Color fluctuation phenomena in high energy proton & photon-A collisions

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Outline

- Intro: Importance of coherence in high energy scattering

- Further evidence for x -dependent color fluctuations in nucleons (LHc and RHIC)

Ultraperipheral collisions at the LHC:

- Color fluctuations in coherent photoproduction of vector mesons

- Color fluctuations in incoherent photon - nucleus scattering

Fluctuations of overall strength of high energy NN interaction

High energy projectile stays in a frozen configuration distances $l_{coh} = c\Delta t$

$$\Delta t \sim 1/\Delta E \sim \frac{2p_h}{m_{int}^2 - m_h^2}$$

At LHC for $m_{int}^2 - m_h^2 \sim 1\mathrm{GeV}^2$ $l_{coh} \sim 10^7$ fm>> $2R_A$>> $2r_N$

coherence up to $m_{int}^2 \sim 10^6\mathrm{GeV}^2$

Hence system of quarks and gluons passes through the nucleus interacting essentially with the same strength but changes from one event to another different strength

Extend to arbitrary ν: introduce quantity - $P(\sigma)$ -probability that hadron/photon interacts with cross section σ with the target.

$\int P(\sigma)d\sigma = 1$, $\int \sigma P(\sigma) d\sigma = \sigma_{tot}$,

$$\frac{\frac{d\sigma(pp\to X+p)}{dt}}{\frac{d\sigma(pp\to p+p)}{dt}}\Bigg|_{t=0} = \frac{\int(\sigma-\sigma_{tot})^2 P(\sigma)d\sigma}{\sigma_{tot}^2} \equiv \omega_\sigma$$

variance Pumplin &Miettinen

$\int (\sigma - \sigma_{tot})^3 P(\sigma)d\sigma = 0$, Baym et al from pD diffraction

$$P(\sigma)_{|\sigma\to 0} \propto \sigma^{n_q-2}$$

Baym et al 1993 - analog of QCD counting rules probability for all constituents to be in a small transverse area

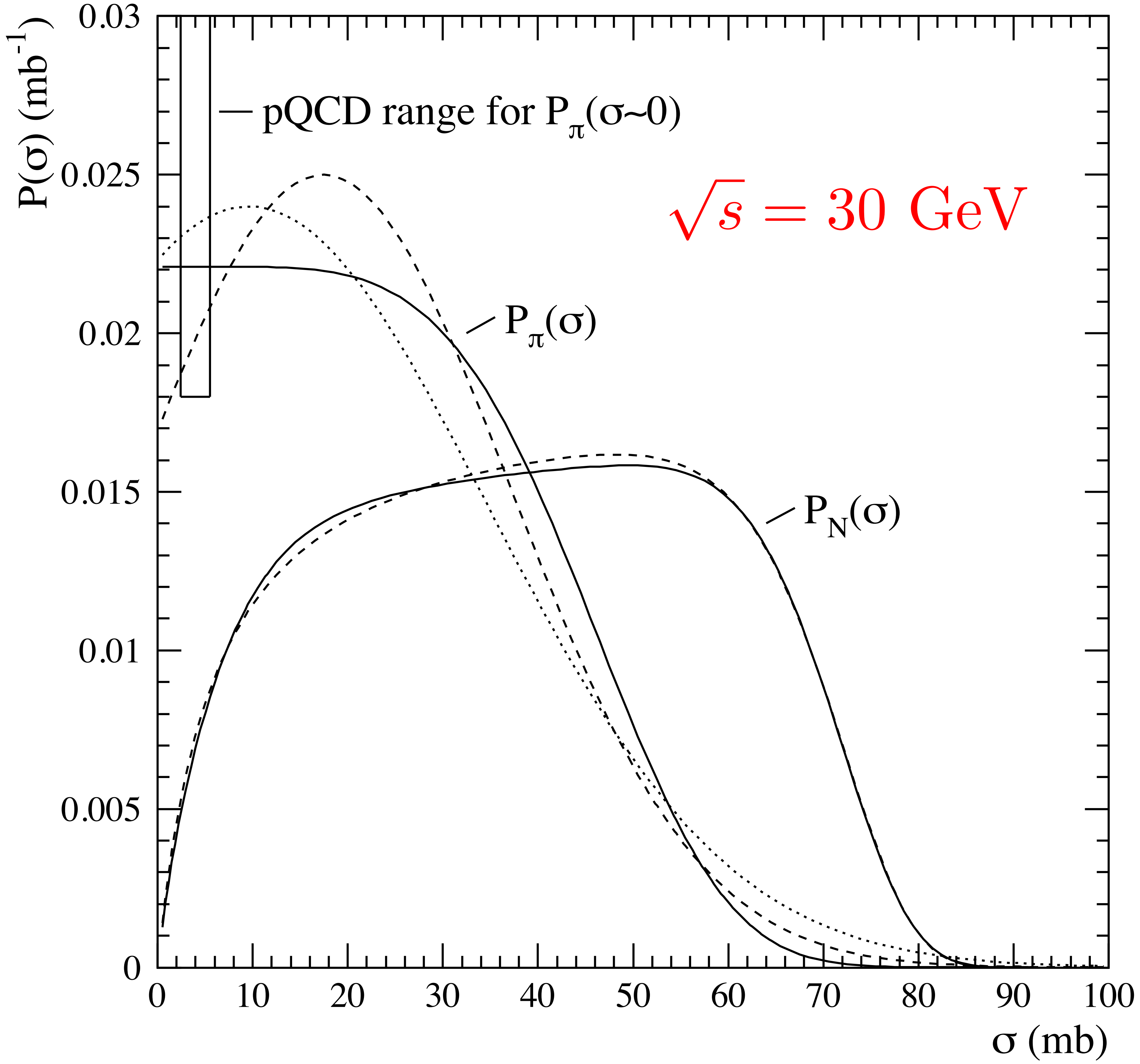
+ additional consideration that *for a many body system fluctuations near average value should be Gaussian*

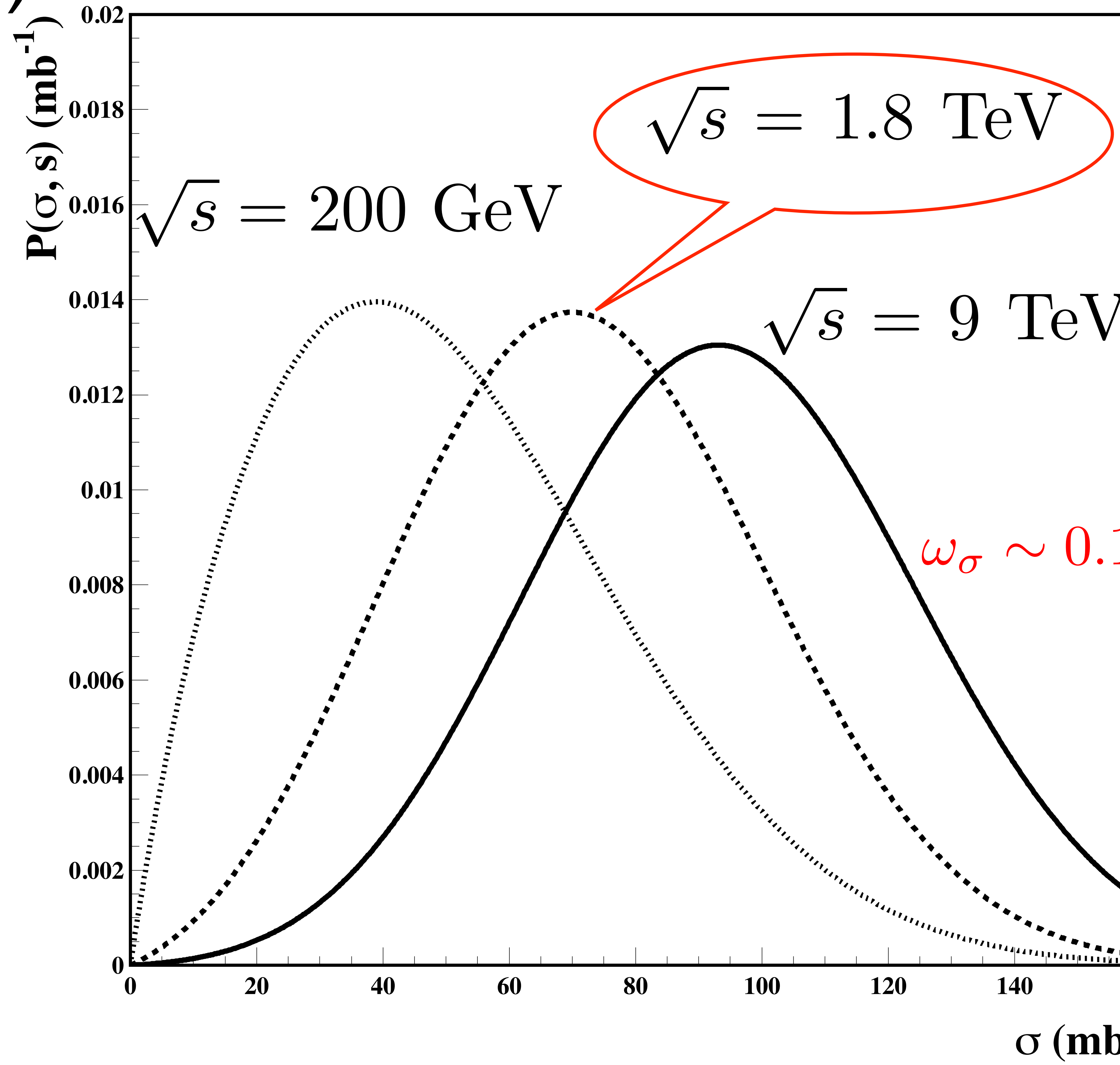
$$P_N(\sigma_{tot}) = r\frac{\sigma_{tot}}{\sigma_{tot}+\sigma_0} exp\{-\frac{(\sigma_{tot}/\sigma_0 - 1)^2}{\Omega^2}\}$$

$$\boxed{P_\gamma(\sigma)_{|\sigma\to 0} \propto \sigma^{-1} \quad \gamma = \text{mix of small } q\bar{q} \text{ and mesonic configurations}}$$

Test: calculation of coherent diffraction off nuclei: $\pi A\to XA$, $p A\to XA$ through $P_h(\sigma)$ -works

