Bulk observables in small colliding systems using Yang-Mill dynamics and Lund string fragmentation

Prithwish Tribedy

BROOKHAVEN NATIONAL LABORATORY

3rd International Conference on the Initial Stages in High-Energy Nuclear Collisions

Instituto Superior Técnico, Alameda Campus, Lisbon, Portugal, on May 23rd-27th 2016

TÉCNICO LISBOA

U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

Initial state models based on CGC —> *ab-initio* framework for correlated multi-particle production in small systems

How to propagate the correlations generated in initial state to the final state particles ?

Approach I : Hydrodynamic evolution (widely discussed in this conference)

Approach II : Scheme of fragmentation (topic of this talk)

This is the very first attempt to combine solutions of **CYM equation** with **Lund string fragmentation**

Work in progress in collaboration with : B. Schenke, S. Schlichting & R. Venugopalan

Outline

Goal : Study the role of initial state dynamics on bulk observables that are attributed to collectivity

Focus : High multiplicity events in the collisions of small systems : p+p and p/d+A

We need :

- An *ab-initio* framework of particle production
- Full treatment of different sources of fluctuations
- State-of-the art treatment of fragmentation

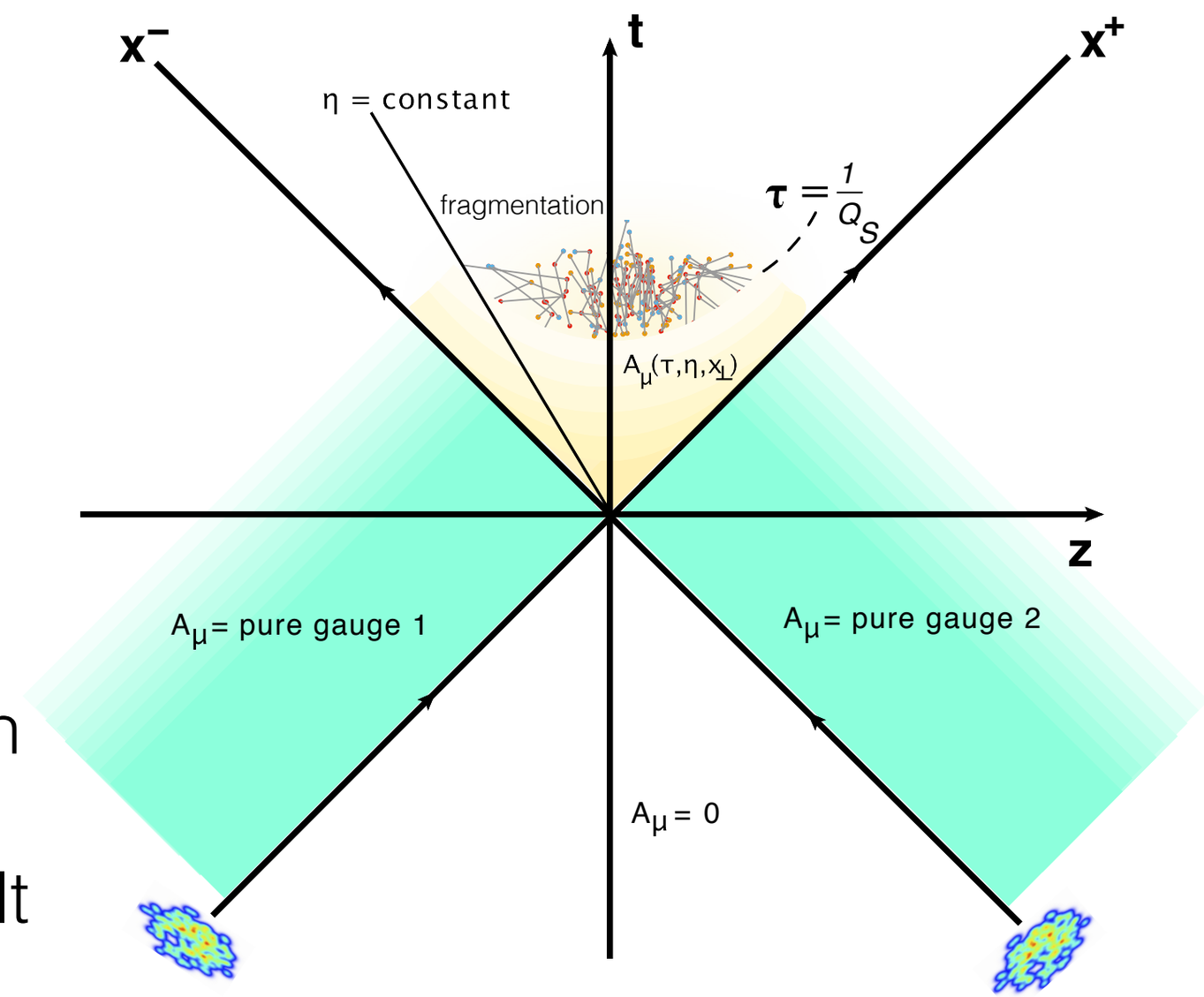
Details of the framework

- Full solutions of CYM on 2+1D lattice : IP-Glasma Monte-Carlo model of initial conditions : constrained by HIC data

Schenke, PT, Venugopalan 1202.6646

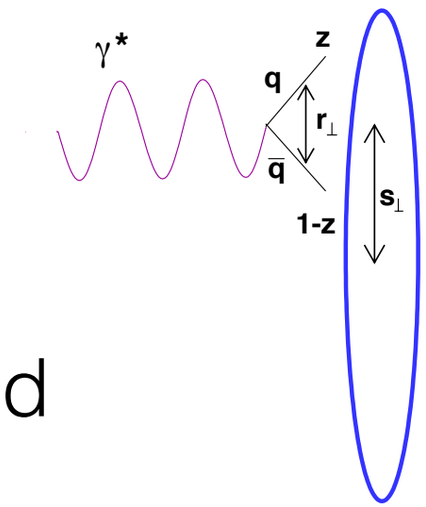
- Lund model of fragmentation in PYTHIA to produce particles from gluons: default parameters to avoid tuning

Sjostrand, Mrenna, Skands hep-ph/0603175



Initial state of the IP-Glasma model

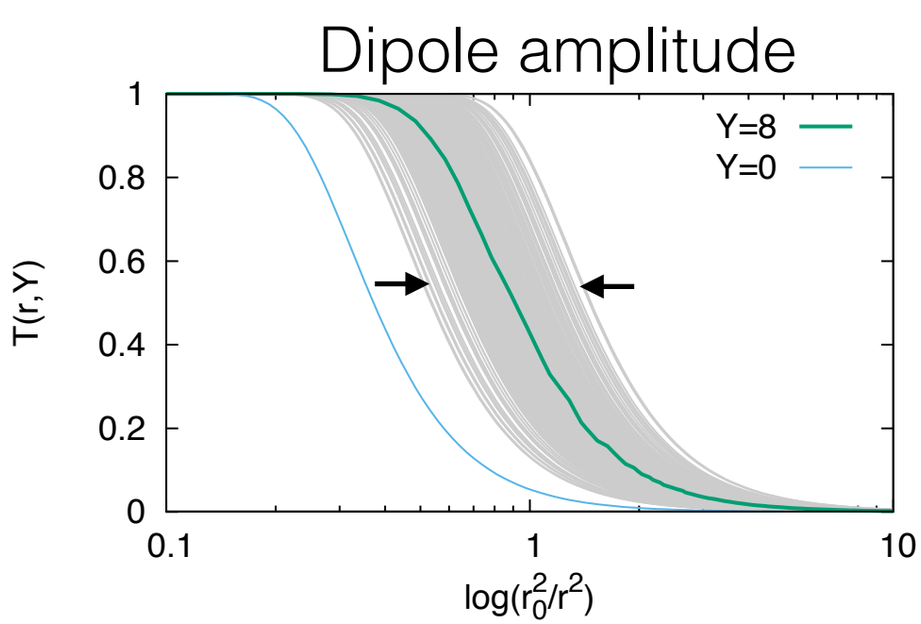
- IP-Sat model —> color charge density of colliding hadrons : constrained by HERA DIS e-p data



- Non-perturbative sources of fluctuations introduced by fluctuating the average saturation scale

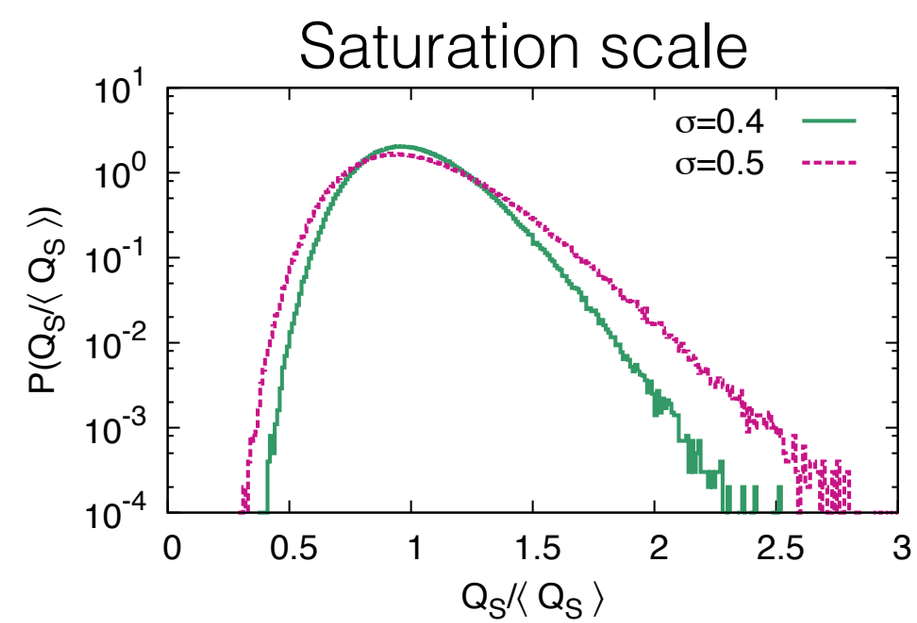
McLerran, PT 1508.03292

$$P(\ln(Q_S^2/\langle Q_S^2\rangle)) = \frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{\ln^2(Q_S^2(\mathbf{s}_\perp)/\langle Q_S^2(\mathbf{s}_\perp)\rangle)}{2\sigma^2}\right) \qquad \sigma^2(Y) = \sigma_0^2(Y_0) + \sigma_1^2(Y - Y_0)$$



