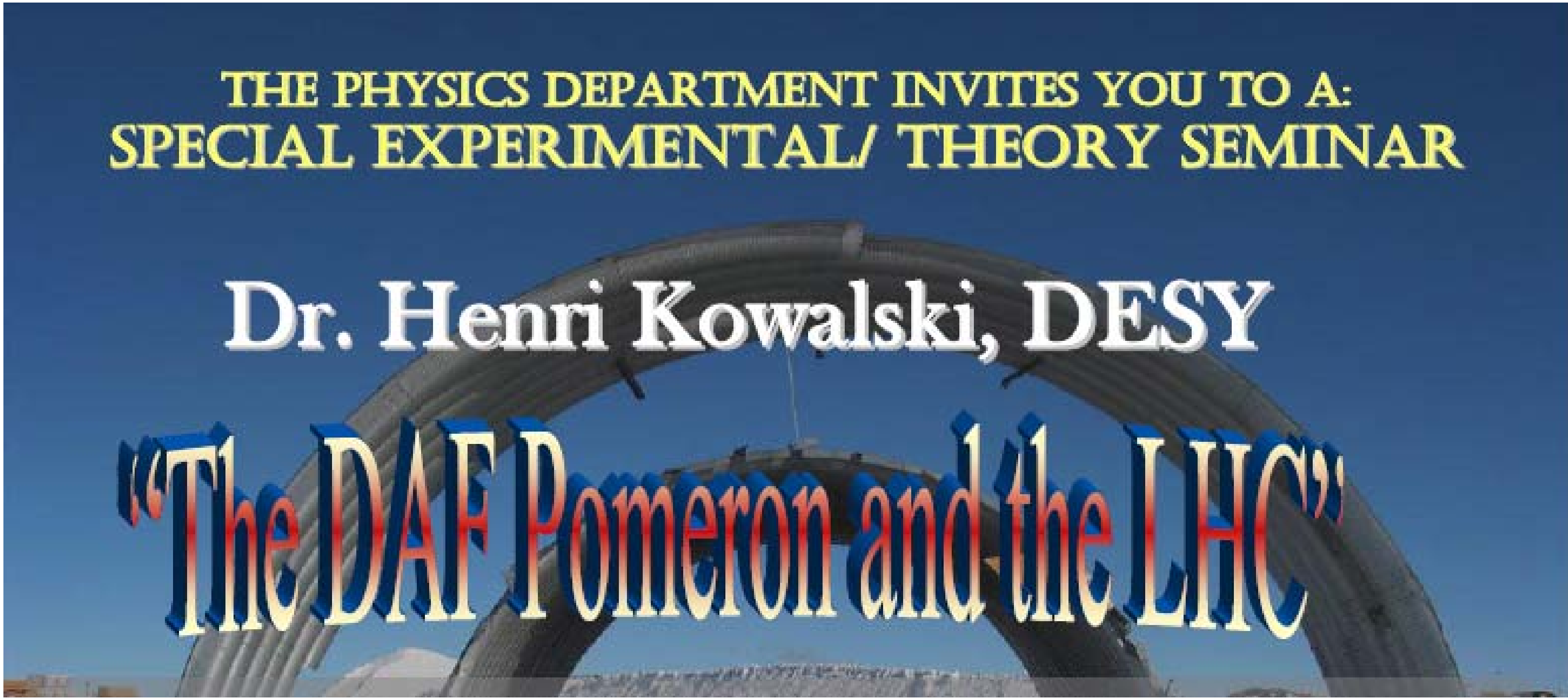
Gluon Density in the Dipole Model & in the DAF-BFKL Pomeron @ HERA and LHeC & EIC

Henri Kowalski

Divonne
2nd of September 2008

Ongoing Investigation
First talks at Columbia & Hampton Universities, May 2008



Evidence for the discrete asymptotically-free BFKL Pomeron from HERA data

J. Ellis [a], H. Kowalski [b], D.A. Ross [a,c,*]

Physics Letters B **in print**

Outline of the talk:

Short review of low x HERA data, Dipole Picture,
Saturation, oomph factor and all that

Why Pomeron at HERA?,

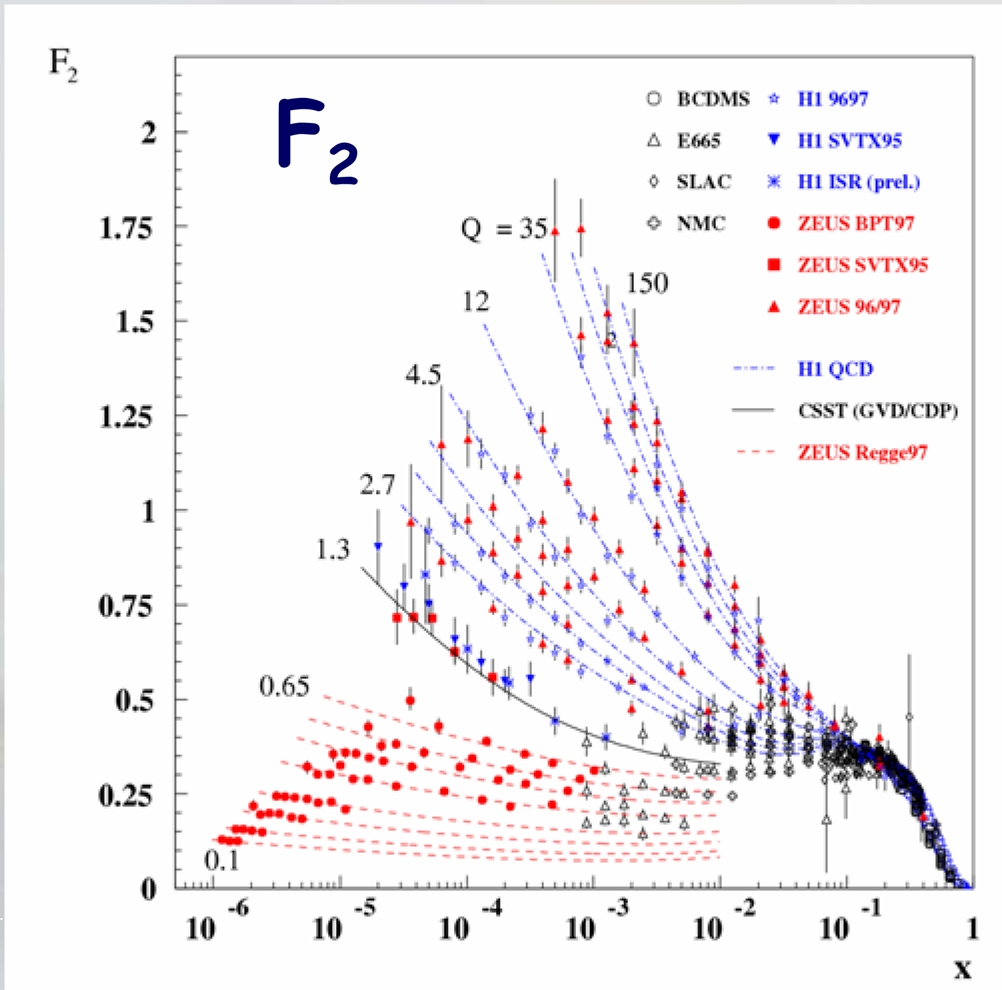
What is DAF-BFKL Pomeron
Evidence for DAF-Pomeron from HERA data

Relation with DGLAP
MRST ↔ EKR

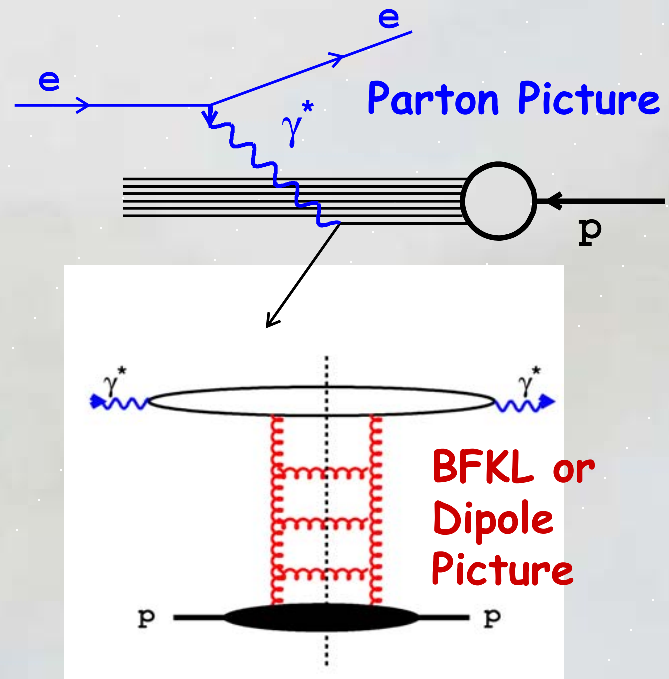
Pomeron-Graviton Correspondence

Consequences for RHIC, LHC, EIC, LHeC

Low-x Physics @ HERA

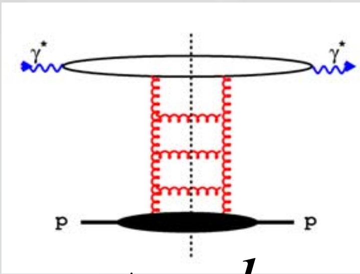


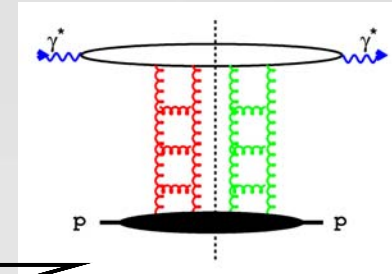
- At low x and high Q^2, steep rise in structure function



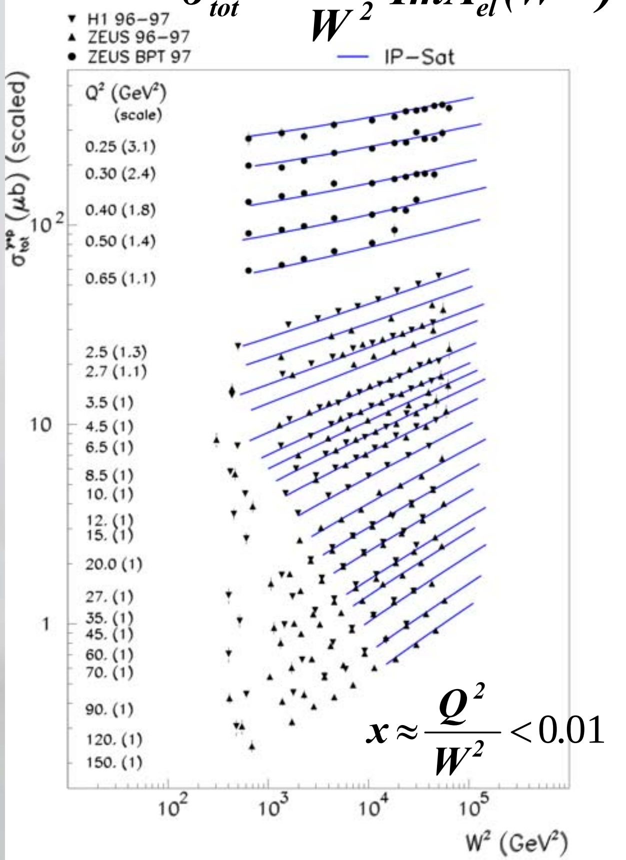
Behavior of F_2 is dominated by gluon density at small-x

Low-x Physics @ HERA





$$\sigma_{tot}^{\gamma^* p} = \frac{1}{W^2} Im A_{el}(W^2)$$

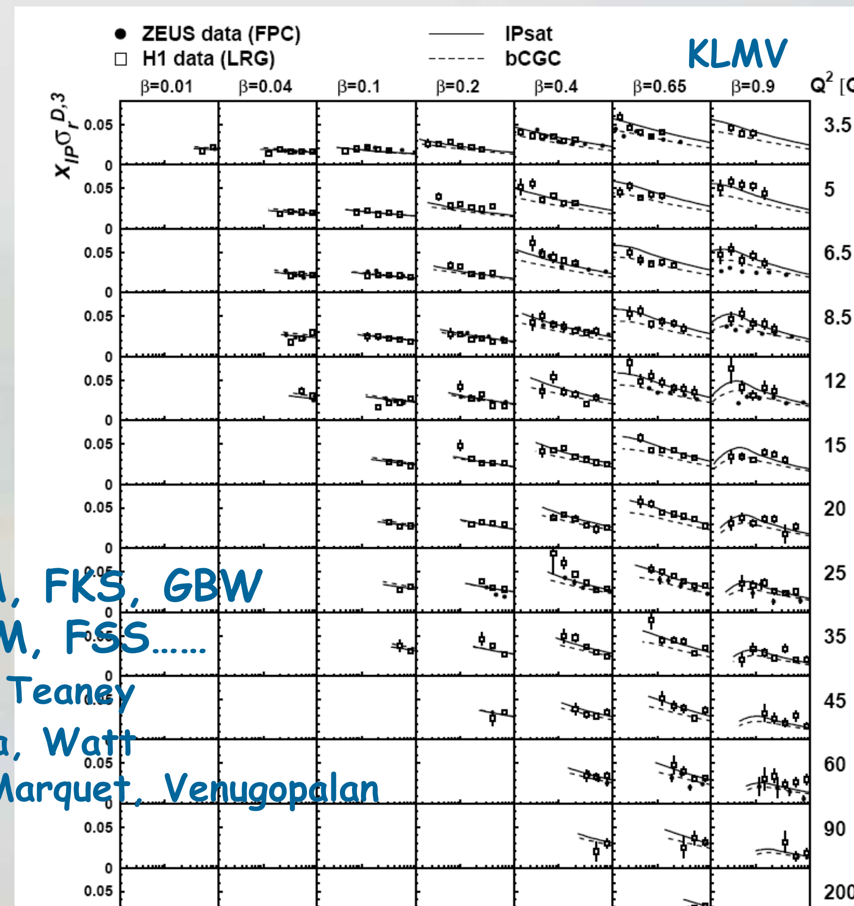


$$x \approx \frac{Q^2}{W^2} < 0.01$$

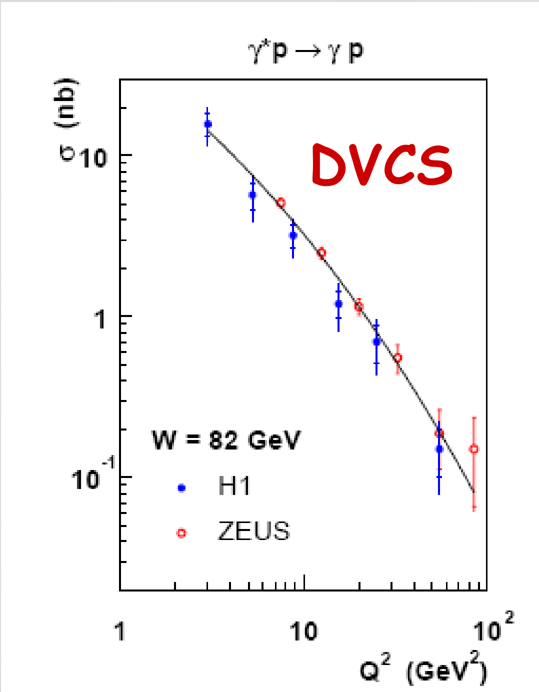
$$\sigma_{tot}^{\gamma^* P}(W,Q^2) = \frac{4\pi^2 \alpha_{em}}{Q^2} \cdot F_2(x,Q^2)$$

