Azimuthal correlations of forward di-pions in d+Au collisions suppressed by saturation

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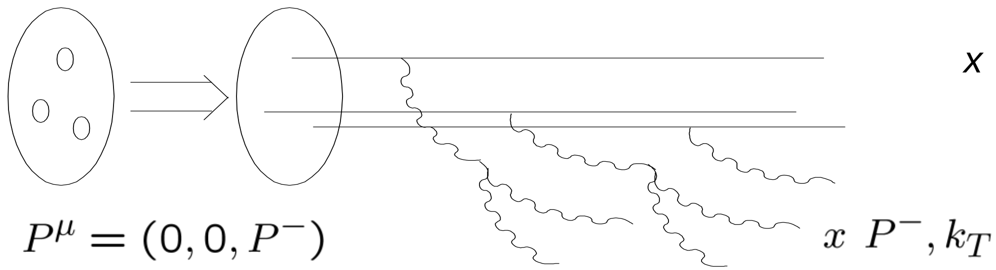
Based on : C.M., *Nucl. Phys.* **A796** (2007) 41-60
J.L. Albacete and C.M., arXiv:1005.4065

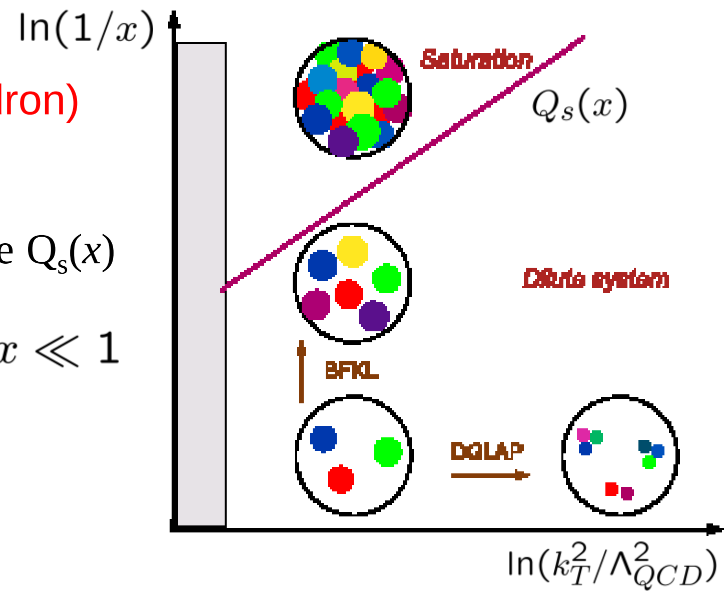
Parton saturation



x : parton longitudinal momentum fraction

k_T : parton transverse momentum

the distribution of partons as a function of x and k_T :



QCD linear evolutions: $k_T \gg Q_s$

DGLAP evolution to larger k_T (and a more dilute hadron)

BFKL evolution to smaller x (and denser hadron)

dilute/dense separation characterized by the saturation scale $Q_s(x)$

QCD non-linear evolution: $k_T \sim Q_s$ meaning $x \ll 1$

$\rho \sim \frac{xf(x, k_\perp^2)}{\pi R^2}$ gluon density per unit area it grows with decreasing x

$\sigma_{rec} \sim \alpha_s / k^2$ recombination cross-section

recombinations important when $\rho\ \sigma_{rec} > 1$

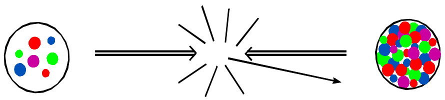
the saturation regime: for $k^2 < Q_s^2$ with $Q_s^2 = \frac{\alpha_s x f(x, Q_s^2)}{\pi R^2}$

this regime is non-linear yet weakly coupled $\alpha_s(Q_s^2) \ll 1$

Why di-hadron corelations ?

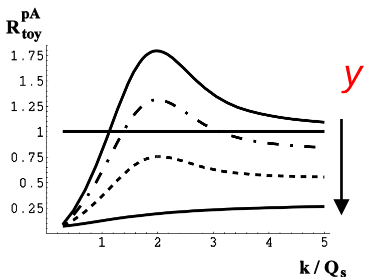
- after the first d+Au run at RHIC, there was a lot of new results on single inclusive particle production at forward rapidities

d Au → h X



the spectrum $\frac{d\sigma^{dAu\to hX}}{d^2k dy}$ and

the modification factor $R_{dA} = \frac{1}{N_{coll}} \frac{dN^{dA\to hX}}{d^2kdy} \bigg/ \frac{dN^{pp\to hX}}{d^2kdy}$ were studied



the suppressed production (R_{dA} < 1) was predicted in the Color Glass Condensate picture of the high-energy nucleus

