Investigating hadronic molecules via femtoscopic correlation functions with general partial waves

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Cooperators: 吕文韬，谢聚军

Chin. Phys. Lett. 43, 050202 (2026)； arXiv:2604.25630

2026年轻强子专题研讨会

商丘，2026年5月16日

CONTENTS

1. Background & Motivation

- Why do we need higher partial wave

2. Formalism

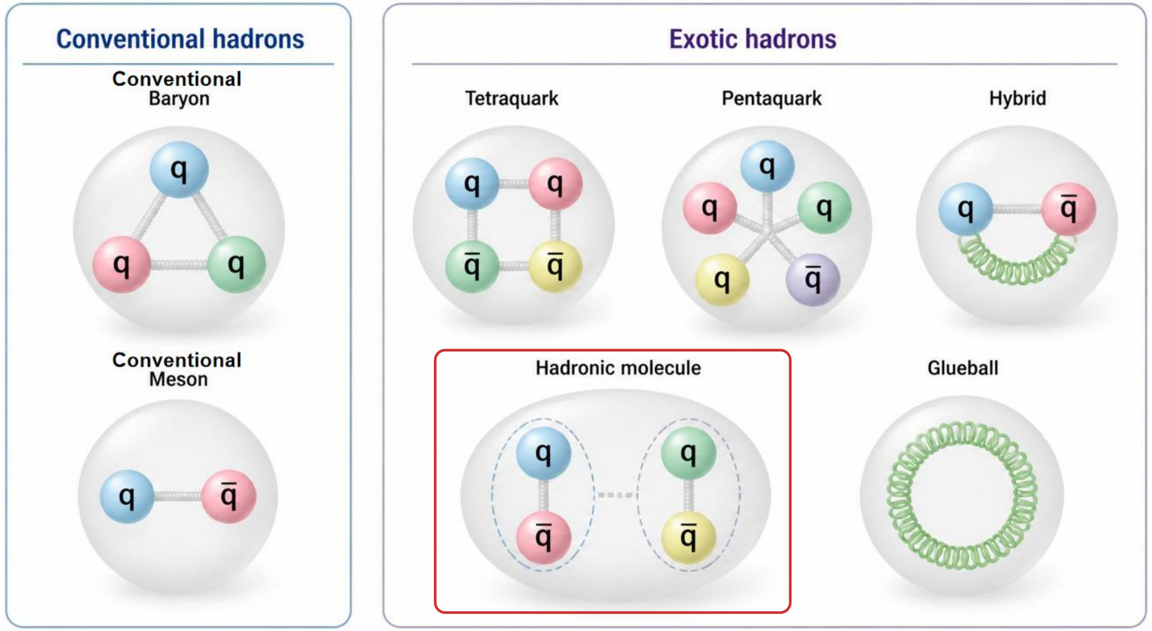
- How to do it

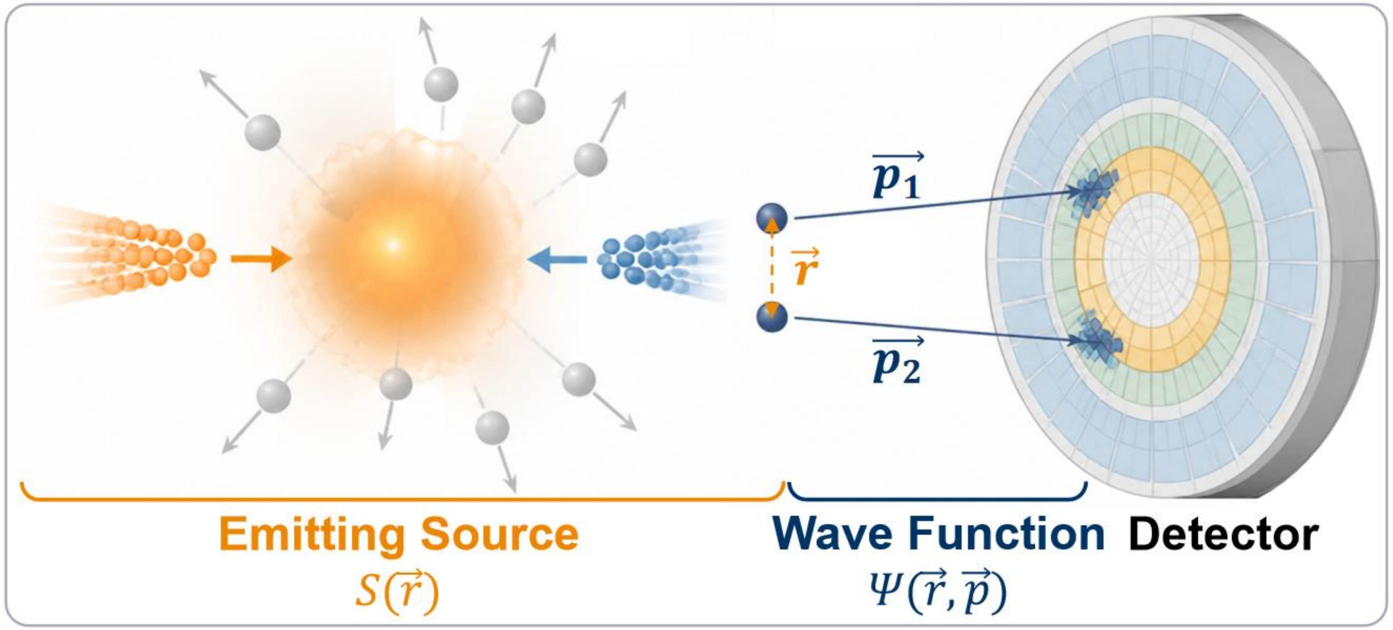
3. Results

- Application to the $\Lambda(1520)$
- Predicting the $\Omega(2012), \Omega(2380), \Omega_c(3120)$

4. Summary

Background & Motivation: Hadronic molecule





What are the true natures of excited hadrons?

