Ultraperipheral collisions at LHC and small x physics

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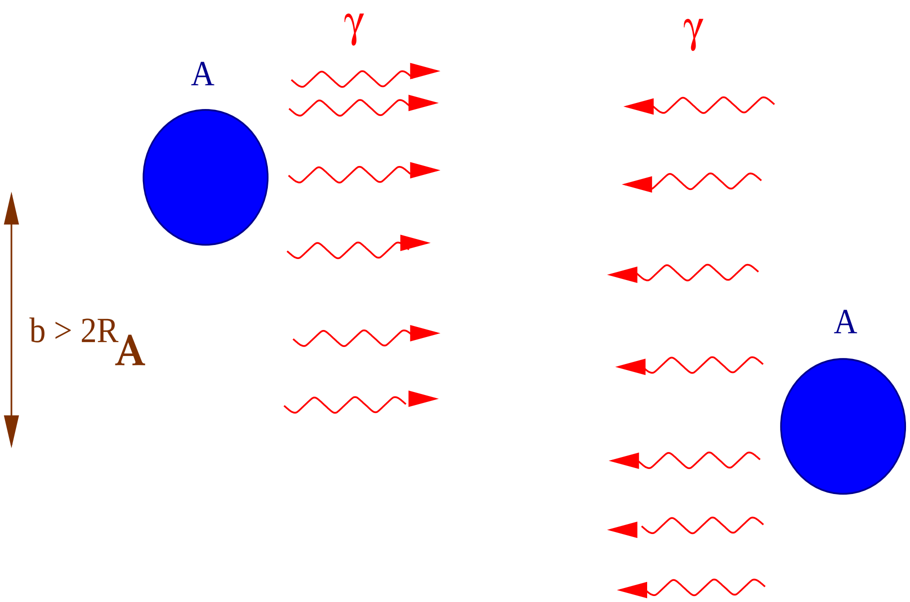
Outline

1. Introduction: What is UPC and why it is doable
2. Lessons/ questions from HERA
3. What can be measured/discovered

A study group is working now on the Yellow CERN report: UPC studies at LHC

Vth Workshop on Small-x and Diffractive Physics, September 17, 2003

Definition of UPC: collisions of nuclei at impact parameters $b \geq 2R_A$ where strong interactions are negligible



Ultraperipheral Nucleus–Nucleus Collision

Trigger: One or both nuclei remain intact

Breakup of nuclei due to the Coulomb excitations are allowed (emission of few soft (in the nucleus rest frame) neutrons. Contribution of strong interactions due to nucleus-nucleus scattering at $b \sim 2R_A$ is a small correction (weak A-dependence & small probability of diffraction). One can also study asymmetric UPC - $pA, \& AA$

Counting rates are large up to

$$s_{eff}^{\gamma A}(LHC) \sim (1TeV)^2, \sim 10 s_{max,\ HERA}(\gamma p)$$

Example: exclusive vector meson production

$$\frac{d\sigma(AA \to VAA)}{dy} = N_\gamma(y)\sigma_{\gamma A \to VA}(y) + N_\gamma(-y)\sigma_{\gamma A \to VA}(-y).$$

$$rapidity \quad y = \frac{1}{2}\ln\frac{E_V - p_3^V}{E_V + p_3^V} = \ln\frac{2k}{m_V}.$$

The flux of the equivalent photons $N_\gamma(y)$ is

$$N(y) = \frac{Z^2\alpha}{\pi^2}\int d^2b\Gamma_{AA}(\vec{b})\frac{1}{b^2}X^2[K_1^2(X) + \frac{1}{\gamma}K_0^2(X)].$$

