Summary of doctoral activities

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March 10th, 2009

Nucleons at large x

My aim is to apply perturbative Quantum Chromo-Dynamics (pQCD) to the study of the polarized and unpolarized nucleon structure in terms of quark and gluons degrees of freedom. The main focus is the region of large parton fractional momentum x, where the parton distribution functions (PDFs) are poorly determined. Knowledge of PDFs at large x is vital for understanding the nonperturbative nucleon structure, and is crucial to support a broad range of experimental programs in hadronic, neutrino, and beyond the standard model physics. Using the framework of collinear factorization, I am developing the theoretical tools necessary to fully study the large-x region, accounting for various effects not previously considered and merging them in a consistent framework. The theoretical advances will allow one for the first time to fully utilize the recent and future high-precision data on structure functions and other observables, and to obtain a set of precise PDFs optimized for large x.

Achievements to date include: (i) the computation of Target and Jet Mass Corrections in collinear factorization, which solves the long standing "threshold problem", for both unpolarized and polarized structure functions [1, 2]; (ii) a derivation of nuclear corrections for structure functions at finite kinematics, for inclusive and semi-inclusive electron-nucleus scattering [3]. An application of these results to global QCD fits of parton distributions is ongoing in collaboration with theorist and experimentalist from Jefferson Lab, and from the CTEQ collaboration.

Parton propagation and fragmentation in QCD matter

The transition from colored partons to colorless hadrons – the so-called fragmentation or hadronization process – is an exemplary QCD process which still lacks a quantitative understanding from first principles calculations, but can be experimentally studied by using nuclei as femtometer scale detectors of the process.

On the theory side, I am pursuing a deeper understanding of parton propagation and hadronization in nuclear matter, ideally rooted as much as possible in perturbative QCD. On the phenomenological side, I am studying absoprtion and energy loss models and applying them to the analiysis of recent high precision data in electron-nucleus collisions. JLab and its planned upgrade to a 12 GeV beam and the future Electron-Ion Collider (EIC) are ideally suited to advance our understanding of hadron attenuation, p_T-broadening, and 2-particle correlations. In particular, contemporary models of nuclear modifications of hadron production need to be carefully extended to include (i) heavier mesons like ϕ, η, ω, for comparison to their light counterparts; (ii) heavier baryons, like Λ; to better understand baryon fragmentation and transport (iii) heavy mesons like D and B, to help sunder standing the larger than expected heavy flavor meson suppression at RHIC, and strengthen Quark-Gluon Plasma studies at the LHC.

Achievements to date include: (i) the development of a hadron absorption model based on the Lund string fragmentation, for use in nuclear DIS [4, 5]; (ii) a refinement of energy-loss models to include realistic nuclear geometry [6, 7]; (iii) a "formation time scaling" analysis of the HERMES experiment data showing that hadronization starts on short time scales [8]; (iv) a quantitative estimate of the prehadron formation time [9]; (v) an estimate of hadron attenuation in proton-nucleus collisions [10]. I am also a member of the "e+A working group" of the EIC collaboration, and I am coordinating the preliminary study and simulation of hadronization in electron-nucleus collisions [11].

Multiple parton scattering and the Cronin effect

The Cronin effect is, broadly speaking, the nuclear modification of the p_T-spectrum of single inclusive hadron production in hadron-nucleus ($h+A$) or electron-nucleus collisions, leading to an enhanced hadron or lepton yield at intermediate momenta.

I have studied the Cronin effect in $h + A$ collision as an effect of semihard parton multiple scatterings in the nuclear target [12]. In collaboration with M. Gyulassy and D. Treleani, I have developed a "Glauber-Eikonal" model of the process which well describes, without adjustable parameters, experimental data for mid-rapidity pion production in the $\sqrt{s} = 20 - 200$ GeV range [13–16]. Subsequently, I used this model to estimate at what centrality a Quark-Gluon Plasma is created in heavy ion collisions at RHIC [17].

I also used a variant of this formalism to develop a "saturation" model for the centrality dependence of charged hadrons produced in nucleus-nucleus collisions, and to predict with good accuracy midrapidity results at RHIC's top energy [18, 19].

Color confinement and topological field theories

The Yang-Mills (YM) theory is widely accepted as the theory of strong interactions. At the classical level the YM theory can be formulated in an equivalent way by introducing an auxiliary field $B_{\mu\nu}$, so that it becomes of first order in the color field-strength $F_{\mu\nu}$. The Lagrangian of the obtained "BFYM" theory becomes the sum of the so-called *BF topological field theory* and a deformation piece. The goal of this approach is to use the topological theory contained in the YM theory to describe its long range features, in particular finding a dynamical mechanism for color confinement.

My contributions include the correct quantization of the BFYM theory in 3 and 4 dimensions, and the proof of its equivalence with YM [20, 21]. Furthermore, I showed that by a suitable redefinition of the fields the BFYM Lagrangian splits in 2 parts: the Topological Yang-Mills (TYM) Lagrangian, which describes the dynamics of the non-perturbative fields, and a deformation Lagrangian which describes the dynamics of the gluons over such a non-perturbative background [22]. Contact with confinement is made by observing that the TYM theory is a twisted version of the N=2 supersymmetric YM theory (SYM), where confinement is realized by a dual superconductor mechanism when the supersymmetry is manually broken to N=1. In the BFYM theory such a mechanism could be dynamically induced by the deformation part, which already explicitly breaks the supersymmetry to nearly N=0, retaining only the scalar supercharge of the SYM Lagrangian.

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