# Initial state effects and collectivity in p+p and p+A collisions at the LHC

Prithwish Tribedy



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# Ridge : remarkable effect of MPI@LHC



Di-hadron correlations in relative pseudorapidity (Δη) & azimuth (Δφ) High multiplicity  $p+p/A \rightarrow$  strikingly similar to  $A+A$ 

# Ridge : remarkable effect of MPI@LHC



Things look very different in min-bias p+p/A collisions

# The ridge in all systems



# High multiplicity events & collectivity



Two main puzzles :

Some times many particles come out, but why ? The particles in high multiplicity events show collectivity.

# What do I mean by collectivity ?

Strong correlations do not necessarily mean collectivity





Di-jets produce strong correlations but no collectivity ~falls off 1/N (random walk)

Fluid dynamic correlations correlations in are collective

Let me give you a working definition :

Correlations among particles over a wide range of momentum space

# The ridge in all systems



There could be different ways to approach this problem

# The Qualitative picture



Experimentally observed correlations (both should contribute) <sup>16</sup>

# The Phase Diagram of Correlation



# The Qualitative picture



Experimentally observed correlations (both should contribute) <sup>16</sup>  $\Gamma_{\text{V}}$ 

### The landscape of QCD : particle production Represention of OCD : particle production ape or QUD : particle production



# The IP-Glasma model of CGC

• Compute fields due to fluctuating color charge density inside colliding hadrons/nuclei by solving

$$
[D_\mu, F_{\mu\nu}] = J_\nu
$$

after collisions and the simple expression of in terms of the gauge fields of the colliding nuclei 5  $\frac{1}{5}$ unit matrices in this gauge  $\mathcal{L}$ • Compute & evolve the color fields

$$
A^{i} = A^{i}_{(A)} + A^{i}_{(B)} \quad A^{\eta} = \frac{ig}{2} \left[ A^{i}_{(A)}, A^{i}_{(B)} \right]
$$





#### Iteratively solving *x* = *Qs* (b?*,x*) Lumpy color charge density distribution *c*<br>
Lumpy color color charge density distribution *g*<br>
denoted a 2 denoted and 2 denoted a 2 d<br>
denoted a 2 d w.<br>MF  $\overline{u}$ Quark Matter 2014, Darmstadt, Germany **IP-MILIE.<br>1988 : Color Color Color**<br>Lett. 108 (201 **IP-Sate:**<br> **IP-Sate:**<br> **ACH**<br> **IP-SATE:**<br> **ACH**<br> **IP-SATE:**  $\frac{1}{2}$  included<br> **ch**<br> *Stt.* **108 (2012) p Solution Street Str**  $\overline{\text{0eq}}$ <br>(2012) 25 *A S*dip(r *,* ? *x* b*,*  $\overline{a}$ ed<br> *A S*dip ! distribution of nuclear saturation scale *Q* b(*s ,* ? *x*) solving : للصين المستشرق المستش<br>المستشرق المستشرق ا in this approach

Schenke, PT, Venugopalan Phys. Rev. Lett. 108 (2012) 252301

P.Tribedy, MPI@LHC, Shimla, 2017 The Glasma fields are the Glasma fields and the Glasma fields are the Glasma fields and the Glasma fields and t<br>The Glasma fields are the Glasma fields and the Glasma fields and the Glasma fields and the Glasma fields and  $\ldots$   $\ldots$ 

# Initial state correlations : IP-Glasma model

### Momentum space information



*SA SA*  $sions$ Input for hydro, transport, p+A , A+A collisions

smororre<br>Schenke, PT, Venugopalan Phys. Rev. Lett. 108 (2012) 252301 Kowalski, Lappi, Venugopalan 0705.3047 Lett. 108 (20)<br>
1998 : Color Color<br>
1998 : Color Lett. 108 (201)<br>|
| DIS ! proton-dipole scattering matrix *p S*dip(r *,* ? *x* b*,* ) ? ⇠ exp 2*r* 2 *Q / sp* 2