Marquet et al
hep-ph/0606233

Stochastic splitting of dipoles



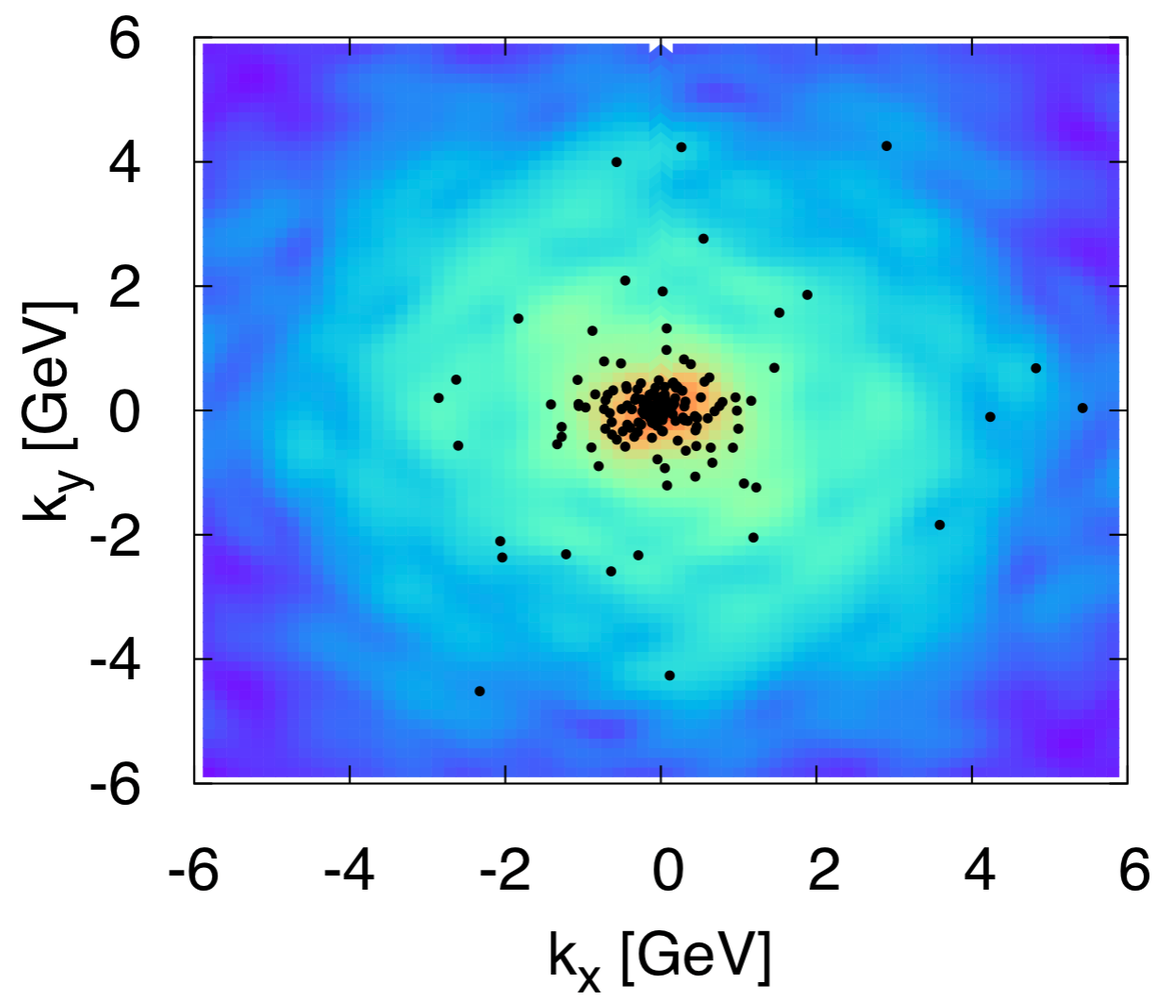
Step-I : sample gluons from IP-Glasma

Perform e-by-e classical Yang-Mills evolution till time $\tau \sim 1/Q_s$

$$\frac{dN_g}{dyd^2k_T} = \frac{2}{N^2}\frac{1}{\tilde{k}_T}\left[\frac{g^2}{\tau}\mathrm{tr}\left(E_i(\mathbf{k}_\perp)E_i(-\mathbf{k}_\perp)\right) + \tau\,\mathrm{tr}\left(\pi(\mathbf{k}_\perp)\pi(-\mathbf{k}_\perp)\right)\right]$$

Sample gluons in momentum space in the range :

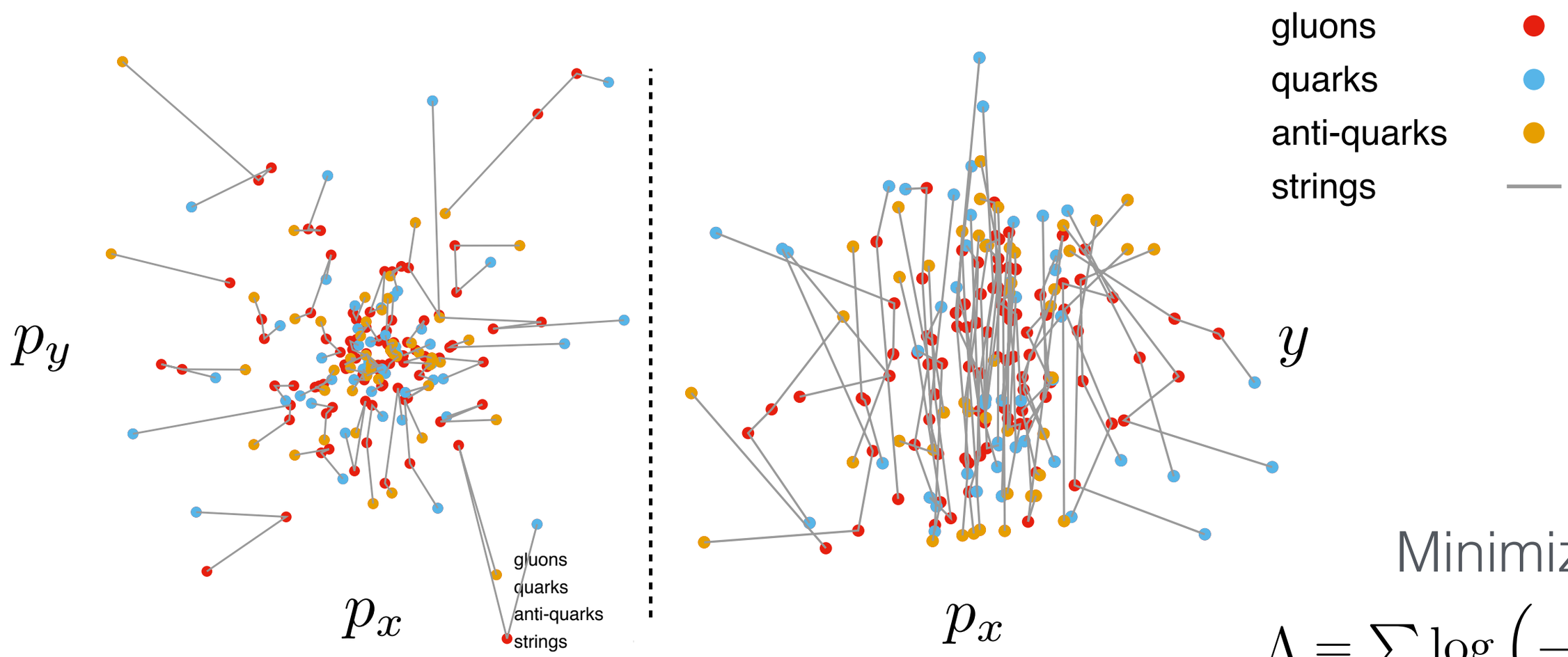
$$0 < |y_{\max}| < \log(\sqrt{s}/2m_p)$$



Glasma distribution is boost invariant :

Distribution of Gluons —> uniform in rapidity

Step-II : Implementing PYTHIA Strings

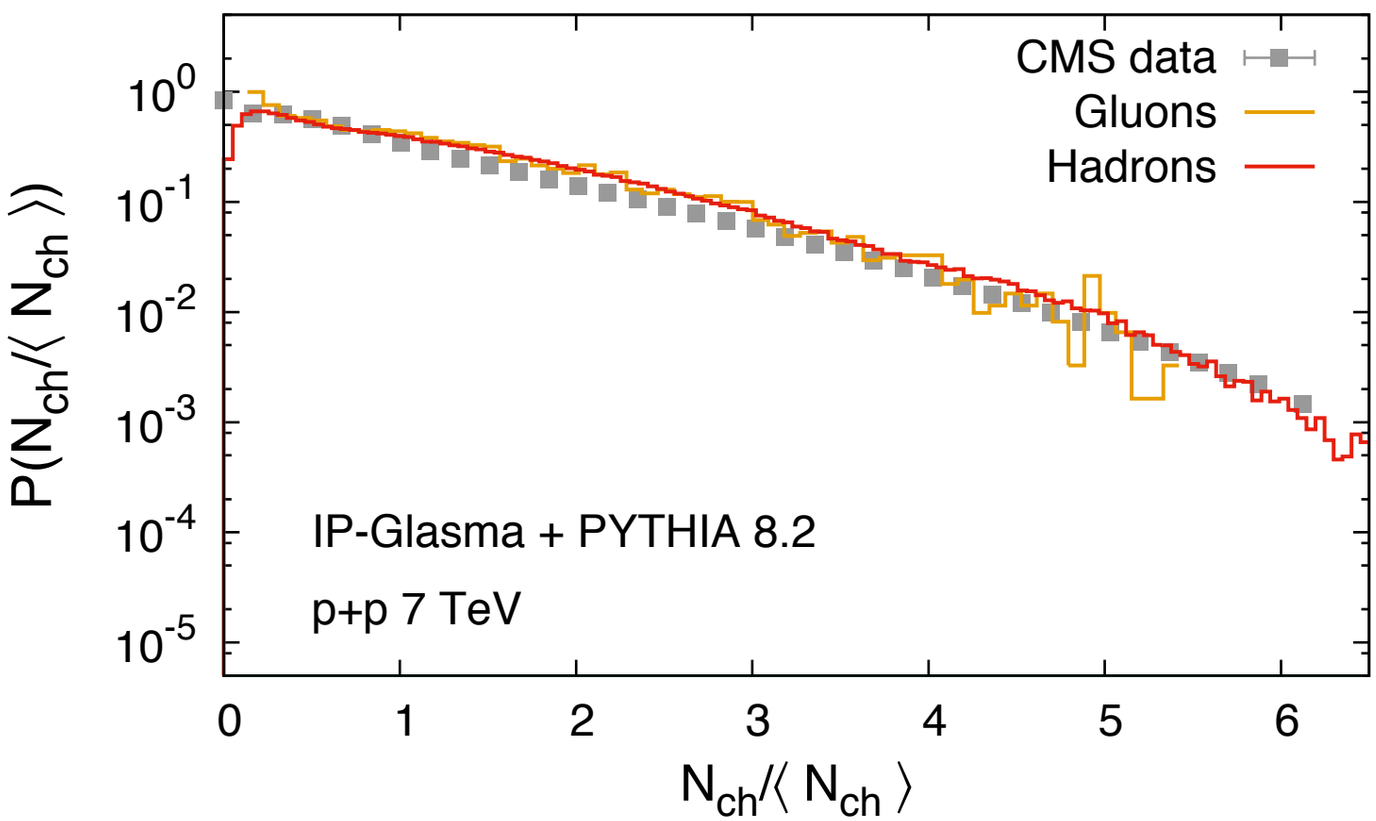


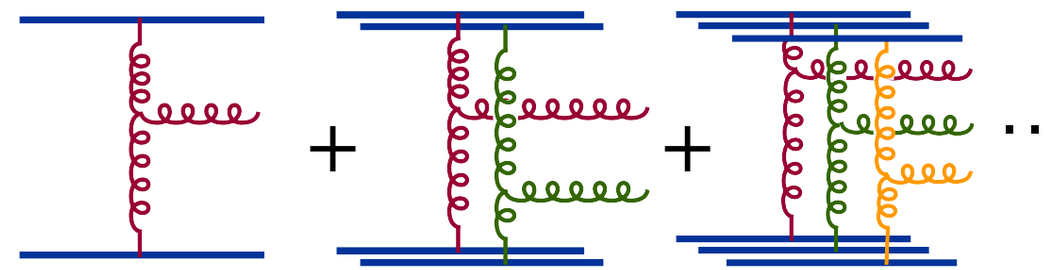
Minimize :

$$\Lambda = \sum_i \log\left(\frac{s_i}{2\Lambda_{\rm QCD}^2}\right)$$

Connect the gluons close in phase space to color neutral strings with ~ $N_{\rm gs} = N_g/\langle Q_S^2 S_\perp\rangle$ of gluons per strings

