HEAVY QUARK STATE DECAYS AND NONPERTURBATIVE GLUE

THE SIGMA & THE SIGMA-GLUEBALL MODEL. POMERON & SIGMAS. CMU/IHEP & $Q\bar{Q}$ STATES.

THE ρ–π PUZZLE; CHARMONIUM, UPSILON, and D-DECAYS TO SIGMAS

HYBRID QUARKONIUM & THE SIGMA-GLUEBALL

HYBRID QUARKONIUM AT FINITE T (RHIC)

HYBRID CHARMONIUM AND THE $\rho-\pi$ PUZZLE

UPSILON DECAYS TO SIGMAS

D-DECAYS TO SIGMAS

CONCLUSIONS

Leonard Kisslinger

LANL July 11, 2007

THE SIGMA [I=0, L=0, $\pi - \pi$ RESONANCE]

Zou-Bugg, Phys. Rev. D50, 591 (1994)

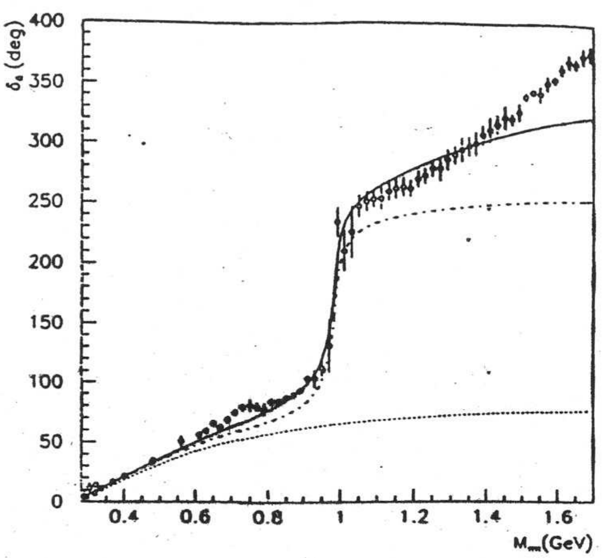
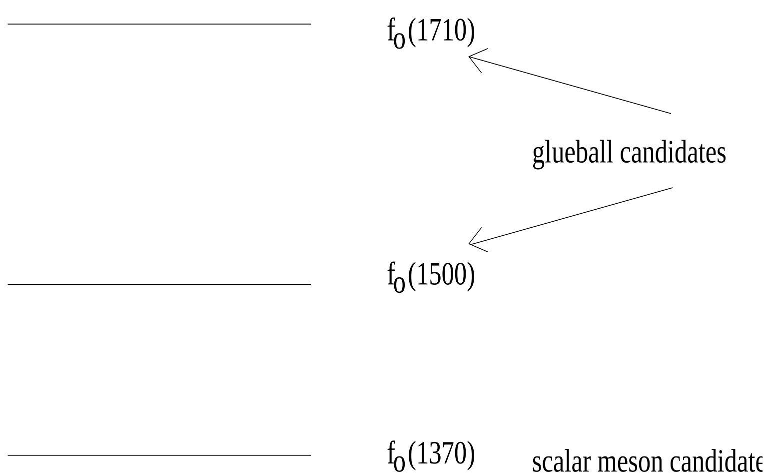


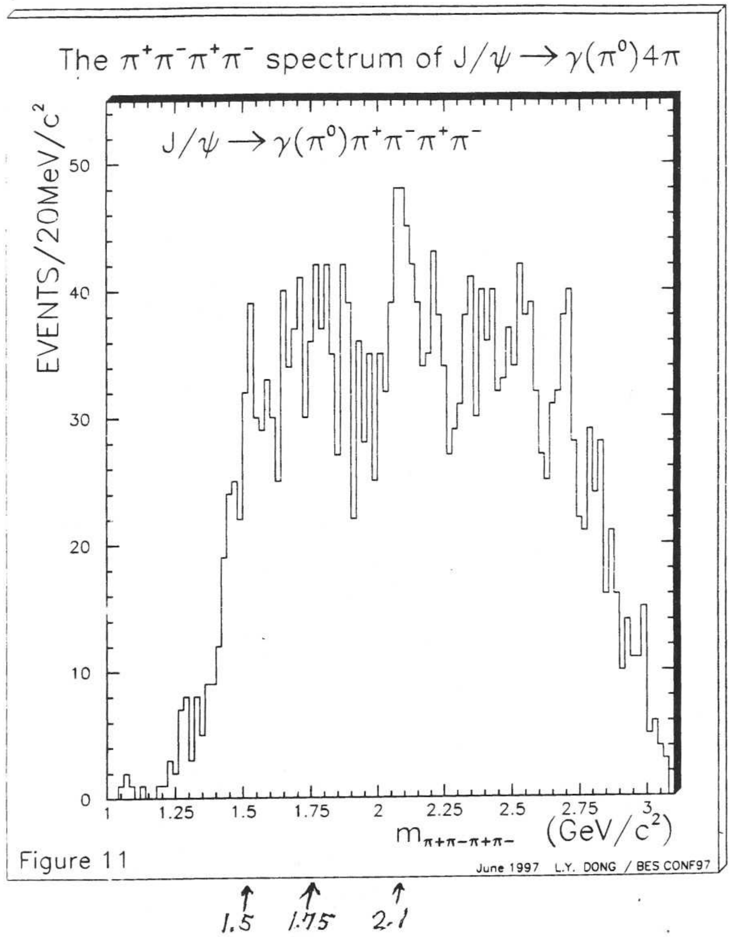
FIG. 1. The isoscalar *S*-wave phase shift δ_0 for $\pi\pi$ scattering [18–20]. The dashed line includes only the contribution from the *t*-channel ρ exchange. The dot-dashed line includes the contribution of the *s*-channel resonance $f_0(975)$ in addition. The solid line further includes the contribution from the *t*-channel $f_2(1275)$ exchange.