Diffraction at HERA is a shadow of DIS

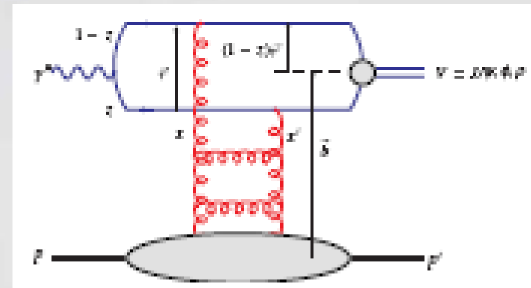
➔ dipole picture, equivalent to LO p-QCD for small dipoles, Q~1/r



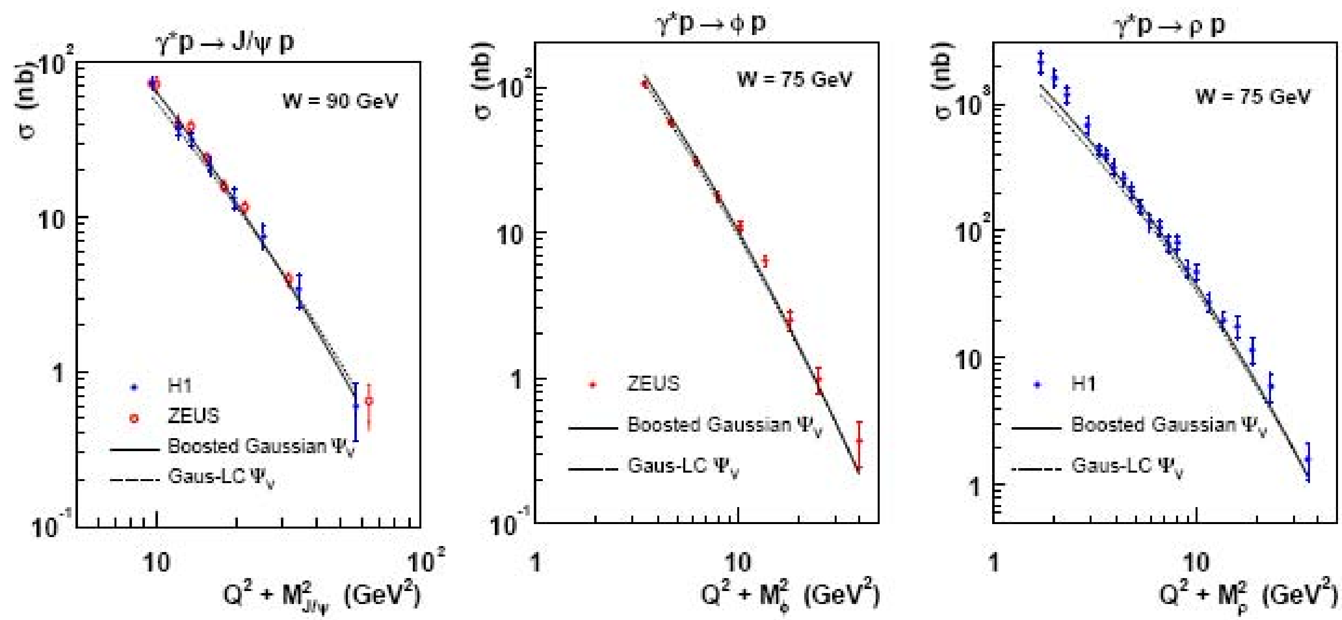
NNPZ, AM, GLM, FKS, GBW
DGKP, BGBK, IIM, FSS……
KT - Kowalski, Teaney
KMW - K, Motyka, Watt
KLMV – K, Lappi, Marquet, Venugopalan



Dipole Picture-gluon density convoluted with the dipole wave functions ➔ simultaneous prediction/description of many reactions

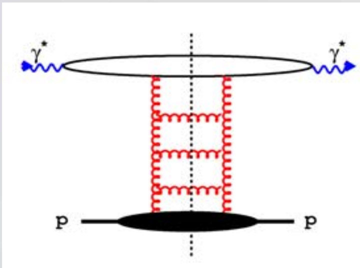


Vector Mesons



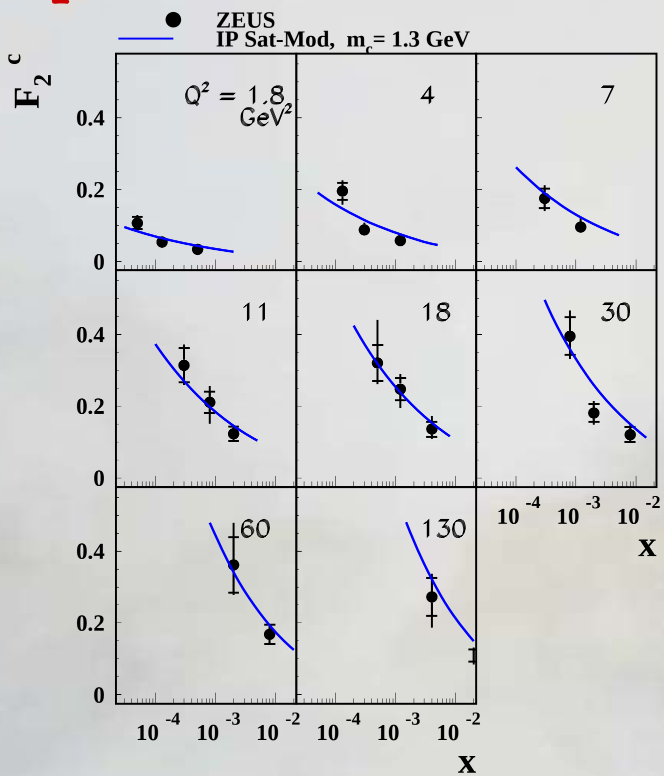
Note: educated guesses for VM wf work very well

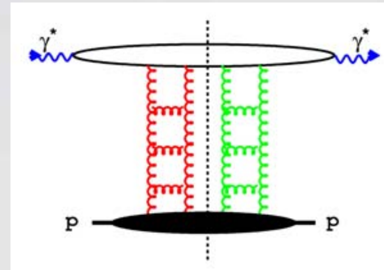
Dipole Picture-gluon density convoluted with the dipole wave functions ➔ simultaneous prediction/description of many reactions



KT

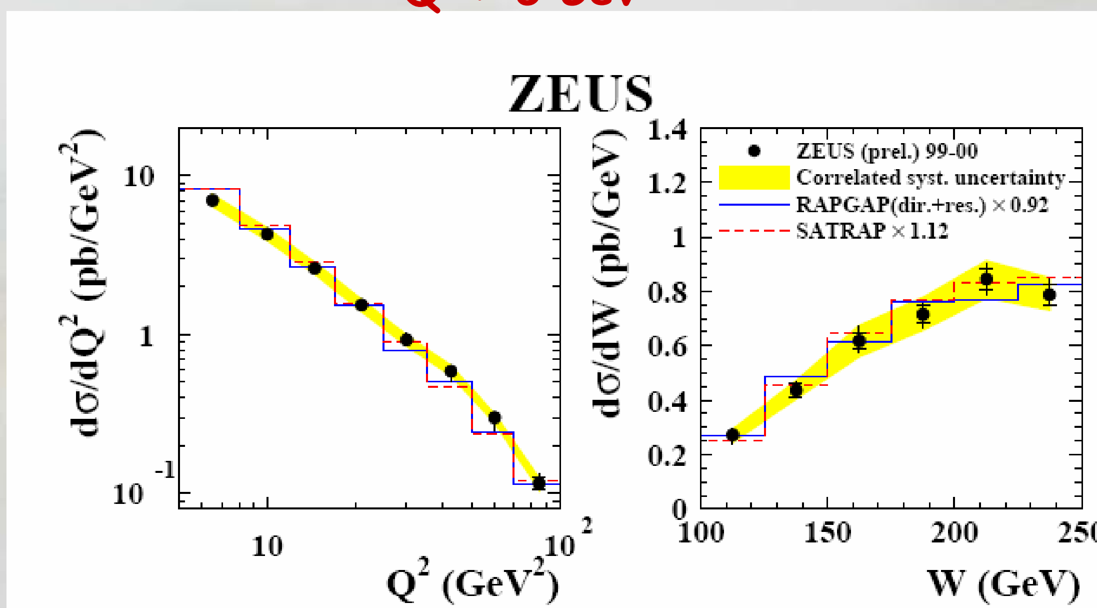
$F_2{}^c$

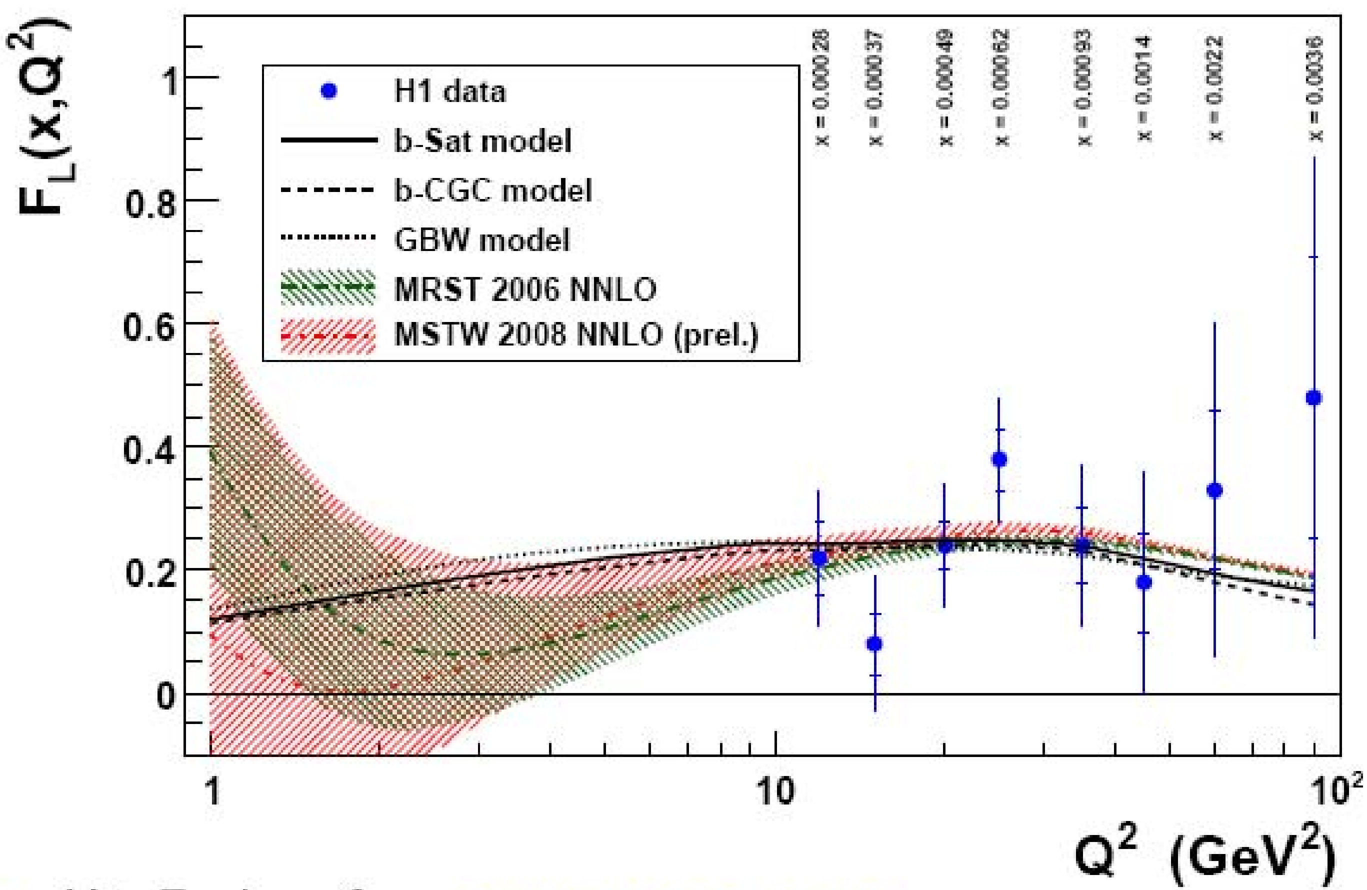




Diffractive Di-jets

$Q^2 > 5$ GeV^2

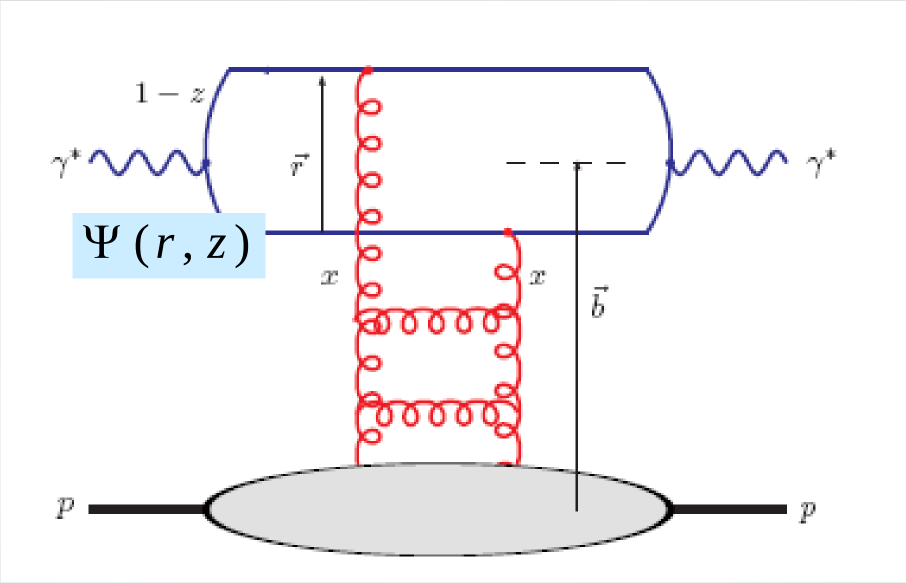




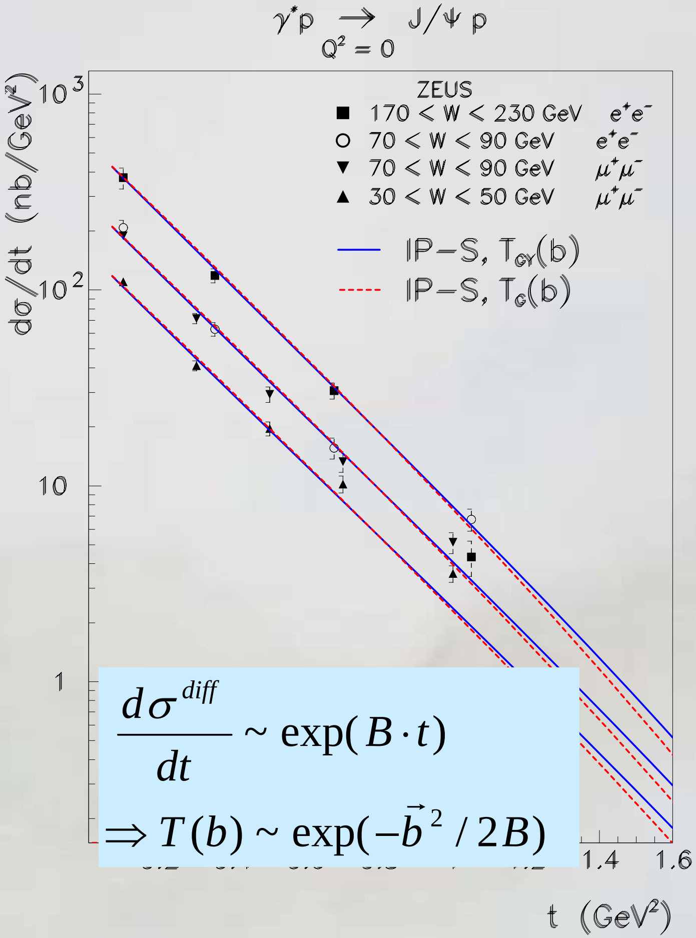
- H1 F_L data from arXiv:0805.2809.

