Probing extreme QCD through ridge-like correlations in small systems: status and problems

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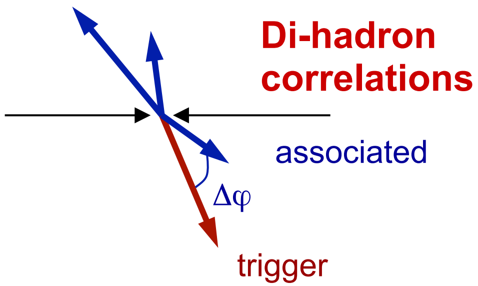
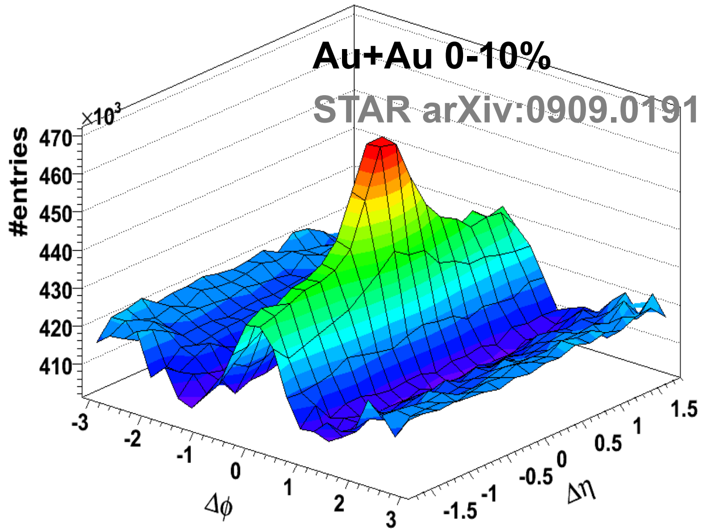
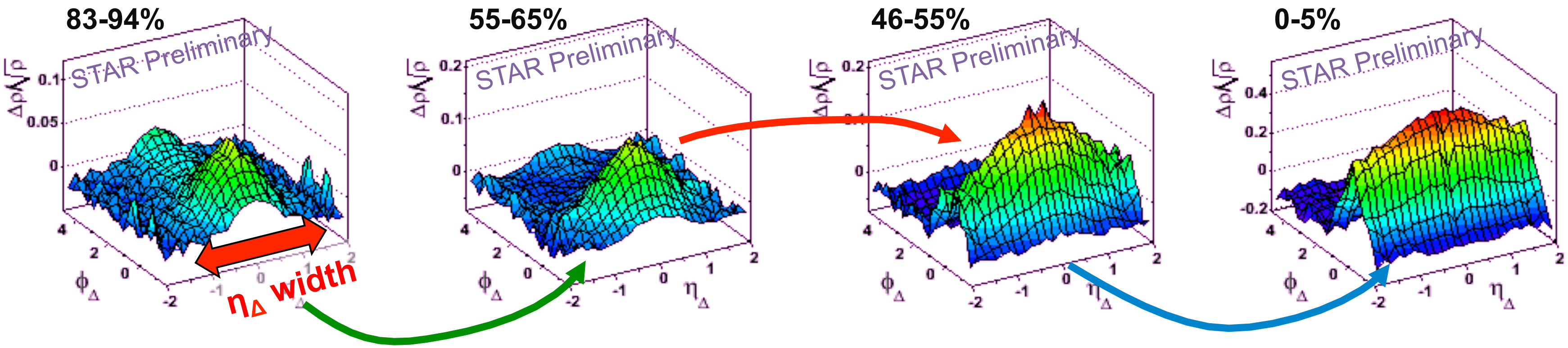
INT workshop, May 15, 2017

The ridge in A+A collisions





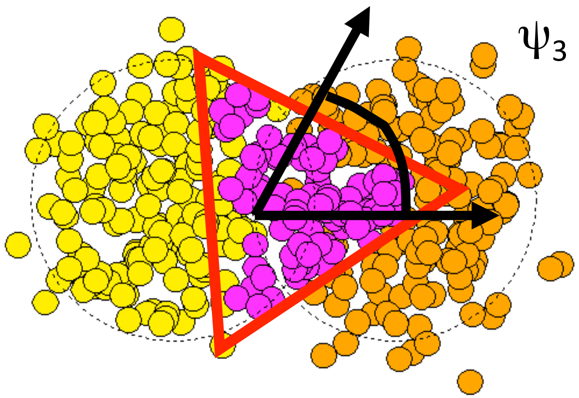
3 < $p_{t,trigger}$ < 4 GeV
$p_{t,assoc.}$ > 2 GeV

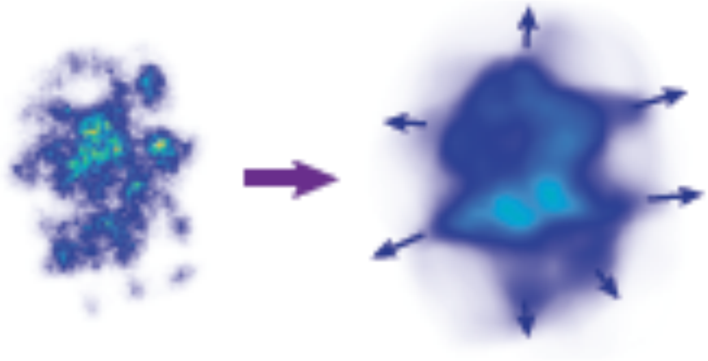


Collimated, long range rapidity correlations:
First seen by RHIC Au+Au experiments: STAR, PHOBOS, PHENIX

The ridge in A+A collisions

Alver, Roland, PRC81(2010) 054905
Alver, Gombeaud, Luzum, Ollitrault, PRC82 (2010) 03491

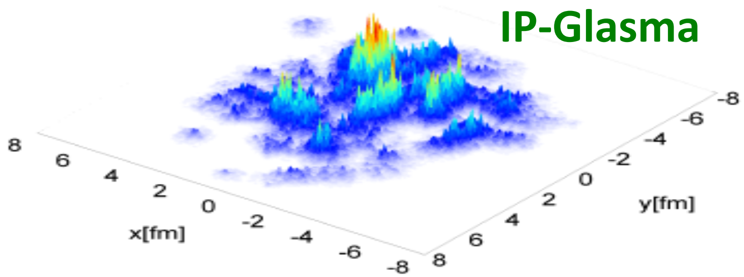


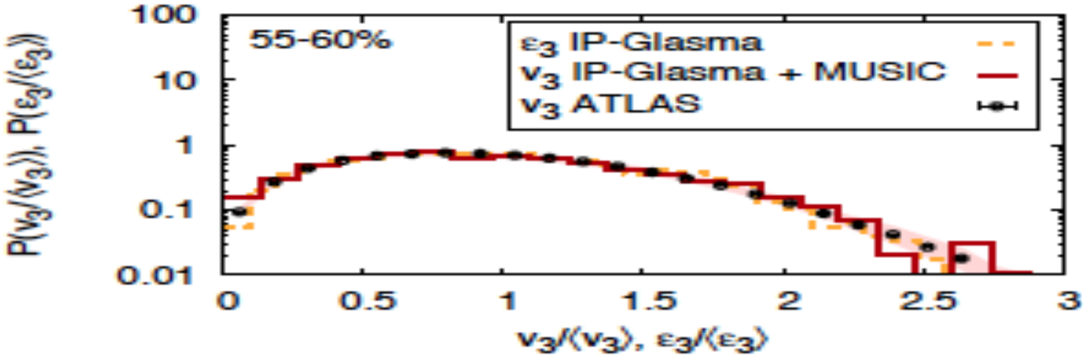


Structure of ridge-correlations can be understood as hydrodynamic flow driven by event-by-event fluctuations in nucleon positions

$$\frac{1}{N_{\text{trig}} N_{\text{assoc.}}} \frac{d^2N}{d\Delta\Phi} = 1 + V_1\, Cos(\Delta\Phi) + V_2\, Cos(2\Delta\Phi) + \cdots$$

Gale,Jeon,Schenke,Tribedy,Venugopalan, PRL110 (2013) 012302



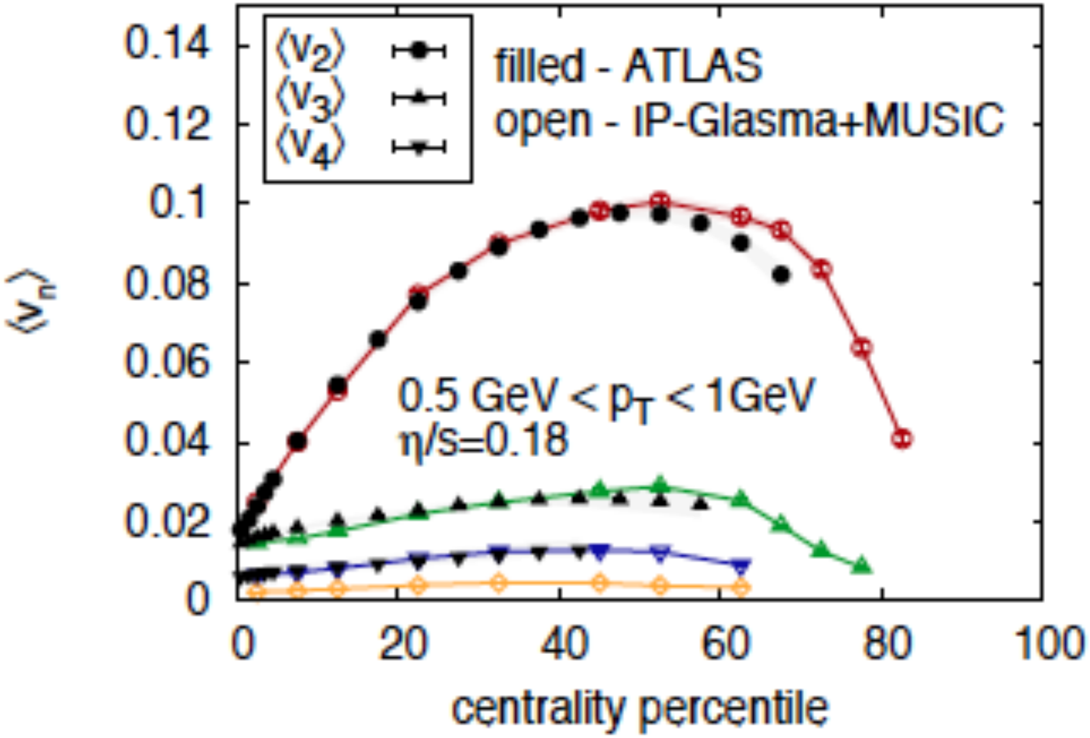


Some evidence of sensitivity of data to sub-nucleon scale fluctuations

What's the smallest sized QGP droplet?

IP-Glasma= initial state
MUSIC=event.by.event. hydro

Schenke, Venugopalan, PRL 113 (2014) 102301



Where does the hydro paradigm break down?

Higher cumulants of elliptic flow

m-particle flow cumulants

$$c_n\{2m\} = \langle\langle e^{in(\phi_1+\cdots\phi_m-\phi_{m+1}-\cdots\phi_{2m})}\rangle\rangle$$

Borghini,Dinh,Ollitrault, nucl-th/0105040

$$v_n\{2\}^2 \equiv c_n\{2\} \quad v_n\{4\}^4 \equiv -c_n\{4\} \quad v_n\{6\}^6 \equiv c_n\{6\}/4$$

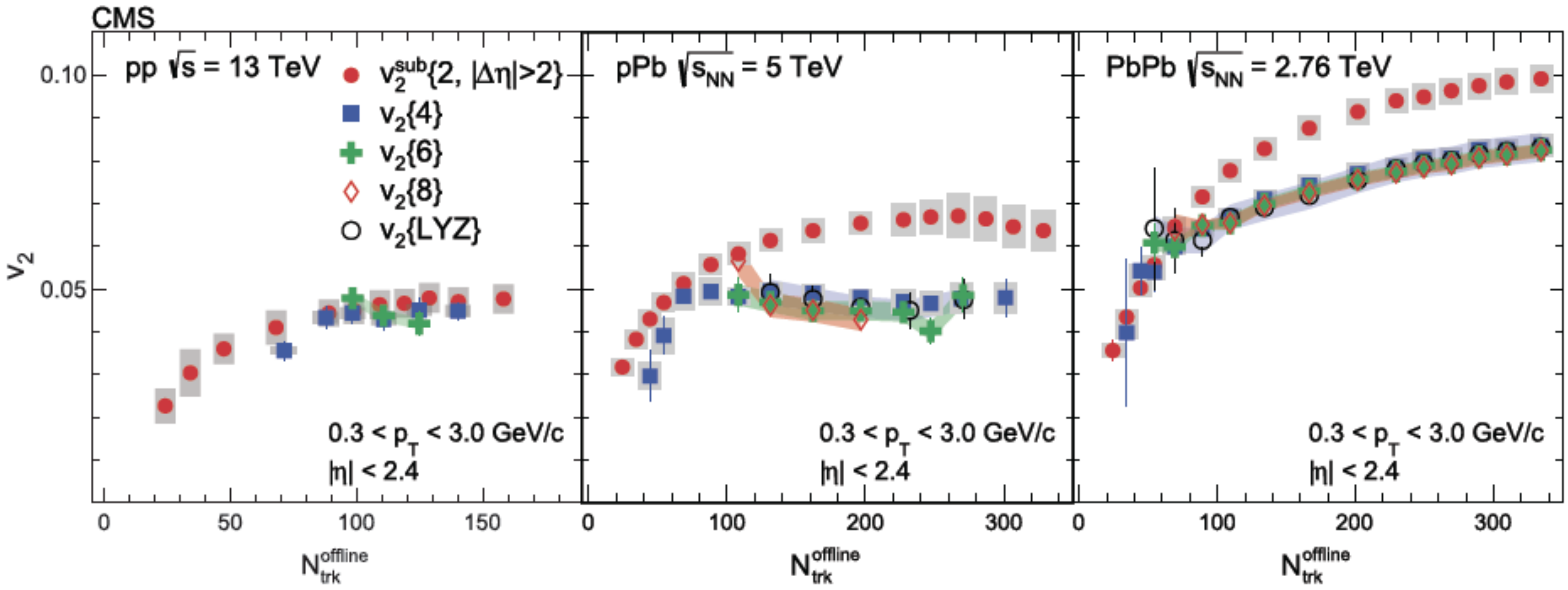
Spatial eccentricities: $$\epsilon_n = \frac{1}{< r_\perp^n >}\int d^2r_\perp\, e^{in\phi_r}\, r_\perp^n \,\frac{dN}{dyd^2r_\perp}$$

A number of simple models give $\epsilon_n\{2\} > \epsilon\{4\} = \epsilon\{6\} = \cdots$