SCALAR GLUEBALLS AND THE SIGMA-GLUEBALL MODEL

SCALARS: MESON/GLUEBALL CANDIDATES

THE FOLLOWING SCALARS WERE DISCUSSED AT CHARM 2006 AS MESON/GLUEBALL CANDIDATES





The $\pi^+\pi^-\pi^+\pi^-$ spectrum of $J/\psi \rightarrow \gamma(\pi^0)4\pi$
$J/\psi \rightarrow \gamma(\pi^0)\pi^+\pi^-\pi^+\pi^-$
EVENTS/20MeV/c^2
0
10
20
30
40
50
1
1.25
1.5
1.75
2
2.25
2.5
2.75
3
$m_{\pi+\pi-\pi+\pi-}$ (GeV/c^2)
June 1997 L.Y. DONG / BES CONF97
1.5
1.75
2.1

Figure 11

Decay Modes Used in the Final Fit

L is the orbital angular momentum between the two final state particles following the decay of the resonance

J^P	Mass	channel	L or $^{2S+1}L_2$
2^+	$f_2(1270)$	$\rho\rho$	$^1D_2$ $^3D_2$
0^-	$\eta(1420)$	$\rho\rho$	$L = 1$
0^+	$f_0(1500)$	$\sigma\sigma$	$L = 0$
2^+	$f_2(1560)$	$\rho\rho$	$^5S_2$ $^1D_2$ $^3D_2$
2^+	$f_2(1710)$	$\rho\rho$	$^5S_2$
0^+	$f_0(1750)$	$\sigma\sigma$	$L = 0$
2^+	$f_2(2010)$	$\sigma\sigma$	$^1D_2$ $^3D_2$
		$\rho\rho$	$^1D_2$ $^3D_2$
		$f_2(1270)\sigma$	$^5S_2$
0^+	$f_0(2100)$	$\sigma\sigma$	$L = 0$
2^+	$f_2(2220)$	$\sigma\sigma$	$^5S_2$ $^3D_2$
		$\rho\rho$	$^5S_2$ $^3D_2$
		$f_2(1270)\sigma$	$^5S_2$

Table 2

SCALAR GLUEBALLS AND SIGMA DECAY

The $f_o(1500)$ and $f_o(1710)$ are glueball candidates

The 4-pion channel dominates $f_o(1500)$ and $f_o(1710)$ decay.

From the BES analysis:

$$\frac{Br(f_o(1500) \rightarrow 4\pi)}{Br(f_o(1500) \rightarrow 2\pi)} = 3.3 \pm 0.8$$

The 4-pion decay from the $f_o(1500)$ decay, from the BES analysis, is dominated by 2-σ decay, as is the $f_o(1710)$ (L.Y. Dong/BES CONF97)

This observation was an important motivation for the scalar Glueball-Sigma picture

SCALAR MESONS/GLUEBALLS VIA QCD SUM RULES

L.Kisslinger, J.Gardner, C.Vanderstraeten, PLB410, 1 (97)

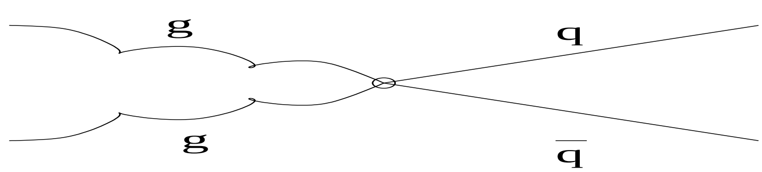
L.Kisslinger, M.Johnson, PLB523, 127 (2001)

Scalar glueball, scalar meson, and mixed glueball meson operators

$$
\begin{aligned}
J^G(x) &= \alpha_s G^2 \\
J^m(x) &= \frac{1}{2}(\bar{u}(x)u(x) - \bar{d}(x)d(x)) \\
J_{0^{++}} &= \beta M_o J_m + (1- \mid \beta \mid) J_G
\end{aligned}
$$

Glueball-meson coupling theorem: Novikov et al, NPB191

$$
\begin{aligned}
\int dx T[J^G(x) J^m(0)] &\simeq -\frac{32}{9} < \bar{q}q > \\
< \bar{q}q > &= \text{QUARK CONDENSATE} .
\end{aligned}
$$



RESULTS

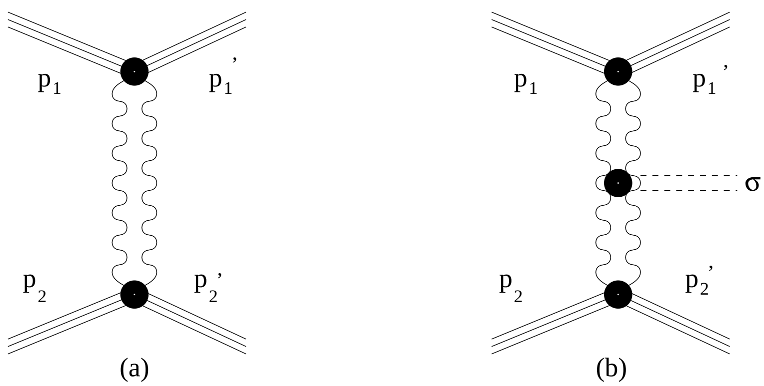
80% scalar glueball at 1500 MeV–f$_o$(1500)

