Report of Theory Group E01

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Feb. 28 - Mar. 1, 2011
Elucidation of New Hadrons with a Variety of Flavors

Weakly coupled (bound) groups

Spectroscopy
Quark models for qqq, Qqq, … $QQ\bar{q}\bar{q}$
Hadronic composites qqq-qq, qqq-$\bar{Q}$q, …
Takeuchi, Takizawa, Yasui,
Harada, Ma, Kanchan
Their mixings Nagahiro, Nawa

Vacuum to matter at finite ρ and T
Chiral theory, Holographic model
Harada, Nakamura, Suganuma

Structure functions
Quark distributions, fragmentations
Kumano, Saito, Kawamura, Morimatsu

Reactions
Scatterings, productions,…
Jido, Hyodo, Nagahiro, Nawa

From models to QCD
HLS --> Holographic
Harada, Nakamura, Suganuma

Quark, hadron potential
Lattice
Suganuma, Morimatsu

Activities

Postdocs: Y.L. Ma (Nagoya), S. Nakamura (Kyoto)
K.Khemchandani (RCNP), H. Kawamura, S. Yasui (KEK)

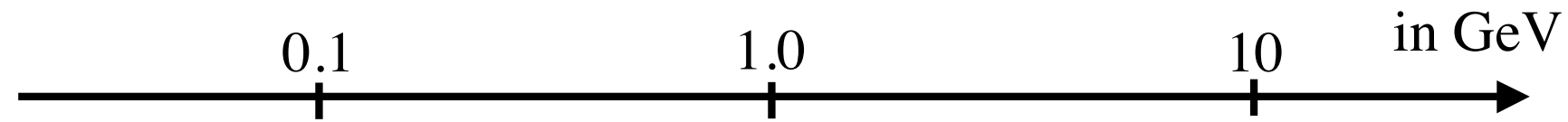
Visitors: A. Titov, H-Ch Kim, V. Dmitrasinovic, …

Hadron square:
Five times, incl. series of lectures by S. Nakamura

Summer school: 8/18-20, Osaka JICA
Quark model, Structure function, Holographic QCD