# The Qualitative picture



 $\Gamma_{\text{MMA}}$ Experimentally observed correlations (both should contribute)

IP-Glasma gluon dist→ Sampling gluons → Strings → Hadronization



### Momentum space anisotropy is already built in

Schenke, PT, Venugopalan Phys. Rev. Lett. 108 (2012) 252301

IP-Glasma gluon dist→ Sampling gluons → Strings → Hadronization



### Sampled gluons carry momentum space anisotropy

Schenke, PT, Venugopalan Phys. Rev. Lett. 108 (2012) 252301

IP-Glasma gluon dist→ Sampling gluons → Strings → Hadronization



No color-reconnection effect unlike standard PYTHIA

IP-Glasma gluon dist→ Sampling gluons → Strings → Hadronization





$$
f(z, m_T) = \frac{1}{z}(1-z)^a \exp\left(-\frac{b \, m_T{}^2}{z}\right)
$$

### Lund String Fragmentation

A new Monte-Carlo event generator : CGC+Lund (CGC+PYTHIA)

#### Results from CGC + PYTHIA (Lund) Doculto from CCC, DVTLIIA (Lund) JUU TI IIIIIIII (LUIIU)  $D_{\text{Aou}}$ <sup>1</sup> $h_{\text{A}}$  from  $\bigcap_{\text{A}}$  ,  $D'$ <sup>282</sup> standalone mode where it was found that color-reconnection scheme plays  $from CCP \perp DVTIIIA (Lund)$ <sup>284</sup> strong growth of transverse momentum with multiplicity is already gener-**Doculto from CCC+LUVTLINII** assults from Guy + F I THATL  $C \cap I$ Kesults from CGC + PYTHIA (Lund) fects are also obtained in PYTHIA calculations are also obtained in PYTHIA calculations within PYTHIA calculatio<br>The calculations with the calculations with the calculations with the calculations with the calculations with mentum hp*r*<sub>*T*</sub> i for charged hadrons over the experimental  $\overline{R}$ tally used range of transverse momentum 0*.*15 GeV *<* from  $CGC + PVTHIA (Lund)$ ber of independent parties in the showers frager showers. The shower showers frager showers from the shower showers of the shower showers from the shower showers from the shower shower showers from the shower showers from mentum h*p<sup>T</sup>* i for charged hadrons over the experimen-Results from CGC + PYTHIA (I und) *p<sup>T</sup> <* 10*.*0 GeV and *|*⌘*| <* 0*.*3, and for identified hadrons  $\Delta$  (I und)

0.08

SCHENKE, PT, V Schenke, PT, Venugopalan Phys. Rev. Lett. 108 (2012) 252301  $\Omega$  strong growth of transverse momentum with multiplicity is already general general general  $\Omega$ 285 at the gluonic level, i.e. in the CGC initial state before hadronization. In the CGC initial state before h Schenke, PT, Venugopalan Phys. Rev. Lett. 108 (2012) 252301

#### Mass ordering of p<sub>T</sub>  $\mathbf{z}$ ∕ l*c*  $\mathbf{r} = \mathbf{r} \cdot \mathbf{r}$ wiass ordering of pt **Mass ordering of p**T  $286$  This is because showers, the concept of particles in some showers,  $M$  is and particles in showers,  $M$ **287 color-reconnection is also connected.** In the formulation is also connected to the connection  $\mathbf{r}$ **286 This is a rapidity range of participants of parton showers, Mass ordering of p** $\tau$ 0*.*5, with no cuts on transverse momentum. We compare