80% scalar meson at 1350 MeV–f$_o$(1370)

Light Scalar Glueball 400-600 MeV–The Glueball-Sigma

SIGMA PRODUCTION IN PROTON-PROTON COLLISIONS

L.Kisslinger, W-x Ma, and P. Shen, PRD71, 094021 (2005)

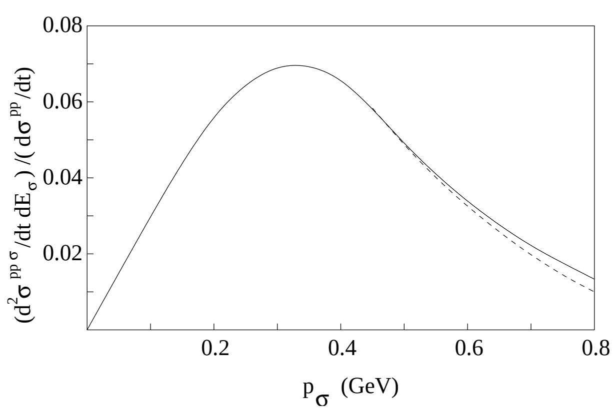


$A^{pp\sigma}$ = amplitude for σ production in p-p collisions

$$A^{pp\sigma} \simeq V(t_1)\bar{D}^P_\sigma(t_1,t_2,s)V(t_2) \; ,$$

where V(t)=pomeron-nucleon vertex and $\bar{D}^P_\sigma$ is the Pomeron propagator with a σ emission. [See figure]

Ratio of $pp \to pp\sigma$ to elastic $pp \to pp$ scattering:



QUARKONIUM STATES: MANY NEW $Q\bar{Q}$ STATES FOUND BY CLEO, BES, BaBar, Belle (FPCP 2006, Vancouver, BC)

Recent Effective Hadronic Hamiltonian calculations of quarkonium states by PRC theorists:

F-K. Guo, P-N. Shen, H-C. Chiang, and R-G. Ping

Nucl. Phys. A761, 269 (2005)
hep-ph/0601120
hep-ph/0603072
hep-ph/0603117

F-K. Guo, P-N. Shen, H-C. Chiang, R-G. Ping, B-S. Zou

hep-ph/0509050

IHEP-CMU theoretical studies being planned on $Q\bar{Q}$ states:

Further use of hadronic models to predict quarkonium states
P-N. Shen, F-K.Guo and collaborators

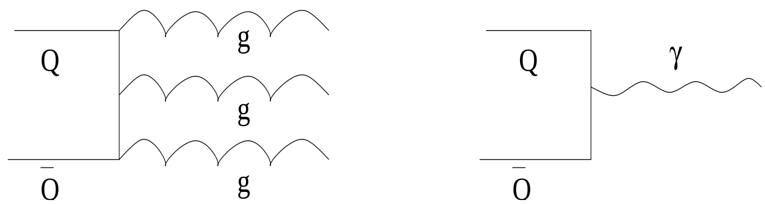
Bethe-Salpeter and Dyson equations will be used to study amplitudes:
W-x. Ma and Zhou Lijian and collaborators

QCD sum rules will be used for NPQCD investigations of new states:

THE $\rho - \pi$ PUZZLE FOR $c\bar{c}$ STATES

Using the lowest order perturbative diagram for $Q\bar{Q}$ decays into hadrons, illustrated below,

LOWEST ORDER DIAGRAMS FOR $Q\bar{Q}$ DECAYS



by taking ratios the wave functions at the origin cancel, and for many years it has been known that for $c\bar{c}$ decays into hadrons (h) the ratios of branching rates

$$R \;=\; \frac{B(\Psi'(c\bar{c}) \to h)}{B(J/\Psi(c\bar{c}) \to h)} \;=\; \frac{B(\Psi'(c\bar{c}) \to e^+e^-)}{B(J/\Psi(c\bar{c}) \to e^+e^-)} \simeq 0.15$$

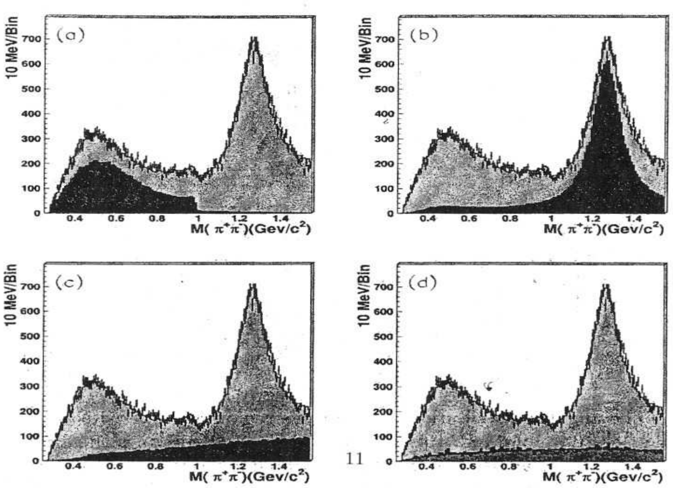
for all hadronic decays except the $\rho - \pi$ decay. The $\rho - \pi$ decay ratio is more than an order of magnitude smaller. This is the famous $\rho - \pi$ puzzle. Many, many theoretical attempts to explain this puzzle have still left the puzzle.

