New opportunities with UPC in pA And AA collisions

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Joint EF07 and EP06 discussion, 10/13/2020

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)

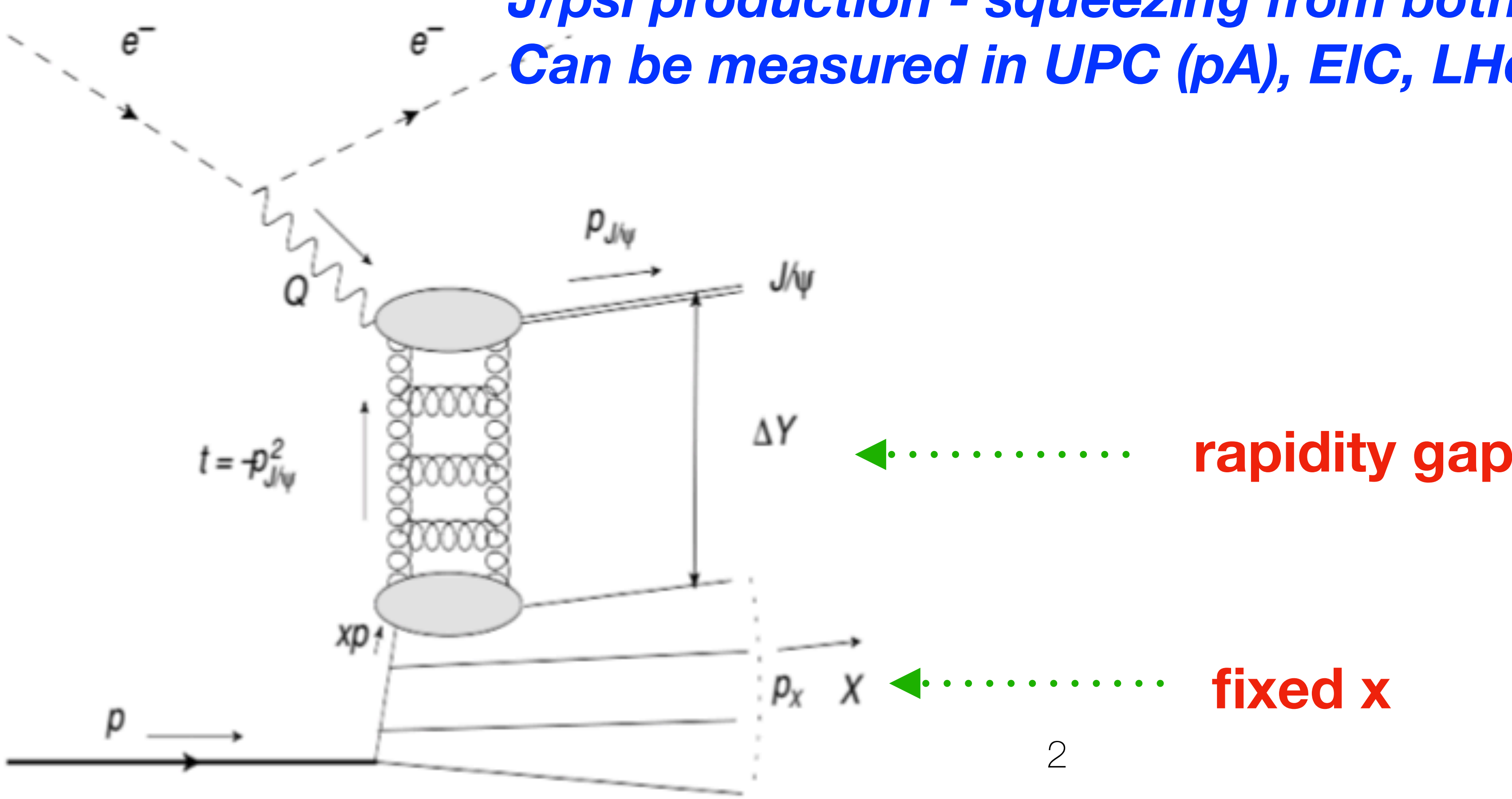
BFKL elastic amplitude $f(s) = (s/s_0)^{1+\omega}$

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

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

Main reason for different 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), EIC, LHeC



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

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

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

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

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

in UPC AA

PRL **102,** 232001 (2009) PHYSICAL REVIEW LETTERS

Tracking Fast Small Color Dipoles through Strong Gluon Fields at the LHC at large t

