西安交通大學
XI'AN JIAOTONG UNIVERSITY

Polarization of $\Lambda(1405)$ in the $\gamma p \to K^+\pi\Sigma$ reaction

王柯

西安交通大学

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Ke Wang, Bo-Chao Liu, Phys. Lett. B 813, 136019 (2021)

Motivation

1. Pentaquarks before LHCb P_c states

Fate of the first pentaquark predicted and observed:

1959: $\bar{K}N$ molecule predicted by Dalitz-Tuan, PRL2, 425

1961: $\Lambda(1405) \rightarrow \Sigma\pi$ observed by Alston et al., PRL6, 698

1964: Quark model (uds) for $\Lambda(1405)$

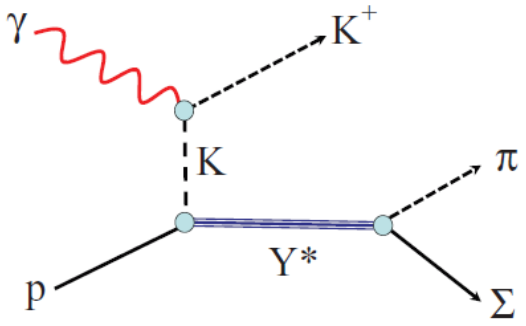
1995: $\bar{K}N$ dynamically generated -- Kaiser et al., NPA954, 325

2001: 2 pole structure by $\bar{K}N$-$\Sigma\pi$ -- Oller et al., PLB500, 263

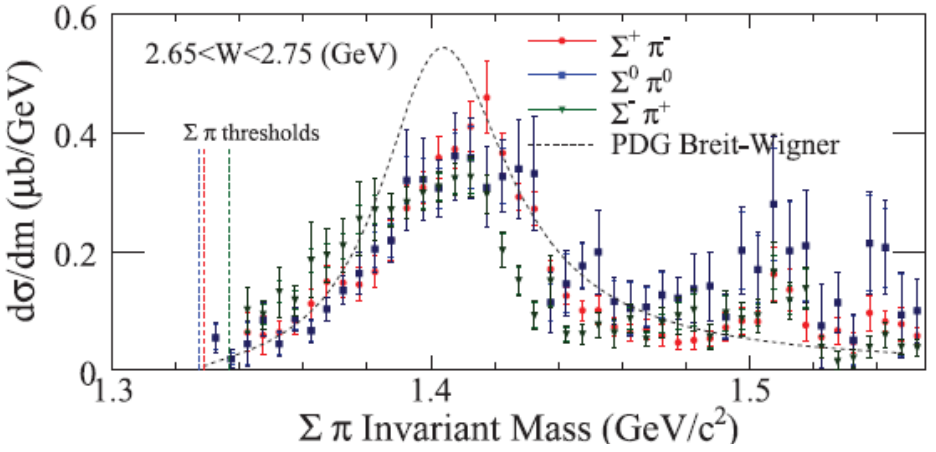
PDG2010: "The clean Λ_c spectrum has in fact been taken to settle the decades-long discussion about the nature of the $\Lambda(1405)$ —true 3-quark state or mere $\bar{K}N$ threshold effect?— unambiguously in favor of the first interpretation."

