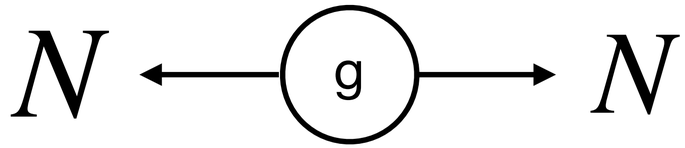
Long-range $N - J/\psi$ interaction from an operator product expansion perspective

Seokwoo Yeo, In Woo Park and Su Houng Lee, arXiv:2508.04980 (2025).

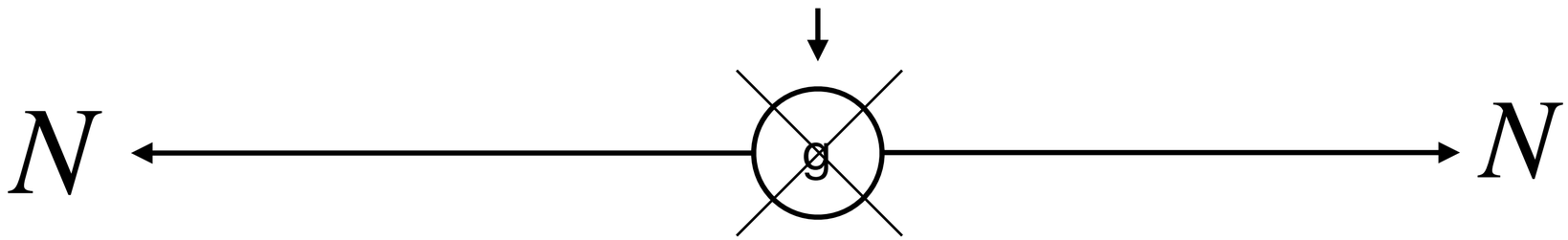
Seokwoo Yeo*, In Woo Park, Su Houng Lee (Yonsei U.)
Talk at Baryons 2025
November 13, 2025
(*Speaker)

