Transverse momentum spectra of cumulative particles and the quark coherent coalescence

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Outline

- Introduction. Definition of cumulative phenomenon.
- Cumulative kinematics: projectile and target fragmentation regions.
- Quark counting rules and the limiting fragmentation of nuclei.
- Deep Inelastic Scattering (DIS) in cumulative region.
- Description of flucton structure function asymptote near cumulative thresholds by the intrinsic diagrams of QCD in light-cone gauge.
- Explanation of the different slopes for DIS and for particle production in cumulative region.
- Direct and spectator contributions to the cumulative quark formation.
- Transverse momentum spectra of cumulative pions.
- Production of cumulative protons by Coherent Coalescence of three quarks (correspondence with the approach of Few Nucleon Short-Range Correlations in Nuclei).
- Suppression of contributions from non-diagonal quark coalescence diagrams.
- Transverse momentum spectra of cumulative protons.
- Comparison of transverse momentum spectra of cumulative pions and protons for various cumulative numbers.

Cumulative Particle Production

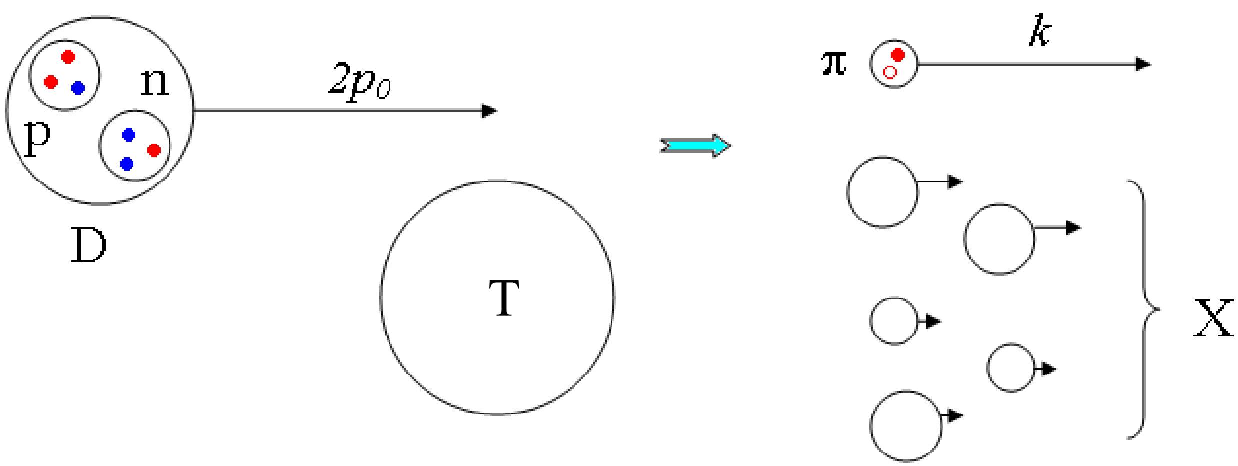
Production of particles from nuclei in a region, kinematically forbidden for reactions with free nucleons.

Cumulative Pion Production

1970 - Nuclotron@Dubna – beams of relativistic deutrons (p_0=5 *GeV/c/nucleon*)
Stavinskiy V.S. =>
Fragmentation of projectile deuterons, D, on some target, T.
*Baldin A.M. et al., Yad.Fiz.**18** (1973) 79*

$$D + T \Rightarrow \pi + X$$

$p_0 >> m_N$: $p_0 < k < 2p_0$ - cumulative pions



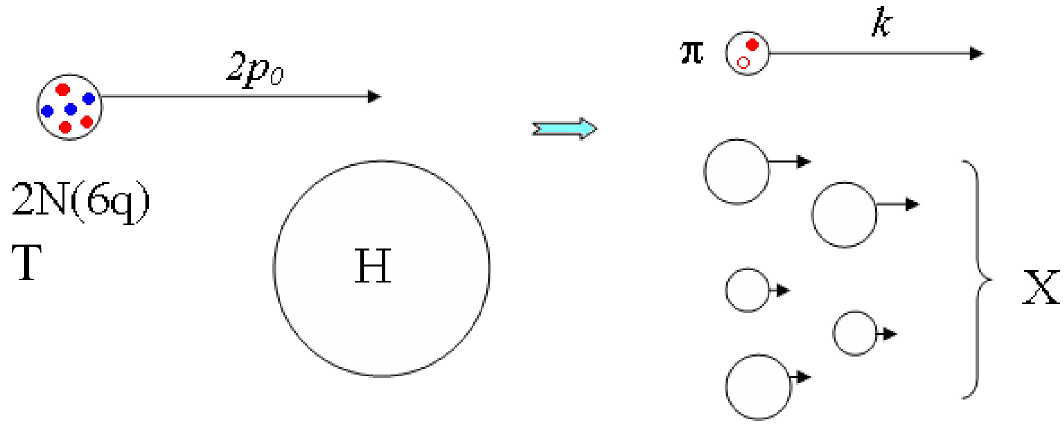
Fluction – intrinsic droplet of dense cold nuclear matter in a nucleus

*Blokhintsev D.I., JETP **33** (1957) 1295*

(2N flucton – 6 quark state)

~5% 2N(6q) – flucton admixture in D

Common 6q-bag



Fragmentation of projectile nucleus <=> Fragmentation of target nucleus

(the same phenomenon in different frames of reference)

Cumulative fragmentation of target nucleus:

The 1st experimental observations of the backward particle production in p+A collisions on a fixed target nucleus:

G.A. Leksin et al., ZhETF 32, 445 (1957)

L.S. Azhgirej et al., ZhETF 33, 1185 (1957)

Yu.D. Bayukov et al., Izv. AN SSSR 30, 521 (1966)

The Reserford-like experiments indicating the presence of droplets of dense nuclear matter in a target nucleus (fluctons).

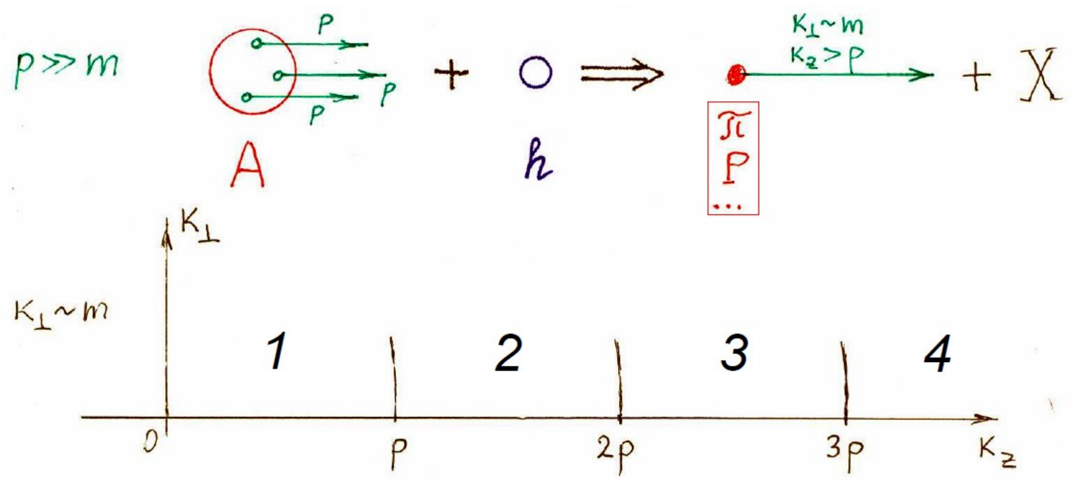
Kinematics of cumulative production

Fragmentation of projectile nucleus

$$x \equiv \frac{k_+}{p_+} = \frac{k_0 + k_z}{p_0 + p_z} \approx \frac{k_z}{p}$$

$$k_z,\ p \gg m,\ \ m - \text{nucleon mass}$$

$$x = 1, 2, 3, \ldots, A$$

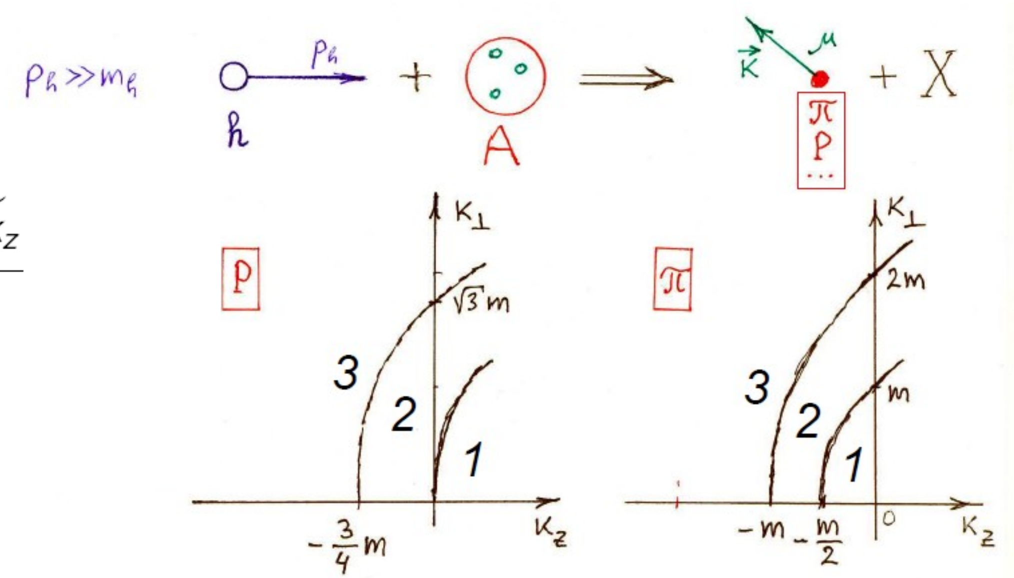


The borders increase with *p*

Fragmentation of target nucleus

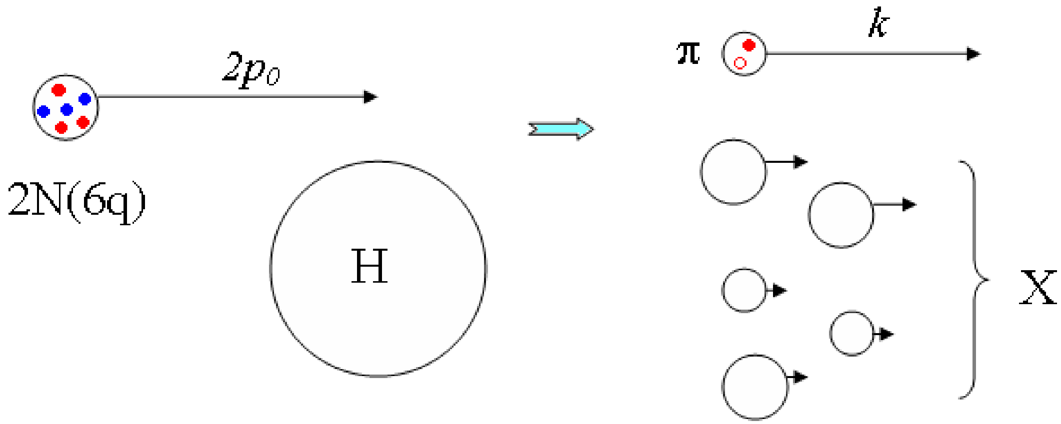
$$x \equiv \frac{k_-}{p_-} = \frac{\tilde{k}_0 - \tilde{k}_z}{m} = \frac{\sqrt{\tilde{k}_z^2 + k_\perp^2 + \mu^2} - \tilde{k}_z}{m}$$

$$\tilde{k}_z = -\frac{xm}{2} + \frac{k_\perp^2 + \mu^2}{2xm}$$



The borders are fixed at *p>>m*

Limiting fragmentation of light nuclei. Quark counting rules.



1 < x < 2 - the cumulative region (*1 < x < f* - *for the fN flucton*)

Theoretical description near upper threshold: for 2N(6q) flucton $k \to 2p_0$, $x = k/p_0 \to 2$
(Limiting fragmentation of a nucleus)

Quark counting rules: $I \sim \Delta^{2p-1}$

Δ – the deviation of x from its maximal value f, $\Delta = f - x$

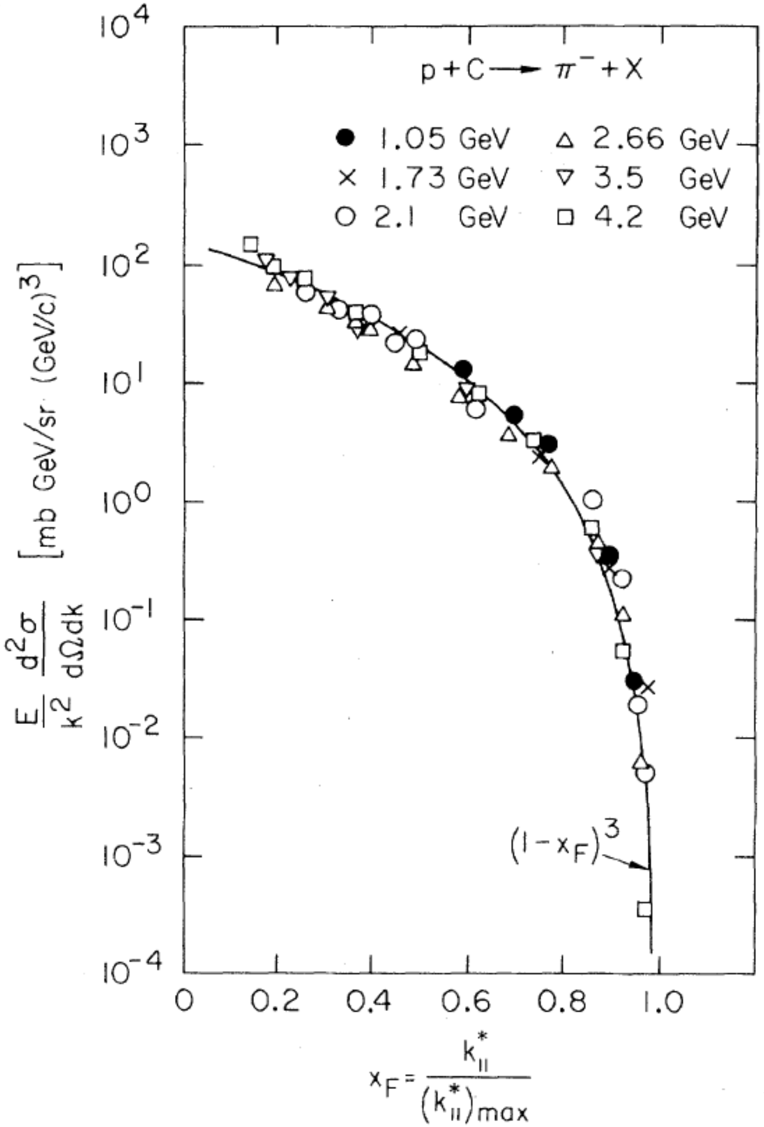
p – the number of "donors", stopped quarks, $p = n - 1$

n – the number of constituents.

