中国科学院近代物理研究所
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Study of the light hadrons in strangeness production

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Outline

Introduction

Quark model and the status of low-lying baryon resonances

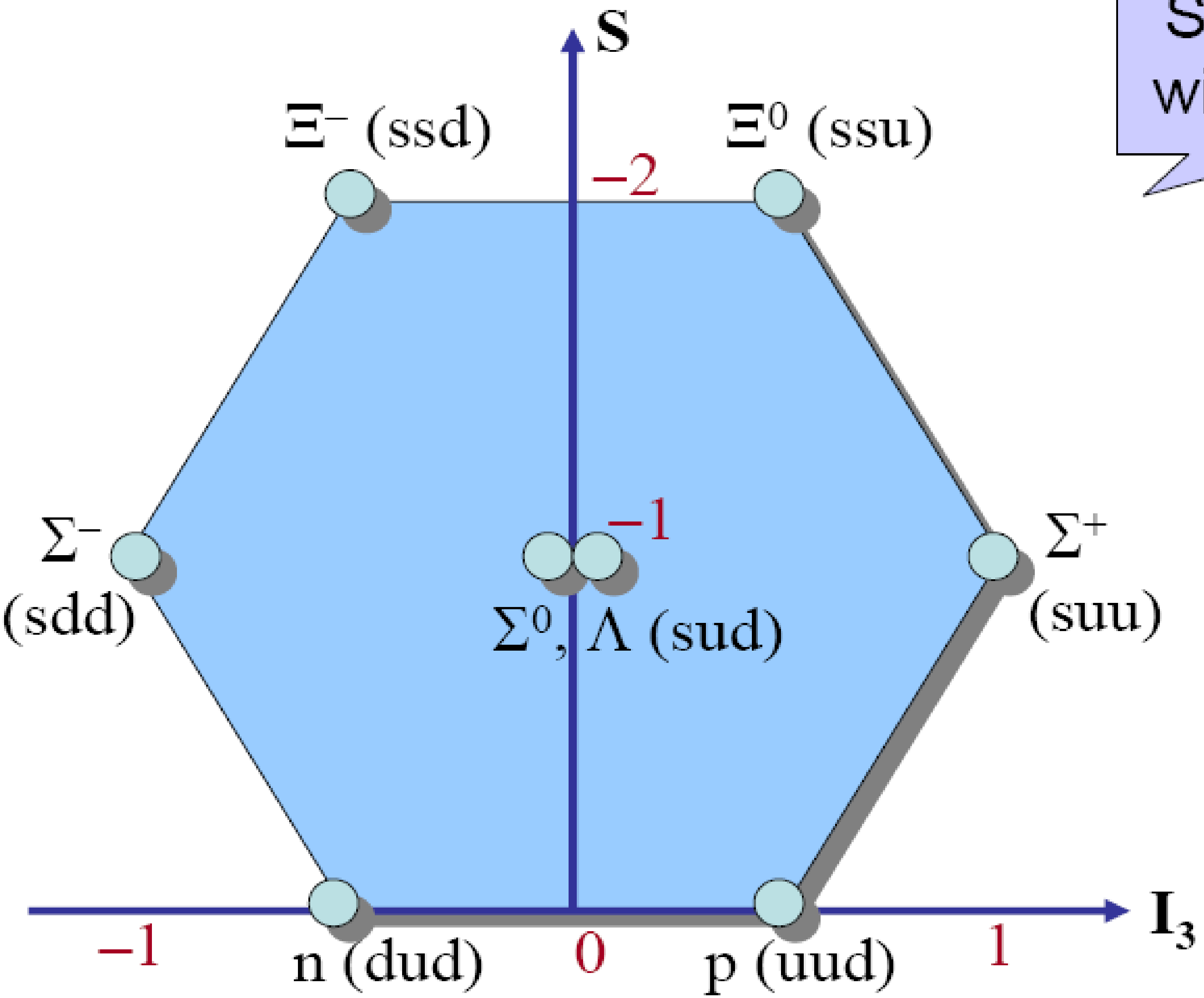
Effective Lagrangian approach and resonance model

$N^*(2120)$ *in* $\gamma p \to p\phi$ *and* $\gamma p \to K^+\Lambda(1520)$ *reactions*

$\Sigma(1380)$ *state in* $\Lambda_c^+ \to \eta\pi^+\Lambda$ *decay*

Summary

SU(3) multiplets of baryons made of u, d, and s



SU(3) octet
with $J^P=1/2^+$

Gell-Mann - Nishijima:
$Q=I_3+Y/2=I_3+(B+S)/2$

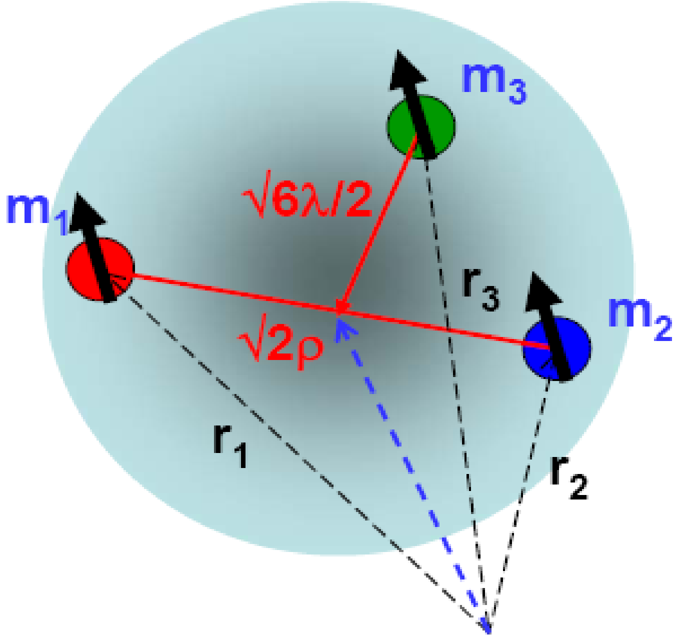
$$3\otimes3\otimes3$$
$$=(\ \bar{3}\oplus 6)\otimes 3$$
$$=(1\oplus8)\oplus(8\oplus10)$$

$$\frac{1}{\sqrt{2}}(udu - duu)$$
$$\frac{1}{\sqrt{6}}(2uud - duu - udu)$$

Symmetric spin wavefunction: S=3/2
Symmetric flavor wavefunction: sss
Symmetric spatial wavefunction: L=0

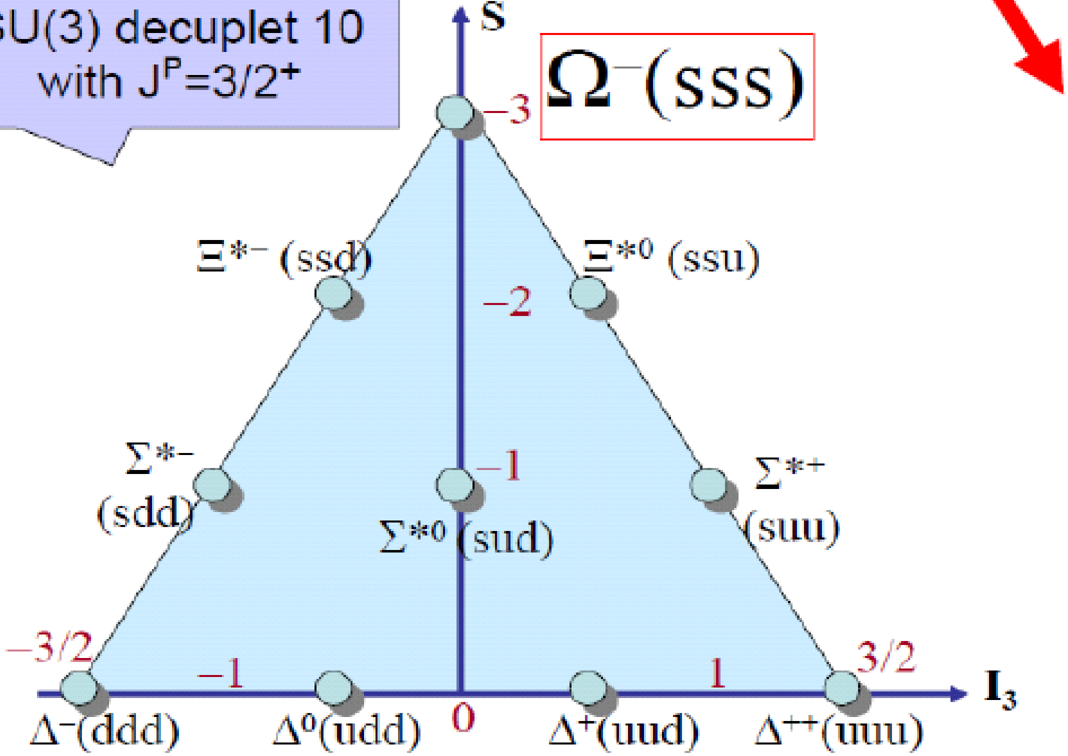
A problem encountered:

Violation of the Pauli principle and Fermi-Dirac statistics for the identical strange quark system?



Jacobi coordinate

SU(3) decuplet 10
with $J^P=3/2^+$



$\Omega^-(sss)$

- An additional degrees of freedom, **Colour**, is introduced.
- Quark carries colour, while hadrons are colour neutral objects.

$$3 \otimes 3 \otimes 3$$
$$= (\bar{3} \oplus 6) \otimes 3$$
$$= (1 \oplus 8) \oplus (8 \oplus 10)$$

Outstanding problems for the classical 3q model

- Mass order reverse problem for the lowest excited baryons

uud (L=1) $\frac{1}{2}^-$ ~ $N^*(1535)$ should be the lowest

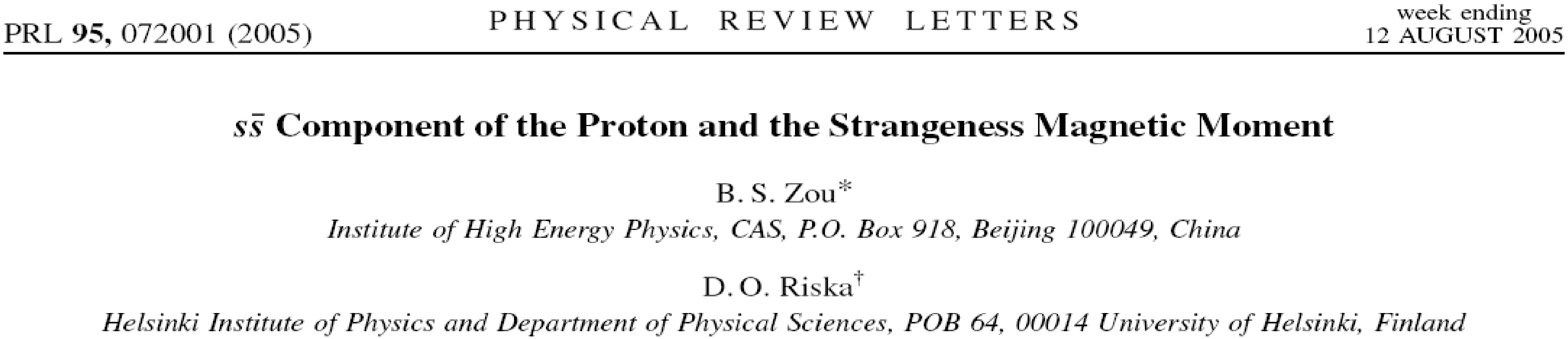
uud (n=1) $\frac{1}{2}^+$ ~ $N^*(1440)$

uds (L=1) $\frac{1}{2}^-$ ~ $\Lambda^*(1405)$

harmonic oscillator $(2n + L + 3/2)\, h\omega$

- The number of predicted states is much less than observed
  "missing" baryon states : non-existence / to be observed ?

