Staturation and Critical Phenomena in Deep-Inelastic Scattering

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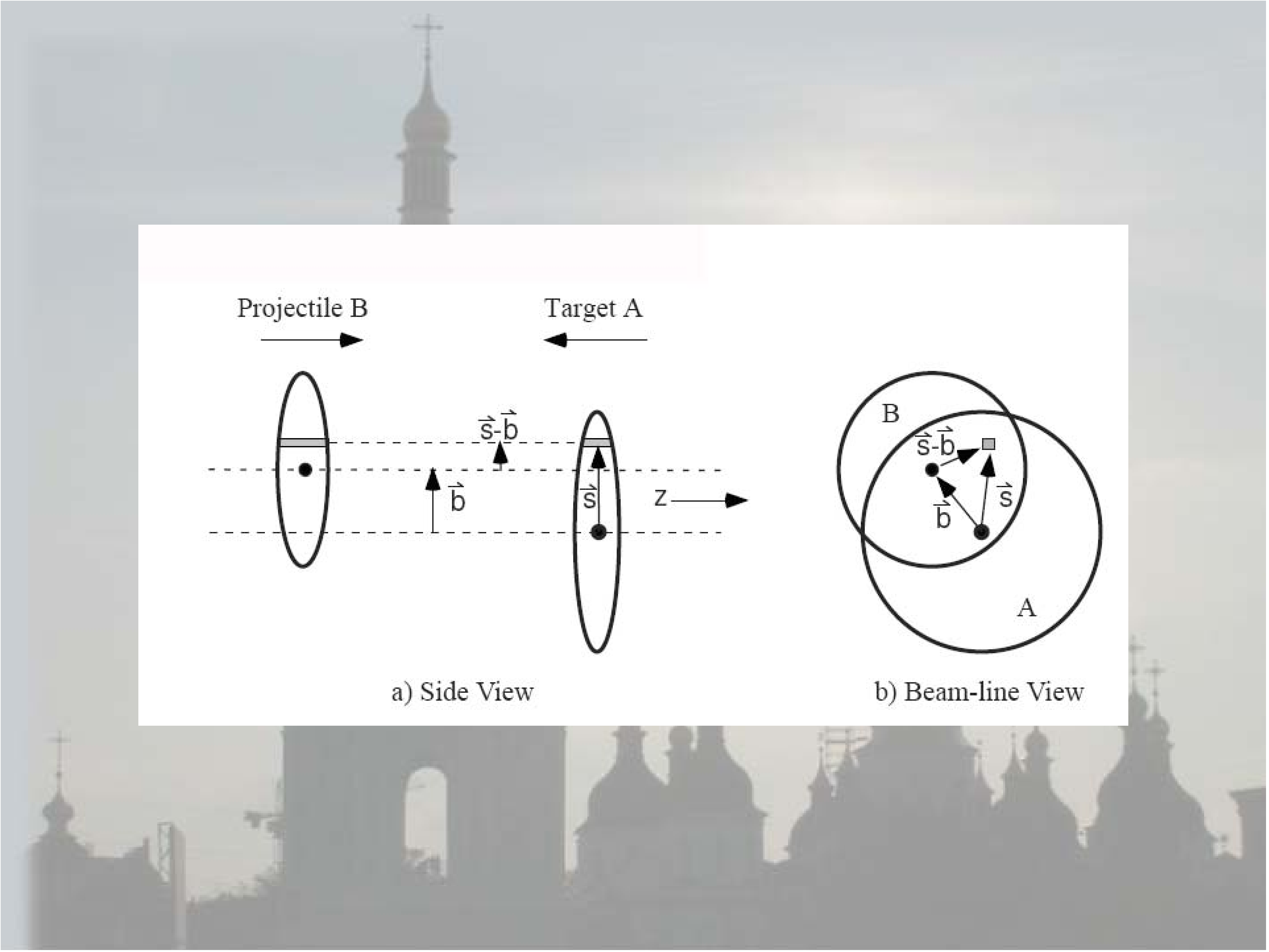
Based on work in collab. with L. Bulavin, S.Troshin and N.Tyurin

Dedicated to A.A. Slavnov on his 70-th birthday

Plan:

1. Collecitive effects and critical phenomena in hh and AA collisions;
2. Saturation in deep-inelastic scattering (DIS);
3. Collective effects (critical phenomena) (in DIS)


Projectile B
Target A
$\vec{s}$-$\vec{b}$
$\vec{b}$
$\vec{s}$
z
a) Side View
B
A
$\vec{s}$-$\vec{b}$
$\vec{s}$
$\vec{b}$
b) Beam-line View

Experimental inputs:

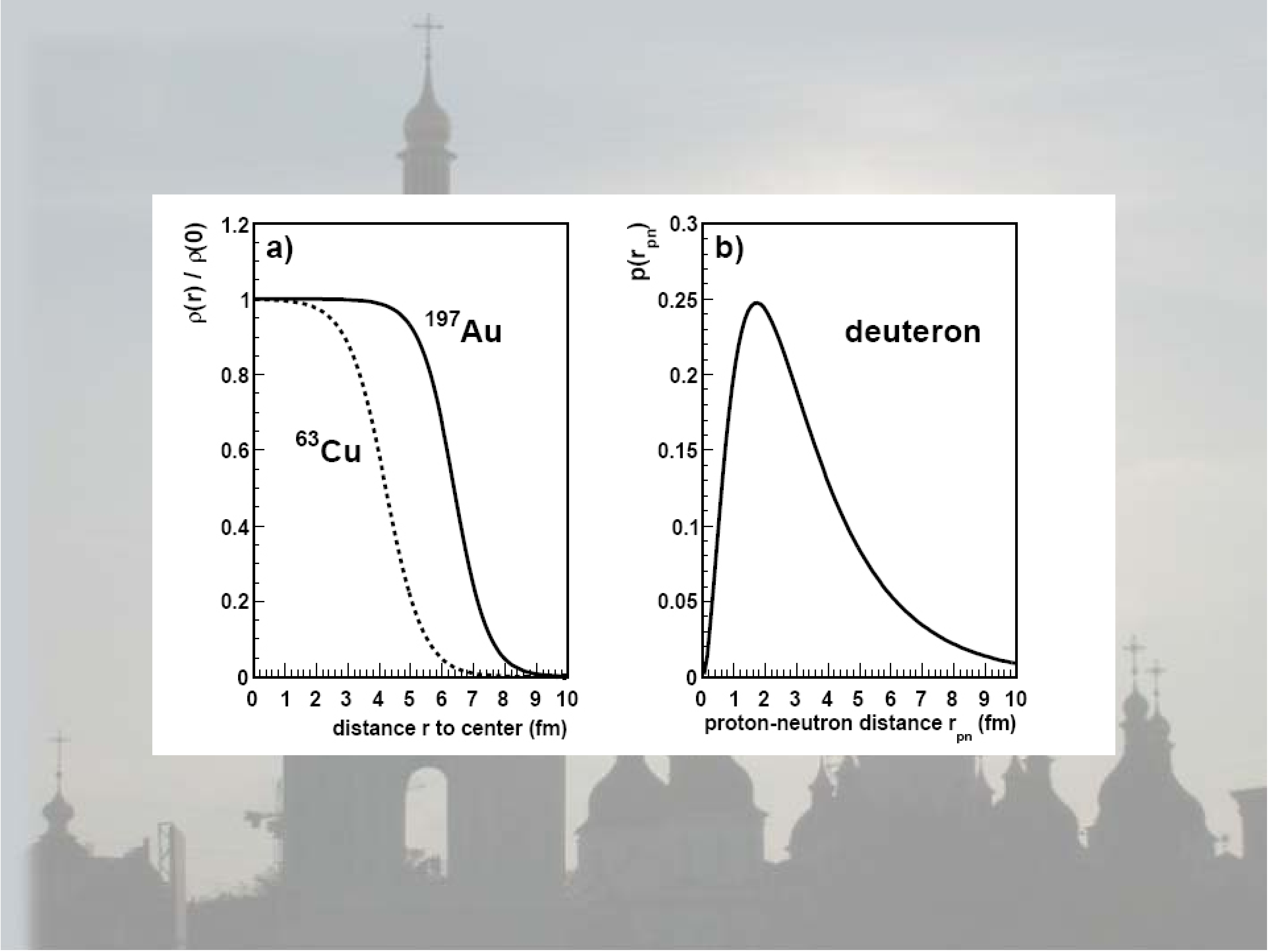
1. Nuclear charge densities $\rho(r)$, (e.g., Fermi)

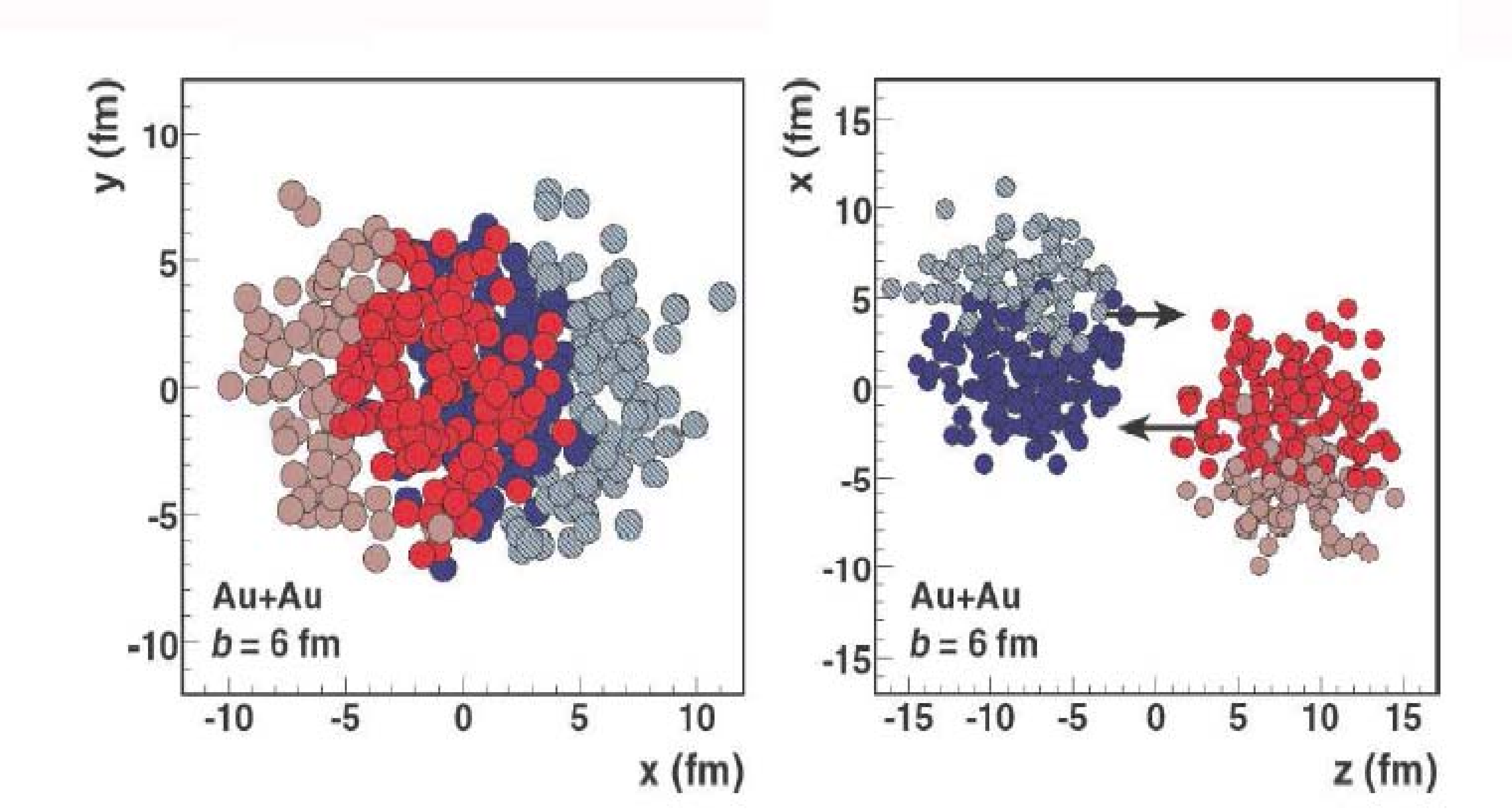
$$\rho(r) = \rho_0 \frac{1+\omega(r/R)^2}{1+exp(r-R/a)}.$$

2. Energy dependence of NN cross sections

$$\sigma_t(s) = \sigma_{el}(s)+\sigma_{in}(s) = \sigma_0[1+\lambda \log^{\nu}(s/s_0)], \ (\sim s^{0.1})$$

e.g. $\sigma_t^{NN} = [16 + 3.5 \ln(500 + s)]mb$, yielding $\sigma_t^{NN} \approx 40(ISR)$, $60(SPS), 70(Tevatron), 100mb$ (LHC). However, $\sigma_{el}/\sigma_t \longrightarrow const$, 0? (Unitarity and/or black/grey-disc-limit, see, e.g., L. Jenkovszky, E. Martynov, B. Struminsky, *How fast do cross sectons rise?*, Phys. Lett. **B249** (1990) 535 or L. Jenkovszky, *Diffraction in NN and eN reactions*,J.Part.Nucl. (EChAYa), **34** (2003) 1196.


a)
$\rho(r) / \rho(0)$
^{197}Au
^{63}Cu
distance r to center (fm)
b)
$p(r_{pn})$
deuteron
proton-neutron distance r_{pn} (fm)



GS Monte Carlo event (Au+Au at 200 GeV with impact parameter b=6 fm) viewed in the transverse plane (left) and along the beam axis (right). Darker are the participating (wounded) nucleons (from M.L. Miller et al.).

