WG2 Highlights
Small x, Diffraction and Vector Mesons
Theory

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Thank you to all participants! 40 talks

Theory and phenomenology

Recent theoretical developments on high-energy effective theories

Victor Fadin, Martin Hentschinski, Grigorios Chachamis, Handreas Van Hameren

High density, saturation

Adrien Besse, Michal Deak, Krzysztof Kutak, Stéphane Munier, Cyrille Marquet, Amir Rezaeian

Exclusive processes related issues

Franck Sabatié, Ruben Sandapen

Testing QCD in the perturbative Regge limit at LHC

Cristiano Brenner Mariotto, Michal Deak, Bertrand Ducloué, Wolfgang Schaefer, Antoni Szczurek

Multiparton interactions

Markus Diehl, Emilia Lewandowska

The Regge limit at LHC

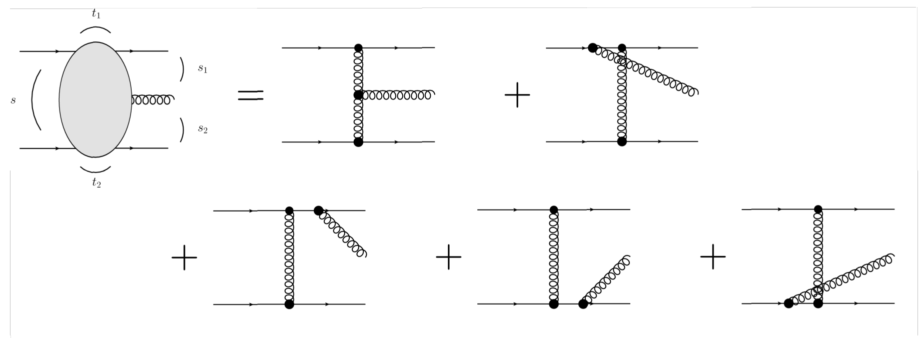
Daniel Fagundes, Antoni Szczurek

QCD effective actions at high-energy.
Are they *really* effective ?

The Lipatov action has been constructed in 1995-1997... but had no application !

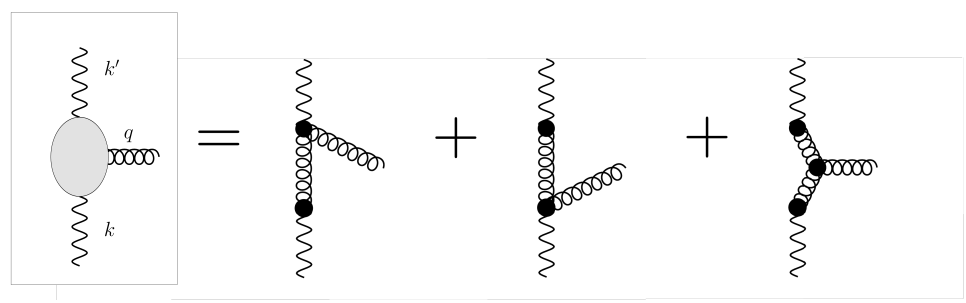
In a nutshell :

Lipatov vertex :
combines
the QCD triple-vertex +
Bremsstrahlung emissions
Key point : the emitted gluon is soft
with respect to the emitter
~ eikonal line

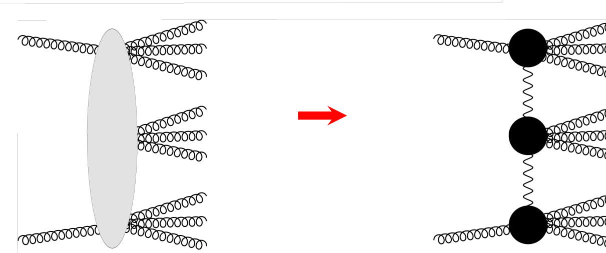


double Regge kinematics $s \gg s_1, s_2 \gg -t_1, -t_2$

Define two Reggeon fields A_+, A_-
which incorporate this eikonal
nature, either from upper or
lower side, on top of usual
QCD gluons



Now iterate : key point = locality in rapidity multiregge
(LO) or quasi-multiregge (NLO) kinematics
The effective action should be supplemented with
additional rules... which makes life hard



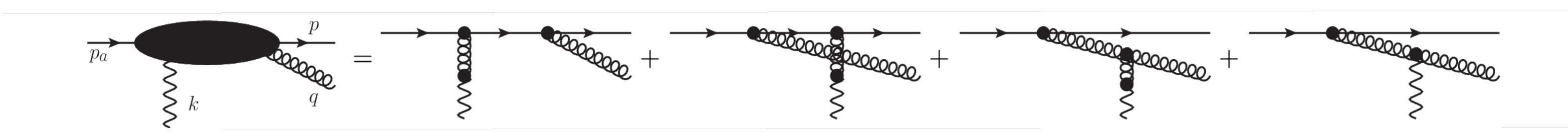
Yes, the Lipatov action can now be used practice. Important progresses have been made recently :

Analytically

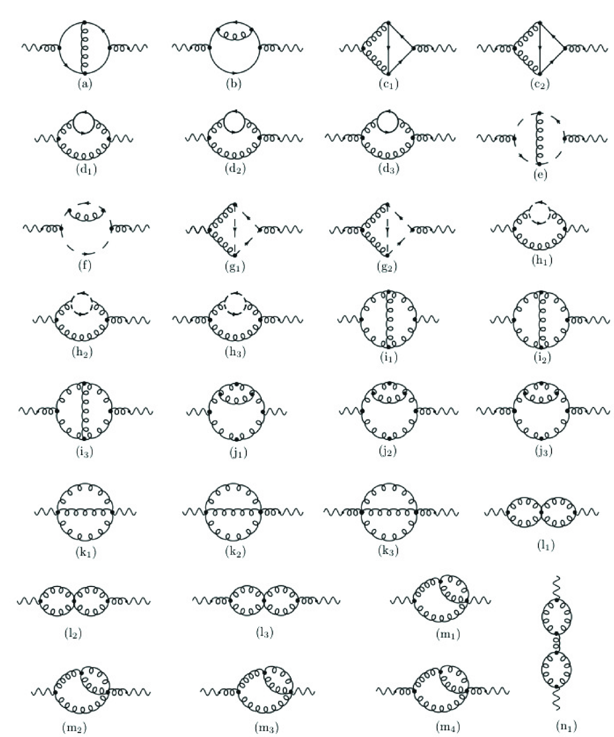
See Martin Hentschinski and Grigorios Chachamis

Several non trivial results which have been reobtained :

- Quasi-elastic quark vertex at NLO (building block for Mueller Navelet jets) = jet vertex

