Rapidity correlations and azimuthal correlations of strong color field

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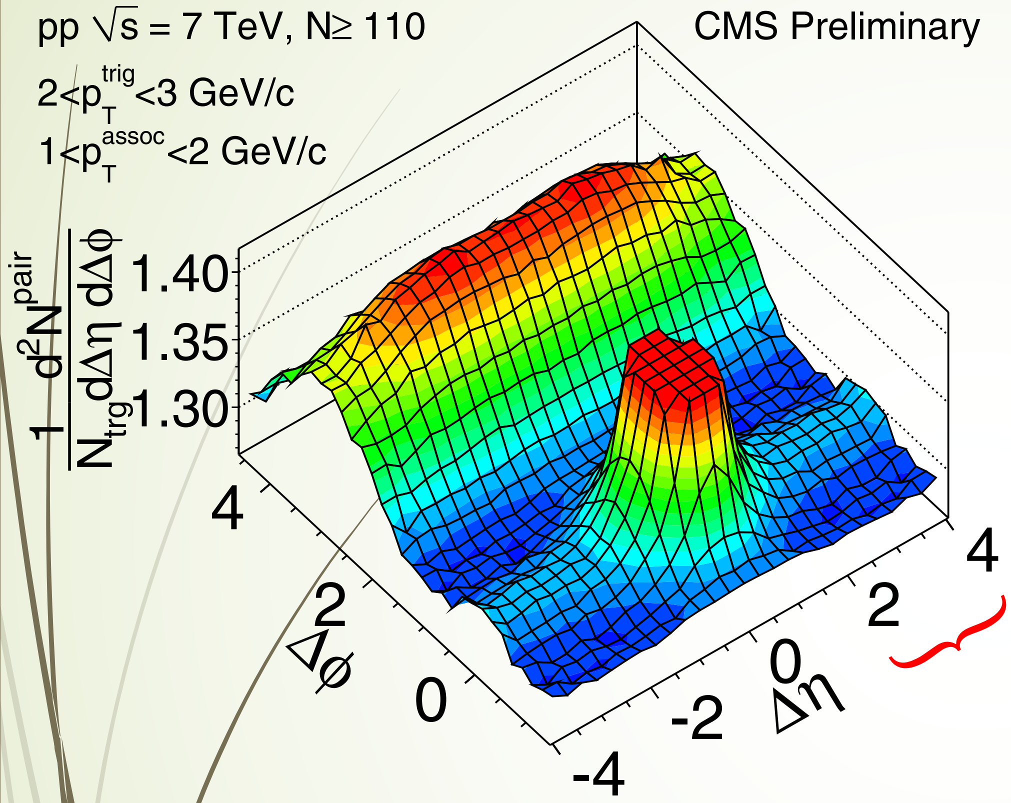
References:

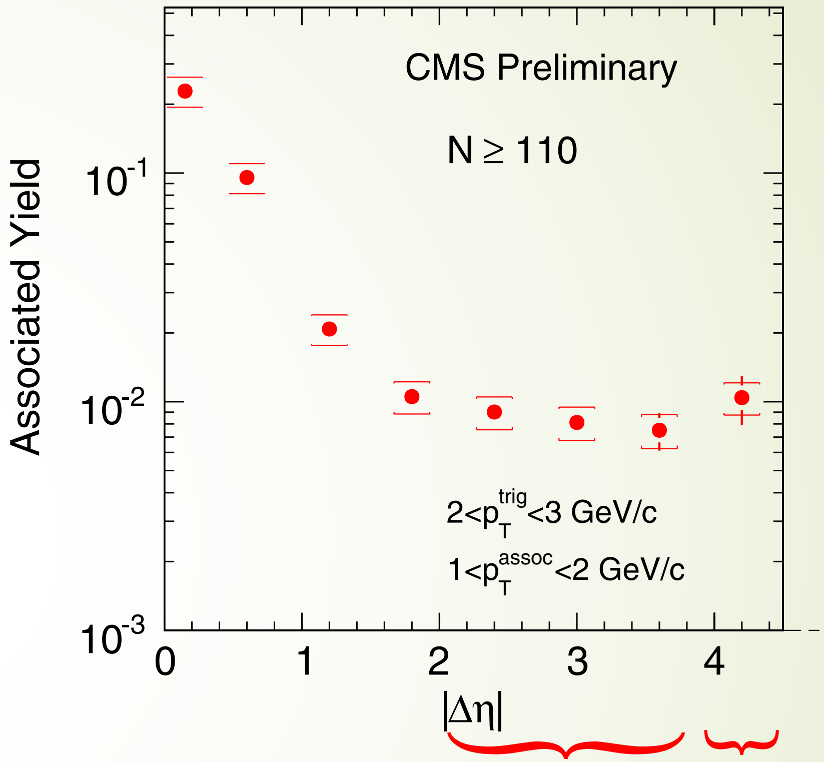
[1] Yeyin Zhao, Mingmei Xu, Hengying Zhang, Yuanfang Wu, Nucl. Phys. A 955, 88 (2016).
[2] Hengying Zhang, Donghai Zhang, Yeyin Zhao, Mingmei Xu, Xue Pan and Yuanfang Wu, Phys. Rev. D, 034003 (2018).
[3] Donghai Zhang, Yeyin Zhao, Mingmei Xu, Xue Pan and Yuanfang Wu, Nucl. Phys. A 1011, 122201 (2021).
[4] Donghai Zhang, Yeyin Zhao, Mingmei Xu and Yuanfang Wu, Phys. Rev. D 107, 056017 (2023).

