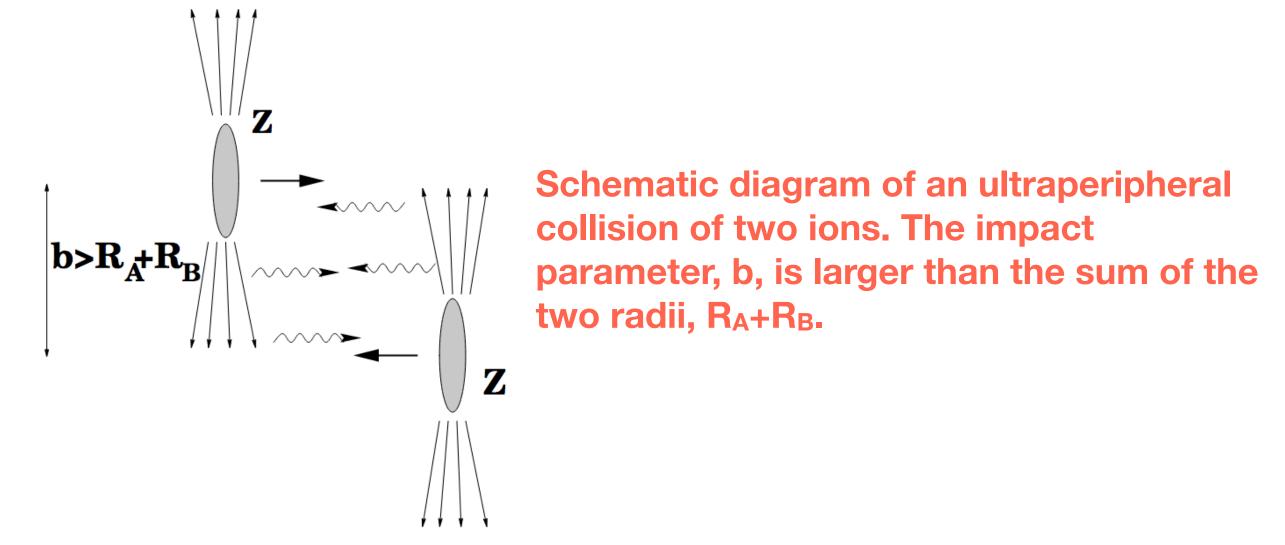


Nice (introductory) talk by Peter Steinberg (BNL) on Monday & few shorter UPC talks

Tremendous progress since Phys. Rep. 2008 - my focus is what UPC can contribute to small x physics

Next 10 -15 years - the only reasonably direct way to probe small x and moderate virtualities are different ultraperipheral collisions



Depending on the channel W_{yN} up to 1 TeV can be reached. Hardness of the process can be regulated using different final states.

for moderate virtualities (J/psi), $x=10^{-3}$ was reached - much smaller x in the future. $\sim 10^{-5} - 10^{-6}$

EIC - - high precision, more tools (DIS,..) but smallest x_A which can be reached is $x \sim 10^{-3}$ for $Q^2 > \text{few GeV}^2$

At LHC charm is attractive tool to study paQCD regime at moderate virtualities. will give several examples; thanks to hMaria Garzelli for asking.

Basic features of QCD relevant for small x phenomena (diffraction, etc)

Basic guiding features of QCD relevant for diffraction in QCD

a) cross section of a small dipole off a proton/ nucleus interaction is small, proportiona to area of dipole occupied by color, and to gluon density of target and hence grows with decrease of x.

$$\sigma(q\bar{q}T) = \frac{\pi^2}{3} r_{tr}^2 x g_T(x, Q^2 = \lambda/r_t^2) \alpha_s(Q^2)$$

- -> factorization theorem for exclusive meson production (Collins, Frankfurt and MS 1997)
- b) Diffraction in DIS is the leading twist effect (formal proof Collins 1998)
- rescatterings of a small dipole off several nucleons are not suppressed by power of r^2_{tr}
- qualitative difference from eikonal: n-th rescaattering is suppressed by Q²ⁿ

theory of leading twist parton shadowing (Frankfurt, Guzey, MS)



Fundamental feature of QCD: ratio

$$rac{\sigma_{inel\,diff}}{\sigma_{el}}$$

is small and decreasing with energy for soft interactions (pp)

large (> 1) (
$$\propto Q^2/Q_0^2$$
) and increasing with energy for small dipoles interactions (DIS)

Sample of interesting hard phenomena xxwhich can be studied in UPC at the LHC

Issues: gluon pdfs and gpd's, gluon shadowing) most popular now

× • quasielastic $\gamma + p(A) \rightarrow J/\psi + Y$ at small t

Issues; color fluctuations in nucleons and nuclei; gluon shadowing; gluon fluctuations for -t <1/(nucl.radius)²

Dijet production (inclusive and with charm production - 40% of total), low p_T charm at small x window to large shadowing domain.

