Two-Gluon Correlations in Heavy-Light Ion Collisions

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Based on the works:

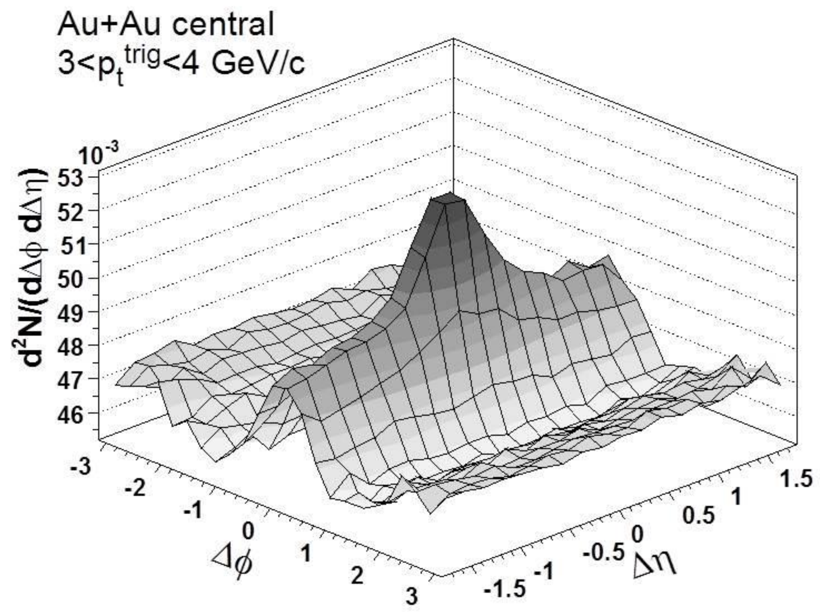
YV Kovchegov, DE Wertepny, Long-Range Rapidity Correlations in Heavy-Light Ion Collisions, Nuclear Physics A (2013), arXiv:1212.1195.

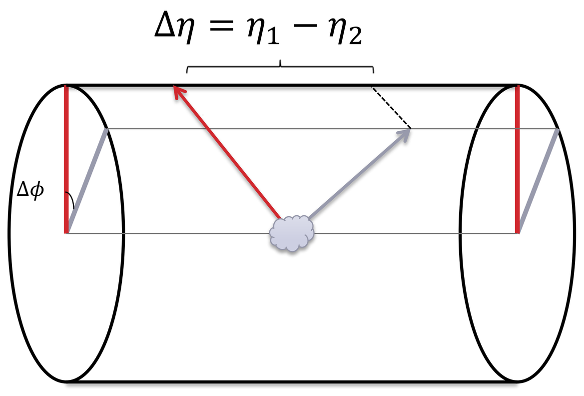
YV Kovchegov, DE Wertepny, Two-Gluon Correlations in Heavy-Light Ion Collisions: Energy and Geometry Dependence, IR Divergences, and k_T-Factorization, Nuclear Physics A (2014), arXiv:1310.6701

I) Abstract

We derive the cross-section for two-gluon production in heavy-light ion collisions in the saturation/Color Glass Condensate framework. This is the first-ever two-gluon production calculation including saturation effects to all orders in one of the nuclei (heavy ion) along with a single saturation correction in the projectile (light ion). The calculation of the correlation function predicted (qualitatively) two identical ridge-like correlations, near- and away-side. This prediction was later supported by experiment findings. Concentrating on the energy and geometry dependence of the correlation functions we find that the correlation function is nearly center-of-mass energy independent. The geometry dependence of the correlation function leads to an enhancement of near- and away-side correlations for the tip-on-tip U+U collisions when compared with side-on-side U+U collisions, an exactly opposite behavior from the correlations generated by the elliptic flow of the quark-gluon plasma.

