ABSTRACT

These are the mini-proceedings of the CHARMEX workshop. The meeting focused on recent developments in charm spectroscopy, especially on the possible role of the states that do not fit into the quark model classification — the so-called exotic states. The goal of this write-up is to provide the community with a short summary of the individual talks as well as a comprehensive, up-to-date list of relevant references.
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1 Introduction

1.1 Scope of the workshop

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Until the turn of the millennium there was a strong belief that hadrons containing the charm quark and among those especially the charmonia (states with a charm and an anticharm quark) can be largely understood on the basis of the non-relativistic quark model. Corrections were believed to be calculable within Heavy Quark Effective Field Theory (HQEFT). However, especially since BaBar and BELLE started to enter the field of charm spectroscopy, a large number of new states were discovered that because of their mass and/or their properties do not at all match the described picture. How can we understand their nature in terms of QCD? Can they be included in the quark model after some refinements or are they of completely different origin — options suggested in the literature range from glueballs over hybrids to molecules? How can one distinguish among those different scenarios? What are the proper theoretical tools for the analysis of these states?

To address these questions is especially important now, when the components of the FAIR projects are in their final phase of planning. Charm spectroscopy will be studied in the PANDA experiment at the High Energy Storage Ring. Insights on relevant observables and requests on the resolution or particle identification that might emerge from nowadays discussions can still influence some aspects of the detector. In this context it is very important to identify and further refine, on the basis of what can be expected in the near future from Belle, BaBar, BES-III, CLEO-c, D0, and CDF, the minimal requirements for the PANDA detector to make sure that the experiment will indeed improve our understanding of QCD.

The webpage of the conference, which contains all talks, can be found under

www.fz-juelich.de/ikp/charmex

The meeting would not have been possible without the support by the Wilhelm and Else Heraeus foundation. All participants especially appreciated the efficient and unbureaucratic style of the foundation. The Wilhelm and Else Heraeus foundation is the most important private foundation to support natural sciences. For more information see http://www.weheraeus-stiftung.de/. We would also like to thank the staff of the Physikzentrum, in particular V. Gomer, for the efficient organization.
2 Short summary of the talks

2.1 Exotics at Belle and BaBar

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A review of some of the recent experimental developments concerning the $X$, $Y$ and $Z$ charmoniumlike mesons states is presented. New mass measurements from Belle and CDF place the mass of the $X(3872)$ at $0.35 \pm 0.41$ MeV below the $m_{D^*} + m_{D^*}$ threshold. No strong evidence if seen for $B \rightarrow K^*(890) X(3872)$ in contrast to all known charmonium states for which strong signals for $B \rightarrow K \omega J/\psi$+charmonium are seen. Belle reports a new, near-threshold $\omega J/\psi$ mass peak in $\gamma \gamma \rightarrow \omega J/\psi$ decays, with mass and width consistent with BaBar’s recent measured values for the $Y(3940)$ from $B \rightarrow K \omega J/\psi$ decays. A Belle search for $Y(3940) \rightarrow D^* D$ resulted in an upper limit that contradicts earlier measurements for the $X(3940)$ ($D^* D$ peak seen in $e^+ e^- \rightarrow J/\psi D^* D$ annihilation), thereby establishing the $Y(3940)$ and $X(3940)$ as distinct states. No evidence is seen for the $1^{--}$ $Y$ states in any open charmed decay channels, including the $D^{**} \bar{D}$ channels favored by c$\bar{c}$-gluon hybrid models. A Belle reanalysis of $B \rightarrow K \pi^+ \psi'$ decays using Dalitz techniques confirms their earlier claims for a charged $Z(4430)^+ \rightarrow \pi^+ \psi'$ resonance.

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2.2 Exotic Charmonia

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In this talk, I discussed the $c\bar{c}$ mesons above the $D\bar{D}$ threshold that have been discovered in recent years. I summarized the various proposals for identifying some of these states as exotic $c\bar{c}$ mesons. I then focused on a specific state that is definitely an exotic $c\bar{c}$ meson: the $X(3872)$. I explained how existing data implies unambiguously that this state is a loosely-bound charm-meson molecule. I also discussed various misconceptions that have preventing this identification from being universally accepted in the particle physics community.

In the references below, I list some review articles on $c\bar{c}$ mesons above the $D\bar{D}$ threshold [1, 2, 3, 4, 5]. I also list my papers on the $X(3872)$ in which I have been developing the case for this state as a loosely-bound charm-meson molecule [6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16].

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2.3 Selected Topics in BES and Belle experiments

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The following topics were discussed: (1) the $Y(2175)$ signals observed in $J/\psi \rightarrow \phi f_0(980)\eta$ at BES [1] and in $e^+e^- \rightarrow \phi \pi^+\pi^-$ [2] at Belle experiments; (2) the anomalous structure in the total cross section around 3.77 GeV [3] in the $e^+e^-$ annihilation observed at BESII experiment; (3) the $X(3915)$ particle observed in two-photon process $\gamma\gamma \rightarrow \omega J/\psi$ [4]: Belle observed a resonance-like enhancement in $\gamma\gamma \rightarrow \omega J/\psi$ process with a statistical significance of $7.7\sigma$ composed of $55\pm 14$ events in the peak region. The mass and width are measured to be $M = 3914\pm 3\pm 2$ MeV/$c^2$ and $\Gamma = 23\pm 10^{+2}_{-3}$ MeV, respectively. It is noted that these values are close to those of the $Y(3940)$ from the BaBar measurement [5]. The total width from the same kind of the Belle result seems to be a little larger [6]. This state may be identical to either $Y(3940)$ or $Z(3930)$ [7] but not very conclusive; (4) the evidence for a new resonance $X(4350)$ in two-photon process $\gamma\gamma \rightarrow \phi J/\psi$ [8] at Belle experiment: Evidence is reported for a narrow structure at 4.35 GeV/$c^2$ in the $\phi J/\psi$ mass spectrum in two-photon process $\gamma^*\gamma^* \rightarrow \phi J/\psi$. The analysis is based on a data sample of 825 fb$^{-1}$ collected on and off the $\Upsilon(nS)$ ($n = 1, 3, 4, 5$) resonances with the Belle detector. A signal of $8.8^{+1.2}_{-1.6}$ events, with statistical significance of 3.9 standard deviations, is observed. The mass and natural width of the structure (named as $X(4350)$) are measured to be $4350.6^{+1.6}_{-5.1}$ (stat) $\pm 0.7$ (syst) MeV/$c^2$ and $13.3^{+17.9}_{-9.1}$ (stat) $\pm 4.1$ (syst) MeV/$c^2$, respectively. The products of its two-photon decay width and branching fraction to $\phi J/\psi$ is measured to be $\Gamma_{\gamma\gamma}(X(4350))B(X(4350) \rightarrow \phi J/\psi) = 6.4^{+3.1}_{-2.3}\pm 1.1$ eV for $J^P = 0^+$, or $1.5^{+0.7}_{-0.5}\pm 0.3$ eV for $J^P = 2^+$. No $Y(4143)$ signal [9] is observed, and $\Gamma_{\gamma\gamma}(Y(4143))B(Y(4143) \rightarrow \phi J/\psi) < 39$ eV for $J^P = 0^+$ or $< 5.7$ eV for $J^P = 2^+$ is determined at the 90% C.L.; and (5) the status of the BESIII experiment at the BEPCII: BESIII started taking data for physics study since spring 2009. Up to now, 107 M $\psi(2S)$ events and about 200 M $J/\psi$ events have been accumulated. There is a rich physics program at BESIII experiment [10].

