Photoproduction of the Λ(1405) at CLAS and Future Spectroscopy Studies at GlueX

Kei Moriya[1]

1. kmoriya@indiana.edu

INDIANA UNIVERSITY

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Outline

CLAS@6GeV

- Measurements of the Λ(1405) line shape in photoproduction
- Measurements of the cross sections of Λ(1405), Σ(1385), Λ(1520)

GlueX@12GeV

- Prospects of studies with GlueX
  - exotic mesons
  - Ξ baryons
  - further searches

What is the $\Lambda(1405)$?

- State known since 1950's[1]
- Not known where it belongs in spectrum - CQM does not predict the mass correctly[2]
- Decays to $\Sigma\pi$: "line shape" = invariant mass spectrum is not a simple Breit-Wigner form
- Mass is just below $N\bar{K}$ threshold, but strongly couples to $N\bar{K}$ - why?

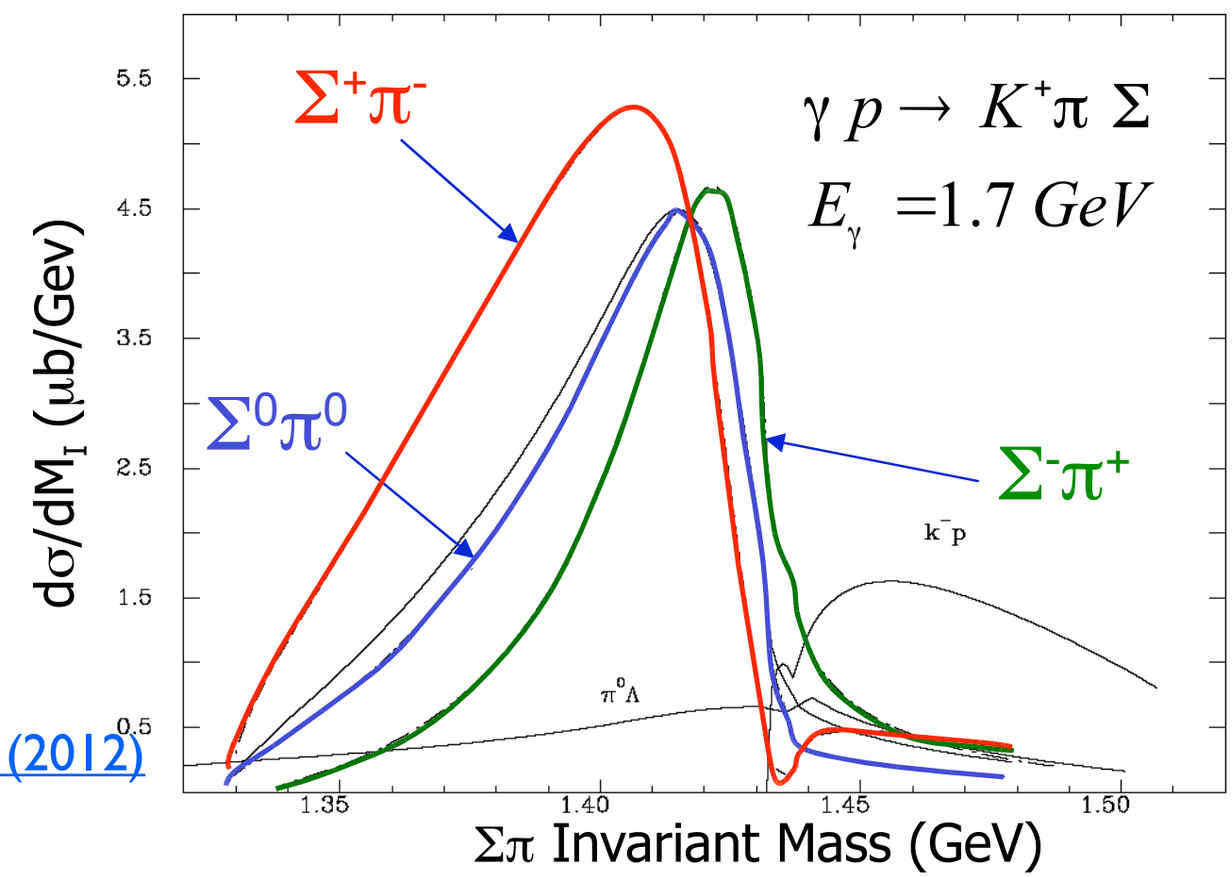
What are the dynamics of the $\Lambda(1405)$?

1. Dalitz, Tuan, Ann. Phys. 8, 100 (1959), Ann. Phys. 10, 307 (1960)
2. Isgur, Karl, PRD 18, 4187 (1978)

Line shape of Λ(1405)

- Chiral Unitary Theory (χUT) predicted the line shape of the Λ(1405)→Σπ in photoproduction [1]
- Interference with I=1 amplitude causes line shape to be different for each Σπ channel
- "Dynamically generated" resonance? [2]
- Reaction:

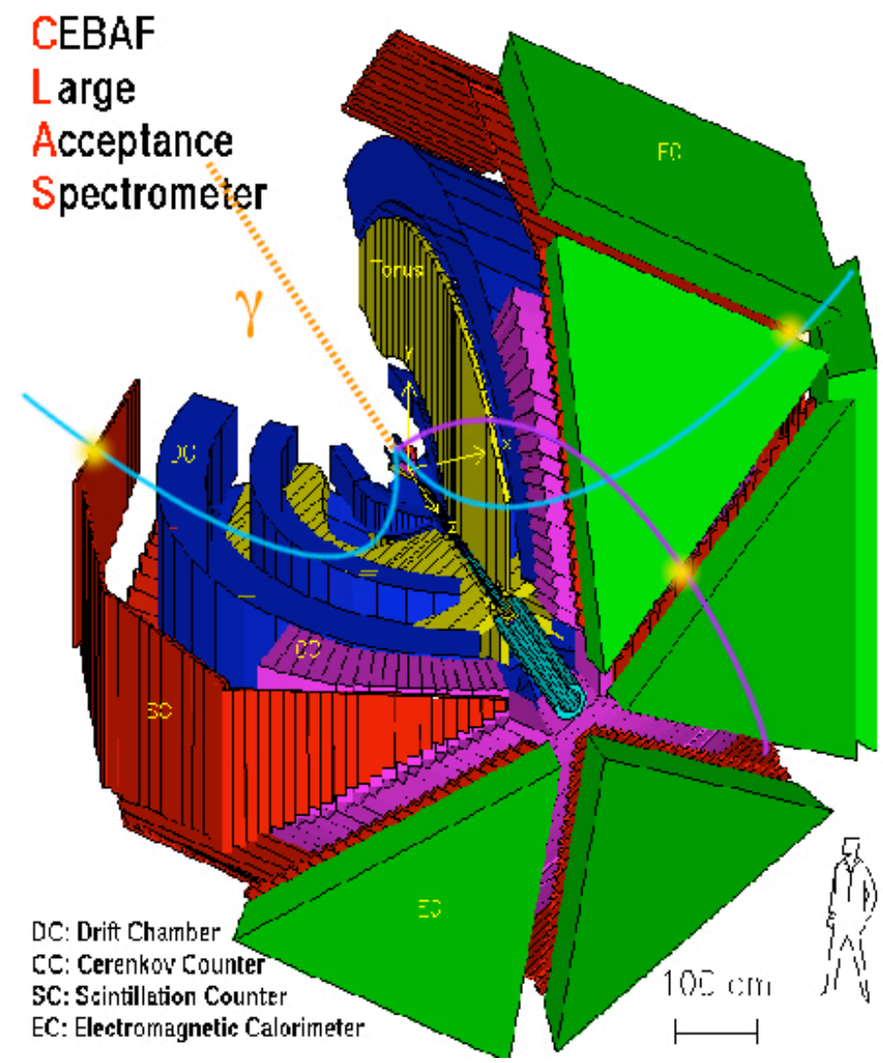
$$\gamma + p \rightarrow K^{+} + \Lambda(1405)$$
$$\rightarrow \Sigma\,\pi$$



1. Nacher, Oset, et al., Phys. Lett. B 455, 55 (1999)
2. Recent review in Hyodo, Jido, Prog. Part. Nucl. Phys. 67, 55 (2012)

Jefferson Lab and CLAS

- Located in Newport News, VA (USA)
- CEBAF accelerator provides electron beam every 2 ns
- Currently up to 6 GeV, future running @12 GeV
- CLAS detector provides charged particle tracking with DC/TOF
- Photoproduction on a liquid H_2 target
- Large statistics, more than 20B triggers



