Collectivity from interference

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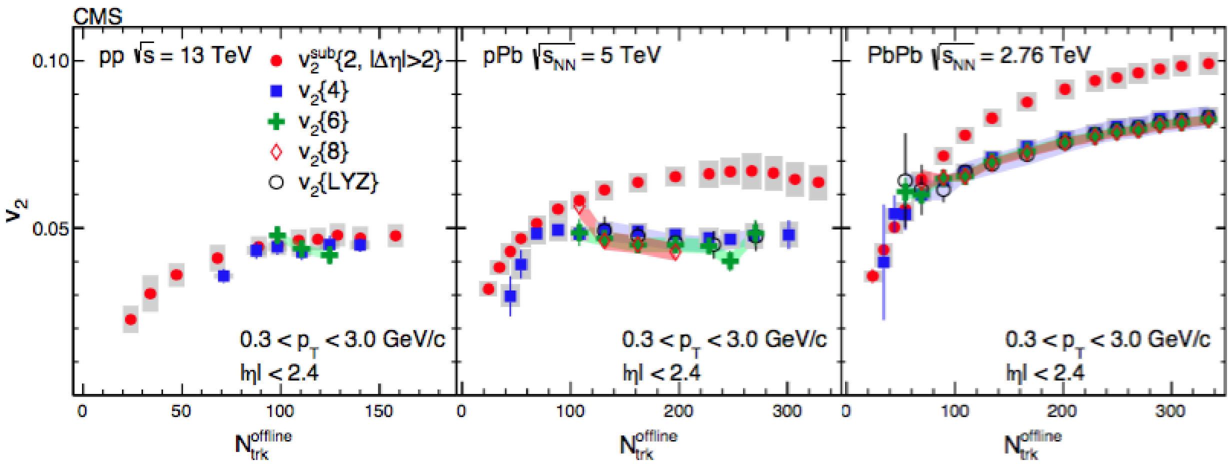
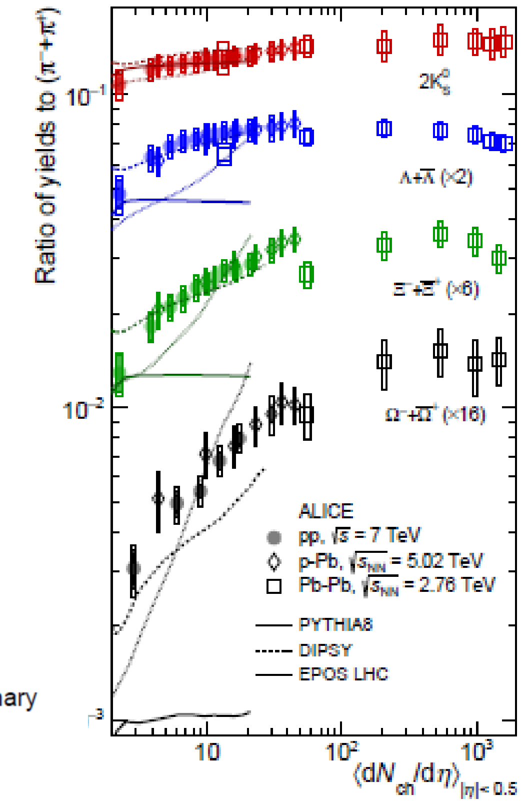
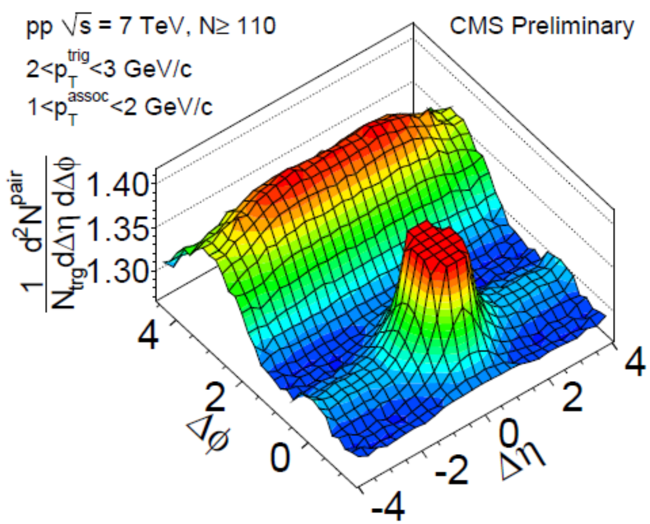
JHEP 1712 (2017) 074
e-Print: ***arXiv:1708.08241***

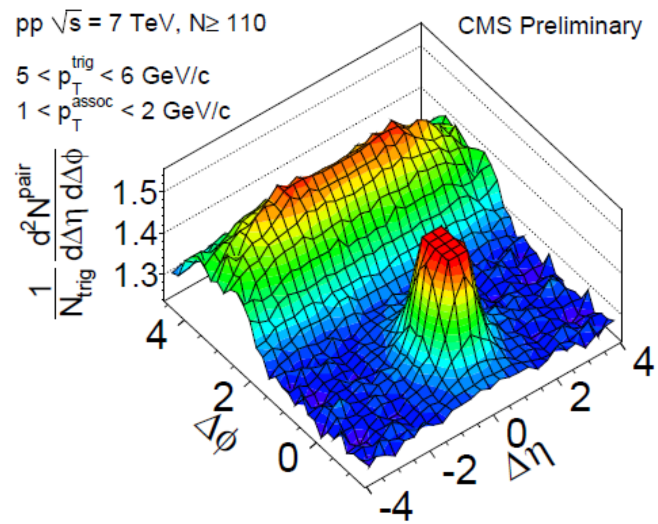
Problem:heavy ion like behavior, in particular ridge is seen even in pp collisions, as it was found at LHC by all 3 collaborations: CMS,ATLAS,Alice. The appearance of such ridge correlations first seen in A-A collisons at RHIC is quite remarkable, since it was always assumed that such correlations arise naturally as a result of strong final state interactions (FSI) that occur in AA collisions. Together with jet quenching they are considered as main signs of QGP.





Large FSI is a basis of both hydrodynamics and jet quenching





There are several possibilities:
1)FSI effects may be large but lead to small quenching rates-so hydrodynamical approach is still valid (for experimental signatures
of such scenario see B.Nachman, M. Mangano.
2) Saturation models, based on CGC (color glass condensate approach) based on saturation effects in initial state wave function of hadrons.
T. Altinluk, N. Armesto, G. Beuf, A. Kovner and M. Lublinsky,
T. Lappi, B. Schenke, S. Schlichting and R. Venugopalan,
A. Dumitru, K. Dusling, F. Gelis, J. Jalilian-Marian, T. Lappi and R. Venugopalan
A. Kovner and M. Lublinsky, Y. V. Kovchegov and D. E. Wertepny,
K. Dusling and R. Venugopalan,, E. Iancu and A. H. Rezaeian,
L. McLerran and V. Skokov,

Such models however can not explain good description of many properties of underlying event (UE) , including large multiplicity pp events by MC generators. Can one have description of collective flow requiring only mild extension of current MC generators? Can ridge have different nature in pp and AA collisions?

