— NSTAR 2011 —

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

Kei Moriya (Indiana University)

advisor: Reinhard Schumacher

(Carnegie Mellon University)

May 19, 2011

Outline

1. Introduction
   - What is the $\Lambda(1405)$?
   - Chiral Unitary Theory of the $\Lambda(1405)$
2. CLAS Analysis
   - Introduction to JLab and CLAS
   - Decay Channels of Interest
   - $\Sigma^0(1385)$ and K^* Background
   - Fit to Extract $\Lambda(1405)$ Lineshape
3. Results
   - $\Lambda(1405)$ Lineshape Results
   - $\Lambda(1405)$ Cross Section Results
   - $\Lambda(1520)$ Cross Section Results
   - Cross Section Comparison
4. Conclusion

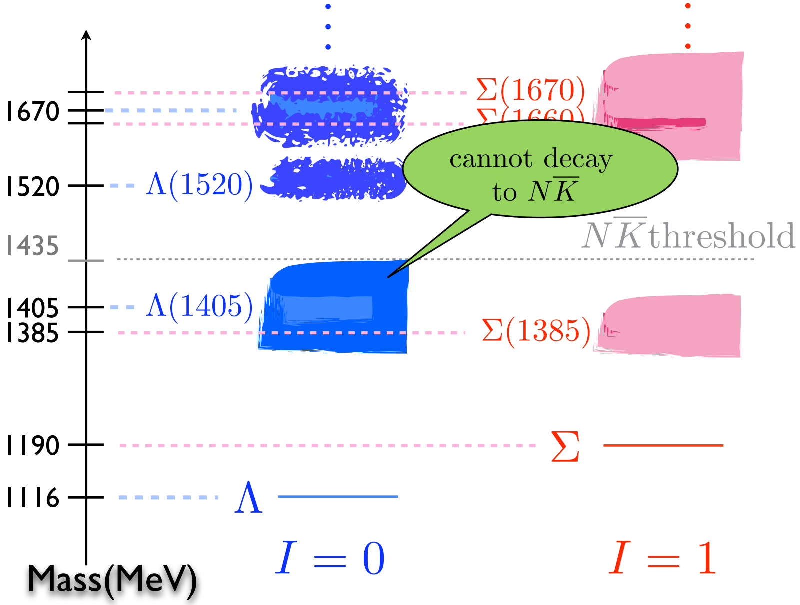
What is the $\Lambda(1405)$?

- **** resonance just below $N\overline{K}$ threshold (~ 1435 MeV)
- $I(J^P) = 0(\frac{1}{2}^-)$ **[experimentally unconfirmed until now]**
- Decays exclusively to $(\Sigma\pi)^0$
- Past experiments have found the **lineshape** (= invariant $\Sigma\pi$ mass distribution) is distorted from a simple Breit-Wigner form

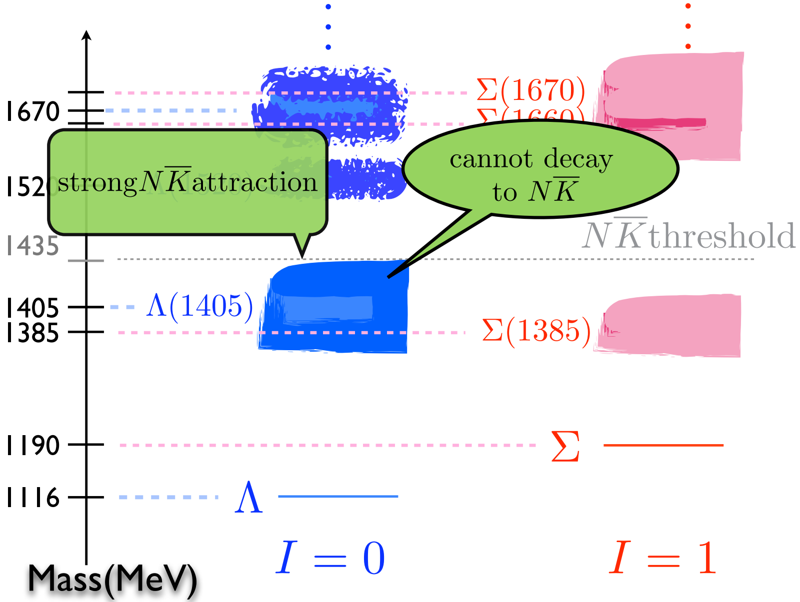
Main Question:

What is the nature of this distorted lineshape?

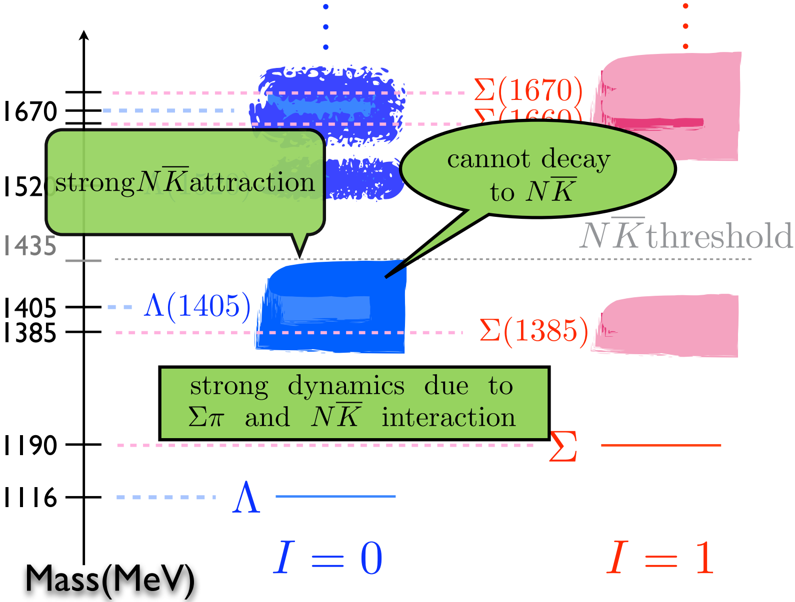
The Λ(1405) in Hadron Spectroscopy



The $\Lambda(1405)$ in Hadron Spectroscopy



The Λ(1405) in Hadron Spectroscopy



The Lineshape of the $\Lambda(1405)$

- Several theories exist on the nature of the distorted lineshape
- **All** theories agree that there is a strong coupling between the
  - $\Sigma\pi$ channel (below $N\overline{K}$ threshold)
  - $N\overline{K}$ channel (above $N\overline{K}$ threshold)
- Various theories:
  - "normal" qqq-baryon resonance
    (the constituent quark model has difficulty with $\Lambda(1405)$ mass)
  - unstable bound state of $N\overline{K}$ (promoted by Dalitz and others)
  - deeply bound state of $N\overline{K}$
  - $qqqq\overline{q}$
  - **dynamically generated resonance** in
    unitary coupled channel approach

Coupled Channel Chiral Unitary Theory

Chiral Theory

Effective chiral Lagrangian describes the interactions of the ground state baryons and mesons.

$$+$$

Coupled Channels

Exact unitarity is enforced amongst the coupled channels

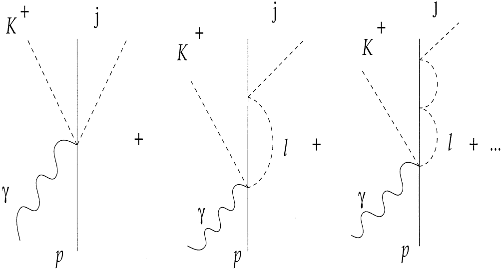
$$\Downarrow$$

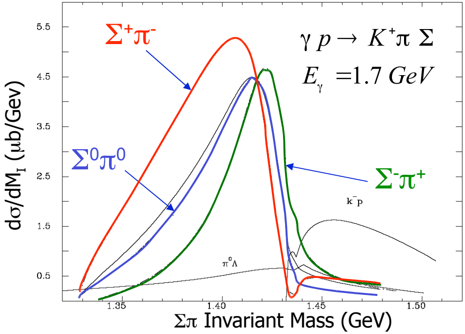
- Many predictions on hadrons have been given by E. Oset and others

Chiral Unitary Coupled Channel Approach

dynamically generate $\Lambda(1405)$
based on chiral unitary model

⇓





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

Difference in Lineshape

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

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

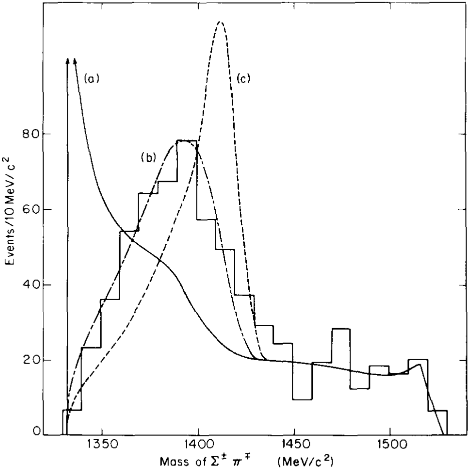
$$\frac{d\sigma(\pi^0\Sigma^0)}{dM_I} \propto \frac{1}{3}\left|T^{(0)}\right|^2 + O\left(T^{(2)}\right)$$

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

- Difference in lineshapes is due to interference of isospin terms in calculation ($\mathrm{T}^{(\mathrm{I})}$ represents amplitude of isospin I term)
- Distortion of the lineshape is connected to underlying QCD amplitudes that generate the $\mathbf{\Lambda(1405)}$
- This analysis will measure **all three** $\Sigma\pi$ channels

Summary of Current Experimental Status

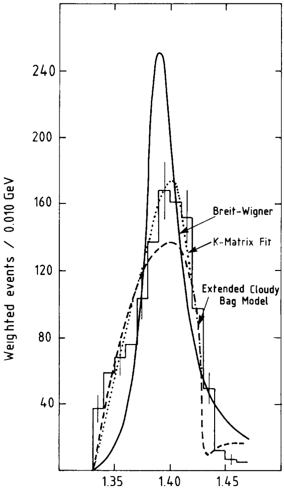
- Data is sparse
- All experiments show a distortion from a Breit-Wigner
- **more data is needed**



D. W. Thomas et al., Nucl. Phys. B56, 15 (1973)

Summary of Current Experimental Status

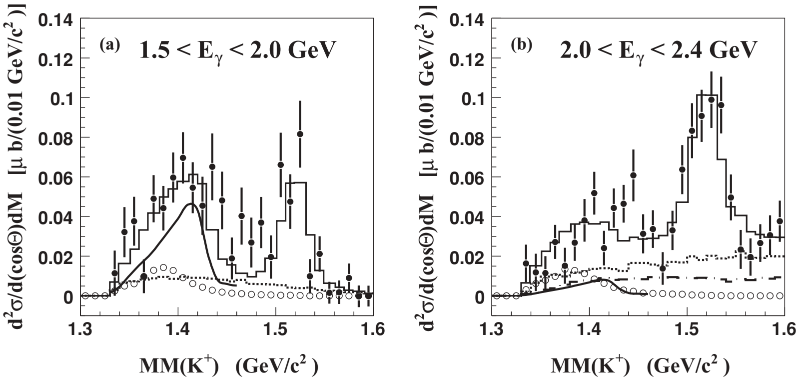
- Data is sparse
- All experiments show a distortion from a Breit-Wigner
- **more data is needed**



R. J. Hemingway, Nucl. Phys. B253, 742 (1985)

Summary of Current Experimental Status

- Data is sparse
- All experiments show a distortion from a Breit-Wigner
- **more data is needed**



M.

