Study of the nuclear interaction asymptotics at Serpukhov energy

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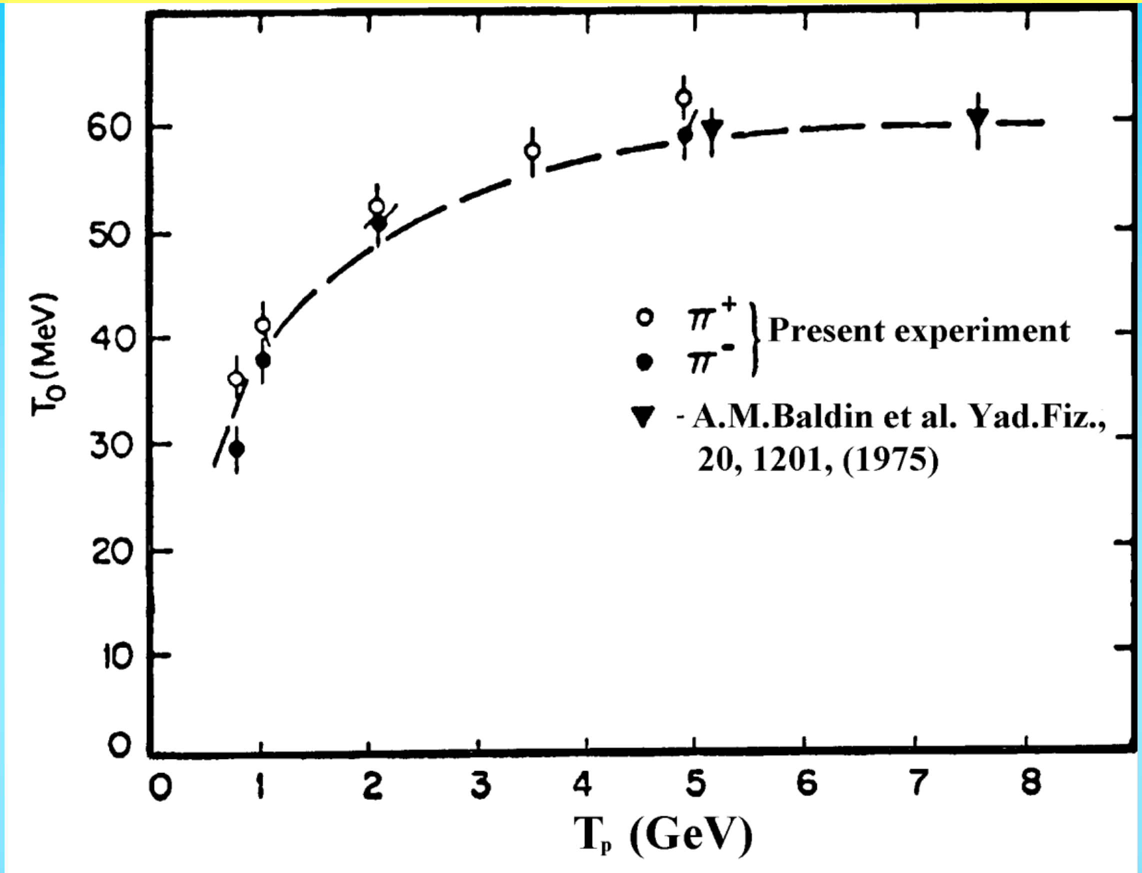
L.S.Schroeder et al. Phys. Rev. Lett., v.43, No.24, 1979, p.1787



Dependence of T_0 parameter for pion at 180^o for p-Cu collisions on the energy of incident proton T_p. Pion cross-section parameterized by the form $E \cdot d\sigma/dp^3 = C \cdot \exp(-T/T_0)$, where T is the pion laboratory kinetic energy

$$I + II \rightarrow 1 + 2 + 3 + \ldots$$

$$b_{ik} = -(u_i - u_k)^2$$

$$u_i = p_i / m_i$$

$$u_k = p_k / m_k$$

$$i, k = I, II, 1, 2, 3, \ldots$$

A.M.Baldin and L.A.Didenko. Fortschr. Phys. **38** (1990) 4, 261-332.