This talk: ridge correlations appear without strong FSI or saturation
In the fame work of no interaction baseline, only from interference /coherence between different multiparton interactions (MPIs), that are part of conventional description of pp collisions by MC generators.
Low density scenario, Collectivity from interference –This Talk
1. No initial density, no initial asymmetry, no final state interactions
2. The cumulants naturally come from quantum-mechanical (QM) interference and color correlations.

Hence:1)does not imply jet quenching in pp/pA
2) natural extension of MC generators, that contain in UE up to 10-20 MPI events (Sjostrand)
The interference occurs not between gluons radiated by separate partons, but between different
Hard processes, i.e. different MPIs, which we call “sources

Observation of flow-like signatures in pp and pA motivates to revisit fluid dynamical paradigm.

- Fluid dynamics and transport theory invoke final state interactions.

- But final state interactions imply jet quenching, which is not seen in pp and pA.

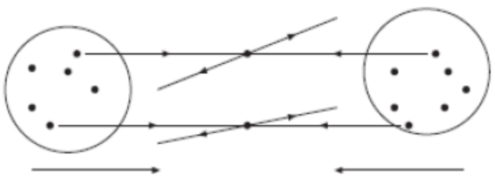
$\Rightarrow$ Either, jet quenching exists in pp & pA but effects are too small to be observed so far,

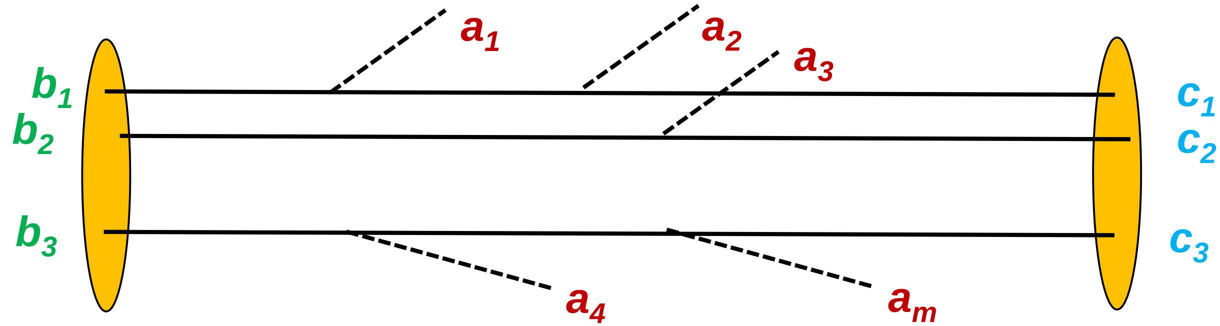
$\Rightarrow$ Or collectivity can build up without final state interactions. How? By quantum interference?

This question motivates the present study.

A simplified model of multi-parton production

- Schematic picture: pp collision = multiple parton-parton interactions at positions y_i.

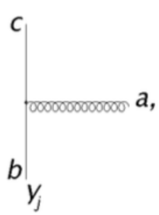




Source lines start (end) with colors b_i (c_j) at rapidity of 1[st] (2[nd]) hadron.

- Diagrammatic rules: gluon emission keeps track of **color** and **phases** exactly.

(basis for understanding QCD interference effects)

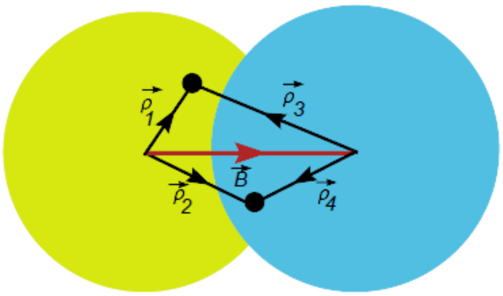


$$= \boxed{T^a_{b_i c_i}} \int d\mathbf{x}\, \vec{f}(\mathbf{x}-\mathbf{y}) \boxed{e^{i\,\mathbf{k}.\mathbf{x}}} \equiv T^a_{b_i c_i} \boxed{\vec{f}(\mathbf{k})} \exp\left[i\,\mathbf{y}.\mathbf{k}\right]$$

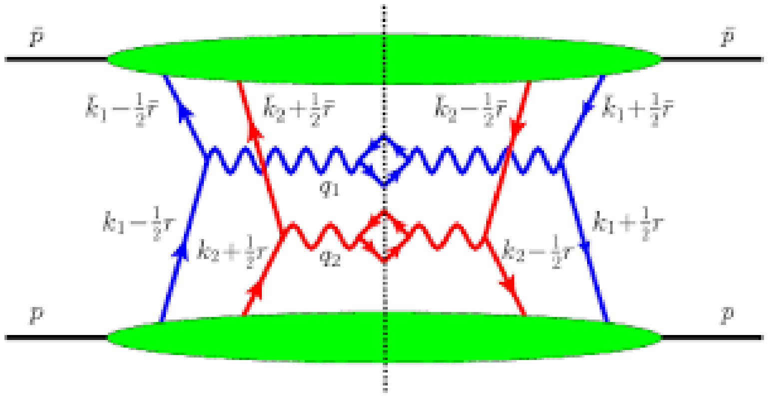
- Simplifications (to make calculation of m-particle emission possible)
    - Don't specify **kinematics**.
    - Flat rapidity dependence of f(k).
    - Gluons do not cross.

Set-up without final state interactions and without initial state density effects <u>allows for calculation of m-particle interference and higher order cumulants</u>.

Basic ideas about MPI geometry



$$\sigma_{2\ MPIs} = \frac{\sigma_1\,\sigma_2}{\sigma_{\text{eff}}}$$



$$\sigma_{N\,\mathrm{MPI}} = \frac{\sigma_1 \ldots \sigma_N}{K_N}\,.$$

- *Generalized parton distribution functions (GPDs) carry geometrical information*

$$\frac{1}{K_N} = \int \left(\prod_{i=1}^{N} \frac{d\boldsymbol{\Delta}_i}{(2\pi)^2}\right) \frac{G_N(\{x_i\},\{Q_i^2\},\{\boldsymbol{\Delta}_i\})\,G_N(\{x_i'\},\{Q_i^2\},\{\boldsymbol{\Delta}_i\})}{\prod_{i=1}^{N}(f(x_i,Q_i^2)\,f(x_i',Q_i^2))}\,\delta^{(2)}\left(\sum_{i=1}^{N}\boldsymbol{\Delta}_i\right)$$

- *Probabilistic interpretation of GPDs in a mean-field approximation* **Blok, Dokshitzer, Frankfurt, Strikman, PRD 83, 071501 (2011)**

$$G_N(\{x_i\},\{Q_i^2\},\{\boldsymbol{\Delta}_i\}) = \prod_{i=1}^{N} G_1(x_i,Q_i,\boldsymbol{\Delta}_i) = \prod_{i=1}^{N} f(x_i,Q_i)F_{2g}(\boldsymbol{\Delta}_i)$$

