The Abdus Salam
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Educational, Scientific and
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IAEA
International Atomic Energy Agency

SMR/1842-9

International Workshop on QCD at Cosmic Energies III

28 May - 1 June, 2007

Lecture Notes

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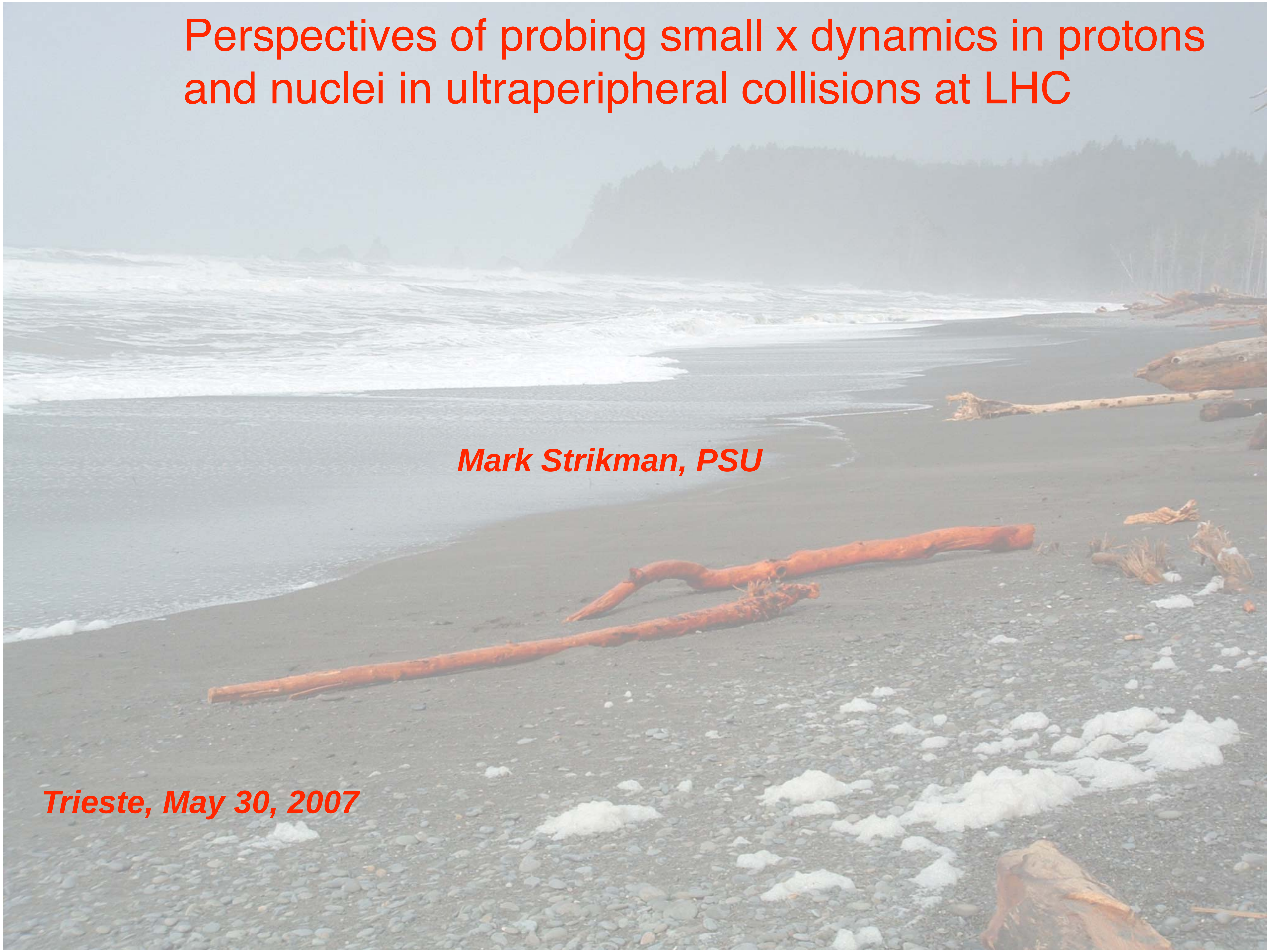
Perspectives of probing small x dynamics in protons and nuclei in ultraperipheral collisions at LHC



Mark Strikman, PSU

Trieste, May 30, 2007

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

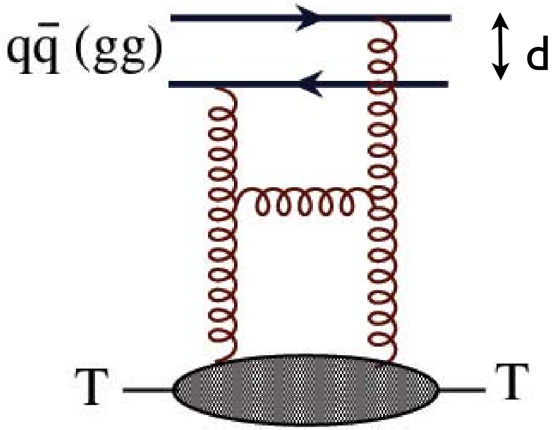
Theory - gluons are most interesting for small x:

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

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

Summary: How strong is the interaction of small dipoles?

Consider first "small dipole - hadron" cross section



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

Baym et al 93

F^2 Casimir operator of color SU(3)

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

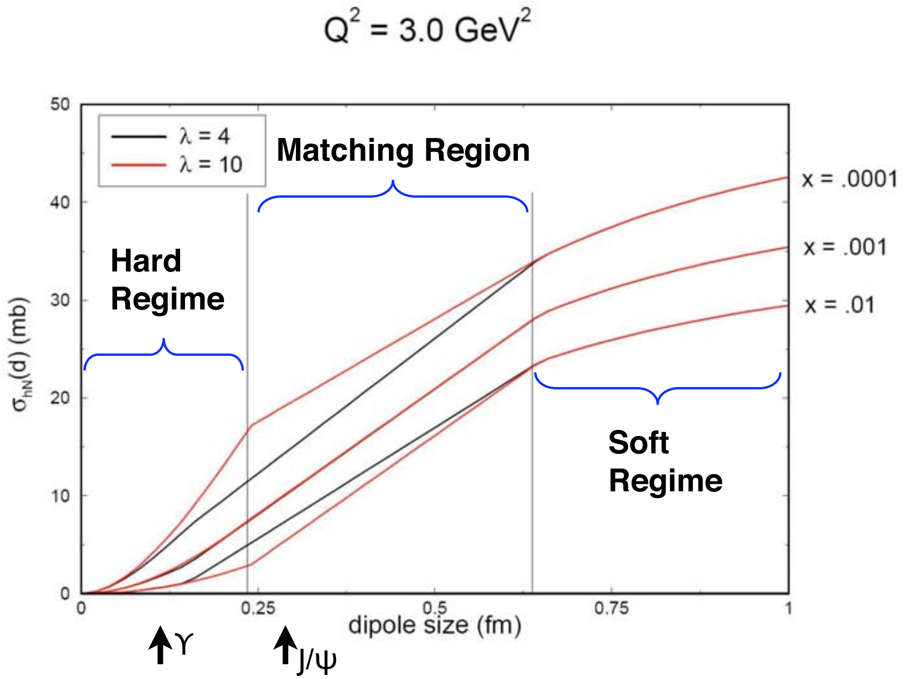
Comment: This simple picture is valid only in LO. NLO would require introducing mixing of different components. Also, in more accurate expression there is an integral over x, and and extra term due to quark exchanges

For review of the most topics discussed in this talk see FS & Weiss, Annual Review of Nucl. & Particle Physics 05

New high energy QCD regime: regime of complete absorption for small α_s: limit - fixed Q & large energies -black disk regime (BDR)

Evidence for proximity to BDR at HERA

studies of the "quark-antiquark dipole"(transverse size d) - nucleon cross section based pQCD and HERA data



Provided a reasonable prediction for σ_L

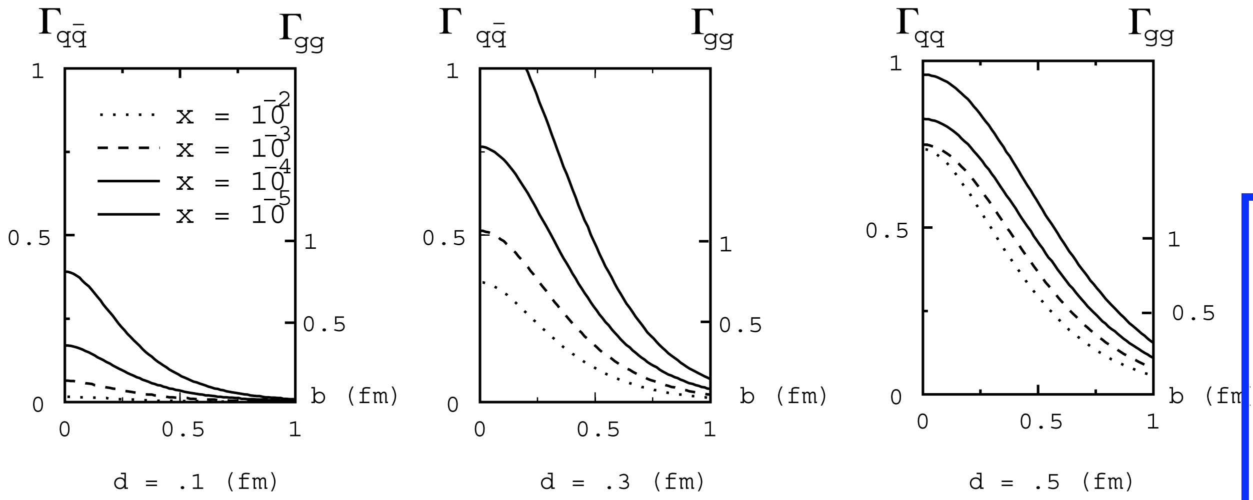
Frankfurt et al 2000-2001

Combine with: analysis of exclusive hard processes (t-dependence of the dipole - nucleon scattering)

determine impact factors for elastic $q\bar{q} - N\,scattering$

$$\Gamma_h(s,b) = \frac{1}{2is}\frac{1}{(2\pi)^2}\int d^2\vec{q}\,e^{i\vec{q}\vec{b}}A_{hN}(s,t)$$

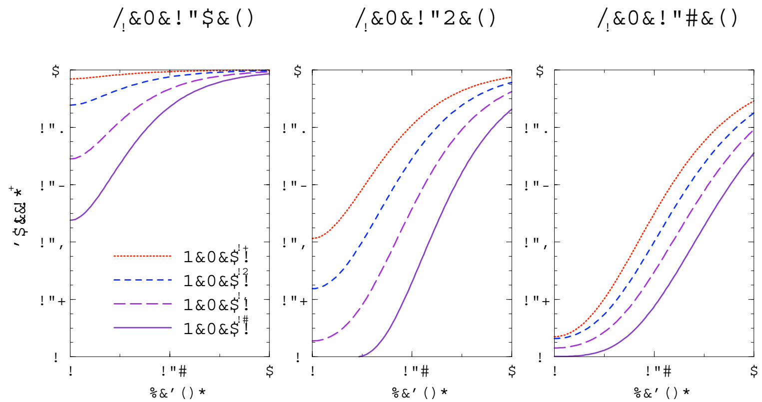
$\Gamma = 1$ *corresponds to regime of complete absorption - BDR*

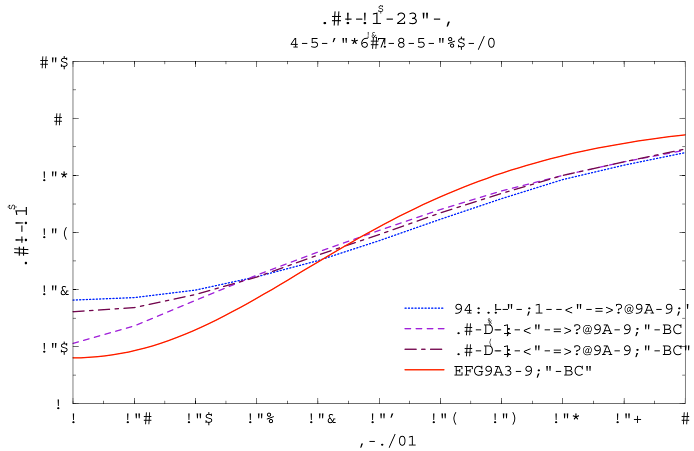


T.Rogers et al

In the case gg-N scattering we assume pQCD relation

$$\Gamma_{gg} = \frac{9}{4}\Gamma_{q\bar{q}}$$





$|1-\Gamma(b)|^2$ -

probability not to interact at given b

gg -N interaction seems close to BDR for $Q^2 \sim 4$ GeV^2, $x \sim 10^{-4}$

↓

for $Q^2 \sim 4$ GeV^2, $x \sim 10^{-3}$ gg - Pb interaction at b=0 is deep in BDR $q\bar{q}$ - Pb interaction in BDR

for these x nuclear leading twist gluon shadowing effect is rather small

↓

Significant fractional energy losses and p_t broadening for partons propagating through black media (FS 01-03)

Suppression of the leading hadron production in pA scattering at large p_t comparable to the scale of Black disk regime at given energy (FS 01-06)

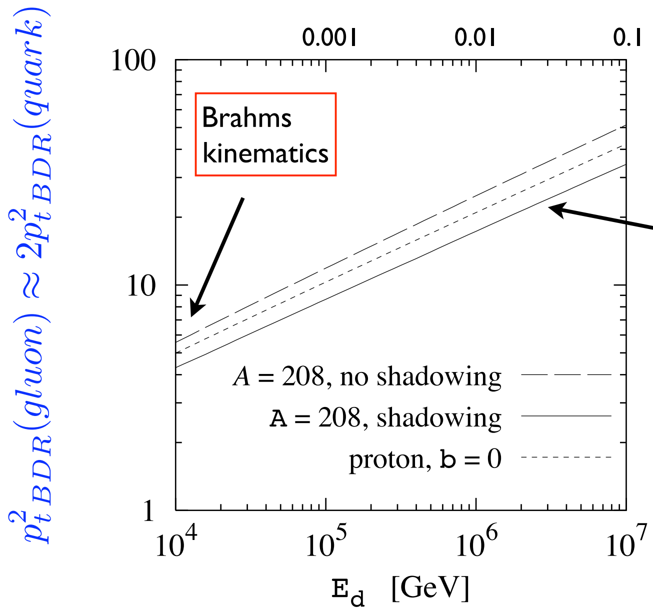
$\Rightarrow$

Natural explanation of the BRAHMS result at RHIC, the only one consistent with the STAR data on correlations

$$p_{t\,BDR} \sim \frac{\pi}{2d}$$

where d is the minimal size of the gg (qq) dipole for which Γ(b=0) ≥ 1 in LT

x_F for pp at LHC



Gluon densities in nuclei and proton at b=0 are very similar!!!!

