J Bartels

Summary : Diffraction

part I : theory

Contributions from:

- Vacca
- I. Ivanov
- Collins
- Schoeffel
- Golec Biernat
- Peschanski
- Stasto
- Schildknecht
- Royon
- Gieseke
- Enberg
- Guzey
- Teubner

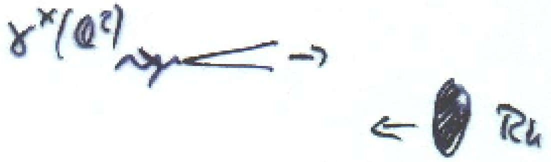
Preface I

What are the long-term prospects of (hard) diffraction?

Before HERA: diffraction in hadron-hadron collisions
"large-large"

typical distance scale: hadron radius
→ nonperturbative

At HERA: diffraction in γ^*-hadron collisions
"small-large"



pQCD applicable around the virtual photon

At LEP, TESLA: diffraction in $\gamma^*\gamma^*$-collisions
"small-small"

pQCD applicable

→ Diffraction at small and large (transverse) distances

→ that is what we need for QCD!

Diffractive scattering at high energies:

small transverse size projectiles

"γ^*"

- strong growth with energy

$$\sigma_{tot}^{\gamma^* p} \sim \left(\frac{1}{x}\right)^{\lambda \sim 0.3}$$

- at large Q^2: no growth

$$\alpha'_{\mathbb{P}} \approx 0$$

- language of QCD partons
gluon radiation
DGLAP, BFKL, ...

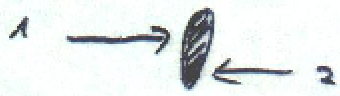
large transverse size projectiles

"p"

- weaker growth

$$\sigma_{tot}^{pp}, \sigma_{tot}^{\gamma p} \sim (W^2)^{\epsilon}$$

- growth of interaction size



$$\frac{d\sigma}{dt} \sim e^{Bt}, \quad B^2 = R_1^2 + R_2^2 + 2\alpha' \ln s$$

$$\alpha' = 1/4 \ \mathrm{GeV}^{-2}$$

"manifestation of QCD binding forces"

hadronic degrees of freedom:
Pomeron, Regge,
Vector dominance, ..
"effective theories"

$$\boxed{\text{transition from pQCD to: "confinement in high energy scattering"}}$$

analysis of small-distance part

transition: "saturation"

concepts of hadron-scattering

Preface II

Fundamental issue in QCD:

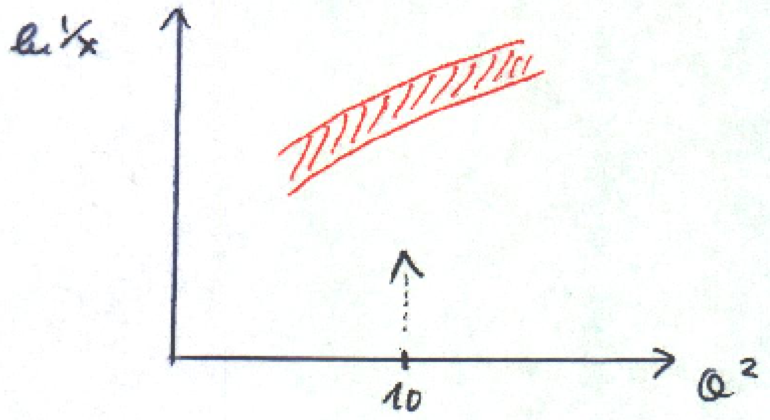
analysis, measurement of parton densities

HERA contribution:

new kinematical region: small-x_B. (at sizable Q^2).

Before transporting this to LHC (and future colliders):

how far down in x can we use **pdf's** and DGLAP?