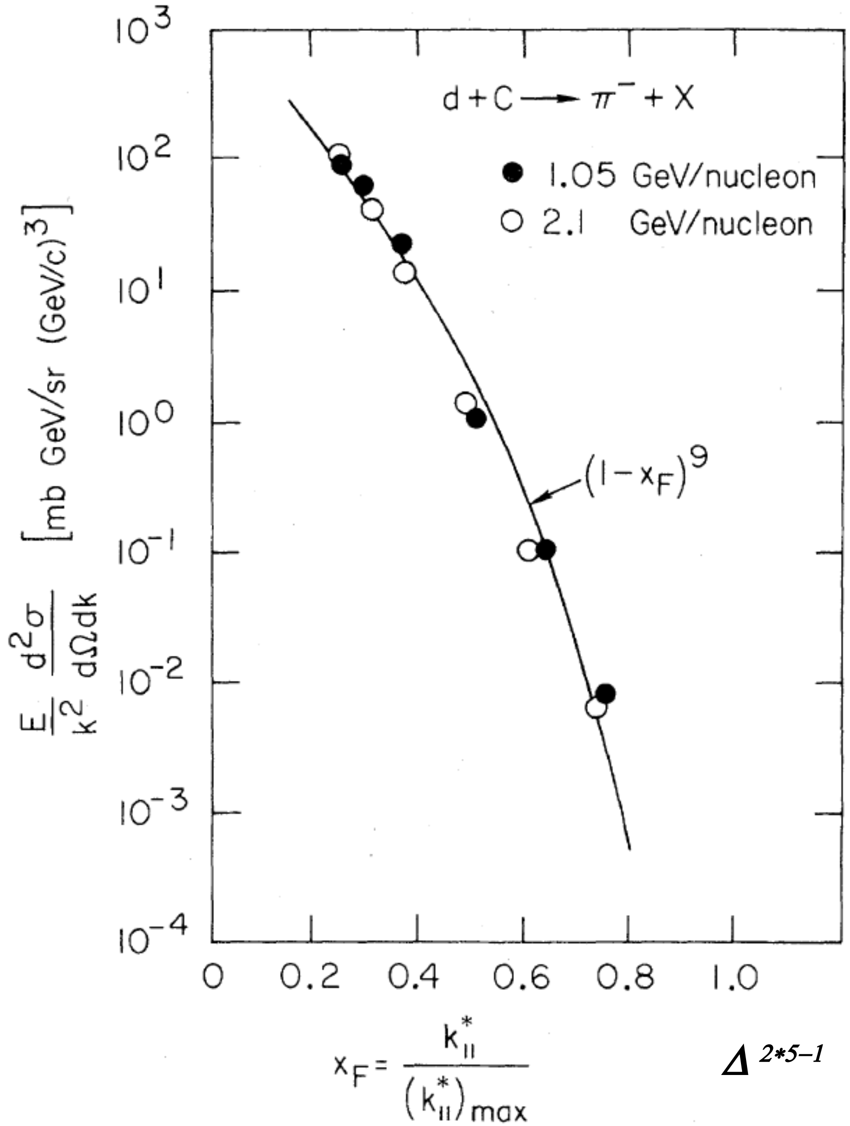
For 2N(6q) flucton $f = 2$, $n = 6$, $p = 5$, *then* $I \sim (2-x)^{2*5-1} = (2-x)^9 = \Delta^9$

Brodsky S., Farrar G. Phys.Rev.Lett. 31 (1973) 1153
Matveev V.A., Muradyan R.M., Tavkhelidze A.N. Lett. Nuovo Cimento 7 (1973) 719
Brodsky S.J., Chertok B.T. Phys.Rev. ***D14*** *(1976) 3003; Phys.Rev.Lett.* ***37*** *(1976) 269*

Schmidt I.A., Blankenbecler R. Phys.Rev. ***D15*** *(1977) 3321*



*Δ 2*2–1*

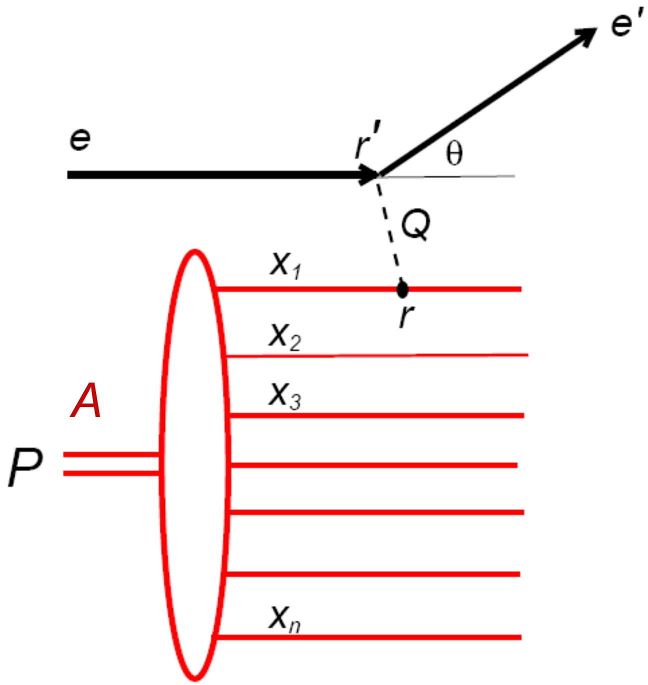


*Δ 2*5–1*

The experimental points from J. Papp et al., Phys.Rev.Lett. 34, 601 (1975).

Deep Inelastic Scattering (DIS) in cumulative region

Lehman E., Phys.Lett.62B (1976) 296 – connection of the limiting fragmentation of deutron into pions with deutron DIS structure function F_2 *(5% 2N(6q)-flucton admixture in D)*



$$|\mathbf{r}-\mathbf{r'}| \sim 1/|Q|, \quad |Q| \gg m$$

$$\xi \equiv \frac{-Q^2}{2(pQ)} = \frac{-Q^2}{2mQ_0}, \quad p = P/A$$

$$0 < \xi < A, \quad 1 < \xi < A - \text{cumulative region}$$

$$Q^2 = -4EE' \sin^2\frac{\theta}{2}, \quad Q_0 = E - E'$$

$$x_1 \equiv \frac{k_{1+}}{p_+} \approx \frac{k_{1z}}{p} \geq \xi \text{ - Bjorken scaling variable}$$

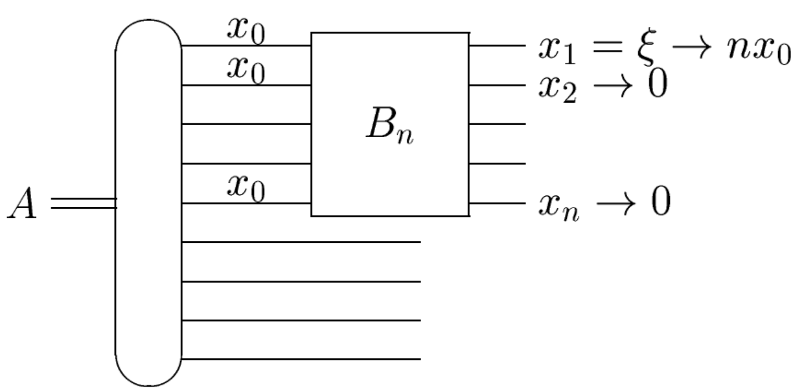
$$(x_1 = \xi \text{ for elastic } \gamma q)$$

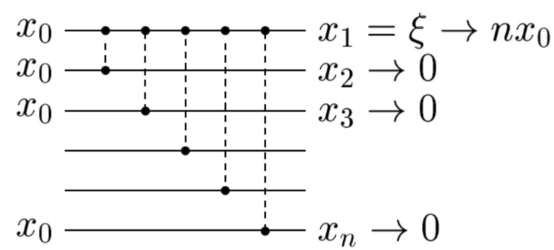
Experimental observations of DIS in cumulative region:

Shuetz W.P. et al., Phys.Rev.Lett., 38 (1977) 259 [D]
Filippone B.W. et al., Phys.Rev.C, 45 (1992) 1582 [Fe]
Benvenuti A.C. et al. (BCDMS collaboration) Z. Phys. C63 (1994) 29 [C]
Egiyan K.S., et al., Phys.Rev.Lett. 96 (2006) 082501 [^{3}He,^{4}He,C,Fe]

Description of the hadron asymptotics at x->1
by the intrinsic diagrams of QCD in light-cone gauge
with low-x spectator quarks interact with the target
*Brodsky S.J., Hoyer P., Mueller A., Tang W.-K., Nucl.Phys. **B369** (1992) 519*

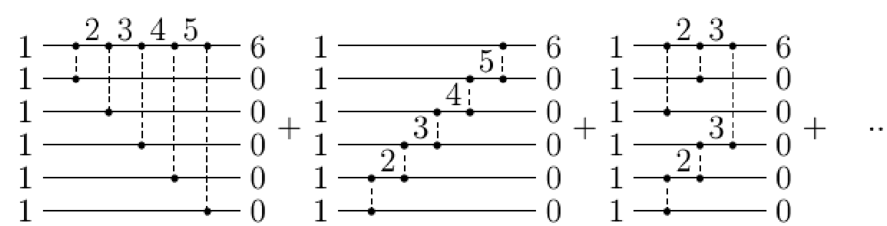
Description of the flucton asymptotic at *x->f*,
f - the number of nucleons in flucton, *n* - the number of quarks in flucton, $x_0 = f / n$ (=1/3).
*M.A. Braun, V.V. Vechernin, Nucl.Phys. **B427** (1994) 614.*

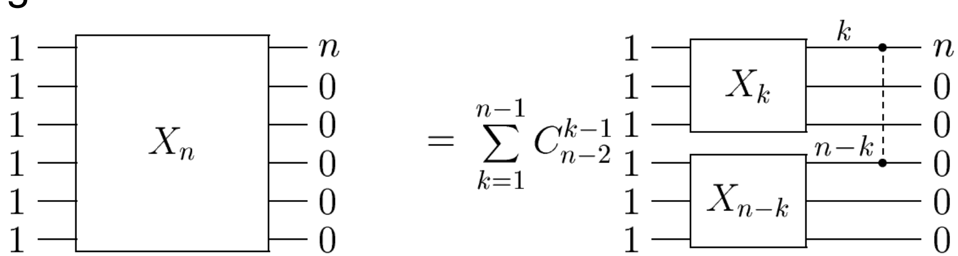




$\sim \Delta^{2p-1}$
p=n-1
$\Delta = f - \boldsymbol{x} = nx_0 - \xi$

At $x_1 \to f$ => all $x_2, \ldots, x_n \to 0$ => all $|q_i| \gg m$ =>
pQCD works => min.number of hard exchanges.
Simple instantaneous Coulomb part dominates
in light-cone gauge.