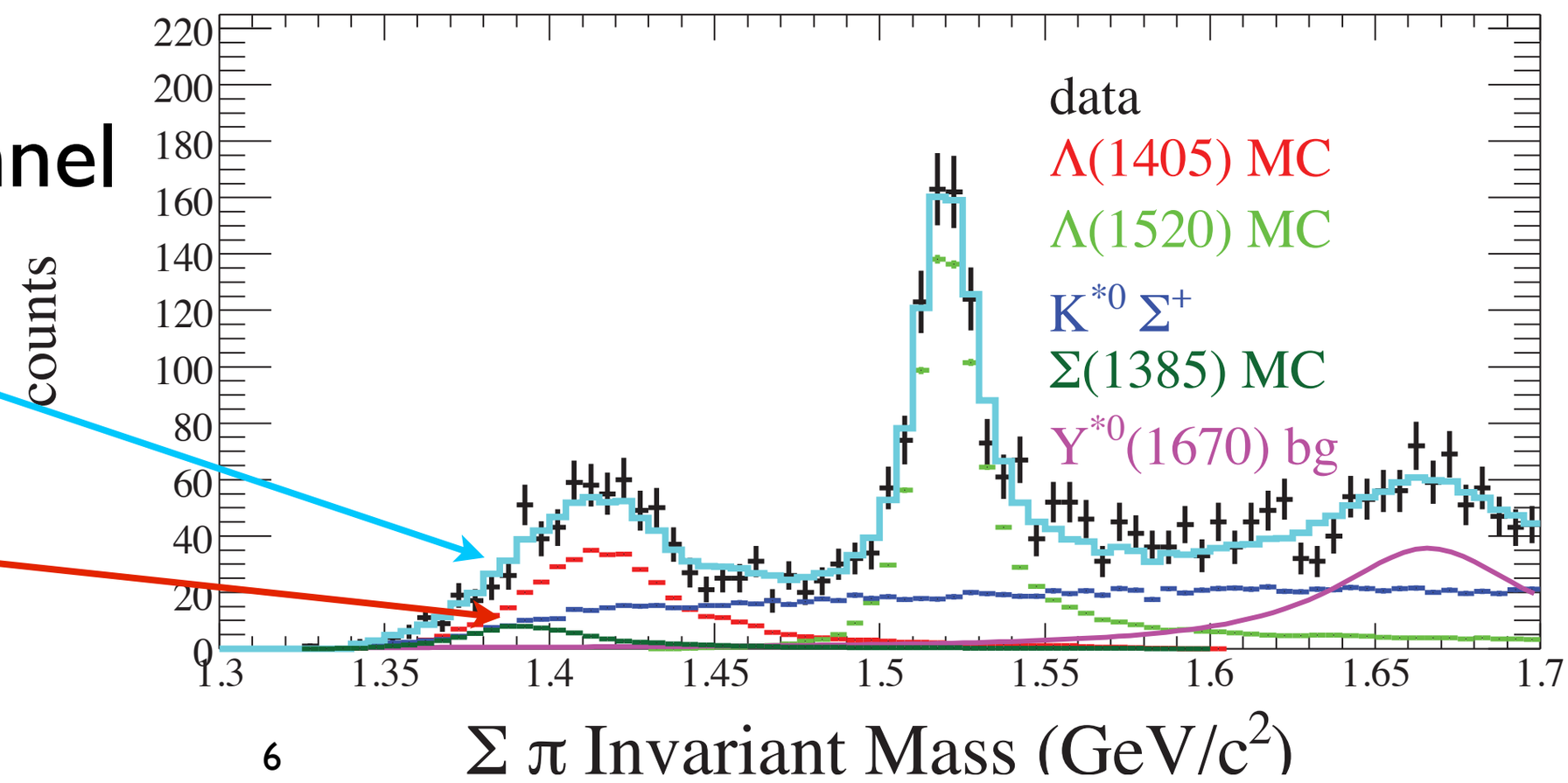
Extraction of Λ(1405)

- Reconstruct ground state Λπ, Σπ states
- Remove Σ(1385)→Σπ by scaling down contribution from dominant Λπ channel
- Remove other channels ($K^*\Sigma$, Λ(1520)) by incoherent fits with Monte Carlo templates

Fit to $\Sigma^+\pi^-$ channel

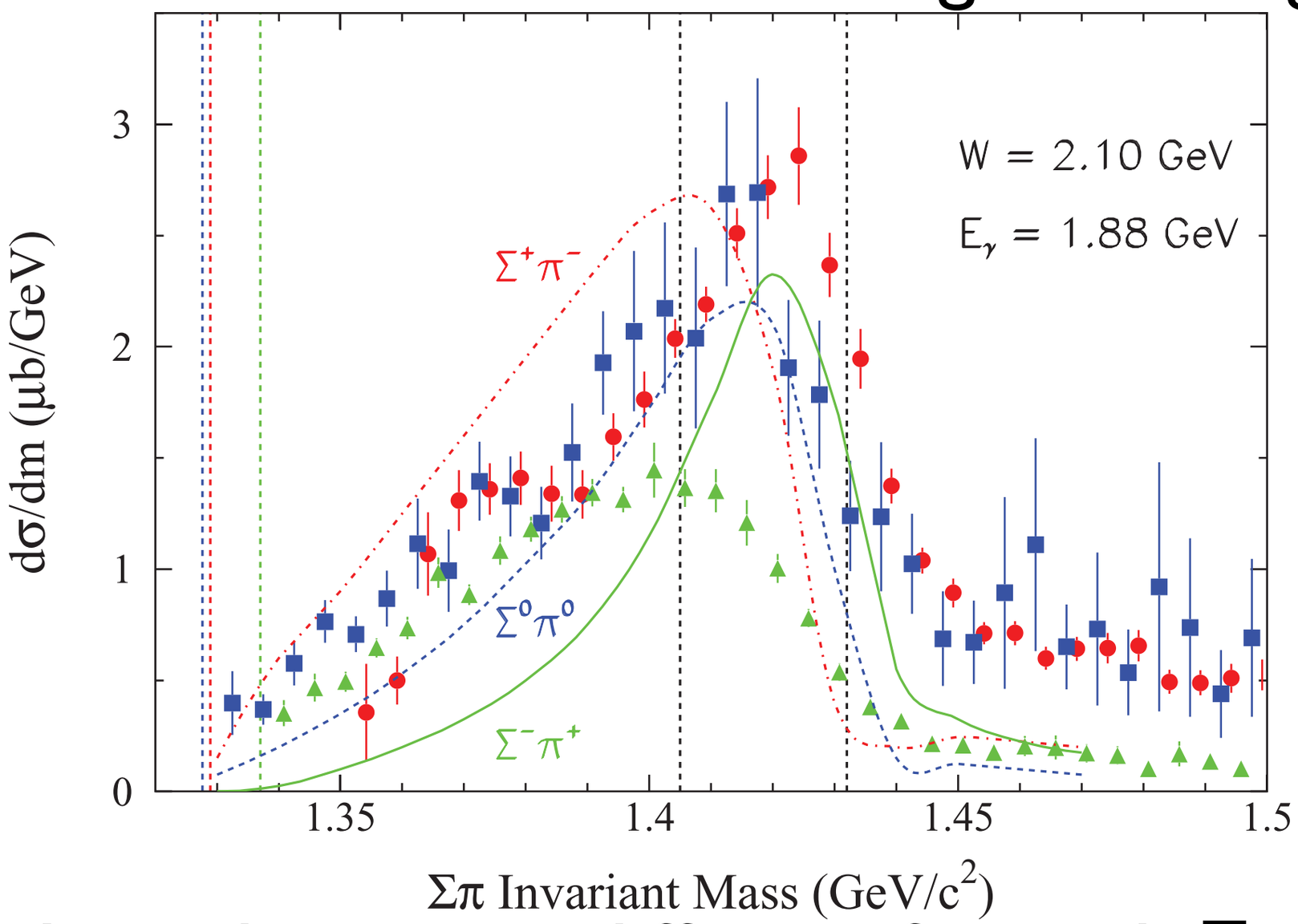
total fit result

iterated Λ(1405) line shape



Line shape of the Λ(1405)

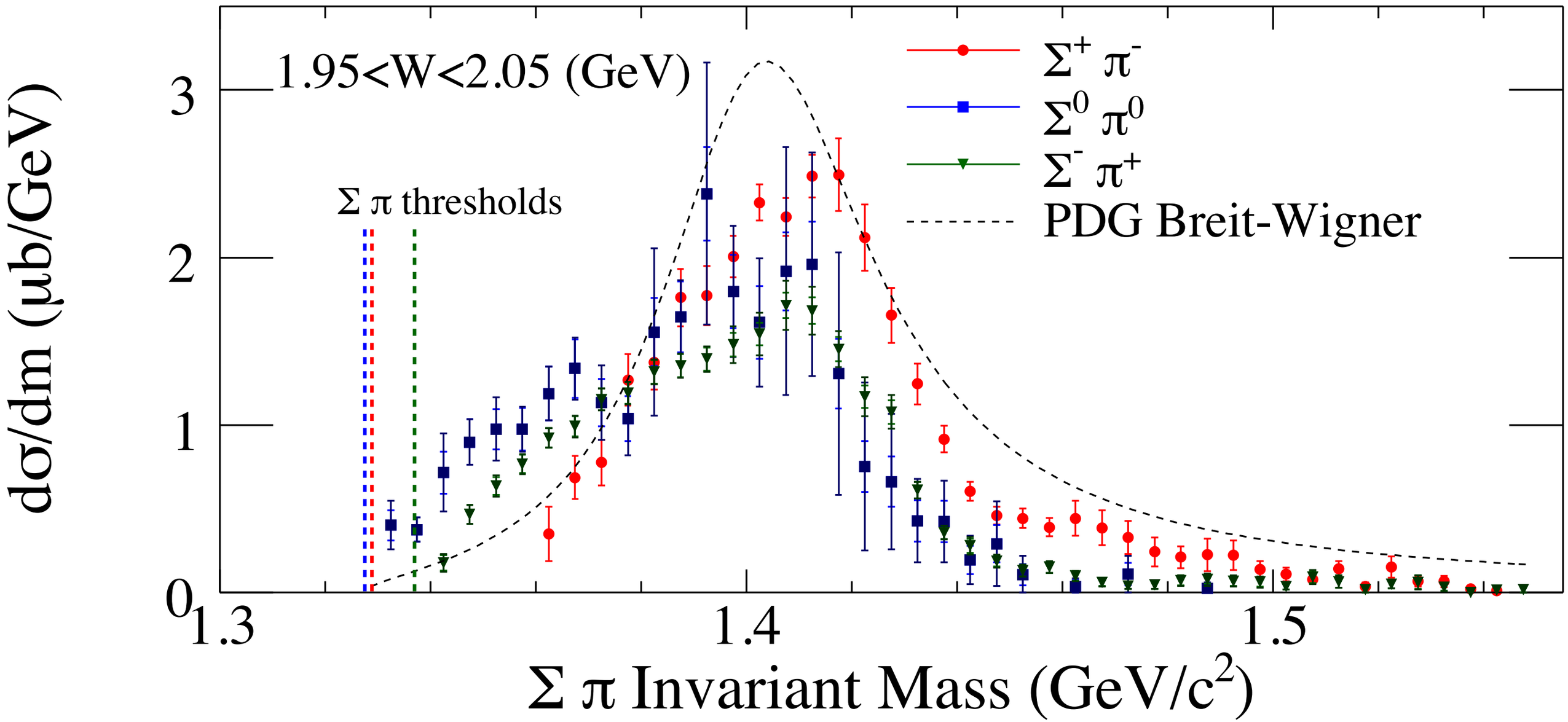
- CLAS has measured the line shape for all Σπ channels over a broad range of energies[1]



