Probing small x QCD in ultraperipheral collisions at LHC

HERA III at LHC

Mark Strikman, PSU

Based on the analyses performed together with
L.Frankfurt, V.Guzey, R.Vogt, C.Weiss, S.White, M.Zhalov

KEK, December 6, 2005

Outline

- Introduction: What is UPC, why it is doable and why small x are interesting

- Breakdown of pQCD at small x and the black disk scenaio

- Lessons & questions from HERA

- What can be measured/discovered

Our study group is finishing work on the CERN Yellow report on UPC

Main thrusts of the HERA small x QCD physics:

- Small x parton densities
- Inclusive hard diffractive processes
- Hard exclusive processes: vector meson production, dijets, ...

Main issues:

- high gluon densities, violation of DGLAP,
- diffractive pdf’s   - leading twist vs higher twist;
- generalized parton densities at small x

Theory - gluons are most interesting for small x:

- they drive evolution and quark sea,
- interaction in the gluon sector is much stronger

• Crucial for understanding the structure of the underlying events in *central* pp collisions at LHC (the only collisions contributing to the new particle production) F & S & Weiss 03:

A parton with a given x_1 *and resolution* p_t *is sensitive to partons in another nucleon with*

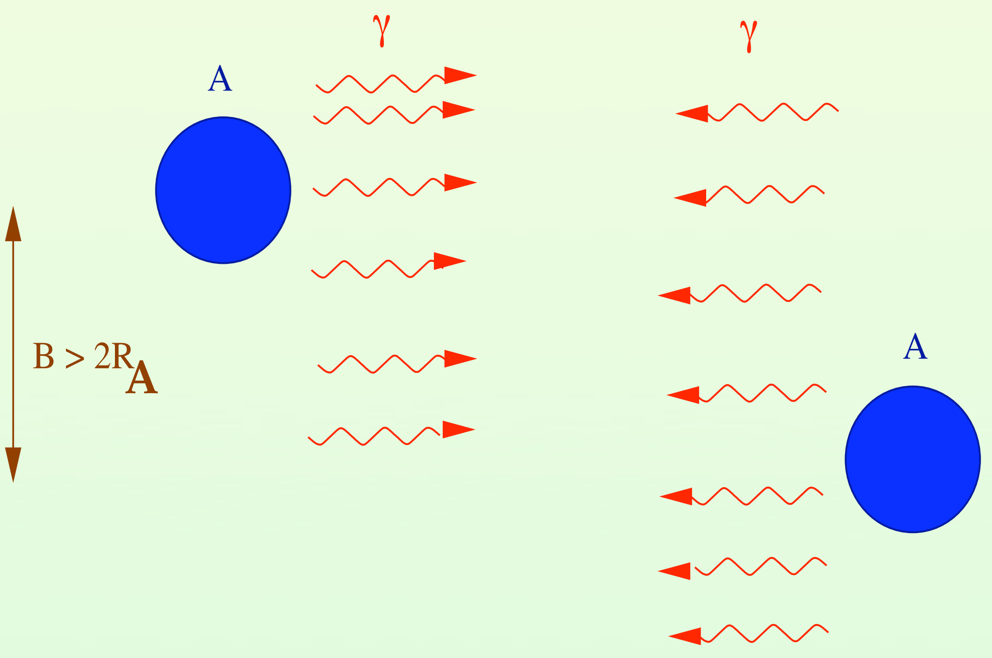
$$x_2 = \frac{4p_t^2}{s_{NN} x_1}$$

At LHC for $x_1 = 0.01, p_t = 2$GeV/c, $x_2 \sim 10^{-5}$!!.

Theory & HERA experience: photoproduction of dijets, heavy quarks, exclusive heavy meson production are good "*gluonometers*"

Ultraperipheral Collisions $\equiv$ *UPC*

What is UPC? Collisions of nuclei (pA) at impact parameters $b \geq 2R_A$ where strong interaction between colliding particles is negligible



Ultraperipheral Nucleus–Nucleus Collision

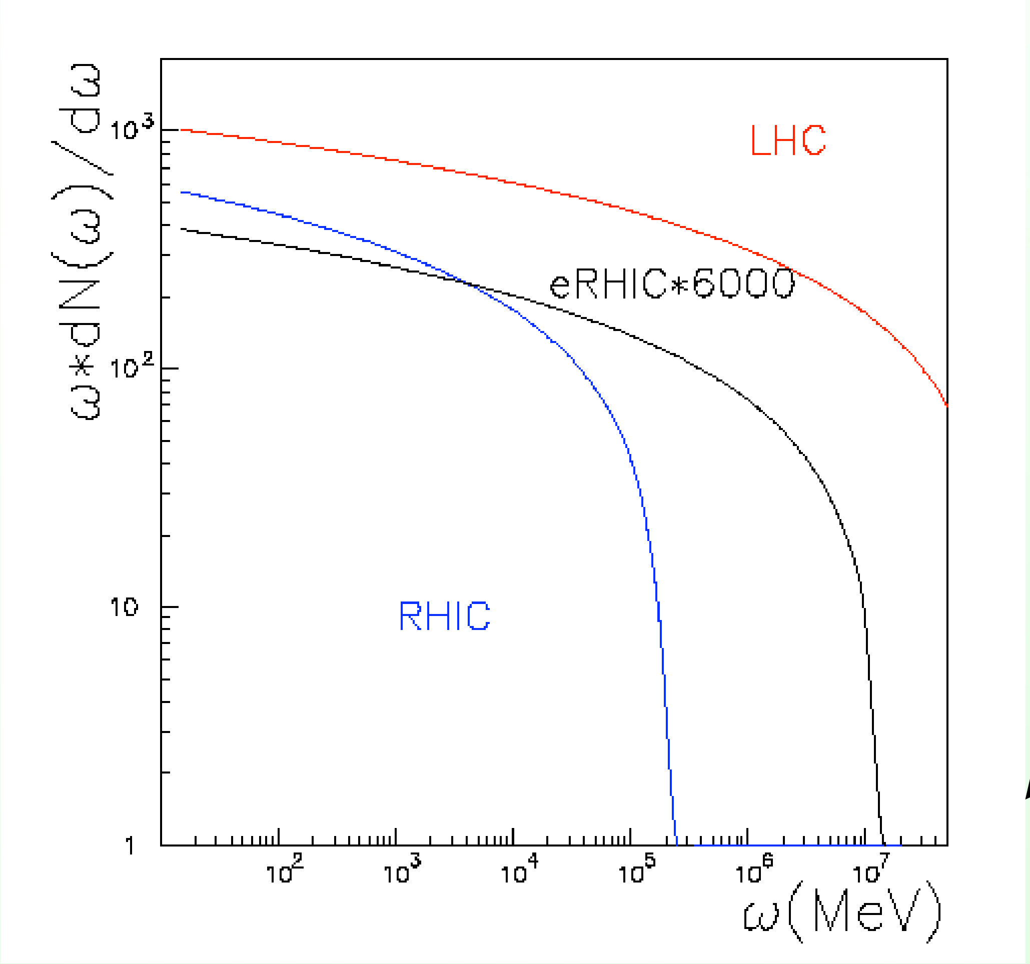
Trigger: One or both nuclei remain intact

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

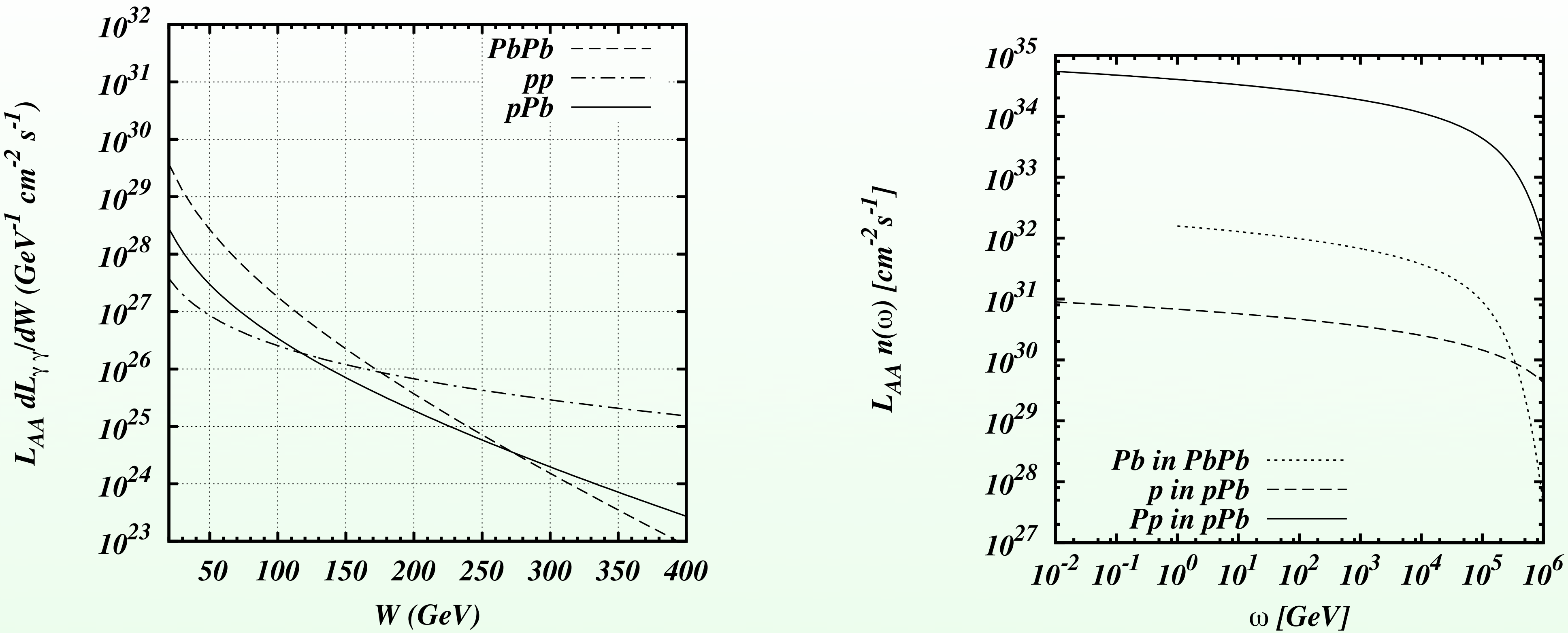
$$s_{eff}^{\gamma A}(LHC) \sim (1TeV)^2, \sim 10 s_{max,\ HERA}(\gamma p)$$

Equivalent Photon spectrum in target nucleus frame



"Quasi-real" γ spectra compared to an e-hadron collider

->100 TeV @ LHC



(a) The effective γA luminosity, $L_{AB}n(\omega)$, is shown for the cases where the photon is emitted from the proton(γPb) and the ion (γp) as well as when the proton is emitted from the ion in a Pb+Pb collision (γPb@Pb+Pb).
(b) The photon-photon luminosities, $L_{AB}dL_{\gamma\gamma}/dW$, are compared for pp, pPb and Pb+Pb collisions at the LHC.

Example: exclusive vector meson production

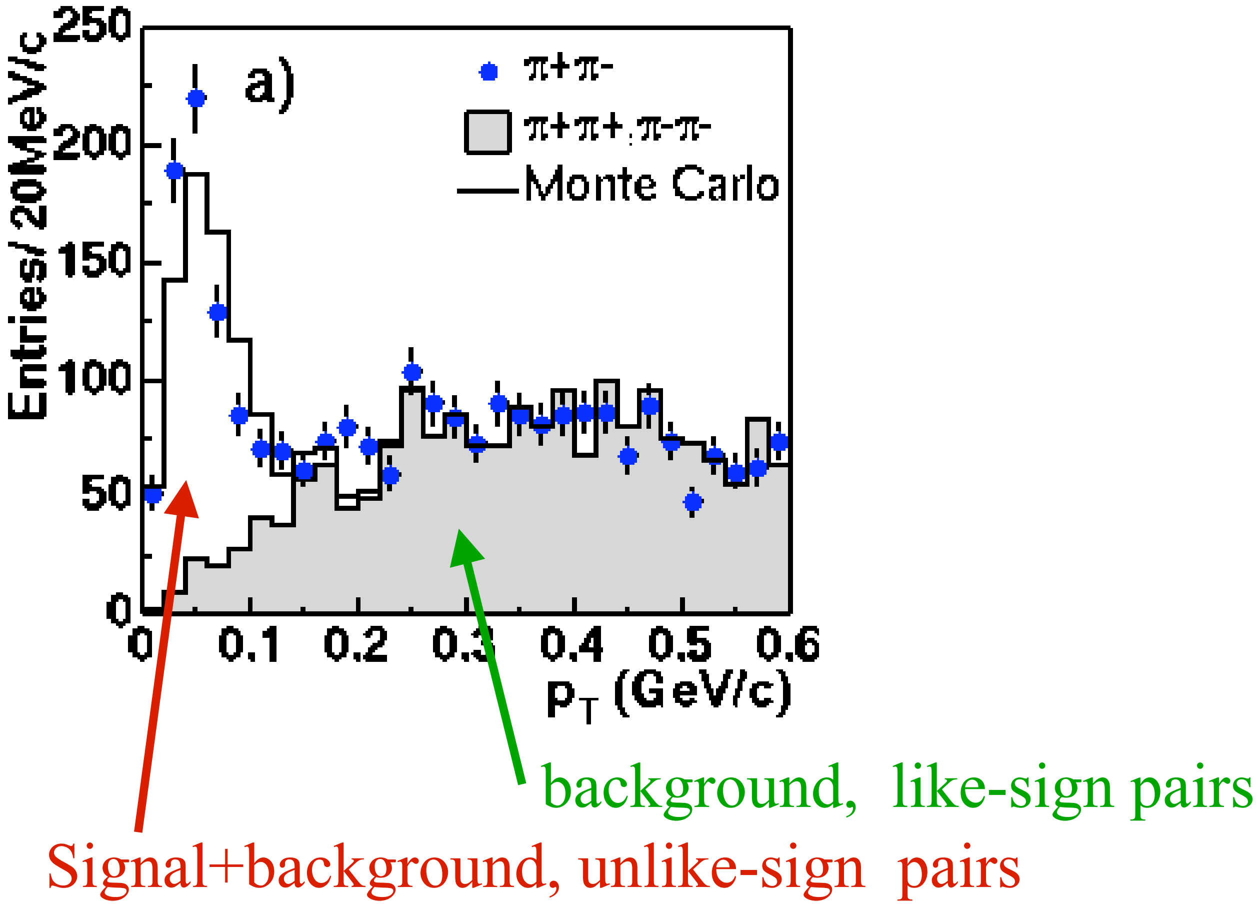
$$\frac{d\sigma(AA \to VAA)}{dy} = N_\gamma(y)\sigma_{\gamma A \to VA}(y) + N_\gamma(-y)\sigma_{\gamma A \to VA}(-y).$$

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

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

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

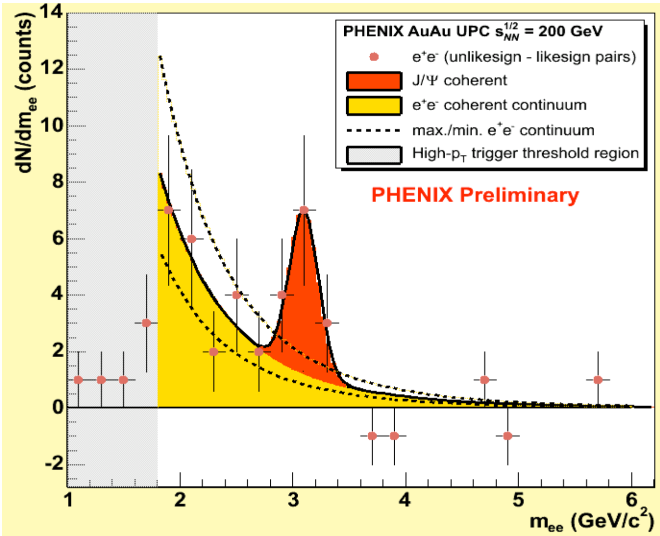
$K_0(X), K_1(X)$ – modified Bessel functions with argument $X = \frac{bm_V e^y}{2\gamma}$, γ is Lorentz factor and $\vec{b}$ is the impact parameter.



