— MENU 2010 —

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

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Outline

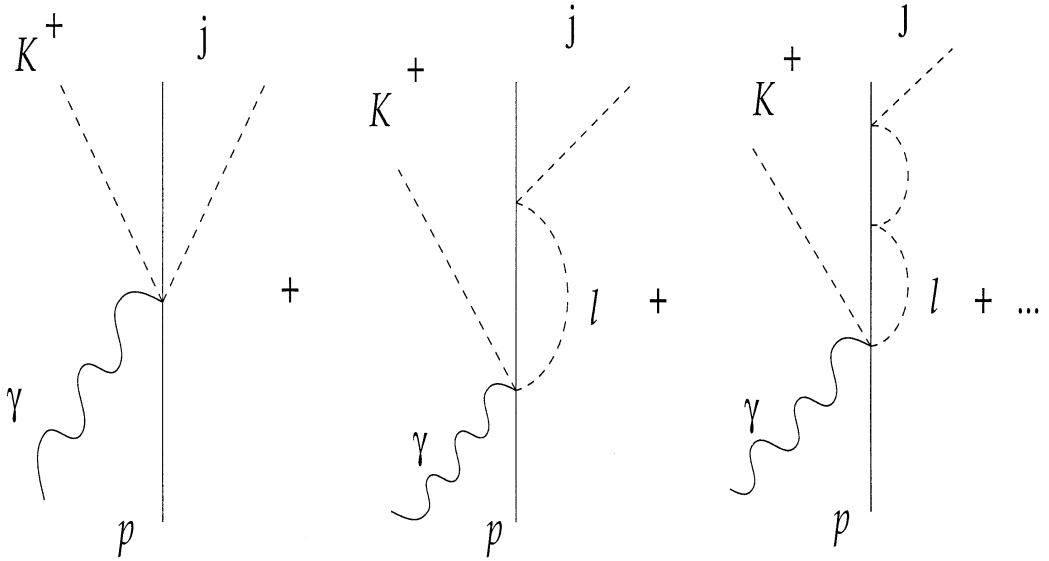
1. Introduction
   - What is the $\Lambda(1405)$?
   - Theory of the $\Lambda(1405)$
2. CLAS Analysis
   - Selecting Decay Channels of Interest
   - Removing $\Sigma^0(1385)$ and K^* Background
   - Fit to Extract $\Lambda(1405)$ Lineshape
3. Results
   - $\Lambda(1405)$ Lineshape Results
   - $\Lambda(1405)$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

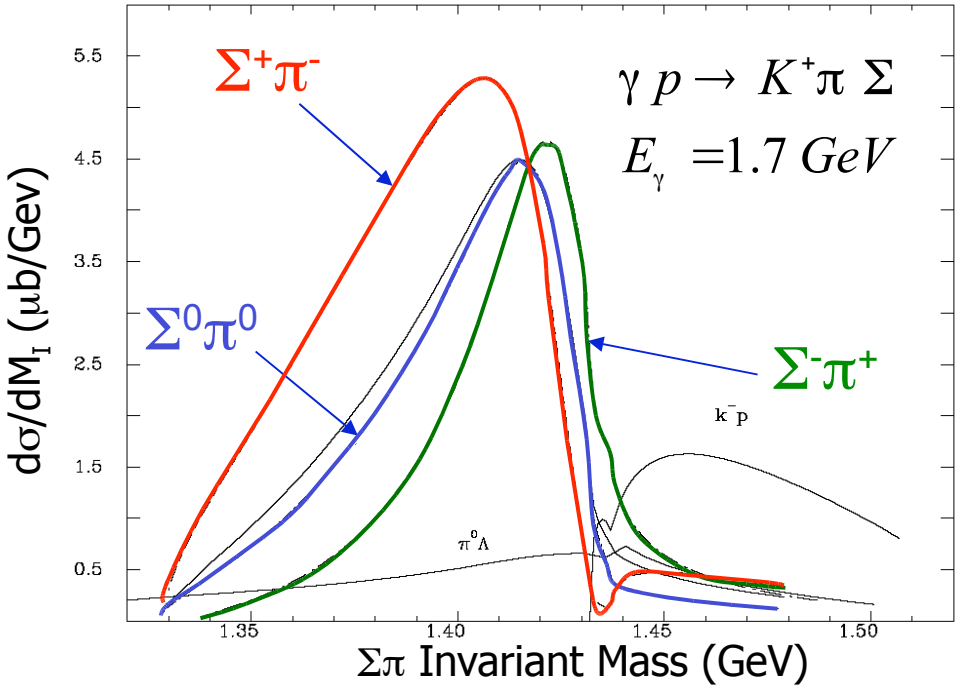
What is the $\Lambda(1405)$?

- **** 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
- what is the nature of this distorted lineshape?
  - "normal" qqq-baryon resonance
  - dynamically generated resonance in unitary coupled channel approach

Chiral Unitary Coupled Channel Approach

dynamically generate Λ(1405)





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

Difference in Lineshape

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

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

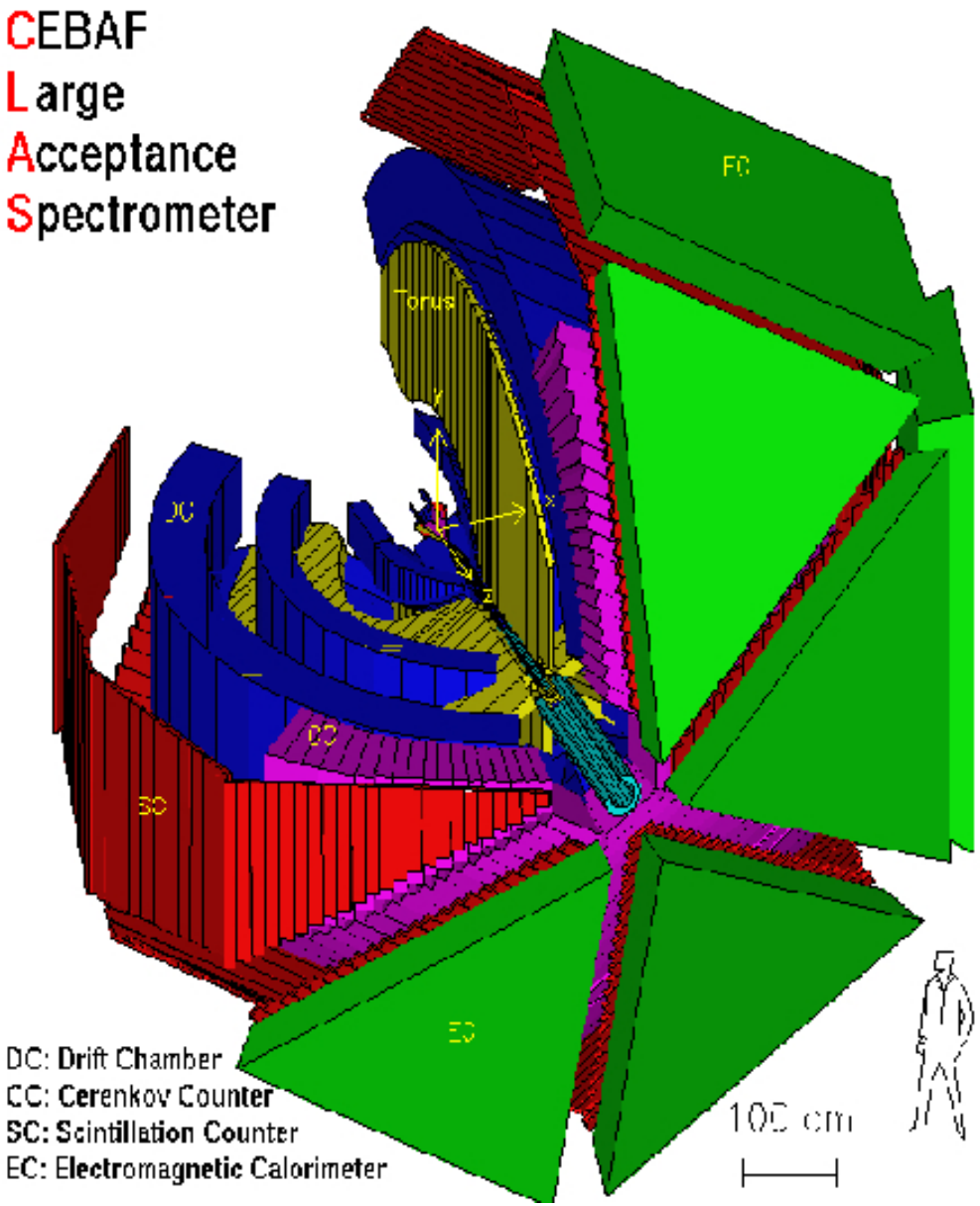
$$\frac{d\sigma(\pi^0\Sigma^0)}{dM_I} \propto \frac{1}{3}\left|T^{(0)}\right|^2 + O\left(T^{(2)}\right)$$

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

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

Data From CLAS@JLab

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



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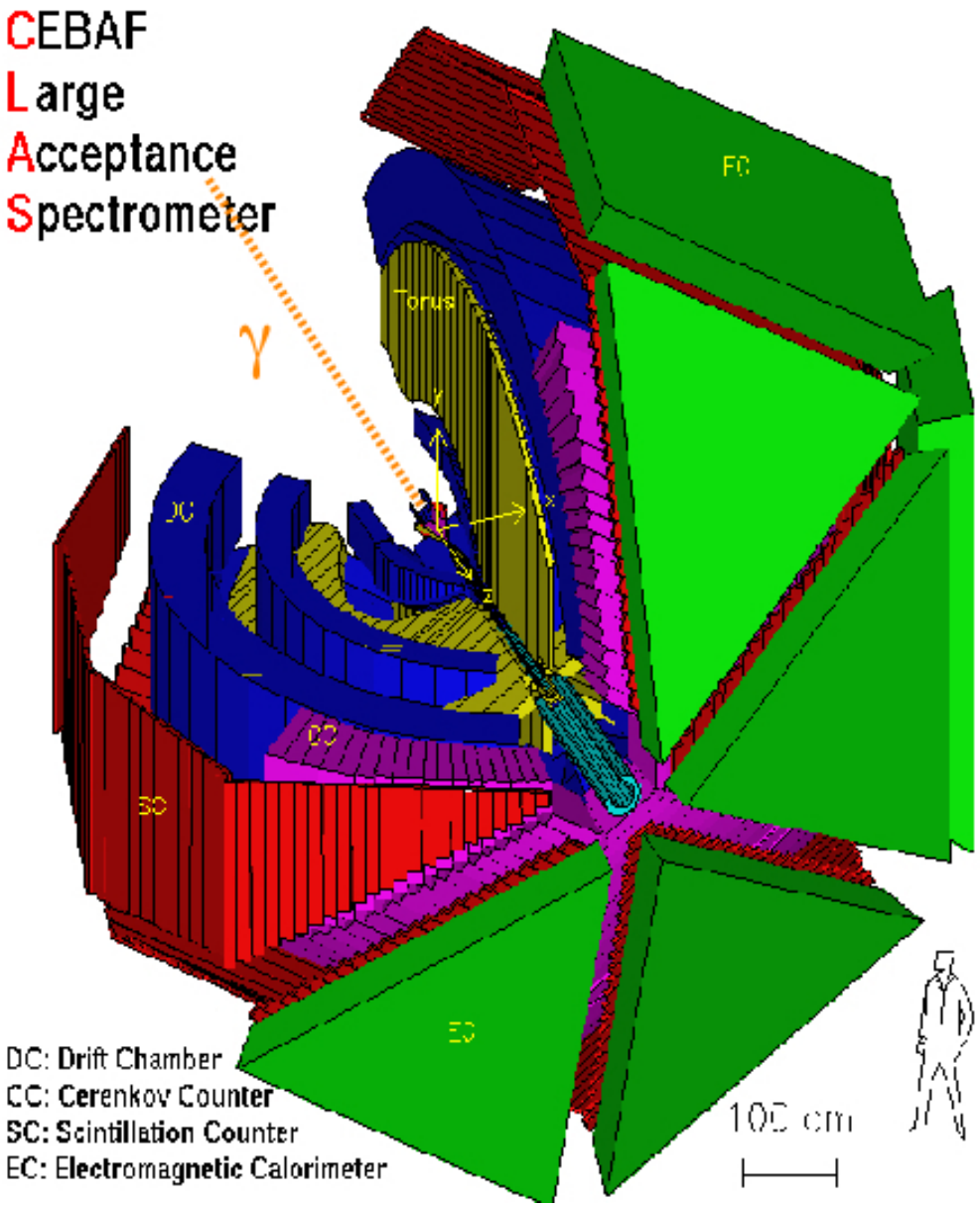
- real unpolarized photon beam
- $E_\gamma < 3.84$ GeV
- $\sim$ 20B total triggers



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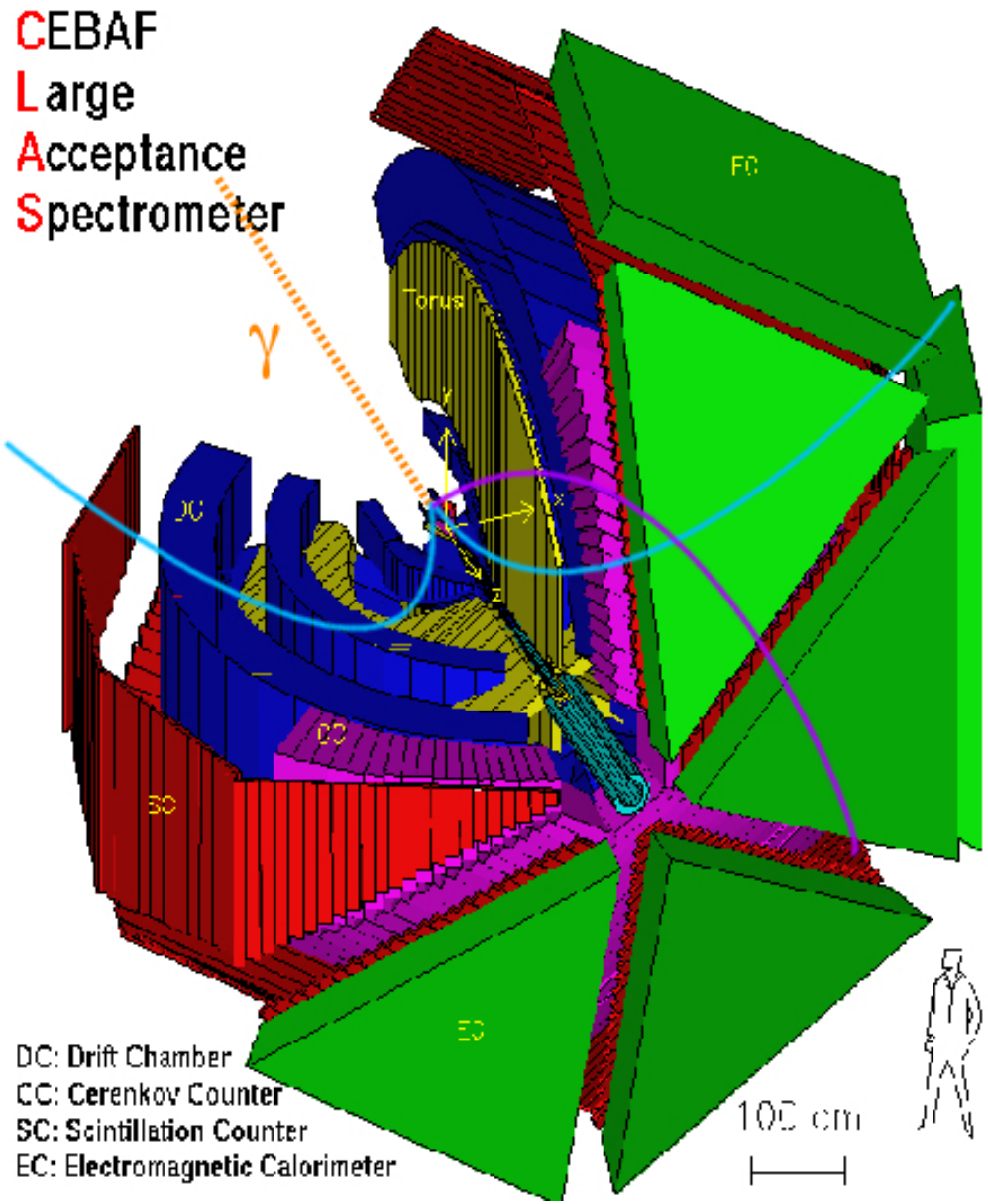
  - $\vec{\mathbf{p}}$ with **drift chambers**



