Universality of Multi-Particle Production in the CGC Framework

Fabio Dominguez
IPhT Saclay

Based on arxiv:1210.1141 in collaboration with C. Marquet, A. Stasto, B. Xiao

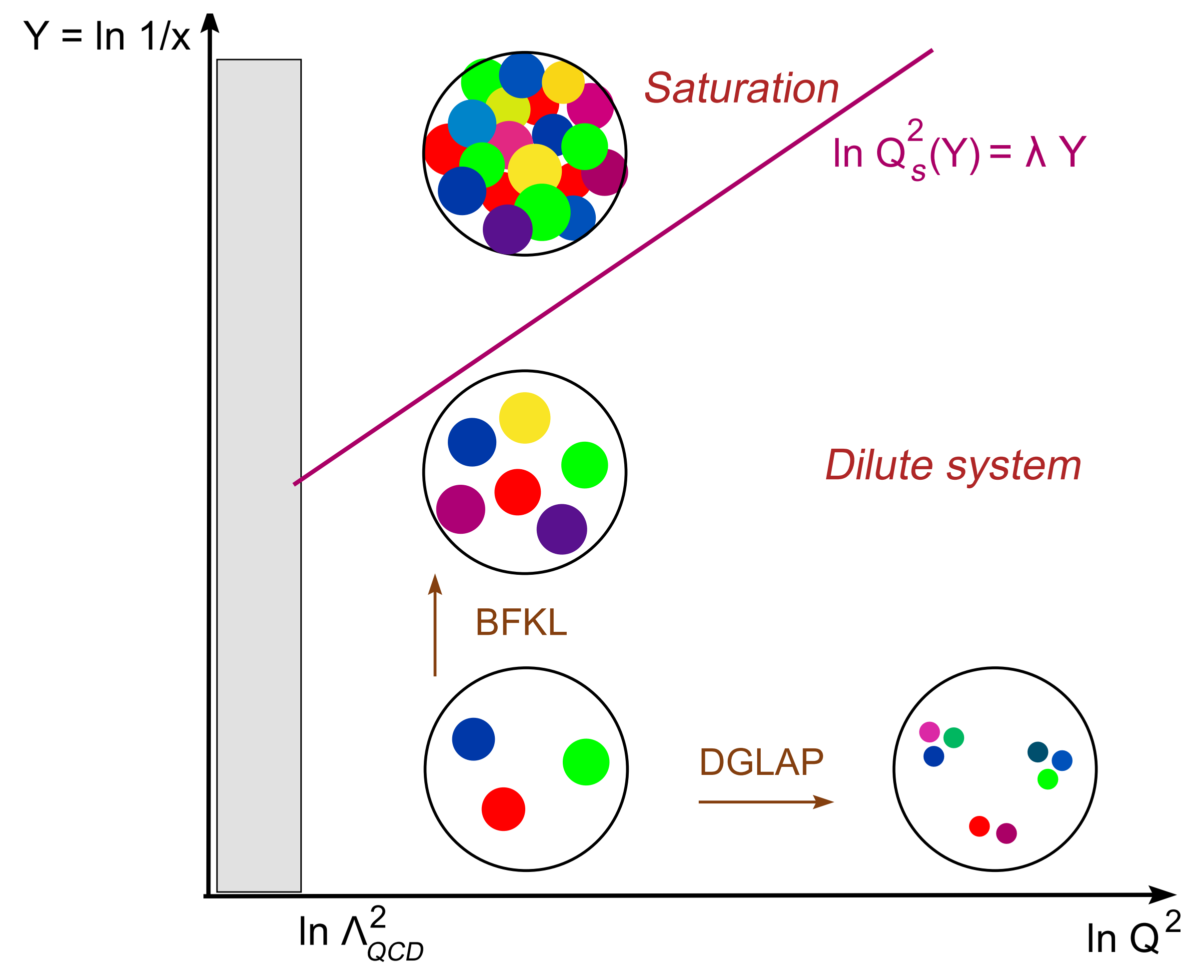
h3QCD Workshop
Trento, June 17, 2013

Motivation

- Probe the low-x degrees of freedom of hadronic (nuclear) matter
- Look for saturation effects
- Fundamental to understand the early stages of heavy ion collisions

Basics of CGC

- Low-x degrees of freedom considered as classical field due to large occupation numbers
- Properly take into account non-linear effects at high densities
- Energy dependence computed perturbatively (JIMWLK)

