ANGULAR CORRELATIONS IN GLUON EMISSION AT HIGH ENERGY.

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with Misha Lublinsky (arXiv:1012.3398) and (arXiv:1109.0347)

"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

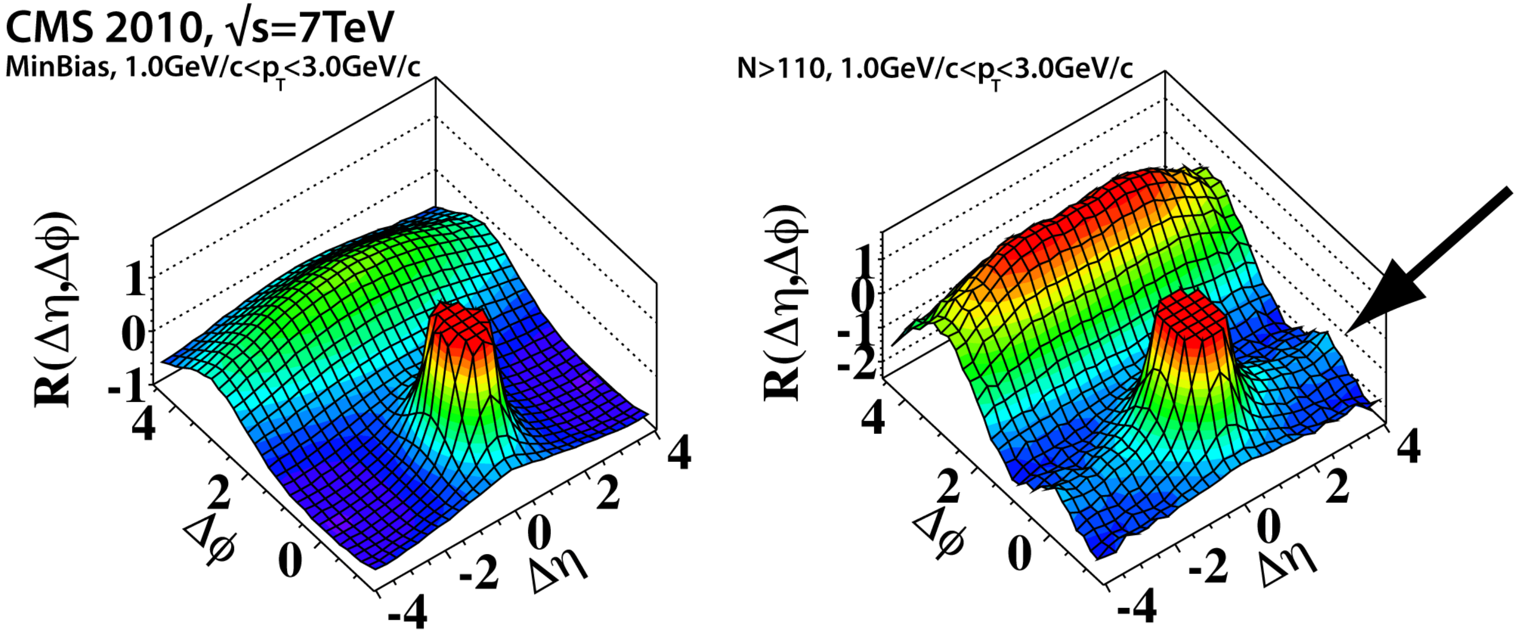


Figure 1: THE CMS RIDGE.

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 - FINAL STATE INTERACTIONS CAN GENERATE RADIAL FLOW WHICH PRODUCES ANGULAR CORRELATIONS INDEPENDENT FROM THOSE IN THE INITIAL STATE.

HERE - NO FINAL STATE, ONLY PERTINENT TO THE CMS MEASUREMENTS.

AN ONGOING CALCULATIONAL EFFORT TO DESCRIBE THE CMS CORRELATION QUANTITATIVELY.