Long-range hadron—hadron interaction



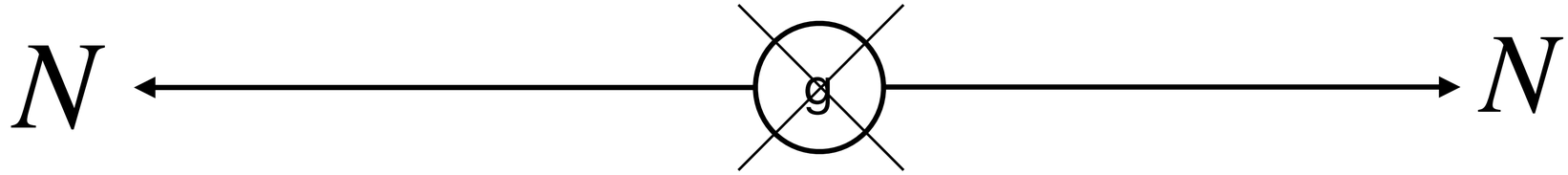
short range

Confinement → strong force mediated by meson



long range

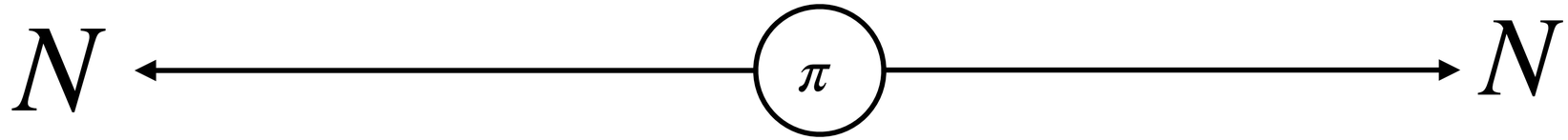
Long-range hadron—hadron interaction



long range

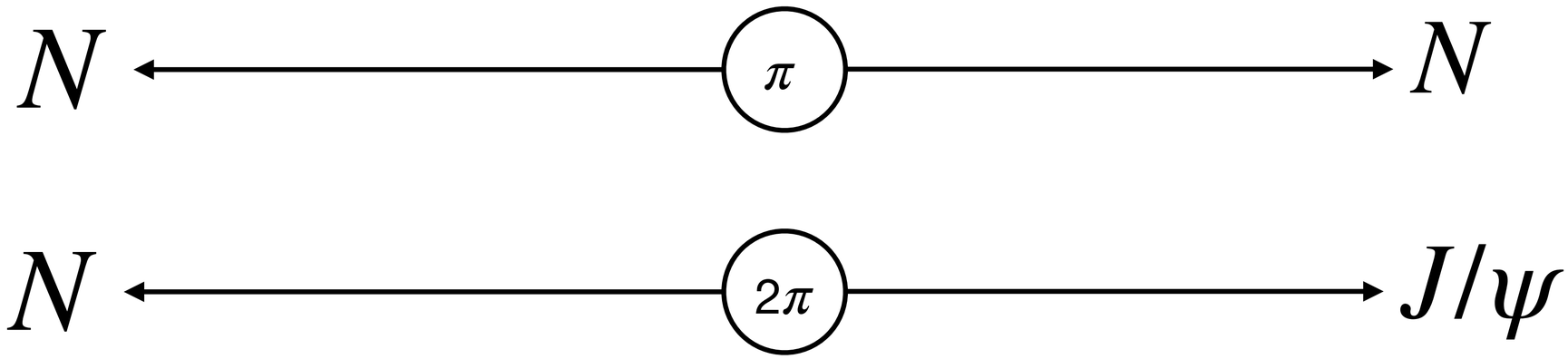
The lightest meson is Pion!

At long distances, one-pion exchange is leading contribution to the NN potential.



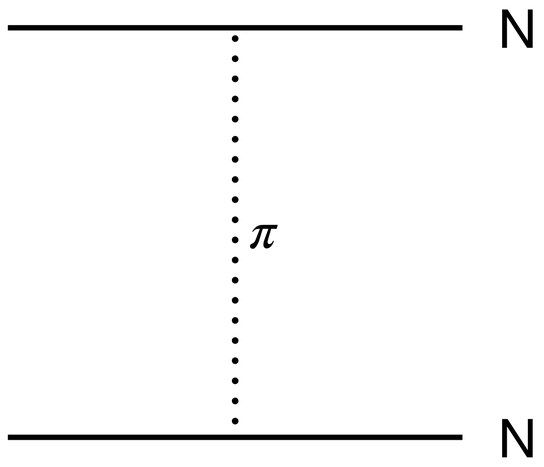
Long-range hadron—hadron interaction

What is the difference?

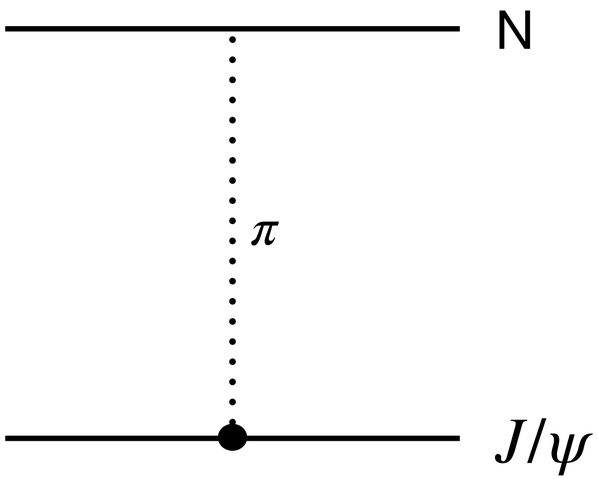


(One-pion exchange is OZI suppressed)