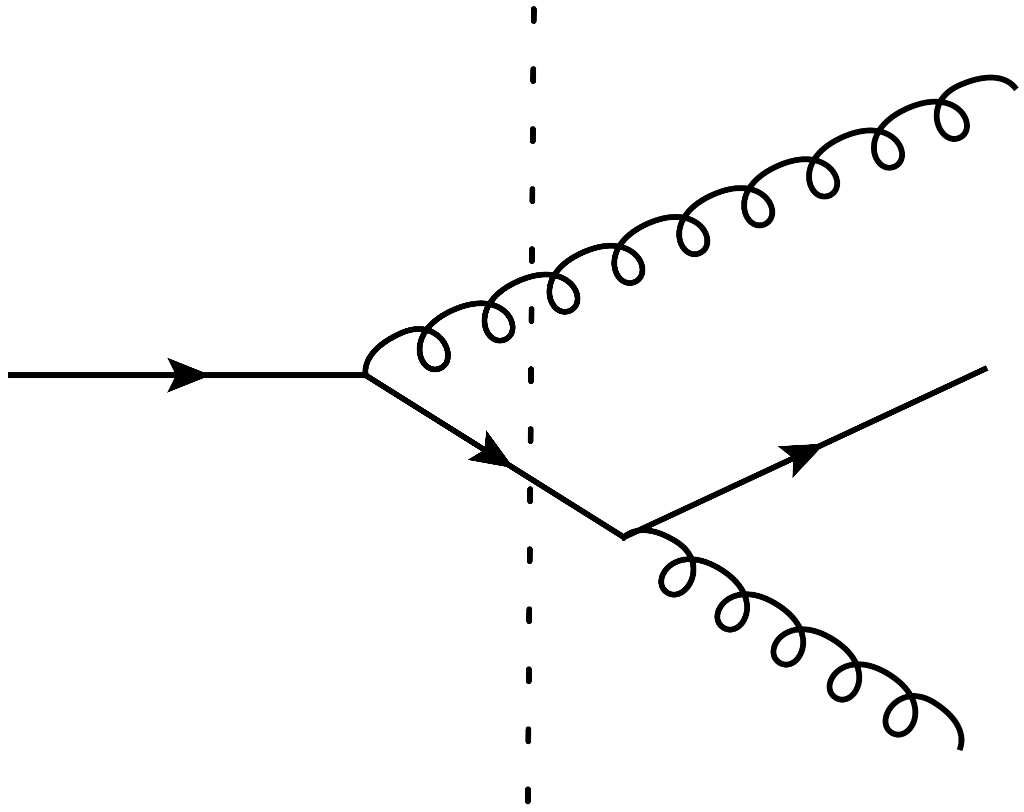


Probing High Density Regime

- Dilute projectile probing a dense target (DIS, pA collisions)
- Use the eikonal approximation to account for the multiple scatterings of a fast moving parton in a background field (in a covariant gauge)
- Calculate observables in a fixed background field, then average over field configurations with an appropriate weighting functional
- Medium effects are visible through the field correlators

Particle Production

- High energy parton splits
- Whole system interacts coherently with high energy target
- Interaction looks instantaneous due to Lorentz contraction
- Final particles can have any rapidity



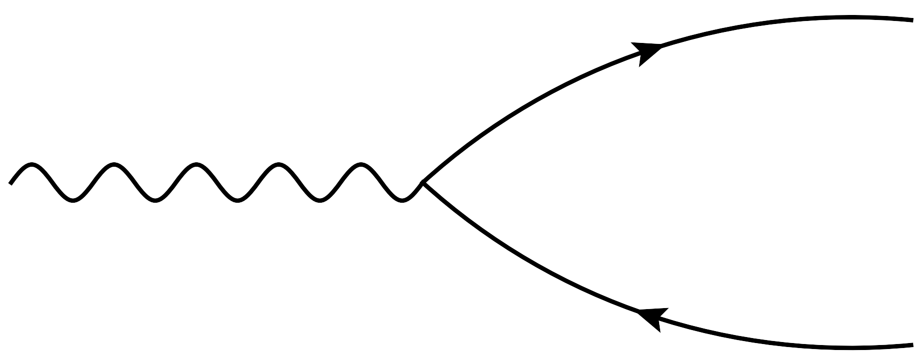
Known Results

- DIS total cross section
- One-particle observables
  - SIDIS
  - Single-hadron production in pA colisions
  - Vector meson photoproduction
- Two-particle observables
  - Di-hadron production in DIS
  - Di-hadron production in pA colisions
    - Quark channel
    - Gluon channel

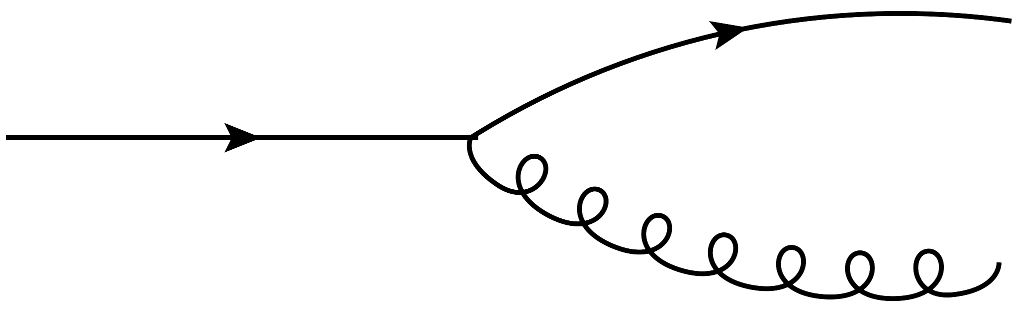
See talks by Heikki Mantysaari and Julien Laidet