Looking for "missing N^* resonances" in $N^* \to \eta N,\ K\Sigma,\ K\Lambda,\ \rho N,\ \omega N,\ \phi N,\ \gamma N,\ \ldots$



PRL **95,** 072001 (2005) PHYSICAL REVIEW LETTERS week ending 12 AUGUST 2005

$s\bar{s}$ Component of the Proton and the Strangeness Magnetic Moment

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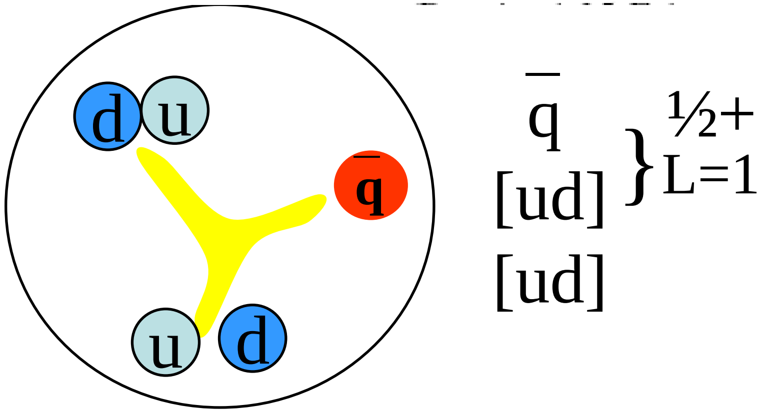
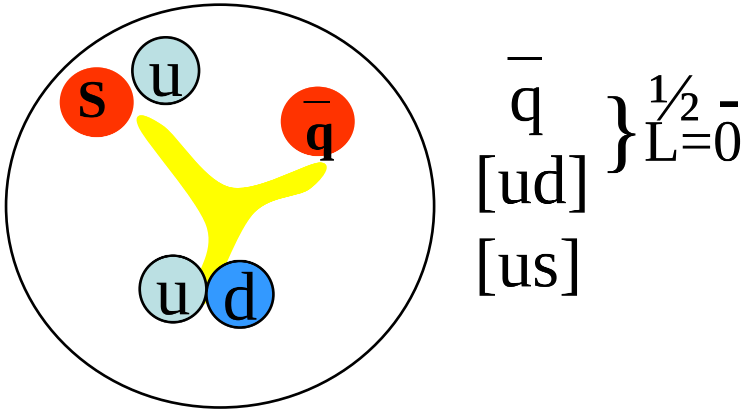


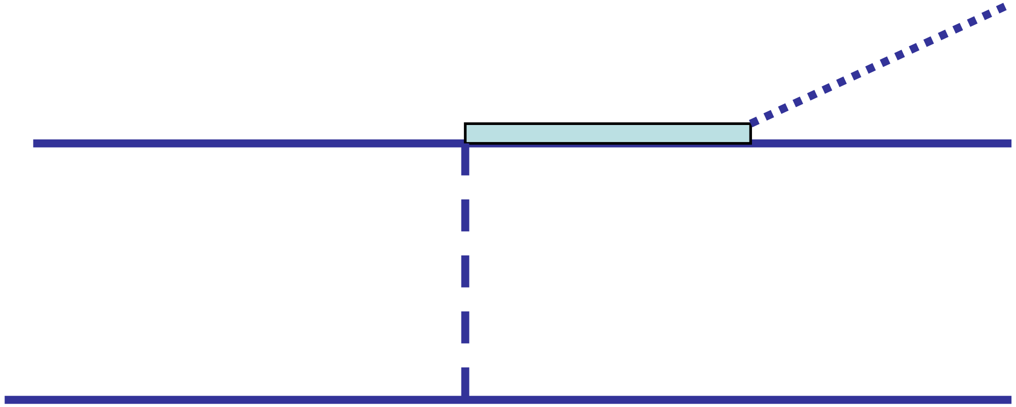


$$
\begin{aligned}
N^*(1535) &\sim uud(L=1) + \alpha[ud][us]\bar{s} + \ldots \\
N^*(1440) &\sim uud(n=1) + \beta[ud][ud]\bar{d} + \ldots \\
\Lambda^*(1405) &\sim uud(L=1) + \gamma[ud][su]\bar{u} + \ldots
\end{aligned}
$$

Larger [ud][us] $\bar{s}$ component in $N^*(1535)$ makes it coupling stronger to Nη & KΛ, weaker to Nπ, and heavier!

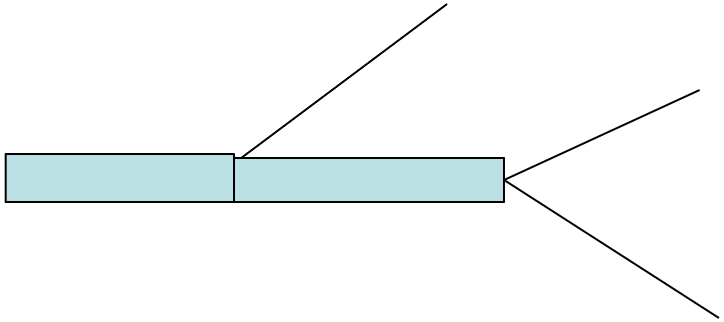
B.C.Liu, B.S.Zou, PRL 96 (2006) 042002

The effective Lagrangian approach and resonance model



- Hadron level
- Vertex: effective Lagrangian
- Resonance: Breit-Wigner

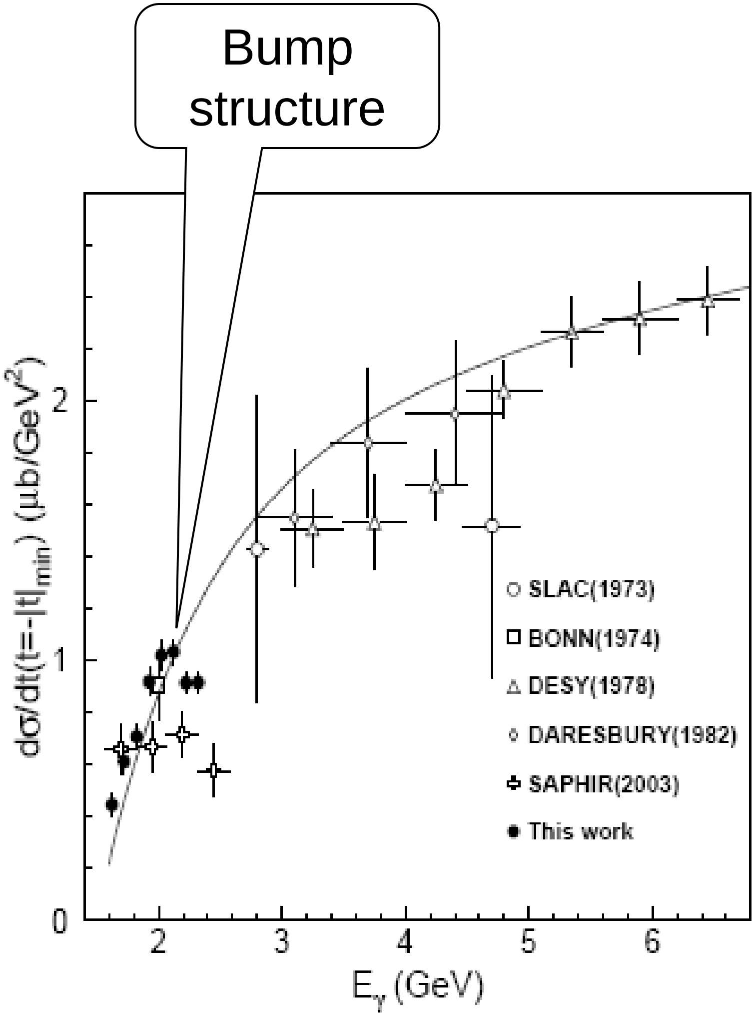
$$\frac{C}{s-M_R^2+iM_R\Gamma_R}$$



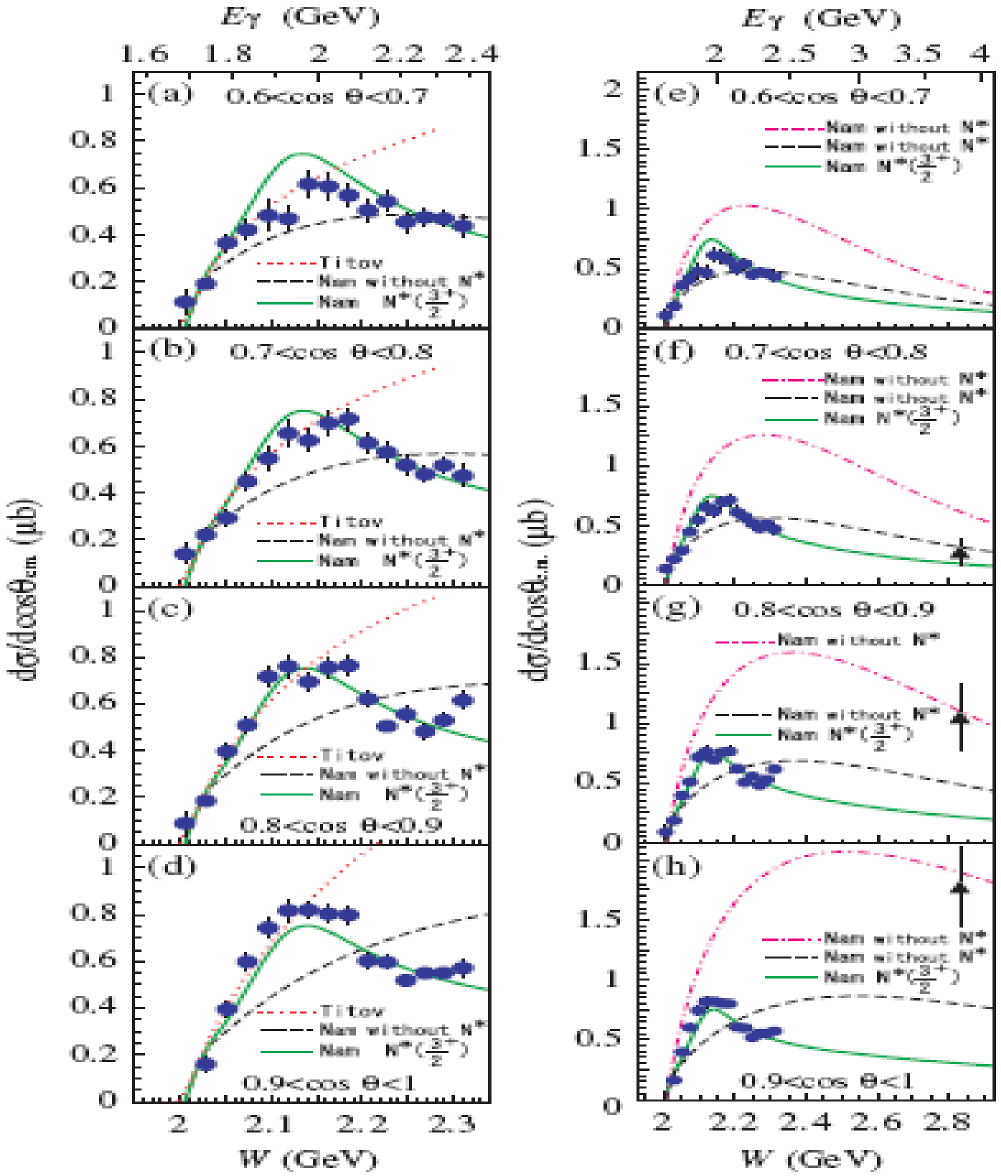
$$d\Gamma = \frac{1}{(2\pi)^3}\frac{1}{8M}\,\overline{|\mathscr{M}|^2}\,dE_1\,dE_2$$

$$= \frac{1}{(2\pi)^3}\frac{1}{32M^3}\,\overline{|\mathscr{M}|^2}\,dm_{12}^2\,dm_{23}^2$$

Study “N*(2080)” in γp->pϕ and γp-> K$^+$Λ(1520) reactions



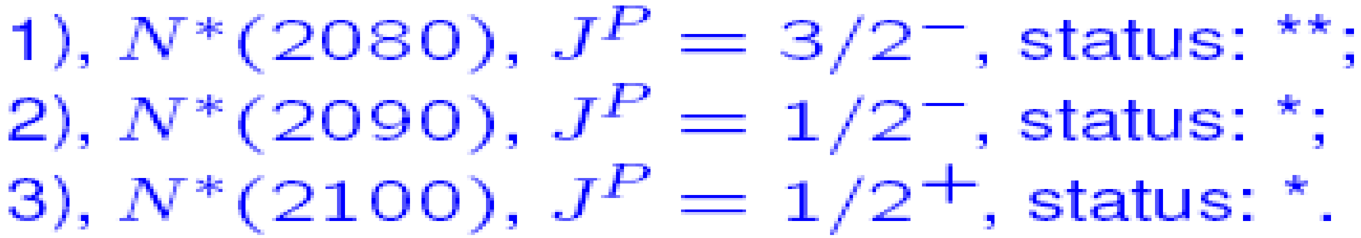
$\gamma p \rightarrow p\phi$ *reaction*



$\gamma p \rightarrow K^{+}\Lambda(1520)$ *reaction*

PRL, 95, 182001 (2005); PRL, 104, 172001 (2010), LEPS Collaboration.

Why $N^*(2080)$



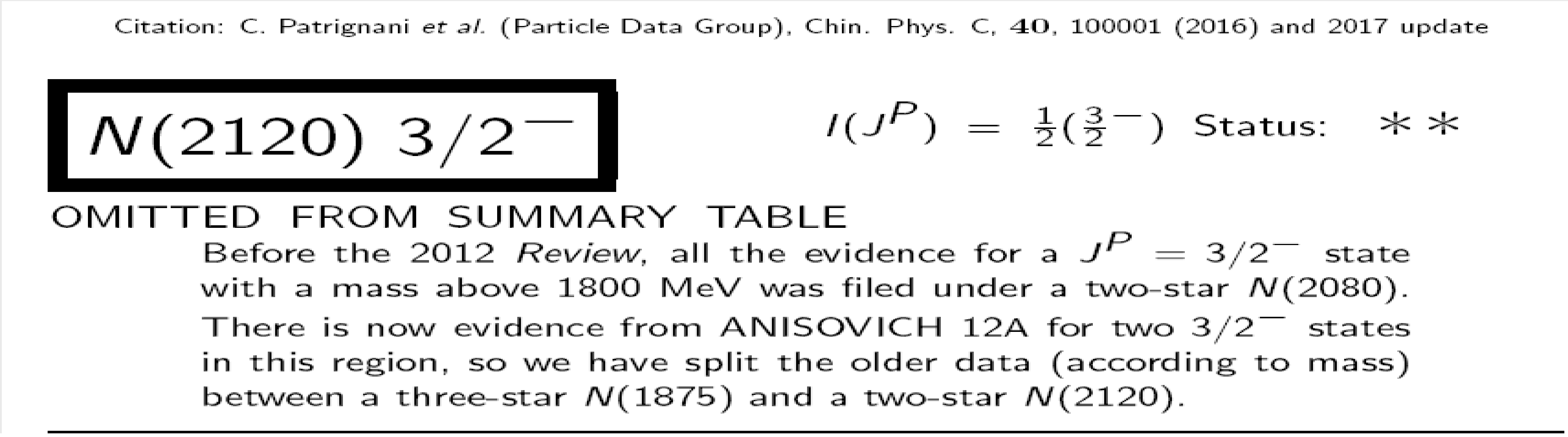
1), $N^*(2080)$, $J^P = 3/2^-$, status: **;
2), $N^*(2090)$, $J^P = 1/2^-$, status: *;
3), $N^*(2100)$, $J^P = 1/2^+$, status: *.