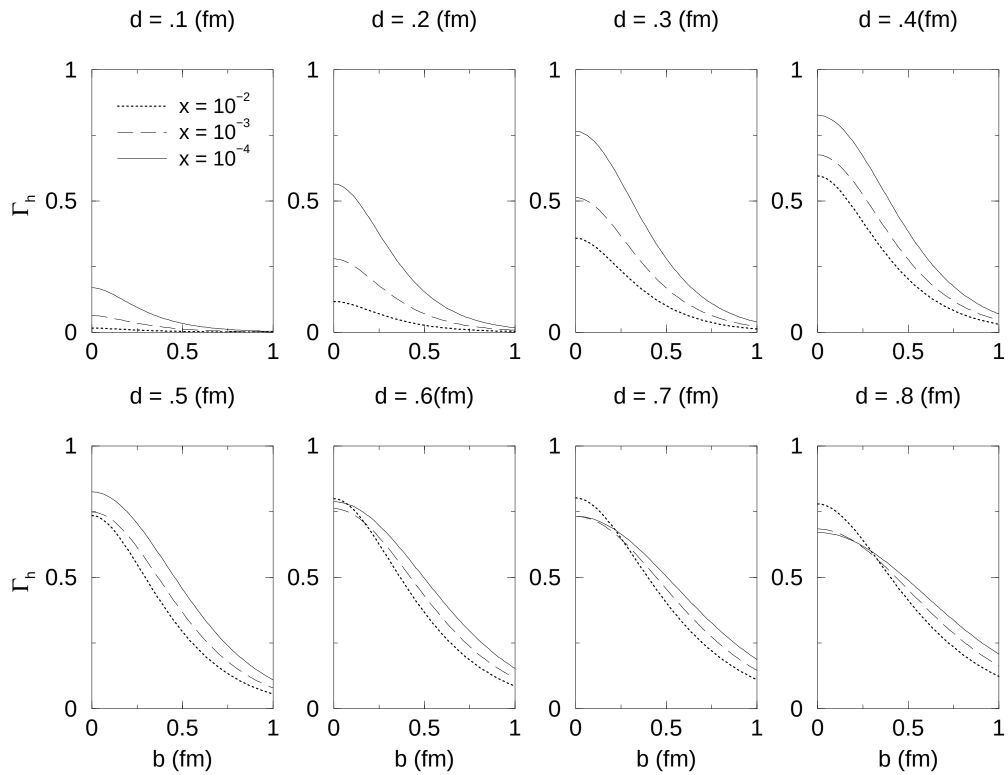
$K_0(X), K_1(X)$ – modified Bessel functions with argument $X = \frac{bm_V e^y}{2\gamma}$, γ is Lorentz factor and $\vec{b}$ is the impact parameter.

The first data from STAR (RHIC) (S.Klein talk). Corrections to vector dominance model + Glauber are small $\longrightarrow$ reaction tests understanding of the UPC picture: $\sigma_{coh}^{th} = 490$ mb (Frankfurt, Zhalov, MS) to be compared to the STAR value $\sigma_{coh}^{exp} = 370 \pm 170 \pm 80$ mb.