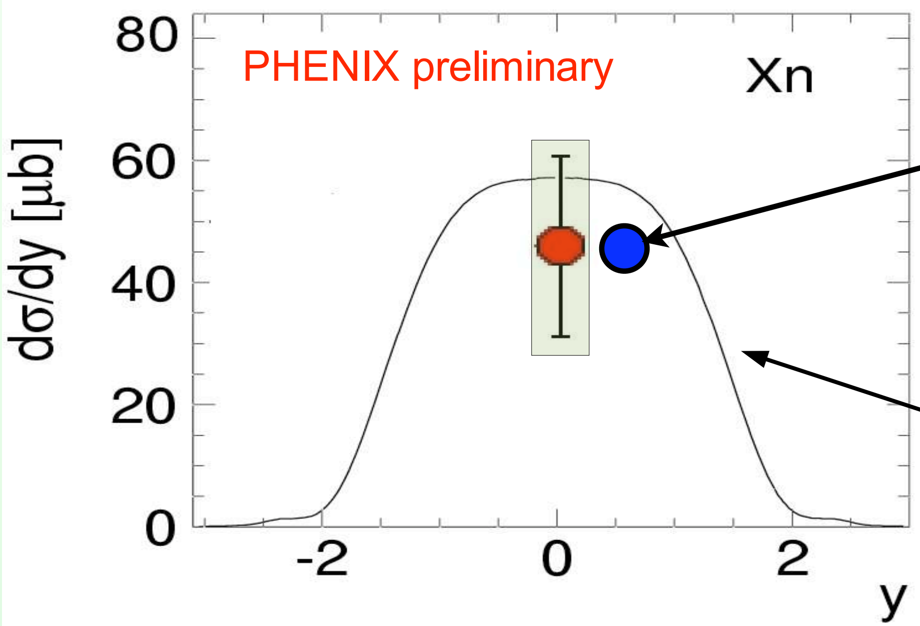
The first data from STAR (RHIC) (S.Klein group). Analysis can be done using vector dominance model coupled with the Glauber model (corrections are small for heavy nuclei)

$\longrightarrow$ reaction tests understanding of the UPC picture: $\sigma^{th}_{coh} = 490$ mb (Frankfurt, Zhalov, MS) to be compared to the STAR value $\sigma^{exp}_{coh} = 370 \pm 170 \pm 80$ mb.

dN/dm$_{ee}$ (background subtracted) w/ fit to (MC) expected dielectron continuum and J/Ψ signals:



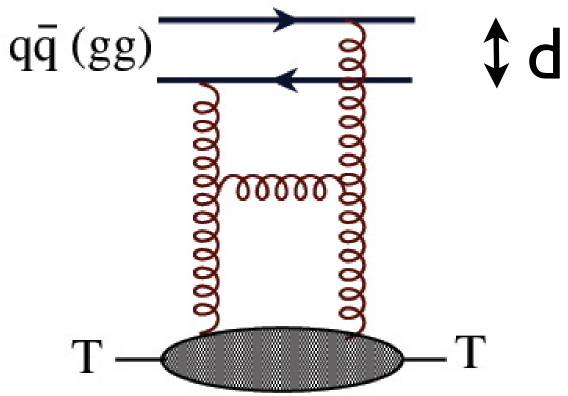
$\boxed{d\sigma_{J/\psi}/dy|_{y=0} = 44 \pm 16\ (\mathrm{stat}) \pm 18\ (\mathrm{syst})\ \mu b}$



MS, Tverskoy, Zhalov - coherent + quasielastic, σ_{eff} (J/ψ N)=3 mb

Nystrand, coherent

Strength of interaction for a small color dipole with hadron



$$\sigma_{inel} = \frac{\pi^2}{3} F^2 d^2 \alpha_s(\lambda/d^2) x G_T(x.\lambda/d^2)$$

F^2 Casimir operator of color SU(3)

F^2 (quark) =4/3 F^2 (gluon)=3

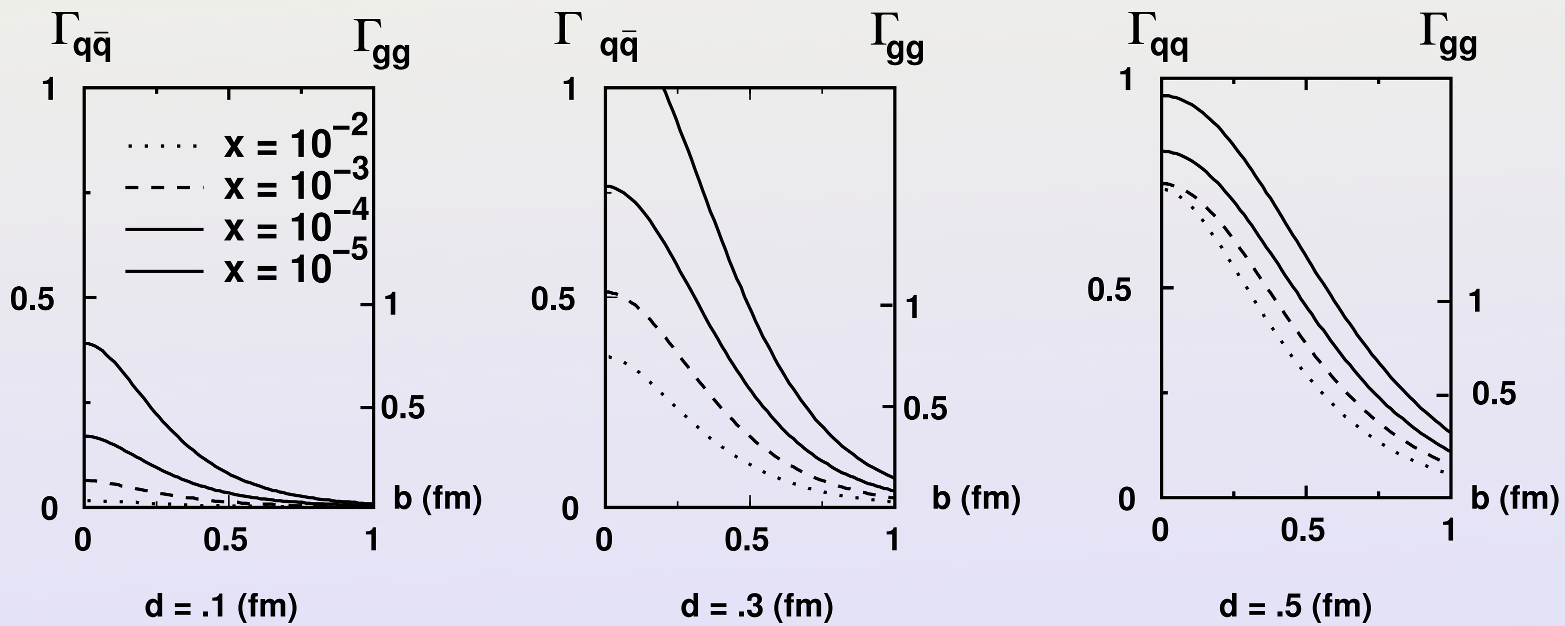
Comment: This simple picture is valid only in LO. NLO would require introducing mixing of different components.

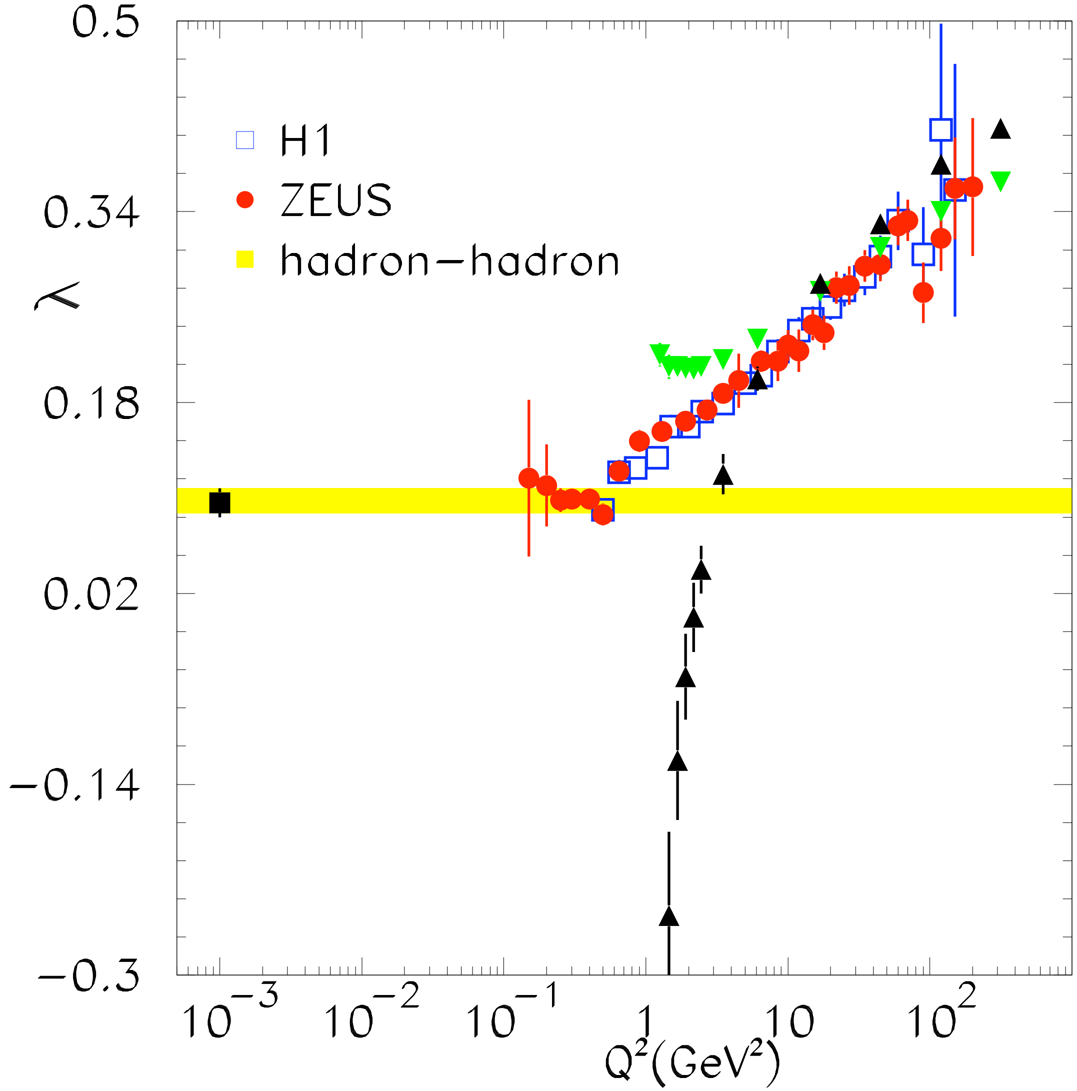
Using information on DIS cross total cross sections and the exclusive hard processes we can also estimate t-dependence of the elastic dipole-nucleon scattering and hence estimate impact factors for $q\bar{q}-N\,scattering$ - $\Gamma_{q\bar{q}-N}$

$$\Gamma_h(s,b)=\frac{1}{2is}\frac{1}{(2\pi)^2}\int d^2\vec{q}e^{i\vec{q}\vec{b}}A_{hN}(s,t);\quad ImA=s\sigma_{tot}\exp(Bt/2)$$

$\Gamma=1$ *corresponds to the black disk limit = BDL -complete absorption*

In the case gg-N scattering we assume pQCD relation $\Gamma_{gg}=\frac{9}{4}\Gamma_{q\bar{q}}$





NLO Fits by ZEUS:

$x\bar{q}(x,Q^2) \propto x^{-\lambda}$

$F_{2p}(x,Q^2) \propto x^{-\lambda}$

$xg(x,Q^2) \propto x^{-\lambda}$

Theoretical prediction: drop of $\lambda(Q^2)$ at small enough x
(Altarelli et al, Ciafaloni et al)

Further evidence for proximity to the black disk regime

- Diffractive phenomena - inclusive diffraction and measurement of diffractive pdf's

Collins factorization theorem: consider hard processes like

$$\gamma^* + T \to X + T(T'),\ \gamma + T \to\ jet_1\ +\ jet_2 + X + T$$

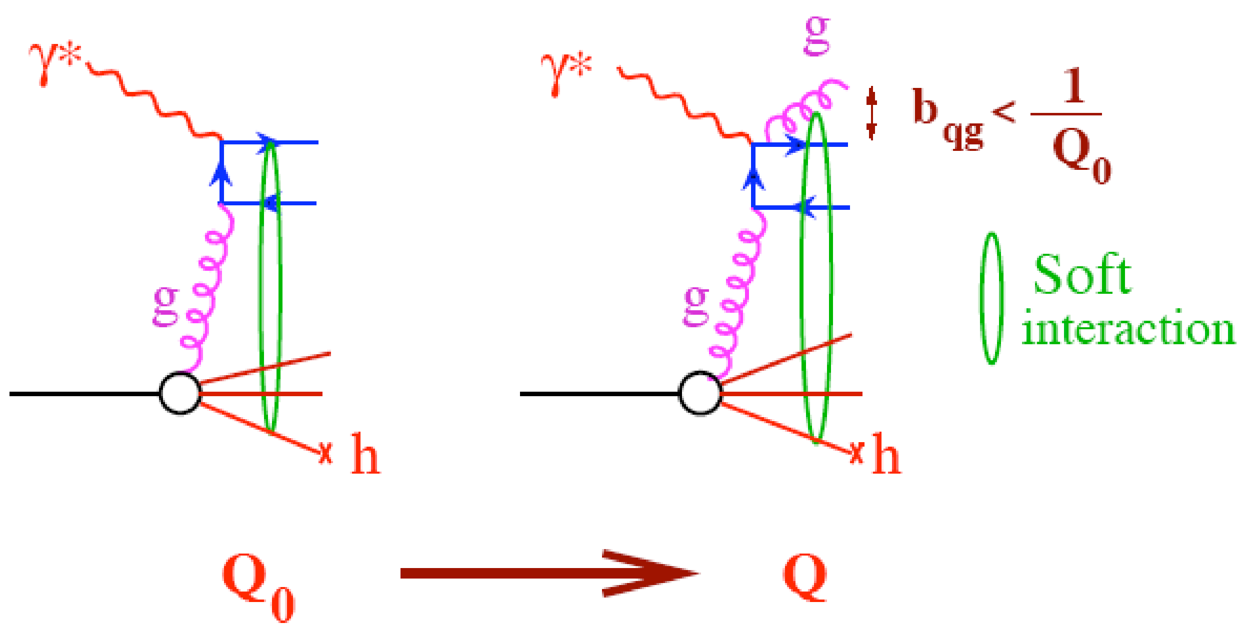
one can define conditional (fractional) parton distributions

$f_j^D(\frac{x}{x_{I\!P}}, Q^2, x_{I\!P}, t)$ where $x_{I\!P} \equiv 1 - x_{T_f}$

Theorem: for fixed $x_{I\!P},\ t$

the same Q evolution as for normal pdf's.

Physics of factorization theorem: Soft interactions between "h" and the partons emitted in the $\gamma^* - parton$ interaction does not resolve changes of color distribution between the scale $Q_0 \gg soft\ scale$ and $Q^2 > Q_0$



$\rightarrow$ Production of "h" when a parton at x, Q^2 is hit is the same as when an "ancestor" parton is hit at x, Q_0^2.

