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Color fluctuations effects in hard pA & UPC

Outline

- Color fluctuations in hadron - new pattern of high energy hadron - nucleus scattering - going beyond single parton structure of nucleon.
- Further evidence for x -dependent color fluctuations in nucleons
- A new frontier : Color fluctuations in ultraperipheral (γA) collisions
- New strategy for observing DPS in pA collisions

Fluctuations of overall strength of high energy NN interaction

- High energy projectile stays in a frozen configuration distances much larger than nucleus size (10^6 fm at LHc energies)

  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

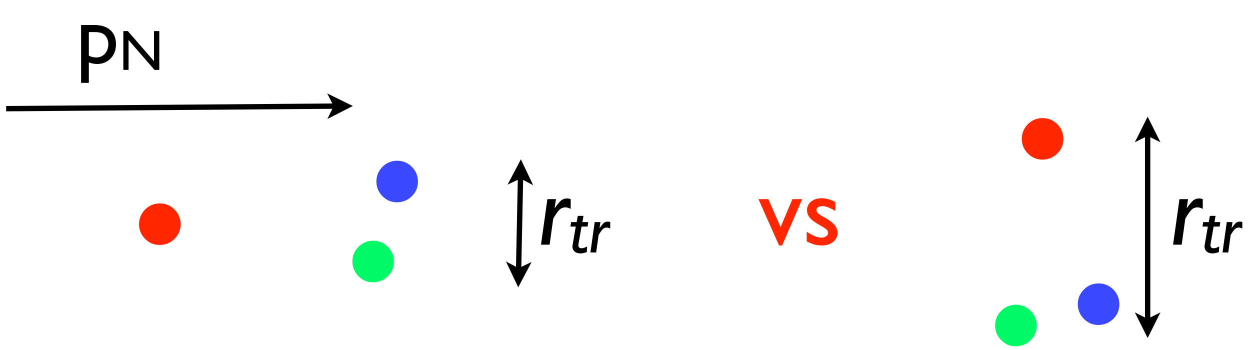
- Strength of interaction of white small system is proportional to the area occupies by color.

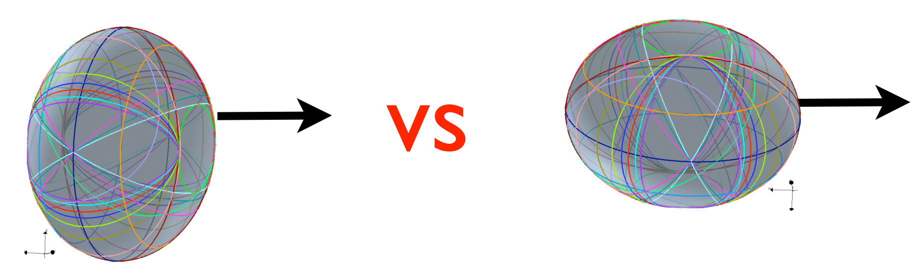
  QCD factorization theorem for the interaction of small size color singlet wave package of quarks and gluons.

We will refer fluctuations of the strength of interaction of nucleon, photon,.. as color fluctuations of interaction strength - studying them allows to go beyond single parton 3-D mapping of the nucleon

Fluctuations of the strength of interaction of a fast hadron can originate for example due to fluctuations of the overall size /orientation, strength of the gluon field,...

$$|N\rangle = (3q) + (3qg) + (3q+\pi) + \ldots$$



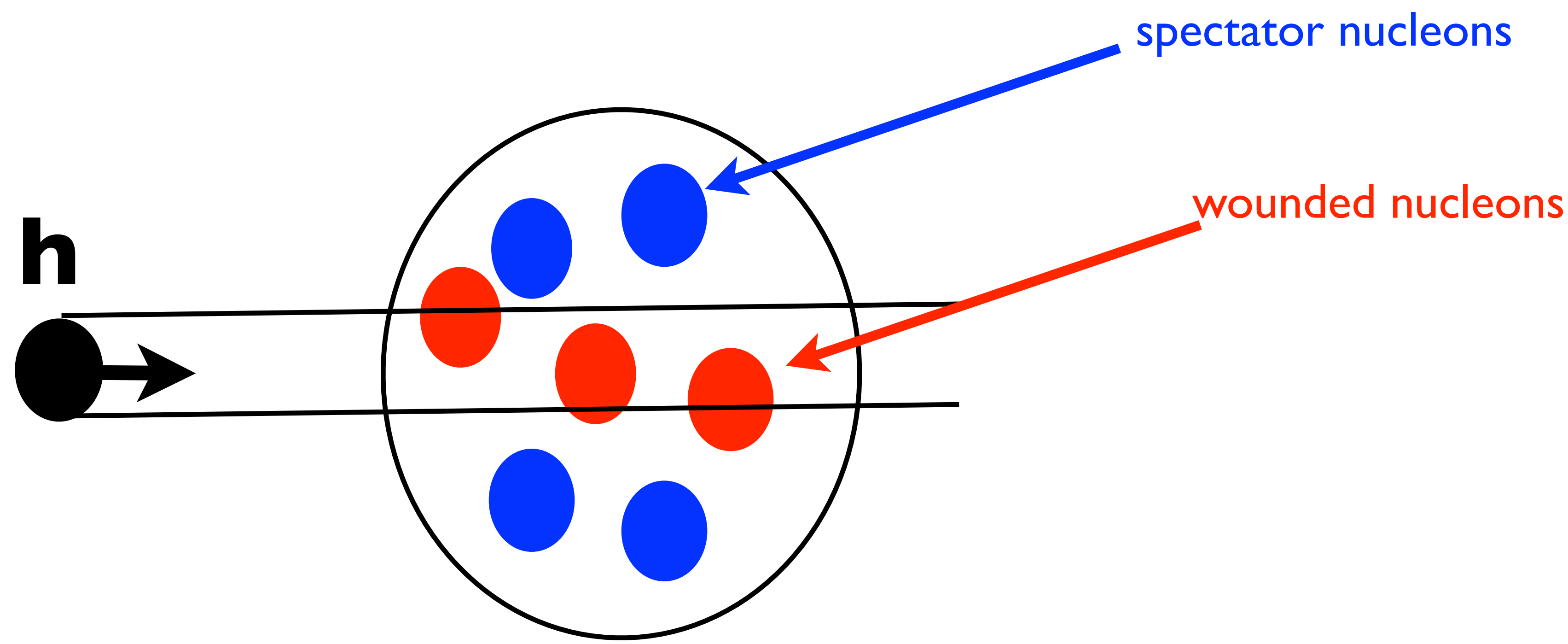


⇒ Various triggers allow to change proportion of small and large configurations in the data sample

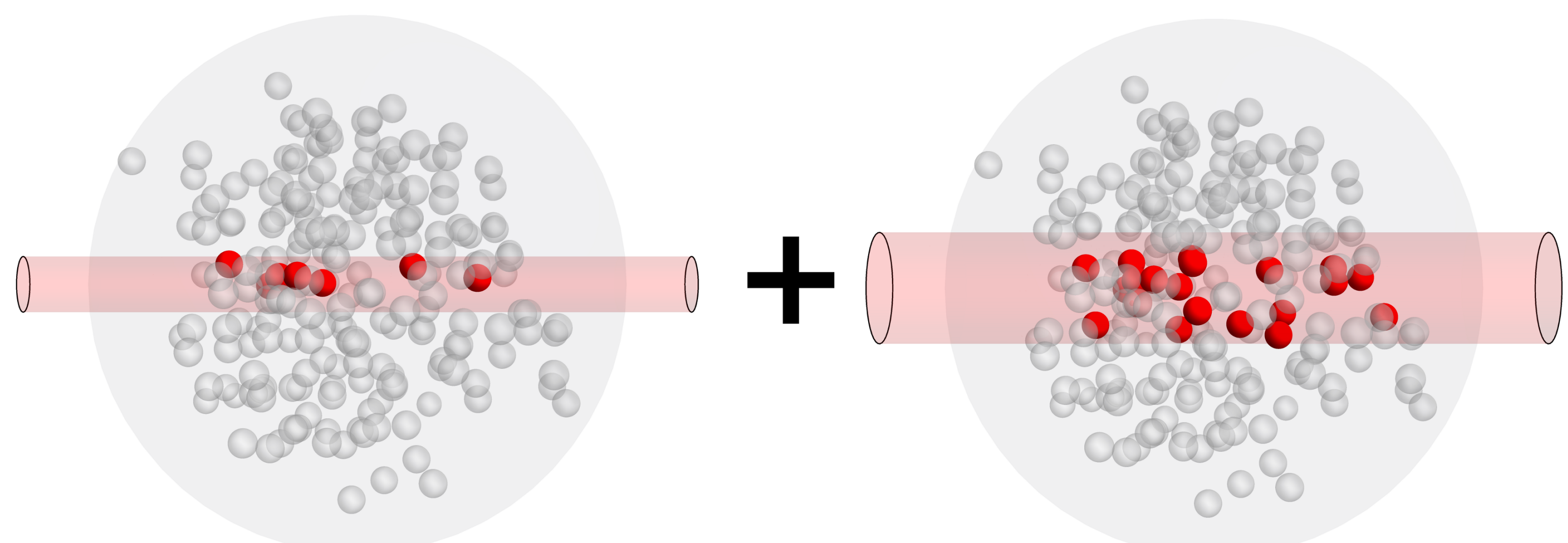
⇒ *Inelastic processes are sensitive to presence of large & small size configurations in projectile - longer the target (nucleus) -- higher the sensitivity.*

