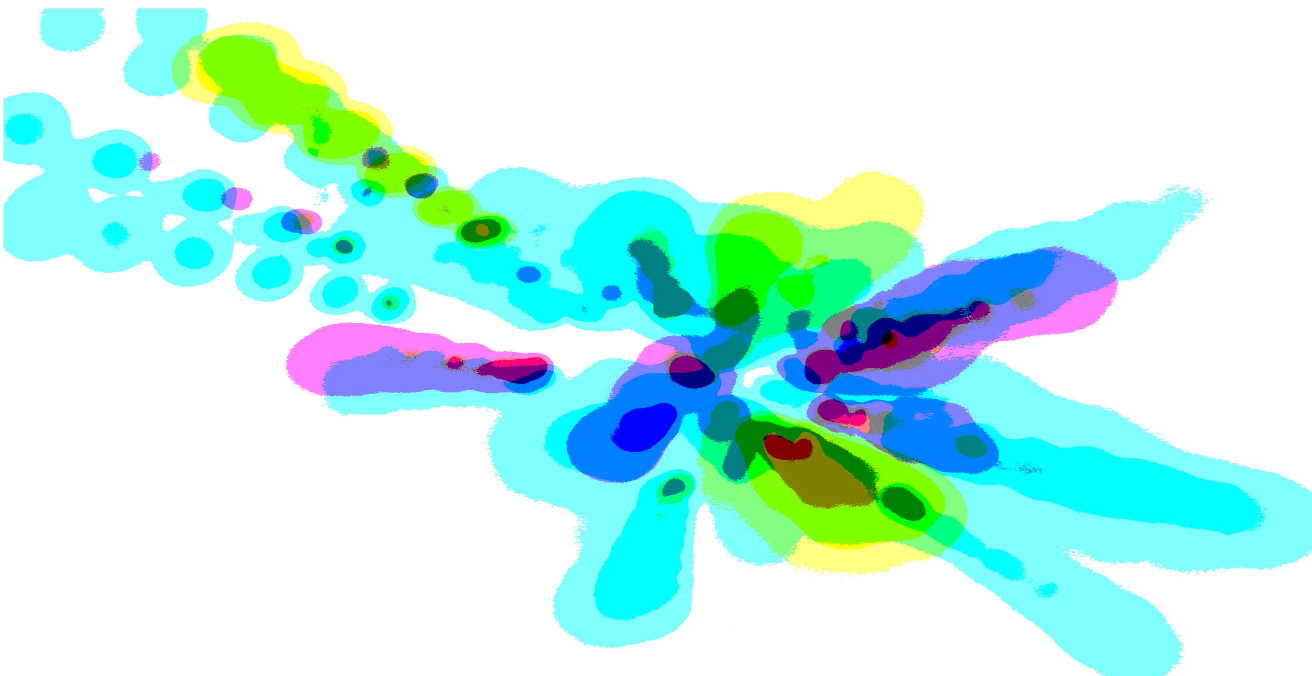
Many body QCD: from RHIC (& LHC) to the EIC

