Theoretical analysis of the K^-p and meson-baryon correlation functions from high-energy collisions

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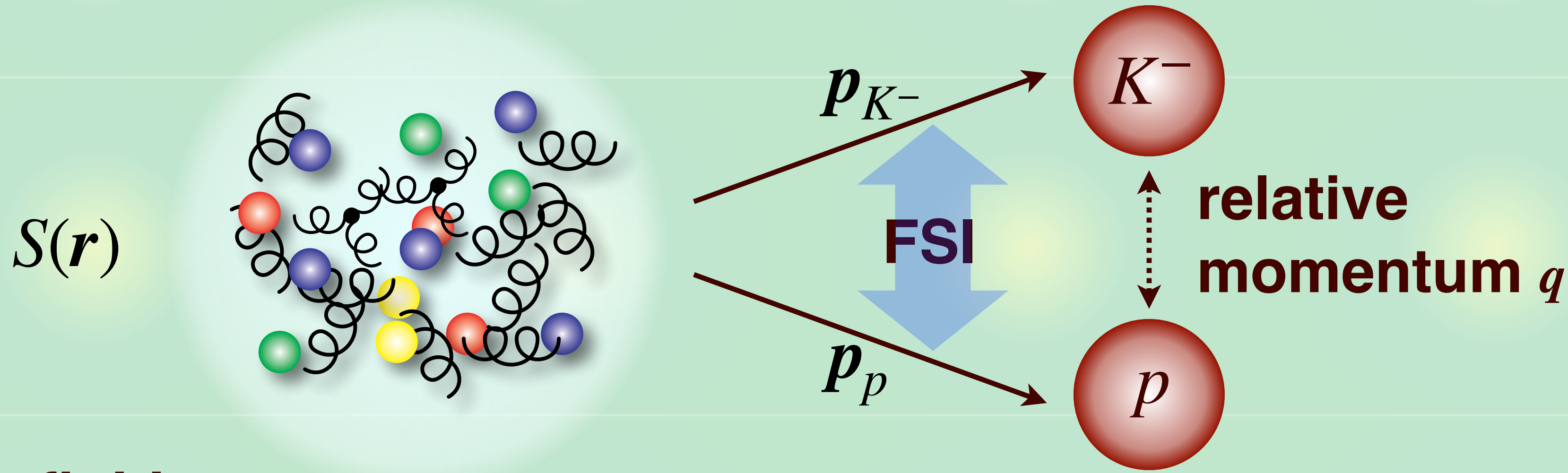
Correlation function and hadron interaction

High-energy collision: chaotic source $S(r)$ of hadron emission



- Definition

$$C(\boldsymbol{q}) = \frac{N_{K^-p}(\boldsymbol{p}_{K^-}, \boldsymbol{p}_p)}{N_{K^-}(\boldsymbol{p}_{K^-})N_p(\boldsymbol{p}_p)}$$ **(= 1 in the absence of FSI)**

- Theory (Koonin-Pratt formula)

$$C(\boldsymbol{q}) \simeq \int d^3\boldsymbol{r}\, S(\boldsymbol{r})\, |\Psi_{\boldsymbol{q}}^{(-)}(\boldsymbol{r})|^2$$

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

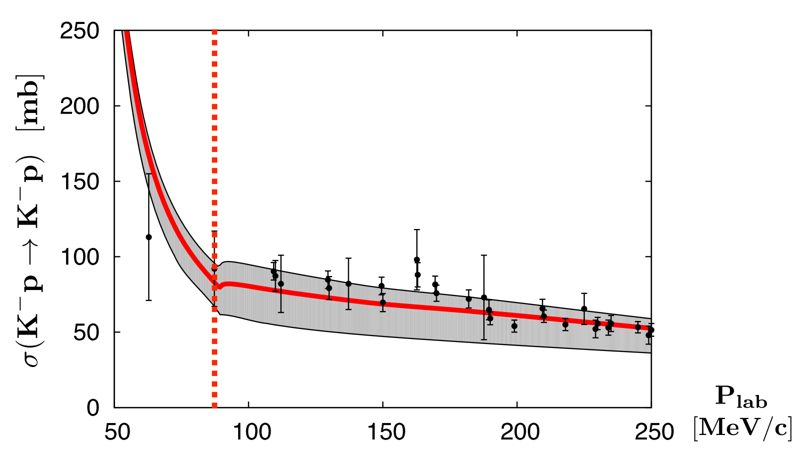
ALICE collaboration, Nature 588, 232 (2020); …

