高エネルギー衝突実験での $K^{-}p$ 相関と反 K 中間子核子相互作用

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$\bar{K}$ meson and $\bar{K}N$ interaction

Two aspects of $K/\bar{K}$ meson

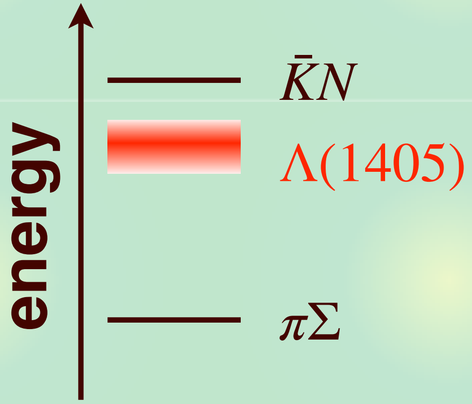
- **NG boson of chiral** $\mathrm{SU(3)_R \otimes SU(3)_L \to SU(3)_V}$
- **Massive by strange quark:** $m_K \sim 496$ MeV

—> Spontaneous/explicit symmetry breaking

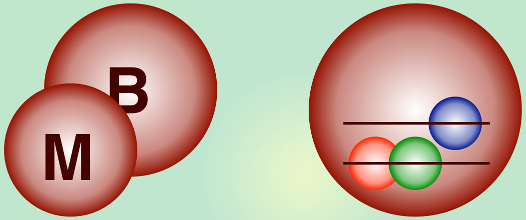
$\bar{K}N$ interaction ...

T. Hyodo, D. Jido, PPNP 67, 55 (2012)

- **is coupled with $\pi\Sigma$ channel**
- **generates $\Lambda(1405)$ below threshold**



molecule



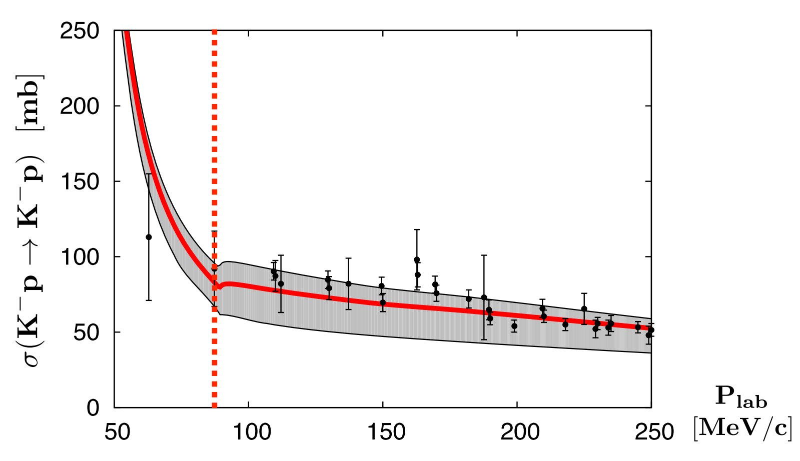
three-quark

- **is fundamental building block for $\bar{K}$-nuclei, $\bar{K}$ in medium, ...**

Experimental data

K^-p total cross sections

Y. Ikeda, T. Hyodo, W. Weise, PLB 706, 63 (2011)



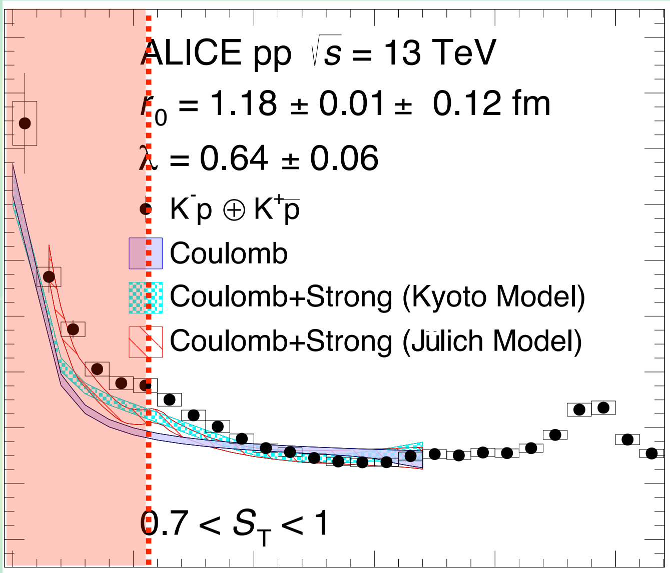
- Old bubble chamber data

K^- hydrogen

- Branching ratios (old)
- Shift/width by SIDDHARTA (new)

