Multiple Particle Production in the Presence of Saturation

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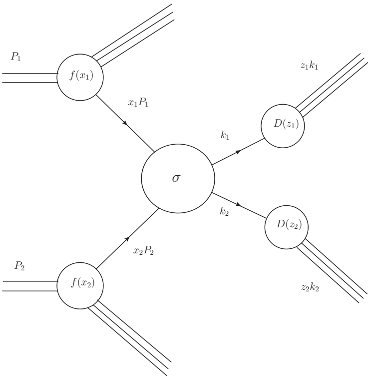
IPhT - Saclay

Excited QCD 2012
Peniche, Portugal

Particle Production in Hadronic Collisions



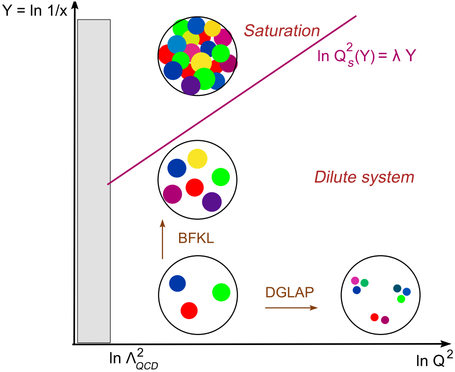
- Factorization of perturbative and non-perturbative regimes
- Assumptions:
  - All energy scales (except for masses) are of the same order
  - Mostly inclusive processes
  - Single large momentum transfer

Problems with Collinear Factorization

- Transverse momentum dependence:
  - Less inclusive processes
  - Wider range for transverse momentum of produced particles

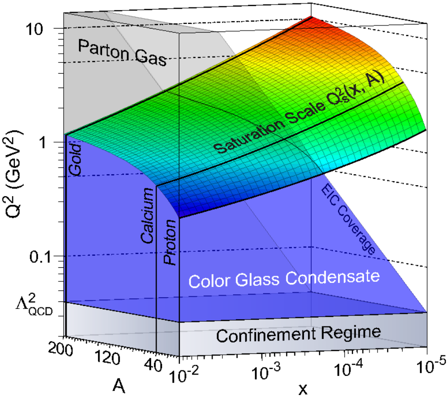
- Enhancement of factorization breaking terms:
  - Very high energies
  - Nuclear effects
  - High densities in the small-x regime

High Densities at Small-x



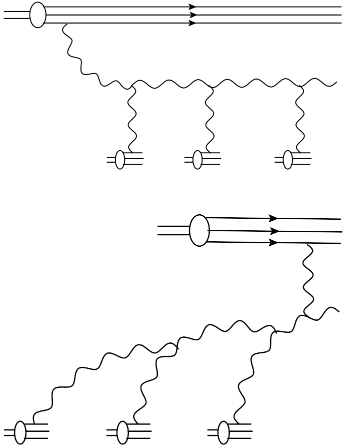
- Soft gluon emission is enhanced at large rapidities
- BFKL dynamics predicts a large growth in gluon densities at small-x
- Nonlinear dynamics predicts the generation of a semi-hard momentum scale which justifies the use of perturbative techniques

Saturation in Nuclei



- Nuclear enhancement factor $A^{1/3}$
- Saturation region is available at lower energies and in the perturbative regime

Factorization at Small x (in nuclei)



- Covariant gauge:
  - Resummation of multiple scatterings
  - Transverse momentum broadening
- Light-cone gauge:
  - Appropriate choice of boundary conditions turns off final (initial) state interactions
  - Modified distribution function
- Transverse momentum of partons can no longer be ignored

Resummation of Multiple Scatterings

- Eikonal approximation $\rightarrow$ Representation in coordinate space
- Choose a covariant gauge
- Take high density target as a strong static color field
- Effect of multiple scatterings can be resummed into a Wilson line

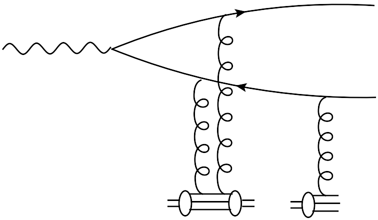
$$U(x) = \mathcal{P} \exp \left\{ ig \int dz^+ \, \alpha_a(z^+, x) \, T^a \right\}$$

Medium Average

$$\langle \mathcal{O} \rangle_Y = \int \mathcal{D}\alpha \; W_Y[\alpha] \; \mathcal{O}[\alpha]$$

- Weight function is given by non-perturbative physics
- Quantum dynamics determined by CGC effective theory
- Fundamental piece to understand the color correlations among the partons participating in a given process