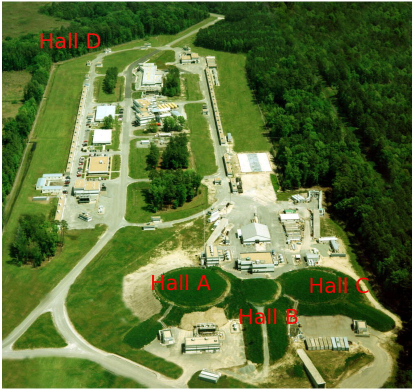
Niiyama et al., Phys. Rev. C78, 035202 (2008)

Outline

1. Introduction
   - What is the $\Lambda(1405)$?
   - Chiral Unitary Theory of the $\Lambda(1405)$
2. CLAS Analysis
   - Introduction to JLab and CLAS
   - Decay Channels of Interest
   - $\Sigma^0(1385)$ and K^* Background
   - Fit to Extract $\Lambda(1405)$ Lineshape
3. Results
   - $\Lambda(1405)$ Lineshape Results
   - $\Lambda(1405)$ Cross Section Results
   - $\Lambda(1520)$ Cross Section Results
   - Cross Section Comparison
4. Conclusion

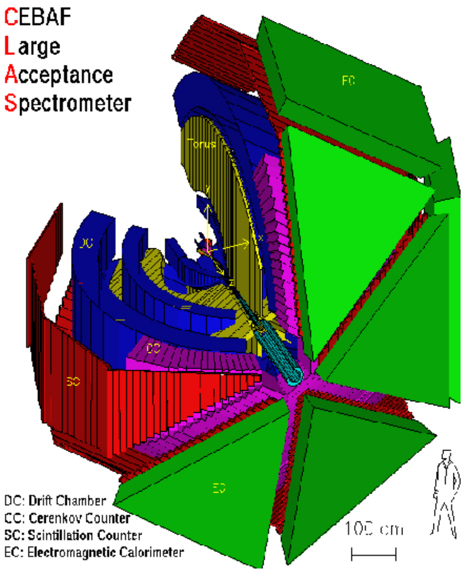
JLab and CLAS

- Jefferson Lab (JLab) located in Newport News, VA
- CEBAF (Continuous Electron Beam Accelerator Facility) gives 2 ns timing electron beam up to 6 GeV
- Halls A, B, C ($+$ D: upcoming)
- Hall B $=$ CLAS (CEBAF Large Acceptance Spectrometer) collaboration



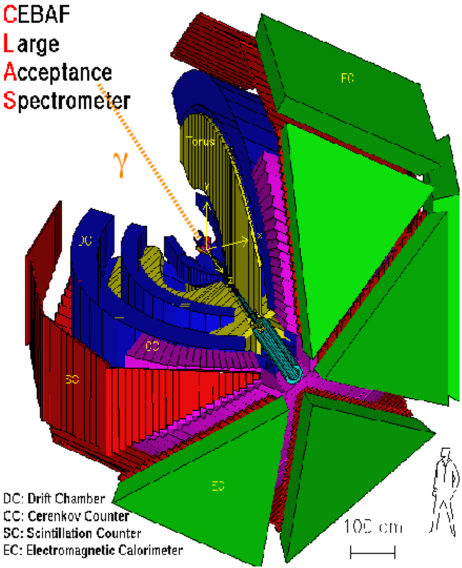
Data From CLAS@JLab

- CLAS@Jefferson Lab
- liquid LH_2 target
- $\gamma + \mathrm{p} \rightarrow \mathbf{K^+} + \mathbf{\Lambda(1405)}$



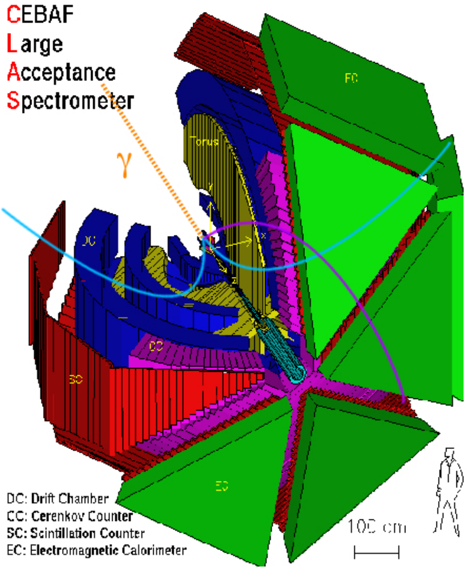
Data From CLAS@JLab

- CLAS@Jefferson Lab
- liquid LH_2 target
- $\gamma + \mathrm{p} \rightarrow \mathbf{K^+} + \mathbf{\Lambda(1405)}$
- real unpolarized photon beam
- $E_\gamma < 3.84$ GeV
- ~ 20B total triggers



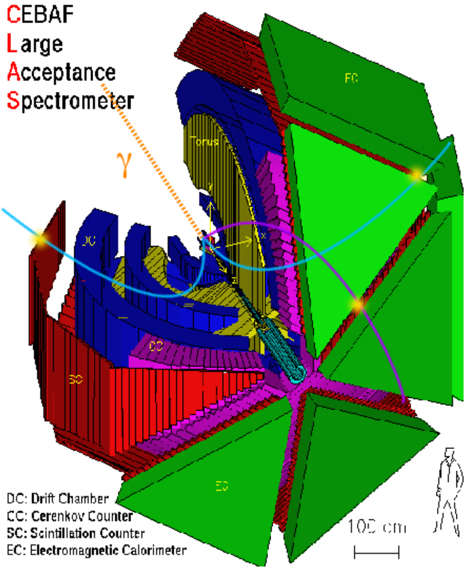
Data From CLAS@JLab

- CLAS@Jefferson Lab
- liquid LH_2 target
- $\gamma + \mathrm{p} \rightarrow \mathbf{K^+} + \mathbf{\Lambda(1405)}$
- real unpolarized photon beam
- $E_\gamma < 3.84$ GeV
- ~ 20B total triggers
- measure charged particle
  - $\vec{\mathrm{p}}$ with **drift chambers**



Data From CLAS@JLab

- CLAS@Jefferson Lab
- liquid LH_2 target
- $\gamma + \mathrm{p} \rightarrow \mathbf{K}^+ + \mathbf{\Lambda(1405)}$
- real unpolarized photon beam
- $E_\gamma < 3.84$ GeV
- ~ 20B total triggers
- measure charged particle
  - $\vec{\mathrm{p}}$ with **drift chambers**
  - timing with **TOF walls**



Reaction of Interest

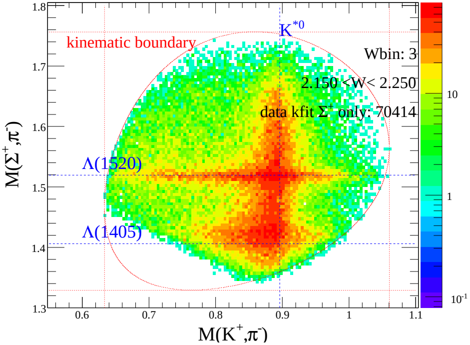
$\gamma + \mathrm{p} \to K^+ + \Lambda(1405) \to K^+ + \Sigma + \pi$

- Final state of interest is K^+, Σ, π
- $\Sigma\pi$ resonances: $\Sigma(1385)$, $\Lambda(1405)$, $\Lambda(1520)$
- $K^+\pi$ resonance: K^* when $\pi = \pi^+$ or π^0
- besides the $K^+\Sigma\pi$ state, we will also detect the $K^+\Lambda\pi$ state
  - Resonance of $\Lambda\pi$ will be $\Sigma(1385)$
  - Resonance of $K^+\pi$ will be K^*
- Background channels:
  - $\Sigma(1385)$ – close in mass, large width (~ 35 MeV)
  - K^* – overlap in 3-body phase space plot of K^+, Σ, π

Background Channels

- $\Sigma^0(1385) \to \Sigma\pi$
  - $BR(\Lambda\pi^0) = 87\% \gg BR(\Sigma^\pm\pi^\mp) = 6\%$ each
    $\Rightarrow$ measure in $\Lambda\pi^0$, scale down to each $\Sigma\pi$ channel
  - influence should be small due to branching ratio
- $K^*\Sigma$
  - broad width – will overlap with signal
  - subtract off incoherently