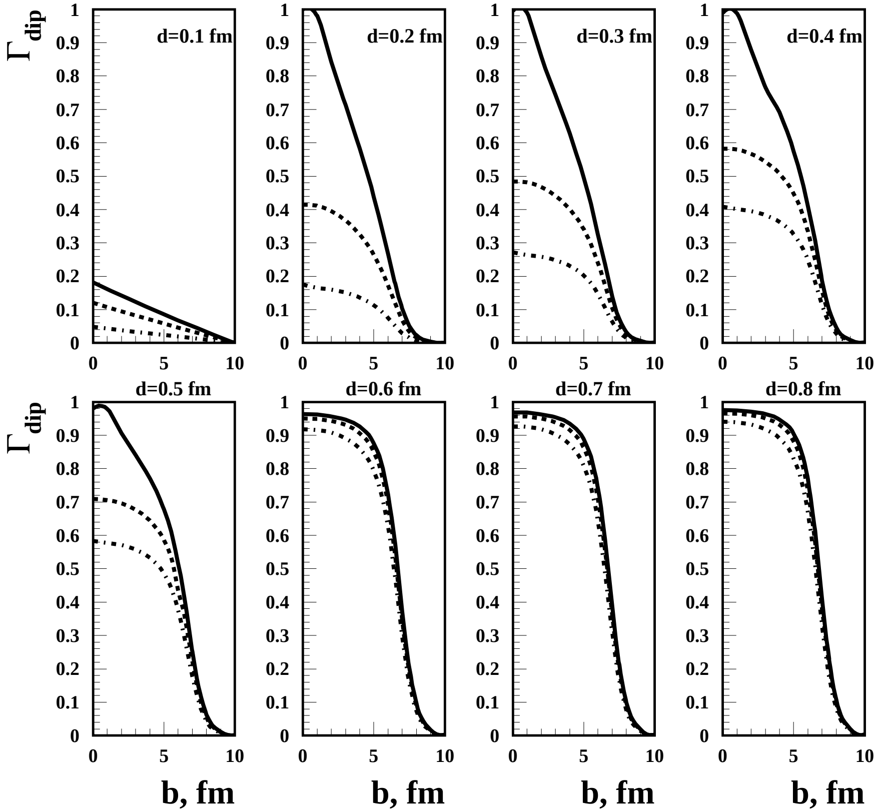
Lessons from HERA

- Interaction of small dipoles approaches black body limit (BBL) with increase of energy. One needs higher energies in the quark sector than the ones available at HERA for protons. One can extract from the analysis of the HERA data the profile functions for scattering of the quark-triplet dipoles of size d with nucleon and nucleus (remember in pQCD for 88^* dipole -hadron scattering $\Gamma(b)$ is 9/4 times larger).

$\Gamma(b) = 1$ corresponds to the BBL $\sigma_{inel} = \sigma_{el}$.



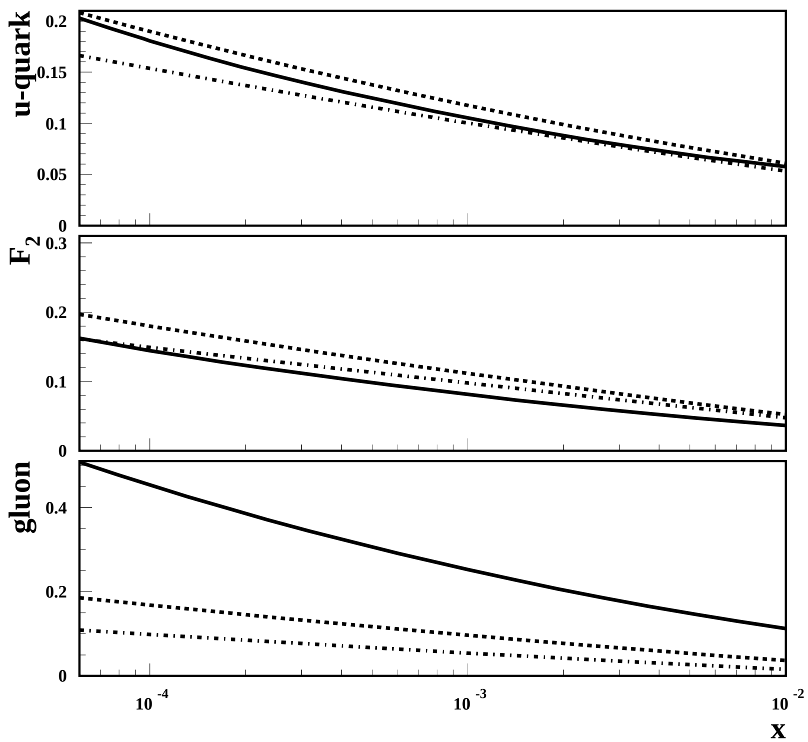
The hadronic configuration-nucleon profile function for different x values. The large $\Gamma_h(b)$ region ($\Gamma_h \geq 1/2$) is reached for intermediate hadronic sizes. T.Rogers, et al



The hadronic configuration-nucleus (^{208}Pb) profile function. The solid curves correspond to $x = 3 \times 10^{-4}$; the dashed curves correspond to $x = 10^{-3}$; the dot-dashed curves correspond to $x = 0.01$. T.Rogers, et al

$\Gamma_A(b)$ is significantly larger than $\Gamma_N(b)$ (in spite of taming due to the leading twist shadowing). Also, $\Gamma_A(b) \sim 1$ for a large b range.

