eA Physics @ eRHIC

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DIS highlights

- Bjorken scaling: the parton model.
- Scaling violations: QCD- asymptotic freedom, renormalization group; precision tests of pQCD.
- Rapid growth of gluon density at small x, significant hard diffraction.
- Measurement of polarized structure functions: scaling violations, the “spin crisis”.
- QCD in media:EMC effect, shadowing,color transparency,…

Principal physics goals of eRHIC

Extend DIS Paradigm for quantitative QCD studies in largely ``terra incognita" small x-large Q^2 regime

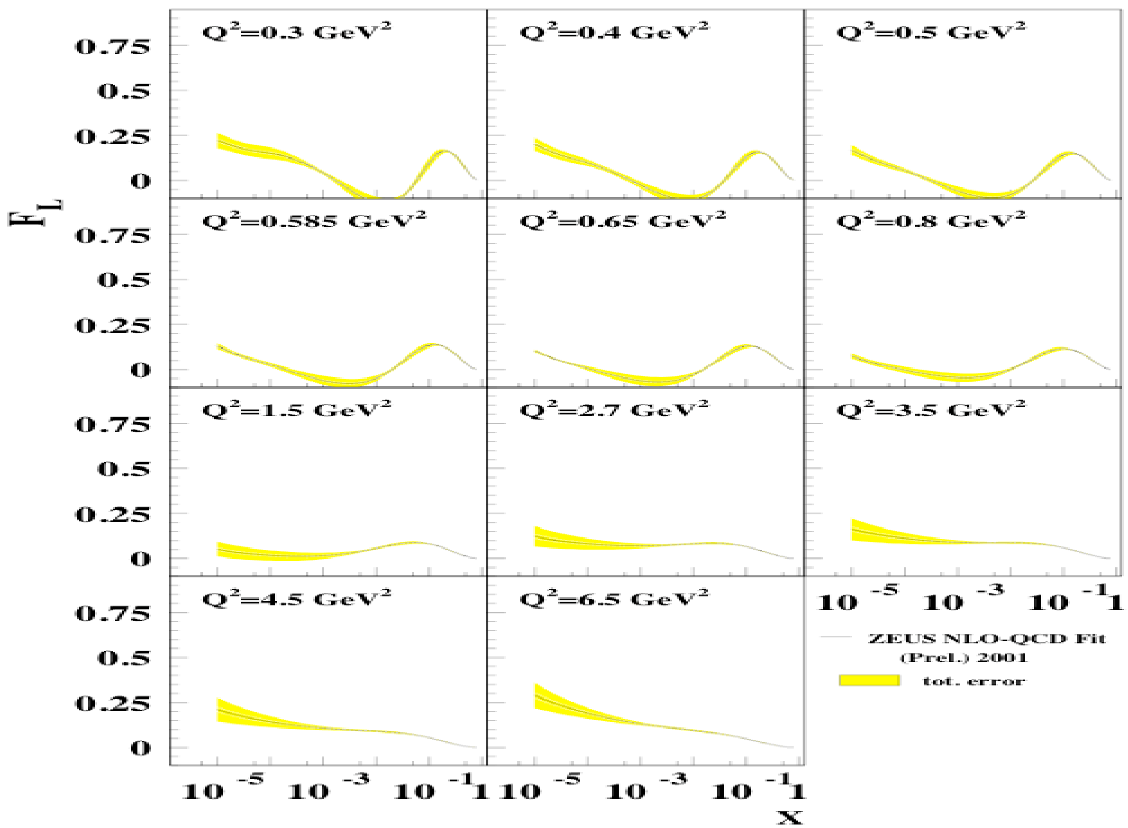
Three pronged approach

- **High luminosity (~100 times HERA) unpolarized e-p scattering**
- **Polarized e-pol. P - highest energies and collider mode for the first time**
- **First eA collider - detailed map of QCD in nuclear media & very high parton densities.**

Why is unpolarized ep/eA scattering at small x interesting ?

- Measure several observables (F_L, G_A, F_{diff,A},…) in wide kinematic region for the first time

- Corroborate or disprove novel QCD based ideas about the structure of hadrons at small x
  - these ideas have predictive power for above stated observables
  - and for our interpretation of P/D-A and A-A collisions at high energies.

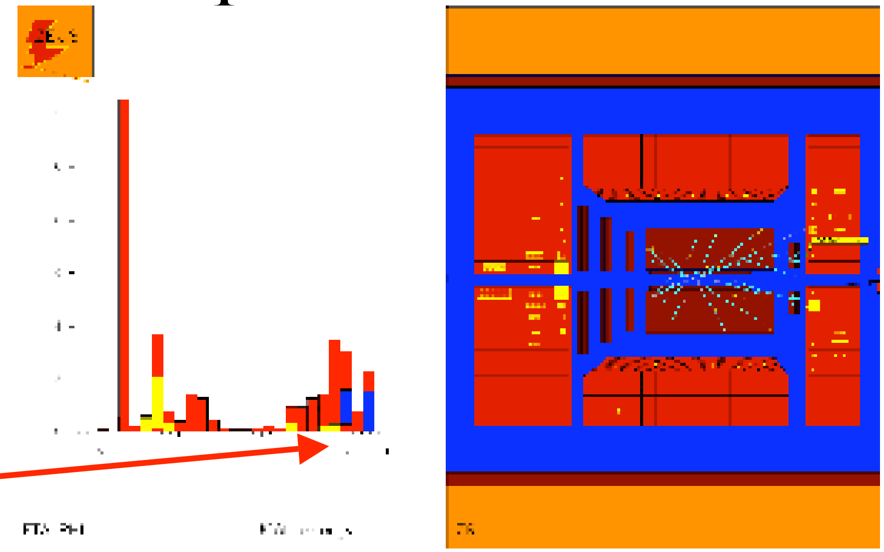


$$F_L \propto \alpha_S \, x \, G(x, Q^2)$$

F_L is a positive definite quantity- more sensitive to higher twists than F_2 ?
- clarify comparision with leading twist NLO pQCD at low x and moderate Q^2

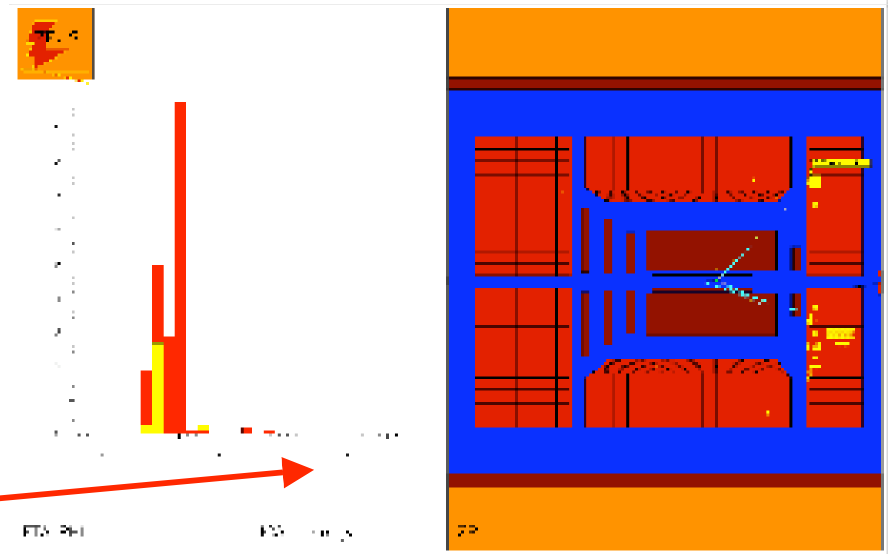
Diffractive Surprises

‘Standard DIS event’



Detector activity in proton direction

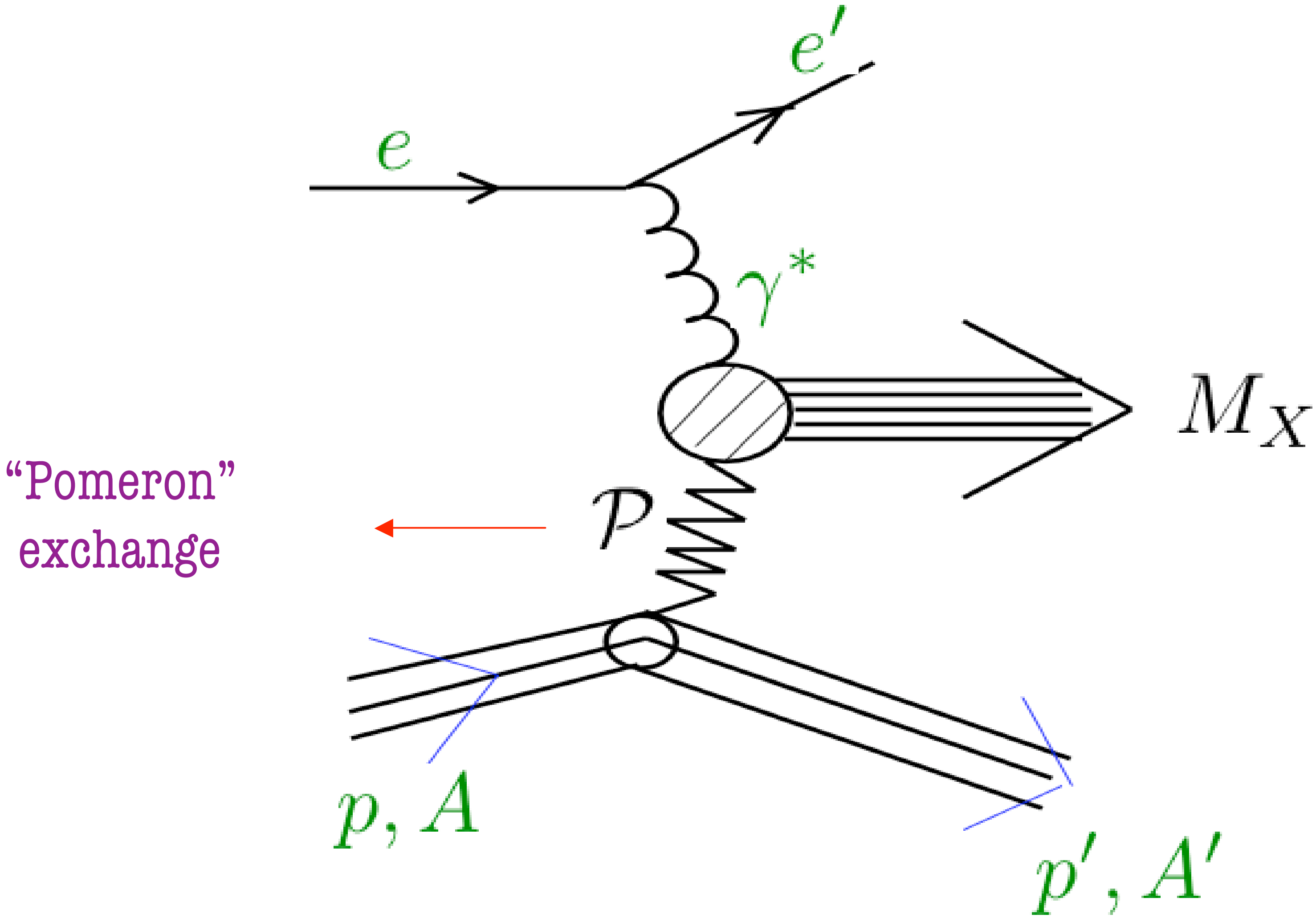
Diffractive event



No activity in proton direction

APPROXIMATE 10% OF EVENTS ARE HARD DIFFRACTIVE EVENTS!