Experience has shown:

- F_2 + DGLAP very relevant
- useful approach: color dipole picture

$$\sigma_{tot}^{\gamma^* p} = \frac{4\pi^2\alpha}{Q^2} F_2 = C \otimes \text{pdf} \quad = \int_0^1 dz \int d^2r \, \Psi^*(Q,z,\vec{r}) \, \sigma_{q\bar{q}}(z,\vec{r},x) \, \Psi(Q,z,\vec{r})$$

studied in diffraction

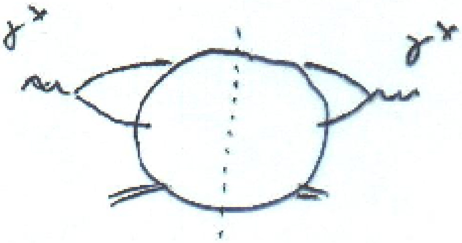
Special ~~remark on diffraction at HERA~~:

"Diffractive final states give much more information on $\sigma_{q\bar{q}}(z, \vec{r}, x_B)$ than F_2 alone"

a) Dependence upon $\vec{r}$:

From F_2:

$\sigma_{tot}^{\gamma^* p} = \frac{1}{s} \mathrm{Im}\, T^{\gamma^*\gamma^*}(W^2, 0)$:



$$\int dz \int d^2r \; \psi^*(Q, z, \vec{r}) \, \sigma_{q\bar{q}} \, \psi(Q, z, \vec{r})$$

From diffraction:

$$T^{\gamma^* V} \sim \int dz \int d^2r \; \psi^* \; \sigma_{q\bar{q}} \; \psi^V(Q, z, \vec{r})$$

$$\frac{d\sigma}{dt} \sim \int dz \int d^2r \; \psi^* \; \sigma_{q\bar{q}}^2 \; \psi$$

b) Dependence upon t: dependence upon impact parameter

interaction radius

$$\frac{d\sigma}{dt} \sim e^{-B|t|}$$

→ this information can be obtained only from diffraction!

Organization of this report:

(A) Work on the short distance region

(B) Transition region: Saturation

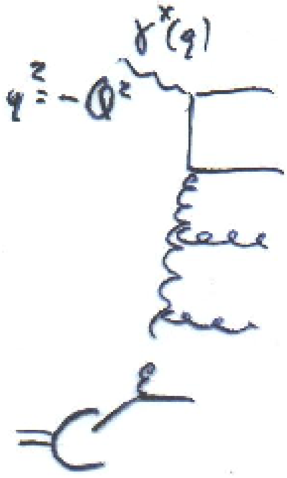
[(C) Hadronic Concepts]

A. The short-distance region: pQCD

Identify questions which need to be answered: J. Collins

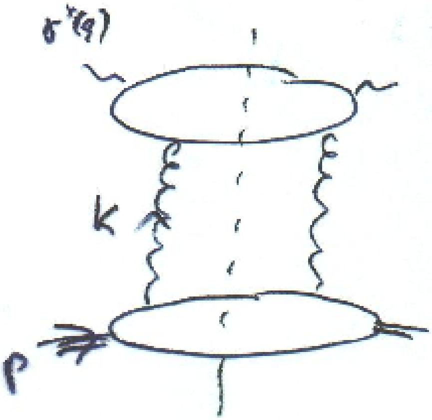
For structure function F_2 at small x:

1) unintegrated parton densities may be better suited (kT-factorization)



↓ large partons, smaller $k_\perp$ (usually)

Factorization:



no logs of Q or x

k^-: neglect in top part

k_T: if $\ll Q$, absorb k_T-integral into lower part

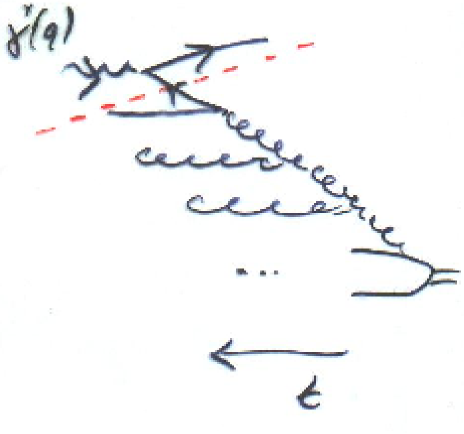
if not negligible vs Q: k_T-integral → convolution → unintegrated pdf.

Can this be done consistently, in NLO etc?

