Antikaon-nucleon interactions and the momentum correlation functions in high-energy collisions

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Clusters & Hierarchies

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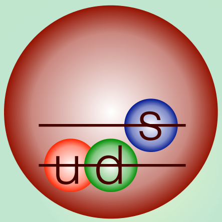
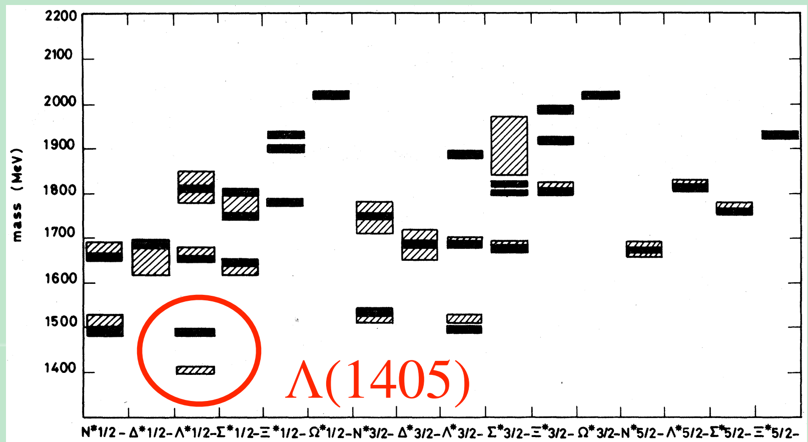
$\Lambda(1405)$ and $\bar{K}N$ scattering

