DUALITY OF DYNAMICAL AND THERMAL DESCRIPTIONS IN PARTICLE INTERACTIONS

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OUTLINE

I. Motivation of the statistical and dynamical descriptions of particle interactions

II. Deep inelastic scattering and nucleon structure functions

III. Quark distributions over x within the dynamical and thermal approaches

IV. Quark distributions over p_t within the dynamical and thermal approaches

V. Summary

Pioneering statistical models for description of the hadron production in particle interactions

E.Fermi (1950), I.Pomeranchuk (1951), L.D.Landau (1953), R,Hagedorn (1965)

$$f(m_t) \sim \exp(-m_t/T)$$

Here m_t is the transverse mass of produced hadrons and the "temperature" $T \sim 150 - 160$ MeV.

See the talks presented at the CPOD-2010
Marek Gazdzicki: Onset of confinement in heavy-ion collisions

Mark Gorenstein: Statistical models of hadron production

Statistical model works well at low p_t.
At large p_t the dynamical mechanism (for example, the non statistical fluctuations) works better.

We suggest the **duality** *between the statistical and dynamical mechanisms in the particle interactions.*

Our main goal is to illustrate that the duality results in a matching of these two descriptions.

DIS and proton structure function

(*A.Capella, A.B.Kaidalov, C.Merino & J.Tran Than Van, Phys.Lett. B***337***, 358 (1994), ibid Phys.Lett. B***343***, (1995) 403; M.Gluck, P.Jimenez-Deldago, E.Ray, Eur..Phys.J., C***53*** (2004) 355; A.Martin, W.J.Stirling, R.S.Thorne and J.Watt, Eur..Phys.C* **63** *(2004) 189.*)

A more standard form describing the experimental data on the DIS:

$$F_2(x,Q_0^2) = \sum_{flavour} x\left(q_f(x,Q_0^2)+\bar{q}_f(x,Q_0^2)\right) = A_s x^{-a_s}(1-x)^{b_s} \; + \; B_v x^{a_v}(1-x)^{b_v} \ ,$$

where the first term is due to the sea quark distribution which is enhanced at low x, according to the DIS experimental data, whereas the second term is due to the valence quark distribution.

$$xq_v(x) \simeq B_{q_v} x^{a_v} \exp\left(-xb_{q_v}\right) \ .$$

On the other hand,

$$xq(x) = \frac{B_1 X_{0q} x^{b_1}}{\exp\left((x-X_{0q})/\bar{x}\right)+1} + \frac{B_2 X_{0q} x^{b_2}}{\exp(x/\bar{x})+1} \ ,$$

(*C. Bourrely, F. Buccella and J. Soffer, Eur. Phys. J. C 23 (2002) 487; C. Bourrely and J. Soffer, Mod. Phys. Lett. A 21 (2006) 143.*)

Therefore, the proton structure function $F_2(x, Q_0^2))$ has also a thermodynamical form. According to *J.Cleymans & R.L.Thews, Z.Phys., C**37** (1988) 315; E.Mac & E.Ugaz, Z.Phys., C**43** (1989) 655.*

$$q(p_z) \sim \exp\left\{-\left(\frac{P \cdot p_q}{mT} - \frac{\mu}{T}\right)\right\} ,$$

where E, P and m are the energy, the momentum and the mass of the nucleon moving in the z-direction, ϵ and p_z are the energy and momentum in the z-direction of a parton in the nucleon, T is the temperature and μ is the chemical potential. For massless partons and $\mu \simeq 0$ one gets

$$q(x) \sim \exp\left(-\frac{mx}{2T}\right) \equiv \exp(-\frac{x}{\bar{x}}) .$$

where $x = p_z/P$ is the longitudinal fraction of the parton momentum and $\bar{x} = 2T/m$.
For the u-quarks $\bar{x} = 1/b_v$, therefore for the massless quarks $T = m/(2b_v) \simeq 120 - 150$ MeV.
(*J. Cleymans, G. L., A.N. Sissakian, A.S. Sorin, O.V. Teryaev arXiv:1004.2770 [hep-ph]*)

The inclusion of of the quark transverse momentum k_{qt} results in $E\epsilon - Pp_z \simeq m^2 x(1 + k_{qt}^2/(x^2 m^2))$.
It means that the relativistic invariant variable x is replaced by the variable $x(1 + k_{qt}^2/(x^2 m^2))$
(*A. V. Efremov, P. Schweitzer, O. V. Teryaev and P. Zavada, Phys. Rev. D 80 (2009) 014021.*)