Issues:direct and resolved photon (parton structure of resolved photon), gluon pdfs, factorization in diffraction

 \checkmark γ +p (A) \rightarrow J/ψ(large t) + rapidity gap + Y

Issues BFKL at -t > 1 GeV²; propagation of small dipoles through strong color fields

- \times Multiparton interactions in γ +p (A) \rightarrow charm + balancing jet, anti charm + balancing jet + Y
- × Looking for analog of BRAHMS effect in photon fragmentation

Coherent J/ψ production - update (Guzey, Kryshen, Zhalov, MS 2020)

Theory (Frankfurt, Guzey, MS): Leading twist theory of nuclear shadowing expressing shadowing through LT diffractive PDFs. Alternative - fitting small x data - very limited sample

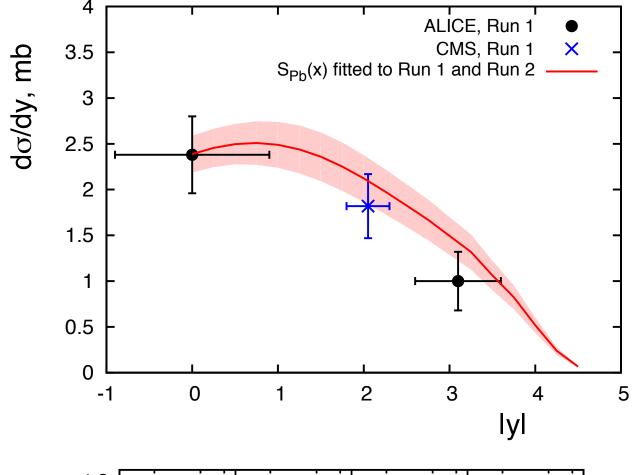
Predicted correctly shadowing for J/ ψ in UPS. Use new LHC data to go below y=0, x=m_{J/ ψ} /E_N

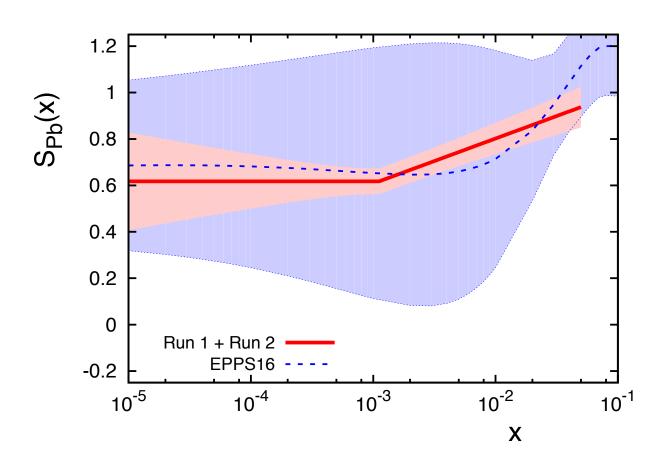
where $x_{\pm} = M_{J/\eta}^2 / W_{\gamma_0}^{\pm 2}$

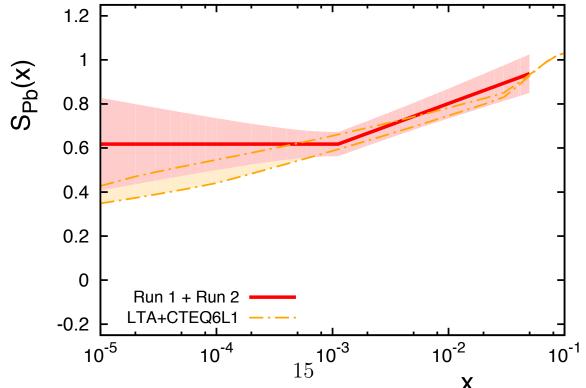
$$S_{Pb}(x) = \sqrt{\frac{\sigma_{\gamma A \to J/\psi A}(W_{\gamma p})}{\sigma_{\gamma A \to J/\psi A}^{\mathrm{IA}}(W_{\gamma p})}} = \mathsf{ga(x, \mu)/g_p(x, \mu)}$$

$$= \left(\frac{d\sigma_{AA \to J/\psi AA}(\sqrt{s_{NN}}, y)/dy}{d\sigma_{AA \to J/\psi AA}^{\mathrm{IA}}(\sqrt{s_{NN}}, y)/dy}\right)^{1/2}$$

$$= \left(\frac{N_{\gamma/A}(W_{\gamma p}^+)S_{Pb}^2(x_+)\sigma_{\gamma A \to J/\psi A}^{\mathrm{IA}}(W_{\gamma p}^+) + N_{\gamma/A}(W_{\gamma p}^-)S_{Pb}^2(x_-)\sigma_{\gamma A \to J/\psi A}^{\mathrm{IA}}(W_{\gamma p}^-)}{N_{\gamma/A}(W_{\gamma p}^+)\sigma_{\gamma A \to J/\psi A}^{\mathrm{IA}}(W_{\gamma p}^+) + N_{\gamma/A}(W_{\gamma p}^-)\sigma_{\gamma A \to J/\psi A}^{\mathrm{IA}}(W_{\gamma p}^-)}\right)^{1/2}$$

