Nucleon resonances near 2 GeV

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OUTLINE

- Motivation
- N* near 2 GeV in the photoproductions
  - The Λ(1520) photoproduction and N(2120)
  - The Σ(1385) photoproduction and Δ(2000)
- The internal structures of N(1875) and N(2120)
- Research decay of N(2120) to N(1675) in experiment
- Summary

MOTIVATION

Particle	J^P	Status overall	πN	γN	$N\eta$	$N\sigma$	$N\omega$	ΛK	ΣK	$N\rho$	$\Delta\pi$
					Status as seen in —						
N	$1/2^+$	****									
$N(1440)$	$1/2^+$	****	****	****		***				*	***
$N(1520)$	$3/2^-$	****	****	****	***					***	***
$N(1535)$	$1/2^-$	****	****	****	****					**	*
$N(1650)$	$1/2^-$	****	****	***	***			***	**	**	***
$N(1675)$	$5/2^-$	****	****	***	*			*		*	***
$N(1680)$	$5/2^+$	****	****	****	*	**				***	***
$N(1685)$	$?^?$	*									
$N(1700)$	$3/2^-$	***	***	**	*			*	*	*	***
$N(1710)$	$1/2^+$	***	***	***	***		**	***	**	*	**
$N(1720)$	$3/2^+$	****	****	***	***			**	**	**	*
$N(1860)$	$5/2^+$	**	**							*	*
$N(1875)$	$3/2^-$	***	*	***			**	***	**		***
$N(1880)$	$1/2^+$	**	*	*		**		*			
$N(1895)$	$1/2^-$	**	*	**	**			**	*		
$N(1900)$	$3/2^+$	***	**	***	**		**	***	**	*	**
$N(1990)$	$7/2^+$	**	**	**					*		
$N(2000)$	$5/2^+$	**	*	**	**			**	*	**	
$N(2040)$	$3/2^+$	*									
$N(2060)$	$5/2^-$	**	**	**	*				**		
$N(2100)$	$1/2^+$	*									
$N(2150)$	$3/2^-$	**	**	**				**			**
$N(2190)$	$7/2^-$	****	****	***			*	**		*	
$N(2220)$	$9/2^+$	****	****								
$N(2250)$	$9/2^-$	****	****								
$N(2600)$	$11/2^-$	***	***								
$N(2700)$	$13/2^+$	**	**								

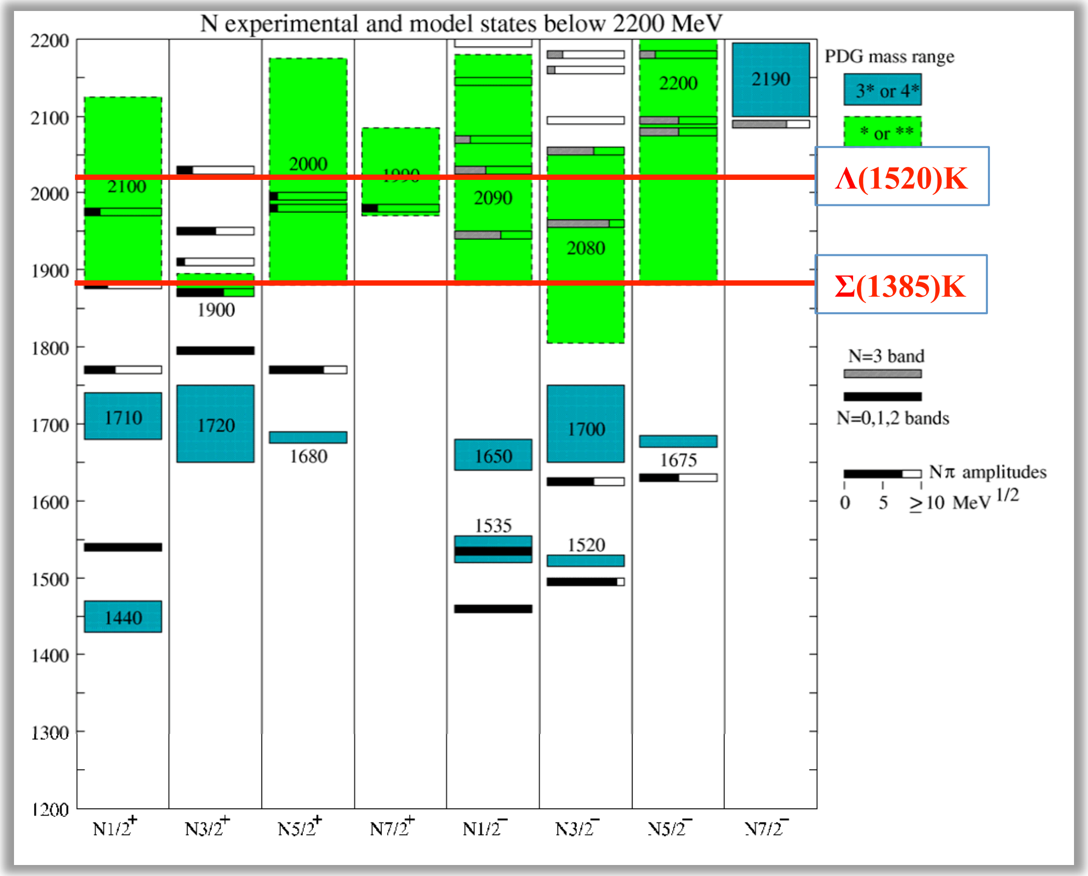
**** Existence is certain, and properties are at least fairly well explored.
*** Existence is very likely but further confirmation of quantum numbers and branching fractions is required.
** Evidence of existence is only fair.
* Evidence of existence is poor.

PDG2014

The number of predicted states is much larger than observed
"missing resonances"

N* around 2.0 GeV :
in confusion

CQM: about two dozens in n = 3 shell.
Only a few of them observed



Photoproductions with high thresholds have advantage in study about N* near 2.0GeV

N* NEAR 2 GEV IN THE PHOTOPRODUCTIONS

Experiment:

$\Lambda(1520)$ photoproduction

N. Muramatsu et al.(LEPS Collaboration), Phys. Rev. Lett. 103, 012001 (2009).

H. Kohri *et al. (*LEPS Collaboration), Phys. Rev. Lett. 104, 172001 (2010).

$\Sigma(1385)$ photoproduction

Cambridge Bubble Chamber Group, Phys. Rev. 156, 1426(1967).

R. Erbe *et al.,* Phys. Rev. 188, 2060 (1969).

$\Lambda(1405)$, $\Lambda(1520)$, $\Sigma(1385)$ photoproductions

K.Moriya et al. (CLAS Collaboration),Phys. Rev. C 88, 045201(2013).

Theory :

$\Lambda(1520)$ photoproduction

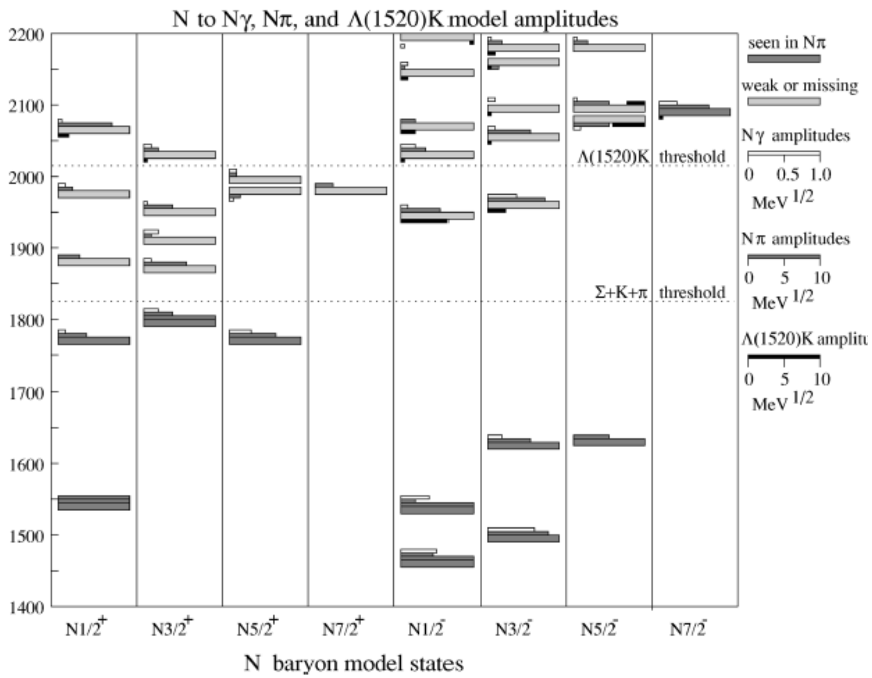
J. J. Xie et al., Phys. Rev. C 82, 045205 (2010) , Phys.Rev. C90 (2014) 6, 065203