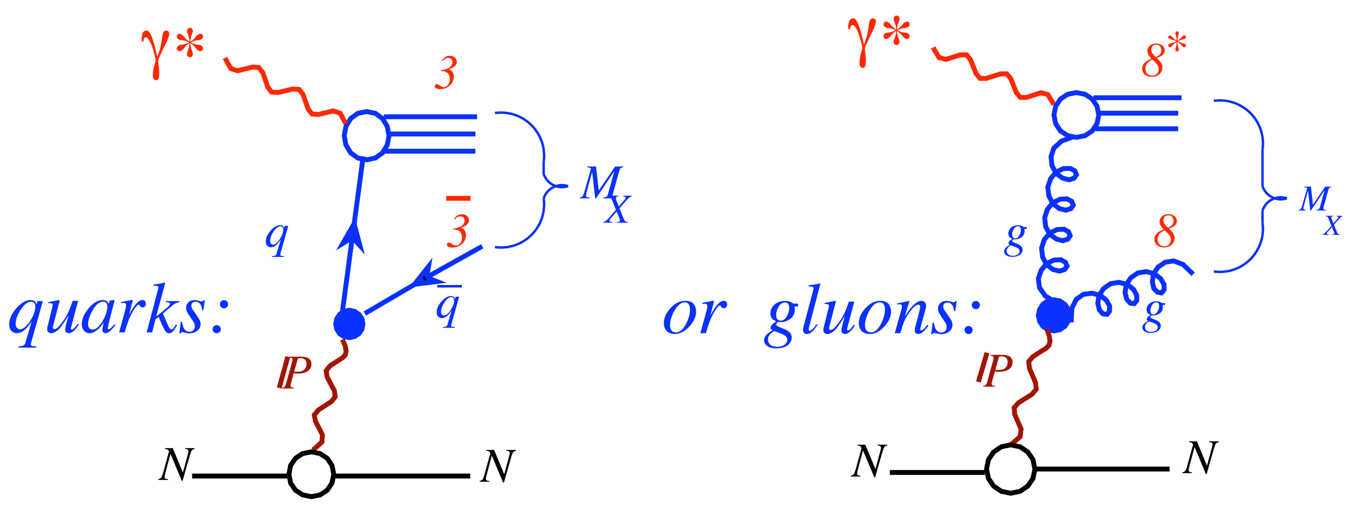
HERA data

(a) Approximate scaling for the diffractive structure functions $f_j(\beta, Q^2, x_{I\!P}, t)$ for $Q^2 \geq 4\, GeV^2$ and large probability of the rapidity gap:

$$P_q = \frac{\sigma(\gamma^* + p \to X + p)_{x_{I\!P} \leq 0.01, x \leq 10^{-3}}}{\sigma_{tot}(\gamma^* + p)} \approx 0.1$$

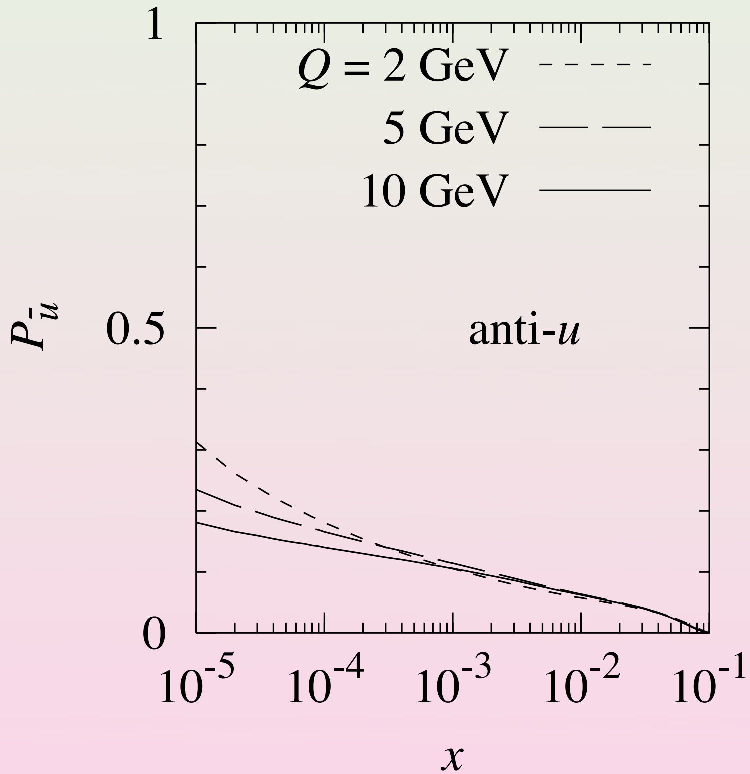
(b) Factorization theorem allows to define a probability $P_j(x, Q^2) =$

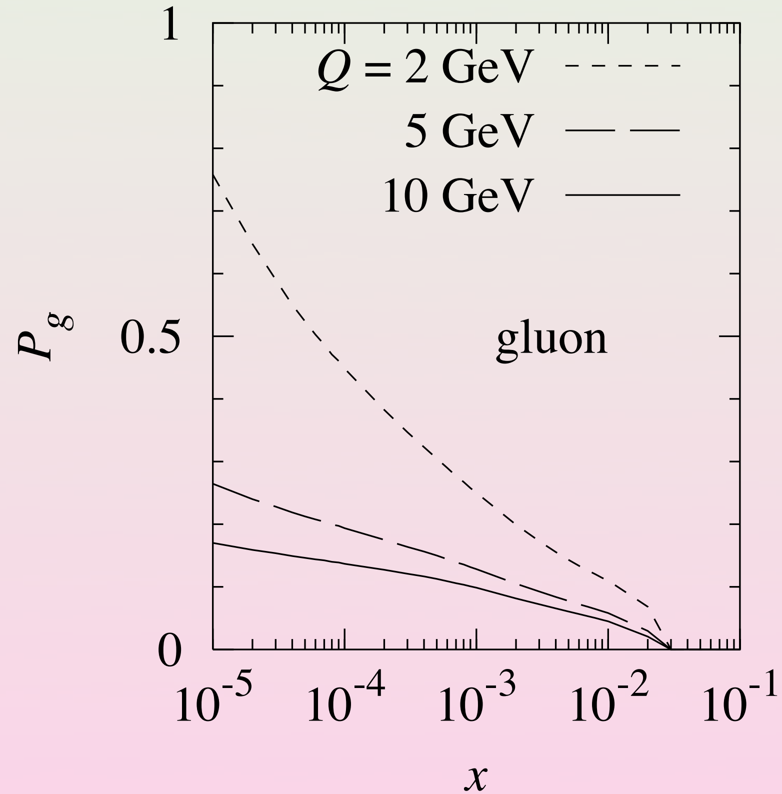
$\int f_j^D(\frac{x}{x_{I\!P}}, Q^2, x_{I\!P}, t) dt dx_{I\!P} / f_j(x, Q^2)$ of diffractive gaps for the hard processes induced by hard scattering off



If the interaction in the gluon sector at small x reaches strengths close to the unitarity limit we should expect P_g *to be reach values rather close to 1/2 and be much larger than* P_q

Consistent with the analysis of the HERA data:

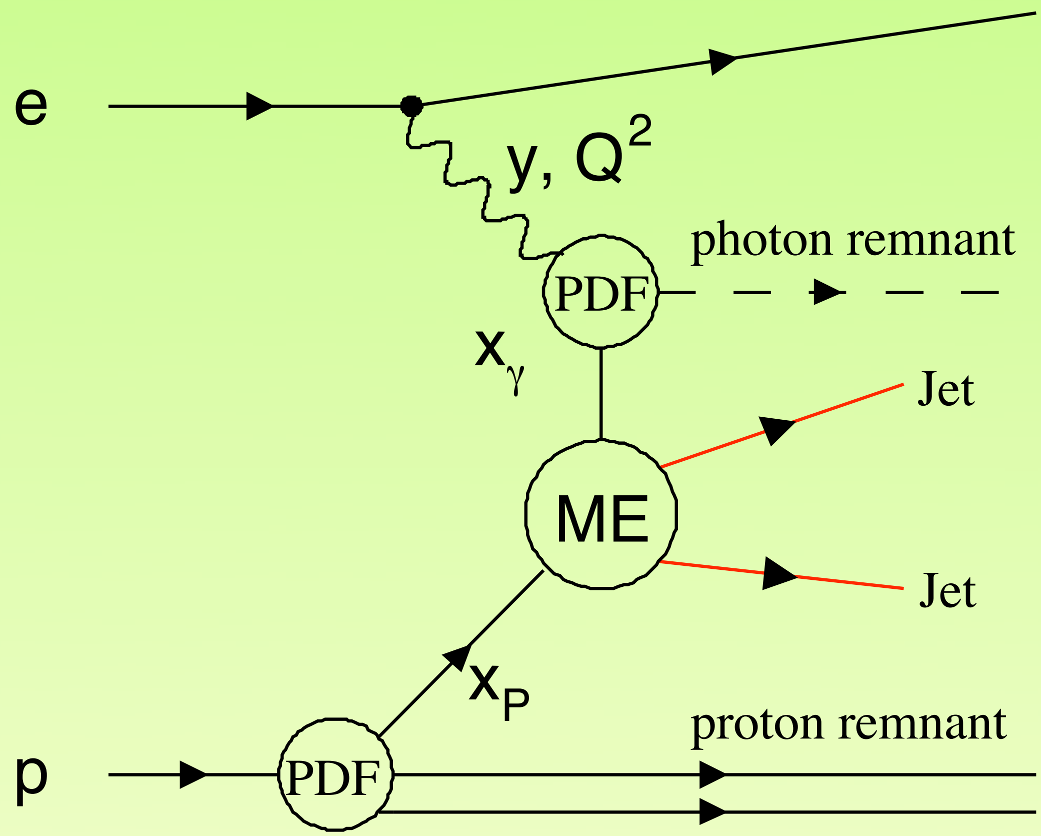




Probability of diffractive scattering from anti– quarks(left)and gluons(right), extracted from a fit to the H1 data.

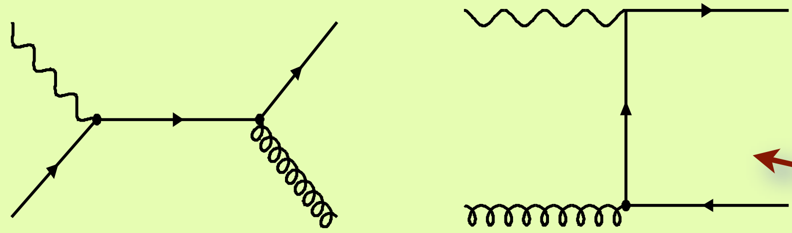
Another lesson from HERA

Real photon was effectively used for the QCD studies



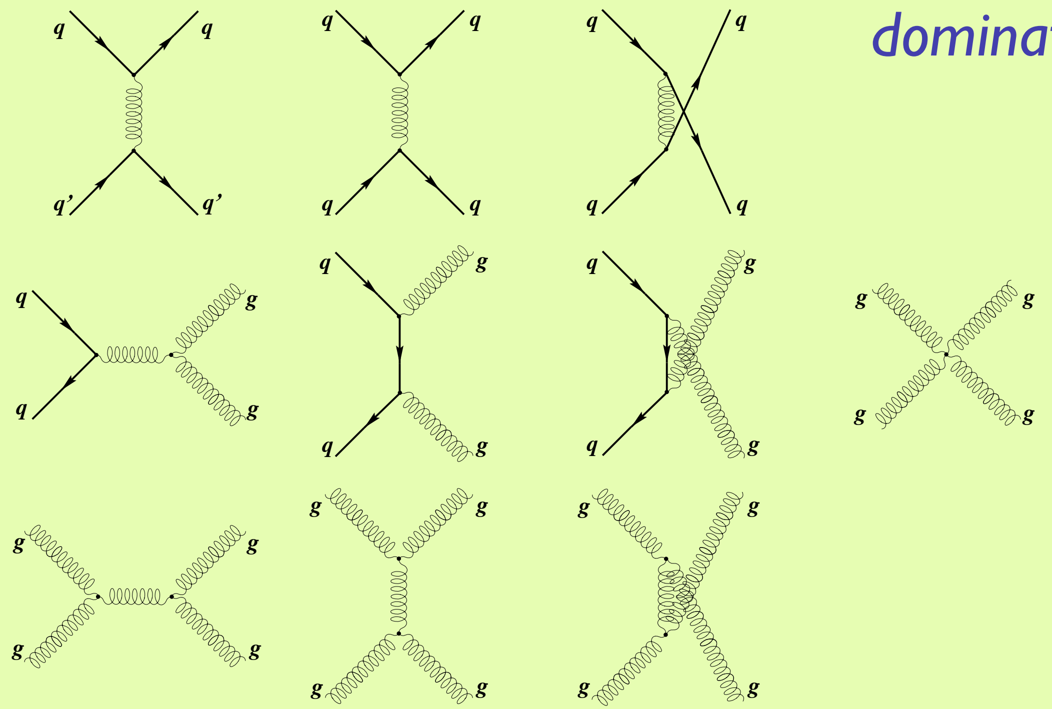
Schematic view of dijet production in ep *scattering studied at HERA*

x_γ *and* x_p *are light cone fractions of partons of photon and proton*



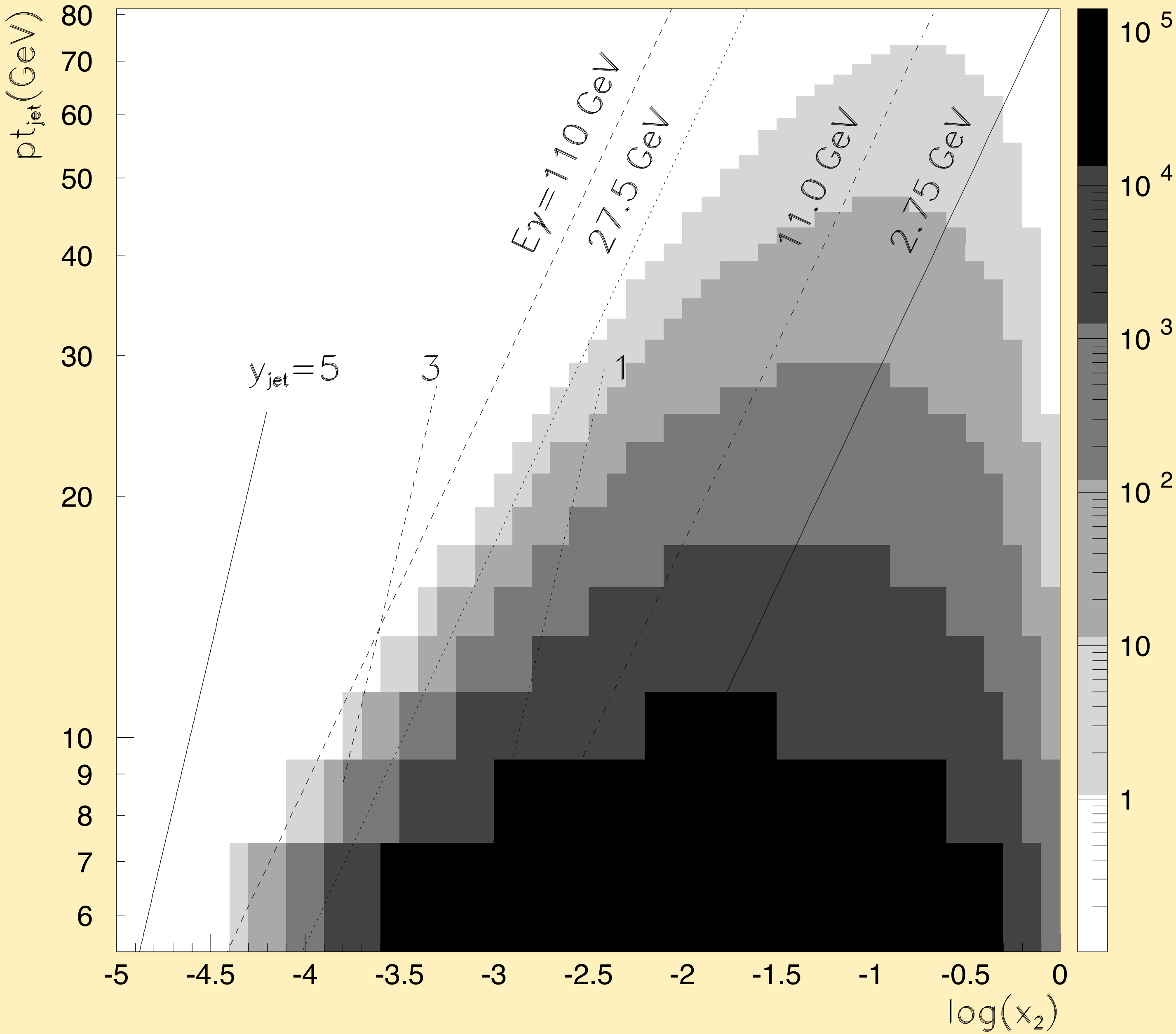
LO diagrams for direct photon: $x_\gamma = 1$