- *Only purpose for the following:* $F_{2g}^2(\Delta) = \exp(-B\Delta_i^2)$

$$\boxed{B = 2\,\mathrm{GeV}^{-2} \quad \longleftrightarrow \quad \sigma_{\text{eff}} \approx 20\,\mathrm{mb}}$$

LHC data set scale of parameter B

- *Density distribution of colliding partons in pp*

$$\rho(\{\mathbf{y}_i\},\mathbf{b}) = \prod_j \frac{1}{(4\pi B)^2}\exp\left[-\frac{\mathbf{y}_j^2}{4B}\right]\exp\left[-\frac{(\mathbf{y}_j-\mathbf{b})^2}{4B}\right]$$

The new GPDs can be explicitly expressed through the light cone wave functions of the hadron as

$$
\begin{aligned}
D & (x_1, x_2, p_1^2, p_2^2, \overrightarrow{\Delta}) = \sum_{n=3}^{\infty} \int \frac{d^2 k_1}{(2\pi)^2} \frac{d^2 k_2}{(2\pi)^2} \theta(p_1^2 - k_1^2) \\
\times & \theta(p_2^2 - k_2^2) \int \prod_{i \neq 1,2} \frac{d^2 k_i}{(2\pi)^2} \int_0^1 \prod_{i \neq 1,2} dx_i \\
\times & \psi_n(x_1, \vec{k}_1, x_2, \vec{k}_2, .., \vec{k}_i, x_i..) \\
\times & \psi_n^+(x_1, \overrightarrow{k_1} + \overrightarrow{\Delta}, x_2, \overrightarrow{k_2} - \overrightarrow{\Delta}, x_3, \vec{k}_3, ...) \\
\times & (2\pi)^3 \delta(\sum_{i=1}^{i=n} x_i - 1) \delta(\sum_{i=1}^{i=n} \vec{k}_i).
\end{aligned}
$$

Here psi are the light cone wave functions of the nucleon in the initial and final states.

The approximation of independent particles.

Suppose the multiparton wave faction factorise, i.e. we neglect possible interparton correlations and recoil effects. Then it's straightforward to see that the two particle GPDs factorise and acquire a form: •

$$D(x_1, x_2, p_1^2, p_2^2, \vec{\Delta}) = G(x_1, p_1^2, \vec{\Delta})G(x_2, p_2^2, \vec{\Delta}),$$

The one-particle GPD-s G are conventionally written in the dipole form:

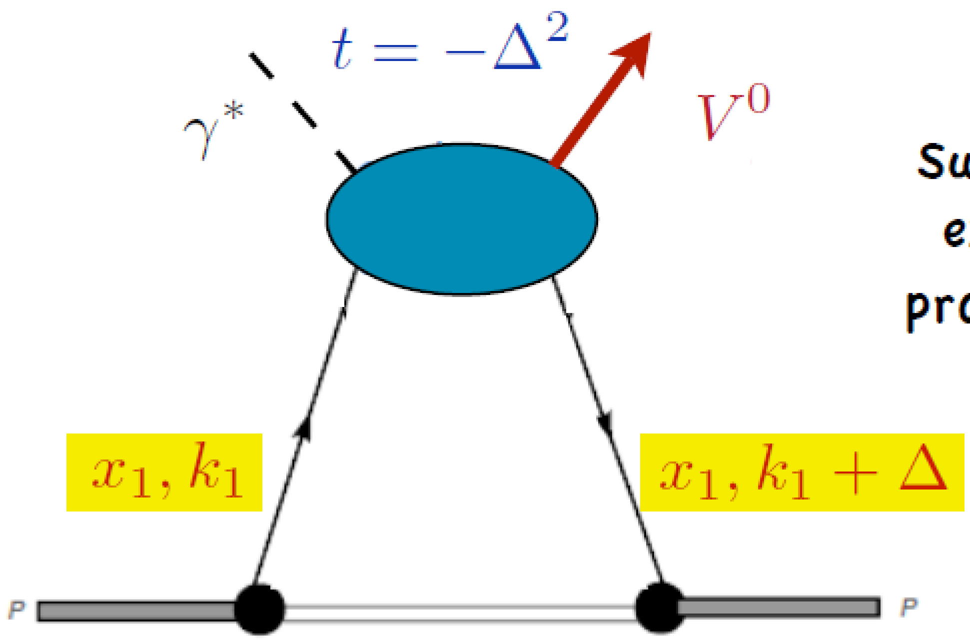
$$G_N(x, Q^2, \vec{\Delta}) = G_N(x, Q^2)F_{2g}(\Delta)$$

G - the usual 1-parton distribution (determining DIS structure functions)

F - the two-gluon form factor of the nucleon

the dipole fit : $$F_{2g}(\Delta) \simeq \frac{1}{\left(1 + \Delta^2/m_g^2\right)^2}$$

$$m_g^2(x \sim 0.03, Q^2 \sim 3\mathrm{GeV}^2) \simeq 1.1\mathrm{GeV}^2$$

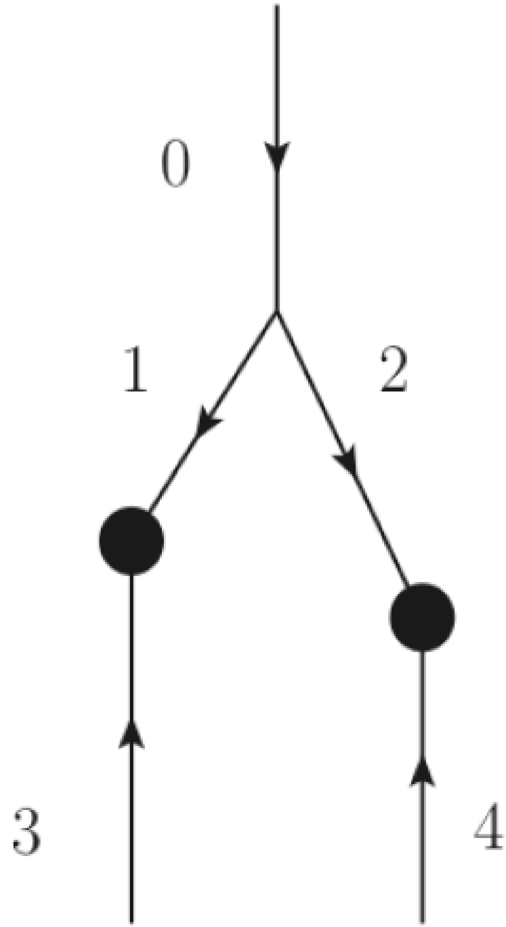


G P D

Such an amplitude describes exclusive photo-(/electro-) production of vector mesons at HERA !