K+Watt

Extracting Proton Vertex using Dipole Models



$\Psi(r,z)$



$$\frac{d\sigma^{diff}}{dt} \sim \exp(B \cdot t)$$

$$\Rightarrow T(b) \sim \exp(-\vec{b}^2 / 2B)$$

Can use vector meson production to extract proton profile:

$$\frac{d\sigma_{VM}^{\gamma^* p}}{dt} = \frac{1}{16\pi} \left| \int d^2\vec{r} \int d^2 b e^{-i\vec{b}\cdot\vec{\Delta}} \int_0^1 dz \Psi_{VM}^* \; 2\left\{1 - \exp(-\frac{\Omega}{2})\right\} \Psi \right|^2$$

KT, KMW

$$\Omega = \frac{\pi^2}{N_C} r^2 \alpha_s(\mu^2) xg(x,\mu^2) T(b)$$

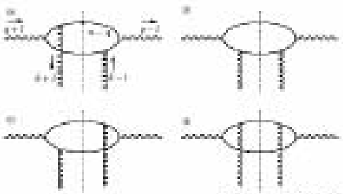
T(b)-proton shape

Description of the size of interaction region B_D

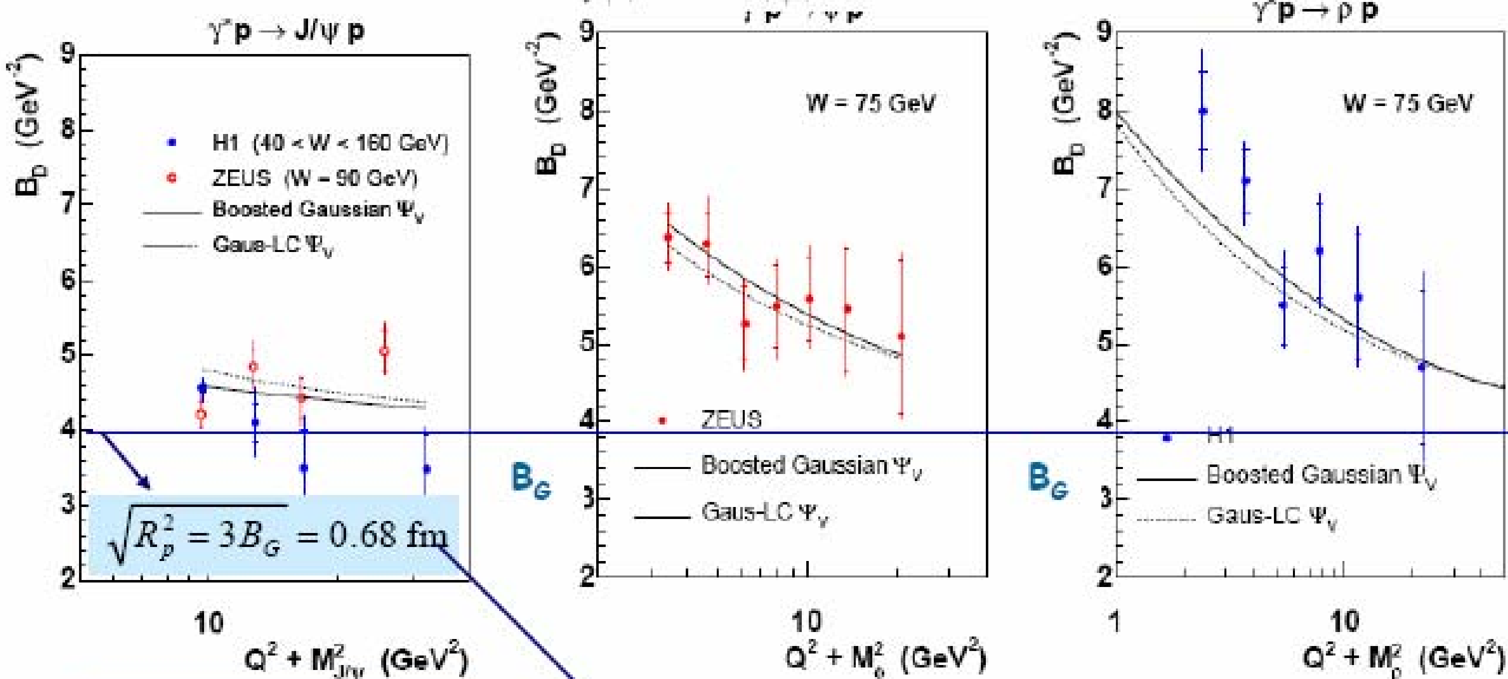
$$\frac{d\sigma^{diff}}{dt} \sim \exp(B_D \cdot t) \qquad \Rightarrow T(b) \sim \exp(-\vec{b}^2 / 2B_G)$$

Modification by Bartels, Golec-Biernat, Peters

$$e^{i\vec{b}\cdot\vec{\Delta}} \to e^{i(\vec{b}+(1-z)\vec{r})\cdot\vec{\Delta}}$$



KMW



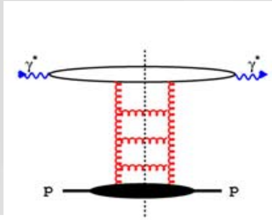
$$\sqrt{R_p^2 = 3B_G} = 0.68 \text{ fm}$$

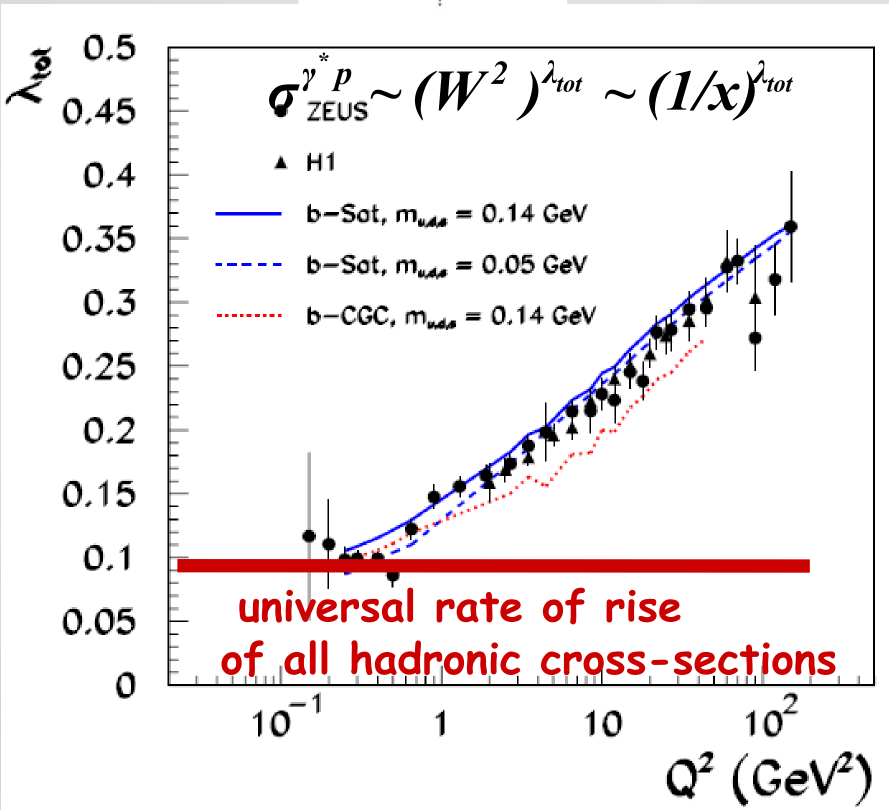
$$R_p = 0.870 \pm 0.008 \text{ fm}$$

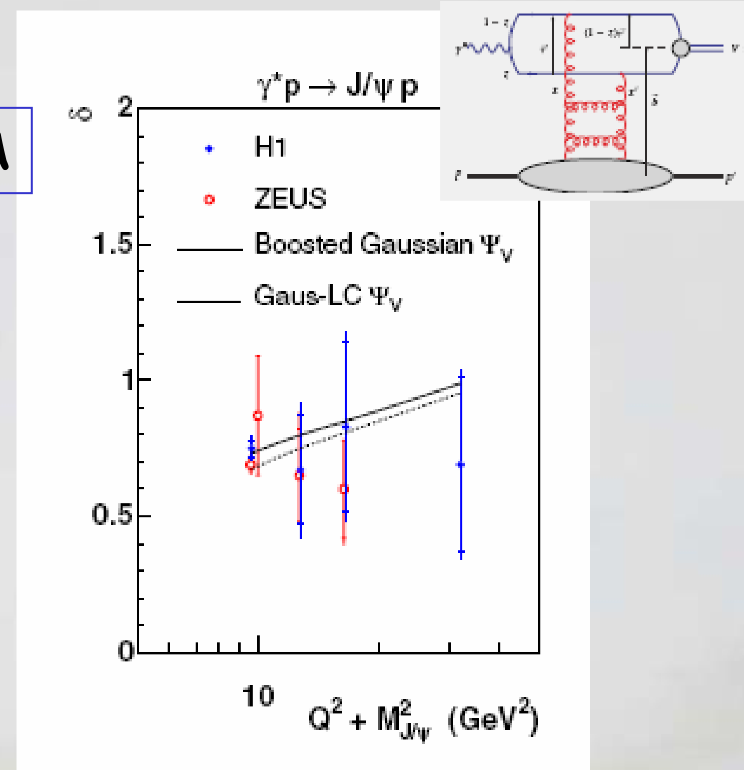
$$\Rightarrow B_G = 6.48 \text{ GeV}^2$$

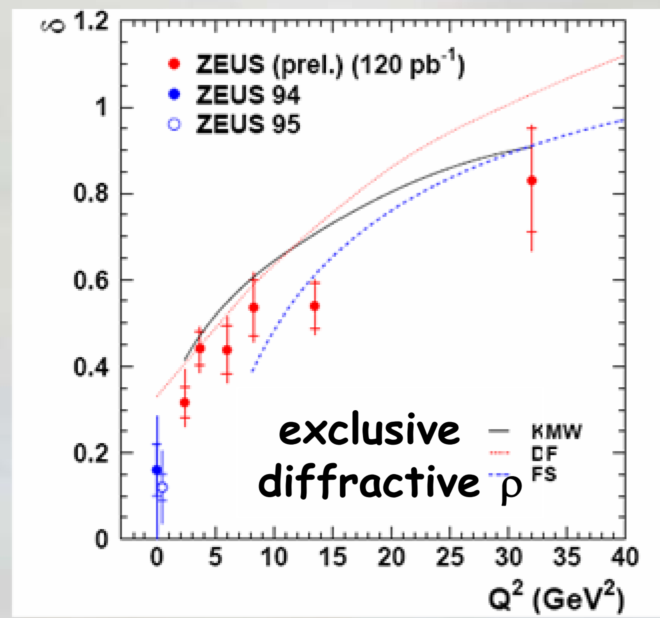
the gluonic proton radius smaller than the quark radius

Discovery of HERA









Universality of the observed intercepts

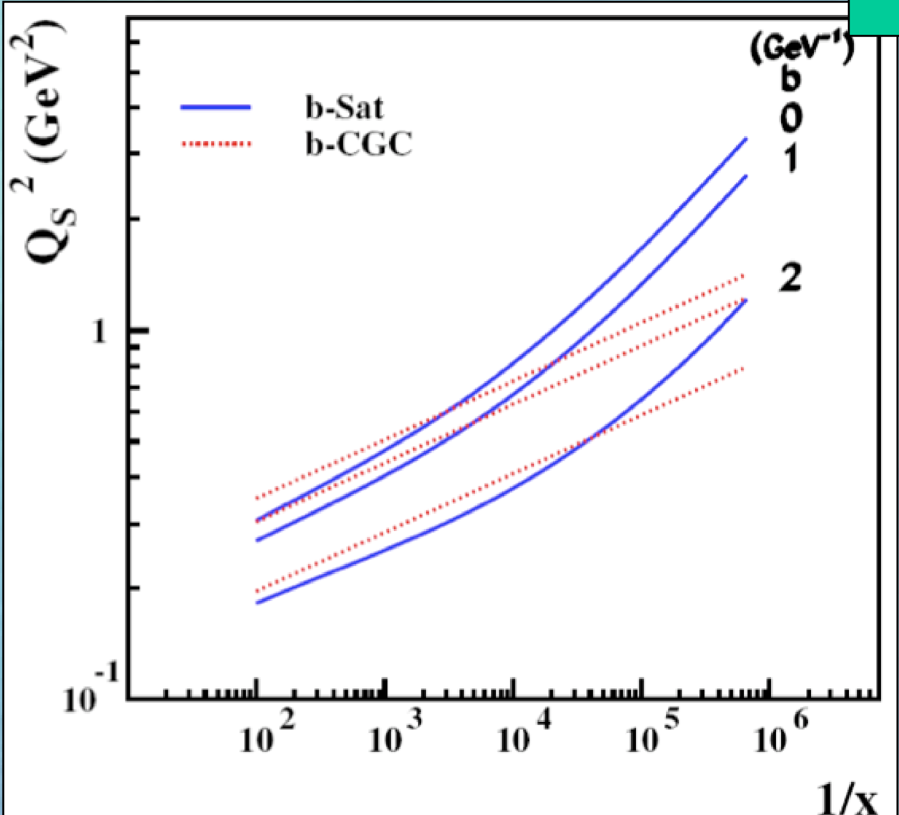
➔ Universal, "Pomeron like" QCD object
soft and hard Pomeron join together

