Asymptotic freedom in the mechanics of hadron collisions at high energies

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Contents :

- couple words on the parton model
- asymptotic freedom in mechanics of DIS
- asymptotic freedom in mechanics of hh interactions
- some illustration
- conclusion

Introduction (... beforehand conclusion)

The application of the asymptotic freedom hypothesis to consider the mechanics of deep inelastic scattering processes (DIS), allows one to reveal the elastic form of the partons ($x_a m_a$ and $x_b m_b$) scattering also for hadron – hadron interactions of particles *a* and *b* having masses m_a and m_b with subsequent hadronization of them into the hadron showers.

It is shown, that the hadronic mass produced in DIS (at the final part of interaction), can be expressed through the parton parameters corresponding to the first part of interaction. The elastic character of the partons interaction in the first step of hadron-hadron collisions helps to define the invariant variables (Bjorken x_a , Bjorken x_b and square four - momentum transfer Q^2) similar to DIS through the parameters of two hadron showers in the c.m.s. of a- and b- particles.

This two-step particle interaction mechanism becomes as a universal one also due to A.M. Baldin's hypothesis on the existence of some groups of constituents (nucleons, quarks, partons) inside nuclei . The idea is that this groups of constituents elastically interact in the first step of particle or nuclear scattering process.

Some results of calculations of 2000 pp-interactions at LHC at 10 TeV generated by PYTHIA, are presented. This approach can be of interest for QCD-treatment of hh-interactions, development of the concept of cumulative phenomena and its investigations, search for quark-gluon plasma and phase transition in project NICA. The new invariants could be included in a list of visible values.

Parton model

J.D. Bjorken Phys.Rev. **185**, 1975 (1969)

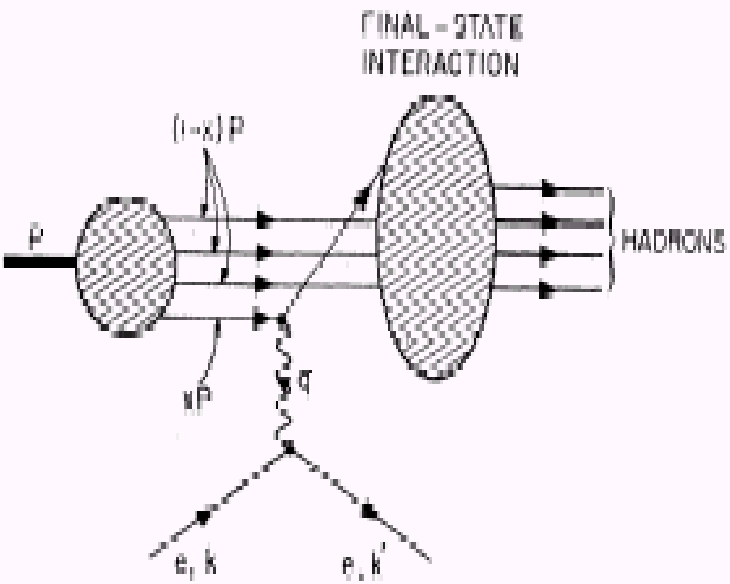


FIG. 1. Kinematics of lepton-nucleon scattering in the parton model.

At infinite momentum, we visualize the intermediate state from which the electron scatters as follows:

(a) It consists of a certain number N of free partons (with probability P_N).

(b) The longitudinal momentum of the ith parton is a fraction x_i of the total momentum of the proton:

$$\mathbf{p}_i = x_i \mathbf{P}. \qquad (2.10)$$

(c) The mass of the parton, before and after the collision, is small (or does not significantly change).

(d) The transverse momentum of the parton before the collision can be neglected, in comparison with $\sqrt{(Q^2)}$, the transverse momentum imparted as $p \to \infty$.

two - step of particle interaction picture

The 2004 Nobel Prize in Physics

David J. Gross
Kavli Institute of Theoretical Physic
University of California at Santa Barbara USA (b. 1941)

H. David Politzer
California Institute of Technology
USA (b. 1949)

Frank Wilczek
Massachusetts Institute of Technology
USA (b. 1951)

“for the discovery of asymptotic freedom in strong interactions”

$1,300,000

The two arms of physics

Variables: what are the things that make up what we study …analysis

Dynamics: how do the variables interact and move ….synthesis

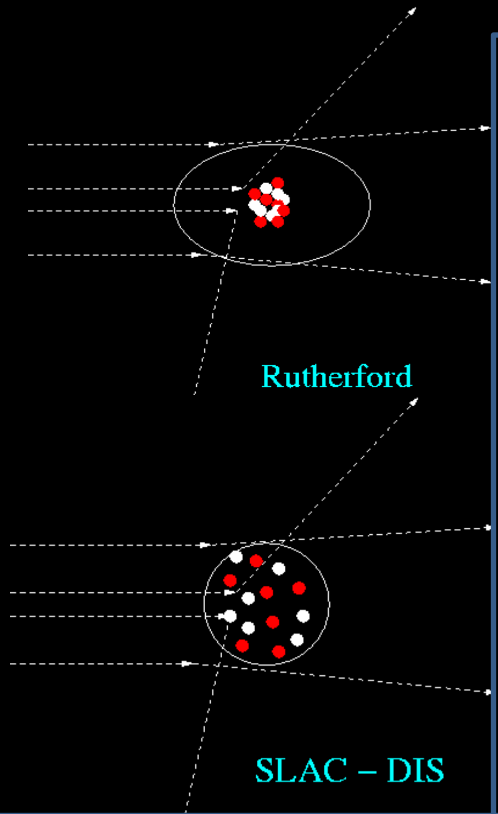
The crucial experiment

Deep inelastic scattering- the 'Rutherford experiment' of particle physics

First view of quarks

Friedman, Kendall, Taylor (1969)

Bjorken, Feynman



QCD is born (SLAC to LEP)

Asymptotic freedom allowed computation of deep-inelastic cross sections, predicted lepton pair production, jets, etc

…many physicists

(1970s to 1990s)

Short introduction to the velocity space

- $E/c^2 = m / \sqrt{(1-\beta^2)} = m \operatorname{ch} \rho/c$
- $P/c = m \beta / \sqrt{(1-\beta^2)} = m \operatorname{sh} \rho/c$
- $v/c = \beta = \operatorname{th} \rho/c \Longrightarrow \rho/c = ½ \ln[(1+\beta)/(1-\beta)]$

(c =1)

Let us $K_a(E_a, \mathbf{P}_a)$ and $K_b(E_b, \mathbf{P}_b)$ - 4 – vectors of a- and b- particles:

$K_a K_b = E_a E_b - |\mathbf{P}_a| |\mathbf{P}_b| \cos\theta =$

$= m_a m_b (\operatorname{ch}\rho_a \operatorname{ch}\rho_b - \operatorname{sh}\rho_a \operatorname{sh}\rho_b \cos\theta) = m_a m_b \operatorname{ch} \rho_{ab}$

$(K_a + K_b)^2 = K_a^2 + 2K_a K_b + K_b^2 = m_a^2 + 2m_a m_b \operatorname{ch}\rho_{ab} + m_b^2 = M^2 = s$

$(K_a - K_b)^2 = K_a^2 - 2K_a K_b + K_b^2 = m_a^2 - 2m_a m_b \operatorname{ch}\rho_{ab} + m_b^2 = q^2$,

