SCNT

Southern Center for Nuclear-Science Theory

J/ψ-Nucleon Scattering Length

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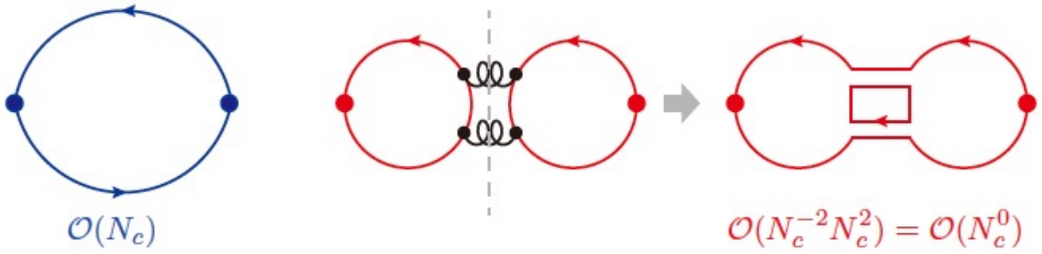
Bing Wu, Xiang-Kun Dong, Meng-Lin Du, FKG, Bing-Song Zou, arXiv:2403.xxxxx

Workshop on Near-Threshold Production of Heavy Quarkonium

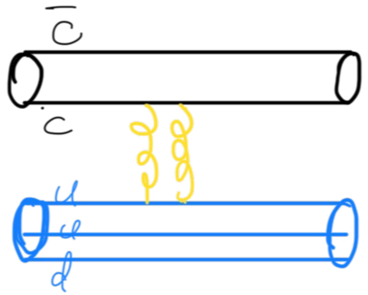
19-23 February 2024

J/ψ-nucleon scattering and photoproduction

- OZI suppressed scattering
  - ☐ Relatively suppressed by $O(1/N_c)$
  - ☐ General mechanisms (take $J/\psi - N$ as an example)



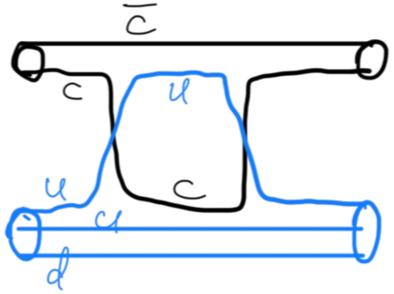
➢ Gluon exchanges



Gluonic matrix elements
- ☐ $\langle J/\psi|GG|J/\psi\rangle$ ~Chromopolarizabilities,
- ☐ $\langle N|GG|N\rangle$: trace anomaly contribution to the nucleon mass

talks by Yun-Hua Chen and Alexey Nefediev

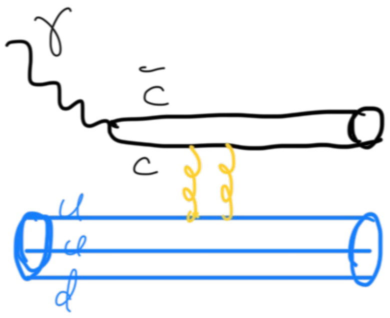
➢ Coupled-channel: $J/\psi N - \Lambda_c \bar{D}^{(*)}/\Sigma_c^{(*)}\bar{D}^{(*)} - J/\psi N$



Importance of coupled-channel mechanism in evading OZI suppression in mesonic sector: H. Lipkin, B.-S. Zou, PRD 53 (1996) 6693

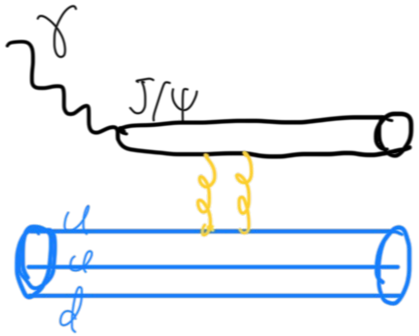
J/ψ-nucleon scattering and photoproduction

- The J/ψ photoproduction probes the gluonic contribution to the nucleon mass
  - ☐ if the mechanism of gluon exchanges is dominant



  - ☐ if the J/ψ photoproduction can be modeled by vector-meson dominance

D. Kharzeev, H. Satz, A. Syamtomov, G. Zinovjev, EPJC 9 (1999) 459



$$\frac{d\sigma_{\gamma N\to\psi N}}{dt}(s,t=0) = \frac{3\Gamma(\psi\to e^+e^-)}{\alpha m_\psi}\left(\frac{k_{\psi N}}{k_{\gamma N}}\right)^2 \times \frac{d\sigma_{\psi N\to\psi N}}{dt}(s,t=0)$$