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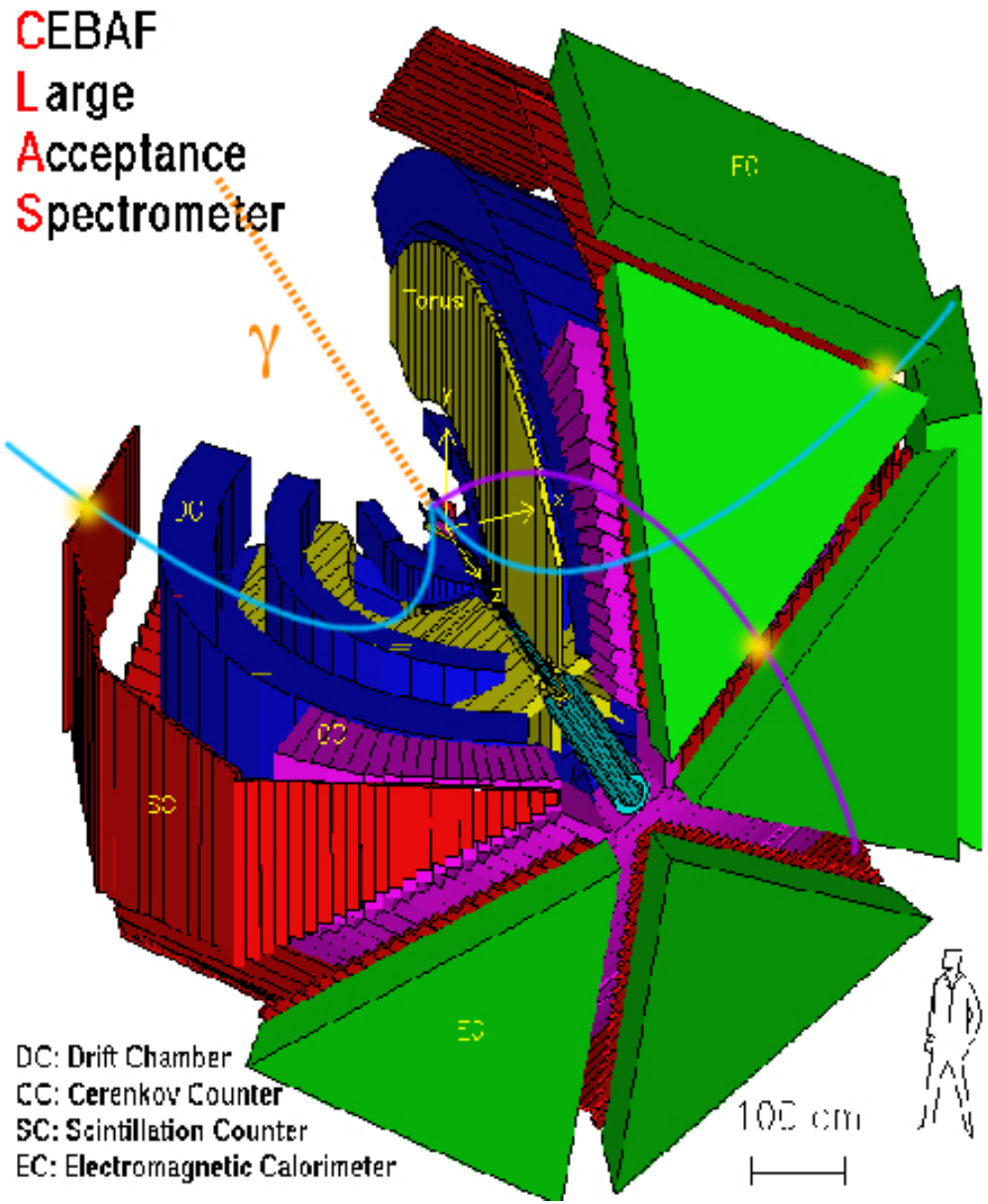
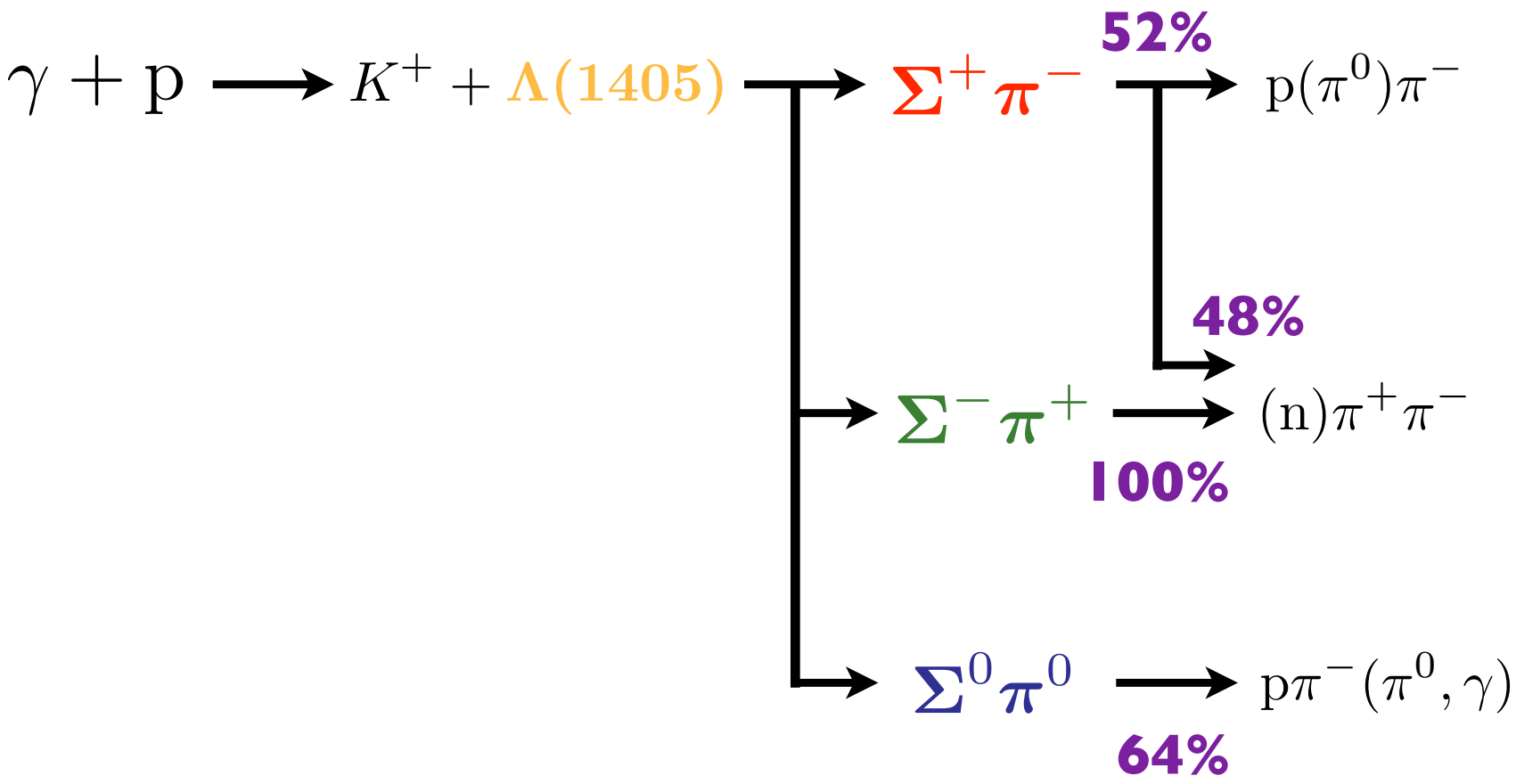
  - timing with **TOF walls**



Reaction of Interest



detected particles	K^+,p,π^-			K^+,π^+,π^-	
missing particle(s)	(π^0)		(π^0,γ)	(n)	
intermediate hyperon	Λ	Σ^+	$\Sigma^0(\rightarrow \gamma\Lambda)$	Σ^+	Σ^-
kinematic fit	**yes**		**no**	**yes**	
reaction	**$\Sigma(1385)$**	**$\Sigma(1385)$, $\Lambda(1405)$, $\Lambda(1520)$**			

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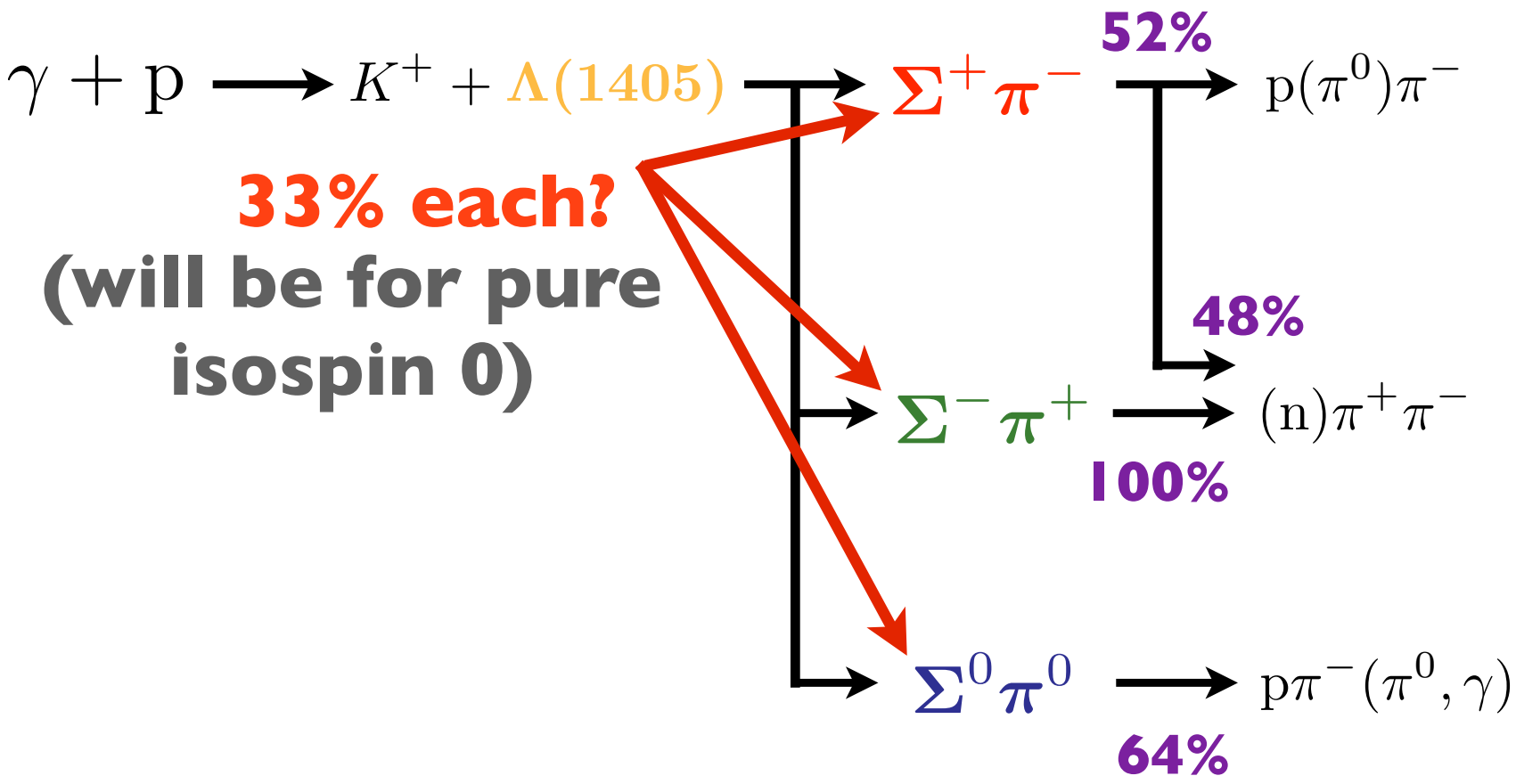

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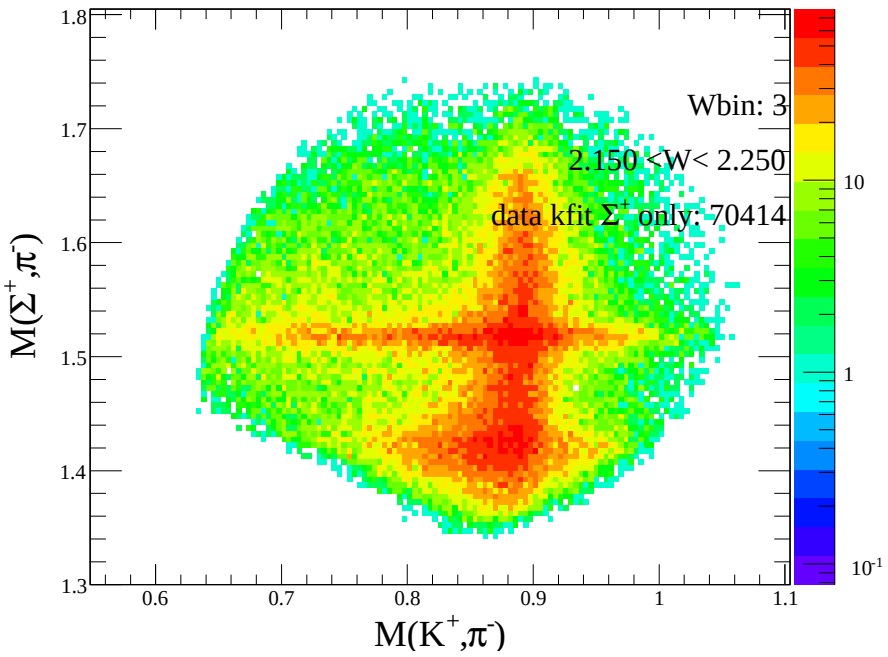
Background

- $\Sigma^0(1385) \rightarrow \Sigma\pi$
  - $BR(\Lambda\pi^0) = 88\% \gg BR(\Sigma^{\pm}\pi^{\mp}) = 6\%$ 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



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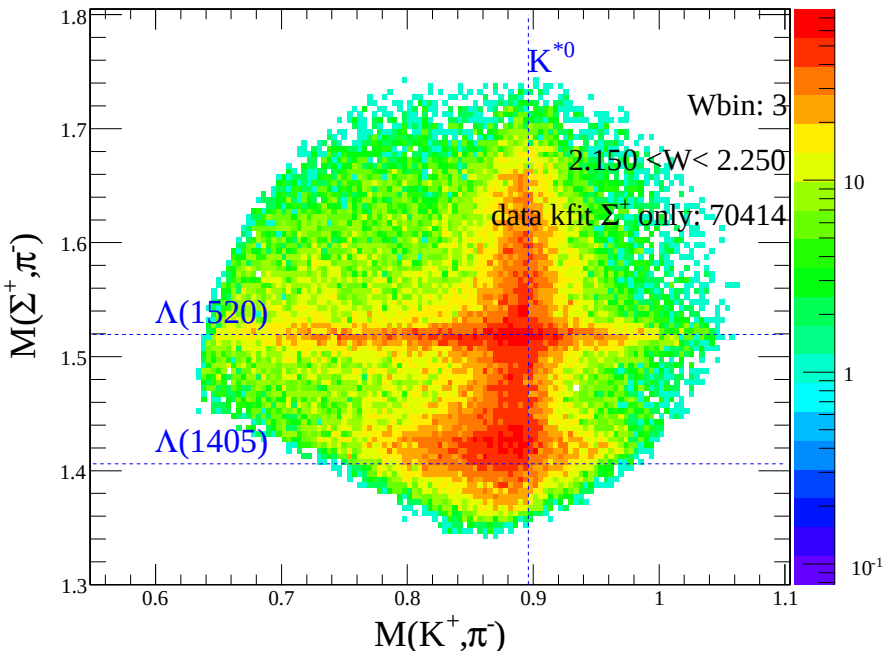

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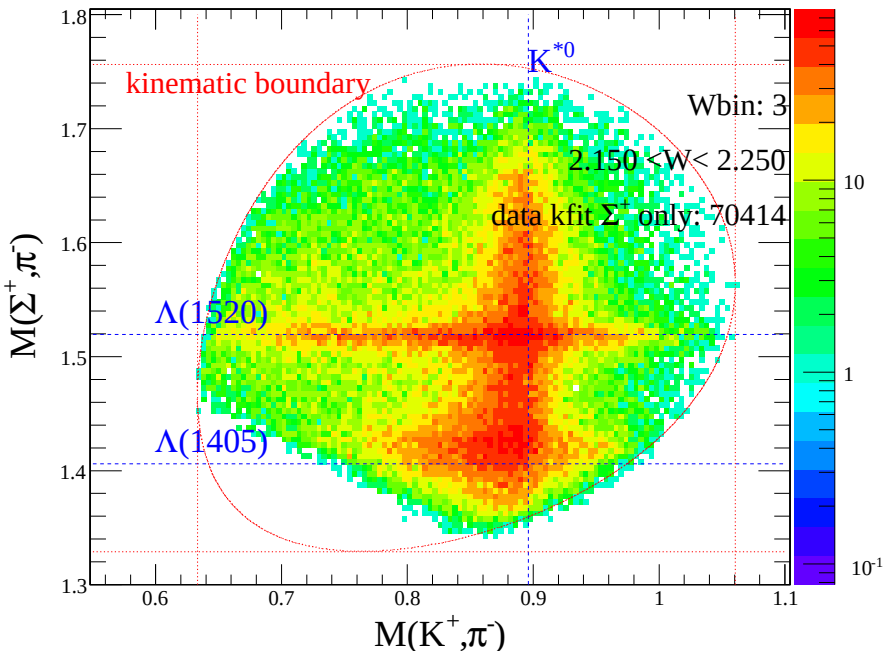
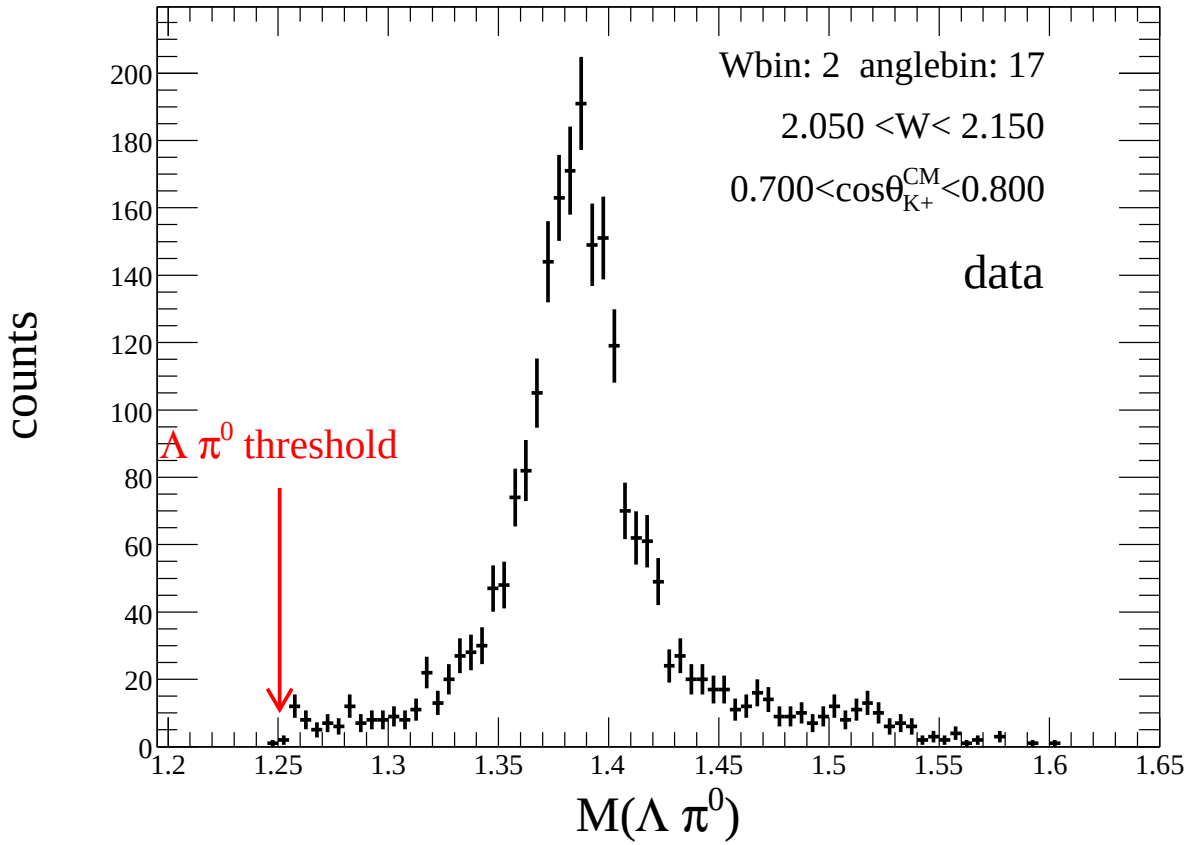


$\Sigma(1385)$ is Fit in $\Lambda\pi^0$ Channel ($\gamma + \mathrm{p} \rightarrow K^+ + \mathrm{p} + \pi^- + \pi^0$)



