Slicing nuclear Pomerons in UPC using ZDCs

what have we learned and some directions for the future studies

Mark Strikman

based on papers with L. Frankfurt, V,Guzey, M.Zhalov, A.T.Lee Stasto, E.Krushin, A.Larionov

STUDIES OF UPC GROUP in 2006 -2998 C9NnCLUDED THAT UPC AT TH LHC WOULD PROVIDE VALUABLE INFORMATION ON SMALL X DYNAMICS

1) Larger W than at ep collider

2) Simpler final state than in pp, pA hence possibility to study Jets at smaller pt than at the LHC.

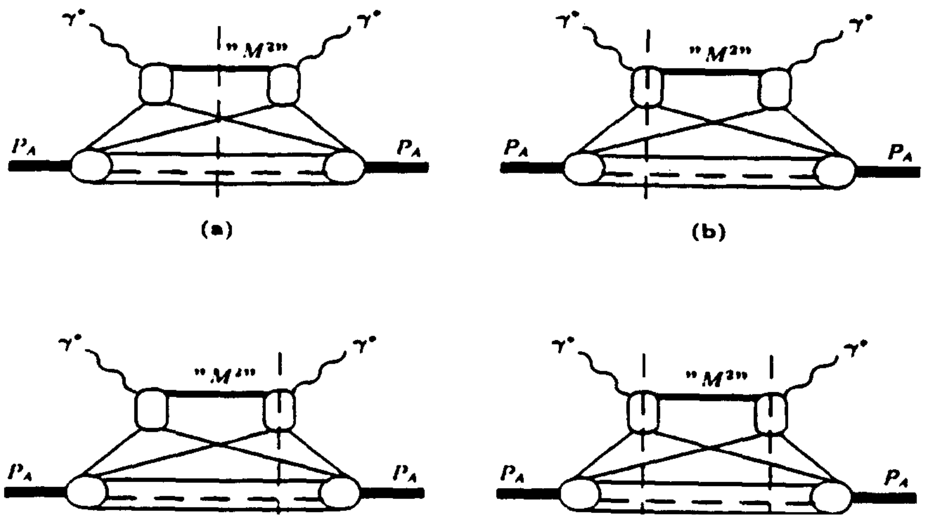
3) Dffraction - soft and hard

4)Much larger radpidity coverage especially wit ZDC

Confirmed largerly in diffraction. Main finding lrge supprerddion sion of coherent production of vector mrdond both in the sof t And hard regimes. Difficult to check through global fits w 9)Focus nparticular feature of different mechanism

UPC is clearly s forerunner of RIC. - data now not in 20 years.

For many UPC flagship EIC reactions, EIC would have to make emphasis on few % precision A - dependence.



Cuts of double scattering diagram corresponding to diffraction (a),

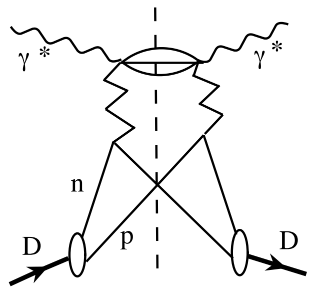
Screening of the scattering of a single nucleon (b/c), double multiplicity (d)

Unitarity relates these cuts - Abramovski, Gribov, Kancheli

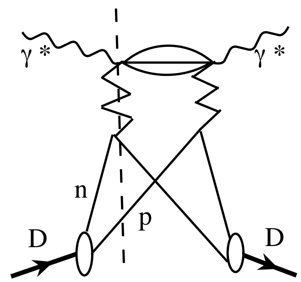
$$\sigma_{tot} = \sigma_{impulse} + \sigma_{shad}$$

$$\sigma_{shad} = \sigma_{dif} + \sigma_{single} + \sigma_{double} = -\sigma_2$$

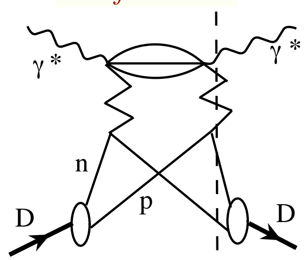
AGK relation between cross sections of different channels:



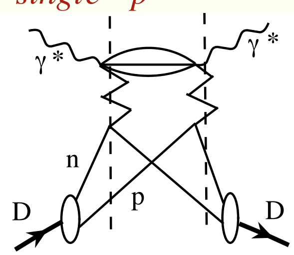
$$\sigma_{dif} = \sigma_2$$



$$\sigma_{single\ "p"} = -2\sigma_2$$



$$\sigma_{single\ "n"} = -2\sigma_2$$



$$\sigma_{double} = 2\sigma_2$$

Using AGK we re-derived original Gribov result for nuclear shadowing extending it to include the real part effects. This approach does not require separation of diffraction into leading twist and higher twist parts.