 $\partial \hat{\mathbf{P}}$  0 1 2 3 4 5 6 0 1 1.5 2  $0 \t{)} 1 \t{)} 2 \t{)} 3 \t{)} 4 \t{)} 5 \t{)} 6$ 〈<sup>p</sup> r 【Deval(19)<br>《 Text》 NGH (NU<sub>ch</sub>) p(€<br>P  $\mathfrak{R}$ ี<br>ห÷ิ่  $\frac{1}{\pi}$  $\frac{1}{2}$  and  $\frac{1}{2}$   $\frac{1}{2$ CANDGA ALIQH  $\mathfrak{Z}$  $0.4 + 1.4$ rem Ginsho 2<|∆η|<4.8 , 0.3<pT asc<3 GeV menting from independent showers will have h*p<sup>T</sup>* i to be  $\ddot{\phantom{1}}$ 1.19 PA 15  $O_{\gamma}$  -CH  $\gamma$   $\gamma$  -CHV <u>) MR - CAAP</u>  $\tilde{\mathbf{r}}$  $\mathbf{H}$ ŕ Λ/(<sup>−</sup> Λ)  $\blacksquare$ v $\boldsymbol{\gamma}$  $\mathbf{v}$ ! U ber of independent parton showers. These hadrons frag- $\frac{1}{2}$  of  $N$  inhibitor inclusion longed on  $\epsilon$   $N_g \propto Q_S^2 S_\perp$ dependent of the including the other dependent menting from independent showers will have independent showers will have independent showers will have the beat<br>The beat of the beat independent of the beat of th  $\frac{1}{2}$ independent of the number of  $\frac{1}{2}$  the n min de te ferieration and contribute the theory of the correlation of the correlation of the correlation of the  $\text{arton}^{\circ}\text{showering}_{N\mathcal{C}_{n}}\tilde{\mathcal{M}}_{\mathcal{C}_{n}}\text{multi-part\^{on}}$ *<sup>S</sup>* and ⇤*/*(⇤¯) for a rapidity range of *<sup>|</sup>y<sup>|</sup> <sup>&</sup>lt;* ptag<del>i the ups on momentum. We compared to</del> sur lovEc from the ALICE is and their 288 flux-tube picture divant lands in Fig.2(right), as shown in Fig.2(right), as shown in Fig.2(right), as shown in Fig.2(right), and the fig.2(right), and the fig.2(right), and the fig.2(right), and the fig.2(right), and that **produce a length scale and convention** for the correlation of 12 and 2 a **THE STREET SHIPPION PLANE IS A 28 . ONE FINDS OF THE SERVICE OF THE SERVICE OF THE SERVICE OF THE SERVICE OF T** 201 tion to the empty of the number of the saturday of saturday is the same of the saturday of the saturday is  $2000018$   $2941010010 \text{ m}$   $200001 \text{ V} \cdot \frac{200001 \text{ V}}{200001 \text{ V}}$  $21$  contracted model model model and also propagates to the e $\alpha$  $p_{\text{T}}$  [GeV]  $\mathbf{g}$ **)**  $\mathbf{g}$  and the terms the  $\mathbf{g}$   $\$ showering<sub>Nea</sub>n<sub>d<sub>ch</sub>, multi-parton</sub> *<sup>S</sup>* and ⇤*/*(⇤¯) for a rapidity range of *<sup>|</sup>y<sup>|</sup> <sup>&</sup>lt;* 0*.*5, with no cuts on transverse momentum. We compare aib l surements for the ALICE EST<br>Surfata  $\frac{1}{2}$ de and  $\mathfrak{p}_\mathfrak{p}$  is the variable va our calculation to the stoep or snowers and the<br>ALICE Concreting collaboration tentiscomsessent to perfo  $\text{arton}^{\circ}\text{showering}_{\text{N@N@},\text{M@}_{\text{ch}}}\text{multi-part}^{\mathbf{5}}_{\text{part}}$ 

