Z_c(3900) from lattice QCD

based on Y. Ikeda et al., (HAL QCD), arXiv.1602.03465(hep-lat).

Yoichi IKEDA (RCNP, Osaka Univ.)

HAL QCD (Hadrons to Atomic nuclei from Lattice QCD)

S. Aoki, D. Kawai, T. Miyamoto, K. Sasaki (YITP, Kyoto Univ.)

T. Doi, T. Hatsuda, T. Iritani (RIKEN)

S. Gongyo (Univ. Tours)

T. Inoue (Nihon Univ.)

Y. Ikeda, N. Ishii, K. Murano (RCNP, Osaka Univ.)

H. Nemura (Univ. Tsukuba)

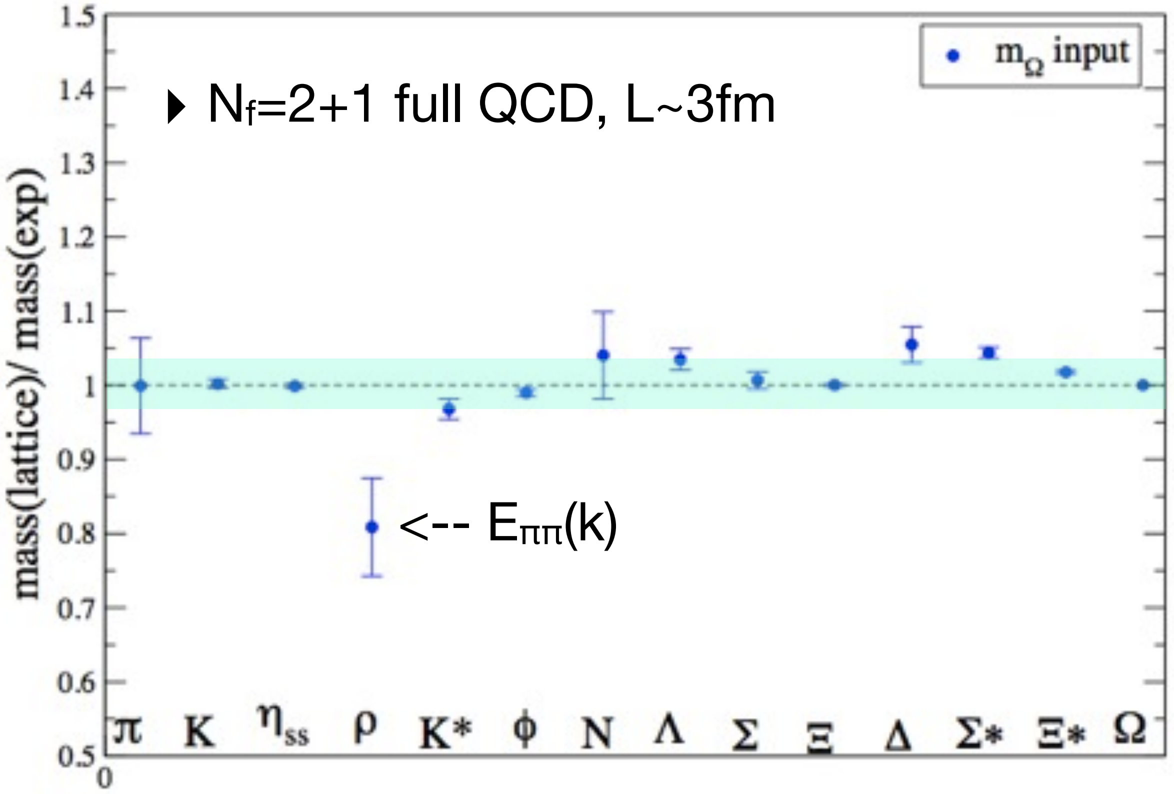
Long-term workshop in Realistic Hadron Interactions in QCD (RHIQCD2016)

@YITP, Kyoto (Dec. 2, 2016.)

Single hadron spectroscopy from LQCD

★ **Low-lying (stable) hadrons on physical point (physical m_q)**

light hadrons

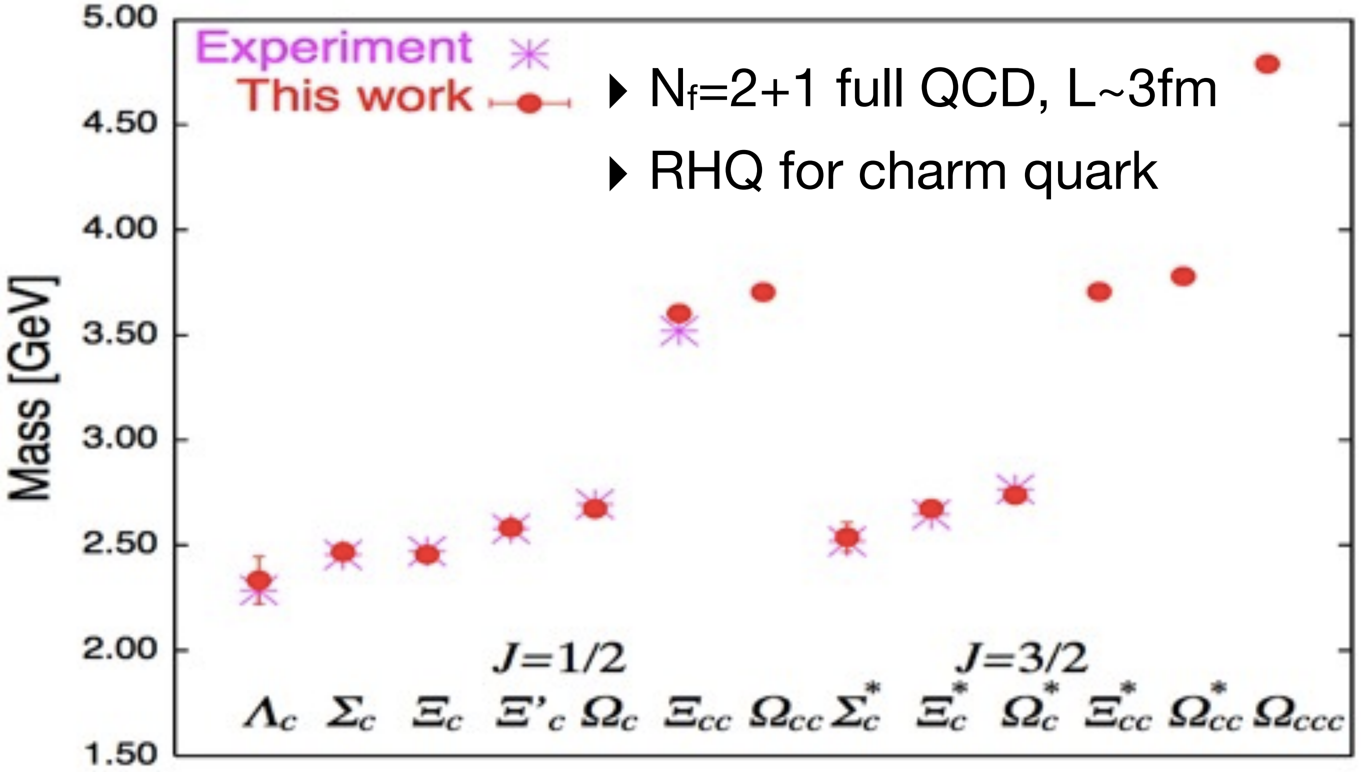


- $N_f=2+1$ full QCD, L~3fm

<-- $E_{\pi\pi}(k)$

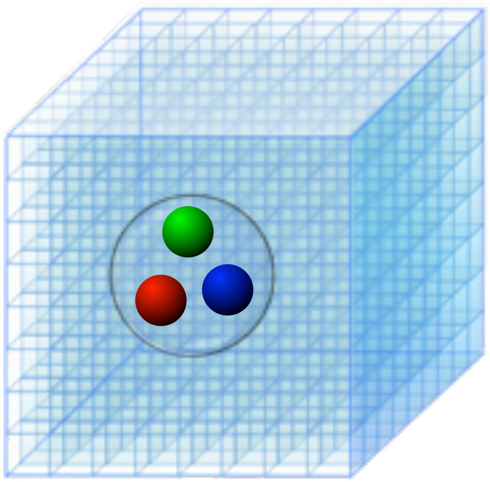
Aoki et al. (PACS-CS), PRD81 (2010).

charm baryons



- $N_f=2+1$ full QCD, L~3fm
- RHQ for charm quark

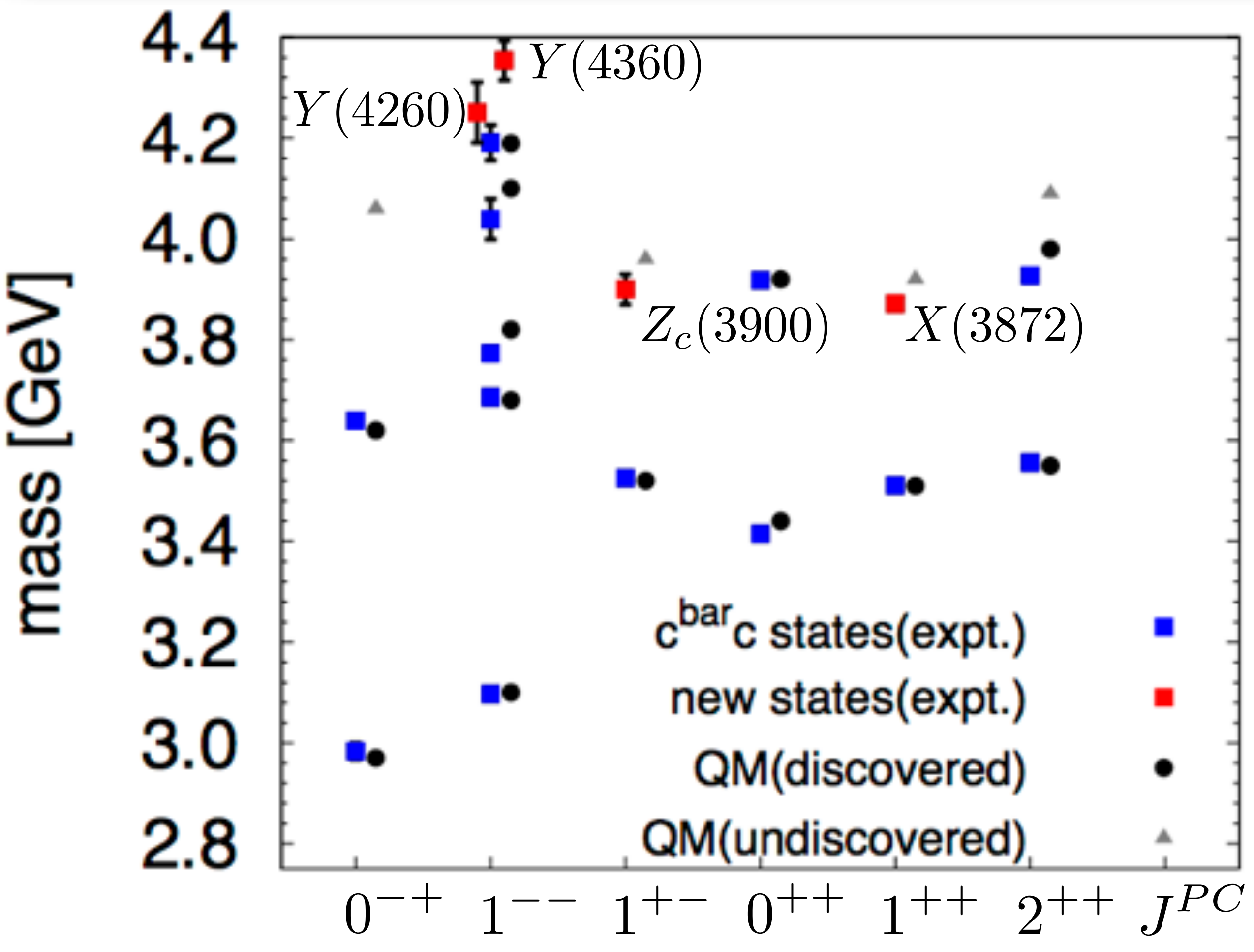
Namekawa et al. (PACS-CS), PRD84 (2011); PRD87 (2013).



- a few % accuracy already achieved for single hadrons
- LQCD now can predict undiscovered charm hadrons (Ξ_{cc}, Ξ^*_{cc}, Ω_{ccc},...)

➡ **Next challenge : multi-hadrons (resonances)**

Charmonium-like states

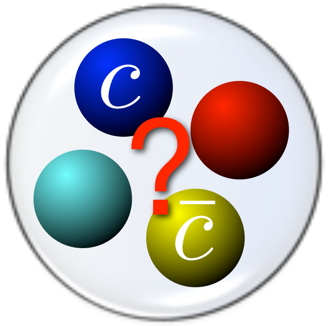


✓ Quark models well describe observed mass spectra at low energies (< 3.8 GeV)

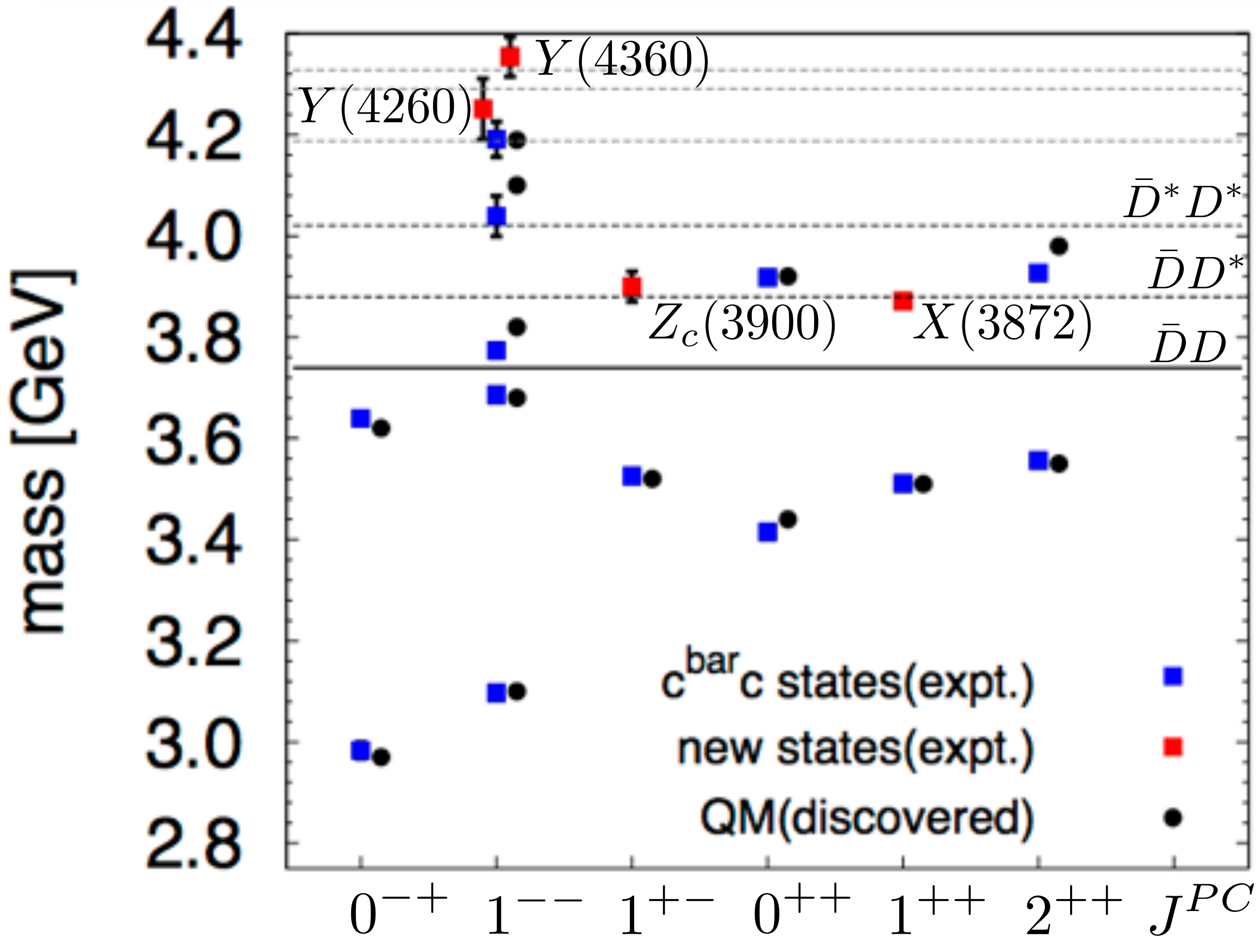
✓ Several states at high energies (> 3.8GeV) are not discovered

Godfrey, Isgur, PRD 32 (1985).
Barnes, Godfrey, Swanson, PRD 72 (2005).

- NEW (X, Y, Z) states observed in expt. which are NOT within QM spectrum
- Non-$c^{bar}c$ structures = exotic hadrons?



Charmonium-like states



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- NEW (X, Y, Z) states observed in expt. which are NOT within QM spectrum
- Non-c$^{\text{bar}}$c structures = exotic hadrons?

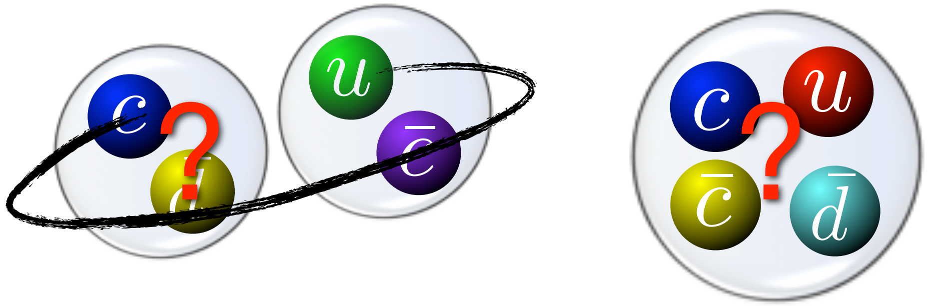
- All X, Y, Z states are found above 3.8 GeV

✓ Lowest open charm threshold (D$^{\text{bar}}$D) is 3.75 GeV

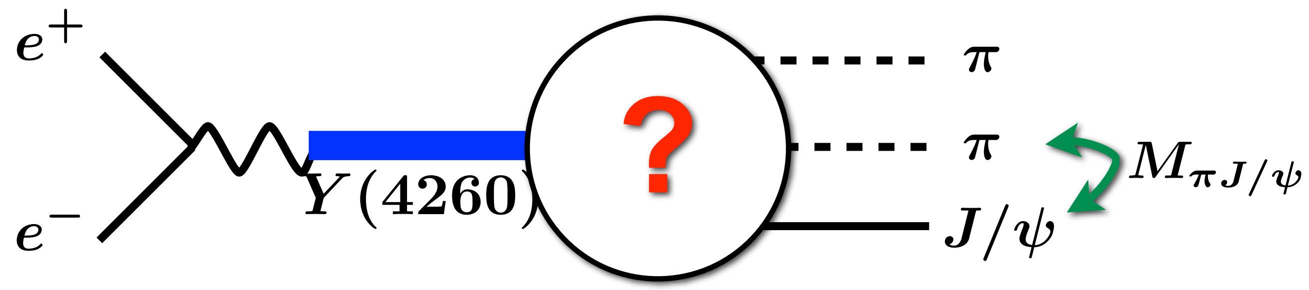
✓ All new states embedded in two-meson continuum (D$^{\text{bar}}$D, D$^{\text{bar}}$D*, D$^{\text{bar}*}$D*,...)

✓ Channel coupling could be a key to investigate X, Y, Z states

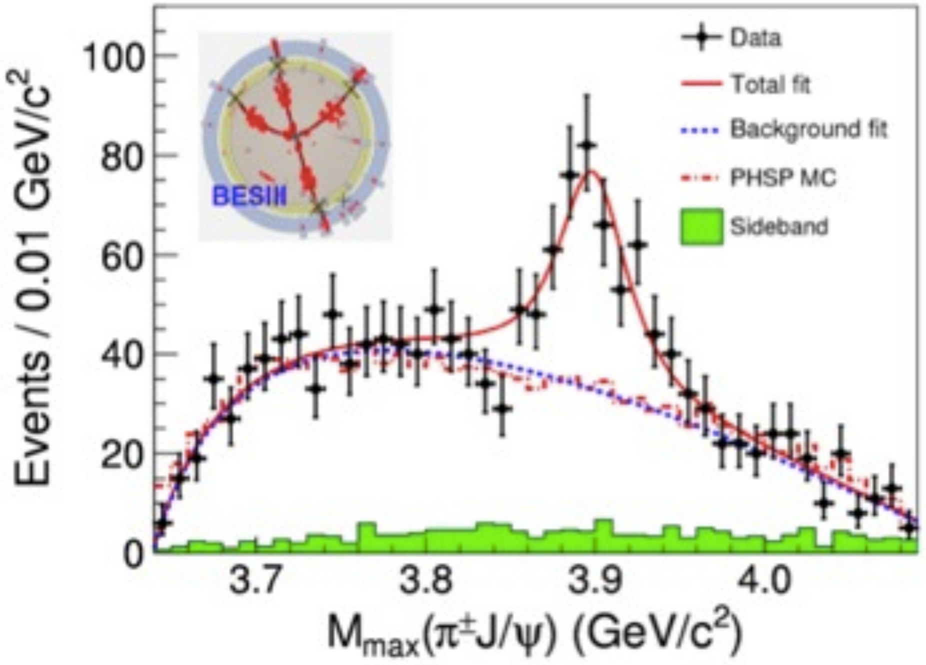
- Our target : charmonium-like Z$_c$(3900)



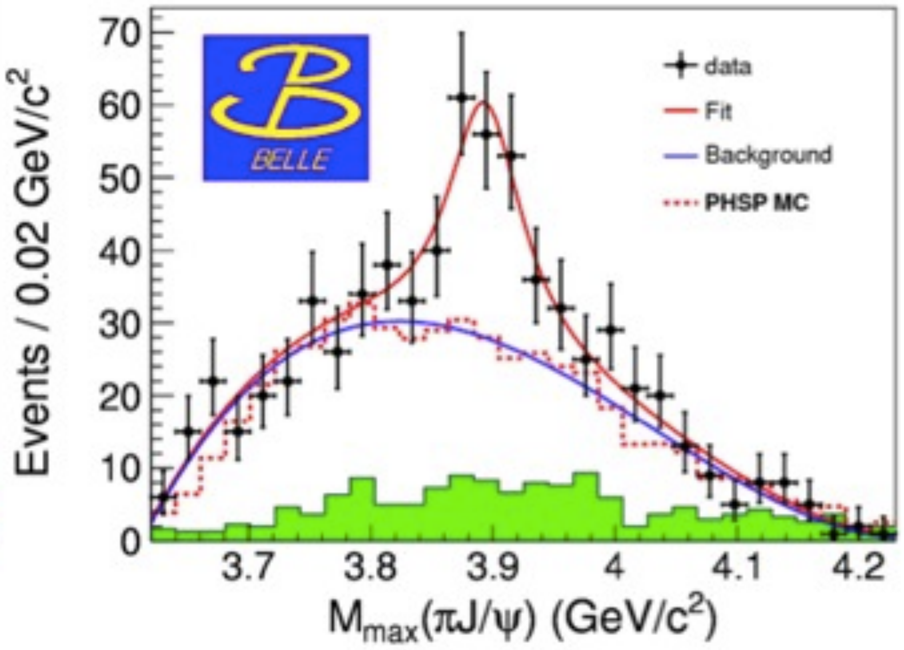
What is Z_c(3900)?

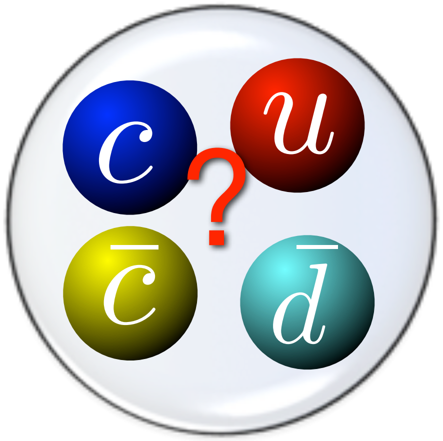


BESIII Coll., PRL110, 252001, (2013).



