Remarks on the hidden-color component

Jialun Ping, Hongxia Huang
Nanjing Normal University
Fan Wang
Nanjing University

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Contents

- Motivation
- Physics bases and symmetry bases
- Hidden-color channel
- Summary

Outline

- Motivation
- Physics bases and symmetry bases
- Applications of hidden-color channel
- Summary

Motivation

- What is the hidden-color components?

Quark cluster model for multiquark system($q^m\bar{q}^n, m+n>3$):

two clusters, A and B ➔ multiquark system

Clusters A and B are colorless, A+B colorless,
color singlet component

Clusters A and B are colorful, A+B colorless,
hidden-color component

Multiquark states

- Tetraquark: Zc(3900), Zb(10610)
- Pentaquark: Pc(4380), Pc(4450)
- Dibaryon: d* ($IJ^P=03^+$), WASA-at-COSY experiments:
  NΩ ? (star@RHIC)

PRL 102, 052301 (2009); M=2.36 GeV, Γ=80 MeV
PRL 106, 242302 (2011); M=2.37 GeV, Γ=70 MeV IJP=03+
PLB 721, 229 (2013); M=2.37 GeV, Γ=70 MeV
PRC 88, 055208 (2013); M=2.37 GeV, Γ=70 MeV
PRL 112, 202301 (2014); M=2.380±0.010 GeV, Γ=40±5 MeV

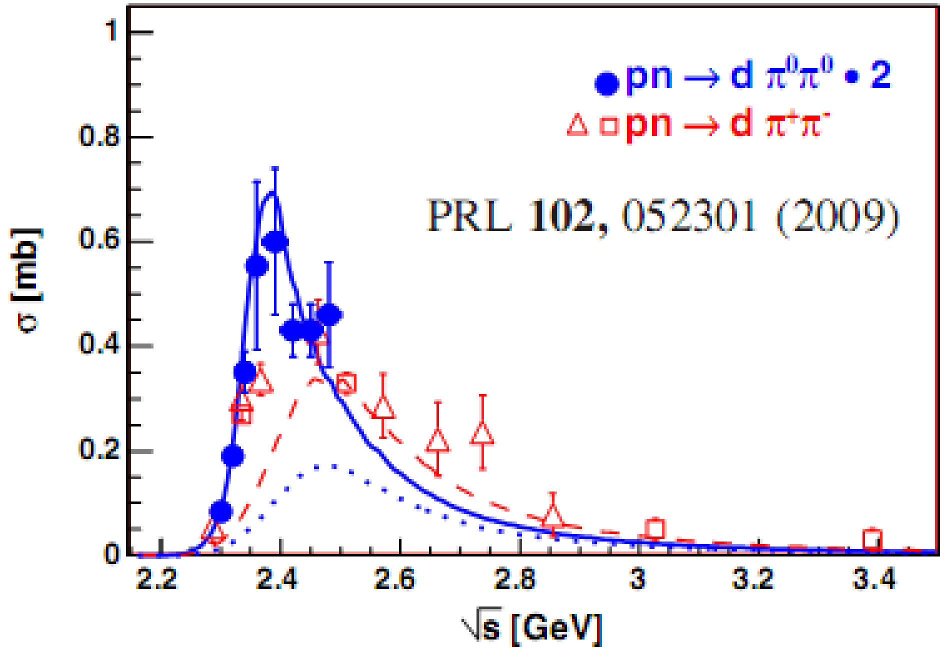


FIG. 4 (color online). Energy dependence of the total cross section for the $pn \to d\pi^+\pi^-$ reaction from threshold ($\sqrt{s} = 2.15$ GeV) up to $\sqrt{s} = 3.5$ GeV. Experimental data are from Refs. [8] (open squares) and [4] (open triangles). The results of this work for the $\pi^0\pi^0$ channel—scaled by the isospin factor of 2—are given by the full circles. Dashed and dotted lines represent the cross sections for $\pi^+\pi^-$ and $\pi^0\pi^0$ channels, respectively, as expected from the isovector $\pi^+\pi^0$ data by isospin relations (see text). The solid curve includes an s-channel resonance in the $\Delta\Delta$ system adjusted to describe the ABC effect in the $\pi^0\pi^0$ channel.

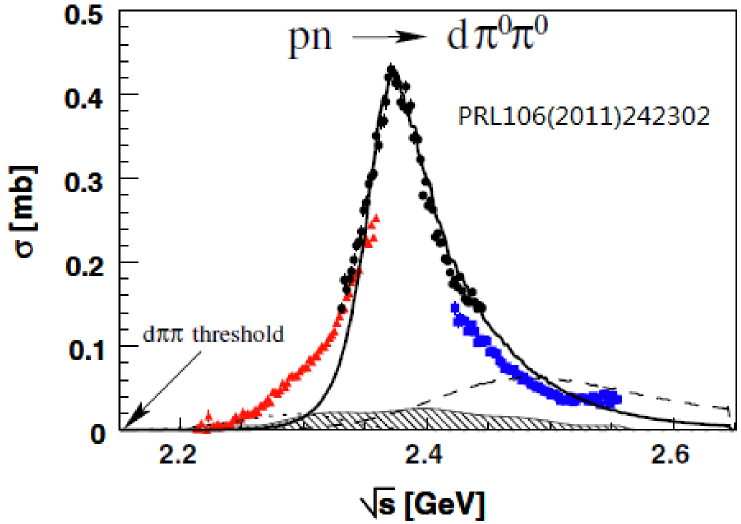


FIG. 2 (color online). Total cross sections obtained from this experiment on $pd \to d\pi^0\pi^0 + p_{\mathrm{spectator}}$ for the beam energies $T_p = 1.0$ GeV (triangles), 1.2 GeV (dots), and 1.4 GeV (squares) normalized independently. Shown are the total cross section data after acceptance, efficiency and Fermi motion corrections. The hatched area indicates systematic uncertainties. The drawn lines represent the expected cross sections for the Roper excitation process (dotted) and the t-channel $\Delta\Delta$ contribution (dashed) as well as a calculation for a s-channel resonance with $m = 2.37$ GeV and $\Gamma = 68$ MeV (solid).

