First Measurement of Differential Photoproduction Cross Sections and Lineshapes of the $\Lambda(1405)$ Using CLAS

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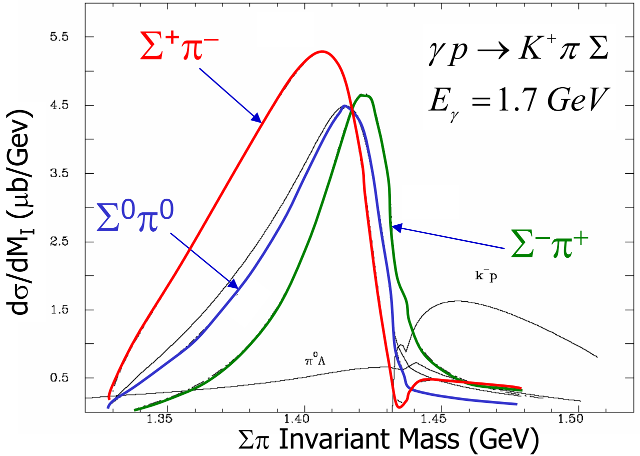
what is the $\Lambda(1405)$?

- well-established resonance just below $N\overline{K}$ threshold
- long-standing peculiarity on what its nature is:
  - assignment of $L = 1$ SU(3)-singlet within constituent quark model
  - unstable $N\overline{K}$ bound state
  - dynamically generated resonance in unitary meson-baryon channel coupling
- as a signal of its "peculiar nature", past experiments have found the lineshape (= invariant mass distribution) to be distorted from a simple Breit-Wigner form



J. C. Nacher et al.,

Nucl. Phys. B455, 55

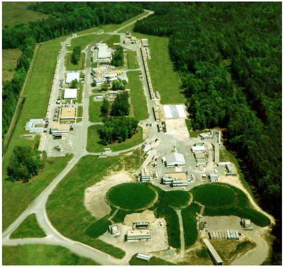
prediction:

not only is the lineshape distorted from a Breit-Wigner form,

it is different for each $\Sigma\pi$ decay mode

overview of data

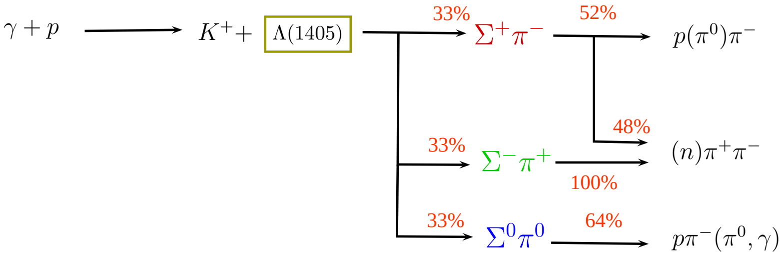
- data was taken at Jefferson Lab in Newport News, VA
  - Hall B, **CLAS** detector
- photoproduction on a proton target with $E_\gamma < 3.84$ GeV
- large data set with ~ 20 B triggers

