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

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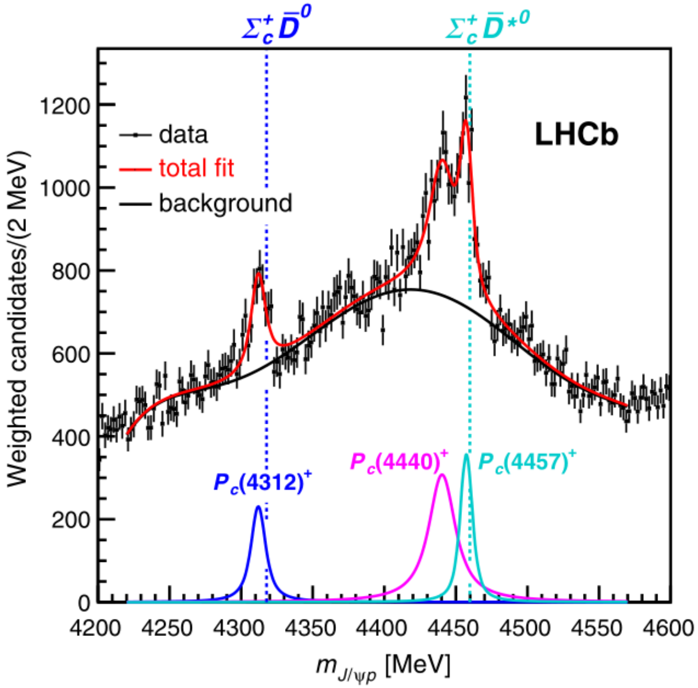
Phys. Rev. C 98, 015201 (2018)

Presented by
Shuntaro Sakai [Institute of Theoretical Physics, CAS (China)]

Recent observation in heavy baryon decays

--Three P_c peaks in $J/\psi N$ invariant mass distribution in $\Lambda_b \to K^- J/\psi p$



LHCb Collab. [PRL122,222001(2019)]

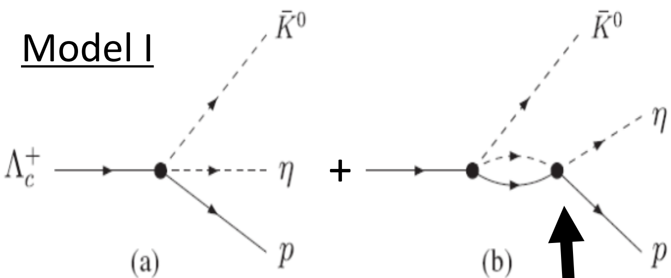
- $\Sigma_c \overline{D}^{(*)}$ molecule
- Compact pentaquark
- Kinematical effect,...

Heavy-baryon decay ➔ Study baryon resonances

Study of $N^*(1535)$ in $\Lambda_c \to \bar{K}^0 \eta p$

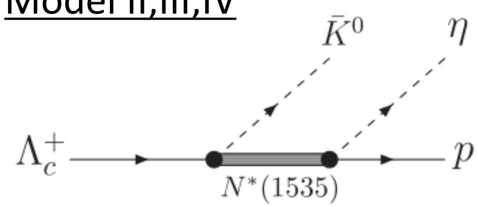
by J.J. Xie and L.S. Geng, Phys. Rev. D 96, 054009 (2017)

Model I

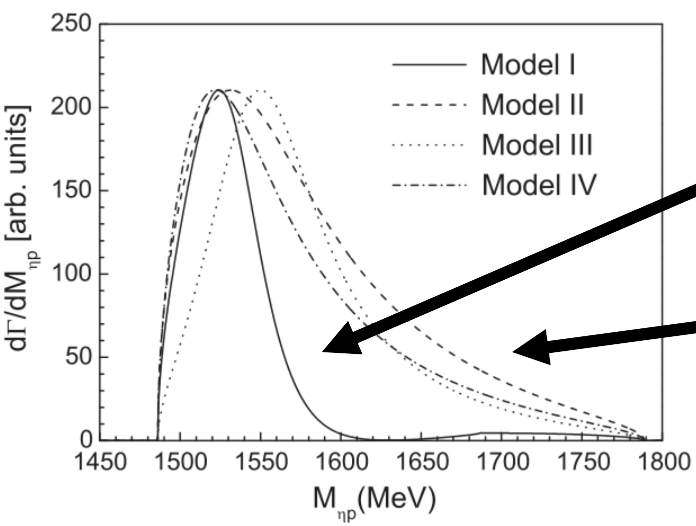


$N^*(1535)$ in final-state rescattering

Model II,III,IV



$N^*(1535)$ produced directly



Tree + $N^*(1535)$ in rescattering

directly produced $N^*(1535)$

Different line shapes

- destructive interference in Model I

$N^*(1535)$

$N^*(1535)$ in PDG

		branching fraction
Γ_1	$N\pi$	32–52 %
Γ_2	$N\eta$	30–55 %
Γ_3	$N\pi\pi$	3–14 %
Γ_4	$\Delta(1232)\pi$	
Γ_5	$\Delta(1232)\pi$, D-wave	1–4 %
Γ_6	$N\sigma$	2–10 %
Γ_7	$N(1440)\pi$	5–12 %
Γ_8	$p\gamma$, helicity=1/2	0.15–0.30 %
Γ_9	$n\gamma$, helicity=1/2	0.01–0.25 %