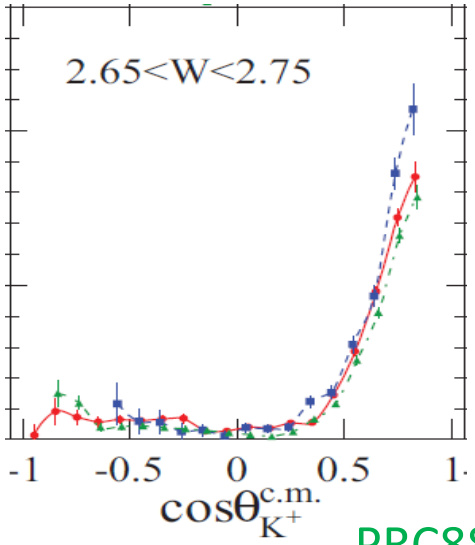
Experiment data

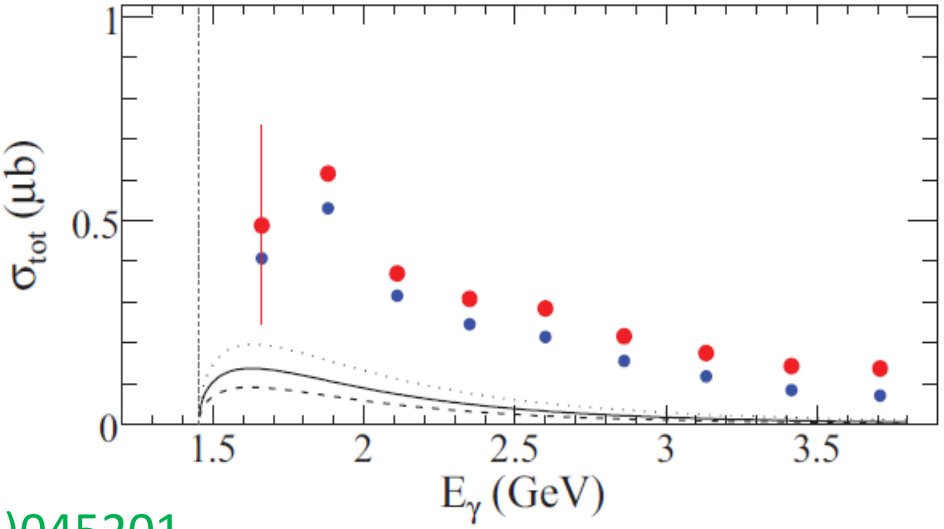
CLAS Collaboration : mass spectrum and angle distribution



PRC87(2013)035206







PRC88(2013)045201

Experiment data

CLAS Collaboration : polarization

PRL112(2014)082004

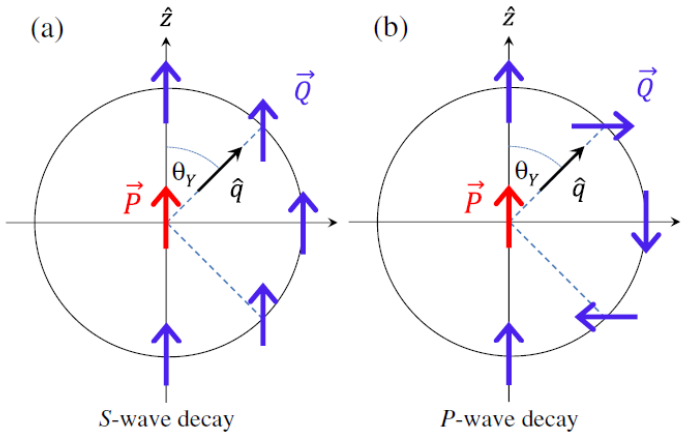


FIG. 1 (color online). Polarization transfer from Y^* to Y in the decay $Y^* \to Y + \pi$, where Y^* has spin $\frac{1}{2}$. The red arrow shows the polarization P of the Y^* taken to be in the z direction, while the blue arrows show the polarization $\vec{Q}$ of Y depending on the decay angle θ_Y around the z axis. (a) is for odd parity; (b) is for even parity.

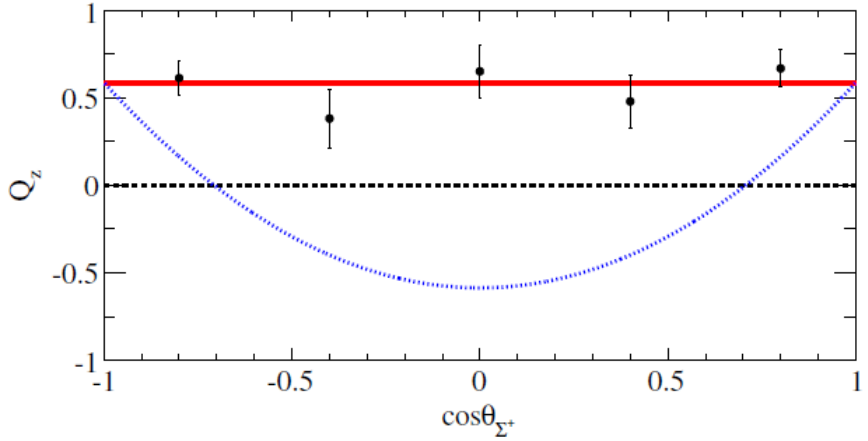
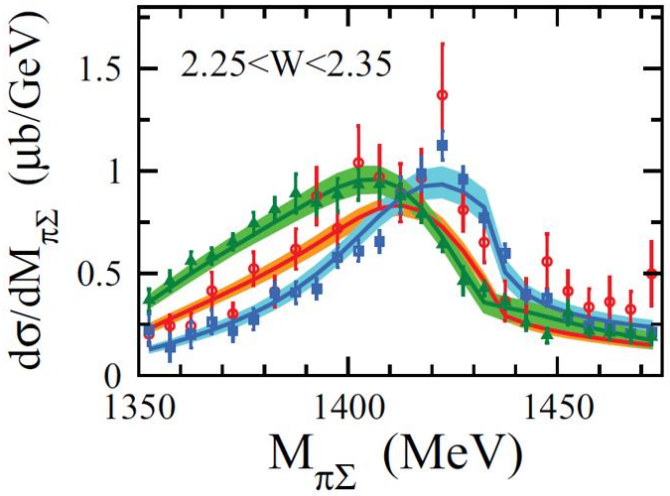