$P_N(\sigma)$



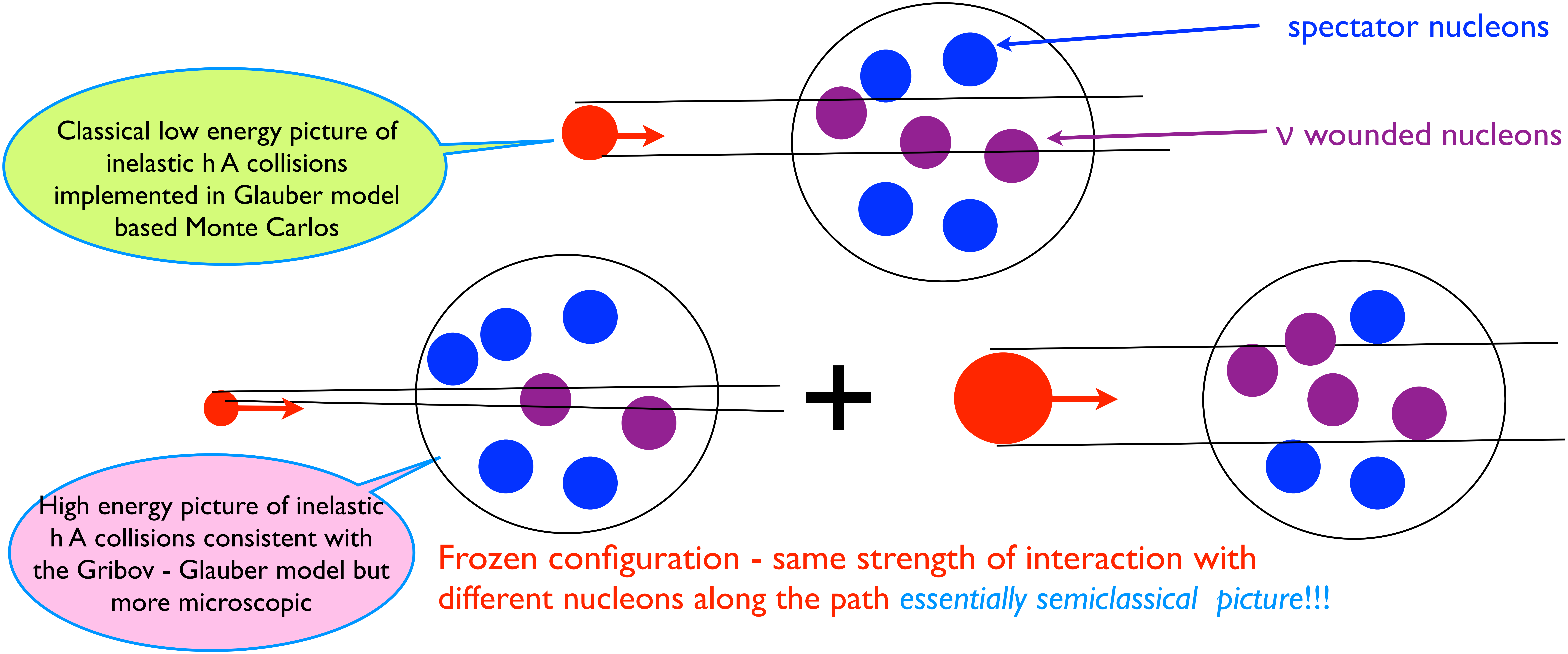


$P_N(\sigma)$ nearly flat in wide range of σ.
Elongated configurations?

Extrapolation of Guzey & MS before the LHC data; consistent with LHC data which are still not too accurate

$P_N(\sigma)$ provides constructive way to account for coherence of the high-energy dynamics

Fluctuations of interaction cross section formalism: *Color fluctuation model*



Frozen configuration - same strength of interaction with different nucleons along the path *essentially semiclassical picture!!!*

$$\sigma_\nu = \int d\sigma P_h(\sigma) \cdot \frac{A!}{(A-\nu)!\,\nu!} \cdot \int d\boldsymbol{b}\,(\sigma T(b)/A)^\nu\,[1-\sigma T(b)/A]^{A-\nu}$$

simplified expression (optical limit)

Natural expectation is that there is a correlation between configuration of hard partons in the hadron and strength of interaction of the hadron

IDEA

Use the hard trigger (dijet) to determine x of the parton in the proton (x_p) and low p_t hadron activity to measure overall strength of interaction σ_{eff} of configuration in the proton with given x. Expectation large x correspond to smaller σ_{eff} FS83

Expectation: large x ($x \gtrsim 0.5$) correspond to much smaller σ → drop of # of wounded nucleons & overall hadron multiplicity for central collisions

DISTRIBUTION OVER THE NUMBER OF COLLISIONS FOR PROCESSES WITH A HARD TRIGGER

M.Alvioli, L.Frankfurt, V.Guzey and M.Strikman, ``Revealing nucleon and nucleus flickering in pA collisions at the LHC,' Phys.Rev. C90 (2014) 3, 034914 arXiv 1402.2868

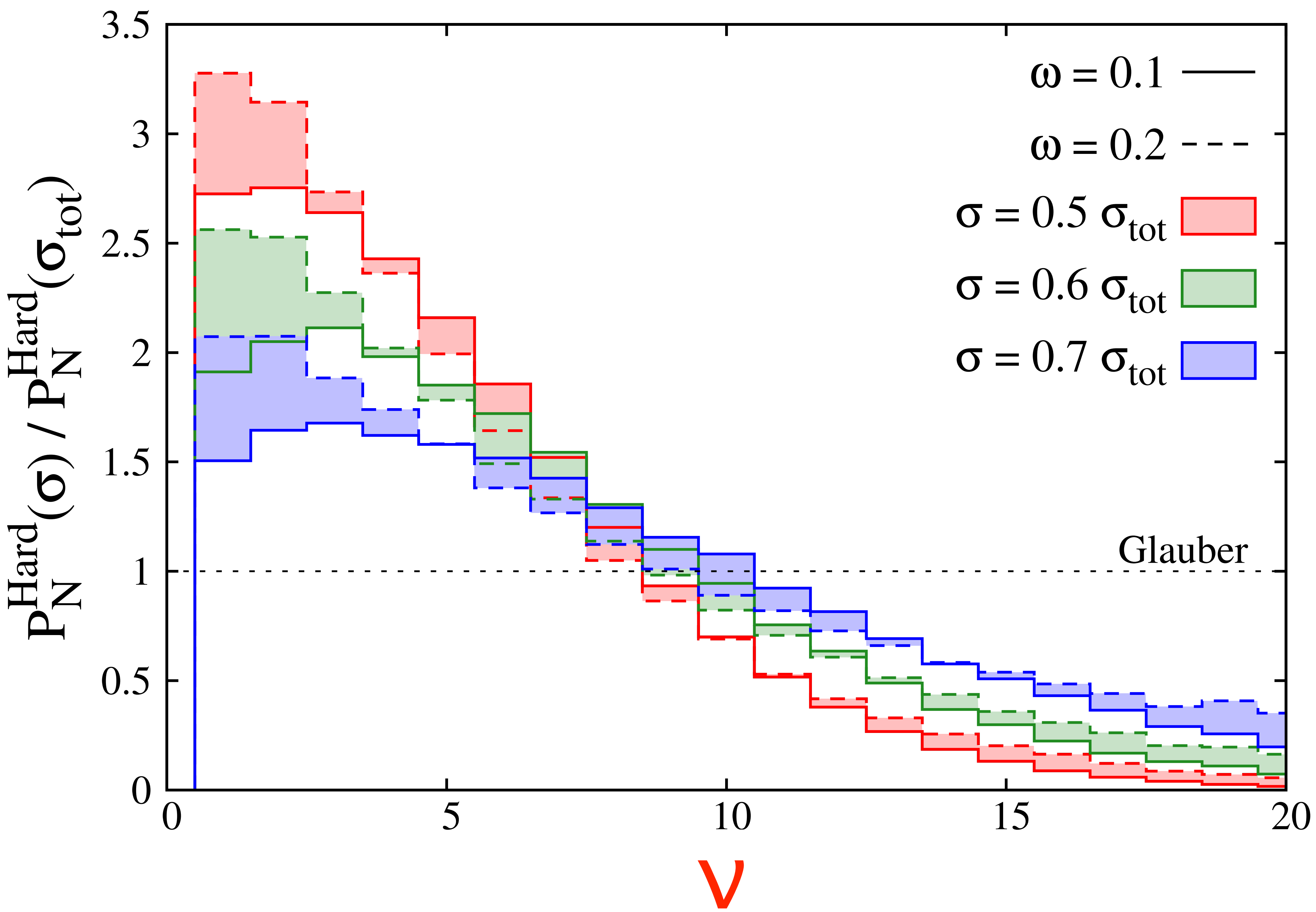
Consider multiplicity of hard events $Mult_{pA}(HT) = \sigma_{pA}(HT+X)/\sigma_{pA}(in)$ as a function of ν -- number of collisions

If the radius of strong interaction is small and hard interactions have the same distribution over impact parameters as soft interactions multiplicity of hard events:

$$R_{HT}(\nu) = \frac{Mult_{pA}(HT)}{Mult_{NN}(HT)\nu} = 1$$

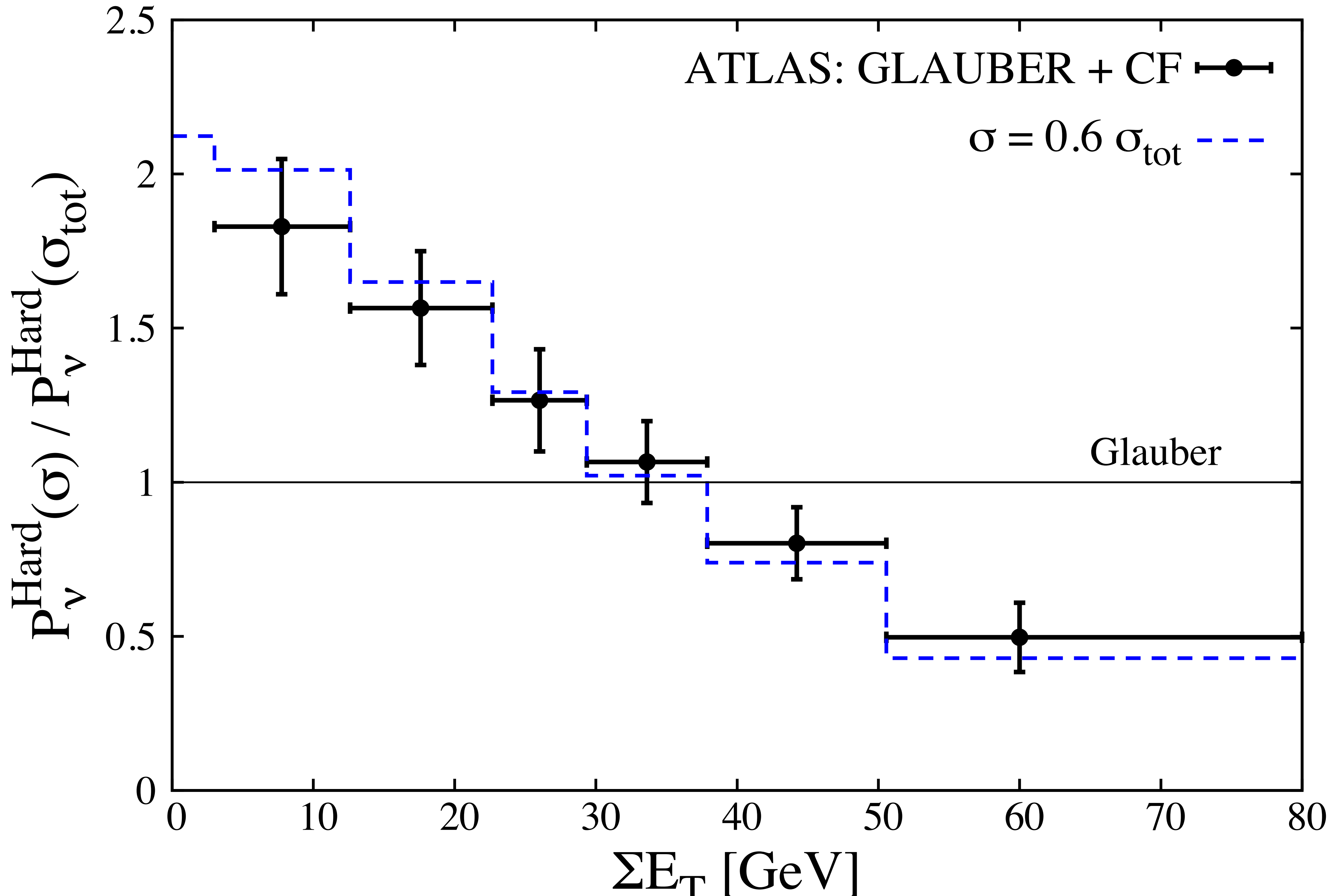
Accuracy? Significant corrections due significantly different distribution over impact parmeters of min bias events and events with hard trigger. Developed MC code to account for these effects as well as NN correlations