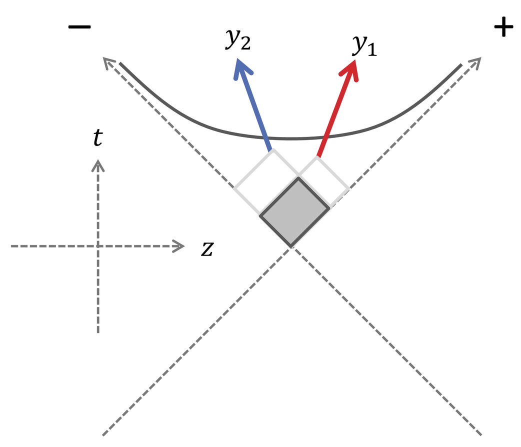
II) The Ridge





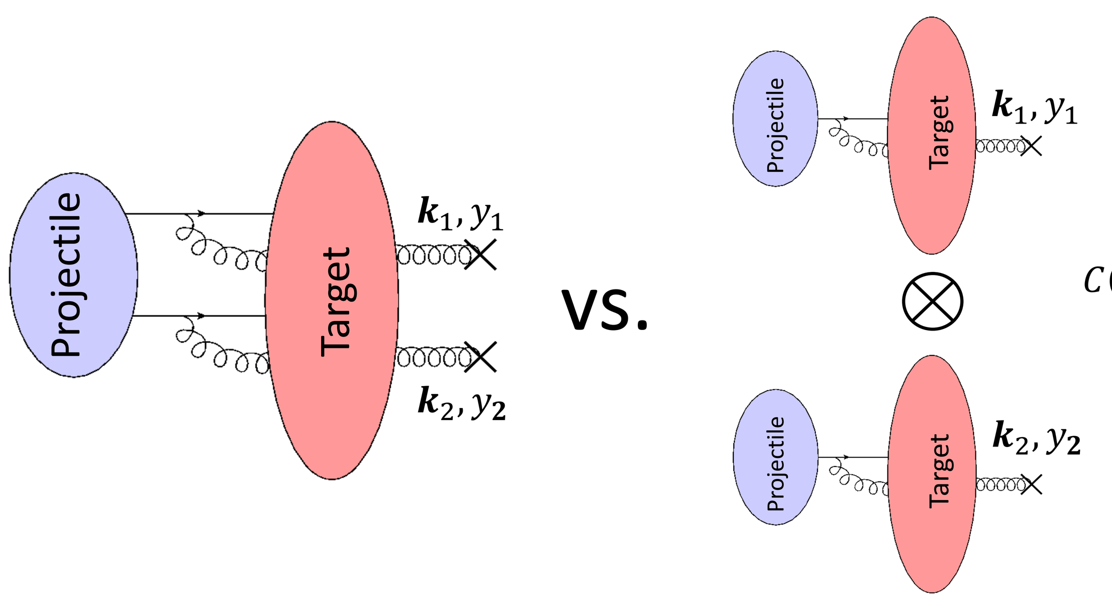
The correlations of interest are **two-particle, ridge like, correlations which are long-range in rapidity and centered in azimuthal angle.** Originally observed in A+A collisions and it has since been observed in p+A and p+p collisions. The data above is from the STAR collaboration for Au+Au collisions. [1]

Due to causality arguments, **long-range rapidity correlations** must originate from **early-time dynamics**.



III) Two-Gluon Correlations

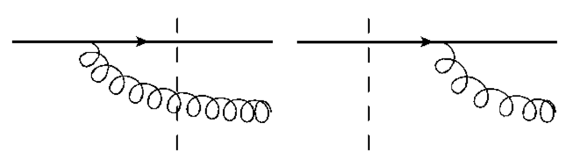
Since gluons dominate the early-time dynamics we model the two-particle correlations by calculating the two-gluon correlations.



$$C(\boldsymbol{k}_1, y_1, \boldsymbol{k}_2, y_2) = N \frac{\frac{d\sigma}{dk_1 dy_1 dk_2 dy_2}}{\frac{d\sigma}{dk_1 dy_1}\,\frac{d\sigma}{dk_2 dy_2}} - 1$$

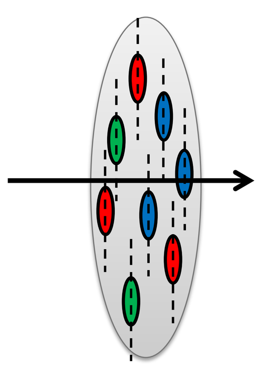
IV) Saturation Physics Calculation

Due to multiple scatterings in high energy ion collisions, the gluon density does not increase indefinitely, it gets cut-off at the **saturation scale**, **Q_s**. This is known as saturation physics and is used to describe the early-time gluon dynamics.