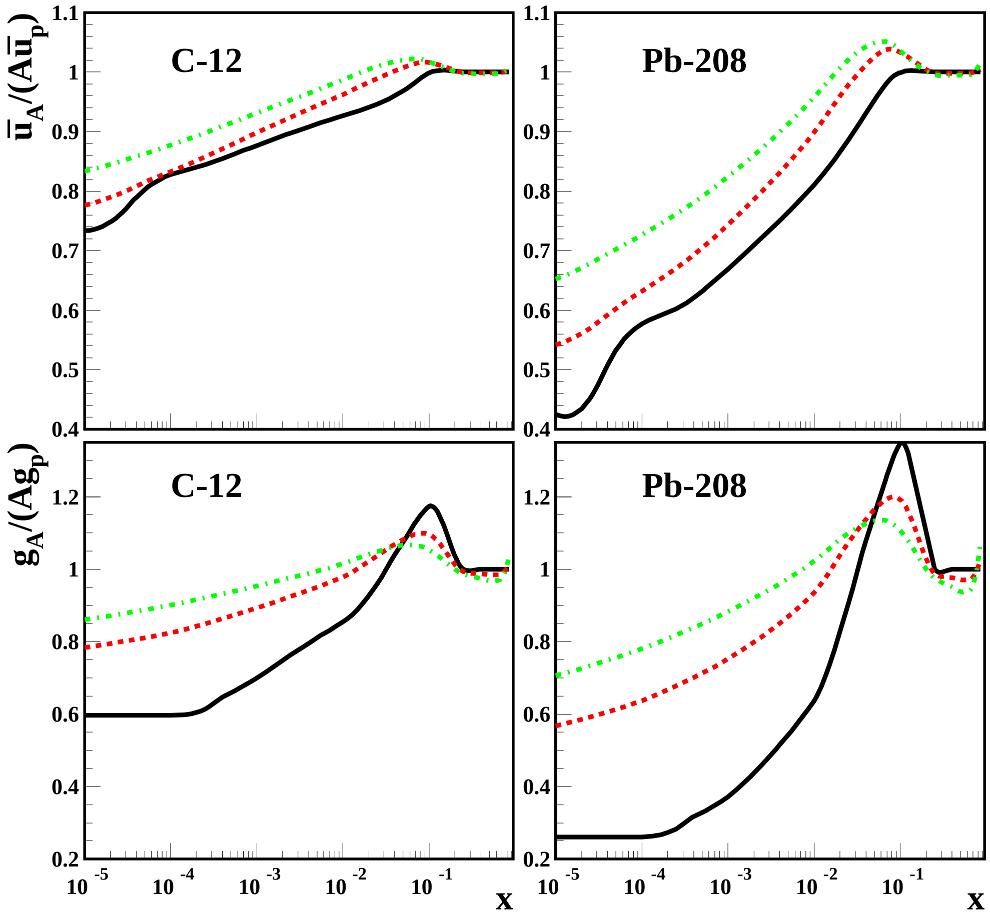
• At HERA hard diffraction in the gluon channel is close to the BBL value of 1/2 for $Q^2 \sim 4GeV^2$ for $x \leq 10^{-3}$. In the figure the ratios of the diffractive parton densities, $f_{j/N}^{D(2)}$ and parton densities $f_{j/N}$ for the u-quarks and gluons and NLO $F_{2N}^{D(2)}/F_{2N}$ are presented. The solid curves correspond to $Q = 2$ GeV; the dashed curves correspond to $Q = 10$ GeV; the dot-dashed curves correspond to $Q = 100$ GeV.



$\Longrightarrow$ Need higher energies, more detailed studies of the channels dominated by direct coupling to gluons, as well as a range of the hadronic beams (protons, nuclei) to investigate the dynamics in the kinematics where interactions at large enough virtualities approach BBL.