The IHEP-CMU theorists will explore the sigma-glueball diagrams for nonperturbative QCD as a possible solution to this puzzle.

CHARMONIUM TRANSITIONS WITH SIGMA EMISSION

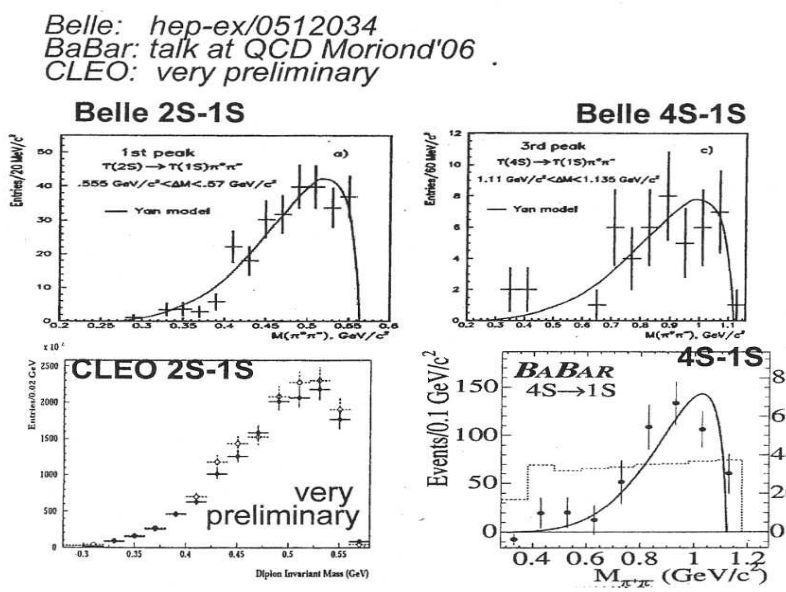
EXAMPLE: THE σ POLE IN $J/\Psi \to \omega\pi^+\Pi^-$

M. Abilkim et. al (BES Collaboration), Phys. Lett. B598, 149 (2004)

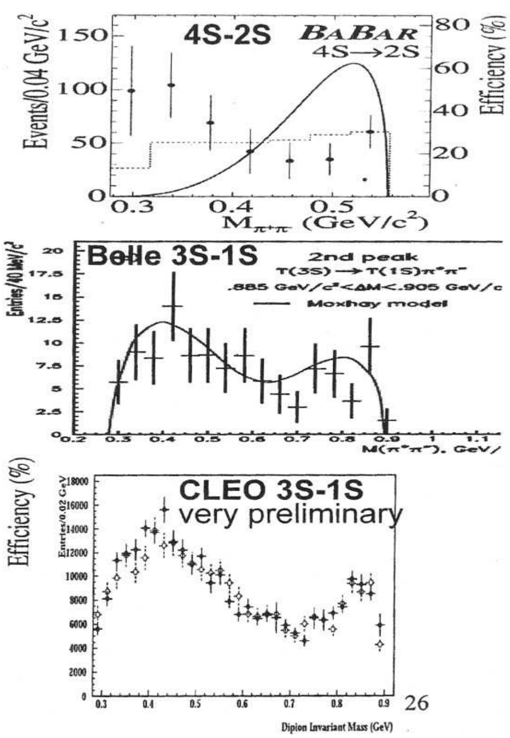


UPSILON TRANSITIONS WITH SIGMA EMISSION

Δn=2 CONJECTURE: H.Vogel at FPCP 2006, Vancouver, BC



UPSILON TRANSITIONS WITH SIGMA EMISSION
(continued)



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D-DECAYS TO SIGMAS

"Experimental Evidence for a Light and Broad Scalar resonance in $D^+ \to \pi^-\pi^+\pi^+$ Decay", E.M. Aitala et al (Fermilab E791 Collaboration), Phys. Rev. Lett. 86, 770 (2001)