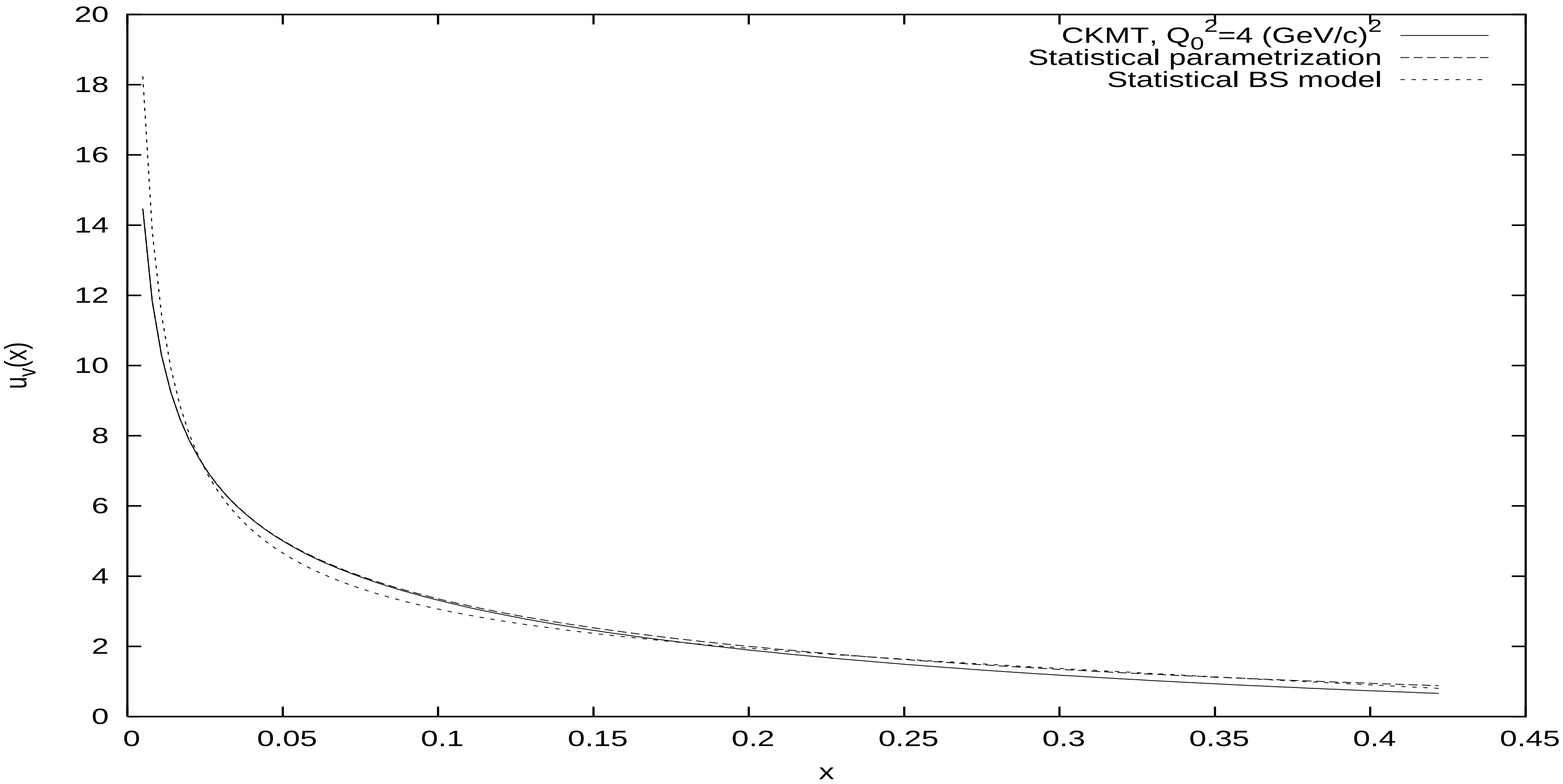

Figure 1: The valence u-quark distribution in the proton as a function of the Bjorken variable x at $Q_0^2 = 4(GeV/c)^2$. The solid curve is the CKMT parametrization, the dashed line corresponds to the statistical parametrization, the dotted curve corresponds to the BS statistical (thermal) model.

The figure shows that all three lines are very close to each other at $0.01 \leq x \leq 0.4$.

Quark distribution in proton: transverse momentum

$$g(k_t) \sim \exp(-\frac{\epsilon_{kt}}{T}) \ ,$$

where $\epsilon_{kt} = \sqrt{k_t^2 + m_q^2}$ is the transverse energy of quarks in proton and m_q is the quark mass. For the massless quarks (the current quarks) $g(k_t)$ can be represented in the following form:

$$g(k_t) \sim \exp(-\frac{k_t}{T}) = \ \exp(-\frac{k_t}{< k_t >}).$$

Applying here the same effective temperature $T \simeq 120 - 150$ MeV, as for longitudinal momentum distribution, we get similar results on $< k_t >$, which were obtained for valence current quarks
A. V. Efremov, P. Schweitzer, O. V. Teryaev and P. Zavada, Phys. Rev. D 80 (2009) 014021.
For the constituent massive quarks T is larger that for the massless quarks by a factor two.
G. I. Lykasov and M. N. Sergeenko, Z. Phys. C 52 (1991) 635; ibid Z. Phys. C 56 (1992) 697;
G. I. Lykasov, Z. M. Karpova, M. N. Sergeenko, V. A. Bednyakov, Europhys.Lett., 86 (2009) 61001.

Therefore, the transverse momentum distribution of partons in proton can also be described in the statistical form with the same value of the temperature T as the parton distributions in proton over the longitudinal momentum or over its fraction x.

SUMMARY

I. We suggest a duality principle which means a similarity of the thermal distributions of partons (quarks and gluons) and the dynamical description of these partons.

II. This duality allowed us to find an effective temperature $T \sim 120 - 150$ *MeV for the massless quarks.*

III. These values for T *are the same for the distributions of partons on the longitudinal and transverse momentum*

IV. Formally it coincides approximately with the freeze-out temperature in central heavy-ion collisions at zero chemical potential. But probably our effective temperature is not exactly the same as the freeze-out temperature.

V. For the massive constituent quarks T *is larger than for the massless quarks by factor about two.*

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