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2.4 Strong Decays on the Lattice

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I started the talk with a brief discussion of the status of lattice QCD [1]. I reported on precision results from lattice QCD calculations, such as the mass of the charm quark ($m_c(m_c)=1.268(9)\text{GeV}$) [2], and the strong coupling $(\alpha_{\overline{MS}}(M_Z,n_f=5)=0.1183(8))$ [2].

I reviewed lattice QCD calculations of: the $\rho$ coupling to $2\pi$ [3], $b_1 \rightarrow \pi \omega$ [4], light $1^{++} \rightarrow \pi b_1$ [4], and light $1^{-+} \rightarrow \pi f_1$ [4]. Other lattice calculations of strong decays were included in the summary tables [5]. I reviewed lattice QCD calculations of the $g_{BB^*\pi}$ coupling [6]. I reported on a lattice QCD of the strong decay of the $B^{**}$ meson [7].

I ended the talk reviewing recent lattice QCD calculations that use L"uscher’s method [8] (and variants of) to study the properties of the $\rho$ and $\Delta$ [9].

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2.5 Excited Charmonium and radiative transitions from lattice QCD

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Using point-all technology on quenched lattices, the excited spectrum of charmonium [1] and radiative transition amplitudes between excited states [2, 3] are computed. That this is possible follows from application of a large basis of composite QCD interpolating fields. Highlights include the first extraction from QCD of a radiative transition featuring an exotic quantum numbered state. Phenomenological implications of these results are presented [4].

Preliminary results in the light meson spectrum are also presented. These follow from the use of distillation technology [5] on dynamical anisotropic lattices [6]. The extracted spectrum at the strange quark mass shows many of the systematics of the quark model with the addition of a number of exotic and non-exotic states which appear to have some properties expected of hybrid mesons [7].

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2.6 QCD Exotics at BNL and JLab

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Searches have been carried out at Brookhaven National Lab looking for light-quark mesons with non-quark-antiquark ($q\bar{q}$) quantum numbers. Lattice calculations [2, 3, 4, 5, 6, 7] predict that several nonets of these mesons should exist, and phenomenology gives some guidance on how they should decay [1]. The first such state reported is an isospin 1 $J^{PC}=1^{-+}$ state ($\pi_1(1400)$) with a mass near 1.4 GeV and a width of around 0.3 GeV [13, 14]. This state was also observed in $\bar{p}n$ annihilation at rest by Crystal Barrel [15, 16]. An alternate analysis of more E852 data on both $\pi^-p \rightarrow n\eta\pi^0$ and $p\eta\pi^-$ found no evidence for the $\pi_1$ [20]. However, a later E852 analysis on $\pi^-p \rightarrow n\eta\pi^0$ confirmed their earlier result [17]. E852 also found evidence for a second $\pi_1$ state in several final states: $\pi^-p \rightarrow p\pi^+\pi^-\pi^-$ [11, 12], $\pi^-p \rightarrow p\eta\pi^0\pi^-$ [10], $\pi^-p \rightarrow p\omega\pi^0\pi^-$ [8] and $\pi^-p \rightarrow pf_1(1285)\pi^-[9]$. This new state appears to have a mass of about 1.6 GeV and a width $\sim 0.3$ GeV. However, the observed production mechanism is not consistent over all the reported observations. Interestingly, an alternate analysis of a more extensive E852 data set seems to indicate that in the $3\pi$ final state, the observed exotic wave is actually leakage from well-known decays of the $\pi_2(1670)$ [19]. The $\pi_1(1600)$ was also looked for in photo production by CLAS in $\gamma p \rightarrow n\pi^+\pi^-\pi^-$ [18], but no evidence was found. Finally, in the $f_1\pi$ and $b_1\pi$ final states, E852 reports weak evidence for a 3’rd exotic state, the $\pi_1(2000)$.

In the future, we anticipate exciting results from the GlueX [21] which will use 8.4–9 GeV linearly polarized photons incident on protons to photoproduce hybrid mesons. With GlueX, we hope to map out the three exotic meson nonets expected from theory. Construction of the energy doubling upgrade of Jefferson Lab as well as GlueX started late in 2008 and first beam is anticipated in GlueX in 2014.

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2.7 Recent Bottomonium results from BaBar

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A search for the bottomonium ground state $\eta_b(1S)$ in the photon energy spectrum was performed using a sample of $(109 \pm 1)$ million of $\Upsilon(3S)$ recorded at the $\Upsilon(3S)$ energy with the BaBar detector at the PEP-II $B$ factory at SLAC [1]. We observe a peak in the photon energy spectrum at $E_\gamma = 921.2^{+3.4}_{-2.5} \text{(stat)} \pm 2.4 \text{(syst)} \text{ MeV}$ with a significance of 10 standard deviations. We interpret the observed peak as being due to monochromatic photons from the radiative transition $\Upsilon(3S) \rightarrow \gamma \eta_b(1S)$. This photon energy corresponds to an $\eta_b(1S)$ mass of $9388.9^{+3.1}_{-2.5} \text{(stat)} \pm 2.7 \text{(syst)} \text{ MeV}/c^2$. The hyperfine $\Upsilon(1S)-\eta_b(1S)$ mass splitting is $71.4^{+2.3}_{-3.1} \text{(stat)} \pm 2.7 \text{(syst)} \text{ MeV}/c^2$. The branching fraction for this radiative $\Upsilon(3S)$ decay is estimated to be $(4.8 \pm 0.5 \text{(stat)} \pm 1.2 \text{(syst)}) \times 10^{-4}$. A similar strategy was utilized to search for the $\eta_b(1S)$ meson in the radiative decay of the $\Upsilon(2S)$ resonance using a sample of 91.6 million $\Upsilon(2S)$ events [2]. A peak was observed in the photon energy spectrum at $E_\gamma = 609.3^{+4.6}_{-4.3} \text{(stat)} \pm 1.9 \text{(syst)} \text{ MeV}$, corresponding to an $\eta_b(1S)$ mass of $9394.2^{+4.8}_{-4.5} \text{(stat)} \pm 2.0 \text{(syst)} \text{ MeV}/c^2$. The branching fraction for the decay $\Upsilon(2S) \rightarrow \gamma \eta_b(1S)$ is determined to be $(3.9 \pm 1.1 \text{(stat)}^{+1.1}_{-0.9} \text{(syst)}) \times 10^{-4}$. We find the ratio of branching fractions $B(\Upsilon(2S) \rightarrow \gamma \eta_b(1S))/B(\Upsilon(3S) \rightarrow \gamma \eta_b(1S)) = 0.82 \pm 0.24 \text{(stat)}^{+0.24}_{-0.20} \text{(syst)}$.