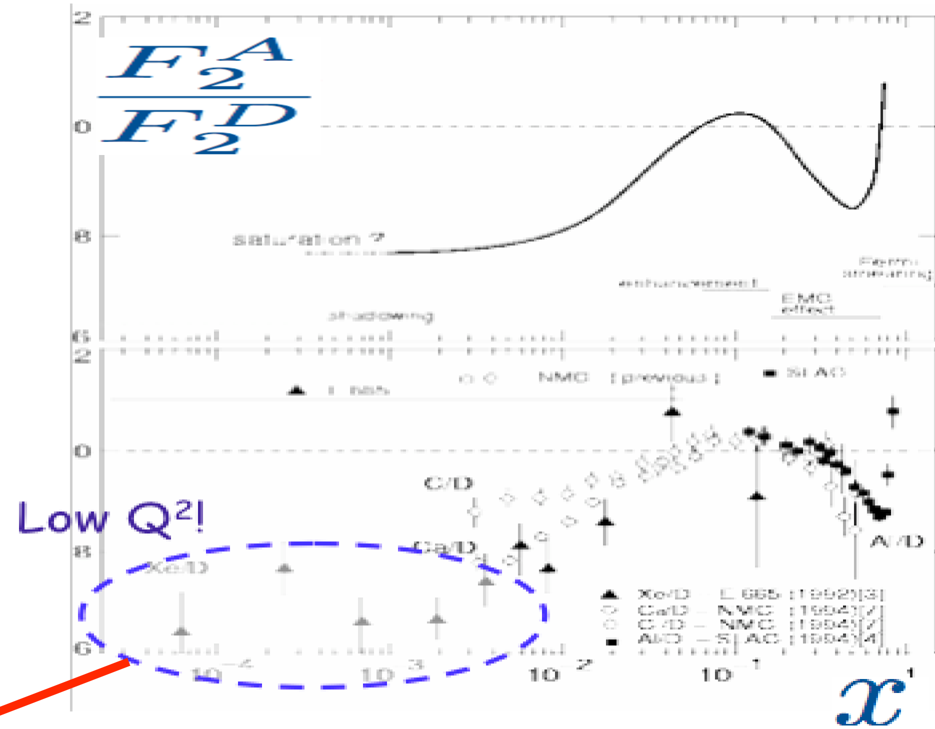
III: Hard diffractive processes



30 % of eRHIC eA events may be hard diffractive events-
Study sizes and distributions of Rapidity Gaps

ELECTRON-NUCLEUS SCATTERING

QUANTITATIVE STUDIES OF QCD MEDIA IN COLLIDER ENVIRONMENT

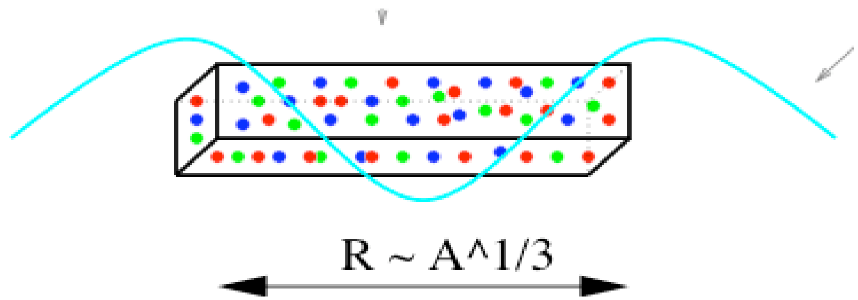


Shadowing: eRHIC will have data with very high statistical accuracy at significantly higher Q^2

Extract $F_2^A \; ; G^A(X, Q^2) \propto \frac{\partial F_2^A}{\partial \ln Q^2} \; ; F_L^A(x, Q^2)$ **for light & heavy nuclei for** $Q^2 \approx 10\, Q^2_{\rm fixed target}$ **at fixed small x**

Virtual photon coherence length:

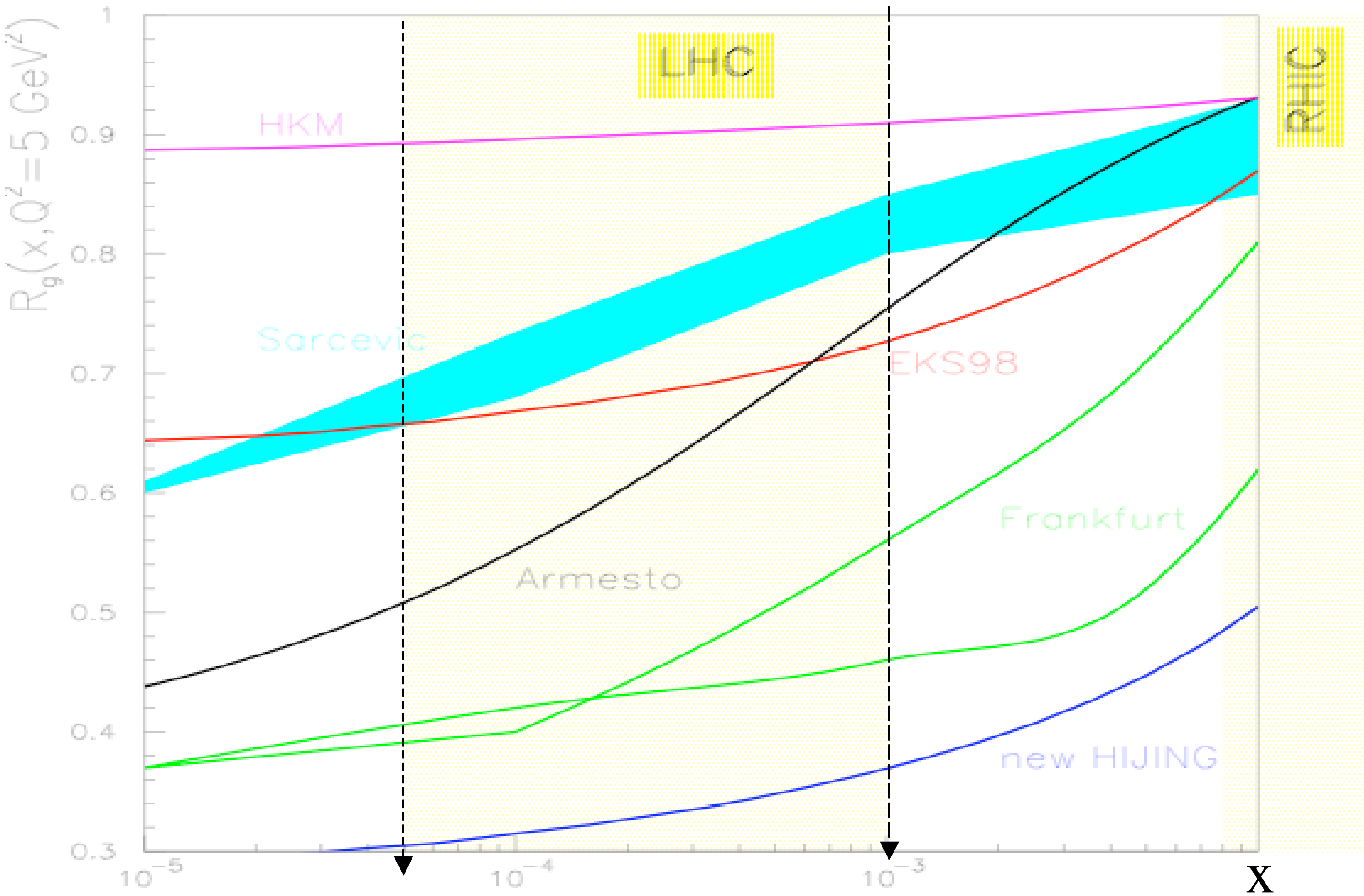
$$l_{\mathrm{coh.}} \propto 1/(2m_n\, x)$$



- x_Bj << 0.01 : Photon coherence length exceeds nuclear size
- 0.01 < x_Bj < 0.1: Intermediate length scale between R_p

  & R_A
- x_Bj >> 0.1: Photon localized to longitudinal size smaller than nucleon size

Ratio of Gluon densities in Lead to Proton at $Q^2 = 5\,\mathrm{GeV}^2$
in x range $10^{-2} - 10^{-5}$



Factor 3 uncertainity in glue => Factor 9 uncertainity in Semi-hard HI-parton cross-sections at LHC!

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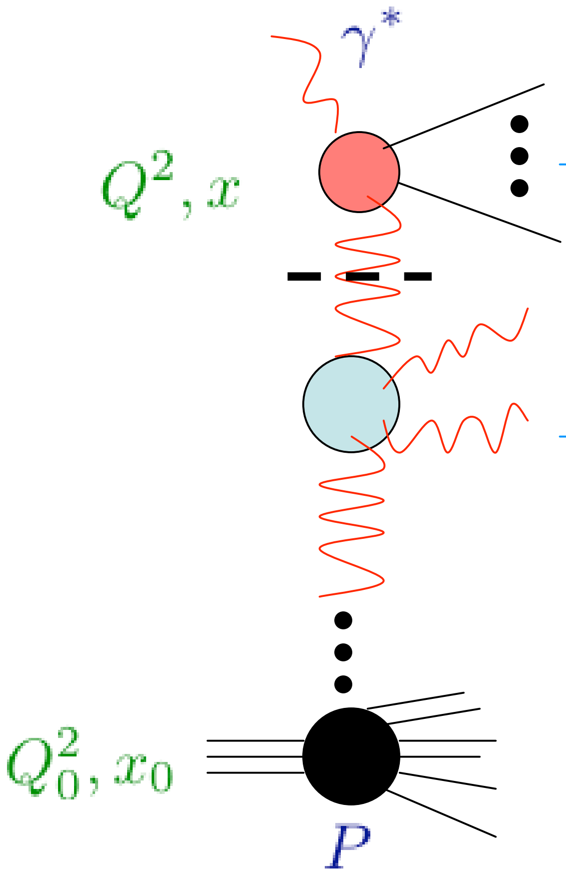
STRUCTURE OF HIGHER ORDER CONTRIBUTIONS IN DIS



$$C_2(x, \alpha_S) = \delta(1-x) + \alpha_S C_2^{(1)}(x) + \alpha_S^2 C_2^{(2)} + \cdots$$