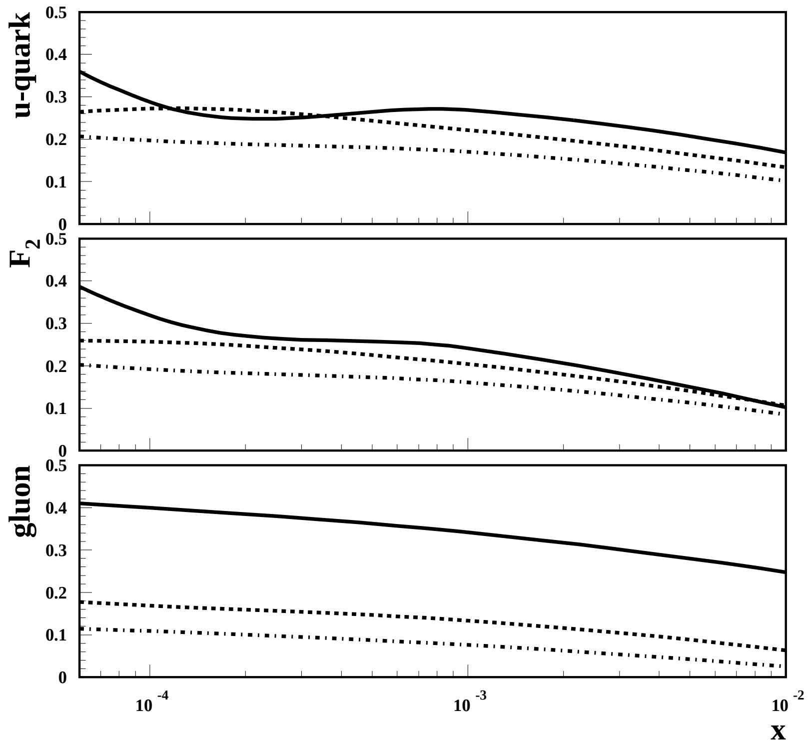
Use of nuclei will allow to study situation much closer to the BBL (no edge effects which will strongly influence scattering off a proton for all energies, L.Frankfurt talk), and also study a new phenomenon - the leading twist nuclear shadowing which is closely related to the leading twist DIS diffraction and can be expressed through diffractive nucleon parton distributions FS 98

Next step: use the HERA measurements of diffractive quark and gluon PDFs which indicate dominance of the gluon induced diffraction to calculate gluon and quark shadowing.



Dependence of G_A/AG_N and $\bar{q}_A/A\bar{q}_N$ on x for Q=2 (solid), 10 (dashed), 100 GeV (dot-dashed) curves calculated using diffractive parton densities extracted from the HERA data, the quasieikonal model for $N \geq 3$, and assuming validity of the DGLAP evolution.

Proximity of the hard interactions with nuclei to BBL leads also to a large probability of diffractive events in nuclei (larger than in the proton). Results of the calculation within the leading twist model (Guzey, et al, 03) are shown the ratios $f_{j/A}^{D(2)}/f_{j/A}$ for the u-quarks and gluons and NLO $F_{2A}^{D(2)}/F_{2A}$ for ^{208}Pb at Q=2,10, 100 GeV.



$\Longrightarrow$ In case of nuclei diffraction at small x should constitute a large fraction of the total cross section up to large Q^2 (p_t of the jets, like in $\gamma + A \rightarrow two\ jets\ + X + A$)

What can be measured/discovered in UPC at LHC

- Hard inclusive processes. Measurement of parton densities using $\gamma - N(A)$ interactions for $W_{\gamma N} \leq 1TeV$. (Photon flux becomes small for larger W). Typical statistics e.g. for production of charm for $x \sim 10^{-5}$ is 10^6 events/nuclear run R.Vogt. Main constrains will come from acceptance of detectors (for charm y up to 5 would be necessary). Using different channels: charm, bottom, dijets, γ-jet measurements of parton densities (primarily gluons) with a number of cross checks (including measurements within the pA program in the case of nuclei).