Basics of nuclear thermodynamics (Bag EoS), $p(T), \quad \mu = 0$:

$$p_q(T) = a_q T^4 - B, \quad p_h(T) = a_h T^4;$$

$$\epsilon_q(T) = 3a_q T^4 - B, \quad \epsilon_h = 3a_h T^4;$$

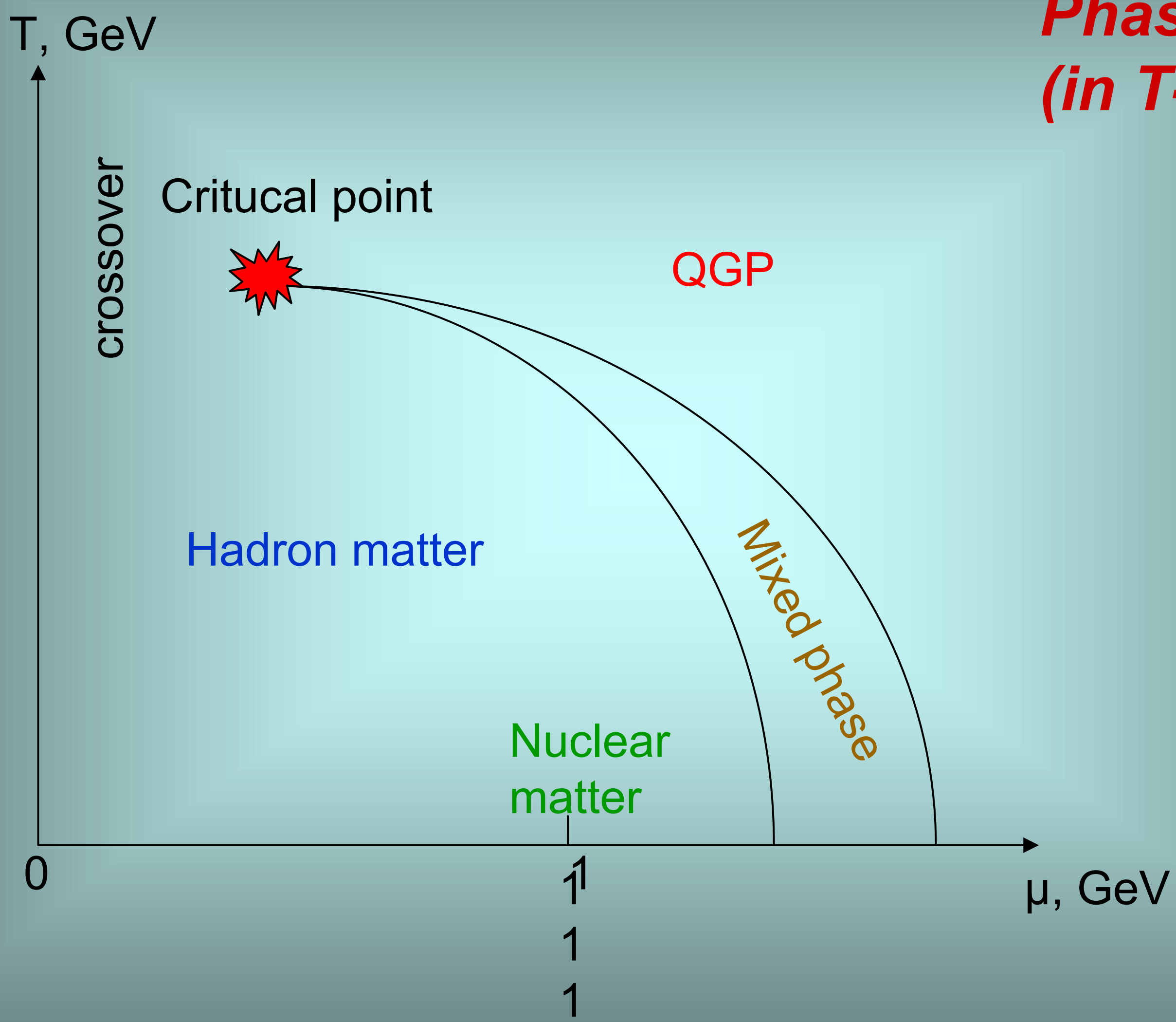
$$s_q(T) = 4a_q T^3, \quad s_h(T) = 4a_h T^3.$$

Further developments:

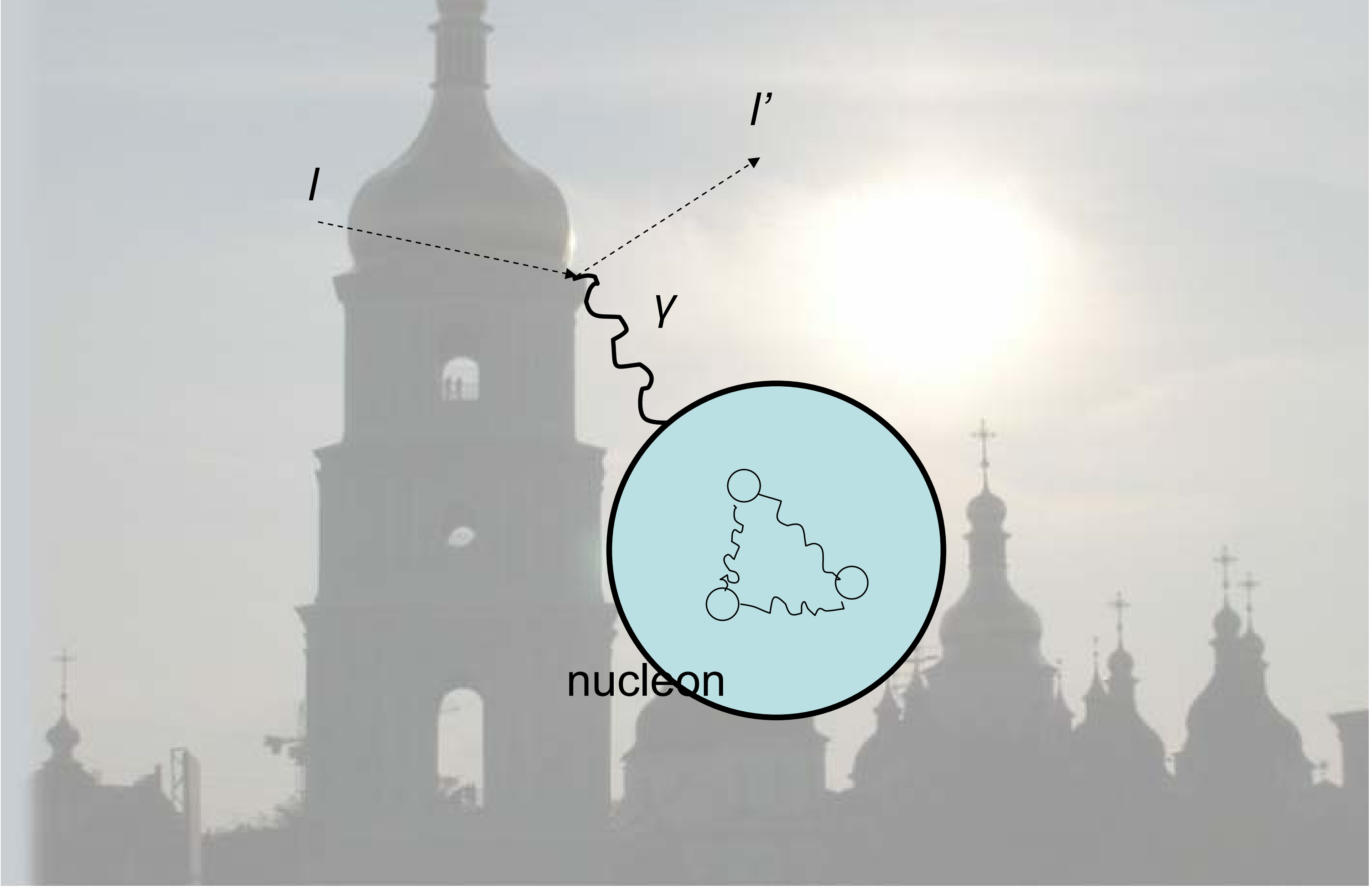
a) $B \to B(T, R)$; (Boyko, Jenkovszky, Sysoev, 90-ies);

b) $p \sim T^4 \to T^6$ (Jenkovszky, Trushevsky, '76).

Phase diagram (in T-μ)



A microscope (“femtoscope”)

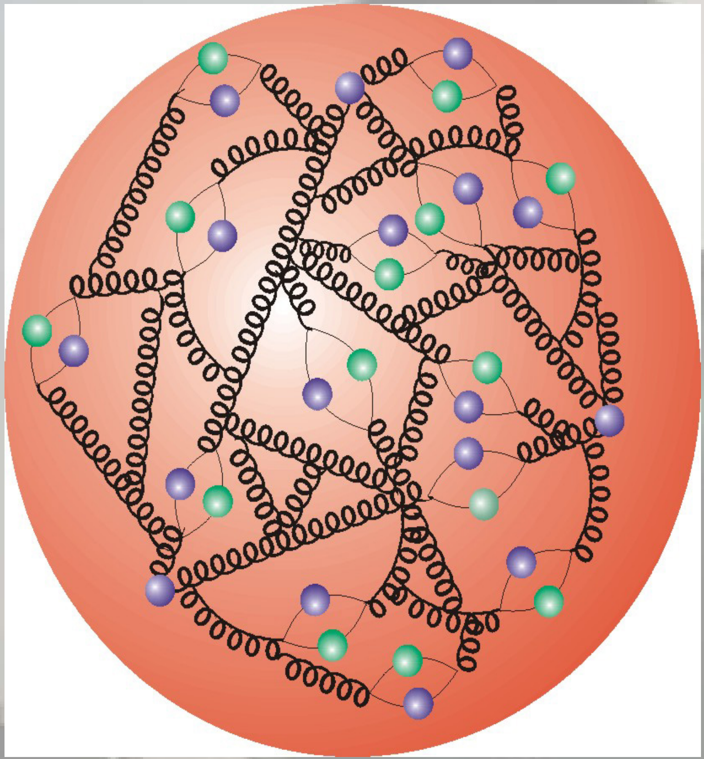


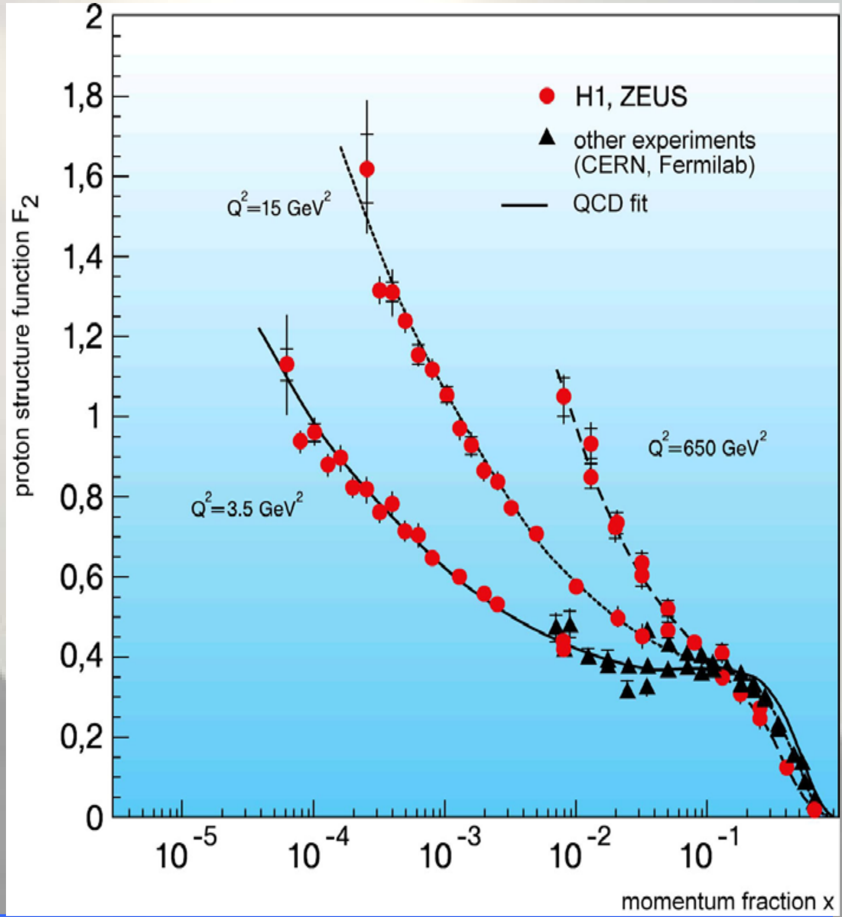
Structure of the Proton

3 “valence quarks”

