$K\Lambda$ interaction and the strangeness of $N^*(1535)$

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➢ the strangeness of $N^*(1535)$

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- Summary

$N(1535)\ 1/2^-$

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

- Pole position $Z_R = [(1500 \sim 1520) - i(40 \sim 65)]$ MeV
- Breit-Wigner parameterization

$$(M_R, \Gamma_R) = (1525 \sim 1545, 125 \sim 175)\text{MeV} = (\simeq 1535, \simeq 150)\text{MeV}$$

N(1535) DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$N\pi$	32–52 %
Γ_2	$N\eta$	30–55 %
Γ_3	$N\pi\pi$	4–31 %

$N(1440)$ DECAY MODES

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

	Mode	Fraction (Γ_i/Γ)
Γ_1	$N\pi$	55–75 %
Γ_2	$N\eta$	$<$ 1 %
Γ_3	$N\pi\pi$	17–50 %

$N(1520)$ DECAY MODES

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

	Mode	Fraction (Γ_i/Γ)
Γ_1	$N\pi$	55–65 %
Γ_2	$N\eta$	0.07–0.09 %
Γ_3	$N\pi\pi$	25–35 %

$N(1650)$ DECAY MODES

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

	Mode	Fraction (Γ_i/Γ)
Γ_1	$N\pi$	50–70 %
Γ_2	$N\eta$	15–35 %
Γ_3	ΛK	5–15 %
Γ_4	$N\pi\pi$	20–58 %

$N^*(1535)$: a dynamically generated state

Chiral dynamics and the $S_{11}(1535)$ nucleon resonance

N. Kaiser, P.B. Siegel[1], W. Weise Physics Letters B 362 (1995) 23–28

The $SU(3)$ chiral effective lagrangian at next-to-leading order is applied to the S-wave meson-baryon interaction in the energy range around the ηN threshold. A potential is derived from this lagrangian and used in a coupled channel calculation of the πN, ηN, $K\Lambda$, $K\Sigma$ system in the isospin-$\frac{1}{2}$, $l = 0$ partial wave. Using the same parameters as obtained previously from a fit to the low energy $\overline{K}N$ data it is found that a quasi-bound $K\Sigma$-$K\Lambda$-state is formed, with properties remarkably similar to the $S_{11}(1535)$ nucleon resonance. In particular, we find a large partial decay width into ηN consistent with the empirical data.

- The direct interaction between the η meson and the nucleon is very weak and there is a small direct coupling between the πN and ηN channels (C_{22} and C_{12} are small).
- However, there is a strong coupling of both the πN and ηN channels to the $K\Sigma$ channel (C_{14} and C_{24} are sizeable).
- Thus *the resonance formed will strongly connect the πN and ηN channels through the coupled channel dynamics*.

the possibility that the $S_{11}(1535)$ resonance is a quasi-bound $K\Sigma$-$K\Lambda$ state. Using the same parameters as obtained from fitting the low energy $\overline{K}N$ data and two finite range parameters, a resonance can be formed at 1557 MeV with the characteristic properties of the $S_{11}(1535)$. The πN S_{11} phase shifts and inelasticities as well as the ηN-production cross section are remarkably well reproduced. The dynamically generated resonance has a full width of 179 MeV and branching ratios extracted from the shape of the resonance of 69% into πN and 31% into ηN final states. Furthermore,

PHYSICAL REVIEW D, VOLUME 64, 116008

$S_{11}-N(1535)$ and $-N(1650)$ resonances in meson-baryon unitarized coupled channel chiral perturbation theory

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(Received 27 April 2001; published 12 November 2001)

The s-wave meson-baryon scattering is analyzed for the strangeness $S=0$ sector in a Bethe-Salpeter coupled channel formalism incorporating chiral symmetry. Four channels have been considered: πN, ηN, $K\Lambda$, $K\Sigma$. The needed two-particle irreducible matrix amplitude is taken from lowest order chiral perturbation theory in a relativistic formalism and low energy constants are fitted to the elastic πN phase shifts and the $\pi^- p \to \eta n$ and $\pi^- p \to K^0 \Lambda$ cross section data. The position of the complex poles in the second Riemann sheet of the scattering amplitude determines masses and widths of the $S_{11}-N(1535)$ and $-N(1650)$ resonances, in reasonable agreement with experiment. A good overall description of data, from πN threshold up to 2 GeV, is achieved, keeping in mind that the two-pion production channel has not been included.

first pole: $M_R = 1496.5 \pm 0.4$, $\Gamma_R = 83.3 \pm 0.7$,

second pole: $M_R = 1684.3 \pm 0.7$, $\Gamma_R = 194.3 \pm 0.8$,

PHYSICAL REVIEW C, VOLUME 65, 035204

Chiral unitary approach to *S*-wave meson baryon scattering in the strangeness *S*=0 sector

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(Received 31 October 2001; published 14 February 2002)

We study the *S*-wave interaction of mesons with baryons in the strangeness $S=0$ sector in a coupled channel unitary approach. The basic dynamics is drawn from the lowest order meson-baryon chiral Lagrangians. Small modifications inspired by models with explicit vector meson exchange in the *t* channel are also considered. In addition the $\pi\pi N$ channel is included and shown to have an important repercussion in the results, particularly in the isospin 3/2 sector. The $N^*(1535)$ resonance is dynamically generated and appears as a pole in the second Riemann sheet with its mass, width, and branching ratios in fair agreement with experiment. A $\Delta(1620)$ resonance also appears as a pole at the right position although with a very large width, coming essentially from the coupling to the $\pi\pi N$ channel, in qualitative agreement with experiment.