CF in NN interactions ⇒ additional mechanism of fluctuations of number of wounded nucleons in in hA collisions

Classical low energy picture of inelastic h A collisions implemented in Glauber model based Monte Carlos

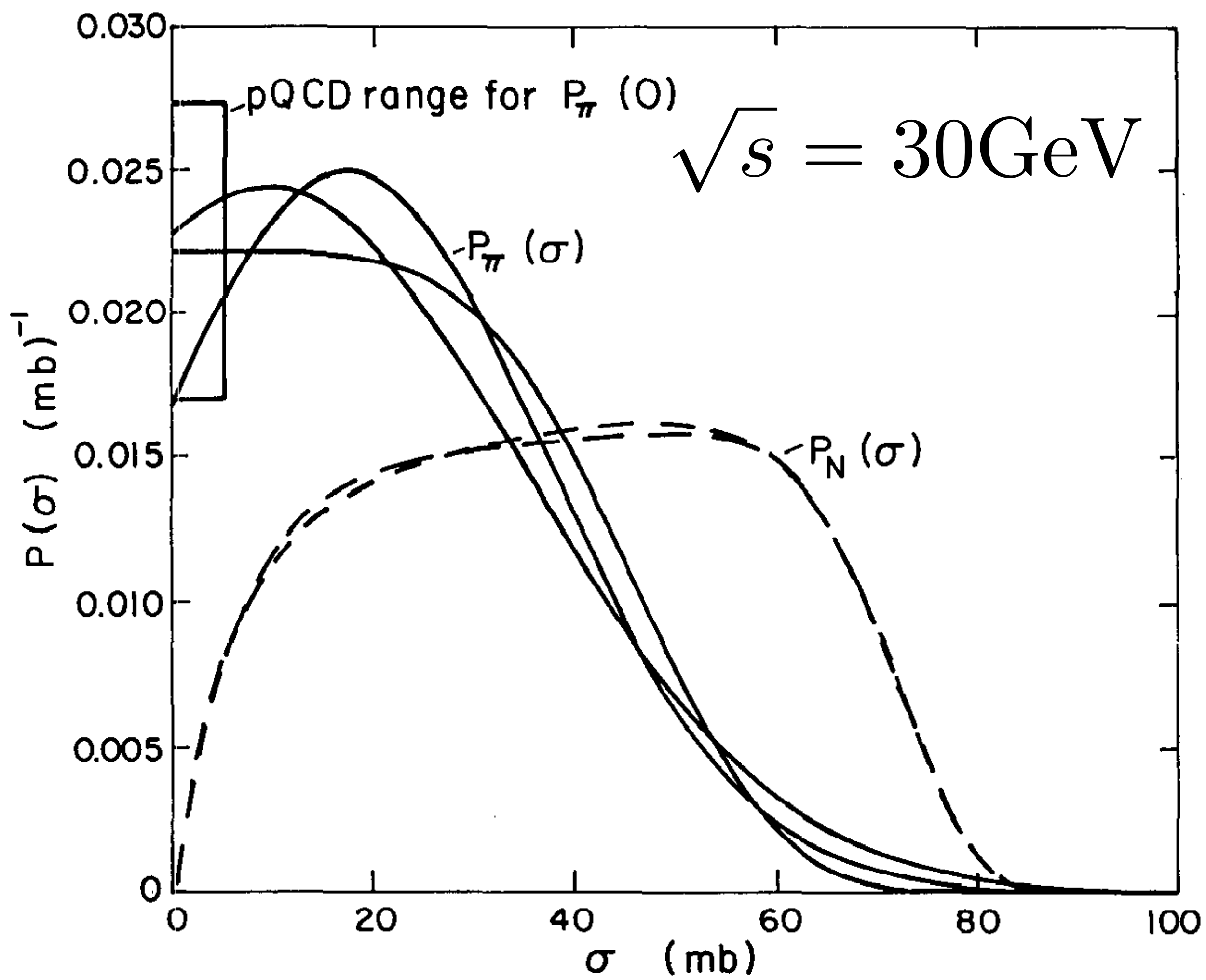


High energy picture of inelastic h A collisions consistent with the Gribov - Glauber model - interaction of frozen configurations

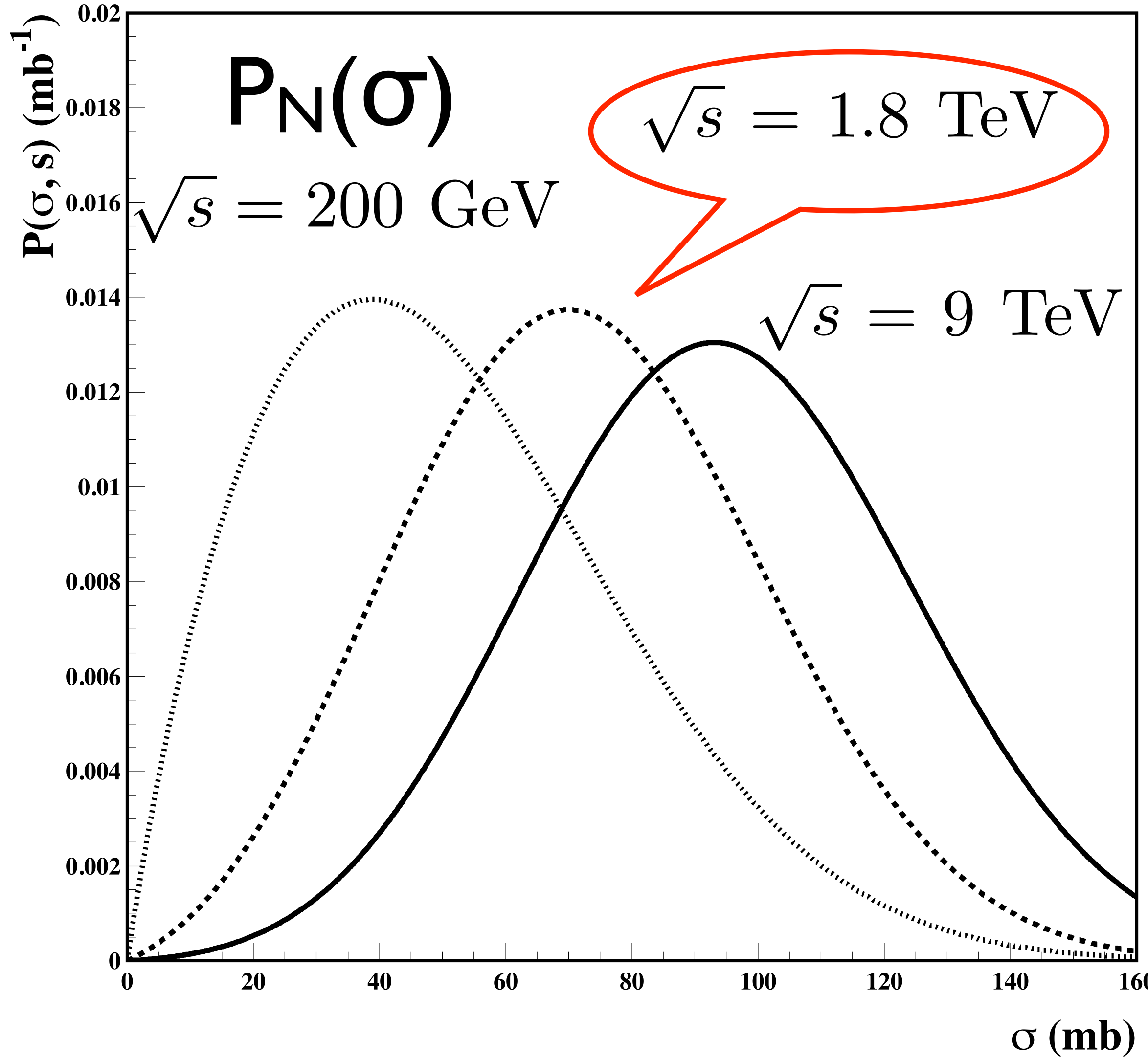


Convenient quantity - P(σ) -probability that hadron/photon interacts with cross section σ with the target. Satisfies normalization constrains, dispersion from diffraction at t=0 & quark counting rules for small σ. Build and use model

$$P_N(\sigma) = C\frac{\sigma}{\sigma + \sigma_0}\exp\left\{-\frac{(\sigma/\sigma_0 - 1)^2}{\Omega^2}\right\}$$



$P_N(\sigma)$ extracted from pp,pd diffraction Baym et al 93. $P_\pi(\sigma)$ is also shown



Guzey & MS (2005) before the LHC data using energy dependent fits to lower energy pp data

In pA case fluctuations show prominently in inelastic processes

Distribution over the number of wounded nucleons, ν in the CF approximation

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

simplified expression (optical limit)