- Line shapes are different for each Σπ channel

1. Moriya et al. (CLAS), PRC 87, 035206 (2013), curves are Nacher, Oset, et al., Phys. Lett. B 455, 55 (1999)

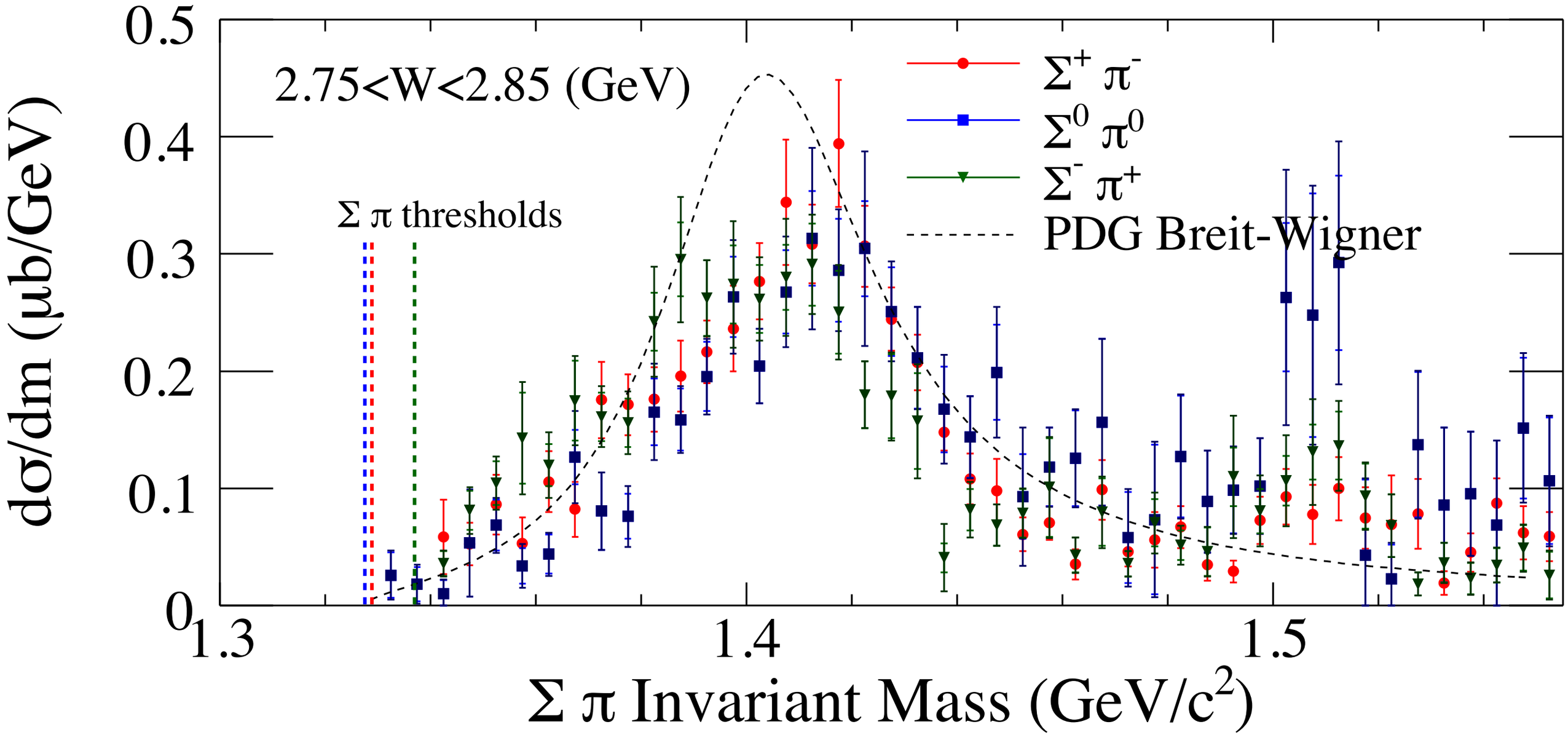
Evolution of Line Shapes



near threshold,
$E_\gamma \sim 1.6$ GeV

Moriya et al. (CLAS), PRC 87, 035206 (2013)

Evolution of Line Shapes



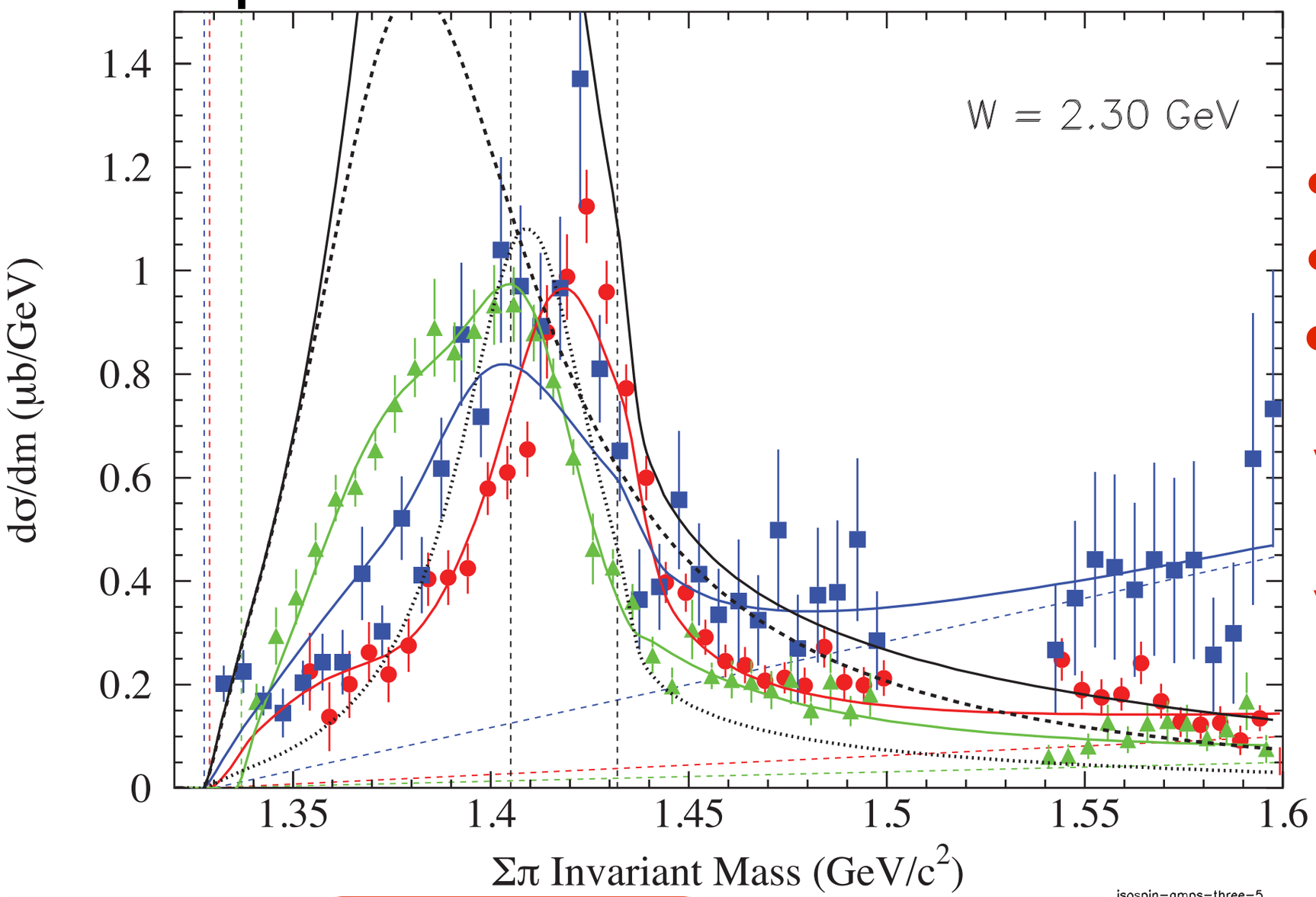
$E_\gamma \sim 3.7$ GeV

Line shapes merge

Moriya et al. (CLAS), PRC 87, 035206 (2013)

Fits to Data

- Difference in $\Sigma\pi$ channel $\Rightarrow$isospin dependence
- Rapid fall-off at $N\bar{K}$ threshold shows strong coupling



Fit with interfering

- I=0 (main Λ(1405))
- I=0 (high mass)
- I=1

Flatté-type Breit-Wigner functions show centroids, widths

isospin-amps-three-5

Amplitude	Centroid m_R (MeV)	Width Γ_0 (MeV)	Phase $\Delta\Phi_I$ (radians)	Flatté γ Factor
I = 0 (low mass)	1338 ± 10	44 ± 10	N/A	0.94 ± 0.20
I = 0 (high mass)	1384 ± 10	76 ± 10	1.8 ± 0.4	N/A
I = 1	1367 ± 20	54 ± 10	2.2 ± 0.4	1.19 ± 0.20

ratio of coupling strengths to $\Sigma\pi/N\bar{K}$

Schumacher, Moriya, Nucl. Phys. A (in press), http://arxiv.org/abs/1303.0860

See also Roca, Oset, PRC 87, 055201 (2013)