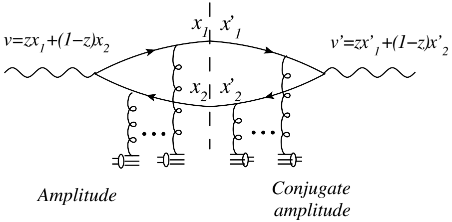
Deep Inelastic Scattering at Small-x



$$\propto \psi(x_1 - x_2)\left[1 - U(x_1)U^\dagger(x_2)\right]$$

- Light-cone wave function
- Multiple scattering in the eikonal approximation in terms of Wilson lines

DIS at Small-x



$$\frac{d\sigma^{\gamma_T^* A\to q\bar{q}X}}{d^3k_1 d^3k_2} = N_c \alpha_{em} e_q^2 \delta(p^+ - k_1^+ - k_2^+) \int \frac{d^2x_1}{(2\pi)^2}\frac{d^2x_1'}{(2\pi)^2}\frac{d^2x_2}{(2\pi)^2}\frac{d^2x_2'}{(2\pi)^2}$$

$$\times\, e^{-ik_{1\perp}\cdot(x_1-x_1')} e^{-ik_{2\perp}\cdot(x_2-x_2')} \sum \psi_T^*(x_1-x_2)\psi_T(x_1'-x_2')$$

$$\times \left[1 + Q_{x_g}(x_1,x_2;x_2',x_1') - S_{x_g}(x_1,x_2) - S_{x_g}(x_1',x_2')\right]$$

$$Q_{x_g}(x_1,x_2;x_2',x_1') = \frac{1}{N_c}\left\langle \mathrm{Tr}U(x_1)U^\dagger(x_1')U(x_2')U^\dagger(x_2)\right\rangle_{x_g} \qquad S_{x_g}(x_1,x_2) = \frac{1}{N_c}\left\langle \mathrm{Tr}U(x_1)U^\dagger(x_2)\right\rangle_{x_g}$$

SIDIS and Total Cross Section

- Integrating over momenta identifies coordinates in the amplitude and conjugate amplitude
- SIDIS

$$1 + S_{x_g}(x_2, x_2') - S_{x_g}(x_1, x_2) - S_{x_g}(x_1, x_2')$$

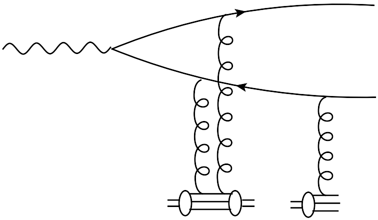
- Total cross section

$$2(1 - S_{x_g}(x_1, x_2))$$

- Quadrupole disappears and cross sections are written in terms of only dipole amplitudes
- Gluon distribution related to Fourier transform of dipole amplitude

Gluon Distribution from DIS Dijet

- Consider limit where two final particle are almost back-to-back
- Make separation between quark and antiquark small
- Singlet pair looks like a colorless object
- Octet pair looks like a gluon



FD, C. Marquet, B. Xiao, F. Yuan, 2011

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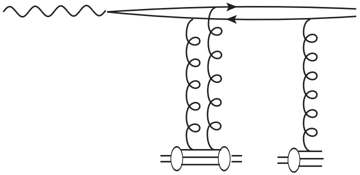

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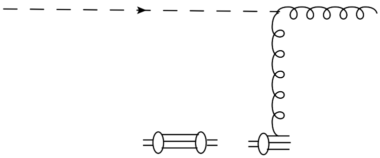


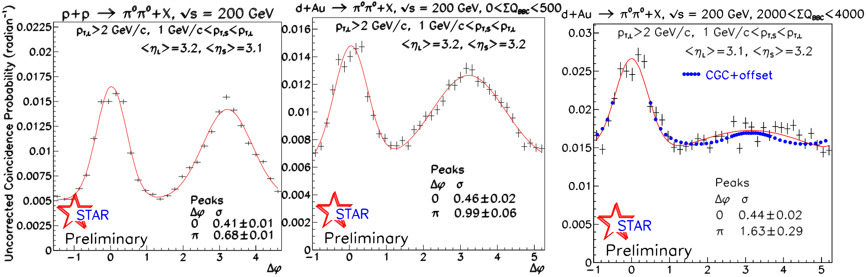
FD, C. Marquet, B. Xiao, F. Yuan, 2011

pA Collisions

- Data available from RHIC (soon LHC)
- Single hadron production
  - Cronin effect
  - Suppression at large rapidities as compared to pp
- Di-hadron correlations