If $m_a = m_b = m$, $-q^2 \equiv Q^2 = 2 m^2 (\operatorname{ch}\rho_{ab} - 1)$

Asymptotic freedom into the mechanics of DIS

$a + b \rightarrow a' + X$

$K_a + xK_b + (1-x)K_b = (1-x)K_b + K'_a + (xK_b)'$

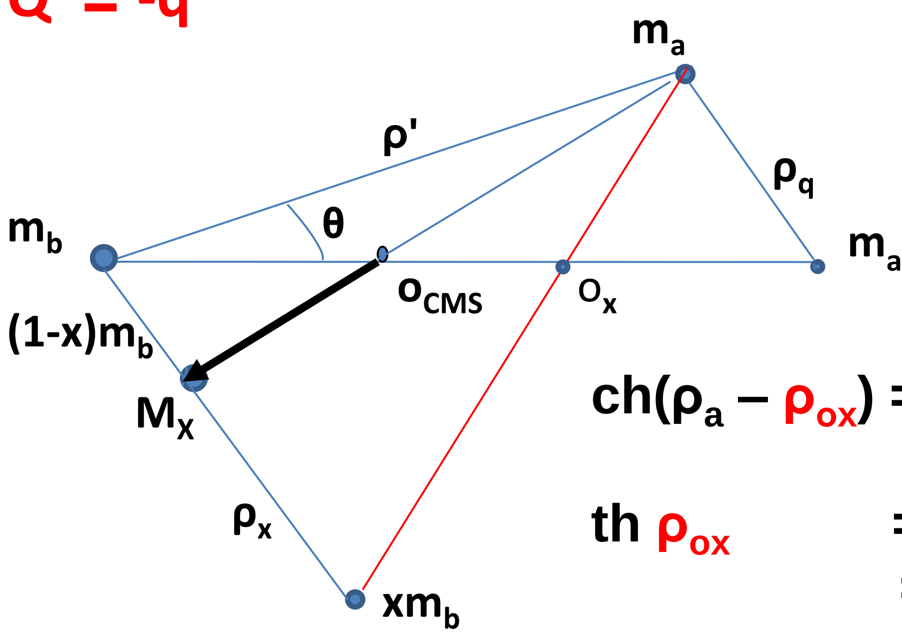
$K_a + K_b = K'_a + K_x$

$q = K_a - K'_a = K_x - K_b$

$Q^2 \equiv -q^2$

$q + xK_b = (xK_b)' \Rightarrow x = -q^2/(2qK_b) = Q^2/2m_b\nu$

$\nu = E_a - E_a'$



Breit system (O_x):

$ch(\rho_a - \rho_{ox}) = ch\,\rho_{ox}\,ch\rho' - sh\,\rho_{ox}\,sh\,\rho' \cos\theta$

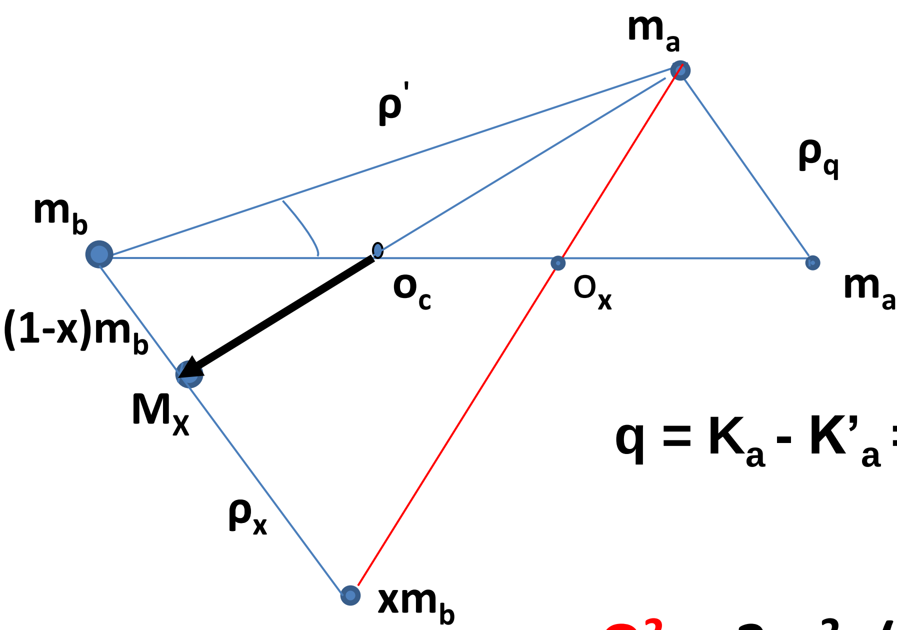
$th\,\rho_{ox} = (ch\,\rho_a - ch\,\rho')\,/\,(sh\rho_a - sh\rho' \cos\theta) =$

$= (E_a - E_a')\,/\,(P_a - P'_L) \equiv \beta_{ox}$

1) $th\,\rho_{ox} = P_a\,/\,(E_a + x\,m_b) \quad \rightarrow \quad x = Q^2/2m_b\nu$

2) $x\,m_b\,sh\,\rho_{ox} = m_a\,sh\,(\rho_a - \rho_{ox}) \quad \rightarrow \quad x = Q^2/2m_b\nu$

DIS: Q^2 and ν as functions of x and ρ_x



$$q = K_a - K'_a = K_x - K_b = xK'_b - xK_b \qquad (Q^2 \equiv -q^2)$$

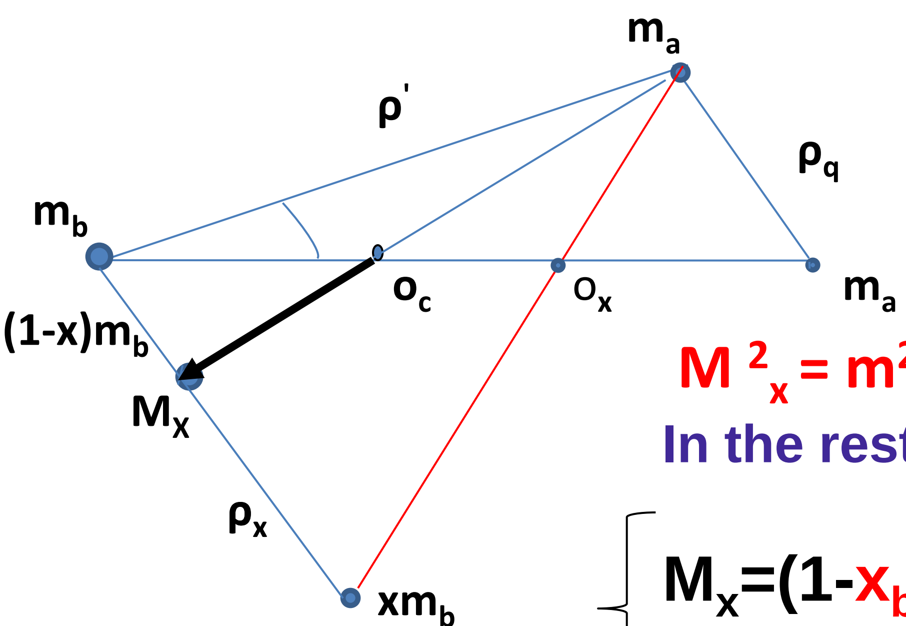
$$Q^2 = 2m_a^2 (\mathrm{ch}\,\rho_q - 1) = 2(x\, m_b)^2 (\mathrm{ch}\,\rho_x - 1)$$

$$Q^2 / 2(x\, m_b) = \nu = x\, m_b(\mathrm{ch}\,\rho_x - 1)$$

Full energy of elastic scattering $s_x = (K_a + xK_b)^2$

$$s_x = (x\, m_b)^2 + 2\, x\, m_b m_a\, \mathrm{ch}\,\rho_a + m_a^2 \;; \qquad s_x \approx x\, s$$