FIG. 4 (color online). Polarization Q_z of Σ^+ versus $\cos\theta_{\Sigma^+}$ for $2.65 < W < 2.75$ GeV and $0.70 < \cos\theta^{\text{c.m.}}_{K^+} < 0.80$. The average is shown as the red solid line. The dotted blue curve is the expectation for P-wave decay.

The analysis shows that the $\Lambda(1405)$ has spin-parity $J^P = \frac{1}{2}^-$

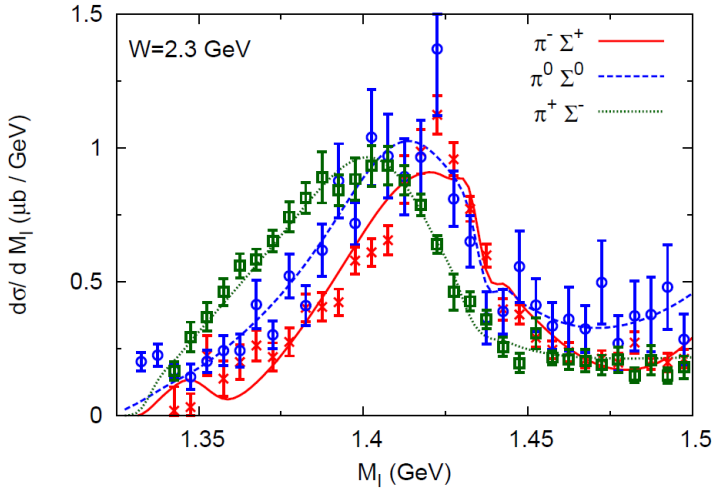
Theoretical research



EPJ Web Conf. 97(2015)00023

ChUM double-pole:

$$M_L = 1352 - 48i\ MeV$$
$$M_H = 1419 - 29i\ MeV$$

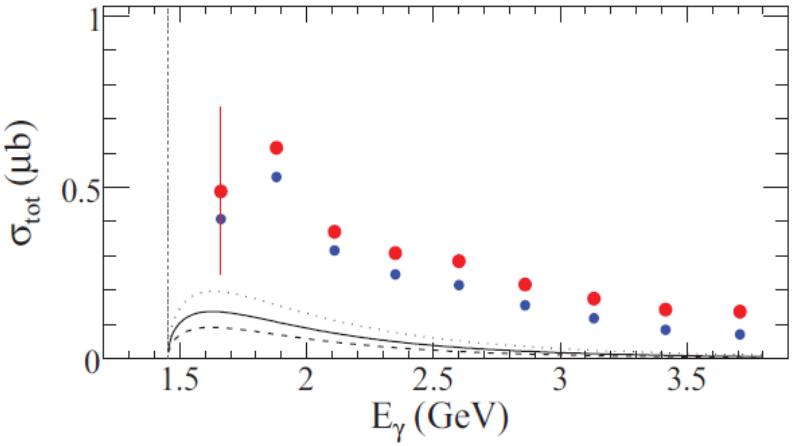


PTEP(2014)023D01

ChUM single-pole:

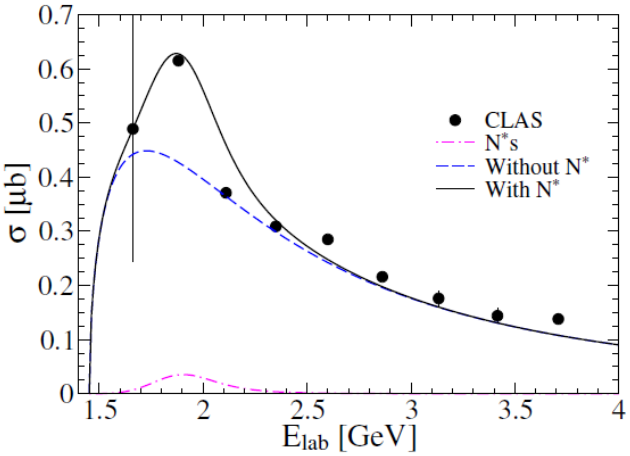
$$M_{BW} = 1412 MeV$$
$$\Gamma_{BW} = 67 MeV$$

Theoretical research

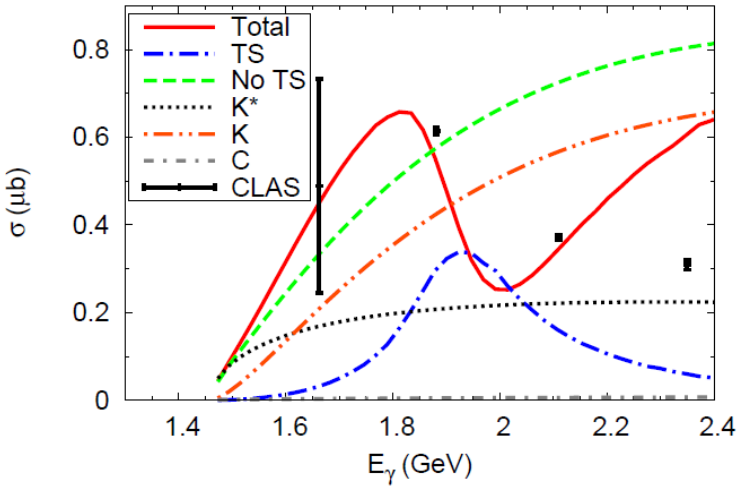


PRC88(2013)045201

Effective Lagrangian:
Nucleon resonances contribution
Triangle singularity contribution