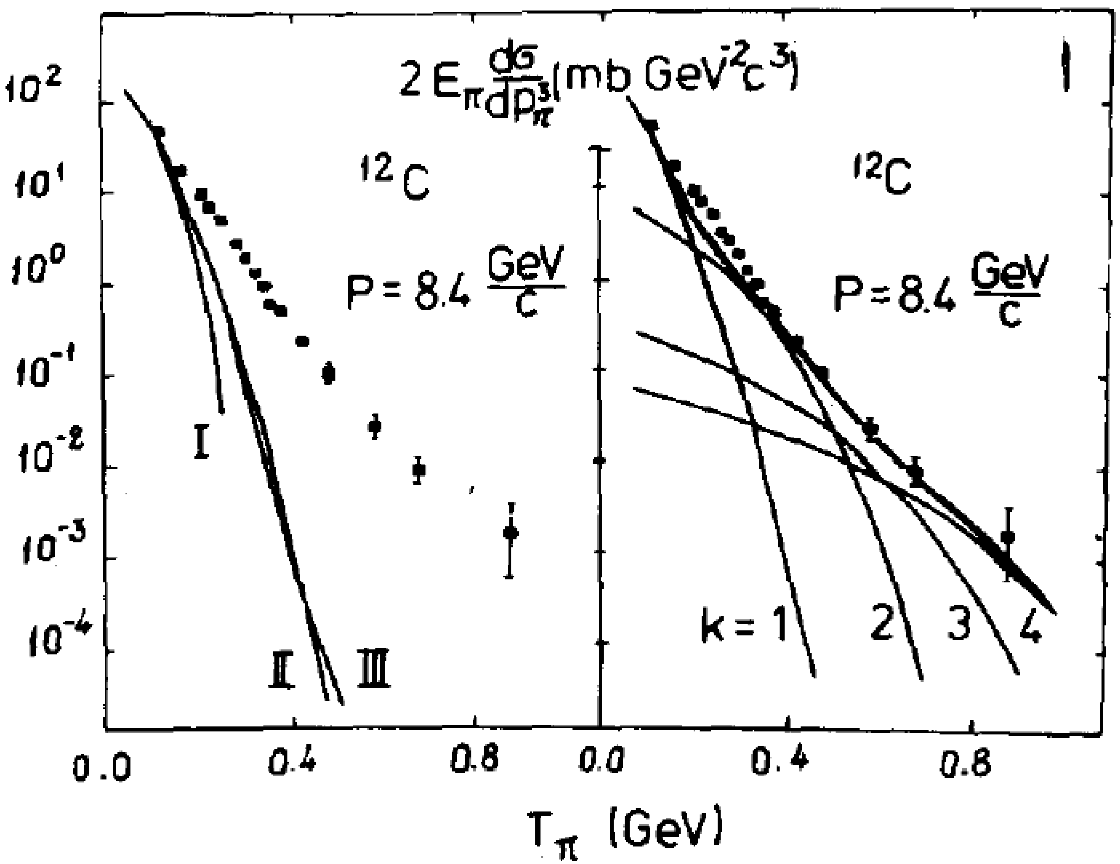




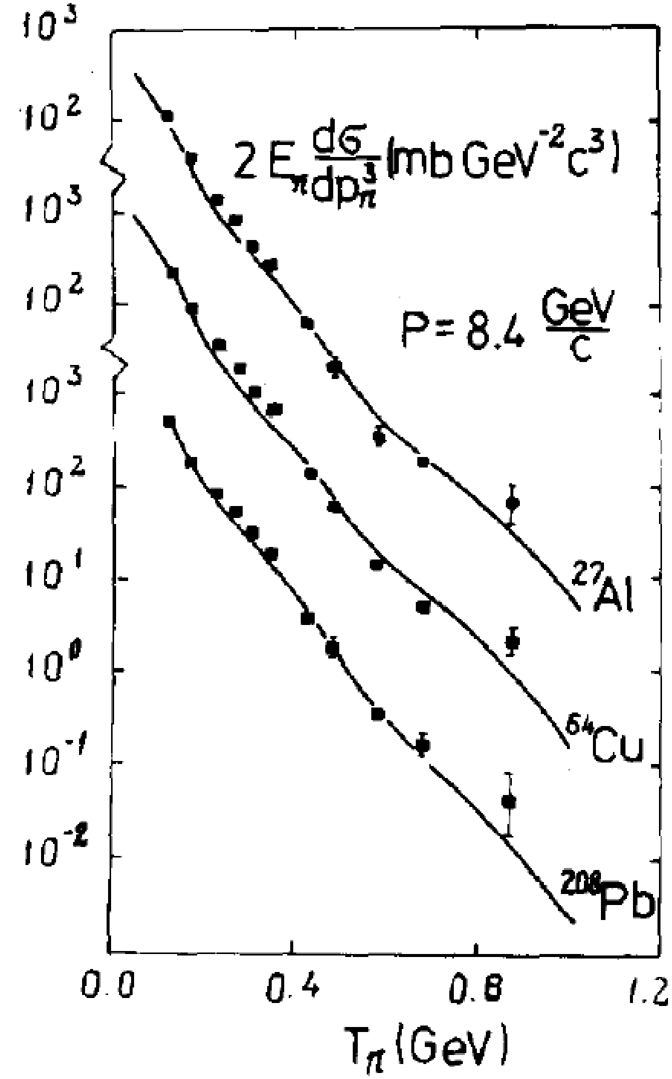
$$X_n = \sum_{k=1}^{n-1} C_{n-2}^{k-1} \, X_k \, X_{n-k}$$

- the recurrence relation

V.V. Burov, V.K. Lukyanov, A.I. Titov, Phys.Lett., 67B (1977) 46

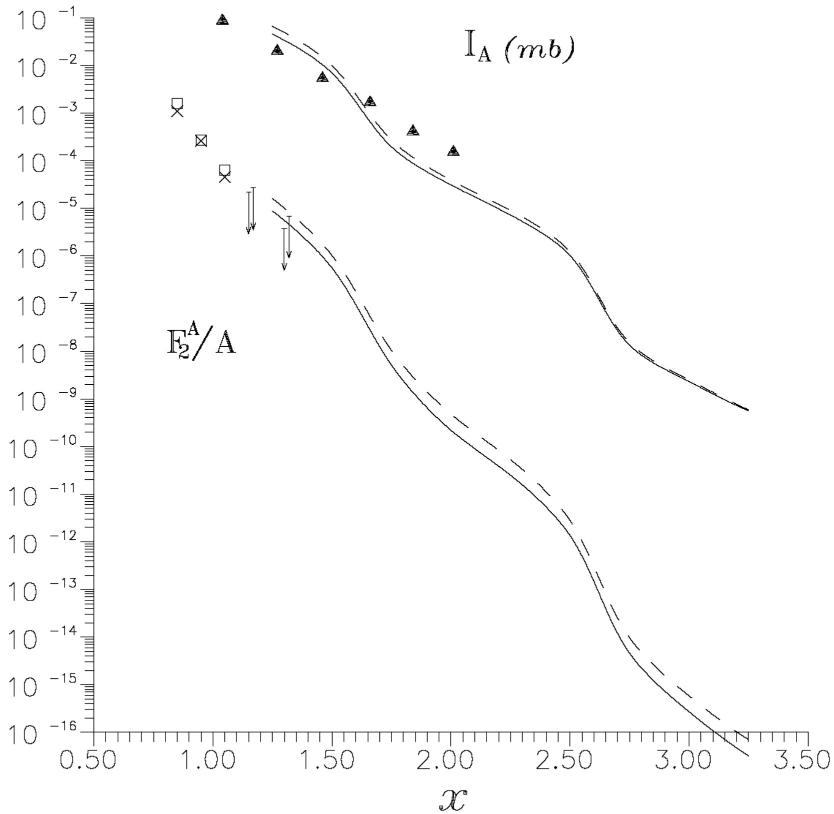


(a) Calculations of the invariant pion production cross section for ^{12}C: I – for the free proton target; II – with fermi motion; III – the relativization effect. (b) The contributions of separate fluctuons with mass $M_k = km_p$ where k is the order of cumulativity.



The experimental points from A.M. Baldin et al., Yad. Fiz. 18 (1973) 79.

The different slopes of spectra for DIS and for particle production in cumulative region



$$F_2^A(x) \sim \exp(-b_0 x) \qquad b_0 \sim 16$$

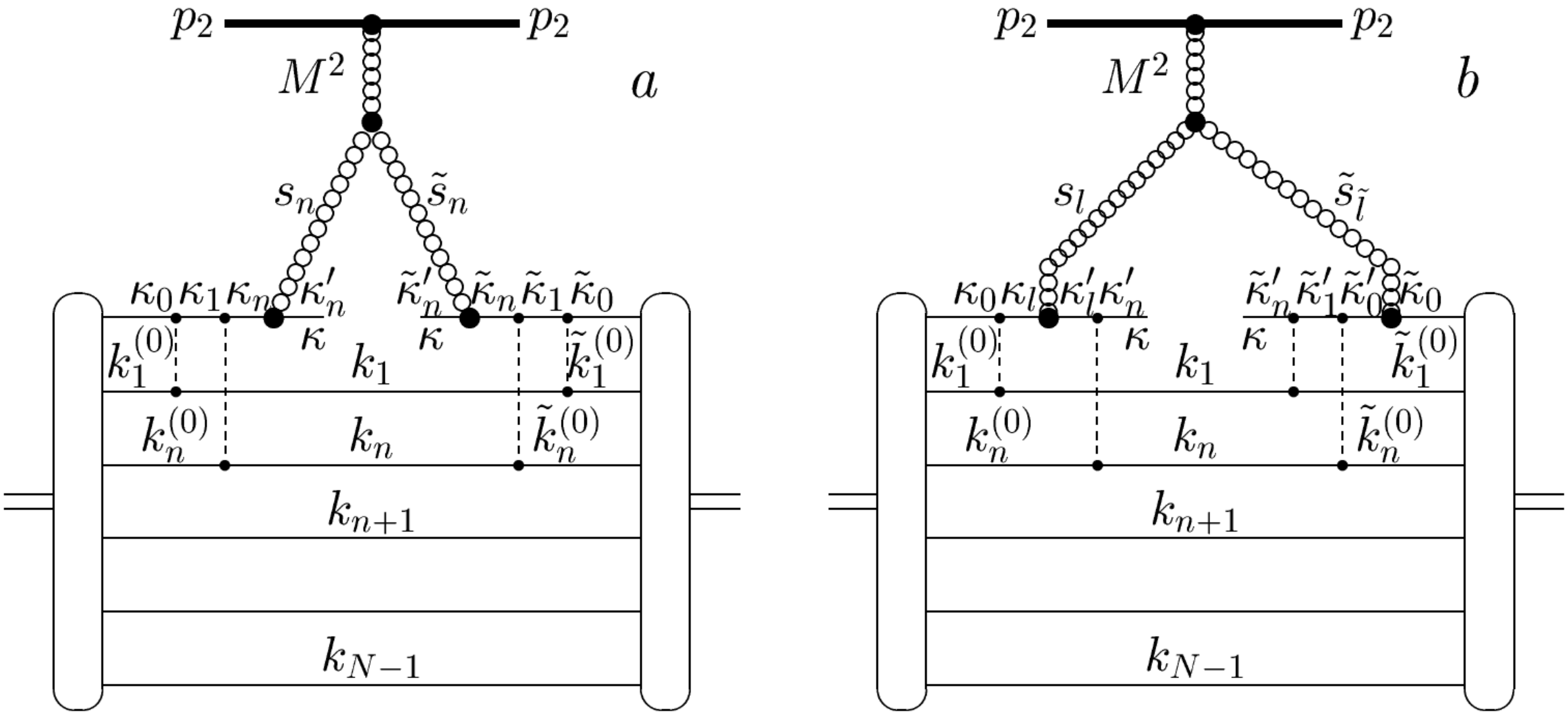
$$I_A(x) \sim \exp(-b_s x) \qquad b_s \sim 6 \div 8$$

The experimental points from

Benvenuti A.C. et al. (BCDMS collaboration) Z. Phys. C63 (1994) 29 [^{12}C, $q^2 = 61\ GeV^2$, $150\ GeV^2$].

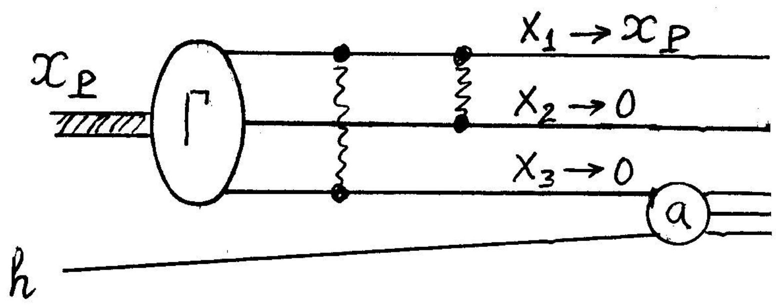
Nikiforov N.A. et al. Phys. Rev. C22 (1980) 700 [p+181Ta->p +X, 400 GeV/c]

Cancellation of the direct contributions to a cumulative quark formation



M.A. Braun, V.V. Vechernin, Phys.Atom.Nucl. ***63*** *(1997) 432*

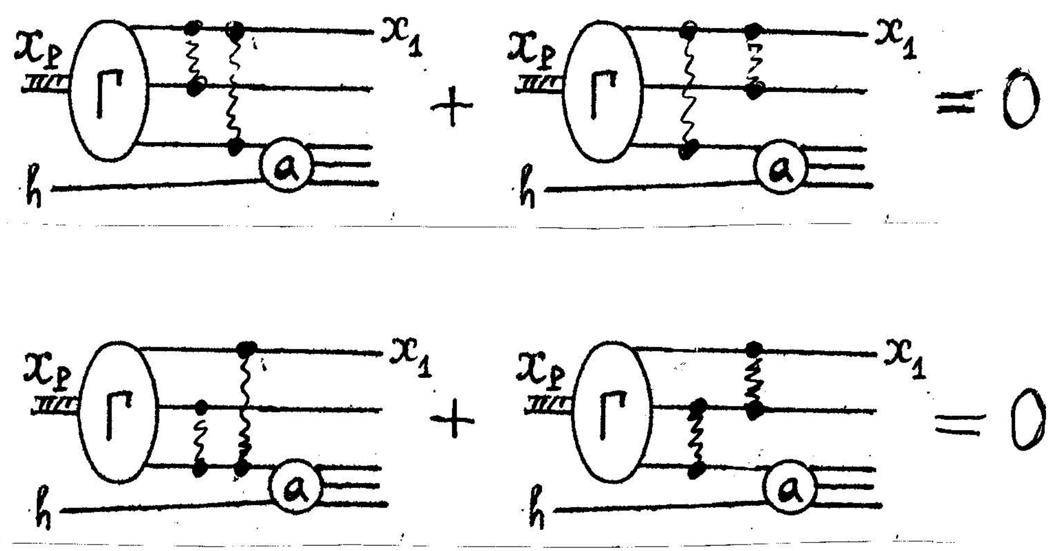
Cancellations in spectator contributions to a cumulative quark formation



$$\sim (x_p - x_1)^{2p-1}$$

$$x_p = 1, 2, \ldots$$

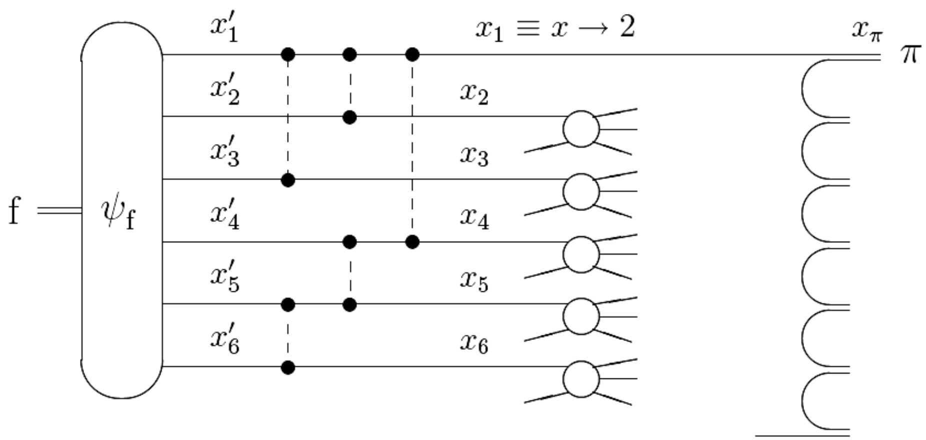
$$p = 2 \Rightarrow \sim (1 - x_1)^3$$



$\sim (1-x_1)^q$

$q > 3$

Transverse momentum spectra of cumulative pions



- the cumulative pion production

k_T – dependence:

M.A. Braun, V.V. Vechernin, Phys.Atom.Nucl. ***63****, 1831 (2000)*

$$\sigma_{pion}(x, k_\perp; p) = C(p)\ (x_{frag} - x)^{2p-1}\ f_p\left(\frac{k_\perp}{m}\right)$$