HERE - A QUALITATIVE DISCUSSION OF PHYSICS WHICH NEEDS TO BE HANDLED BETTER IN ORDER FOR THE CALCULATIONS TO BE RELIABLE.

DUMITRU, DUSLING, GELIS, JALILIAN-MARIAN, LAPPI, VENUGOPALAN - arXiv:1009.5295; DUSLING, VENUGOPALAN- arXiv:1201.2658 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.

FRAMEWORK - SATURATION, 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. AVERAGE VALUE OF COLOR ELECTRIC FIELDS IN THE WAVE FUNCTION.

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

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 SIZES - 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

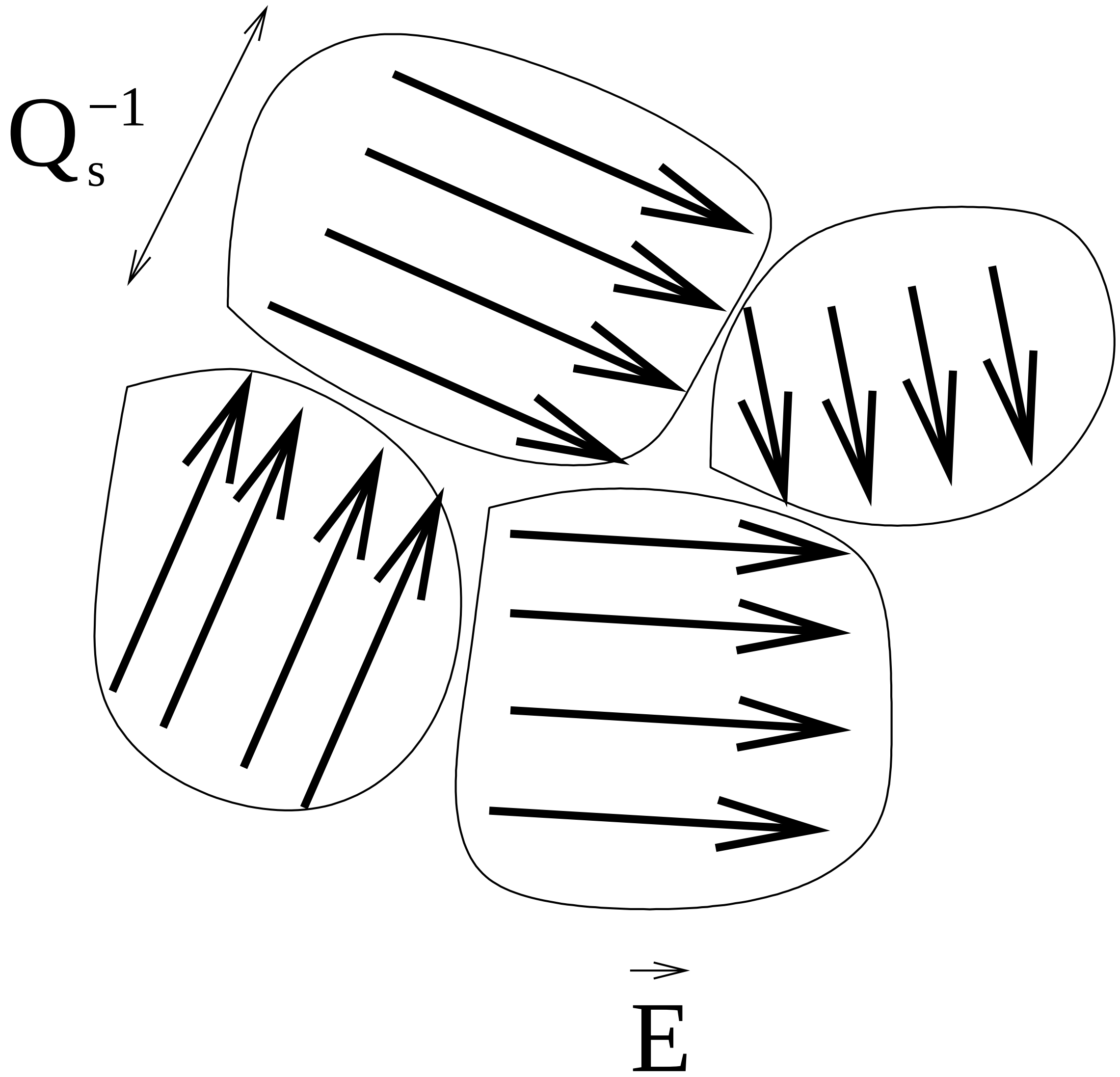


Figure 2: CARTOON OF A TYPICAL FIELD CONFIGURATION IN A SATURATED TARGET.

