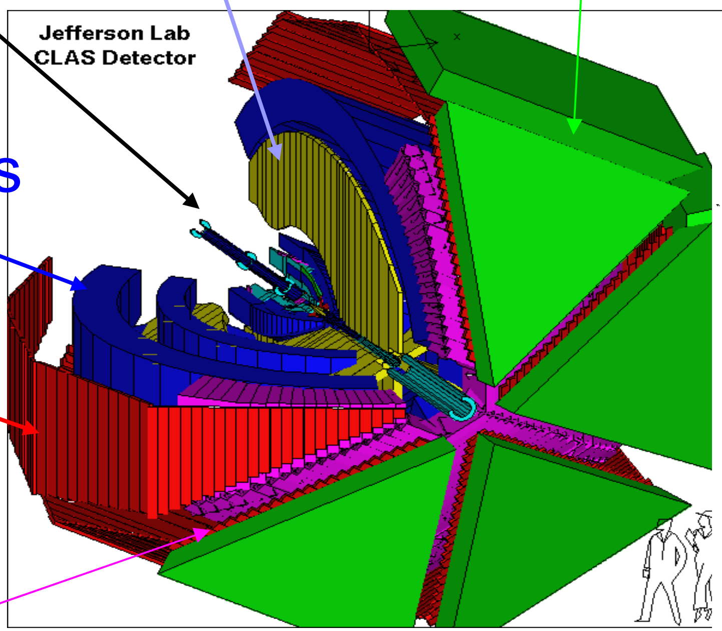
6 Superconducting toroidal coils

Electromagnetic calorimeters

Beam line and the target

Drift chambers

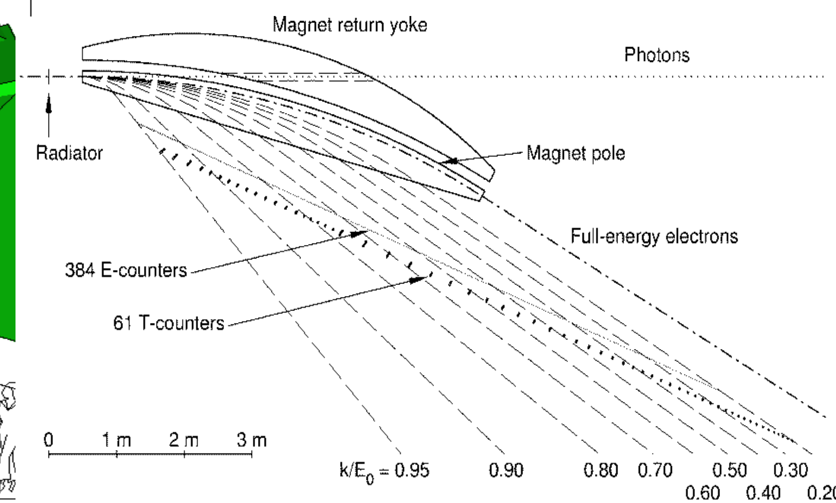
TOF counters



Cherenkov counters

CLAS Detector

Bremsstrahlung tagged photon facility, photon energy resolution ~0.1% (New Tagger Energy Calibration)



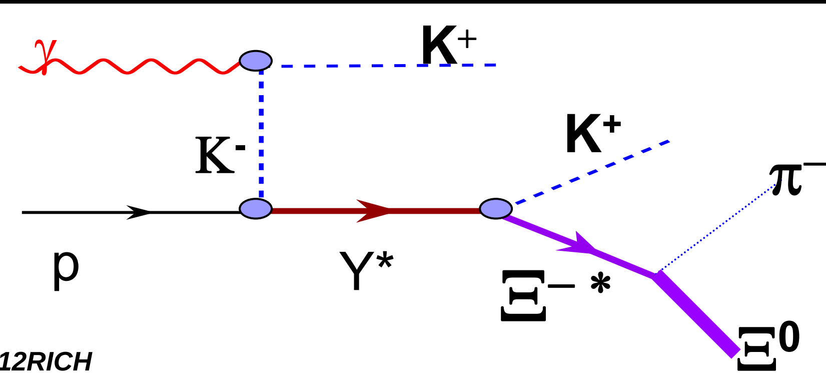
Tagger

Search for $\Xi^{-*} \rightarrow \Xi^{0}\pi^{-}$

- Few excited cascade states observed
- CLAS ideal for Ξ^{-*} in exclusive reaction:

  $\gamma p \rightarrow K^{+} K^{+} \pi^{-}(\Xi^{0})$
- Accessible Ξ^{*} states:
- Complicated by background processes:
  - $\gamma p \rightarrow K^{+} K^{*} (\Xi^{0})$
  - $\gamma p \rightarrow K^{+} Y^{*}$, $Y^{*} \rightarrow Y^{*'} \pi^{-}$, $Y^{*'} \rightarrow K^{+} \Xi^{0}$

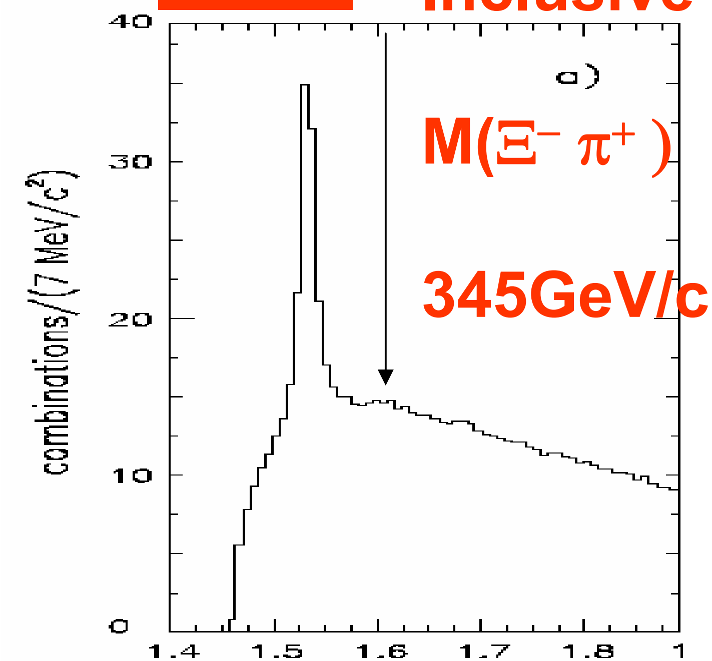
Excited cascades	Mass (GeV/c^2)	Width (MeV/c^2)	$\Xi\pi$ BR
$\Xi^{-0}(1530)$	1.535	9.1	100%
Ξ^{0}(1620) (*)	1.6-1.63	~22	$\Xi\pi$
$\Xi^{-0}(1690)$ (***)	1.69	<30	seen



First observation of $\Xi(1690) \rightarrow \Xi\pi$

X 10^3

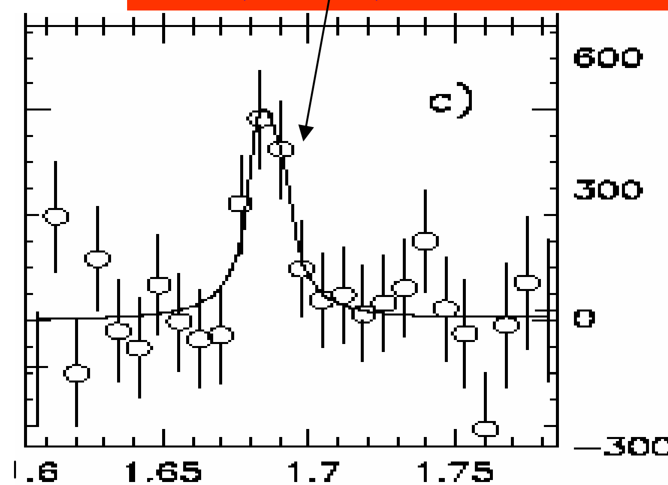
Inclusive reaction: Σ^- **(C, Cu)** $\rightarrow$ $(\Xi^-\pi^+)$ **X**



M($\Xi^- \pi^+$)

345GeV/c

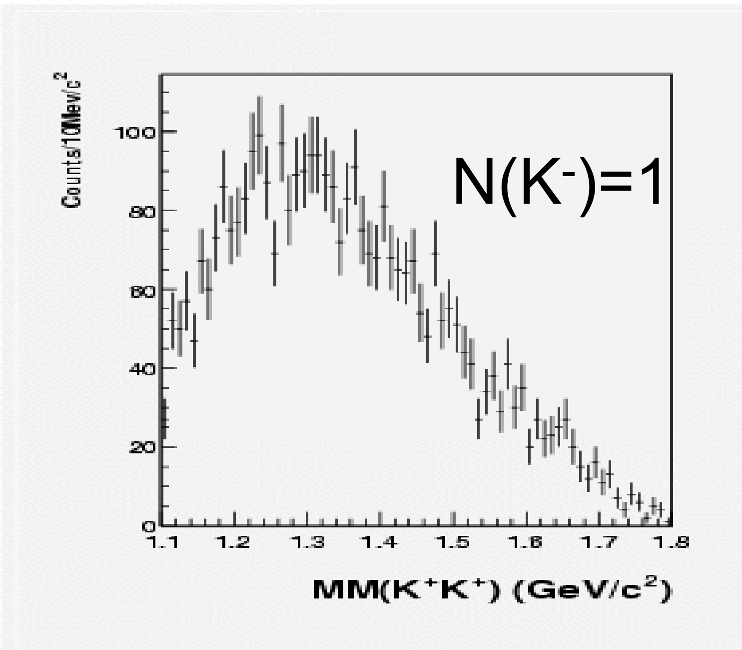
No mention of $\Xi^0(1620)$;
Ξ^0 (1690) claimed

