On QCD road to high energy nuclear theory

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Outline

- The increase of resolution with collision energy allows to test preQCD idea on the strong meson fields in the center of a hadron ,of a heavy heavy neutron stars

The constraints from continuous symmetries of QCD imply finite size of pQCD core within a hadron and of spontaneously broken chiral symmetry.

Factorization theorems for the hard diffractive processes and CT. Brief comparison with data.

CT in quasi-elastic processes and uncertainty principle.

Conclusions

Challenges of low resolution nuclear theory

1. Increase of collision energy leads to the increase of resolution-so feasibility of discovery of phenomena beyond the standard nuclear theory. The discovery of SRC in high energy processes is the recent confirmation of the increase of resolution with increase of collision energies.

2. How L. Landau zero charge phenomenon found in preQCD field theories disappears in QCD.

3. The preQCD field theories predict strong meson fields in the center of a hadron-folklore, of a heavy neutron star (A.B.Migdal). Data on antiquark distribution in a nucleus are hardly consistent with the concept of exchange by strongly virtual meson. (FS).

4. Thus there is need to build description of hadrons, nuclei directly from QCD having effective nuclear theory as low resolution limit.

Symmetries of QCD and wave function of a hadron

Non perturbative QCD phenomena are dominated by chiral condensate(M.Gell Mann) and by gluon condensate(V.S.Z). However the volume where phenomenon of spontaneously broken chiral symmetry occurs is the subject of discussions.

Asymptotic freedom is valid for QCD.

Constraints from continues symmetries can be naturally imposed on l.c. wave functions of a hadron since they account space-time evolution. The constraint from the color gauge invariance for wf of a bound state is space-time evolution of zero size wave package which has no soft modes. This is the generalization of the requirement of finiteness of wave function of bound state at r=0 in the non relativistic quantum mechanics.

Hadron structure consistent with symmetries of QCD

The fundamental object of QCD is zero size color neutral (q\bar q)dipole or (3 q) triplet). Gauge invariance implies that this object has no surrounding soft gluon, quark modes. This was understood in the formulation of the removal of ultraviolet divergencies in the polarization operator of photon in QED. (folklore) But this object is not eigen state of QCD Hamiltonian. Thus in the calculation of wave function of bound state it is necessary. to account for the space-time evolution of this object.

Thus wave function should be calculated as
U|J| dipole(triple)|0>. (V.Gribov,F-S)
Here U is the operator of space-time evolution. J is color neutral local operator. This is generalization to QCD of the short distances constraint separating w.f. of a bound state from continuous spectrum.

pQCD core of a hadron: qualitative and quantitative results. Finite radius of the phenomenon of spontaneously broken chiral symmetry

Qualitative picture: initial condition for a bound state is plc evolving till constituents hit a condensate. Velocity of light is finite. So during the finite interval of time wave package is governed by pQCD equations

Quantitative description follows from the analysis of vacuum matrix element of commutator of currents in the coordinate space $\langle 0|[J(x)J(0)]|0\rangle$ and by the application of DSR approach to select single hadron state. The calculation of radius of pQCD core of a nucleon made by (E.Shuryak) (who did not identify it with the wave function of a hadron) gives:

