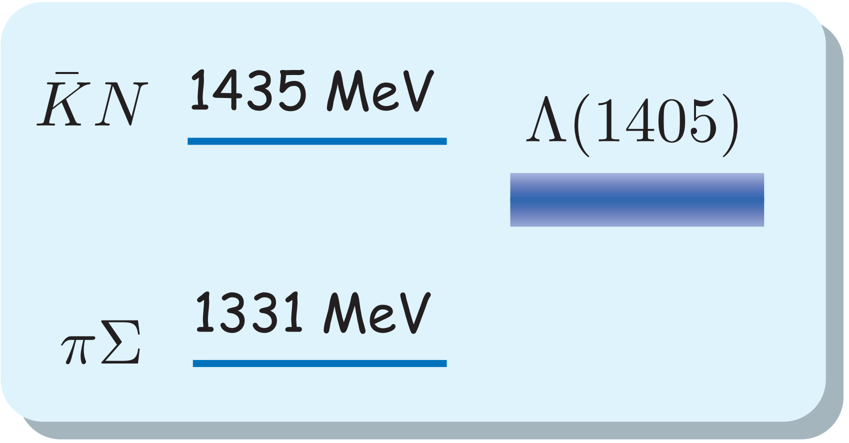
10th International Conference on Hypernuclear and Strange Particle Physics
" Hyp X "

The nature of Λ(1405) in chiral dynamics

D. Jido
(Yukawa Institute, Kyoto)



Λ(1405)

- excited state of Λ with $J^P=(1/2)^-$
- just below threshold of $K^{bar}N$
- important for study of K^{bar} at subthreshold, bound kaon
- decay to πΣ
- πΣ and $K^{bar}N$ dynamics

Coupled-channels approach in chiral dynamics

For example,
Kaiser, Siegel, Weise, NPA594, 325 (95)
Oset, Ramos, NPA635, 99 (98)
Oller, Meissner, PLB500, 263 (01)

Chiral unitary model

a powerful theoretical framework to describe hadronic resonances from hadron dynamics

chiral perturbation theory

low-energy effective theory of QCD

give fundamental interaction of meson-baryon

scattering theory (N/D method)

analyticity and unitarity

general form of scattering amplitude

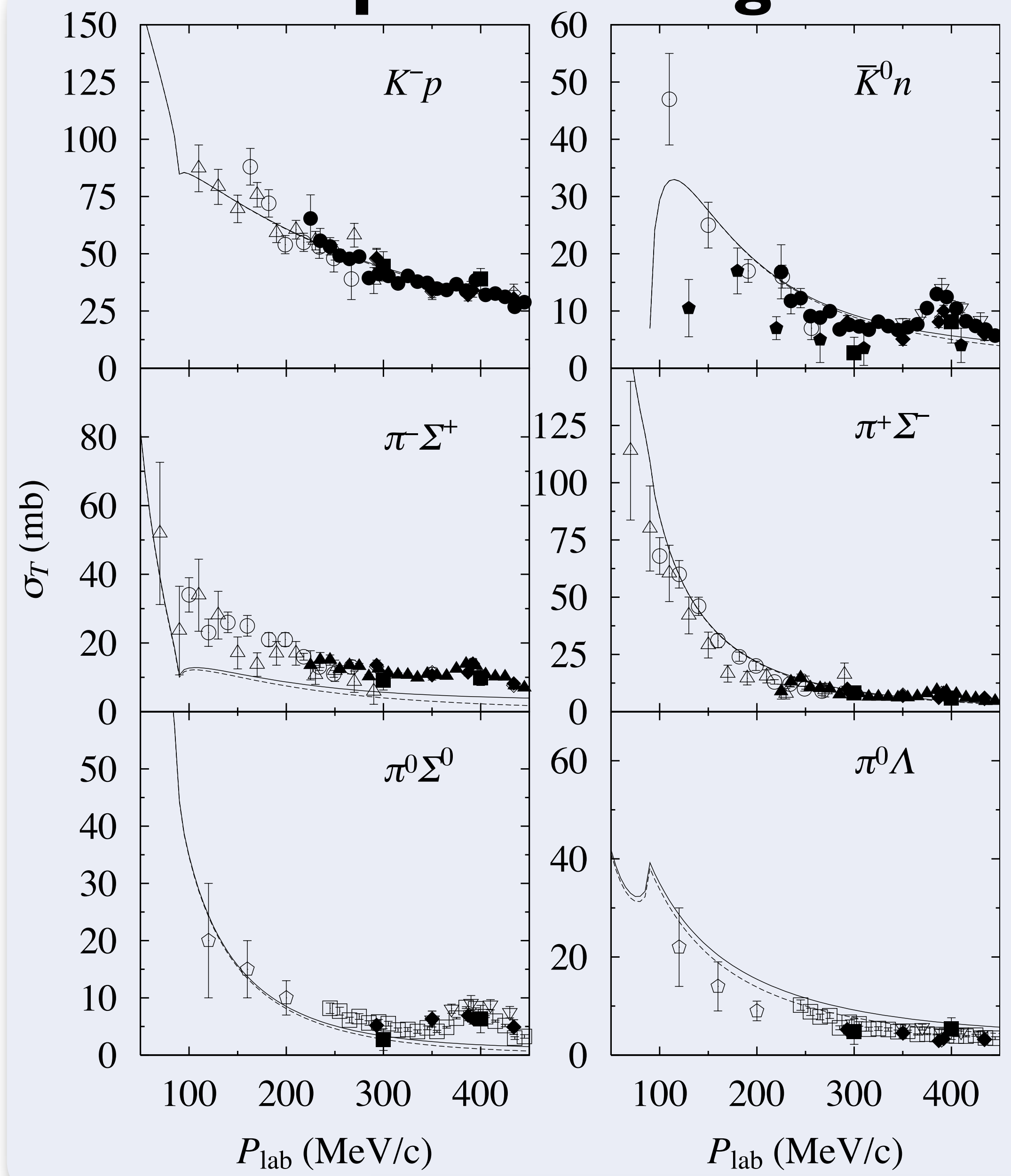
Lippmann-Schwinger eq. $T = V + VGT$

$$\bar{K}N, \pi\Sigma, \eta\Lambda, K\Xi, \pi\Lambda, \eta\Sigma$$

reproduce K⁻p scattering

generate dynamically s-wave Λ(1405) resonances

K⁻p scattering



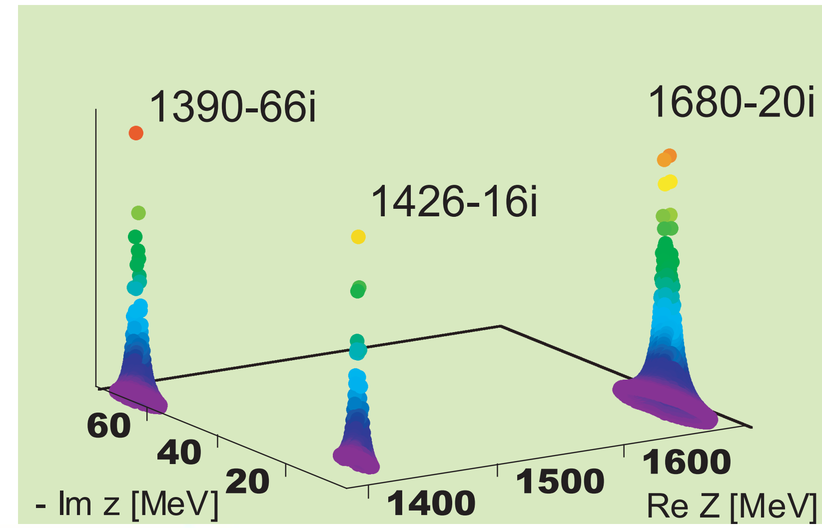
DJ, Oset, Ramos, PRC66, 055203 (02)