Data :1604.06736 ALICE CMS 0.5 from di↵erent showers; this leads to collective hadroniza-tion of strings and the strong correlation observed be-data and our computation, we show the variation of h*p<sup>T</sup>* i to be <sup>h</sup>*p<sup>T</sup>* <sup>i</sup>*<sup>g</sup>* / h*QS*i, leading to <sup>h</sup>*p<sup>T</sup>* <sup>i</sup>*<sup>g</sup>* / <sup>p</sup> <sup>293</sup> *<sup>N</sup>g/S*?. One naturally expects a <sup>292</sup> only scale in the CGC, one finds the typical momentum of produced gluons from di↵erent showers; this leads to collective hadroniza-CGC + Lund tion of strings and the strong correlation observed be-tween h*p<sup>T</sup>* i and h*N*chi. with the scaled charged hadron multiplicity *N*ch*/* h*N*chi <sup>294</sup> strong growth of average transverse momentum with multiplicity in CGC to be <sup>h</sup>*p<sup>T</sup>* <sup>i</sup>*<sup>g</sup>* / h*QS*i, leading to <sup>h</sup>*p<sup>T</sup>* <sup>i</sup>*<sup>g</sup>* / <sup>p</sup> <sup>293</sup> *<sup>N</sup>g/S*?. One naturally expects a 1 1.5 0 1 2 3 4 5 6 K0 S h± IP-Glasma + PYTHIA (p+p 7 TeV) × 0.75 0.04 KS Λ/(<sup>−</sup> Λ) modifies this by generating correlations between partons from di↵erent showers; this leads to collective hadroniza-tions [67]. To perform a consistent comparison between <sup>292</sup> only scale in the CGC, one finds the typical momentum of produced gluons <sup>291</sup> tional to the number of flux tubes. Also since the saturation scale is the independent of the number of showers and therefore independent of h*N*chi. The inclusion of color-reconnections modifies this by generating correlations between partons from di↵erent showers; this leads to collective hadronization of strings and the strong correlation observed between h*p<sup>T</sup>* i and h*N*chi. Both parton showering and multi-parton interactions are included in the CGC framework, and all the parthat produce gluons, are correlated over a length scale of 1*/Q*<sup>2</sup> *<sup>S</sup>* <sup>289</sup> . One finds that the typical number of produced gluons to be *<sup>N</sup><sup>g</sup>* / *<sup>Q</sup>*<sup>2</sup> <sup>290</sup> *<sup>S</sup>S*?, i.e. propor-<sup>291</sup> tional to the number of flux tubes. Also since the saturation scale is the <sup>292</sup> only scale in the CGC, one finds the typical momentum of produced gluons to be <sup>h</sup>*p<sup>T</sup>* <sup>i</sup>*<sup>g</sup>* / h*QS*i, leading to <sup>h</sup>*p<sup>T</sup>* <sup>i</sup>*<sup>g</sup>* / <sup>p</sup> <sup>293</sup> *<sup>N</sup>g/S*?. One naturally expects a <sup>294</sup> strong growth of average transverse momentum with multiplicity in CGC <sup>295</sup> which is already incorporated in the IP-Glasma model that initializes the <sup>296</sup> CGC+Lund model and also propagates to the level of hadrons. The e↵ect <sup>287</sup> color-reconnection is already built in the framework of the CGC. In the <sup>288</sup> flux-tube picture di↵erent independent ladders, as shown in Fig.2(right), that produce gluons, are correlated over a length scale of 1*/Q*<sup>2</sup> *<sup>S</sup>* <sup>289</sup> . One finds dependent of h*N*chi. The inclusion of color-reconnections <sup>290</sup> *<sup>S</sup>S*?, i.e. propor-<sup>294</sup> strong growth of average transverse momentum with multiplicity in CGC 0 0.1 0.2 0.3 0.4 0.5 0 1 2 3 4 5 6 7 8 9 10 p( −p)/π ±running-coupling fixed-coupling IP-Glasma + PYTHIA 8.2 (p+p 7 TeV) 0 1 2 3 4 5 6 0.5 0 1 2 3 4 5 6 〈〉 [GeV] K± IP-Glasma + PYTHIA (p+p 7 TeV) 0.04 0.08 0.12 (p+p 7 TeV) {2CGC + Lund v{2independent of the number of showers and therefore inmodifies this by generating correlations between partons tion of strings and the strong correlation observed be-data and our computation, we show the variation of h*p<sup>T</sup>* i with the scaled charged hadron multiplicity *N*ch*/* h*N*chi dependent of h*N*chi. The inclusion of color-reconnections modifies this by generating correlations between partons from di↵erent showers; this leads to collective hadronization of strings and the strong correlation observed between h*p<sup>T</sup>* i and h*N*chi. Both parton showering and multi-parton interactions our calculation to the preliminary and published measurements from the ALICE [66, 69] and CMS collaborations [67]. To perform a consistent comparison between data and our computation, we show the variation of h*p<sup>T</sup>* i