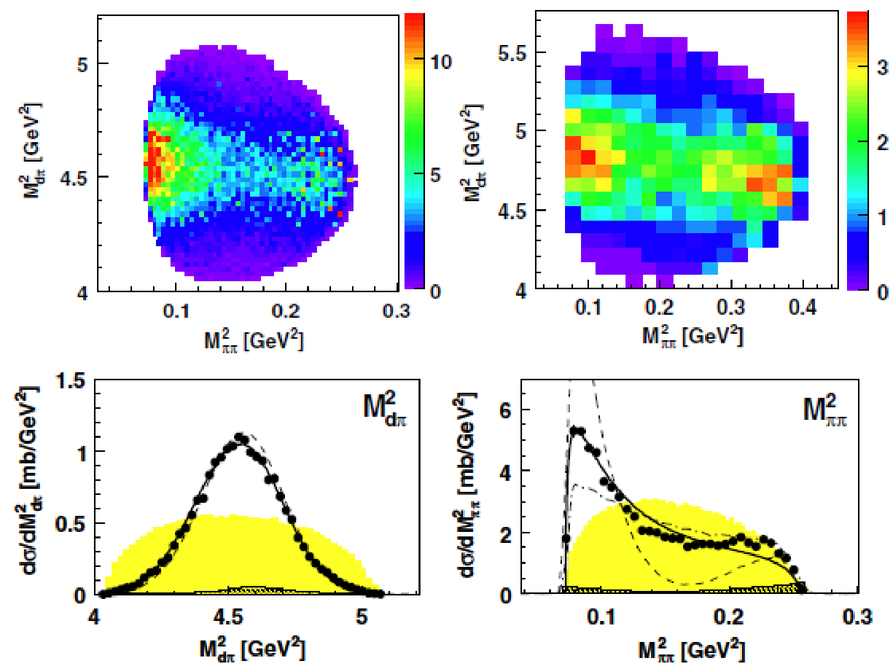
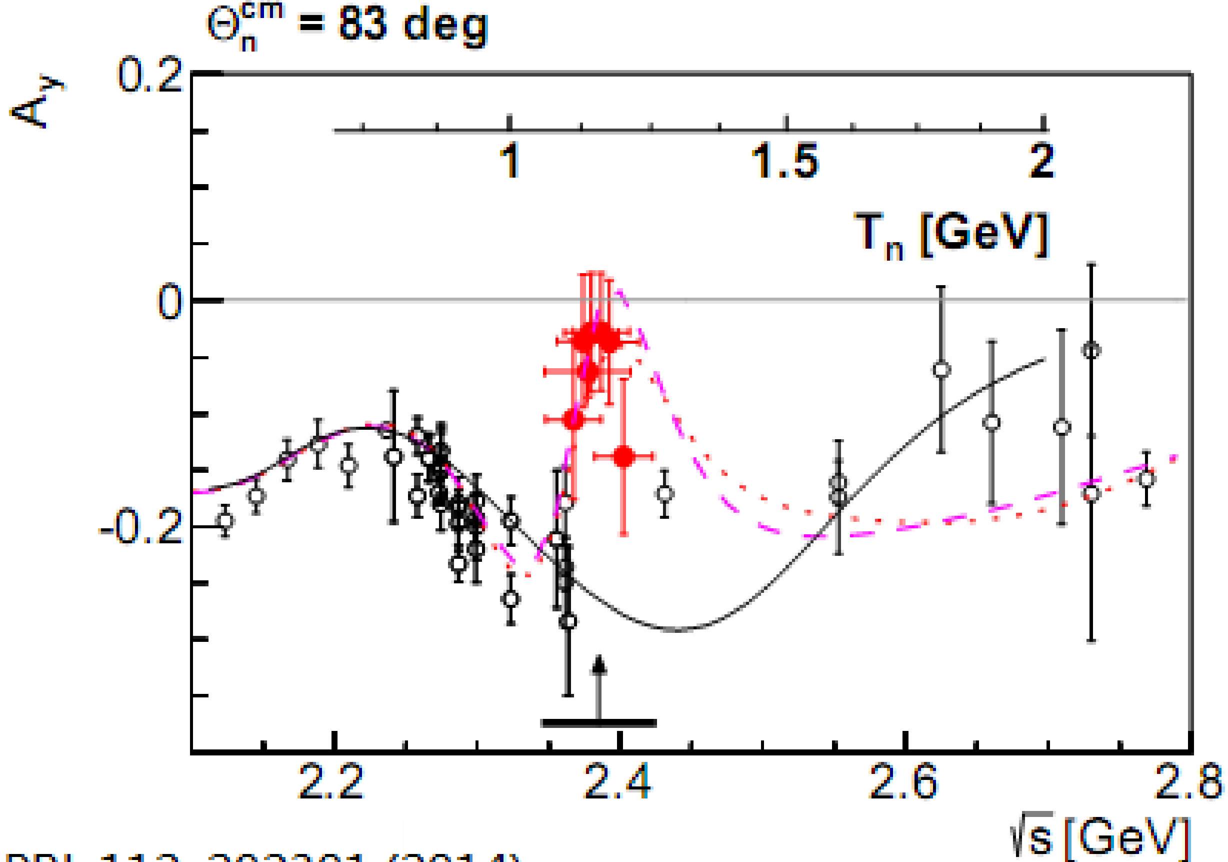
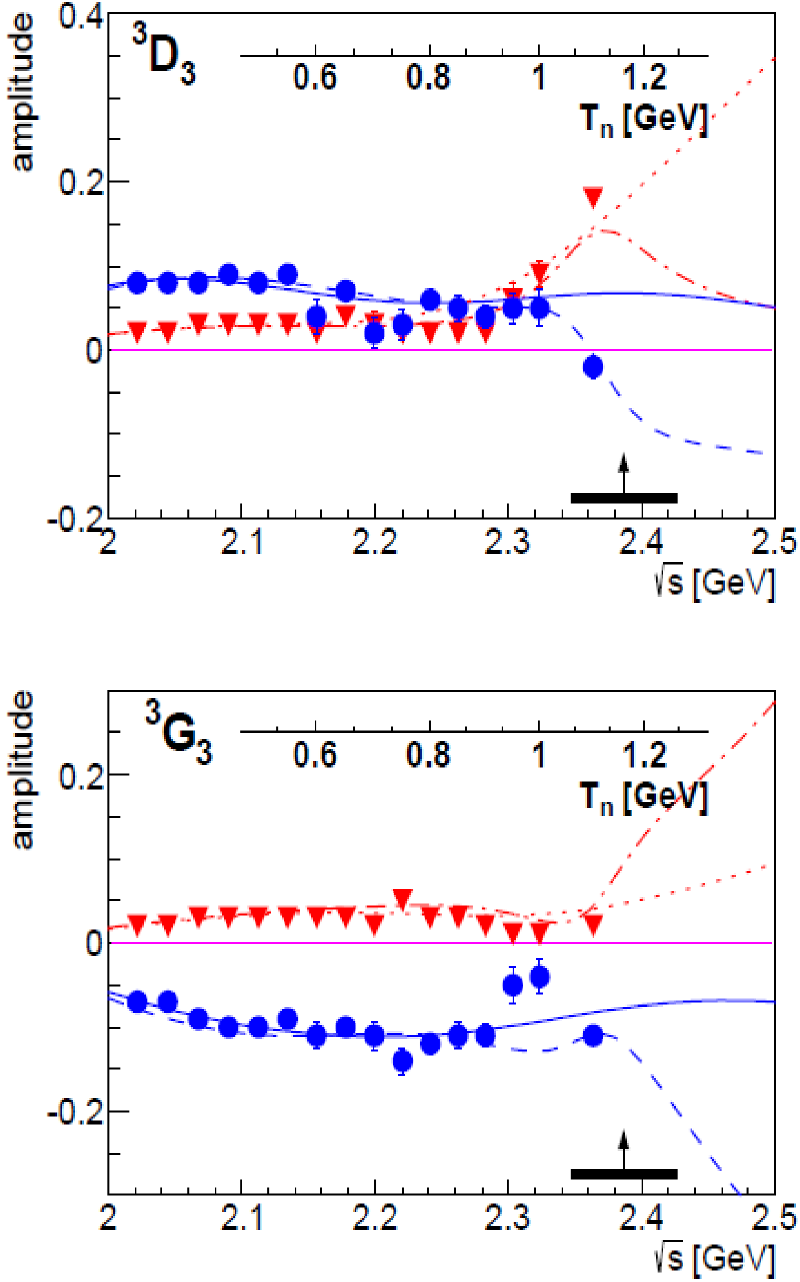


FIG. 4 (color online). Top: Dalitz plots of $M^2_{d\pi^0}$ versus $M^2_{\pi^0\pi^0}$ at $\sqrt{s} = 2.38$ GeV (peak cross section) (left) and at $\sqrt{s} = 2.5$ GeV (right). Bottom: Dalitz plot projections $M^2_{d\pi^0}$ (left) and $M^2_{\pi^0\pi^0}$ (right) axes at $\sqrt{s} = 2.38$ GeV. The curves denote calculations for a s-channel resonance decaying into $\Delta\Delta$ with $J^P = 3^+$ with (solid) and without (dash-dotted) form factor as well as for $J^P = 1^+$ (dashed). Hatched and shaded areas represent systematic uncertainties and phase-space distributions, respectively.



PRL 112, 202301 (2014)

FIG. 4: (Color online) Energy dependence of the np analyzing power at $\Theta_n^{cm} = 83°$. The solid symbols denote the results from this work, the open symbols those from previous work [7–9, 21–25]. For the meaning of the curves see Fig. 1. Vertical arrow and horizontal bar indicate pole and width of the resonance.



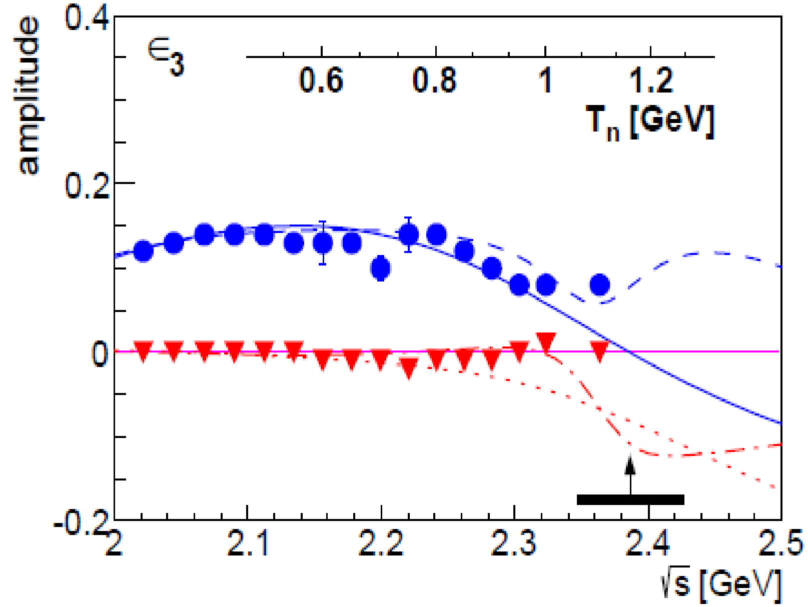


FIG. 3: (Color online) Changes to the (dimensionless) $^3D_3$ (top) and $^3G_3$ (middle) partial waves including their mixing amplitude ϵ_3 (bottom). Solid (dotted) curves give the real (imaginary) part of the partial-wave amplitudes from SP07, whereas the dashed (dash-dotted) curves represent the new (weighted) solution. Results from previous single energy fits [16] are shown by solid circles (real part) and inverted triangles (imaginary part). Vertical arrow and horizontal bar indicate pole and width of the resonance.

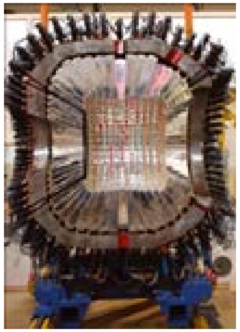
CERN Courier 2011

- http://cerncourier.com/cws/article/cern/46855

Aug 26, 2011

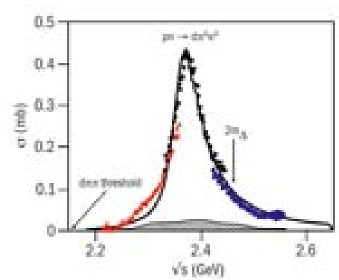
COSY finds evidence for an exotic particle...

Experiments at the Jülich Cooler Synchrotron, COSY, have found evidence for a new complex state in the two-baryon system, with mass 2.37 GeV and width 70 MeV. The structure, containing six valence quarks, could constitute either an exotic compact particle or a hadronic molecule. The result could cast light on the long-standing question of whether there are eigenstates in the two-baryon system other than the deuteron ground-state. This has awaited an answer since Robert Jaffe first envisaged the possible existence of non-trivial six-quark configurations in QCD in 1977.



