Pseudorapidity distributions of hadrons in DIS

Based on B.Blok,M.Strikman and Y.Dokshitzer,in preparation

Why we need to look at final state multiplicities analytically,if there are very good MC generators, and these generators generally give good description of experimental data.

Reason 1.many of these generators have different fit parametersthat may or may not change physical picture

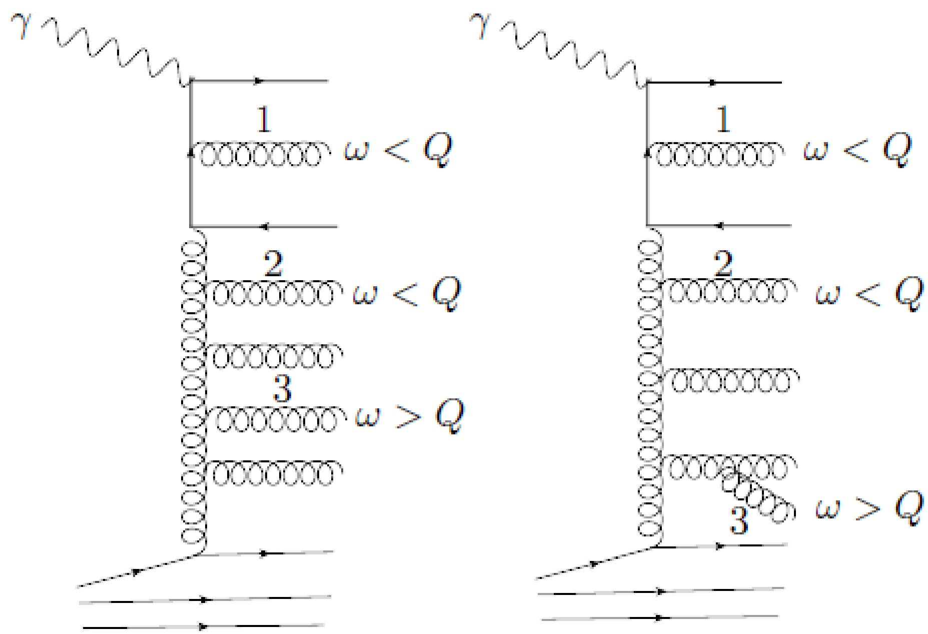
2. Possibility of unexpected physical effects not described by MPI generators, i.e. ridge at LHC.

3.Clear distinction between soft and hard QCD

4.Simple analytic models to control MC calculations.

For DIS analysis of final state multiplicities of hadrons developed in (Gribov,Dokshitzer Khoze and Troian,1988-in DGLAPapproach

(other approaches based on BFKL and CCFM see e.g.Salam,Jung and Salam



Three sources of final state radiation:

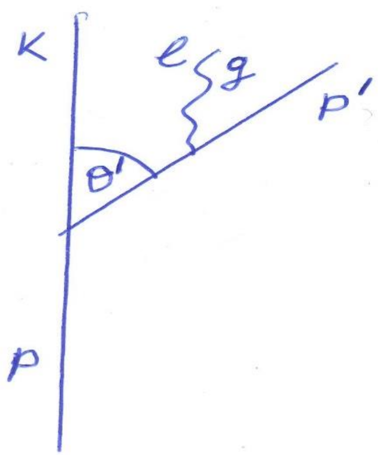
1.Currentfragmentationregion

2. Soft gluons energy l<Q

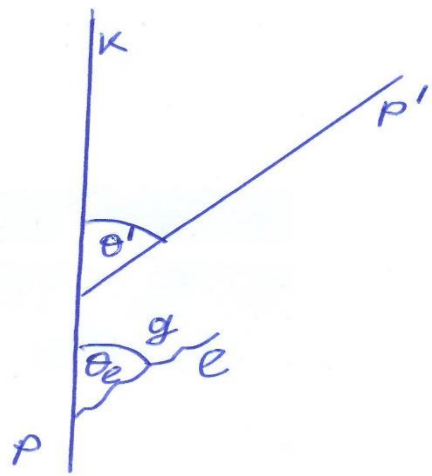
3. a) structure gluons from the rungs l>Q