Difference is in the spread in b

One of fundamental questions:

How small color singlets (dipoles,...) propagate through nuclear media

Intermediate energies - hundred GeV (lab) - color transparency - observed at FNAL in $\pi + A \to 2jets + A$, $\gamma + A \to J/\psi + A$,

High energies - $x_{eff} = Q^2_{eff}/s < 0.01$ - onset of color opacity regime both due to pQCD effects of LT gluon shadowing and proximity to black disk regime

$\Rightarrow$ strong screening of total cross section of dipole -nucleus scattering

$$\sigma_{tot}^{dA} \propto A \Longrightarrow \sigma_{tot}^{dA} \propto A^{2/3}$$

coherent photoproduction of $J/\psi, \Upsilon$

$\Rightarrow$ survival probability, P, for propagation through the nucleus center drops to zero only rim contributes: $P \propto A \Longrightarrow P \propto A^{1/3}$

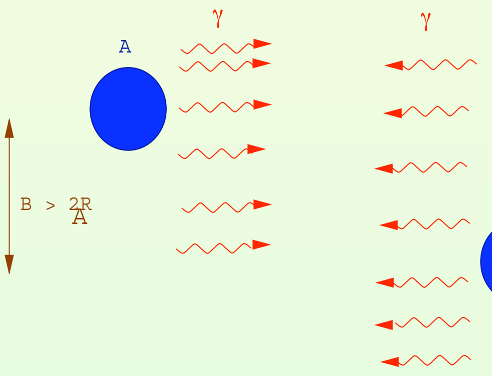
quasielastic photoproduction of $J/\psi, \Upsilon$

large t rapidity gap photoproduction of light vector mesons

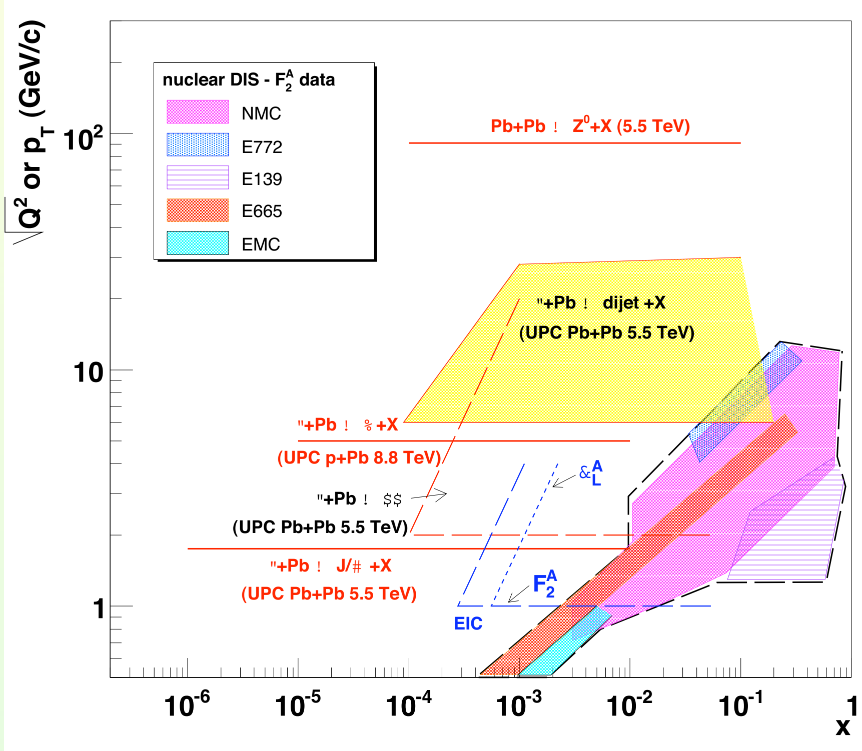
diffractive (rapidity gap between VM and A) photoproduction of $J/\psi, \Upsilon$

Ultraperipheral Collisions ≡ UPC

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



Ultraperipheral Nucleus-Nucleus Collisi



minimal x are a factor of 10 smaller than at HERA

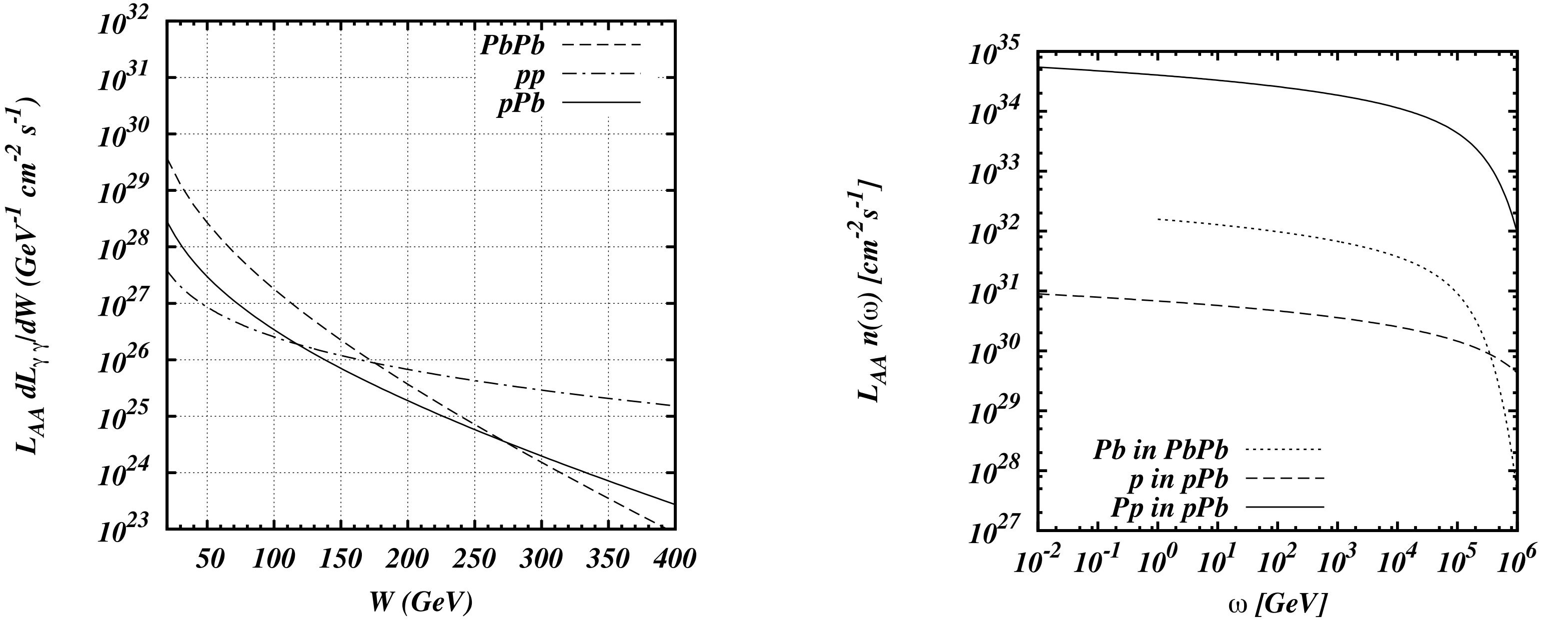
What can be measured/discovered at LHC in UPC to follow up on HERA?

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 $b \quad 2R_A$ is a small correction (weak A-dependence & small probability of di raction). One can also study asymmetric UPC - pA, & AA

Counting rates are large up to

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



(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.

Study of elastic dipole - nucleus scattering: exclusive vector meson production

$$\frac{d\ (AA \quad VAA)}{dy} = N\ (y)\ _{A} \quad _{VA}(y) + N\ (-y)\ _{A} \quad _{VA}(-y).$$

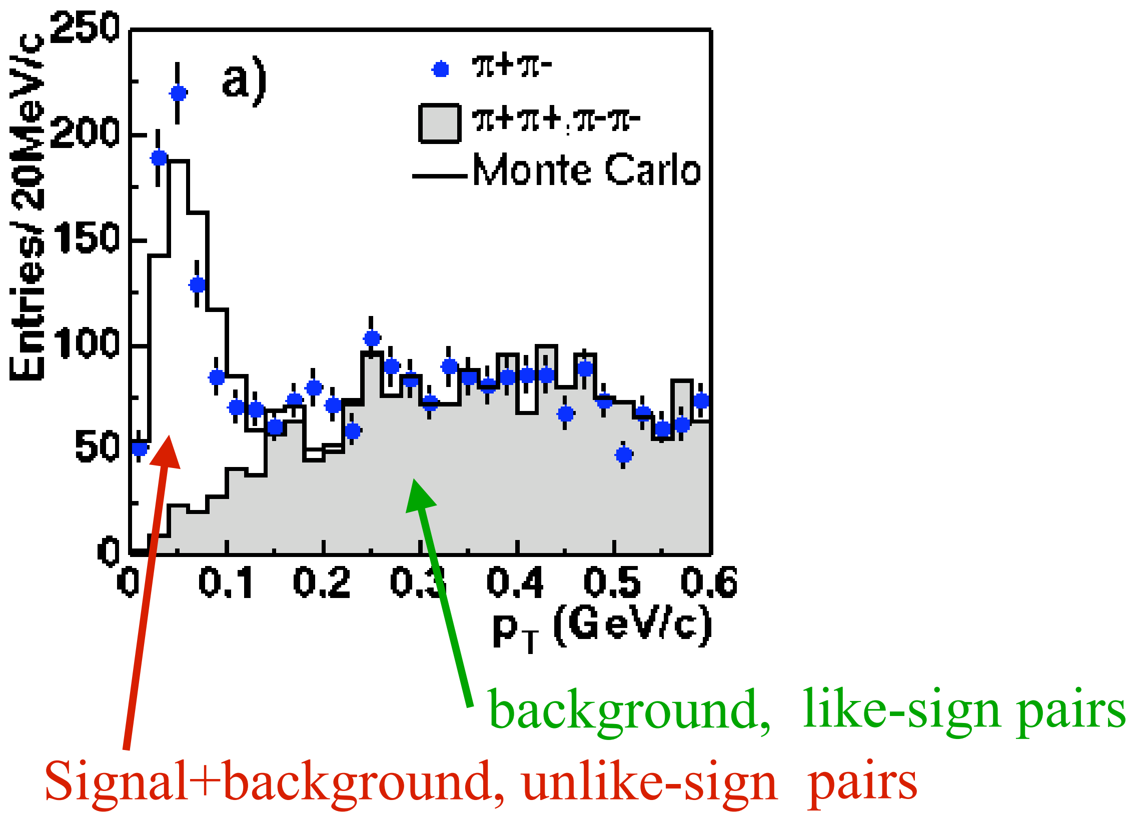
$$\text{rapidity} \quad y = \frac{1}{2}\ln\frac{E_V - p_3^V}{E_V + p_3^V} = \ln\frac{2k}{m_V}.$$

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

$$N\ (y) = \frac{Z^2}{\ \ ^2} \quad d^2b\ _{AA}(b)\frac{1}{b^2}X^2\ K_1^2(X) + \frac{1}{\ }K_0^2(X)\ .$$

$K_0(X), K_1(X)$ – modified Bessel functions with argument $X = \frac{b m_V e^y}{2}$,

is Lorentz factor and b is the impact parameter.



The first data from STAR (group led by S.Klein). Analysis of the photoproduction can be done using vector dominance model coupled with the Glauber model (theoretical uncertainties are small).

The data agree with the theory reasonably well.

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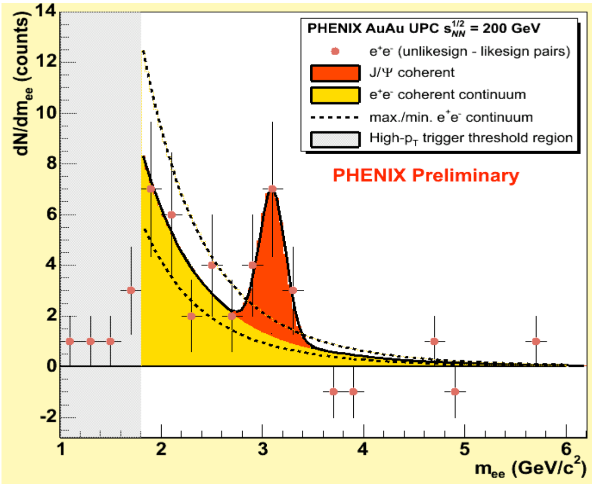

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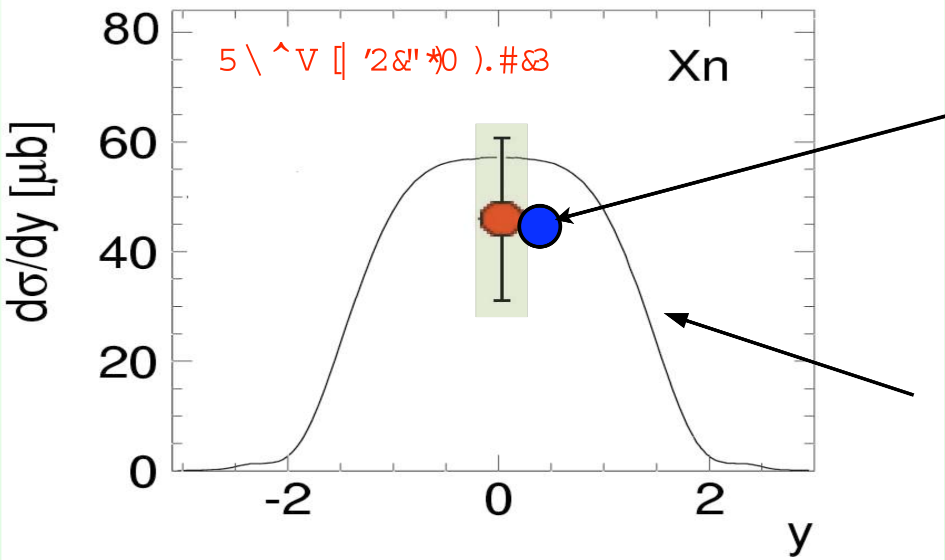
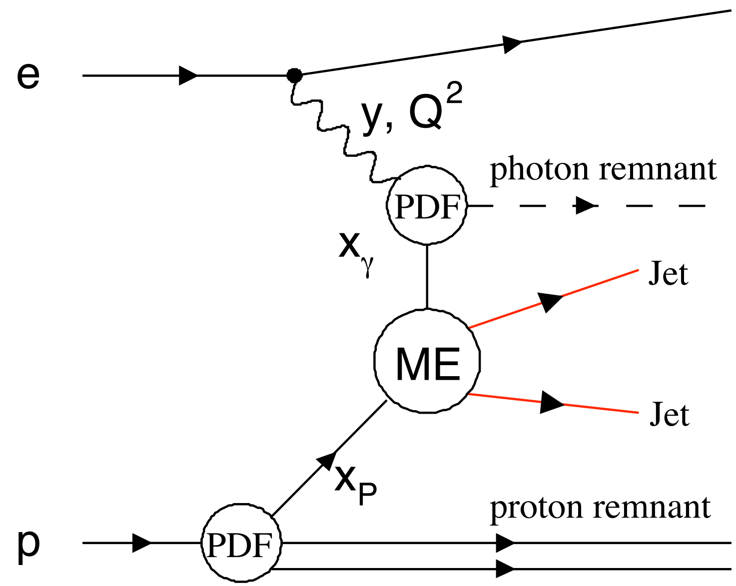


MS, Tverskoy, Zhalov - coherent + quasielastic, σ_{eff} (J/ψ N)=3 mb

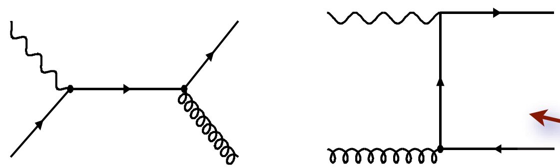
Klein & Nystrand, coherent

Another lesson from HERA

Real photon was effectively used for the QCD studies

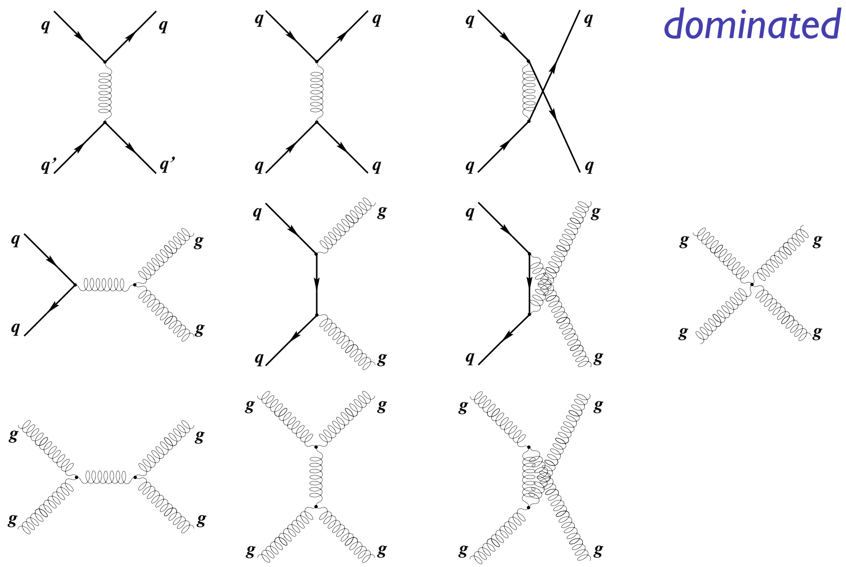


Schematic view of dijet production in ep *scattering studied at HERA*
x_γ *and* x_p *are light cone fractions of partons of photon and proton*



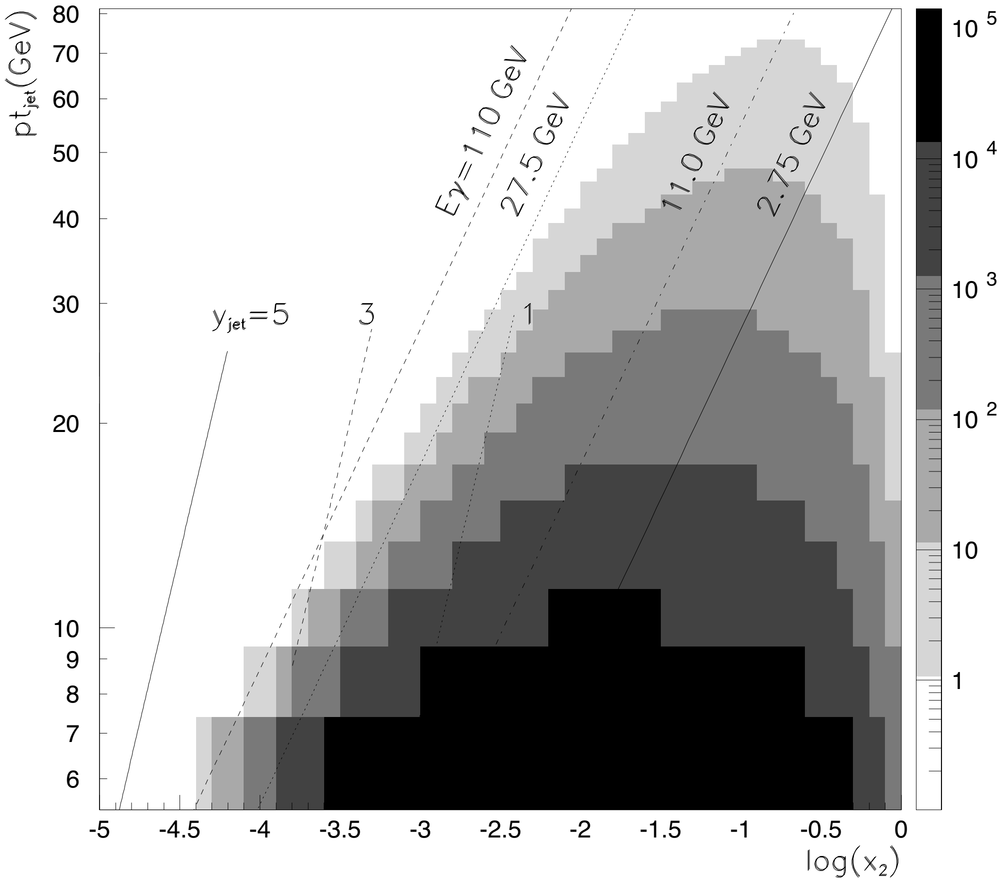
LO diagrams for direct photon: $x_\gamma = 1$