Actual calculation based on MC model of Alvioli and MS which includes
a) Short -range NN correlations in the nucleus wave function,
(b) correct profile function for soft NN interactions,
(c) difference of the impact parameter ranges of soft and hard interactions

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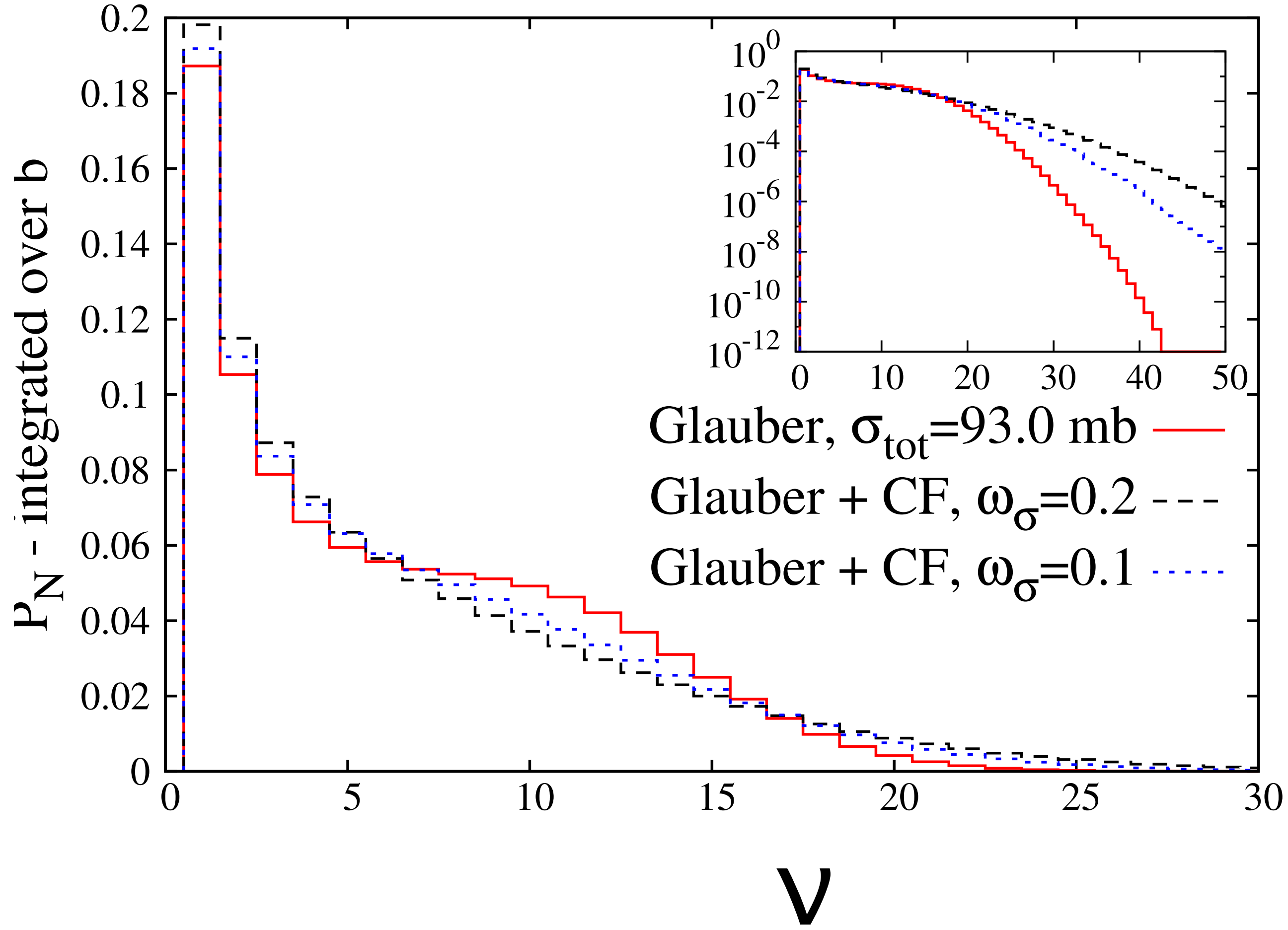


Probability of interaction with ν nucleons integrated over impact parameter b. CF *removes a knee at* $\nu \sim 10$ *and allows a nucleon like distribution on multiplicity in individual collisions in the fit to the multiplicity distributions . (B.Cole, 2014). Preferred value of variance of* $P_N(\sigma)$ *is* $\omega_\sigma=0.1$ *which is close to the LHC data.*

Hadron - nucleus collisions allow to study how □1D distribution (parton density) is correlated with the overall transverse size of the nucleon.

Tool: correlation between the hard (e.g. dijet with fixed x of proton) and soft components of pA interaction

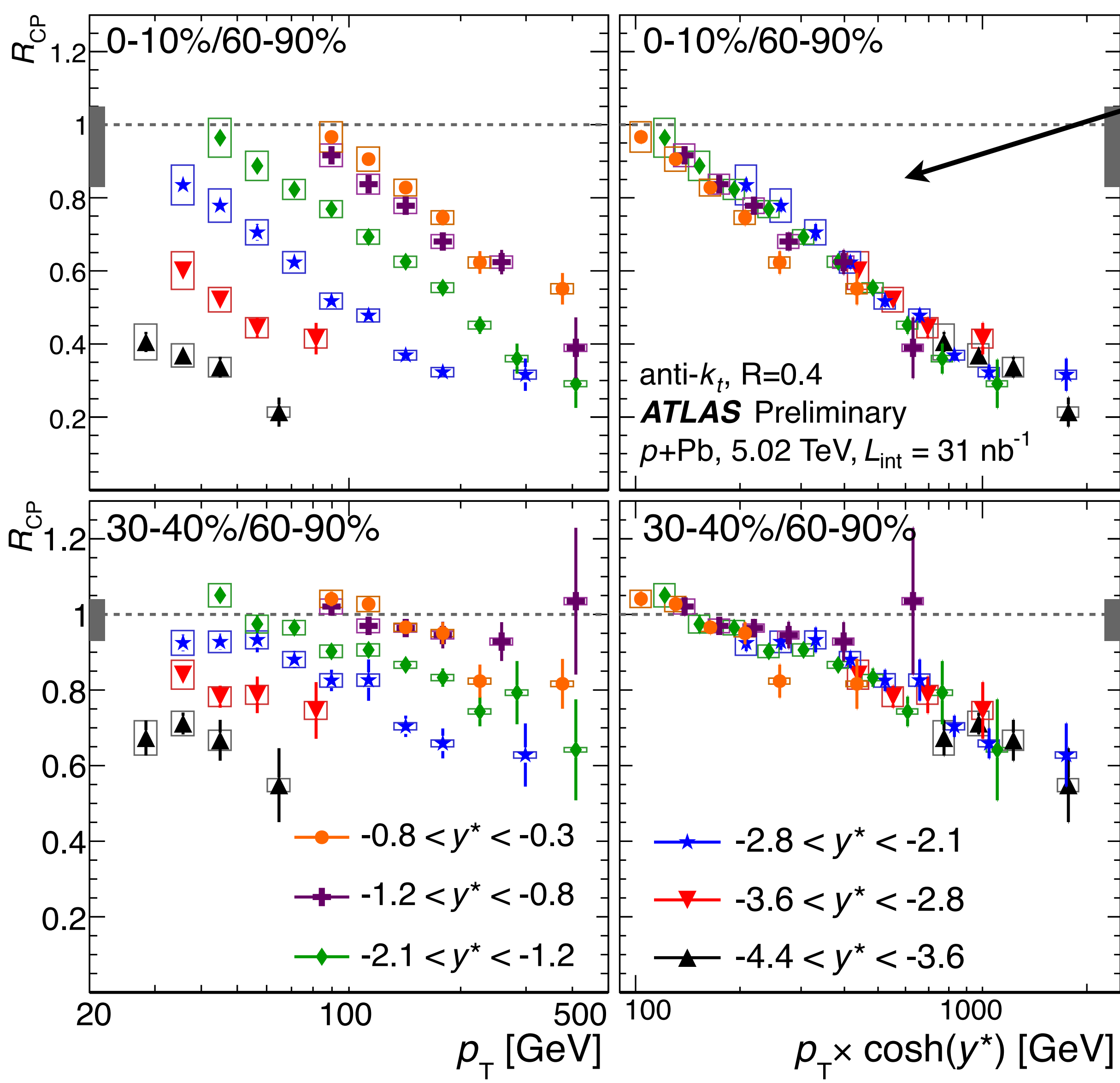
Expectation

Frankfurt&MS83

Configuration in nucleon with large xp quarks nucleon configurations should be more compact than average to suppress gluon fields and hence have $\sigma < \sigma_{inel}$

large x (x≳ 0.2 --0.3) → drop of # of wounded nucleons, central multiplicity.