L. Frankfurt,[1] M. Strikman,[2] and M. Zhalov[3]

$$\gamma + A \rightarrow J/\psi(\rho, 2\pi) + \text{"gap"} + X$$

Complementary to $\gamma + A \rightarrow J/\psi + A$ and has several advantages:

(i) larger W range for UPC (due to ability to determine which of nuclei generated photon)

(ii) Regulating of $\tilde{x}$ for the struck parton in nucleus - shadowing vs linear regime for $G_A(x,Q)$

(iii) More central collisions - larger local gluon density

Qualitative Predictions:

- A_{eff}/A should increase with t at fixed W - smaller dipoles

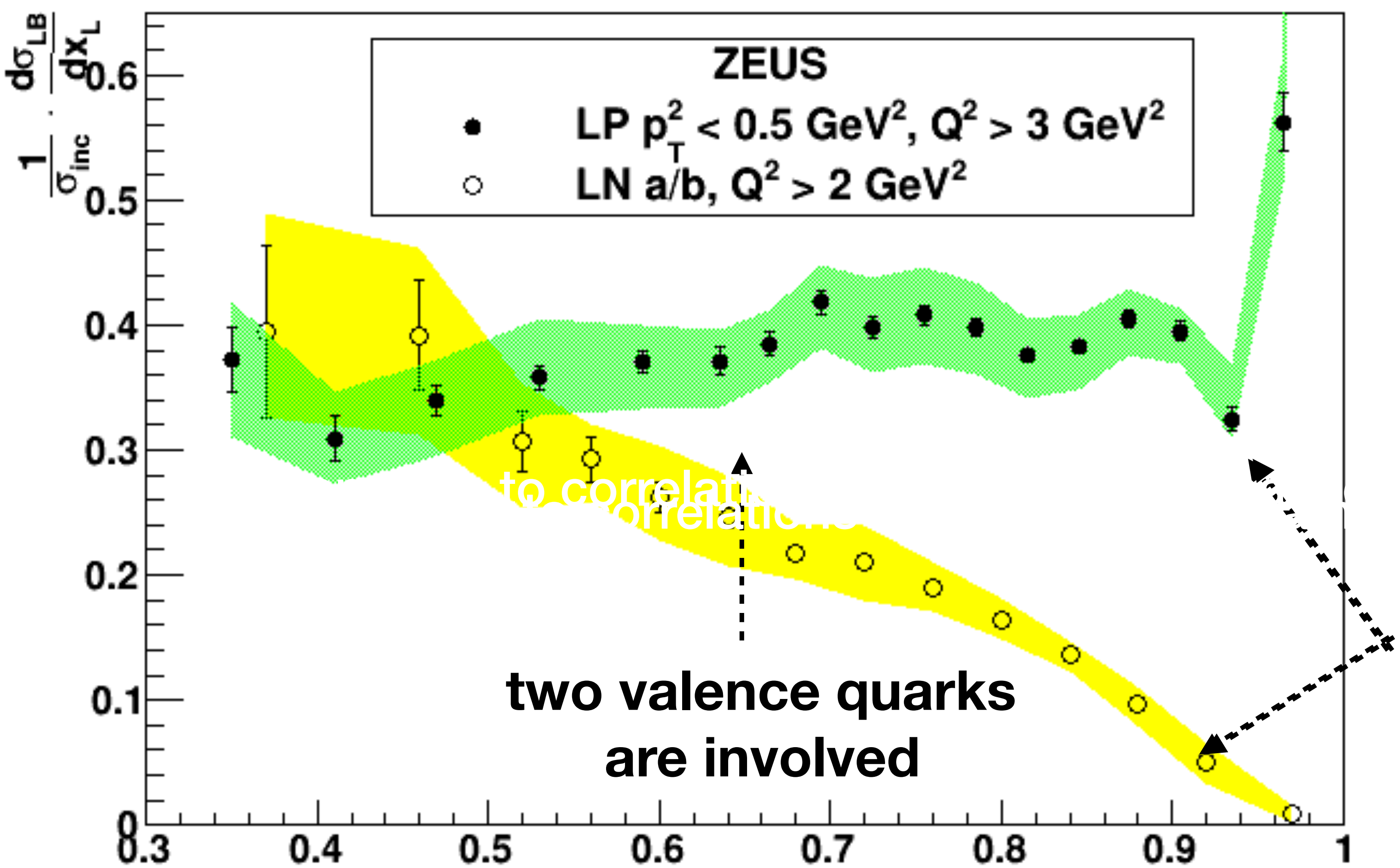
- A_{eff}/A should decrease with increase of W at fixed t - onset of black disk regime. Larger shadowing for small x (regulated by the rapidity covered by X-system)

How nucleons fragment when a parton is removed by a hard probe?

sensitive to parton correlations in nucleon and to pattern of confinement

experimental studies in the scaling limit - HERA for small x.

