# ANGULAR CORRELATIONS IN GLUON EMISSION AT HIGH ENERGY.

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# "RIDGE" CORRELATIONS IN p-p SCATTERING

CMS - TWO PARTICLE CORRELATIONS IN P-P, LONG RANGE IN RAPIDITY AND PEAKED IN FORWARD DIRECTION - "RIDGE" IN P-P COLLISIONS

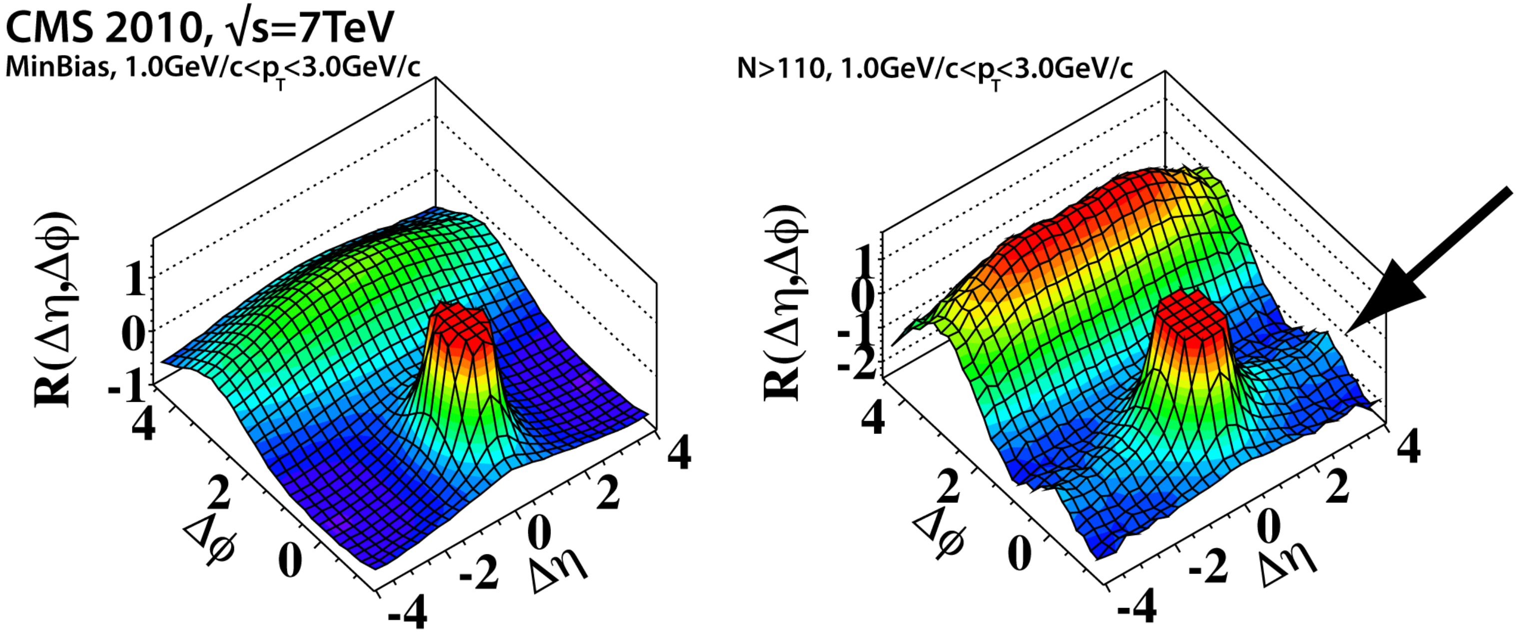


Figure 1: THE CMS RIDGE.

ONLY IN HIGH MULTIPLICITY EVENTS ($\sim 10^{-5}$) AND ONLY A RATHER SMALL EFFECT. STILL STATISTICALLY SIGNIFICANT AND INTERESTING

THE RHIC RIDGE MAY HAVE A DIFFERENT NATURE, AS IT IS BELIEVED THAT FINAL STATE INTERACTIONS CAN GENERATE RADIAL FLOW WHICH PRODUCES ANGULAR CORRELATIONS INDEPENDENT FROM THOSE IN THE INITIAL STATE.

THE DISCUSSION HERE IS DECOUPLED FROM FINAL STATE, AND SO IS ONLY PERTINENT TO THE CMS MEASUREMENTS.

THERE IS AN ONGOING CALCULATIONAL EFFORT IN THE CGC COMMUNITY TO DESCRIBE THE CMS CORRELATION QUANTITATIVELY.

HERE I ONLY GIVE A QUALITATIVE DISCUSSION, BUT DISCUSS SOME PHYSICS WHICH NEEDS TO BE HANDLED BETTER IN ORDER FOR THE CALCULATIONS TO BE QUANTITATIVELY RELIABLE.

DUMITRU, DUSLING, GELIS, JALILIAN-MARIAN, LAPPI, VENUGOPALAN - arXiv:1009.5295 AND ONGOING - THE SAME MECHANISM ALBEIT IN A LITTLE DIFFERENT GUISE OF "GLASMA FLUX TUBES". BUT REALLY THE SAME!

LEVIN, REZAEIAN - arXiv:1105.3275 - AGAIN THE SAME EXACT MECHANISM, BUT DRESSED IN ROBES OF POMERON CALCULUS. GENYA ?

**THE DISCUSSION IS SET IN THE FRAMEWORK OF THE SATURAION IDEAS, SO A VERY SHORT SUMMARY:**

# PERTURBATIVE SATURATION (AKA CGC)

ITS A LONG STORY, BUT IN A NUTSHELL

GLUON DENSITY GROWS RAPIDLY AS ONE GOES TO LOW VALUES OF $x$ IN HADRONIC WAVE FUNCTIONS.

THIS GENERATES "MOMENTUM DIVIDE" AT MOMENTUM SCALE EQUAL TO THE AVERAGE PARTON DENSITY IN THE TRANSVERSE PLANE, "THE SATURATION MOMENTUM" $Q_S \sim \rho$

AT SHORT DISTANCES $x < Q_S^{-1}$ USUAL PARTONIC PHYSICS REMAINS VALID, AS AT THIS SCALES BY DEFINITION EFFECTS OF DENSITY ARE NOT IMPORTANT.