2) Connection between structure function and dipole picture: "different time ordering"

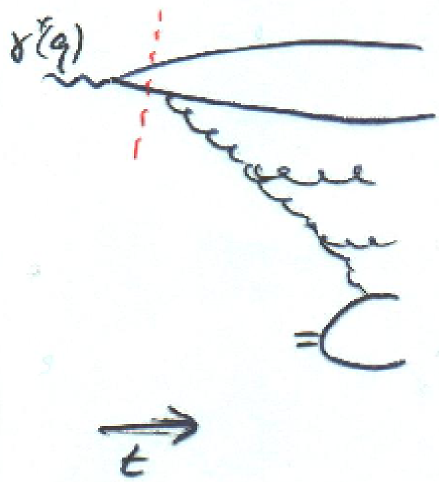
"DIS picture"
(Breit frame)

$F_2 = C \otimes \text{pdf}$



"dipole picture"

$\sigma = \frac{4\pi^2\alpha}{Q^2} F_2 = \int dz\, d^2r\, \psi^* \sigma\, \psi$



"Same Feynman diagrams, when translated to space-time, have different interpretations, depending upon reference frame chosen."

3) Region of validity, overlap?

$F_2 = C \otimes \text{pdf}$ $\qquad\qquad$ $\sigma^{\gamma^* p} = \int dz\, d^2r\, \psi^* \sigma \psi$

DLA $\qquad\qquad$ small r:

$$\sigma \sim \frac{\pi r^2 \alpha_s(\bar{Q}^2)}{3}\, x g(x, \bar{Q}^2)$$

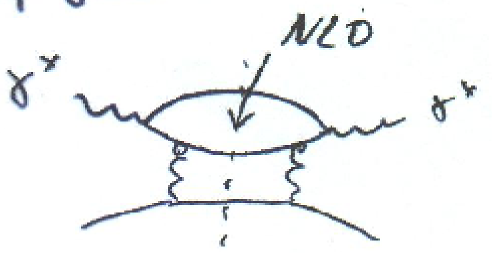
$$\bar{Q}^2 = \frac{\lambda}{r^2}$$

Common region

What about NLO?

Beyond small r^2: modelling (higher twist, nonpert. physics)

Work in progress: $\qquad\qquad$ S. Gieseke



Can this be written as:

$$\int dz_1 \int d^2r\, \psi^*(z,r)^{(1)}\, \sigma^{(2)}\, \psi(z,r)^{(1)} + \dots$$

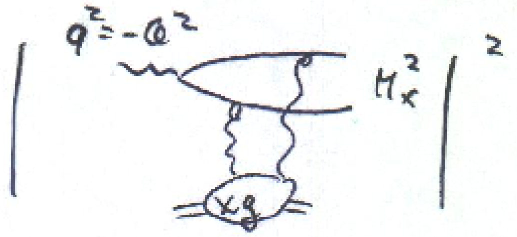
$$+ \int dz_1 dz_2 \int d^2r_1 d^2r_2\, \psi^*(z_1 z_2\, r_1 r_2)\, \sigma^{(3)}\, \psi(z_1 z_2\, r_1 r_2) \quad ?$$

Connection between $\sigma^{(2)}, \sigma^{(3)}$ and NLO pdf?

Exploring the limits of pQCD:

Teubner

Compute F_2^D at $\beta \to 1$:



$\beta = \frac{Q^2}{Q^2+M^2} \to 1$ means small M_x^2

why "good" candidate:

- $q\bar{q}$ dominates
- F_L^D large, calculable in pQCD
- F_T^D also calculable in pQCD, provided β close to 1

Particular interest:

skewedness of gluon density

Results: (Figs. in H. Abramowicz' talk)

- skewedness is an important effect
- seems to discriminate between different gluon density parametrizations

Modelling the transition:

Golec-Biernat

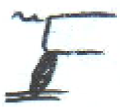
News from GBW-model: used for initial conditions of diffractive parton densities

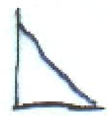
At not too large Q^2: (BEKW)

$$F_2^{D(3)}(\beta, Q^2; x_P) = F^T_{q\bar{q}} + F^L_{q\bar{q}} + F^T_{q\bar{q}g}$$

- model the "exchange" by GBW-dipole cross section
- use DGLAP to evolve to larger Q^2

Define initial conditions (at $Q_0^2 = 3\ \mathrm{GeV}^2$)

 $\rightarrow$  $\rightarrow q^D(\beta, Q^2; x_P)$ 

 $\rightarrow$  $\rightarrow g^D(\beta, Q^2; x_P)$ 

Regge factorization: for the leading-twist part simple x_P-dependence

$$F_2^{D(3)LT} \sim \left(\frac{1}{x_P}\right)^{1+\lambda}, \quad \lambda = 0.29 \text{ from } F_2$$