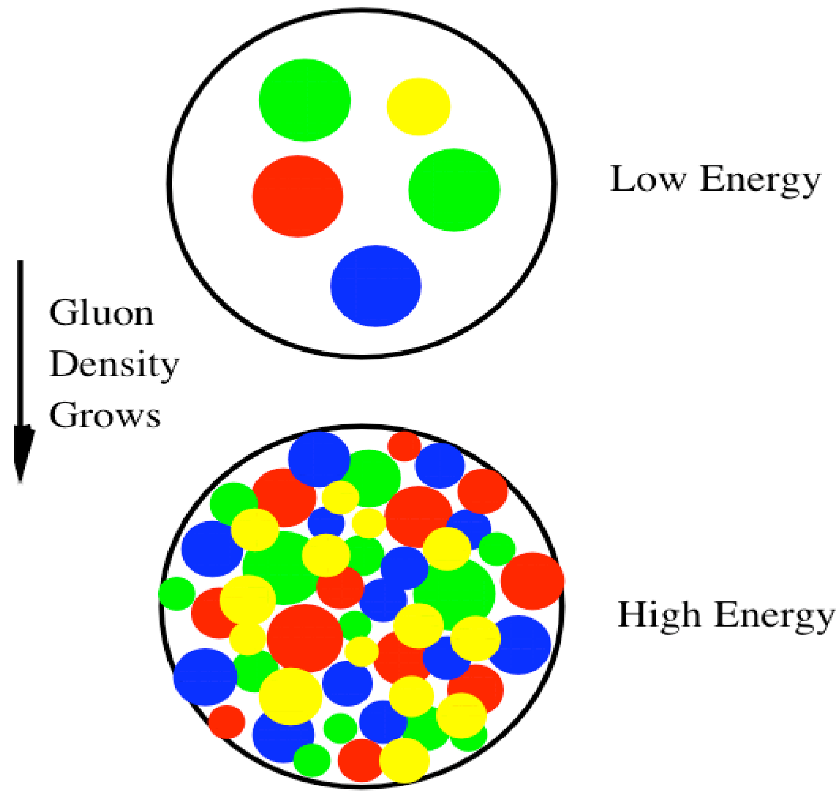
$$\alpha_S P^{(1)} + \alpha_S^2 P^{(2)} + \cdots$$

+ *higher twist (power suppressed) contributions…*

- Coefficient functions - C - computed to NNLO for many processes, e.g., gg -> H Harlander, Kilgore; Ravindran, Van Neerven, Smith; …
- Splitting functions -P - computed to 3-loops recently! Moch, Vermaseren, Vogt

Resolving the hadron in the Regge-Gribov limit

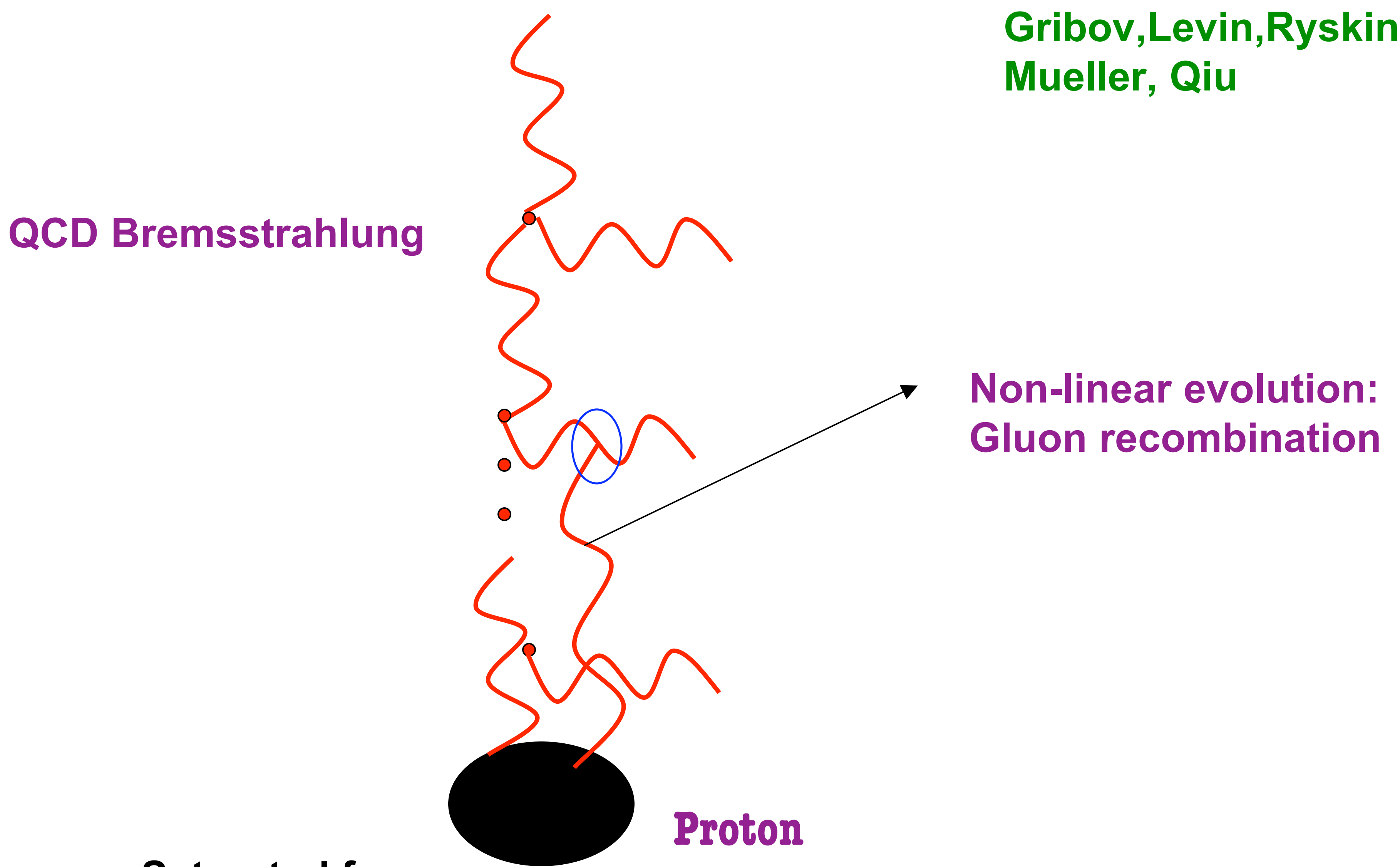
$$x_{Bj} \to 0;\ s \to \infty;\ Q^2 (>> \Lambda^2_{QCD}) = \text{fixed}$$



- Large x

- Small x

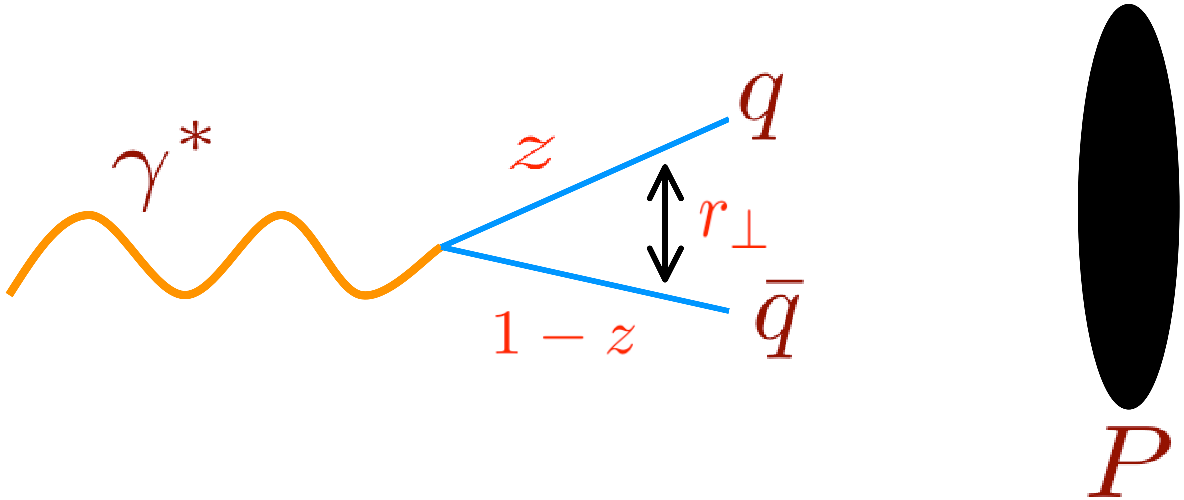
Gluon density saturates at f= $\dfrac{1}{\alpha_S}$



Saturated for

$$Q = Q_s(x) >> \Lambda_{\mathrm{QCD}} \approx 0.2 \ \mathrm{GeV}$$

Golec-Biernat & Wusthoff's model



$$\sigma_{\mathrm{T,L}}^{\gamma^*,P} = \int d^2 r_\perp \int dz\, |\psi_{\mathrm{T,L}}(r_\perp, z, Q^2)|^2\, \sigma_{q,\bar{q},P}(r_\perp, x)$$