Belle Coll., PRL110, 252002, (2013).

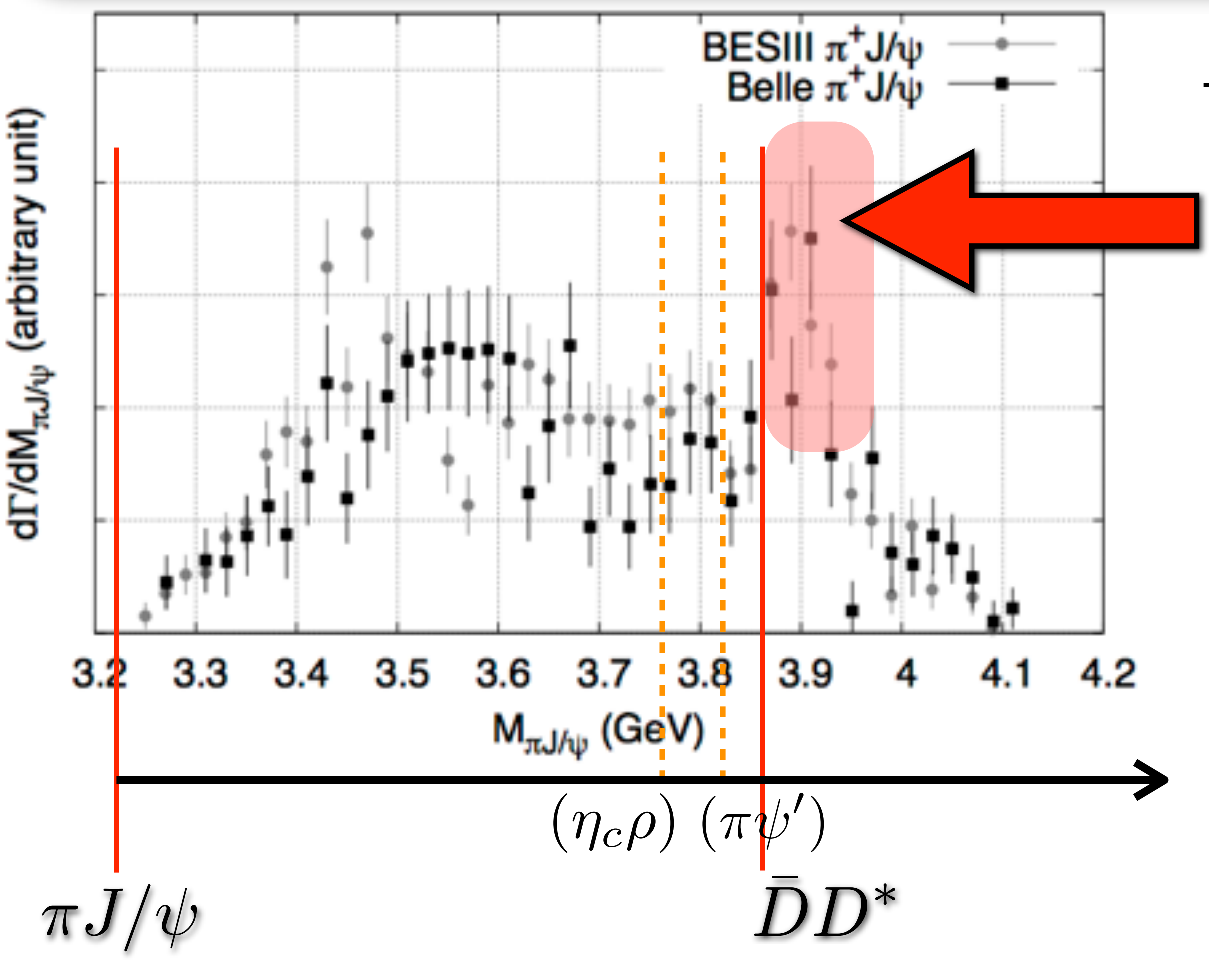




- Z_c(3900) is observed in $\pi^{\pm}J/\psi$ invariant mass
- Minimal quark content : 4 quarks ($c^{bar}c\ u^{bar}d$)
- M ~ 3900, Γ ~ 60 MeV when Breit-Wigner resonance assumed
- spin-parity: $J^{PC}=1^{+-}$ by PWA

BESIII Coll., PRL112 (2014), talik in MENU2016

Structure of $Z_c(3900)$?



<u>Expt. status</u>

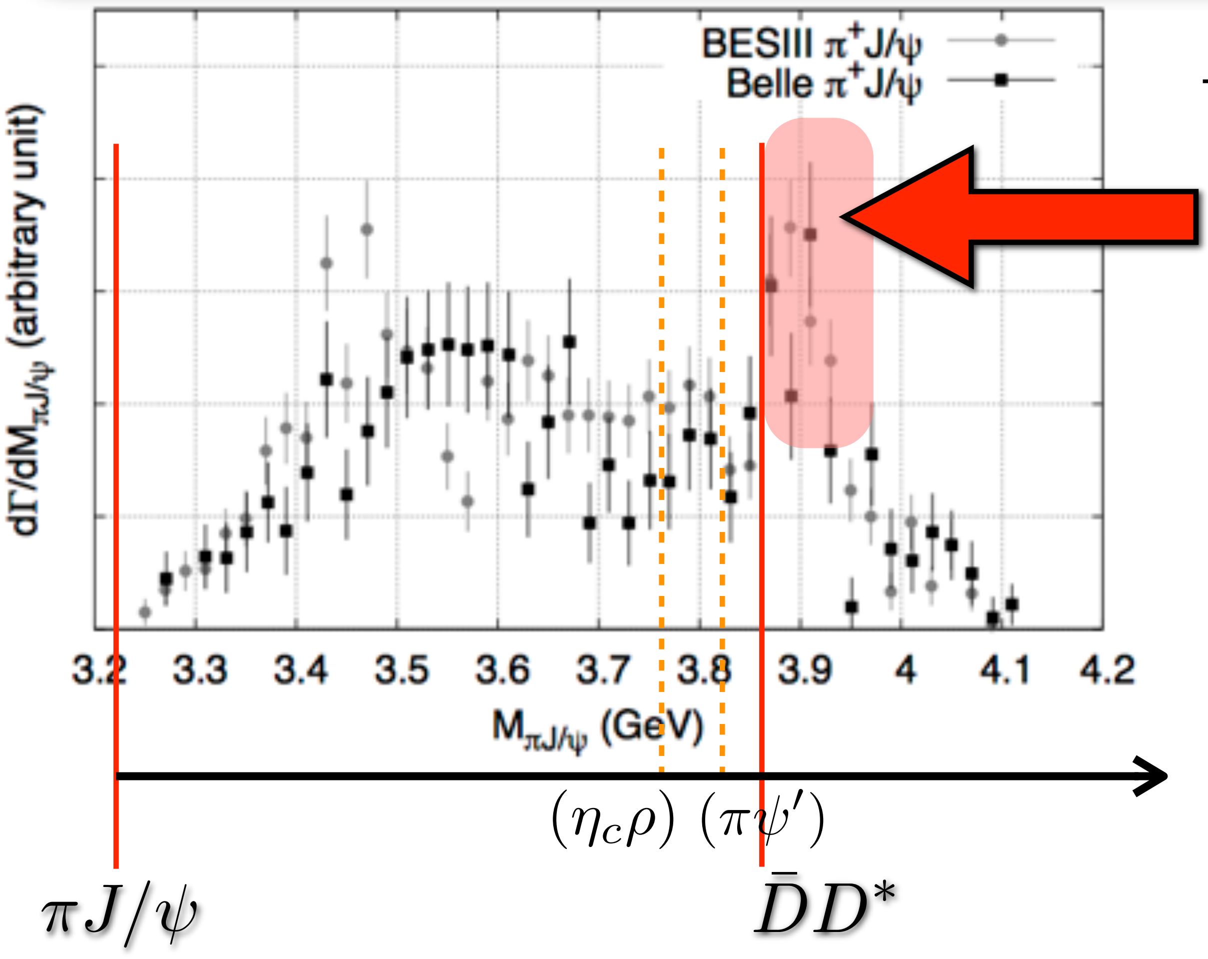
- Peak just above $D^{bar}D^*$ threshold found in $\pi J/\psi$ invariant mass
- $J^P=1^+$ <--> s-wave $\pi J/\psi$ - $D^{bar}D^*$ dynamics

▸ <u>Decay rate of $Z_c(3900)$</u>

$$\frac{\Gamma(Z_c(3900)\to\bar{D}D^*)}{\Gamma(Z_c(3900)\to\pi J/\psi)}\simeq 6.2$$

BESIII Coll., PRL112 (2014).

Structure of $Z_c(3900)$?



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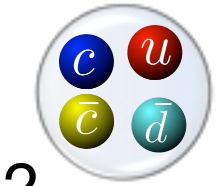
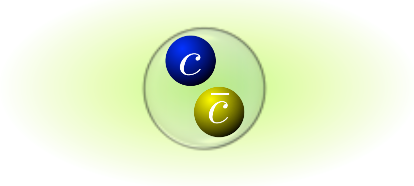
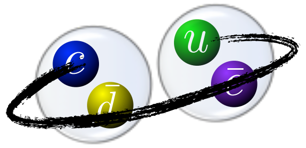
★ Structure of $Z_c(3900)$ from models

- Tetraquark? **Maiani et al. (2013).**



- J/ψ + π cloud, $D^{bar}D^*$ molecule?

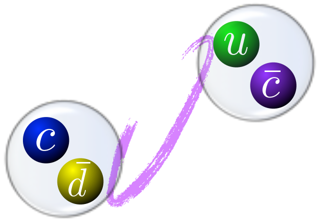




Voloshin (2008),
Nieves et al. (2011),
+ many others

- Threshold kinematical effect?

Chen et al. (2013), Swanson (2015).



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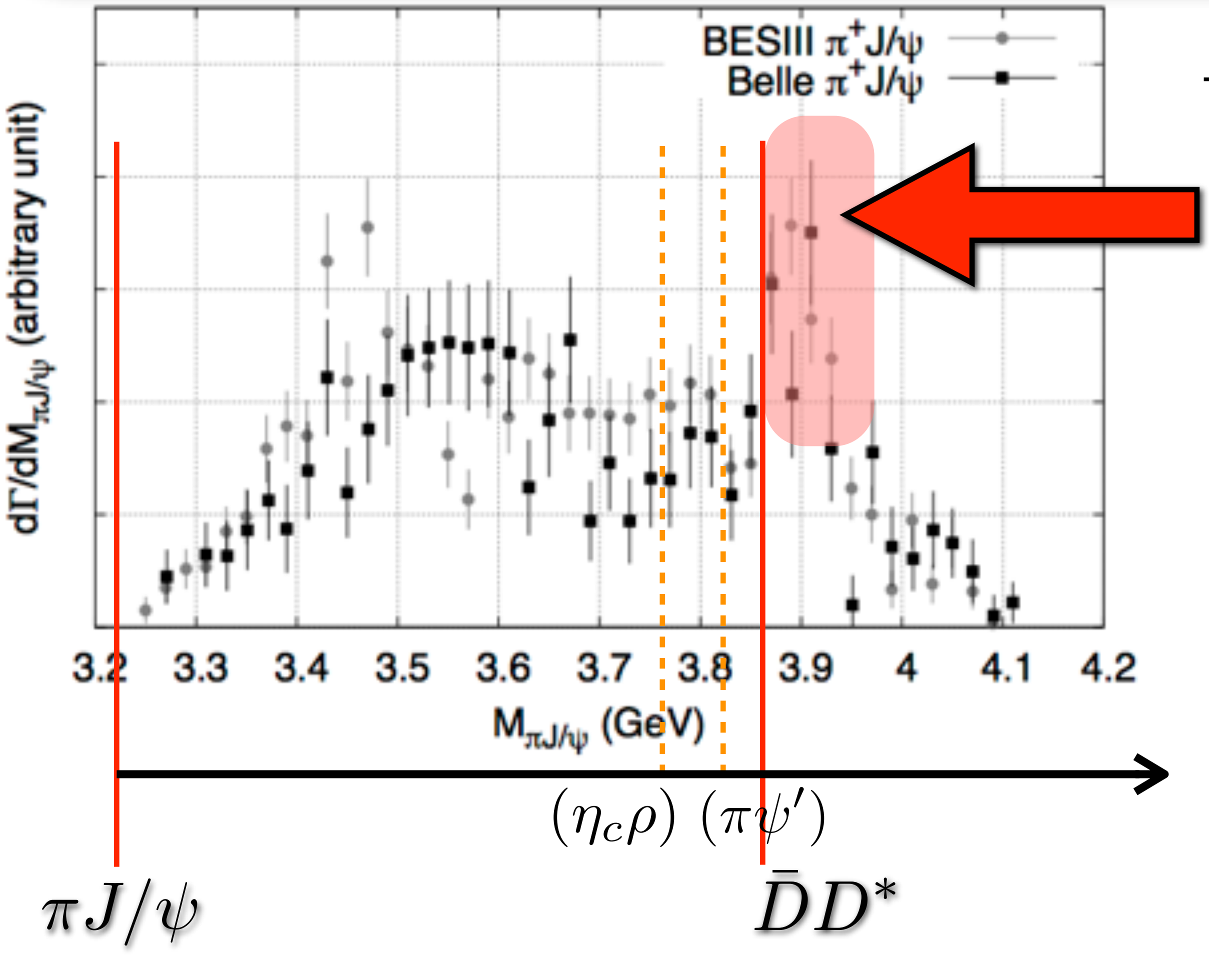

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BESIII Coll., PRL112 (2014).

★ **Structure of $Z_c(3900)$ from models** ➡ **poor information on interactions**

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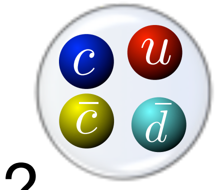

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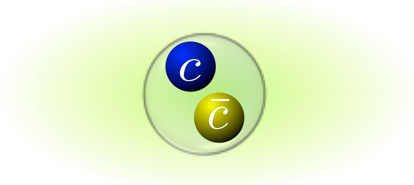

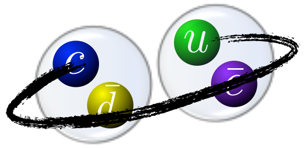

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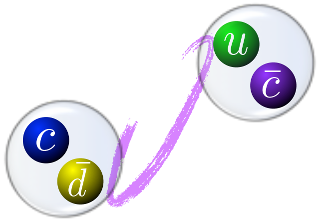
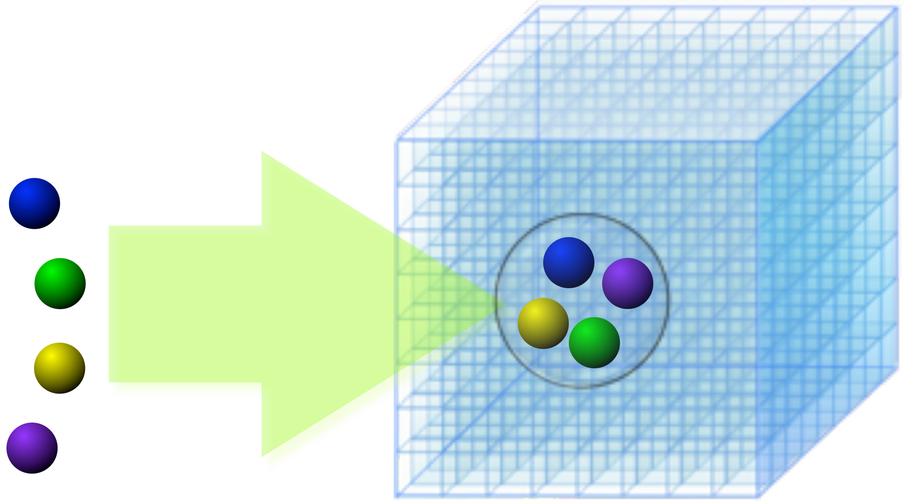


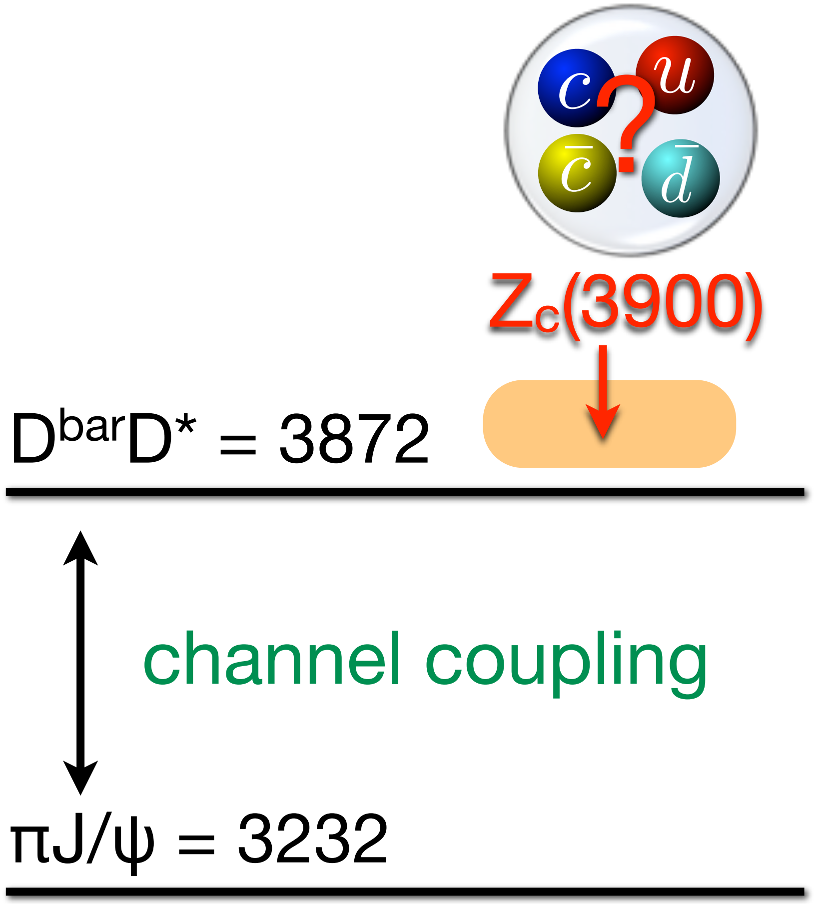
Chen et al. (2013), Swanson (2015).

★ LQCD simulations for $Z_c(3900)$



Contents

- Brief introduction to $Z_c(3900)$
- How to study $Z_c(3900)$ on the lattice?
- Coupled-channel interactions for $Z_c(3900)$ in $I^G(J^{PC})=1^+(1^{+-})$
- Structure of $Z_c(3900)$
- Comparison with experimental data
- Summary



$Z_c(3900)$

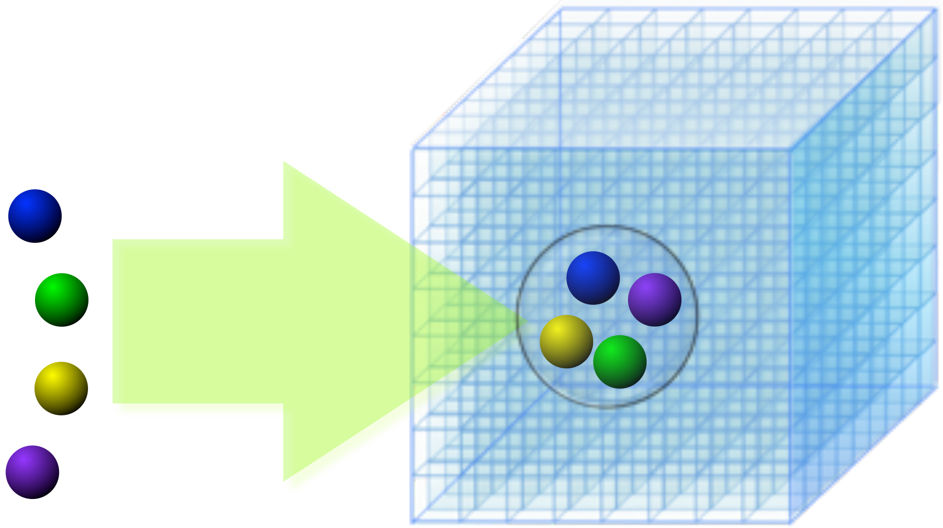
$D^{bar}D^*$ = 3872

channel coupling

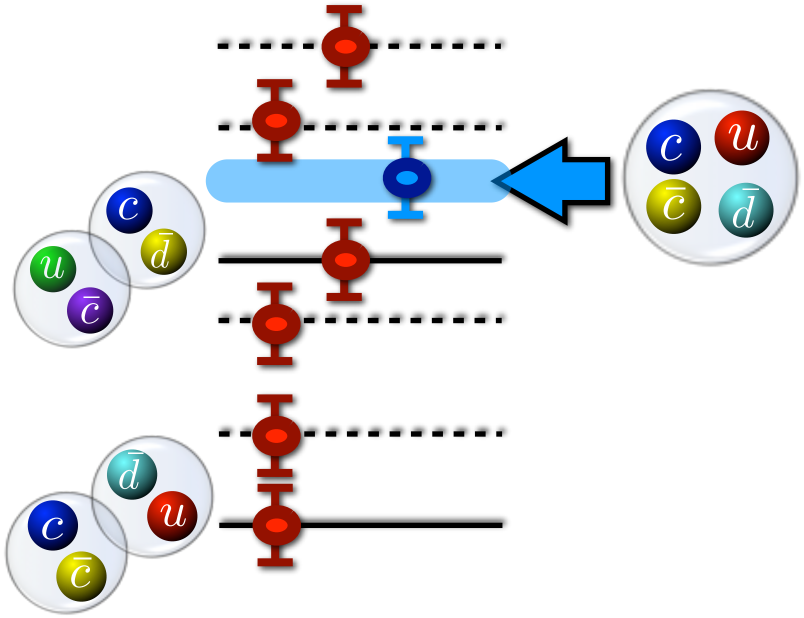
$\pi J/\psi$ = 3232

How to study $Z_c(3900)$ on the lattice?

