DECORRELATION of JETS in DIS off NUCLEI

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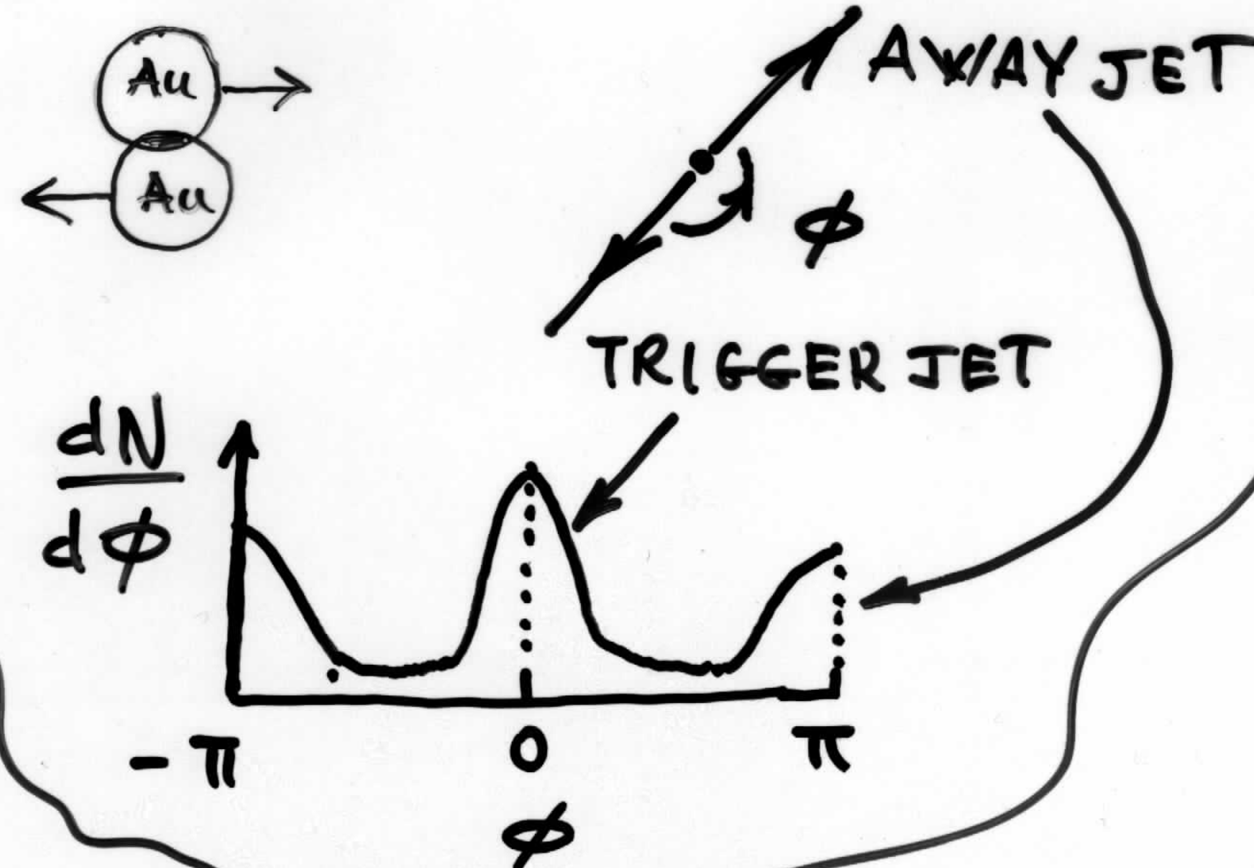
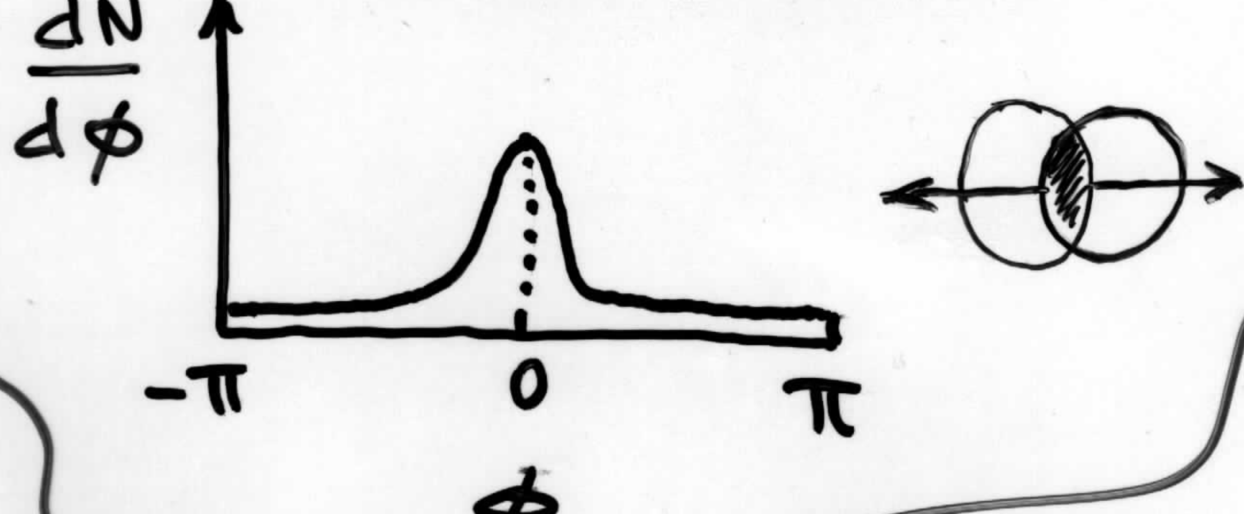
STAR RHIC observation:

* gradual disappearance of back-to-back azimuthal correlations of high $p_\perp$ particles with centrality of collision.