Multiplicity distribution



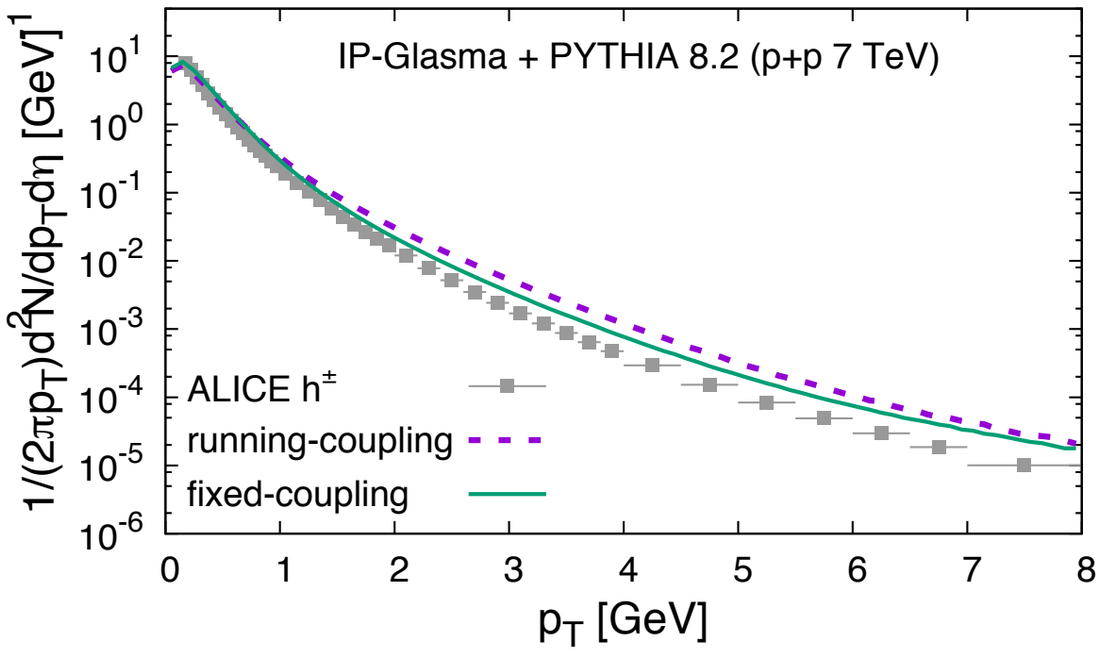


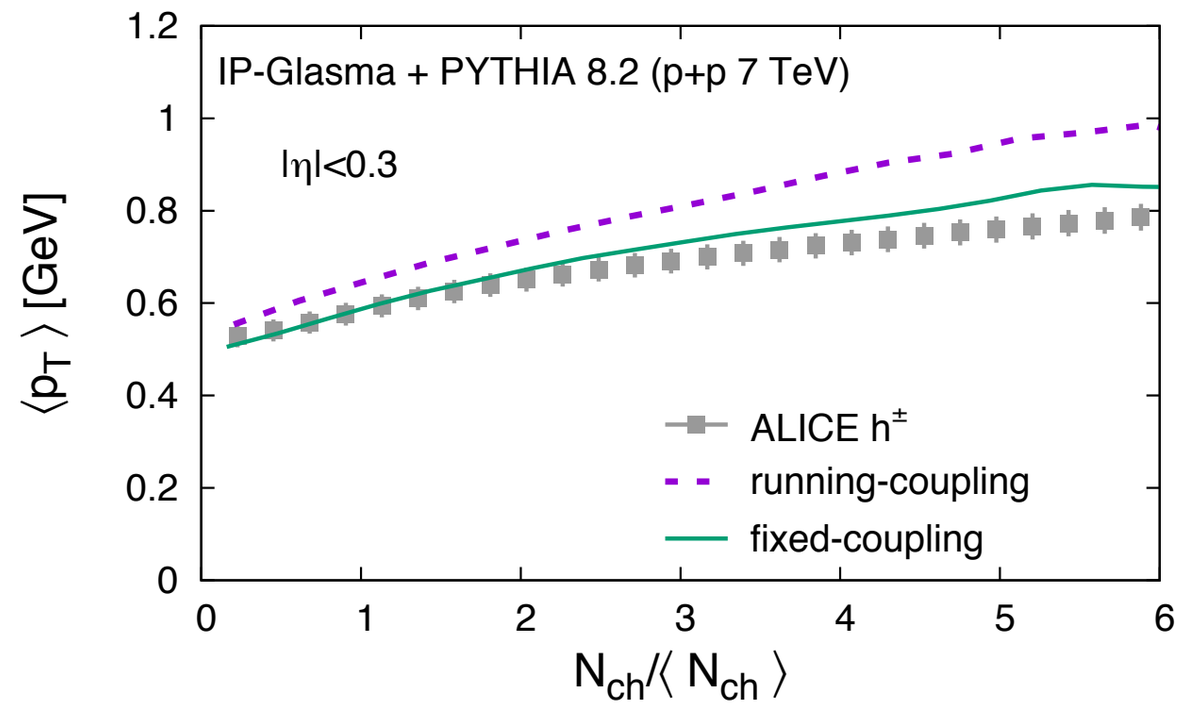
NBD fluctuation is a natural consequence of multi-particle production in CGC

- Promising results on multiplicity distributions
- Observables are to be studied in bins of multiplicity
- Some uncertainties in the estimation of $N_{\rm ch}/\langle N_{\rm ch}\rangle$

Single Inclusive distributions

Minimum bias spectra --> well reproduced

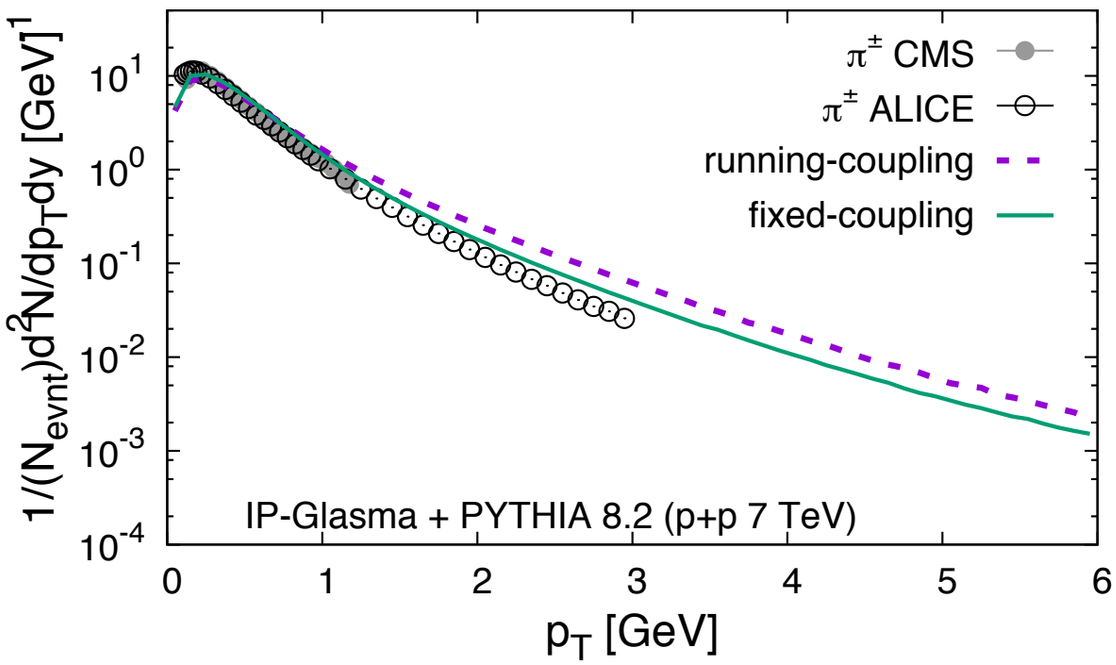


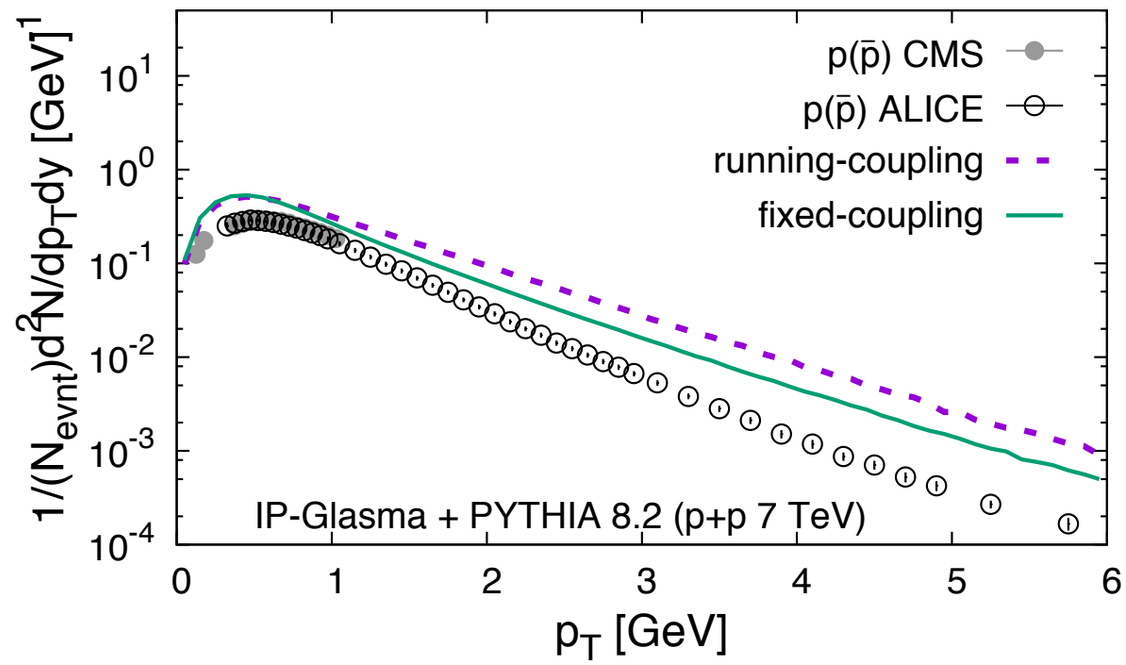


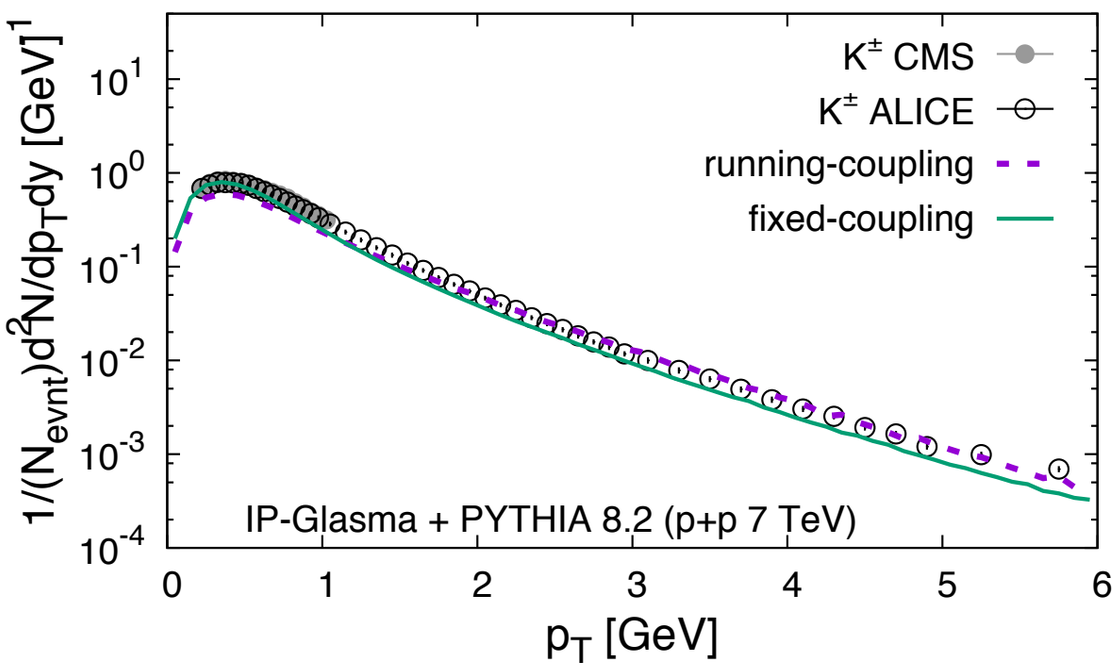
Multiplicity dependence of $\langle p_T \rangle$ —> high multiplicity events in CGC —> driven by rare large Q_S events

