Unitarity cutting rules for hard processes on nuclear targets

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Outline

Overview: nonlinear $k_\perp$–factorization

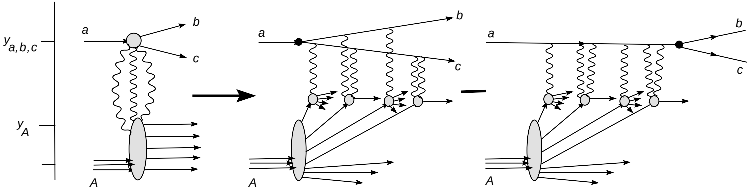
Nuclear collective glue and its unitarity cut interpretation

Standard Abramovskii-Gribov-Kancheli (AGK) vs. QCD

Summary

N.N. Nikolaev & W.S.
Unitarity cutting rules and topological cross sections in hard production off nuclei from nonlinear $k_\perp$–factorization.
Phys. Rev. D74, 074021 (2006).

Production as excitation of beam partons $a \longrightarrow bc$



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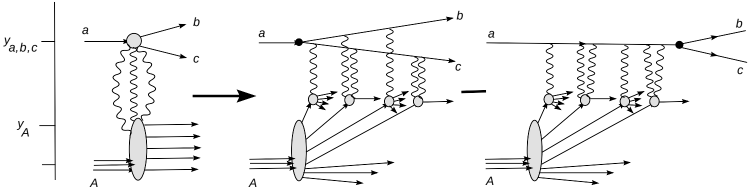

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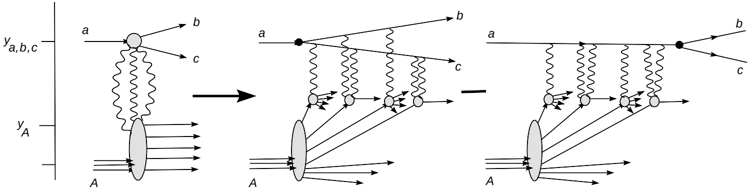

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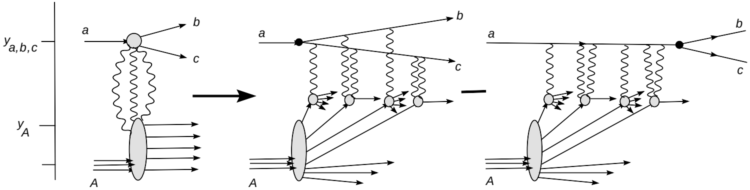

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- Interactions with the nucleus *before* and *after* the virtual decay interfere destructively.
- Nuclear target as a testing ground for unitarity/rescattering effects in hadronic hard interactions.

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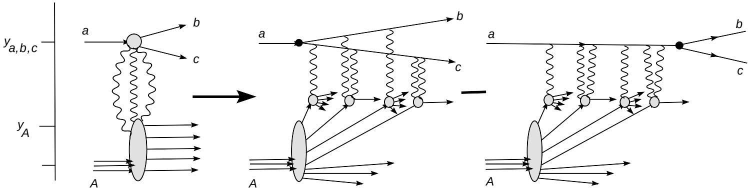

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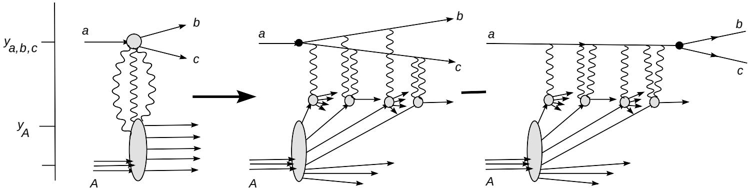

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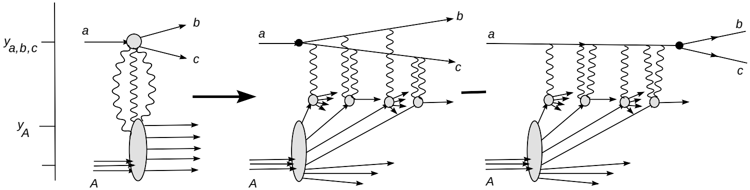

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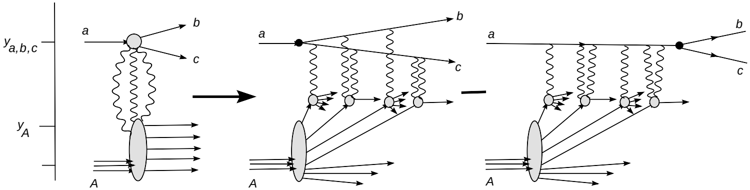

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- predictions for: cut pomeron/topological cross sections; forward-backward correlations; centrality/multiplicity dependence of hard interactions.