$$P_0^R = 1543 - i46 \ \text{MeV}$$

$$|g_{\pi N}| < |g_{K\Lambda}| < |g_{\eta n}| \sim |g_{K\Sigma}|$$

Chiral dynamics of the $S_{11}(1535)$ and $S_{11}(1650)$ resonances revisited

Peter C. Bruns [a], Maxim Mai [b,*], Ulf-G. Meißner [b,c] Physics Letters B 697 (2011) 254–259

We analyze s-wave pion–nucleon scattering in a unitarized chiral effective Lagrangian including all dimension two contact terms. We find that both the $S_{11}(1535)$ and the $S_{11}(1650)$ are dynamically generated, but the $S_{31}(1620)$ is not. We further discuss the structure of these dynamically generated resonances.

$$W_{1535} = (1.506 - 0.140i)\ \text{GeV}$$

$$W_{1650} = (1.692 - 0.046i)\ \text{GeV}$$

$$|g_{\Lambda K^+}|^2 > |g_{p\eta}|^2 > |g_{\Sigma^+ K^0}|^2 \simeq |g_{n\pi^+}|^2 > |g_{\Sigma^0 K^+}|^2 \simeq |g_{p\pi^0}|^2$$

$N^*(1535)$: strongly couples to strangeness channels

	Mode	Fraction (Γ_i/Γ)
Γ_1	$N\pi$	32–52 %
Γ_2	$N\eta$	30–55 %

PRL **96,** 042002 (2006) PHYSICAL REVIEW LETTERS week ending 3 FEBRUARY 2006

Mass and $K\Lambda$ Coupling of the $N^*(1535)$

B. C. Liu[1,3] and B. S. Zou[2,1]

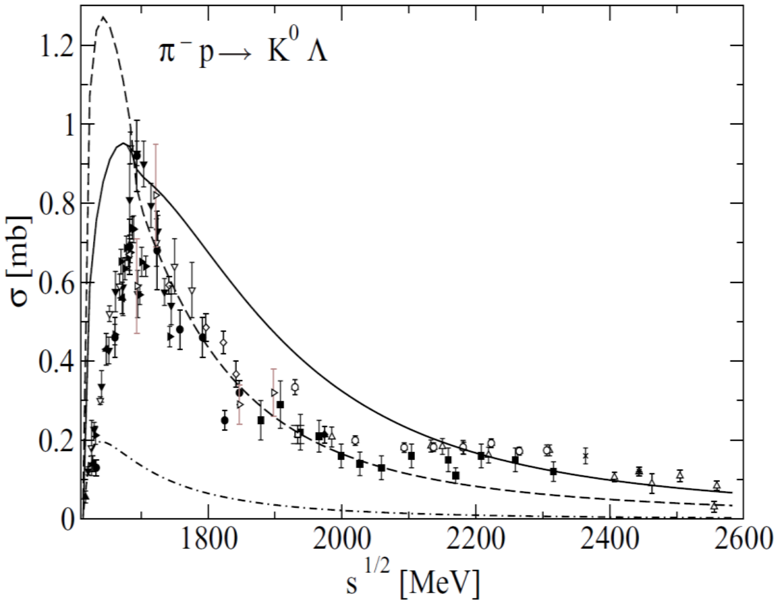
$$\frac{\Gamma(\psi \to \bar{p}N^* \to \bar{p}K^+\Lambda)}{\Gamma(\psi \to \bar{p}N^* + p\bar{N}^* \to \bar{p}p\eta)} \Rightarrow R \equiv \left|\frac{g_{N^*(1535)K\Lambda}}{g_{N^*(1535)N\eta}}\right| \approx 1.3 \pm 0.3.$$

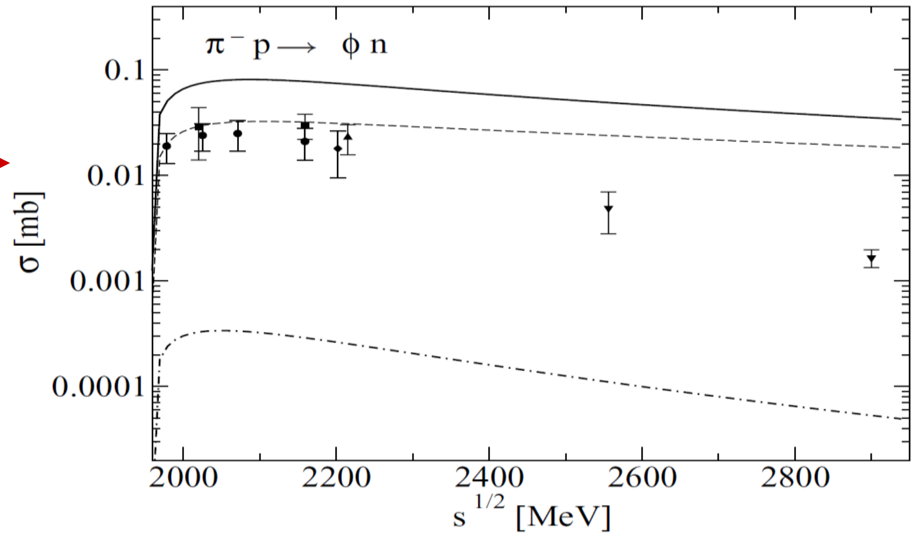
$\rightarrow$ *$N^*(1535)$ couples strongly to the ηN and ΛK channels.*