EIKONAL SCATTERING

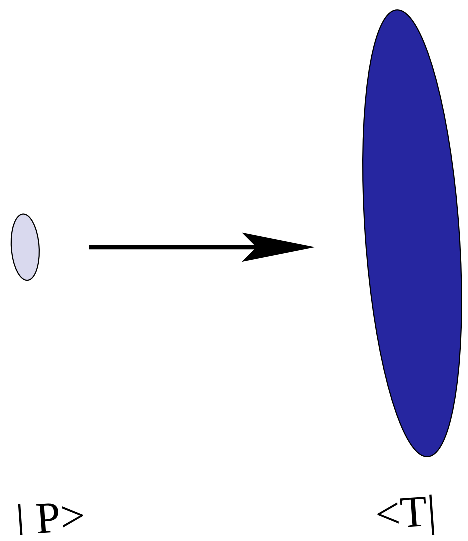


Figure 3: PARTONIC EIKONAL SCATTERING

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.

REINTERACTIONS OF SCATTERED GLUONS ARE NEGLECTED.

NAIVE PICTURE OF EIKONAL GLUON PRODUCTION

LONG RANGE RAPIDITY CORRELATIONS COME ALMOST FOR FREE WITH BOOST INVARIANCE

INCOMING $|P>$ IS BOOST INVARIANT: EXACTLY THE SAME GLUON DISTRIBUTIONS AT η_1 AND η_2. AND THEY SCATTER ON EXACTLY THE SAME TARGET

WHAT HAPPENS AT η_1, HAPPENS ALSO AT η_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 η_1, IT IS ALSO PROBABLE TO PRODUCE GLUON AT η_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