DIS: M_x^2 as function of x and ρ_x



$$K^2_x = (q + K_b)^2$$

$$M^2_x = m^2_b\,[\,x^2 + 2x(1-x)ch\rho_x + (1-x)^2\,]$$

In the rest system of M_x:

$$\begin{cases} M_x = (1-x_b)\, m_b\, ch\rho_{xb1} + x_b m_b ch\rho_{xb2} \\ (1-x_b)\, m_b\, sh\rho_{xb1} = x_b m_b\, sh\rho_{xb2} \end{cases}$$

$$\rho_{xb1} + \rho_{xb2} = \rho_x$$

$$X_b = \frac{2M_x m_b ch\rho_{xb1} - M^2_x - m^2_b}{2m_b(M_x ch\rho_{xb1} - m_b)} = \frac{-(K_x - K_b)^2}{2K_b(K_x - K_b)} = -q_b^2/(2q_b K_b)$$

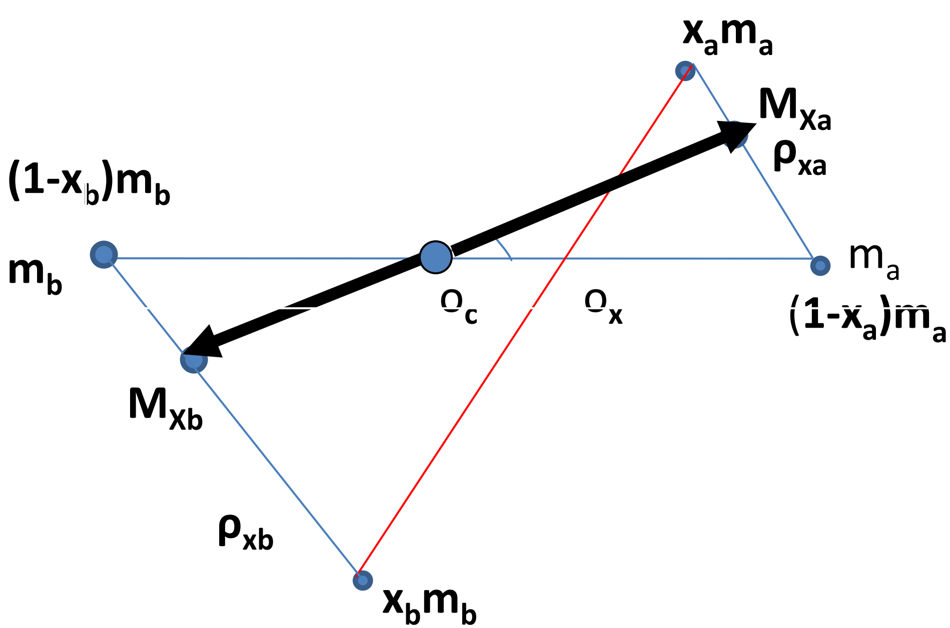
$X_a = -q_a^2/(2q_a K_a)$, $q_a = K'_a - K_a$; $sh\rho_{xb2} = (1 - x_b)\,/\,x_b\, sh\rho_{xb1}$

$X_a = 1$.

Asymptotic freedom into the mechanics of h+h interactions

$$K_a \quad + \quad K_b \quad = \quad K_{xa} \quad + \quad K_{xb}$$

$$(1-x_a)K_a + x_a K_a + x_b K_b + (1-x_b)K_b = (1-x_a)K_a + x_a K'_a + x_b K'_b + (1-x_b)K_b$$



$$K_{xa} = (1-x_a)K_a + x_a K'_a \qquad K_{xa}^2 \equiv M_{xa}^2$$

$$K_{xb} = (1-x_b)K_b + x_b K'_b \qquad K_{xb}^2 \equiv M_{xb}^2$$

$$q_a = K_{xa} - K_a \; ; \quad q_b = K_{xb} - K_b$$

$$q_a = -q_b$$

$$-q_a^2 = -q_b^2 \equiv Q^2$$

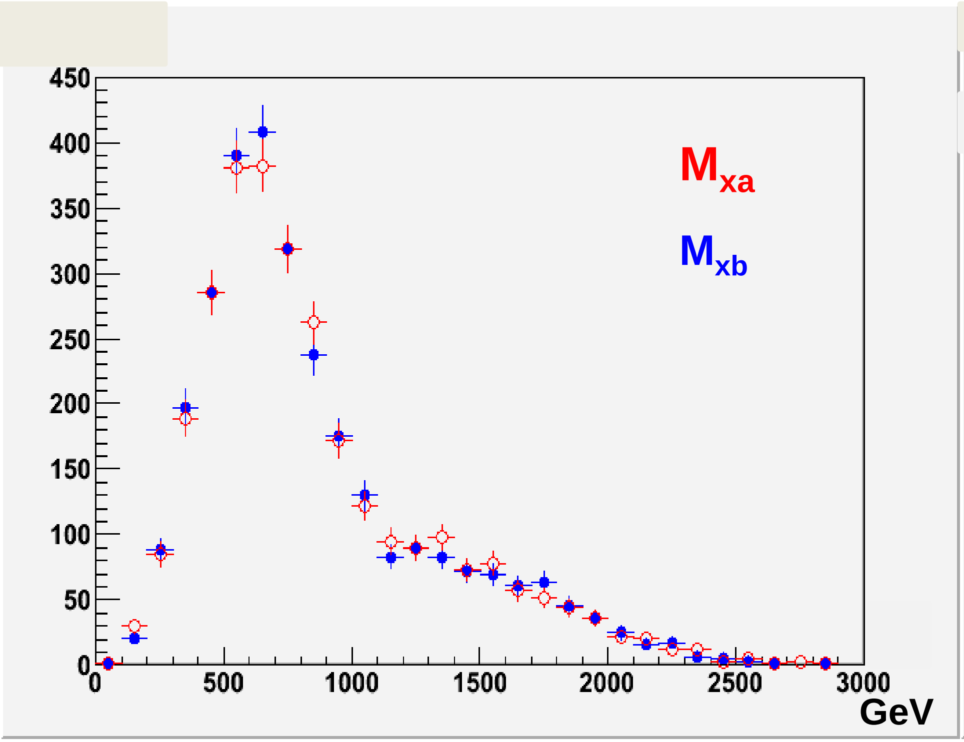
$$x_b = -q_b^2/(2q_b K_b) = Q^2/(Q^2 + M^2_{xb} - m^2_b) = 1/(1 + (M_{xb}^2 - m^2_b)/Q^2)$$

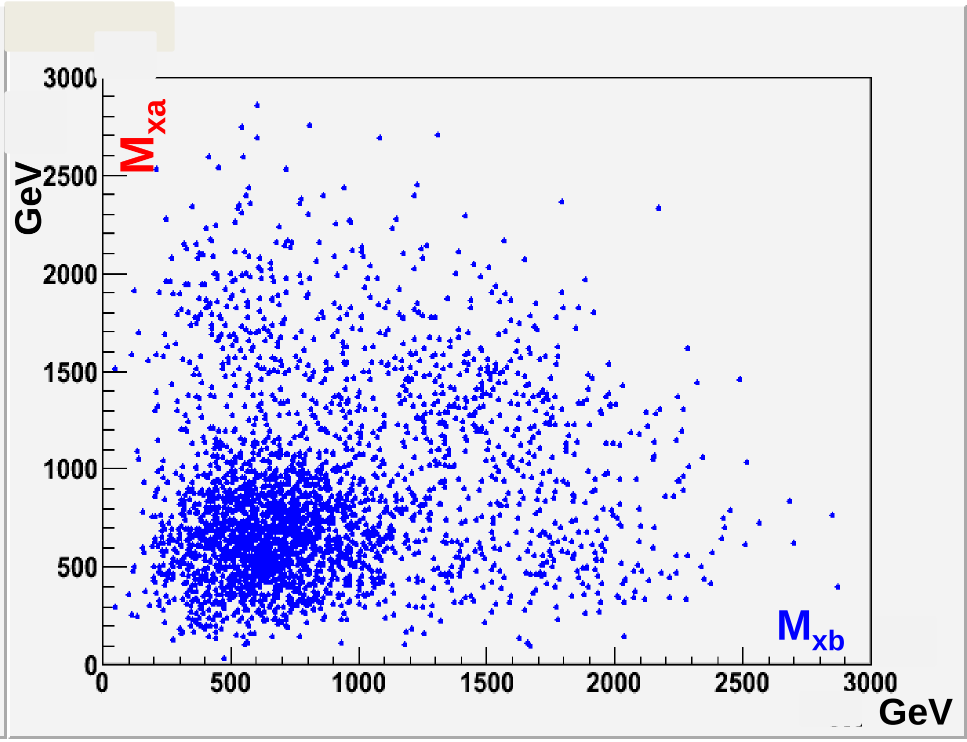
$$x_a = -q_a^2/(2q_a K_a) = Q^2/(Q^2 + M^2_{xa} - m^2_a) = 1/(1 + (M_{xa}^2 - m^2_a)/Q^2)$$

