CHIRAL SU(3) DYNAMICS of the $\bar{K}NN - \pi\Sigma N$ SYSTEM

Wolfram Weise
Technische Universität München

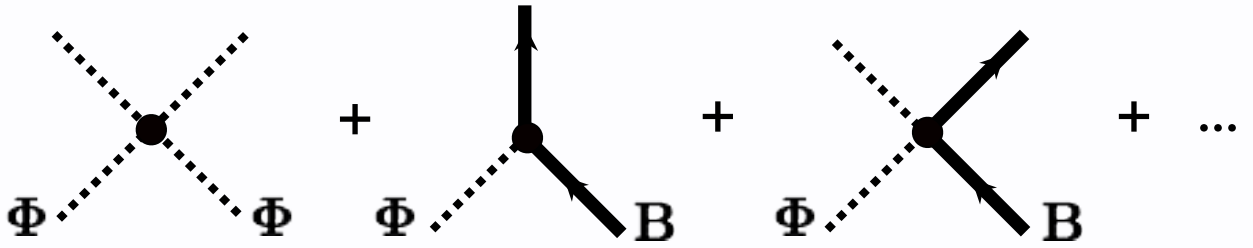
- Low-energy QCD with strange quarks
- Important observables and constraints:
  - $\bar{K}N$ threshold physics
  - $\pi\Sigma$ mass spectra
- Nature and properties of $\Lambda(1405)$: the two-poles scenario
- $\bar{K}NN$ quasibound systems ? Theory status report

CHIRAL SU(3) EFFECTIVE FIELD THEORY

- Interacting systems of **NAMBU-GOLDSTONE BOSONS** (**pions**, **kaons**) coupled to **BARYONS**

$$\mathcal{L}_{eff} = \mathcal{L}_{mesons}(\Phi) + \mathcal{L}_B(\Phi, \Psi_B)$$

- Leading **DERIVATIVE** couplings (involving $\partial^\mu \Phi$) determined by spontaneously broken **CHIRAL SYMMETRY**



higher orders with additional low-energy constants

- Low-Energy Expansion: **CHIRAL PERTURBATION THEORY**

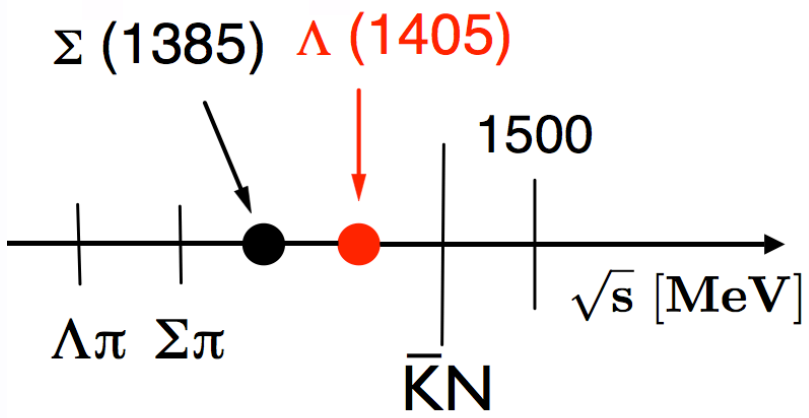
"small parameter": $\dfrac{\mathrm{p}}{4\pi\, \mathrm{f}_\pi} \sim \dfrac{\text{energy / momentum}}{1\ \mathrm{GeV}}$

- works well for low-energy **pion-pion** and **pion-nucleon** interactions

▶ ... but **NOT** for systems with **strangeness** $\mathrm{S} = -1$ $(\bar{\mathrm{K}}\mathrm{N},\ \pi\Sigma,\ \ldots)$

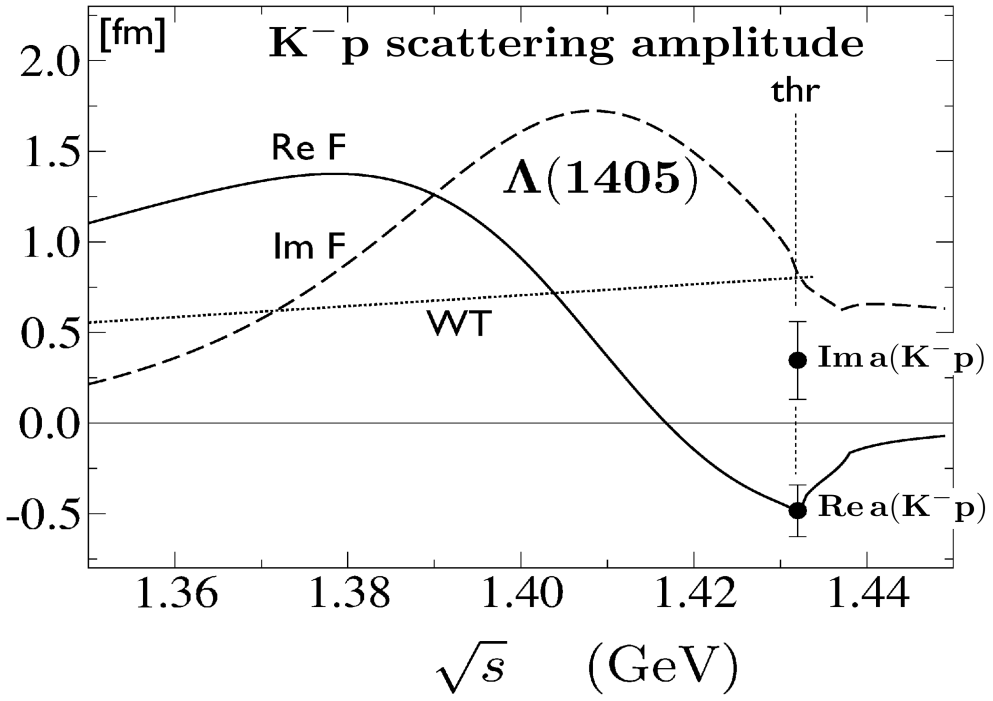
Low-Energy $\bar{K}$ N Interactions

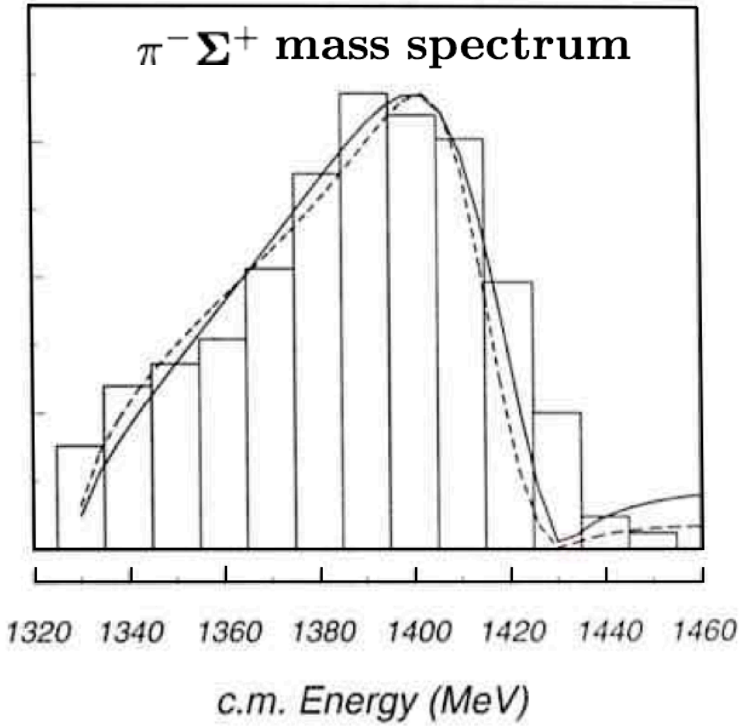
- Chiral Perturbation Theory **NOT** applicable: $\Lambda(1405)$ just below K^-p threshold



Non-perturbative
Coupled Channels
approach based on
Chiral SU(3) Dynamics

N. Kaiser, P. Siegel, W.W. (1995)
E. Oset, A. Ramos (1998)





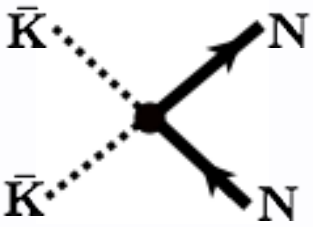
CHIRAL SU(3) COUPLED CHANNELS DYNAMICS

$$T_{ij} = K_{ij} + \sum_n K_{in}\, G_n\, T_{nj}$$

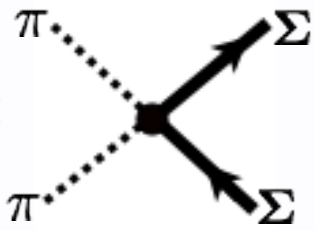
- Leading s-wave I = 0 meson-baryon interactions (Weinberg-Tomozawa)