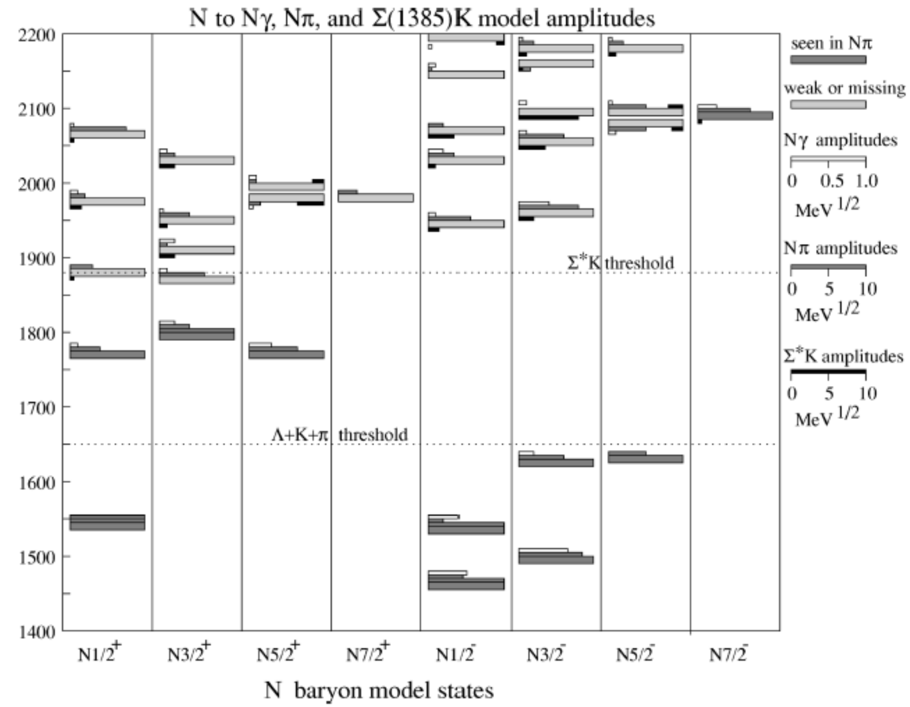
S. I. Nam and C. W. Kao, Phys. Rev. C 81, 055206 (2010)

$\Sigma(1385)$ photoproduction

Y. Oh, C. M. Ko, and K. Nakayama, Phys. Rev. C 77, 045204(2008).

Results about N*→ Λ(1520) K, Σ(1385) K, and N γ from CQM



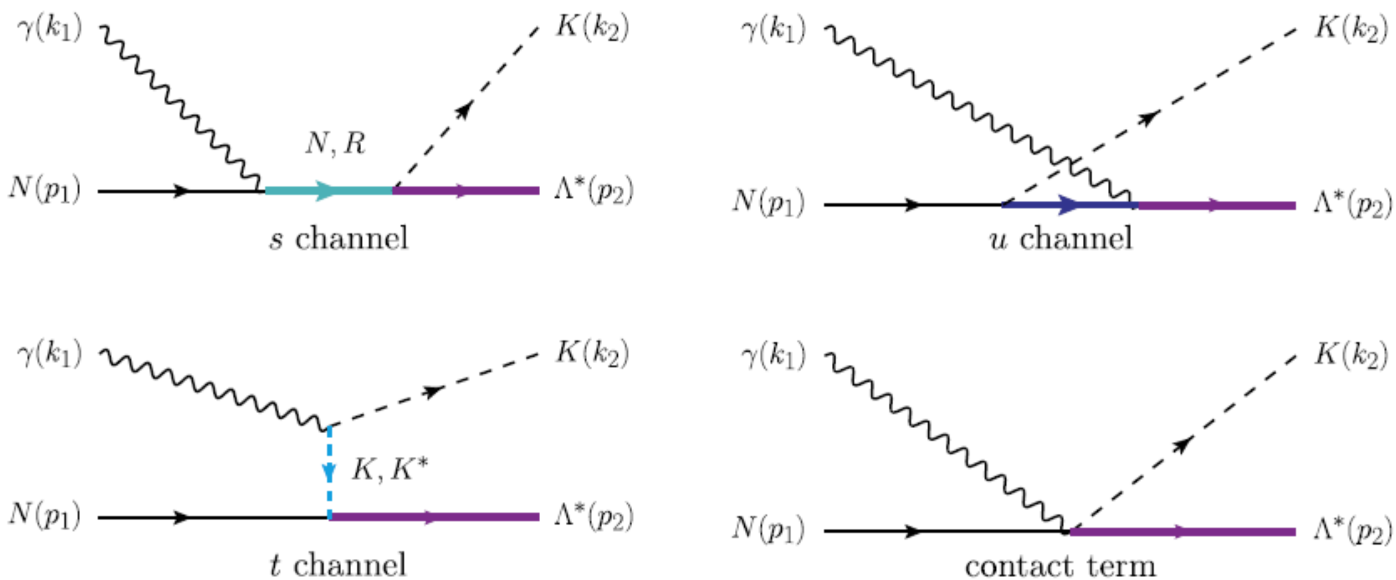


S. Capstick and W. Roberts, Phys. Rev. D 58, 074011 (1998).
S. Capstick, Phys. Rev. D 46, 2864 (1992).

Interaction mechanism

Λ (1520) photoproudction

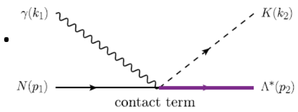
Σ (1385) photoproduction



Gauge invariance and Regge trajectories

Generalized contact term

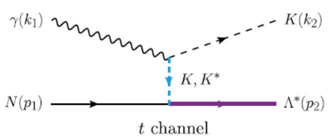
Haberzettl, et al., PRC **74,**045202(2006).



$$M_c^{\mu\nu} = \frac{ie f_{KN\Sigma^*}}{m_K}\left[g^{\mu\nu}F_t + k_2^\mu(2k_2-k_1)^\nu \frac{(F_t-1)[1-h(1-F_s)]}{t-m_K^2} + k_2^\mu(2p_1-k_1)^\nu \frac{(F_s-1)[1-h(1-F_t)]}{s-m_N^2}\right], \quad (6)$$

$$F(q^2) = \left(\frac{n\Lambda^4}{n\Lambda^4+(q^2-M^2)^2}\right)^n,$$

The Reggeized treatment work completely at high photon energies and interpolate smoothly to low photon energy. [S. I. Nam and C. W. Kao, Phys. Rev. C 81, 055206 (2010).]



$$\frac{F_t}{t-m_K^2} \to \frac{F_t}{t-m_K^2}\mathcal{R} = \mathcal{D}_K R + \frac{F_t}{t-m_K^2}(1-R),$$

$$\frac{1}{t-m_K^2} \to \mathcal{D}_K = \left(\frac{s}{s_0}\right)^{\alpha_K}\frac{\pi\alpha'_K}{\Gamma(1+\alpha_K)\sin(\pi\alpha_K)},$$

$$\frac{1}{t-m_{K^*}^2} \to \mathcal{D}_{K^*} = \left(\frac{s}{s_0}\right)^{\alpha_{K^*}-1}\frac{\pi\alpha'_{K^*}}{\Gamma(\alpha_{K^*})\sin(\pi\alpha_{K^*})},$$

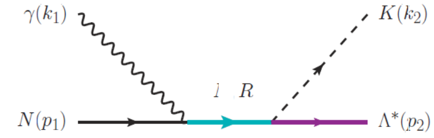
where $R = R_s R_t$ with

$$R_s = \frac{1}{2}\left[1+\tanh\left(\frac{s-s_{\rm Reg}}{s_0}\right)\right],$$

$$R_t = 1-\frac{1}{2}\left[1+\tanh\left(\frac{|t|-t_{\rm Reg}}{t_0}\right)\right].$$

$$i\mathcal{M}_t + i\mathcal{M}_s + i\mathcal{M}_c \to i\mathcal{M}_t^{\rm Regge} + (i\mathcal{M}_s + i\mathcal{M}_c)\mathcal{R}.$$

Nucleon resonances contribution



s−channel

The Lagrangian for the radiative decay can be written as

$$\mathcal{L}_{\gamma NR(\frac{1}{2}^\pm)} = \frac{ef_2}{2M_N}\bar{N}\Gamma^{(\mp)}\sigma_{\mu\nu}F^{\mu\nu}R + \text{h.c.},$$

$$\mathcal{L}_{\gamma NR(J^\pm)} = \frac{-i^n f_1}{(2m_N)^n}\bar{B}^*\gamma_\nu\partial_{\mu_2}\ldots\partial_{\mu_n}F_{\mu_1\nu}\Gamma^{\pm(-1)^{n+1}}R^{\mu_1\mu_2\ldots\mu_n} + \frac{i^{n+1}f_2}{(2m_N)^{n+1}}\partial_\nu\bar{B}^*\partial_{\mu_2}\ldots\partial_{\mu_n}F_{\mu_1\nu}\Gamma^{\pm(-1)^{n+1}}R^{\mu_1\mu_2\ldots\mu_n} + \text{h.c.},$$

The Lagrangian for the strong decay can be written as

$$\mathcal{L}_{RK\Lambda^*} = \frac{ih_2}{2m_K}\partial_\mu K\bar{\Lambda}^*_\mu\Gamma^{(\pm)}R, +\text{h.c.},$$

$$\mathcal{L}_{RK\Lambda^*} = \frac{i^{2-n}h_1}{m_P^n}\bar{B}^*_{\mu_1}\gamma_\nu\partial_\nu\partial_{\mu_2}\ldots\partial_{\mu_n}P\Gamma^{\pm(-1)^n}R^{\mu_1\mu_2\ldots\mu_n} + \frac{i^{1-n}h_2}{m_P^{n+1}}\bar{B}^*_\alpha\partial_\alpha\partial_{\mu_1}\partial_{\mu_2}\ldots\partial_{\mu_n}P\Gamma^{\pm(-1)^n}R^{\beta\mu_1\mu_2\ldots\mu_n} + \text{h.c.}.$$

S.-J. Chang, Phys. Rev. 161, 1308 (1967). J. G. Rushbrooke, Phys. Rev. 143, 1345 (1966). R. E. Behrends and C. Fronsdal, Phys. Rev. 106, 345 (1957).