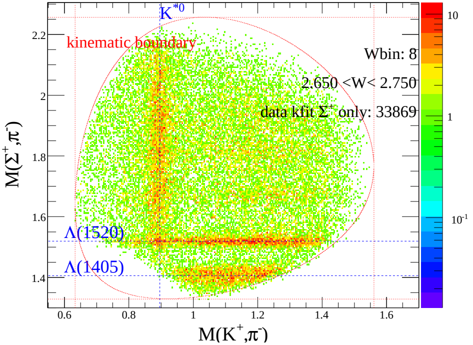
low energy bin



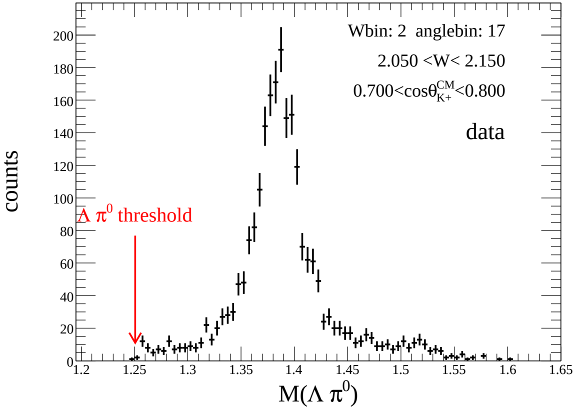
Background Channels

- $\Sigma^0(1385) \to \Sigma\pi$
  - $BR(\Lambda\pi^0) = 87\% \gg BR(\Sigma^\pm\pi^\mp) = 6\%$ each
    $\Rightarrow$ measure in $\Lambda\pi^0$, scale down to each $\Sigma\pi$ channel
  - influence should be small due to branching ratio
- $K^*\Sigma$
  - broad width – will overlap with signal
  - subtract off incoherently

high energy bin



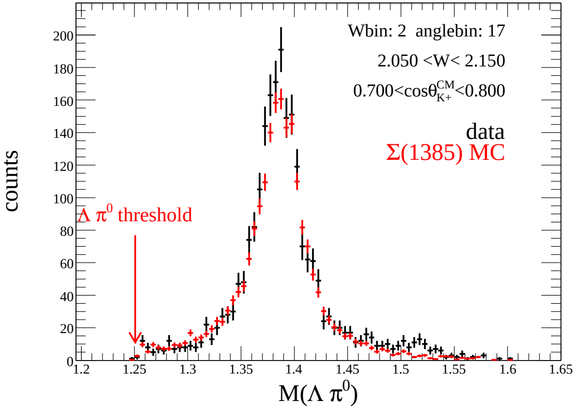
$\Sigma(1385)$ is Fit in $\Lambda\pi^0$ Channel ($\gamma + p \to K^+ + p + \pi^- + \pi^0$)



example:
1 energy and angle
bin out of ~ 150

- $\Sigma(1385)$ is fit with templates of MC of
  - $\Sigma(1385)$ (non-relativistic Breit-Wigner)
  - $K^{*+}\Lambda$ MC
- very good fit results

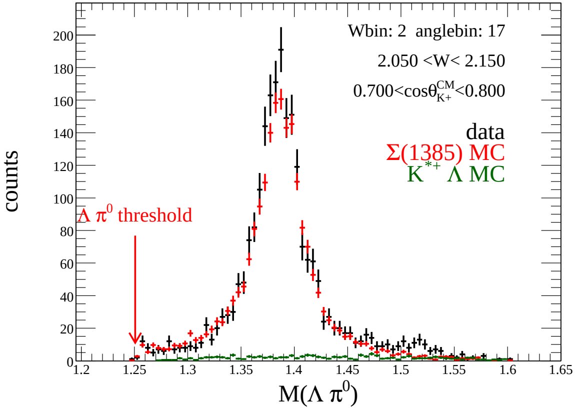
$\Sigma(1385)$ is Fit in $\Lambda\pi^0$ Channel ($\gamma + \mathrm{p} \to K^+ + \mathrm{p} + \pi^- + \pi^0$)



example:
1 energy and angle bin out of ~ 150

- $\Sigma(1385)$ is fit with templates of MC of
  - $\Sigma(1385)$ (non-relativistic Breit-Wigner)
  - $K^{*+}\Lambda$ MC
- very good fit results

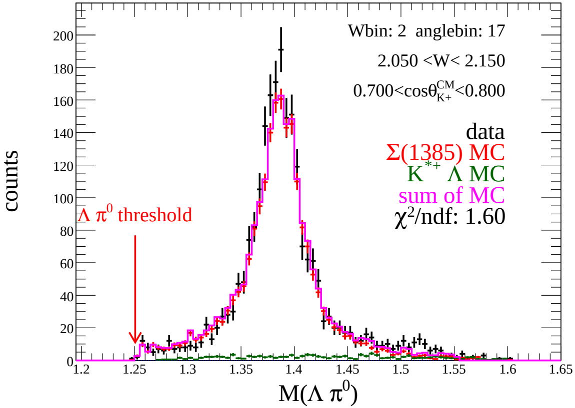
$\Sigma(1385)$ is Fit in $\Lambda\pi^0$ Channel ($\gamma + \mathrm{p} \to K^+ + \mathrm{p} + \pi^- + \pi^0$)



example:
1 energy and angle
bin out of ~ 150

- $\Sigma(1385)$ is fit with templates of MC of
  - $\Sigma(1385)$ (non-relativistic Breit-Wigner)
  - $K^{*+}\Lambda$ MC
- very good fit results

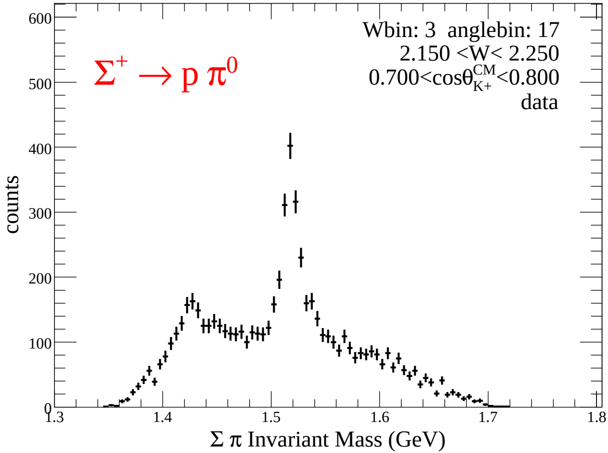
$\Sigma(1385)$ is Fit in $\Lambda\pi^0$ Channel ($\gamma + p \rightarrow K^+ + p + \pi^- + \pi^0$)



example:
1 energy and angle bin out of ~ 150

- $\Sigma(1385)$ is fit with templates of MC of
  - $\Sigma(1385)$ (non-relativistic Breit-Wigner)
  - $K^{*+}\Lambda$ MC
- very good fit results

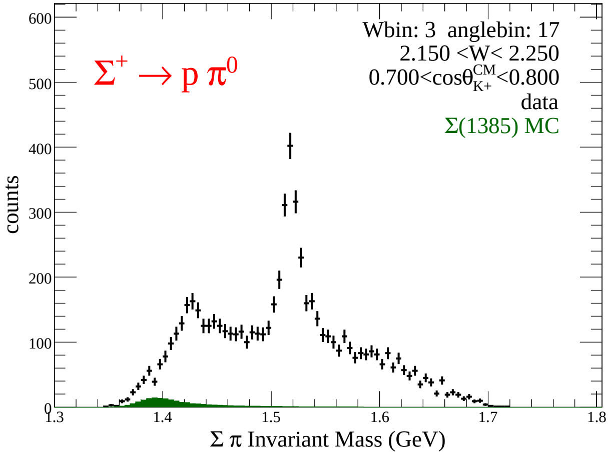
Fit to Lineshape With MC Templates



example:
1 energy and angle bin out of ~ 150

- subtract off $\mathbf{\Sigma(1385)}$, $\mathbf{\Lambda(1520)}$, $\mathbf{K^{*0}}$
- assigned the remaining contribution to the $\mathbf{\Lambda(1405)}$

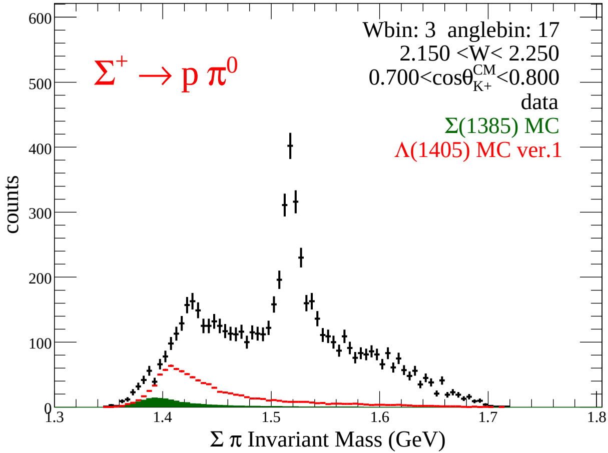
Fit to Lineshape With MC Templates



example:
1 energy and angle bin out of ~ 150

- subtract off $\mathbf{\Sigma(1385)}$, $\mathbf{\Lambda(1520)}$, $\mathbf{K^{*0}}$
- assigned the remaining contribution to the $\mathbf{\Lambda(1405)}$

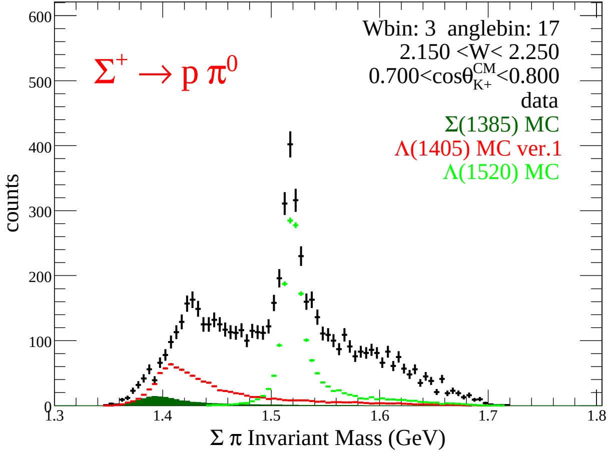
Fit to Lineshape With MC Templates



example:
1 energy and angle
bin out of ~ 150

- subtract off $\boldsymbol{\Sigma(1385)}$, $\boldsymbol{\Lambda(1520)}$, $\mathbf{K^{*0}}$
- assigned the remaining contribution to the $\boldsymbol{\Lambda(1405)}$