Consequences of chiral unitary model

1. Λ(1405) is a superposition of two states having different properties

pole 1: **1390 MeV, width 132 MeV**
strongly couples to **πΣ state**
pole 2: **1426 MeV, width 32 MeV**
dominantly couples to **$K^{bar}N$ state**

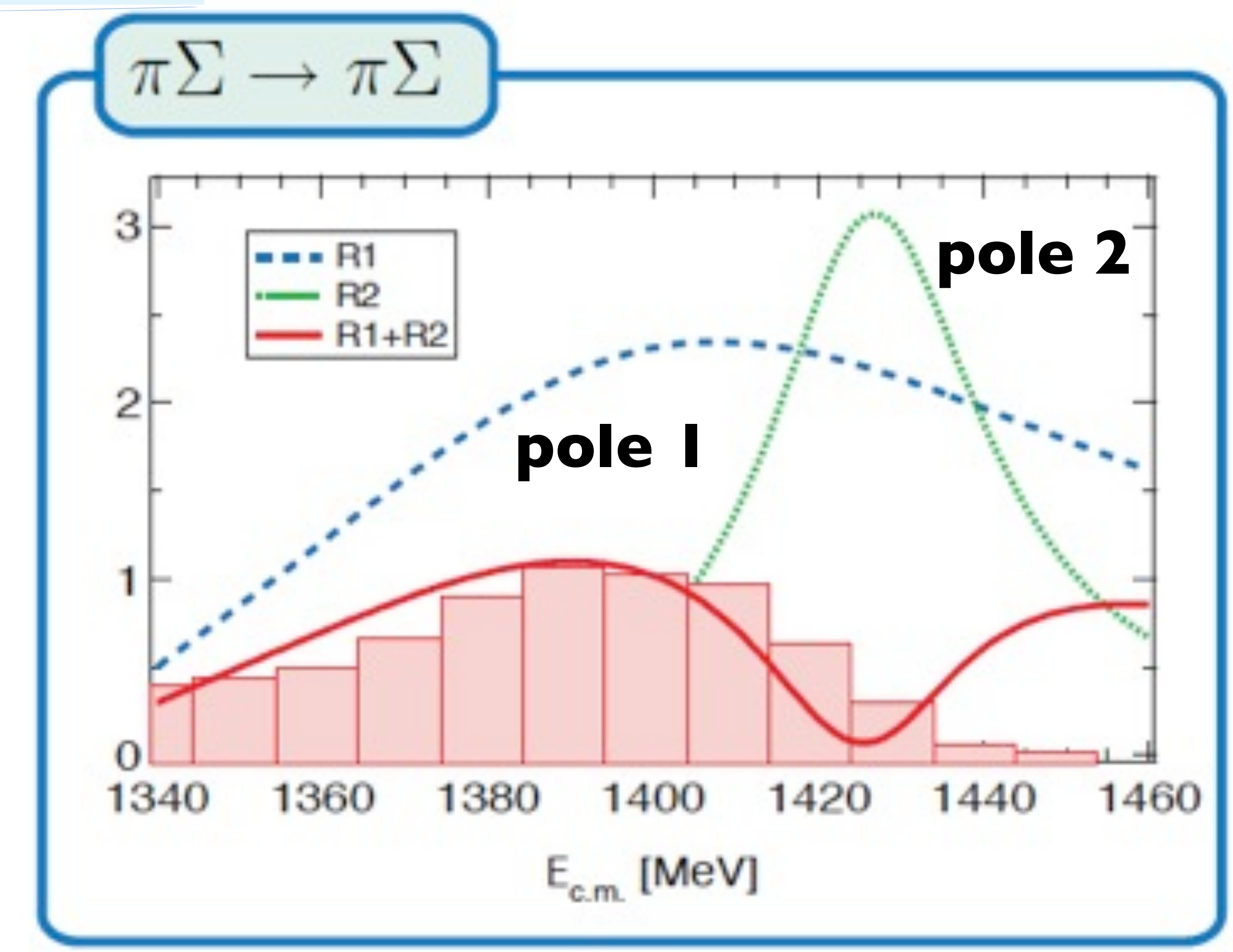
Modulus of T-matrix



Two state cannot be seen separately due to the widths.

Spectrum of Λ(1405) is given by interference of these poles.

DJ, Oller, Oset, Ramos, Meissner
NPA725, 181 ('03)



Double pole structure of Λ(1405)

reason of existence of two poles: **two attractive channels in I=0**

group theoretically SU(3) singlet and octet

physically $K^{bar}N$ and πΣ according to ChPT

-Λ(1405) is essentially described by two channels, $K^{bar}N$ and $\pi\Sigma$.

- in single channel without channel couplings

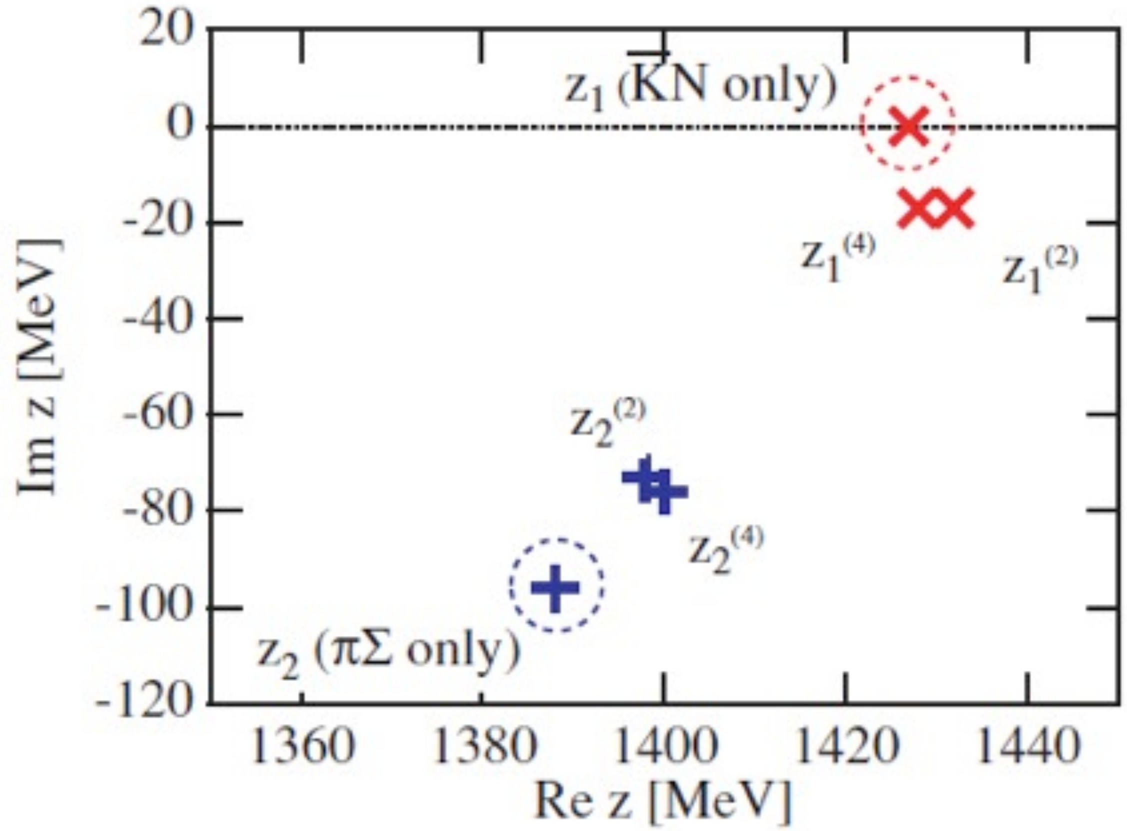
$K^{bar}N$ bound state

$\pi\Sigma$ resonance

s-wave resonance in single channel
due to energy-dependent potential

- coupled channel gives width to bound state

Hyodo, Weise, PRC77, 035204 ('08)



