Spin07 in Dubna

DVCS and vector meson electroproduction with spin

L. Jenkovszky (Bogolubov ITP, Kiev)

Outline of the presentation

- Helicity amplitudes for DVCS and vector meson electroproduction (kinematics)
- Helicity formalism and factorized Regge poles (kinematics and dynamics)
- A Regge pole model for DVCS (vector meson production) (dynamics)
- From DVCS to GPD (Conclusions etc)

Electroproduction

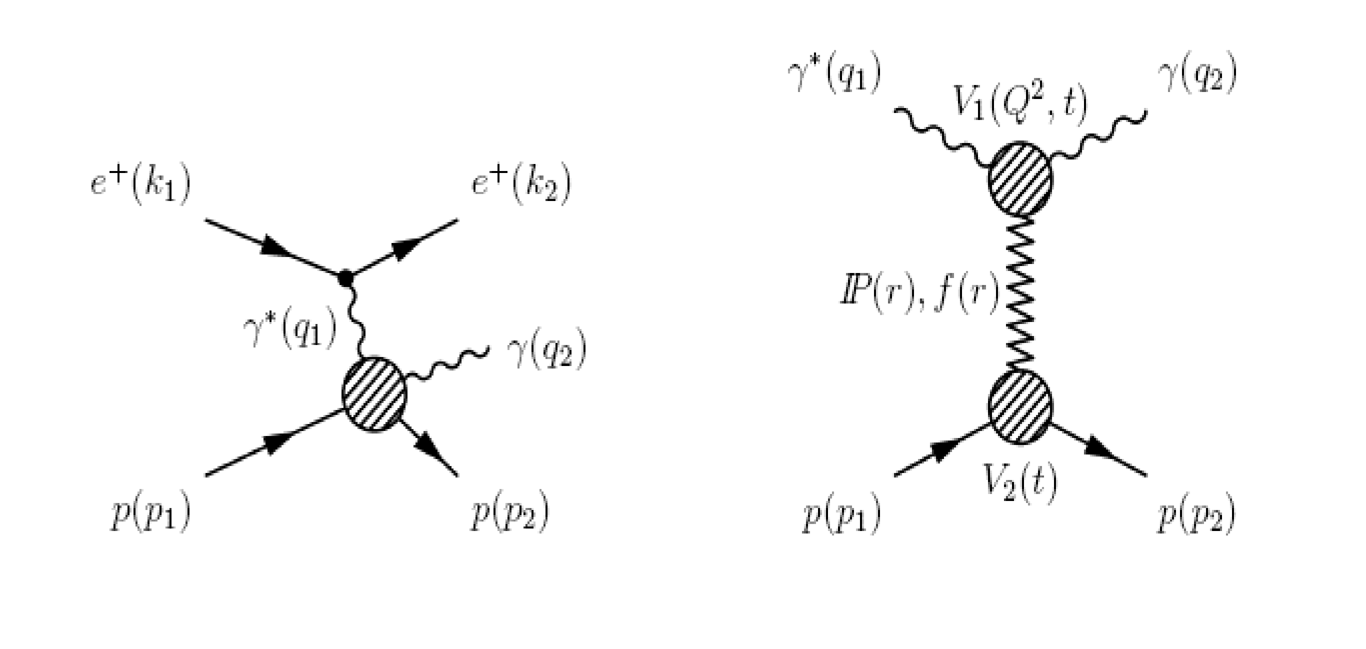
$$e(l) + p(p) \rightarrow e(l') + p(p') + \rho(q'),$$

followed by the decay

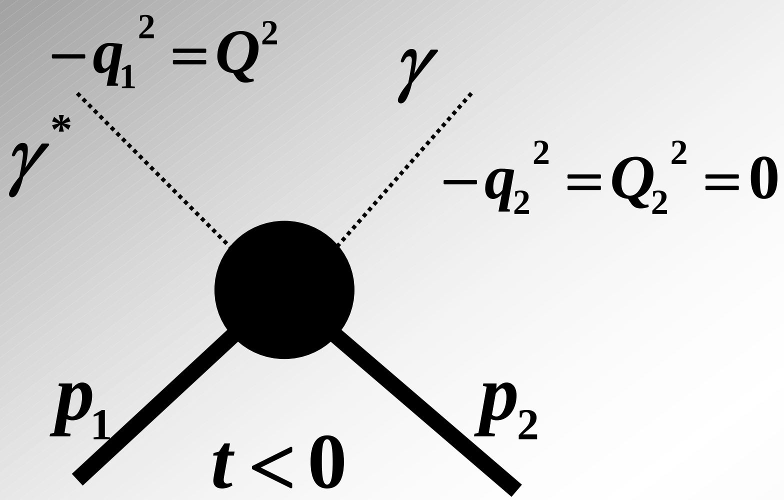
$$\rho(q') \rightarrow \pi^{+}(k) + \pi^{-}(k').$$

The strong interaction dynamics is fully contained in the helicity amplitudes for the subprocess

$$\gamma^{*} p \rightarrow \rho p.$$



DVCS kinematics



$$P = p_1 + p_2,\ q = \left(q_1 + q_2\right)/2$$

$$\Delta = p_2 - p_1,\quad t = \Delta^2$$

$$x_B = \frac{-q_1^{\ 2}}{2p_1q_1} = \frac{Q^2}{2p_1q_1}$$

$$\xi = \frac{-q^2}{2Pq} = x_B \frac{1 + \frac{\Delta^2}{2Q^2}}{2 - x_B + x_B \frac{\Delta^2}{Q^2}}$$

$$\eta = \frac{\Delta q}{Pq} = -\xi \left(1 + \frac{\Delta^2}{2Q^2}\right)^{-1}$$

The helicity formalism for elctroproduction was developed by K.Schilling, G.Wolf (Nucl. Phys. B61 (1973) 381 and by H. Fraas, Annals Phys. 87 (1973) 237, and was recently reviewed by M. Diehl (DESY 070-049, hep-ph/070.1565), see also: C. Bourrely, E. Leader and J. Soffer, Phys. Rep. 59 (1980) 96; A. Borisov, these Proceedings.