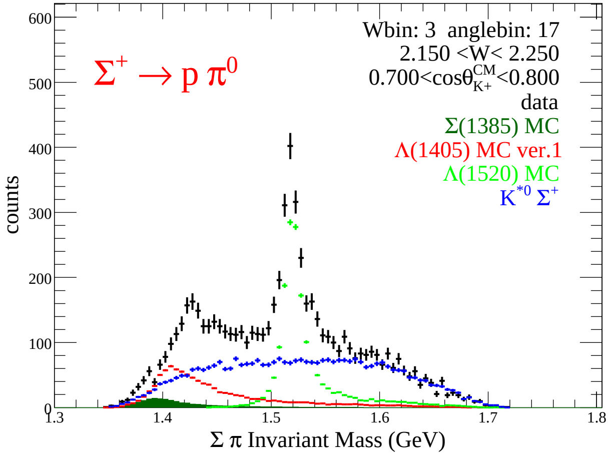
Fit to Lineshape With MC Templates



example:
1 energy and angle bin out of ~ 150

- subtract off $\mathbf{\Sigma(1385)}$, $\mathbf{\Lambda(1520)}$, $\mathbf{K^{*0}}$
- assigned the remaining contribution to the $\mathbf{\Lambda(1405)}$

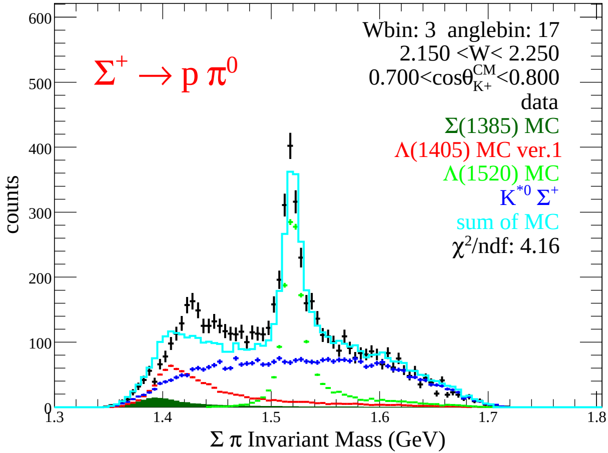
Fit to Lineshape With MC Templates



example:
1 energy and angle bin out of ~ 150

- subtract off $\mathbf{\Sigma(1385)}$, $\mathbf{\Lambda(1520)}$, $\mathbf{K^{*0}}$
- assigned the remaining contribution to the $\mathbf{\Lambda(1405)}$

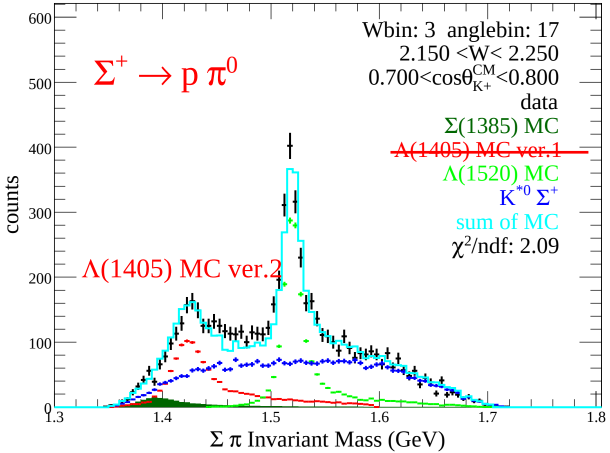
Fit to Lineshape With MC Templates



example:
1 energy and angle bin out of ~ 150

- subtract off $\mathbf{\Sigma(1385)}$, $\mathbf{\Lambda(1520)}$, $\mathbf{K^{*0}}$
- assigned the remaining contribution to the $\mathbf{\Lambda(1405)}$

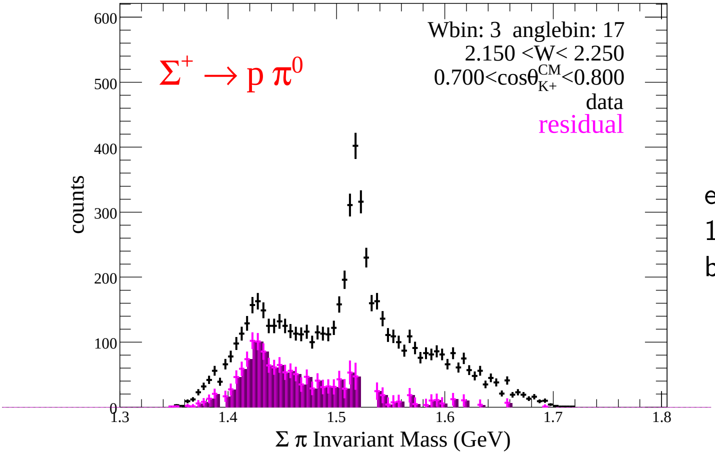
Fit to Lineshape With MC Templates



example:
1 energy and angle bin out of ~ 150

- subtract off $\mathbf{\Sigma(1385)}$, $\mathbf{\Lambda(1520)}$, $\mathbf{K^{*0}}$
- assigned the remaining contribution to the $\mathbf{\Lambda(1405)}$

Fit to Lineshape With MC Templates

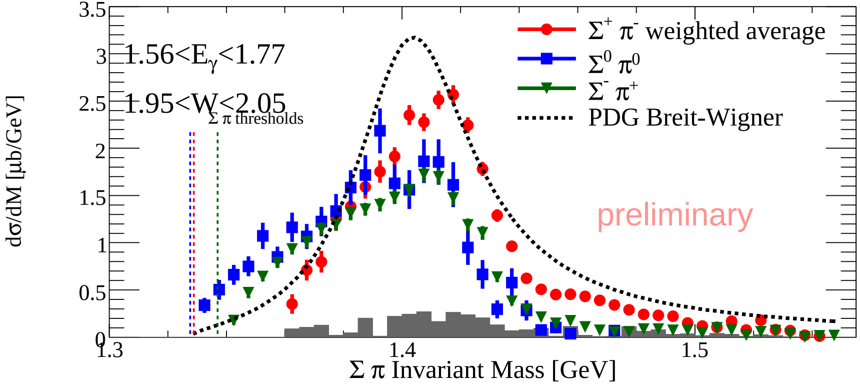


example:
1 energy and angle bin out of ~ 150

- subtract off $\mathbf{\Sigma(1385)}$, $\mathbf{\Lambda(1520)}$, $\mathbf{K^{*0}}$
- assigned the remaining contribution to the $\mathbf{\Lambda(1405)}$

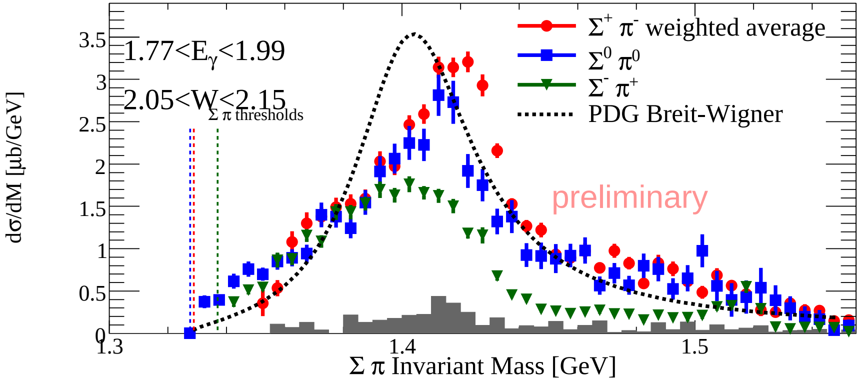
Outline

Results of Lineshape



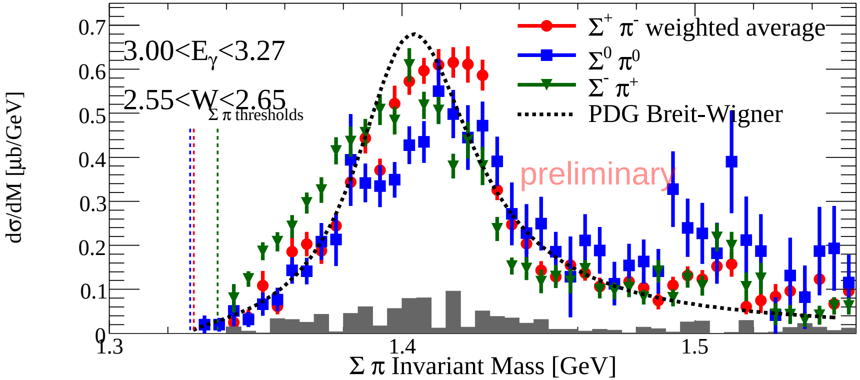
- lineshapes do appear different for each $\Sigma\pi$ decay mode
- $\boldsymbol{\Sigma}^{+}\pi^{-}$ decay mode has peak at highest mass, narrow than $\boldsymbol{\Sigma}^{-}\pi^{+}$
- lineshapes are summed over acceptance region of CLAS
- difference is less prominent at higher energies

Results of Lineshape



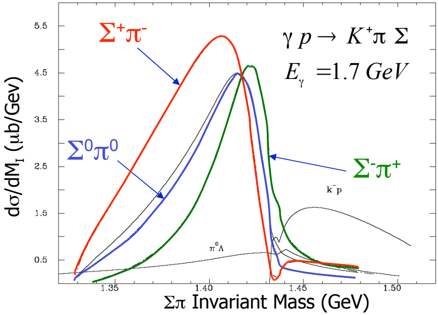
- lineshapes do appear different for each $\Sigma\pi$ decay mode
- $\Sigma^+\pi^-$ decay mode has peak at highest mass, narrow than $\Sigma^-\pi^+$
- lineshapes are summed over acceptance region of CLAS
- difference is less prominent at higher energies

Results of Lineshape



- lineshapes do appear different for each $\Sigma\pi$ decay mode
- $\Sigma^+\pi^-$ decay mode has peak at highest mass, narrow than $\Sigma^-\pi^+$
- lineshapes are summed over acceptance region of CLAS
- difference is less prominent at higher energies

Theory Prediction From Chiral Unitary Approach



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

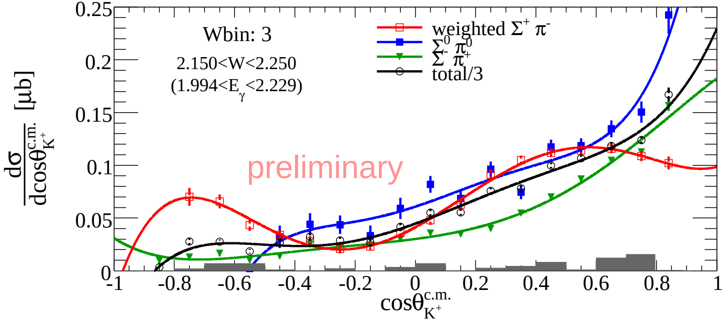
$$\frac{d\sigma(\pi^+\Sigma^-)}{dM_I} \propto \frac{1}{2}\left|T^{(1)}\right|^2 + \frac{1}{3}\left|T^{(0)}\right|^2 + \frac{2}{\sqrt{6}}\mathrm{Re}\left(T^{(0)}T^{(1)*}\right) + O\left(T^{(2)}\right)$$