$$\frac{1}{\pi R_{\rm int}^2} = \int \frac{d^2\Delta}{(2\pi)^2} F_{2g}^4(\Delta) = \frac{m_g^2}{28\pi}.$$

$$R_{\rm int}^2 = 7/2 r_g^2, \qquad r_g^2/4 = dF_{2g}(t)/dt_{t=0}.$$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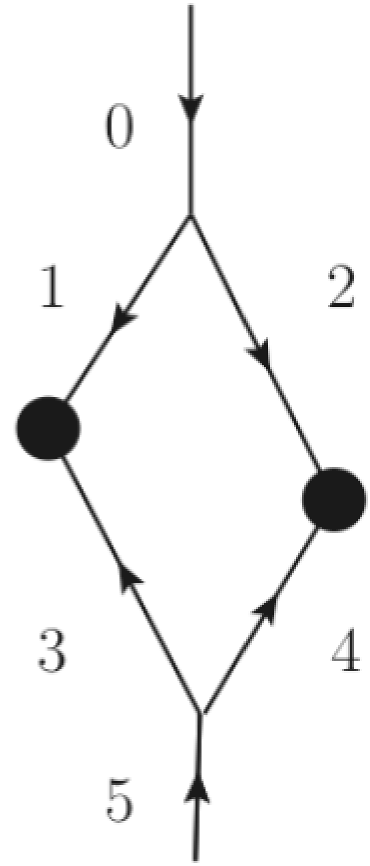
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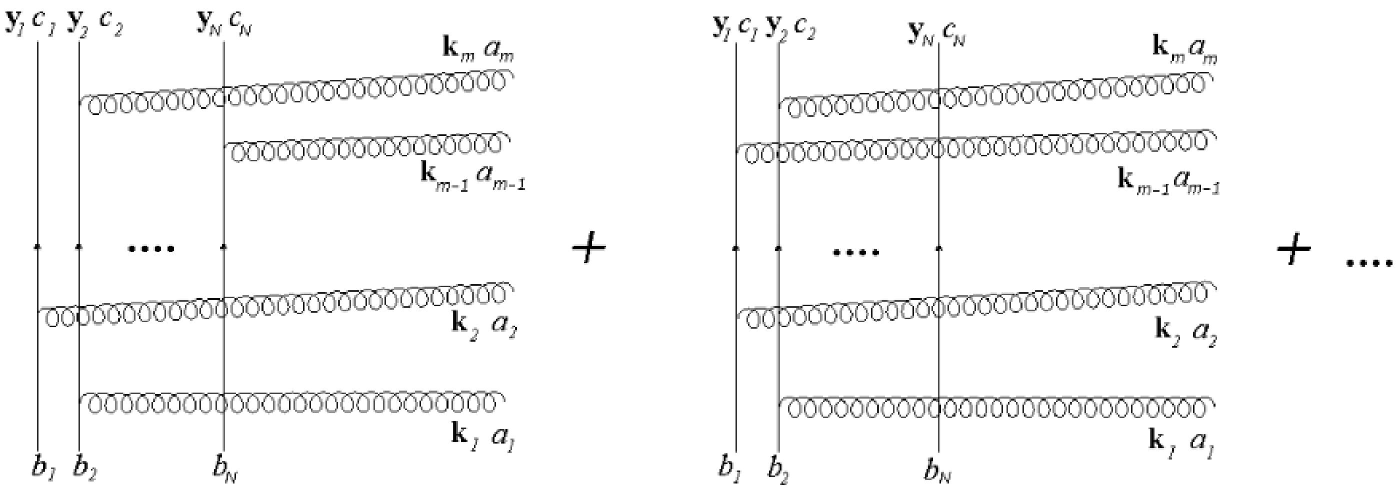
m-gluon emission from N sources: interference effects

- *This model has N^m different m-particle emission amplitudes:*



- *Summing up and squaring these emission amplitudes returns a* ***gluon spectrum for a fixed set of transverse positions y_i.*** *Averaging over transverse positions with a* ***classical weight****,* *one finds the spectrum*

$$\frac{d\Sigma}{d\mathbf{k}_1 ... d\mathbf{k}_m} = \int \left(\prod_{i=1}^{N} d\mathbf{y}_i \right) \boxed{\rho(\{y_i\})} \boxed{\hat{\sigma}\left(\{\mathbf{k}_j\}, \{y_i\}\right)}$$

We want to calculate this spectrum and its azimuthal anisotropies $v_n\{2k\}$ for arbitrary m and N.

Inclusive m-gluon cross section from N sources

- *Complete result in large N limit: (contains sums over source doublets, triplets, quadruplets, pairs of doublets, …)*

B. Blok, C.Jäkel, M. Strikman, U.Wiedemann, JHEP 1712 (2017)

$$
\begin{aligned}
\hat{\sigma} \propto\ & N_c^m \left(N_c^2-1\right)^N \left(\prod_{i=1}^{m} \left|\vec{f}(\mathbf{k}_i)\right|^2\right) N^{m-4} \\
\times \Bigg\{ & N^4 + F_{\rm corr}^{(2)}(N,m)\frac{N^2}{(N_c^2-1)} \sum_{(ab)} \sum_{(lm)} 2^2 \cos(\mathbf{k}_a.\Delta\mathbf{y}_{lm}) \cos(\mathbf{k}_b.\Delta\mathbf{y}_{lm}) \\
& + F_{\rm corr}^{(3i)}(N,m)\frac{N}{(N_c^2-1)^2} \sum_{(abc)} \sum_{(lm)(mn)(nl)} 2^3 \cos(\mathbf{k}_a.\Delta\mathbf{y}_{lm}) \\
& \qquad \times \cos(\mathbf{k}_b.\Delta\mathbf{y}_{mn}) \cos(\mathbf{k}_c.\Delta\mathbf{y}_{nl}) \\
& + F_{\rm corr}^{(4i)}(N,m)\frac{1}{(N_c^2-1)^2} \sum_{(lm),(no)} \sum_{(ab)(cd)} 2^4 \cos(\mathbf{k}_a.\Delta\mathbf{y}_{lm}) \cos(\mathbf{k}_b.\Delta\mathbf{y}_{lm}) \\
& \qquad \times \cos(\mathbf{k}_c.\Delta\mathbf{y}_{no}) \cos(\mathbf{k}_d.\Delta\mathbf{y}_{no}) \\
& + F_{\rm corr}^{(4ii)}(N,m)\frac{1}{(N_c^2-1)^3} \sum_{(lm)(mn)(no)(ol)} \sum_{(abcd)} 2^4 \cos(\mathbf{k}_a.\Delta\mathbf{y}_{lm}) \cos(\mathbf{k}_b.\Delta\mathbf{y}_{mn}) \\
& \qquad \times \cos(\mathbf{k}_c.\Delta\mathbf{y}_{no}) \cos(\mathbf{k}_d.\Delta\mathbf{y}_{ol}) \\
& + F_{\rm corr}^{(5)}(N,m)\frac{N^{-1}}{(N_c^2-1)^3} \sum_{[(lm)(mn)(nl)](op)} \sum_{(abc)(de)} 2^2 \cos(\mathbf{k}_d.\Delta\mathbf{y}_{op}) \cos(\mathbf{k}_e.\Delta\mathbf{y}_{op}) \\
& \qquad \times 2^3 \cos(\mathbf{k}_a.\Delta\mathbf{y}_{lm}) \cos(\mathbf{k}_b.\Delta\mathbf{y}_{mn}) \cos(\mathbf{k}_c.\Delta\mathbf{y}_{nl}) \\
& + F_{\rm corr}^{(6)}(N,m)\frac{N^{-2}}{(N_c^2-1)^3} \sum_{(lm)(no)(pq)} \sum_{(ab)(cd)(ef)} 2^2 \cos(\mathbf{k}_a.\Delta\mathbf{y}_{lm}) \cos(\mathbf{k}_b.\Delta\mathbf{y}_{lm}) \\
& \qquad \times 2^2 \cos(\mathbf{k}_c.\Delta\mathbf{y}_{no}) \cos(\mathbf{k}_d.\Delta\mathbf{y}_{no})\, 2^2 \cos(\mathbf{k}_e.\Delta\mathbf{y}_{pq}) \cos(\mathbf{k}_f.\Delta\mathbf{y}_{pq}) \\
& + O\left(\frac{1}{N}\right) + O\left(\frac{1}{(N_c^2-1)^4}\right) \Bigg\},
\end{aligned}
$$