Hydro linear response: $v_n\{m\} \approx c_n\varepsilon_n\{m\}$

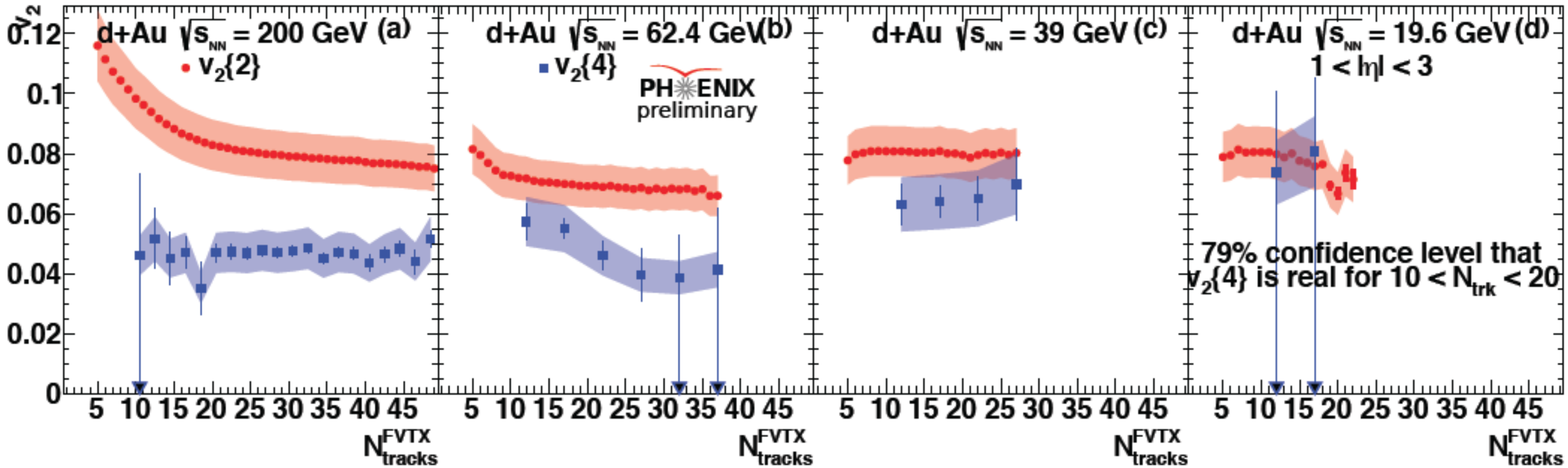
Gardim,Grassi,Luzum,Ollitrault, PRC (2012)024908; Niemi,Denicol,Holopainen,Huovinen, PRC87 (2013)054901
Bzdak,Bozek,McLerran, arXiv:1311.7325, Bzdak, Skokov, arXiv: 1312.7349
Yan, Ollitrault, arXiv:1312.6555, Basar,Teaney, arXiv:1312.6770

Collectivity across system size

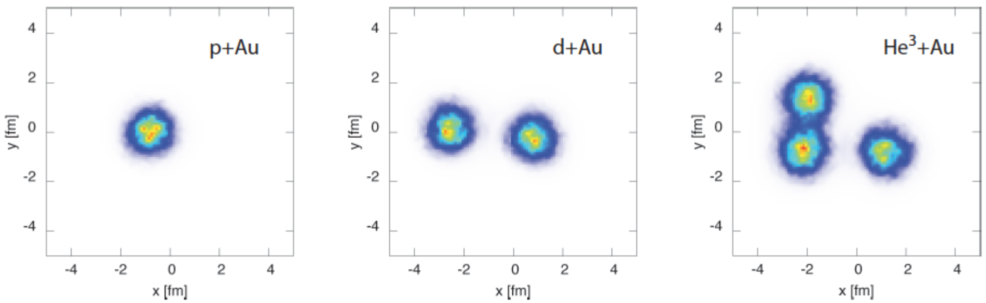


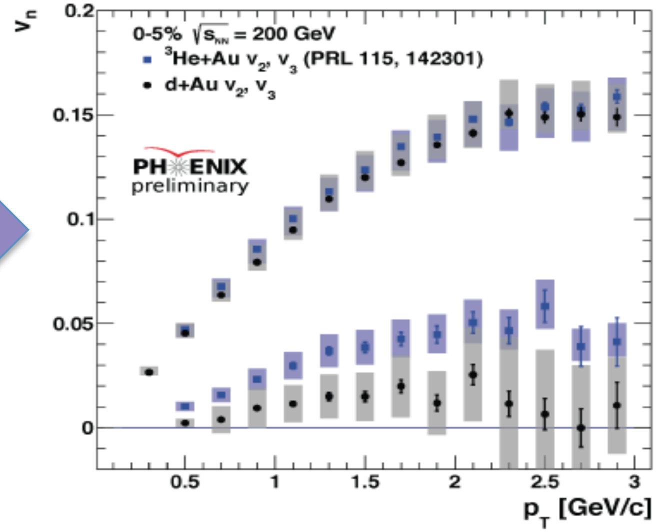
Collectivity across wide energy scales

200 GeV 62.4 GeV 39 GeV 19.6 GeV

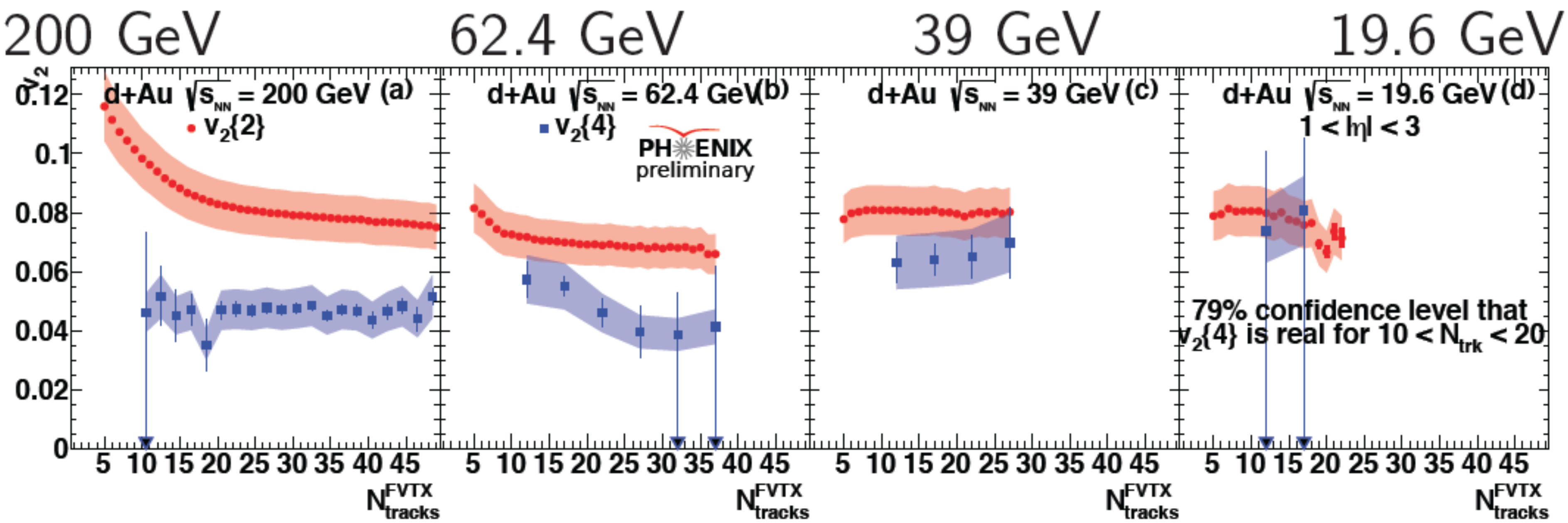


Schenke, RV:1407.7557





Collectivity across wide energy scales



Panta Rhei?

Heraclitus of Ephesus
535-475 BC

Natural in hydro – yet very few ab initio hydro computations of 4-particle cumulants for p+A

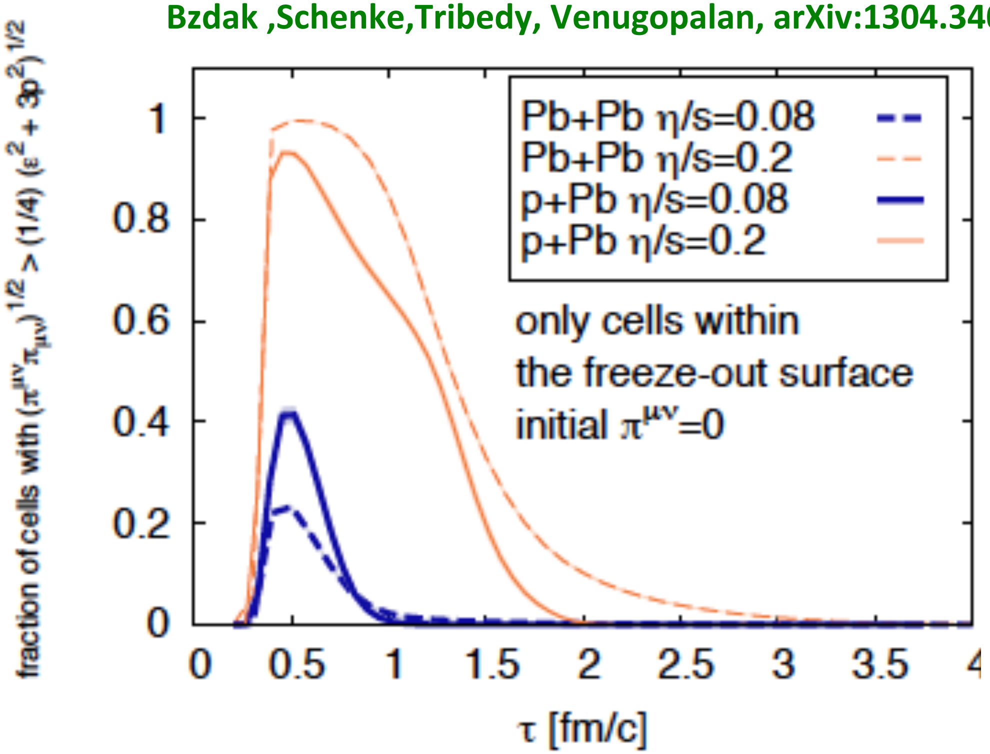
-- none for p+p

Issues with the hydrodynamic paradigm: I

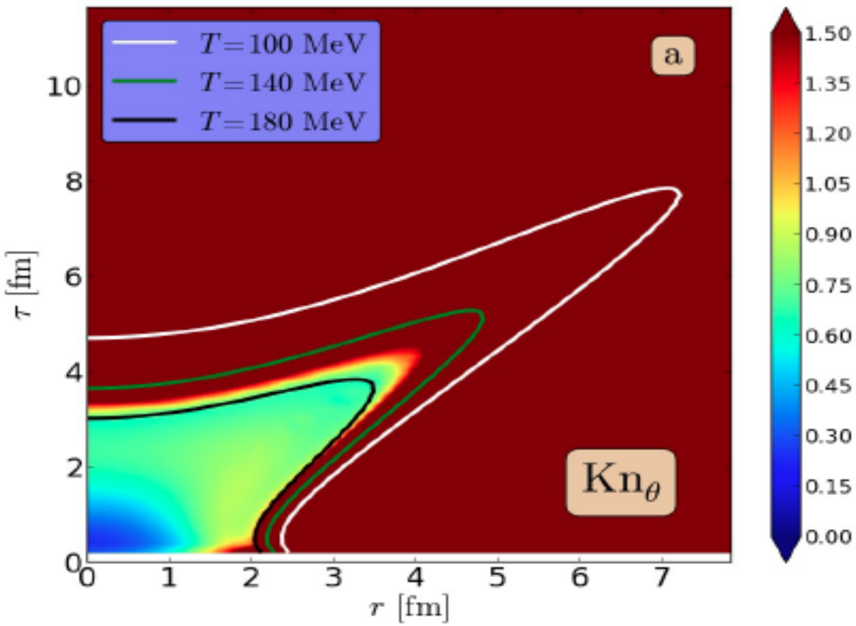
Two frequently used measures: Reynolds # and Knudsen #

$$R^{-1} \propto (\Pi^{\mu\nu}\Pi_{\mu\nu})^{1/2}/(\epsilon^2 + 3P^2)^{1/2} \qquad \mathrm{Kn} = \frac{\tau_\pi}{L} \;;\; \tau_\pi \propto \frac{\eta}{sT}$$

Bzdak ,Schenke,Tribedy, Venugopalan, arXiv:1304.3403



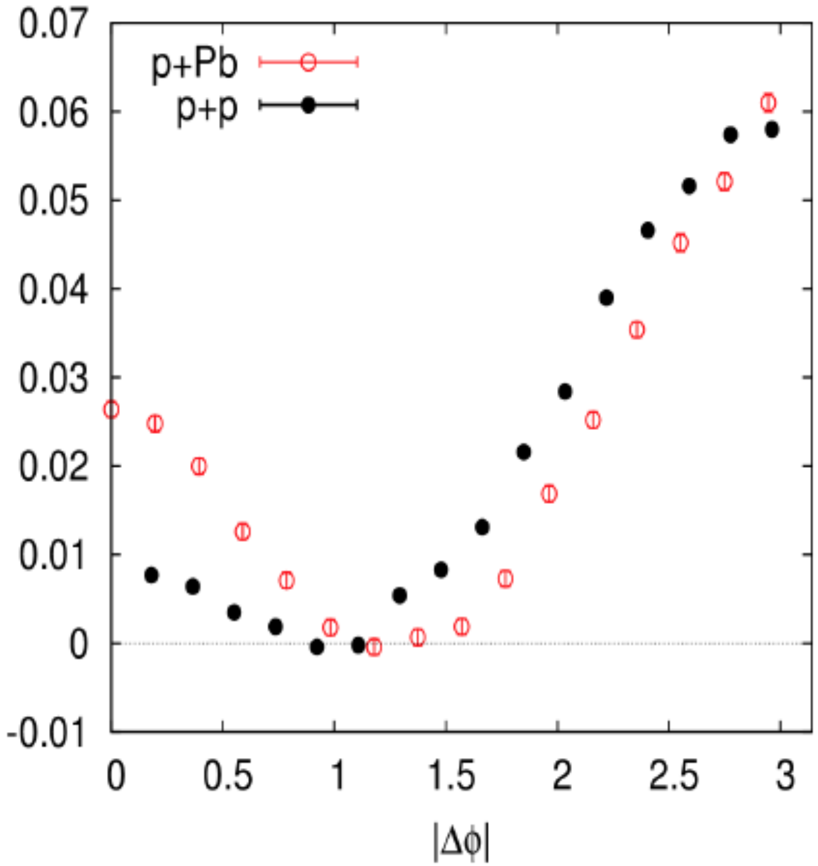
Dumitru,Molnar,Nara,arXiv:0706.2233
Denicol, Niemi, arXiv:1404.7327

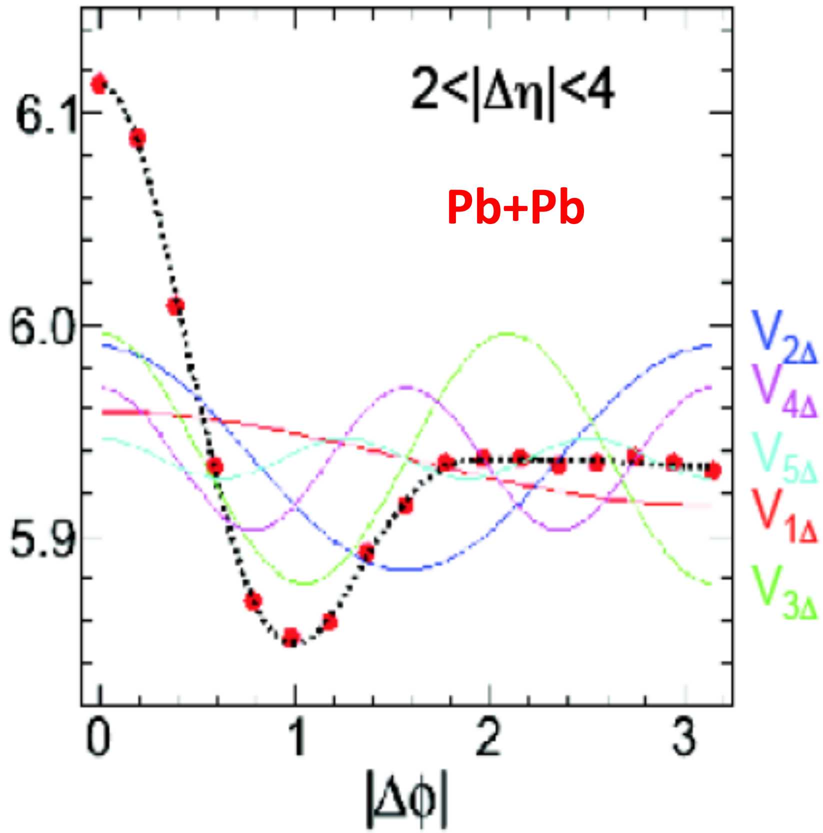


Hydro good for Kn < 0.5,
marginal for K < 1 transient regime;
K > 1 free streaming