Running α_S effect —> high p_T

Identified particle distributions

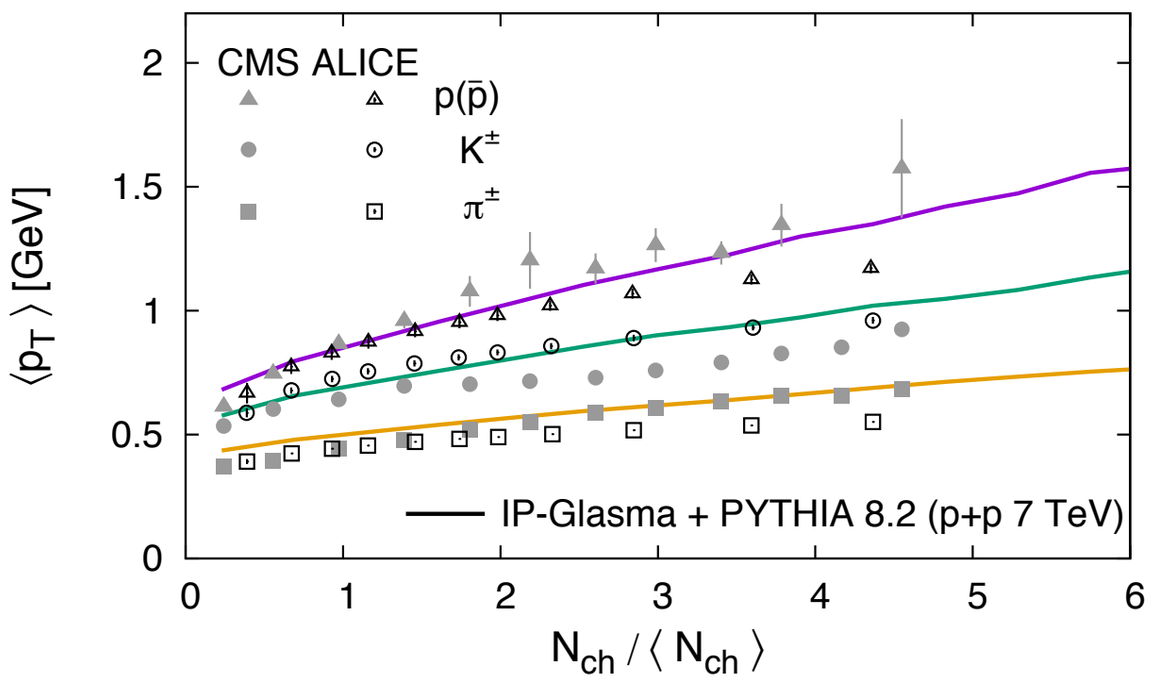




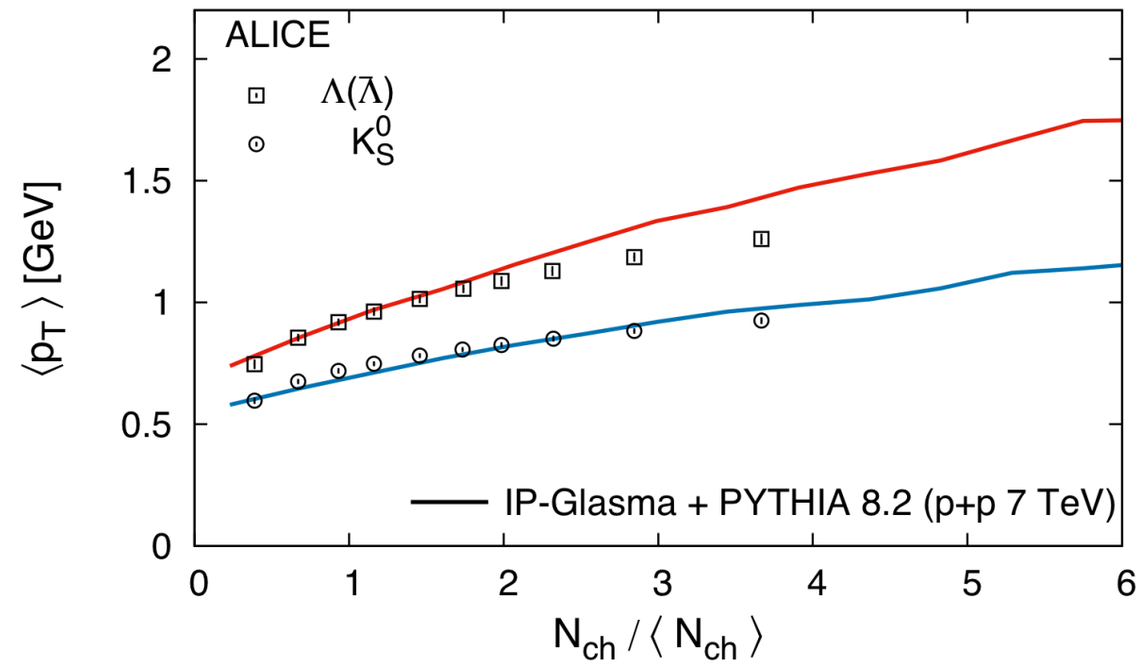


Reasonable agreement without any tuning

Mass ordering of average transverse momentum

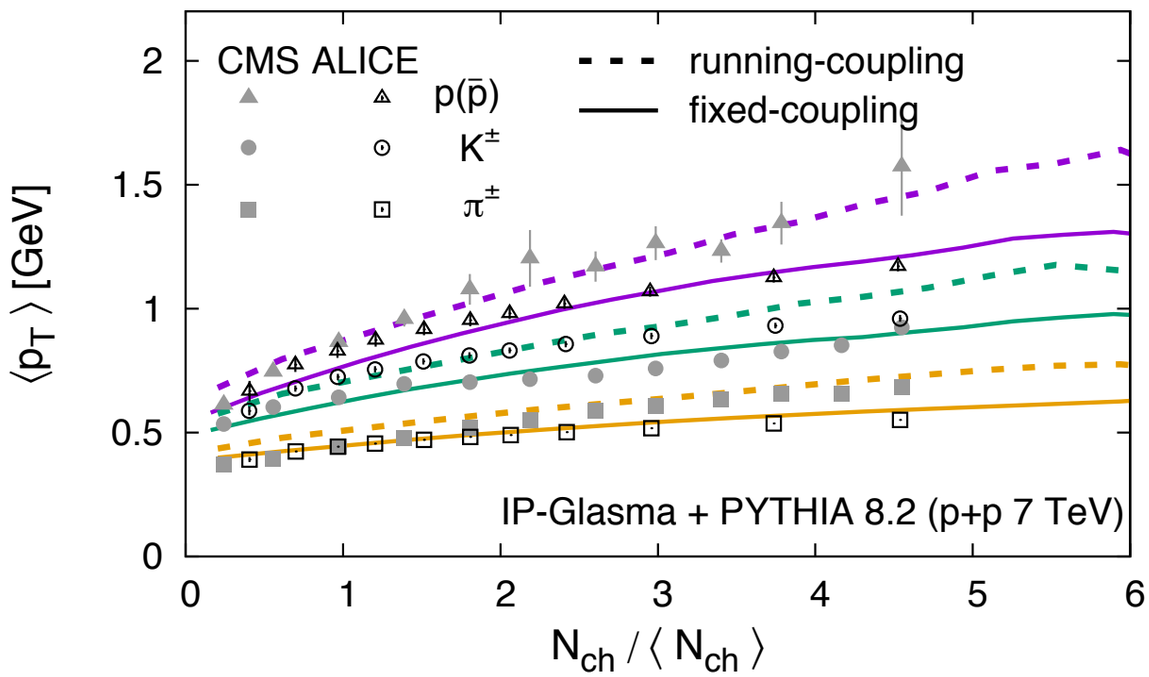


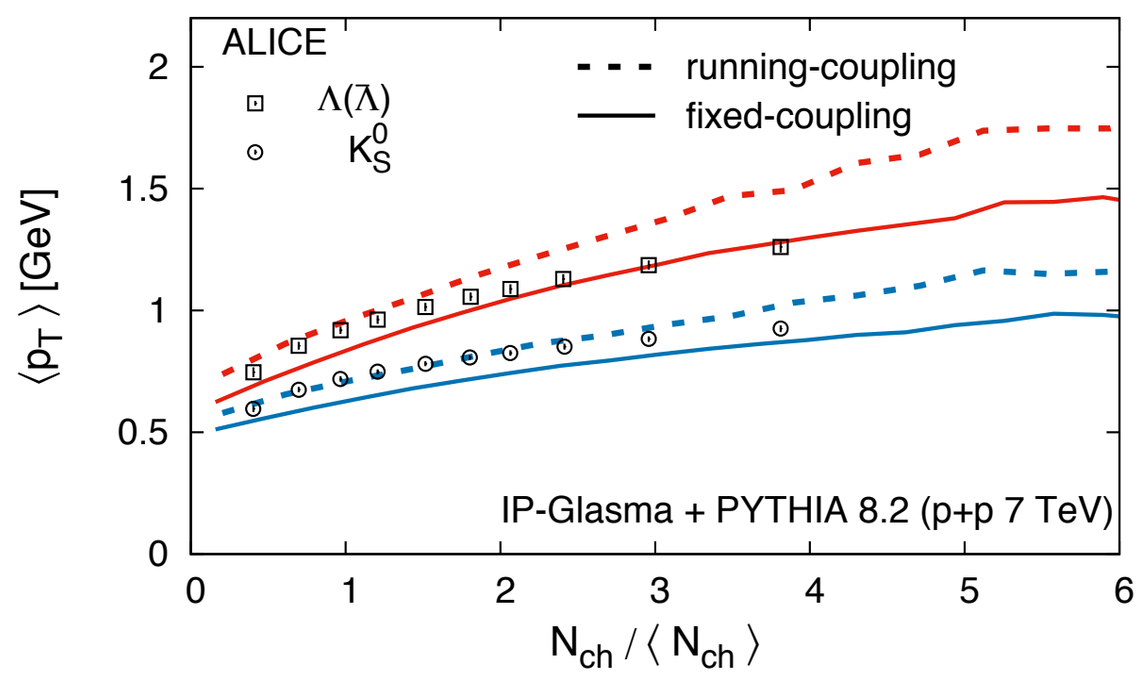
data arXiv :1604.06736



Mass ordering of average transverse momentum—> naturally reproduced in this framework (even at very low multiplicity)