$f_0(980), a_0(980)$ $\quad$ $X(3872), X(6900)$

$\Lambda(1405), \Lambda(1520)$ $\quad$ $\pi_1(1400), \pi_1(1600)$

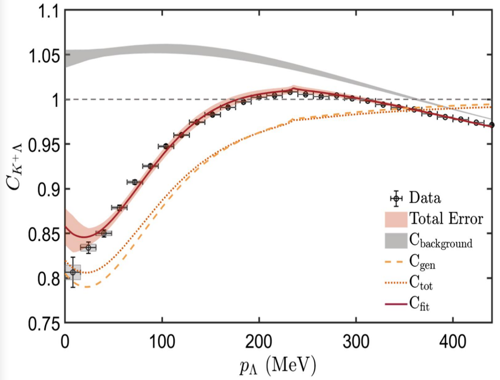
$N(1535), \Omega(2012)$ $\quad$ $f_0(1500), f_0(1710)$

Definition

$$C(\vec{p}) = \frac{P(\vec{p_1}, \vec{p_2})}{P(\vec{p_1})\cdot P(\vec{p_2})} \begin{cases} = 1, & \text{no interaction} \\ > 1, & \text{attractive} \\ < 1, & \text{repulsive} \end{cases}$$

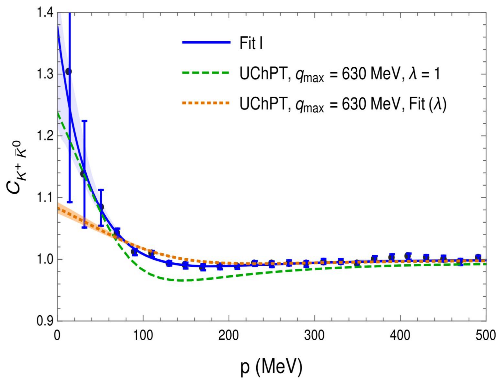
Background & Motivation: Progress and Limitation

$K^+\Lambda$



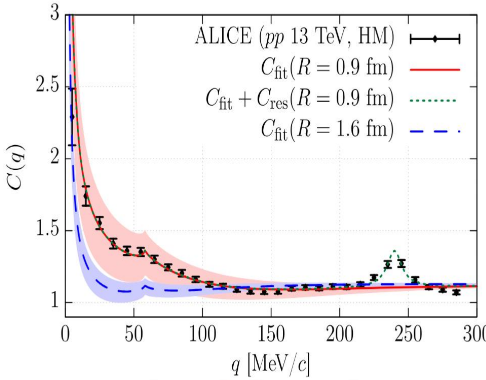
S.-W. Liu, Phys. Rev. D 112, 034027 (2025)

$K^+\bar{K}^0$



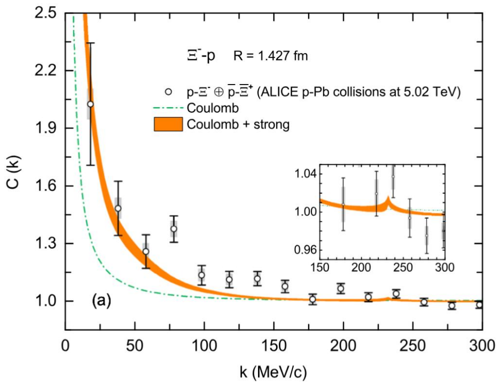
R. Molina, Eur. Phys. J. C 84, 328 (2024)

K^-p



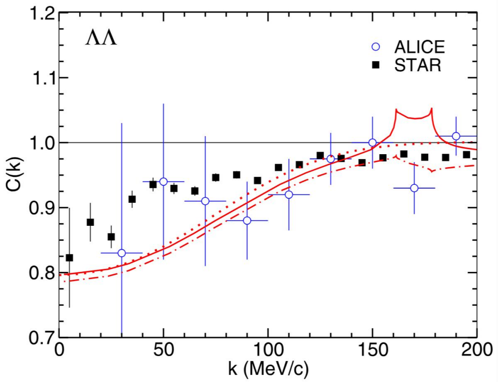
Y. Kamiya, Phys. Rev. Lett. 124, 132501 (2020)

Ξ^-p



Z.-W. Liu, Phys. Rev. D 107, 074019 (2023)

$\Lambda\Lambda$



J. Haidenbauer, Nucl. Phys. A 981, 1-16 (2019)

Only s-wave

$\Lambda(1520), J^P = 3/2^-$

$BR(\Lambda(1520) \to \bar{K}N)$	(45~47)%
$BR(\Lambda(1520) \to \pi\Sigma)$	(42~46)%

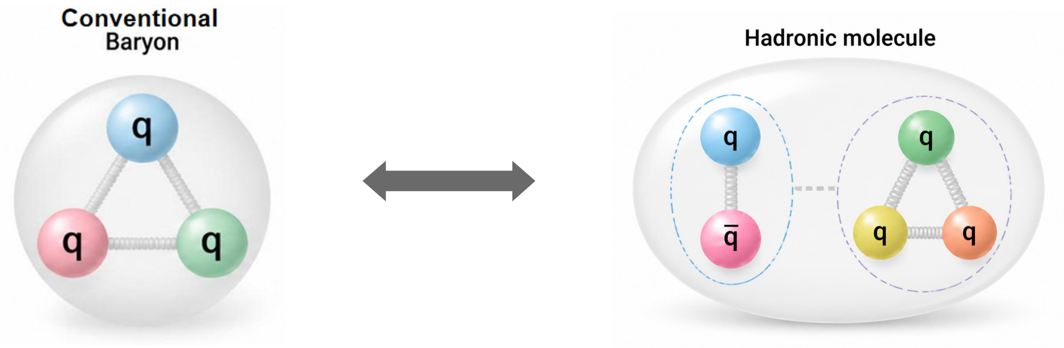
$\Omega(2012), J^P = ?^-$

$BR(\Omega(2012)^- \to K^-\Xi^0)$	34^{+16}_{-12} %
$BR(\Omega(2012)^- \to \bar{K}^0\Xi^-)$	28^{+12}_{-7}%

Higher waves are necessary!