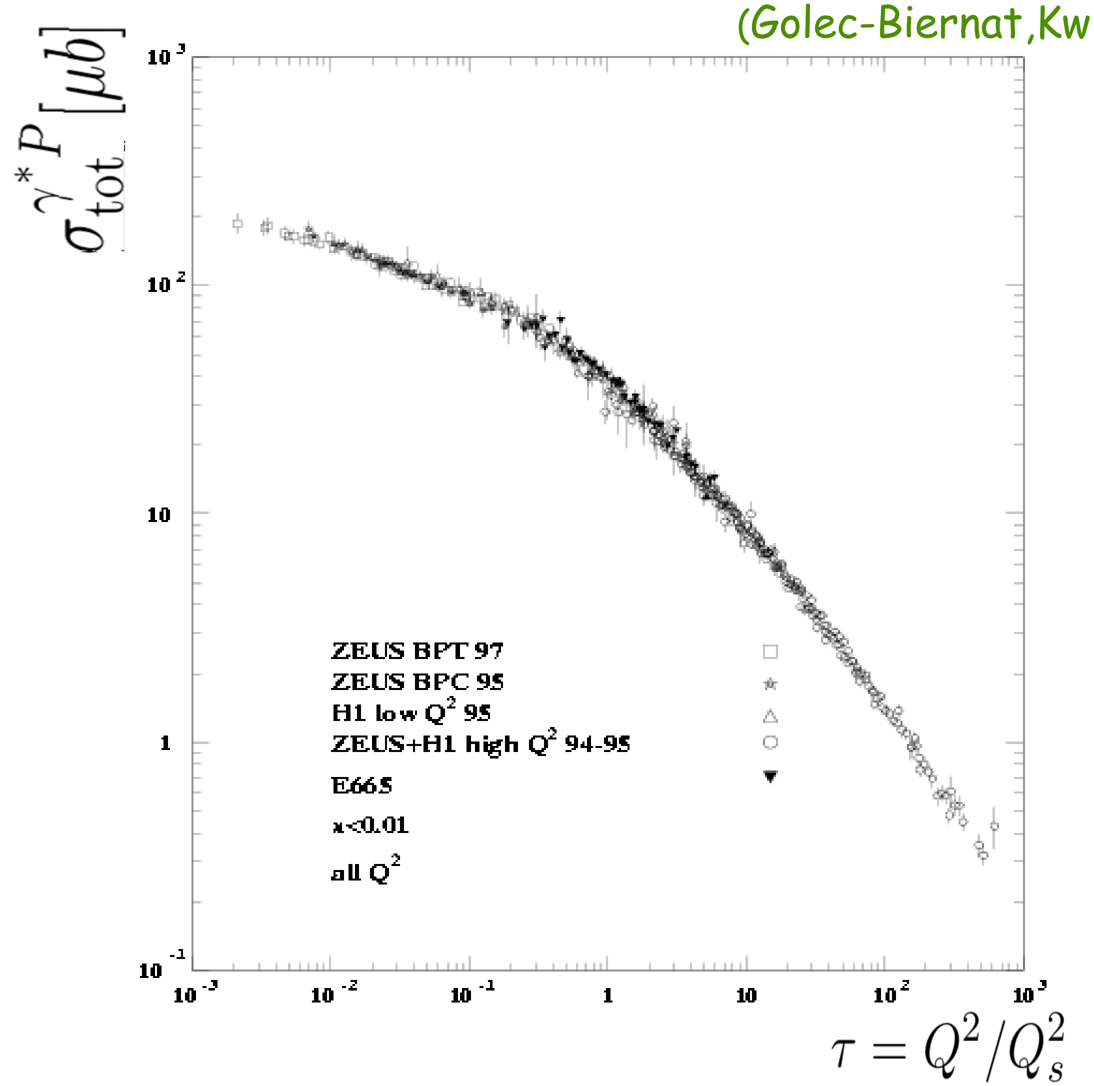
where $\sigma_{q\bar{q}P}(r_\perp, x) = \sigma_0 \left[1 - \exp\left(-r_\perp^2\, Q_s^2(x)\right)\right]$

& $$Q_s^2(x) = Q_0^2 \left(\frac{x_0}{x}\right)^\lambda$$

Parameters: $Q_0 = 1\,\mathrm{GeV}\,;\, \lambda = 0.3\,;\, x_0 = 3 \cdot 10^{-4}$

Geometrical scaling at HERA

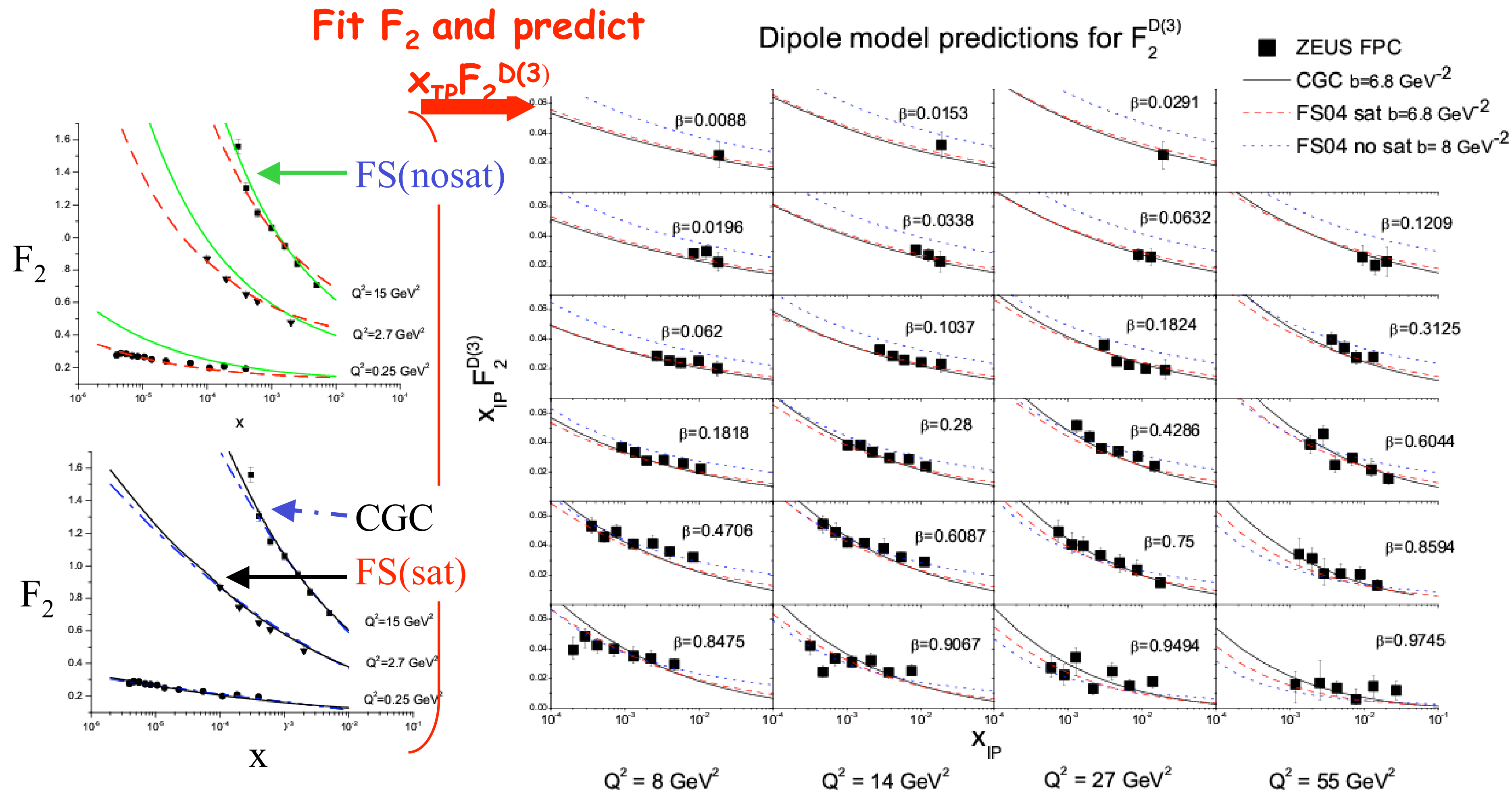
(Golec-Biernat,Kwiecinski,Stasto)



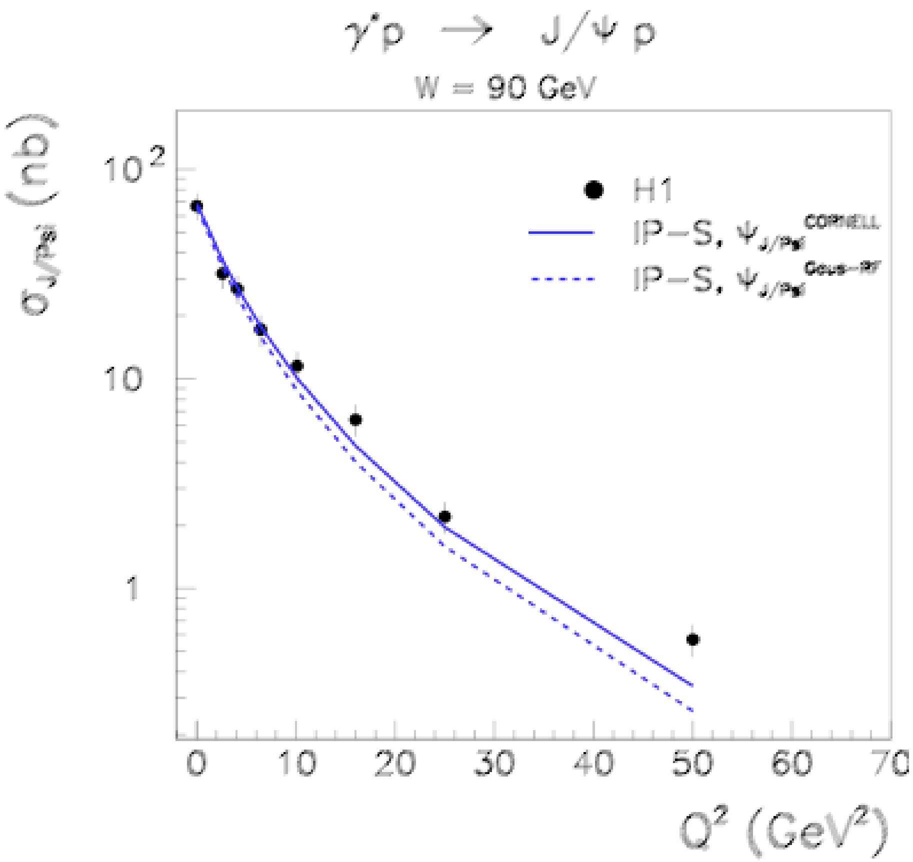
Scaling seen for all x < 0.01 and $0.045 < Q^2 < 450\,\mathrm{GeV}^2$

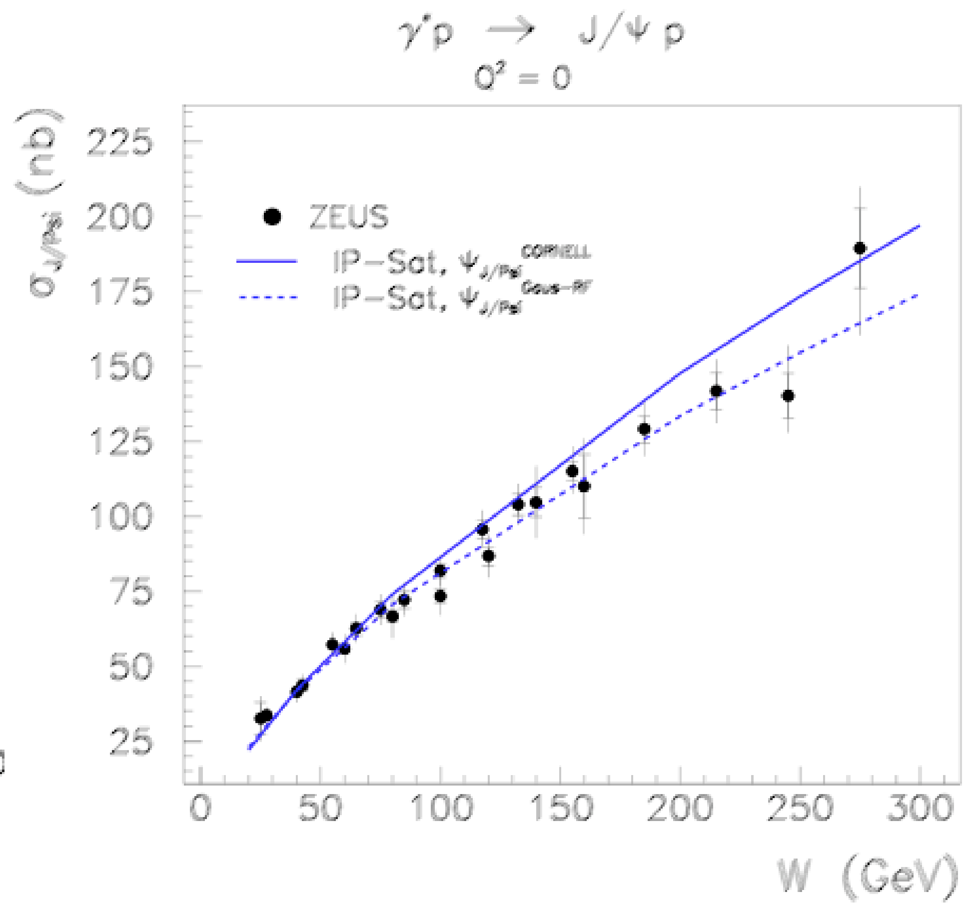
Comparison with Data

FS model with/without saturation and **IIM CGC model**
hep-ph/0411337.