Dominant diagram for small x_p dominated by the nucleon gluon density



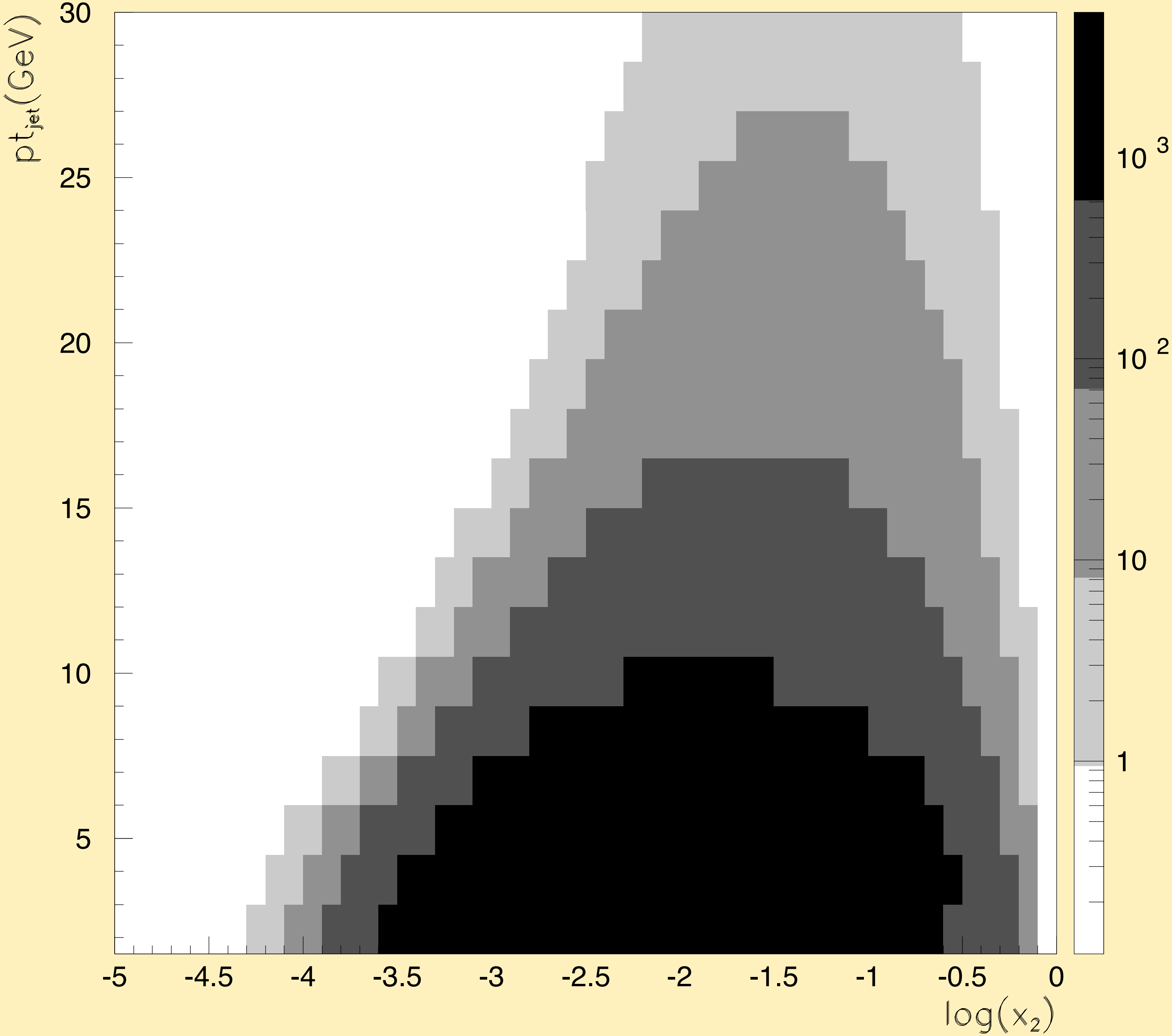
LO diagrams for resolved photon: $x_\gamma < 1$

NLO is important - no separation between direct and resolved mechanisms - recently important theoretical progress - new MC codes are expected to be available soon.

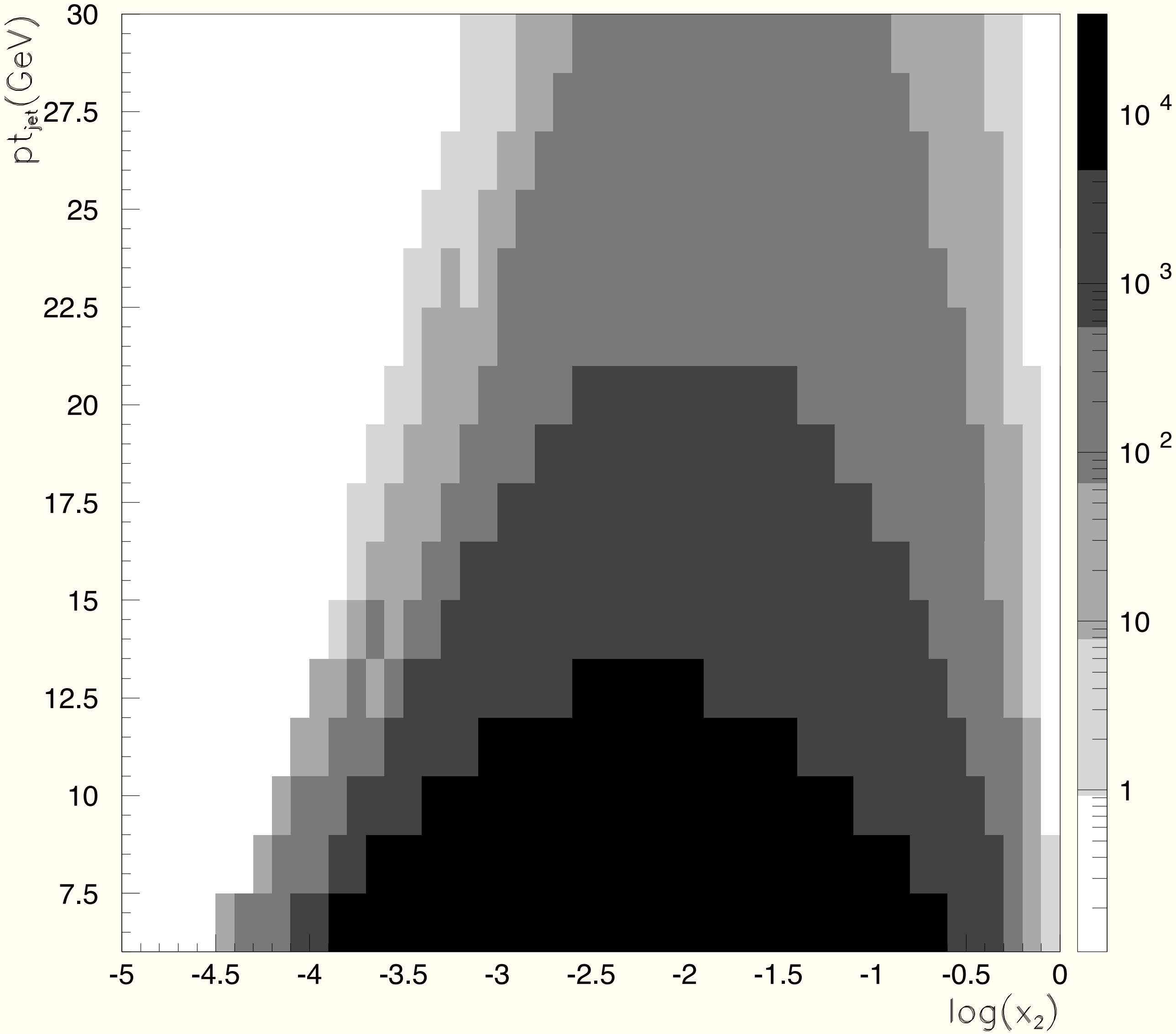


Expected rate of dijet photoproduction for a 1 month LHC Pb+Pb run at 0.4×10^{27} cm^{-2}s^{-1}. Rates are counts per bin of ± 0.25 x_2 and 2 GeV/c in p_T.

R.Vogt, S.White, MS



Rate for b-quark photoproduction. The same as for dijets but p_T bins are 1.5 GeV/c



Expected rate for b-quark photoproduction in a one month LHC pPb run with at 7.4×10^{29} $cm^{-2}s^{-1}$.

Nonlinear effects: AA UPC at LHC vs HERA and eRHIC

The parameter to compare is:
gluon density/unit area * strength of interaction

$$\frac{C\alpha_s(Q^2)xG(x,Q^2)}{Q^2 \text{"}area\text{"}} \qquad where\ C_g \approx 9/4C_q$$

LHC vs ep HERA $\dfrac{(9/4)A^{1/3}\alpha_S(p_T^2)xG_N(x\sim 5\cdot 10^{-5},p_T^2)/p_T^2}{\alpha_S(Q^2)xG_N(x\sim 10^{-4},Q^2)/Q^2}\sim 6$

for central γA collisions (with no centrality trigger the gain is a factor of two smaller). *A factor of 3 gain = change in x by a factor ~100.*

LHC vs eRHIC: eA at $Q=2, x=10^{-3}$ the gain is a factor of 2

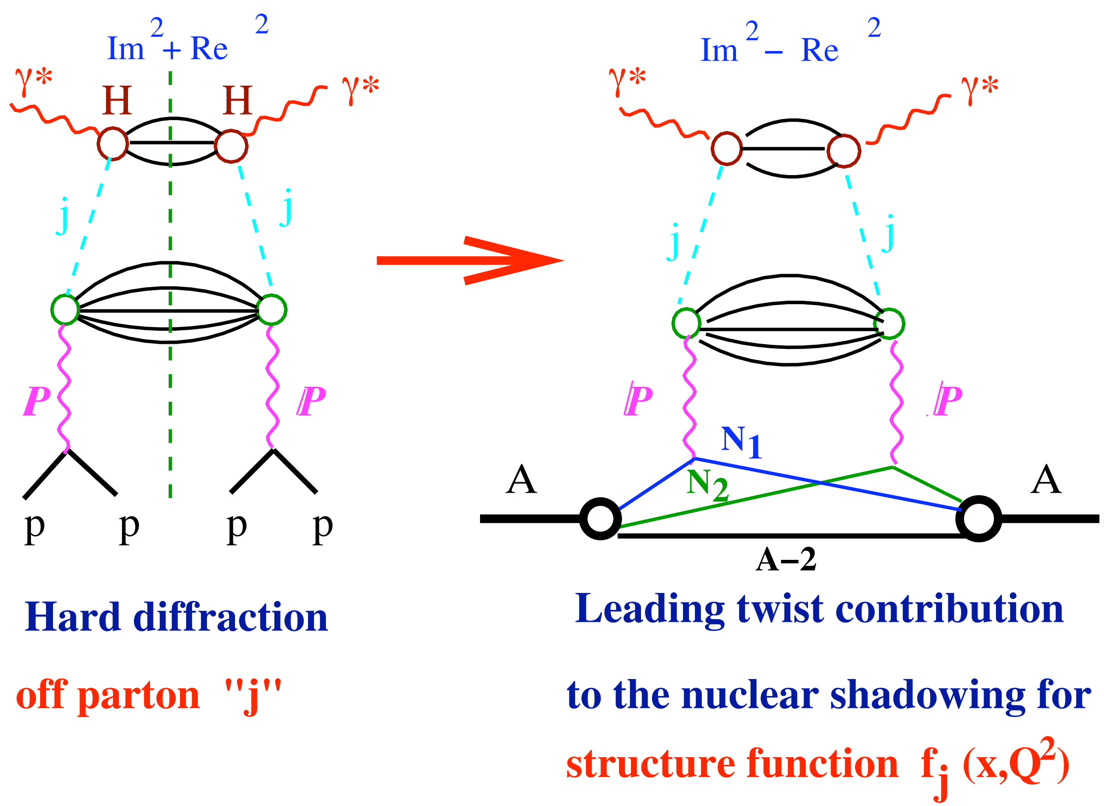
Will be possible to study energy dependence of the dijet cross section in the x range between 10^{-2} and 10^{-4} and check whether taming of the increase is happening at the smallest x.

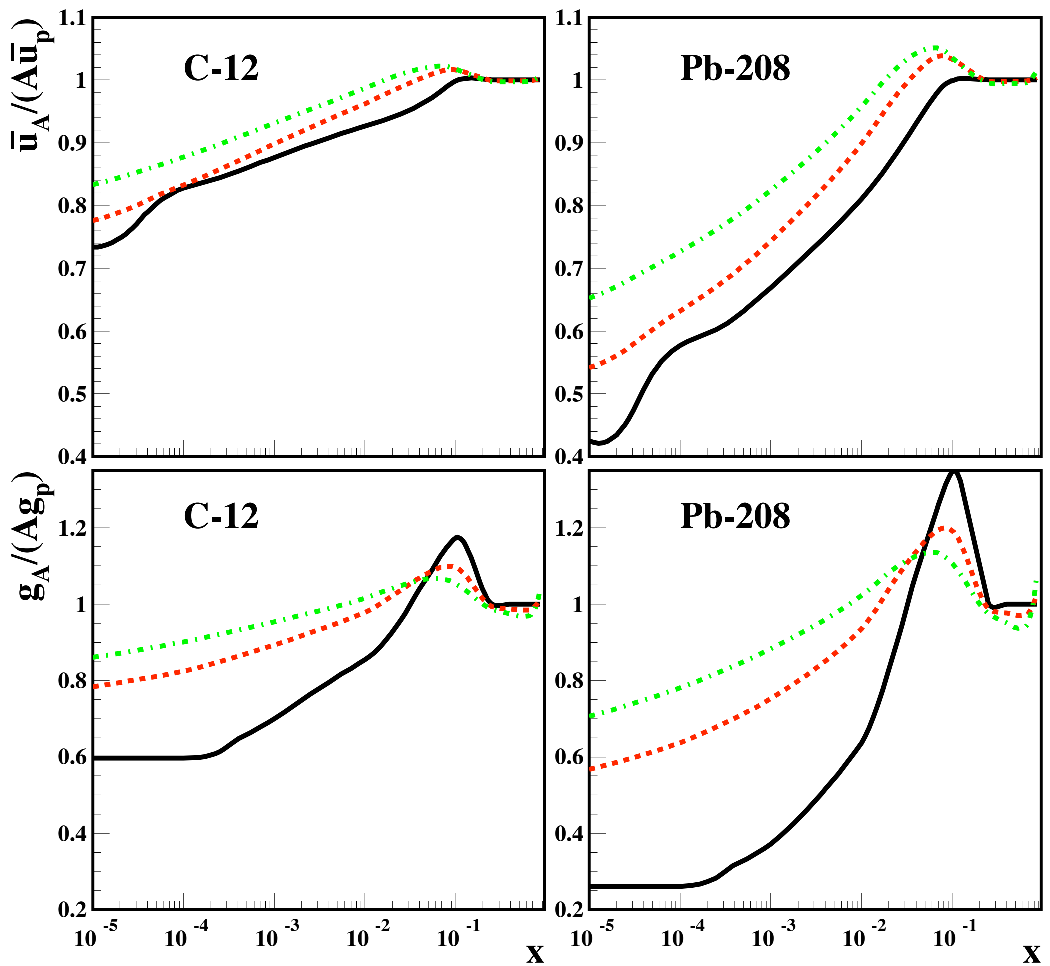
Are significant nuclear effects expected in the UPC AA kinematics at LHC?