Coupling constants f_1, f_2, h_1 and h_2 are determined by decay amplitudes

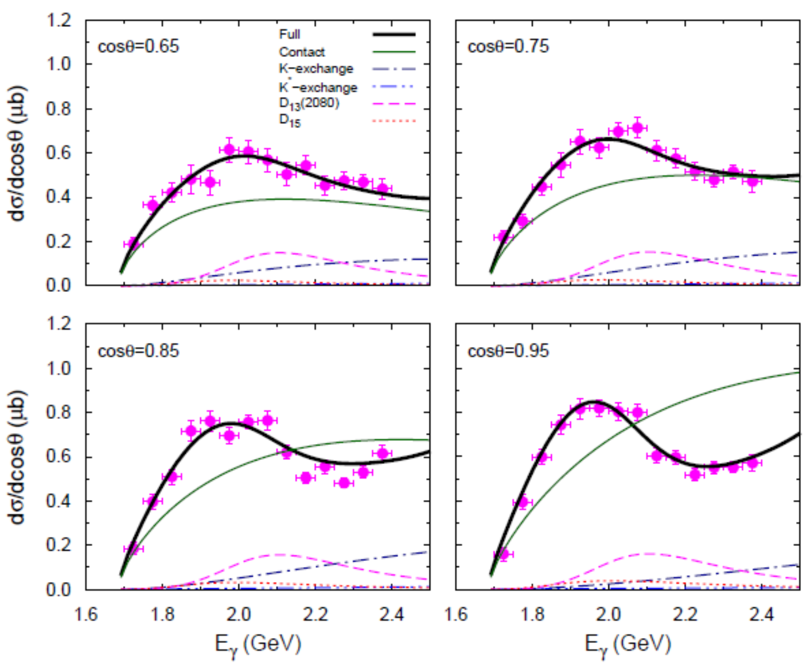
Decay Amplitudes in constituent quark model = Decay Amplitudes with effective Lagrangian

Y. Oh, C. M. Ko, and K. Nakayama, Phys. Rev. C 77, 045204(2008).

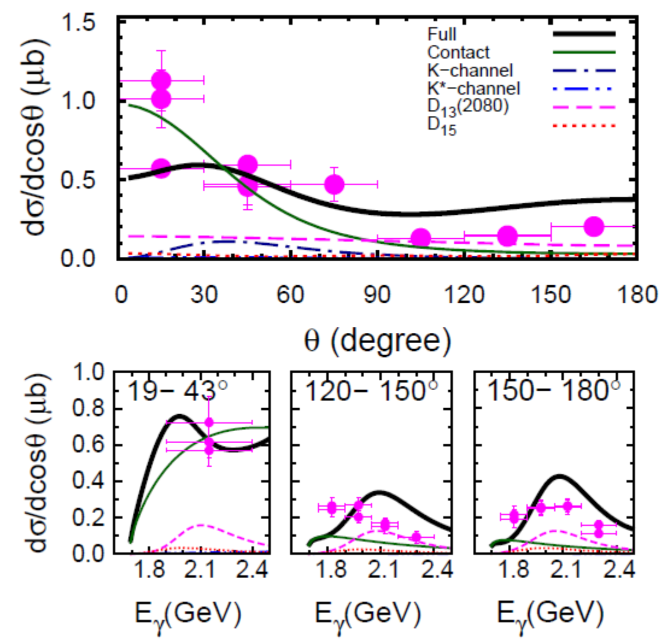
The Λ(1520) photoproduction and N(2120)

TABLE II: The nucleon resonances considered. The mass m_R, helicity amplitudes A_λ and partial wave decay amplitudes $G(\ell)$ are in the unit of MeV, $10^{-3}/\sqrt{\text{GeV}}$ and $\sqrt{\text{MeV}}$, respectively. The last column is for χ^2 after turning off the corresponding nucleon resonance with $\chi^2 = 1.38$ in full model.

State	PDG	m_R	$A^p_{1/2}$	$A^p_{3/2}$	$G(\ell_1)$	$G(\ell_2)$	$\sqrt{\Gamma_{\Lambda(1520)K}}$	χ^2
$[N\frac{1}{2}^-]_3(1945)$	$N(2090)S_{11}$*	2090	12		$6.4^{+5.7}_{-6.4}$		$6.4^{+5.7}_{-6.4}$	1.89
$[N\frac{3}{2}^-]_3(1960)$	$N(2080)D_{13}$**	2150	36	-43	$-2.6^{+2.6}_{-2.8}$	$-0.2^{+0.2}_{-1.3}$	$2.6^{+2.9}_{-2.6}$	12.42
$[N\frac{5}{2}^-]_2(2080)$		2080	-3	-14	$-4.7^{+4.7}_{-1.2}$	$-0.3^{+0.3}_{-0.8}$	$4.7^{+1.3}_{-4.7}$	4.01
$[N\frac{5}{2}^-]_3(2095)$	$N(2200)D_{15}$**	2200	-2	-6	$-2.4^{+2.4}_{-2.0}$	$-0.1^{+0.1}_{-0.3}$	$2.4^{+2.0}_{-2.4}$	1.59
$[N\frac{7}{2}^-]_1(2090)$	$N(2190)G_{17}$****	2190	-34	28	$-0.5^{+0.4}_{-0.6}$	$0.0^{+0.0}_{-0.0}$	$0.5^{+0.6}_{-0.4}$	1.48
$[N\frac{7}{2}^+]_2(2390)$		2390	-14	-11	$3.1^{+0.8}_{-1.2}$	$0.3^{+0.3}_{-0.2}$	$3.1^{+0.8}_{-1.2}$	1.79



LEPS10



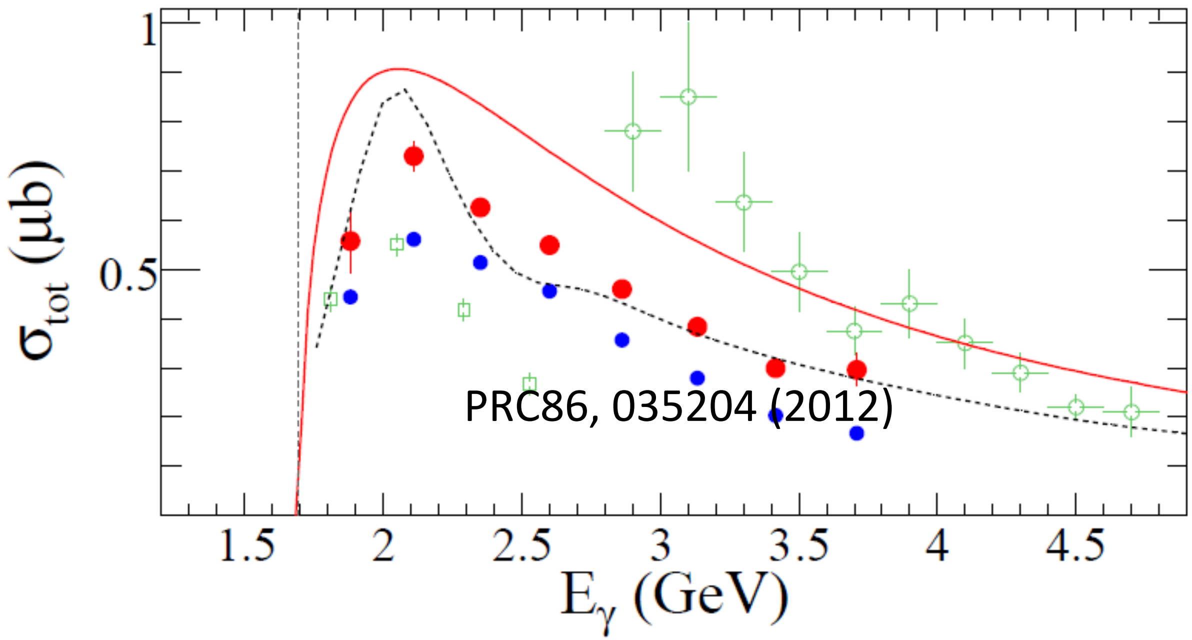
LEPS09

PRC86, 035204 (2012)

