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Exotic Effects at the Charm Threshold and Other Novel Physics Topics at JLab-12 GeV

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I briefly survey a number of novel hadron physics topics which can be investigated with the 12 GeV upgrade at J-Lab. The topics include new the formation of exotic heavy quark resonances accessible above the charm threshold, intrinsic charm and strangeness phenomena, the exclusive Sivers effect, hidden-color Fock states of nuclei, local two-photon interactions in deeply virtual Compton scattering, and non-universal antishadowing.

I. CHARM PHYSICS AT THRESHOLD

Hadrons can interact strongly when their relative velocity β is small and the time for their interactions is maximal. This phenomena has been observed at the thresholds for baryon-pair production in $e^+e^- \to p\bar{p}$, and $e^+e^- \to \Lambda\bar{\Lambda}$ reactions. The baryon pair cross sections remain finite at $\beta \to 0$, even though the phase space vanishes. One also observes enhancements at $\beta_{p\bar{p}} = 0$ in the decay $J/\psi \to p\bar{p}\gamma$[1]. Baryon-pair production at threshold in e^+e^- annihilation may reflect the formation of $J^{PC} = 1^{--}$ resonances just below threshold. For example, six-quark $qqq\bar{q}\bar{q}\bar{q}$ resonances could decay to six pions or other hadronic states.

In the case of QED, the cross section for $e^+e^- \to \mu^+\mu^-$ is enhanced by the Schwinger-Sommerfeld-Sakharov Coulombic interactions, matching the infinite series of nS-state Bohr bound states of "true muonium" just below threshold [2]. True muonium may be produced and observed at the the JLab Heavy Photon Search (HPS) experiment [3].

Analogous bound states at small relative velocity are expected in QCD from gluonic interactions, including the formation of "nuclear-bound quarkonium" states $[J/\psi A]$ due to the QCD van der Waals potential. [4–6] Furthermore, if hadrons share the same valence (or even sea quarks), resonances can be formed from their attractive QCD covalent interactions in analogy to covalent molecular forces. In each case, the strength of the hadronic interactions can overcome the phase-space suppression at zero relative velocity.

A dramatic example of enhanced dynamics near the heavy-quark thresholds is the large 4:1 transverse-transverse spin correlation A_{NN} observed in large-angle elastic proton-proton scattering [7] at $\sqrt{s} \simeq 3$ GeV and $\sqrt{s} \simeq 5$ GeV. These energies correspond to the strange and charm thresholds in the two-baryon system. In fact, the observed strong spin correlations are consistent with the formation of $J = L = S = 1$ $uuds\bar{s}uud$ and $uudc\bar{c}uud$ "octoquark" resonances near the heavy quark pair thresholds. [8]

The enhancement of hadronic interactions at threshold implies that new types of charm-based resonances may be formed and studied in electroproduction at JLab using the upcoming $E_e = 12$ GeV electron beam, This includes possible $J/\psi-$ nucleon resonances at threshold in reactions such as $\gamma^*p \to [J/\psi p], \gamma^*p \to [J/\psi p]\gamma, \gamma^*p \to [J/\psi n]\pi^+$. See. fig. 1 If one uses a deuteron target, one can observe novel resonances in $\gamma^*d \to [J/\psi d]$, as well as $\gamma^*d \to \bar{D}^0 + [\Lambda_c n], \gamma^*d \to \Lambda_c + [\bar{D}^0 n]$ reactions. Such resonances can be formed from the covalent bonds of the shared u quark. In each such case, resonance formation implies strong spin correlations.

II. OTHER NOVEL PHYSICS TOPICS AT JLAB 12 GEV

1. **Intrinsic heavy strange and charm distributions at large x.**

   As shown by Chang and Peng [9], the HERMES electroproduction data [10] for the strange quark distribution in the proton exhibits two components, a contribution at small $x_{Bj} < 0.1$ – consistent with $g \to s\bar{s}$ gluon splitting as incorporated into DGLAP evolution – and an approximately flat component at $0.1 < x < 0.5$ which is consistent with a five-quark Fock state $|uud\bar{s}s>$ intrinsic to the proton eigenstate. These strange quarks arise from diagrams which are multi-connected to the valence quarks, and thus are *intrinsic* to the proton itself. In fact, the broad intrinsic strangeness contribution at large x is consistent with the EMC data [12] for intrinsic charm and the BPHS model [11] at large x when scaled as M_s^2/M_c^2 as predicted by the operator product expansion [13, 14] for non-Abelian theory.