Between March 28 and April 7, 2008 the PEP-II $e^+e^-$ delivered colliding beams at a center-of-mass energy ($\sqrt{s}$) in the range of 10.54 to 11.20 GeV. First, an energy scan over the whole range in 5 MeV steps, collecting approximately 25 pb$^{-1}$ per step for a total of about 3.3 fb$^{-1}$, was performed [3]. It was then followed by a 600 pb$^{-1}$ scan in the range of $\sqrt{s}$=10.96 to 11.10 GeV, in 8 steps with non-regular energy spacing, performed in order to investigate the $\Upsilon(6S)$ region. This data set outclasses the previous scans [4, 5] by a factor $>30$ in the luminosity and $\sim 4$ in the size of the energy steps. For each step in $\sqrt{s}$, $e^+e^- \rightarrow b\bar{b}$ cross section measurements were obtained. A total relative error of about 5% is reached in more than 300 center-of-mass energy steps, separated by about 5 MeV. These measurements can be used to derive precise information on the parameters of the $\Upsilon(5S)$ and $\Upsilon(6S)$ and have the potential to yield information on the bottomonium spectrum and possible exotic extensions.

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2.8 Unquenching, Requenching, and Renormalising the Quark Model

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The issue of incorporating virtual quark effects into the constituent quark model has become more germane with the recent charmonium discoveries in the continuum region. Nevertheless, the importance of this effect has been recognised for a long time[1]. This is a difficult problem that is probably not amenable to an effective field theory approach, and relies on guessing nonperturbative gluodynamics that drives quark pair production in the soft regime. One such guess is the $^3P_0$ model[2], but others based on one gluon exchange[3], or a relativistic kernel[4] exist.

Incorporating unquenching effects is not technically easy[5], but many computations have been made[6]. A recent advance is the establishment of theorems that guarantee that unquenching induced mass splittings will be identical for meson in degenerate SU(6) multiplets[7]. This lends support to the notion that the constituent quark model should be stable with respect to spin splitting effects, however direct computations indicate large residual shifts that cannot be absorbed in the model parameters.

An alternative approach is to incorporate unquenching effects in an effective interaction by implementing a similarity transformation in powers of the inverse quark mass[8]. This yields a spin-independent quark-quark effective interaction and a spin-orbit quark-antiquark interaction, with interesting implications for baryon spectroscopy.

Finally, unquenching quark models necessitates implementing (finite) renormalisation. This applies to typical quark model parameters, which now must be considered cut-off dependent, and to the quark charge.

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The nature of the state $X(3872)$ is discussed as based on the recent experimental data [1]. In particular, the data on the $D\bar{D}^*$ and $\pi^+\pi^-J/\psi$ channels, as provided by the Belle Collaboration [2, 3] and by the BaBar Collaboration [4, 5], are analysed using the method suggested in [6] and based on the Flatté parametrisation of the $D\bar{D}^*$ amplitude. The method is generalised to include into consideration extra decay channels for the $X$, in particular, radiative decay channels [7]. In addition, the effect of the finite $D^*$ width and the interference in the $D\bar{D}^*$ system is discussed. The conclusion is made that the $X(3872)$ is generated dynamically by a strong coupling of the bare $\chi'_c$ charmonium to the $D\bar{D}^*$ hadronic channel, with a large admixture of the $D\bar{D}^*$ molecular component.

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There is strong experimental evidence that the X(3872) is a very weakly bound state of $D^0\bar{D}^{*0}$ and $\pi^0$ mesons. XEFT [1], an effective theory of nonrelativistic $D^0$, $D^{*0}$ and $\pi^0$ mesons, can be used to systematically calculate properties of the X(3872). Power counting shows that pion exchanges can be treated perturbatively. Leading order calculations of $X(3872)\rightarrow D^0\bar{D}^{*0}\pi^0$ in XEFT reproduce results obtained using effective range theory (ERT) [2]. XEFT can be used to systematically analyze corrections to ERT from higher dimension operators and $\pi^0$ exchange. Effects of $\pi^0$ exchange turn out to be quite small. Many of the observed decays of the X(3872) are to final states with charmonium. These decays are sensitive to short distance aspects of the X(3872) and are therefore not completely calculable, but factorization theorems for these decays can be developed [3, 5]. These factorization theorems can be derived by matching Heavy Hadron Chiral Perturbation Theory (HH\textsubscript{\chi}PT) amplitudes onto XEFT operators [4]. Decays of X(3872) to $\chi_{cJ}$ plus pions are interesting because heavy quark symmetry (HQS) makes predictions for the relative rates for decays to states with different $J$. If measured the relative rates could be used to test the molecular interpretation of the X(3872) [6]. In XEFT long distance contributions to these decays can significantly modify HQS predictions for the relative decay rates [4]. Another interesting decay is the recently observed radiative transition $X(3872)\rightarrow \psi(2S)\gamma$ [7]. The observed ratio for $\Gamma[X(3872)\rightarrow \psi(2S)\gamma]/\Gamma[X(3872)\rightarrow J/\psi\gamma]$ is a puzzle for molecular models of the X(3872). XEFT cannot address this problem because the photon in $X(3872)\rightarrow J/\psi\gamma$ is too energetic for XEFT to be applicable. However, the polarization of $\psi(2S)$ in $X(3872)\rightarrow \psi(2S)\gamma$ is calculable. Measurement of this polarization can be used to distinguish different mechanisms that contribute to the decay [8].

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2.11 Scattering properties of the $X(3872)$

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Both the mass (just below the $D^*\bar{D}^0$ threshold) and the likely quantum numbers ($J^{PC} = 1^{++}$) of the $X(3872)$ suggest that it is either a weakly-bound hadronic “molecule” ($X(3872) \sim 1/\sqrt{2}[D^*\bar{D}^0 + \bar{D}^*D^0]$) or a virtual state of charmed mesons (See Ref. [1] and references therein). Assuming the $X(3872)$ is a weakly-bound molecule, the scattering of neutral $D$ and $D^*$ mesons off the $X(3872)$ can be predicted from the $X(3872)$ binding energy. We calculate the phase shifts and cross section for scattering of $D^0$ and $D^{*0}$ mesons and their antiparticles off the $X(3872)$ in an effective field theory for short-range interactions [2]. The total cross section is dominated by S-wave scattering of the $X$ and the $D^{(*)0}$ mesons. For the central value $E_X = 0.26$ MeV of the $X(3872)$ binding energy, the total cross section at threshold will be of the order 800 barns for $D^0X$ scattering and 2600 barns for $D^{*0}X$ scattering. This provides another example of a three-body process, along with those in nuclear and atomic systems, that displays universal properties [3]. It may be possible to extract the scattering within the final state interactions of $B_c$ decays and/or other LHC events.

