# Understand Hadron structure from Wick Contraction

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Preparing…

Shenzhen 2026/10/10

# Outline

- Motivation
- Lattice spectrum of $\pi\pi$ for $\rho$
- New method
- Summary and Outlook

# Background：Beyond Quark Model

Hadron state:
meson, baryon//Exotic

convential hadron

$(q\bar{q})$ $(qqq)$

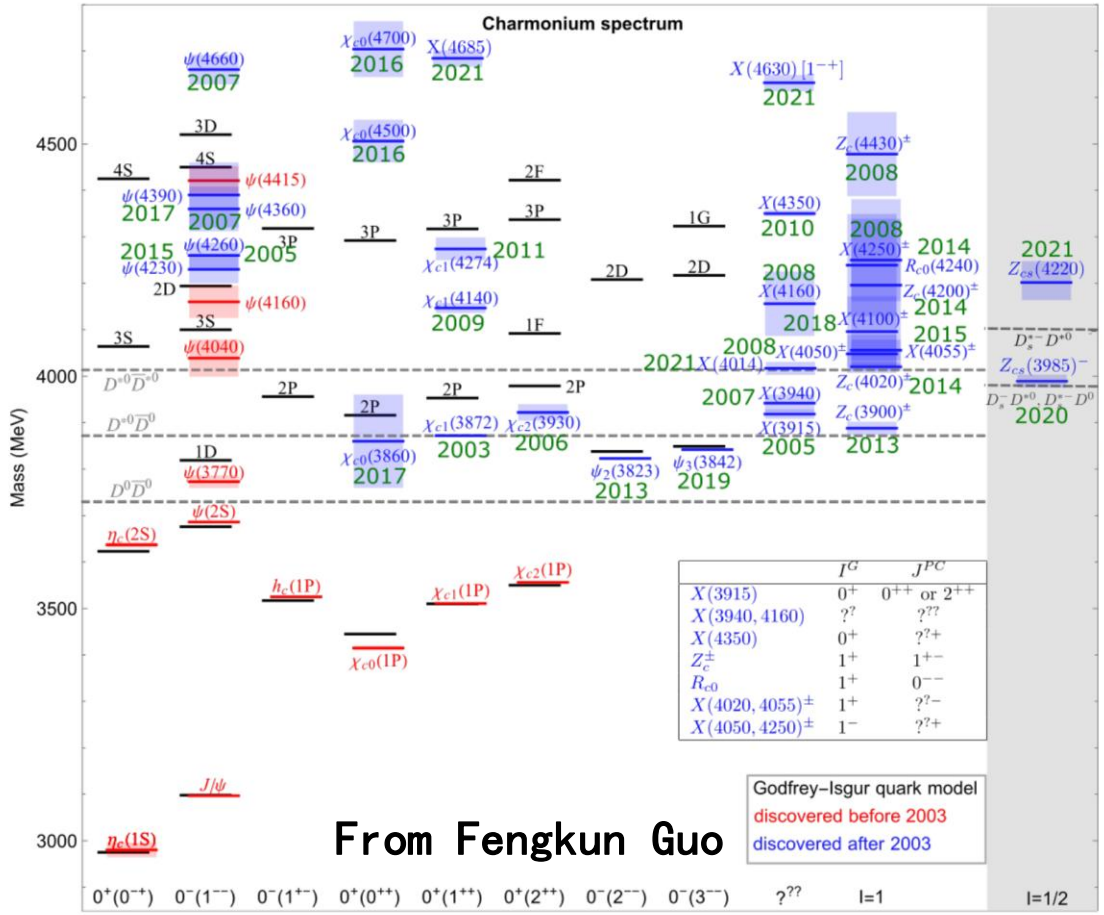
Quark model ?

Quark/Gluon

Exotic

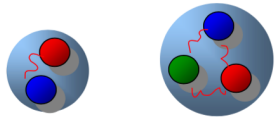
Hybrid Glueball Tetraquark

Pentaquark Hadronic molecule



# Background： the components of Hadron

convential hadron



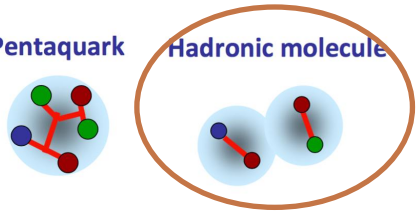
$(q\ \bar{q})$ $(qqq)$

## Exotic

Hybrid Glueball Tetraquark



Pentaquark Hadronic molecule



1. The compositeness
2. The large Nc limit
3. The bare state + coupled channel

Compositeness $X = 1 - e^{\frac{1}{\pi}\int dE \frac{\delta(E)}{E-E_B}}$

Li, Wu, Guo, Pang, PRD105 (2022) 7, L071502

Low Equation $T_{p,k} = V_{p,k} + \frac{g(p)\,g^*(k)}{h_k - E_B} + \int_0^\infty \frac{q^2 dq}{(2\pi)^3} \frac{T_{p,q} T^*_{k,q}}{h_k + i\varepsilon - h_q}$

$$a = -\frac{2X_W}{1+X_W} R + O(m_\pi^{-1}) \quad X_W = \sqrt{\frac{1}{1+2r/a}}$$

$$r = -\frac{1-X_W}{X_W} R + O(m_\pi^{-1}) \quad R = 1/\sqrt{2\mu|E_B|}$$

Weinberg, Phys. Rev. 137, B672 (1965).

ERE 近似下，$p\cot\delta(E) \approx \frac{1}{a} + \frac{r}{2}p^2 + O(p^4)$

当$r < 0, a \in [-R, 0]$时 $X = X_W$

当$r > 0, a \notin [-R, 0]$时 $X = 1$， $X_W > 1$

氘核的散射长度-5.419(7)fm,有效力程1.766(8)fm,束缚能-2.224575(9)MeV,用温伯格公式得到$X_W$=168%

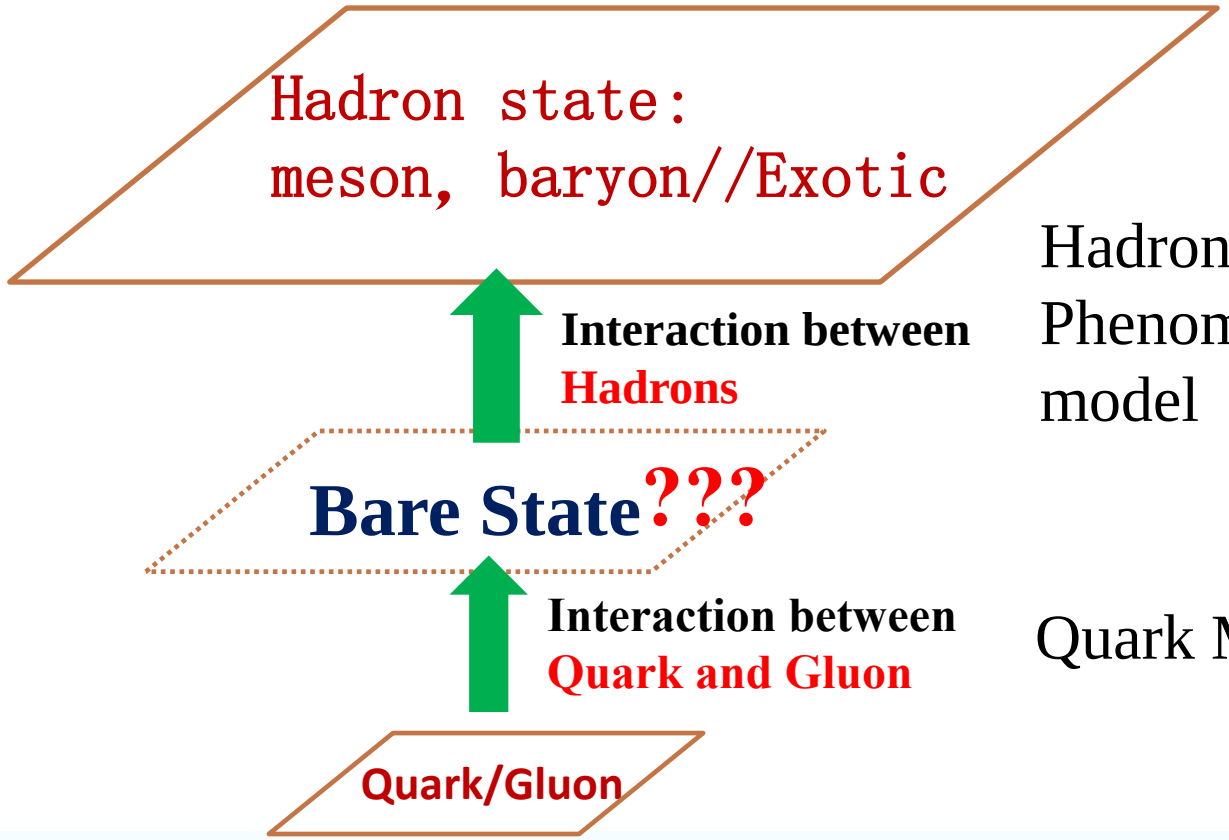
原因：

$$\tilde{g}(p) \equiv \langle p|V|B\rangle = \sqrt{Z}\lambda_b f(p) = \frac{8\pi^2}{\mu^2 R} \begin{cases} \sqrt{\frac{1}{1+2r/a}} + O(p^4) & \left(\sqrt{\frac{1}{1+\frac{2r}{a}}} \in [0.1]\right) \\ \frac{a^2}{R^2}\frac{1}{1+(a+R)^2p^2} + O(p^4) & \left(\sqrt{\frac{1}{1+\frac{2r}{a}}} > 1\right) \end{cases}$$

耦合道和束缚态的耦合形式(Dressed Coupling)