ton ladders in rapidity, localized within a transverse area transverse area transverse area transverse area tr<br>In rapidity, localized with a transverse area transverse area transverse area transverse area transverse area

### *p*<sup>T</sup> is the proton to pion ratio proton to pion ration **25 ordering of p<sub>T</sub>** proton to pion ratio ordering of  $p<sub>T</sub>$  and the number of showers and the number of  $p<sub>T</sub>$  and the number of  $p<sub>T</sub>$

 $p_T$  [GeV]

 $\mathcal{L}(\mathcal{L})$ 

 $\begin{bmatrix} \phantom{-} & \phantom{-} \\ \phantom{-} & \phantom{-} \\ \phantom{-} & \phantom{-} \end{bmatrix}$ 

#### Results from CGC + PYTHIA (Lund) Doculto from CCC, DVTLIIA (Lund) JUU TI IIIIIIII (LUIIU)  $D_{\text{Aou}}$ <sup>1</sup> $h_{\text{A}}$  from  $\bigcap_{\text{A}}$  ,  $D'$ <sup>282</sup> standalone mode where it was found that color-reconnection scheme plays  $from CCP \perp DVTIIIA (Lund)$ <sup>284</sup> strong growth of transverse momentum with multiplicity is already gener-**Doculto from CCC+LUVTLINII** assults from Guy + F I THATL  $C \cap I$ Kesults from CGC + PYTHIA (Lund) fects are also obtained in PYTHIA calculations are also obtained in PYTHIA calculations within PYTHIA calculatio<br>The calculations with the calculations with the calculations with the calculations with the calculations with mentum hp*r*<sub>*T*</sub> i for charged hadrons over the experimental  $\overline{R}$ tally used range of transverse momentum 0*.*15 GeV *<* from  $CGC + PVTHIA (Lund)$ ber of independent parties in the showers frager showers. The shower showers frager showers from the shower showers of the shower showers from the shower showers from the shower shower showers from the shower showers from mentum h*p<sup>T</sup>* i for charged hadrons over the experimen-Results from CGC + PYTHIA (I und) *p<sup>T</sup> <* 10*.*0 GeV and *|*⌘*| <* 0*.*3, and for identified hadrons  $\Delta$  (I und)