Polarization vectors of the virtual photon:

$$\varepsilon_{+1} = -\frac{1}{\sqrt{2}}(0,1,-i,0), \varepsilon_{-1} = \frac{1}{\sqrt{2}}(0,-1,i,0), \varepsilon^{\alpha}{}_{0} = N_{\varepsilon}(q^{\alpha} - \frac{q^{2}}{p \cdot q} p^{\alpha}).$$

Polarization vectors of the vector meson:

$$\varepsilon_{+1} = -\frac{1}{\sqrt{2}}(0, \cos\Theta, -i, \sin\Theta), \varepsilon_{-1} = \frac{1}{\sqrt{2}}(0, \cos\Theta, i, \sin\Theta),$$

$$\varepsilon^{\alpha}{}_{0} = N_{\varepsilon}(q'^{\alpha} - \frac{q'^{2}}{p' \cdot q'} p'^{\alpha}).$$

The scattering amplitude for the subprocess

$$\gamma^*(\mu) + p(\lambda) \to \rho(\nu) + p(\sigma)$$

with definite helicities $\mu, \nu, \lambda, \sigma$,

depending on $Q^2, x_B\ (s), t$,

$$T^{-\nu-\sigma}{}_{-\mu-\lambda} = (-1)^{-\nu-\mu-\sigma+\lambda} T^{\nu+\sigma}{}_{\mu+\lambda}$$

The spin density matrix of the vector meson (upper indices) with the polarizations of the $\gamma^* p$ state (lower indices) from which the vector meson is produced is

$$\rho^{\nu\nu'}{}_{\mu\mu',\lambda\lambda'} = (N_T + \varepsilon N_L)^{-1} \sum_{\sigma} T^{\nu\sigma}{}_{\mu\lambda} (T^{\nu'\sigma}{}_{\mu'\lambda'})^*,$$

$$\varepsilon = \frac{1 - y - \frac{1}{4} y^2 \gamma^2}{1 - y + \frac{1}{2} y^2 + \frac{1}{4} y^2 \gamma^2}$$

is the ratio of the longitudinal to transverse photon flux, and

$$y = (p \cdot q)/(p \cdot l), \gamma = 2 x_B M_N / Q.$$

Helicity amplitudes & Regge poles

In a factorized Regge-pole model (for on-shall hadrons), see: A.B. Kaidalov, B.M. Karnakov, Yad. Fiz. 3 (1966)216 and 6 (1968)152, A. Borisov (at this Conference)

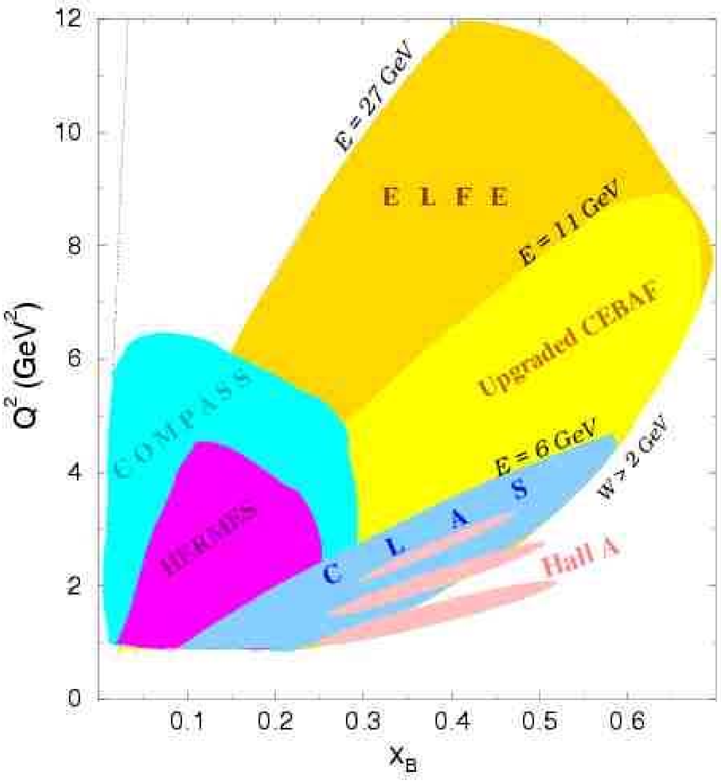
$$\rho_{11} = 2N^{-1}\left(\left|M^{a}_{1/2\,1/2,1}\right|^2 + \left|M^{a}_{1/2\,-1/2,1}\right|^2 + \left|M^{b}_{1/2\,1/2,1}\right|^2\right),$$

$$\rho_{1-1} = 2N^{-1}\left(\left|M^{-a}_{1/2\,1/2,1}\right|^2 + \left|M^{a}_{1/2\,-1/2,1}\right|^2 - \left|M^{b}_{1/2\,1/2,1}\right|^2\right),$$

$$\rho_{00} = 2N^{-1}\left|M^{a}_{1/2\,1/2,1}\right|^2, \rho_{10} = 2N^{-1}M^{b}_{1/2\,1/2,1}M^{*b}_{1/2\,1/2,1}$$

$$T_{\ldots T}(s,t) = \sum_k \xi^k(t)V^k_{\ldots}(t,Q^2)V^k_{\ldots}(t)\left(\frac{s}{s_0}\right)^{\alpha(t)},$$