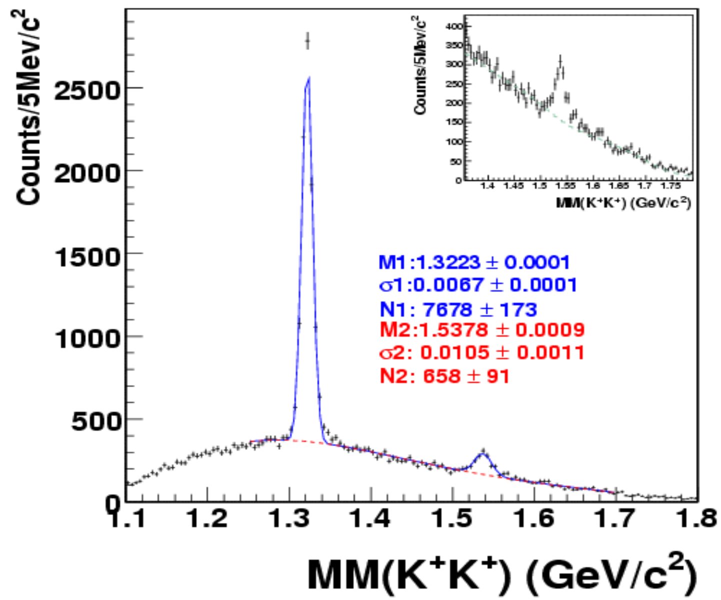


Adamovich et al.
W89 Collaboration
Eur. Phys. J. C5(1998) 621

After backgroud subtraction

CLAS data: $\gamma p \rightarrow K^+ K^+ (X^-)$



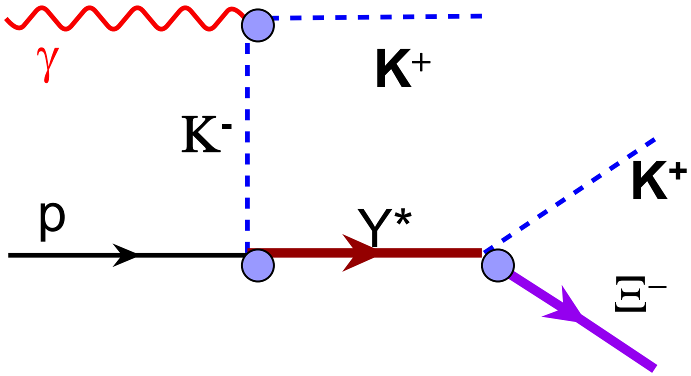


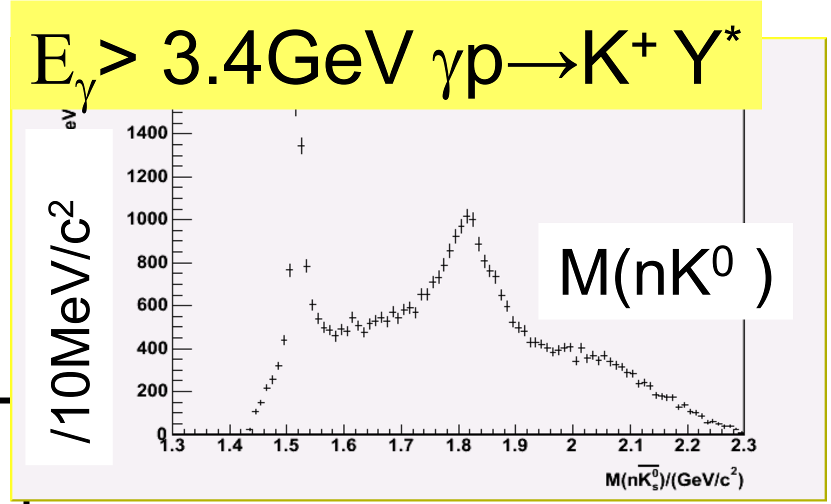
Phys.Rev.C76:025208 (2007)

With multiple Kaons in the final state, pion-veto is essential

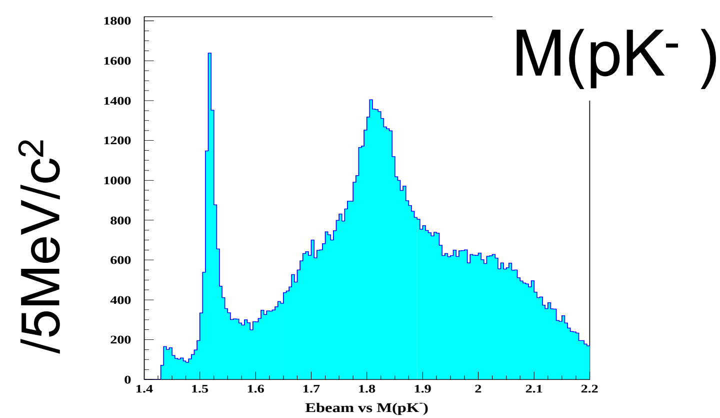
- 1-sector RICH: 30% background suppression ($2K^+$)
- 2-sector: 56% background suppresion

Hyperon candidates decaying to KΞ

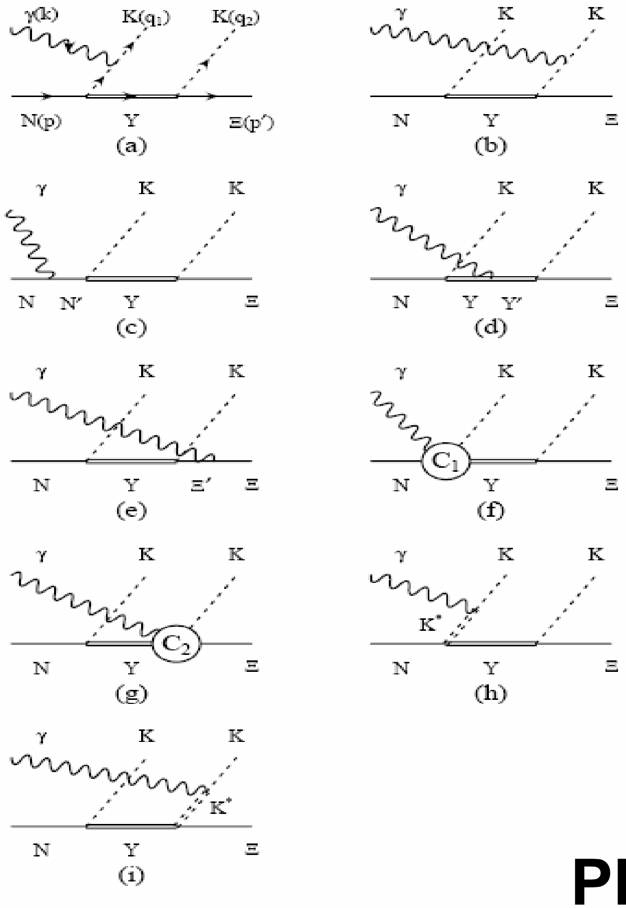




Y*	Mass (GeV)	Width (MeV)	BR→ ΞK
Σ(1940)	1.94	200	N/A
Σ(2030)	2.03	180	<2%
Λ(2100)	2.10	200	<3%



Hadronic model for cascade photoproduction: Oh-Nakayama-Haberzettl model:



Radiative transition processes, various t,s channel processes

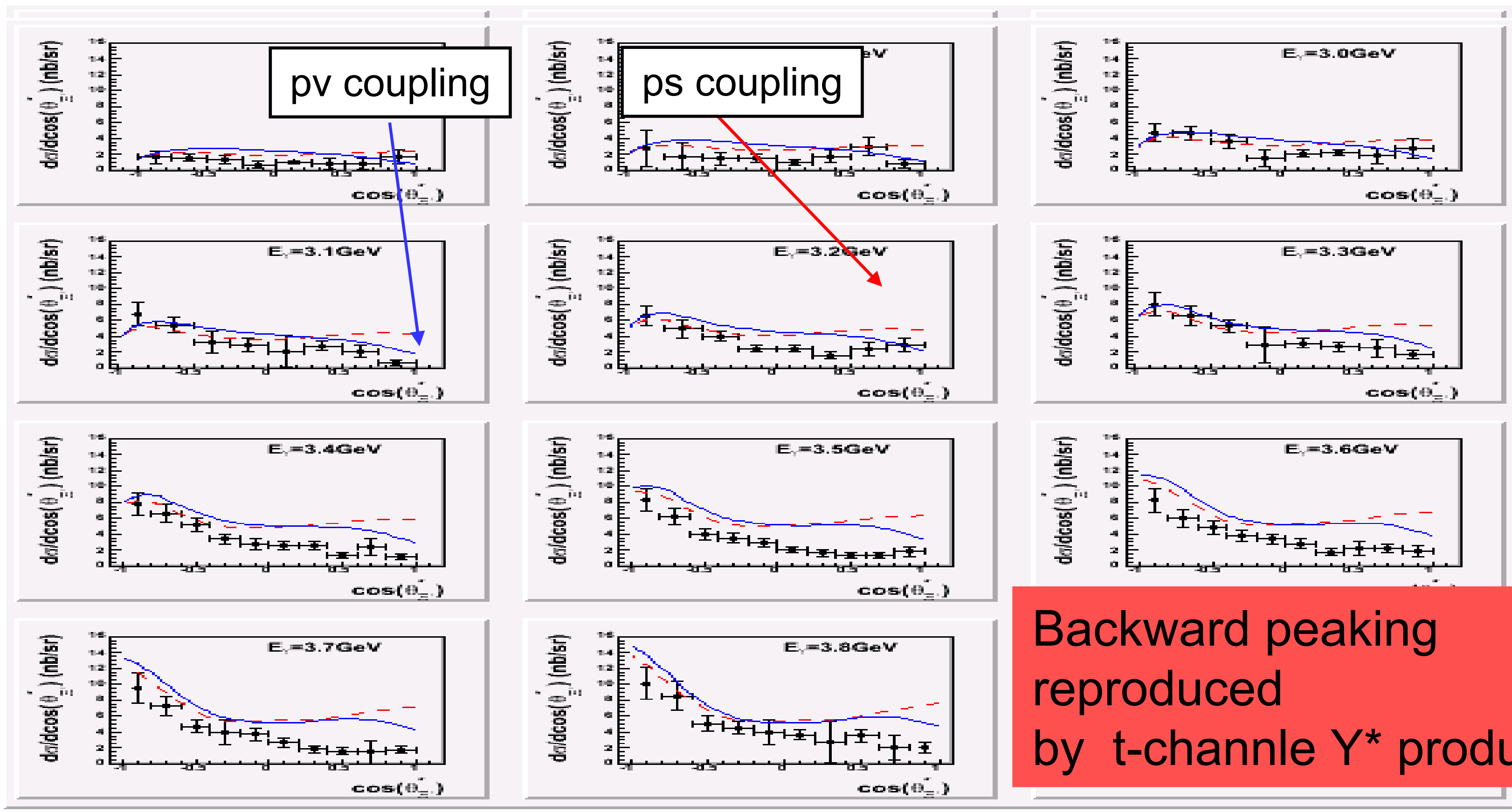
Only K and K* exchange included

Model includes low-lying N*/Δ/Y*

Y: J^P = 1/2⁻ and 3/2⁺ hyperon resonances

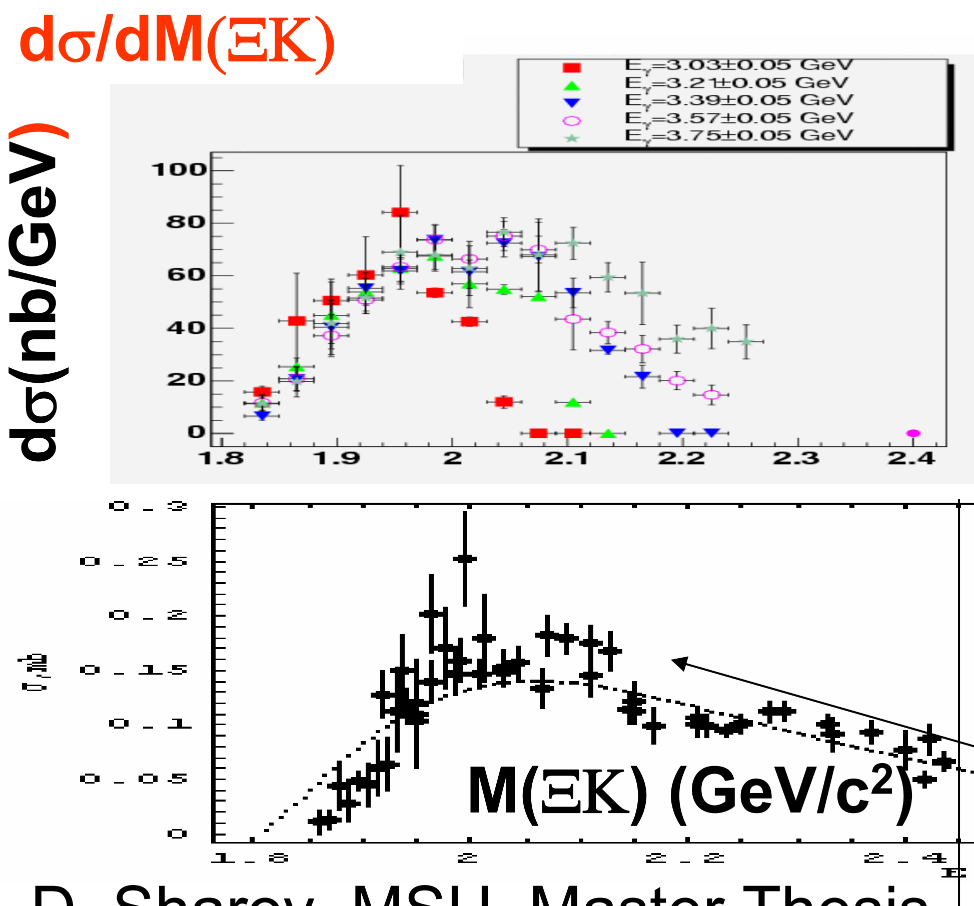
Phys.Rev.C74:035205,2006

Ξ^- differential Cross sections compared with Oh-model: $d\sigma / d\cos(\theta_\Xi)$



Backward peaking reproduced
by t-channle Y* production

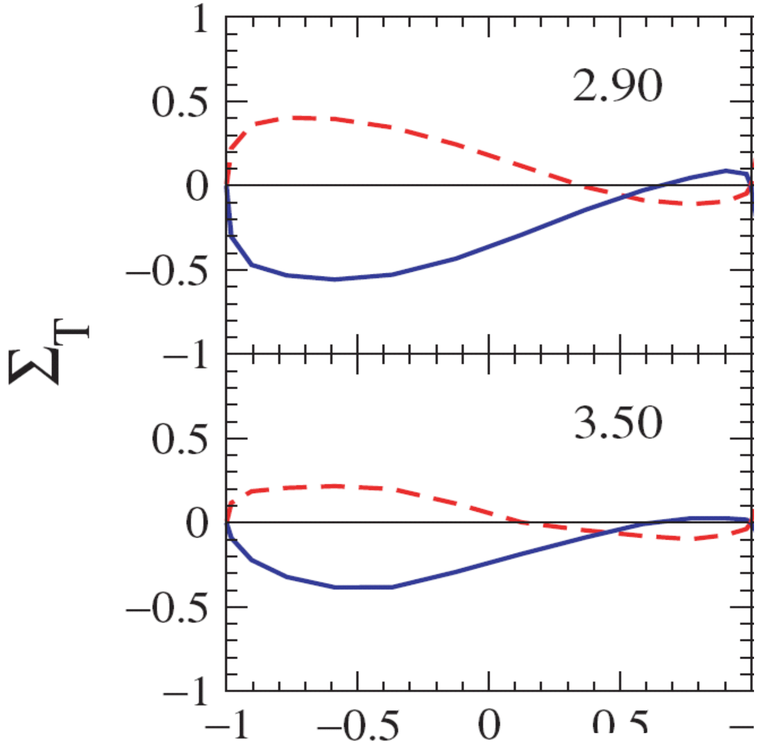
Interesting features of M(ΞK) spectra



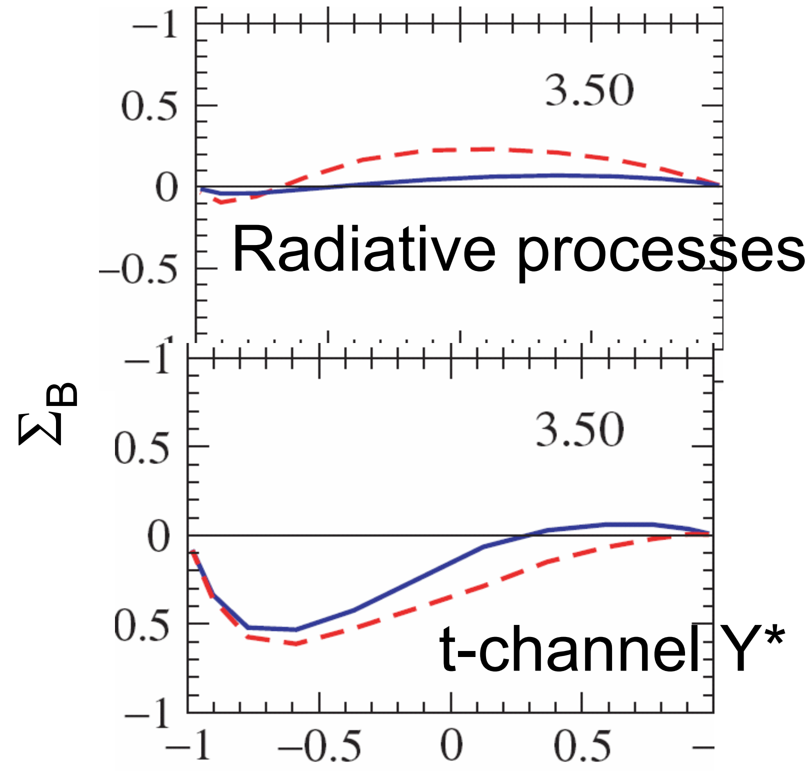
D. Sharov, MSU, Master Thesis

- Statistics insufficient to be conclusive
- Not inconsistent with multiple Y*→ΞK
- dσ strength independent of E_γ at low M(ΞK): Diffractive process?
- Early bubble chamber K^-p data suggestive

Polarization variables necessary to determine production mechanism

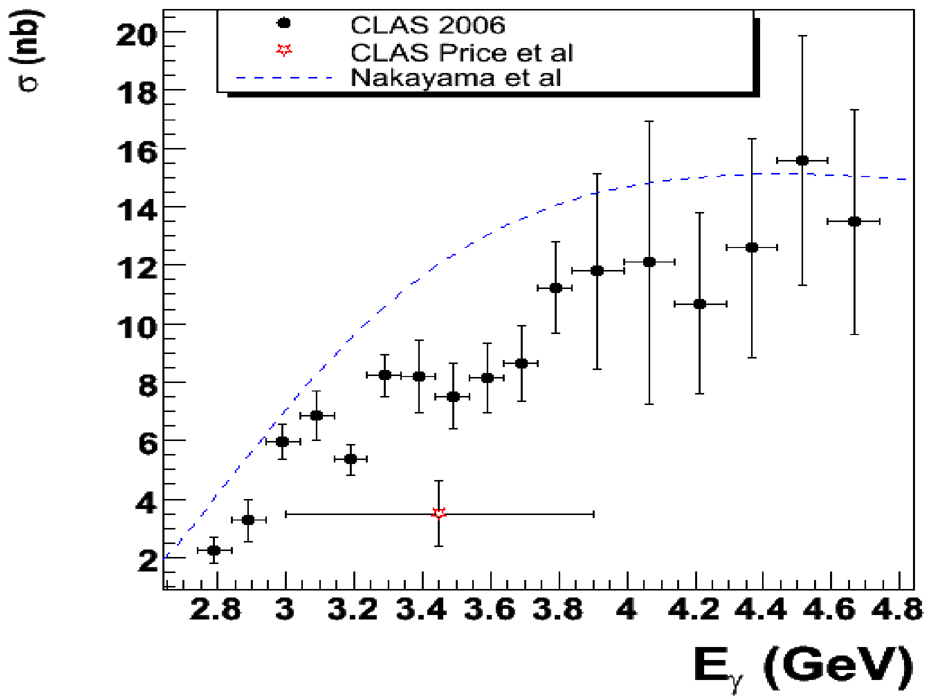


$\cos(\theta_\Xi)$



$\cos(\theta_\Xi)$

Total cross section for $\gamma p \rightarrow K^+ K^+ \Xi^-$

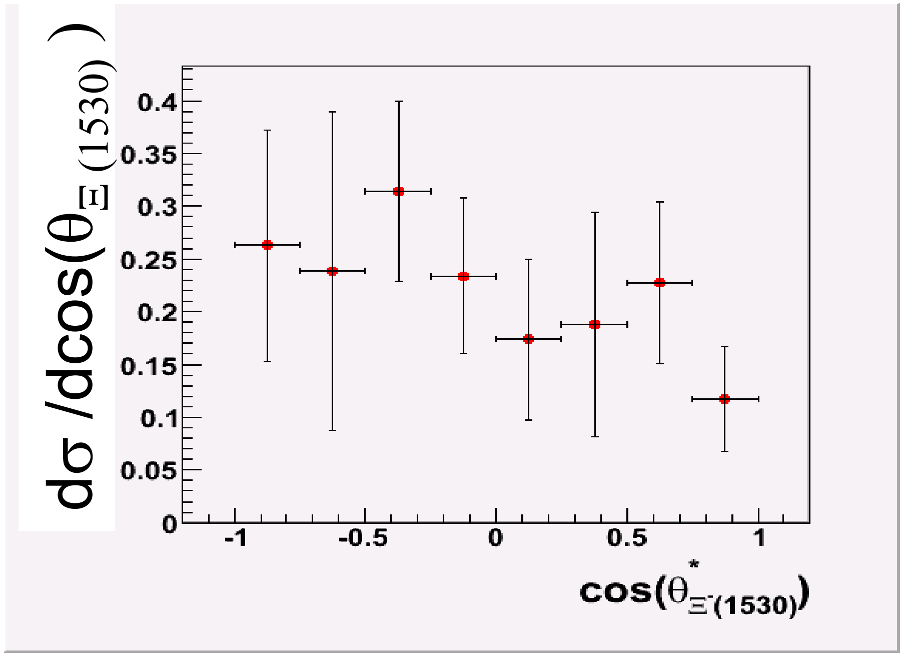


Oh-model used earlier preliminary results (NSTAR05)

SLAC measurement: 117 ± 17 nb from inclusive reaction (K. Abe et al., Phys. Rev. D32, 2869 (1985)

Ξ^{-}(1530) Cross section results

Differential cross section



E_{γ}: 3.35-3.85 GeV

Total cross section:

E_{γ}: 3.35-3.85 GeV

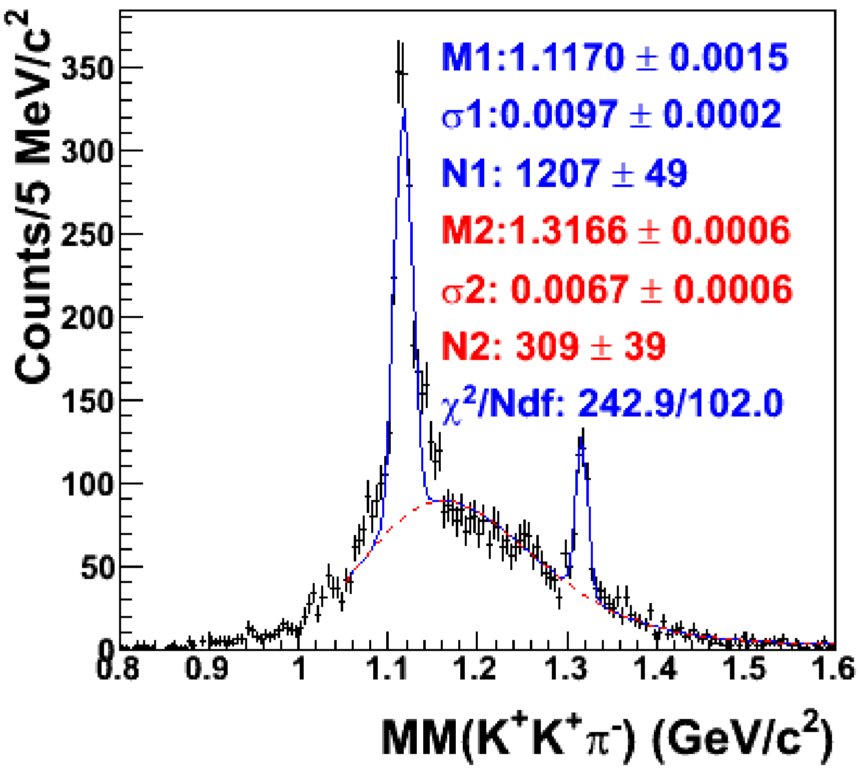
σ:1.13± 0.27nb

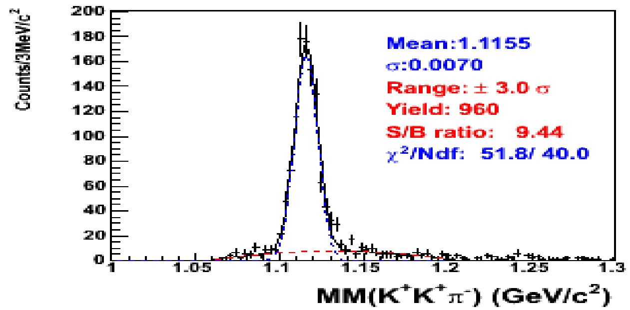
Eγ: 3.85-4.75 GeV

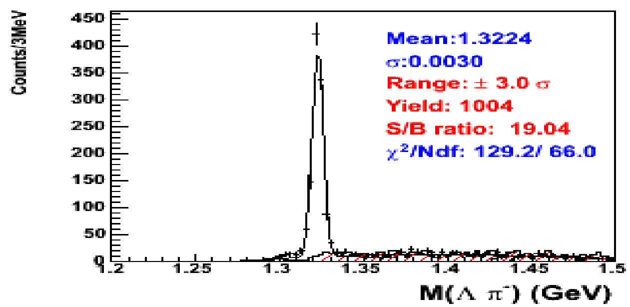
s:1.77 ± 0.40nb

$\gamma p \rightarrow K^+ K^+ \Xi^{-*}$, $\Xi^{-*} \rightarrow \pi^- \Xi^0$

$M(\Xi^-)$-$M(\Xi^0)$=5.5±1.8MeV



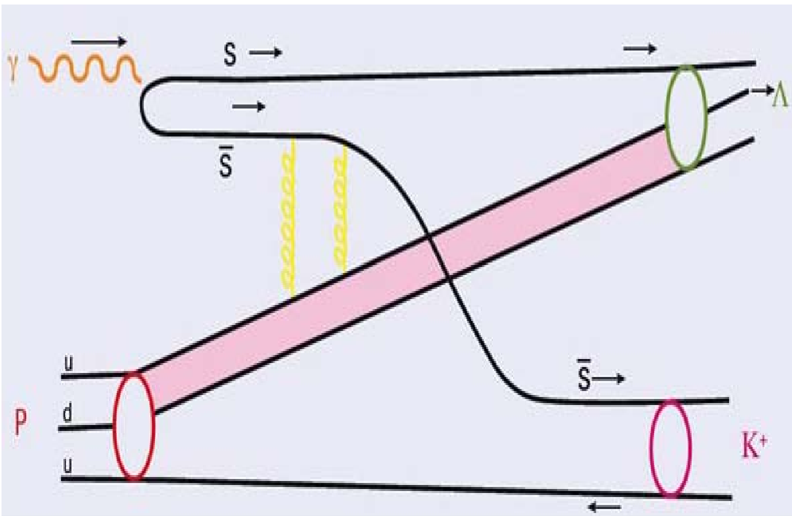




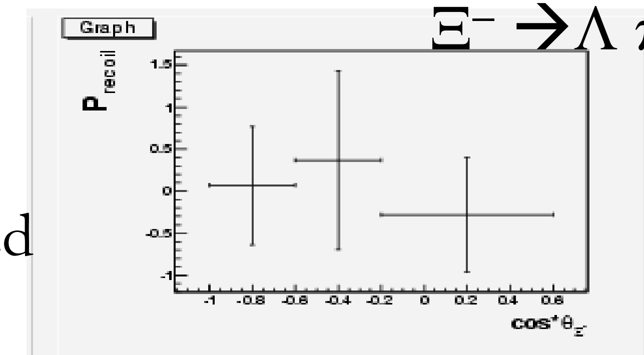
Clean sample of Ξ events

Ξ^- (1320) polarization transfer

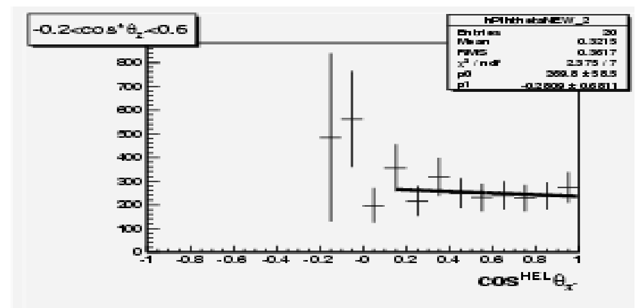
Phtoproducing polarized Λ



Acceptance corrected decay angular distribution (Helicity frame)



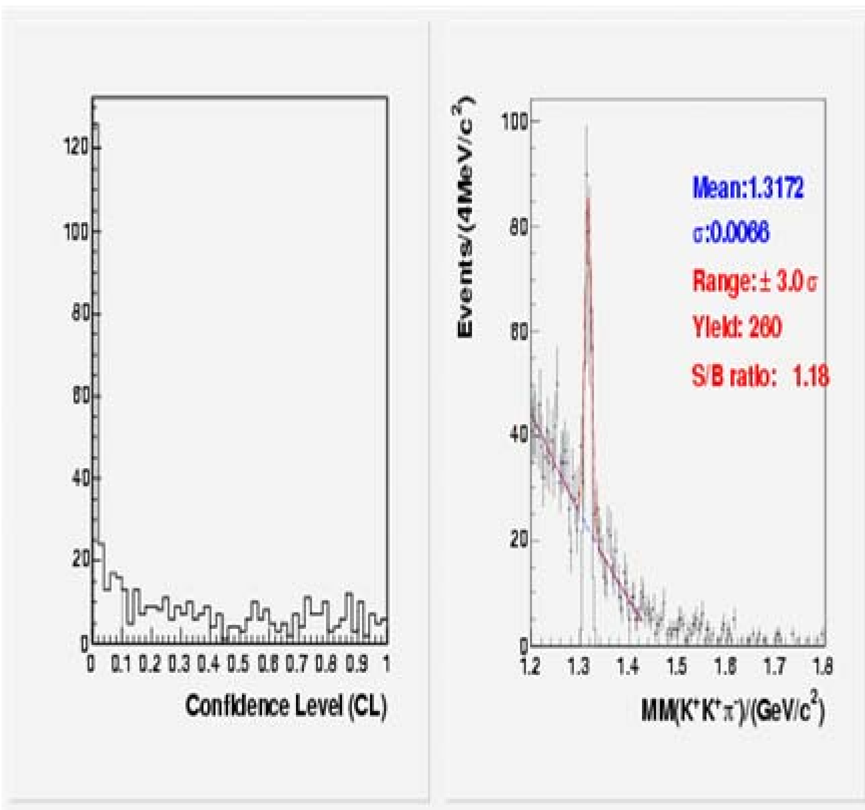
$\Xi^- \rightarrow \Lambda\ \pi^-$

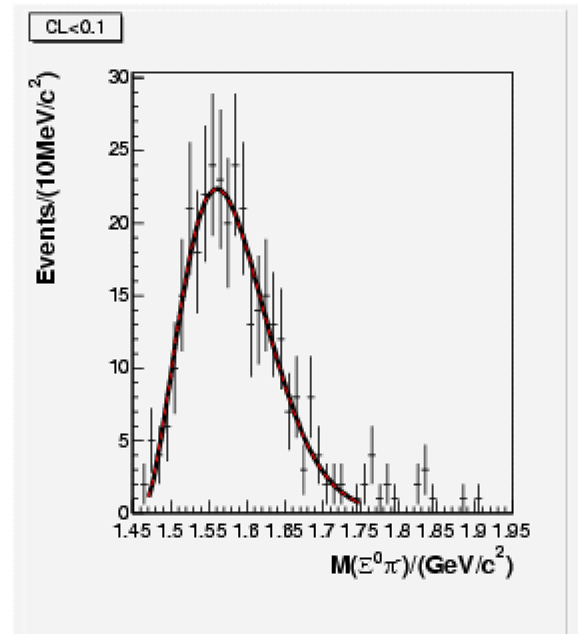


- Ξ can be similarly produced polarized along production plane norm
- Very sensitive to production mechanism

No polarization expected in helicity frame

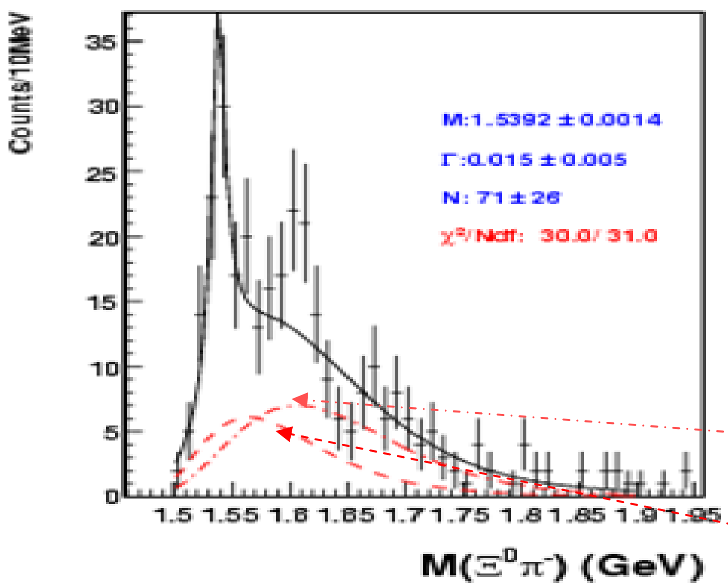
Kinematic fitting results





Non-Ξ^0 events background consistent with out-of-target events background

$\Xi^0\pi^-$ invariant mass spectrum



CL>0.1

Signal other than $\Xi(1530)$ insignificant

K* bakground

Non-Ξ events background

Ξ(1530) yields consistent
With 100% Ξπ BR (0.9±0.3)