PDG
2010

Quark Model prediction:

N(2080) has significant contributions to the $\gamma p \to K^+\Lambda(1520)$ reaction

Capstick, PRD 46, 2864 (1992); 58, 074011 (1998).



Citation: C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C, **40**, 100001 (2016) and 2017 update

$N(2120)$ $3/2^-$

$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$ Status: **

OMITTED FROM SUMMARY TABLE

Before the 2012 *Review*, all the evidence for a $J^P = 3/2^-$ state with a mass above 1800 MeV was filed under a two-star $N(2080)$. There is now evidence from ANISOVICH 12A for two $3/2^-$ states in this region, so we have split the older data (according to mass) between a three-star $N(1875)$ and a two-star $N(2120)$.

Our model

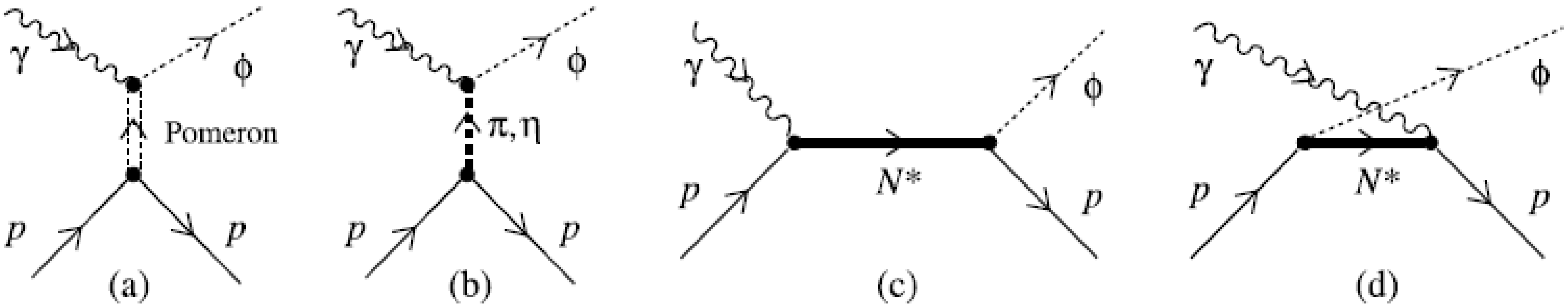
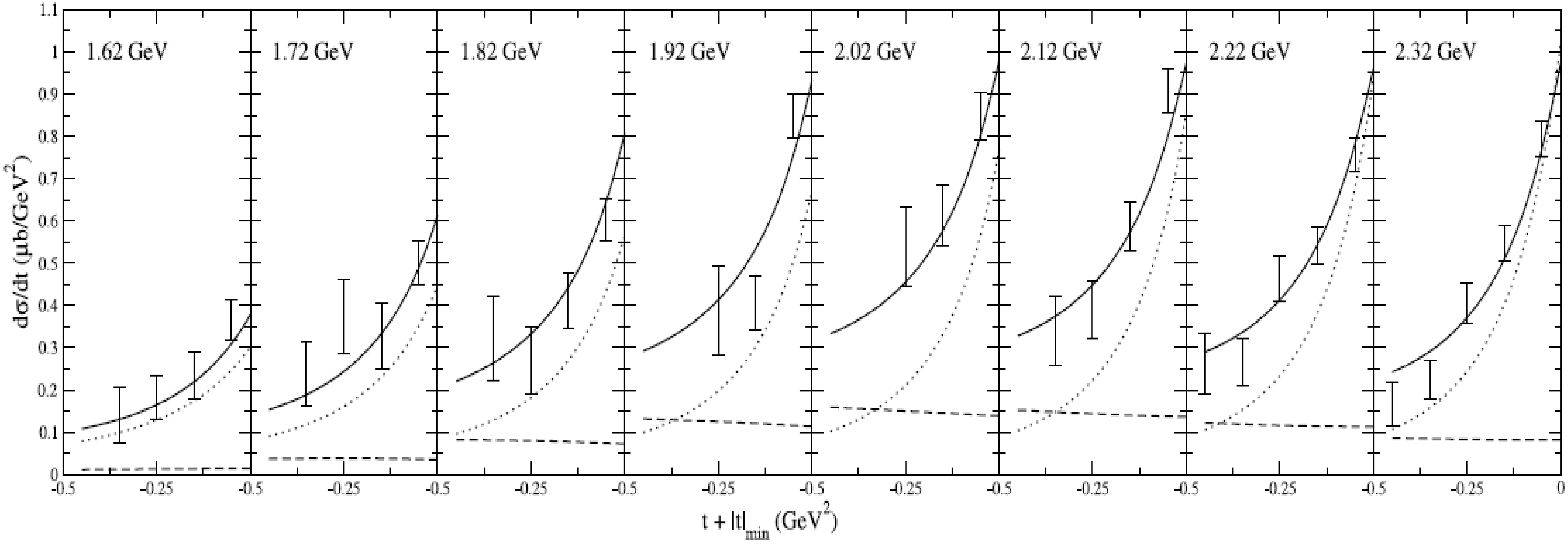


Fig. 1. (a) Pomeron-exchange, (b) (π, η)-exchange, and (c,d) s- and u-channel N^*-exchange diagrams for $\gamma p \to \phi p$ reaction.



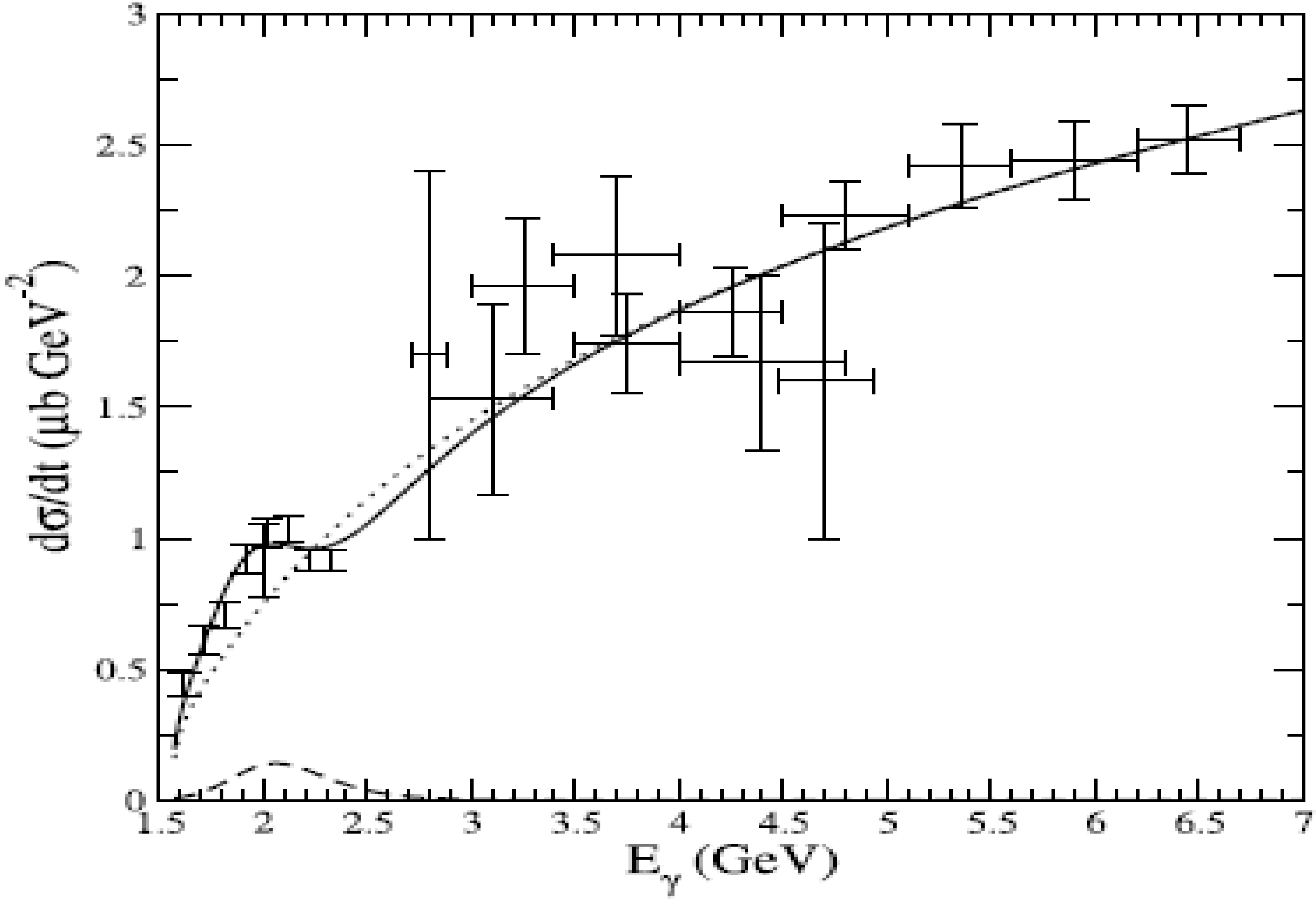
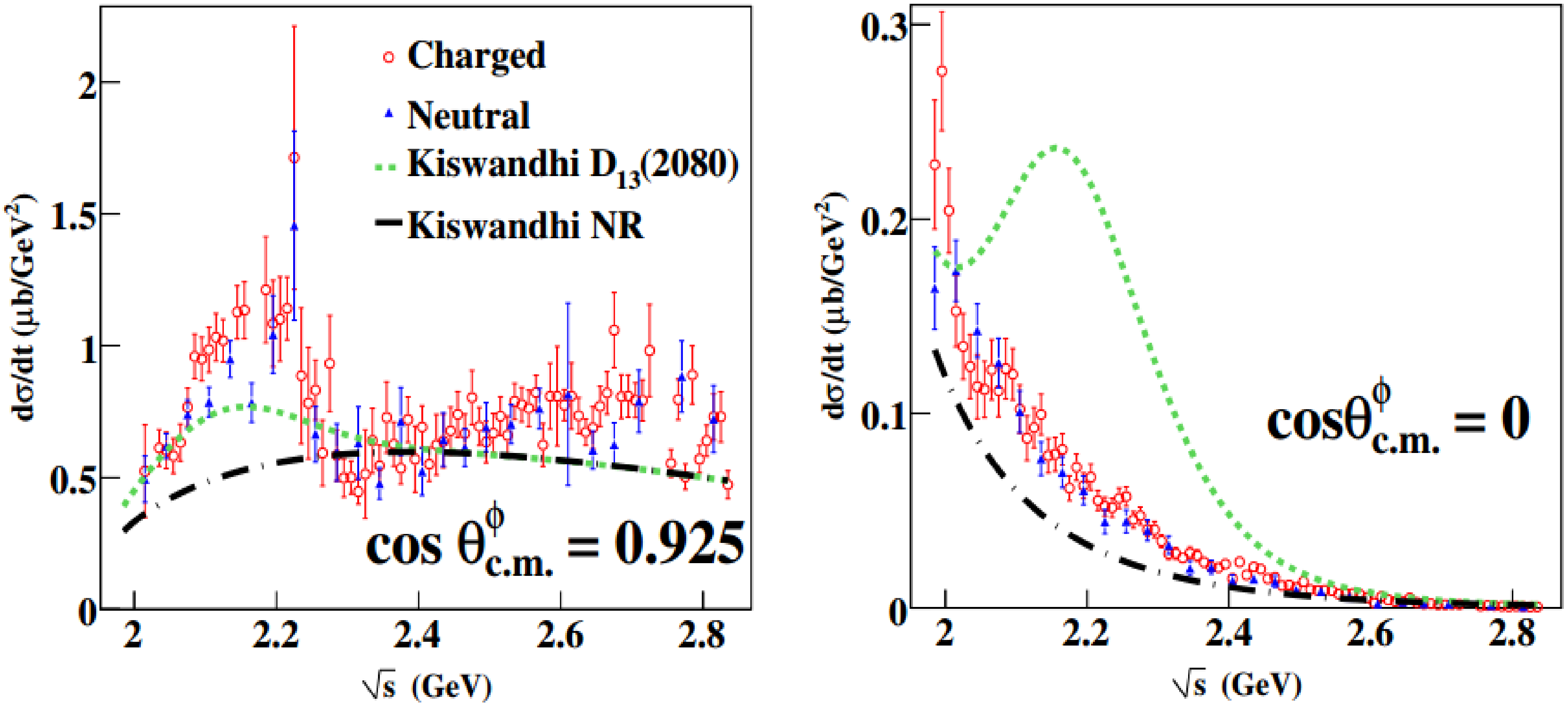


Fig. 2. Differential cross section of $\gamma p \to \phi p$ at forward direction as a function of photon energy E_γ. The dotted, dashed, and solid lines denote contributions from nonresonant, resonance with $J^P = 3/2^-$, and their sum, respectively. Data are from Refs. [10,17].

Alvin Kiswandhi, Ju-Jun Xie, Shin Nan Yang, PLB, 691, 214 (2010).