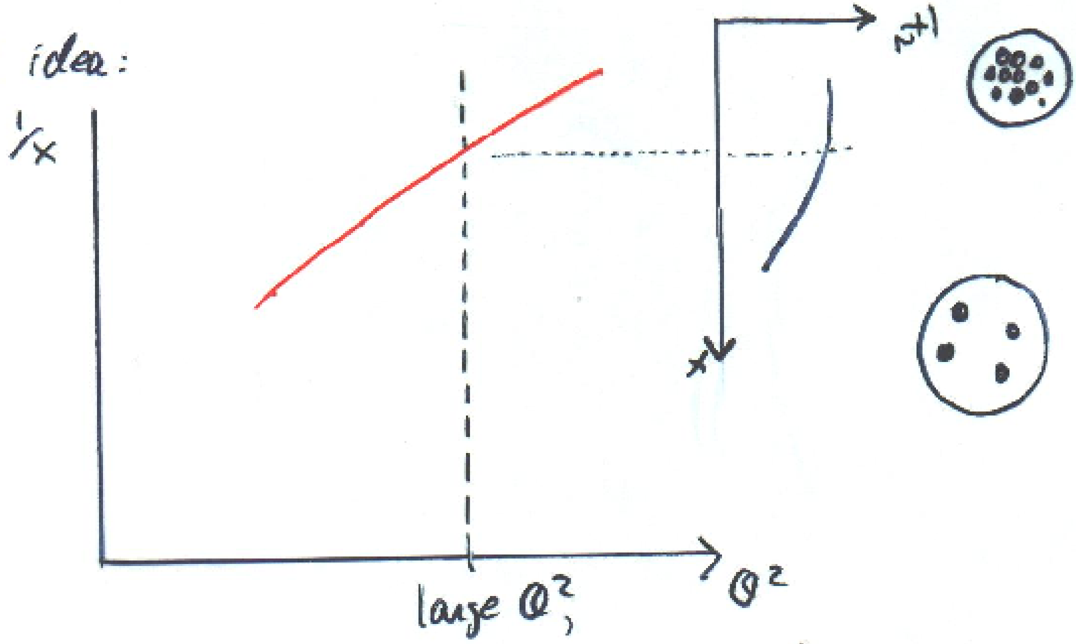
"Regge factorization" with $\alpha_{P\,eff} = 1.15$ $\left(\begin{array}{l} \text{H1: } 1.17 \\ \text{ZEUS: } 1.13 \end{array}\right)$

DGLAP evolution, comparison with H1, ZEUS data: (apart from $Q_0^2 = 3$ no free parameter)

good (except large β, large Q^2)

B. The transition region: saturation

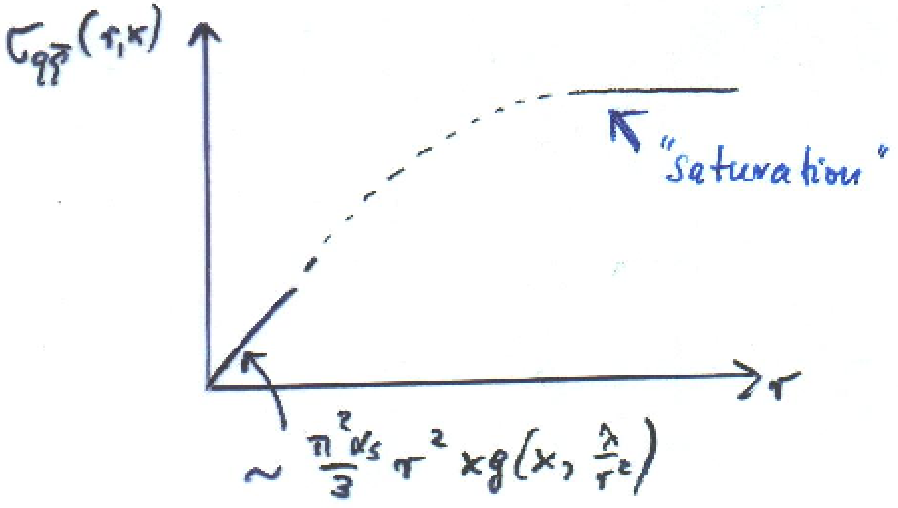
Original idea:



$\left\{ \begin{array}{l} \text{small } \alpha_s, \\ \text{short-distance physics} \end{array} \right\}$

at HERA: flattening in F_2 not seen

Translated into color dipole language:



Golec-Biernat, Wüsthoff

Lublinsky

Schildknecht

"saturation may be present at HERA but evidence more subtle"

$\longrightarrow$ study $\sigma_{q\bar{q}}$ in diffraction!