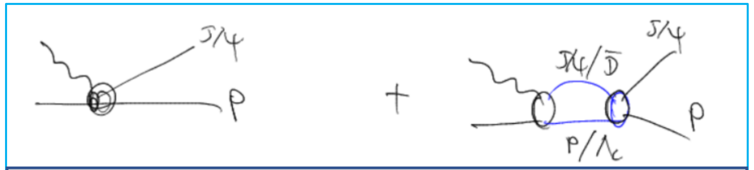
- ➢ Scattering length from VMD and photoproduction: $3-25$ am — L. Pentchev, I. Strakovsky, EPJA 57 (2021) 56

  21.3 ± 8.2 am — GlueX, PRC 108 (2023) 025201

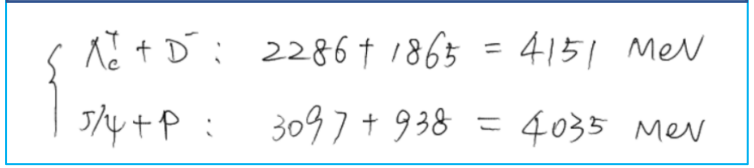
J/ψ in the VMD model would be highly off-shell, but the scattering length and cross section are defined for real J/ψ

J/ψ-nucleon scattering and photoproduction

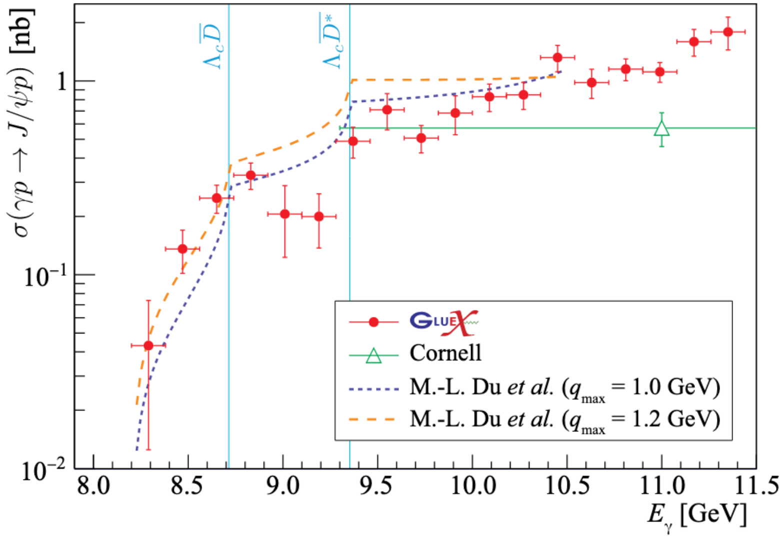
- For the near-threshold photoproduction, possible importance of the coupled-channel mechanism
  - Unique feature: threshold cusps M.-L. Du et al., EPJC 80 (2020) 1053



Unitarity: $J/\psi p \to J/\psi p$ enters w/o VMD, but cannot be singled out



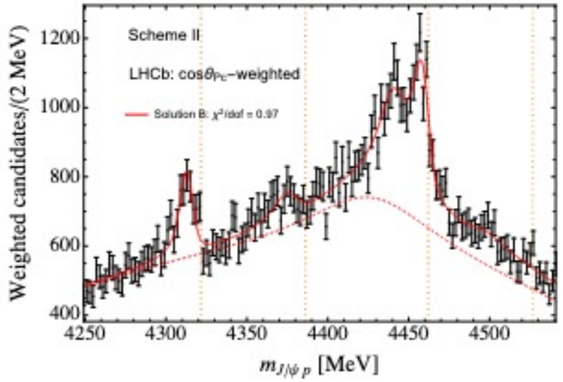
Talks by M.-L. Du and A. Pilloni



GlueX, PRC 108 (2023) 025201; talk by Zhenyu Zhang

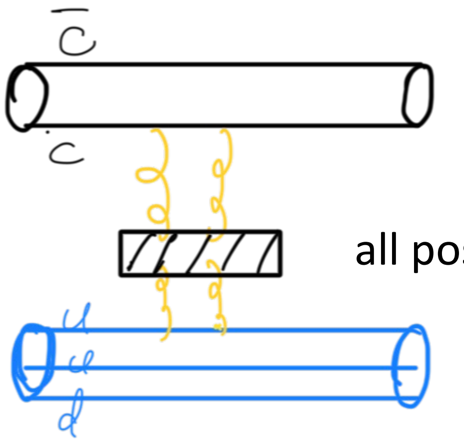
  - Current data are still not conclusive

- J/ψ-nucleon scattering
  - Coupled-channel mechanism
    - ➢ $\Lambda_c\bar{D}^{(*)}$ contribution: $\mathcal{O}(0.2 \ldots 3 \text{ am})$ M.-L. Du et al., EPJC 80 (2020) 1053
    - ➢ $\Sigma_c^{(*)}\bar{D}^{(*)}$ contribution: $\mathcal{O}(0.1 \ldots 10 \text{ am})$, from coupled-channel fits to LHCb data
  - How about gluon exchange? M.-L. Du et al., JHEP 08 (2021) 157



