Arguments on the Light-mass Scalar Mesons and Concluding Remarks of the Meson Sessions

S.F. Tuan

Department of Physics
University of Hawaii at Manoa
Honolulu, HI 96822-2219 U.S.A.

This report attempts to summarize the most interesting (and hopefully important) results leading up to and including those presented at the recent Symposium sponsored jointly by the Institute of Quantum Science at Nihon University and KEK. My task is to present the arguments on light-mass scalar mesons below 1 GeV from both theory and phenomenological viewpoints, including the new insight gained on $\pi-\pi$ production and scattering amplitudes. Specific topics are taken up, particularly on the existence of a $\sigma(500-600)$ as explanation of the twin peak anomaly in $\Upsilon(3S) \rightarrow \Upsilon(1S)\pi\pi$, the status of $J^{PC} = 1^{-+}$ states and a possible crypto-exotic hybrid with $J^{PC} = 0^{-+}$ are discussed, as well as the intriguing enhancement in $p\bar{p}$ radiative decay from $J/\psi$.

1 Introduction

I wish to thank Professors Shin Ishida and Kunio Takamatsu san for assigning me on July 25 last to talk on “Arguments on the light-mass scalar mesons and concluding remarks of the symposium” at this great Symposium, thus postponing one’s UH retirement (except ‘on paper’) in physics by some 7 months. It is an opportunity to express my felicitations to Professor Ishida san upon entering the age of GU-XI which C.N. Yang described as rare since ancient times, and here is best wishes for the next 30 years! Not being an expert myself on scalar mesons, I used the newsgroup approach to prepare myself for this talk, garnering the expertise of worldwide physicists via extensive e-mails to help me. I wish to express my deep appreciation to them all for their contributions unstintingly given during the 7 months leading up to the Symposium. In the end I had to follow the L.B. Okun principle of truth, namely talk only about those subjects I personally am satisfied with. However I may be forgiven for errors of commission or omission because after all T.D. Lee once said that 50% of theoretical physics (and I am a theorist) is emotion, and I am exercising this privilege! In what follows I shall first discuss 5 theoretical options for understanding light-mass scalar
mesons below 1 GeV. This is followed by highlighting the new insights gained on $\pi - \pi$ production and scattering amplitudes. Specific and selective topics as delineated in the abstract above, are discussed mainly based on my familiarity with the subject matter. Concerning the status of $\sigma$ and $\kappa$ and their existence, Session V at this Symposium was truly excellent. Ms. Carla Goble did an outstanding job at presenting the experimental status of these states, and Muneyuki Ishida san did a persuasive job on phase motion for $\sigma$ and $\kappa$ production amplitudes. I will recommend everyone to read the Proceedings articles for Session V [Properties and Spectra of Scalar Mesons I], since all need to savor the contributions here, without the less than adequate explanation of yours truly in summary. I conclude on the basis of Session V that both $\sigma$ and $\kappa$ indeed exist.

2 Theoretical Models

We examine in this section 5 theoretical models which address the issue of low mass scalars below 1 GeV, assuming that $\sigma(500)$ and/or $\kappa(800)$ indeed exist. The options are:-

1. The $[\sigma, \kappa, a_0(980), f_0(980)]$ form an usual $(q\bar{q}) L=1$ scalar nonet below 1 GeV.

This seems quite reasonable at first sight, since it builds on the well known $(q\bar{q}) L=0$ nonet $[\pi, \rho, \text{etc.}]$ below 1 GeV also. There are however a number of problems with this approach as enumerated by Schechter[1] sometimes back. They are:-

- The $a_0(980)$ and $\sigma(500)$ have same number of non-strange quarks but curiously are NOT degenerate.
- As scalar P-wave states, why are they not in $> 1$ GeV energy region of other P-wave states.
- There is no explanation on why $f_0(980) \sim s\bar{s}$, and $a_0^+(980) \sim u\bar{d}$ are degenerate. Achasov[2] regards explanation of $\phi \to f_0(s\bar{s})\gamma$ detached from $a_0(980)$ as ‘awful’ from a theoretical viewpoint.
- We do not deny that Scadron[3] produced in the $q\bar{q}$ approach, not only the famous Nambu relation $m_\sigma \simeq 2m_q$, but also the treasured Sakurai vector meson dominance universality condition. However $q\bar{q}$ $(L=0)$ for low lying vector mesons has not been challenged. They lie in the domain of isolated environment, remote from background, where QCD sum rules agree very well in the words of Achasov[4]. The linear $\sigma$-model (Scadron), effective lagrangians, obtained in the Nambu-Jona Lasinio NJL type model are valid, strictly speaking, only for ‘virtualities’ much less than the threshold for creation of $q\bar{q}$ pair, i.e. light (better still for massless) particles. Sometimes it works, e.g. in the vector channel[4]. I am inclined to agree with Bjorken[5] on $m_\sigma = 2m_q$ that “Sorry, but I don’t have anything useful to say about $\sigma$ mass. It is pushing the limits of what NJL can do in my humble opinion”.