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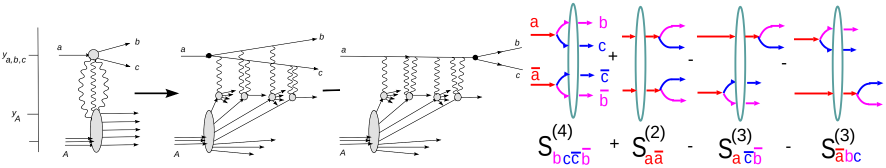

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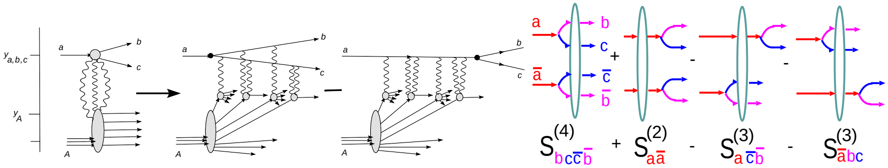

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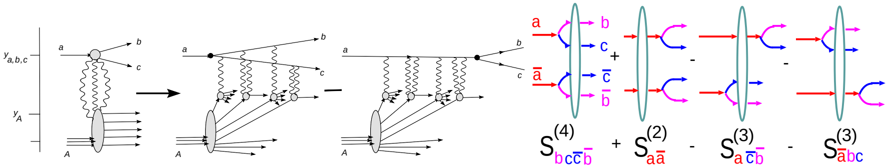

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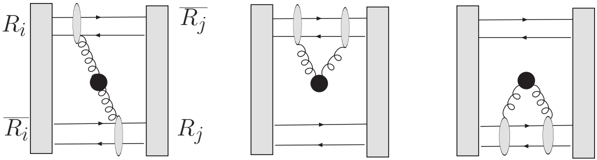
- *first* square, average over target states, and apply closure in summing over the nucleon and nucleus excitation.
- *then* the problem reduces to the calculation of few–particle S–matrices in a color–coupled channel Glauber–Gribov multiple scattering theory.

Four parton dipole cross section operator:



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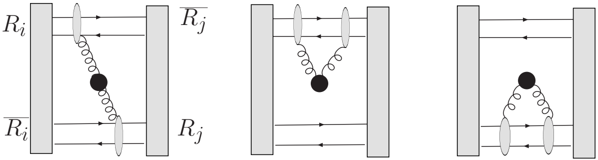

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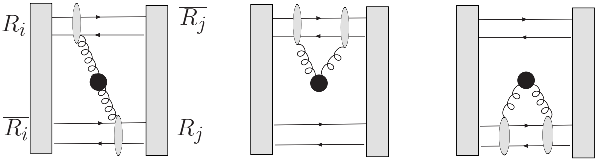

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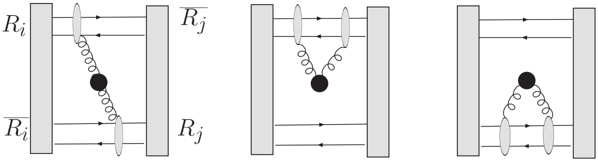

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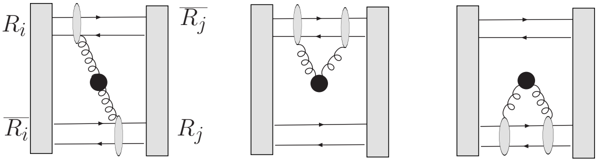

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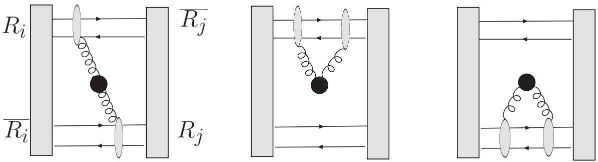

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- Only the sum will be infrared safe, separation into color excitations and elastic rescatterings is infrared sensitive.