comp. of single, two-, four-channel

for physics on the real axis

$K^{bar}N$ bound state and $\pi\Sigma$ strong correlation

are the ingredients of Λ(1405). **Double pole structure**

Consequences of chiral unitary model

2. Resonance position of Λ(1405) depends on channels

pole 1: **1390 MeV, width 132 MeV**
strongly couples to **πΣ state**
pole 2: **1426 MeV, width 32 MeV**
dominantly couples to **K^bar N state**

Due to the presence of two poles having different properties, the πΣ invariant mass spectrum (peak position of Λ(1405)) depends on the initial channel.

πΣ invariant mass spectrum (I=0)

$$\frac{d\sigma}{dM_{\pi\Sigma}} = A|T|^2 q^{\pi\Sigma}_{\rm c.m}$$

The resonance positions depend on the channels by which Λ(1405) is produced.

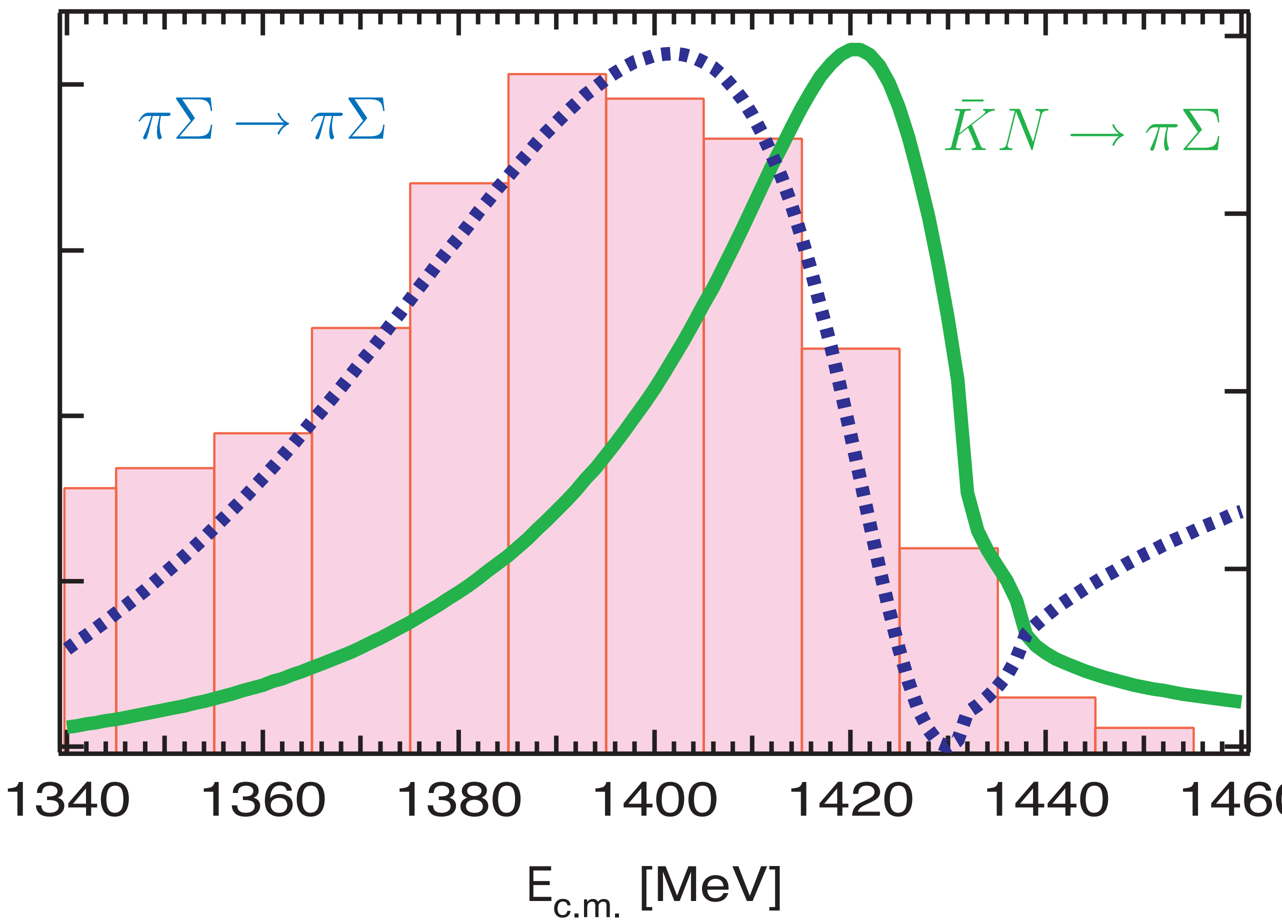
Λ(1405) as K^bar N quasibound state

1420MeV→ binding energy 15MeV

1405MeV→ binding energy 30MeV

the heights are adjusted

πΣ Mass distribution



peak at 1420MeV in K^bar N channel

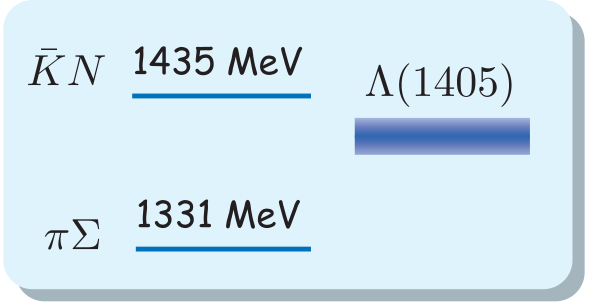
DJ, Oller, Oset, Ramos, Meissner, NPA725, 181 ('03)

Λ(1405) in $K^{bar}N$ channel

Want to see Λ(1405) produced by K^{bar}N !!

