Faddeev方程式による Λ(1405)共鳴生成反応の研究

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in collaboration with

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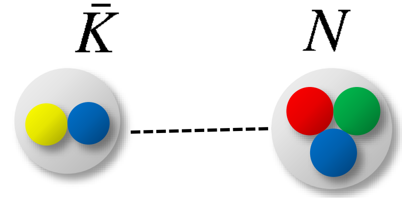
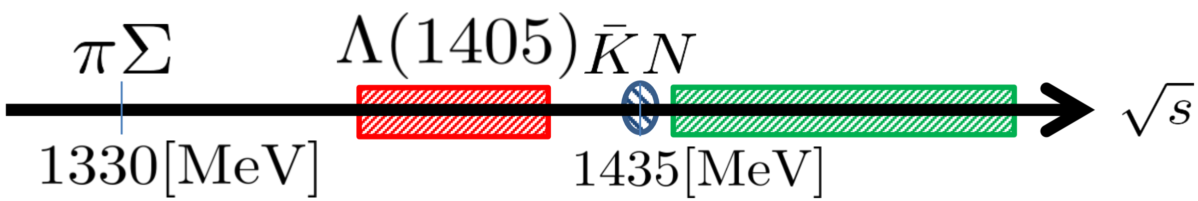
$K^{bar}N$ *interaction*



In order to understand the structure of Λ(1405),
precise determination of $K^{bar}N$-πΣ (I=0) interaction is necessary.

experimental constraint



above $K^{bar}N$ threshold energy: - $K^{-}p$ cross section

at/just-below KN threshold energy: - Branching ratio

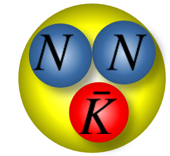
- kaonic atom(new data by SIDDHARTA)

below the $K^{bar}N$ threshold energy:

- So far, cannot perform πΣ elastic scattering experimentally
- πΣ mass spectra from Λ(1405) production reactions

(CLAS, LEPS, HADES, J-PARC)

strange dibaryons $\bar{K}NN - \pi YN \ (Y = \Lambda, \Sigma)$



theoretical investigations:

$\bar{K}N$ interactions	Phenomenological	Chiral SU(3)
Variational	*Akaishi, Yamazaki[1]* *Wycech, Green[5]*	*Doté, Hyodo, Weise[4]* *Barnea, Gal, Liverts[7]*
Faddeev eqs.	*Shevchenko, Gal , Mares[2]*	*Ikeda, Sato[3]* *Ikeda, Kamano, Sato[6]*

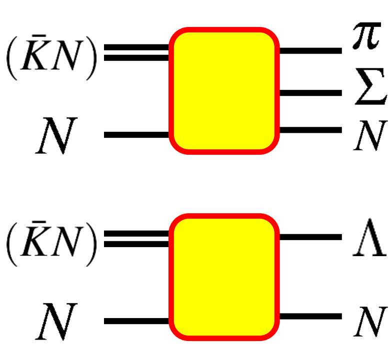
	[1]	[2]	[3]	[4]	[5]	[6]	[7]
B[MeV]	48	50-70	45-80	17-23	40-80	9-16	16
Γ[MeV]	61	90-110	45-75	40-70	40-85	34-46	41

Blue ; E-dep.
Black ; E-indep.

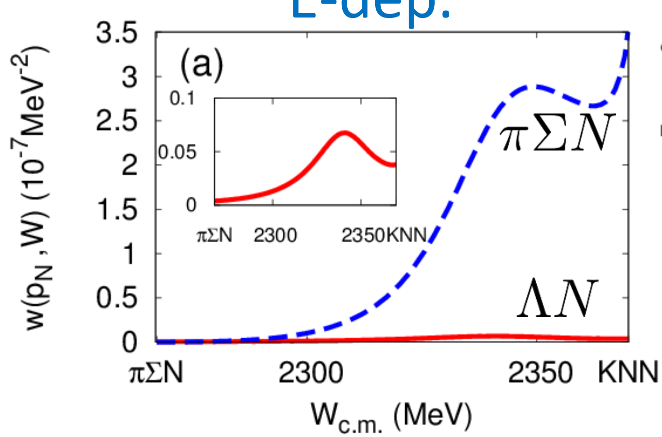
[1] Akaishi, Yamazaki, PRC **65**, 044005 (2002).
[2] Shevchenko, Gal, Mares, PRL. **98**, 082301 (2007).
[3] Ikeda, Sato, PRC **76**, 035203 (2007).
[4] Dote, Hyodo and Weise, NPA **804**, 197 (2008).
[5] Wycech and A. M. Green, PRC **79**, 014001 (2009).
[6] Ikeda, Kamano, Sato, PTP **124**, 533 (2010).
[7] Barnea, Gal, Liverts, PLB **712**, 132(2012).

Signature of strange dibaryons

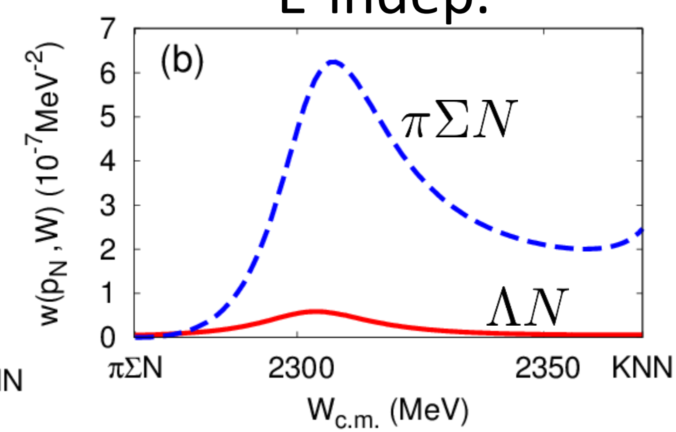
Ohnishi, Ikeda, Kamano, Sato, PRC88, 025204(2013).



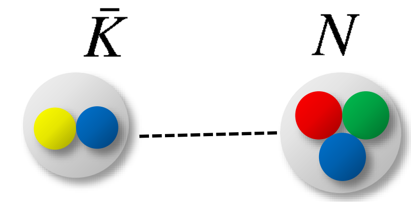
E-dep.



E-indep.