PHYSICAL REVIEW C **78**, 025207 (2008)

Role of the $N^*(1535)$ resonance and the $\pi^- p \to KY$ amplitudes in the OZI forbidden $\pi N \to \phi N$ reaction

M. Döring,[1] E. Oset,[2] and B. S. Zou[2,3]





- The authors study the πN→ϕN reaction near the ϕN threshold using the chiral unitary approach. They combine the reaction amplitudes of πN→KΛ and πN→KΣ, and introduce the ϕ meson coupling to the kaon meson final states through loop contributions.
- When the dominant πN→KΛ amplitude is constrained by experimental cross section data, their results agree well with the experimental measurements.

PHYSICAL REVIEW C **77**, 015206 (2008)

Role of the $N^*(1535)$ in $pp \to pp\phi$ and $\pi^- p \to n\phi$ reactions

Ju-Jun Xie,[1,2,*] Bing-Song Zou,[1,2,3,†] and Huan-Ching Chiang[1,3,4]

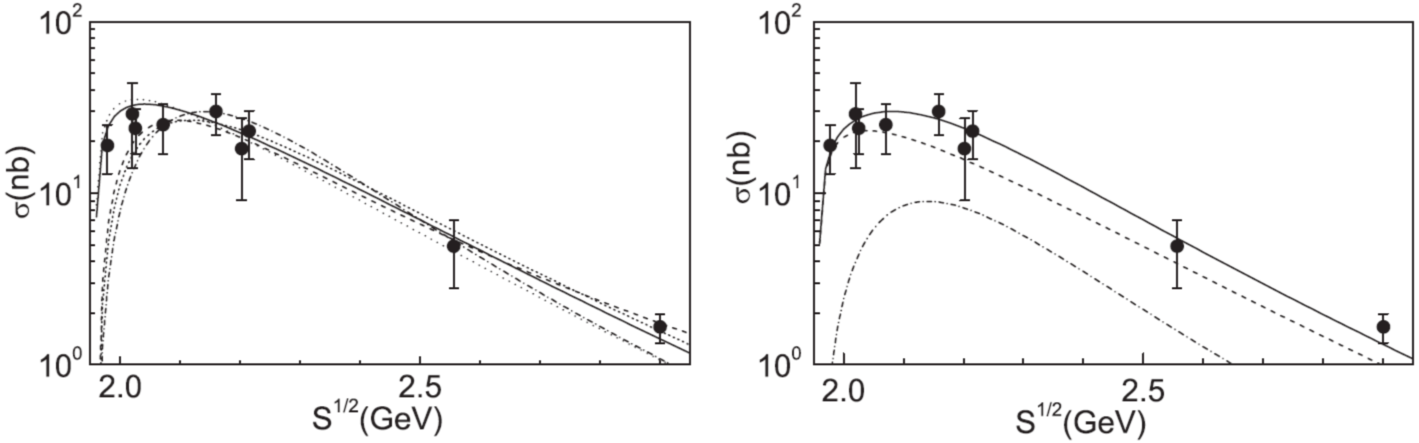
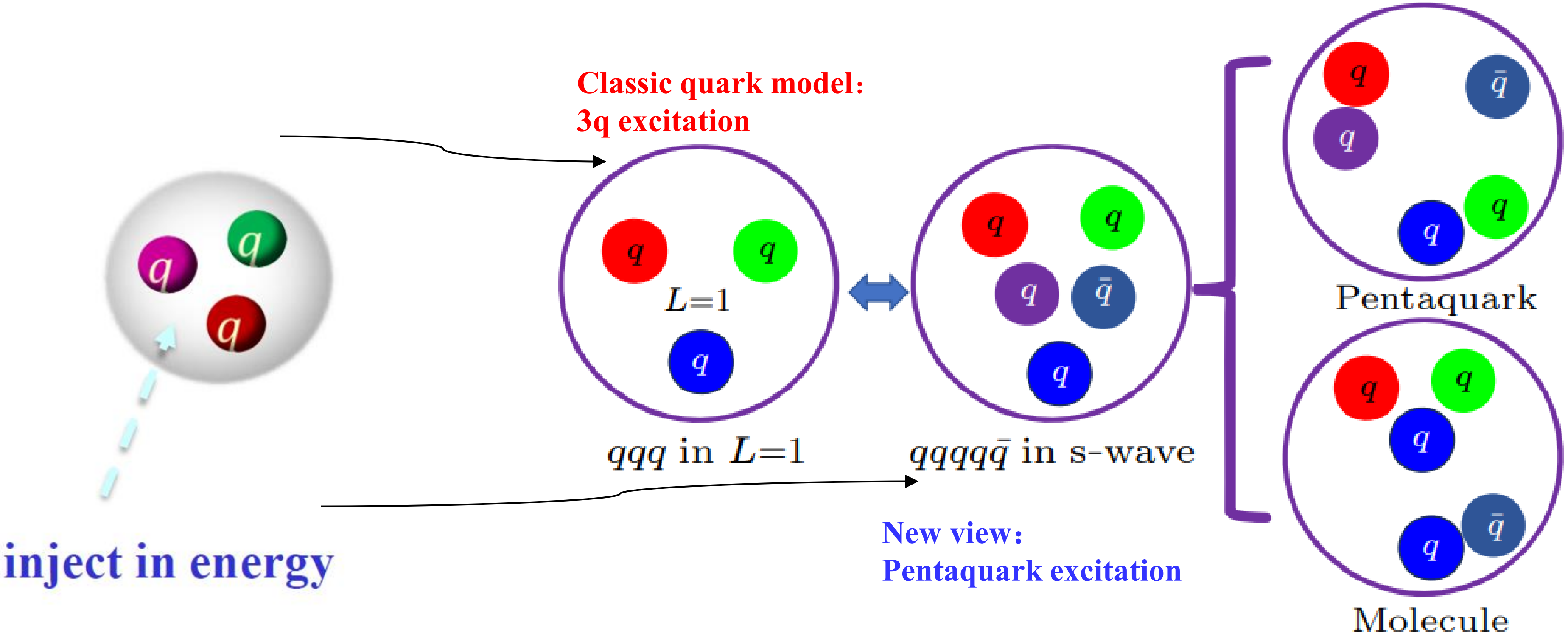
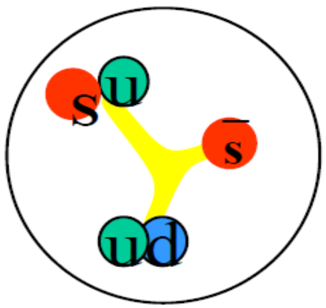