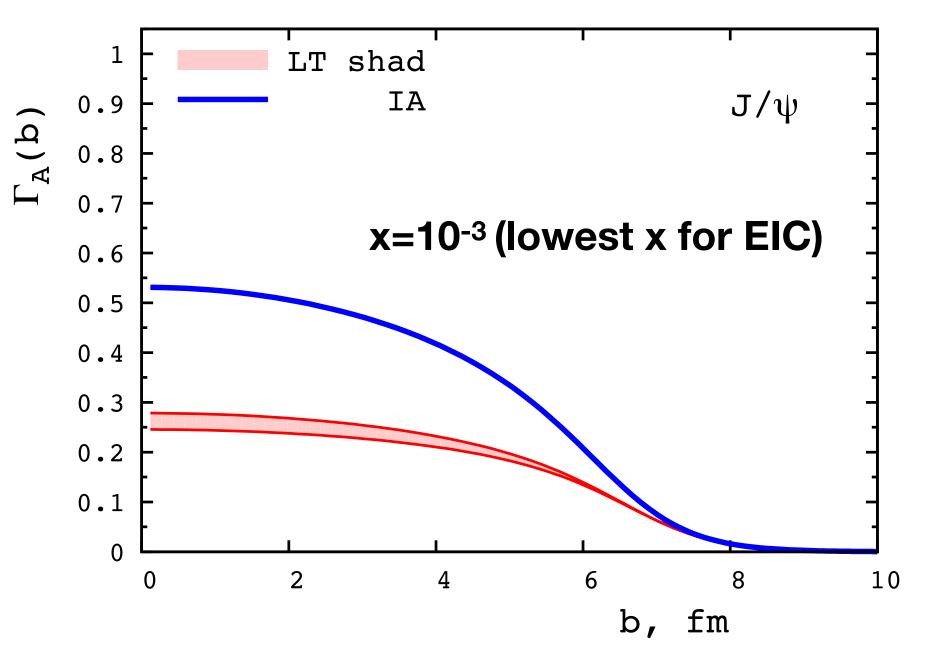






Our prediction for x=10⁻⁴ is bit below the range. Necessary to figure out the reasons for discrepancy between LHCb and ALICE. & study impact parameter dependence of the J/ψ yield

we also predicted increase of t -dependence of coherent J/ψ production as compared to impulse approximation



The scattering amplitude in impact parameter space $\Gamma_A(b)$ for coherent J/ ψ photoproduction on Pb as a function of lbl.

Gluon shadowing changes regime of interaction for $x\sim 10^{-3}$ and small b from close to black (probability to interact inelastically) 1- $(1-\Gamma)^2=0.77$ to gray 1- $(1-\Gamma)^2=0.45$

To reach the black limit x~ 10-5 is necessary

why heavy nucleus did not help significantly?

Where is A^{1/3} factor?

nucleus is much more delta than proton + gluon shadowing

$$\frac{Q_{sA}^2}{Q_{sN}^2} = A \frac{R_{gN}^2}{R_A^2} \frac{g_A(x, Q^2)}{Ag_N(x, Q^2)}$$

$$R_{qN}^2(x=10^{-3})=0.6\,\mathrm{fm}^2$$

$$Q_{sA}^2(b=0)/Q_{sN}^2 = T_A(b=0) \cdot S_A(x,b=0) \cdot 2R_{qN}^2 = 1.2$$
 A~200

Next steps - study of other nuclear shadowing effects - testing presence of large shadowing and pushing to smaller x. $R_A(x, \mu) = g_A(x, \mu)/g_p(x, \mu) \sim 0.6 \text{ for Pb at small } x \sim 10^{-3}, \ \mu^2 \sim 3 \text{ GeV}^2$

J/psi coherent and inelastic diffraction pushing to x~10⁻⁵ using neutron information

Direct measurements: gluon shadowing in γ +p (A)→ leading dijet (charm) + X

Problem 1) - so far jets with $p_{t jet} > 20$ GeV are used where shadowing is small due to larger x, and DGLAP evolution.