Restrict discussion to the leading twist model of Frankfurt, Guzey, Strikman.

Theoretical expectations for nuclear pdf's at small x and large virtualities - leading twist nuclear shadowing

The leading twist DIS diffraction and can be expressed through diffractive nucleon parton distributions FS 98 by combining the Gribov theory of nuclear shadowing and the Collins factorization theorem:





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.

Frankfurt, Guzey, MS 03

Expected suppression is large enough in the UPC kinematics (a factor of two) to be measured. Can be further enhanced with centrality trigger.

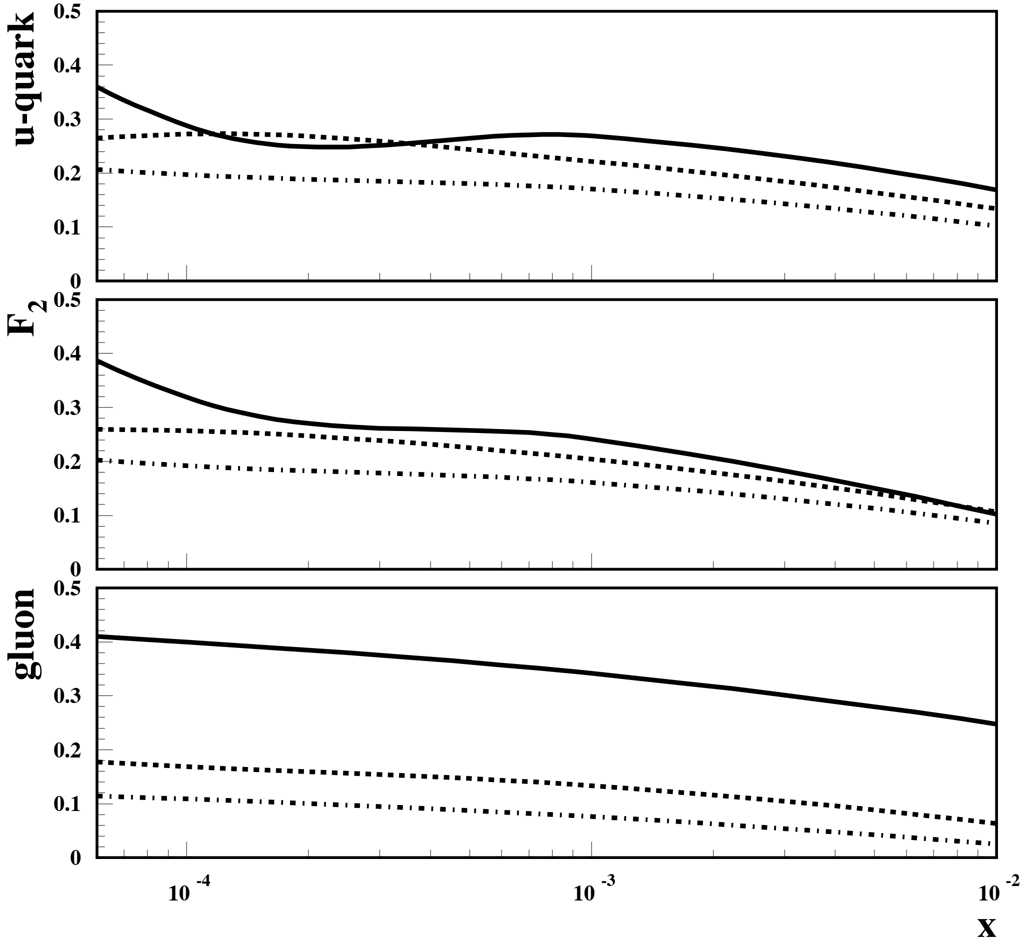
Another critical measurement is hard diffraction:

$\gamma A \rightarrow jet_1 + jet_2 + X + A$ for direct photon: $\beta \approx 1$

In the black disk limit

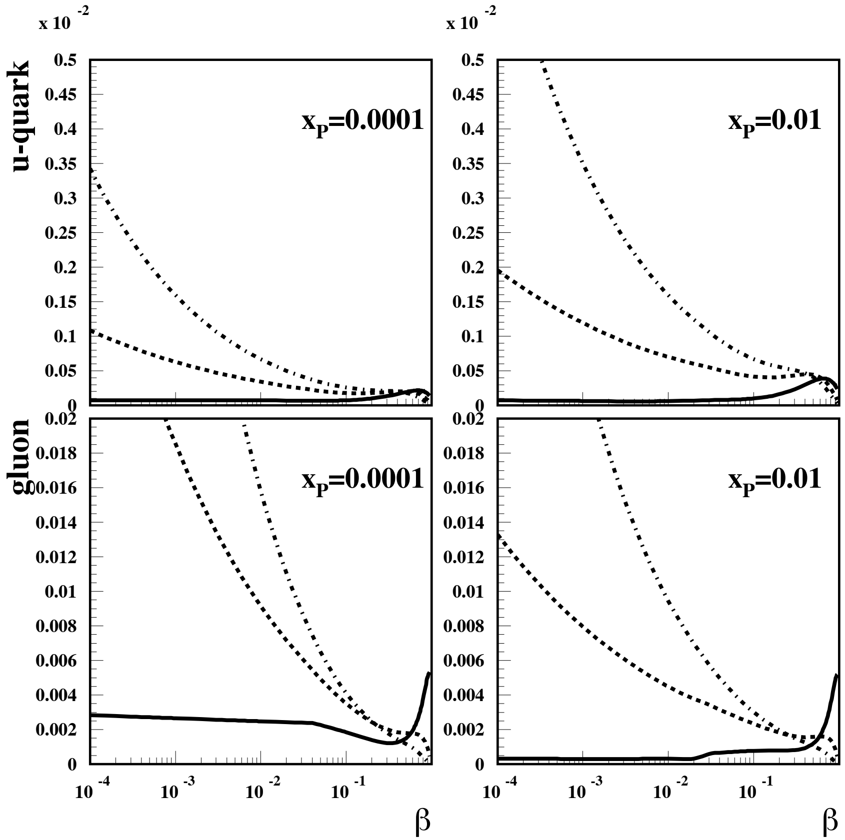
$$\frac{\sigma(\gamma A \rightarrow jet_1 + jet_2 + X + A)}{\sigma(\gamma A \rightarrow jet_1 + jet_2 + X)} \approx 0.5$$

Nuclear diffractive pdfs were calculated by Guzey et al 03 in the same approximations as LT nuclear pdf's (no model necessary for double rescattering)



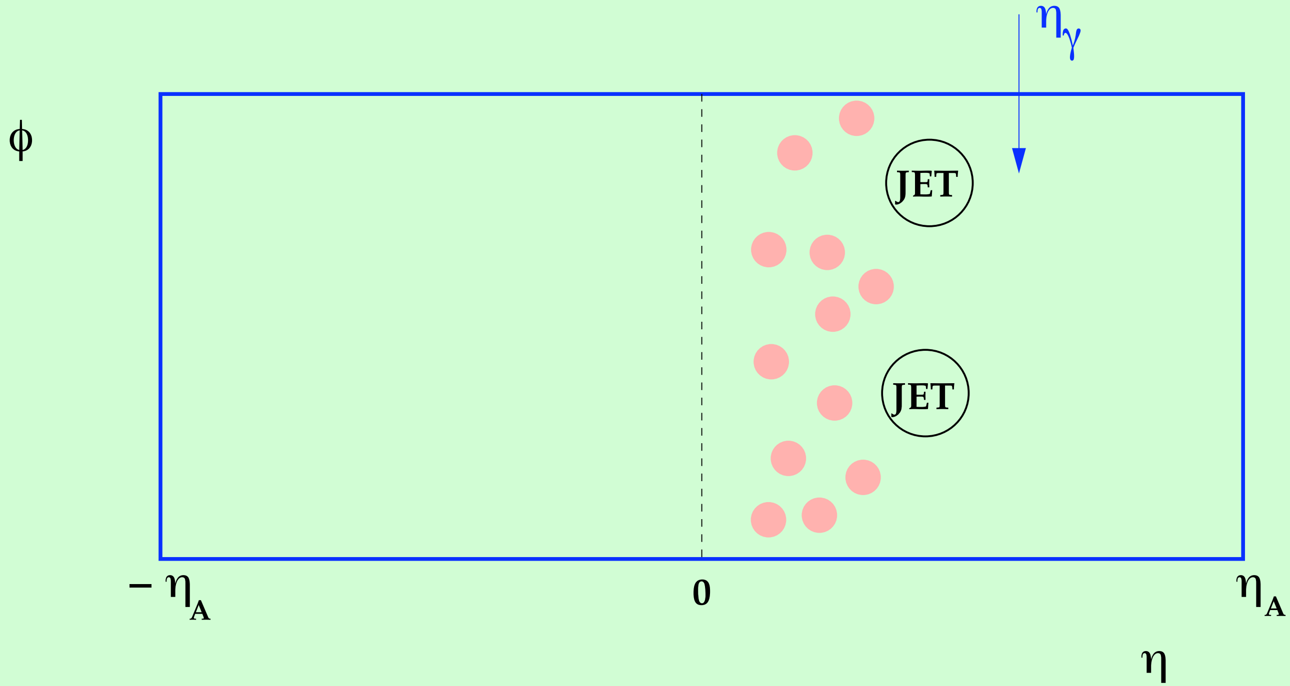
Proximity of the hard interactions with nuclei to BBL leads also to a large probability of diffractive events in nuclei (larger than in the proton). Results of the calculation within the leading twist model (Guzey, et al, 03) are shown the ratios $f_{j/A}^{D(2)}/f_{j/A}$ *for the* u*-quarks and gluons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

☛ *Measurement of the diffractive parton distribution functions.*



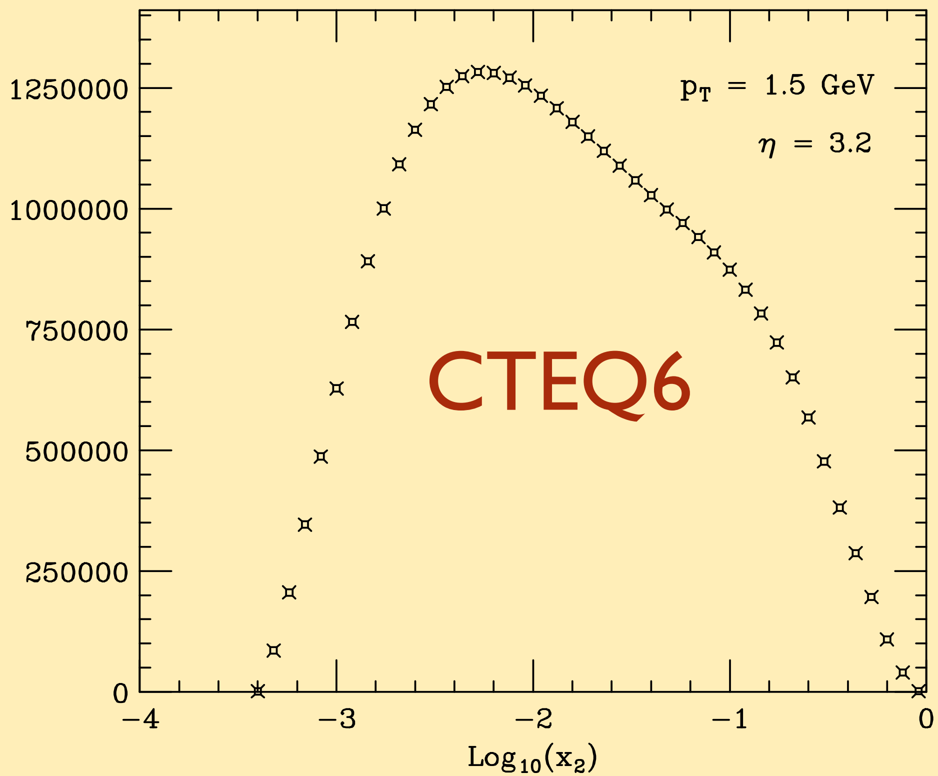
The u-quark and gluon nuclear (^{40}Ca) diffractive parton distribution as a function of β at two fixed values of $x_{I\!P}$. The solid curves correspond to $Q = 2$ GeV; the dashed curves correspond to $Q = 10$ GeV; the dot-dashed curves correspond to $Q = 100$ GeV Frankfurt, Guzey, MS.

In AA scattering it will be possible to measure gluon nuclear diffractive pdfs (or at least rapidity gap probabilities) in most of the small x kinematic range where measurements of nuclear gluon pdfs will be feasible. The key element is the possibility to use the direct photon mechanism to determine which of the nuclei has emitted the photon



UPC induced direct photon hard diffraction: AA−−> AA + 2jets +X

Measurement of the forward inclusive spectrum in γ p vs γA - central detector at LHC!!! Look for origin/presence of the BRAHMS effect. For now, big challenge is figure out the mechanism of the suppression of the contribution from the leading twist with $\langle x_A \rangle = 0.03$ for which no significant effect are present in the parton nuclear structure.



Guzey, MS, Vogelsang

Phys.Lett.B603:173-183,2004

Distribution in $\log_{10}(x_2)$ of the NLO invariant cross section $Ed^3\sigma/dp^3$ at $\sqrt{s} = 200$ GeV, $p_T = 1.5$ GeV and $\eta = 3.2$.