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

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

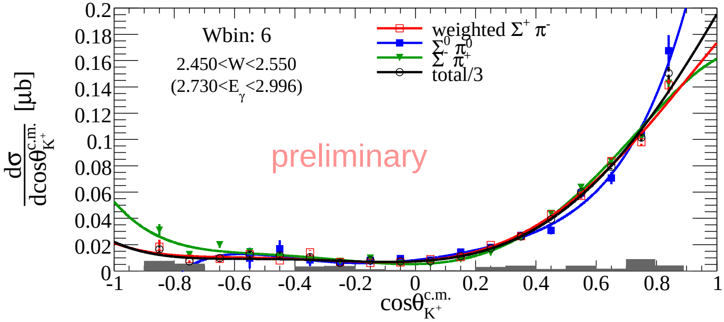
- $\Sigma^-\pi^+$ decay mode peaks at highest mass, most narrow
- difference in lineshapes is due to interference of isospin terms in calculation ($\mathrm{T}^{(\mathrm{I})}$ represents amplitude of isospin I term)
- we have started trying fits to the resonance amplitudes

Λ(1405) Differential Cross Section Results



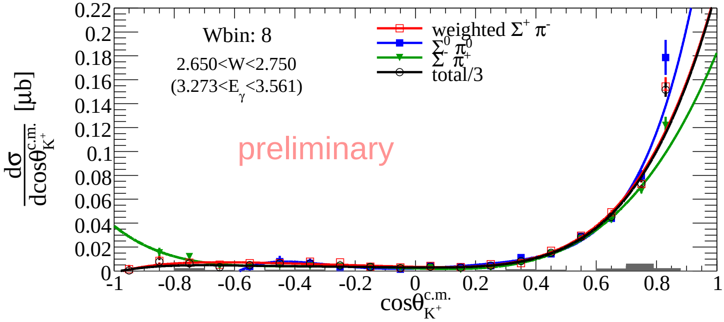
- lines are fits with 6^{rd} order Legendre polynomials
- clear turnover of $\Sigma^+\pi^-$ channel at forward angles
- theory: contact term only, no angular dependence for interference
- experiment: able to see strong **isospin** AND **angular** interference effect

$\Lambda(1405)$ Differential Cross Section Results



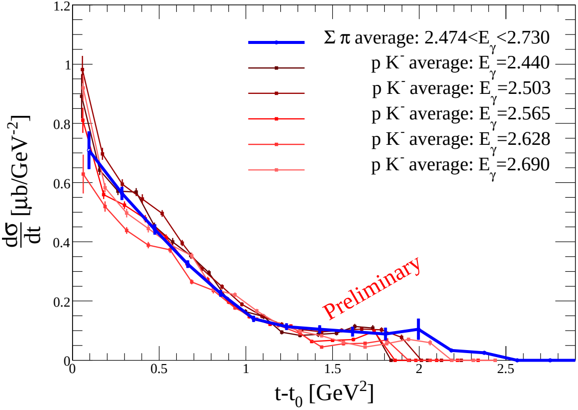
- lines are fits with 6^{rd} order Legendre polynomials
- clear turnover of $\Sigma^+\pi^-$ channel at forward angles
- theory: contact term only, no angular dependence for interference
- experiment: able to see strong **isospin** AND **angular** interference effect

$\Lambda(1405)$ Differential Cross Section Results



- lines are fits with 6^{rd} order Legendre polynomials
- clear turnover of $\Sigma^+\pi^-$ channel at forward angles
- theory: contact term only, no angular dependence for interference
- experiment: able to see strong **isospin** AND **angular** interference effect

$\Lambda(1520)$ Differential Cross Section Comparison

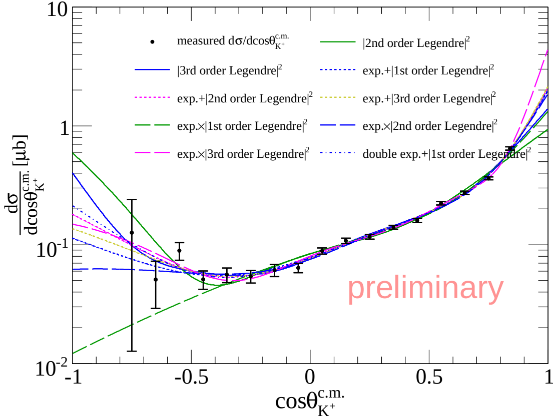


- binning is in $t - t_{\min}$
- good agreement with $\mathrm{p}K^-$ channel from CLAS (unpublished) — data provided by R. de Vita *et al.* (INFN Genova)

Extrapolation of Cross Sections

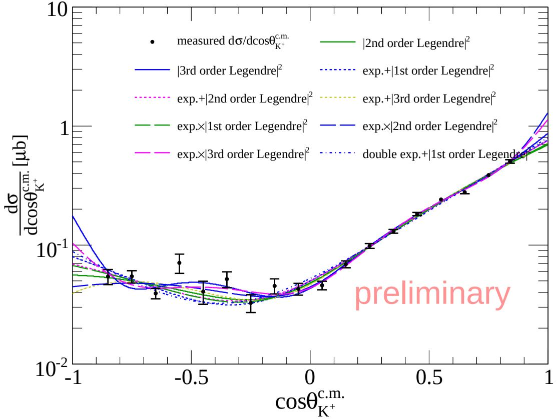
- Ad hoc functions were chosen to fit the measured cross sections
- total cross section $\sigma_{\rm tot}$ depends strongly on how cross section is extrapolated
- final result is a statistical mean of the various fit functions used

- $\Sigma(1385)$



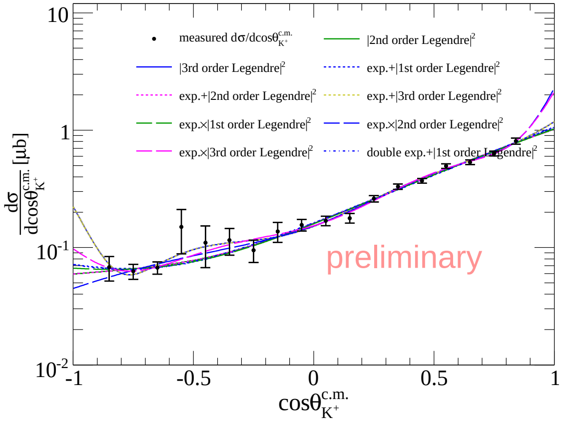
Extrapolation of Cross Sections

- Ad hoc functions were chosen to fit the measured cross sections
- total cross section σ_{tot} depends strongly on how cross section is extrapolated
- final result is a statistical mean of the various fit functions used
- $\Lambda(1405)$



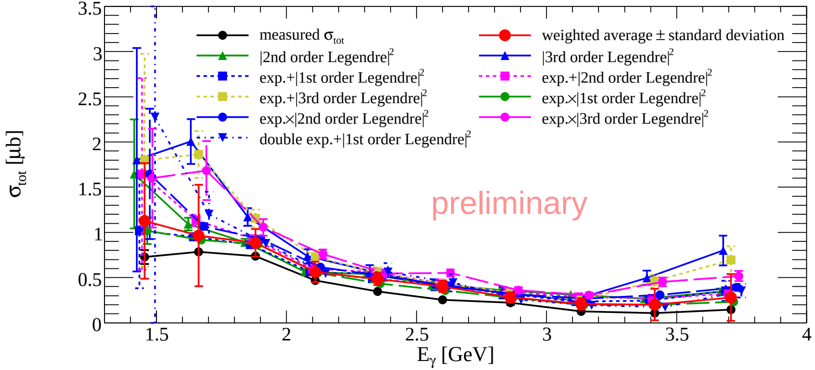
Extrapolation of Cross Sections

- Ad hoc functions were chosen to fit the measured cross sections
- total cross section $\sigma_{\rm tot}$ depends strongly on how cross section is extrapolated
- final result is a statistical mean of the various fit functions used
- $\Lambda(1520)$



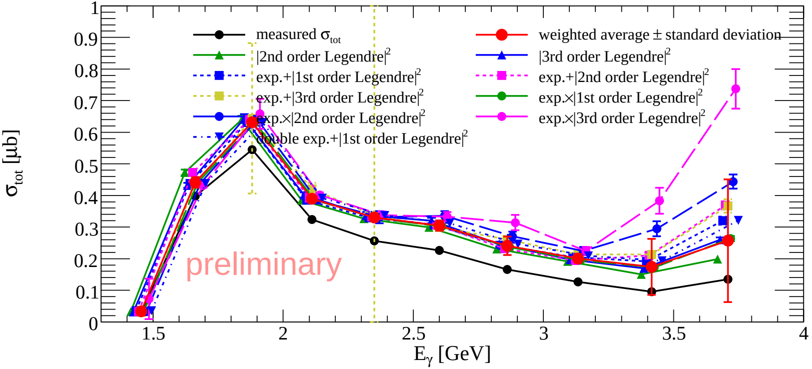
Extrapolated Total Cross Sections

- final result is a statistical mean of the various fit functions used
- $\Sigma(1385)$



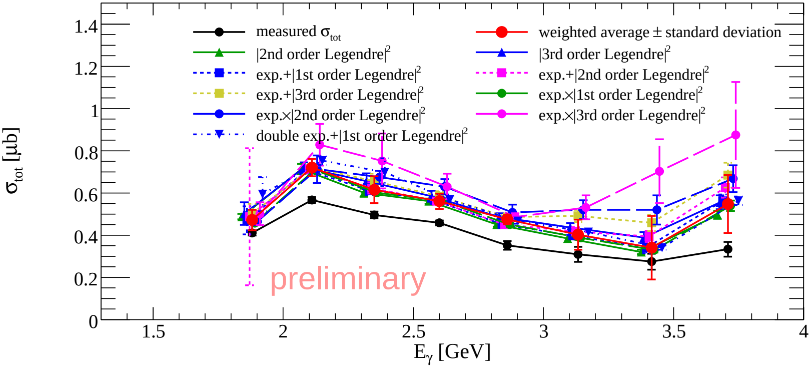
Extrapolated Total Cross Sections

- final result is a statistical mean of the various fit functions used
- $\Lambda(1405)$