   b) anomalous radiationfromt-channell P>l>Q

pQCD calculations-most convenient in Breit frame



a



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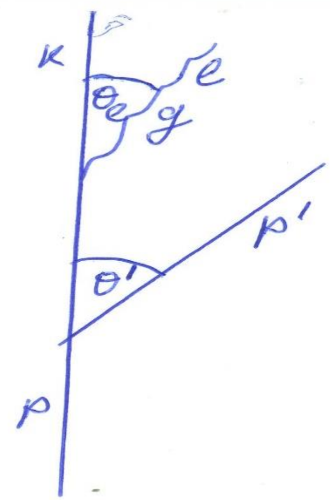

c

Basic idea:look for logarithmically enhanced diagrams (log(1/x)).
Two regions:

$$1 >> \beta' >> \beta_l >> \beta_k$$

$$1 >> \beta' >> \beta_k >> \beta_l$$

In the first region conditions $k^2 >> \kappa_a^2, k^2 >> \kappa_b^2, k^2 >> \kappa_c^2$

For logarithmic enhancement give kinematic conditions:

$$\beta'\beta_l(\theta' - \theta_l)^2 << k_t^2/(\beta'\beta_l)$$

$$l_t^2 << k_t^2 \sim p_t'^2$$

$$p_t'^2 << k_t^2 \sim l_t^2$$

If we translate to angles-two narrow cones around p' and along p. diagram a goes to running coupling constant. however, if full kinematic condition is satisfied-a and b interfere in the region $\theta' << \theta_l << \theta'/\beta_l$

In region 2 also two narrow cones+ radiation in the region $\theta_l >> \theta'$

In the entire region we can use only diagram c

In particular, the radiation of the quark-antiquark pair created by the sea in the highest cell now has radiation from on shell antiquark and by t-channel quark that together form one quark jet.
This leads to the following structure of radiation:

First contribution-the same as for e^+e^- annihilation

Comes from ejected quark and quark-antiquark pair from the sea

In MLLA

$$N(Y,u) = x_1(x_2/x_1)^B(I_{B+1}(x_1)K_B(x_2) + K_{B+1}I_B(x_2)) \cdot 4/9.$$

$$b = 11 - 2/3n_F = 9,\ a = 11/3N_c + 2n_f/(3N_c^2), B = a/b,$$

$$x_1 = \sqrt{16N_c(Y+u)/b}, x_2 = \sqrt{16N_c u/b},$$

$$u = \log(Q_0/\lambda), Y = \log(Q/\lambda).$$

$$\frac{dN_1}{dy} = (\frac{dN(Log(Q/2 \times \sin(\theta(y)/2)}{dy} + \frac{dN(Log(Q/2 \times \sin(\theta(-y)/2)}{dy}) \cdot \frac{C_F}{N_c}.$$

pseudorapidity $y = -\log(\tan(\theta/2))$

Second contribution : soft gluons l<Q

$$\frac{dN_2}{dy} = \int_{Q>k_t, k_t>Q\sin(\theta)} d\xi(k) \frac{dD_h^q(x,k_t^2)}{d\xi(k)} \int_{Q_0}^{k_t/\theta} \frac{dl}{l} \frac{2\alpha_s(l^2\theta^2)N_c}{\pi} N_g(\log(l\sin(\theta)/Q_0))\theta(Q-l)$$

With logarithmic accuracy this can be rewritten in a nice form:

$$\frac{dN_2}{dy} = \frac{dN(Q\sin(\theta(y))}{dy} \frac{D_Q^h(x,Q) - D_Q^h(x,Q\sin(\theta(y))}{D_Q^h(x,Q)}$$