FIG. 3. Total cross sections vs the center-of-mass (c.m.) energy $S^{\frac{1}{2}}$ for $\pi^- p \to n\phi$ reactions with data from Ref. [29]. (Left) The best fits with $N^*(1535)$ (solid), $N^*(1650)$ (dotted), $N^*(1710)$ (dashed), $N^*(1720)$ (short-dashed), and $N^*(1900)$ (dot-dashed), respectively; (right) fit (solid) with $N^*(1535)$ (dashed) plus $N^*(1900)$ (dot-dashed).

- The significant coupling of the $N^*(1535)$ resonance to the ϕN channel together with the earlier findings of large couplings of the $N^*(1535)$ resonance to the $K\Lambda$ and ηN channels gives a coherent picture that there is a large component of strangeness in the $N^*(1535)$ resonance as expected by various theoretical approaches.
- It also gives a natural explanation for the significant enhancement of the ϕ production from πp and pp reactions over the naïve OZI rule predictions.

Configurations for $N^*(1535)\ J^P = \frac{1}{2}^-$





Larger $[ud][us]\bar{s}$ component in N*(1535) makes it coupling strong to Nη & KΛ.

uud (L=1) $1/2^-$ ~ N*(1535) ~ $[ud][us]\ \bar{s}$

The $N^*(1535)$ in $\psi(2S) \to \pi^0 p\bar{p}$ and $\eta p\bar{p}$ decays

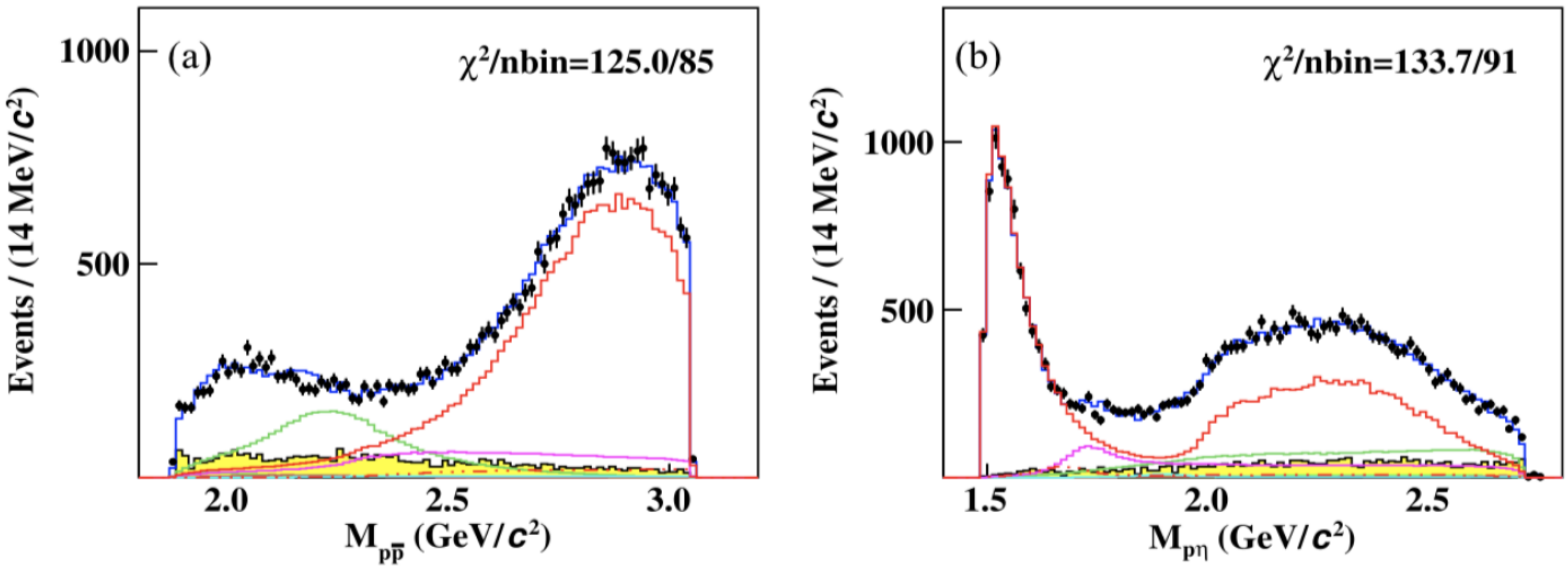
PHYSICAL REVIEW D **111**, 032011 (2025)