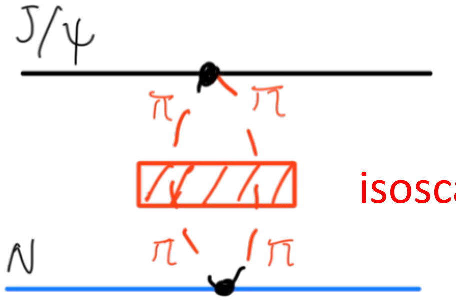
J/ψ-nucleon scattering: contribution from gluon exchange

- We focus on the $J/\psi - N$ scattering at low energies, the scattering length
  - Gluon exchange from the unitarity point of view



all possible color-singlet states that can couple to gluons: $\pi\pi, K\bar{K}, \ldots$

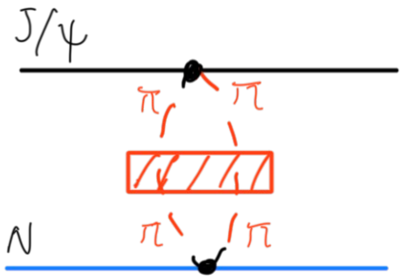
  - The longest-distance (lightest exchange particles) contribution: $\pi\pi$
    - contribution of correlated $\pi\pi$ exchanges



isoscalar scalar $\pi\pi$ rescattering: can be computed using dispersive approach

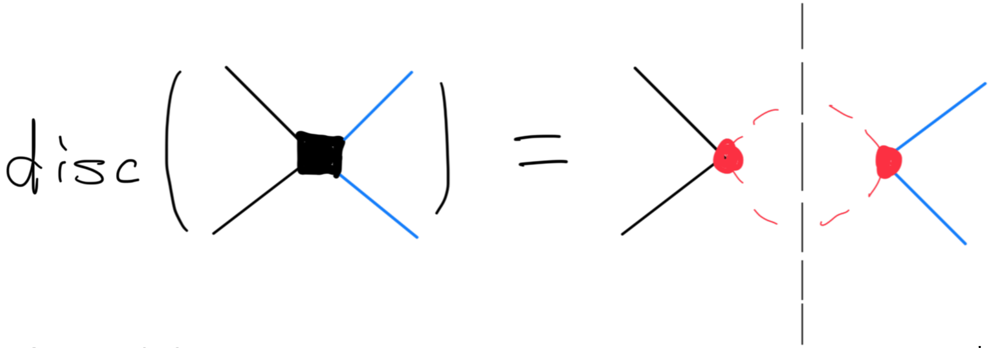
Dispersive approach

- $J/\psi N \to J/\psi N$ scattering amplitude satisfies the dispersion relation
  - Lowest intermediate states from gluon exchange: $\pi\pi \Rightarrow$ cut from the $\pi\pi$ threshold



$$\mathcal{M}(s,t) = \frac{1}{\pi}\int_{4m_\pi^2}^{+\infty} dt' \frac{\mathrm{Im}\,\mathcal{M}(s,t')}{t'-t-i\epsilon} \Rightarrow$$ S-wave $J/\psi N$ scattering amplitude

  - Unitarity $\Rightarrow$ imaginary part of the scattering amplitude



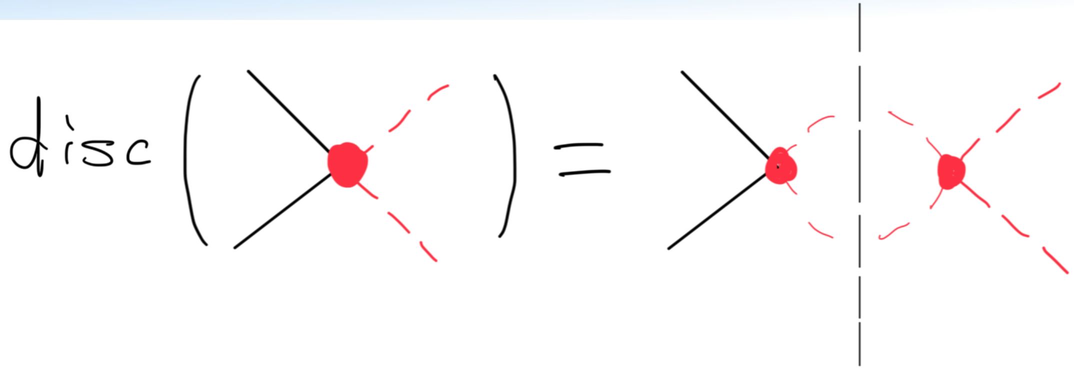
$$2i\,\mathrm{Im}\mathcal{M}_{J/\psi J/\psi \to N\bar{N}} = T_{J/\psi J/\psi \to \pi\pi} \; 2i\rho_\pi \; T^*_{\pi\pi \to N\bar{N}}$$