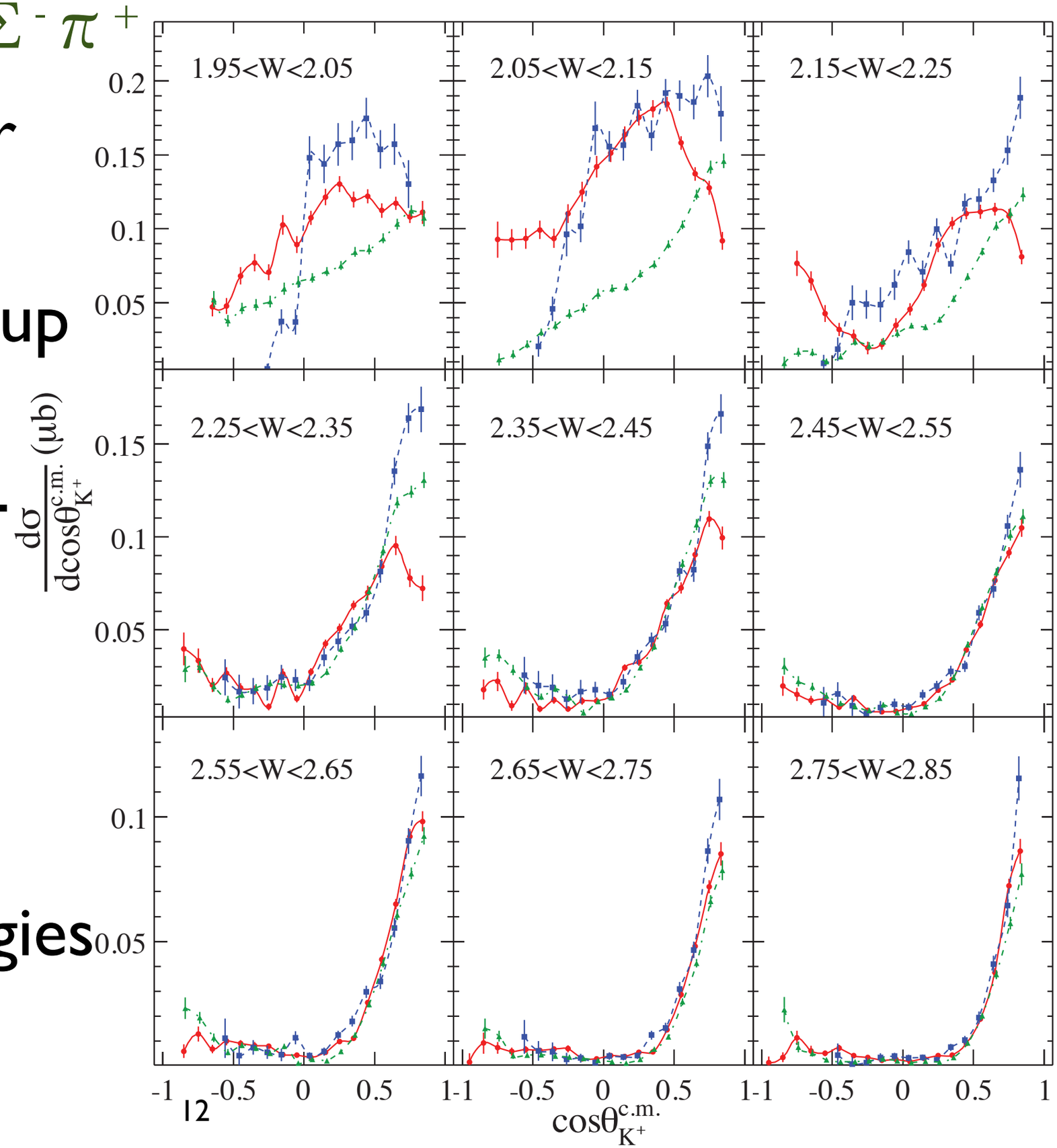
Differential cross sections

- Differential cross sections give information on production mechanism, more understanding of formation dynamics in photoproduction
- Measured for
  - $\Lambda(1405)$ ($J^P = 1/2^-$) in $\Sigma\pi$ channels
  - $\Sigma(1385)$ ($J^P = 3/2^+$) in $\Lambda\pi^0$ channel
  - $\Lambda(1520)$ ($J^P = 3/2^-$) in $\Sigma\pi$ channels
- Interesting to compare the cross sections of three excited hyperons with different quantum numbers

Λ(1405) Cross Sections

- $\Sigma^+\pi^-$ • $\Sigma^0\pi^0$ • $\Sigma^-\pi^+$

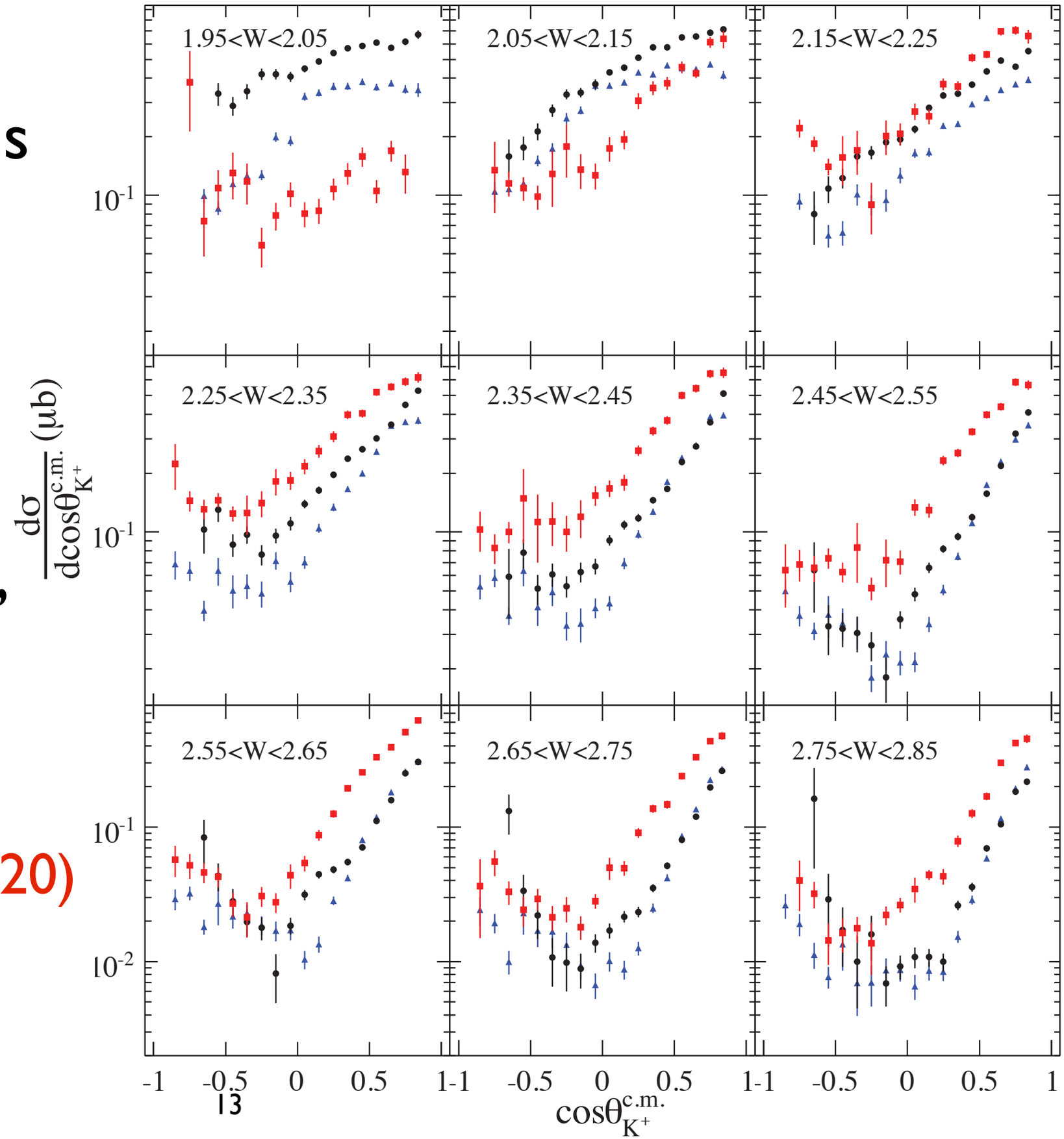
- Λ(1405) measured for each Σπ channel
- Defined as threshold up to 1.5 GeV/c^2
- Very different isospin-dependence at lower energies
- All three merge into forward-peaking behavior at high energies



Moriya et al. (CLAS),
to be submitted to PRC

Comparison of Cross Sections

- All three hyperons show similar forward rise at higher energies
- Similar strengths at lower energies, but Λ(1520) dominates



- Σ(1385)