WASA detector

The new structure has been observed in high-precision measurements carried out by the WASA-at-COSY collaboration, using the Wide-Angle Shower Apparatus (WASA). The data exhibit a narrow isoscalar resonance-like structure in neutron-proton collisions for events where a deuteron is produced together with a pair of neutral pions. From the differential distributions, the spin-parity of the new system is deduced to be $J^P = 3^+$ and its main decay mode is via formation of a ΔΔ system below the nominal threshold of $2m_\Delta$. The collaboration will further test the resonance hypothesis in elastic proton-neutron collisions with a polarized beam; the $J^P = 3^+$ partial waves should be dominated by the new structure, while its contribution to the elastic cross-section should be small.



Measurement of energy dependence

The resonance structure also turns out to be intimately connected to the so-called ABC effect, in which the two pions produced in a nuclear fusion process are emitted preferentially in parallel. This 50-year-old puzzle, which is named after the initial letters of the surnames of its first observers A Abashian, N E Booth and K M Crowe, could now find its explanation in the way that such a resonance decays.

Further reading

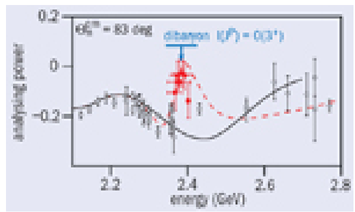
P Adlarson et al. 2011 **Phys. Rev. Lett. 106** *242302.*

CERN Courier 2014

- http://cerncourier.com/cws/article/cern/57836

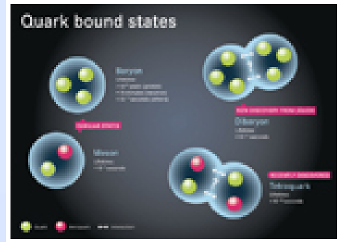
Jul 23, 2014

COSY confirms existence of six-quark states



Energy dependence

Experiments at the Jülich Cooler Synchrotron (COSY) have found compelling evidence for a new state in the two-baryon system, with a mass of 2380 MeV, width of 80 MeV and quantum numbers $I(J^P) = 0(3^+)$. The structure, containing six valence quarks, constitutes a dibaryon, and could be either an exotic compact particle or a hadronic molecule. The result answers the long-standing question of whether there are more eigenstates in the two-baryon system than just the deuteron ground-state. This fundamental question has been awaiting an answer since at least 1964, when first Freeman Dyson and later Robert Jaffe envisaged the possible existence of non-trivial six-quark configurations.



Quark configurations

The new resonance was observed in high-precision measurements carried out by the WASA-at-COSY collaboration. The first signals of the new state had been seen before in neutron-proton collisions, where a deuteron is produced together with a pair of neutral pions (CERN Courier September 2011 p8). Now this state has also been observed in polarized neutron-proton scattering and extracted using the partial-wave analysis technique - the generally accepted ultimate method to reveal a resonance. In the SAID partial-wave analysis, the inclusion of the new data produces a pole in the $^3D_3$ partial wave at (2380±10 - i 40±5) MeV.

The mass of the new state is amazingly close to that predicted originally by Dyson, based on SU(6) symmetry breaking. Moreover, recent state-of-the-art Faddeev calculations by Avraham Gal and Humberto Garcilazo reproduce the features of this new state very well. The quantum numbers favour this state as a dibaryon resonance - the "inevitable" non-strange dibaryon predicted by Terry Goldman and colleagues in 1989.

Further reading

P Adlarson et al. 2014 Phys. Rev. Lett. **112** *202301.*

Multiquark era?!

- Structures: a lots of controversies
  hadronic molecules
  compact multiquark states
  hybrids
  ……
- Hidden-color: a new degree of freedom?

Physical bases and symmetry bases

- Description of multiquark states

- In nuclear physics : Elliott model

$$(SU_4^{\tau\sigma} \supset SU_2^{\tau} \times SU_2^{\sigma}) \times (SU_3 \supset SO_3)$$

$$[\tilde{\upsilon}] \quad IM_I \quad SM_S \quad [\upsilon] \quad LM_L$$

- Symmetry basis:

$$\left| \begin{matrix} \upsilon \\ IM_I LSJM_J \end{matrix} \right\rangle$$

- Physical basis:

$$\mathcal{A}\left[\left[\psi_{I_1 S_1}(A_1)\psi_{I_2 S_2}(A_2)\right]_{IM_I}^{SM_S} F_L(\boldsymbol{R})\right]_{IM_I}^{JM_J}$$

Extended to quark model

M. Harvey: NPA352(1981)301: SU(2) - isospin

J.Q. Chen: NPA393(1983)122

F.Wang, J.L.Ping, T. Goldman: PRC51(1995)1648: SU(3) -- flavor

Group chain:

$$\overset{[1^3]}{SU(36)} \supset \left(\overset{[\nu]}{SU^x(2)} \times \left\{ \overset{[\tilde{\nu}]}{SU(18)} \supset \overset{[\sigma]}{SU^c(3)} \times \left[\overset{[\mu]}{SU(6)} \supset \left(\overset{[f]}{SU^f(3)} \supset \overset{I}{SU^\tau(2)} \times \overset{Y}{U^Y(1)} \right) \times \overset{J}{SU^\sigma(2)} \right] \right\} \right)$$

Physical basis:

$$\begin{aligned} \Psi_{\alpha k}(B_1 B_2) &= \mathcal{A}[\psi(B_1)\psi(B_2)] \overset{[\sigma]}{W} \overset{I}{M_I} \overset{J}{M_J} \\ &= \mathcal{A}\left[\left| [\sigma_1][\mu_1]\overset{[\nu_1]}{[f_1]} Y_1 I_1 J_1 \right\rangle \left| [\sigma_2][\mu_2]\overset{[\nu_2]}{[f_2]} Y_2 I_2 J_2 \right\rangle \right] \overset{[\sigma]}{W} \overset{I}{M_I} \overset{J}{M_J} \ ; \end{aligned}$$

Symmetry basis:

$$\Phi_{\alpha K}(q^6) = \left| [\sigma] W [\mu] \beta \overset{[\nu] l^3 r^3}{[f]} Y I J M_I M_J \right\rangle .$$

Tranformation between physics basis and symmetry basis:

$$\mathcal{A}\left[\left|[\sigma_1][\mu_1]\overset{[\nu_1]l^3}{[f_1]}Y_1I_1J_1\right\rangle\left|[\sigma_2][\mu_2]\overset{[\nu_2]r^3}{[f_2]}Y_2I_2J_2\right\rangle\right]\overset{[\sigma]}{W}\overset{I}{M_I}\overset{J}{M_J}$$

$$=\sum_{\tilde{\nu}\mu\beta f\gamma} C^{[\tilde{\nu}][\sigma][\mu]}_{[\tilde{\nu}_1][\sigma_1][\mu_1][\tilde{\nu}_2][\sigma_2][\mu_2]} C^{[\mu]\beta[f]\gamma J}_{[\mu_1][f_1]J_1,[\mu_2][f_2]J_2} C^{[f]\gamma Y I}_{[f_1]Y_1I_1[f_2]Y_2I_2}\left|[\sigma]W[\mu]\beta\overset{[\nu]l^3r^3}{[f]}YIJM_IM_J\right\rangle .$$

For IJP=03+:

	[6][33][33]	[42][33][33]
ΔΔ	$\sqrt{1/5}$	$\sqrt{4/5}$
CC	$\sqrt{4/5}$	$-\sqrt{1/5}$

[ν][μ][f]

rbital

flavor

flavor-spin

Unitary transformation

- The transformation between two sets of orthonormal bases
- Symmetry bases and physical bases are orthonormal?

  Yes, if the single particle states are orthonormal

$$\langle r|r\rangle = \langle l|l\rangle = 1,\ \langle r|l\rangle = 0$$

The usual single-particle orbital states

$$|l\rangle = \left(\frac{1}{\pi b^2}\right)^{3/4} e^{-\left(\boldsymbol{r}+\frac{\boldsymbol{s}}{2}\right)^2/2b^2}$$

$$|r\rangle = \left(\frac{1}{\pi b^2}\right)^{3/4} e^{-\left(\boldsymbol{r}-\frac{\boldsymbol{s}}{2}\right)^2/2b^2}$$

$$\mathrm{m} = \langle r|l\rangle \neq 0$$

Harvey's method

- Introducing separation dependent normalization factor

$$N([6],s)=\sqrt{1+9m^2+9m^4+m^6}$$
$$N([42],s)=\sqrt{1-m^2-m^4+m^6}$$
$$N([51],s)=\sqrt{1+3m^2-3m^4-m^6}$$
$$N([33],s)=\sqrt{1-3m^2+3m^4-m^6}$$

→ Symmetry bases are orthonormal

- Physical bases are orthonormal if the separation is infinity.