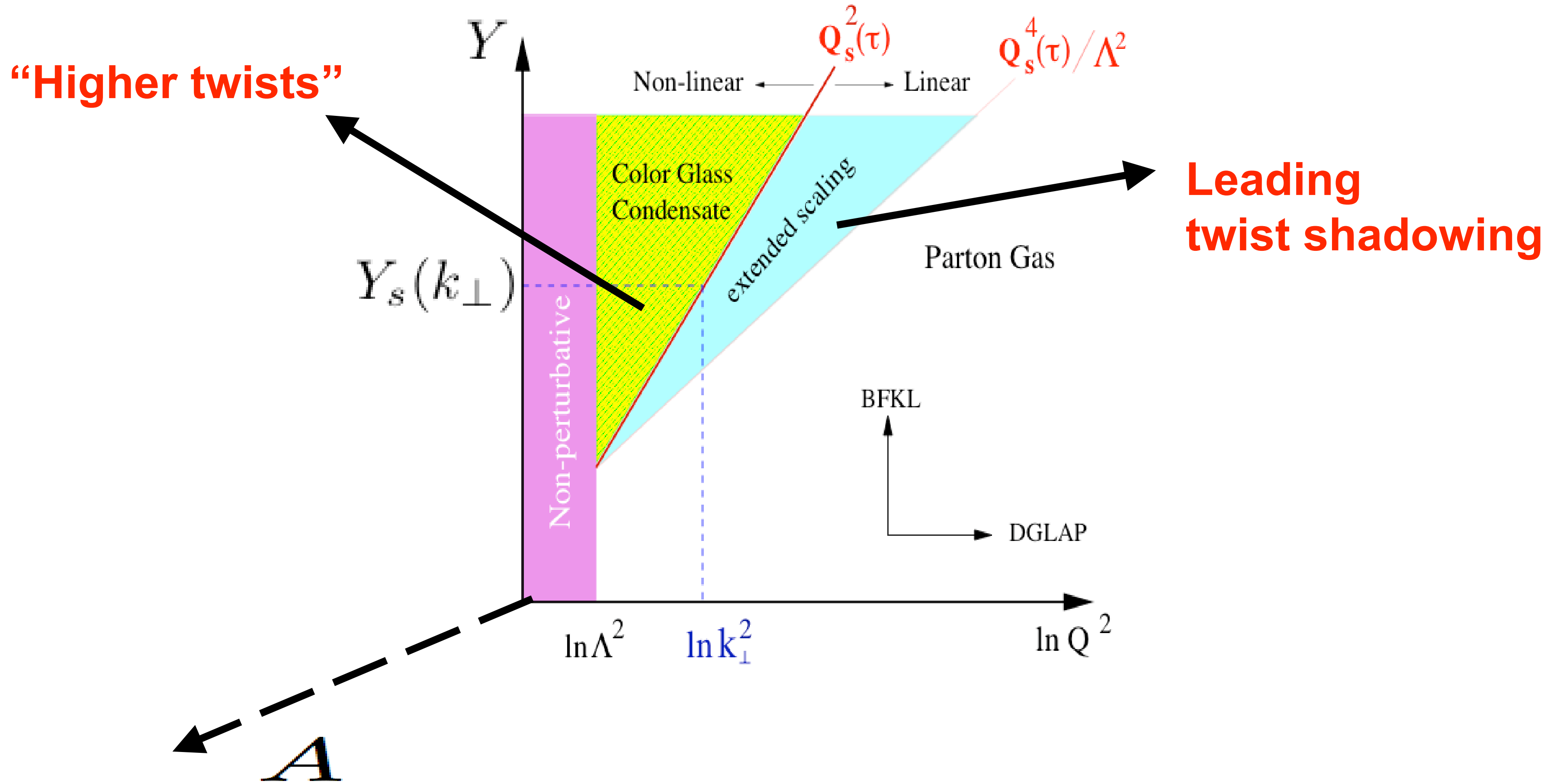
Comparison with Data





Exclusive J/Psi production: Kowalski-Teaney

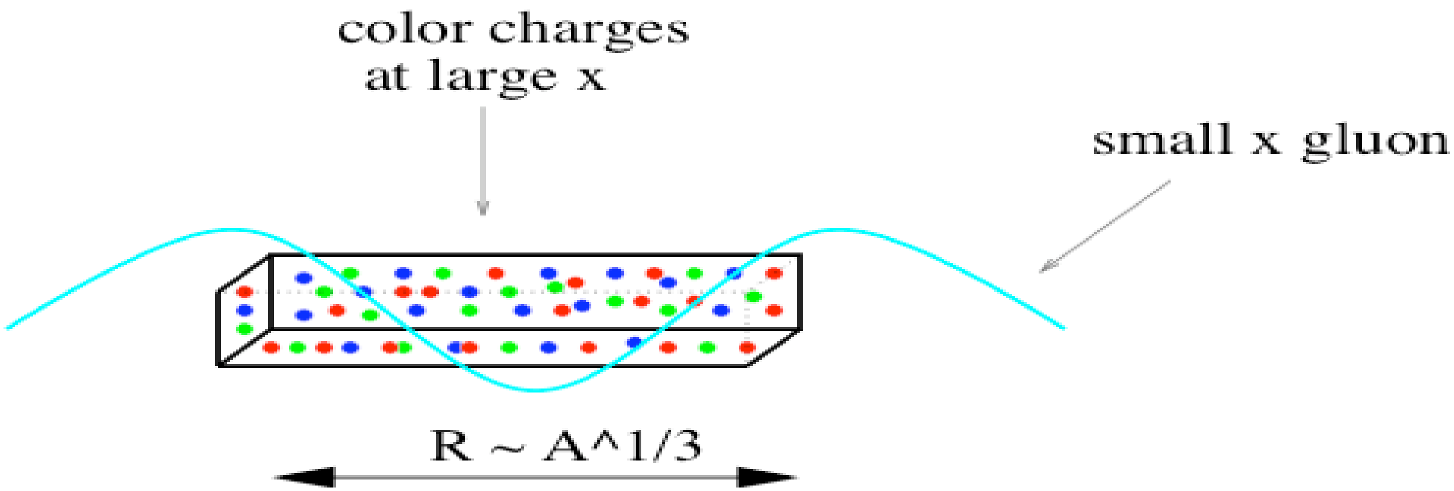
Novel regime of QCD evolution at high energies



Novel RG equations now allow detailed and controlled studies in the Regge-Gribov limit

The nuclear "oomph" factor!

$$Q_s^2 \propto \frac{A^{1/3}}{x^\delta}$$

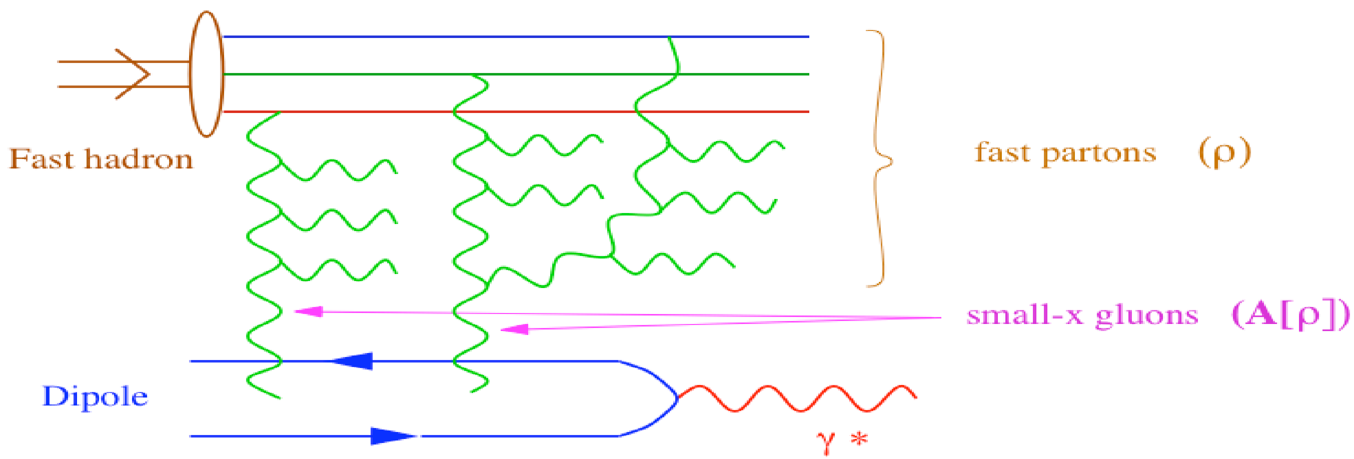


eA at eRHIC $\approx$ same parton density as ep at LHC energies!