Wilson Lines

At the amplitude level:



$$1 - U(x_1)U^\dagger(x_2)$$

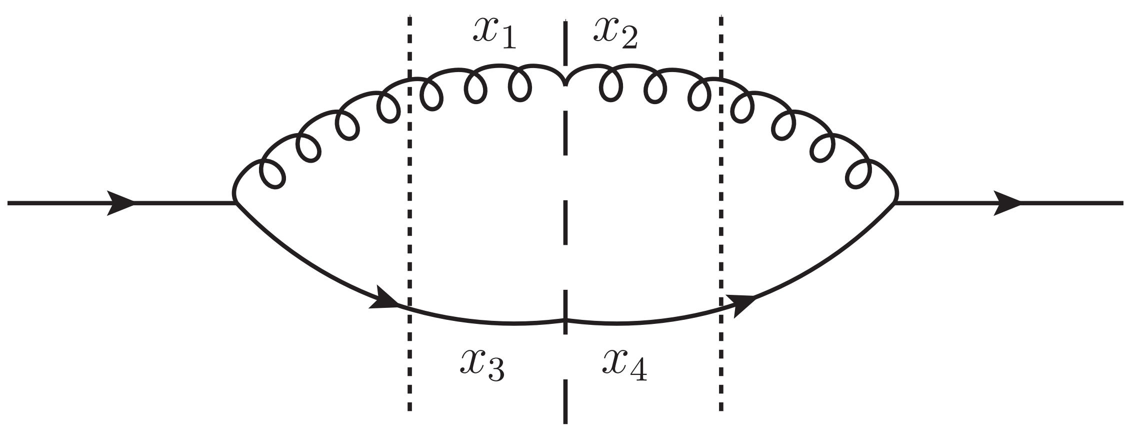


$$U(v)T^a - \tilde{U}_{ab}(x_2)T^b U(x_1)$$

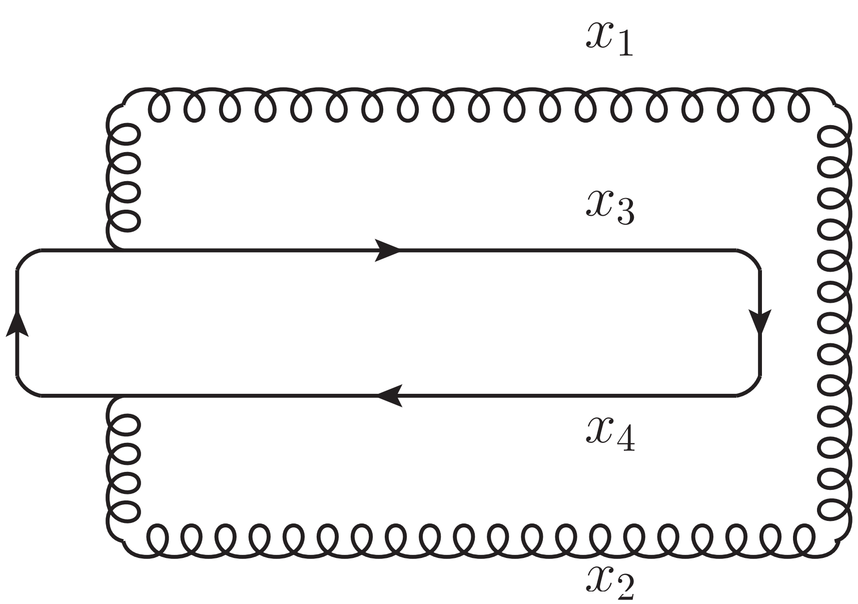
Color Structure

At the cross section level:

- Color conservation implies average is performed over an overall color singlet object

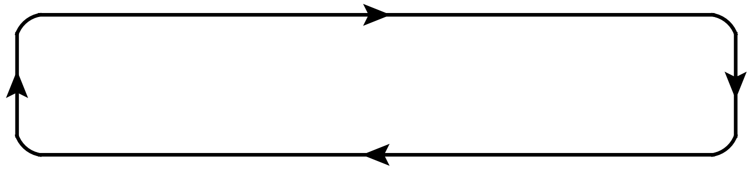


$$\mathrm{Tr}(T^b T^a U(x_3) U^\dagger(x_4)) \tilde{U}_{ac}(x_1) \tilde{U}^\dagger_{bc}(x_2)$$



Inclusive Observables

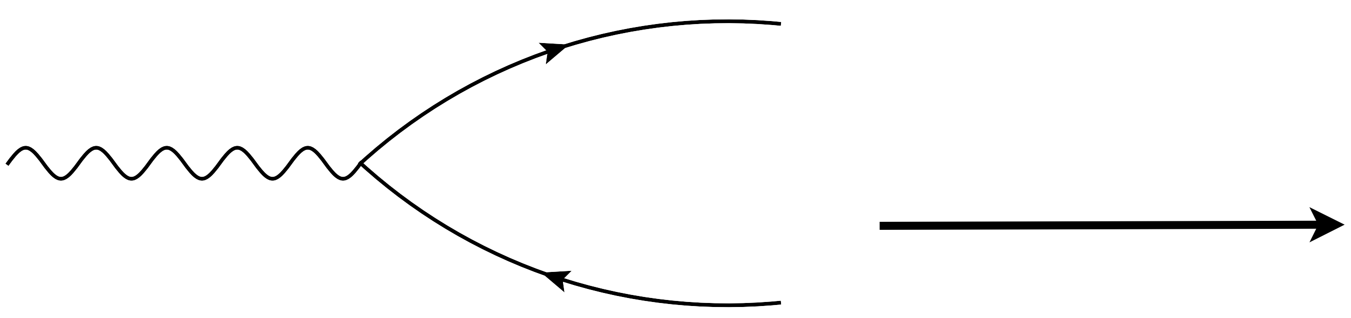
- Integrating over transverse momentum puts the particle at the same transverse coordinate in the amplitude and conjugate amplitude
- Real-virtual cancelations take place
- Total cross sections and single-particle observables can be described with only dipole amplitudes