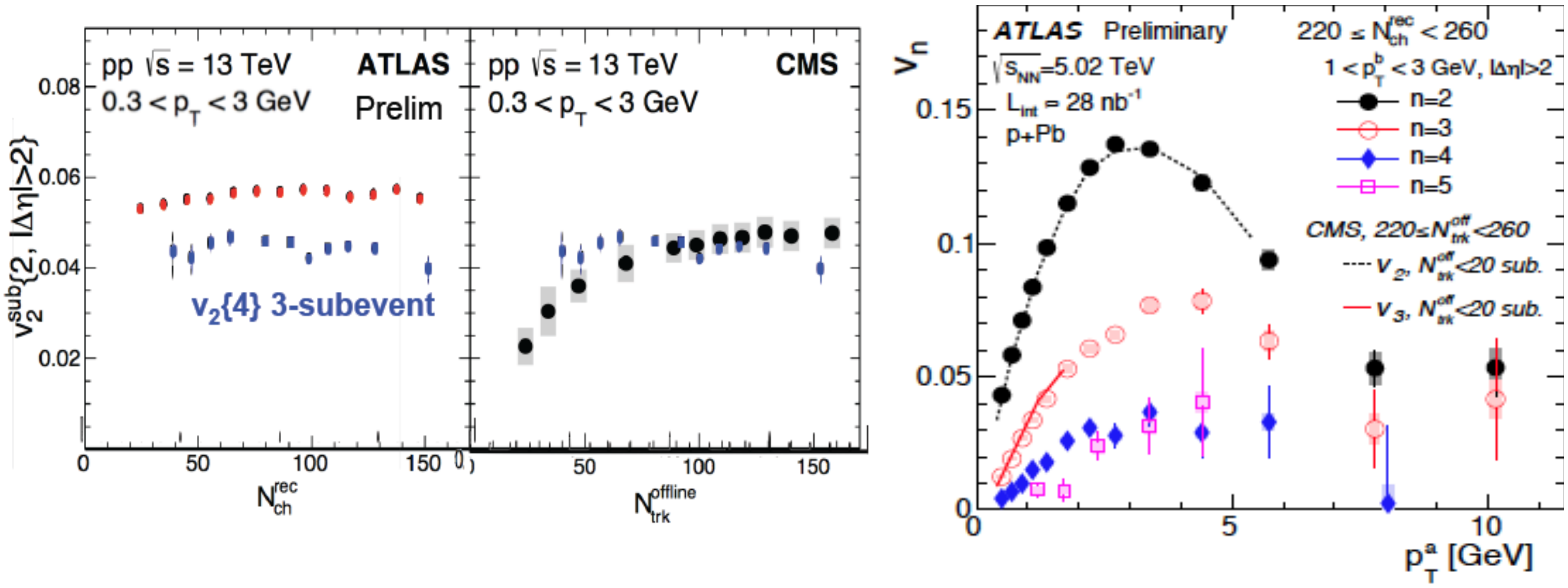
Issues with the hydrodynamic paradigm: II

No (mini-) jet quenching seen in the smaller systems





Issues with the hydrodynamic paradigm: III



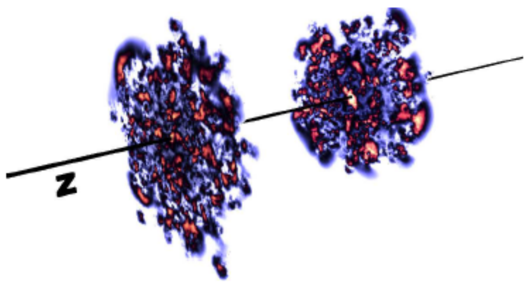
Large anistropies at larger p_T and smaller N_{ch} than one might reconcile with a hydrodynamic description

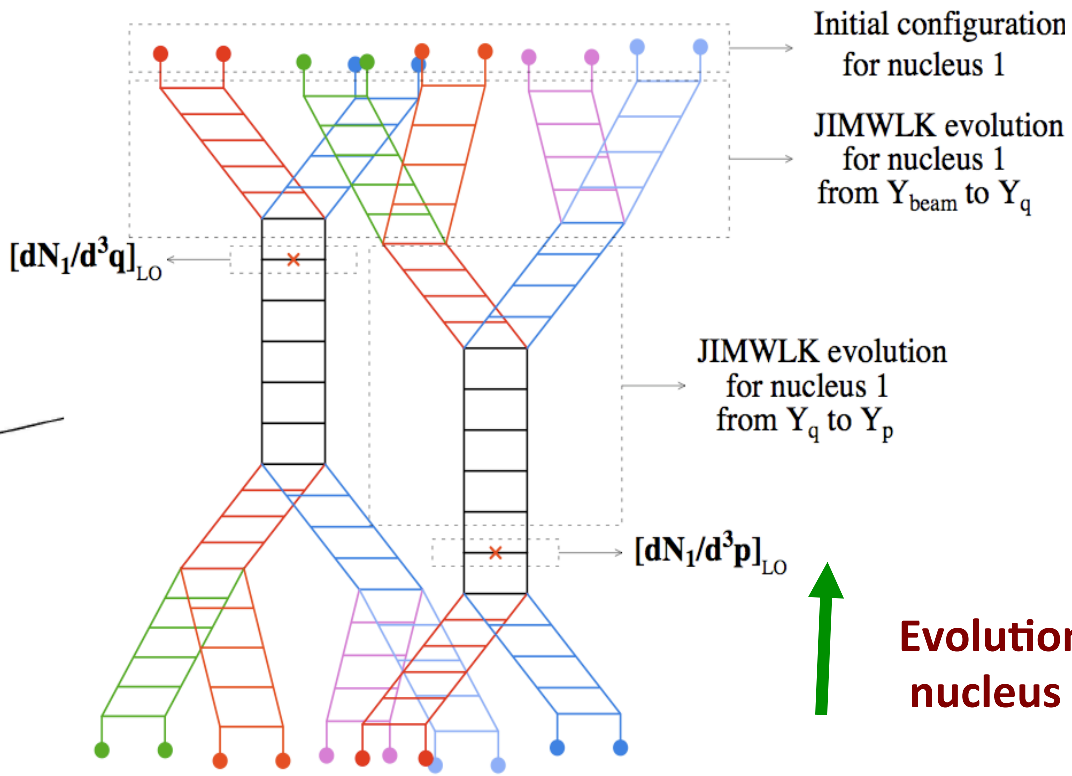
Four-particle collectivity seen in minimum bias events...

Can we understand multiparticle correlations in an *ab initio* approach

Review: Dusling,Li,Schenke, arXiv:1509.07939

Two-parton azimuthal correlations in the CGC





Evolution for nucleus 2

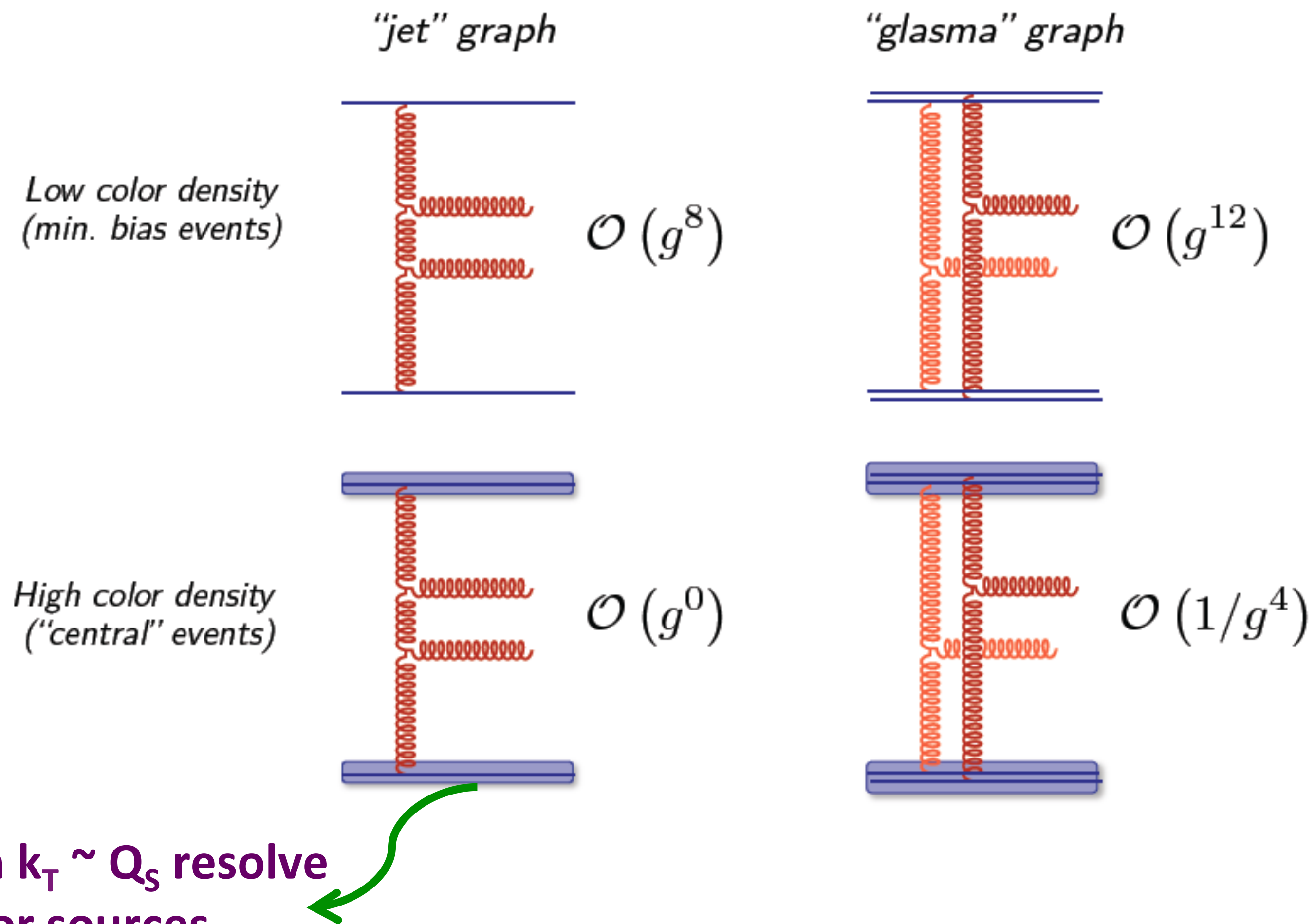
$$\langle \frac{dN_2}{d^3p\, d^3q} \rangle_{\rm LLogs} = \int [d\rho_1][d\rho_2] W_{Y_1}[\rho_1]\, W_{Y_2}[\rho_2]\, \frac{dN}{d^3p}|_{\rm LO}\, \frac{dN}{d^3q}|_{\rm LO}$$

JIMWLK evolution

Solution of Yang-Mills for dense-dense systems (as in A+A)

Dumitru,Gelis,McLerran,Venugopalan: 0804.3858
Gelis, Lappi, Venugopalan, arXiv: 0807.1306
Dusling,Gelis,Lappi,Venugopalan, arXiv:0911.2720

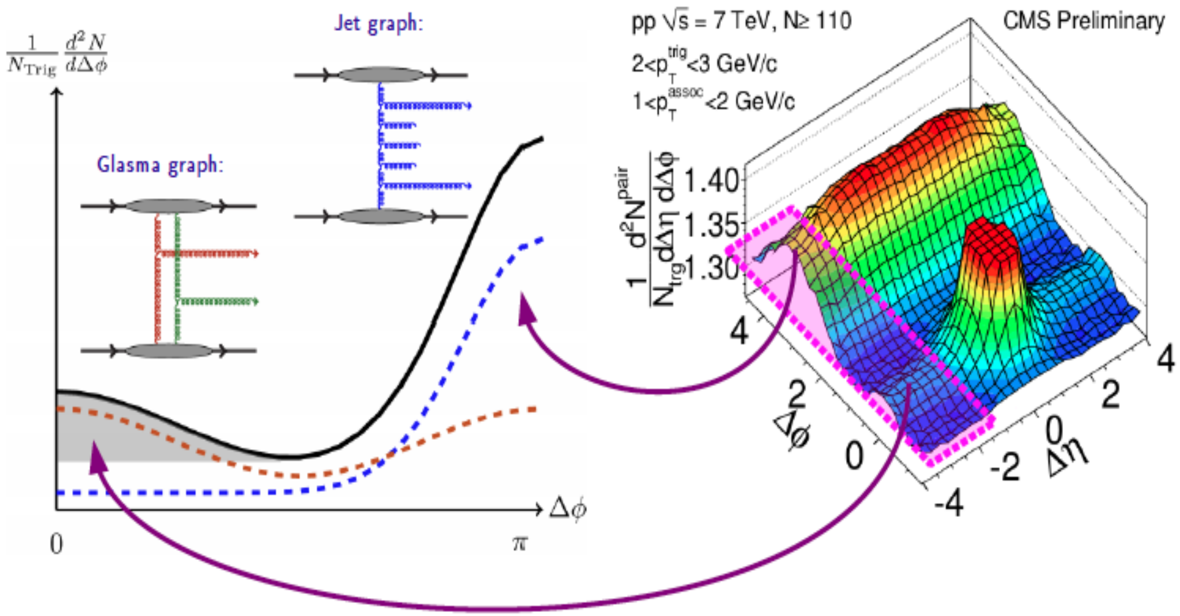
Glasma graph approximation: power counting



Gluons with $k_T \sim Q_S$ resolve
$n \sim 1/g^2$ color sources
Effective coupling: $g*n \sim 1/g$

Dumitru,Dusling,Gelis,Jalilian-Marian,
Lappi,Venugopalan, PLB697 (2011)21
Dusling,Venugopalan,PRL108 (2012)262001

Anatomy of long range collimations



RG evolution of Glasma graphs:

$$C(\mathbf{p},\mathbf{q}) \;\propto\; \frac{g^4}{\mathbf{p}_\perp^2\mathbf{q}_\perp^2}\int \mathrm{d}^2\mathbf{k}_{1\perp}\;\Phi^2_{A_1}(y_p,\mathbf{k}_{1\perp})\Phi_{A_2}(y_p,\mathbf{p}_\perp-\mathbf{k}_{1\perp})\Phi_{A_2}(y_q,\mathbf{q}_\perp-\mathbf{k}_{1\perp})$$
$$+\;\;\text{permutations}$$

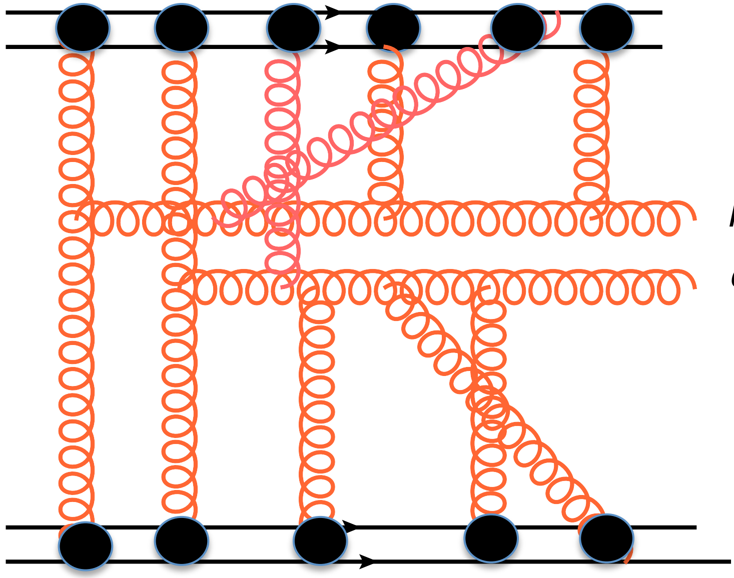
RG evolution of the mini-jets: $C_{\rm dijet}(\mathbf{p},\mathbf{q}) \propto \Phi_A \otimes \Phi_B \otimes G_{\rm BFKL}$