↓

transformation table

- Problem: no direct expressions for physical bases

Transformation (con't)

- The relation

$$\mathcal{A}\left[\left|[\sigma_1][\mu_1]\overset{[\nu_1]l^3}{[f_1]}Y_1 I_1 J_1\right\rangle\left|[\sigma_2][\mu_2]\overset{[\nu_2]r^3}{[f_2]}Y_2 I_2 J_2\right\rangle\right] \overset{[\sigma]}{W}\overset{I}{M_I}\overset{J}{M_J}$$

$$= \sum_{\tilde{\nu}\mu\beta f\gamma} C^{[\tilde{\nu}][\sigma][\mu]}_{[\tilde{\nu}_1][\sigma_1][\mu_1][\tilde{\nu}_2][\sigma_2][\mu_2]} C^{[\mu]\beta[f]\gamma J}_{[\mu_1][f_1]J_1,[\mu_2][f_2]J_2} C^{[f]\gamma Y I}_{[f_1]Y_1 I_1[f_2]Y_2 I_2} \left| [\sigma]W[\mu]\beta\overset{[\nu]l^3 r^3}{[f]}YIJM_I M_J\right\rangle .$$

valid for non-orthogonal single particle orbital states

and without the separation dependent normalization

Note: the physical bases are not orthogonal in general

Applications

- repulsive core of nuclear force ⇦ HC? No

  attribute it to CMI of one-gluon-exchange

$$\langle CMI\rangle_N = -3C\langle\boldsymbol{\lambda}_2\cdot\boldsymbol{\lambda}_3\rangle_A\left[\langle\boldsymbol{\sigma}_2\cdot\boldsymbol{\sigma}_3\rangle_A + \langle\boldsymbol{\sigma}_2\cdot\boldsymbol{\sigma}_3\rangle_S\right]/2 = -8C,$$

$$\langle CMI\rangle_\Delta = -3C\langle\boldsymbol{\lambda}_1\cdot\boldsymbol{\lambda}_2\rangle_A\langle\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2\rangle_S = 8C,$$

$$\langle CMI\rangle_d = -15C\left\{\langle\boldsymbol{\lambda}_5\cdot\boldsymbol{\lambda}_6\rangle_A\left[\frac{5}{30}\langle\boldsymbol{\sigma}_5\cdot\boldsymbol{\sigma}_6\rangle_A + \frac{13}{30}\langle\boldsymbol{\sigma}_5\cdot\boldsymbol{\sigma}_6\rangle_S\right]\langle\boldsymbol{\lambda}_5\cdot\boldsymbol{\lambda}_6\rangle_S\left[\frac{5}{30}\langle\boldsymbol{\sigma}_5\cdot\boldsymbol{\sigma}_6\rangle_A + \frac{7}{30}\langle\boldsymbol{\sigma}_5\cdot\boldsymbol{\sigma}_6\rangle_S\right.\right.$$

$$= -\frac{8}{3}C,$$

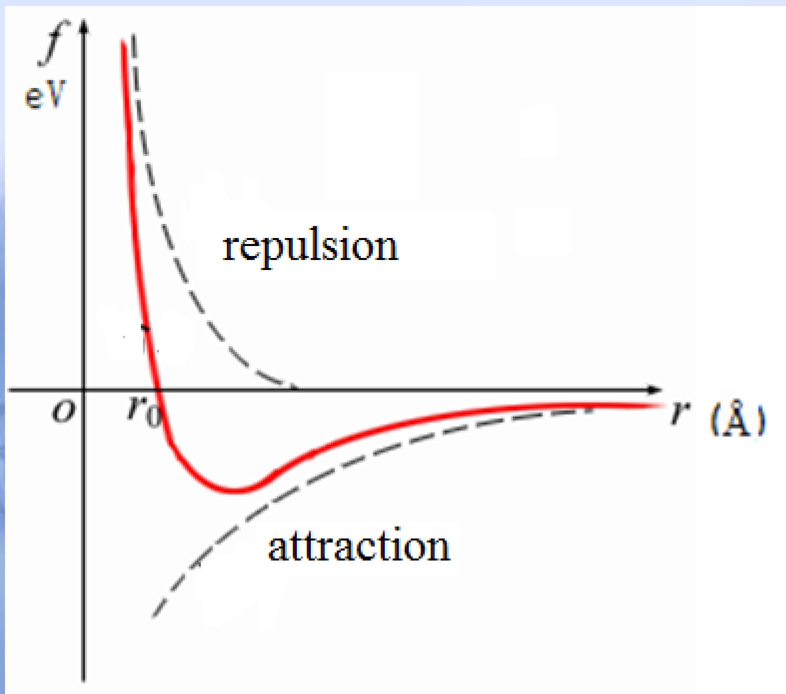
$$\langle CMI\rangle_d - 2\langle CMI\rangle_N = \frac{40}{3}C,$$

$$\langle CMI\rangle_d - 2\langle CMI\rangle_\Delta = -\frac{56}{3}C,$$

Similarity between nuclear force and molecular force

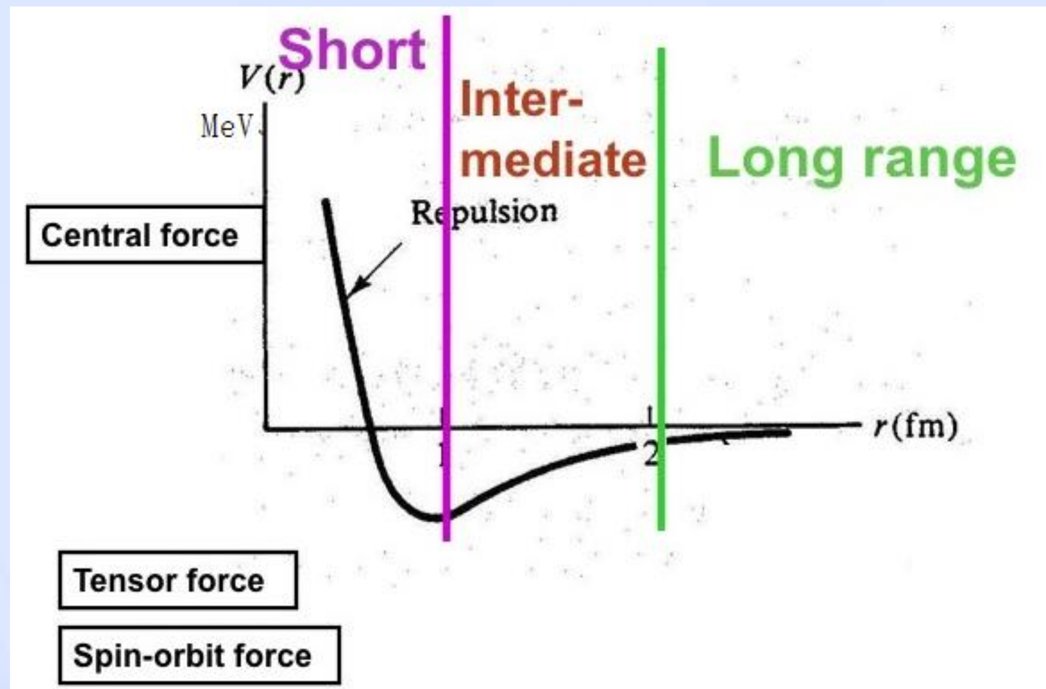
spin singlet

interaction between atoms



spin triplet isospin singlet

interaction in deuteron



CPEP statement in Standard model chart

- The strong binding of color-neutral protons and neutrons to form a nuclei due to residue strong interactions between their color charged constituents. It is similar to the residual electrical interaction that binds electrical neutral atoms to form molecules.

- Intermediate-range attraction ⇐ HC? Yes （partly）
- Quark Delocalization Color Screening Mode:

  model the effect of HC
- the similarity: molecular and nuclear force

Atoms: electric neutral,

electric charge and orbital distortion → molecular force

(electron percolation)

Nucleons: color neutral,

color charge and orbital distortion → nuclear force

(quark delocalization)

QDCSM

- Color screening：

  qq interaction: inside baryon

  outside baryon   different

$$H = \sum_{i=1}^{6}\left(m_i + \frac{p_i^2}{2m_i}\right) - T_c + \sum_{i<j}[V^G(r_{ij}) + V^\pi(r_{ij}) + V^C(r_{ij})],$$

$$V^G(r_{ij}) = \frac{1}{4}\alpha_s \lambda_i \cdot \lambda_j \left[\frac{1}{r_{ij}} - \frac{\pi}{m_q^2}\left(1 + \frac{2}{3}\sigma_i \cdot \sigma_j\right)\delta(r_{ij}) - \frac{3}{4m_q^2 r_{ij}^3} S_{ij}\right] + V_{ij}^{G,LS},$$

$$V_{ij}^{G,LS} = -\frac{\alpha_s}{4}\lambda_i \cdot \lambda_j \frac{1}{8m_q^2}\frac{3}{r_{ij}^3}[\mathbf{r}_{ij} \times (\mathbf{p}_i - \mathbf{p}_j)] \cdot (\sigma_i + \sigma_j),$$

$$V^\pi(r_{ij}) = \frac{1}{3}\alpha_{ch}\frac{\Lambda^2}{\Lambda^2 - m_\pi^2} m_\pi \left\{\left[Y(m_\pi r_{ij}) - \frac{\Lambda^3}{m_\pi^3} Y(\Lambda r_{ij})\right]\sigma_i . \sigma_j + \left[H(m_\pi r_{ij}) - \frac{\Lambda^3}{m_\pi^3} H(\Lambda r_{ij})\right] S_{ij}\right\}\tau_i \cdot \tau_j,$$

$$V_{ij}^{\rm CON}(r_{ij}) = -a_c \lambda_i \cdot \lambda_j [f_{ij}(r_{ij}) + V_0] + V_{ij}^{C,LS},$$

$$f_{ij}(r_{ij}) = \begin{cases} r_{ij}^2 & \text{i,j in the same baryon orbit} \\ \frac{1}{\mu}(1 - e^{-\mu r_{ij}^2}). & \text{otherwise} \end{cases}$$

the color structure is taken into consideration

three gluons exchange ➔0 (inside baryon)

= 0 (outside baryons)

- Quark delocalization:

$$\psi_l = (\varphi_l + \varepsilon\varphi_r)/N, \ \psi_r = (\varphi_r + \varepsilon\varphi_l)/N$$