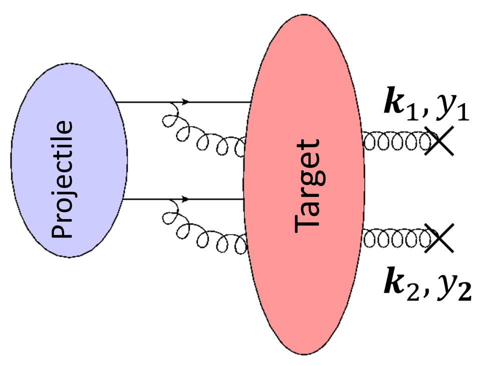
Gluon emission from the projectile is viewed separately from the interaction with the target. Can happen before or after the interaction, represented by a dashed line.

A quark or a gluon propagating through a nucleus at high energy can be thought of as traveling through a shockwave, modelled as a Wilson line.



$$U_{\boldsymbol{x}} = \mathrm{P}\exp\left\{ig\int_{-\infty}^{\infty} dx^+ \, \mathcal{A}^-(x^+, x^- = 0, \boldsymbol{x})\right\}$$

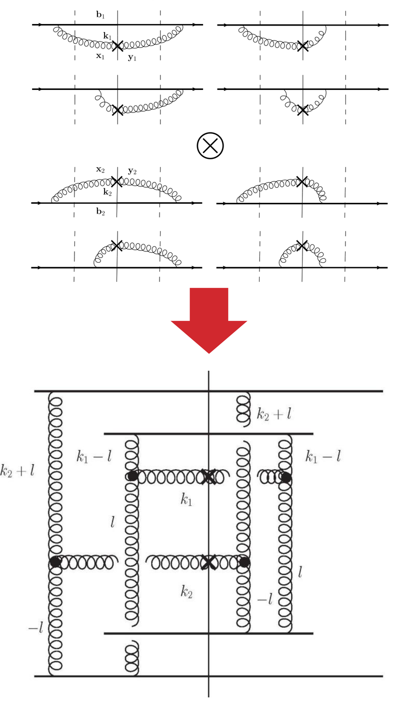
$$\mathcal{A}^- = \sum_i T^a A_i^{a-}$$



We look at **heavy-light ion collisions**. Two gluons are emitted from two different nucleons inside the projectile (the light ion). These gluons then interact with the target (the heavy ion).