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• One notes that Van Beveren, Scadron, et al. [6] argued strongly against the $q\bar{q}$ approach of Shakin-Wang, thus further attenuating a common $q\bar{q}$ modeling of low mass scalars.

2. What if $\sigma$ exists $\leq 1$ GeV, but $\kappa(800)$ does not exist[7]. In Narison’s words[8]

“In addition to the glueball of mass 1.5 GeV found e.g. on the lattice in the quenched approximation as well as from sum rule, a light glueball is needed for simultaneous saturation of the subtracted and unsubtracted sum rules where the stablization scale occurs at different regions due to the important role of the subtraction constant of the two-point correlator in the subtracted sum rule. Contrary to the one at 1.5 GeV which has a U(1) glueball like decay ($\eta - \eta', \ldots$), this light glueball couples strongly to $\pi - \pi$ (OZI violation) and is not found from quenched lattice simulation. A more accurate estimate of this mass on the lattice would need the inclusion of quark loops”. I believe his recent e-print[8] discusses this point further. Ochs and Minkowski[9] appear to endorse this viewpoint, since $f_0(980)/a_0(980)$ can be returned to the $q\bar{q}$ assignment together with above 1 GeV scalars $f_0(1500)$ and $\kappa(1430)$. Of course the case here will be greatly weakened if $\kappa(800)$ is experimentally confirmed.

3. $(qq)(\bar{q}\bar{q})$ - states. This structure allows two configurations in color space: $\bar{3}3$ and $66$. They may mix/rearrange to form $(q\bar{q})(q\bar{q})$ with color configuration, and there could be difficulty to distinguish a tetraquark state from a mesonic molecule. Isgur and Weinstein observed that four quarks in a confining potential are mainly arranged as two color singlets at large (1.5 fm) distance and give birth to MESONIC MOLECULES.[10] Such a loose bound structure appears consistent with Rosner’s statement[11]: “A low-mass ($\sim 600$ MeV) scalar (as a dynamically induced $\pi - \pi$ interaction) is consistent both with theory (current algebra, crossing symmetry, and unitarity) and with experiment. A similar enhancement appears to be occurring in the $I=\frac{1}{2}$ S-wave $K - \pi$ system. Indeed it may even be relevant to the electroweak scale if the Higgs boson turns out to be a broad, dynamically generated object rather than the narrow state everyone is hoping for at 115+ GeV.” Adler[12] is supportive of Rosner, namely the PCAC consistency condition implies the need of a low energy and broad $\pi - \pi$ scattering resonance.

CAVEAT! Theorists have done sophisticated work in building analyticity, unitarity, and crossing symmetry into dispersion theoretic and Roy Equations procedures[13] either for the existence of $\sigma$ or against its existence. A note of caution has been introduced by Anisovich[14] concerning the left-hand cut problem, to wit: “.... The $\pi - \pi$ amplitude has a left-hand cut affected by interaction forces, so constraints coming from left-hand cut are important. Our knowledge is however rather vague (mostly to test individual hypothesis e.g. $\rho$-exchange etc.). The left-hand cut is in fact highly unstable near $\pi - \pi$ threshold s. A comparatively
small change of partial wave amplitudes affect the left-hand cut considerably. The reason being the contributions from different (t and u) channels and different resonances cancel each other out to a great extent.” Thus fitting data within rigid constraints on \( \pi\pi \) amplitudes for \( s < 4m_\pi^2 \) can lead to incorrect amplitude representations in the mass region of \( \sigma \) searched for! In my humble opinion theory methods here may not be definitive concerning the existence/non existence of \( \sigma \)-meson.