Studies of exclusive photoproduction processes:

Hard physics:

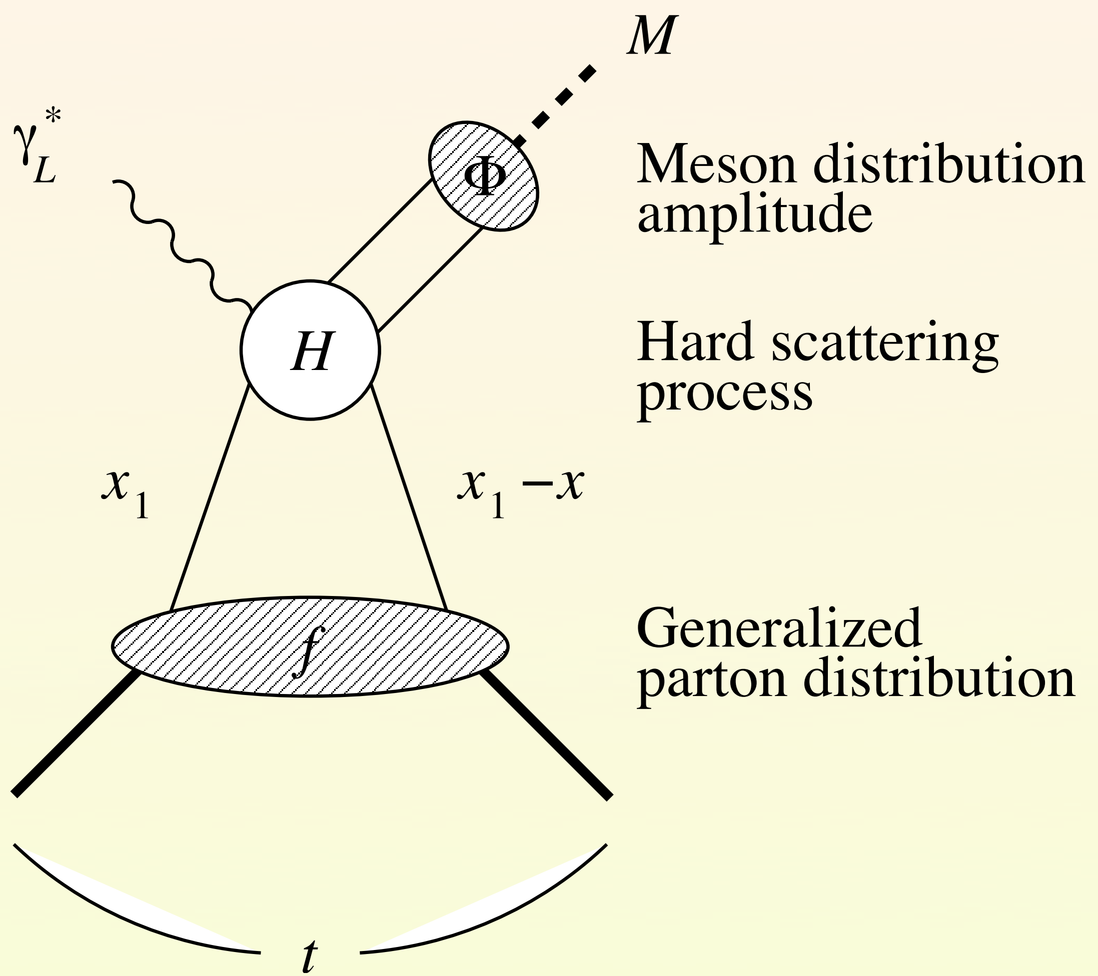
- Onium production
- Diffraction into two, three jets

Soft (Pomeron) physics:

- Energy dependence of production of ρ,φ-mesons

QCD factorization theorem for DIS exclusive processes

(Brodsky,Frankfurt, Gunion,Mueller, MS 94 - vector mesons,small x; general case Collins, Frankfurt, MS 97)



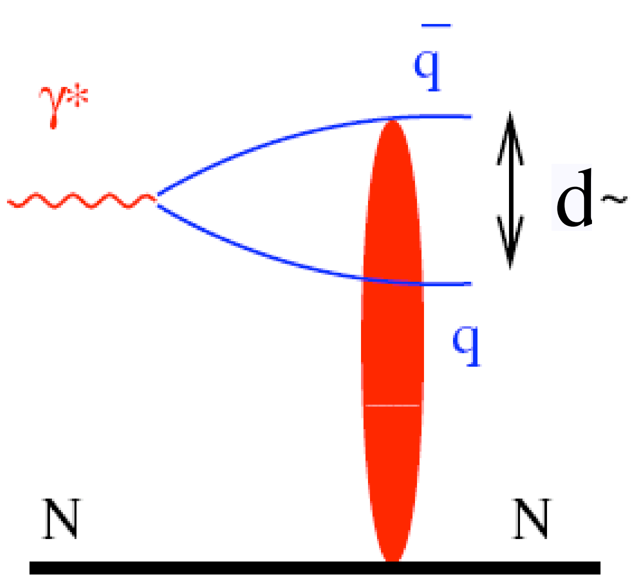
Extensive data on VM production from HERA support dominance of the pQCD dynamics. Numerical calculations including finite transverse size effects explain key elements of high Q^2 data. The most important ones are:

- Energy dependence of J/ψ production; absolute cross section of $J/\psi, \Upsilon$ production.

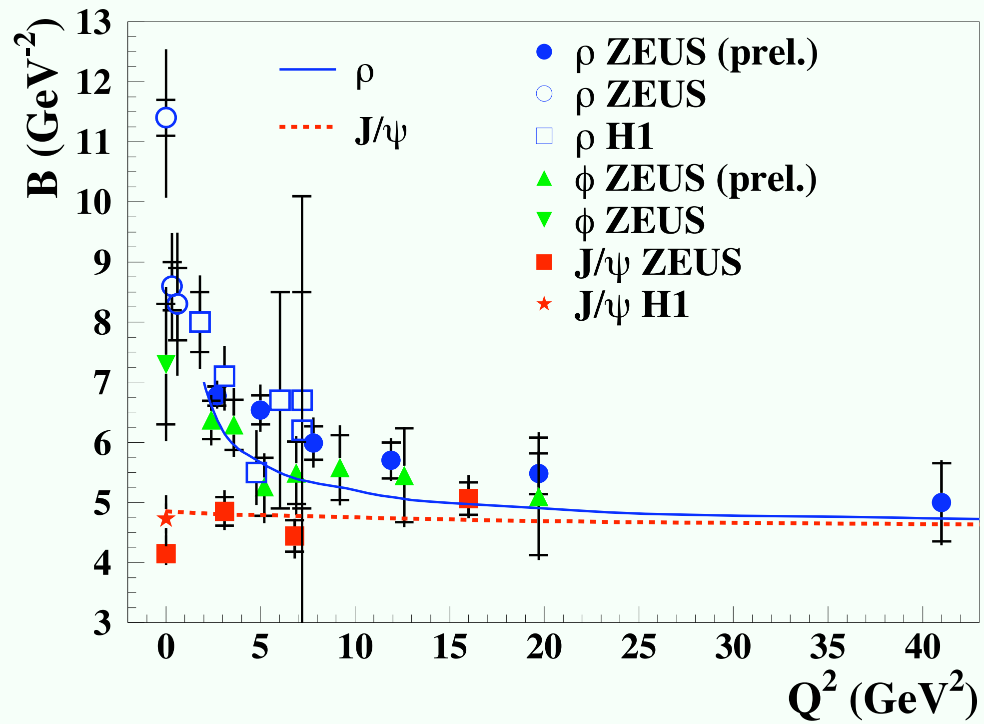
- Absolute cross section and energy dependence of $\rho-$meson production at $Q^2 \geq 20\ GeV^2$. Explanation of the data at lower Q^2 is more sensitive to the higher twist effects, and uncertainties of the low Q^2 gluon densities.

- Universal t-slope: process is dominated by the scattering of quark-antiquark pair in a small size configuration - t-dependence is predominantly due to the transverse spread of the gluons in the nucleon - two gluon nucleon form factor, $F_g(x,t)$. $d\sigma/dt \propto F_g^2(x,t)$.

  Onset of universal regime FKS[Frankfurt,Koepf, MS] 97.



d~ $r_T \propto \frac{1}{Q}(\frac{1}{m_c}) \ll r_N$



Convergence of the t-slopes, B ($\frac{d\sigma}{dt} = A\exp(Bt)$), of ρ-meson electroproduction to the slope of J/psi photo(electro)production.

⇒ Transverse distribution of gluons can be extracted from $\gamma + p \to J/\psi + N$

Study of the onium production off nuclei is a good way to understand how close is interaction of a small dipole to the black disk limit in which

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

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

Dramatic enhancement of the process $\gamma + A \ \to \ 2jets + A$

as compared to the LT expectations (FGMS 02)

$$\sigma_{elastic}(\gamma+A\to J/\psi\ +\ A)\propto A^{2/3}\ \ \sigma_{quasielastic}(\gamma+A\to J/\psi\ +\ A')\propto A^{1/3}$$

as compared to impulse approximation (naive color transparency)

$$\sigma_{elastic}\propto A^{4/3},\ \sigma_{quasielastic}\propto A^{2/3}$$

❑ *Exclusive onium production*

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

The nuclear Coulomb induced dissociation occurs at small impact parameters. At the same time in such events the photon spectrum is harder. (Can be used enhanced contribution of hard photons)Baltz, Klein Nystrand, 02. (Price a factor of 10 reduction in counting rate). Allows to extend measurements for J/ψ *case to* $y \sim 2$, $\rightarrow x \sim 10^{-5}$.

Another approach - use of the break up channels - processes where nucleus emits few neutrons (Tverskoi, MS , Zhalov 05). Allows to determine which nucleus emitted the photon.

The leading twist prediction is

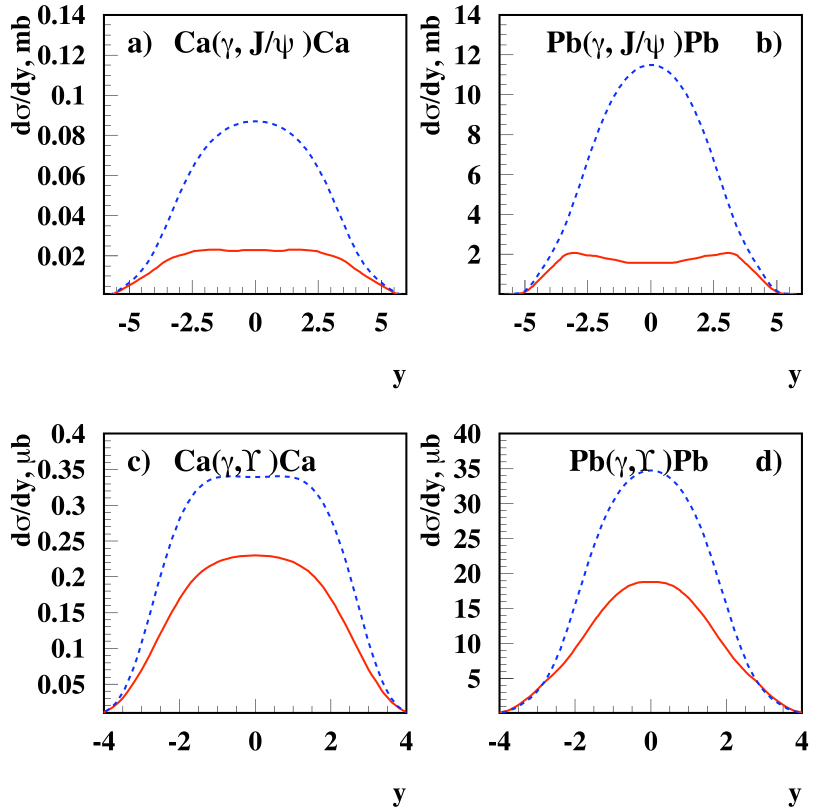
$$\sigma_{\gamma A \to VA}(s) = \frac{d\sigma_{\gamma N \to VN}(s, t_{min})}{dt} \left[\frac{G_A(x_1, x_2, Q^2_{eff}, t=0)}{AG_N(x_x, x_2, Q^2_{eff}, t=0)} \right]^2 .$$

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

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

The expectations for the BBL will be discussed later.

☛ *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).

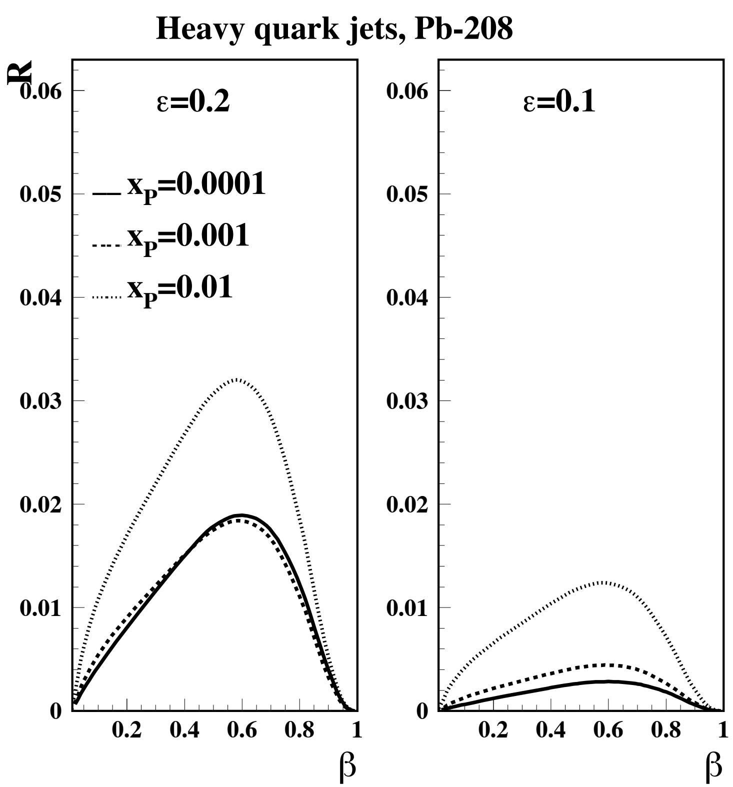
Experimental challenges: Trigger on relatively low transverse momentum leptons. Problem for J/ψ 's for $y=0$, for $y=2\text{-}4$ the ALICE study finds good rates. Acceptance for Upsilons is good in a wide rapidity range. Preliminary studies for CMS suggest that it would be possible to trigger at $y\sim0$ with a large efficiency (P. Yeppes).

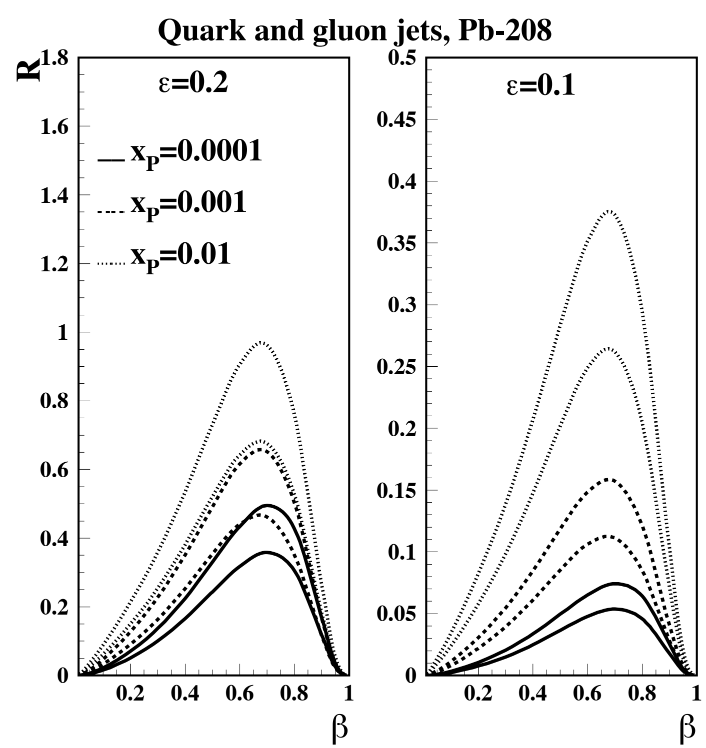
UPC in *pA*

pA ultraperipheral will play dual role -

- extend studies of the nucleon structure
- serve as a reference point to nuclear studies using UPC in AA collisions
- extend studies of the onium exclusive production

Measurement of nucleon gluon pdfs. Situation is more complicated than in AA case (measurement of the nuclear pdfs) as we need to study jet production in the direct photon proton interactions $x_\gamma \sim 1$, and compare it to contribution due to nuclear diffractive pdf's at $\beta \sim 1$. Photon couples well to quarks (in particular heavy quarks), while in the inclusive dijet production gluon- gluon mechanism is strongly enhanced. Net result (Guzey and MS 05) - for heavy quarks photons win, for dijet production "nuclear Pomeron" contribution may win. Rates for heavy quarks are high enough - a slide in the beginning of the talk.