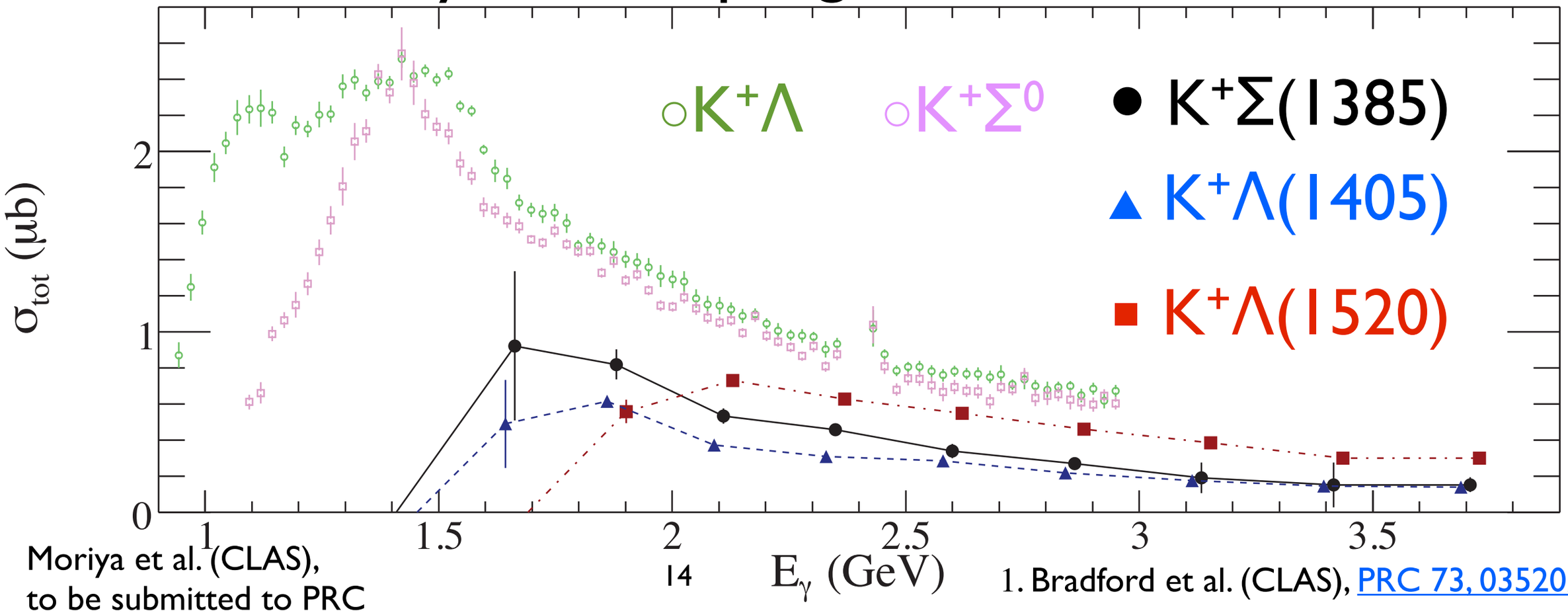
■ Λ(1520)

▲ Λ(1405) (sum)

Moriya et al. (CLAS),
to be submitted to PRC

Total Cross Sections

- Total cross sections are extrapolated over all angles
- Cross sections are comparable to ground state $K^+\Lambda$, $K^+\Sigma^0$ production[1]
- Binning is coarse (100 MeV in W), but detailed studies may find couplings to N^* states



Moriya et al. (CLAS), to be submitted to PRC

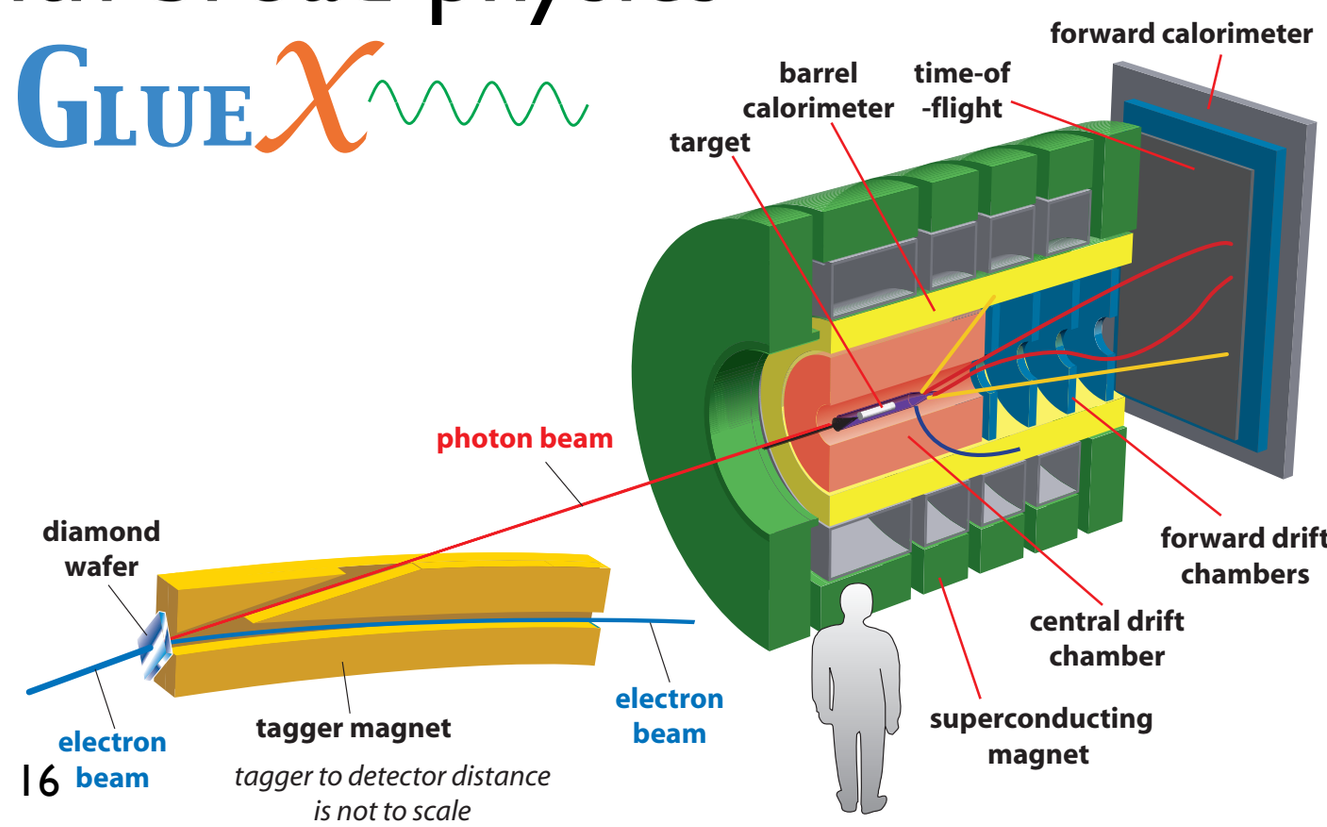
1. Bradford et al. (CLAS), PRC 73, 035202 (2006)

Summary of CLAS Results

- The line shape results of the $\Lambda(1405)$ show the strong dynamics that form the state
- Comparison of differential cross sections show that $\Lambda(1405)$, $\Sigma(1385)$, and $\Lambda(1520)$ are produced with similar strengths, and show similar behavior at higher energies
- New information on rather large cross sections compared to ground state production
- May give hints on coupling of these states to N^* states

Future Plans @12 GeV

- JLab is currently upgrading CEBAF accelerator: 6 GeV → 12 GeV
- New experimental Hall D = GlueX[1]
- High intensity photoproduction experiment
- Multi-purpose detector with broad physics program[2]



1. http://www.jlab.org/Hall-D/
2. current PAC proposal at http://arxiv.org/abs/1305.1523

Search for Exotic Mesons

- $q\,\bar{q}$ states ⇒ Can only have states with specific J^{PC}
- QCD allows states with degrees of freedom beyond $q\bar{q}$, and are predicted by ℓQCD[1]
- If gluonic degrees of freedom contribute to quantum numbers, hybrid states of 0^{--}, 0^{+-}, 1^{-+}, etc. may exist
- These would show previously unknown roles of gluons in QCD