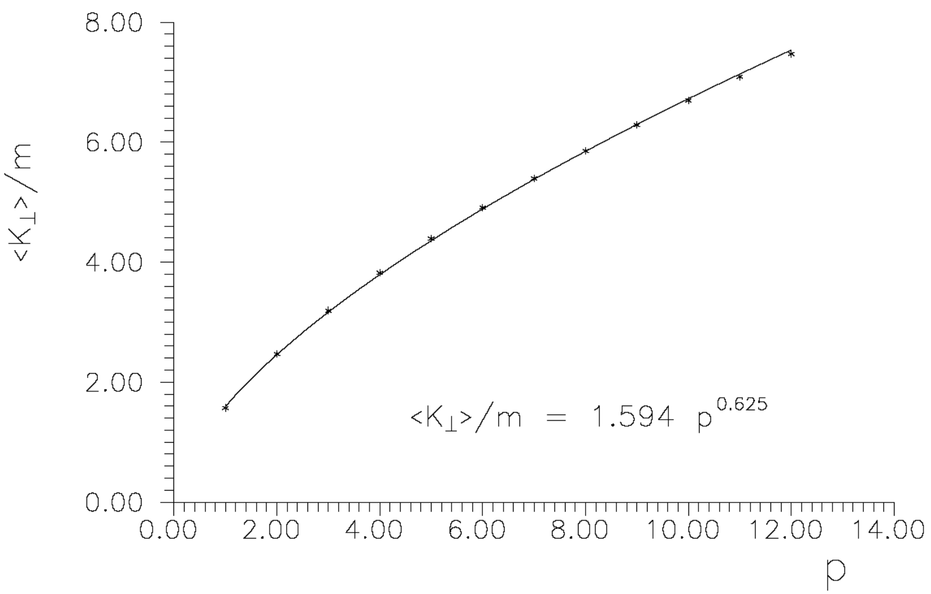
$$x < x_{frag}(p) = 1/3 + p/3$$

p – the number of “donors”, stopped quarks

m – the constituent quark mass

$$f_p(t) = \frac{1}{\pi^p} \int \prod_{i=1}^{p} \frac{d^2 t_i}{(t_i^2+1)^2} (2\pi)^2 \delta^{(2)}\left(\sum_{i=1}^{p} t_i + t\right)$$

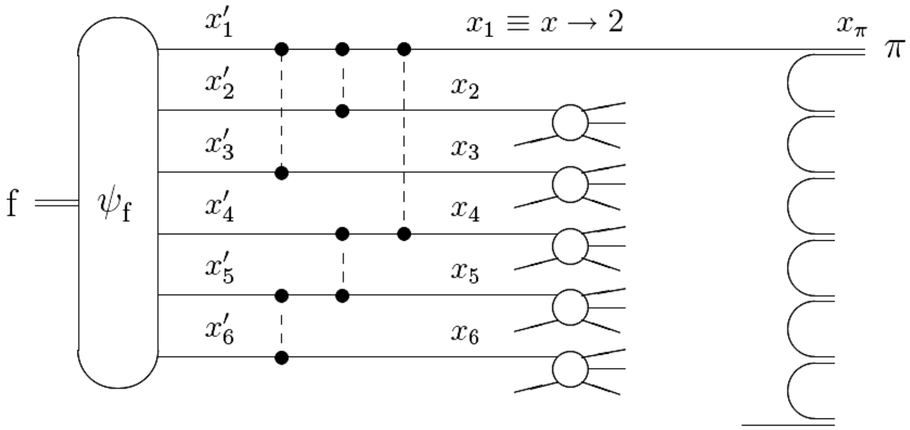
$$t = k_\perp/m, \quad t_i = k_{i\perp}/m$$



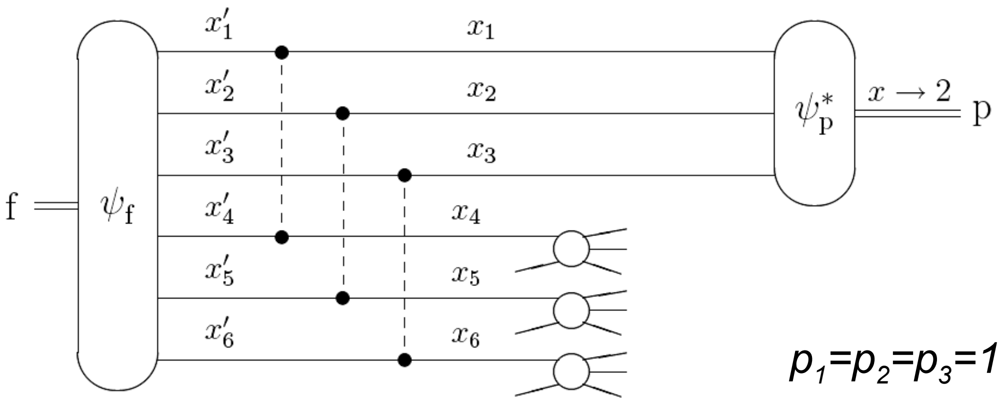
$$f_p(t) = 2\pi \int_0^\infty dz\, z J_0(tz) [z K_1(z)]^p$$

$$\langle |K_\perp| \rangle = pm \int_0^\infty dz K_0(z) (z K_1(z))^{p-1}$$

Coherent Quark Coalescence and Production of Cumulative Protons



- the cumulative pion production by hadronization of one fast quark



$p_1=p_2=p_3=1$

- the cumulative proton production

coherent quark coalescence mechanism:
M.A. Braun, V.V. Vechernin,
Nucl.Phys. ***B92**, 156 (2001);*
Theor.Math.Phys ***139**, 766 (2004)*)

Few nucleon short-range correlations in a nucleus
L.L. Frankfurt, M.I. Strikmann, Phys. Rep. 76, 215 (1981);
ibid 160, 235 (1988).

W_j: $j=1,2,3.$

$n=n_1+n_2+n_3$

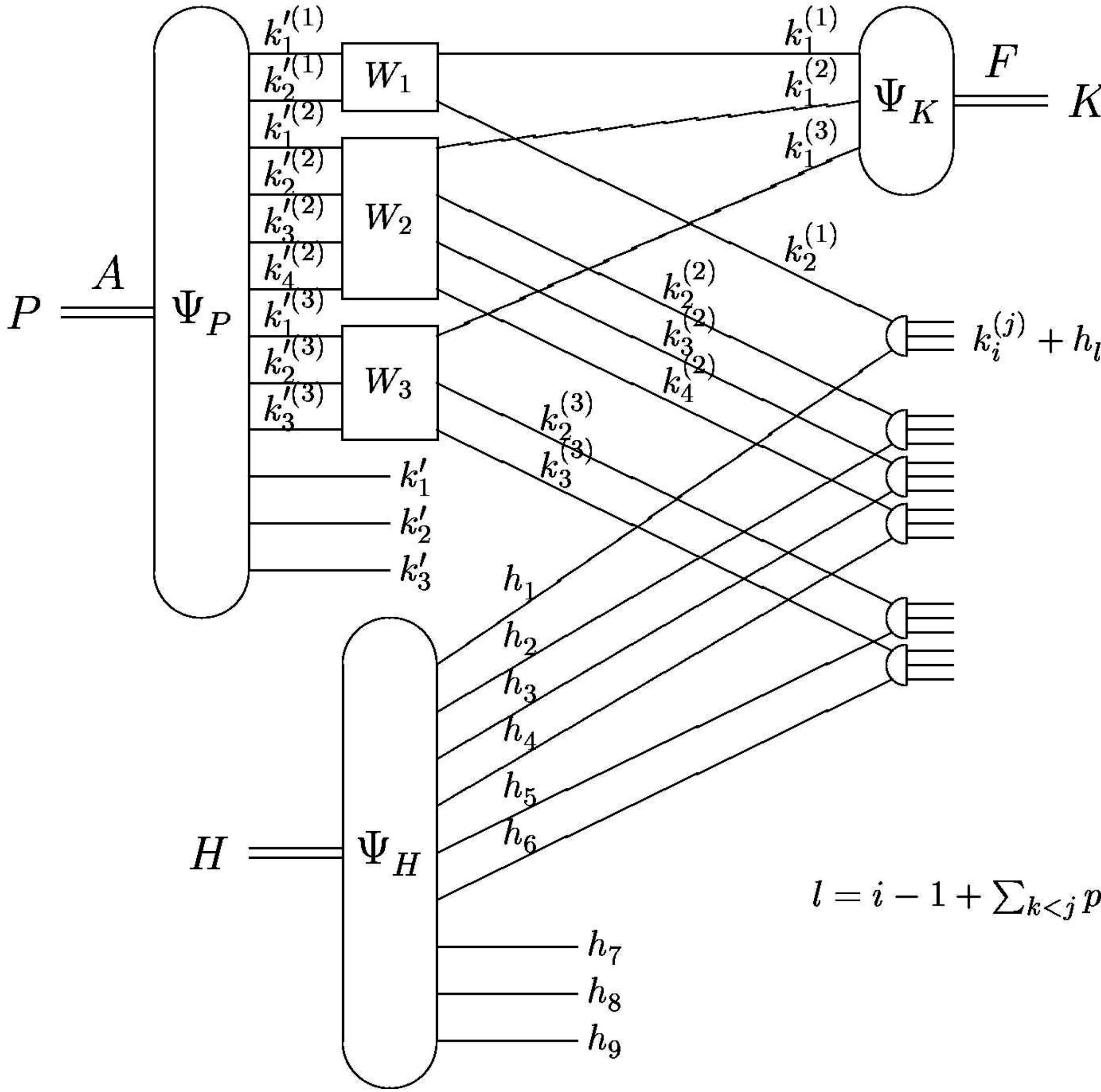
$p_1=n_1-1$

$p_2=n_2-1$

$p_3=n_3-1$

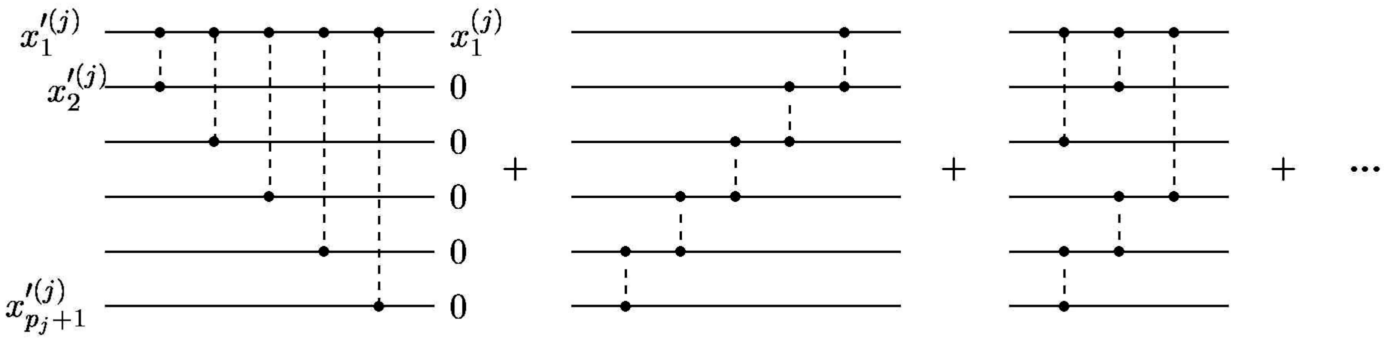
$p=p_1+p_2+p_3=1+3+2=6$

$n=p+3=9$

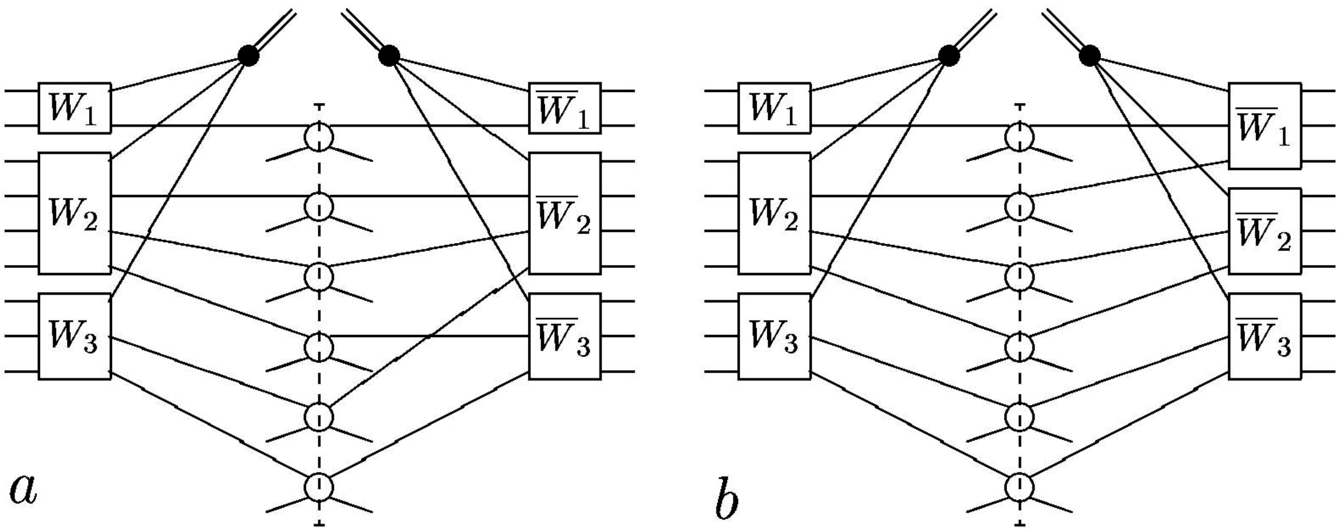


$l = i - 1 + \sum_{k<j} p_k$

Contributions to the blobs W_j:

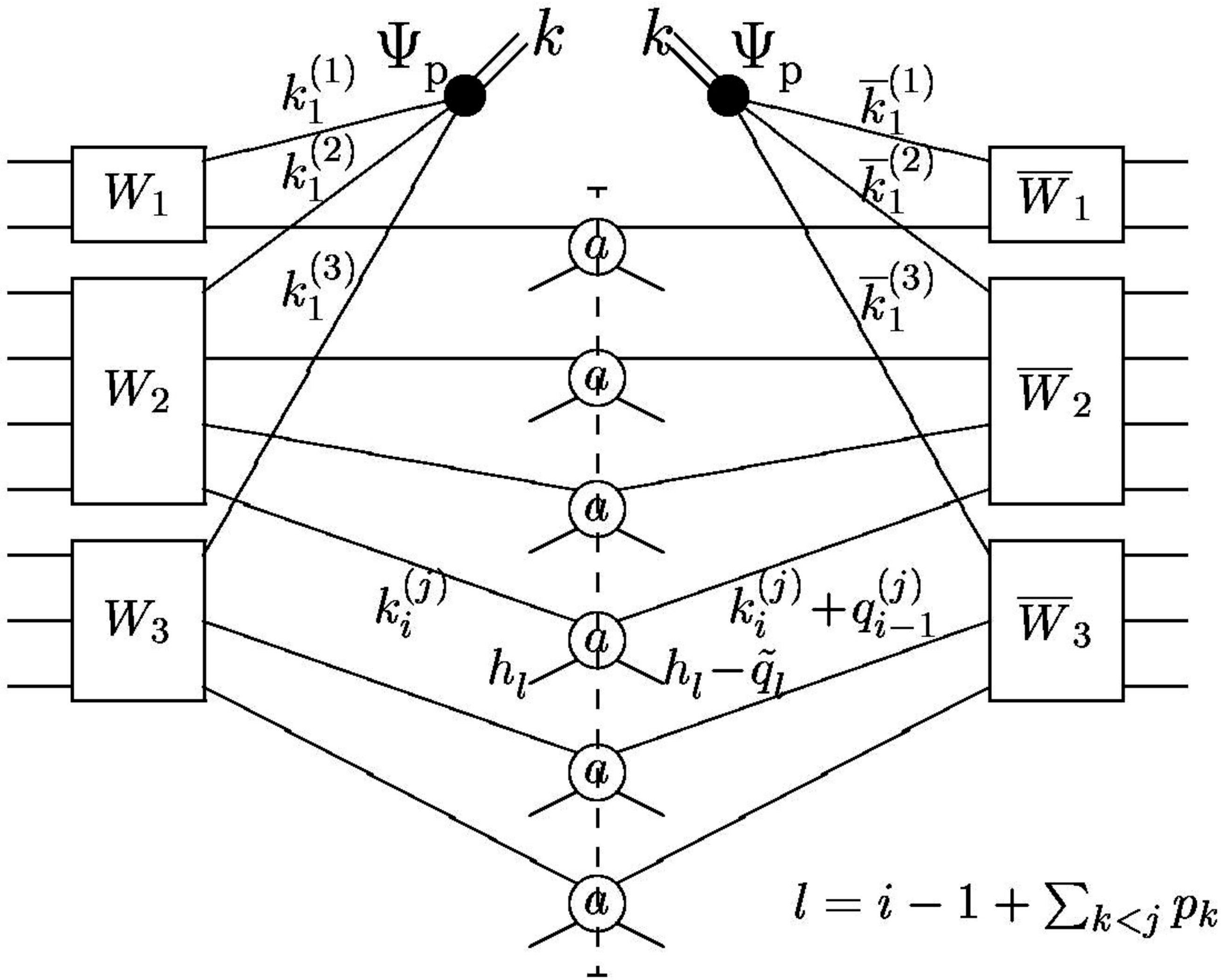


$$\sim \Delta^{2p_j-1}$$



The examples of two types of non-diagonal contributions to the cross section of cumulative proton production:
a – all $p_j = \overline{p}_j$, *b* – some $p_j \neq \overline{p}_j$

$$\frac{r_q^2}{r_N^2}$$



The diagonal contribution to the cross section of cumulative proton production.

Note the presence of the interference effects also in this case!

$$\sigma_{pion}(x, k_\perp; p) = C(p)\ (x_{frag} - x)^{2p-1}\ f_p\left(\frac{k_\perp}{m}\right)$$

$$x < x_{frag}(p) = 1/3 + p/3$$

p=n-1

M.A. Braun, V.V. Vechernin, Phys.Atom.Nucl. ***63****, 1831 (2000)*

$$\sigma_{prot}(x, k_\perp; p_1, p_2, p_3) = C(p_1, p_2, p_3)\,(x_{coal} - x)^{2p-1}\, f_{p_1}\left(\frac{k_\perp}{3m}\right)\ f_{p_2}\left(\frac{k_\perp}{3m}\right)\ f_{p_3}\left(\frac{k_\perp}{3m}\right)$$

$$x < x_{coal}(p) = 1 + p/3\ , \qquad p = p_1 + p_2 + p_3$$

p=n-3

M.A. Braun, V.V. Vechernin, Theor.Math.Phys. ***139****, 766 (2004)*

$$f_p(t) = 2\pi \int_0^\infty dz\, z J_0(tz)[zK_1(z)]^p$$

$J_0(z)$ - the Bessel function, $K_1(z)$ - the modified Bessel function.

$$(2\pi)^{-2} \int f_p(|\mathbf{b}|)\ d^2\mathbf{b} = (2\pi)^{-1} \int_0^\infty f_p(t)\ t\, dt = 1$$

$$e^{-b_s x} = 10^2,$$
$$b_s \approx 7, \quad x = -2/3$$

Note that for *p=1* it can be simplified to $f_1(t) = 4\pi/(t^2+1)^2$

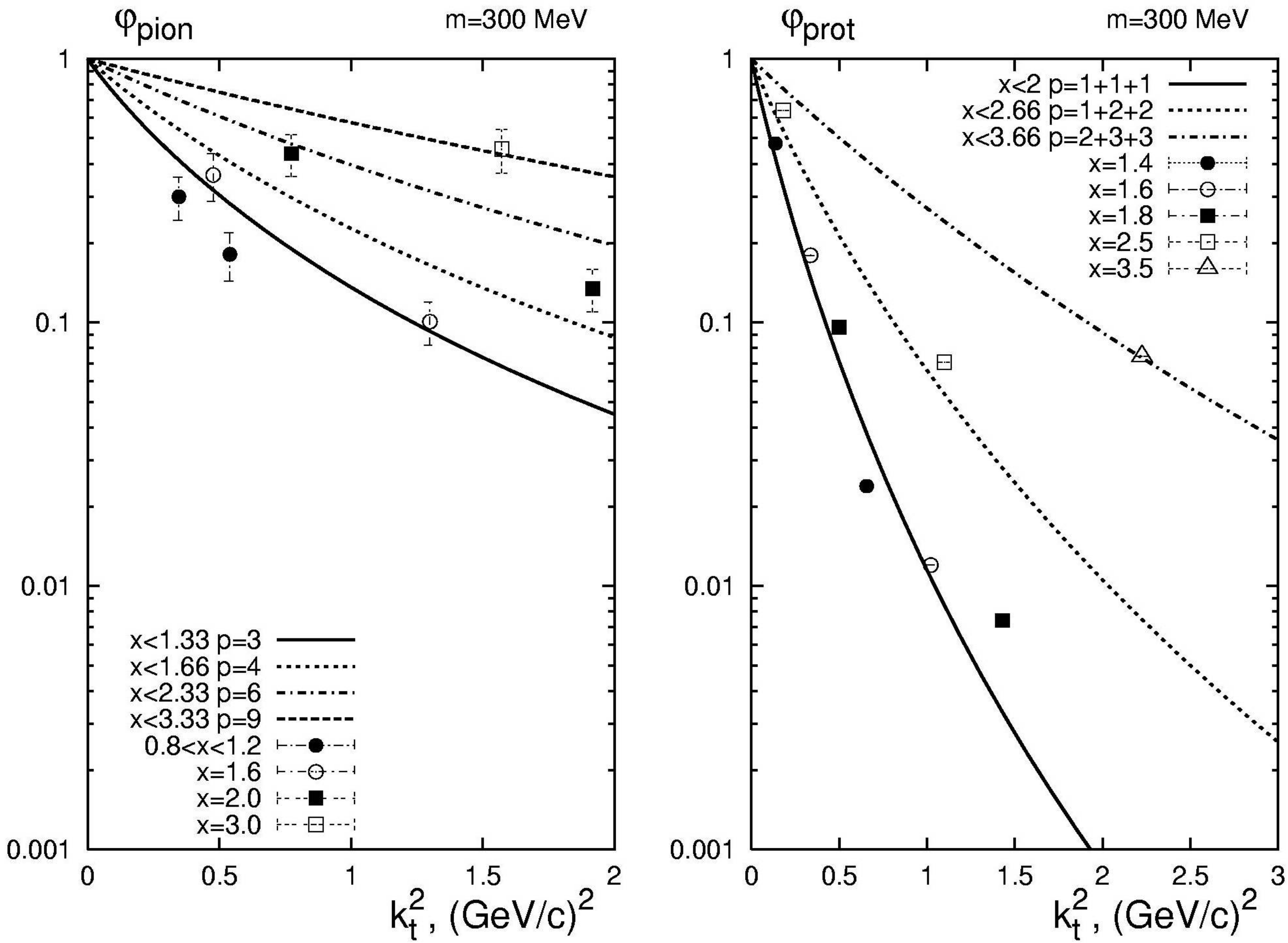
$$\varphi_{pion}(k_\perp, p) \equiv \sigma_{pion}(x, k_\perp; p)/\sigma_{pion}(x, 0; p) = f_p\left(\frac{k_\perp}{m}\right)/f_p(0)$$

$$\varphi_{prot}(k_\perp, p) \equiv \sigma_{prot}(x, k_\perp; p)/\sigma_{prot}(x, 0; p)$$

$$\varphi_{prot}(k_\perp, p) = \frac{\sum_{p_1,p_2,p_3} \delta_{p\ p_1+p_2+p_3}\ C(p_1, p_2, p_3)\ f_{p_1}\left(\frac{k_\perp}{3m}\right)\ f_{p_2}\left(\frac{k_\perp}{3m}\right)\ f_{p_3}\left(\frac{k_\perp}{3m}\right)}{\sum_{p_1,p_2,p_3} \delta_{p\ p_1+p_2+p_3}\ C(p_1, p_2, p_3)\ f_{p_1}(0)\ f_{p_2}(0)\ f_{p_3}(0)}$$

$$\varphi_{prot}(k_\perp, p_1, p_3, p_3) \equiv \frac{\sigma_{prot}(x, k_\perp; p_1, p_2, p_3)}{\sigma_{prot}(x, 0; p_1, p_2, p_3)} = \frac{f_{p_1}\left(\frac{k_\perp}{3m}\right)}{f_{p_1}(0)}\frac{f_{p_2}\left(\frac{k_\perp}{3m}\right)}{f_{p_2}(0)}\frac{f_{p_3}\left(\frac{k_\perp}{3m}\right)}{f_{p_3}(0)}$$

No free parameters (!) only *m* – the constituent quark mass: *m = 300 MeV.*

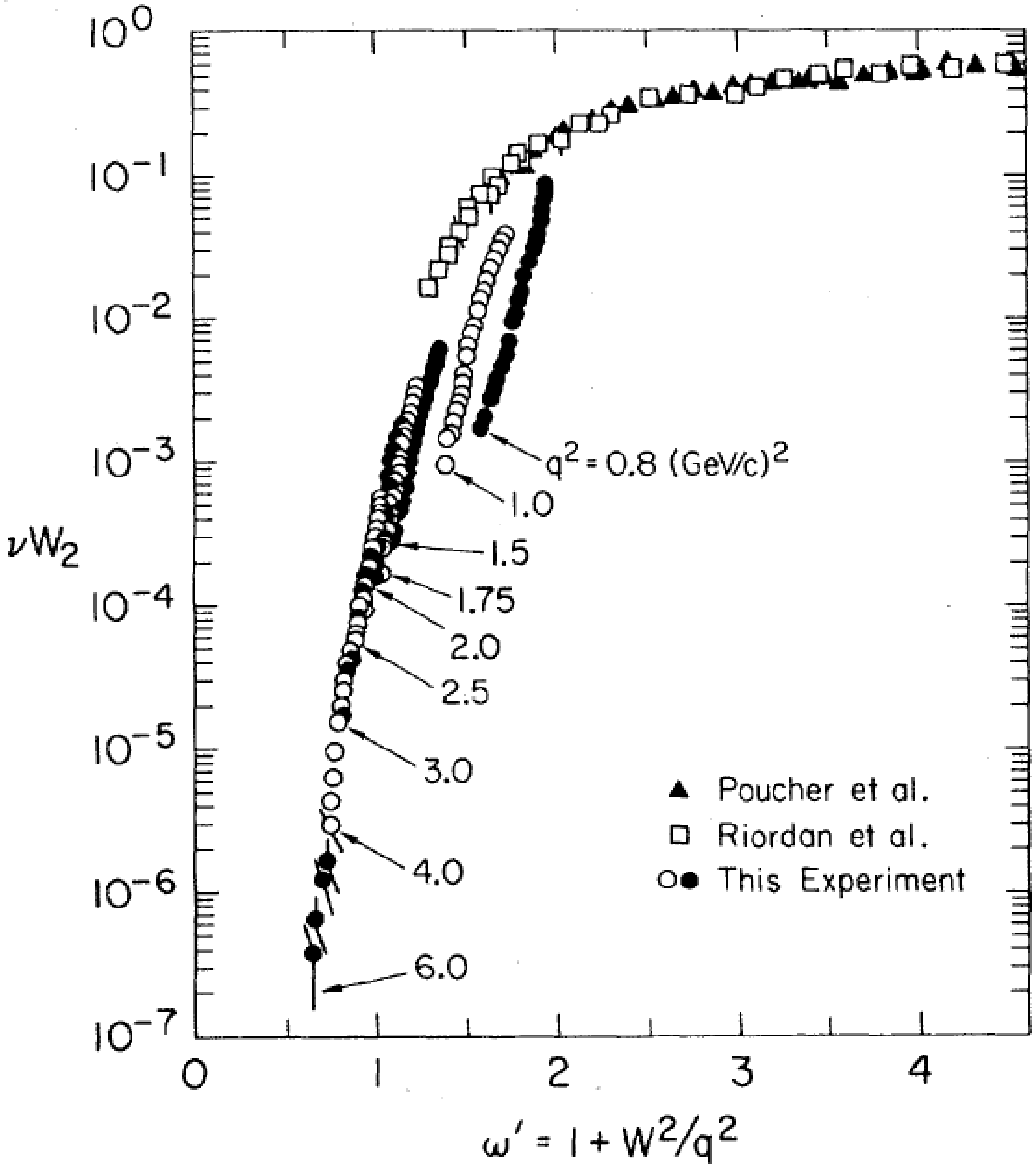


V. Vechernin, AIP Conference Proceedings 1701 (2016) 060020.

S.V. Boyarinov et al., Sov.J.Nucl.Phys. ***46****, 871 (1987)*
S.V. Boyarinov et al., Physics of Atomic Nuclei ***57****, 1379 (1994)*
S.V. Boyarinov et al., Sov.J.Nucl.Phys. ***55****, 917 (1992)*