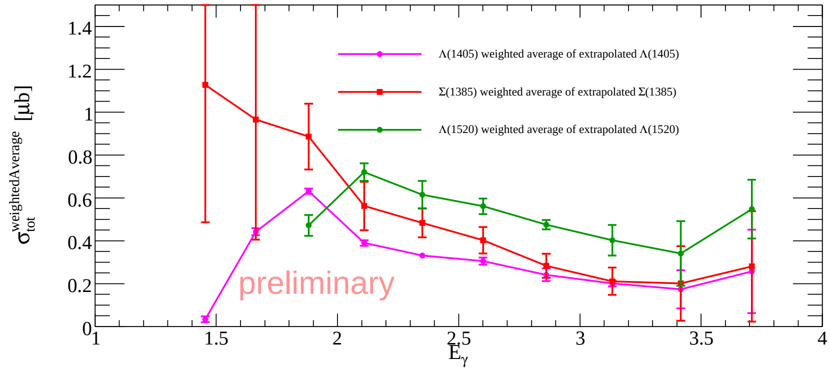
Extrapolated Total Cross Sections

- final result is a statistical mean of the various fit functions used
- $\Lambda(1520)$



Extrapolated Total Cross Sections

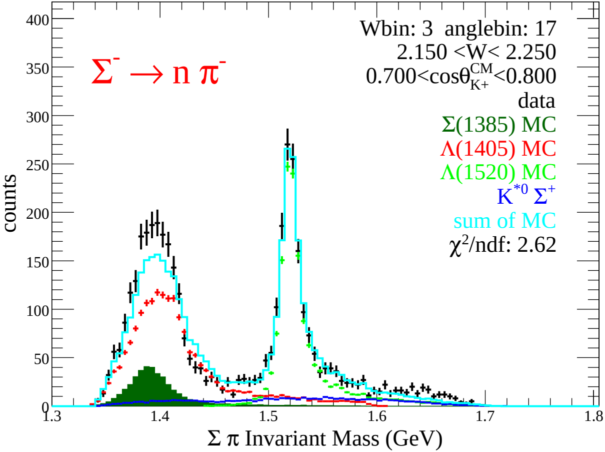
- final result is a statistical mean of the various fit functions used
- comparison of $\Sigma(1385)$, $\Lambda(1405)$, $\Lambda(1520)$



Conclusion

- Most precise measurement of $\Lambda(1405)$ for any reaction
- Strong hints of "dynamical" nature
- **Difference in lineshapes** observed
  - Strong effects of *both* isospin $I = 0$ and $I = 1$
  - Hints of dynamical nature of $\Lambda(1405)$?
  - Shifts in opposite direction compared to theory
- **Difference in $\mathbf{d}\boldsymbol{\sigma}/\mathbf{d}\cos\boldsymbol{\theta}^{\mathbf{c.m.}}_{\boldsymbol{K}^+}$ behavior** observed
  - Again, effects of *both* isospin $I = 0$ and $I = 1$
  - Cross sections for $\Sigma(1385)$ and $\Lambda(1520)$ also measured
- **Spin and parity experimentally determined for first time**
  - $J^P = \frac{1}{2}^-$
  - Polarization at forward K^+ angles, higher energies $W \sim 2.5$-2.8 GeV is $\sim 40\%$
  - Falloff of lineshape at $N\overline{K}$ threshold also supports $J^P = \frac{1}{2}^-$

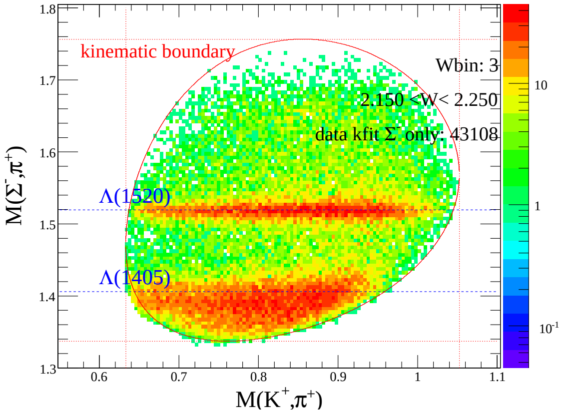
Fit to Lineshape With MC Templates



example:
1 energy and angle bin out of ~ 150

- subtract off $\mathbf{\Sigma(1385)}$, $\mathbf{\Lambda(1520)}$, $\mathbf{K^+\Sigma^-\pi^+}$ **phase space**
- assigned the remaining contribution to the $\mathbf{\Lambda(1405)}$

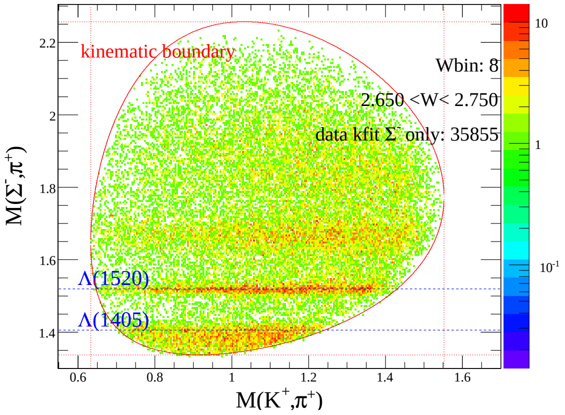
$M(\Sigma^-\pi^+)$ vs $M(K^+\pi^+)$ Plots



low energy bin

acceptance is good over entire area

$M(\Sigma^-\pi^+)$ vs $M(K^+\pi^+)$ Plots

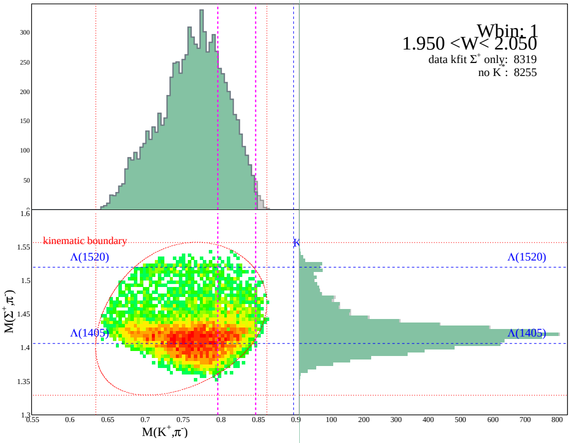


high energy bin

acceptance is good over entire area

Effect of K^* on Lineshape

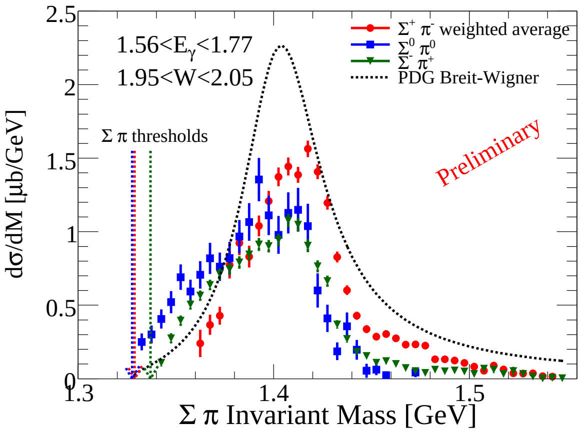
$1.950 < W\,[\mathrm{GeV}] < 2.050$ (below K^* threshold)



K^* vs Y^* mass plot for Σ^+channel

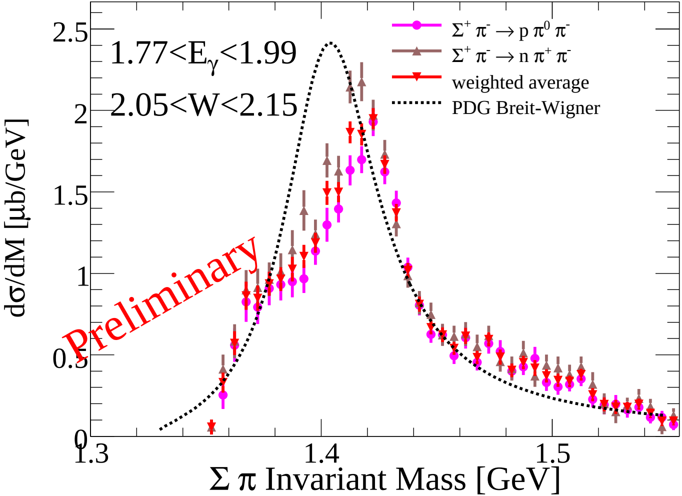
Effect of K^* on Lineshape

$1.950 < W\,[\mathrm{GeV}] < 2.050$ (below K^* threshold)

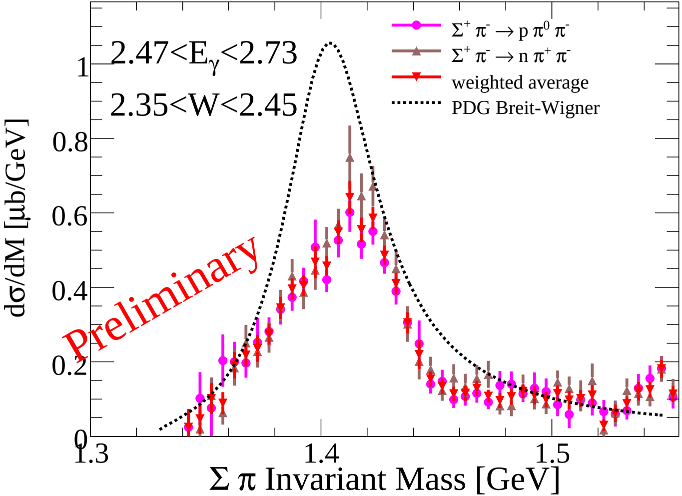


extracted lineshape

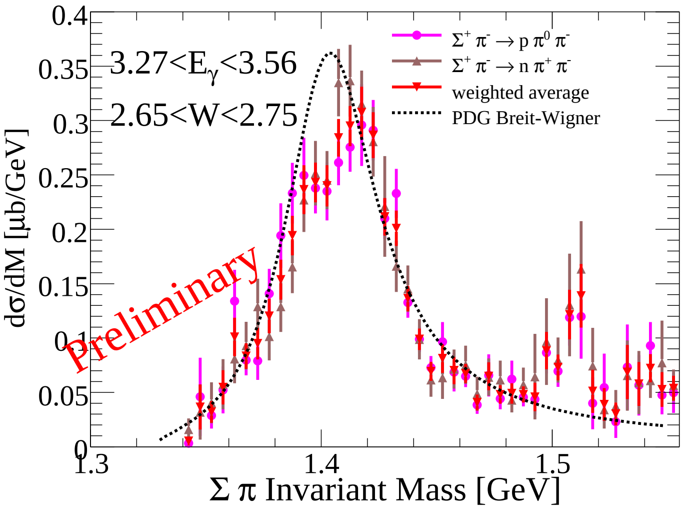
Comparison of Lineshapes for Two Σ^+ Channels