4. Ishida Model of Chiral Particles/Covariant Level Classification. Törnqvist[15] in his Kyoto summary commented on Professor Ishida san’s relativistic S-wave \( q\bar{q} \) bound states (“chiralons”) with \( J^{PC} = 0^{++} \) quantum numbers. They would appear only at low masses, thus the possible low mass scalars \( (\sigma, \kappa, a_0(980), f_0(980)) \) below 1 GeV could be potential candidates for the chiralon model. He allowed that the model is very speculative, but would open up a new approach. Since the low mass scalars enumerated here can be given alternative explanations, I asked where is the ‘smoking gun’ test of the Ishida model? and concentrated on the prediction of a scalar \( B_\chi^3 \) in the B-meson system, because it has been proposed[16] as possibly relevant to the explanation of the double peak anomaly in \( \Upsilon(3S) \to \Upsilon(1S)\pi\pi \) also. Ito et al.[17] pointed out that the \( B_\chi^3 \) has a mass of \( \sim 5550 \) MeV, hence \( B_\chi^3 \to B + \pi \) (S-wave) is allowed, as they analysed from the data of L3 and Aleph. Also at this Symposium Yamauchi[18] suggested a width \( \sim 20 \) MeV for \( B_\chi^3 \) state. Clearly it is important to have independent affirmation of this state by an experimental group, e.g. at CLEO where much fine features of B-physics are done. I did push my CLEO friend Sheldon Stone very hard on this since July, 2002. However Sheldon’s reply[19] is “I don’t have much to add. The new CLEO \( \Upsilon(3S) \) data shows the same double peak structure as before. I don’t think we are going to be able to say much about \( B_\chi^3 \). Have fun in Tokyo. Sheldon”.

5. Mesonic Molecules Revisited. Inspired by Isgur-Weinstein[10] \((qq)(\bar{q}\bar{q})\) case but considering only mesonic degree of freedom (i.e. color singlets), e.g. \( \rho \)-exchange between \( K\bar{K} \leftrightarrow f_0(980) \), a very compact molecule can be obtained. The reason is that radiative \( \phi \) decay data exclude the extended loosely bound Isgur-Weinstein molecule, while giving strong evidence for a compact \( K\bar{K} \)-state or a compact four-quark state[19]. I think the Adler-Jaffe-Achasov approach[12] could be a mix of option 3. above and option 5. here. We need a broad \( \sigma: \pi - \pi \) resonance at low mass and would like to accommodate \( f_0(980) \) as a compact four-quark state - to form below 1 GeV scalar nonet.

Anisovich argues that classification of Kaon states on a \((J, M^2)\)-plane [20], points out that a \( \kappa(\sim 900 \) MeV), much under discussion at this Symposium, does not belong to \((J, M^2)\) trajectories related to \( q\bar{q} \) states. This could be a strong argument against \( \kappa \) as \( q\bar{q} \) since all other \( q\bar{q} \) states lie on these linear trajectories well. We can turn this
argument around. A $\kappa$(800-900 MeV) cannot be a glueball (isospin); it is implausible to be a hybrid (believed to be significantly higher than 1 GeV in mass). What else can it be if existence is established? A reductio ad absurdum mathematical reasoning would conclude:- $\kappa$ is a multi-quark state!

**Important Point**: The quark content of $(\sigma, f_0(980), a_0(980), \kappa)$ are “virtuality” dependent in the Bogoliubov sense. Adler[21] calls it coherent states which is worth following up in the future. The developments at Hadron 2001[12] have persuaded Törnqvist[22] to be no longer troubled that the pion could end up as a 4q state. He has embraced a viewpoint proposed earlier by Kunihiro and Nambu[23] that these low lying scalars are emerging Goldstone Higgs nonet (of strong nonperturbative interactions when a hidden local symmetry is spontaneously broken) and is a superposition of $q\bar{q}, qqq\bar{q}, qqqqq\bar{q},...$ The word ‘emerging’ was coined from a Bjorken paper[24] where Jaffe’s natural nonlinear realization relation[12]

$$\sigma = [f^2 - \vec{\pi}^2]^{1/2} = f - \frac{\vec{\pi}^2}{2f} + .... (1)$$

is reproduced in Bjorken’s Eq. (12)[24]. Thus there is a convergence of views!

**Observations:**

- If the scalar nonet is predominantly of the Jaffe 4q-state $(3,\bar{3})$ coupled in color to form a picture of a “cryptoexotic” nonet below 1 GeV, than an inverted equally spaced spectrum follows[22]. The currently touted low energy scalars $a_0(980)/f_0(980), \kappa(\sim 800), \sigma(\sim 600)$ follow this spacing rule remarkably well. The physical picture is that of a four quark component in the core transforming to a meson-meson description in the periphery as first proposed by Jaffe and Low[25].