Master formula for dijets

$$\frac{d\sigma(a^* \to bc)}{dz_b d^2\boldsymbol{p}_b d^2\boldsymbol{p}_c} = \int \frac{d^2\boldsymbol{b}_b d^2\boldsymbol{b}_c d^2\boldsymbol{b}'_b d^2\boldsymbol{b}'_c}{(2\pi)^4} e^{-i\boldsymbol{p}_b(\boldsymbol{b}_b-\boldsymbol{b}'_b)-i\boldsymbol{p}_c(\boldsymbol{b}_c-\boldsymbol{b}'_c)}$$

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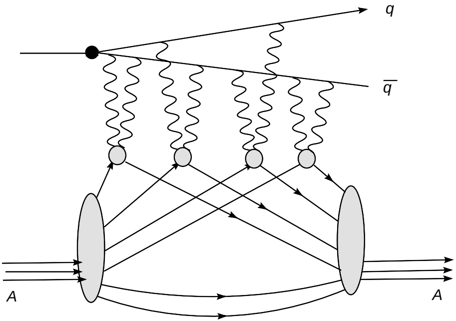
- Central dijets

  $g \to gg \quad \Longrightarrow \quad \underbrace{1}_{1(N_c-\text{suppressed})} + \underbrace{8_A + 8_S}_{N_c^2} + \underbrace{10 + \overline{10} + 27 + R_7}_{N_c^2 \times N_c^2}$

Diffractive dijets define nuclear unintegrated glue



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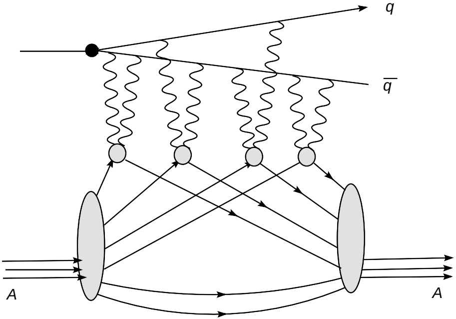

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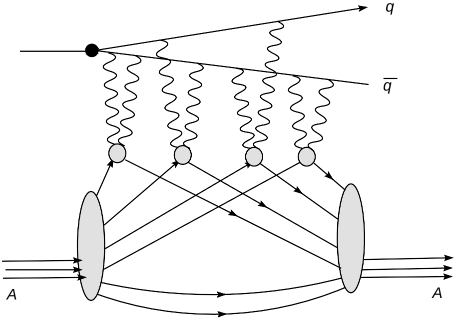

- Diffractive hard dijets from pions: $\pi A \rightarrow Jet_1 + Jet_2$
- Hard jets acquire $\boldsymbol{p}_\perp$ from gluons
- Collective glue is a physical observable: $M_A(\boldsymbol{p}) \propto \phi(\boldsymbol{b}, \boldsymbol{p})$.

Nuclear unintegrated glue

- nuclear coherent glue per unit area in impact parameter space:

$$\phi(\boldsymbol{b}, \boldsymbol{\kappa}) = \sum w_j(\boldsymbol{b}) f^{(j)}(\boldsymbol{\kappa})$$

- collective glue of j overlapping nucleons :

$$f^{(j)}(\boldsymbol{\kappa}) = \int [\prod^{j} d^2\boldsymbol{\kappa}_i f(\boldsymbol{\kappa}_i)] \delta(\boldsymbol{\kappa} - \sum \kappa_i)$$

- probab. to find j overlapping nucleons

$$w_j(\boldsymbol{b}) = \frac{\nu_A^j(\boldsymbol{b})}{j!} \exp[-\nu_A(\boldsymbol{b})] \, , \, \nu_A(\boldsymbol{b}) = \frac{1}{2}\sigma_0 T(\boldsymbol{b}) \, , \, \sigma_0 = \sigma(r \to \infty)$$