$r_{core}\approx 0.4$ Fm

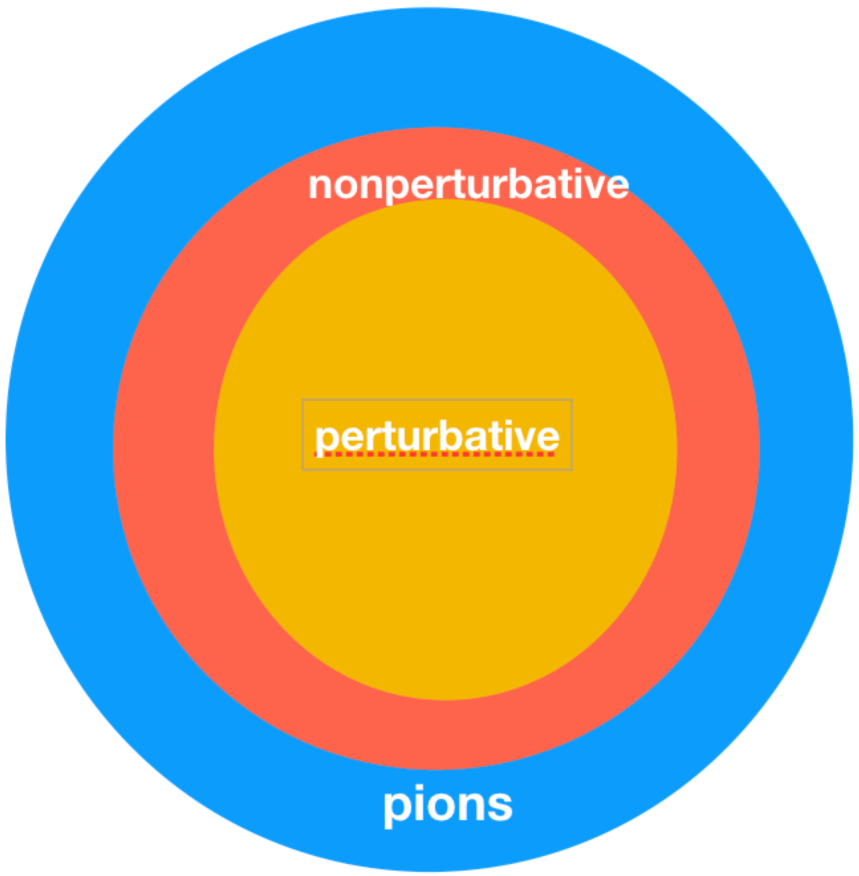
Quark model of a hadron consistent within QCD

A hadron is the system of overlapping three layers. The center is pQCD core of radius r_c resulting from the pQCD evolution which starts from the minimal Fock component of a hadron wf. QCD evolution leads to the appearance of other Fock components, to the running coupling constant and to the running mass of a quark. Second layer accounts for the spontaneous violation of chiral symmetry due to interaction of constituents with the condensates.

Third layer is formed by the cloud of pseudoGoldstone mesons-pions. Only this layer is accounted for in the consideration of low energy phenomena. Thus quark model accounting for the QCD phenomena differs from that based on the popular quark models of a hadron.

Finite size of pQCD core of a hadron indicates that the radius of the phenomenon of spontaneously broken chiral symmetry has also finite size. This prediction differs from that in the popular preQCD Nambu, Iona-Lasinio model but consistent with the asymptotic freedom and with current data on the pion wave function.

Visual description of a QCD quark model of a hadron.



Common wisdom is that asymptotic freedom in QCD substitutes Landau zero charge phenomenon which was found for the hadron-hadron interactions. On the contrary the asymptotic freedom was calculated for the interaction between quarks and gluons.

pQCD core of a hadron signals that color screening phenomenon ensures the absence of strong meson fields within a core of a hadron i.e. it resolves Landau puzzle for the hadron-hadron interactions. pQCD core of a hadron is important for the theory of heavy neutron stars where preQCD field theories predict meson (pion) condensate, for the establishing of the origin of short-range inter-nucleon forces.

Variety of new QCD phenomena are expected
However model independent predictions are feasible at present for the hard diffractive processes only.

Amplitudes of hard diffractive processes are calculable in QCD. A few such processes and related new phenomena: pQCD core of a meson and CT have been observed in the processes:

pion+T\to 2jet +T, (FNAL)
gamma^*+N\to (rho, omega,\phi) +N. (HERA)
gamma+T\to J/\psi+N. (LHC)

The adequate tool for the theoretical description of HT hard diffractive processes(HDP) is to derive QCD factorization theorems.

Factorization theorem is known for the few types of HDP.