- How about instanton effects that Narison[8] emphasizes as important at least in the context of the $\eta'$ problem. Could it cause trouble for the multi-quark approach as proposed for instance by Adler-Jaffe-Achasov[12]? Kochelev[26] maintains that “From his point of view, a multi-quark interaction, induced by instantons, could be the reason for the observed enhancements in 0++ channels.”

- Iwasaki[27] in connection with ‘Meson Bound-State Experiment’ in a nuclear medium says that $\sigma$ below 280 MeV (two pion threshold) would become stable (hence very narrow width). This seems to resonate with the work of Jaikumar and Zahed[28] which discusses scalar-isoscalar excitation in the different context of dense quark matter (up to neutron star density). Here $\sigma$-meson in this (color-flavor locked) phase appears as a 4q state (diquark and anti-diquark) with a well-defined mass and extremely small width, as a consequence of its small coupling to two pions. My question is that in the A-J-A inspired paper[12], it was argued that when Bogoliubov virtuality of $\sigma$-state is $\sim m_\pi$ mass, the state has $q\bar{q}$ characteristics, as the chiral partner of $\pi$. But when virtuality of $\sigma \leq 1$ GeV, it exhibits 4q state characteristics. Is Jaikumar and Zahed[28] saying that
even below the $2\pi$ threshold (significantly closer to $m_\pi$ than to 1 GeV), $\sigma$ continues to retain 4q characteristic? Perhaps the experimental work of the Dirac Collaboration[29] on Pionium, Kaonium will clarify this issue.

**The Future**

Beyond the light scalars $< 1\text{GeV}$, lies the $U(3) \times U(3)$ linear $\sigma$ model (L$\sigma$M) where Törnqvist[15] identified Joe Schechter as one of the originators. This model[30] does not exist in the tree approximation (unfortunately!). The model is renormalizable and strategically (my favorite word) its study on the lattice above 1 GeV say, is very intriguing. **But the existence of $\kappa(800)$ is of course critical to the theory here under our option 5.**

### 3 Significant New Insight

Muneyuki Ishida san[31] makes an important critique of conventional analysis concerning $\pi\pi$ production amplitude $F$ and scattering amplitude $T$ usually written as

$$F_{\pi\pi} = \alpha(s)T_{\pi\pi}; \alpha(s) : \text{slowly varying real function.} \quad (2)$$

This implies that $F$ and $T$ have the same phases and the same structure. There is also the implication of common positions of poles, if they exist.

It has often been argued that the amplitudes for $J/\psi \rightarrow \omega\pi\pi$ and $D^+ \rightarrow \pi^-\pi^+\pi^+$ (for $\pi\pi$ production) must assume same phase as the $\pi\pi$ scattering phase, since to take the case for $J/\psi$ the energy range $m_{\omega\pi}(\sim M_{J/\psi})$ is large, and $\pi\pi$ decouples from $\omega$ in the final state channel. Hence phase constraint is argued to come from $\pi\pi$ elastic unitarity condition [Fermi-Watson-Migdal Theorem].

However according to the excellent work of Suzuki-Achasov[32], large relative strong phase is needed for $J/\psi \rightarrow VP(\omega\pi^0, \omega\eta^0, \rho\pi, K^*\bar{K}, \text{etc.})$ for the famous puzzle here, likewise for $J/\psi \rightarrow PP$. We are in the domain of long distance effect and non-perturbative QCD regime. Suzuki[33] put it succinctly as ‘In $J/\psi \rightarrow \omega\pi\pi$, the invariant $m_{\omega\pi} \leq 1.6 \text{GeV}$. There are “overlapping resonant phases”, in fact many non strange resonances up to 2 GeV in the PDG Table can contribute. For $D \rightarrow K\pi$, the $K$ and $\pi$ are back to back at 1.87 GeV. The CLEO experiment says[34] that $K - \pi$ interaction is very large ($\sim 90^\circ$) in final state interaction phase difference $\delta_2 - \delta_1$ at $m_D$. Hence $K - \pi$ scattering at 1.87 GeV is definitely not in perturbative QCD regime. The same is true for $K^*-\pi$ at 1.87 GeV.’ The situation in $B \rightarrow D\pi, D\rho, D^*\pi$ has been discussed recently by Rosner-Chiang[35].