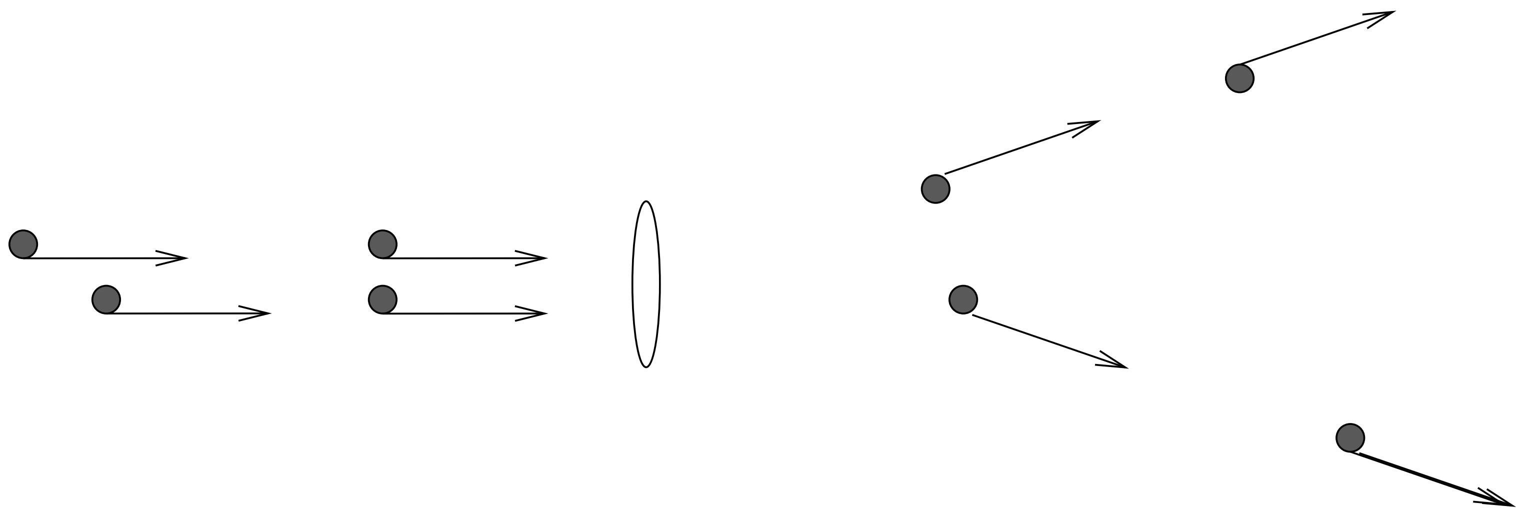


Figure 4: SAME IMPACT PARAMETER - SAME KICK

THE DOMAIN CARTOON - A PARTON WITH CHARGE q HITS AT AN IMPACT PARAMETER x AND PICKS UP A MOMENTUM

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

THE NEXT PARTON (AT A DIFFERENT RAPIDITY) PICKS UP EXACTLY THE SAME MOMENTUM, IF IT HAS THE SAME CHARGE q AND HITS AT THE SAME IMPACT PARAMETER (WITHIN THE SAME DOMAIN).