Partial wave analyses of $\psi(3686) \to p\bar{p}\pi^0$ and $\psi(3686) \to p\bar{p}\eta$

M. Ablikim *et al.**
(BESIII Collaboration)

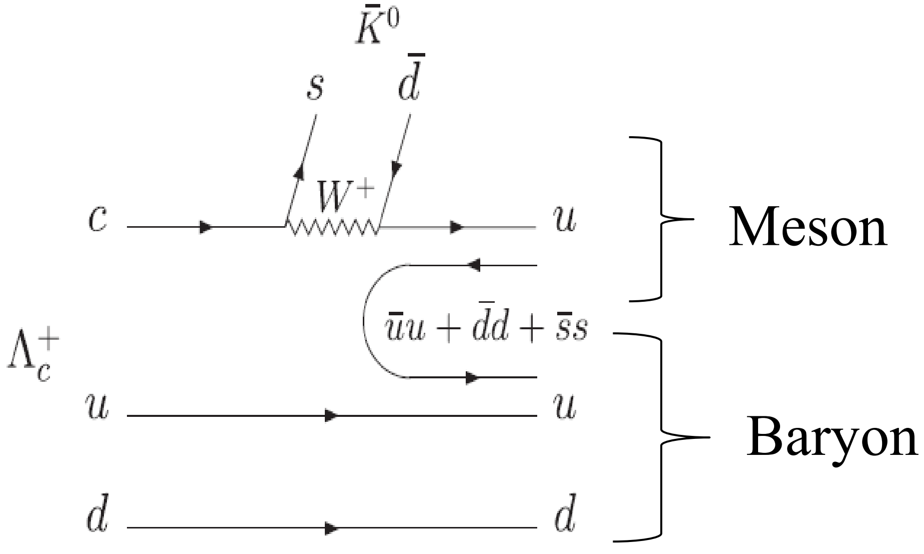
$$\frac{Br[N^*(1535) \to N\pi]}{Br[N^*(1535) \to N\eta]}$$

$$= 0.99 \pm 0.05 \pm 0.19$$



Confirms the exotic property of $N^*(1535)$ and suggests a strong $s\bar{s}$ component!

$N^*(1535)$ in the $\Lambda_c^+ \to \bar{K}^0 \eta p$ decay



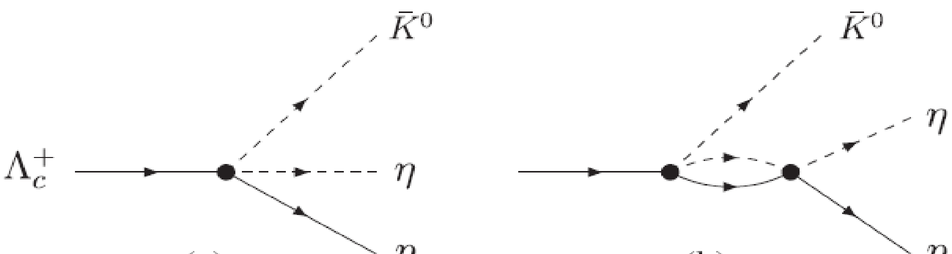
$$|uud> \to \frac{1}{\sqrt{2}}|u(ud - du)>$$

$$\bar{u}u + \bar{d}d + \bar{s}s$$

$$|MB\rangle = \frac{\sqrt{3}}{3}|\eta p\rangle + \frac{\sqrt{2}}{2}|\pi^0 p\rangle + |\pi^+ n\rangle - \frac{\sqrt{6}}{3}|K^+\Lambda\rangle,$$

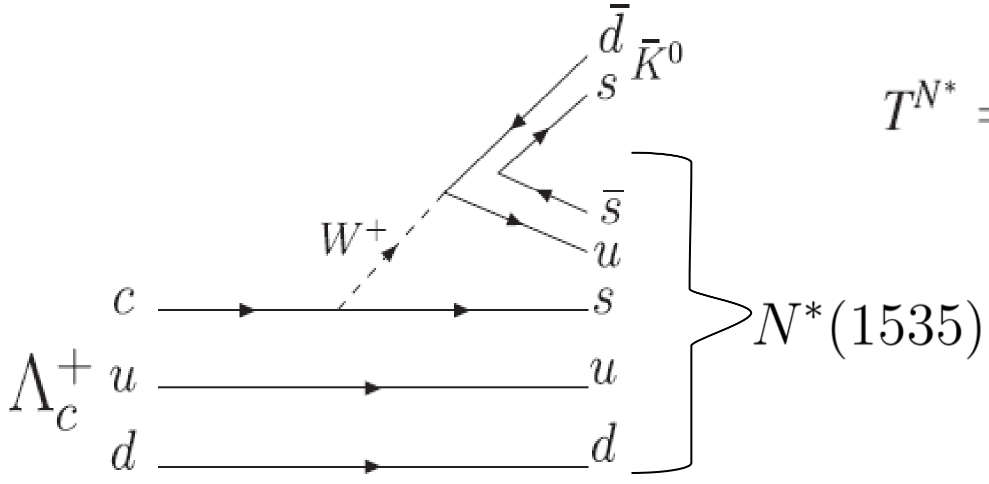
$$\begin{aligned} T^{MB} = V_P \Bigg(& \frac{\sqrt{3}}{3} + \frac{\sqrt{3}}{3} G_{\eta p}(M_{\eta p}) t_{\eta p \to \eta p}(M_{\eta p}) \\ & + \frac{\sqrt{2}}{2} G_{\pi^0 p}(M_{\eta p}) t_{\pi^0 p \to \eta p}(M_{\eta p}) \\ & + G_{\pi^+ n}(M_{\eta p}) t_{\pi^+ n \to \eta p}(M_{\eta p}) \\ & - \frac{\sqrt{6}}{3} G_{K^+\Lambda}(M_{\eta p}) t_{K^+\Lambda \to \eta p}(M_{\eta p}) \Bigg), \end{aligned}$$