If $F = \alpha(s)T$ is not true for say $J/\psi \rightarrow \omega\pi\pi, \pi K\pi K$ and $D \rightarrow \pi\pi\pi, K\pi\pi$, even though the question of rescattering and its importance remains debatable, we need to separate analysis involving ($n \geq 3$) multi-hadron final states as listed here from the clean $n=2$ case. To wit, following Ishida[31], let us take the FOCUS

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$D^+ \rightarrow K^-\pi^+\mu^+\nu$ with $n=2$. The $K^-\pi^+$ piece is isolated at strong interaction level, hence Fermi-Watson-Migdal FWM theorem is applicable. This in turn implies that $\mathcal{F}$ and $\mathcal{T}$ have common phase. FOCUS[36] says that $D^+ \rightarrow K^0\mu^+\nu$ is dominant, with a small S-wave ($K^-\pi^+$ component, which exhibits a more or less constant phase $\delta = \frac{\pi}{4}$ in the region of $\kappa$ with $m_{K\pi} \sim 0.8 \text{ GeV}$.) This $\delta$ is suggested by Ochs and Minkowski[9] to be the same as $K - \pi$ scattering phase shift by the extensive LASS data[37]. Hence FWM theorem is respected. It is of interest to note that Shabalin[38] studied $K e^+\pi^-$ decay, using SU(3) and L$\sigma$M, by treating $K^+ \rightarrow \pi^+\pi^- e^+\nu$ as $K^+ \rightarrow \sigma e^+\nu (\sigma \rightarrow \pi^+\pi^-)$ to explain the large width of $K_{e4}$ decay (twice as large as soft pion prediction). Here also the amplitude observes the FWM theorem and has the same phase as $\pi\pi$ scattering phase shift; the $\sigma$ Breit-Wigner phase motion is not observed, but the large width suggests nevertheless that $\sigma$ is being produced! This case is quite analogous to the FOCUS situation discussed above.

Take now the E791 experiment[39] (with $n=3$) on $D^+ \rightarrow (K^-\pi^+)\pi^+$. Here $K^-\pi^+$ piece is not isolated in strong interactions (rescattering or other mechanism can prevail) and the FWM theorem becomes questionable. Indeed E791 sees large phase motion and Breit-Wigner in the $\kappa(800)$ region. Evidently production amplitude $\mathcal{F}_{K\pi}$ can have different phase from $\mathcal{T}_{K\pi}$ of scattering. I am impressed that Ms. Carla Goble, who participated in both E791 and FOCUS experiments, reported at this Symposium that there is no contradiction between E791 and FOCUS.

Though Carla has no doubt improved the sophistication of analysis since the E791 publication[39], I am attracted by Brian Meadows[40] and his statement that ‘E791 did an excellent job in showing that a “NR” (contact) amplitude with magnitude and phase independent of position on the Dalitz plot simply did not work as it had for earlier data. The next simplest assumption, a S-wave Breit Wigner, did however give an excellent description of the data, both magnitude and phase - in both $K\pi$ and $\pi\pi$ systems. Really that is all.’ I applaud this as a most sensible way to proceed - the next simplest assumption. I urge CLEO[41] which studies $D^0 \rightarrow K_S^0\pi^+\pi^-$ with a currently null result on $\kappa^-(800) \rightarrow K_S^0\pi^-$, and BABAR[42] with a null result on $\kappa^+(800)K^- \rightarrow K^0K^-\pi^+$ Dalitz plot analysis, to follow the next simplest assumption to verify/refute E791. The Breit-Wigner and phase motion should be similar to E791 in CLEO/Babar according to Ishida[31].

Remark: Bugg[43] maintains that ‘Particles are to be identified as poles. If you allow the pole position to be different in different processes, you are allowing the particles to have different mass and width in different processes. This is not true for $\rho(770)$ and $f_2(1270)$ in different processes......’ However $\rho(770)$ and $f_2(1270)$ could again be a case of isolated environment, remote from background[4]. Indeed our experience[11] with reactions $\gamma\gamma \rightarrow \pi\pi$ indicates that the way in which a broad resonance (like $\sigma$, $\kappa$) manifests itself can differ significantly from process to process, particularly comparing elastic versus inelastic channels. I think Eric Swanson’s comment at the end of my Symposium talk best summarizes this point. Namely, ‘the position of a pole in the S-matrix is a fixed property of the underlying field theory. Thus its position cannot
depend on the observable used to obtain it (of course, one must extrapolate to obtain pole positions, so numerical+experimental error may lead to different numbers). On the other hand, the Breit-Wigner formula is an approximation to what may be a complicated experimental situation and BW parameters (such as resonance mass and width) can change depending on the channel. However, one expects these variations to be small if the resonance is narrow.