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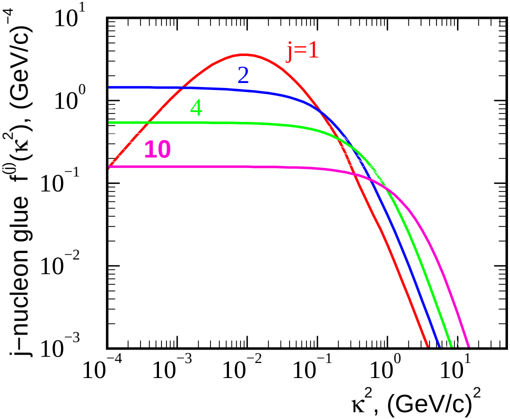
Nuclear unintegrated glue: salient features

collective glue $f^{(j)}(\boldsymbol{\kappa})$



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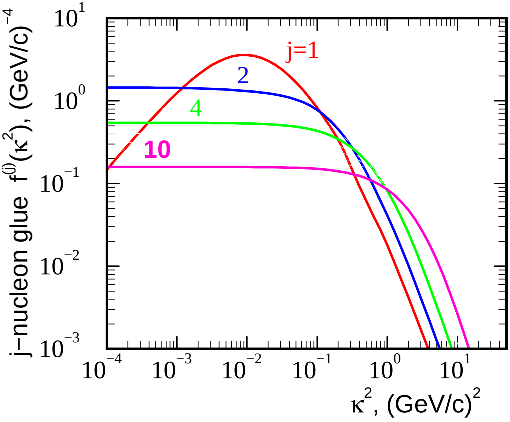

- nuclear coherent glue per unit area in impact parameter space:

$$\phi(\boldsymbol{b}, \boldsymbol{\kappa}) = \sum w_j(\boldsymbol{b}) f^{(j)}(\boldsymbol{\kappa})$$

- typical scale: the saturation scale $Q_A^2 \sim 0.8 \div 1$ GeV^2 for realistic glue and heavy nuclei.

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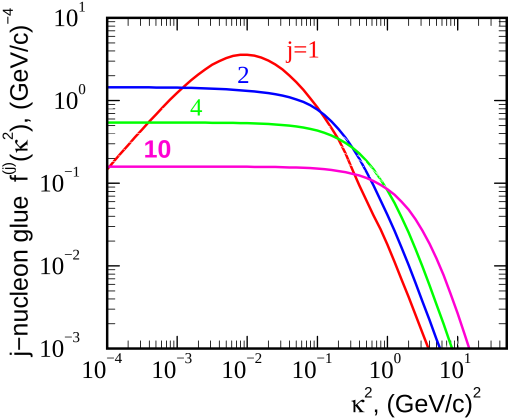

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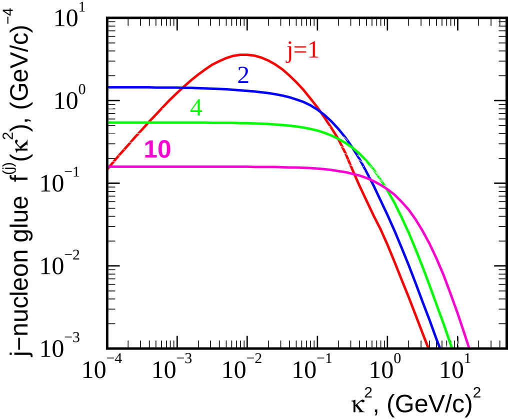

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- large–$\boldsymbol{\kappa}^2$ Cronin–type antishadowing enhancement
- furnishes linear $k_\perp$–factorization of inclusive deep inelastic, forward jets in DIS, and diffractive dijets.

Nuclear unintegrated glue: small-x evolution

- unintegrated glue:

$$\Phi(\boldsymbol{b}, x, \boldsymbol{p}) \equiv \int \frac{d^2\boldsymbol{r}}{(2\pi)^2} \exp[-i\boldsymbol{p}\boldsymbol{r}]\, S_{q\bar{q}}(\boldsymbol{b}, x, \boldsymbol{r}) = w_0\, \delta^{(2)}(\boldsymbol{p}) + \phi(\boldsymbol{b}, x, \boldsymbol{p})$$

- small–x evolution *Nikolaev, Zakharov, Zoller / Mueller'94*:

$$S_{q\bar{q}}(\boldsymbol{b}, x_0, \boldsymbol{r}) \to S_{q\bar{q}}(\boldsymbol{b}, x_0, \boldsymbol{r}) + \log(x_0/x)\delta S_{q\bar{q}}(\boldsymbol{b}, x, \boldsymbol{r})$$