温伯格在计算中就只取了$\tilde{g}(p)$的领头阶，即常数。这和ERE取到次零头阶其实是不自洽的。

# Background： Bare state + Coupled channel




Hadron level
Phenomenological model

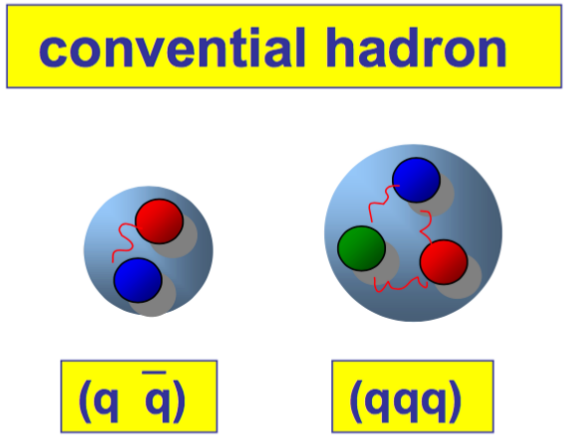
Quark Model

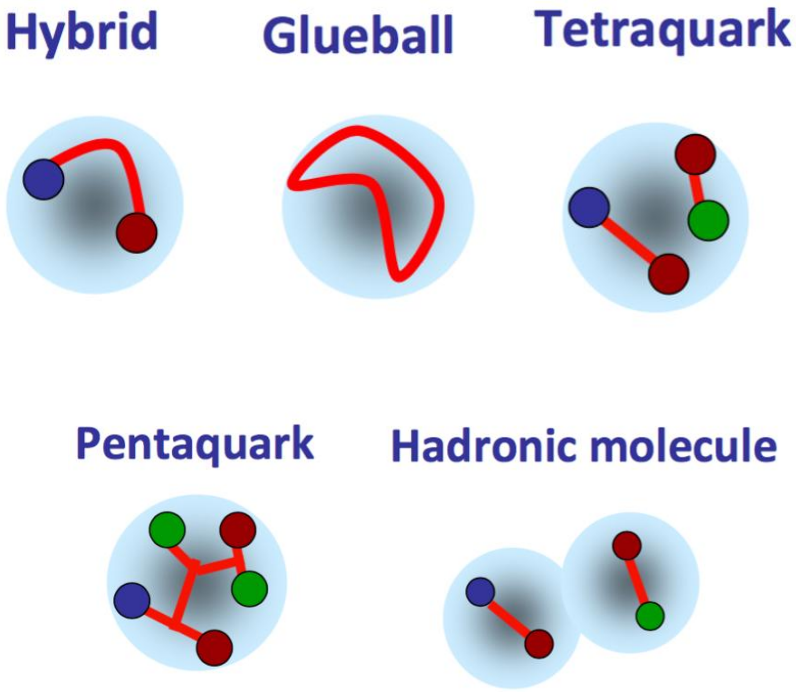
**Coupled channel**

Bare state(Single)
+multi-hadron

The number of hadrons is **not conserved**!

# Background： How to clear define these components



# ρ meson spectra on LQCD -- Operator

| $[000]T_1^-$ | $[001]A_1$ | $[001]E_2$ | $[011]A_1$ |
|---|---|---|---|
| $\rho_{[000]}$ | $\rho_{[001]}$ | $\rho_{[001]}$ | $\rho_{[011]}$ |
| $\pi_{[001]}\pi_{[00-1]}$ | $\pi_{[000]}\pi_{[001]}$ | $\pi_{[0-10]}\pi_{[011]}$ | $\pi_{[000]}\pi_{[011]}$ |
| $\pi_{[011]}\pi_{[0-1-1]}$ | $\pi_{[0-10]}\pi_{[011]}$ | $\pi_{[0-1-1]}\pi_{[111]}$ | $\pi_{[-100]}\pi_{[111]}$ |
| $\pi_{[111]}\pi_{[-1-1-1]}$ | $\pi_{[-1-10]}\pi_{[111]}$ | | $\pi_{[01-1]}\pi_{[002]}$ |
| | $\pi_{[00-1]}\pi_{[002]}$ | | |

| $[011]B_1$ | $[011]B_2$ | $[111]A_1$ | $[002]A_1$ |
|---|---|---|---|
| $\rho_{[011]}$ | $\rho_{[011]}$ | $\rho_{[111]}$ | $\rho_{[002]}$ |
| $\pi_{[010]}\pi_{[001]}$ | $\pi_{[-100]}\pi_{[111]}$ | $\pi_{[000]}\pi_{[111]}$ | $\pi_{[000]}\pi_{[002]}$ |
| $\pi_{[110]}\pi_{[-101]}$ | $\pi_{[110]}\pi_{[-101]}$ | $\pi_{[100]}\pi_{[011]}$ | |
| $\pi_{[0-11]}\pi_{[002]}$ | | $\pi_{[200]}\pi_{[-111]}$ | |

$$\rho^0 = \frac{1}{\sqrt{2}}(\bar{u}\Gamma^P u - \bar{d}\Gamma^P d)$$
$$\rho^{0\dagger} = \frac{1}{\sqrt{2}}(\bar{u}\bar{\Gamma}^P u - \bar{d}\bar{\Gamma}^P d)$$
$$\pi^+ = \bar{d}\Gamma^k u, \quad \pi^- = \bar{u}\Gamma^k d$$

$$\pi\pi = \frac{1}{\sqrt{2}}(\pi^+(k_1)\pi^-(k_2) - \pi^-(k_1)\pi^+(k_2))$$
$$= \frac{1}{\sqrt{2}}(\bar{d}\Gamma^{k_1}u\bar{u}\Gamma^{k_2}d - \bar{u}\Gamma^{k_1}d\bar{d}\Gamma^{k_2}u)$$

$$(\pi\pi)^\dagger = \frac{1}{\sqrt{2}}(\bar{d}\bar{\Gamma}^{k_2}u\bar{u}\bar{\Gamma}^{k_1}d - \bar{u}\bar{\Gamma}^{k_2}d\bar{d}\bar{\Gamma}^{k_1}u)$$

# ρ meson spectra on LQCD -- correlation function

$$C_{ij} = \left\langle 0 \left| \mathcal{O}_i \mathcal{O}_j^{\dagger} \right| 0 \right\rangle = \sum_n Z_i^n Z_j^{n*} e^{-E_n t}$$

**Computed based on wick contraction and quark propagator calculated based on the configuration.**

**To parameterize the correlation function !**

**Energy level in the finite volume**

- **Solve the generalized eigenvalue problem(GEVP)**

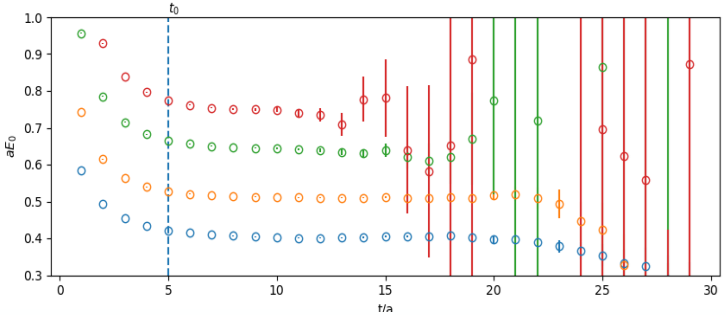
$$\mathcal{G}_{ij}(t_0 + dt) u_j^{\alpha} = \mathrm{e}^{-m_{\alpha} dt} \mathcal{G}_{ij}(t_0) u_j^{\alpha},$$

$$[\mathcal{G}^{-1}(t_0)\mathcal{G}(t_0 + dt)]_{ij} u_j^{\alpha} = c^{\alpha} u_i^{\alpha}$$

$$v_i^{\alpha} [\mathcal{G}(t_0 + dt)\mathcal{G}^{-1}(t_0)]_{ij} = c^{\alpha} v_j^{\alpha},$$

