Low-x QCD at the LHC with the ALICE detector

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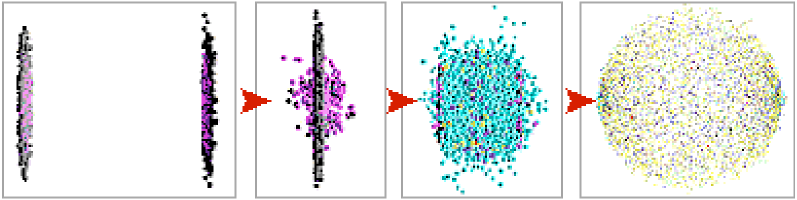
on behalf of the ALICE collaboration

13/02/09

1. Introductory material
2. Consequences for the experiments
3. Study of the CGC with the ALICE experiment
4. Summary

Evolution of the heavy ion collision

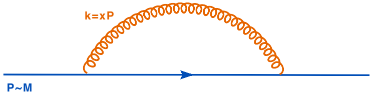


- $\tau < 0$ fm/c ⇒ initial conditions: gluon saturation
- $\tau \sim 0$ fm/c ⇒ hard particles production: heavy quarks, jets, direct photons
- $\tau \sim 0.2$ fm/c ⇒ semi-hard particles production: bulk of the reaction, $p_t \leq 2$ - 3 GeV
- $\tau \sim 1$ - 2 fm/c ⇒ thermalization
- $2 \leq \tau \leq 10$ fm/c ⇒ Quark Gluon Plasma
- $10 \leq \tau \leq 20$ fm/c ⇒ Hadron gas
- $\tau > 20$ fm/c ⇒ Freeze-out

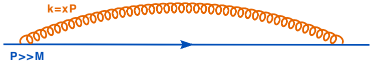
Parton picture

The lifetime of the gluon of the momentum fraction x=k/P in the:

- proton rest frame P $\sim$ M



- infinite momentum frame P $\gg$ M

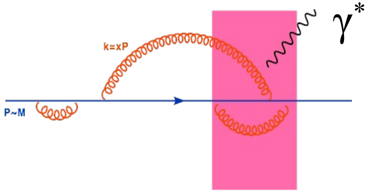


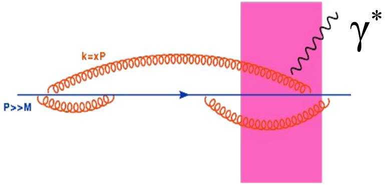
Timescale dilation in the propagation direction:

$$\Delta t_{IMF} \approx \gamma \Delta t_{RF}; \quad \gamma \gg 1$$

Interaction with an external probe

virtual photon with the virtuality Q^2





The probe sees the parton if:

$$\Delta t_{parton} \sim \frac{2xP}{k_t^2} \quad > \quad \Delta t_{interaction} \frac{2xP}{Q^2}$$

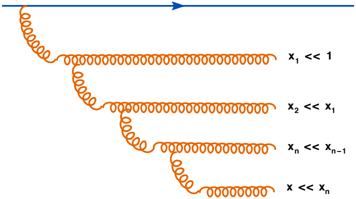
$$\Downarrow$$

$$k_t^2 \quad \ll \quad Q^2$$

What is the high energy proton made of ?

1. QPM
    - a static object composed of 3 valence quarks, no interaction between constituents
    - Bjorken scaling: for $Q^2 \to \infty$ and x fixed the proton structure functions are independent of Q^2
2. QCD improved QPM
    - a dynamic object with a very complicated structure, it contains fluctuations smaller than its own size, only the fluctuations that are longer lived than the external probe participate in the interaction process
    - new partons (gluons) are emitted with the probability $\sim \alpha_s \ln(1/x)$
    - a photon interacting with a quark at Q^2 probes the proton with a resolution $\sim 1/Q^2$. When Q^2 increases, the probability to probe small x partons is bigger !
3. CGC
    - lifetime of soft gluons is much larger than the typical timescales for interaction processes
    - the proton seen by a probe becomes more and more crowded, as long as the density of partons is small the evolution is linear
    - partons start overlapping and they recombine: parton recombination becomes favorable, the evolution in non-linear $\Rightarrow$ CGC