From the compilation of $\sigma$, $\kappa$ poles\cite{44} they would appear to be significantly broader than $\rho(770)$ and $f_2(1270)$.

If $\sigma$ exists at low mass, the 50% emotional component of the theorist in me, would urge that it be deployed to solve other outstanding puzzles. Here the phenomenological work of the Ishida group\cite{45} excites me. Remember multipole expansion of QCD has more or less successfully treated the suppression of spectra near $\pi\pi$ threshold [the resulting amplitude has Adler zero around $s \sim 0$] in

$$\psi(2S) \to \psi(1S)\pi\pi \Delta E = 589\text{MeV} \ k a \sim 0.7$$
$$\Upsilon(2S) \to \Upsilon(1S)\pi\pi \Delta E = 563\text{MeV} \ k a \sim 0.3$$
$$\Upsilon(3S) \to \Upsilon(2S)\pi\pi \Delta E = 332\text{MeV} \ k a \sim 0.18$$

(3)

here $k$ is typical momentum of the emitted gluons and $a$ is size of $Q\bar{Q}$ system estimated from potential models, with $k$ given by\cite{46}

$$k \sim \frac{1}{2}(m_{\Phi'} - m_{\Phi}), \Phi = \psi, \Upsilon$$

(4)

for two gluon emission. Similar results are obtained if we choose $\frac{1}{2} \sim 1\text{fm}$, as typical size of light hadrons. It is also known from nuclear physics\cite{46} that the classification of multipole orders is valid even for $ka \sim 1$. The fly in the ointment is in

$$\Upsilon(3S) \to \Upsilon(1S)\pi\pi \Delta E = 895\text{MeV} \ k a \sim 0.48$$

(5)

where the $\pi\pi$ spectrum exhibit the double peak anomaly. Why is the multipole approach failing for such reasonable $ka \sim 0.48$ value? The Ishida group\cite{45} proposes the tantalizing intervention of the $\sigma$ in this dipion mass range $0 < m_{\pi\pi} \leq 900\text{MeV}$. Actually they introduce the production amplitude $F_2^{G\pi}$ (where $G$ depict ground-state tensor and scalar intermediary glueballs, which seem a straightforward extension of two gluon intermediary of multipole/QCD work) and take form

$$F_2^{G\pi} \approx -2\xi^G p_{1\mu} p_{2\nu}, \text{ vanishes when } p_{1\mu} \to 0_{\mu}. \quad (6)$$

Thus, it has Adler zero, satisfies general constraint from chiral symmetry, and does not vanish at $s = m_{\pi}^2$. In a relevant process, Adler limit $p_{1\mu} \to 0_{\mu}$ implies neglect of $\Delta E$ in comparison with $m_{\pi}$. For $\Upsilon(3S) \to \Upsilon(1S)\pi\pi$ transition at dipion threshold $s = 4m_2^2$, $p_{1\mu} = p_{2\mu}$, which in turn implies $p_{10} = p_{20} \approx \Delta E = 450\text{MeV} \gg m_{\pi}$. Hence $F_2^{G\pi}$ is almost $s$-independent in the physical region, and has no zero close to threshold. There is therefore no suppression near threshold, and the $\pi\pi$ spectrum can show steep
increase from its threshold. Including both $F_\sigma$ Breit-Wigner for $\sigma$ and a $F_{2\pi}$ for a direct $2\pi$ amplitude, we can write the phenomenology as an amplitude

$$F_{\text{phen}} \equiv F_{\sigma+2\pi}^{\text{phen}} + F_{2\pi}^G. \quad (7)$$

Remarks:

- Constraints of chiral symmetry require that the $F_\sigma$ amplitude must be strongly cancelled by non-resonant repulsive $\pi - \pi$ amplitude in $\pi\pi$ scattering, i.e. destructive interference between $F_\sigma$ and $F_{2\pi}$ explains suppression of threshold spectra for $\Upsilon(3S) \to \Upsilon(2S)\pi\pi$, $\Upsilon(2S) \to \Upsilon(1S)\pi\pi$, and $\psi(2S) \to \psi(1S)\pi\pi$. For $\Upsilon(3S) \to \Upsilon(1S)\pi\pi$, these amplitudes interfere constructively. These behaviors of production amplitudes are consistent with chiral symmetry constraint. Of special interest is that the valley between double peak $\pi\pi$ spectrum structure in $\Upsilon(3S) \to \Upsilon(1S)\pi\pi$ appears correlated to where $\sigma$ reaches peak position. Hence the spectrum is well reproduced by interference between direct $F_{2\pi}$ with zero phase and $F_\sigma$ with moving phase. We are in fact observing the very phase motion of $\sigma$-Breit-Wigner via this double peak anomaly puzzle!