$K^{bar}N$ interaction



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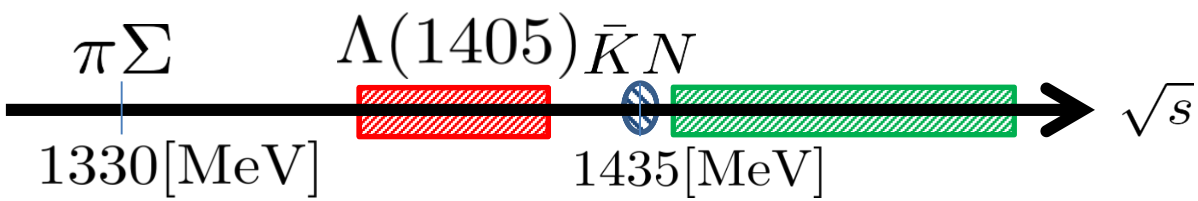

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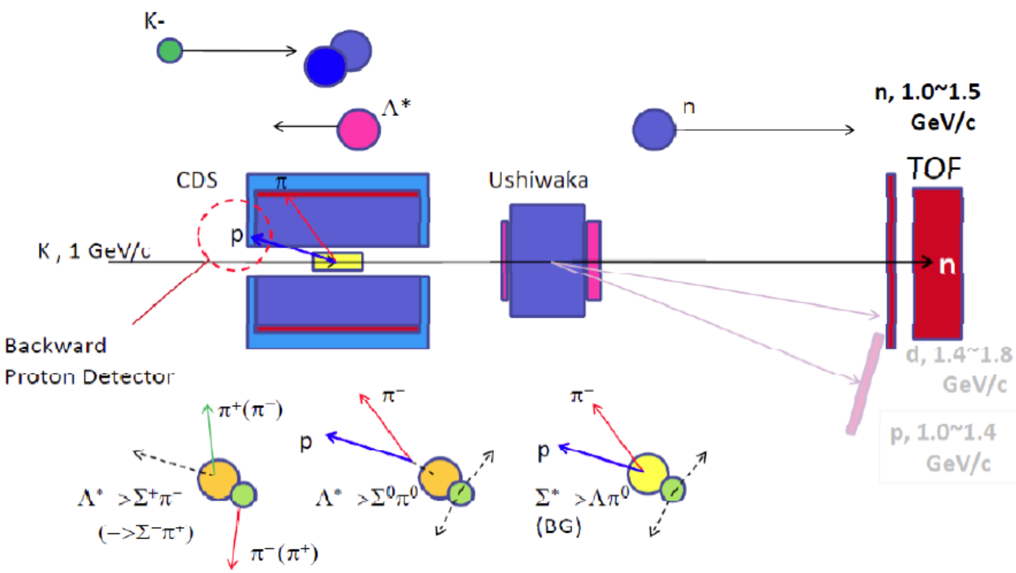
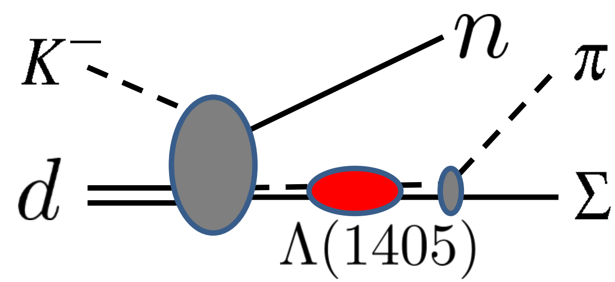
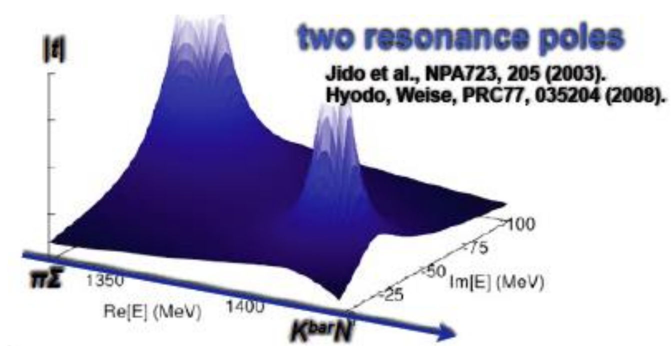
J-PARC E31 experiment

http://j-parc.jp/researcher/Hadron/en/pac_0907/pdf/Noumi.pdf

- ✓ Λ(1405) production via the (K^{-},n) reaction on deuteron target.
- ✓ We can access below the $K^{bar}N$ threshold.
- ✓ Λ(1405) in $K^{bar}N$ channel *Jido, Oset, Sekihara, EPJA42, 257(2009).*







- $p_K^{lab.}$= 1GeV
- detect forward neutron
- Missing mass distribution for $\pi^{+}\Sigma^{-}/\pi^{0}\Sigma^{0}/\pi^{-}\Sigma^{+}$

Strategy of this work

- Study the cross section for J-PARC E31 with $K^{bar}NN\text{-}\pi YN$ Faddeev (AGS) approach based on chiral SU(3) dynamics
  - Full three-body calculation for $K^{bar}NN\text{-}\pi YN$ systems with relativistic kinematics and higher partial waves for 1GeV incident momentum

Two-step: Jido, Oset, Sekihara, EPJA42, 257(2009).
Miyagawa, Haidenbauer, PRC85,065201(2012).
Yamagata-Sekihara, Sekihara, Jido, PTEP043D02(2013).
See also, Revai , Few Body Syst. 54 (2013).
(Faddeev, s-wave & w/o $\pi\Lambda N$ calc.):

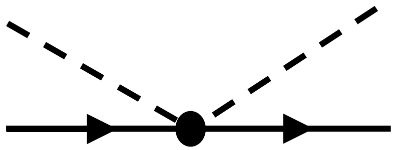
- investigate how the signal of $\Lambda(1405)$ resonance appears on $\pi\Sigma$ mass spectrum

Meson-baryon potential based on chiral SU(3)

- NG boson associated with spontaneous breaking of chiral SU(3) symmetry
- Leading order of chiral perturbation theory: Weinberg-Tomozawa (WT) term

Weinberg, PRL 17, 616 (1966).
Tomozawa, Nuov. Cim. 46A, 707 (1966).

$$\mathscr{L}_I = \frac{i}{8F_\pi^2}\mathrm{tr}[\bar{B}\gamma_\mu[[\phi,\partial^\mu\phi],B]]$$



ϕ: PS meson fields, B: baryon fields

Derive the potentials by matching with WT amplitude

"energy-dependent" potentials

$$V_{\alpha\beta}(E) = \frac{C_{\alpha\beta}}{2F_\pi^2}(2E - M_\alpha - M_\beta)$$