$$(a):\alpha(t) = "P","f",\ldots(b):\ldots$$



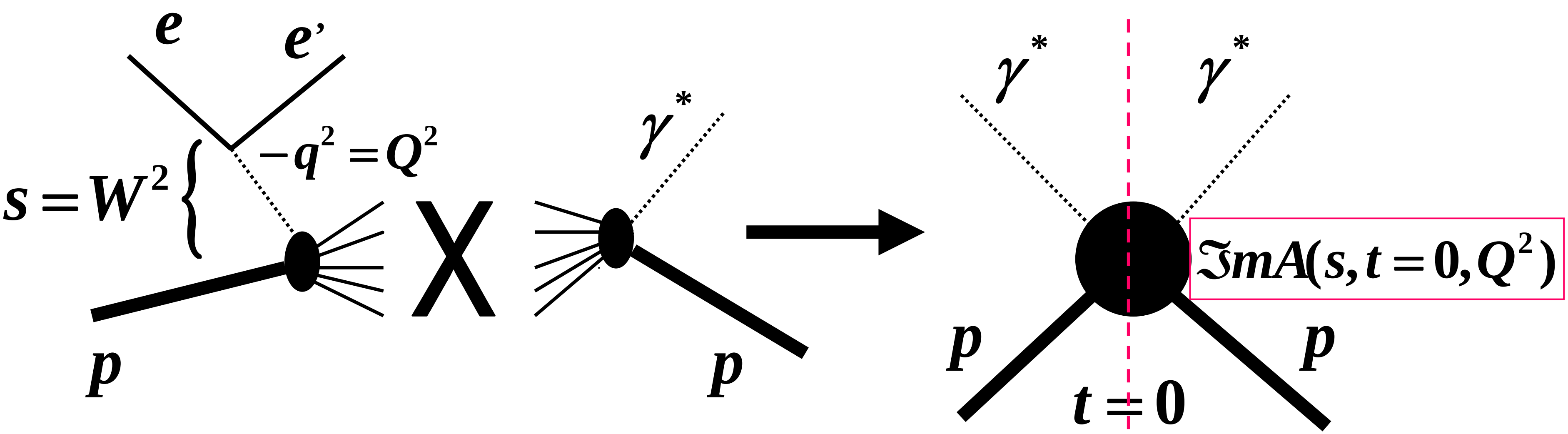
HERMES, E=27 GeV, low luminosity

JLab, E=4-6 GeV

Upgrated CEBAF/Jlab, E=12 GeV

COMPAS, E=200 GeV

DIS (and ordinary parton distributions)



$$x = \frac{Q^2}{2pq}$$

$$s = \frac{Q^2(1-x)}{x} + M^2 \approx \frac{Q^2}{x},\ x \ll 1$$

The proton is smashed (completely destroyed)

The basic object of the theory

$A(s,t,Q^2)$

$$A(s,t,Q^2=m^2)$$ (on mass shell)

$$\Im m A(s,t=0,Q^2) \sim F_2$$ DIS

Reconstruction of the DVCS amplitude from DIS

$$F_2 \sim \Im m A(\gamma^* p \to \gamma^* p)\Big|_{t=0} \to \Im m A(\gamma^* p \to \gamma p)\Big|_{t=0}$$

$$\to A(\gamma^* p \to \gamma p)\Big|_{t=0} \to A(\gamma^* p \to \gamma p)$$

or

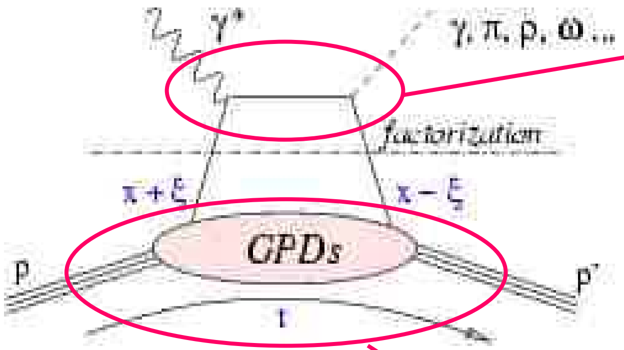
$$\Im m A(\gamma^* p \to \gamma^* p)\Big|_{t=0} \sim F_2(x_B,Q^2) = x_B q(x_B,Q^2)$$

$$q(x_B,Q^2) \to q(\xi,\eta,t,x_B,Q^2)$$ →

?

→ $$\xi q(\xi,\eta,t,x_B,Q^2) = GPD(\xi,\eta,t,x_B,Q^2)$$

QCD-factorized form of a DVCS scatterigg amplitude ⊗ GPD
("box")



pQCD

$$F_2(x,Q^2) \sim xq(x,Q^2)$$

non-perturbative region

GPDs cannot be measured directly,
instead they appear as convolution integrals,
difficult to be inverted !

$$A(\xi,\eta,t) \sim \int_{-1}^{1} dx \frac{GPD(x,\eta,t)}{x-\xi+i\varepsilon}$$

"Handbag"

We need clues from phenomenological models - Regge behaviour, t-factorization etc.

$$\sigma_{tot} \sim \Im m A, \qquad \frac{d\sigma}{dt} \sim \left|A\right|^2$$

$$A(\xi,\eta,t,x_B,Q^2) \sim \int_{-1}^{1} dx \frac{GPD(x,\eta,t,x_B,Q^2)}{x-\xi+i\varepsilon}$$

If we are interested only in $\Im m A \sim \sigma_{tot}$ →

$$\Im m A(\xi,\eta,t,x_B,Q^2) = i\pi GPD(\xi,\eta,t,x_B,Q^2)$$

$$t=0, Q^2 \to 0, x_B \to 0,$$

$$\xi = -\eta = \frac{x_B}{2}$$ →

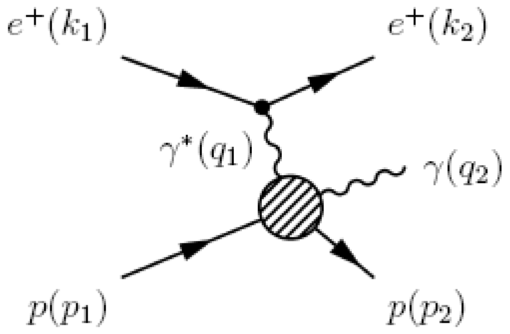
$$\Im m A_{DVCS}(x_B/2,-x_B/2,t=0,x_B,Q^2) =$$

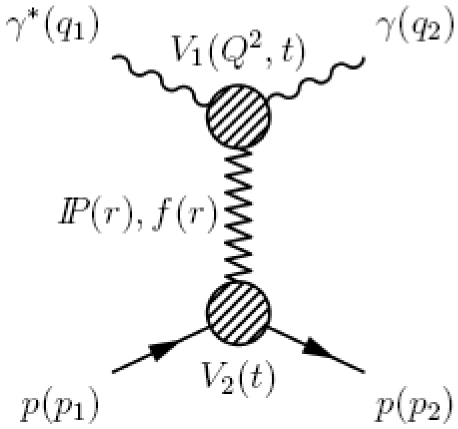
$$\Im m A_{DIS}(x_B,Q^2) \sim F_2(x_B,Q^2) \sim \left(\frac{1}{x_B}\right)^{\alpha_t(0)-1}$$

The sub-process $\gamma^* p \rightarrow \gamma p$ in a Regge-factorized form:

$$A(s,t,Q^2) \sim V_1(Q^2,t) V_2(t) s^{\alpha(t)}$$

$r^2 = t = (q_1 - q_2)^2$ r is the four-momentum of the Reggeon exchanged in the t channel,and $s = W^2 = (q_1 + p_1)^2$ is the squared centre-of-mass energy of the incoming system.