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 $\partial \hat{\mathbf{P}}$  0 1 1.5 2  $0 \t{)} 1 \t{)} 2 \t{)} 3 \t{)} 4 \t{)} 5 \t{)} 6$ 〈<sup>p</sup> r 【Deval(19)<br>《 Text》 NGH (NU<sub>ch</sub>) p(€<br>P  $\mathfrak{R}$ ี<br>ห÷ิ่  $\frac{1}{\pi}$  $\gamma$ 11 + CGC it is part (p+ $\chi$   $\overline{P}$  TeV) CANDGA ALIQH  $\mathfrak{Z}$  $0.4 + 1.4$ rem Ginsho  $\Gamma$  $\mathbf{a}$ :  $\Gamma$  $\mathbb{C}$   $\mathbb{V}$  $\ddot{\phantom{1}}$  $\sqrt{11}$ 1.19 PA 15  $O_{\gamma}$  -CH  $\gamma$   $\gamma$  -CHV <u>) MR - CAAP</u>  $\tilde{\mathbf{r}}$  $\mathbf{H}$ ŕ  $\lim_{\epsilon\to 0} \log \log \frac{1}{\epsilon}$  $\blacksquare$ v $\boldsymbol{\gamma}$  $\mathbf{v}$ ! U ber of independent parton showers. These hadrons fragmentish<del>opseyppompen typping weles mindell</del> independent of the number of the short of the<br>The short of the sh dependent of the including the other dependent menting from independent showers will have independent showers will have independent showers will have the beat<br>The beat of the beat independent of the beat of th  $\frac{1}{2}$ independent of the number of  $\frac{1}{2}$  the n min de te ferieration and contribute the theory of the correlation of the correlation of the correlation of the  $\text{arton}^{\circ}\text{showering}_{N\mathcal{C}_{n}}\tilde{\mathcal{M}}_{\mathcal{C}_{n}}\text{multi-part\^{on}}$ *<sup>S</sup>* and ⇤*/*(⇤¯) for a rapidity range of *<sup>|</sup>y<sup>|</sup> <sup>&</sup>lt;* ptag<del>i the ups on momentum. We compared to</del> het proting to the inclusion little olome sur lovEc from the ALICE is and their that **produce a length scale and convention** for the correlation of 12 and 2 a **THE STREET SHIPPION PLANE IS A 28 . ONE FINDS OF THE SERVICE OF THE SERVICE OF THE SERVICE OF THE SERVICE OF T** 201 tion to the empty of the number of the saturday of saturday is the same of the saturday of the saturday is <sup>295</sup> which is already incorporated in the IP-Glasma model that initializes the  $21$  contracted model model model and also propagates to the e $\alpha$  $\mathbf{g}$ **)**  $\mathbf{g}$  and the terms the  $\mathbf{g}$   $\$  $2944 \text{ GHz}$  strong growth of average transverse momentum  $0 \text{ yr}$  and  $0 \text{ yr}$ showering<sub>Nea</sub>n<sub>d<sub>ch</sub>, multi-parton</sub> *<sup>S</sup>* and ⇤*/*(⇤¯) for a rapidity range of *<sup>|</sup>y<sup>|</sup> <sup>&</sup>lt;* 0*.*5, with no cuts on transverse momentum. We compare aib l surements for the ALICE EST<br>Surfata  $\frac{1}{2}$ de and  $\mathfrak{p}_\mathfrak{p}$  is the variable va our calculation to the stoep or snowers and the<br>ALICE Concreting collaboration  $\text{arton}^{\circ}\text{showering}_{\text{N@N@},\text{M@}_{\text{ch}}}\text{multi-part}^{\mathbf{5}}_{\text{part}}$ 



### *p*<sup>T</sup> is the proton to pion ratio proton to pion ration **25 ordering of p<sub>T</sub>** proton to pion ratio ordering of  $p<sub>T</sub>$  and the number of showers and the number of  $p<sub>T</sub>$  and the number of  $p<sub>T</sub>$



#### **Solution Ridge and its mass ordering** ZU **Fidge and its mass ordering** ton ladders in rapidity, localized with  $R$  is ⇠ <sup>1</sup>*/Q*<sup>2</sup> *<sup>S</sup>* are correlated. Specifically, with regard to the Ridge and its mass ordering <sup>297</sup> of mass ordering comes purely from the Lund string fragmentation. Ridge and its mass ordering case are shown by solid and its mass ordering ordering of average transverse momentum of average transverse momen Both parton showering and multi-parton interactions Our results for the multiplicity dependence of h*p<sup>T</sup>* i in

0.08





P.Tribedy, MPI@LHC, Shimla, 2017 **20** ready assigned to strings depending on their momenta. The hardening of the transverse momentum distribu-distribu-distribu-distribu-distribu-distribu-distribu-distri The strong multiplicity dependence of h*p<sup>T</sup>* i and the mass ordering was demonstrated to arise in the fragmen- The hardening of the transverse momentum distribuverselverselverselverselver species and hp*P*. Tribedy, MPI@LHC, Shimla, 2017  $f(x) = \frac{f(x) - f(x)}{2}$ ordering for di↵erent species: h*p<sup>T</sup>* i*<sup>p</sup> >*h*p<sup>T</sup>* i*<sup>K</sup> >*h*p<sup>T</sup>* i⇡