Dominant diagram for small x_p dominated by the nucleon gluon density



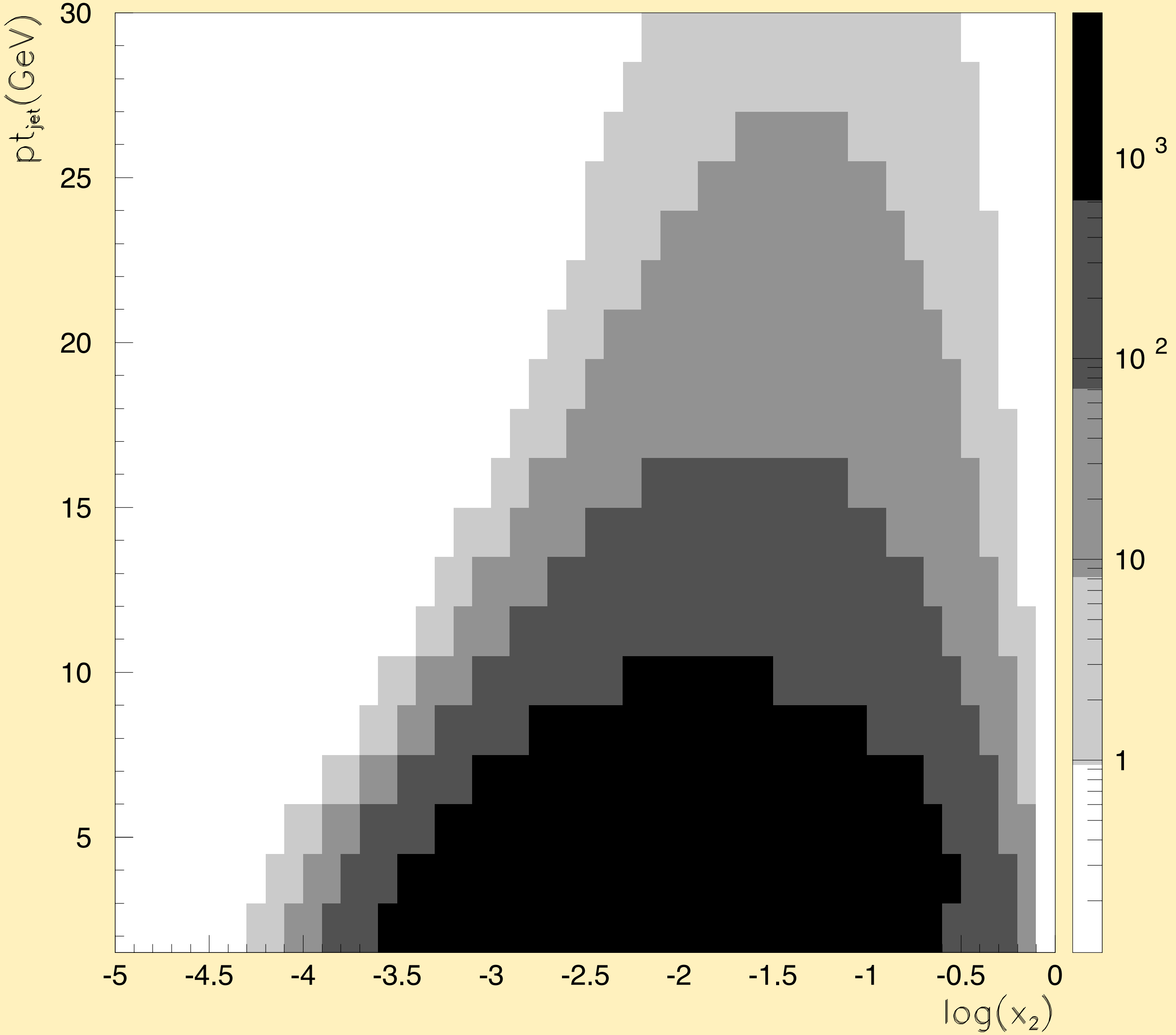
LO diagrams for resolved photon: $x_\gamma < 1$

NLO is important - no separation between direct and resolved mechanisms - recently important theoretical progress - new MC codes are now available, more to come soon.

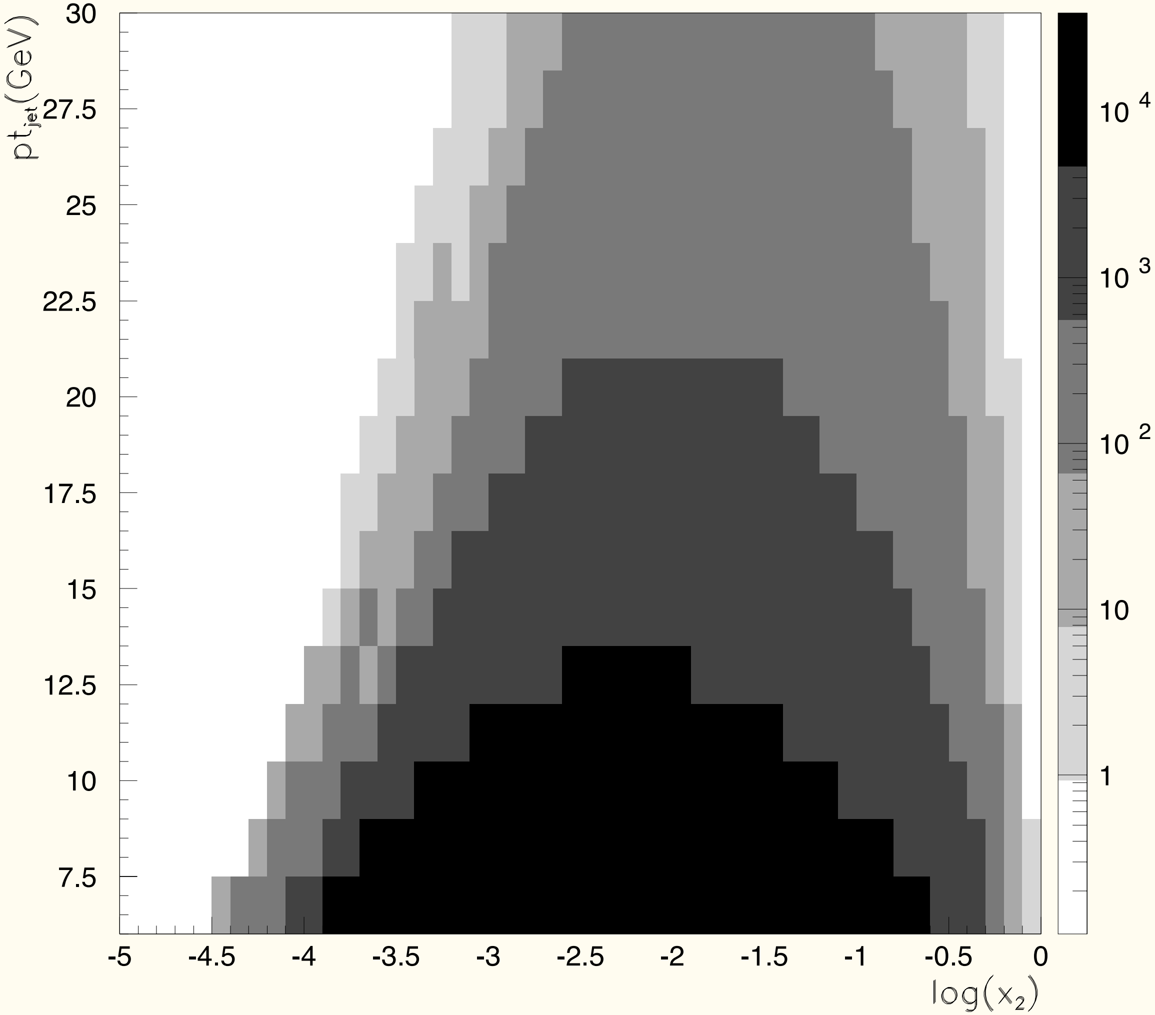


Expected rate of dijet photoproduction for a 1 month LHC Pb+Pb run at $0.4 \times 10^{27}\ cm^{-2}s^{-1}$. Rates are counts per bin of ± 0.25 x_2 and 2 GeV/c in p_T.

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

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

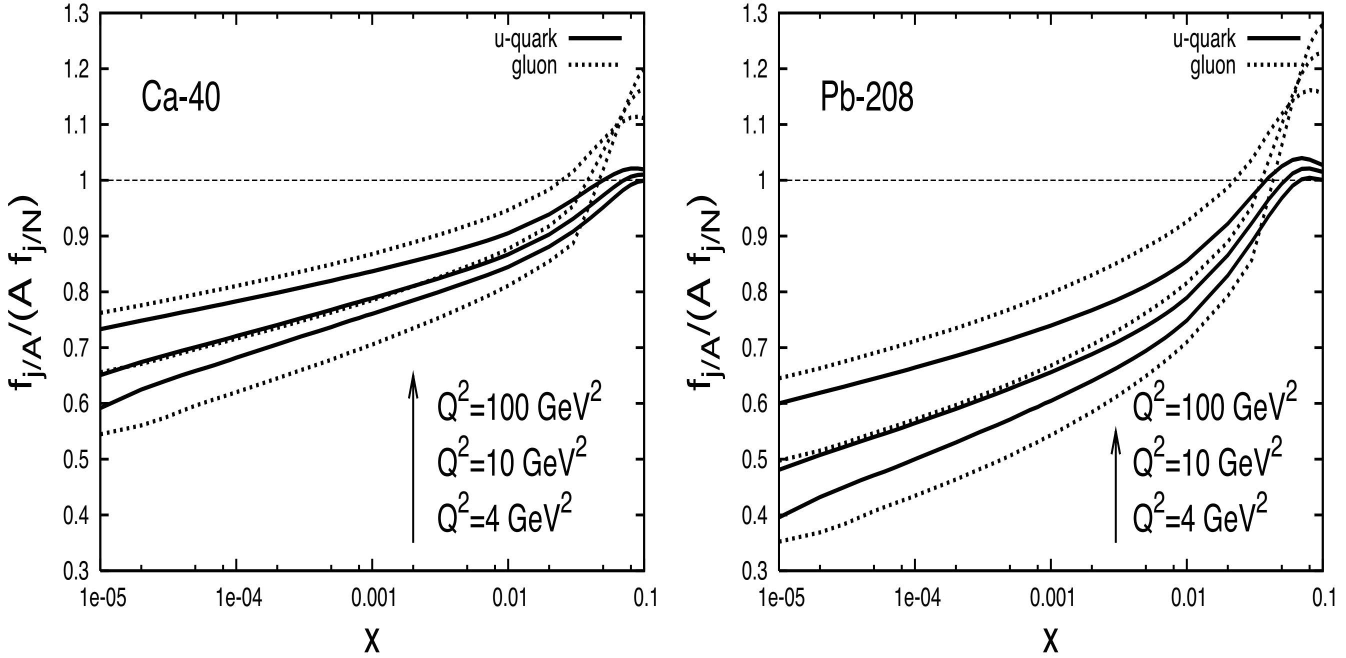
LHC vs ep HERA $\quad \frac{(9/4)A^{1/3} \quad {}_s(p_T^2)xG_N(x \quad 5\cdot 10^{-5}, p_T^2)/p_T^2}{{}_s(Q^2)xG_N(x \quad 10^{-4}, Q^2)/Q^2} \quad$ **3**

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 1.5

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? The leading twist approximation FS 98 based on AGK cutting rules and Collins factorization theorem for diffraction indicates that effects are likely to be significant (will briefly discuss later)



Shadowing for nuclear pdfs using H1 2006 diffractive pdfs

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

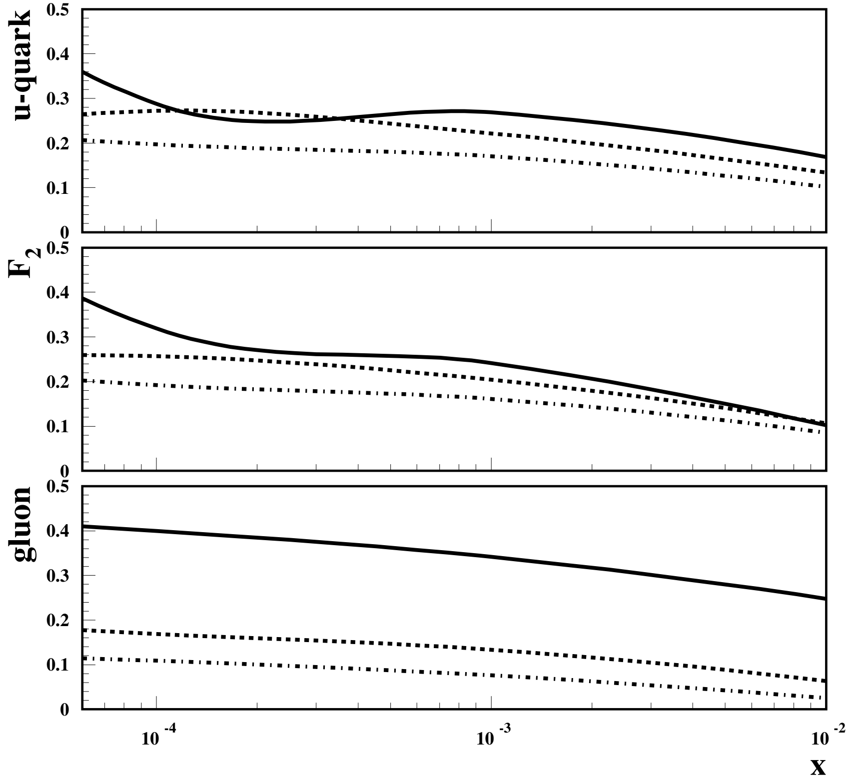
Another critical measurement is hard diffraction:

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

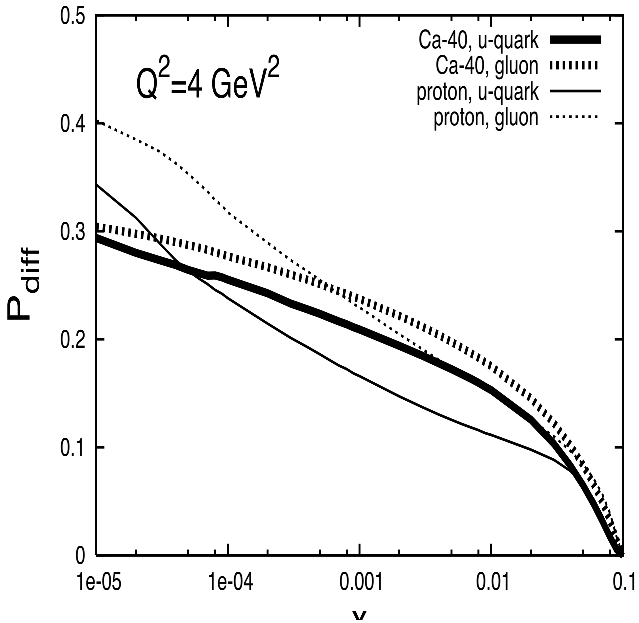
In the black disk limit

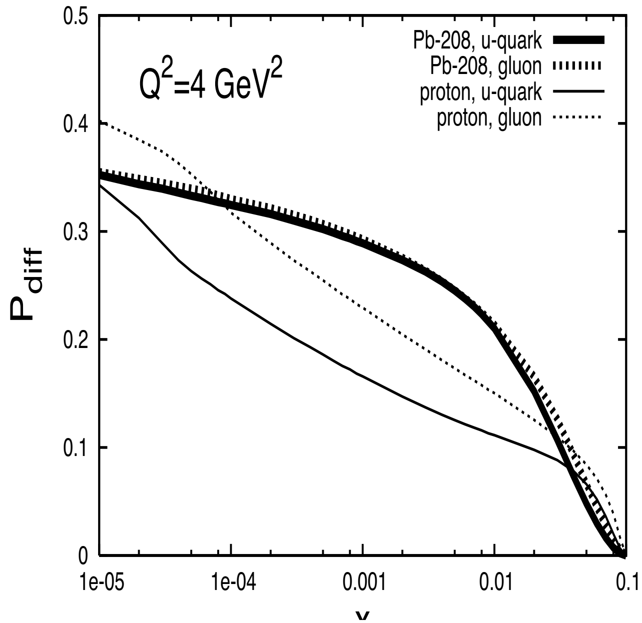
$$\frac{(A \quad jet_1 + jet_2 + X + A)}{(A \quad jet_1 + jet_2 + X)} \quad 0.5$$

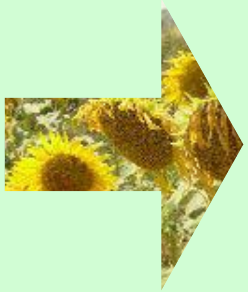
Nuclear diffractive pdfs were calculated by Guzey et al 03 in the same approximations as LT nuclear pdf's