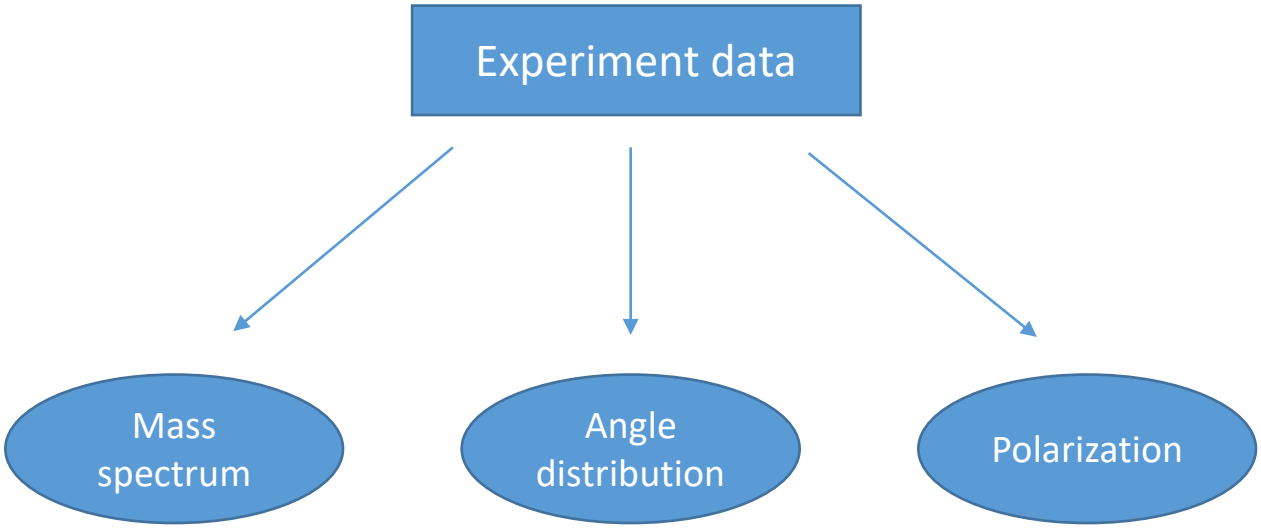


PRD96(2017)014003



PRC95(2017)015205

Purpose



1. Discuss the mechanisms for the polarization of the $\Lambda(1405)$ in the photo-induces process.

2. Discuss the effects due to the pole structure of the $\Lambda(1405)$ on the $\Lambda(1405)$ polarization.

Model and ingredients

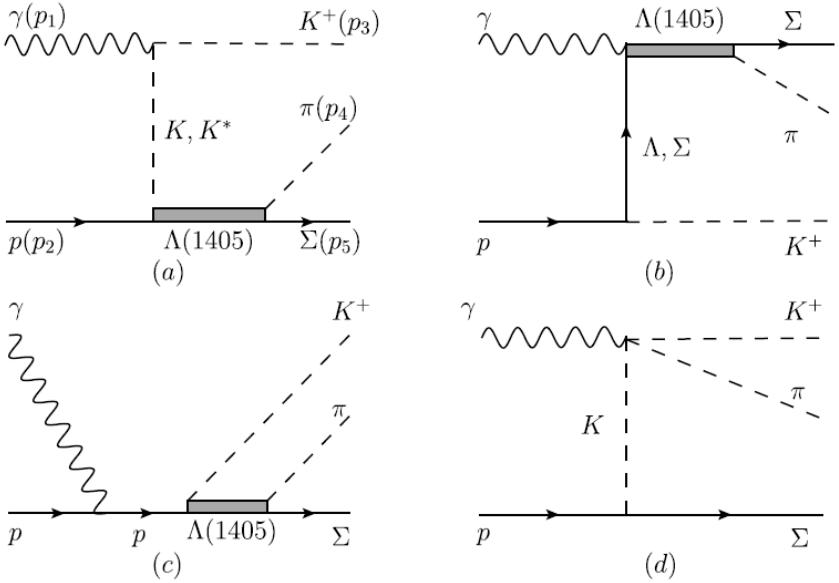


Fig. 1. Feynman diagrams for the $\gamma p \to K^+ \pi \Sigma$ reaction.

Other resonance states:

K^* and $\Sigma(1385)$ PRC87(2013)035206

Parameterization:

Form factors PRD96(2017)014003

Regge propagators EPJ.A55(2019)152

Energy-dependent width

PRC88(2013)015203

One pole: $M = M_K + M_N + M_{K^*} + M_Y + M_C$

Two pole: $M = \left(M_K^L + M_N^L + M_{K^*}^L + M_Y^L\right) + \left(M_K^H + M_N^H + M_{K^*}^H + M_Y^H\right)\mathrm{e}^{\mathrm{i}\phi} + \mathrm{M_C}\mathrm{e}^{\mathrm{i}\phi_c}$

$\phi = \pi$

Fitting results

Table 2
Fitted parameters for the one-pole case ($\chi^2/dof = 2.41$).

Parameter	Value	Parameter	Value
Λ_B	2.00 ± 0.05 GeV	γ	2.36 ± 0.02
$\mu_{\Lambda^*\Lambda}$	0.077 ± 0.002	g_c	-8.57 ± 0.12