# The Qualitative picture



Experimentally observed correlations (both should contribute)

#### Classical Yang-Mills approach on 2+1D lattice  $\mathbf{A}$  collision takes place, we find a solution of the equation of the equations of  $\mathbf{A}$ *<sup>J</sup>* <sup>=</sup> (*x*+)⇢2(*x*?)  $\overline{A}$  thing  $\overline{A}$ and we have restricted ourselves to work in a gauge where the link operators along A fluid dynamic simulation (p+A, A+A)

 $H$ *PD* $H$ <sup>*H*</sup> *F F Z H*<sup>*N*</sup> *ION* colliding to  $H$  $\mathbf{S}$   $\mathbf{$ Heavy ion collisions have been studied extensively E-by-E solve CYM for two colliding nuclei : [*Dµ, F <sup>µ</sup>*⌫] = *J*⌫ This is a solution of the Yang-Mills equations in all of space-time except on or



must add in order to have a solution. This will be a solution of the solution of the solution of the solution o **CUSE Vallo** Two point correlations correlations and containing the Avenue A  $\sim$ of fluid-dynamic response to boost-invariant initial spatial anisotropy **9** *Mearvation of lone* Observation of long-range ridge-like azimuthal correlations is a signature  $\sum_{i=1}^{n}$  sampled from  $\sum_{i=1}^{n}$ 

## Results from CGC + Hydrodynamics (p+Pb)

In CGC (IP-Glasma) the initial spatial anisotropy for  $p+Pb$ collisions is determined by the shape of proton



HERA DIS  $e+p$  data  $\rightarrow$  round proton  $\rightarrow$  not eccentric enough, can't generate azimuthal anisotropy like data

## New inputs from DIS data: snapshot of proton m DIS data: snapshot of proton



 $\blacksquare$ Qu  $\overline{\phantom{a}}$ Κ. S. **UC**  $t$ <sub>u</sub> $r_0$  (botc nc  $\mathbf{d} = \mathbf{d} \cdot \mathbf{b}$ Quark structure (hotspots) → essential to describe Incoherent DIS data  $\mathcal{L}$  2: Coherent and incoherent and incoherent cross section as a function of  $\mathcal{L}$  $e$  (hotspots)  $\rightarrow$  essential to desc  $\mathcal{F}$  data  $\mathcal{F}$  , so  $\mathcal{F}$ FIG. 3: Four configurations of the proton in the IP-Glasma  $\bm{p}$ e Incoherent DIS data

## Results from CGC + Hydrodynamics + transport

Mantysaari, Schenke, Shen, PT 1705.03177



### With eccentric proton (hot spot) much better agreement is achieved

# Combined approach



# Combined approach

### Qualitative Picture : Small systems IP-Glasma (CGC)+Boltzmann Approach to Multiparton Scatterings (BAMPS)



Greif, Greiner, Schenke, Schlichting, Xu 1708.02076

Initial state dominate : low mult & high  $p_T$ 

Final state dominate : high mult & low  $p_T$ 

# Summary

Observation in high multiplicity events in small collision systems show remarkable similarity with heavy ion collision & evidence of collectivity

- Many aspects of such collective behavior can be explained by purely initial state effects due to momentum space correlations
- In sufficiently high multiplicity events, initial state effects momentum space correlations will eventually dilute to show sensitivity to spatial & geometric correlations

The framework of CGC provides an *ab initio* approach to describe both initial state momentum and position space correlations. When combined with Lund (PYTHIA), Hydrodynamics or partonic transport, one can explain global data in p+p, p+A & A+A, in principle have a combined description of all systems into a single framework.