Theorem: in the low thickness limit (or for x>0.005)

$$f_{j/A}(x,Q^2)/A = f_{j/N}(x,Q^2) - \frac{1}{2+2\eta^2}\int d^2b \int_{-\infty}^{\infty} dz_1 \int_{z_1}^{\infty} dz_2 \int_x^{x_0} dx_{I\!P} \cdot$$

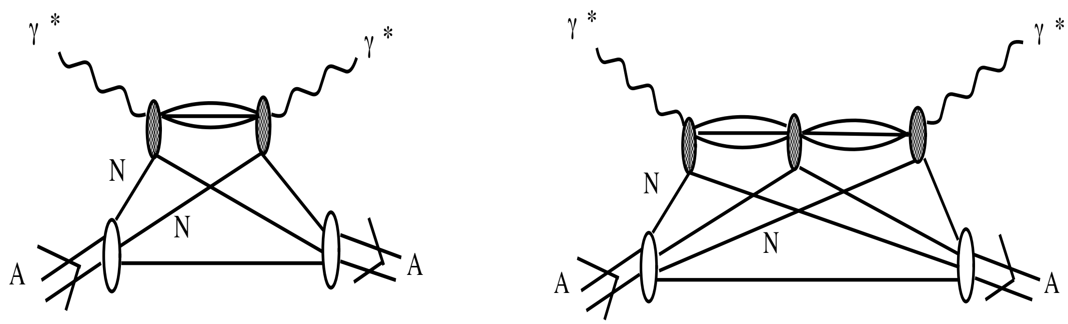
$$\cdot f^D_{j/N}\left(\beta, Q^2, x_{I\!P}, t\right)_{|k_t^2=0} \, \rho_A(b,z_1)\, \rho_A(b,z_2)\; \mathrm{Re}\left[(1-i\eta)^2 \exp(i x_{I\!P} m_N (z_1 - z_2))\right],$$

where $f_{j/A}(x,Q^2), f_{j/N}(x,Q^2)$ are nucleus(nucleon) pdf's,

$\eta = ReA^{diff}/ImA^{diff} \approx 0.3,\ \rho_A(r)$ nuclear matter density.

$x_0(quarks) \sim 0.1,\ x_0(gluons) \sim 0.03$

Including higher order terms



+ ....

AGK allows to rewrite sign alternating series as a series all positive terms

$$\sigma^{(1)}_{Ncoll} = \sigma_1 - 4\sigma_2; \sigma^{(2)}_{Ncoll} = 2\sigma_2; \sigma^{(diff)}_{Ncoll} = \sigma_2;$$

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_T of charm, p_T of leading pion in current fragmentation region.

Not tested experimentally

“

Looking for tail corresponding to 3 - 5 wounded nucleons.

Neutrons are far from main action and hence could serve a measure of

Centrality / periphericity without strong trigger bias..

Neutrons are far from main action and hence could serve a measure of

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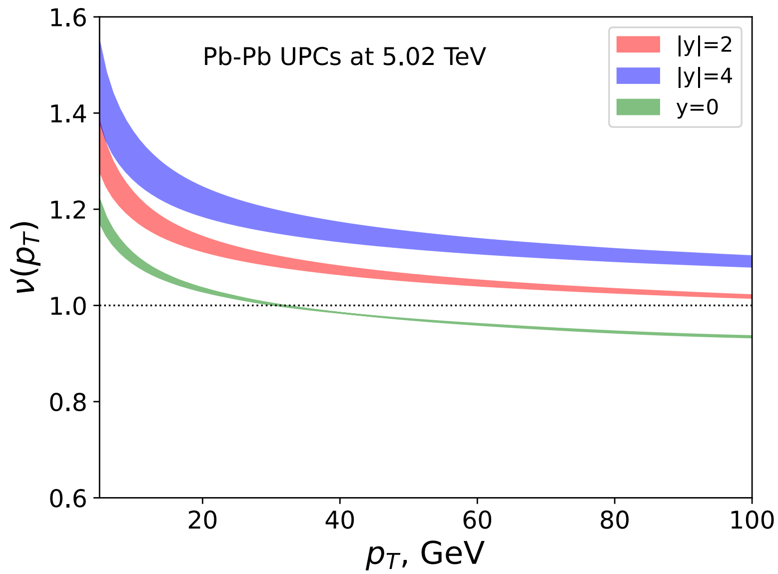
Denoting $R_g(x) = g_A(x)_{(}/g_N(x)$