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

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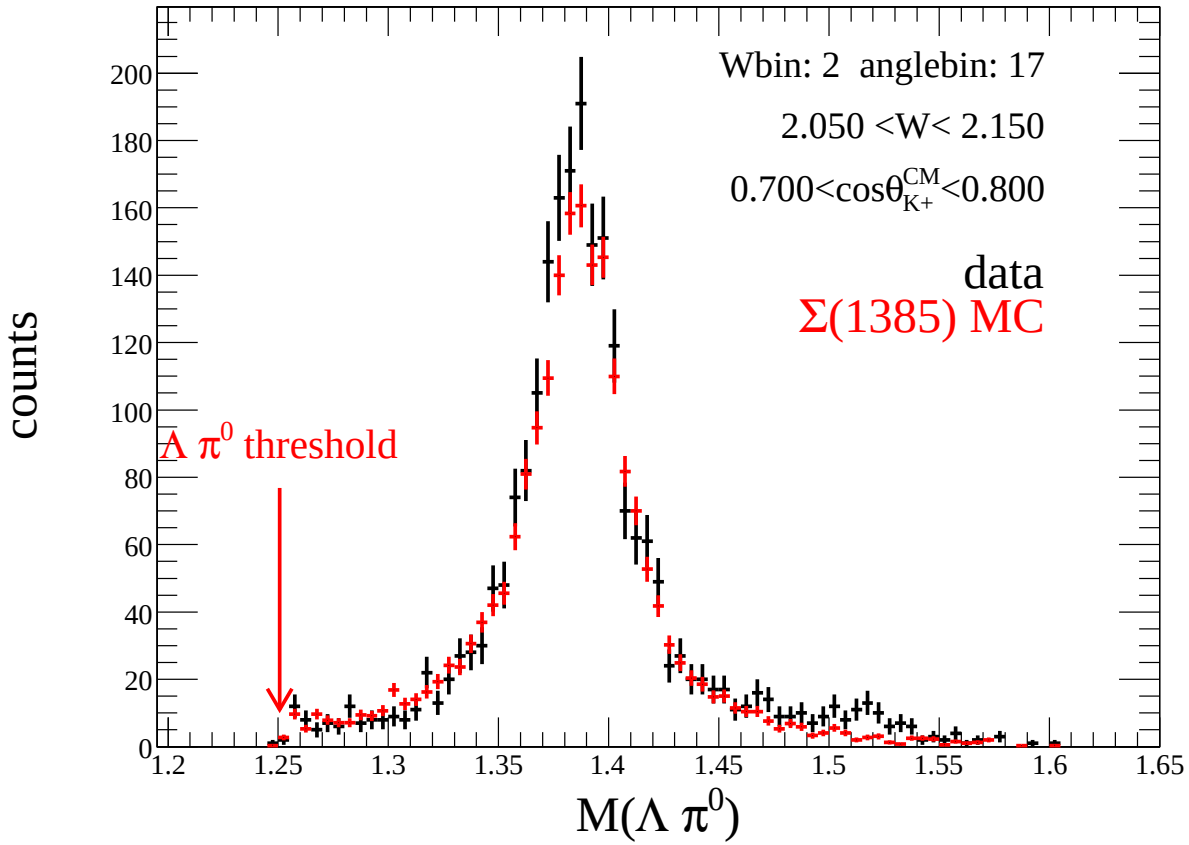

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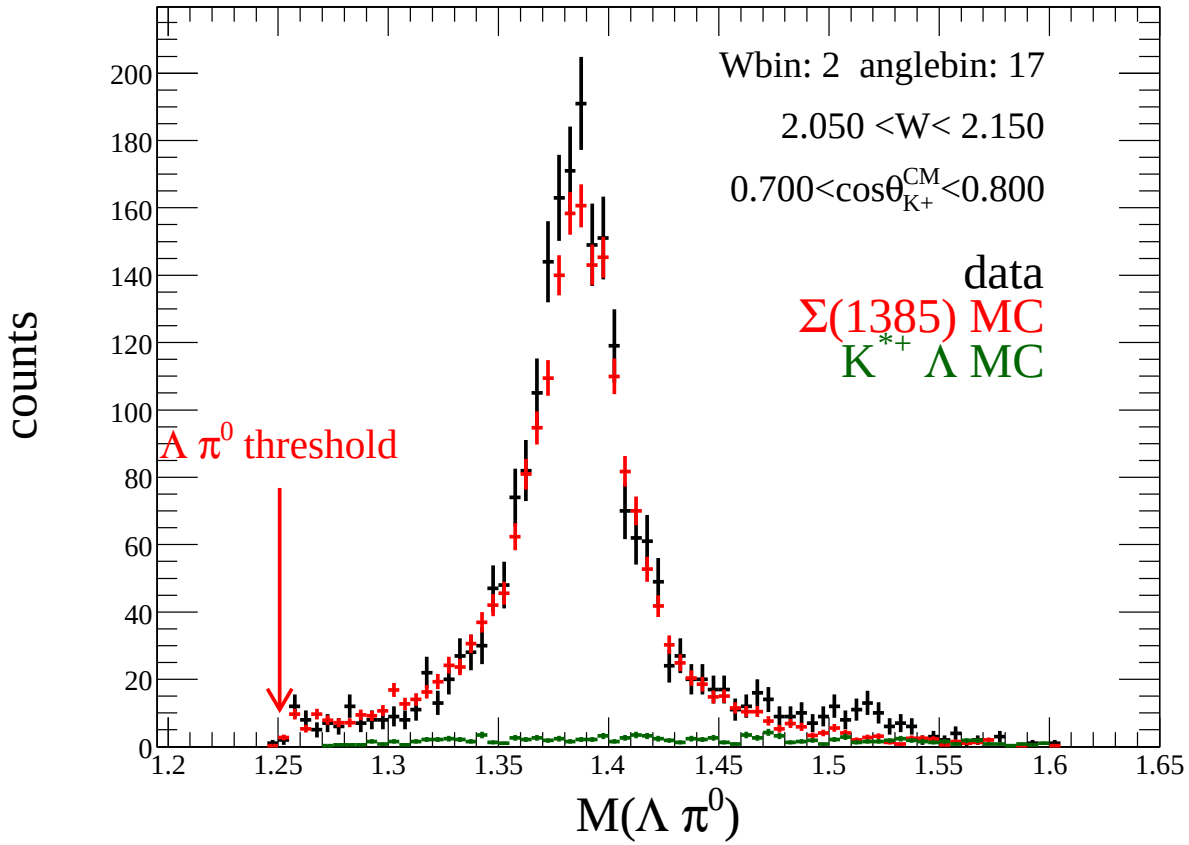

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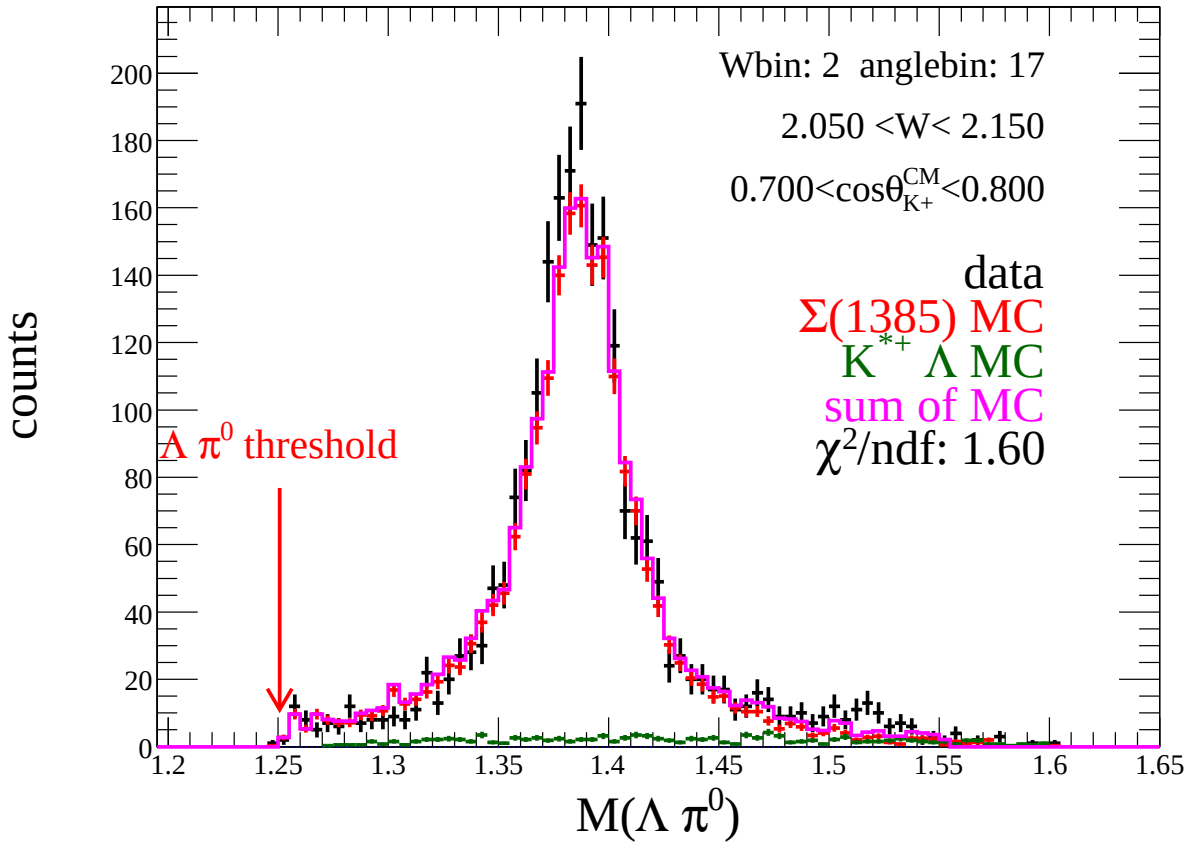

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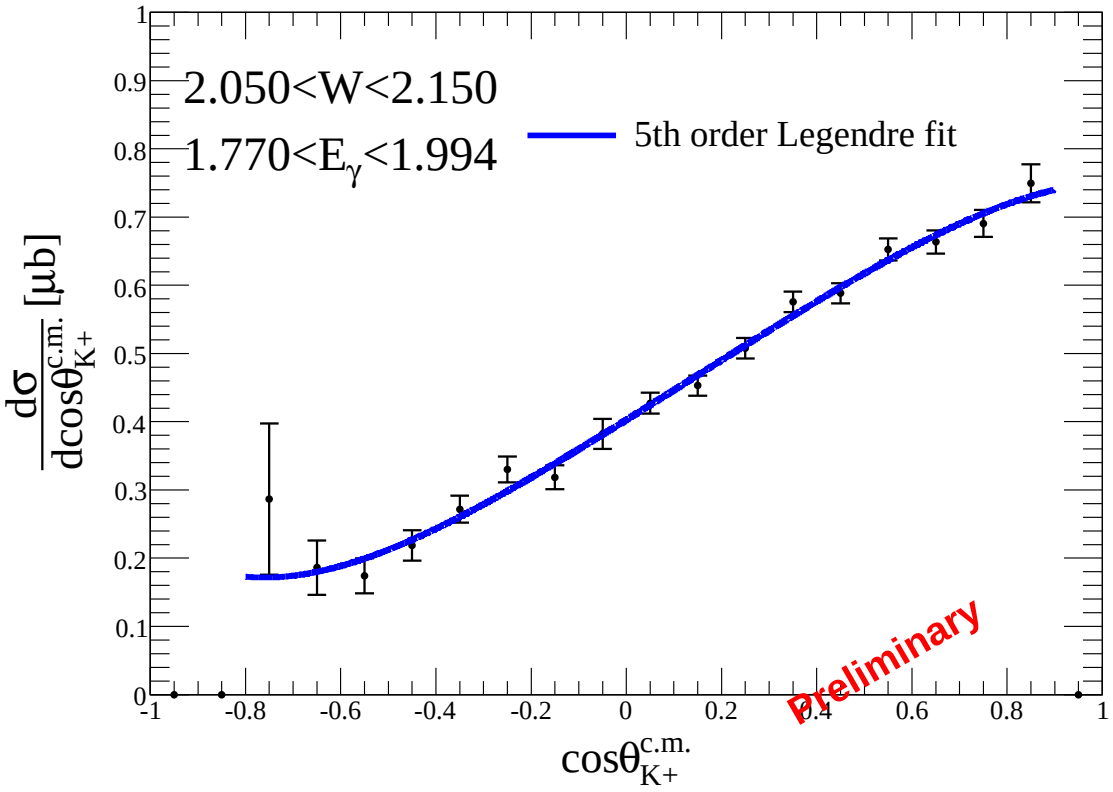
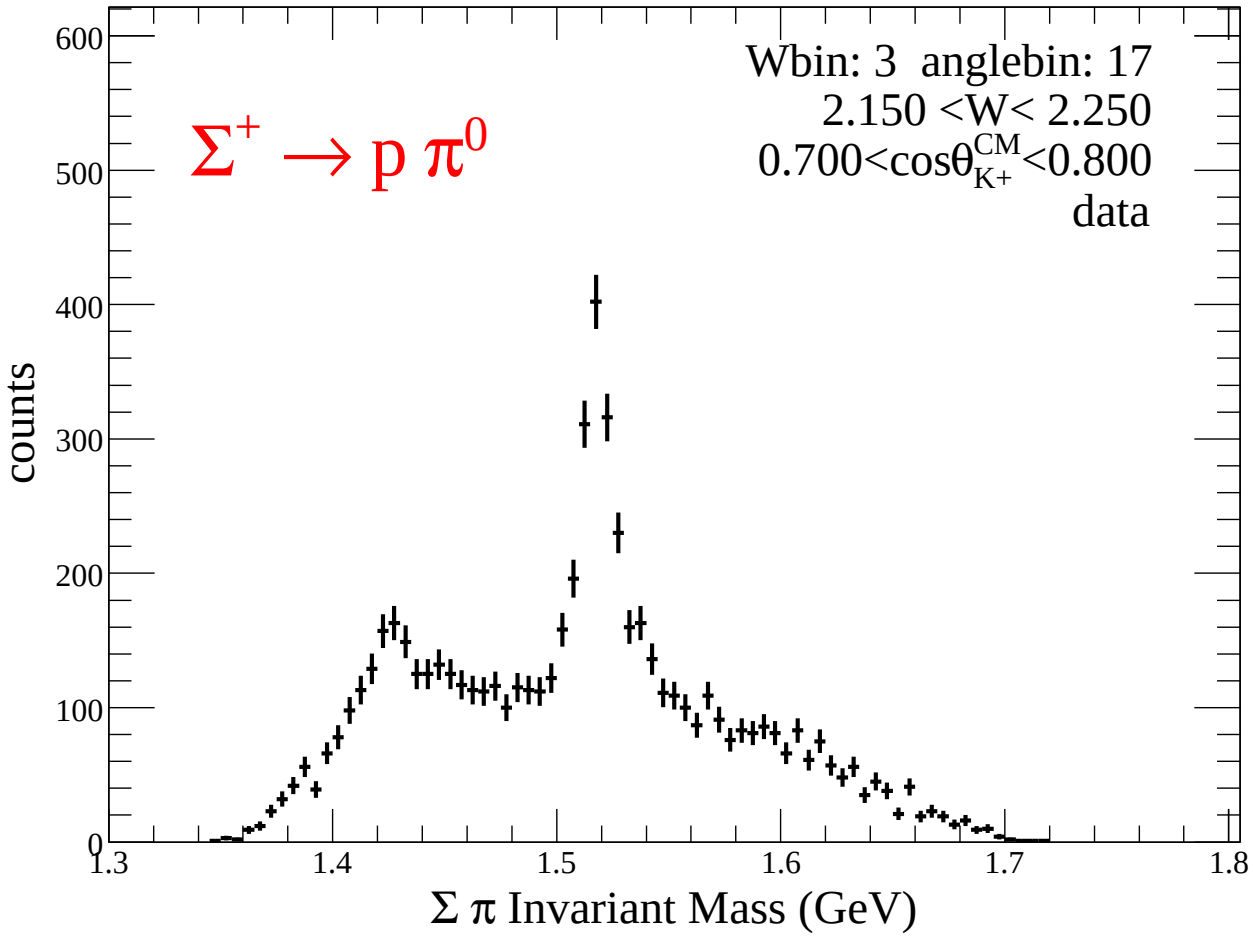
$\Sigma(1385)$ Cross Section From $\Lambda\pi^0$ Channel



- scale by **branching ratio** and **acceptance** into each $\Sigma\pi$ channel
- $\mathrm{BR}(\Lambda\pi) = 89\% \gg \mathrm{BR}(\Sigma\pi) = 11\%$
- $\Sigma^0\pi^0$ channel does not have $\Sigma(1385)$

Fit to Lineshape With MC Templates



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

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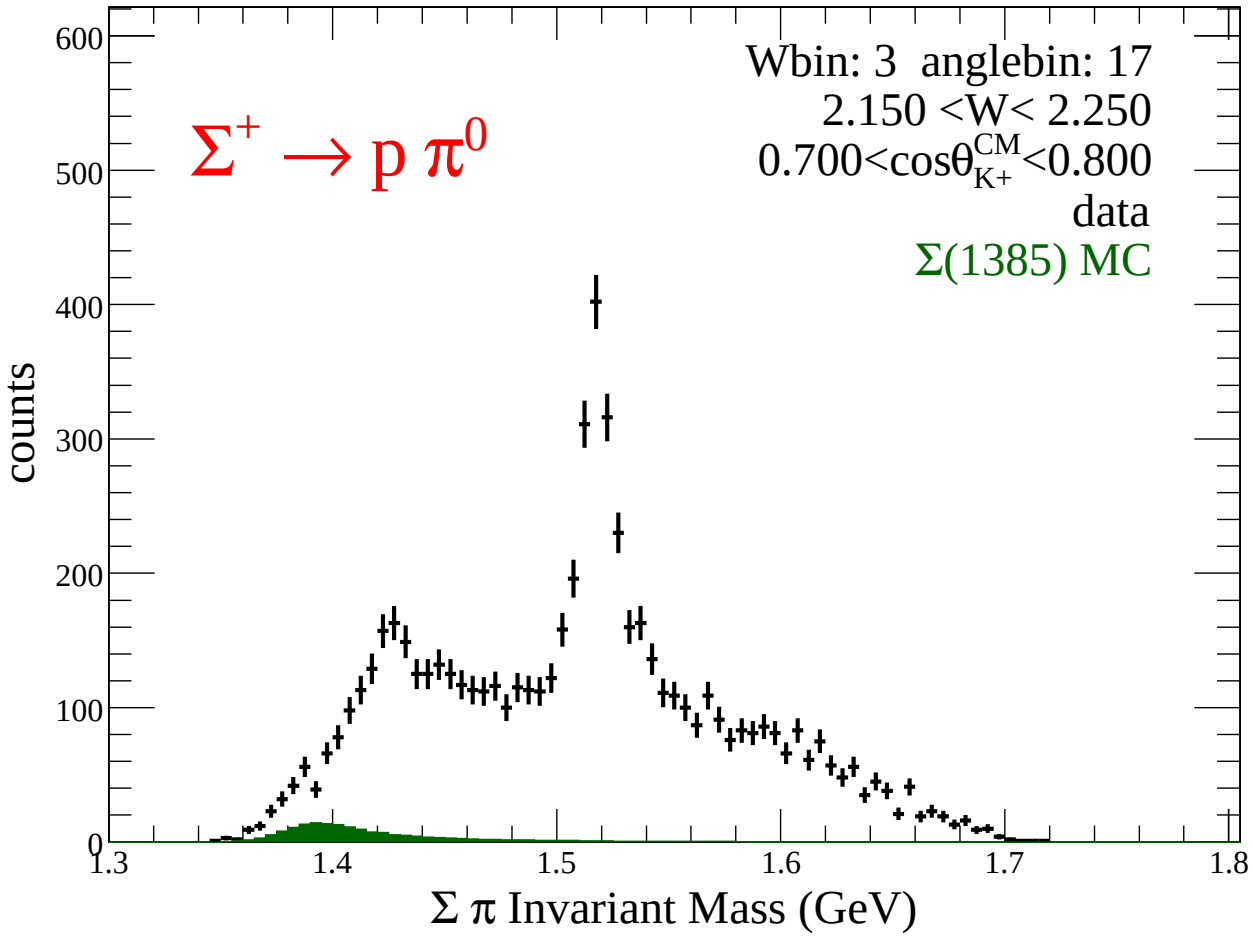