$\boxed{\textit{The } N^*(1535) \textit{ as a dynamically generated state}}$



(a) (b)

Effective Lagrangian approach and the N*(1535) resonance as a Breit-Wigner resonance

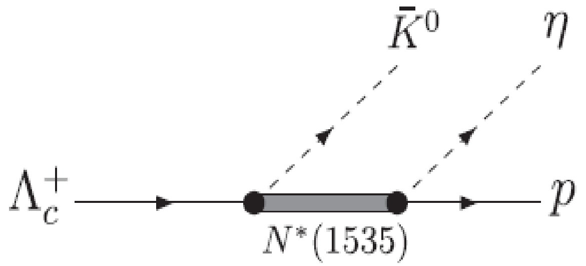


(a)

$$T^{N^*} = i g_{N^* N \eta} \bar{u}(p_3, s_p) G_{N^*}(q)(A + B\gamma_5) u(p, s_{\Lambda_c^+}),$$

$$G_{N^*}(q) = i \frac{\not{q} + M_{N^*}}{q^2 - M_{N^*}^2 + i M_{N^*} \Gamma_{N^*}(q^2)},$$

$$\Gamma_{N^*}(q^2) = \Gamma_{N^* \to \pi N}(q^2) + \Gamma_{N^* \to \eta N}(q^2) + \Gamma_0,$$