- ✦ Conventional approach: LQCD spectrum
  - ➡ identify all relevant $W_n(L)$ (n=0,1,2,3,...)



$$\langle 0|\Phi[c\bar{c}u\bar{d}](\tau)|W_n\rangle = e^{-W_n\tau}$$



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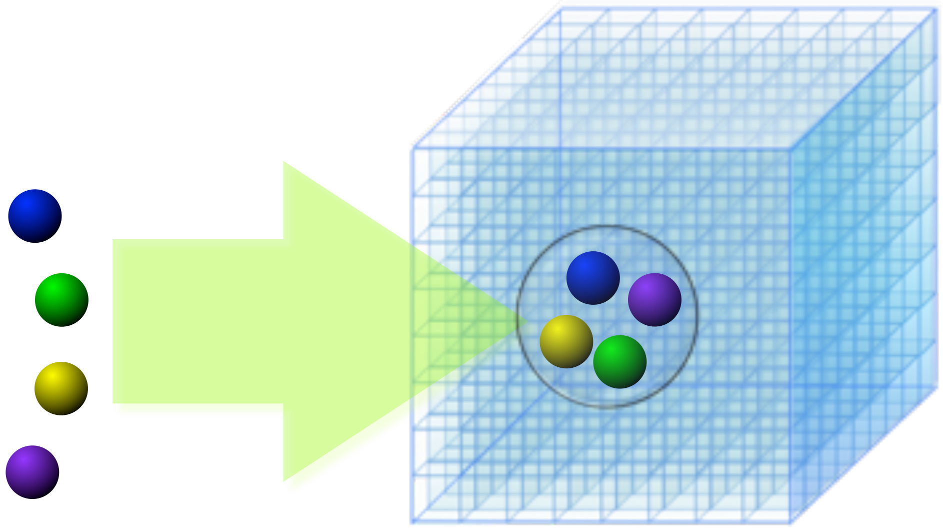

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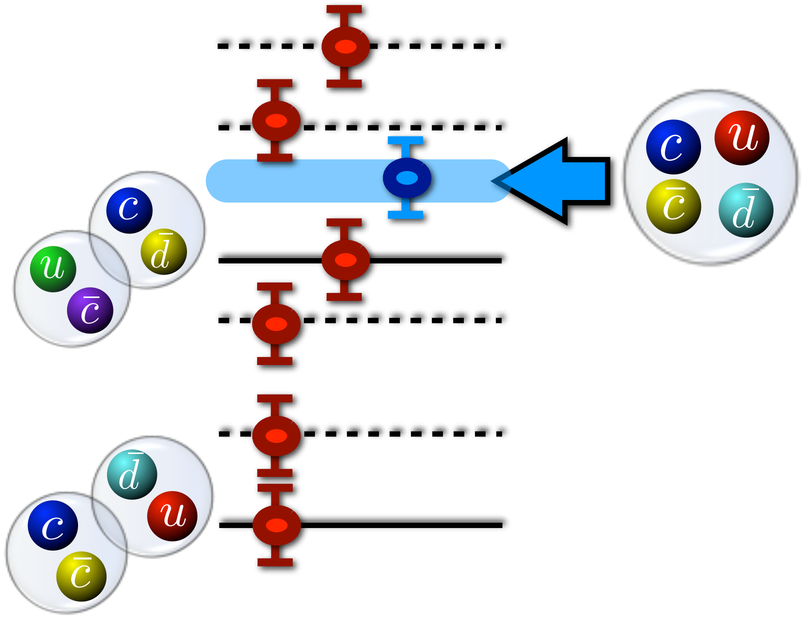

✓ No positive evidence for $Z_c(3900)$ in $J^{PC}=1^{+-}$

S. Prelovsek et al., PLB 727, 172 (2013).
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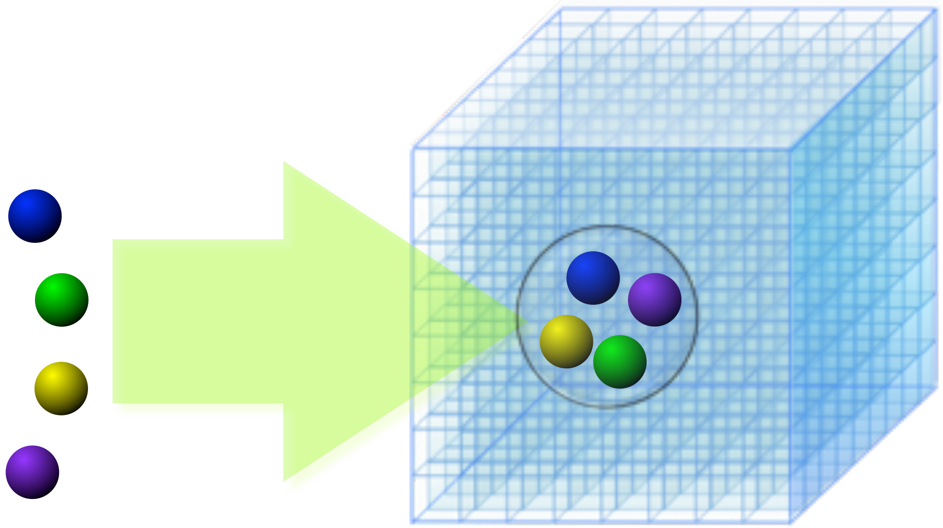

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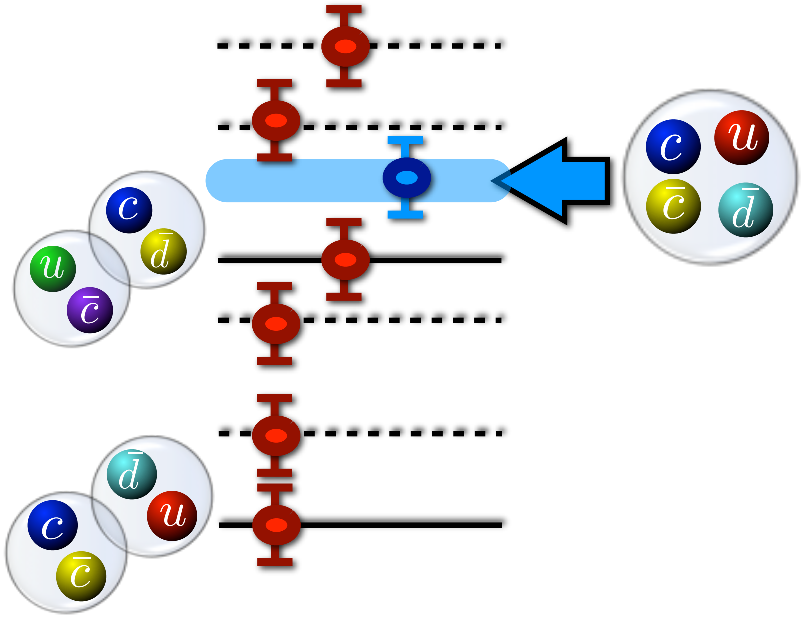

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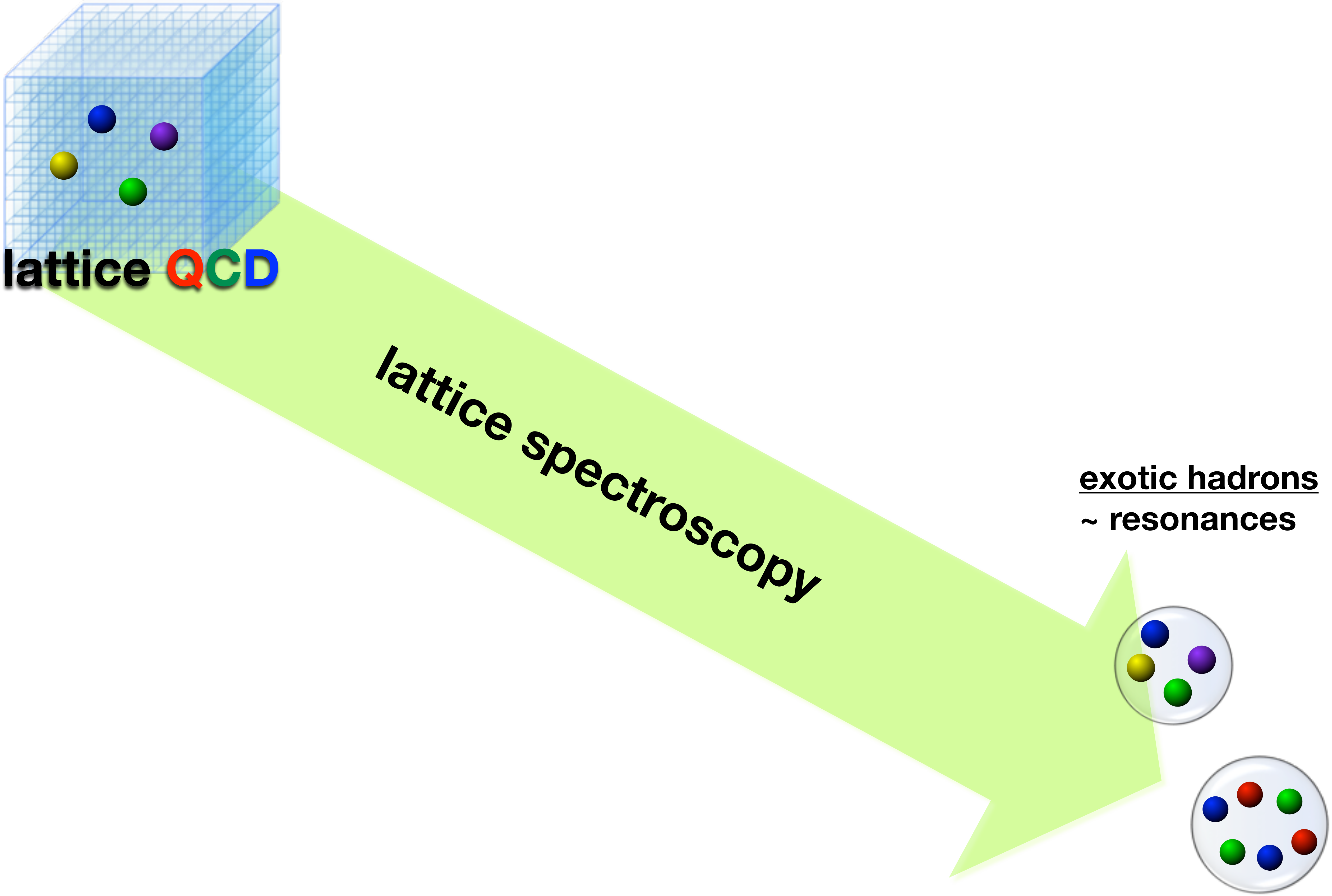
★ Why is the peak observed in expt.?

- broad resonance? threshold effect?

➡ To understand expt. signals for exotics from QCD is very challenging

Why is resonance study so hard?



lattice QCD

lattice spectroscopy

exotic hadrons

~ resonances

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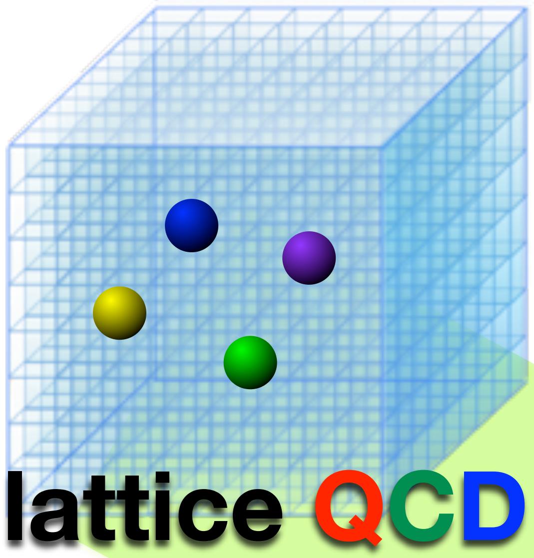
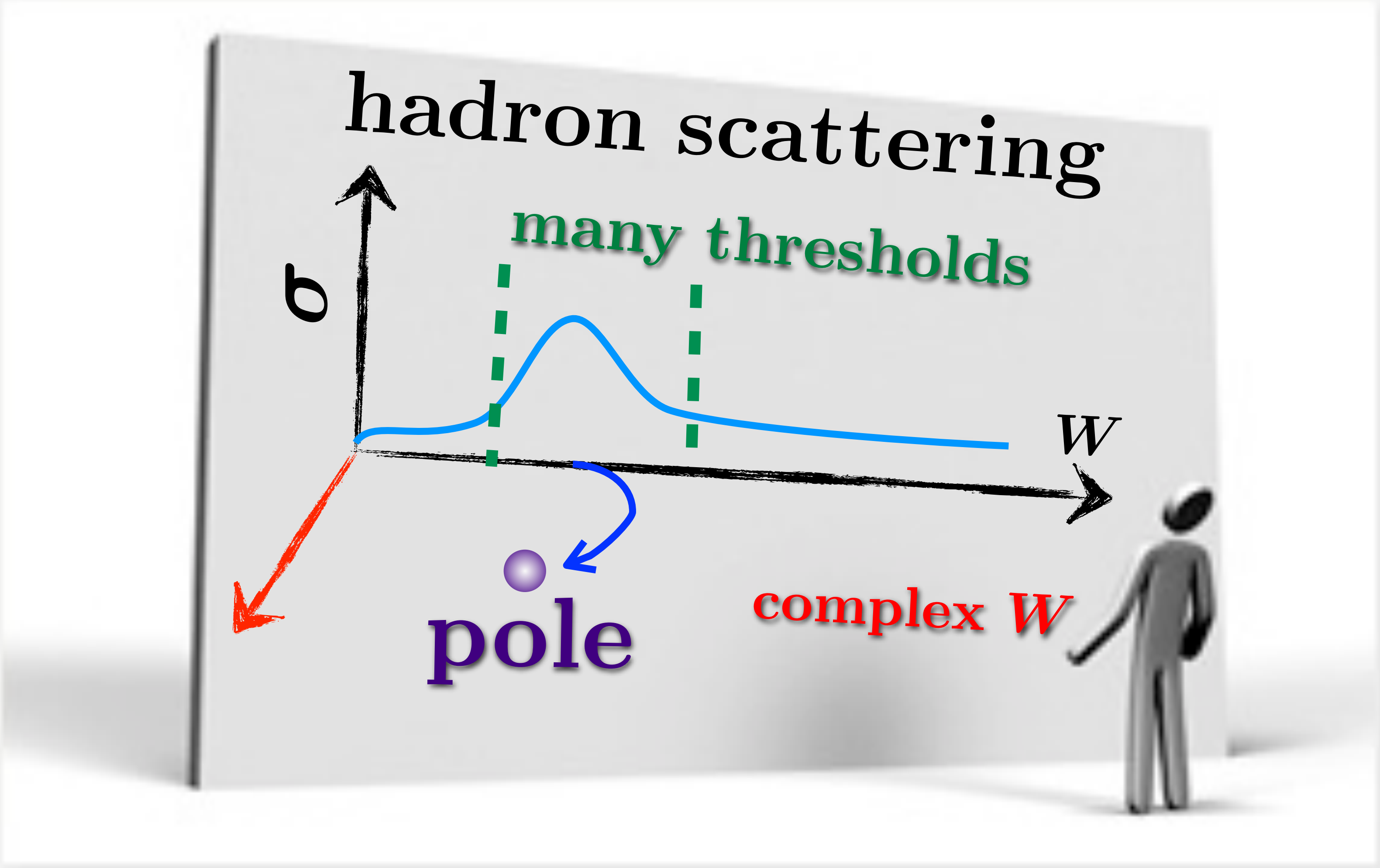


lattice QCD



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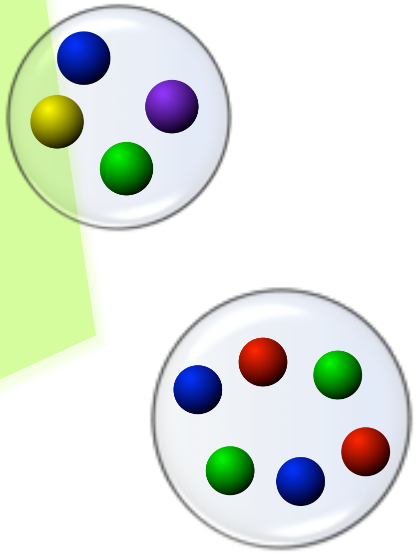
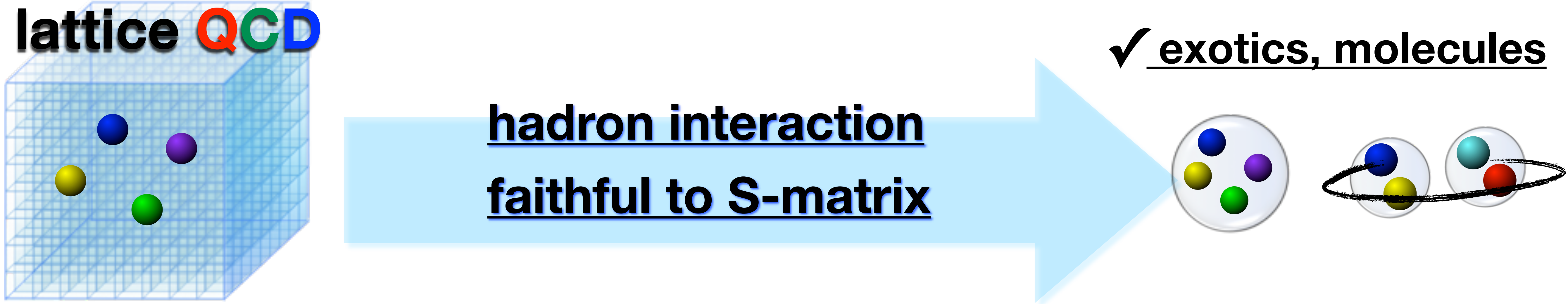


Key is coupled-channel hadronic interactions

How to extract hadron interactions?



lattice QCD

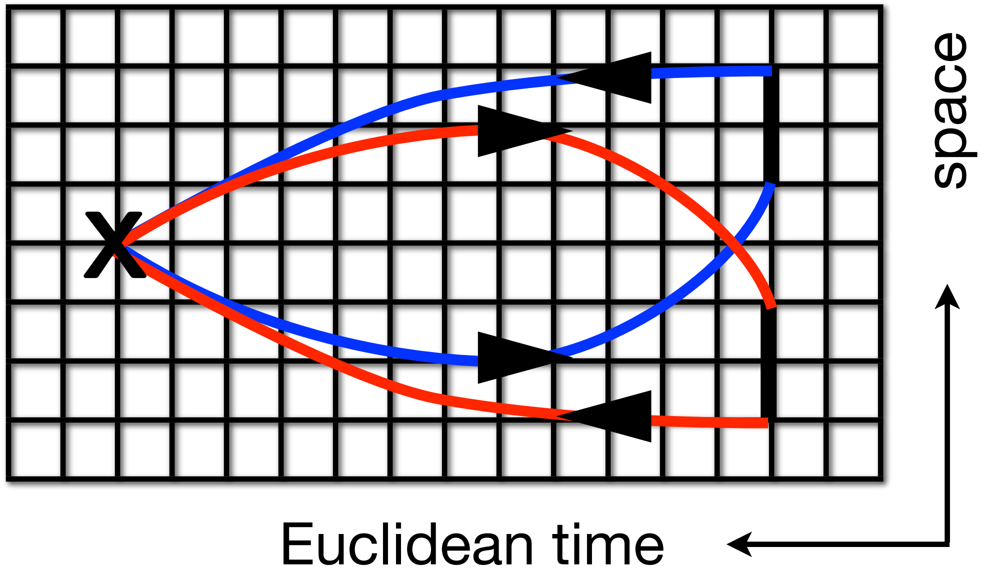
hadron interaction

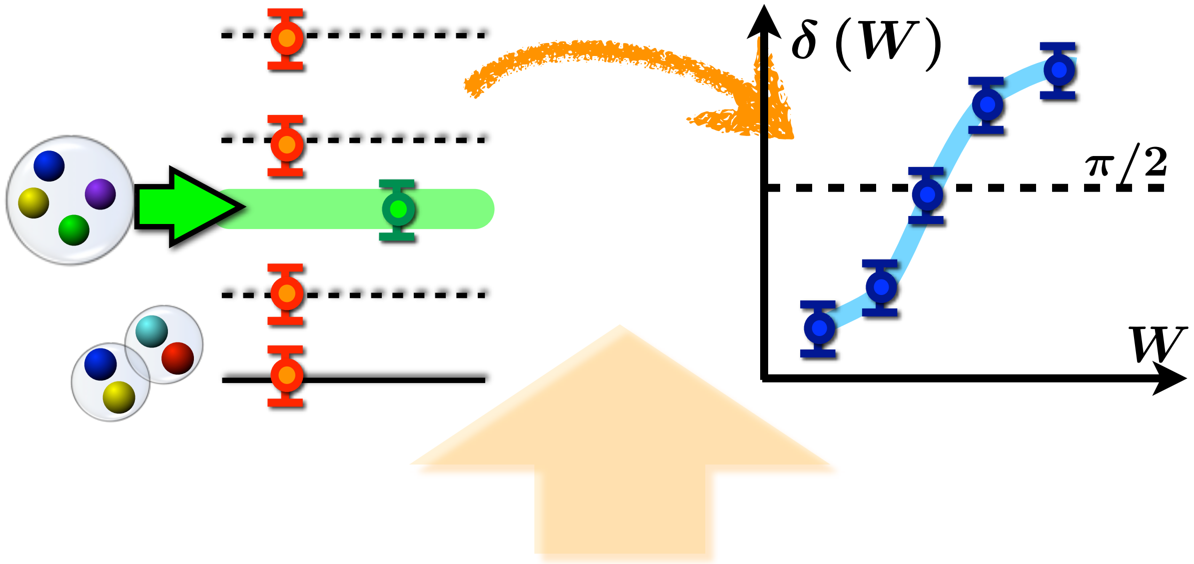
faithful to S-matrix

✓ **exotics, molecules**

★ single channel scattering

$$\langle 0|\Phi(\tau)\Phi^\dagger(0)|0\rangle = \sum_n A_n e^{-W_n \tau}$$



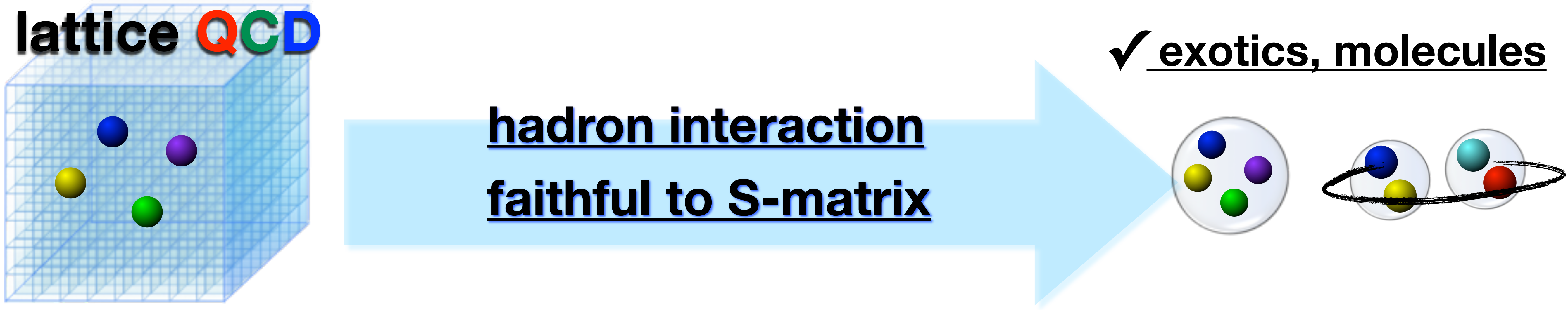


❖ Lüscher's formula Lüscher, NPB354 (1991).

- finite V spectrum --> phase shift $\delta(W_n)$

$$k_n \cot\delta(k_n) = \frac{4\pi}{L^3}\sum_{m\in\mathbb{Z}^3}\frac{1}{\vec{p}_m^{\,2} - k_n^2}$$

Problem in coupled-channel scattering



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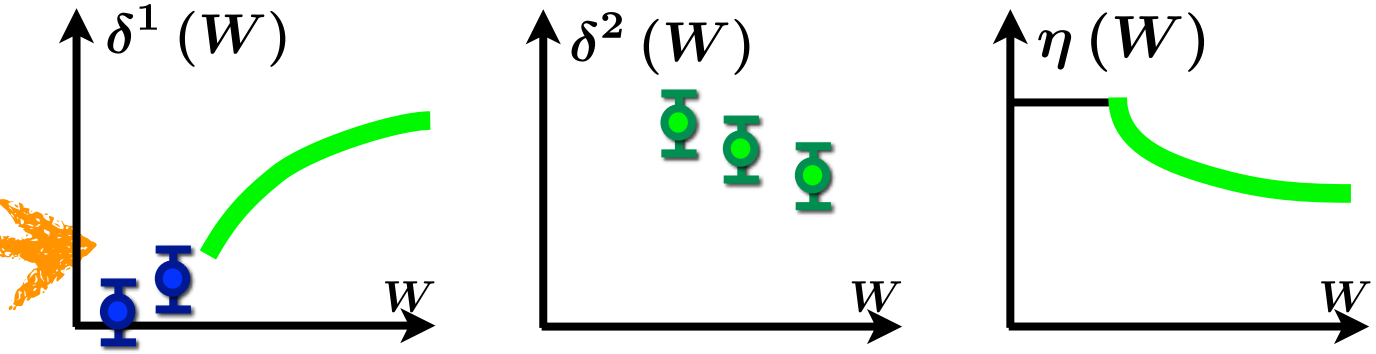


➡ coupled-channel Lüscher's formula

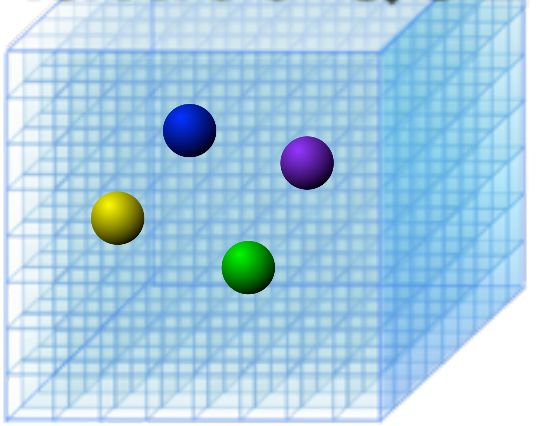
elastic region: W --> δ(W)

inelastic region: W --> $\delta^1(W)$, $\delta^2(W)$, $\eta(W)$ **--> find W(L_1)=W(L_2)=W(L_3)**

➡ assumptions about interactions or K-matrices necessary...