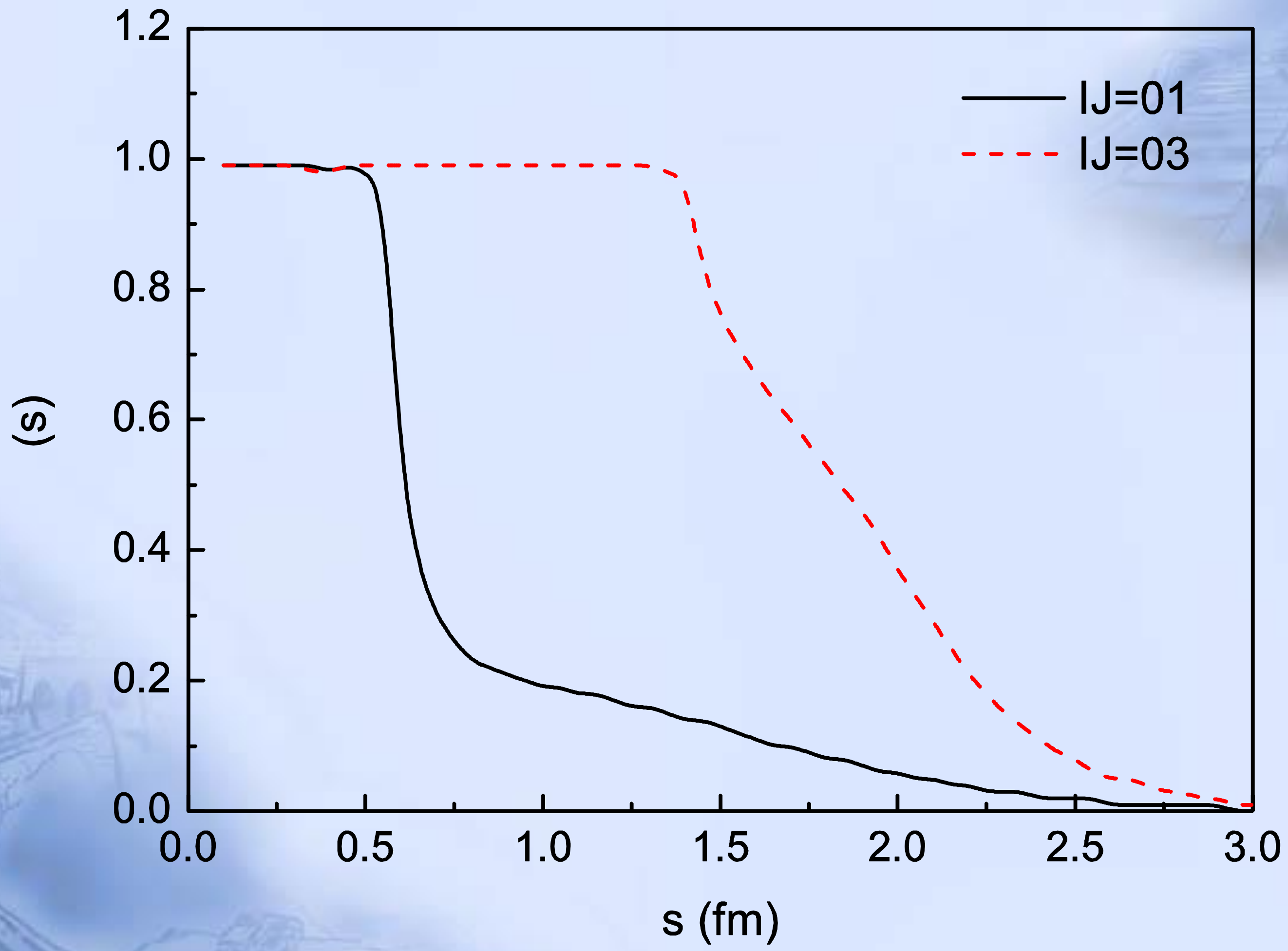
$$\varphi_l = \left(\frac{1}{2\pi b^2}\right)^{3/4} e^{-\frac{(\mathbf{r}+\mathbf{s}/2)^2}{2b^2}}, \quad \varphi_r = \left(\frac{1}{2\pi b^2}\right)^{3/4} e^{-\frac{(\mathbf{r}-\mathbf{s}/2)^2}{2b^2}}$$

the parameter ε is determined by system dynamics。

- The main advantage of QDCSM :

Quark and gluon distribution: self-consistent

the delocalization parameter is determined through its own dynamics, so multiquarksystem choose its most favorable configuration by variation.


1.2
1.0
0.8
0.6
0.4
0.2
0.0
(s)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
s (fm)
IJ=01
IJ=03

deuteron

TABLE II. The properties of the deuteron.

	Salamanca model	QDCSM		
		set 1	set 2	set 3
B (MeV)	2.0	1.94	2.01	2.01
$\sqrt{r^2}$ (fm)	1.96	1.93	1.92	1.94
$P_D(\%)$	4.86	5.25	5.25	5.25

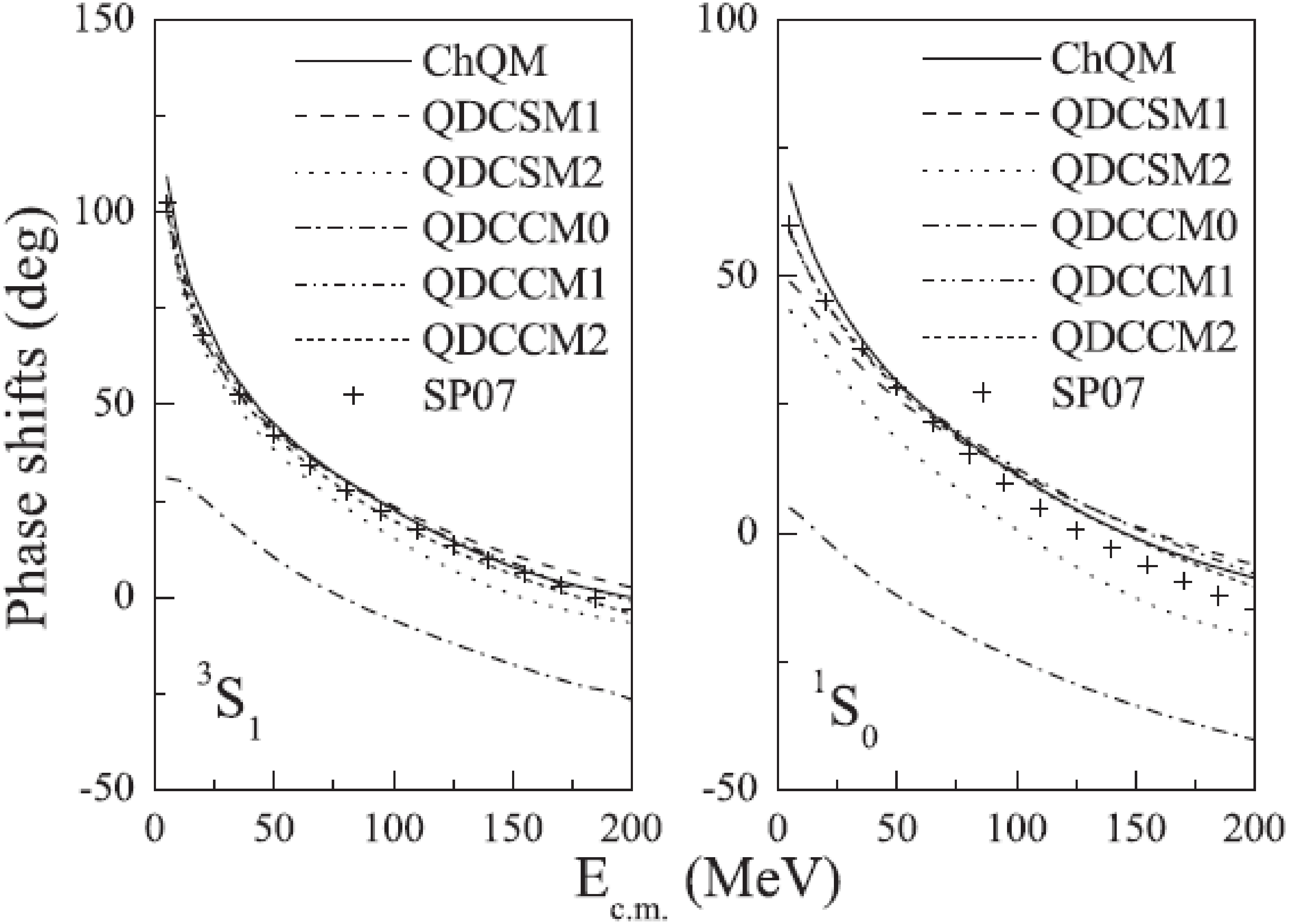


FIG. 1. The phase shifts of NN S-wave scattering.