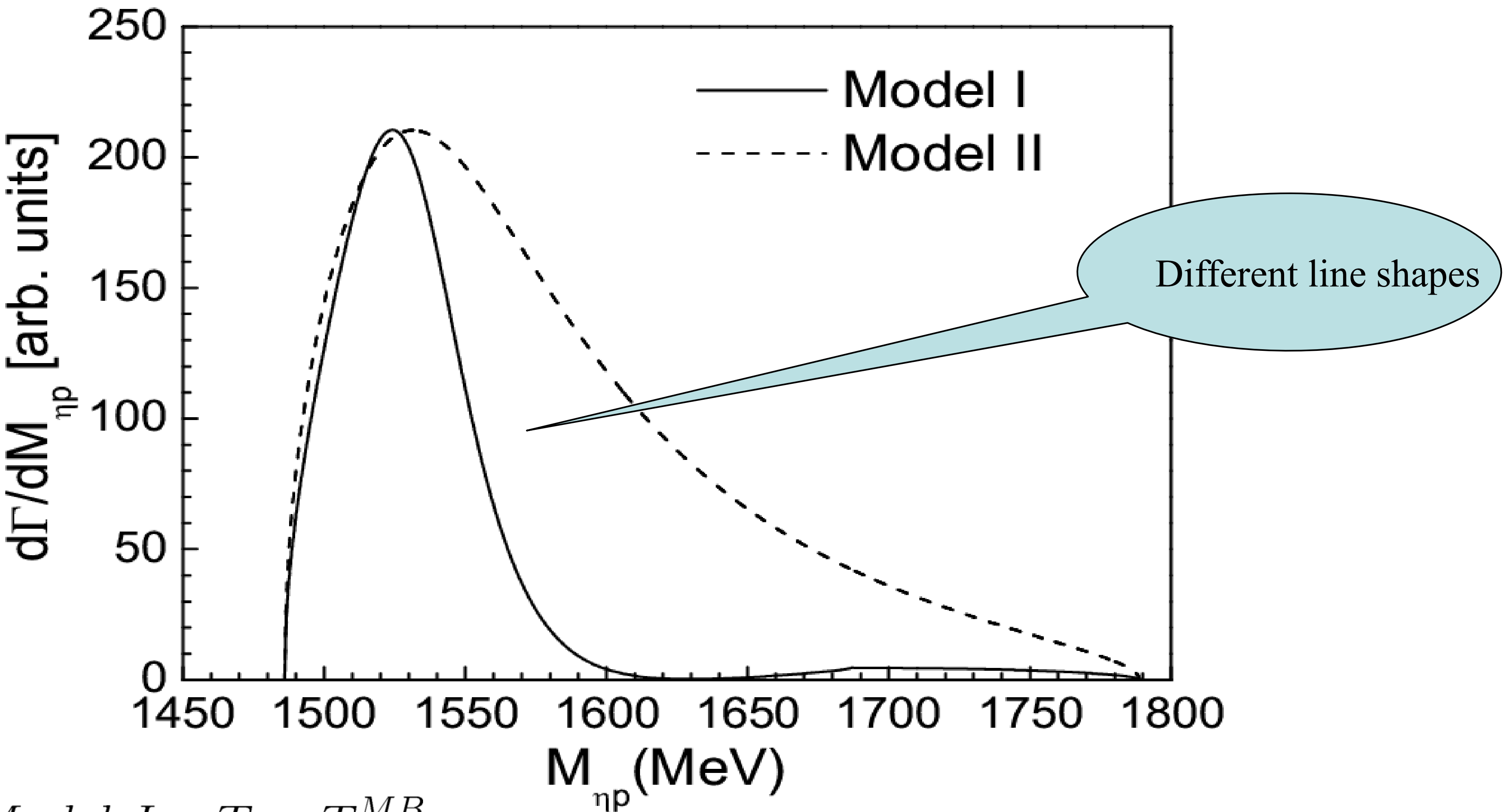


(b)

$$\Gamma_0 = 19.5 \text{ MeV } for \ \Gamma_{N^*}(\sqrt{q^2} = 1535 \text{ MeV}) = 150 \text{ MeV}$$

Ju-Jun Xie and Li-Sheng Geng, PRD 96, 054009 (2017).

Invariant ηp mass distributions



$$Model\ I:\ T = T^{MB}$$

$$Model\ II:\ T = T^{N^*},\ M_{N^*} = 1535\ \mathrm{MeV},\ \Gamma_{N^*} = \Gamma_{N^*}(q^2)$$

Other contributions

$$N^*(1650) \to \eta p$$

$$\Sigma^* \; resonances$$

$$\to \bar{K}^0 p$$

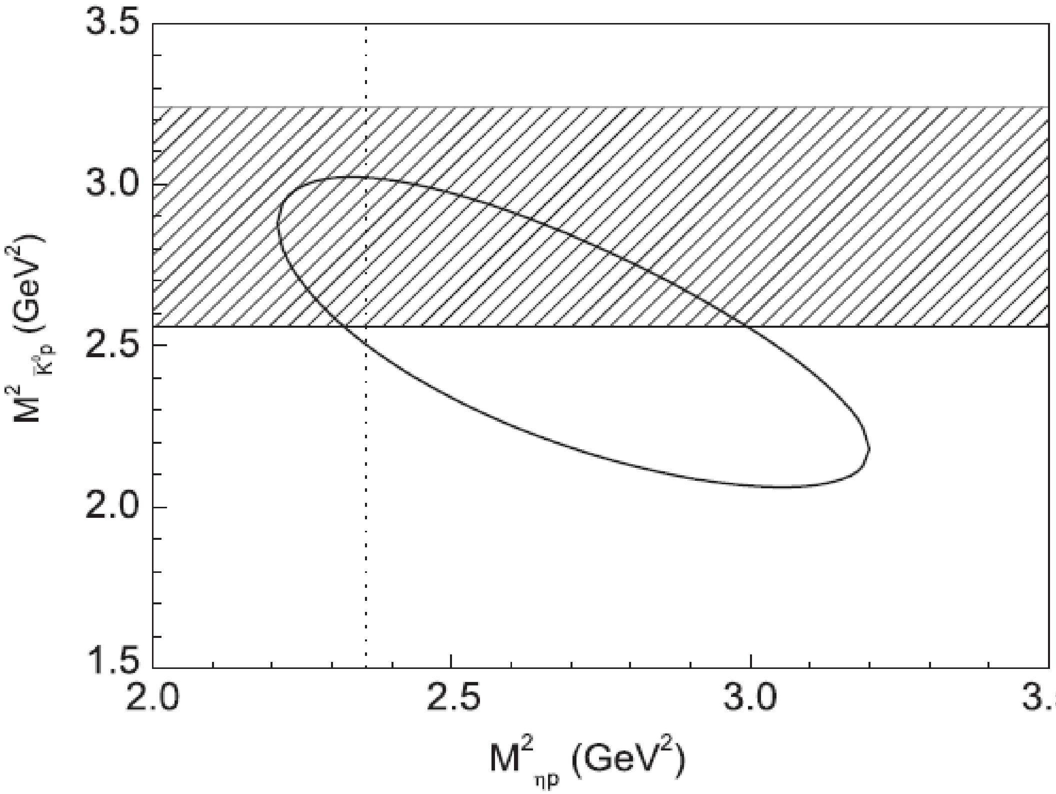


FIG. 7. Dalitz plot for $M^2_{\eta p}$ and $M^2_{\bar{K}^0 p}$ in the $\Lambda_c^+ \to \bar{K}^0 \eta p$ decay. The $N^*(1535)$ energy is shown by the vertical dotted line, and the horizontal band represents the masses of Σ^* states from 1600 to 1800 MeV.