Two-Particle Observables

- Having two independent momenta in the final state leads to four independent transverse coordinates
- Cross sections involve traces of four Wilson lines at different coordinates

Di-hadron in DIS:

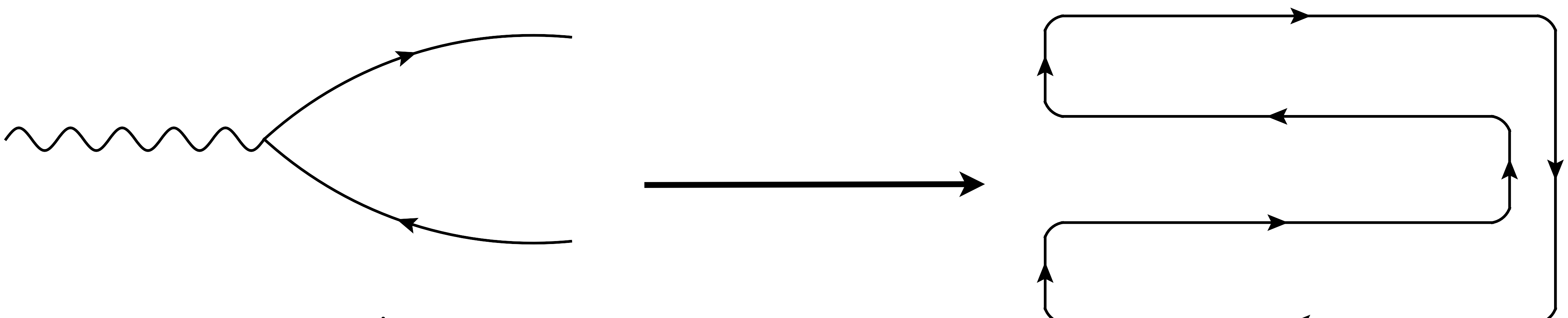


$$1 - U(x_1)U^\dagger(x_2)$$

Two-Particle Observables

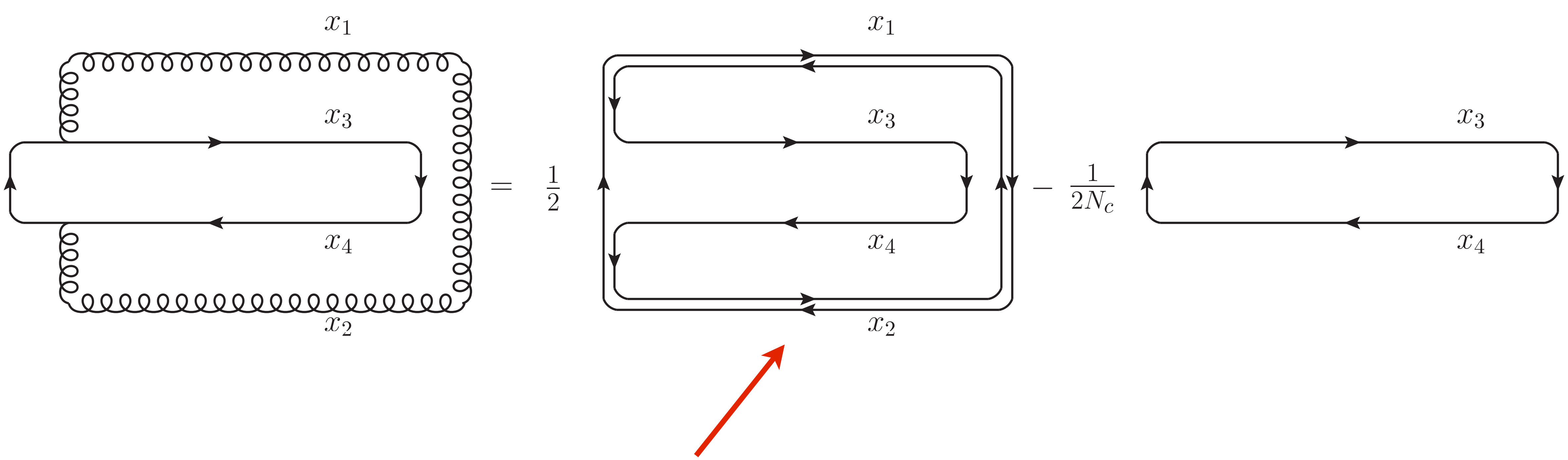
- Having two independent momenta in the final state leads to four independent transverse coordinates
- Cross sections involve traces of four Wilson lines at different coordinates

Di-hadron in DIS:



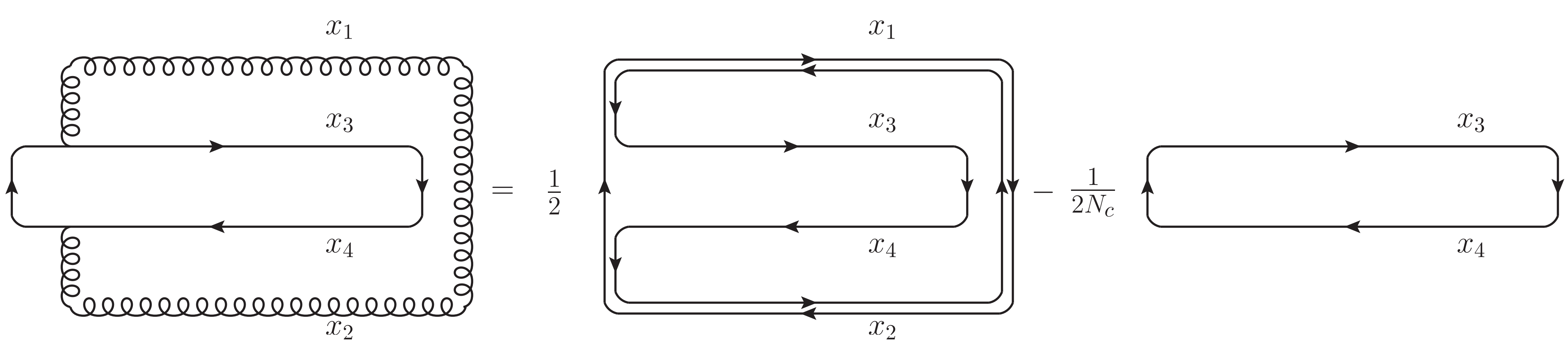
$$1 - U(x_1)U^{\dagger}(x_2)$$

Di-hadron in pA



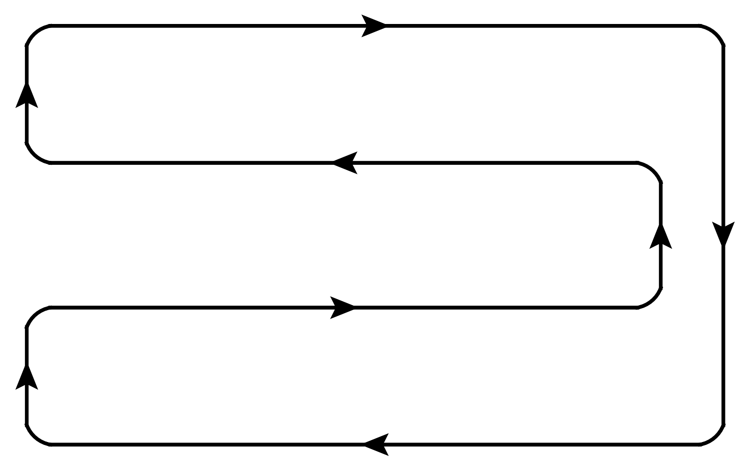
$$\mathrm{Tr}\left(U_1 U_2^\dagger\right) \mathrm{Tr}\left(U_1^\dagger U_3 U_4^\dagger U_2\right)$$

Di-hadron in pA



$$\mathrm{Tr}\left(U_1 U_2^\dagger\right)\,\mathrm{Tr}\left(U_1^\dagger U_3 U_4^\dagger U_2\right)$$

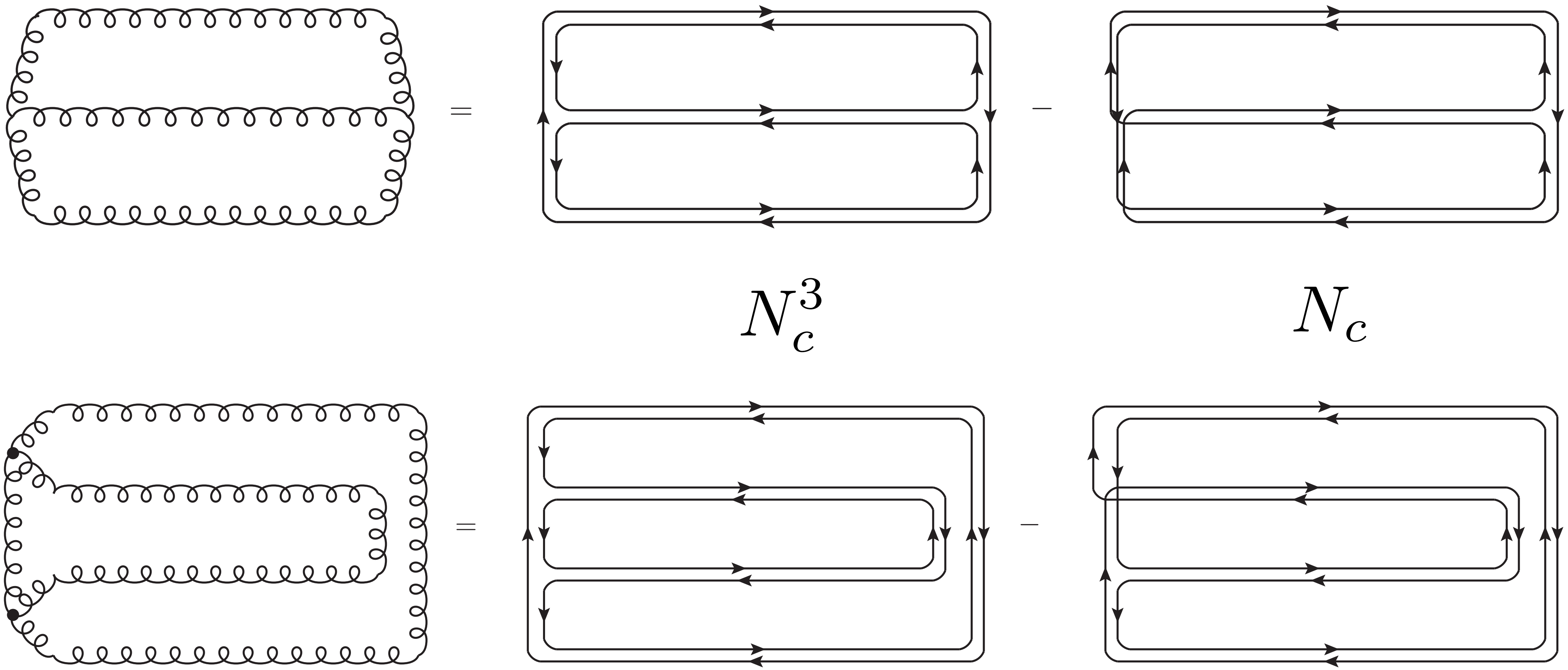
Quadrupole



Large-Nc Limit

- Replace gluon lines with quark-antiquark pairs
- Averages of products of traces of fundamental Wilson lines factorize
- Each trace gives a factor of Nc