**BUT** WHEN PROBED ON TRANSVERSE DISTANCE SCALE $x > Q_S^{-1}$ THE HADRON THEN LOOKS LIKE A DENSE SYSTEM.

**$Q_S$ PLAYS A DUAL ROLE IN THIS PICTURE:**

**A. IT IS THE AVERAGE VALUE OF COLOR ELECTRIC FIELDS IN THE WAVE FUNCTION.**

**B. IT IS THE INVERSE OF THE LENGTH OVER WHICH THE COLOR ELECTRIC FIELDS ARE CORRELATED.**

**LET US USE THE STANDARD DIPOLE DIAGNOSTICS.**

A COLOR NEUTRAL DIPOLE PROBE SCATTERS ON OUR SATURATED TARGET. (FOR A GIVEN CONFIGURATION OF ELECTRIC FIELD), THE SCATTERING AMPLITUDE IS

$$N(r) = 1 - \mathrm{Tr}[S^\dagger(0)S(r)]$$

WHERE $S(x) = e^{ig\int dx^+ A^-(x)}$.

THE POTENTIAL $A^-(x)$ (DISREGARDING COLOR FOR THE MOMENT) IS JUST THE USUAL $\partial_i A^- = F^{-i}$.

DEFINE THE "'ELECTRIC FIELD"' $E_i = \int dx^+ F^{-i}$.

THEN (ROUGHLY)

$$N(r) \sim 1 - e^{-(g\vec{r}\cdot\vec{E})^2}$$

FOR SMALL a $r$ WE HAVE PERTURBATIVE $N(r) \sim g^2 r^2 E^2$

REACHES UNITY FOR $r_s^2 = Q_S^{-2} \sim (gE)^{-2}$

**ALSO WE KNOW THAT THE GLUON DISTRIBUTION IN THE TARGET IS CUTOFF BELOW MOMENTA $P_T \sim Q_S$. THUS COLOR ELECTRIC FIELDS ARE NOT LONG RANGE, BUT MUST BE DOMINATED BY WAVELENGTHS $\lambda \sim Q_S^{-1}$.**

WHEN THINK ABOUT TARGET - THINK THIS

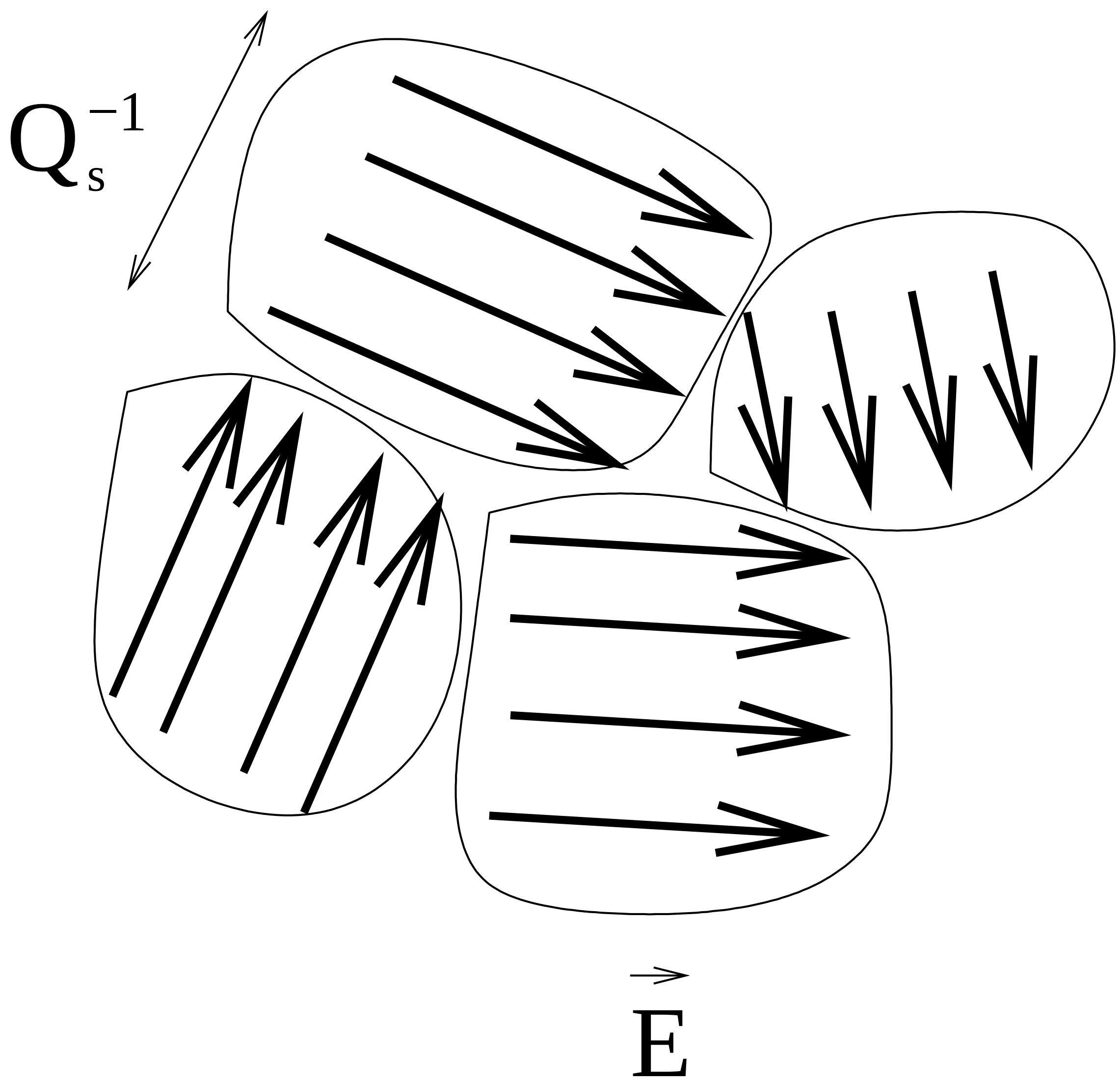


Figure 2: CARTOON OF A TYPICAL FIELD CONFIGURATION IN A SATURATED TARGET.

# CHOICE OF FRAME

LAB FRAME IS GOOD FOR EIKONAL THINKING -

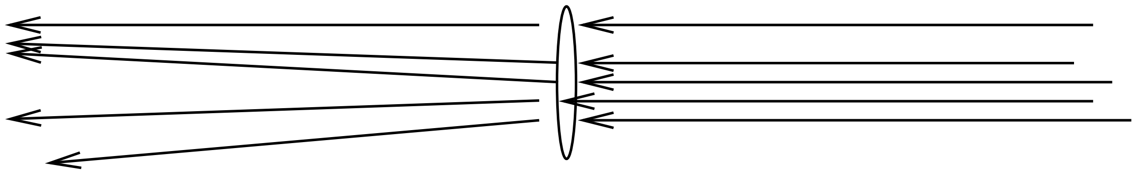


Figure 3: COLLISION IN LAB FRAME - EIKONAL OK.