OUTLINE

- Introduction
- Physical picture for long-range ridge correlations in CGC
- Rapidity correlations and dependences on p_t and $\sqrt{s_{NN}}$
- Fine structures of azimuthal correlations
- The features of two dimensional Δy-$\Delta\varphi$ correlations

Ridge in small systems observed in experiments





long range ridge structure

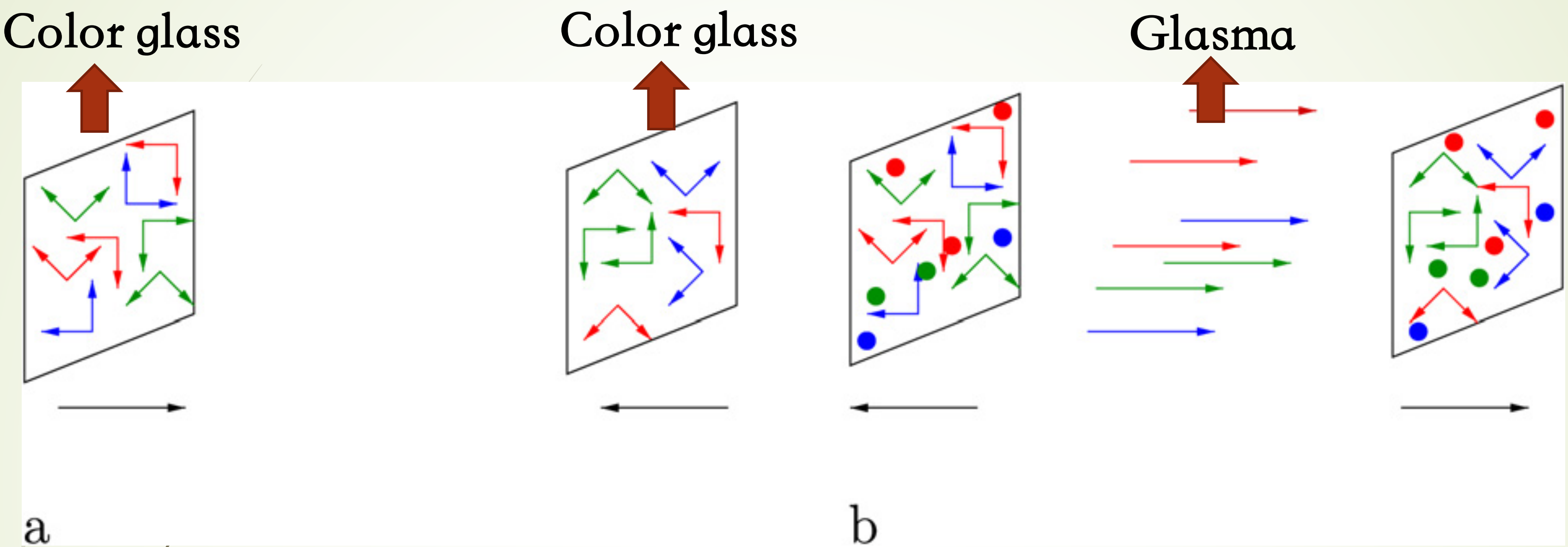
- the plateau at $2 < |\Delta\eta| \lesssim 3.6$
- the rebound at $|\Delta\eta| \approx 4$

The CMS collab., J. Phys. G 38 (2011) 124051.

The physics underlying long range ridge correlations in small systems is inconclusive yet.

- Final state effects, i.e. Hydrodynamics
- Initial correlations, CGC

CGC dynamics describe Initial state in high energy collisions

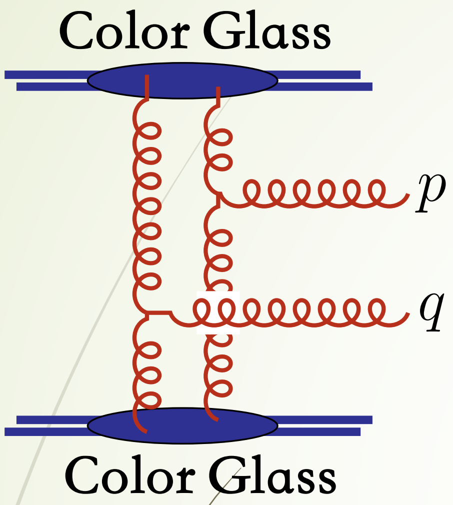


strong longitudinal color field

approximately boost invariant

N. Armesto, L. McLerran, C. Pajares, NPA 781 (2007) 201.

Achievement of CGC on long range ridge correlations



- N_{ch} and p_t dependence of the long range azimuthal correlations in pPb collisions at 5.02 TeV at the LHC
- Describe CMS, ALICE and ATLAS data simultaneously with a common set of parameters