From the spectra to v_n's and higher order cumulants

- *Once spectrum is known, azimuthal phase space averages can be formed*

N. Borghini, P. M. Dinh and J. Y. Ollitrault,

$$T_n(k_1,k_2) = \binom{m}{2} \int_\rho \int_0^{2\pi} d\phi_1\, d\phi_2\, \exp\left[in(\phi_1-\phi_2)\right] \left(\int \prod_{b=3}^{m} k_b\, dk_b\, d\phi_b \right) \hat{\sigma}$$

- *Suitably normalized, these define v_n's (2nd order cumulants)*

$$\overline{T}(k_1,k_2) = \binom{m}{2} \int_\rho \int_0^{2\pi} d\phi_1\, d\phi_2 \left(\int \prod_{b=3}^{m} k_b\, dk_b\, d\phi_b \right) \hat{\sigma}$$

$$\boxed{v_n^2\{2\}(k_1,k_2) \equiv \langle\langle e^{in(\phi_1-\phi_2)} \rangle\rangle(k_1,k_2) \equiv \frac{T_n(k_1,k_2)}{\overline{T}(k_1,k_2)}}$$

- *Higher order cumulants obtained in close similarity*

$$S(k_1,k_2,k_3,k_4) = \binom{m}{4} \int_\rho \int_0^{2\pi} d\phi_1\, d\phi_2\, d\phi_3\, d\phi_4\, e^{in(\phi_1+\phi_2-\phi_3-\phi_4)} \left(\int \prod_{b=5}^{m} k_b\, dk_b\, d\phi_b \right) \hat{\sigma}$$

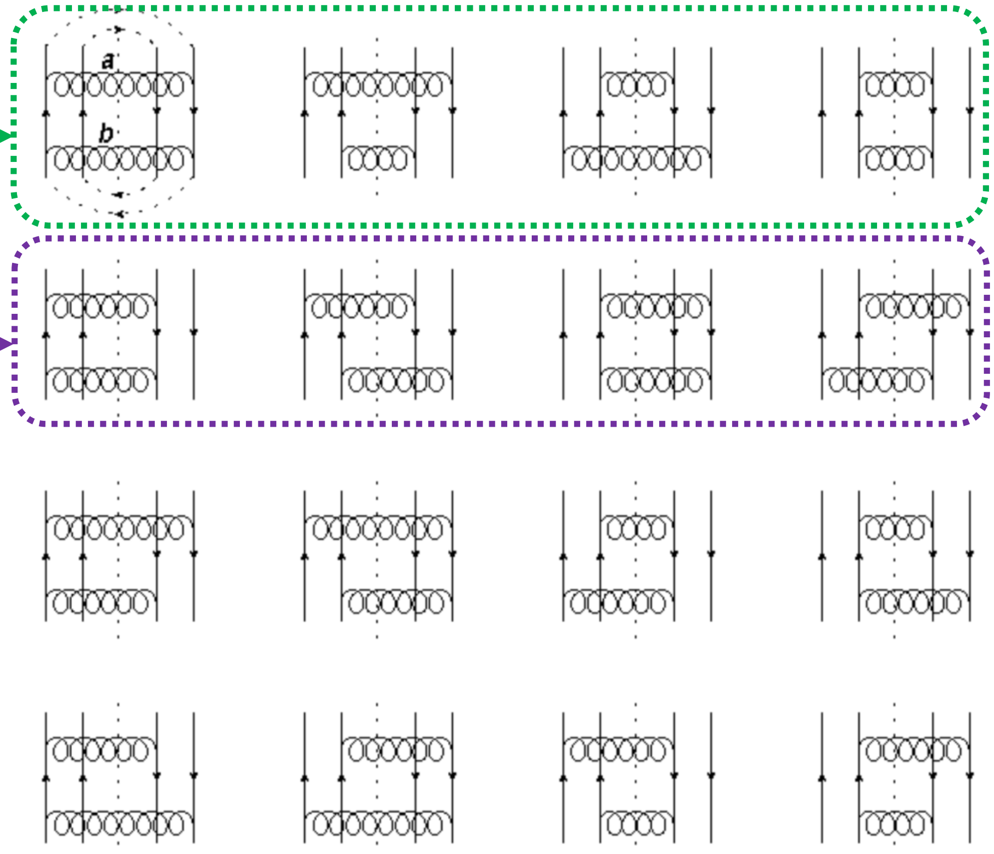
$$\langle\langle e^{in(\phi_1+\phi_2-\phi_3-\phi_4)} \rangle\rangle_c = \langle\langle e^{in(\phi_1+\phi_2-\phi_3-\phi_4)} \rangle\rangle - \langle\langle e^{in(\phi_1-\phi_3)} \rangle\rangle \langle\langle e^{in(\phi_2-\phi_4)} \rangle\rangle - \langle\langle e^{in(\phi_1-\phi_4)} \rangle\rangle \langle\langle e^{in(\phi_2-\phi_3)} \rangle\rangle$$

Simplest case: emitting m=2 gluons from N=2 sources

- *Color can be read easily from diagrams*

$$\mathrm{Tr}\left[T^aT^bT^bT^a\right]\,\mathrm{Tr}\left[\mathbb{1}\right] = N_c^2\,\left(N_c^2-1\right)^2$$

$$\mathrm{Tr}\left[T^aT^b\right]\,\mathrm{Tr}\left[T^bT^a\right] = N_c^2\,\left(N_c^2-1\right)$$



$$\text{phases} \propto e^{i\mathbf{k}.\mathbf{y}_i}\ \left(\propto e^{-i\mathbf{k}.\mathbf{y}_i}\right)$$

in amplitude (complex conj. amplitude)

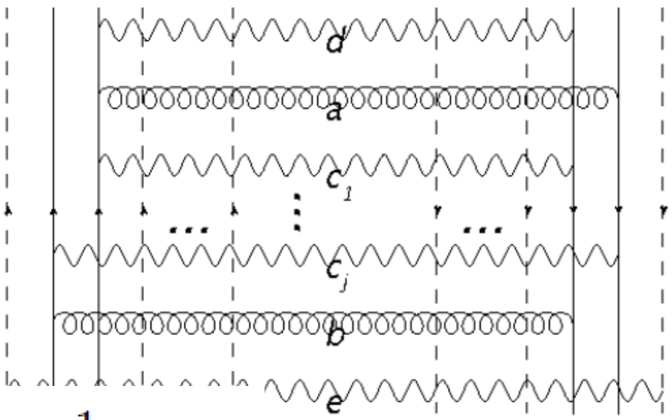
$$\frac{d\Sigma}{d\mathbf{k}_1 d\mathbf{k}_2} \propto \left|\vec{f}(\mathbf{k}_1)\right|^2 \left|\vec{f}(\mathbf{k}_2)\right|^2 \left[1 + \frac{\left(e^{-B(\mathbf{k}_1+\mathbf{k}_2)^2} + e^{-B(\mathbf{k}_1-\mathbf{k}_2)^2}\right)}{(N_c^2-1)}\right]$$

- *For $B = 1/Q_s^2$, this QCD agrees with CGC calculations,*

Altinoluk et al, PLB 751 (2015) 448; PLB 752 (2016) 113
Lappi, Schenke, Schlichting, Venugopalan JHEP 1601 (2016) 061

but it does not invoke saturation effects.