Isospin argument

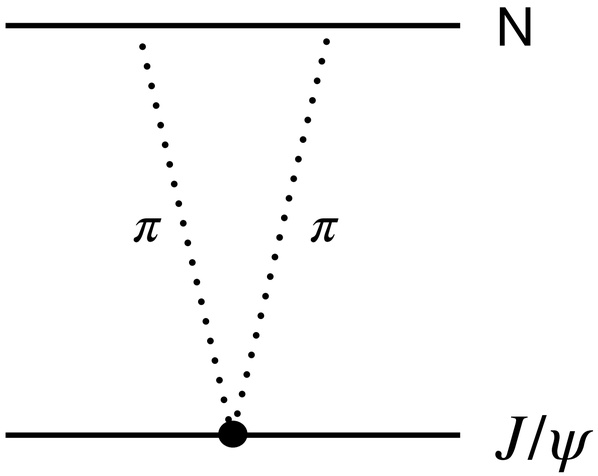


$$\frac{1}{2} \otimes 1 = \frac{1}{2} \oplus \frac{3}{2} \leftrightarrow \frac{1}{2}$$



$$0 \otimes 1 \leftrightarrow 0$$

Suppressed



$$0 \otimes 1 \otimes 1 = 0 \oplus 1 \oplus 2 \leftrightarrow 0$$

Isoscalar **two-pion exchange** is leading term in this case

Long-range hadron—hadron interaction

- Lattice QCD study[1] → attractive at all r; $a_{N-J/\psi} \simeq 0.3 - 0.4\mathrm{fm}$; TPE tail.

↓

Extracting TPE induced mass shift (~ a few MeV).

↓

We compare the Lattice TPE-induced mass shift with QCD Sum Rule (QSR).

- Dispersive Analysis[2]: consistent with lattice; $|a_{N-J/\psi}| \gtrsim 0.16\mathrm{fm}$; long-range TPE.

1. Y. Lyu, T. Doi, T. Hatsuda, and T. Sugiura, Physics Letters B 860, 139178 (2025).
2. B. Wu *et al*., Fundamental Research 10.1016/j.fmre.2025.07.005 (2025).

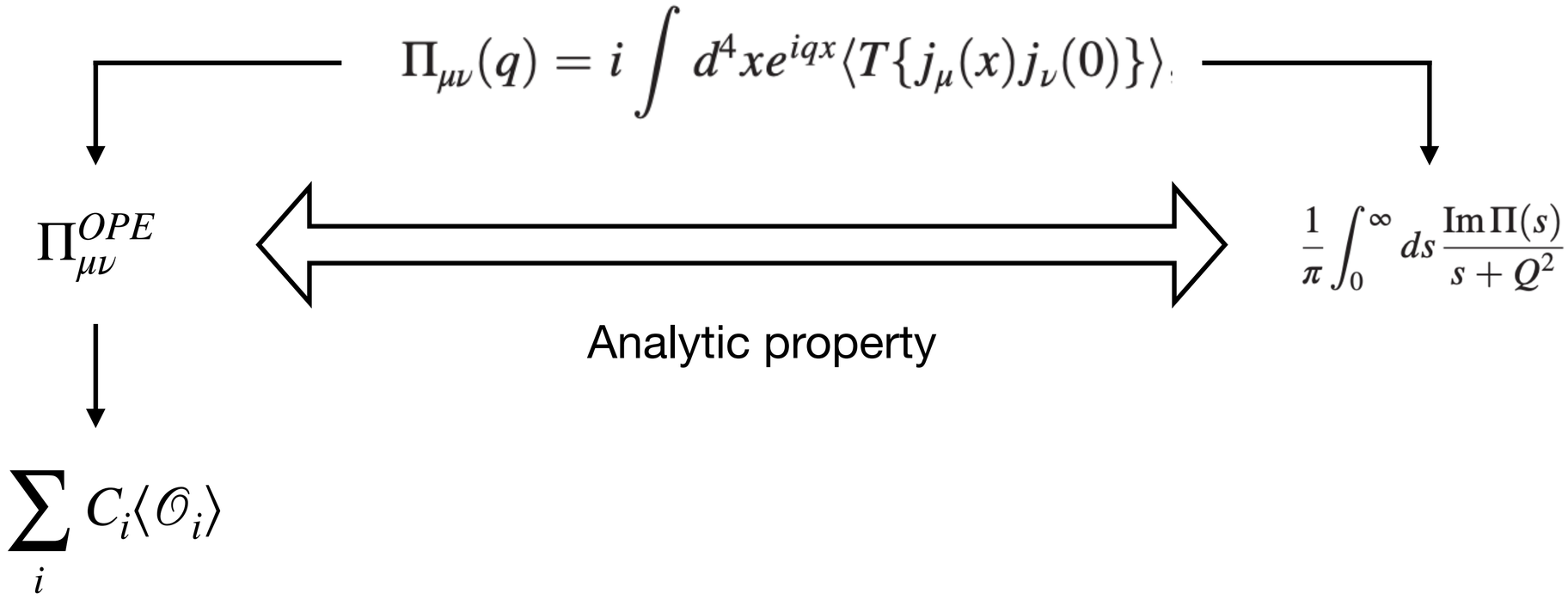
QCD Sum Rules(QSR)