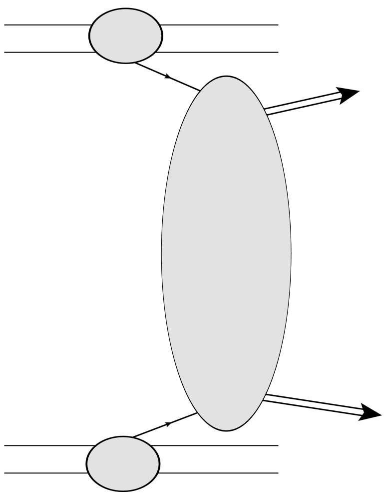


- Two-loop gluon Regge trajectory

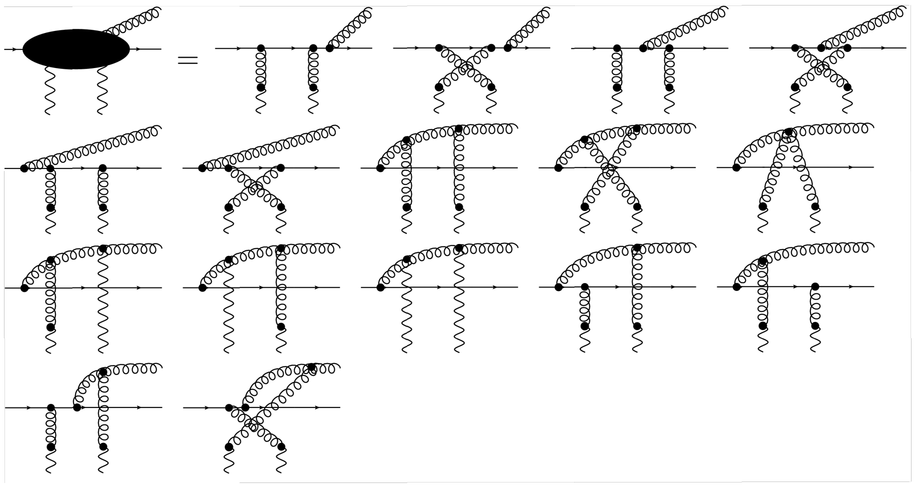


A new result which have been obtained using the Lipatov action

Forward-backward jets with rapidity gap



Jet vertex at NLO :



Yes, the Lipatov action can now be used practice. Important progress have been made recently :

Numerical implementation See Handreas Van Hameren

- we are just interested in a gauge invariant amplitude $\mathcal{A}(g^*g^* \to X)$
- the amplitude $\mathcal{A}(q_A q_B \to q_A q_B + X)$ must be gauge invariant, must be completely on-shell, but does not have to be physical
- introduce complex on-shell momenta $p_A, p_{A'}, p_B, p_{B'}$

$$\ell_3^\mu = \tfrac{1}{2}\langle\ell_2|\gamma^\mu|\ell_1] \qquad \ell_4^\mu = \tfrac{1}{2}\langle\ell_1|\gamma^\mu|\ell_2]$$

$$\ell_1^2 = \ell_2^2 = 0 \qquad \ell_3^2 = \ell_4^2 = 0 \qquad \ell_{1,2}\cdot\ell_{3,4} = 0 \qquad \ell_1\cdot\ell_2 = -\ell_3\cdot\ell_4$$

$$p_A^\mu = (\Lambda + x_1)\ell_1^\mu - \frac{\ell_4\cdot k_{1\perp}}{\ell_1\cdot\ell_2}\,\ell_3^\mu \qquad p_{A'}^\mu = \Lambda\ell_1^\mu + \frac{\ell_3\cdot k_{1\perp}}{\ell_1\cdot\ell_2}\,\ell_4^\mu$$

$$p_B^\mu = (\Lambda + x_2)\ell_2^\mu - \frac{\ell_3\cdot k_{2\perp}}{\ell_1\cdot\ell_2}\,\ell_4^\mu \qquad p_{B'}^\mu = \Lambda\ell_2^\mu + \frac{\ell_4\cdot k_{2\perp}}{\ell_1\cdot\ell_2}\,\ell_3^\mu$$

Now we have both the high-energy limit and on-shellness:

$$p_A^\mu - p_{A'}^\mu = x_1\ell_1^\mu + k_{1\perp}^\mu \qquad p_B^\mu - p_{B'}^\mu = x_2\ell_2^\mu + k_{2\perp}^\mu$$

$$p_A^2 = p_{A'}^2 = p_B^2 = p_{B'}^2 = 0$$

for any value of the dimensionless parameter Λ.

The transverse momenta are now complex. There are replaced by spinors.
The kinematics is not approximated at that stage.
The obtained rules are equivalent to Lipatov action.
They can be numerically implemented.

A process computed at tree level based on a numerical implementation of the effective action :

Ratio of observable distributions for p-p vs. p-Pb collisions.
Use unintegrated gluon densities from Phys.Rev.D86(2012)094043 for off-shell gluon.

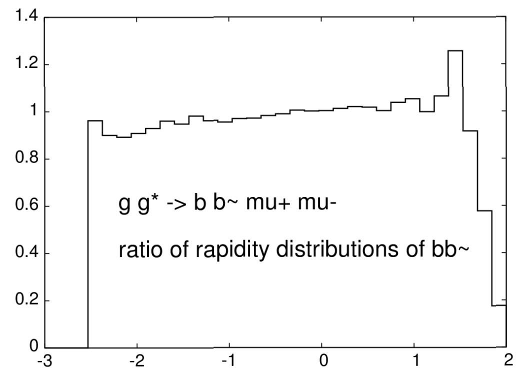
$$gg^* \to b\bar{b}\,\mu^+\mu^-$$

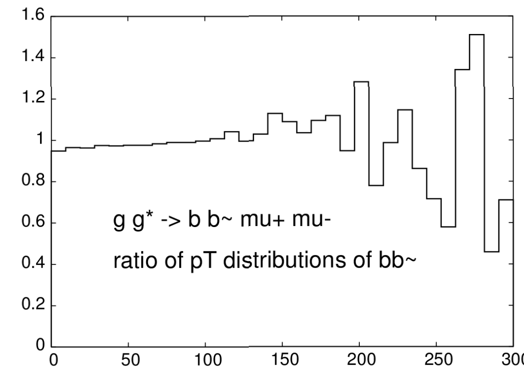
$$p_T(q) > 20\,\text{GeV} \quad y(q) < 2.5$$

$$p_T(\mu) > 20\,\text{GeV} \quad y(\mu) < 2.1$$

$$dR(q,q) > 0.4 \quad dR(q,\mu) > 0.4$$

$$\sqrt{s} = 8\,\text{TeV}$$





$$ug^* \to b\bar{b}\,\mu^+\nu_\mu\,d$$

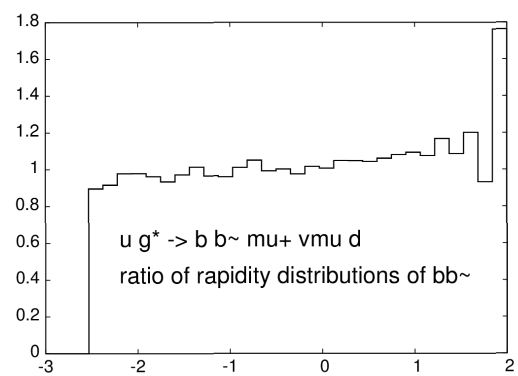
$$p_T(q) > 20\,\text{GeV} \quad y(q) < 2.5$$