Fluctuations for configurations with small σ maybe different than for average one so we considered both $\omega_\sigma(x\sim0.5)$ =0.1 & 0.2



Sensitivity to ω_σ is small, so we use ω_σ =0.1 for following comparisons

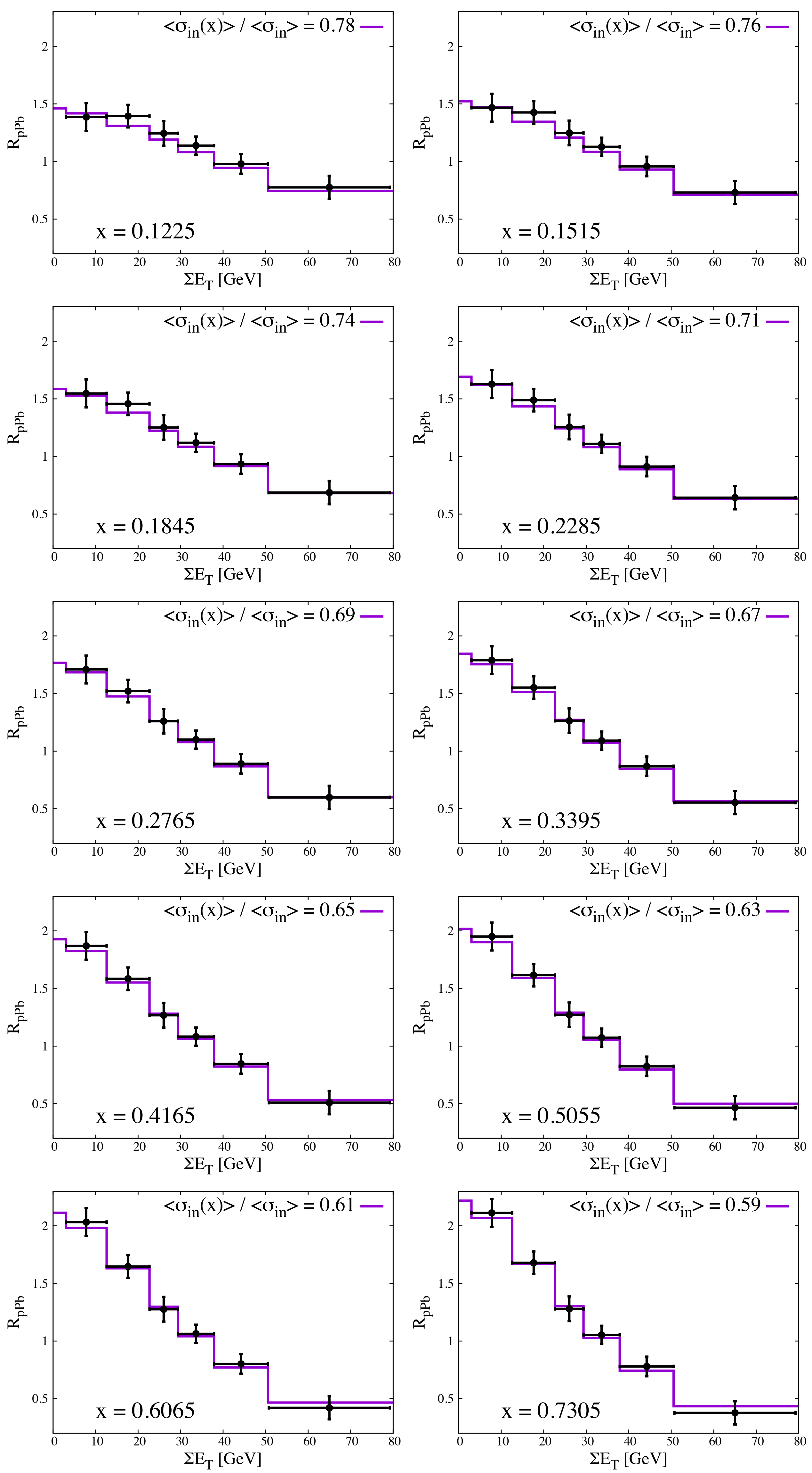
We first focused on large x_p where effect is largest and hence corrections for transverse geometry are small (though we do include them)

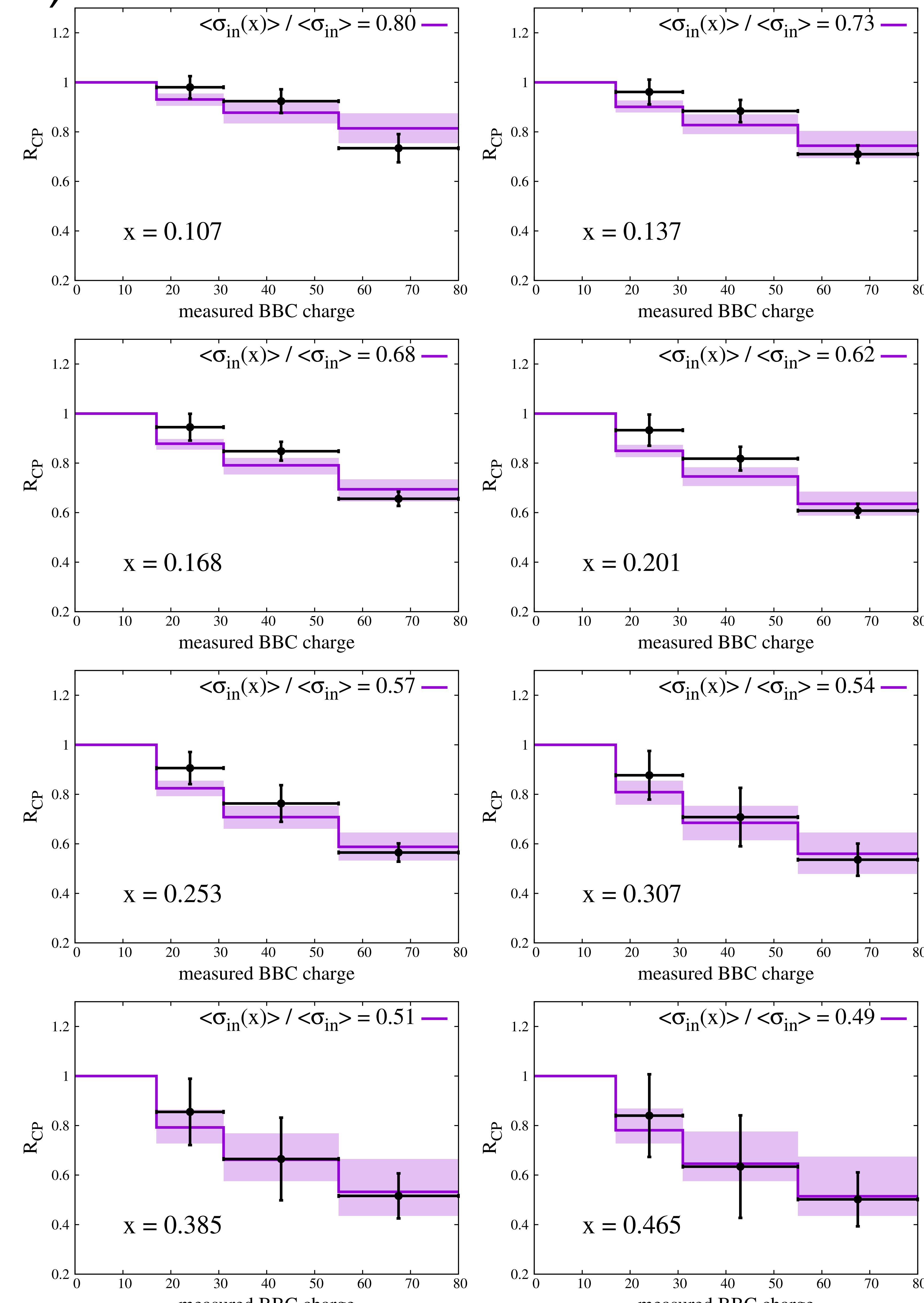


R^{hard} for $x = E_{jet}/E_p = 0.6$ for centrality bins extracted from the ATLAS data using ν's of the CF model. Errors are combined statistical and systematic errors. The solid line is the Glauber model expectation.

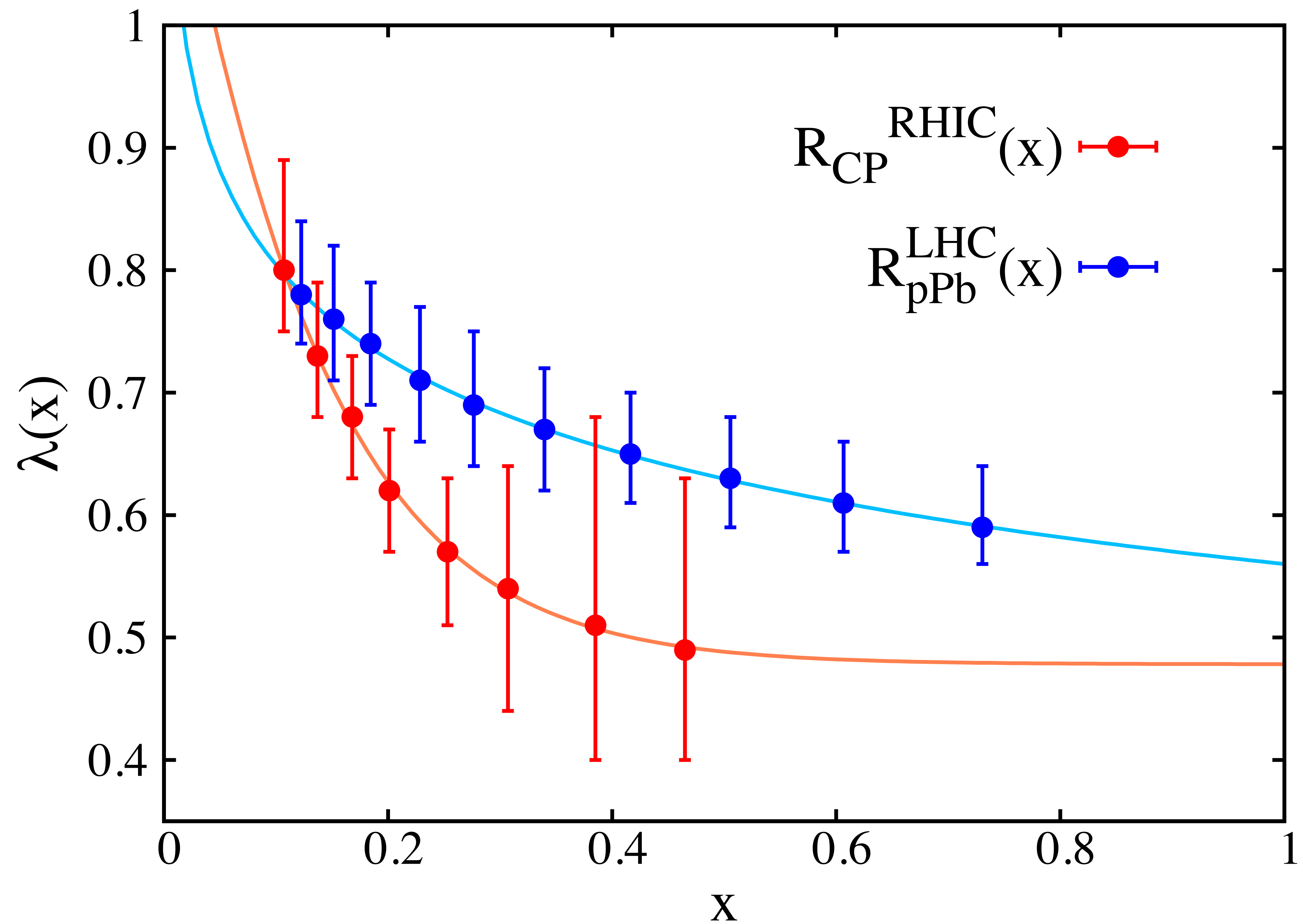
Further analysis of LHC and RHIC d Au data