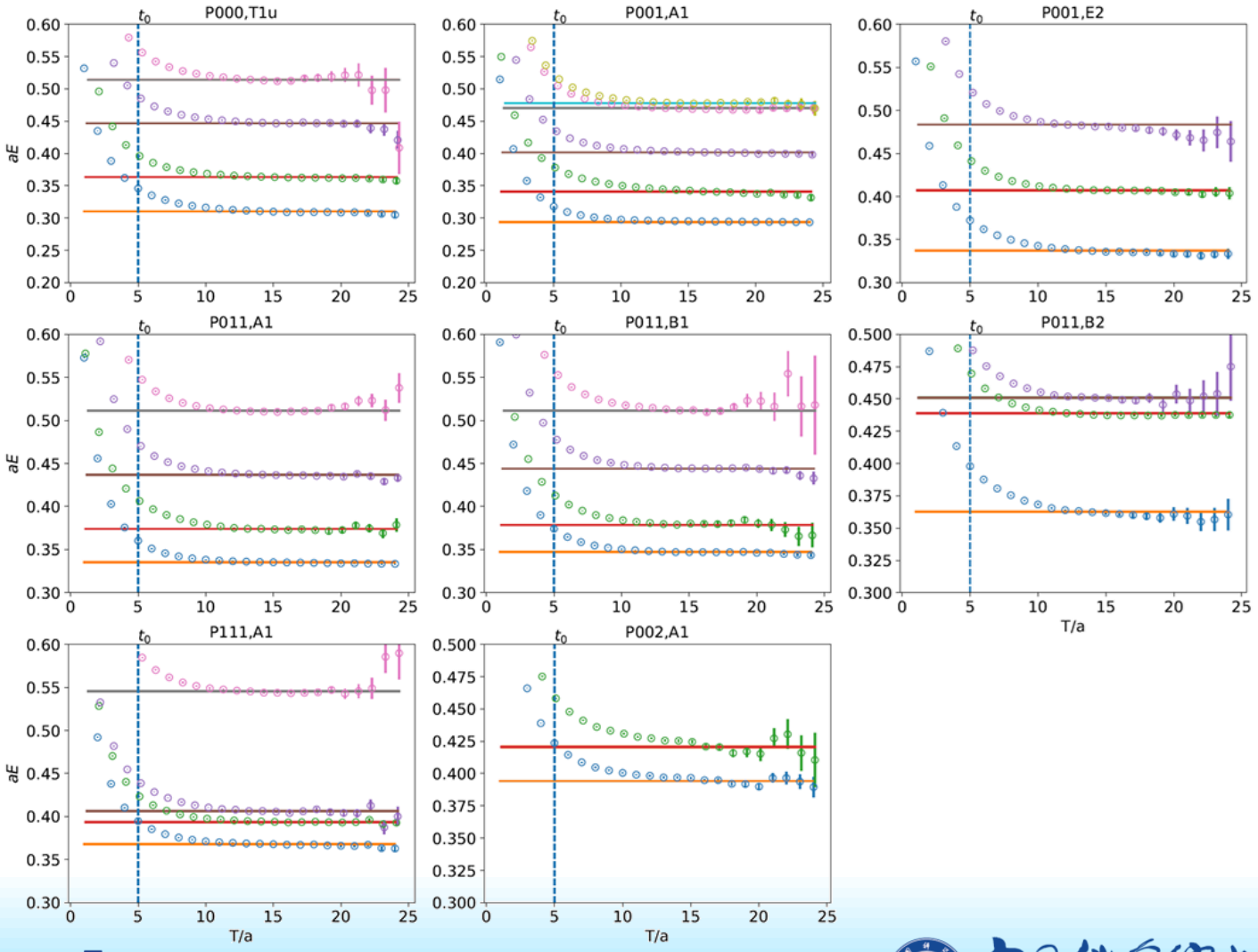
$$\mathcal{G}^{\alpha}(t) = v_i^{\alpha} \mathcal{G}_{ij}(t) u_j^{\alpha},$$

$$E^{\alpha}(t) = \frac{1}{n} \log \frac{\mathcal{G}^{\alpha}(t)}{\mathcal{G}^{\alpha}(t+n)},$$




Kiratidis, et al., PRD 91, 094509 (2015)

# ρ meson spectra on LQCD -- Spectra




## Configuration: F48P30

There are 8 different spectra with different total momentum and irreps, including following irreducible representations.:

$p^2 = 0 \ : \ T_1^-$,

$p^2 = 1 \ : \ A_1$ and $E_2$,

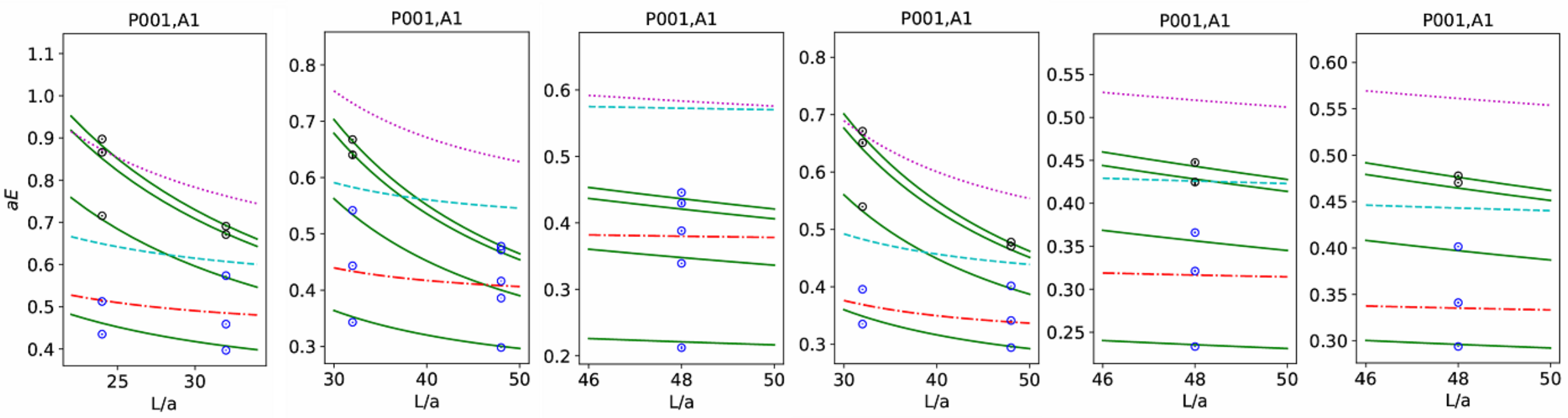
$p^2 = 2 \ : \ A_1$, $B_1$ and $B_2$,

$p^2 = 3 \ : \ A_1$,

$p^2 = 4 \ : \ A_1$.

# ρ meson spectra on LQCD -- Spectra

| C32P29/C48P29 | C48P23/C32P23 | C48P14 | F48P30/F32P30 | F48P21 | H48P32 |
|---|---|---|---|---|---|
| $m_\pi$ ~ 300 MeV | ~ 230 MeV | ~ 135 MeV | ~ 300 MeV | ~ 220 MeV | ~ 300 MeV |



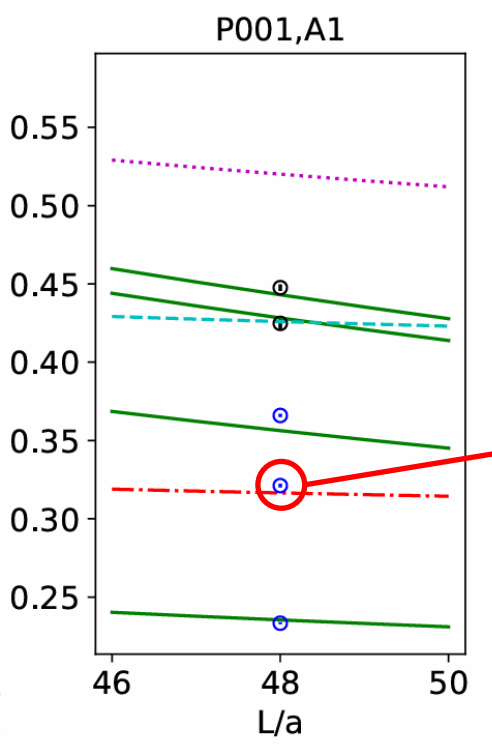

**a ~ 0.105 fm** **a ~ 0.077 fm** **a ~ 0.052 fm**

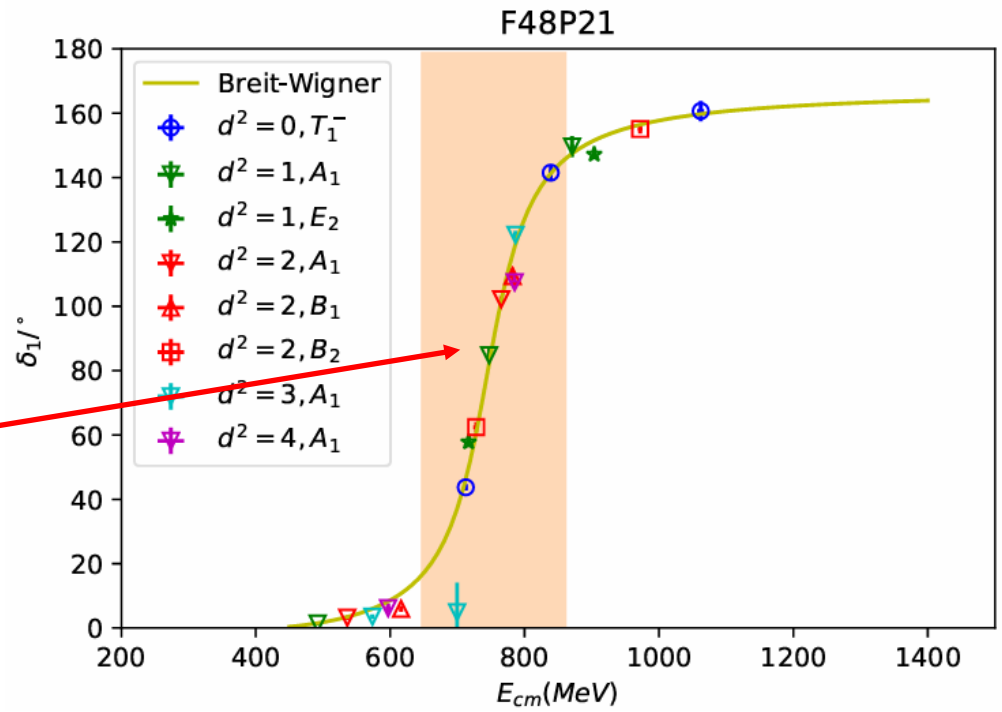
# ρ meson spectra on LQCD -- Phase shift of $\pi\pi$

| $d^2$ | $\Lambda, \mu$ | $M_{11,11}^{(\vec{P},\Lambda,\mu)}$ |
|---|---|---|
| 0 | $T_1^-, 2$ | $w_{0,0}$ |
| 1 | $A_1, 1$ | $w_{0,0} + 2w_{2,0}$ |
| 1 | $E_2, 1$ | $w_{0,0} - w_{2,0}$ |
| 1 | $E_2, 2$ | $w_{0,0} - w_{2,0}$ |
| 2 | $A_1, 1$ | $w_{0,0} + \frac{1}{2}w_{2,0} + i\sqrt{6}w_{2,1} - \frac{\sqrt{6}}{2}w_{2,2}$ |
| 2 | $B_1, 1$ | $w_{0,0} + \frac{1}{2}w_{2,0} - i\sqrt{6}w_{2,1} - \frac{\sqrt{6}}{2}w_{2,2}$ |
| 2 | $B_2, 1$ | $w_{0,0} - w_{2,0} + \sqrt{6}w_{2,2}$ |
| 3 | $A_1, 1$ | $w_{0,0} - i2\sqrt{6}w_{2,2}$ |

$$\det\left(M_{ln,l'n'}(k) - \delta_{ll'}\delta_{nn'}\cot(\delta_l)\right) = 0, \quad \delta_1 = \operatorname{arccot} M_{11,1}^{(\vec{P},}$$

$$w_{j,s} = \frac{\mathcal{Z}_{js}(1,q^2)}{\pi^{3/2}\sqrt{2j+1}\gamma q^{j+1}}, \quad q = \frac{kL}{2\pi}, \quad \delta_{l\geq 3} \text{ are negligible}$$