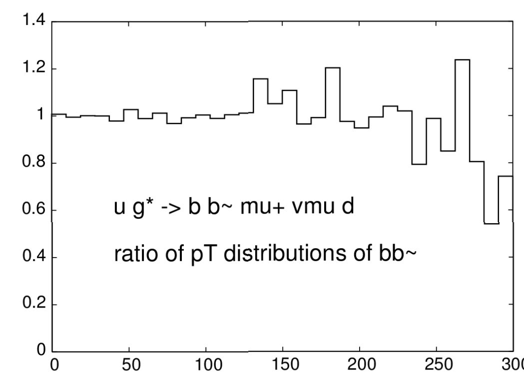
$$20\,\text{GeV} < p_T(\mu^+) < 50\,\text{GeV}$$

$$y(\mu) < 2.1$$

$$\not{E}_T > 20\,\text{GeV}$$

$$dR(q,q) > 0.4 \quad dR(q,\mu) > 0.4$$





The (global) (quasi) conformal symmetry is central for BFKL at LO and NLO

Victor Fadin

In the singlet channel :

- The full momentum space NLO BFKL kernel (i.e. also the non-forward part of the NLO BFKL kernel) can be obtained from the Möbius form (i.e. dipole, in coordinate space), which is quasi-conformal invariant (i.e. conformal up to the running coupling effect)
- It is then possible to get, in momentum space, the difference between the two forms of the kernel

In the octet channel :

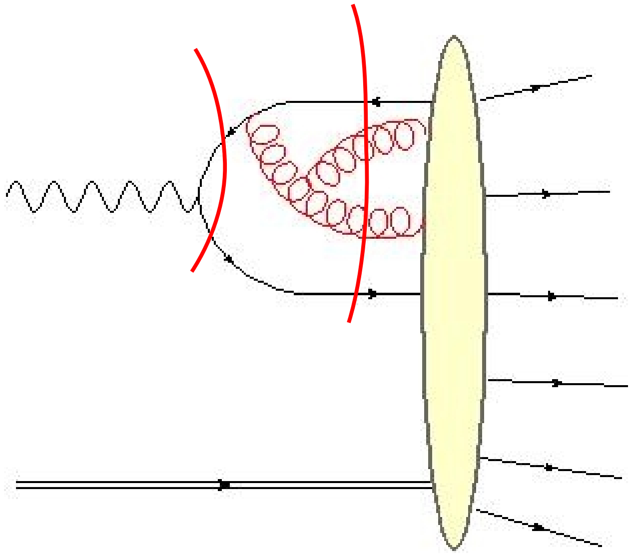
- There is a similarity which relates the quasi-conformal and the standard BFKL NLO kernel
- The explicit form of this transform has been obtained

QCD at high density: How to test it?

The dipole model : a key, inspiring and powerful paradigm

At an **electron-hadron collider**:

- DIS can be understood as a dipole of “tunable” size r interacting with the target (p or A), that gets denser at higher energies.
- exclusive final states can be included with an appropriate wave function



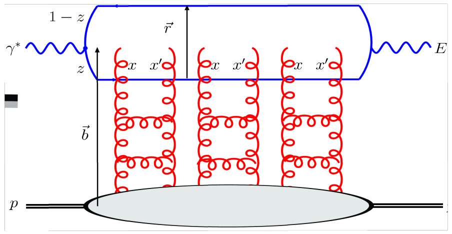
A lot of understanding of the dipole scattering amplitude was gained at HERA, at the border of the dense/saturation regime of QCD!

It is “easy” to formulate the QCD evolution of the dipole amplitude with the energy as **radiative corrections to the dipole wave function**.

BFKL (at low density), BK, JIMWLK equations (accounting for high-density effects)

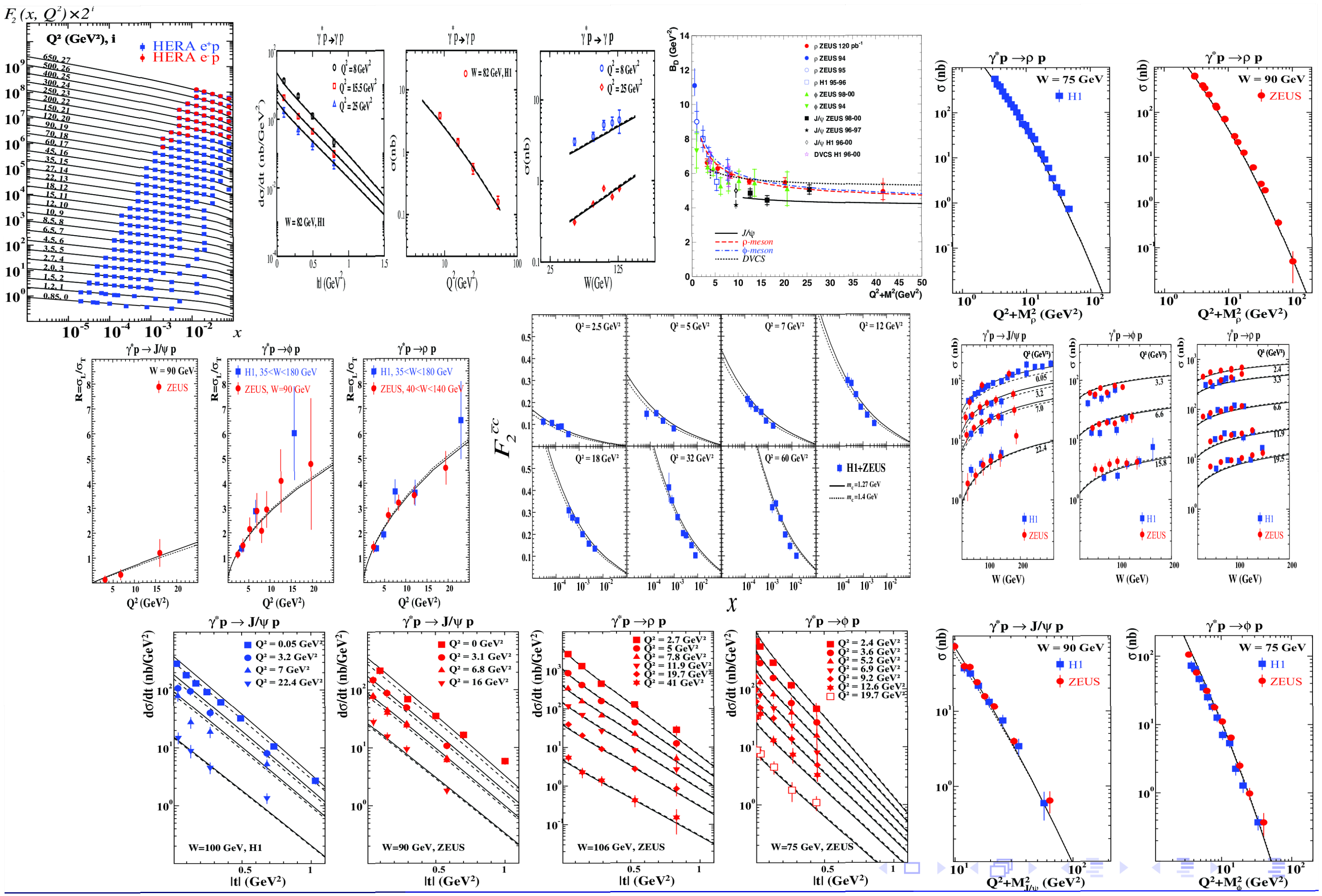
Impact-Parameter dependent Saturation model