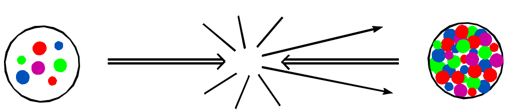
- but single particle production probes limited information about the CGC

(only the 2-point function)

to strengthen the evidence, we need to study more complex observables

- focus on di-hadron azimuthal correlations

a measurement sensitive to possible modifications of the back-to-back emission pattern in a hard process

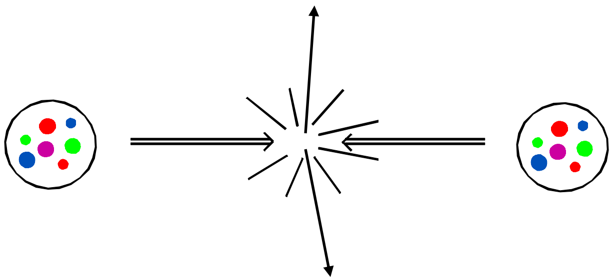


$\mathrm{d\ Au} \to \mathrm{h_1\ h_2\ X}$

Di-hadron final-state kinematics

final state : $k_1, y_1 \quad k_2, y_2$ $\quad x_p = \frac{k_1 e^{y_1} + k_2 e^{y_2}}{\sqrt{s}} \quad x_A = \frac{k_1 e^{-y_1} + k_2 e^{-y_2}}{\sqrt{s}}$

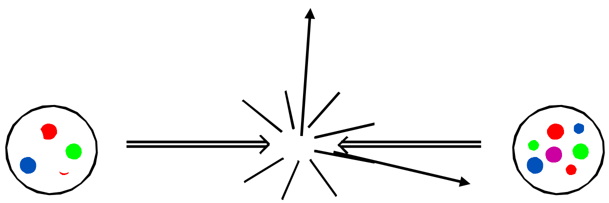
- scanning the wave-functions



$$x_p \sim x_A < 1$$

central rapidities probe moderate x

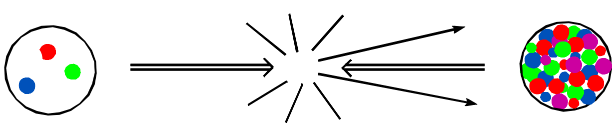
x_p increases | x_A ~ unchanged



$$x_p \sim 1,\ x_A < 1$$

forward/central doesn't probe much smaller x

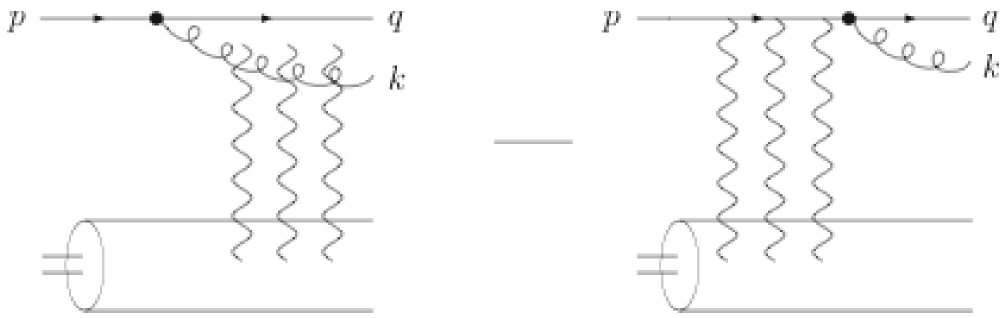
x_p ~ unchanged | x_A decreases



$$x_p \sim 1,\ x_A << 1$$

forward rapidities probe small x

Forward di-jet production



b: quark in the amplitude
x: gluon in the amplitude
b': quark in the conj. amplitude
x': gluon in the conj. amplitude