Problem in coupled-channel scattering

lattice QCD



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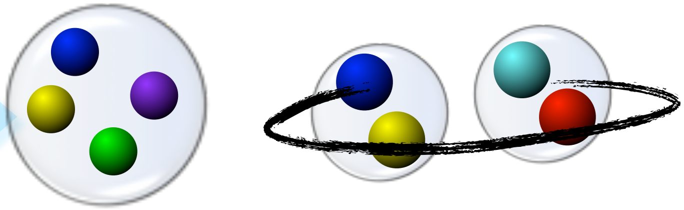

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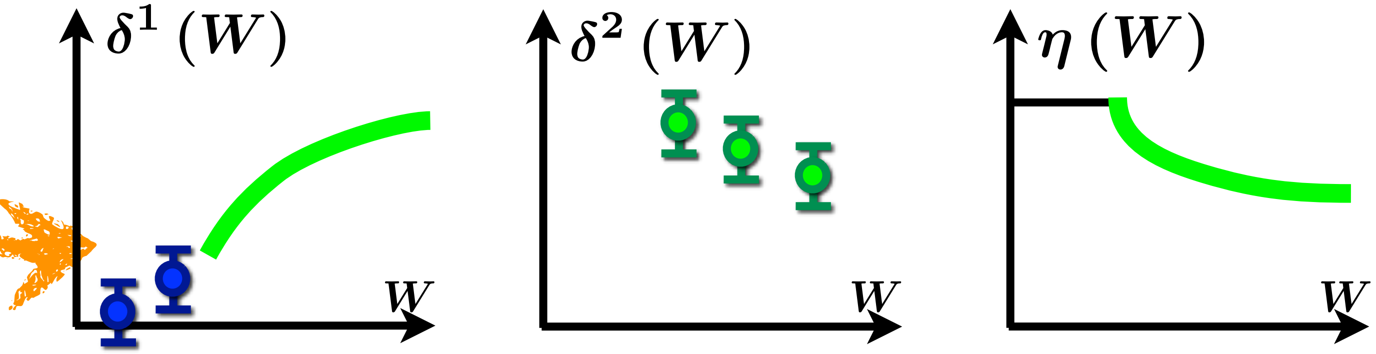

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➡ assumptions about interactions or K-matrices necessary...

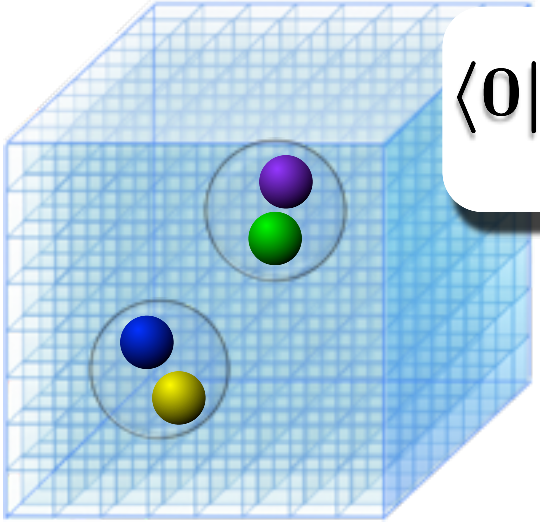
★ indicate more information mandatory to solve coupled-channel scatterings

➡ What can we measure in addition to temporal correlations?

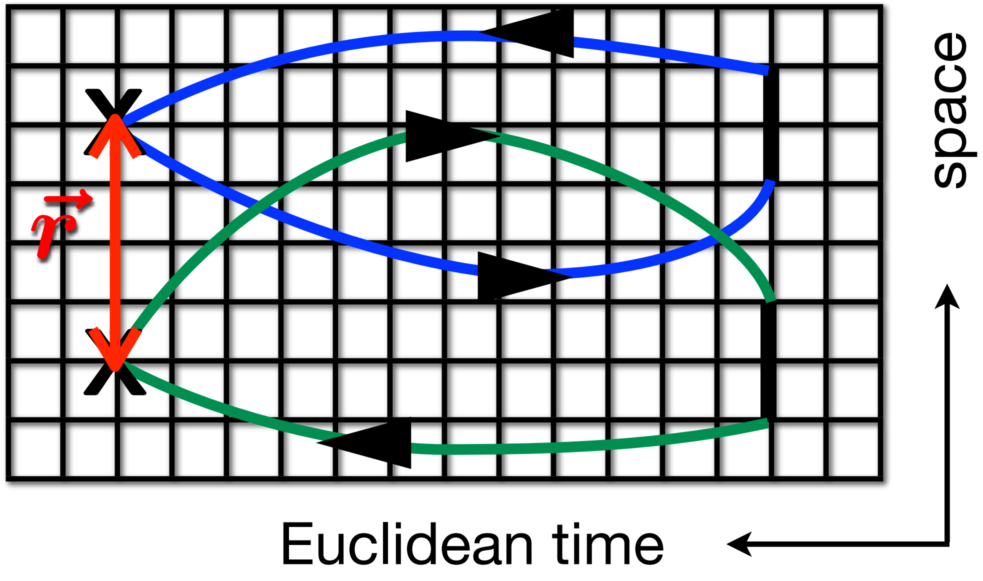
HAL QCD approach “potential” as representation of S-matrix

✦ HAL QCD approach: extract energy-independent interaction kernel

➡ measure spatial correlation as well as temporal correlation



$$\langle 0|\phi_1(\vec{x}+\vec{r},\tau)\phi_2(\vec{x},\tau)\Phi^\dagger(0)|0\rangle = \sqrt{Z_1Z_2}\sum_n A_n\psi_n(\vec{r})e^{-W_n\tau}$$



Ishii, Aoki, Hatsuda, PRL99, 02201 (2007).
Aoki, Hatsuda, Ishii, PTP123, 89 (2010).
Ishii et al,(HAL QCD), PLB712, 437(2012).

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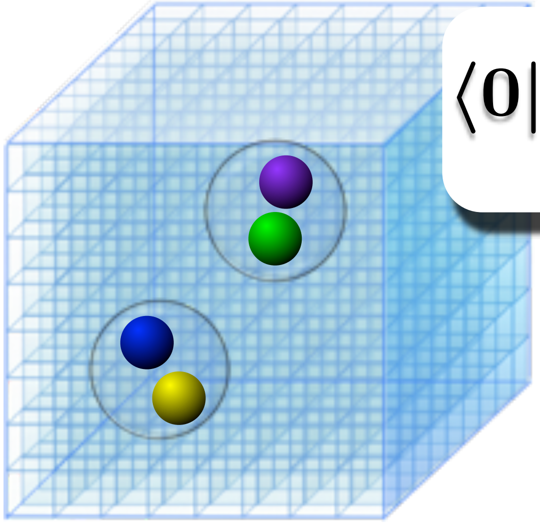

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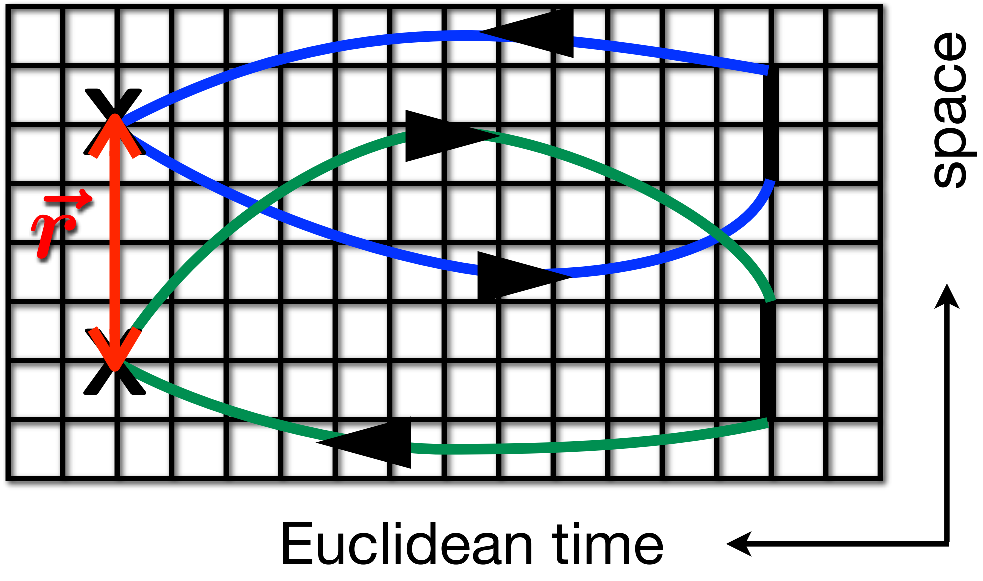

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★ Nambu-Bethe-Salpeter wave functions: $\psi_n(r)$

- NBS wave functions outside interactions --> Helmholtz equation

$$\boxed{\left(\nabla^2 + \vec{k}_n^2\right)\psi_n(\vec{r}) = 0 \quad (|\vec{r}| > R)}$$

➡ S-matrix

Nambu-Bethe-Salpeter wave function

Full details, see, Aoki, Hatsuda, Ishii, PTP123, 89 (2010).

Equal-time choice of NBS amplitudes (e.g., ππ scattering)

$$\begin{aligned}\Psi(\vec{x}_1, t; \vec{x}_2, t) &\equiv \langle 0|\pi(x_1)\pi(x_2)|\pi(\vec{k})\pi(-\vec{k}); in\rangle \\ &= \psi_{\pi\pi}(\vec{r}; W)e^{-iWt}\end{aligned}$$

$$W = 2\sqrt{m_\pi^2 + \vec{k}^2}$$

Outside interactions, NBS amplitudes satisfy non-interacting Klein-Gordon equations:

$$(\partial_t^2 - \nabla_i^2 + m_\pi^2)\Psi(\vec{x}_1, t; \vec{x}_2, t) = 0 \quad (i = 1, 2)$$

$$(\nabla_r^2 + \vec{k}^2)\psi_{\pi\pi}(\vec{r}; W) = 0$$

- NBS wave functions satisfy Helmholtz equation
- Asymptotic form of NBS wave function:

$$\psi_{\vec{k}}^{(l)}(r) \sim \frac{e^{i\delta_l(k)}}{kr}\sin\bigl(kr + \delta_l(k) - l\pi/2\bigr)$$

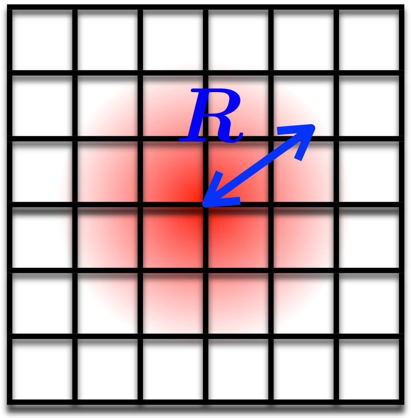
--> faithful to scattering phase shift

NBS wave function in quantum field theory is the best analogue to wave function in quantum mechanics

“Potential” as representation of S-matrix

- NBS wave func. in interacting region --> half-off-shell T-matrix

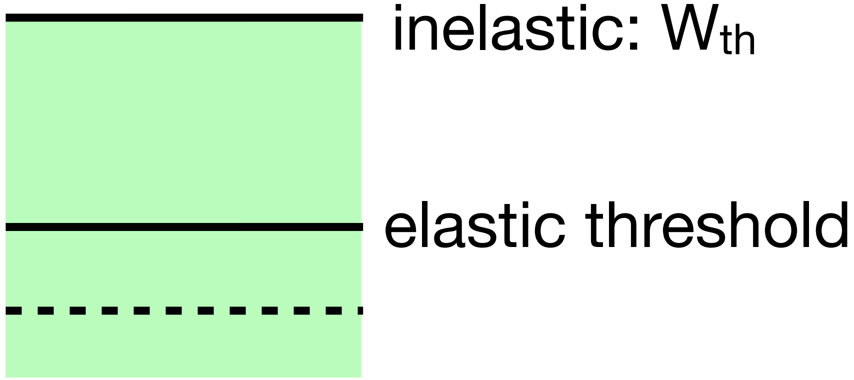
$$\boxed{(\nabla^2 + \vec{k}_n^2)\psi_n(\vec{r}) = 2\mu\mathcal{K}_n(\vec{r}) \quad (|\vec{r}| < R)}$$



- Energy-independent potentials (faithful to phase shifts)

$$\boxed{U(\vec{r},\vec{r}\,') = \sum_n^{W_{th}} \mathcal{K}_n(\vec{r})\overline{\psi_n}(\vec{r}\,')}$$

★ U(r,r’) contains all 2PI contributions



above W_{th}: coupled-channel analysis

- “Potentials” become kernels of Schrödinger-type equations

$$\boxed{\left(\nabla^2 + \vec{k}_n^2\right)\psi_n(\vec{r}) = 2\mu \int d\vec{r}\,' U(\vec{r},\vec{r}\,')\psi_n(\vec{r}\,')}$$

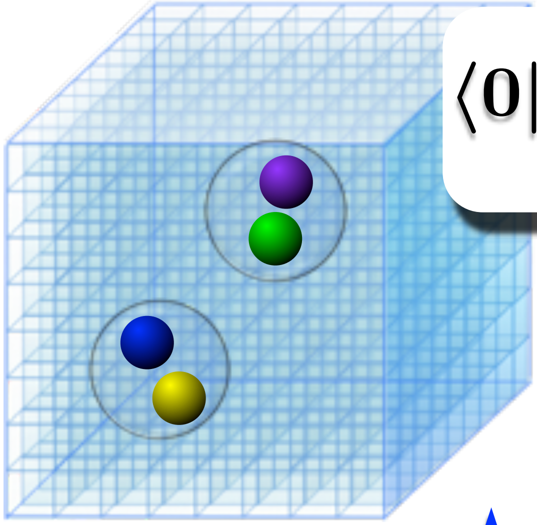
Ishii, Aoki, Hatsuda, PRL99, 02201 (2007).

Aoki, Hatsuda, Ishii, PTP123, 89 (2010).

HAL QCD approach “potential” as representation of S-matrix

✦ HAL QCD approach: extract energy-independent interaction kernel

➡ measure spatial correlation as well as temporal correlation

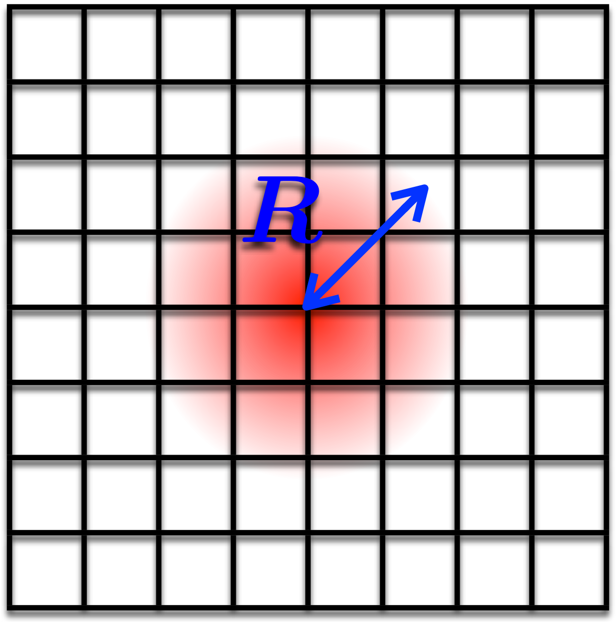


$$\langle 0|\phi_1(\vec{x}+\vec{r},\tau)\phi_2(\vec{x},\tau)\Phi^\dagger(0)|0\rangle = \sqrt{Z_1 Z_2}\sum_n A_n\psi_n(\vec{r})e^{-W_n\tau}$$

Ishii, Aoki, Hatsuda, PRL99, 02201 (2007).
Aoki, Hatsuda, Ishii, PTP123, 89 (2010).
Ishii et al,(HAL QCD), PLB712, 437(2012).

★ NBS wave functions inside interactions: half-offshell T-matrix

$$\left(\nabla^2+\vec{k}_n^2\right)\psi_n(\vec{r}) = 2\mu\int d\vec{r}\,'U(\vec{r},\vec{r}\,')\psi_n(\vec{r}\,')$$

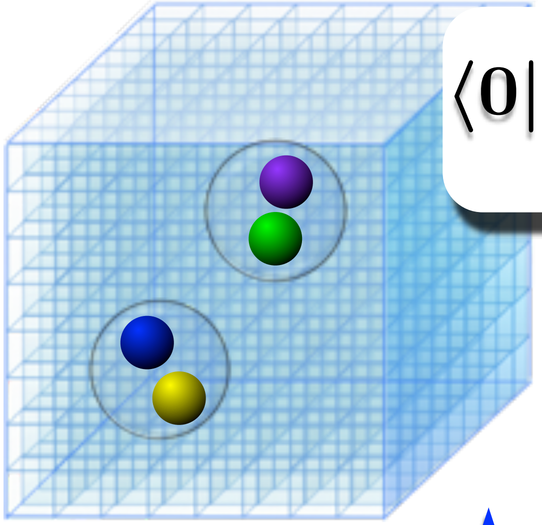


- U(r,r’) is faithful to S-matrix in elastic region
- U(r,r’) is energy-independent (until new threshold opens)
- U(r,r’) contains all 2PI contributions
- U(r,r’) is not an observable (applied to ab initio calc.)

Coupled-channel HAL QCD approach

✦ HAL QCD approach: extract energy-independent interaction kernel

➡ measure spatial correlation as well as temporal correlation



$$\langle 0|\phi_1^a(\vec{x}+\vec{r},\tau)\phi_2^a(\vec{x},\tau)\Phi^\dagger(0)|0\rangle = \sqrt{Z_1^a Z_2^a}\sum_n A_n \psi_n^a(\vec{r}) e^{-W_n\tau}$$

Ishii, Aoki, Hatsuda, PRL99, 02201 (2007).
Aoki, Hatsuda, Ishii, PTP123, 89 (2010).
Ishii et al,(HAL QCD), PLB712, 437(2012).

★ channel wave functions defined in asymptotic region: $\psi^a_n(r)$

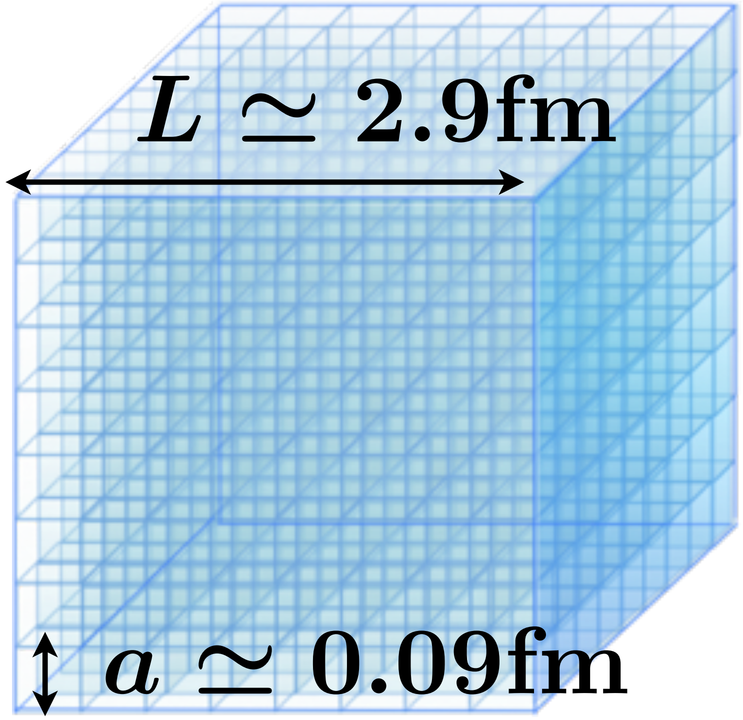
$$\left(\nabla^2 + (\vec{k}_n^a)^2\right)\psi_n^a(\vec{r}) = 2\mu^a \sum_b \int d\vec{r}' U^{ab}(\vec{r},\vec{r}')\psi_n^b(\vec{r}')$$

★coupled-channel potential $U^{ab}(r,r')$:

- $U^{ab}(r,r')$ is faithful to S-matrix in both elastic and inelastic regions
- $U^{ab}(r,r')$ is energy-independent (until new threshold opens)
- $U^{ab}(r,r')$ contains all 2PI contributions

Full details, Aoki et al. [HAL QCD Coll.], PTEP 2012, 01A105 (2012); Proc. Jpn. Acad., Ser. B, 87 (2011).

Lattice QCD setup



★N_f=2+1 full QCD

PACS-CS Coll., S. Aoki et al., PRD79, 034503, (2009).

- Iwasaki gauge & O(a)-improved Wilson quark actions
- a=0.0907(13) fm --> L~2.9 fm (32^3 x 64)

★Relativistic Heavy Quark action for charm

S. Aoki et al., PTP109, 383 (2003).
Y. Namekawa et al., PRD84, 074505 (2011).

- remove leading cutoff errors $O((m_c a)^n)$, $O(\Lambda_{QCD} a)$, ...