Raju Venugopalan
Brookhaven National Laboratory



BNL Drell-Yan workshop, May 11-13, 2011

Many body QCD @ RHIC

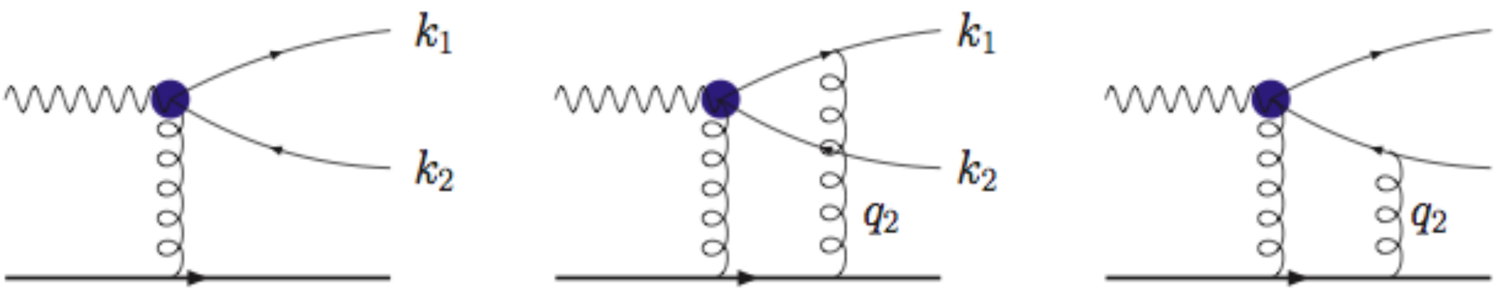
- **If QCD is the "perfect theory", a serious study of its many body features is of fundamental interest. Many body QED constitutes a large part of present day physics**

- **RHIC has ushered in a new era of studies of many body QCD: jet quenching, perfect fluidity, gluon saturation... unanticipated connections to other sub-fields in physics**

- **A quantitative understanding demands ultimately no less than understanding the high energy (many body) structure of hadrons**

- **A lot can be learned from Drell-Yan and other hadron-hadron final states. Isolating universal structure and precision studies of final states will require a high luminosity polarized electron-ion collider**

Semi-inclusive DIS: quadrupole evolution



Dominguez,Marquet,Xiao,Yuan (2011)

$$\frac{d\sigma^{\gamma^*_{\mathrm{T,L}}A\to q\bar{q}X}}{d^3k_1 d^3k_2} \propto \int_{x,y,\bar{x}\bar{y}} e^{ik_{1\perp}\cdot(x-\bar{x})} e^{ik_{2\perp}\cdot(y-\bar{y})} \left[1 + Q(x,y;\bar{y},\bar{x}) - D(x,y) - D(\bar{y},\bar{x})\right]$$

$$D(x,y) = \frac{1}{N_c}\langle \mathrm{Tr}(V_x V_y^\dagger)\rangle_Y \qquad Q(x,y;\bar{y},\bar{x}) = \frac{1}{N_c}\langle \mathrm{Tr}(V_x V_{\bar{x}}^\dagger V_{\bar{y}} V_y^\dagger)\rangle_Y$$

Cannot be further simplified a priori even in the large N_c limit

(See talks by Mueller, Xiao, Jalilian-Marian)

B-JIMWLK hierarchy: Langevin realization

Numerical evaluation of Wilson line correlators on 2+1-D lattices:

$$\left\langle \mathcal{O}[U] \right\rangle_Y = \int D[U]\, W_Y[U]\, \mathcal{O}[U] \longrightarrow \frac{1}{N} \sum_{U \epsilon W} \mathcal{O}[U]$$

Langevin eqn:

Gaussian random variable

$$\partial_Y [V_x]_{ij} = [V_x i t^a]_{ij} \left[\int d^2y\, [\mathcal{E}^{ab}_{xy}]_k\, [\xi^b_y]_k + \sigma^a_x \right]$$

$$\mathcal{E}^{ab}_{xy} = \left(\frac{\alpha_S}{\pi^2}\right)^{1/2} \frac{(x-y)_k}{(x-y)^2} \left[1 - U^\dagger_x U_y\right]^{ab}$$

"square root" of JIMWLK kernel

$$\sigma^a_x = -i \left(\frac{\alpha_S}{2\pi^2} \int d^2z \frac{1}{(x-z)^2} \mathrm{Tr}(T^a\, U^\dagger_x U_z) \right)$$