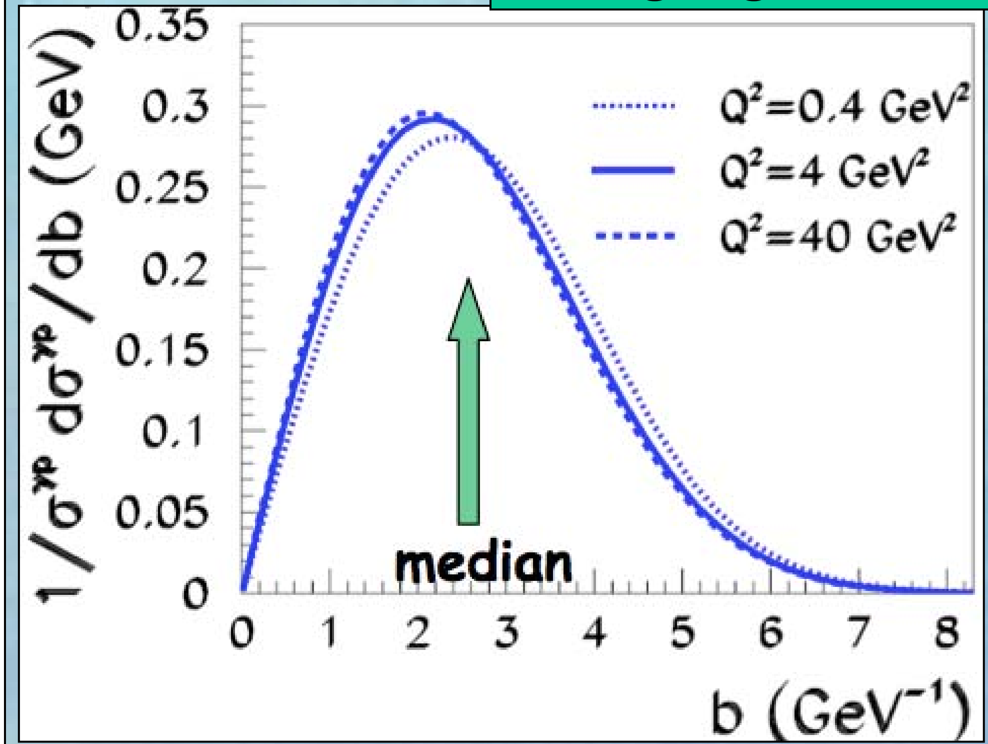
Saturation

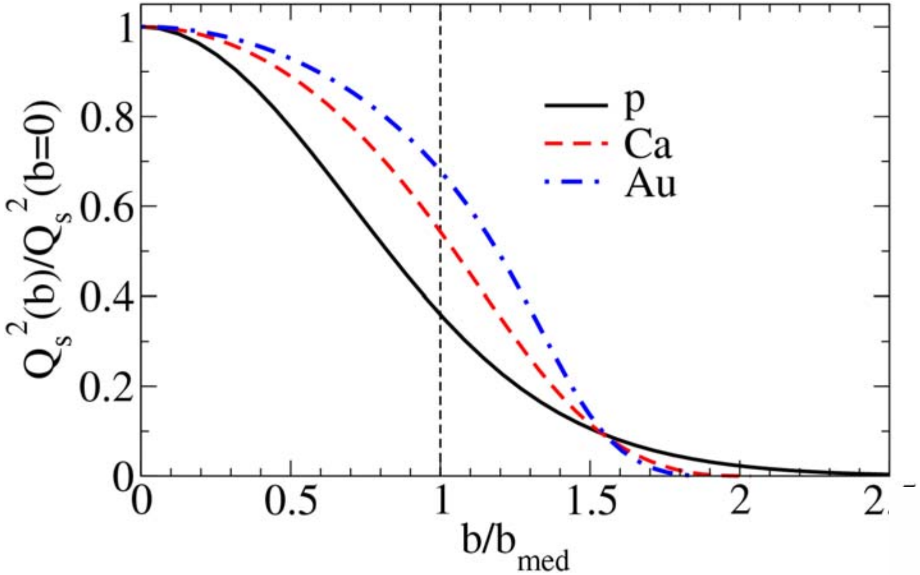
Estimate of Q_s

Apparently little saturation at $Q_s^2 = 4\ GeV^2$

➔ Oomph factor Increase saturation by going to nuclei



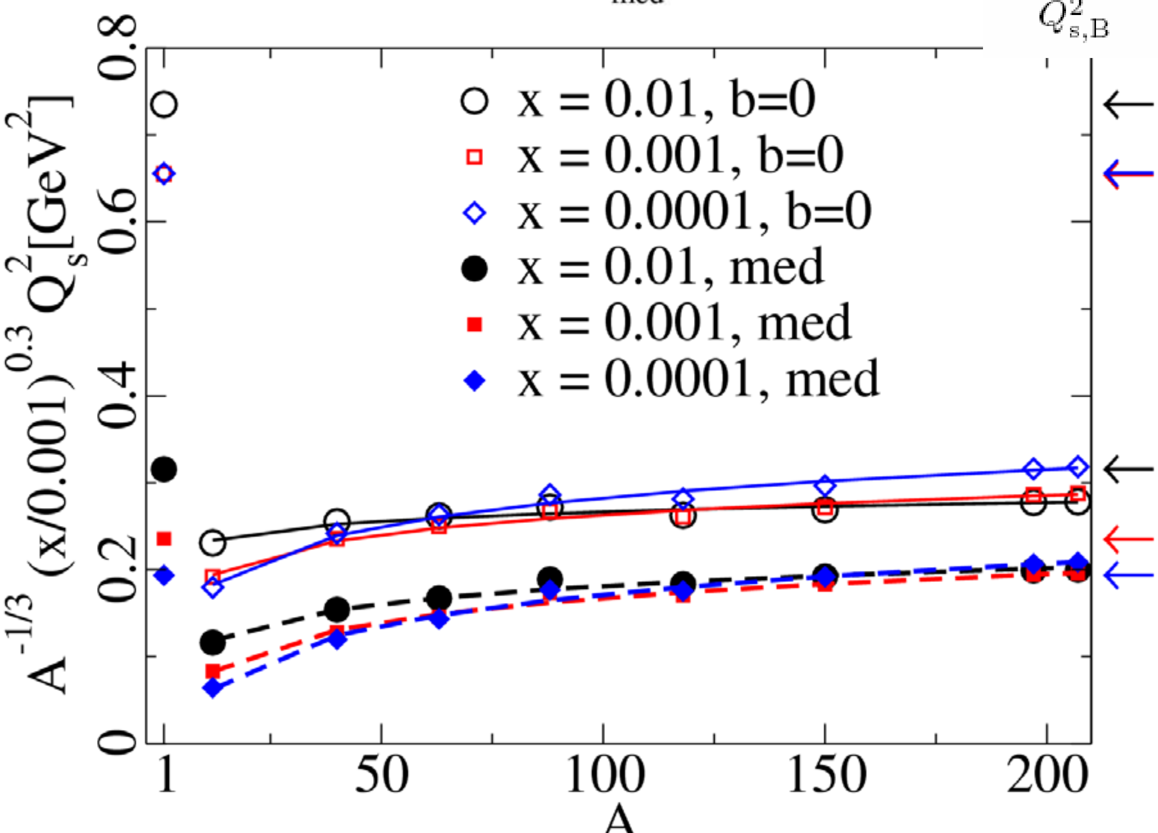




Nuclear enhancement of universal dynamics of high parton densities

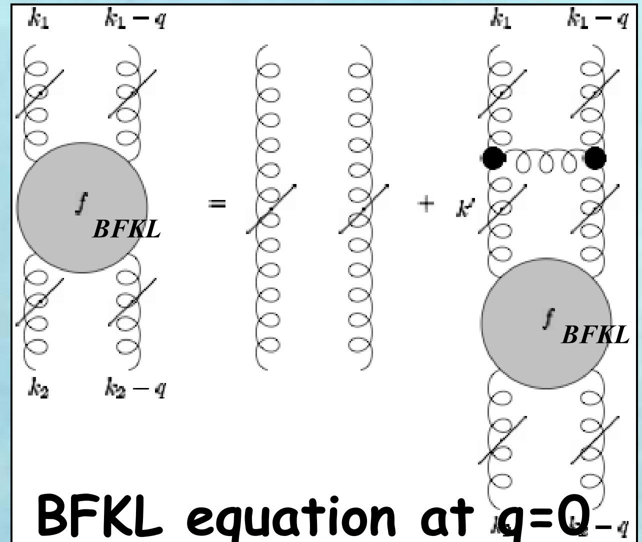
Kowalski, Lappi, Venugopalan
K, L, Marquet, V

$$\frac{Q^2_{s,A}}{Q^2_{s,B}} = \frac{A}{B}\frac{T_A(b_\perp)}{T_B(b_\perp)}\frac{F(x,Q^2_{s,A})}{F(x,Q^2_{s,B})} \sim \frac{A^{1/3}}{B^{1/3}}\frac{F(x,Q^2_{s,A})}{F(x,Q^2_{s,B})}$$



large enhancement of saturation scale in nuclei
$200^{1/3} \sim 6$ ➔
Equivalent center of mass energy ~ 14 time larger than in ep

Basics of BFKL



BFKL equation at q=0

Conformal invariance

solved by finding a complete set of eigenfunctions

$$\omega \tilde{f}(\omega, \mathbf{k_1}, \mathbf{k_2}) = \delta^2(\mathbf{k_1} - \mathbf{k2}) + \frac{\alpha C_A}{\pi^2} \int \frac{d^2\mathbf{k}'}{(\mathbf{k_1} - \mathbf{k}')^2} \Big[\tilde{f}(\omega, \mathbf{k}', \mathbf{k_2}) - \frac{\mathbf{k_1}^2}{\mathbf{k}'^2 + (\mathbf{k}' - \mathbf{k_1})^2} \tilde{f}(\omega, \mathbf{k_1}, \mathbf{k_2}) \Big]$$

Eigen-functions

$$f_\omega(k^2) = \frac{(k^2)^{i\nu}}{\sqrt{k^2}}$$

Characteristic function

$$\omega = \bar{\alpha_s} \chi(\nu)$$

$\chi(\nu) = -2\gamma_E - \psi(1/2 + i\nu) - \psi(1/2 - i\nu)$

ψ is the Digamma function

Green function

$$f_{BFKL}(\omega, k_1, k_2) = \int_{-\infty}^{\infty} d\nu \left(\frac{k_1^2}{k_2^2} \right)^{i\nu} \frac{1}{2\pi^2 k_1 k_2} \frac{1}{(\omega - \bar{\alpha_s} \chi(\nu))}$$

NLO BFKL with running α_s

NLO

$$\omega \;\equiv\; \chi(\alpha_s,\nu) \;=\; \bar{\alpha}_s\,(1-A\bar{\alpha}_s)\,\chi_0\left(\frac{1}{2}+\bar{\alpha}_sB+i\nu+\frac{\omega}{2}\right)+\bar{\alpha}_s^2\chi_1(\nu).$$

Fadin, Lipatov
G. Salam
resummation

running coupling

$$\omega \;=\chi\left(\alpha_s(k),\nu_\omega(k)\right).$$

$$\omega \;=\; \chi(\alpha_s(k_{\rm crit}),0).$$

property of χ:
largest ω at $\nu=0$

Airy functions are solving BFKL eq. around $k \sim k_{crit}$

$$\left[\frac{d^2}{d\ln(k^2/k_0^2)}+\frac{\beta_0}{2\pi}\frac{\dot{\chi}(\alpha_s(k_{\rm crit}),0)}{\chi''(\alpha_s(k_{\rm crit}),0)}\ln\left(\frac{k^2}{k_0^2}\right)\right]\overline{f_\omega}(k) \;=\; 0,$$