➡ We are left with $O((a\Lambda_{QCD})^2)$ syst. error (~ a few %)

Light meson mass (MeV)

m_π= 411(1), 572(1), 701(1)
m_K= 635(2), 714(1), 787(1)
m_ρ= 896(8), 1000(5), 1097(4)

Charmed meson mass (MeV)

$m_{\eta c}$= 2988(1), 3005(1), 3024(1)
$m_{J/\psi}$= 3097(1), 3118(1), 3143(1)
m_D= 1903(1), 1947(1), 2000(1)
m_{D^*}= 2056(3), 2101(2), 2159(2)

Lattice QCD setup : thresholds

✦ S-wave meson-meson thresholds in $I^G J^{PC}=1^+1^{+-}$ channel

LQCD simulation

$D^{bar}D^*$ = 4159, 4048, 3959

$\rho\eta_c$ = 4121, 4005, 3884

$\pi J/\psi$ = 3844, 3688, 3508

Physical thresholds

$D^{bar}D^*$ = 3872

$\pi\psi'$ = 3821

$\pi\pi\eta_c$ = 3256

$\pi J/\psi$ = 3232

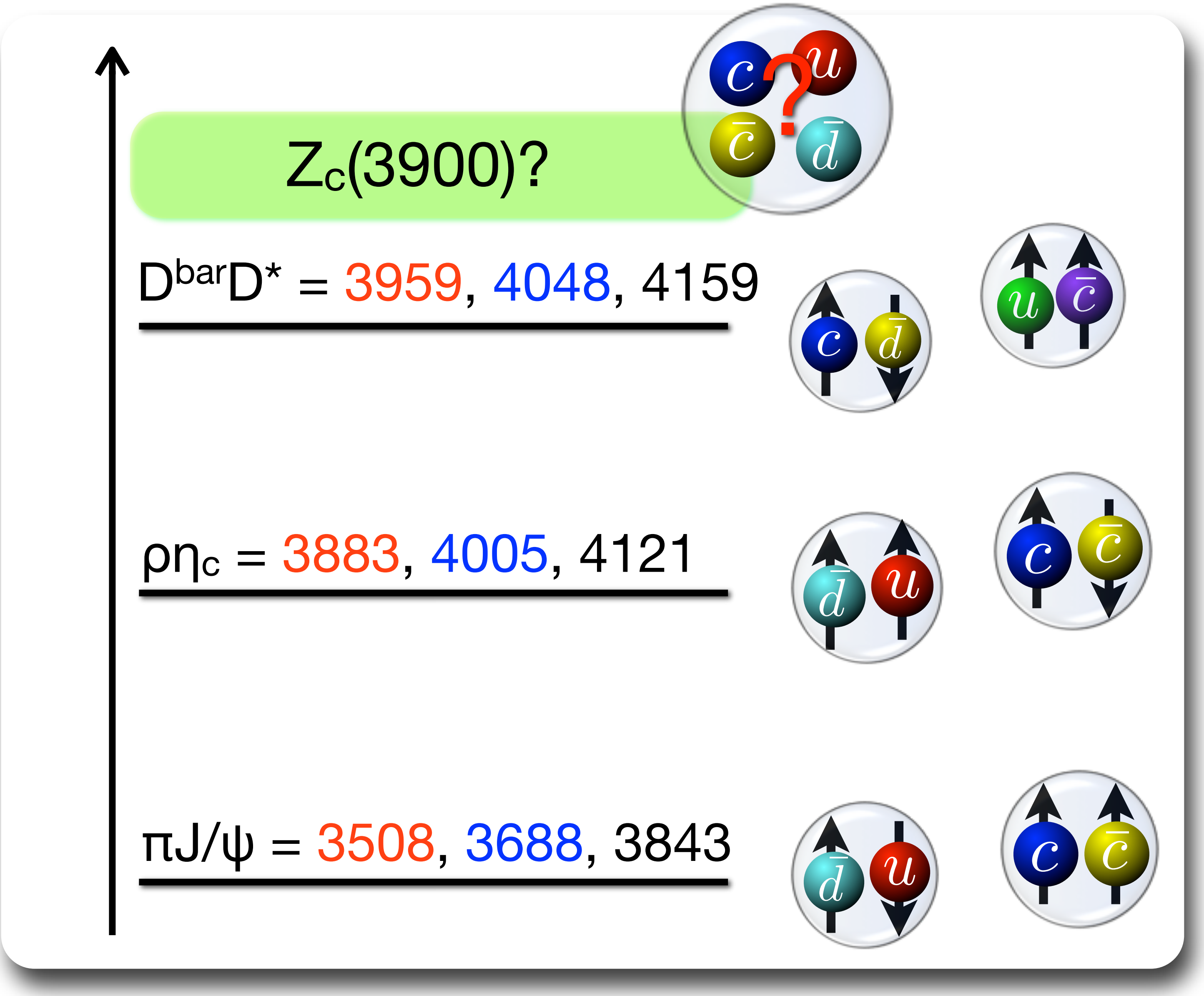
- $M_{\pi\psi'} > M_{D^{bar}D^*}$ due to heavy pion mass
- ρ-->ππ decay not allowed w/ L~3fm

✤ S-wave $\pi J/\psi$ - $\rho\eta_c$ - $D^{bar}D^*$ coupled-channel analysis

(reliable upto $D^{bar*}D^*$ threshold)

Y. Ikeda et al., [HAL QCD], arXiv.1602.03465 [hep-lat] (2016).

Potential matrix in $I^G(J^{PC})=1^+(1^{+-})$: s-wave $\pi J/\psi$ - $\rho\eta_c$ - $D^{bar}D^*$



$Z_c(3900)$?

$D^{bar}D^*$ = 3959, 4048, 4159

$\rho\eta_c$ = 3883, 4005, 4121

$\pi J/\psi$ = 3508, 3688, 3843

✓ Velocity expansion:

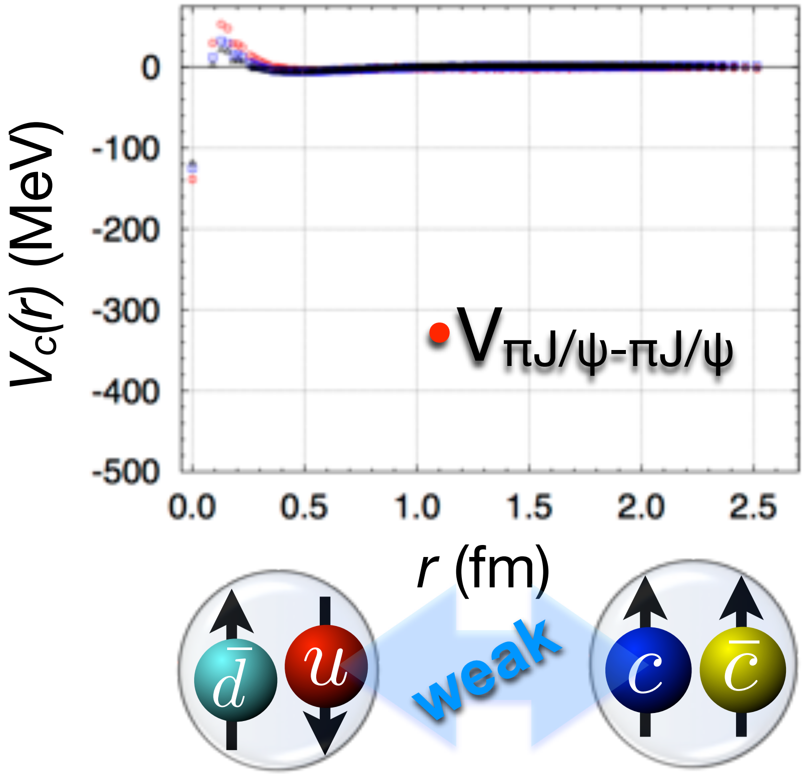
$$U(\vec{r}, \vec{r}') = V(\vec{r}, \nabla)\delta(\vec{r} - \vec{r}')$$

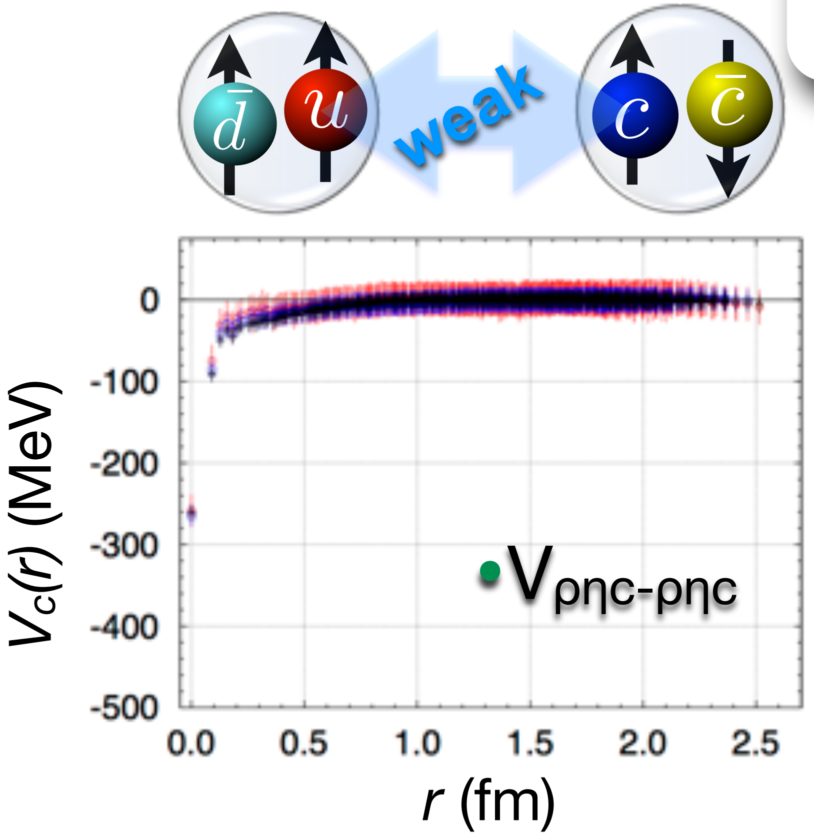
$$V(\vec{r}, \nabla) = V_{\mathrm{LO}}(\vec{r}) + \mathcal{O}(\nabla)$$

Extract (effective) LO potential :

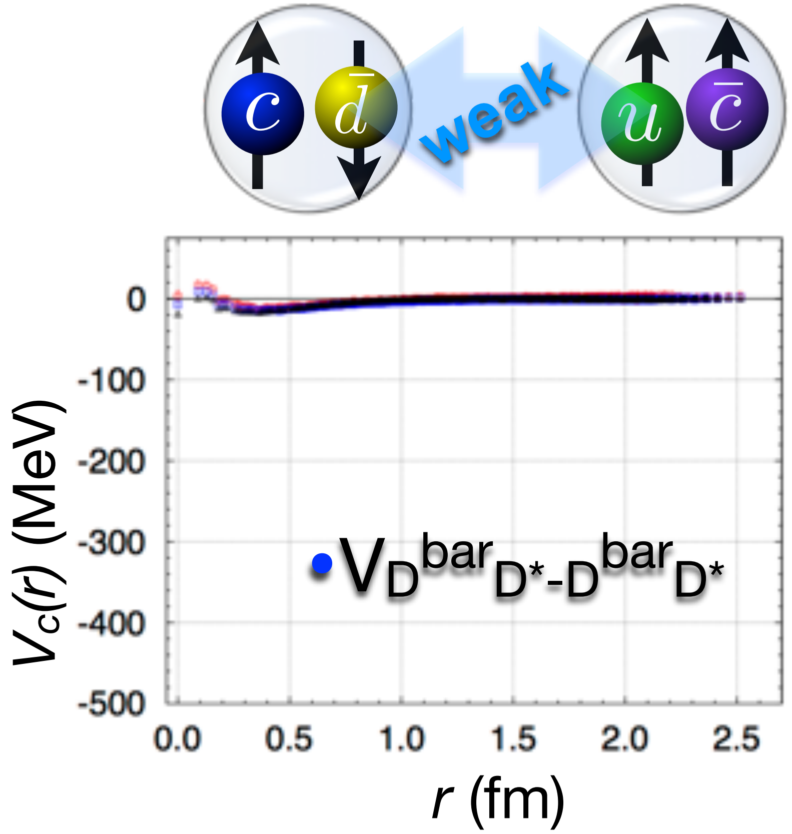
$$\boxed{\left(\nabla^2 + (\vec{k}_n^a)^2\right)\psi_n^a(\vec{r}) = 2\mu^a \sum_b V^{ab}(\vec{r})\psi_n^b(\vec{r})}$$

Potential matrix ($\pi J/\psi$ - $\rho\eta_c$ - $D^{bar}D^*$)



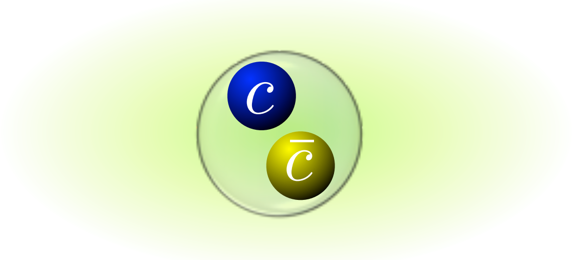


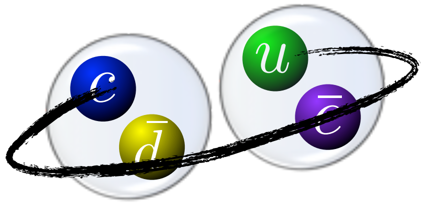
- m_π=410MeV
- m_π=570MeV
- m_π=700MeV



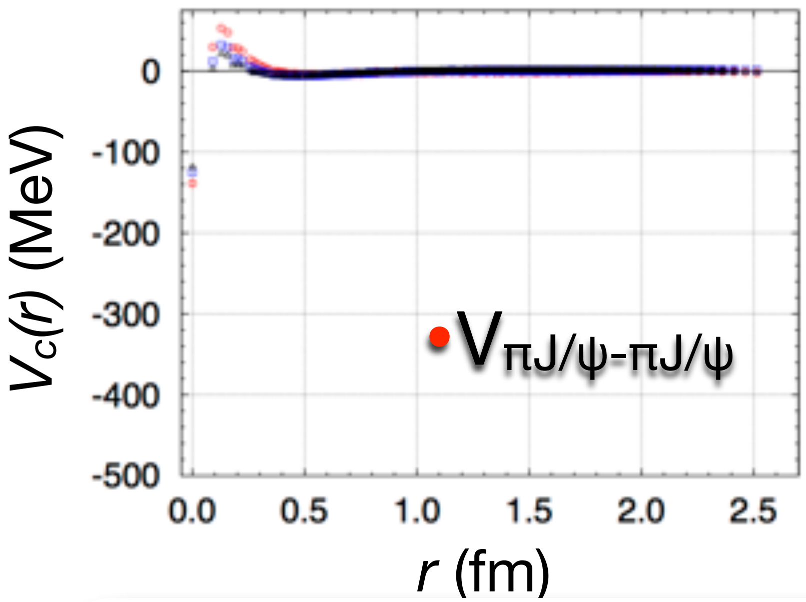
- All diagonal potentials are weak

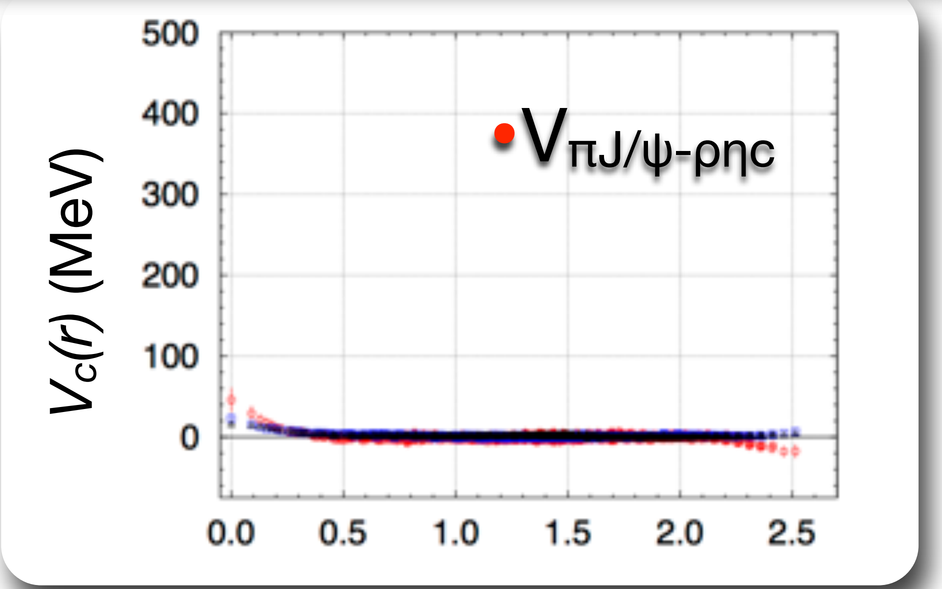
  ➡ no bound/resonant $\pi J/\psi$, $D^{bar}D^*$

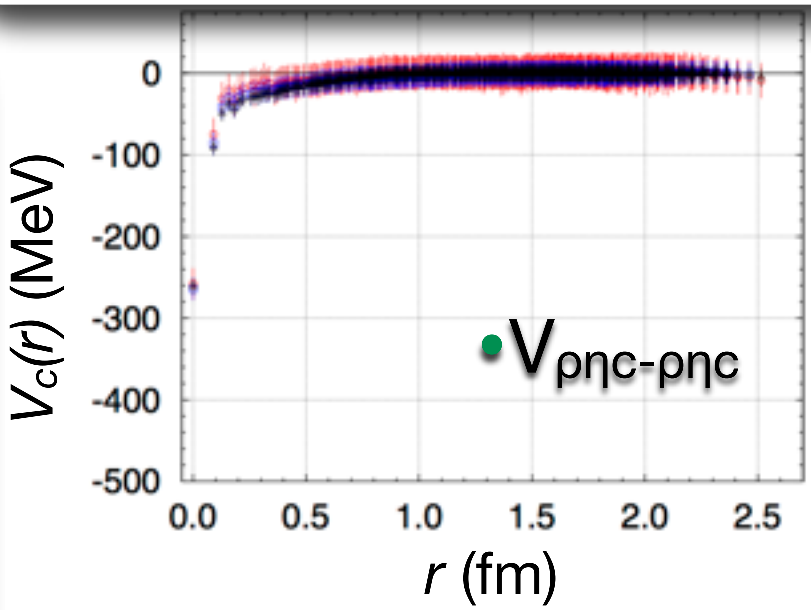


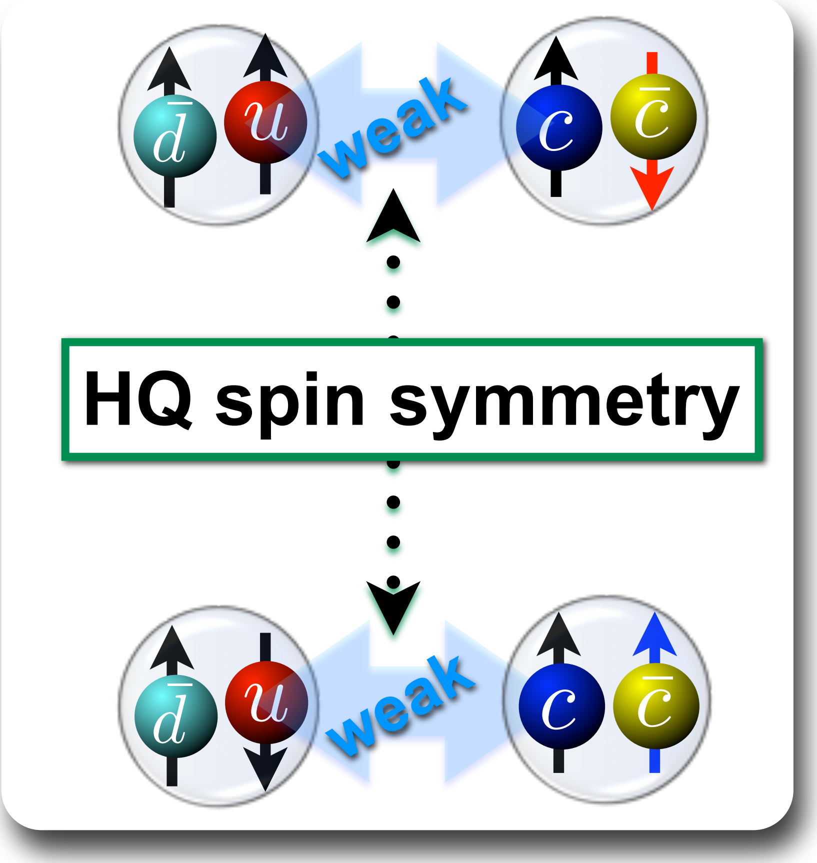


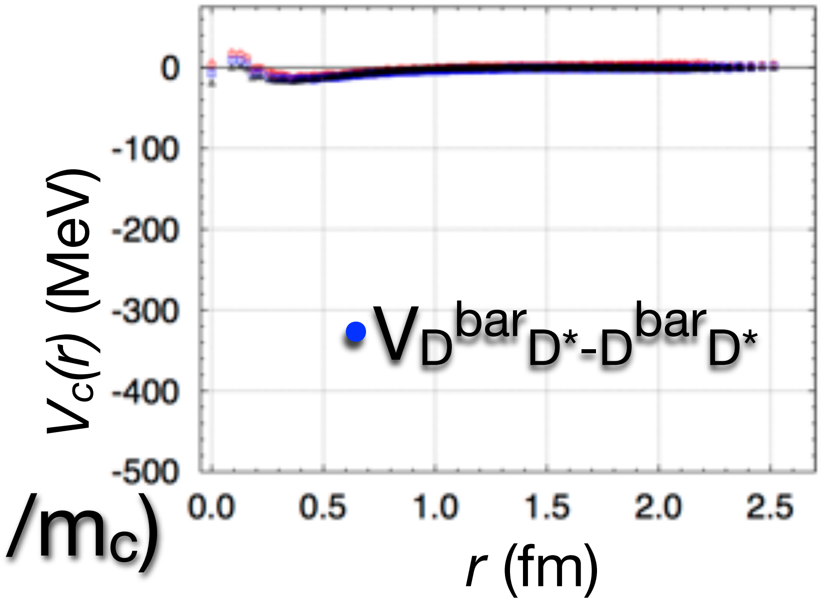
Potential matrix ($\pi J/\psi$ - $\rho\eta_c$ - $D^{bar}D^*$)







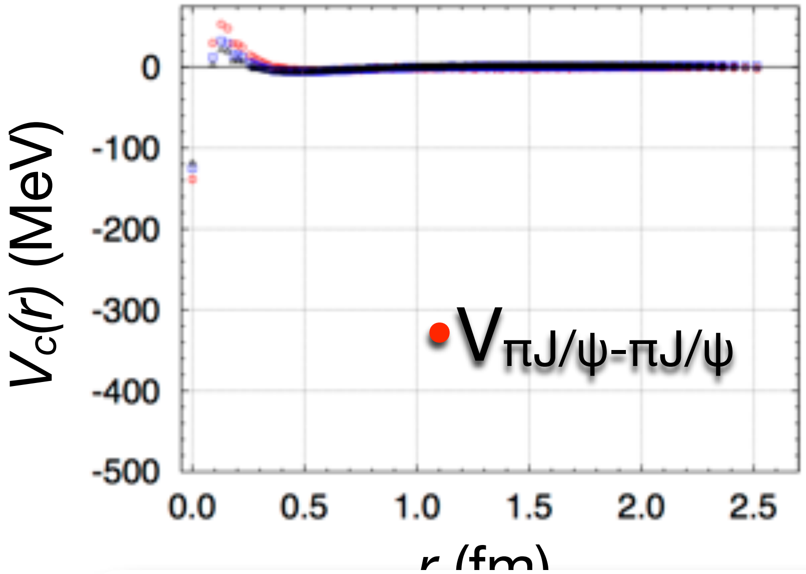


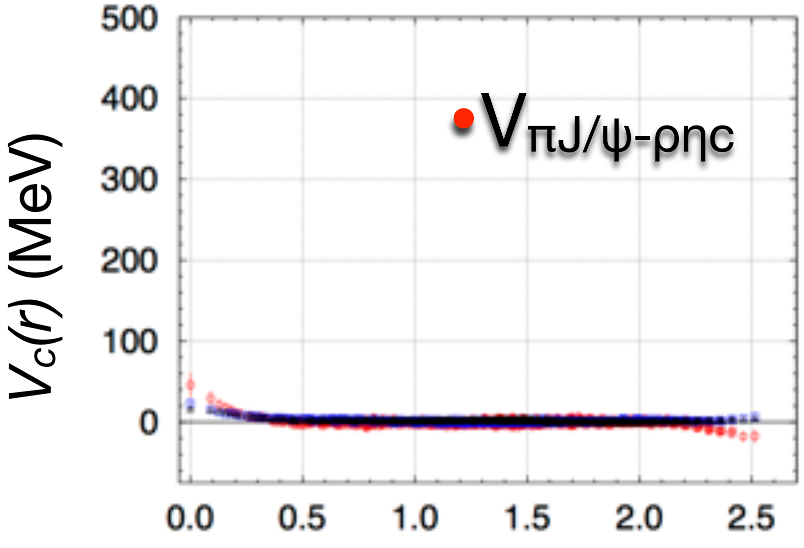


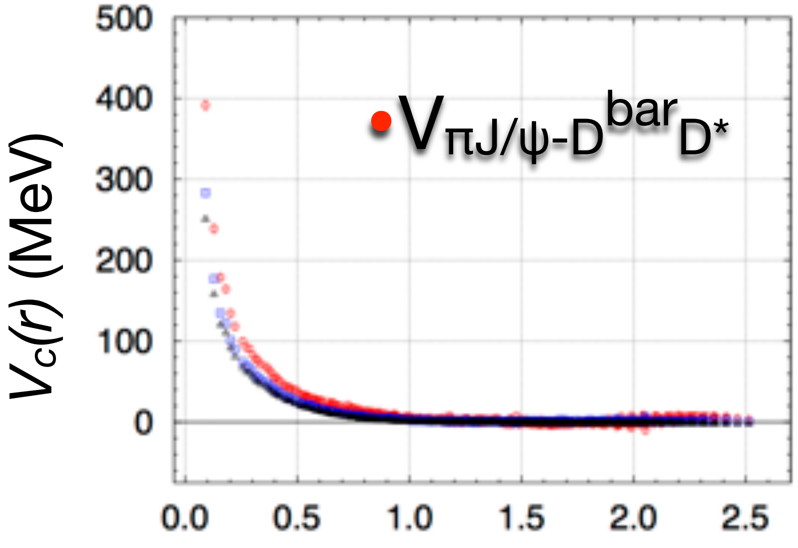
- Weak $\pi J/\psi$-$\rho\eta_c$ potential