Mean field solution of JIMWLK = B-K equation

Balitsky-Kovchegov

DIS:



Dipole amplitude N satisfies

BFKL kernel

$$\frac{\partial \mathcal{N}}{\partial \ln(1/x)} = K * [\mathcal{N} - \mathcal{N}^2]$$

Remarkable correspondence of high energy QCD With Stat. Mech. :

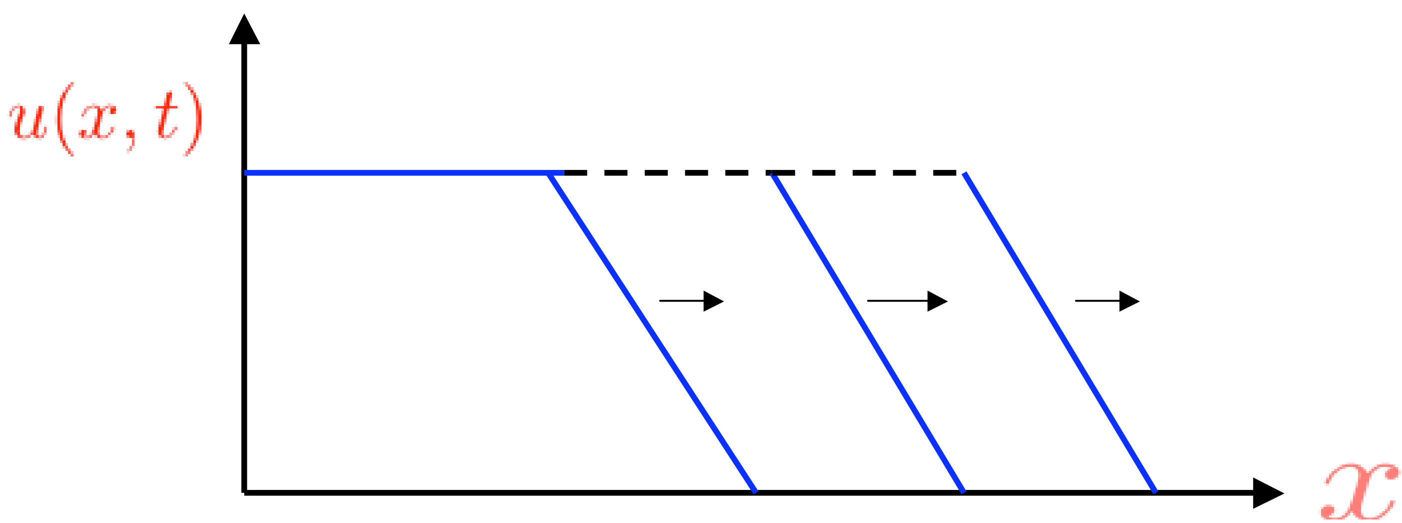
Munier-Peschanski;
Iancu-Mueller-Munier

B-K same universality class as FKPP equation

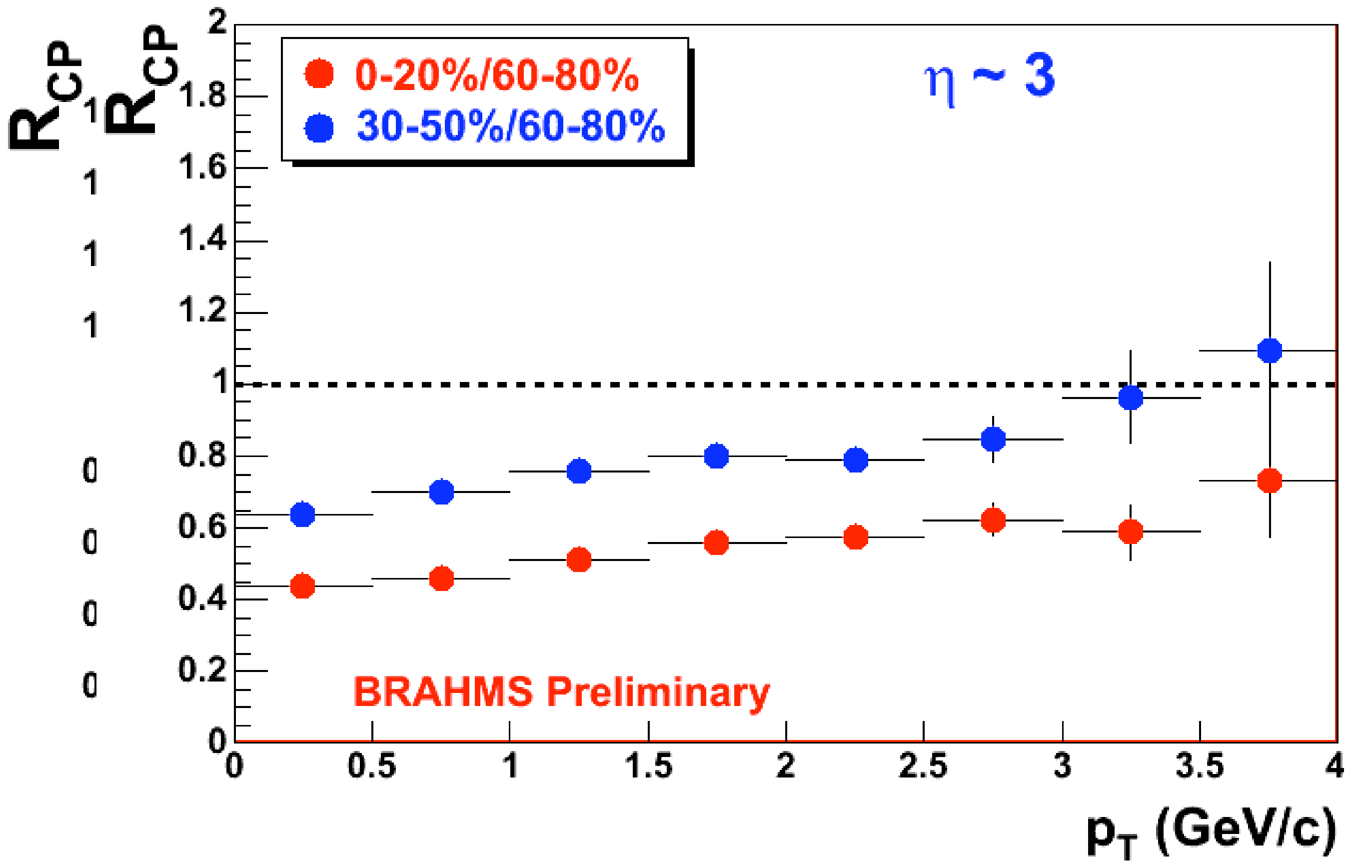
FKPP = Fisher-Kolmogorov-Petrovsky-Piscunov

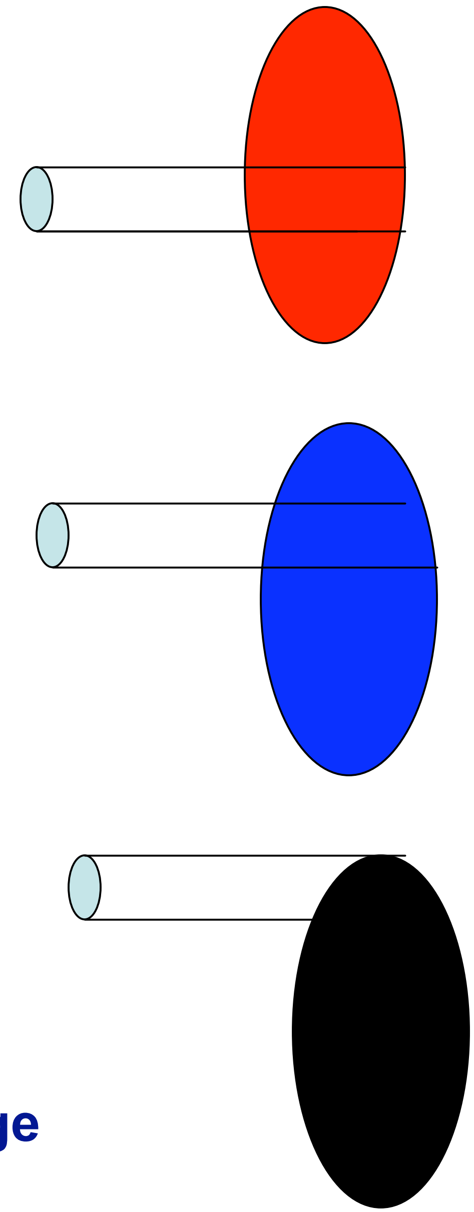
FKPP-describes unstable travelling wave fronts -

B-K correspond to spin glass phase of FKPP



STRONG HINTS FROM RHIC OF NEW PHYSICS



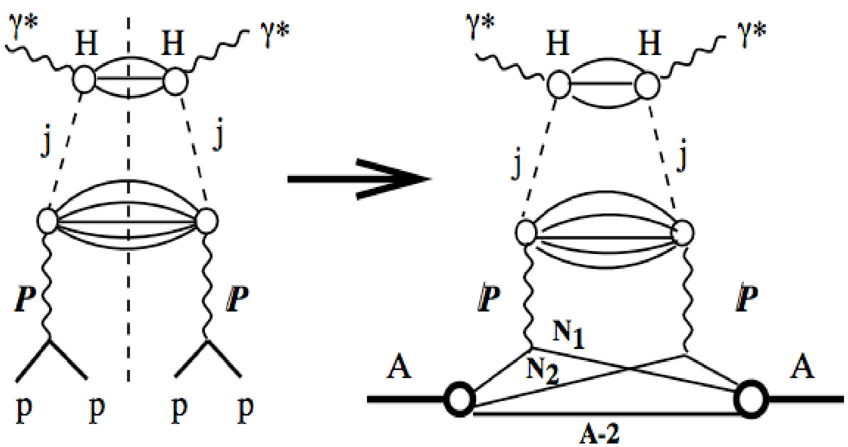


Phenomenon well within eRHIC kinematic range

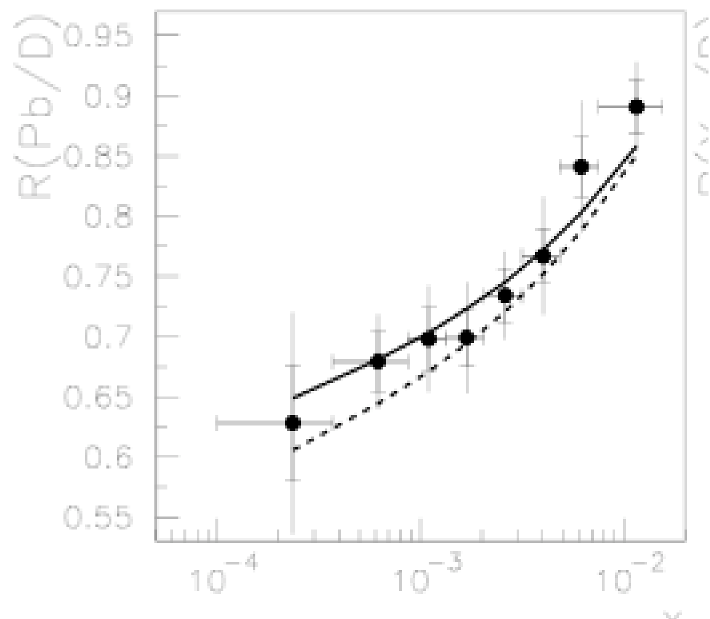
Shadowing and diffraction:

- **Is shadowing a non-perturbative leading twist phenomenon, or is generated by weak coupling, high parton density effects?**