Spin-Parity determination of Ξ^*

- Spin can be measured by angular distributions (PWA)
- Parity measurement challenge: Minami ambiguity

  $\Xi^* \rightarrow Y\,(1/2^+) + M_1\,(0^-)$: two solutions $J^{\pm P}$

- Double Moment Analysis (DMA)

  $Y\,(1/2^+) \rightarrow B\,(1/2^+) + M_2\,(0^-)$

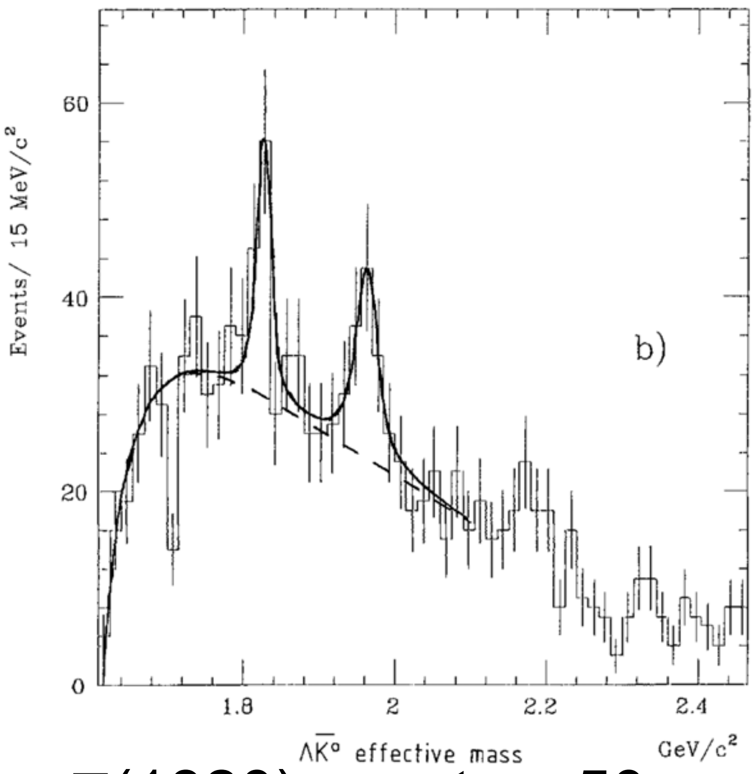
  Double moments: $H(lmLM) = \Sigma\, D^L_{Mm}(\theta_1, \phi_1)\, D^l_{m0}(\theta_2, \phi_2)$

  DMA:

$$H(11LM) = P(-1)^{J+\frac{1}{2}} \frac{2J+1}{\sqrt{2L(L+1)}} H(10LM)$$

  Linear dependence gives simple, mutiple tests for J, P
  For any odd $L \leq 2J$ and $M \leq L$

Parity measurement of Ξ(1820)



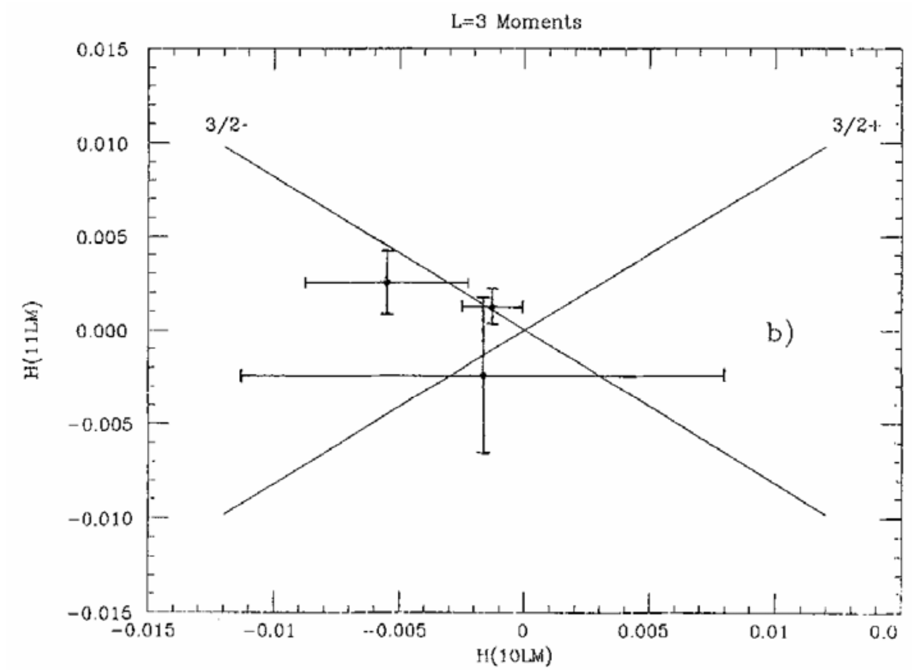
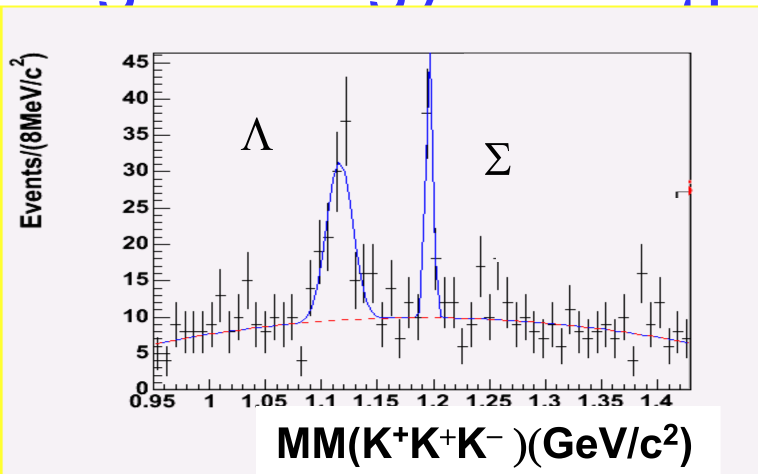


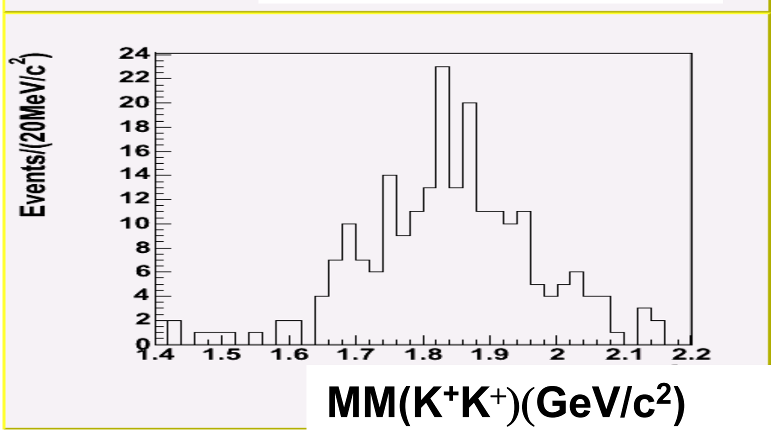
Fig. 4a, b. As in Fig. 3, but for the decay sequence $\Xi(1820) \rightarrow \Lambda \bar{K}^0$, $\Lambda \rightarrow p\pi^-$

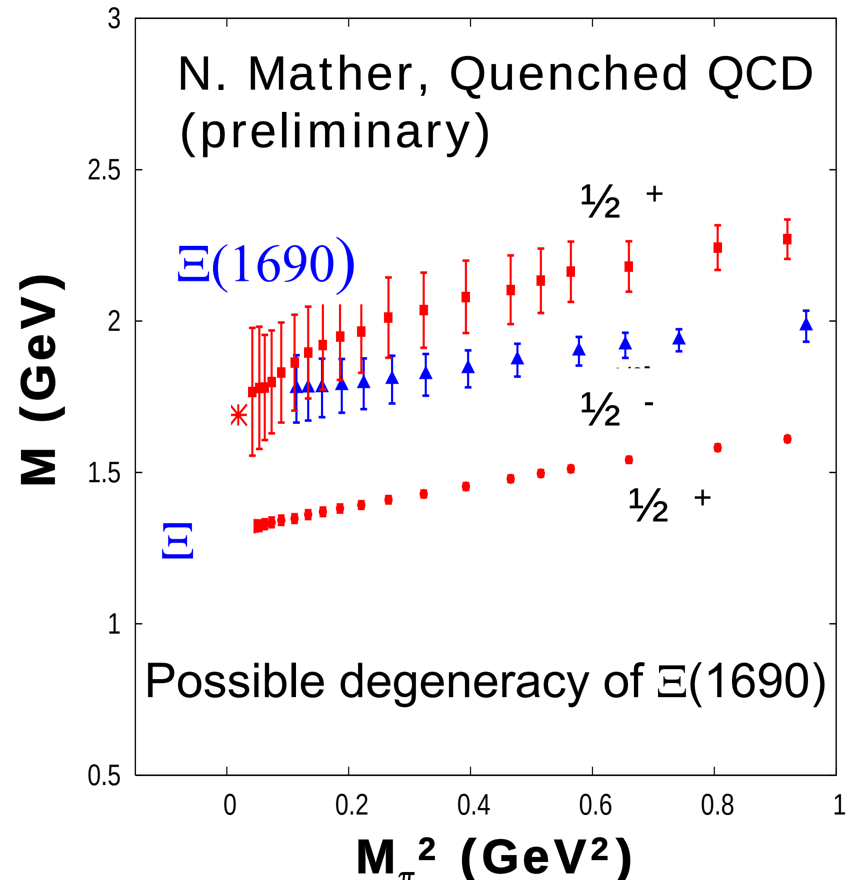
Ξ(1820) counts: ~50

Excited states

high energy data: $\gamma p \to K^+ K^+ \Xi^{-*}$, $\Xi^{-*} \to K^- \Lambda/\Sigma$