$\Lambda(1405)$ does not fit in standard picture —> exotic candidate

N. Isgur and G. Karl, PRD18, 4187 (1978)



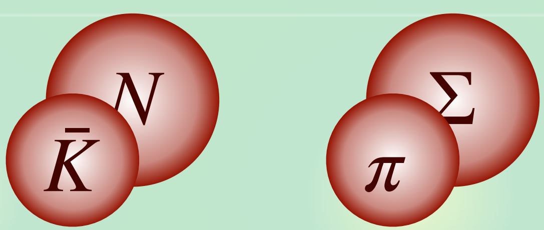


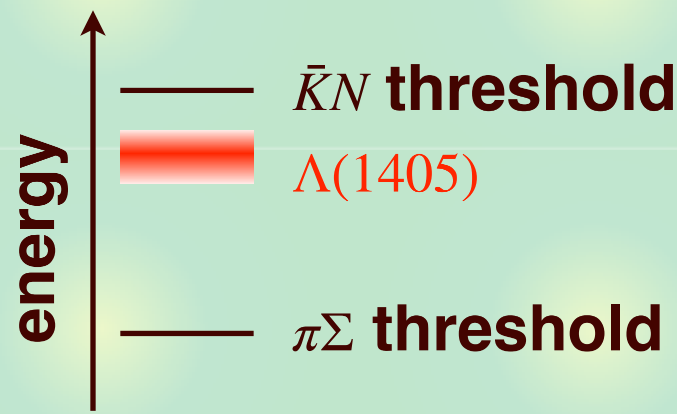
▬ : theory

▨ : experiment

Resonance in coupled-channel scattering

- Coupling to MB states





Detailed analysis of $\bar{K}N$-$\pi\Sigma$ scattering is necessary

Strategy for $\bar{K}N$ interaction

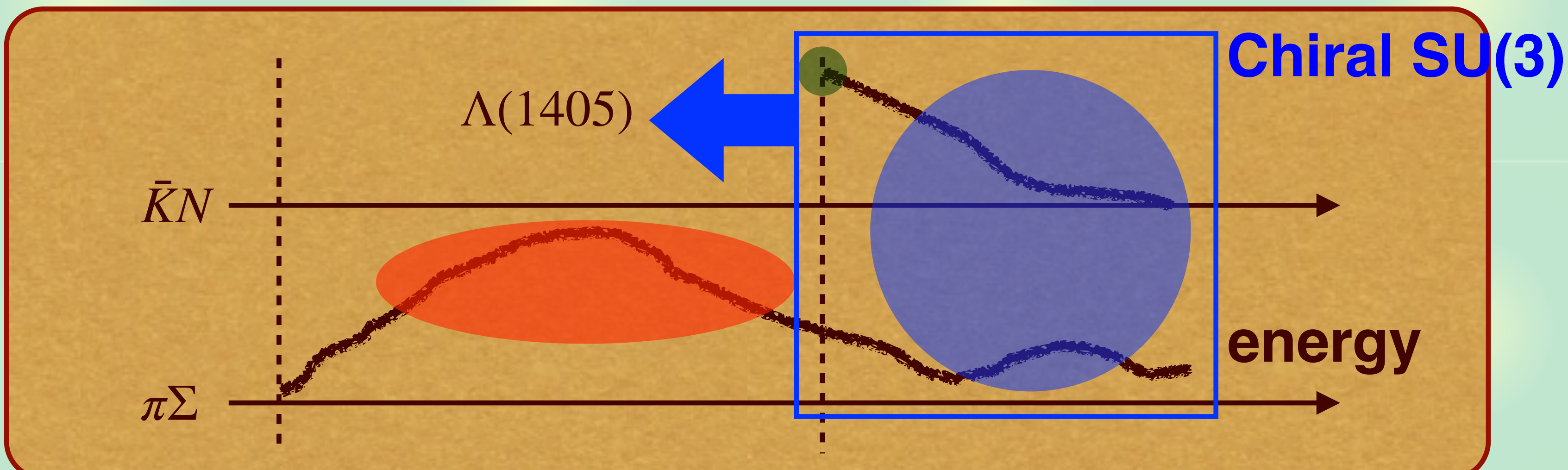
Above the $\bar{K}N$ threshold : direct constraints

- K^-p **total cross sections (old data)**
- $\bar{K}N$ **threshold branching ratios (old data)**
- K^-p **scattering length (new data : SIDDHARTA)**

Y. Ikeda, T. Hyodo, W. Weise, PLB 706, 63 (2011); NPA 881, 98 (2012)

Below the $\bar{K}N$ threshold: indirect (reaction model needed)

- $\pi\Sigma$ **mass spectra (LEPS, CLAS, HADES, J-PARC, …)**



Best-fit results by chiral SU(3) dynamics

K at rest

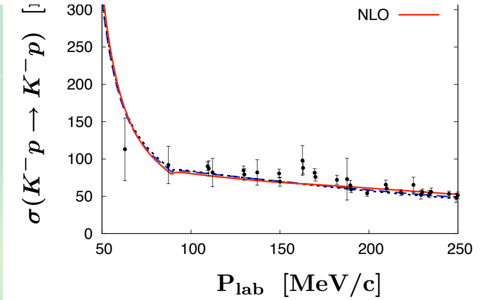
	TW	TWB	NLO	Experiment	
ΔE [eV]	373	377	306	$283 \pm 36 \pm 6$	[10]
Γ [eV]	495	514	591	$541 \pm 89 \pm 22$	[10]
γ	2.36	2.36	2.37	2.36 ± 0.04	[11]
R_n	0.20	0.19	0.19	0.189 ± 0.015	[11]
R_c	0.66	0.66	0.66	0.664 ± 0.011	[11]
χ^2/d.o.f	1.12	1.15	0.96		

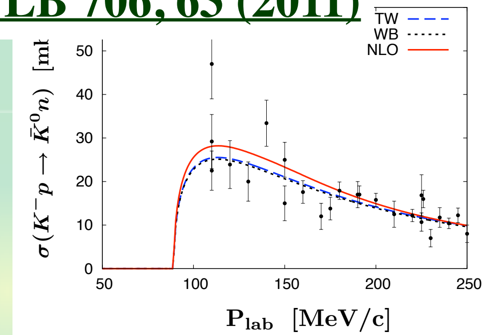
} **SIDDHARTA** (ΔE, Γ)