$$f_\omega(k^2) \;=\; \frac{\overline{f_\omega}(k)}{\sqrt{k^2}},$$

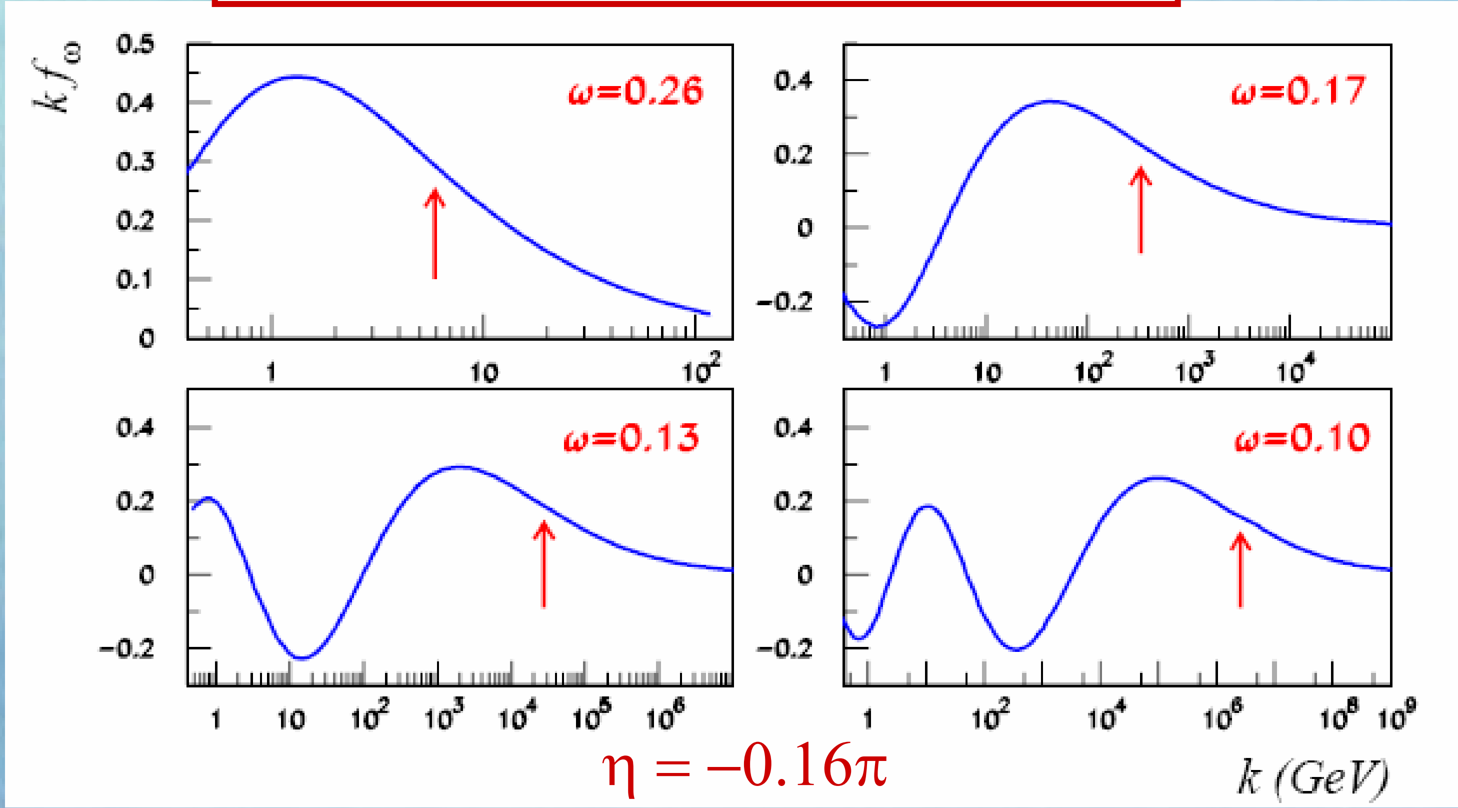
away of k_{crit}

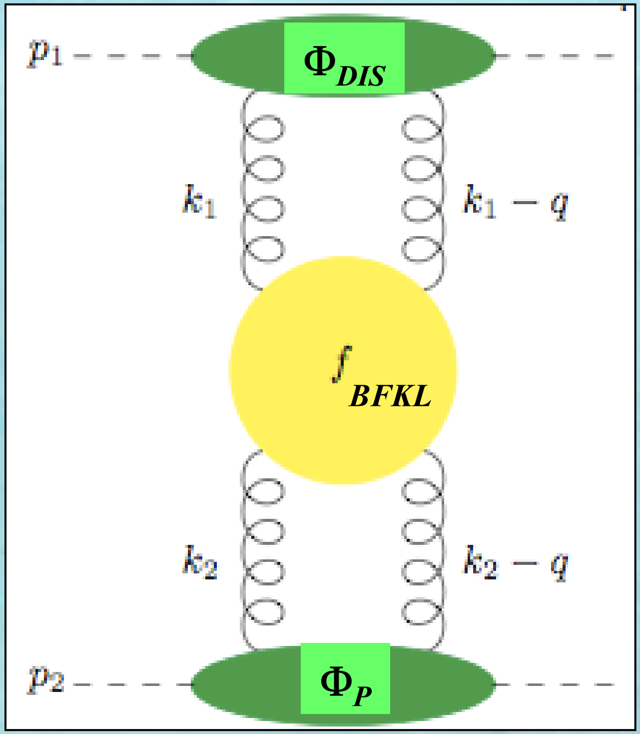
$$\overline{f_\omega}(k) \;=\; e^{\pm i\varphi_\omega(k)},$$

$$\varphi_\omega(k) \;=\; 2\int_k^{k_{\rm crit}} \frac{dk'}{k'}\,|\nu_\omega(k)|\,.$$

Matching the solutions at $k=k_{crit}$ determines the phase of oscil.= $\pi/4$
Lipatov 86 ➔ encode the infrared behaviour of QCD by assuming a fixed phase η at k_0

$$\varphi_\omega(k_0) \;\equiv\; 2\int_{k_0}^{k_{\rm crit}} \frac{dk'}{k'}\,|\nu_\omega(k)| \;=\; \left(n-\frac{1}{4}\right)\pi+\eta,$$





Structure functions in DIS

$$F_2(x, Q^2) = \int_x^1 dz \int \frac{dk}{k} \Phi_{\mathrm{DIS}}(z, Q, k) xg\left(\frac{x}{z}, k\right),$$

unintegrated gluon density

$$xg(x,k) = \sum_n \int \frac{dk'}{k'} \Phi_p(k') \left(\frac{k'x}{k}\right)^{-\omega_n} k^2 f^*_{\omega_n}(k') f_{\omega_n}(k),$$

enhancement of leading eigenfun.by $(1/x)^{\omega}$

$$xg(x,k) = \sum_n a_n x^{-\omega_n} k^{(2+\omega_n)} f_{\omega_n}(k).$$

HERA
LHeC

no enhancement of leading eigenfun.

$$\Phi_p(k) = \sum_n a_n k^{(2-\omega_n)} f_{\omega_n}(k),$$

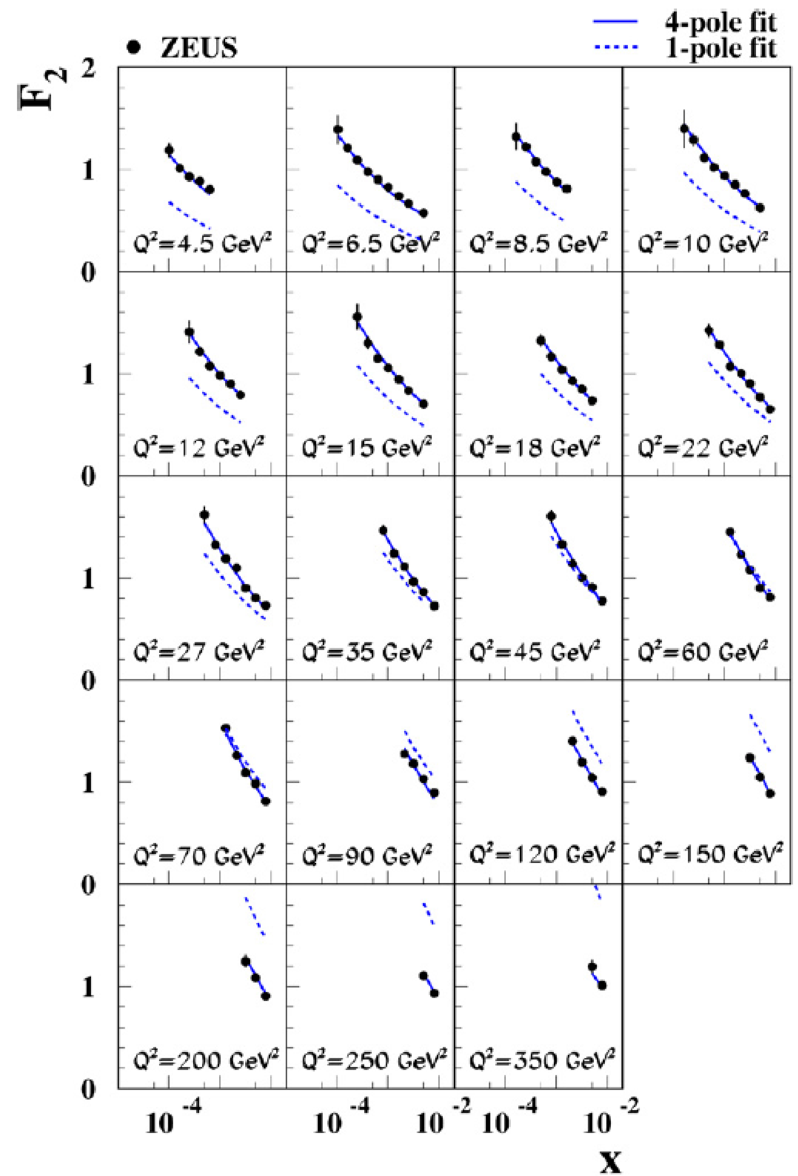
Φ_{DIS} known in QCD

Φ_P barely known

Fit with charm

Correct qualitative behaviour from leading singularity

Excellent fit to data for $x < 10^{-2}$ with 4 poles



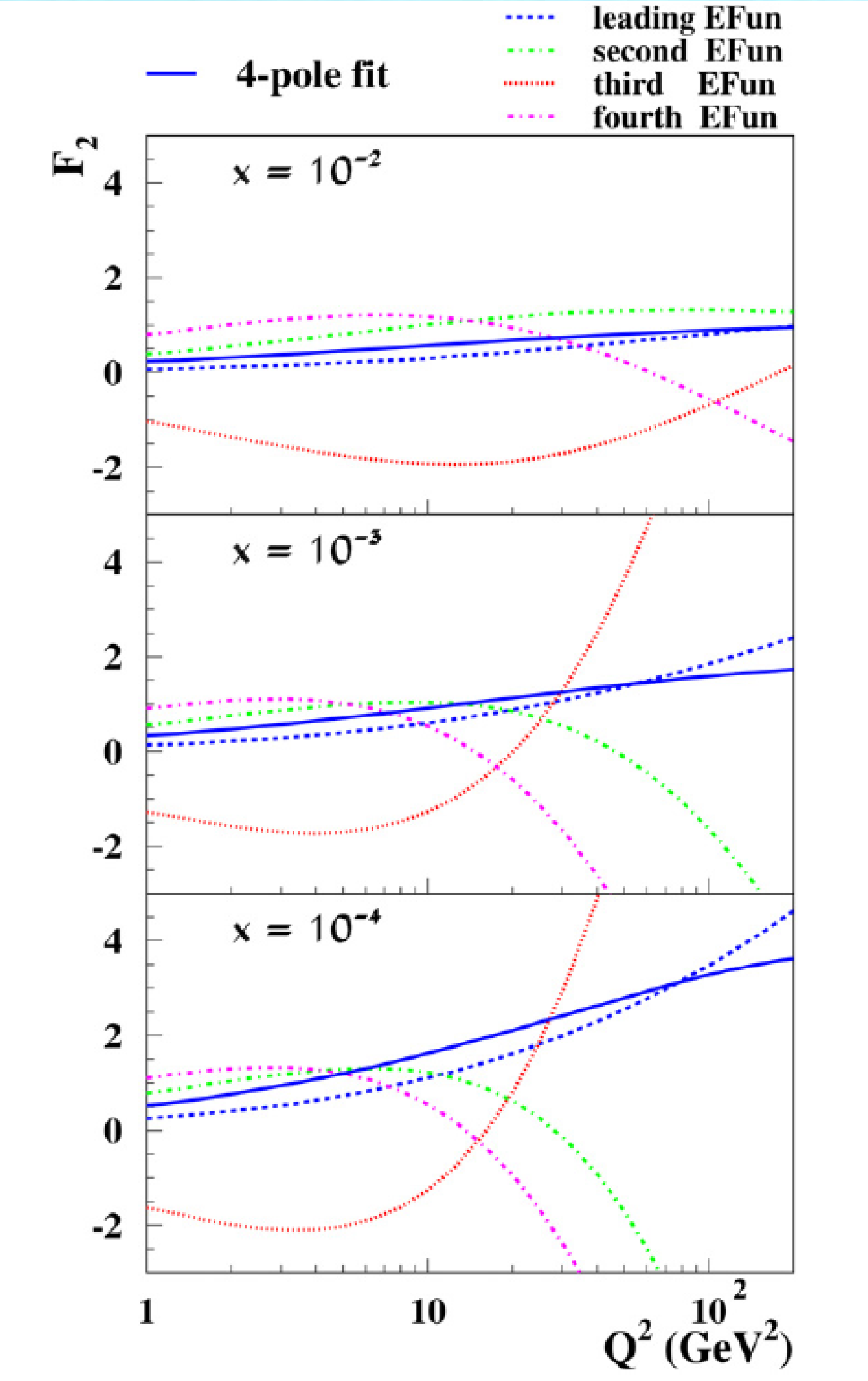
The qualities of fits using up to 4 poles, and the corresponding pole residues, assuming $\eta = -0.16\pi$ at $k_0 = 0.3$ GeV

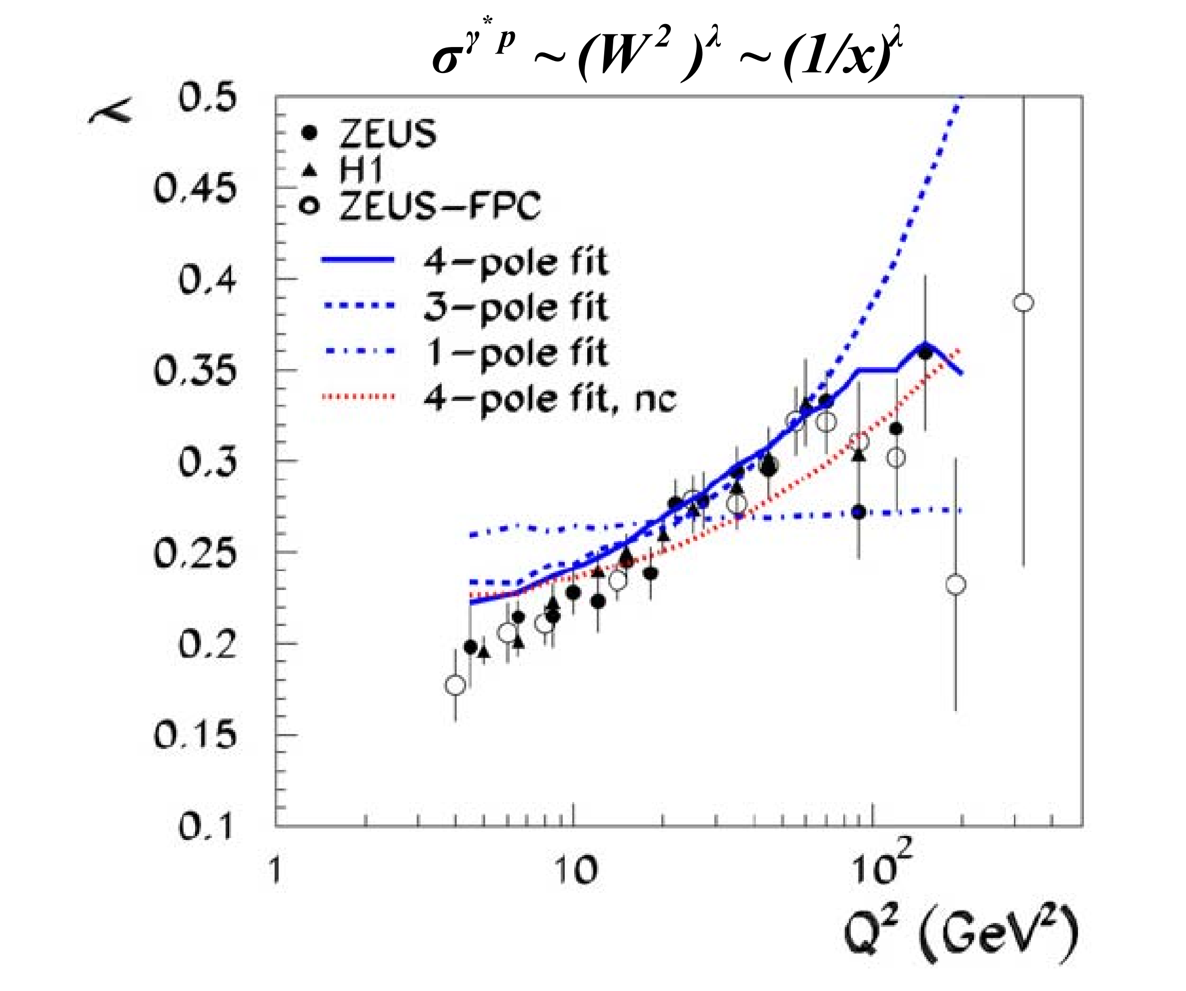
Number of poles	χ^2/N_{df}	a_1	a_2	a_3
1	11 894/101	0.478	–	–
2	1157/100	0.566	−0.98	–
3	167/99	0.707	0.87	3.70
4	83.3/98	0.483	−6.32	−26.0

Contributions to F_2 of the individual eigenfunctions

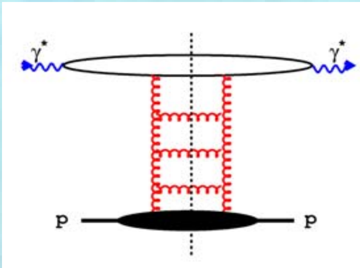
good data description due to interferences

➔ phase η precisely determined

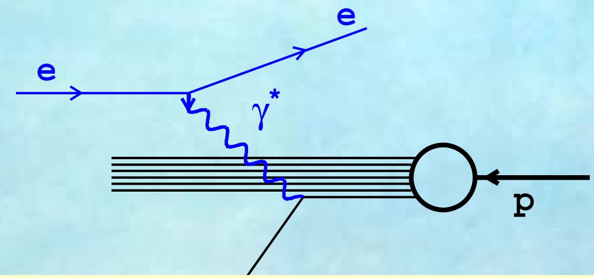




Sum of contributions with small eigenvalues can give a larger rate of rise than the leading eigenvalue !!!