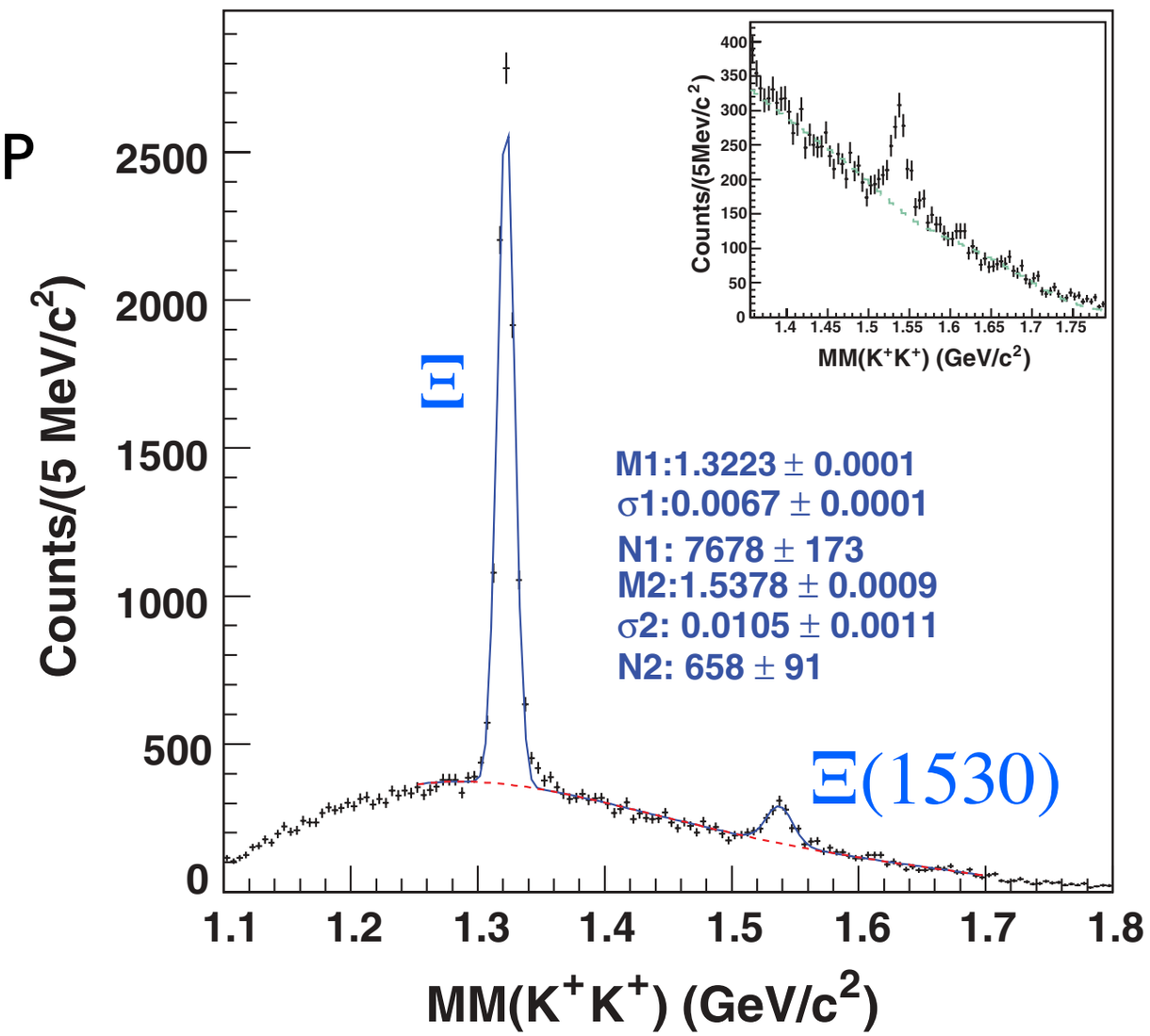
S=0		S=1	
L:even	L:odd	L:even	L:odd
0^{-+}	1^{+-}	1^{--}	0^{++}
2^{-+}	3^{+-}	2^{--}	1^{++}
4^{-+}	5^{+-}	3^{--}	2^{++}
⋮	⋮	⋮	⋮

allowed J^{PC} for $q\,\bar{q}$

1. J. Dudek, PRD 84, 074023 (2011)

Search for $\Xi^{(*)}$ States

- Ξ baryons have two s-quarks
- Spectrum of Ξ^* not well-known
  - 2 **** states, 4 *** states
  - almost no information on J^P
  - relatively narrow widths
- CLAS[1] did not have enough energy/statistics to confirm higher Ξ^* states
- GlueX will have much higher energy range, higher forward acceptance - expect ~800k Ξ, ~100k $\Xi(1530)$



1. Guo et al. (CLAS) PRC 76, 025208 (2007)

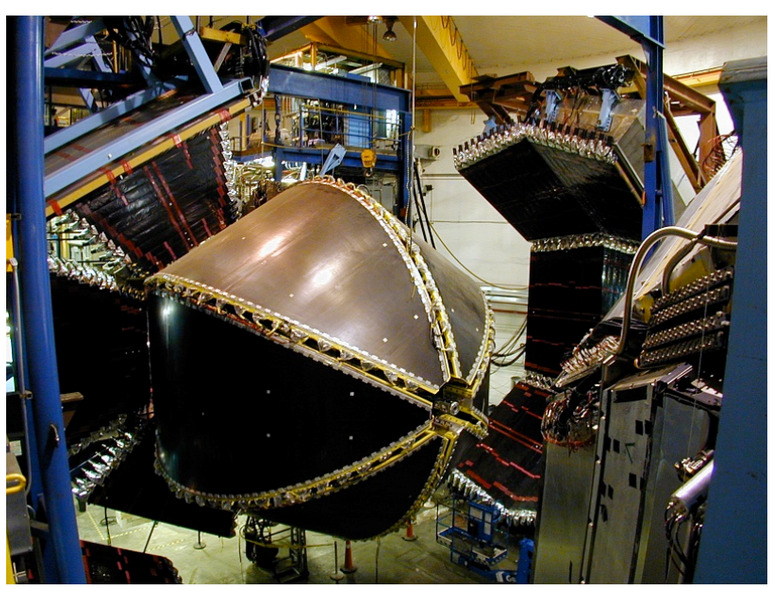
Conclusions

- JLab@6 GeV has produced many results for nuclear/hadron studies
- Line shape, cross section measurements of $\Lambda(1405)$ and other excited hyperons are input towards a systematic understanding of QCD
- The 12 GeV upgrade at JLab is ongoing
- GlueX will have a broad physics program, including searches for exotic mesons, $\Xi^{(*)}$ baryons, and more

Jefferson Lab[1] (JLab)

BACKUP

- Located in Newport News, VA (USA)
- CEBAF accelerator provides electron beam every 2 ns
- Currently up to 6 GeV, future running @12 GeV



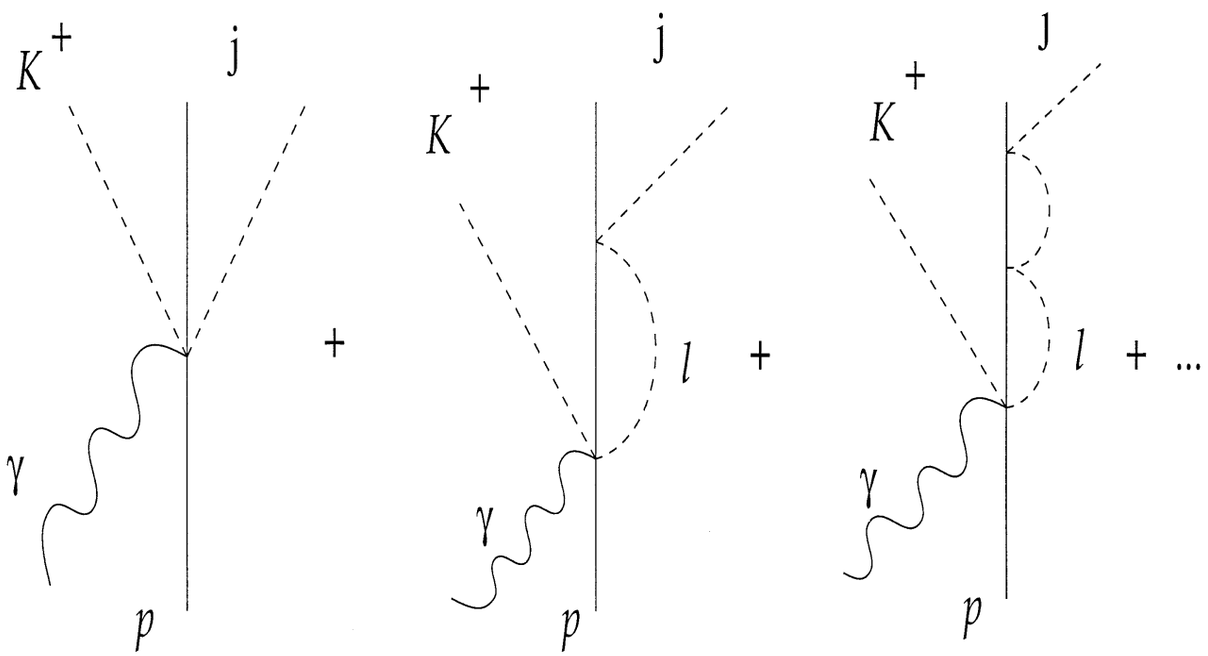
CLAS detector (6 GeV era)

1. https://www.jlab.org

BACKUP

Details of Chiral Dynamics

Effective chiral Lagrangian + Unitary coupled channels



Rescattering of meson baryon interaction creates Λ(1405)