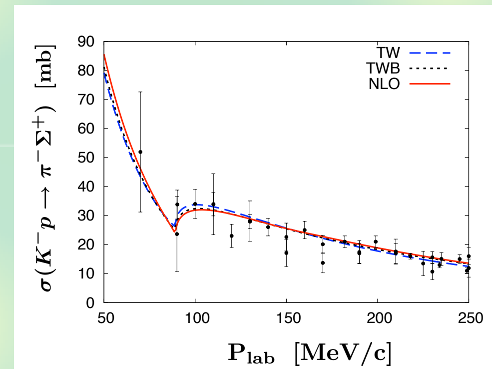
} **Branching ratios** (γ, R_n, R_c)

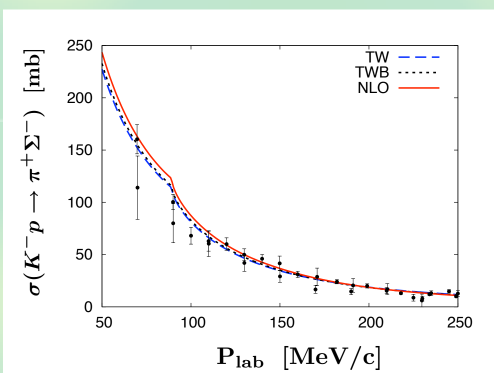
Y. Ikeda, T. Hyodo, W. Weise, PLB 706, 63 (2011)

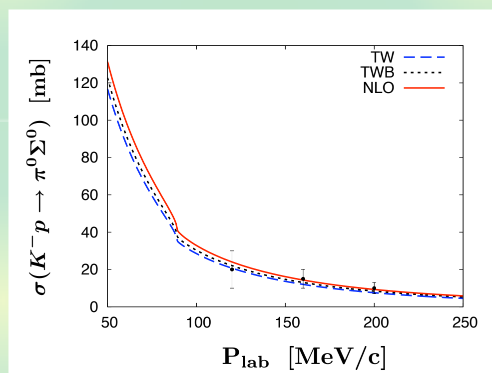
$K^- p$ cross sections

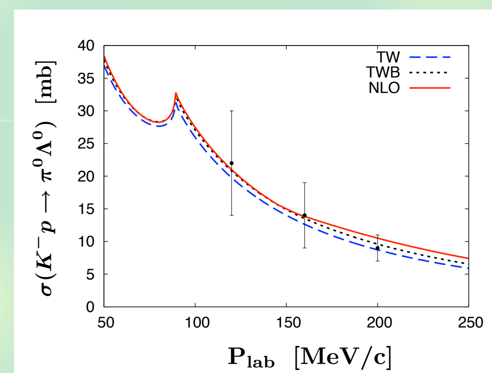












Accurate description of all existing data ($\chi^2/\mathrm{d.o.f} \sim 1$)

PDG has changed

2020 update of PDG

Y. Ikeda, T. Hyodo, W. Weise, PLB 706, 63 (2011); NPA 881, 98 (2012); ▲
Z.H. Guo, J.A. Oller, PRC87, 035202 (2013); ×
M. Mai, U.G. Meißner, EPJA51, 30 (2015) ■ ○