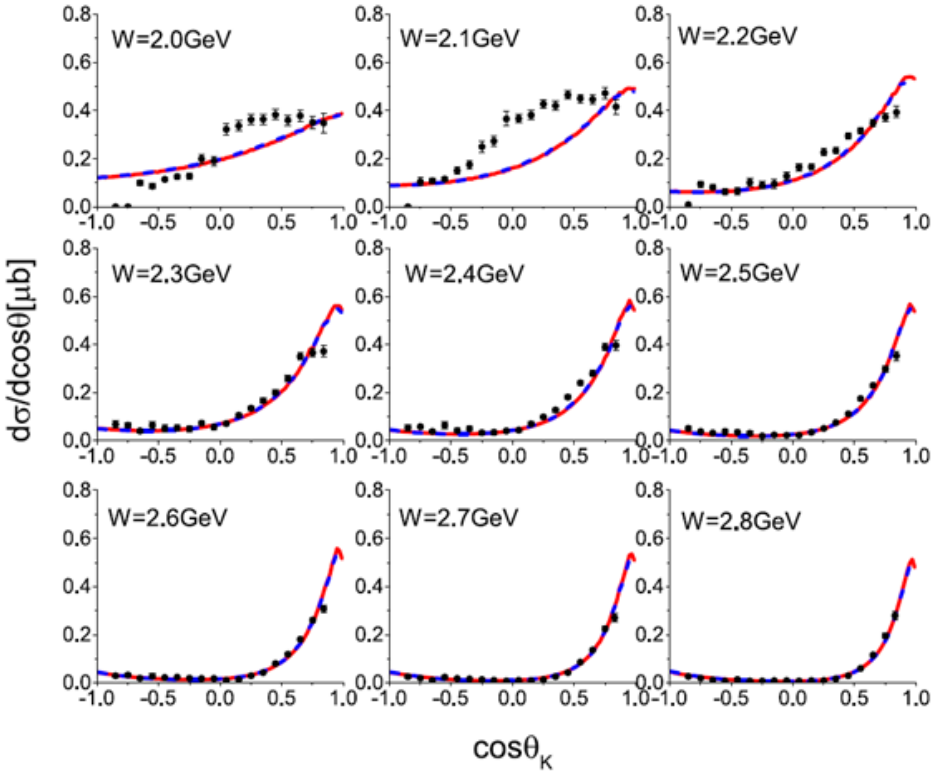
$M_L = 1352 - 48i\ MeV$
$M_H = 1419 - 29i\ MeV$

Table 3
Fitted parameters for the two-pole case ($\chi^2/dof = 2.13$).

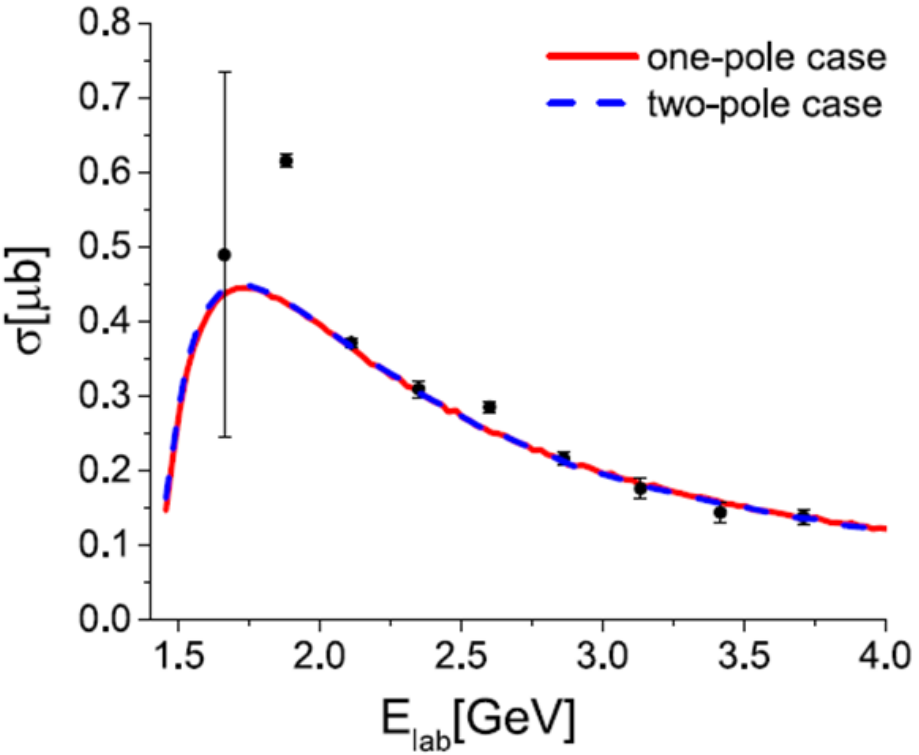
Parameter	Value	Parameter	Value
Λ_B	1.94 ± 0.09 GeV	$\mu_{\Lambda^*_{L/H}\Lambda}$	0.069 ± 0.006
g_c	8.35 ± 0.16	ϕ_c	-0.92 ± 0.12
$M_{\Lambda^*_L}$	1357.9 ± 1.1 MeV	$M_{\Lambda^*_H}$	1425.1 ± 3.4 MeV
$g_{\Lambda^*_L \pi \Sigma}$	1.13 ± 0.05	$g_{\Lambda^*_H \pi \Sigma}$	1.04 ± 0.07