Baryons'10: 12/7-11, Osaka Univ.
170 participants, incl. Y. Nambu

QCD at different mass scales



$m_{u,\,d}$ m_s $\Lambda_{\rm QCD}$ m_c m_b

Non-perturbative ***Perturbative***

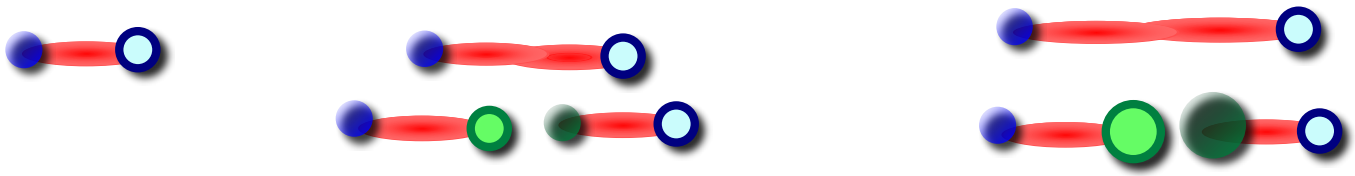
Light flavor
Constituent quarks

Heavy flavor
Heavy quarks

Chiral symmetry HQ symmetry

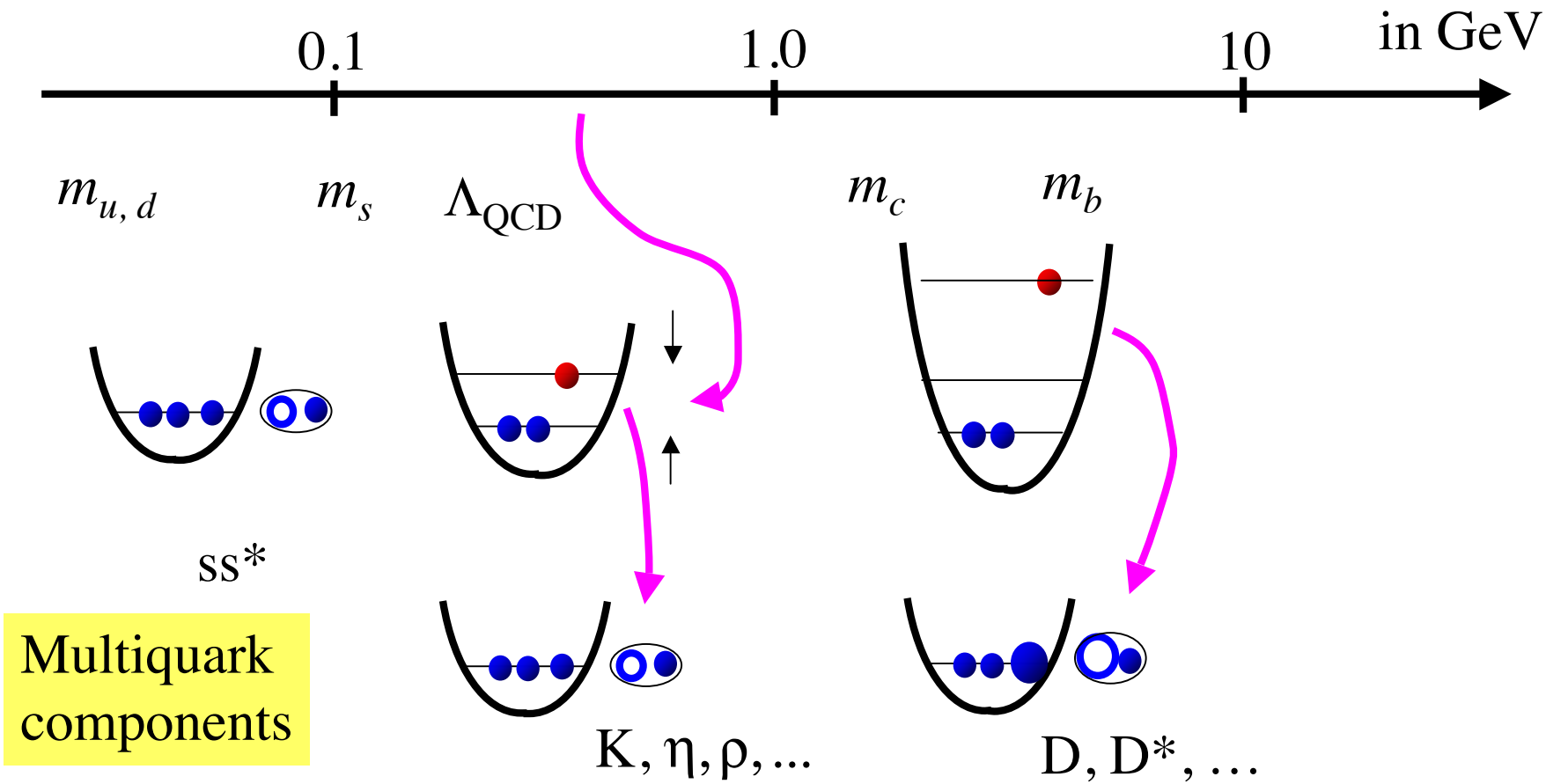
Confinement

Ground state Excited states

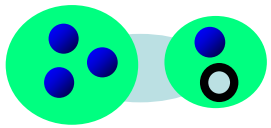


qq* (light) creation QQ* (heavy) creation

QCD at different mass scales



If there is sufficient attraction => Hadronic molecule



Rich ***multiquark tree***

Diquark-antiquark analogue $d \sim [qq] \rightarrow \bar{q}$

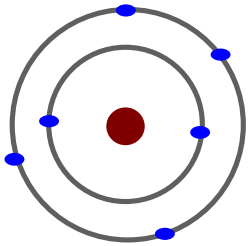
$3 \times 3 = 3^* + 6$

$$Qqq \rightarrow [\bar{Q}\bar{Q}]qq$$

We can make a ***tree classification*** ==> Takeuchi

Strong interaction

Atoms



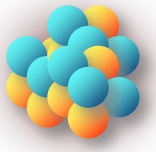
$m_e \sim 500{,}000$ eV

$E_B \sim 1$ eV

E_B / *Mass* $\sim 1/100000$

Int. structure is irrelevant

Nuclei



$m_N \sim 1{,}000$ MeV

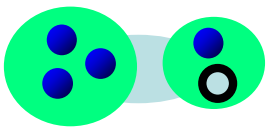
$E_B \sim 10$ MeV

E_B / *Mass* $\sim 1/100$

Int. structure maybe irrelevant

Form factor

Hadronic comp.