Experimental data of K^-p correlation

K^-p total cross sections

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

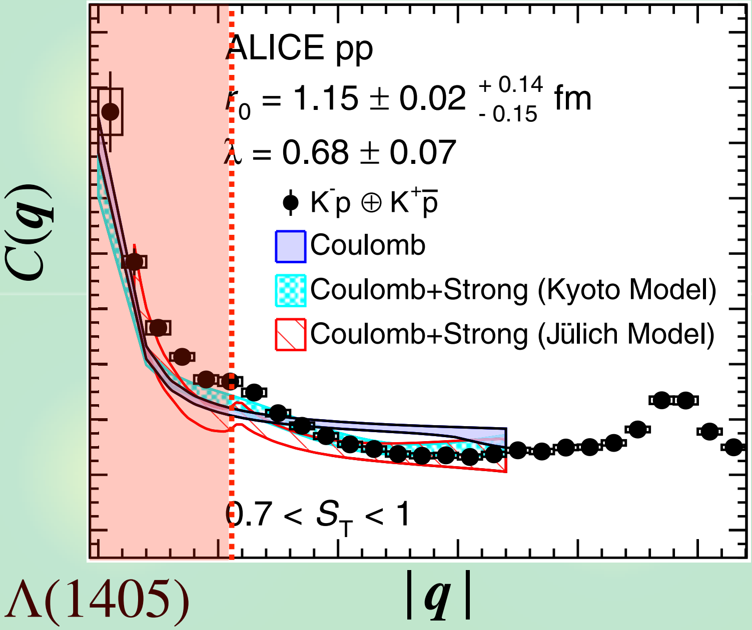
- Old bubble chamber data
- Resolution is not good
- Threshold cusp is not visible



K^-p correlation function

ALICE collaboration, PRL 124, 092301 (2020)

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



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

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)

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

- **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.