Good agreement with data for $p_T > Q_S$

However no odd harmonics v_3, v_5 for gluons
because C(p,q) = C(p,-q)

Dusling,RV, PRD 87, 051502 (R) (2013); PRD87 (2013) 094034
Dusling,Tribedy,RV,PRD93 (2016) 014034

Beyond glasma graphs



Coherent multiple scattering is of the same order in the coupling: power suppressed for $p_T >> Q_S$, important for $p_T < Q_S$

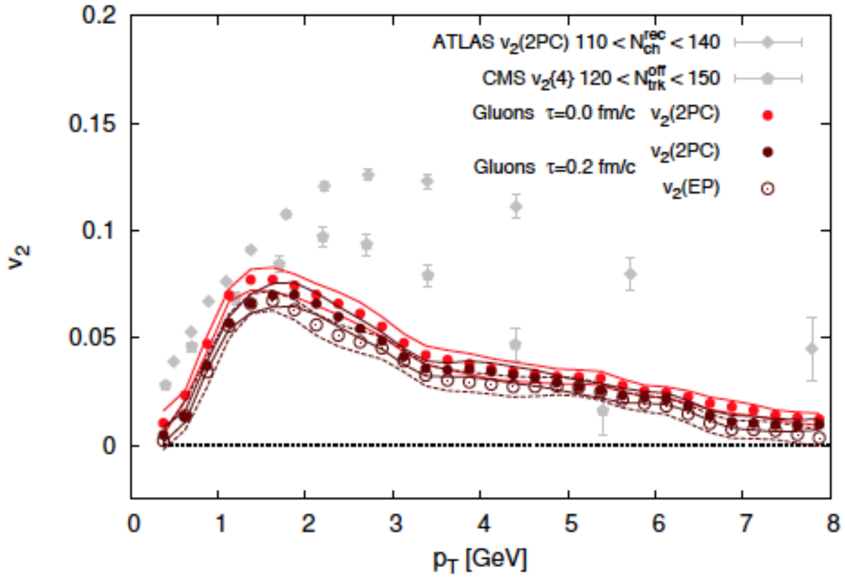
Compute (numerically) by solving Yang-Mills equations In presence of two light cone sources: IP-Glasma model Schenke,Tribedy,Venugopalan, arXiv:1202.6646, 1206.6805

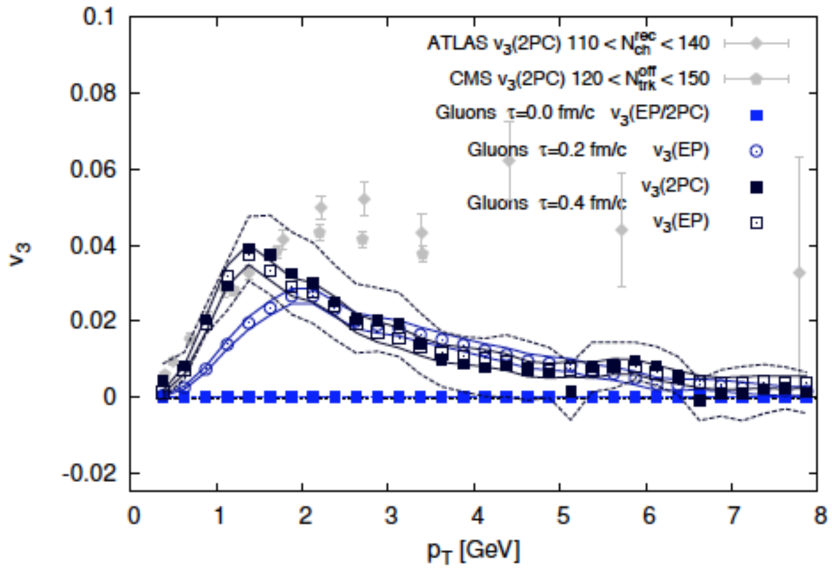
$$\left\langle \frac{d^2N}{d^2p_T q_T} \right\rangle = \int D\rho_A \, D\rho_B \, e^{-\int d^2x_T \rho_A^2/Q_{s,A}^2} \, e^{-\int d^2x_T \rho_B^2/Q_{s,B}^2} \, \frac{dN}{d^2p_T}[\rho_A, \rho_B] \, \frac{dN}{d^2q_T}[\rho_A, \rho_B]$$

C(p,q) ≠ C(p,-q) -- all harmonics contribute

Lappi,Srednyak,Venugopalan, arXiv:0911.2068

Azimuthal anistropy from Yang-Mills dynamics





Schenke,Schlichting,RV, PLB747(2015)76

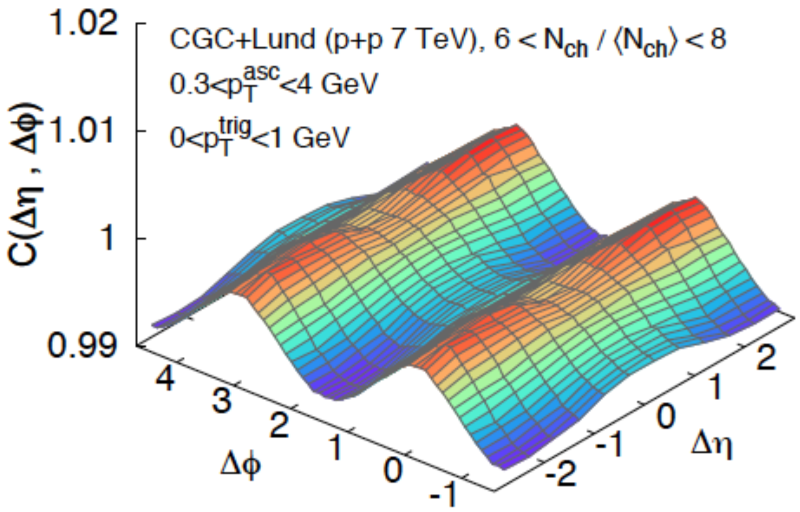
Recent analytical work in dilute-dense approx:

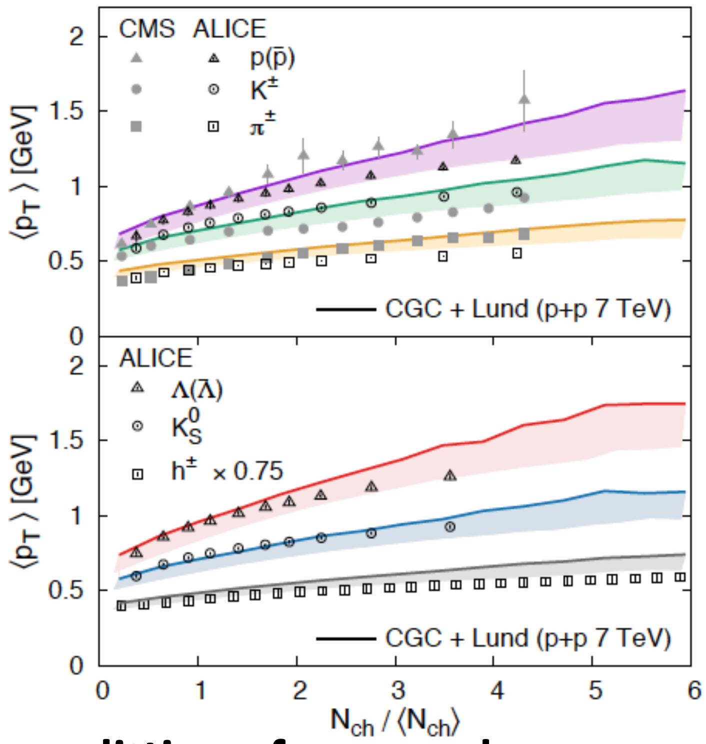
Kovchegov,Wertepny,NPA906 (2013)50

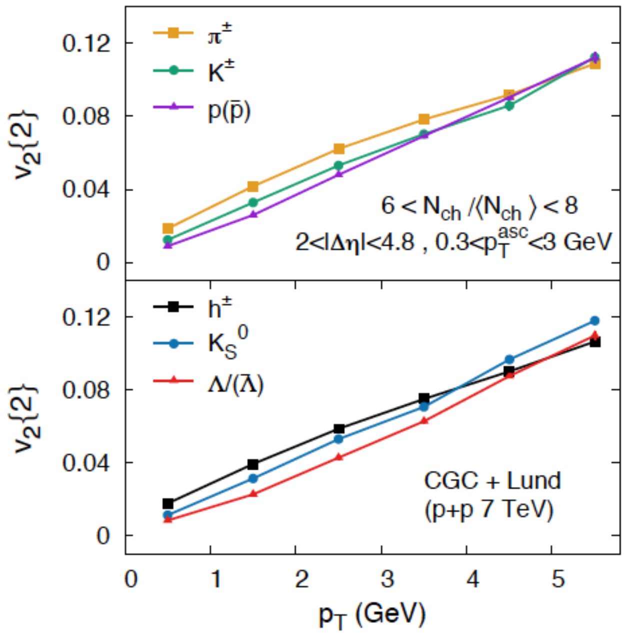
McLerran, Skokov arXiv:1611.09870

Kovner,Lublinsky,Skokov, arXiv:1612.07790

IP-Glasma+Lund fragmentation







Pattern of mass splitting of <p_T> and v_2 seen in high multiplicity events is reproduced Schenke,Schlichting,Tribedy,RV, PRL117(2016)162301

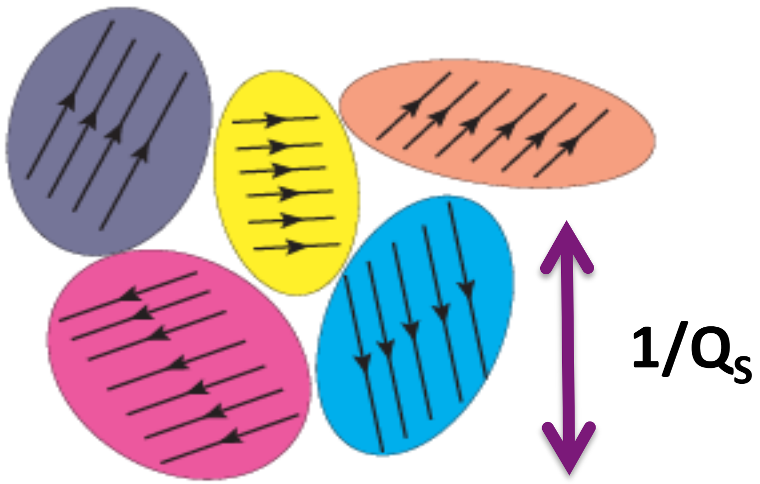
What about 4-particle collectivity?
Numerically very challenging-in progress

Schenke,Schlichting,Tribedy,RV

Tracing azimuthal initial state correlations

Simple ab initio initial state model:
Multi-particle correlations from Eikonal scattering of partons off color domains in a nuclear target

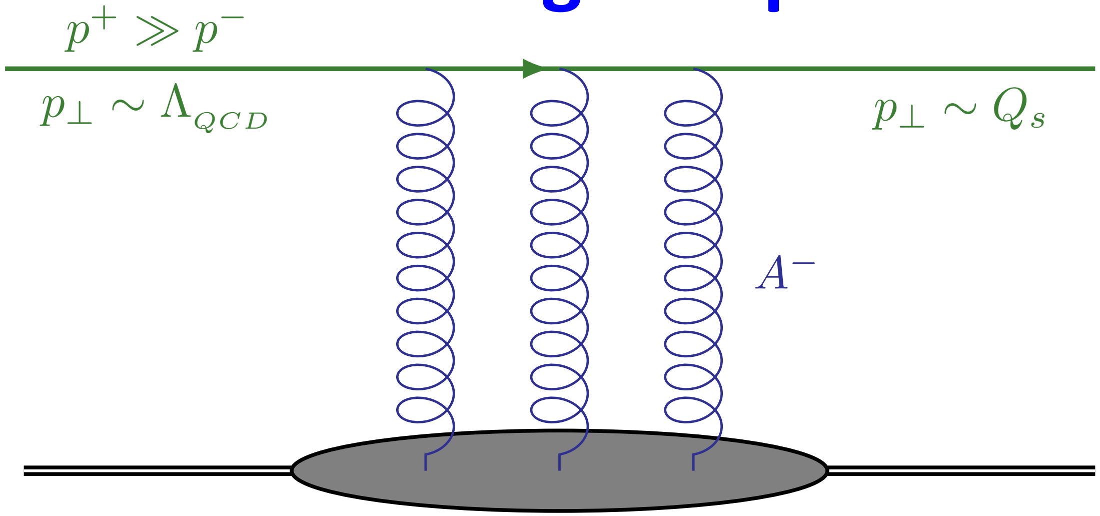
Lappi, arXiv:1501.05505
Lappi,Schenke,Schlichting,RV, arXiv:1509.03499
Dusling,Mace,RV, arXiv:1705.00745



Color domain model:

Kovner,Lublinsky,arXiv:1012.3398,1109.0347
Dumitru,Gianini, arXiv:1406.5781
Dumitru,Skokov,arXiv:1411.6630,
Dumitru,McLerran,Skokov,arXiv:1410.4844

Eikonal scattering: the parton model



Color rotation of parton in external field by a lightlike Wilson line

$$W[A](x) = \mathcal{P} \exp \left[ig \int dz^+ A_a^-(z^+, x) \right]$$

Parton distribution after coherent multiple scattering off nucleus:

$$\frac{dN}{d^2p} \simeq \frac{1}{\pi B_p} \int_{x\bar{x}} e^{-(x^2+\bar{x}^2)/2B_p} \left\langle \frac{1}{N_c} \mathrm{Tr} \left[W(x) W^\dagger(\bar{x}) \right] \right\rangle e^{ip\cdot(x-\bar{x})}$$

B_p is the transverse area of the proton

Bjorken, Kogut, Soper, Phys. Rev., D3:1382, (1971)
Dumitru, Jalilian-Marian, Phys. Rev. Lett., 89:022301, (2002)

Multiparton Eikonal scattering

Two partons:

$$\frac{d^2N}{d^2p_1 d^2p_2} \simeq \frac{1}{(\pi B_p)^2} \int_{x\bar{x}y\bar{y}} e^{-(x^2+\bar{x}^2)/2B_p} \, e^{-(y^2+\bar{y}^2)/2B_p} e^{ip_1\cdot(x-\bar{x})} e^{ip_2\cdot(y-\bar{y})}$$

$$\times \left\langle \frac{1}{N_c} \mathrm{Tr}\left[W(x)W^\dagger(\bar{x})\right] \frac{1}{N_c} \mathrm{Tr}\left[W(y)W^\dagger(\bar{y})\right] \right\rangle$$

$$\propto \langle D\, D \rangle$$

Dipole correlator: $D(x,\bar{x}) = \dfrac{1}{N_c} \mathrm{Tr}\left[W(x)W^\dagger(\bar{x})\right]$