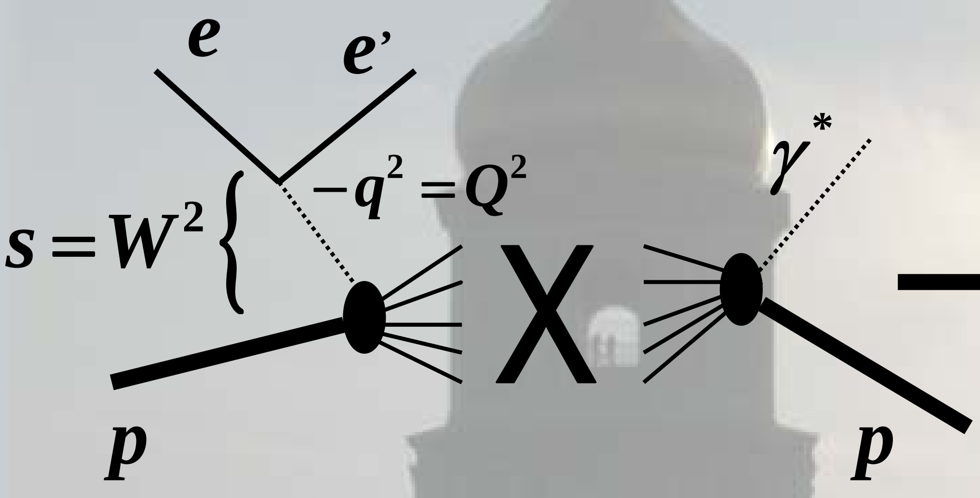
+

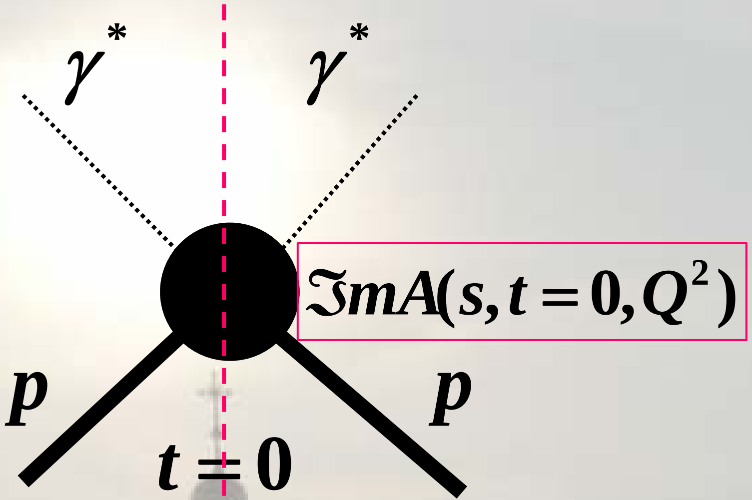
“sea” of gluons and short lived qq pairs





DIS (and ordinary parton distributions)