- Looking for the breakdown of the QCD factorization (γA versus AA)
- Violation of the DGLAP equations
- measurement/discovery of the leading twist gluon shadowing

Exclusive onium production

For J/ψ photoproduction off a nucleon can be measured in pA scattering up to $W = 800 GeV$ (FELIX study). For $x \sim m^2_{J/\psi}/W^2 \sim 10^{-5}$ dipoles with $d \sim 0.25 fm$ are likely to interact with $\Gamma(b) \sim 1$ for $b \leq 0.5 fm$.

$\longrightarrow$ Onset of new regime.

AA collisions - one can reach $W_{\gamma N} = \sqrt{4 E_N m_V}$ due to the dominance of photons with smaller energy. $\longrightarrow x_{min}(J/\psi) = 0.0005, x_{min}(\Upsilon) \sim 0.0015.$

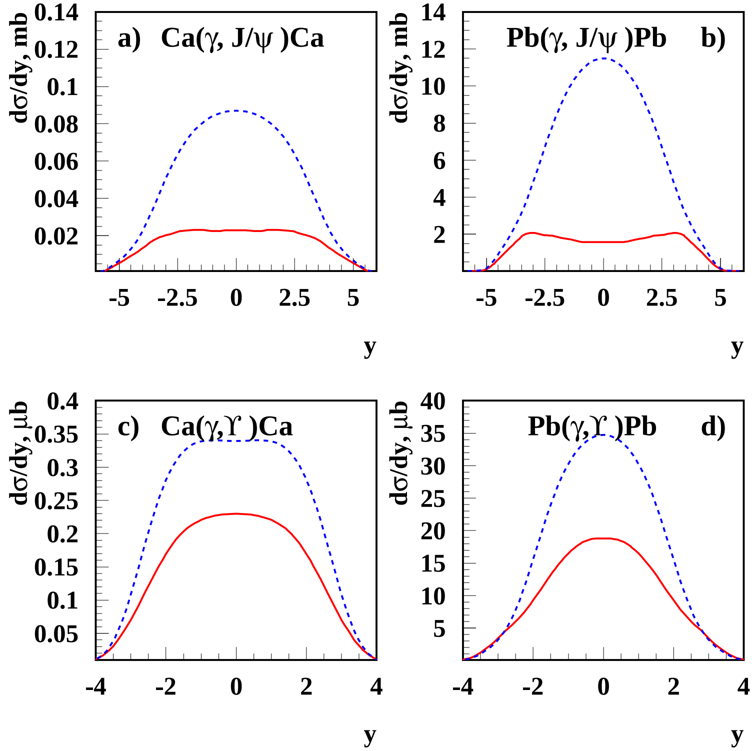
The leading twist prediction is

$$\sigma_{\gamma A\to VA}(s) = \frac{d\sigma_{\gamma N\to VN}(s,t_{min})}{dt}\left[\frac{G_A(x_1,x_2,Q^2_{eff},t=0)}{AG_N(x_x,x_2,Q^2_{eff},t=0)}\right]^2.$$

$$\cdot\int\limits_{-\infty}^{t_{min}} dt\left|\int d^2b dz e^{i\vec{q}_t\cdot\vec{b}} e^{-q_l z}\rho(\vec{b},z)\right|^2,$$

where $x_1 - x_2 = \frac{m_V^2}{s} \equiv x$.

☛ Onset of perturbative color opacity at small x and onium coherent photoproduction.



The rapidity distributions for the J/ψ and Υ coherent production off Ca and Pb in UPC at LHC calculated with the leading twist shadowing based on H1 parameterization of gluon density(solid line) and in the Impulse Approximation(dashed line).