$\pi\pi$ phase space factor

  - $J/\psi J/\psi \to \pi\pi$ and $\pi\pi \to N\bar{N}$ amplitudes are again expressed using dispersion relation

Dispersive approach

- $J/\psi J/\psi \to \pi\pi$ amplitude
  - $\pi\pi$ scattering well-known
  - equation for $T_{J/\psi J/\psi\to\pi\pi}$ in a closed form
  - Solution is formally known as the Muskhelishvili-Omnès (MO) representation



$$2i\,\mathrm{Im}T_{J/\psi J/\psi\to\pi\pi} = T_{J/\psi J/\psi\to\pi\pi} \quad 2i\rho_\pi \quad T^*_{\pi\pi\to\pi\pi}$$

- $N\bar{N} \to \pi\pi$ amplitude can be similarly obtained
  - The MO solution with both $\pi\pi$ and $K\bar{K}$ channels

$$\vec{T}_0(s) = \vec{L}_0(s) + \Omega_0(s)\left[\vec{P}_{n-1}(s) - \frac{s^n}{\pi}\int_{4M_\pi^2}^{+\infty} \mathrm{d}z \frac{\mathrm{Im}\left[\Omega_0^{-1}(z)\right]\vec{L}_0(z)}{(z-s)z^n}\right],$$

with

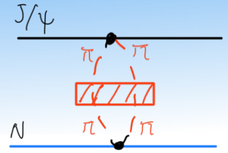
$$\vec{T}_0(s) = \begin{pmatrix} T_{N\bar{N}\to\pi\pi,0}(s) \\ \frac{2}{\sqrt{3}}T_{N\bar{N}\to K\bar{K},0}(s)\end{pmatrix}, \quad \vec{L}_0(s) = \begin{pmatrix} L_{N\bar{N}\to\pi\pi,0}(s) \\ \frac{2}{\sqrt{3}}L_{N\bar{N}\to K\bar{K},0}(s)\end{pmatrix}, \quad \vec{P}_{n-1}(s) = \begin{pmatrix} P_{n-1}^{N\bar{N}\to\pi\pi}(s) \\ \frac{2}{\sqrt{3}}P_{n-1}^{N\bar{N}\to K\bar{K}}(s)\end{pmatrix}$$