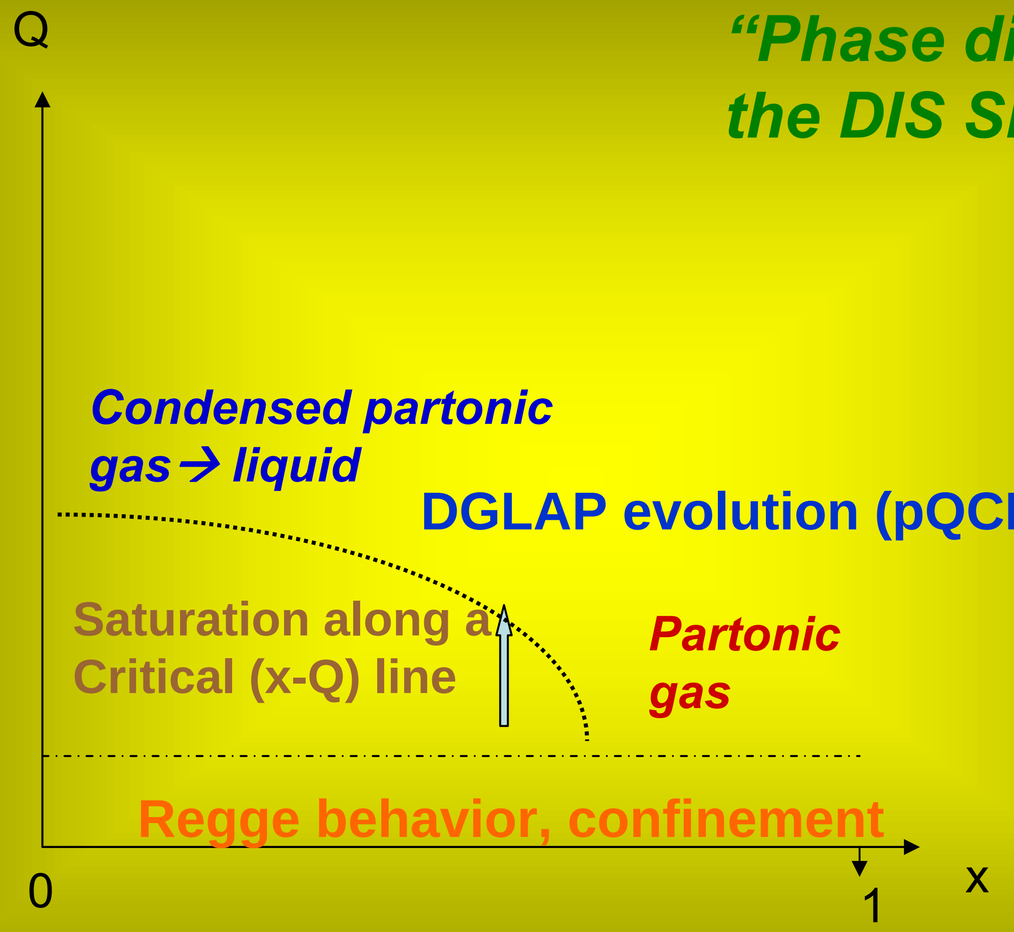


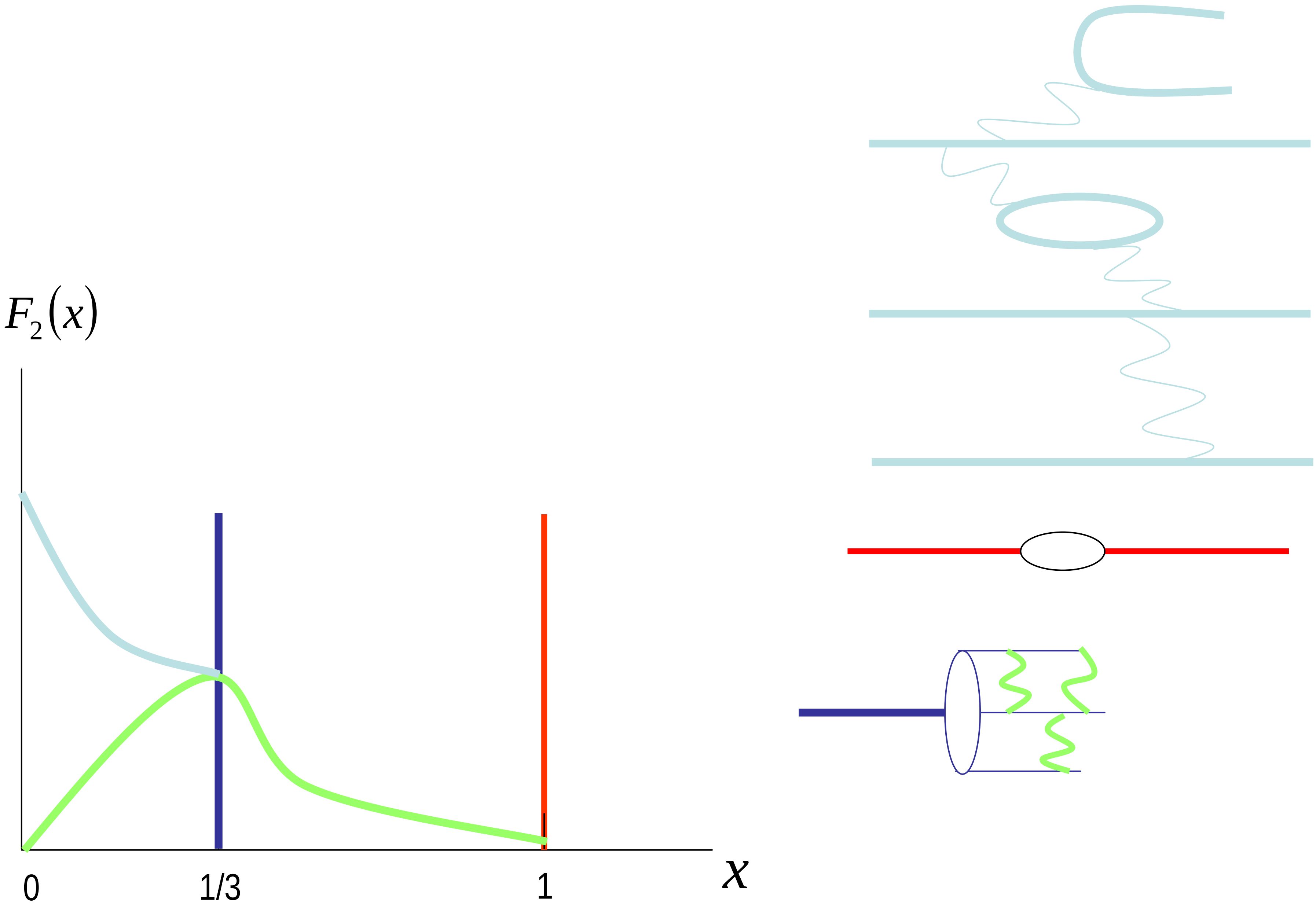
$$x = \frac{Q^2}{2pq}$$

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

The proton is smashed (completely destroyed)

“Phase diagram” of the DIS SF





$F_2(x)$
0
1/3
1
x

A typical nucleon structure function:

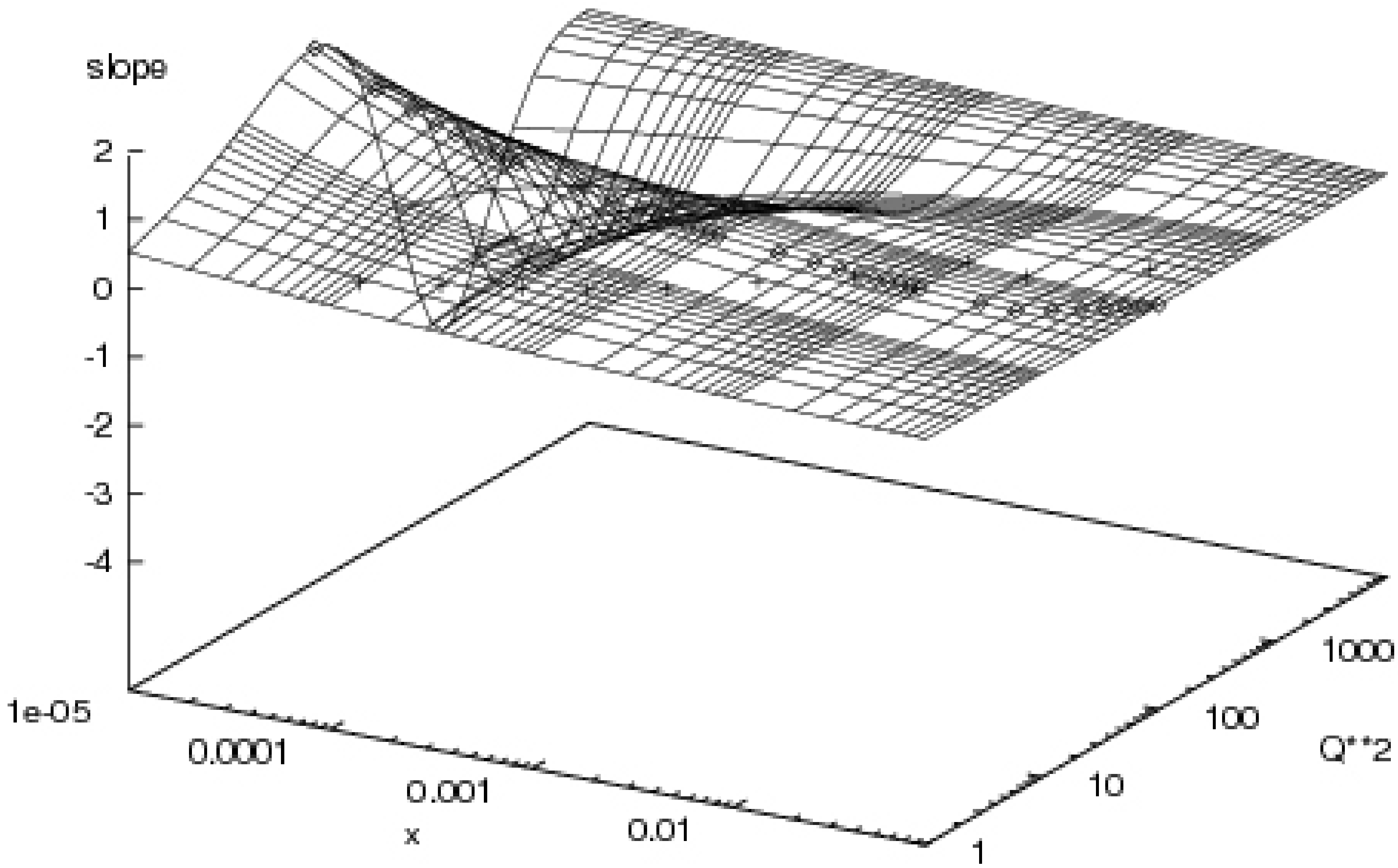
$$F_2(x, Q^2) = \Im A(s, t = 0, Q^2), \quad x \sim Q^2/s.$$

$$F_2(x, Q^2) = \int_0^1 x^{-\alpha(0)+1}(1-x)^n.$$

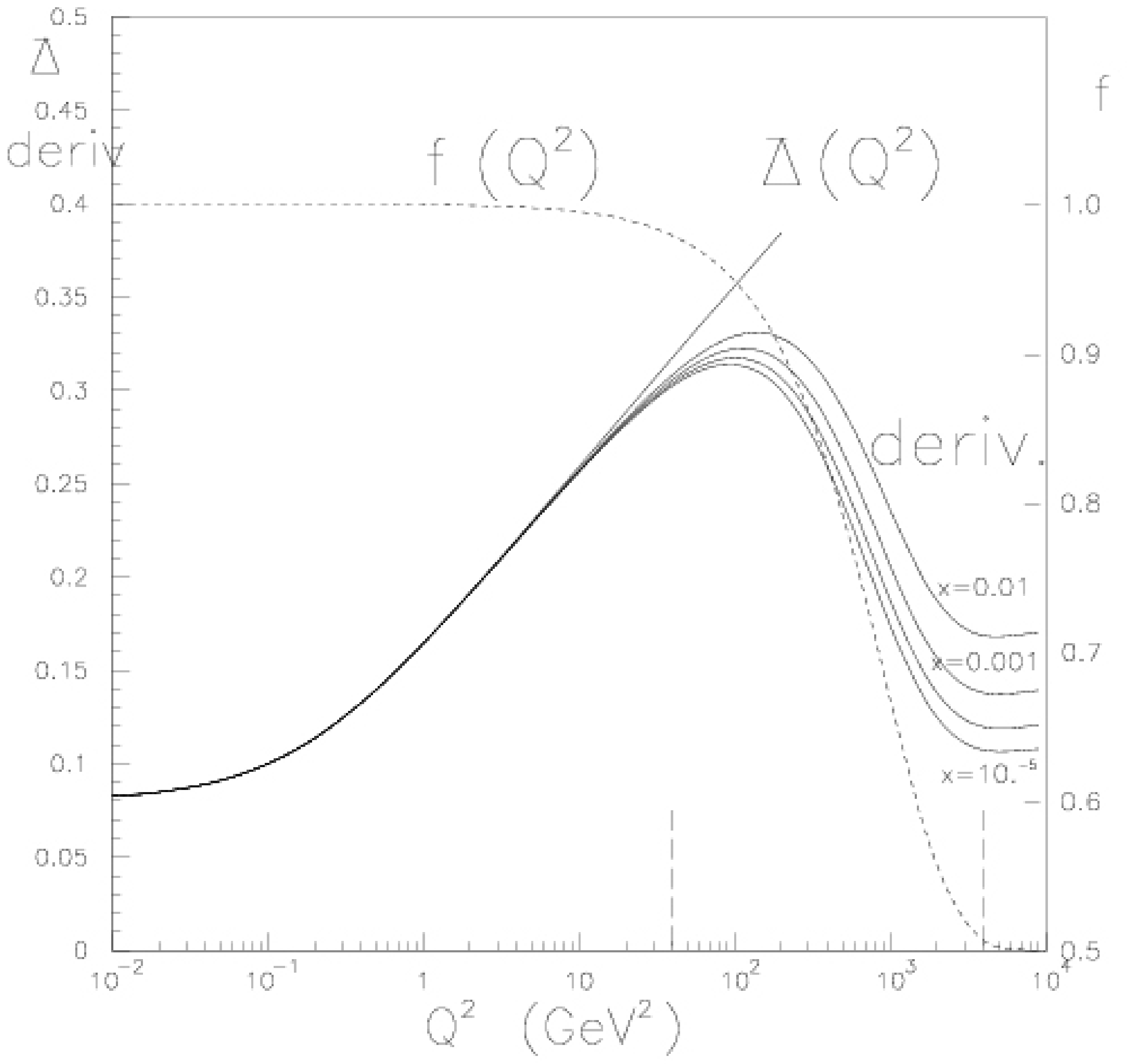
The saturation line in the $x - Q^2$ plane, the turning point (line) of the derivatives

$$B_Q(x,Q^2) = \frac{\partial F_2(x,Q^2)}{\partial(\ln Q^2)}, \quad B_x(x,Q^2) = \frac{\partial F_2(x,Q^2)}{(\partial \ln(1/x))}, \tag{1}$$

called B_Q or B_x slopes, where $F_2(x,Q^2)$ is the structure function, satisfying the basic theoretical requirements, yet fitting the data.



