Properties of the $\Lambda(1405)$ Measured at CLAS

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Outline

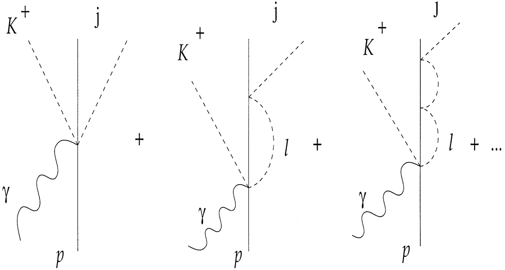
1. Introduction
   - motivation for the study of the $\Lambda(1405)$ – what is it?
   - theory of the $\Lambda(1405)$
2. CLAS Analysis
   - data of CLAS at Jlab
   - overview of analysis flow
3. Results
   - lineshape
   - cross section
4. Conclusion

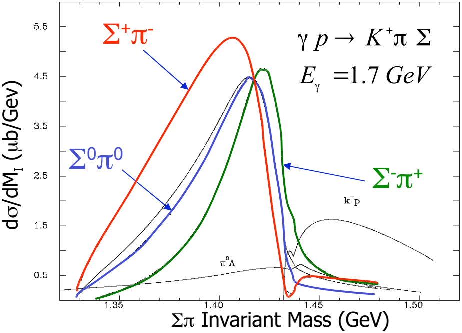
what is the $\Lambda(1405)$?

- **** resonance just below $N\overline{K}$ threshold
- $J^P = \frac{1}{2}^-$ (**experimentally unconfirmed**)
- decays exclusively to $(\Sigma\pi)^0$
- past experiments: the lineshape (= invariant $\Sigma\pi$ mass distribution) is distorted from a simple Breit-Wigner form
- many questions regarding the $\Lambda(1405)$:
  - what is the nature of this distorted lineshape?
  - single pole or double pole?
  - molecular $N\overline{K}$ bound state?
  - dynamically generated resonance in unitary coupled channel approach?

unitary coupled channel approach

dynamically generate Λ(1405)





J. C. Nacher et al., Phys. Lett. B455, 55 (1999)

difference in lineshape

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

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

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

J. C. Nacher et al., Nucl. Phys. B455, 55

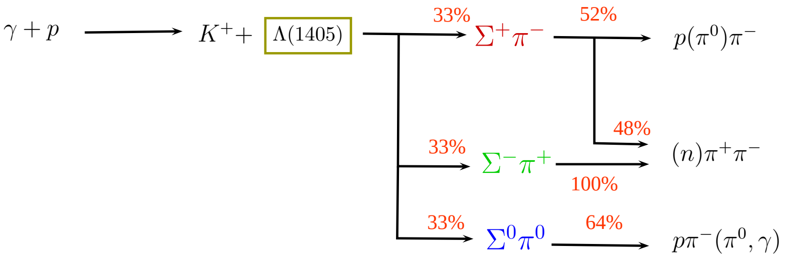
- difference in lineshapes is due to interference of isospin terms in calculation ($T^{(I)}$ represents amplitude of isospin I term)

data from CLAS@Jlab

- CLAS is a large acceptance detector housed in Hall B of Jlab
- photoproduction experiment on a proton target
- photon energies from below $\Lambda(1405)$ threshold to 3.84 GeV
- large dataset with $\sim$ 20 billion triggers
- many channels analyzed already:

η, η'	Williams *et al.*, PRC 80, 045213
ω	Williams *et al.*, PRC 80, 065208, PRC 80, 065209
$\pi^+\pi^-(f_0(980))$	Battaglieri *et al.*, PRD 80, 072005, PRL 102, 102001
$K^+\Lambda$	McCracken *et al.*, PRC 81, 025201 ←NEW!!
$K^+\Sigma^0$	Dey *et al.*, to be submitted soon