←comparable to πN

$$N^* \sim qqq \ (q = u, d)$$

$$\eta = \frac{1}{\sqrt{6}}(\bar{u}u + \bar{d}d - 2\bar{s}s)$$

small coupling

Description as hadronic molecule

Kaiser-Siegel-Weise: Phys. Lett. B362(1995)23

$$N^* \sim MB = [q\bar{s}][sqq], [\bar{s}s][qqq], \dots$$

s-wave pseudo-scalar—baryon: $\pi N, \eta N, K\Lambda, K\Sigma$

★ Theoretical consideration on CDD pole

➔ Necessity of some contribution in addition to $\pi N, \eta N, K\Lambda, K\Sigma$

Hyodo-Jido-Hosaka [Phys. Rev.C78, 025203 (2008)]

- Coupled-channel analysis with PB and VB channels

Khemchandani et al. [Phys. Rev. D88, 114016 (2013)],
Garzon-Oset [Phys. Rev. C91, 025201 (2015)],...

-- PB-VB coupling: non-vanishing contribution even in low energies

🡐 Kroll-Rudermann term

-- VB channel ρN $K^*\Sigma$

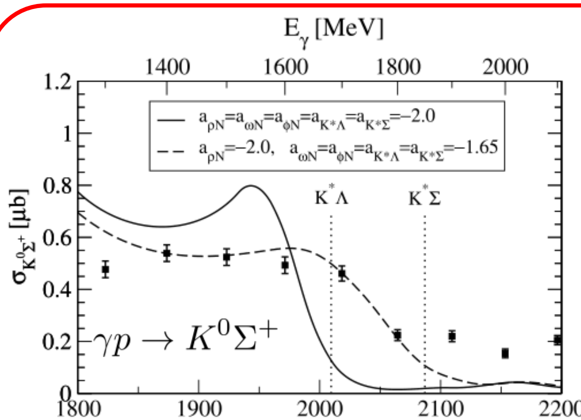
Prediction of N^* around 1.7 GeV and 2 GeV

Oset-Ramos (2013)

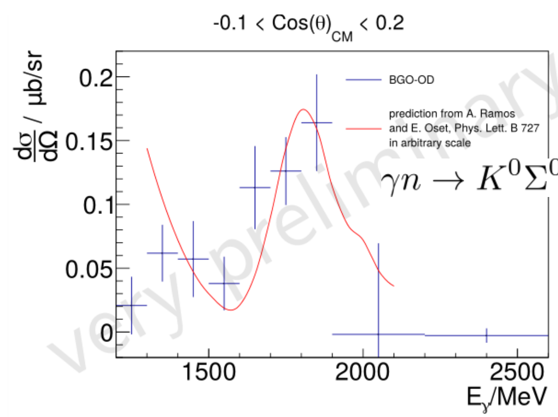
$J = 1/2, \boxed{3/2}$

$\boxed{N(1700)\ 3/2^-}$ $I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$ Status: ∗∗∗

Theoretical work:
Garzon-Xie-Oset PRC87,055204(2013)
- PB-VB coupling in J=3/2 sector



Ramos-Oset [Phys. Lett. B 727 (2013) 287]



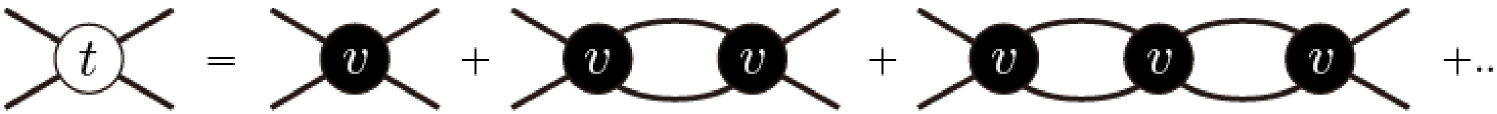
Talk of Kartin Kohl@NSTAR2019

data: CBELSA/TAPS

- Coupled channel analysis with PB and VB channels

Garzon-Oset [Phys. Rev. C91, 025201 (2015)]

-- chiral unitary approach



$$t = v + vgv + vgvgv + \ldots$$

$$= v + vgt = [1 - vg]^{-1} v$$: implement elastic unitarity

$N^*(1535)$	Theory	PDG [34]
Re(Pole)	1508.1	1490–1530
2Im(Pole)	90.3	90–250
Channel		
$N\pi(1077)$	58.6	35–55
$N\eta(1487)$	37.0	42 ± 10
$\Lambda K(1609)$	0.0	
$\Sigma K(1683)$	0.0	
$N\rho(1714)$	1.0	2 ± 1
$\Delta\pi(1370)$	3.3	0–4