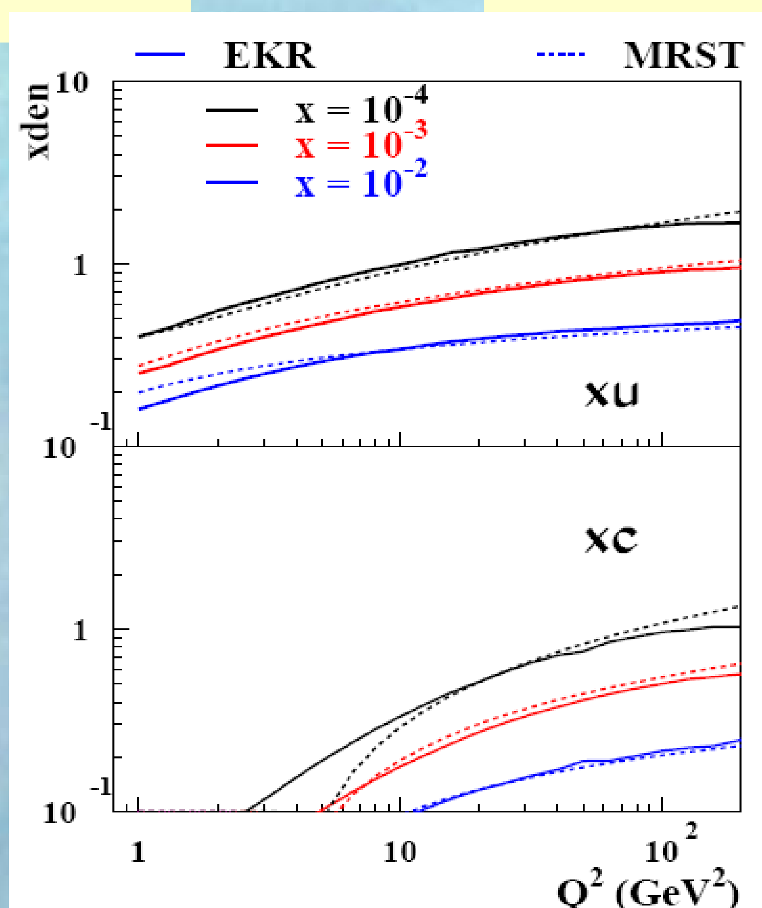


$$F_2(x,Q^2) = x\sum_q e_q^2 q(x,Q^2)$$



$$q(x,Q) = \int_0^Q \frac{dk}{k}\Phi_{DIS}(Q,k)xg(x,k)$$

$$q(x,\mu^2) = q_0(x) + \frac{\alpha_s}{\pi}\int_x^1 \frac{d\xi}{\xi} q_0(\xi)\left\{P_{qq}\left(\frac{x}{\xi}\right)\ln\mu/\kappa + \ldots\right.$$



Where Do BFKL and DGLAP Meet

Lipatov, private communication

Unintegrated BFKL gluon density (LO, no running α_s)

$$xg(x,k^2) = \int d\gamma \Phi_p(\gamma) \left(\frac{k^2}{\mu^2}\right)^\gamma x^{-\bar{\alpha_s}\chi(\gamma)} = \int d\gamma \Phi_p(\gamma) \exp(F(\gamma))$$

$\gamma = ½ + i\nu$

Saddle point

$$(F(\gamma))' = (\gamma \ln(k^2/\mu^2) + \bar{\alpha_s} \ln(1/x)\chi(\gamma))' = 0$$

$$\chi(\gamma) = \frac{1}{\gamma} - 2\zeta(3)\gamma^2 + \cdots \quad \Rightarrow \quad \gamma^2 = \frac{\bar{\alpha}\ln(1/x)}{\ln(k^2/\mu^2)}$$

$$\omega \approx \bar{\alpha_s}/\gamma = \sqrt{\frac{\bar{\alpha_s}\ln(k^2/\mu^2)}{\ln(1/x)}}$$

valid if $\bar{\alpha}(k^2)\ln(1/x) \ll 1,$

! not fulfilled for HERA or even Higgs at LHC !

equal to DLL limit of DGLAP (LO, no running α_s)

Pomeron and Gauge/String Duality

Brower, Polchinski, Strassler, and Tan, hep-th/0603115

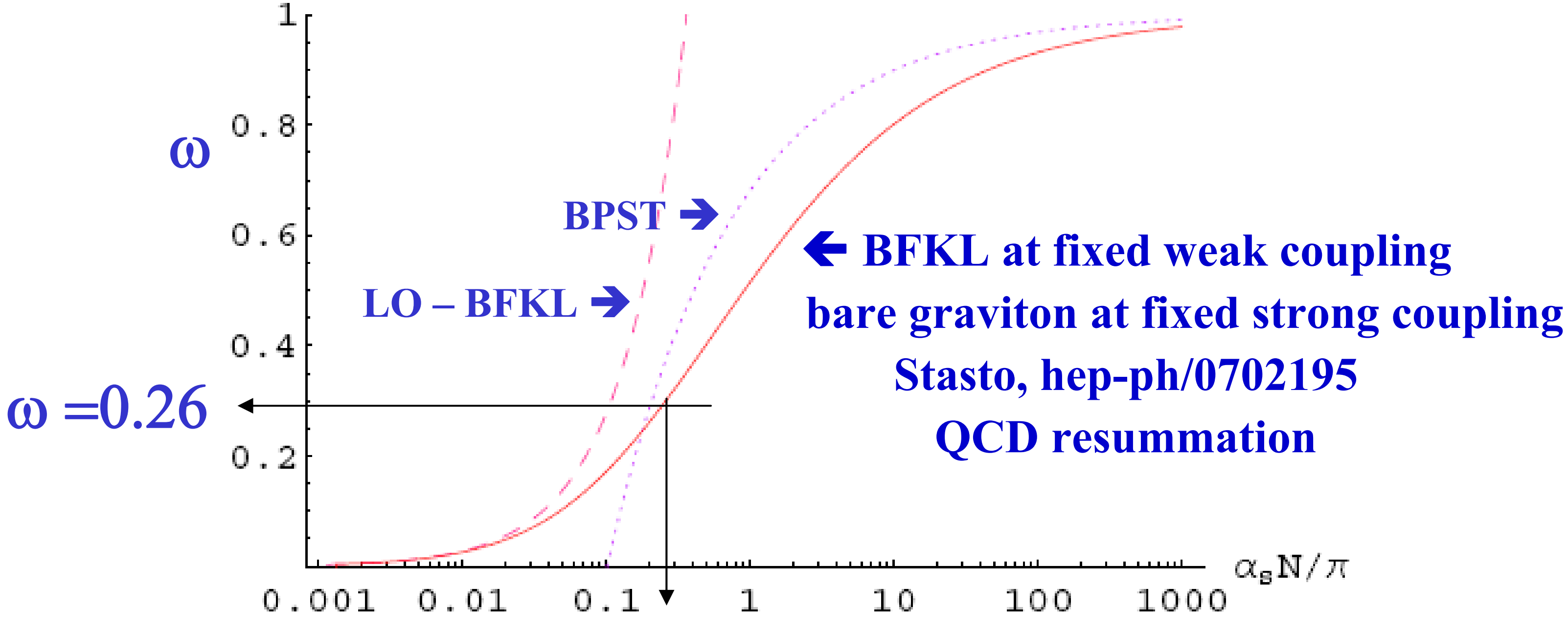
Pomeron is a coherent color-singlet object, build from gluons, with universal properties; it is a closed string propagating in ADS space, when the conformal symmetry is broken at some infrared point in the fifth dimension

$$1+\omega = 2 - \frac{2}{\sqrt{4\pi\alpha_s N}}$$

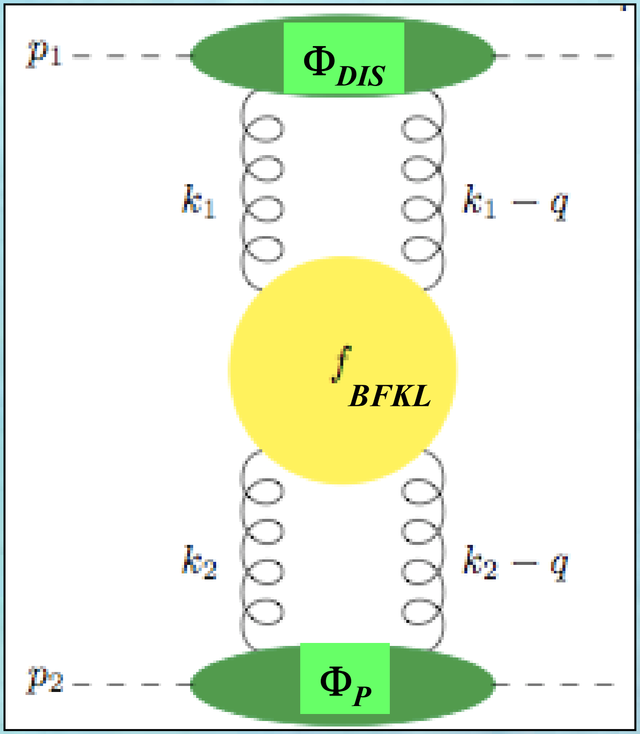
in ADS/CFT

in N=4 YM SuSy QCD

Kotikov, Lipatov, Onishchenko, Velizhanin, Physt. Lett. B 632, 754 (2006)



Φ_{DIS} *known in QCD*



Φ_P *barely known*

Consequences

HERA finding:
Proton consists mainly of gluons
they determine its main propeties,
like the mass

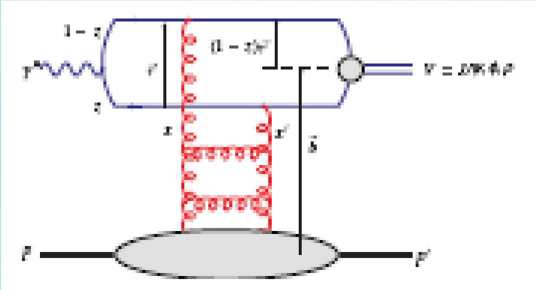
LHeC will substantially improve the knowledge of gluon density

enhancement of leading eigenfun.by $(1/x)^{\omega}$

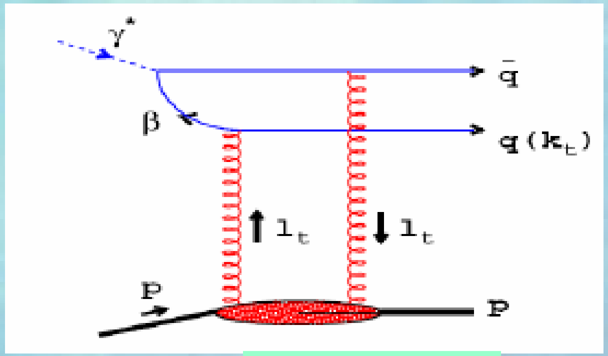
$$xg(x,k) = \sum_n \int \frac{dk'}{k'} \Phi_p(k') \left(\frac{k'x}{k}\right)^{-\omega_n} k^2 f^*_{\omega_n}(k') f_{\omega_n}(k),$$

$\Phi_{p,N}$ -Direct access to the gluonic structure of Protons and Nuclei

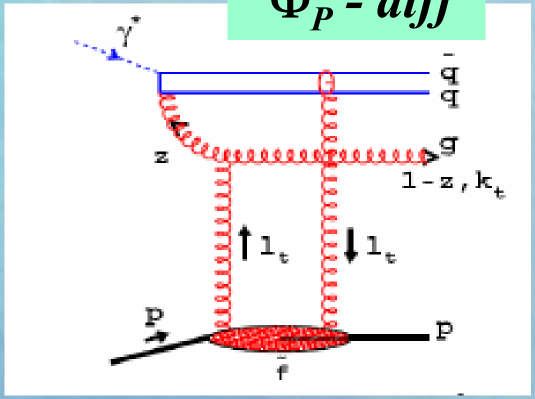
Diffractive Vector Mesons



Diffractive Jets



Φ_P - *diff*



Consequences

Diffraction measurements at LHeC and EIC will substantially improve the knowledge of $\Phi_{p,N}$ – gluonic structure of matter

Pomeron- Graviton relation:
e.g.
Measure the t-dependence of ω:
Is DAF-Pomeron moving towards the Graviton or away from it?

Build detectors which are able to measure diffractive reacti with high precision

Instead of Conclusions

Study of Gluon Density are very important because
it is the analog of Black Body Radiation in QED

It seemed hopeless to study pure Gluon Radiation
since it is never free. However, it is becoming free
for a short moment in HEP reactions

HERA has shown that physics processes at low-x are
completely dominated by pure Gluon Density,

Investigation of Gluon Density has a chance to become as
fundamental as Black Body radiation

The QCD improved parton model
MRST/CTEQ approach

sea quark densities (input: $q_0(x)$ for every quark species..)

$$q(x,\mu^2) = q_0(x) + \frac{\alpha_S}{2\pi}\int_x^1 \frac{d\xi}{\xi} q_0(\xi)\left\{P_{qq}\left(\frac{x}{\xi}\right) ln\frac{\mu^2}{\kappa^2} + C_q\left(\frac{x}{\xi}\right)\right\} + \frac{\alpha_S}{2\pi}\int_x^1 \frac{d\xi}{\xi} g_0(\xi)\left\{P_{qg}\left(\frac{x}{\xi}\right) ln\frac{\mu^2}{\kappa^2} + C_g\left(\frac{x}{\xi}\right)\right\}$$

MS-bar scheme

$$F_2(x,Q^2) = x\sum_q e_q^2 \int_x^1 \frac{d\xi}{\xi} q(\xi,Q^2)\left\{\delta(1-\frac{x}{\xi}) + \frac{\alpha_S}{2\pi} C_q^{\overline{MS}}\left(\frac{x}{\xi}\right) + \ldots\right\} + x\sum_q e_q^2 \int_x^1 \frac{d\xi}{\xi} g(\xi,Q^2)\left\{\frac{\alpha_S}{2\pi} C_g^{\overline{MS}}\left(\frac{x}{\xi}\right) + \ldots\right\}$$

second term gives a very small contribution

How Important is Saturation?