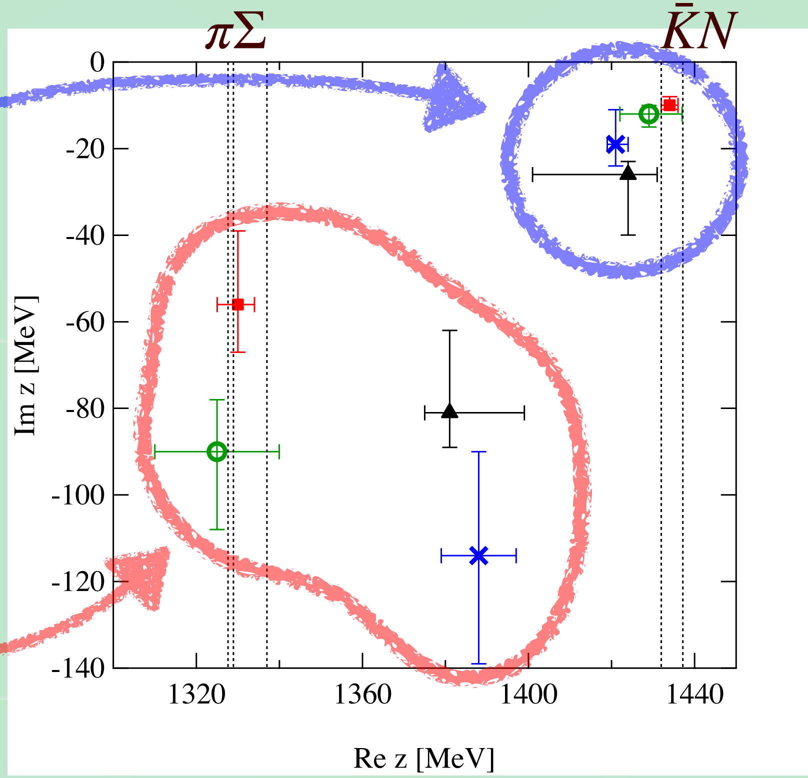
- Particle Listing section:

Citation: P.A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020)

Λ(1405) 1/2⁻ $I(J^P) = 0(\frac{1}{2}^-)$ Status: ∗∗∗∗

Citation: P.A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020)

Λ(1380) 1/2⁻ new! $J^P = \frac{1}{2}^-$ Status: ∗∗



T. Hyodo, M. Niiyama, Prog. Part. Nucl. Phys. 120, 103868 (2021)

- "Λ(1405)" is no longer at 1405 MeV but ~ 1420 MeV.
- Lower pole : two-star resonance Λ(1380)

Construction of $\bar{K}N$ potentials

Local $\bar{K}N$ potential is useful for various applications

meson-baryon amplitude
(chiral SU(3) EFT)

T. Hyodo, W. Weise, PRC 77, 035204 (2008)

Kyoto $\bar{K}N$ potential
(single-channel, complex)

K. Miyahara. T. Hyodo,
PRC 93, 015201 (2016)

Kyoto $\bar{K}N$-$\pi\Sigma$-$\pi\Lambda$ potential
(coupled-channel, real)