Production of $N^*(1535)$ and $N^*(1650)$ in $\Lambda_c \to \overline{K}^0 \eta p$ (πN) decay

R. Pavao,* S. Sakai, and E. Oset PRC 98, 015201 (2018).

PHYSICAL REVIEW D **107,** 032004 (2023)

Measurement of branching fractions of $\Lambda_c^+ \to pK_S^0K_S^0$ and $\Lambda_c^+ \to pK_S^0\eta$ at Belle

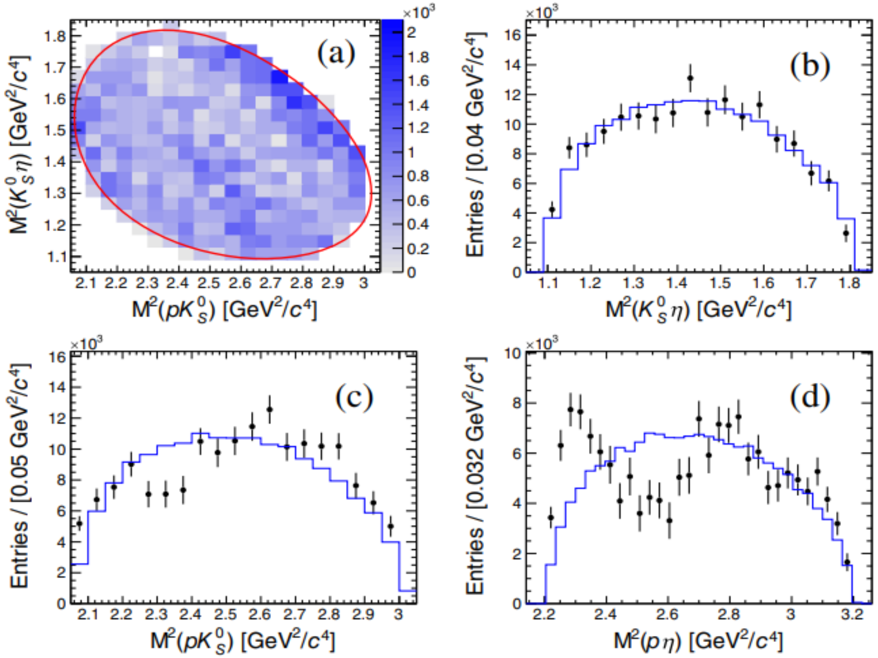
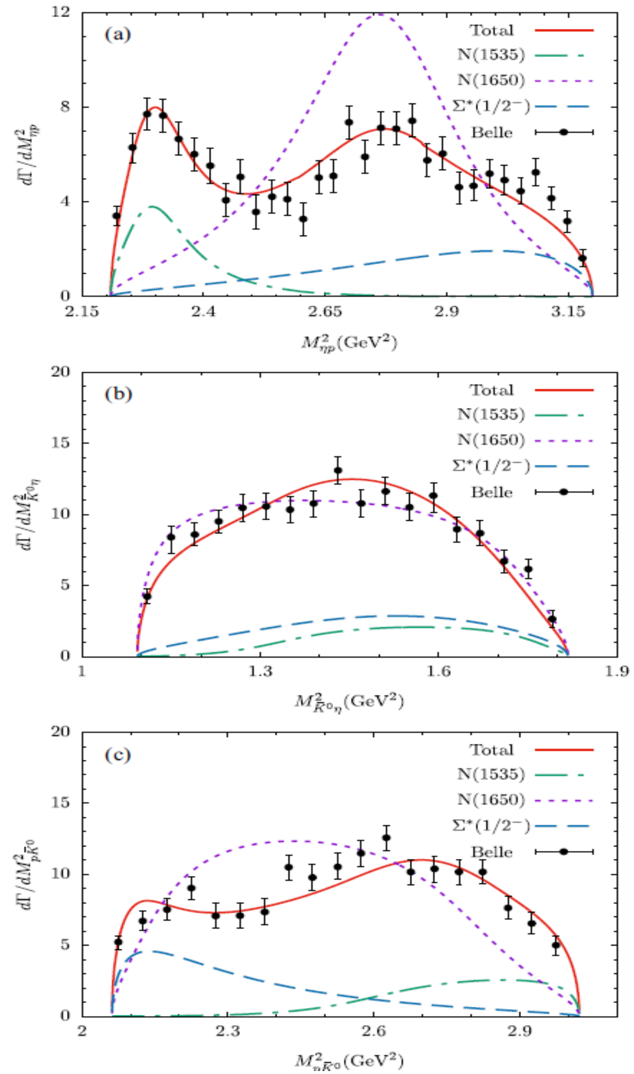


FIG. 4. For $\Lambda_c^+ \to pK_S^0\eta$, the Dalitz plot after background subtraction and efficiency correction bin-by-bin and its projections superimposing with signal MC produced by phase space mode (blue histograms). A significant structure of $N^*(1535)$ near the $p\eta$ threshold is found.

PHYSICAL REVIEW D **110,** 074010 (2024)

Theoretical study of $N(1535)$ and $\Sigma^*(1/2^-)$ in the Cabibbo-favored process $\Lambda_c^+ \to p\bar{K}^0\eta$

Ying Li,[1] Si-Wei Liu,[2,3] En Wang,[1,4,*] De-Min Li,[1,†] Li-Sheng Geng,[5,6,7,8,‡] and Ju-Jun Xie[2,3,8,§]



Summary

- ✓ The $N^*(1535)$ resonance couples strongly to those strangeness channels
- ✓ The $\Lambda_c^+ \to \bar{K}^0 \eta p$ decay can be used to study the strangeness nature ($uuds\bar{s}$, $udds\bar{s}$) of $N^*(1535)$ resonance
- ✓ Multiquark configuration is crucial for hadron spectroscopy and structure

Thank you very much for your attention!