Detecting Λ will enable the parity determination

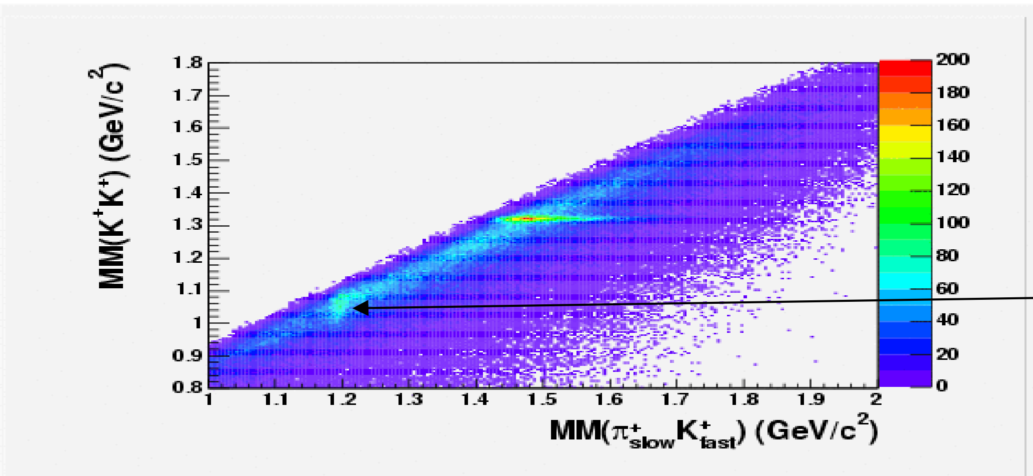
Prospects at CLAS12

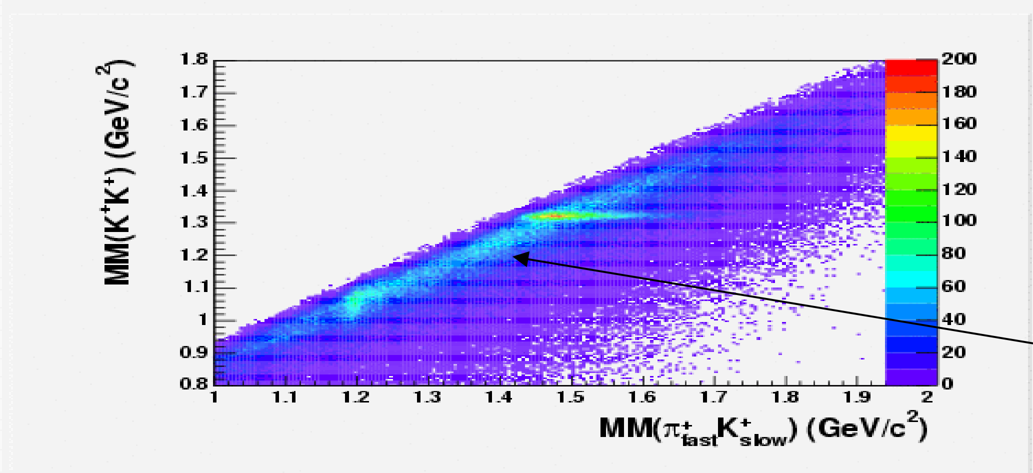
- Photoproduction of cascades
  - E_0~6.6 GeV: $M(\Xi^{*-})$~3GeV
  - E_0~6.6 GeV: $M(\Xi^{*-})$~2.6 GeV
  - K/π/P separation up to 5 GeV
- Polarization measurement
  - Extracting production mechanism information
  - Hadronic picture/Quark-gluon framework
- Spin-parity measurement
  - Necessary to establish resonances

Summary and outlook

- CLAS good instrument for Cascade photoproduction
- $\Xi^-(1320)$ cross section obtained for E_γ =2.8~4.7 GeV ($\sigma(E_\gamma) \propto E_\gamma$?)
- Data suggestive of t channel production of Y*→ $\Xi^- K^+$
- Polarization variables essential to understand production mechanism
- RICH detector will significantly improve data quality, and make J^P measurements easier.

Reaction $\gamma p \rightarrow K^{+} K^{+}(\Xi^{-})$ Misidentified pion background