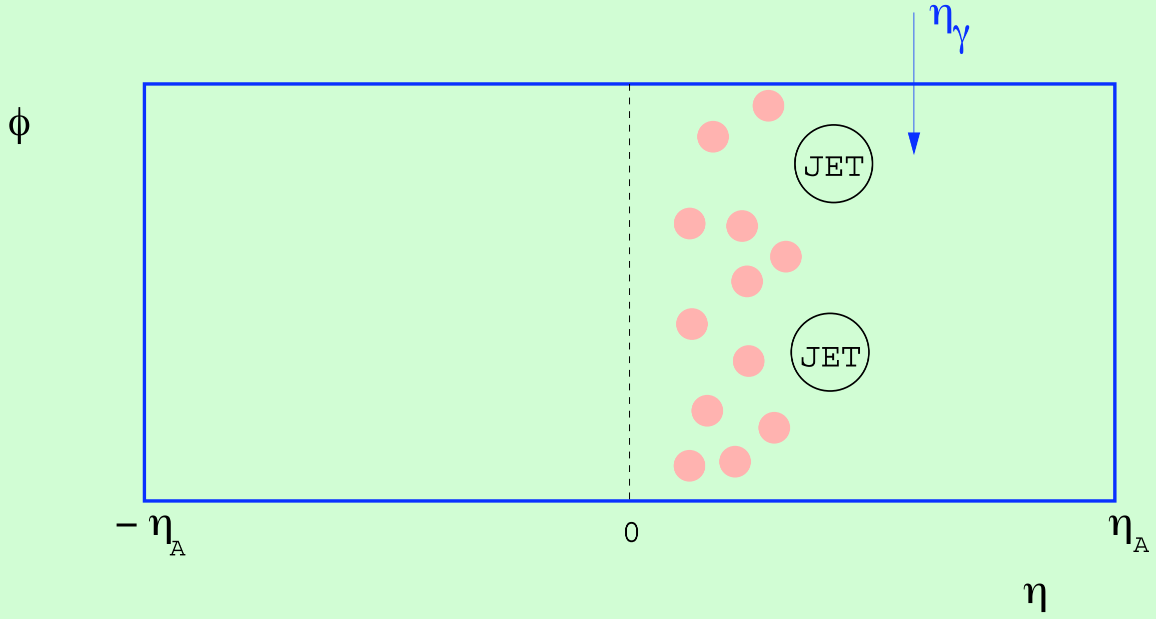
Proximity of the hard interactions with nuclei to BBL leads also to a large probability of diffractive events in nuclei (larger than in the proton). Results of the calculation within the leading twist model (Guzey, et al, 03) are shown the ratios $f^{D(2)}_{j/A}/f_{j/A}$ for the u-quarks and gluons and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







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

Studies of exclusive photoproduction processes:

Hard physics:

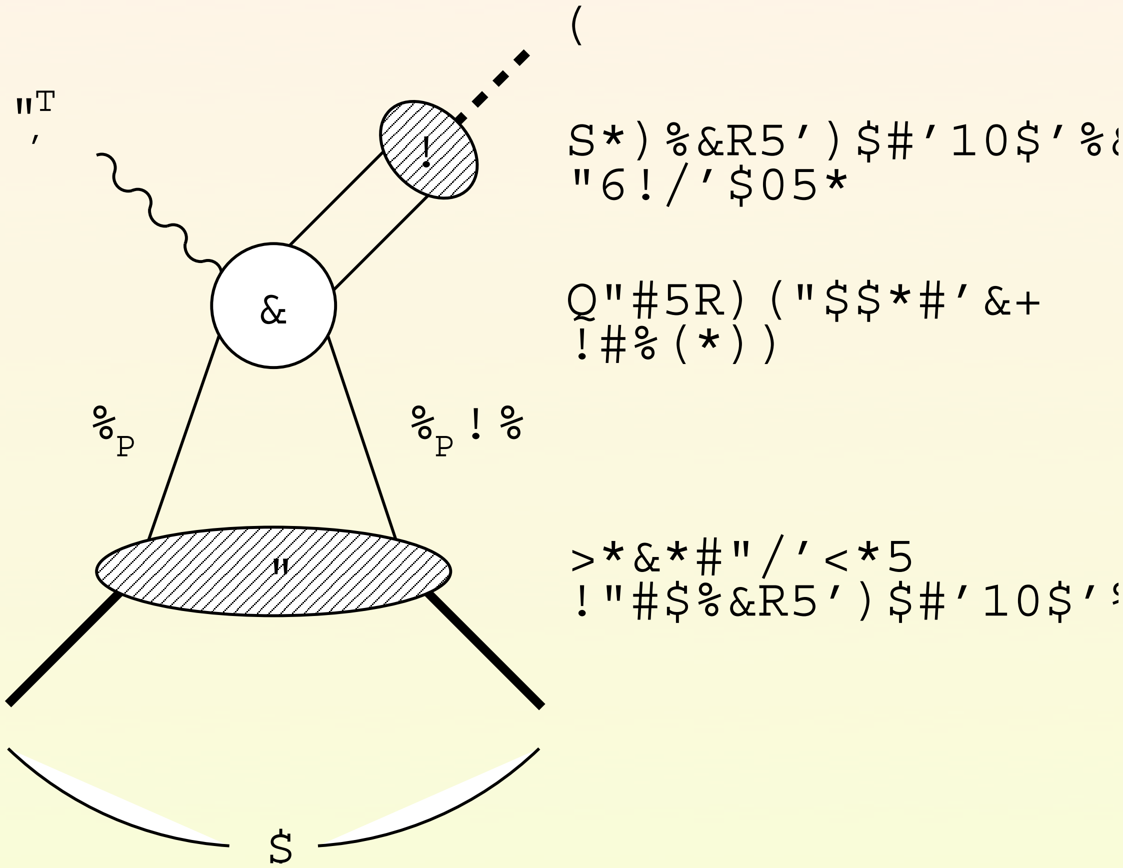
- Onium production
- Diffraction into two, three jets

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)



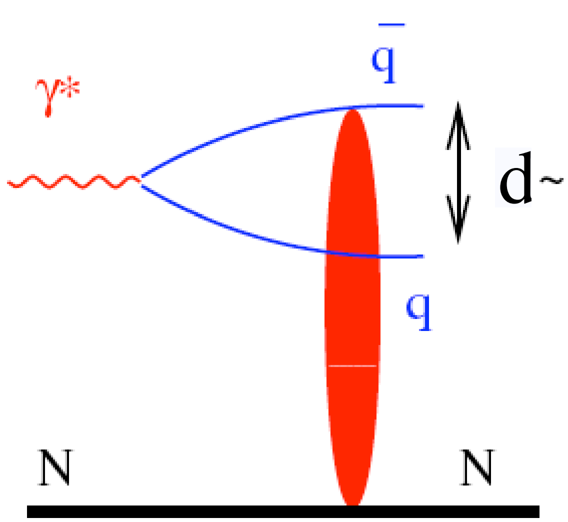
Extensive data on VM production from HERA support dominance of the pQCD dynamics. Numerical calculations including finite transverse size effects explain key elements of high Q^2 data. The most important ones are:

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

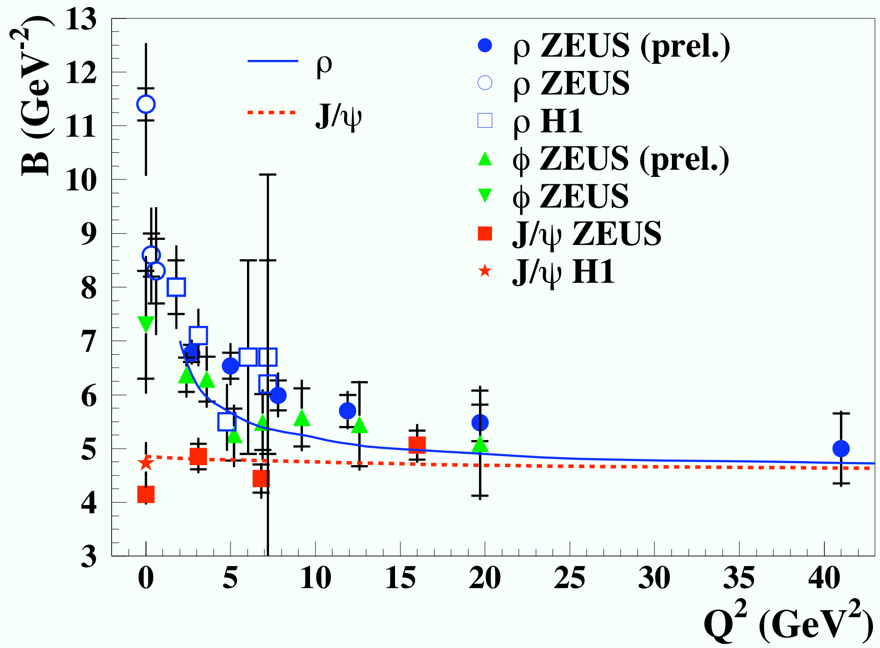
- Absolute cross section and energy dependence of ρ−meson production at $Q^2 \geq 20\ GeV^2$ Explanation of the data at lower Q^2 is more sensitive to the higher twist effects, and uncertainties of the low Q^2 gluon densities.

- 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.



$$d \sim r_T \propto \frac{1}{Q}\left(\frac{1}{m_c}\right) \ll r_N$$



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.

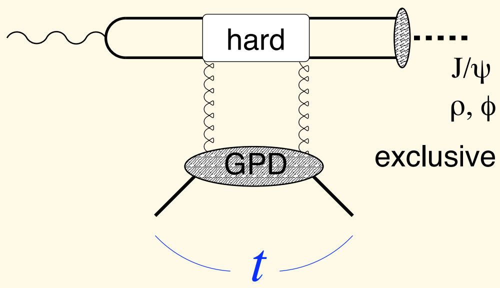
⇒ Transverse distribution of gluons can be extracted from $\gamma + p \rightarrow J/\psi + N$

! Presence of small size $q\bar{q}$ Fock componentss in light mesons is unambigously established

! At transverse separations $d \leq 0.3$ fm pQCD reasonably describes "small $q\bar{q}$ - dipole"- nucleon interaction for $10^{-4} < x < 10^{-2}$

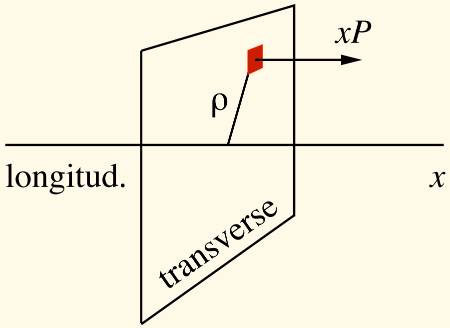
! Color transparency is established for the interaction of small dipoles with nucleons and with nuclei (for $x \sim 10^{-2}$)

- Transverse spatial distribution of gluons



$$G(x, Q^2_{\text{eff}}; t) \;=\; G(x, Q^2_{\text{eff}}) \;\times\; F_g(x, Q^2_{\text{eff}}; t)$$

generalized gluon dist'n — two–gluon formfactor



$$F_g(x, t) \;=\; \int d^2\rho \; e^{-i\vec{\Delta}_\perp \cdot \vec{\rho}} \; F_g(x, \boldsymbol{\rho})$$

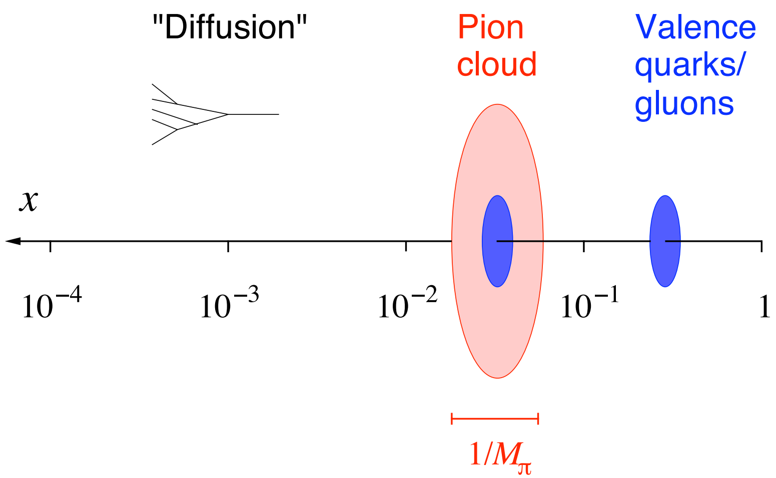
transverse spatial distribution of gluons

$$\langle \rho^2 \rangle_g \;=\; 4 \, \frac{\partial}{\partial t} F_g(x, t)$$

gluonic transverse size of nucleon, x–dependent!

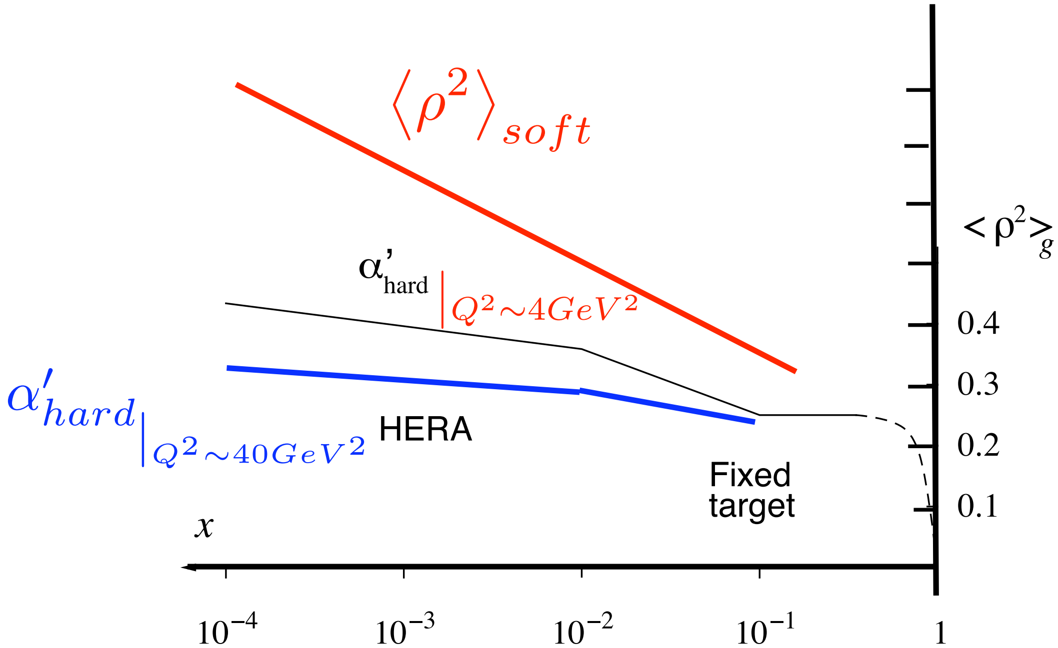
– Can be extracted from t–dependence of $\dfrac{d\sigma}{dt}(\gamma^* p \to V p)$

Gluonic transverse size - x dependence



Gluon transverse size decreases with increase of x

Pion cloud contributes for $x < M_\pi/M_N$ [MS &C.Weiss 03]



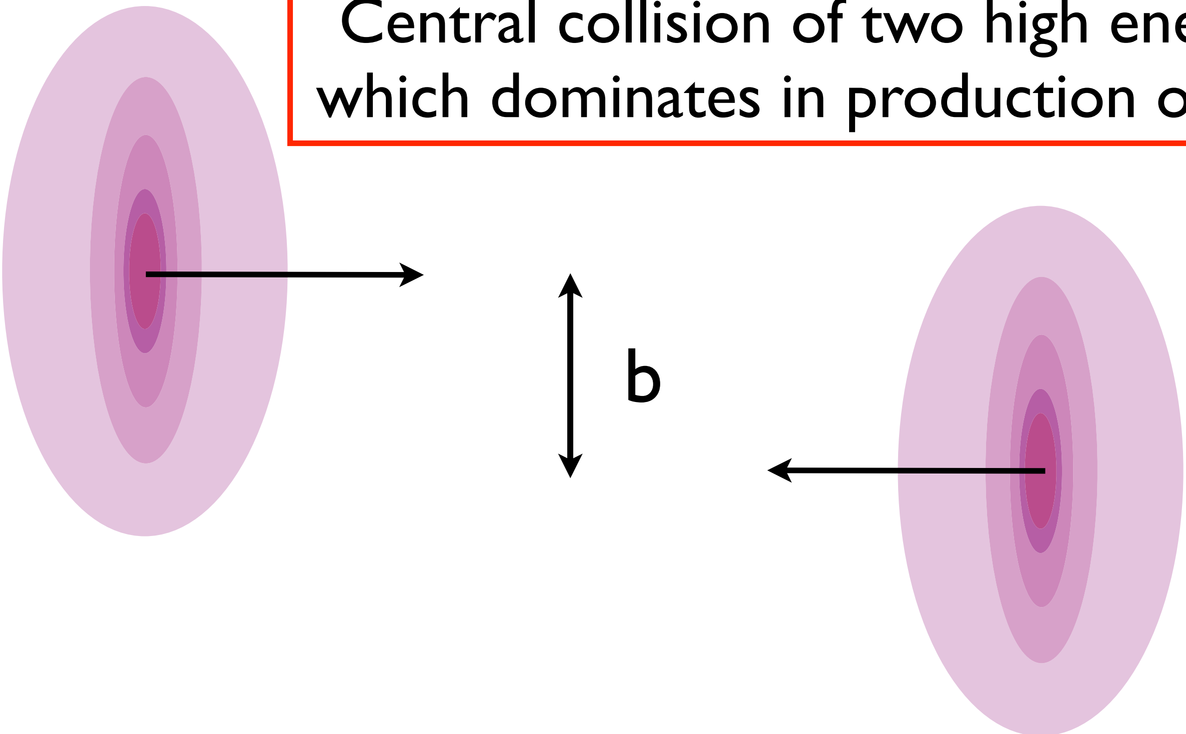
Transverse size of large x partons is much smaller than the transverse range of soft strong interactions

$$\langle \rho^2 (x > 10^{-2} \rangle \ll R^2_{soft}$$

$$\Downarrow$$

Two scale picture

Central collision of two high energy protons which dominates in production on SUSY,Higgs



Valence quarks/gluons of the protons are interacting with probability ~ one, loosing energy and getting large transverse momenta growing with energy. Soft interactions are suppressed - minimal scale/virtuality of strong interaction is few GeV and growing with energy. Gross suppression of particle production in fragmentation region, much higher rate of hadron production away from the fragmentation region.