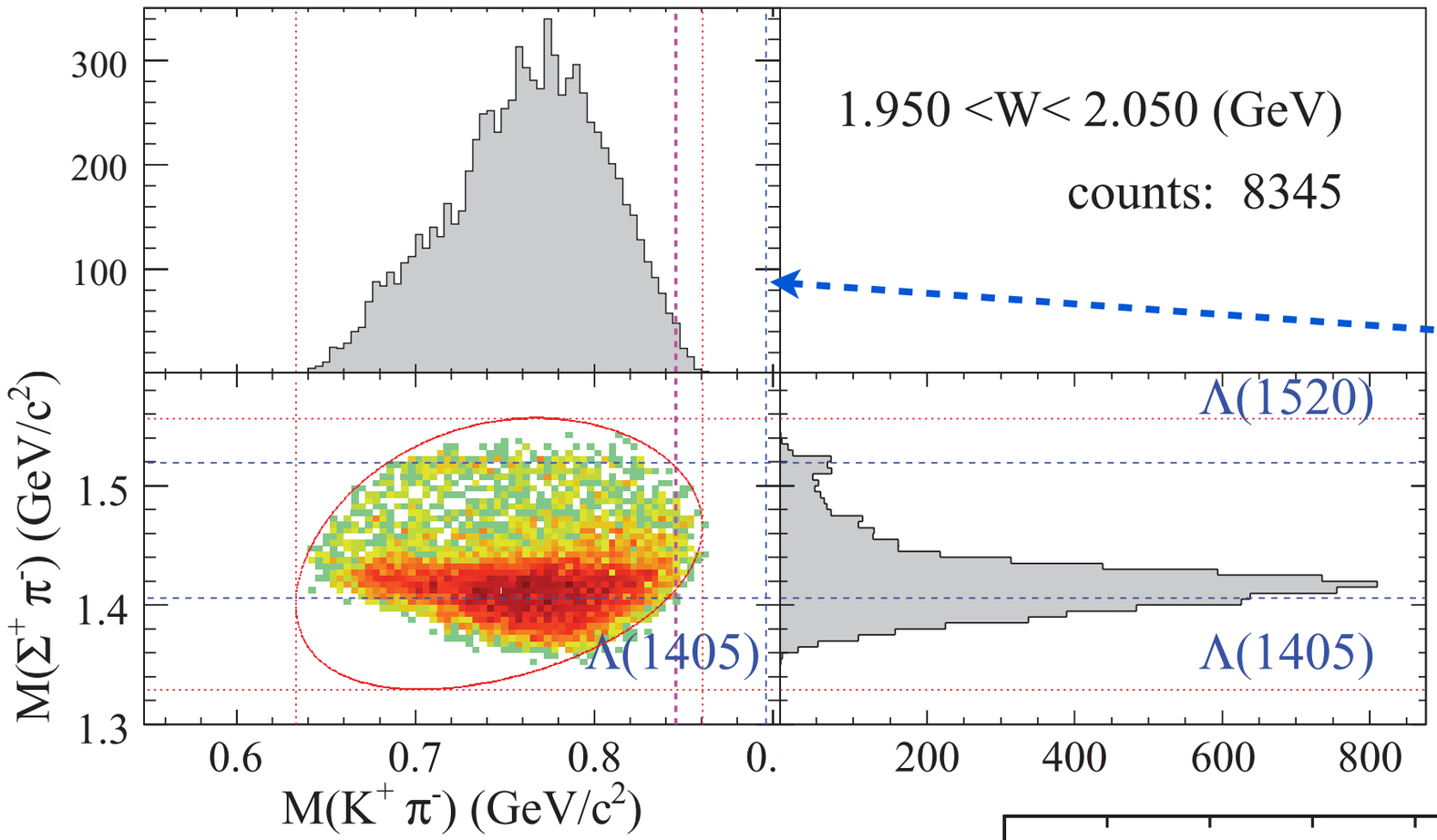
isospin decomposition

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

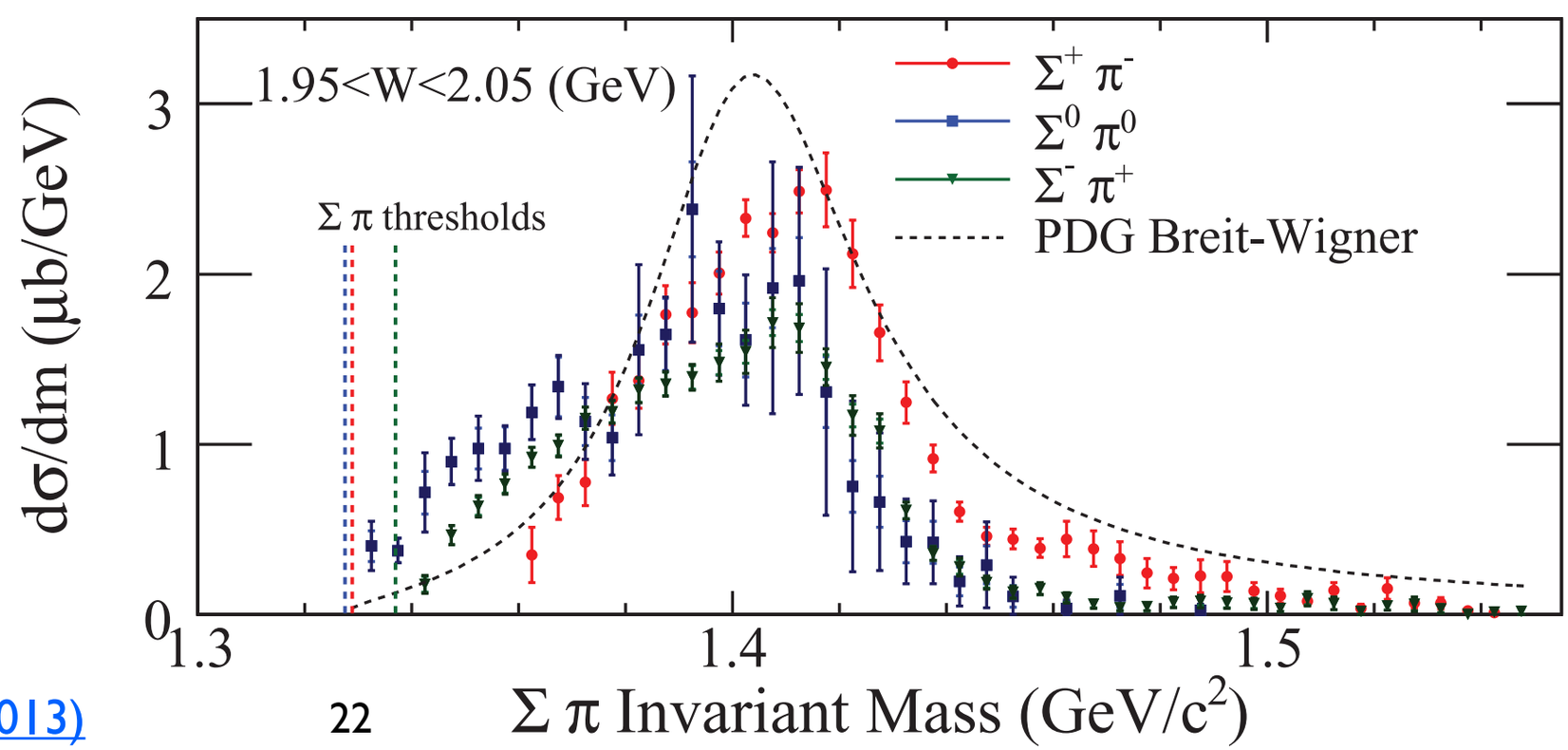
$$\frac{d\sigma(\pi^-\Sigma^+)}{dM_I} \propto \frac{1}{2}\left|T^{(1)}\right|^2 + \frac{1}{3}\left|T^{(0)}\right|^2 - \frac{2}{\sqrt{6}}\mathrm{Re}\left(T^{(0)}T^{(1)*}\right) + O\left(T^{(2)}\right)$$