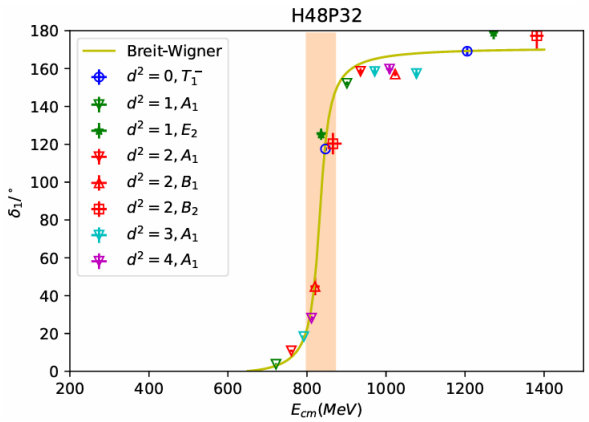


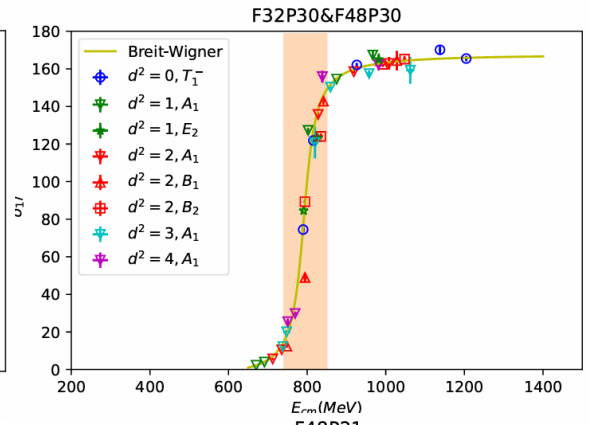



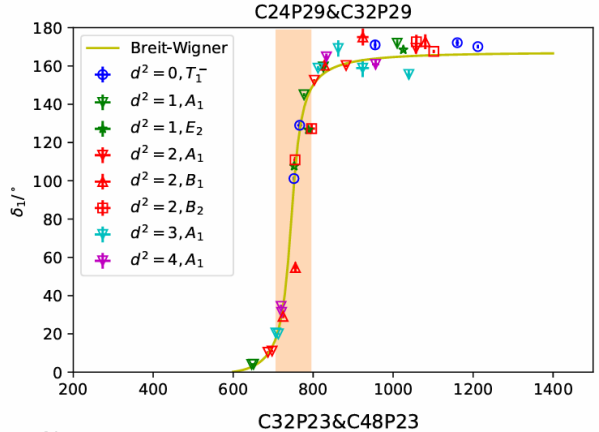

$$E_{cm} = \sqrt{E_{001}^2 - 4\pi^2/L^2} = \sqrt{(0.34/a)^2 - 4\pi^2/(48a)^2} = 771\ \text{MeV}$$

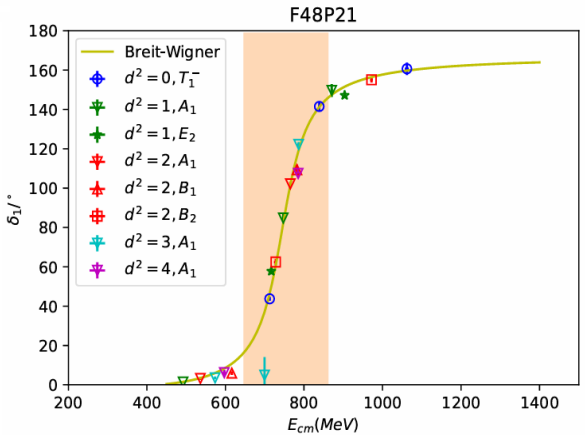
# ρ meson spectra on LQCD -- Phase shift of ππ

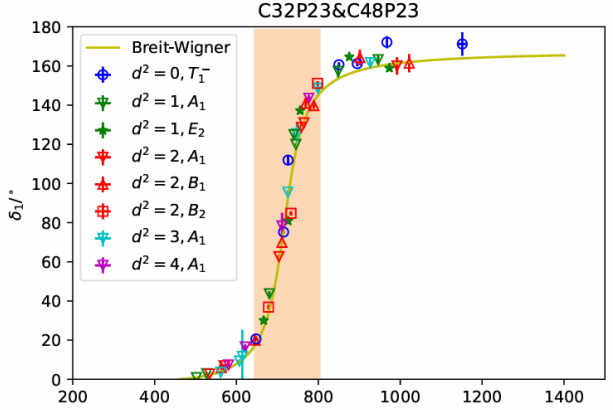
| | $m_\rho$ (MeV) | $g_{\rho\pi\pi}$ |
|---|---|---|
| C24P29/C32P29 | 749.0(6.0) | 5.859(79) |
| C32P23/C48P23 | 723.9(5.6) | 5.827(14) |
| C48P14 | 714.0(34.5) | 6.300(440) |
| F32P30/F48P30 | 795.5(4.2) | 5.775(58) |
| F48P21 | 754.2(3.0) | 5.954(38) |
| H48P32 | 834.8(7.4) | 4.916(45) |

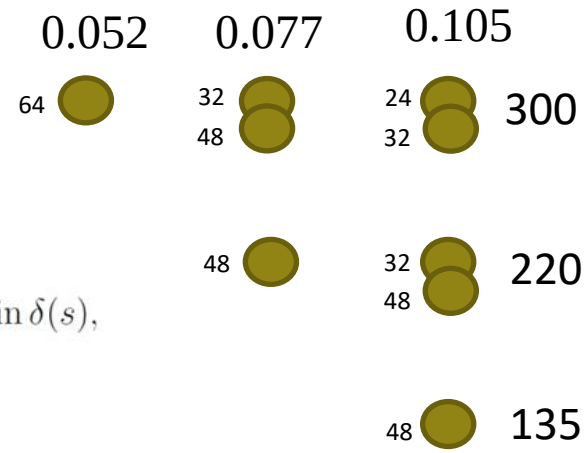


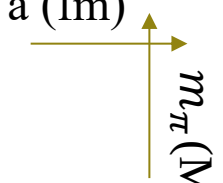



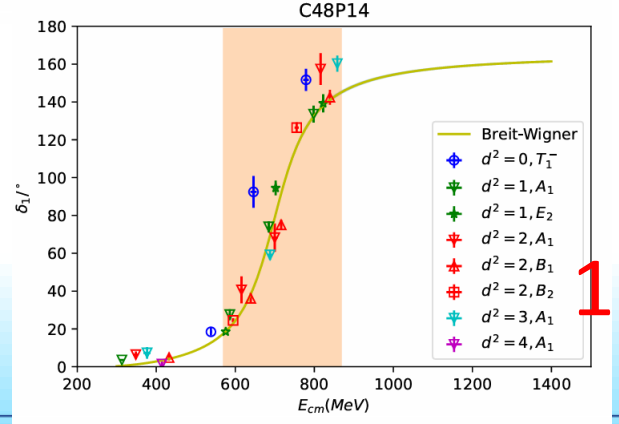




$$a_1 = \frac{-\sqrt{s}\Gamma(s)}{s - m_\rho^2 + \mathrm{i}\sqrt{s}\Gamma(s)} = \mathrm{e}^{\mathrm{i}\delta(s)} \sin\delta(s),$$