K^-p correlation function

ALICE collaboration, arXiv:1905.13470 [nucl-ex]



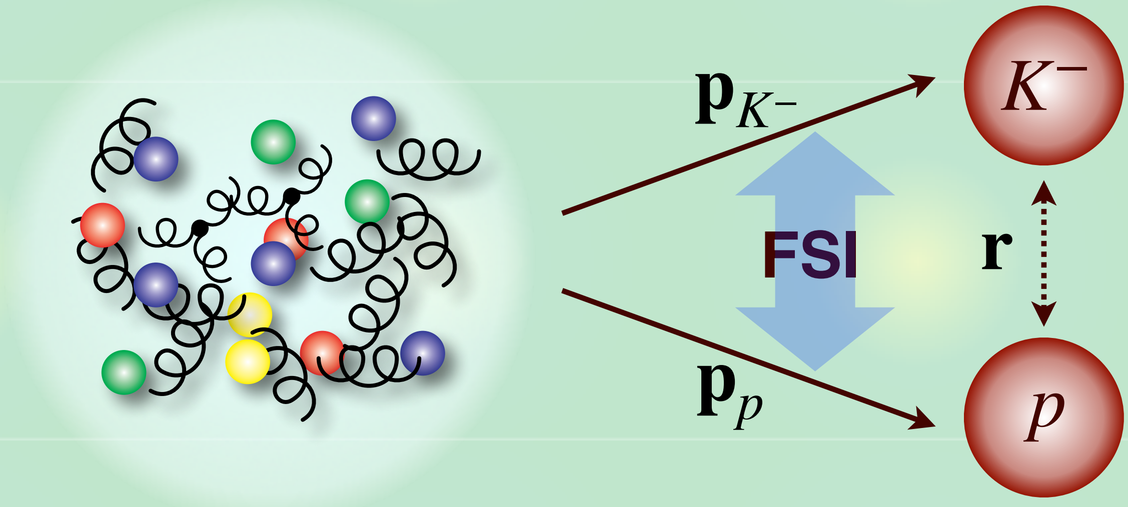
- Excellent precision ($\bar{K}^0 n$ cusp)
- Low-energy data below $\bar{K}^0 n$

—> Important constraint on $\bar{K}N$ and $\Lambda(1405)$

Correlation function

High-energy collision: chaotic source $S(\mathbf{r})$ of hadron emission

$S(\mathbf{r})$



$$\mathbf{q} = \frac{\mathbf{p}^*_{K^-} - \mathbf{p}^*_p}{2}$$

- Experiment

$$C(\mathbf{q}) = \frac{N_{K^-p}(\mathbf{p}_{K^-}, \mathbf{p}_p)}{N_{K^-}(\mathbf{p}_{K^-})N_p(\mathbf{p}_p)}$$

= 1 in the absence of FSI

- Theory

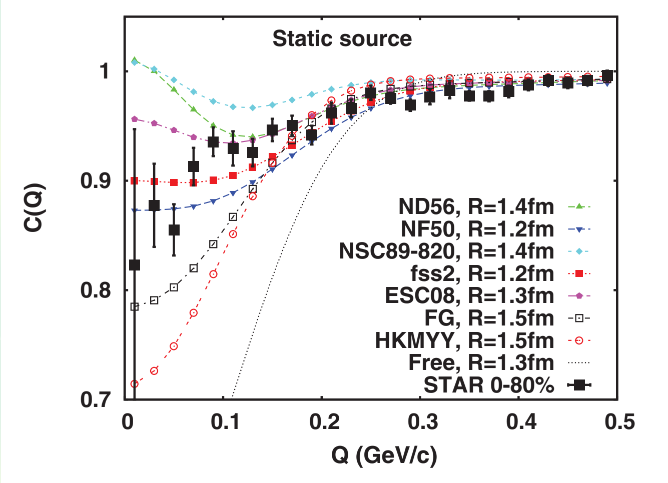
$$C(\mathbf{q}) \simeq \int d^3\mathbf{r}\, S(\mathbf{r})\, |\Psi^{(-)}_{\mathbf{q}}(\mathbf{r})|^2$$