Amir Rezaeian

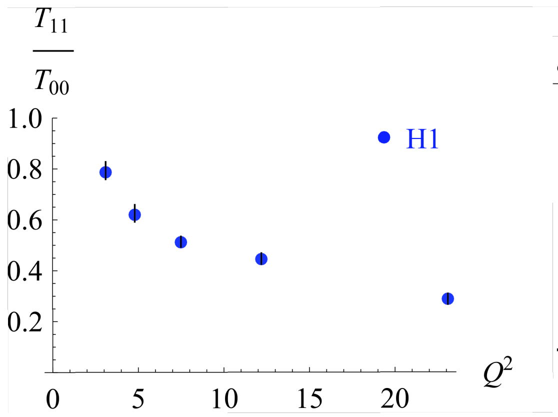


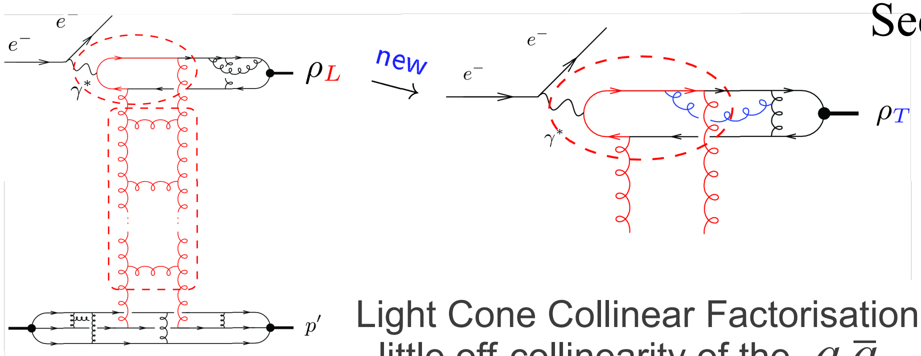
Mueller-Glauber (no small-x dynamics à la BK)
+ fit for b

→ Unified description of x, Q^2, W and t HERA data



But what about power corrections in exclusive processes ?



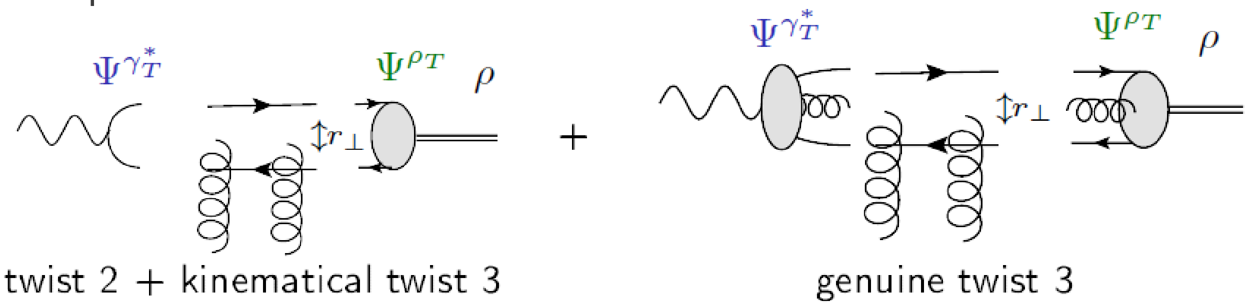


See Adrien Besse

Light Cone Collinear Factorisation : two sources of T-pol.
- little off-collinearity of the $q\,\bar{q}$
- $q\,\bar{q}\,g$

How to combine consistently two mechanisms :
- collinear factorisation to produce a meson beyond leading twist
- the dipole QCD at high density

Key ideas :
- Reformulate the Light-Cone Collinear Factorisation in coordinate space
- Use QCD equations of motions



The dipole is still valid, at finite Nc, at twist 3

This provides a way to relate the wave function with the Distribution Amplitude

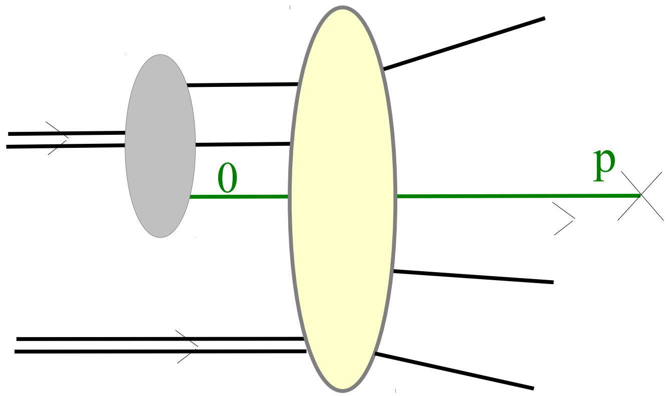
Wave function = non-perturbative object :
see talk of Ruben Sandapen for a result based on AdS/QCD correspondence

QCD at high density: How to test it?