$m_{\bar{K}} \sim 500$ MeV

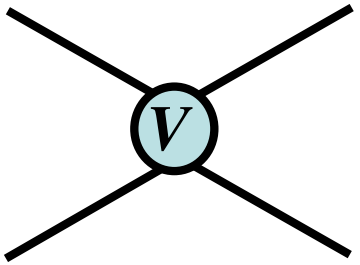
$E_B \sim 30$ MeV

E_B / *Mass* ~ 10

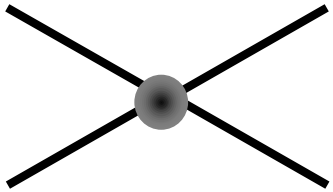
Int. structure maybe relevant

Questions in hadronic composites

Interaction V **Chiral symmetry**

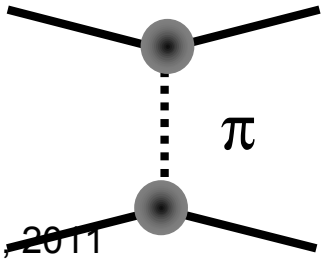


ρ-exchange (***short range***) ~ WT



$\delta(x)$ or typical hadron size ~ 0.5 fm

Pion exchange (***long range***) ~ tensor force in NN (deuteron)

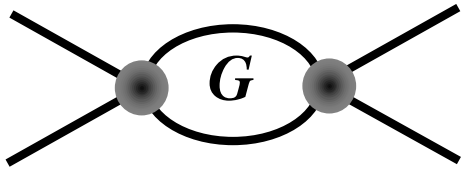


$$\frac{1}{q^2 + m_\pi^2}$$ ~ 1.4 fm

ρ-exchange (***short range***) ~ WT

Natural condition *for hadronic composite*

corresponding to hadron size ~ 0.5 fm



Cut-off scheme

$$G(E) \sim i\int \frac{d^4q}{(2\pi)^4} \frac{2M}{(P-q)^2 - M^2 + i\varepsilon} \frac{1}{q^2 - m^2 + i\varepsilon} \sim \sum_n^{\Lambda} \frac{1}{E - E_n}$$

$\Lambda \sim 0.5 - 1\,\mathrm{GeV}$

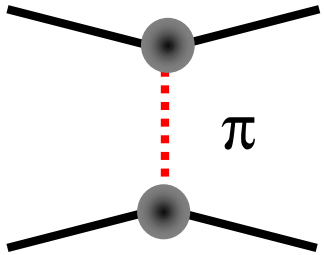
Dim-reg. scheme

$$G(\sqrt{s}) = \frac{2M_T}{(4\pi)^2}\left\{a(\mu) + \ln\frac{M_T^2}{\mu^2} + \frac{m^2 - M_T^2 + s}{2s}\ln\frac{m^2}{M_T^2}\right.$$
$$+ \frac{\bar{q}}{\sqrt{s}}[\ln(s - (M_T^2 - m^2) + 2\sqrt{s}\bar{q}) - \ln(-s + (M_T^2 - m^2) + 2\sqrt{s}\bar{q})$$
$$\left. + \ln(s + (M_T^2 - m^2) + 2\sqrt{s}\bar{q}) \quad - \ln(-s - (M_T^2 - m^2) + 2\sqrt{s}\bar{q})]\right\}$$

$a \sim -2$

T. Hyodo, D. Jido, A. Hosaka,
Phys.Rev.C78:025203,2008;
arXiv:0803.2550 [nucl-th]

Pion exchange (***long range***)