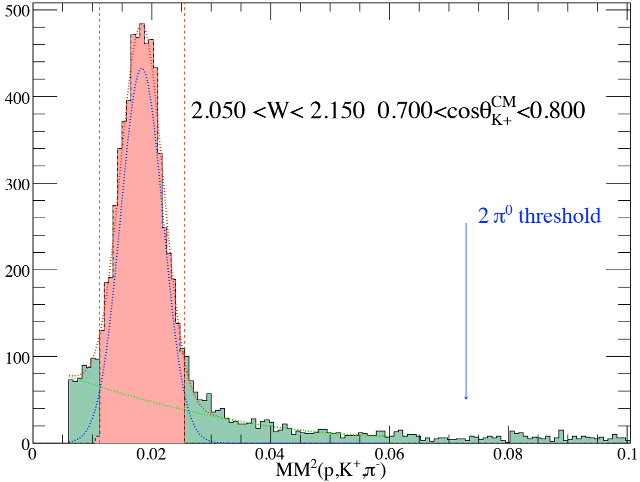
reaction of interest



- 3 $\Sigma\pi$ decay channels (2 decay modes for $\Sigma^+\pi^-$)
- This will be the first experimental result to compare all 3 $\Sigma\pi$ decay modes

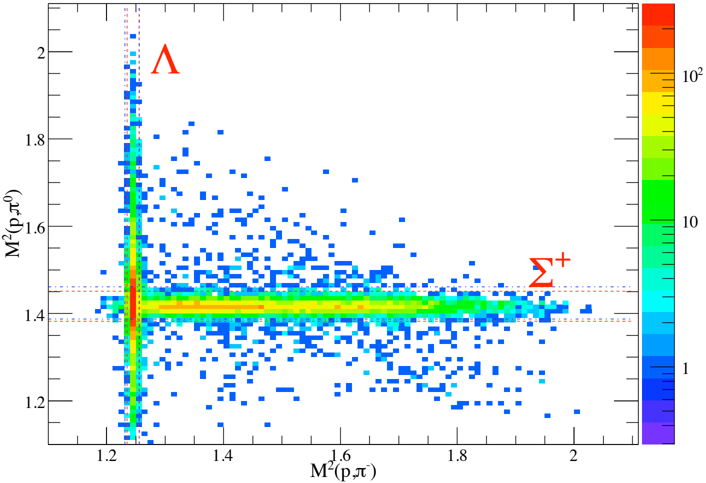
MM^2

example: $\gamma + \mathrm{p} \rightarrow K^+ + \mathrm{p} + \pi^- + X$ ($X = \pi^0, \pi^0 + \gamma$)
(used in $\Lambda(1405) \rightarrow \Sigma^+\pi^-$ and $\Sigma(1385) \rightarrow \Lambda\pi^0$ analysis)



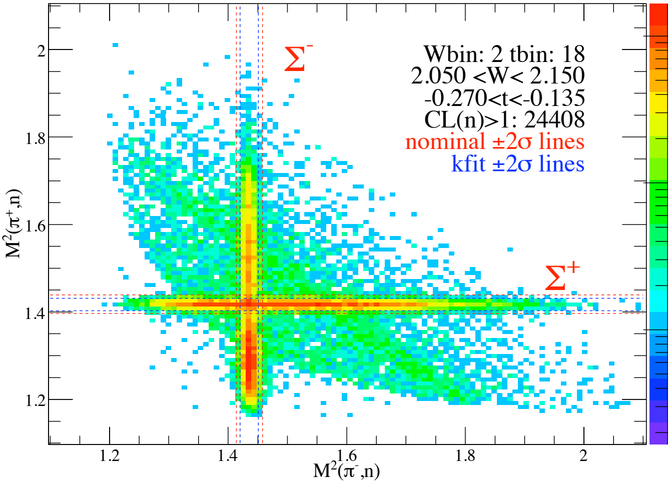
intermediate hyperon

example: $\gamma + \mathrm{p} \rightarrow K^{+} + \mathrm{p} + \pi^{-} + \pi^{0}$
plot $M^2(\mathrm{p}, \pi^0)$ vs $M^2(\mathrm{p}, \pi^-)$