P.Desgrolard, L.Jenkovszky and F. Paccanoni, EPJ, 1998



Δ
deriv
f (Q²)
Δ (Q²)
f
deriv.
x=0.01
x=0.001
x=10.⁻⁵
Q² (GeV²)

A nucleon of mass M consists of a gas of massless particles (quarks, antiquarks and gluons) in equilibrium at temperature T in a spherical volume V with radius $R(s)$ increasing with squared c.m.s. energy s as $\ln s$ (or $\ln^2 s$). The invariant parton number density in phase space is given by

$$\frac{dn^i}{d^3p^i d^3r^i} = \frac{dn}{d^3p d^3r} = \frac{g f(E)}{(2\pi)^3},$$

where g is the degeneracy ($g = 16$ for gluons and $g = 6$ for q and $\bar{q}$ of a given flavor), E, p is the parton four-momentum and $f(E) = (\exp[\beta(E - \mu)] \pm 1)^{-1}$ is the Fermi or Bose distribution function with $\beta \equiv T^{-1}$.

The invariant parton density dn^i/dx in the IMF is related to dn/dE and $f(E)$ in the proton rest frame as follows

$$\frac{dn^i}{dx} = \frac{gV(s)M^2x}{(2\pi)^2}\int_{xM/2}^{M/2} dE f(E),$$

and the structure function

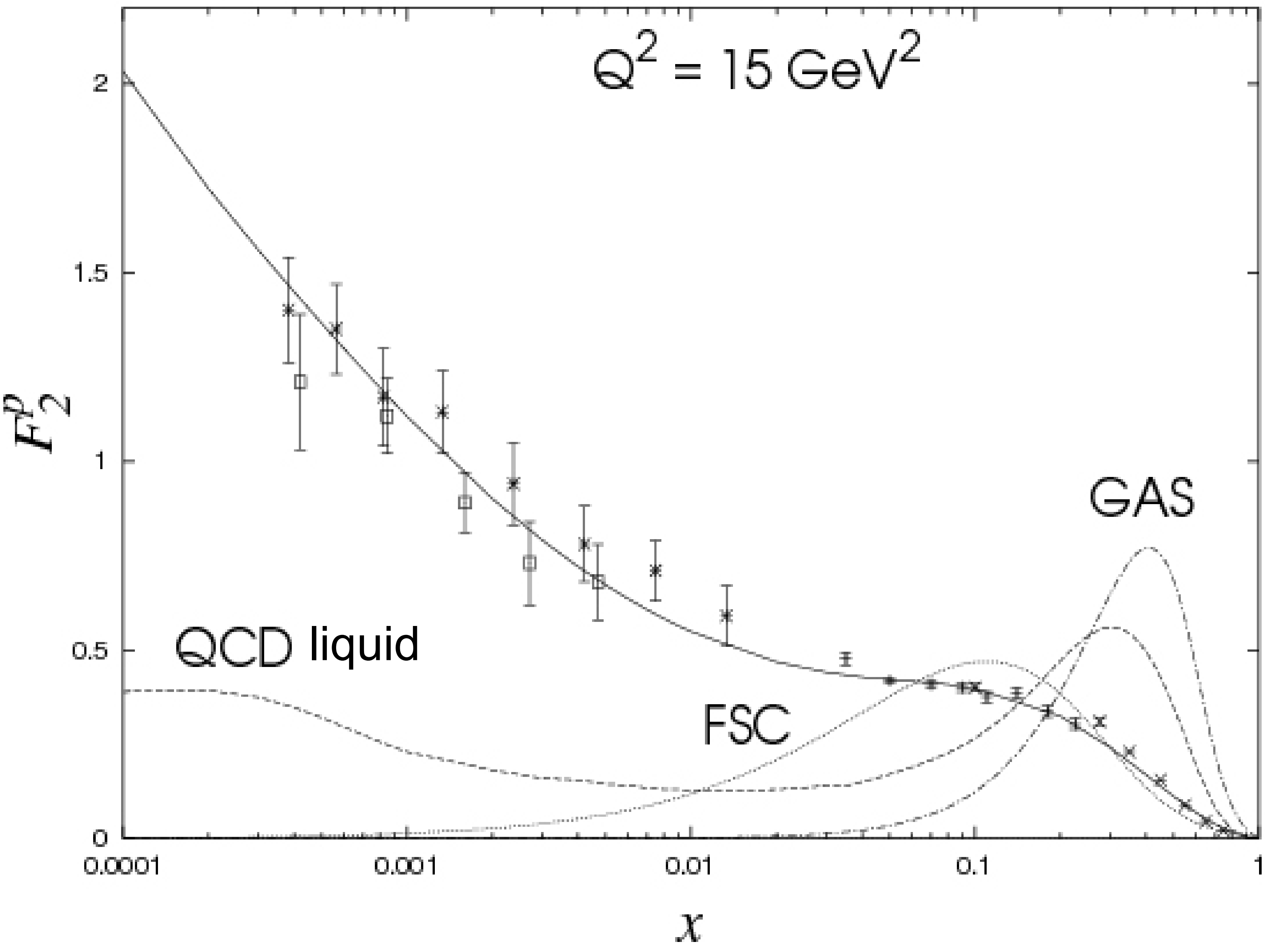
$$F_2(x) = x\sum_q e_q^2[(\frac{dn^i}{dx})_q + (\frac{dn^i}{dx})_{\bar{q}}].$$

Finite volume effects can be incorporated as

$$dn/dE = gf(E)(VE^2/2\pi^2 + aR^2E + bR),$$

where V and R are energy dependent and a, b, in front of the surface and curvature terms (CONFINENENT!).

Figure 2



Conclusions and Outlooks

- Bjorken scaling in DIS, observed at moderate *x* and *Q*^2 (with weak, logarithmic Q^2-dependence) of the SF, corresponds to a proton filled with a nearly free gas of partons – valence and sea quarks and gluons;
- With decreasing *x* (increasing energy) and increasing *Q*^2*,* the partons in the nucleon start overlapping, gradually filling (saturating) the available space in the nucleon ~R(s)^3~ln^3 s. According to the observed violent increase of the SF towards small *x,* the space occupied by the partonic gas increases faster than the volume of the nucleon, thus leading to its saturation and, consequently to the condensation (coalescence) of the partonic gas into a partonic liquid (phase transition?). This phenomenon can be described by the methods of statisctical physics, similar to the case of hadronic or nuclear collisions.

Thank you!