Fourier transform $k_\perp$ and $q_\perp$ into transverse coordinates

collinear factorization of quark density in deuteron

$$\frac{d\sigma^{dAu\to qgX}}{d^2k_\perp dy_k d^2q_\perp dy_q} = \alpha_S C_F N_c\, x_d q(x_d,\mu^2)\int \frac{d^2x}{(2\pi)^2}\frac{d^2x'}{(2\pi)^2}\frac{d^2b}{(2\pi)^2}\frac{d^2b'}{(2\pi)^2}\, e^{ik_\perp.(\mathbf{x}'-\mathbf{x})}e^{iq_\perp.(\mathbf{b}'-\mathbf{b})}$$

$$\left|\Phi^{q\to qg}(z,\mathbf{x}-\mathbf{b},\mathbf{x}'-\mathbf{b}')\right|^2\left\{S^{(4)}_{qg\bar{q}g}[\mathbf{b},\mathbf{x},\mathbf{b}',\mathbf{x}';x_A] - S^{(3)}_{qg\bar{q}}[\mathbf{b},\mathbf{x},\mathbf{b}'+z(\mathbf{x}'-\mathbf{b}');x_A]\right.$$

$$\left.-S^{(3)}_{\bar{q}gq}[\mathbf{b}+z(\mathbf{x}-\mathbf{b}),\mathbf{x}',\mathbf{b}';x_A] + S^{(2)}_{q\bar{q}}[\mathbf{b}+z(\mathbf{x}-\mathbf{b}),\mathbf{b}'+z(\mathbf{x}'-\mathbf{b}');x_A]\right\}$$

pQCD $q \to qg$ wavefunction

interaction with hadron 2 / CGC

$$z = \frac{|k_\perp|e^{y_k}}{|k_\perp|e^{y_k}+|q_\perp|e^{y_q}}$$

n-point functions that resums the powers of $g_S A$ and the powers of $\alpha_S \ln(1/x_A)$

computed with JIMWLK evolution at NLO (in the large-Nc limit), and MV initial conditions

no parameters

CGC predictions

with a large-Nc approximation to practically handle to 4-point function

C.M. (2007) $S^{(4)}$ and $S^{(3)}$ expressed as non-linear functions of $S^{(2)}$

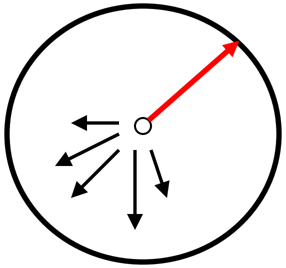
even though the knowledge of $S^{(2)}$ is enough to predict the
forward dihadron spectrum, there is no k_T factorization:
the cross section is a non-linear function of the gluon distribution

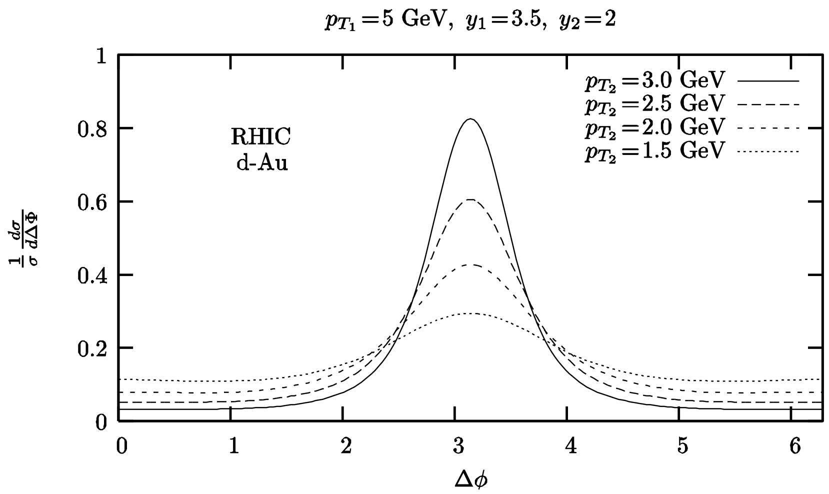
- some results for $(1/\sigma)\, d\sigma/d\Delta\Phi$

$$k_1 = 5 \text{ GeV},\ y_1 = 3.5,\ y_2 = 2$$

k_2 is varied from 1.5 to 3 GeV

as k_2 decreases, it gets closer to Q_S and the correlation in azimuthal angle is suppressed





azimuthal correlations are only a small part of the information contained in $\dfrac{d\sigma^{pA\to h_1 h_2 X}}{d^2k_1 dy_1 d^2k_2 dy_2}$