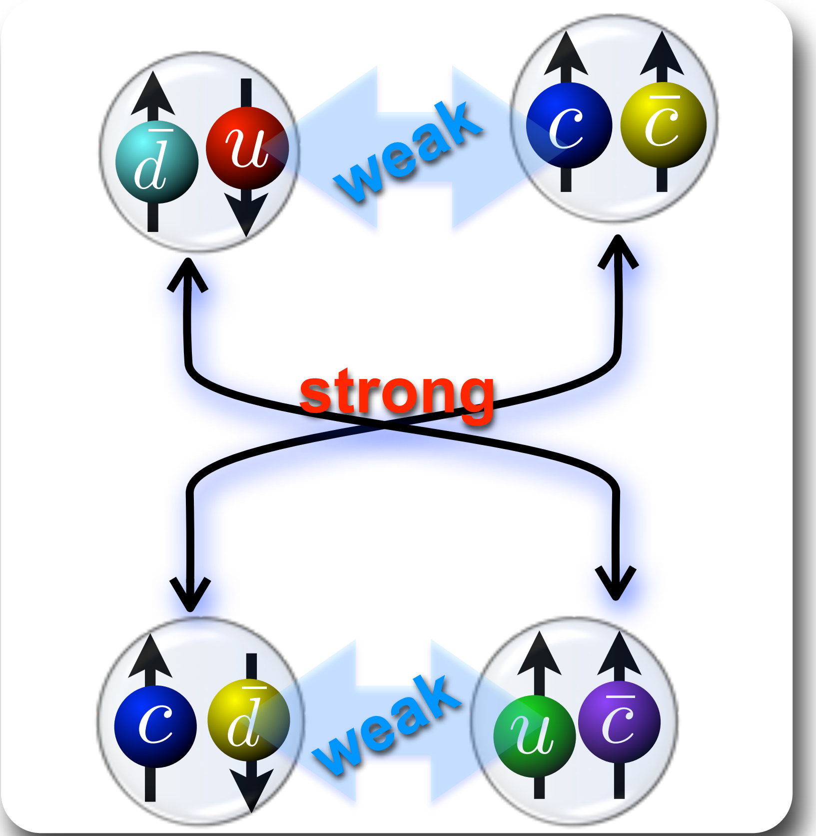
➡charm quark spin-flip is suppressed by O($1/m_c$)

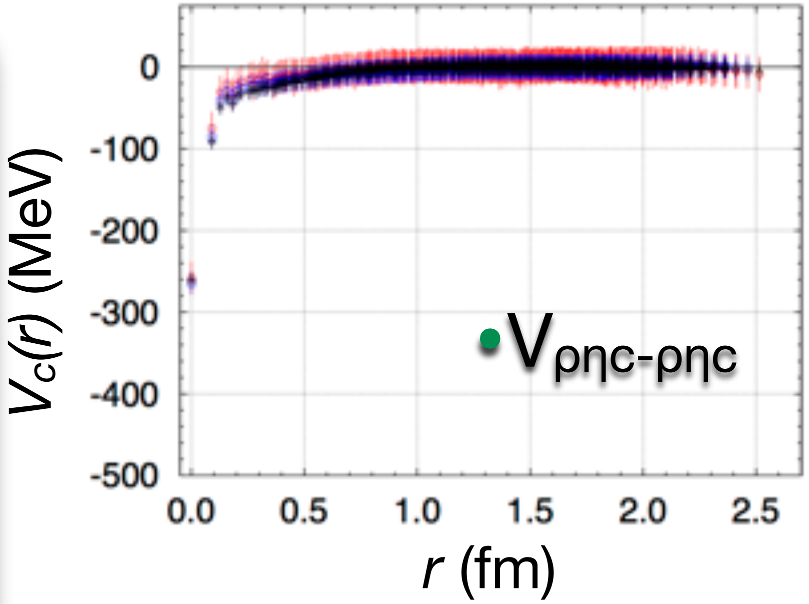
Potential matrix ($\pi J/\psi$ - $\rho\eta_c$ - $D^{bar}D^*$)

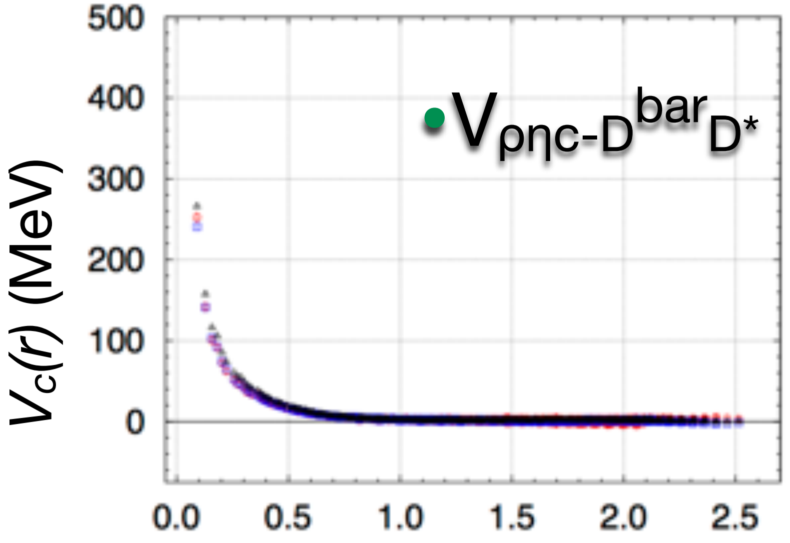


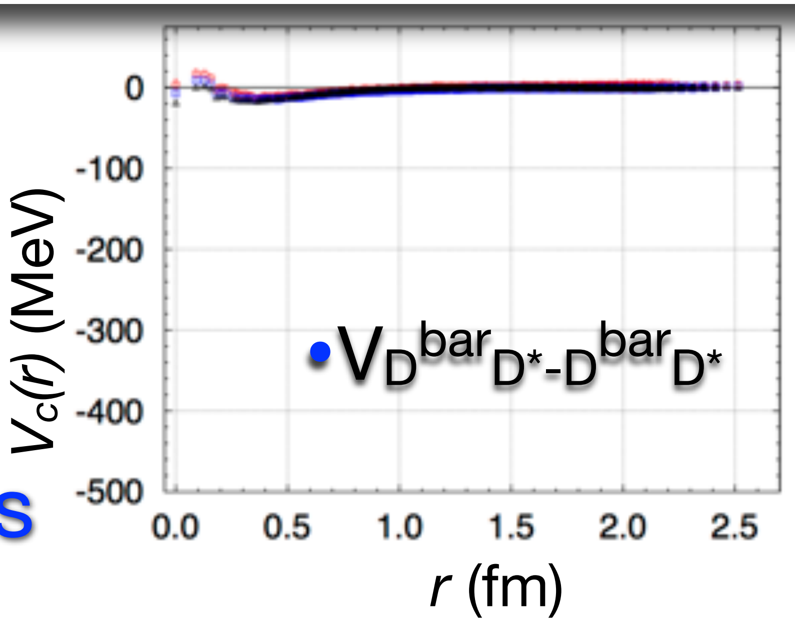








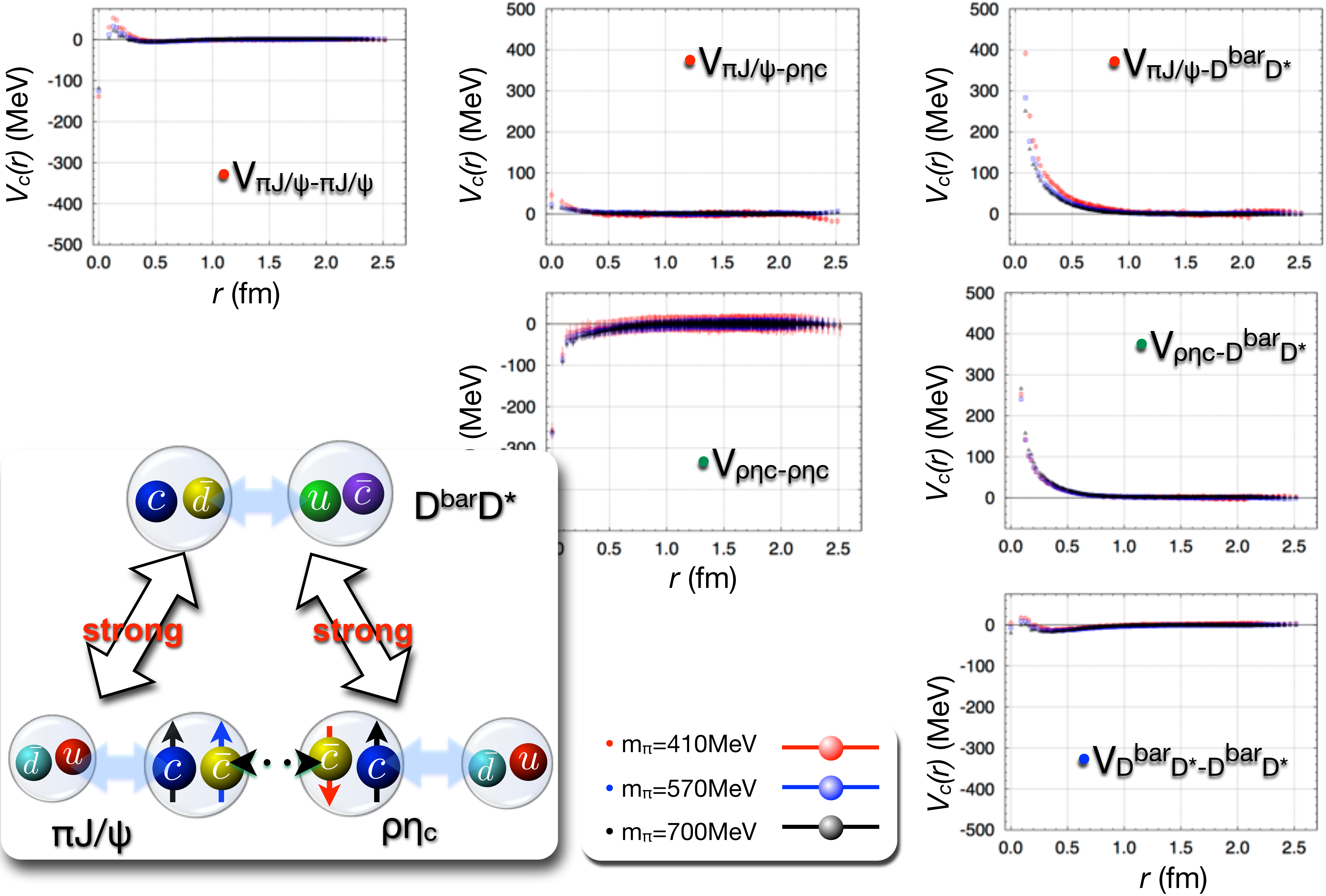




- Strong off-diagonal $D^{bar}D^*$ potentials

✓ strong charm-quark-exchange interactions

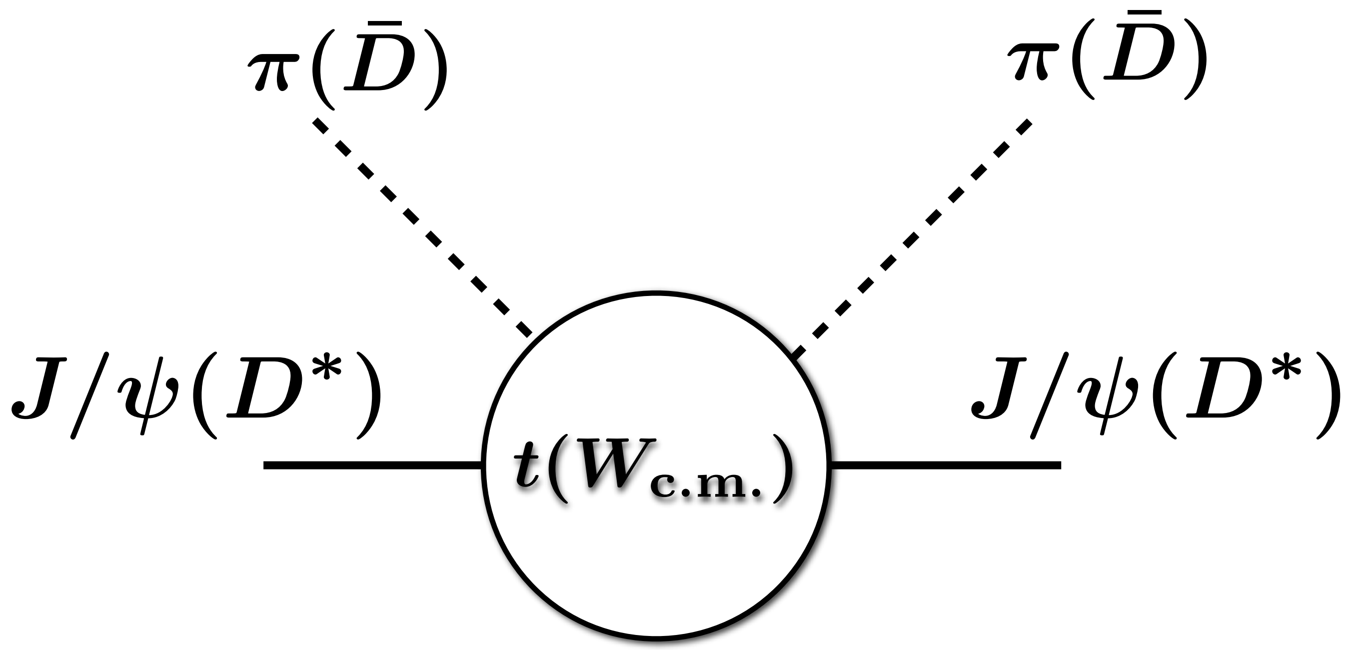
Potential matrix ($\pi J/\psi$ - $\rho\eta_c$ - $D^{bar}D^*$)



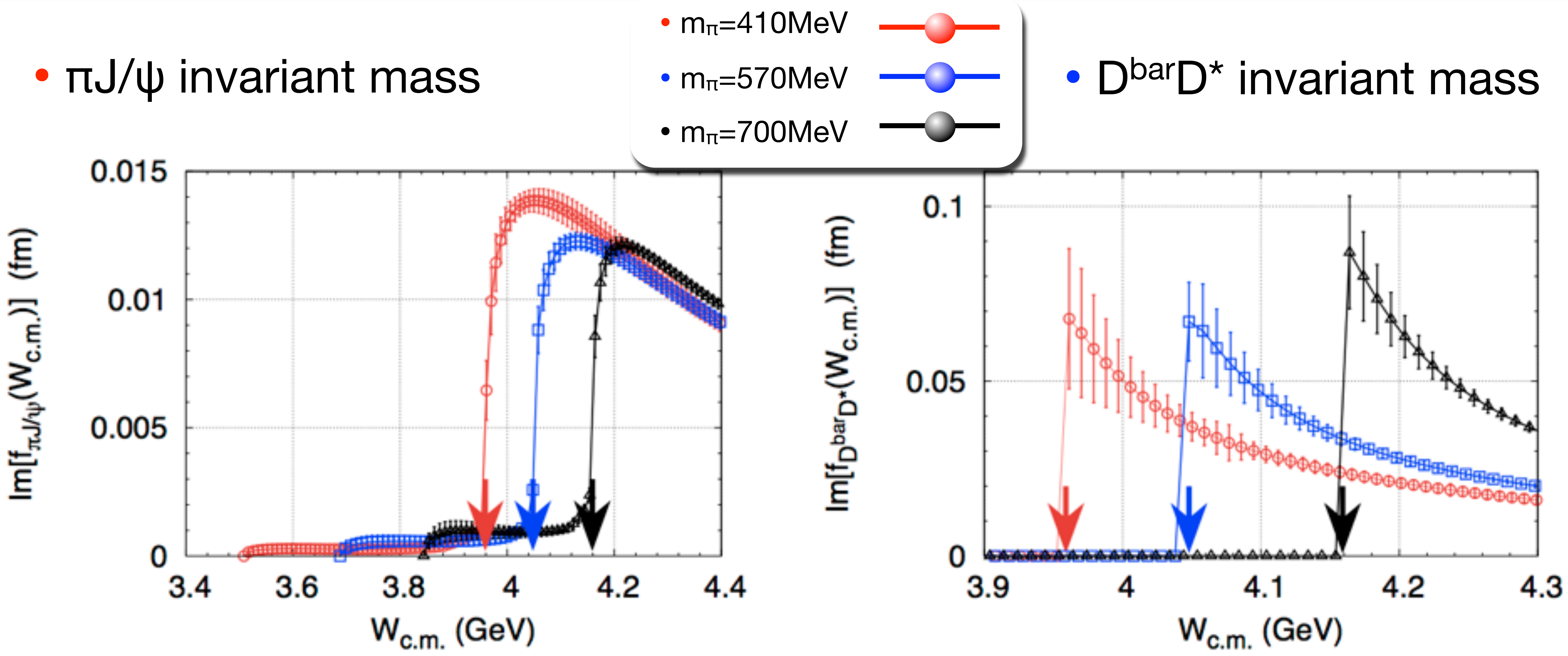
Two-body observables : structure of $Z_c(3900)$ in $I^G(J^{PC})=1^+(1^{+-})$

★ Two-body πJ/ψ & $D^{bar}D^*$ s-wave scattering

➡ ideal scattering reaction to study structure of $Z_c(3900)$



Invariant mass spectra of πJ/ψ & $D^{bar}D^*$



- πJ/ψ invariant mass
- $D^{bar}D^*$ invariant mass

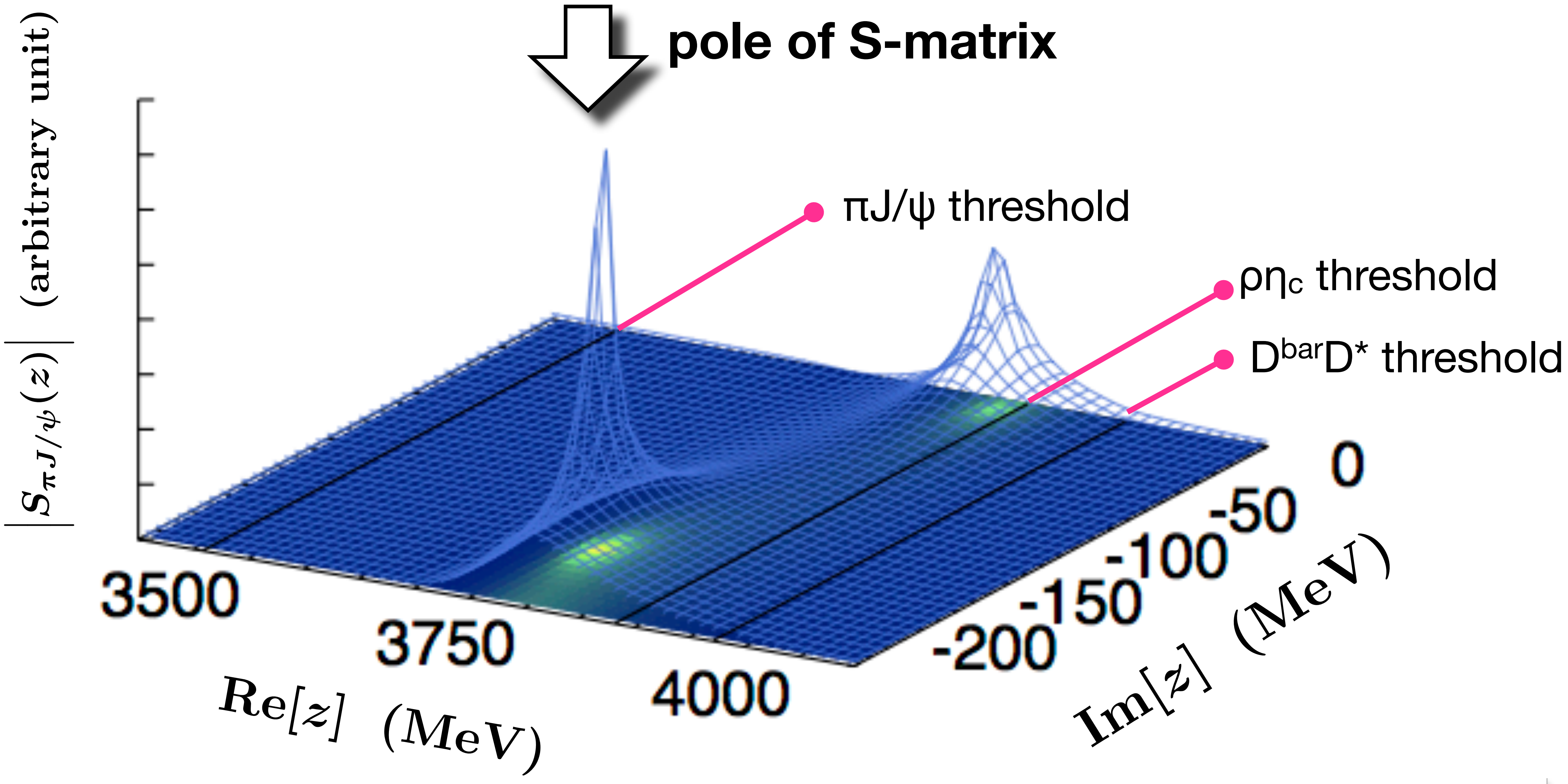
✓ Enhancement near $D^{bar}D^*$ threshold due to large πJ/ψ-$D^{bar}D^*$ coupling

- Peak in πJ/ψ invariant mass (Not Breit-Wigner line shape)
- Threshold enhancement in $D^{bar}D^*$ invariant mass (cusp behavior)

(No m_q dependence on qualitative behaviors of line shapes)

➡ Is Zc(3900) a conventional resonance?

Complex pole position ($\pi J/\psi$:2nd, $\rho\eta_c$:2nd, $D^{bar}D^*$:2nd)



- "Virtual" pole on [2nd, 2nd, 2nd] sheet is found (far below $D^{bar}D^*$ threshold)
- No pole on other relevant sheets to $Z_c(3900)$
- $Z_c(3900)$ is not a conventional resonance
- How large does the pole contribute to amplitudes?

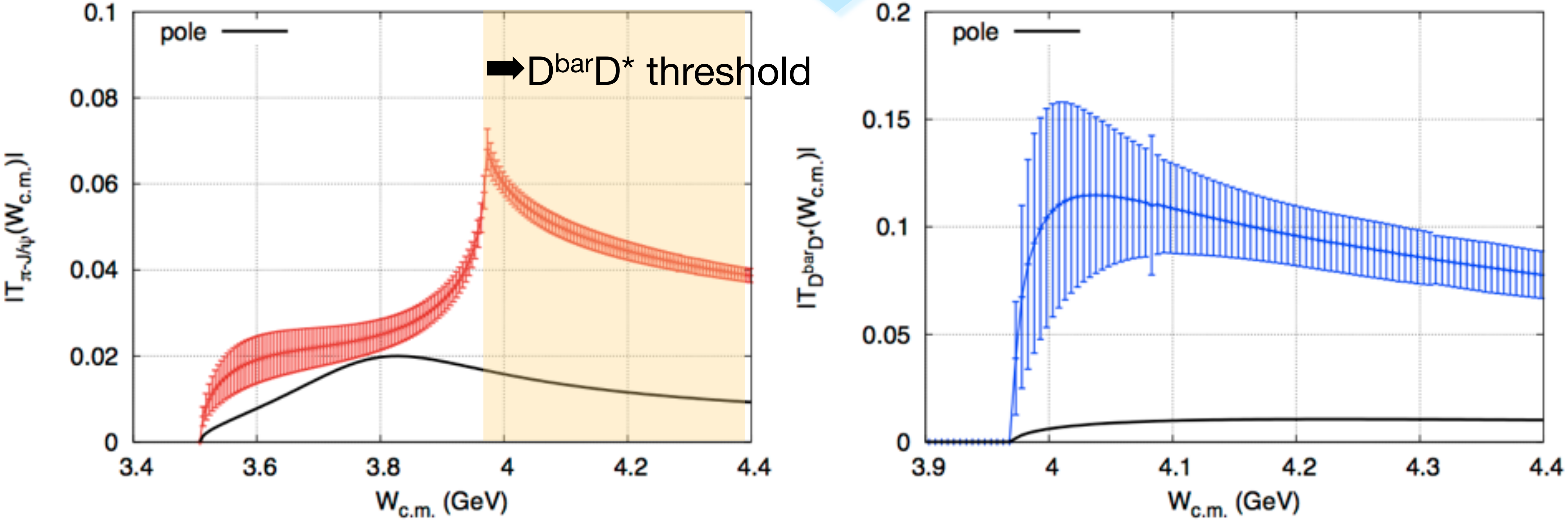
Y. Ikeda et al., [HAL QCD], arXiv.1602.03465 [hep-lat] (2016).