Form factor

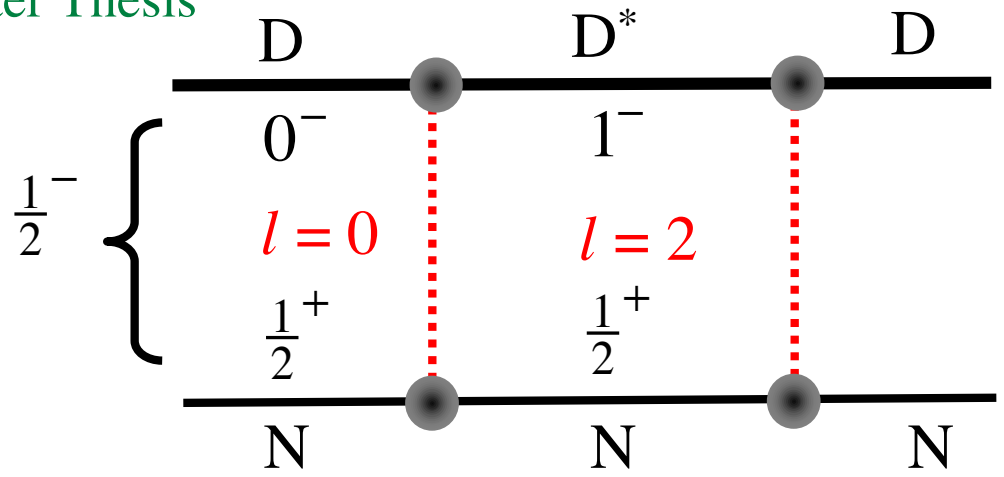
Solve the Schrodinger eq. directly

Loosely bound or resonance of $\bar{D}N$ ($\bar{c}qqqq$)

Heavy Q symmetry for $\bar{D}\,\bar{D}^*$ --> Coupled channel of $\bar{D}N$ and $\bar{D}^*N$

Yasui-Sudoh, PRD80, 034008, 2009
Yamaguchi-Ohkoda, Master Thesis

Tensor of OPEP



Sufficient attraction with HQ symmetry $M_D \sim M_{D^*}$

Mass effects

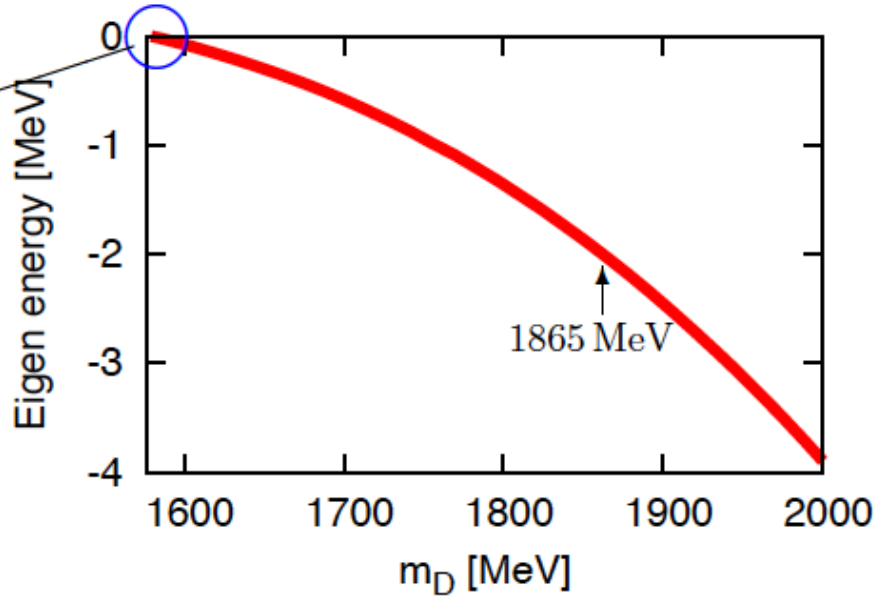
Heavy mass is easier to be bound

Yasui (Yamaguchi-Ohkoda):

$\bar{D}N$ and $\bar{D}^*N$ Change the mass

$m_{\bar{D}} = 1579\,\mathrm{MeV}$
$m_{\bar{D}^*} = 1777\,\mathrm{MeV}$

Disappearance of bound states



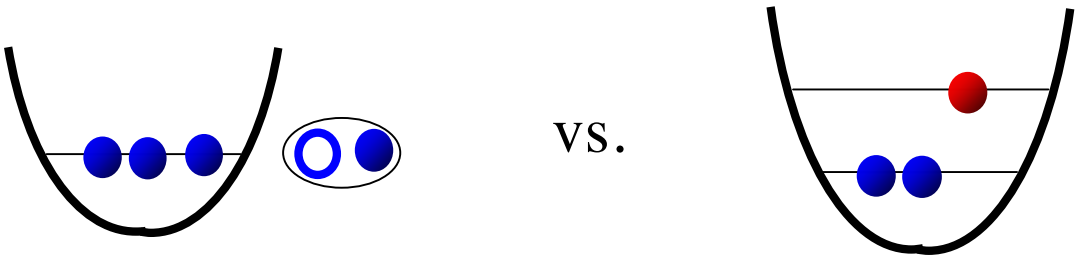
Charm is likely to be marginal for long range bound states