PARTONS SCATTER EVER SO SLIGHTLY - $P^+ \gg P_T$ - EIKONAL APPROXIMATION IS OK

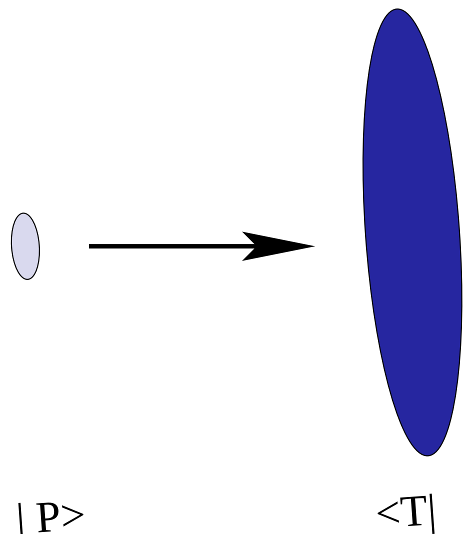


Figure 4: PARTONIC EIKONAL SCATTERING

PARTONS OF THE PROJECTILE SCATTER OFF THE FIELDS OF THE TARGET.

PROJECTILE CARRIES COLOR CHARGE DENSITY $\rho^a(x)$.

IN THE LAB FRAME THE SCATTERING EVENT IS DESCRIBED AS A BUNCH OF INCOMING GLUONS THAT SCATTER ON A GIVEN CONFIGURATION OF THE TARGET FIELDS.

WE NEGLECT REINTERACTIONS OF SCATTERED GLUONS, SO FOR NUCLEUS-NUCLEUS IS MOST LIKELY NOT VALID!

# NAIVE PICTURE OF EIKONAL GLUON PRODUCTION

LONG RANGE RAPIDITY CORRELATIONS COME FOR FREE WITH BOOST INVARIANCE

INCOMING $|P>$ IS BOOST INVARIANT: EXACTLY THE SAME GLUON DISTRIBUTIONS AT $\eta_1$ AND $\eta_2$. AND THEY SCATTER ON EXACTLY THE SAME TARGET

**WHAT HAPPENS AT $\eta_1$, HAPPENS ALSO AT $\eta_2$**

TRUE **CONFIGURATION BY CONFIGURATION** IF THERE IS A "'CLASSICAL"' AVERAGE FIELD IN THE PROJECTILE - FLUCTUATIONS ARE SMALL. BUT EVEN OTHERWISE ONE CERTAINLY EXPECTS SOME LONG RANGE CORRELATIONS IN RAPIDITY.

IF IT IS PROBABLE TO PRODUCE A GLUON AT $\eta_1$, IT IS ALSO PROBABLE TO PRODUCE GLUON AT $\eta_2$

BUT EXACTLY BY THE SAME LOGIC THERE MUST BE ANGULAR CORRELATIONS:

IF THE FIRST GLUON IS MOST LIKELY TO BE SCATTERED TO THE RIGHT, THE SECOND GLUON **AT THE SAME IMPACT PARAMETER** WILL BE ALSO SCATTERED TO THE RIGHT

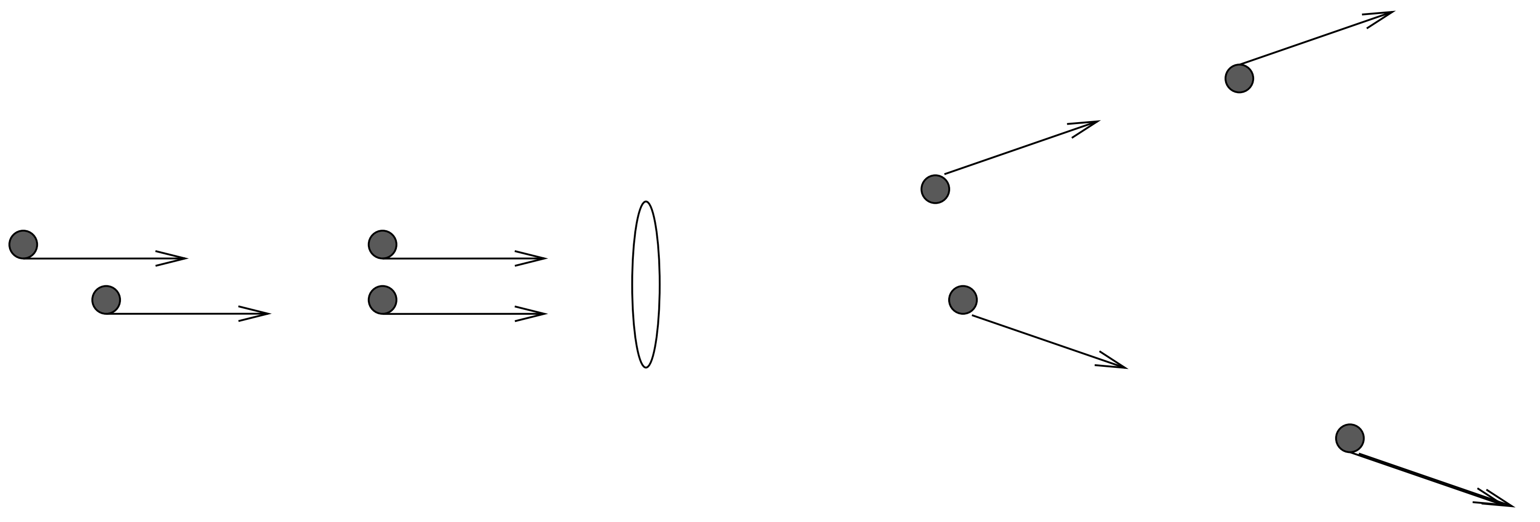

Figure 5: SAME IMPACT PARAMETER - SAME KICK

IN TERMS OF THE DOMAIN TYPE CARTOON OF THE TARGET, THE PARTON WITH CHARGE q THAT HITS AT AN IMPACT PARAMETER $x$ PICKS UP A MOMENTUM

$$\Delta \vec{P}_T = gq \int dx^+ \vec{F}^- = gq\vec{E}(x)$$

THE NEXT PARTON (AT ANOTHER RAPIDITY) PICKS UP EXACTLY THE SAME MOMENTUM, IF IT HAS THE SAME CHARGE $q$.

SINCE THE INCOMING WAVE FUNCTION IS BOOST INVARIANT, THE TWO PARTONS VERY LIKELY WILL HAVE THE SAME CHARGE $q$.