T-matrix of πJ/ψ & $D^{bar}D^*$

- calculate residues of T-matrices in πJ/ψ & $D^{bar}D^*$ channels

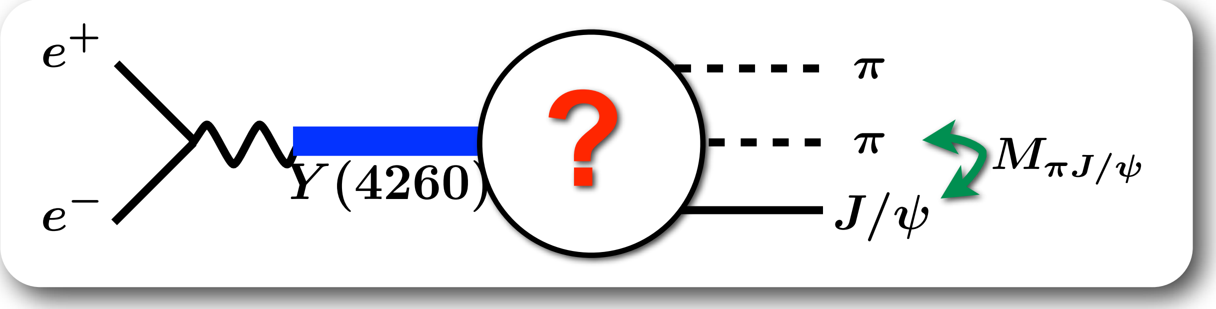
$$S(k) = 1 + 2iT(k)$$

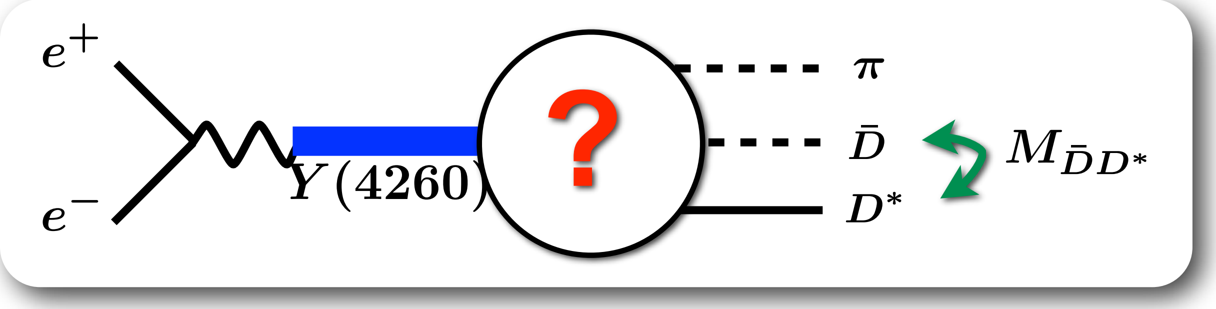
- πJ/ψ-πJ/ψ T-matrix
- $D^{bar}D^*$-$D^{bar}D^*$ T-matrix

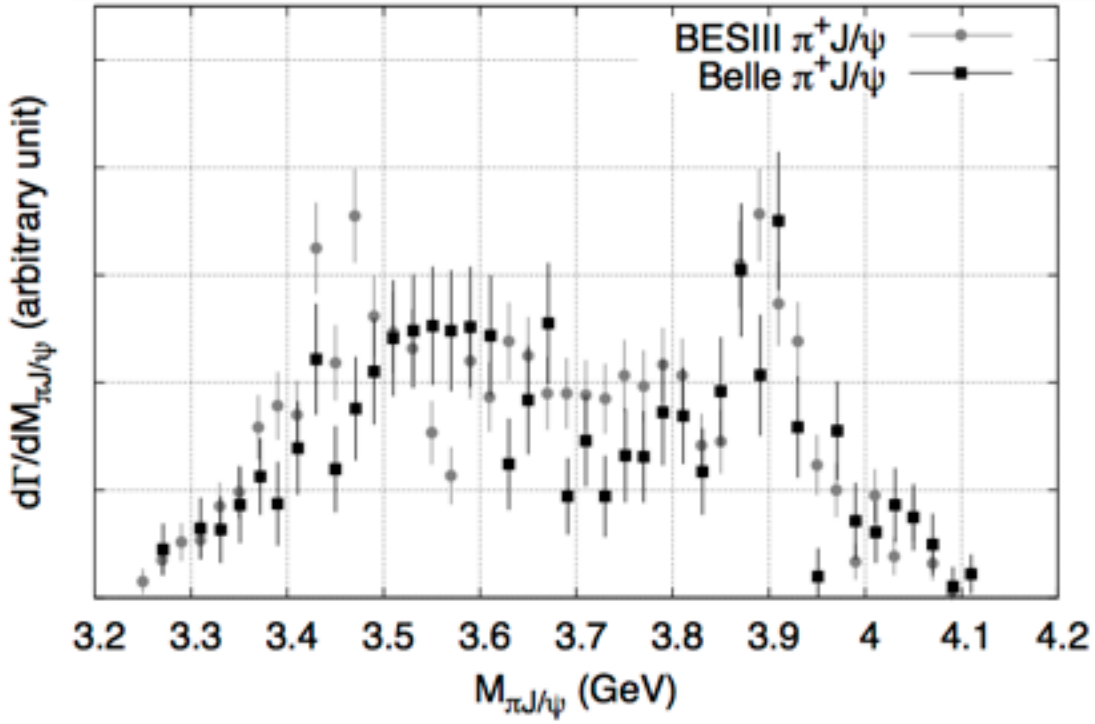


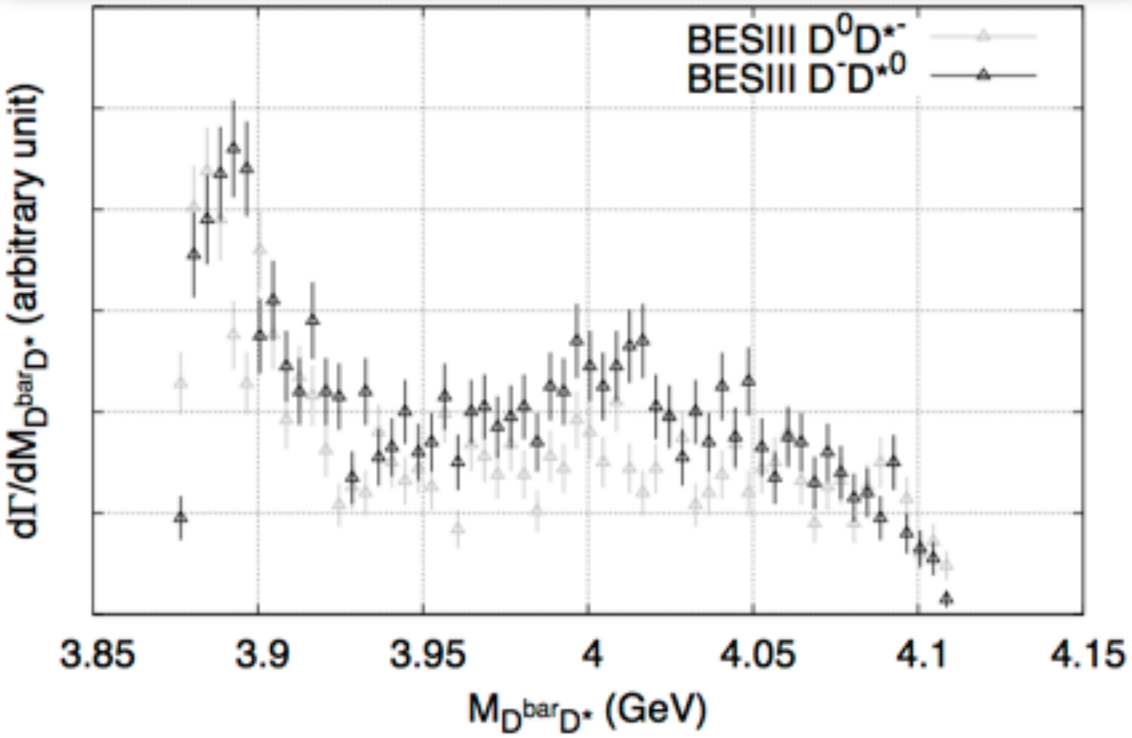
- contribution from virtual pole to T-matrix is small
- Z_c(3900) is cusp at $D^{bar}D^*$ threshold induced by off-diagonal $V^{\pi\psi,\, DbarD^*}$

Comparison with expt. data : $Z_c(3900)$ production via Y(4260) decay









BESIII Coll., PRL110, 252001, (2013).

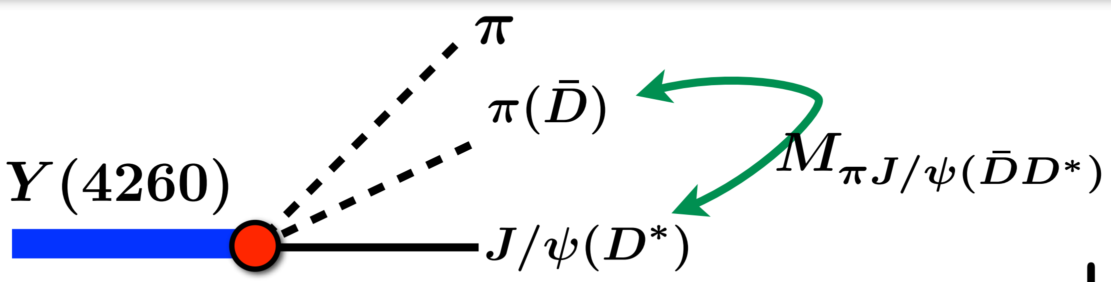
Belle Coll., PRL110, 252002, (2013).

BESIII Coll., PRL112, 022001, (2014).

✓ check whether event distributions of Y(4260) decays can be reproduced with HAL QCD coupled-channel potentials at m_π=410 MeV

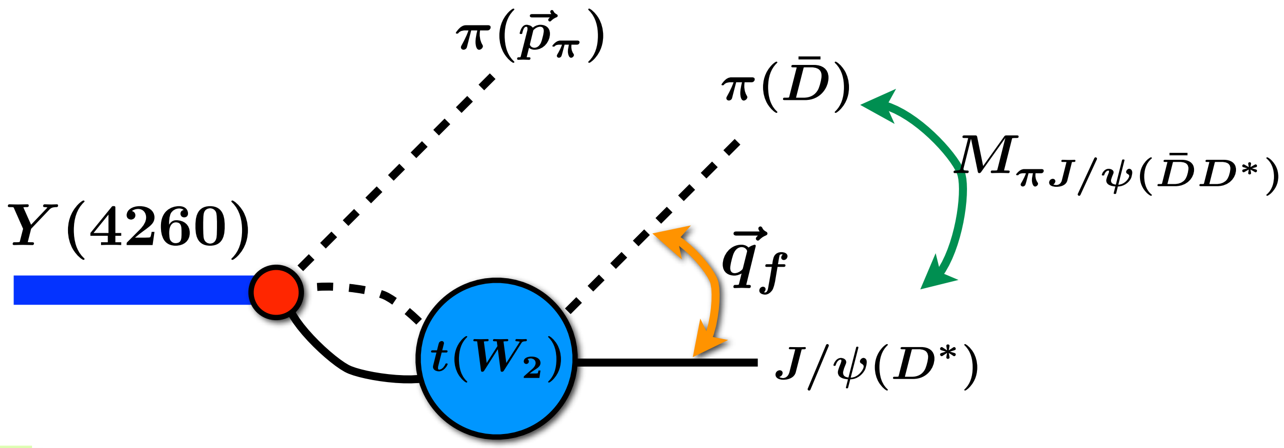
Three-body decay of Y(4260)

$$d\Gamma_f \propto (2\pi)^4 \delta(W_3 - E_\pi(\vec{p}_\pi) - E_f(\vec{q}_f)) d^3p_\pi d^3q_f |T_f(\vec{p}_\pi, \vec{q}_f; W_3)|^2$$



➡ constant primary vertex is assumed (2 parameters)

$+$



★ input $V^{\mathrm{LQCD}}(r)$ --> *t*-matrix

➡ No parameter

✓ Three-body amplitudes

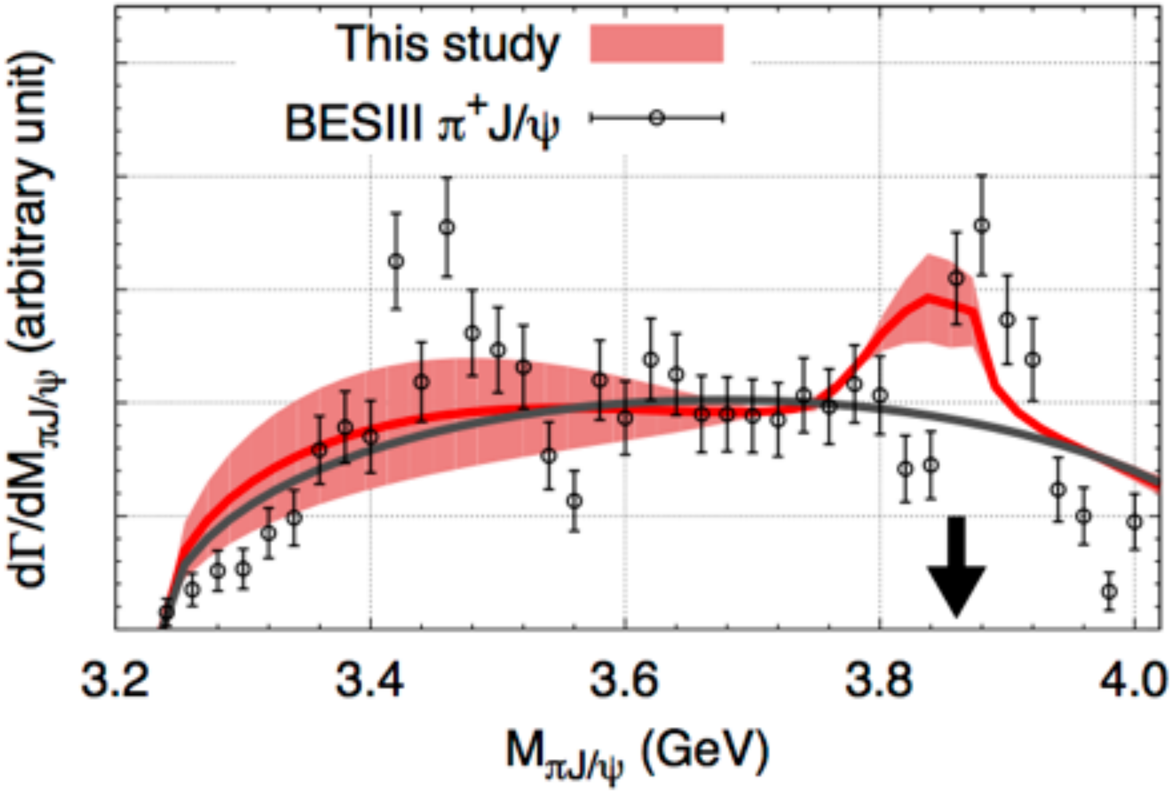
$$T_f(\vec{p}_\pi, \vec{q}_f; W_3) = \sum_{n=\pi\pi J/\psi, \pi\bar{D}D^*} C_n^{Y(4260)} \left[\delta_{nf} + \int d^3q' \frac{t_{nf}(\vec{q}', \vec{q}_f, \vec{p}_\pi; W_3)}{W_3 - E_\pi(\vec{p}_\pi) - E_n(\vec{q}', \vec{p}_\pi) + i\epsilon} \right]$$

physical hadron masses employed to compare w/ expt. data

✓ fix decay vertex by Y(4260) --> ππJ/ψ expt. data

✓ predict Y(4260) --> $\pi D^{\mathrm{bar}} D^*$ decay spectrum

Mass spectra ($\pi J/\psi$ w/ nonrelativistic kinematics)

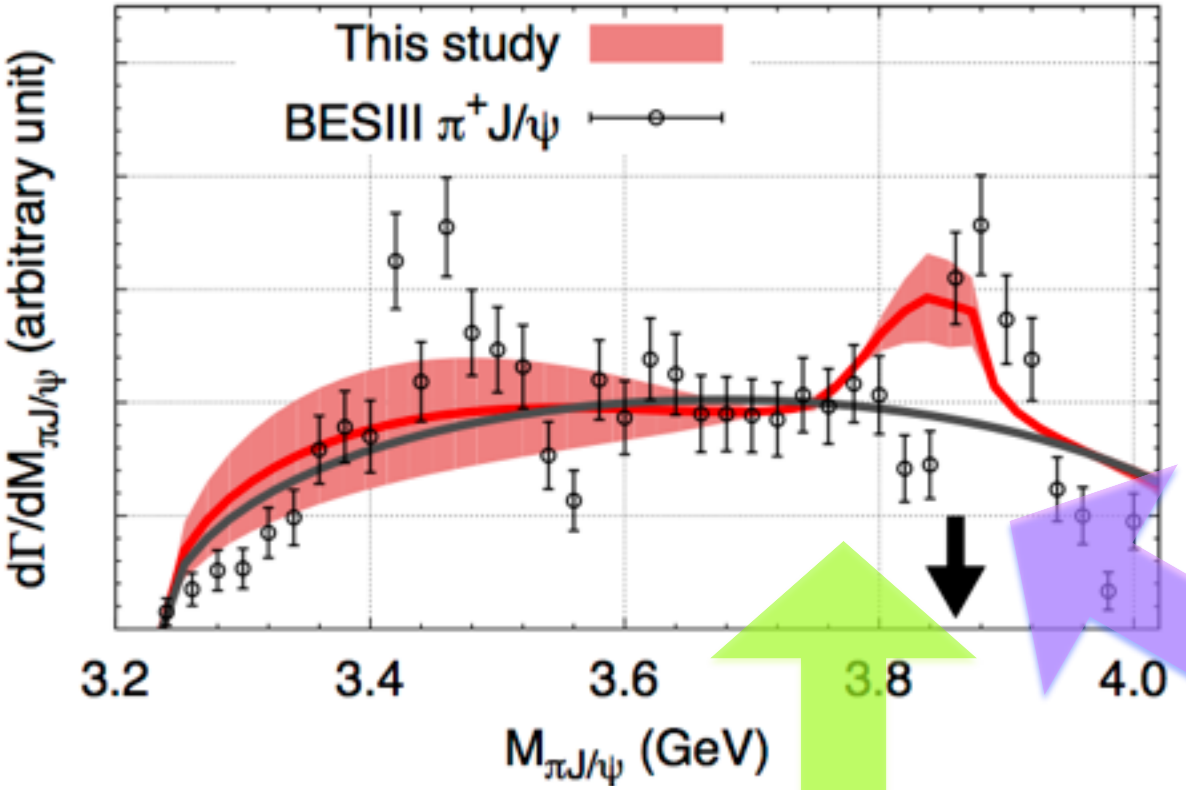


parameters: $C_{\pi D^{bar}D^*}/C_{\pi\pi J/\psi} = Re^{i\theta}$

--> R=0.95(18), θ=-58(44) deg. (+overall factor)

- peak nicely reproduced (a bit broad)
- peak induced by $V^{\pi J/\psi,\ DbarD^*}$
- no reflection peak due to nonrelativistic kinematics

Mass spectra (πJ/ψ w/ nonrelativistic kinematics)



parameters: $C_{\pi D}{}^{bar}{}_{D^*}/C_{\pi\pi J/\psi} = Re^{i\theta}$

--> R=0.95(18), θ=-58(44) deg. (+overall factor)

