Overview of Initial State WG

How to parametrize and/or compute initial conditions for the small x evolution?

Vladi Skokov

Members

Faculty

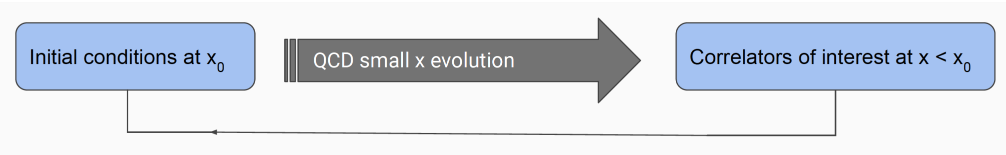
- Adrian Dumitru
- Yacine Mehtar-Tani
- Swagato Mukherjee
- Peter Petreczky
- V. S.

Graduate students

- Shaswat Tiwari

Blocked group meeting time: Wednesdays at 4 pm.

Broad goals and motivation



Current approach:

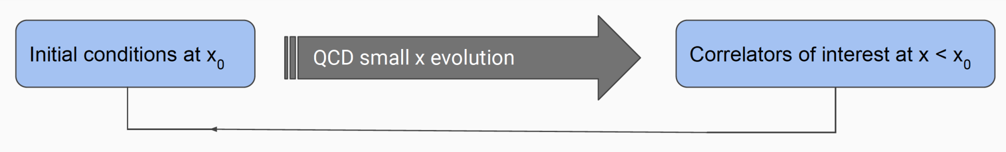
- ad-hoc parametrization of ICs is adjusted to optimize the fit of data
- most of ICs are based on modifications of McLerran-Venugopalan model

$$N(r, x_0) = 1 - \exp\left[-\frac{1}{4}(r^2 Q_{s0}^2)^\gamma \ln\left(\frac{1}{r\Lambda} + e\right)\right]$$

Fits of small-x inclusive HERA data $\rightsquigarrow \gamma \sim 1.1 - 1.2$

AAMQS, 2009 & 2011
T. Lappi & H. Mäntysaari, Phys.Rev.D 88 (2013) 114020

Broad goals and motivation



Drawbacks:

- data-driven fit; no connection to underlying QCD dynamics
- no explanation of the x_0-dependence
- available ICs are most appropriate for large* nuclei at high energy

  *modulo quantum corrections, Yacine's talk (Friday)
- variety of other issues

  Adrian's talk (Thursday)

Desired approach: model-independent first-principle-based determination of ICs

Specific goals for Years 1-2

Non-Gaussian corrections for large nuclei I

- Non-Gaussian corrections for large nuclei
  Inspired by studies in the context of the transverse momentum broadening of a jet
- For large nucleus the effective saturation momentum receives quantum correction:

$$Q_s^2(A) \sim Q_0^2 A^{1/3} \left(1 + \frac{\bar{\alpha}}{2} \ln^2 A^{1/3} + \ldots\right)$$

P. Caucal and Y. Mehtar-Tani, Phys. Rev. D 106, L051501 (2022); JHEP 09, 023 (2022); arXiv:2209.08900

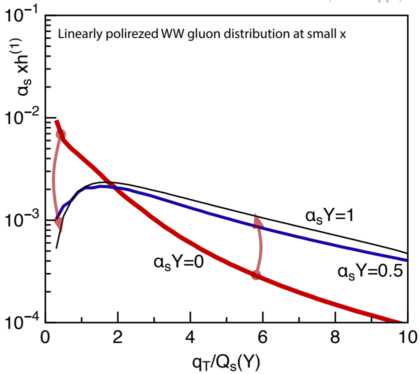
- Ressumation of the double logarithm leads to the anomalous scaling and to non-Gaussian ICs
  $r-$dependence changes as well $N \to 1 - \exp(-r^2 Q^2(r))$, where $Q^2(r)$ is not just $\ln \frac{1}{r\Lambda}$
- Goals
  - Account for quantum correction in the ICs
  - Generalize to running coupling
  - Study quantitative impact on DIS observables

Is there an observable sensitive to the modification of MV's log?!

Yacine, Friday

Non-Gaussian corrections for large nuclei II

A. Dumitru, T. Lappi, and V.S., Phys.Rev.Lett. 115 (2015) 25, 252301



In a Gaussian model: $xh^{(1)}(x,q^2) \propto \int d|r|\,|r|^3 J_2(|q|\,|r|)\,(1-D(r))\,\frac{\Gamma^{(2)}(r^2)}{\Gamma(r^2)}$
where $\Gamma(r^2) \propto \langle A^-(0)A^-(r)\rangle$ and $\Gamma^{(2)}(r^2)$ it the second derivative wrt r^2

$xh^{(1)}$ is zero in GBW model due to $\Gamma(r^2) \propto r^2$; in contrast to MV due to $\Gamma(r^2) \propto r^2 \ln(\Lambda r)$