E; two body scattering energy

$C_{\alpha\beta}$; determined by flavor SU(3) structure

"energy-independent" potentials

$$V_{\alpha\beta} = \frac{C_{\alpha\beta}}{2F_\pi^2}(m_\alpha + m_\beta)$$

Energy is fixed at threshold

M; baryon mass

m ; meson mass

We introduce phenomenological dipole form factor to regularize loop integrals

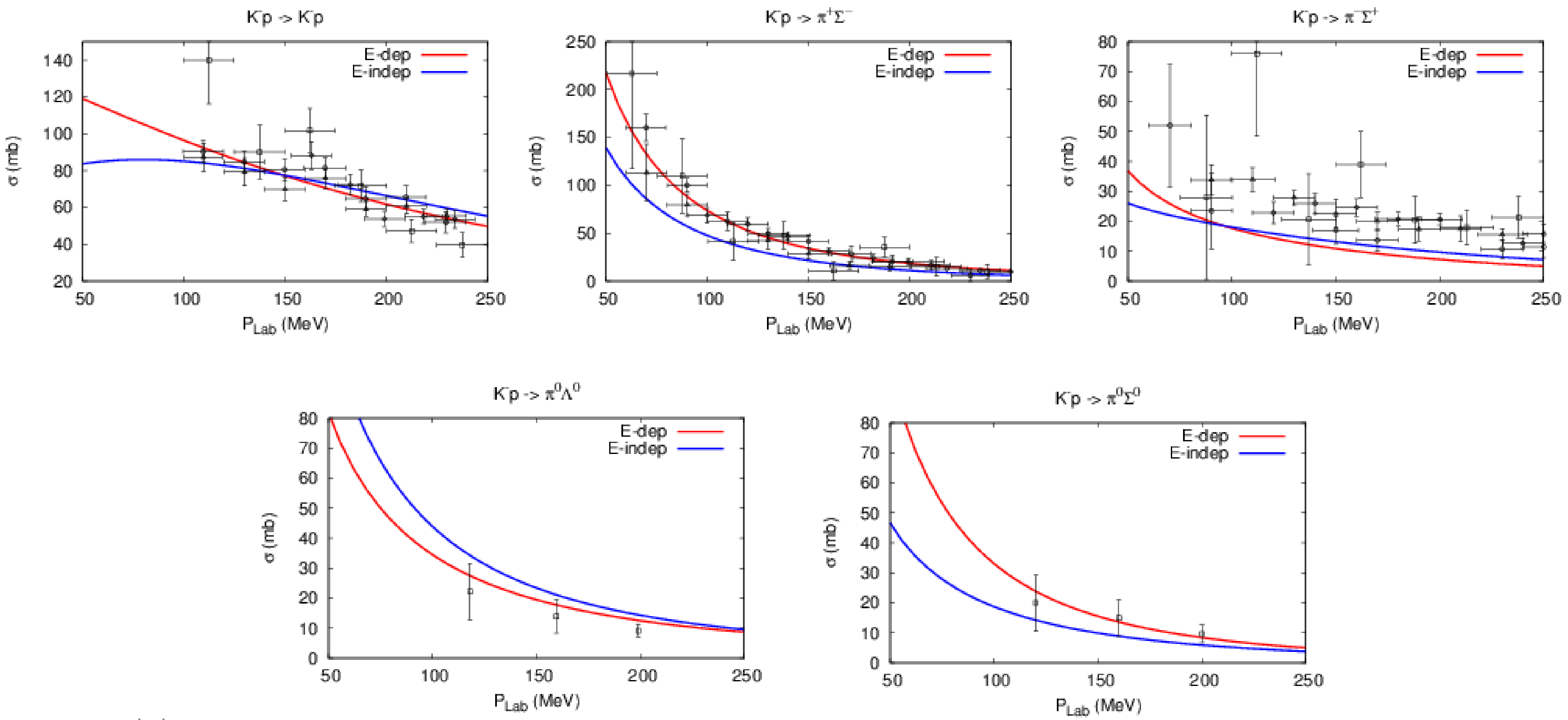
$$V_{\alpha\beta} \to V_{\alpha\beta}\left(\frac{\Lambda_\alpha^2}{q_\alpha^2+\Lambda_\alpha^2}\right)^2\left(\frac{\Lambda_\beta^2}{q_\beta^2+\Lambda_\beta^2}\right)^2$$

Cutoff parameters Λ are determined to reproduce the K^- p cross section

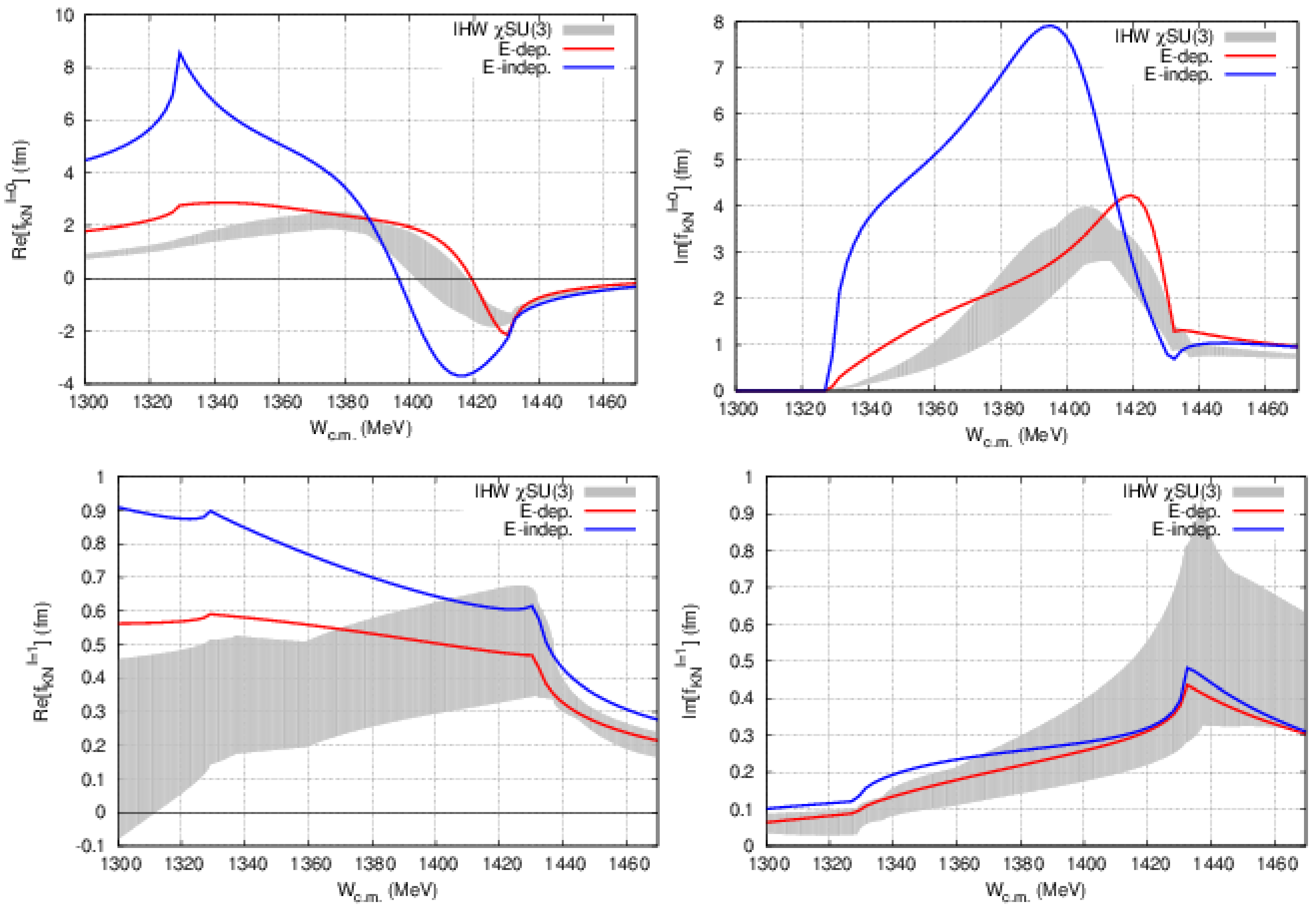
cutoff (model parameters)

We determine the cutoff parameters to reproduce $K^{-}p$ cross sections.