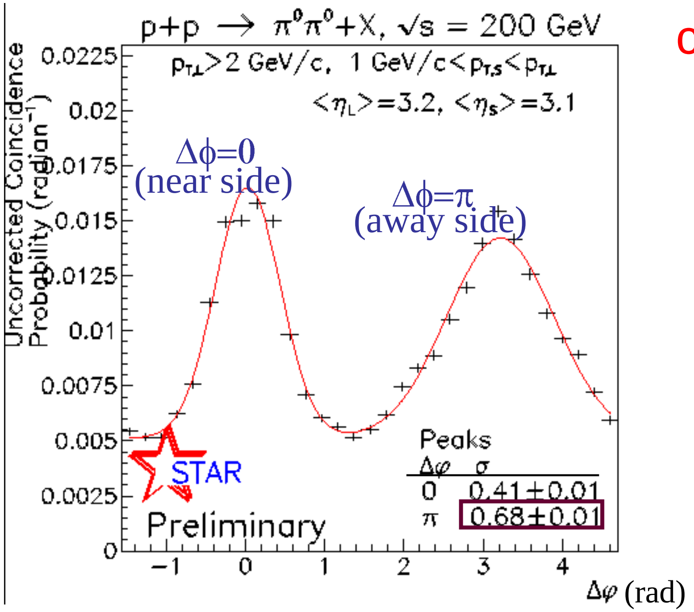
Evidence of monojets

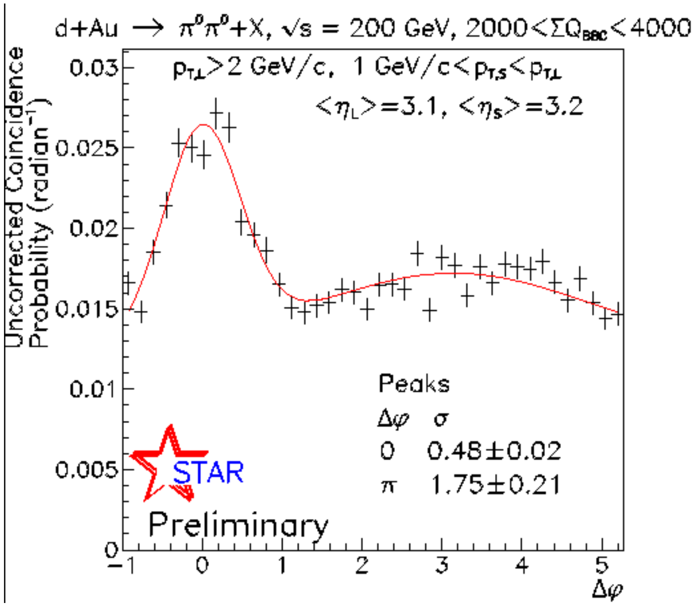
$$CP(\Delta\phi) = \frac{1}{N_{trigger}} \frac{dN_{pair}}{d\Delta\phi}$$

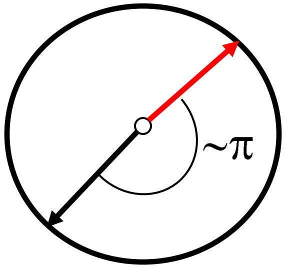
p+p

d+Au central

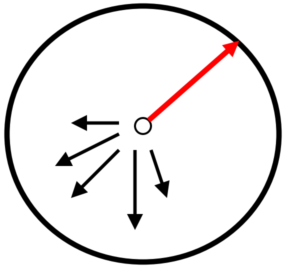
coincidence probability







transverse view



Comparison with CGC

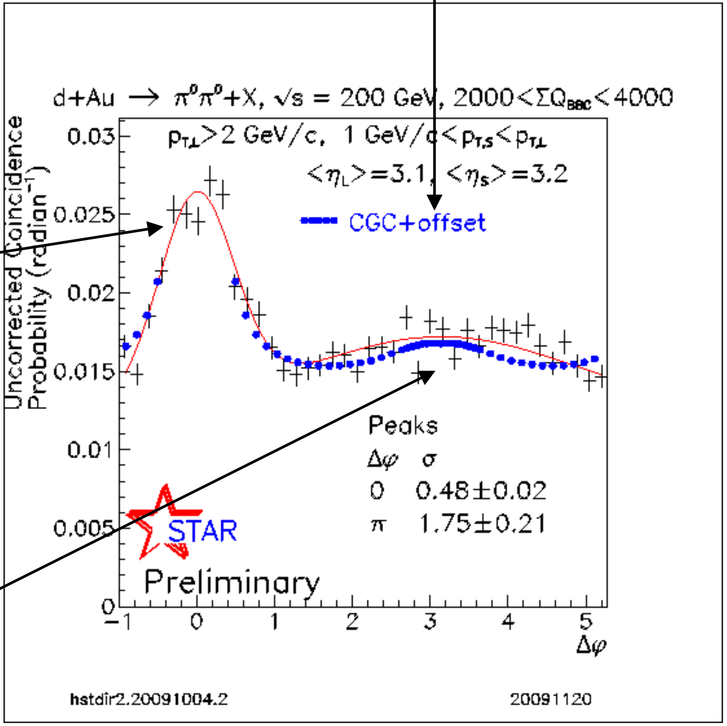
- in central collisions where Q_S is the biggest