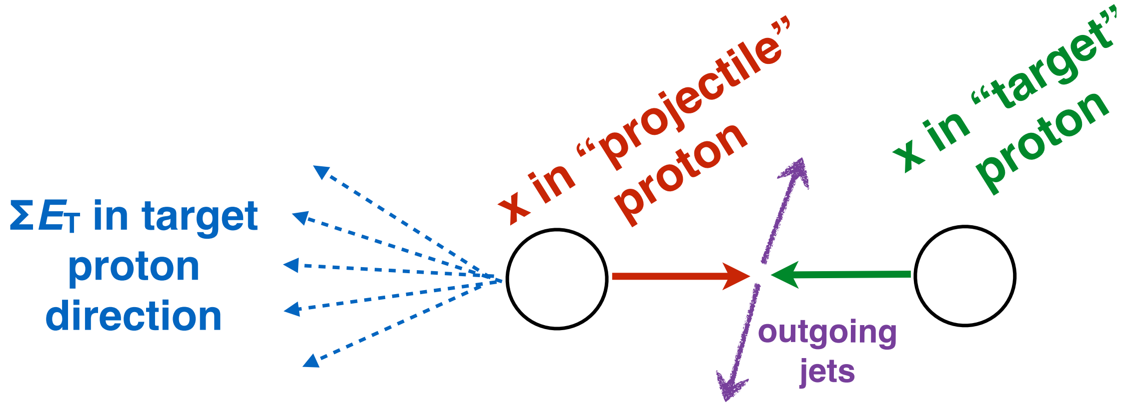
ATLAS & CMS studied dijet production in pA. Both observed that nuclear effects for inclusive observables are minor and consistent with nuclear pdfs. Strong function of centrality as estimated using E_T at negative rapidities. Deviations from Glauber are mainly function of x_q and not p_T. For large xq central collisions are suppressed & peripheral are enhanced. Consistent with large x_q quarks belonging to configrations with $\sigma < \sigma_{inel}$



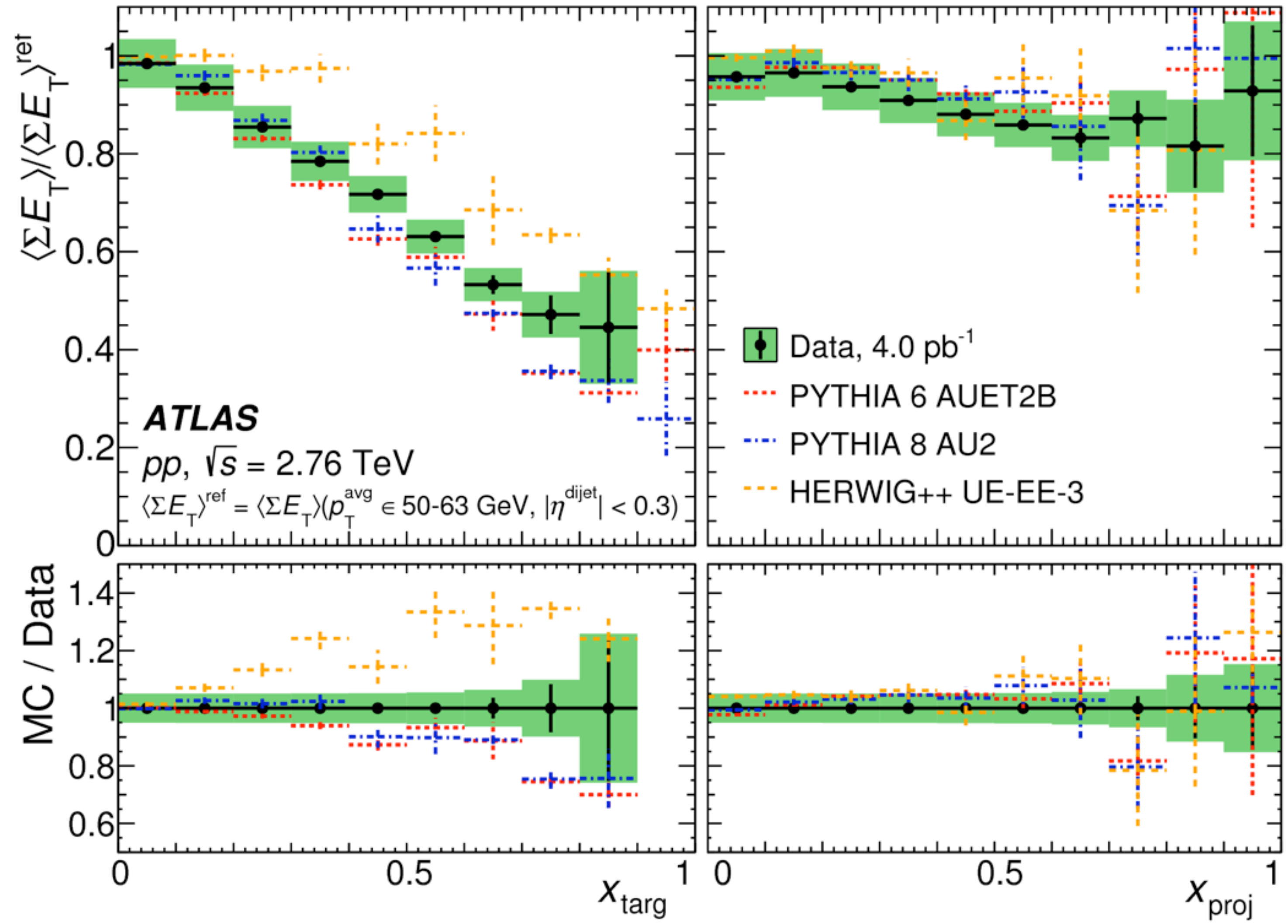
$x_q \sim 0.5$

R_{CP}, is a function of x of the quark.
No p_T dependence for fixed x

ATLAS, Phys. Lett. B 748 (2015) 392-413



Measure ΣE_T at large pseudorapidity vs.
x in the **projectile** proton (moving away)
x in the **target** proton (moving towards)



[ATLAS:Physics Letters B 756 (2016) 10-28]

➠Energy conservation local in rapidity ➔Justifies ATLAS 's model for centrality determination

We analyzed in 2014-2015 large x_p pA data (Alvioli, Cole Frankfurt, Perepelitsa , MS) arXiv:1409.7381 Recently we completed a global analyses of pPb ATLAS data and dAu PHENIX data (Alvioli, Frankfurt, Perepelitsa , MS **arXiv:1709.04993**

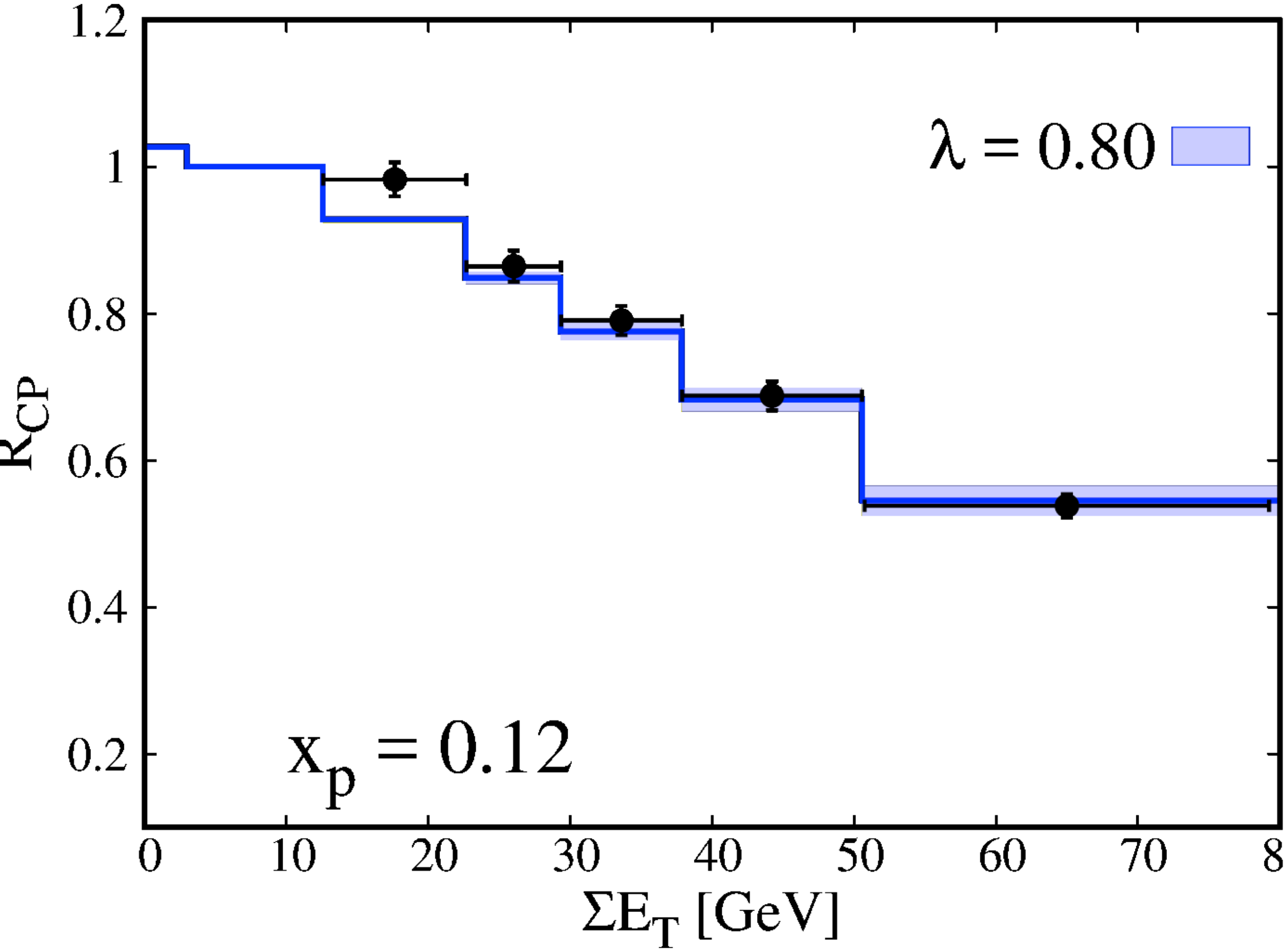
Ingredients: a) MC with realistic NN correlations, correct profile functions for inelastic NN interaction and for hard interactions,
b) Model for soft interactions (E_T distribution at negative rapidities for ATLAS, BBC charge PHENIX), c) one free parameter: ratio of cross section of interaction in MB x_p configuration and MB configuration

$$\lambda(x_p) = \left\langle \sigma_{NN}^{MB}(x_p) \right\rangle / \sigma_{NN}^{MB}$$

