HOW TO BUILD A RIDGE IN pA COLLISIONS.

Alex Kovner

University of Connecticut

THE "RIDGE" IN p-p AND p-A

CMS IN p-p, FOLLOWED BY ALICE, ATLAS, CMS IN p-Pb. - TWO PARTICLE CORRELATIONS IN P-P, LONG RANGE IN RAPIDITY AND PEAKED IN FORWARD DIRECTION - "RIDGE" IN P-P COLLISIONS

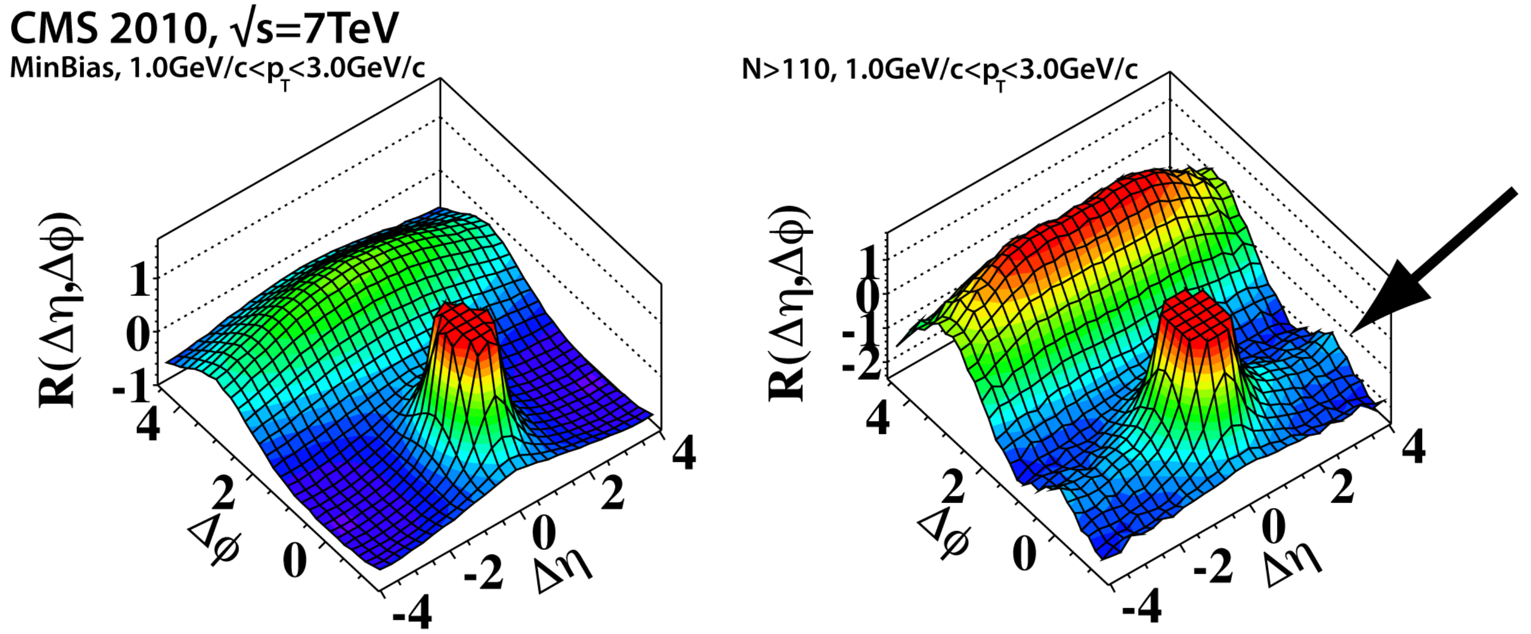


Figure 1: THE CMS p-p RIDGE-ONLY IN HIGH MULTIPLICITY EVENTS $\sim 10^{-5}$.