A novel look at saturation:

A. Stasto

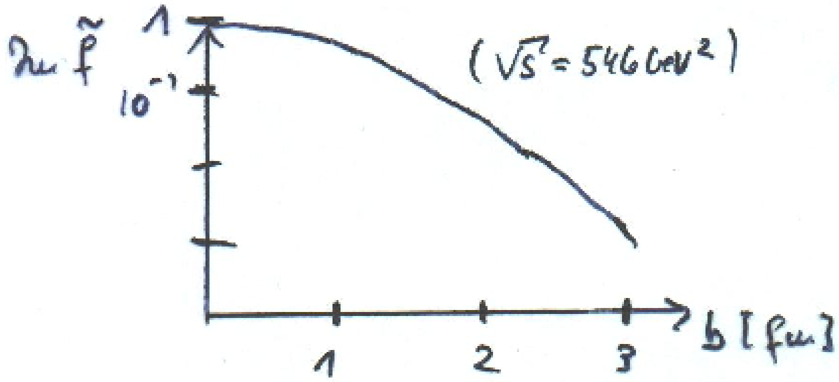
Saturation in pp-scattering (Arnaldi-Schubert):

$$\frac{d\sigma}{dt} = |f(t)|^2 \quad : \text{measurement} \to f(t)$$

In impact-parameter space:

$$\tilde{f}(b) = \frac{1}{2\pi^{3/2}} \int d^2q \, e^{i\vec{q}\vec{b}} f(-\vec{q}^{\,2}) \qquad t = -\vec{q}^{\,2}$$

unitarity bound: $\text{Im}\,\tilde{f}(b) \leq 1$



(Kopeliovich et al.)

$\to$ saturation, energy dependence depends upon $\vec{b}$

Same analysis for $\gamma^* p \to V p$:

$$f(t) \to \sum \int d^2r \, \psi^* f^{q\bar{q}}(x, \vec{r}, \vec{q}) \, \psi$$

depends upon size $\vec{r}$!
Needs unfolding
$\longrightarrow$ fits.

(Longitudinal ρ_0)