M. Capua, S. Fazio, R. Fiore, L. Jenkovszky, and F. Paccanoni*A Deeply Virtual Compton Scattering Amplitude*, Phys. Letters B645 (2007) 161, arXiv: hep-ph/0605319 ***and*** **R. Fiore, L.J., V. Magas, and A. Prokudin, *Interplay between Q^2- and t-dependences in DVCS*. In the Proceedings of the Crimean Conf., Yalta, 2005.**

The basic idea is that Q^2 and t, both having the meaning of a squared mass of a virtual particle (photon or Reggeon), should be treated on the same footing, by means a new variable, defined as

$$z = aq_1^2 + t = t - aQ^2, \qquad (1)$$

where a is a parameter (for simplicity we set $a = 1$), in the same way as the vector meson mass squared is added to the squared photon virtuality, giving $\tilde{Q}^2 = Q^2 + M_V^2$ in the case of vector meson electroproduction

For convenience, and following the arguments based on duality, the t dependence of the pPp vertex is introduced via the $\alpha(t)$ trajectory: $V_2(t) = e^{b\alpha(t)}$ where b is a parameter. A generalization of this concept is applied also to the upper, $\gamma^* P \gamma$ vertex by introducing the trajectory

$$\beta(z) = \alpha(0) - \alpha_1 \ln(1 - \alpha_2 z),$$

where the value of the parameter α_2 may be different in $\alpha(t)$ and $\beta(z)$.

Hence the scattering amplitude, with the correct signature, becomes

$$A(s,t,Q^2)_{\gamma^* p \to \gamma p} = -A_0 e^{b\alpha(t)} e^{b\beta(z)} (-is/s_0)^{\alpha(t)} =$$

$$-A_0 e^{(b+L)\alpha(t) + b\beta(z)},$$

where $L \equiv \ln(-is/s_0)$.

Photoproduction- and DIS limits (a consistency check)

In the $Q^2 \to 0$ limit the scattering amplitude becomes

$$A(s,t) = -A_0 e^{2b\alpha(t)}(-is/s_0)^{\alpha(t)}$$

where we recognize a typical Regge-behaved photoproduction (or, for $Q^2 \to m_H^2$, on-shell hadronic (H)) amplitude. The related deep inelastic scattering structure function is recovered by setting $Q_2^2 = Q_1^2 = Q^2$ and $t = 0$, to get a typical elastic virtual forward Compton scattering amplitude:

$$A(s,Q^2) = -A_0 e^{b(\alpha(0)-\alpha_1 \ln(1+\alpha_2 Q^2))} e^{(b+\ln(-is/s_0))\alpha(0)} \propto$$

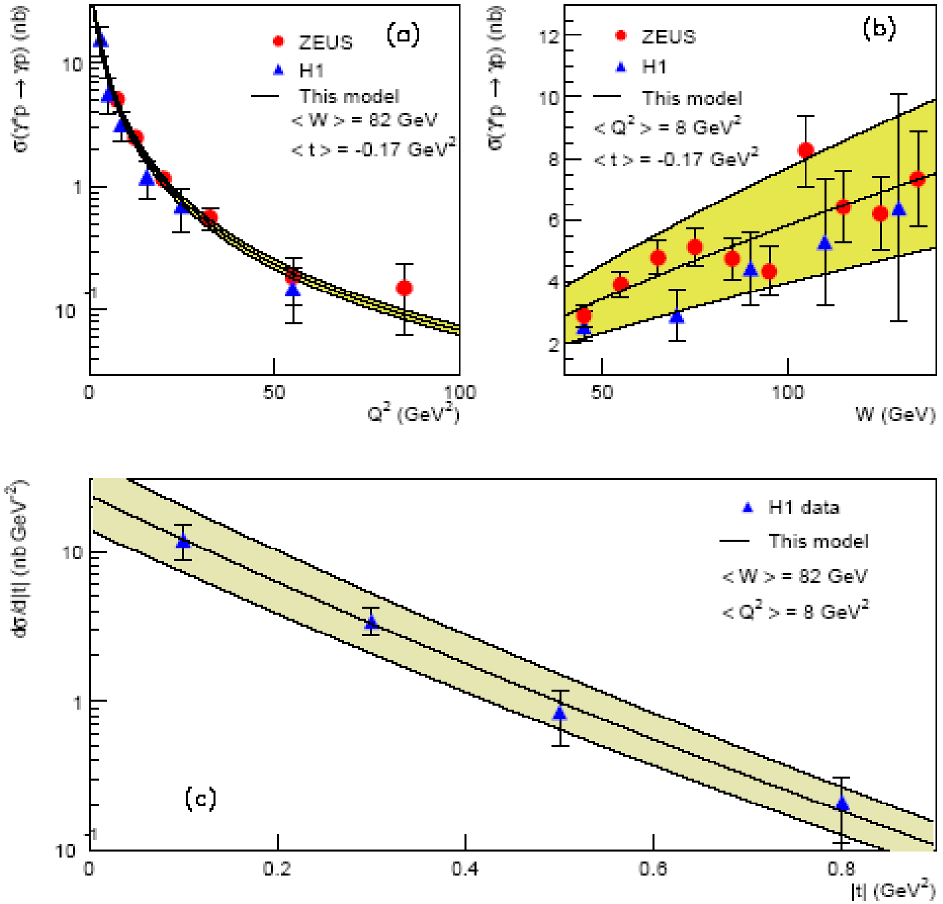
$$-(1+\alpha_2 Q^2)^{-\alpha_1}(-is/s_0)^{\alpha(0)}.$$