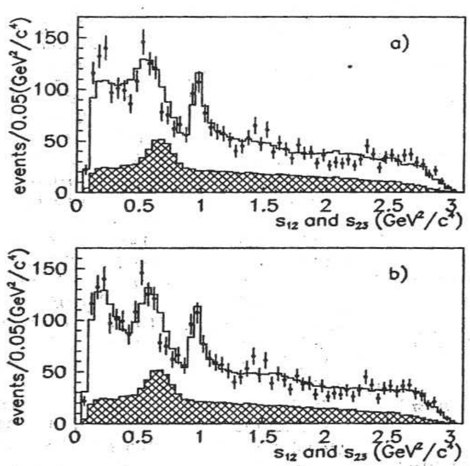
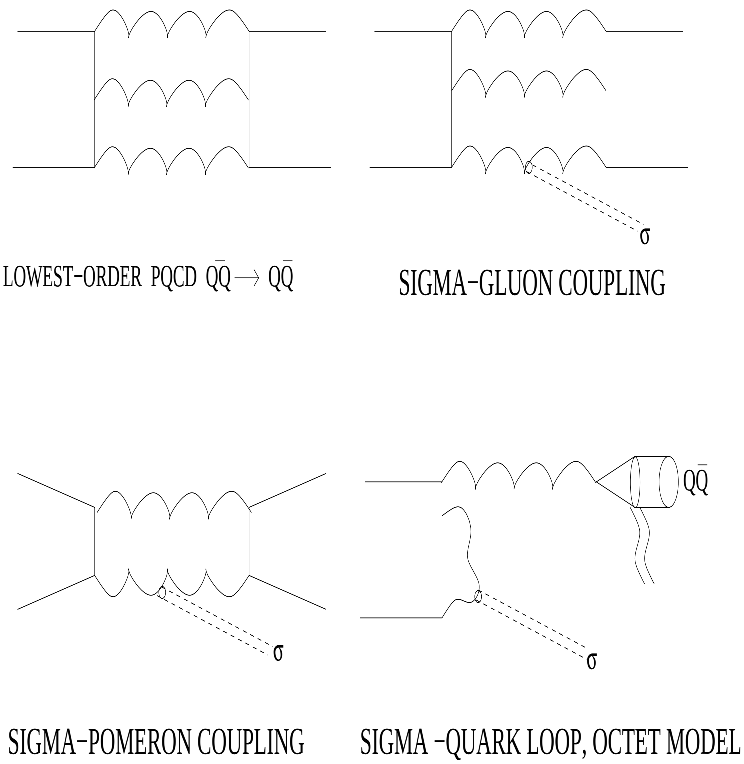


FIG. 2. s_{12} and s_{13} projections for data (error bars) and fast MC (solid line). The shaded area is the background distribution, (a) solution with the Fit 1, and (b) solution with Fit 2.

POSSIBLE SIGMA-GLUBALL TREATMENTS OF

σ PRODUCTION IN QUARKONIUM TRANSITIONS



SIMILAR MECHANISM FOR CHARMONIUM ($\rho - \pi$ PUZZLE), UPSILON (Δn=2 THEOREM, AND D-DECAYS IS POSSIBLE

Studies by L. Kisslinger, Seamus Reardon and Diana Seymour, and collaborators are in progress.

HYBRID QUARKONIUM: $q\bar{q}$g STATES WITH VALENCE GLUE

Search for hybrids using QCD Sum Rules:

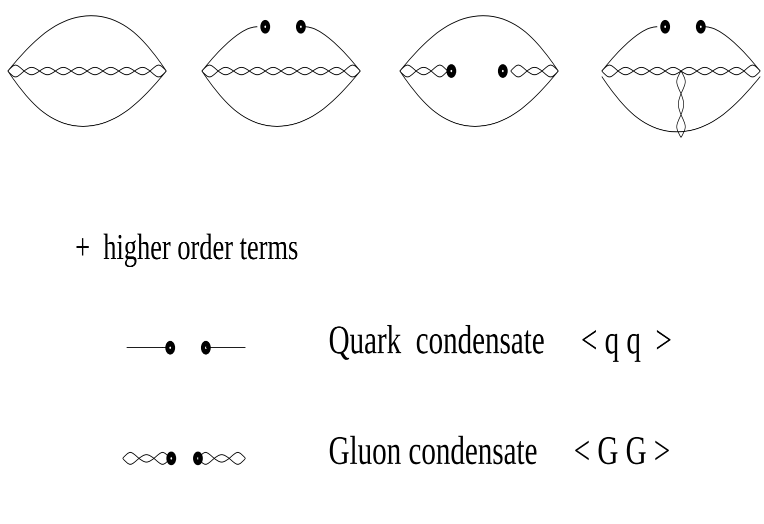
Vector hybrid current ($J^{PC} = 1^{--}$)

$$J_\mu \;=\; \bar{q}^a_A \gamma^\nu \gamma_5 \frac{\lambda^n_{ab}}{2} \tilde{G}^n_{\mu\nu} q^b_B \;,$$

where A,B are flavor indices, a,b are color indices, and $\tilde{G}^n_{\mu\nu}$ is the dual gluon field operator. The QCD Sum Rule method starts with the two-point correlator

$$\Pi_{\mu\nu}(q^2) \;=\; i \int d^4x e^{iq\cdot x} < 0|J_\mu(x) J_\nu(0)|0 > \;\; .$$

The correlator is evaluated using Feynman-like diagrams:



Correlator in coordinate space

$$
\begin{aligned}
<0|J_\mu(x)J_\nu(0)|0> &= <0|Tr[S^{ab}(x)\gamma_\sigma S^{ba}(-x)\gamma_\delta Tr[G^{\mu\delta}G^{\nu\sigma}]|0> \\
S^{ab}(x) &= S^{ab,P}(x)+<0|:q^a(x)\bar{q}^b(0):|> \\
S^{ab,P}(p) &= \delta^{ab}\frac{\not{p}+m}{p^2-m^2} \,.
\end{aligned}
$$

LIGHT VECTOR HYBRIDS [$S^{ab,P}(p) = \delta^{ab}\frac{\not{p}}{p^2}$ (F-K Guo, P-N Shen, Z-G Wang, W-H Liang, L.S. Kisslinger,hep-ph/0703062)

$q\bar{q}g(q=u,d), q\bar{s}g, and s\bar{s}g$ states have M=2.3-2.6 GeV

HEAVY-LIGHT VECTOR HYBRIDS (L.S. Kisslinger, S. Reardon, D. Seymour)

Mass($Q\bar{q}g$) -Mass($Q\bar{q}$) lowest states $\simeq$ 600 Mev

HEAVY-HEAVY VECTOR HYBRIDS–LSK, SR, DS (in process) expected to be similar to heavy-light results.