**CAN WE EASILY SEE IT IN THE ACTUAL GLUON PRODUCTION FORMULAE?**

# TWO GLUON INCLUSIVE PRODUCTION

WE NEGLECT THE EVOLUTION BETWEEN THE TWO PRODUCED GLUONS

AND ALSO ASSUME DILUTE PROJECTILE

(almost Bayer, A.K, Nardi, Wiedemann 2005)

$$\frac{dN}{d^2p\,d^2k\,d\eta\,d\xi} = < A^{ab}(k,p)A^{*ab}(k,p) >_{P,T}$$

WITH

$$A^{ab}(k,p) = \int_{u,z} e^{ikz+ipu}$$

$$\int_{x_1,x_2} \Big\{ g f_i(z-x_1)\,[S(x_1) - S(z)]^{ac}\,\rho^c(x_1) \Big\} \Big\{ g f_j(u-x_2)\,[S(u) - S(x_2)]^{bd}\,\rho^d(x_2) \Big\}$$

$$-\frac{g}{2}\int_{x_1} f_i(z-x_1) f_j(u-x_1) \Big\{ [S(x_1) - S(z)]\,\bar{\rho}(x_1) \Big[ S^\dagger(u) + S^\dagger(x_1) \Big] \Big\}^{ab}$$

$$+g\int_{x_1} f_i(z-u) f_j(u-x_1) \Big\{ (S(z) - S(u))\,\bar{\rho}(x_1) S^\dagger(u) \Big\}^{ab} .$$

HERE

$$\bar{\rho} \equiv T^a \rho^a, \qquad f_i(x-y) = \frac{(x-y)_i}{(x-y)^2}$$

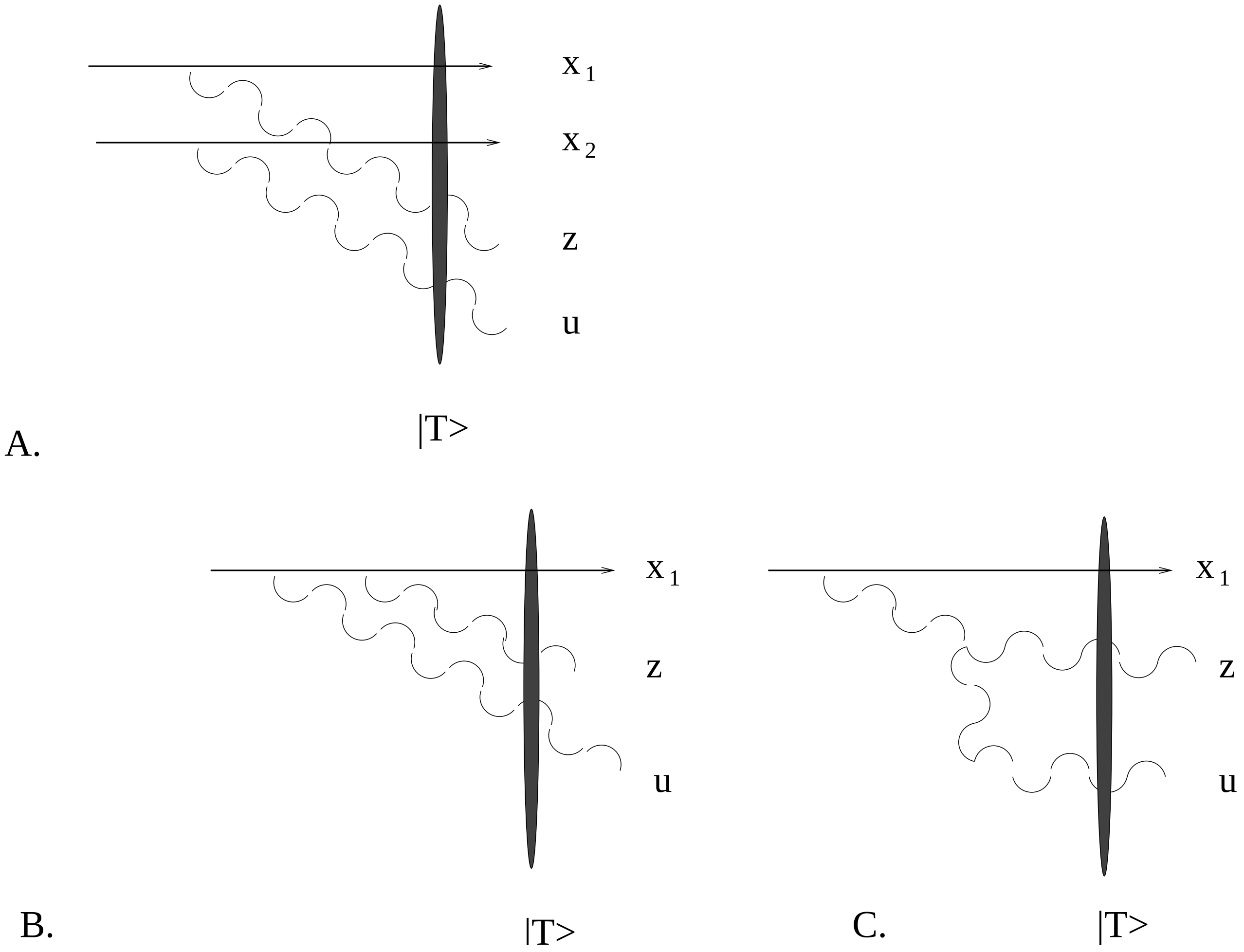


Figure 6: THE THREE CONTRIBUTION TO PRODUCTION AMPLITUDE.

**A.** IS LEADING IN THE LARGE FIELD LIMIT $\rho \propto \frac{1}{g}$. IT IS INDEPENDENT EMISSION OF THE TWO GLUONS BY TWO COLOR CHARGES TWO POMERONS

**B.** IS THE EMISSION OF THE TWO GLUONS FROM THE SAME VALENCE

SOURCE

C. IS EMISSION OF THE GLUON AT $u$ WHICH SUBSEQUENTLY EMITS THE GLUON AT $z$

THESE CORRESPOND TO TWO GLUON PRODUCTION FROM A SINGLE POMERON AND ARE NOT RELEVANT TO THE PRESENT DISCUSSION.