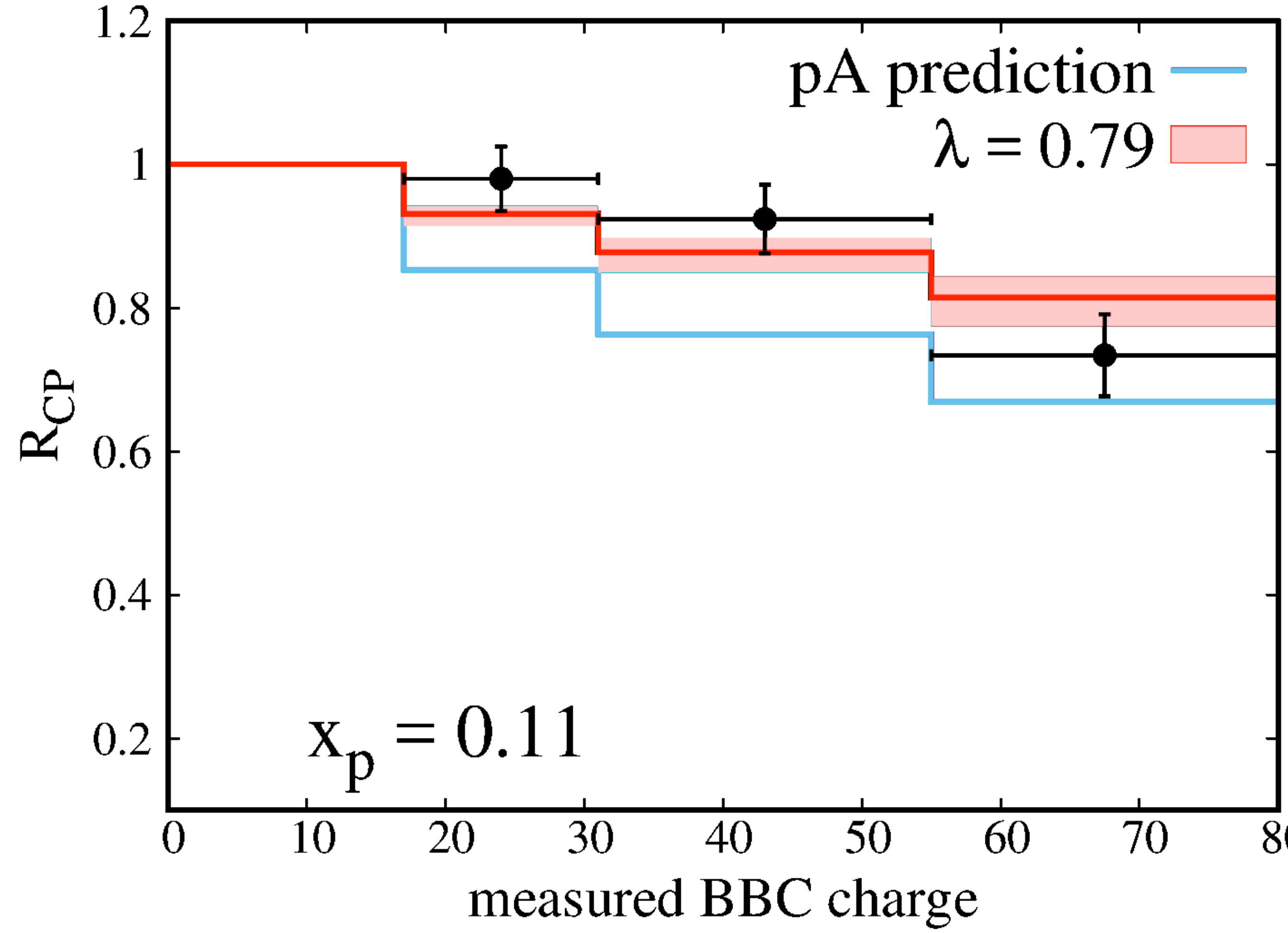
We calculate conditional (fixed x_p) R_{CP} normalizing to the most peripheral bin.

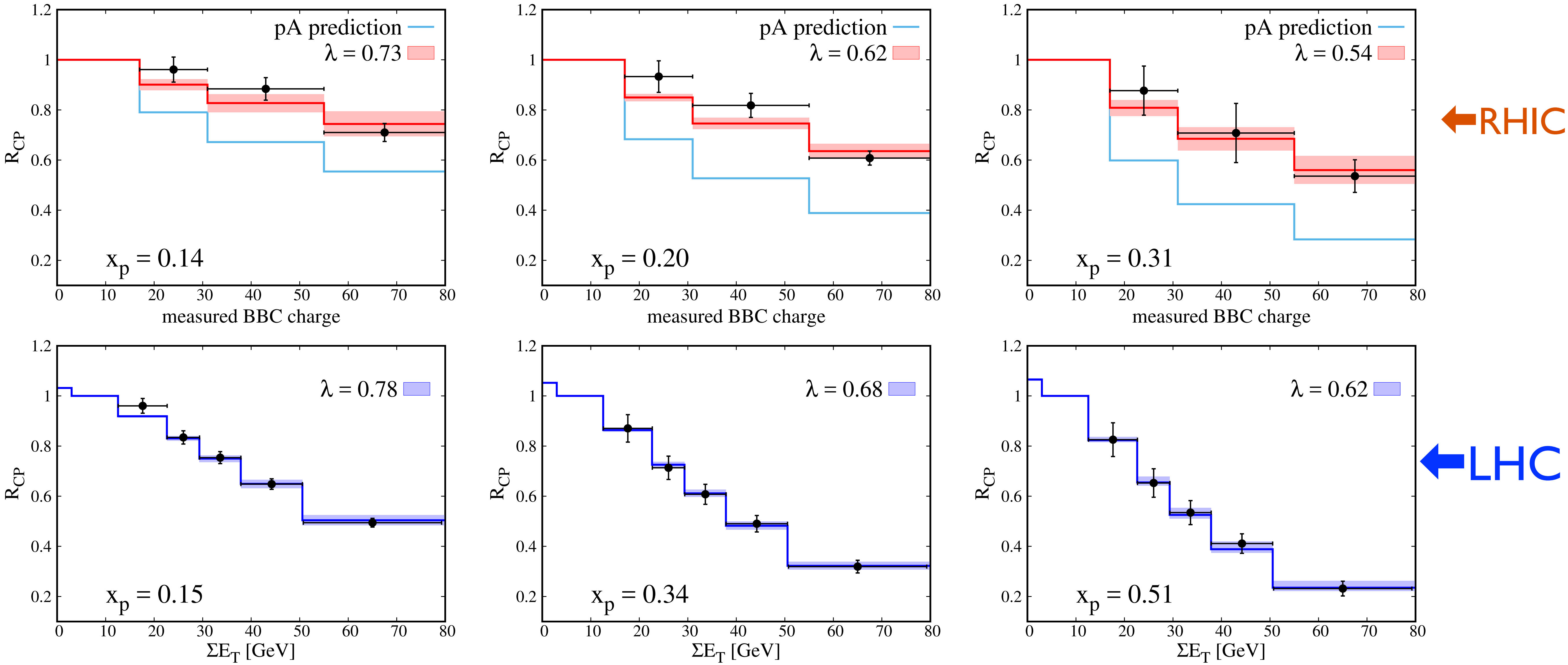
Since inclusive R_{CP} =1 we don't loose this way any information and reduce the experimental errors