Total cross section for the Λ(1520) photoproduction

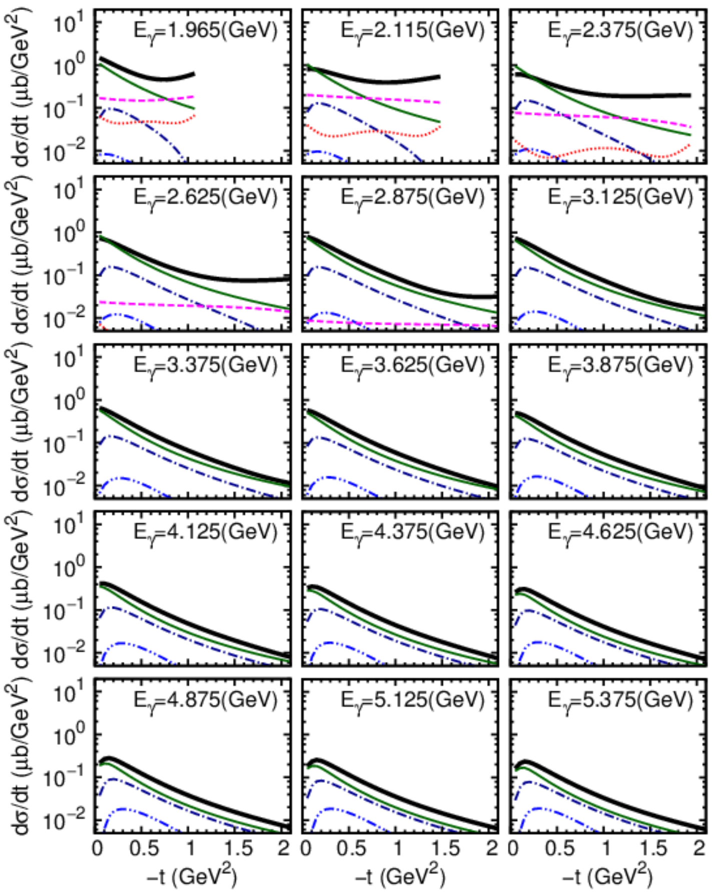
Our results about the total cross section was confirmed by the experimental results released by CLAS@Jlab

CLAS, Phys. Rev. C 88, 045201 (2013)

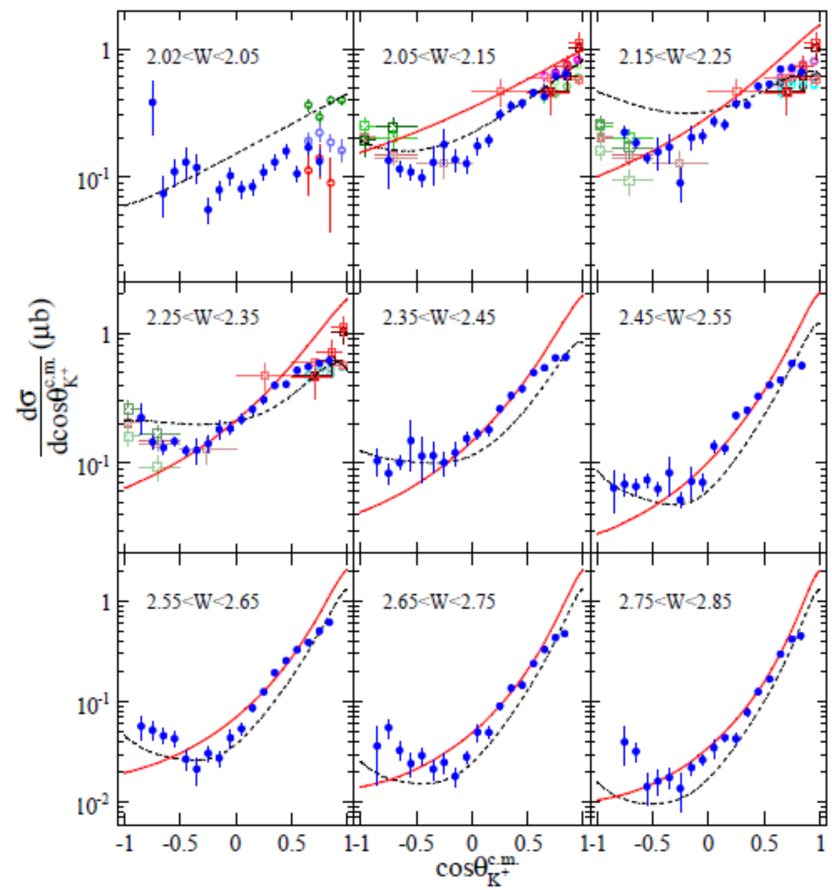


Differential cross section

PRC86, 035204 (2012)

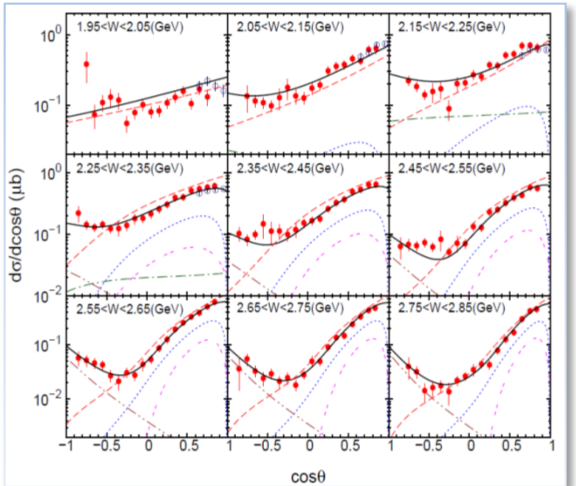


CLAS, Phys. Rev. C 88, 045201 (2013)

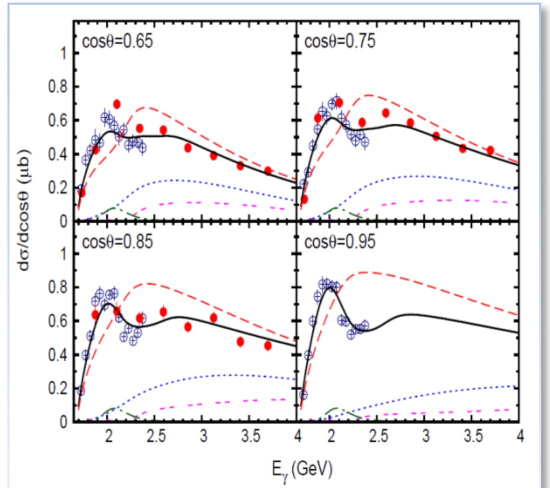


Refitting based on the CLAS experiment He, Nucl. Phys. A927:24 (2014)