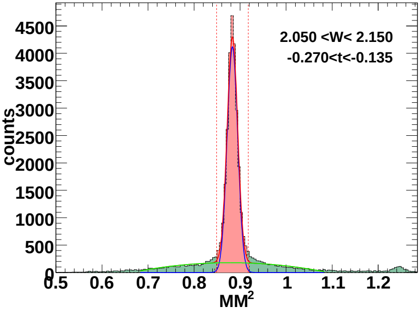


aerial view of Jefferson Lab

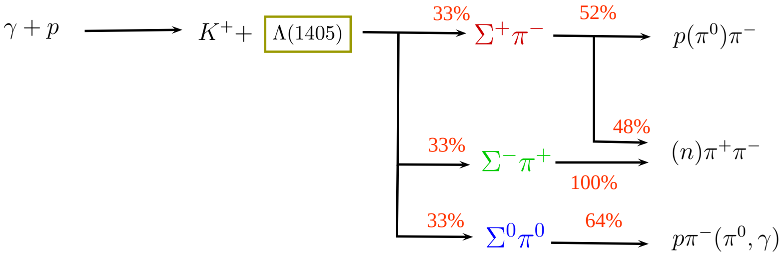
opened CLAS detector

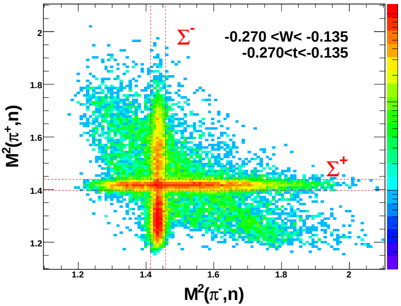
reaction of interest



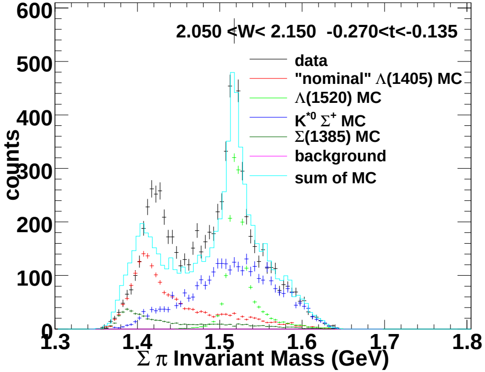


detect charged particles, reconstruct missing particle (neutron)





reconstruct and select
intermediate hyperons of interest

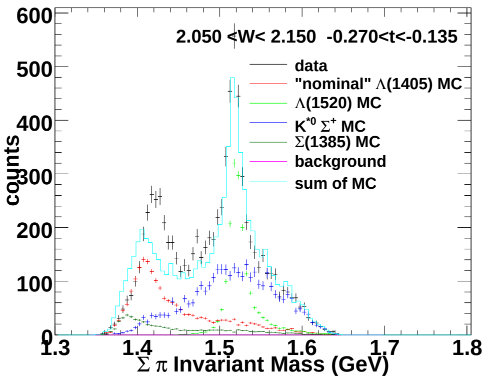


reaction:

$$\gamma + p \rightarrow K^+ + \boxed{\Lambda(1405)}$$
$$\rightarrow \boxed{\Sigma^+} + \pi^-$$
$$\rightarrow n + \pi^+$$

"nominal" $\Lambda(1405)$

- Monte Carlo generated with PDG values of mass, width
- all Monte Carlo was processed through detector simulation

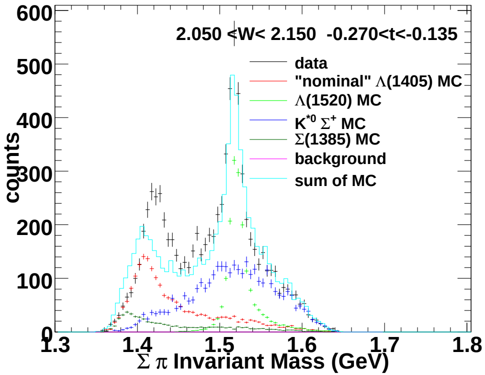


reaction:

$$\gamma + p \to K^+ + \boxed{\Lambda(1405)}$$
$$\to \boxed{\Sigma^+} + \pi^-$$
$$\to n + \pi^+$$

$\Sigma(1385)$

- strong overlap with $\Lambda(1405)$ due to close mass and width
- $\Lambda\pi^0$ decay mode was used to fix yield in $\Sigma\pi$ decay modes
- Monte Carlo generated with PDG values of mass, width

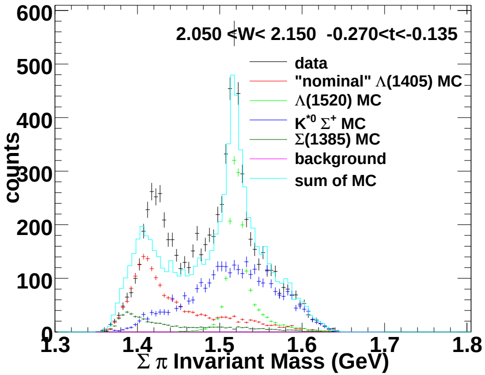


reaction:

$$\gamma + p \rightarrow K^+ + \boxed{\Lambda(1405)}$$
$$\rightarrow \boxed{\Sigma^+} + \pi^-$$
$$\rightarrow n + \pi^+$$