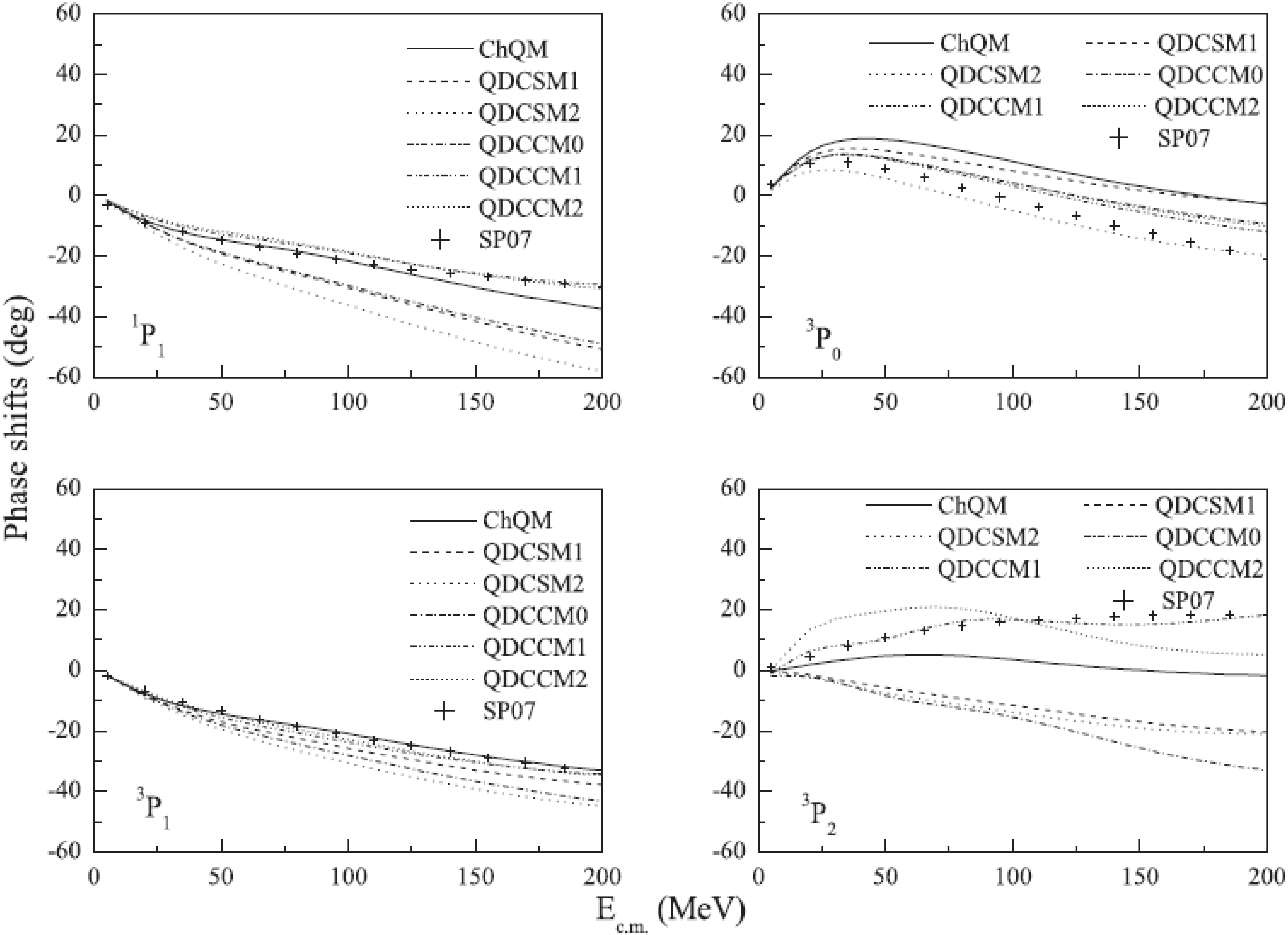


FIG. 2. The phase shifts of NN P wave scattering.

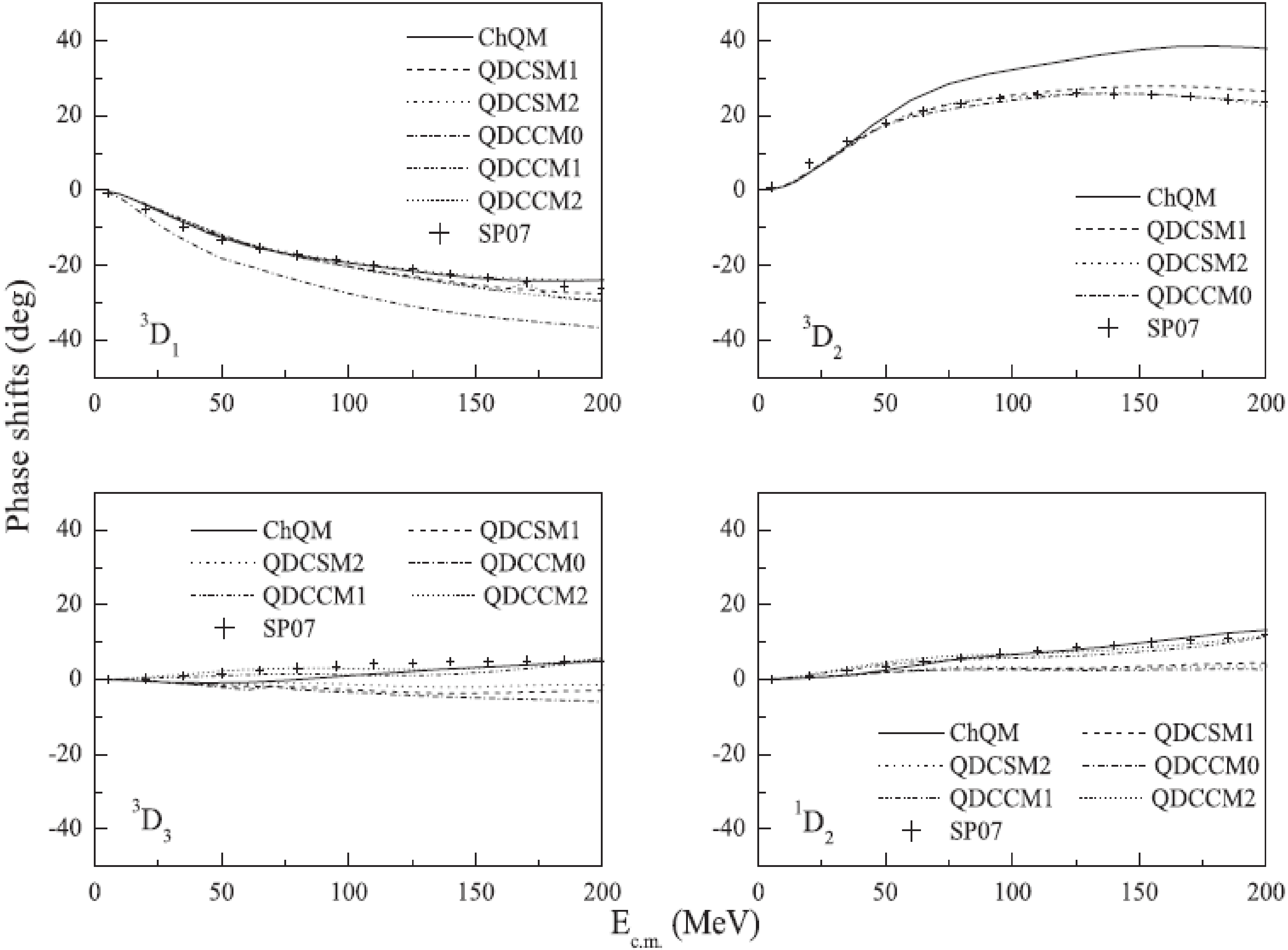


FIG. 4. The phase shifts of NN D-wave scattering.

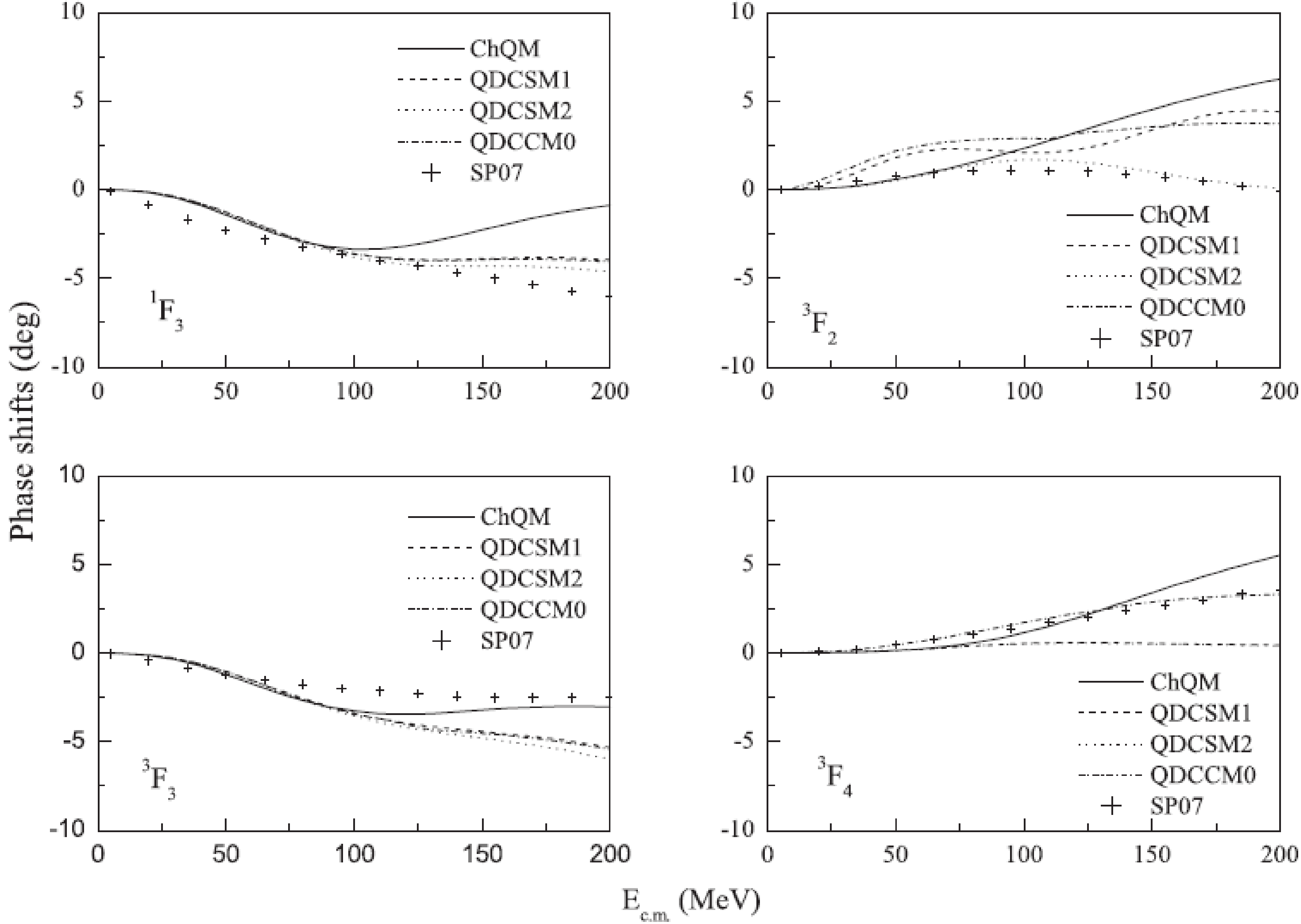


FIG. 5. The phase shifts of NN F-wave scattering.