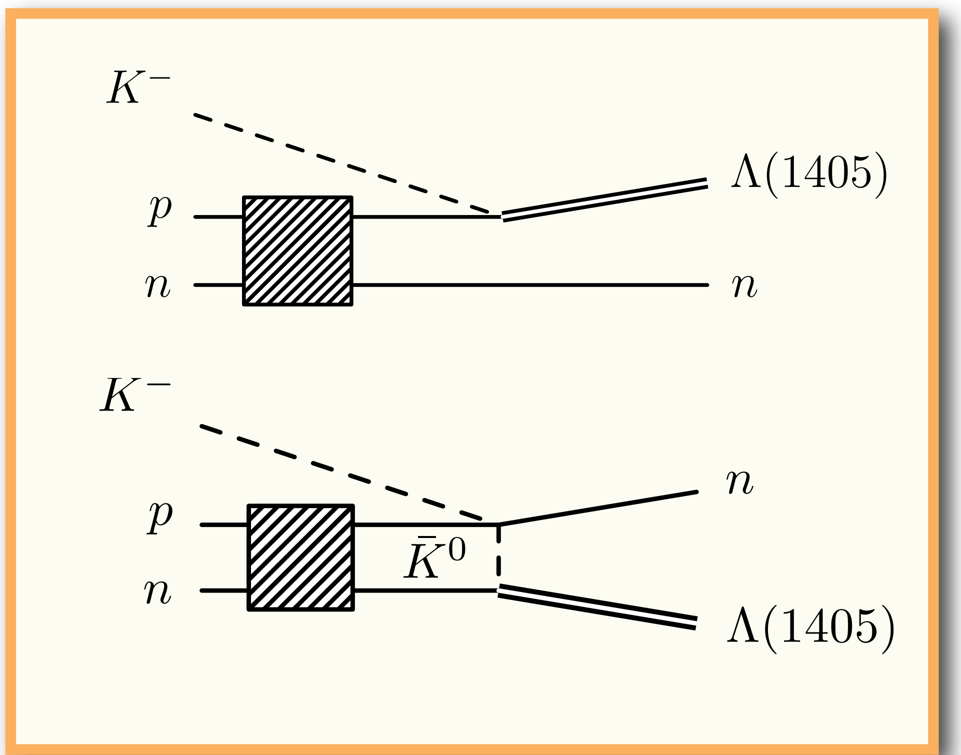
Λ(1405) is located below the K^{bar}N threshold