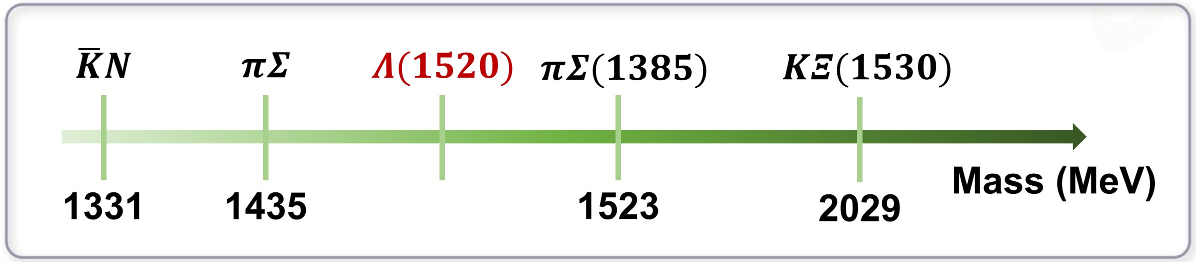
Background & Motivation: $\Lambda(1520)$

Internal structure



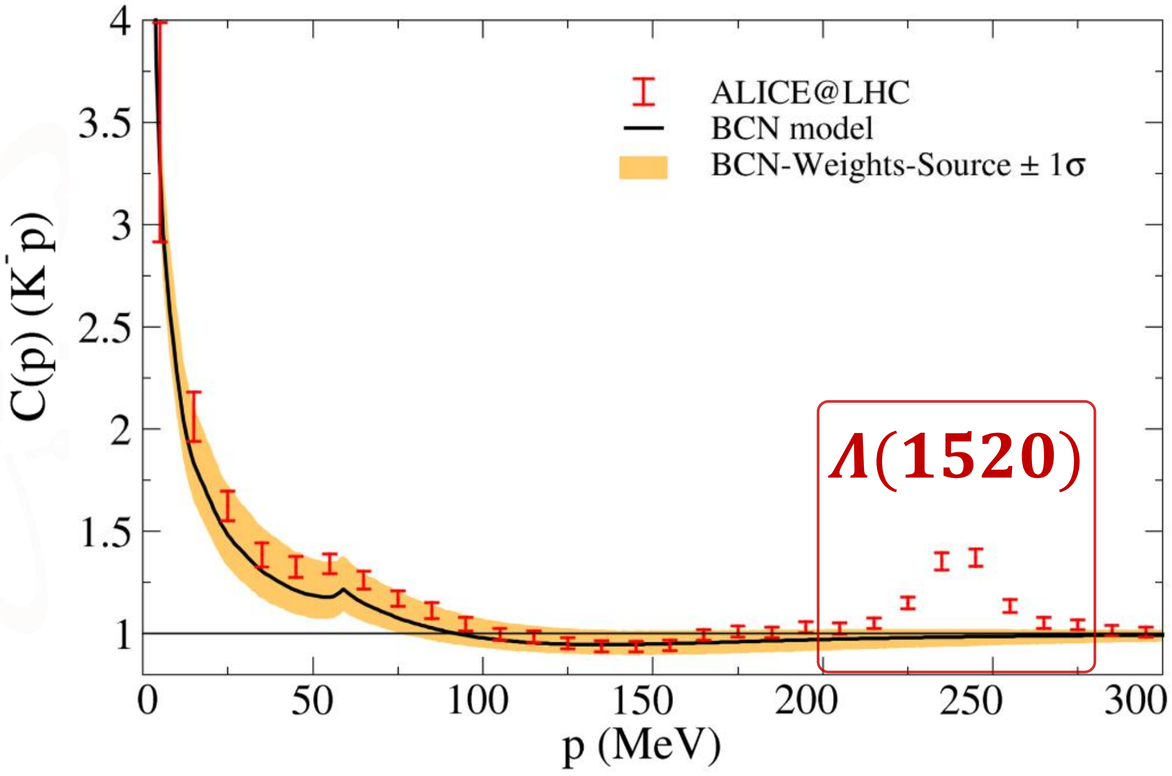
N. Isgur, Phys. Rev. D 18, 4187 (1978)
C. S. Kalman, Phys. Rev. D 26, 2326 (1982)
Anthony J.G. HEY , Phys. Rep. 96, 71-204 (1983)

S. Sarkar, Phys. Rev. C 72, 015206 (2005)
L. Roca, Phys. Rev. C 73, 045208 (2006)
F. Aceti, Phys. Rev. C 90, 025208 (2014)