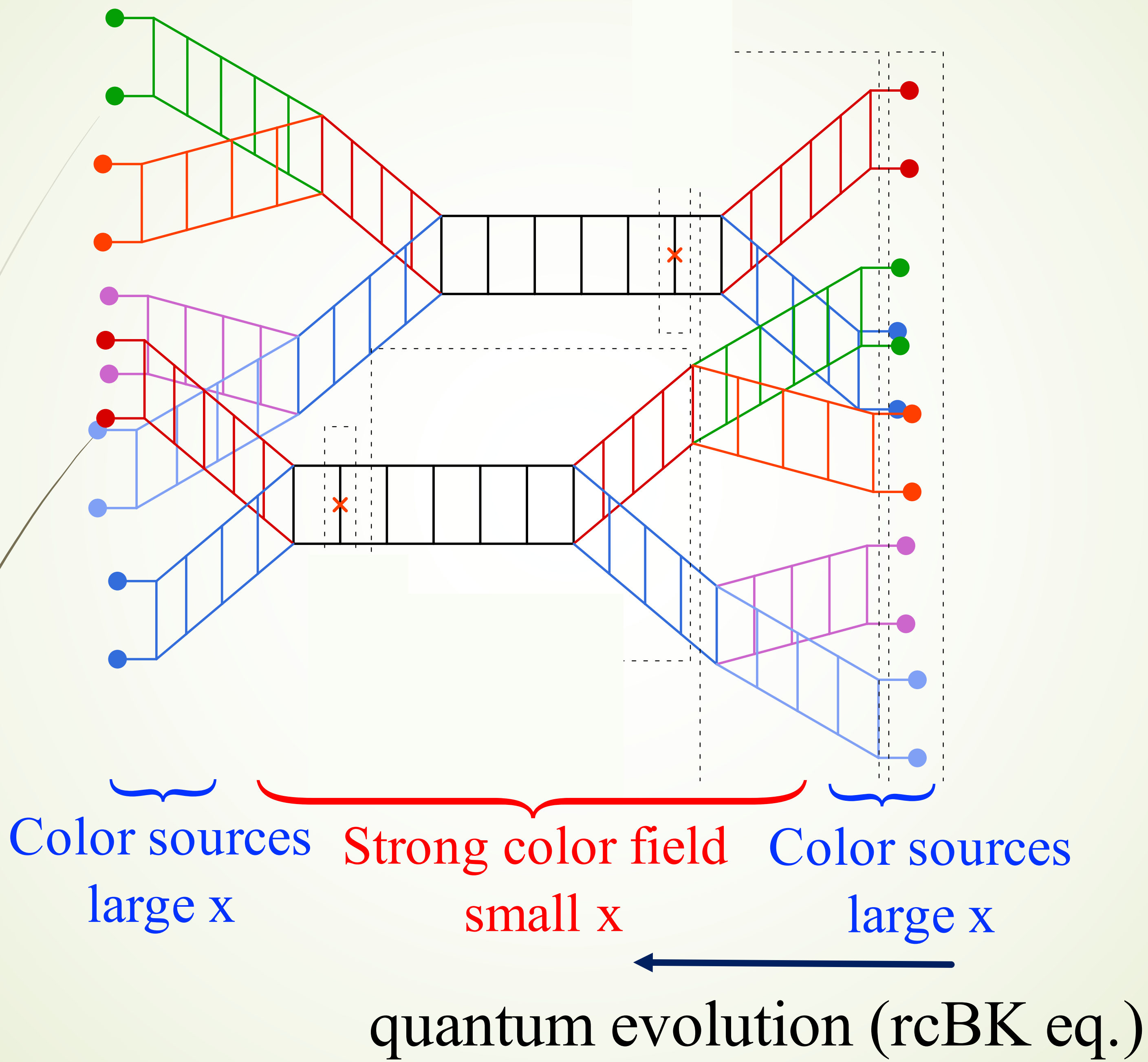
Glasma graph

K. Dusling, R. Venugopalan, Phys. Rev. D 87 (2013) 051502(R).
K. Dusling, R. Venugopalan, Phys. Rev. D 87 (2013) 054014.
K. Dusling, R. Venugopalan, Phys. Rev. D 87 (2013) 094034.

(1) Only focus on azimuthal correlations at large $|\Delta\eta|$
(2) Lack a clear physical picture of correlation structure in η direction

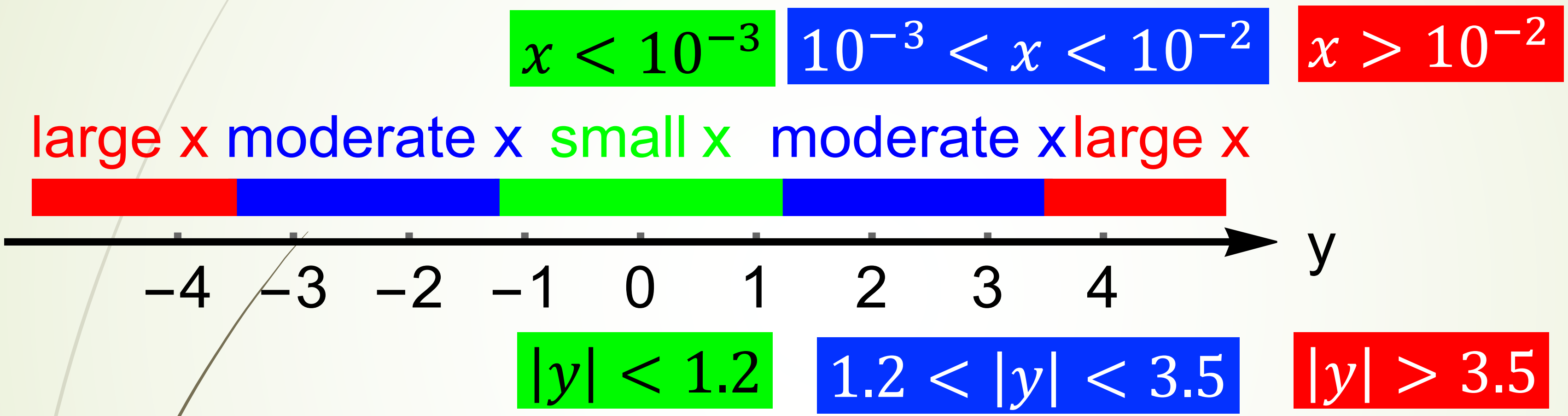
We will focus on η direction in this study.

Effective degrees of freedom in CGC



$\because x = \frac{p_\perp}{\sqrt{s}} e^{\pm y}$, + right moving projectile

For $\sqrt{s} = 7$ TeV, $p_\perp = 2$ GeV,



radiated gluons | source gluons

(r) (m) (s)

- Gluons of different x are located at different rapidity regions
- Gluon dynamics is a function of y.