$$S = M_{xa}^2 + 2 M_{xa} M_{xb} \, ch\rho_{xab} + M_{xb}^2$$

$$S_{xab} \approx x_a x_b S$$

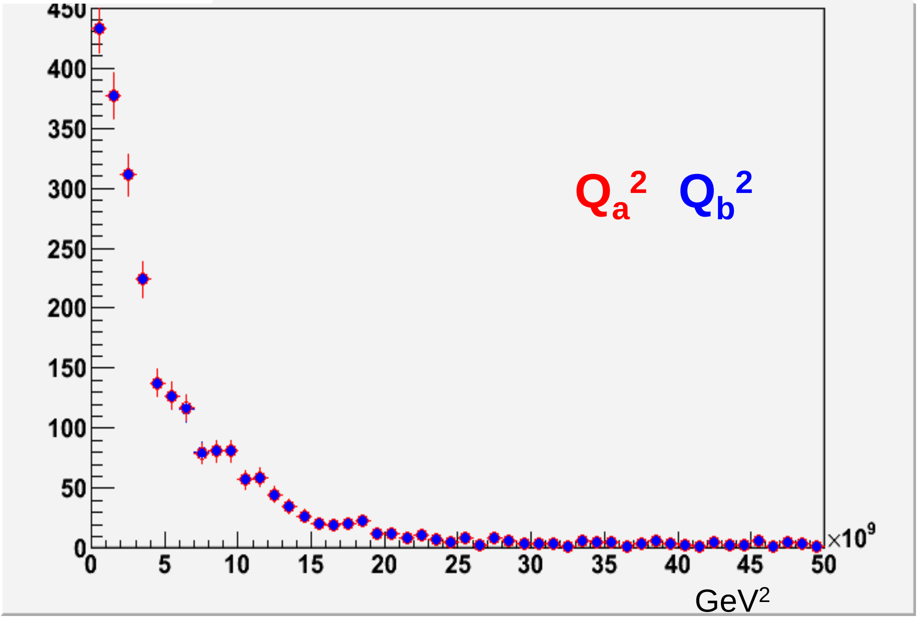
PYTHIA6.5: pp, 10 TeV, two-jet events

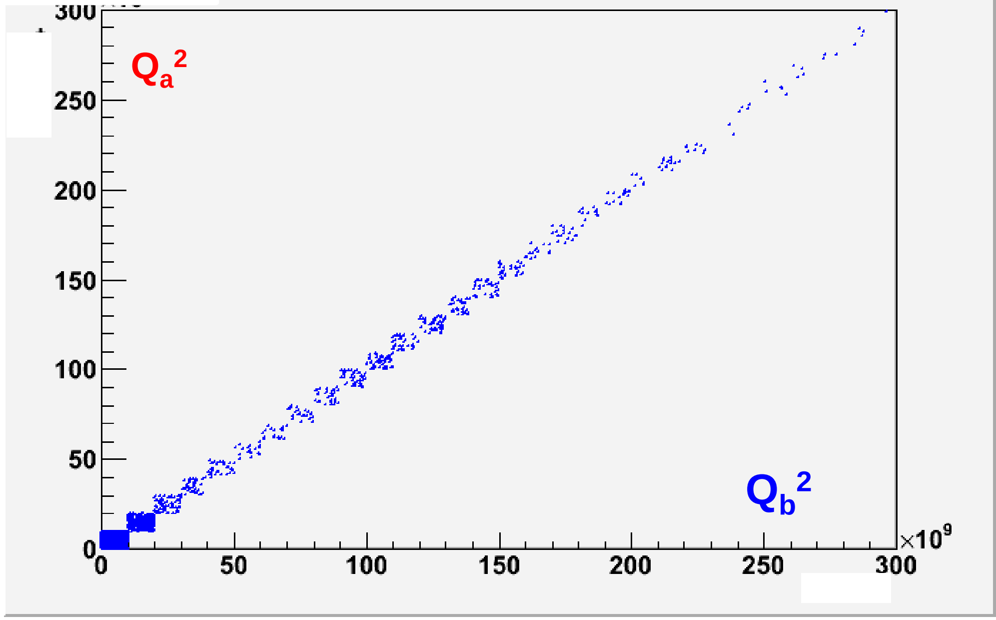




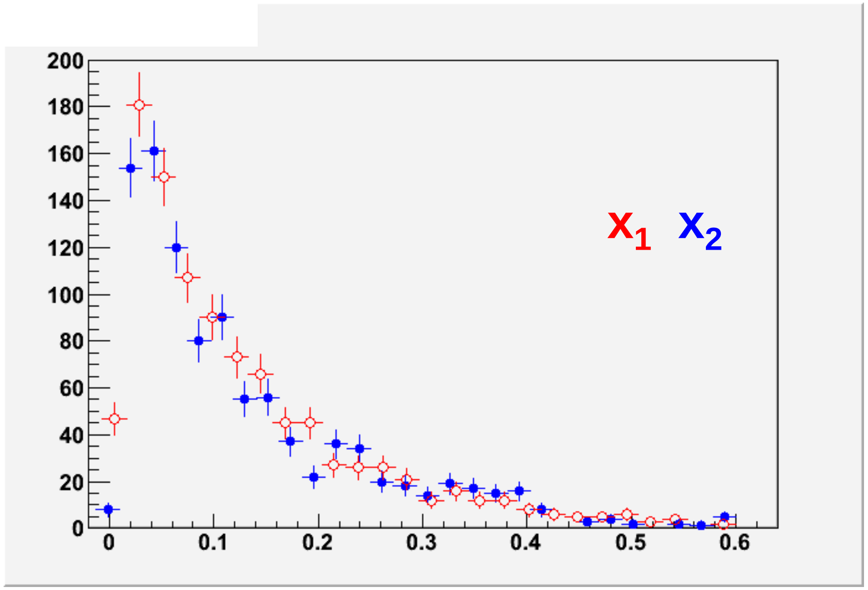
Effective masses of hadron showers

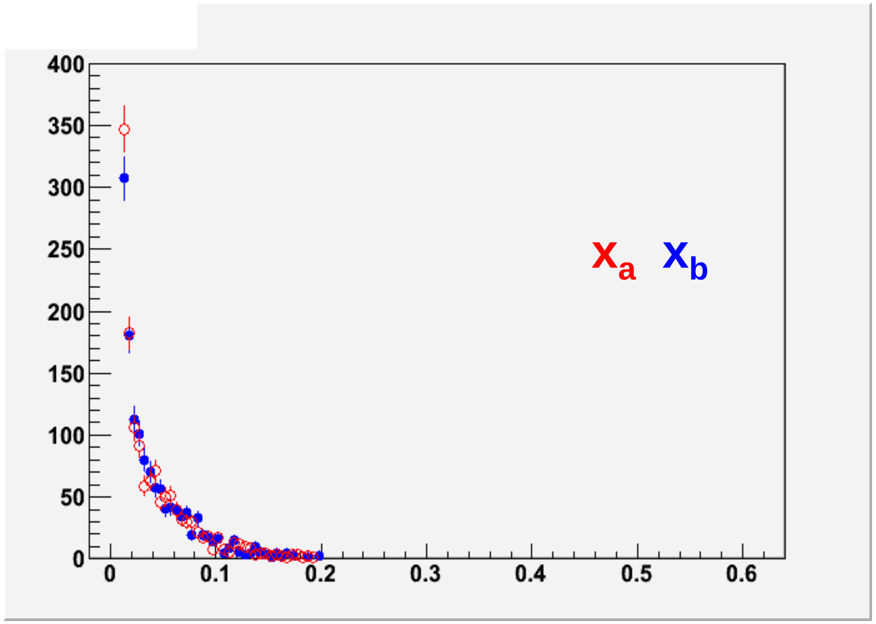
PYTHIA6.5: pp, 10 TeV, two-jet events

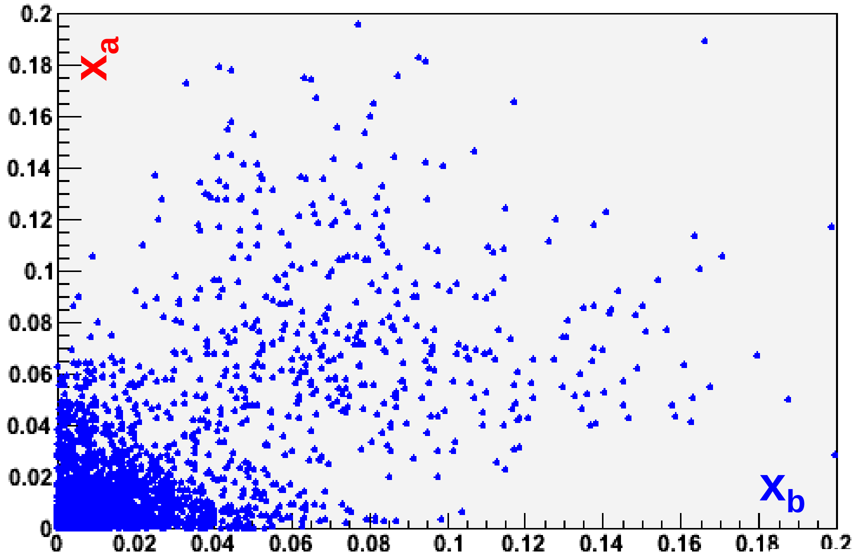




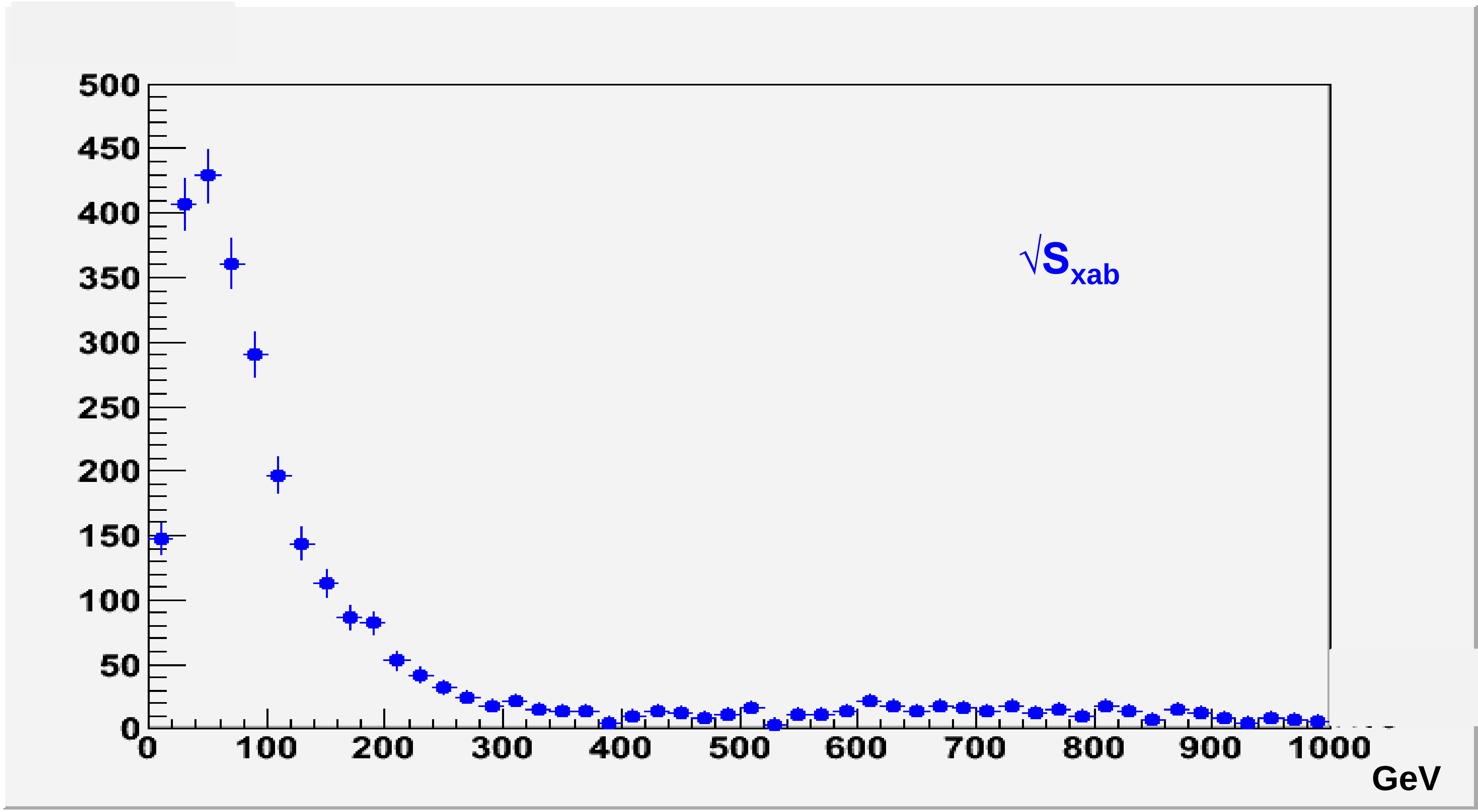
PYTHIA6.5: pp, 10 TeV, two-jet events







PYTHIA6.5: pp, 10 TeV, two-jet events



Full energy of two elastically interacted partons:

$$S_{xab} = (m_a x_a)^2 + 2\, x_a m_a\; x_b m_b \,\mathrm{ch}\, \rho_{ab} + (m_b x_b)^2$$

Conclusion:

- The application of the AF- hypothesis in the mechanics of hadron collisions at high energies has been considered.

  - It is shown that the AF causes (as well as Feyman model) the two steps interaction mechanism: the elastic scattering of groups constituents at the first step with the subsequent hadronization them into the visible particles - on the second step ;

  - the hadron mass produced at the second step can be expressed through the parameters of the first one;

  - the groups of constituents x_g coinside with Bjorken invariant x .

- It is shown that the parton elastic character of interaction allows, in its turn, to define the invariant variables (x_a, x_b and 4-momentum transfer Q^2), similar to used in DIS, through the parameters of two (in c.m.s.) registered hadron showers;

  - the new invariants could be included in a list of visible values.

- The offered approach can be of interest for QCD- treatment of joint data DIS and hadron-hadron interactions ((global fit), for development of the concept of cumulative events, seach for a quark-gluon plasma and an intermediate phase on NICA .