1.In the leading alpha_s log(x/x_0) approximation in (B.G.F.M.S) and in the leading alpha_s log(Q^2/Q_0^2) approximation factorization theorem has been proved in (C.F.S) for the process :

gamma^*+N\to \rho(\omega,\phi) +N (HERA)

In the same approximation factorization theorem is valid for the process pi+T\to 2jet +T (F.M.S) which has been measured at FNAL gamma+T\to J/\psi(Y)+T (F.S)

This process has been measured at HERA off a proton target, in the ultra peripheral heavy ion collisions at LHC for nucleon, nucleus targets.

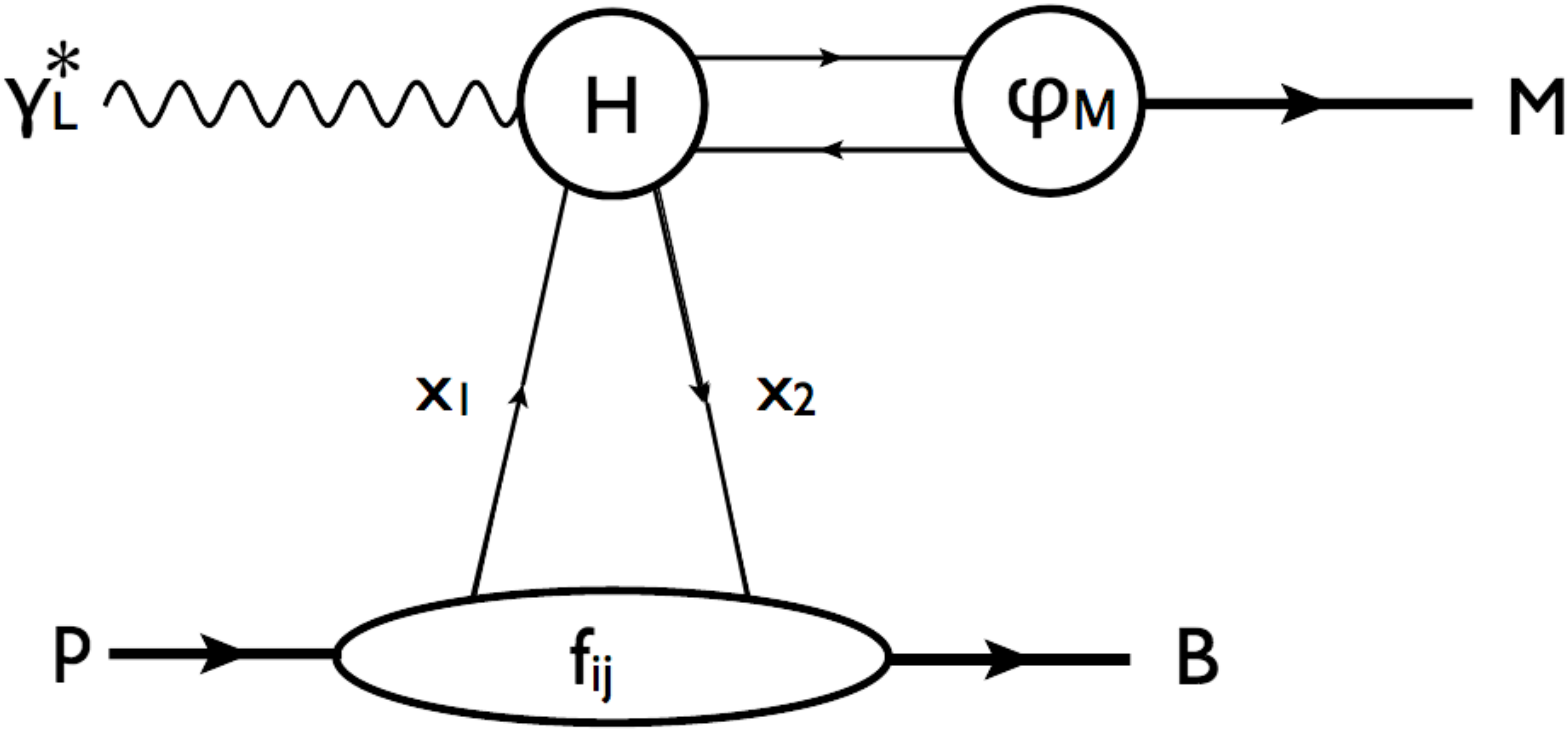
Trigger for the pQCD core is large Q^2 or large mass of heavy quark: c, b.