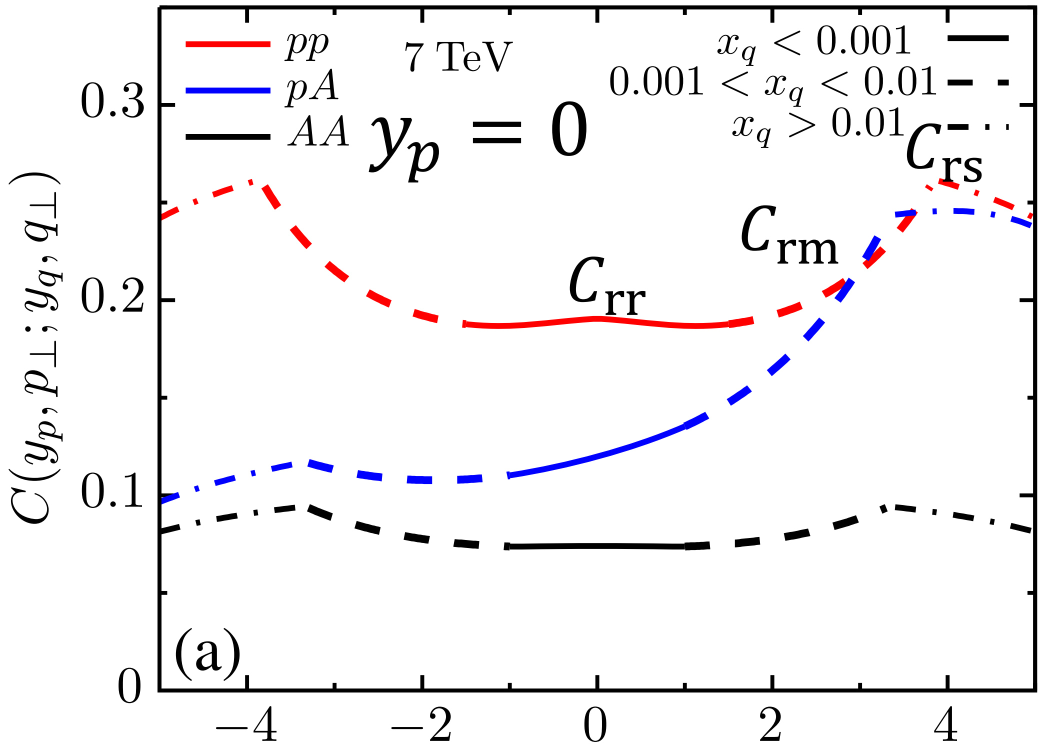
Observable:

$$C\left(\mathbf{p}_\perp, y_p, \mathbf{q}_\perp, y_q\right) = \frac{\dfrac{\mathrm{d}N_2}{\mathrm{d}^2\mathbf{p}_\perp \mathrm{d}y_p \mathrm{d}^2\mathbf{q}_\perp \mathrm{d}y_q}}{\dfrac{\mathrm{d}N}{\mathrm{d}^2\mathbf{p}_\perp \mathrm{d}y_p}\dfrac{\mathrm{d}N}{\mathrm{d}^2\mathbf{q}_\perp \mathrm{d}y_q}} - 1 = \frac{\dfrac{\mathrm{d}N_2^{\mathrm{corr.}}}{\mathrm{d}^2\mathbf{p}_\perp \mathrm{d}y_p \mathrm{d}^2\mathbf{q}_\perp \mathrm{d}y_q}}{\dfrac{\mathrm{d}N}{\mathrm{d}^2\mathbf{p}_\perp \mathrm{d}y_p}\dfrac{\mathrm{d}N}{\mathrm{d}^2\mathbf{q}_\perp \mathrm{d}y_q}}$$

where “p” and “q” are used to mark the two gluons.

(1) Physical Picture of Long Range Ridge Correlations

$\Delta\phi = 0, p_\perp = q_\perp = 1.5$ GeV for pp

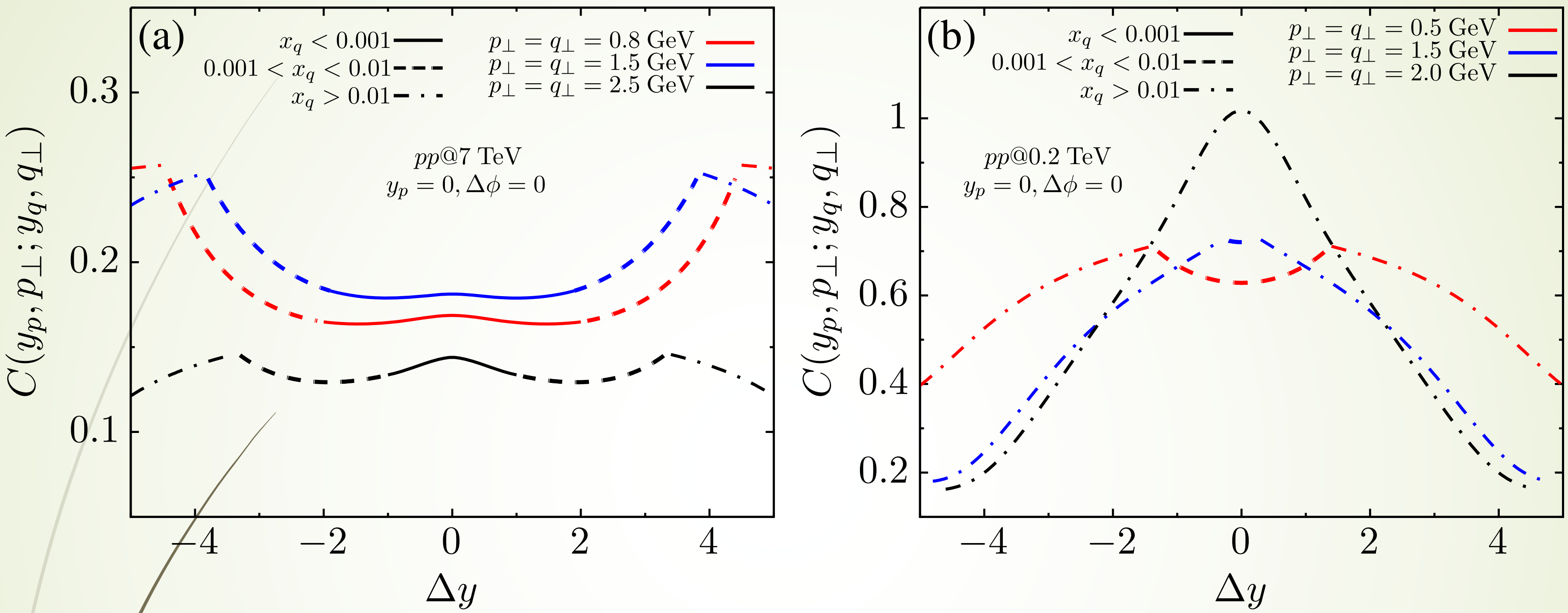


$\Delta y = y_q - 0$ long range

- Origin: strong correlations between source gluons and radiated gluons
- The same origin in pp and AA
- "W" shape