SQUARING THE AMPLITUDE OF COURSE LEADS TO ZILLIONS OF TERMS -

WE WILL ONLY LOOK EXPLICITLY AT THE PRODUCTION FROM TWO POMERONS

$$\sigma^4 = \int_{z,\bar{z},u,\bar{u},x_1,\bar{x}_1,x_2\bar{x}_2} e^{ik(z-\bar{z})+ip(u-\bar{u})} \alpha_s^2 \vec{f}(\bar{z}-\bar{x}_1)\cdot\vec{f}(x_1-z)\,\vec{f}(\bar{u}-\bar{x}_2)\cdot\vec{f}(x_2-u)$$

$$\times \left\{\rho(x_1)[S^\dagger(x_1)-S^\dagger(z)][S(\bar{x}_1)-S(z)]\rho(\bar{x}_1)\right\}\left\{\rho(x_2)[S^\dagger(u)-S^\dagger(x_2)][S(\bar{u})-S(\bar{x}_2)\rho(\bar{x}_2)\right\}$$

# ROBUST CORRELATION

$$\sigma^4 = \langle \sigma_1(k)\sigma_1(p) >$$

CONFIGURATION BY CONFIGURATION (FOR FIXED CONFIGURATION OF PROJECTILE CHARGES $\rho$ AND FIXED TARGET FIELDS $S$)

$$\sigma_1(k) = \int_{z,\bar{z},x_1,\bar{x}_1} e^{ik(z-\bar{z})}\alpha_s \vec{f}(\bar{z}-\bar{x}_1)\cdot\vec{f}(x_1-z)\ \left\{\rho(x_1)[S^\dagger(x_1) - S^\dagger(z)][S(\bar{x}_1) - S(z)]\rho(\bar{x}_1)\right\}$$

$\sigma_1(k)$ IS A SINGLE GLUON EMISSION PROBABILITY FOR A **GIVEN** CONFIGURATION OF COLOR CHARGES IN THE PROJECTILE AND A **GIVEN** CONFIGURATION OF TARGET FIELDS

$\sigma_1(k)$ IS A NONTRIVIAL REAL FUNCTION OF $k$, WHICH HAS A MAXIMUM AT SOME VALUE $k = q_0$. CLEARLY THEN THE TWO GLUON PRODUCTION PROBABILITY CONFIGURATION BY CONFIGURATION HAS A MAXIMUM AT

$$k = p = q_0$$

THE VALUE OF $q_0$ DEPENDS ON CONFIGURATION, BUT THE FACT THAT $k$ AND $p$ ARE THE SAME DOES NOT.

IS THE MAXIMUM OF $\sigma_1$ UNIQUE?

$$\sigma_1(k) = a(k)a^*(k) = a(k)a(-k)$$

$$a(k) = \int_{z,x_1,} e^{ikz} g\vec{f}(x_1 - z)\,[S(x_1) - S(z)]\rho(x_1)$$

THUS $\sigma_1$ IS SYMMETRIC UNDER $k \to -k$ AND IS DOUBLY DEGENERATE - WITH MAXIMA AT $q_0$ AND $-q_0$

THIS MEANS THAT $\sigma^4$ HAS A SYMMETRY $k, p \to -k, p$ AND THEREFORE **HAS MAXIMA AT TWO RELATIVE ANGLES** $\phi = 0$ **AND** $\phi = \pi$

THE MAXIMUM AT $\phi = \pi$ IS OF COURSE VERY DIFFICULT TO DISTINGUISH EXPERIMENTALLY

**PS:** DEGENERACY IS EASY TO UNDERSTAND IN OUR SIMPLE PICTURE.

THE FIELDS ARE COLORED AND THE PARTONS ARE GLUONS - ALSO COLORED.

SUPPOSE THE TARGET ELECTRIC FIELD IS IN THE THIRD DIRECTION IN COLOR SPACE, $E_i^3$; AND INCOMING GLUON FIELD HAS INDEX $1$, $b_i^1$.

WITH RESPECT TO THE THIRD DIRECTION SUCH A GLUON FIELD HAS EQUAL NUMBER OF POSITIVELY AND NEGATIVELY CHARGED PARTONS $W_1 = W^+ + W^-$.

THUS PROBABILITY TO BE SCATTERED PARALLEL AND ANTIPARALLEL TO THE FIELD ARE EQUAL, DUR TO REALITY OF THE ADJOINT REPRESENTATION.

THE DEGENERACY THUS DOES NOT HOLD FOR QUARKS, AND ONE EXPECTS SHARPER CORRELATION AT VANISHING AZYMUTHAL ANGLE.

# WHAT ABOUT "NONCLASSICAL" TERMS?

FIRST OFF, THERE IS NO ANGULAR DEGENERACY

THE AMPLITUDE DOES NOT FACTORIZE, SO ITS REALITY MEANS ONLY PARITY SYMMETRY $k, p \to -k, -p$

IS THERE POSITIVE CORRELATION AT $\phi = 0$?

$$A_{u \text{ emits } z} = g \int_{x_1} f_i(z-u) f_j(u-x_1) \left\{ (S(z) - S(u)) \, \bar{\rho}(x_1) S^\dagger(u) \right\}^{ab}$$

FOR $z$ TO DECOHERE FROM $u$, AND THEREFORE BE EMITTED, THE TWO GLUONS MUST PREFERRABLY HIT AT DIFFERENT IMPACT PARAMETERS. WHEN EMITTED AT THE SAME IMPACT PARAMETER THE TWO GLUONS WILL HAVE OPPOSITE TRANSVERSE MOMENTA DUE TO CORRELATIONS IN THE INITITAL STATE - LARGE AWAY SIDE RAPIDITY INDEPENDENT MAXIMUM AT $\Delta\phi = \pi$

$$A_{x \text{ emits } u \text{ and } z} = -\frac{g}{2}\int_{x_1} f_i(z-x_1) f_j(u-x_1) \Big\{ \left[S(x_1) - S(z)\right] \bar{\rho}(x_1) \left[S^\dagger(u) + S^\dagger(x_1)\right] \Big\}^{ab}$$

HERE $z$ HAS TO HIT FAR FROM $x$, BUT $u$ LIKES TO BE CLOSE TO $x$ IN FACT THIS TERM PROBABLY PRODUCES ONE GLUON AT RELATIVELY LARGE $p_T$ - GREATER THAN $q_s$ WITH THE BALANCING MOMENTUM APPEARING AT MORE FORWARD RAPIDITY

# HOW BIG IS THE EFFECT?

TRANSVERSE CORRELATION LENGTH IN THE HADRON $L = \frac{1}{Q_s}$

TO BE CORRELATED THE TWO GLUONS HAVE TO BE IN THE SAME INCOMING STATE AND HAVE TO SCATTER OF THE SAME TARGET FIELD HAVE TO SIT WITHIN $\Delta X < L_{min}$ OF EACH OTHER.