- Eikonal exponentiation (Glauber-Mueller, MV):

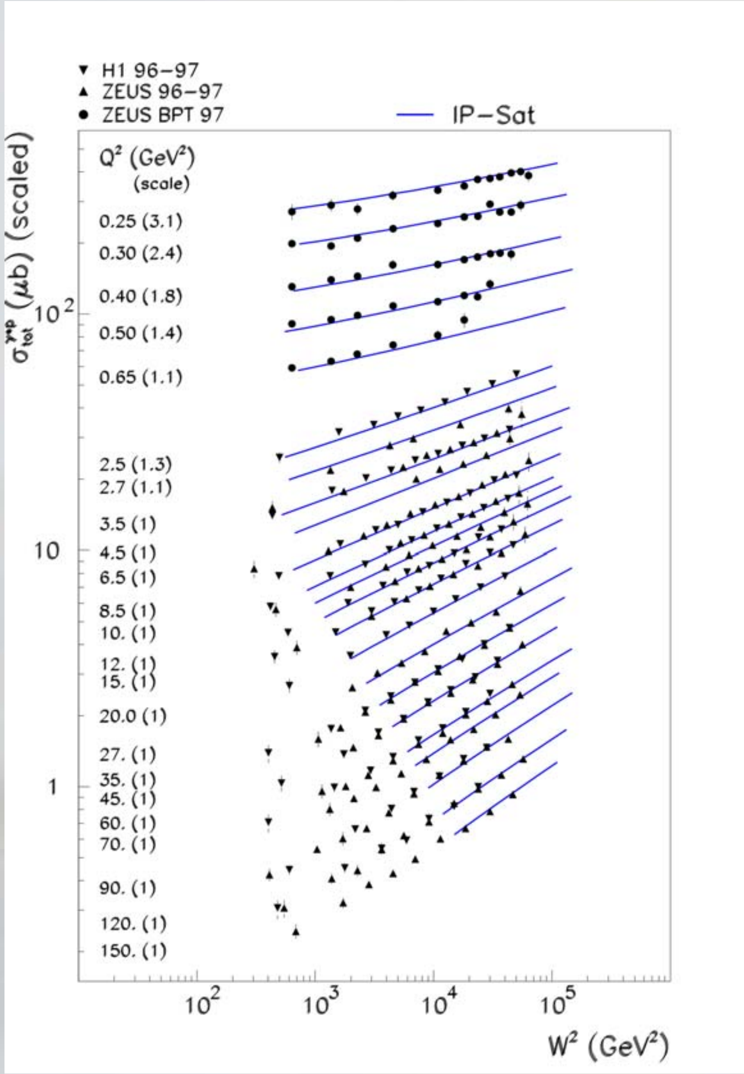
$$\frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}^2 \boldsymbol{b}} = 2\left[1 - \exp\left(-\frac{\pi^2}{2N_c} r^2 \alpha_S(\mu^2) x g(x,\mu^2) T(b)\right)\right]$$

- Depends on impact parameter, momentum scale
- Define saturation scale Q_s by

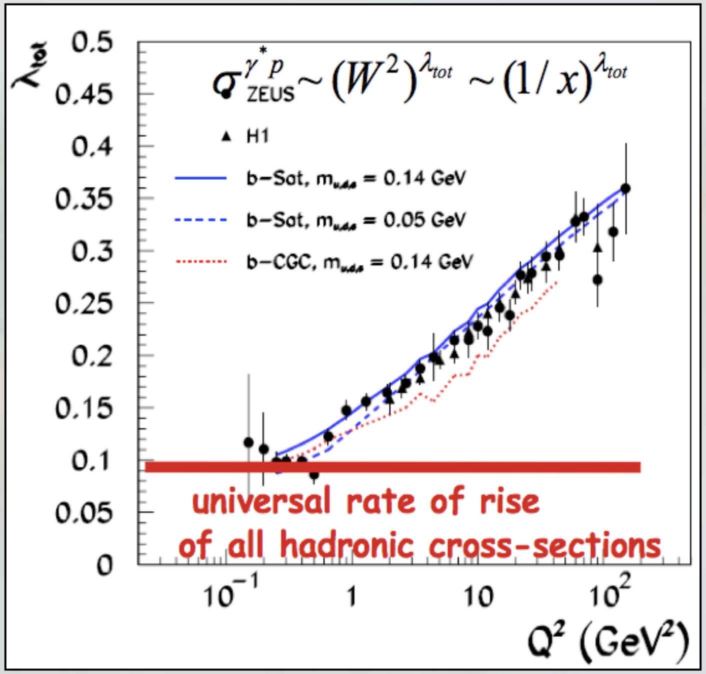
$$\frac{d\sigma_{qq}(x, r^2 = 2/\mathrm{Q}_S^2(x,b))}{d^2 b} = 2\cdot\{1 - \exp(-1/2))\}$$

- Estimate Q_s using indicative models for proton impact-parameter profile and gluon distribution:
- $$xg(x,\mu_0^2) = A_g \left(\frac{1}{x}\right)^{\lambda_g} (1-x)^{5.6}$$ + DGLAP evol.

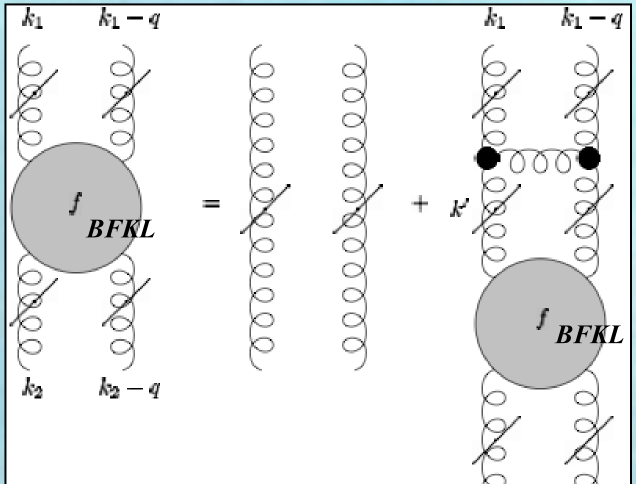
Low-x Physics @ HERA



- Increasing rate of growth with Q^2, well described by DGLAP evolution



Basics of BFKL



BFKL equation at q=0

Conformal invariance

solved by finding a complete set of eigenfunctions

$$\omega \tilde{f}(\omega, \mathbf{k_1}, \mathbf{k_2}) = \delta^2(\mathbf{k_1} - \mathbf{k2}) + \frac{\alpha C_A}{\pi^2} \int \frac{d^2\mathbf{k}'}{(\mathbf{k_1} - \mathbf{k}')^2} \Big[\tilde{f}(\omega, \mathbf{k}', \mathbf{k_2}) - \frac{\mathbf{k_1}^2}{\mathbf{k}'^2 + (\mathbf{k}' - \mathbf{k_1})^2} \tilde{f}(\omega, \mathbf{k_1}, \mathbf{k_2}) \Big]$$

Eigen-functions

$$f_\omega(k^2) = \frac{(k^2)^{i\nu}}{\sqrt{k^2}}$$

Characteristic function

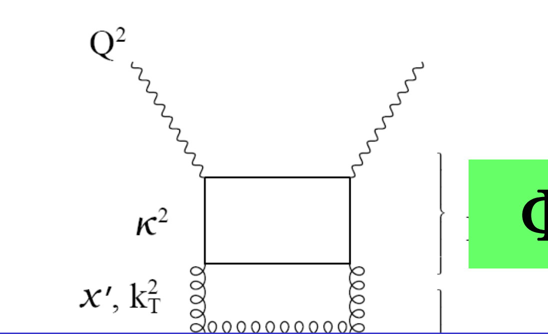
$$\omega = \bar{\alpha}_s \chi(\nu)$$

$\chi(\nu) = -2\gamma_E - \psi(1/2 + i\nu) - \psi(1/2 - i\nu)$

ψ is the Digamma function

Green function

$$f_{BFKL}(\omega, k_1, k_2) = \int_{-\infty}^{\infty} d\nu \left(\frac{k_1^2}{k_2^2} \right)^{i\nu} \frac{1}{2\pi^2 k_1 k_2} \frac{1}{(\omega - \bar{\alpha}_s \chi(\nu))}$$



Φ_{DIS}

Kwiecinski, Martin Stasto

$$S_q(x,Q^2) = \frac{Q^2}{4\pi^2}\int\frac{dk^2}{k^4}\int_0^1 d\beta\int d^2\kappa'\alpha_S\left\{[\beta^2+(1-\beta)^2]\left(\frac{\boldsymbol{\kappa}}{D_{1q}}-\frac{\boldsymbol{\kappa}-\boldsymbol{k}}{D_{2q}}\right)^2\right.$$

$$\left. + \; [m_q^2+4Q^2\beta^2(1-\beta)^2]\left(\frac{1}{D_{1q}}-\frac{1}{D_{2q}}\right)^2\right\} f\left(\frac{x}{z},k^2\right)\Theta\left(1-\frac{x}{z}\right)$$

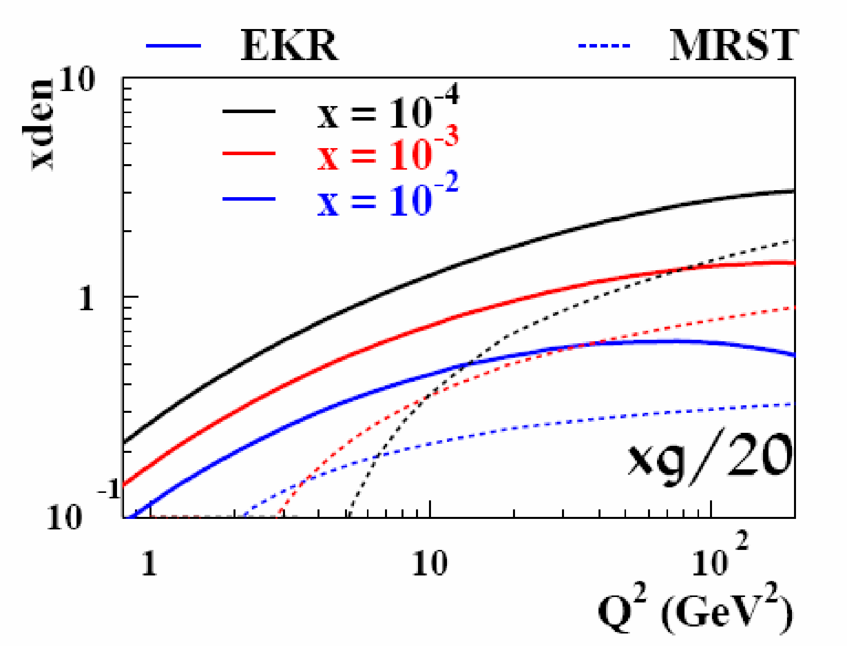
$\kappa' = \kappa - (1-\beta)k$ and

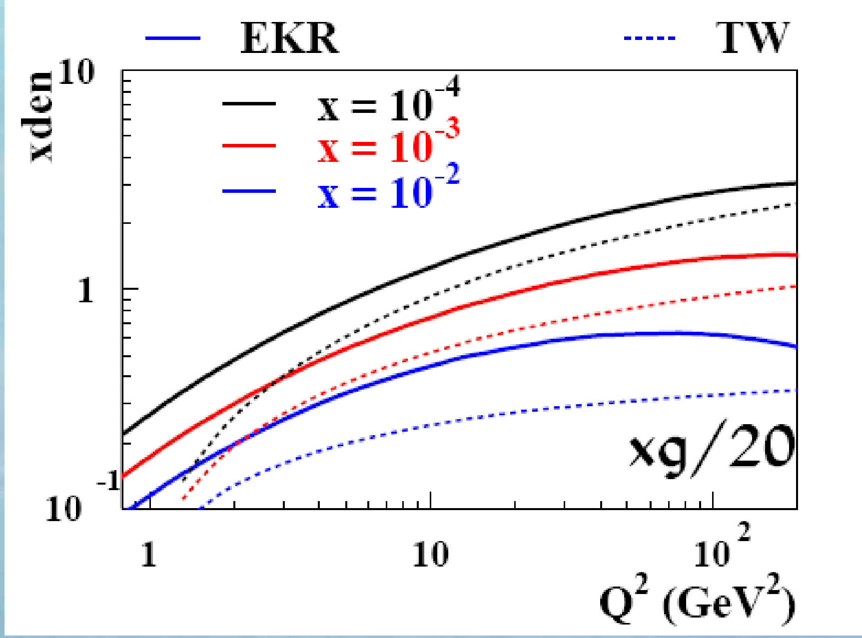
$$D_{1q} = \kappa^2 + \beta(1-\beta)Q^2 + m_q^2$$

$$D_{2q} = (\boldsymbol{\kappa}-\boldsymbol{k})^2 + \beta(1-\beta)Q^2 + m_q^2$$

$$z = \left[1 + \frac{\kappa'^2+m_q^2}{\beta(1-\beta)Q^2} + \frac{k^2}{Q^2}\right]^{-1}.$$

$$F_2 = \sum_q e_q^2(S_q+V_q),$$


EKR
MRST
xden
x = 10^{-4}
x = 10^{-3}
x = 10^{-2}
xg/20
Q^2 (GeV^2)


EKR
TW
xden
x = 10^{-4}
x = 10^{-3}
x = 10^{-2}
xg/20
Q^2 (GeV^2)

Pomeron-Graviton Correspondence

$$\alpha(t) = \alpha_0 + \alpha' t$$

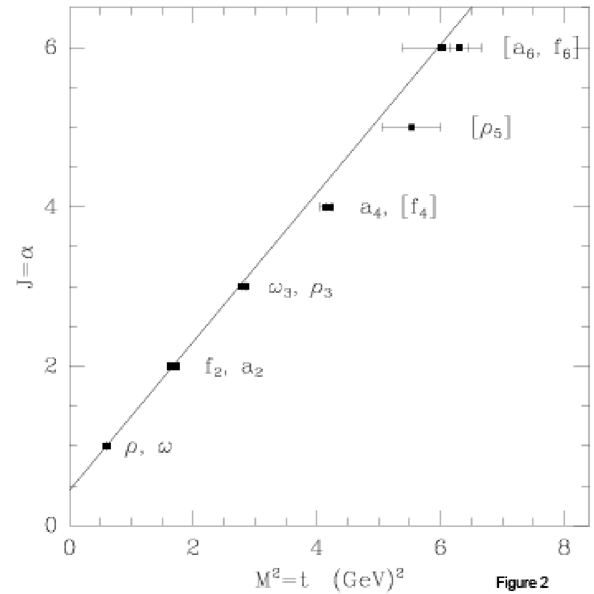


Figure 2

String theory emerged out of phenomenology of hadron-hadron scattering

Dolan-Horn-Schmid duality between s-channel and t-channel Regge-pole description of hadronic X-sections

$$\sum_r \frac{g_r^2(t)}{s-(M_r-i\Gamma_r)^2} \simeq \beta(t)(-\alpha' s)^{\alpha(t)} .$$

➔ Veneziano amplitude

$$A_{\pi^+\pi^-\to\pi^+\pi^-}(s,t) = g_o^2 \frac{\Gamma[1-\alpha_\rho(t)]\Gamma[1-\alpha_\rho(s)]}{\Gamma[1-\alpha_\rho(s)-\alpha_\rho(t)]}$$

generalization by Virasoro ➔ dual models

$$A(s,t,u)=\beta\frac{\Gamma(\frac{1}{2}-\frac{1}{2}\alpha(s))\Gamma(\frac{1}{2}-\frac{1}{2}\alpha(t))\Gamma(\frac{1}{2}-\frac{1}{2}\alpha(u))}{\Gamma(1-\frac{1}{2}\alpha(t)-\frac{1}{2}\alpha(u))\Gamma(1-\frac{1}{2}\alpha(s)-\frac{1}{2}\alpha(u))\Gamma(1-\frac{1}{2}\alpha(s)-\frac{1}{2}\alpha(t))}$$

➔ mesons are open strings, closed strings necessary for unitarity

L - string length, $E = c\,L$, $J = \alpha' E^2$

Virasoro-amplitude for $\alpha(0)$=1 has a pole at $s = t = 0$ with J = 2, a graviton ➔ starting point for theory of quantum gravity

Superstring Theory, Green, Schwarz, Witten (1987)
R. Brower hep-th/0508036

Maldacena Conjecture

from the talk by J. Maldacena

Particle theory = gravity theory

Most supersymmetry QCD theory	=	String theory on $AdS_5 \times S^5$

(J.M.)