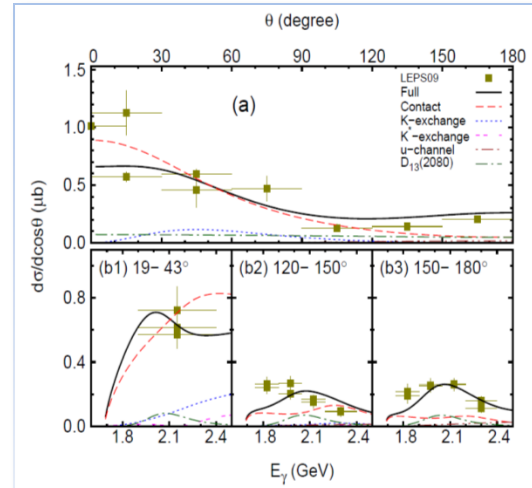
CLAS



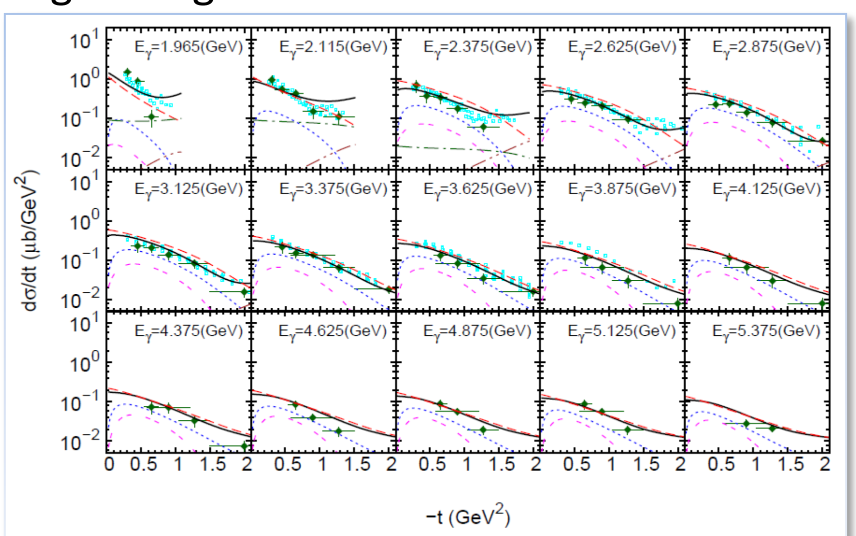
LEPS&CLAS



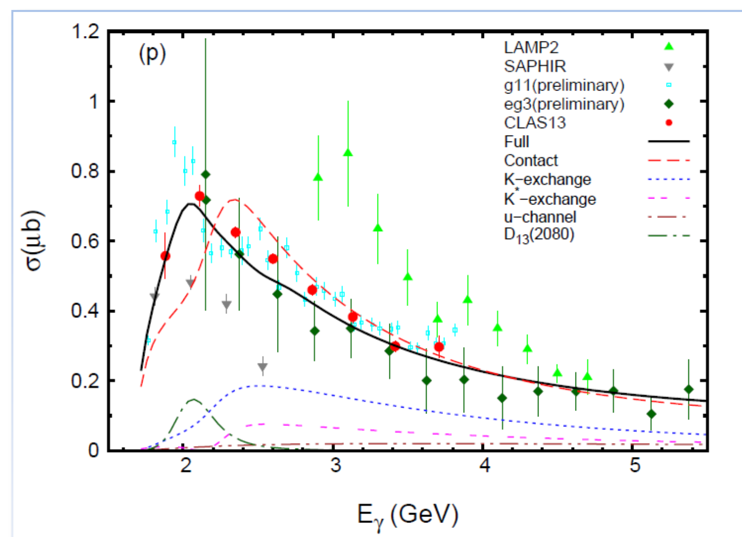
LEPS



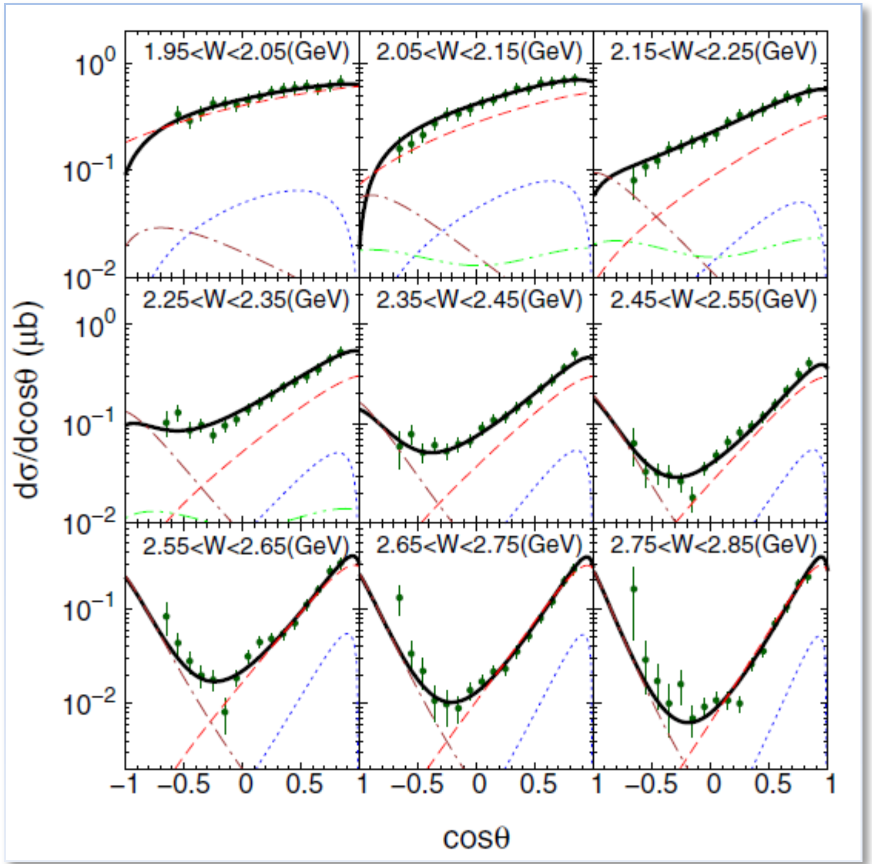
eg3 and g11

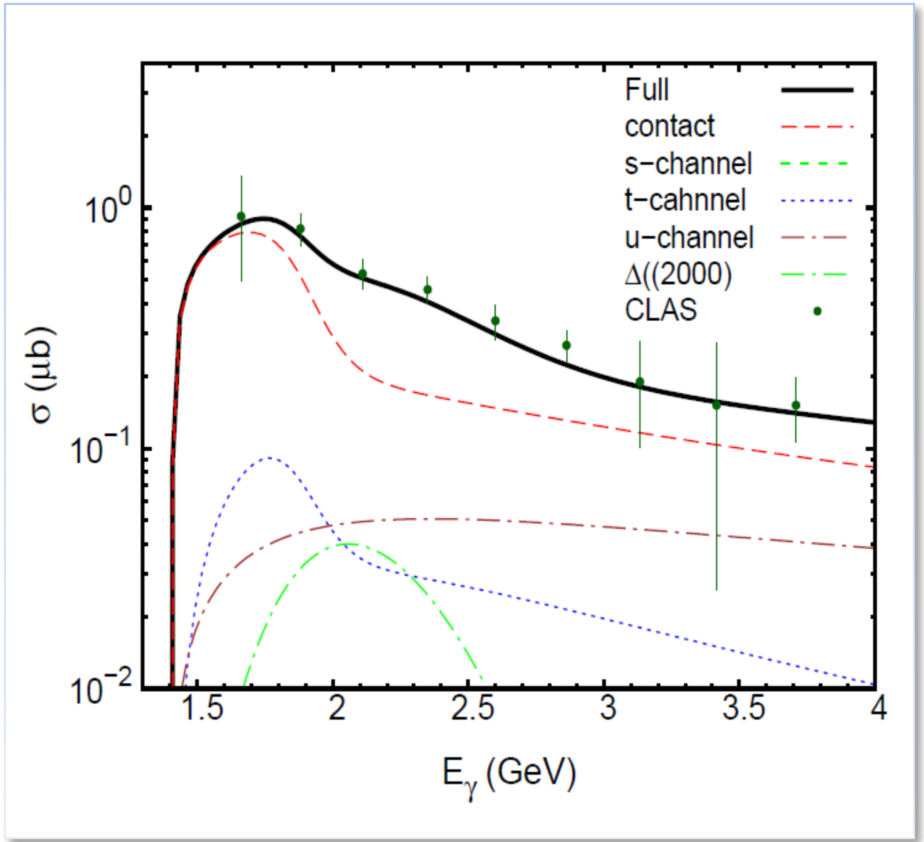


Total cross section



The Σ(1385) photoproduction and Δ(2000)





➢The contact term is dominant in the interaction mechanism

➢The *u* channel is responsible to the behavior of differential cross section at backward angles.