Analytical control over effects of diagonal gluons



Using, $T^{c_j} T^a T^{c_j} = \frac{1}{2} N_c T^a$ we can resum contributions from arbitrarily many diagonal gluons in color correction factors

$$\hat{\sigma} \propto (N_c^2 - 1)^N N_c^m \left(\prod_{i=1}^{m} \left| \vec{f}(\mathbf{k}_i) \right|^2 \right)$$
$$\times \left\{ N^m + \boxed{F_{\rm corr}^{(2)}(N, m)} \frac{N^{m-2}}{(N_c^2 - 1)} \sum_{(ab)} \sum_{(ij)} 4 \cos(\mathbf{k}_a . \Delta \mathbf{y}_{ij}) \cos(\mathbf{k}_b . \Delta \mathbf{y}_{ij}) \right.$$
$$\left. + O\left(\frac{1}{N} \frac{1}{(N_c^2 - 1)} \right) + O\left(\frac{1}{(N_c^2 - 1)^2} \right) \right\}.$$

$$F_{\rm corr}^{(2)}(N, m) = \frac{1}{\mathcal{N}_{\rm incoh}} \sum_{j=0}^{m-2} N^{m-2-j} (m - 1 - j) \left(\sum_{l=0}^{j} \binom{j}{l} 2^l (N-2)^{j-l} \frac{1}{2^l} \right)$$
$$= \frac{2}{m(m-1)} N^{1-m} \left(N(N-1)^m + m N^m - N^{1+m} \right) .$$

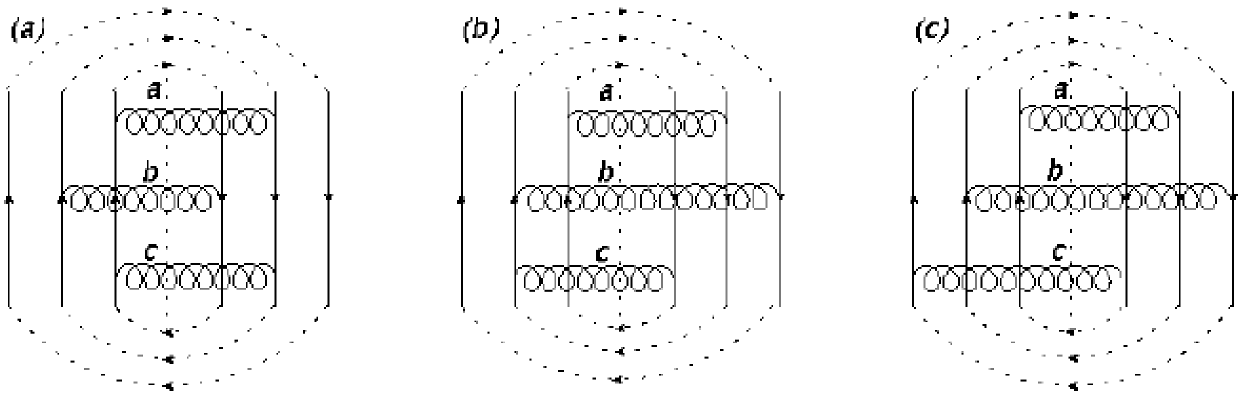
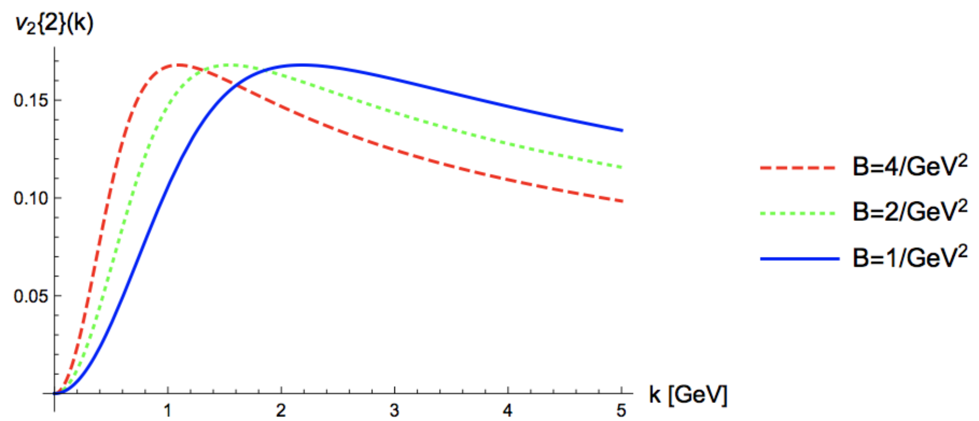


Figure 11. Examples for diagrammatic contributions with 3 off-diagonal gluons that link between one (a), two (b) and three (c) different pairs of sources. Contributions of type (b) vanish while contributions of type (a) and (c) have color traces that differ by a factor $(N_c^2 - 1)/4$, see text for more details.

2^{nd} order cumulant: v_2

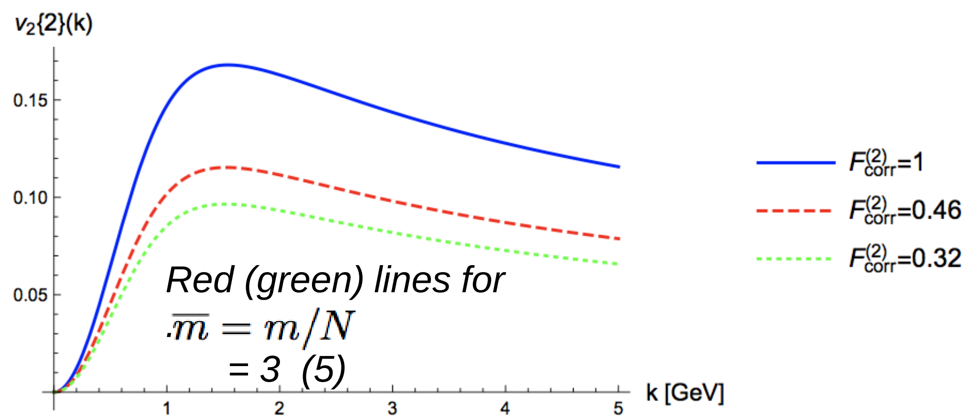
$$v_2^2\{2\}(k_1,k_2) \equiv \langle\langle e^{i2(\phi_1-\phi_2)}\rangle\rangle(k_1,k_2)$$
$$\equiv \frac{F^{(2)}_{\rm corr}(N,m)\int_\rho \frac{1}{N^2}\sum_{(ij)} 2^2 J_2\left(k_1\Delta y_{ij}\right)\, J_2\left(k_2\Delta y_{ij}\right)}{(N_c^2-1)+F^{(2)}_{\rm corr}(N,m)\int_\rho \frac{1}{N^2}\sum_{(ij)} 2^2 J_0\left(k_1\Delta y_{ij}\right)\, J_0\left(k_2\Delta y_{ij}\right)} + O\left(\frac{1}{(N_c^2-1)^2}\right)$$