Four partons:

$$d^4N \sim \int \langle \mathrm{Tr}\left[W(w)W^\dagger(\bar{w})\right] \mathrm{Tr}\left[W(x)W^\dagger(\bar{x})\right] \mathrm{Tr}\left[W(y)W^\dagger(\bar{y})\right] \mathrm{Tr}\left[W(z)W^\dagger(\bar{z})\right] \rangle$$

$$\propto \langle D\, D\, D\, D \rangle$$

and so on $\ldots$

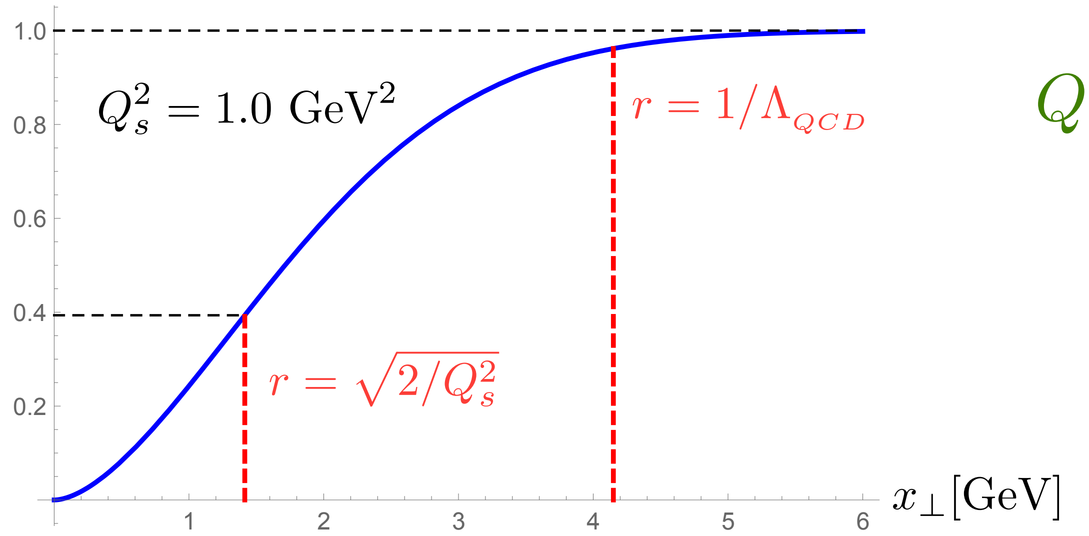
Averaging over color representations in the target

Dipole correlator is evaluated in the MV model where color correlations in the target are Gaussian (random walk in color)

$$g^2 \left\langle A_a^-(x) A_b^-(y) \right\rangle = \delta^{ab} L_{xy} \qquad L_{xy} = -\frac{g^4\mu^2}{16\pi} |x-y|^2 \ln \frac{1}{\Lambda |x-y|}$$

gives $D(x,\bar{x}) = \dfrac{1}{N_c} \mathrm{Tr}\left[W(x) W^\dagger(\bar{x})\right] = \exp(C_F L_{x\bar{x}})$

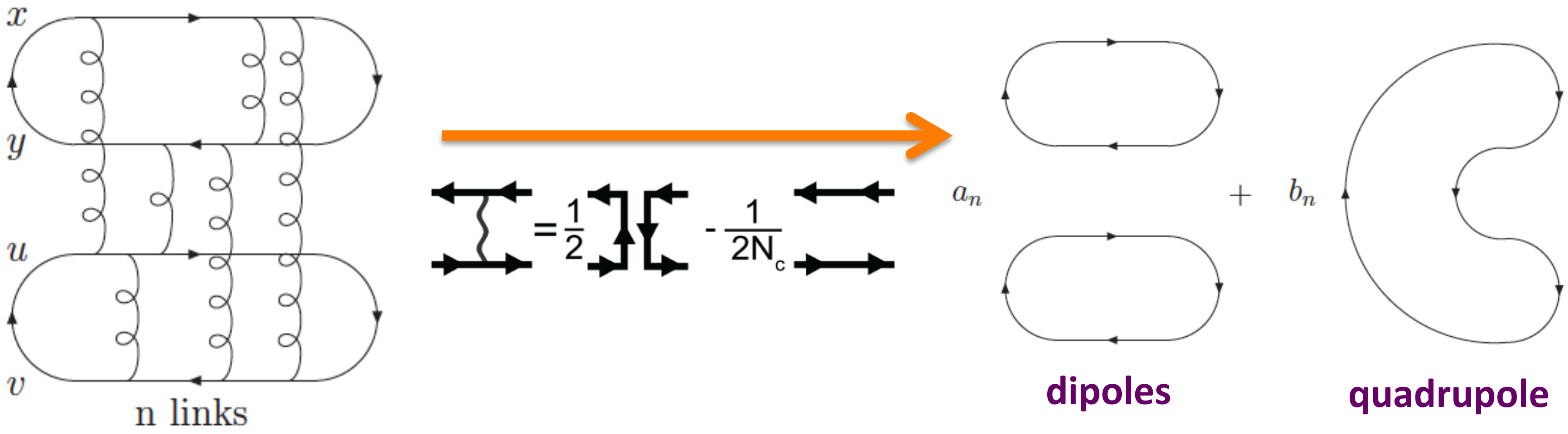
$N(x_\perp) =$
$1 - D(x_\perp)$



$Q_s \propto g^2 \mu$

Averaging over multi-point dipole correlators

To compute the 2-dipole correlator:



Use $W(x) \equiv \mathcal{P}\exp\left[ig\int dz^+ A_a^-(z^+,x)\right] \simeq V(x)\left[1 + igA_a^-(\xi,x)T^a + \cdots\right]$

This gives $\langle D_{x\bar{x}}D_{y\bar{y}}\rangle_W \simeq \alpha_{x\bar{x}y\bar{y}}\,\langle D_{x\bar{x}}D_{y\bar{y}}\rangle_V + \beta_{xy\bar{x}\bar{y}}\,\langle Q_{x\bar{y}y\bar{x}}\rangle_V$

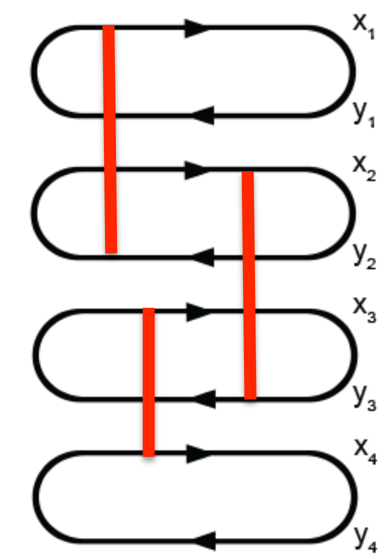
Equivalently, $\begin{pmatrix} \langle D_{x\bar{x}}D_{y\bar{y}}\rangle \\ \langle Q_{x\bar{y}y\bar{x}}\rangle \end{pmatrix}_W = \begin{pmatrix} \alpha_{x\bar{x}y\bar{y}} & \beta_{xy\bar{x}\bar{y}} \\ \beta_{xy\bar{y}\bar{x}} & \alpha_{x\bar{y}y\bar{x}} \end{pmatrix}\begin{pmatrix} \langle D_{x\bar{x}}D_{y\bar{y}}\rangle \\ \langle Q_{x\bar{y}y\bar{x}}\rangle \end{pmatrix}_V$

Kovner, Wiedemann, Phys. Rev., D64:114002, (2001)
Fujii, Nucl. Phys., A709:236 (2002).
Blaizot, Gelis, Venugopalan. Nucl. Phys., A743:57, (2004)
Dominguez, Marquet, Wu, Nucl. Phys., A823:99, (2009)

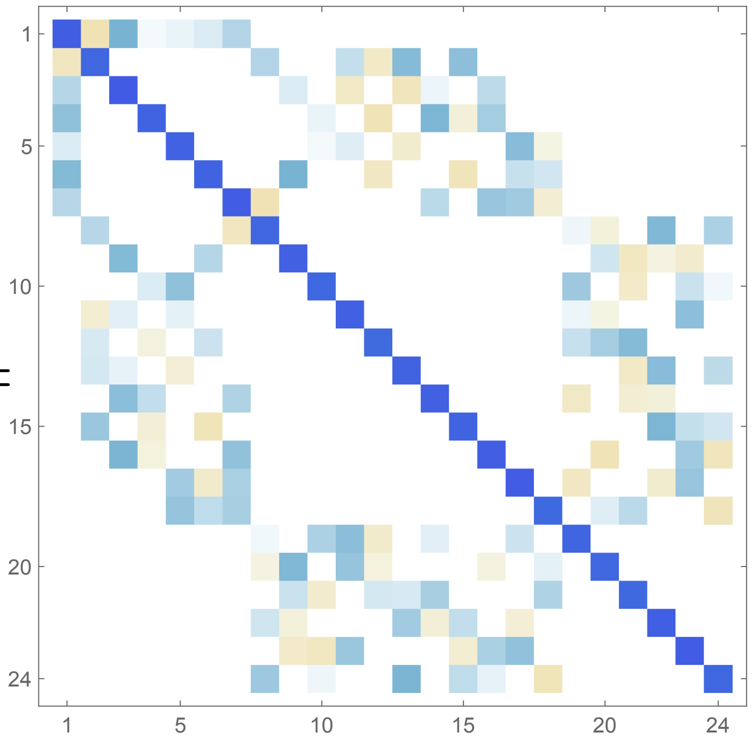
Iterate, diagonalize,exponentiate, to compute correlator

Averaging over multi-point dipole correlators

4-dipole correlator:

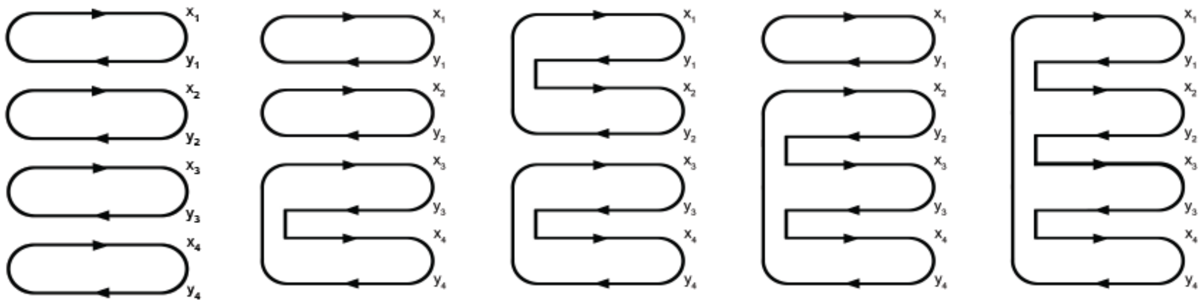


$$\begin{bmatrix} \langle D_{w\bar{w}}D_{x\bar{x}}D_{y\bar{y}}D_{z\bar{z}}\rangle \\ \langle Q_{w\bar{w}x\bar{x}}D_{y\bar{z}}D_{z\bar{y}}\rangle \\ \langle Q_{w\bar{w}x\bar{y}}D_{y\bar{x}}D_{z\bar{z}}\rangle \\ \langle Q_{w\bar{w}x\bar{y}}D_{y\bar{z}}D_{z\bar{x}}\rangle \\ \langle Q_{w\bar{w}x\bar{z}}D_{y\bar{x}}D_{z\bar{y}}\rangle \\ \langle Q_{w\bar{w}x\bar{z}}D_{y\bar{y}}D_{z\bar{x}}\rangle \\ \langle Q_{w\bar{x}x\bar{w}}D_{y\bar{y}}D_{z\bar{z}}\rangle \\ \langle Q_{w\bar{x}x\bar{w}}Q_{y\bar{z}z\bar{y}}\rangle \\ \langle Q_{w\bar{x}x\bar{y}}Q_{y\bar{w}z\bar{z}}\rangle \\ \langle Q_{w\bar{x}x\bar{y}}Q_{y\bar{z}z\bar{w}}\rangle \\ \langle S_{w\bar{x}x\bar{z}y\bar{w}}D_{z\bar{y}}\rangle \\ \langle S_{w\bar{x}x\bar{z}y\bar{y}}D_{z\bar{w}}\rangle \\ \langle S_{w\bar{y}x\bar{w}y\bar{x}}D_{z\bar{z}}\rangle \\ \langle S_{w\bar{y}x\bar{w}y\bar{z}}D_{z\bar{x}}\rangle \\ \langle S_{w\bar{y}x\bar{x}y\bar{w}}D_{z\bar{z}}\rangle \\ \langle S_{w\bar{y}x\bar{x}y\bar{z}}D_{z\bar{w}}\rangle \\ \langle S_{w\bar{y}x\bar{z}y\bar{w}}D_{z\bar{x}}\rangle \\ \langle S_{w\bar{y}x\bar{z}y\bar{x}}D_{z\bar{w}}\rangle \\ \langle O_{w\bar{z}x\bar{w}y\bar{x}z\bar{y}}\rangle \\ \langle O_{w\bar{z}x\bar{w}y\bar{y}z\bar{x}}\rangle \\ \langle O_{w\bar{z}x\bar{x}y\bar{w}z\bar{y}}\rangle \\ \langle O_{w\bar{z}x\bar{x}y\bar{y}z\bar{w}}\rangle \\ \langle O_{w\bar{z}x\bar{y}y\bar{w}z\bar{x}}\rangle \\ \langle O_{w\bar{z}x\bar{y}y\bar{x}z\bar{w}}\rangle \end{bmatrix}_W =$$



$$\begin{bmatrix} \langle D_{w\bar{w}}D_{x\bar{x}}D_{y\bar{y}}D_{z\bar{z}}\rangle \\ \langle Q_{w\bar{w}x\bar{x}}D_{y\bar{z}}D_{z\bar{y}}\rangle \\ \langle Q_{w\bar{w}x\bar{y}}D_{y\bar{x}}D_{z\bar{z}}\rangle \\ \langle Q_{w\bar{w}x\bar{y}}D_{y\bar{z}}D_{z\bar{x}}\rangle \\ \langle Q_{w\bar{w}x\bar{z}}D_{y\bar{x}}D_{z\bar{y}}\rangle \\ \langle Q_{w\bar{w}x\bar{z}}D_{y\bar{y}}D_{z\bar{x}}\rangle \\ \langle Q_{w\bar{x}x\bar{w}}D_{y\bar{y}}D_{z\bar{z}}\rangle \\ \langle Q_{w\bar{x}x\bar{w}}Q_{y\bar{z}z\bar{y}}\rangle \\ \langle Q_{w\bar{x}x\bar{y}}Q_{y\bar{w}z\bar{z}}\rangle \\ \langle Q_{w\bar{x}x\bar{y}}Q_{y\bar{z}z\bar{w}}\rangle \\ \langle S_{w\bar{x}x\bar{z}y\bar{w}}D_{z\bar{y}}\rangle \\ \langle S_{w\bar{x}x\bar{z}y\bar{y}}D_{z\bar{w}}\rangle \\ \langle S_{w\bar{y}x\bar{w}y\bar{x}}D_{z\bar{z}}\rangle \\ \langle S_{w\bar{y}x\bar{w}y\bar{z}}D_{z\bar{x}}\rangle \\ \langle S_{w\bar{y}x\bar{x}y\bar{w}}D_{z\bar{z}}\rangle \\ \langle S_{w\bar{y}x\bar{x}y\bar{z}}D_{z\bar{w}}\rangle \\ \langle S_{w\bar{y}x\bar{z}y\bar{w}}D_{z\bar{x}}\rangle \\ \langle S_{w\bar{y}x\bar{z}y\bar{x}}D_{z\bar{w}}\rangle \\ \langle O_{w\bar{z}x\bar{w}y\bar{x}z\bar{y}}\rangle \\ \langle O_{w\bar{z}x\bar{w}y\bar{y}z\bar{x}}\rangle \\ \langle O_{w\bar{z}x\bar{x}y\bar{w}z\bar{y}}\rangle \\ \langle O_{w\bar{z}x\bar{x}y\bar{y}z\bar{w}}\rangle \\ \langle O_{w\bar{z}x\bar{y}y\bar{w}z\bar{x}}\rangle \\ \langle O_{w\bar{z}x\bar{y}y\bar{x}z\bar{w}}\rangle \end{bmatrix}_V$$