In the Bjorken limit, when both s and Q^2 are large and $t = 0$ (with $x \approx Q^2/s$ valid for large s), the structure function is given by:

$$F_2(s,Q^2) \approx \frac{(1-x)Q^2}{\pi\alpha_e} \Im A(s,Q^2)/s,$$

Fits to the $ep \to e\gamma p$ data

$$\frac{d\sigma}{dt}(s,t,Q^2) = \frac{\pi}{s^2}|A(s,t,Q^2)|^2 \qquad A = A^P + A^f$$



parameter	σ_{DVCS} vs Q^2	σ_{DVCS} vs t	σ_{DVCS} vs W
$\|A_0\|^2$	0.08 ± 0.01	0.11 ± 0.24	0.06 ± 0.01
b	0.93 ± 0.05	1.04 ± 0.91	1.08 ± 0.10
$\chi^2/ndof$	0.57	0.15	1.15

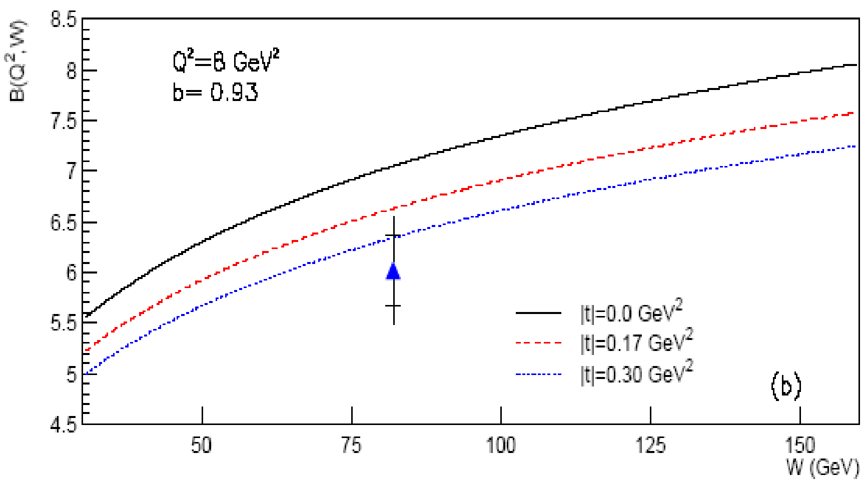
SLOPE OF THE DIFFRACTION CONE

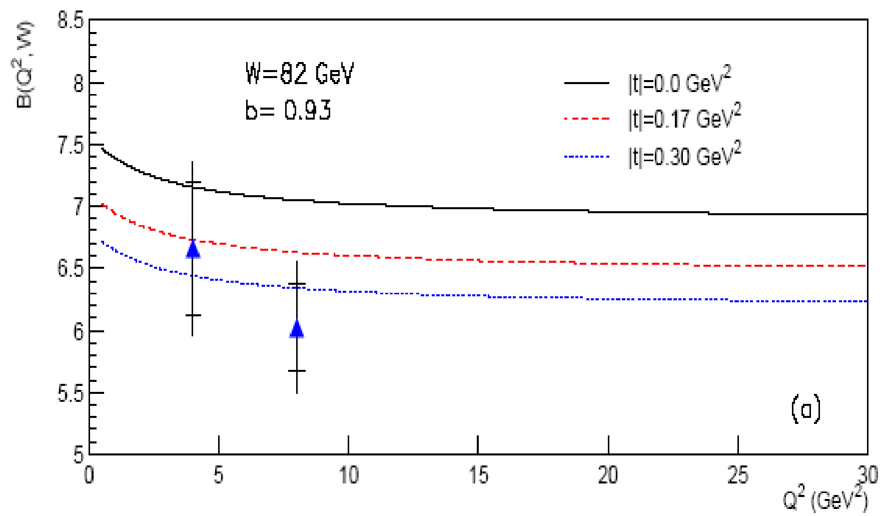
$$B(s,Q^2,t) = \frac{d}{dt}\ln|A|^2 = 2\left[b+\ln\left(\frac{s}{s_0}\right)\right]\frac{\alpha'}{1-\alpha_2 t} + 2b\,\frac{\alpha'}{1-\alpha_2 z},$$

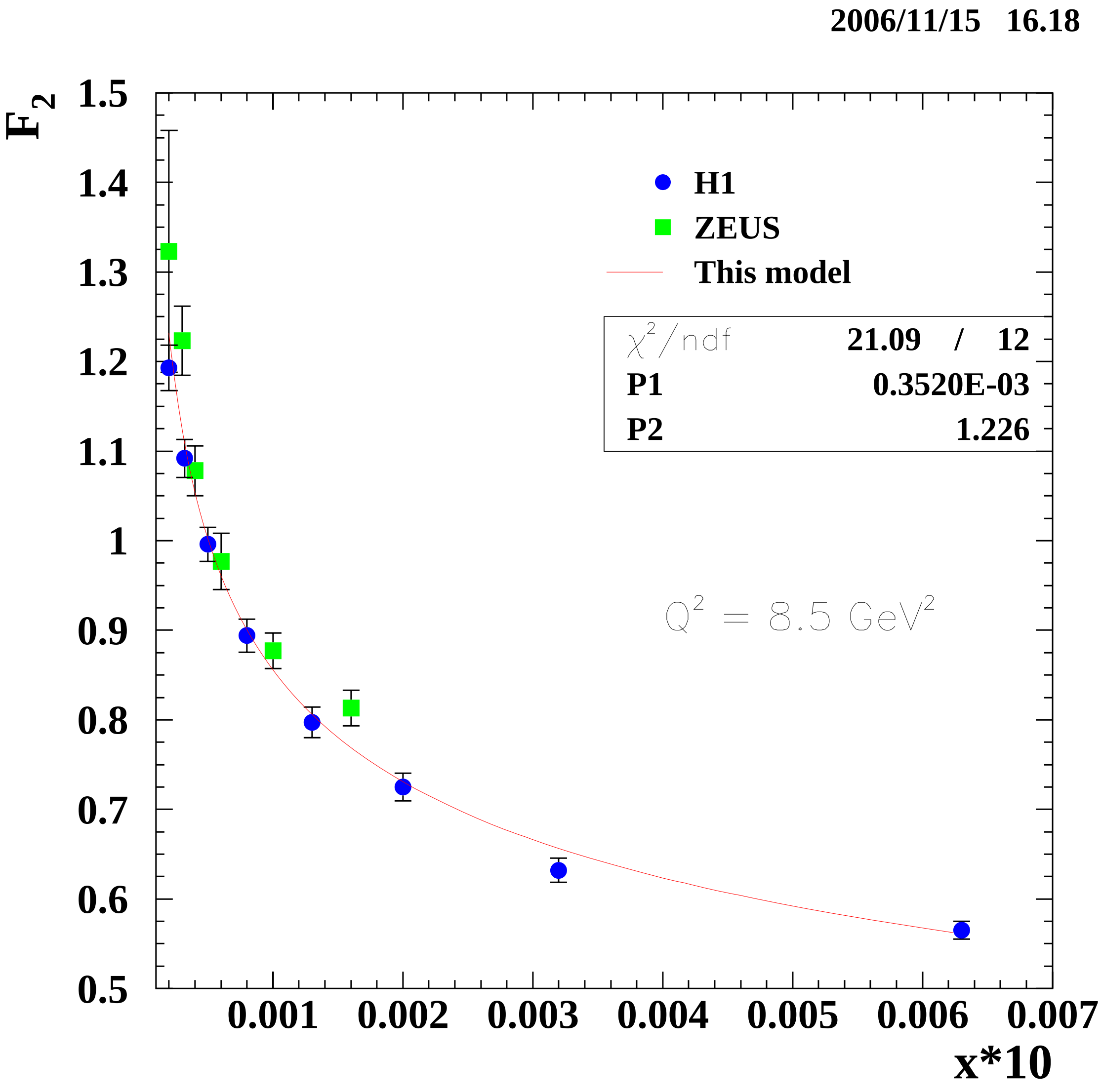
shows shrinkage in s and antishrinkage in Q^2.