Contributions from nucleon resonances

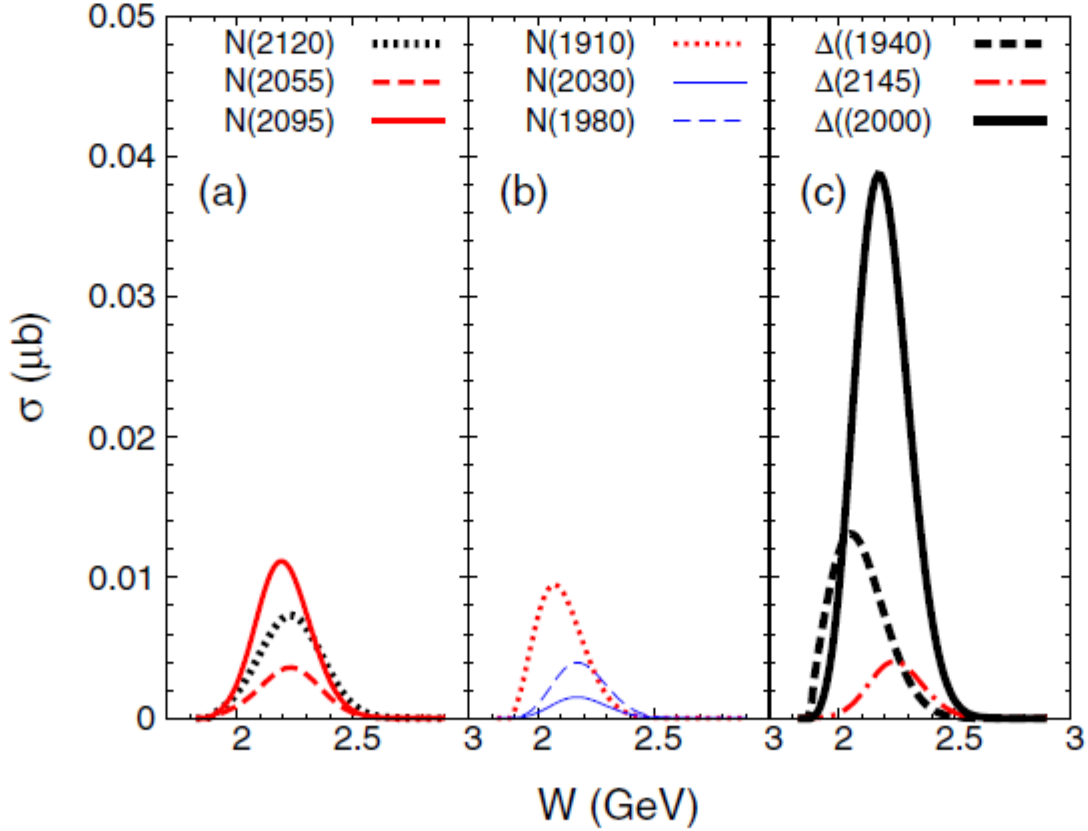
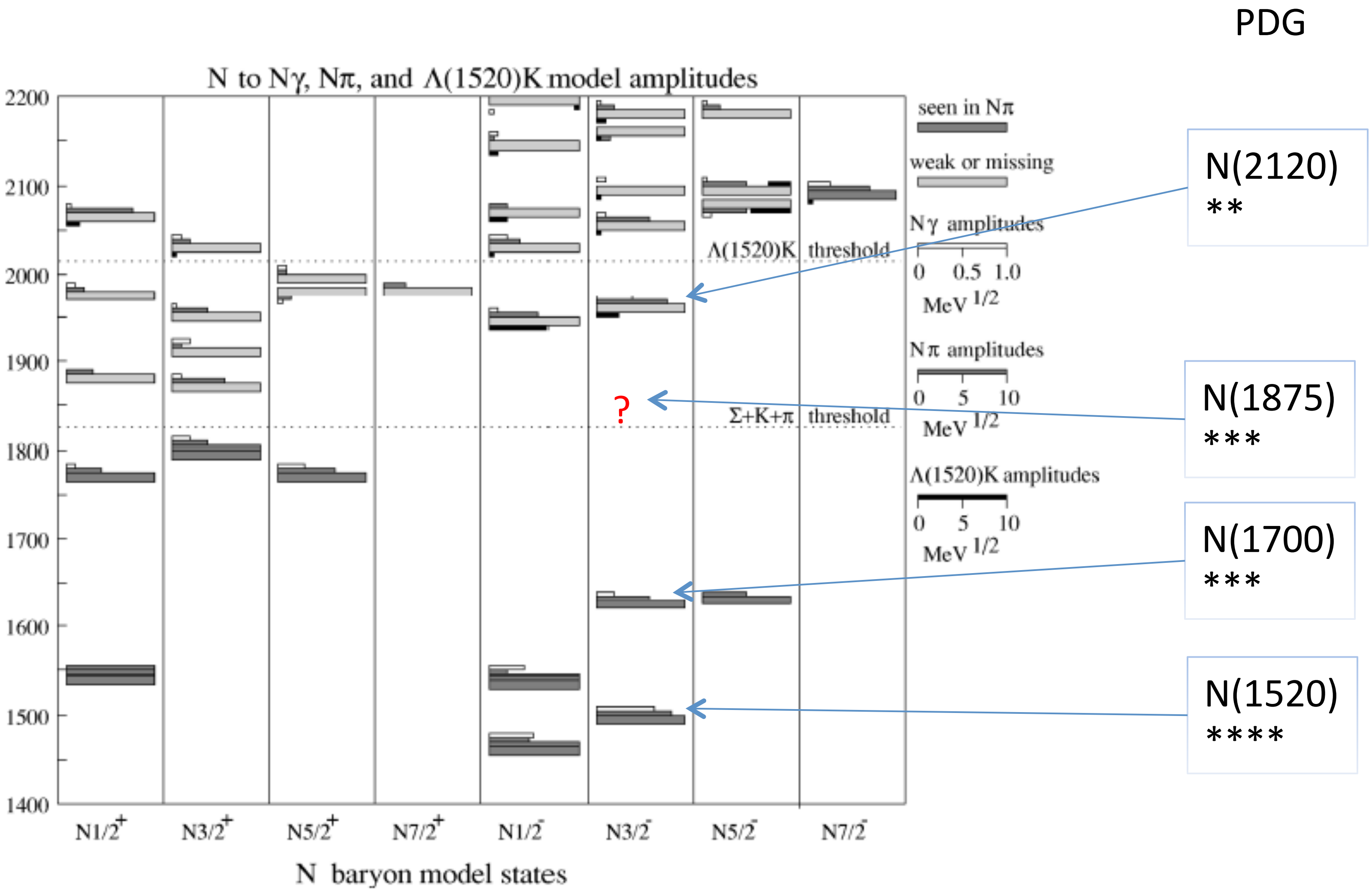
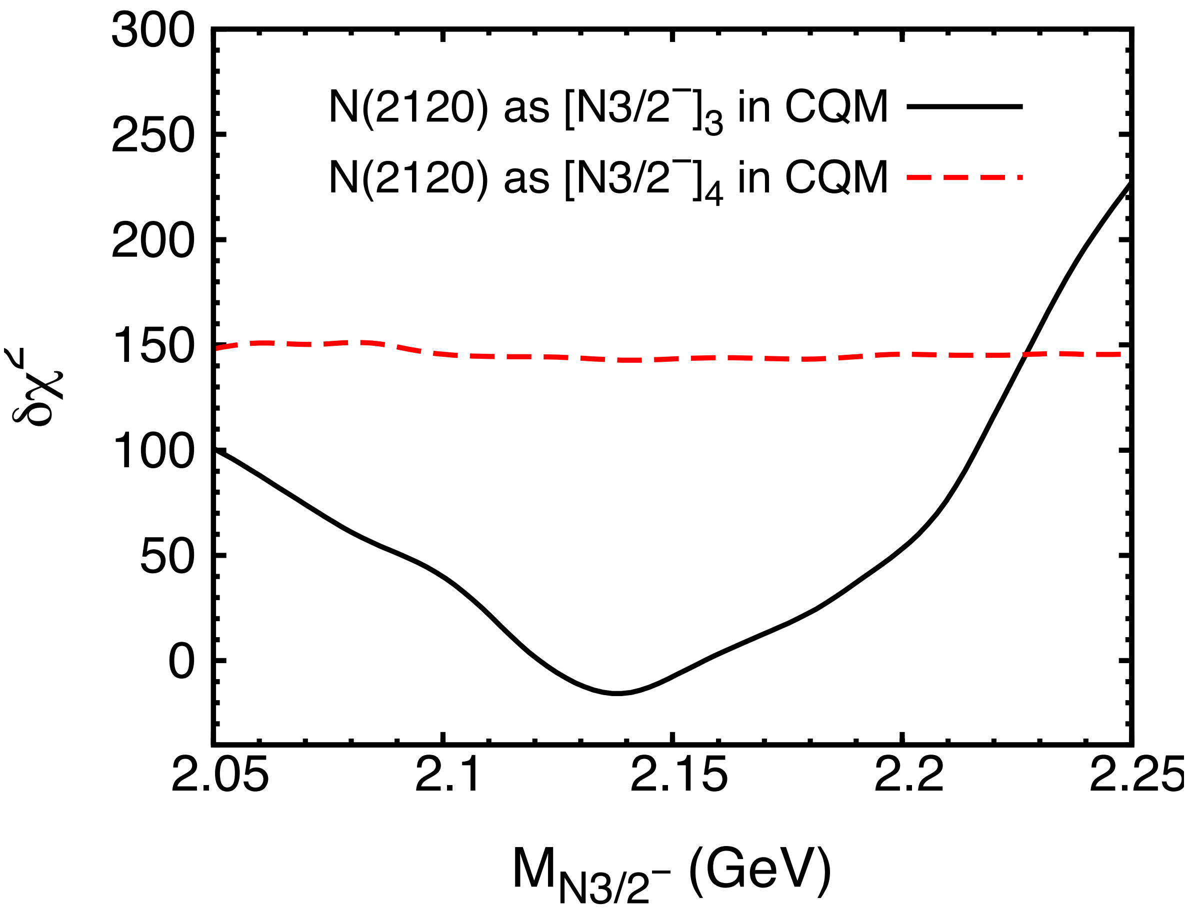