Threshold

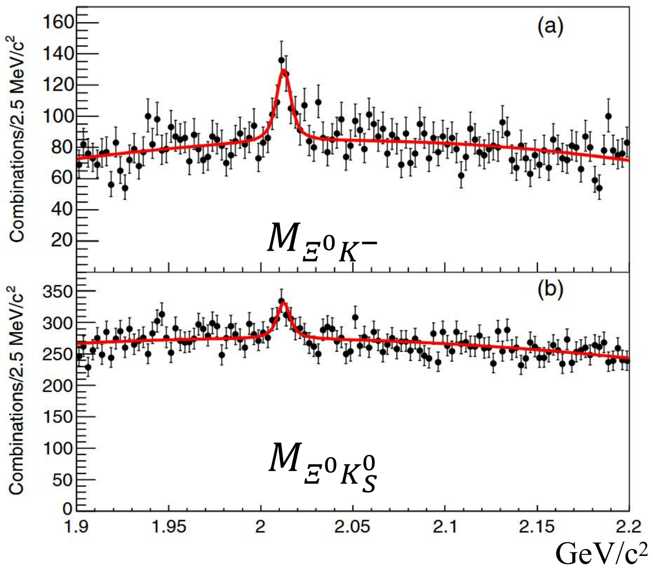
Correlation function



P. Encarnación, Phys. Rev. D 111, 114013 (2025)

Background & Motivation: $\Omega(2012)$, $\Omega(2380)$ and $\Omega_c(3120)$

$\Omega(2012)$



$M = 2012.5 \pm 0.6$ MeV

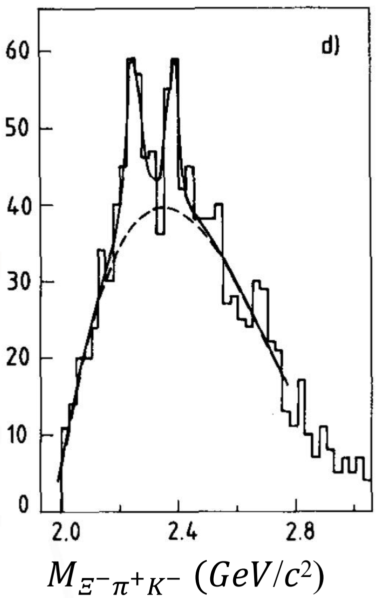
$\Gamma = 6.4^{+3.0}_{-2.6}$ MeV

$R^{\Xi\pi\bar{K}}_{\Xi\bar{K}} = 0.99 \pm 0.26 \pm 0.06$

Belle Collaboration, Phys. Rev. Lett. 121, 052003 (2018)

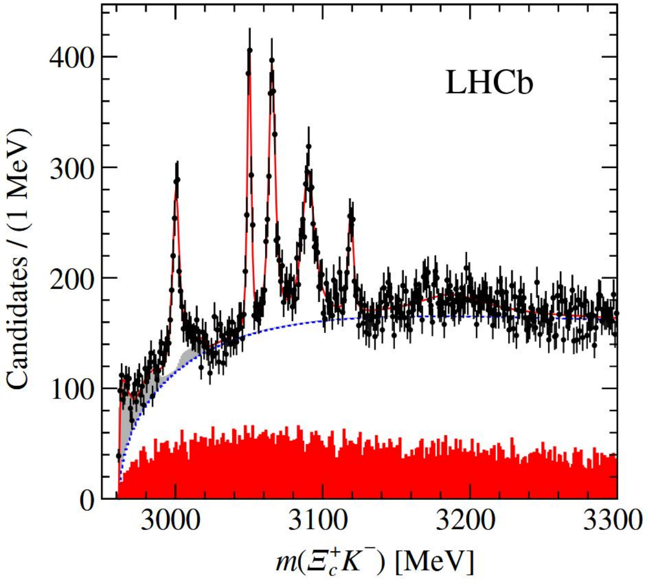
Belle Collaboration, Phys. Lett. B 860, 139224 (2025)

$\Omega(2380)$



S. F. Biagi, Z. Phys. C 31, 33-38 (1986)

$\Omega_c(3120)$



LHCb Collaboration, Phys. Rev. Lett. 118, 182001 (2017)

$\Xi^0 K^-$ 1809 | $\Xi^- \bar{K}^0$ 1819 | $\Omega(2012)$ | $\Xi^{*0} K^-$ 2026 | $\Xi^{*-} \bar{K}^0$ 2033 | $\Omega\eta$ 2220

$\Omega(2380)$ | $\Xi^{*0} K^{*-}$ 2423 | $\Xi^{*-} \bar{K}^{*0}$ 2431 | $\Omega\omega$ 2455 | $\Omega\phi$ 2692

$\Xi_c^+ K^-$ 2961 | $\Xi_c^0 \bar{K}^0$ 2968 | $\Omega_c(3120)$ | $\Xi_c^{*+} K^-$ 3134 | $\Xi_c^{*0} \bar{K}^0$ 3143 | $\Omega_c^{*0}\eta$ 3314

Mass (MeV)

Threshold

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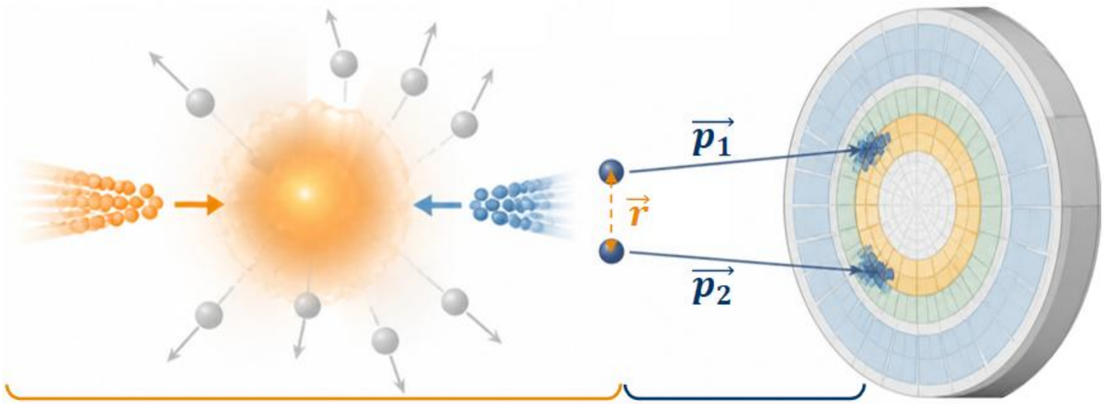
Formalism: Correlation function