$$\Gamma(s) = \frac{p^{*3}}{s} \frac{g_{\rho\pi\pi}^2}{6\pi}.$$





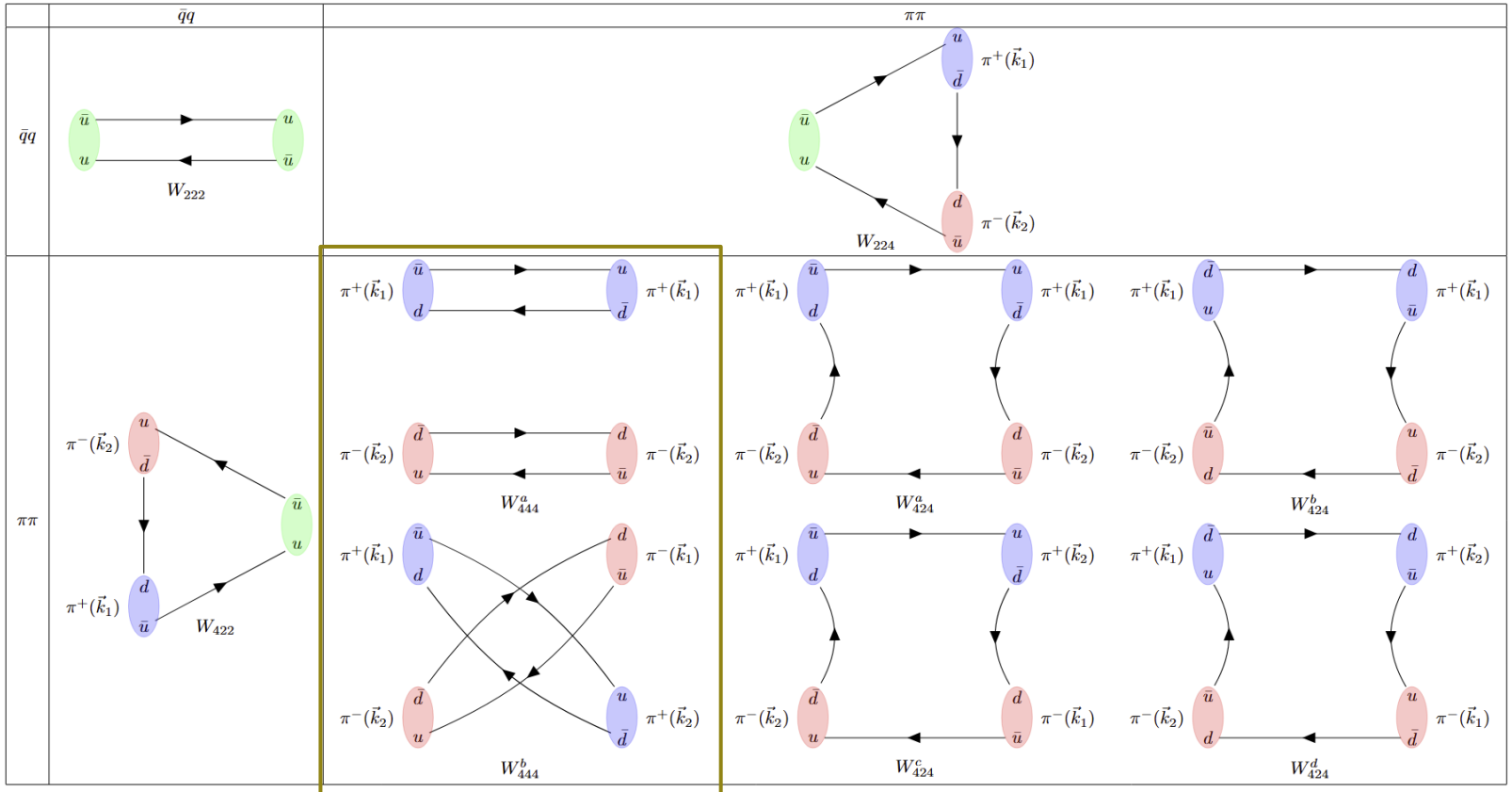

中国科学院大学
University of Chinese Academy of Sciences

# The wick contraction of ρ system

$q\bar{q}$ operator----2 quark

$\pi\pi$ operator----4 quark

$$W^a_{inj}$$

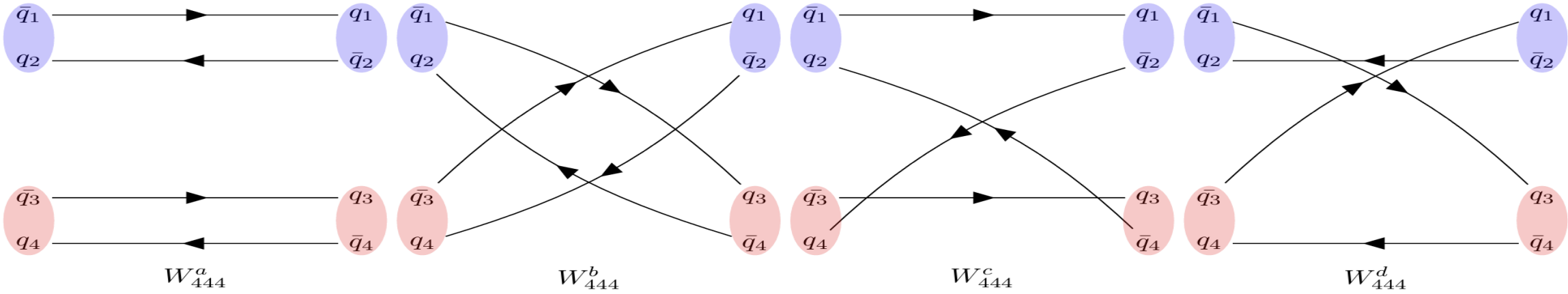



$$W^a_{444} - W^b_{444}$$

Can we exactly calculate these two contribution ???

**There are four quark lines at any spacetime point.**

# $W^a_{444}$ diagrams




$\boldsymbol{\pi^+\pi^+ \longrightarrow \pi^+\pi^+}$ ⟹ $W^a_{444} + W^b_{444} + W^c_{444} + W^d_{444}$

$\boldsymbol{KD, D_s\pi \longrightarrow KD, D_s\pi}$ ⟹ $\begin{pmatrix} W^a_{444} & W^{c/d}_{444} \\ W^{c/d}_{444} & W^a_{444} \end{pmatrix} \Rightarrow W^a_{444} \pm W^{c/d}_{444}$

$\boldsymbol{\pi^+K^+ \longrightarrow \pi^+K^+}$ ⟹ $W^a_{444} + W^{c/d}_{444}$

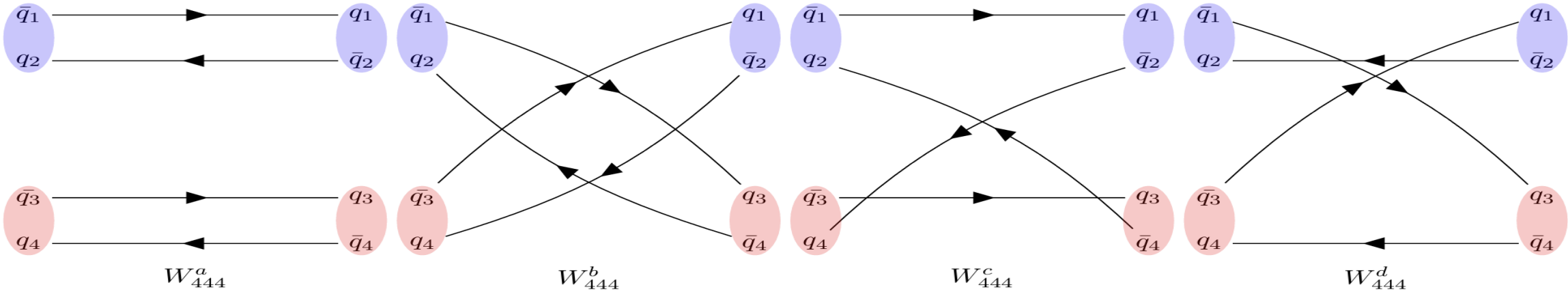
Partially-quenched:

valence quark mass

$\neq$

sea quark mass

# $W^a_{444}$ diagrams




$\pi^+\pi^+ \longrightarrow \pi^+\pi^+$ ⟹ $W^a_{444} + W^b_{444} + W^c_{444} + W^d_{444}$

$KD, D_s\pi \longrightarrow KD, D_s\pi$ ⟹ $\begin{pmatrix} W^a_{444} & W^{c/d}_{444} \\ W^{c/d}_{444} & W^a_{444} \end{pmatrix} \Rightarrow W^a_{444} \pm W^{c/d}_{444}$

$\pi^+K^+ \longrightarrow \pi^+K^+$ ⟹ $W^a_{444} + W^{c/d}_{444}$

Partially-quenched:

valence quark mass ≠ sea quark mass

Open question: such correlation function is really exact calculated?

$$C_{ij} = \left\langle 0 \middle| \mathcal{O}_i \mathcal{O}_j^\dagger \middle| 0 \right\rangle \stackrel{?}{=} \sum_n Z_i^n Z_j^{n*} e^{-E_n t}$$

# Rest Frame

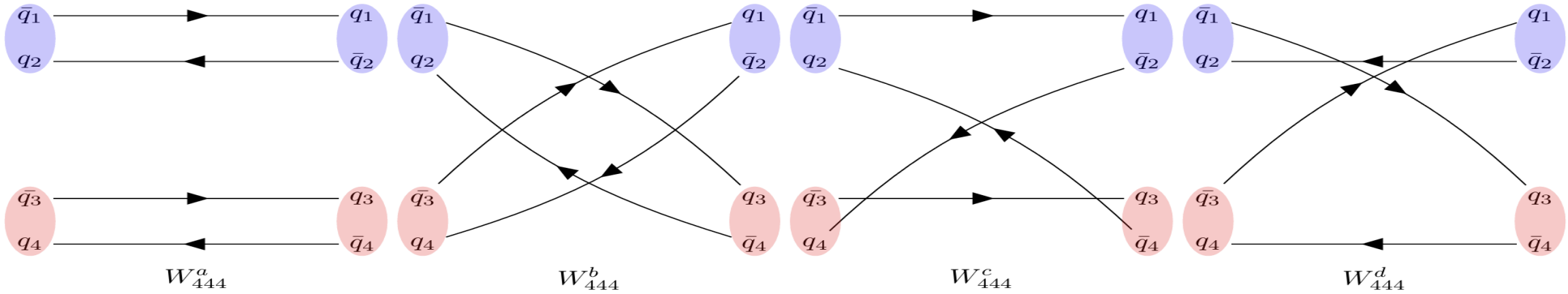
$$W^a_{444} - W^b_{444} = 2W^a_{444}$$

I=1 $\pi\pi$ operators for irrep $T_1^-$ always take such form

$$\pi^+[\boldsymbol{p}_1]\pi^-[-\boldsymbol{p}_1] - \pi^+[-\boldsymbol{p}_1]\pi^-[\boldsymbol{p}_1] + \pi^+[\boldsymbol{p}_2]\pi^-[-\boldsymbol{p}_2] - \pi^+[-\boldsymbol{p}_2]\pi^-[\boldsymbol{p}_2] + \ldots$$

$W^a_{444} = -W^b_{444}$

$Re[W^c_{444}] = Re[W^d_{444}] = 0$




$\boldsymbol{\pi^+\pi^+ \longrightarrow \pi^+\pi^+}$ $\Rightarrow$ $W^a_{444} + W^b_{444} + W^c_{444} + W^d_{444}$ $\Rightarrow$ 0