To compute n-gluon exchange, diagonalize 24×24 matrix and exponentiate



dipoles **quadrupoles** **sextupole** **octupole**

Dusling,Mace,Venugopalan,arXiv:1705.00745

Results for azimuthal anisotropies from multiparton eikonal scattering

Mace,Dusling,Venugopalan,arXiv:1705.00745

Objects to be computed

N-particle distributions:

$$\frac{d^n N}{d^2p\cdots} \sim \int \overbrace{e^{-(x^2+\bar{x}^2)/2B_p\cdots}}^{B_p = 4\ \mathrm{GeV}^{-2}} \left\langle \overbrace{\frac{1}{N_c}\mathrm{Tr}\left[W(x)W^\dagger(\bar{x})\right]\cdots}^{Q_s^2 \sim 1-3\ \mathrm{GeV}^2} \right\rangle e^{ip\cdot(x-\bar{x})\cdots}$$

Two-particle cumulants:

$$c_n\{2\} = \frac{\kappa_n\{2\}}{\kappa_0\{2\}}, \quad v_n\{2\} = \sqrt{c_n\{2\}}$$

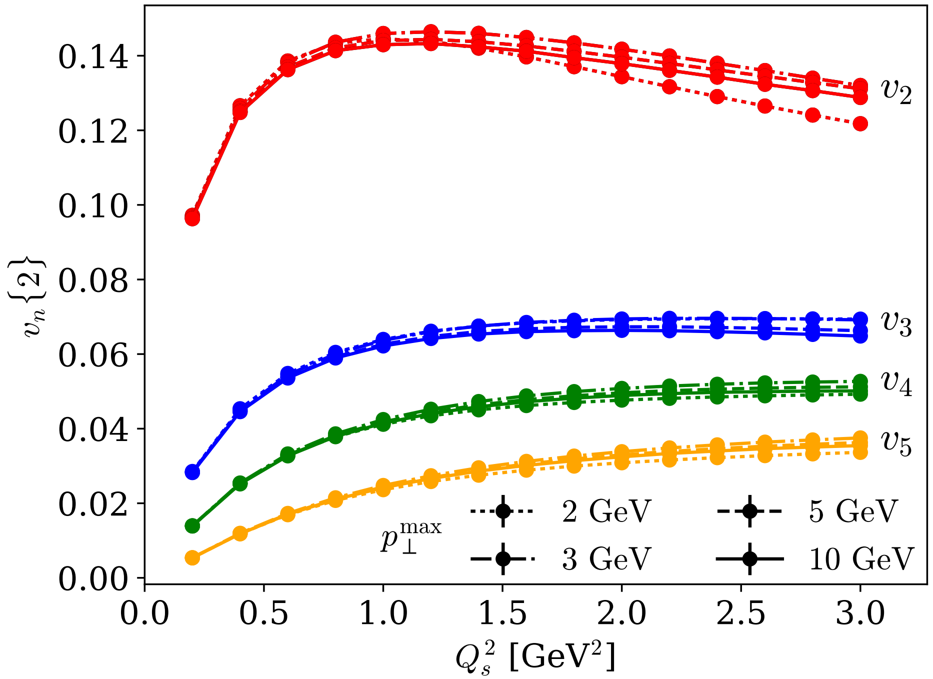
$$\kappa_n\{2\} = \int d^2p_1 d^2p_2 \cos[n(\phi_{p1} - \phi_{p2})]\,\frac{d^2N}{d^2p_1 d^2p_2}$$

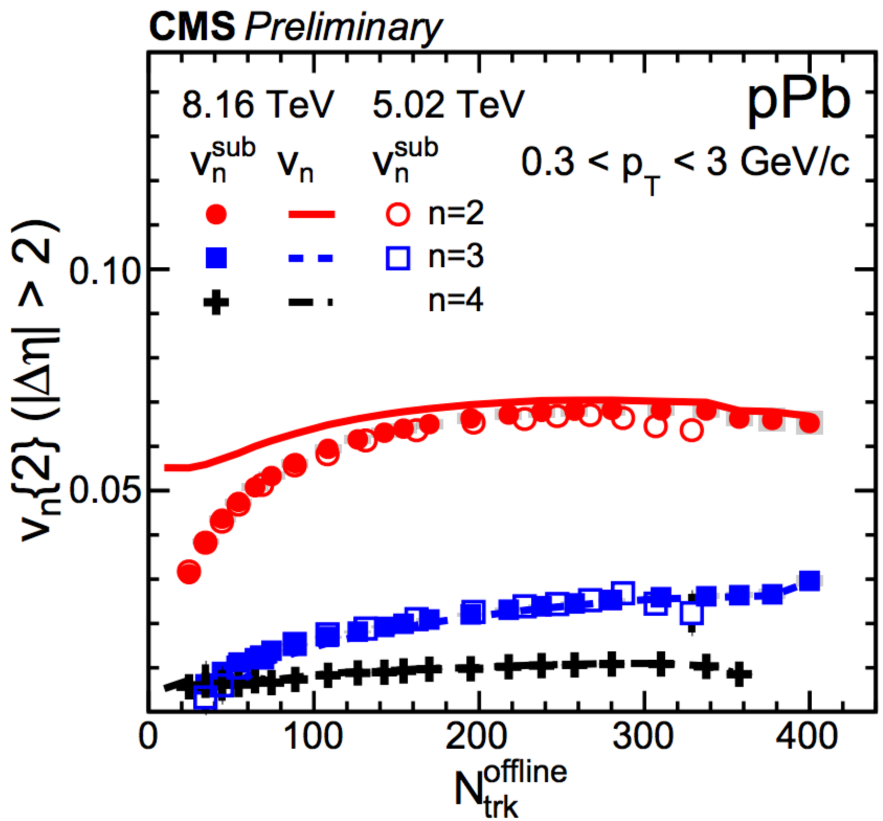
Four-particle cumulants:

$$c_n\{4\} = \frac{\kappa_n\{4\}}{\kappa_0\{4\}} - 2\left(\frac{\kappa_n\{2\}}{\kappa_0\{0\}}\right)^2, \qquad v_n\{4\} = (-c_n\{4\})^{1/4}$$

$$\kappa_n\{4\} = \int d^2p_1 d^2p_2 d^2p_3 d^2p_4 \cos[n(\phi_{p1} + \phi_{p2} - \phi_{p3} - \phi_{p4})]\,\frac{d^4N}{d^2p_1 d^2p_2 d^2p_3 d^2p_4}$$

Integrated anisotropy coefficients



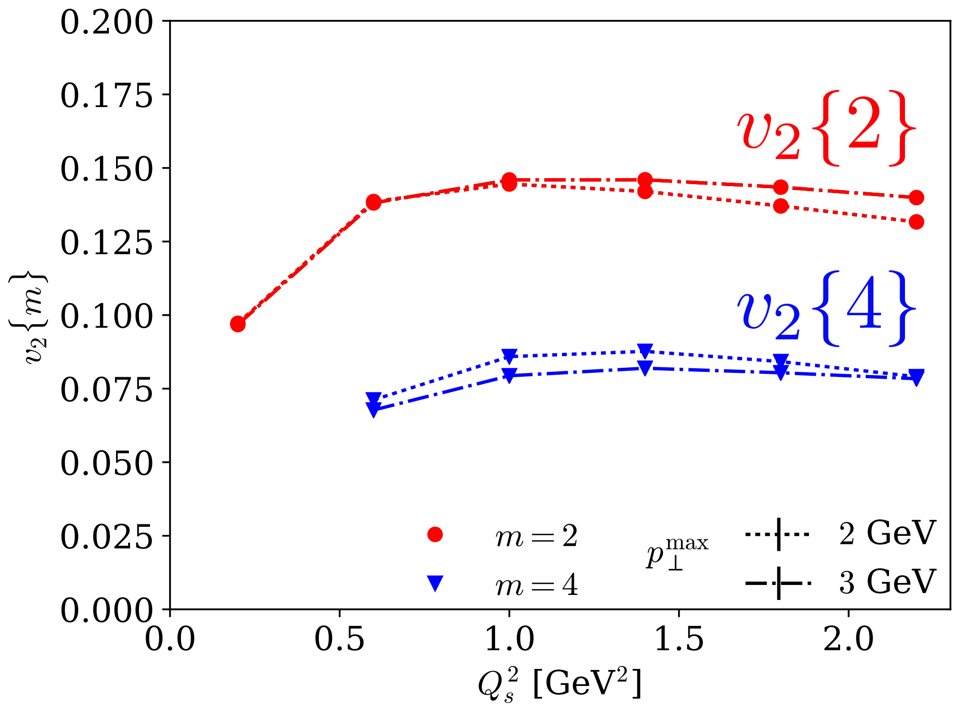


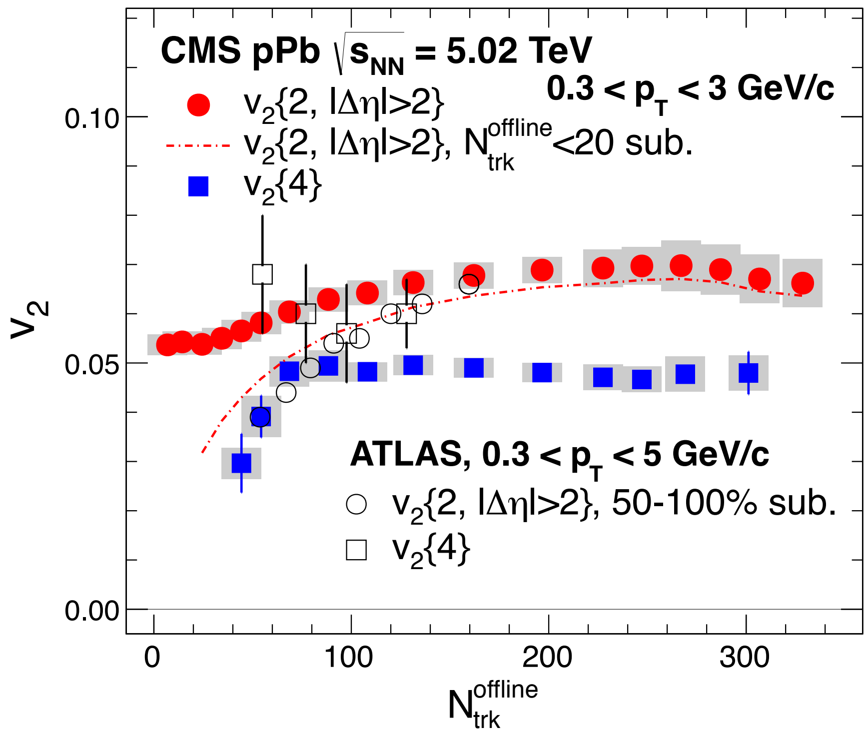
Similar ordering of "Flow" coefficients as seen in the data

Important caveat: No simple map between theory and experiment
Theory results are for quarks, Q_s^2 is the saturation scale in the target

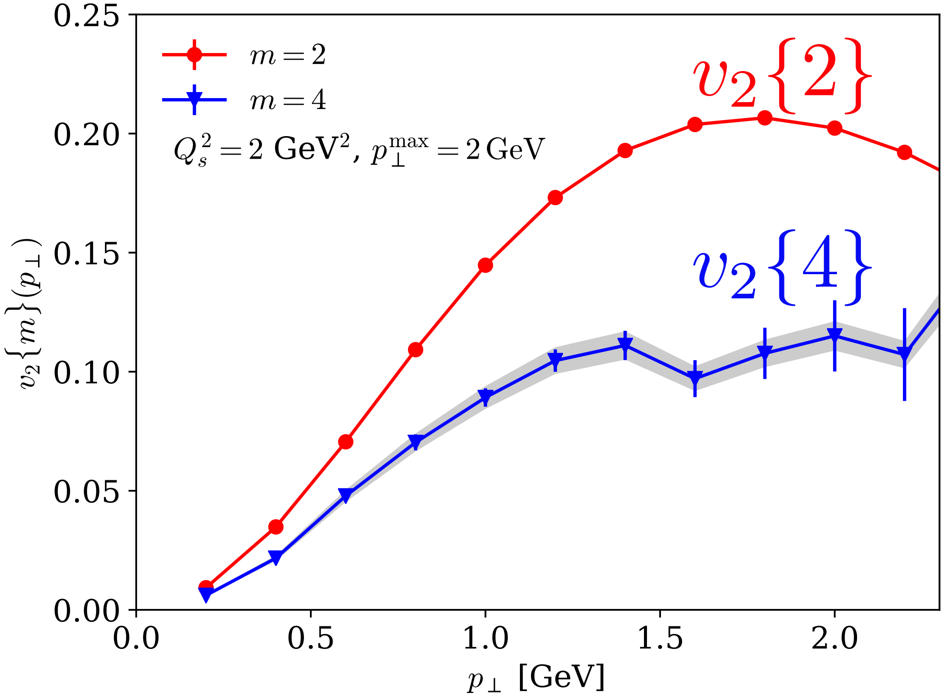
Lappi, Phys. Lett., B744:315, (2015)
Lappi, Schenke, Schlichting, Venugopalan. JHEP, 01:061, (2016)

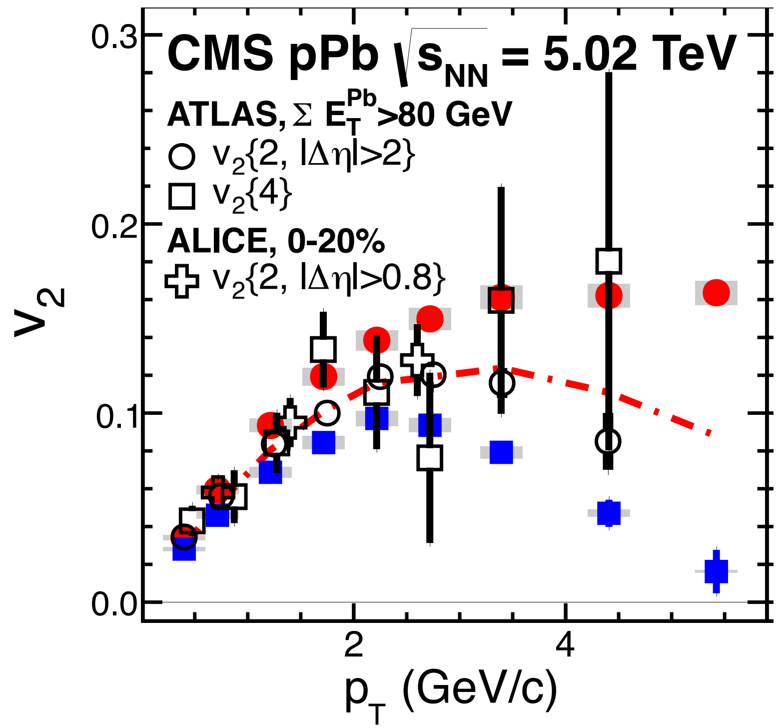
Integrated anisotropy coefficients





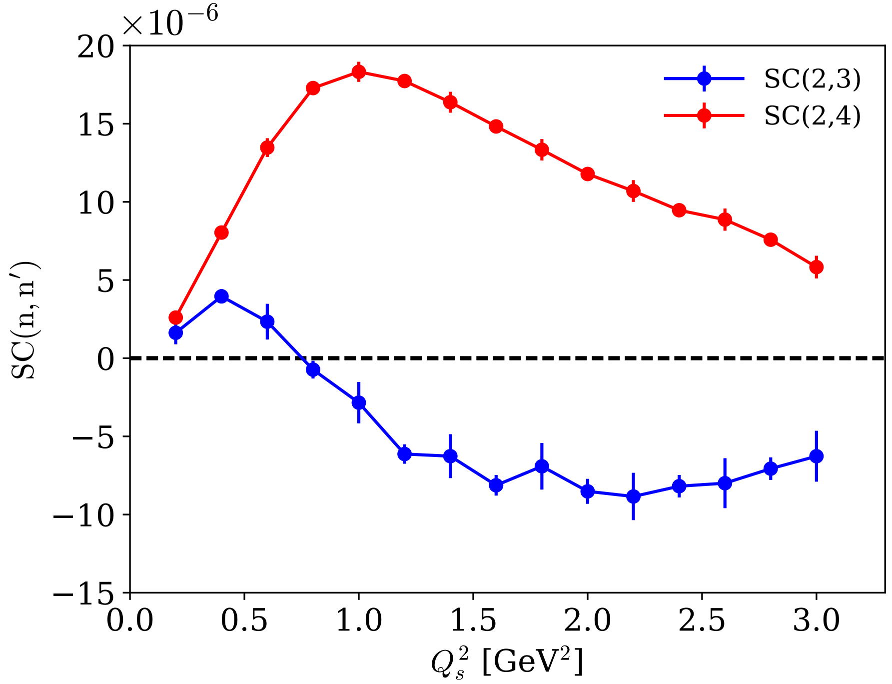
p_T dependence of anisotropy coefficients