Ω_0: $\pi\pi - K\bar{K}$ Omnès matrix

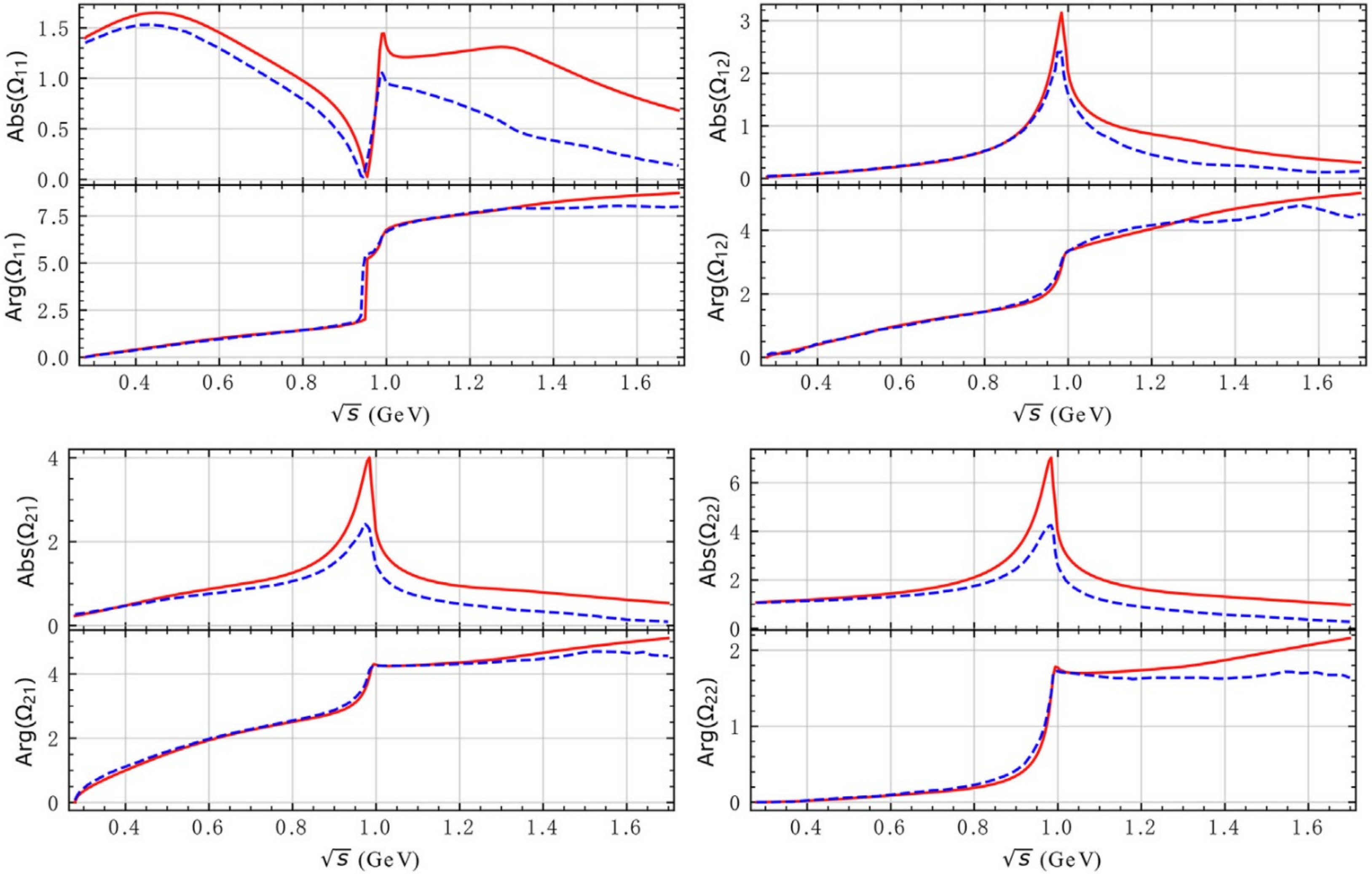
Do not have the right-hand cut

Subtraction polynomials, fixed by matching to chiral amplitudes

Inputs to the dispersive approach: Omnès matrix

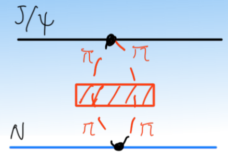


- $\pi\pi - K\bar{K}$ Omnès matrix: the $f_0(500)$ or σ, $f_0(980)$ contributions are included automatically



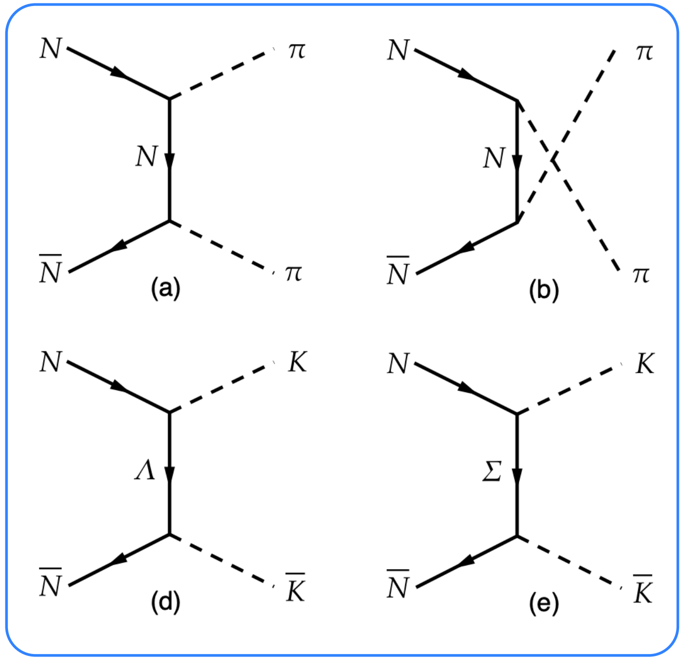
Red: S. Ropertz et al., EPJC 78 (2018) 1000; blue: M. Hoferichter et al., JHEP 06 (2012) 063

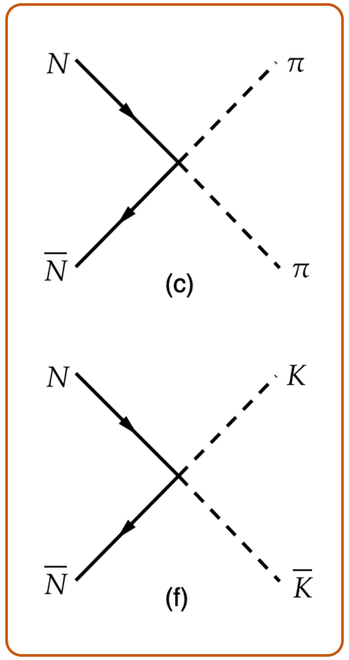
Inputs to the dispersive approach: $NN\pi\pi$



- $N\bar{N} \to \pi\pi$ without $\pi\pi - K\bar{K}$ rescattering: L_0, P_{n-1}

Vertices from LO chiral Lagrangian





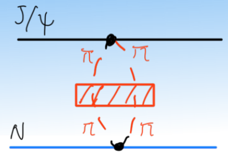
Vertices from NLO chiral Lagrangian
Low-energy constants (LECs) fixed in
X.-L. Ren et al., JHEP 12 (2012) 073