$y_p = 0$ (r)
- solid (r) C_{rr}: platform, approx. boost invariance
- dash (m) C_{rm}: ridge-like corr. appears
- dot-dash (s) C_{rs}: ridge-like corr. fully develop

(2) Rapidity correlations and dependences on p_t and $\sqrt{s_{NN}}$)



- Maximum corr. at $p_\perp = q_\perp \sim Q_{sA} + Q_{sB} = 2Q_{sp} \approx$ 1.5 GeV
- At lower energy, no small x in the central rapidity region, no ridge

(3) Fine structures of azimuthal correlations

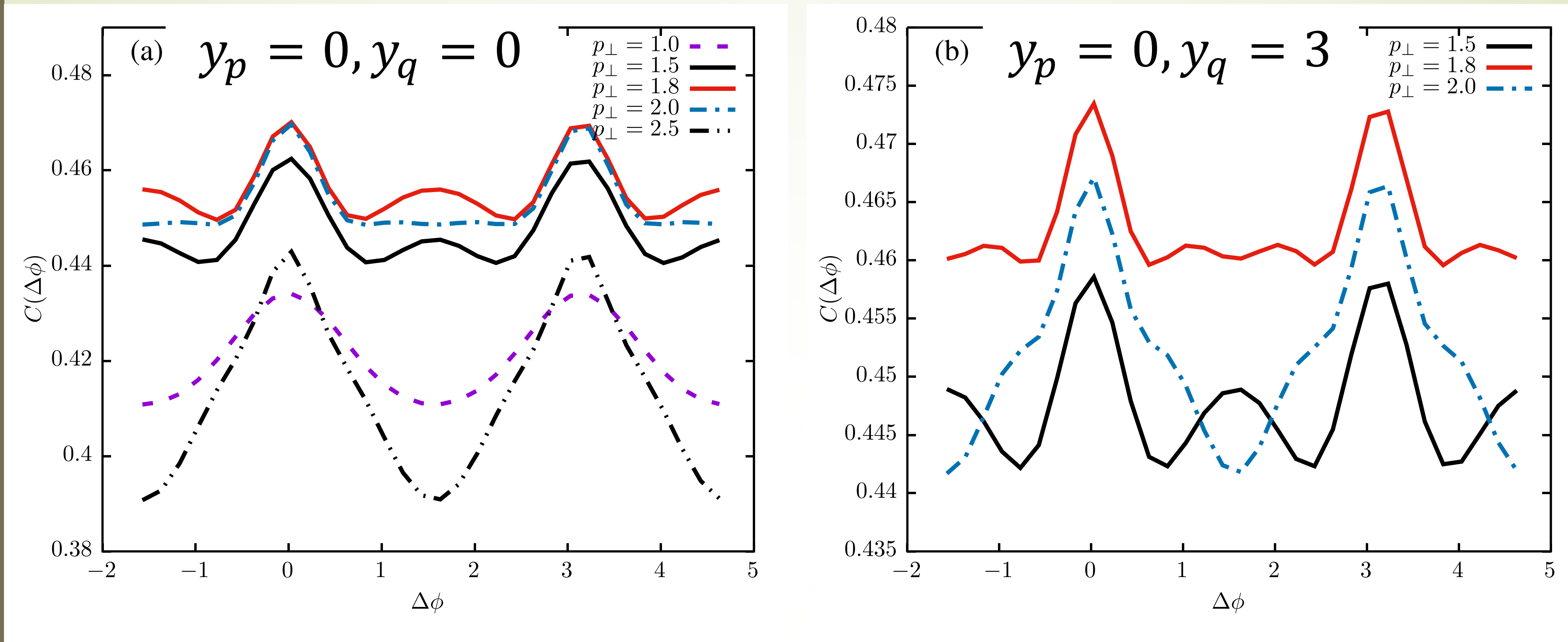
To explore the contributions of different x degrees of freedom

$$C(\Delta\phi) = \int d\phi_p \int d\phi_q \, \delta(\phi_q - \phi_p - \Delta\phi) C(\mathbf{p}_\perp, y_p, \mathbf{q}_\perp, y_q)$$

- Finer binning in $p_\perp$
- Dependences on specific y, not Δy

pp@$\sqrt{s} = 7$ TeV

Fine Structures around $\Delta\phi = \pi/2$



- $p_\perp$=1.0 GeV: a valley
- $p_\perp$=1.5 GeV: a single bump
- $p_\perp$=1.8 GeV: a single bump
- $p_\perp$=2.0 GeV: flat
- $p_\perp$=2.5 GeV: a valley

- $p_\perp$=1.5 GeV: a single bump at $\Delta\phi = \pi/2$
- $p_\perp$=1.8 GeV: double bumps at $\Delta\phi \approx 1,\ 2$
- $p_\perp$=2.0 GeV: double shoulders at $\Delta\phi \approx 1,\ 2$

Fine structures is related to harmonic components of $\cos n\Delta\phi$.