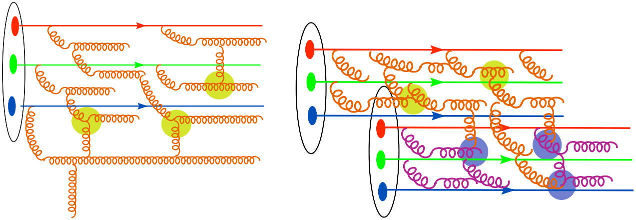
High energy evolution: BFKL equation



- the gluon emission is strongly ordered in x:
  $x \ll x_n \ll x_{n-1} \ll ... \ll x_2 \ll x_1 \ll 1$
- the transverse momentum of emitted gluons are of the same order:
  $k_t \sim k_t^n \sim k_t^{n-1} \sim ... \sim k_t^2 \sim k_t^1$
- the lifetime of the gluon is $\propto$ to its longitudinal momentum:
  x $\searrow$ thus Δt_{gluon} $\searrow$
- the gluon density increases linearly
- the gluons with large x act as a frozen color sources for the emission of the gluons with small x

Towards the Color Glass Condensate

Production versus Recombination: JIMWLK equation



$$\frac{\partial n(k_t,y)}{\partial y} \propto c_1 n(k_t,y) - \alpha_s c_2 n^2(k_t,y) \qquad \text{with } y \equiv \log\frac{1}{x}$$

- for n $\ll 1/\alpha_s$: the gluon recombination is negligible $\Rightarrow$ n grows
- for n $\sim 1/\alpha_s$: the gluon recombination is important $\Rightarrow$ n stops growing $\Rightarrow$ SATURATION

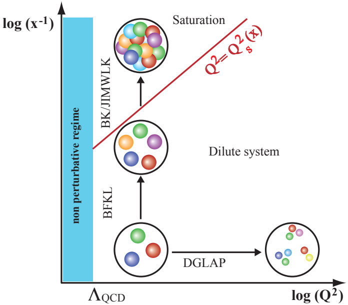
What is the Color Glass Condensate

The CGC is a new form of nuclear matter which controls the hadronic interactions at asymptotically large energies

- Color: made of gluons which carry the color charge
- Glass: the system has degrees of freedom whose timescale is much larger than the typical timescales of interaction processes
- Condensate: the soft degrees of freedom are as densely packed as they can

Universal approach: in this limit all hadrons behave in the same way

QCD diagram



Saturation criterion

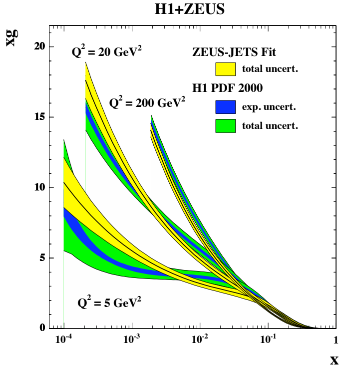
- number of partons per unit area $\rho \sim \frac{xG(x,Q^2)}{\pi R^2}$
- recombination cross-section $\sigma_{gg\to g} \sim \frac{\alpha_s}{Q^2}$
- recombination if $\rho\sigma_{gg\to g} \geq 1$ thus $Q^2 \leq Q_s^2$
- saturation scale $Q_s^2 \sim \frac{\alpha_s xG(x,Q_s^2)}{\pi R^2}$

⊛ increasing Q^2 ($Q^2 > Q_s^2$) ⇒ evolution towards the dilute system

⊛ increasing y ($Q^2 < Q_s^2$) ⇒ evolution towards the high density system

Gluon distribution at HERA

The gluon density rises **very** fast for decreasing x ($\sim 1/x^{\lambda}$, $\lambda \sim 0.3$)

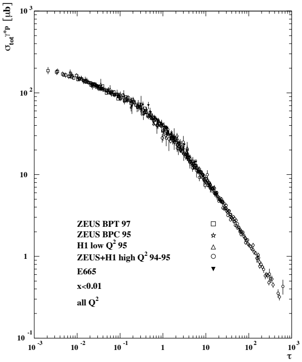


The ZEUS Collaboration Phys.Lett. B487, 53, 2000

Geometric scaling at HERA

At small x (x < 0.01) the total cross section in $\gamma^\star p$ collisions is a function of τ instead of being a function of x and Q^2 separately