New measurements

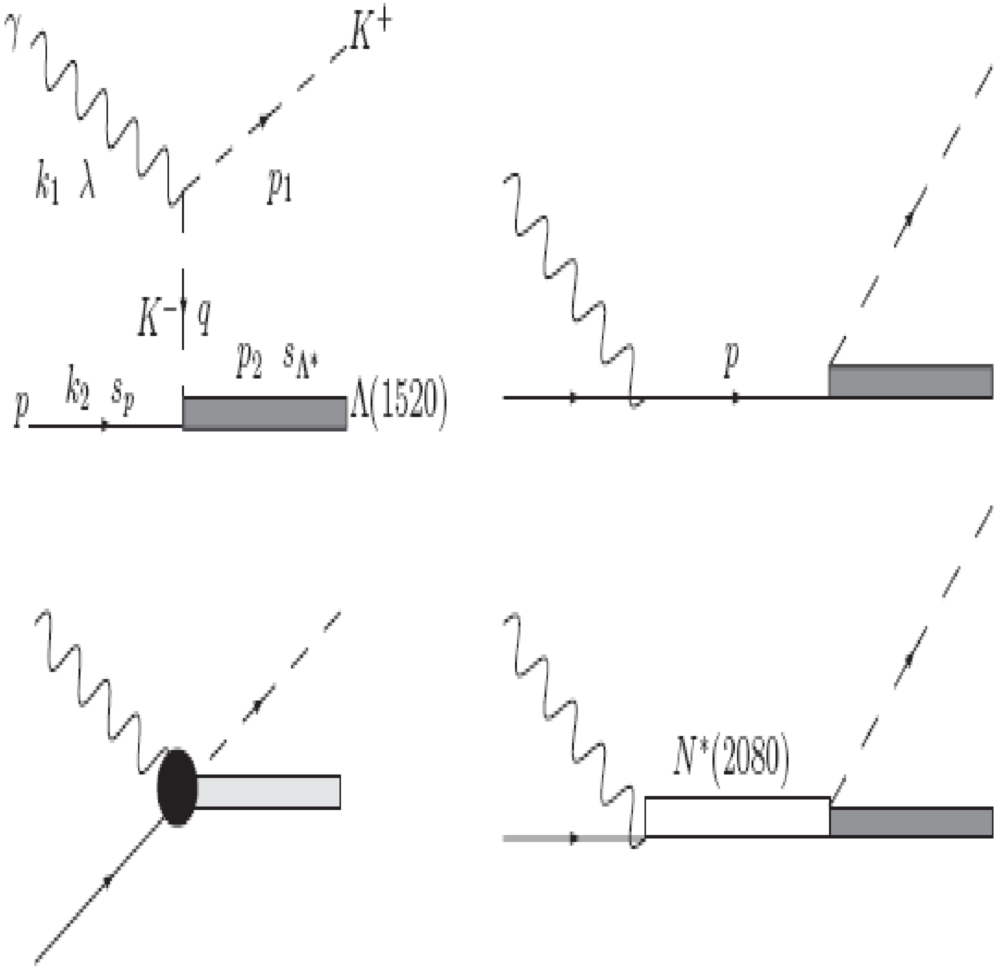


(a) (b)

FIG. 1: (Color online) Comparison between the charged- and neutral-mode ϕ data from CLAS [1] and model predictions from Kiswandhi *et al.* [3] that include a $D_{13}(2080)$ resonance exchange in the s-channel. The data shows a local structure at (a) forward-angles but none at (b) mid-angles.

arXiv:1403.3730 PHYSICAL REVIEW C **89**, 055208 (2014)

Theγp->K$^+$Λ(1520) reaction



$$\mathcal{L}_{\gamma KK} = -ie(K^-\partial^\mu K^+ - K^+\partial^\mu K^-)A_\mu, \qquad (1)$$

$$\mathcal{L}_{Kp\Lambda^*} = \frac{g_{KN\Lambda^*}}{m_K}\bar{\Lambda}^{*\mu}(\partial_\mu K^-)\gamma_5 p + \text{H.c.}, \qquad (2)$$

$$\mathcal{L}_{\gamma pp} = -e\bar{p}\left(\not{A} - \frac{\kappa_p}{2M_N}\sigma_{\mu\nu}(\partial^\nu A^\mu)\right)p + \text{H.c.}, \qquad (3)$$

$$\mathcal{L}_{\gamma Kp\Lambda^*} = -ie\frac{g_{KN\Lambda^*}}{m_K}\bar{\Lambda}^{*\mu}A_\mu K^-\gamma_5 p + \text{H.c.}, \qquad (4)$$

$$\mathcal{L}_{\gamma NN^*} = \frac{ief_1}{2m_N}\bar{N}^*_\mu\gamma_\nu F^{\mu\nu}N - \frac{ef_2}{(2m_N)^2}\bar{N}^*_\mu F^{\mu\nu}\partial_\nu N + \text{H.c.}, \qquad (5)$$

$$\mathcal{L}_{K\Lambda^*N^*} = \frac{g_1}{m_K}\bar{\Lambda}^*_\mu\gamma_5\gamma_\alpha(\partial^\alpha K)N^{*\mu} + \frac{ig_2}{m_K^2}\bar{\Lambda}^*_\mu\gamma_5(\partial^\mu\partial_\nu K)N^{*\nu} + \text{H.c.}, \qquad (6)$$

Scattering amplitudes

$$-iT_i = \bar{u}_\mu(p_2, s_{\Lambda *})A_i^{\mu\nu} u(k_2, s_p)\epsilon_\nu(k_1, \lambda),$$

$$A_t^{\mu\nu} = -e\frac{g_{KN\Lambda^*}}{m_K}\frac{1}{q^2 - m_K^2}q^\mu(q^\nu - p_1^\nu)\gamma_5 f_c, \tag{8}$$

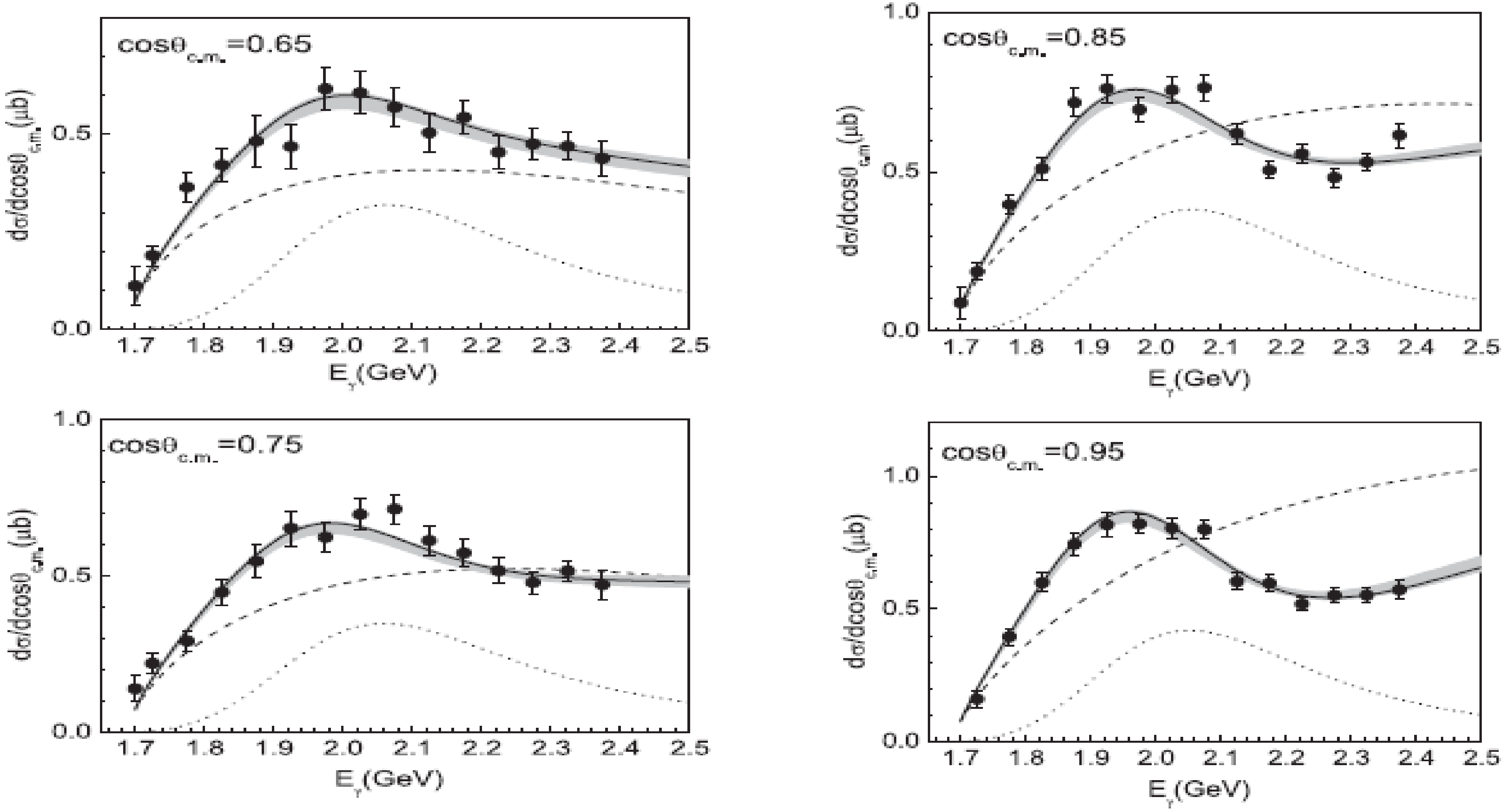
$$\begin{aligned} A_s^{\mu\nu} = {} & -e\frac{g_{KN\Lambda^*}}{m_K}\frac{1}{s - M_N^2}p_1^\mu\gamma_5\biggl\{k_1\gamma^\nu f_s + (\not{k}_2 + M_N)\gamma^\nu f_c \\ & + (\not{k}_1 + \not{k}_2 + M_N)i\frac{\kappa_p}{2M_N}\sigma_{\nu\rho}k_1^\rho f_s\biggr\}, \end{aligned} \tag{9}$$

$$A_c^{\mu\nu} = e\frac{g_{KN\Lambda^*}}{m_K}g^{\mu\nu}\gamma_5 f_c, \tag{10}$$

$$\begin{aligned} A_R^{\mu\nu} = {} & \gamma_5\left(\frac{g_1}{m_K}\not{p}_1 g^{\mu\rho} - \frac{g_2}{m_K^2}p_1^\mu p_1^\rho\right)\frac{\not{k}_1 + \not{k}_2 + M_{N^*}}{s - M_{N^*}^2 + iM_{N^*}\Gamma_{N^*}} \\ & \times P_{\rho\sigma}\biggl[\frac{ef_1}{2m_N}(k_1^\sigma\gamma^\nu - g^{\sigma\nu}\not{k}_1) \\ & + \frac{ef_2}{(2m_N)^2}(k_1^\sigma k_2^\nu - g^{\sigma\nu}k_1\cdot k_2)\biggr]f_R. \end{aligned} \tag{11}$$

Fitted results

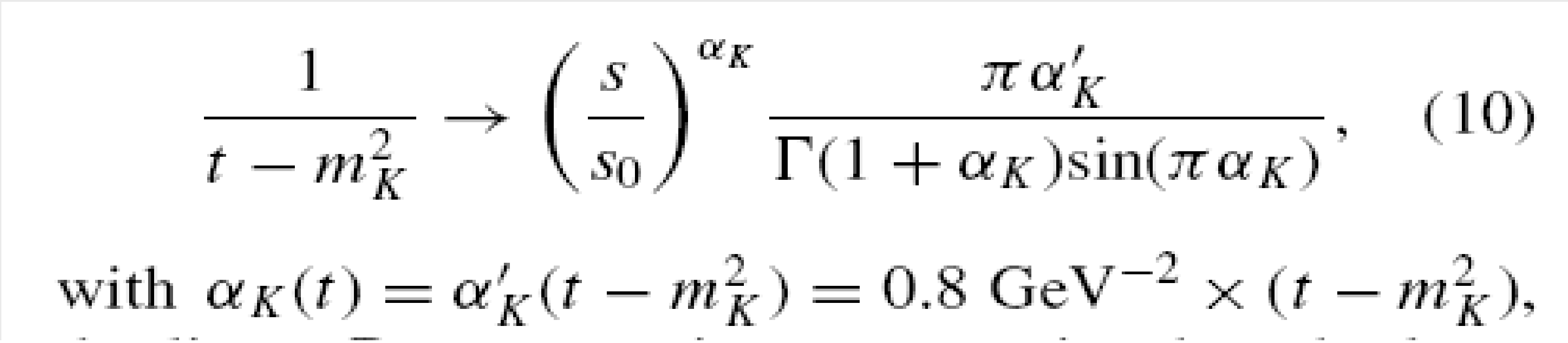
$$\left.\frac{d\sigma}{d\Omega}\right|_{\text{c.m.}} = \frac{|\vec{k}_1^{\,\text{c.m.}}||\vec{p}_1^{\,\text{c.m.}}|}{4\pi^2}\frac{M_N M_{\Lambda^*}}{\left(s - M_N^2\right)^2}\left(\frac{1}{2}\sum_{s_p, s_\Lambda^*}|T|^2\right)$$



Ju-Jun Xie, and Juan Nieves, Phys. Rev. C 82, 045205 (2010)

Regge contributions

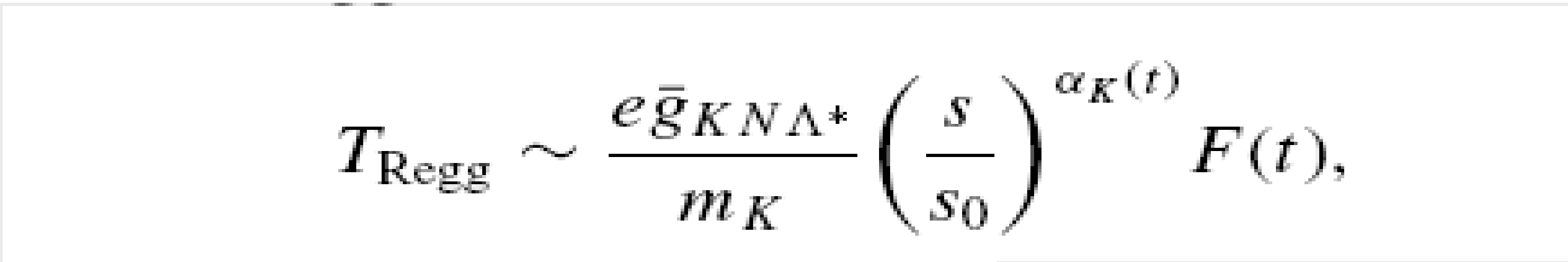
Model A



$$\frac{1}{t-m_K^2} \rightarrow \left(\frac{s}{s_0}\right)^{\alpha_K} \frac{\pi \alpha'_K}{\Gamma(1+\alpha_K)\sin(\pi \alpha_K)}, \quad (10)$$