Precision measurement of t -dependence of onium photoproduction off proton crucial for reliable modeling of these phenomena

❑ Exclusive onium production

AA collisions - maximal W^2 one can effectively probe is $W^2 = 2m_V E_N$ due to dominance of photons with smaller energy

$x_{min} \equiv m_V^2/W^2 = m_V/2\,E_N$ separate problem - how to trigger for y=0

At LHC $x_{min}\,(J/\psi) = .0005,\ x_{min}\,(\Upsilon) = .002$

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/ case to y 2, x 10^{-5}.

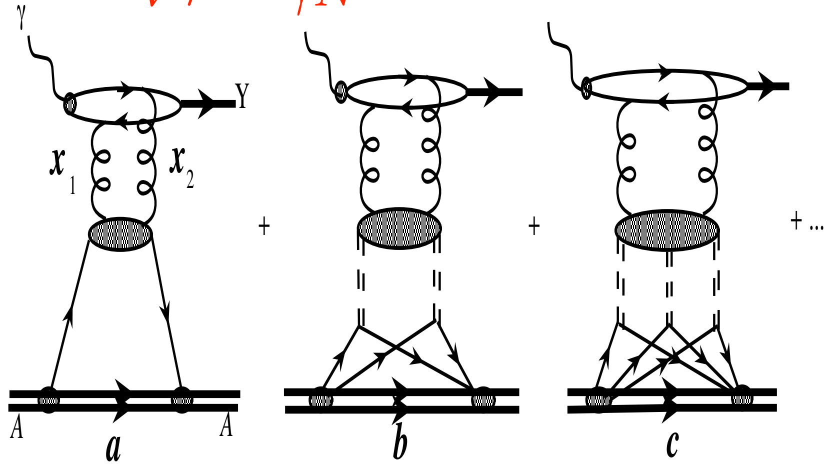
Numerical study is still needed

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 (neglecting small t dependence of shadowing)

$$\sigma_{\gamma A\to VA}(s) = \frac{d\sigma_{\gamma N\to VN}(s,t_{min})}{dt}\left[\frac{G_A(x_1,x_2,Q^2_{eff},t=0)}{AG_N(x_x,x_2,Q^2_{eff},t=0)}\right]^2 \int_{-\infty}^{t_{min}} dt \left|\int d^2b dz e^{i\vec{q}_t\cdot\vec{b}} e^{iq_l z}\rho(\vec{b},z)\right|^2.$$

$$where\ x = x_1 - x_2 = m_V^2/W_{\gamma N}^2$$



: High energy quarkonium photoproduction in the leading twist approximation.

for small d - LT much larger screening than eikonal

⇓

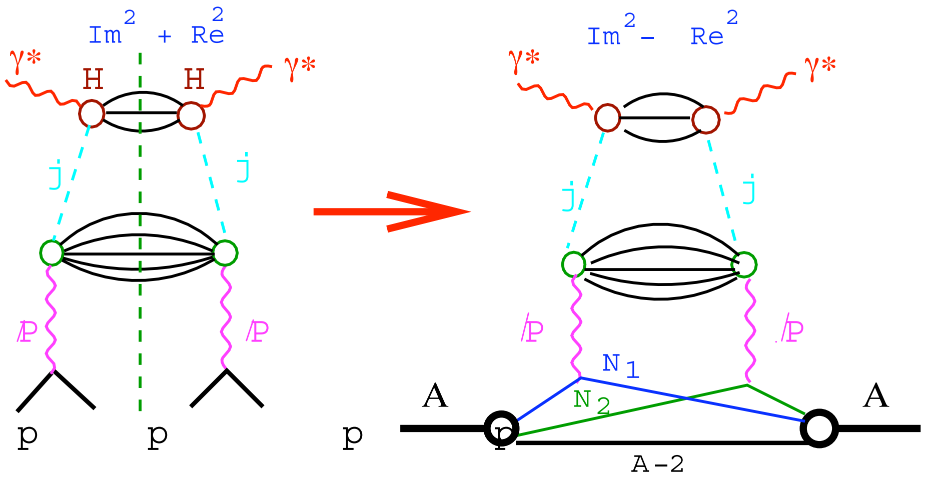
$$\frac{G_A(x_1,x_2,Q^2_{eff},t=0)}{G_N(x_1,x_2,Q^2_{eff},t=0)} \approx \frac{G_A((x_1+x_2)/2,Q^2_{eff},t=0)}{G_N((x_1+x_2)/2,Q^2_{eff},t=0)}$$

$$\frac{(x_1+x_2)_{J/\psi}}{2} \approx x; \quad \frac{(x_1+x_2)_{\Upsilon}}{2} \approx x/2$$

Factor of > 1.5 suppression of cross sections at x< 0.001 for onium production for all Q (see Guzey talk for discussion of shadowing)

Theoretical expectations for shadowing in the LT limit

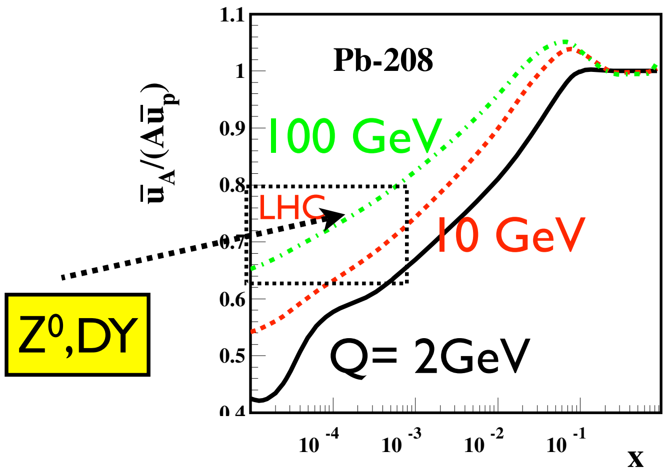
Combining Gribov theory of shadowing and the Collins pQCD factorization theorem for diffraction in DIS (confirmed by experiments at HERA) allows to calculate LT shadowing for all parton densities (FS98)

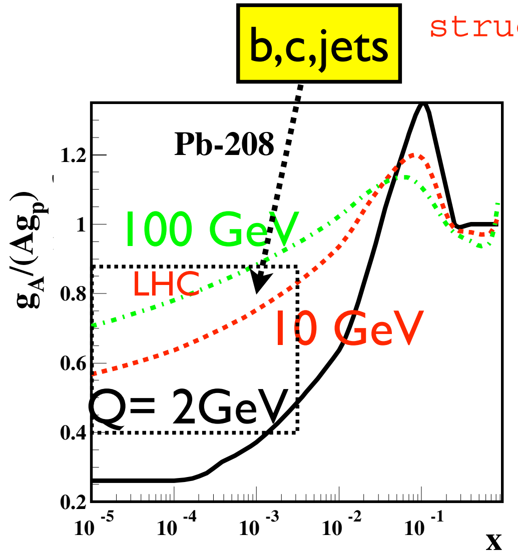


Hard diffraction off parton "j"

Leading twist contrib to the nuclear shadow structure function f$_j$(x, Q^2)

LHC

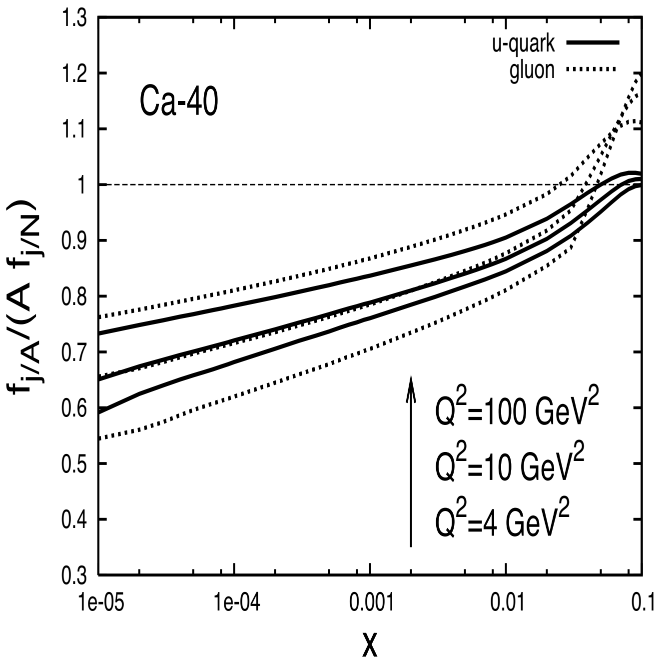


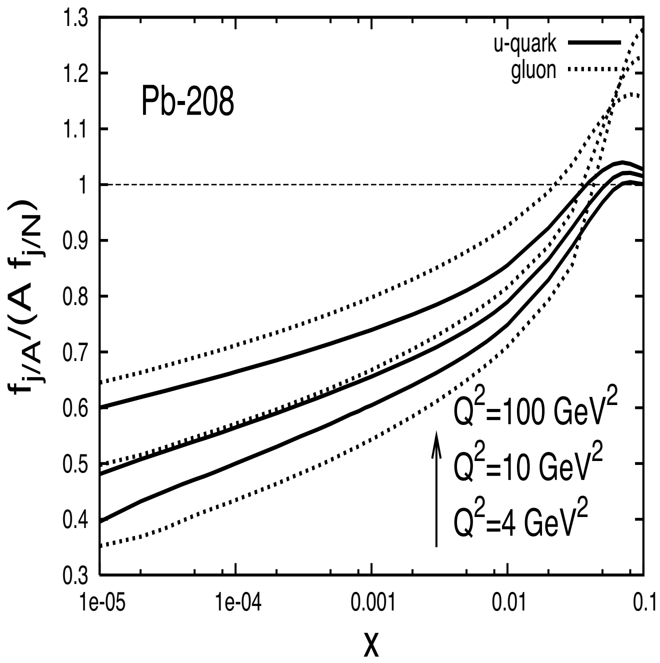


Numerical results using H1 diffractive pdfs 2001

First results of the analysis using H1 pdfs 2006 - next slide

Guzey, MS

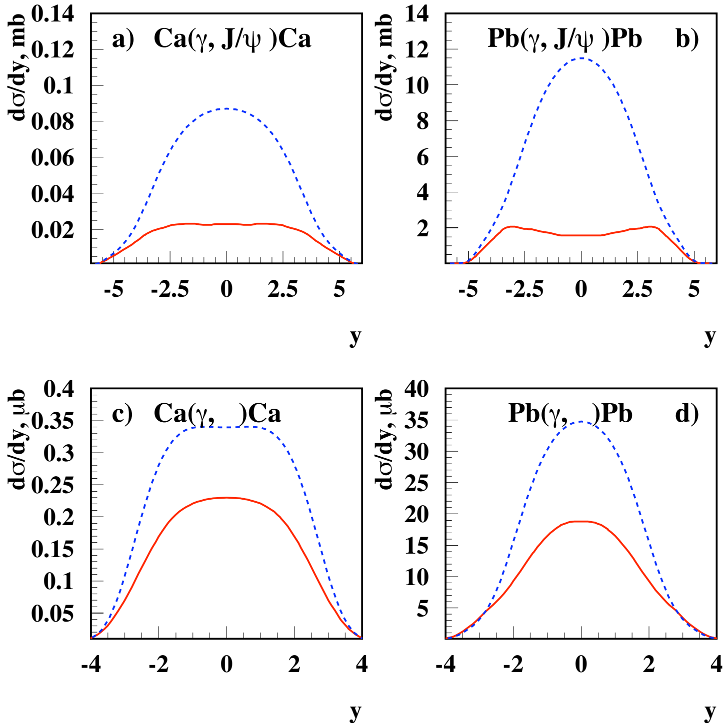




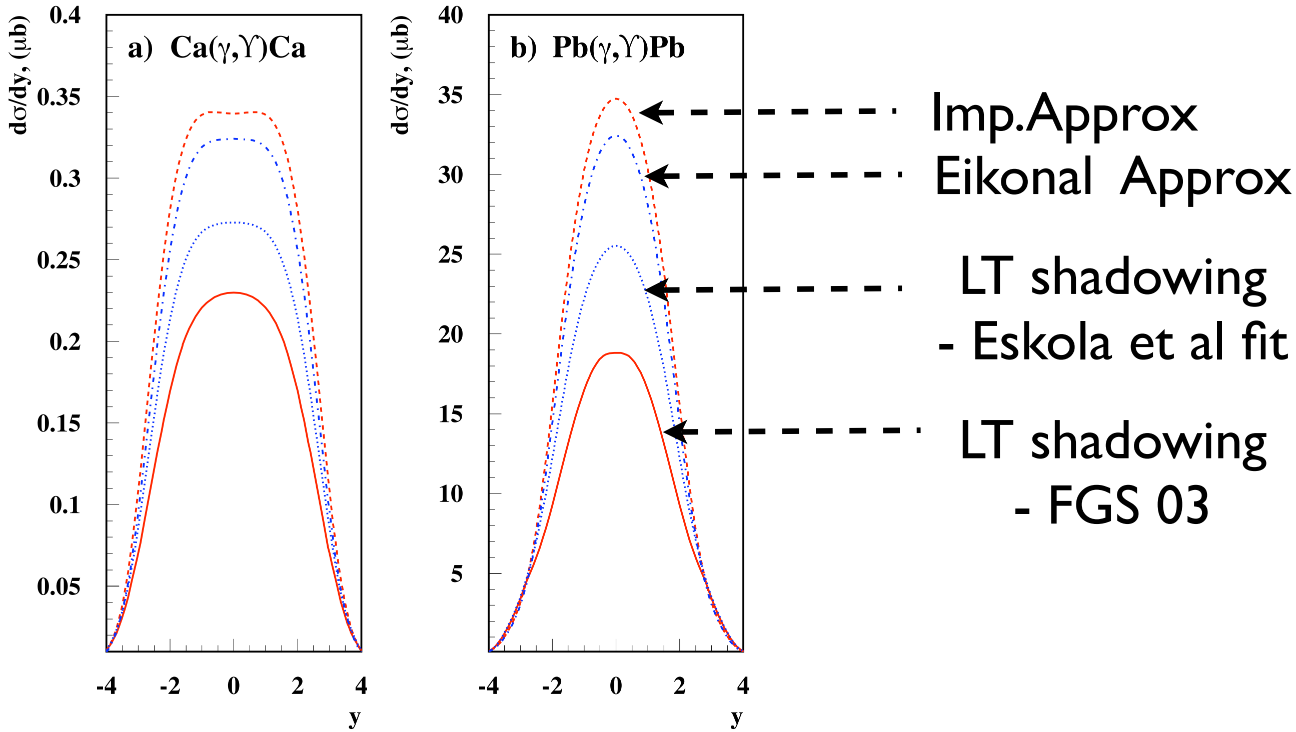
Shadowing for nuclear pdfs using new H1 diffractive pdfs

Leads to a factor of two (1.5) smaller shadowing for coherent production of J/ψ (Υ) at y=0

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



The rapidity distributions for the J/ and coherent production o 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).



The rapidity distribution for coherent Υ production in Ca-Ca and Pb-Pb ultraperipheral collisions at the LHC
The solid curve corresponds to the calculation including leading twist nuclear shadowing using H1 diffractive pdfs of 2000; the dotted curve corresponds to the calculation with the model of shadowing of Eskola et al.; the dot-dashed curve is the calculation in the eikonal dipole rescattering model; the dashed curve corresponds to the impulse approximation.

Experimental challenges: Trigger on relatively low transverse momentum leptons. Problem for J/ψ 's for y=0(??) for y=2-4 the ALICE study finds good rates. Acceptance for ϒ is good in a wide rapidity range. CMS - seems to have good capabilities as well.