PLB813(2021)136019

Fitting results



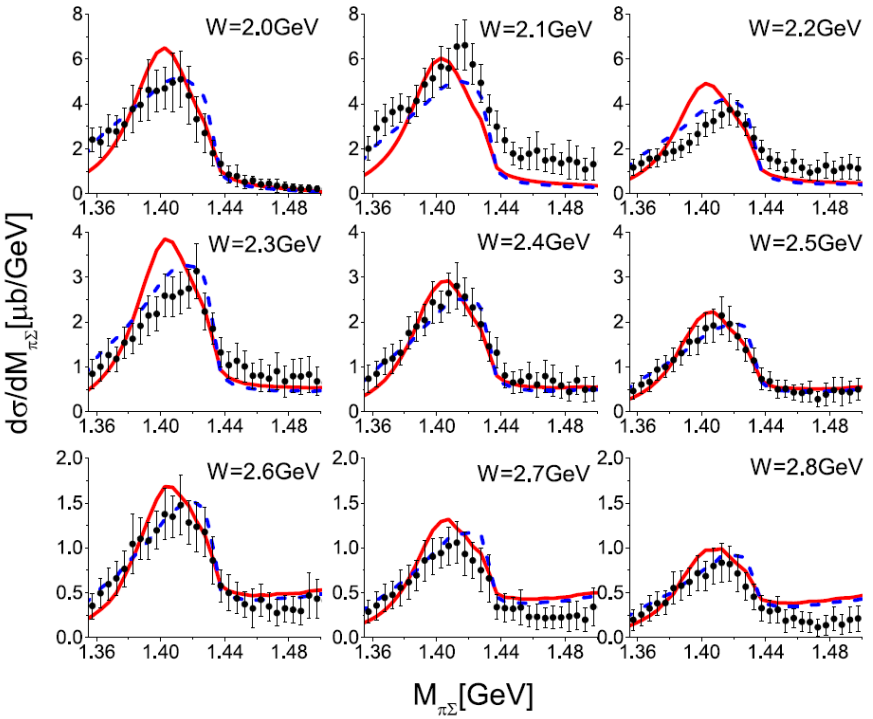
Angular distribution



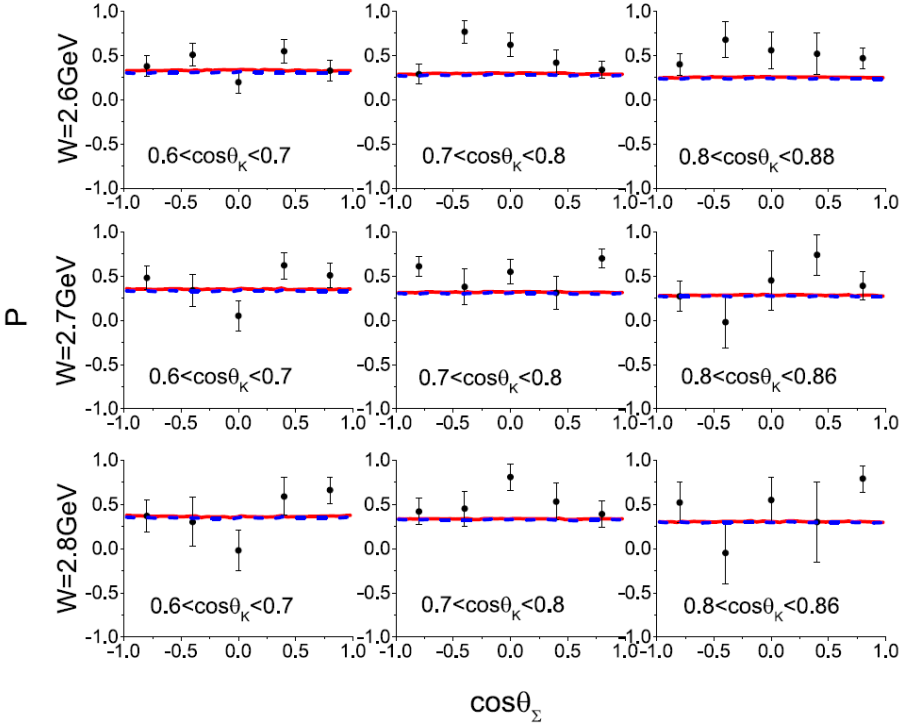
Total cross section

Angle distribution can't be used to distinguish the structure of $\Lambda(1405)$!