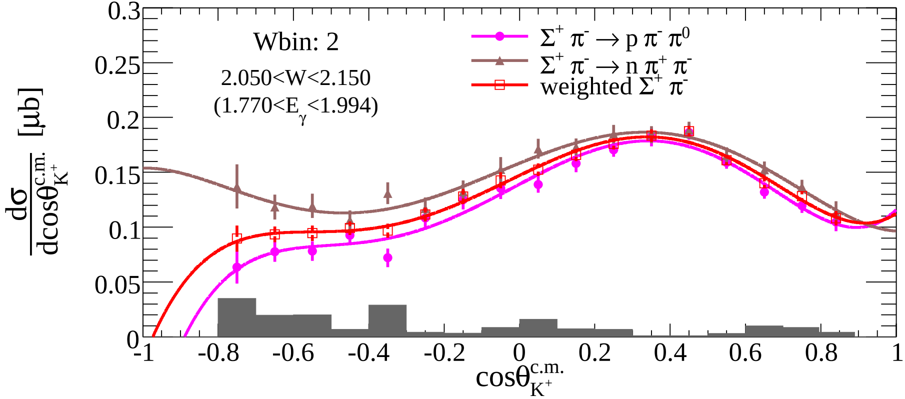
Comparison of Lineshapes for Two Σ^+ Channels



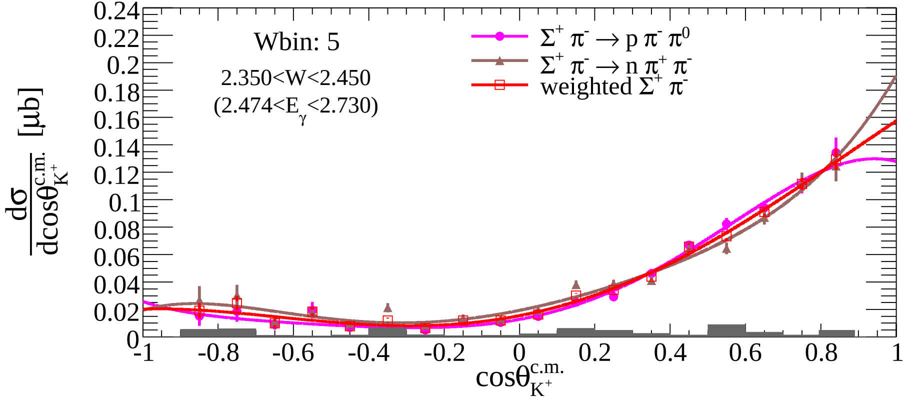
Comparison of Lineshapes for Two Σ^+Channels



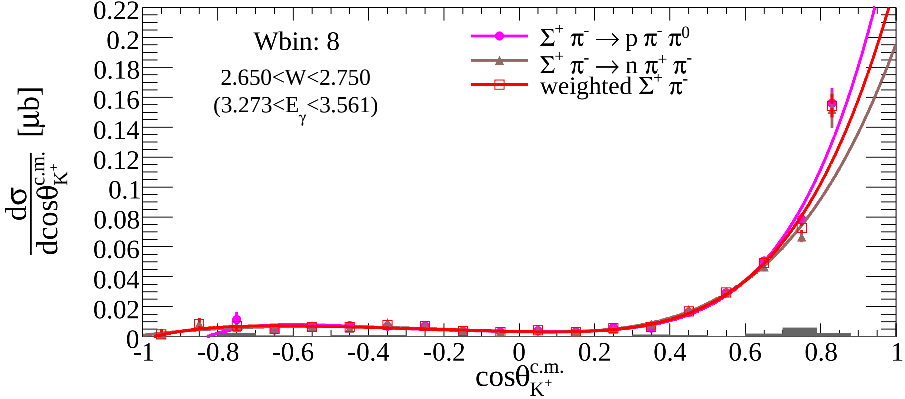
$\Lambda(1405)$ Comparison of Two Σ^+Channels



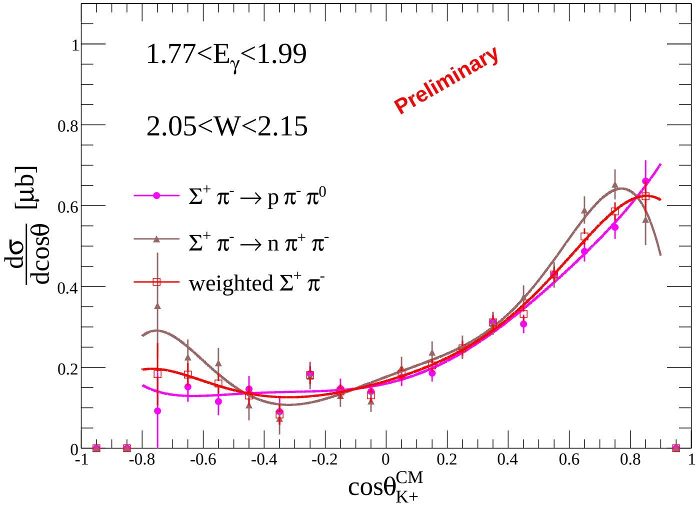
$\Lambda(1405)$ Comparison of Two Σ^+Channels



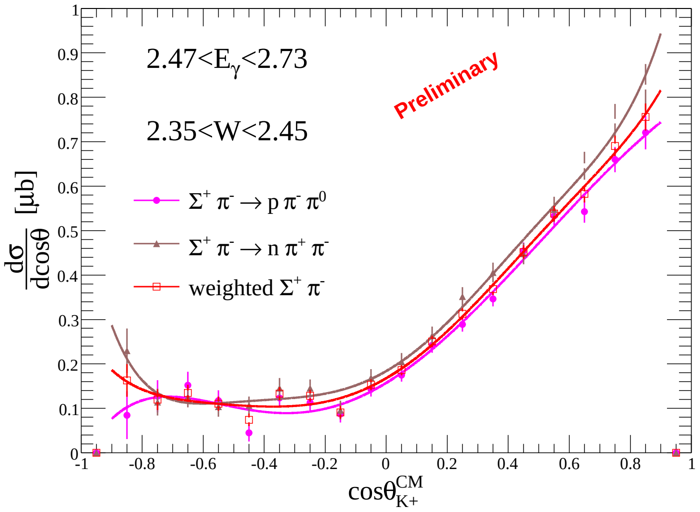
$\Lambda(1405)$ Comparison of Two Σ^+Channels



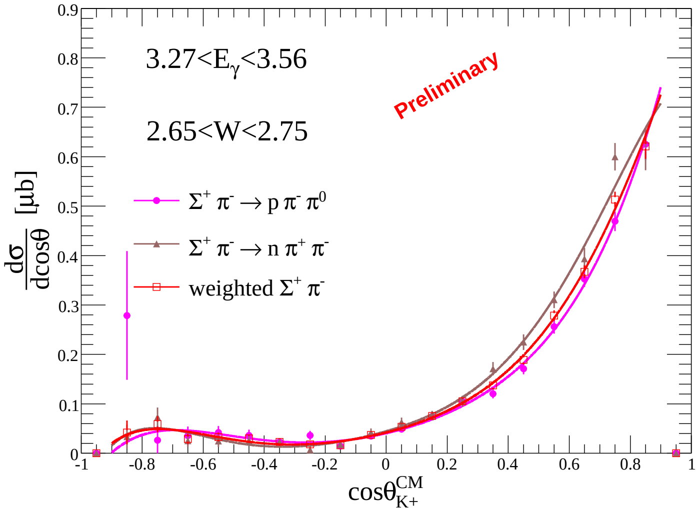
$\Lambda(1520)$ Comparison of Two Σ^+Channels



$\Lambda(1520)$ Comparison of Two Σ^+ Channels



$\Lambda(1520)$ Comparison of Two Σ^+Channels



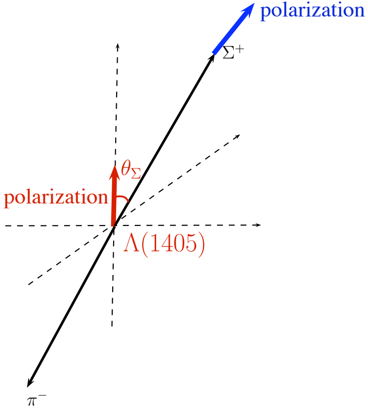
Outline

$\mathbf{J^P}$ of $\mathbf{\Lambda(1405)}$

no previous **direct experimental evidence** for the spin and parity (PDG **assumes** $1/2^-$) "Note on the $\Lambda(1405)$" 1998 PDG, R.H. Dalitz

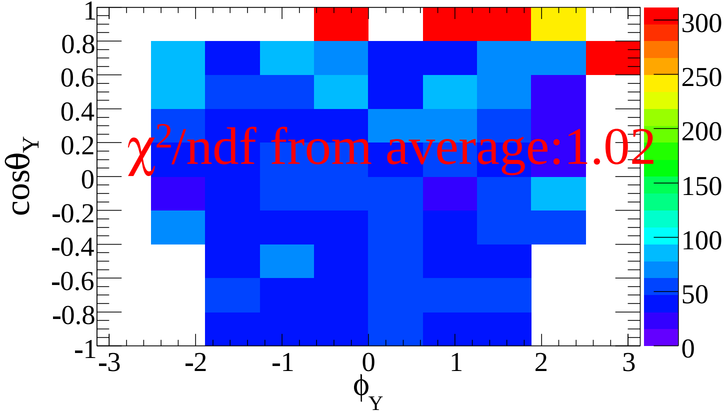
How do we measure these quantities?