For a current that can probe a specific hadron state, let us examine the structure through the two-current correlator.

$$\Pi_{\mu\nu}(q) = i \int d^4x e^{iqx} \langle T\{j_\mu(x) j_\nu(0)\} \rangle$$

We take an Operator Product Expansion(OPE): low-energy QCD is parametrized by local condensates $\langle \mathcal{O}_i \rangle$, while the short-distance Wilson coefficients C_i are computed in perturbative QCD. Since for timelike $q^2 > 0$, the correlator contains hadron spectrum and the OPE does not apply, we work in the Euclidean (spacelike) region with $q^2 < 0$ (i.e., $Q^2 \equiv -q^2 > 0$)

QCD Sum Rules(QSR)



QCD Sum Rules(QSR)

1. Extracting the leading-order four-quark operator that can couples to two pions and calculating its contribution to the J/ψ mass in nuclear matter, to linear order in density.
2. Using a Fierz transformation, we project onto the pseudoscalar and axial-vector Dirac structures that couple to two-pion states.
3. We apply vacuum saturation hypothesis to estimate the four-quark condensates. κ is introduced to correct the results obtained from the vacuum saturation.(κ range will be discussed later)

$$\langle \bar{q}_i \gamma_\mu \lambda^a q_i \bar{q}_j \gamma_\mu \lambda^a q_j \rangle \xrightarrow{1} 2\langle \bar{q}_i \gamma_5 q_j \bar{q}_j \gamma_5 q_i \rangle + \langle \bar{q}_i \gamma_5 \gamma_\mu q_j \bar{q}_j \gamma_5 \gamma_\mu q_i \rangle \xrightarrow{2} \frac{2}{3}\kappa \langle \bar{u}u \rangle^2 \xrightarrow{3}$$

What we compare

QSR vs **Lattice-TPE potential**

- First, we compute the effective mass shift from the lattice TPE potential, then compare it with the QSR result.

Lattice-TPEP induced mass shift

- We adopt Lattice TPE potential

$V(r) = -\alpha \dfrac{e^{-2m_\pi r}}{r^2}$ with potential strengths $\alpha_{J/\psi}^{(S=3/2)} = 22$ and $\alpha_{J/\psi}^{(S=1/2)} = 23$ MeV $\cdot$ fm^2