Third contribution-from target fragmentation region (structure +t-channell)

$$\frac{dn^{(3)}}{dy^*} = \int_0^{\xi_Q} d\xi \int_Q^{kt/\theta} \frac{dl}{l} \frac{\alpha_s(l^2\theta^2)}{4\pi}$$
$$\times\ D_h^q(l/P, k_t^2/Q_0^2) \frac{d^2 D_G^q(Q/l, Q^2/k_t^2)}{d^2\xi(Q^2,k_t^2)} N_g(l\sin(\theta)/Q_0)/(1+\exp(-y))$$

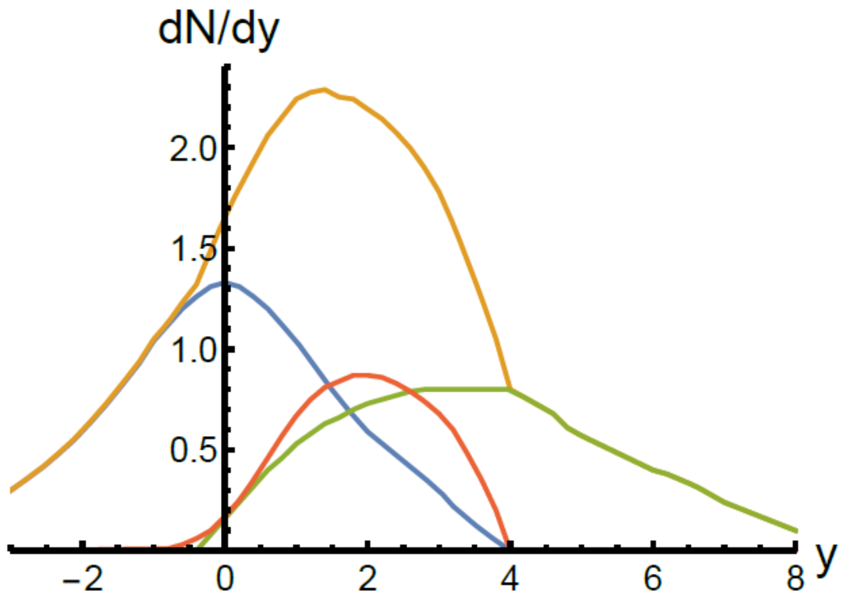

FIG. 2: The pseudorapidity distribution of inal hadronic states in DIS. Q=10 GeV, x=0.001, Here and in 3 subsequent pictures the four curves in the figure correspond to total, current (left), soft(middle) and structural plus anomalous (right) contributions to multiplicity. Note that here and in the following 3 pictures the graphs are in Breit frame the target fragmentaion region corresponds to pocitive pseudorapidities as in [7]. This is in distinction of choice of direction in c.m. frame in [9] where the target fragmentation region corresponds to positive pseudorapidities.

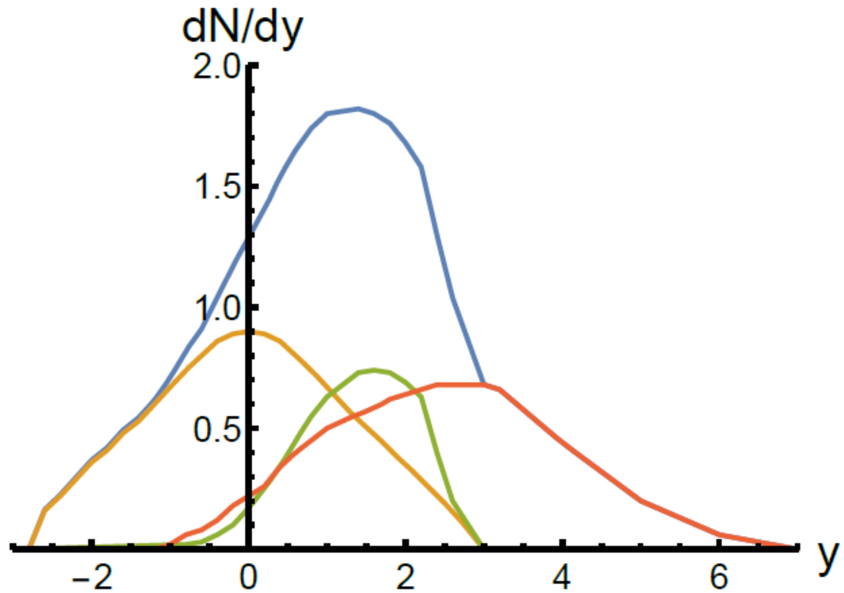

FIG. 3: Pseudorapidity distribution in DIS, Q=4.5 GeV,x=0.001

Comparison with experimental data:

Strictly speaking---

$$\frac{\alpha_s(Q^2)}{\pi}\log(1/x) << 1$$

The reason-for smaller x we expect violation of kt ordering and transition from DGLAP to Regge kinematics. However we shall expect this approximation to work in transition region ,that covers Almost the entire region currently available .

$$\frac{\alpha_s(Q^2)}{\pi}\log(1/x) \leq 1$$

$$Q^2 > 10 \text{ GeV}^2,\ x \geq 10^{-4} - 10^{-5}$$

On the other side, for large x the anomalous contribution was enhanced by log(1/x), thus for large x the angular ordered contributions discussed are not enhanced, and one needs full NLO analysis+nonperturbative contributions. Such contributions give dN/dy of order 1 in gluon ladder+"pedjestal" which may be significant for quark-antiquark jet. In addition we need of course the dominance of double logarithmic structure of ladder, i.e. x less than 0.01 at least.for larger x-NLO corrections. In addition characteristic lt sufficiently large-so that works MLLA approximation for jets,i.e. Q>10 GeV at least. (jets have energy Q/2 in DIS).

Nevertheless, we have reasonable agreement with HERA data, even without adding nonperturbative contributions.

HERA data is organized in bins, and taken in proton-photon center of mass system,
So one needs to go to c.m.s. from Breit frame-not very good procedure,
Especially for particles with nonzero mass.

The average over bins is carried with the help of

$$\frac{d\bar{N}}{d\eta} = \frac{\int dx dQ^2 dy \frac{d\sigma_{DIS}}{dx dQ^2} \frac{dN}{d\eta}(-\eta + \log(1/x)/2)}{\int dx dQ^2 dy \frac{d\sigma_{DIS}}{dx dQ^2}}$$

$$\frac{d\sigma_{DIS}}{dx dQ^2} = \frac{4\pi\alpha^2}{Q^4}((1+(1-y)^2)F_1 + (1-y)(F_2 - 2xF_1)/x)$$

and with current accuracy we use $F_2 = 2xF_1$, $F_2(x, Q^2(, F_!(x, Q^2)$ are standard electromagnetic structure functions, and $y = Q^2/(xs)$, where s is the invariant squared center of mass energy $s = 4 * 28 * 800$ GeV^2 for HERA. For F_2 we can use