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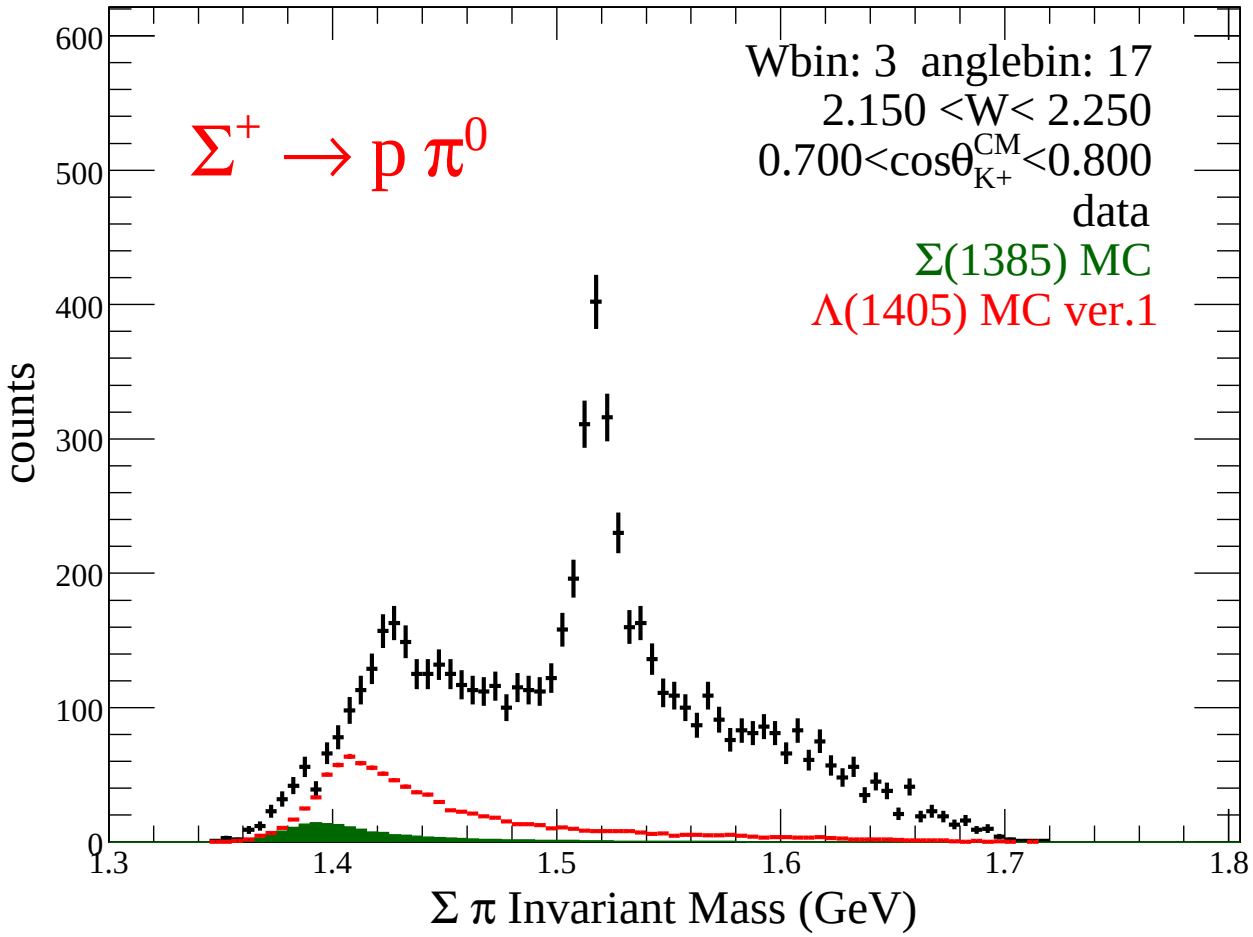

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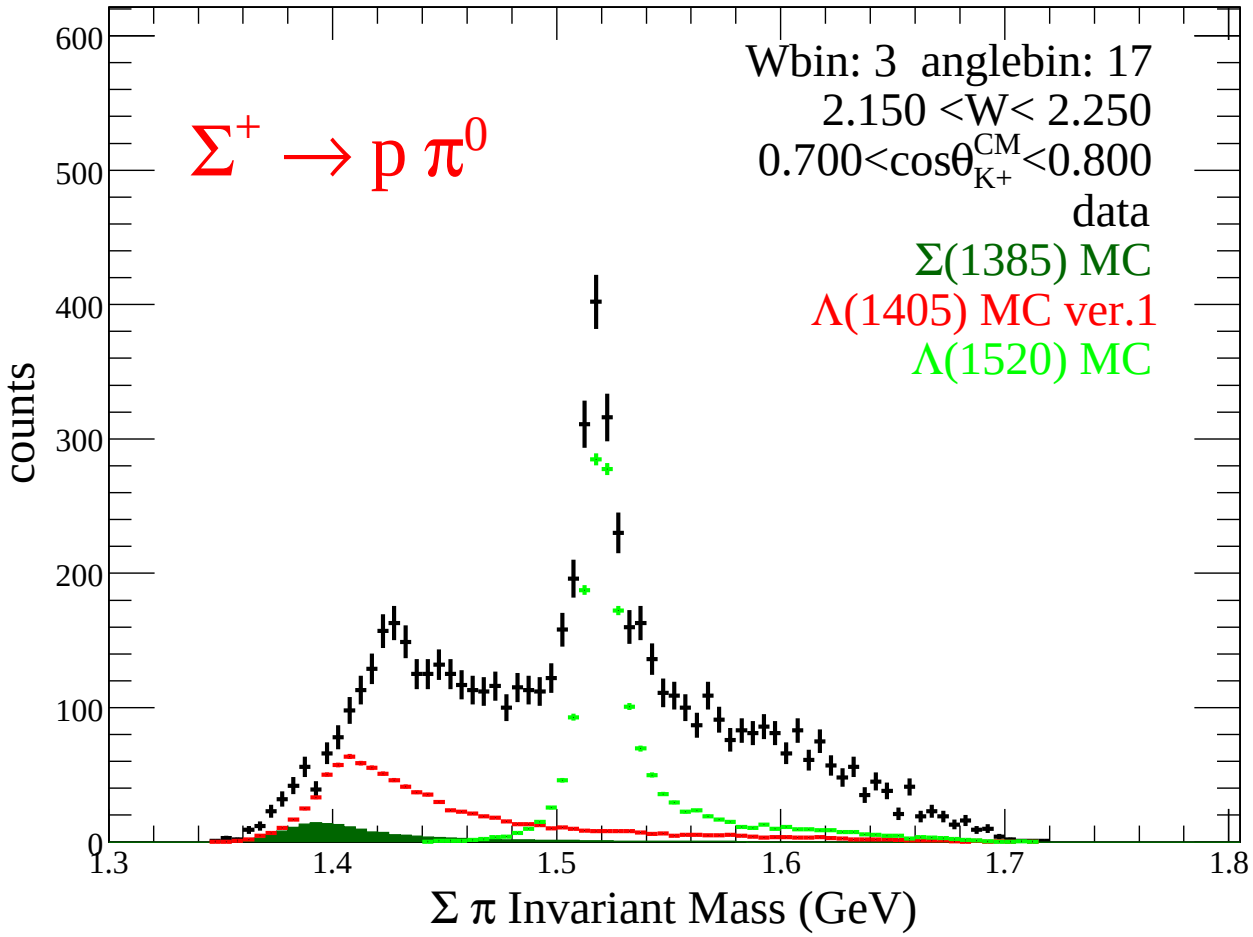

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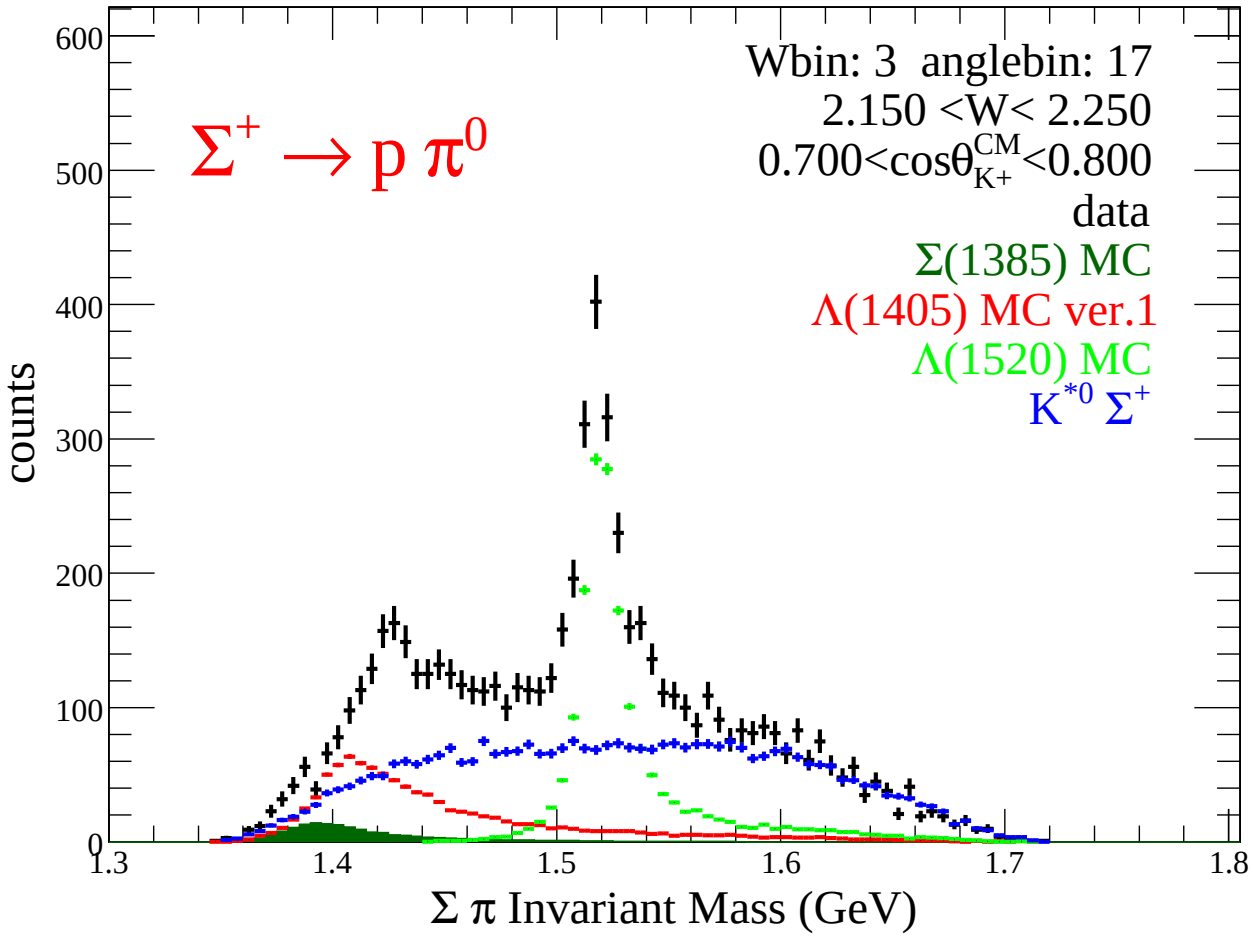

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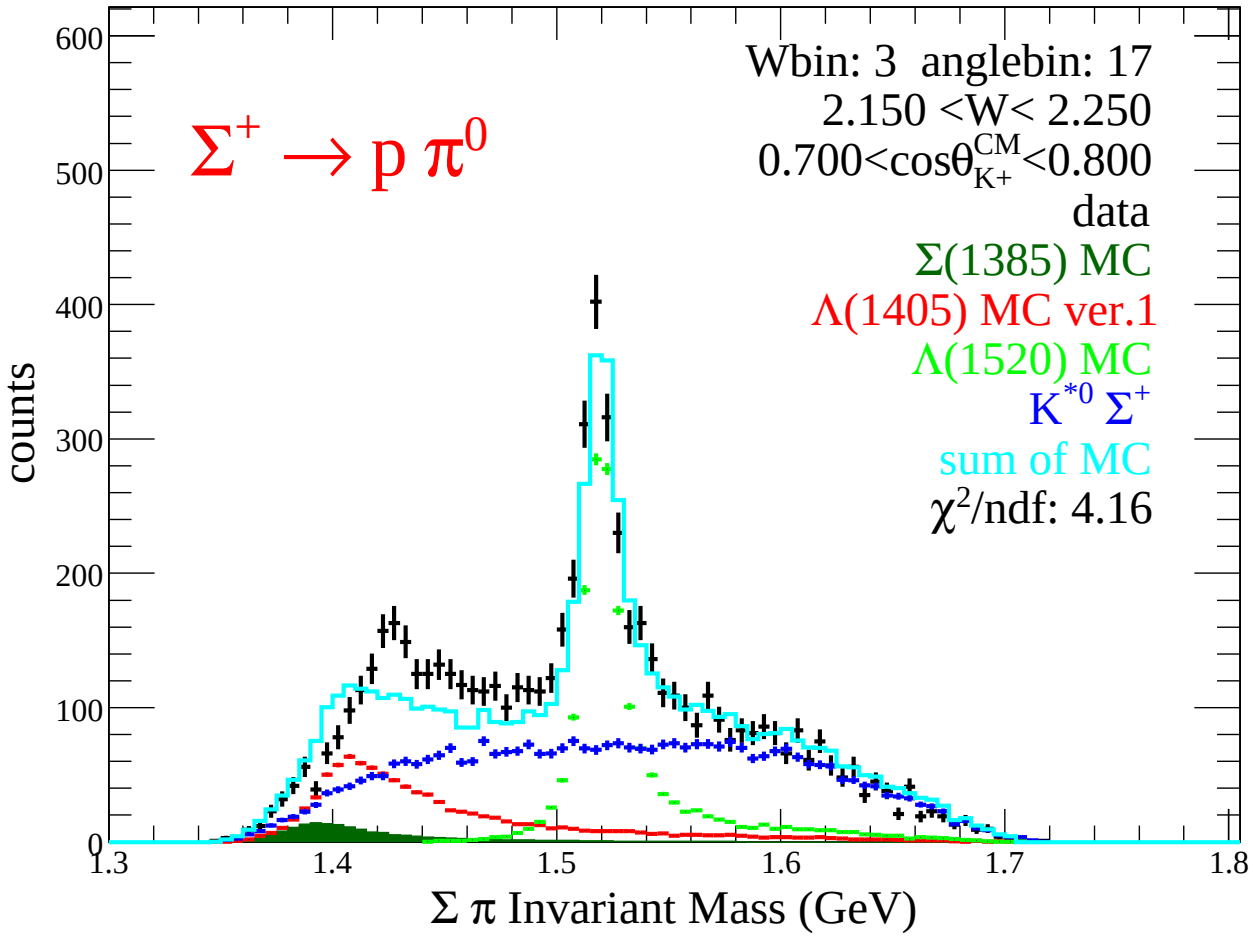

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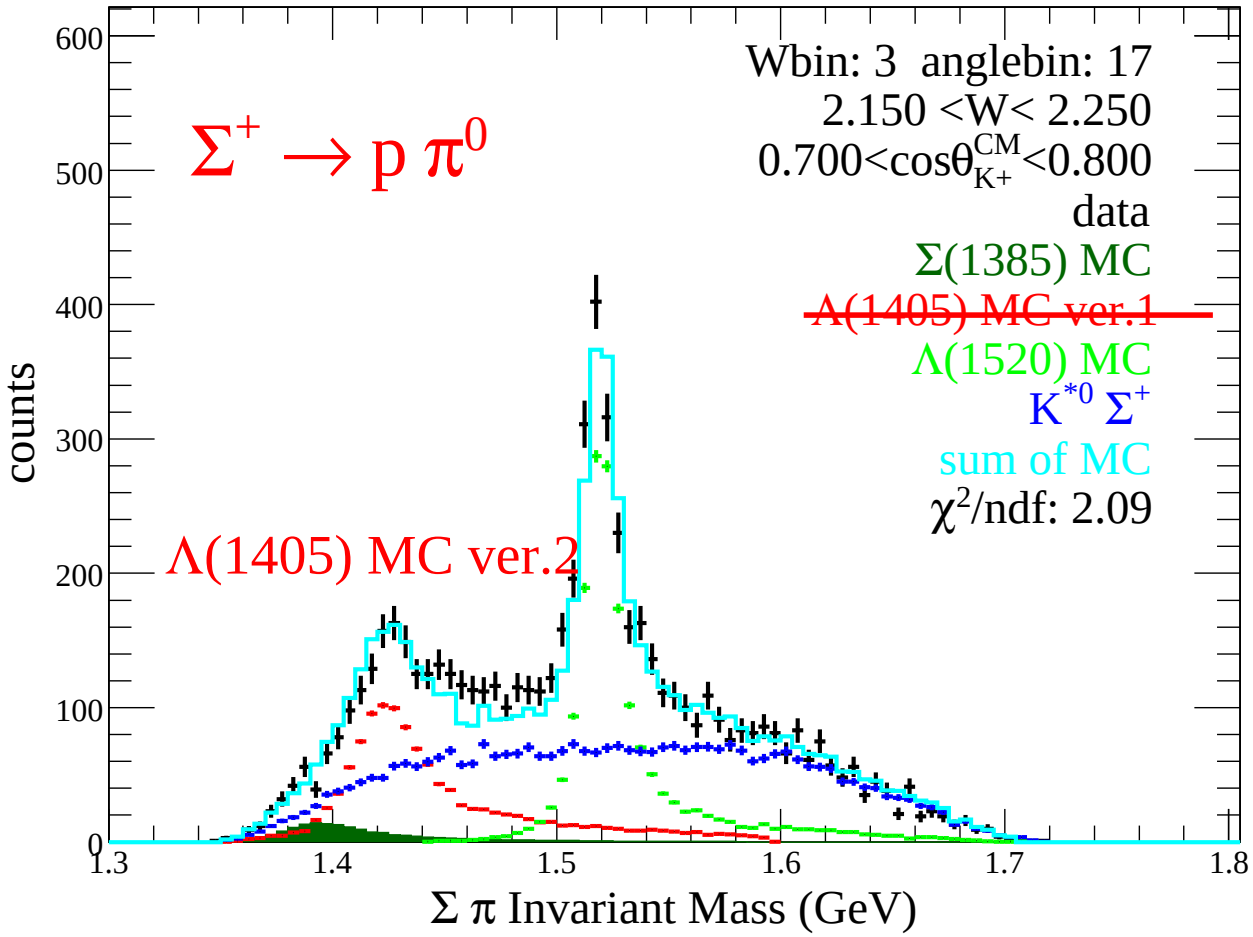