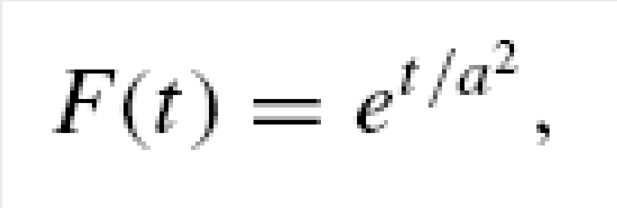
with $\alpha_K(t) = \alpha'_K(t-m_K^2) = 0.8\ \mathrm{GeV}^{-2} \times (t-m_K^2)$,

Model B

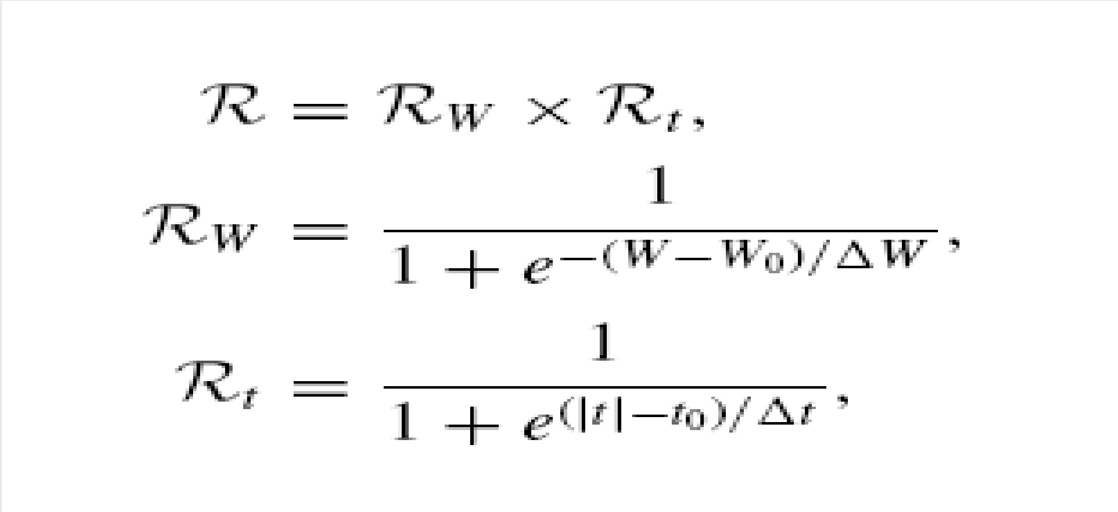


$$T_{\mathrm{Regg}} \sim \frac{e\bar{g}_{KN\Lambda^*}}{m_K} \left(\frac{s}{s_0}\right)^{\alpha_K(t)} F(t),$$

$$T = T_{\mathrm{Hadron}}(1-\mathcal{R}) + T_{\mathrm{Regg}}\mathcal{R}$$



$$F(t) = e^{t/a^2},$$

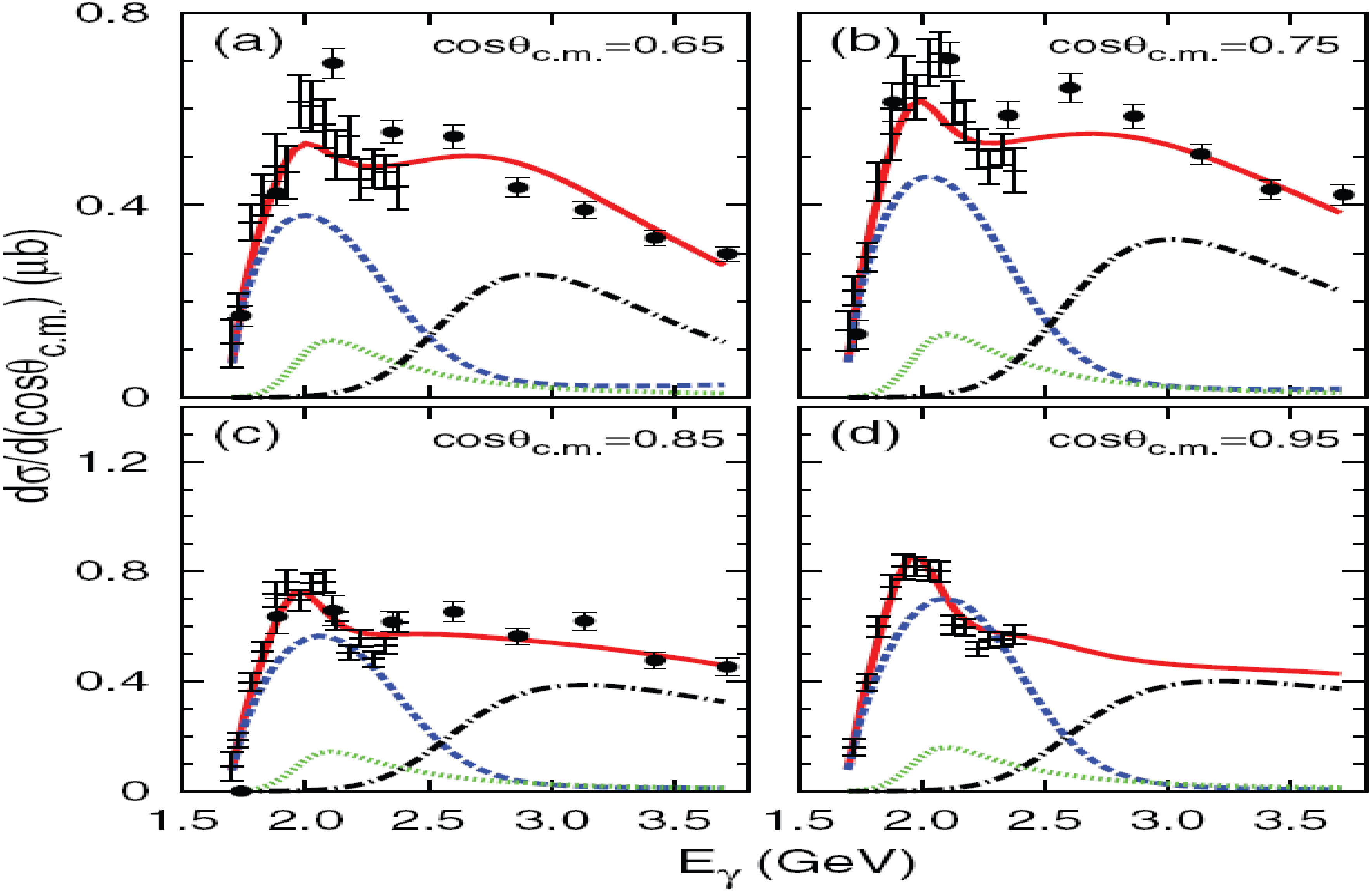


$$\mathcal{R} = \mathcal{R}_W \times \mathcal{R}_t,$$

$$\mathcal{R}_W = \frac{1}{1+e^{-(W-W_0)/\Delta W}},$$

$$\mathcal{R}_t = \frac{1}{1+e^{(|t|-t_0)/\Delta t}},$$

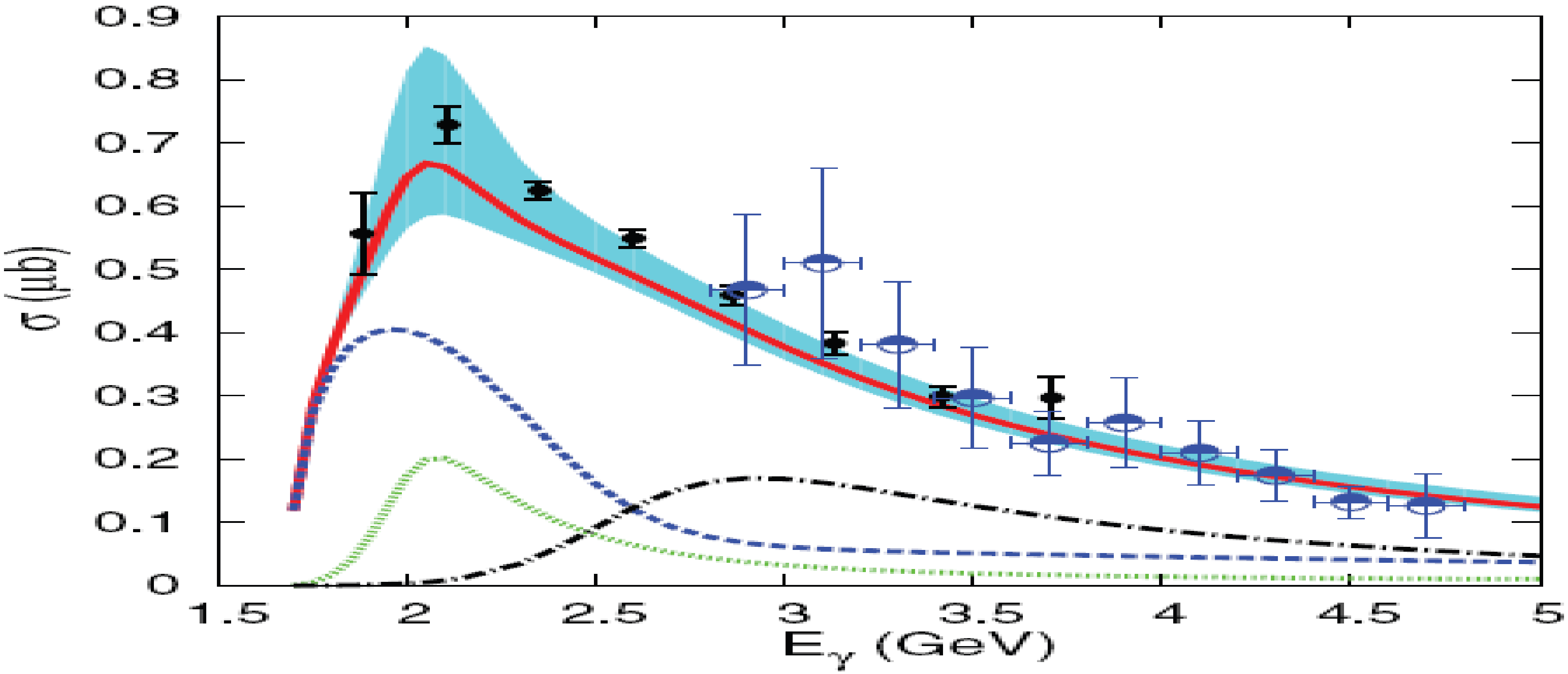
Fitted results with Regge contributions



New data from CLAS Collaboration: K. Moriya, et.al., PRC 88, 045201 (2013).

Fitted parameters for N(2120) and the total cross section

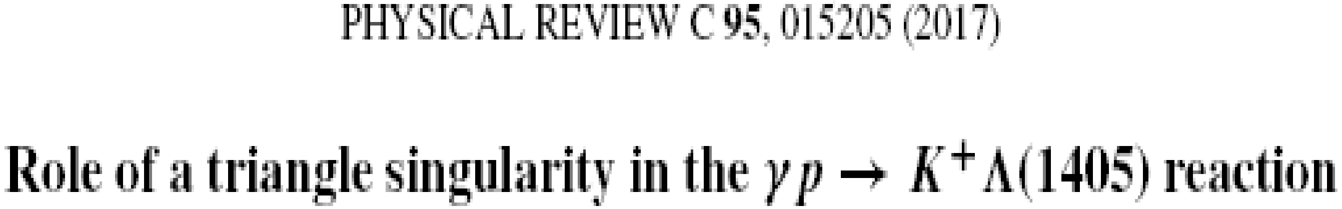
M_{N^*} (MeV)	2146±5	2145±5	2135±4
Γ_{N^*} (MeV)	174±14	171±13	184±11



Nature of N(2120)

- The N(2120) in KΛ(1520) photoproduction is a three-qurak state
- The N(1875) and N(2100) in pϕ photoproduction are hadronic molecular states, which can be see as the strangeness partners of the LHCb pentaqurks

Jun He, ``Nucleon resonances N(1875) and N(2100) as strange partners of LHCb pentaquarks," Phys. Rev. D 95, 074031 (2017).