This work was done in collaboration with David Canham and Roxanne Springer. It was supported in part by the DFG through SFB/TR 16 “Subnuclear structure of matter,” the BMBF under contract No. 06BN411.

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2.12 Prominent candidates of hidden and open charm hadronic molecules

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In this talk, I discussed how can we identify hadronic molecules and then apply the methods to specific examples. For an $S$-wave loosely bound state, the binding energy, and hence the scattering length, determines the coupling constant of the bound state to its constituents completely [1, 2]. While the coupling constant can be used to calculate the decay width and the line shape of the hadronic molecule, which can be measured experimentally, the scattering length can be simulated in lattice QCD. This method was used to show that the present data support the interpretation of the vector $Y(4660)$ observed in the $\psi' \pi^+ \pi^-$ mass distribution as a $\psi' f_0(980)$ bound state [3]. We also calculated the isospin-violating decay width of the $D_s^*(2317)$ in the hadronic molecular picture [4]. As a result of the large coupling of the $D_s^*(2317)$ to the constituents $DK$, the neutral and charged meson mass differences in loops play an important role, and the resulting value of the decay width $\Gamma(D_s^*(2317) \rightarrow D_s \pi^0) = 180 \pm 110$ keV is much larger than that given in the $c\bar{s}$ and tetraquark pictures. Furthermore, we show the predicted quark mass dependence of the scattering lengths between the charmed and light mesons agree well with the lattice simulations [5]. For heavy flavor hadronic molecules, heavy quark spin symmetry gives us a new approach to test the hadronic molecule assumptions of some newly observed open and hidden charm (and also bottom in the future) resonances [6]. As an application, we predicted that there should be an $\eta_c' f_0(980)$ bound state, were the $Y(4660)$ a $\psi' f_0(980)$ bound state, with a mass of $4616^{+6}_{-5}$ MeV and the prominent decay mode $\eta_c' \pi \pi$ [6]. The width is predicted to be $\Gamma(\eta_c' \pi \pi) = 60 \pm 30$ MeV. We suggest to search it in the $B^\pm \rightarrow K^\pm \eta_c' \pi^+ \pi^-$ decays.

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2.13 Radiative and isospin-violating decays of $D_s$-mesons in the hadrogenesis conjecture

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The hadrogenesis conjecture was first formulated for the baryon spectrum in [1] and generalized to the meson spectrum in [2, 3]. In both cases the spectrum is conjectured to be the consequence of final state interactions of preselected hadronic degrees freedom with quantum numbers $J^P = 0^-, 1^-$. In this talk we focus on the spectrum and isospin-violating strong decays of charmed mesons with strangeness. In the heavy-light sector of QCD besides the chiral symmetry of the light quark there are constraints from the heavy-quark symmetry. The latter symmetry groups the pseudoscalar and vector D mesons with $J^P = 0^-$ and $1^-$ into a common multiplet. At leading order their masses are degenerate. Only after the demonstration that axialvector states are generated by chiral coupled-channel dynamics [4], the way was paved for an application of the hadrogenesis conjecture to heavy-light systems [5, 6]. A simultaneous study of scalar and axialvector states is mandatory if the heavy-quark symmetry of QCD is to be kept.

The scalar $D_{s0}^*(2317)^\pm$ and the axial vector $D_{s1}^*(2460)^\pm$ states are generated by coupled-channel dynamics based on the leading order chiral Lagrangian. The effect of chiral corrections is investigated. We show that taking into account large-$N_c$ relations implies a measurable signal for an exotic axial vector state in the $\eta D^*$ invariant mass distribution. The hadronic decay widths of the scalar $D_{s0}^*(2317)^\pm$ and the axial vector $D_{s1}^*(2460)^\pm$ are predicted to be 140 keV [6].

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2.14 Exotic Multiplets from unitarized chiral amplitudes

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Using the hidden gauge formalism for pseudoscalar and vector meson interactions [1] a study is made of the interaction of pseudoscalar mesons with or without charm, leading to scalar resonances with open and hidden charm [2]. Similarly, the interaction of vector mesons with pseudoscalars also leads to dynamically generated mesons, with open and hidden charm. The X(3872) resonance is one of those dynamically generated [3], but we obtain two resonances with different C-parity.

The interaction of vector mesons among themselves also leads to a new sort of states. Those with open charm can be identified with known resonances as the $D_s^*(2460)$ and the $D^*(2640)$ [4], the last one without experimental spin and parity assignment. In the hidden charm sector one finds several X,Y, Z resonances around 3960-4200 MeV [5].

Finally, a thorough study of the X(3872) is made taking into account $D\bar{D}^* + cc$ components neutral and charged, together with other coupled channels and paying special attention to the exact masses of the particles and the width of the $D^*$ [6], making a comparison with the two recent experiments on $J/\psi \pi\pi$ and $D^0\bar{D}^{*0} + cc$ decay from Babar and Belle.

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2.15 Is the $X(3872)$ Production Cross Section at Tevatron Compatible with a Hadron Molecule Interpretation?

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The $X(3872)$ is universally accepted to be an exotic hadron. In this letter we assume that the $X(3872)$ is a $D^0\bar{D}^{*0}$ molecule, as claimed by many authors, and attempt an estimate of its prompt production cross section at Tevatron. A comparison with CDF data allows to draw rather compelling quantitative conclusions about this statement [1]. In particular we have simulated the production of open charm mesons in high energy hadronic collisions at the Tevatron. The generated samples have been examined searching for $D$ and $D^*$ mesons being in the conditions to form, through resonant scattering, bound states with binding energy as small as $\sim 0.25$ MeV. These $X(3872)$ candidates have been required to pass the same kinematical selection cuts used in the CDF data analysis. This allows to estimate an upper bound for the theoretical prompt production cross section of $X(3872)$ at CDF. Averaging the results obtained with Pythia and Herwig we find this to be approximately 0.085 nb in the most reasonable region of center of mass relative momenta $[0, 35]$ MeV of the open charm meson pair constituting the molecule. This value has to be compared with the lower bound on the experimental cross section, namely $3.1 \pm 0.7$ nb, extracted from CDF data. The intuitive expectation that $S-$wave resonant scattering is unlikely to allow the formation of a loosely bound $D^0\bar{D}^{*0}$ molecule in high energy hadron collision is confirmed by this analysis.