(Alvioli, Perepelitsa, MS)





Used fit to correct for spread in x in the x- bins



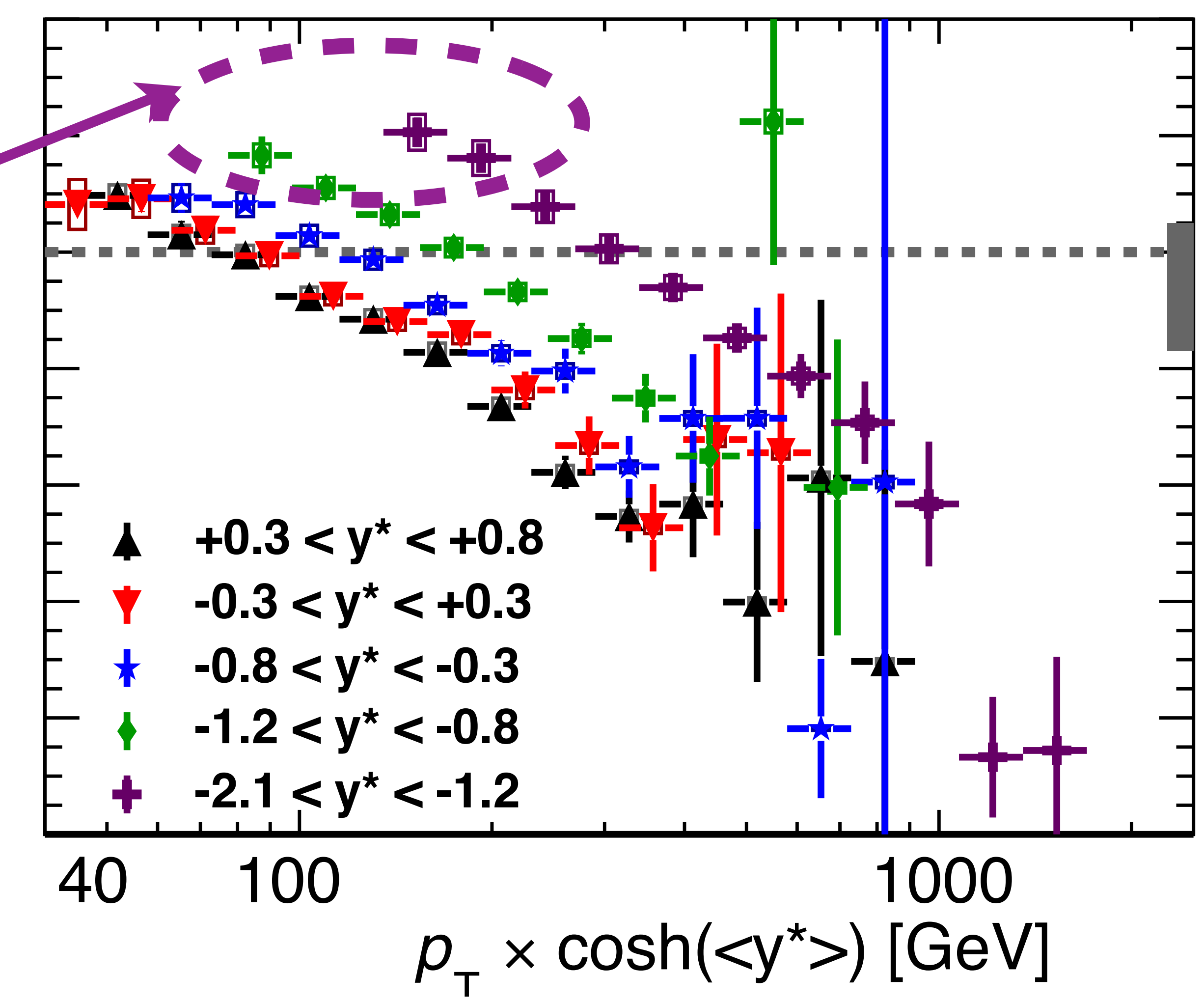
Conclusion: LHC and BNL data are consistent. Somewhat smaller $\lambda(x)= \sigma(x)/\sigma_{in}$ for lower energies - natural as rate of the increase of cross section with energy is stronger for smaller fluctuations

Outlook

☛ try to separate scattering contributions of gluons and quarks at $x_p \sim 0.1$

☛ Transition to dominance of larger than average size - $x < 10^{-1}$?

Change of the pattern of dependence on centrality: suppression of peripheral and enhancement of central collisions



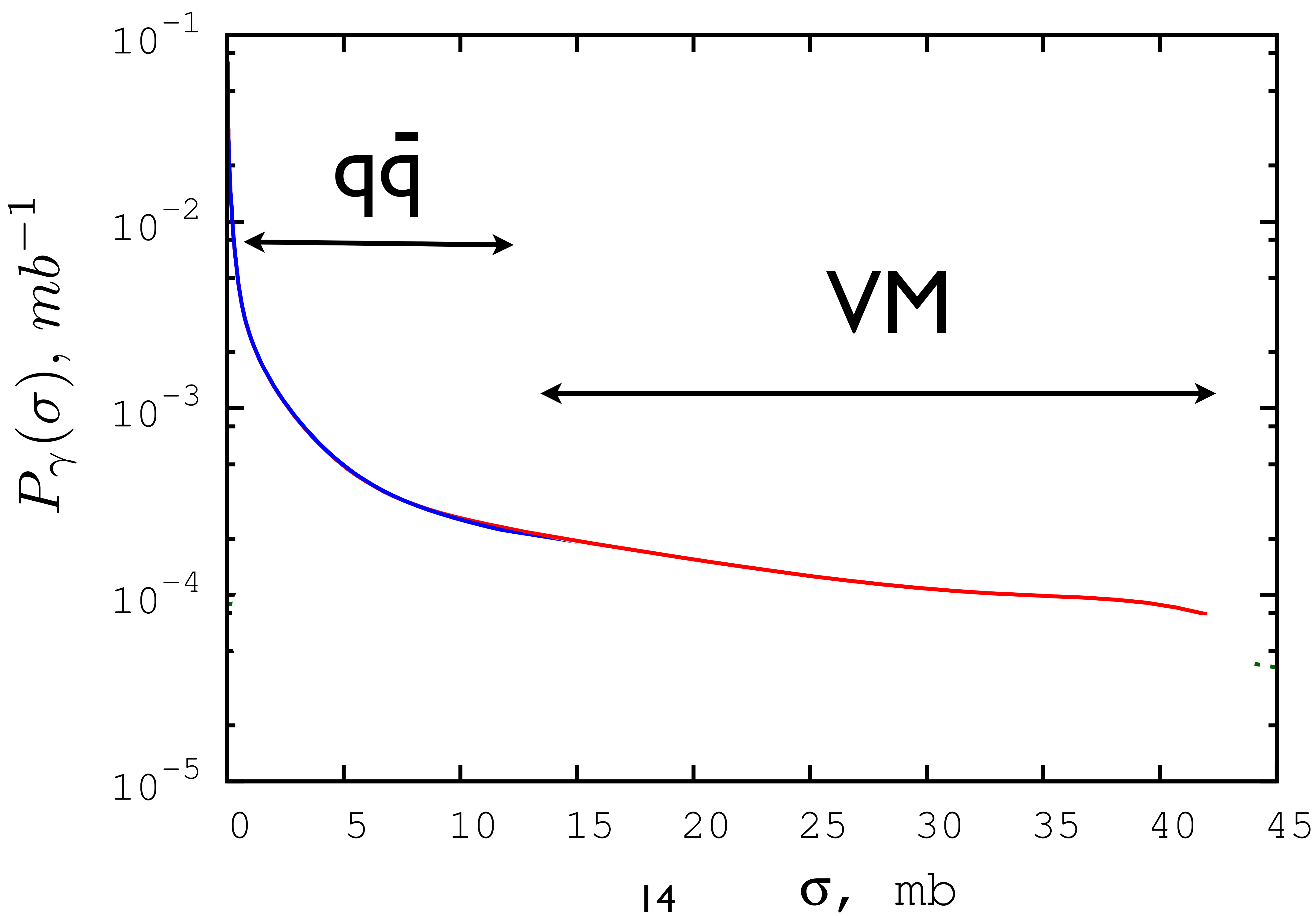
Color fluctuations in photon - nucleus collisions

Ultraperipheral collisions at the LHC - intro in the Wednesday talks

Photon is a multiscale state:

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

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



Exclusive processes of vector meson production off nuclei at LHC in ultraperipheral collisions allow to test theoretical expectations for small and large σ