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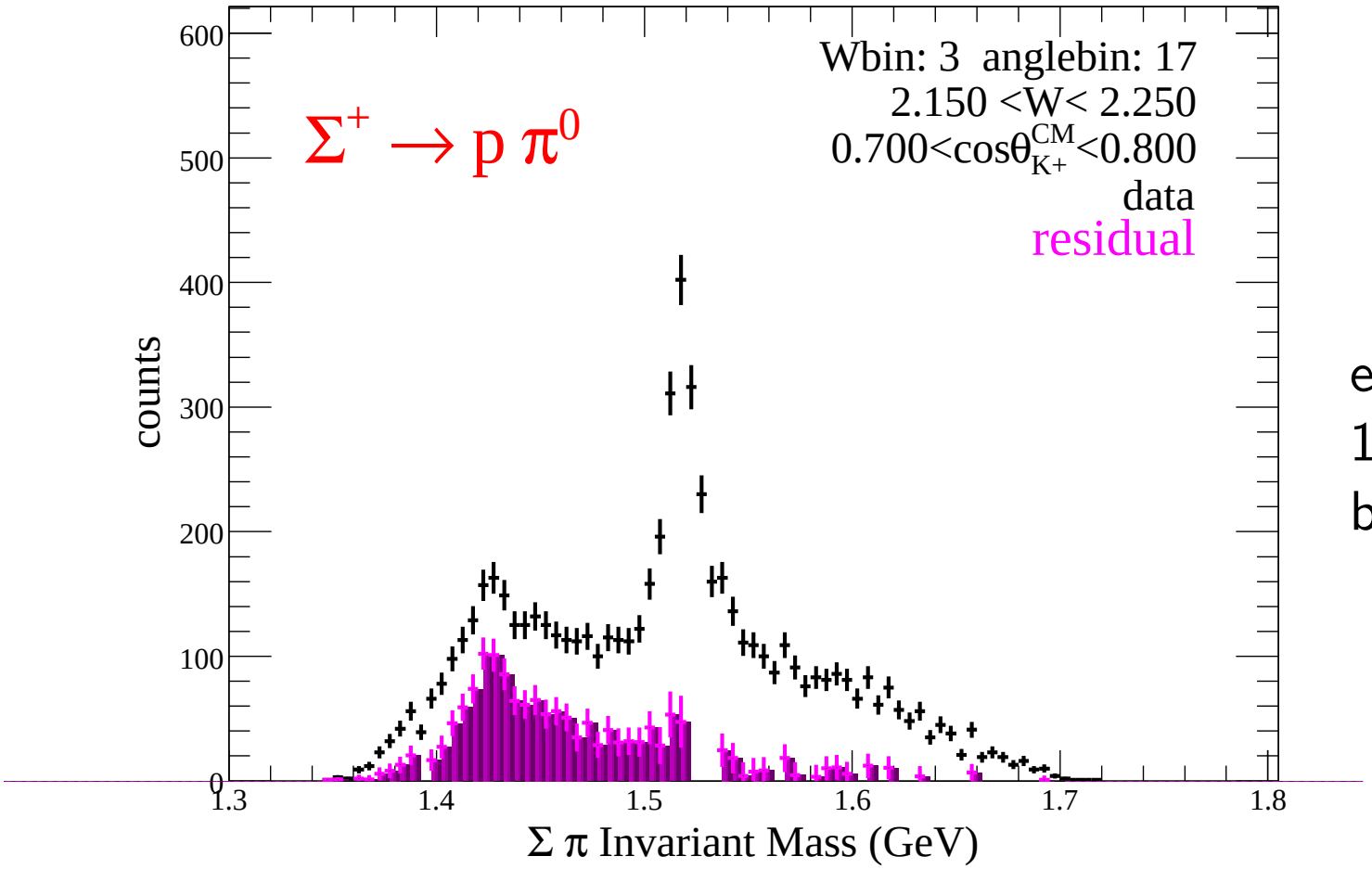

example:
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- subtract off **$\Sigma(1385)$**, **$\Lambda(1520)$**, **K^{*0}**
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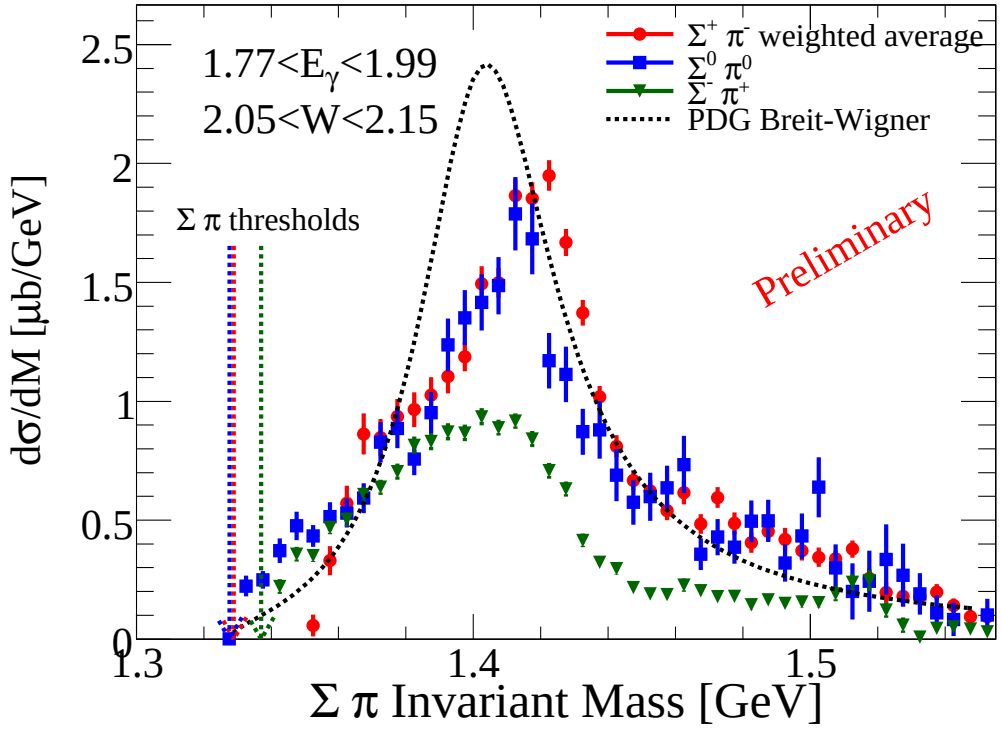
Results of Lineshape



- 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

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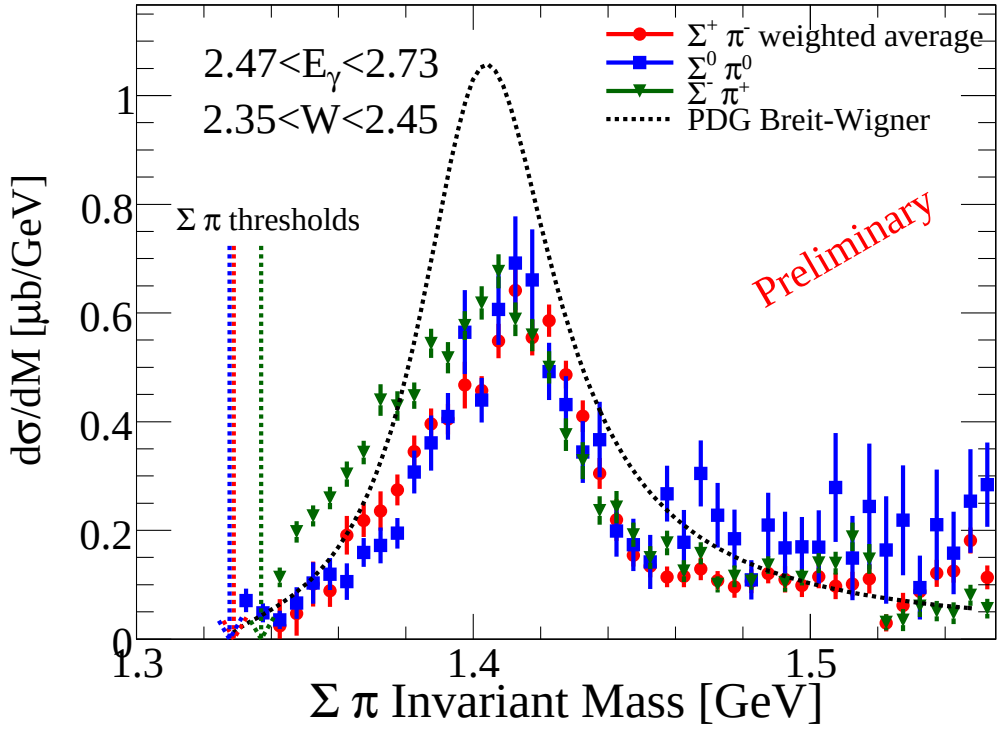

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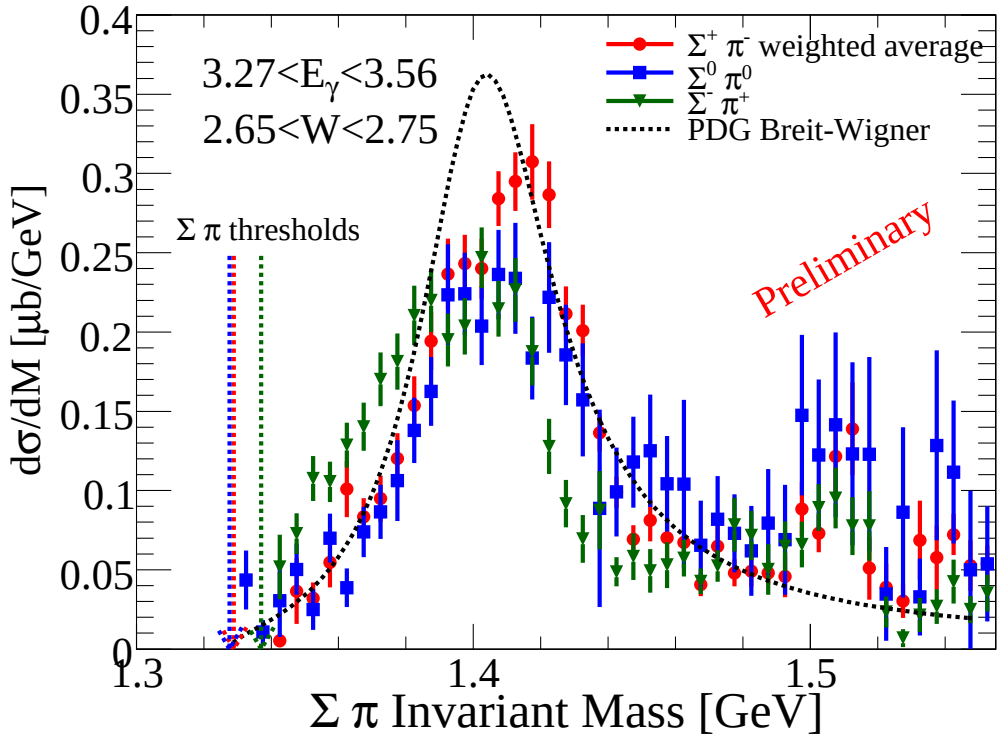

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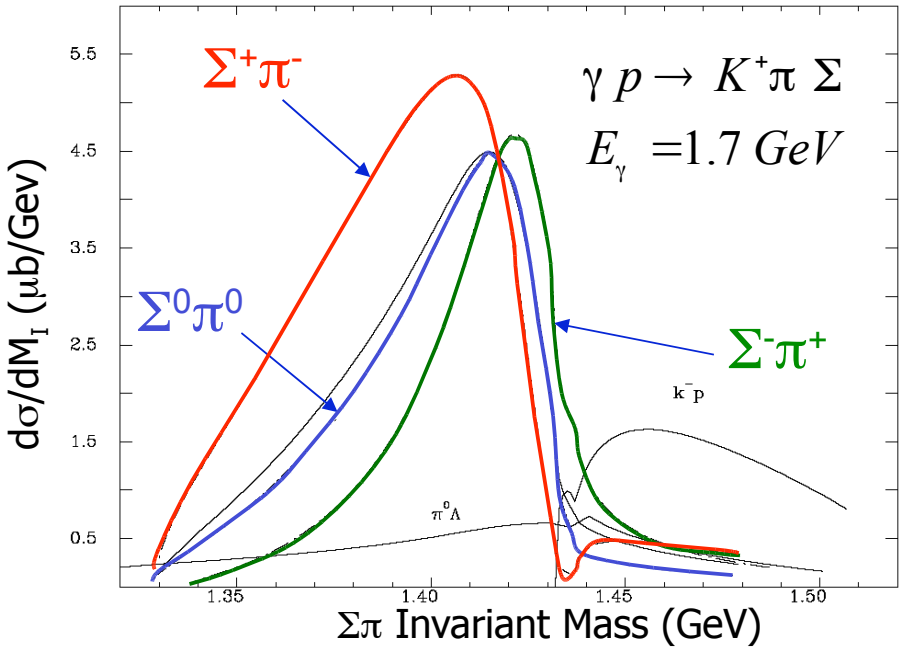
Theory Prediction From Chiral Unitary Approach



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

- $\Sigma^-\pi^+$ 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

Isospin Decomposition

- Separate $\{\Sigma^+\pi^-, \Sigma^0\pi^0, \Sigma^-\pi^+\}$ into I=0 and I=1 amplitude contributions

$$T^{(0)} \equiv \left\langle \{\Sigma\pi\}_{I=0} \,|\, \hat{T}^{(0)} \,|\, \gamma p \right\rangle$$

$$T^{(1)} \equiv \left\langle \{\Sigma\pi\}_{I=1} \,|\, \hat{T}^{(1)} \,|\, \gamma p \right\rangle$$

$$\cancel{T^{(2)} \equiv \left\langle \{\Sigma\pi\}_{I=2} \,|\, \hat{T}^{(2)} \,|\, \gamma p \right\rangle}$$

$$\left|A_{\Sigma^+\pi^-}\right|^2 = \frac{1}{3}\left|T^{(0)}\right|^2 + \frac{1}{2}\left|T^{(1)}\right|^2 - \frac{2}{\sqrt{6}}\left|T^{(0)}\right|\left|T^{(1)}\right|\cos\Delta\phi_{01}$$

$$\left|A_{\Sigma^0\pi^0}\right|^2 = \frac{1}{3}\left|T^{(0)}\right|^2$$

$$\left|A_{\Sigma^-\pi^+}\right|^2 = \frac{1}{3}\left|T^{(0)}\right|^2 + \frac{1}{2}\left|T^{(1)}\right|^2 + \frac{2}{\sqrt{6}}\left|T^{(0)}\right|\left|T^{(1)}\right|\cos\Delta\phi_{01}$$

$$\frac{d\sigma}{dm} = \frac{(\hbar c)^2}{16\pi}\frac{\alpha}{W^2}\frac{p_f(m)}{p_i(W)}\left|(I_{3\Sigma}, I_{3\pi}\,|\,0,0)T^{(0)} + (I_{3\Sigma}, I_{3\pi}\,|\,1,0)T^{(1)} + \cancel{(I_{3\Sigma}, I_{3\pi}\,|\,2,0)T^{(2)}}\right|^2$$

$$T^{(0,1,2)}(m) = g^{(0,1,2)}\frac{m\Gamma_0\dfrac{\rho}{\rho_0}}{(m_0^2 - m^2) - im\Gamma(q)}$$

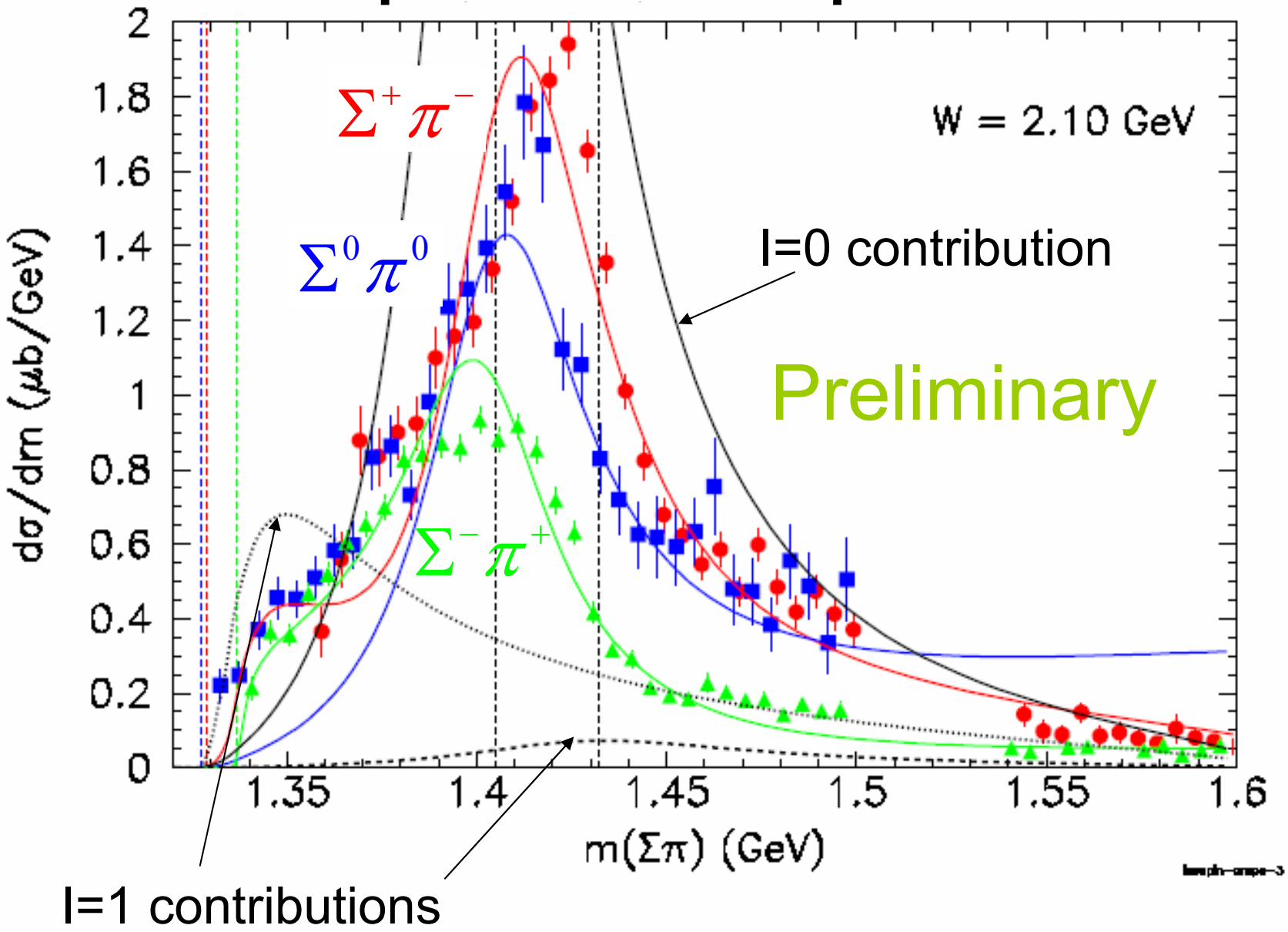
$$\rho = 2q/m$$

$\Sigma\,\pi$ phase space factor

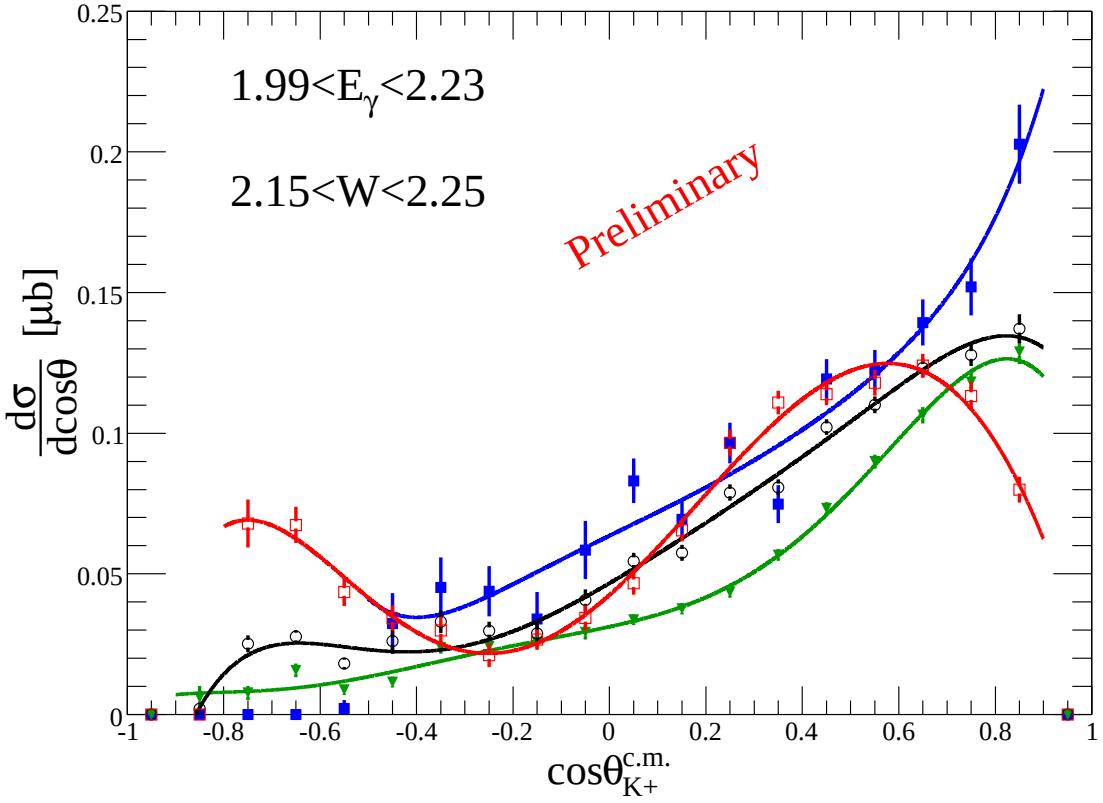
$$\Gamma(m) = \Gamma_0\frac{q(m)}{q_0}$$