$N^*(1650)$	Theory	PDG [34]
Re(Pole)	1672.3	1640–1670
2Im(Pole)	158.2	100–170
Channel		
$N\pi$	58.9	50–90
$N\eta$	27.6	5 –15
ΛK	5.7	
ΣK	0.0	
$N\rho$	5.6	1 ± 1
$\Delta\pi$	2.2	0 –25

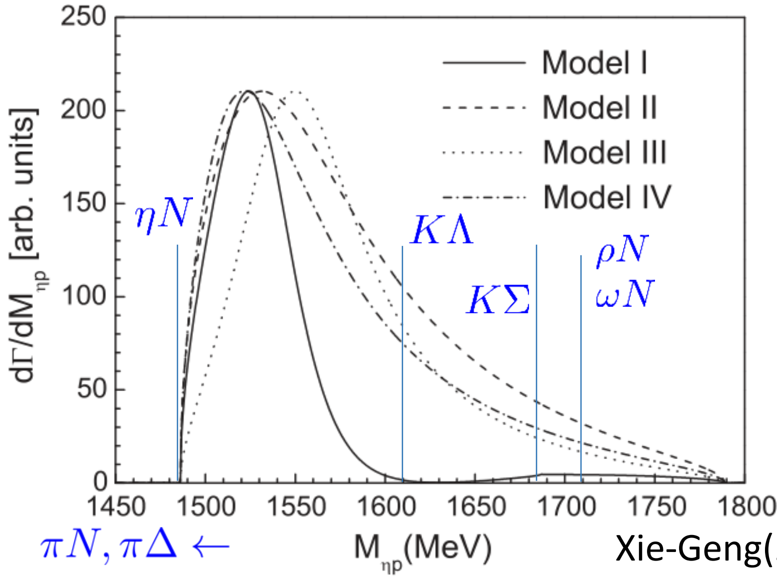
In PDG: $N(1535)$ $1/2^-$ ****
$N(1650)$ $1/2^-$ ****

Channel	$N^*(1535)$ g_i	$N^*(1535)$ $\lvert g_i \rvert$	$N^*(1535)$ g_iG_i	$N^*(1650)$ g_i	$N^*(1650)$ $\lvert g_i \rvert$	$N^*(1650)$ g_iG_i
$N\pi$	$1.03 + i\, 0.21$	1.05	$-6.68 - i\, 24.29$	$1.37 + i\, 0.54$	1.47	$2.52 - i\, 36.51$
$N\eta$	$1.40 + i\, 0.78$	1.60	$-30.50 - i\, 29.20$	$1.08 - i\, 0.60$	1.24	$-33.89 - i\, 2.51$
ΛK	$1.71 + i\, 0.48$	1.78	$-38.06 - i\, 14.50$	$0.10 - i\, 0.68$	0.69	$-9.96 + i\, 17.67$
ΣK	$1.70 + i\, 1.24$	2.10	$1.58 - i\, 2.77$	$3.21 - i\, 1.34$	3.47	$-28.75 - i\, 13.14$
$N\rho$	$2.96 + i\, 0.11$	2.96	$17.71 - i\, 2.61$	$0.94 + i\, 1.51$	1.78	$7.83 - i\, 2.25$
$\Delta\pi$	$0.31 - i\, 0.04$	0.31	$-8.17 - i\, 3.20$	$0.31 + i\, 0.03$	0.31	$-6.03 - i\, 6.72$

Many studies on $N^*(1535/1650)$

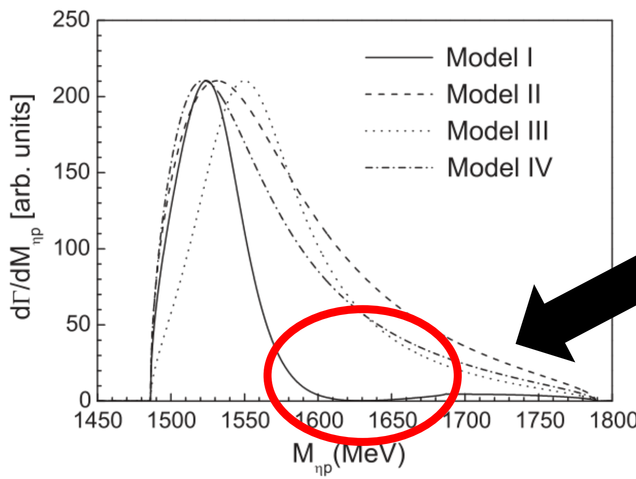
- Quark-model calculation
  - -- Isgur-Karl: Phys. Rev., D18, 4187(1978),…
- Coupled channel analysis for $N^*(1535)$ (and $N^*(1650)$)
  - -- Kaiser-Siegel-Weise: Phys. Lett. B362, 23(1995)
  - -- Nieves-Ruiz Arriola: Phys. Rev.D64, 116008(2001)
  - -- Inoue et al.: Phys. Rev. C65, 035204(2002)
  - -- R. A. Arndt et al. Phys. Rev. C 74, 045205 (2006)
  - -- Gamermann et al.: Phys. Rev. D84, 056017 (2011)
  - -- Bruns-Mai-Meissner: Phys. Lett. B697, 254(2011)
  - -- Khemchandani et al.: Phys. Rev. D88, 114016 (2013)
  - -- Roenchen et al.: Eur. Phys. J. A49, 44 (2013)
  - -- Shklyar-Lenske-Mosel: Phys. Rev. C87, 015201 (2013)
  - -- Garzon-Oset: Phys. Rev. C91, 025201(2015),…
- $K\Lambda$ coupling to $N^*(1535)$
  - -- Liu-Zou: Phys. Rev. Lett. 96, 042002 (2006)
  - -- Mart: Phys. Rev. C87, 042201(2013),…
- $qqqq\bar{q}$ contribution
  - -- Helminen-Riska, Nucl. Phys. A699, 624(2002),…
- Photoproduction
  - -- Kaiser-Waas-Weise: Nucl. Phys. A612, 297(1997)
  - -- Tiator et al.: Eur. Phys. J. A54, 210(2018),…