Mass ordering of average transverse momentum

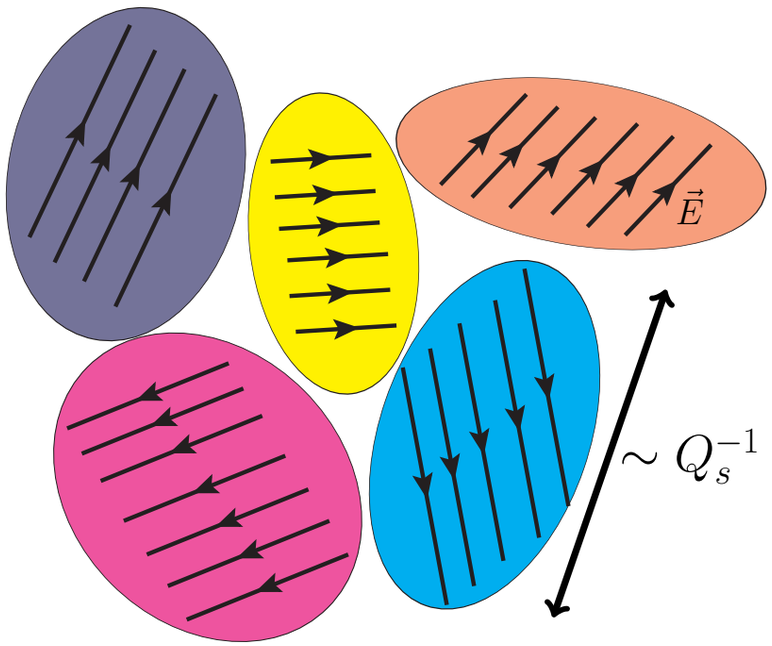




Effect of running coupling —> increase in $\langle p_T \rangle$

Azimuthal Correlations in CGC

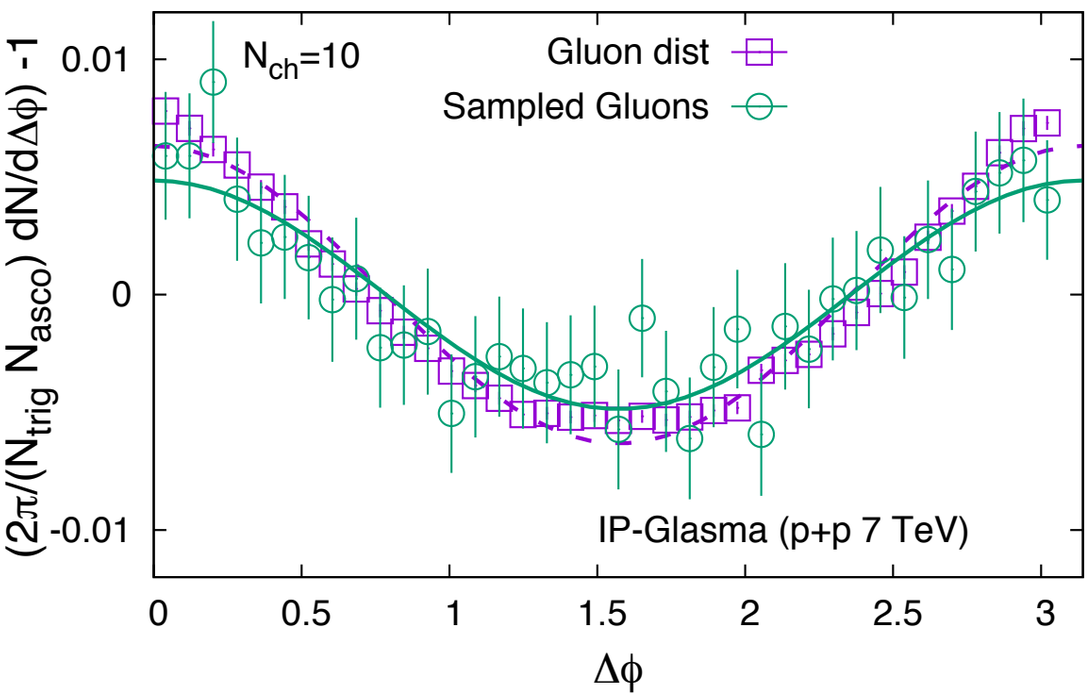
- Intrinsic momentum space correlation from initial state
- Originate from partons (probe) scattering off a color domain (target)
- Suppressed by number of color sources / domains

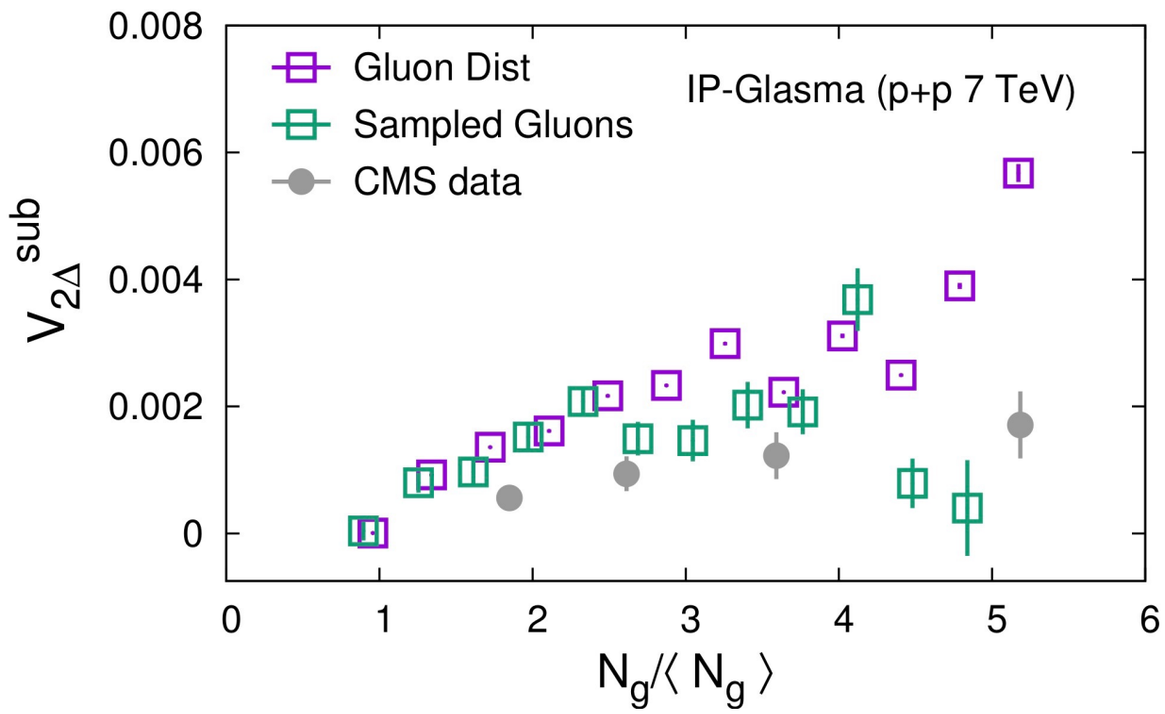


Dumitru, Dusling, Gelis, Jalilian-Marian, Lappi, Venugopalan 1009.5295
Kovner, Lublinsky 1012.3398
Dusling, Venugopalan 1201.2658
Kovchegov, Wertepny 1212.1195
Dumitru, Giannini 1406.5781
Lappi, Schenke, Schlichting, Venugopalan 1509.03499

Very distinct from Hydrodynamic flow (driven by geometry)

Azimuthal correlations in CGC (gluons only)

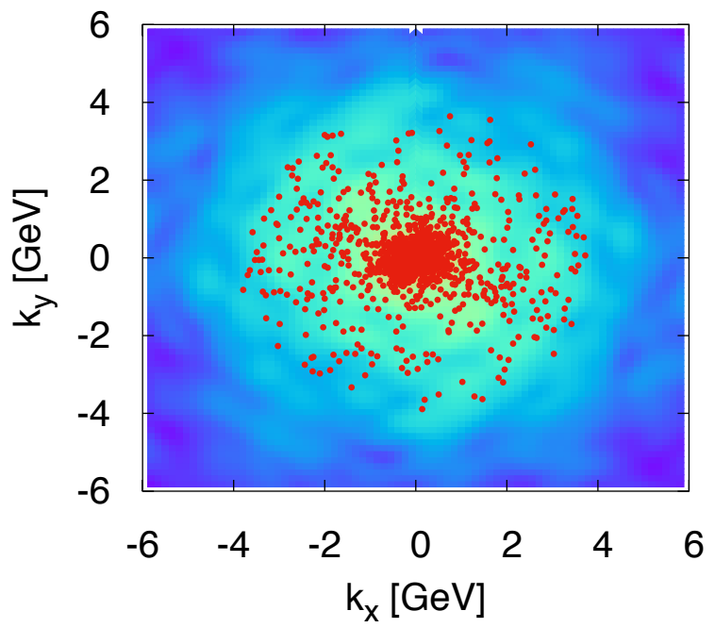




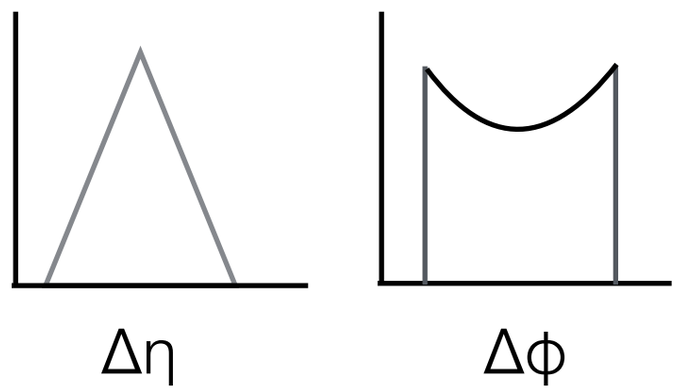
$$\frac{dN^{\rm pair}}{d\Delta\phi} = \left\langle \frac{1}{2\pi}\int_0^{2\pi} \frac{dN}{d\phi}(\phi)\frac{dN}{d\phi}(\phi+\Delta\phi)\right\rangle,$$

$$\frac{2\pi}{N_{\rm trig}N_{\rm assco}}\frac{dN^{\rm pair}}{d\Delta\phi} = 1 + \sum_n 2V_{n\Delta}\cos(n\Delta\phi).$$

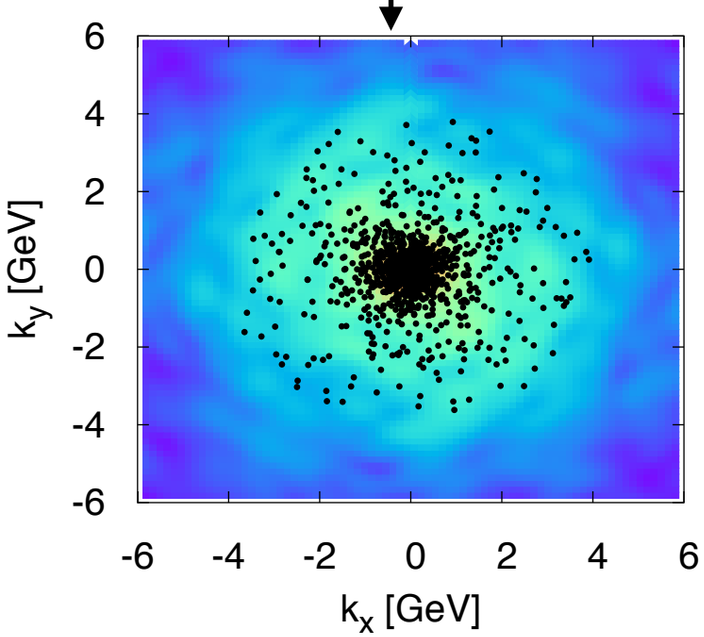
Azimuthal correlations (after fragmentation)