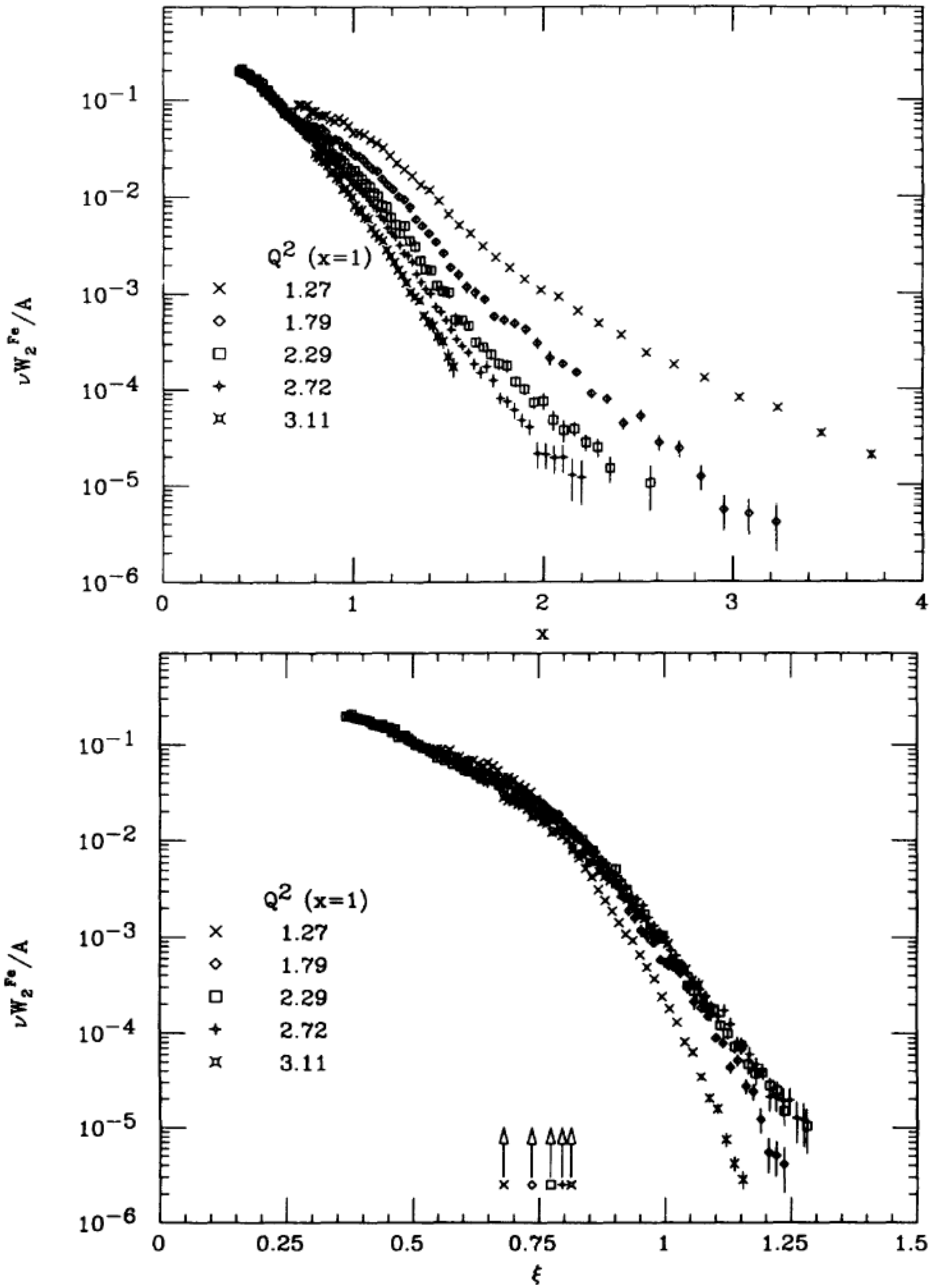
Backup slides

Shuetz W.P. et al., Phys.Rev.Lett., 38 (1977) 259



$$W^2 = M^2 + 2M\nu - q^2$$

$$\omega' = \frac{1}{\xi} + \frac{M^2}{q^2} = \frac{1}{\xi} + \frac{m^2}{|Q^2|}$$



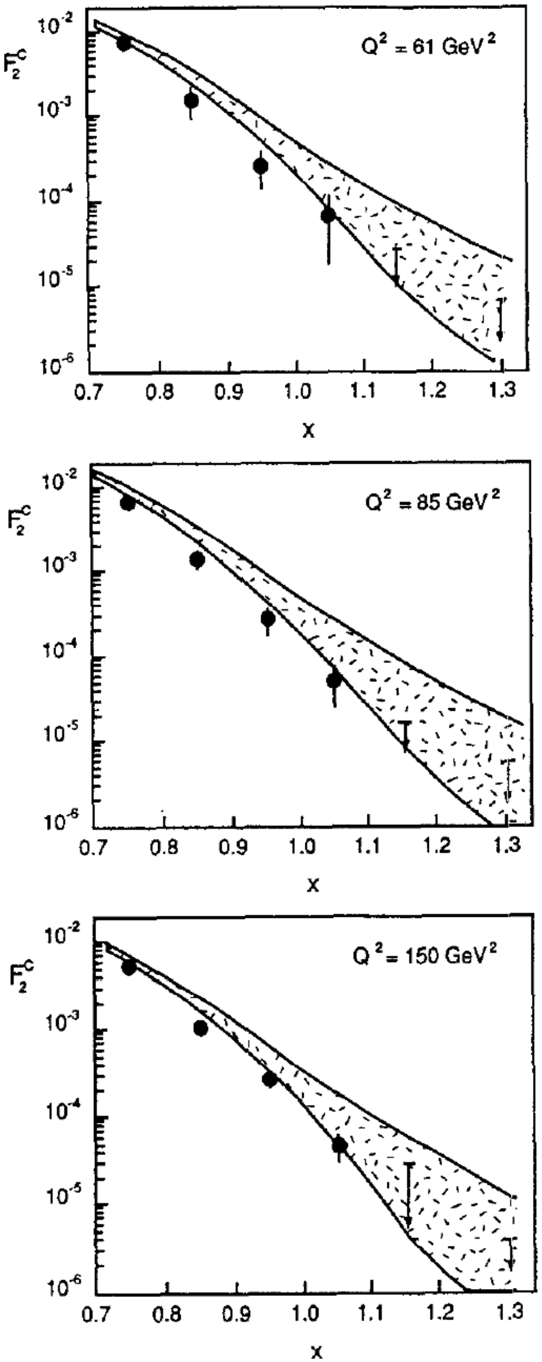
Filippone B.W. et al.,
Phys.Rev.C, 45 (1992) 1582

Freedom at moderate energies:
Masses in color dynamics

Georgi H., Politzer H.D.

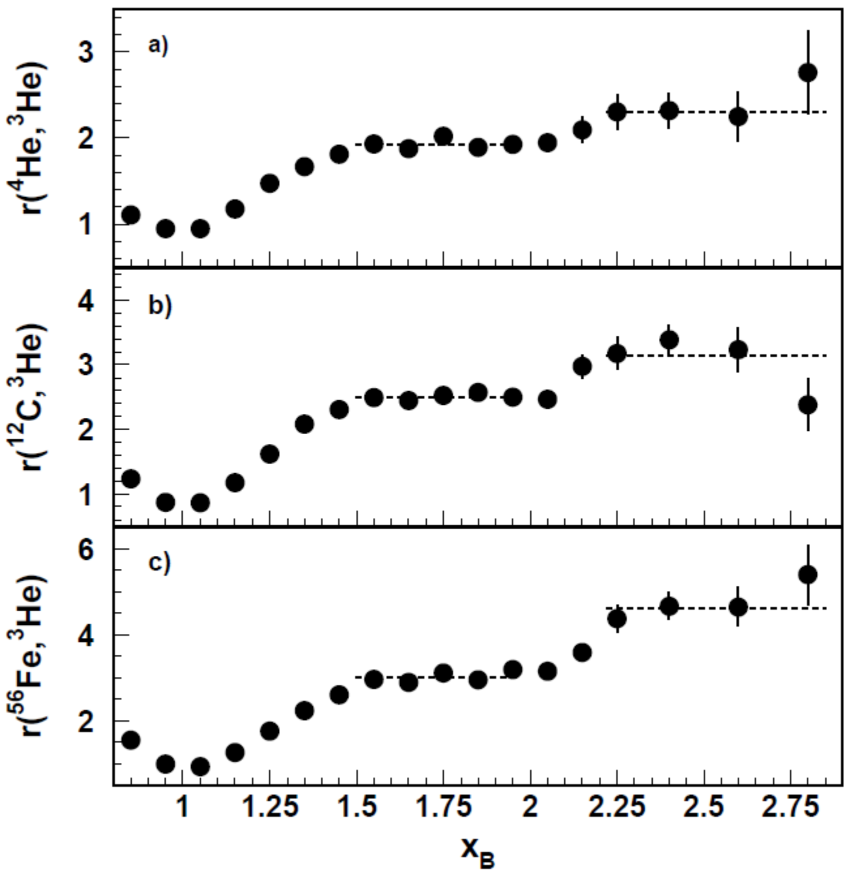
Phys. Rev. D 14, 1829 (1976)

$$\xi = 2x / [1 + (1 + 4M^2x^2/Q^2)^{1/2}]$$



Benvenuti A.C. et al. (BCDMS collaboration) Z. Phys. C63 (1994) 29

L. Frankfurt, M. Strikman, Phys. Rep. 160 (1988) 325

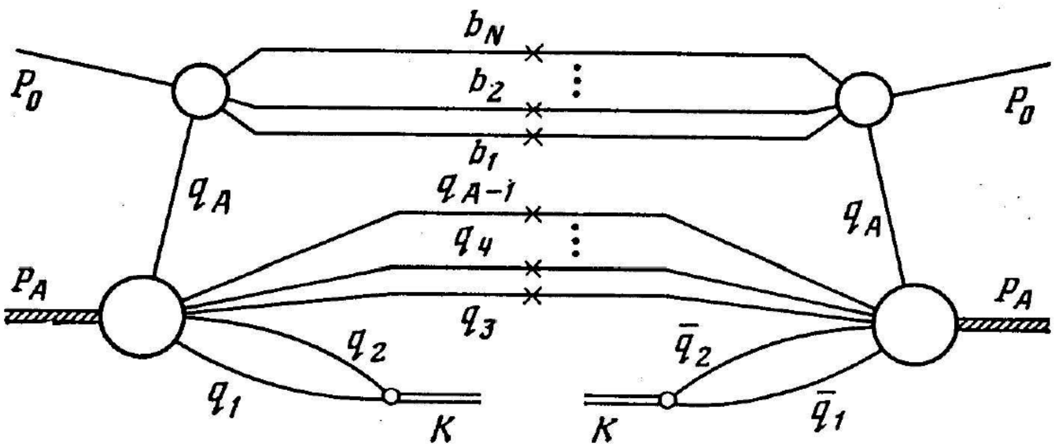


K.S. Egiyan, et al., Phys.Rev.Lett. 96 (2006) 082501

$$r(A,{}^3\mathrm{He}) = \frac{A(2\sigma_{ep}+\sigma_{en})}{3(Z\sigma_{ep}+N\sigma_{en})}\frac{3\mathcal{Y}(A)}{A\mathcal{Y}({}^3\mathrm{He})}C^A_{\mathrm{rad}}$$

	$a_2(A/^3\mathrm{He})$	$a_{2N}(A)(\%)$	$a_3(A/^3\mathrm{He})$	$a_{3N}(A)(\%)$
^{3}He	1	8.0±1.6	1	0.18±0.06
^{4}He	1.93±0.01± 0.03	15.4±3.2	2.33±0.12±0.04	0.42±0.14
^{12}C	2.49±0.01± 0.15	19.8±4.4	3.18±0.14±0.19	0.56±0.21
^{56}Fe	2.98±0.01± 0.18	23.9±5.3	4.63±0.19±0.27	0.83±0.27

Coherent Coalescence at nucleon level, formation of light cumulative fragments (criticism of the Butler-Pearson coalescence model).