  Note: **ENERGY DEPENDENCE** characteristic of Nambu-Goldstone Bosons

ch. 1 :



ch. 2 :

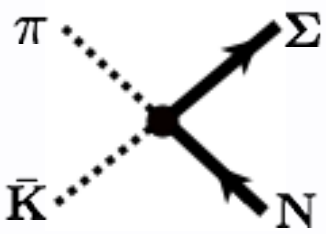


strong enough to produce

- $\bar{K}N$ **bound state**
- $\pi\Sigma$ **resonance**

$$K_{11} = \frac{3}{2f^2}(\sqrt{s} - M_N) \qquad K_{22} = \frac{2}{f^2}(\sqrt{s} - M_\Sigma)$$

- **strong** channel coupling $12 \leftrightarrow 21$:



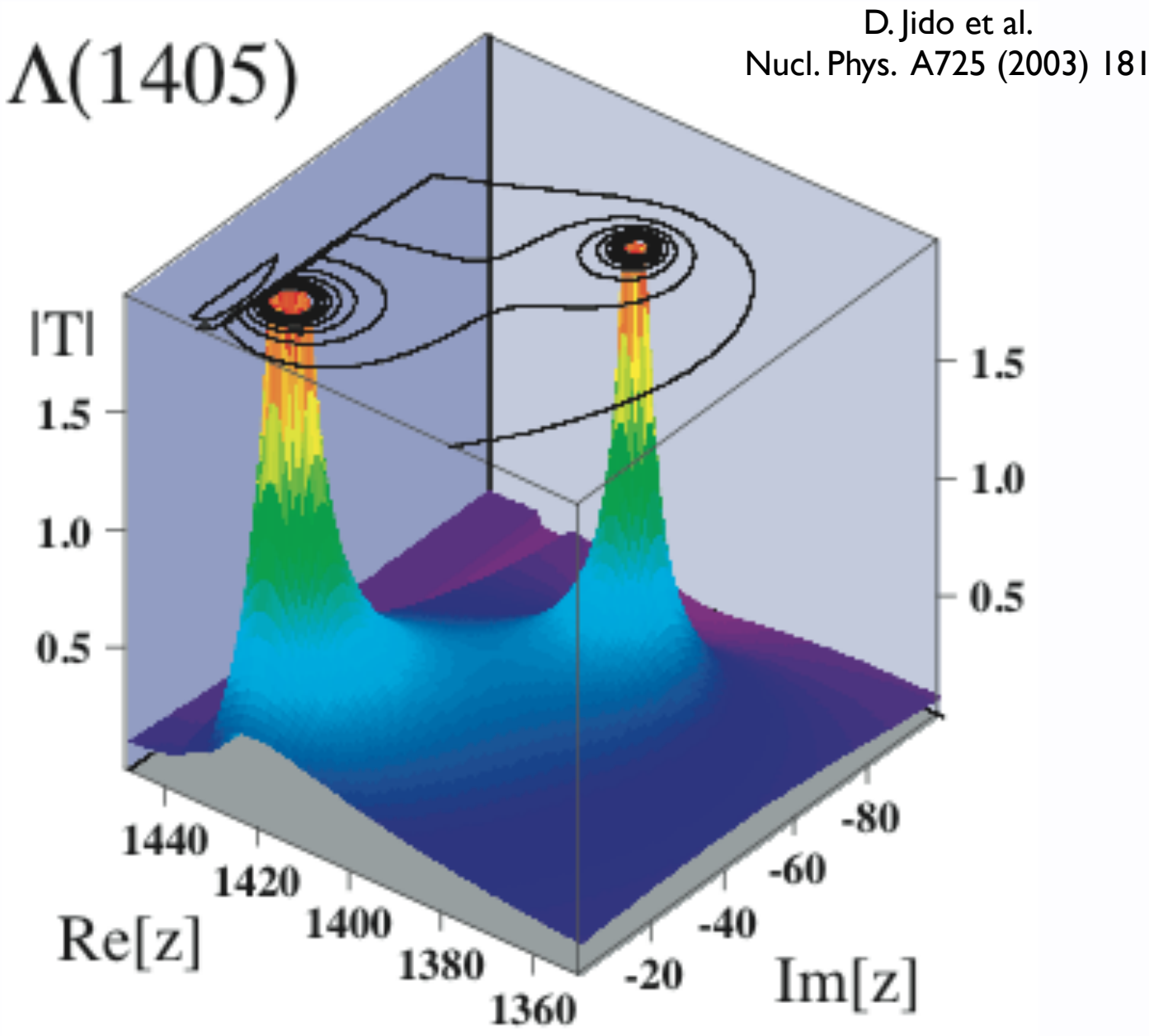
$$K_{12} = \frac{-1}{2f^2}\sqrt{\frac{3}{2}}\left(\sqrt{s} - \frac{M_N + M_\Sigma}{2}\right)$$

- Dynamical generation of $\Lambda(1405)$ as **quasi-bound KN (I = 0) state**

early history: R.H. Dalitz et al. (1967)

The TWO POLES scenario

D. Jido et al.
Nucl. Phys. A725 (2003) 181



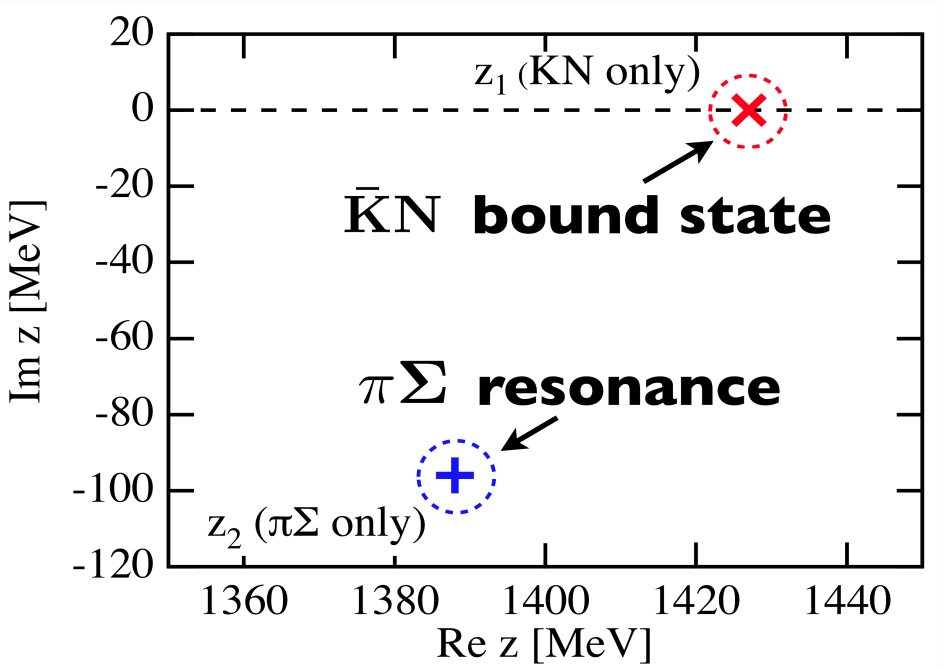
The TWO POLES scenario

T. Hyodo, W.W., Phys. Rev. C77 (2008) 03524

- Singularities of $\bar{K}N$ amplitude in the complex energy plane

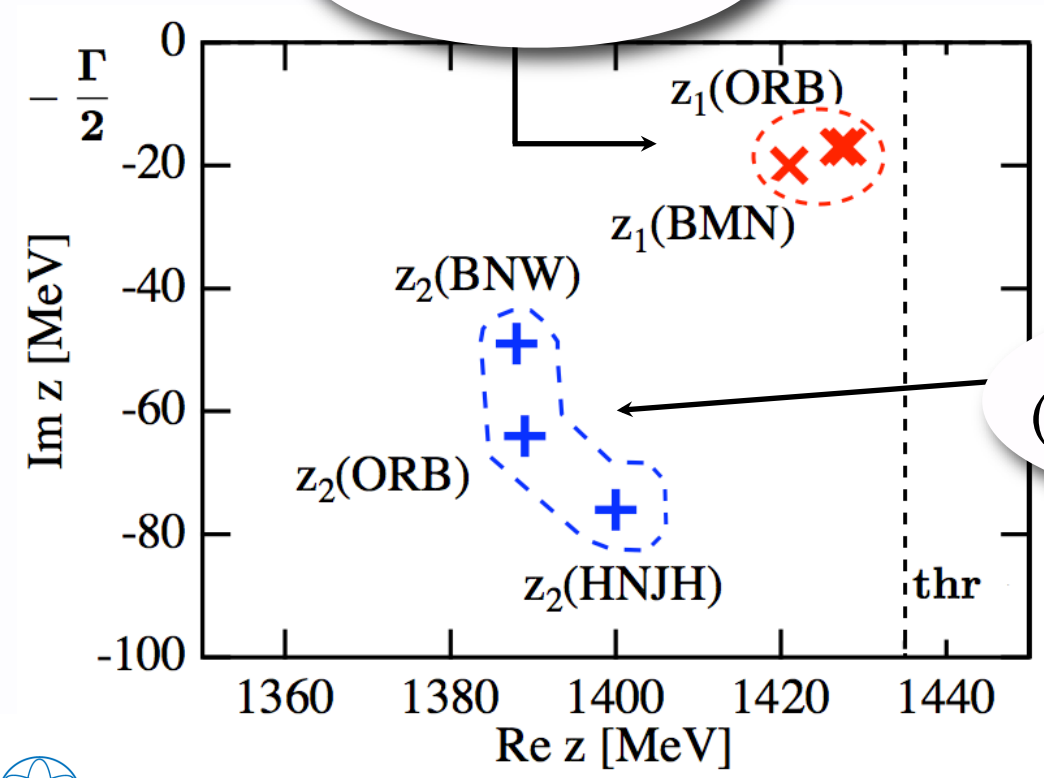
starting point:

no channel coupling



Pole I

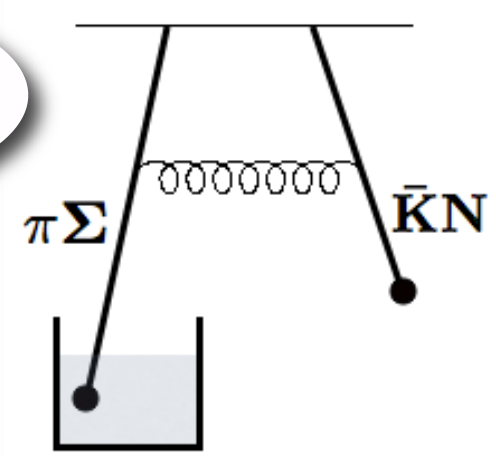
(dominantly $\bar{K}N$)



channel coupling at work

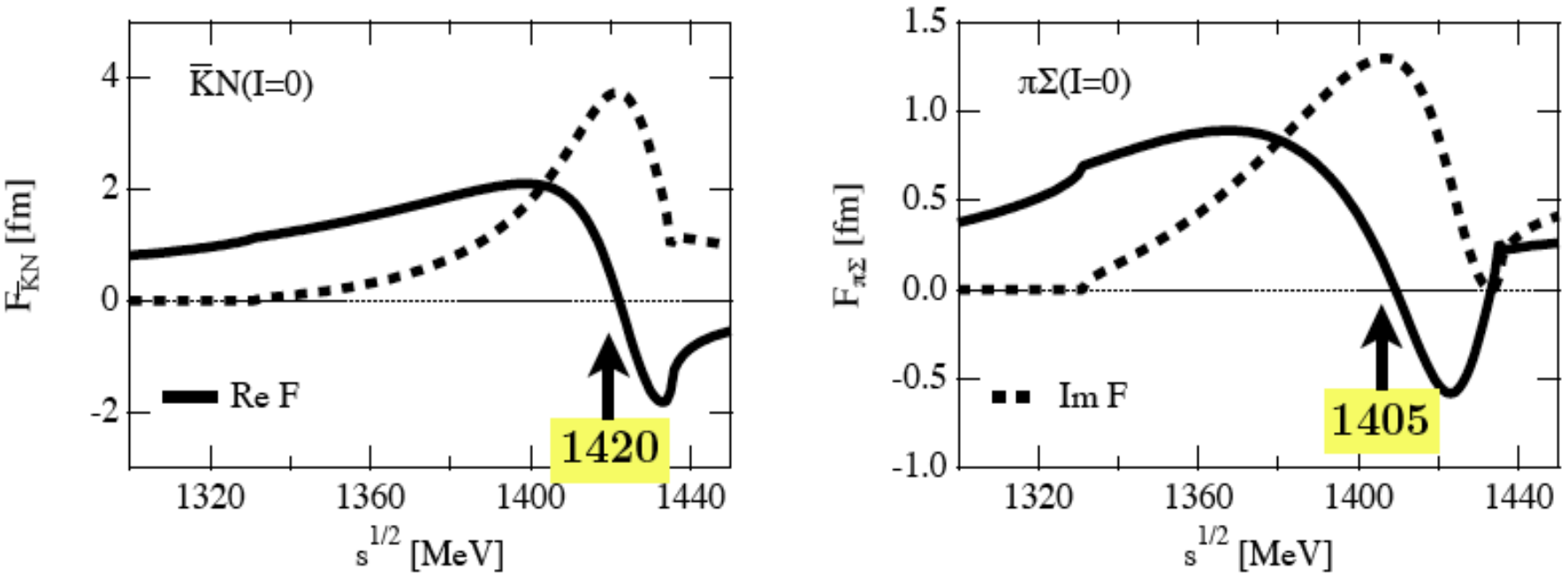
Pole II

(dominantly $\pi\Sigma$)



The TWO POLES scenario (contd.)

- $\bar{K}N$ and $\pi\Sigma$ amplitudes



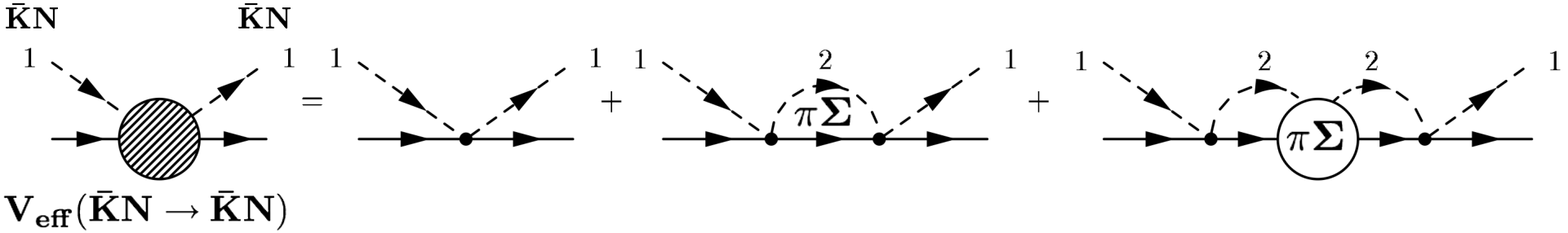
- **Note difference** in pole positions and spectra of $\bar{K}N$ and $\pi\Sigma$

  D. Jido et al., NP A725 (2003) 263

- Equivalent $\bar{K}N$ **effective interaction** should produce quasibound state at **1420** MeV (**not** 1405 MeV)

I = 0 $\bar{K}N$ Effective Interaction

T. Hyodo, W.W.: Phys. Rev. C 77 (2008) 03524

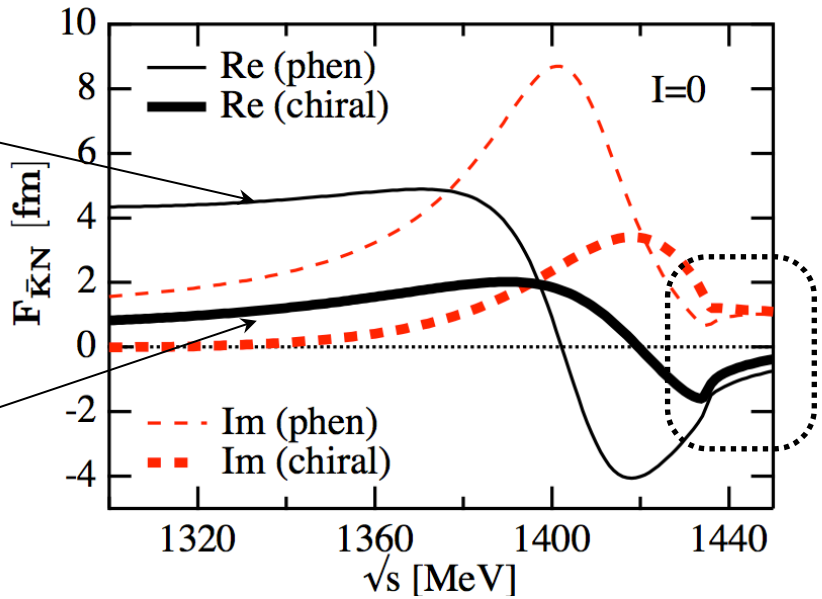


$\mathbf{V_{eff}(\bar{K}N \to \bar{K}N)}$ is:

- **complex**
- **energy dependent**
- **non-local**

Akaishi-Yamazaki phenom. potential

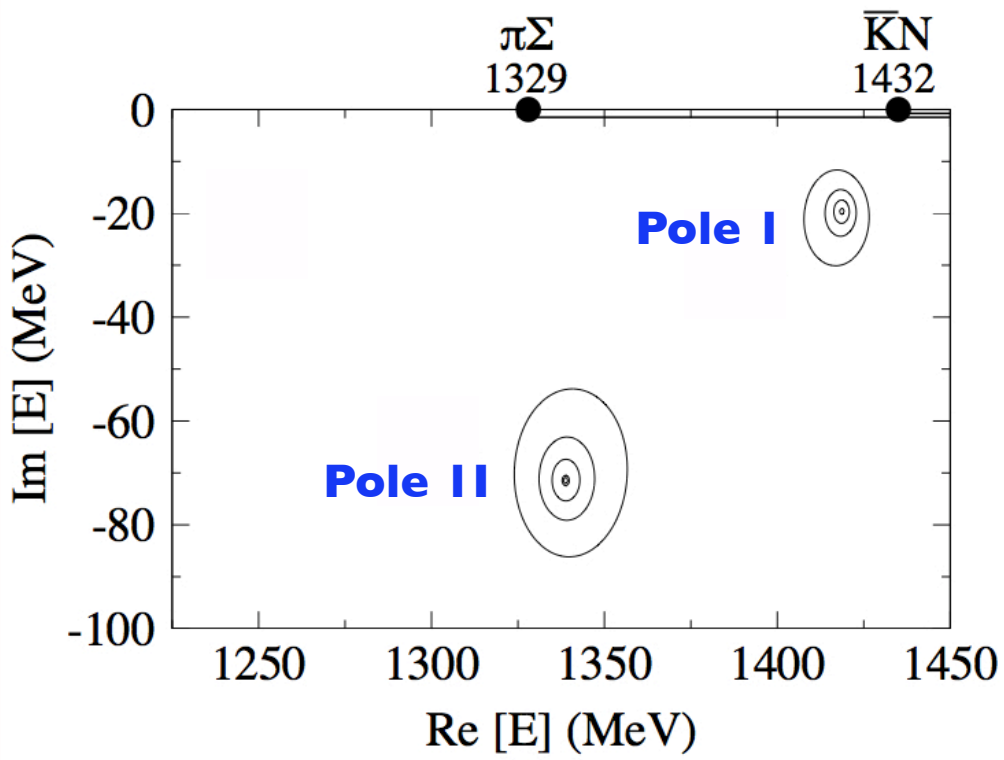
chiral SU(3) dynamics



large differences in **subthreshold** extrapolations

- **Chiral dynamics** predicts significantly **weaker attraction** than Akaishi - Yamazaki (local, energy independent) potential

The TWO POLES scenario (contd.)

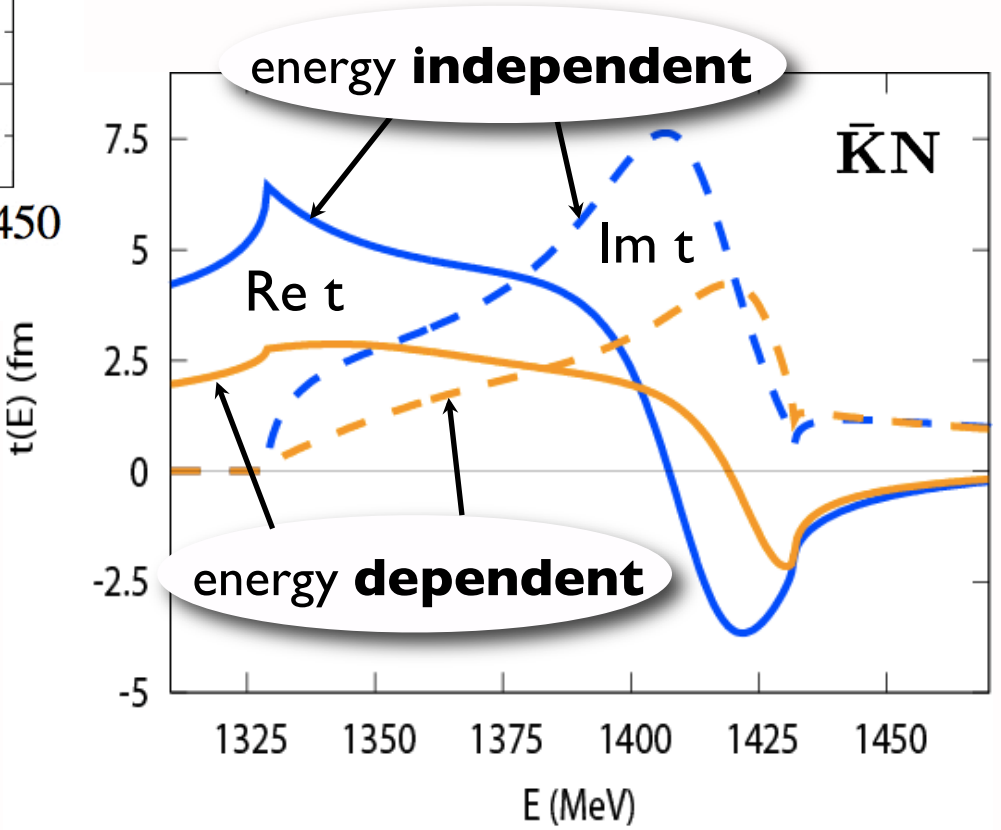


- Note: **NO** differences at and above $\bar{K}N$ threshold

- But: **STRONG** differences for subthreshold extrapolations

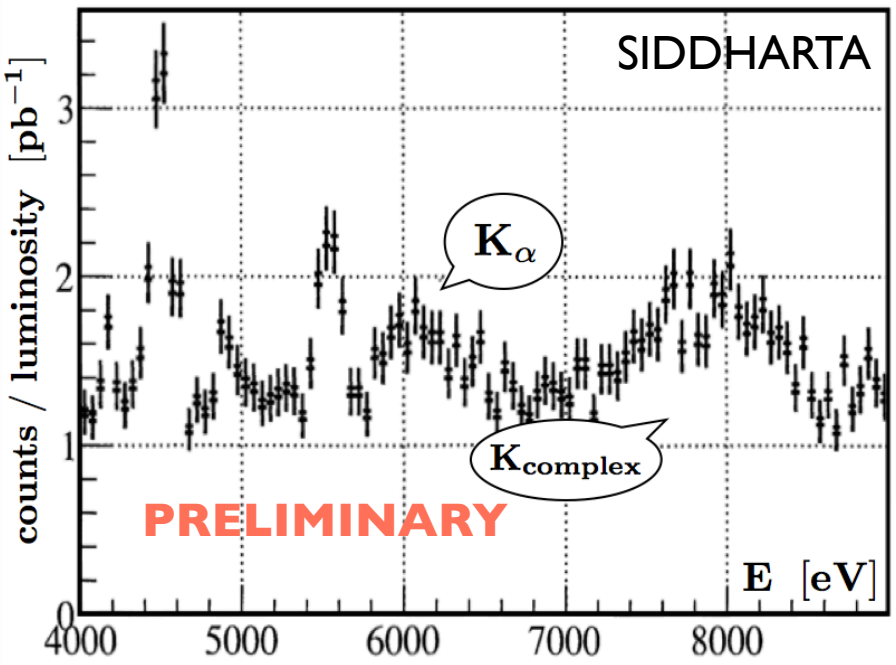
Y. Ikeda, H. Kamano, T. Sato
arXiv:1004.4877 [nucl-th]

- Two-pole scenario confirmed
- Role of **energy dependent** (chiral) driving interactions



NEWS from SIDDHARTA

- New **kaonic hydrogen** precision data (2010)



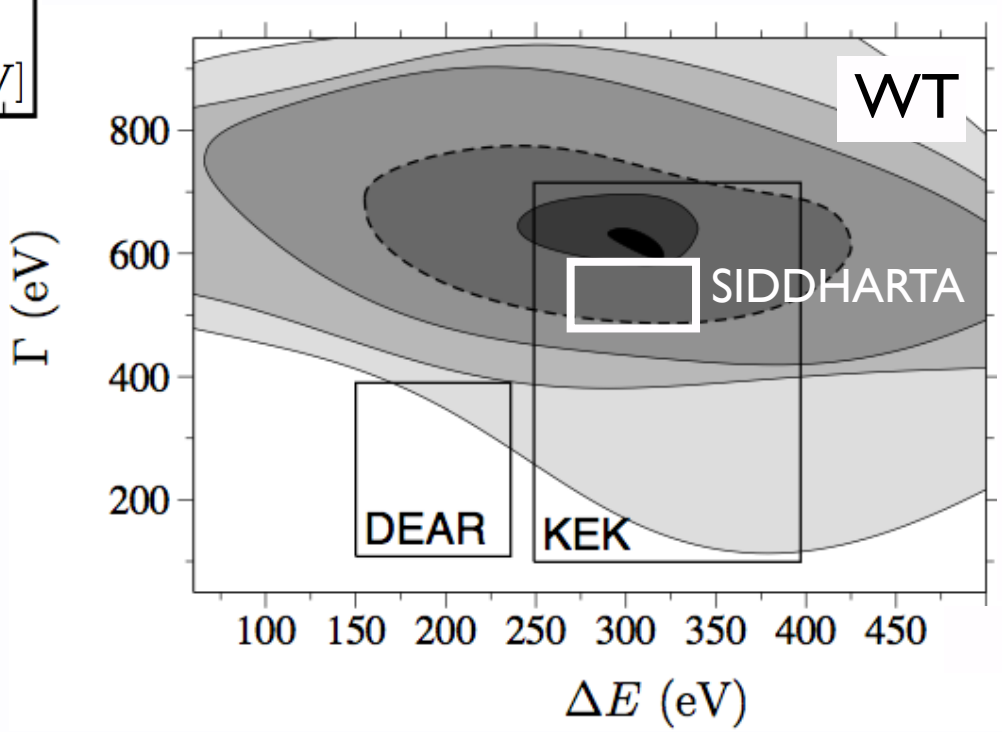
- strong interaction shift and width:

(preliminary)

$$\Delta E = 305 \pm 31 \text{ eV}$$
$$\Gamma = 512 \pm 77 \text{ eV}$$

B. Borasoy, R. Nissler, W.W.
Eur. Phys. J. A25 (2005) 79

R. Nissler
PhD thesis (2008)



- note:
  remarkable agreement with **Tomozawa-Weinberg** (leading order) prediction from chiral SU(3) dynamics

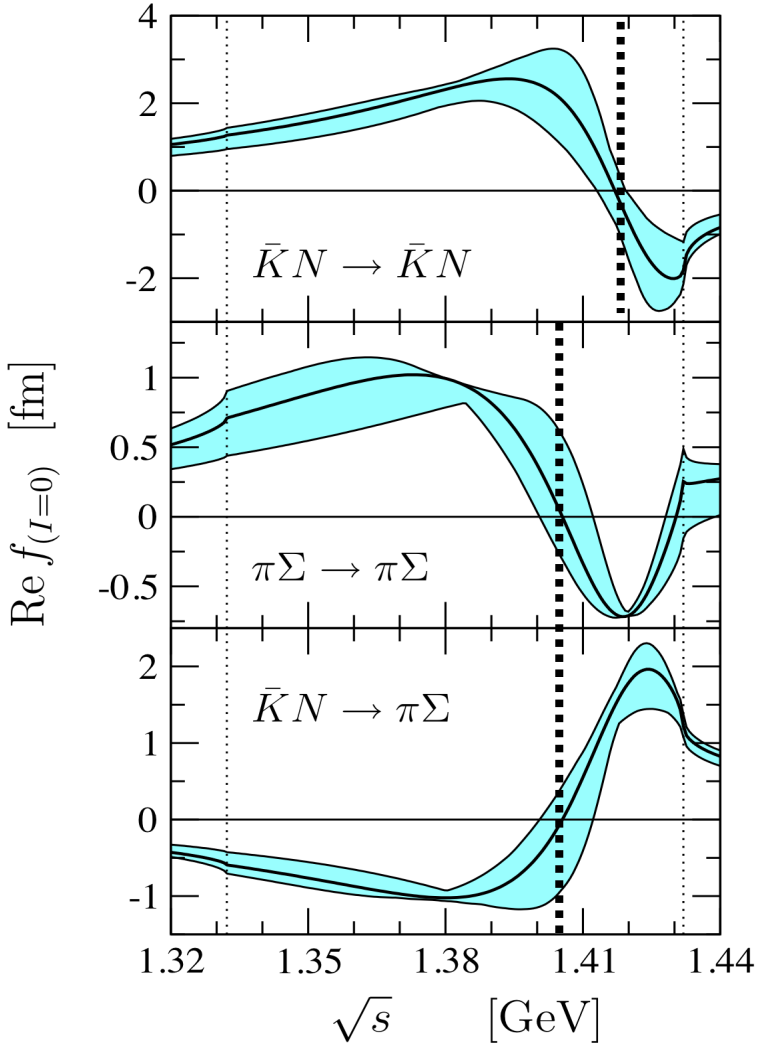
- fine-tuning in progress
  T. Hyodo, Y. Ikeda, W.W. (2010)

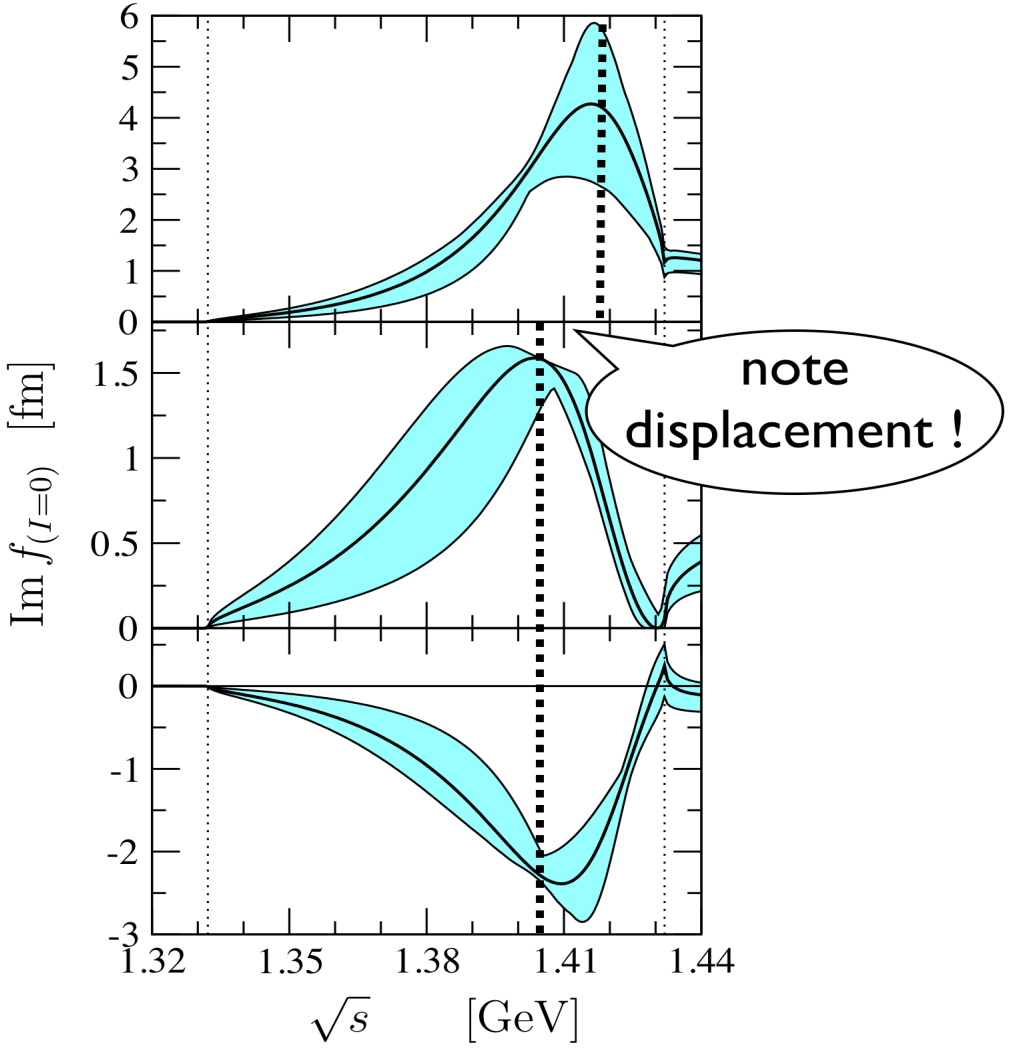
Chiral SU(3) Coupled Channels Dynamics

- Relevant amplitudes, subthreshold extrapolations and uncertainty analysis

R. Nissler PhD thesis (2008)

B. Borasoy, R. Nissler, W.W.: Eur. Phys. J. A25 (2005) 79
B. Borasoy, U.-G. Meissner, R. Nissler, Phys. Rev. C74 (2006) 055201