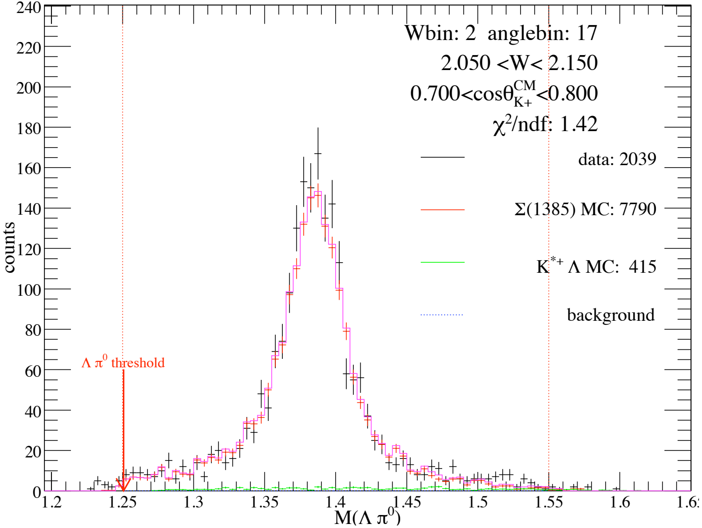
intermediate hyperon

example: $\gamma + \mathrm{p} \rightarrow K^{+} + \mathrm{n} + \pi^{+} + \pi^{-}$
plot $M^{2}(\mathrm{n}, \pi^{+})$ vs $M^{2}(\mathrm{n}, \pi^{-})$

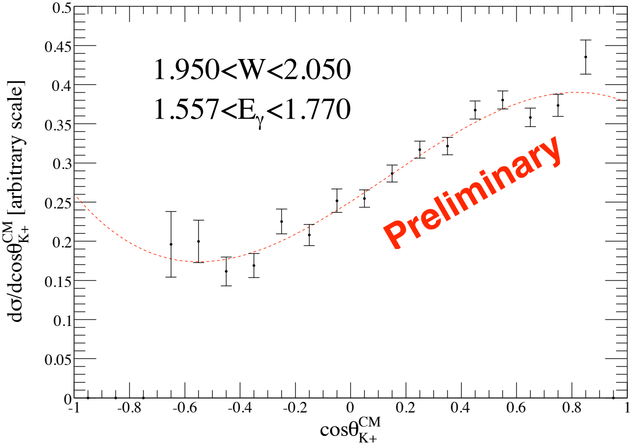


fit to Σ(1385)

after selecting Λ, fit to MC templates to extract yield of Σ(1385)



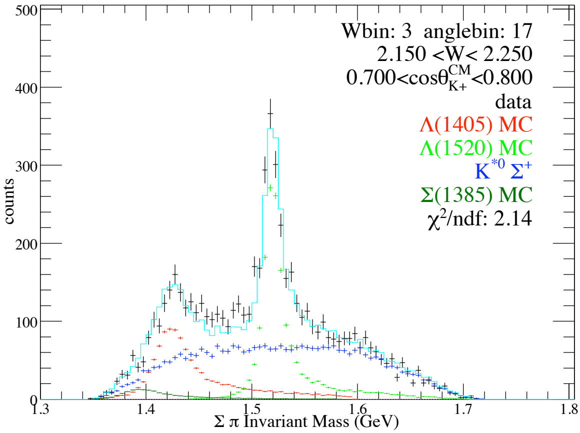
$\Sigma(1385)$ cross section



- line is fit with 3rd order Legendre polynomial (very preliminary!!)
- scale by branching ratio into each $\Sigma\pi$ channel
- $\Sigma^0\pi^0$ channel does not have $\Sigma(1385)$

fit to lineshape with MC templates

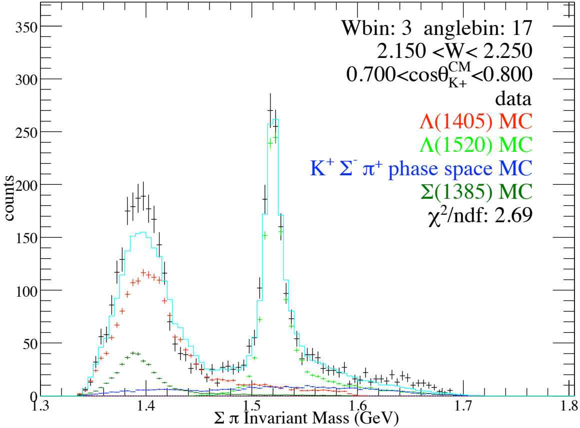
$\Sigma^+ \to p\pi^0$



after fitting with the above templates, we subtracted off contributions from the **Σ(1385)**, **Λ(1520)** , **K^{*0}**, and assigned the remaining contribution to the **Λ(1405)**