$\Lambda(1520)$

- Monte Carlo generated with PDG values of mass, width
- well-established Breit-Wigner lineshape



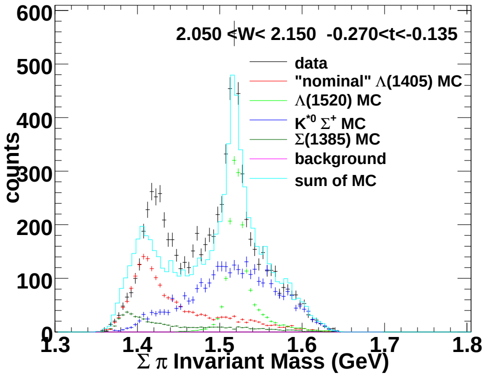
reaction:

$$\gamma + p \to K^+ + \boxed{\Lambda(1405)}$$
$$\to \boxed{\Sigma^+} + \pi^-$$
$$\to n + \pi^+$$

K^{*0}

- strong kinematic overlap with $\Lambda(1405)$
- Monte Carlo generated with PDG values of mass, width

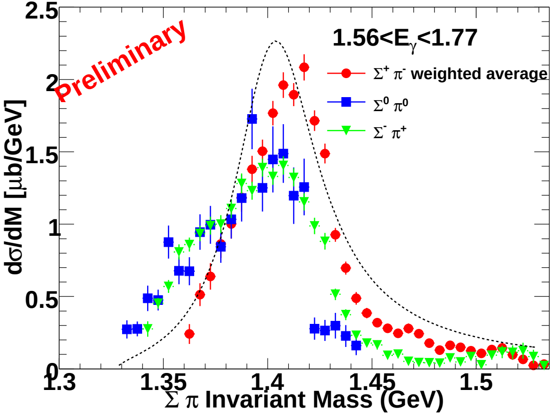
example of fit to lineshape



reaction:

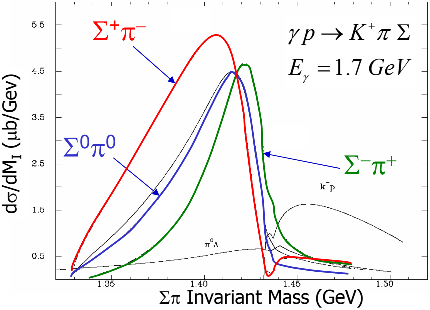
$$\gamma + p \to K^+ + \boxed{\Lambda(1405)}$$
$$\to \boxed{\Sigma^+} + \pi^-$$
$$\to n + \pi^+$$

$\Rightarrow$ after fitting with the above templates, we subtracted off contributions from the $\Sigma(1385)$, $\Lambda(1520)$, K^{*0}, and assigned the remaining contribution to the $\Lambda(1405)$.



different lineshapes for each $\Sigma\pi$ decay mode

- lineshapes do appear different for each $\Sigma\pi$ decay mode
- $\Sigma^+\pi^-$ decay mode has peak at highest mass, most narrow



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$$\frac{d\sigma(\pi^+\Sigma^-)}{dM_I} \propto \frac{1}{2}\left|T^{(1)}\right|^2 + \frac{1}{3}\left|T^{(0)}\right|^2 + \frac{2}{\sqrt{6}}\mathrm{Re}\left(T^{(0)}T^{(1)*}\right) + O\left(T^{(2)}\right)$$

$$\frac{d\sigma(\pi^-\Sigma^+)}{dM_I} \propto \frac{1}{2}\left|T^{(1)}\right|^2 + \frac{1}{3}\left|T^{(0)}\right|^2 - \frac{2}{\sqrt{6}}\mathrm{Re}\left(T^{(0)}T^{(1)*}\right) + O\left(T^{(2)}\right)$$

$$\frac{d\sigma(\pi^0\Sigma^0)}{dM_I} \propto \frac{1}{3}\left|T^{(0)}\right|^2 + O\left(T^{(2)}\right)$$