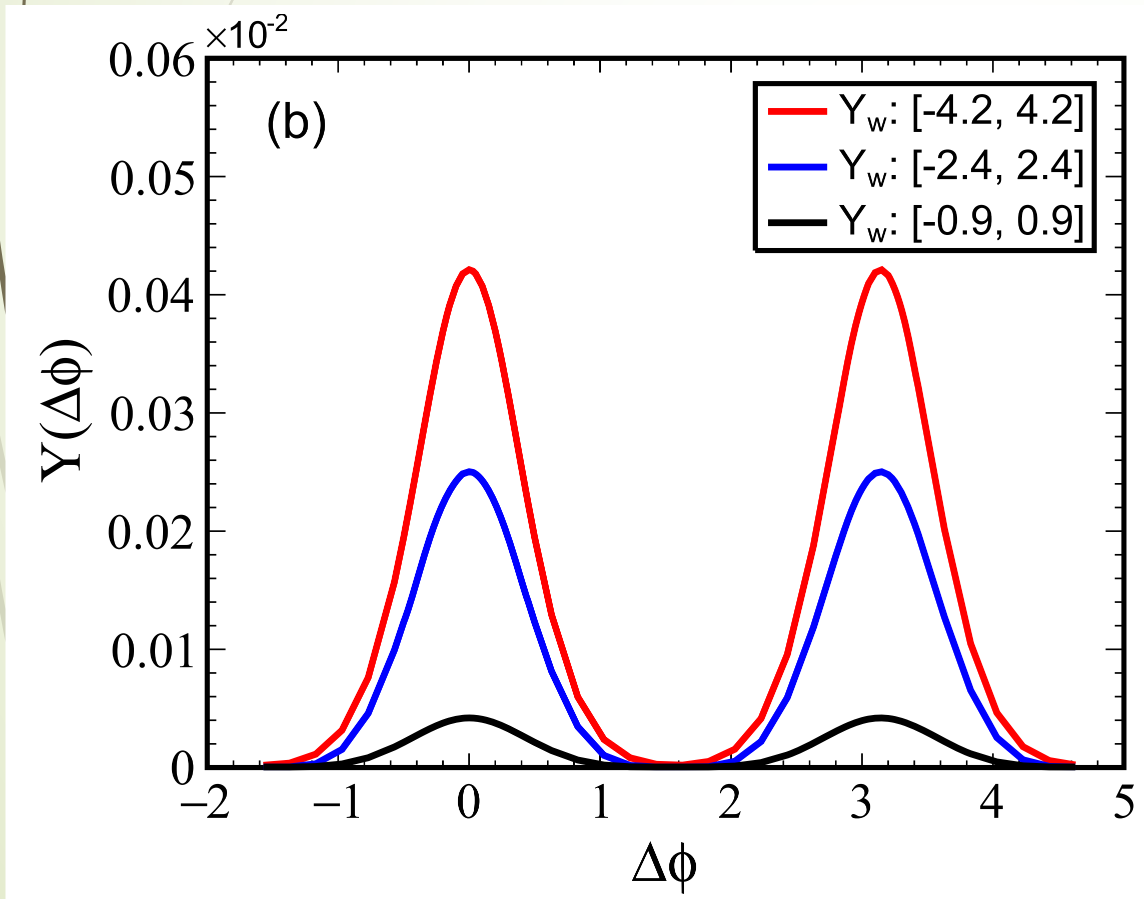
Fine structures in azimuthal corr. show up when:

- Finer binning in $p_\perp$ (integration over $p_\perp$ will smear it)
- Near $p_\perp \sim 2Q_{sp} = 1.8$ GeV, associated with the saturation momentum of colliding particles
- At least one gluon located at small rapidity, specific to small-x region

(4) Two dimensional Δy-$\Delta\varphi$ correlations

- Per-trigger yield

$$Y(\Delta\phi, \Delta y) = \frac{1}{N_{\text{Trig}}} \frac{d^2 N_{\text{Assoc}}}{d\Delta\phi d\Delta y}$$



- $Y_W \uparrow$, $Y(\Delta\phi) \uparrow$
contribution of source gluons

$$\frac{1}{N_{\mathrm{Trig}}}\frac{\mathrm{d}^2 N^{\mathrm{pair}}}{\mathrm{d}\Delta y \mathrm{d}\Delta\phi}$$

$$S(\Delta y, \Delta\phi) = \frac{1}{N_{\mathrm{Trig}}}\frac{\mathrm{d}^2 N^{\mathrm{same}}}{\mathrm{d}\Delta y \mathrm{d}\Delta\phi},$$

$$B(\Delta y, \Delta\phi) = \frac{1}{N_{\mathrm{Trig}}}\frac{\mathrm{d}^2 N^{\mathrm{mixed}}}{\mathrm{d}\Delta y \mathrm{d}\Delta\phi},$$

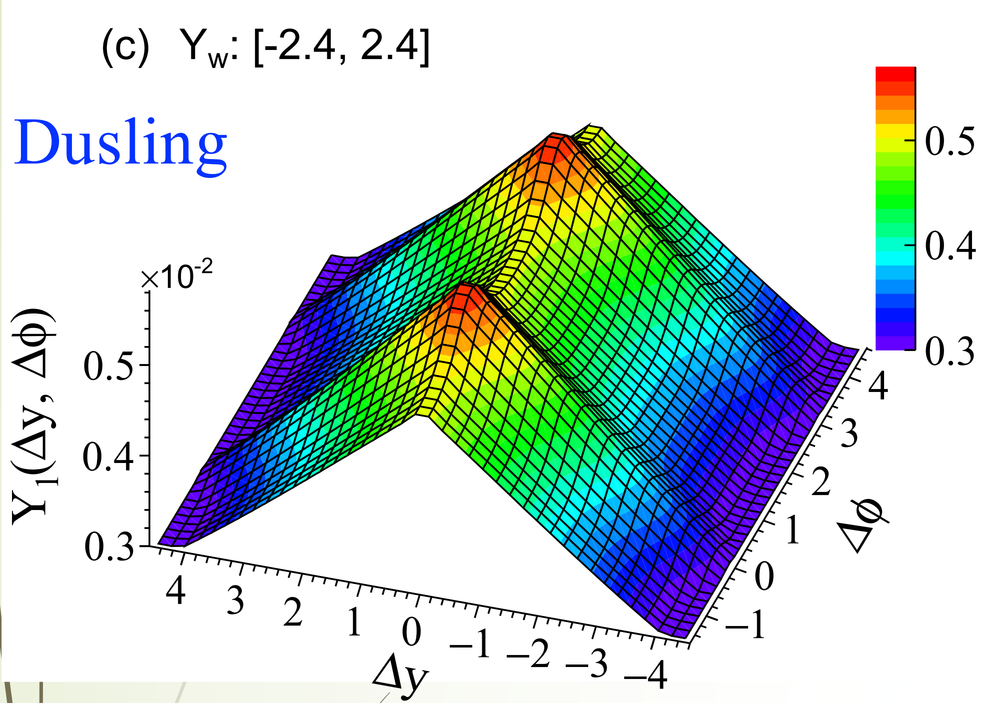
$$Y(\Delta y, \Delta\phi) = B(0,0)\frac{S(\Delta y, \Delta\phi)}{B(\Delta y, \Delta\phi)}$$