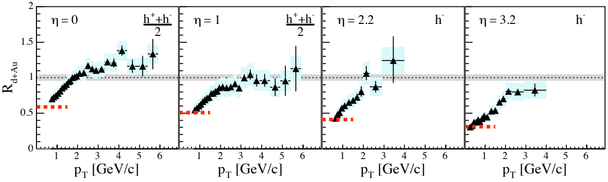
$$\sigma^{\gamma^\star p}(x, Q^2) \approx \sigma^{\gamma^\star p}(\tau) \text{ with } \tau = Q^2/Q_s^2(x), Q_s^2(x) = Q_0(x/x_0)^\lambda, \lambda \sim 0.3$$



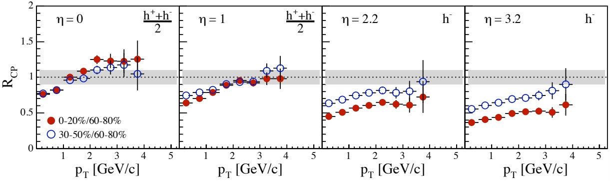
K. Golec-Biernat and M. Wüsthoff, Phys. Rev. D59, 014017, 1999

Particle production at RHIC

- R_{dAu}



- R_{CP}



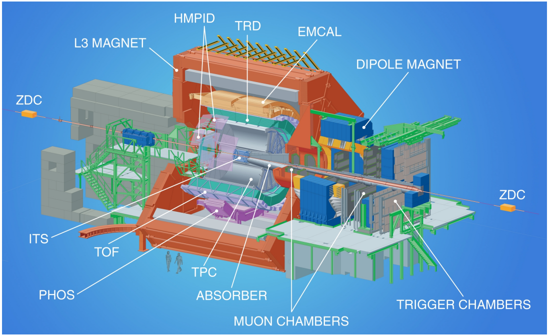
- RHIC data are reproduced by the CGC formalism

The main motivation to introduce the CGC into the ALICE

The BRAHMS Collaboration Phys.Rev.Lett. 93, 242303, 2004

ALICE

A **L**arge **I**on **C**ollider **E**xperiment: the LHC detector dedicated to the study of heavy ion collisions



- size: 16 $\times$ 26 m
- weight: 10000 t
- members: $\sim$ 1000
- countries: $\sim$ 28

colliding systems: p+p @14 TeV, Pb+Pb @5.5 TeV, p+Pb @8.8 TeV

How?

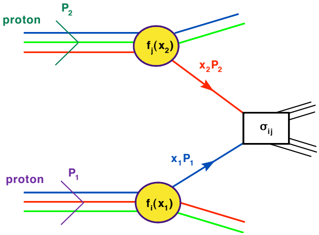
- at LHC heavy quarks are produced in the early stage of the collision mainly through gluon-gluon fusion processes
- the Bjorken-x variable: $x_{\pm} = \frac{m_t}{\sqrt{s}} e^{\pm y}$ for central rapidity

machine	SPS	RHIC	LHC	LHC
system	Pb+Pb	Au+Au	Pb+Pb	p+p
energy (GeV)	17	200	5500	14000
$c\bar{c}$	$x \simeq 10^{-1}$	$x \simeq 10^{-2}$	$x \simeq 4 \times 10^{-4}$	$x \simeq 2 \times 10^{-4}$
$b\bar{b}$	-	-	$x \simeq 2 \times 10^{-3}$	$x \simeq 6 \times 10^{-4}$

Charm and beauty production cross sections at the LHC are significantly affected by parton dynamics in the small x region !

Cross section of heavy quark production in H_1-H_2 collision

$$\sigma^{H_1,H_2} = \sum_{i,j} \int dx_1 dx_2 f_j(x_2)^{H_2} f_i(x_1)^{H_1} \sigma_{ij}(x_1, x_2, s)$$



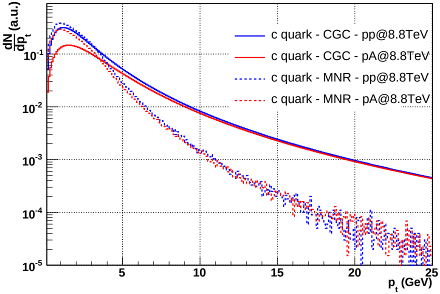
- $f_{i/j}^{H_1/H_2}$: parton distribution function
- $\sigma_{ij}(x_1, x_2, s)$: partonic cross section