- The hadron-hadron-σ couplings can be systematically derived in this way; results for octet baryons

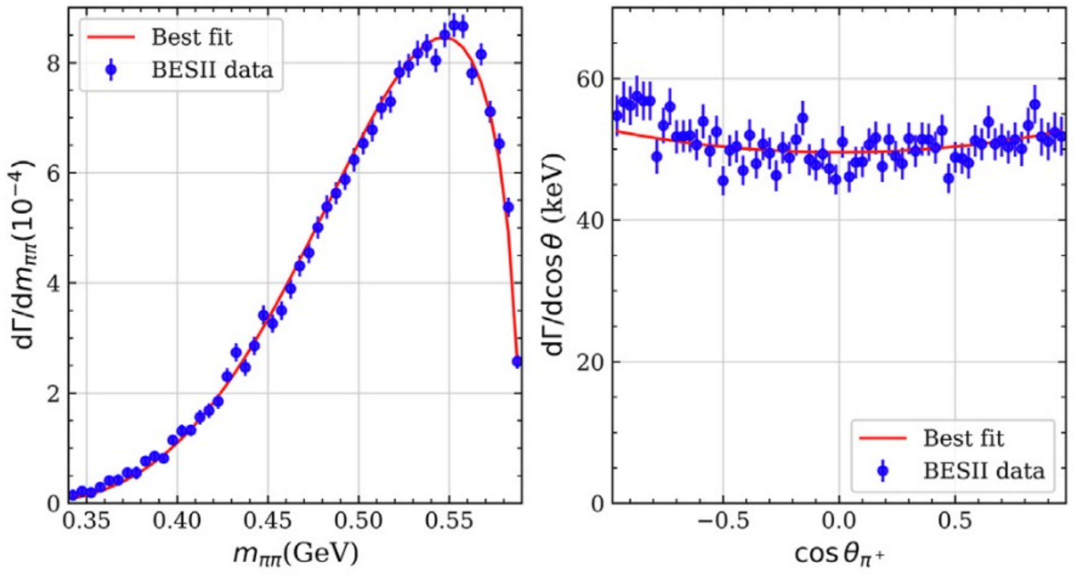
B. Wu, X.-H. Cao, X.-K. Dong, FKG, PRD (2024) in press [arXiv:2312.01013]

	LHC	RHC	Total	[33]	[18]	[34]	[37]	[36]	[24]	[23]	m_σ
$g_{\Sigma\Sigma\sigma}$	$1.8^{+0.5}_{-0.5}$	$3.5^{+2.0+0.8}_{-1.8-0.9}$	$3.5^{+1.8+0.4}_{-1.3-0.4}$	...	...	10.85(8.92)	4.65	...	...	...	519^{+50}_{-48}
$g_{\Xi\Xi\sigma}$	$0.2^{+0.1}_{-0.1}$	$2.6^{+1.5+0.5}_{-1.4-0.6}$	$2.5^{+1.5+0.5}_{-1.3-0.6}$	...	...	...	...	...	3.4	...	614^{+56}_{-81}
$g_{\Lambda\Lambda\sigma}$	$1.2^{+0.4}_{-0.3}$	$6.7^{+1.0+1.4}_{-1.1-1.7}$	$6.8^{+1.0+1.1}_{-1.0-1.4}$	...	...	8.18(6.54)	4.37	...	...	6.59	596^{+41}_{-51}
$g_{NN\sigma}$	$2.9^{+0.9}_{-0.8}$	$8.8^{+1.4+1.9}_{-1.4-2.3}$	$8.7^{+1.3+1.1}_{-1.3-1.4}$	12.78	8.46	8.46	8.58	13.85	10.2	9.86	558^{+33}_{-42}
$g^{SU(2)}_{NN\sigma}$	$2.7^{+0.8}_{-0.8}$	$12.5^{+0.2+2.6}_{-0.2-3.2}$	$12.2^{+0.2+1.9}_{-0.2-2.3}$								586^{+38}_{-48}

Inputs to the dispersive approach: $\psi\psi\pi\pi$ vertex



- Two LECs for the $J/\psi\pi \to J/\psi\pi$ scattering:
  - $J/\psi\pi \to J/\psi\pi$ scattering unknown
  - Use $\psi' \to J/\psi\pi\pi$ data to extract similar LECs (off-diagonal from $\psi(2S)$ to J/ψ)