$\boldsymbol{KD, D_s\pi \longrightarrow KD, D_s\pi}$ $\Rightarrow$ $W^a_{444} \pm W^{c/d}_{444}$ $\Rightarrow$ $W^a_{444}$

$$W^a_{444} = \sum_i |Z_i|^2 e^{-E_i t}$$

# Moving Frame

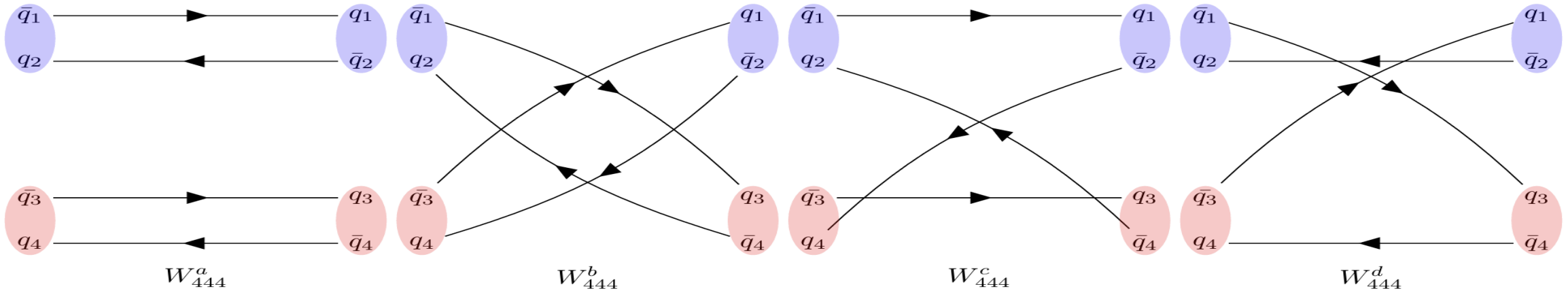
$W_{444}^{a} - W_{444}^{b}$

I=1 $\pi\pi$ operators for irrep $T_1^-$ always take such form

$$\pi^+[\boldsymbol{p}_1]\pi^-[\boldsymbol{p}_2] + \pi^+[\boldsymbol{p}_3]\pi^-[\boldsymbol{p}_4] + \ldots,\ \boldsymbol{p}_1 + \boldsymbol{p}_2 = \boldsymbol{p}_3 + \boldsymbol{p}_4 = \boldsymbol{P}$$

$W_{444}^{a} \neq -W_{444}^{b}$

$Re[W_{444}^{c}] = Re[W_{444}^{d}] = 0$




$\boldsymbol{\pi^+\pi^+ \longrightarrow \pi^+\pi^+}$ ⟹ $W_{444}^{a} + W_{444}^{b} + W_{444}^{c} + W_{444}^{d}$

$W_{444}^{a} + W_{444}^{b} + W_{444}^{c} + W_{444}^{d} = \sum_i |Z_i|^2 e^{-E_i t}$

$\boldsymbol{KD, D_s\pi \longrightarrow KD, D_s\pi}$ ⟹ $W_{444}^{a} \pm W_{444}^{c/d}$

$W_{444}^{a} \pm W_{444}^{c/d} = \sum_i |Z_i|^2 e^{-E_i t}$

# Result

| Config | $L^3 \times T$ | $a[fm]$ | $m_\pi[MeV]$ | $N_{cfg}$ | Irrep |
|---|---|---|---|---|---|
| C32P23 | $32^3 \times 64$ | 0.10530(18) | 228.0(1.2) | 450 | $T_1^-, A_1$ |
| C48P23 | $48^3 \times 64$ | | | 265 | $T_1^-$ |

Z. Wang, D. B. Leinweber, et al., JHEP 08, 064 (2025)

**C32P23 :**

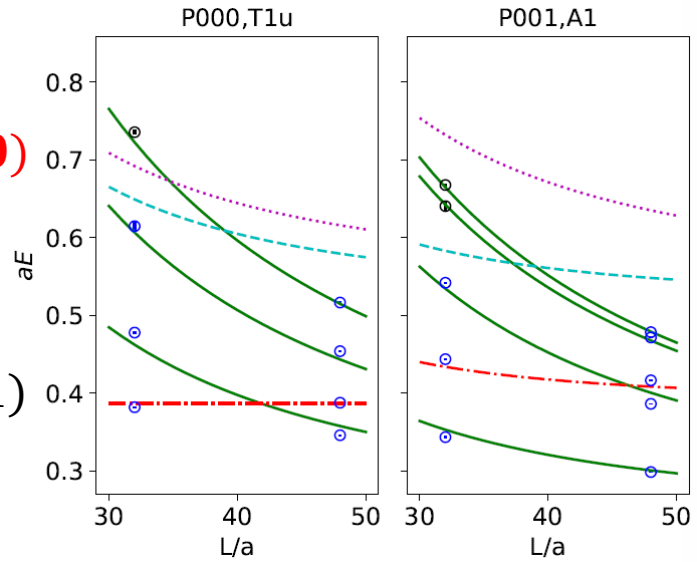
**rest frame, $2\mathbf{E}(1) > m_\rho > 2m_\pi$**

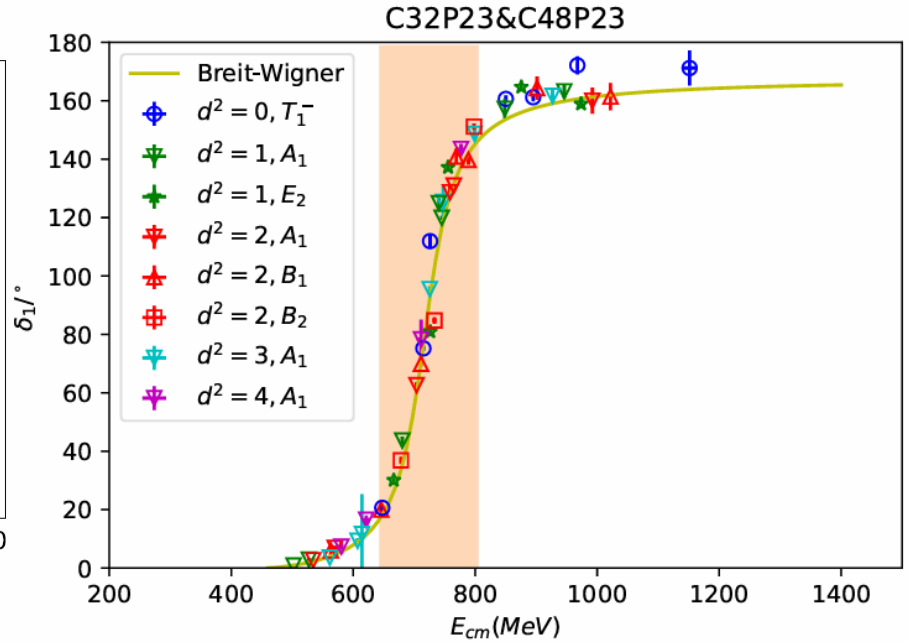
**Moving, $\mathbf{E}(2) + \mathbf{E}(1) > m_\rho > \mathbf{E}(1) + \mathbf{E}(0)$**

**C48P23 :**

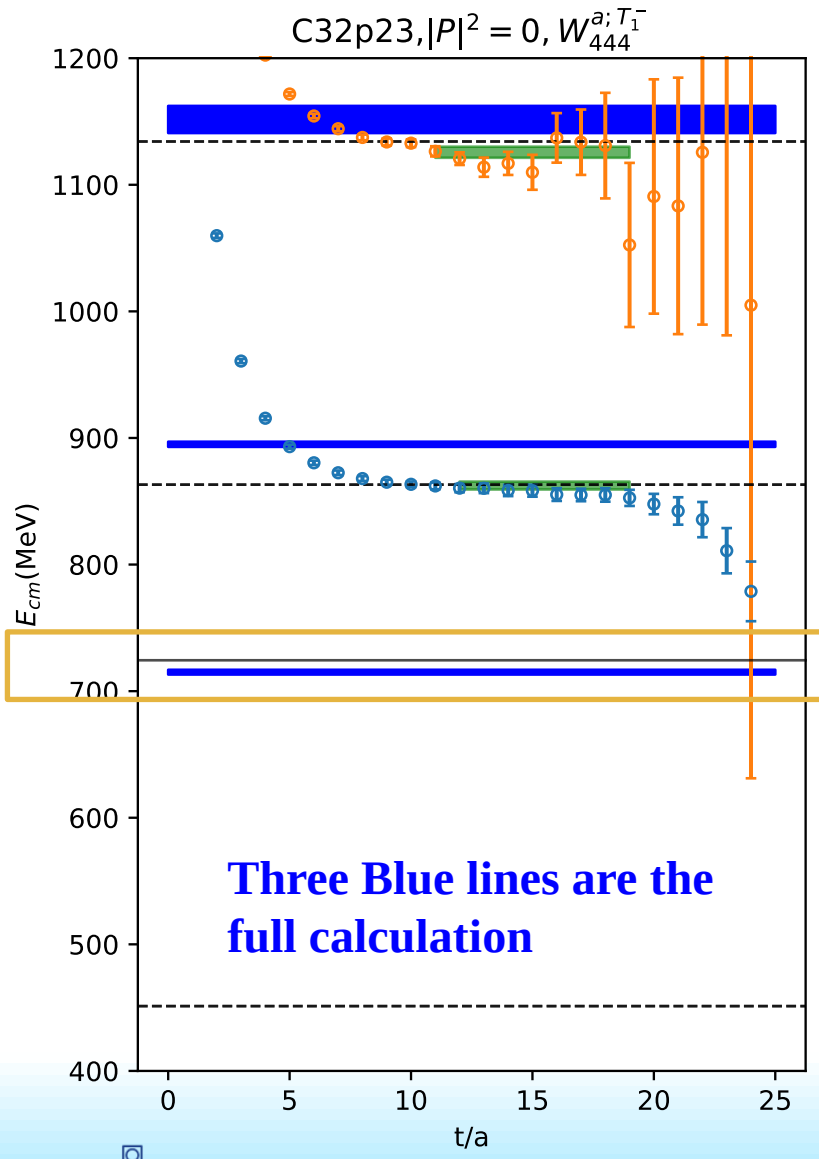
**rest frame, $2\mathbf{E}(2) > m_\rho > 2\mathbf{E}(1)$**