At a **hadron collider**, we need to find appropriate production processes:

- p_T -broadening:

S. Munier

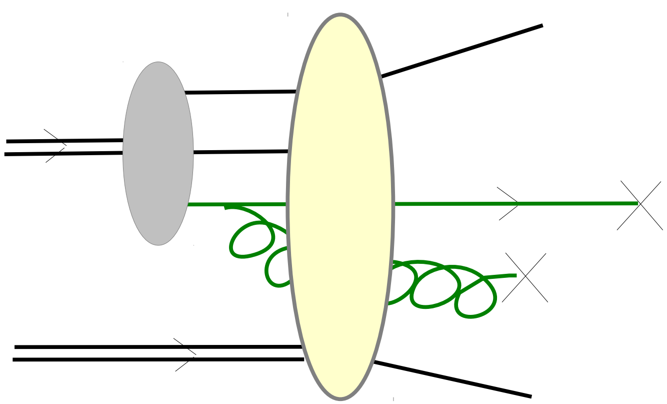


Observe a jet of transverse momentum

$p \sim Q_s$

- Forward dijet azimuthal correlations:

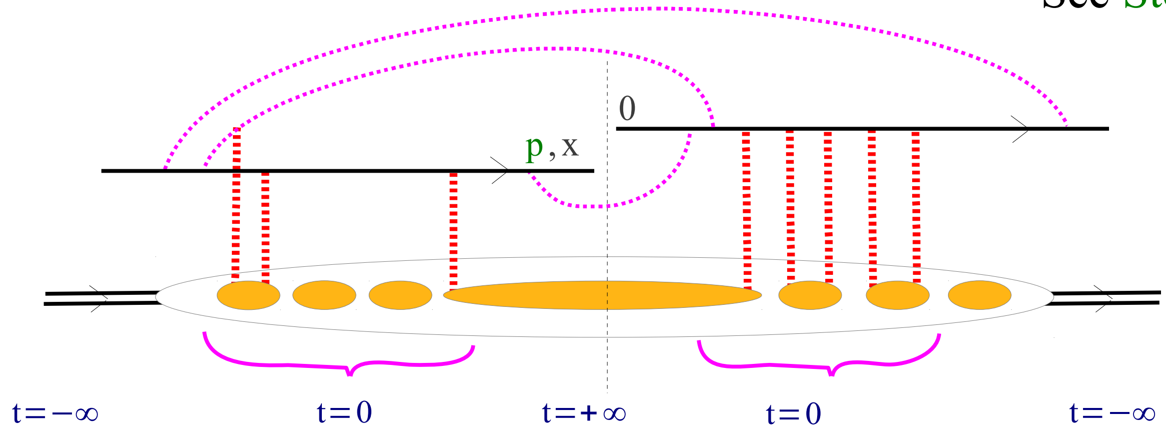
C. Marquet



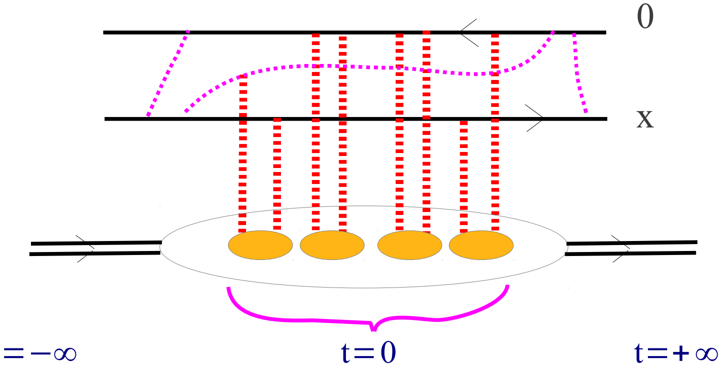
Observe two forward jets, which are back-to-back if the target is dilute

at NLO, pt-broadening = dipole scattering amplitude

See Stéphane Munier



$$\frac{dN}{d^2p} = \int \frac{d^2x}{(2\pi)^2} e^{-ipx} \left\langle \frac{1}{N_c} \mathrm{Tr}\left(T V_0^* e^{-i\int d^4y L_I}\right)\left(T V_x e^{i\int d^4y L_I}\right)\right\rangle$$



=

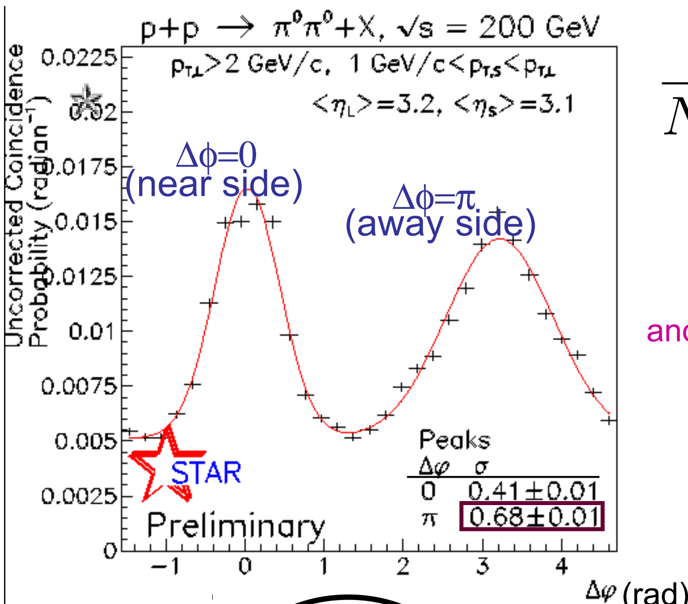
$$S_{dipole}(x) = \left\langle \frac{1}{N_c} \mathrm{Tr}\left(T V_0^* V_x e^{i\int d^4y L_I}\right)\right\rangle$$