Peripheral gold-gold collision



CENTRAL Au-Au



Part 1: $\gamma A \to jet + jet + X$

Exact results basedon

hep-ph/0303024 NN Nikolaev
W Schäfer
BG Zakharov
VRZ

keywords: Small-x QCD,
Color dipoles,
Breakup of photon,
Dijets,
Decorrelation phenome...
...

Part 2. (Speculative)

$$AA \to jet + jet + X$$

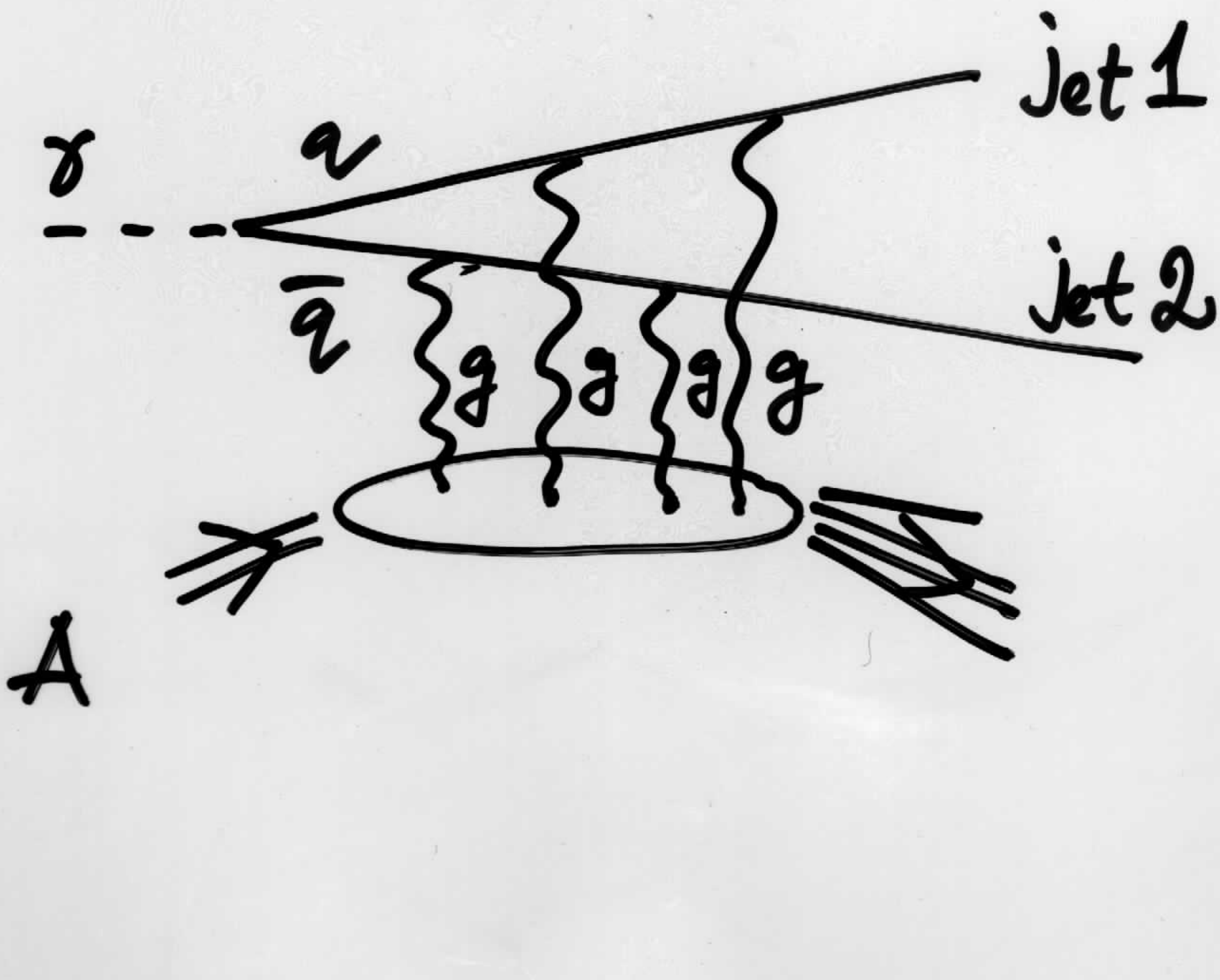
Comments on a relevance of our γA analysis to

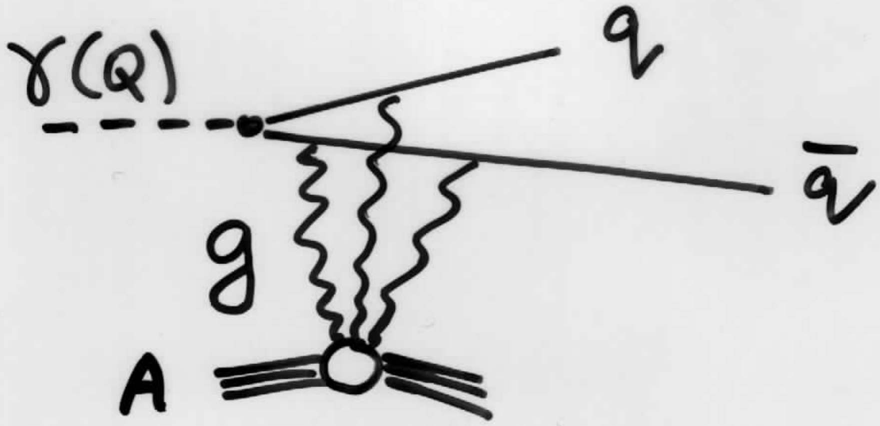
AA at RHIC

or

Does the photon look like heavy ION ?