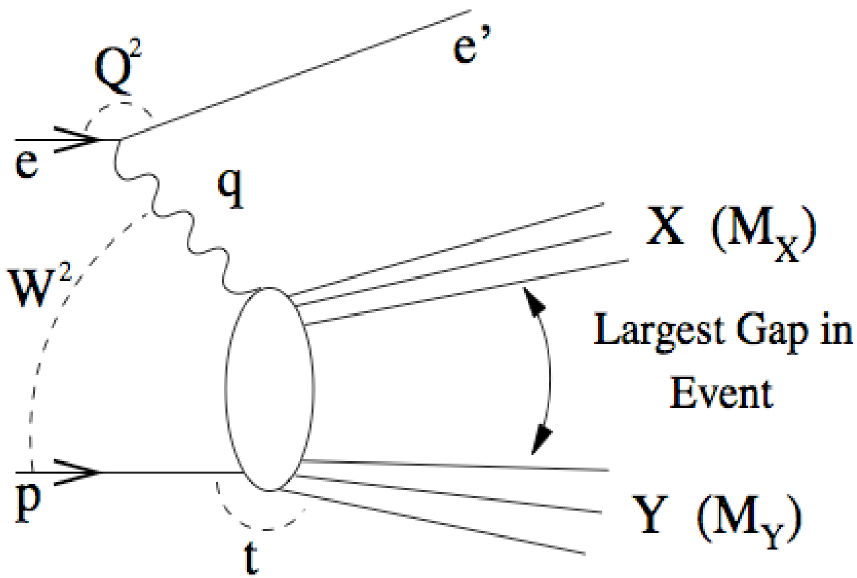
- **What is the relation of shadowing to diffraction? AGK rules relating the two are valid at low parton densities-how do these generalize to large parton densities?**



$$F_{2,p}^{\mathrm{diff.}} \longrightarrow F_{2,A}^{\mathrm{incl.}}$$



Armesto,Capella,Kaidalov, Salgado



$$R_{A_1,A_2}(\beta,Q^2,x_{\mathcal{P}}) = \frac{F_{2,A_1}^{D(3)}(\beta,Q^2,x_{\mathcal{P}})}{F_{2,A_2}^{D(3)}(\beta,Q^2,x_{\mathcal{P}})}$$

R_{A1,A2} = 1 => Pomeron flux is A -independent
= f(A1,A2) - universal form

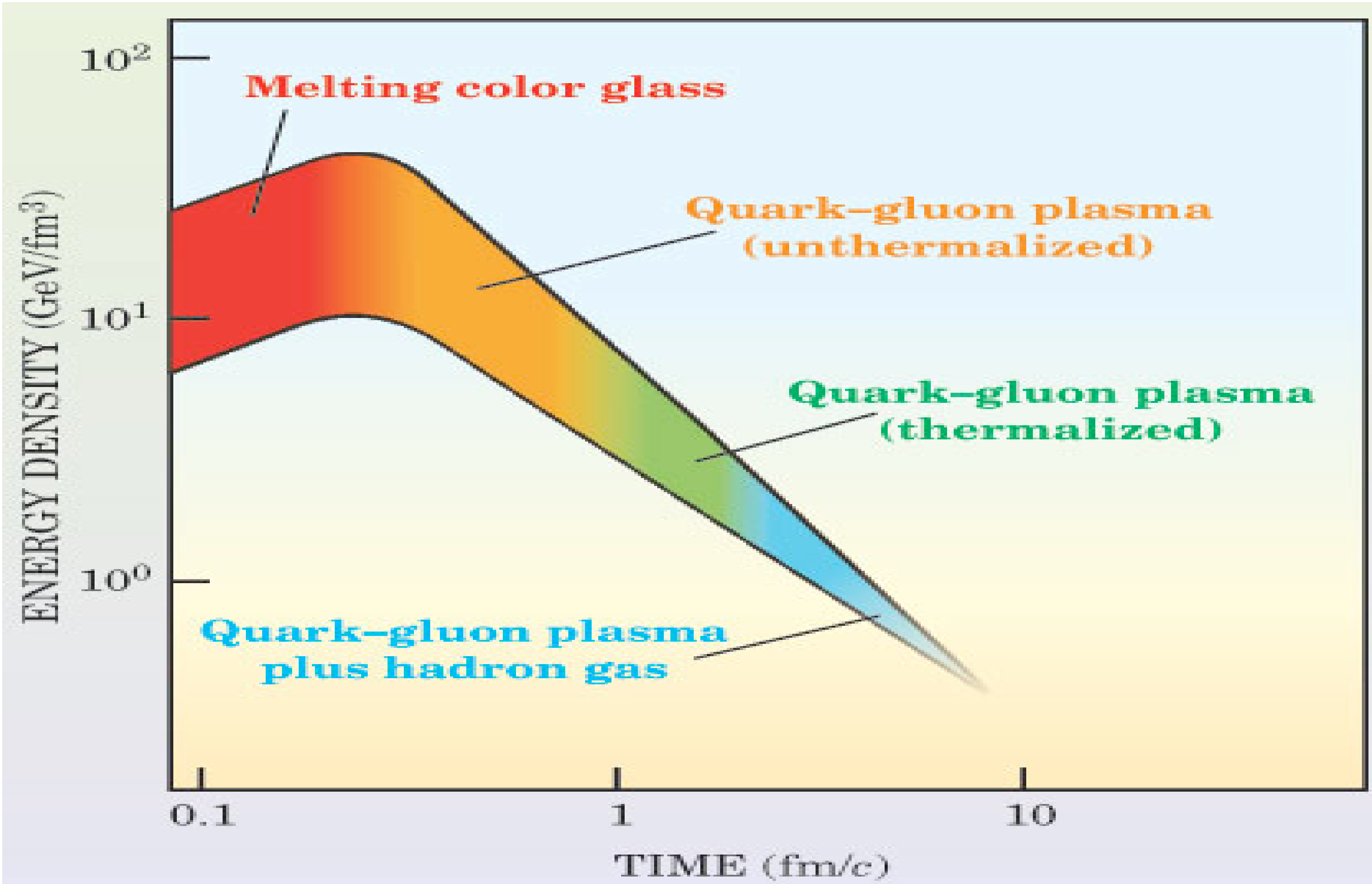
Diffractive Vector Meson Production:

$$\frac{d\sigma}{dt}|_{t=0}(\gamma^* A \to V A) \propto \alpha_S^2 \left[G_A(x,Q^2)\right]$$

Very sensitive to small x glue!

Brodsky,Gunion,Mueller, Frankfurt,Strikman

Initial conditions for the QGP



McLerran, Ludlam;
Physics Today

Concluding remarks on eA:

- Very significant progress in theory-novel RG equations- eRHIC can test to high precision new phenomena- expect scaling violations very different from DGLAP

- Besides inclusive signatures, semi-inclusive measurements (vector mesons, hard diffraction,…) - especially sensitive to the high parton density state.

- eRHIC extends previous "in-media" studies of fixed target (NMC, HERMES,…) experiments to new kinematic regions in clean collider environment (see Bernd's talk)

- Both eA & pA essential to test universality of these ideas (see extra slides)

- Only preliminary studies for eA done.
  Urgently require detailed studies with eRHIC kinematic acceptance - student/post-doc support essential

Extra Slides

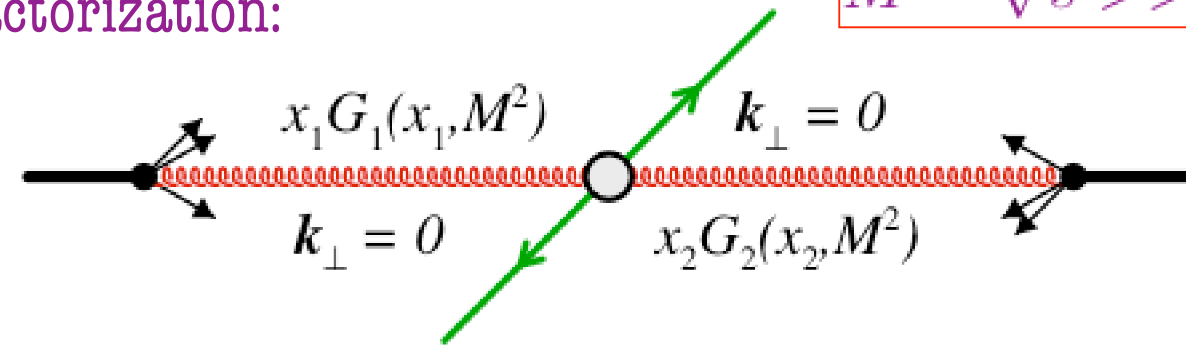
Complementary physics of pA & eA at RHIC

- Both p/D-A & eA can probe small x region-important to test universal aspects of new physics.
- eA due to independent "lever arms" in x and Q^2 well equipped for precision measurements. Much harder with pA
- eA & pA have important qualitative differences for hard diffractive processes. May be 30-40% of cross-section in eA!

I: Universality: collinear versus k_t factorization

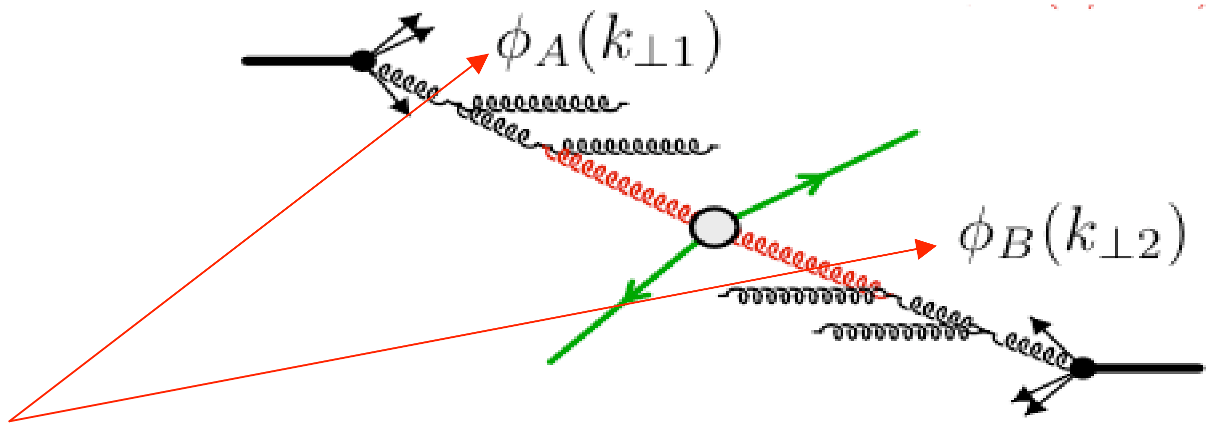
Collinear factorization:

$M \sim \sqrt{s} >> \Lambda_{QCD}$



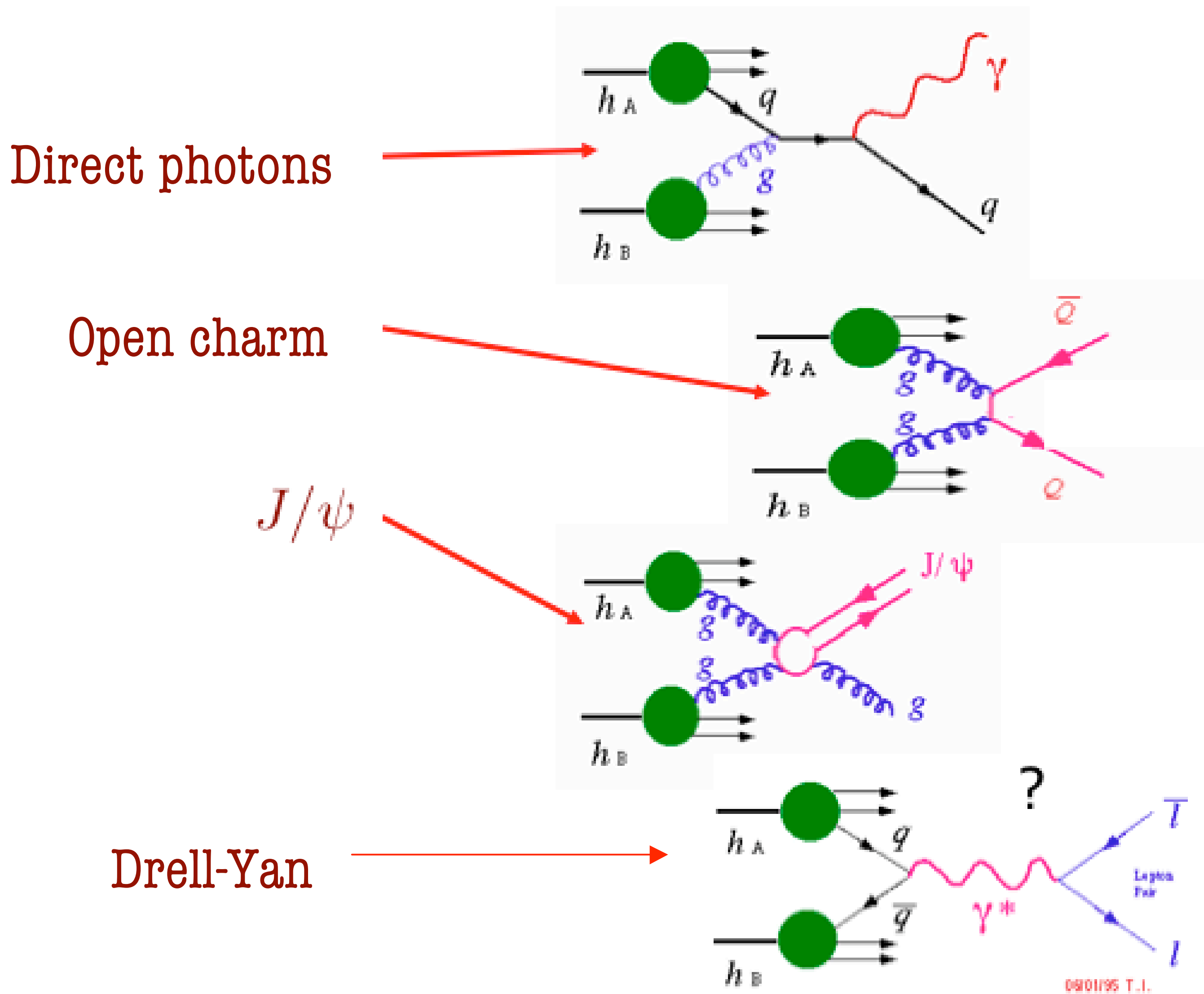
k_t factorization:

$\Lambda_{QCD} << M << \sqrt{s}$



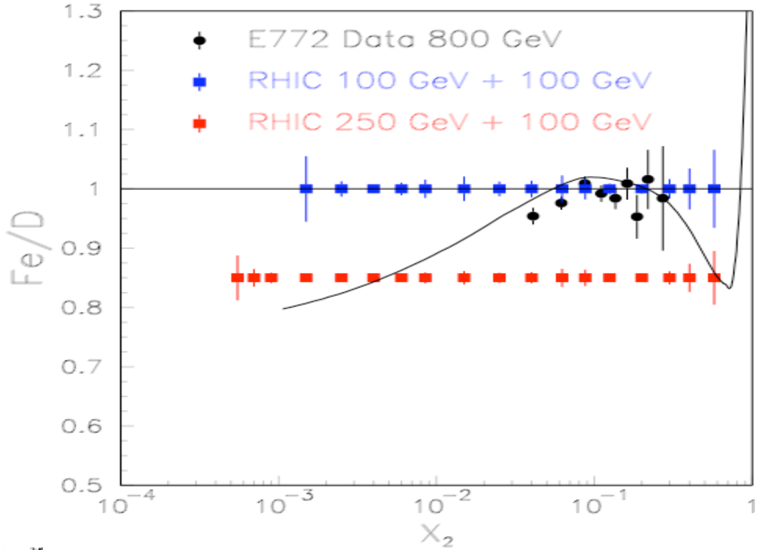
Are these objects universal? Very important for extraction of "gluon" distributions.

II: Extracting gluon distributions in pA relative to eA

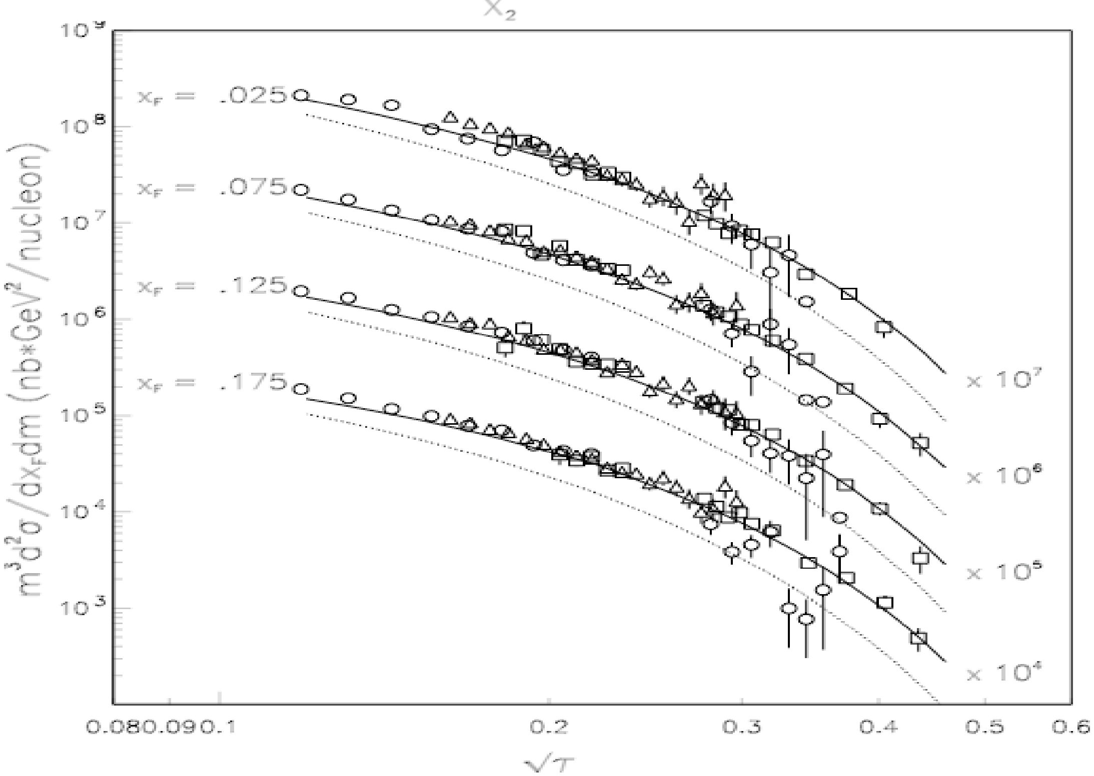


As many channels…but more convolutions, kinematic constraints-limit precision and range.

Drell-Yan



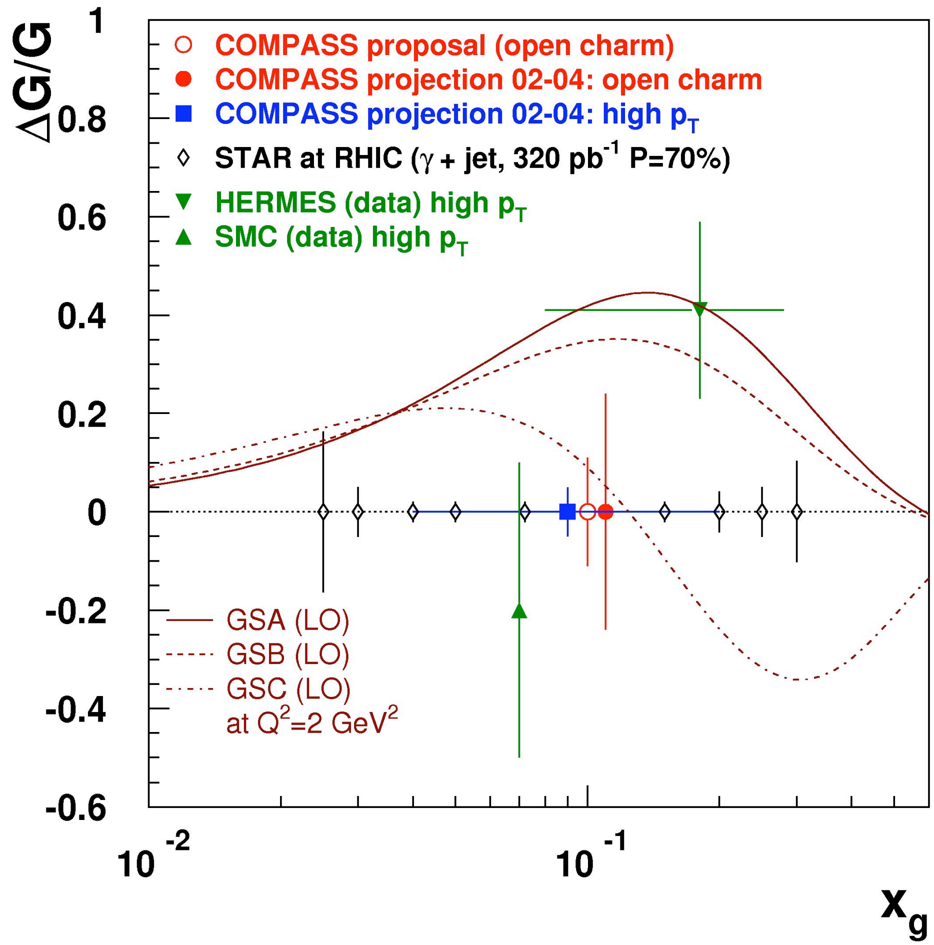
Impressive reach...



But very difficult to see scaling violations

$$M^2 > 16\,GeV^2$$

Direct photons: promising-need wide coverage to go to small x-need simulations at forward rapidity…kt issues to be resolved .



❖ Factorization theorems for diffractive parton distributions only hold for Lepton-Hadron processes- NOT for Hadron-Hadron processes.

❖ Spectator interactions destroy Rapidity Gaps in pA scattering

Study of Rapidity Gaps - links the study of CGC physics & confinement- can provide major advance in our understanding.