K. Miyahara, T. Hyodo, W. Weise,
PRC 98, 025201 (2018)

Kaonic nuclei

Kaonic deuterium

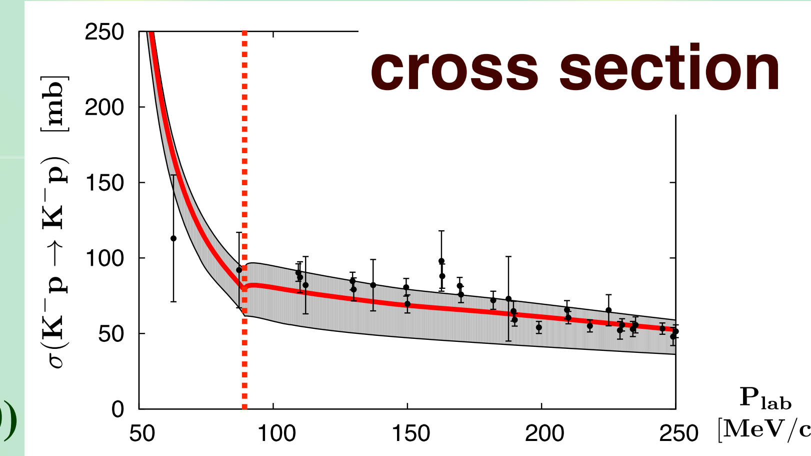
$K^{-}p$ correlation function

K^-p correlation function

K^-p total cross sections

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

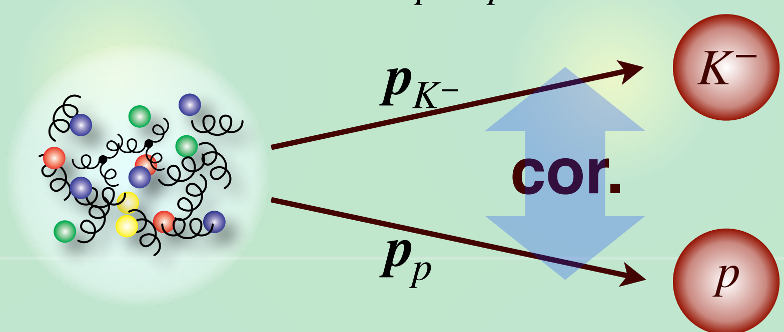
- Old bubble chamber data

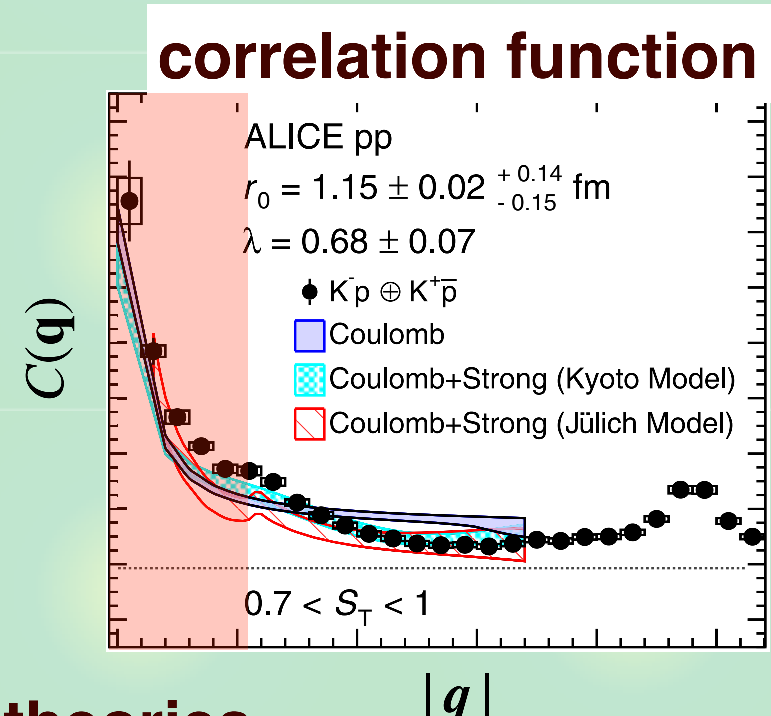


K^-p correlation function

S. Acharya *et al.* (ALICE), PRL 124, 092301 (2020)

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





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

—> Important constraint on $\Lambda(1405)$ theories

Coupled-channel correlation function

Schrödinger equation (s-wave)

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

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)