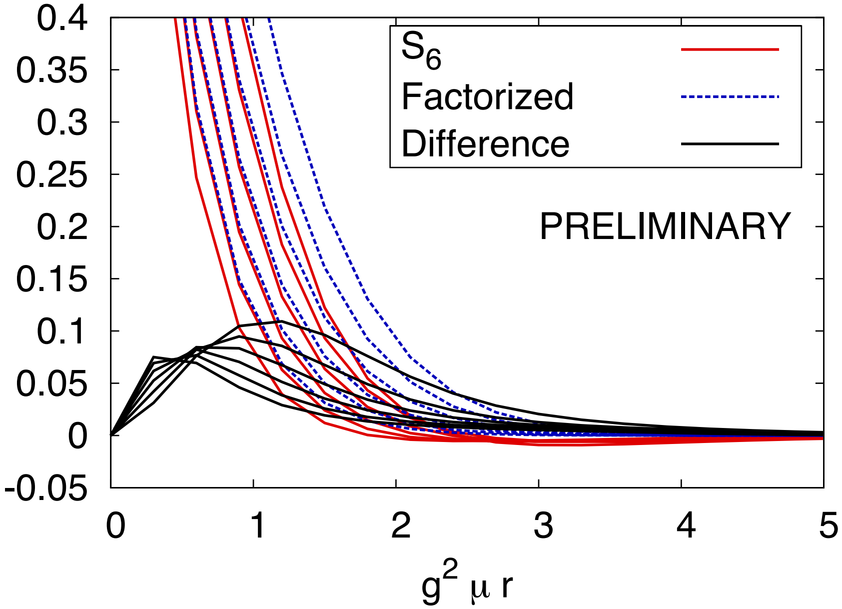
"drag"

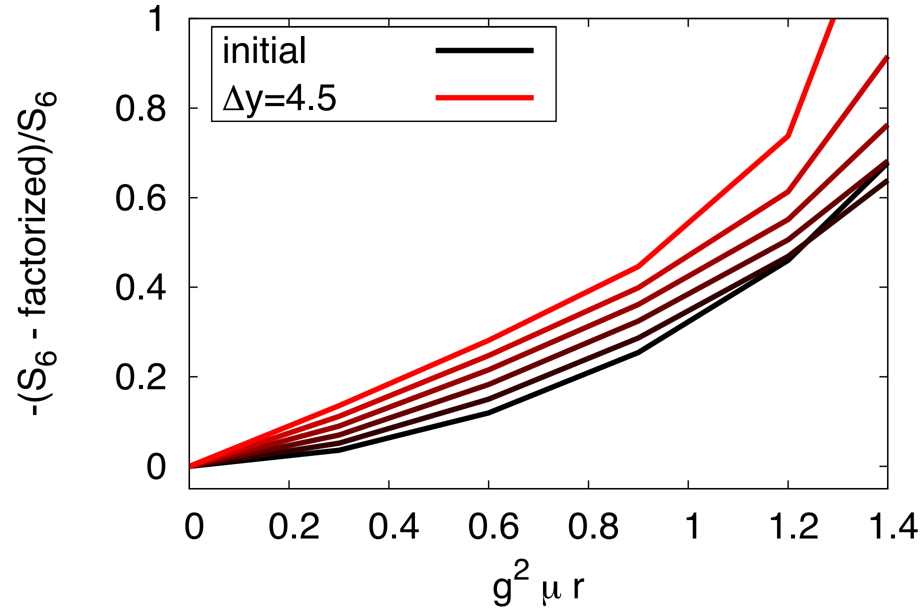
- **Initial conditions for V's from the MV model**
- **Daughter dipole prescription for running coupling**

Numerical results-IV

Lappi,Schenke,RV

How about the quantity S_6 containing quadrupoles that appear in di-hadron correlations ?





Violations large for large r and for large Y
(i.e., when saturation effects are important) – confirming analytical estimates

Outlook - I

❖ The JIMWLK hierarchy contains non-trivial "many body" correlations
-these are now being explored using numerical and analytical techniques

❖ It is likely that they could be inferred (given sufficient precision) from experiments thereby providing key insight into QCD many body dynamics in the Regge-Gribov limit

❖ There are many open questions that hopefully will be resolved in the next decade, such as i) NLL corrections, ii) matching to OPE based analyses at larger x and Q^2