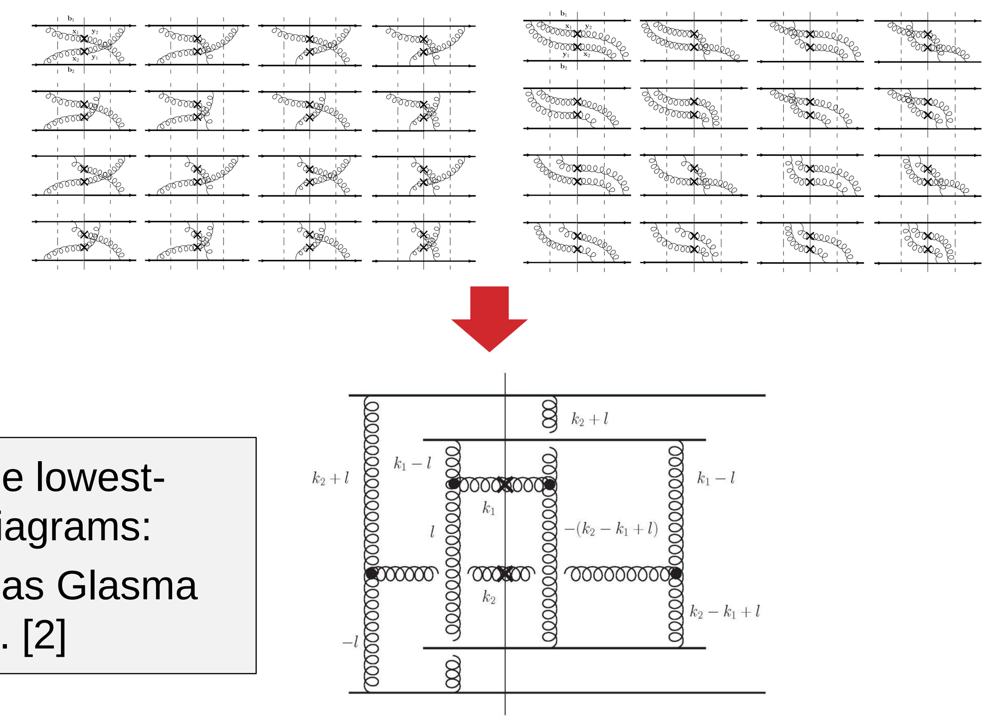
We sum up all of the resulting diagrams, including **all-orders in saturation** in the target.

Separated



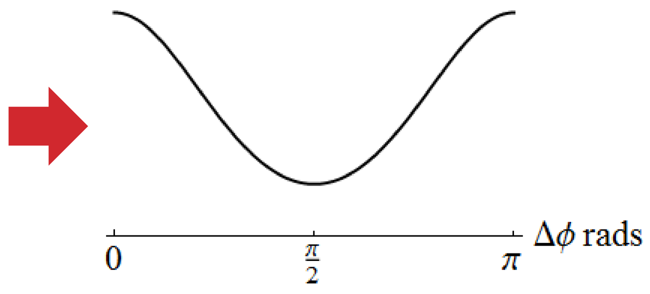
Example lowest-order diagrams: Known as Glasma Graphs. [2]

Crossed

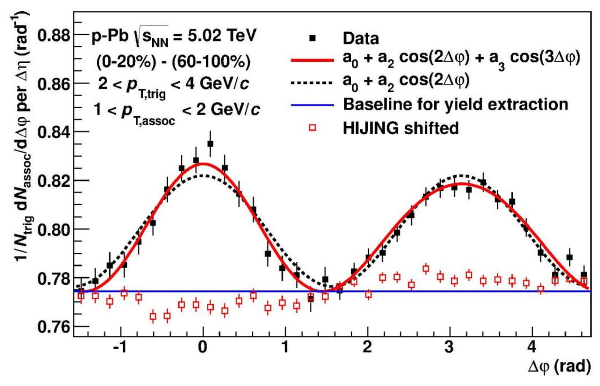


The all-order in saturation result (with the lowest-order result given below) is symmetric under **$k_2 \to -k_2$**.