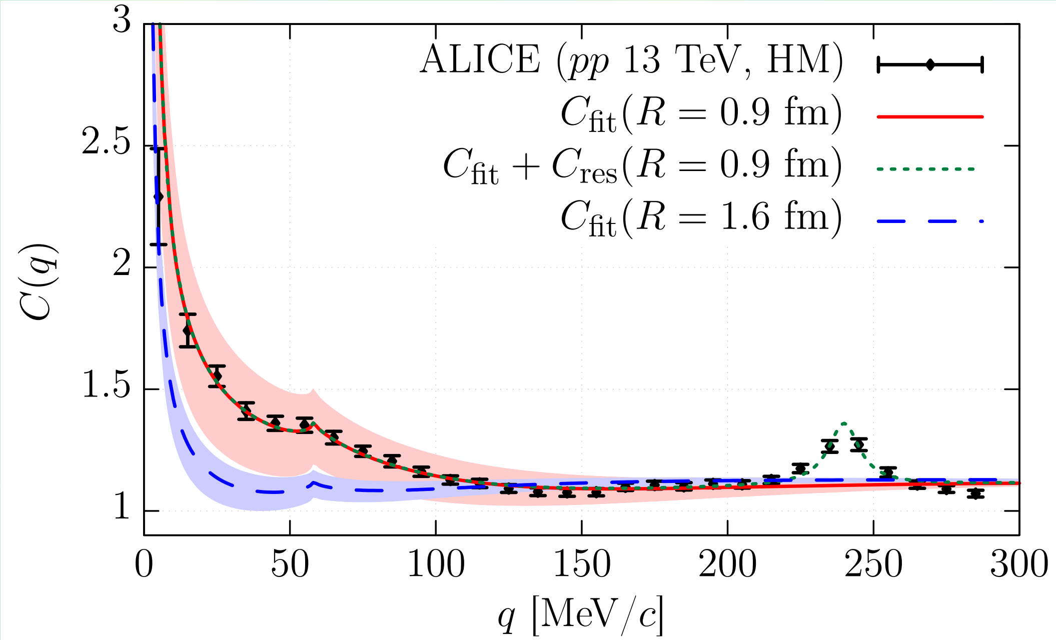
Correlation from chiral SU(3) dynamics

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

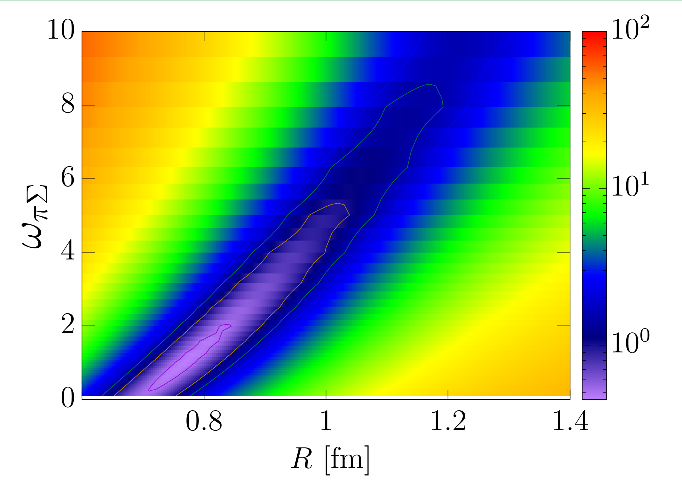
K. Miyahara, T. Hyodo, W. Weise. PRC98, 025201 (2018)

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

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



reduced χ^2



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

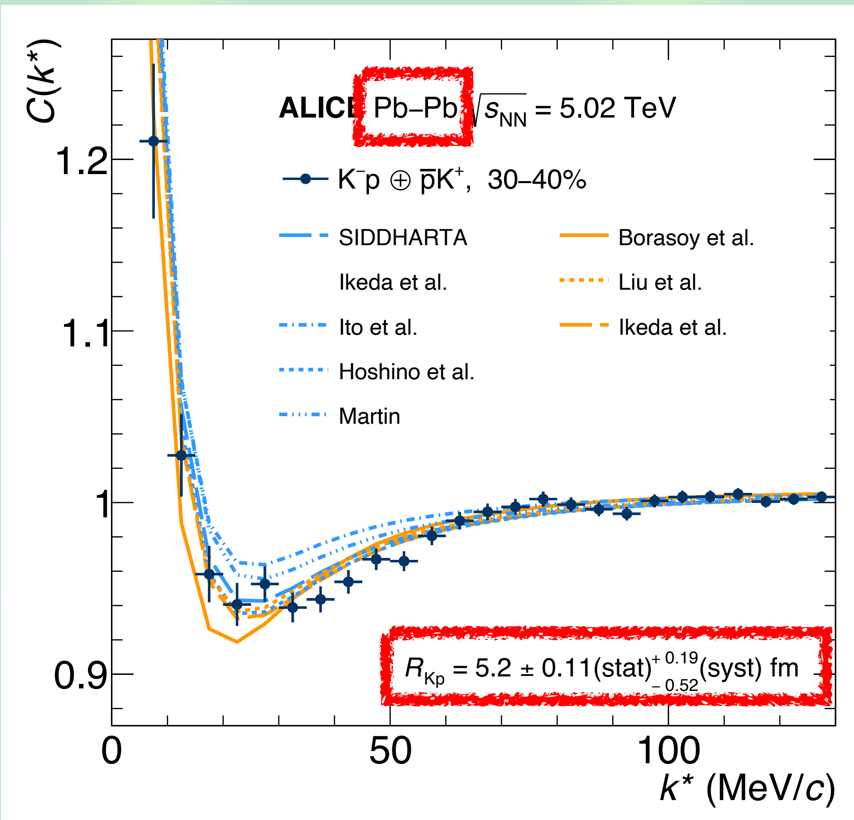
Correlation function by ALICE is well reproduced