$Ncoll= 1/R_A(x)$

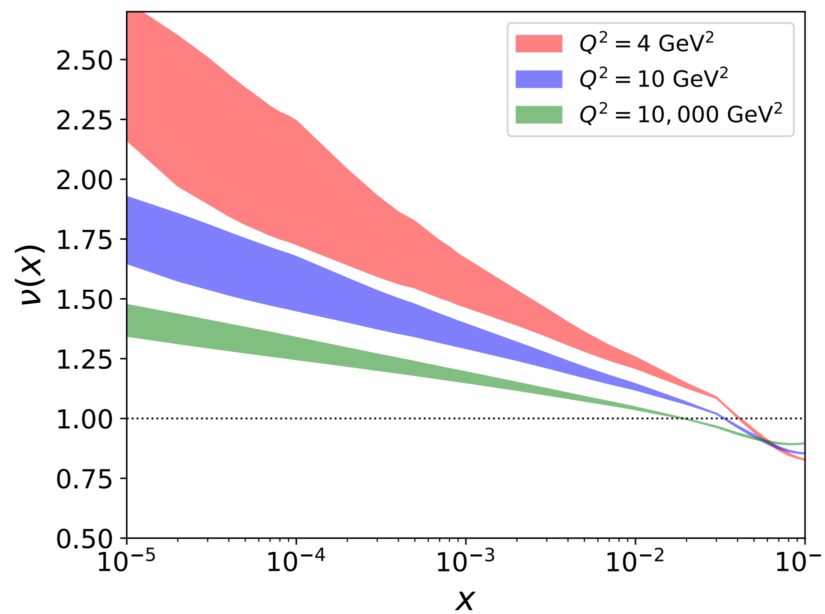
Here one integrates over impact parameters, loosing valuable information.

Can one measure Rg as a function of impact parameter? Use set of nuclei,

Central hadron multiplicity (rather strong trigger bias, we suggest to try soft neutrons originating from decay of heated nucleus



Average number of wounded nucleons as a function of. pt



Average number of wounded nucleons as a function of. X

For central rapidities (y~ 0) for low pt charm production Rg=0.6. N= 1/0.6 ~1.6, Can one measure Rg as a function of impact parameter?Nuclear diagonal gds.

Use set of nuclei,

Central hadron multiplicity (rather strong trigger bias, we suggest to try soft neutrons originating from decay of heated nucleus. Huge rapidity interval - smaller energy, etc … correlation

What is known about soft neutron production?

E665 FNAL measured μ Pb — > neutron +X At <Eμ> ~ 200 GeV

Found <Nn> ~ 5 : 7 depending on cutoff for neutron energy. .

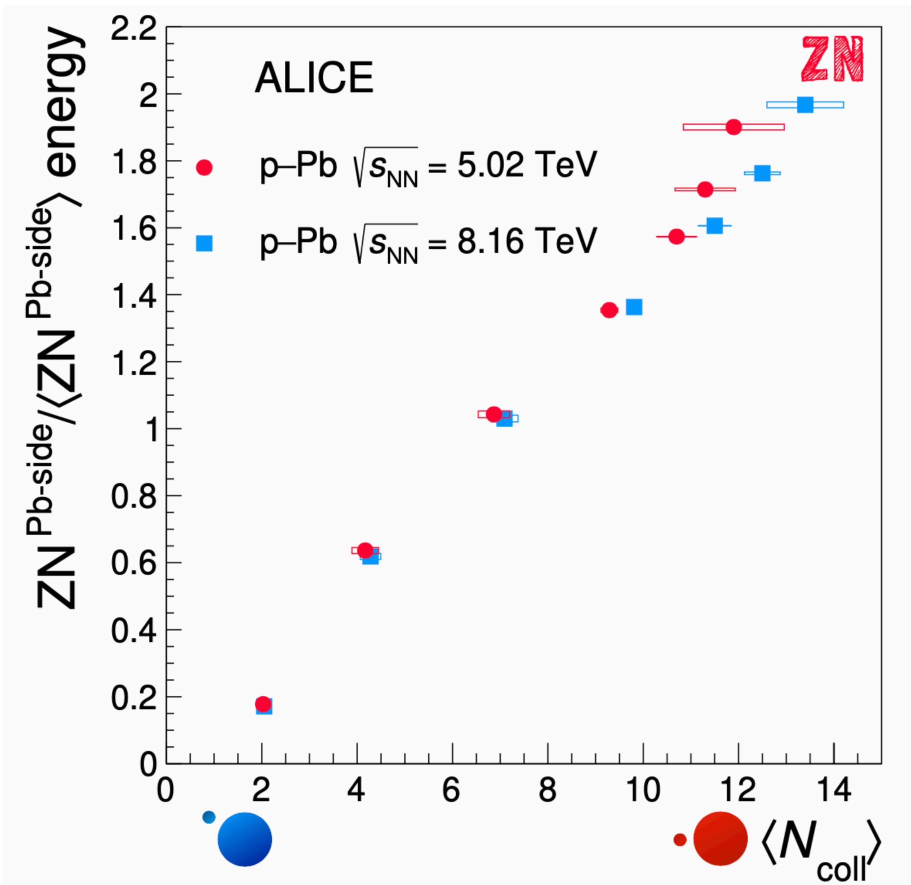
Needs a very strong suppression\ of cascades already

for E_h = 1 GeV. Needs testing relation between number of collisions and ZDC signal.