$$C(\boldsymbol{k}_1, y_1, \boldsymbol{k}_2, y_2)\big|_{LO} = \frac{1}{N_c^2}\,\frac{\int d^2B\, d^2b\, [T_1(\boldsymbol{B}-\boldsymbol{b})]^2\, Q_{s0}^4(\boldsymbol{b})}{\int d^2B\, d^2b_1\, d^2b_2\, T_1(\boldsymbol{B}-\boldsymbol{b}_1)\, T_1(\boldsymbol{B}-\boldsymbol{b}_2)\, Q_{s0}^2(\boldsymbol{b}_1)\, Q_{s0}^2(\boldsymbol{b}_2)}$$
$$\times \frac{\boldsymbol{k}_1^2\, \boldsymbol{k}_2^2}{\ln\frac{k_1^2}{\Lambda^2}\, \ln\frac{k_2^2}{\Lambda^2}} \left\{2\int_\Lambda \frac{d^2l}{(\boldsymbol{l}^2)^2}\left[\frac{1}{(\boldsymbol{k}_1-\boldsymbol{l})^2\,(\boldsymbol{k}_2+\boldsymbol{l})^2} + \frac{1}{(\boldsymbol{k}_1-\boldsymbol{l})^2\,(\boldsymbol{k}_2-\boldsymbol{l})^2}\right]\right.$$
$$+\frac{1}{8}\left[\int \frac{d^2l}{(\boldsymbol{l}^2)^2\,((\boldsymbol{l}-\boldsymbol{k}_1+\boldsymbol{k}_2)^2)^2\,((\boldsymbol{k}_1-\boldsymbol{l})^2)^2\,((\boldsymbol{k}_2+\boldsymbol{l})^2)^2}\left[\boldsymbol{l}^2\,(\boldsymbol{k}_2+\boldsymbol{l})^2 + (\boldsymbol{k}_1-\boldsymbol{l})^2\,(\boldsymbol{l}-\boldsymbol{k}_1+\boldsymbol{k}_2)^2 - \boldsymbol{k}_1^2\,(\boldsymbol{k}_2-\boldsymbol{k}_1+2\,\boldsymbol{l})^2\right]\right.$$
$$\left.\left.\times\left[\boldsymbol{l}^2\,(\boldsymbol{k}_1-\boldsymbol{l})^2 + (\boldsymbol{k}_2+\boldsymbol{l})^2\,(\boldsymbol{l}-\boldsymbol{k}_1+\boldsymbol{k}_2)^2 - \boldsymbol{k}_2^2\,(\boldsymbol{k}_2-\boldsymbol{k}_1+2\,\boldsymbol{l})^2\right] + (\boldsymbol{k}_2 \to -\boldsymbol{k}_2)\right]\right\}.$$

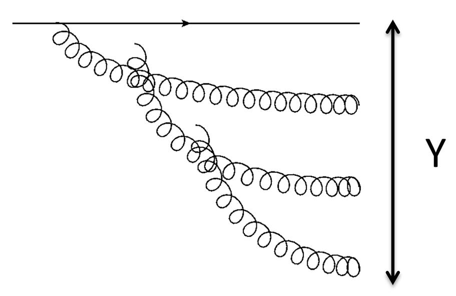


ALICE result, which was published after the initial publication of our first paper, supported the symmetric nature of the correlation function. [3]



V) Energy Dependence

We use the **BK evolution equations** to **evolve the center of mass energy of the two gluons**, increasing the rapidity gap between the projectile and the emitted gluons. The BK equation cannot be solved exactly but there exists known analytic approximations. We are using the **k_1, $k_2 \gtrsim Q_s(Y)$** limit.



$$\partial_Y S_{BK}(\boldsymbol{x}, \boldsymbol{y}, Y) = \frac{\alpha_S N_c}{2\pi^2}\int d^2z \frac{(\boldsymbol{x}-\boldsymbol{y})^2}{(\boldsymbol{x}-\boldsymbol{z})^2(\boldsymbol{y}-\boldsymbol{z})^2}\left[S_{BK}(\boldsymbol{x}, \boldsymbol{z}, Y) S_{BK}(\boldsymbol{z}, \boldsymbol{y}, Y) - S_{BK}(\boldsymbol{x}, \boldsymbol{y}, Y)\right]$$

$$1 - S_{BK}(\boldsymbol{x}, \boldsymbol{y}, Y) \propto \left[|\boldsymbol{x}_1 - \boldsymbol{x}_1|\, e^{\lambda Y/2}\, Q_{s0}\right]^{1+2i\nu_0}$$