- peak nicely reproduced (a bit broad)
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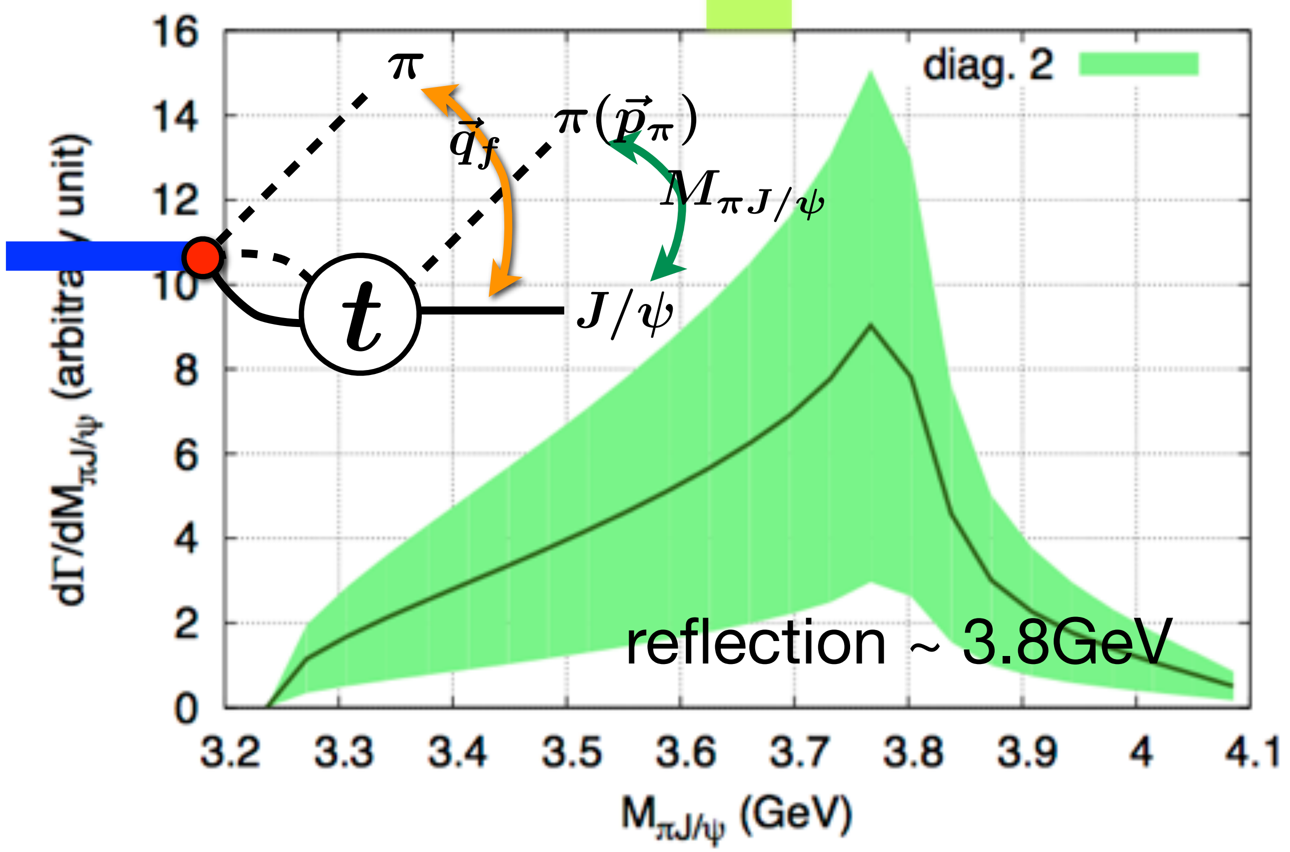
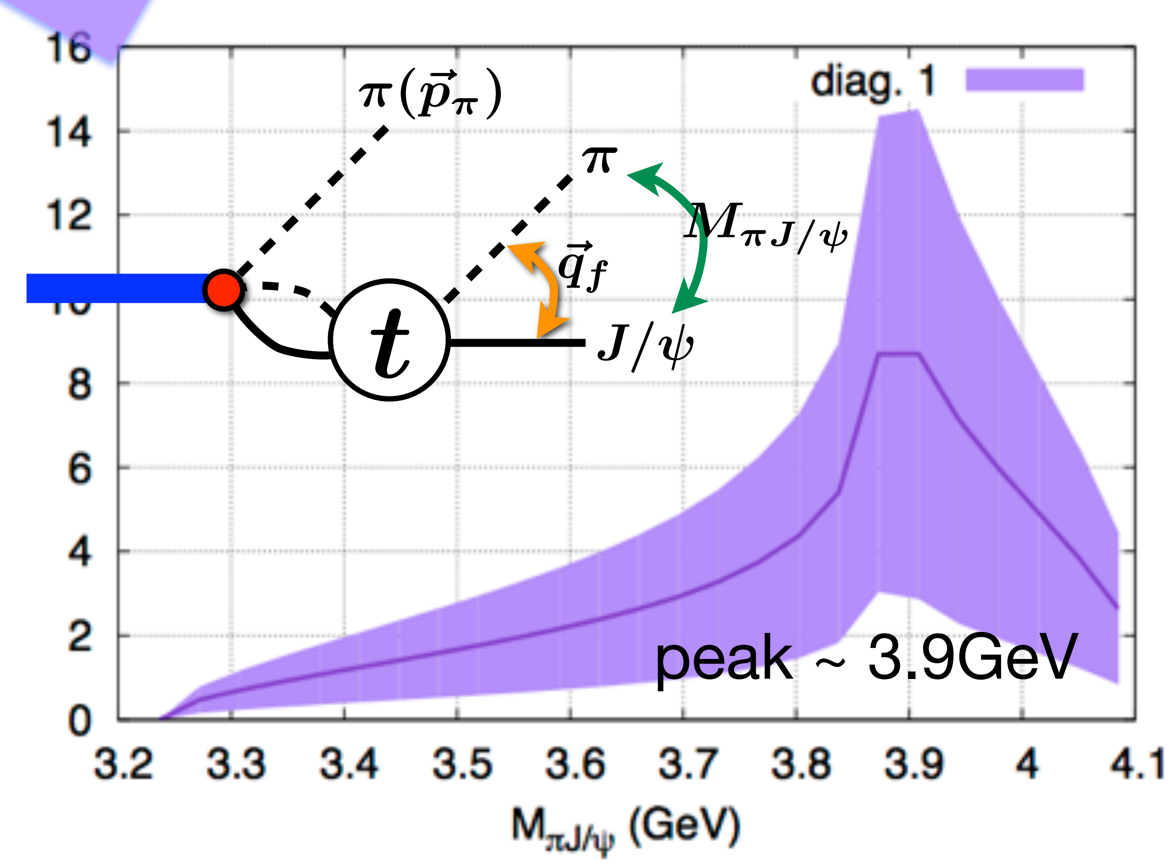
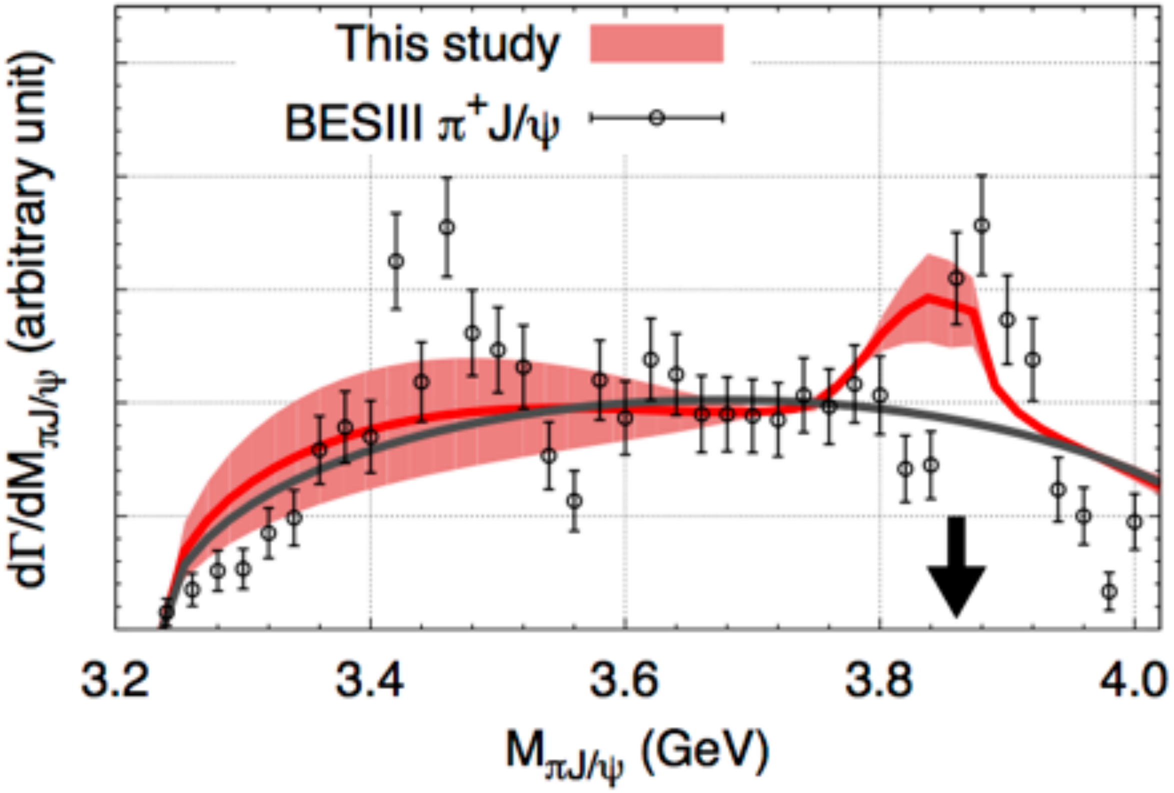


reflection ~ 3.8GeV



peak ~ 3.9GeV

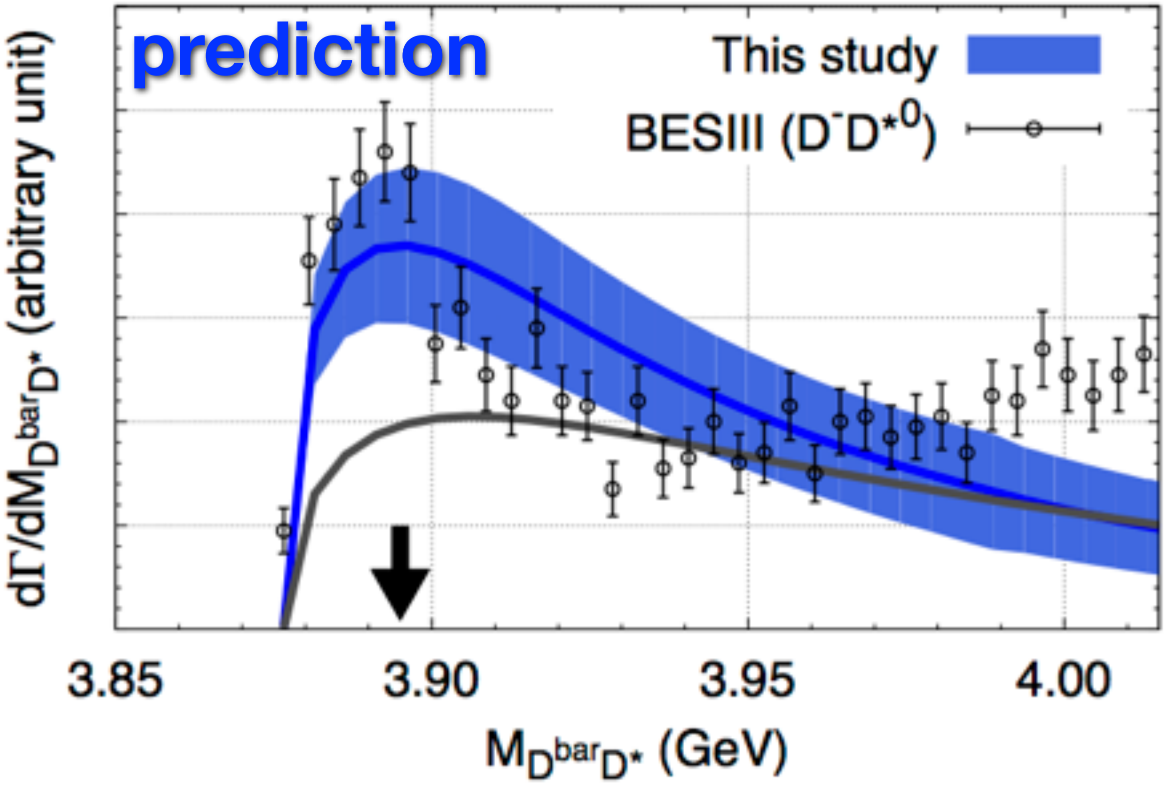
Mass spectra ($\pi J/\psi$ & $D^{bar}D^*$w/ nonrelativistic kinematics)



parameters: $C_{\pi D^{bar}D^*}/C_{\pi\pi J/\psi} = Re^{i\theta}$

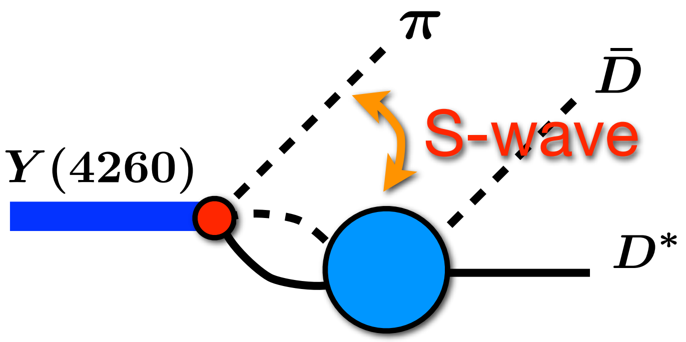
--> R=0.95(18), θ=-58(44) deg. (+overall factor)

- peak nicely reproduced (a bit broad)
- peak induced by $V^{\pi J/\psi,\ DbarD^*}$
- no reflection peak due to nonrelativistic kinematics

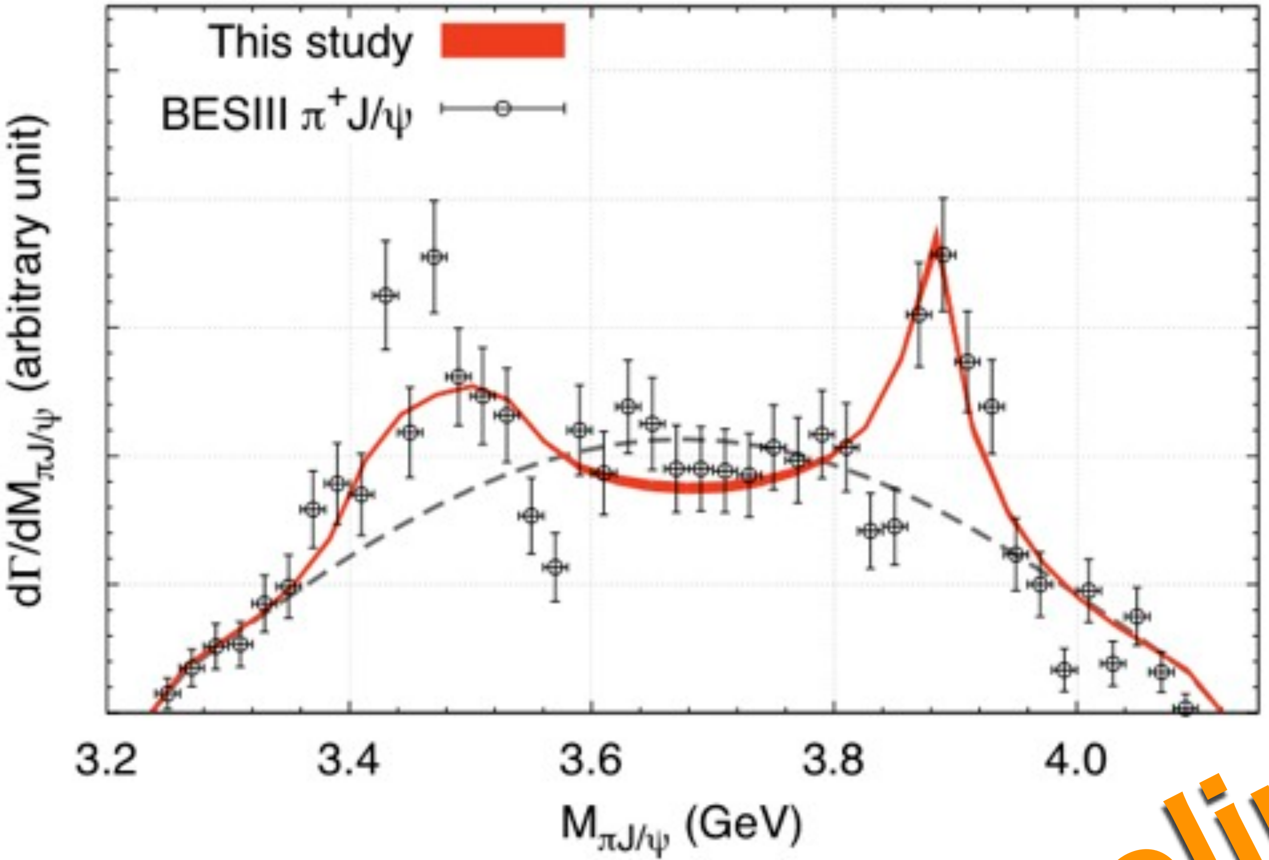


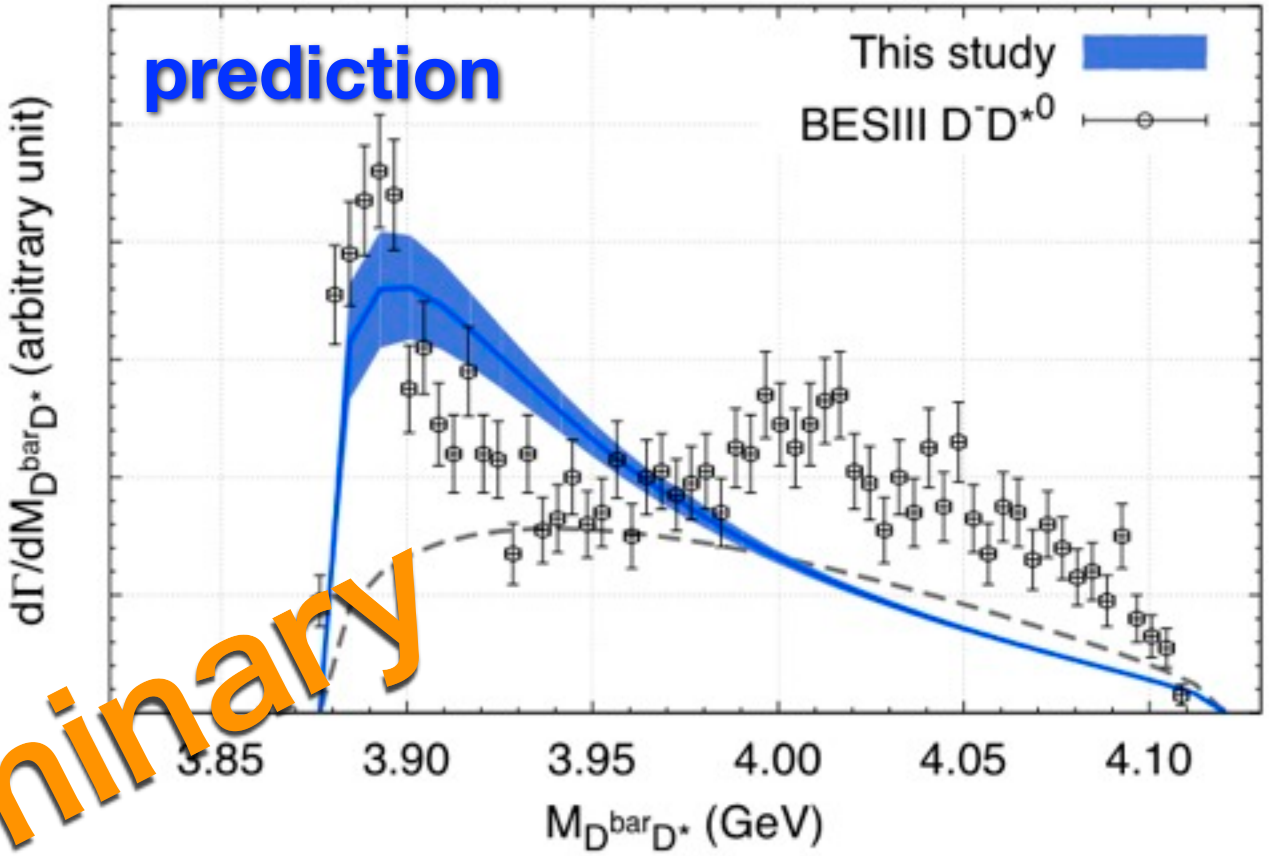
★ Good agreement around 3.9 GeV

- Deviation from expt. data at high energies
- large B.G. for single-D tag data?
- explicit $D^{bar*}D^*$ channel coupling?
- higher partial wave?

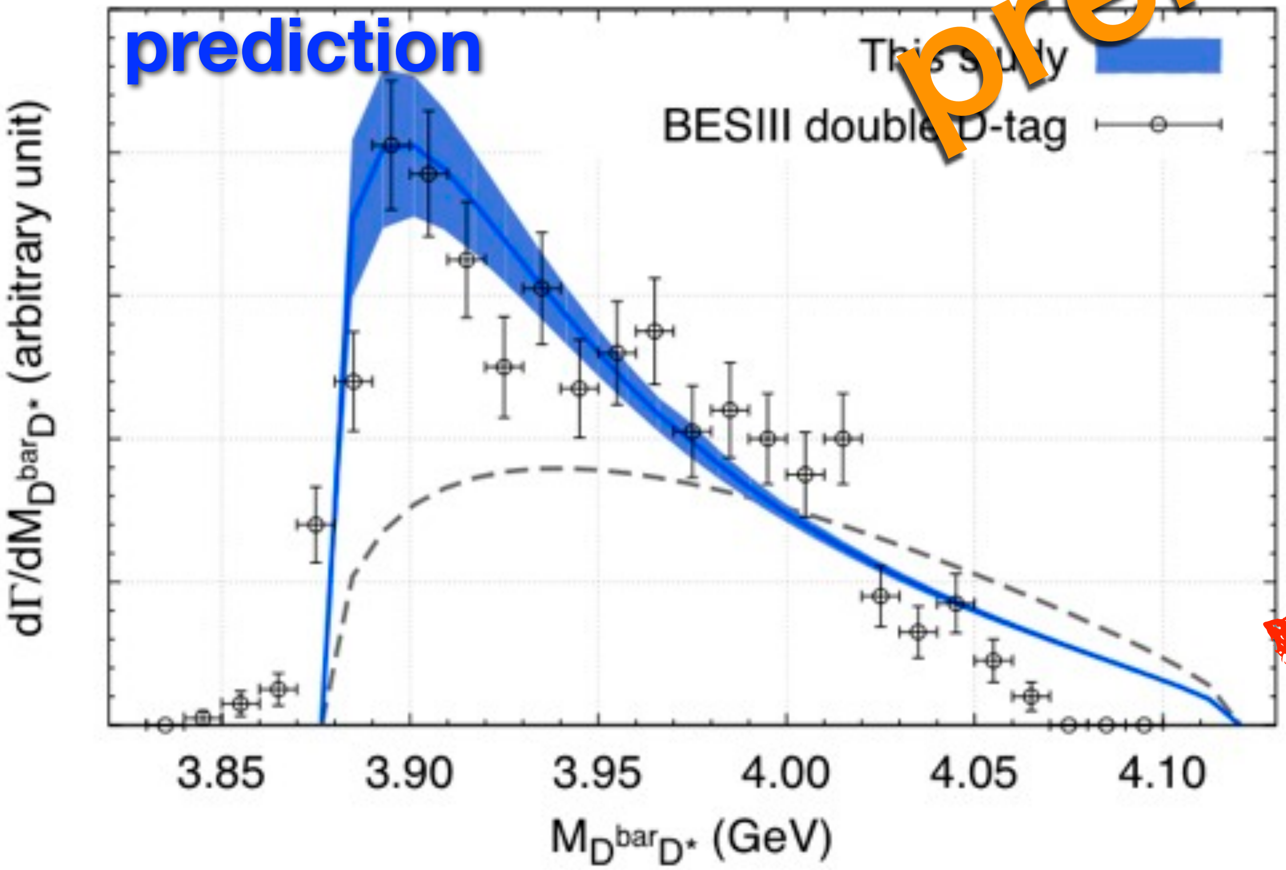


Mass spectra ($\pi J/\psi$ & D^{bar}D* w/ relativistic kinematics)





preliminary



- Deviation from expt. data at high energies due to large B.G. for single-D tag data
- good agreement with double-D tag data

BESIII Coll., PRD92, 9, 092006, (2015).
B. Wang, MENU2016

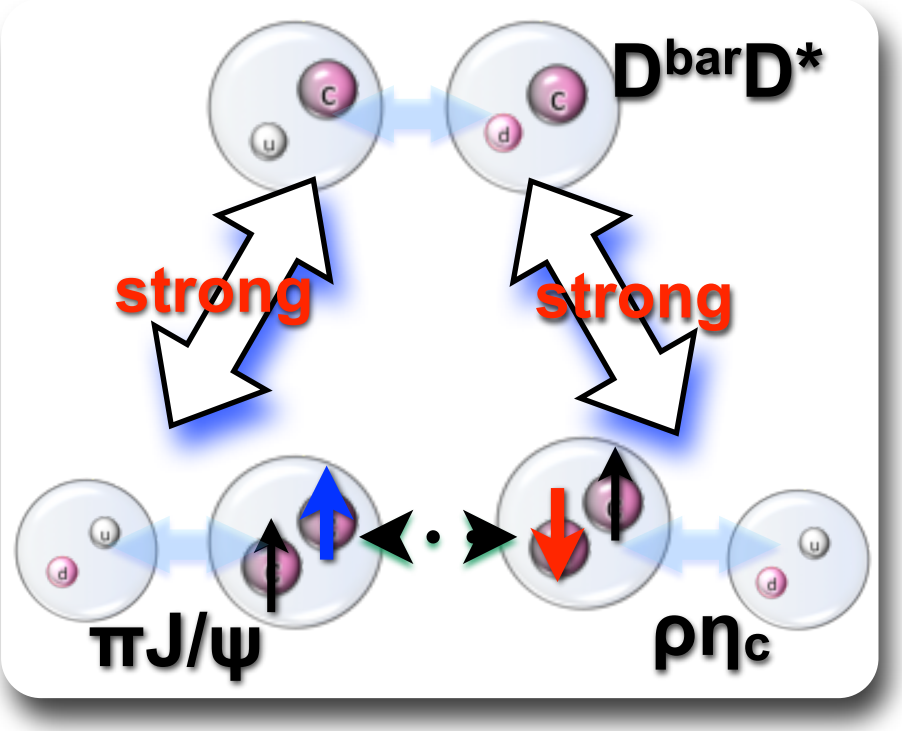
Summary

✦ **Z_c(3900) in $I^G(J^P)=1^+(1^+)$ channel on the lattice@m_π>400MeV**

- ★ Large channel coupling between πJ/ψ and $D^{bar}D^*$ is a key
- ★ Enhancement at $D^{bar}D^*$ threshold in mass spectra
- ★ Heavy quark spin symmetry is observed in c.c. potentials

- Z_c(3900) is neither simple $D^{bar}D^*$ molecule nor hadro-charmonium
- Virtual pole on complex energy plane is found (very far from $D^{bar}D^*$ threshold)

➡ **Z_c(3900) is threshold effect induced by $D^{bar}D^*$-πJ/ψ coupling**



✤ Physical point simulation is the next step

✤ Future plans

- other systems : X(3872)
- extension to bottom systems

Thank you for your attention!!