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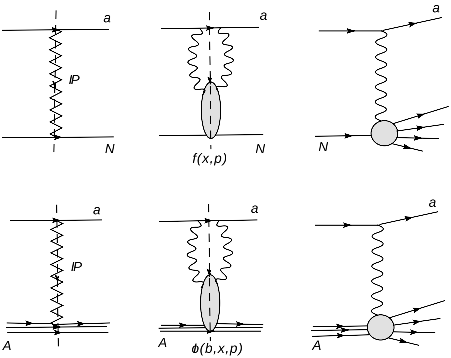
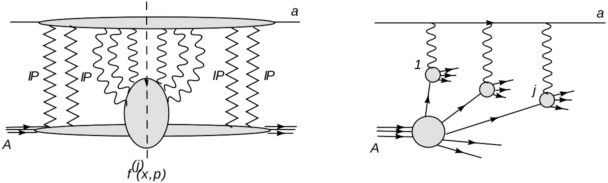
Unitarity cut interpretation of the nuclear glue



$$\phi(\boldsymbol{b}, x, \boldsymbol{\kappa}) = \sum_{j \geq 1} w_j\big(\nu_A(\boldsymbol{b})\big) f^{(j)}(x, \boldsymbol{\kappa})$$



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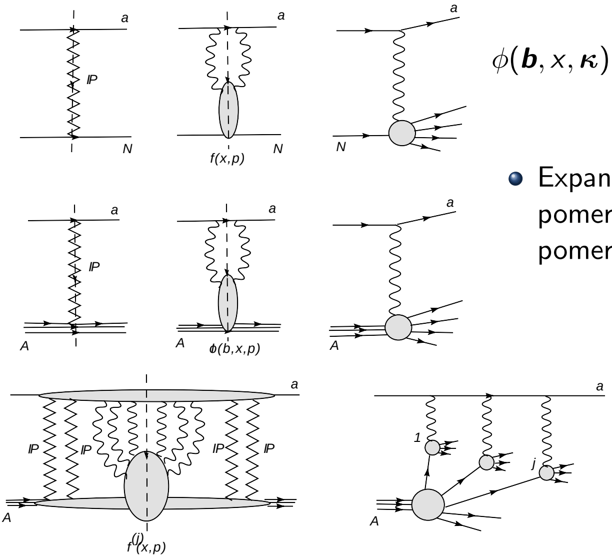

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- Expansion of the cut nuclear pomeron in the cut free-nucleon pomerons

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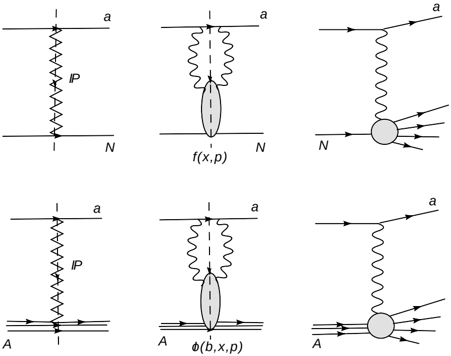

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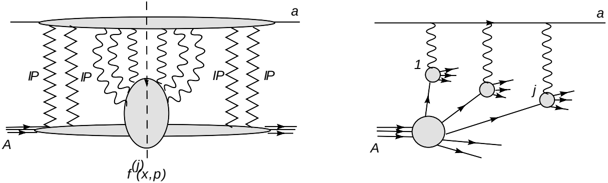
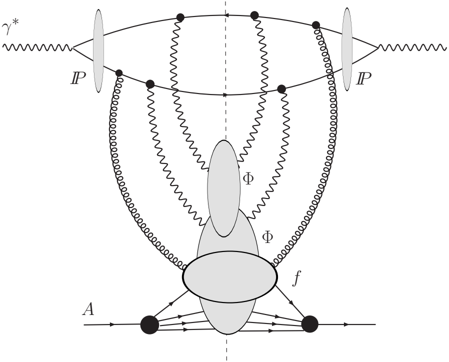
- Expansion of the cut nuclear pomeron in the cut free-nucleon pomerons
- Screening by uncut pomerons in the expansion coefficients



Uncut, and two types of cut Pomerons



- coherent distortion of lightcone WF $\longrightarrow$ uncut Pomeron exchanges.

