# Photonic and Diffractive Processes in QCD

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The prospect of proton-proton and ion-ion collisions at the LHC collider has led to a new focus on diffractive collisions where one or both of the projectiles remain intact. In this talk I emphasize a number of novel physics features of photon-photon and photon-pomeron collisions which are accessible in diffractive and ultra-peripheral reactions.

1. The equivalent photon distribution [1] of a nucleus in light-cone fraction $x$ and $k_\perp$ is most easily derived using frame-independent light-front methods. Nuclear coherence is maintained for $x < (M_A R_A)^{-1}$, leading to a remarkably large kinematic range for particle production from photon-photon and photon-pomeron interactions up to hundreds of GeV for heavy ion collisions at the LHC. Coulomb corrections as expressed by the Schwinger-Sommerfeld interaction [2] with large nuclear charge give large distortions of the trajectories of the charged particles, particularly when relative velocities are small. The Coulomb corrections also produce interesting charge asymmetries in ultra-peripheral lepton-pair production [3]. Hadron production in diffractive interactions can involve both photon and multi-gluon/pomeron exchange, giving amplitudes with different charge conjugation which can interfere and thus also produce charge asymmetries.

2. The elastic Coulomb scattering of heavy ions is modified by quantum corrections associated with vacuum polarization and light-by-light scattering, giving $\mathcal{O}(\alpha)$ corrections to the effective Lippmann-Schwinger kernel when $Z\alpha = \mathcal{O}(1)$.

3. Diffractive deep inelastic scattering $\ell p \to \ell p + X$ arises in QCD at leading twist from the final-state interactions of the struck quark [4]. This in turn leads to nuclear shadowing and corrections to the observed structure functions of hadrons and nuclei at leading twist which are not in the wavefunction of the target hadron computed in isolation [5]. Such final-state interactions also give single-spin asymmetries in single-inclusive DIS which measure the orbital angular momentum of quarks and gluons in the target hadron [6, 7]. In the case of the Drell-Yan reaction, one gets analogous leading-twist effects from initial-state interactions, but with a sign reversal of the single-spin asymmetry [8, 9]. When one allows for both the quark and antiquark to interact in the initial state, one gets a leading-twist contribution to the $\cos 2\phi$ distribution of the lepton pair which violates the Lam-Tung relation of PQCD [10, 11]. An important lesson is that one must include - even at leading twist - the interactions of the active quarks with the spectator quarks due to the "dangling gluons" associated with the Wilson line. The same effects arise from other Feynman diagrams in the case of light-cone gauge [4].

4. Diffractive dijet production, such as $\pi A \to \mathrm{JetJet} + A$ as measured in the E791 experiment at Fermilab [12] not only tests QCD color transparency [13], a fundamental property of color gauge theory, but they also measure the frame-independent light-front wavefunction of the projectile [14] . Such measurements can be used to determine the proton LFWF by measuring $ep \to e\mathrm{JetJetJet}$ at HERA or diffractive tri-jet production $pA \to \mathrm{JetJetJet} + A$ in proton-ion collisions. The hadronic input, the non-perturbative LFWFs of hadrons can be predicted using AdS/CFT [15] . Diffractive $dA$ reactions can also provide a new test of "hidden color" in the deuteron wavefunction [16]. Hard exclusive processes, such as $\gamma\gamma \to H\bar{H}$ at large $s$ and $-t$, and diffractive photoproduction $\gamma p \to V^0 p$ are also sensitive to the shape of the hadron light-front wavefunction or distribution amplitude of the produced mesons [17].

5. The existence of intrinsic charm and bottom Fock states [18] in the proton $|uudQ\bar{Q}>$ with probability $1/M_Q^2$ [19] leads to doubly diffractive processes such as $pp \to \Upsilon + p + p$ and $pp \to H + p + p$ [20], where a heavy quarkonium state such as an $\Upsilon$ or the neutral Higgs couples to both members of the intrinsic heavy quark pair and thus can attain a longitudinal momentum fraction $x_F$ as large as 0.8. The fact that the intrinsic heavy quark Fock states have a large color-octet dipole moment, such as $|(uud)_{8C}(c\bar{c})_{8C}>$ requires that the gluon exchange producing the color-singlet quarkonium occurs at the nuclear surface,

thus explaining the remarkable $A^{2/3}$ behavior of $pA \to J/\psi X$ cross section observed at high $x_F$ [21]. Double intrinsic charm Fock states [22] lead to double $J/\psi$ production as observed by NA3 [23] and the doubly charmed baryons observed by SELEX [24] at large $x_F$.

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