LHC easy - take γA—> dijet +X for $x_g > 10^{-2}$. Only one nucleon is hit.

Measure number of neutrons , Quasi elastic J/psi charm,....

Pb fragmentation vs. collision geometry

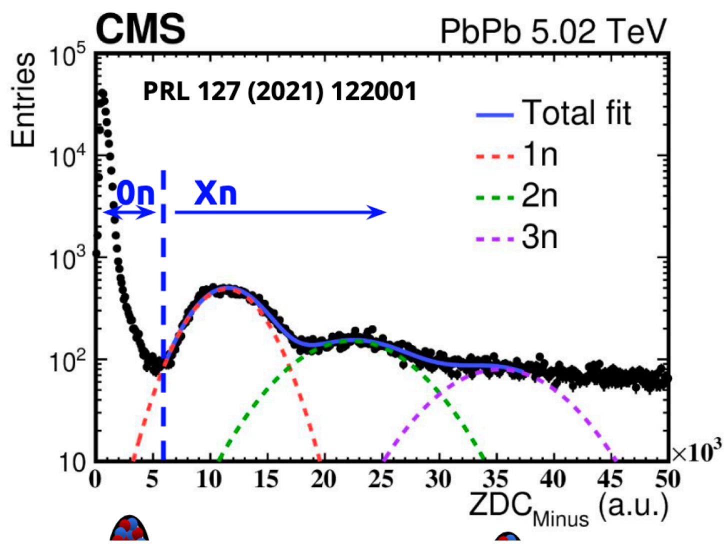


ALICE coll., arXiv 2107.10757

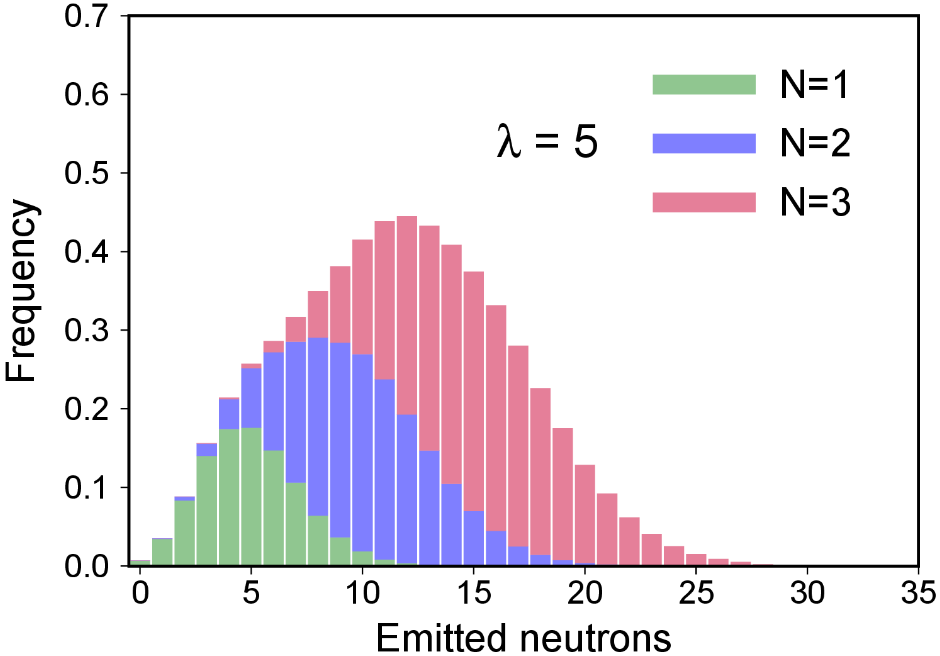
Energy carried by neutrons emitted from the Pb nucleus (slow neutrons) increases linearly with the number of binary N-N collisions (as already observed at smaller energies)