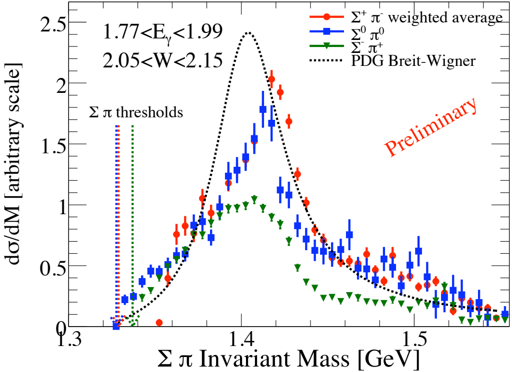
fit to lineshape with MC templates

$\Sigma^- \to n\pi^-$



after fitting with the above templates, we subtracted off contributions from the **Σ(1385)**, **Λ(1520)** , **$K^+\Sigma^-\pi^+$ phase space**, and assigned the remaining contribution to the **Λ(1405)**

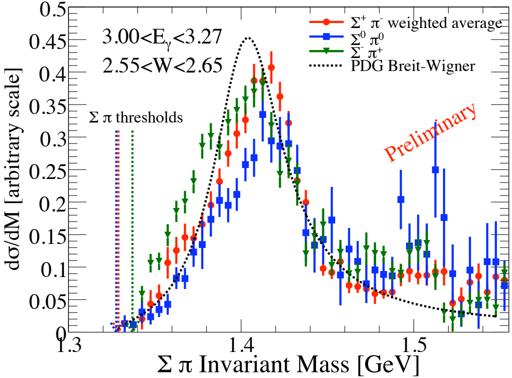
previous results of lineshape shown at HYP-X etc.



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

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

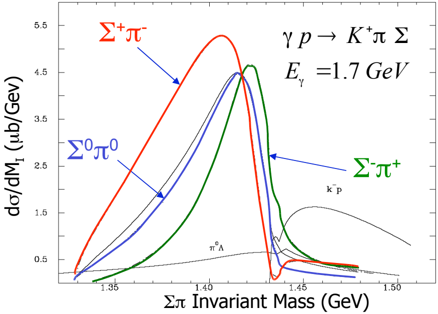
previous results of lineshape shown at HYP-X etc.



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

- difference is less prominent at higher energies

theory prediction from chiral unitary approach



J. C. Nacher et al., Nucl. Phys. B455, 55

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

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

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

- $\Sigma^-\pi^+$ 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)

problem with angular coverage of experiment

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

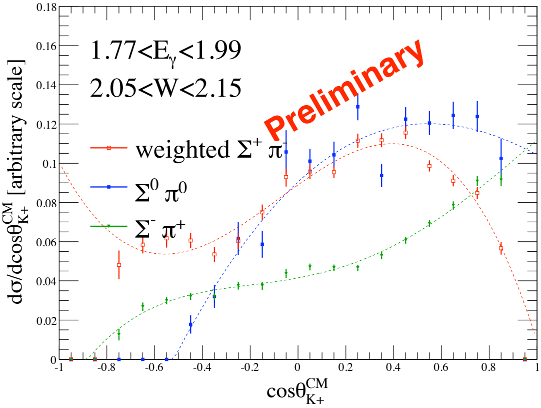
$$\frac{d\sigma(\pi^-\Sigma^+)}{dM_I} \propto \frac{1}{2}\left|T^{(1)}\right|^2 + \frac{1}{3}\left|T^{(0)}\right|^2 - \frac{2}{\sqrt{6}}\mathrm{Re}\left(T^{(0)}T^{(1)*}\right) + O\left(T^{(2)}\right)$$

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

- simple addition and subtraction of lineshapes should give $I = 0, 1$ amplitudes
- problem is that CLAS does not cover full production angles ($\cos\theta_{K+}^{CM}$)
- integrating lineshape from $\Sigma\pi$ threshold to 1.500 GeV gives differential cross section

Λ(1405) differential cross section for each $\Sigma\pi$ channel

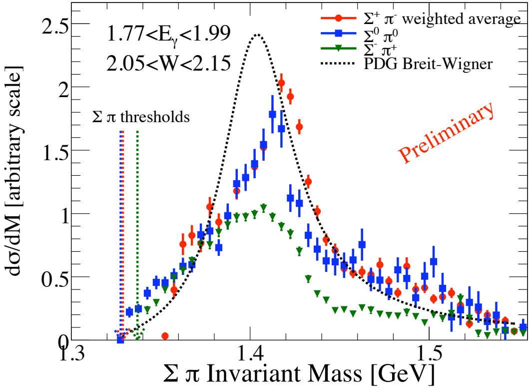
$W = 2.1$ GeV



- lines are fits with 3rd order Legendre polynomials (very preliminary!!)
- clear turnover of $\Sigma^+\pi^-$ channel at forward angles