MANY THANKS ！

- Рассмотренно применение гипотезы АС в механике столкновения составных частиц при высоких энергиях. Показано, что АС обуславливает (как и модель Фейнмана) двухэтапный механизм взаимодействия: упругое рассеяние групп конституентов на первом этапе с последующей их адронизацией – на втором; сами группы конституентов x_g совпадают с партонами Бьёркена x .

- Показано, что упругий характер столкновения партонов позволяет, в свою очередь, определить инвариантные переменные (x_a, x_b и переданный импульс Q^2), аналогичные используемым в ГНР, через параметры двух регистрируемых адронных ливней.

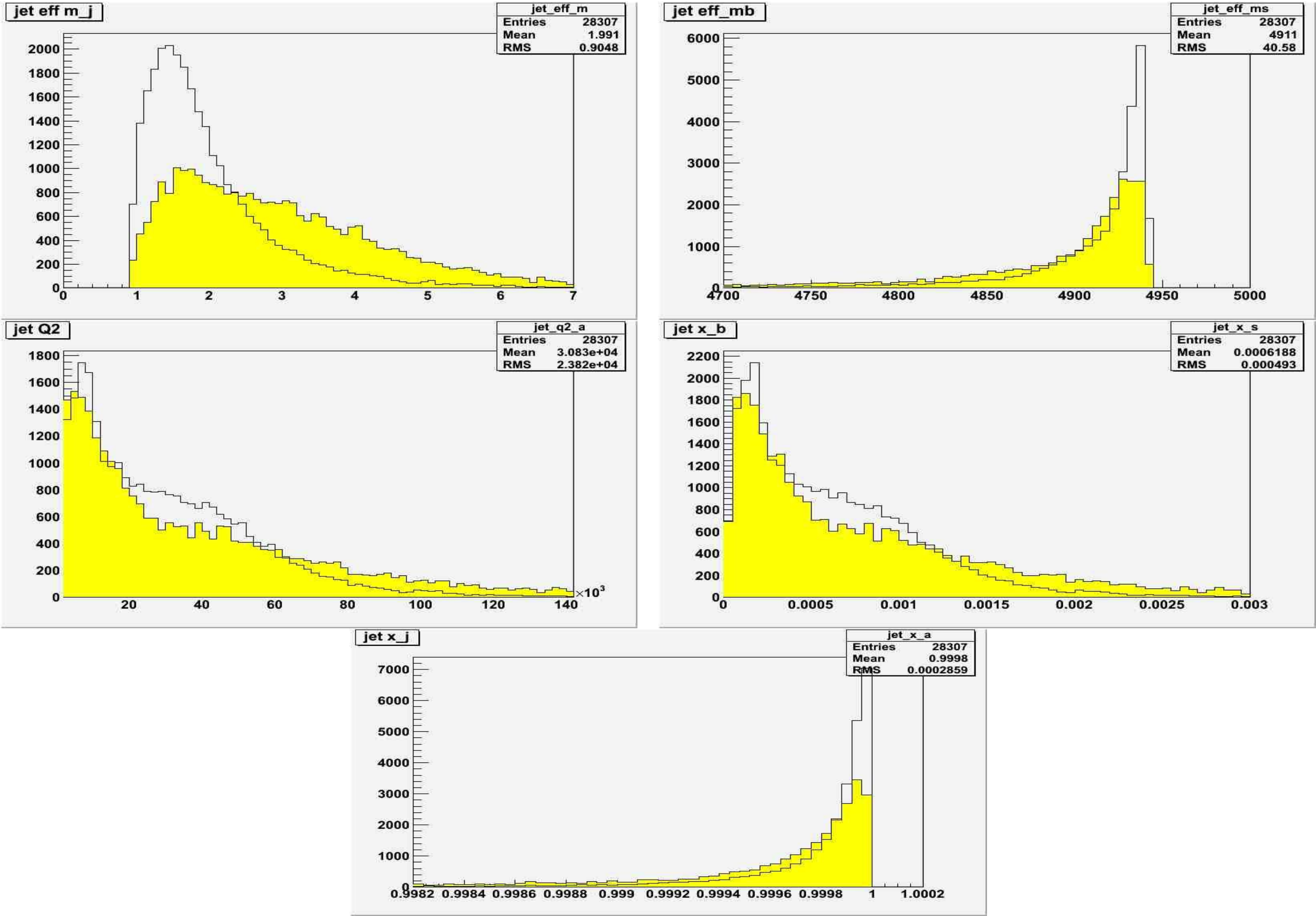
- Предложенный подход может представлять интерес для КХД-обработки адронных взаимодействий, для развития концепции кумулятивных событий, поиска кварк – глюонной плазмы и промежуточной фазы на NICA (здесь требуется дополнительное изучение).

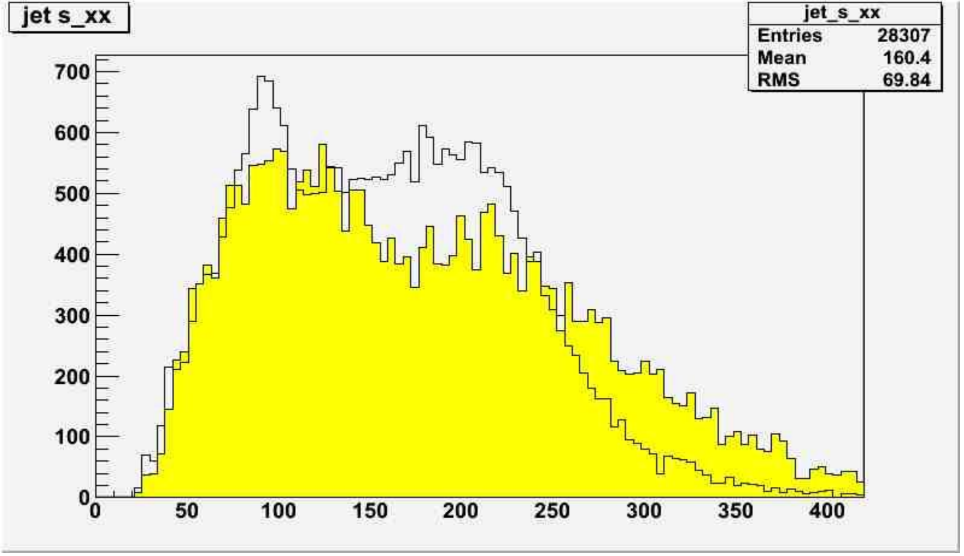
Data:

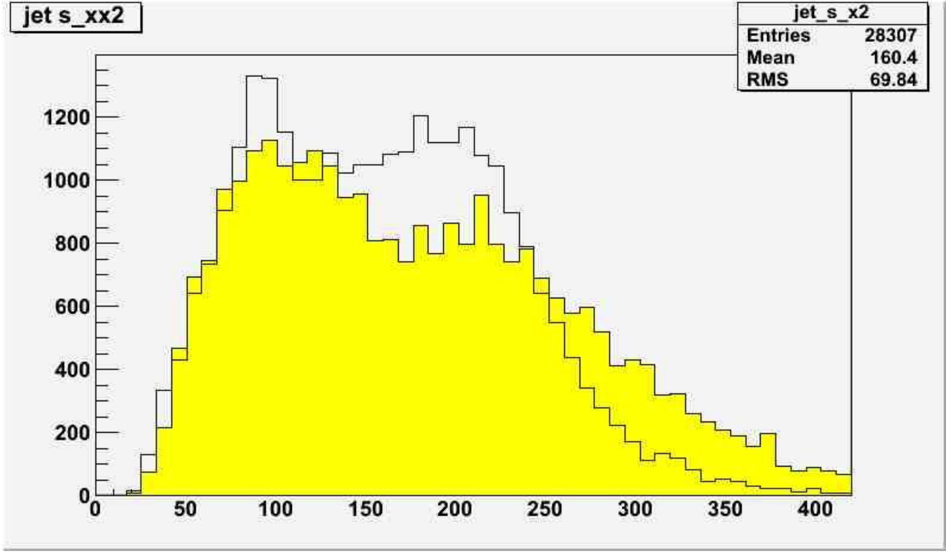
Data10_7TeV.00152221.physics_MinBias.merge.AOD.f238_p115_f239_m427