- *Partonic v_2, may be modified by hadronization*
- *Signal persists to multi-GeV region*



- *For fixed average multiplicity per source, $\overline{m} = m/N$*

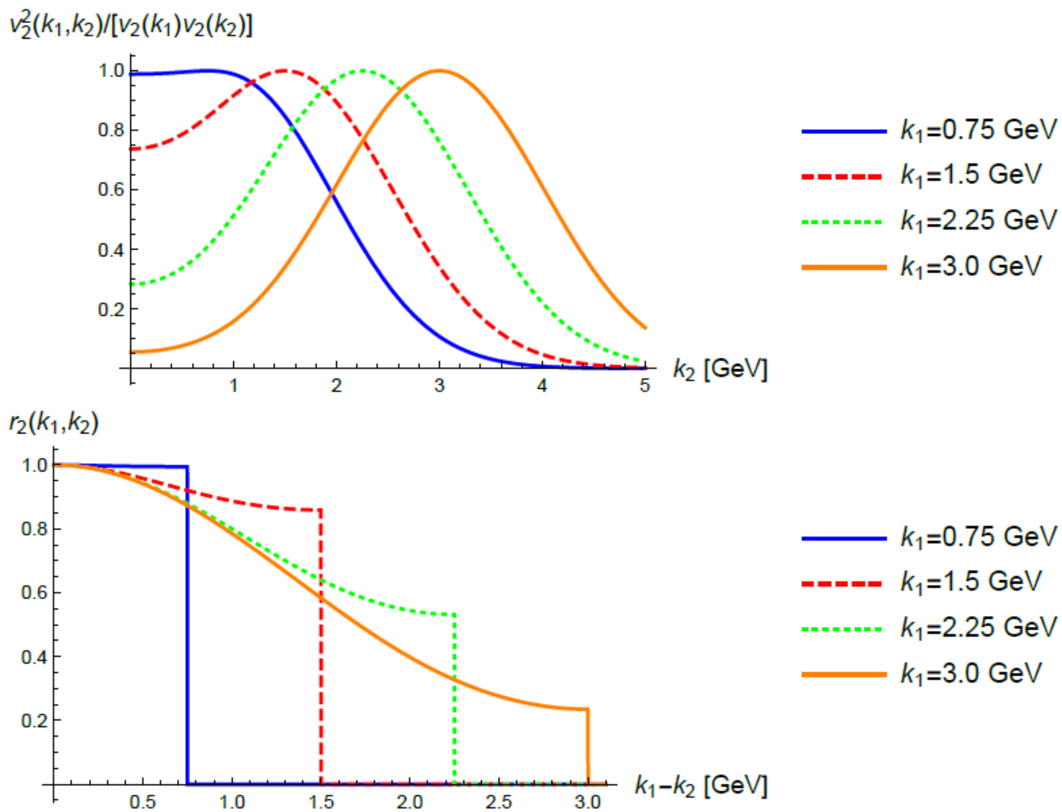
$$\lim_{m\to\infty} F^{(2)}_{\rm corr}(m/\overline{m}, m) = \frac{2\overline{m}+2e^{-\overline{m}}-2}{\overline{m}^2}\,.$$



For any multiplicity m, $v_2^2\{2\}$ is finite in the limit $N \to \infty$ of a large number of sources.

$v_2^2\{2\}(k_1, k_2)$ does not factorize except for small transverse momentum.

Compatible with hydrodynamics



4^{th} order cumulant: v_2

$$\langle\langle e^{i2(\phi_1+\phi_2-\phi_3-\phi_4)}\rangle\rangle_c = (Bk_1^2)\,(Bk_2^2)\,(Bk_3^2)\,(Bk_4^2)$$

$$\Big\{\frac{1}{(N_c^2-1)^2}\left(\boxed{2\,F^{(4i)}_{\rm corr} - 2F^{(2)}_{\rm corr}F^{(2)}_{\rm corr}} + O\left(N^{-1}\right)\right)$$

$$+\frac{1}{(N_c^2-1)^3}\Big(2\,F^{(6)}_{\rm corr}(m-4)(m-5) - 4\,F^{(2)}_{\rm corr}\,F^{(4i)}_{\rm corr}(m-2)(m-3)$$

$$+4\,F^{(5)}_{\rm corr}(m-4) - 4\,F^{(2)}_{\rm corr}F^{(3)}_{\rm corr}(m-2)$$

$$+2\,F^{(4ii)}_{\rm corr} + 8\left(F^{(2)}_{\rm corr}\right)^3 - 4\,F^{(4i)}_{\rm corr}F^{(2)}_{\rm corr}\Big) + O\left(N^{-1}\right)\Big\}$$

$$+O\left(1/(N_c^2-1)^4\right)\,.$$

The leading order ~ $\frac{1}{(N_c^2-1)^2}$ *vanishes but the next order ~* $1/(N_c^2-1)^3$ *is always negative!*

$$v_n\{4\} \equiv \sqrt[4]{-\langle\langle e^{in(\phi_1+\phi_2-\phi_3-\phi_4)}\rangle\rangle_c}$$