and so on…



Xie-Geng(2017)

Pseudoscalar-baryon and Vector-baryon channels

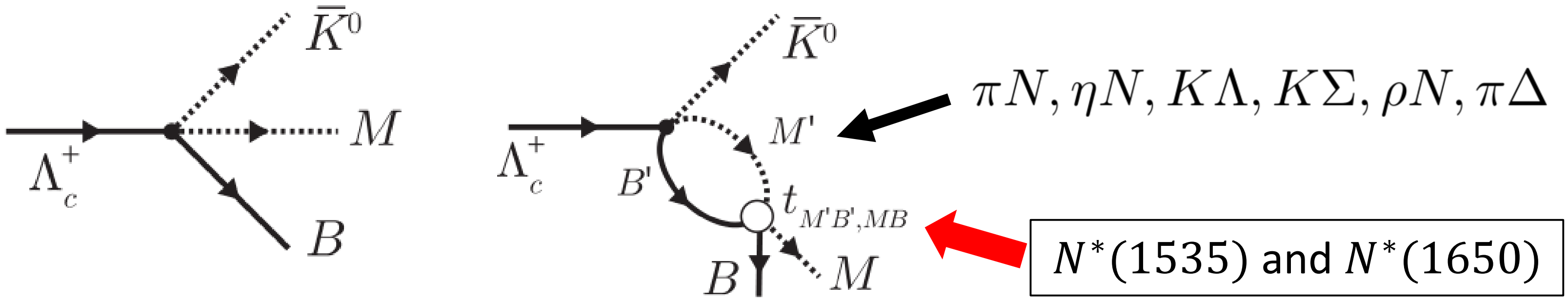


Possible modification!

Inclusion of $N^*(1650)$ and VB coupling is needed

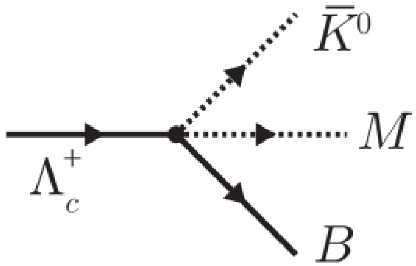
Investigate $\Lambda_c \to \bar{K}^0 MB$ with $N^*(1535)$ and $N^*(1650)$

$(MB = \eta p, \pi N, K\Sigma)$

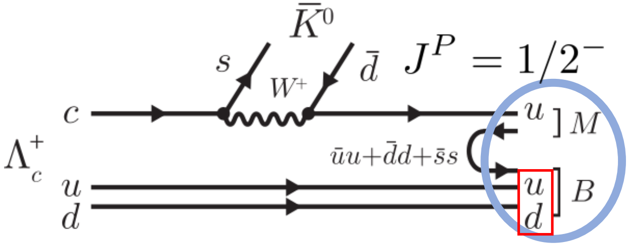


(The same framework as Xie-Geng(2017))

Λ_c decay amplitude



-- Quark-level picture



$$\underbrace{u\bar q_i}_{M(=P,V)}\underbrace{q_i[qq]_{I=0}}_{B}$$

$$\bar q_i q_j = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}}+\frac{\eta}{\sqrt{3}}+\frac{\eta'}{\sqrt{6}} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}}+\frac{\eta}{\sqrt{3}}+\frac{\eta'}{\sqrt{6}} & K^0 \\ K^- & \bar K^0 & -\frac{\eta}{\sqrt{3}}+\sqrt{\frac{2}{3}}\eta' \end{pmatrix}_{ij}$$

$$\begin{pmatrix} \frac{\rho^0}{\sqrt{2}}+\frac{\omega}{\sqrt{2}} & \rho^+ & K^{*+} \\ \rho^- & -\frac{\rho^0}{\sqrt{2}}+\frac{\omega}{\sqrt{2}} & K^{*0} \\ K^{*-} & \bar K^{*0} & \phi \end{pmatrix}_{ij}$$

$$p = \frac{u(ud-du)}{\sqrt{2}}, \ldots$$

$I = 0 \Rightarrow \pi\Delta, K\Sigma$: suppressed

$$\Rightarrow\; t_{\Lambda_c,\bar K^0 MB} = V_P h_{MB} f_{MB}$$

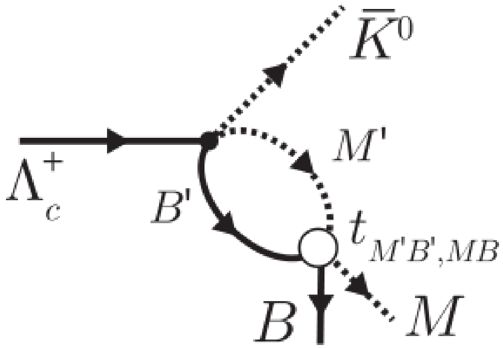
flavor

spin

$^3P_0$ model $\begin{cases} 1 \text{ for } M = P \\ \frac{1}{\sqrt{3}} \text{ for } M = V \end{cases}$