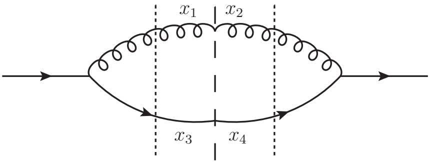
Di-hadron correlations

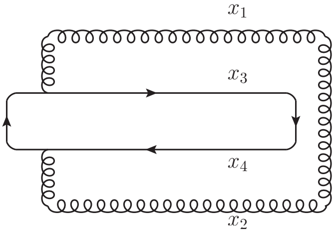
- Observed suppression of away side peak in azimuthal correlation in the forward region
- Considered strongest evidence of saturation so far



J. Albacete, C. Marquet, 2010

Quark Initiated Processes

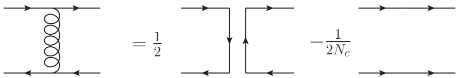


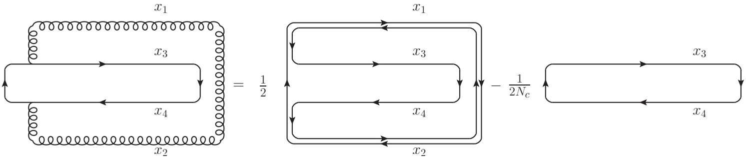


$$\mathrm{Tr}[U(x_3)U^\dagger(x_4)T^aT^b]\tilde{U}_{ac}(x_1)\tilde{U}^\dagger_{cb}(x_2)$$

Quark Initiated Processes - Large-N_c

Use Fierz identities

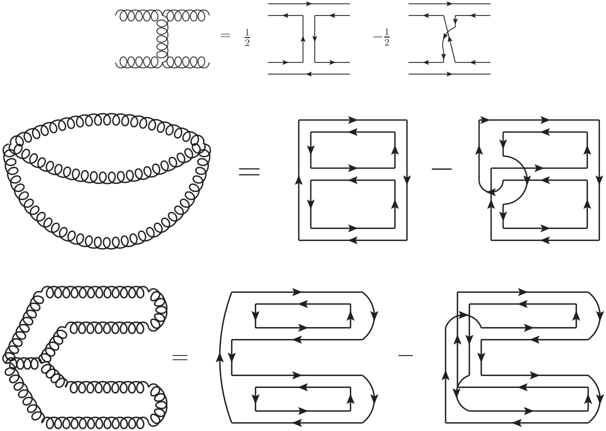




Leading term:

$$\mathrm{Tr}[U(x_1)U^\dagger(x_2)]\mathrm{Tr}[U^\dagger(x_1)U(x_3)U^\dagger(x_4)U(x_2)]$$

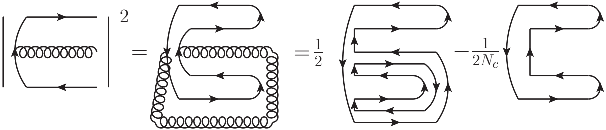
Gluon Initiated Processes



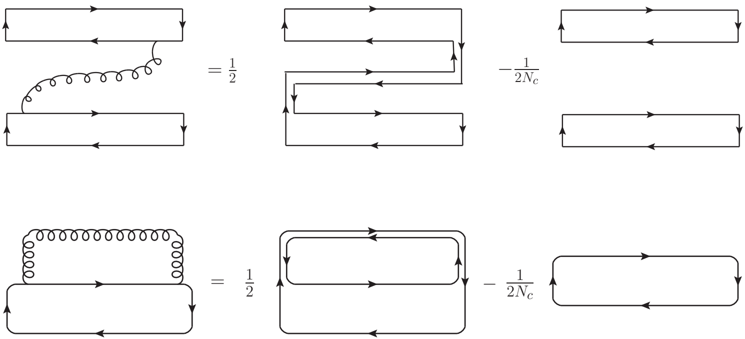
More Complicated Processes

Increasing the number of particles in the final state increases the complexity of the correlators?

For example, look at DIS with one extra gluon:



Additional Gluons in Large-N_c Limit



Additional Gluons in Large-N_c Limit

- Leading contribution comes from attaching both gluon legs to the same fermion loop
- Adding a gluon to either a dipole or a quadrupole gives only dipoles and quadrupoles in the large-N_c limit
- In the large-N_c limit, the only correlators needed to describe production of an arbitrary number of particles are the dipole and the quadrupole

FD, C. Marquet, B. Xiao, In preparation

Conclusions

- The study of multi-particle production in asymmetric collisions can provide valuable information to determine the dynamics of the small-x degrees of freedom in nuclei
- The large-N_c limit greatly simplifies the description of such processes
- Further studies of the quadrupole amplitude are desirable
- Simplification of correlators in the large-N_c limit is not a property of the CGC set-up and can be generalized to other cases of particles scattering in a background field configuration