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2.16 Impact of $D$ meson loops on charmonium decays

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The obvious discrepancies between BES [1] and CLEO-c [2] on the measurement of the $\psi(3770)$ non-$D\bar{D}$ decay branching ratios bring the question of dynamics for gluon hadronizations in $\psi(3770) \rightarrow \text{lighthadrons}$. Meanwhile, although NRQCD calculations for $\psi(3770) \rightarrow \text{lighthadrons}$ to next-to-leading order (NLO) indicate a non-negligible branching ratio for $\psi(3770)$ non-$D\bar{D}$ decays, it may suggest a possible failure of perturbation expansion due to large QCD corrections from NLO [3]. Since $\psi(3770)$ is close to the $D\bar{D}$ open channel, we expect that the open channel effects would be important. Thus, we propose a non-perturbative transition mechanism via intermediate $D$ meson loops for $\psi(3770) \rightarrow VP$ [4]. By identifying the leading meson loop transitions and constraining the model parameters with the available experimental data for $\psi(3770) \rightarrow J/\psi\eta, \phi\eta$ and $\rho\pi$, we succeed in making a quantitative prediction for all $\psi(3770) \rightarrow VP$ with $BR_{VP}$ from 0.41% to 0.64%. It indicates that the OZI-rule-evading long-range interactions are playing a role in $\psi(3770)$ strong decays, and could be a key towards a full understanding of the mysterious $\psi(3770)$ non-$D\bar{D}$ decay mechanism.

Such a mechanism may be useful for our understanding of the long-standing “$\rho\pi$ puzzle” since $\psi'$ is also close to the open $D\bar{D}$ threshold. Based on a systematic investigation of $J/\psi(\psi') \rightarrow VP$ [5, 6], we identify the role played by the short-range $c\bar{c}$ annihilation, electromagnetic (EM) transition and intermediate meson loop transitions, which are essential ingredients for understanding the $J/\psi$ and $\psi'$ couplings to $VP$. We show that on the one hand, the EM transitions have relatively larger interferences in $\psi' \rightarrow \rho\pi$ and $K^*\bar{K} + \text{c.c.}$ as explicitly shown by vector meson dominance (VMD). On the other hand, the strong decay of $\psi'$ receives relatively larger destructive interferences from the intermediate meson loop transitions. By clarifying these mechanisms in an overall study of $J/\psi(\psi') \rightarrow VP$, we provide a coherent prescription of the “$\rho\pi$ puzzle”.

In brief, we present a coherent study of charmonium decays of $J/\psi$, $\psi'$ and $\psi(3770) \rightarrow VP$. It shows that the open channel effects could be a key for understanding some of those long-standing questions in charmonium decays. Further theoretical studies of charmonium radiative decays [7], and isospin-violating transitions, such as $\psi' \rightarrow J/\psi\pi^0$ [8] and $\psi' \rightarrow h_c\pi^0$, would be useful for providing further evidence for such a mechanism. Experimental data from BESIII in the near future would be very helpful for justifying this idea.

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2.17 Interplay of Quark and Meson Degrees of Freedom

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A method to identify hadronic molecules is discussed, based on model–independent analysis of $S$–wave low–energy hadronic observables, suggested in [1], [2], and generalized in [3] and [4]. The formalism is applied if the momenta involved are much smaller than the inverse range of force. In this case the parameters entering Flattè formula for the scattering amplitude contain information on the nature of the near–threshold resonance. In particular, it is shown that Weinberg–Flattè analysis of production differential rates provides a direct measure for the admixture of a bare $q\bar{q}$ state in the resonance wavefunction.

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The first charmonium state $J/\psi(1S)$, the bound system consisting of the charmed quark $c$ and anti-quark $\bar{c}$, was discovered in 1974. Nine more charmonium states, the $\eta_c(1S)$, $\chi_c(1P)$, $\psi(2S)$, $\psi(3770)$, $\psi(4040)$, $\psi(4160)$ and $\psi(4415)$ were observed shortly afterwards. Some of them, the so called $\psi$ resonances have masses above open charm threshold. During the next two decades no other charmonium states were found. A new charmonium era started in 2002. During the past six years numerous charmoniumlike states were discovered. Among them, only the $h_c(1P)$, $\eta_c(2S)$ and $Z(3930) \equiv \chi_c(2P)$ have been identified as candidates for conventional charmonium, while a number of other states with masses above open charm threshold have serious problems with a charmonium interpretation. In particular the nature of the whole family of charmonium-like states, found in $e^+e^- \rightarrow \pi^+\pi^-J/\psi(2S)\gamma_{ISR}$ processes, with quantum numbers $J^{PC} = 1^{--}$ remains unclear. Among them are the $Y(4260)$ state observed by BaBar [1, 2], confirmed by CLEO [3, 4] and Belle [5]; the $Y(4350)$ discovered by BaBar [6] and confirmed by Belle [7]; two structures, the $Y(4008)$ and the $Y(4660)$ seen by Belle [5, 7].

The observation of the $Y$ family motivated numerous measurements of exclusive $e^+e^-$ cross sections for charmed hadron final states near threshold. Most of them were performed at $B$-factories using initial-state radiation. Belle presented the first results on the $e^+e^-$ cross sections to the $D\bar{D}$, $D^+D^-, D^{*-}\bar{D}$, $D^0\bar{D}^\ast\pi^+$ (including the first observation of $\psi(4415) \rightarrow D\bar{D}^{\ast}(2460)$ decays) [8, 9, 10] and $\Lambda_c^+\Lambda_c^-$ final states [11]. BaBar measured $e^+e^-$ cross sections to $D\bar{D}$ and recently to the $D\bar{D}^\ast$, $D^+\bar{D}^\ast$ final states [12, 13]. CLEO-c performed a scan over the energy range from 3.97 to 4.26 GeV and measured exclusive cross sections for the $D\bar{D}$, $D\bar{D}^\ast$, and $D^+\bar{D}^\ast$ final states at thirteen points with high accuracy [14]. The measured open charm final states nearly saturate the total cross section for charm hadron production in $e^+e^-$ annihilation in the $\sqrt{s}$ region up to $\sim 4.3$ GeV.

No clear evidence for open charm production associated with any of $Y$ states has been observed. In fact the $Y(4260)$ peak position appears to be close to a local minimum of both the total hadronic cross section [15] and of the exclusive cross section for $e^+e^- \rightarrow D^\ast\bar{D}^\ast$ [9, 13]. The $X(4630)$, recently found in the $e^+e^- \rightarrow \Lambda_c^+\Lambda_c^-$ cross section as a near-threshold enhancement [11], has a mass and width (assuming the $X(4630)$ to be a resonance) consistent within errors with those of the $Y(4660)$. However, this coincidence does not exclude other interpretations of the $X(4630)$, for example, as the conventional charmonium state [16, 17] or as a baryon-antibaryon threshold effect [18].