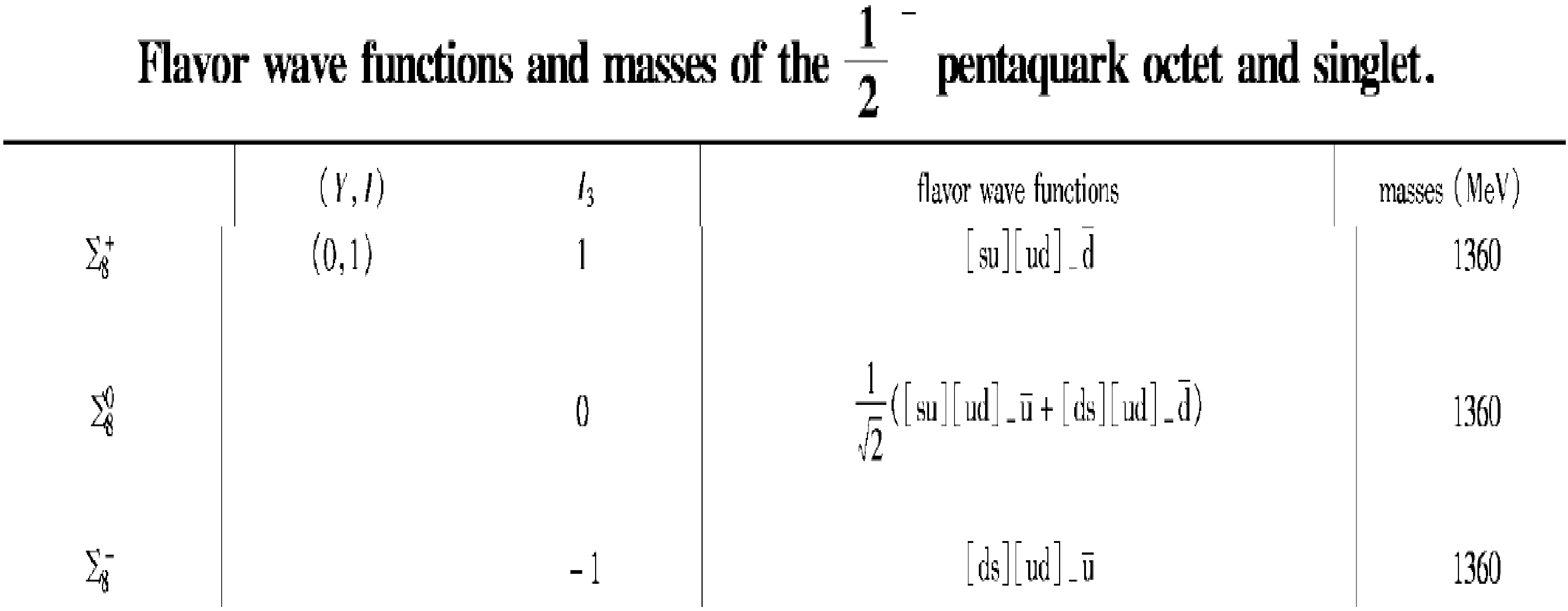


PHYSICAL REVIEW C 95, 015205 (2017)

Role of a triangle singularity in the $\gamma p \to K^+\Lambda(1405)$ reaction

En Wang, JJX, Wei-Hong Liang, Feng-Kun Guo, and E. Oset

A possible Σ(1380) state with $J^P = \frac{1}{2}^-$



Flavor wave functions and masses of the $\frac{1}{2}^-$ pentaquark octet and singlet.

	(Y, I)	I_3	flavor wave functions	masses (MeV)
Σ_8^+	(0,1)	1	$[su][ud]_-\bar{d}$	1360
Σ_8^0		0	$\frac{1}{\sqrt{2}}([su][ud]_-\bar{u}+[ds][ud]_-\bar{d})$	1360
Σ_8^-		-1	$[ds][ud]_-\bar{u}$	1360

Ao Zhang, Y. R. Liu, P.Z. Huang, W.Z. Deng, X.L. chen and S.L. Zhu, High Energy Phys. Nucl. Phys. 29, 250 (2005).

PHYSICAL REVIEW D **80,** 017503 (2009)

Evidence for a new Σ^* resonance with $J^P = 1/2^-$ in the old data of the $K^- p \to \Lambda\pi^+\pi^-$ reaction

Jia-Jun Wu,[1] S. Dulat,[2,3] and B. S. Zou[1,3]

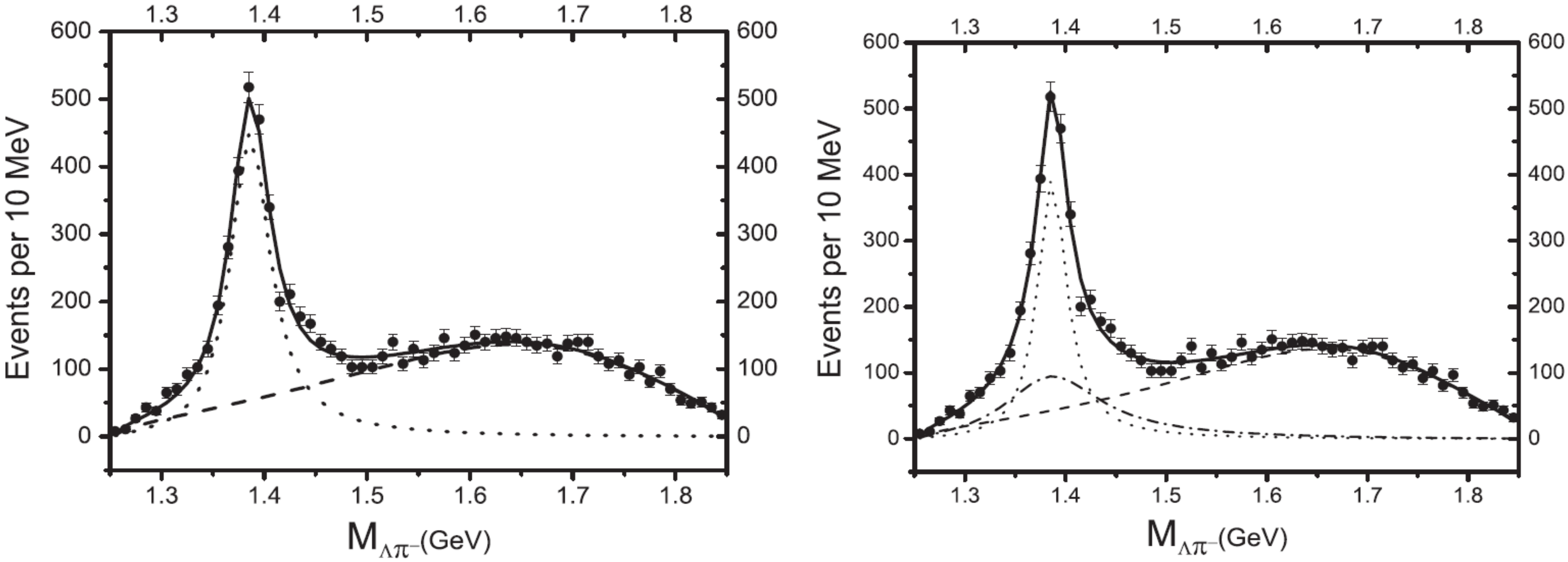
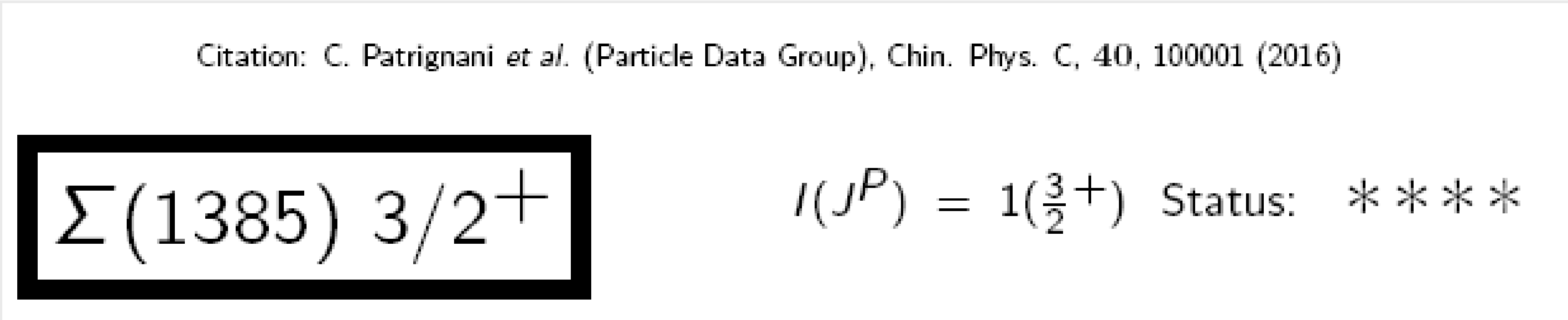


FIG. 1. Fits to the $\Lambda\pi^-$ mass spectrum with a single Σ^* (left panel) and two Σ^* resonances (right panel) around 1385 MeV with fitting parameters listed in Table I. The experiment data are from Ref. [14].

TABLE I. Fitted parameters with statistical errors and χ^2 over the number of degrees of freedom (ndf) for the fits with a single (Fit1) and two Σ^* resonances (Fit2) around 1385 MeV.

	$M_{\Sigma^*(3/2)}$	$\Gamma_{\Sigma^*(3/2)}$	$M_{\Sigma^*(1/2)}$	$\Gamma_{\Sigma^*(1/2)}$	χ^2/ndf (Fig. 1)	χ^2/ndf (Fig. 2)
Fit1	1385.3 ± 0.7	46.9 ± 2.5			68.5/54	10.1/9
Fit2	$1386.1^{+1.1}_{-0.9}$	$34.9^{+5.1}_{-4.9}$	$1381.3^{+4.9}_{-8.3}$	$118.6^{+55.2}_{-35.1}$	58.0/51	3.2/9

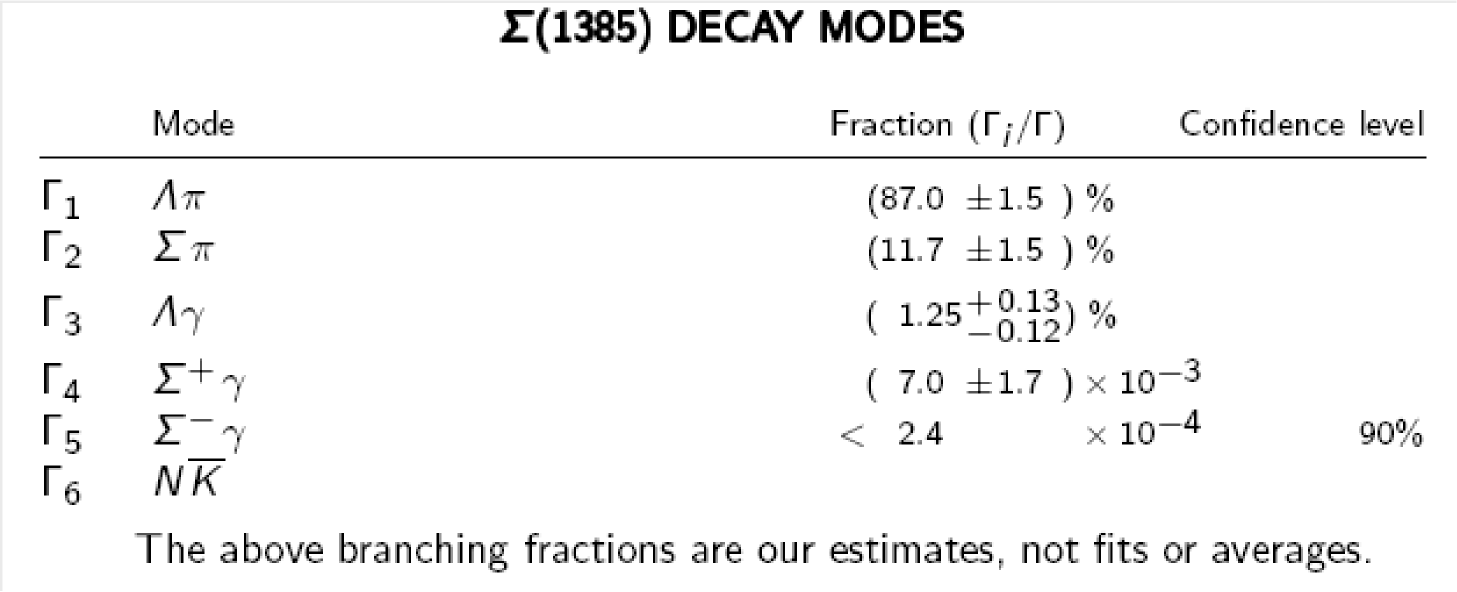
$\Sigma^*(1385)$



Citation: C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C, 40, 100001 (2016)

$\Sigma(1385)\ 3/2^+$

$I(J^P) = 1(\frac{3}{2}^+)$ Status: ∗∗∗∗

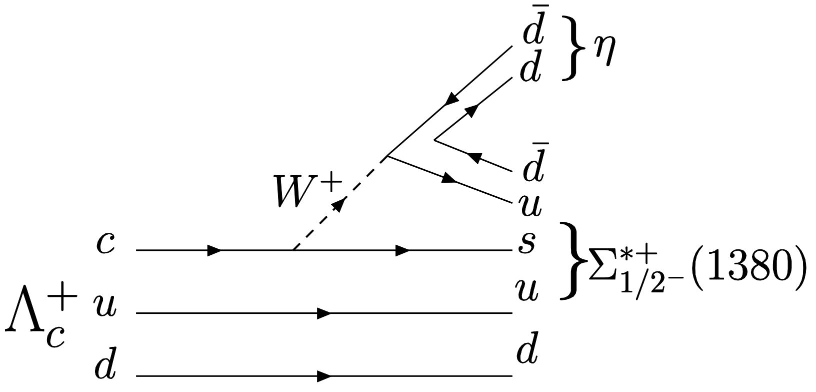


Σ(1385) DECAY MODES

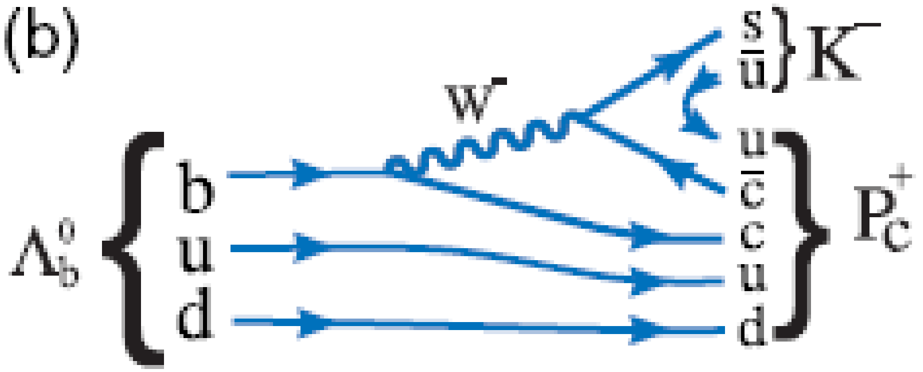
	Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1	$\Lambda\pi$	(87.0 ± 1.5) %	
Γ_2	$\Sigma\pi$	(11.7 ± 1.5) %	
Γ_3	$\Lambda\gamma$	$(1.25^{+0.13}_{-0.12})$ %	
Γ_4	$\Sigma^+\gamma$	$(7.0 \pm 1.7) \times 10^{-3}$	
Γ_5	$\Sigma^-\gamma$	$< 2.4 \times 10^{-4}$	90%
Γ_6	$N\overline{K}$		

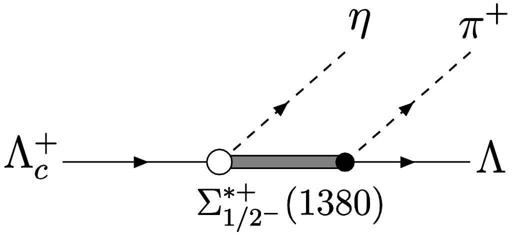
The above branching fractions are our estimates, not fits or averages.