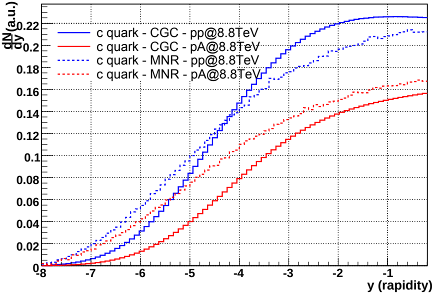
Simulations: CGC vs MNR

1. MNR: reference simulations for the ALICE experiment
   - PDF:
     - p+p described with CTEQ5L
     - p+Pb extrapolation from p+p collisions based on the Glauber model. Shadowing effects are included via nuclear modification factor (EKS98 parametrisation)
   - $\hat{\sigma}_{ij}(x_1, x_2, s)$: calculated to the NLO with HVQMR program
2. CGC: simulations made in collaboration with **F.Gelis** and **A.Charpy**
   - PDF: proton/lead described using the CGC formalism with $Q_s^2(x=x_0=10^{-2})=0.33/1.93$ GeV^2. For $x < x_0$ using JIMWLK equation with the initial condition for fixed $x = x_0$ with McLerran-Venugopalan model.
   - $d\sigma^{sat}_{gg\rightarrow Q\overline{Q}}$: the cross section for gluon fusion into a pair of heavy quarks takes into account the rescattering effects that are important in the saturation regime

Results for charm yield

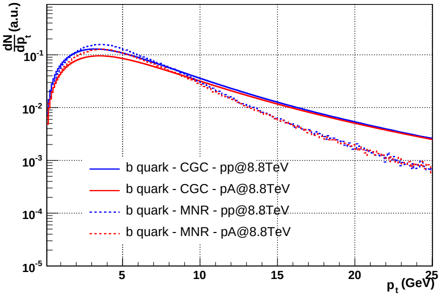
Charm: $m_c = 1.20$ GeV

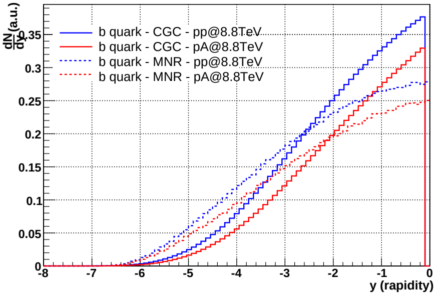




Results for beauty yield

Beauty: $m_b = 4.75$ GeV

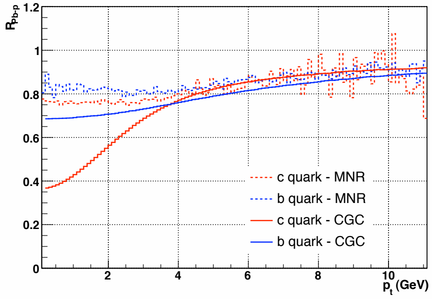


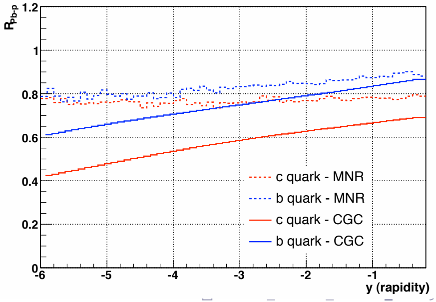


Nuclear modification factor on the quark level

$$R_{pA} = \frac{dN^{pA}/dp_t y}{N_{coll} dN^{pp}/dp_t y}$$

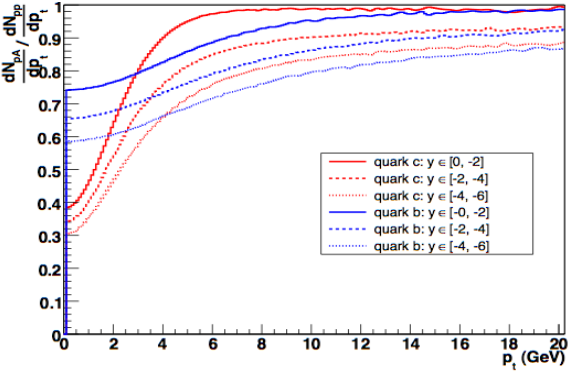
- $R_{pA} = 1 \Rightarrow$ absence of nuclear and medium effects, a p-nucleus collision is the superposition of independent nucleon-nucleon collisions
- $R_{pA} \neq 1 \Rightarrow$ presence of initial state effects !