The absence of open charm decay channels for $Y$ states, large partial widths for decay channels to charmonium plus light hadrons and the lack of available $J^{PC} = 1^{--}$ charmonium levels are inconsistent with the interpretation of the $Y$ states as conventional charmonia. To explain the observed peaks, some models assign the $3^3D_1(4350)$, $5^3S_1(4660)$ with shifted masses [17], other explore coupled-channel effects and rescattering of charm mesons [19].
More exotic suggestions include hadro-charmonium [20]; multiquark states, such as a $[cq][ar{c}q]$ tetraquark [21] and $D\bar{D}_1$ or $D_0\bar{D}_0$ molecules [22]. One of the most popular exotic options for the $Y$ states are the hybrids expected by LQCD in the mass range from 4.2 − 5.0 GeV [23]. In this context, some authors expect the dominant decay channels of the $Y(4260)$ to be $Y(4260) \to D^*(\rightarrow D\pi)\pi$.

Recently Belle reported the first measurement of the $e^+e^- \to D^0D^{*-}\pi^+$ exclusive cross section at threshold [24]. The values of the amplitude of the $Y(4260)$, $Y(4350)$, $Y(4660)$ and $X(4630)$ signal function obtained in the fit to the $M_{D^0D^{*-}\pi^+}$ spectrum are found to be consistent with zero within errors. Belle found no evidence for $Y(4260) \to D^0D^{*-}\pi^+$ decays as predicted by hybrid models and obtained the upper limit on $Br(Y(4260) \to D^0D^{*-}\pi^+)/Br(Y(4260) \to \pi^+\pi^-J/\psi) < 9$ at the 90% C.L.

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Double charmonium production in $e^+e^-$, new states and unexpectedly large cross sections

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Prompt charmonium production in $e^+e^-$ annihilation is important for studying the interplay between perturbative QCD and non-perturbative effects. The production rate and kinematic characteristics of $J/\psi$ mesons in $e^+e^-$ annihilation are poorly described by theory, and even the production mechanisms are not well understood. An effective field theory, non-relativistic QCD (NRQCD), based on leading order perturbative QCD calculations, predicted that prompt $J/\psi$ production at $\sqrt{s} \approx 10.6$ GeV is dominated by $e^+e^- \rightarrow J/\psi gg$ with a 1 pb cross section [1]; the $e^+e^- \rightarrow J/\psi g$ contribution may be of the same order, is uncertain due to poorly-constrained color-octet matrix elements [2]. The $e^+e^- \rightarrow J/\psi c\bar{c}$ cross section is predicted to be $\sim 0.05 - 0.1$ pb [3].

By contrast, in 2002 Belle observed the ratio of the $J/\psi c\bar{c}$ and inclusive $J/\psi$ production cross sections to be $0.59^{+0.15}_{-0.13} \pm 0.12$ [4], and thus found $\sigma(e^+e^- \rightarrow J/\psi c\bar{c}) \gtrsim \sigma(e^+e^- \rightarrow J/\psi gg)$. In 2009, using an order of magnitude larger data sample Belle measured the cross sections for the processes $e^+e^- \rightarrow J/\psi c\bar{c}$ and $J/\psi X_{\text{non-}}c\bar{c}$ in a model independent way [5]. The measured cross sections are $(0.74 \pm 0.08^{+0.09}_{-0.08})$ pb and $(0.43 \pm 0.09 \pm 0.09)$ pb, respectively, thus the last measurements confirmed that $e^+e^- \rightarrow J/\psi c\bar{c}$ is the dominant mechanism for $J/\psi$ production in $e^+e^-$ annihilation, contrary to earlier NRQCD predictions. Recently, both $e^+e^- \rightarrow J/\psi gg$ and $J/\psi c\bar{c}$ cross sections have been recalculated including NLO corrections and are in better agreement with the experimental data [6, 7]. However, the measured $e^+e^- \rightarrow J/\psi c\bar{c}$ cross section exceeds the perturbative QCD prediction $\sigma(e^+e^- \rightarrow c\bar{c}c\bar{c}) \approx 0.3$ pb [8], which includes the case of fragmentation into four charmed hadrons, rather than $J/\psi c\bar{c}$.

The $e^+e^- \rightarrow J/\psi c\bar{c}$ process is dominated by $c\bar{c}$ fragmentation to open charm, with a $(16 \pm 3\%)$ contribution from double charmonium production, i.e. production of a second charmonium below the open charm threshold in the event with $J/\psi$. The large rate for processes of the type $e^+e^- \rightarrow J/\psi \eta_c$ reported by Belle ($\sigma(e^+e^- \rightarrow J/\psi \eta_c) = (25.6 \pm 2.8 \pm 3.4)$ fb) [4, 9], also remained a puzzle for many years. The first NRQCD calculations [10] gave at least an order of magnitude smaller value ($\sim 2$ fb) than those measured by Belle. The importance of relativistic corrections was realized in Ref. [11, 12]: the authors, using light cone approximation to take into account the relative momentum of heavy quarks in the charmonium, managed to calculate the cross section which is close to the experimental value. Alternatively, authors of Ref. [13] suggested to resolve the discrepancy within the NRQCD approach by the resummation of relativistic corrections, contribution from pure QED diagram, the corrections of next-to-leading order in $\alpha_s$.

Double charmonium production in $e^+e^-$ annihilation can be used to search for new charmonium states with charge conjugation $C = +1$, recoiling against known and easily reconstructed $C = -1$ charmonium mesons such as the $J/\psi$ or $\psi'$. Studies of various double charmonium final states have demonstrated that scalar and pseudoscalar charmonia are produced
copiously recoiling against a $J/\psi$ or $\psi'$ and there is no significant suppression of the production of radially excited states. In 2008, Belle observed the processes $e^+e^- \rightarrow J/\psi D\bar{D}$ ($D^{*}\bar{D}$, $D^{*}\bar{D}^s$) and reported the observation of the clear enhancement with a significance of $5.1\sigma$ in the invariant mass distribution of $D^{*}\bar{D}^s$ combinations in the process $e^+e^- \rightarrow J/\psi D^{*}\bar{D}^s$, which was interpreted as a new charmonium-like state, the $X(4160)$ [14]. The $X(4160)$ parameters are $M = (4156^{+25}_{-20} \pm 15)~\text{MeV}/c^2$ and $\Gamma = (139^{+111}_{-61} \pm 21)~\text{MeV}$. Belle also confirmed the observation of the charmonium-like state, $X(3940)$, produced in the process $e^+e^- \rightarrow J/\psi X(3940)$ with a significance of $5.7\sigma$. The $X(3940)$ mass and width are $M = (3942^{+7}_{-6} \pm 6)~\text{MeV}/c^2$ and $\Gamma = (37^{+26}_{-15} \pm 8)~\text{MeV}$, consistent with the first Belle result [15].