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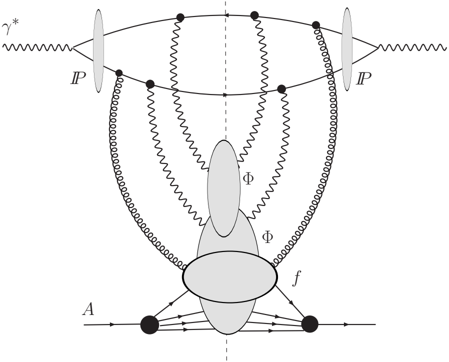

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- Color coupled channel property $\longrightarrow$ two types of cut pomerons:

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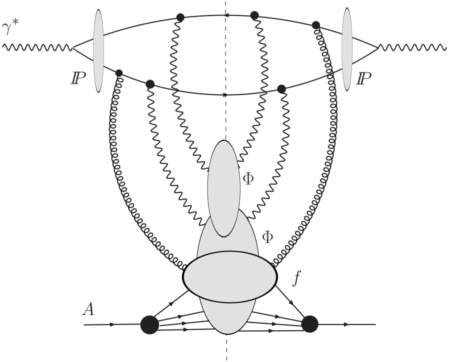

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- Color coupled channel property $\longrightarrow$ two types of cut pomerons:
  - transitions between two multiplets of different dimensionality (here $1 \rightarrow 8$): necessarily leaves a color excited nucleon, coupling $\propto T_A(\boldsymbol{b}) f(x, \boldsymbol{\kappa})$, couples to both constituents.

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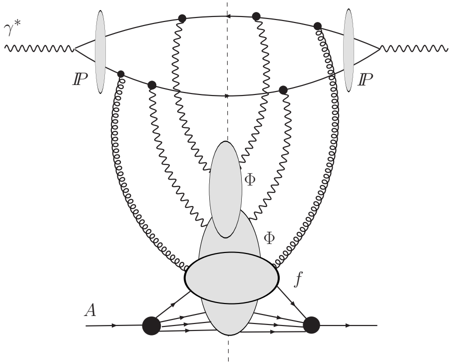

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  - rotations within the same color multiplet: summed up in the nuclear Reggeons. Coupling $\propto \Phi(\boldsymbol{b}, x, \boldsymbol{\kappa}_i)$.

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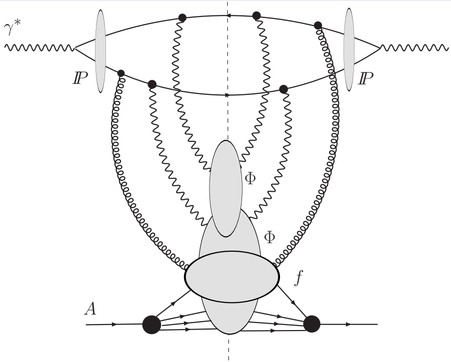

- A color rotation Pomeron contributes j color excited nucleons with a weight $\propto w_j(\boldsymbol{b})\, f^{(j)}(x, \boldsymbol{\kappa}_i)$.

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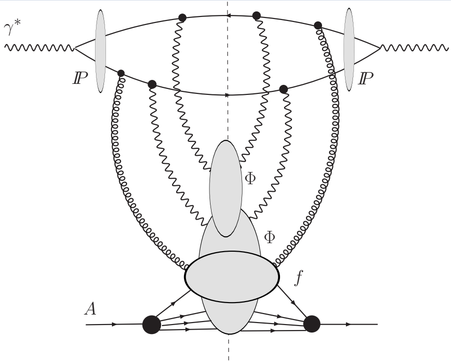

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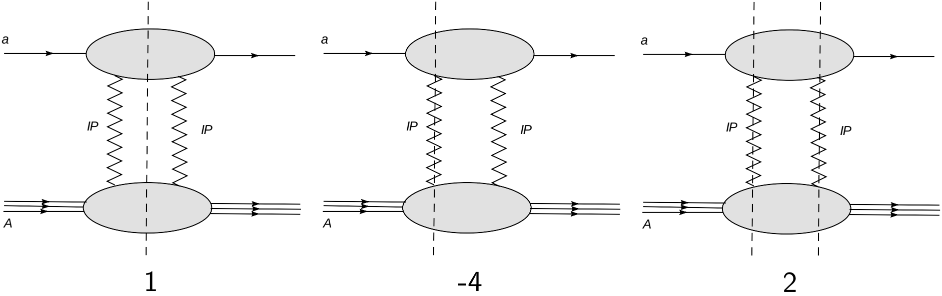
- Even for single–particle spectra, in topological cross sections, *spectator interactions leave a trace*