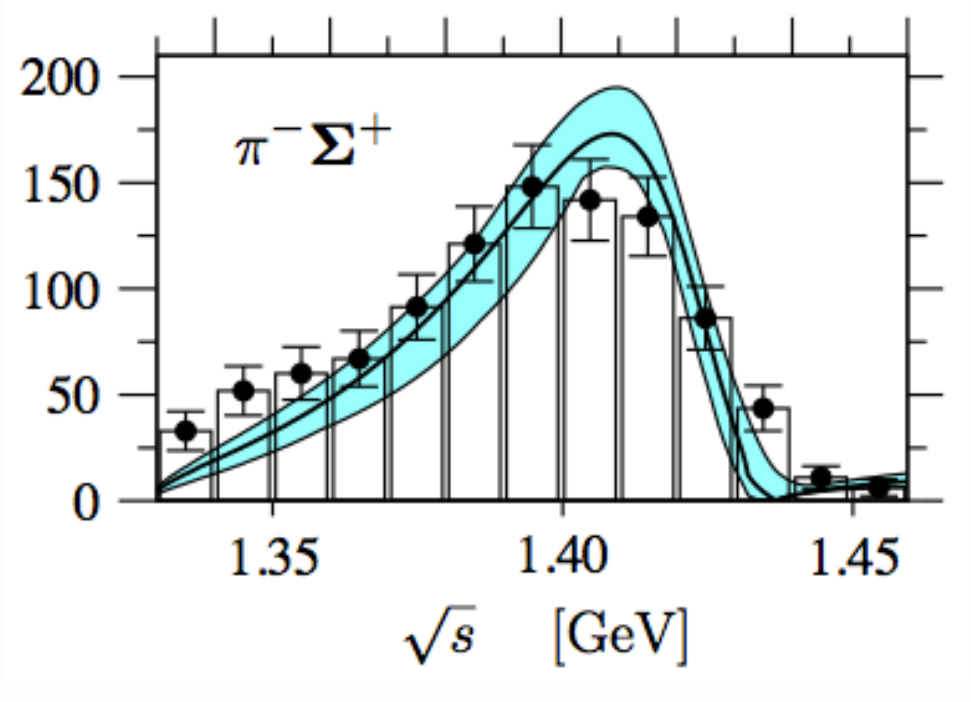


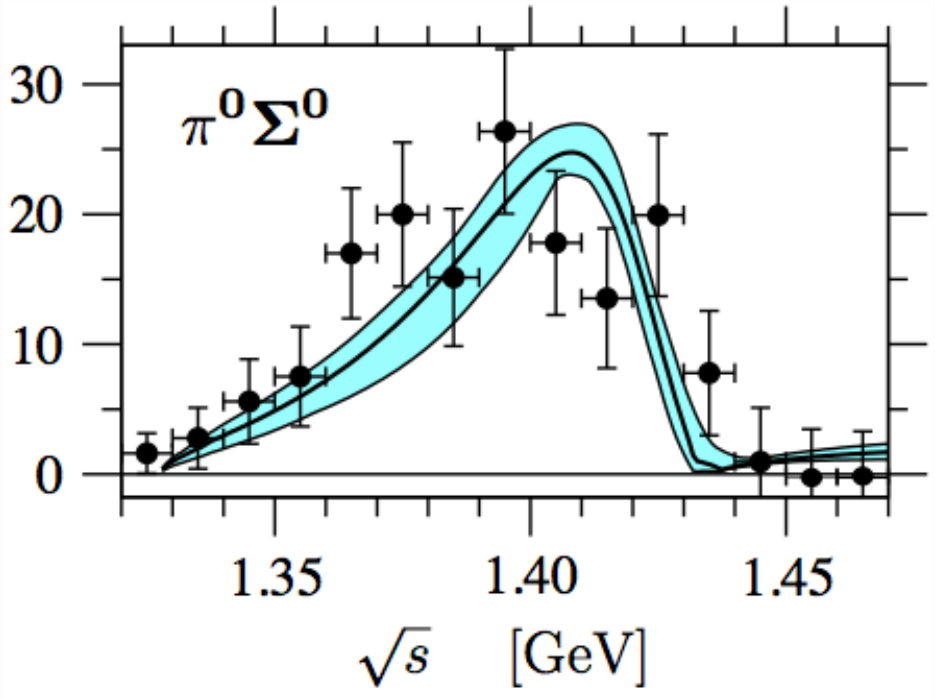
- reduction of uncertainties expected in view of new SIDDHARTA data

$\pi\Sigma$ MASS SPECTRA

- Chiral SU(3) dynamics with uncertainty analysis

R. Nissler, PhD thesis (2008)





"old" data

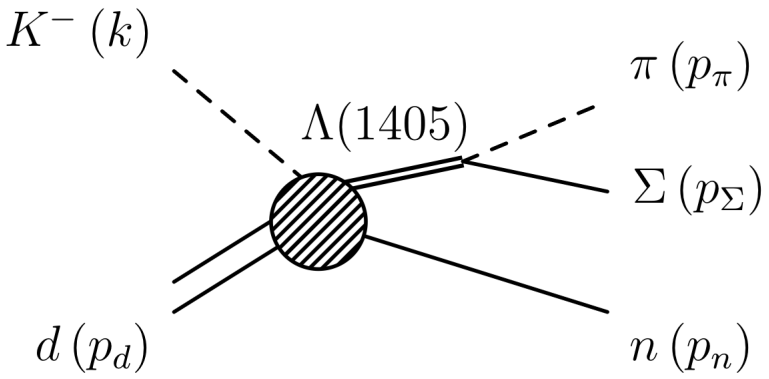
R.J. Hemingway,
Nucl. Phys. B253 (1985) 742

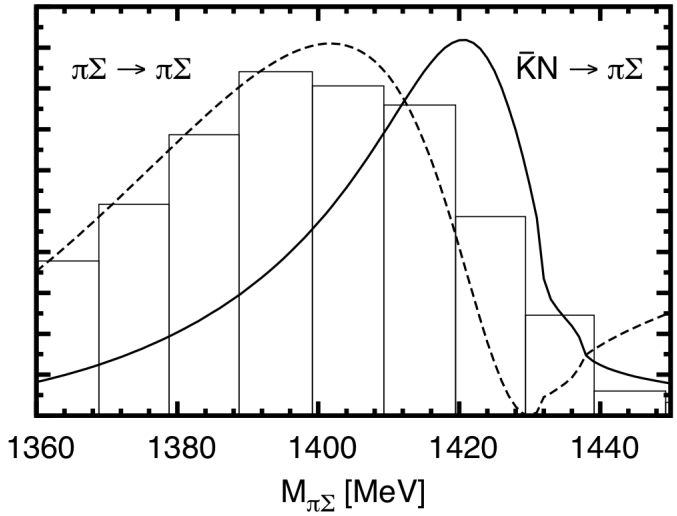
ANKE data (COSY / Jülich)

I. Zychor et al.
Phys. Lett. B660 (2008) 167

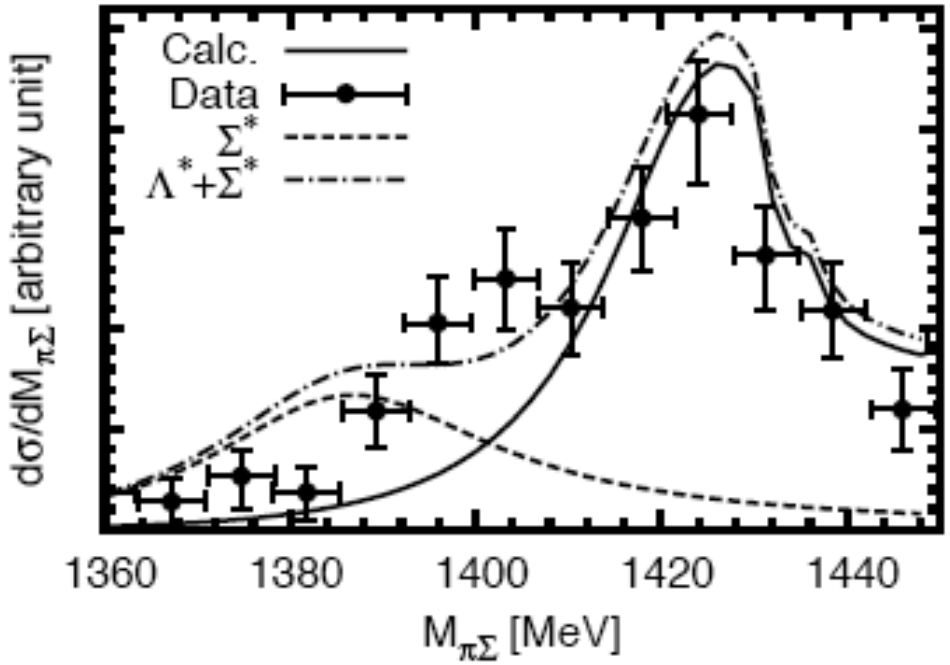
$\pi\Sigma$ MASS SPECTRA (contd.)