THE CORRELATED PRODUCTION $\propto S/Q_s^2$,

WHILE THE TOTAL MULTIPLICITY $\propto S$

$$\left[\frac{d^2N}{d^2pd^2k} - \frac{dN}{d^2k}\frac{dN}{d^2p}\right] / \frac{dN}{d^2k}\frac{dN}{d^2p} \sim \frac{1}{(Q_s^{max})^2 S_{min}}\,.$$

# IS IT $N_c$ SUPPRESSED?

SUPPOSE WE ASSUME FACTORIZATION (AS THE BNL GROUP DOES).

AT LARGE $N_c$ THE LEADING CONTRIBUTION IS WHEN THE CHARGE DENSITIES ARE PAIRWISE IN COLOR SINGLETS. HAVE TO AVERAGE OVER THE PROJECTILE AND TARGET WAVE FUNCTIONS

$$\langle\rho^a(x_1)\rho^a(\bar{x}_1)\rho^b(x_2)\rho^b(\bar{x}_2)\rangle_P$$

$$\times\langle\mathrm{Tr}\left\{[S^\dagger(x_1)-S^\dagger(z)][S(\bar{x}_1)-S(\bar{z})]\right\}\mathrm{Tr}\left\{[S^\dagger(x_2)-S^\dagger(u)][S(\bar{x}_2)-S(\bar{u})]\right\}\rangle_T\,.$$

THE SIMPLEST "'PERTURBATIVE"' APPROACH

EXPAND ALL $S=1+\alpha$ ; KEEP ONLY LEADING TERM

$$N\propto\{\rho\alpha\alpha\rho\}(k)\{\rho\alpha\alpha\rho\}(p)$$

NOW AVERAGE WITH GAUSSIAN WEIGHTS

$$<\rho\rho\rho\rho>=3<\rho\rho><\rho\rho>;\qquad <\alpha\alpha\alpha\alpha>=3<\alpha\alpha><\alpha\alpha>$$

TAKE $<\rho\rho>=\Phi_{BK}$ AND THE SAME FOR $<\alpha\alpha>$ GIVES

$$N \propto 9\Phi^P_{BK}\Phi^P_{BK}\Phi^T_{BK}\Phi^T_{BK}$$

WITH GAUSSIAN AVERAGING

$$\langle\rho^a(x_1)\rho^a(\bar{x}_1)\rho^b(x_2)\rho^b(\bar{x}_2)\rangle_{Gauss\ and\ leading\ N_c} = \langle\rho^a(x_1)\rho^a(\bar{x}_1)\rangle_{Gauss}\langle\rho^b(x_2)\rho^b(\bar{x}_2)\rangle_{Gauss}\,.$$

AND THE SAME FACTORIZATION FOR THE TARGET AVERAGES OF $S$'s

AND SO

$$\frac{d^2N}{d^2p\,d^2k} = \frac{dN}{d^2k}\frac{dN}{d^2p}$$

WITHIN GAUSSIAN (FACTORIZABLE) APPROXIMATION CORRELATIONS ARE SUBLEADING IN $1/N_c$

BUT IT DOES NOT HAVE TO BE LIKE THIS!

WHEN IS FACTORIZABLE AVERAGING GOOD? WHEN THE POINTS ARE FAR AWAY IN SPACE

$$\langle \rho^a(x_1)\rho^a(\bar{x}_1)\rho^b(x_2)\rho^b(\bar{x}_2)\rangle$$

IF $(x_1, \bar{x}_1)$ IS FAR FROM $(x_2, \bar{x}_2)$ THEY DON'T KNOW ABOUT EACH OTHER AND THE AVERAGE FACTORIZES.

BUT WE ARE INTERESTED PRECISELY IN THE OPPOSITE SITUATION - WHEN ALL FOUR POINTS ARE WITHIN THE CORRELATION LENGTH, AND THEREFORE WE ARE SAMPLING CONFIGURATIONS WHICH AT ALL POINTS ARE SIMILAR

FACTORIZABILITY IS NOT AN INHERENT PROPERTY OF THE LARGE $N$ LIMIT. E.G. FOR "DIPOLE DENSITY"

$$n(x_1,\bar{x}_1)=\left(\rho^a(x_1)-\rho^a(\bar{x}_1)\right)^2.$$

IN BFKL EVOLVED WAVE FUNCTION OF A SINGLE DIPOLE (PARENT DIPOLE LARGER THAN DAUGHTERS)

$$\langle n(x_1,\bar{x}_1)n(x_2,\bar{x}_2)\rangle-\langle n(x_1,\bar{x}_1)\rangle\langle n(x_2,\bar{x}_2)\rangle\sim\langle n(x_1,\bar{x}_1)\rangle\langle n(x_2,\bar{x}_2)\rangle\left(\frac{b}{x}\right)^{-\lambda}$$

THERE IS NO REASON AT ALL TO BELIEVE THAT THE AVERAGES FACTORIZE. THUS VERY LIKELY THERE IS A CONTRIBUTION TO THE CORRELATED PRODUCTION ALREADY IN THE LEADING ORDER IN LARGE $N_C$

# EXPLORING CORRELATIONS

WE TRIED TO EXPLORE THE ANGULAR CORRELATIONS WITHIN THE "'PROJECTILE"' DIPOLE MODEL.

LEADING $N_C \to$ "'DIPOLE MODEL"'

**PROJECTILE DIPOLE MODEL OR TARGET DIPOLE MODEL?**

**A.** PROJECTILE DIPOLE MODEL - PROJECTILE WAVE FUNCTION IS APPROXIMATED IN THE LRGE $N_C$ LIMIT - EVOLVES ACCORDING TO DIPOLE MODEL.

**CORRESPONDS TO THE TARGET EVOLUTION ACCORDING TO THE LARGE $N_C$ LIMIT OF JIMWLK.**

**B.** TARGET DIPOLE MODEL - THE TARGET IS DILUTE AND EVOLVES ACCORDING TO THE DIPOLE MODEL.

# PROJECTILE DIPOLE MODEL EVOLUTION

START WITH A DISTRIBUTION OF SCATTERING AMPLITUDES WHICH CONTAINS CORRELATIONS, AND EVOLVE ACCORDING TO THE PROJECTILE DIPOLE MODEL.

$$\frac{d}{dY}W[s] = \frac{\bar{\alpha}_s}{2\,\pi}\int_{x,y,z}\frac{(x-y)^2}{(x-z)^2\,(z-y)^2}\,[\,s(x,\,y)\;-\;s(x,z)\,s(y,z)\,]\,\frac{\delta}{\delta s(x,y)}W[s]$$

EQUIVALENTLY;

$$\int Ds W_Y[s]s(x,y)s(u,v) = \int Ds W_0[s]s_Y(x,y)s_Y(u,v)$$

WHERE $s(x,y)$ SATISFIES BK EQUATION.