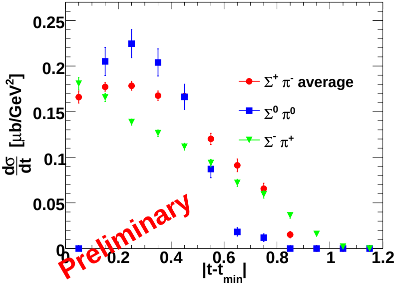
- $\Sigma^-\pi^+$ decay mode peaks at highest mass, most narrow
- difference in lineshapes is due to interference of isospin terms in calculation ($T^{(I)}$ represents amplitude of isospin I term)

differential cross sections

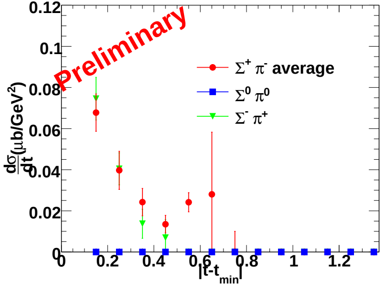
- summing over the lineshape gives differential cross section
- $\mathbf{\Lambda(1520)}$ serves as a check of systematics
- at lower energies where lineshape is different, difference in $\frac{d\sigma}{dt}$ is observed

$$1.56 < E_\gamma < 1.77 \text{ (GeV)}$$

$\Lambda(1405)$



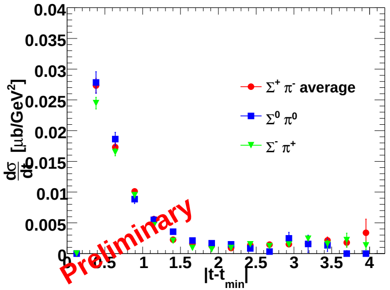
$\Lambda(1520)$



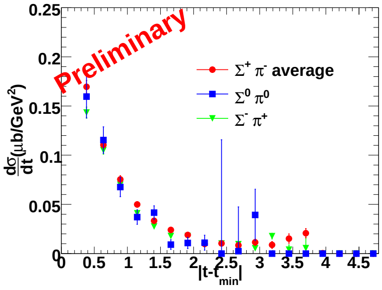
- summing over the lineshape gives differential cross section
- $\Lambda(1520)$ serves as a check of systematics
- at lower energies where lineshape is different, difference in $\frac{d\sigma}{dt}$ is observed

$$3.27 < E_\gamma < 3.56 \text{ (GeV)}$$

$\Lambda(1405)$



$\Lambda(1520)$

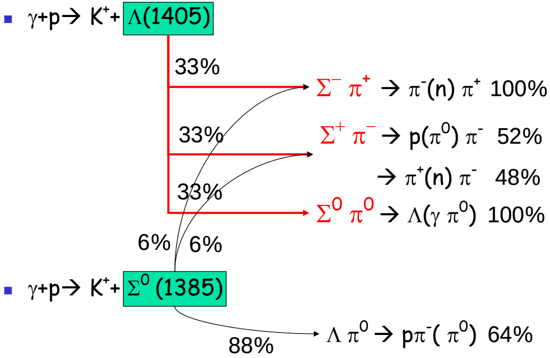


conclusion

- high statistics measurement of $\Lambda(1405)$ photoproduction
- **difference in lineshape for different decay modes** has been observed
- **difference in cross section for different decay modes** has been observed
- working to test dynamical resonances generated in chiral unitary models

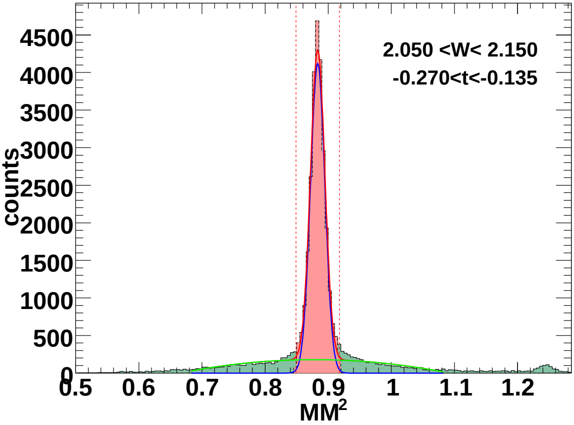
$\Rightarrow$ **first clues of a possible deviation from a simple qqq-structure.**