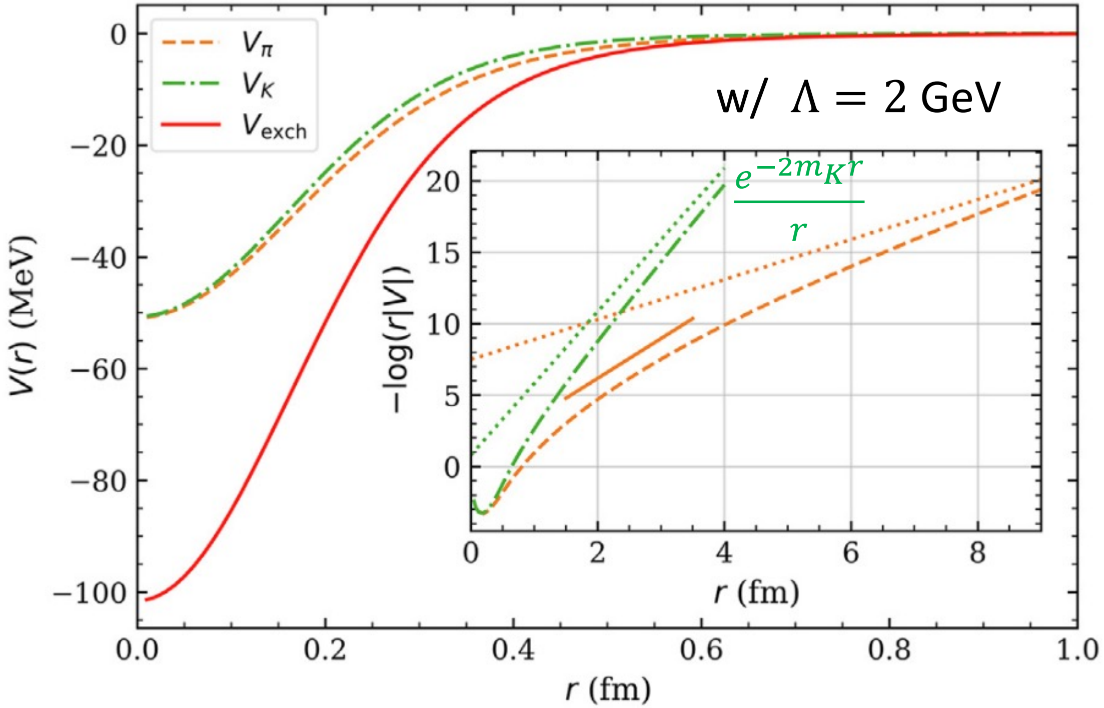
X.-K. Dong et al., Sci.Bull. 66 (2021) 1577;
See also talk by Yun-Hua Chen

- Fit to BESII data for $\psi' \to J/\psi\pi^+\pi^-$
  - ✓ $\pi^+\pi^-$ invariant mass distribution
  - ✓ helicity angular distribution
  - ✓ $\pi\pi$ final state interaction considered using dispersion relation
- Assume the LECs for $J/\psi\pi \to J/\psi\pi$ scattering to be the same as those for $\psi'\pi \to J/\psi\pi$ (in reality, the former should be even larger)

$J/\psi J/\psi$ scattering

- $J/\psi J/\psi$ scattering calculated in the same manner — X.-K. Dong et al., Sci.Bull. 66 (2021) 1577
  - $J/\psi J/\psi$ scattering potential given by a dispersive integral (regularized with a form factor)

$$V_{\rm exch}(r,\Lambda) = -\frac{1}{4\pi M_{J/\psi}^2}\int\frac{d^3q}{(2\pi)^3}e^{i\vec{q}\cdot\vec{r}}\int_{4m_\pi^2}^{\infty} d\mu^2\,\frac{{\rm Im}\mathcal{M}_{J/\psi J/\psi}(\mu^2)}{\mu^2+q^2}e^{-\frac{q^2+\mu^2}{\Lambda^2}},$$