$$F_2 = \frac{4}{9}x(u(x) + \bar{u}(x)) + \frac{1}{9}(d(x) + \bar{d}(x))$$

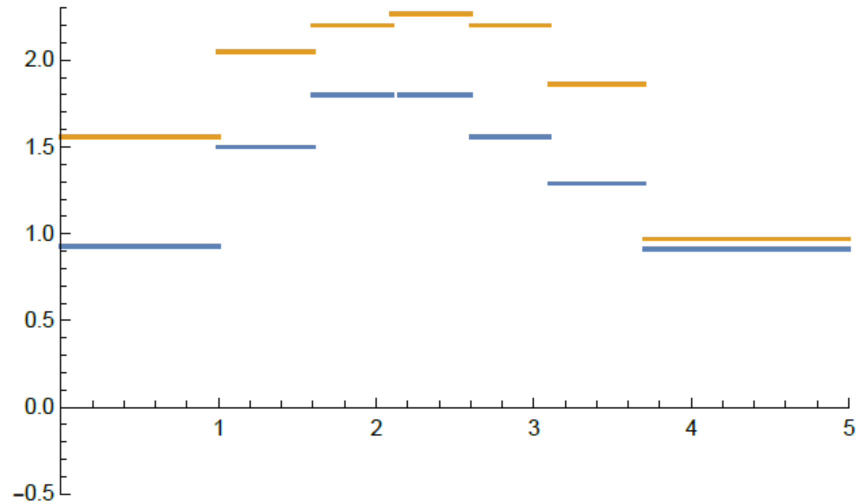

FIG. 6: The averaged over bins pseudorapidity distribution: $20 < Q^2 < 100$ GeV^2,$0.0004 < x < 0.0017$:experiment versus pQCD. Note that the pictures are in c.m. frame of [9], and the target fragmentation correponds to negative values of pseudorapidities-opposite to Figs. 2-5.

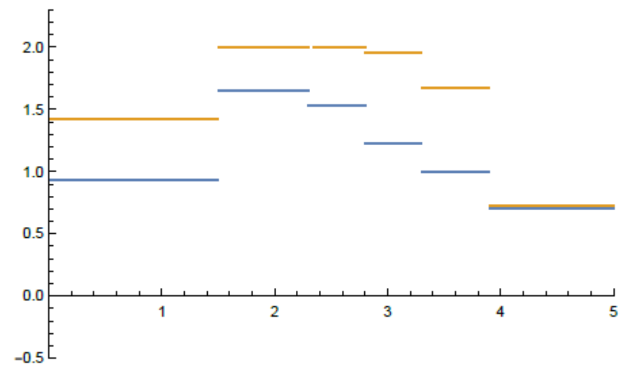

FIG. 9: The averaged over bins pseudorapidity distribution:$10 < Q^2 < 20$ GeV^2,$0.00052 < x < 0.0017$

The agreement is quite reasonable,especially ifwe shall add nonperturbative Radiation. Possible will become perfect at LeHC.

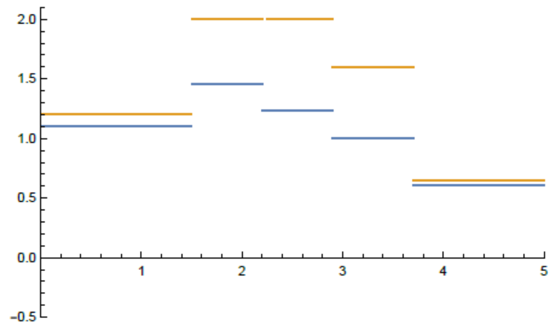

FIG. 7: The averaged over bins pseudorapidity distribution: $20 < Q^2 < 100$ GeV^2, $0.0017 < x < 0.01$

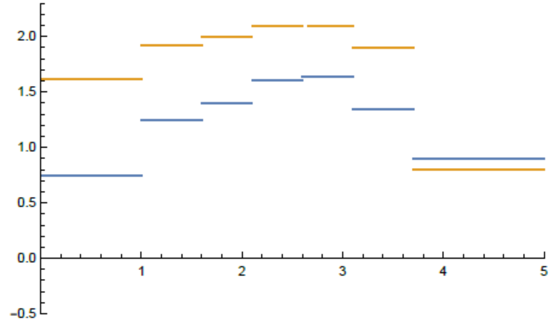

FIG. 8: The averaged over bins pseudorapidity distribution: $10 < Q^2 < 20$ GeV^2, $0.0002 < x < 0.00052$

In the last picture-first bin is determined entirely by target fragmentation region.

Conclusions:

- pQCD gives distribution qualitatively and quantatively agreeing with experimental data.
- The maximum position slowly shift towards target region with decrease of x
- Increase of Q leads to slow increase in height of the maximum
- Can be used to study more complicated case of final state radiation in DGLAP gluonic ladder

Regions: l<Q L>Q

L<Q :ejected quark+quark-antiquark pair

Soft gluons from ladder as a whole angle of order k_t/Q

L>Q

Structure k<l<p

Kt=lt>>pt

Anomalous kt=pt>>lt   k<<l<<p

All other regions are suppressed due to color interference (angular ordering)