Di-hadron angular correlations as a sign of saturation

See Cyrille Marquet

comparisons between d+Au → h_1 h_2 X (or p+Au → h_1 h_2 X) and p+p → h_1 h_2 X

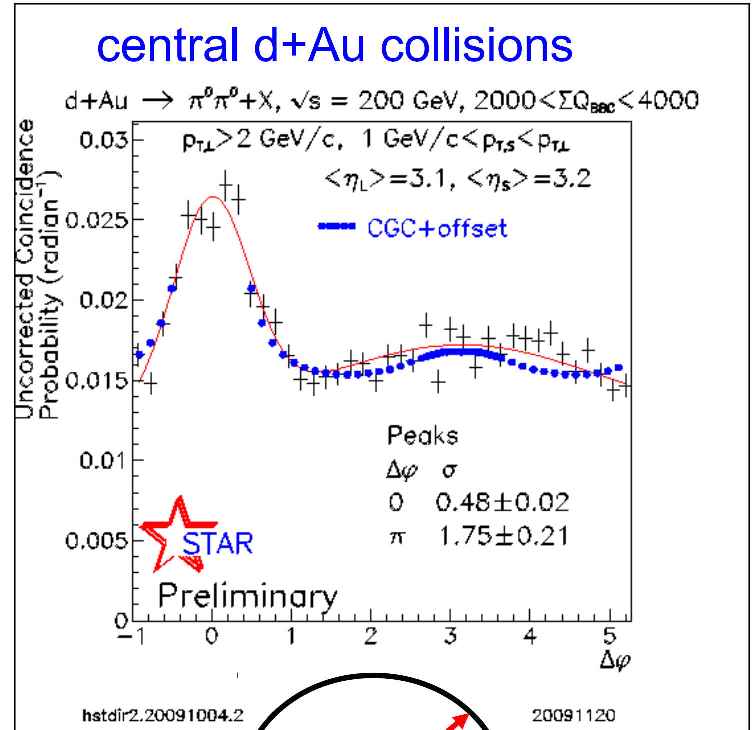
p+p collisions

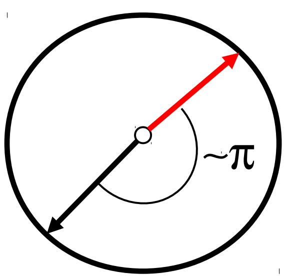


$$\frac{1}{N_{trig}}\frac{dN_{pair}}{d\Delta\varphi}$$

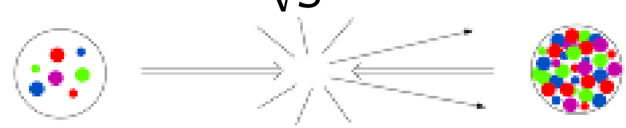
Albacete
and C.Marquet (2010)

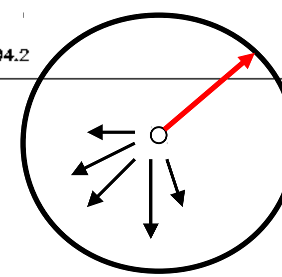
central d+Au collisions





$$x_A = \frac{k_1 e^{-y_1} + k_2 e^{-y_2}}{\sqrt{s}} << 1$$



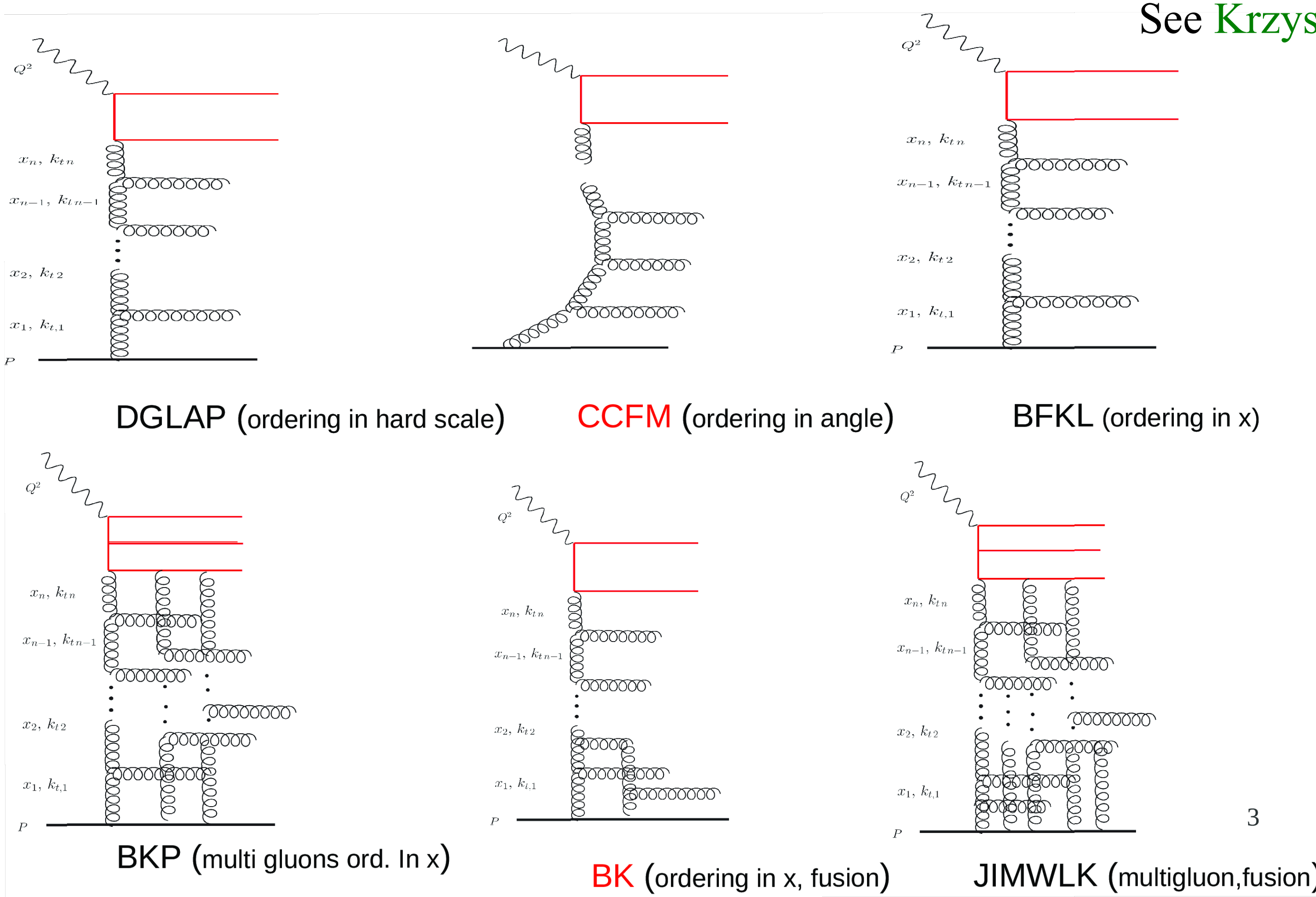


however, when $y_1 \sim y_2 \sim 0$ (and therefore $x_A \sim 0.03$),
the p+p and d+Au curves are almost identical

New : - dipole and quadrupole contributions are enough in the large Nc limit
- this remains true for multiparticle production