$$C(\vec{p}) = \frac{P(\vec{p_1},\vec{p_2})}{P(\vec{p_1})\cdot P(\vec{p_2})}$$

⬇

$$C(\vec{p}) = \int d^3\vec{r}\, S(\vec{r})\, |\Psi(\vec{r})|^2$$

Emitting Source

$$S(\vec{r}) = \frac{1}{(4\pi R^2)^{3/2}} e^{-\frac{|\vec{r}|^2}{4R^2}}$$

Correlation Analysis Tool using the Schödinger equation (CATS) Formalism

$$\left[-\frac{\hbar^2}{2\mu}\nabla^2 + V(\vec{r})\right]\psi(\vec{r}) = E\psi(\vec{r})$$

D. L. Mihaylov, Eur. Phys. J. C 78, 394 (2018)

Lednický–Lyuboshits (LL) Formalism

$$\Psi(\vec{r}) = e^{-ikr\cos\theta} + f(k)\frac{e^{-ikr}}{r}, \quad f(k) = \frac{1}{a_0^{-1} + 0.5r_0k^2 - ik}$$

R. Lednický, Sov.J.Nucl.Phys. 35, 770 (1982)

Koonin-Pratt (KP) Formalism

$$T = V + VGT, \qquad \Psi = \phi + GT\phi$$

S. Pratt, Phys. Rev. D 53, 1219 (1984)

Formalism: Correlation function with general partial waves

Interaction potential $\langle \vec{p}' \vert V \vert \vec{p} \rangle$	**s wave[1-4]**	constant or $f(s)$
	general wave[5-7]	$v(2l+1)P_l(\cos\theta_{\hat{p}'\hat{p}})\vert\vec{p}'\vert^l\vert\vec{p}\vert^l$
Scattering wave function $\Psi(r)$	**s wave**	$j_0(pr)+R(p), \quad R(p)=\int_0^\Lambda d^3q\, j_0(qr)G(q)T(q,p)$
	general wave	$(2l+1)P_l(\cos\theta_{\hat{r}\hat{p}})[j_l(pr)+R(p)],\ R(p)=\int_0^\Lambda d^3q\, j_l(qr)G(q)T(q,p)$
Correlation function $C(\vec{p})$	**s wave**	$1+\int d^3r\, S(r)\left[\vert R(p)\vert^2+2Re[j_0(pr)R(p)]\right]$
	general wave	$1+(2l+1)\int d^3r\, S(r)\left[\vert R(p)\vert^2+2Re[j_l(pr)R(p)]\right]$

[1] *I. Vidaña, Phys. Lett. B 846, 138201 (2023)*
[2] *R. Molina, Eur. Phys. J. C 84, 328 (2024)*
[3] *Y.-B. Shen, Phys. Rev. D 113, 074034 (2026)*
[4] *D.-L. Ge, arXiv:2603.24980*
[5] *J. Yamagata-Sekihara, Phys. Rev. D 83, 014003 (2011)*
[6] *F. Aceti, Phys. Rev. D 86, 014012 (2012)*
[7] *F. Aceti, Eur. Phys. J. A 50, 57(2014)*

Results: Properties of the resonance

Analytic continuation of the propagator

$$\widetilde{G}_i^{II} = \begin{cases} \widetilde{G}_i, & Re[\sqrt{s}] < m_i + M_i \\ \widetilde{G}_i^{(II)}, & Re[\sqrt{s}] \geq m_i + M_i \end{cases}$$

$$\widetilde{G}_i^{(II)} = \widetilde{G}_i + i\frac{2M_i}{4\pi\sqrt{s}} p_i^{2l+1}$$

Pole of t

$$t = \left(1 - v\widetilde{G}^{II}\right)^{-1} v$$

$$\mathrm{Det}\left[1 - v\widetilde{G}^{II}\right]\Big|_{s=s_{\mathrm{pole}}} = 0$$

$$\sqrt{s}_{\mathrm{pole}} = M_R - i\frac{\Gamma_R}{2}$$

s_{pole}

Coupling

$$T_{ij} = \frac{g_i g_j}{\sqrt{s} - \sqrt{s_{\mathrm{pole}}}}$$

Decay width

$$\Gamma_i = \frac{|g_i|^2}{8\pi} \frac{p_i\,(E_i + M_i)}{M_{\mathrm{R}}}$$

J.-X. Lu, Eur. Phys. J. C 80, 361 (2020)

Compositeness

$$X_i = -\frac{g_i^2}{p_i^{2l}} \frac{d\widetilde{G}_i^{II}}{d\sqrt{s}}\Bigg|_{s=s_{\mathrm{pole}}}$$

T. Hyodo, Int. J. Mod. Phys. A 28, 1330045 (2013)

T. Sekihara, Prog. Theor. Exp. Phys. 6, 063D04 (2013)

CONTENTS

Results: Formalism for studing the $\Lambda(1520)$

Chiral lagrangian $\mathcal{L} = - i\bar{T}^{\mu} \not{D} T_{\mu}$

Potential

	$\pi\Sigma(1385)$	$K\Xi(1530)$	$\bar{K}N$	$\pi\Sigma$
$\pi\Sigma(1385)$	$4F$	$\sqrt{6}F$	γ_{13}	γ_{14}
$K\Xi(1530)$		$3F$	0	0
$\bar{K}N$			γ_{33}	γ_{34}
$\pi\Sigma$				γ_{44}