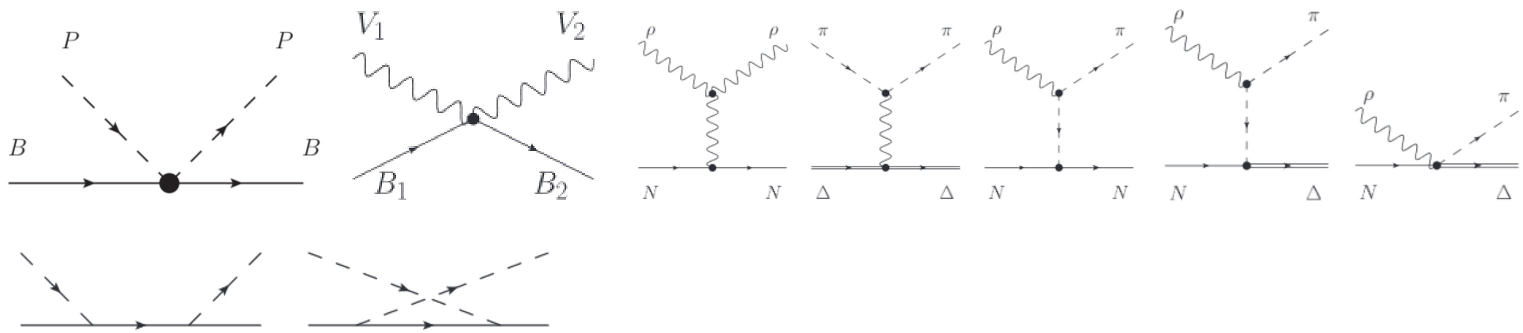
[see, e.g., Eur. Phys. J. C 77, 39(2017)]

-- MB amplitude Garzon-Oset (2015)