	$\Lambda_{\bar{K}N}^{I=0}$(MeV)	$\Lambda_{\pi\Sigma}^{I=0}$(MeV)	$\Lambda_{\bar{K}N}^{I=1}$(MeV)	$\Lambda_{\pi\Sigma}^{I=1}$(MeV)	$\Lambda_{\pi\Lambda}^{I=1}$(MeV)
E-dep.	1100	1100	800	800	800
E-indep.	1160	1100	1100	850	1250



$K^{bar}N$ amplitude and scattering length (output)



Ikeda, Hyodo, Weise NPA 881 (2012) 98.

- SIDDHARTA $a_{K^-p} = -0.65(0.10) + i0.81(0.15)\text{fm}$
- xSU(3) NLO $a_{K^-p} = -0.70 + i0.89\text{fm}$
- E-dep. $a_{K^-p} = -0.72 + i0.77\text{fm}$
- E-indep. $a_{K^-p} = -0.54 + i0.46\text{fm}$

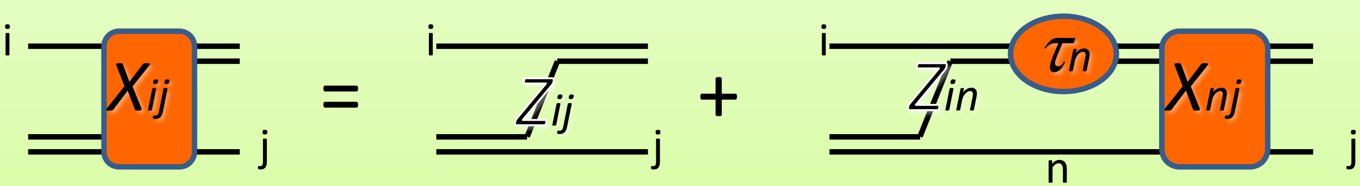
Coupled channel equation for $\bar{K}NN - \pi YN$ $(Y = \Lambda, \Sigma)$

Faddeev eq. $$T_i(W) = t_i(W - E_i) + \sum_{j \neq i} t_i(W - E_i) G_0(W) T_j(W)$$

separable 2-body Interaction ; $$V(\mathbf{q}', \mathbf{q}) = \lambda g(\mathbf{q}') g(\mathbf{q})$$

Alt-Grassberger-Sandhas(AGS) eq. : X_{ij} ; quasi two-body amplitude

$$\begin{aligned} X_{i,j}(\mathbf{p}_i, \mathbf{p}_j, W) &= (1 - \delta_{i,j}) Z_{i,j}(\mathbf{p}_i, \mathbf{p}_j, W) \\ &+ \sum_{n \neq i} \int d\mathbf{p}_n Z_{i,n}(\mathbf{p}_i, \mathbf{p}_n, W) \tau_n(W - E_n) X_{n,j}(\mathbf{p}_n, \mathbf{p}_j, W) \end{aligned}$$

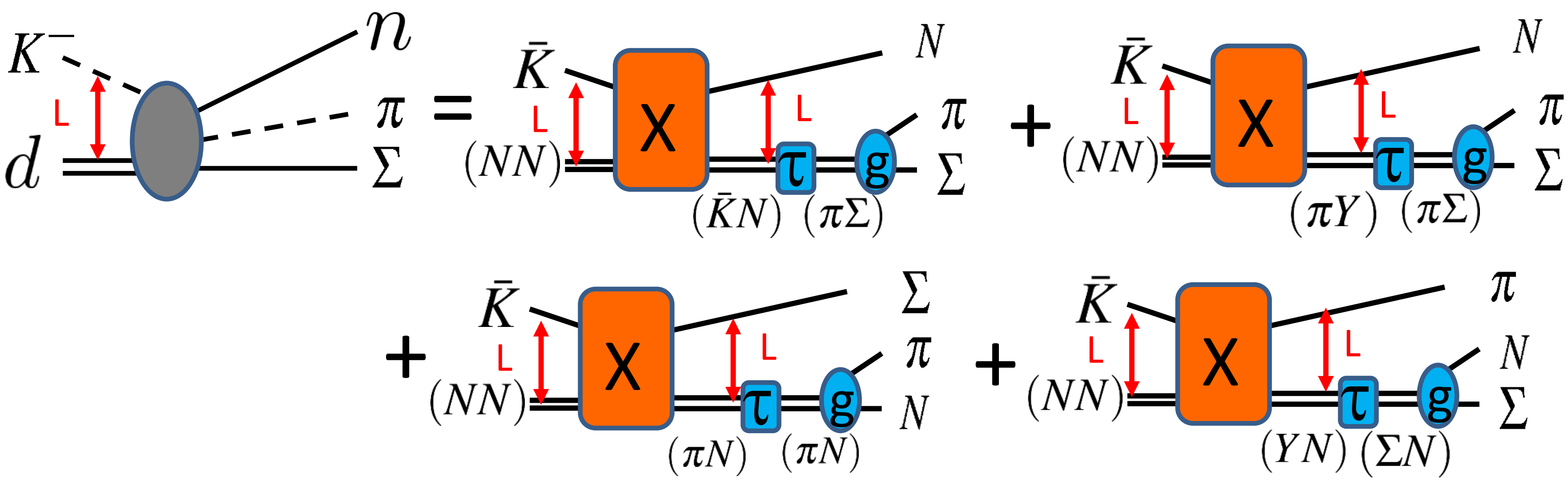


$$Z_{i,j}(p_i, p_j, W) = 2\pi \int_{-1}^{1} d(\hat{\mathbf{p}}_i \cdot \hat{\mathbf{p}}_j) \frac{g(q_i) g(q_j)}{W - E_i(p_i) - E_j(p_j) - E_k(\mathbf{p}_i + \mathbf{p}_j)}$$

$$t_i(\mathbf{q}', \mathbf{q}, W - E_i) = g(\mathbf{q}') \tau(W - E_i) g(\mathbf{q})$$