- **spin** – measure distribution into $\Sigma\pi$
  - flat distribution is best evidence possible for $J = 1/2$
- **parity** – measure polarization of Σ from $\Lambda(1405)$
  - Polarization direction as a function of Σ decay angle will be determined by J^P of $\Lambda(1405)$



Determination of Spin

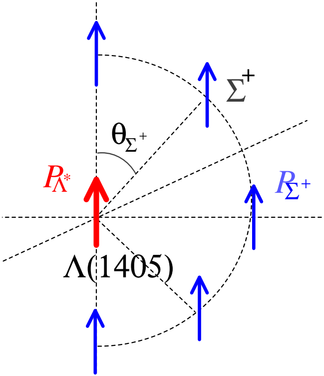
Fit to $\Sigma\pi$ distribution is FLAT



- consistent with $J = 1/2$
- fits to higher moments may be necessary

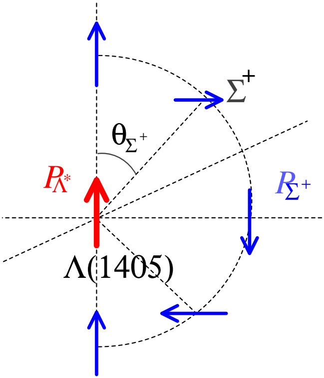
s-wave, p-wave Scenario

$$\frac{L = 0 \ \text{(s-wave)}}{\vec{P}_{\Sigma^+} = \vec{P}_{\Lambda^*}}$$



$\Lambda(1405) \rightarrow \Sigma\pi$ is s-wave
$\Leftrightarrow J^P = 1/2^-$

$$\frac{L = 1 \ \text{(p-wave)}}{\vec{P}_{\Sigma^+} = |\vec{P}_{\Lambda^*}|\hat{n}(2\theta_{\Sigma^+})}$$

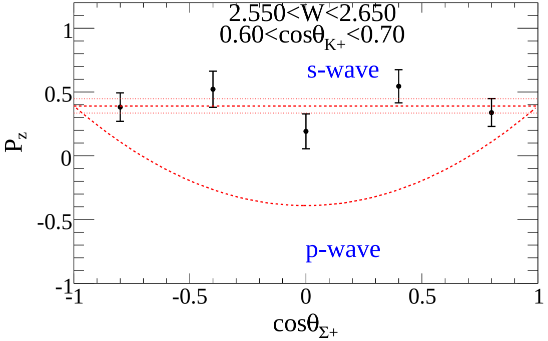


$\Lambda(1405) \rightarrow \Sigma\pi$ is p-wave
$\Leftrightarrow J^P = 1/2^+$

Determination of Parity

polarization of $\Lambda(1405)$ in direction $\perp$ to production plane is measured

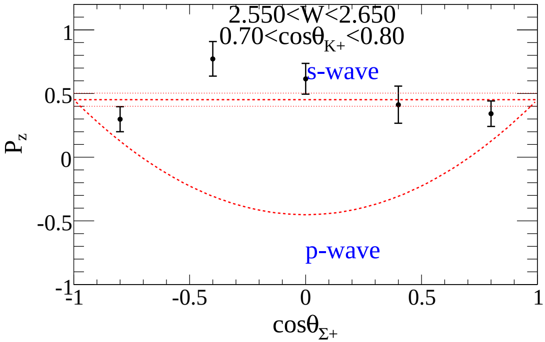
- $W = 2.6$ GeV
- forward K^+angles
- use reaction: $\Lambda(1405) \to \Sigma^+\pi^-$, $\Sigma^+ \to p\pi^0$
- very large hyperon decay parameter $\alpha = -0.98$
- background is $\sim 10\%$ $\Sigma(1385)$



Determination of Parity

polarization of $\Lambda(1405)$ in direction $\perp$ to production plane is measured

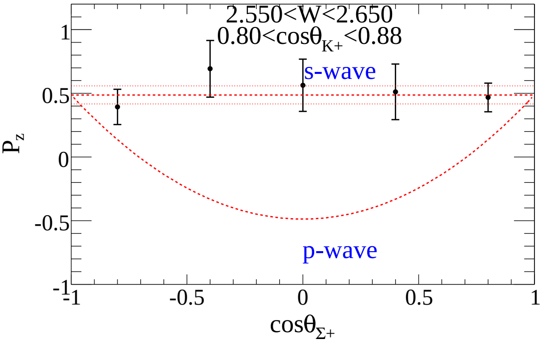
- $W = 2.6$ GeV
- forward K^+angles
- use reaction:
  $\Lambda(1405) \to \Sigma^+\pi^-$,
  $\Sigma^+ \to p\pi^0$
- very large hyperon decay parameter $\alpha = -0.98$
- background is $\sim 10\%$ $\Sigma(1385)$



Determination of Parity

polarization of $\Lambda(1405)$ in direction $\perp$ to production plane is measured

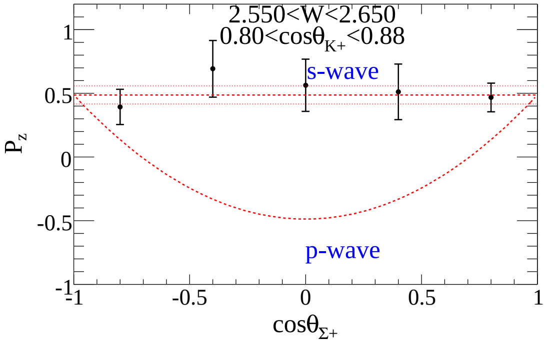
- $W = 2.6$ GeV
- forward K^+angles
- use reaction:
  $\Lambda(1405) \to \Sigma^+\pi^-$,
  $\Sigma^+ \to p\pi^0$
- very large hyperon decay parameter $\alpha = -0.98$
- background is $\sim 10\%$ $\Sigma(1385)$



Determination of Parity

polarization of $\Lambda(1405)$ in direction $\perp$ to production plane is measured

- $W = 2.6$ GeV
- forward K^+angles
- use reaction: $\Lambda(1405) \to \Sigma^+\pi^-$, $\Sigma^+ \to p\pi^0$
- very large hyperon decay parameter $\alpha = -0.98$
- background is $\sim 10\%$ $\Sigma(1385)$

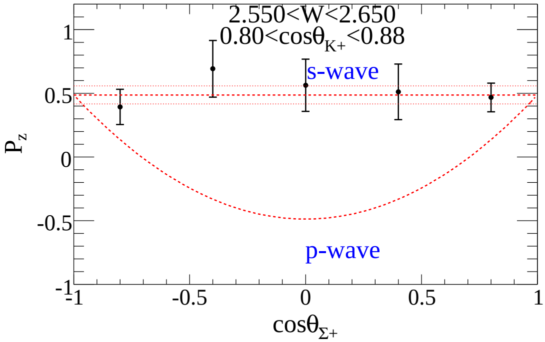


polarization does not change with Σ^+ angle (θ_{Σ^+})

Determination of Parity

polarization of $\Lambda(1405)$ in direction $\perp$ to production plane is measured

- $W = 2.6$ GeV
- forward K^+angles
- use reaction: $\Lambda(1405) \to \Sigma^+\pi^-$, $\Sigma^+ \to p\pi^0$
- very large hyperon decay parameter $\alpha = -0.98$
- background is $\sim 10\%$ $\Sigma(1385)$



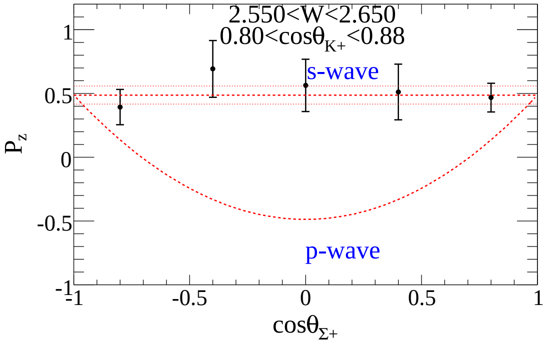
polarization does not change with Σ^+ angle (θ_{Σ^+})

$\Rightarrow$ $J^P = 1/2^-$ is confirmed

Determination of Parity

polarization of $\Lambda(1405)$ in direction $\perp$ to production plane is measured

- $W = 2.6$ GeV
- forward K^+angles
- use reaction: $\Lambda(1405) \to \Sigma^+\pi^-$, $\Sigma^+ \to p\pi^0$
- very large hyperon decay parameter $\alpha = -0.98$
- background is $\sim 10\%$ $\Sigma(1385)$



polarization does not change with Σ^+ angle (θ_{Σ^+})

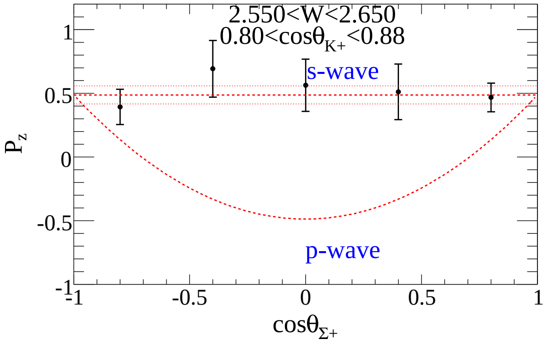
$\Rightarrow$ $J^P = 1/2^-$ is confirmed

furthermore, this measured Σ^+ polarization **is** the $\Lambda(1405)$ polarization

Determination of Parity

polarization of $\Lambda(1405)$ in direction $\perp$ to production plane is measured

- $W = 2.6$ GeV
- forward K^+angles
- use reaction: $\Lambda(1405) \rightarrow \Sigma^+\pi^-$, $\Sigma^+ \rightarrow p\pi^0$
- very large hyperon decay parameter $\alpha = -0.98$
- background is $\sim 10\%$ $\Sigma(1385)$



polarization does not change with Σ^+ angle (θ_{Σ^+})

$\Rightarrow$ $J^P = 1/2^-$ is confirmed

furthermore, this measured Σ^+ polarization **is** the $\Lambda(1405)$ polarization

$\Rightarrow$ $\Lambda(1405)$ is produced with $\sim +40\%$ polarization