A. Metz & J. Zhou, Phys.Rev.D 84 (2011) 051503

ICs from low-energy light-cone wave function of proton I

- There is a variety of existing effective non-perturbative light-front wave functions

$$
\begin{aligned}
|P\rangle &= \frac{1}{\sqrt{6}} \int \frac{x_1 x_2 x_3}{\sqrt{x_1 x_2 x_3}} \delta(1 - x_1 - x_2 - x_3) \int \frac{{}^2k_1^2 k_2^2 k_3}{(16\pi^3)^3} 16\pi^3 \delta(\mathbf{k}_1 + \mathbf{k}_2 + \mathbf{k}_3) \\
&\times \psi(x_1, \mathbf{k}_1; x_2, \mathbf{k}_2; x_3, \mathbf{k}_3) \sum_{i_1, i_2, i_3} \epsilon_{i_1 i_2 i_3} |p_1, i_1;\, p_2, i_2;\, p_3, i_3\rangle
\end{aligned}
$$

Example of a model wave function ψ (Brodsky & Schlumpf)

$$
\psi_{\text{H.O.}}(x_1, \mathbf{k}_1; x_2, \mathbf{k}_2; x_3, \mathbf{k}_3) = N_{\text{H.O.}} \exp(-\mathcal{M}^2/2\beta^2), \quad \mathcal{M}^2 = \sum_{i=1}^{3} \frac{\mathbf{k}_i^2 + m^2}{x_i} .
$$

Parameters: input from proton radius, p/n magnetic moments & axial vector coupling.

- Beyond leading order in perturbation theory

$$
|P\rangle \sim \psi_{qqq}|qqq\rangle + \psi_{qqqg}|qqqg\rangle + \dots
$$

Adrian's talk, Thursday

ICs from low-energy light-cone wave function of proton II

Specific goals

- Formulate x-/impact parameter-/transverse momentum-dependent ICs beyond three-quark state of LF WF
- Prepare data tables, interpolation routines, and set up the workflow for subsequent small-x evolution
- ICs for $N(r, b; x_0)$ for $x_0 = 0.01 - 0.05$

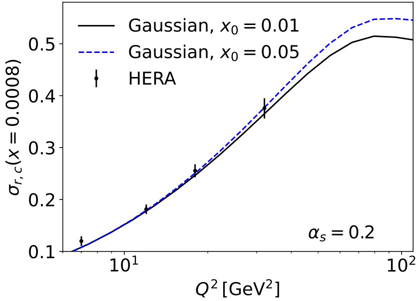
A. Dumitru, H. Mäntysaari, R. Paatelainen, Phys. Rev. D 107, 114024, 2023

- All goals are already delivered; the tables are put to use (talk by A. Kaushik, yesterday)

ICs from low-energy light-cone wave function of proton III

Application to experimental data:

- ICs from low-energy light-cone wave function $\rightarrow$ BK equation
- Explore sensitivity to initial x_0
- Charm production cross-section:



A. Dumitru, H. Mäntysaari, R. Paatelainen, Phys. Rev. D 107, 114024, 2023

- Parameters of the wave function were not adjusted!
- Only one free parameter: α_s

ICs from low-energy light-cone wave function of proton: further extension

- Lattice QCD input on proton/meson wave function
- Imaginary part due to perturbative C-odd ggg exchange
- ...

ICs from Lattice QCD I

Model-independent first-principle-based determination of ICs

A. Tarasov & S. Tiwari; S. Mukherjee, P. Petreczky, V.S.

Current status: Lattice QCD to extract x-dependent PDFs, TMDs, and GPDs (e.g. via LaMET)

Small x regime is unattainable

- Bridge the gap between non-perturbative lattice QCD calculations and small x evolution
  - Balitsky-Kovchegov equation: ICs on dipole S-matrix
  - LO JIMWLK equation: ICs on the distribution of Wilson lines

$$V_{Y+\Delta Y}(x) = \exp\left(- i\frac{\sqrt{\alpha\Delta}}{\pi}\int_z K_i(x-z)V_Y(z)\xi_i(z)V_Y^\dagger(z)\right)V_Y(x)\exp\left(i\frac{\sqrt{\alpha\Delta}}{\pi}\int_z K_i(x-z)\xi_i(z)\right)$$

ICs from Lattice QCD II

- Explore LaMET to QCD-like theory to assess the effectiveness of the approach toward moderate/small x
- Obtain ICs for JIMWLK evolution (distribution of Wilson lines) in a QCD-like theory

This is a high-risk/high-reward goal of our group.
Progress report during the next SURGE meeting.

List of talks

- Monday, 2:20 pm: Andrey, “Anomaly zero modes and sub-eikonal corrections at small-x”
- Monday, 2:40 pm: Haowu, “Color Neutralization and Initial Conditions”
- Thursday, 9:25 am: Adrian, “Initial conditions for small-x evolution of the dipole scattering amplitude on a proton”
- Friday, 10:40 am: Yacine, “Exploring quantum corrections to the initial condition for high energy evolution”

We welcome everyone to join our group!

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