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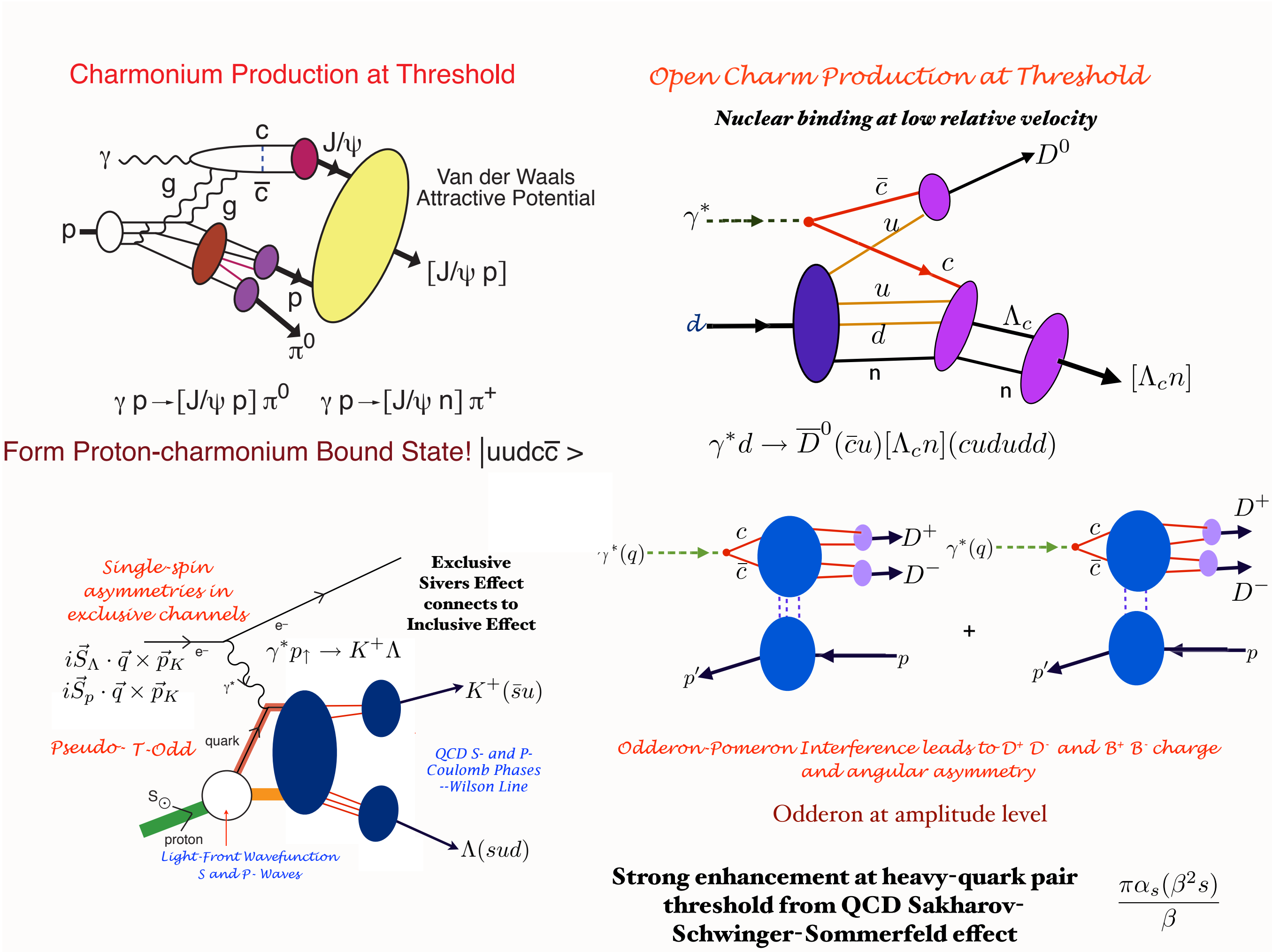