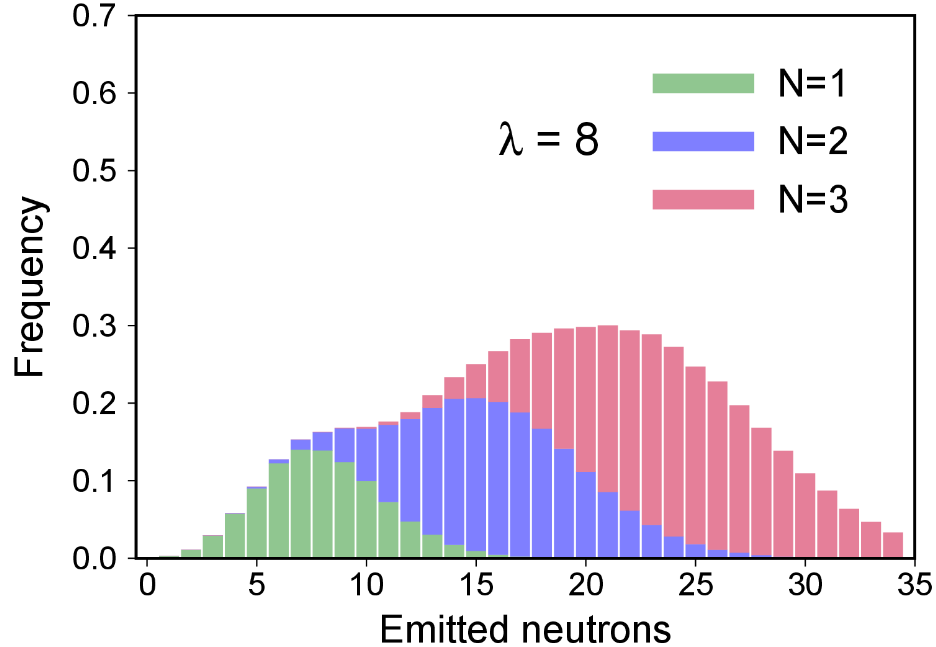
MS: There are corrections to linear dependence of neutron energy/ average neutron energy — need to work on corrections for small N_{coll}, via e.g. quasielastic J/psi

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



Deconvolution to contributions of different N wlould benefit from N=1 information discussed above. Interesting also to compare different projectiles : photons, protons st RHIC and LHC





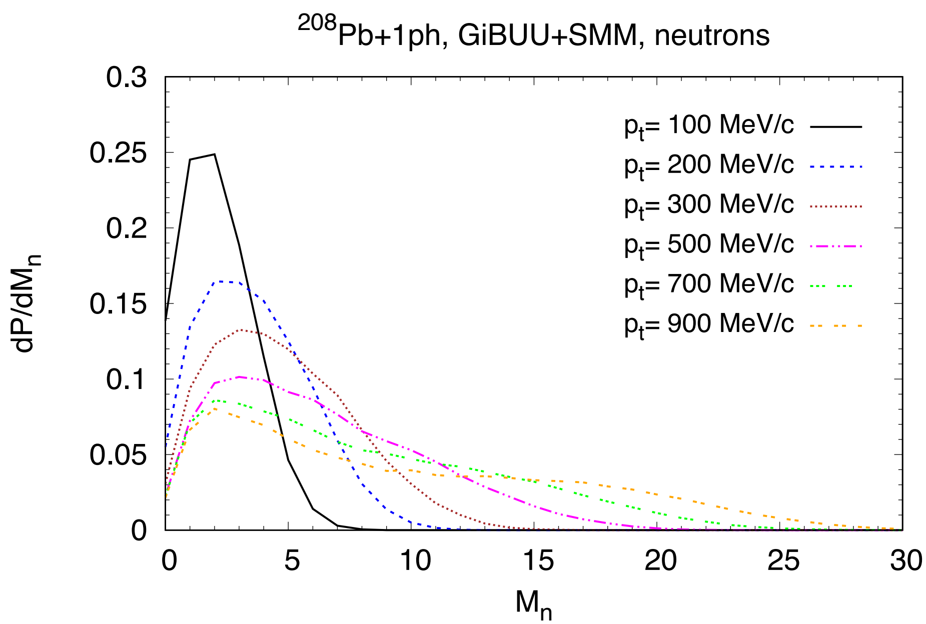
Number of neutrons per wounded nucleon

More nucleons per wounded nucleon , easier to distinguish

Contributions from from N=1, N=2,...

Theory of neutron production

Larionov and MS (Phys.Rev.C 101 (2020)) - extended transport model GiBUU to include emission of neutrons



$$\gamma + Pb \to J/\psi(p_T) + M\ neutrons + A^*$$

Consistency check of leading twist model of shadowing

For example, N=1, N=2 values test interaction in the rim region.

$$\propto \int d^2b \cdot y(b) e^{-y(b)}$$

$$y(b) = \sigma_{eff}(T(b)$$

σ_{eff} includes fluctuations of diffractive cross section

Needs a very strong suppression of cascades already

for E_h = 1 GeV. Needs testing relation between number of collisions and ZDC signal.