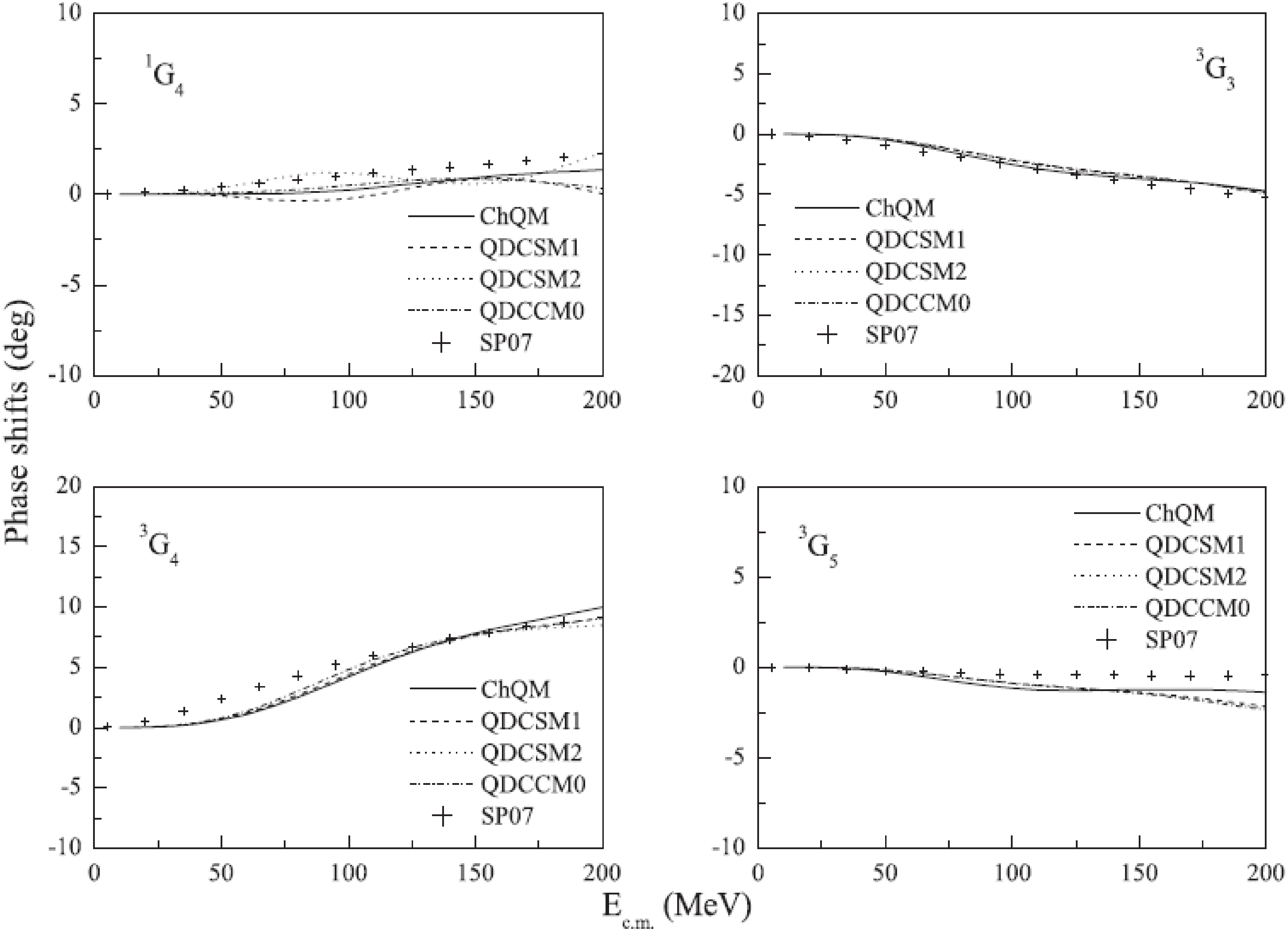


FIG. 6. The phase shifts of NN G-wave scattering.

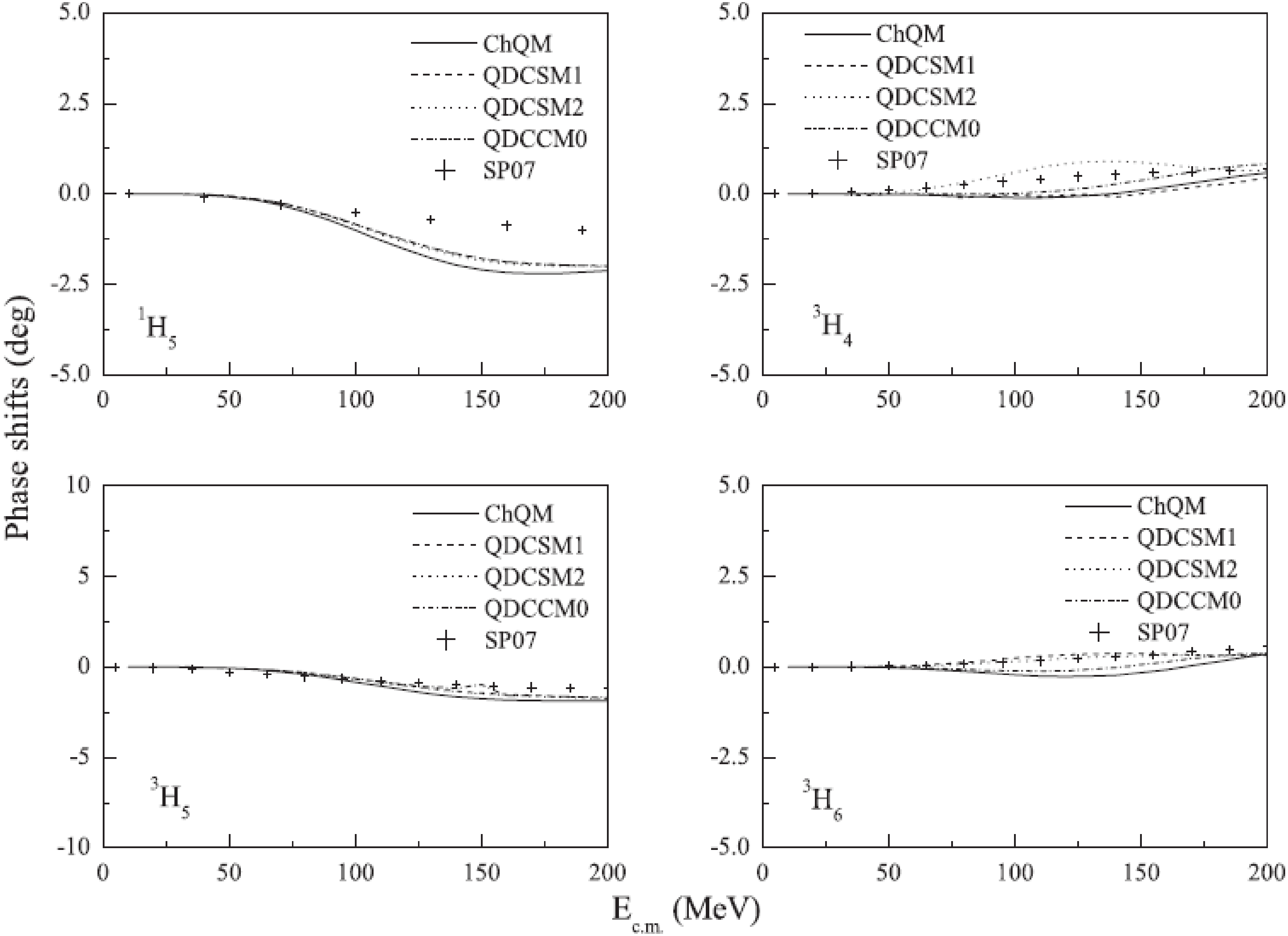


FIG. 7. The phase shifts of NN H-wave scattering.

narrow width of d*

Bashkanov-Brodsky-Clement: PLB 727(2013)438

According to M. Harvey [66] there are only two possible quark structures for an $I(J^P) = 0(3^+)$ resonance in the two-baryon system:

$$|\Psi_{d^*}\rangle = \sqrt{\frac{1}{5}}|\Delta\Delta\rangle + \sqrt{\frac{4}{5}}|6Q\rangle \quad \text{and}$$

$$|\Psi_{d^*}\rangle = \sqrt{\frac{4}{5}}|\Delta\Delta\rangle - \sqrt{\frac{1}{5}}|6Q\rangle.$$

Here $\Delta\Delta$ means the asymptotic $\Delta\Delta$ configuration and $6Q$ is the genuine “hidden color” six-quark configuration. The first solution denotes a S^6 quark structure (all six quarks in the S-shell), the second one a S^4P^2 configurat
quarks in the P-shell). The quark
pling would correspond to a delt
is natural to assign the observed
predominantly “hidden color” sta
for its narrow decay width.