We relate the BK solution to our result using Gaussian truncation. Process has numerical support. [4]

$$N_G(\boldsymbol{x}_1, \boldsymbol{x}_2, Y) \approx 1 - [S_{BK}(\boldsymbol{x}, \boldsymbol{y}, Y)]^2 \approx c_0\left[|\boldsymbol{x}_1 - \boldsymbol{x}_1|\, e^{\lambda Y/2}\, Q_{s0}\right]^{1+2i\nu_0}$$

$$\frac{d\sigma}{d^2k dy} \propto e^{\lambda(1+2i\nu_0)Y/2}$$

$$\frac{d\sigma}{d^2k_1 dy_1 d^2k_2 dy_2} \propto e^{\lambda(1+2i\nu_0)Y}$$

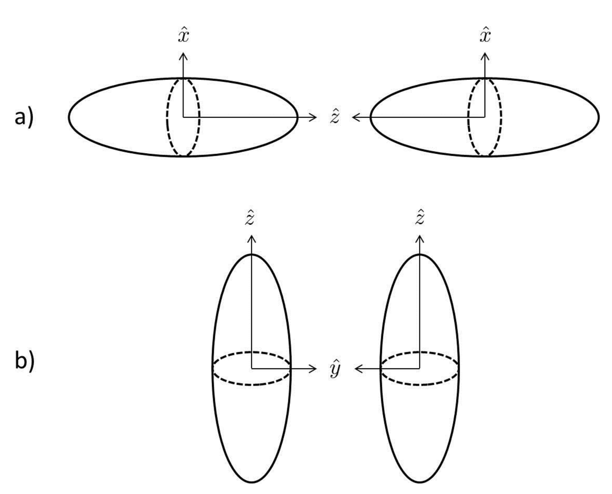
Energy dependence of the two gluon cross-section can be similarly determined.

The resulting correlation function is **nearly energy independent**.

$$C(\boldsymbol{k}_1, y_1, \boldsymbol{k}_2, y_2) = N \frac{\frac{d\sigma}{dk_1 dy_1 dk_2 dy_2}}{\frac{d\sigma}{dk_1 dy_1}\,\frac{d\sigma}{dk_2 dy_2}} - 1 \propto \mathrm{const(Y)}$$

VI) U+U Collisions

To see ellipticity's effect on the correlation we compare two different collisional geometries of U+U, head- and side-on collisions. The Uranium is modeled as a prolate ellipsoid, the collision at zero impact parameter and at leading order in saturation scale (in the large **k_T** limit). We insert the below nuclear profile functions in the lowest-order correlation function result.



$$\rho(\vec{\boldsymbol{r}}) = \rho_0\, e^{-\frac{x^2}{R^2} - \frac{y^2}{R^2} - \frac{\lambda^2}{R^2} z^2}$$

$$T_{head-on}(\boldsymbol{b}) = \sqrt{\pi}\,\frac{R}{\lambda}\,\rho_0\, e^{-\frac{b^2}{R^2}}$$

$$T_{side-on}(\boldsymbol{b}) = \sqrt{\pi}\, R\, \rho_0\, e^{-\frac{x^2}{R^2} - \frac{\lambda^2}{R^2} z^2}$$

$$\frac{C_{head-on}(\boldsymbol{k}_1, y_1, \boldsymbol{k}_2, y_2)\big|_{LO}}{C_{side-on}(\boldsymbol{k}_1, y_1, \boldsymbol{k}_2, y_2)\big|_{LO}} = \frac{1}{\lambda} \approx 1.26$$

Results in an **enhancement for head-on collisions as compared to side-on collisions**. **Opposite of elliptic flow**, it can be used to differentiate the two effects.

Bibliography

1) STAR Collaboration Collaboration, B. Abelev et. al., Long range rapidity correlations and jet production in high energy nuclear collisions, Phys.Rev. C80 (2009) 064912, [arXiv:0909.0191].
2) A. Dumitru, F. Gelis, L. McLerran, and R. Venugopalan, Glasma flux tubes and the near side ridge phenomenon at RHIC, Nucl. Phys. A810 (2008) 91–108, [arXiv:0804.3858].
3) ALICE Collaboration Collaboration, B. Abelev et. al., Long-range angular correlations on the near and away side in p-Pb collisions at sqrt(sNN) = 5.02 TeV, [arXiv:1212.2001].
4) A. Dumitru, J. Jalilian-Marian, T. Lappi, B. Schenke, and R. Venugopalan, Renormalization group evolution of multi-gluon correlators in high energy QCD, Phys.Lett. B706 (2011) 219{224, [arXiv:1108.4764].