QCD vs. standard AGK: two-Pomeron cuts



- AGK for DIS off a nucleus:

$$\Delta_2 \Gamma_2^{in}(\not{\mathbb{P}}\not{\mathbb{P}}; \boldsymbol{b}, \boldsymbol{r}) = -[\sigma(x, \boldsymbol{r}) T(\boldsymbol{b})]^2$$

$$\Delta_2 \Gamma_D(\mathbb{P}\mathbb{P}; \boldsymbol{b}, \boldsymbol{r}) : \Delta_2 \Gamma_1^{in}(\not{\mathbb{P}}\mathbb{P}; \boldsymbol{b}, \boldsymbol{r}) : \Delta_2 \Gamma_2^{in}(\not{\mathbb{P}}\not{\mathbb{P}}; \boldsymbol{b}, \boldsymbol{r}) = 1 : -4 : 2$$

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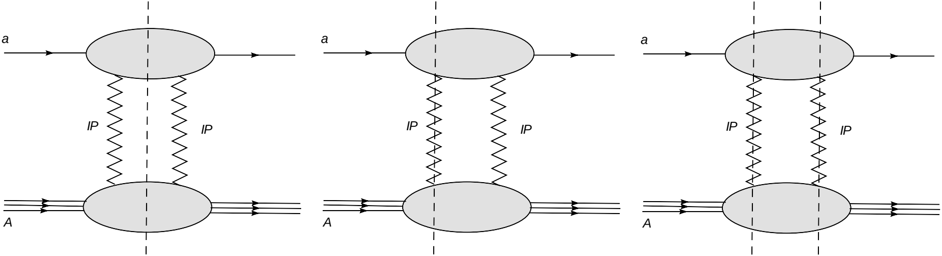

- QCD: the cut pomerons couple differently to singlet–to–octet excitation and octet–to–octet rotation:

$$\Delta_2\Gamma_1^{in}(\not{\mathbb{P}}_e\,\mathbb{P};\boldsymbol{b},\boldsymbol{r}) = -\frac{1}{2}\cdot[\sigma_0(x)T(\boldsymbol{b})]\cdot[\sigma(x,\boldsymbol{r})T(\boldsymbol{b})] - \frac{1}{2}[\sigma(x,\boldsymbol{r})T(\boldsymbol{b})]^2$$

$$\Delta_2\Gamma_2^{in}(\not{\mathbb{P}}_r\,\not{\mathbb{P}}_e;\boldsymbol{b},\boldsymbol{r}) = \frac{1}{2}\cdot[\sigma_0(x)T(\boldsymbol{b})]\,[\sigma(x,\boldsymbol{r})T(\boldsymbol{b})]$$

QCD vs. standard AGK: topological cross sections

Inelastic cross section of the $q\bar{q}$-dipole-Nucleus interaction:

$$\begin{aligned}
\Gamma^{inel}(\boldsymbol{r}, \boldsymbol{b}) &= 1 - \exp[-\sigma(\boldsymbol{r}) T(\boldsymbol{b})] \\
&= \exp[-\sigma(\boldsymbol{r}) T(\boldsymbol{b})] \sum_{\nu} \frac{1}{\nu!} [\sigma(\boldsymbol{r}) T(\boldsymbol{b})]^{\nu}
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- Following Capella-Kaidalov-Bertocchi-Treleani:
  $\exp[-\sigma(\boldsymbol{r})T(\boldsymbol{b})][\sigma(\boldsymbol{r})T(\boldsymbol{b})]^{\nu}/\nu! =$ contribution from ν cut Pomerons

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- Invalid in QCD. Ignores the role of spectator interactions and the two types of cut Pomerons.
- Spectrum of forward quarks in DIS. ν cut Pomerons affect x_F distribution:

$$\frac{d\sigma_{\nu}}{d^2\boldsymbol{b}dx_F} = \int d^2\boldsymbol{r}\left|\psi(x_F,\boldsymbol{r})\right|^2\Gamma^{(\nu)inel}(\boldsymbol{r},\boldsymbol{b})$$

Summary

- Topological cross sections follow directly from nonlinear-$k_\perp$ factorization for inclusive cross sections
- Novel property of QCD unitarity cutting rules: two kinds of cut pomerons
- Comover/spectator interactions contribute to topological cross sections