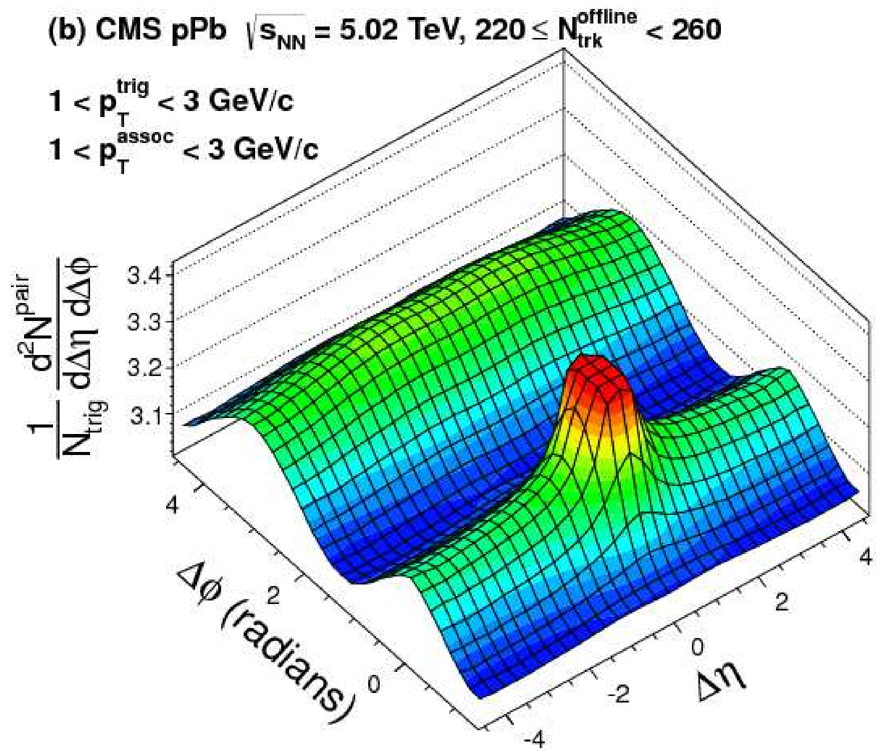


Figure 2: NEW CMS RIDGE

RIDGE IS UBIQUITOUS IN A-A COLLISIONS. MAY HAVE THE SAME NATURE, BUT MAYBE NOT.

INITIAL STATE ("SATURATION") MECHANISM(S)

KEVIN'S TALK: SERIOUS QUANTITATIVE EFFORT TO DESCRIBE DATA :

DUSLING, VENUGOPALAN + DUMITRU, GELIS, JALILIAN-MARIAN, LAPPI - Phys.Lett. B697 (2011) 21 (arXiv:1009.5295), Phys.Rev.Lett. 108 (2012) 262001 (arXiv:1201.2658); arXiv:1302.7018

PHYSICS: **BOSE ENHANCEMENT IN THE WAVE FUNCTION**

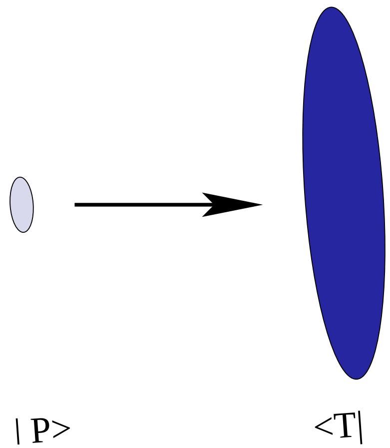
THIS IS THE MOST DETAILED AND MOST PUBLICIZED, BUT NOT THE ONLY WORK. IT DOES NOT ACCOUNT FOR TWO IMPORTANT PHYSICAL MECHANISMS FOR COLLIMATION, WHICH MAY WELL BE EVEN MORE IMPORTANT.

LOCAL ANISOTROPY KOVNER, LUBLINSKY : Phys.Rev. D83 (2011) 034017 (arXiv:1012.3398); Int. J. Mod. Phys. E Vol. 22 (2013) 1330001 (arXiv:1211.1928)

DENSITY VARIATION : LEVIN, REZAEIAN: Phys.Rev. D84 (2011) 034031 (arXiv:1105.3275)

THE DISCUSSION IS IN THE FRAMEWORK OF THE SATURATION IDEAS,
BUT SATURATION IS NOT CENTRAL TO MOST OF THE PHYSICS

EIKONAL GLUON PRODUCTION



EVENT: A BUNCH OF INCOMING GLUONS FROM THE PROJECTILE SCATTER ON A GIVEN CONFIGURATION OF THE TARGET FIELDS.

LONG RANGE RAPIDITY CORRELATIONS COME FOR FREE WITH BOOST INVARIANCE

INCOMING PROJECTILE 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, ESPECIALLY IF THERE IS A "'CLASSICAL"' AVERAGE FIELD IN THE PROJECTILE

LOCAL ANISOTROPY

INCOMING PARTICLES SCATTER ON **VECTOR** FIELD - LOCALLY A PREFERRED DIRECTION

THE LOCAL STRUCTURE IN THE TARGET WAVE FUNCTION IS GOVERNED BY THE SATURATION MOMENTUM Q_S.