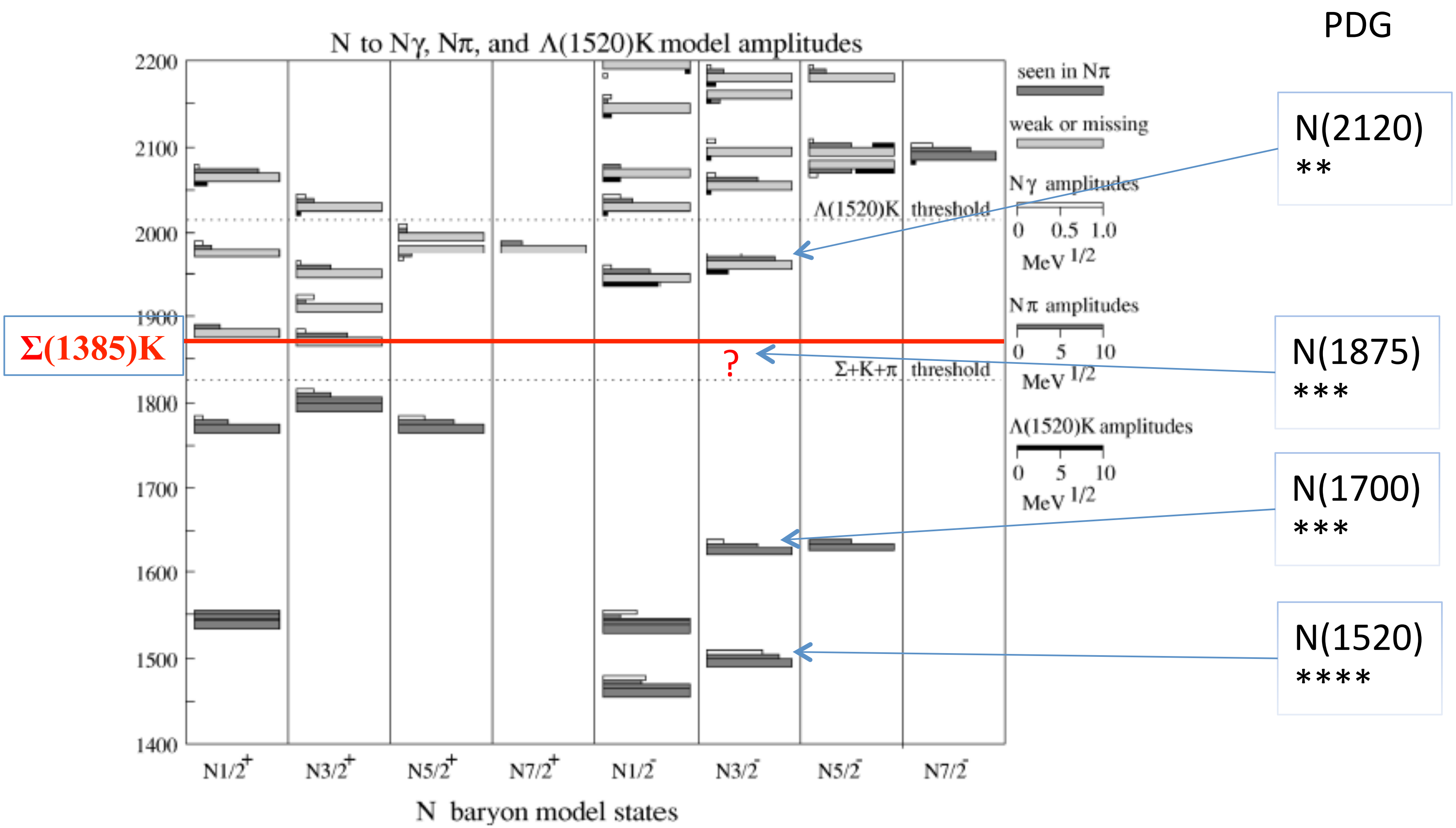
FIG. 2. (Color online) Total cross section σ for corresponding nucleon resonance as a function of the photon energy W in center-of-mass frame.

➢THE INTERNAL STRUCTURE OF N(1875) AND N(2120)





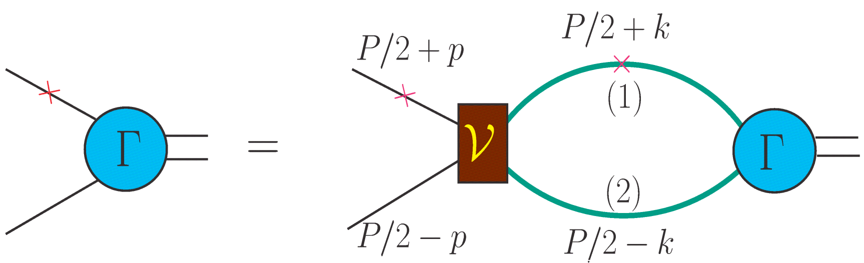
The N(2120) is essential to reproducing the experimental data with assumption it is the third state with spin parity $3/2^-$.



N(1875) is close to Σ(1835)K threshold

N(1875) as a bound state from Σ(1385)K interaction

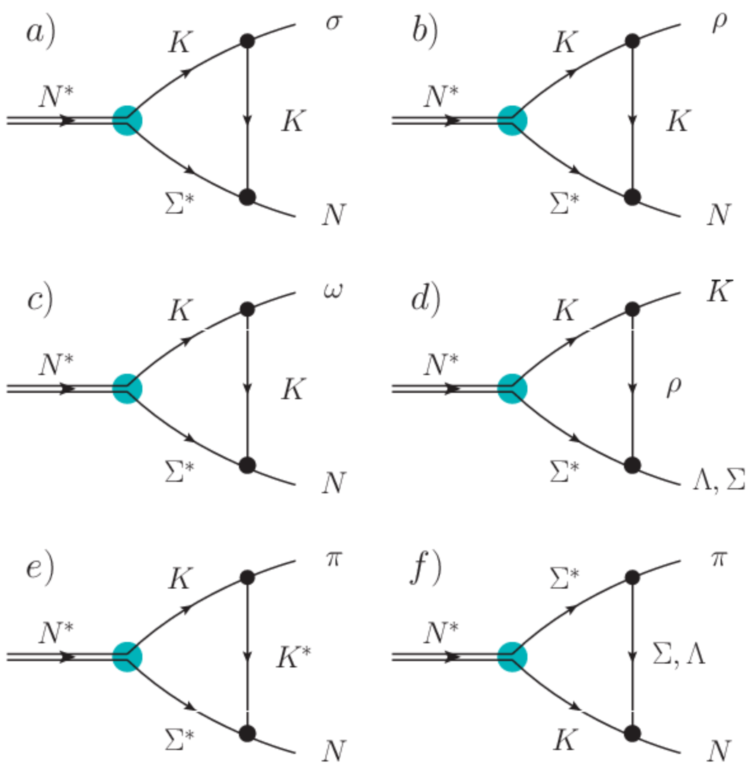
Bethe-Salpeter equation for vertex



$$|\Gamma_\lambda\rangle = \sum_{\lambda'} \mathcal{V}_{\lambda\lambda'}\ G_0\ |\Gamma_{\lambda'}\rangle.$$

$$G_0 = 2\pi i \frac{\delta^+(k_1^2 - m_1^2)}{k_2^2 - m_2^2}$$

Decay through hadronic loop mechanism



$$\mathcal{M} = \sum_{\lambda} A_\lambda G_0 |\Gamma_\lambda\rangle$$

Jun He. Phys.Rev. C91 (2015) 1, 018201

Binding energy and branch ratio

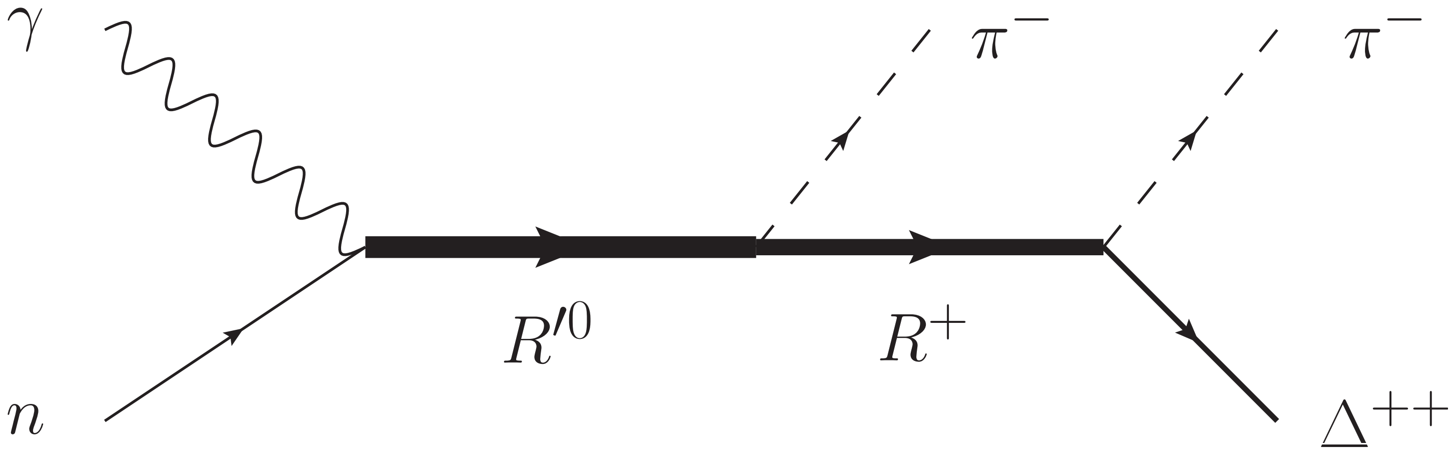
TABLE II: The binding energies E for $\Sigma^* K$ system with different cut off Λ The cut off Λ, binding energy and branch ratio are in the units of GeV, MeV and %, respectively.