- The energy shift of the J/ψ in a nuclear matter

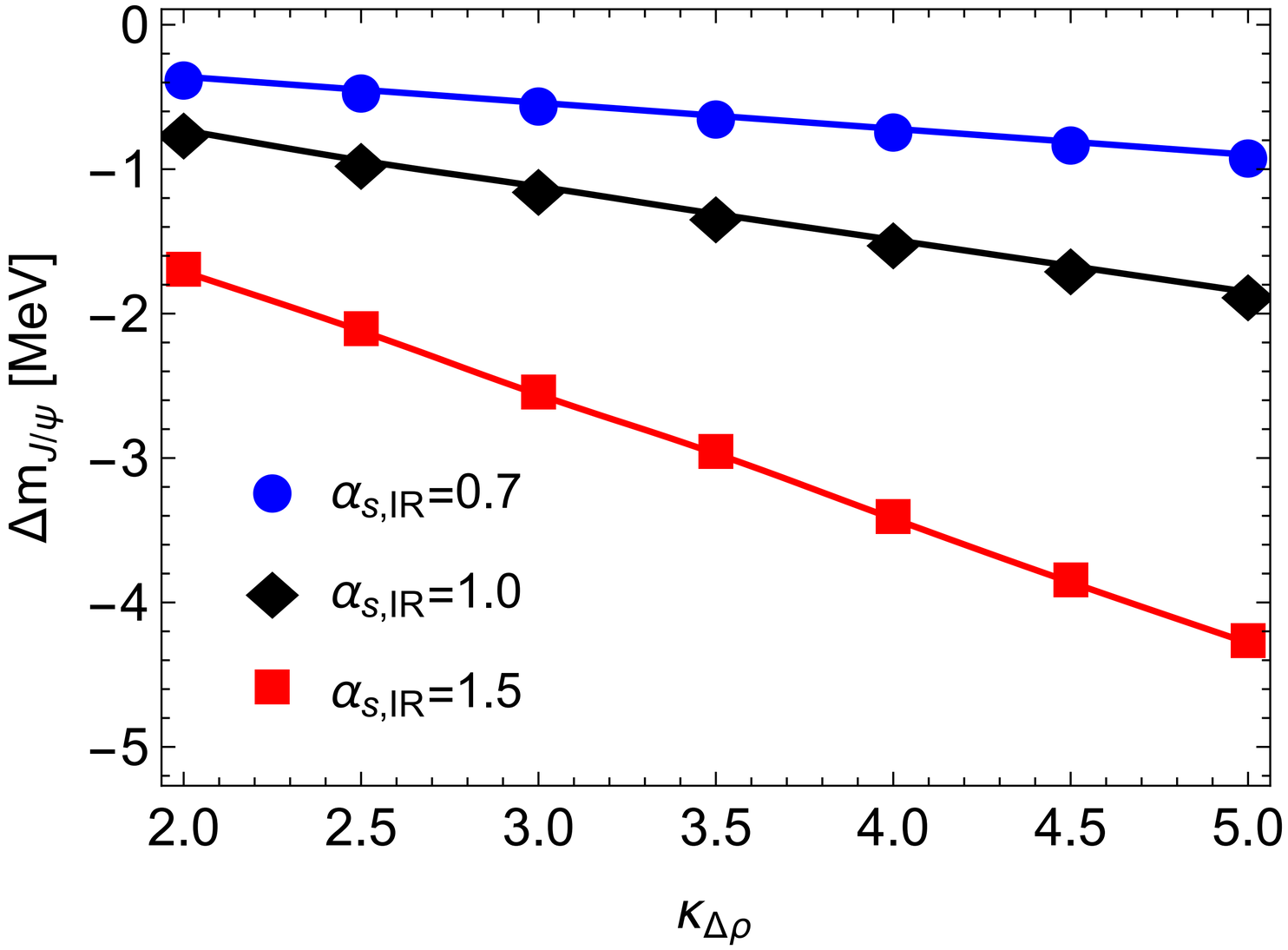
$\Delta E_V = \int_{r_{min}}^{r_{max}} d^3x V(r)\rho(r)$, where $\rho(r)$ is the nucleon density.

1. $r_{min} = 1.0$ fm
2. $r_{max} = 1.8$ fm

⟶ The spin-averaged energy shift is $\Delta m_{J/\psi}^{TPE} = -5$ MeV.

⟶ We take a few MeV as the reference scale.