Nuclear modification factor on the quark level

different rapidity windows



more forward rapidity $\hookrightarrow$ smaller x $\hookrightarrow$ R_{pA} decreases

Comparison between two formalisms: numbers

- yield ratio for p+p collisions

N_b/N_c	MNR	CGC
5.5 TeV	0.03	0.09
8.8 TeV	0.03	0.10
14 TeV	0.04	0.11

- nuclear modification factor (p+Pb/p+p) @ 8.8 TeV

R_{Pb-p}	charm	beauty
MNR	0.77	0.85
CGC	0.60	0.80

Remarks about the p_t and y distributions

1. quarks kinematical distributions
   - significantly harder p_t distributions for the CGC model compared to the MNR one
   - the multiple scattering processes present in the CGC populate the mid-p_t range of the spectra
   - depletion in the forward region of the rapidity distributions (for charm)
   - the cross section ratios for beauty over charm production for different collision energies is smaller than 5% for the MNR model, the CGC model gives a ratio larger than 10%
2. nuclear modification factor
   - the values of shadowing factors for beauty production are very close in both models
   - for charm production the shadowing factor shows a large influence of gluon recombination effects in the CGC model, larger than the shadowing in the EKS98 parametrisation used in the MNR model
   - because of a smaller mass, charm is more sensitive to the recombination effect

Fragmentation and decay

- Fragmentation function (Peterson): gives the probability to transform the quark q into the hadron H
- Decay of hadrons via semi-muonic channel

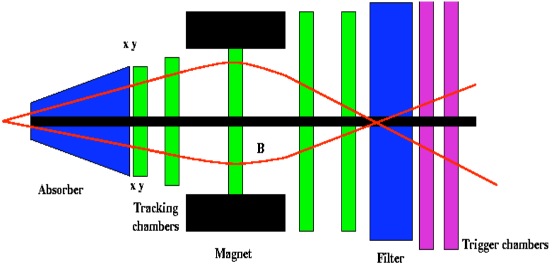
Saturation observation via muons?

Dimuon Forward Spectrometer of ALICE is composed of:

- the front absorber: absorbs all particles except muons coming from the vertex
- **the inner beam shield**: protects against particles produced at small angles
- the tracking system: 5 stations of two Cathode Pad Chambers $\sim$ 100 m^2
- the passive muon filter: an iron wall of 1.2 m thickness
- the trigger chambers: 4 planes of Resistive Plate Chambers
- **the large dipole magnet**

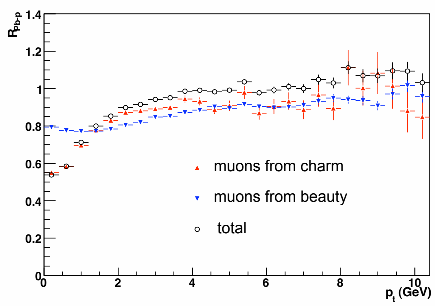
Main characteristics:

- the pseudorapidity range is -4 $\leq \eta \leq$ -2.5
- the mass resolution $\sim$ 70 (100) MeV/c^2 for J/ψ (Υ)
- the spatial resolution < 100 μm in the bending plane
- tracking: 1.1 millions channels, occupancy < 5%
- up to 500 hits on the first station
- trigger for muons: "low" and "high" p_t cut are 1 and 2 GeV/c respectively

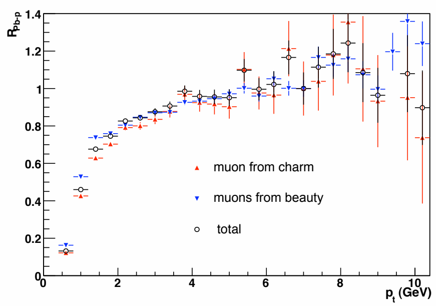


Single muons spectra

generation



reconstruction



Conclusions and perspectives

1. Conclusions
   - ⊛ for charm: big difference between CGC and MNR formalism
   - ⊛ for beauty: good agreement between the two models

In CGC case, charm is more sensitive than beauty to the effect of the gluon recombination and multiple scattering

2. Perspectives
   - ⊛ multiplicity of the charged particles at forward rapidity region ⇒ under study
   - ⊛ J/ψ production in the CGC formalism ⇒ work in progress