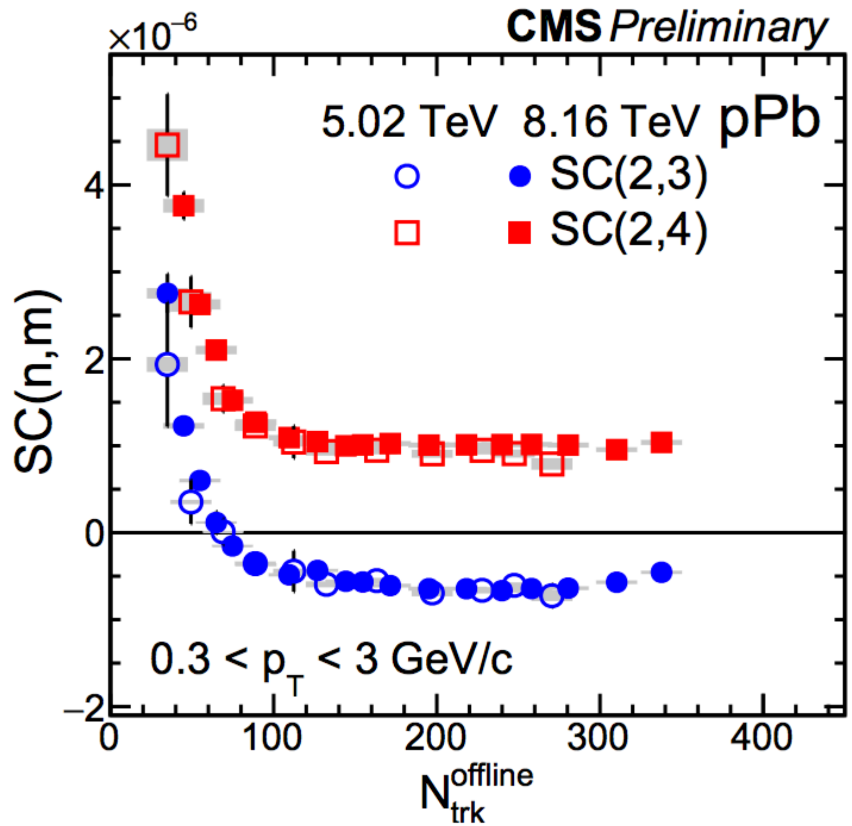




Symmetric cumulants

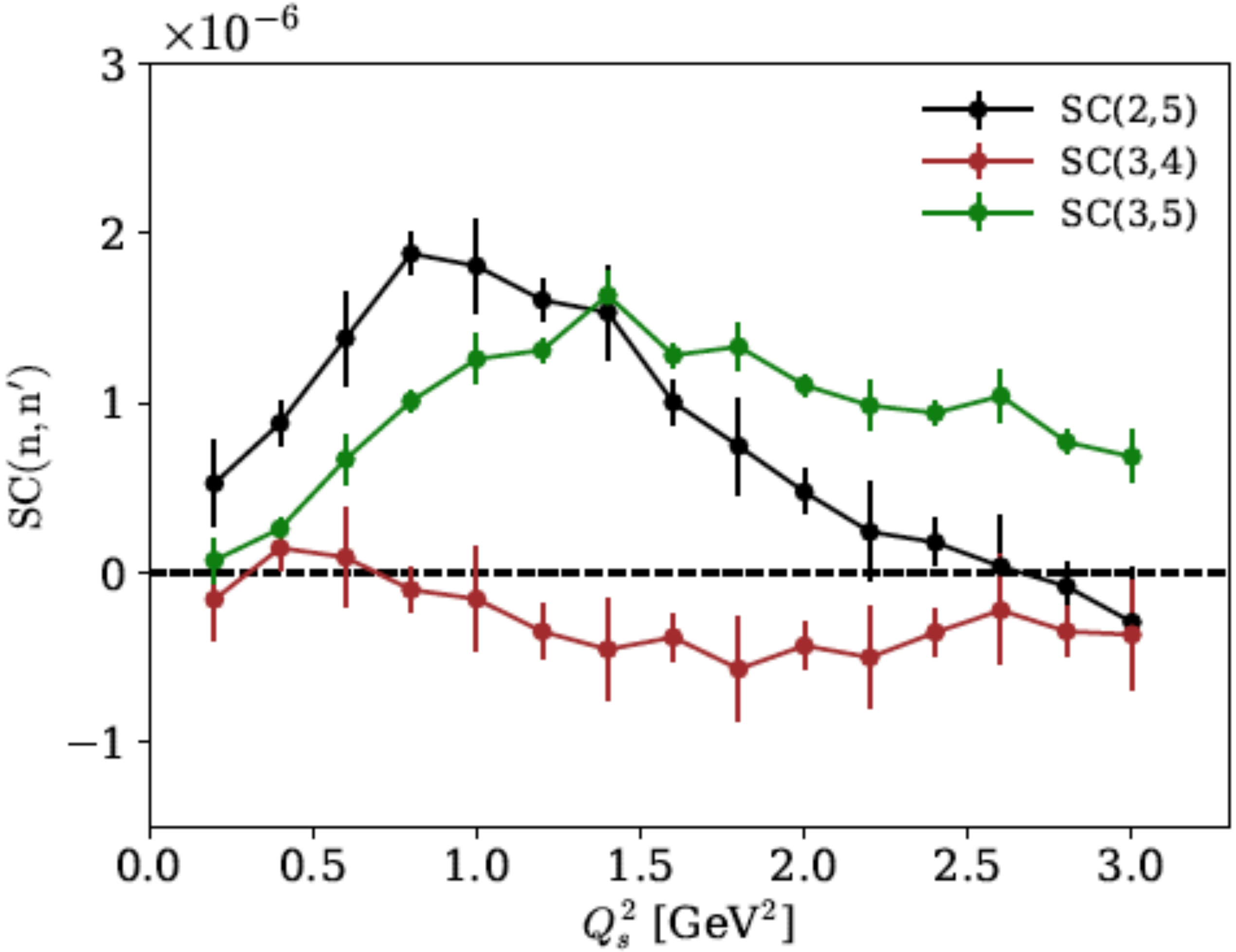
$$SC(m,n) = \langle v_m^2 v_n^2 \rangle - \langle v_m^2 \rangle \langle v_n^2 \rangle$$



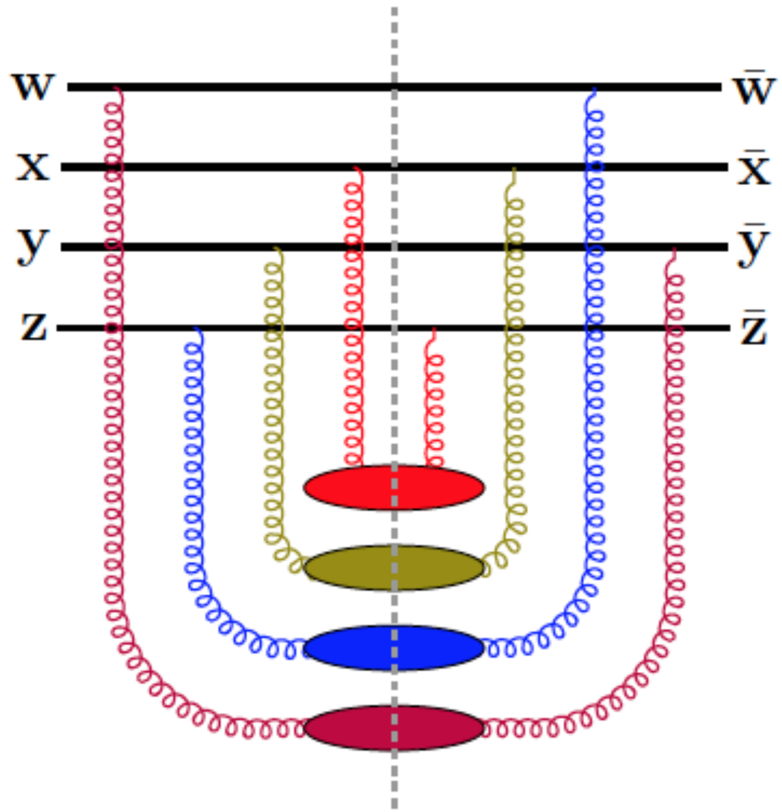


In hydro, SC(m,n) are a measure of the nonlinear response of the system

Predictions for p+A symmetric cumulants



Back to glasma graphs

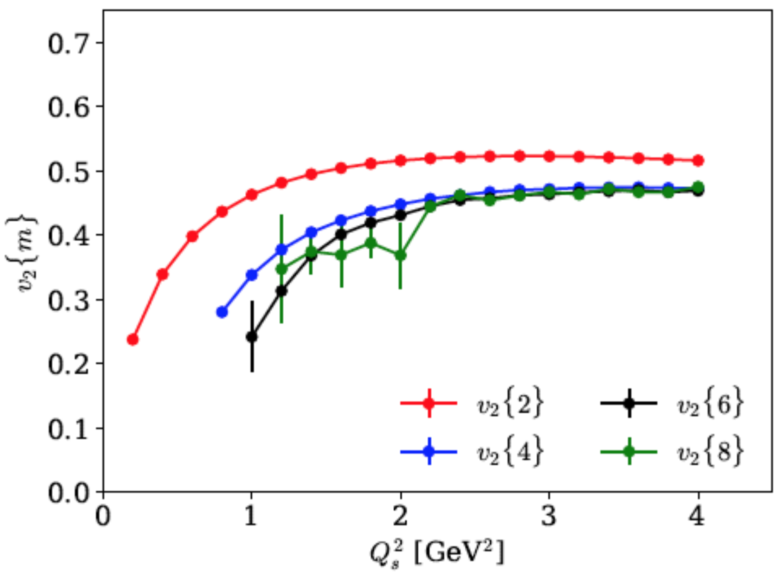


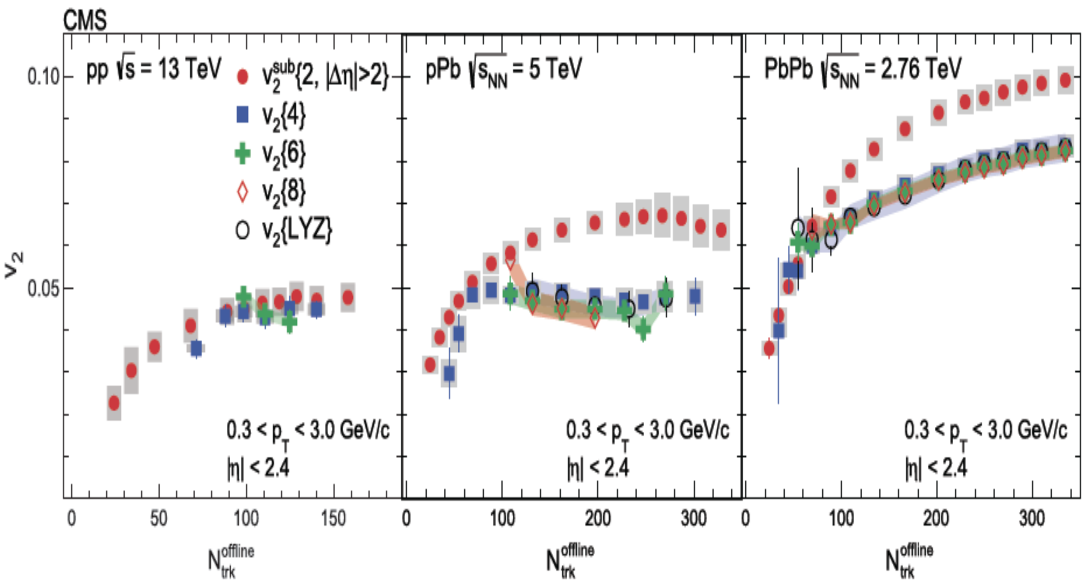
Glasma graph (single scattering) correlations are very strong
− the n-particle distribution is close to a Bose distribution

Gelis,Lappi,McLerran, arXiv:0905.3234

But $v_2\{4\}$ is imaginary…
For real $v_2\{4\}$, must have dominance of first two moments of distribution

Higher cumulants from scattering off coherent Abelian fields





Replace $N_C \times N_C$ trace with simple path ordered exponentials (N_C=1)