LHC easy to find out- take $\gamma A \longrightarrow$ dijet +X for $x_g > 10^{-2}$. Only one nucleon is hit.

Measure number of neutrons , Quasi elastic J/psi charm,....

Space - time dynamics of parton interaction in the nucleus fragmentation region in DIS

Question: what is formation time of hadrons produced in the nucleus fragmentation region?

Puzzle in nuclear fragmentation: a factor > 2 fewer slow neutrons are produced in the DIS process

μ +Pb → μ + n +X **E665, 1995**

than according to cascade models

Zhalov, Tverskoi, MS 96 - confirmed by Larionov &MS 2019 and M.Baker group 2020

Option 1:Pythia not modeling well fragmentation of nucleons in DIS (not very likely such a gross effect)

Option 2: novel coherence effect - perhaps related to ability of DIS in which a small x parton is removed to break effectively a nucleon (no time to discuss).

Test in UPC (both LHC and RHIC) by looking at neutrons in ZDC

γPb → dijet (direct photon) + X+ neutrons in ZDC

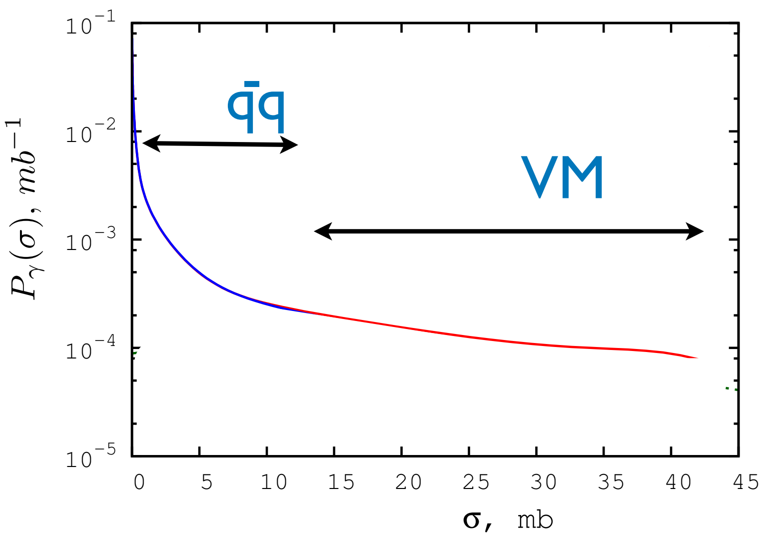
Probability, $P_\gamma(\sigma)$ for a photon to interact with nucleon with cross section σ, gets contribution from point - like configurations and soft configurations (vector meson (VM) like) - color fluctuations (CF). *Unique opportunity to compare soft and hard interactions*

Photon is a multi scale state:

Parton structure of photon - Color fluctuations in γA collisions

$P_\gamma(\sigma) \propto 1/\sigma$ for $\sigma \ll \sigma(\pi N)$

$P_\gamma(\sigma) \propto P_\pi(\sigma)$ for $\sigma > \sigma(\pi N)$

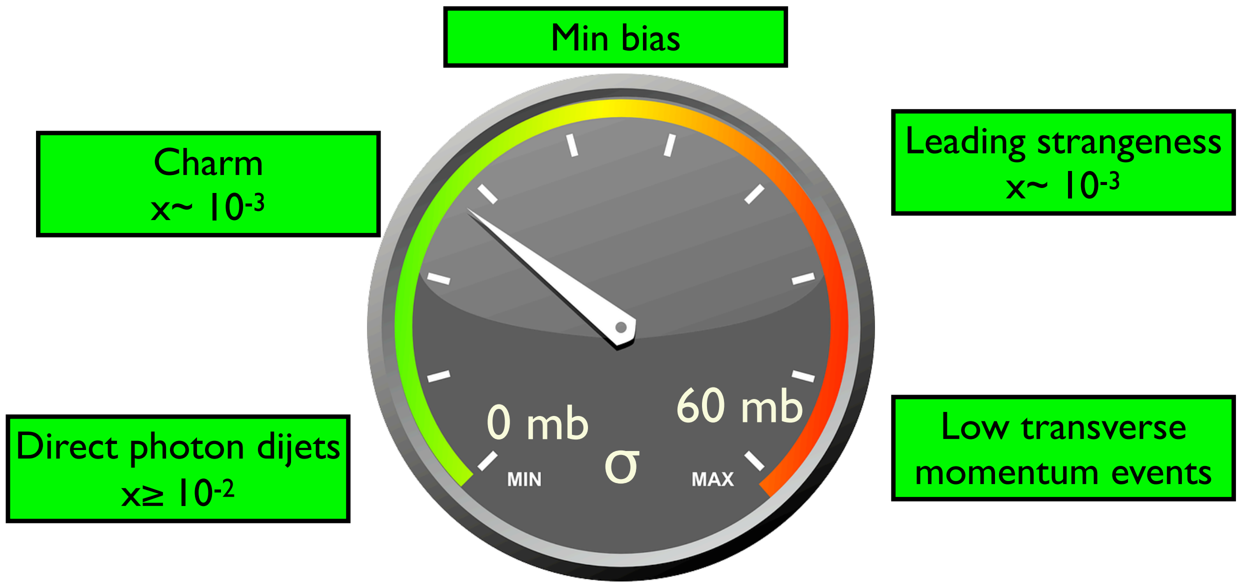


Alvioli et al 2017

Important feature of QCD

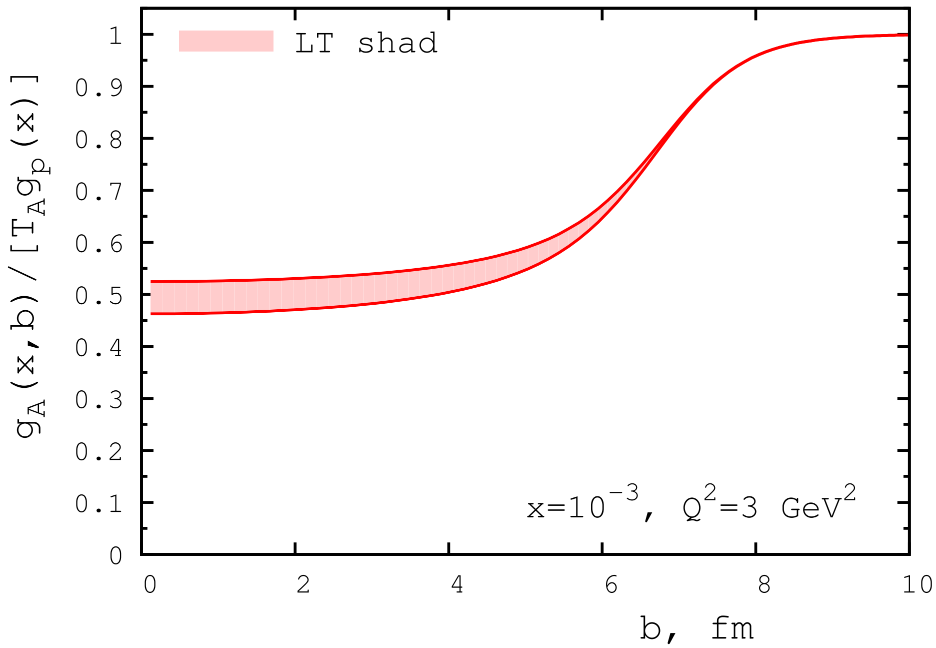
Manifested in Ultraperipheral collisions at LHC ($W_{\gamma N}$< 500 GeV)

allow to tune strength of interaction of configurations in photons and testing it among other options by detecting neutron production



EIC & LHC - Q^2 dependence *"2D strengthonometer"* - - decrease of role of "fat" configurations, multinucleon interactions due to LT nuclear shadowing

Novel way to study dynamics of γ &γ interactions*



Leading twist gluon shadowing in impact parameter space for coherent J/ψ photoproduction on Pb as a function of $|\vec{b}|$.

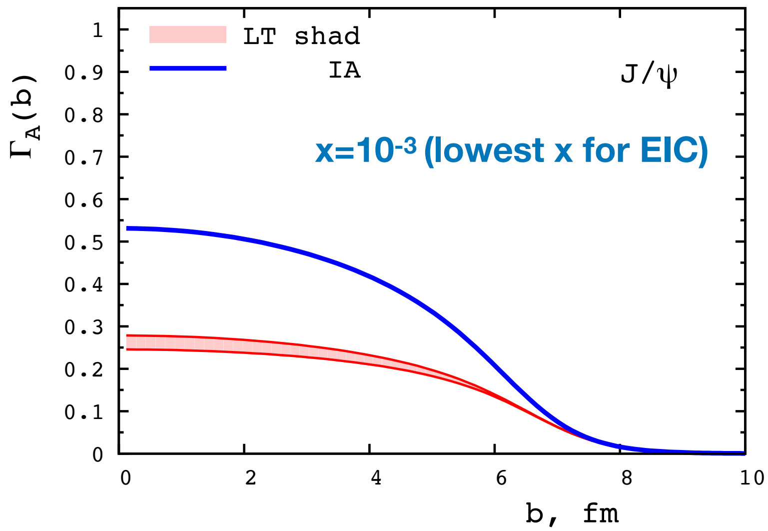
Different configuration have different strength (σeff) of interaction