Factorization theorems accounts for the continious symmetries such as gauge invariance, the energy-momentum constraints contrary to the dipole model. So the important difference is in the formulae.

The starting point for the analysis is the factorization theorem for the process

$\gamma_L^* (q) + p \to$ "Meson"$(q + \Delta)$ + "Baryon"$(p - \Delta)$ at large Q^2, with t and $x = Q^2/(2p \cdot q)$

fixed.



The dominance of nonsense polarizations of gluon in the gluon ladder.

Our interest is in the kinematics of large s and

$|t/s\ll 1|$

where $s=(q+p)^2$ and $t=(q-q_{final})^2$

In this kinematics two gluon ladder dominates.

Corrections are decreasing as power of "s". Because of the difference between masses of projectile and outgoing particle standard scheme used for the calculations of DIS processes should be modified.

d_{\mu,\lambda}=(p_{\mu)q_{\mu}/(p,q)k^2
(V.Gribov) .

The application of Ward identities and energy-momentum conservation allows to rewrite effective projection operators in the propagators of both exchanged gluons in the form:

d^{1}_{\mu,\lambda}= k_{t ,\mu}k_{t,\lambda}/(pq)x_{1}

d^{2}_{\mu.\lambda}=k_{t,\mu}k_{t,\lambda}/(pq)x_2

k_t is the exchanged gluon momentum in the plane ortoghonal to the plane formed by vectors p, q. These formulae account for the difference in the masses of particles in the initial and final states

Thus the final formulae obtains the form (F.S):

A=\int d alpha/(alpha(1-alpha))d^2b
\psi(\gamma^*_{L}(\alpha, b)
sigma_{T}(b^2,x_1,x_2,Q^2_{eff})
\psi_{final}(\alpha, b,)

Here b^2=-delta^{2}_{k} is the transverse distance between constituents within the wave function of virtual photon. \delta^2 is two dimensional Laplacian

alpha is the fraction of projectile momentum .

$$\sigma(x_1,x_2,Q^2_{eff})=(\pi^2/3)\, b^2\, x_1\, G_T(x_1,x_2,Q^2_{eff}). \qquad \text{(F.S,F.S.R)}$$

The value of sigma follow from the color gauge invariance, asymptotic freedom, conservation of energy.

The factor b^2 plays key role in the theoretical description of hard diffractive processes including CT. CT is another form of the dominance of the nonsense gluon polarizations. G_T is the skewed gluon distribution within the target T.

Dominance of nonsense polarizations of gluons is the generalization to high energies of two photon Coulomb exchanges between neutral atoms in atomic physics where potential of interaction of two neutral atoms has the form:

$$V(r)=c\langle r^2_1\rangle\langle r_2^2\rangle/r^5$$

Here r is inter-atomic distance, $\langle r^2\rangle$ is the average quadratic radius of an interacting atom.

Derived formulae differ from that suggested within the frame of dipole model where Fermi motion of constituents within the projectile is usually ignored (Ryskin et all) . Dipole model assumes et hog value of Q^2(eff) for gluon GPD and contains no factor b^2.

The factor b^2 guarantees applicability of non relativistic description of heavy quarkoniums: charmonium and bottonium produced in the hard diffractive processes.

Asymptotic freedom implies that hard diffractive processes are dominated by minimal Fock component of the wave functions of projectile and outgoing hadron.cf also the description of high Q^2 behavior of e.m. form factors of a nucleon within the democratic chain approximation (Brodsky, Lepage).