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

Below K* threshold



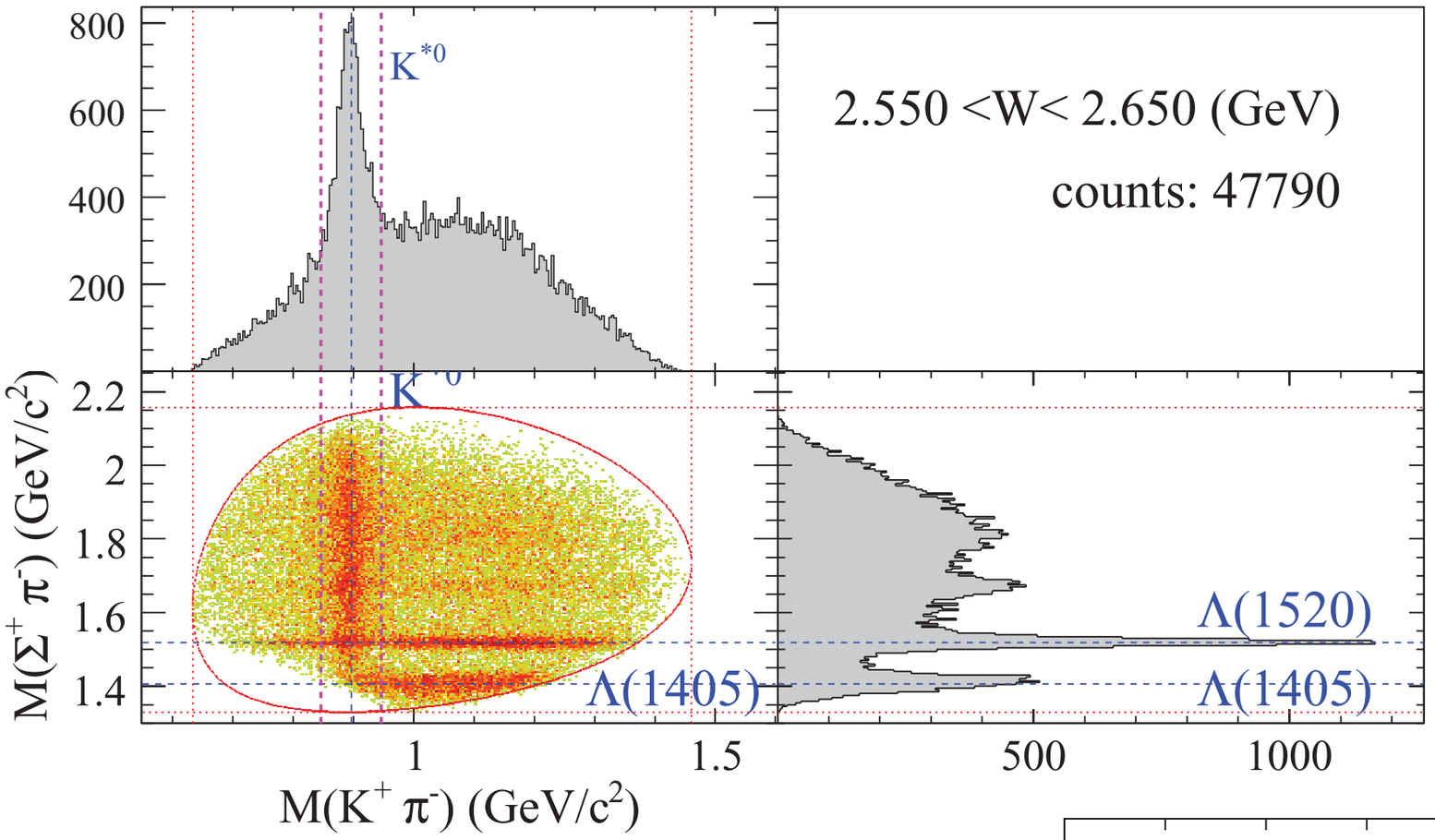
Lowest bin is below K* threshold



Line shapes are still very different

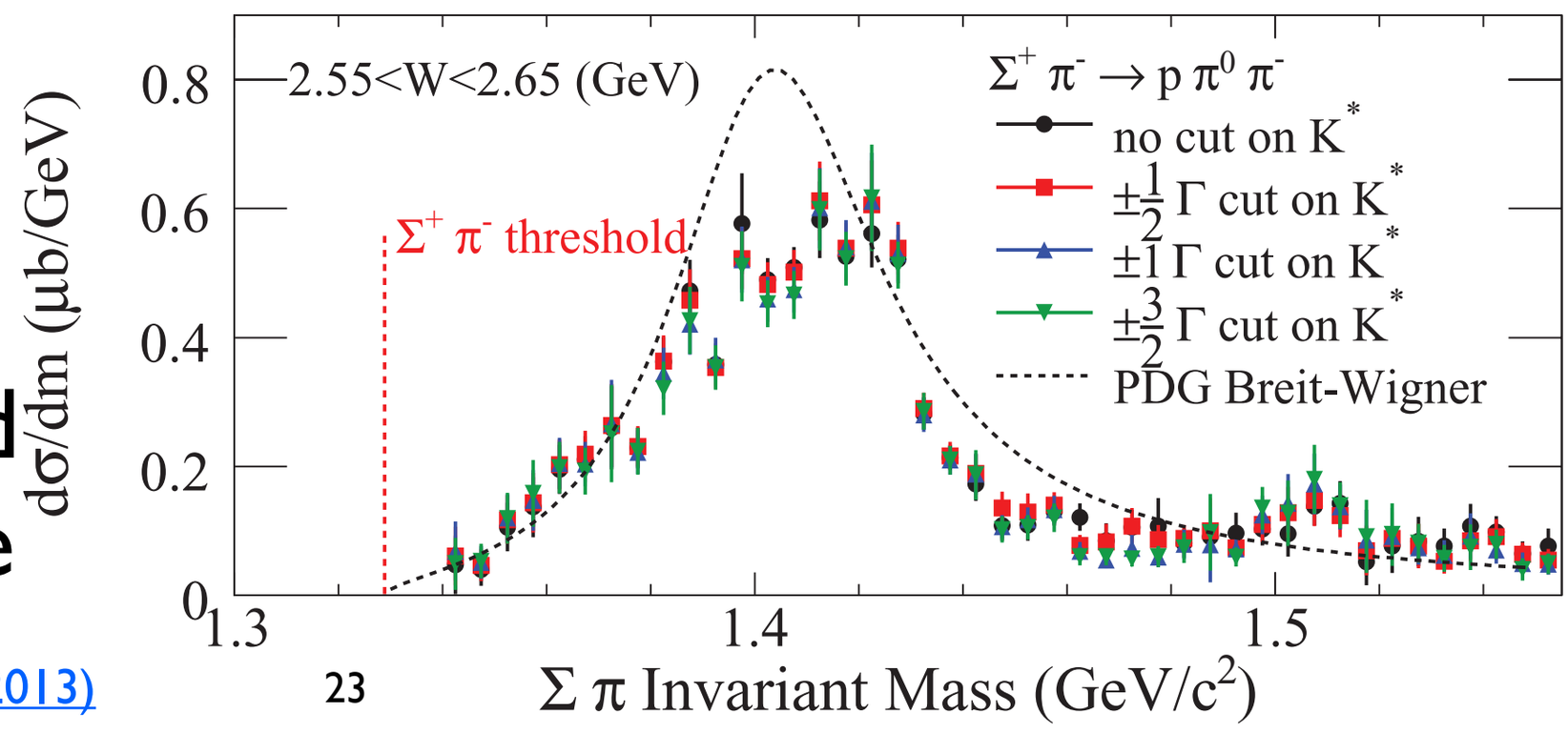
Moriya et al. (CLAS), PRC 87, 035206 (2013)

K^* Background Studies



remove regions centered around K^*

acceptance-corrected results do not change



Moriya et al. (CLAS), PRC 87, 035206 (2013)

Flatté Function[1]

For a 2-channel resonance where the resonance straddles the threshold to one channel, preserve analyticity to below threshold

Breit-Wigner amplitude

$$B_I(m) = \sqrt{\frac{2}{\pi}}\left[\frac{\sqrt{m_R m \Gamma_I^0 (q/q_R)^{2L}}}{m_R^2 - m^2 - i m_R \Gamma_{\rm tot}(q)}\right]$$

total width

$$\Gamma_{\rm tot}(m) = \Gamma_{I,1}(q_1(m)) + \Gamma_{I,2}(q_2(m))$$

dependence of Γ on breakup momentum

$$\Gamma_{\rm tot}(q) \to \Gamma_{I,1}(q_1) = \Gamma_{I,1}^0 \frac{m_R}{m}\left(\frac{q_1(m)}{q_R}\right)^{2L+1}$$

analyticity:

Below threshold for decay mode 2, the total decay width is

$$\Gamma_{\rm tot}(m) = \Gamma_{I,1}(q_1(m)) + i\gamma\Gamma_{I,1}(q_2{}'(m)), \qquad (25)$$

while above the threshold the total decay width is

$$\Gamma_{\rm tot}(m) = \Gamma_1(q_1(m)) + \gamma\Gamma_1(q_2(m)), \qquad (26)$$

1. Flatté, PLB 63, 224 (1976)

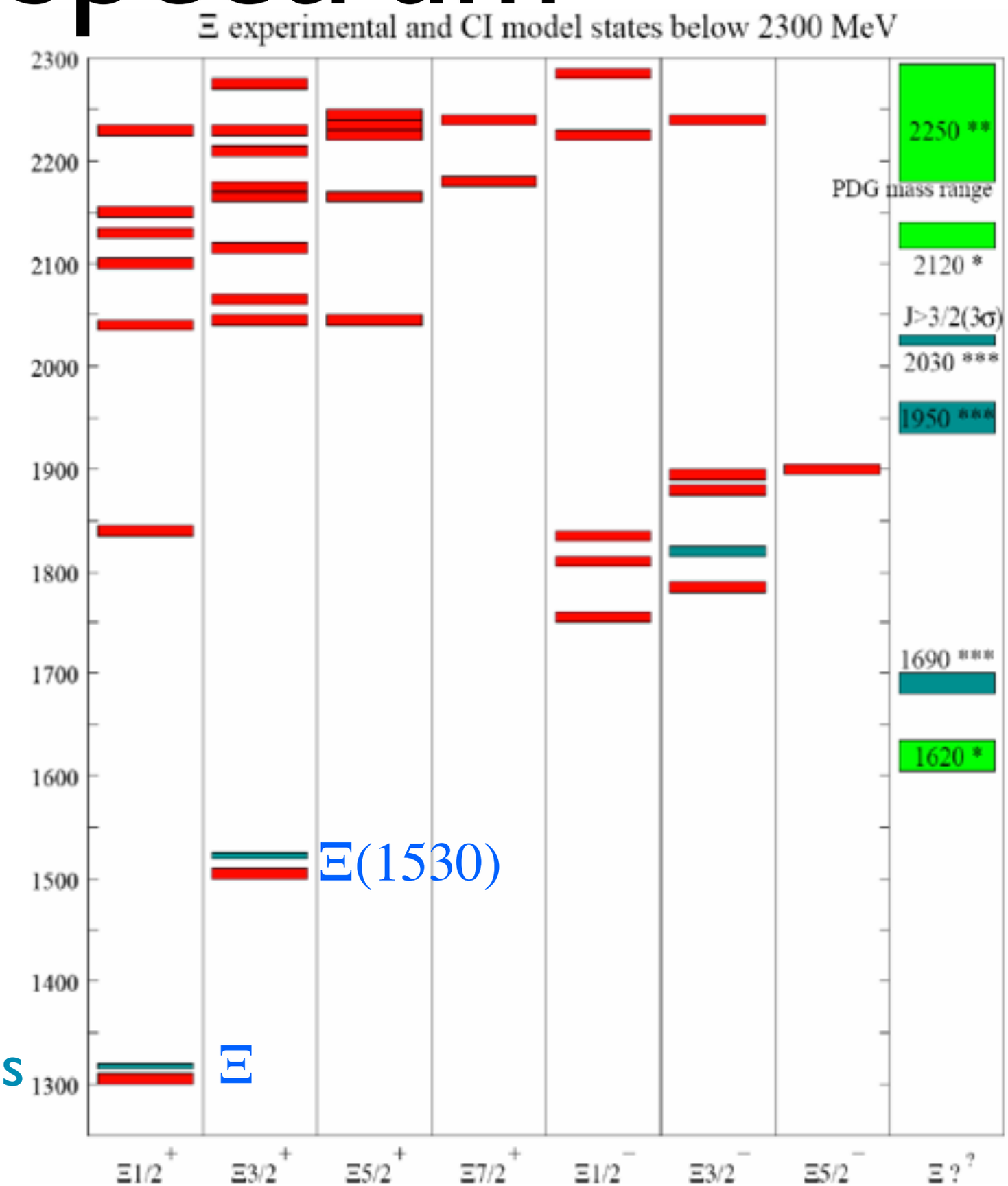
for details, see Moriya et al. (CLAS), PRC 87, 035206 (2013)

More Info On GlueX

- Webpage (goals, physics, members): http://gluex.org
- Current PAC proposal: http://arxiv.org/abs/1305.1523

$\Xi^{(*)}$ Spectrum

- Many predicted states
- Only 2 ****, 4 *** states
- J^P determined for only three states



predicted states

discovered states

Figure due to S. Capstick (Florida State U)