$\sigma_{eff}(Q\bar{Q}) < \sigma_{eff}(s\bar{s}) < \sigma_{eff}(u\bar{u})$

Coupling to diffraction

Can be tested using correlation of hadrins,…in current region with ZDC signal

For large systems elastic channel dominates; for small - inelastic



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

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 $1-(1-\Gamma)^2 = 0.45$

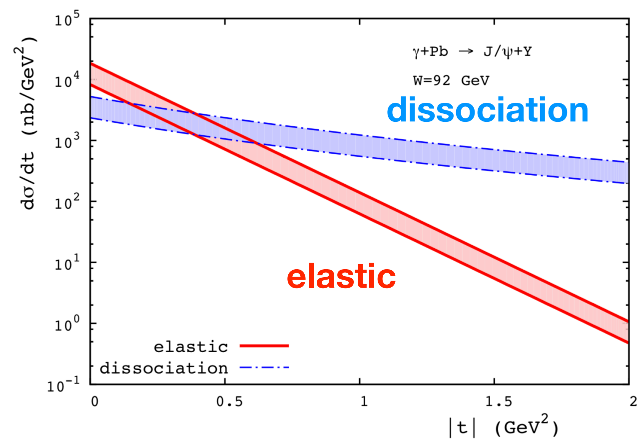
To reach the black disk limit $x \sim 10^{-5}$ is necessary

Neutron information is critical to separate low energy and high energy photon contributions and reach $x \ll 10^{-2}$

next steps:

- pushing to $x \sim 10^{-5}$ using neutron information
- shadowing for quasielastic and inelastic diffraction:: separating $J/\psi + A^*$ and $J/\psi + Y + A^*$ using ZDC information

$\gamma + p\ (A) \to J/\psi(x_F < 0.8) + X$



$\gamma + p\ (A) \to$ leading dijet (charm) + X

$R_A(x=10^{-3}, \mu) \sim 0.6$ → average number of wounded nucleons $\nu = 1/R_A$

enhanced hadron production for $y_{UPC}=0$

more neutrons in ZDC

why heavy nucleus did not help significantly?

Where is $A^{1/3}$ factor?

nucleus is much more delute than proton +effect of gluon shadowing

$$\frac{Q^2_{sA}}{Q^2_{sN}} = A\,\frac{R^2_{gN}}{R^2_A}\,\frac{g_A(x,Q^2)}{Ag_N(x,Q^2)}$$

$$R^2_{gN}(x=10^{-3}) = 0.6\,\mathrm{fm}^2$$

$$Q^2_{sA}(b=0)/Q^2_{sN} = T_A(b=0)\cdot S_A(x,b=0)\cdot 2R^2_{gN} = 1.2$$

A~200

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

Problem for the study - two large parameters ln Q^2, and ln 1/x.

DIS - both parameters enter (DGLAP); BGKL - only ln 1/x (scattering of two small dipoles)

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

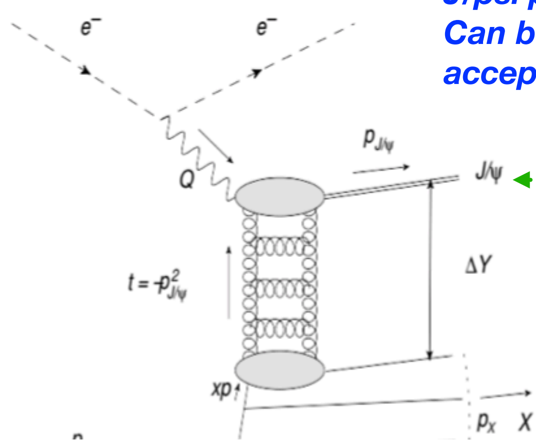
$$\omega_{/P} = a_1\alpha_S - a_2\alpha_S^2 + \ldots$$

leading log $\omega_{/P}$ ~ 0.5 ÷ 0.8 , NLO ~ 0.1, resummation ~0.25

Main reason for small values of $\omega_{/P}$ energy conservation

Promising direction: Rapidity gaps at large t for J/psi production - squeezing from both ends. Can be measured in UPC (pA) if good acceptance in proton region

a simpler process than Mueller and Tung dijet



rapidity gap

fixed x

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rapidity gap

fixed x

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* $d_{q\bar{q}} \propto 1/\sqrt{-t} \sim 0.15\mathrm{fm}\ \mathrm{for}\ J/\psi\ \mathrm{for}\ -t \sim m^2_{J/\psi}$

$$\frac{d\sigma_{\gamma+p\to V+X}}{dt d\tilde{x}} = $$

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

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

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

Δ Y up to 4 maybe possible at EIC, and Δ Y up to 8 at LHC in pA