Neutron tagging of quasielastic J/ψ and ϒ photoproduction off nucleus

If $\sigma_{tot}^{J/\psi N}$ the effective quarkonium($Q\bar{Q}$)-nucleon total cross section

is small (~ 3mb for J/ψ for s~ 200 GeV²)

$$\sigma_{inc}^{\gamma A \to J/\psi A'} = 2\pi\sigma(\gamma N \to J/\psi N) \cdot \int_0^\infty b d\, b \int_{-\infty}^{\infty} dz \rho(\vec{b}, z) \exp[-\sigma_{tot}^{J/\psi N} T(\vec{b})]$$

Here $$T(\vec{b}) = \int_{-\infty}^{\infty} \rho(\vec{b}, z) d\, z$$

$$\sigma_{elastic}(\gamma A \to J/\psi + A) \propto A^{4/3}, \sigma_{quasielastic}(\gamma A \to J/\psi + A') \propto A$$

$\Downarrow$ *LT shadowing*

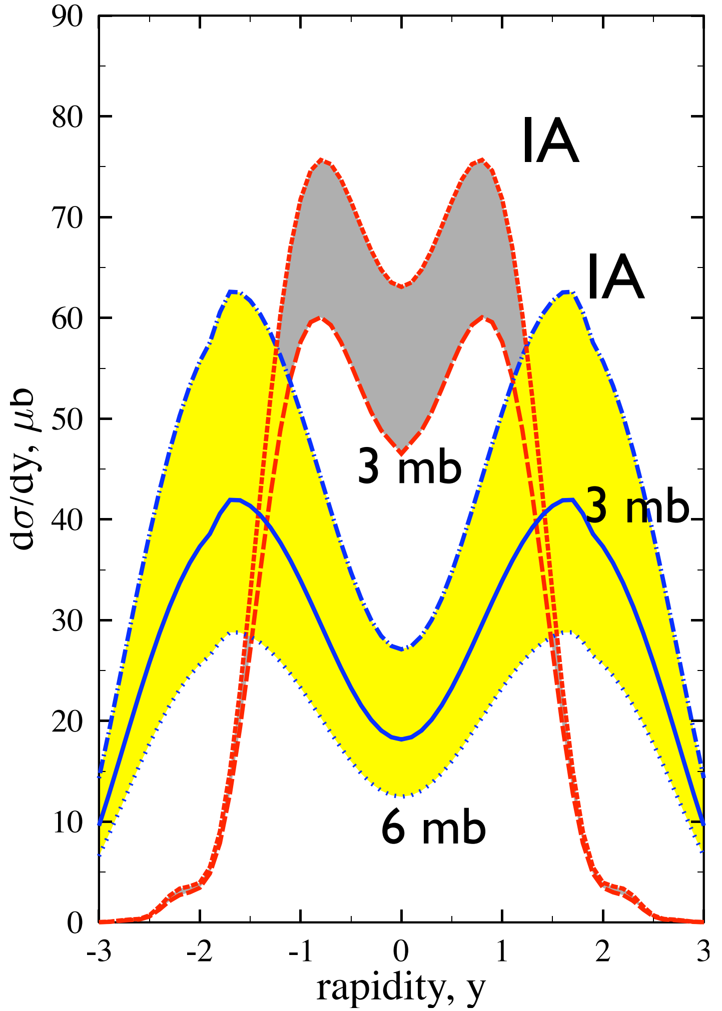
$\Downarrow$ *BDR*

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

Change of A dependence by a factor ~$A^{2/3}$ for both processes !!!

Both processes allow to study new QCD domain

QE channel allows to reach a factor of ~100 smaller x !!

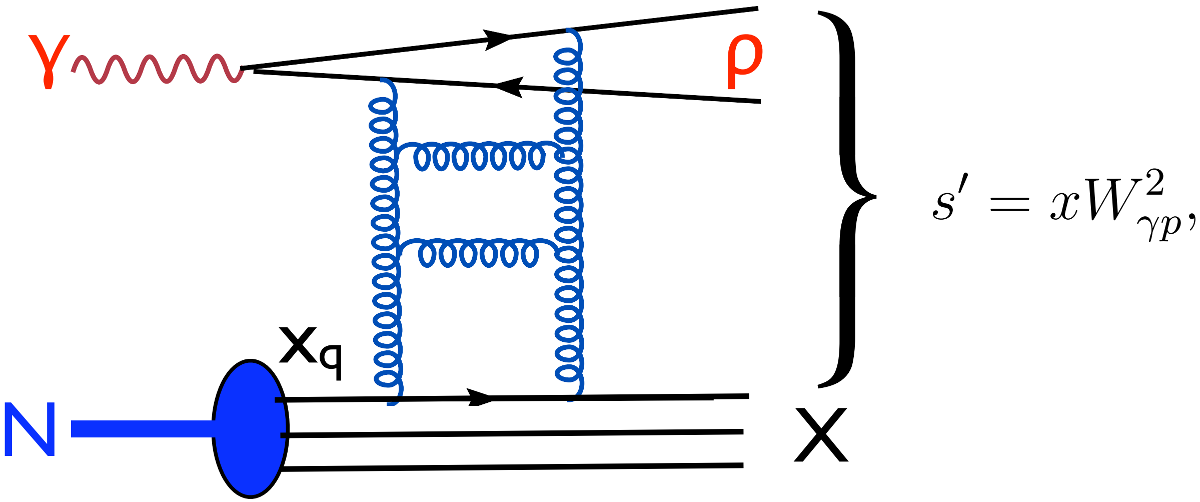


The integrated over momentum transfer rapidity distributions for the J/ψ coherent photoproduction in UPC of Au ions at RHIC calculated with effective cross section for J/ψ - nucleon interaction of 3 mb (long-dashed line) and in the Impulse Approximation (short-dashed line). The incoherent J/Ψ production cross section estimated in the Glauber model for J/ψ - nucleon cross section of 3 mb (solid line) and 6 mb (dotted line), and in the IA (dot-dashed line)

All plans/measurements involve selecting events where nucleus emitted neutrons - efficiency ~100% for QE and ~50% (RHIC)/ ~70% LHC

Hence QE/ELASTIC ~0.3 → ~40% (RHIC) - 35% (LHC) for observed events

Rapidity gap processes at large $t=(p_\rho-p_\gamma)^2$: from HERA to LHC



Elementary reaction - scattering of a hadron (γ, γ*) off a parton of the target at large $t=(p_\gamma-p_V)^2$

$$x = \frac{-t}{(-t + M_X^2 - m_N^2)}$$

FS 89 (large t pp→p +gap + jet), FS95

Mueller & Tung 91

Forshaw & Ryskin 95

The rapidity gap between the produced vector meson and knocked out parton (roughly corresponding to the leading edge of the rapidity range filled by the hadronic system X) is related to $W_{\gamma p}$ and t (for large t, $W_{\gamma p}$ as

$$y_r = \ln \frac{x W_{\gamma p}^2}{\sqrt{(-t)(m_V^2 - t)}}$$

The choice of large t ensures two important simplifications. First, *the parton ladder mediating quasielastic scattering is attached to the projectile via two gluons*. Second is that *attachment of the ladder to two partons of the target is strongly suppressed*. Also the transverse size $d_{q\bar{q}} \propto 1/\sqrt{m_c^2 - t/4}$

$$\frac{d\sigma_{\gamma+p\to V+X}}{dtdx} = \frac{d\sigma_{\gamma+quark\to V+quark}}{dt}\left[\frac{81}{16}g_p(x,t) + \sum_i (q_p^i(x,t) + \bar{q}_p^i(x,t))\right]$$

$$\frac{d\sigma_{N+q(g)\to N+q(g)}}{dt} \propto \frac{1}{t^6} \qquad \frac{d\sigma_{\gamma+q(g)\to V+q(g)}}{dt} \propto \frac{1}{t^4}$$

Energy dependence of $f_q(s',t) \propto [s']^{\delta(t)}$

$\delta(-t >> 1\ \mathrm{GeV}^2)$?

Soft QCD $\delta<-0.5$

Two gluon exchange $\delta=0$

DGLAP / resummed BFKL for t=0 $\delta=0.2$ -- 0.3

subtle points in BFKL analysis for t away from 0

We analyzed the rho-meson data using a fit

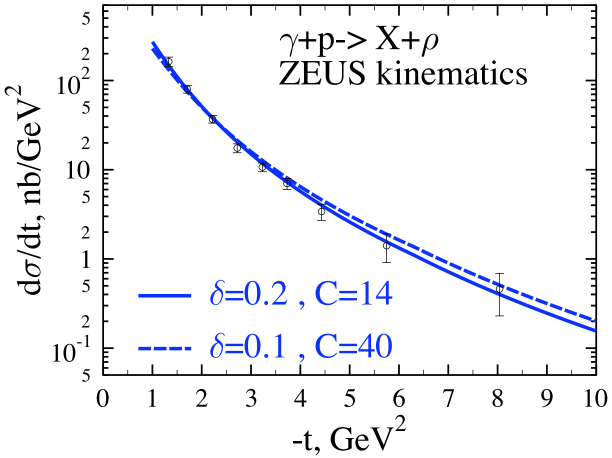
$$\frac{d\sigma_{\gamma+p\to\rho+X}}{dt} = \frac{C}{(1-t/t_0)^4}\left(\frac{s}{{m_V}^2 - t}\right)^{2\delta(t)} I(x_{min}, t)$$

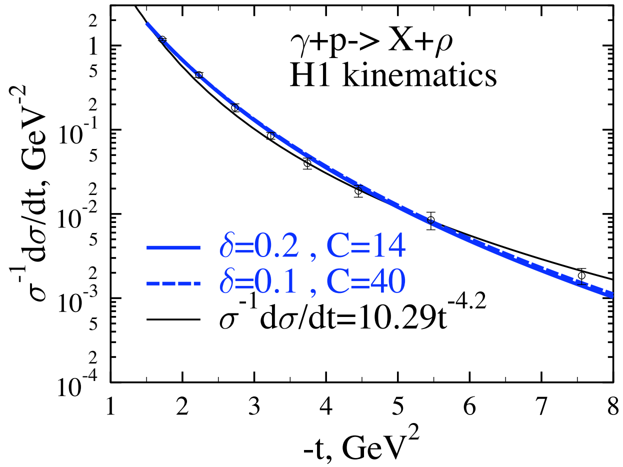
$$I(x_{min}, t) = \int_{x_{min}}^{1} x^{2\delta(t)} \left[\frac{81}{16} g_p(x,t) + \sum_i [q_p^i(x,t) + \bar{q}_p^i(x,t)\right] dx$$

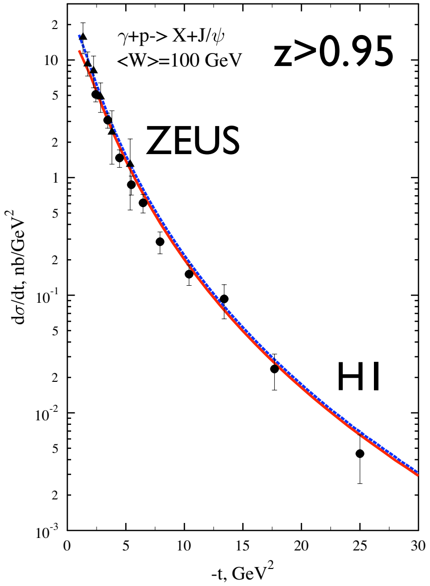
$t_0 \sim 1\ \text{GeV}^2$, δ=0.1 -0.2 is consistent with the data at large t

For J/ψ we changed

$$\frac{1}{(1-t/t_0)^4} \to \frac{1}{(1-t/t_0)(1-t/m_{J/\psi}^2)^3}$$



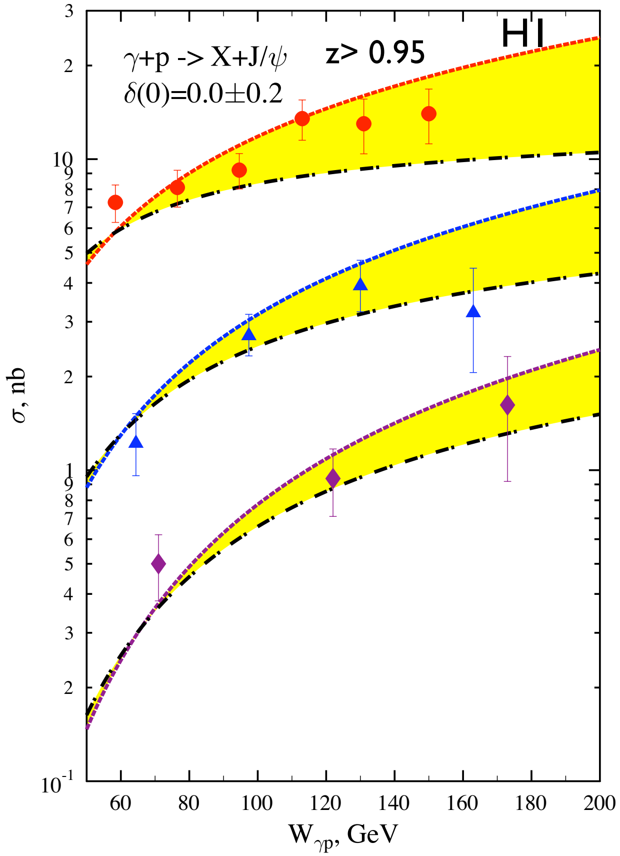


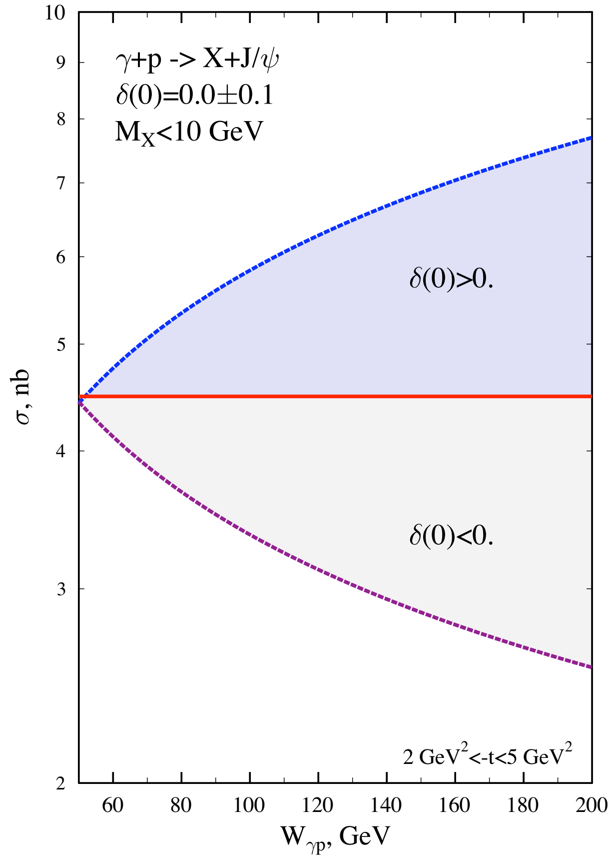


Description of ZEUS and H1 data for t-dependence of the large t and rapidity gap cross section. ZEUS data were taken at average $W_{\gamma p}$=100 GeV with fixed cut M_X < 25 GeV and additional restriction 0.01 <x< 1. The H1 data were taken at average $W_{\gamma p}$=85 GeV and cut M_X < 5 GeV.

Sensitivity to the energy dependence is weak.

t-dependence of J/ψ production is consistent with dominance of hard dynamics





Study of the VM production with gaps is mostly sensitive to gluon pdfs if the cut is on z_{min} or M_X^2/W^2 is made. Sensitivity to the energy dependence of dipole - parton amplitude $f(s',t)\propto s'^{\delta}$ is minor. On the contrary if the cut on $M_X <$ const is made, sensitivity to the value of δ is very high.

Analyses with z cut, M^2_X/s < const cuts are good for study of the dominance of the mechanism of scattering off single partons. However they correspond to rapidity interval between VM and jet which are typically of the order $\Delta y = 2 - 3$.

Optimal way to study BFKL dynamics is to keep
M^2_X < const and vary W

Difficult but not impossible at HERA natural at LHC

At LHC one can energy depedence of elastic $q\bar{q}$ - parton scattering at W'=20 GeV - 400 GeV

$$\sigma_{el}(q\bar{q} - q(g)(W' = 400GeV)/\sigma_{el}(q\bar{q} - q(g)(W' = 20GeV) \sim 10\,!!!$$ if δ=0.2

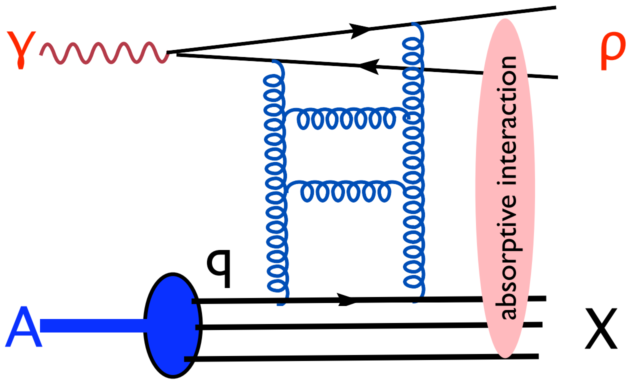
- $\gamma + A \rightarrow \rho + \text{gap} + X$

UPC [LHC & RHIC11(?)]