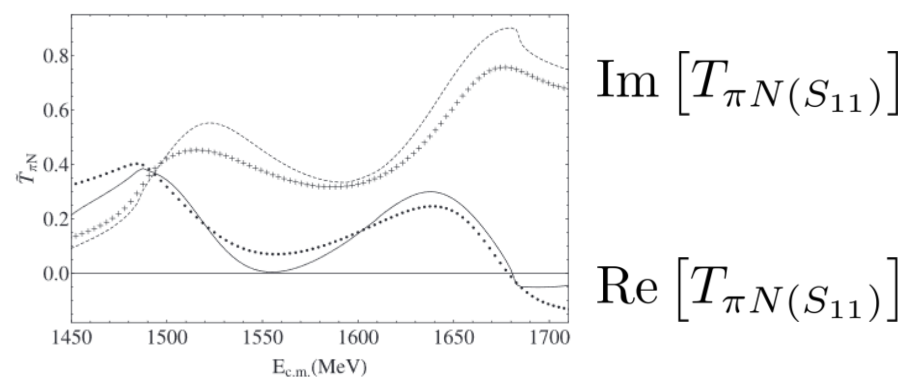
$$t = v + vgt = [1 - vg]^{-1} v$$

interaction kernel v: meson(V, P)-exchange, Born, Kroll-Rudermann terms



<u>Input:</u>

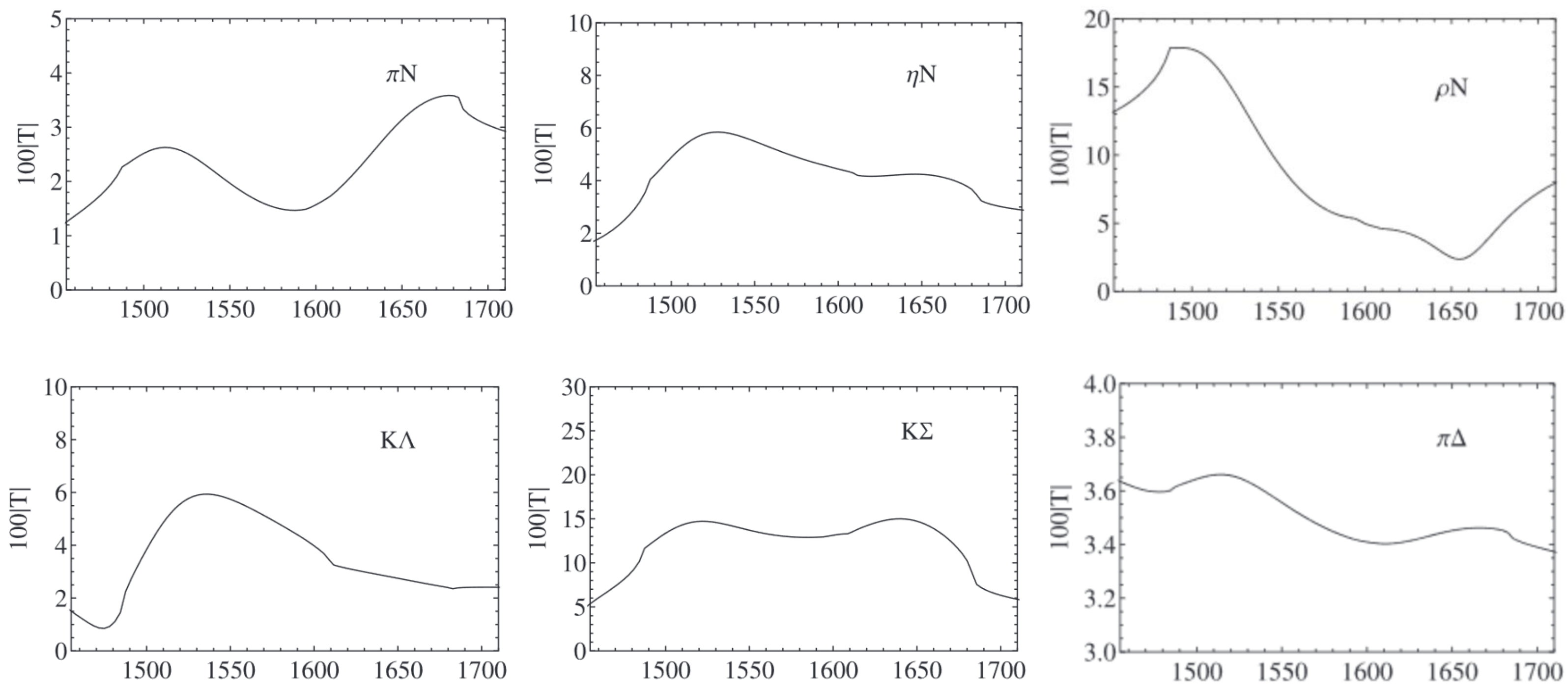
πN scattering amplitude



-- Meson-Baryon amplitude Garzon-Oset (2015)

■ Some structures around 1500MeV and 1650MeV

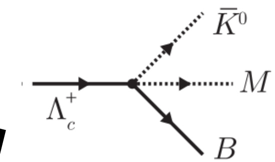
← different shapes in each channel



Channel	N*(1535)							N*(1650)						
	g_i			$\|g_i\|$	g_iG_i			g_i			$\|g_i\|$	g_iG_i		
$N\pi$	1.03	$+i$	0.21	1.05	−6.68	$-i$	24.29	1.37	$+i$	0.54	1.47	2.52	$-i$	36.51
$N\eta$	1.40	$+i$	0.78	1.60	−30.50	$-i$	29.20	1.08	$-i$	0.60	1.24	−33.89	$-i$	2.51
ΛK	1.71	$+i$	0.48	1.78	−38.06	$-i$	14.50	0.10	$-i$	0.68	0.69	−9.96	$+i$	17.67
ΣK	1.70	$+i$	1.24	2.10	1.58	$-i$	2.77	3.21	$-i$	1.34	3.47	−28.75	$-i$	13.14
$N\rho$	2.96	$+i$	0.11	2.96	17.71	$-i$	2.61	0.94	$+i$	1.51	1.78	7.83	$-i$	2.25
$\Delta\pi$	0.31	$-i$	0.04	0.31	−8.17	$-i$	3.20	0.31	$+i$	0.03	0.31	−6.03	$-i$	6.72

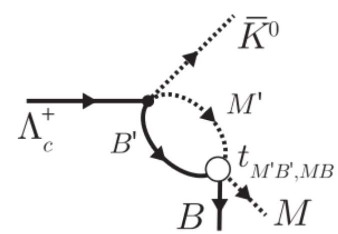
$$t_{ij} \sim \frac{g_{iR}g_{jR}}{\sqrt{s} - m_R + i\Gamma_R/2} + \text{non res.}$$

$$\frac{d\Gamma_{\Lambda_c^+,\bar{K}^0MB}}{dM_{MB}} \sim p_{\bar{K}^0}\tilde{p}^{\,*}_M\left|t_{\Lambda_c^+,\bar{K}^0MB}\right|^2$$