$\Sigma(1380)$ in $\Lambda^+_c \to \eta\pi^+\Lambda$ decay



(a)

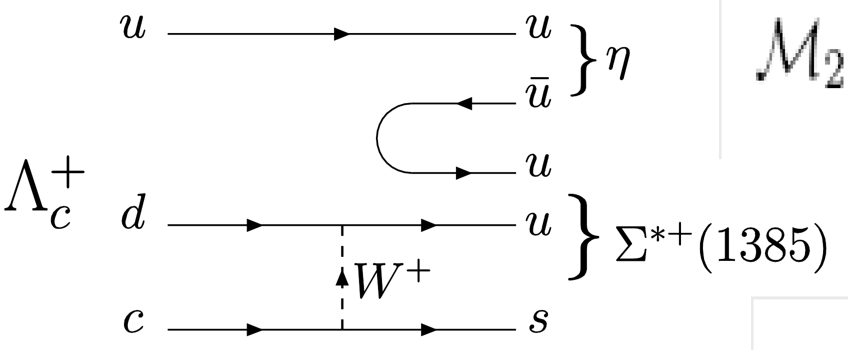




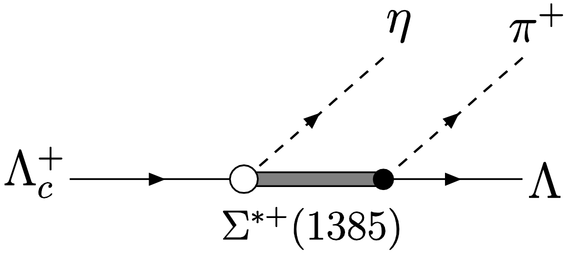
(b)

$$\mathcal{M}_1 = i g_{\pi\Lambda\Sigma_1^*} \bar{u}(p_3) G^{\Sigma_1^*}(q)(A_1 + B_1\gamma_5)u(p),$$

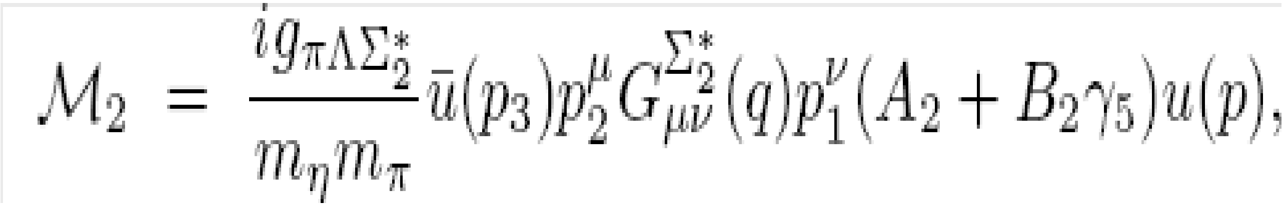
$$G^{\Sigma_1^*}(q) = i\frac{\not{q} + M_{\Sigma_1^*}}{q^2 - M^2_{\Sigma_1^*} + iM_{\Sigma_1^*}\Gamma_{\Sigma_1^*}};$$



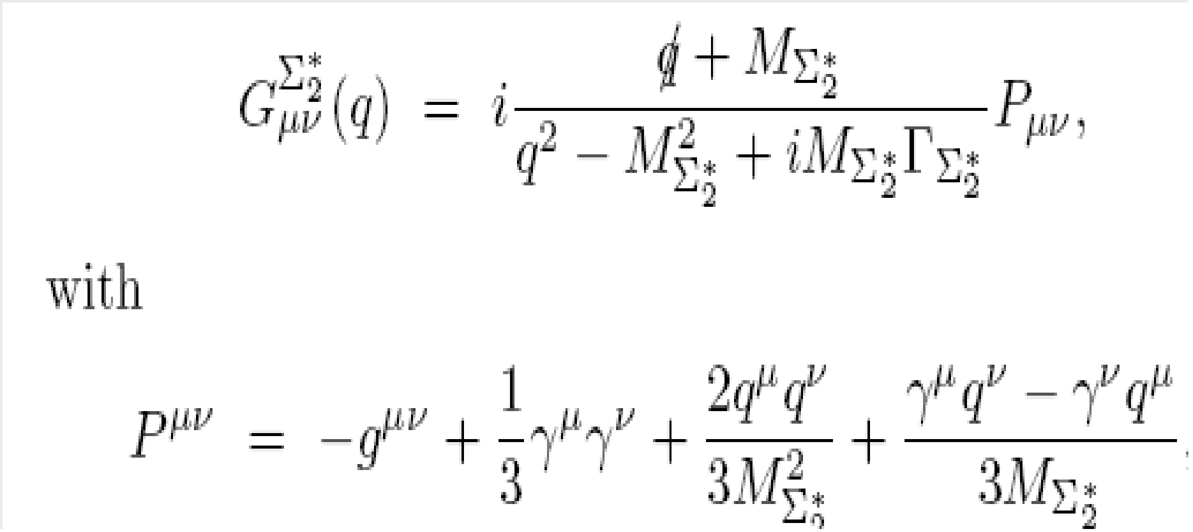
(a)



(b)



$$\mathcal{M}_2 = \frac{i g_{\pi\Lambda\Sigma_2^*}}{m_\eta m_\pi}\bar{u}(p_3)p_2^\mu G^{\Sigma_2^*}_{\mu\nu}(q)p_1^\nu(A_2+B_2\gamma_5)u(p),$$



$$G^{\Sigma_2^*}_{\mu\nu}(q) = i\frac{\not{q}+M_{\Sigma_2^*}}{q^2-M^2_{\Sigma_2^*}+iM_{\Sigma_2^*}\Gamma_{\Sigma_2^*}}P_{\mu\nu},$$

with

$$P^{\mu\nu} = -g^{\mu\nu}+\frac{1}{3}\gamma^\mu\gamma^\nu+\frac{2q^\mu q^\nu}{3M^2_{\Sigma_2^*}}+\frac{\gamma^\mu q^\nu-\gamma^\nu q^\mu}{3M_{\Sigma_2^*}}$$

Invariant mass distributions

$$\frac{d\Gamma}{dM_{\pi^+\Lambda}} = \frac{m_\Lambda}{32\pi^3 M_{\Lambda_c^+}} \int \sum |\mathcal{M}|^2 |\vec{p}_1||\vec{p}^{\,*}| d\cos\theta^*$$

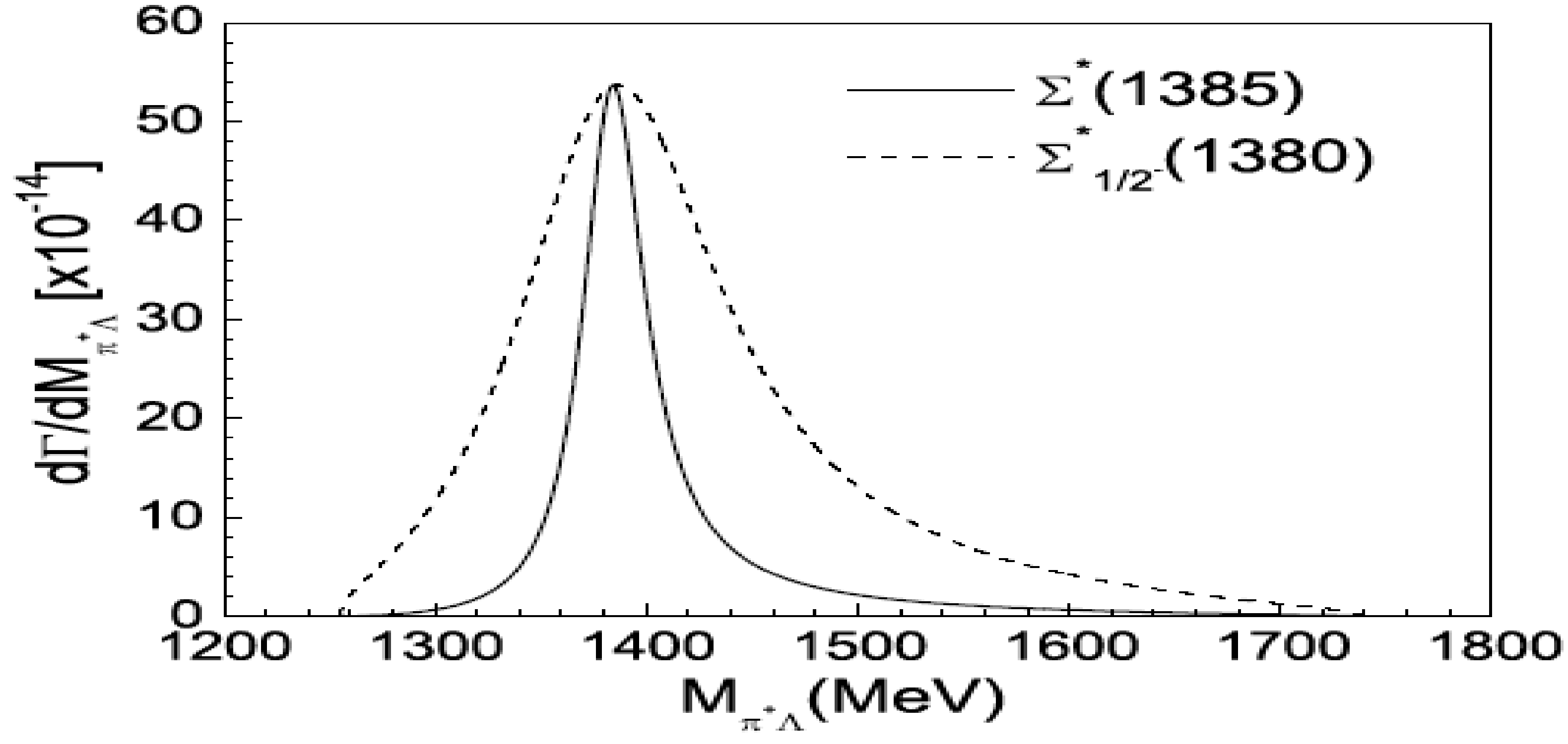


FIG. 5: Invariant mass distributions $d\Gamma/dM_{\pi^+\Lambda}$ as a function of $M_{\pi^+\Lambda}$.

$$\frac{d\Gamma}{d\cos\theta^*} = \frac{m_\Lambda}{32\pi^3 M_{\Lambda_c^+}} \int \sum |\mathcal{M}|^2 |\vec{p}_1||\vec{p}^{\,*}| dM_{\pi^+\Lambda}$$

$$\frac{d\Gamma}{dE_{\pi+}} = \frac{m_\Lambda}{32\pi^3} \int \sum |\mathcal{M}|^2 dE_\Lambda,$$

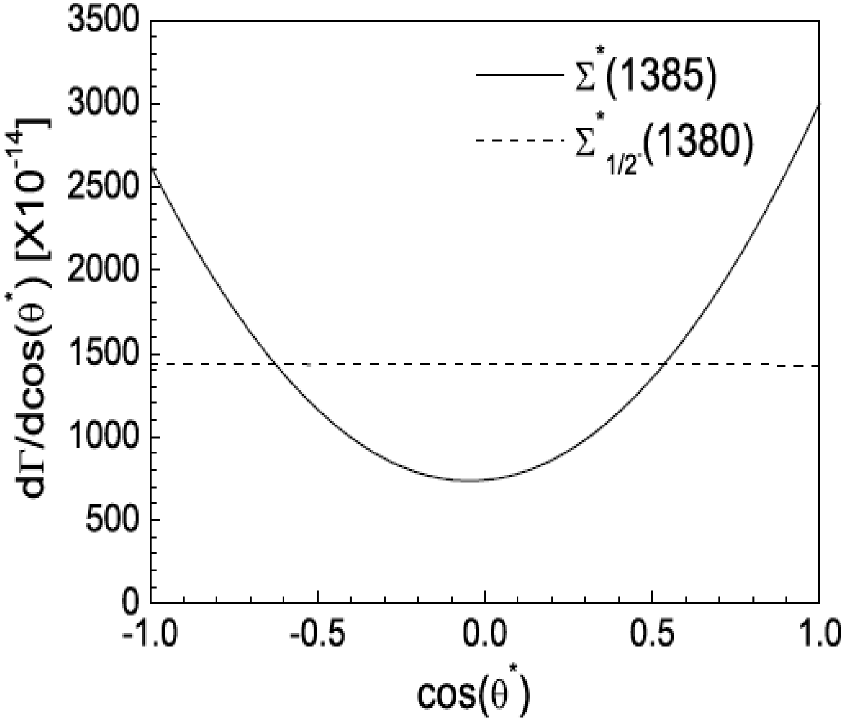


FIG. 6: Angle distributions $d\Gamma/d\cos\theta^*$ in the c.m. frame of $\pi^+\Lambda$ system as a function of $\cos\theta^*$.