Mechanism of decorrelation - multiple scatterings of $q\bar{q}$ in gluon field of nucleus.





$$Q = (\nu, \vec{Q}), \quad x = Q^2/2m_N\nu$$

$$x \ll 1$$

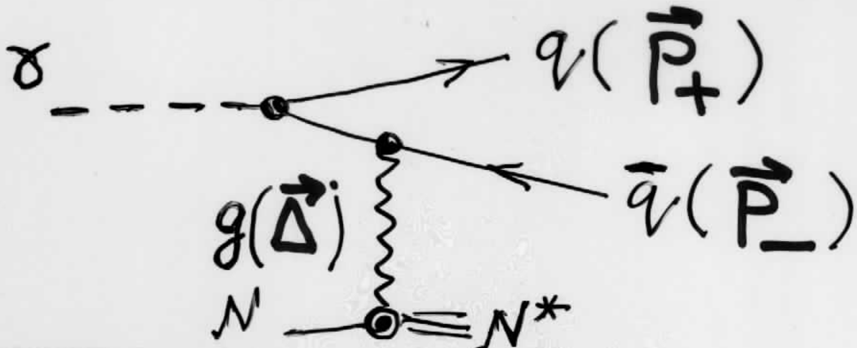
Focus on small-x ! –

– The realm of gluon exchange

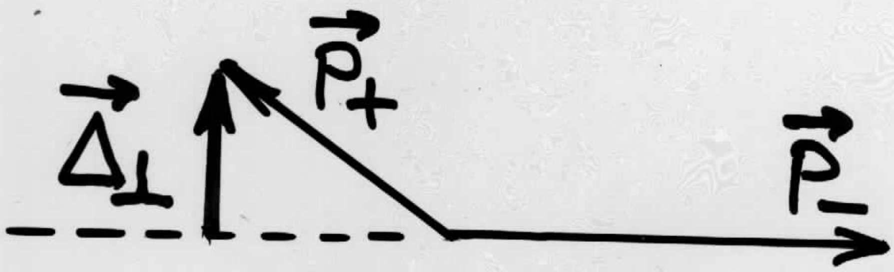
More definitions:

DECORRELATION MOMENTUM

/simple example: 1g-exchange/



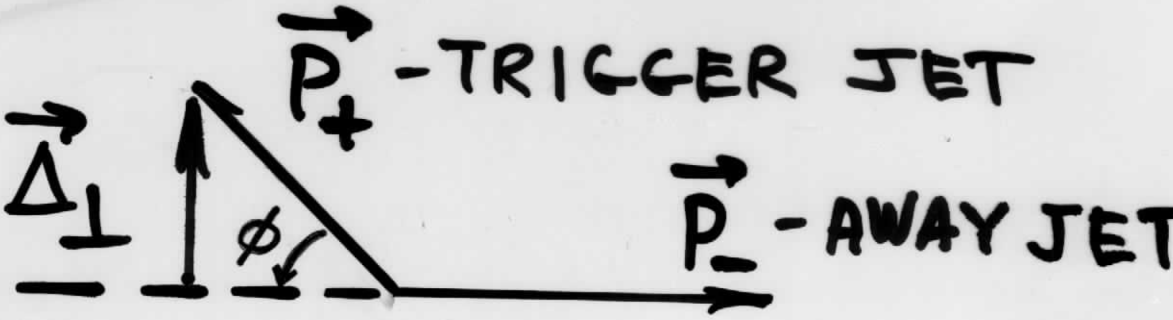
IMPACT PARAMETER PLANE



$$\vec{\Delta} = \vec{P}_+ + \vec{P}_-$$

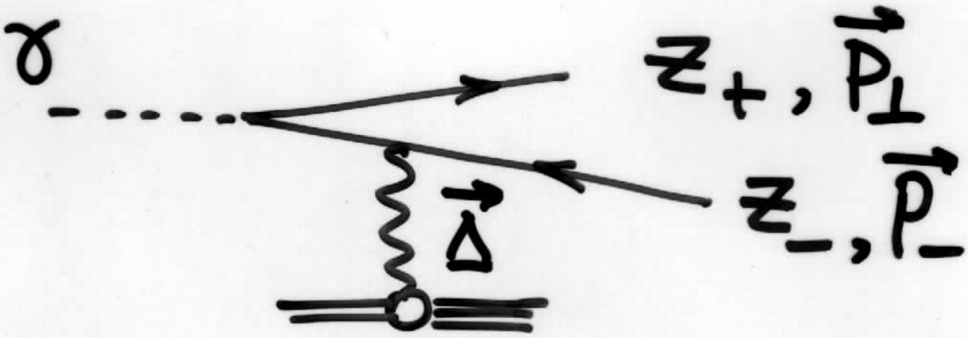
$\vec{\Delta}_\perp$ – DECORRELATION MOMENTUM

DIJET SELECTION



- $0 < \phi < \pi/2$ – q and $\bar{q}$ jets are in different hemispheres
- fixed $|\vec{P}_+|$ mom. of q-jet
- $|\vec{P}_-| > |\vec{P}_+|$