(a) ρ-meson production: $\gamma + A \to \rho + A$

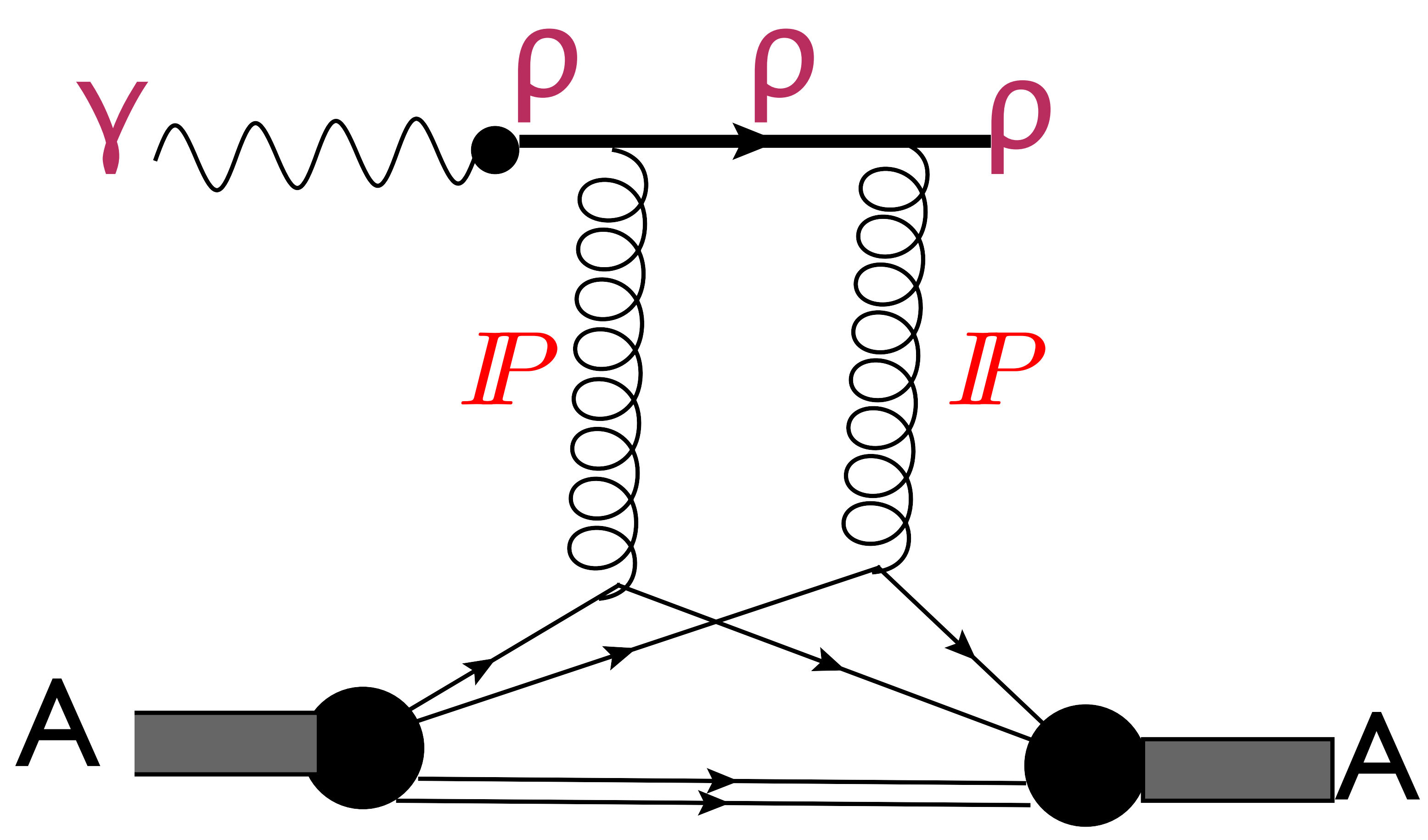
Expectations:

- *vector dominance model for scattering off proton* $\sigma(\rho N) < \sigma(\pi N)$

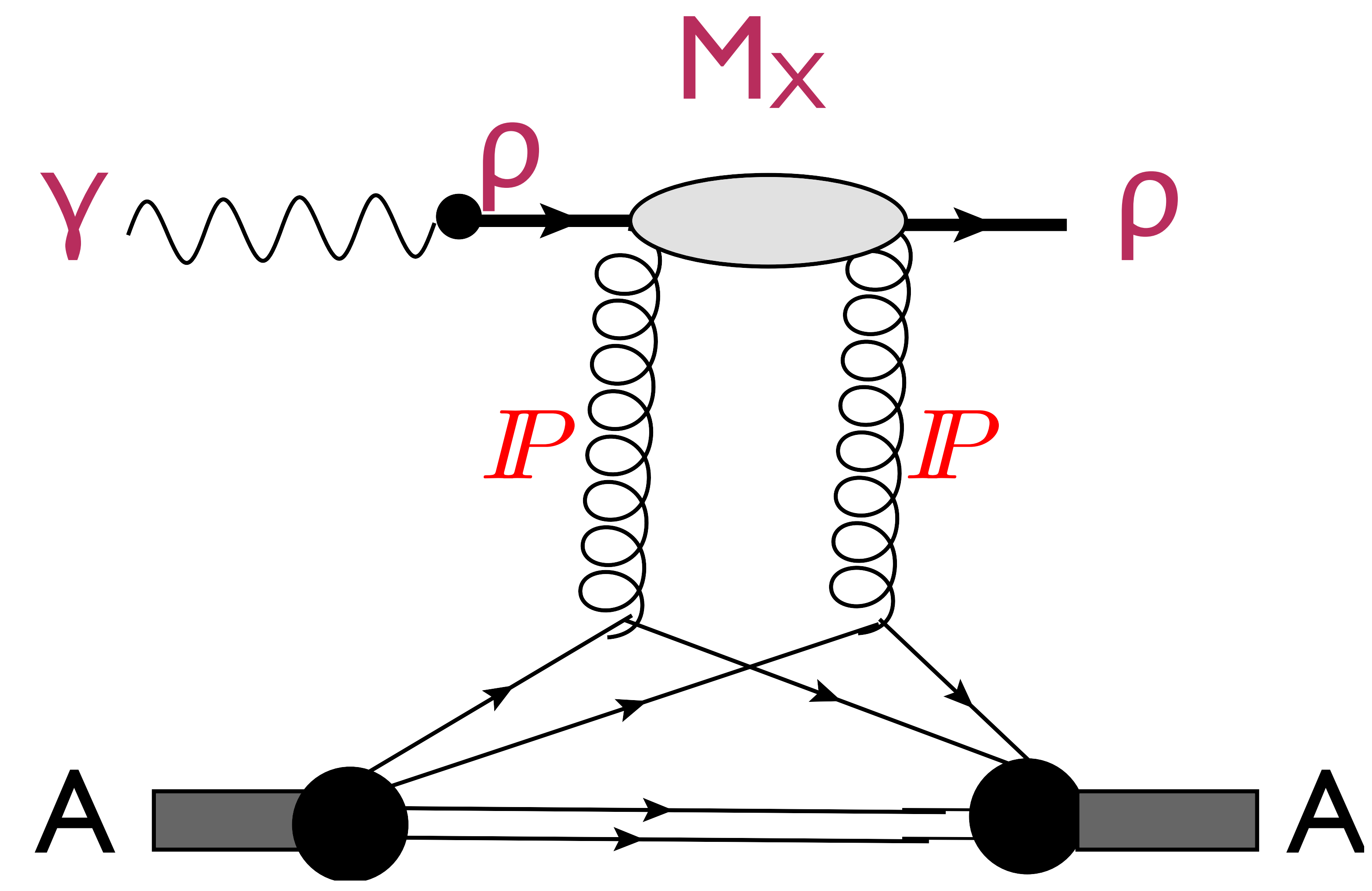
since overlapping integral between γ and ρ suppressed as compared to $\rho \to \rho$ case

observed at HERA but ignored before our analysis: $\sigma(\rho N)/\sigma(\pi N) \approx 0.85$

Analysis of Guzey, Frankfurt, MS, Zhalov 2015 (1506.07150)