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

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

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

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

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

HERE

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

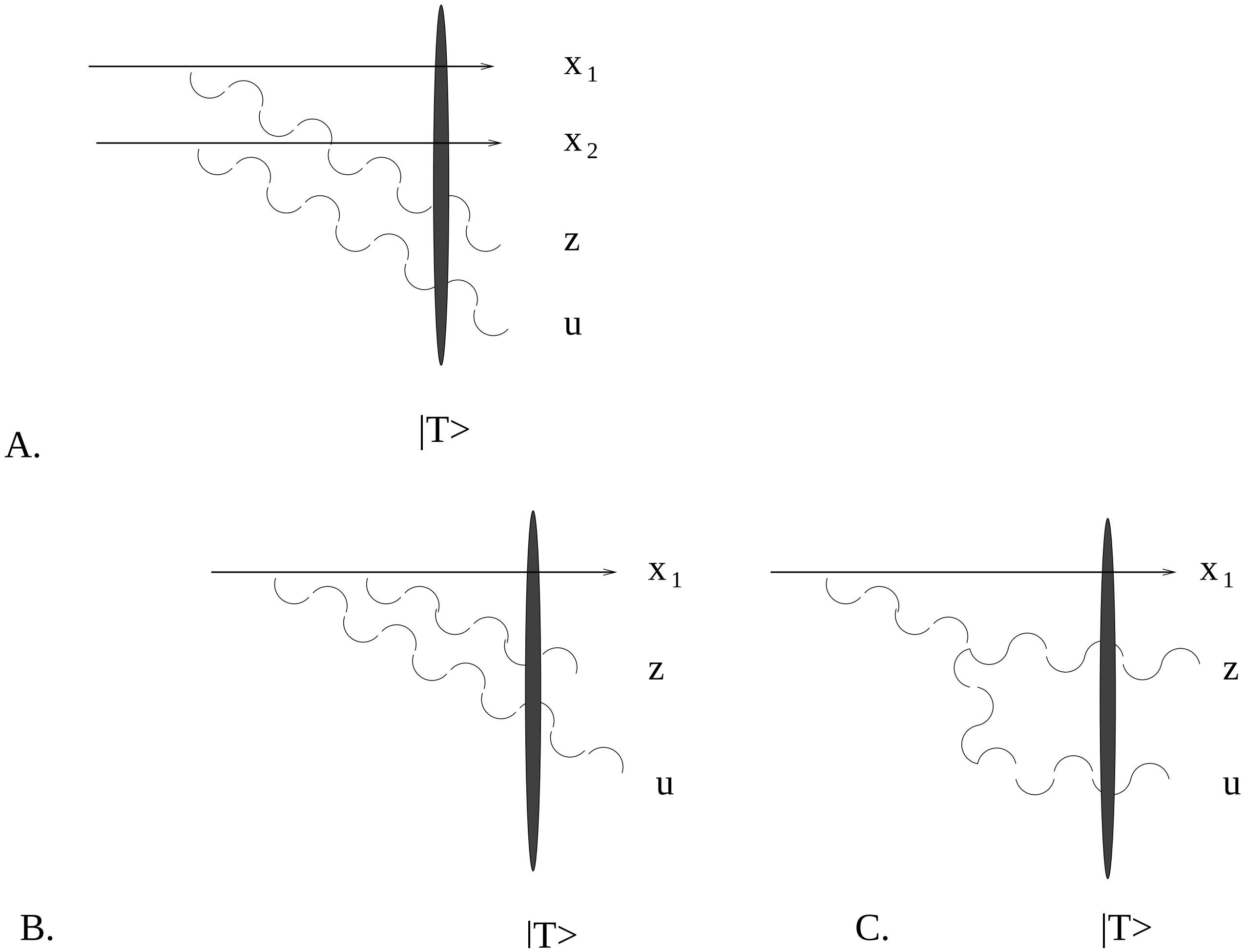


Figure 5: THE THREE CONTRIBUTION TO PRODUCTION AMPLITUDE.

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

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

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

FIRSTLY - ROBUST CORRELATION

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

CONFIGURATION BY CONFIGURATION (FOR FIXED CONFIGURATION OF PROJECTILE CHARGES ρ 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 σ_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 σ_1 IS SYMMETRIC UNDER $k \to -k$ AND IS DOUBLY DEGENERATE - WITH MAXIMA AT q_0 AND $-q_0$

THIS MEANS THAT σ^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 $\propto S$

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

THE EFFECT SEEMS TO DECREASE WITH TOTAL ENERGY, SINCE Q_s GROWS.

BUT WE DON'T KNOW MUCH ABOUT THE CONFIGURATIONS OF PROTON WHICH LEAD TO HIGH MULTIPLICITY EVENTS - IF IT IS ONE SMALL BLACK SPOT $Q_s^2 \sim S$, AND THE EFFECT STAYS ORDER ONE.

IS IT N_c SUPPRESSED?

SUPPOSE WE ASSUME FACTORIZATION (AS IN CURRENT NUMERICAL IMPLEMENTATIONS).

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 OUR INTEREST IS IN THE OPPOSITE SITUATION - WHEN ALL FOUR POINTS ARE WITHIN THE CORRELATION LENGTH, AND THEREFORE WE ARE SAMPLING STRONGLY CORRELATED CONFIGURATIONS

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

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

IN BFKL (DIPOLE MODEL- MUELLER-HATA) THE 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 QCD CONTAINS A CONTRIBUTION TO THE CORRELATED PRODUCTION ALREADY IN THE LEADING ORDER IN LARGE N_C

EXPLORING CORRELATIONS

HOW TO EXPLORE THE ANGULAR CORRELATIONS WITHIN THE DIPOLE MODEL?

WHY DIPOLE MODEL? BECAUSE LEADING $N_C \to$ "DIPOLE MODEL".

BUT PROJECTILE DIPOLES OR TARGET DIPOLES?