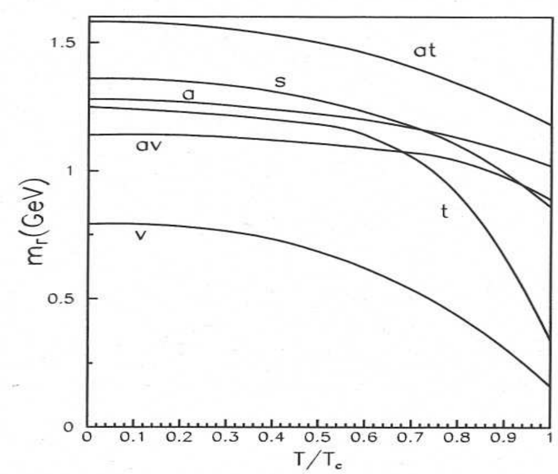
NOTE E(ψ(2S))-E(J/ψ(1S)) $\simeq$ 600 MeV.

NOTE Energy differences of Υ(nS) states also in the 600 Mev range

HYBRID QUARKONIUM AT FINITE T (RHIC)

QCD PHASE TRANSITION:
QUARK CONDENSATE$=<\bar{q}q>\rightarrow 0$

MESON MASSES AT FINITE T (M.B.Johnson & L.S.Kisslinger, PRD61 (2000) 074014)

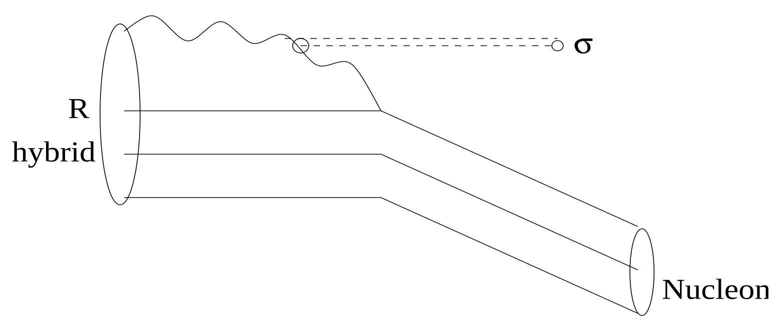


THUS WE EXPECT THAT HEAVY-QUARK HYBRIDS AND THE QUARKONIUM DECAYS WILL BE STRONGLY AFFECTED FOR T NEAR THE QCD PHASE TRANSITION

HYBRID CHARMONIUM AND SIGMA-GLUEBALL

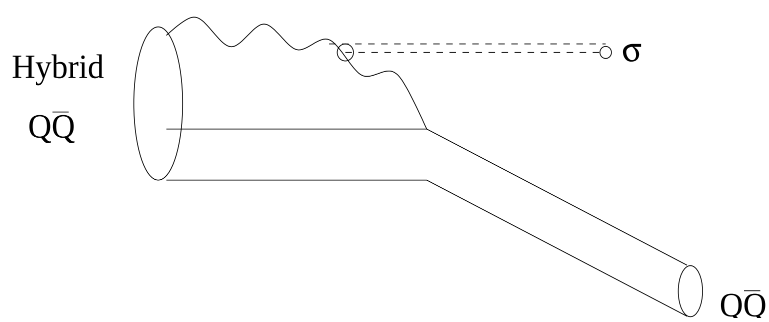
Example of possible hybrid baryon: the Roper

L. Kisslinger and Z. Li, Phys. Rev. D51, R5986 (1995)
Phys. Lett. B445, 271 (1999)



HYBRID QUARKONIUM STATES (see, e.g., S Godfrey, FPCP 2006, Vancouver, BC)

Expect sigma decay:



Our IHEP-CMU group expects to investigate such hybrid quarkonium states via sigma decays.

NEW CHARMONIUM HYBRID CANDIDATES

As discussed by G. Rong (IHEP) at CHARM 2006:

$$\psi(3770) \ \rightarrow \ J/\psi \pi^+ \pi^- (\sigma)$$

and as widely discussed by a number of speakers at CHARM 2006 the

$$Y(4260)$$

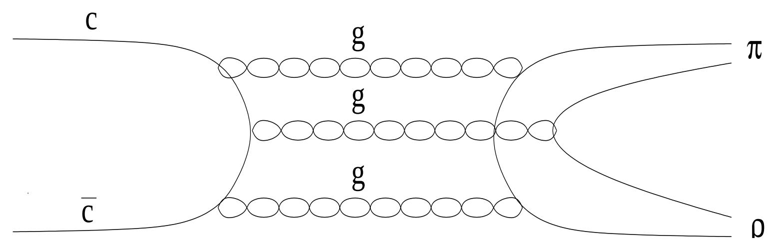
does not fit the $c\bar{c}$ spectrum of successful models.

The $Y(4260)$ is a hot new state, and experimental investigations of its properties are planned.