Glauber double scattering

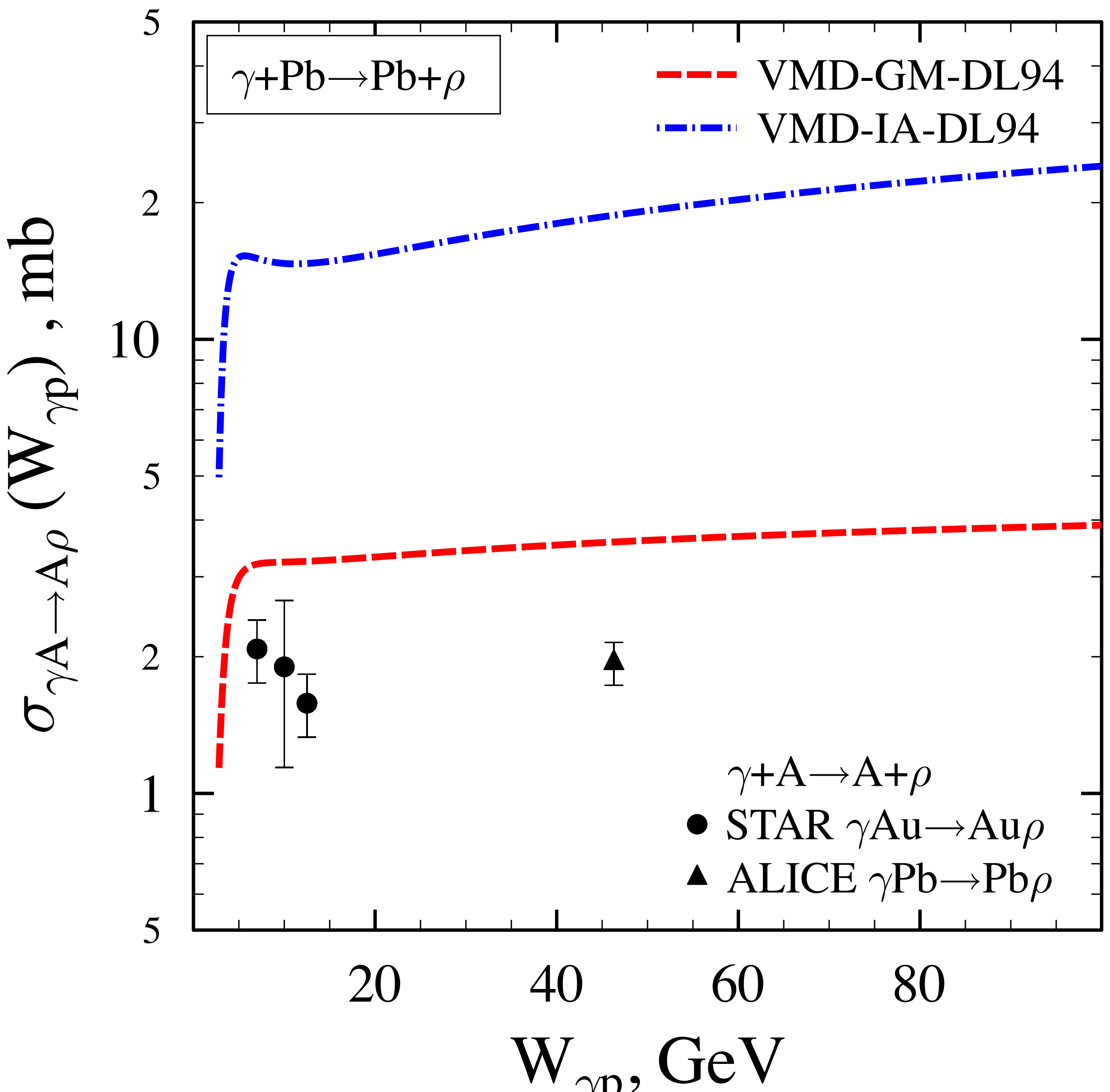


Gribov inelastic shadowing

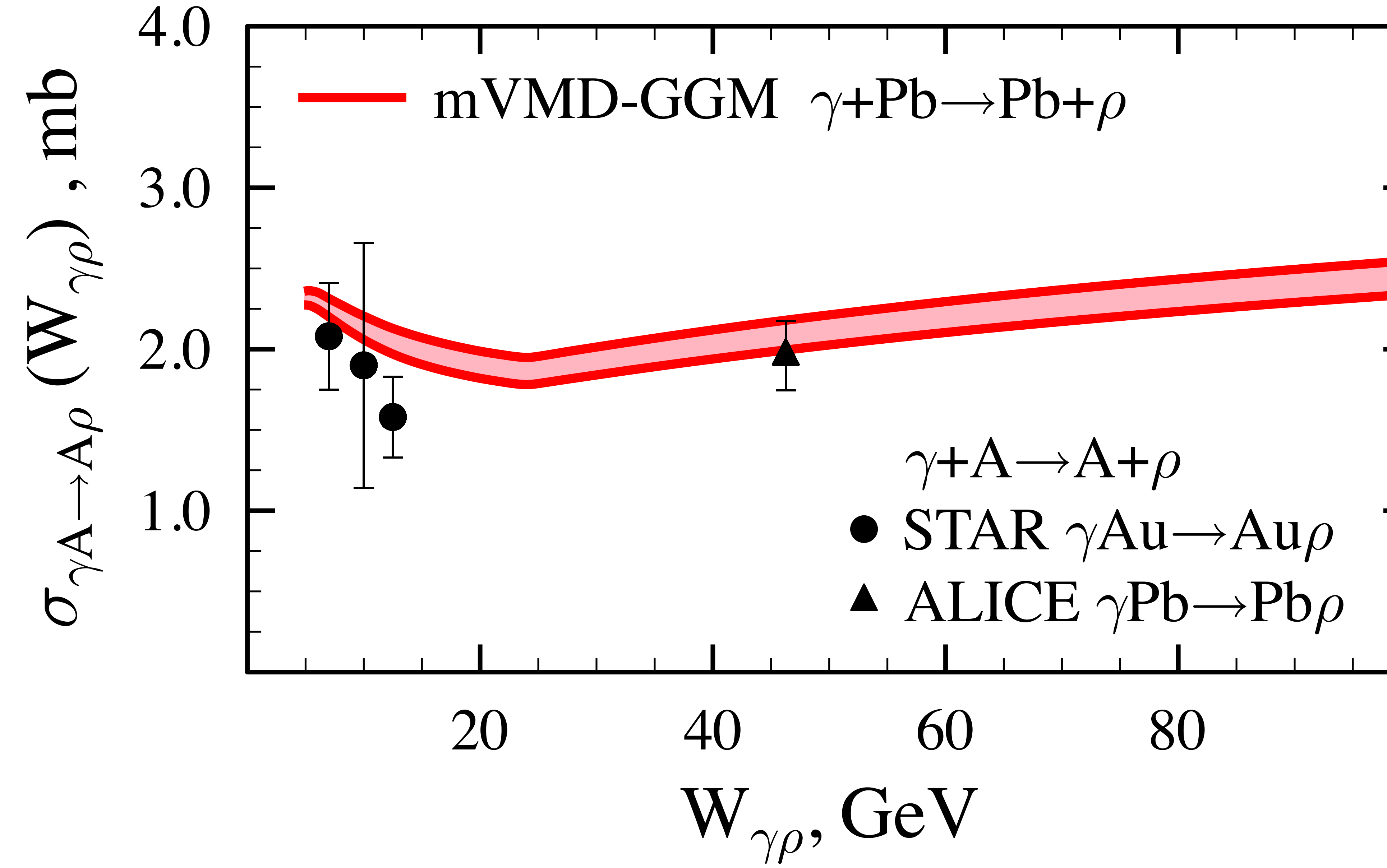
❖ Gribov type inelastic shadowing is enhanced in discussed process - fluctuations grow with decrease of projectile - nucleon cross section. We estimate $\omega_{\gamma\to\rho} \sim 0.5$ and model $P_{\gamma\to\rho}(\sigma)$

Next we use $P_{\gamma\to\rho}(\sigma)$ to calculate coherent ρ production. Several effects contribute to suppression a) large fluctuations, b) enhancement of inelastic shadowing is larger for smaller σ_{tot}. for the same ω, c) effect for coherent cross section is square of that for σ_{tot}.

Glauber model grossly overestimates the cross section (at LHC factor ~2)



Gribov - Glauber model with cross section fluctuations



(b) Modeling interactions of small configurtions

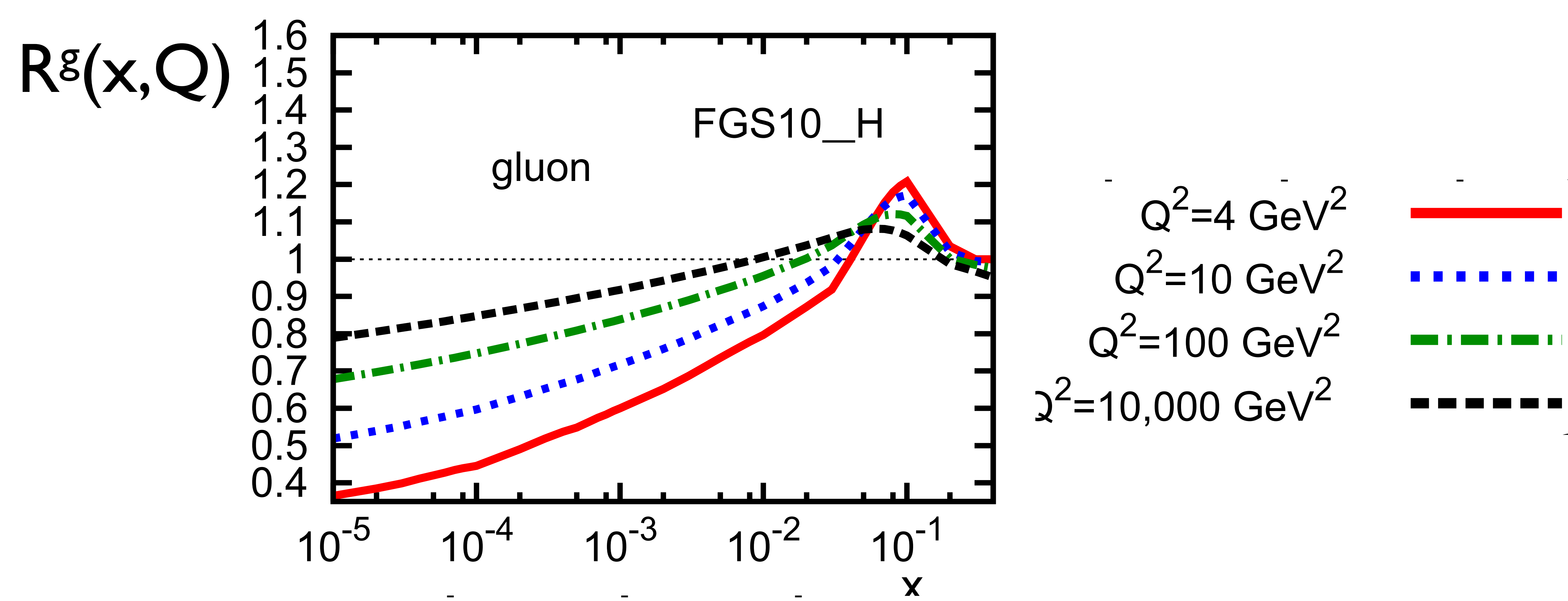
J/ψ-meson production: γ+A → J/ψ +A

Small dipoles ➟ QCD factorization theorem

$$S_{Pb} = \left[\frac{\sigma(\gamma A \to J/\psi + A)}{\sigma_{imp.approx.}(\gamma A \to J/\psi + A)}\right]^{1/2} = \frac{g_A(x,Q^2)}{g_N(x,Q^2)} \cong 0.6 \text{ for } x = 10^{-3}$$

Much larger shadowing than in the eikonal dipole model

Prediction of the LT theory of nuclear shadowing based on factorization theorem for diffraction and AGK



Multiple rescatterings of small dipoles are not suppressed

Outline of calculation of inelastic γA scattering - distribution over ν

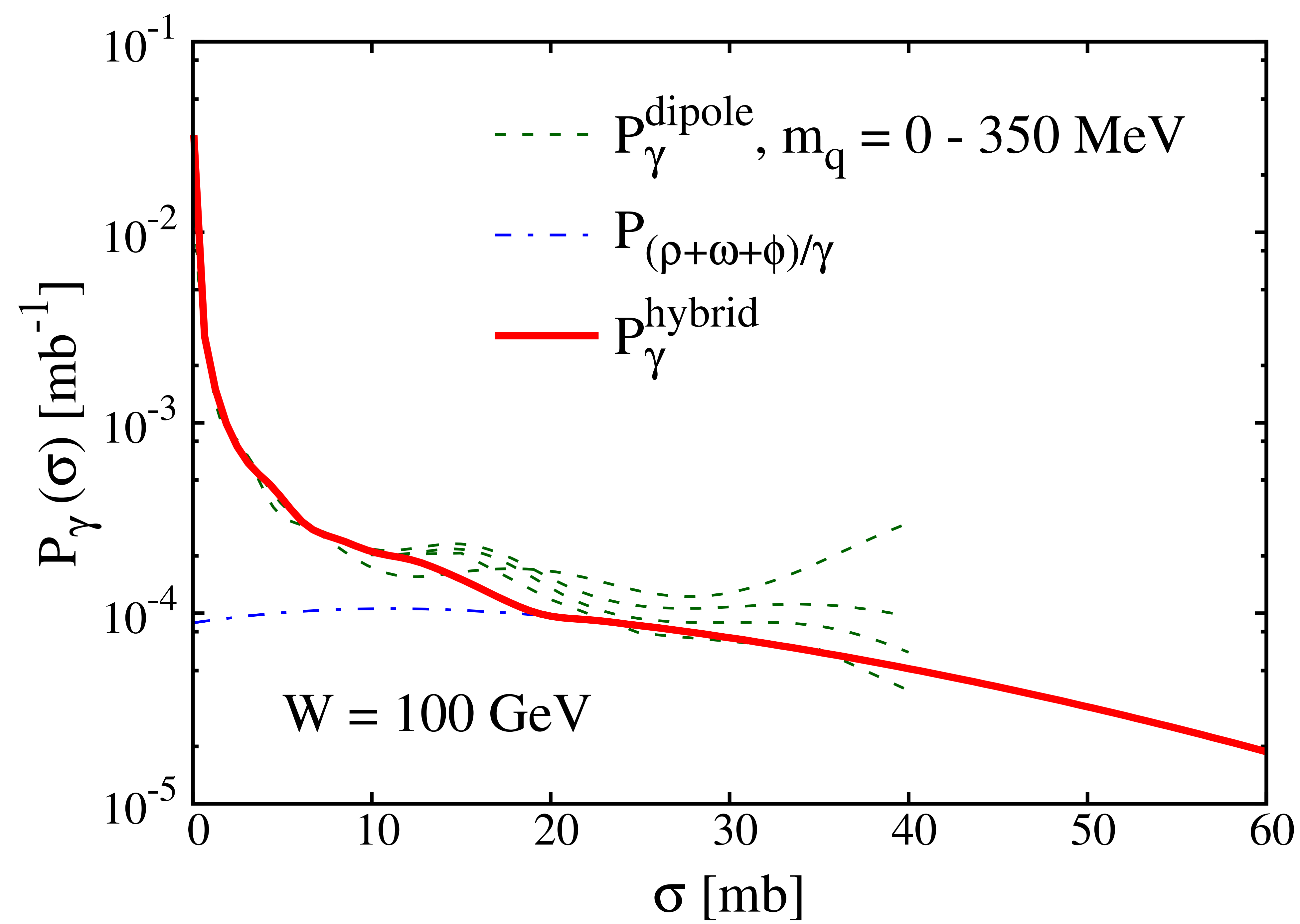
- Modeling $P_\gamma(\sigma)$

For $\sigma > \sigma(\pi N), P_\gamma(\sigma) = P_{\gamma\to\rho}(\sigma) + P_{\gamma\to\omega}(\sigma) + P_{\gamma\to\phi}(\sigma)$