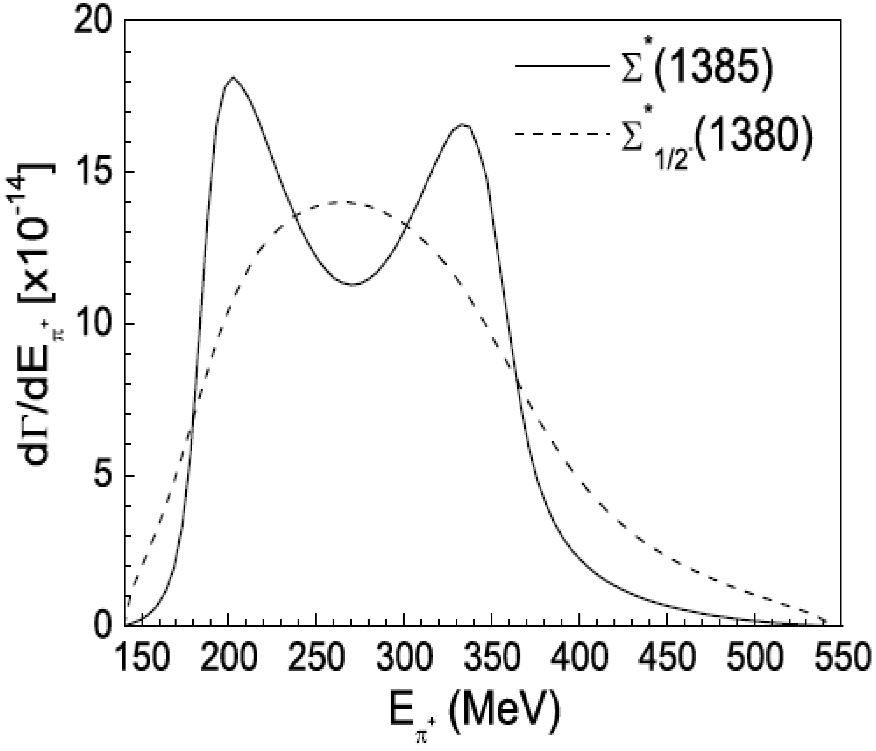
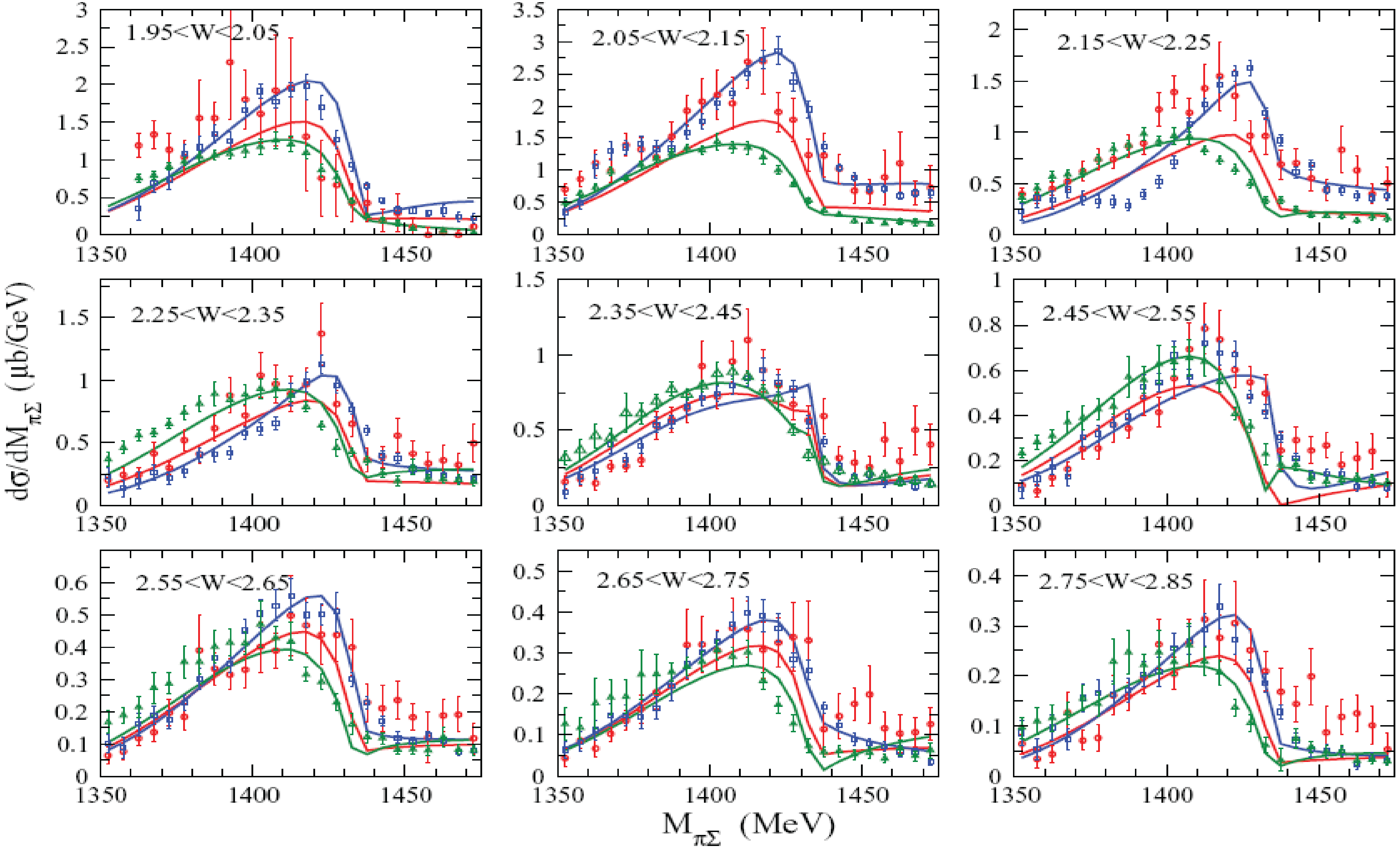


FIG. 7: Energy distributions $d\Gamma/dE_{\pi+}$ in the rest frame of Λ_c^+ as a function of $E_{\pi+}$.

Ju-Jun Xie and Li-Sheng Geng, arXiv:1703.09502; PRD95， 074024 (2017).

More evidence for Σ(1380) from $\gamma p \to K^+(\Sigma\pi)$

PRC **88**, 055206 (2013)



$Red: \ \pi^0\Sigma^0 \quad Blue: \ \pi^-\Sigma^+ \quad Green: \pi^+\Sigma^-$

Date from: PRC 87, 035206 (2013) [CLAS Collaboration]

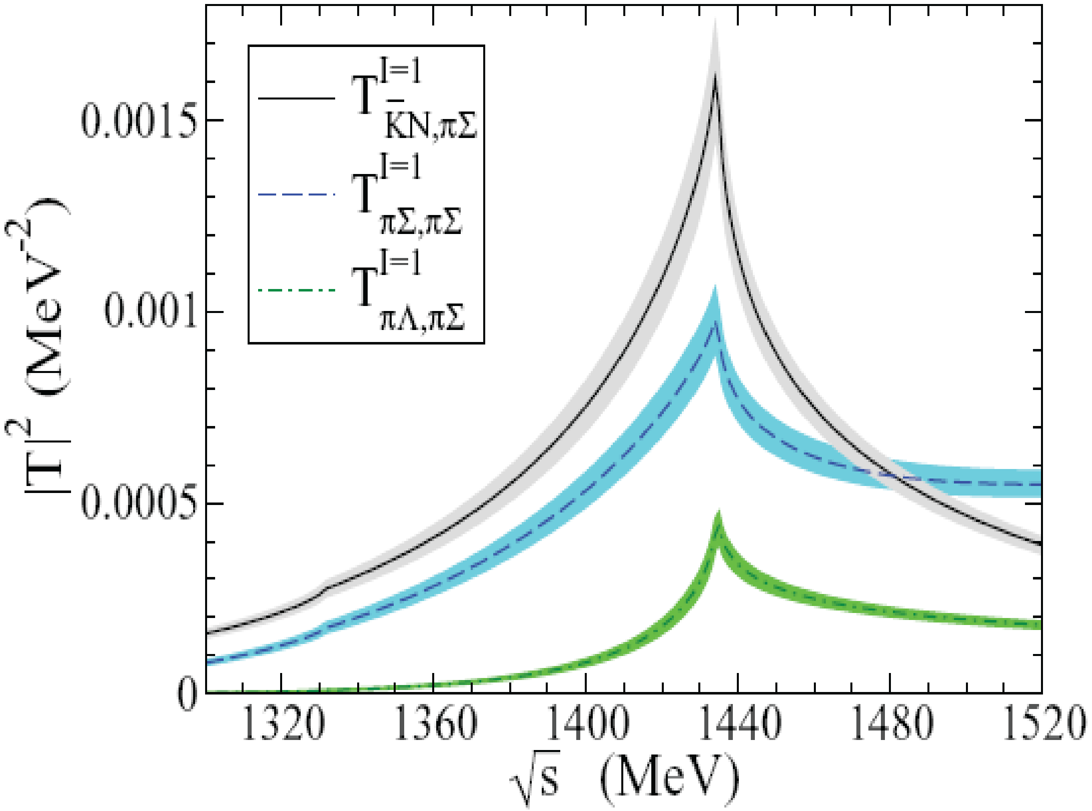


FIG. 5. (Color online) Modulus squared of the $I = 1$ meson-baryon unitarized amplitudes $T^{I=1}_{\pi\Sigma,\pi\Sigma}$ (solid line), $T^{I=1}_{\bar{K}N,\pi\Sigma}$ (dashed line), and $T^{I=1}_{\pi\Lambda,\pi\Sigma}$ (dashed-dotted line).

Z.H. Guo and J.A. Oller, Meson-baryon reactions with strangeness -1 within a chiral framework, PRC 87, 035202 (2013)

Poles were found in I = 1 which are more dependent on the details of the fits.

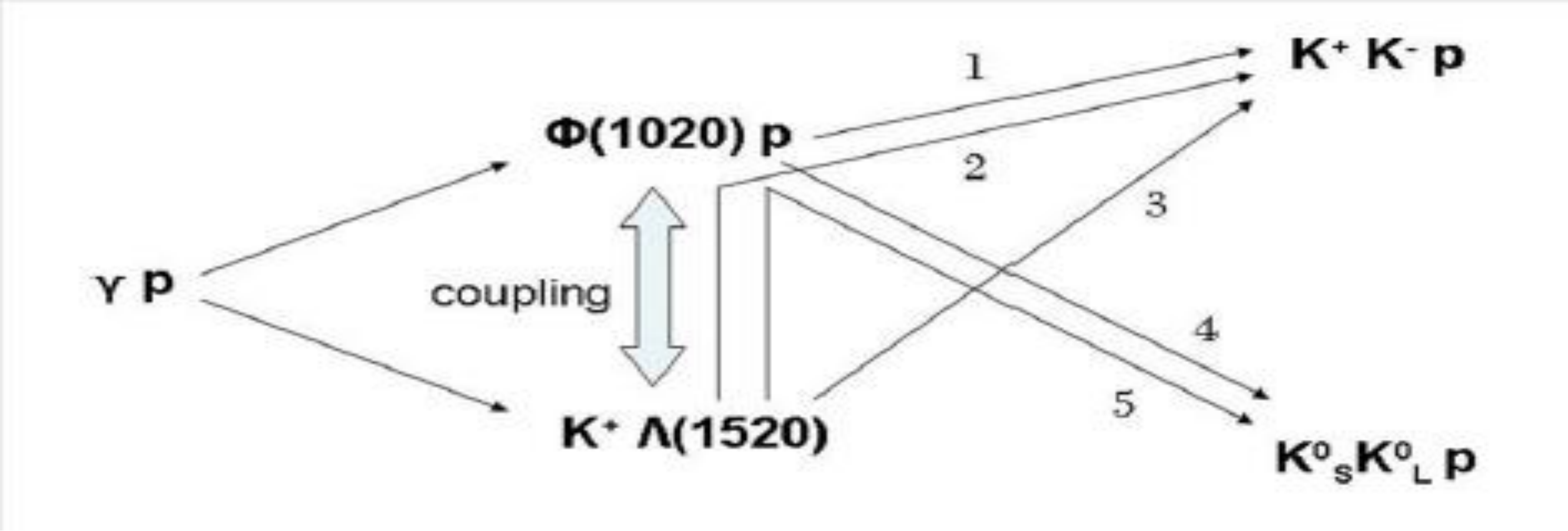
L. Roca, and E. Oset, PRC **88**, 055206 (2013)

Monday, Parallel Session 4 (14:55-15:20**)**
by En Wang

Summary

1, The N(2120) has significant coupling to KΛ(1520) channel and gives important contribution to the KΛ(1520) production, but, its nature is still unclear

2, The γp->pϕ and γp-> $K^+\Lambda(1520)$ reactions should be studied together



3,The Λ^+_c->$\eta\pi^+\Lambda$ decay can be used to study the Σ(1380) state.

Thank you very much for your attention!