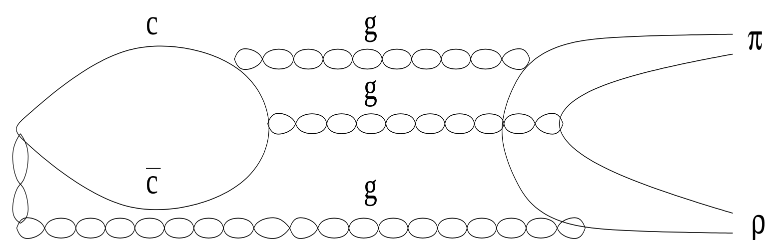
Our IHEP-CMU theory group will study these as $c\bar{c}g$ hybrids and predict decay rates.

HYBRID MIXING MODEL FOR THE $\rho - \pi$ PUZZLE

The standard quarkonium $\rho{-}\pi$ decay from the ψ'(2S) charminium state with the lowest order pQCD diagram:



involves the matrix element $< \pi\rho|O|\psi'(c\bar{c},2S) >$, while the corresponding hybrid decay, with the diagram:



involves the matrix element $< \pi\rho|O'|\psi'(c\bar{c}g,2S) >$. Assuming that the 2s state is a $c\bar{c}$-$c\bar{c}g$ admixture:

$$|\psi'(2S) > \; = \; b|\psi'(c\bar{c},2S) > + \sqrt{1-b^2}|\psi'(c\bar{c}g,2S) > ,$$

and recognizing that the O and O' matrix elements, with $g \simeq 1$, are approximately 1, and that the solution to the $\rho - \pi$ puzzle requires

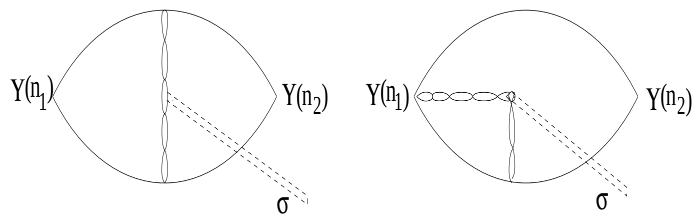
$$b + \sqrt{1-b^2} \; \simeq \; 0.1 ,$$

the solution of the $\rho - \pi$ puzzle is given if

$$b \; \simeq \; -.7 .$$

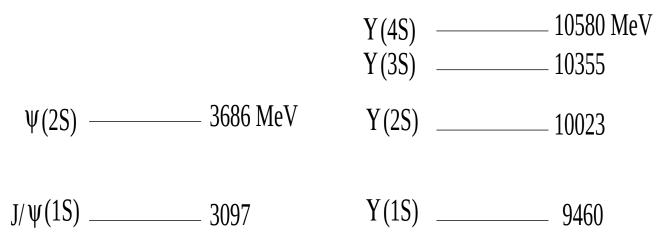
UPSILON DECAYS AND THE ΔN=2 THEOREM

UPSILON AND HYBRID UPSILON DECAYS TO UPSILON + SIGMA



Upsilon sigma decay   Hybrid Upsilon sigma decay

CHARMONIUM AND UPSILON SPECTRA



ΔM(2S−1S) = 589 MeV ΔM(2S−1S) = 563 MeV

Upsilon to Upsilon + Sigma matrix elament:

$$< \Upsilon(b\bar{b}, nS)|V_\sigma|\Upsilon(b\bar{b}, mS) > \; = \; -\frac{64}{3} g_\sigma g^2 < G^2 >$$
$$< \Psi(nS)|\frac{1}{k^2 + i\epsilon}|\psi(mS) > ,$$

which except for constants is a standard matrix of a Hydrogen atom with a Coulomb potential.

Hybrid Upsilon to Upsilon + Sigma matrix element:

$$< \Upsilon(b\bar{b}g, nS)|V'_\sigma|\Upsilon(b\bar{b}, mS) > \; = \; < \Upsilon(b\bar{b}, nS)|V_\sigma|\Upsilon(b\bar{b}, mS) >, \quad (1)$$

since $s \simeq 1$ and the matrix elements are very similar, as can be seen from the two figures above.

Therefore, with the energy separation of the Upsilon states similar to the Charmonium states, the same type of linear combinations for Upsilon and hybrid Upsilon that explain the $\rho - \pi$ puzzle for the $\Psi'(2s) vs. J/\Psi$ decays could explain the ΔN=2 observation for the $\Upsilon(nS) - \Upsilon(1S)$ decays.

PROCESSES FOR D DECAYS INTO SIGMAS

Using an effective Hamiltonian (L.Kisslinger, hep-ph/0103326) the unique skeletal diagram, with an internal W^+ is (Fig 1):

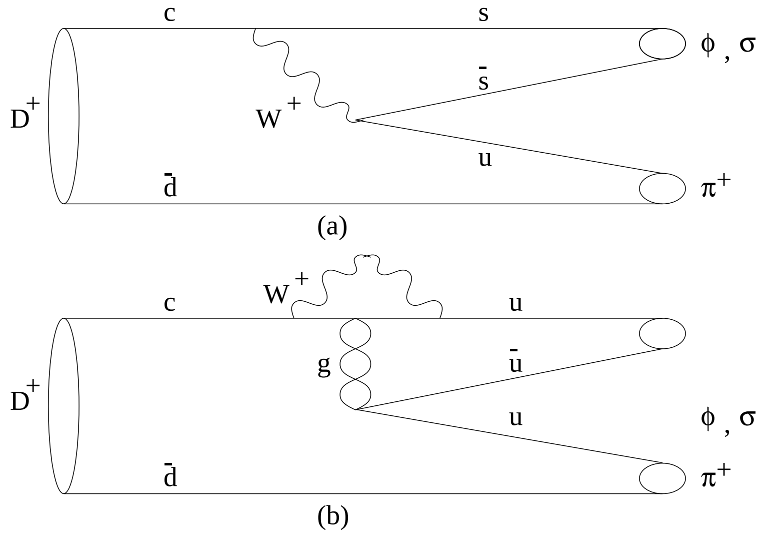


Fig. 1 D^+ decay to π^+ and ϕ or σ (a) via internal W^+ emission or (b) penguin diagram