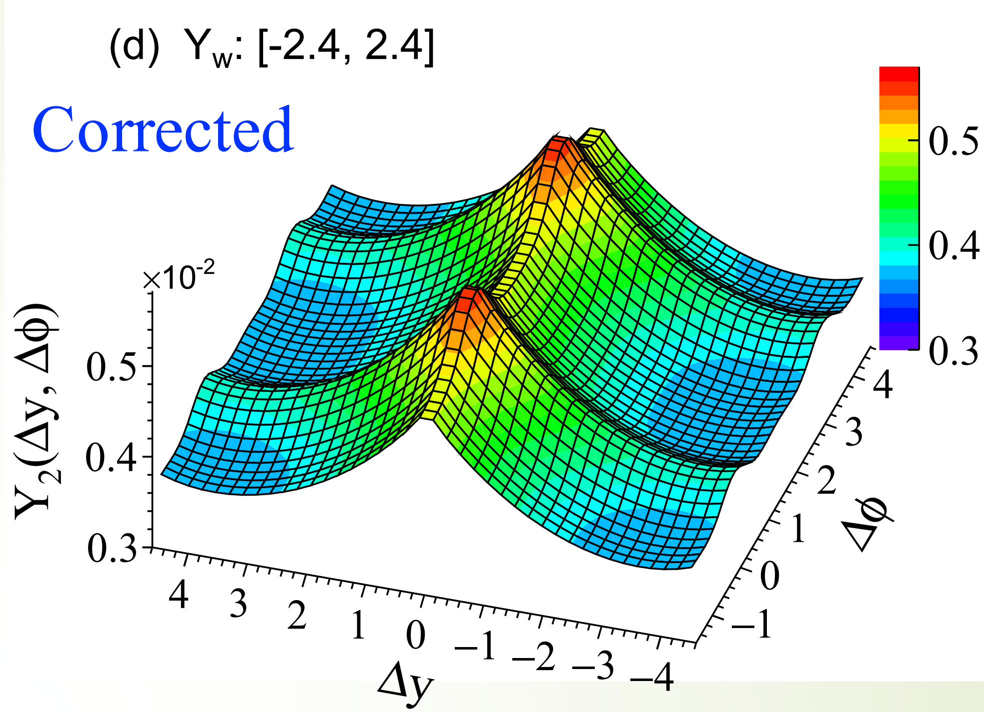
- Approximate normalization factor
  assuming a boost invariant rapidity distribution

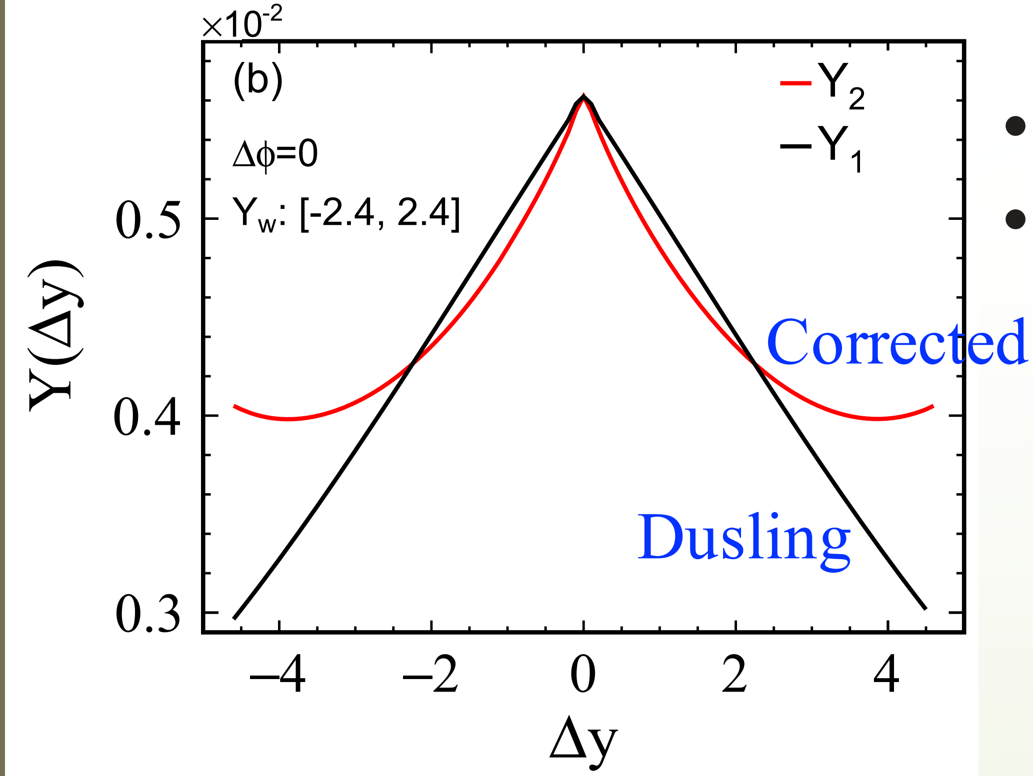
K. Dusling, R. Venugopalan, Phys. Rev. D 87 (2013) 094034.

$$\frac{B(\Delta y, \Delta\phi)}{B(0,0)} = 1 - \frac{|\Delta y|}{y^{\mathrm{max}} - y^{\mathrm{min}}}$$