Analysis of HERA ZEUS data



plot prepared by W. Schmidke

r_LP = 0.299 +/- 0.003 (stat.) +0.008 -0.007 (syst.)
r_LN = 0.159 +/- 0.008 (stat.) +0.019 -0.006 (syst.)

Puzzle: a lot (50%) of baryons are produced below x_L =0.3

UPC allows to study fragmentation in direct photon interactions: dijet + X + neutron (p) , other channels.

Allows to answer a question

How proton fragments after removal of gluon differs from the case when a quark is removed?

Are there data from pA run?? Future runs? Only chance to learn more on fragmentation before EIC.

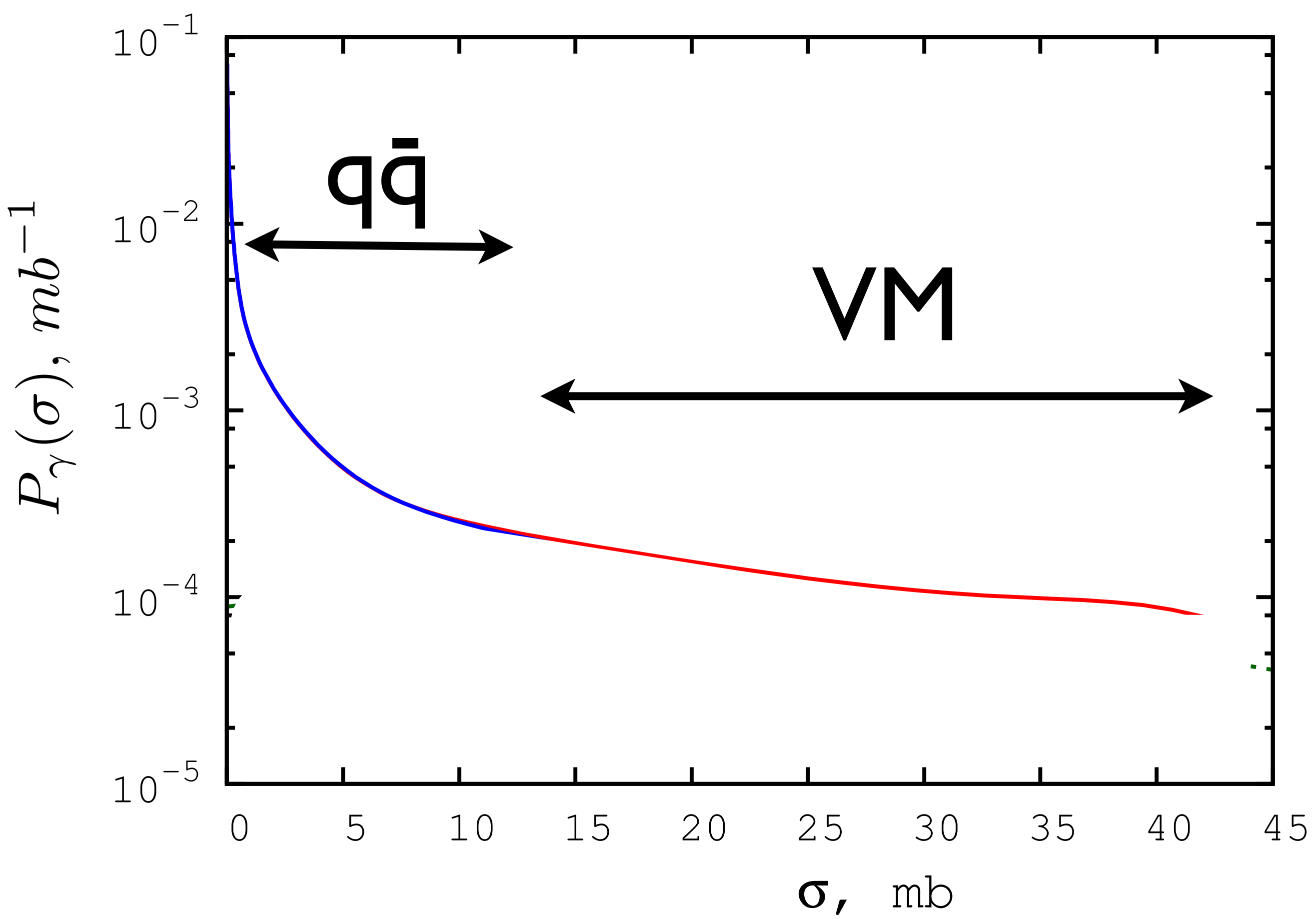
Parton structure of photon - Color fluctuations in γA collisions