Λ	E	Γ	$N\sigma$	$N\rho$	$N\omega$	$N\pi$	ΛK	ΣK
1.68	3	41	55.9	4.7	14.1	22.4	2.3	0.6
1.72	8	73	55.8	4.7	14.0	22.6	2.3	0.6
1.76	16	111	55.7	4.7	14.0	22.7	2.2	0.6
1.80	28	155	55.6	4.8	14.2	22.8	2.1	0.5
1.84	44	204	55.3	4.9	14.6	22.7	2.0	0.5
1.88	67	257	54.9	5.1	14.9	22.9	1.8	0.4
1.92	100	312	53.6	5.1	14.7	24.8	1.5	0.3
PDG [1]	30^{+25}_{-25}		24^{+24}_{-24}	6^{+6}_{-6}	20^{+4}_{-4}	7^{+6}_{-6}		$0.7^{+0.4}_{-0.4}$
BnGa [2]	0^{+20}_{-20}	200^{+20}_{-20}	60^{+12}_{-12}			3^{+2}_{-2}	4^{+2}_{-2}	15^{+8}_{-8}
$[N(\frac{3}{2}^-)]_3$	-85	324		57.1	12.3	20.8	9.7	0

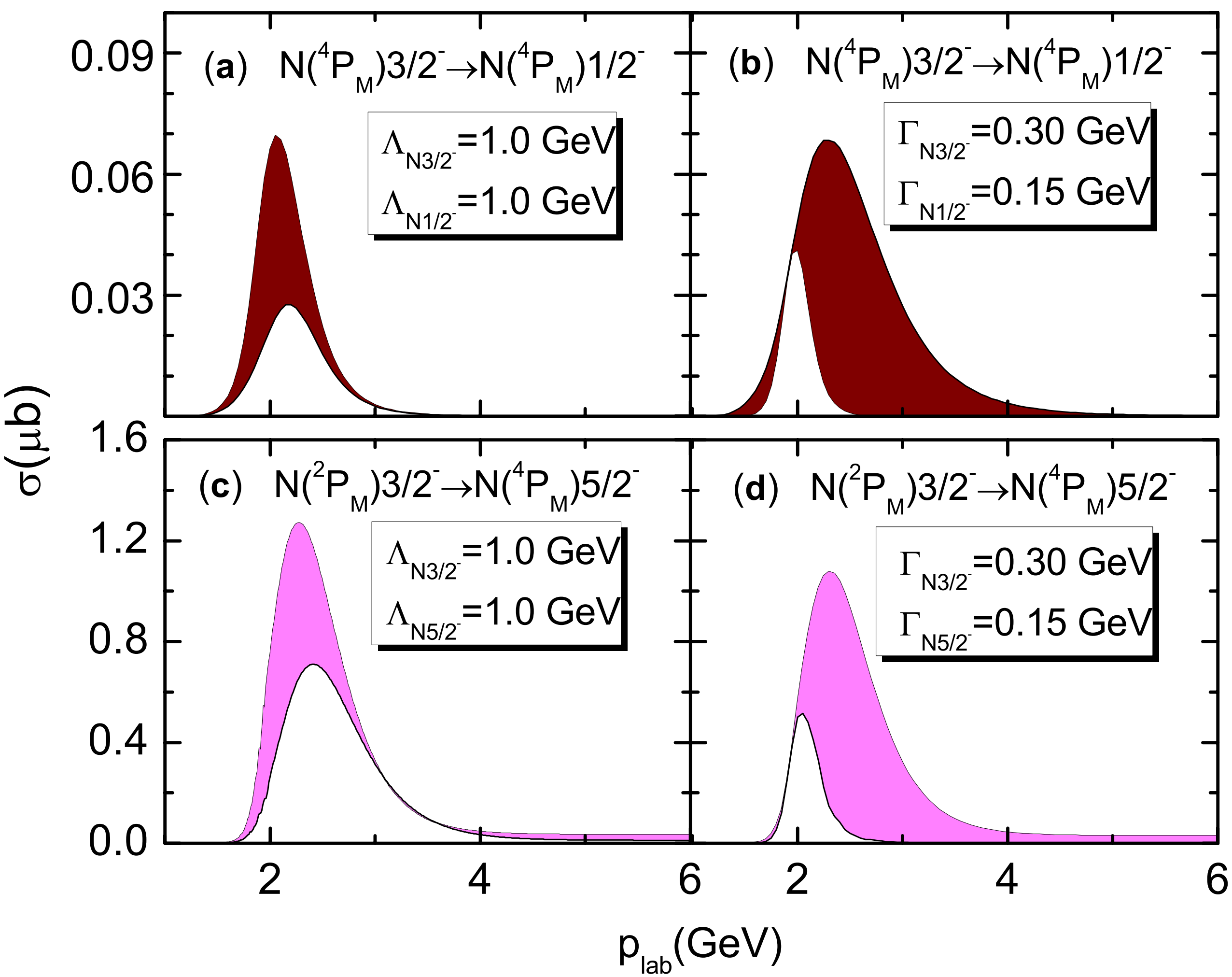
Branch ratio is not sensitive to the cut off
The results support molecular state assumption

➢RESEARCH DECAY OF N(2120) TO N(1675) IN EXPERIMENT

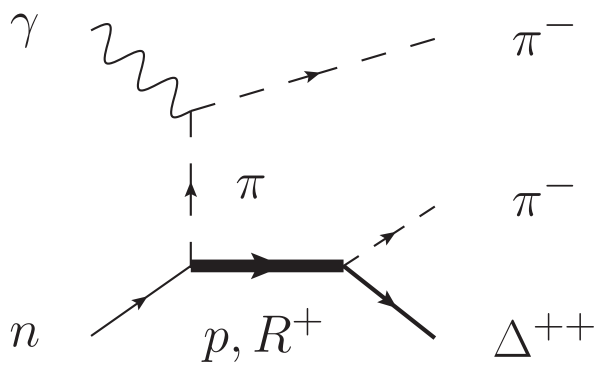
Why not research N* near 2 GeV in the photoproduction of a nucleon resonance?



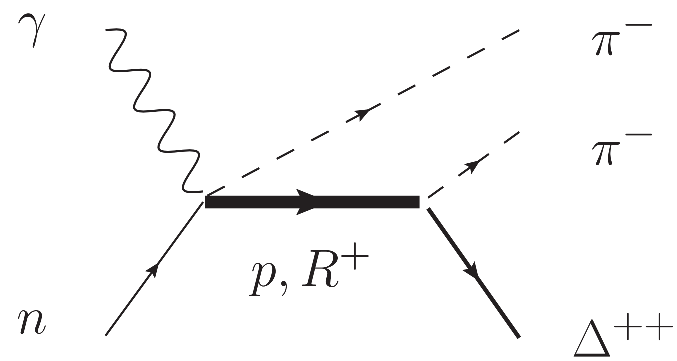
Total cross section with the cascade decay



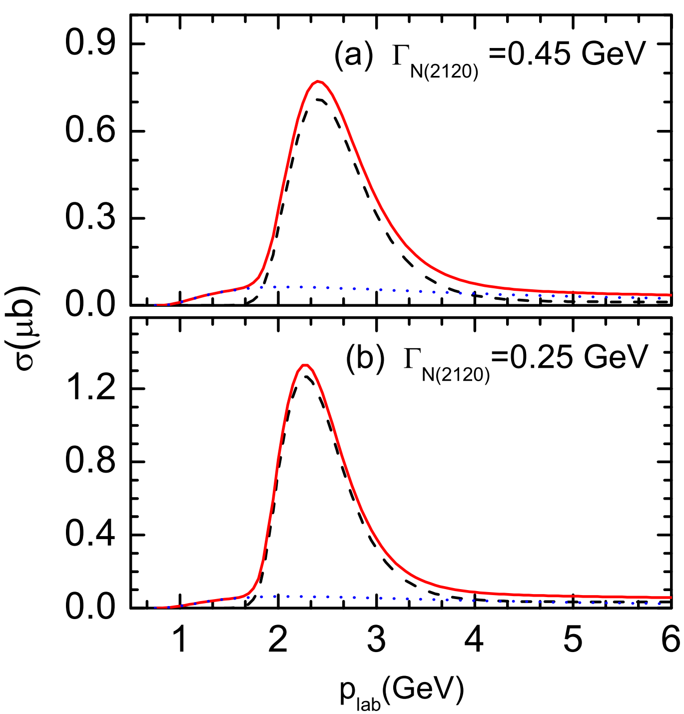
Background

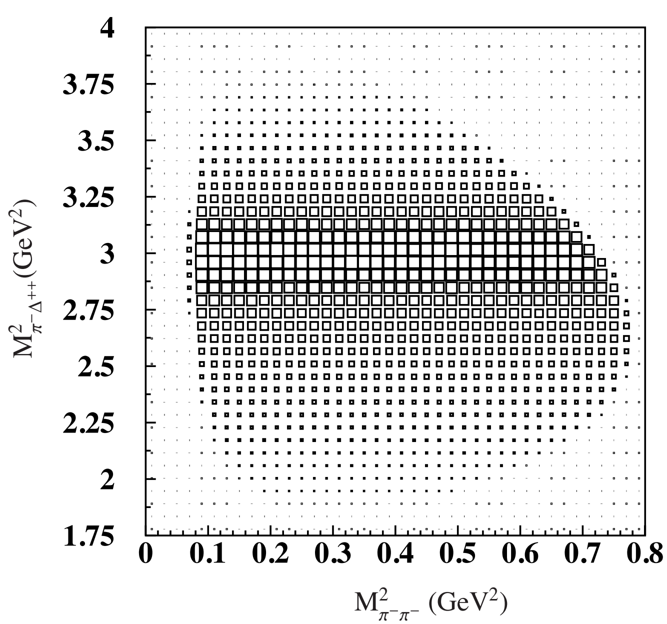


(a)



(b)





SUMMARY

The $\gamma N \rightarrow K\Lambda(1520)/K\Sigma(1385)$ reaction is studied.

- The resonance $\Delta(2000)$ is most important in the $\Sigma(1385)$ photoproduction.
- The resonance N(2120) is most important in the $\Lambda(1520)$ photoproduction.
- The contributions from other nucleon resonances are negligible.

- N(1875) can not be put into CQM. a Σ^*K molecular state.
- The nucleon resonances with high mass can be studied with the photoproduction of nucleon resonances

Thank you!