$|t| < |t_{max}| = 0.6\,\text{GeV}^2$

$b > 0.3$ fm

Saturation may be present at HERA for small $\vec{b}$, low Q^2

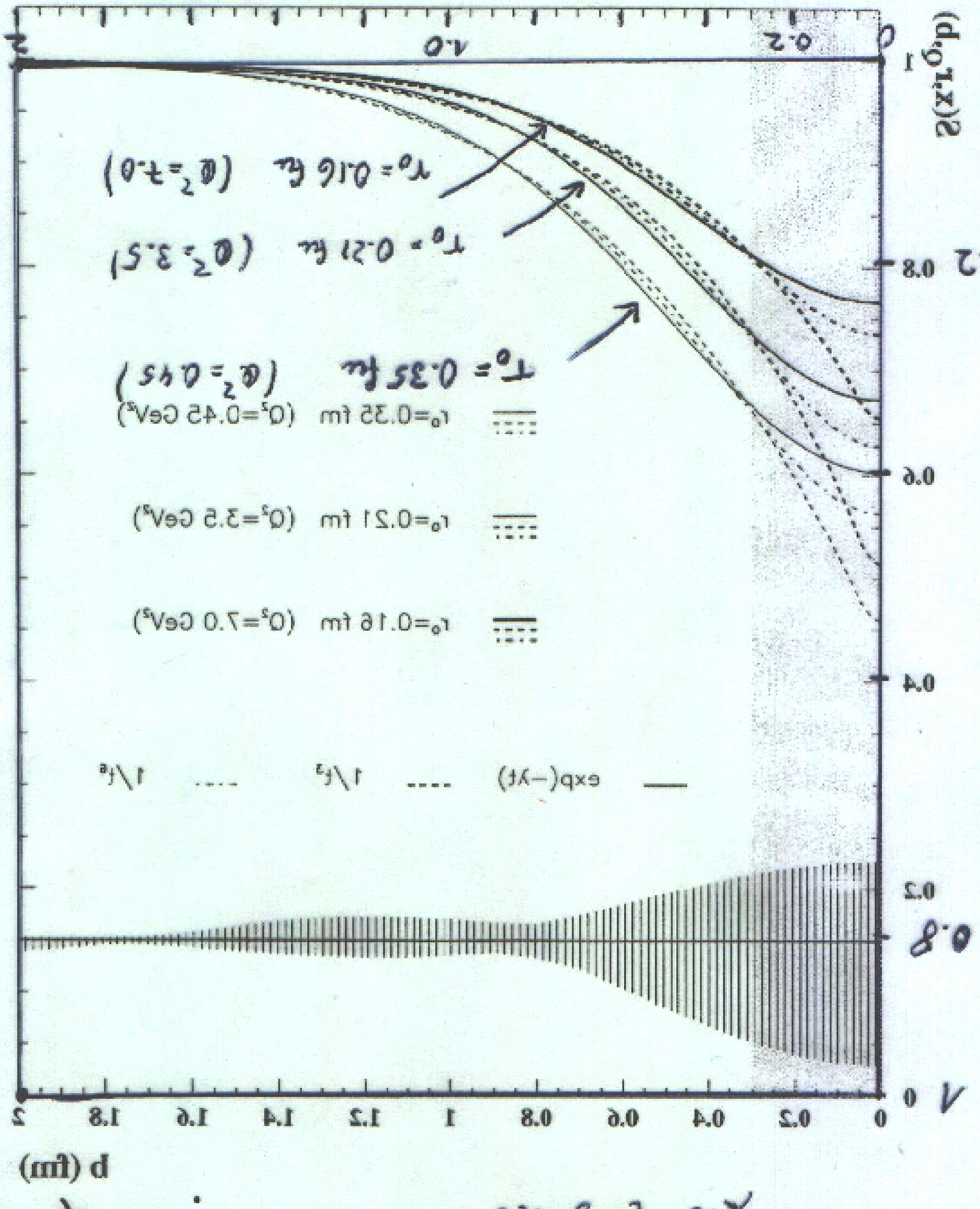
Estimate for saturation scale:

$Q_S^2 = 1 - 1.5\,\text{GeV}^2$ for $b = 0.3$ fm

$Q_S^2 = 0.2\,\text{GeV}^2$ for $b = 1$ fm

S - matrix as a function of impact parameter b, plotted for different values of Q^2

$(x \simeq 4 \div 5 \cdot 10^{-4})$



$x \sim 4 - 5 \cdot 10^{-4}$

impact parameter

The Odderon - Issue

Vacca
Ivanov
Golling

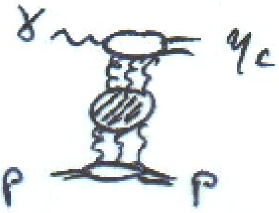
Old problem in hh-scattering:

is there a C-odd partner of the Pomeron with intercept $\alpha_{odd}(0) \simeq 1$?

If so: contributes to diffraction!

Experimental evidence: from $\frac{d\sigma^{pp}}{dt} - \frac{d\sigma^{p\bar{p}}}{dt}$, not unambiguous

Start from short distance, pQCD:



bound state of 3 gluons exists, with $\alpha_{odd}(0) = 1$

$(< \alpha_{BFKL}(0) = 1 + O(\alpha_s))$

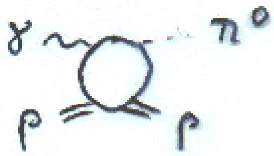
(curious:  $\sim$ )

3 gluon photon

model calculation:

$\sigma \approx 11$ pb

$\frac{d\sigma}{dt} =$  dip structure

A nonperturbative model (Heidelberg) for 

$\rightarrow \quad \sigma \sim 400$ nb

Idea for Odderon search at HERA: asymmetry in $\pi^+\pi^-$

predict large effect (~~10~~ - 20%)

Experimental search: $\gamma p \to \pi^0 p$

Not seen: $\sigma < 39$ nb

Summary

Present status:

- identify theoretical questions:
  unintegrated pdf, color dipole, Pomeron ...

- exploring the short distance region:
  do we agree with pQCD, how far can we go

- the transition region:
  search for signals of saturation; QCD-models: nonlinear evolution equations

- start from hadronic concepts

The Future:

- we need QCD calculations (demanding!)
  for the short-distance region

- transition region: don't forget the Pomeron slope $\alpha_P' \neq 0$!
  What about pions - not contained in nonlinear evolution equations!