R is the ratio of "nuclear Pomeron" and photon contributions

Color fluctuations in the nucleon wave function & 3-dimensional mapping of the nucleon

$$|N\rangle = 3q + 3qg + 3q + \pi +$$

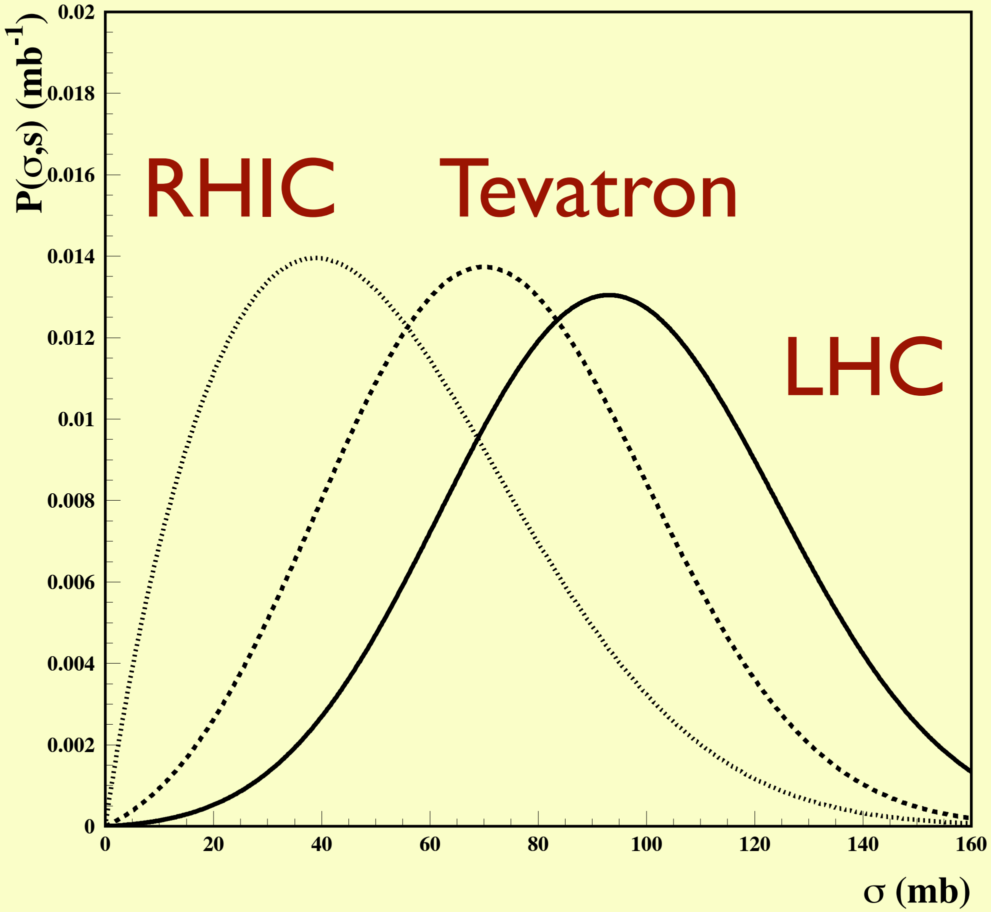
Fluctuations of interaction strength are likely to be correlated with quark content of the hadron. Smallest configurations are most likely the minimal Fock state ones.

Important feature of QCD: QCD sum rules, form factors at large Q, chiral dynamics.

Experimental evidence: Pion diffraction into two jets, inelastic coherent diffraction off nuclei.

At RHIC energies the variance of the interaction strength is still large

$\omega_\sigma \sim 0.25 \div 0.3$ At LHC it is expected to drop to $\omega_\sigma \sim 0.06$



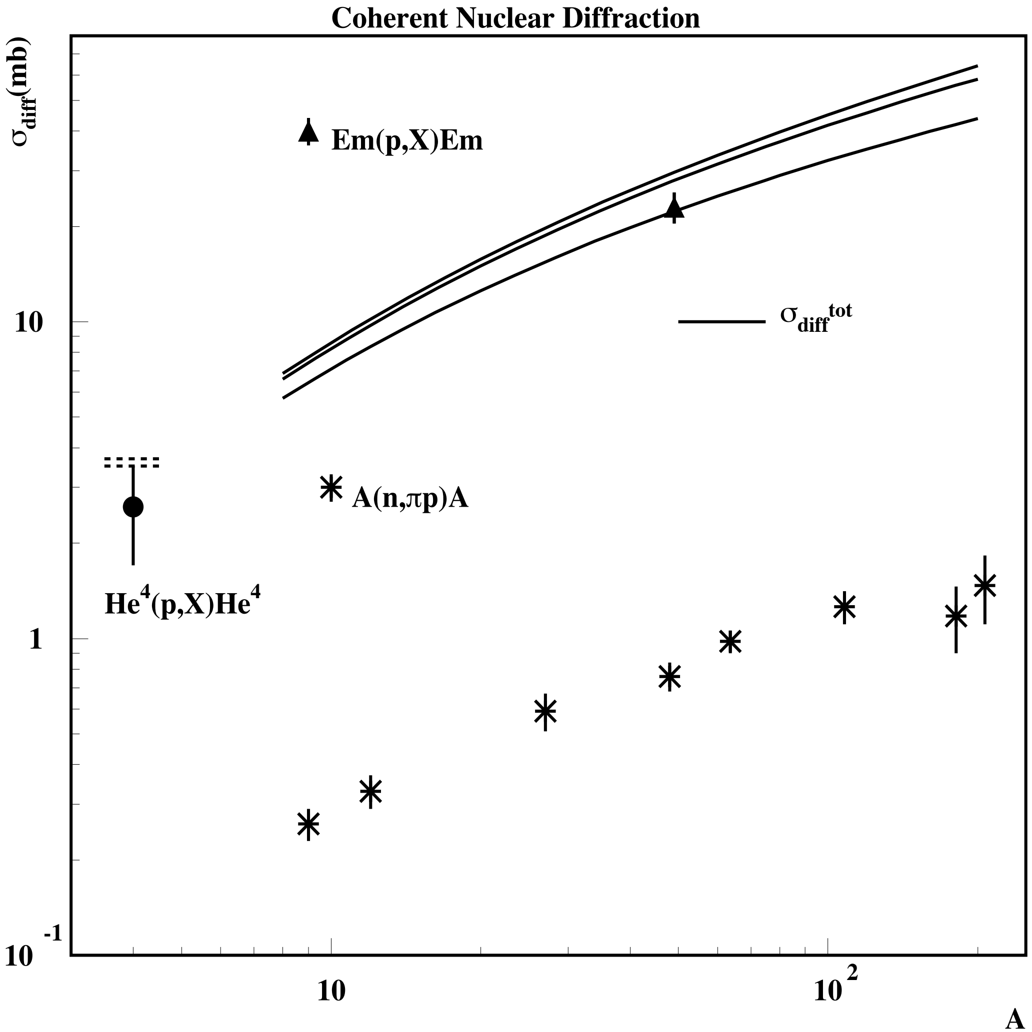
Comment: Fluctuations of strength of nucleon interaction lead to strong modifications of the distribution over the number of wounded nucleons (Baym, LF, MS 93)

Guzey and MS 05

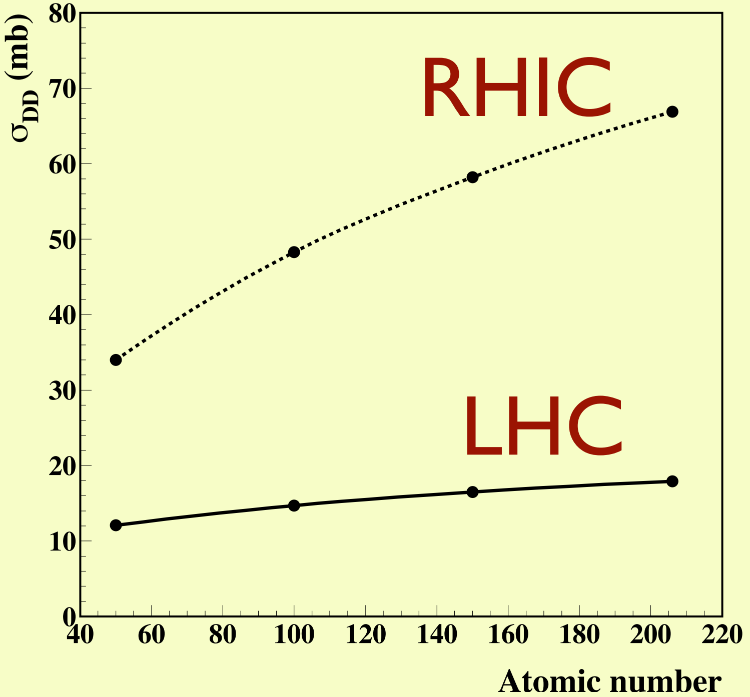
The inelastic small t coherent diffraction off nuclei provides one of the most stringent tests of the presence of the fluctuations of the strength of the interaction in NN interactions. The answer is expressed through $P(\sigma)$ - probability distribution for interaction with the strength σ. (Miller &FS 93)

$$\sigma^{hA}_{diff} = \int d^2b \Bigg(\int d\sigma P_h(\sigma) |\langle h|F^2(\sigma,b)|h\rangle| - \Big(\int d\sigma P(\sigma) |\langle h|F(\sigma,b)|h\rangle| \Big)^2 \Bigg) .$$

Here $F(\sigma,b) = 1 - e^{-\sigma T(b)/2}$, $T(b) = \int_{-\infty}^{\infty} \rho_A(b,z)dz$, and $\rho_A(b,z)$ is the nuclear density.

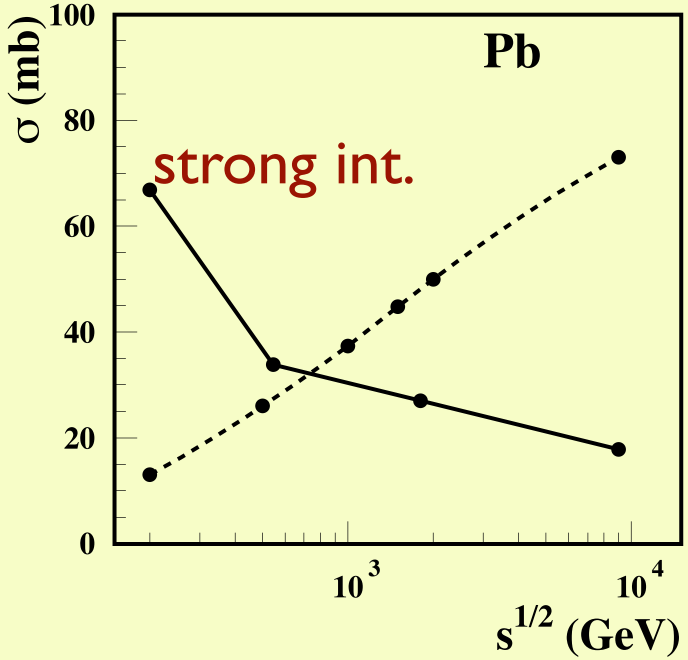


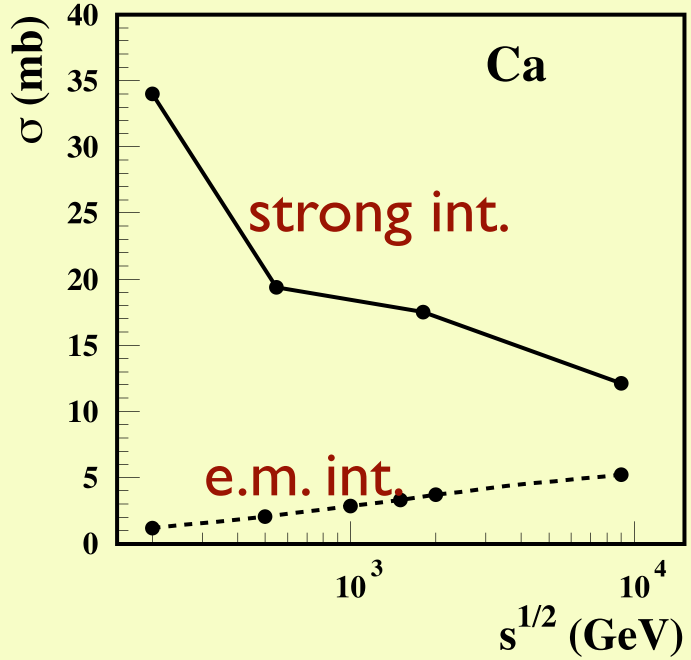
The cross section of coherent diffraction dissociation of protons and neutrons on nuclei as a function of the atomic number A. The solid lines are the theoretical prediction based on the above eqn. Total cross section data are from the FNAL emulsion and ^{4}He jet target experiments. The FNAL data on the reaction $n + A \to p\pi^- + A$ a small fraction of the total diffractive cross section is presented as stars have similar A-dependence for all masses and provide a good indication of the overall trend of the A-dependence. The theoretical prediction for coherent diffraction on ^{4}He is given by the dashed lines.



$$\sigma_{DD} \equiv \sigma(pA \to X + A)$$

Guzey and MS 05





e.m. int. = inelastic interaction of protons with the Coulomb field of the nucleus

Further effect for large $W_{\gamma N}$:

UPC W dependence: $$\frac{dW^2}{W^2}\sigma_{\gamma p}(W) \approx \frac{dW^2}{W^2}(W^2/W_0^2)^{0.08}$$

strong diffraction W
(diffractive mass) dependence: $$\frac{dM_X^2}{M_X^2} \equiv \frac{dW^2}{W^2}$$

Strong background for large W is ~10 %

Situation is even better since we want to study jet production in the direct photon proton interactions $x_\gamma \sim 1$, corresponding to nuclear diffractive pdf's at $\beta \sim 1$.

Measurement of nucleon diffractive gluon pdfs.

Situation is likely to be better than for inclusive case as the probability of diffraction in γp is much higher (~10%) than in pp. Further theoretical analysis is necessary of the pp background for dijets (for heavy quarks definitely no problems) - but the counting rates are high.

Note that the 420 m Roman pots stations which are currently proposed for the Higgs searches will allow to detect protons for $x_{I\!P}$ between 10^{-2} and 10^{-3}. This would allow

a) To remove the processes

$$\gamma + p \rightarrow jet_1 + jet_2 + X + N^*(small\, diffractive\, mass)$$

b) Measure diffractive proton transverse momentum (even better $x_{I\!P}$ as well)

- Allow much more reliable comparison between the planned LHC hard diffraction data and and theory without absorption - no HERA data in most of the kinematics to be probed at LHC.