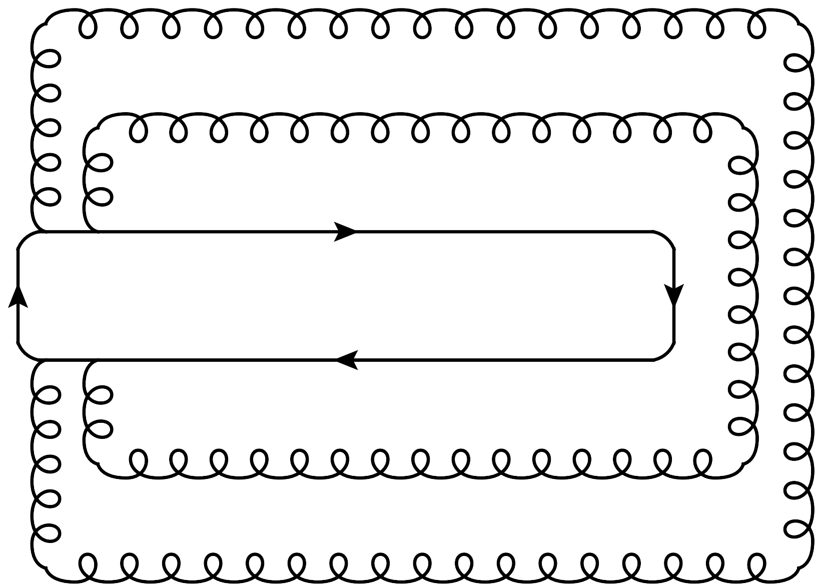
Di-Hadron in pA - Gluon Channel



Diagrams with only dipoles and quadrupoles dominate for large-Nc

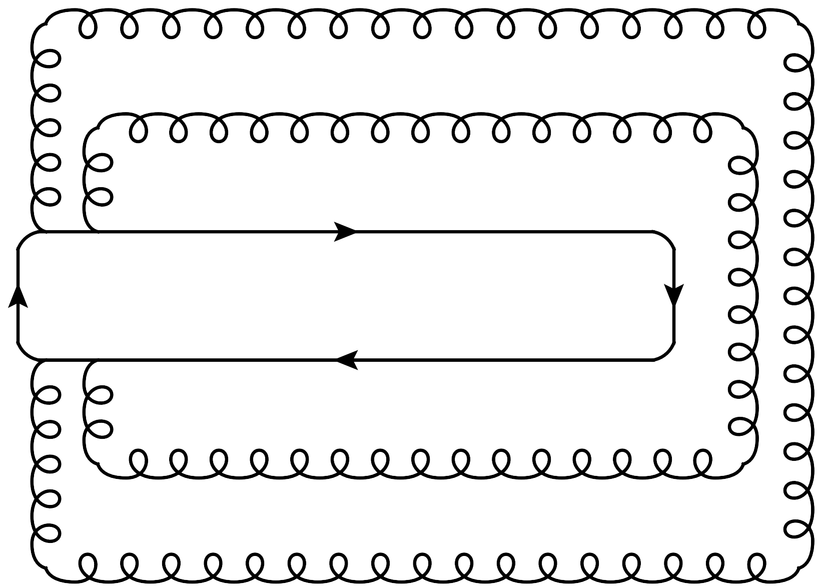
More Complicated Processes

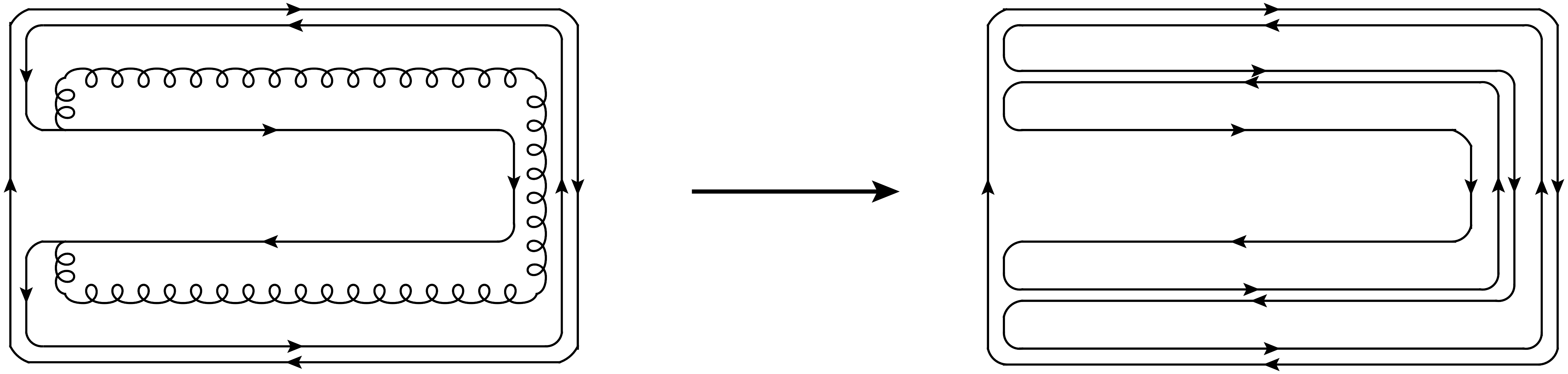
- Adding more particles increases the complexity of the correlators?