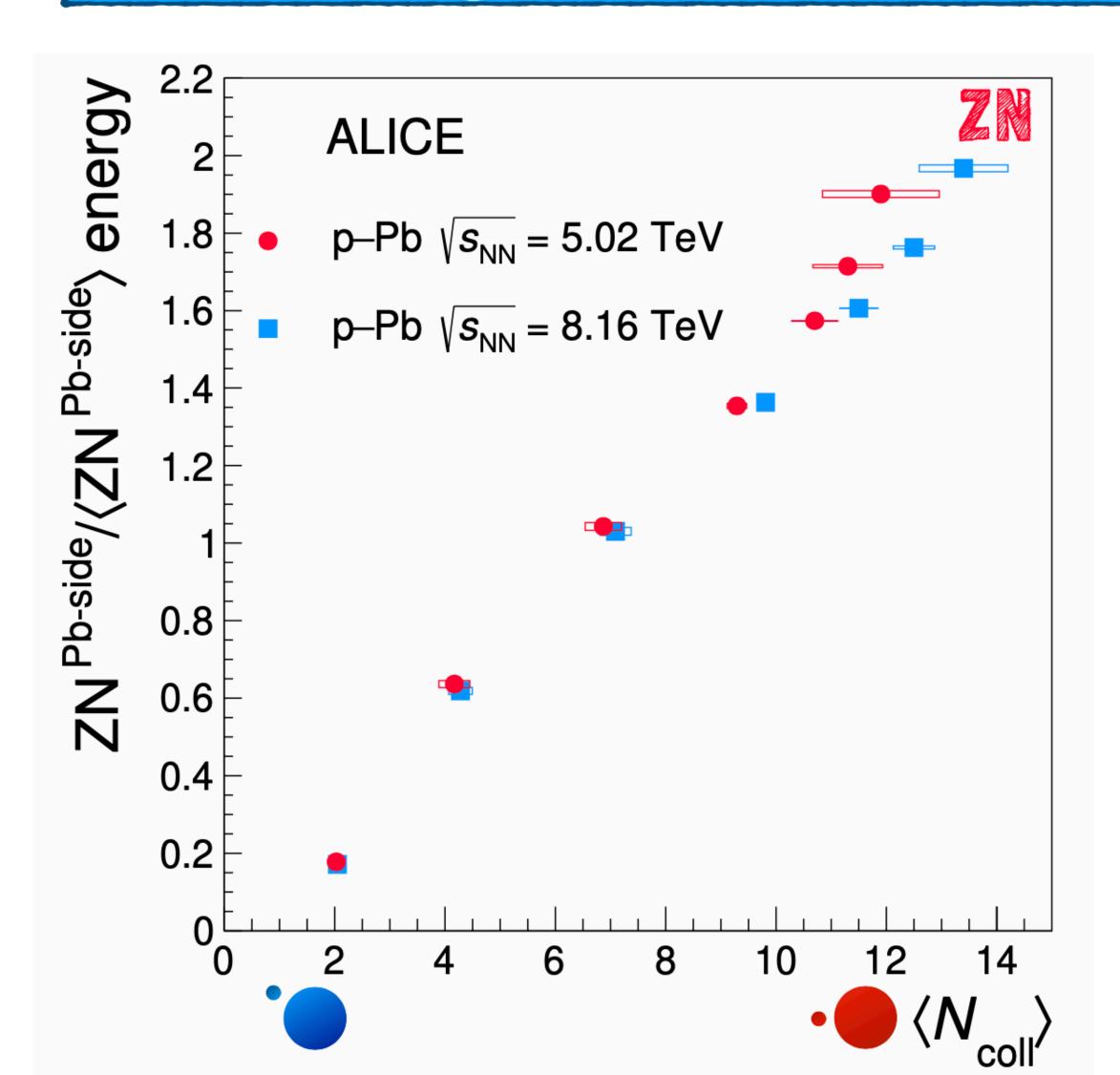
Problem 2) at large pt dijet charm/ dijet total =0.4. If one can separate probably much smaller pt could be used.

Theory of LT shadowing suggests another method: Measuring average number of wounded nucleons

For central rapidities for γN and low p_T charm $N_{coll} = 1/0.6 \sim 1.7$ at $x \sim 10^{-3}$

Observable". N_{coll} (or number of neutrons in ZDC) vs. x_A . Const for $x_A > 0.02$, graduate increase with decrease of x_A , decrease of the effect with increase of p_{tT} of charm, p_T of leading pion in current region