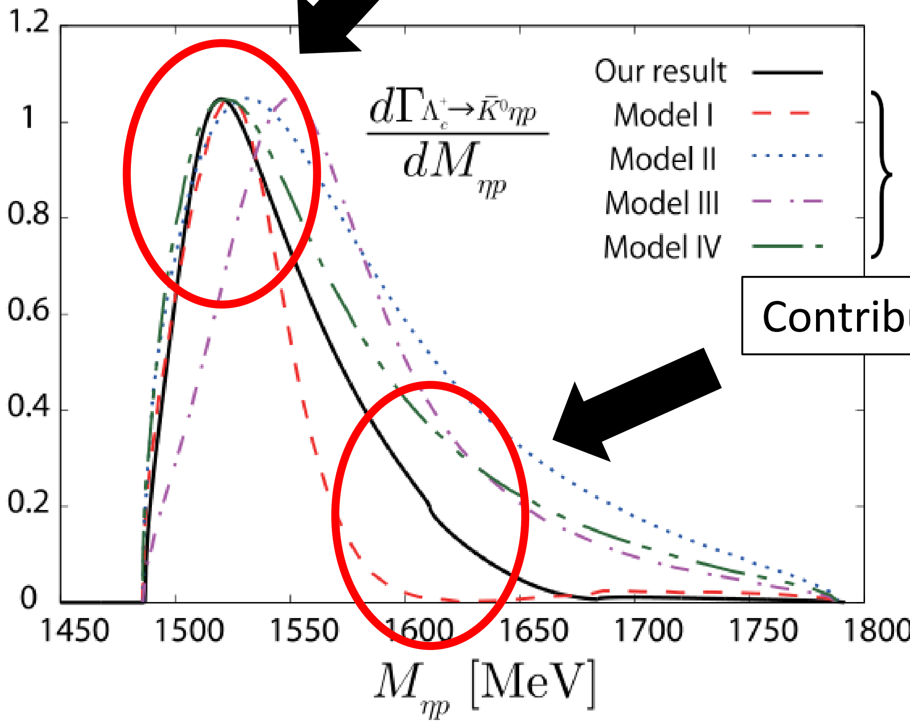
$$\boxed{\begin{aligned} t_{\Lambda_c^+,\bar{K}^0MB} =& V_P h_{MB} f_{MB} \\ &+ V_P h_{M'B'} f_{M'B'} G_{M'B'} t_{M'B',MB} \end{aligned}}$$

$$M'B' = \pi N, \eta N, K\Lambda, \rho N$$
$$\cancel{K\Sigma, \pi\Delta}$$



- $\Lambda_c^+ \to \bar{K}^0 \eta p$

Clear peak of $N^*(1535)$!

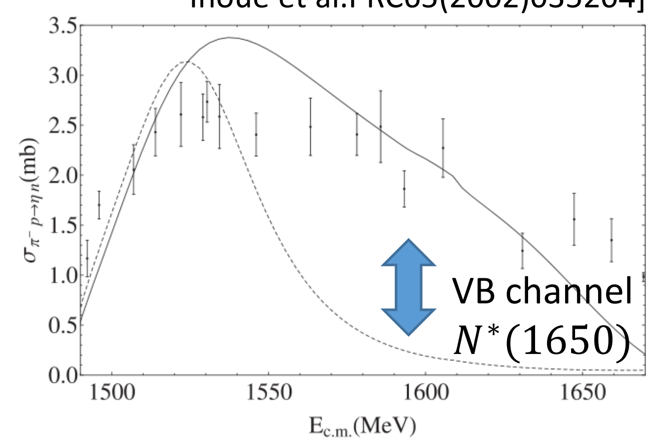


Results of Xie-Geng(2017)

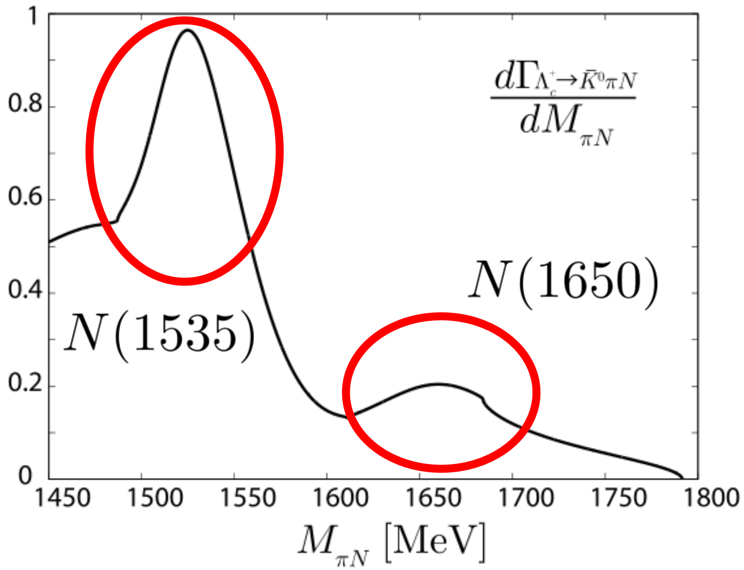
Contribution from $N^*(1650)$!