The matrix element for decay into π^+ and σ, ϕ (called X) is

$$< X\pi^+ \mid H^{eff} \mid D^+ > \; = \; \frac{G_F}{\sqrt{2}} cos\theta_c sin\theta_c C_3 < X \mid (\bar{s}s)_L \mid 0 >< \pi^+ \mid (\bar{u}c)_L \mid D^+ > .$$

Taking the ratio, so constants drop out, and using known values of the gluon and quark condensates it was estimated that

$$\frac{\Gamma(D^+ \to \sigma\pi^+)}{\Gamma(D^+ \to \phi\pi^+)} \; \simeq \; 0.15.$$

This value is in agreement with E791 experimental results.

PROCESSES FOR D DECAYS INTO SIGMAS (continued)

Other known processes, the annihilation-hairpin and final state interactions are illustrated in Fig.2

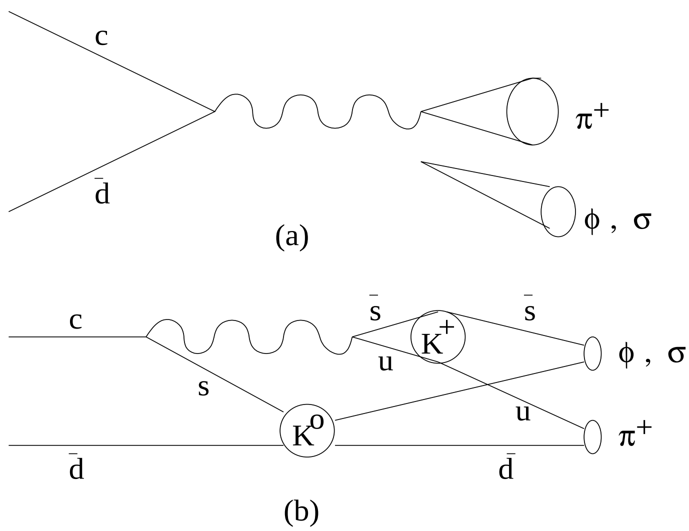


Fig. 2 (a) Annihilaton−hairpin, (b) Final state interaction

These processed are harder to evaluate, and are a subject for IHEP-CMU theoretical research

PROCESSES FOR D_s and τ DECAYS INTO SIGMAS

For D_s decays into π^+ a σ of a ϕ the spectator and annihilation diaagrams are illustrated in Fig. 3

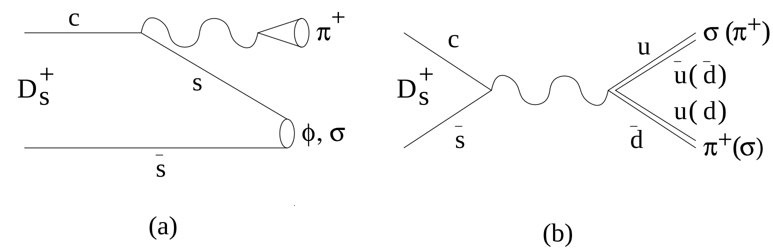


Fig. 3 (a) Spectator, (b) Annihilation

A rough evaluation (LSK hep-ph/0103326) finds the ratio of σ to ϕ rates for D_s decay are reduced in comparison with D decay, in general agreement with E791.

The skeletal diagram for $\tau^- \to \sigma$ is illustrated in Fig. 4.

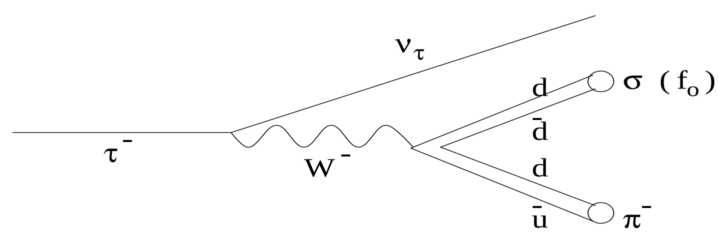


Fig. 4 Diagram for $\tau^- \longrightarrow \nu_\tau\ \pi^-\ \sigma$ (or scalar meson)

The IHEP-CMU theorists plan to investigate D and τ decay processes, particularly looking for σ decays.

CONCLUSIONS

There are many new heavy quark states that have been found recently

Hybrid heavy quark states are expected and are being investigated.

Methods for treating nonperturbtive gluonic effects are needed

The sigma-glueball model is useful for treating many nonperturbative QCD effects.

Our CMU/IHEP studues have found hybrids and have possible explanations of the $\rho - \pi$ charmonium puzzle and the Δn=2 Upsilon decay observations. A number of theoretical studies are in progress.

Many of these effects would be dramatically altered at finite T near the QCD phase transition, and might be observable with RHIC experiments.