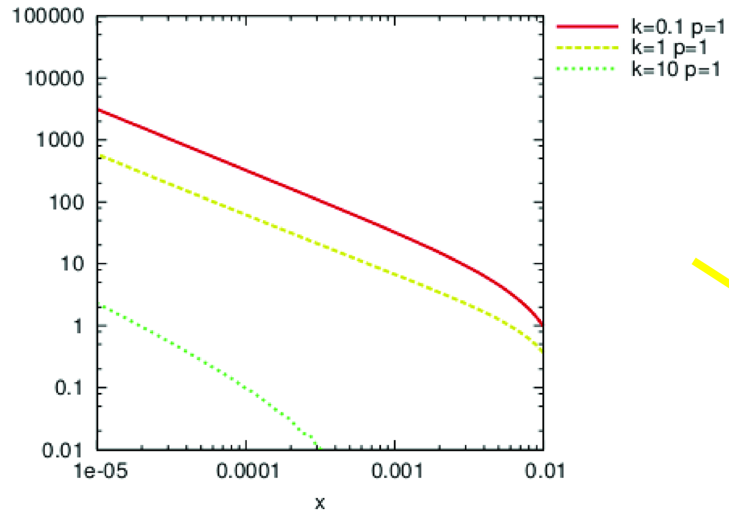
Exclusive final states and saturation

See Krzysztof Kutak

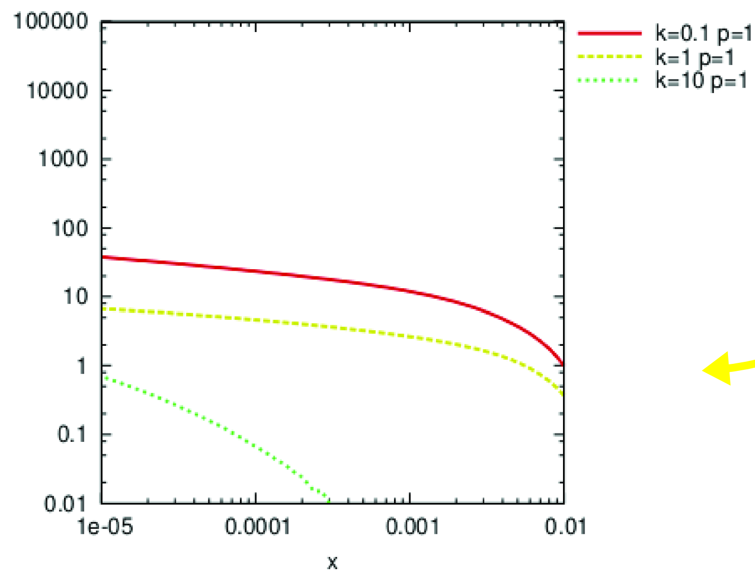


CCFM + BK → KGBJS equation
Trick : use a resummed form of BK which is more suitable in view of including exclusive final states effects
Then postulate …
(see also the talk of Michal Deak)

CCFM



KGBJS



low k saturates
for small x

Testing QCD in the perturbative Regge limit at LHC

One needs an hard scale :

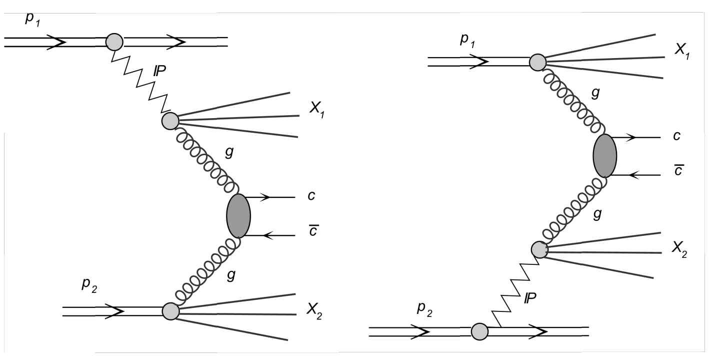
$M_{J/\psi}$ for $\gamma\gamma \to J/\psi\, J/\psi$ in ultraperipheral $A\,A \to A\,A\,J/\psi\, J/\psi$

Box diagram versus BFKL ladder ?

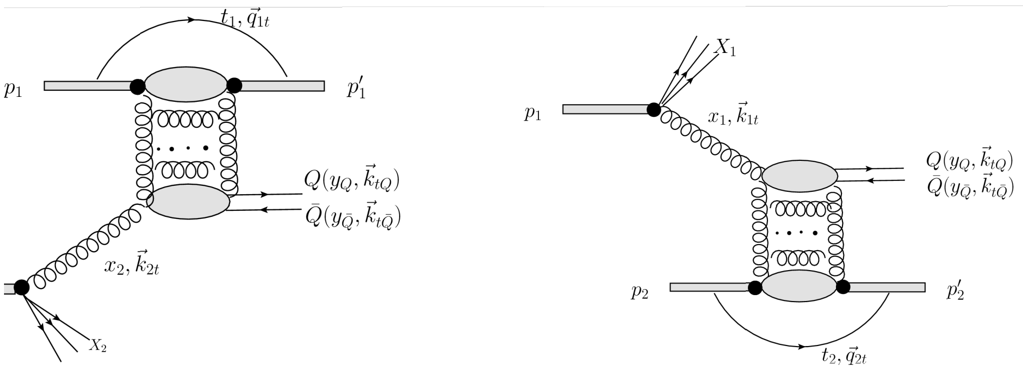
Wolfgang Schaefer

M_Q for diffractive $Q\bar{Q}$ production Antoni Szczurek

further studies needed : several mechanism are possible

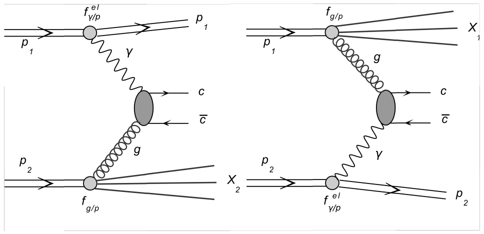


Ingelman-Schlein model
dominates



Gluon dissociation

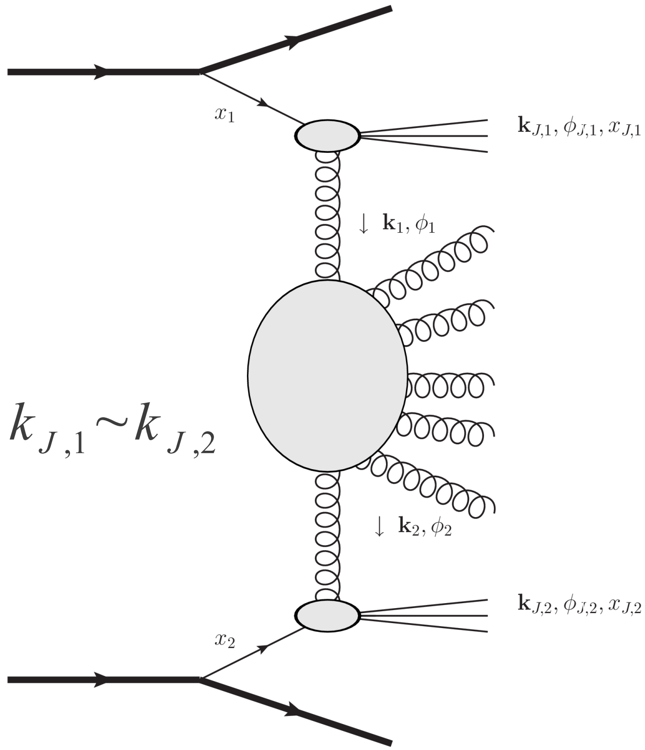
Competitive mechanism :