$K^{-}d \to \pi\Sigma n$ reaction

$$\bar{K}NN - \pi\Sigma N - \pi\Lambda N$$



$(Y = \Lambda, \Sigma)$

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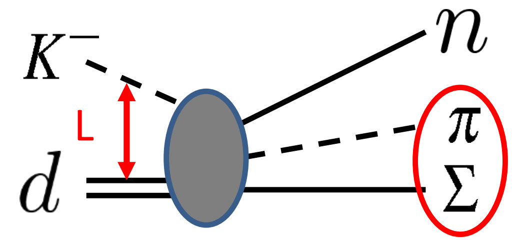
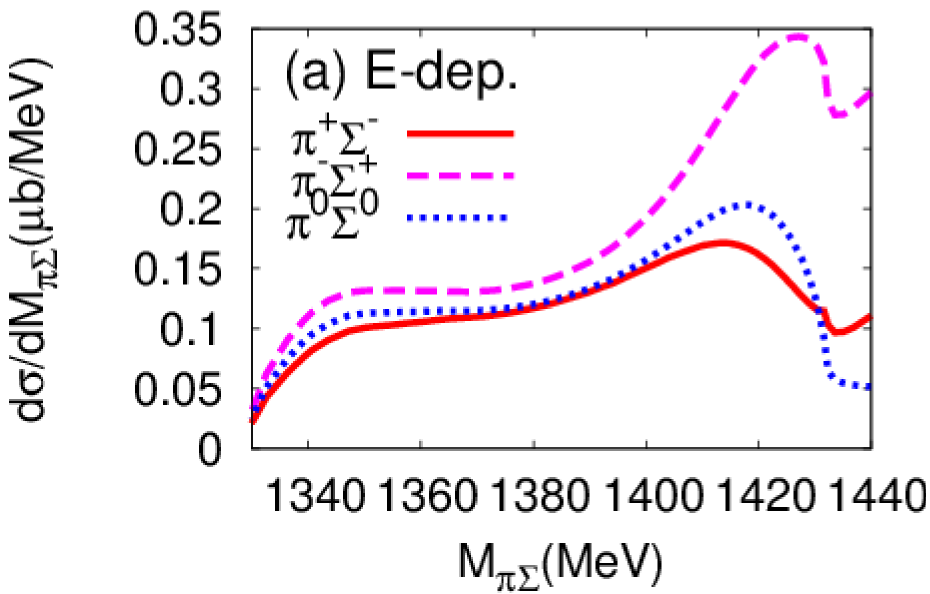
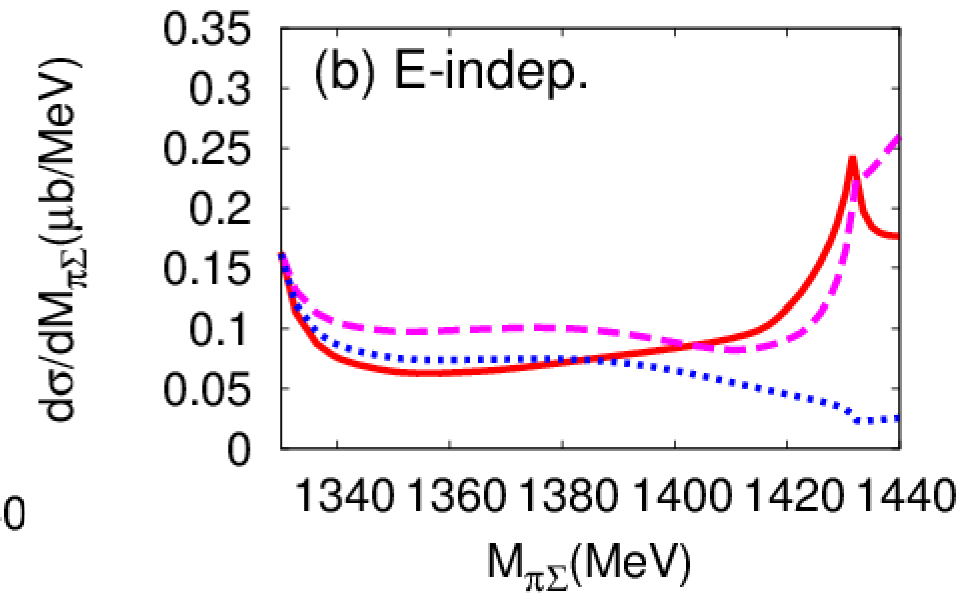
$\pi\Sigma$ invariant mass spectrum

$p_K^{\mathrm{lab}} = 1000\ \mathrm{MeV},$



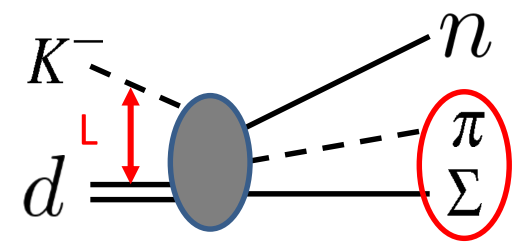


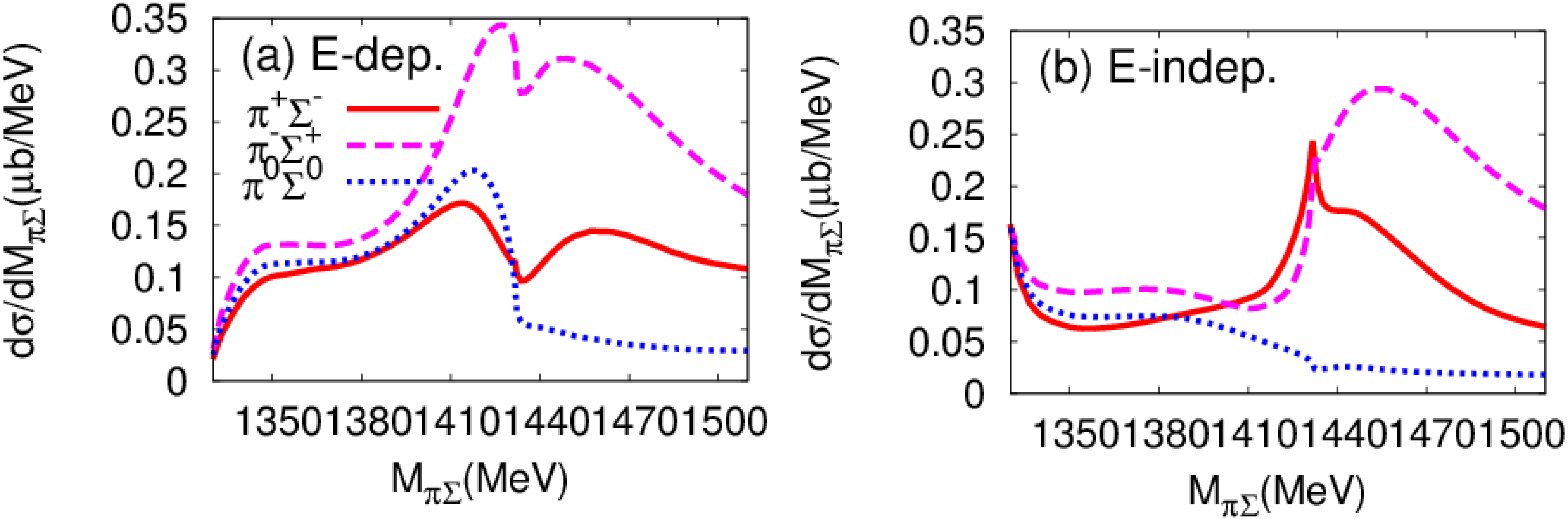


- For E-dep. model, signature of $\Lambda(1405)$ appears on $\pi\Sigma$ invariant mass spectrum around the binding energy of $\Lambda(1405)$
- For E-indep. model, signature of $\Lambda(1405)$ is weak, and cusp appears at $\pi\Sigma$ threshold

$\pi\Sigma$ *invariant mass spectrum*

$p_K^{\mathrm{lab}} = 1000\ \mathrm{MeV},$





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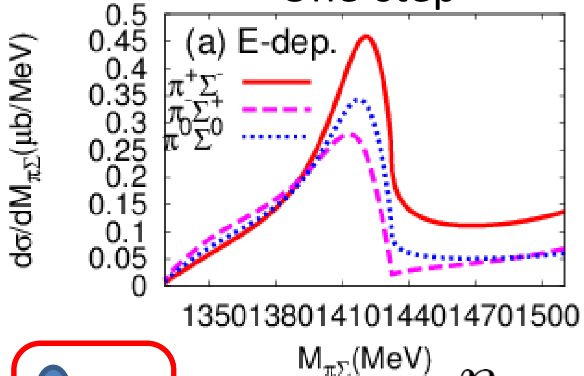
- For E-indep. model, signature of $\Lambda(1405)$ is weak, and cusp appears at $\pi\Sigma$ threshold
- Bump appears above the $K^{bar}N$ threshold