Photon is a multi scale state:

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*

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

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



Alvioli et al 2017

Hard regime: $\gamma A \to$ jets + X

1) *Direct photon & $x_A > 0.01$, $\nu = 1$?* ν *- number of wounded nucleons*

Color charge propagation through matter.
Color exchanges ? ➠ nucleus excitations, ZDC & very forward detectors

2) *Direct photon & $x_A < 0.005$ - nuclear shadowing increase of ν*

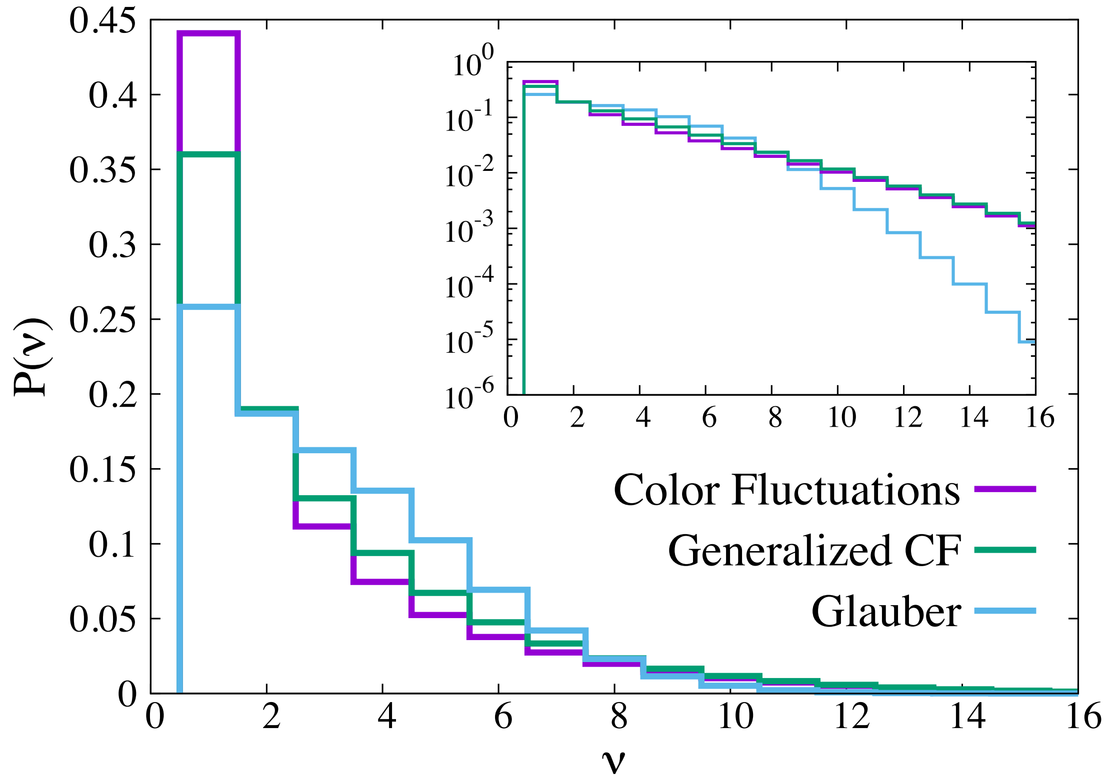
3) *Resolved photon - increase of ν with decrease of x_γ and x_A*

W dependence

Centrality dependence of the forward spectrum in $\gamma A \to h + X$
— connection to modeling cosmic rays cascades in the atmosphere

Ultraperipheral minimum bias γA at the LHC ($W_{\gamma N} < 0.5$ TeV)

Huge fluctuations of the number of wounded nucleons, ν,in interactions of both small and large dipoles with nuclei



distribution over the number of wounded nucleons in γA scattering, W ~ 70 GeV

Alvioli, Guzey, Zhalov, LF, MS

Phys.Lett. B767 (2017) 450-457

CFs broaden very significantly distribution over ν.
"pA ATLAS/CMS like analysis" using energy flow at large rapidities would test both presence of configurations with large σ ~40 mb, and weakly interacting configurations.