If the $X(3940)$ has $J = 0$ the absence of a $D\bar{D}$ decay mode strongly favors $J^P = 0^{-+}$, for which the most likely charmonium assignment is the $\eta_c''$. The fact that the lower mass $\eta_c$ and $\eta'_c$ are also produced in double charm production supports this assignment. However, there is a problem that the measured mass of the $X(3940)$ is below potential model estimates of $\sim 4050~\text{MeV}/c^2$ or higher [16]. A further complication is the observation by Belle of $X(4160)$, which could also be attributed to the $3^1S_0$ state, using similar arguments. But the $X(4160)$ mass is well above expectations for the $3^1S_0$ and well below those for the $4^1S_0$, which is predicted to be near 4400 MeV/$c^2$ [16]. Although either the $X(3940)$ or the $X(4160)$ might conceivably fit a charmonium assignment, it seems very unlikely that both of them could be accommodated as $c\bar{c}$ states.

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The initial state radiation technique (ISR) allows to exploit flavor factories as usual $e^+e^-$ experiments with energy scan in the center of mass. A generic hadronic state $X_{\text{had}}$, with mass lower than the fixed energy of the machine, can be studied through the process $e^+e^- \rightarrow X_{\text{had}}\gamma_{IS}$, where the photon $\gamma_{IS}$ is emitted by one of the initial leptons. In Born approximation $X_{\text{had}}$ has quantum numbers $J^{PC} = 1^{--}$. Using the ISR technique BABAR discovered the first element of the charmonium-like $Y$ family, i.e. the $Y(4260)$ [1] in the channel $e^+e^- \rightarrow J/\psi\pi^+\pi^-\gamma_{IS}$. This observation was confirmed by Belle [2], in the same $J/\psi\pi^+\pi^-$ dominant decay channel, and by CLEO [3], not only in $J/\psi\pi^+\pi^-$ but also in $J/\psi2\pi^0$ and $J/\psi K^+K^-$. Looking for the $Y(4260)$ Belle identified also another structure with lower mass in the same $J/\psi\pi^+\pi^-$ channel, this additional state has been called $Y(4008)$ [2]. In 2007 BABAR observed another $Y$ state in the channel $\Psi(2S)\pi^+\pi^-$ with $\Psi(2S) \rightarrow J/\psi\pi^+\pi^-$. This structure, called $Y(4325/4360)$ [4], emerged very close to the $\Psi(2S)\pi^+\pi^-$ threshold, has been confirmed by Belle, in the same channel, but with a slightly different mass [5]. In the same investigation, thanks to a larger data sample, Belle discovered also another resonance decaying in $\Psi(2S)\pi^+\pi^-$, the $Y(4660)$ [5].

The simplest interpretation of these resonances as the still missing states in the charmonium spectrum of the time-honored quark model [6] has been largely disfavored by their non-observation [7] in the charmonia dominant decay channels, i.e. decays in charmed hadrons. Nevertheless, the $e^+e^- \rightarrow \Lambda_c^+\Lambda_c^-$ cross section, recently measured by Belle [8], shows a clear near-threshold enhancement that has been identified as a further $J^{PC} = 1^{--}$ resonance, the $X(4630)$, which is compatible with the $Y(4660)$.

To summarize, two main classes of $Y$ resonances have been identified: the lightest $Y(4008)$ and $Y(4260)$, which decay in $J/\psi\pi\pi$, and the heaviest $Y(4325/4360)$ and $Y(4660)$ decaying only in $\Psi(2S)\pi\pi$. No signals for those structures have been found in open charm final states. The $X(4630)$ seems to escape this classification.

The possible interpretation, besides the disproved charmonium states, is based on three main ideas: hybrid charmonia [9], molecules and hadro-charmonia [10], and threshold effects [11]. The relatively small widths contrast the tetraquark hypothesis. However, all the attempted interpretations have the negative feature to consider only one $Y$ state individually. It is, indeed, manifest that all these $J^{PC} = 1^{--}$ states show incredibly similar properties: they share the same decay channels, they have similar total widths, as well as similar $\Psi(1S,2S)\pi\pi$ branching fractions. It follows that a more comprehensive description is needed. An attempt in this direction has been made in Ref. [12], where it is shown how the spectrum of higher charmonium, obtained using a screened $c\bar{c}$-potential, describe quite well all the new $Y$ states.
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2.21 Perspectives for spectroscopy at super-B factories

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The B-factories observed a number of charmonium-like states which do not easily fit into the conventional charmonium picture [1]. The present knowledge of the properties of these states is generally based on small samples of events.

The large samples that would be collected at either of the proposed super-B factories [2], [3], [4] would allow to understand the nature of these states, discriminating among the many different proposed interpretations.

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3 Short summary of the posters

3.1 Franck-Condon principle for Heavy Quarkonium Decays and Heavy Quark Effective Theory

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In [1] we have proposed to adapt the Franck-Condon principle of molecular physics to ascertain the nature of Heavy Quarkonium above open flavor threshold in terms of its heavy quark constituents. Our current formulation presented at Charm-ex applies to Heavy Quarkonium decaying to heavy mesons carrying one heavy quark each plus any number of pions or perhaps other light degrees of freedom. The principle states that "The velocity distribution of heavy mesons carrying one heavy quark each following heavy quarkonium decay, coincides with the velocity distribution of those heavy quarks inside the heavy quarkonium". Once such velocity distributions have been measured experimentally, they can provide invaluable insight into the structure of excited heavy quarkonium, whether to study valence or sea degrees of freedom. We have discussed possible applications with conference attendees. This principle we now understand to be a consequence of essentially all heavy quark effective theories proposed [2] to date, such as NRQCD or HQQET. Their Lagrangian densities describe the motion of heavy quarks whose velocity is not changed by QCD interactions in leading order of $\Lambda_{QCD}/M_Q$. We are trying to develop a way to estimate corrections at first order (work in progress in collaboration with Juan Torres Rincón and Ignazio Scimemi).

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3.2 Mixing of S-wave charmonia with $D\bar{D}$ molecule states

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One possible decay channel of charmonia is into $D\bar{D}$ molecule states by creation of a light quark-/antiquark pair. The investigation of such decays sheds light on the higher fock state contributions to the charmonia wavefunction \cite{1} and potential mass shifts. A variational approach is applied to a mixing matrix containig both charmonia and $D\bar{D}$ molecule interpolating fields. The calculation of several diagramms appearing in this matrix requires all-to-all propagators, which are realised by sophisticated stochastic estimator techniques \cite{2}. The runs are performed on $N_f = 2 \times 24^3 \times 48$ with $M_\pi \approx 380$ MeV configurations using the non-perturbatively improved Clover-Wilson action, both for valence and sea quarks.