Getting the three final states:



fit to intermediate states

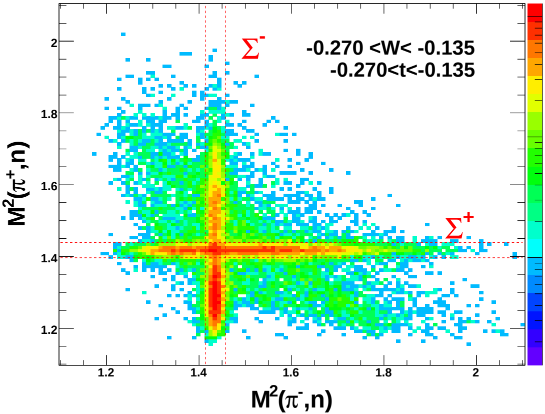
example: $K^+, \pi^+\pi^-, (n)$ channel



fit to neutron

fit to intermediate states

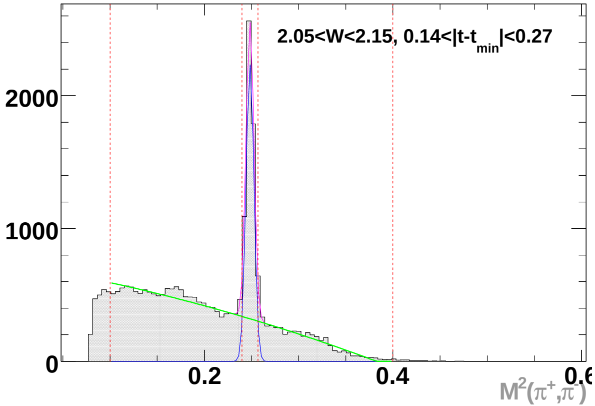
example: $K^+, \pi^+ \pi^-, (n)$ channel



fit to $\Sigma^+$and Σ^-

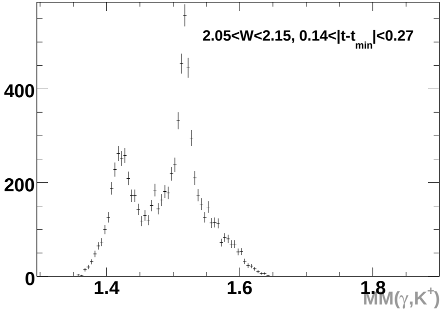
fit to intermediate states

example: $K^+, \pi^+\pi^-, (n)$ channel

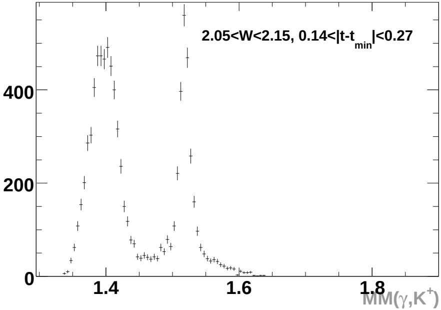


fit to K^0

example: $K^+, \pi^+ \pi^-, (n)$ channel



lineshape for Σ^+channel

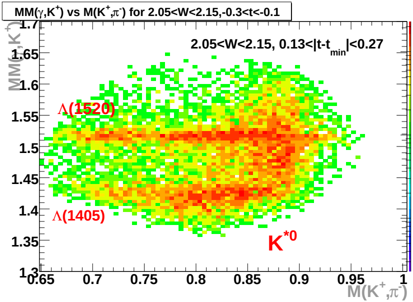


lineshape for Σ^-channel

$\Rightarrow$ end up with $MM(\gamma, K^+)$ spectrum for each decay mode

K^*

cannot separate due to strong overlap (kinematically separated at higher energy bins)



$\Sigma(1385)$

cannot distinguish with close mass and width

	$\Lambda(1405)$	$\Sigma(1385)$
mass	~ 1405	~ 1385
width	~ 50	~ 35

$\Rightarrow$ use MC to model both backgrounds. scale of $\Sigma(1385)$ fixed by $\Lambda\pi^0$ decay mode.