**Q: WHAT WILL HAPPEN?**

ENSEMBLE OF INITIAL CONFIGURATIONS:

$$N(Y_0, \vec{r}) \;=\; 1 - Exp\Big\{ -a\, r^2\, xg^{LOCTEQ6}(x_0, 4/r^2)\, F(\theta) \Big\}; \qquad a \;=\; \frac{\alpha_s(r^2)\,\pi}{2\,N_c\,R^2}$$

WITH

$$F(\theta) \;=\; \frac{1}{4} + \frac{3}{2}\, cos^2(\theta)$$

"'ALMOST"' INTERACTION WITH A COLOR FIELD IN A FIXED DIRECTION IN SPACE. THEN AVERAGE OVER THE ANGLE WITH CONSTANT MEASURE.

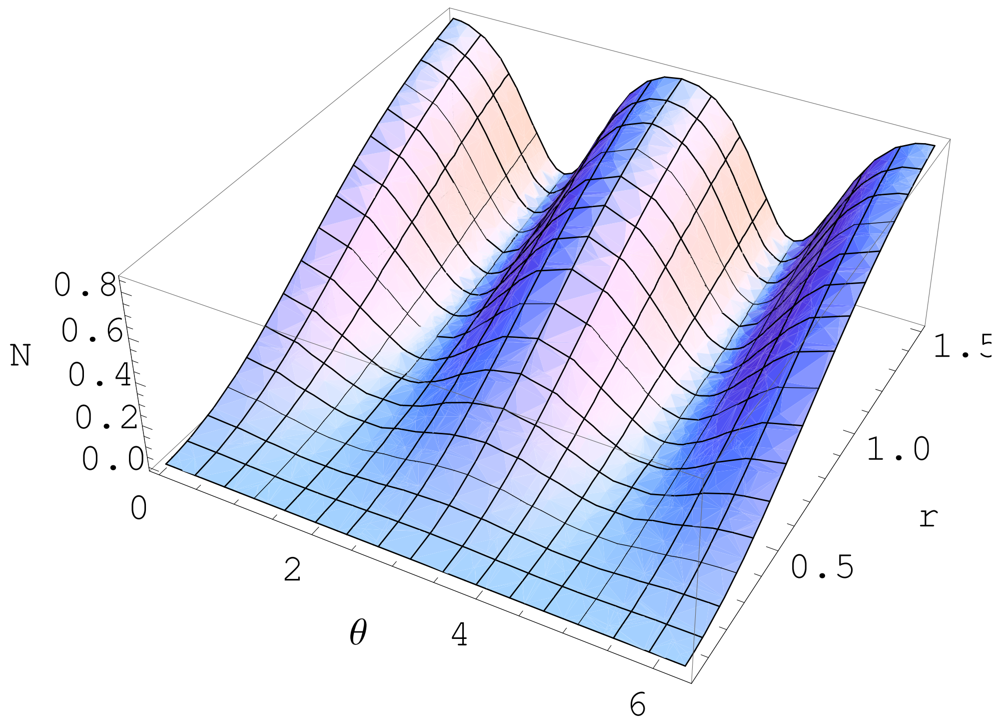


Figure 7: INITIAL AMPLITUDE.

## THE ANGULAR DEPENDENCE DISAPPEARS VERY QUICKLY

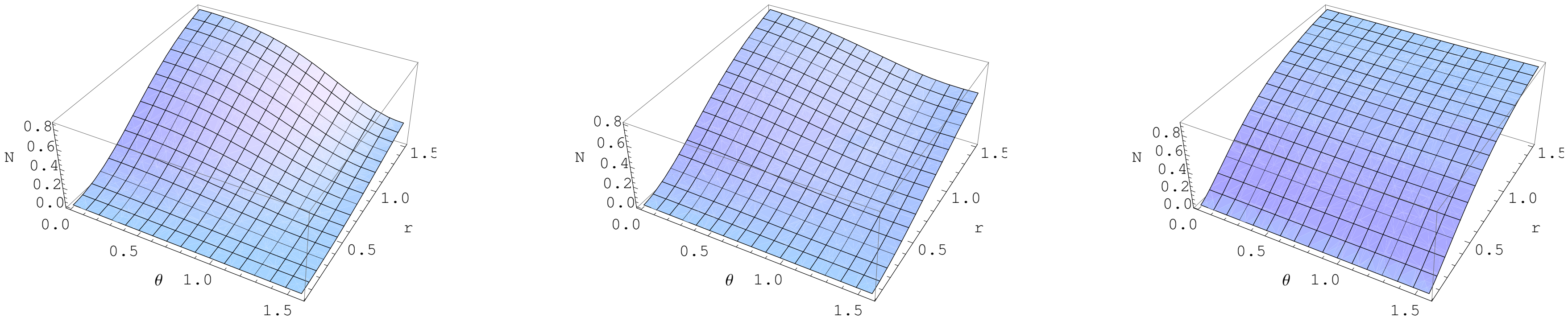


Table 1: $N$ as a function of $r$ and $\theta$ at various values of rapidity: $Y = Y_0$, $Y = 6$, $Y = 10$

## E.G. ONE ASYMETRY MEASURE $A(Y,r) \equiv \frac{N(Y,r,0) - N(Y,r,\pi/2)}{N(Y,r,0) + N(Y,r,\pi/2)}$

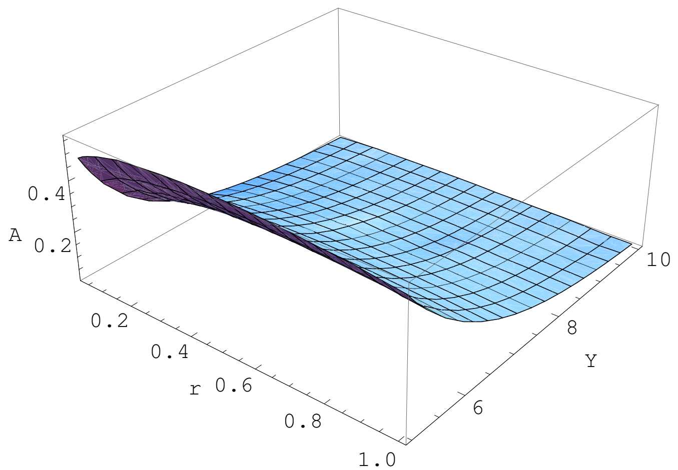


Figure 8: A(Y)