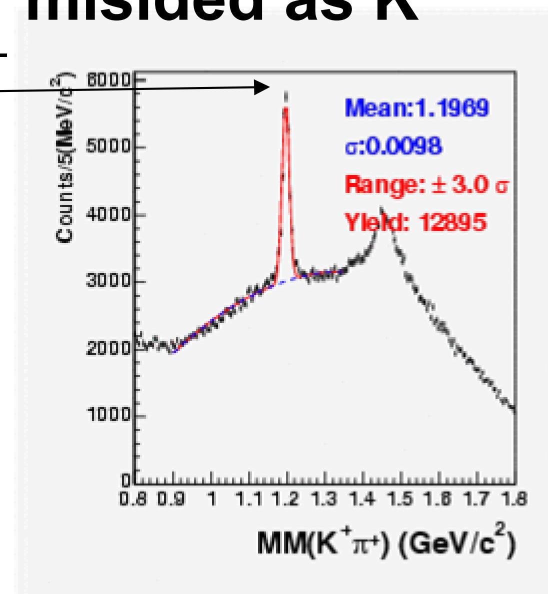




$\gamma p \rightarrow K^{+} \pi^{+}(\Sigma^{-})$,

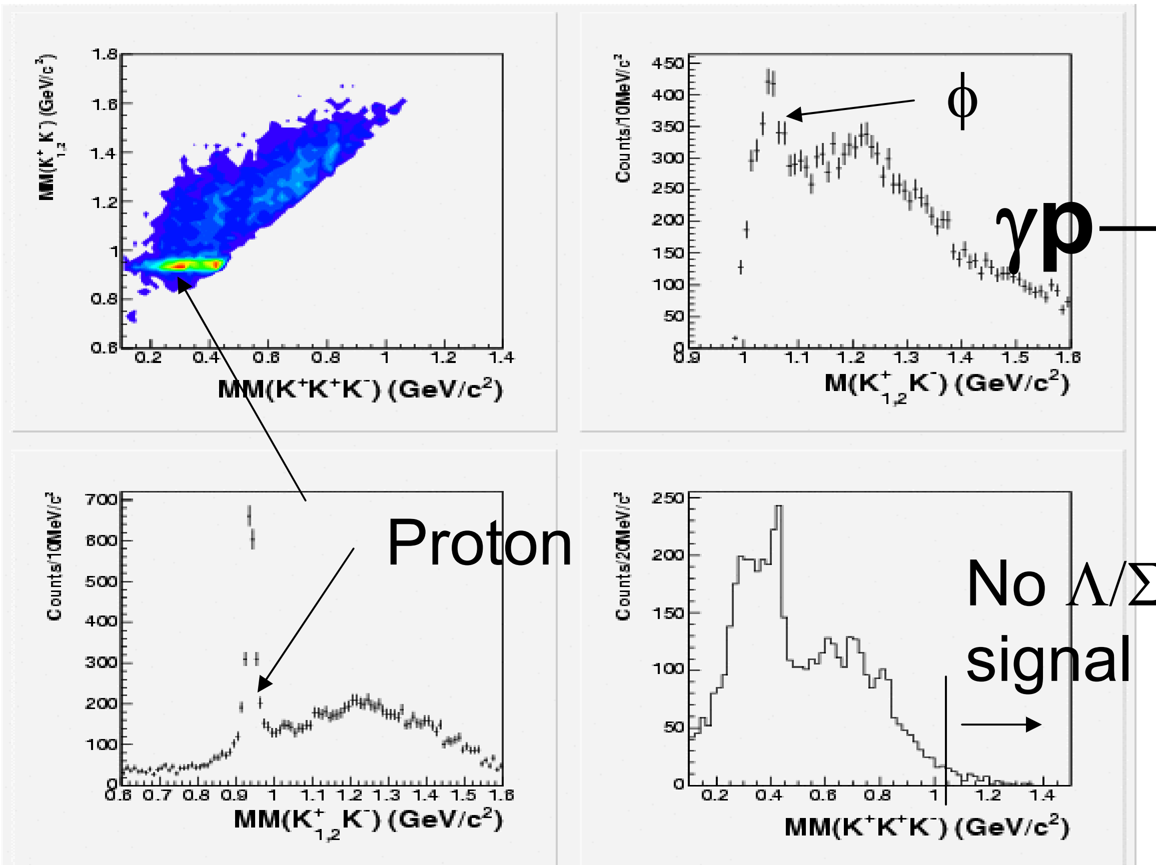
π^{+} misided as K^{+}

Σ^{-}



Linear band non-physica

Background events with K^- detected

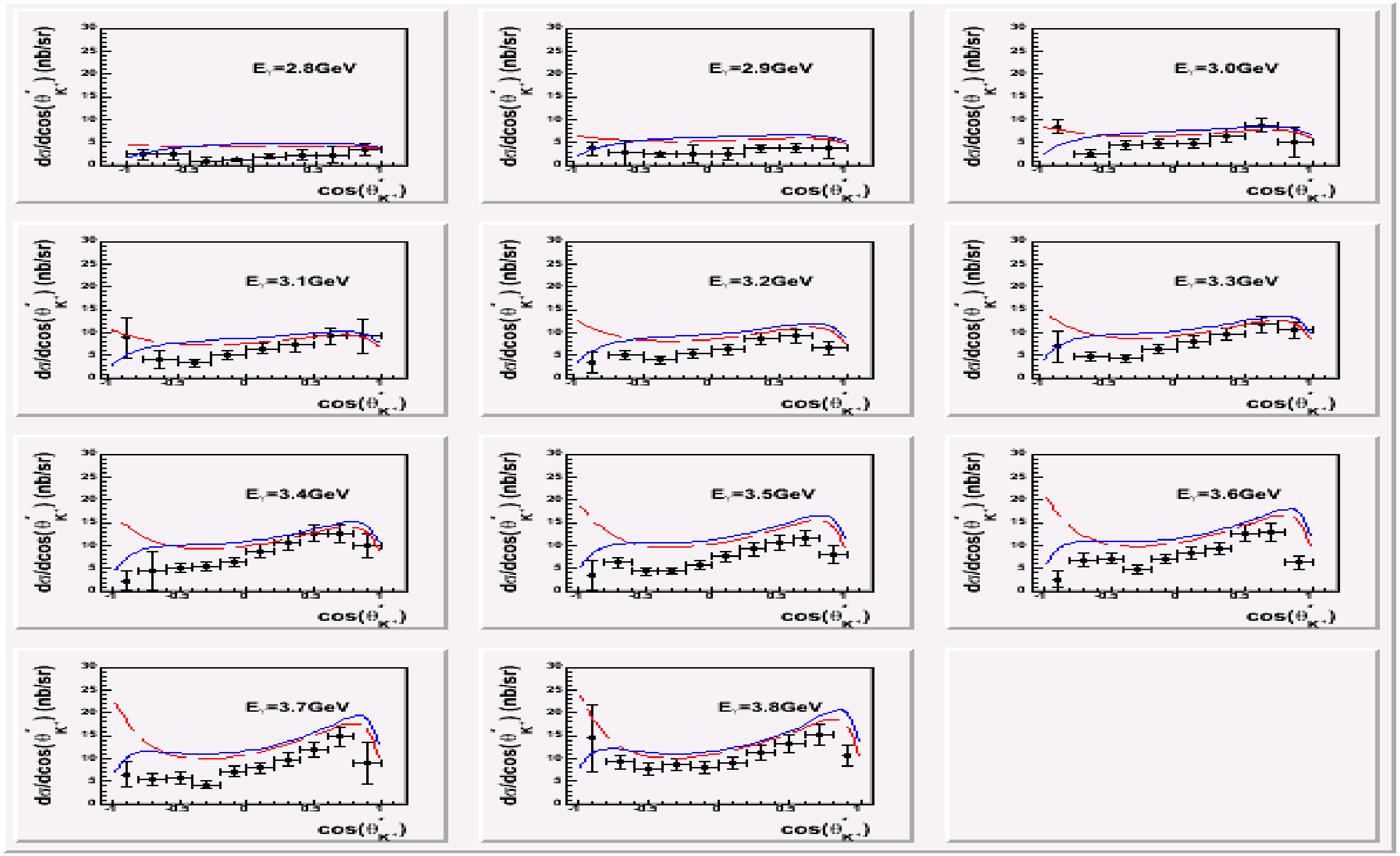


$\gamma p \rightarrow K^+ K^+ K^-(\Lambda/\Sigma)?$

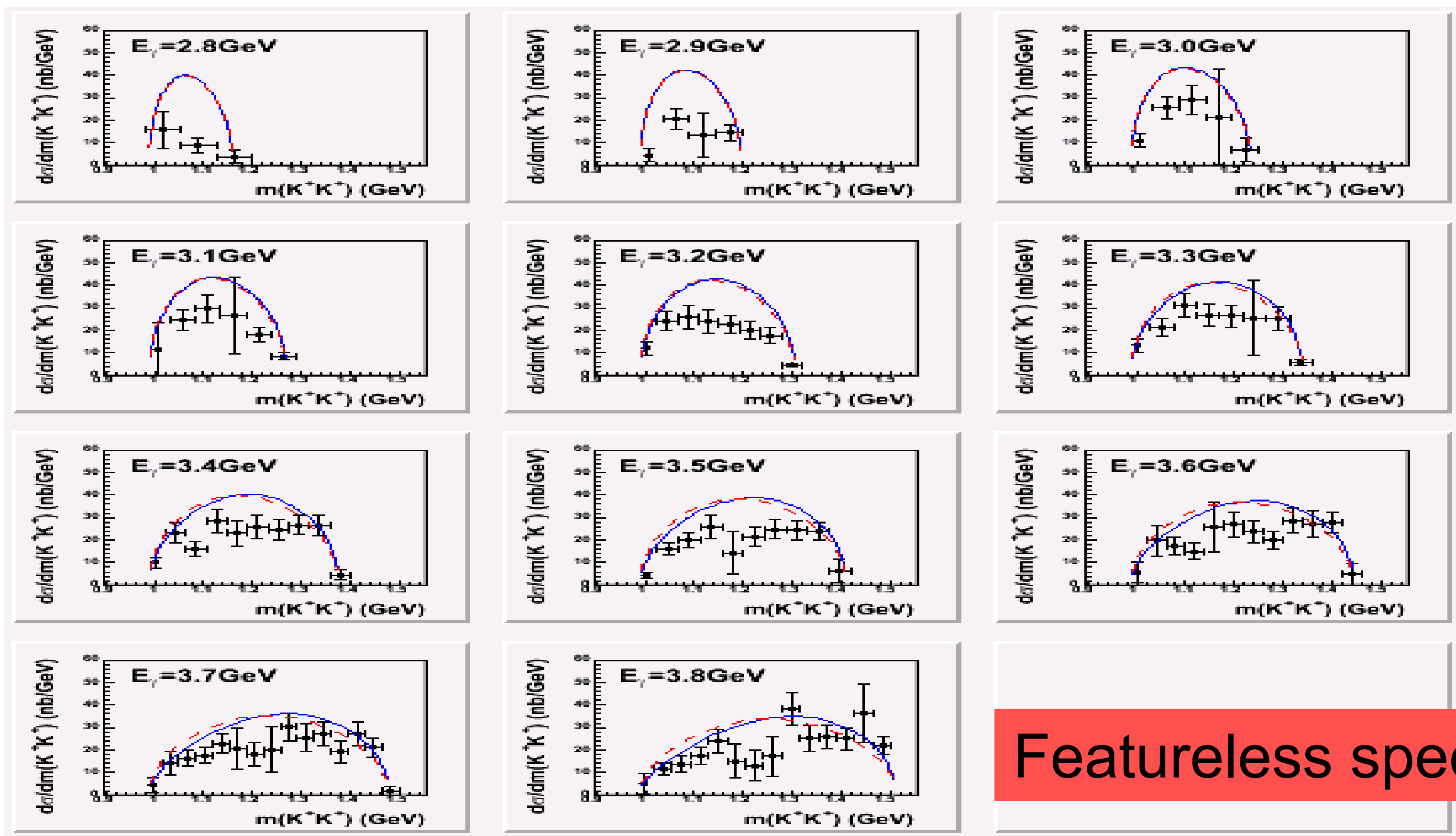
$\gamma p \rightarrow K^- \Lambda(\Sigma)\phi$

$\gamma p \rightarrow K^+ K^+ (\Xi^*)$

Ξ^- differential Cross sections $d\sigma/d\cos(\theta_K)$

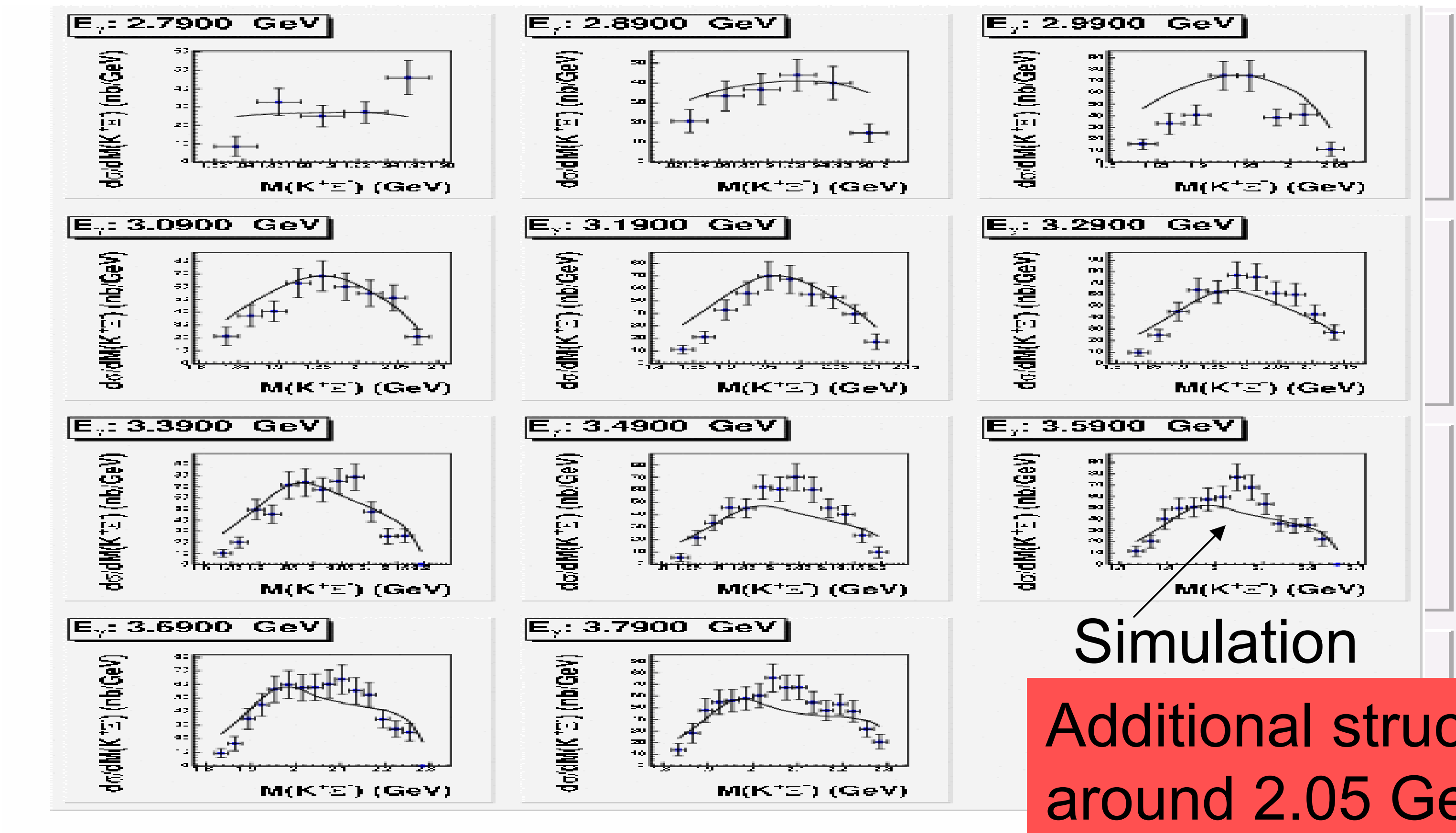


Ξ⁻ differential Cross sections: dσ /dM(KK)



Featureless spectra

Ξ^- differential Cross sections $d\sigma / dM(K\Xi)$



Simulation

Additional strucure around 2.05 GeV at high Eγ

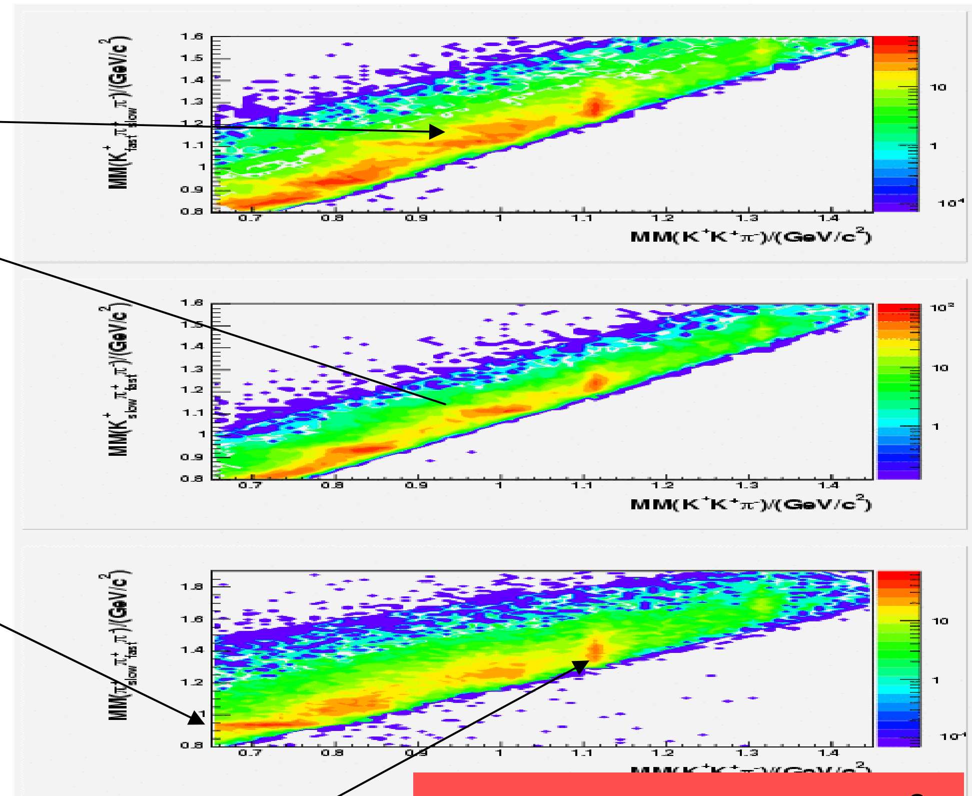
$\gamma p \to K^+ K^+ \Xi^{-*}$, $\Xi^{-*} \to \pi^- \Xi^0$ background events