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3.3 Spectra of low and high spin mesons with light quarks from lattice QCD

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We present results for excited meson spectra from $N_f = 2$ clover-Wilson configurations provided by the CP-PACS Collaboration. In our study we investigate both low and high spin mesons.

For spin-0 and spin-1 mesons, we are especially interested in the excited states. To access these states we construct several different interpolators from quark sources of different spatial smarings including ones which resemble p-waves and then calculate a matrix of correlators. We then apply the variational method [1] and solve a generalized eigenvalue problem for this matrix. For spin-2 and spin-3, we extract only the lowest lying states using interpolators which have been successful in spectroscopy calculations of charmonia [2]. We are able to successfully isolate excited states in the pseudoscalar and vector channel and obtain a number of high spin mesons up to $J = 3$.

First results have been published in Refs. [3]. Our final results can be found in Ref. [4].

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3.4 Charmonium Hybrids at PANDA

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A $c\bar{c}$-pair bound by an excited gluonic flux tube is called a charmonium hybrid. The spin contribution of the flux tube can lead to spin-exotic states, of which the $1^{-+}$-state (labelled $\tilde{\eta}_{c1}$ in this work) is commonly expected to be the lightest with a mass between 4.1 and 4.4 GeV/c$^2$ [1],[2],[3]. Open and hidden charm decays are predicted such as $\tilde{\eta}_{c1} \to \chi_{c1}\pi^0\pi^0$ and $\tilde{\eta}_{c1} \to D\bar{D}^*$. Hybrid states are believed to appear in gluon-rich processes as seen in $p\bar{p}$ annihilations. One of the focuses of the PANDA experiment, which is going to be built at the antiproton storage ring (HESR) in course of the FAIR project at the GSI in Darmstadt, Germany, will be the search for gluonic excited charmonium states.

To demonstrate the sensibility of the PANDA experiment on detection of these states, Monte Carlo studies have been performed for $p\bar{p} \to \tilde{\eta}_{c1}\eta$ production at the highest available energy $\sqrt{s} = 5.47$ GeV [4]. Final states with a high photon multiplicity need to be reconstructed, wherefore an outstanding electromagnetic calorimeter is needed. In addition, a good identification of electrons, pions and kaons is mandatory.

Possible background channels are events with a similar signature as the signal reactions (such as $J/\psi\pi^0\pi^0\pi^0\eta$ or $D^0\bar{D}^{*0}\pi^-\pi^0$). Considering these reactions, a signal-to-background ratio of better than 200 ($p\bar{p} \to \tilde{\eta}_{c1}\eta \to \chi_{c1}\pi^0\pi^0$) and better than 4000 ($p\bar{p} \to \tilde{\eta}_{c1}\eta \to D\bar{D}^*$) can be achieved. Assuming a cross section of 30 pb (calculated from the reverse reaction $\Psi(2S) \to \eta p\bar{p}$ for conventional charmonium [5]), the number of reconstructed events per month are $N = B(\tilde{\eta}_{c1} \to \chi_{c1}\pi^0\pi^0) \times 5$ and $N = B(\tilde{\eta}_{c1} \to D\bar{D}^*) \times 2$.

Thus, to detect the investigated reactions having low cross sections, the PANDA experiment in conjunction with the high luminosity of HESR is well suited.

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3.5 The BES III Tau-Charm Factory

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The BES III experiment [1] at the symmetric electron positron storage ring BEPC II (Beijing) running in the energy range $\sqrt{s} = 2\ldots4.4$ GeV has started its operation in summer 2008. The high luminosity of the machine in conjunction with the good tracking, particle identification and calorimetry of the detector offers excellent opportunities for light and charmed hadron spectroscopy, the study of charmonium transitions, $D\bar{D}$ mixing, $CP$-violation in $D$ meson decays, $\tau$ physics and other topics. During the first run periods in March-April and June-July 2009 data samples corresponding to more than $1 \cdot 10^8 \psi(2S)$ and $2 \cdot 10^8 J/\psi$ events, respectively, have been recorded.

Preliminary results on fully reconstructed $\psi(2S) \to \chi_{cJ}\gamma$ decays, with $\chi_{cJ}$ decaying into $\pi^+\pi^-\pi^+\pi^-$, $K^+K^-K^+K^-$, and $\pi^+\pi^-p\bar{p}$ have been presented. Clean $\chi_{cJ}$ signals for all three hadronic final states are observed, demonstrating the capabilities of the detector. Also an inclusive study of $\psi(2S) \to h_c\pi^0$, $h_c \to \gamma\eta_c$ decays has been performed. Events are tagged by the radiative photon. The $h_c$ is identified in the recoil spectrum of the reconstructed $\pi^0$, confirming the observation of the $h_c$ recently reported by the CLEO collaboration [2, 3].

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3.6 The PANDA Electromagnetic Calorimeter

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Antiproton-proton annihilations in the high energy antiproton storage ring (HESR) of the future FAIR facility in Darmstadt will allow sensitive tests of quantum chromo dynamics. The PANDA detector aims at precision studies of charm-quark mesons, glue balls and hybrid mesons. One of the crucial detector components for those studies is the electromagnetic calorimeter [1]. Its overall concept is presented in the Technical Design Report for the PANDA EMC [2]. The PANDA calorimeter consists of about 15000 lead tungstate crystals in a barrel part, one forward and one backward endcap covering - in combination with a forward spectrometer - 99% of the whole solid angle. The scintillator material is radiation hard, allows a compact design, a high rate capability, a low energy threshold of 10 MeV, and an energy range up to 15 GeV. The energy resolution of the calorimeter is expected to be

\[ \frac{\sigma_E}{E} \leq 1\% + \frac{2\%}{\sqrt{E/\text{GeV}}} \]

In order to raise the light yield of the scintillator material the operation temperature of the calorimeter will be -25°C. The result is a factor of four more light compared to an operation at room temperature. Unfortunately the temperature dependence of the light yield at -25°C increases to \( dLY/dT = 3\% \). Therefore temperature stability is essential for a high energy resolution. A sophisticated high insulating airtight casing is needed to keep the temperature stable and to prevent icing on the crystals. The thermal requirements are a temperature variation of less than 0.1°C and a temperature inhomogeneity along a crystal of less than 0.1°C per centimeter.

The monitoring of temperature and humidity inside the calorimeter is done by 'Temperature and Humidity monitoring boards for PANDA' (THMPs), designed for the readout of 64 channels each and rated for radiation doses up to 700 Gy at an operating range of -30°C to +30°C. PT 100 platinum temperature sensors with a thickness of only 60 \( \mu \text{m} \), fitting in the space between adjacent crystals, have been developed. The achievable precision of the temperature monitoring is 0.05°C.

There is a 192 crystal calorimeter endcap prototype under construction that will allow tests of the components and its composition under PANDA operating conditions.

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