F. Aceti, Phys. Rev. C 90, 025208 (2014)

Lippmann-Schwinger equation

$$t = v + v\widetilde{G}t, \qquad \Psi = \phi + \widetilde{G}t\phi$$

cutoff method

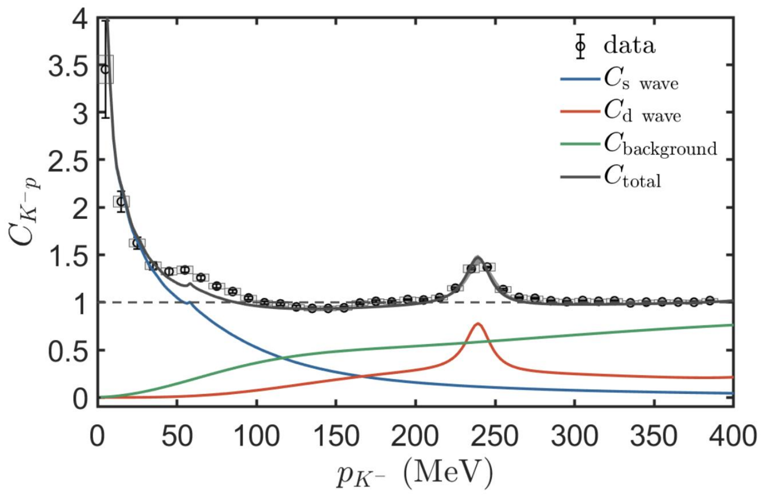
$$\widetilde{G} = \int_0^{\Lambda} \frac{d^3q}{(2\pi)^3} \frac{2M(\omega_M + \omega_m)q^{2l}}{2\omega_M\omega_m(s - (\omega_M + \omega_m)^2 + i\epsilon)}$$

Correlation function with general partial waves in coupled channels

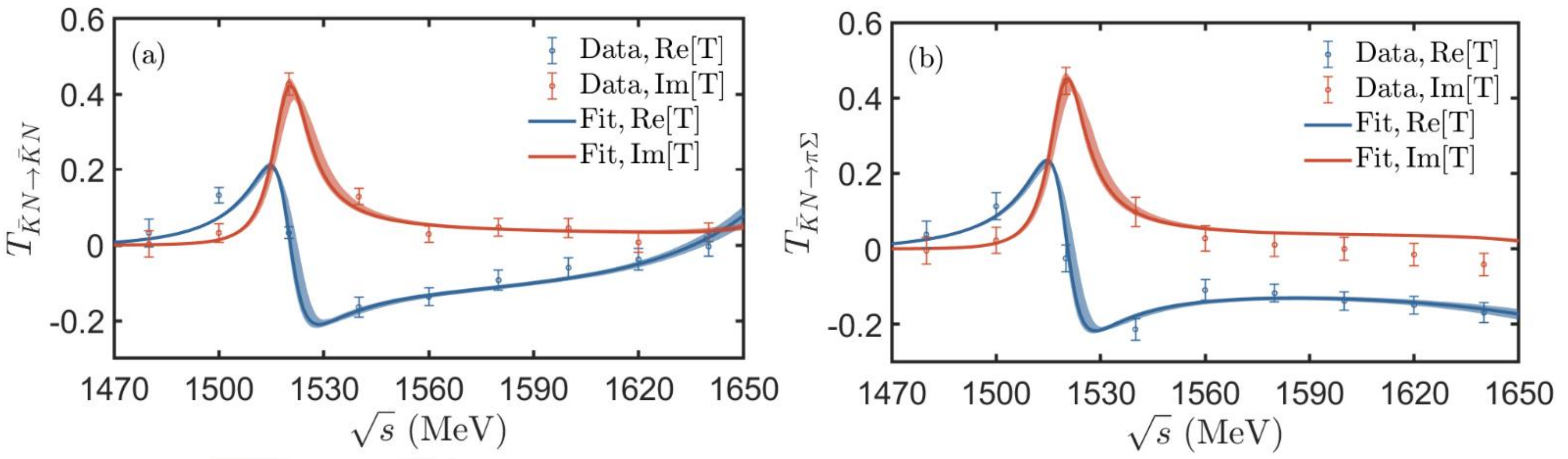
$$C_i(\vec{p}) = 1 + \sum_j (2l_{ij} + 1) \int d^3r\, S(r) \left[\left|R_{ij}(p_i)\right|^2 + \delta_{ij}\, 2Re\left[j_{l_{ij}}(p_j r) R_{ij}(p_i) \right] \right]$$

Results: Application to the $\Lambda(1520)$

1. Correlation function of K^-p



2. Scattering amplitude



3. Properties of $\Lambda(1520)$

	Mass (MeV)	Width (MeV)	Br[$\Lambda(1520)\to\bar{K}N$]	Br[$\Lambda(1520)\to\pi\Sigma$]	$X_{\bar{K}N}$	$X_{\pi\Sigma}$
This work	1519.75	13.14	40 %	47 %	0.43	0.24
PDG	1519.4±0.2	15.7±0.3	(45~47) %	(42~46) %		