- Bugg[43] understood Ishida group’s background phase shift $\delta_{BG}$ to be repulsive in the following way. Take for orientation $\sigma : M - i\Gamma \approx 550 - i250\,\text{MeV}$. This implies a scattering length $\sim \frac{1}{m_\sigma}$. But the $K_{e4}$ data demand a scattering length $\sim \frac{0.22}{m_\sigma}$. Hence repulsive short range interaction is needed to balance $\sigma$ resonance contribution. Here at the Symposium M. Ishida san answered the mechanism for such a repulsion as due to model independent chiral cancellation.

- Ishida san[47] suggested that the $F_{2\pi}^G$ derivative type interaction may have other origin. For instance all sequential two-pion production gives this type of amplitude according to the Adler self-consistency condition. Indeed the explanation of double peak anomaly by postulating the existence of $X(b\bar{b}q\bar{q})$ resonance with S-wave decay into $\Upsilon(1S) - \pi$ in the 10.4-10.8 GeV mass range[48] does include the sequential two-pion production diagram. Hence in a partial sense this approach is consistent with the Ishida group[45] analysis of the double peak anomaly in $\Upsilon(3S) \to \Upsilon(1S)\pi\pi$. The convergence to seek an unified viewpoint (and hence an unique interpretation) of the anomaly is far from complete however, since Anisovich et al.[48] count heavily on the importance of the rescattering triangle graph (leading to logarithmic singularity) in their work. Indeed in a recent communication Anisovich[14] again maintains the possible existence of logarithmic (triangle) singularities near $\pi\pi$ threshold, and they should be taken into account in search of $\sigma$ meson in three particle process. The influence of such singularities on $\pi\pi$ spectra are important for low $\pi\pi$ mass (e.g. at $f_0(980)$) and surely will be more so at the lower $\sigma$ mass.

From an experimental point of view the $X(b\bar{b}q\bar{q})$ model[48] is difficult to establish. We need $\Upsilon(nS) \to \pi + \Upsilon(1S) + \pi$ with $n \geq 6$ to do an adequate $\pi + \Upsilon(1S)$ mass
distribution plot. On the other hand Sheldon Stone[49] at CLEO has recently expressed interest in the $\sigma$ explanation when he writes ‘If the $\sigma$ explanation is correct, are there any other physical variables predicted besides the $\pi - \pi$ mass spectrum? Any angular distributions etc...?’ I leave this as a challenge for the Ishida group to work out.

4 Selected Meson Topics of Symposium Beyond 1 GeV

Here I will take liberty by commenting only on those states above 1 GeV for which I have some familiarity from the past. Hence my apologies to Symposium speakers whose very good work I am unable to summarize because of my own lack of experience in their subject matter.

The $J^{PC} = 1^{-+}$ state has long intrigued me. At Protvino (Hadron, 2001) Ted Barnes[50] in his summary talk concluded that the VES collaboration (V. Dorofeev, Hadron 2001) had no clear preference for a $\pi_1(1400)$ (this is the M(1405) of GAMS experiment in 1988 with $I = 1, J^{PC} = 1^{-+}$) resonance interpretation. Fit of similar quality can be obtained from a non resonant signal. Hence the critique of Dalitz et al.[51] about P-wave interfering background of GAMS(1988) still has some vitality. The E852/Brookhaven (A. Popov, Hadron 2001 Proceedings) favors the C-exotic $\pi_1(1600) \rightarrow \eta' - \pi, \rho - \pi$, and $b_1(1235) - \pi$. Nevertheless for a hybrid $q\bar{q}g$ state, theory [Flux tubes[50], confining field theory[52]] continues to maintain a mass prediction for $1^{-+}$ between 1.9-2.1 GeV! Given my comfort with multi-quark scalars below 1 GeV, I ask why not treat $\pi_1(1600)$ as the lightest (?) C-exotic from multi-quark (e.g. 4q) configuration? It is good to hear from Tsuru san at this Symposium a historical review of the search for $J^{PC} = 1^{-+}$ states since 1988. It is also pleasing to hear from Director Alexander Zaitsev[53] that VES search in $\pi^- A \rightarrow [b_1(1235)\pi]A$ supports a four quark interpretation for $\pi_1(1600)$ in $\pi^- p \rightarrow \eta\pi n, \eta'\pi n$ charge exchange. His suggestion of the existence of $\pi(1800)$ with $J^{PC} = 0^{-+}$, where $\pi(1800) \rightarrow f_0(980)\pi, \epsilon(\sigma)\pi, a_0\eta, f_0(1500)\pi$ [mostly unitary singlet + octet?] but NOT to $\rho\pi$ [octet + octet] points towards a crypto-exotic hybrid $q\bar{q}g$ (longitudinal fluctuation of flux tube). This intriguing possibility surely deserves further study.