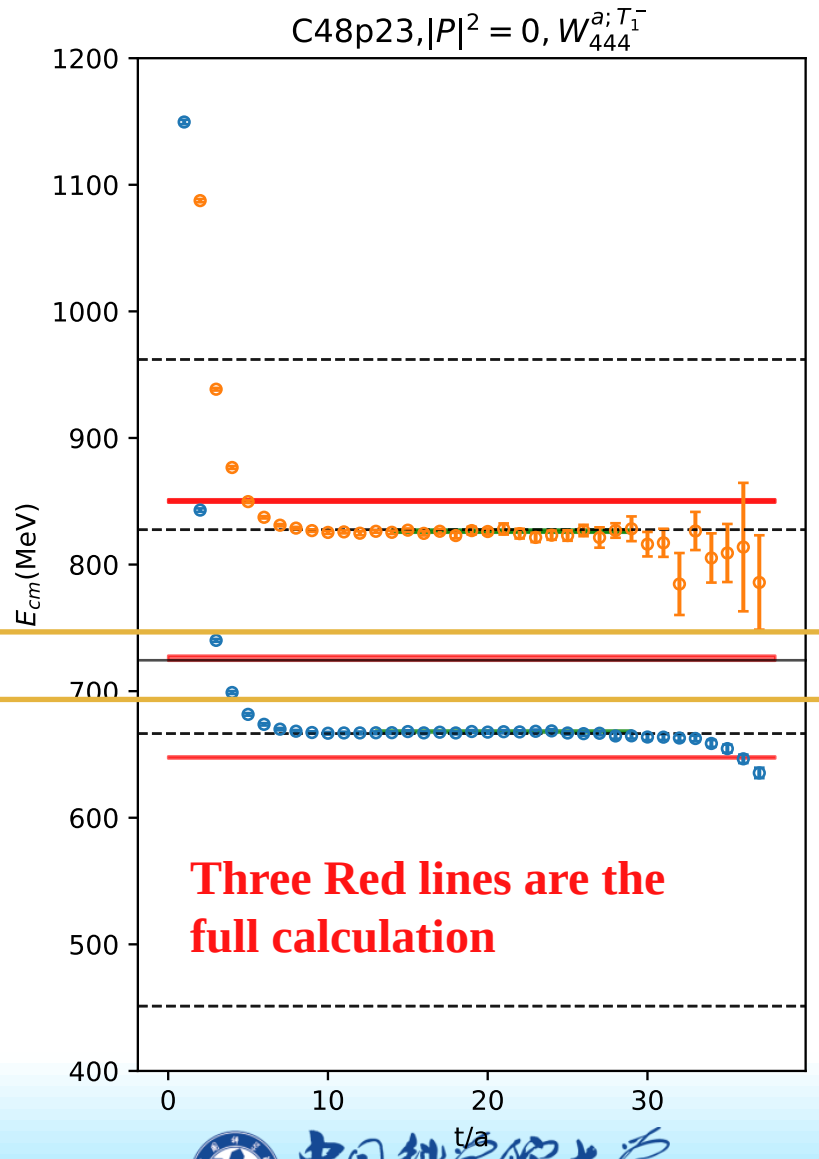
We include two $\pi\pi$ operator, for $\pi(1)\pi(-1)$ and $\pi(2)\pi(-2)$ for rest frame, and for $\pi(0)\pi(1)$ and $\pi(1)\pi(2)$ for moving frame.

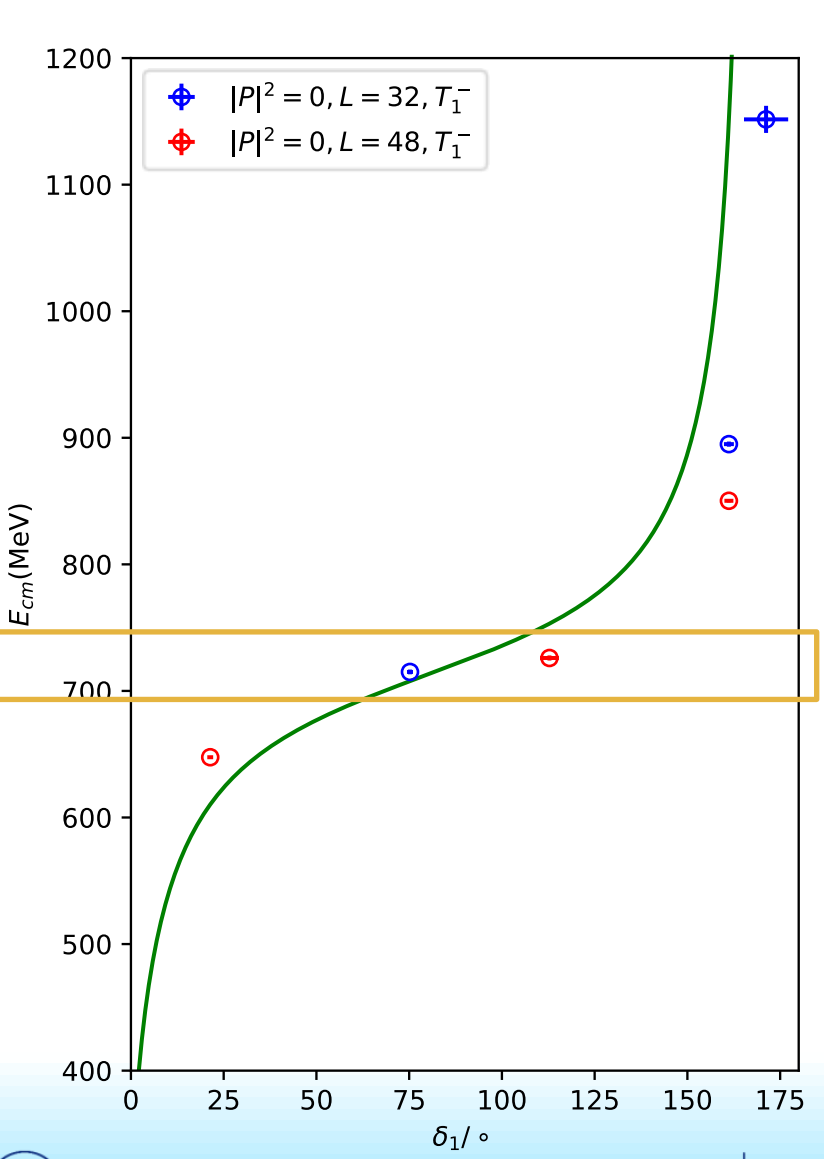


# Result: Rest frame



# Result: Moving frame

Now for moving frame, total momentum $|P|^2 = 1$ , irrep $A_1$ , we can calculate correlation function like

$$W^a_{444} + W^b_{444} + W^c_{444} + W^d_{444} = \sum_{i=1}^{2} a_i e^{-E_i^1 t} \begin{pmatrix} v_1^i u_1^i & v_1^i u_2^i \\ v_2^i u_1^i & v_2^i u_2^i \end{pmatrix},$$

$$W^a_{444} + W^c_{444} = \sum_{i=1}^{2} b_i e^{-E_i^2 t} \begin{pmatrix} m_1^i n_1^i & m_1^i n_2^i \\ m_2^i n_1^i & m_2^i n_2^i \end{pmatrix},$$

$$W^a_{444} + W^d_{444} = \sum_{i=1}^{2} c_i e^{-E_i^3 t} \begin{pmatrix} k_1^i l_1^i & k_1^i l_2^i \\ k_2^i u_1^i & k_2^i l_2^i \end{pmatrix},$$

Here $i$ refers to $i$-th momentum operator, $v_1^i$ and $u_1^i$ are components of generalized eigenvectors. If we need to extract $W^a_{444} - W^b_{444}$

$$W^a_{444} - W^b_{444} = (W^a_{444} + W^c_{444}) + (W^a_{444} + W^d_{444}) - (W^a_{444} + W^b_{444} + W^c_{444} + W^d_{444})$$

$$W^a_{444} - W^b_{444} = \sum_{i=1}^{2} b_i e^{-E_i^2 t} \begin{pmatrix} m_1^i n_1^i & m_1^i n_2^i \\ m_2^i n_1^i & m_2^i n_2^i \end{pmatrix} + \sum_{i=1}^{2} c_i e^{-E_i^3 t} \begin{pmatrix} k_1^i l_1^i & k_1^i l_2^i \\ k_2^i l_1^i & k_2^i l_2^i \end{pmatrix} - \sum_{i=1}^{2} a_i e^{-E_i^1 t} \begin{pmatrix} v_1^i u_1^i & v_1^i u_2^i \\ v_2^i u_1^i & v_2^i u_2^i \end{pmatrix}$$