EXPERIMENTAL SIGNATURES



L. mom. fractions $z_\pm$ for observed jets add up to unity

$$z_+ + z_- = 1$$

Hence, dubbing this process a break-up of the photon = unresolved/direct photon interaction

One more signature:

Small rapidity separation of forward jets, $z_+ \approx z_-$

Problem to solve:

$$\left\langle \left(\vec{p}_+ + \vec{p}_-\right)_\perp^2 \right\rangle = \langle \Delta_\perp^2 \rangle = ?$$

at fixed trigger momentum $\vec{p}_+$

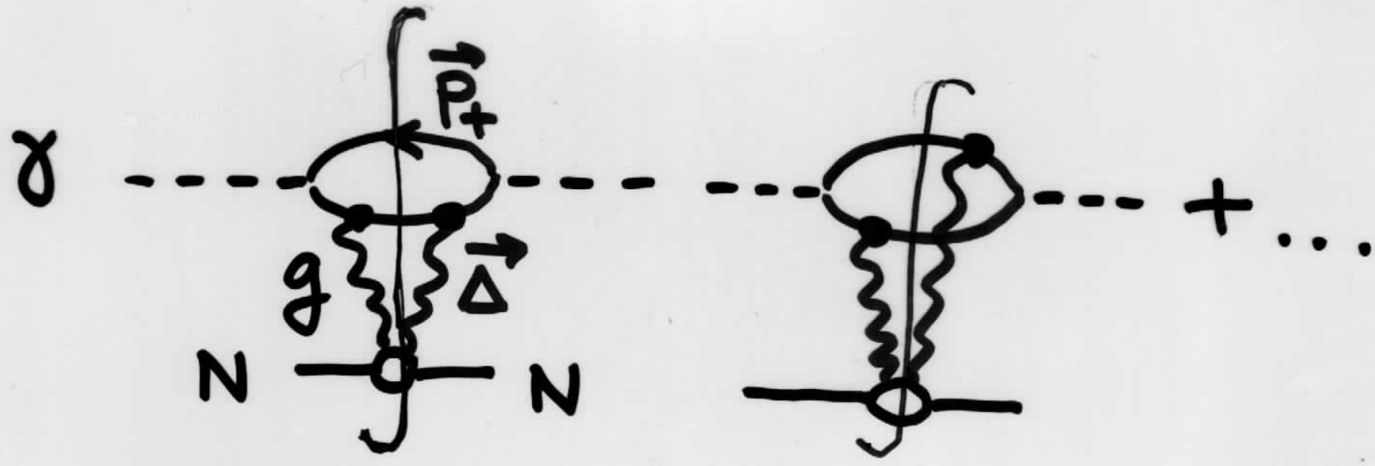
and

integrated over $\vec{p}_-$

$$\langle \Delta_\perp^2 \rangle = \int_{p_+}^{\infty} dp_- \ldots$$

Just to have single-scale problem

$\gamma N \to jet + jet + X$



gluon momentum = decorrel. mom.

$$\frac{d\sigma_N}{d^2\vec{p}_+ d^2\vec{\Delta}} = \frac{\alpha_s(p_+^2)}{2\pi N_c} \cdot \frac{\mathcal{F}(x,\Delta^2)}{\Delta^4} \cdot \left| \langle \gamma | \vec{p}_+ \rangle - \langle \gamma | \vec{p}_+ - \vec{\Delta} \rangle \right|^2$$

$\langle \gamma | \vec{p}_+ \rangle$ – W/F of $q\bar{q}$ Fock state of photon

$\mathcal{F}(x,\Delta^2) = \partial G(x,\Delta^2) / \partial \log \Delta^2$ – unintegrated gluon Str. Fun. of the nucleon

From

$$\frac{d\sigma_N}{d^2\vec{p}_+ d^2\vec{\Delta}} \sim \left[\frac{\mathcal{F}(x,\Delta^2)}{\Delta^4}\right] \cdot \left|\Psi_\gamma(\bar{p}_+,\bar{\Delta})\right|^2$$