One π^+ misidentified as K^+

$\gamma p \to K^+ \pi^+ \pi^- (\Lambda/\Sigma)$

Both π^+ misidentified as K^+

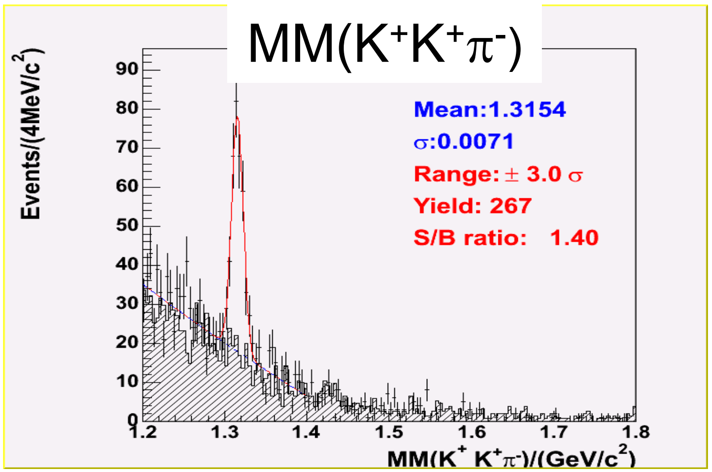
$\gamma p \to \pi^+ \pi^+ \pi^- (n)$



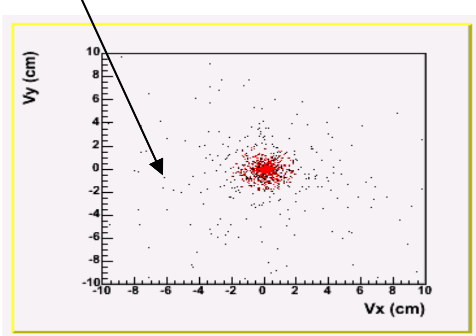
MM($K^+K^+\pi^-$) (GeV/c^2)

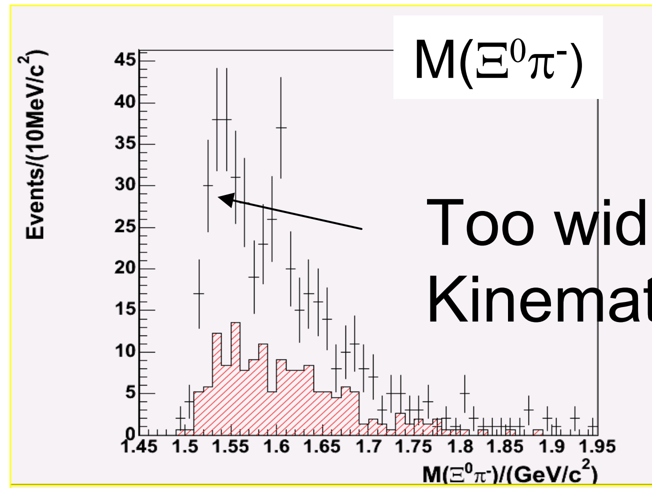
Real events: $\gamma p \to K^+ K^+ \Xi^-$, $\Xi^- \to \pi^- \Lambda$

Using out-of-vertex events for background estimate

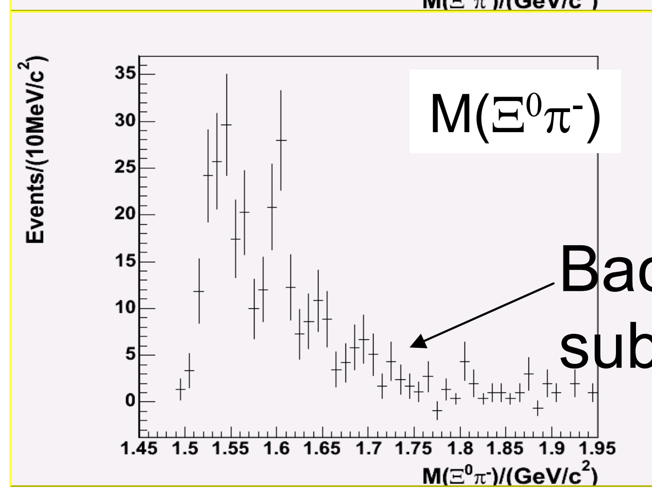


Shaded events: Background from out of target events



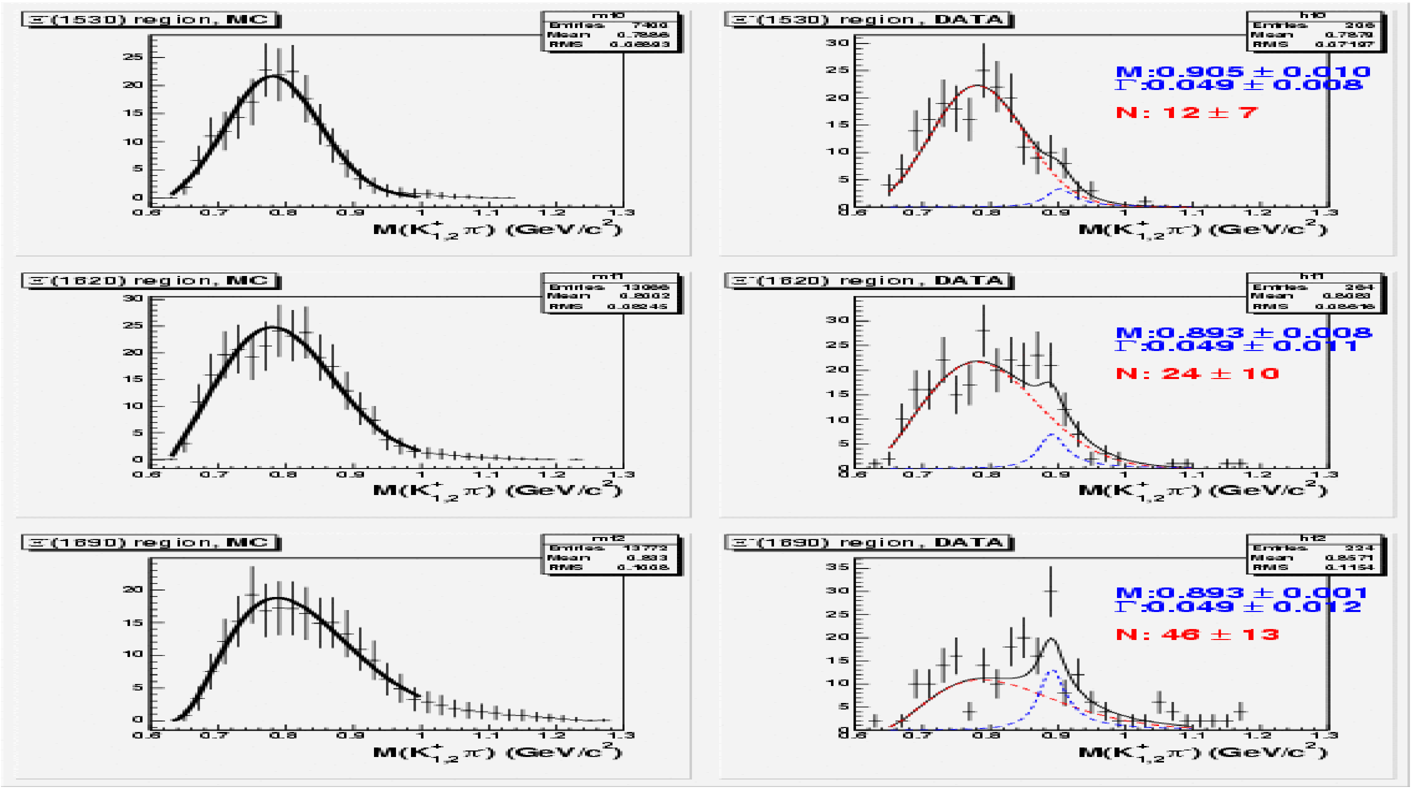


Too wide, need Kinematic fitting



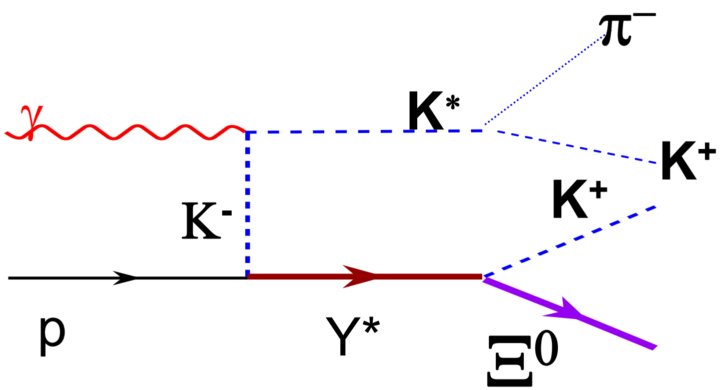
Background subtracted

Simulation: $\gamma p \rightarrow K^+ K^+ \Xi^{-*}$, $\Xi^{-*} \rightarrow \pi^- \Xi^0$
Comparing $M(K^+ \pi^-)$: MC VS data



Up to 30% events could be K*

Possible additional background: $\gamma p \to K^+ K^* \Xi^0$

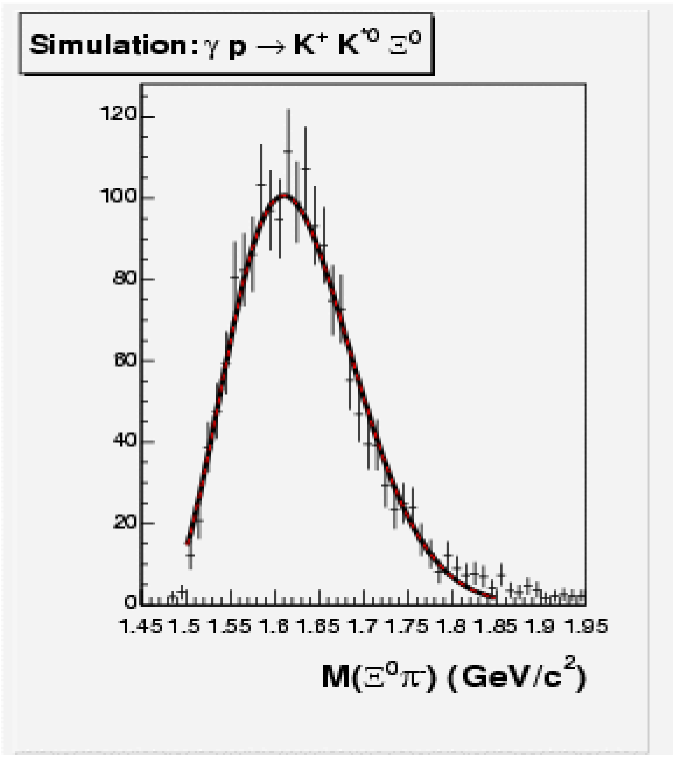


Simulation parameters:

M(Y*)=1.9GeV

G(Y*)=120MeV

Other bg processes not included



Peaking around 1.6GeV