Pb fragmentation vs. collision geometry

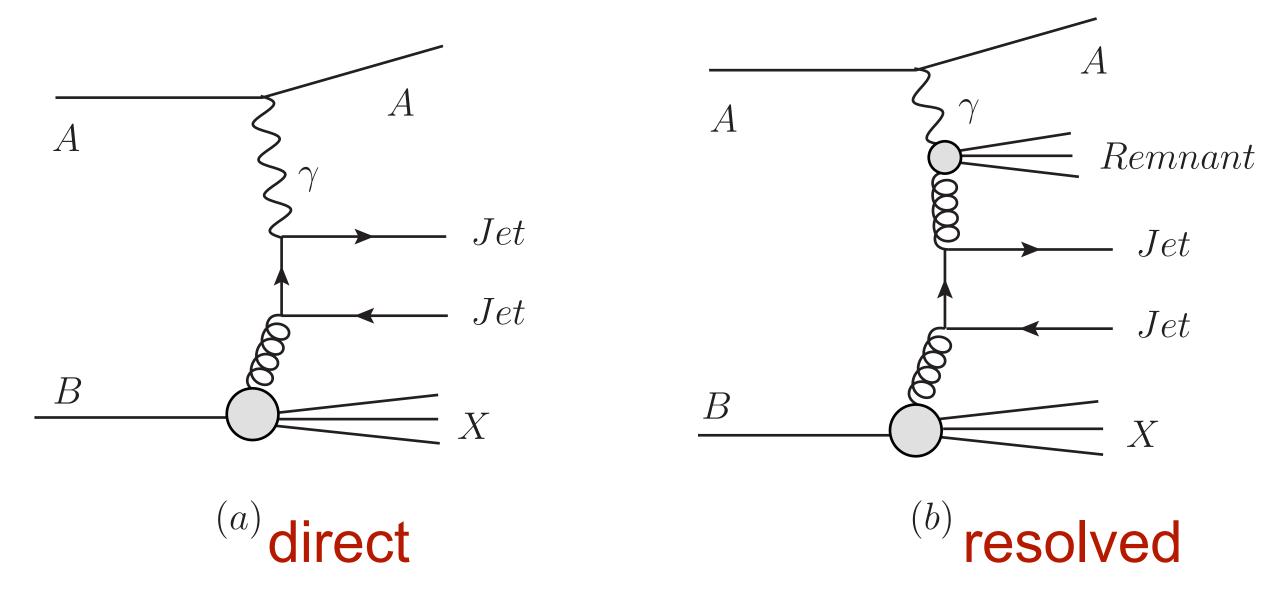


ALICE coll., arXiv 2107.10757

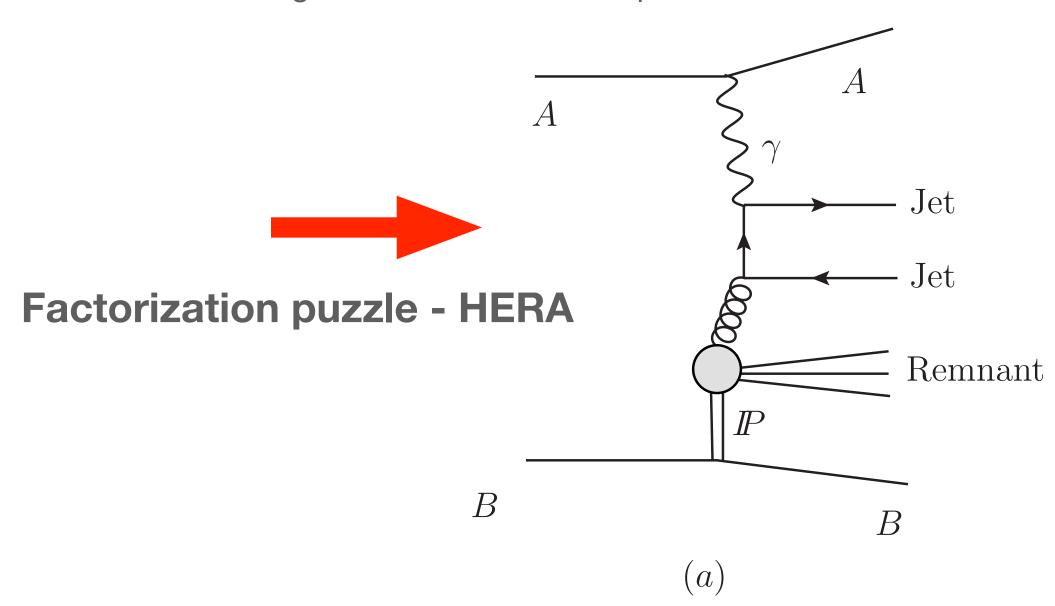
Energy carried by neutrons emitted from the Pb nucleus (slow neutrons) increases linearly with the number of binary N-N collisions (as already observed at smaller energies)

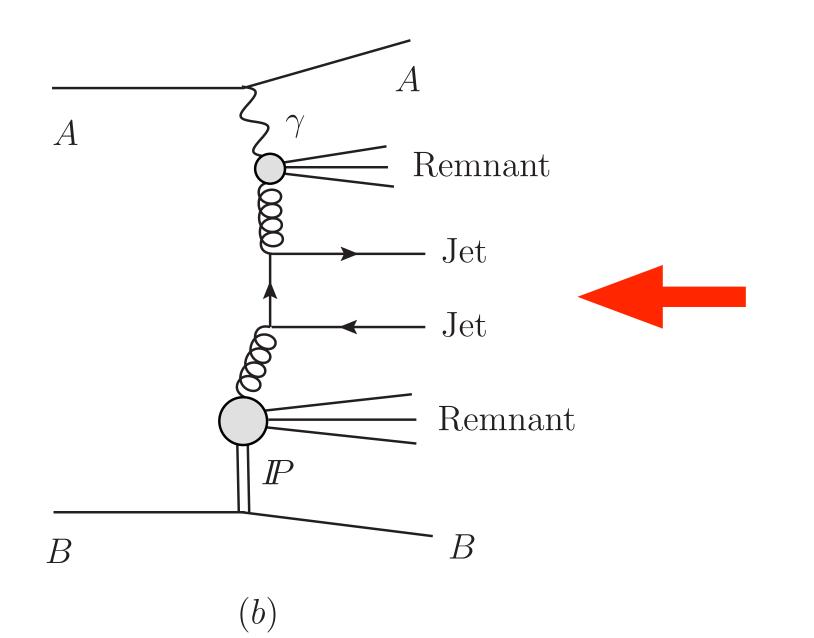
MS: There are corrections to linear dependence of neutron energy/ average neutron energy — need to work on corrections for small N_{coll} , via e.g. quasielastic J/psi

C. Oppedisano, CFNS Ad-hoc Workshop, February 2022



Checking. Factorization - HERS puzzle





Jet

Photpn transverse size as a function of from A-dependence of gap survival

Perturbative Pomeron: what is energy dependence cross section in vacuum channel?