- Kaonic (in-flight) production of $\Lambda(1405)$ from deuterium





Two-Pole scenario

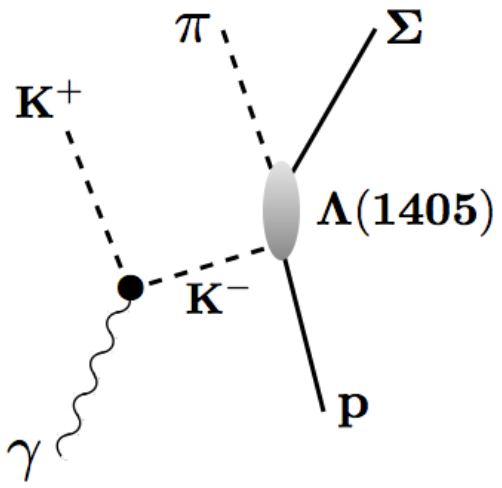


D. Jido, E. Oset, T. Sekihara
Eur. Phys. J. A42 (2009) 268

exp. data:
O. Braun et al.
Nucl. Phys. B129 (1977) 1

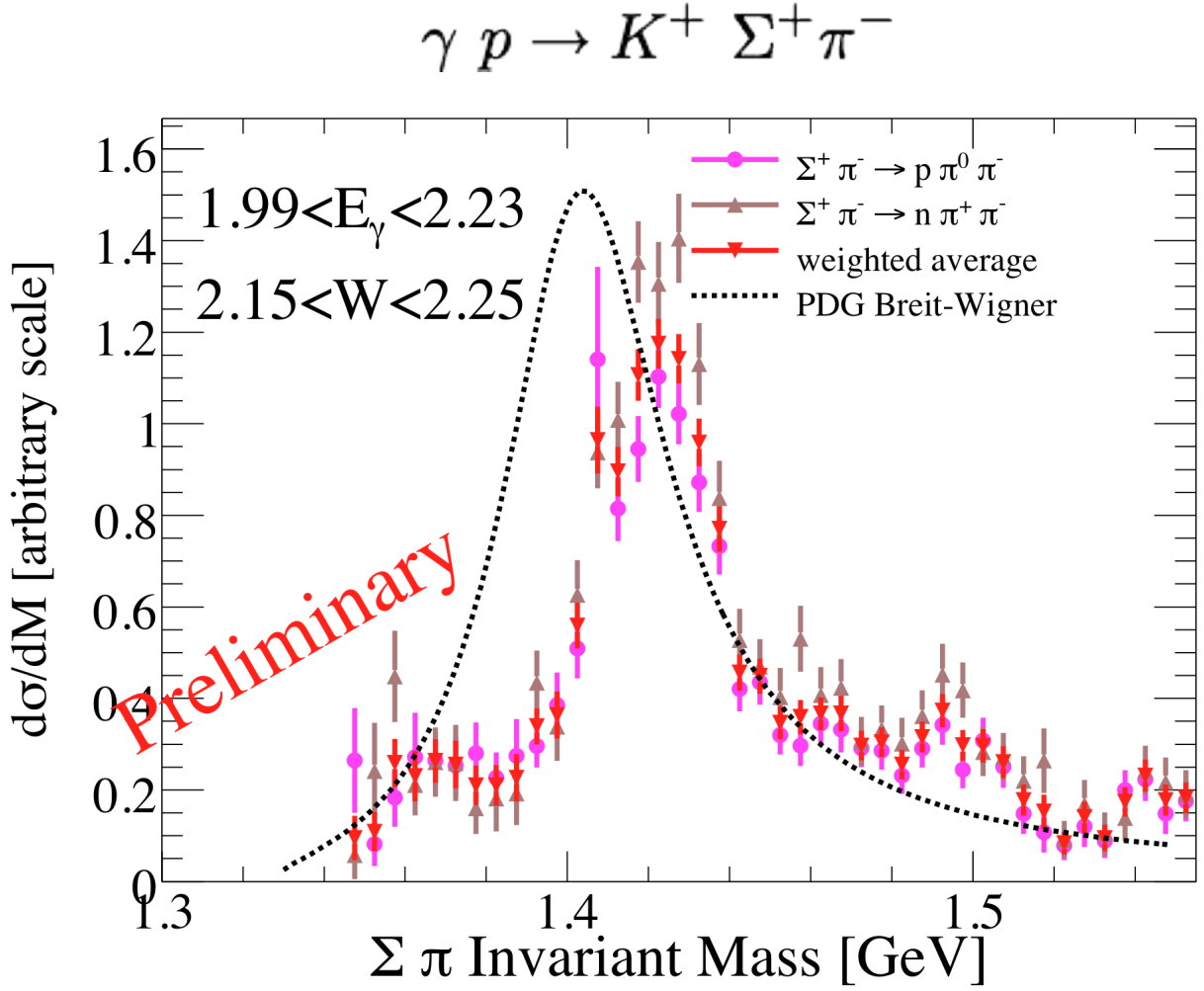
$\pi\Sigma$ MASS SPECTRA (contd.)

- Photoproduction of $\Lambda(1405)$ (CLAS @ JLAB)



K. Moriya, R. Schumacher
HYP-X Conference (2009)
Nucl. Phys. A 835 (2010) 231

K. Moriya, NFQCD
Kyoto (2010)

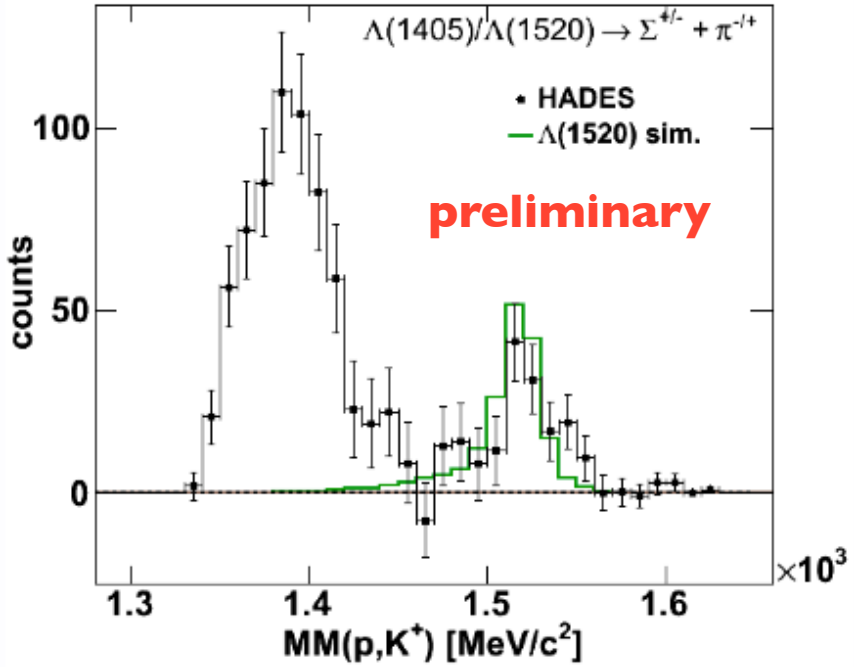


- Note: shift of $\Lambda(1405)$ spectrum as compared to "standard" PDG listing

$\pi\Sigma$ MASS SPECTRA (contd.)

- News from HADES

$$p\,p \rightarrow p\,K^{+}\{\pi^{\pm}\Sigma^{\mp}\}$$

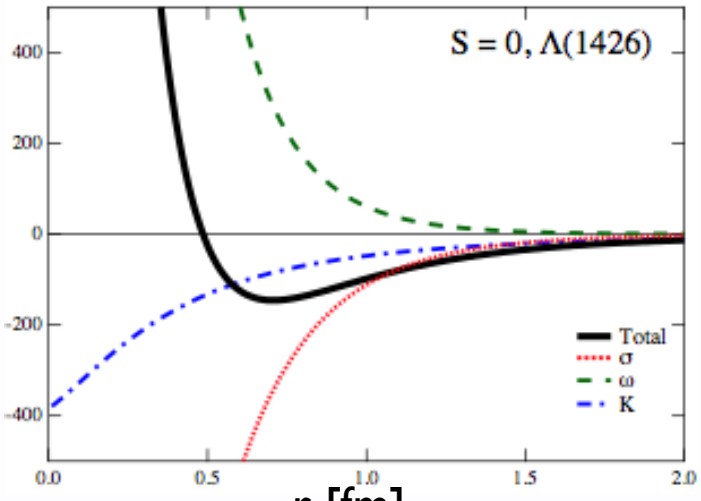


L. Fabbietti,
E. Epple, J. Siebensohn,
et al. (2010)

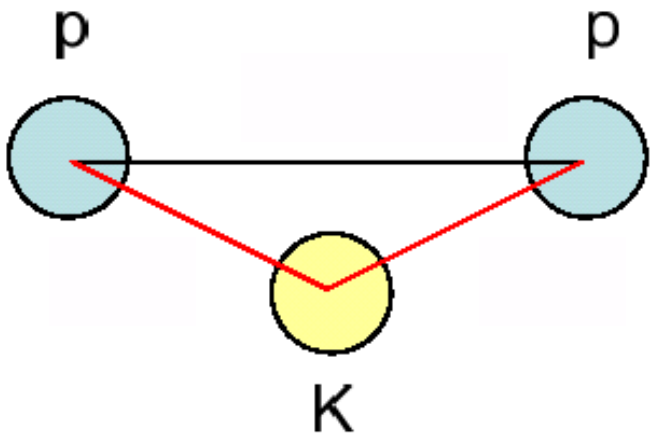
- Downward shift of $\Lambda(1405)$ by final state interactions ?