Coexistence

Example of a_1: Nagahiro

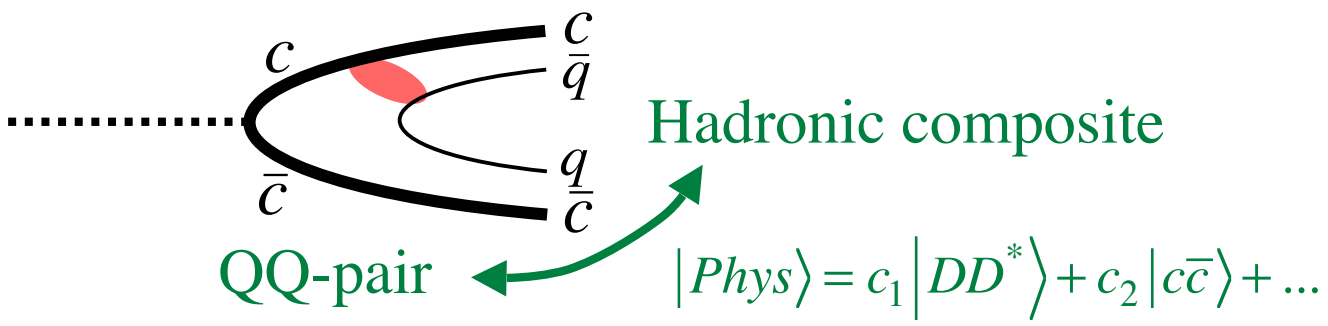
$$|\mathbf{a_1}\rangle_{\mathbf{phys}} = c_1 \Big| \rho\,\pi \Big\rangle_{\mathbf{composite}} + c_2 \Big| a_1 \Big\rangle_{q\bar{q}} + \ldots$$

Reasonably truncated model space

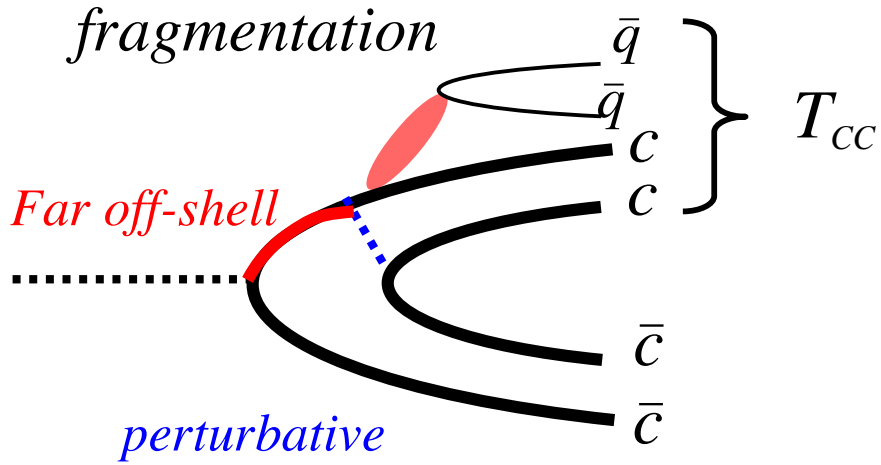


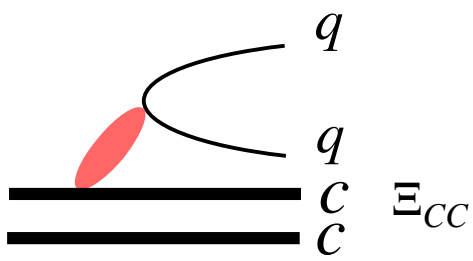
Productions

- Produce *quark core* or *composite* components



- Double charm





~ 0.1 pb

L ~ 1000 fb^{-1}

--> 1000 1/year

(Efficiency ~ 1%)

To be studied

From *light* to heavy *flavors*

Generation of constituent quarks (Chiral symmetry)

What is the inter-quark force (Lattice) => (colored) correlations

Change in the dynamics as functions of M

Coexistence of ***single particle*** excitation and ***clusters***

CDD pole

Hadronic composites

Short and long range forces

Pscalars, Vectors, …

Multiquark trees (tetraquark, pentaquark)

Scale dependence of structure/dynamics

(deep inelastic to low q regions)

How these properties changes as **density and T** are turned on