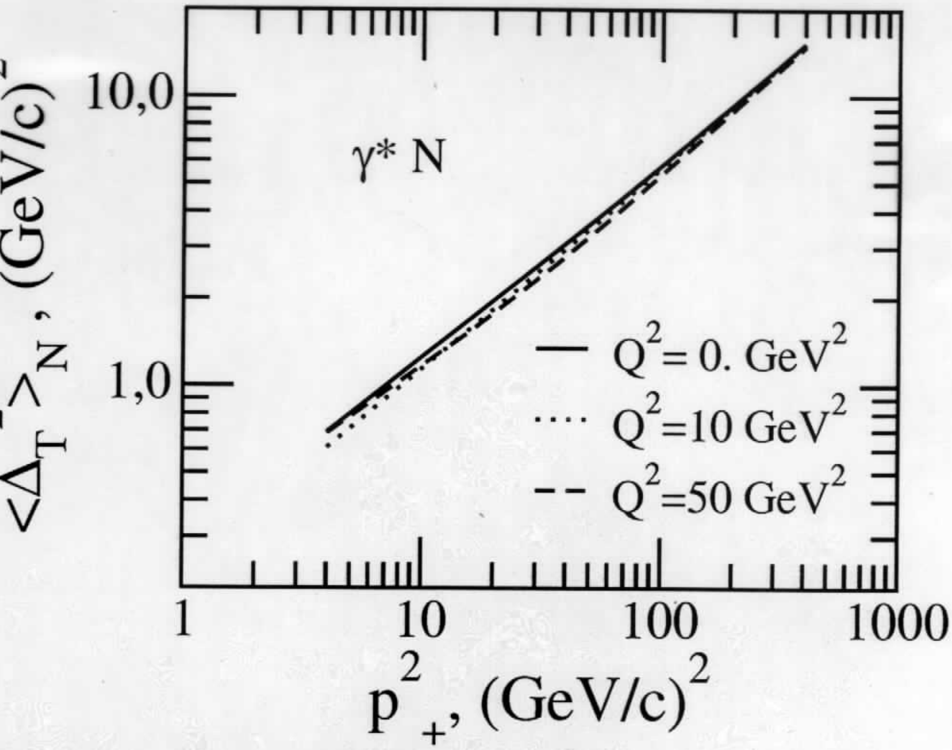
and

$$\frac{\mathcal{F}(x,\Delta^2)}{\Delta^4} \sim \frac{\alpha_S(\Delta^2)}{\Delta^4}$$

it follows that in γN Large transverse momentum of jets comes from intrinsic momentum of q and $\bar{q}$ in the photon light-cone Wave Function due to short distance singularity

As far as $P_+^2 \gtrsim z(1-z)Q^2 \approx Q^2/4$

$\langle\Delta_\perp^2\rangle_N$ does not depend on Q^2



Quick estimate:

$$\langle\Delta_\perp^2\rangle_N \approx \frac{1}{2} \cdot \frac{F(x, p_+^2)}{G(x, p_+^2)} \cdot p_+^2$$

is numerically very accurate

$\gamma A \to \text{jet} + \text{jet} + X$

Focus on DIS at moderately small-x

$$x \lesssim x_A = \frac{1}{R_A m_N} \ll 1$$

Therefore,

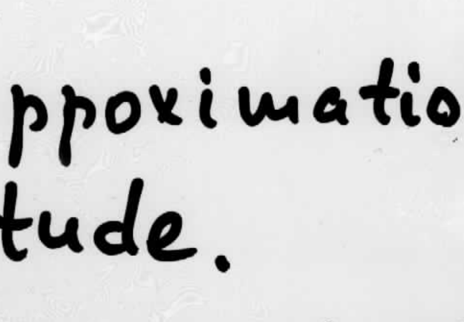
$$|\gamma\rangle = |q\bar{q}\rangle + \cancel{|q\bar{q}g\rangle} + \ldots$$

higher Fock states of $|\gamma\rangle$ and $\mathrm{Log}(1/x)$-evolution can be neglected

- For $x \lesssim x_A \ll 1$
  use the straight-path (Glaube-Gribov) appoxim. to describe propagation of $q\bar{q}$ in color field of nucleus

- Use the 2g-appoximation for γN amplitude. Smallness of the unitarity corrections to 2g follows from