Fitting results



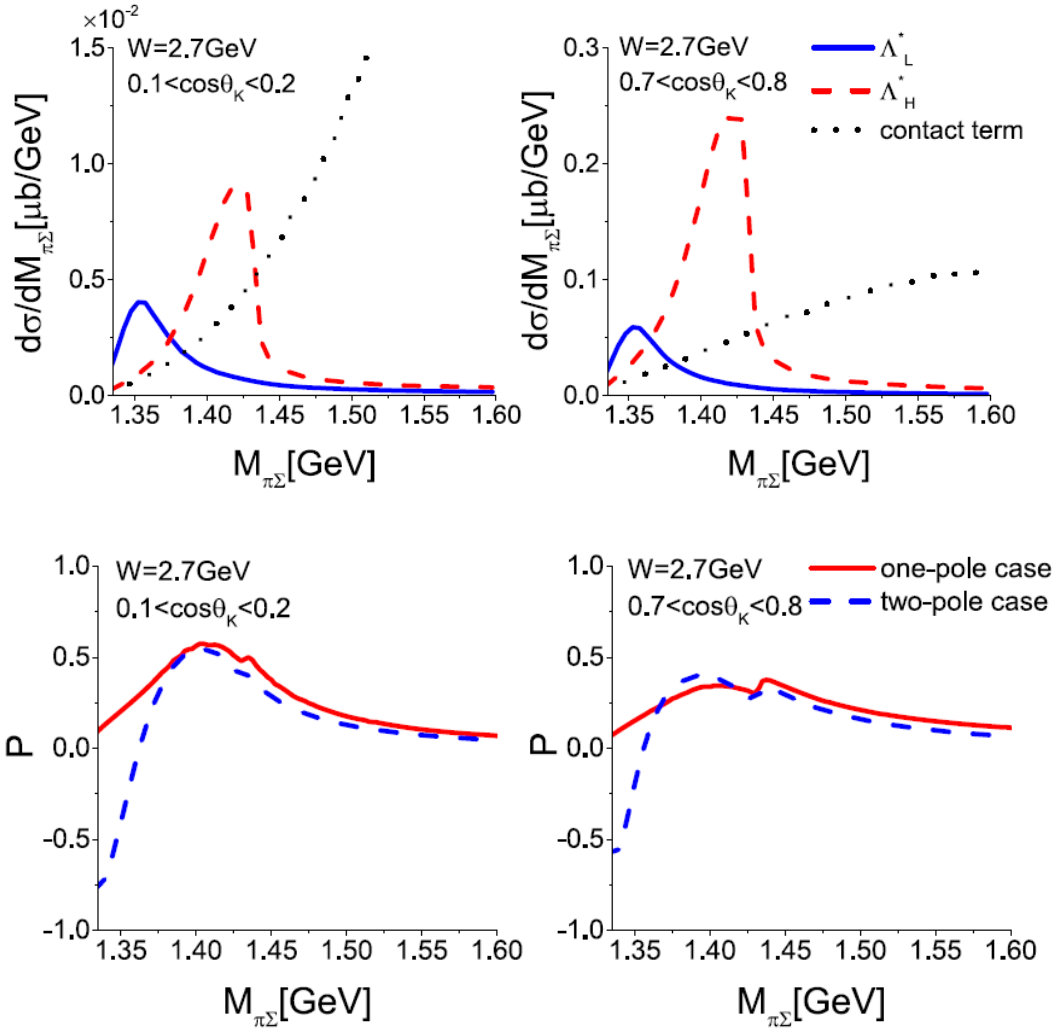
Invariant mass spectrum



Polarization

Mass spectrum and polarization also can't be used to distinguish the structure of $\Lambda(1405)$!

Results and Discussions



Polarization as a function of $M_{\pi\Sigma}$

Model dependence

Background:

K^* , $\Sigma(1385)$, …

Phase:

$$\phi = \frac{\pi}{2}, \frac{3\pi}{2}, \ldots$$

Summary

1. The contact term is necessary for interpreting the $\Lambda(1405)$ polarization.

2. Although both the one-pole and two-pole models can give a good description of the angular distribution and the invariant mass spectrum data, they give distinct predictions for the polarization of the final Σ versus the $M_{\pi\Sigma}$.

THANK YOU FOR YOUR ATTENTION!