For $\sigma \leq 10mb$ (cross section for a J/ψ -dipole) use pQCD for $\psi_\gamma(q\bar{q})$

$$\sigma(d,x) = \frac{\pi^2}{3}\alpha_s(Q^2_{eff})d^2xG_N(x,Q^2_{eff})$$

+ smooth interpolation in between



Calculation of distribution over the number of wounded nucleons

(a) Color fluctuation model

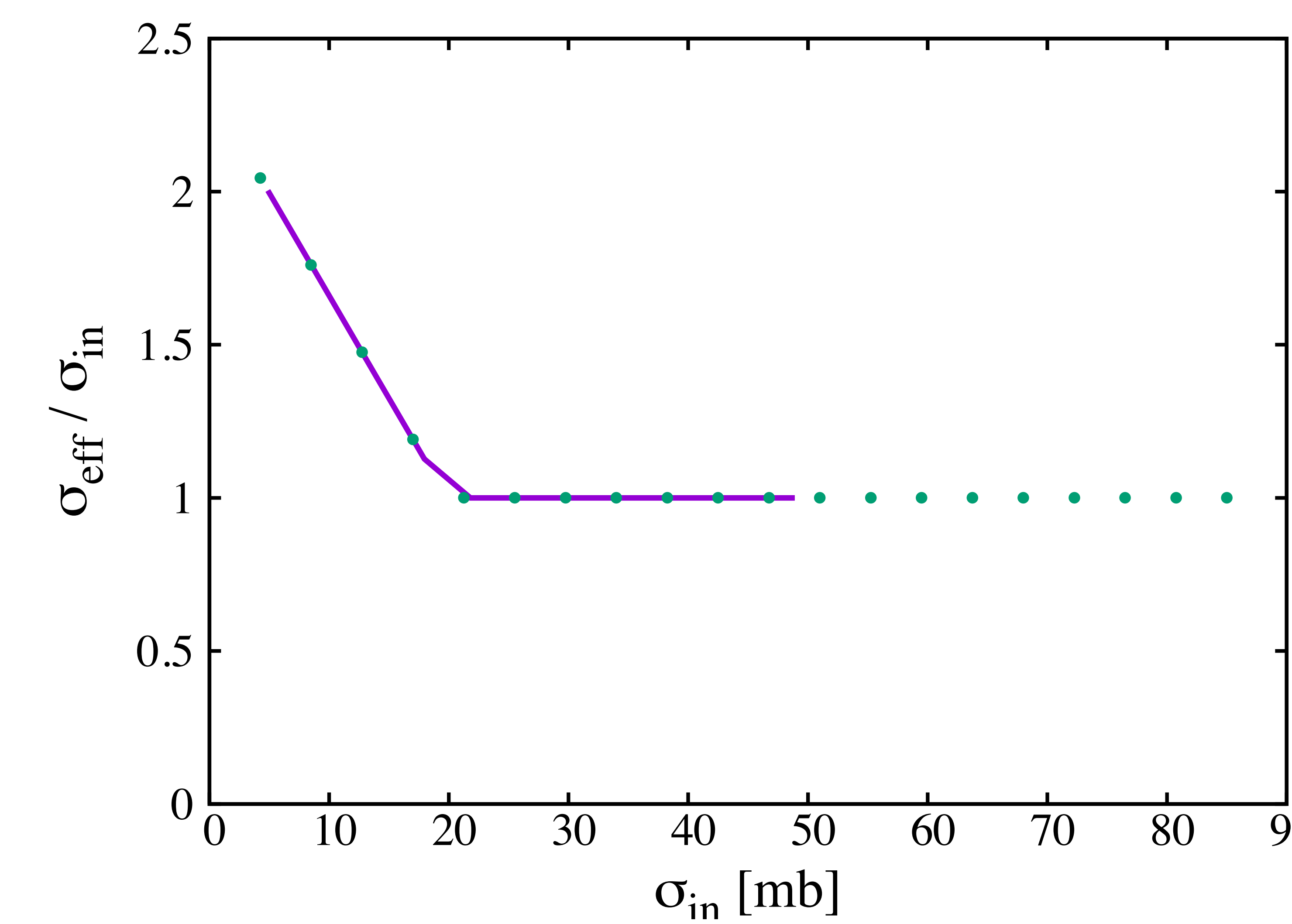
$$\sigma_\nu = \int d\sigma P_\gamma(\sigma) \left(\begin{array}{c} A \\ \nu \end{array} \right) \times \int d\vec{b} \left[\frac{\sigma_{in}(\sigma)T(b)}{A}\right]^\nu \left[1 - \frac{\sigma_{in}(\sigma)T(b)}{A}\right]^{A-}$$

$$p(\nu) = \frac{\sigma_\nu}{\sum_1^\infty \sigma_\nu}.$$

(b) Generalized Color fluctuation model (includes LT shadowing for small σ)

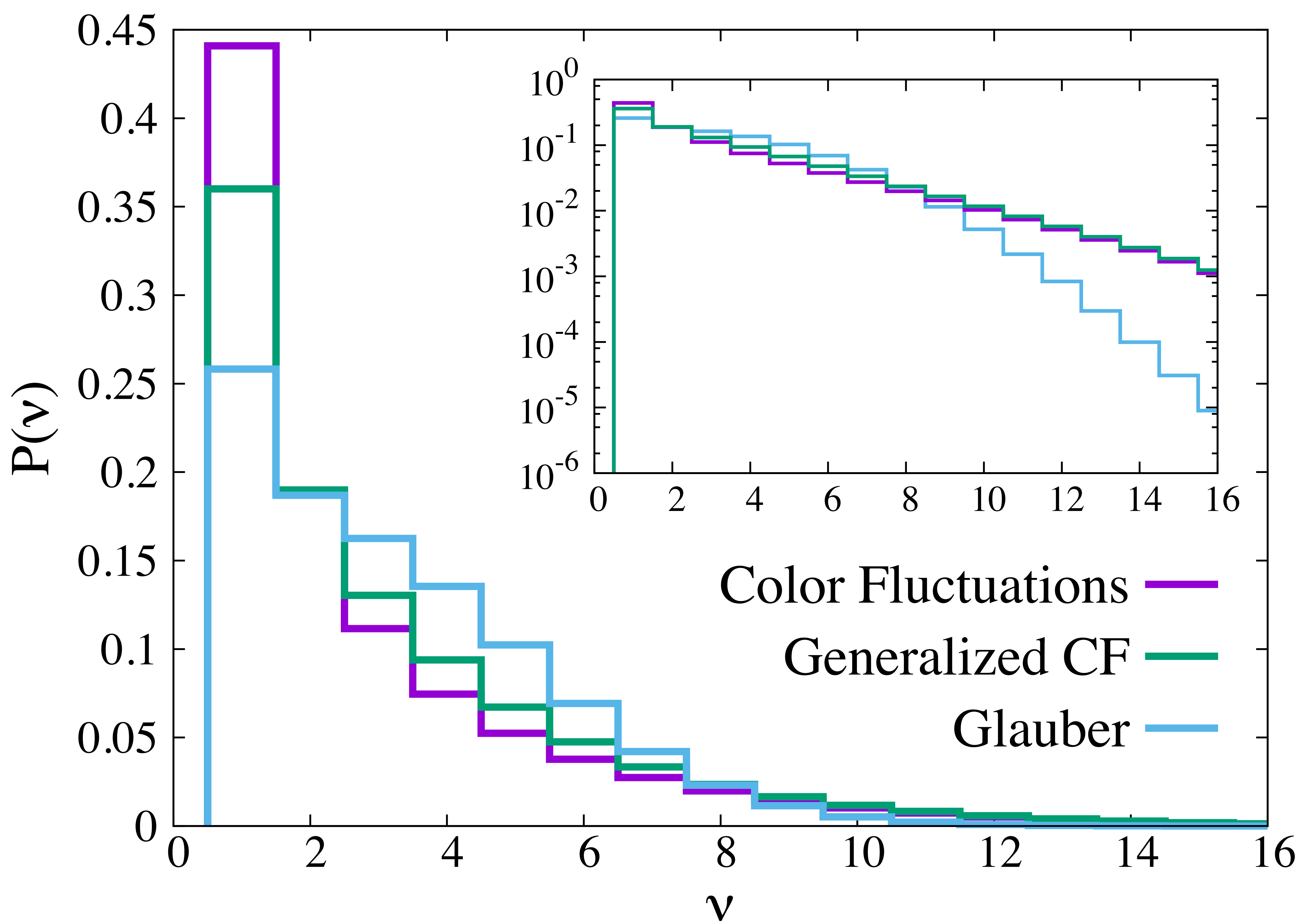
$$P_\gamma(\sigma) \left(\begin{array}{c} A \\ \nu \end{array} \right) \times \frac{\sigma^{in}}{\sigma^{in}_{eff}} \int d\vec{b} \left[\frac{\sigma_{eff}T(b)}{A}\right]^\nu \left[1 - \frac{\sigma_{eff}T(b)}{A}\right]^{A-\nu}$$

σ_{eff}/σ calculated in the LT nuclear shadowing theory for small σ



CF 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.