Problem for the study - two large parameters $\ln Q^2$, and $\ln I/x$.

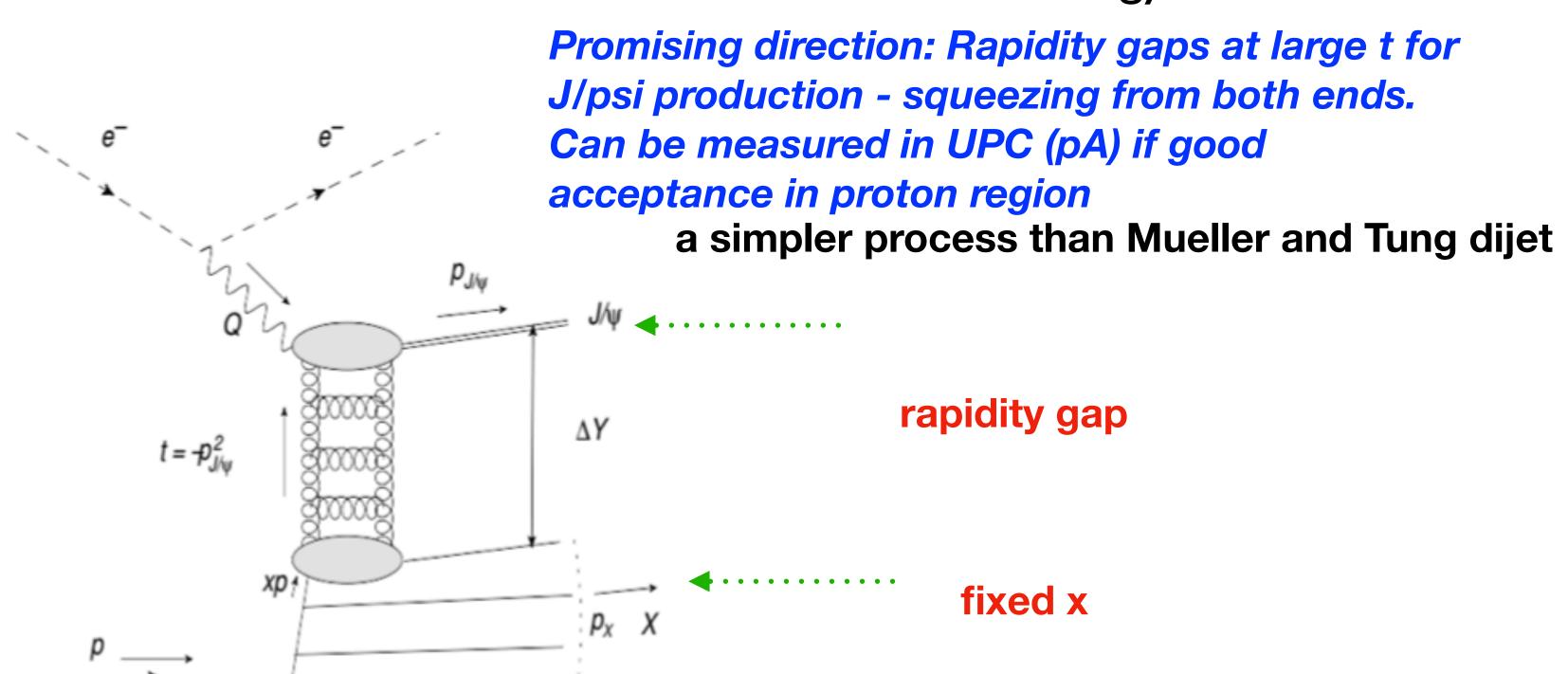
DIS - both parameters enter (DGLAP); BGKL - only In I/x (scattering of two small dipoles)