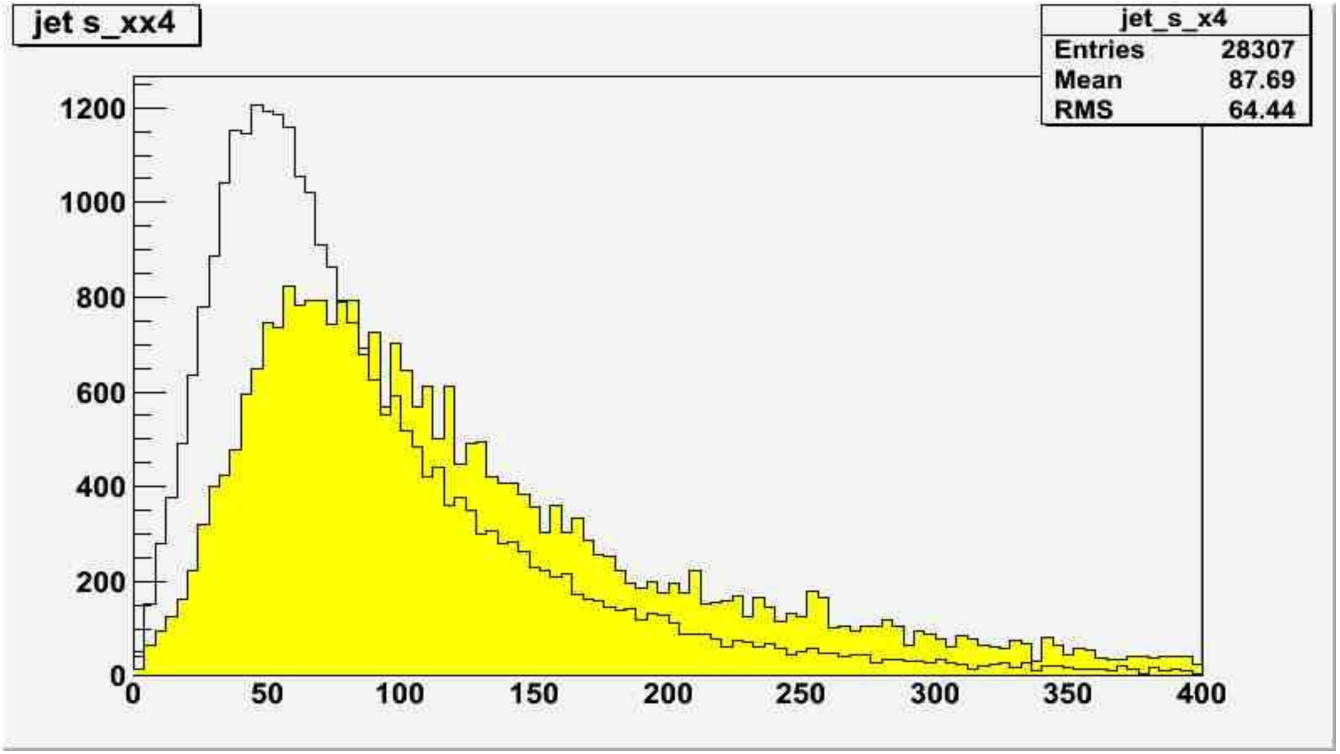
mc09_7TeV.115020.J1_pythia_jetjet_Pro.recon.ESD.e530_s766_s767_r1206_tid125052_0