$\gamma A \rightarrow$ jets + X

1) *Direct photon & $x_A > 0.01$, $\nu = 1$?*

Color change propagation through matter.
Color exchanges ? ➠ nucleus excitations, ZDC

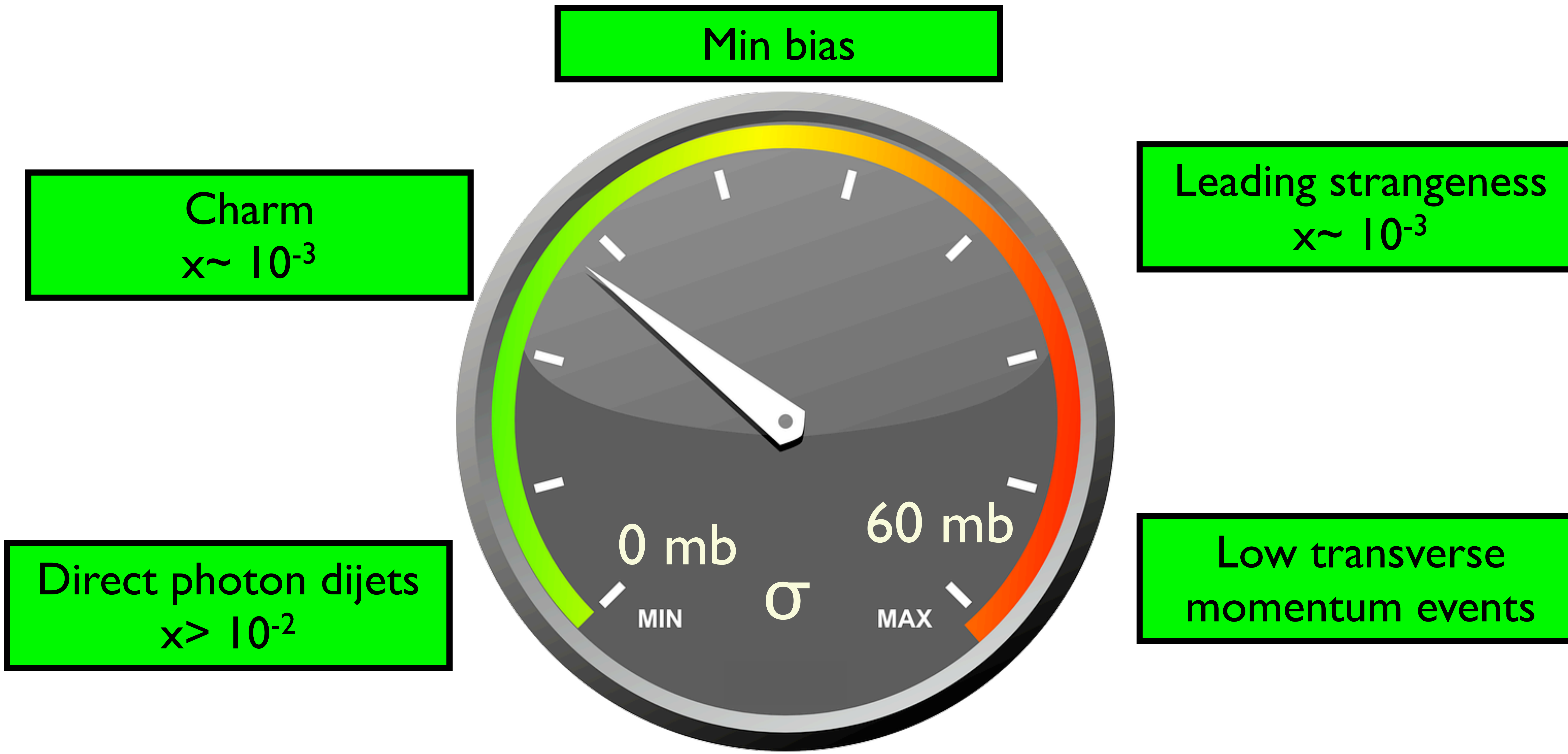
2) *Direct photon & $x_A < 0.005$ - nuclear shadowing increase of ν*

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

W dependence

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

Tuning strength of interaction of configurations in photon



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

Novel way to study dynamics of γ & γ^* interactions with nuclei

Conclusions

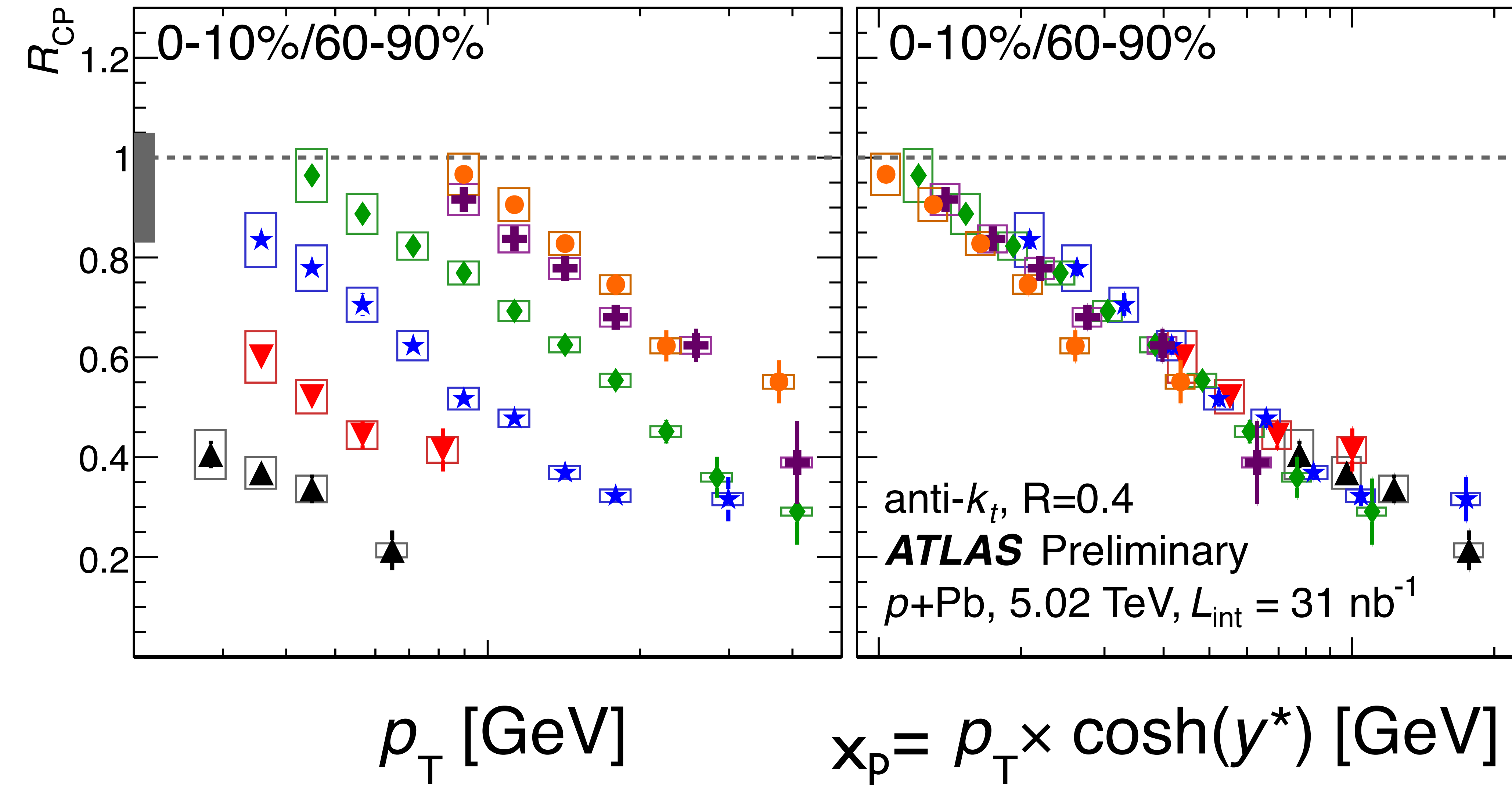
- ✷ Color fluctuations are an important feature of high energy dynamics
- ✷ Color fluctuation with large x - have smaller size
- ✷ Opportunities for studing global 3D structure of nucleon and photon
- ✷ Fruitful to perform parallel studies of γA and pA processes

supplementary slide

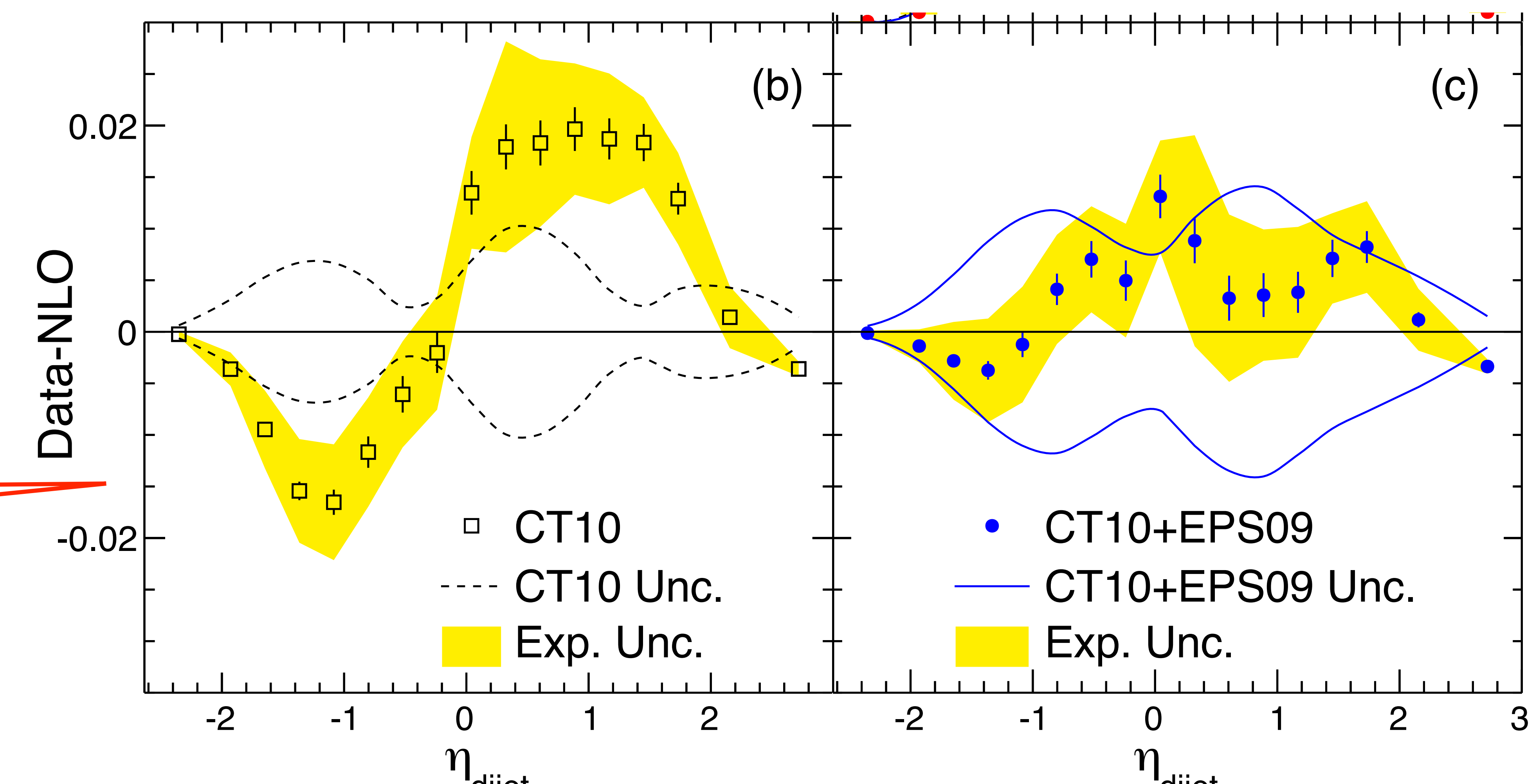
Data - ATLAS & CMS on correlation of jet production and activity in forward rapidities

Key relevant observations:

✔ The jet rates for different centrality classes do not match geometric expectations. Discrepancy scales with x of the parton of the proton and maximal for large x_p



✔ pQCD works fine for inclusive production of jets



rules out energy loss explanation of the effect

To calculate the expected CF effects accurately it is necessary to take into account grossly different geometry of minimum bias and hard NN collisions