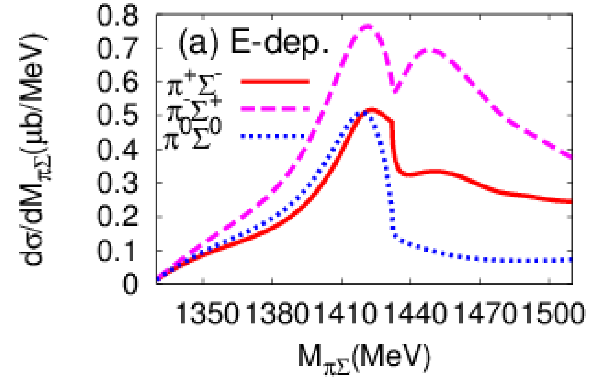
Bump structure above KN threshold

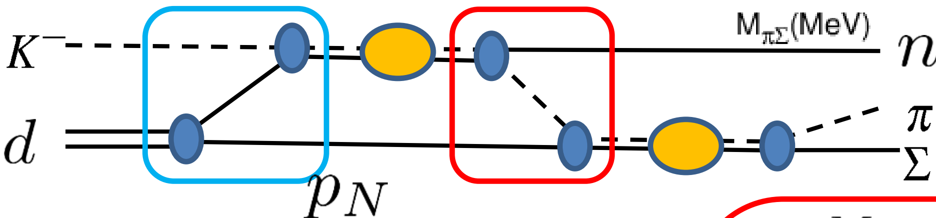
$$p_K^{lab} = 800\text{MeV}$$

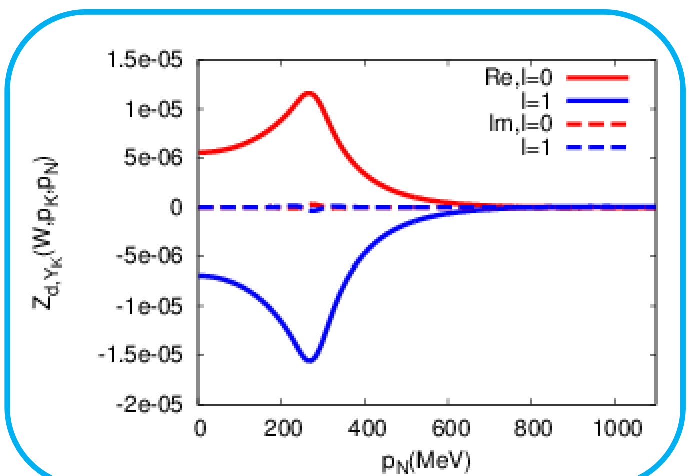
One-step

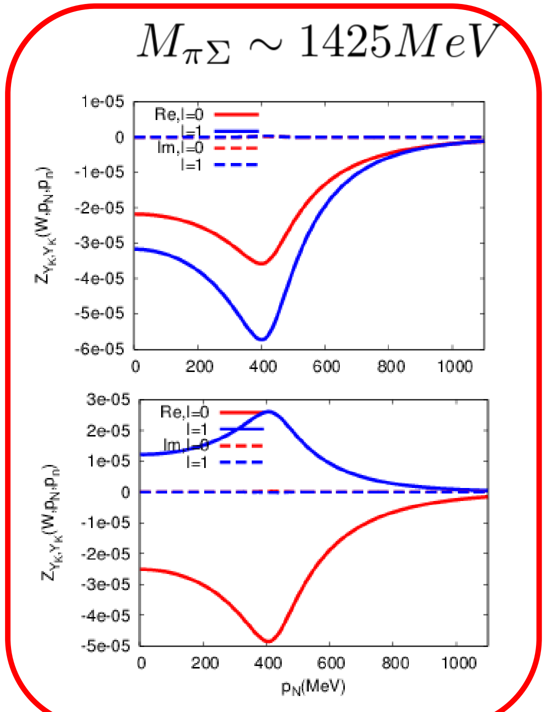


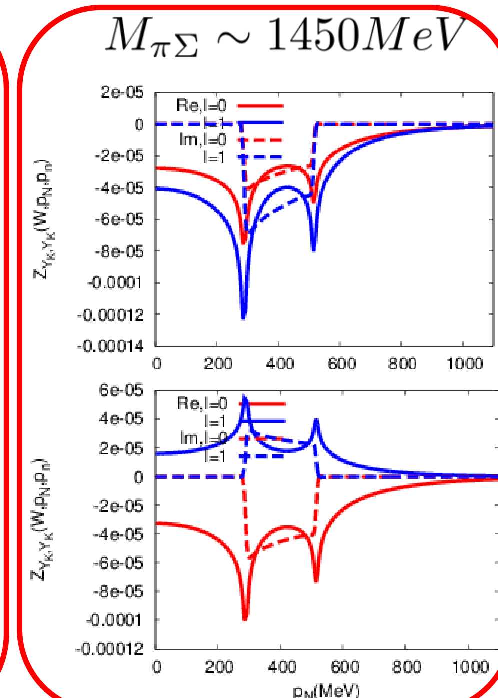
One- and two-step









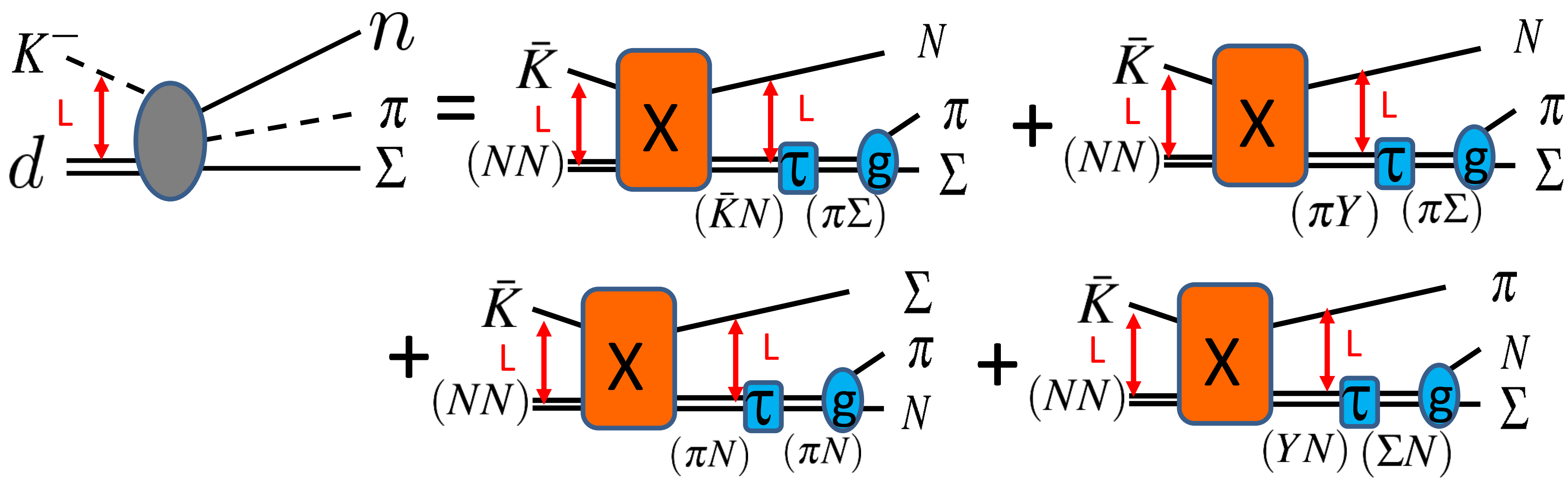