Steve Olsen[54] at this Symposium discussed the observation of a near -threshold enhancement in the $p\bar{p}$ mass spectrum from radiative $J/\psi \rightarrow \gamma p\bar{p}$ decays, using the 58 million $J/\psi$ sample at BES. Fitted as an S-wave, the peak mass is below $2m_p$ (1876.54 MeV) at 1859 MeV with total width $\Gamma < 30MeV$ (90% C.L.). They are not yet seen in $J/\psi \rightarrow (p\bar{p})\pi^0, (p\bar{p})\eta^0$ which in Ishida language could mean the $p\bar{p}$ are not isolated at the strong interaction level (n=3 final state) in contrast to $\gamma p\bar{p}$ where $p\bar{p}$ is isolated in strong interaction (n=2). Note at BELLE[55] $B \rightarrow (p\Lambda)\pi$ threshold enhancement is seen for $p\Lambda$. Here the $\pi$ from phase space consideration may have moved significantly away from the $p\Lambda$ environment. Implications of the Olsen discovery has
been thoroughly analysed by Rosner[56], hence I will comment only on some items of particular interest to me.

- The threshold enhancement of $p\bar{p}$ in $J/\psi \rightarrow \gamma p\bar{p}$ is not due to Coulomb attraction as Olsen showed at this Symposium.

- The Nambu relation $m_\sigma = 2m_q$ mentioned earlier should strictly be applied to the nucleon mass as $m_\sigma = 2m_p$, since the Nambu-Jona Lasinio papers[57] were written some two years earlier than the invention of the quark model. If the threshold enhancement[54] is treated as a $J^{PC} = 0^{++}$ scalar state, the fit yields a peak mass $2m_p$ and a very narrow total width $\sim 4.6$ MeV.

- If the S-wave interpretation with $J^{PC} = 0^{-+}$ is correct, Suzuki[33] points out that they could be baryon-antibaryon six quark molecular states $(qqqq\bar{q})$ where the $(qqq)$ and $(\bar{q}q\bar{q})$ are pulled together by the gluon equivalent of the molecular Van der Waals force (analogous to the suspected charmonium $DD$ molecular state mode of $cc\bar{c}\bar{c}$). The emphasis is then on the deuteron analogy, and not on Fermi/Yang or Sakata model dynamics.

5 Conclusion

We have seen that a credible picture for the existence of a nonet of scalars $[\sigma, \kappa, f_0(980), a_0(980)]$ has emerged from this Symposium. Indeed perhaps a multi-quark interpretation of these states has once again become an attractive possibility for theoretical understanding. The natural question to ask is ‘how about the baryons’. At the end of Professor Oka san’s Symposium summary on the baryon system, I asked whether in connection with the $\Lambda(1405)$, it could also be a case of what Steve Adler[21] calls coherent states $qqq,qqqq\bar{q},....$ in the Bogoliubov sense as applied to baryons. I believe Pakvasa and I actually alluded to this possibility in our paper[58] together with some other baryon examples, though the clarification for mesons (as coherent states) only came later at Protvino[12]. We have certainly come a long way from the traditional naive quark model classification of hadron states[59] of some 37 years ago. Hadron 2001 at Protvino and now at this Tokyo Symposium have jointly contributed towards an exciting and challenging future for hadron physics! In addition to the general acknowledgement given in the Introduction, this work was supported also in part by the U.S. Department of Energy under Grant DE-FG-03-94ER40833 at the University of Hawai‘i at Manoa.

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