In the forward limit, $t=0$ it reduces to

$$B(s,Q^2) = 2\left[b+\ln\left(\frac{s}{s_0}\right)\right]\alpha' + 2b\,\frac{\alpha'}{1+\alpha_2 Q^2}.$$






2006/11/15 16.18
F2
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
H1
ZEUS
This model
χ2/ndf 21.09 / 12
P1 0.3520E-03
P2 1.226
Q2 = 8.5 GeV2
0.001
0.002
0.003
0.004
0.005
0.006
0.007
x*10

QCD-evolution of a DVCS amplitude

Evolution in DVCS (similar to the DGLAP equation) was studied in an early paper by L.N.Lipatov et al. and more recently in V.Gusey and M.V.Polyakov, hep-ph/0507183; an M.Kirsh, A.Manashov, A. Schafer, Phys. Rev. D72 (2005) 114006; A.V. Vinnikov, hep-ph/0604248.

Interpolation between a Regge-behaved (for small x and fixed Q^2 DIS SF:

$$F_2(x,Q^2) \sim \left(\frac{Q^2}{A^2+a}\right)^{1+\tilde{\Delta}(Q^2)} \left(\frac{x}{x_0}\right)^{\tilde{\Delta}(Q^2)}$$

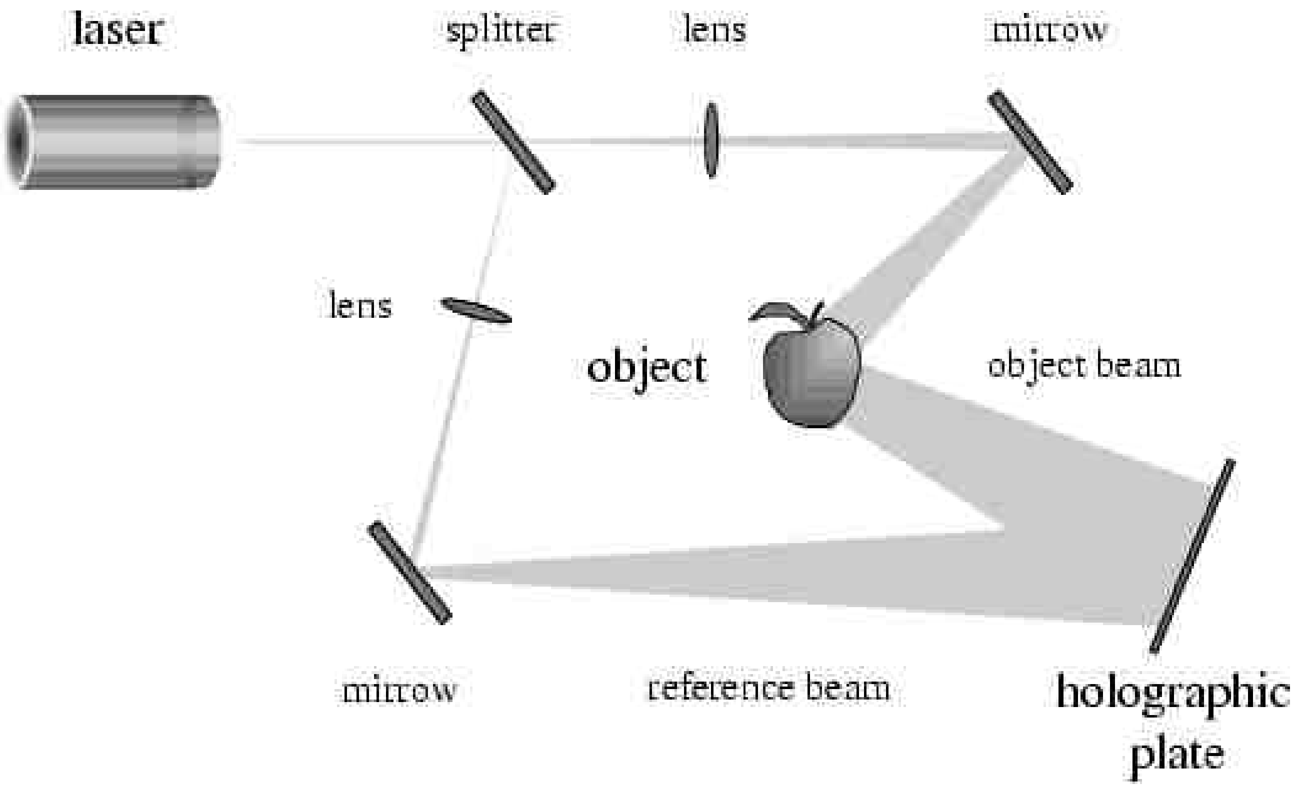
and its large-Q^2 behavior as given by DGLAP:

$$F_2(x,Q^2) \sim \exp\left(\sqrt{\gamma \ln\ln\frac{Q^2}{Q_0^2}\ln\frac{x_0}{x}}\right).$$