A. DIPOLE MODEL FOR THE PROJECTILE $\leftrightarrow$ LARGE N_C JIMWLK FOR THE TARGET

THIS IS WHAT CURRENT CALCULATIONS USE

B. TARGET DIPOLE MODEL - THE TARGET IS DILUTE AND EVOLVES ACCORDING TO THE DIPOLE MODEL- LARGE N_C KLWMIJ.

PROJECTILE DIPOLE MODEL EVOLUTION

PROGRAM: 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:

$$\int DsW_Y[s]s(x,y)s(u,v) = \int DsW_0[s]s_Y(x,y)s_Y(u,v)$$

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

WHAT WILL HAPPEN TO THE CORRELATIONS?

ENSEMBLE OF INITIAL CONFIGURATIONS:

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

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.

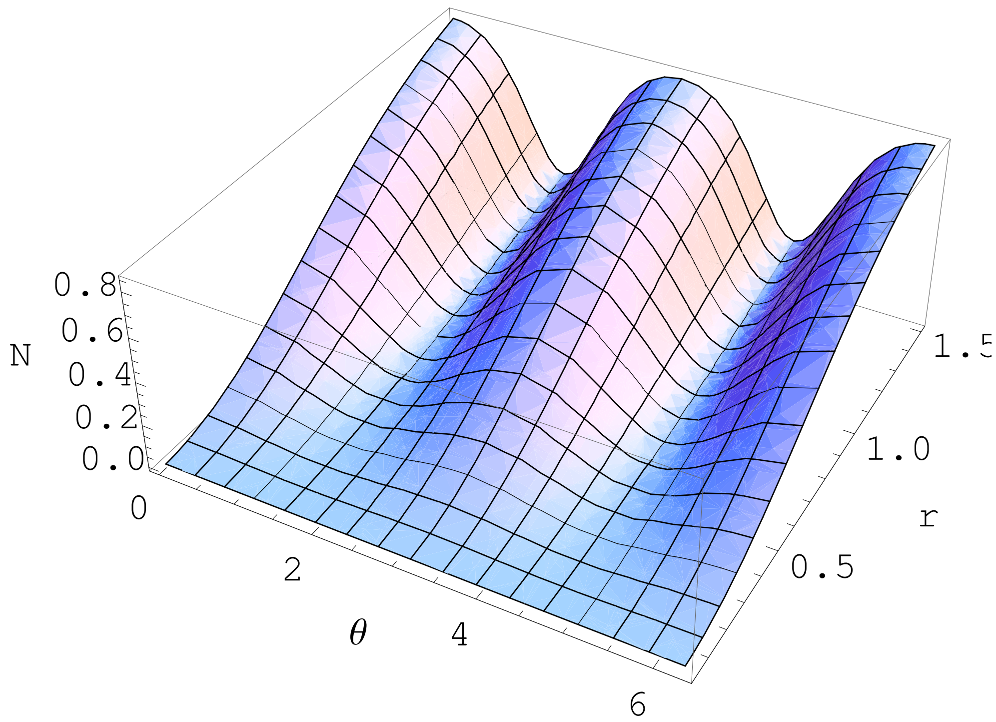


Figure 6: INITIAL AMPLITUDE.