$\Lambda(1405)$ differential cross section for each $\Sigma\pi$ channel

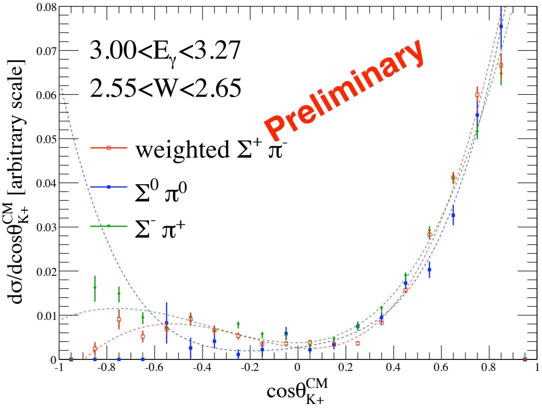
$W = 2.1$ GeV



- summed over CLAS acceptance angles
- simple sum/difference cannot be taken

$\Lambda(1405)$ differential cross section for each $\Sigma\pi$ channel

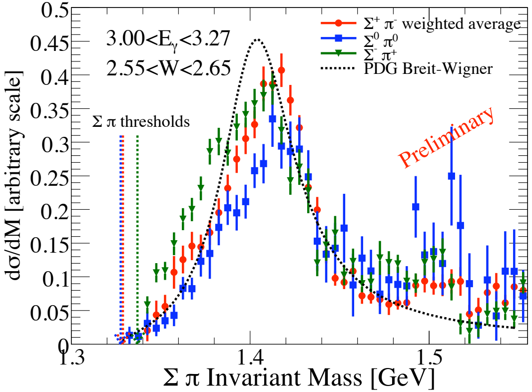
$W = 2.6$ GeV



- lines are fits with 3rd order Legendre polynomials (very preliminary!!)
- three channels agree in behavior

Λ(1405) differential cross section for each Σπ channel

$W = 2.6$ GeV



- summed over CLAS acceptance angles
- simple sum/difference cannot be taken

conclusion

- high statistics measurement of Λ(1405) photoproduction has been done with CLAS at Jlab
- **difference in lineshape** has been observed
- **difference in differential cross section** has been observed

previous results shown at HYP-X etc. include:

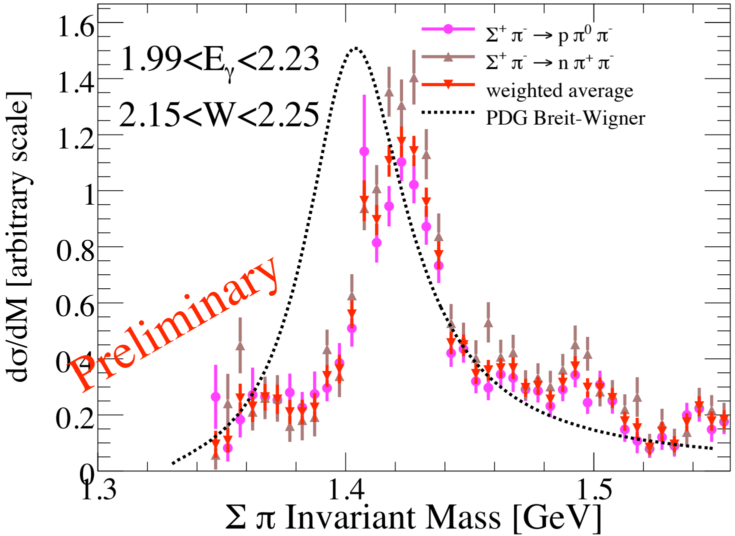
- spin and parity are experimentally established for the first time
- polarization of $\mathbf{\Lambda(1405)}$ is found to be $\sim +\mathbf{40}\%$ at $\mathbf{W} \sim \mathbf{2.6}$ GeV, forward $\mathbf{K}^+$ angles

experimental analysis of Λ(1405) starting to converge

strong interference effects being observed

⇒ **hoping to stimulate theoretical interest**

agreement of two Σ^+channels



agreement of two Σ^+channels