Q_S PLAYS A DUAL ROLE IN THIS PICTURE:

A. IT IS THE AVERAGE VALUE OF COLOR ELECTRIC FIELDS IN THE WAVE FUNCTION $Q_S^2 \sim (gE)^2$.

B. IT IS THE INVERSE OF THE LENGTH OVER WHICH THE COLOR ELECTRIC FIELDS ARE CORRELATED $\lambda \sim Q_S^{-1}$.

IN TERMS OF THE INTEGRATED COLOR ELECTRIC FIELD

$E_i(x) \equiv \int_{x^-} dx^- E_i(x, x^-)$

WHEN THINK ABOUT TARGET - THINK THIS

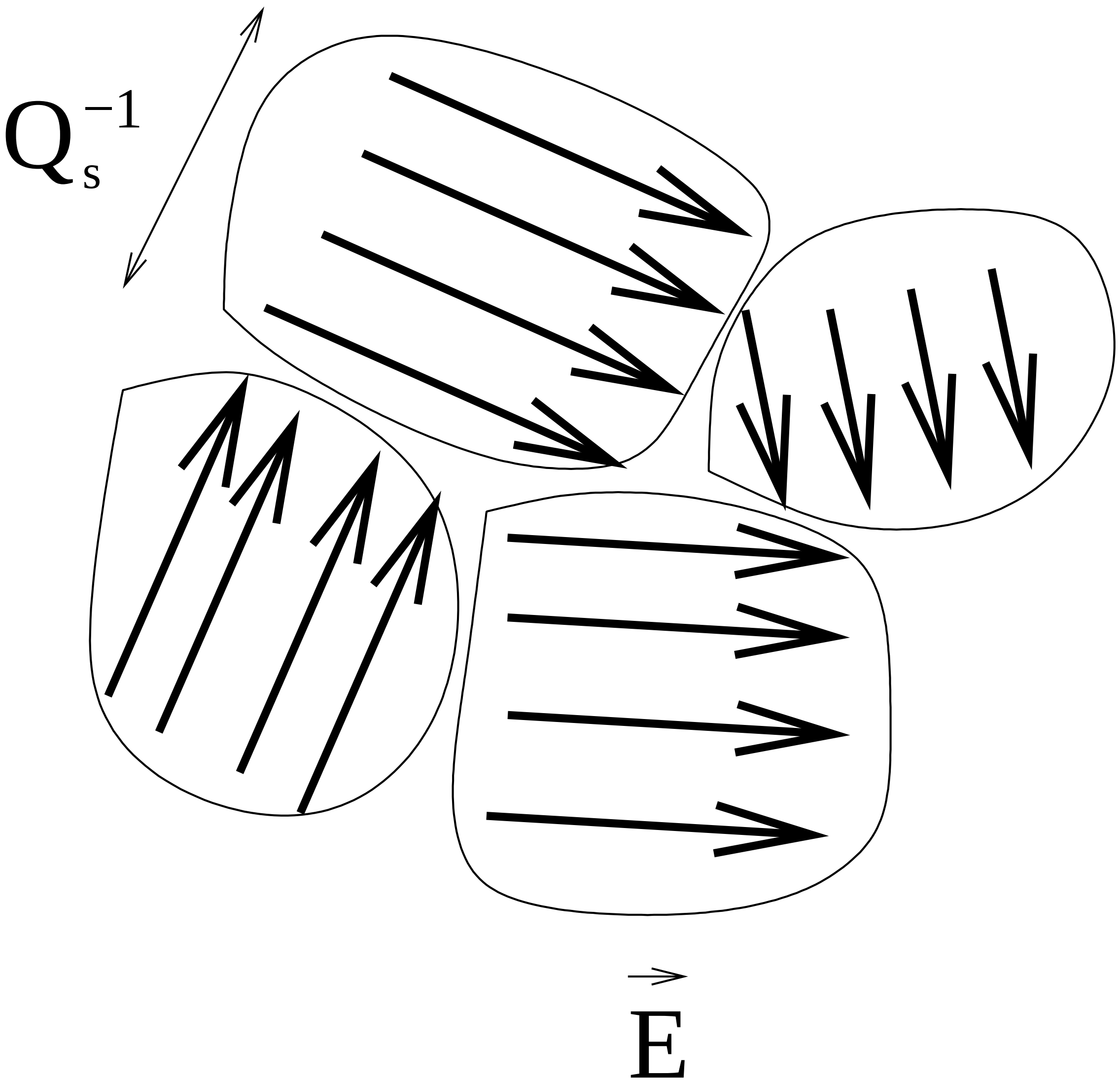


Figure 3: CARTOON OF A TYPICAL FIELD CONFIGURATION IN A SATURATED TARGET.