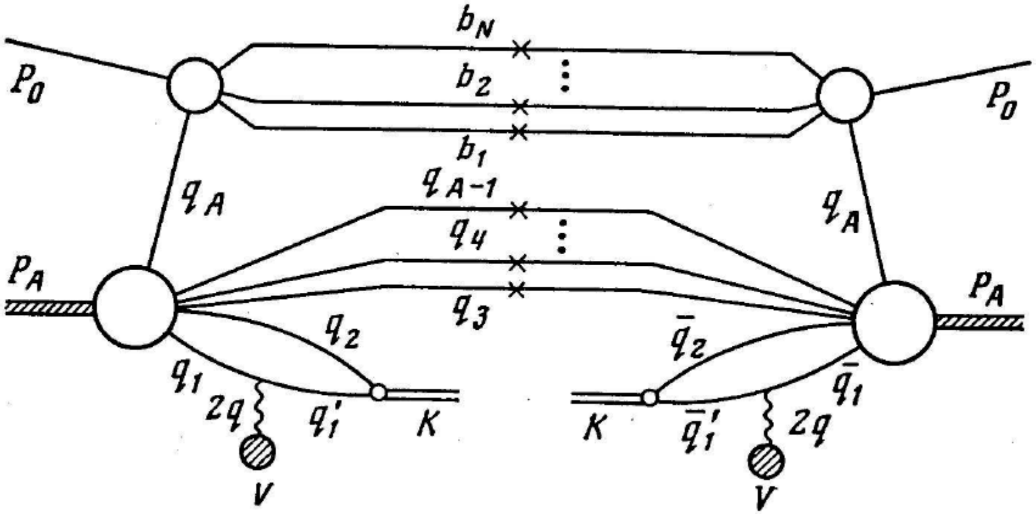
$$X(\mathbf{k}) = \frac{I_A^{(d)}(2\mathbf{k})/A}{(I_A(\mathbf{k})/A)^2},$$

$$(m\varepsilon_A)^{\frac{1}{2}} \ll k \ll m \le P_0$$

M.A. Braun, V.V. Vechernin, Yad.Fiz. 36 (1982) 614

$$\rho_d(\mathbf{K}) = \int d\mathbf{q}_1\, d\bar{\mathbf{q}}_1\, \varphi\left(\frac{\mathbf{q}_1 - \mathbf{q}_2}{2}\right) \varphi^*\left(\frac{\bar{\mathbf{q}}_1 - \bar{\mathbf{q}}_2}{2}\right) \times$$
$$\times \int \prod_{j=3}^{A-1} d\mathbf{q}_j\, \varphi_A(\mathbf{q}_1, \mathbf{q}_2, ..., \mathbf{q}_j, ...)\varphi_A^*(\bar{\mathbf{q}}_1, \bar{\mathbf{q}}_2, ..., \mathbf{q}_j, ...)\ .$$

- nucleons are off mass shell => direct coalescence is possible
- coherence of the coalescence process



M.A. Braun, V.V. Vechernin, Yad.Fiz. 44 (1986) 784

Butler S.T., Pearson C.A., Phys.Rev. 129 (1963) 863

$$X^{\rm BP} = \frac{A\sigma_N}{\sigma_A} 48^2 \pi I(R) \gamma m^2 \frac{W_0^2}{K^2}$$

олное сечение взаимодействия налетающей част

а $I(R)$ - безразмерная функция, убывающая с рост

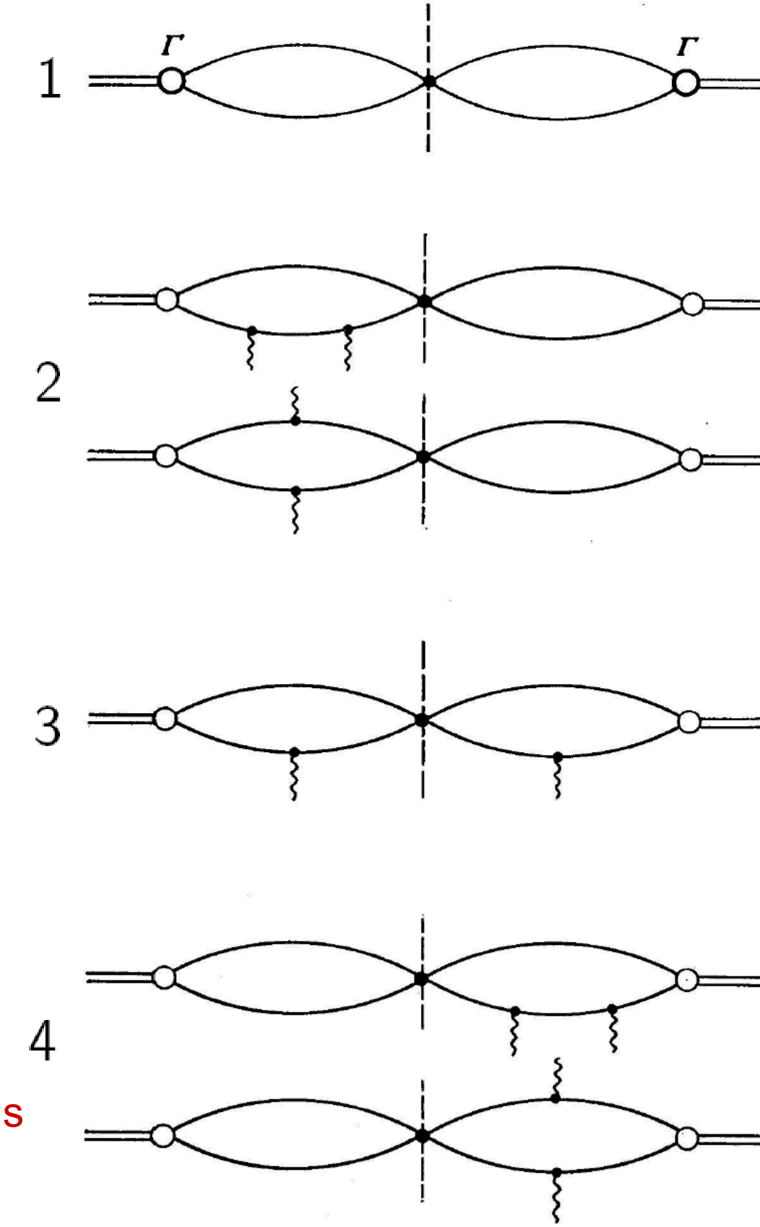
$$\mathbf{q}_{1,2} = \mathbf{K}/2 \pm \mathbf{k}\,, \qquad \bar{\mathbf{q}}_{1,2} = \mathbf{K}/2 \pm \bar{\mathbf{k}}$$

$$\int |A_1(\mathbf{k}) + A_2(\mathbf{k})|^2\, d\mathbf{k} =$$

$$= \int \{|A_1(\mathbf{k})|^2 + |A_2(\mathbf{k})|^2 + A_1(\mathbf{k})A_2^\star(\mathbf{k}) + A_1^\star(\mathbf{k})A_2(\mathbf{k})\}\, d\mathbf{k}$$

$$\left| \int \{A_1(\mathbf{k}) + A_2(\mathbf{k})\}\, d\mathbf{k} \right|^2 =$$

$$= \iint \{A_1(\mathbf{k})A_1^\star(\bar{\mathbf{k}}) + A_2(\mathbf{k})A_2^\star(\bar{\mathbf{k}}) + A_1(\mathbf{k})A_2^\star(\bar{\mathbf{k}}) + A_1^\star(\mathbf{k})A_2(\bar{\mathbf{k}})\}\, d\mathbf{k}\, d\bar{\mathbf{k}}$$



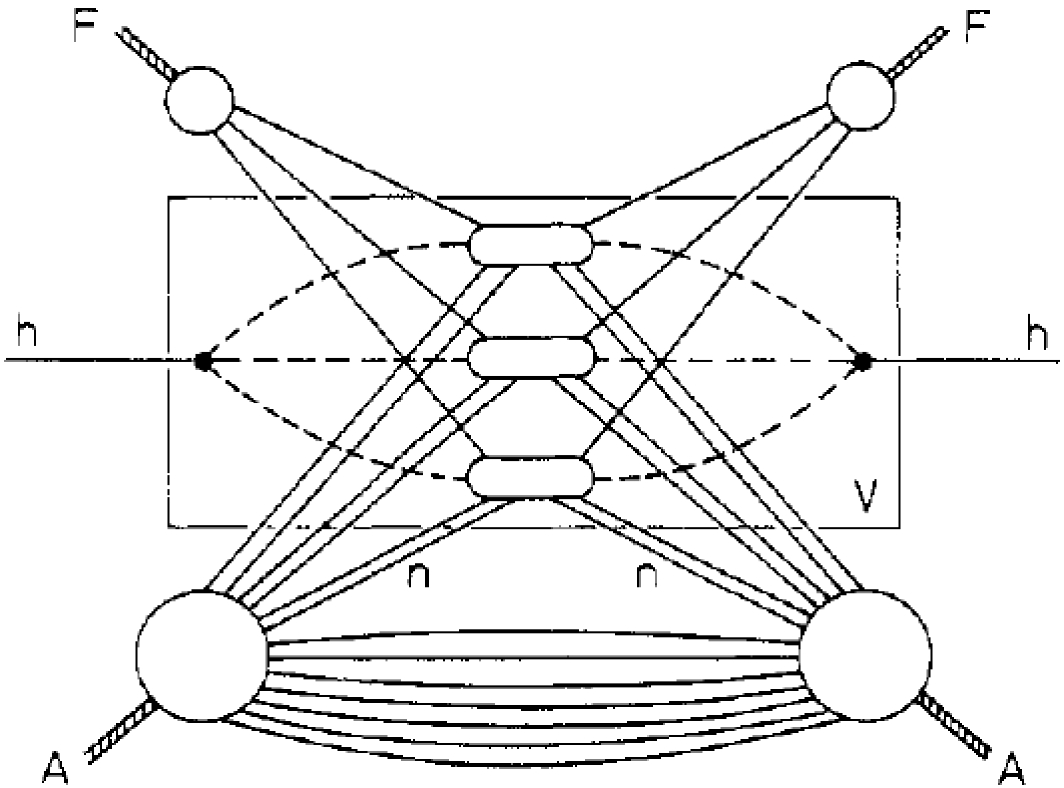
For a real potential *V* the contributions 2 and 4 cancel the BP contribution 3

Braun M.A., Vechernin V.V.
Production of fast fragments in high-energy hadron collisions with nuclei
J. Phys. G 16 (1990) 1615-1626

$$D_F = 2sF\, I_F, \qquad I_F = (2\pi)^3\, 2 f_F, \qquad f_F = p_{F0}\, d^3\sigma_F / d^3\mathbf{p}_F$$

$$\frac{D_{\mathrm{F}}^{(n)}}{2s} = \frac{(nF)!}{(n!)^F} C_{\mathrm{A}}^{nF} (2m)^{1-nF} \left(\frac{d_n}{2s}\right)^F J_{\mathrm{F}}^{(n)}$$

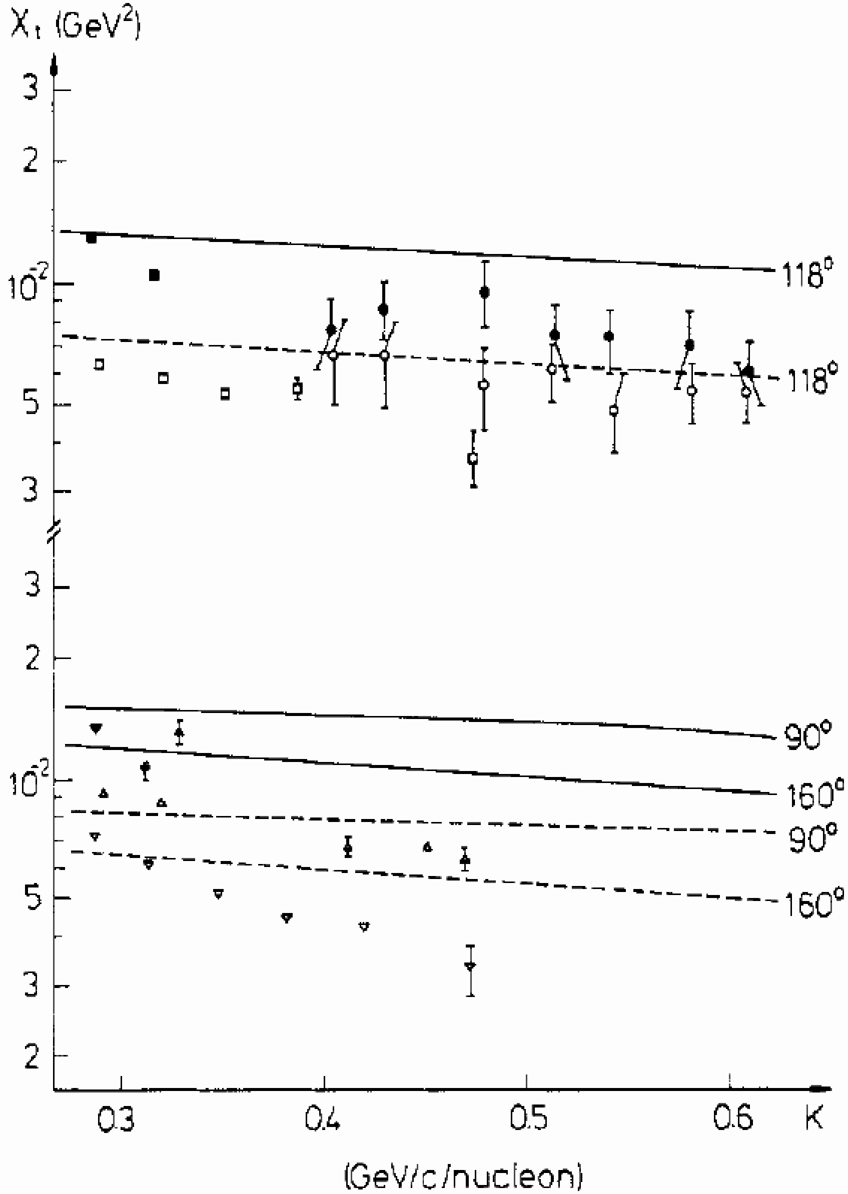
$$J_{\mathrm{F}}^{(n)} = \int \mathrm{d}^2\boldsymbol{b}\, \mathrm{d}z_1 \ldots \mathrm{d}z_F\, |\psi_{\mathrm{F}}(\boldsymbol{y}_i)|^2 \rho_{\mathrm{A}}(\boldsymbol{b}, z_1; \ldots \leftarrow n \rightarrow \ldots \boldsymbol{b}, z_1; \ldots, \boldsymbol{b}, z_F; \ldots \leftarrow n \rightarrow \ldots \boldsymbol{b}, z_F)$$