Heavy mass of c and b quarks ensures dominance of plc

J/ψ and Y have significantly smaller radii than the pion in the quarkonium models which describe properties of hadrons containing heavy quarks:
$r_\pi = 0.5 fm$, $r_{J/\psi} \approx 0.2 fm$, $r_Y \approx 0.1 fm$.

As a consequence of color screening heavy quarkonia relatively weakly interact with hadrons made of light quarks. Thus CT should reveal itself in the photoproduction of heavy quarkonium. Beginning of CT - discovery of narrow J/ψ - November 74 and observation of small cross section for its photoproduction. Within VDM σ_{tot} (J/psi +N)= 1 mb . This number actually underestimates genuine J/ψ-N cross section due to production of J/ψ in a small size configurations ~1/mc FS85 So σ_{tot}(J\psi+N)= 4 mb

.

The leading twist expression is

dσ(γ^*N→VN)/ dt_{t=0} =12πΓ(V→e+e)M_{V}α_s^2(Q)η_{V}^2[1+i\pi /2\pi dlnx] xGT(x_1,x_2,Q)/ α(EM) $Q^6 Nc^2$

- Here, $\Gamma_{V \to e^+e^-}$ is the decay width of $V \to e^+e^-$
- is close to the asymptotic value at $Q^2 \sim$ a few GeV^2.

For large Q^2, the non-diagonal GPD is calculable (Guzey, Freund) through the diagonal one since the DGLAP evolution for GPDs conserves $x = x_1 - x_2$, while the light-cone fractions essential at the starting point of the evolution grow with an increase of Q^2.

First prediction and discovery of high energy CT phenomenon

$$\pi + N(A) \to \text{“}2\ high\ p_t\ jets\text{''} + N(A)$$

Mechanism: Pion approaches the target in a frozen small size $q\bar{q}$ configuration and scatters elastically via interaction with $G_{target}(x, Q^2)$.

- First attempt of the theoretical analysis of πN process - Randa 80 - power law dependence of p_t of the jet (wrong power)
- First attempt of the theoretical analysis of πA process - Brodsky et al 81 - exponential suppression of p_t spectra, weak A dependence ($A^{1/3}$)
- pQCD factorization theorem - Frankfurt, Miller, MS 93; elaborated arguments related to factorization 2003.Experiment confirmed a number of the predicted features of the reaction.:A-dependence (CT), p_t and $z=E_{jet}/E_\pi$ -dependence,.

- Presence of small size qq Fock components in light mesons is unambiguously established
- At transverse separations d ≤ 0.3 fm pQCD reasonably describes "small qq - dipole"- nucleon interaction for $10^{-4} < x < 10^{-2}$
- Color transparency is established for the small dipole interaction with nucleons, nuclei (for x ~10^{-2})

CT is easier to probe for mesons than for baryons as only two quarks have to come close

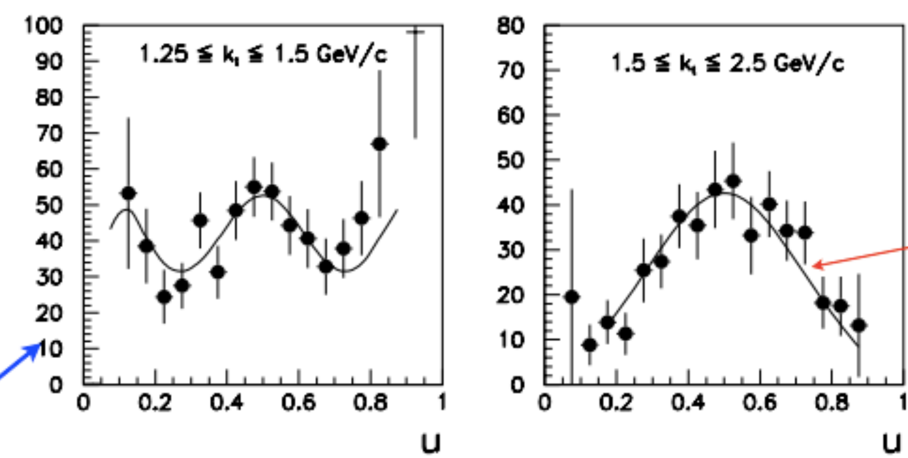
Data(Ashery)