LHC 10 x bins



RHIC 8 x bins

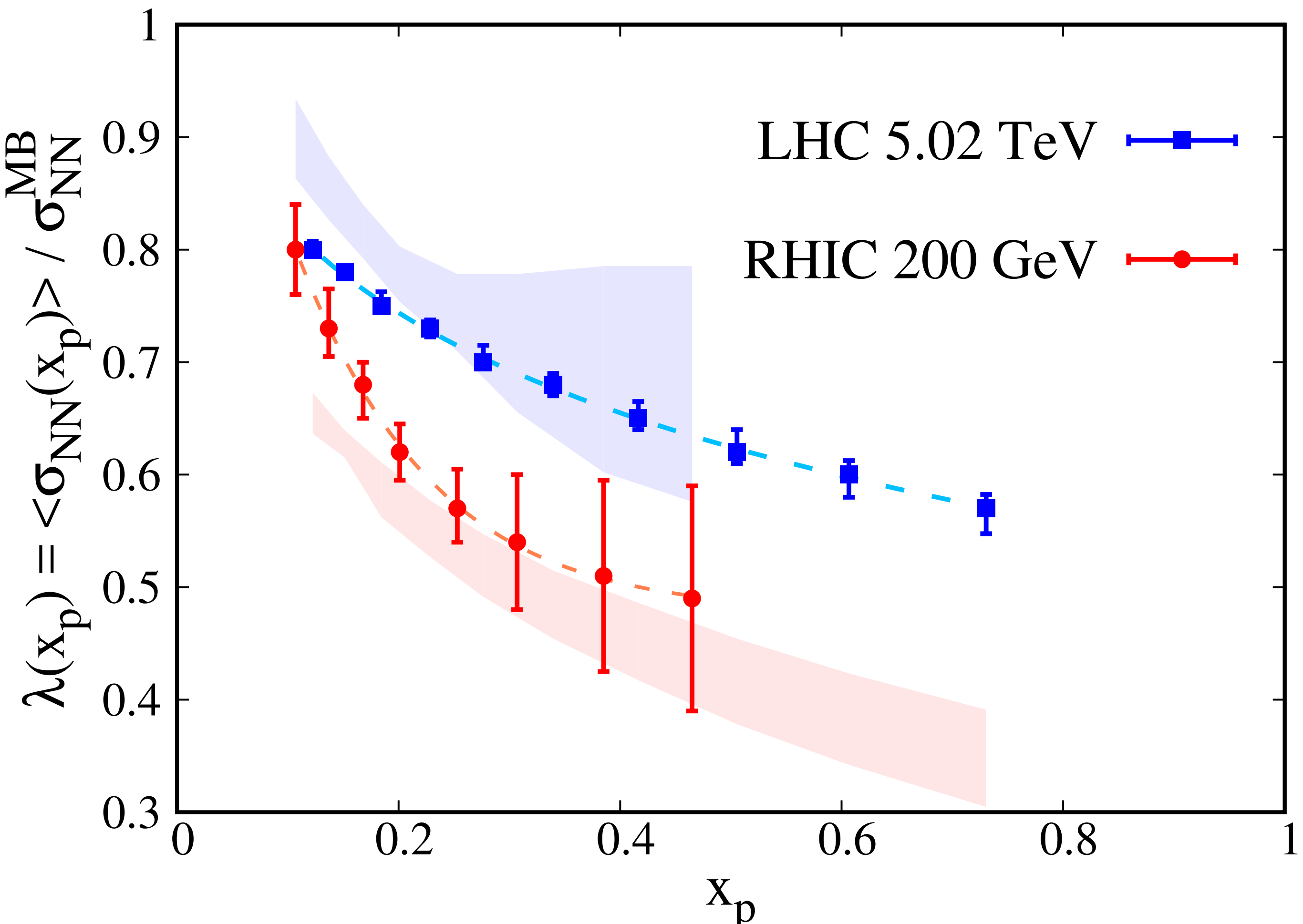




Sample of fits to the data

Implicit eqn for relation of $\lambda(x_p, s_1)$ and $\lambda(x_p, s_2)$

$$\int_0^{\lambda(x_p;\sqrt{s_1})\sigma_{tot}(\sqrt{s_1})} d\sigma\, P_N(\sigma;\sqrt{s_1}) = \int_0^{\lambda(x_p;\sqrt{s_2})\sigma_{tot}(\sqrt{s_2})} d\sigma\, P_N(\sigma;\sqrt{s_2})$$



HIghly nontrivial consistency check of interpretation of data at different energies and in different kinematics

suggests $\lambda(x_p=0.5, \text{low energy}) \sim 1/4$). Would naturally explain the EMC effect as due to suppression of small size configurations in bound nucleons (Frankfurt & MS83)

Future directions of experimental studies

- Tests of universality - different hard probes for same flavor and x - the same pattern of dependence on centrality (E_T)
- Measurement of λ separately for gluons and quarks
- looking for $\lambda>1$ for small x
- Promising channels: photon + jet, Z-boson: centrality change of jet shape (broader for gluon jets)
- Centrality studies in UPC = γA & γp

A new frontier : Color fluctuations in photons via ultraperipheral (γA) collisions

Photon is a chameleon -often e.m. photon, sometimes looks as a vector meson (VM) , sometimes as small dipole - hence huge CFs.

$$|\gamma_{phys}\rangle = |\gamma_{e.m.}\rangle + \alpha\left(|VM\rangle + |q\bar{q}(\text{small dipoles and aligned jets})\rangle\right)$$

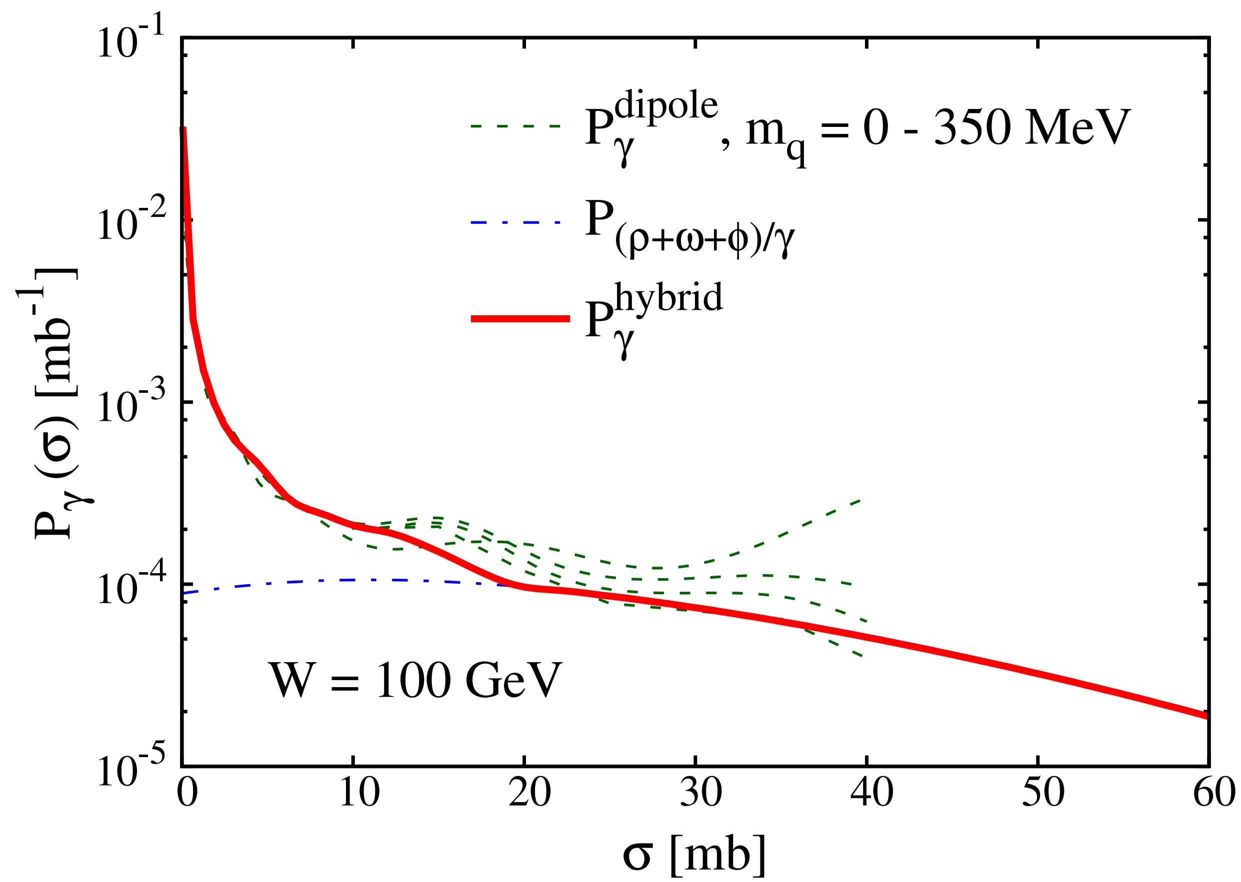
First model of P_γ (σ)   Alvioli, Guzey, Frankfurt, MS, Zhalov, 2016

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

analysis of the LHC $\gamma Pb \to \rho$ Pb which indicate large CFs (Glauber is off by factor ~2)