Mass-dependent width for relativistic Breit Wigner

Isospin Decomposition



Λ(1405) Differential Cross Section Results



$\Sigma^+\pi^-$

$\Sigma^0\pi^0$

$\Sigma^-\pi^+$

total/3

- lines are fits with 6rd 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

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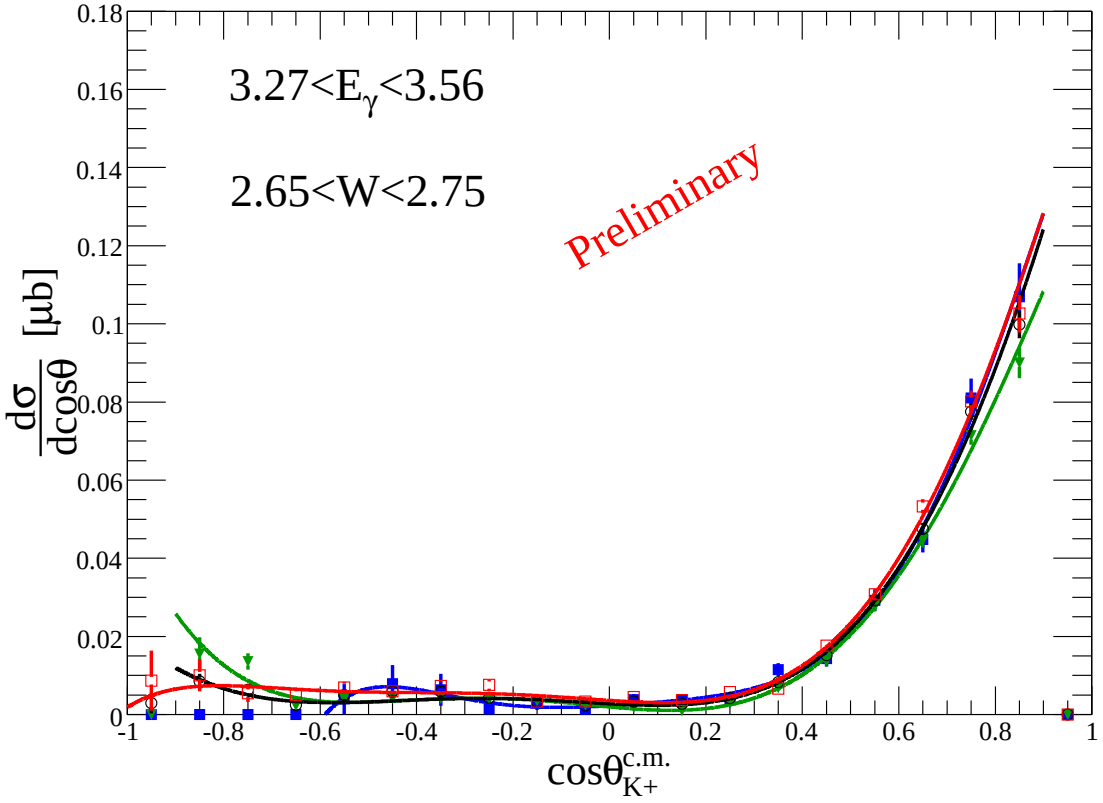
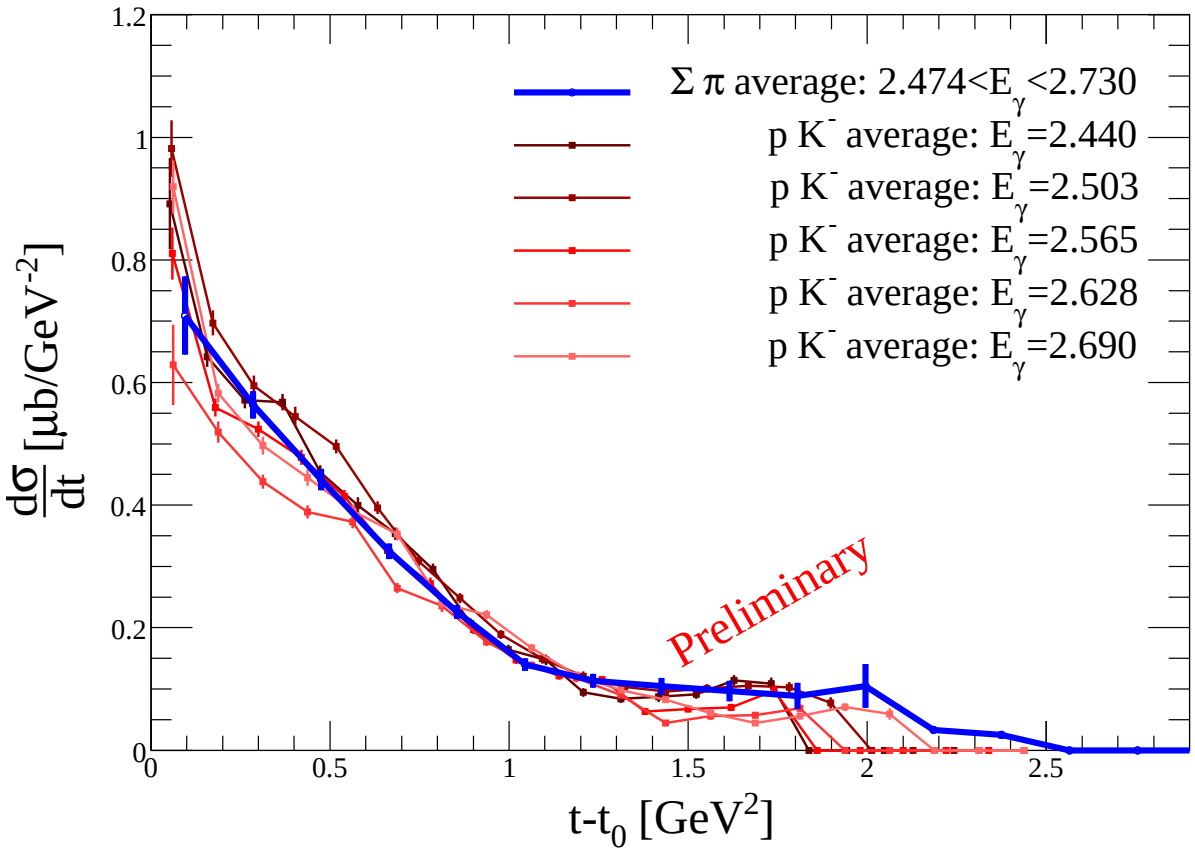


$\Sigma^+\pi^-$
$\Sigma^0\pi^0$
$\Sigma^-\pi^+$
total/3

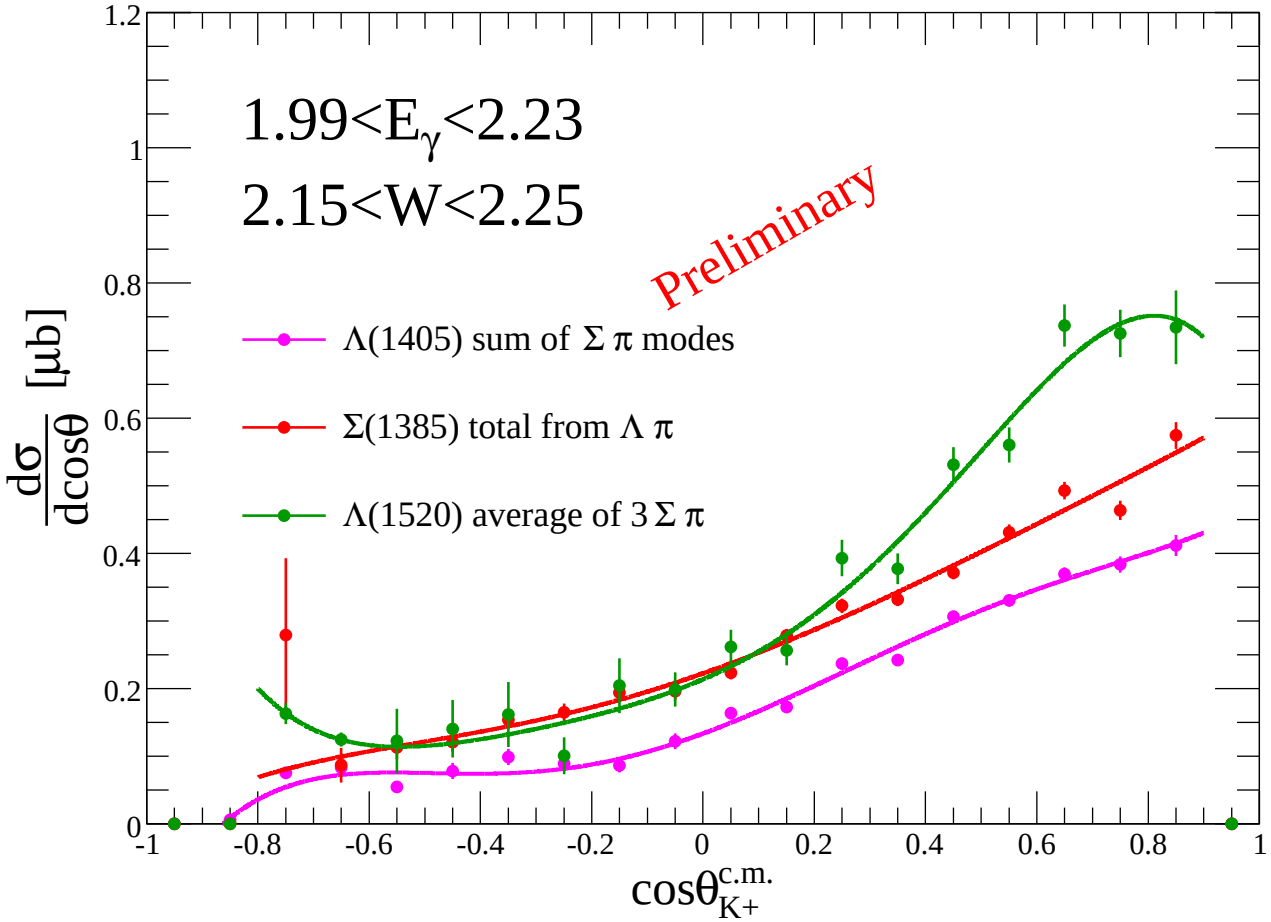
- lines are fits with 6rd order Legendre polynomials
- clear turnover of $\Sigma^+\pi^-$ channel at forward angles
- theory: contact term only, no angular dependence for interference
- experiment: able to see strong **isospin** AND **angular** interference effect

Λ(1520) Differential Cross Section Comparison



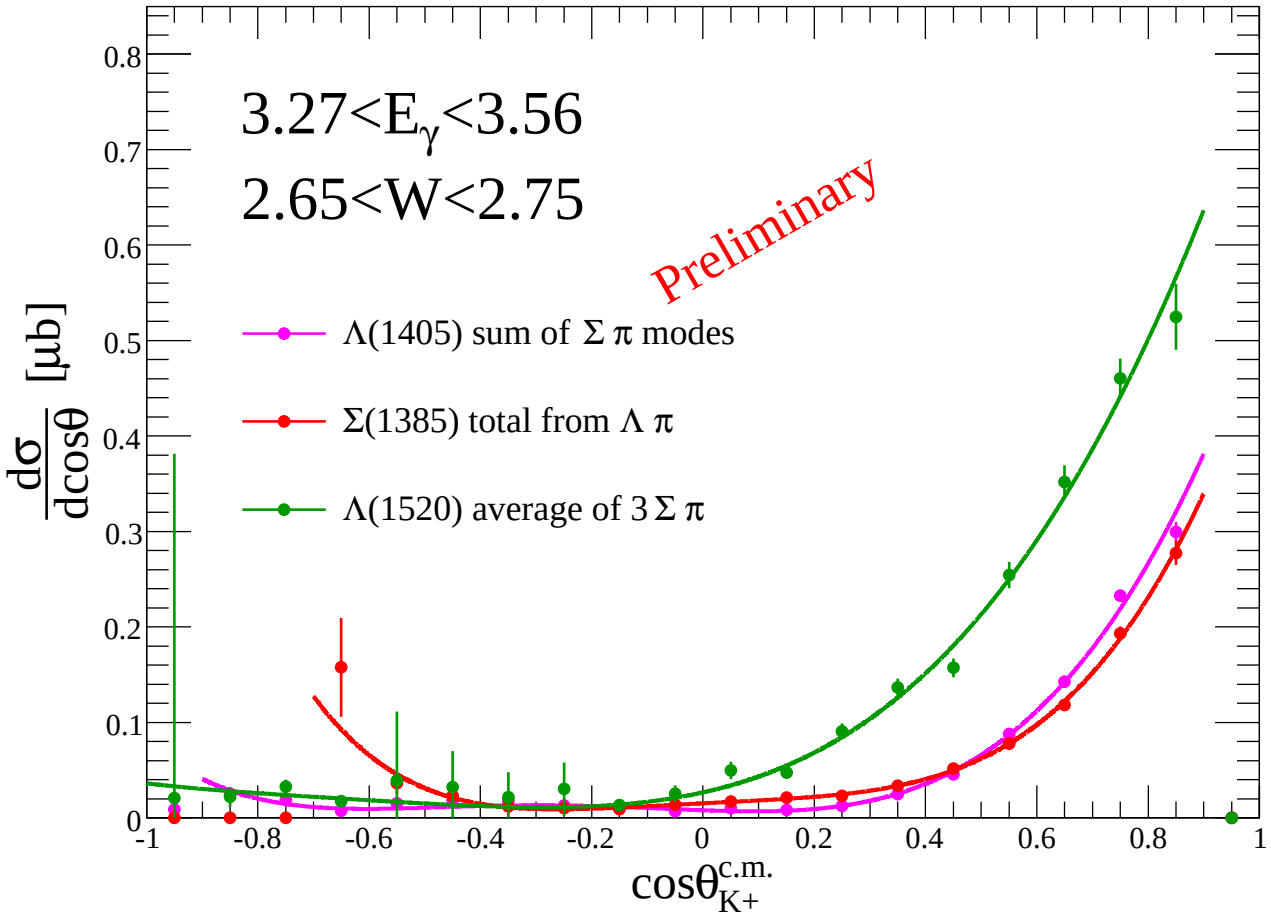
- binning is in $t - t_{\min}$
- good agreement with pK^- channel from CLAS (unpublished) — data provided by de Vita *et al.* (INFN Genova)

Comparison of Σ(1385)/Λ(1405)/Λ(1520) Cross Sections



- lines are fits with 5th order Legendre polynomials

Comparison of Σ(1385)/Λ(1405)/Λ(1520) Cross Sections



- lines are fits with 5th order Legendre polynomials

Conclusion

- **difference in lineshapes** observed
- **difference in** $\mathbf{d\sigma/dcos\theta^{c.m.}_{K^+}}$ **behavior** observed
- doing our own isospin decomposition of resonance amplitudes
- systematics under study

strong dynamical effects being observed for the Λ(1405)

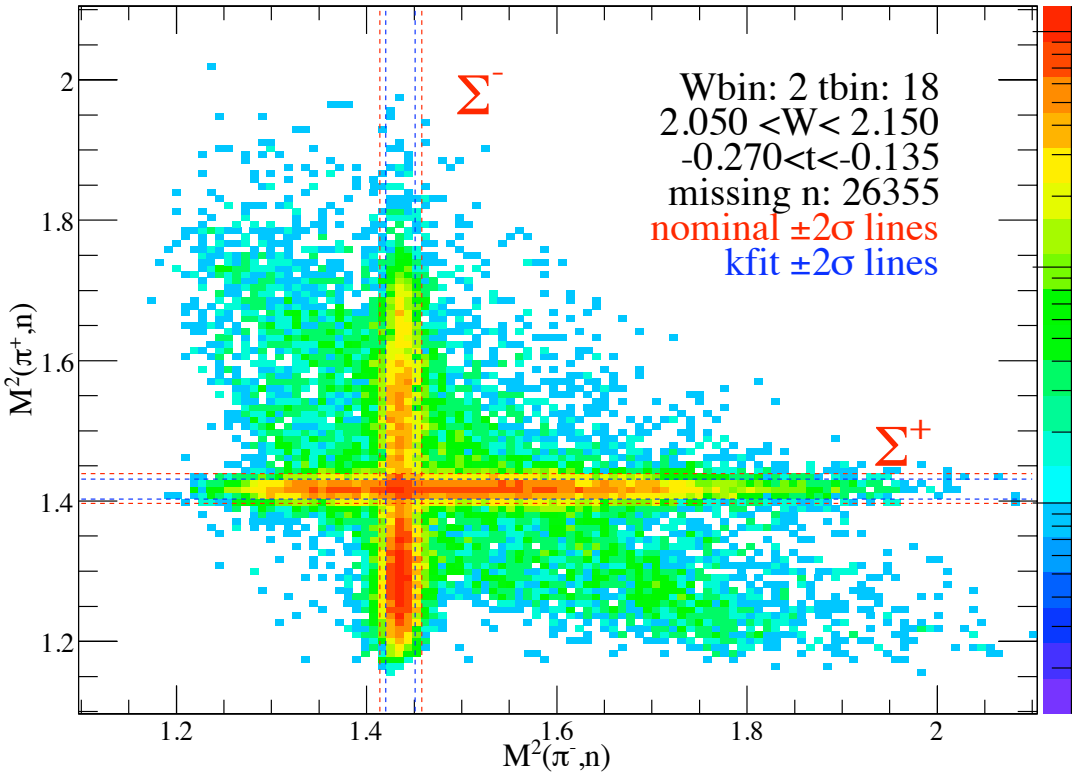
hoping to finalize analysis soon

effect of kinematic fit on resolution

example in 1 bin:

- neutron combined with $\pi^{\pm}$ reconstructs $\Sigma^{\pm}$
- project on each axis, select $\pm 2\sigma$, exclude other hyperon
- diagonal band (K^0 from $\pi^+\pi^-$) is also excluded

(without kinematic fit)



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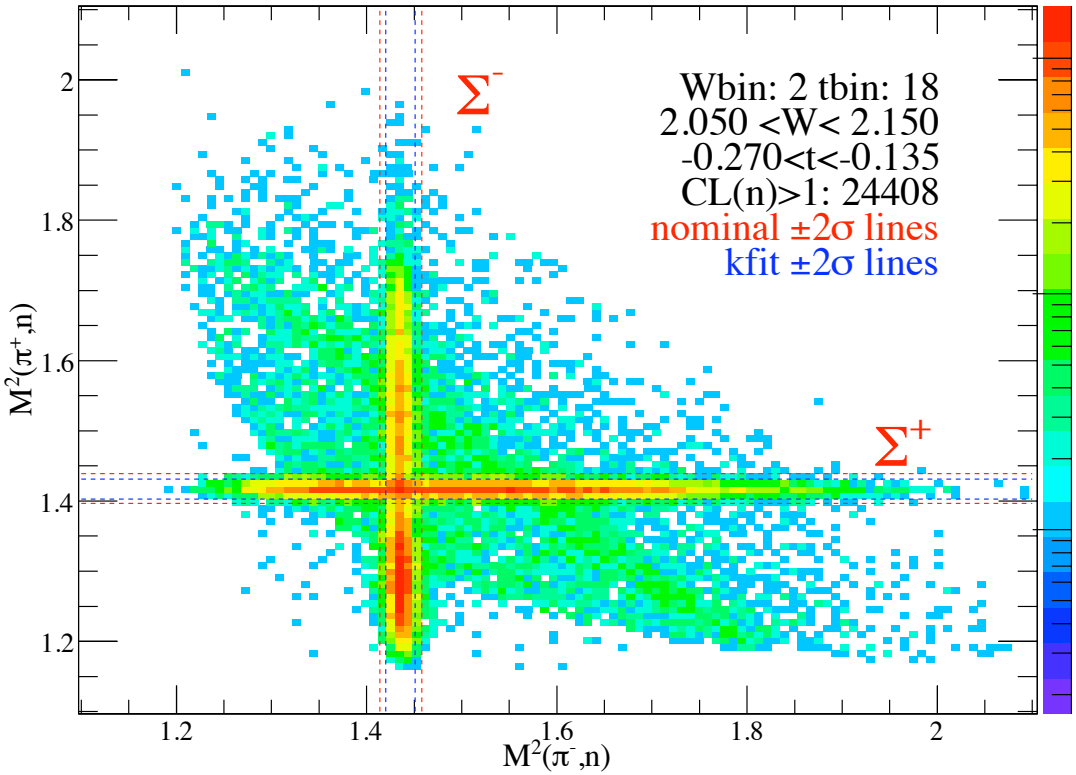
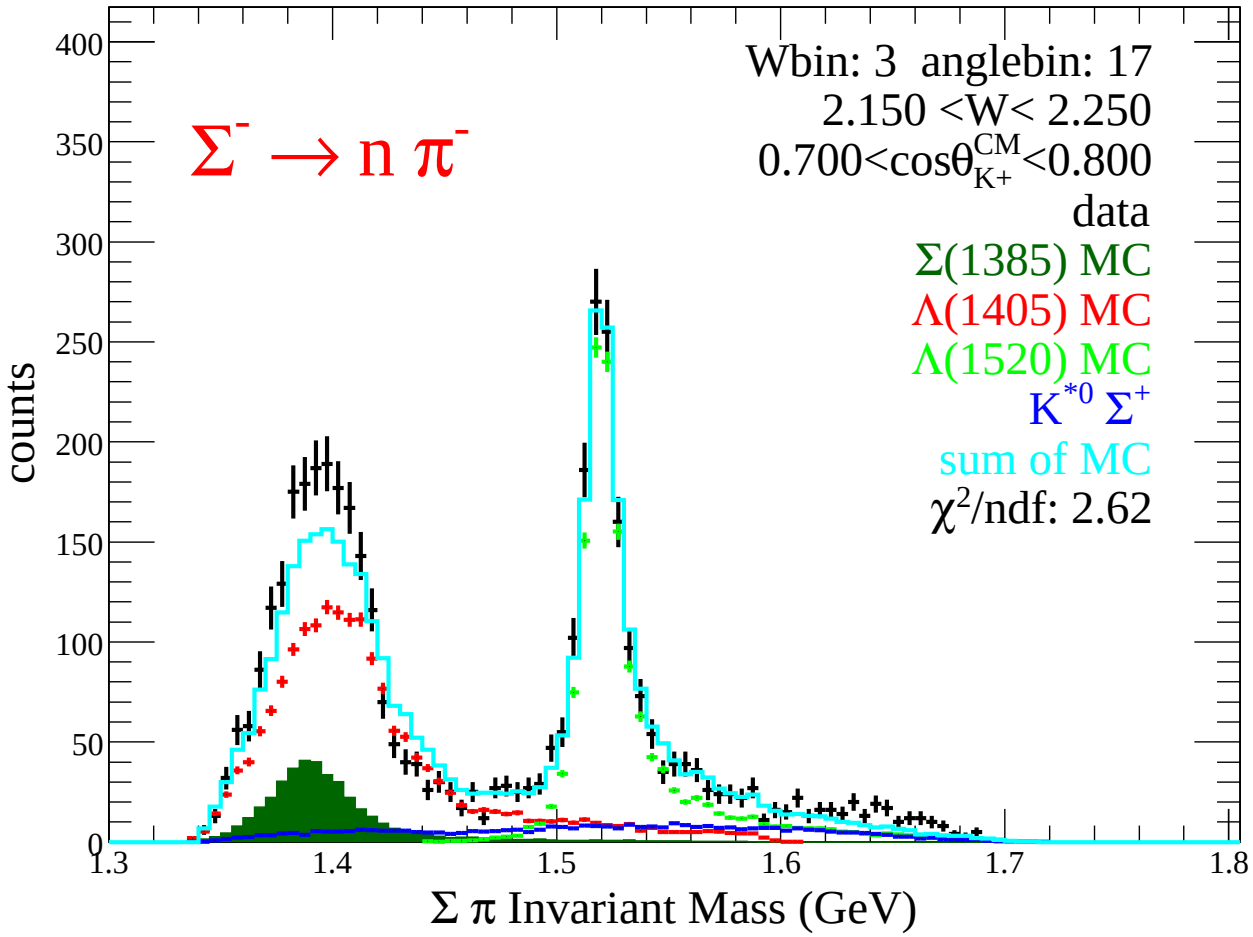


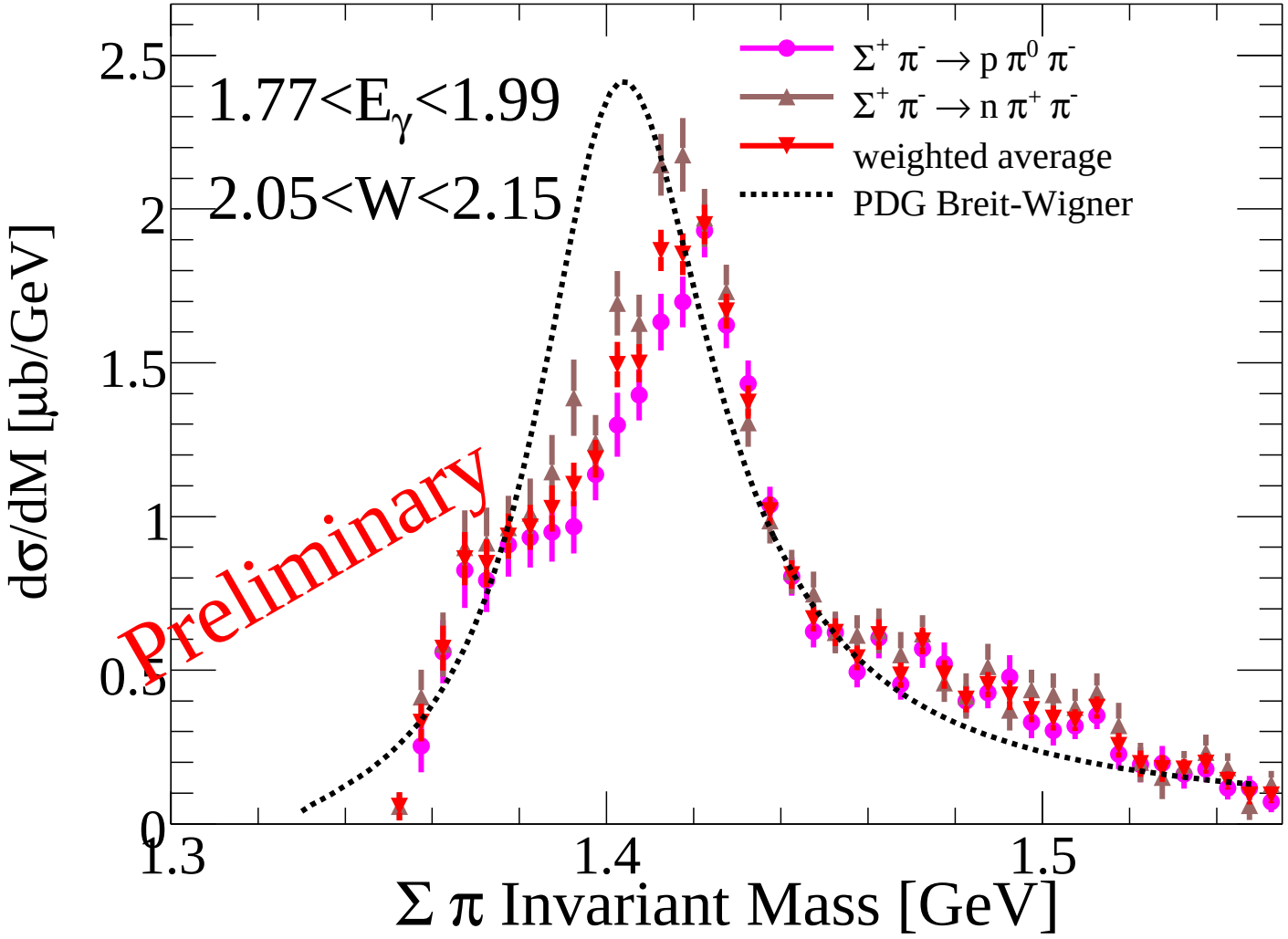
Fit to Lineshape With MC Templates



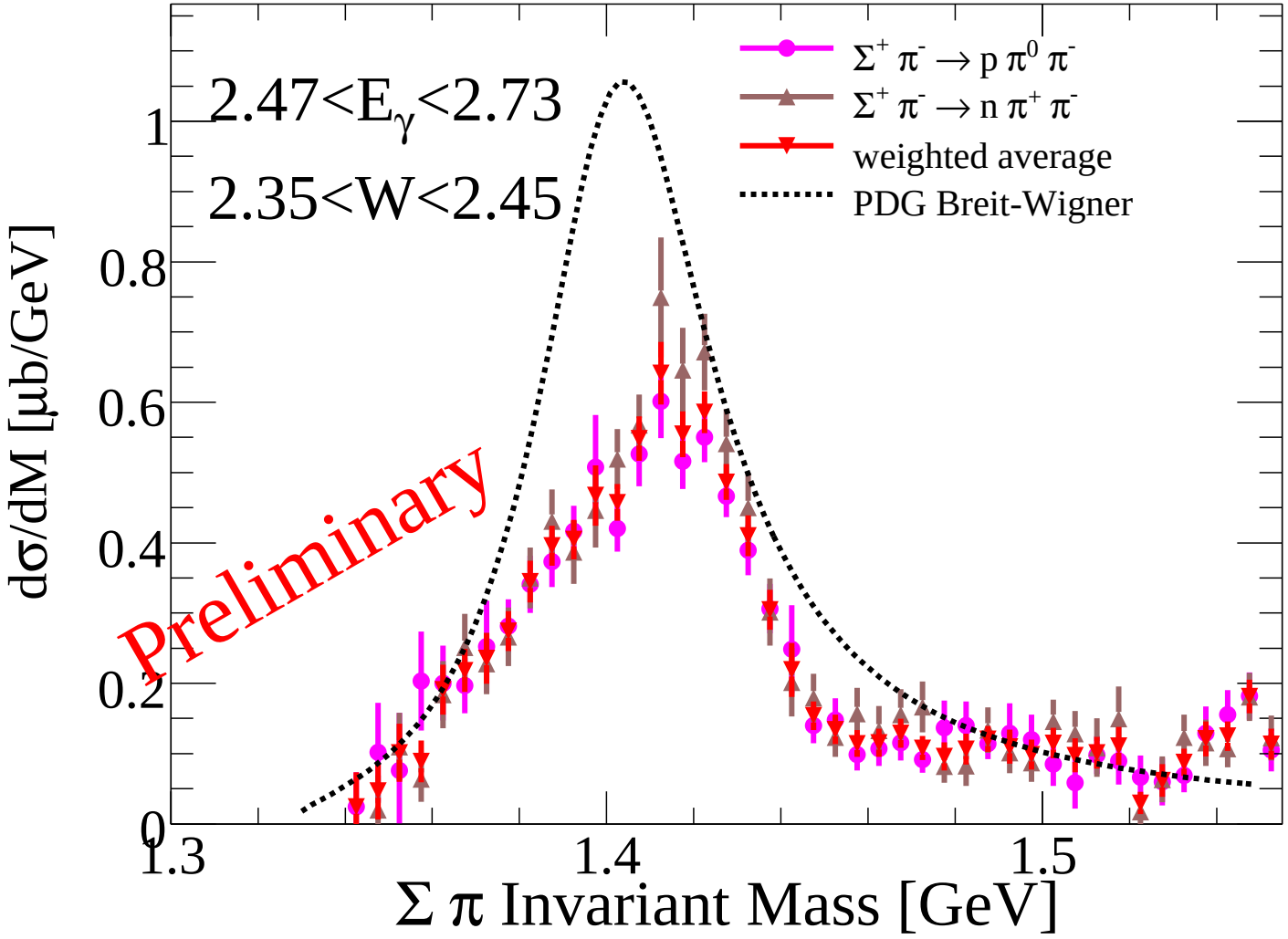
example:
1 energy and angle bin out of $\sim$ 150

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

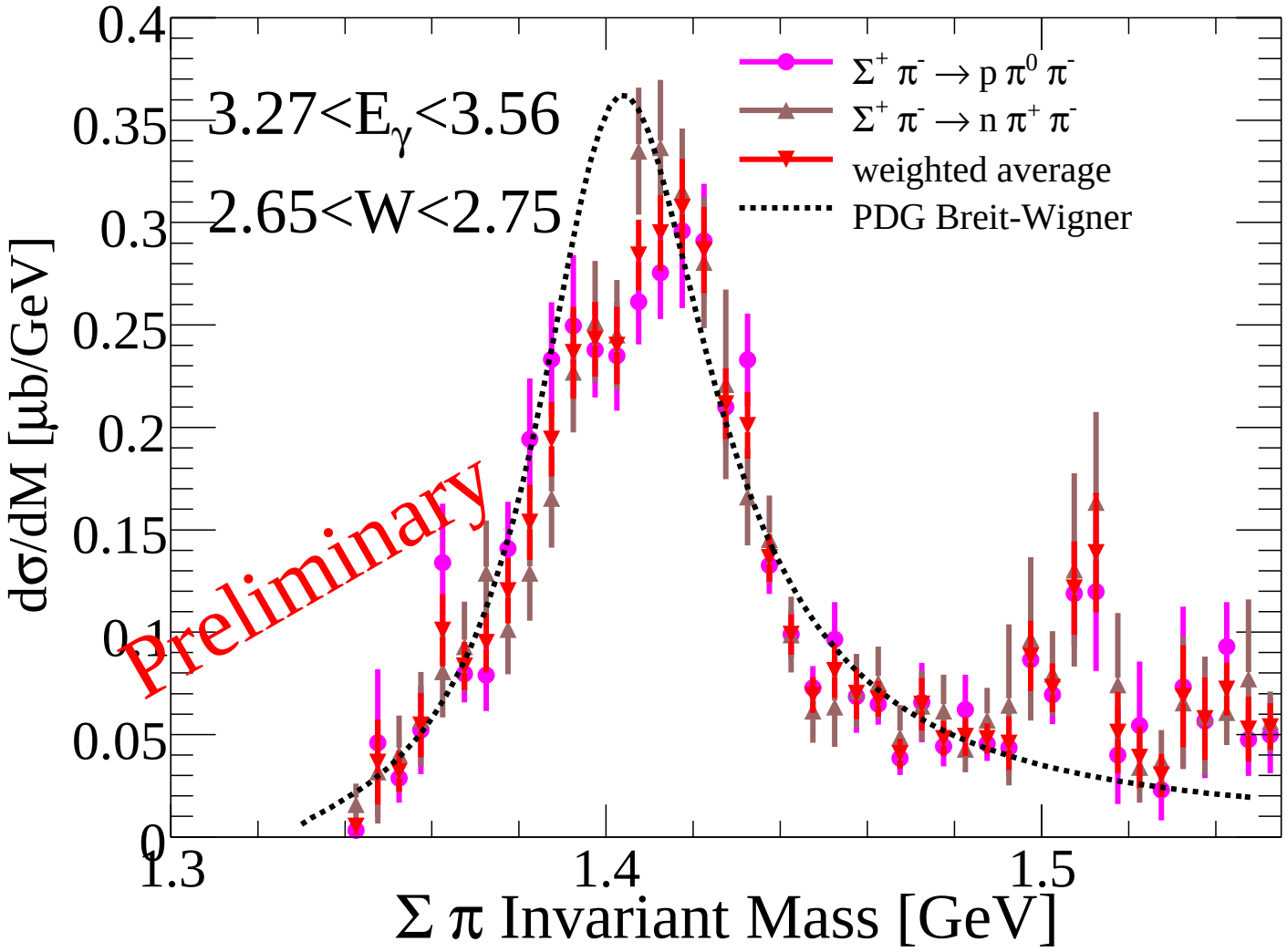
Comparison of Lineshapes for Two Σ^+Channels