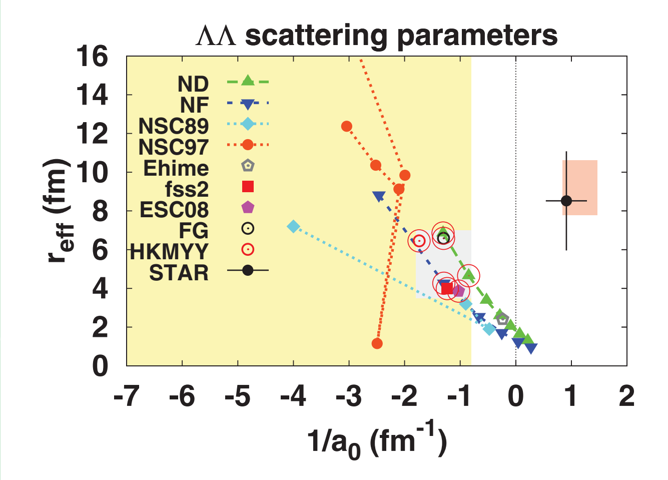
Source function <—> two-body wave function (FSI)

Extraction of hadron interaction

$\Lambda\Lambda$ interaction

K. Morita, T. Furumoto, A. Ohnishi, PRC 91, 024916 (2015)





- Correlation function —> constraint on the interaction

$K^- p$ case:

- Open coupled channels ($\pi^+\Sigma^-, \pi^0\Sigma^0, \pi^-\Sigma^+, \pi^0\Lambda$)
- Coulomb interaction
- Energy difference between $K^- p$ and $\bar{K}^0 n$ (isospin breaking)

Coupled-channel correlation function

Schrödinger equation (s-wave)

$$\begin{pmatrix} -\frac{\nabla^2}{2\mu_1} + V_{11}(r) + V_C(r) & V_{12}(r) & \cdots \\ V_{21}(r) & -\frac{\nabla^2}{2\mu_2} + V_{22}(r) + \Delta_2 & \cdots \\ \vdots & \vdots & \ddots \end{pmatrix} \begin{pmatrix} \psi_{K^-p}(r) \\ \psi_{\bar{K}^0 n}(r) \\ \vdots \end{pmatrix} = E \begin{pmatrix} \psi_{K^-p}(r) \\ \psi_{\bar{K}^0 n}(r) \\ \vdots \end{pmatrix}$$

Coulomb threshold energy difference

Coupled-channel formulation

R. Lednicky, V.V. Lyuboshitz, V.L.Lyuboshitz, Phys. Atom. Nucl. 61, 2050 (1997);
J. Haidenbauer, NPA 981, 1 (2019)

$$C_{K^-p}(\mathbf{q}) \simeq \int d^3\mathbf{r}\, S_{K^-p}(\mathbf{r})\, |\Psi^{(-)}_{K^-p,\mathbf{q}}(\mathbf{r})|^2 + \sum_{i \neq K^-p} \omega_i \int d^3\mathbf{r}\, S_i(\mathbf{r})\, |\psi^{(-)}_{i,q}(r)|^2$$

- transition from $\bar{K}^0 n, \pi^+\Sigma^-, \pi^0\Sigma^0, \pi^-\Sigma^+, \pi^0\Lambda$
- ω_i : weight of source channel i relative to K^-p

Boundary conditions

Asymptotic ($r \to \infty$) wave function

$$\begin{pmatrix} \psi_{K^-p}(r) \\ \psi_{\bar{K}^0 n}(r) \\ \vdots \end{pmatrix} \propto \begin{pmatrix} \#e^{-iqr} + \#e^{iqr} \\ \#e^{-iq_2 r} + \#e^{iq_2 r} \\ \vdots \end{pmatrix}$$

incoming + outgoing

- Usual scattering: normalize incoming flux of beam

$$\begin{pmatrix} \psi_{K^-p}(r) \\ \psi_{\bar{K}^0 n}(r) \\ \vdots \end{pmatrix} \propto \begin{pmatrix} e^{-iqr} + c_1^{(+)} e^{iqr} \\ + c_2^{(+)} e^{iq_2 r} \\ \vdots \end{pmatrix}$$