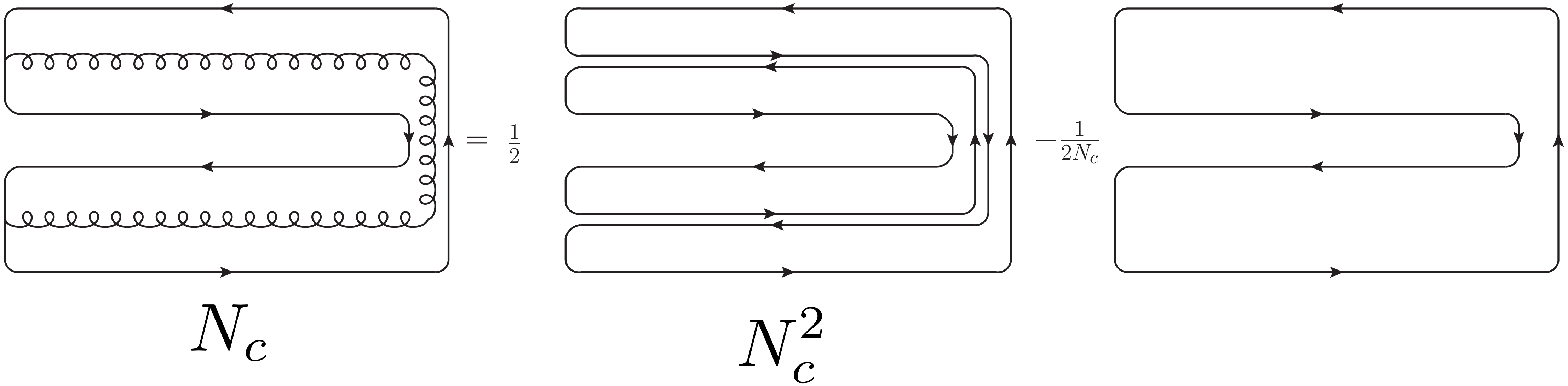
More Complicated Processes

- Adding more particles increases the complexity of the correlators?