Summary-I

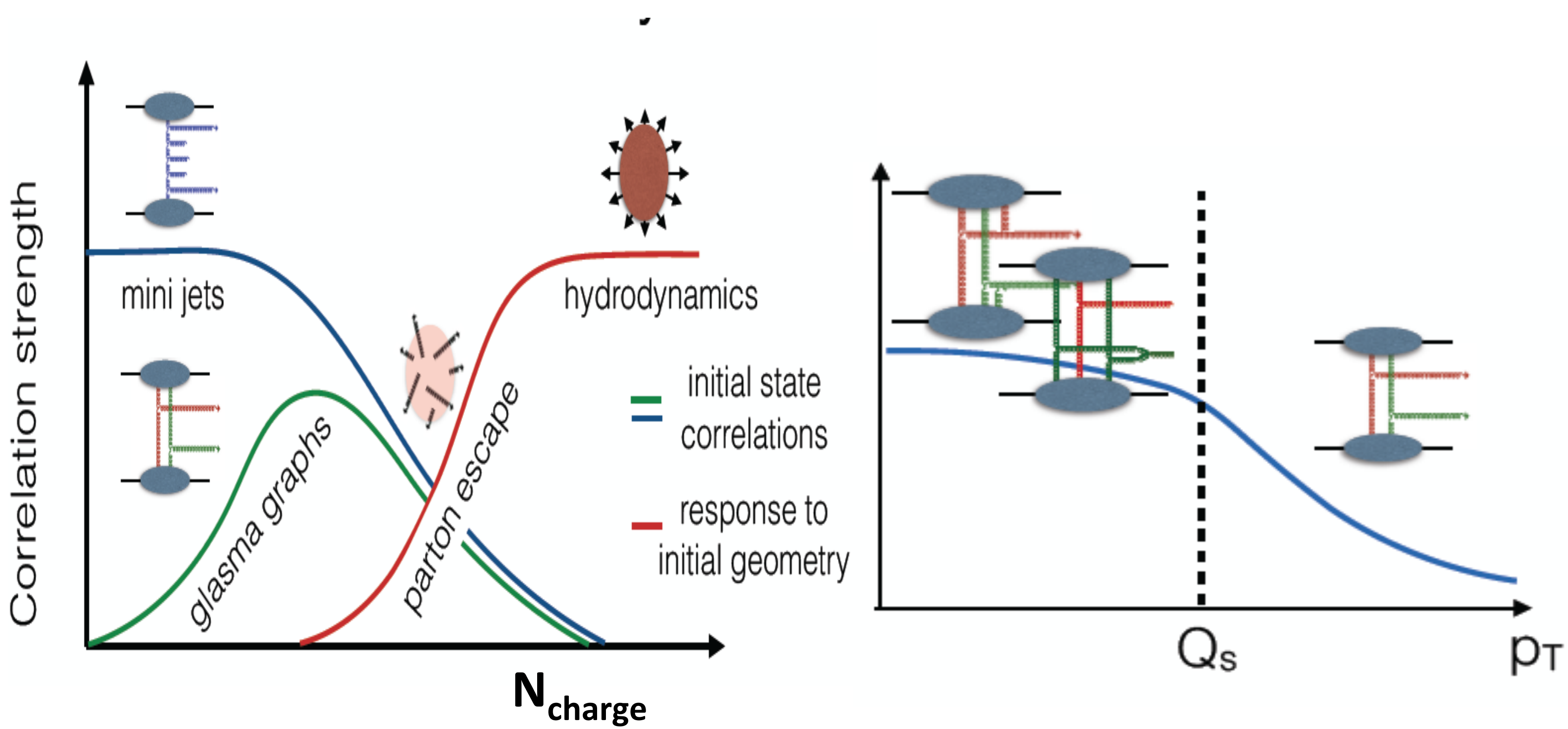
Hydrodynamic paradigm appears to describe multi-particle correlations even in the smallest systems

There are however puzzling features of the data,
questions about the the validity of hydro, fine tuning of initial conditions (requiring implicitly strong initial state correlations),
··· and explanation of anisotropies for p_T > few GeV

Initial state QCD frameworks now also able to explain many features of the data but systematic treatments are still in their infancy

Despite much progress no satisfactory explanation of the data
-- the problem is still wide open

Summary-II



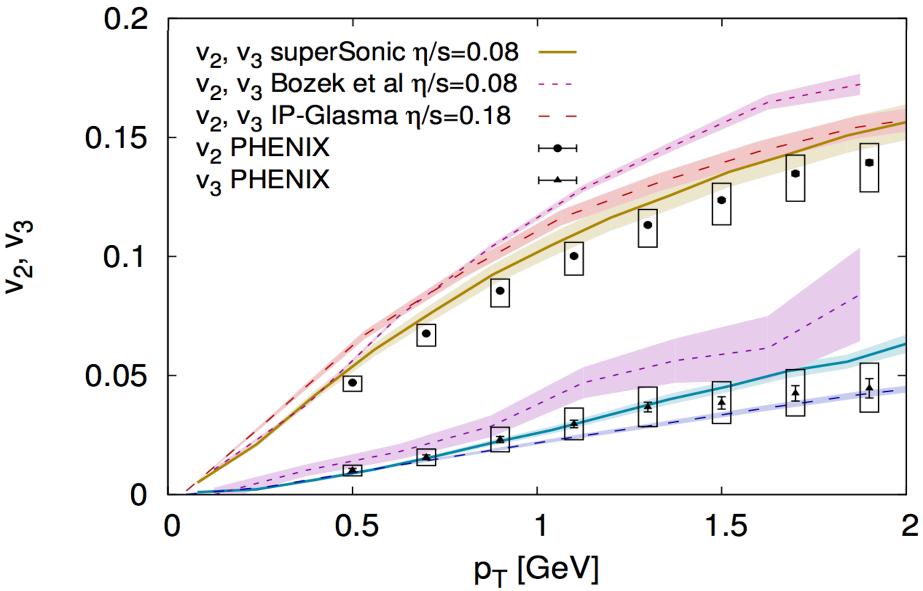
**Event engineering across system sizes, energies, and varieties of probes, offers the exciting possibility of exploring dynamical evolution of strongly correlated quark-gluon matter from high occupancy, out of equilibrium, dynamics…
to hydrodynamics**

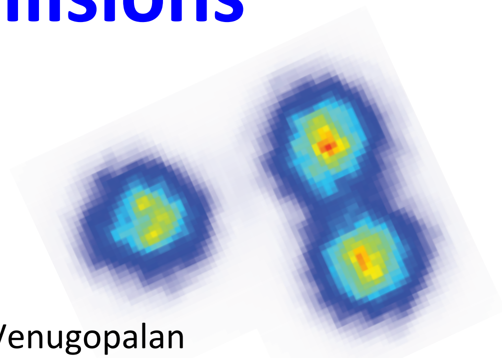
Figures: S. Schlichting at Quark Matter 2015

Thanks for listening!

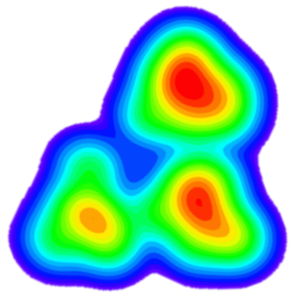
Collectivity in 3He+Au collisions

A. Adare et al. (PHENIX Collaboration)
Phys. Rev. Lett. 115, 142301 (2015)

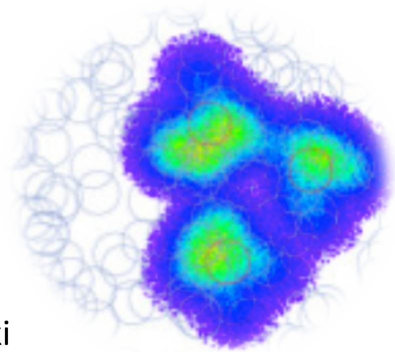




Schenke, Venugopalan
Nucl. Phys. A931 (2014) 1039-1044



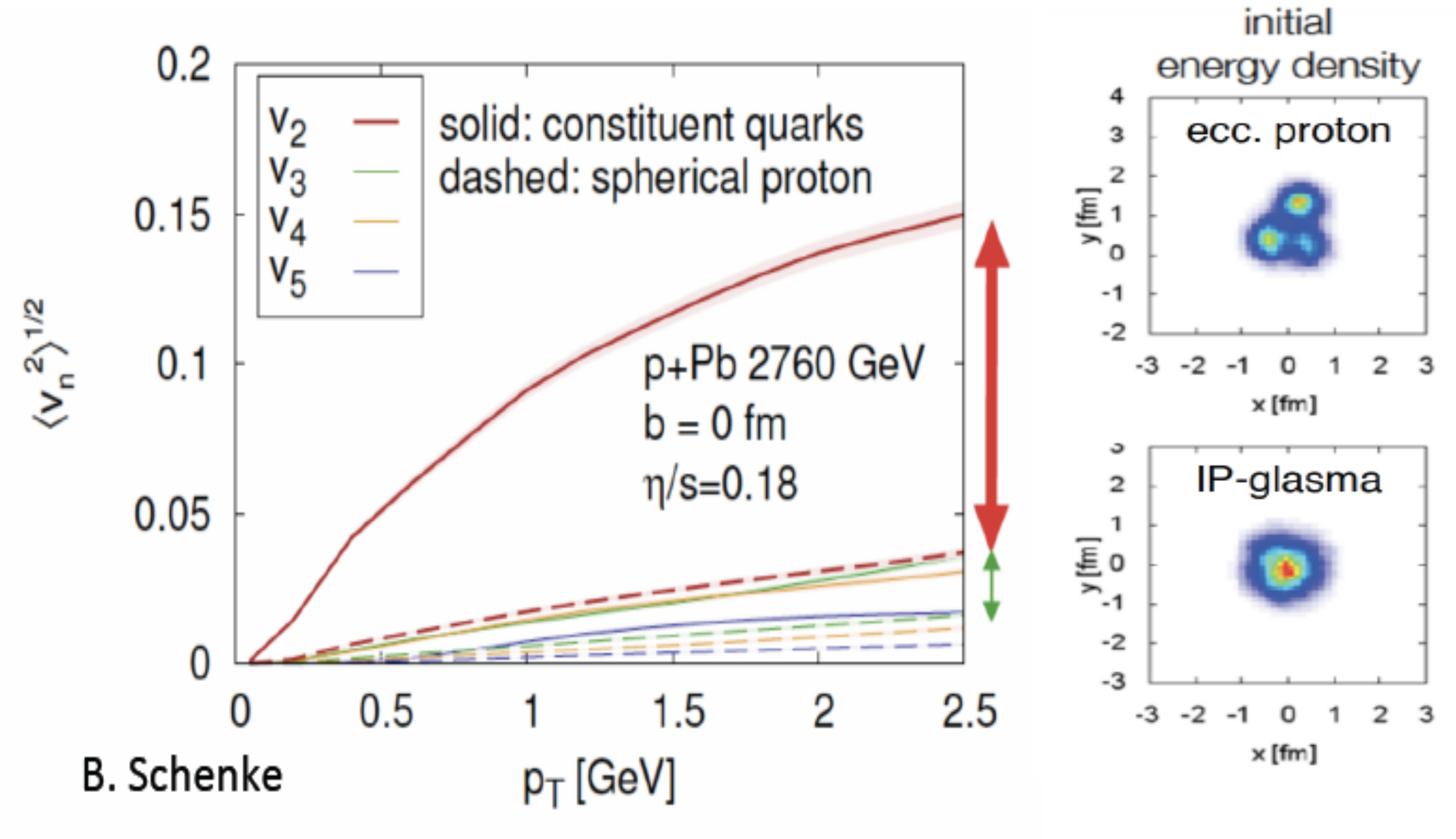
J.L. Nagle, et al.
Phys. Rev. Lett. 113, 112301



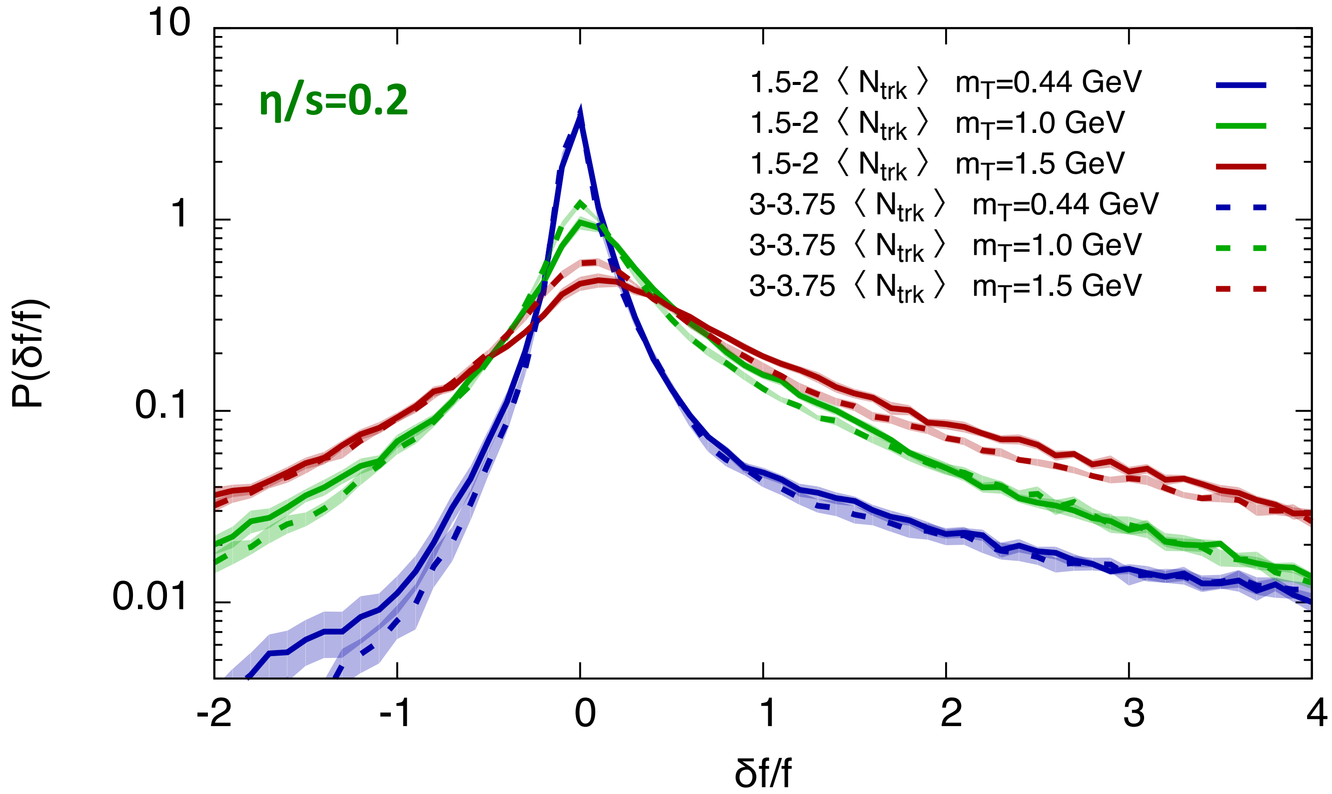
Bożek, Broniowski
Physics Letters B 747 (2015) 135–138

Shape matters ?

Schenke,Schlichting, 1407.8458



Freeze-out corrections in p+Pb as function of p_T



Plot by Bjoern Schenke

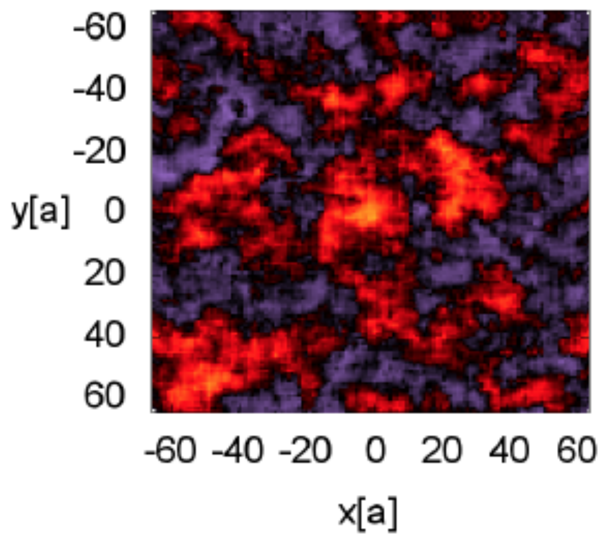
For m_T = 1 GeV, 26% of hydro cells have a 100% correction
For m_T = 1.5 GeV, 43% have a 100% correction

Mantysaari,Schenke,Shen,Tribedy, arXiv:1705.03177

Higher cumulants in the color domain model

Dumitru,McLerran,Skokov, 1410.4844

$\mathrm{Re}\,\mathrm{Tr}\left(V^{\dagger}(0,0)V(x,y)\right)/N_c$



Color domain model: express intrinsic higher point correlators as correlators of produced particles with a target field in a color domain, averaged over all orientations of the field.

$$c_2\{2\} = \frac{1}{N_D}\left(\mathcal{A}^2 + \frac{1}{4(N_c^2-1)}\right)$$

$$c_2\{4\} = -\frac{1}{N_D^3}\left(\mathcal{A}^4 - \frac{1}{4(N_c^2-1)^3}\right)$$

"A" term is the correlation induced between projectile particles due to color field orientation of target (more generically, non-Gaussian correlations)

The N_c term is the "connected Glasma graph" (Gaussian correlations)

N_D is # of color domains – few in p+A, several in A+A