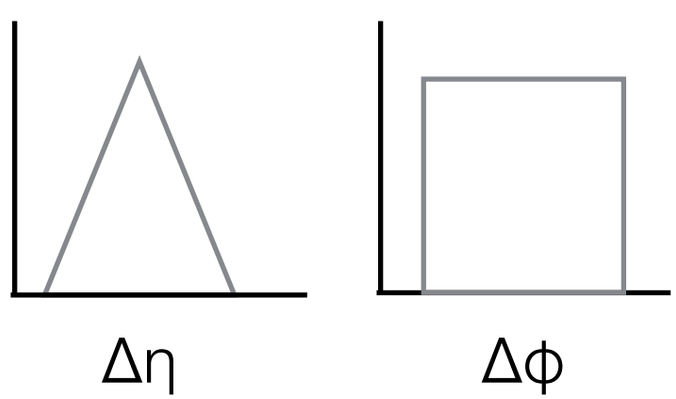
Real events

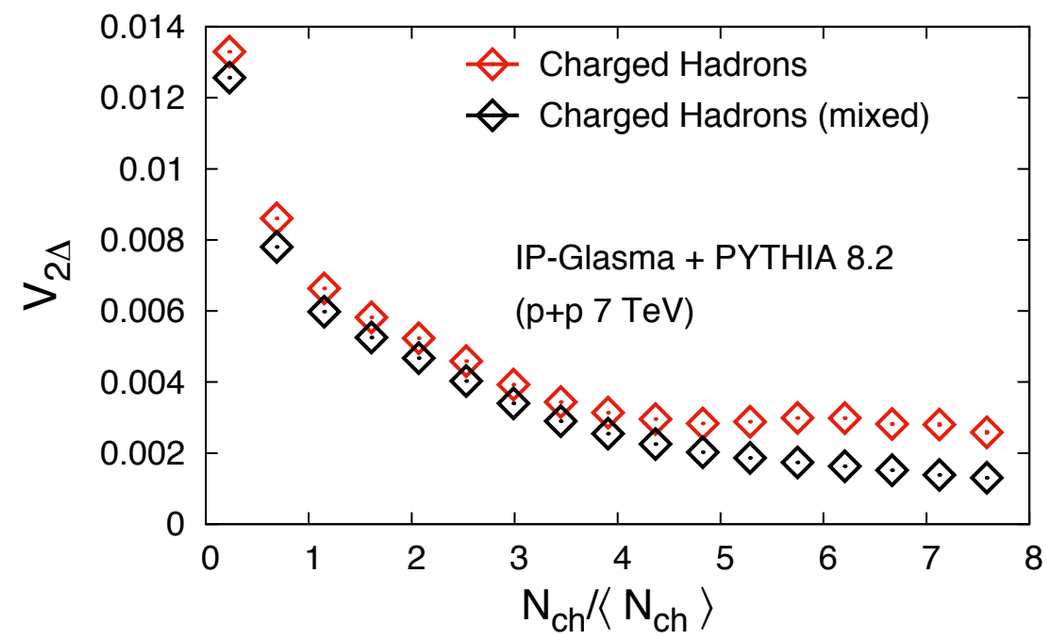


randomize ϕ [0-2π]

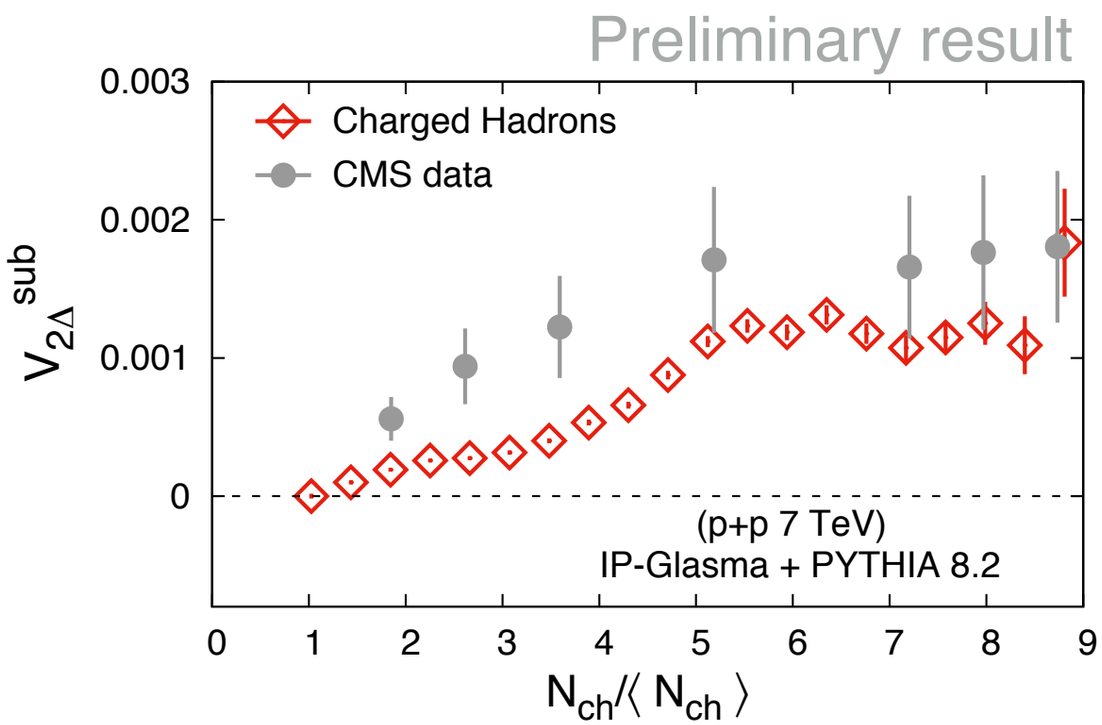


Mixed events





Azimuthal correlations for charged hadrons



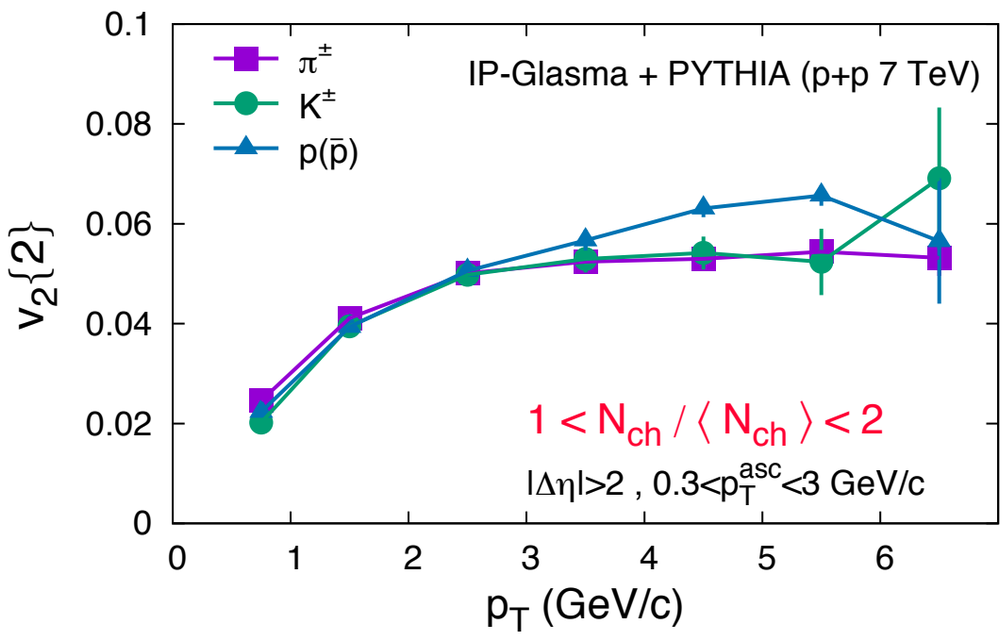
After subtraction of
1) Mixed-events
2) Low-mult events

$$V_{n\Delta}^{\rm sub} = V_{n\Delta} - V_{n\Delta}^{\rm low-mult} \times \frac{N_{\rm assoc}^{\rm low-mult}}{N_{\rm assoc}}$$

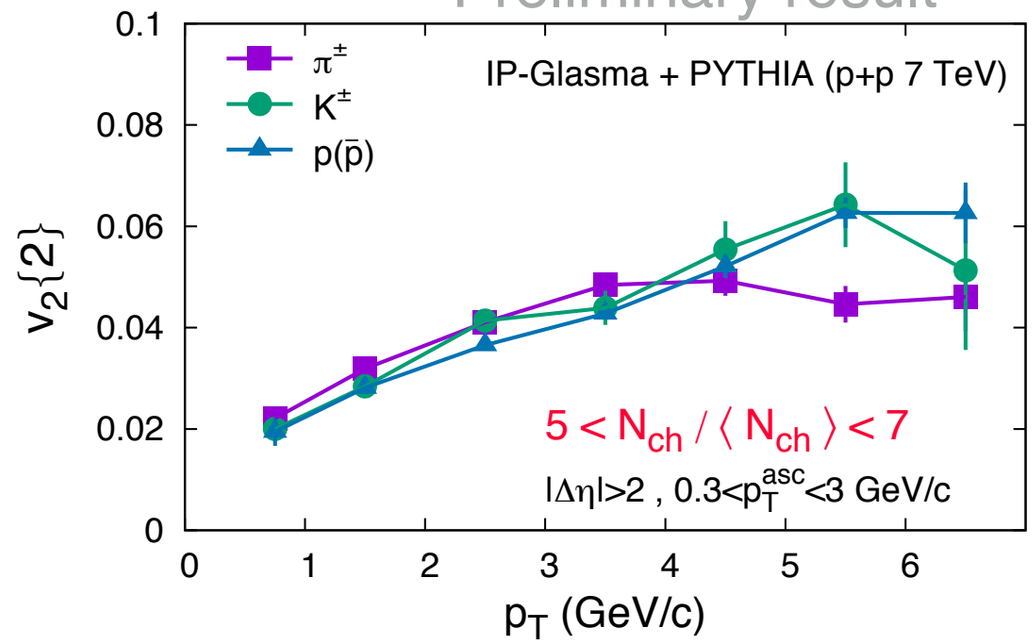
Dilution of correlations after the fragmentation