$I = 0$

$I = 1$

K⁻d -> πΣn reaction

$$\bar{K}NN - \pi\Sigma N - \pi\Lambda N$$



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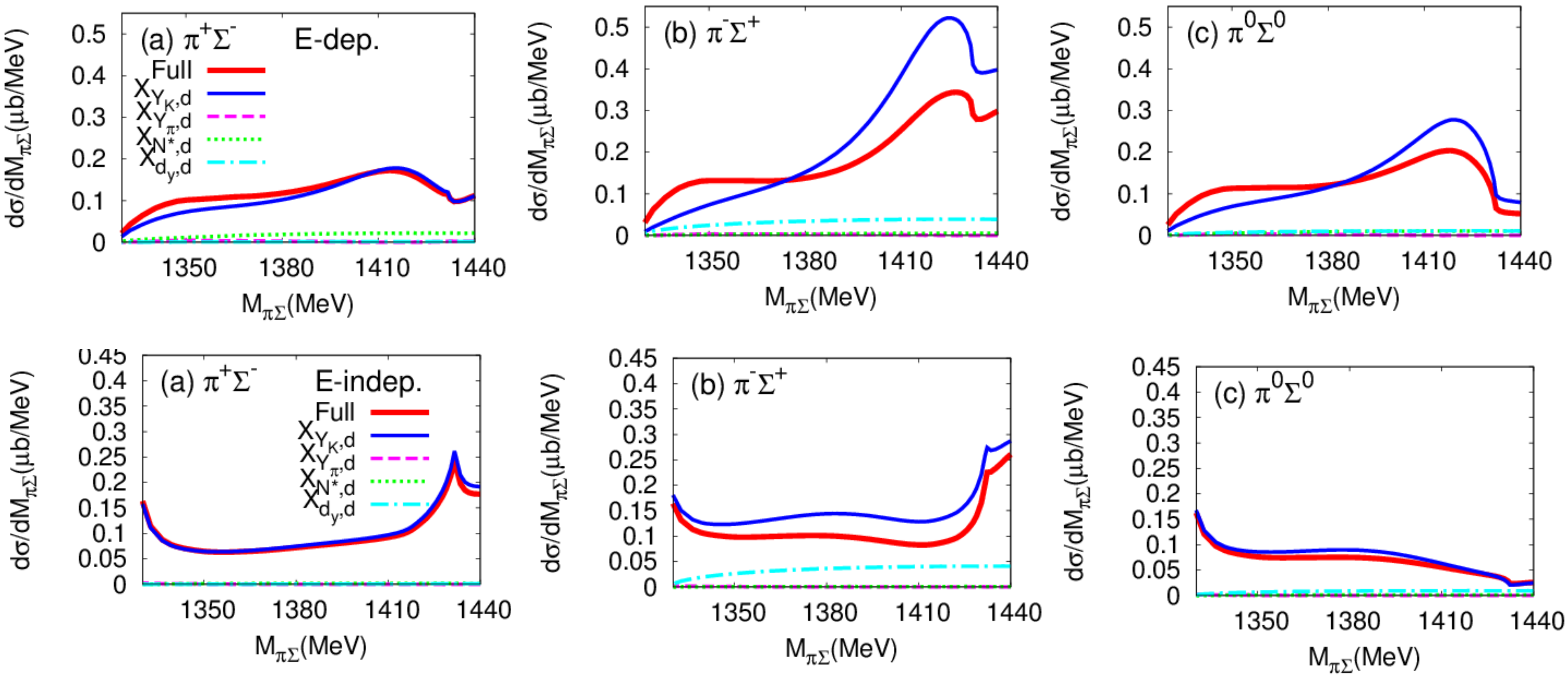
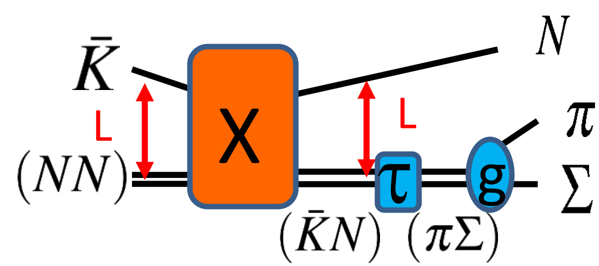
Contribution of each amplitude

$$Y_K \equiv \bar{K}N$$
$$Y_\pi \equiv \pi Y$$
$$N^* \equiv \pi N$$
$$d_y \equiv YN$$