an offset is needed to account for the background

there is a very good agreement of the saturation predictions with STAR data

Albacete and C.M. (2010)

to calculate the near-side peak, one needs di-pion fragmentation functions



- the focus is on the away-side peak

where non-linearities have the biggest effect

suppressed away-side peak

standard (DGLAP-like) QCD calculations cannot reproduce this

The centrality dependence

it can be estimated by modifying the initial condition for NLO-BK evolution

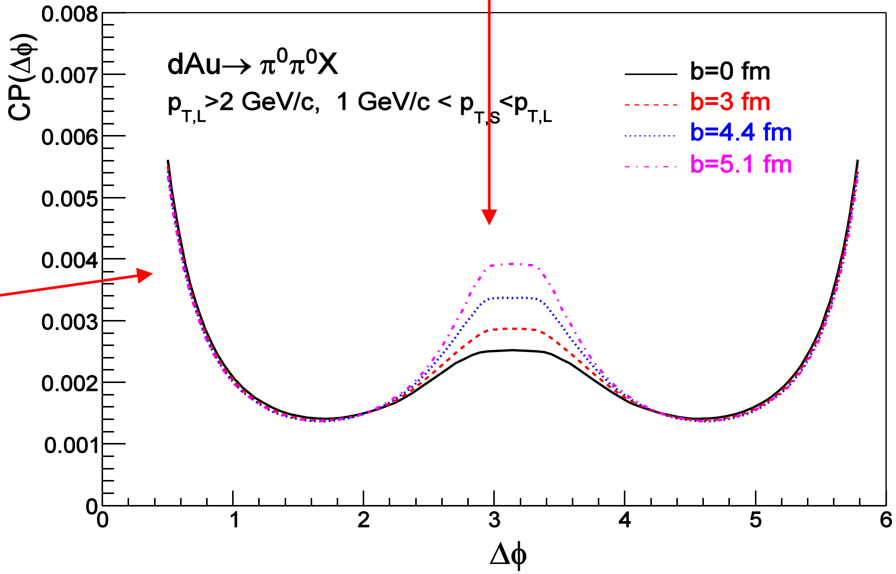
for a given impact parameter,
the initial saturation scale used is

$$Q_s^2(b) = Q_s^2(0)\sqrt{1 - b^2/R^2}$$

the away-side peak is reappearing
when decreasing the centrality

d+Au peripheral collisions
are like p+p collisions

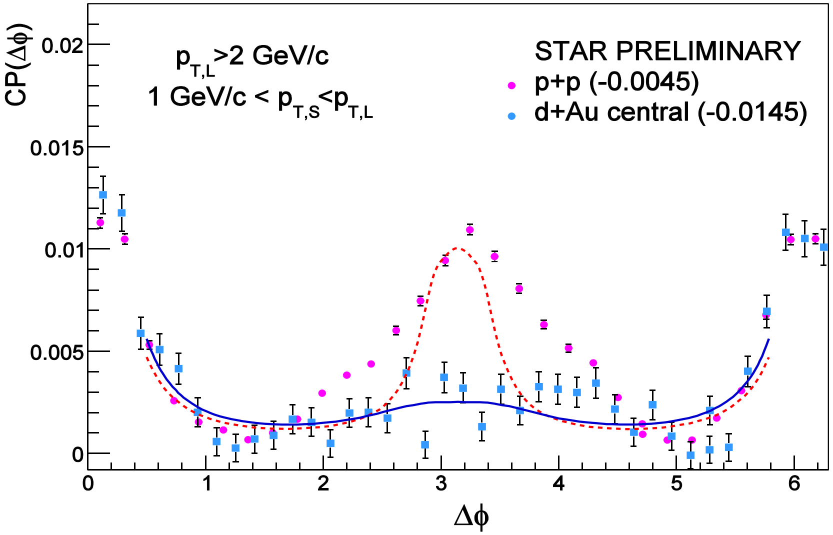
the near-side peak is unchanged



Conclusions

the magnitude of the away-side peak,
compared to that of the near-side peak,
decreases from p+p to d+Au central

this happens at forward rapidities,
but at central rapidities, the p+p and
d+Au signal are almost identical



$\Rightarrow$ the suppression of the away-side peak occurs when Q_S increases

this was predicted, in some cases quantitatively with no parameter adjustments

so far all di-hadron correlations measured in d+Au vs. p+p are consistent with saturation