-- Single broader peak (⇔two peaks)

$\pi^- p \to \eta n$ [Garzon-Oset(2015), Inoue et al.PRC65(2002)035204]



- $\Lambda_c^+ \to \bar{K}^0 \pi N$

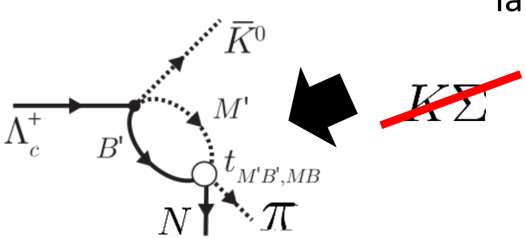


-- Two-peak structure

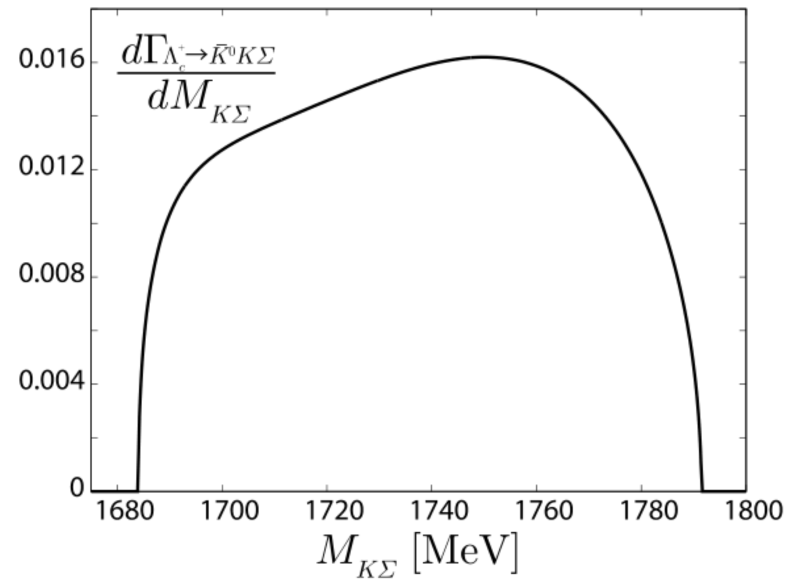
-- Suppression of $K\Sigma$ prod. in Λ_c decay

→ small $N^*(1650)$ peak

large coupling to $K\Sigma$



- $\Lambda_c^+ \to \bar{K}^0 K \Sigma$



-- Tail of $N^*(1650)$

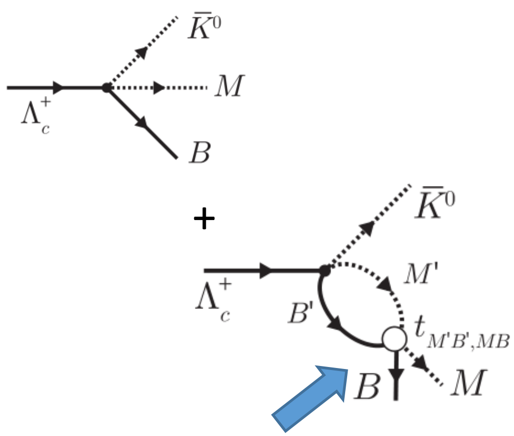
-- $K\Sigma$: Small production from Λ_c

Summary

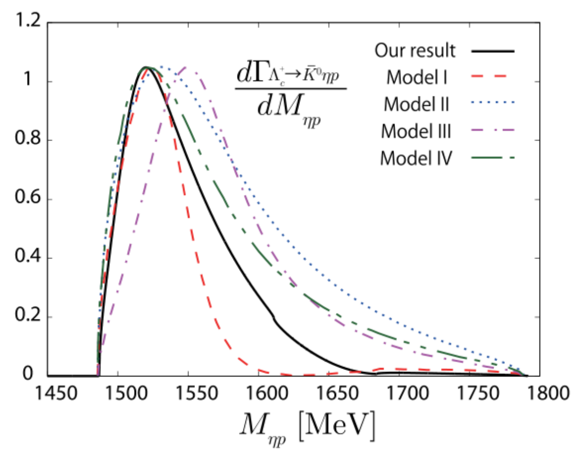
- Effect of <u>$N^*(1535)$ and $N^*(1650)$</u>

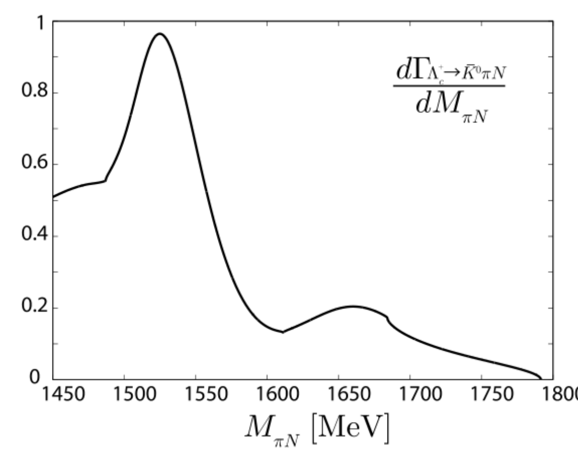
<u>Dynamically generated from meson-baryon dynamics</u>

in $\Lambda_c \to \bar{K}^0 MB(MB = \eta p, \pi N, K\Sigma)$



Dynamically generated
$N^*(1535)$ and $N^*(1650)$





different shapes

← <u>**Molecular nature of $N^*(1535)$ and $N^*(1650)$**</u>

Thank you for your attention.