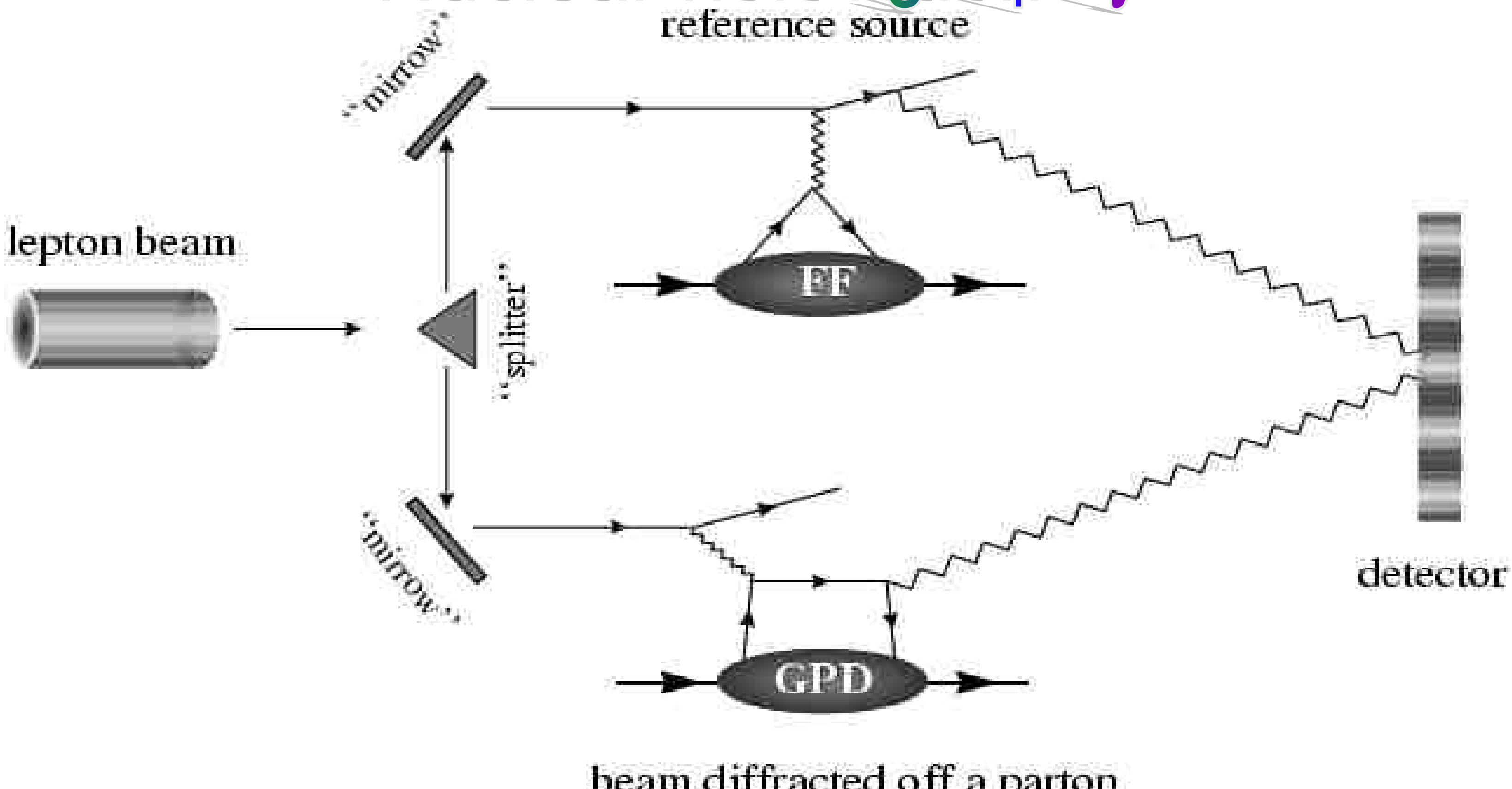
P. Desgrolard, L. Jenkovszky, F. Paccanoni, Eur. Phys. J. C **7** (1999) 263.