- Comparison with hard diffraction in AA UPC - which correspond to t~0

- Check of the leading twist theory of gluon shadowing - answer is expressed through the gluon diffractive pdf's at t~0

pPb run will allow measurements of diffractive gluon nucleon pdf's at $x \sim 10^{-2} \div 10^{-4}, Q \geq 7 \div 10\, GeV/c$

Studies of exclusive photoproduction processes in pA UPC:

Hard physics:

- Onium production
- Diffraction into two, three jets

Soft (Pomeron) physics:

- Energy dependence of production of ρ,φ-mesons

Assessment of the HERA experimental situation:

Main problems are

- small W interval
- low lumi at high W
- lack of the proton detection

significant uncertainties in the t-slope and its energy dependence, poor information about Upsilon production which is the cleanest case theoretically

Note - *knowledge of t-dependence of GPDs at small x crucial for realistic modeling on pp collisions with production of new particles at LHC*

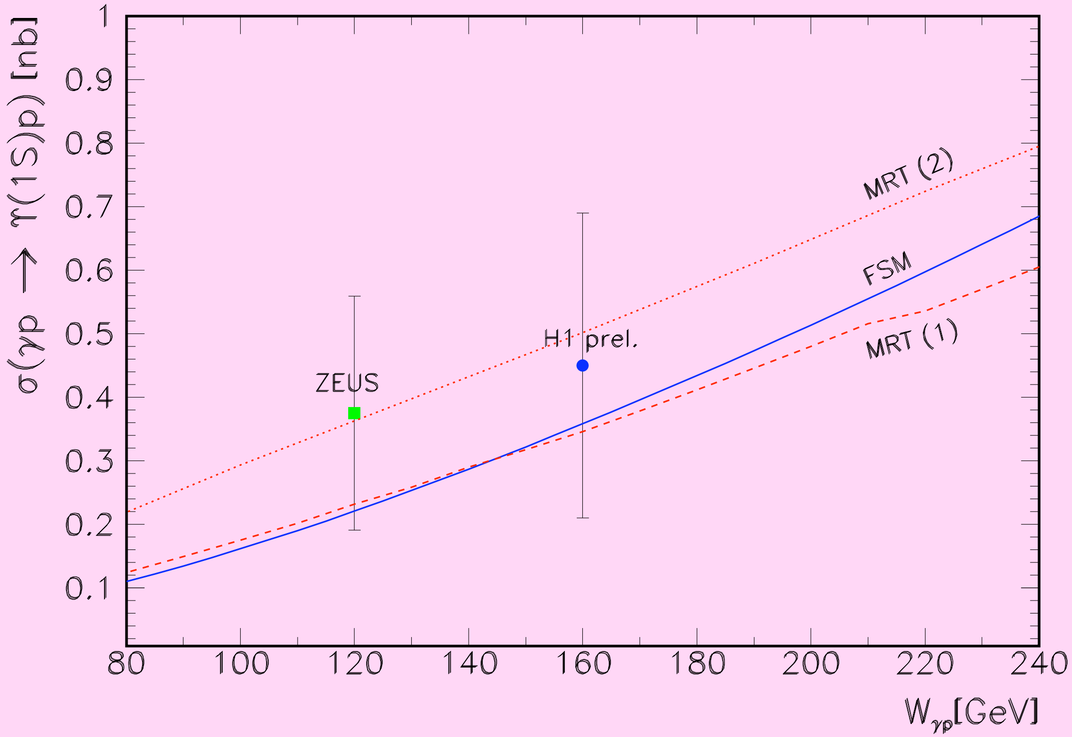
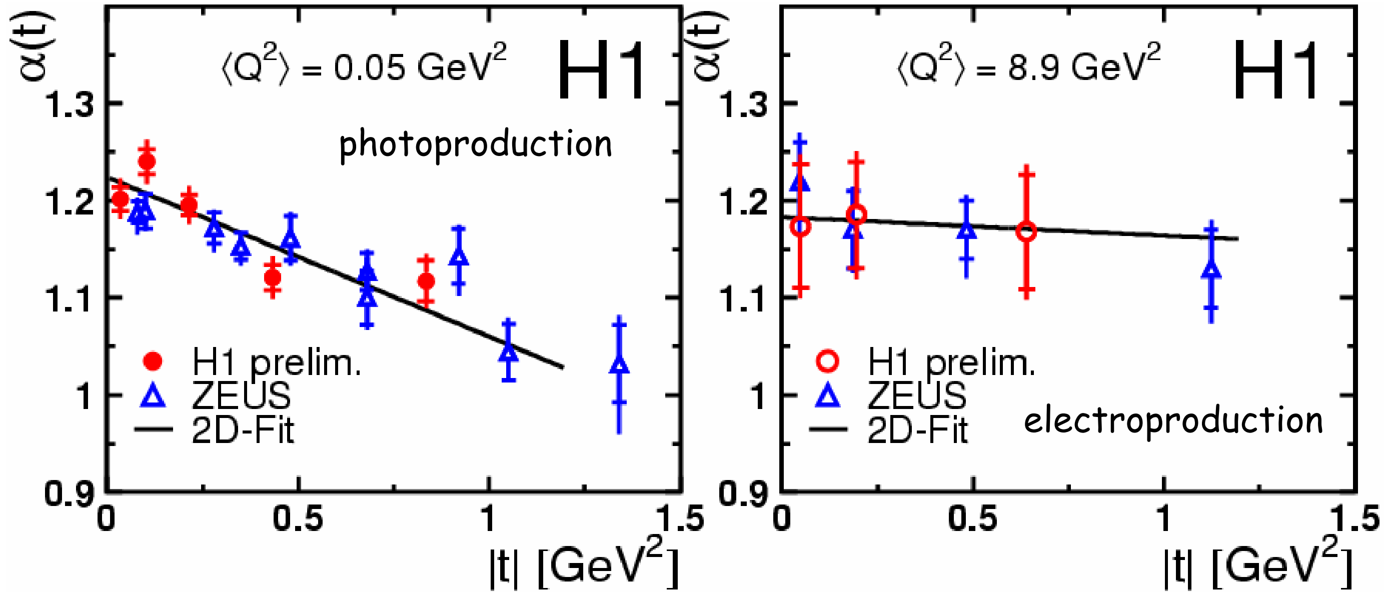


Figure 2: Measurements from the H1 and ZEUS collaborations of the elastic $\Upsilon(1S)$ photoproduction cross section. The error bars show the quadratic sum of statistical and systematic uncertainties. The curves show the results of QCD-based calculations which take into account a variety of effects beyond leading order [8]

Effective Pomeron trajectory

2 dim. fit: $\alpha(t) = \alpha_0 + \alpha' t$



photoproduction:

$$\frac{d\sigma}{dt} = f(t)\left(\frac{s}{s_0}\right)^{2\alpha(t)-1}$$

$$\alpha(t) = (1.224 \pm 0.010 \pm 0.012) + (0.164 \pm 0.028 \pm 0.030)\ \text{GeV}^{-2}\ t$$

electroproduction:

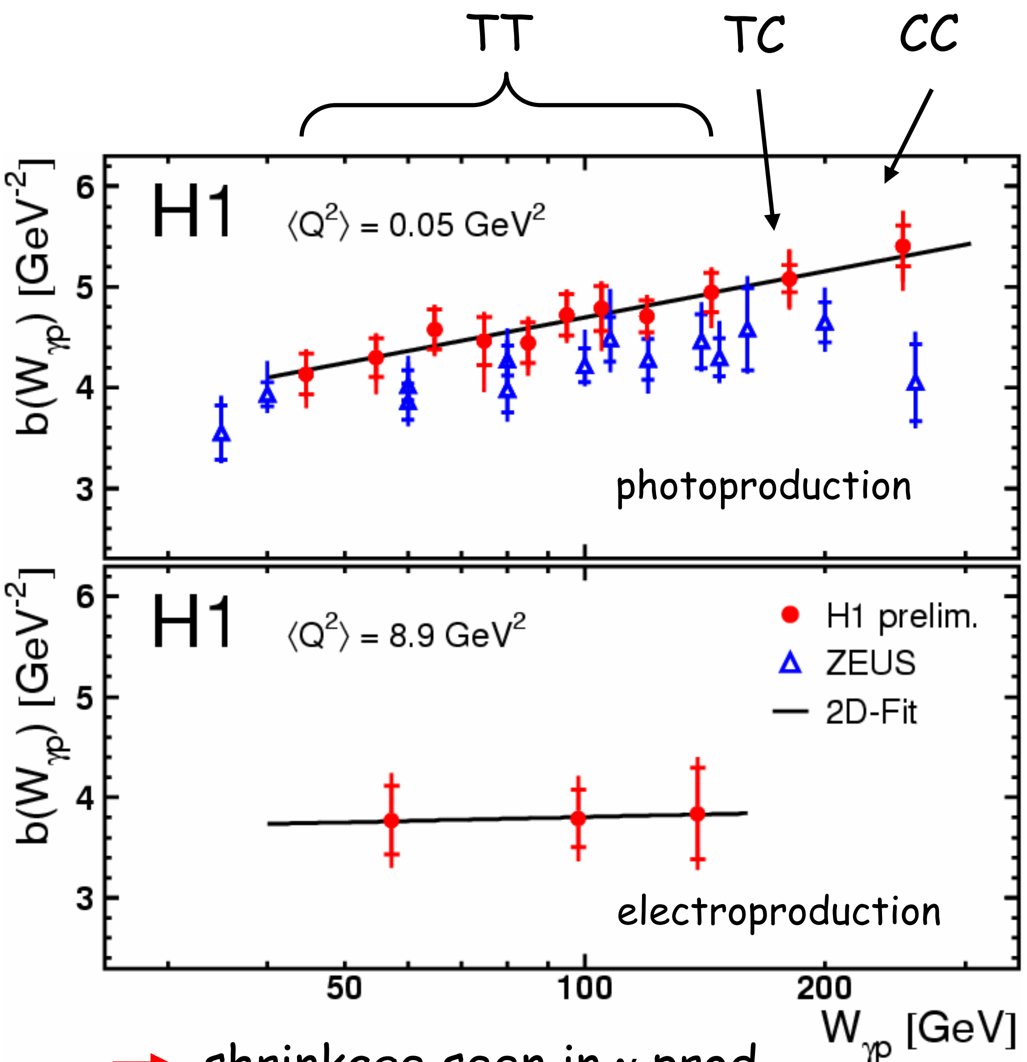
$$\alpha(t) = (1.183 \pm 0.054 \pm 0.030) + (0.019 \pm 0.139 \pm 0.076)\ \text{GeV}^{-2}\ t$$

→ trajectories similar within errors

$$\alpha_{I\!P} = (1.200 \pm 0.009) + (0.115 \pm 0.018)t$$ ZEUS photoproduction

$$\alpha_{I\!P} = (1.20 \pm 0.03) + (0.07 \pm 0.05)t$$ ZEUS electroproduction

Shrinkage of the Forward Peak



→ shrinkage seen in γ prod.

data point from 1D fits to $e^{-b|t|}$

line from a 2D Fit (W and t) :

$$b(W) = b_0 + 4\alpha' \ln \frac{W}{W_0}$$

photoproduction

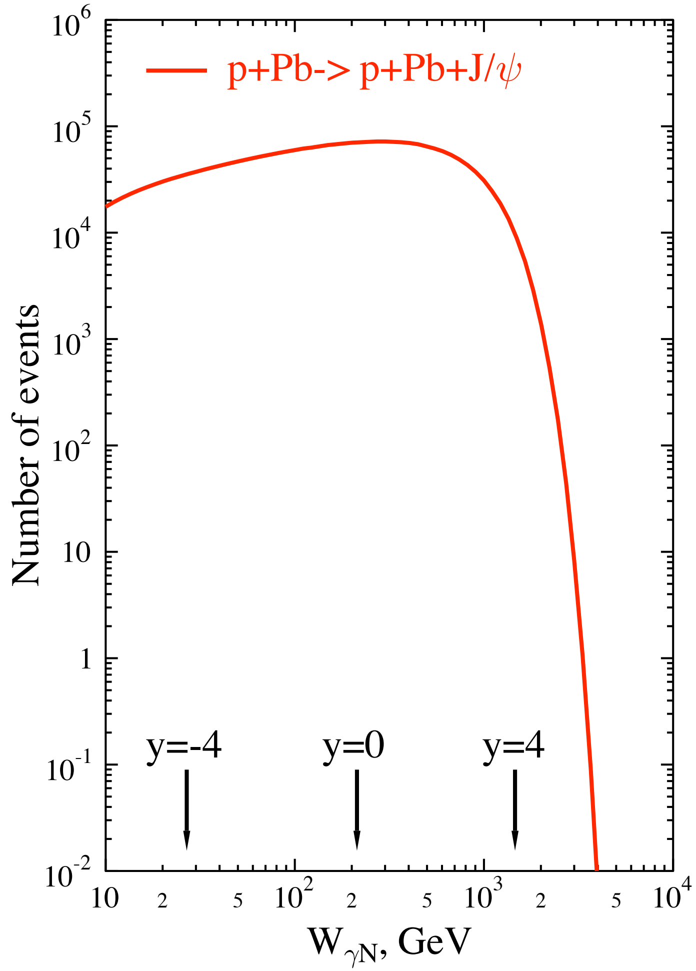
$$b_0 = 4.630 \pm 0.060 \begin{array}{l} +0.043 \\ -0.163 \end{array}$$

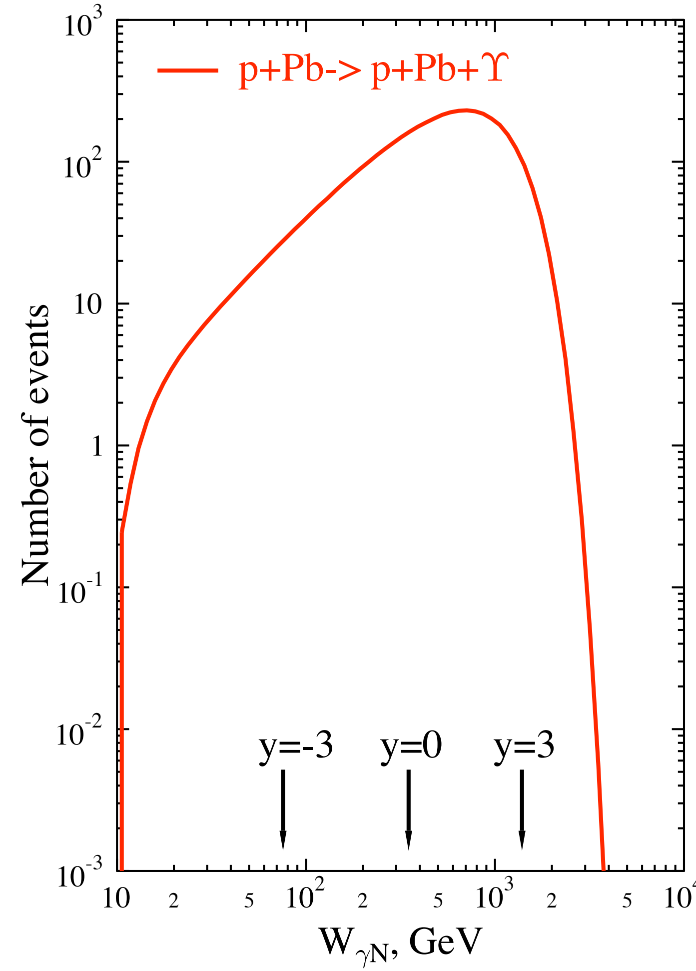
$\alpha' = (0.164 \pm 0.028 \pm 0.030)$ GeV^{-2}

electroproduction

$$b_0 = 3.86 \pm 0.13 \pm 0.31$$

$\alpha' = (0.019 \pm 0.139 \pm 0.076)$ GeV^{-2}





Zhalov & MS 05

Number of $\gamma+p \rightarrow V+N$ events per unit rapidity for a standard proton-lead run - branching of decay to muons is included. Comparable number of coherent $\gamma+A \rightarrow V+A$ is not shown.

Sufficient to check pQCD prediction of $\sigma \sim W^{1.6}$ for Upsilon production determination of the t-slope provided protons could be detected (420 m proposal)

Rates of VM production are sufficient
to improve significantly on the HERA results.

Minimal requirement for the experimental setup: ability to eliminate proton dissociation

Great gains if the proton is detected
- with the current design/plans will be feasible
in a substantial part of the phase space

Conclusions

Studies of UPC at LHC will address many (though not all) of the benchmark issues of HERA III proposal including

- ★ *Small x physics with protons and nuclei in* **a factor of ten** *larger energy range though at higher virtualities both in inclusive and diffractive channels*
- ★ Interaction of small dipoles at ultrahigh energies - approach to regime of black body limit, color opacity
- ★ Low Q will be missed - will require studies at eRHIC

Several of the discussed measurements though doable from the angle of luminosity and kinematics are a challenge for detector design (β^*), triggering, systematics, etc. Need for joint studies by theorists, experimentalists, accelerator experts.