cannot be produced by direct reaction $\bar{K}N \to \Lambda(1405)$



indirect reaction

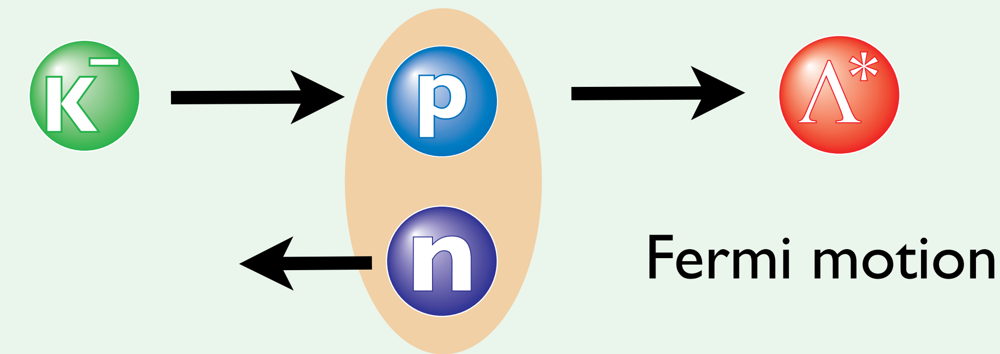
$$K^- d \to \Lambda(1405) n$$



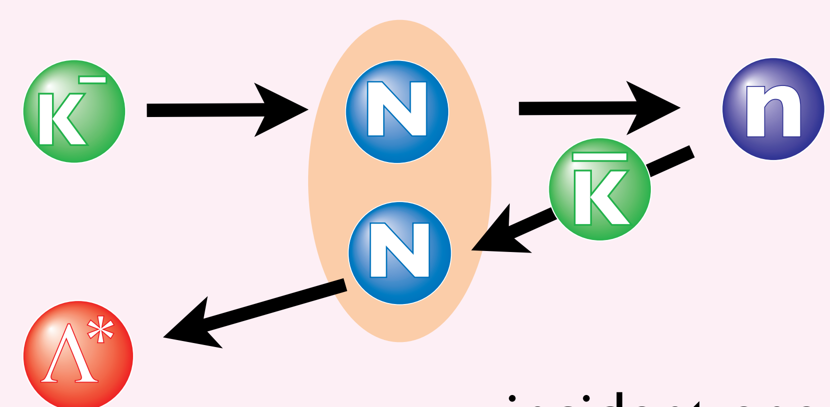
flow of strangeness is clear

Λ(1405) is produced by K^{bar}N

- single step **Λ* forward**



- double step **Λ* backward**



dominant

incident energy is shared by two nucleons

DJ, Oset, Sekihara, accepted by Eur.Phys.J.A. arXiv 0904.3410

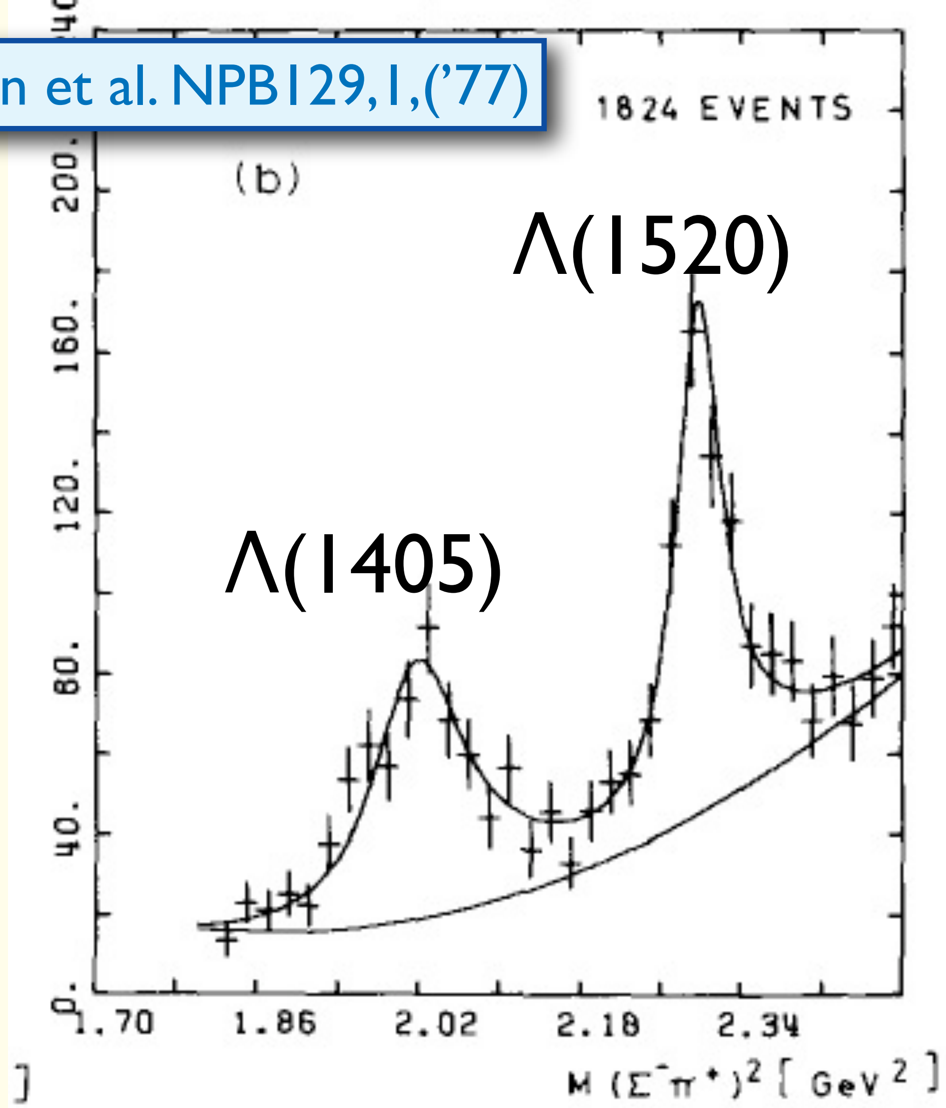
$\Lambda(1405)$ in $K^{bar}N$ channel

Experiment bubble chamber initial K momentum 686 ~ 844 MeV/c

πΣ invariant mass spectrum

$$K^- d \to \pi^+ \Sigma^- n$$

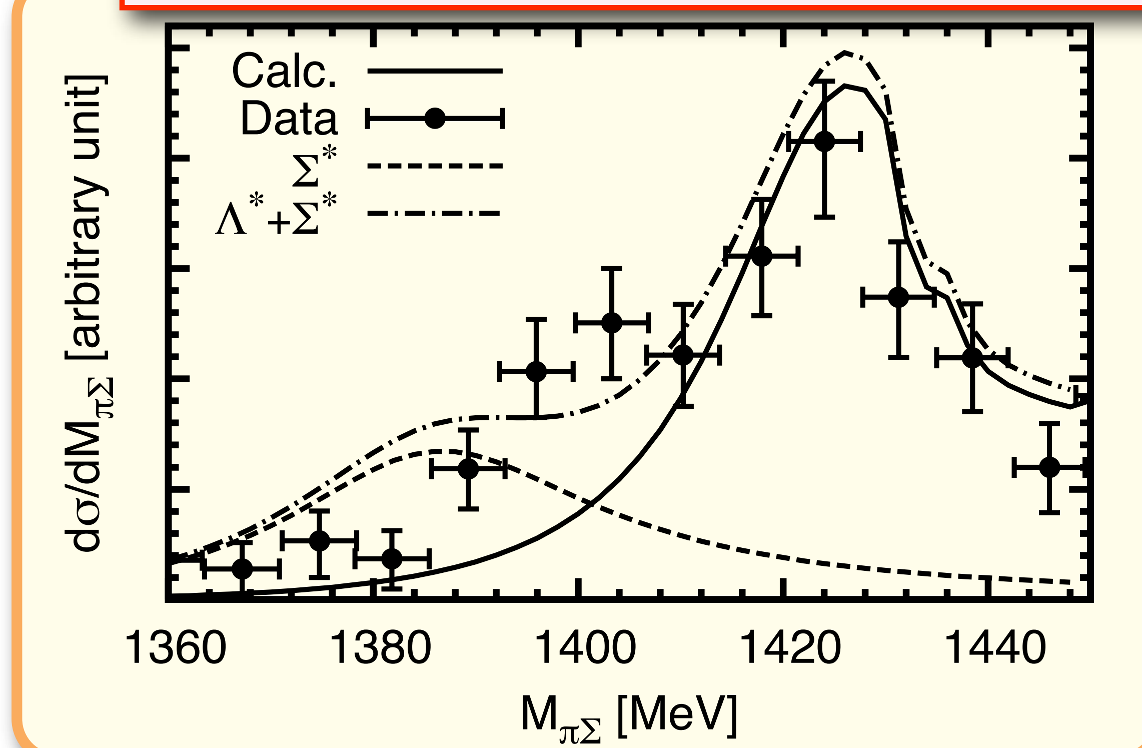
Braun et al. NPB129,1,('77)



peak position 1420 MeV

theoretical calculation in ChUM

DJ, Oset, Sekihara, accepted in Eur.Phys.J.A.



production cross section of Λ(1405)

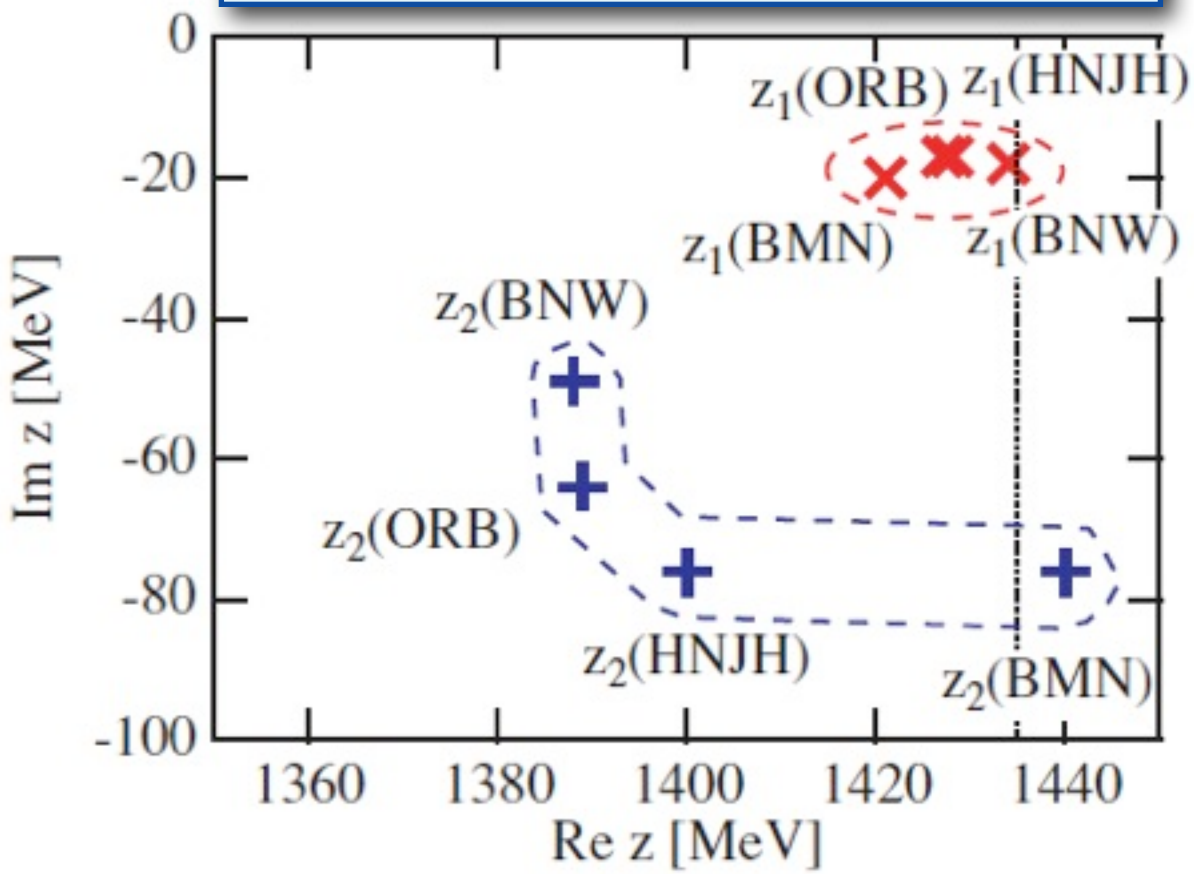
385 μb @ 800MeV/c (exp. 410 ± 100 μb)
agrees with data in shape and size
bump around 1385 MeV is found to be from Σ*
inclusion of Σ* does not distort the shape.