Result & Discussion



S. Yeo, I.W. Park, S.H. Lee, arXiv:2508.04980 (2025).

Parameter set

Infrared coupling

1. $\alpha_{\mathrm{S,IR}}$ can be ↑ at $r >$ 1fm

   We choose $\alpha_{\mathrm{S,IR}} =$ 0.7,1.5, and 1.5

Deviation parameter

2. We take $\kappa_{\Delta\rho}$ = 2—5, for three reasons:

(Starting from $\kappa_{\Delta\rho} = 1$)

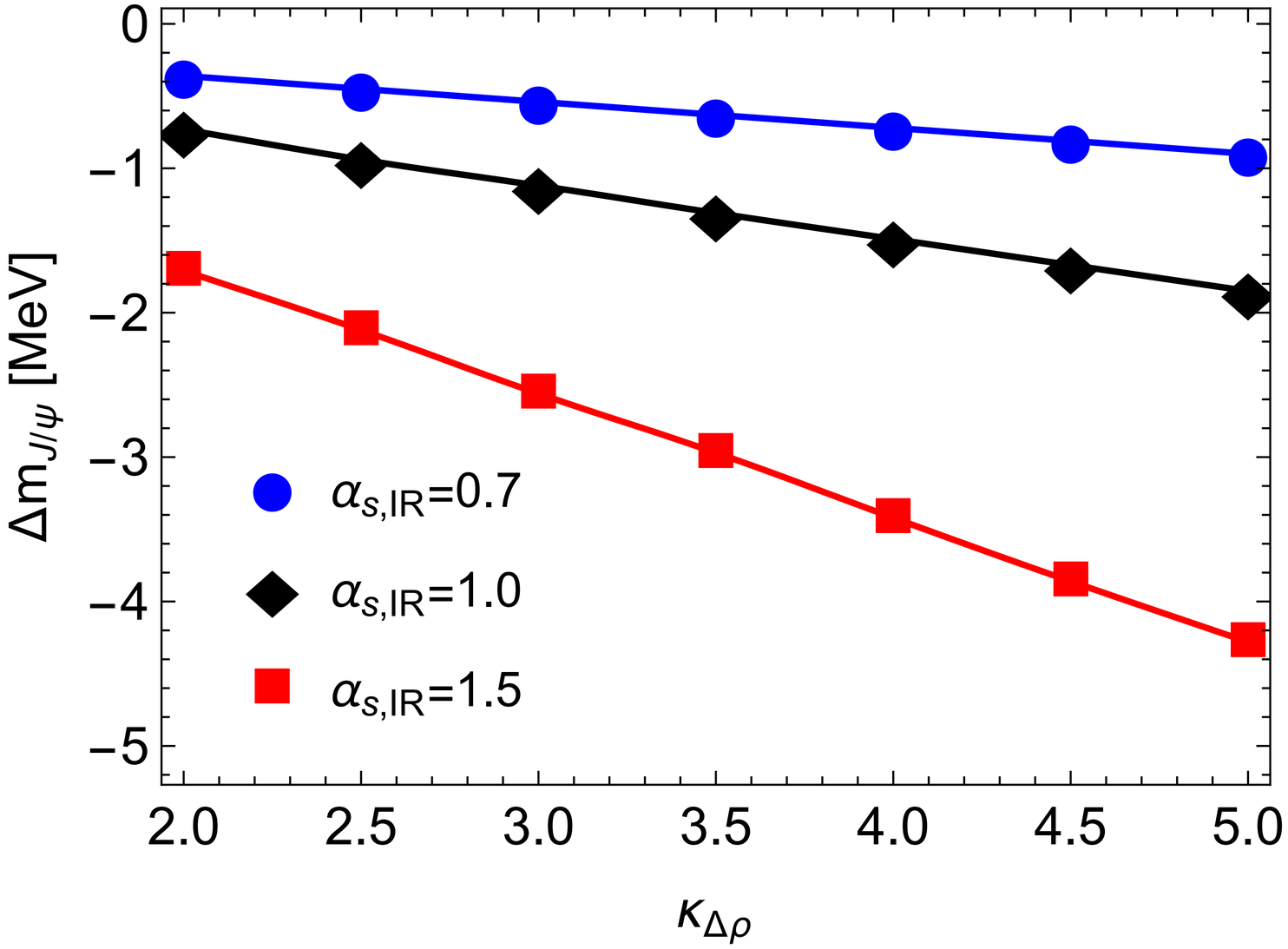
- χ-even $\simeq$ χ-odd (J. Kim *et al.*[1])
  ⟶ $\kappa_{\Delta\rho}$= 2
- perturbative k-factor in QCD(analogy)
  ⟶ another factor of about 2
- Intermediate states in medium
  ⟶ weaken vac. dominance