FIG. 1: Examples of novel QCD phenomenology measureable at JLAB-12 GeV

The intrinsic heavy quark distributions can be quark/antiquark asymmetric [15]; e.g. $s(x) \neq \bar{s}(x)$ as well as have novel spin properties. For a recent review of intrinsic heavy quark phenomenology, see ref. [16]

As discussed in ref. [17], the cross section for charm production measured in photoproduction at CESR [18] at the charm threshold is larger than expected from phase space suppression. The production of heavy quark states at threshold requires that the valence quarks can efficiently transfer their four-momentum to the heavy quark production process. This is possible since the five-quark intrinsic charm Fock state $|uudc\bar{c}>$ in the proton has maximum probability at minimum off-shellness; i.e., when all of the quarks have the same rapidity.

2. **The exclusive and inclusive Sivers effect: breakdown of pQCD leading-twist factorization** The Sivers pseudo-T-odd correlation of the target hadron's spin with the virtual photon to jet plane arises from rescattering of the struck quark; i.e. a final-state lensing effect [19]. The Sivers effect satisfies Bjorken scaling and is leading twist, but it does not have the normal factorization properties of pQCD. One can also study such lensing effects at JLab 12 GeV in *exclusive* electroproduction channels such as $\gamma^* p^\updownarrow \to K^+\Lambda$.

3. **Non-universal antishadowing.** There is evidence that the nuclear dependence of structure functions measured in charged-current deep inelastic neutrino-nucleus scattering is different than in deep inelastic lepton-nucleus scattering [20]. Experiments at JLab 12 GeV can investigate flavor-tagged electroproduction to see whether shadowing and antishadowing are quark specific. A model of non-universal antishadowing is discussed in ref. [21].

4. **Hidden color of nuclear wavefunctions.** The deuteron six-quark $|uudddu>$ Fock state has five different color-singlet configurations. The *hidden color* [22] Fock states which are not identified with the *np* configuration

are activated when the six quarks have small transverse separation. Hidden-color QCD phenomena can be investigated at JLab 12 GeV in high Q^2 elastic, transition and inelastic deuteron form factors.

5. $J = 0$ **fixed pole and local two photon couplings to quarks** Local two-photon four -point interactions with the quarks is a fundamental prediction of QCD. In the case of scalar charged fields, these are the familiar "seagull" $e_q^2 \vec{A}^2 \phi^\dagger \phi$ interactions required by electromagnetic gauge invariance. A similar four-point $q\gamma\gamma\bar{q}$ interaction arises for spin-1/2 quarks when one eliminates the dependent fermion fields using light-front quantization.

   Thomson scattering on electrons in atomic physics arises from the high energy Compton scattering on the atomic electrons. The analogous local four-point $\gamma q \to \gamma q$ interaction on quarks can be investigated at JLab 12 GeV by identifying a contribution to the virtual Compton scattering amplitude $\gamma^* p \to \gamma p$ which is energy- and q^2-independent at fixed t [23, 24]. This fundamental local two-photon amplitude measures the square of quark charges, illuminates their $\frac{1}{x}$ moment, and eliminates $D-$term ambiguities in deeply virtual Compton scattering [25]. This local interaction could also be relevant to the muonic hydrogen Lamb Shift anomaly [26].

6. **Odderon phenomenology.** The existence of Odderon exchange, the $C = -$ three-gluon exchange analog of the Pomeron, is predicted to exist in QCD, but it has never been observed. The interference of two-gluon and three-gluon exchange will lead to charm meson $D^\pm$ asymmetries in $\gamma^* p \to D^+ D^- p$ reactions [27] which may be testable at JLab-12 GeV.

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