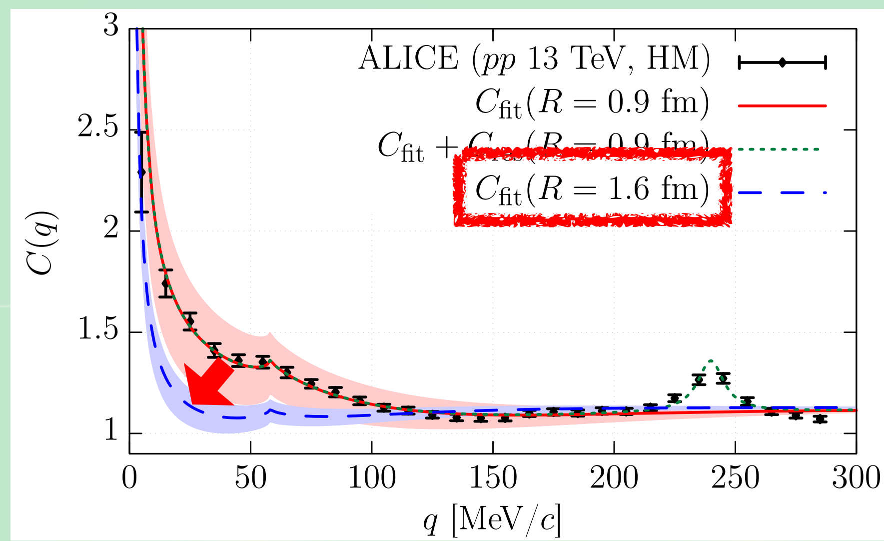
Source size dependence

New data of Pb-Pb collisions at 5.02 TeV

ALICE collaboration, arXiv:2105.05683 [nucl-ex]

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





Correlation is suppressed at larger R, as predicted

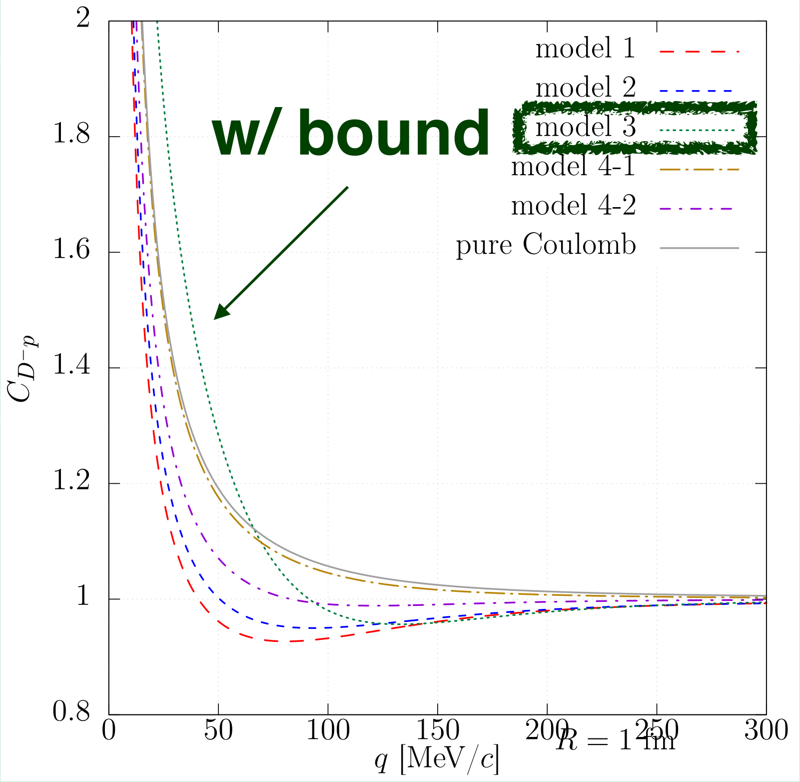
Exotic charm sector

D^-p correlation functions ($\bar{c}duud$, exotic channel)