N colors

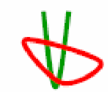
N = magnetic flux through S^5

Radius of curvature

$$R_{S^5} = R_{AdS_5} = \left(g_{YM}^2 \; N\right)^{1/4} l_s$$

Duality:

$g^2 N$ is small → perturbation theory is easy – gravity is bad



$g^2 N$ is large → gravity is good – perturbation theory is hard

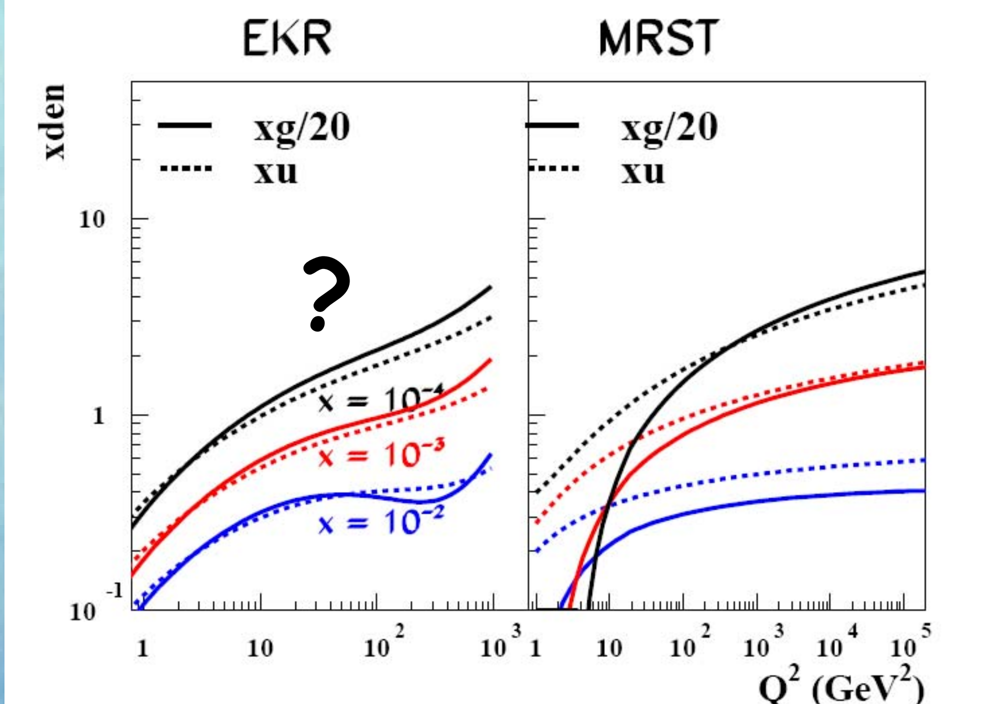
Strings made with gluons become fundamental strings.

Consequences for LHC

Good knowledge of gluon density around $x \sim 10^{-2}$ and $Q^2 \sim 10000$ GeV^2 is essential for LHC physics (Higgs region)

Large effort is going into precise measurement of W and Z inclusive X-sections ➔ precise determination of sea-quark distributions
➔ precise gluon density

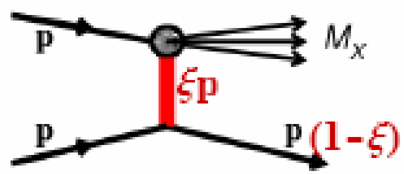
Is the sea-quark ←→ gluon density relation the same in the DGLAP-like picture (MRST/CTEQ) and DAF-Pomeron?



sea-quark←→ gluon relation can be checked by the jets with p_T around 50 GeV

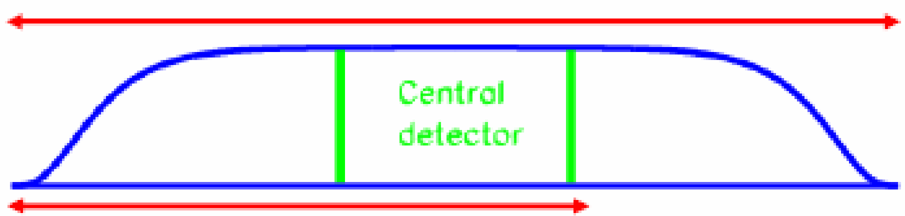
Consequences for LHC

Proton dissociation



In high pp (ep) reactions particles are emitted approximately uniformly along the rapidity axis ➔

rapidity range in ND $= \ln(s/m^2_\pi)$



rapidity range in SD $= \ln(M_X^2/m_\pi^2)$ ➔ rapidity gap $\Delta Y = \ln(s/M_X^2)$

$M_X^2/s = \xi$ - fraction of the proton momentum carried by the pomeron

ξ is called x_{IP} in *ep*,

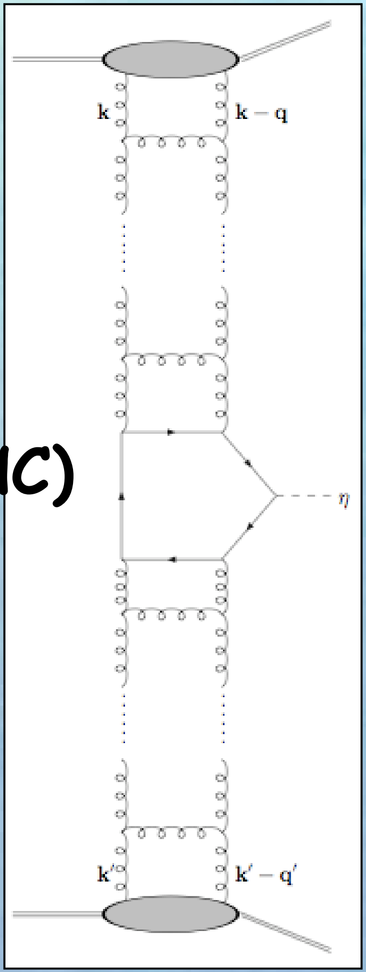
minimum ξ at LHC $= 1.4/s = 7 * 10^{-9}$ *(deep in the saturation region)*

probability to find ξ, $P(\xi) \sim 1/\xi \, d\xi$

Can be measured with help of forward detectors down to x~10^{-7} ?

Consequences for LHC

- Consider diffractive production of a 'small' object
- Single or double diffraction?
  - $y = \ln(s/m_X^2)$ or $y_1 + y_2 = \ln(s/m_X^2)$?
  - Examples:
    - pp $\rightarrow$ p (jet pair), pp $\rightarrow$ p (D Λ_c)
    - pp $\rightarrow$ p η_c p, **(RHIC)** pp $\rightarrow$ p H p **(LHC)**
    - pp $\rightarrow$ p (jet pair) p



Measure the t-dependence of ω:
Is DAF-Pomeron moving towards
the Graviton or away from it? (EIC)

Consequences for EIC

Measure precisely the dependence of inclusive
and exclusive diffractive processes (DVCS, J/Psi, rho, phi…)
➔Investigate QCD evolution with diffractive processes
pure evolution of ~(gluon density)^2
t-dependence of effective exponents

➔!!! Investigate Structure of Matter as x increases !!!

Note: QCD evolution at HERA studied only with F_2
H1 and ZEUS measurement for F_2 agree to ~3%
for diffractive processes systematic differences
are factor 10 larger

Main reason: HERA experiments control only ~2/3
of the rapidity range

NLO BFKL with running α_s

solution away from k_{crit}

$$\overline{f_\omega}(k) = e^{\pm i\varphi_\omega(k)},$$

$$\varphi_\omega(k) = 2\int_k^{k_{\rm crit}} \frac{dk'}{k'} |\nu_\omega(k)|.$$

for all regions:

$$\begin{aligned}\overline{f_\omega}(k) &= \sqrt[3]{\varphi_\omega(k)}\left[J_{\frac{1}{3}}(\varphi_\omega(k)) + J_{-\frac{1}{3}}(\varphi_\omega(k))\right], \quad (k < k_{\rm crit}),\\ &= \sqrt{3}\sqrt[3]{\varphi_\omega(k)} K_{\frac{1}{3}}(\varphi_\omega(k)), \qquad (k > k_{\rm crit}),\end{aligned}$$

Matching the solutions at $k=k_{crit}$ determines the **phase of oscillations** = $\pi/4$

near $k \sim k_0$

$$\overline{f_\omega}(k) \sim \sin\left(\frac{\nu_\omega(k_0)}{k_0^2}\left(k^2 - k_0^2\right) - \eta\right).$$

Lipatov 86 ➔ encode the infrared behaviour of QCD by assuming a **fixed phase η at k_0**

Quantization condition

$$\varphi_\omega(k_0) \equiv 2\int_{k_0}^{k_{\rm crit}} \frac{dk'}{k'} |\nu_\omega(k)| = \left(n - \frac{1}{4}\right)\pi + \eta,$$

The QCD improved parton model
MRST/CTEQ approach

sea quark densities

$$q(x,\mu^2) = q_0(x) + \frac{\alpha_S}{2\pi}\int_x^1 \frac{d\xi}{\xi} q_0(\xi)\left\{P_{qq}\left(\frac{x}{\xi}\right) ln\frac{\mu^2}{\kappa^2} + C_q\left(\frac{x}{\xi}\right)\right\} + \frac{\alpha_S}{2\pi}\int_x^1 \frac{d\xi}{\xi} g_0(\xi)\left\{P_{qg}\left(\frac{x}{\xi}\right) ln\frac{\mu^2}{\kappa^2} + C_g\left(\frac{x}{\xi}\right)\right\}$$

MS-bar scheme

$$F_2(x,Q^2) = x\sum_q e_q^2 \int_x^1 \frac{d\xi}{\xi} q(\xi,Q^2)\left\{\delta(1-\frac{x}{\xi}) + \frac{\alpha_S}{2\pi} C_q^{\overline{MS}}\left(\frac{x}{\xi}\right) + \ldots\right\} + x\sum_q e_q^2 \int_x^1 \frac{d\xi}{\xi} g(\xi,Q^2)\left\{\frac{\alpha_S}{2\pi} C_g^{\overline{MS}}\left(\frac{x}{\xi}\right) + \ldots\right\}$$

second term gives a very small contribution

Consequences for EIC

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pure evolution of (gluon density)^2

t-dependence of effective exponents!

Note: QCD evolution at HERA studied only with F_2

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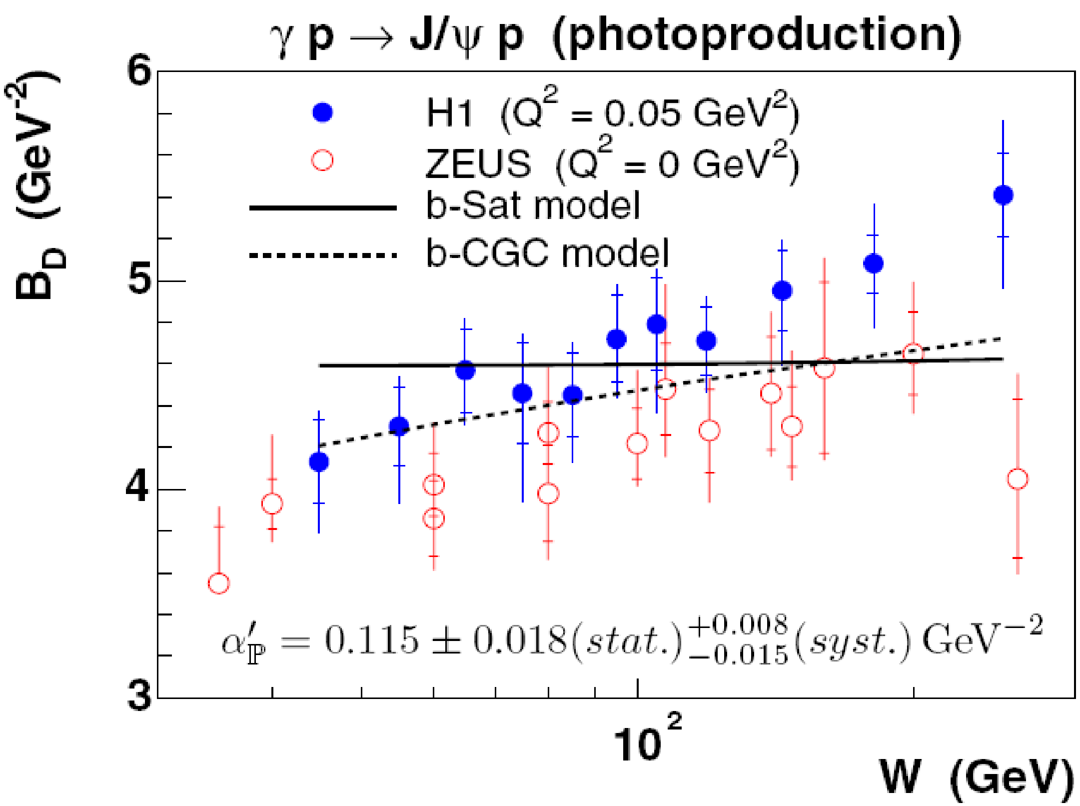
for diffractive processes systematic diffrences are factor 10 larger

Main reason: HERA experiments control only ~2/3 of the rapidity range

measurement of α’



Significant slope is expected for a leading pomeron trajectory Lipatov (1986)

$$J_n(t) = 1 + \frac{c}{n + \delta(t)}$$

BPST ➔ $\alpha' = R^2 / g_{YM}\sqrt{N}$