- Correct normalization scheme
  use real single-gluon distribution



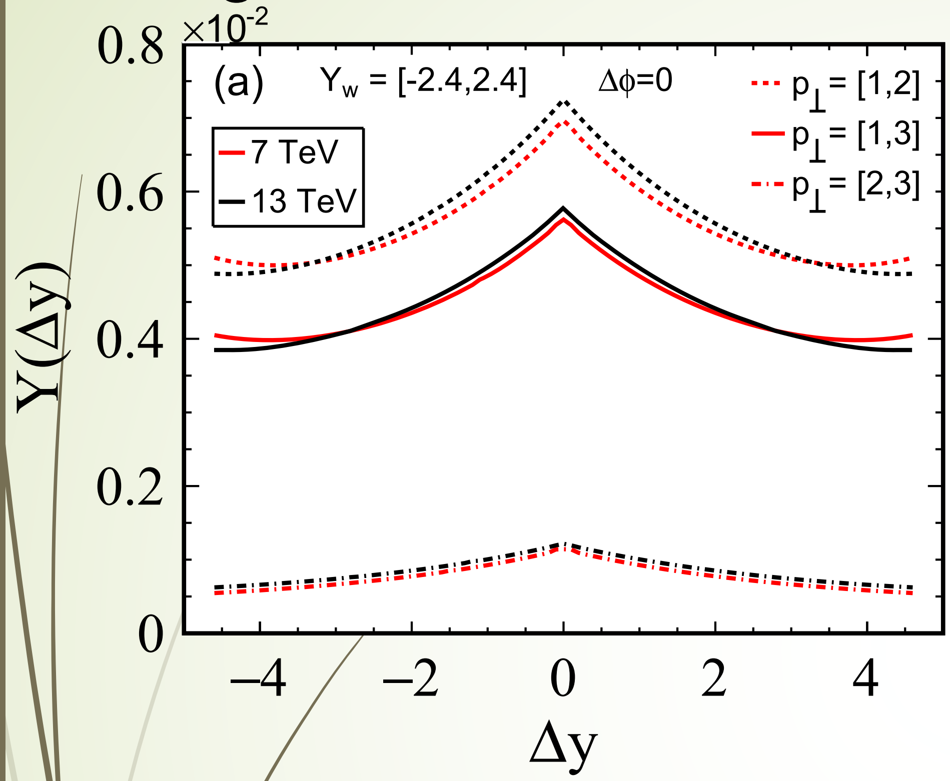




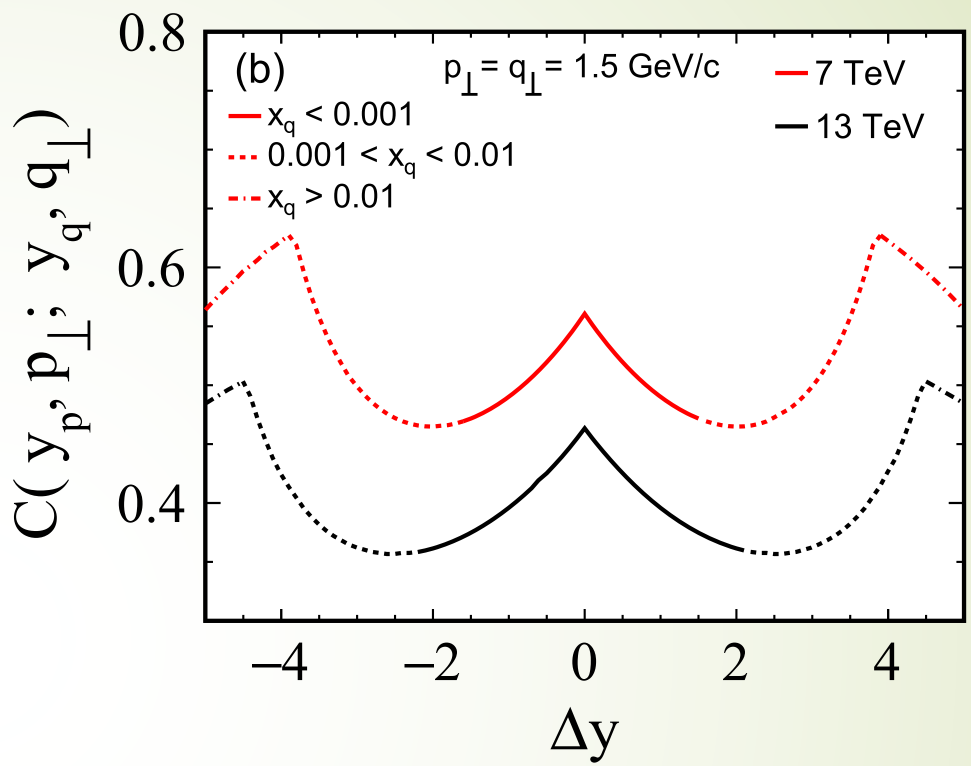
- the plateau at $2 < |\Delta y| \lesssim 3.6$
- the rebound at $|\Delta y| \approx 4$

is reproduced and described by CGC

integrated correlation function



differential correlation function



- The rebound is more easily observed in the differential correlation function --- a more obvious "W" shape

PHENIX and STAR collaborations report different values of v2 / v3. Their detectors cover forward and central rapidity regions.

Gluon dynamics is a function of rapidity. Due this, there may be no discrepancy between PHENIX and STAR measurements.

SUMMARY

- Physical Picture: Different rapidity regions has different degrees of freedom of gluon
- Calculate ridge corr. at large $|\Delta y|$
- Structures in Δy direction consistent with CMS measurements
- These features can be used to directly test the CGC dynamics

Thank you!

- the leading logarithmic accuracy in x
- the leading graphs of $\frac{p_\perp}{Q_s}$
- $p_\perp, q_\perp \gtrsim Q_s$
- one-loop approximation of BK eq.
- AAMQS initial condition
- $Q_{s0p}^2 = 0.168\ \mathrm{GeV}^2$ pp collision at 7 TeV, $Q_{s0A}^2 = 0.504\ \mathrm{GeV}^2$
- the leading order Balitsky-Kovchegov (BK) equation with a running coupling kernel, Balitsky's prescription

dipole forward scattering amplitude

$$\Phi_{A(B)}(x, \mathbf{k}_\perp) = \frac{N_c k_\perp^2}{4\alpha_s} \int d^2\mathbf{r}_\perp e^{i\mathbf{k}_\perp \cdot \mathbf{r}_\perp} [1 - \mathcal{N}_{\mathrm{ad.}}(\mathbf{r}_\perp, Y)]$$

unintegrated gluon dis. (uGD)

- a phenomenological extrapolation of uGD at large x

$$\Phi(x, \mathbf{k}_\perp) = \left(\frac{1-x}{1-x_0}\right)^\beta \Phi(x_0, \mathbf{k}_\perp) \text{ for } x > x_0$$