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

- 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

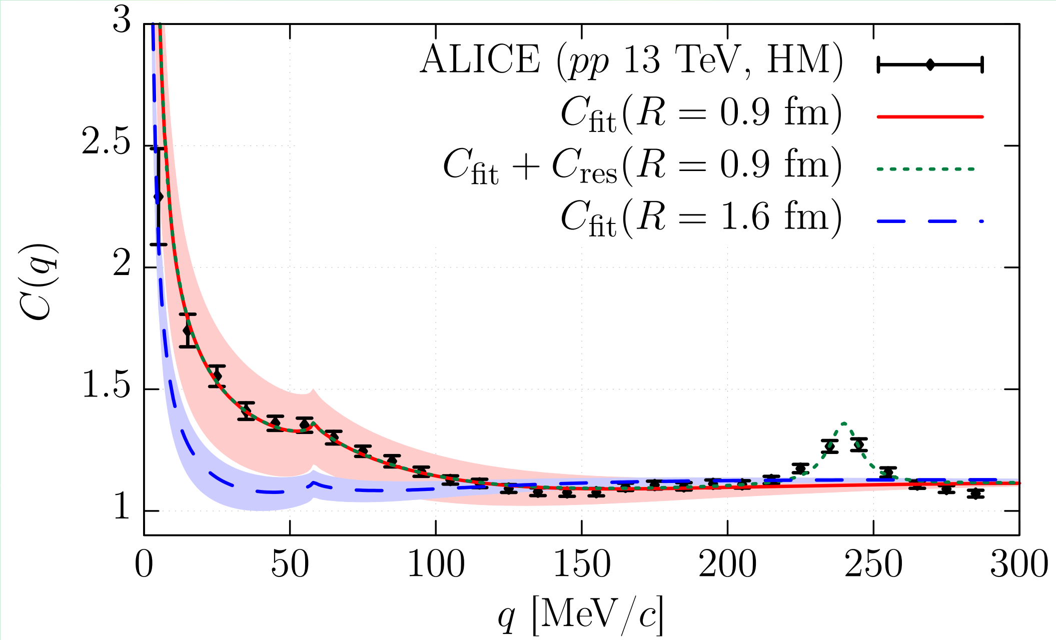
Correlation function in pp (small)

Wave function $\Psi_{\boldsymbol{q}}^{(-)}(\boldsymbol{r})$: Kyoto $\bar{K}N$-$\pi\Sigma$-$\pi\Lambda$ potential

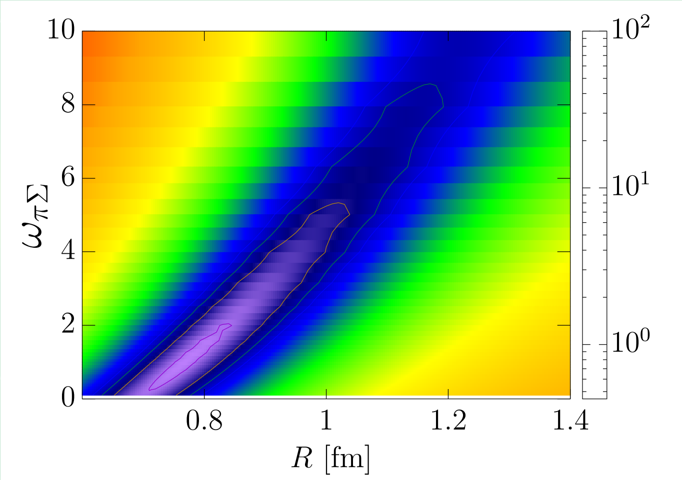
K. Miyahara, T. Hyodo, W. Weise. PRC98, 025201 (2018)