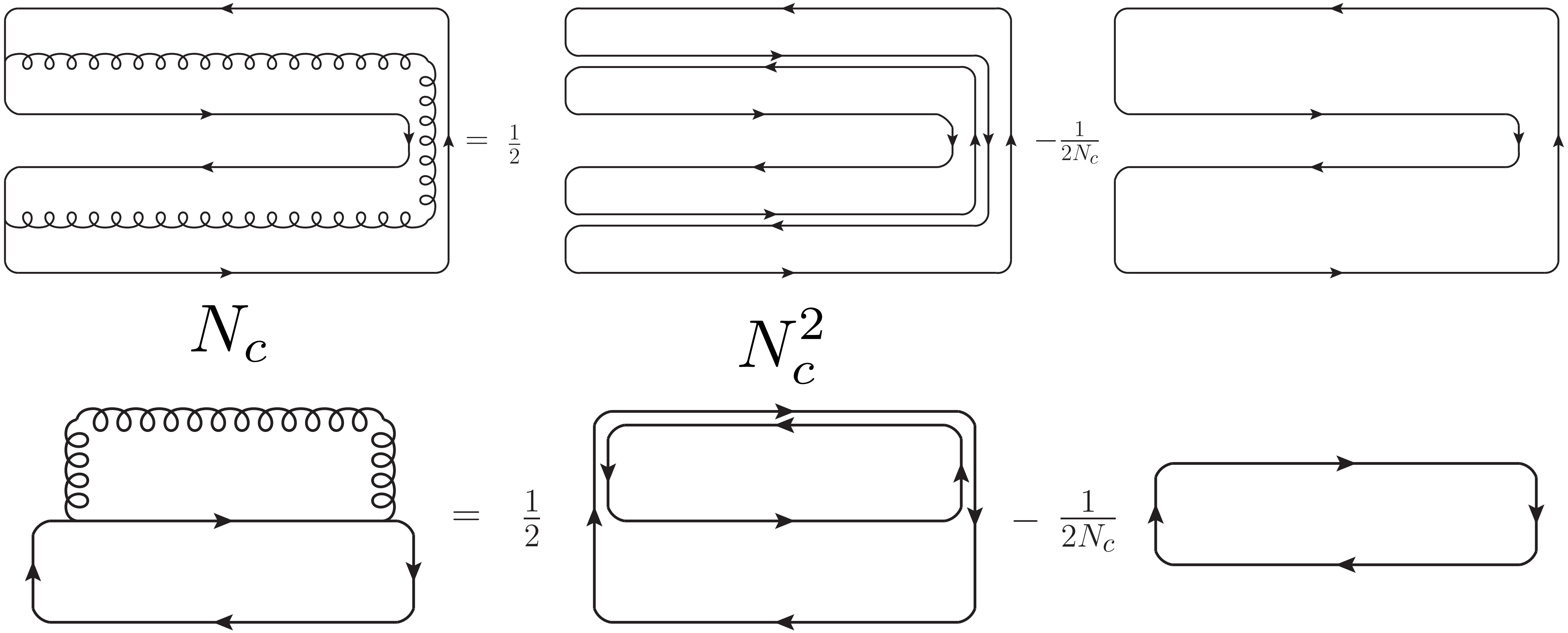




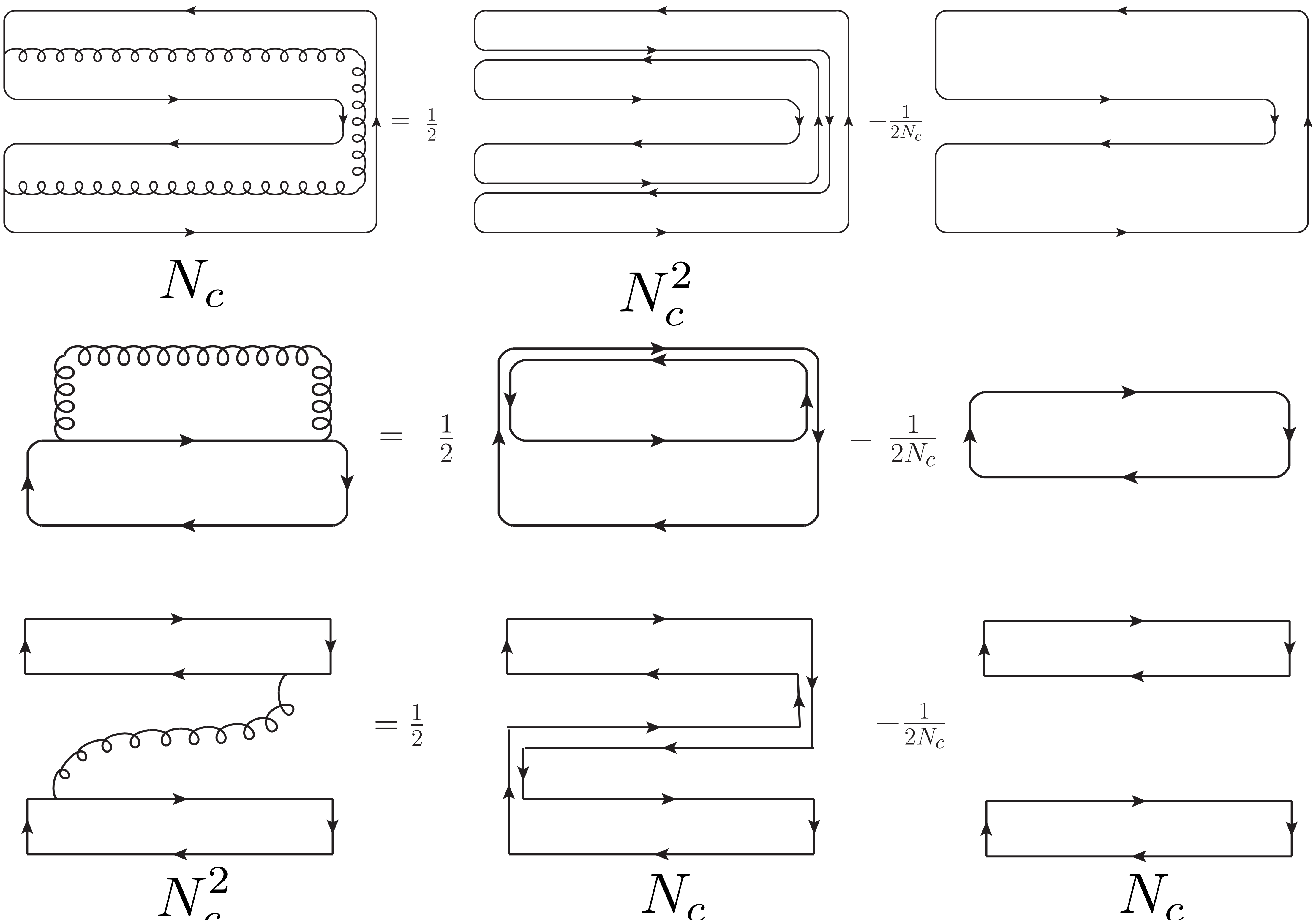
Adding More Gluons



Adding More Gluons



Adding More Gluons



Higher Orders

- Diagrammatic analysis does not distinguish between particles in the amplitude and conjugate amplitude
- Most complicated correlators come from diagrams where a maximal number of particles participate in the interaction with the background field
- Additional gluons can be virtual

Summary

- Only dipole and quadrupole amplitudes are necessary for an arbitrary number of particles
- Still valid at higher orders (additional gluons can be virtual fluctuations)
- This property is not affected by evolution in rapidity (see also Kovner and Lublinsky, 2006)
- Valid for any rapidity values of the final particles

Additional Comments

- Even though the analysis was performed under the CGC framework, the same conclusion is valid for any process involving a fast moving parton in a background field (e.g. a hot medium)
- In order to have higher correlators at leading Nc one has to impose restrictions on the final color state (such as bound states forming a singlet - quarkonia)