coefficient ~ S-matrix

$$c_i^{(+)} \propto S_{1i}(q)$$

- Correlation function: normalize outgoing flux

$$\psi^{(-)} = \begin{pmatrix} \psi_{K^-p}(r) \\ \psi_{\bar{K}^0 n}(r) \\ \vdots \end{pmatrix} \propto \begin{pmatrix} c_1^{(-)} e^{-iqr} + e^{iqr} \\ c_2^{(-)} e^{-iq_2 r} \\ \vdots \end{pmatrix}$$

$$c_i^{(-)} \propto S_{1i}^{\dagger}(q)$$

—> $\psi^{(-)}$ should be calculated with full coupled channels.

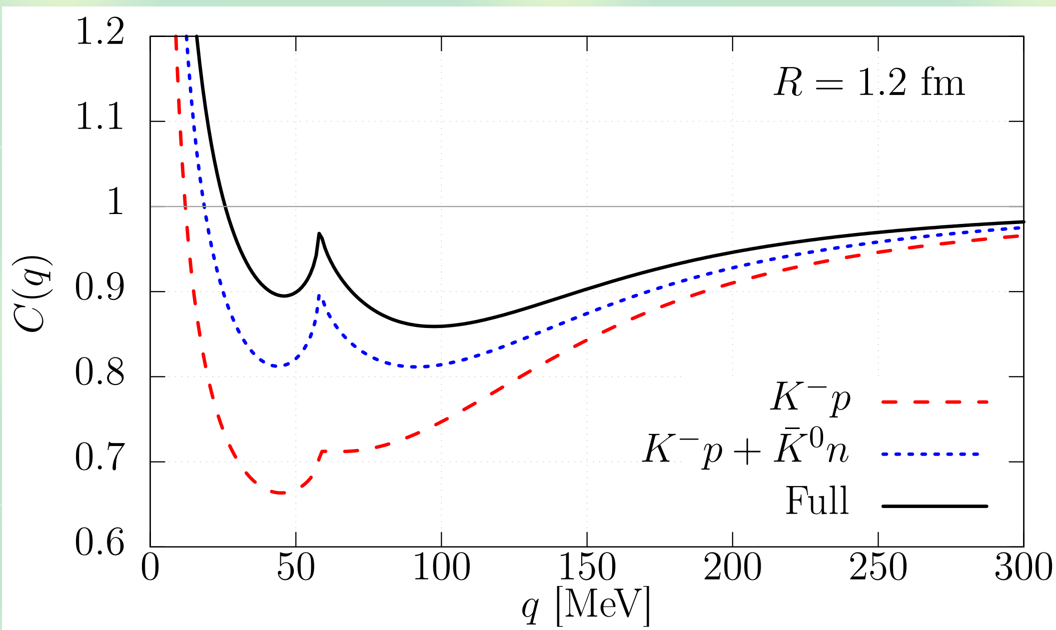
Results

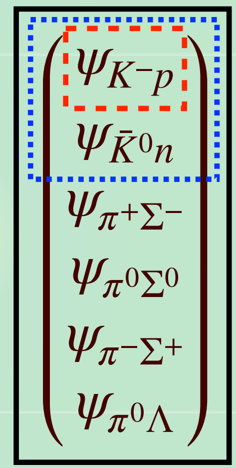
Setup

- interaction: coupled-channel $\bar{K}N$-$\pi\Sigma$-$\pi\Lambda$ potential

  K. Miyahara. T. Hyodo, W. Weise, PRC98, 025201 (2018)

- static spherical source $S(\mathbf{r})$, weight $\omega_i = 1$





- $\bar{K}^0n$ cusp is prominent with inclusion of $\psi_{\bar{K}^0n}$
- Coupled channels enhance K^-p correlation

Summary

- **Accurate** experimental data of $K^- p$ correlation function at very low energy is now available.

- We develop theoretical framework to include

  - coupled-channel effect,
  - Coulomb interaction, and
  - energy difference of $K^- p$ and $\bar{K}^0 n$

- **Coupled-channel effects** are important for the $K^- p$ correlation function.

Y. Kamiya. T. Hyodo, K Morita, A. Ohnishi, in preparation