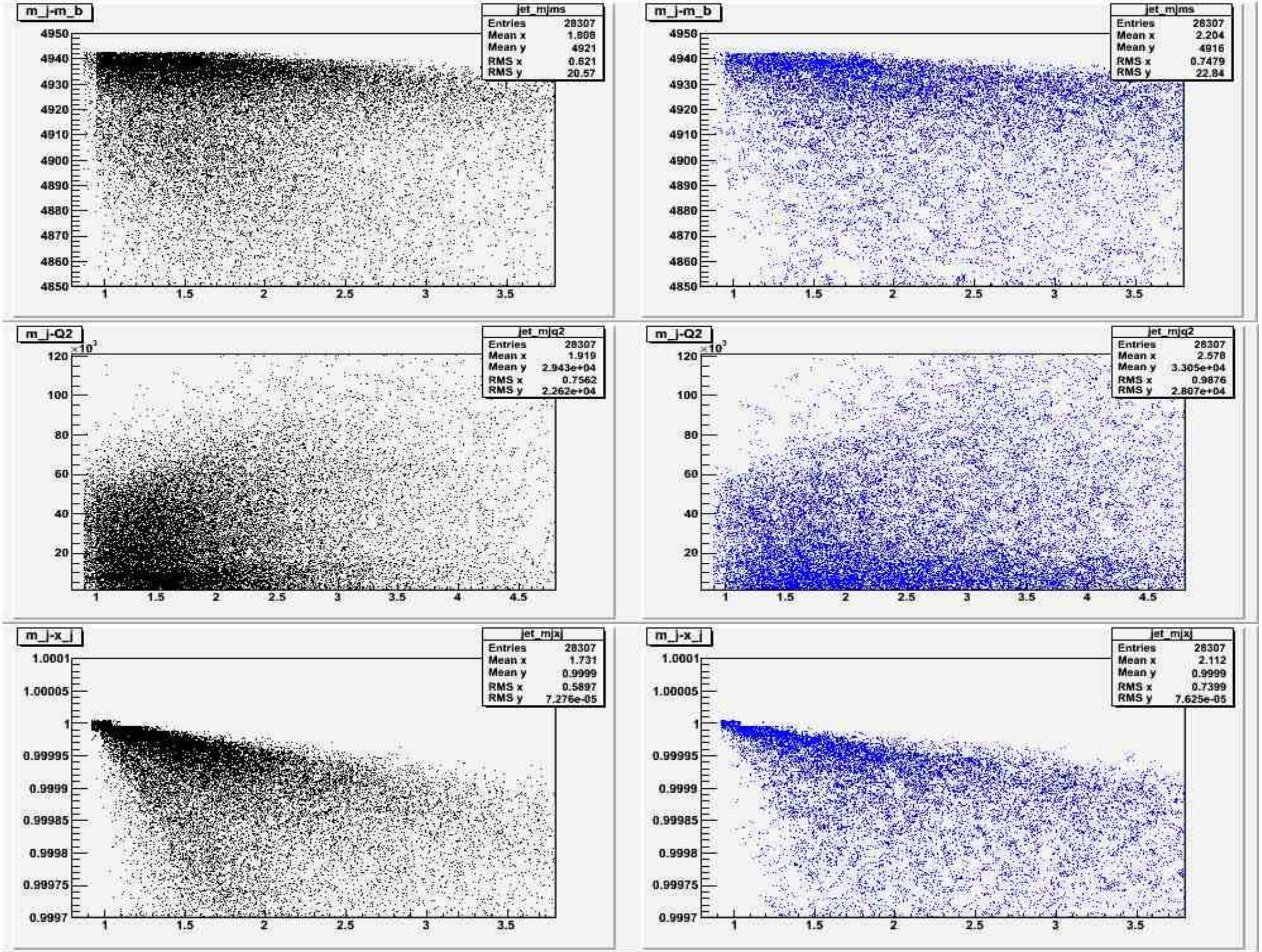
Some results




jet s_xx
jet_s_xx
Entries 28307
Mean 160.4
RMS 69.84


jet s_xx2
jet_s_x2
Entries 28307
Mean 160.4
RMS 69.84


jet s_xx4
jet_s_x4
Entries 28307
Mean 87.69
RMS 64.44


m_j-m_b
jet_mjms
Entries 28307
Mean x 1.808
Mean y 4921
RMS x 0.621
RMS y 20.57
m_j-m_b
jet_mjms
Entries 28307
Mean x 2.204
Mean y 4916
RMS x 0.7479
RMS y 22.84
m_j-Q2
jet_mjq2
Entries 28307
Mean x 1.919
Mean y 2.943e+04
RMS x 0.7562
RMS y 2.262e+04
m_j-Q2
jet_mjq2
Entries 28307
Mean x 2.578
Mean y 3.305e+04
RMS x 0.9876
RMS y 2.807e+04
m_j-x_j
jet_mjxj
Entries 28307
Mean x 1.731
Mean y 0.9999
RMS x 0.5897
RMS y 7.276e-05
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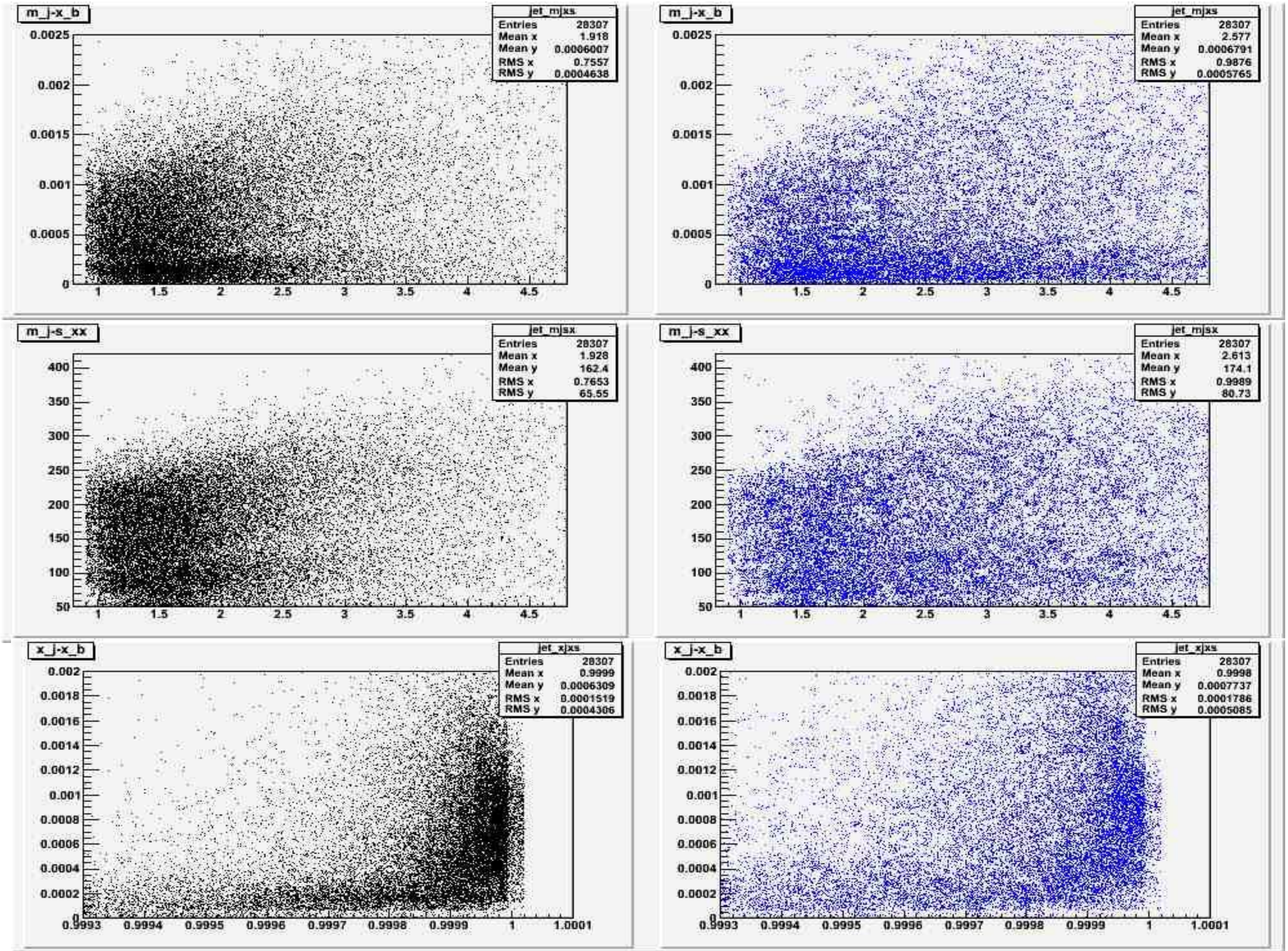
jet_mjxj
Entries 28307
Mean x 2.112
Mean y 0.9999
RMS x 0.7399
RMS y 7.625e-05


m_j-x_b
jet_mjxs
Entries 28307
Mean x 1.918
Mean y 0.0006007
RMS x 0.7557
RMS y 0.0004638
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jet_mjxs
Entries 28307
Mean x 2.577
Mean y 0.0006791
RMS x 0.9876
RMS y 0.0005765
m_j-s_xx
jet_mjsx
Entries 28307
Mean x 1.928
Mean y 162.4
RMS x 0.7653
RMS y 65.55
m_j-s_xx
jet_mjsx
Entries 28307
Mean x 2.613
Mean y 174.1
RMS x 0.9989
RMS y 80.73
x_j-x_b
jet_xjxs
Entries 28307
Mean x 0.9999
Mean y 0.0006309
RMS x 0.0001519
RMS y 0.0004306
x_j-x_b
jet_xjxs
Entries 28307
Mean x 0.9998
Mean y 0.0007737
RMS x 0.0001786
RMS y 0.0005085

Асимптотическая свобода в механике неупругих столкновений составных частиц при высоких энергиях

Н.Г. Фадеев

Содержание доклада:

- несколько слов о партонной модели
- асимптотическая свобода в механике ГНР
- асимптотическая свобода в механике h+h
- некоторые иллюстрации
- заключение

Введение (...предваряя заключение)

На основе применения гипотезы асимптотической свободы (АС) в рассмотрении механики глубоконеупругих (e ,μ) h - взаимодействий (ГНР) в пространстве скоростей выявлены такие свойства бьёркеновской переменной x, которые позволяют обобщить лептон – адронный механизм двух-этапного рассеяния на все неупругие процессы столкновения составных частиц при высоких энергиях.

Универсальный характер этот механизм приобретает так же благодаря гипотезе А.М.Балдина о существовании групп из конституентов (нуклонов, кварков, партонов) в ядрах. Реакции ГНР указывают на возможность существования и в нуклонах групп партонов, масса которых определяется через x.

На основе АС и по аналогии с ГНР полагается, что во взаимодействиях частиц a и b именно эти группы участвуют в первом этапе столкновения. Показано, что в этом случае массы групп можно определить через x_a и x_b , а их численную оценку можно сделать в СЦМ через два измеренных адронных ливня (так же, как в ГНР).

Приводятся некоторые результаты вычислений для pp – событий, сгенерированных программой PYTHIA для эксперимента АТЛАС на LHC при энергии 10 ТэВ.

Предложенные идеи представляют интерес для КХД-анализа h+h - взаимодействий, для развития концепции кумулятивных событий и, возможно, для поиска QGP и промежуточной фазы на NICA.