$$\frac{\sigma^{\gamma N}_{DD}}{\sigma^{\gamma N}_{tot}} \ll 1$$



$\sigma^{\gamma N}_{DD}$

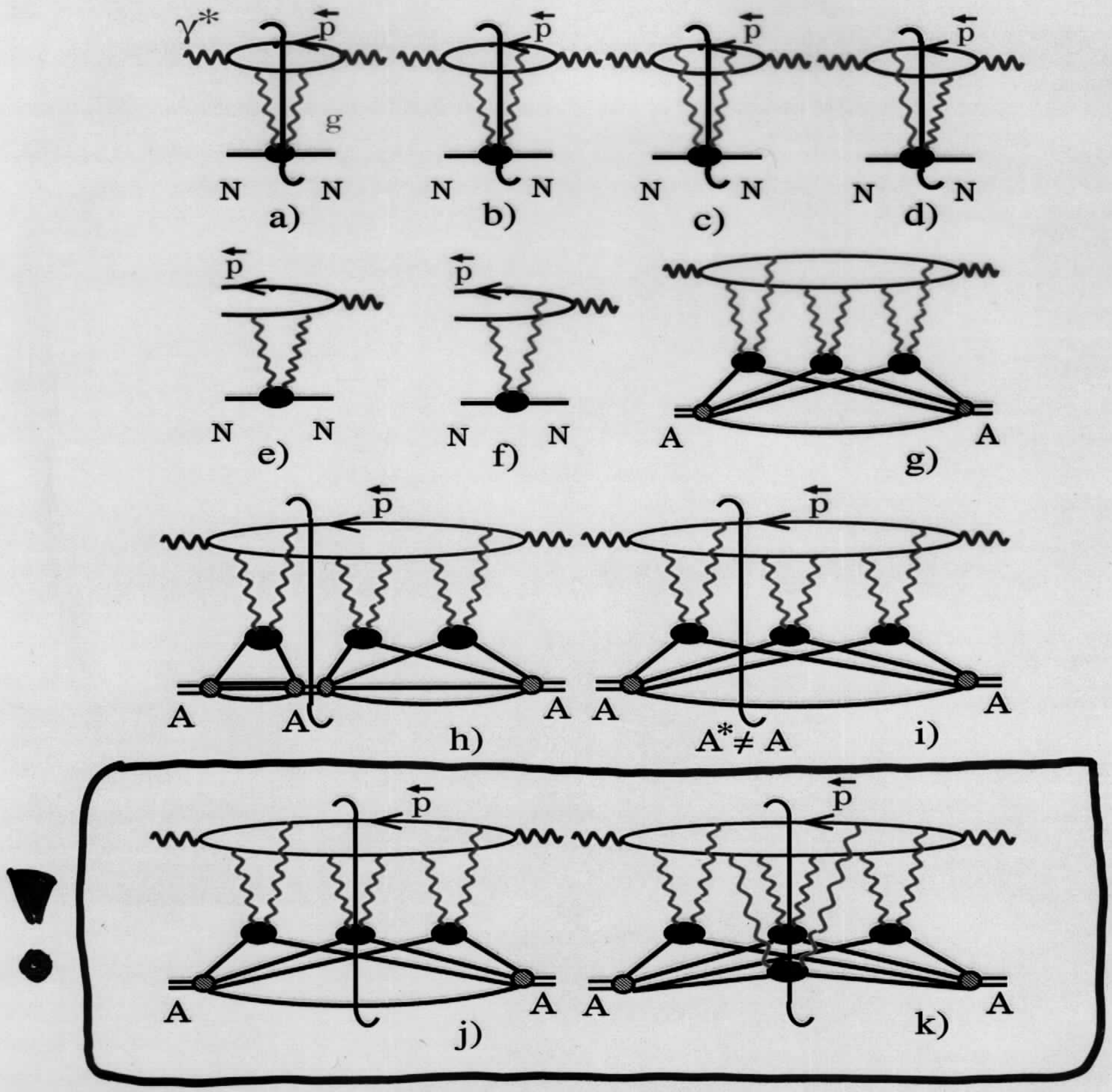


Figure 3: *The pQCD diagrams for inclusive (a-d) and diffractive (e,f) DIS off protons and nuclei (g-k). Diagrams (a-d) show the unitarity cuts with color excitation of the target nucleon, (g) - a generic multiple scattering diagram for Compton scattering off nucleus, (h) - the unitarity cut for a coherent diffractive DIS, (i) - the unitarity cut for quasielastic diffractive DIS with excitation of the nucleus A^*, (j,k) - the unitarity cuts for truly inelastic DIS with single and multiple color excitation of nucleons of the nucleus.*

$\gamma A \to jet + jet + X$

$$\frac{d\sigma_{in}}{d^2\bar{b}\, d^2\bar{p}_t\, d^2\bar{\Delta}} \approx T(b) \cdot \sum_{j=0}^{\infty} w_j(b) \cdot$$

$$\times \int d^2\vec{x}\, f^{(j)}(\bar{\Delta}-\bar{x}) \frac{d\sigma_N}{d^2\bar{p}_t\, d^2\bar{x}}$$

$$w_j(b) = \frac{[\nu(b)]^j}{j!} \cdot \exp[-\nu(b)]$$

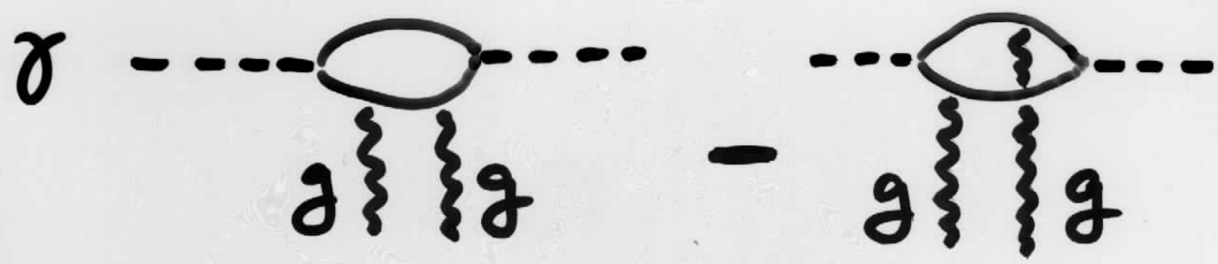
$$\nu(b) = \frac{1}{2} \cdot \frac{N_c^2}{N_c^2-1} \cdot \alpha_s(p_t^2) \cdot \sigma_0 \cdot T(b)$$

w_j – probability of finding j spatially overlapping nucleons

$f^{(j)}$ – collective gluon field of j overlapping nucleons

$$\frac{d\sigma_{in}}{d^2\bar{b}\, d^2\bar{p}_t\, d^2\bar{\Delta}}$$ is of probabilistic form.

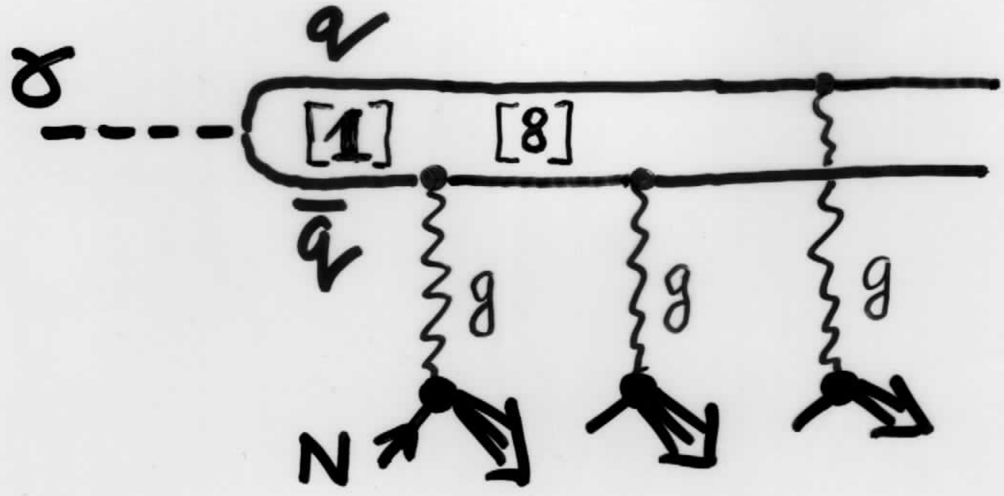
No traces of QM interference



which, in particular, leads to

$$\sigma_{q\bar{q}}(r) \sim r^2$$

r – dipole moment of $q\bar{q}$ pair



$$|\gamma\rangle = |q\bar{q}\rangle_{[1]}$$ ← initial state

$$|q\bar{q}\rangle_{[1]} \rightarrow g + |q\bar{q}\rangle_{[8]}$$

Color charges of $q\bar{q}$ in [8] state do not neutralize each other.