## UNSURPRISINGLY CORRELATIONS ALSO VANISH VERY QUICKLY

$$\Delta_\theta(Y, r, \theta) \equiv \frac{\langle N(Y,r,0)\, N(Y,r,\theta)\rangle - \langle N(Y,r,0)\rangle \langle N(Y,r,\theta)\rangle}{\langle N(Y,r,0)\rangle^2},$$

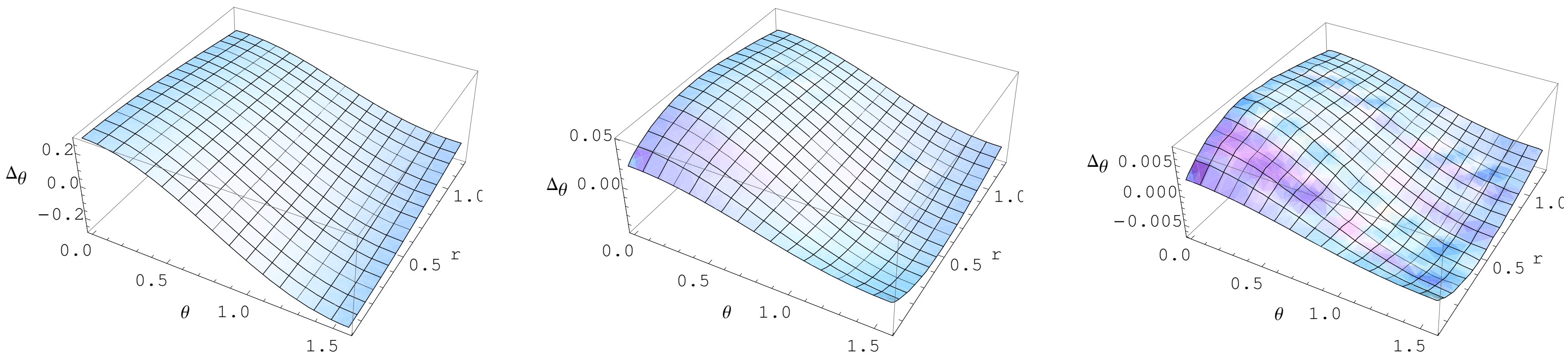


Table 2: Normalized angular correlations $\Delta_\theta$. Left: $Y = Y_0$; Middle: $Y = 6$; Right: $Y = 7.5$

ROUGHLY

$$A(r_{max}) \sim e^{-\lambda_A Y}, \qquad \lambda_A \simeq 0.6$$

$$\Delta_\theta(Y, R_s(Y), \theta) \sim e^{-2\,\lambda_A Y},$$

# AND WHY IS THAT?

WE BELIEVE THE PROBLEM IS WITH JIMWLK/PROJECTILE DIPOLE MODEL.

MULLER-HATA USED THE DIPOLE MODEL FOR TARGET EVOLUTION AND FOUND O(1) CORRELATIONS KLWMIJ

$$g(p,Y) \propto e^{c\alpha_s Y}; \qquad \frac{d}{d\eta} g(p,\eta) \propto e^{c\alpha_s \eta}\theta(Y-\eta)$$

IN THE WAVE FUNCTION MOST GLUONS SIT AT THE SMALLEST RAPIDITY

WHEN CLOSE IN RAPIDITY THE GLUONS ARE CORRELATED. YOU PROBE SUCH WAVE FUNCTION - YOU SEE CORELATIONS.

BUT JIMLWK: GLUON EMISSION AMPLITUDE DOES NOT DEPEND ON DENSITY

$$A \propto \frac{D_i}{D^2} E_i$$

RANDOM WALK - GLUONS IN THE WAVE FUNCTION ARE DISTRIBUTED HOMOGENEOUSLY IN RAPIDITY

$$\frac{d}{d\eta} g(p, \eta) = C \, .$$

PROBE SUCH A WAVE FUNCTION WITH TWO DIPOLES - THEY WILL SCATTER ON GLUON COMPONENTS VERY DIFFERENT IN RAPIDITY, AND NO CORRELATIONS ARE SEEN.

**KLWMIJ PRESERVES CORRELATIONS, BUT JIMLWK DOES NOT!**

BUT WHAT DO WE NEED? WE NEED TO PROBE ADJACENT IMPACT PARAMETERS - SO TRANSVERSE MOMENTA ABOVE $Q_S$ - SO KLWMIJ.

BUT WAIT! REALLY WE NEED TO PROBE SCALES JUST AROUND $Q_S$ - THESE DISTANCES WILL DOMINATE CORRELATED EMISSION.

IT MEANS CORRELATED EMISSION PROBES SCALES AT WHICH KLWMIJ AND JIMLWK ARE EQUALLY IMPORTANT, AND NEITHER DOMINATES.

**FOR BETTER OR WORSE WE NEED POMERON LOOPS!**

# CONCLUSIONS

GLUON PRODUCTION AT HIGH ENERGY LEADS NATURALLY TO RAPIDITY CORRELATIONS (TRIVIALLY) AND ANGULAR CORRELATIONS (A LITTLE LESS TRIVIALLY). THERE JUST HAVE TO BE MANY GLUONS SO THAT MORE THAN ONE IS PRODUCED AT FIXED IMPACT PARAMETER (WITHIN $\Delta b \sim \frac{1}{Qs}$ (- HOT SPOTS, HIGH MILTIPLICITY EVENTS?))

CORRELATIONS EXIST CONFIGURATION BY CONFIGURATION AND THEREFORE GAUSSIAN AVERAGING VERY LIKELY UNDERESTIMATES THEM.

WE HAVE TO UNDERSTAND HOW TO EVOLVE IN RAPIDITY OBJECTS MORE COMPLICATED THAN "DIPOLES" - AND WE ALSO NEED TO INCLUDE POMERON LOOPS IN THE EVOLUTION - THEY GIVE THE LEADING EFFECT.

"'CLASSICAL"' TERM LEADS TO THE STRONGEST CORRELATIONS - THUS THE CORRELATIONS SHOULD BE STRONGEST FOR NUCLEUS PROJECTILE WHERE IT DOMINATES. ON THE OTHER HAND EFFECT BECOMES WEAKER WITH INCREASING $Q_S$. SO MAYBE ACTUALLY THE OTHER WAY ROUND - IT IS STRONGEST FOR $p - p$ IN A LIMITED RANGE OF ENERGIES?