- Coupled with $\bar{D}^0 n$
- No decay channels below
- Theoretical models

[1] J. Hofmann, M.F.M. Lutz, NPA763, 90 (2005);
[2] J. Haidenbauer *et al.*, EPJA33, 107 (2007);
[3] Y. Yamaguchi *et al.*, PRD84, 014032 (2011);
[4] C. Fontoura *et al.*, PRD87, 025206 (2013)

- Effective potentials <— $a_0(I=0,1)$



- Model 3 with a **bound state** : dip structure
- To be compared with experiments in future

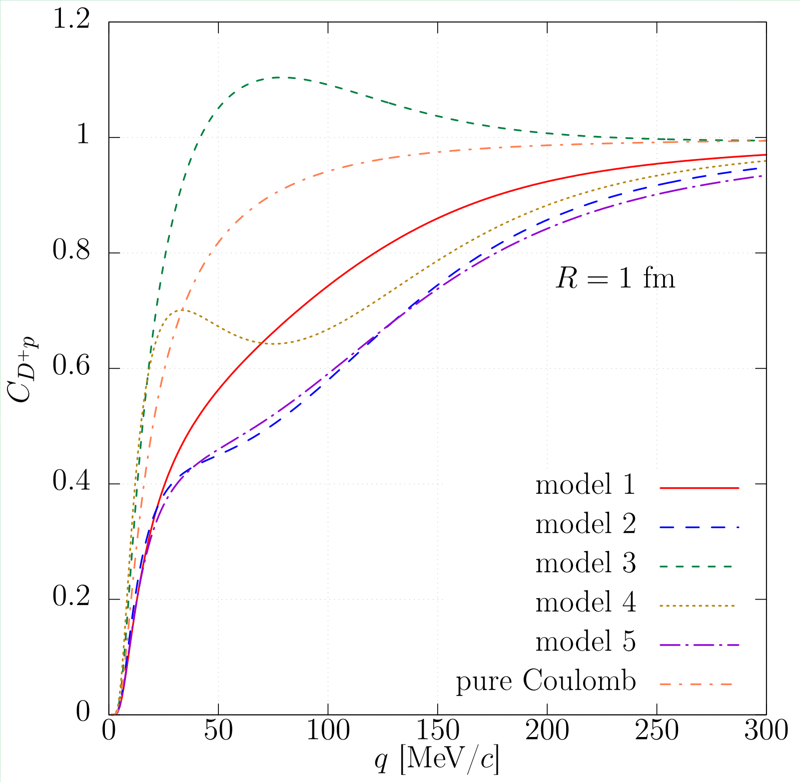
<u>Y. Kamiya, T. Hyodo, A. Ohnishi, in preparation</u>

Non-exotic charm sector

D^+p correlation functions ($c\bar{d}uud$, non-exotic channel)

- No isospin partner in DN
- With decay channels ($\pi\Lambda_c$, $\pi\Sigma_c$)
- Theoretical models

[1] J. Hofmann, M.F.M. Lutz, NPA763, 90 (2005);
[2] T. Mizutani, A. Ramos, PRC74, 065201 (2006);
[3] C. Garcia-Recio *et al.*, PRD79, 054004 (2009);
[4] J. Haidenbauer *et al.*, EPJA47, 18 (2011);
[5] U. Raha *et al.*, PRC98, 034002 (2018)



- Effective single-channel potential

<— $a_0(I=1)$

- Sizable dependence on the scattering length

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Summary

- **Correlation functions are useful to study hadron interactions.**
- K^-p **correlation in** pp **collisions can be well described by chiral SU(3) dynamics. Source size dependence will be further studied.**

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

- D^-p **and** D^+p **correlations are predicted based on scattering lengths in various models. Measurements will give first experimental information in these sectors.**

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