Azimuthal correlations identified particles

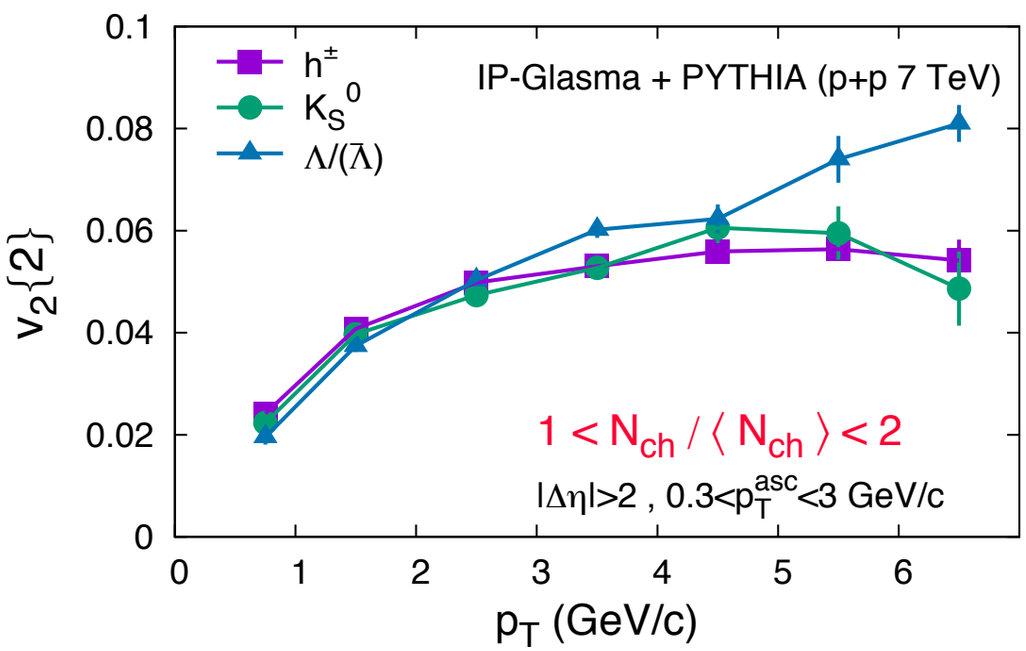
Preliminary result



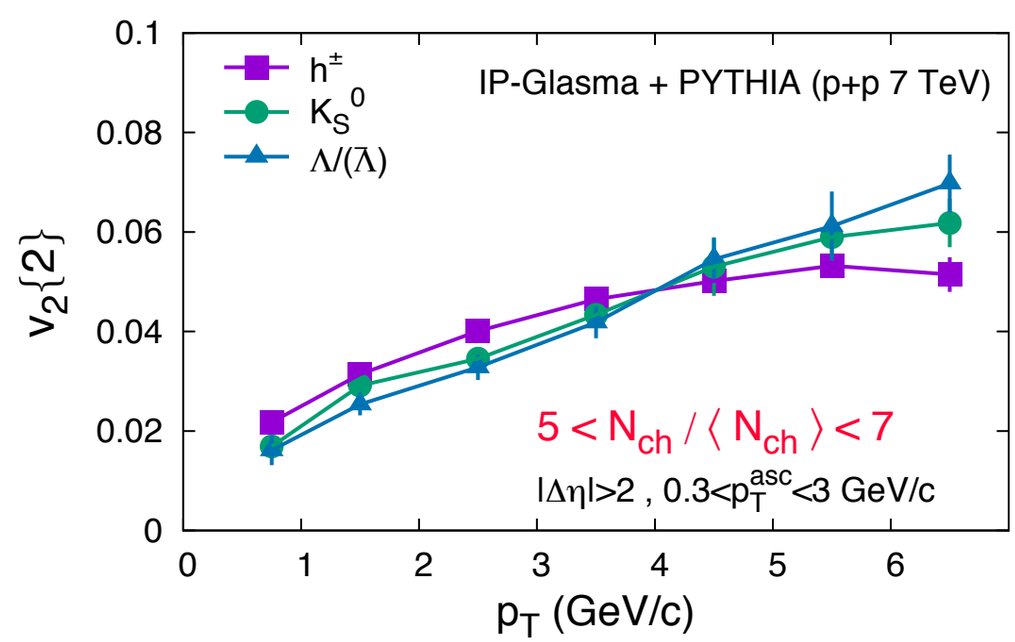
π, K, p



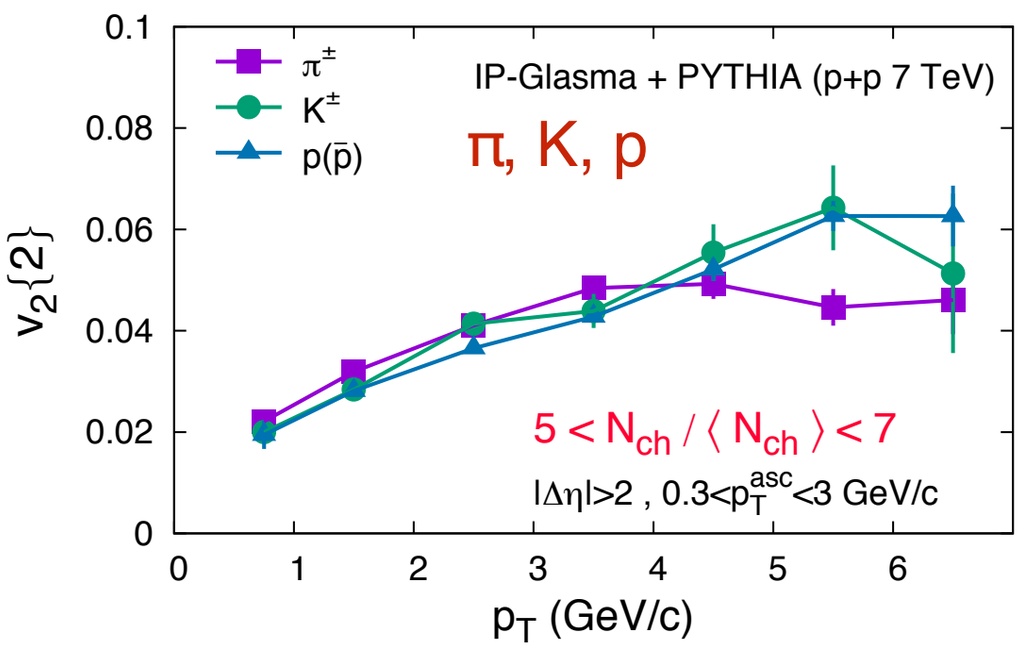
Low multiplicity → High multiplicity



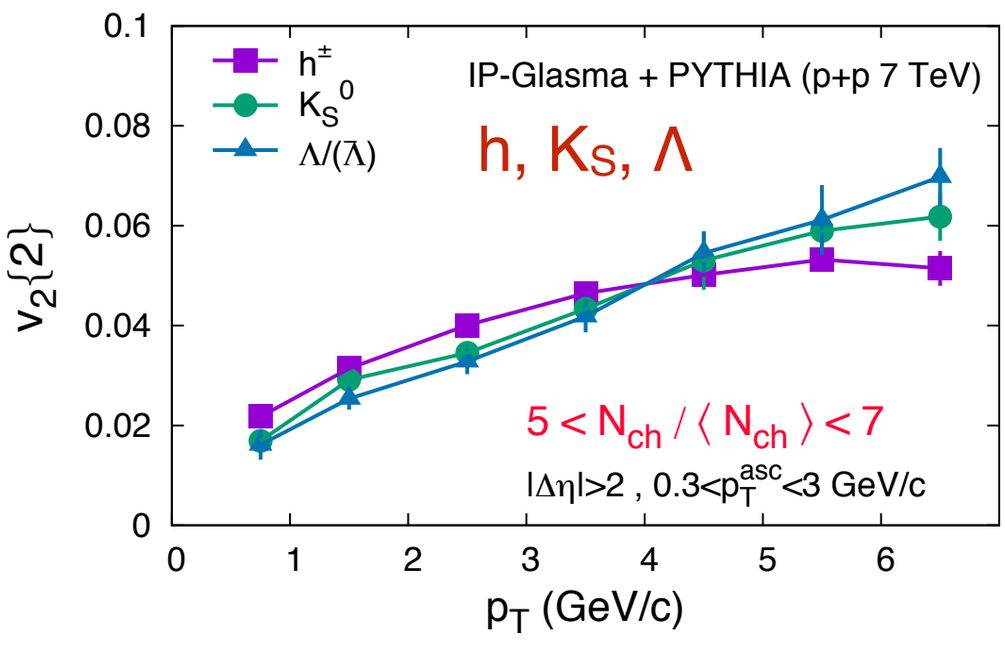
h, K_S, Λ

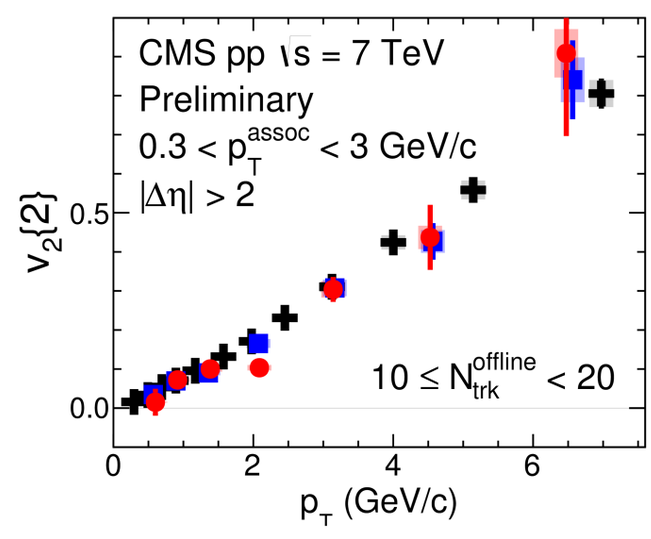


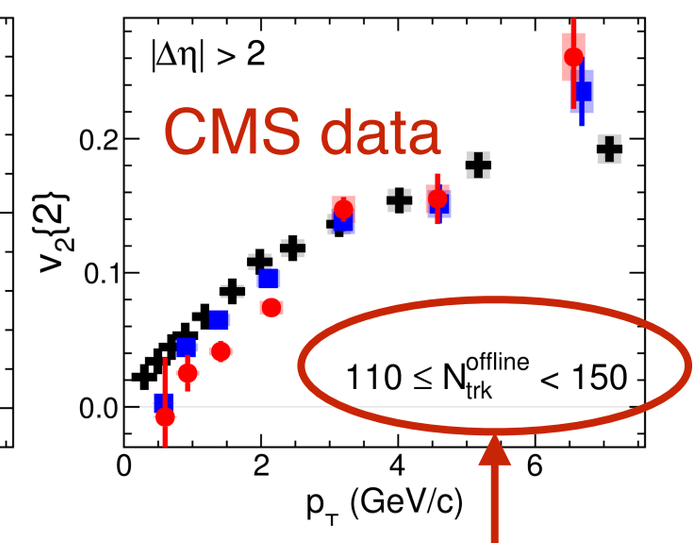
Azimuthal correlations identified particles



Some hints of mass dependence
—> Need to study even **higher** multiplicity events & p+p @13 TeV



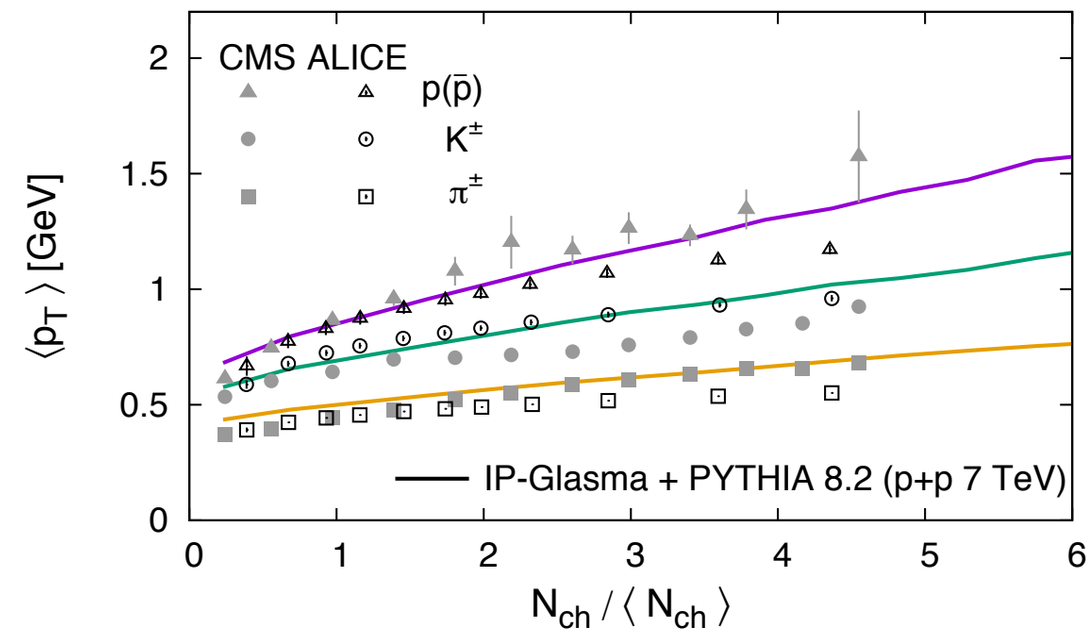


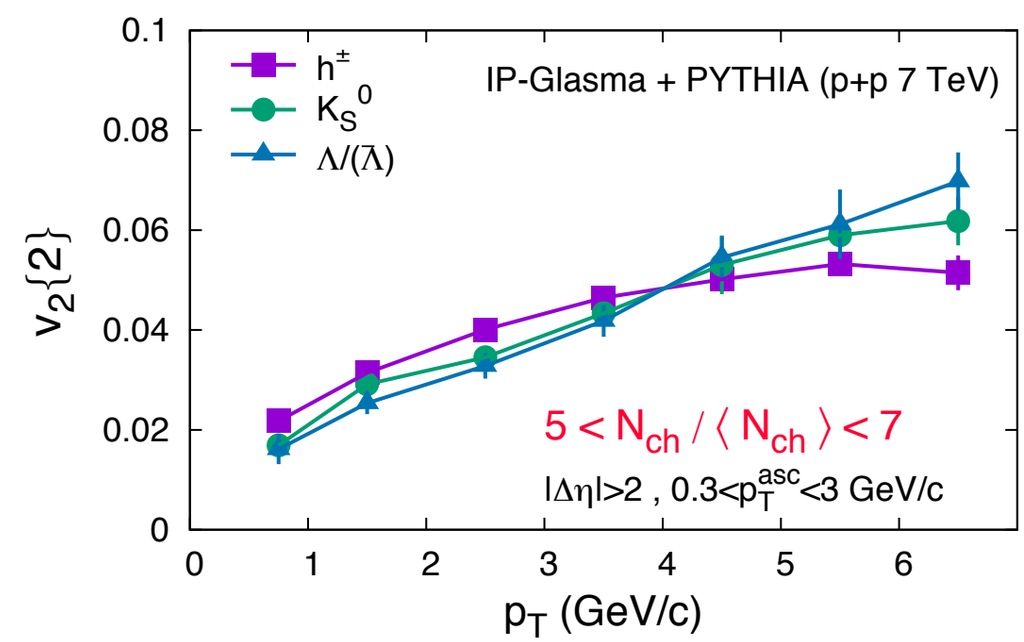


$8 < N_{ch}/\langle N_{ch} \rangle < 11$

Summary

- Very first attempt to combine CGC based IP-Glasma with Lund model of fragmentation in PYTHIA
- Quantitative description for a number on of bulk observables in p+p collisions looks promising
- Observed mass ordering of $\langle p_T \rangle$ is very well reproduced
- Hints of mass dependence of v_2 observed —> need to study higher multiplicity bins





