Λ(1405) production in $K^- d \rightarrow n \pi \Sigma$ at DAFNE

E. Oset, D. Jido, T. Sekihara, M. Bayar and J. Yamagata

Kbar N interaction and the two Λ(1405) states
$K^- d \rightarrow n \pi \Sigma$ with finite $K^-$ momentum
$K^- d \rightarrow n \pi \Sigma$ at DAFNE
A possible Kbar NN strongly bound state with $S=1$ for NN
The Kbar N interaction is studied using chiral lagrangians and unitary techniques in coupled channels: Chiral Unitary Approach.

Several resonances are dynamically generated, including two Λ(1405) states, from the interaction of the octet of pseudoscalar mesons and the octet of baryons: Kbar N, π Σ, π Λ, η Σ, η Λ, K Ξ

Kbar N, π Σ are the most important channels for the Λ(1405).
$8 \otimes 8 = 1 \oplus 8_s \oplus 8_a \oplus 10 \oplus 10 \oplus 27$

$M_i(x) = M_0 + x(M_i - M_0)$,
$m_i^2(x) = m_0^2 + x(m_i^2 - m_0^2)$,
$a_i(x) = a_0 + x(a_i - a_0), \quad X \in [0,1]$

Couples strongly to pi Sigma

Couples strongly to Kbar N
Effect of coupling to the different states in different amplitudes

![Graph showing the effect of coupling to different states in different amplitudes. The x-axis is labeled $M_{\pi\Sigma}$ [MeV] with values ranging from 1360 to 1440. The graph includes histograms and curves for processes $\pi\Sigma \rightarrow \pi\Sigma$ and $\bar{K}N \rightarrow \pi\Sigma$.](image-url)
The nominal $\Lambda(1405)$ has this mass, the theory says that if we excite the resonance induced by $K\bar{N}$ we should mostly excite the narrow state around 1520 MeV...... Example of $K^- p \rightarrow \pi^0 \pi^0 \Sigma^0$, Prakhov ......

A new reaction to test it : $K^- d \rightarrow n \pi \Sigma$, $\Lambda(1405)$ is below Kbar N threshold ?????

The single scattering contributes mostly at large $M_{\text{inv}}$ corresponding to free $K^- p$ scattering with $K^-$ in flight.
What happens if we decrease the K- momentum?

Single scattering catches up and distorts the signal.
DAFNE conditions: K coming from $\phi$ decay:

Hope restored: measure $n$ in coincidence forward in CM (n from single scattering go backwards)
The signal of the $\Lambda(1405)$ is predicted clearly around 1420-1425 MeV, like in Braun experiment.

The cross sections obtained are measurable in a few months run, while data are collected for other purposes.

Nevio Grion is planning the experiment.
Byproduct: can there be a strongly bound (not kaonic state) of K⁻d?

The Kbar NN system has been thoroughly studied theoretically: Consensus that there is bound state. Differences in mass and width. \( B=10-70 \text{ MeV}, \Gamma=50-110 \text{ MeV} \)

Experimentally: several claims, which have been disproved. No evidence, \( \Gamma \) too big???


All them search and find a state with \( S_{NN}=0 \) which is the most bound. No one looked for \( S_{NN}=1 \), like \( K^{-}d \) state.
Kbar NN scattering Fixed Center approximation to Faddeev equations

M. Bayar, J. Yamagata, E. O.

\[ T = T_1 + T_2 \]

\[ T_1 = t_1 + t_1 G_0 T_2 \]

\[ T_2 = t_2 + t_2 G_0 T_1 \]

\[ t_1 = t_2 \]

\[ G_0 = \int \frac{d^3 q}{(2\pi)^3} F_{NN}(q) \frac{1}{q^2 - \bar{q}^2 - m_K^2 + i\epsilon} \]

\[ T = \frac{2t_1}{1 - t_1 G_0} \]

NN form factor
Explicit $\pi \Sigma$ in three body

$S_{NN}=0$

Kbar NN threshold: 2372 MeV

NN size of deuteron

NN decreased size to about half radius from Hyodo et al.

State bound by 45-50 MeV
$\Gamma$ around 50 MeV

State bound by 30 MeV
$\Gamma$ around 50 MeV

Extra width from Kbar absorption
For $S_{\text{NN}}=0$ the FCA provides results similar to those of Hyodo, Dote, Weise, since same input is used.

Novel prediction for $S_{\text{NN}}=1$, $K^- d$ strongly bound state. Not found before because people used variational calculations to get minimum energy, or those who used Faddeev preassumed $S_{\text{NN}}=0$.

Experiments continue: the existence of new $S_{\text{NN}}=1$ state might make the observation more difficult because overlap of two states.

Theoretical confirmation with other methods welcome!!
Conclusions

Mounting evidence that there are two $\Lambda(1405)$ states

The $K^- d \rightarrow n \pi \Sigma$ reaction with $K^-$ in flight gives evidence of the high energy, narrow $\Lambda(1405)$ state

DAFNE low energy Kaons still good, but neutrons forward must be measured in coincidence. Proposal planned.

There is a strongly bound $K\bar{K}NN$ system, with $S_{NN}=1$ like in $d$

This is a novel theoretical finding since only $S_{NN}=0$ has been investigated so far. Caveat with the width for experimental identification.