FS & Zhalov 06

measure of the strength of inelastic interactions of small dipole in the processes initiated by BFKL elastic $q\bar{q}$ - parton scattering at W=30 GeV - 1 TeV

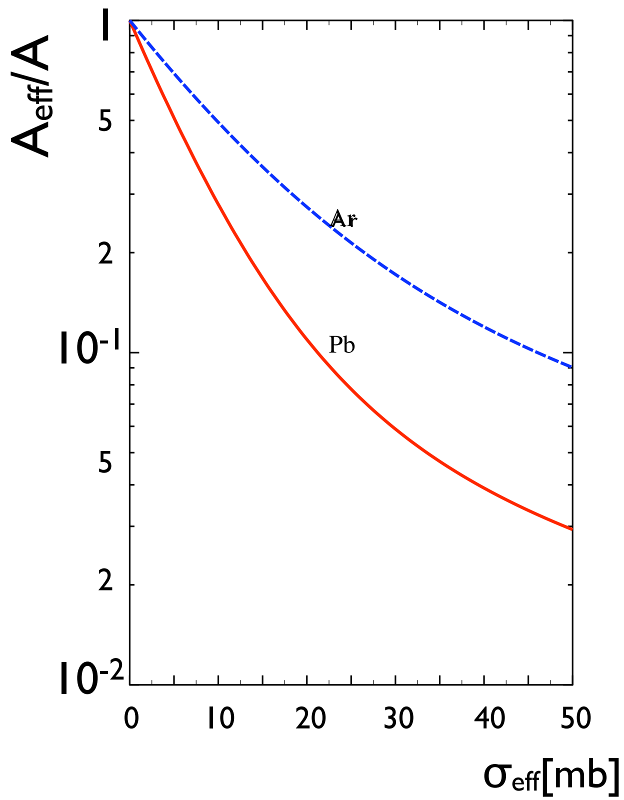
$$\sigma_{el}(q\bar{q} - q(g)(W = 1TeV)/\sigma_{el}(q\bar{q} - q(g)(W = 30GeV) > 30\,!!!$$



Advantages:

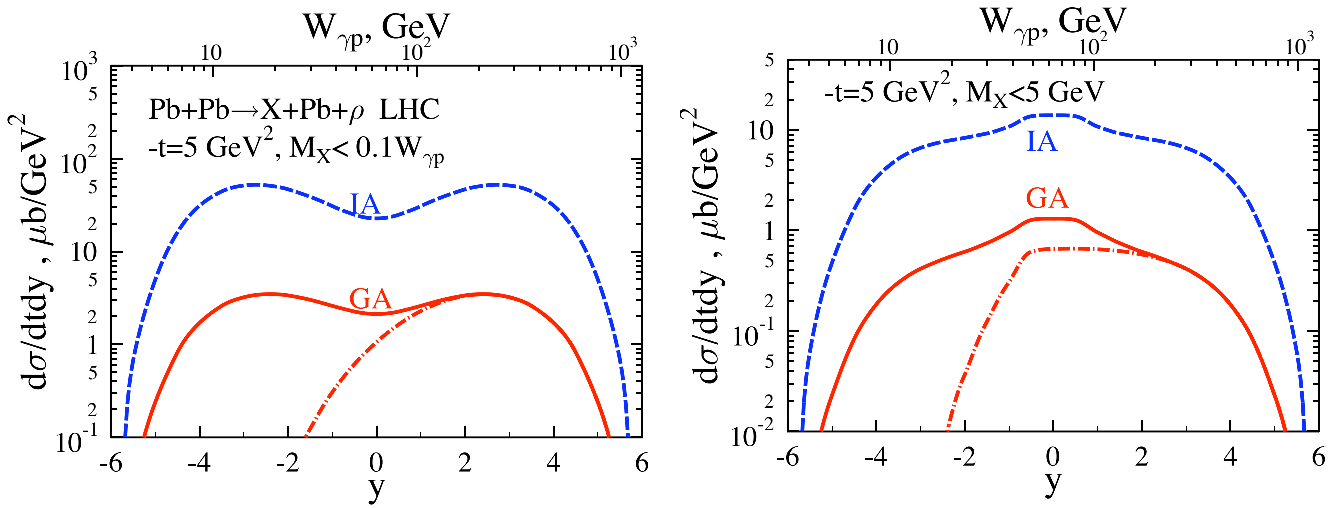
trigger on hadron production in a rapidity interval close to one of the nuclei

no ambiguity which of the nuclei emitted photon - Large W are possible



Strong sensitivity of A_{eff}/A to the strength of inelastic $q\bar{q}$-N interactions

Complementary to quasielastic process - no small x partons in the nucleus are involved on the trigger level



Integrated over mass of produced system cross section of the nucleon dissociative ρ meson photoproduction at $-t=5\ GeV^2$ in the ultraperipheral lead-lead collisions at LHC. The upper figure - the limit of the mass of produced system M_X is proportional to the photon-nucleon center of mass energy $M_X < 0.1 W_{\gamma p}$, in the right figure for central rapidities the limit of M_X is fixed by restriction $M_X < 5 GeV$. Solid line - calculations with Glauber-Gribov screening, dashed line calculations in the leading twist approximation neglecting nuclear shadowing correction which is very small for discussed kinematics, dot-dashed line - one-side contribution when ρ meson is produced by photons emitted by only one nucleus: large positive rapidities correspond to vector mesons produced by high energy photons. The counting rate can be estimated using expected luminosity for PbPb collisions $L=10^{-3}\ \mu b^{-1}\ sec^{-1}$.

Exclusive UPC processes 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

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

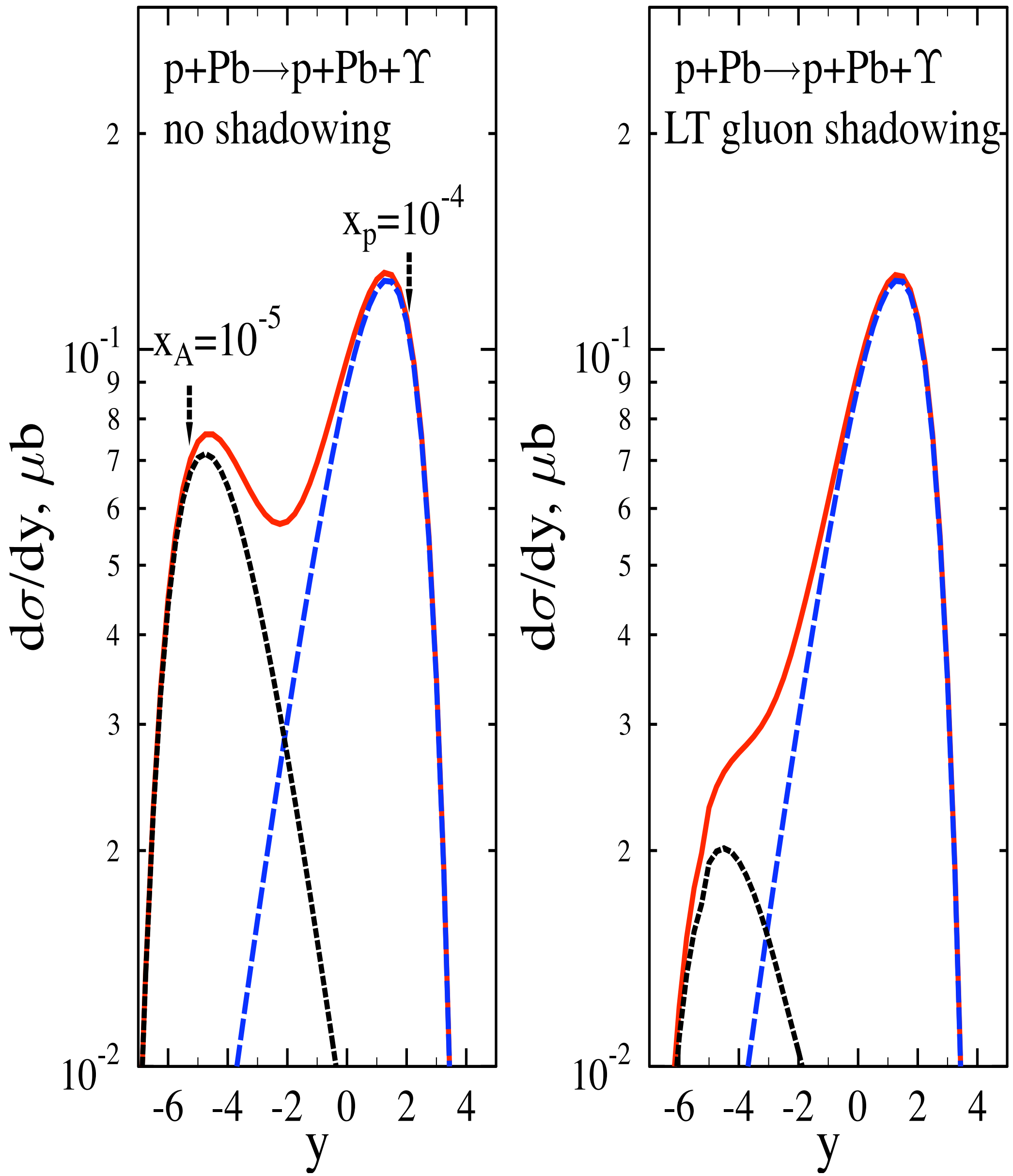
Assessment of the HERA experimental situation:

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

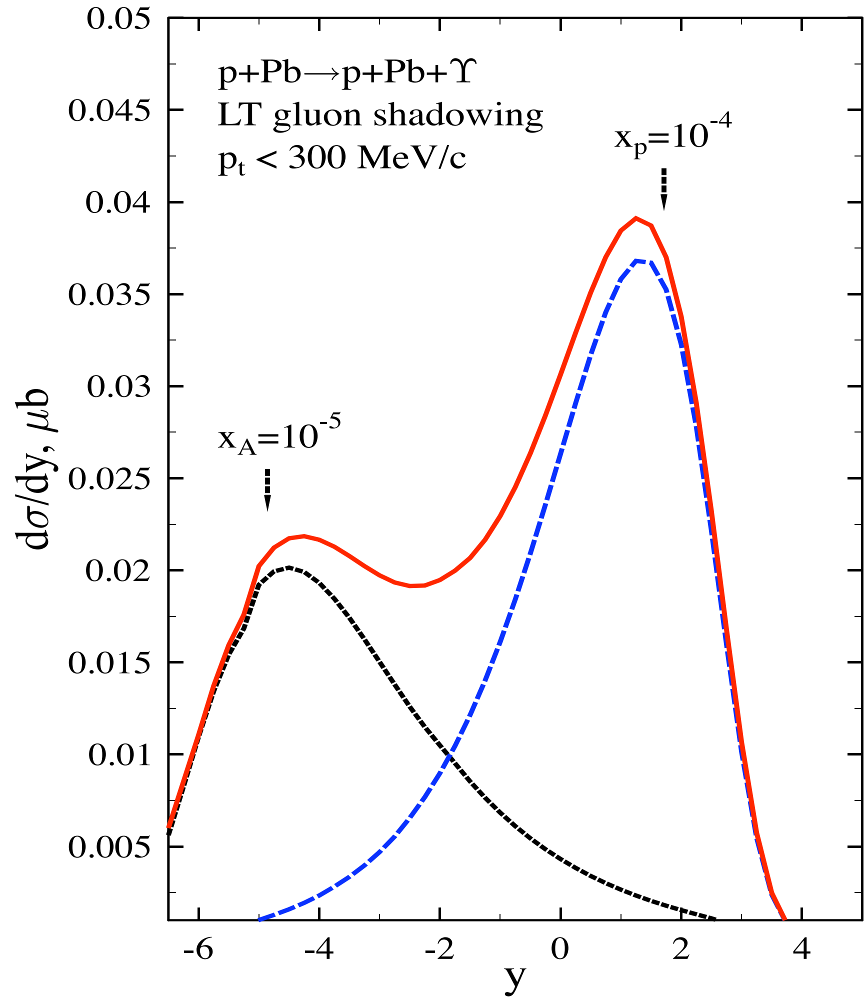
Reminder - *knowledge of t-dependence of GPDs at small x crucial for realistic modeling on pp collisions with production of new particles at LHC*



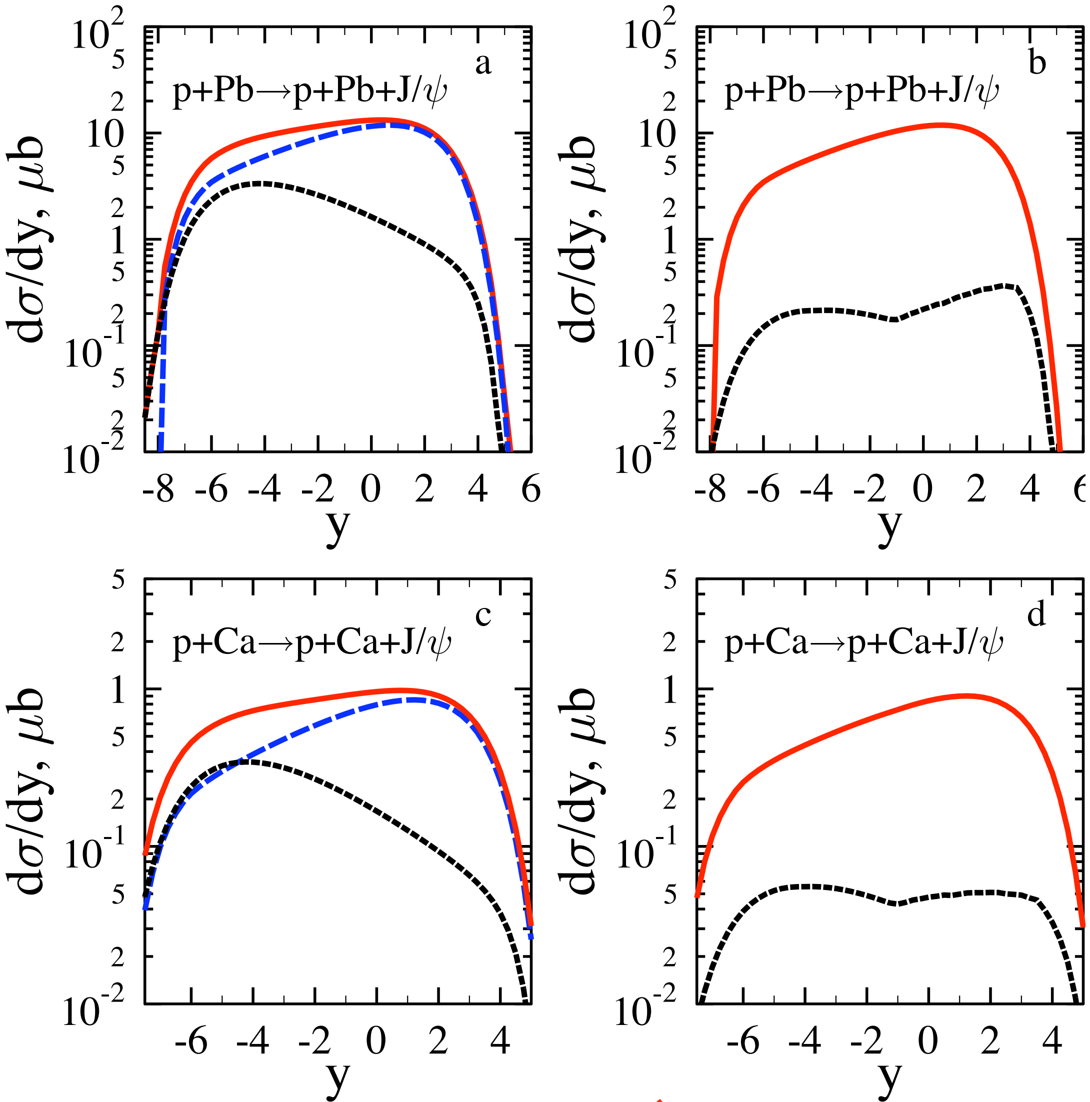
Zhalov & MS 05

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) and measure nuclear shadowing at $Q^2=40\ GeV^2$

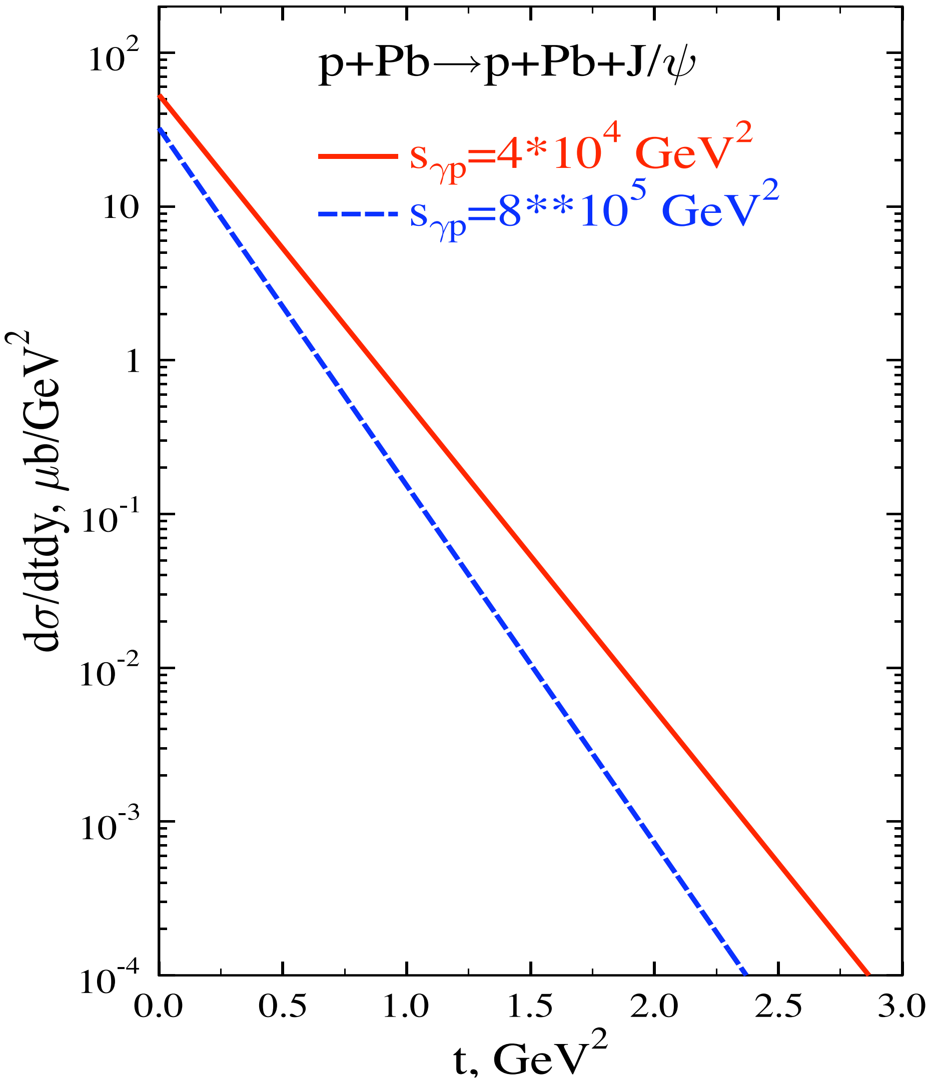
Production of ϒ's in pA collisions : coherent $\gamma+A \to V+A$ is shown by black lines, and $\gamma+p \to V+p$ by blue lines.