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

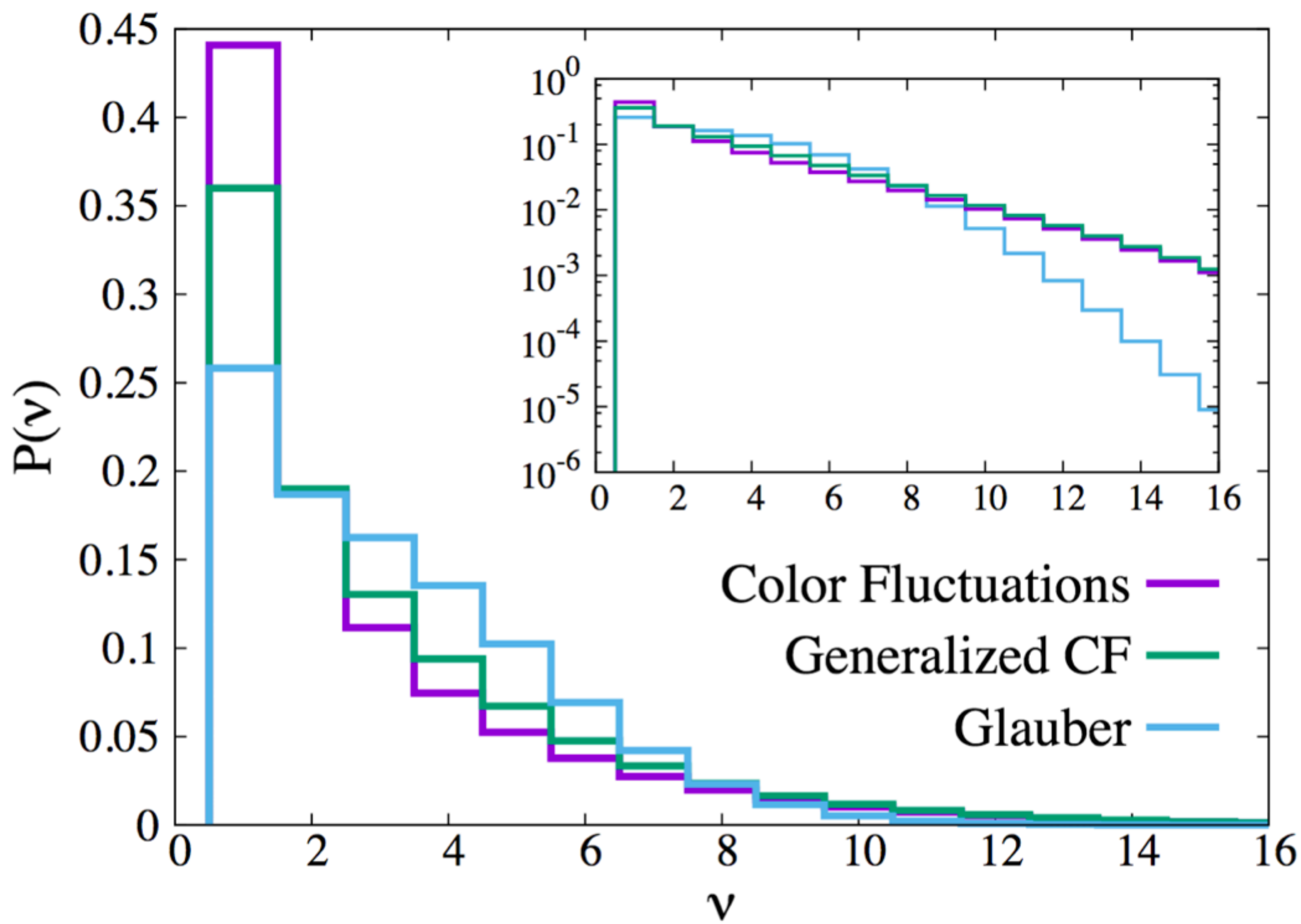
$$\sigma(d,x) = \frac{\pi^2}{3}\alpha_s(Q^2_{eff})d^2xG_N(x,Q^2_{eff})$$



- Smooth interpolation in between with m_q~ 300 MeV

Calculation of distribution over the number of wounded nucleons

- CF model (like for pA)
- Generalized CF model (accounting for LT shadowing for small dipoles



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

Photon scans:

- Inclusive γA: Huge dynamical range : 50 GeV < $W_{\gamma N}$ < 500 GeV

  Increase of shadowing/ decrease of $\nu=1$ fraction with W increase

- $x_\gamma=1$ (direct photon) dijet production

  from $x_A=0.01$ - no shadowing, $\nu=1$

  to $x_A=0.0003$ - shadowing, $\langle\nu\rangle=2$

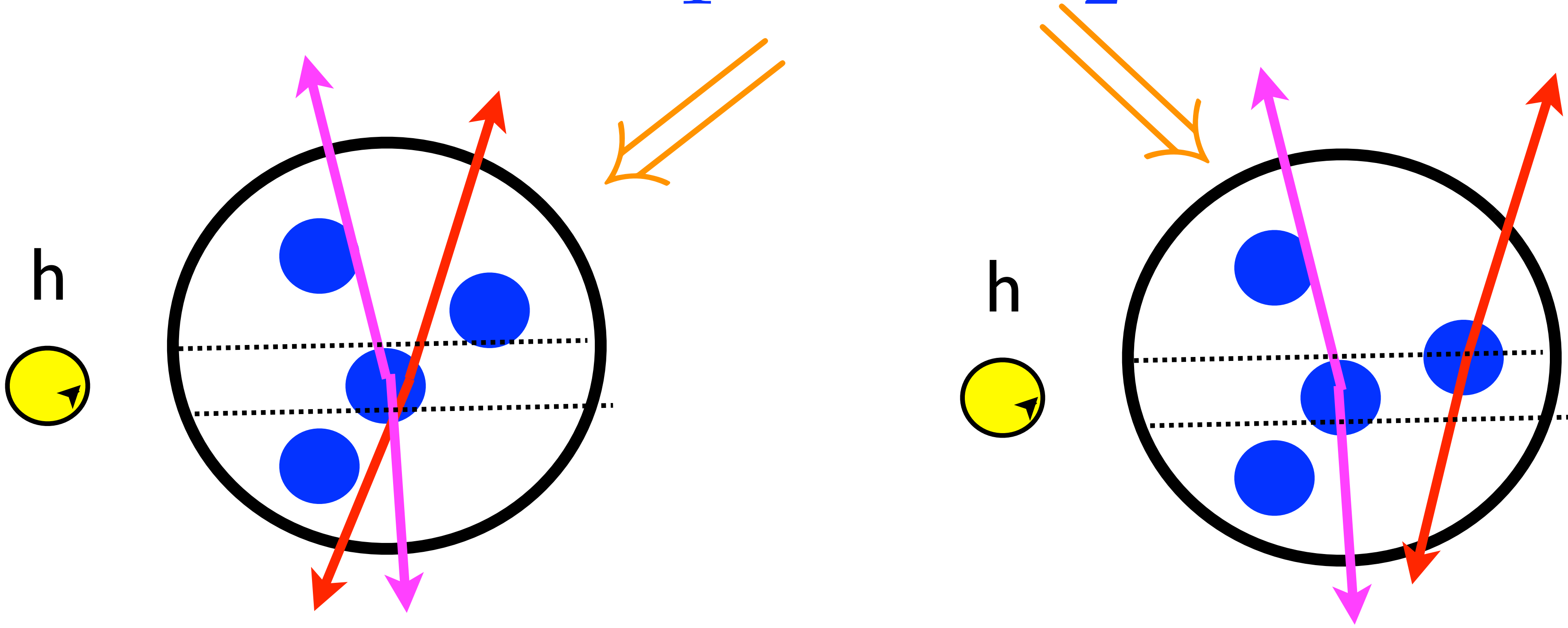
- scan from $x_\gamma=1$ to $x_\gamma=0.2$: from $\nu=1$ to $\langle\nu\rangle=3$