Source function $S(\boldsymbol{r})$: Gaussian, $R \sim 1$ fm in K^+p data

Source weight $\omega_{\pi\Sigma} \sim 2$ by statistical model estimate



reduced χ^2



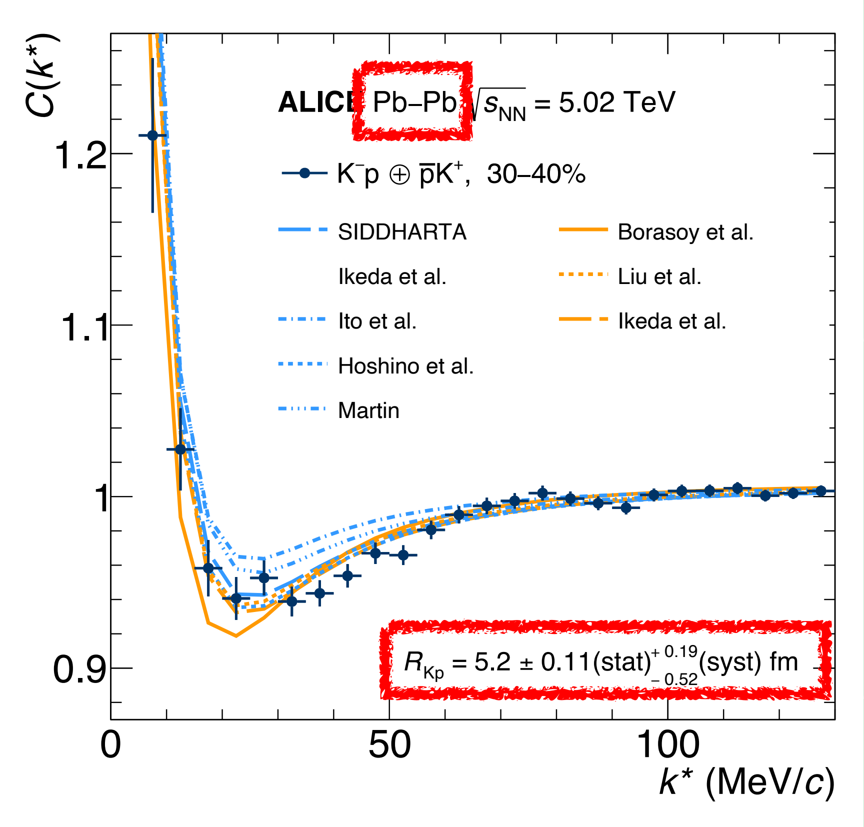
Y. Kamiya, T. Hyodo, K. Morita, A. Ohnishi, W. Weise. PRL124, 132501 (2020)

Correlation function in pp by ALICE is well reproduced

Correlation function in Pb-Pb (large)

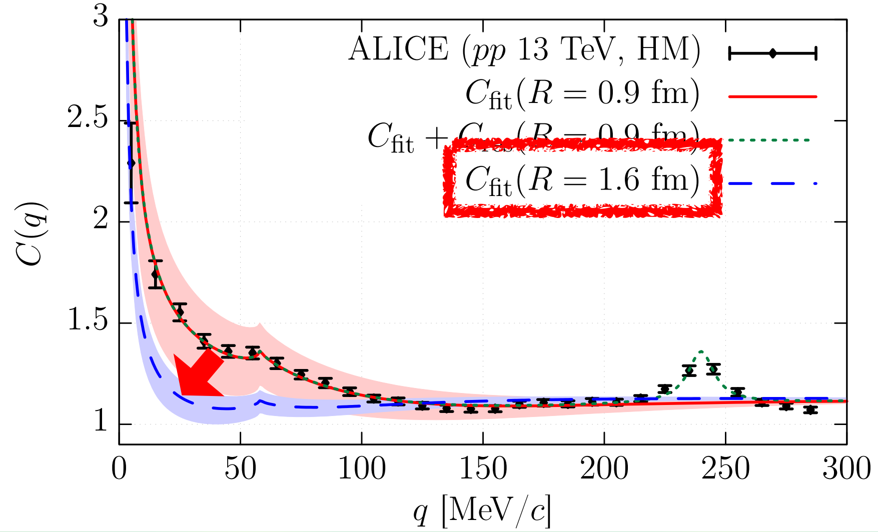
Large source: Pb-Pb collisions at 5.02 TeV