G. Inv. condition relaxed.

Multiple scatterings becomes uncorrelated. ⇒

$\frac{d\sigma}{dp_+ dp_-}$ follows probabilistic picture.

The convolution property of the hard dijet cross section suggests:

$$\langle \Delta_\perp^2(b) \rangle_A \approx \langle \Delta_\perp^2 \rangle_N + \langle \varkappa_\perp^2(b) \rangle_A$$

$\langle \Delta_\perp^2 \rangle_N$ refers to DIS on a free nucleon

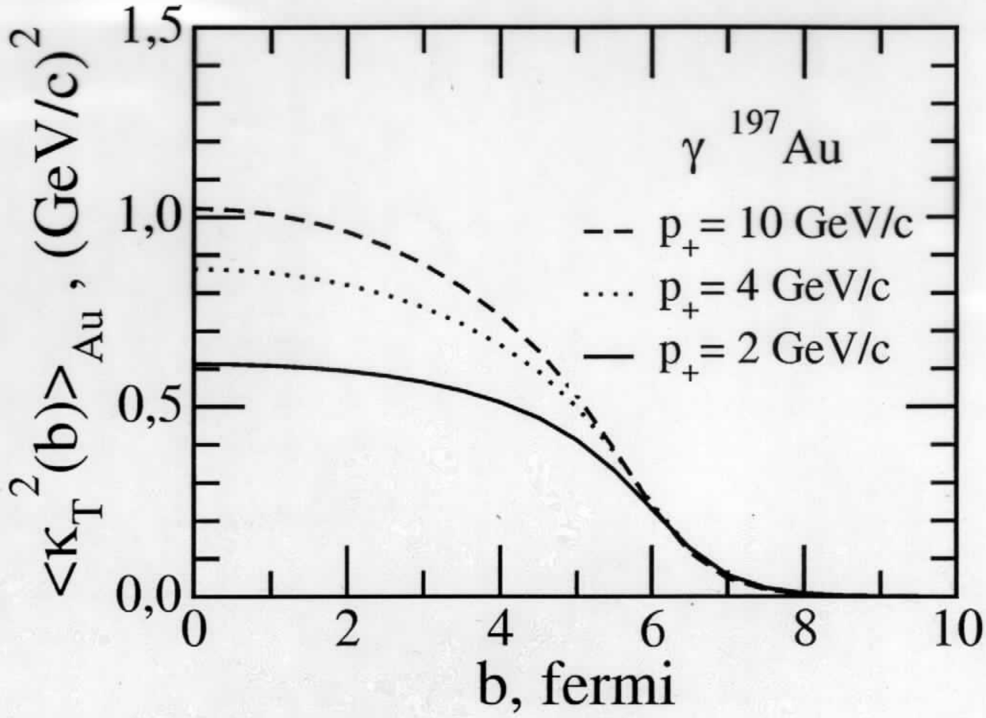
$\langle \varkappa_\perp^2(b) \rangle_A$ – the nuclear broadening term

$$\langle \varkappa^2(b) \rangle_A \sim \frac{N_c^2}{N_c^2-1} \cdot Q_A^2(b) \cdot \log \frac{P_+}{Q_A(b)}$$

$$Q_A(b) \approx \frac{4\pi^2}{N_c} \cdot \underbrace{\alpha_s(Q^2) \cdot G(Q^2)}_{\approx 1 \text{ at } x \sim 10^{-2}} \cdot T(b)$$

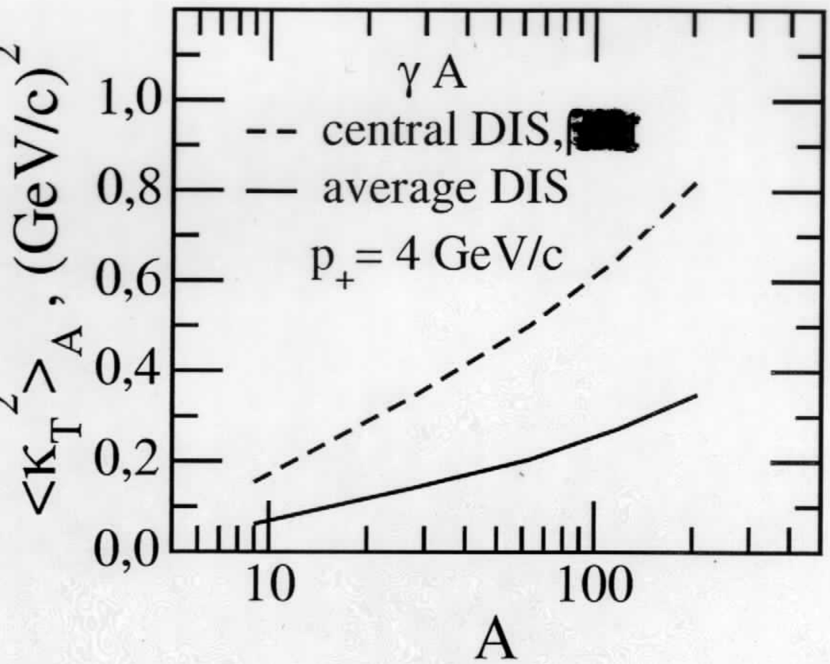
$\langle Q_A^2(b) \rangle_{Au} \approx 0.8\ \mathrm{GeV}^2$, $T(0) \approx \frac{3A^{1/3}}{2\pi r_0^2}$