  transverse size of photon as a function of x_γ

DPS in pA - tool to observe DPS, and probe nucleon structrue

MS & Treleani 95 - PRL 2002

$$\sigma = \sigma_1 \cdot A + \sigma_2$$



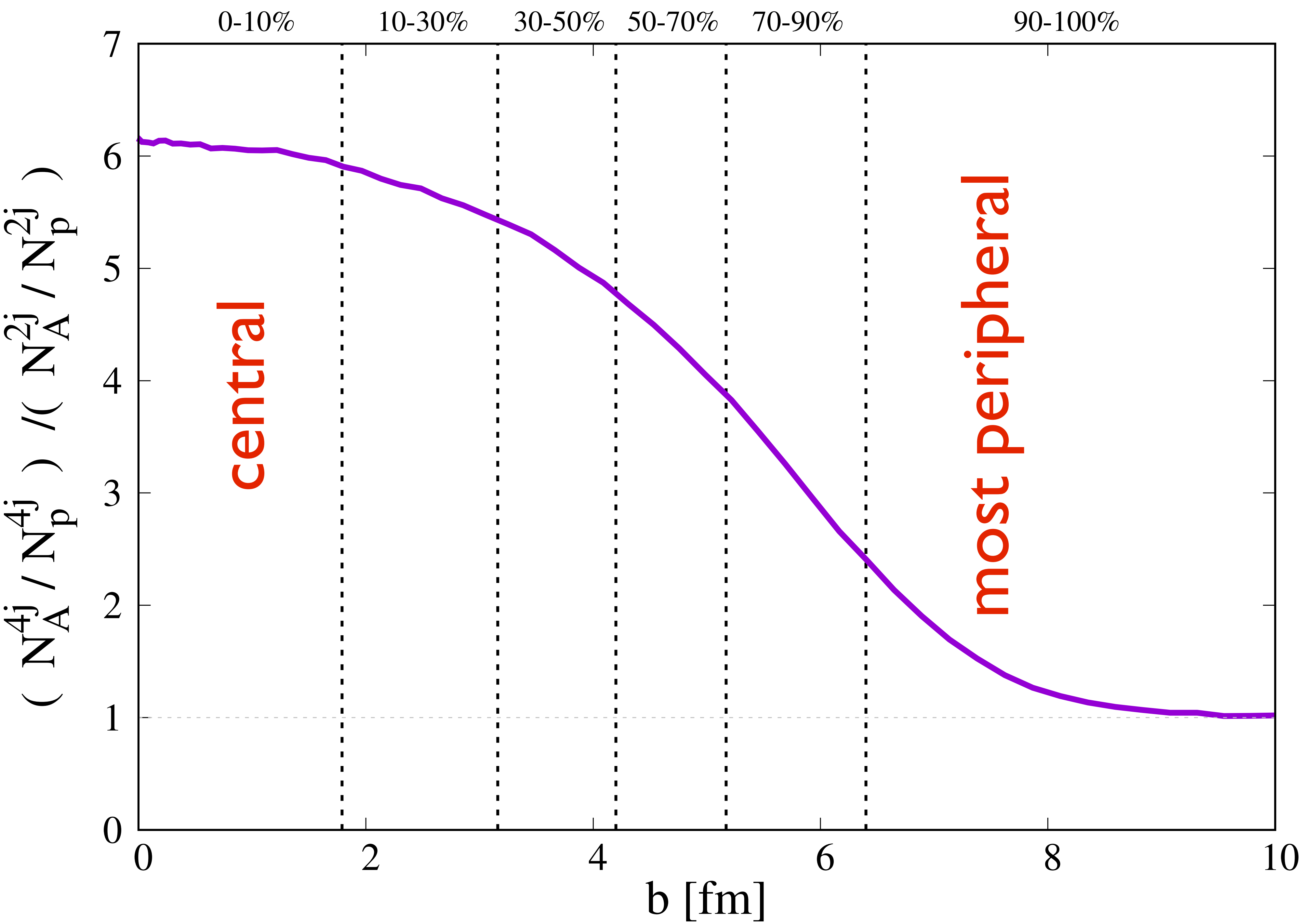
$$R \equiv \frac{\sigma_2}{\sigma_1 \cdot A} \approx \frac{(A-1)}{A^2} \cdot \sigma_{eff} \int T^2(b)\ d^2b \approx 1.0 \cdot \left(\frac{A}{12}\right)^{0.39} \Big|_{A \geq 12, \sigma_{eff} \sim 20mb}$$

$$T(b) = \int_{-\infty}^{\infty} dz \rho_A(z,b), \int T(b) d^2b = A.$$

"Antishadowing effect": For A=200, and σ_{eff}=20 mb, R=4.0. QCD ievolution induced correlation enhance R by ~a factor 1.2

Blok, MS , Wiedemann 2013: QCD analysis - small correction to the parton model result

$$\frac{\left.\frac{DPS(b)}{SPS(b)}\right._A}{\left.\frac{DPS}{SPS}\right._p}$$



Alvioli & MS

Strategy for observing DPS: consider build double ratios :of the rate of candidate DPS events and SPS events in central and peripheral collisions. Expect - a fast increase of the ratio with centrality since all competing 2 --> 4 processes are linear in T(b)..

Next step would be centrality for DPS

Example: Find out how nucleon overall size changes if $x_1 + x_2 > 0.5$

Summary

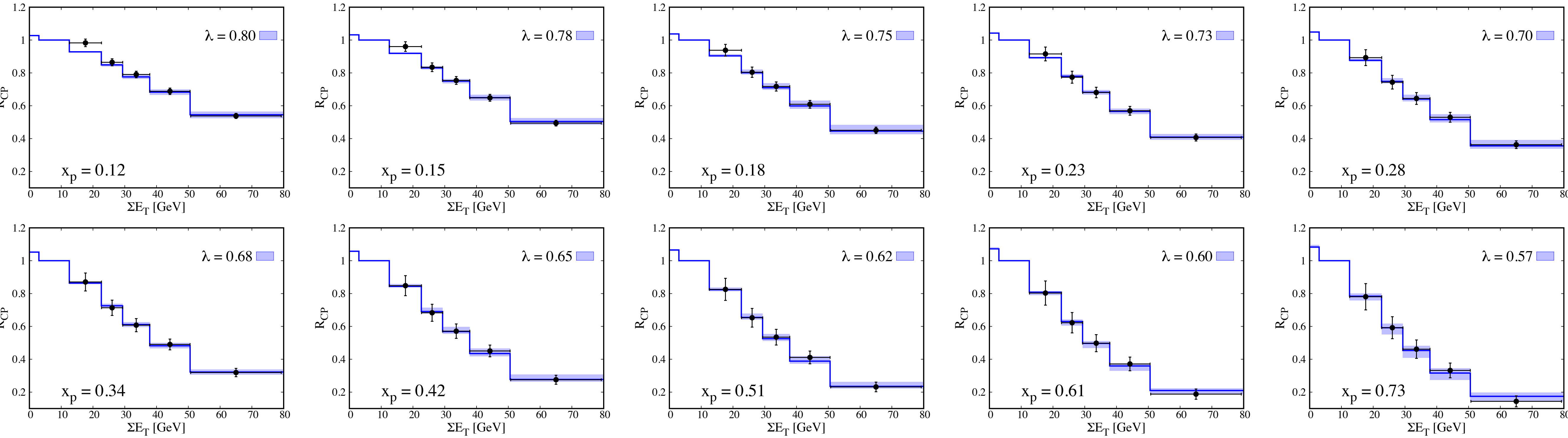
- Jet production at RHIC and LHC produced first glimpse of the global quark - gluon structure of nucleons as a function of x. Nucleon becomes smaller at large x. Interact weaker than in average, but faster grows with energy. Need to separate gluons and quarks in hard processes at x ~0.1.

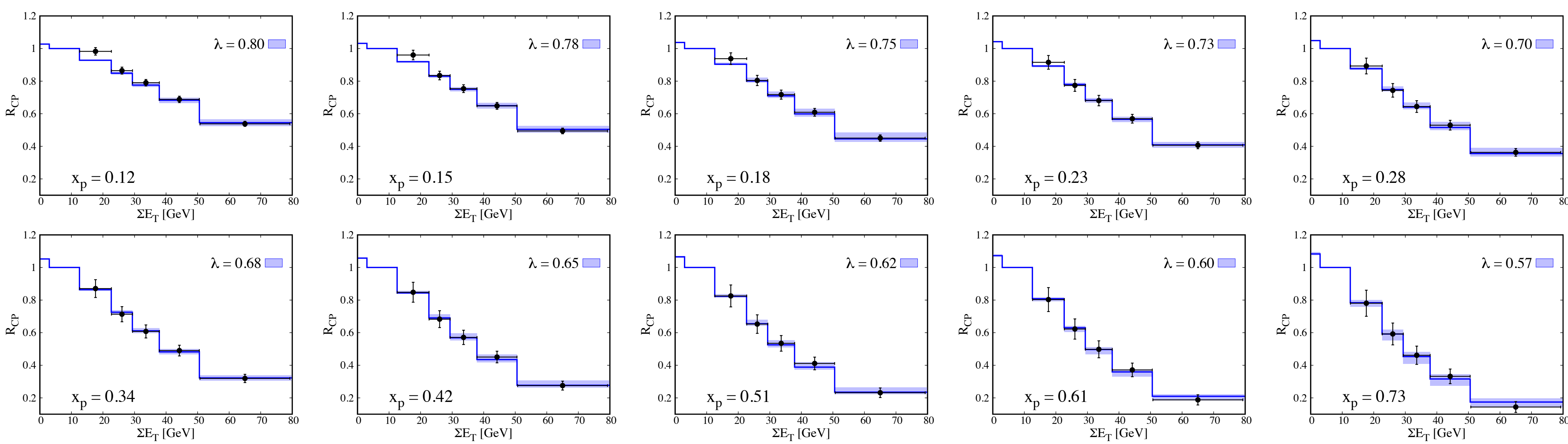
- Color fluctuations are a regular feature of high energy nucleon, photon collisions... Effects in very central AA collisions are present.

- Nontrivial link between nuclear DIS (EMC effect), and centrality jet physics in pA. Strong discriminator of the models of the EMC effect. Link to physics of the cores of neutron stars.

- DPS in pA is strongly enhanced especially in central collisions - new stratagy for observing DPS

LHC


λ = 0.80
x_p = 0.12
λ = 0.78
x_p = 0.15
λ = 0.75
x_p = 0.18
λ = 0.73
x_p = 0.23
λ = 0.70
x_p = 0.28
λ = 0.68
x_p = 0.34
λ = 0.65
x_p = 0.42
λ = 0.62
x_p = 0.51
λ = 0.60
x_p = 0.61
λ = 0.57
x_p = 0.73
R_CP
ΣE_T [GeV]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R_CP
ΣE_T [GeV]

RHIC