Proposal of J-PARC experiment
H. Noumi, Poster M15, today

Influence of πΣ correlation to Λ(1405)

Model dependence of pole positions in chiral coupled channels approach

Hyodo, Weise, PRC77, 035204 ('08)



higher pole dominantly couples to $K^{bar}N$

less model-dependent

around 1420 MeV

constrained by $K^{bar}N$ scatt. data

lower pole strongly couples to πΣ

strongly model-dependent

lack of $\pi\,\Sigma$ scattering data

need any data for πΣ scattering

Model calculation of I=0 πΣ scattering length (fm)	BNW	ORB	HNJH	BMN
	0.517	**0.789**	**0.692**	**0.770**

Ikeda, Hyodo, DJ, et al. in preparation

How strong $\pi\Sigma$ interaction ?

More interesting question

$\pi\,\Sigma$: resonance or virtual state ??

$\pi\Sigma$ interaction is attractive.

If attraction is unexpectedly enough strong, there could be a **$\pi\Sigma$ virtual state** below threshold. In this case, $\Lambda(1405)$ consists of single pole.

Energy-independent potentials also provide $\pi\Sigma$ virtual states.

If virtual state exists **$\pi\Sigma$ scattering length ~ 5 fm**

for $\pi\Sigma$ resonance case

Model calculation of I=0 $\pi\Sigma$ scattering length (fm)	BNW	ORB	HNJH	BMN
	0.517	**0.789**	**0.692**	**0.770**

More systematic study will be public soon.

Ikeda, Hyodo, DJ, et al. in preparation

Consequences of chiral unitary model

3. Λ(1405) is a quasibound state of meson-baryon

a theoretical indication

the details are given in Hyodo' talk (Sep. 17, parallel session 2A)

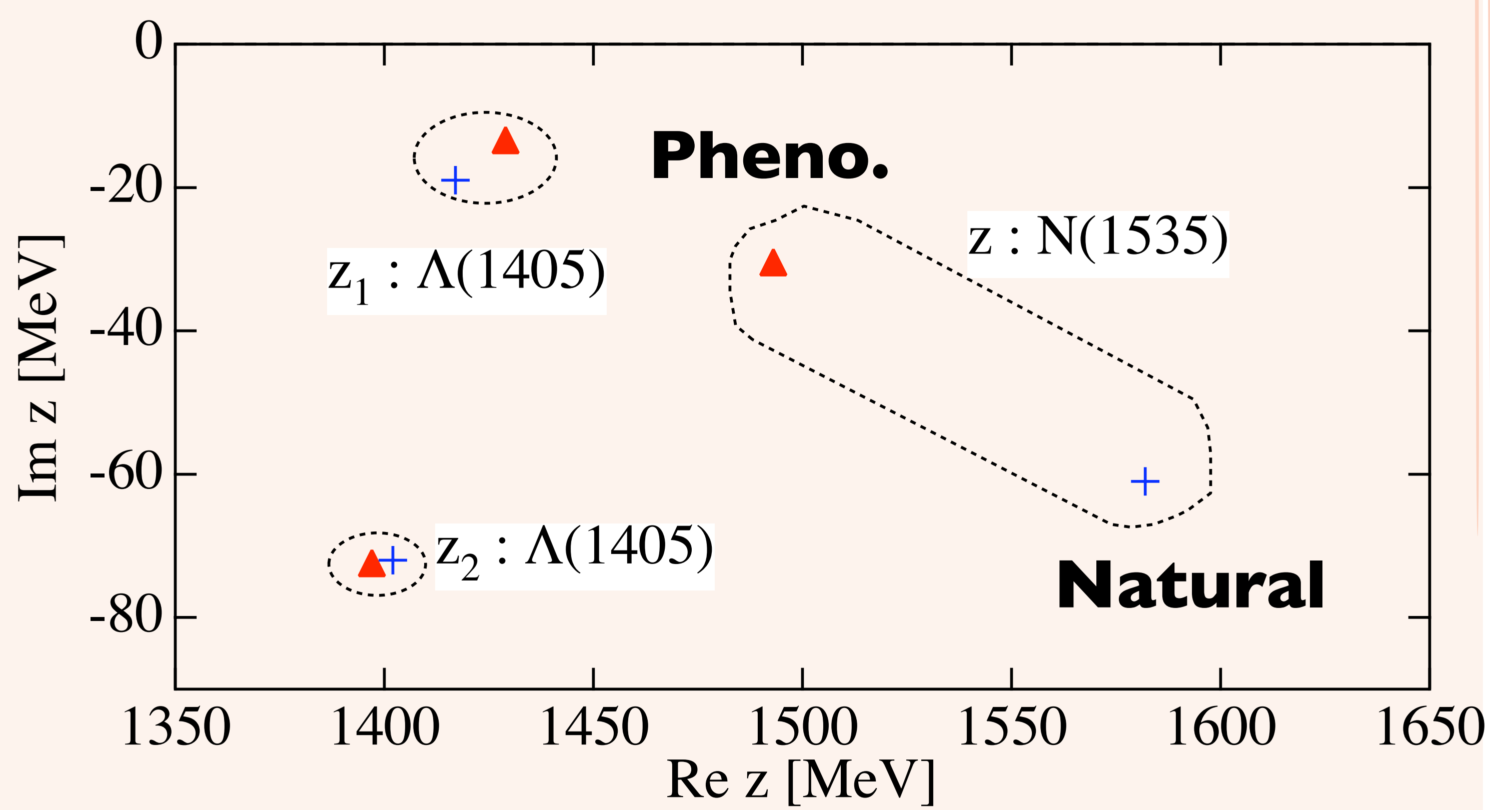
chiral unitary model

model parameters tuned so as to

a) reproduce scattering data
▲ **Pheno.**

b) exclude quark-originated states theoretically
+ **Natural**

V : WT term



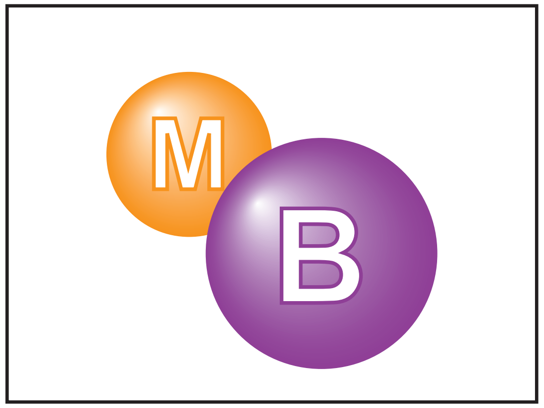
Λ(1405) has mostly meson-baryon components.