A PARTON WITH CHARGE q THAT HITS AT AN IMPACT PARAMETER x PICKS UP 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, THERE IS A GOOD CHANCE THAT THE TWO PARTONS HAVE THE SAME CHARGE q.

IN EQUATIONS:

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

$$\frac{dN}{d^2p d^2k d\eta d\xi} =< \sigma_1(k)\sigma_1(p) >_{P,T}$$

where

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

HERE

$$f_i(x-y) = \frac{(x-y)_i}{(x-y)^2}$$

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

$\sigma_1(k)$ HAS A MAXIMUM AT SOME VALUE $k = q_0$, SO THE TWO GLUON PRODUCTION PROBABILITY CONFIGURATION BY CONFIGURATION HAS A MAXIMUM AT (CONFIGURATION DEPENDENT)

$$k = p = q_0$$

IT IS NOT N_c SUPPRESSED

IF WE ASSUME FACTORIZATION, THE LEADING N_C CONTRIBUTION IS.

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

THEN NO ANGULAR CORRELATION IN LEADING ORDER

$$\langle \sigma_1(k)\sigma_1(p)\rangle_{P,T}=\langle \sigma_1(k)\rangle\langle \sigma_1(p)\rangle_{P,T}$$

BUT THERE IS NO BASIS FOR FACTORISATION HYPOTHESIS UNLESS THE POINTS ARE FURTHER THE $1/Q_S$ APART. THIS IS NOT THE INTERESTING REGIME FOR EXPLORING CORRELATIONS.

LOCAL ANISOTROPY: LEADING ORDER IN N_C; PEAKED AROUND Q_S.

SUBLEADING ENERGY DEPENDENCE?

DENSITY GRADIENTS

CONSIDER LEADING N_C CONTRIBUTION IN THE BFKL APPROXIMATION.

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

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

FOR PROJECTILE AVERAGES (T - BFKL DIPOLE SCATTERING AMPLITUDE)

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

CONCENTRATE ON THE REGION WHERE THE TWO DIPOLES ARE AT THE SAME IMPACT PARAMETER. LEADING ENERGY BEHAVIOR FROM THE LEADING BFKL EIGENFUNCTION:

$$T(\vec{r}, \vec{b}) \propto \frac{r^2}{|\vec{r} - \vec{b}||\vec{r} + \vec{b}|}$$

THIS IS LOCALLY ISOTROPIC: FOR $|\vec{r}| \ll b$ NO ANGULAR DEPENDENCE

$$T(\vec{r},\vec{b}) \propto \frac{r^2}{b^2}$$

FOR $r^2 \gg b^2$:

$$\hat{T}(\vec{r},\vec{b}) = const$$

LOCALLY ISOTROPIC, ROTATIONALLY INVARIANT SCATTERING AMPLITUDE ON A DENSITY PROFILE $\propto 1/b^2$.

BUT FOR $r^2 \sim b^2$ THERE IS STRONG ANGULAR DEPENDENCE, E.G.

$$T_{perpendicular}(b,b)/T_{parallel}(b,b) = 3/5$$

ANGULAR SENSITIVITY WHEN THE EMISSION POINTS PROBE THE GRADIENT OF THE DENSITY (OR SATURATION MOMENTUM). MAXIMAL FOR

$$k, p \sim \frac{1}{Q_s}\frac{dQ_s}{db}$$

PROBES A DIFFERENT MOMENTUM SCALE: NOT $1/Q_S$, BUT THE CORRELATION LENGTH OF Q_S. PARAMETRICALY DIFFERENT

$$\lambda_{Q_S} \propto \frac{1}{Q_S} e^{a\ln^2(1/\alpha_S)}$$

FOR AN INDIVIDUAL HOT SPOT THIS IS THE SIZE OF THE HOT SPOT

DENSITY VARIATION: LEADING IN N_C; LEADING IN ENERGY;