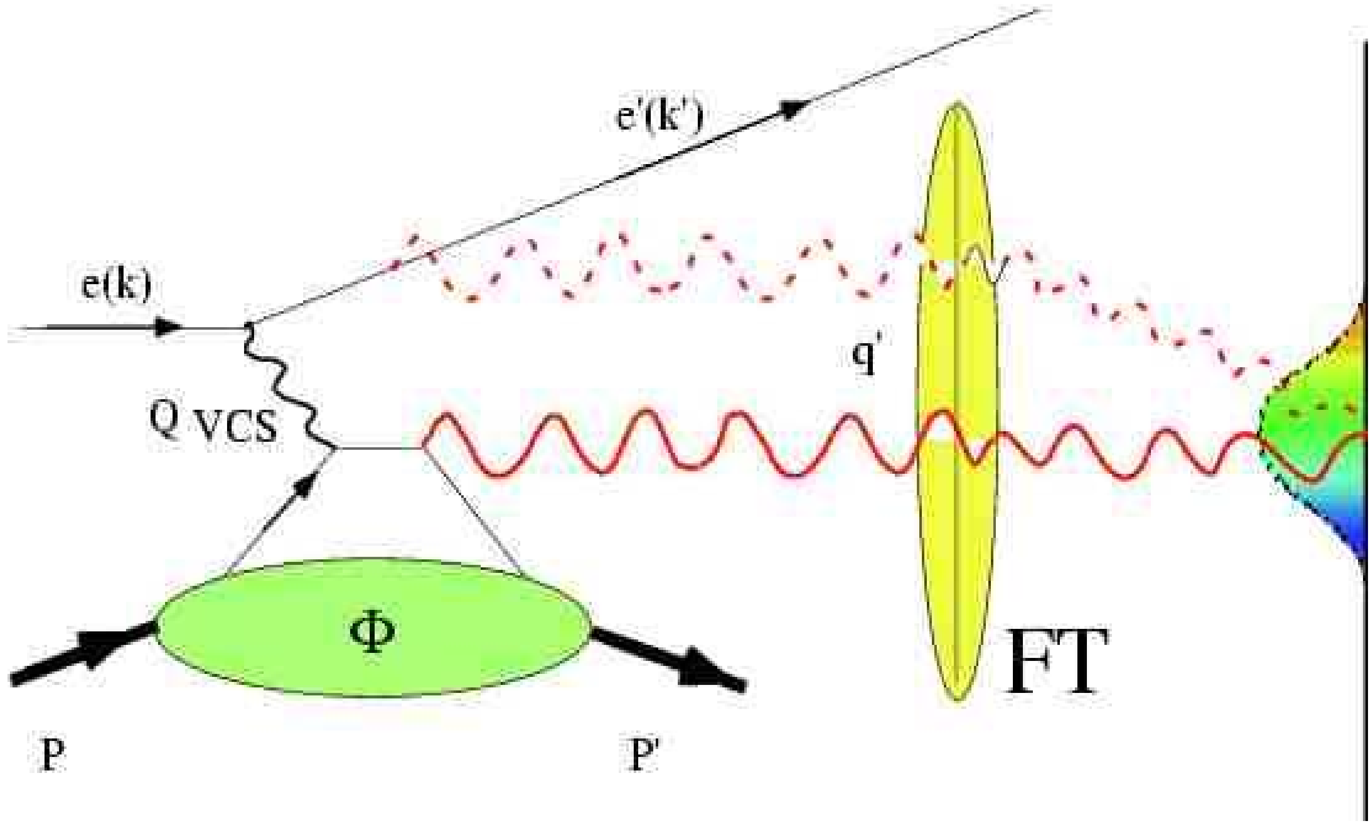
Holography

Dénes Gábor,1948; Born in 1900 (Budapest), Nobel Prize in 1971, Died in 1979 (London)

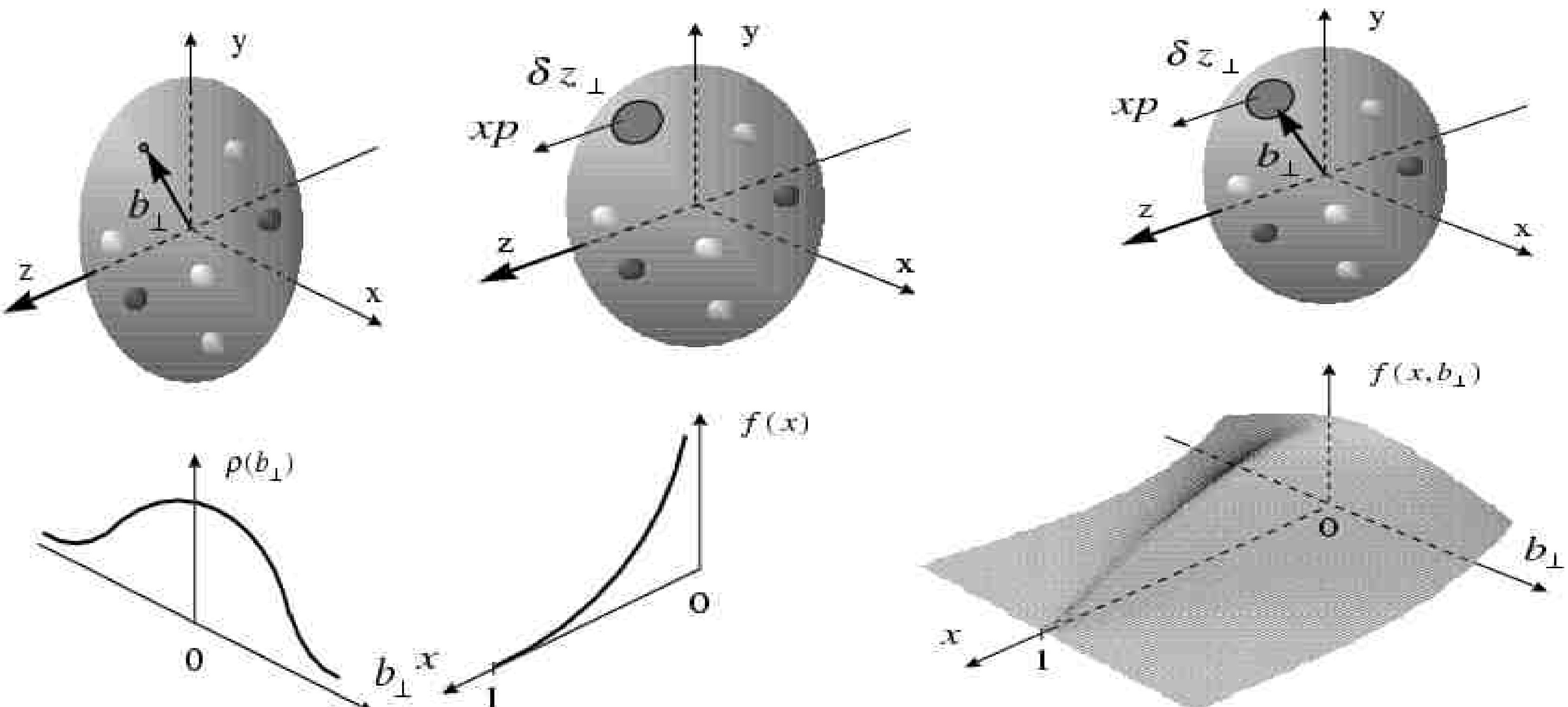


Nuclear holography




e(k)
e'(k')
Q VCS
q'
Φ
FT
P
P'

- Form factor
- Parton density
- Generalized parton distribution at η=0



Conclusions

1. Where is QCD? Its place is in large - Q^2 evolution, to replace Regge behavior;

2. Experimental verification of the "z-scaling": $\sigma(t,Q^2) \Rightarrow \sigma(z)$

3. More refined fits of the model to the present and future data, with:
$Q^2 -$
a) the f (and other) trajectory(ies) and their modified forms added;
b) b) unitarity effects (cuts) included;
c) d) extrapolation to lower energies (COMAPAS, HERMES, JLab) (resonances in s, large-x factor of the SF, quark-hadron duality etc.);

4. Use of the explicit DVCS amplitude to calculate GPD.

5. Spin, polarization and the density matrix.