BFKL elastic amplitude $f(s) = (s/s_0)^{1+\omega_p}$

$$\omega_{P} = a_1 \alpha_S - a_2 \alpha_S^2 + \dots$$

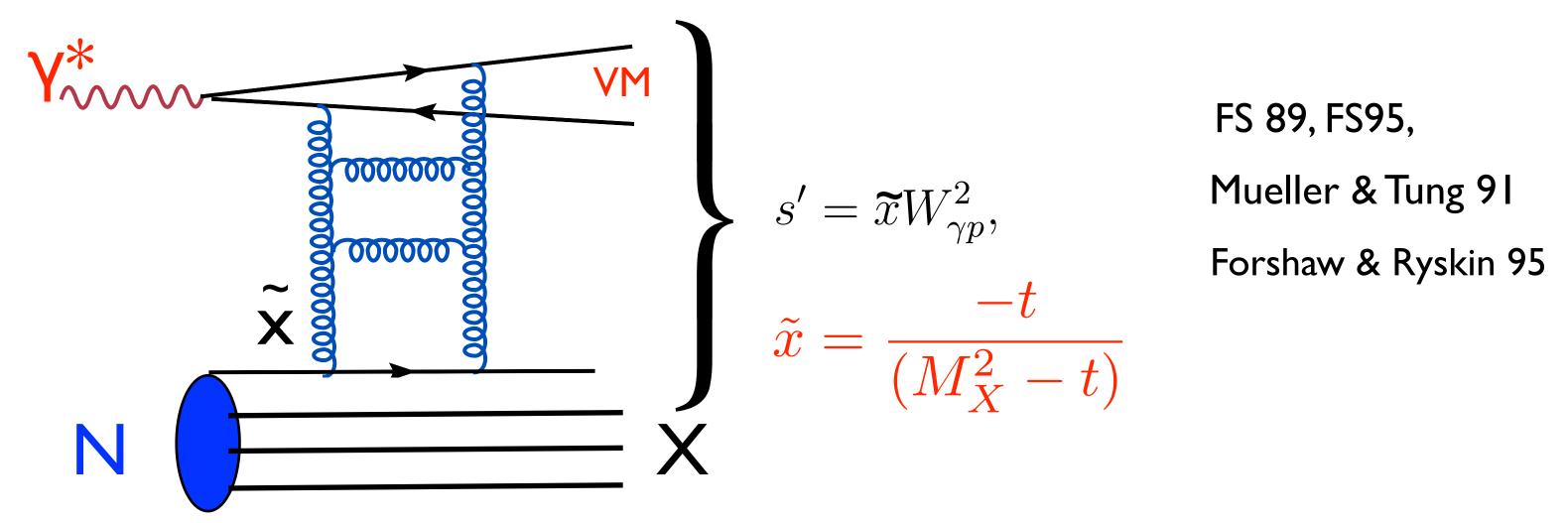
leading log $\omega_P \sim 0.5 \div 0.8$, NLO ~ 0.1, resummation ~0.25

Main reason for small values of ω /P energy conservation



13

elementary reaction scattering of projectile off a parton of the target at large t belongs to a class of reactions with hard white exchange in t-channel



best way to measure of the strength of inelastic interactions of small dipole in the processes initiated by elastic small dipole - parton scattering. In HI via UPC feasible for at $[s']^{1/2}=20$ GeV - 100 GeV at the LHC

The choice of large t ensures several important simplifications:

- * the parton ladder mediating quasielastic scattering is attached to the projectile via two gluons.
- ** attachment of the ladder to two partons of the target is strongly suppressed.
- *** small transverse size $d_{q\bar{q}} \propto 1/\sqrt{-t} \sim 0.15 {\rm fm~for} J/\psi \, {\rm for} t \sim m_{J/\psi}^2$

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

 $\exp(2\omega_{P} \Delta Y)$

resummation predicts a huge effect - between $\Delta Y = 2$ and $\Delta Y = 4$ σ is expected to increase by a factor of 3 !!!

if EIC would have a detector with high acceptance in the nucleon fragmentation region. Ar LHC much larger ΔY can be reached -> even larger effect

$$\gamma + A \rightarrow J/\psi + gap + Y$$

 $s' = \tilde{x}W_{\gamma N}^2$

F& S & Zhalov - PRL 2009

Complementary to coherent J/ψ.