CORRELATION PEAKS FOR MOMENTA SMALLER THAN $1/Q_S$

BOSE-EINSTEIN ENHANCEMENT

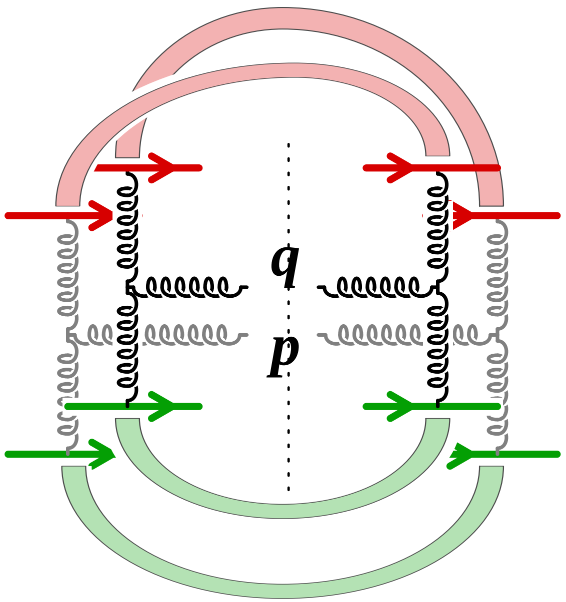
DUSLING-VENUGOPALAN NUMERICAL FITS.

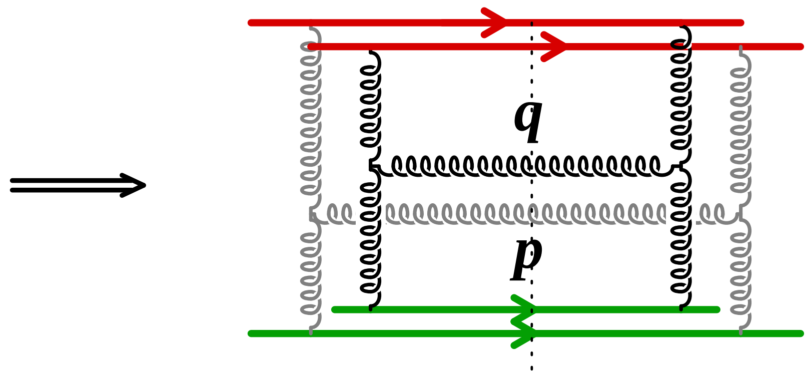
GAUSSIAN CONTRACTION ANSATZ

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

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

THE CONTRACTION THAT LEADS TO CORRELATIONS:





THIS HAS A VERY SIMPLE INTERPRETATION AS BOSE ENHANCEMENT FOR GLUONS IN THE PROJECTILE WAVE FUNCTION.

MOMENTUM FLOW:

$q_1,\ q_2$ - PROJECTILE AMPLITUDE AND CONJUGATE AMPLITUDE;

$l_1,\ l_2$ - TARGET AMPLITUDE AND CONJUGATE AMPLITUDE:

$$q_1 + l_1 = p; \quad q_1 + l_2 = k; \quad q_2 + l_2 = k; \quad q_2 + l_1 = p$$

SOLUTION: $q_1 = q_2$ - THE TWO GLUONS THAT SCATTER HAVE THE SAME MOMENTA IN THE PROJECTILE WAVE FUNCTION INITIALLY. **DENSITY AT THE SAME MOMENTUM IS ENHANCED DUE TO THE USUAL BOSE ENHANCEMENT.**

MAKE IT MORE PRECISE.COLOR CHARGE DENSITY IN THE AMPLITUDE IS RELATED TO GLUON CREATION OPERATOR: $f(x-y)\rho(y) = a^\dagger(x)$, IN THE CONJUGATE AMPLITUDE $f(x-y)\rho(y) = a(x)$.

OUR OBSERVABLE IS THE GLUON DENSITY-DENSITY CORRELATOR IN THE PROJECTILE WAVE FUNCTION

$$\langle a^\dagger(q_1)a(q_1)a^\dagger(q_2)a(q_2)\rangle = \langle a^\dagger(q_1)a(q_1)\rangle\langle a^\dagger(q_2)a(q_2)\rangle + \delta(q_1-q_2)\langle a^\dagger(q_1)a(q_1)\rangle$$

THE COLOR OF THE TWO INCOMING GLUONS IS ALSO THE SAME - MANDATORY FOR BOSE ENHANCEMENT. THUS THE EFFECT IS SUBLEADING IN N_C, SINCE IN GENERAL COLOR INDICES OF THE INCOMING PARTONS ARE NOT CORRELATED.

BOSE ENHANCEMENT: LEADING IN ENERGY (PROBABLY); PEAKED AROUND Q_S, SINCE MOST GLUONS ARE AT THIS MOMENTUM SUBLEADING IN N_C

CONCLUSIONS

THERE IS MORE TO CORRELATIONS THAN BOSE ENHANCEMENT.

IF FITS ARE TO BE RELIABLE, THE LEADING IN N_C EFFECTS HAVE TO BE EITHER INCLUDED, OR IT HAS TO BE UNDERSTOOD WHY THEY ARE NOT IMPORTANT.