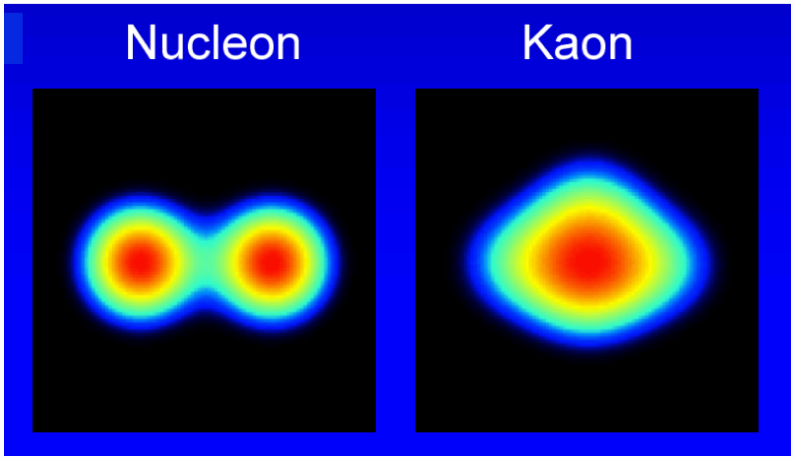
- hint:
  model calculation of $\Lambda^{*}\,N$ potential
  based on chiral SU(3) coupled channels and boson exchange

  T. Hyodo, T. Uchino, M. Oka (2010)



Prototype Antikaon-Nuclear Few-Body System: K^-pp





- **3-Body (Faddeev) Calculations**
- **Variational Calculations**

- **Issues** in both approaches:
  energy dependence of basic input amplitudes,
  subthreshold / off-shell extrapolations, necessary approximations, ...

OVERVIEW

- Binding energies and widths of quasibound $\{\bar{K}[NN]_{T=1}\}_{I=1/2}$

Variational

two-body input:

B [MeV]	Γ		
48	61	phenomenological potential (energy independent)	[1]
20 ± 3	$40 - 70$	chiral SU(3) dynamics	[2]
$40 - 80$	$40 - 85$	coupled channels phenomenological (incl. p wave)	[3]

Faddeev

3-body coupled channels
two-body input:

B [MeV]	Γ		
$50 - 70$	$90 - 110$	phenomenological	[4]
$45 - 80$	$45 - 70$	(energy independent)	[5]
14 *)	58 *)	chiral SU(3) dynamics (energy dependent)	[6]

*) KbarNN pole position

[1] T. Yamazaki, Y. Akaishi
Phys. Lett. B535 (2002) 70
Phys. Rev. C76 (2007) 045201

[2] A. Doté, T. Hyodo, W.W.
Nucl. Phys. A804 (2008) 197
Phys. Rev. C79 (2009) 014003

[3] S. Wycech, A.M. Green
Phys. Rev. C79 (2009) 014001

[4] N.V. Shevchenko, A. Gal, J. Mares
Phys. Rev. Lett. 98 (2007) 082301
(+ J. Révay)
Phys. Rev. C76 (2007) 044004

[5] Y. Ikeda, T. Sato
Phys. Rev. C76 (2007) 035203
Phys. Rev. C79 (2009) 035201

[6] Y. Ikeda, H. Kamano, T. Sato
arXiv:1004.4877 [nucl-th] (2010)

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energy dependent

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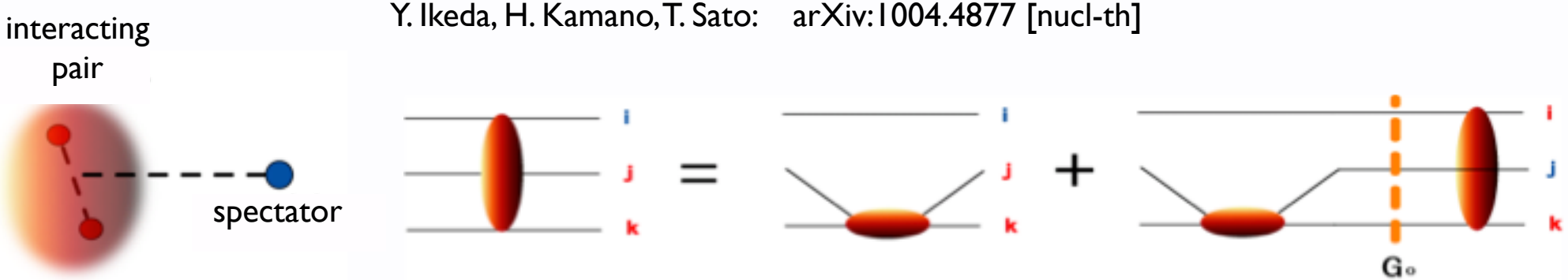
Phys. Rev. C76 (2007) 035203
Phys. Rev. C79 (2009) 035201

[6] Y. Ikeda, H. Kamano, T. Sato
arXiv:1004.4877 [nucl-th] (2010)

K^-pp System: Coupled-Channels Faddeev Approach

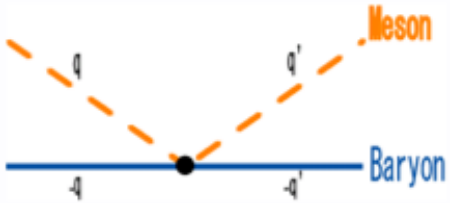
(contd.)

Y. Ikeda, H. Kamano, T. Sato: arXiv:1004.4877 [nucl-th]



- Recent advanced calculation:
  Importance of full, **energy dependent** $\bar{K}N$ and $\pi\Sigma$ interactions

based on



chiral SU(3) dynamics

$$V_{MB}(q',q) = -4\pi\lambda^{(I)}_{\alpha\beta}\frac{1}{(2\pi)^3}\frac{1}{8F_\pi^2}\frac{1}{\sqrt{\omega'\omega}}\frac{\omega'+\omega+E'_B+E_B-M'-M}{2}$$

- **Two-pole structure** also seen in **3-body** amplitude

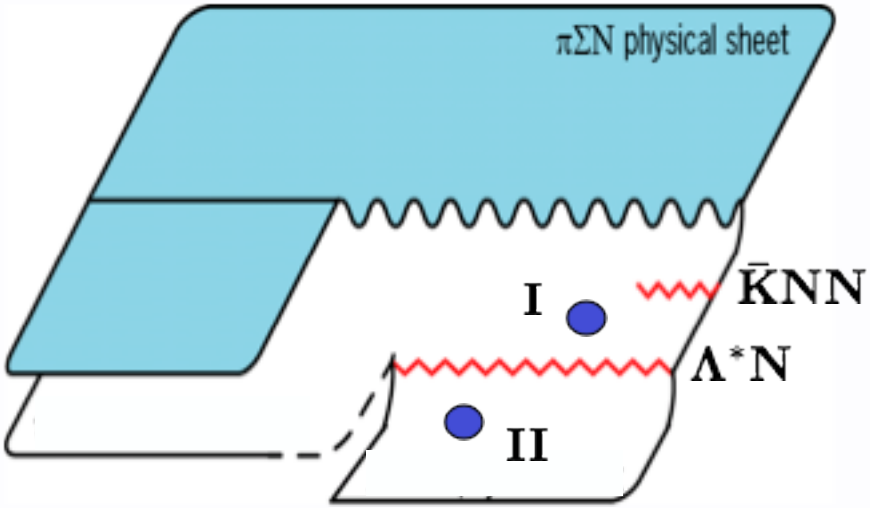
K^-pp System: Coupled-Channels Faddeev Approach

(contd.)

Y. Ikeda, H. Kamano, T. Sato arXiv:1004.4877 [nucl-th]

- Search for **3-body resonances** on $\bar{K}NN$ physical sheet

- **Energy dependent** interactions
  - ► **two poles** in 3-body amplitude



	pole I	pole II
$\bar{K}$- and N-exchanges	$-14.5 - i28.7$	$-36.7 - i109.3$
$\bar{K}$-, N- and π-exchanges	$-13.6 - i27.8$	$-45.8 - i104.0$
Full	$-13.7 - i29.0$	$-37.2 - i93.3$

[MeV]

► implications for spectral functions ? ► **weak binding**

Summary

- **Low-Energy QCD**:
  spontaneous chiral symmetry breaking scenario well established
  - **Chiral** SU(3) x SU(3) **Effective Field Theory** :
    Successful framework for low-energy hadron physics with s-quarks
  - Structure of $\Lambda(1405)$ governed by (chiral) SU(3) coupled-channels dynamics and two-poles scenario

- **Antikaons** in interaction: $\bar{K}NN$ **quasibound** systems ?
  - Extrapolations to **far-subthreshold** region still an issue
  - **Weak binding** + large width from chiral SU(3) dynamics
  - DISTO and FINUDA signals are **not** understood in terms of deeply bound $\bar{K}NN$ states ($\rightarrow \pi YN$ dynamics ?)
  - needed:

    high-precision $\bar{K}N$ **threshold data**

    much improved $\pi\Sigma$ **mass spectra**

    answers in sight: SIDDHARTA ... J-PARC, AMADEUS, GSI