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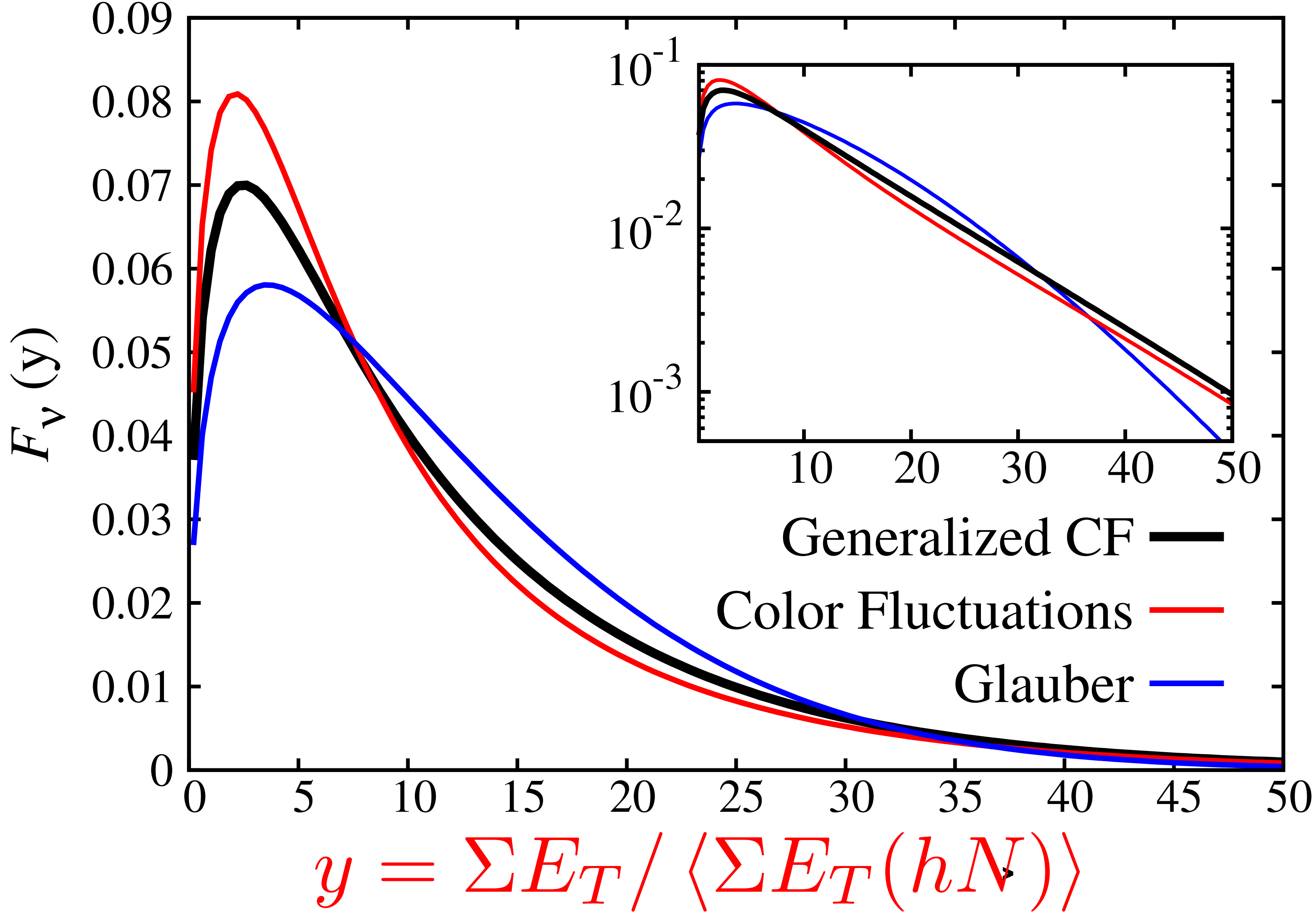
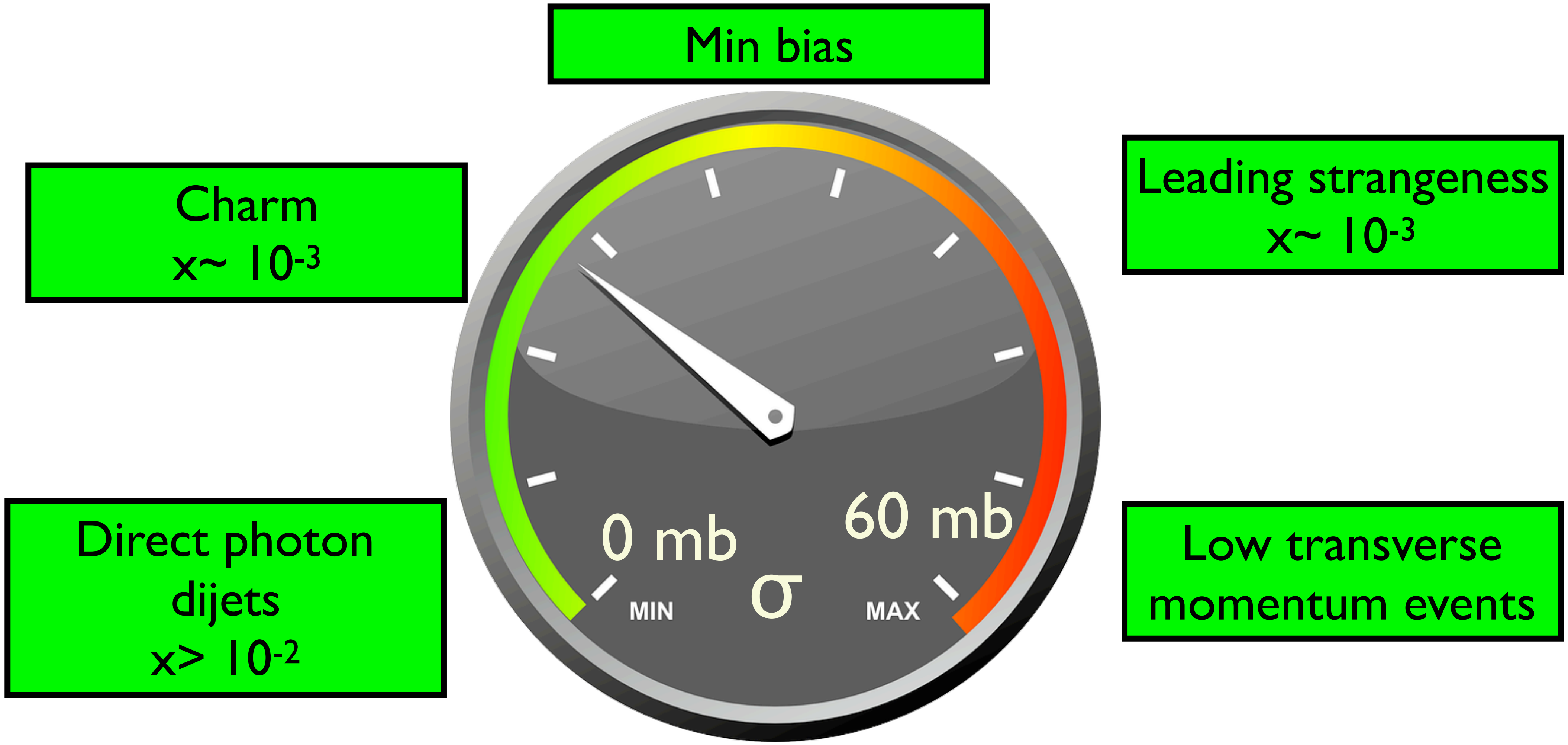


The probability distributions over the transverse energy in the Generalized Color Fluctuations (GCF) model assuming distribution over E_T is the same for pA and γA collisions for same ν.

Using forward detector for centrality via measurement of "y" advantageous: larger rapidity interval - smaller kinematical/ energy conservation correlations. For using ΣE_T for centrality determination one needs $\Delta y > 4$.

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

Tuning strength of interaction of configurations in photon



EIC & LHeC - 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*

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 (discussed earlier).

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

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

Conclusions

UPC have a tremendous potential for probing many features of QCD. SOme data are already on tape, some will be possible to accumulate in the next pA and AA LHC runs.

May provide answers to a number of questions to be addressed at EIC (higher energy though probably a lower statistics).

Will help to optimize the EIC detectors.