Hyodo, Jido, Hosaka, PRC78, 025203 ('08)

Λ(1405) as quasibound state of hadrons

1. large Nc behavior

Hyodo, DJ, Roca, PRD77, 056010 (2008)
Roca, Hyodo, DJ, NPA809,65, (2008)



different scaling of the width from quark model

T. Hyodo, poster M19, today

2. Electromagnetic radii

Sekihara, Hyodo, DJ, PLB669, 133 (2008)

Λ(1405): quasibound state of $K^{bar}N$ with 10~30 MeV

spatially extended almost real Kaon surrounding nucleon
larger radius than neutron charge radius

$$\langle r^2\rangle_{\rm E} = -0.12 \quad [{\rm fm}^2]$$ virtual pion cloud

negative charge radius K^- spreads widely around proton

electromagnetic form factor of Λ(1405) in chiral unitary model

$$\langle r^2\rangle_{\rm E} = -0.13 + 0.30i \quad [{\rm fm}^2]$$

moduls $|\langle r^2\rangle_{\rm E}| = 0.33 \quad [{\rm fm}^2]$

complex number

remove decay chan. $\langle r^2\rangle_{\rm E} = -0.52 \quad [{\rm fm}^2]$

Potential model for Λ(1405)

Λ(1405) : quasibound state with a small binding energy ~ 10-30 MeV

Λ(1405) can be described by single-channel potential model with πΣ decay channel in the imaginary part

πΣ coupled channel effect will be important, if binding energy is large.

Hyodo-Weise potential (HW-HNJH)

PRC77,035204 (08)

derived from chiral dynamics

energy dependent, but small in energy of interest

resonance position ~ **1420 MeV**

Akaishi-Yamazaki potential (AY)

PRC64,044005 (02)

obtained phenomenologically

I=0 : reproduce Λ(1405) as quasi-bound state of $K^{bar}N$

mass: **1405 MeV**, width: 40 MeV

$K^{bar}NN$ one of the simplest nuclear system Akaishi-Yamazaki

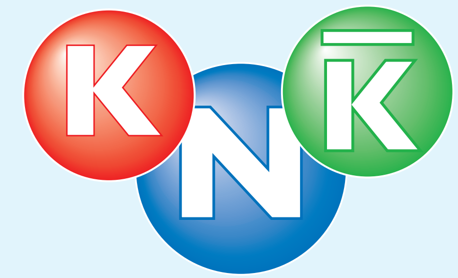
later various models applied to this system

present achievement in theory : bound with large width

we have controversy over the binding energy and width

$K\bar{K}N$ system with I=1/2, $J^P=1/2^+$

assumption



s-wave

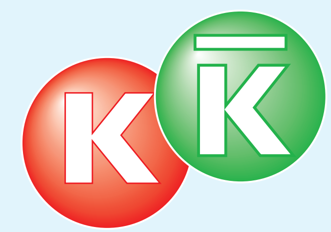
non-relativistic potential model

Λ(1405) is a quasi-bound state of $K^{bar}N$

$f_0(980)$ and $a_0(980)$ are quasi-bound states of KK^{bar}

Λ(1405)

$f_0(980)$, $a_0(980)$



Interactions in $KK^{bar}N$ system

		I=0	I=1	threshold
	attraction			
$\bar{K}N$		$\Lambda(1405)$	weak attraction	1434.6 MeV
$K\bar{K}$		$f_0(980)$	$a_0(980)$	991.4 MeV
	repulsion			
KN		very weak	strong repulsion	1434.6 MeV

DJ, Y. Kanada-En'yo, **PRC78, 035203 (2008)**

Result KK^barN   N* at 1910 MeV

$K\bar{K}N$ is bound blow thresholds of Λ(1405)+K, $a_0(f_0)$+N

DJ, Y. Kanada-En'yo, **PRC78, 035203 (2008)**

- loosely bound system

B.E. from KK^berN	width
HW: **19 MeV**	**88 MeV**
AY: **39 MeV**	**98 MeV**

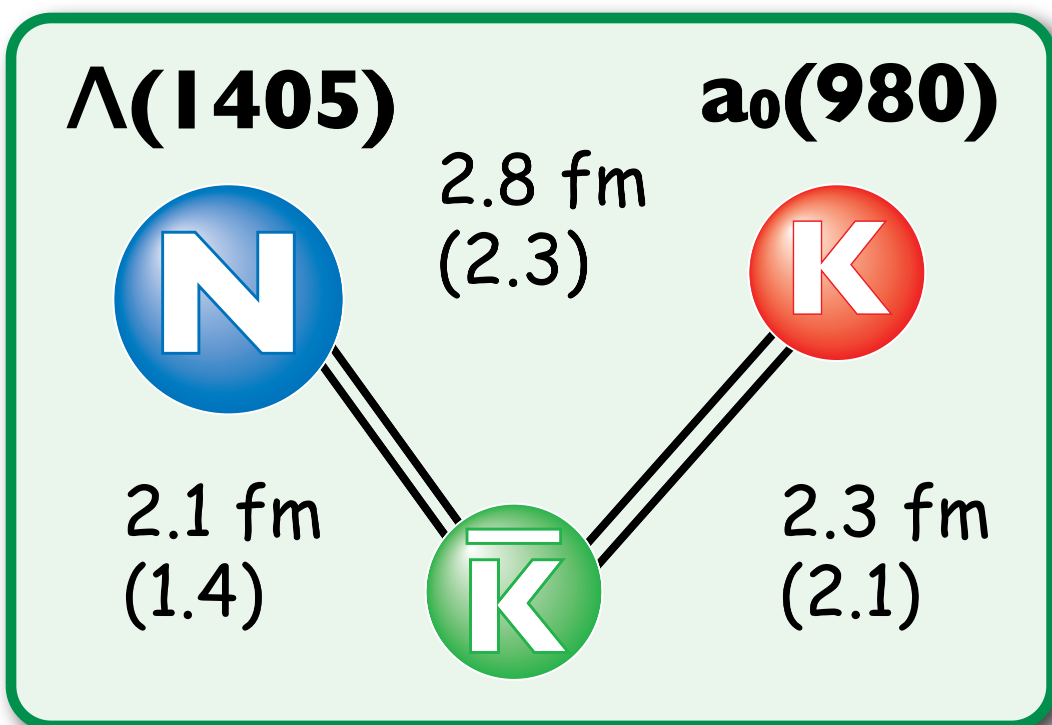
sum of those of isolated two-particle systems

Faddeev calculation also obtains this resonance A.M. Torres's Talk, 15 Sep.

Martinez Torres, Khemchandani, Oset, **PRC79**, 065207 (2009)

N*


spatial structure



r.m.s radius: **1.7 fm**
hadron-hadron distances are comparable with nucleon-nucleon distances in nuclei

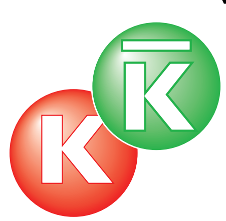
main decay modes $\pi\Sigma K$ from Λ(1405)
$\pi\eta N$ from a_0(980)

- coexistence of two quasi-bound states keeping their characters Λ(1405)+K, a_0(980)+N

Λ(1405)

HW: 1.9 fm
AY: 1.4 fm

a_0(980)



HW: 2.1 fm
AY: 2.2 fm

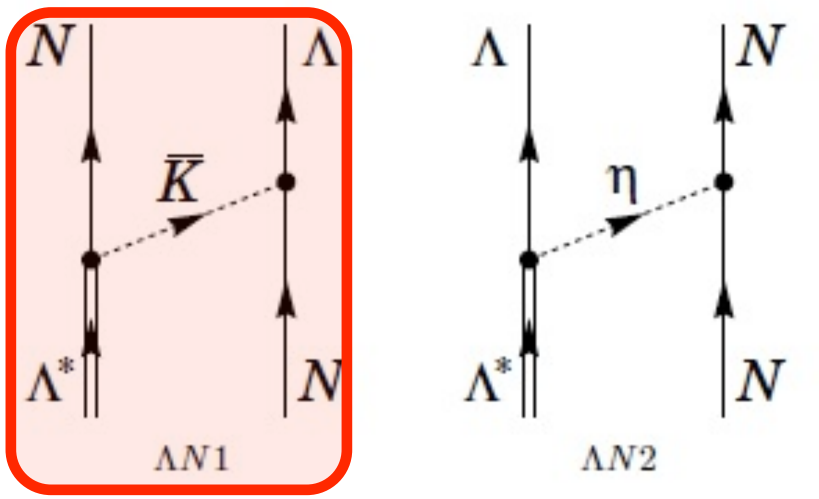
Nonmesonic decay of Λ(1405) in nuclear matter