A- dependence $A^{4/3}$ = A^2/R_A^(2/3)(vs Bertsch, Brodsky et al $A^{1/3}$)

light-cone z distribution $z^2(1-z)^2$

$1/k_t^8$. vs BB ...exp (- a k_t^2)

pQCD prediction differs from the mean field approximation by the power dependence on kt.



prediction

(π wave funct)^2

Squeezing occurs already before the leading term (1-z)z dominates!!!

5

$Q^2(\pi\ f.f.) \sim 4k_t^2(jet)$

$\Downarrow$

strong squeezing in π form facto for Q^2=6 GeV^2

Minimal Fock component of wave function is not eigen state of QCD Hamiltonian. So it expands. This expansion being kind of uncertainty principle may violate condition of applicability of factorization theorem. This phenomenon is especially important for the processes off a nuclear target. The criterium can be formulated in terms of the concept of coherence length-L_c.

The formulae for L_c has been derived by (V.Gribov,B.Ioffe,I.Pomeranchuk) by analyzing Fourier transform of structure functions into coordinate space. L_c=1/2m_Nx

Actually this is implication of uncertainty principle. (F.S)

The criterium of validity of formulae derived in the frame of factorization theorem is

$L_c \gg R_T$

where R_T is the radius of a targe T. When this condition is valid QCD predicts unambiguously CT. Most effective method to check this prediction is to investigate ultra-peripheral heavy ion collisions at LHC where maximal energies for hard diffractive processes is achieved.

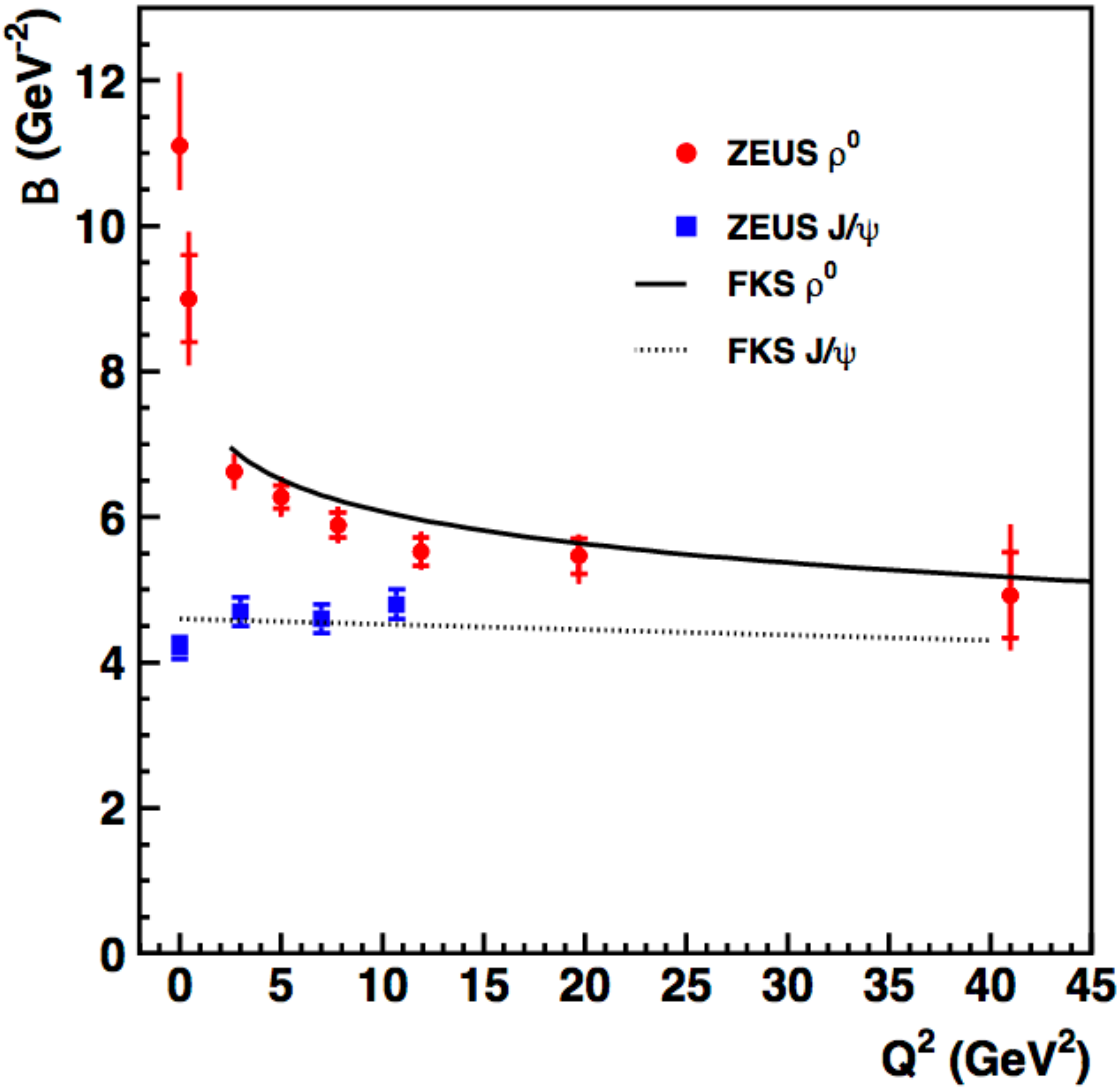
(F.S. et all)