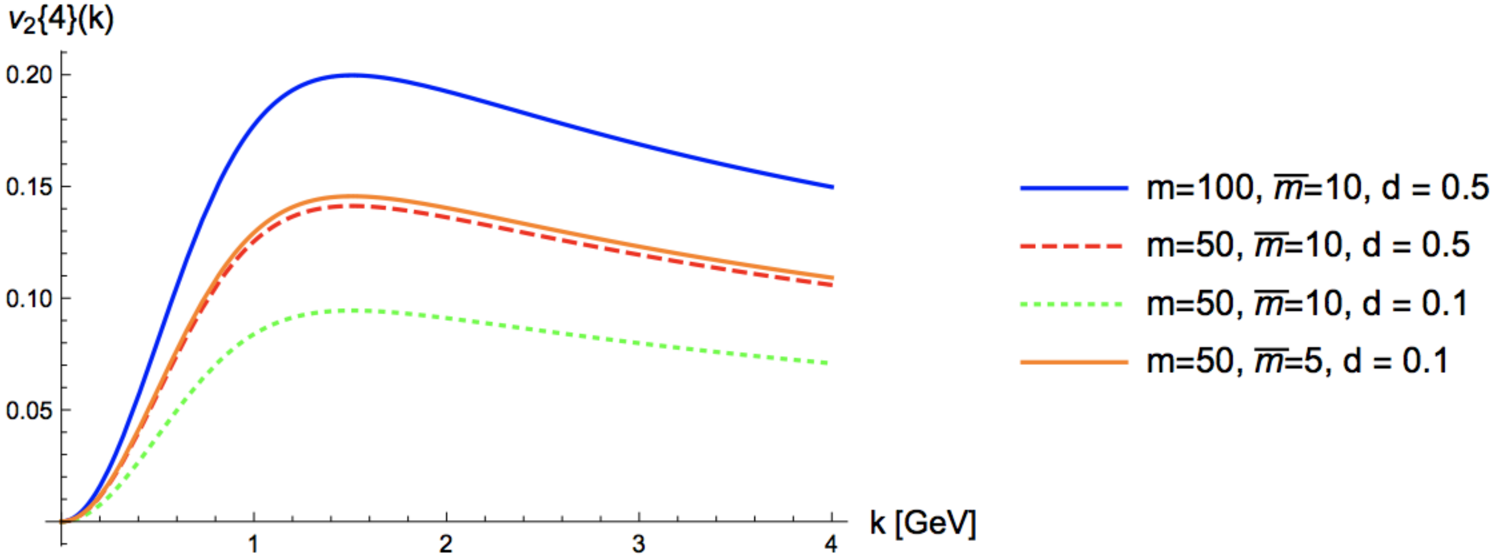
$$\boxed{v_2\{4\}(k) \simeq \frac{1}{(N_c^2-1)^{3/4}}2^{1/4}\sqrt{m}\,B\,k^2}$$

…4th order cumulant, cont'd …

CGC result for $v_2\{4\}$ has same N_c but different m- (N?)-dependencies,

$$v_n\{4\} \equiv \sqrt[4]{-\langle\langle e^{in(\phi_1+\phi_2-\phi_3-\phi_4)}\rangle\rangle_c}\,.$$

$$\boxed{v_2\{4\}(k) \simeq \frac{1}{(N_c^2-1)^{3/4}} 2^{1/4}\sqrt{m}\,B\,k^2}$$



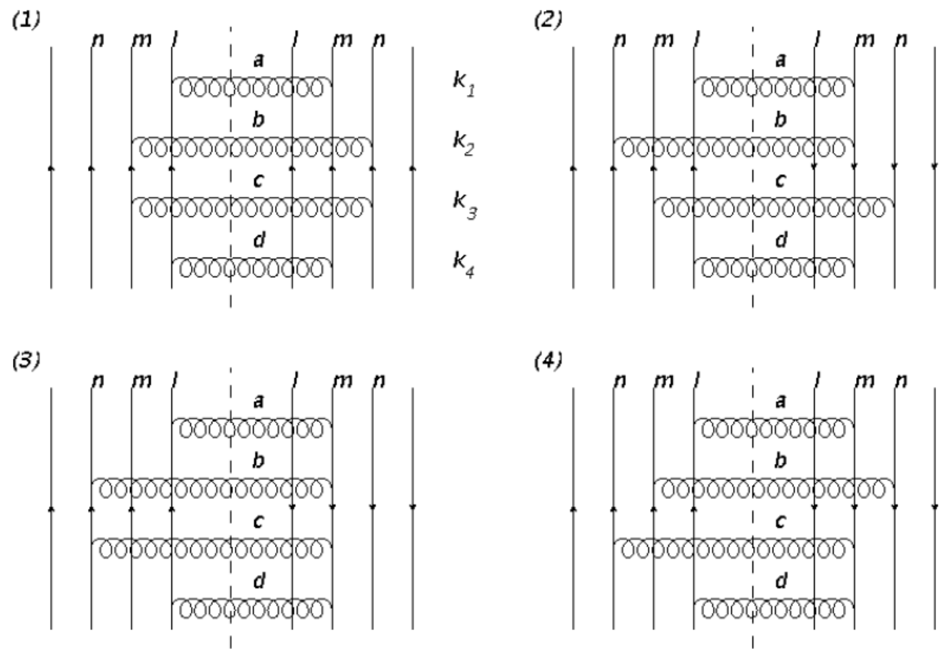
Odd **harmonics**

$$\mathrm{Tr}\,[\mathbb{1}]\ \mathrm{Tr}\left[T^c T^b\right]\ \mathrm{Tr}\left[T^b T^c T^d T^a\right]\ \mathrm{Tr}\left[T^a T^d\right] = N_c^4\,\left(N_c^2-1\right)^2$$

$$\mathrm{Tr}\,[\mathbb{1}]\ \mathrm{Tr}\left[T^b T^c\right]\ \mathrm{Tr}\left[T^c T^d T^b T^a\right]\ \mathrm{Tr}\left[T^a T^d\right] = \frac{1}{2} N_c^4\,\left(N_c^2-1\right)^2$$

$$\mathrm{Tr}\,[\mathbb{1}]\ \mathrm{Tr}\left[T^b T^c\right]\ \mathrm{Tr}\left[T^d T^c T^b T^a\right]\ \mathrm{Tr}\left[T^a T^d\right] = N_c^4\,\left(N_c^2-1\right)^2$$

$$\mathrm{Tr}\,[\mathbb{1}]\ \mathrm{Tr}\left[T^c T^b\right]\ \mathrm{Tr}\left[T^b T^d T^c T^a\right]\ \mathrm{Tr}\left[T^a T^d\right] = \frac{1}{2} N_c^4\,\left(N_c^2-1\right)^2$$



To order 1/N, differences in color factors break the k to –k symmetry

$$e^{i\,\mathbf{k}_2.\mathbf{\Delta y}_{mn}}\left(e^{i\,\mathbf{k}_3.\mathbf{\Delta y}_{mn}}+\frac{1}{2}e^{-i\,\mathbf{k}_3.\mathbf{\Delta y}_{mn}}\right)+e^{-i\,\mathbf{k}_2.\mathbf{\Delta y}_{mn}}\left(\frac{1}{2}e^{i\,\mathbf{k}_3.\mathbf{\Delta y}_{mn}}+e^{-i\,\mathbf{k}_3.\mathbf{\Delta y}_{mn}}\right)$$
$$= 3\cos\left(\mathbf{k}_2.\mathbf{\Delta y}_{mn}\right)\,\cos\left(\mathbf{k}_3.\mathbf{\Delta y}_{mn}\right) - \sin\left(\mathbf{k}_2.\mathbf{\Delta y}_{mn}\right)\,\sin\left(\mathbf{k}_3.\mathbf{\Delta y}_{mn}\right). \qquad (5.$$

Odd harmonics occur!

Conclusion

- The zero-final state interaction baseline for v_2 (and v_n) is not vanishing, but it is given by quantum interference and it may take sizes and p_T-shapes comparable to those observed in pp, pA

- Work is in progress (Boris Blok & Urs Wiedemann)
  - to resum effects to all orders in $m^2/(N_c^2 -1)$
  - to push this line of investigation to higher order cumulants
  - to understand relation to CGC formalism