THE ANGULAR DEPENDENCE DISAPPEARS VERY QUICKLY

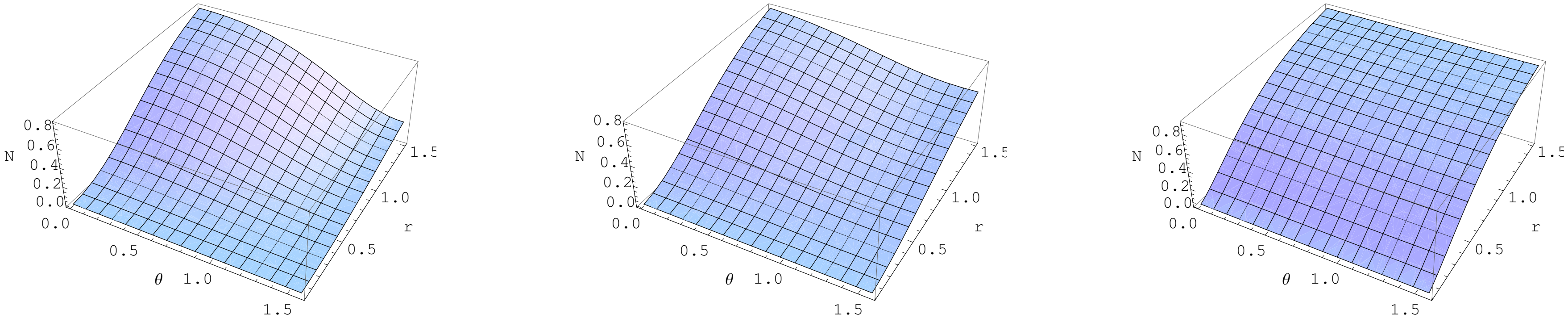


Table 1: N as a function of r and θ at various values of rapidity: $Y = Y_0 = 4.6$, $Y = 6$, $Y = 10$

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

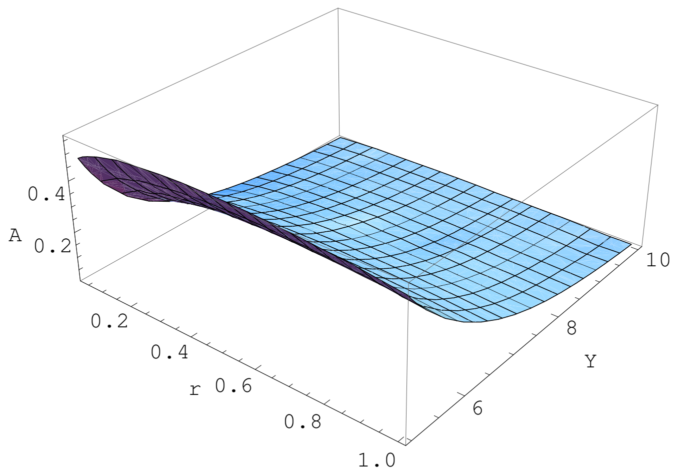
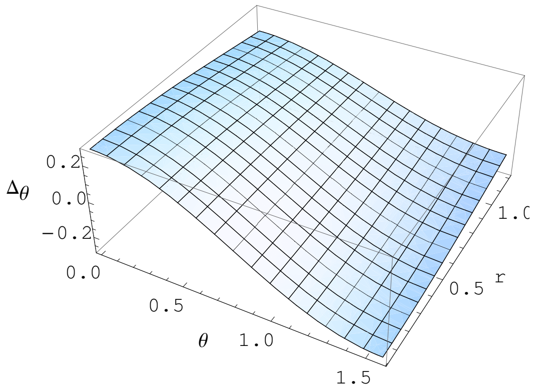
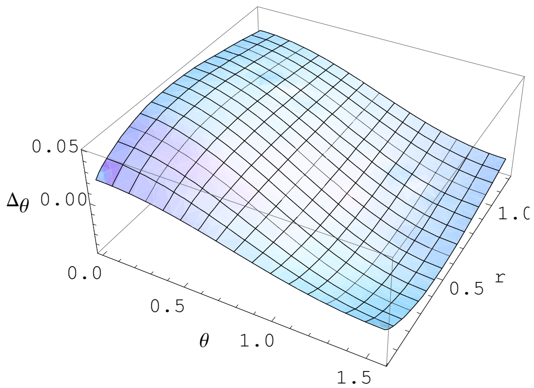


Figure 7: A(Y)