The existence of pQCD core of a meson has been confirmed in several processes:

gamma^*+p\to rho +p at HERA and in the process pi +A\to 2jet +A at FNAL.

To observe pQCD core one need to observe and investigate at LHC the process: N+A\to 3jet +A. This is difficult at present.

I want to draw attention that hard diffractive processes are impossible within the preQCD field theories where minimal Fock component of the wave function of a hadron is suppressed by Sudakov form factor. (Gribov, DDT…)



The slopes of the dependence on t tends to the same value i. observing squeezing of rho meson.

CT for quasielastic processes.

In the democratic chain approximation (Brodsky and Lepage) found that form factor of a hadron is dominated by its plc. Competing model has been investigated by (Brodsky and Teramond) where e.m. form factors of a nucleon are dominated by end point contribution in the integration over fraction carried by constituents.

$$F(q_t^2)=\int dz/z(1-z)\psi(z,k_t)\psi_f(z,k_t +z q_t)$$

(Kogut.Susskind)

This contribution is slowly squeezed by Sudakov form factors-so slow onset of CT in this model.

Additional restriction for the validity of CT is

$L_c=2q/(M^2-m_N^2)>>R_A$

Here q is hadron momentum, M is the mass of dominant configuration, R_A is the radius of the target nucleus.

Quasielastic processes can be considered as the lab for the investigation of space-time evolution of plc through its final state interaction with the rest of a nucleus.

The example of using nucleus as femtometer is the process:

$\gamma^*+d\to N+N$

In the kinematics where deutron wave function is understood-nucleon momenta are around 150MeV the expected effect is the decrease of f.s.i. with increase of Q^2. (Strikman)

Conclusion.

The theoretical ideas and methods of high energy physics allow to investigate structure of the nucleus beyound the frame of low resolution Hamiltonian of low energy nuclear physics, to investigate the interplay between pQCD and nonperturbative QCD phenomena.

This is the only road to investigate and develop theory of superdense nuclear matter, to calculate limiting mass of a heavy neutron star.