$$\boldsymbol{y}_i = \left(\mathbf{0}_\perp, \frac{k_-}{m} z_i\right)$$

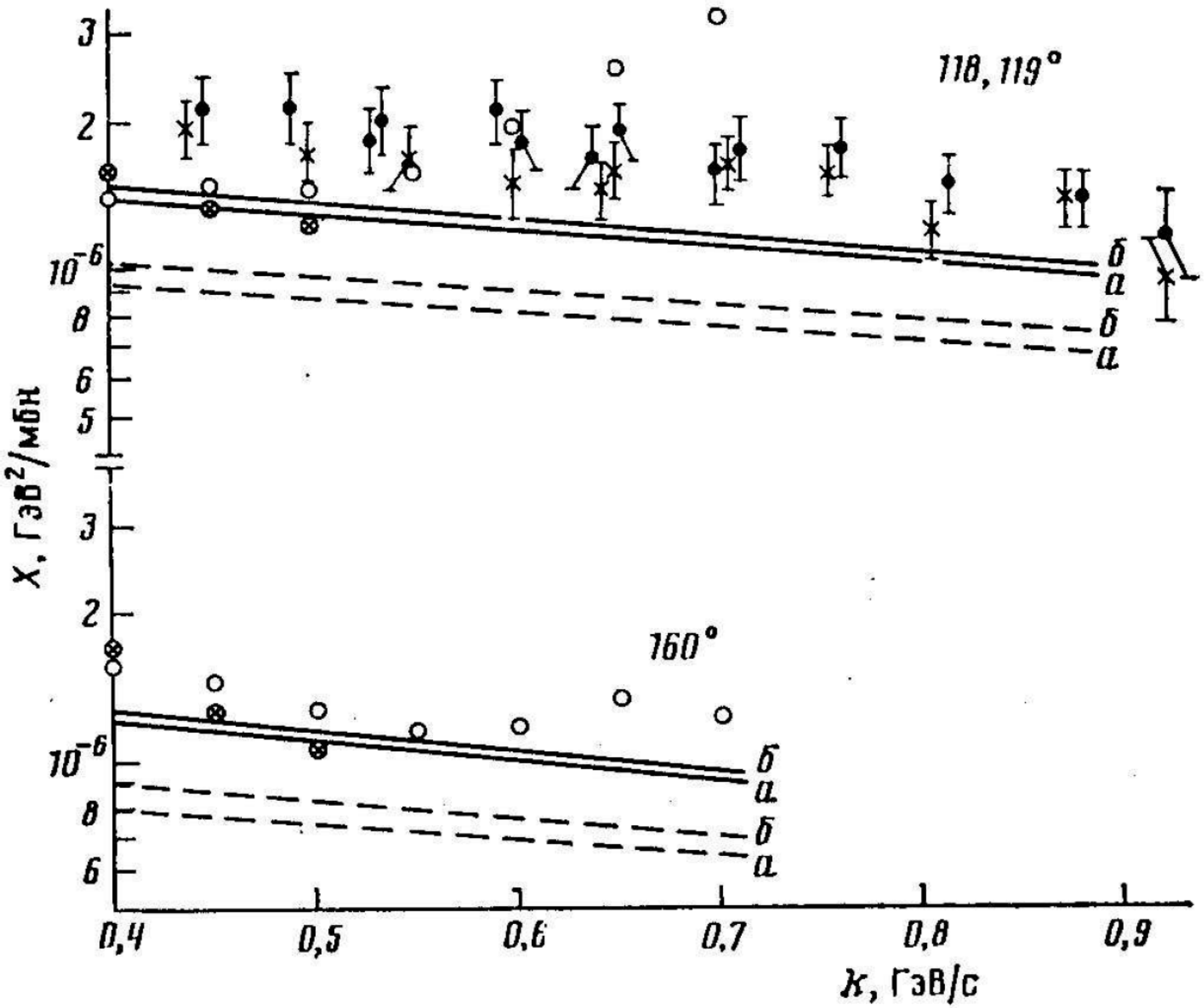
$$k_- = k_0 - k_z = (k^2 + m^2)^{1/2} - k \cos\theta.$$

k_- - scaling
of the coalescence coefficient



$$[\chi_F(\boldsymbol{k})]^{F-1} = \frac{f_F(F\boldsymbol{k})/\sigma_A^{in}}{[f_1(\boldsymbol{k})/\sigma_A^{in}]^F} = [2(2\pi)^3\sigma_A^{in}]^{F-1}\,\frac{I_F}{(I_1)^F}$$

The coalescence coefficient for the emission of tritium in the backward hemisphere in the lab. system, (i.e. in the cumulative area of the target nucleus fragmentation region of the process (1)). The full and broken curves are the results of our calculations with a formula, which is similar to (29) but with $n = 2$, for the target nuclei Cu and Ta, respectively. The experimental data points correspond to the production of tritium in the following reactions: ▲, ■ and ▼, on Cu for the angles 90°, 118° and 160°, △, □ and ▽, on Ta for the same angles at the initial energy 400 GeV [10]; ● and ○, on Cu and Ta for the angle 119° at the initial energy 10 GeV [2].



M.A. Braun, V.V. Vechernin, Yad.Fiz. 47 (1988) 1452

$$X = (I_A^{(d)}/A)/(I_A/A)^2$$

Quark counting rules for elastic and quasi elastic reactions with nuclei

Brodsky S., Farrar G. Phys.Rev.Lett. 31 (1973) 1153
*Brodsky S., Chertok B.T., Phys.Rev. **D14** (1976) 3003*
Matveev V.A., Muradyan R.M., Tavkhelidze A.N. Lett. Nuovo Cimento 7 (1973) 719

$s \to \infty, \quad t/s$ fixed

$(d\sigma/dt)_{\pi p \to \pi p} \sim s^{-8}, \ (d\sigma/dt)_{pp \to pp} \sim s^{-10}, \ (d\sigma/dt)_{\gamma p \to \pi p} \sim s^{-7}, \ (d\sigma/dt)_{\gamma p \to \gamma p} \sim s^{-6}$

$\sim \boldsymbol{s}^{-n}$ $\quad$ $A+B \to C+D$ $\quad$ $n=n_A+n_B+n_C+n_D-2$ $\quad$ $n_p=3 \ \ n_\pi=2 \ \ n_\gamma=1$

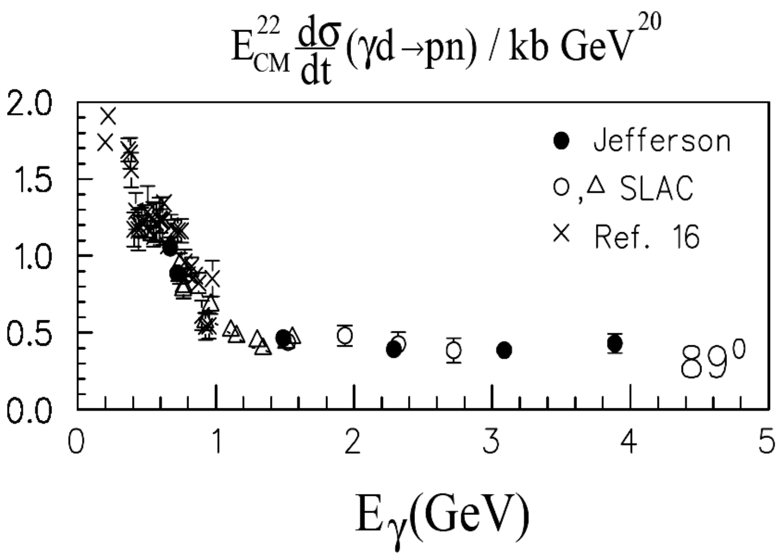
$$\frac{d\sigma}{dt}(A+B \to C+D) \to \frac{1}{t^{N-2}} f(t/s)$$

$N=n_A+n_B+n_C+n_D$

Dokshitzer Yu.L.
QCD Phenomenology, Lectures at the CERN–Dubna School, Pylos, August 2002:

$$\gamma + D \to p + n,$$

1+6+3+3=13 => $\sim s^{-11} = E^{-22}$



C. Bochna et al., Phys. Rev. Lett. **81** (1998) 4576.

Too early ?

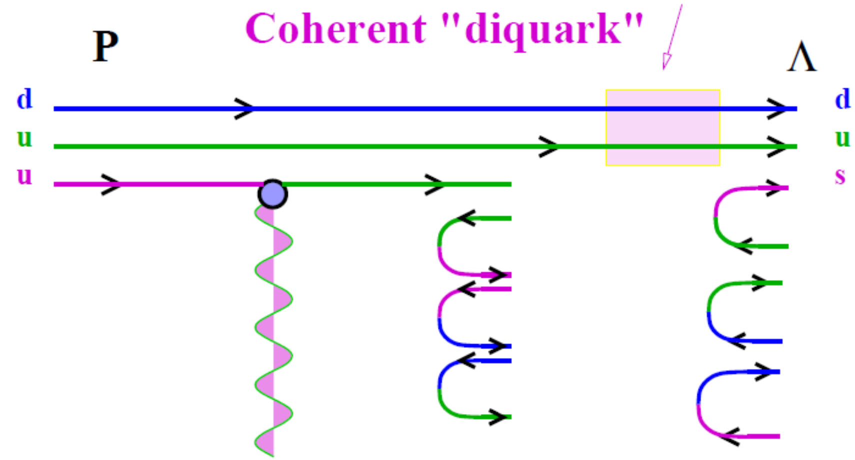


Fig. 4a: Gluon exchange produces a leading baryon.

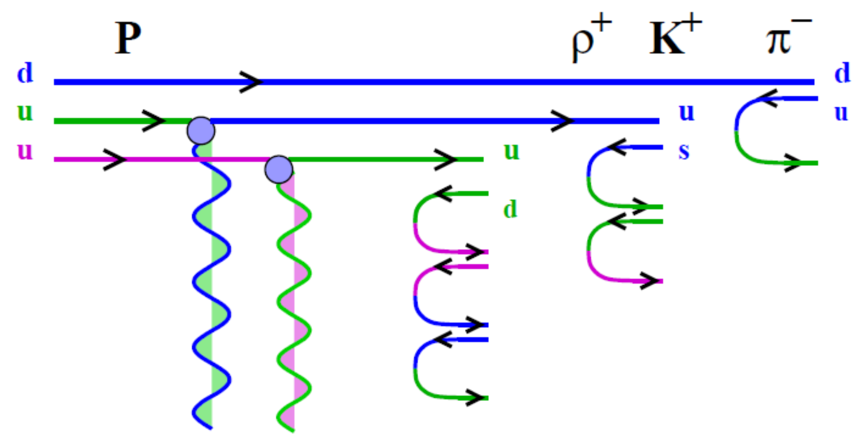


Fig. 4b: Double exchange "breaks up" the proton.

Uzikov Yu.N., JETP Letters 81 (2005) 303

$dd \to p^3H$ $dd \to n^3He$ $pd \to pd$

6+6+3+9-2=22 3+6+3+6-2=16

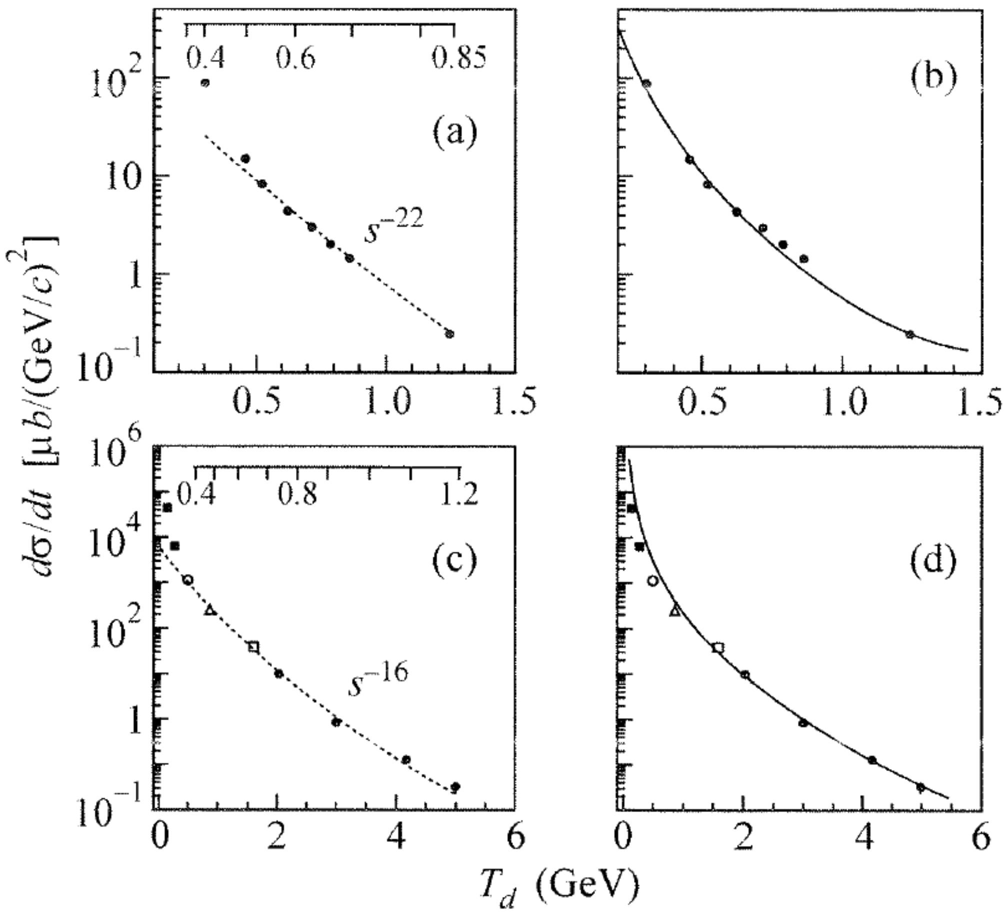


Fig. 2. The differential cross section of the $dd \to n^3He$ and $dd \to p^3H$ reactions at $\theta_{cm} = 60°$ (a), (b) and $dp \to dp$ at $\theta_{cm} = 127°$ (c), (d) versus the deuteron beam kinetic energy. Experimental data in (a), (b) are taken from [20]. In (c), (d), the experimental data (closed squares), (○), (△), (open square), and (●) are taken from [22–26], respectively. The dashed curves give the s^{-22} (a) and s^{-16} (c) behavior. The full curves show the result of calculations using the Regge formalism given by Eqs. (2)–(4) with the following parameters: (b) $C_1 = 1.9$ GeV^2, $R_1^2 = 0.2$ GeV^{-2}, $C_2 = 3.5$, $R_2^2 = -0.1$ GeV^{-2}; (d) $C_1 = 7.2$ GeV^2, $R_1^2 = 0.5$ GeV^{-2}, $C_2 = 1.8$, $R_2^2 = -0.1$ GeV^{-2}. The upper scales in (a) and (c) show the relative momentum q_{pn} (GeV/c) in the deuteron for the ONE mechanism.