Based on the arguments above, we obtain $\kappa_{\Delta\rho} = 5.$

Thus, we adopt $\kappa_{\Delta\rho}$= 2—5 as a reasonable range.

1. J. Kim and S. H. Lee, Phys. Rev. D 103, L051501 (2021),
J. Kim and S. H. Lee, Phys. Rev. D 105, 014014 (2022).

Result & Discussion

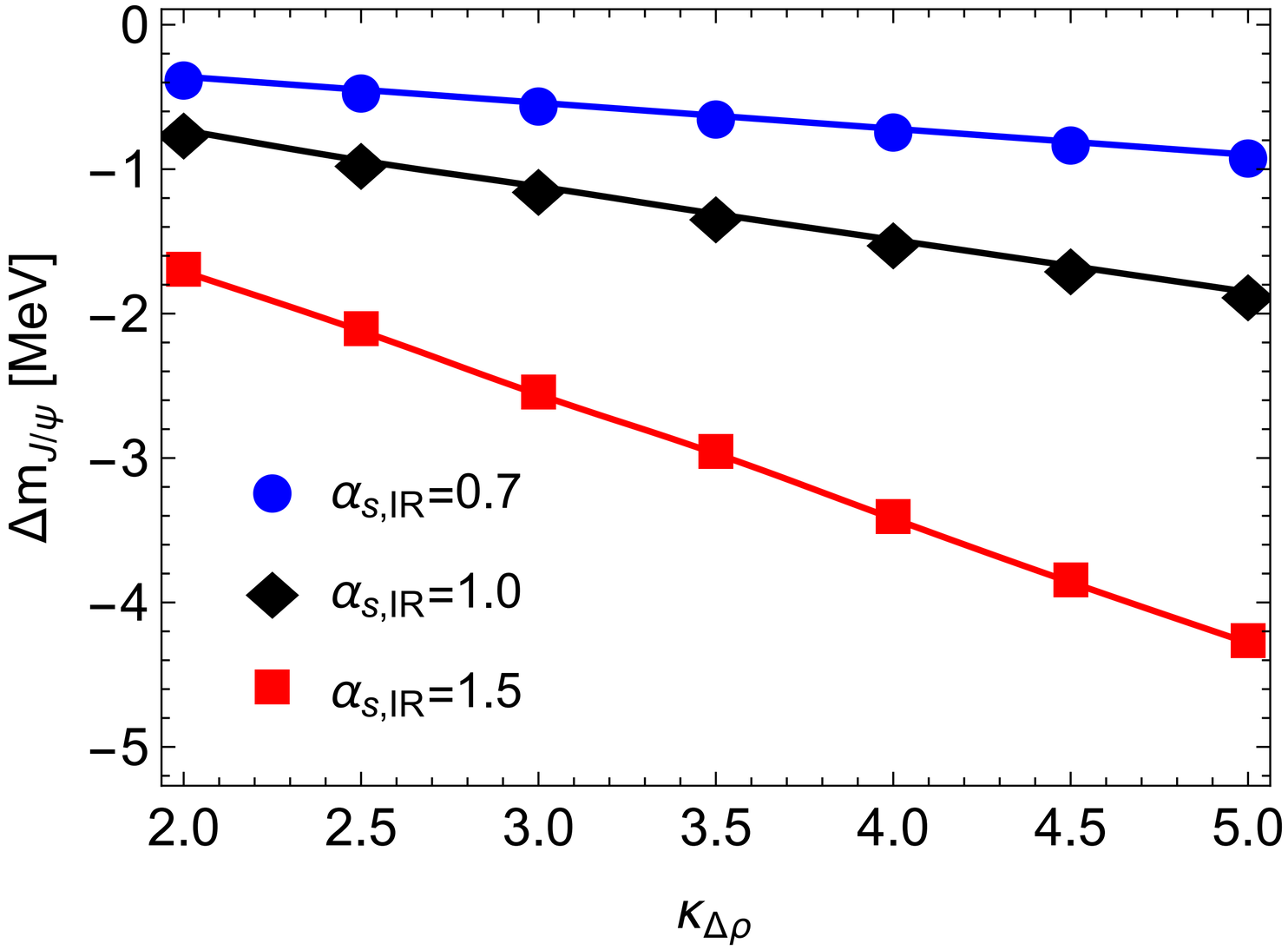


- $\alpha_{s,IR}$=0.7 → $|\Delta m| = 0.36-0.90$ MeV
- $\alpha_{s,IR} \uparrow \rightarrow |\Delta m| \uparrow$
- $\kappa \uparrow \rightarrow |\Delta m| \uparrow$
- $\alpha_{s,IR}$=1.5 → $|\Delta m| = 1.71-4.28$ MeV

With physically relevant values of $\kappa_{\Delta\rho}$ and $\alpha_{s,IR}$, QSR estimates few-MeV, same order as lattice TPE

S. Yeo, I.W. Park, S.H. Lee, arXiv:2508.04980 (2025).

Result & Discussion(additional)



- w/o Fierz → Repulsion

  The Fierz projection matters

- $\alpha_{\mathrm{s,IR}} \downarrow \ \rightarrow |\Delta m| \downarrow$

  Implying TPE↓ at short distance

- $m_q \uparrow \ \rightarrow |\Delta m| \downarrow$