$r_0^2 \approx 1.2\ \mathrm{fm}^2$



$<\kappa_T^2(b)>_{Au}$, $(GeV/c)^2$
1,5
1,0
0,5
0,0
0
2
4
6
8
10
b, fermi
γ ^{197}Au
p_+= 10 GeV/c
p_+= 4 GeV/c
p_+= 2 GeV/c

<u>scale of effect</u>:
different for different nuclei; for central and aver.

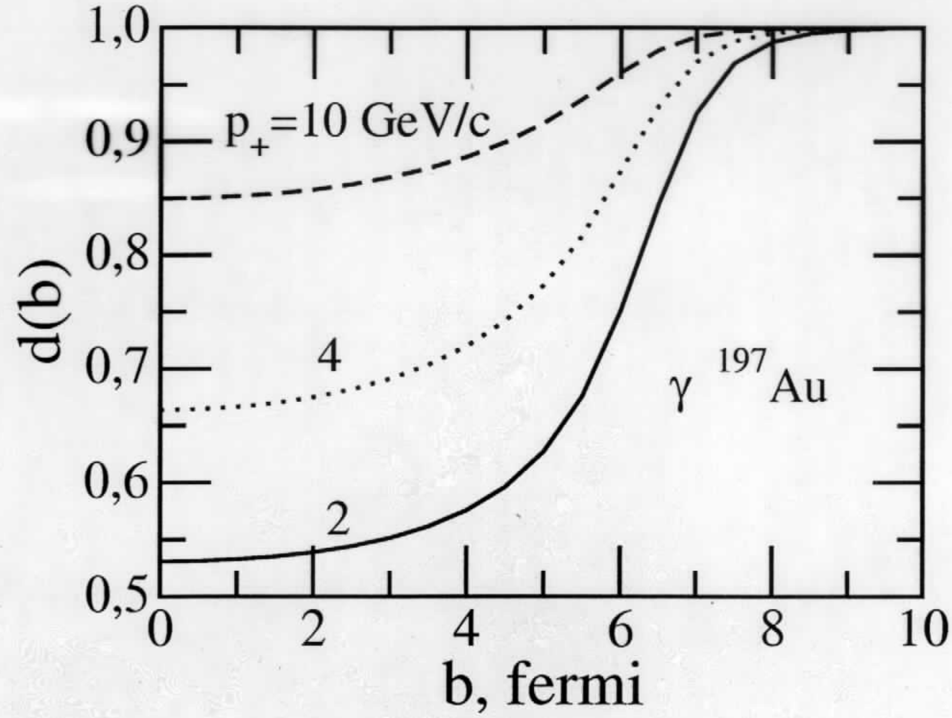


$$\langle \Delta_\perp^2(b)\rangle_A \approx \langle \Delta_\perp^2\rangle_N + \langle \varkappa_\perp^2(b)\rangle_A$$

$\langle \Delta_\perp^2\rangle_N$ refers to DIS on a free nucleon

$\langle \varkappa_\perp^2(b)\rangle_A$ – the nuclear broadening term

$$d(b) = \frac{\langle \Delta_\perp^2 \rangle_N}{\langle \Delta_\perp^2 \rangle_N + \langle \varkappa_\perp^2(b) \rangle_A}$$



d(b) – "no-decorrelation" «probability» or the probability of observing back-to-back jets.

RHIC-STAR:

★ $A + A \longrightarrow \text{jet} + \text{jet} + X$

At RHIC energies jets at moderately large $p_\perp$ are mostly due to gluon-gluon collisions

- $$\sigma_{gg}(r) = \sigma_{q\bar{q}}(r) \cdot \frac{C_A}{C_F}$$

$$\frac{C_A}{C_F} = \frac{2N_c^2}{N_c^2 - 1} = \frac{9}{4}$$

Effective thickness of nuclear matter is about twice that in central γA-collision

The γ Au-results suggest that ~~for~~ central Au-Au collision the nuclear broadening is quite substantial:

$$\langle \varkappa_\perp^2 (b=0) \rangle_{AuAu} \sim$$

$$\sim \langle \varkappa_\perp^2 (b=0) \rangle_{\gamma Au} \cdot \frac{9}{4} \cdot 2 \sim$$

$$\sim 3-4\ (GeV/c)^2$$

From $\langle \Delta_\perp^2 \rangle_N \sim 3-4\ (GeV/c)^2$ at $p_+ = 6\,G$

it follows that

$$d(b=0) \approx 1/2$$

$$\boxed{\text{From peripheral to central AuAu collision probability to observe back-to-back trigger and away jets decreases approximately twofold.}}$$

for central pA-collisions

we expect :

$$\langle x_\perp^2(0) \rangle_{pAu} \sim 1.5\,(GeV/c)^2$$

at $p_+ = 6$ GeV/c

Conclusions:

- Theory of breakup of photons into dijets in DIS off nuclei formulated
- Qualitative estimates of decorrelation effect in centrall gold-gold collisions presented
- Mechanism of multiple scatterings contribute substantially to observed decorrelation effect: we do understand at least one half of the effect.

 But where is second half?