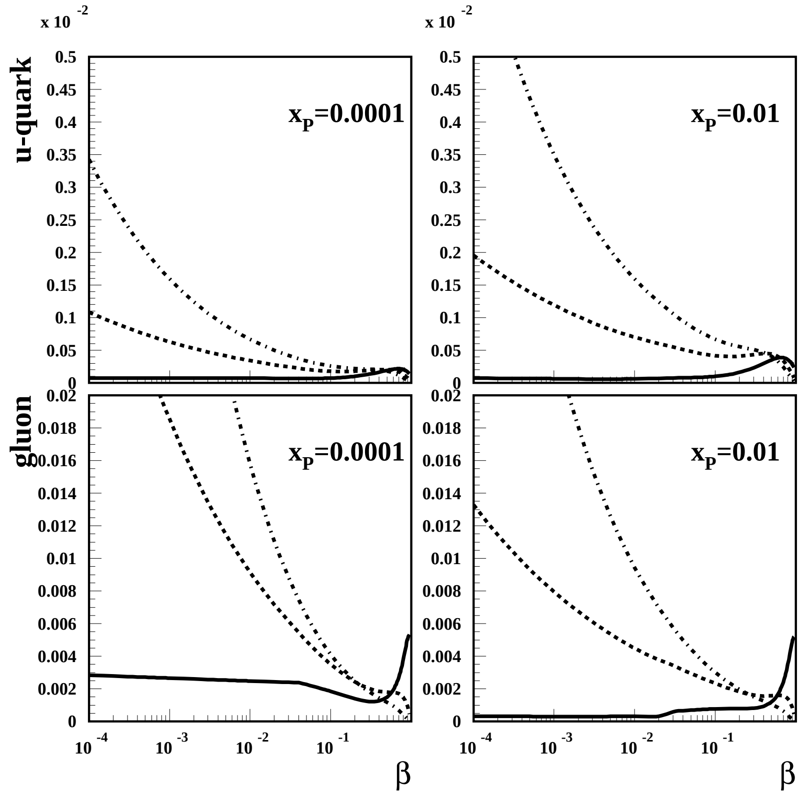
Approximation	Ca-Ca at LHC($\gamma = 3500$)	Pb-Pb at LHC($\gamma = 2700$)
Impulse	0.6 mb	70 mb
Leading twist	0.2 mb	15 mb

Table 1: Total cross sections of J/ψ production in UPC at LHC.

Approximation	Ca-Ca at LHC($\gamma = 3500$)	Pb-Pb at LHC($\gamma = 2700$)
Impulse	1.8 μb	133 μb
Leading twist	1.2 μb	78 μb

Table 2: Total cross sections of Υ production in UPC at LHC.

☛ Measurement of the diffractive parton distribution functions.



The u-quark and gluon nuclear (^{40}Ca) diffractive parton distribution as a function of β at two fixed values of $x_{I\!P}$. The solid curves correspond to $Q = 2$ GeV; the dashed curves correspond to $Q = 10$ GeV; the dot-dashed curves correspond to $Q = 100$ GeV.

The measurements are doable practically for the whole range where inclusive measurement of pdf's will be possible. Key element - possibility to use the direct photon mechanism to determine which of the nuclei has emitted the photon.

- Probing the onset of the BBL

  - In the BBL amplitudes weakly depend on the virtualities for the scales where BBL holds.
  - Strong suppression of the leading hadron production combined with a very significant broadening of the p_t spectrum Dumitru, Gerland, MS
  - Strong enhancement of the process $\gamma + A \to 2jets + A$ (Guzey et al 02) as compared to the leading twist predictions.

$$\frac{d\sigma_{(\gamma+A\to``M''+A)}}{dtdM^2} = \frac{\alpha_{em}}{3\pi}\frac{(2\pi R_A^2)^2}{16\pi}\frac{\rho(M^2)}{M^2}\frac{4\left|J_1(\sqrt{-t}R_A)\right|^2}{-tR_A^2},$$

where $\rho(M^2) = \sigma(e^+e^- \to hadrons)/\sigma(e^+e^- \to \mu^+\mu^-)$.

Conclusions:

- UPC collisions will allow to probe QCD in the energy range overlapping with HERA, extending it a factor of ten, and adding an important new dimension - nuclei.

- Minimal virtualities will be significantly larger, corresponding to $Q^2 \geq 10 GeV^2$ except for J/ψ photoproduction.

- Complementary to measurements in proton-ion collisions at LHC which can reach smaller x, but hardly can go below $Q^2 \sim 50 GeV^2$ for the gluon channel.

- Adding forward acceptance and (for some of the detectors) handle low multiplicity events is desirable.

- TOTEM will be very useful for UPC especially for pA scattering