Next step : higher multiplicity p+p and p+Pb in this framework

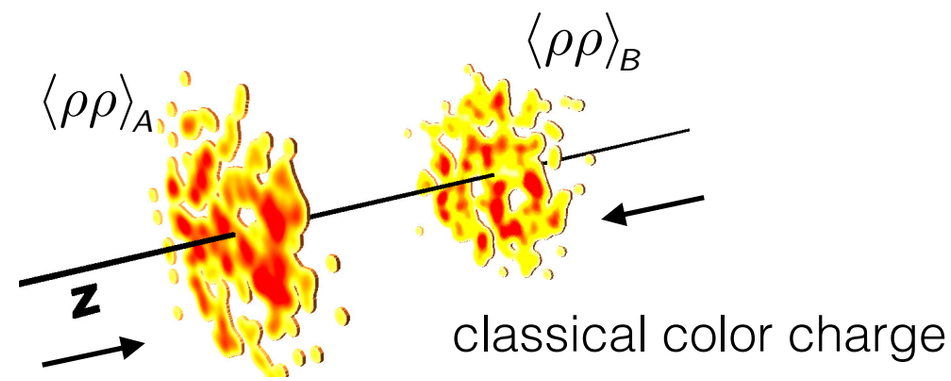
back-up

Details of CGC the framework

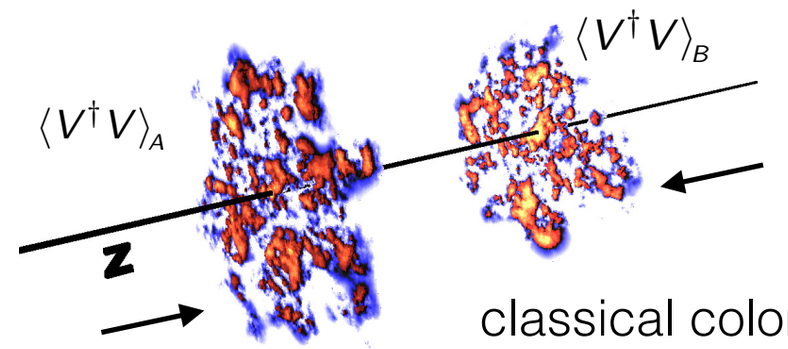
- Fundamental objects are Color Charge density matrices $\rho^a(x_\perp, Y)$
  Local Gaussian distribution $W[\rho]$
  (MV-Model)

$$\langle \rho^a(\mathbf{x}_\perp)\rho^b(\mathbf{y}_\perp)\rangle = \delta^{ab}\delta^2(\mathbf{x}_\perp - \mathbf{y}_\perp) g^2\mu^2(\mathbf{x}_\perp)$$

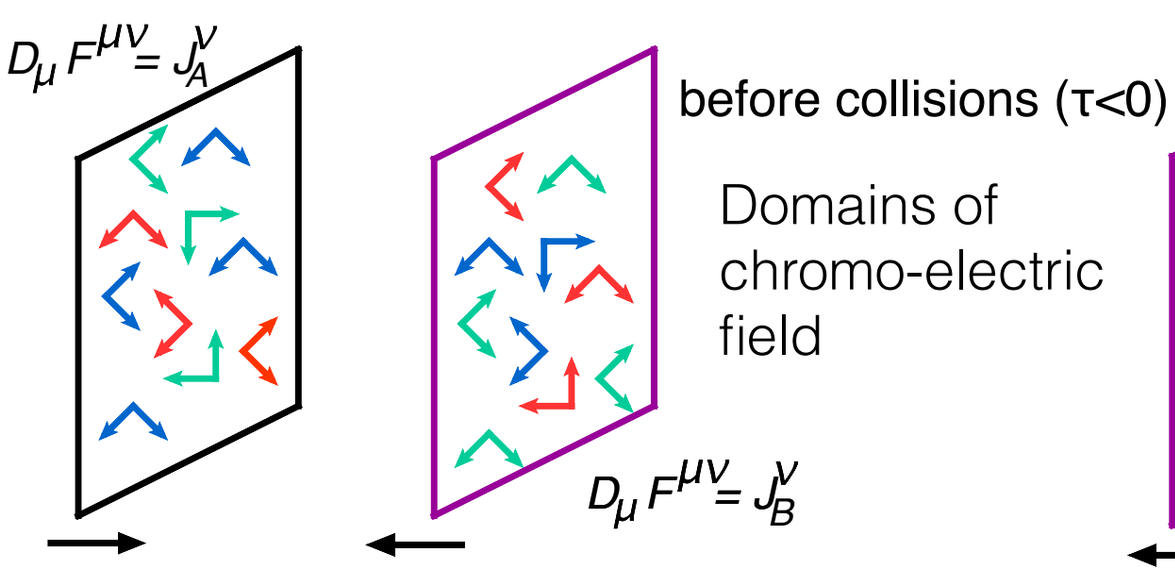
- Color field before collisions : solving Yang Mills equations $[D_\mu, F_{\mu\nu}] = J_\nu$ for each configuration of source $\rho(x_\perp)$



classical color charge

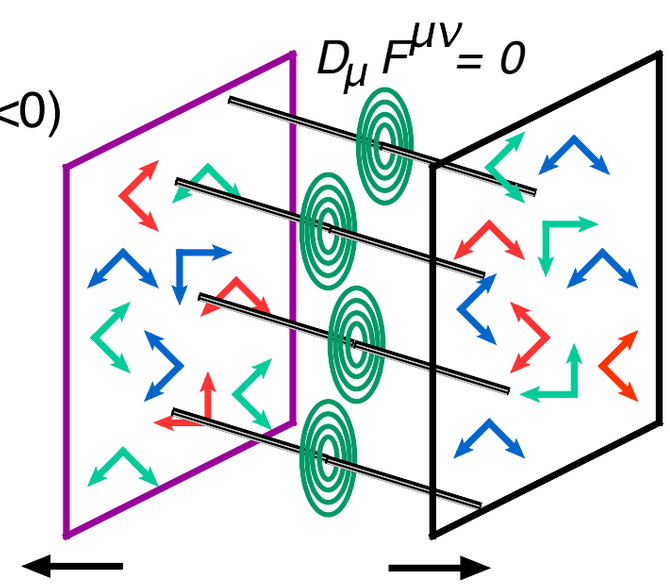


classical color field



before collisions (τ<0)

Domains of chromo-electric field



after collisions (τ>0)

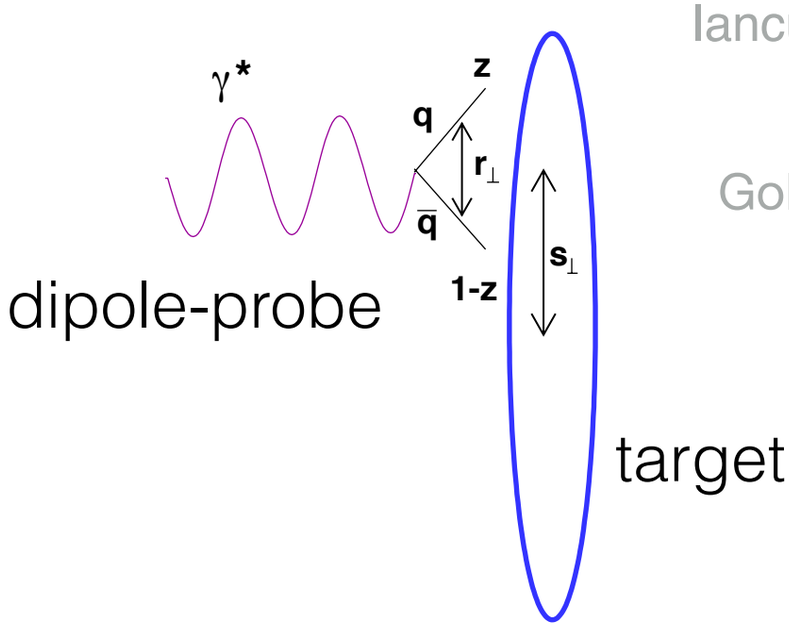
Glasma flux tubes —> free streaming gluons

hep-ph/9809433,
hep-ph/0303076,
arXiv: 1206.6805
arXiv: 1202.6646

(III) Intrinsic fluctuations of saturation scale

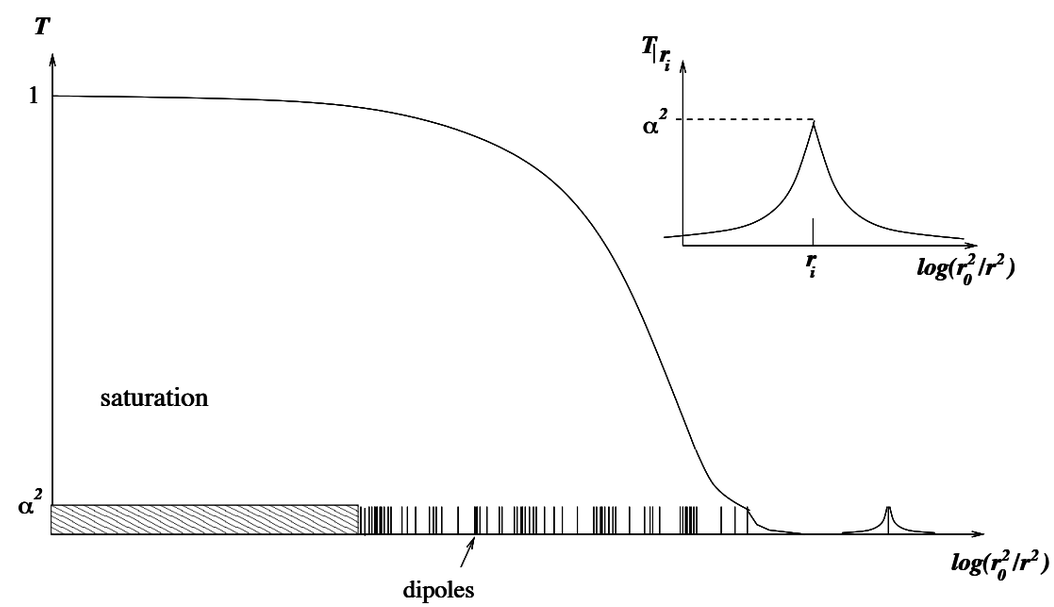
Input to CGC framework —> dipole cross section e+p/A

Color dipole picture : distribution of partons —> dist. of color dipoles



Iancu, Mueller, Munier
(hep-ph/0410018)

Golec-Biernat, Wusthoff
hep-ph/9807513



With evolution of rapidity each dipole split with probability ~ α_s dY
—> dipole splitting is however stochastic

Stochastic dipole splitting —> not present in BK/JIMWLK —>beyond CGC

Momentum flow in Glasma graph (origin of ridge-like correlation)

Dusling, Li, Schenke 1509.07939