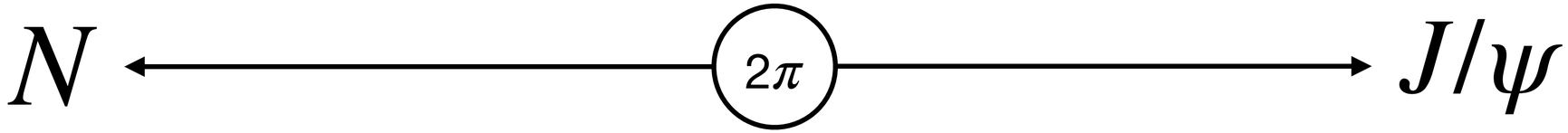
  Chromoelectric polarizability

  Potential strength(in TPEP) trend

  $\alpha_\phi(=91) > \alpha_{J/\psi}(=22) > \alpha_\Upsilon \left[\mathrm{MeV}\cdot\mathrm{fm}^2\right]$

S. Yeo, I.W. Park, S.H. Lee, arXiv:2508.04980 (2025).

Summary



- Lattice[1]: attractive at all r; $a_{N-J/\psi} \simeq 0.3 - 0.4\mathrm{fm}$; TPE tail.
- Extracting TPE induced mass shift (~ a few MeV).

- Dispersive[2]: consistent with lattice; $|a_{N-J/\psi}| \gtrsim 0.16\mathrm{fm}$; long-range TPE.

- **QSR[3](This work)**: reproduced long-range TPE; attractive mass shift (~ a few MeV); **consistent** with the lattice result within reasonable parameters.

  (→ shows small but finite effect of partial χ-symmetry restoration in heavy-quark systems.)

1. Y. Lyu, T. Doi, T. Hatsuda, and T. Sugiura, Physics Letters B 860, 139178 (2025).
2. B. Wu *et al*., Fundamental Research 10.1016/j.fmre.2025.07.005 (2025).
3. S. Yeo, I.W. Park, S.H. Lee, arXiv:2508.04980 (2025).