Sekihara, DJ, Y. Kanada-En'yo, PRC79, 062201(R) (2009); Sekihara, parallel session 2-A

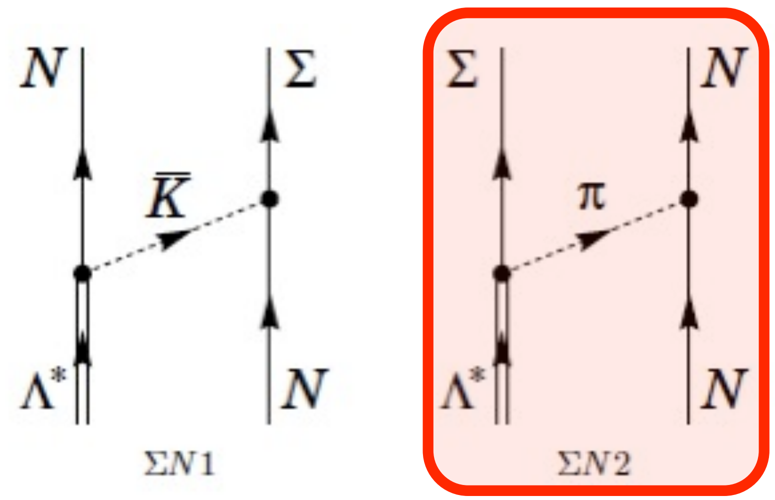
Kaonic nuclei = hadronic excitation of hypernuclei

Λ* can be doorway of kaon absorption

$\Lambda^* N \to \Lambda N$

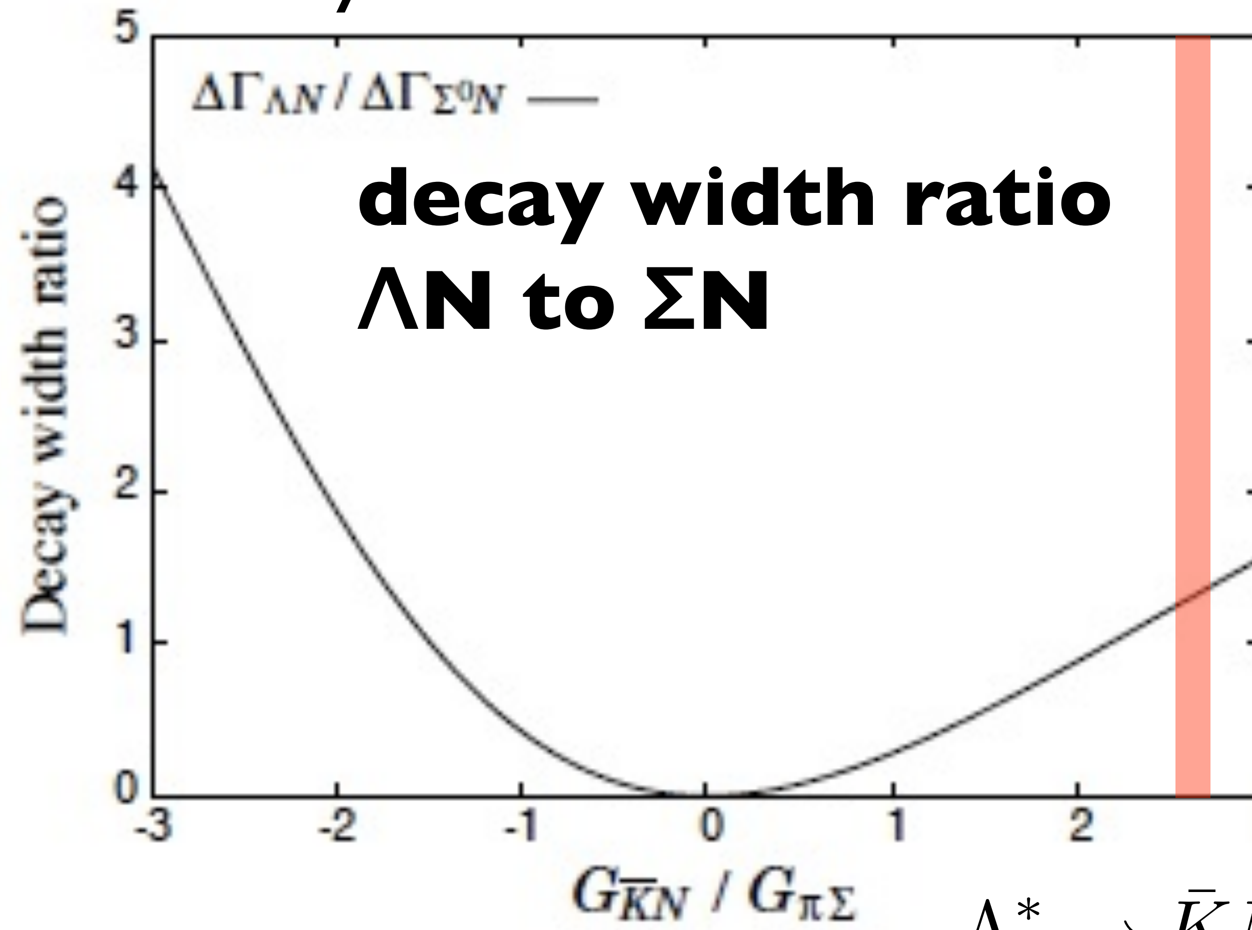


$\Lambda^* N \to \Sigma N$



one-meson exchange model

Decay width ratio of ΛN to ΣN



ratio of couplings $\Lambda^* \to \bar{K}N$, $\Lambda^* \to \pi\Sigma$

total nonmesonic decay of L*: 20 MeV at ρ_0

Summary

Λ(1405) is the gift of meson-baryon dynamics

- quasibound state of meson and baryon
  large spatial size
- double pole structure
  strong attraction in $K^{bar}N$ and $\pi\Sigma$ channels
  $K^{bar}N$ bound state and $\pi\Sigma$ resonance
- resonance position depends on channels

$K^- d \to \Lambda(1405) n$ any information of $\pi\Sigma$(I=0) scattering

Λ(1405) in few-body systems

another example of kaon bound system: $K^{bar}KN$
a new N* resonance N(1910) coexistence of Λ(1405)-K and a_0(980)-N

doorway state of K absorption

Collaborators

Sekihara (Kyoto)

Hyodo (Tokyo Tech.)

Kanada-En'yo (YITP, Kyoto)

Hosaka (RCNP, Osaka)

Ikada (RIKEN & Tokyo)

Roca (Murcia)

Oller (Murcia)

Oset (Valencia)

Ramos (Barcelona)

Meißner (Bonn, Jülich)