Testing QCD in the perturbative Regge limit at LHC

Mueller-Navelet jets : the only observable for which a full NLO BFKL analysis is available

See Bertrand Ducloué



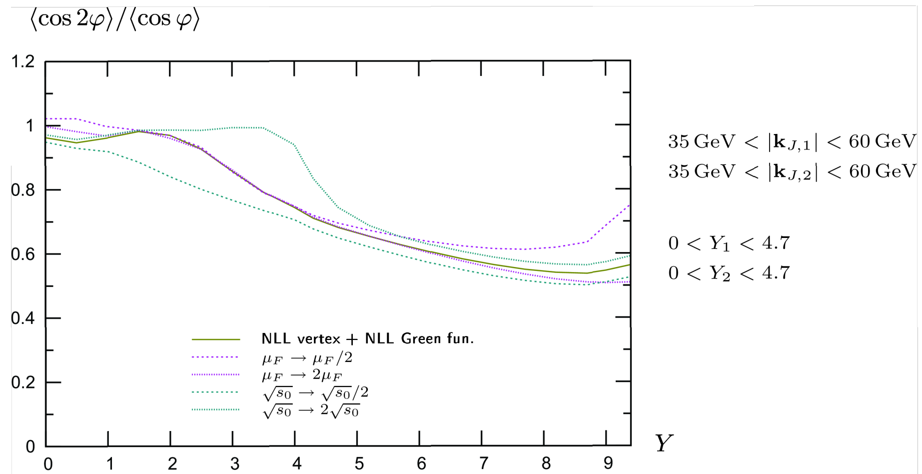
$k_{J,1} \sim k_{J,2}$

$$\varphi = \varphi_{J,1} - \varphi_{J,1} - \pi$$

Surprisingly small decorrelation

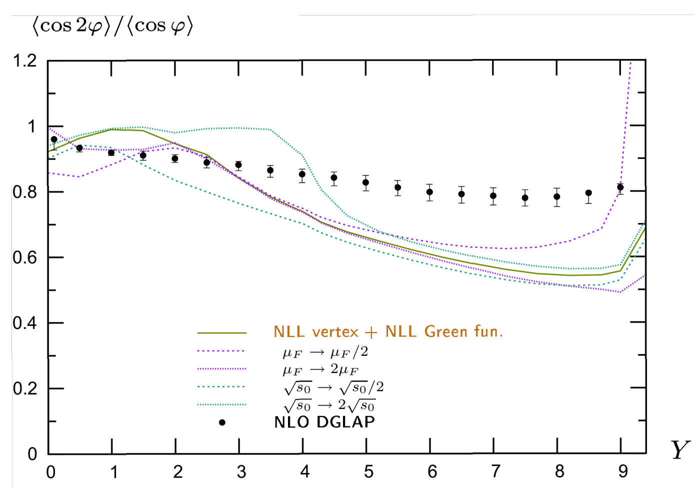
Predictions are stable with respect to

s_0, μ_F , PDFs, in the range 4.5 < Y < 8



Symmetric configuration

See CMS data



for typical CMS bins:

35 GeV < $|\mathbf{k}_{J,1}|$ < 60 GeV

50 GeV < $|\mathbf{k}_{J,2}|$ < 60 GeV

0 < Y_1 < 4.7

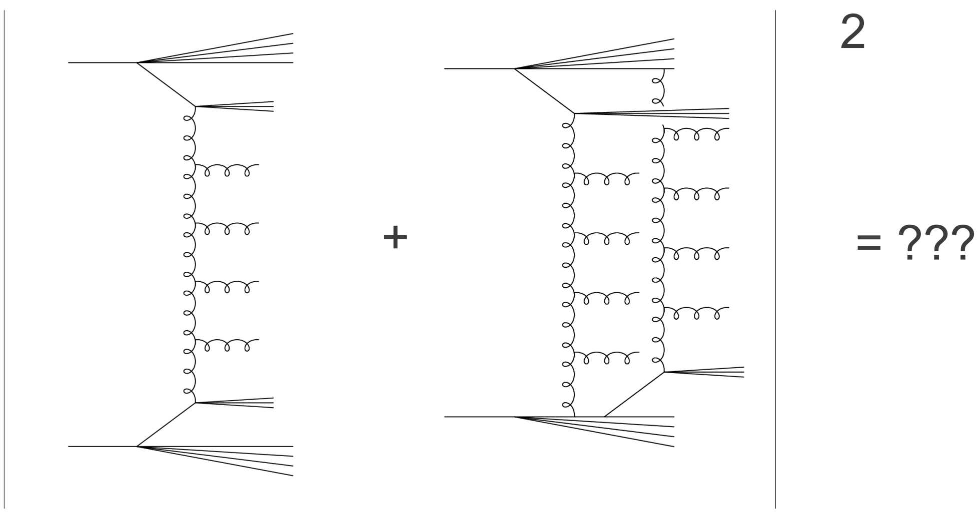
0 < Y_2 < 4.7

Could be extracted

Asymmetric configuration

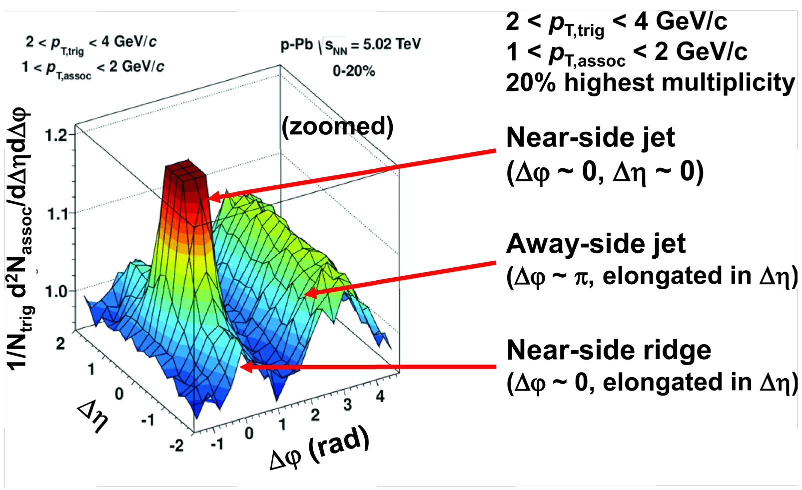
Testing QCD in the perturbative Regge limit at LHC

Mueller-Navelet jets : another mechanism ?



BFKL ladder

Color Glass Condensate ?
~ MPI at small x ?



Similar issues for the
ridge effect in pp, pA

MPI at medium x : see Talks of Markus Diehl
Very few models for double parton distributions
Not so easy to satisfy sum rules (see talk of Emilia Lewandowska)