S. Acharya *et al.* (ALICE), PLB 822, 136708 (2021)



—> Scattering length

$a_{K^-p} = -0.91 + 0.92i$ fm



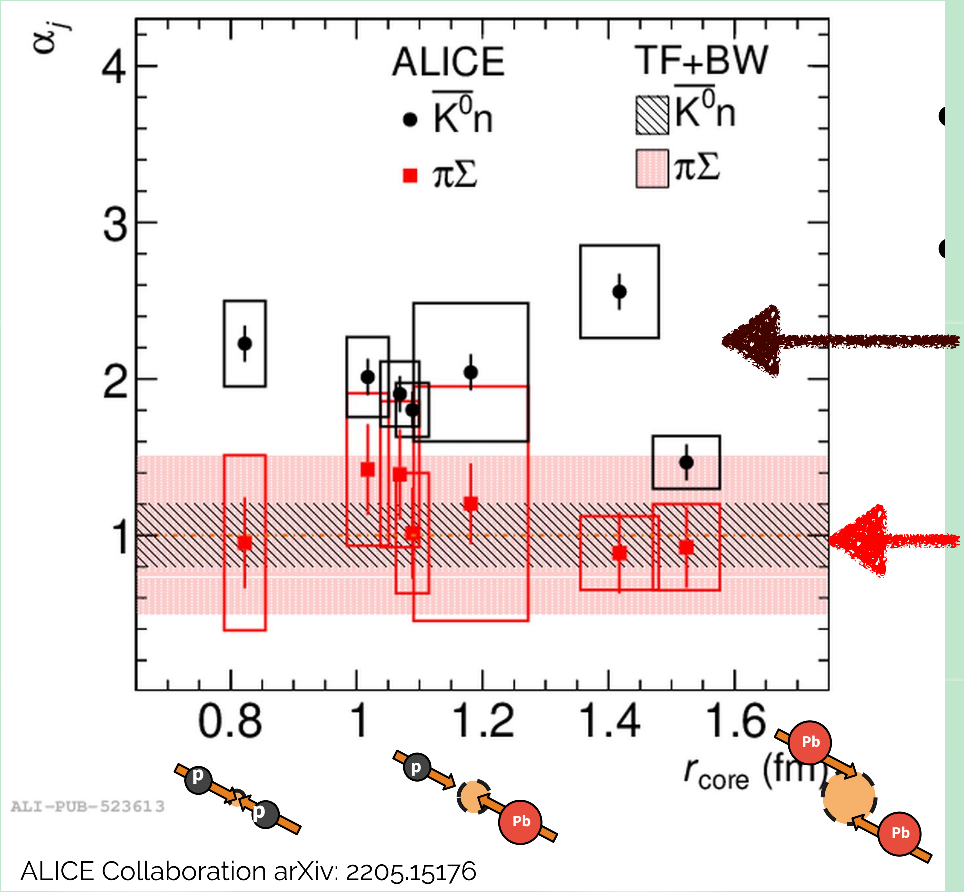
Y. Kamiya, T. Hyodo, K. Morita, A. Ohnishi, W. Weise. PRL124, 132501 (2020)

Correlation is suppressed for larger source, as predicted

Systematic study of source size dependence

Correlations in pp, p-Pb, Pb-Pb by Kyoto $\bar{K}N$-$\pi\Sigma$-$\pi\Lambda$ potential

S. Acharya et al. (ALICE), arXiv:2205.15176 [nucl-ex]



enhancement needed to explain data

Expected weight ω_i by Thermal Fist + Blast Wave

More strength is needed in the $\bar{K}^0 n$ channel

Summary

- K^-p scattering data and kaonic hydrogen data are well described by chiral SU(3) dynamics. Corresponding Kyoto $\bar{K}N$-$\pi\Sigma$-$\pi\Lambda$ potential is constructed.

  Y. Ikeda, T. Hyodo, W. Weise, PLB 706, 63 (2011); NPA 881, 98 (2012);
  K. Miyahara, T. Hyodo, W. Weise, PRC 98, 025201 (2018)

- Global structures of K^-p correlation functions are reproduced by Kyoto $\bar{K}N$-$\pi\Sigma$-$\pi\Lambda$ potential. Detailed study of source size dep. indicates the lack of strength in the $\bar{K}^0n$ channel.

  Y. Kamiya, T. Hyodo, K. Morita, A. Ohnishi, W. Weise. PRL124, 132501 (2020);
  S. Acharya et al. (ALICE), arXiv:2205.15176 [nucl-ex]