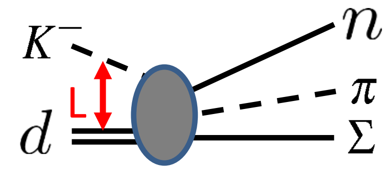


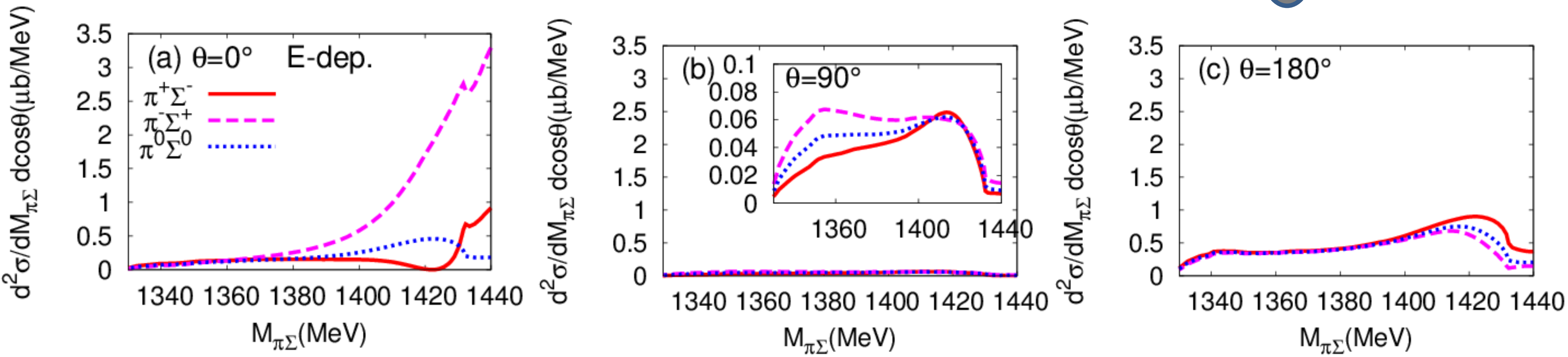
- $X_{YK,d}$ component is dominant

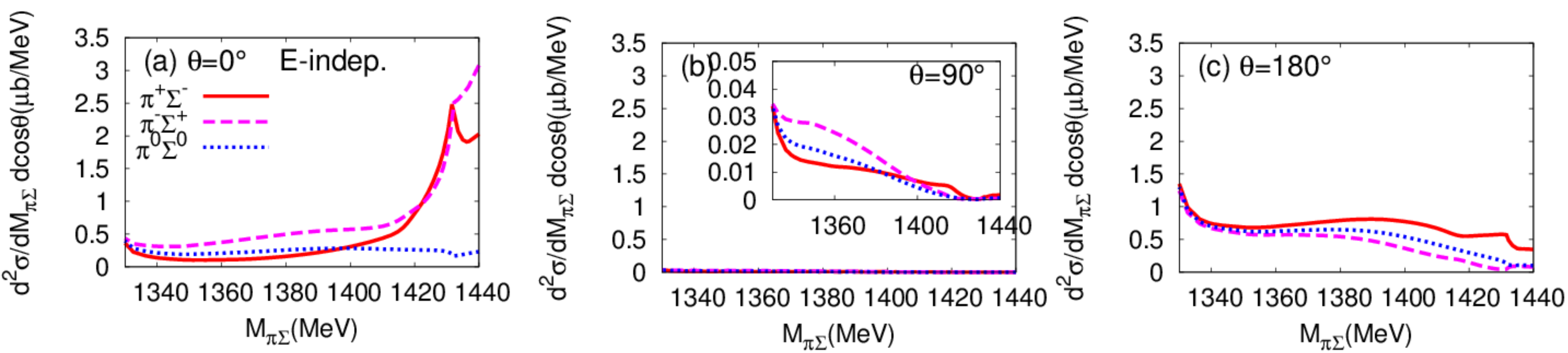


Angular dependence

θ; *n* angle in C.M.





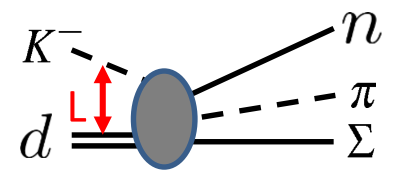


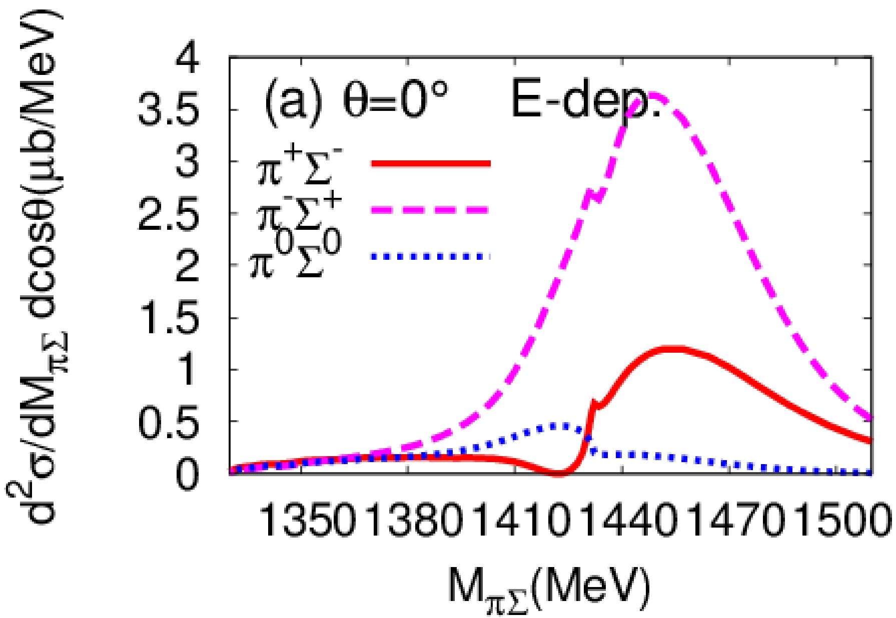
- *KN* threshold cusp is enhanced in forward angle
- Channel dependence is also large in forward angle

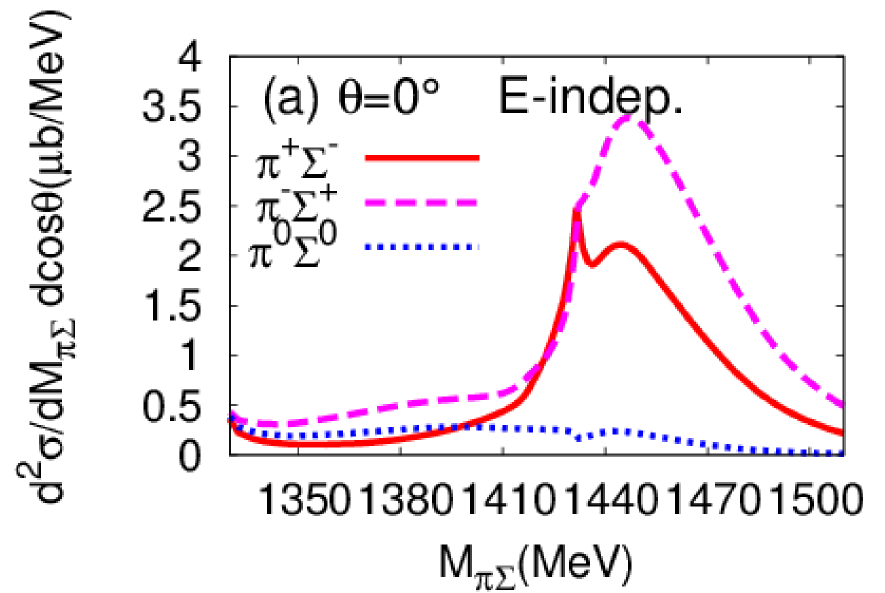
$$[\bar{K}[NN]_{I=0}]_{I=1/2} = -1/2[[\bar{K}N]_{I=0}N]_{I=1/2} + \sqrt{3}/2[[\bar{K}N]_{I=1}N]_{I=1/2}$$

Angular dependence

θ; *n* angle in C.M.







- *KN* threshold cusp is enhanced in forward angle
- Channel dependence is also large in forward angle
- bump above *K*^{bar}*N* threshold energy is enhanced in θ=0

Summary

- We investigate how the signature of the $\Lambda(1405)$ appears in $K^{-}d$ scattering reaction.
- How the signatures appear depends on the two-body interaction models.
- The production reaction would be used to distinguish dynamical model of $\Lambda(1405)$.
- Channel dependence of the cross section is large
- We would also obtain the information on *I=1* $K^{bar}N$-$\pi\Sigma$ interactions from $K^{-}d$ scattering.
- Bump appears above the KN threshold, and it is enhanced in θ=0

Future work

- Improve the two-body interaction model
  - Higher order of chiral perturbation
  - Higher partial wave
- Cutoff parameters dependence
- Compare with forthcoming J-PARC E31