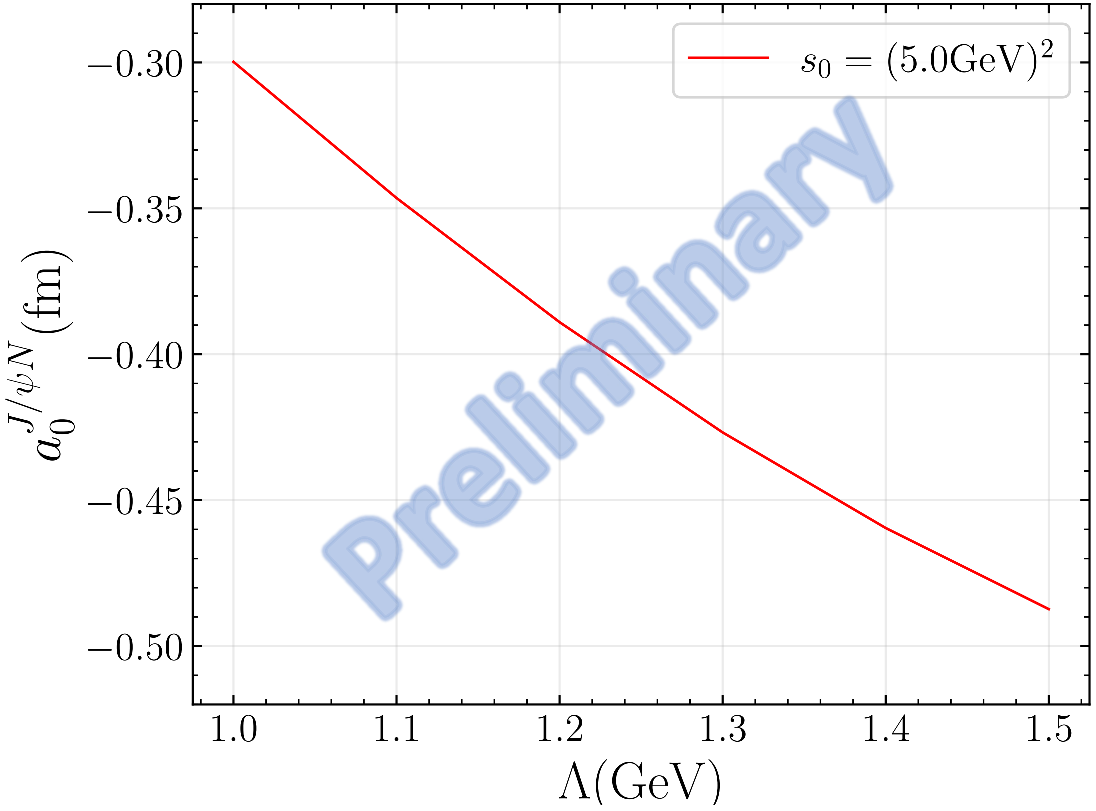


Long-distance behavior $\propto \frac{e^{-2m_\pi r}}{r}$

$\Rightarrow$ existence of $J/\psi J/\psi$ bound state is plausible

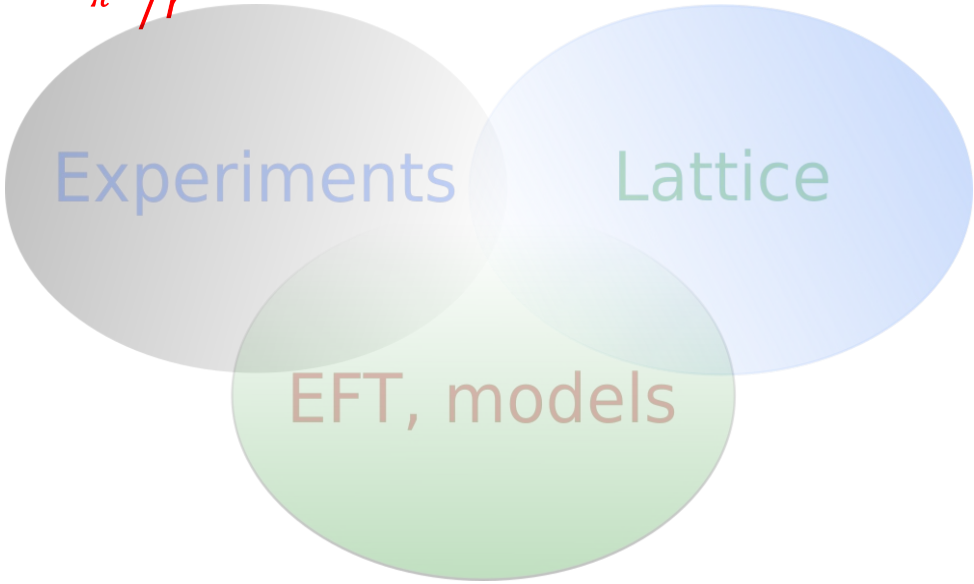
Results on the $J/\psi N$ scattering length

- S-wave scattering length: $\propto J/\psi N$ S-wave scattering amplitude at the threshold
  - $|a_{J/\psi N,0}|$ from the gluon exchange mechanism: $\mathcal{O}(0.4\ \mathrm{fm})$
  - Significantly larger than that from the coupled-channel mechanism ($\lesssim \mathcal{O}(0.01\ \mathrm{fm})$)



Summary and outlook

- $J/\psi N$ scattering length from the gluon-exchange mechanism estimated using dispersive approach by identifying it to the exchange of correlated $\pi\pi$ and $K\bar{K}$
- Significantly larger than that from the open-charm coupled-channel mechanism
- Possible check:
  - Behavior of the long-distance potential from lattice QCD (HAL QCD did that for DD^* scattering)
  - We expect that the long-distance potential from gluon exchange for OZI suppressed scattering potential should always behave as $e^{-2m_\pi r}/r$



Thank you for your attention!

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