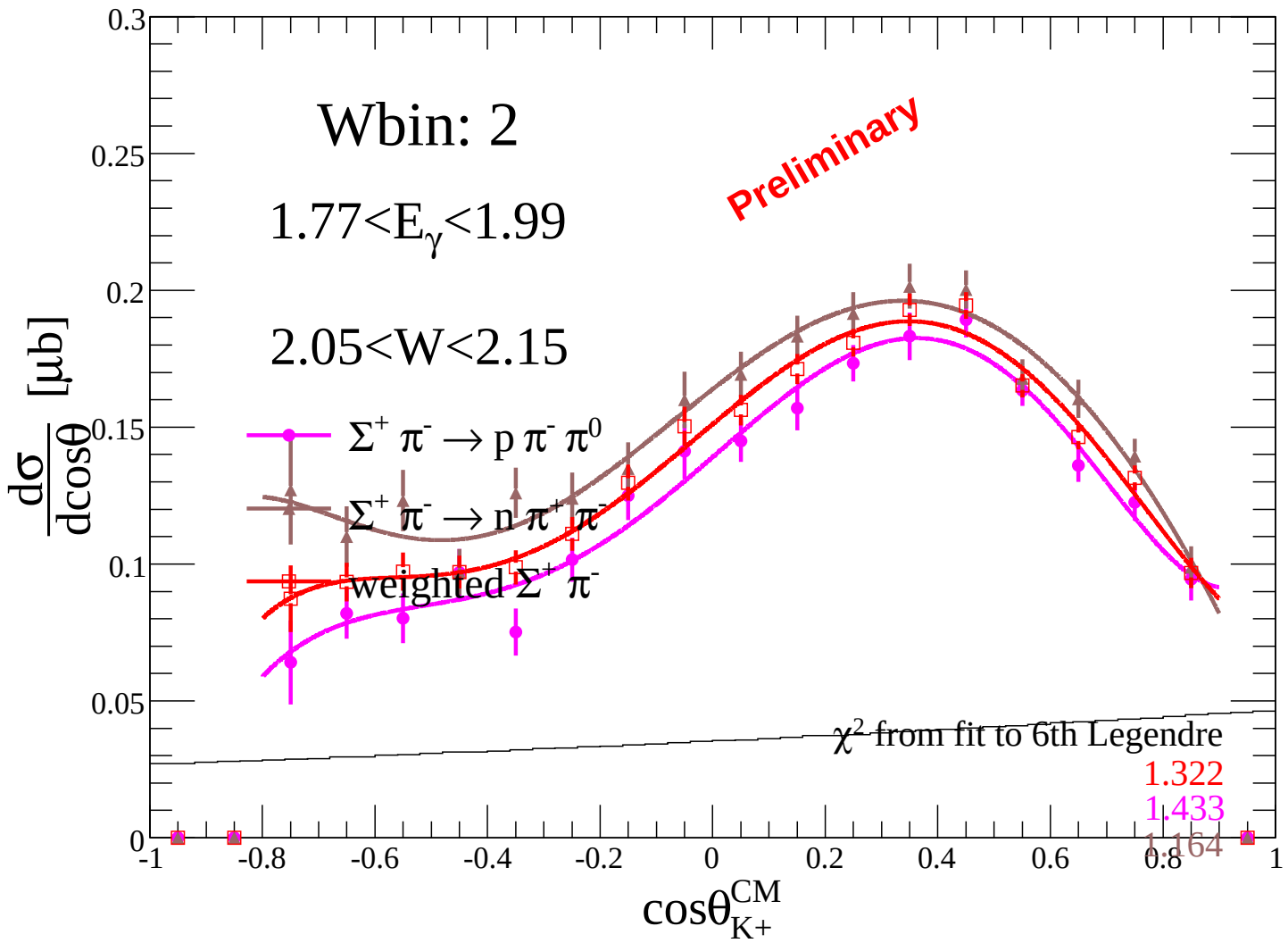
Comparison of Lineshapes for Two Σ^+Channels



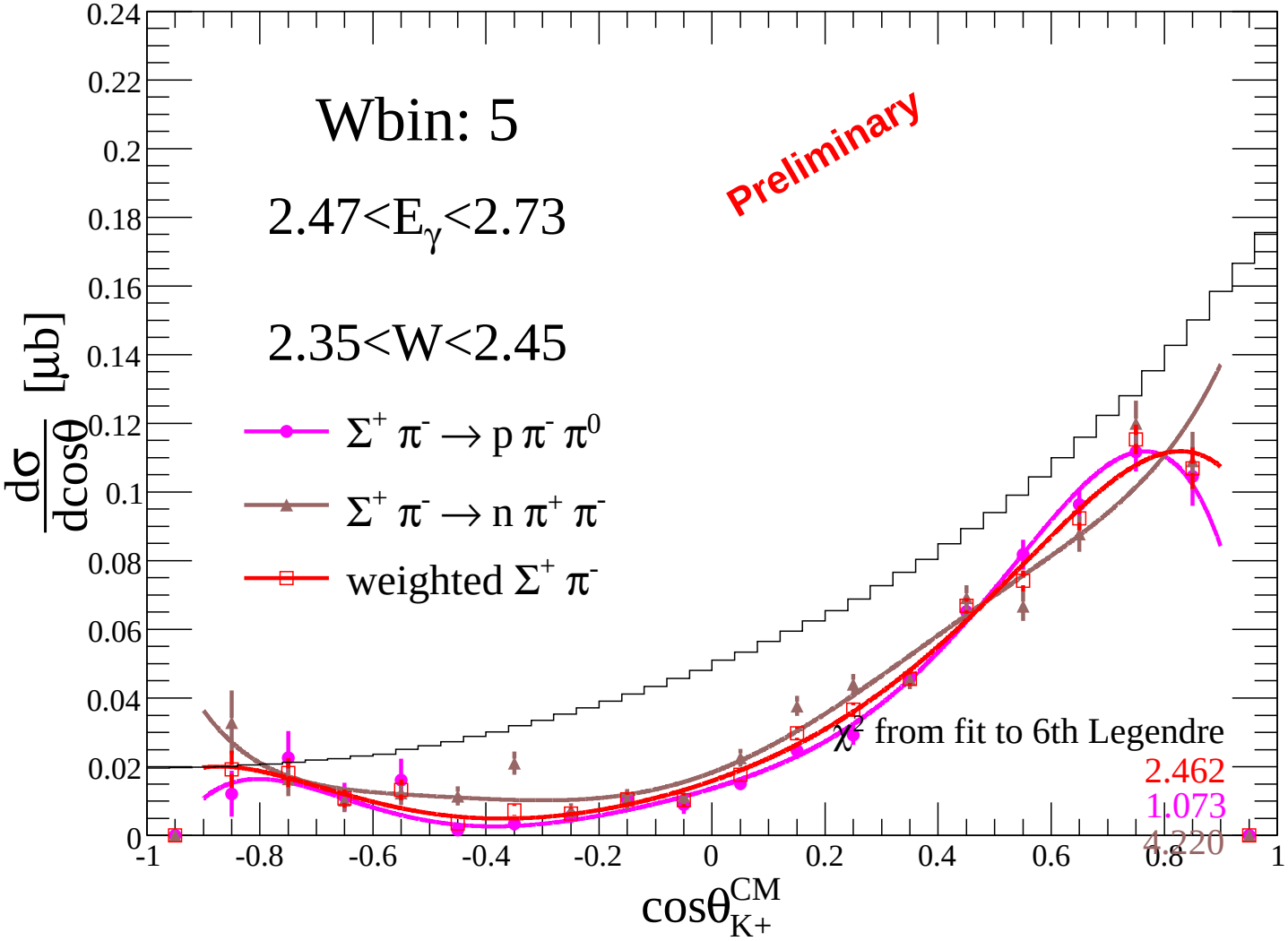
Comparison of Lineshapes for Two Σ^+Channels



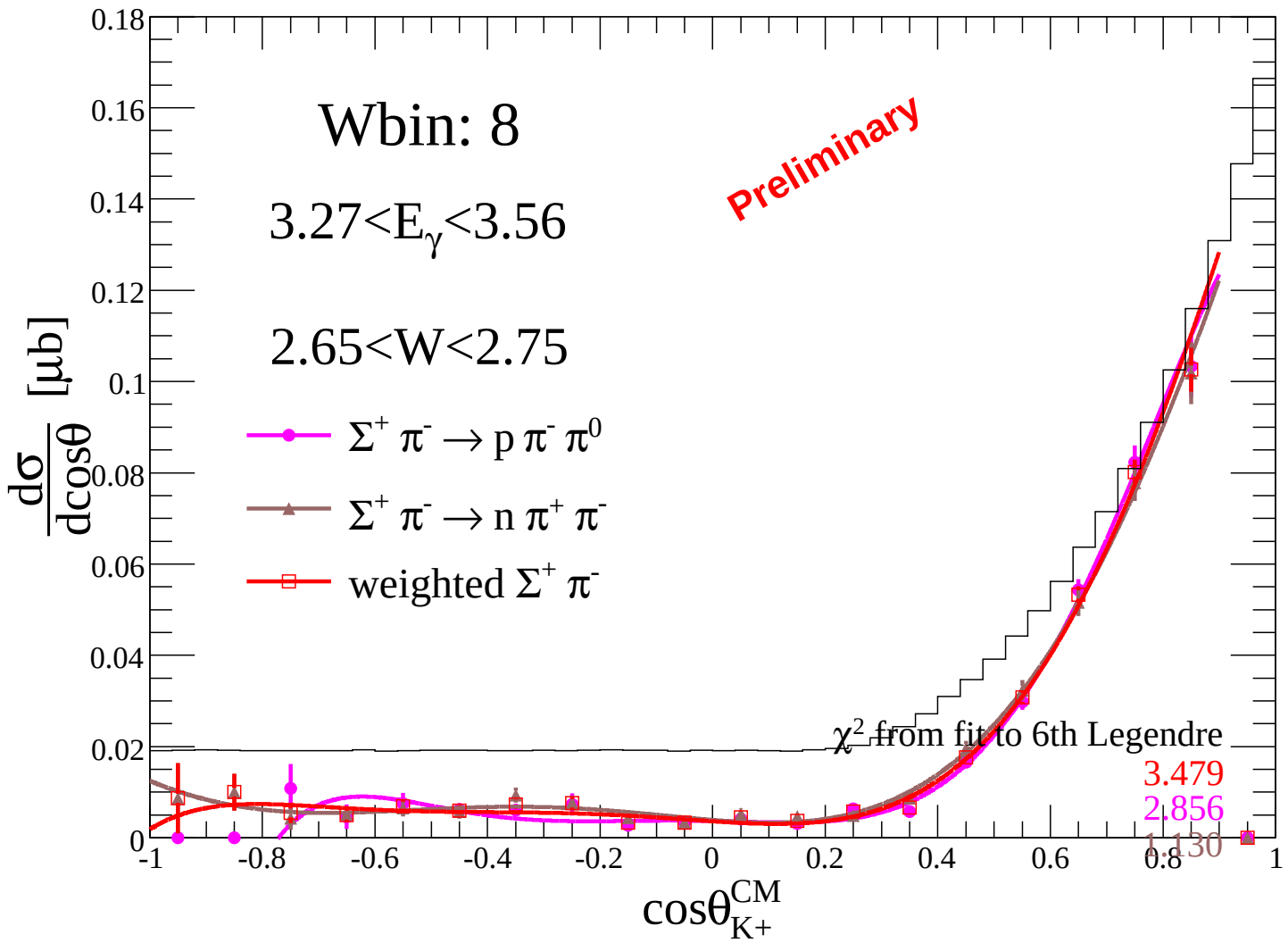
Λ(1405) Comparison of Two Σ^+Channels



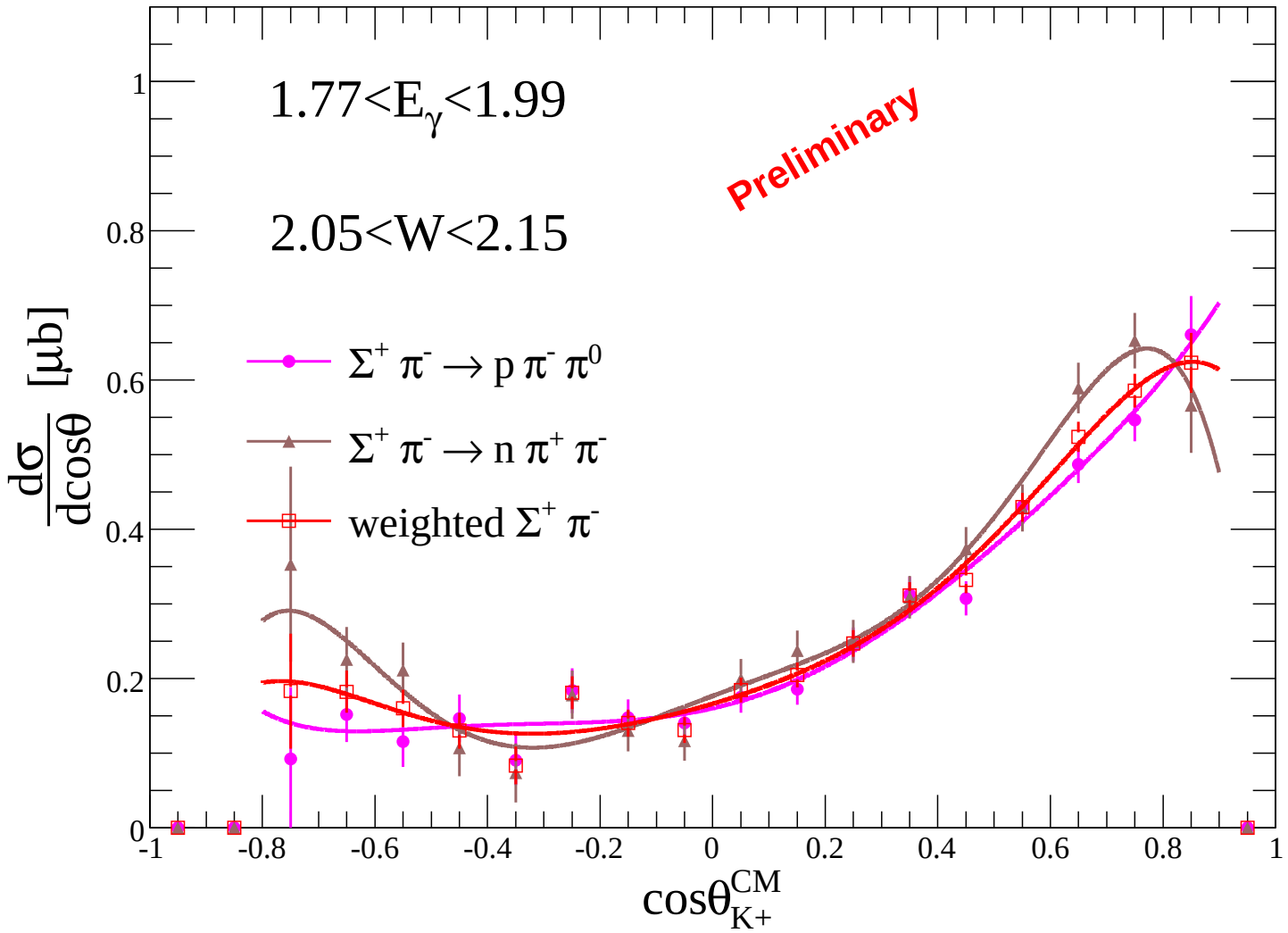
Λ(1405) Comparison of Two Σ^+Channels



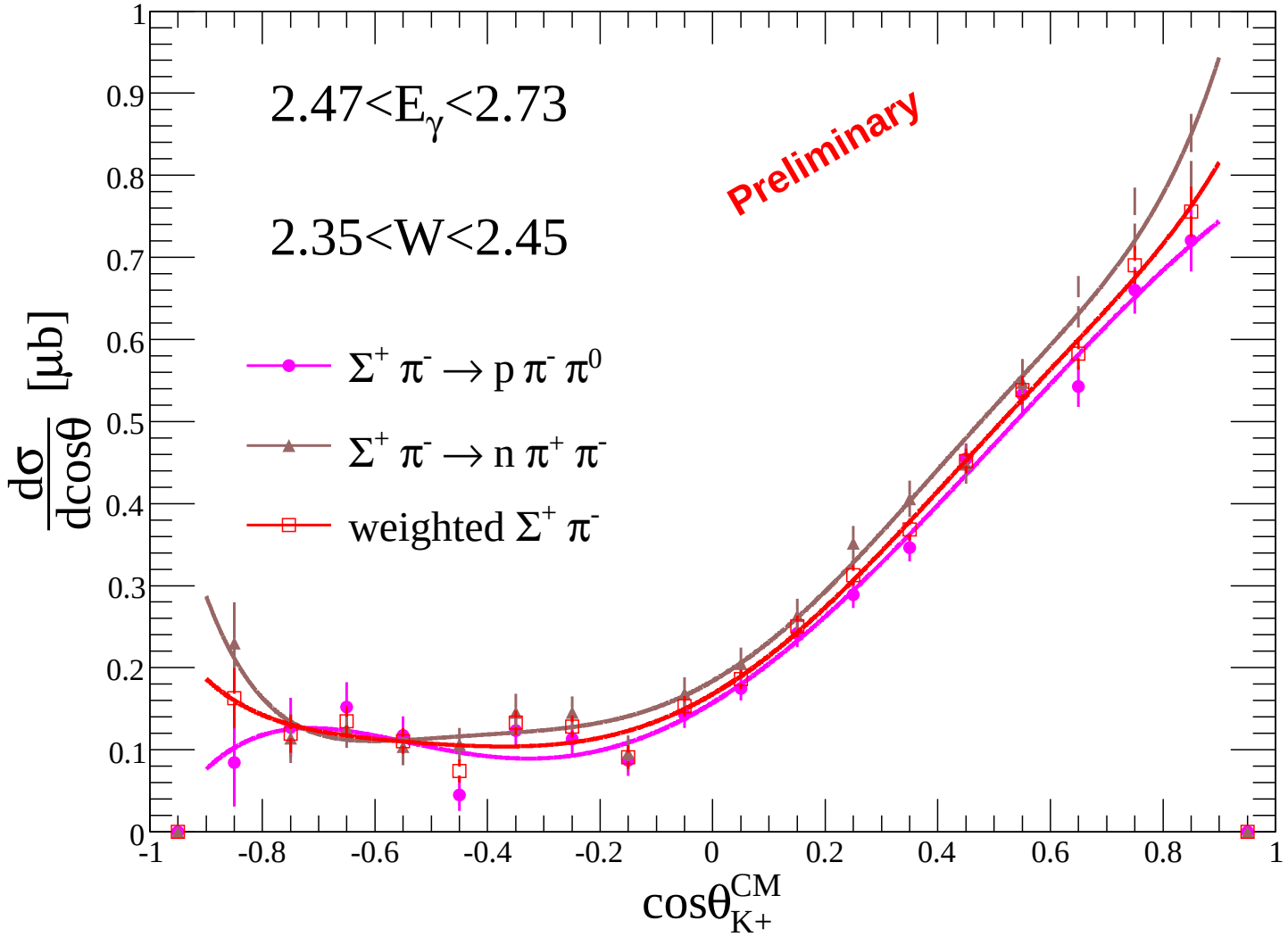
Λ(1405) Comparison of Two Σ^+Channels



Λ(1520) Comparison of Two Σ^+Channels



Λ(1520) Comparison of Two Σ^+Channels



Λ(1520) Comparison of Two Σ^+Channels