	[6][33][33]	[42][33][33]
$\Delta\Delta$	$\sqrt{1/5}$	$\sqrt{4/5}$
CC	$\sqrt{4/5}$	$-\sqrt{1/5}$

Huang-Zhang-Shen-Wang: arXiv:1408.0458

CC channel: 66%--68% → 70 MeV

Huang-Ping-Wang: PRC89(2014)034001

(rms: 1.2—1.3fm)

Juan-Diaz,T.S.H. Lee,

Matsuyama, Sato:

PRC76(2007)065201

$$\Gamma_{b\Delta}(M_{b\Delta}) \approx \Gamma_{f\Delta}\frac{k_b^{2\ell}\rho(M_{b\Delta})}{k_f^{2\ell}\rho(M_{f\Delta})},$$

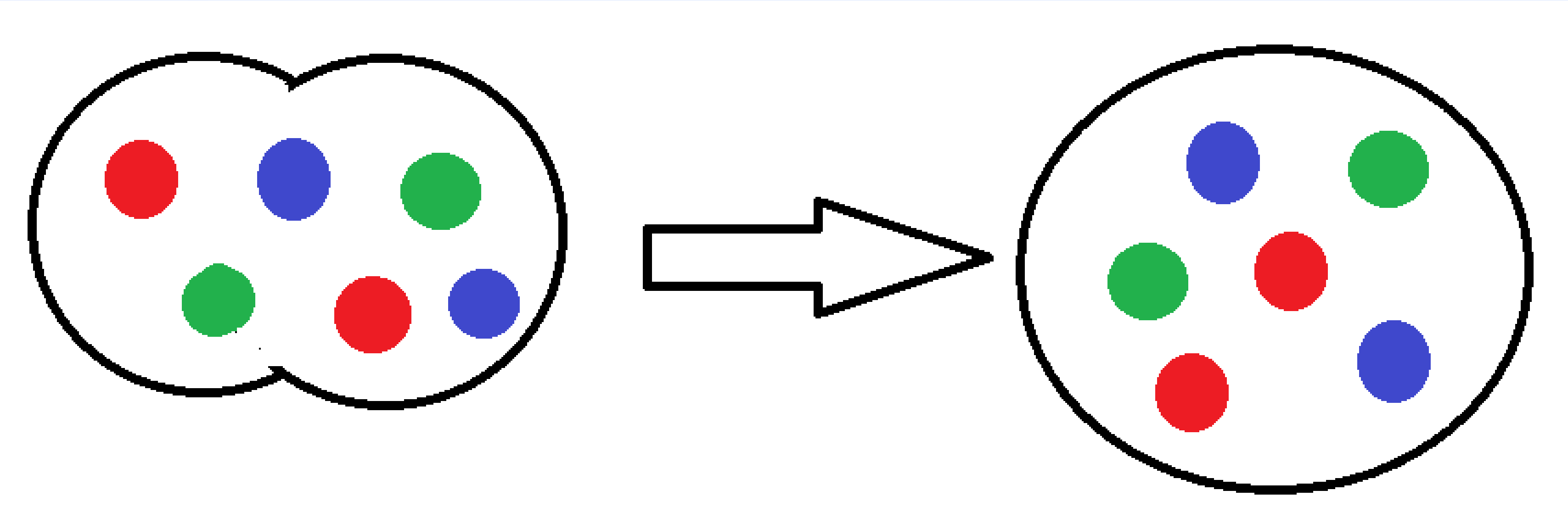
TABLE III. ΔΔ or resonance mass M and decay width Γ, in MeV, in two quark models for the $IJ^P = 03^+$ state.

	QDCSM		ChQM		
	sc	4 cc	sc	4 cc	10 cc
M	2365	2357	2425	2413	2393
Γ_{NN}	–	14	–	14	14
$\Gamma_{\rm inel}$	103	96	177	161	136
Γ	103	110	177	175	150

hidden-color channel

d* compact object -----

taking limit: six quarks in one bag



6 quarks are in the same orbit: $[\nu]=[6]$ remains,

[42] disappears

Symmetry basis: only [6][33][33] exists

------> number of physical basis: 1

ΔΔ and CC are the same !

$< \Delta\Delta \mid CC > =1$

Numerical results

Calculation method: RGM+GCM

$$|\Psi_{6q}\rangle = \mathcal{A}\sum_{L}\left[\left[\Phi_{B_1}\Psi_{B_2}\right]^{[\sigma]IS}\otimes\chi_L(\vec{R})\right]^J,$$

$$\chi(\vec{R}) = \frac{1}{\sqrt{4\pi}}\sum_{L}\left(\frac{3}{2\pi b^2}\right)^{3/4}\sum_{i}C_{i,L}\int e^{-\frac{3}{4}(\vec{R}-\vec{S}_i)^2/b^2}Y^L(\hat{\vec{S}}_i)\,d\Omega_{S_i}.$$

$$\Psi_{6q} = \mathcal{A}\sum_{i,L}C_{i,L}\int\frac{d\Omega_{S_i}}{\sqrt{4\pi}}\prod_{\alpha=1}^{3}\phi_\alpha(\vec{S}_i)\prod_{\beta=4}^{6}\phi_\beta(-\vec{S}_i)$$
$$\times\left[\left[\eta_{I_1S_1}(B_1)\eta_{I_2S_2}(B_2)\right]^{IS}Y^L(\hat{\vec{S}}_i)\right]^J\left[\chi_c(B_1)\chi_c(B_2)\right]^{[\sigma]},$$

$$\phi_\alpha(\vec{S}_i) = \left(\frac{1}{\pi b^2}\right)^{3/4}e^{-\frac{1}{2}(\vec{r}_\alpha-\vec{S}_i/2)^2/b^2},$$

$$\phi_\beta(-\vec{S}_i) = \left(\frac{1}{\pi b^2}\right)^{3/4}e^{-\frac{1}{2}(\vec{r}_\beta+\vec{S}_i/2)^2/b^2}.$$

+S/2, -S/2: the reference centers of baryons

S→0, [6] exists, [42] disappears

$< \Delta\Delta \mid CC > = 1$

Continuity → $< \Delta\Delta \mid CC >$ approx. 1, when S is small.

S (fm)	$< \Delta\Delta \mid CC >$	S (fm)	$< \Delta\Delta \mid CC >$
3	0	0.3	0.997
2	7×10^{-3}	0.2	0.999
1	0.7	0.1	0.99996
0.5	0.98	0.001	~ 1
0.4	0.99		

Matrix elements:

S (fm)	< ΔΔ |H| ΔΔ >	< CC |H|CC >	< ΔΔ |H| CC >
3	2580	7770	~0
2	2571	4870	9.9
1	2451	2679	1616
0.5	2649	2714	2609
0.3	2739	2763	2741
0.2	2771	2782	2774
0.1	2791	2794	2792

d* in chiral quark model (two channels: ΔΔ and CC)

ΔS(fm)	0.1	0.2	0.3	0.4	0.5
E(MeV)	2404.0	2404.0	2404.1	2404.1	2405.0
ΔΔ (%)	50	50.2	40.8	85.2	94.2
CC(%)	50	49.8	59.2	14.8	5.8

Physical basis and symmetry basis: same results

Using Harvey's method

S(fm)	0.1	0.3	0.5	0.7	0.9
E(MeV)	2745.7	2706.4	2635.0	2546.0	2463.5
ΔΔ (%)	46	46	50	54	60
CC(%)	54	54	50	46	40

S(fm)	1.1	1.3	1.5	1.7	1.9
E(MeV)	2423.6	2454.0	2513.7	2550.6	2567.1
ΔΔ (%)	71	87	97	100	100
CC(%)	29	13	3	0	0

CC is not dominant

Multiquark only system

- Color-singlet is complete.

$$|\text{Singlet I}\rangle_{1234} = \begin{array}{|c|c|}\hline 1 & 3 \\ \hline 2 & 4 \\ \hline\end{array} = |\text{Singlet}\rangle_{12}|\text{Singlet}\rangle_{34},$$

$$|\text{Singlet II}\rangle_{1234} = \begin{array}{|c|c|}\hline 1 & 2 \\ \hline 3 & 4 \\ \hline\end{array} = |\text{Triplet}\rangle_{12}|\text{Triplet}\rangle_{34}$$

$$= (2|\text{Singlet}\rangle_{13}|\text{Singlet}\rangle_{24} - |\text{Singlet}\rangle_{12}|\text{Singlet}\rangle_{34})/\sqrt{3}.$$

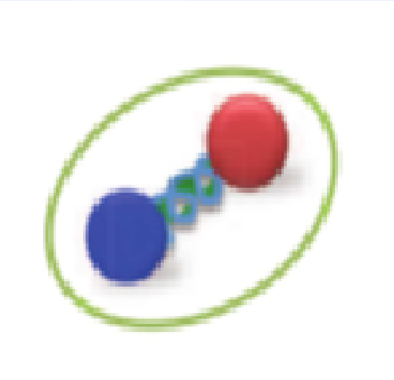
- But the color distribution in the space can show up the hidden-color channels.

hybrid

- Hybrid: a good place to study the hidden-color channels.

  gluon: color octet, [21] $q\bar{q}$ must be in color octet, [21]

  [21] x [21] == [222]



- Problem: how to identify the hybrid?

Summary

- For compact object, the color-singlet channel has a large overlap with hidden-color channel.

- To explain the narrow width of d* by using hidden-color channel is questionable.

- It is difficult to identify the hidden-color channels.

  In compact object:

  color-singlet channel   larger overlap   hidden-color channels;

  For the loosely system (molecules):

  color confinement   say no   to hidden-color channels

- Hybrid is good place to study the hidden-color channels.

Thanks!!!