Rapidity distribution for Υ photoproduction in pPb UPC at LHC with(solid line)
with gluon shadowing and the cut of the quarkonium transverse momentum $p_t < 300 MeV/c$.



High enough rates down to $x \sim 10^{-6}$, however extracting nuclear contribution would be a challenge if indeed the nuclear shadowing is as high as in FGS05. Would require resolution in transverse momentum of J/ψ of ~150 MeV/c.



Need proton detector/ veto

Momentum transfer distribution for J/ψ photoproduction in pA at LHC

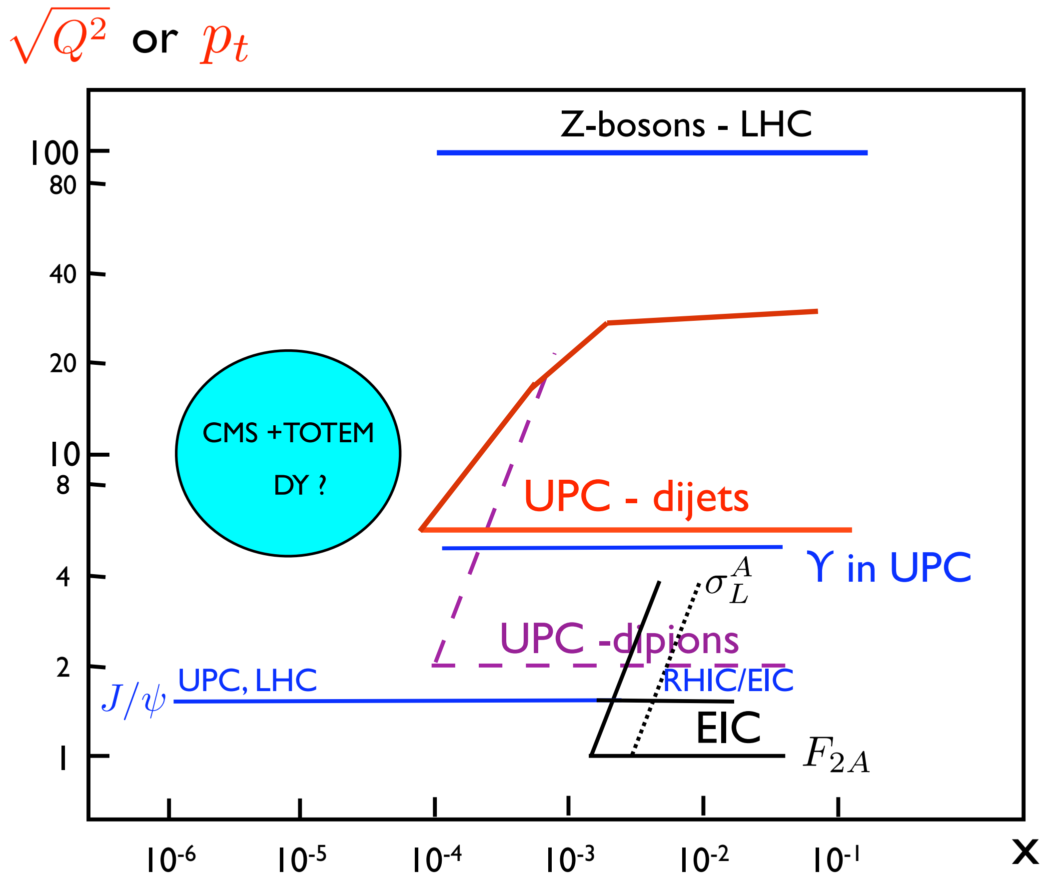
Conclusions

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 black body regime, color opacity

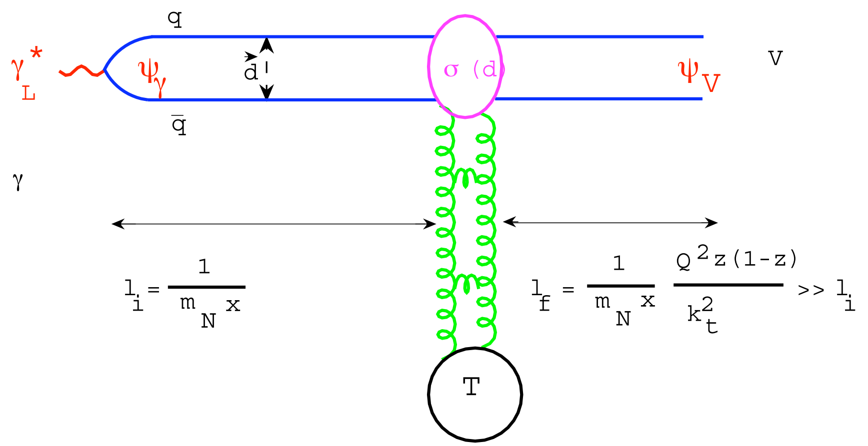
- Low Q will be missed - will require studies at eRHIC



Supplementary slides

Vector meson diffractive production: Theory and HERA data

Space-time picture of Vector meson production at small x in the target rest frame



Similar to the + T 2jets + T process, A (L + p V + p) at $p_t = 0$ is a convolution of the light-cone wave function of the photon |qq̄ , the amplitude of elastic $q\bar{q}$ - target scattering, A ($q\bar{q}T$), and the wave function of vector meson, V : A = d^2d L (z,d) (d,s) $^{q\bar{q}}_V$(z,d).

$$\sigma(q\bar{q}N) = \frac{\pi}{3} d^2 \alpha_s(Q^2_{eff}) \left[x_N G_N(x_N, Q^2_{eff}) + 2/3 x_N S_N(x_N, Q^2_{eff})\right]$$

The leading twist parameter free answer is BFGMS94

$$\left.\frac{d\ ^{L}_{N\ \ VN}}{dt}\right|_{t=0} =$$

$$\frac{12\ ^{3}\ _{V\ \ e^+e^-}\ M_V\ \ ^2_s(Q)\ ^2_V\ \ 1+i\frac{}{2}\frac{d}{d\ln x}\ \ xG_T(x,Q^2)^2}{_{EM}\ Q^6 N_c^2}$$

. Here, $_{V\ \ e^+e^-}$ is the decay width of $V \quad e^+e^-$;

$$_V \qquad \frac{1}{2}\ \frac{\frac{dz\,d^2k_t}{z(1-z)}\ \ _V(z,k_t)}{dz\,d^2k_t\ \ _V(z,k_t)} \qquad 3\ \ |b^2$$

Note: In the leading twist d= 0 in $_V(z,d)$. Finite b e ects in the meson wave function is one of the major sources of the higher twist e ects.

In the convolution integral a rather narrow $d \propto \frac{1}{Q}, 1/m_c$

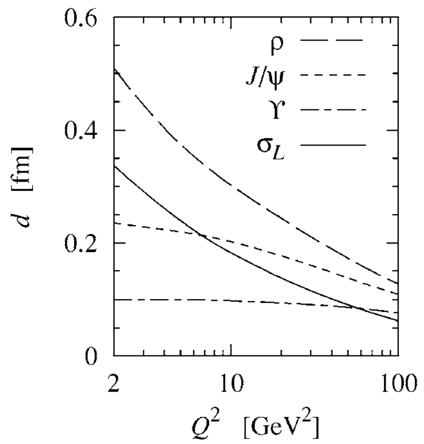
$\Psi^{L}_{\gamma^*}(d)(\Psi^{Q\bar{Q}}_{\gamma}(d))$ is convoluted with a broad wave function

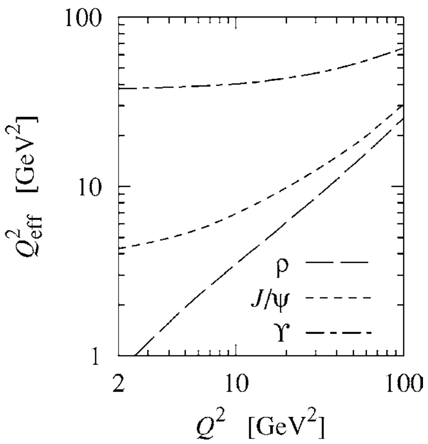
of a light vector meson (a broader wave function of onium)

⇒ Average distances are smaller in σ_L than in light VM production

⇒ Effective Q^2 for light VM production is smaller than in σ_L

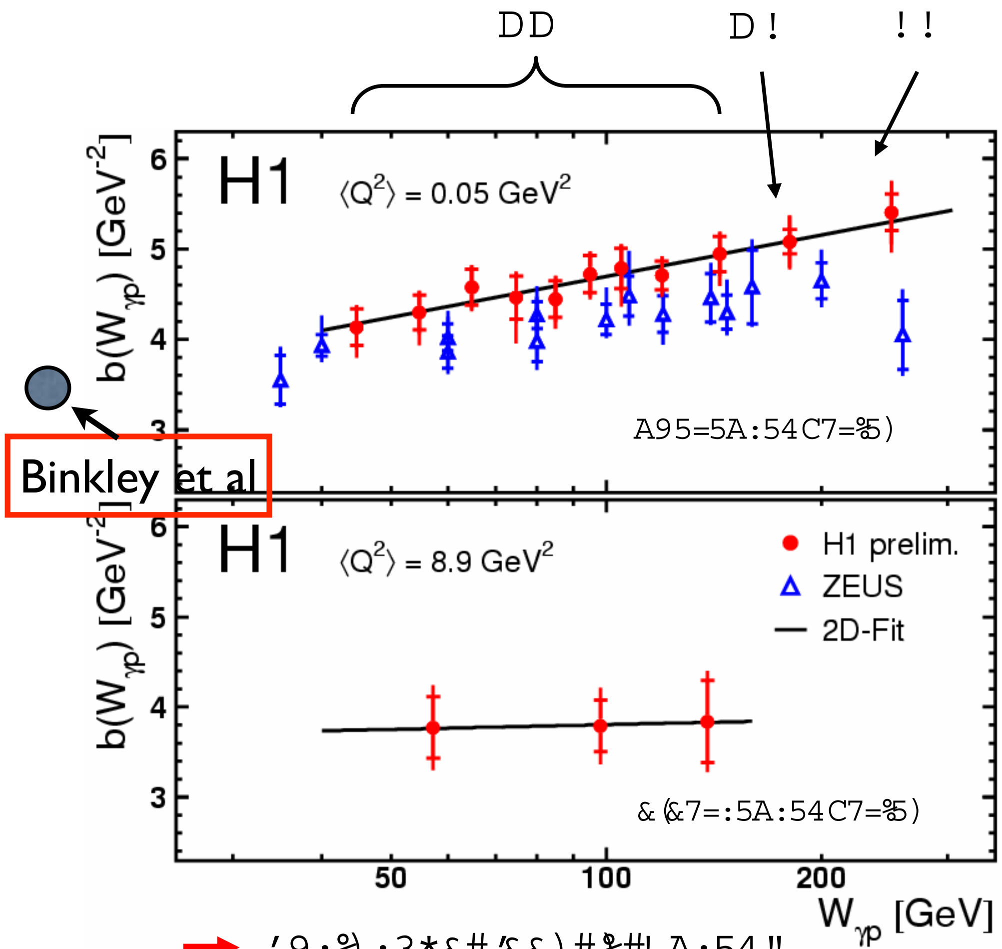
⇒ Effective Q^2 for onium photoproduction $> m_Q^2$





F &Koepf & S (95-97)

Hence next to leading order LT corrections are significant and one can try to model them by changing $Q^2 \to Q^2_{eff}$ in gluon pdfs



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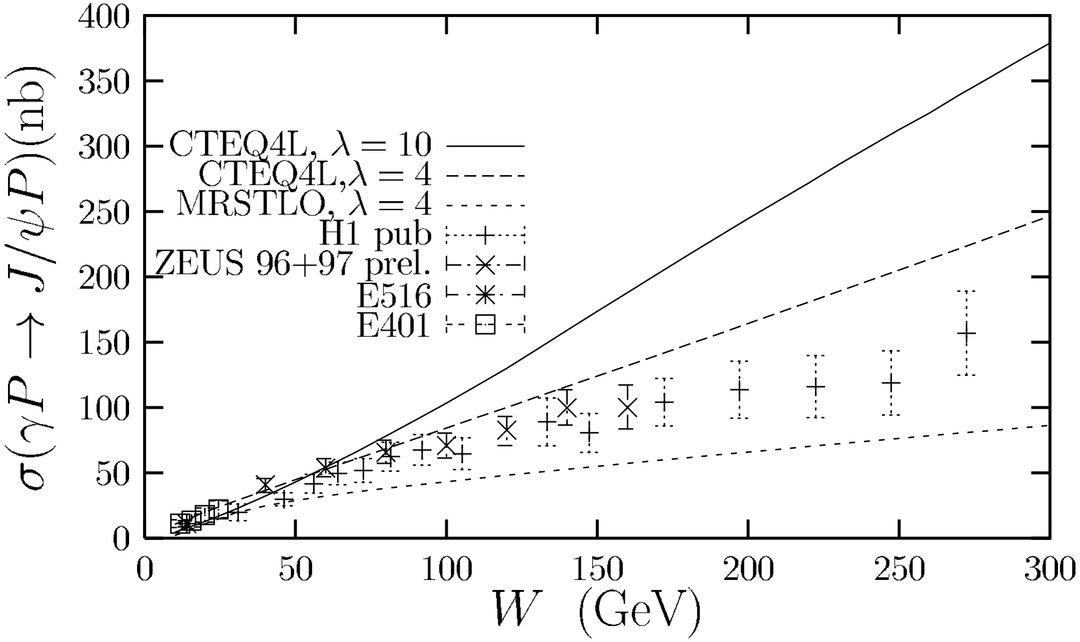
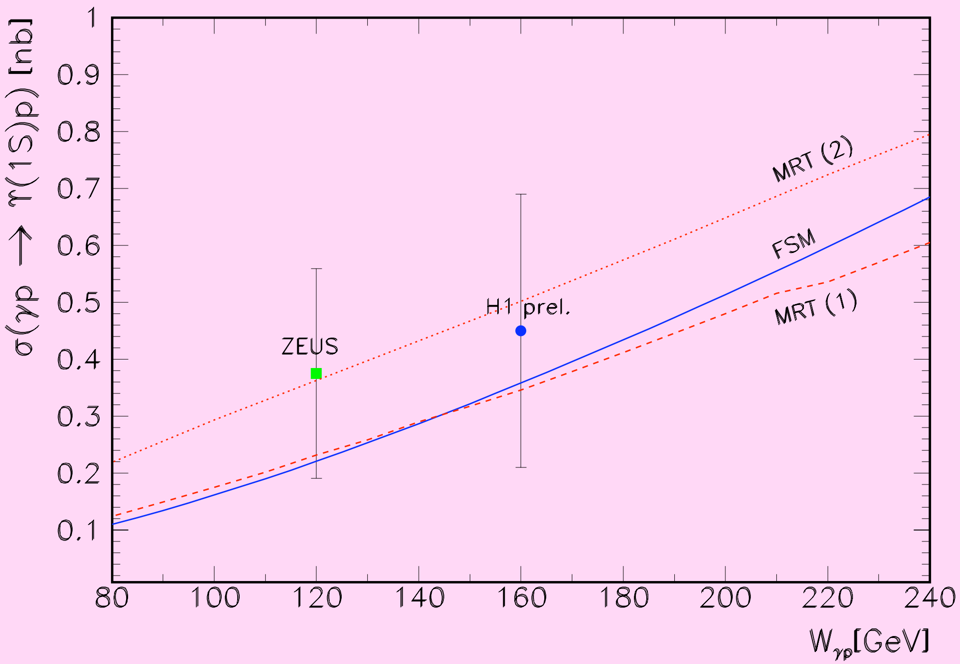


Sensitivity of the absolute cross section to input gluon pdf and NLO effects related to matching between transverse size and Q

L. Frankfurt, M. McDermott and M. Strikman, A fresh look at di ractive J/ photoproduction at HERA, with predictions for Thera, J. High Energy Phys. 03 (2001) 045 [hep-ph/0009086].



MRT= Martin, Ryskin , Teubner
hep-ph/9901420

FSM= Frankfurt,McDermott, MS
hep-ph/9812316

Figure 2: Measurements from the H1 and ZEUS collaborations of the elastic (1S) photo-production 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 e ects beyond leading order[8]

Two important effects as compared to J/psi production:

a) enhancement due to skewedness $x_1 >> x_2$

b) Re/Im