CONTENTS

Results: Predictions of $\Omega(2012)$, $\Omega(2380)$ and $\Omega_c(3120)$

$\Omega(2012)$

	$\Xi^{*0}K^-$	$\Xi^{*-}\bar{K}^0$	$\Omega\eta$	Ξ^0K^-	$\Xi^-\bar{K}^0$
$\Xi^{*0}K^-$	$-F$	F	$-\frac{3}{\sqrt{2}}F$	$\frac{1}{2}\alpha_1$	$-\frac{1}{2}\alpha_1$
$\Xi^{*-}\bar{K}^0$		$-F$	$-\frac{3}{\sqrt{2}}F$	$\frac{1}{2}\alpha_1$	$-\frac{1}{2}\alpha_1$
$\Omega\eta$			0	$-\frac{1}{\sqrt{2}}\beta_1$	$\frac{1}{\sqrt{2}}\beta_1$
Ξ^0K^-				0	0
$\Xi^-\bar{K}^0$					0

J.-X. Lin, arXiv: 2603.18610

$\Omega(2380)$

	$\Xi^{*0}K^{*-}$	$\Xi^{*-}\bar{K}^{*0}$	$\Omega\omega$	$\Omega\phi$
$\Xi^{*0}K^{*-}$	$-F$	F	$-\sqrt{\frac{3}{2}}F$	$\sqrt{3}F$
$\Xi^{*-}\bar{K}^{*0}$		$-F$	$-\sqrt{\frac{3}{2}}F$	$\sqrt{3}F$
$\Omega\omega$			0	0
$\Omega\phi$				0

S. Sarkar, Eur. Phys. J. A 44, 431-443 (2010)

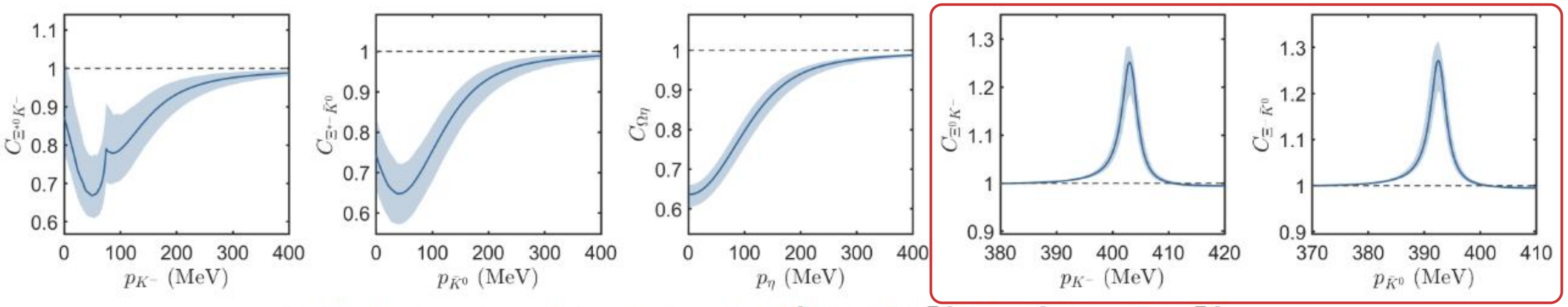
$\Omega_c(3120)$

	$\Xi_c^{*+}K^-$	$\Xi_c^{*0}\bar{K}^0$	$\Omega_c^{*0}\eta$	$\Xi_c^+K^-$	$\Xi_c^0\bar{K}^0$
$\Xi_c^{*+}K^-$	0	F	$-\frac{2\sqrt{6}}{3}F$	$\frac{1}{2}\alpha_2$	$\frac{1}{2}\alpha_2$
$\Xi_c^{*0}\bar{K}^0$		0	$-\frac{2\sqrt{6}}{3}F$	$\frac{1}{2}\alpha_2$	$\frac{1}{2}\alpha_2$
$\Omega_c^{*0}\eta$			0	$-\frac{1}{\sqrt{2}}\beta_2$	$-\frac{1}{\sqrt{2}}\beta_2$
$\Xi_c^+K^-$				0	0
$\Xi_c^0\bar{K}^0$					0

V. R. Debastiani, Phys. Rev. D 97, 094035 (2018)

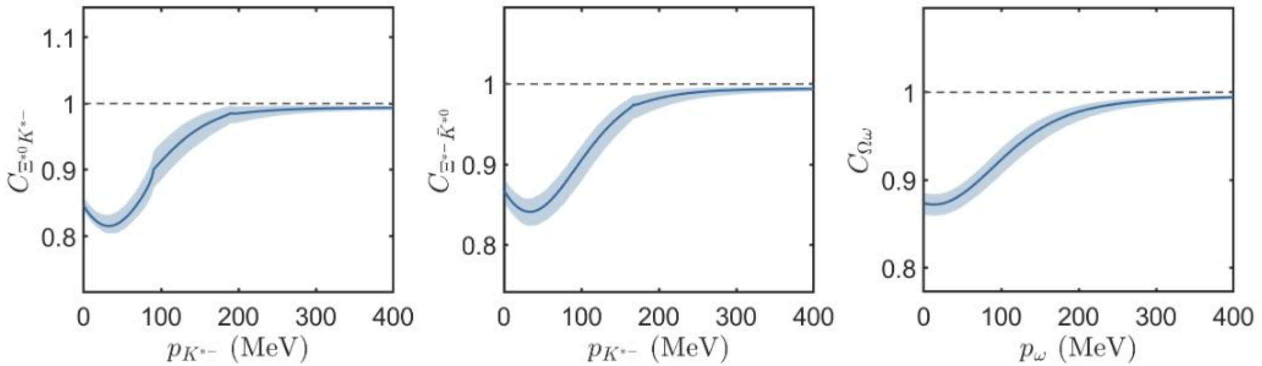
Results: Predictions of $\Omega(2012)$, $\Omega(2380)$ and $\Omega_c(3120)$

$\Omega(2012)$:



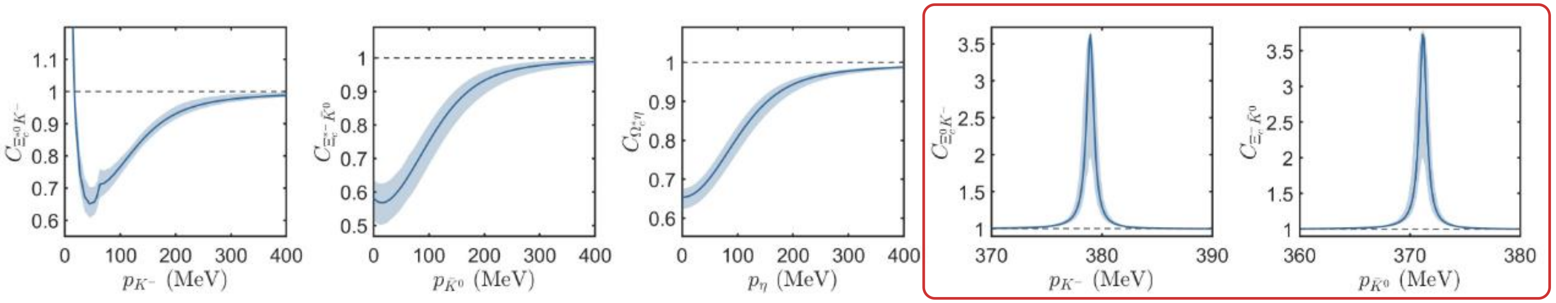
(a) The femtoscopic correlation functions for $\Xi^{*0}K^-$, $\Xi^{*-}\bar{K}^0$, $\Omega\eta$, Ξ^0K^- and $\Xi^-\bar{K}^0$ channels

$\Omega(2380)$:



(b) The femtoscopic correlation functions for $\Xi^{*0}K^{*-}$, $\Xi^{*-}\bar{K}^{*0}$ and $\Omega\omega$ channels

$\Omega_c(3120)$:



(c) The femtoscopic correlation functions for $\Xi_c^{*+}K^-$, $\Xi_c^{*0}\bar{K}^0$, $\Omega_c^{*0}\eta$, $\Xi_c^+K^-$ and $\Xi_c^0\bar{K}^0$ channels

$\Omega(2012)$

Experiment

$M = 2012.5 \pm 0.6$ MeV

$\Gamma = 6.4^{+3.0}_{-2.6}$ MeV

$R^{\Xi\pi\bar{K}}_{\Xi\bar{K}} = 0.99 \pm 0.26 \pm 0.06$

Theory

$M = 2012.68$ MeV

$\Gamma = 3.24$ MeV

$R^{\Xi\pi\bar{K}}_{\Xi\bar{K}} = 0.75$

CONTENTS

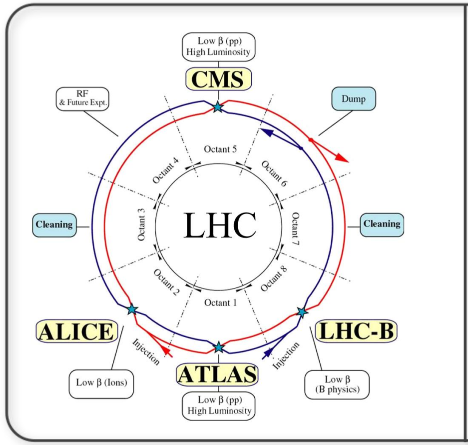
Summary

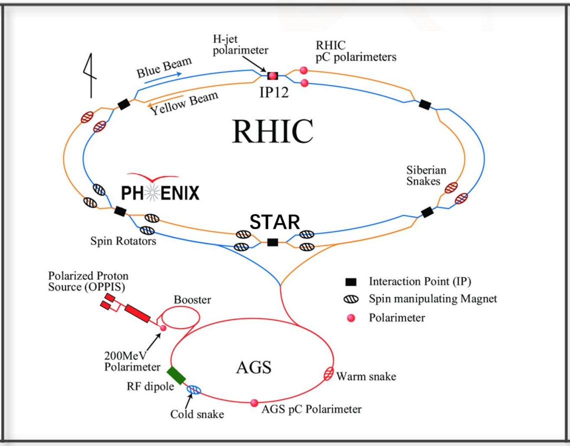
- A formalism incorporating the femtoscopy correlation function with general partial waves is established.

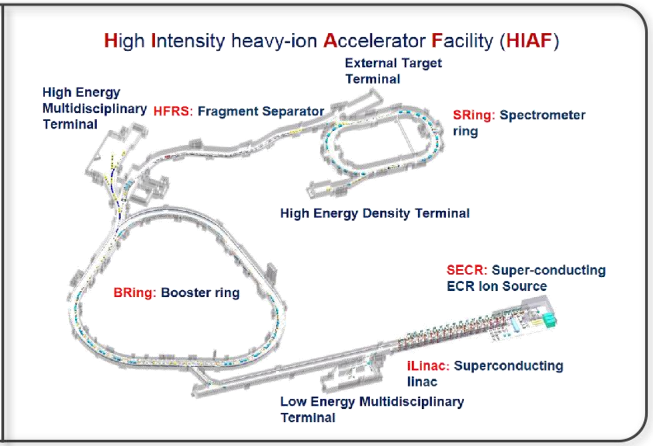
- This formalism is successfully applied to the $\Lambda(1520)$, $\Omega(2012)$, $\Omega(2380)$ and $\Omega_c(3120)$ systems.

  1. Successfully explained the peak caused by $\Lambda(1520)$ in the C_{K^-p}, and calculated its hadronic molecule properties.

  2. Predicted the correlation functions of $\Omega(2012)$, $\Omega(2380)$ and $\Omega_c(3120)$, and pointed out the "golden observation channel" for future experiments.







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Thanks for your listening!