UNSURPRISINGLY CORRELATIONS ALSO VANISH VERY QUICKLY

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





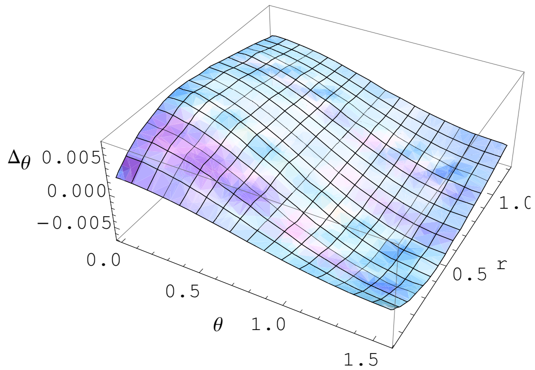


Table 2: Normalized angular correlations Δ_θ. Left: $Y = Y_0$; Middle: $Y = 6$; Right: $Y = 7.5$

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?

DOES THAT MEAN OUR PICTURE WITH CORRELATIONS OF $O(1)$ IS INCORRECT?

WE THINK NOT. THE PROBLEM IS THAT WE MISSED A CRUCIAL ELEMENT (JUST LIKE EVERYBODY ELSE). THE JIMWLK/PROJECTILE DIPOLE MODEL IS INADEQUATE.

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

IN KLWMIJ THIS IS VERY NATURAL. GLUON DENSITY IS EXPONENTIAL:

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

IN THE WAVE FUNCTION MOST GLUONS SIT AT THE SMALLEST RAPIDITY

ONE EXPECTS THE GLUONS WHICH ARE CLOSE IN RAPIDITY TO BE CORRELATED, SINCE IN THE EVOLUTION THEY ARE EMITTED FROM THE SAME SOURCE.

WHEN SUCH A WAVE FUNCTION IS PROBED, CORRELATIONS SHOULD BE STRAIGHTFORWARDLY OBSERVED.

BUT JIMLWK (PROJECTILE DIPOLE MODEL) IS FUNDAMENTALLY DIFFERENT

HERE GLUON EMISSION AMPLITUDE DOES NOT DEPEND ON DENSITY

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

EVOLUTION IS A 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 - THE TWO WILL SCATTER ON GLUON COMPONENTS VERY DIFFERENT IN RAPIDITY, AND NO CORRELATIONS ARE SEEN.

KLWMIJ EVOLUTION PRESERVES (AND, INDEED GENERATES) CORRELATIONS, BUT JIMLWK DOES NOT!

BUT WHICH EVOLUTION IS RELEVANT IN OUR SITUATION? WE NEED TO PROBE ADJACENT IMPACT PARAMETERS - SO TRANSVERSE MOMENTA ABOVE Q_S - SO KLWMIJ?

IF THAT'S THE CASE WE HAVE BEEN BARKING AT THE WRONG TREE WITH OUR NUMERICS - WE USE EVOLUTION EQUATION RELEVANT TO THE DENSE REGIME IN THE TARGET, WHEREAS ACTUALLY WE WANT TO PROBE IT IN THE DILUTE REGIME.

THAT WOULD BE GOOD NEWS - WE WOULD JUST NEED TO EVOLVE THE TARET WITH KLWMIJ, WHICH SHOULD BE DOABLE.

UNFORTUNATELY LIFE IS MORE COMPLICATED. WE REALLY NEED TO PROBE SCALES JUST AROUND Q_S - THESE DISTANCES WILL DOMINATE CORRELATED EMISSION SIMPLY BEACUASE OF THE PHASE SPACE.

IT MEANS THAT CORRELATIONS PROBE SCALES AT WHICH KLWMIJ AND JIMLWK ARE EQUALLY IMPORTANT, AND NEITHER DOMINATES THE EVOLUTION.

IT LOOKS THAT FOR BETTER OR WORSE WE NEED POMERON LOOPS, IF WE WANT TO UNDERSTAND CORRELATIONS QUANTITATIVELY.

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 $\Delta b \sim \frac{1}{Q_s}$ (- 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?