Tracks dipole though ~ 10 fm of nuclear matter

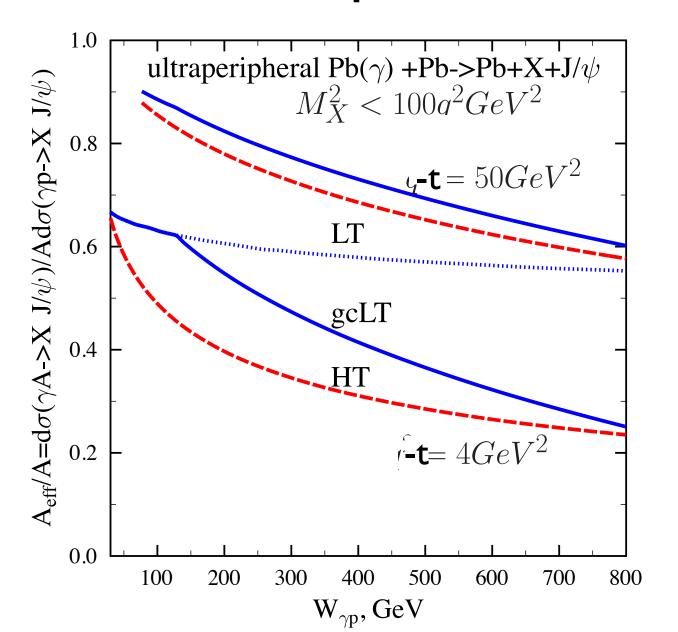


Allows to measure dipole size as a function of q²



Can reach maximal W of LHeC

Estimate of dipole size for $q^2=0$



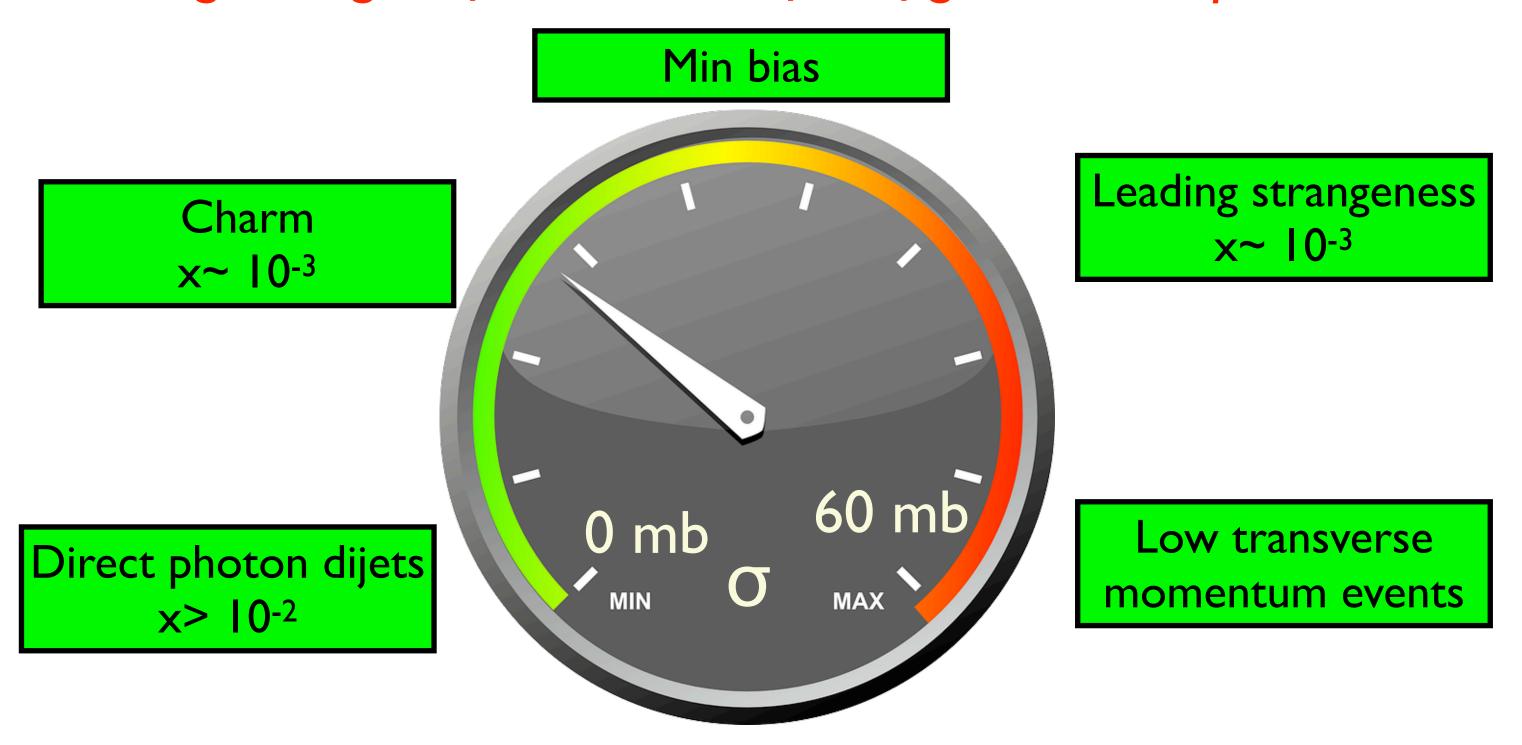
$$d^{2}(-t)/d^{2}(0) \approx (1 - t/4m_{c}^{2})^{-1}$$

$$(d_{0} = .25 \text{fm}, m_{c} = 1.5 \text{ GeV}$$

Significant absorption is expected in the leading twist and higher twist models of dipole interaction. One can select x_g both in the LT shadowing region and above 0.01

Ultraperipheral collisions at LHC (W_{YN} < 500 GeV)

Tuning strength of interaction of configurations in photon



EIC & LHeC - Q² dependence "2D strengthonometer" - - decrease of role of "fat" configurations, multinucleon interactions due to LT nuclear shadowing

Novel way to study dynamics of $\gamma \& \gamma^*$ interactions

Conclusions

UPC at the LHC have a tremendous potential for probing many features of QCD including the small x dynamics. Some data are already on tape, some will be possible to accumulate in the next pA and AA LHC runs. Improvements of acceptance in the fragmentation region would be highly desirable.

These studies may provide answers to a number of questions to be addressed at EIC (higher energy though probably a lower statistics) and higher minimal resolution scale.

Will help to optimize the EIC detectors.