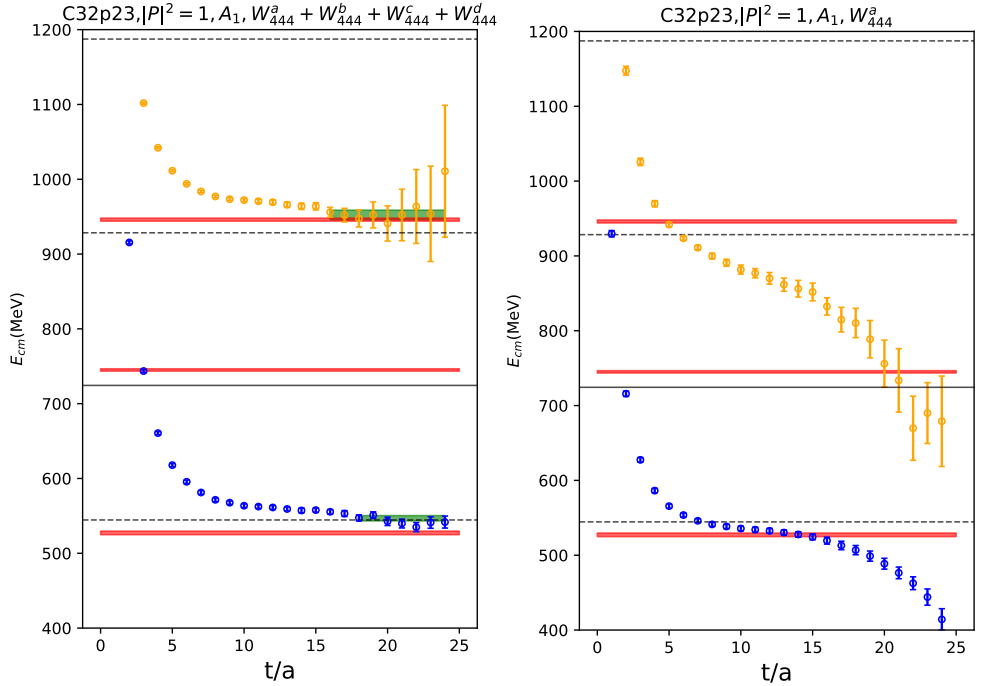
# Result: Moving frame

Now for moving frame, total momentum $|P|^2 = 1$ , irrep $A_1$ ,
we can calculate correlation function like

$$W^a_{444} + W^b_{444} + W^c_{444} + W^d_{444} = \sum_{i=1}^{2} a_i e^{-E^1_i t} \begin{pmatrix} v^i_1 u^i_1 & v^i_1 u^i_2 \\ v^i_2 u^i_1 & v^i_2 u^i_2 \end{pmatrix},$$

$$W^a_{444} + W^c_{444} = \sum_{i=1}^{2} b_i e^{-E^2_i t} \begin{pmatrix} m^i_1 n^i_1 & m^i_1 n^i_2 \\ m^i_2 n^i_1 & m^i_2 n^i_2 \end{pmatrix},$$

$$W^a_{444} + W^d_{444} = \sum_{i=1}^{2} c_i e^{-E^3_i t} \begin{pmatrix} k^i_1 l^i_1 & k^i_1 l^i_2 \\ k^i_2 u^i_1 & k^i_2 l^i_2 \end{pmatrix},$$




Here $i$ refers to $i$-th momentum operator, $v^i_1$ and $u^i_1$ are components of generalized eigenvectors. If we need to extract $W^a_{444} - W^b_{444}$

$$W^a_{444} - W^b_{444} = (W^a_{444} + W^c_{444}) + (W^a_{444} + W^d_{444}) - (W^a_{444} + W^b_{444} + W^c_{444} + W^d_{444})$$

$$W^a_{444} - W^b_{444} = \sum_{i=1}^{2} b_i e^{-E^2_i t} \begin{pmatrix} m^i_1 n^i_1 & m^i_1 n^i_2 \\ m^i_2 n^i_1 & m^i_2 n^i_2 \end{pmatrix} + \sum_{i=1}^{2} c_i e^{-E^3_i t} \begin{pmatrix} k^i_1 l^i_1 & k^i_1 l^i_2 \\ k^i_2 l^i_1 & k^i_2 l^i_2 \end{pmatrix} - \sum_{i=1}^{2} a_i e^{-E^1_i t} \begin{pmatrix} v^i_1 u^i_1 & v^i_1 u^i_2 \\ v^i_2 u^i_1 & v^i_2 u^i_2 \end{pmatrix}$$

# Result: Moving frame

$$W^a_{444}+W^b_{444}+W^c_{444}+W^d_{444}=0.530*e^{-659.3(2.2)t}\begin{pmatrix}0.916 & -0.018\\ -0.018 & 3\times10^{-4}\end{pmatrix}+1.75*e^{-1020.2(6.0)t}\begin{pmatrix}0.083 & 0.289\\ 0.289 & 0.999\end{pmatrix}$$

$$W^a_{444}+W^c_{444}=0.551*e^{-656.9(2.3)t}\begin{pmatrix}0.980 & 0.009\\ 0.009 & 9\times10^{-5}\end{pmatrix}+0.697*e^{-991.6(5.2)t}\begin{pmatrix}0.020 & 0.142\\ 0.142 & 0.999\end{pmatrix}$$

$$W^a_{444}+W^d_{444}=0.546*e^{-656.5(2.2)t}\begin{pmatrix}0.967 & 0.009\\ 0.009 & 8\times10^{-5}\end{pmatrix}+0.692*e^{-991.6(5.6)t}\begin{pmatrix}0.020 & 0.140\\ 0.140 & 0.992\end{pmatrix}$$

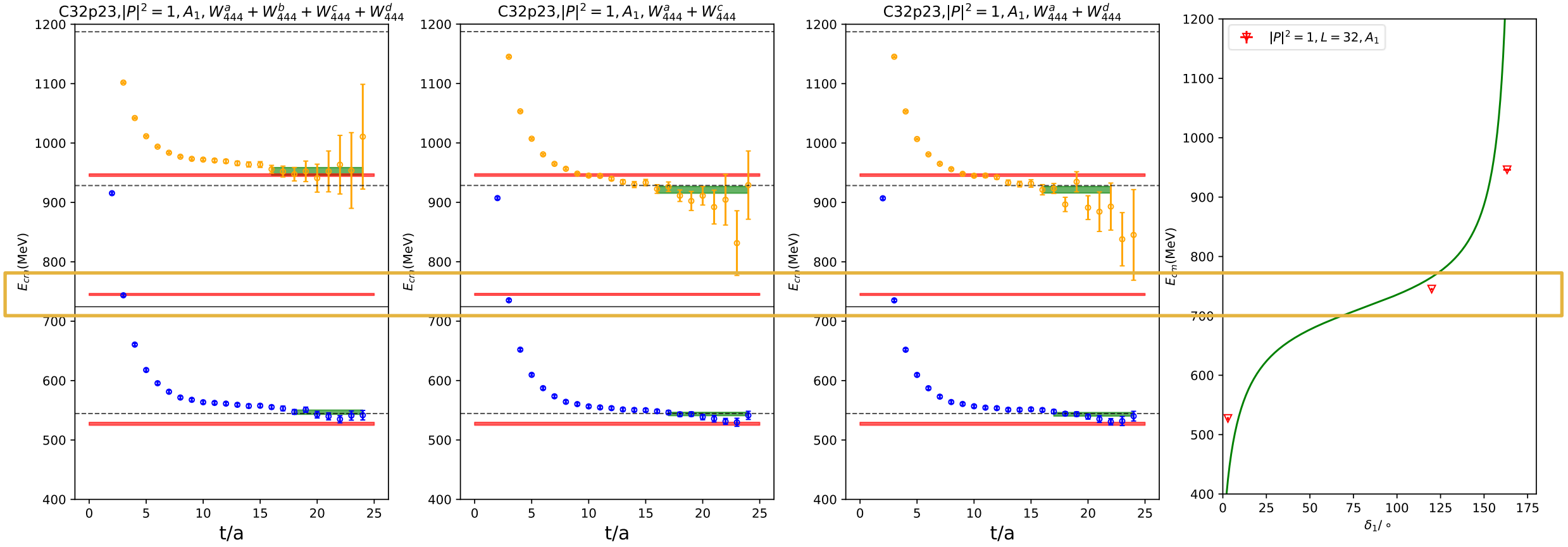
Then finally we obtain

$$W^d_{444}-W^a_{444}=\begin{pmatrix}0.48548 & -0.00954\\ -0.00954 & 0.000159\end{pmatrix}e^{-659.3(2.2)t}+\begin{pmatrix}0.14525 & 0.50575\\ 0.50575 & 1.74825\end{pmatrix}e^{-1020.2(6.0)t}$$

$$-\begin{pmatrix}0.53998 & 0.004959\\ 0.004959 & 0.00004959\end{pmatrix}e^{-656.9(2.3)t}-\begin{pmatrix}0.01394 & 0.098974\\ 0.098974 & 0.696303\end{pmatrix}e^{-991.6(5.2)t}$$

$$-\begin{pmatrix}0.527982 & 0.004914\\ 0.004914 & 0.00004368\end{pmatrix}e^{-656.5(2.2)t}-\begin{pmatrix}0.01384 & 0.09688\\ 0.09688 & 0.686464\end{pmatrix}e^{-991.6(5.6)t}$$

# Result: Moving frame




Conclusion: $W^a_{444} - W^b_{444}$ term can not provide $\rho$ energy level, in other words, $\rho$ is mainly originated from $q\bar{q}$.

# Summary and OutLook

- **We divide wick contraction diagrams as two parts of $\pi\pi$ p-wave channel for $\rho$ meson.**
- **We use partially-quenched method to calculate 4 quark connected wick contraction diagrams, and we can extract the energy levels from these connected diagrams.**
- **We find these energy levels are all far away from the energy levels corresponding to the $\rho$ meson.**

- **If this method is available, we can test f0(980) is a $K\bar{K}$ hadronic molecular state or a $q\bar{q}$ state.**

**Thanks for your attention !**

# Thanks for attention