Classification of Relativistic Nuclear Collisions on b_{ik}

$b_{ik} \sim 10^{-2}$

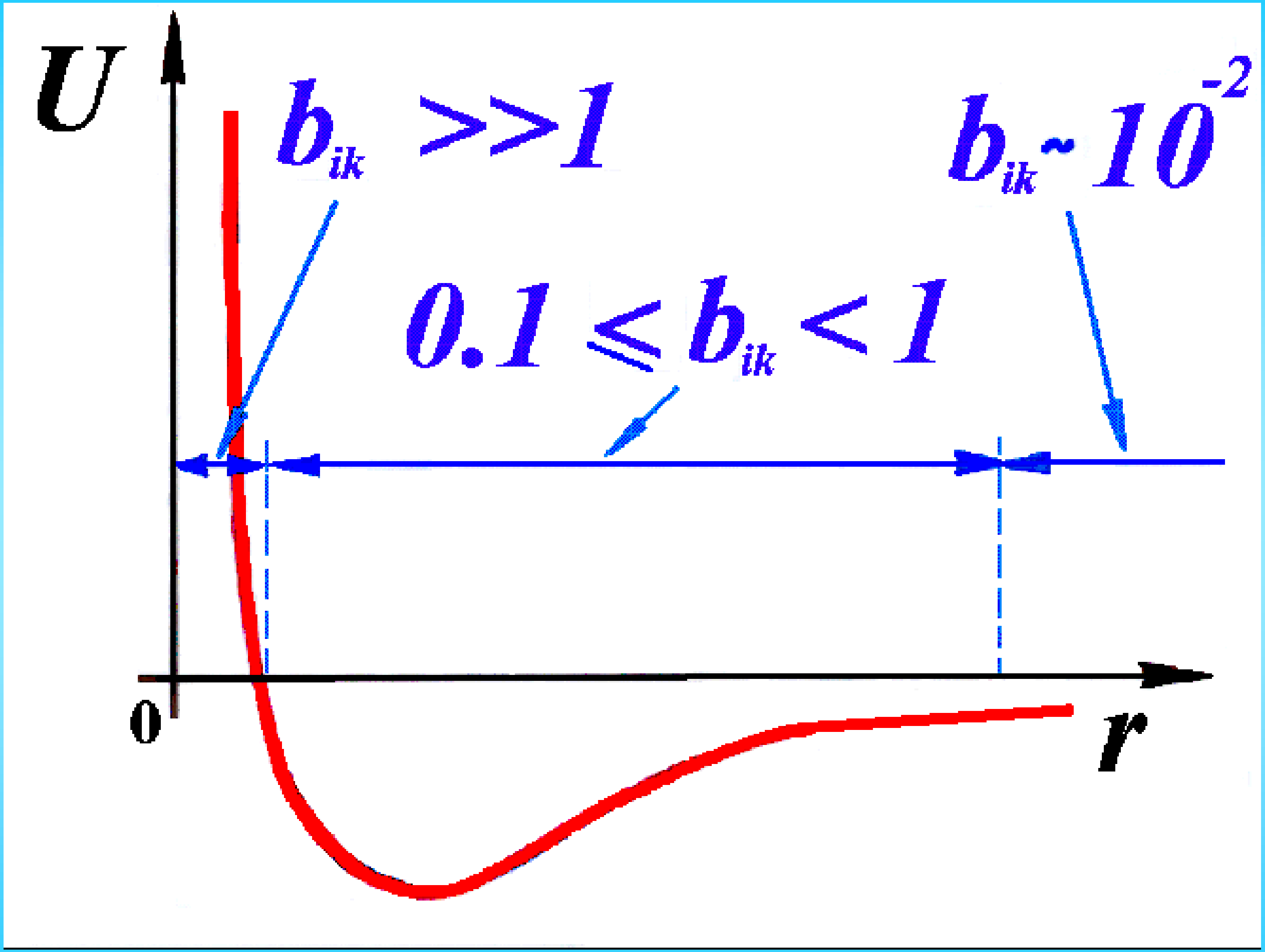
classic nuclear physics

$0.1 \leq b_{ik} < 1$

intermediate domain

$b_{ik} >> 1$

nuclei should be considered as quark-gluon systems


U
$b_{ik} >> 1$
$b_{ik} \sim 10^{-2}$
$0.1 \leq b_{ik} < 1$
0
r

Invariant Definition of Hadron Jets

The jet is a cluster of hadrons with small relative b_{ik}.

The jet axis (a unit four-vector):

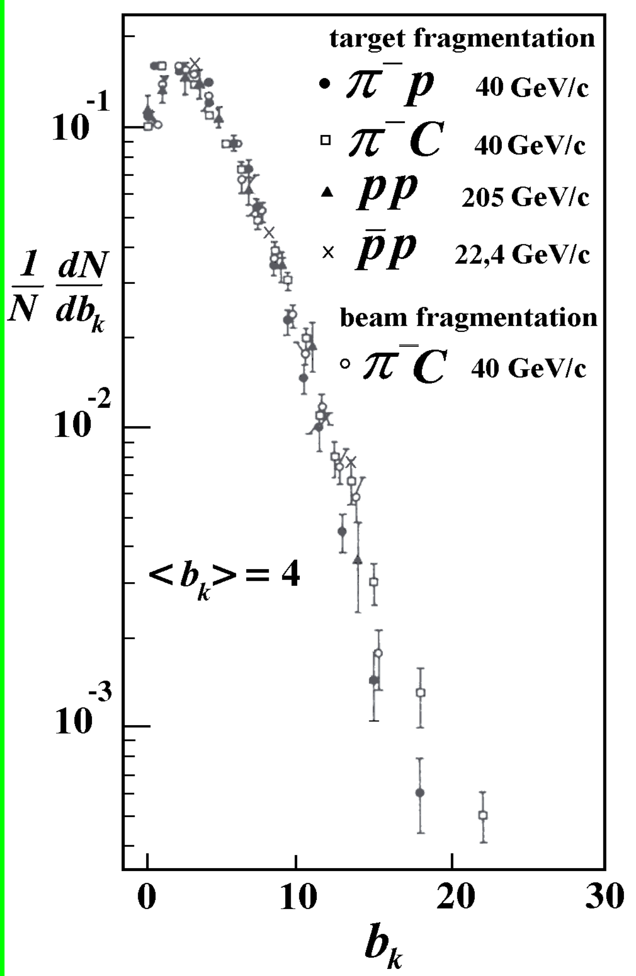
$$V = \Sigma(u_i / \sqrt{(\Sigma u_i)^2})$$

$$V_o^2 - V^2 = 1.$$

The summation is performed over all the particles belonging to the selected particle group (cluster).

It is possible to determine the squared four-velocity with respect to the jet axis:

$$b_k = -(V - u_k)^2.$$



- Distributions of π - mesons on b_k in jets of hadron-hadron and hadron-nucleus collisions at high energies are **UNIVERSAL**. They do not depend either on the collision energy, or on the type of fragmenting system (p, π, p^-, C, ...)

- $<b_k> = 4$ characterizes the average four-velocity of π mesons with respect to the jet axis in the fragmentation of various quark objects

- The discovered **UNIVERSALITY** of the properties of four-dimensional hadron jets indicates that the hadronisation of quark systems is defined by the dynamics of interaction of a color charge with QCD vacuum

Correlation Depletion Principle (CDP)

CDP was offered by ***Bogolyubov N.N. in statistical physics*** as a universal property of the probability distributions for particle location in ordinary space-time (***r***,*t*).

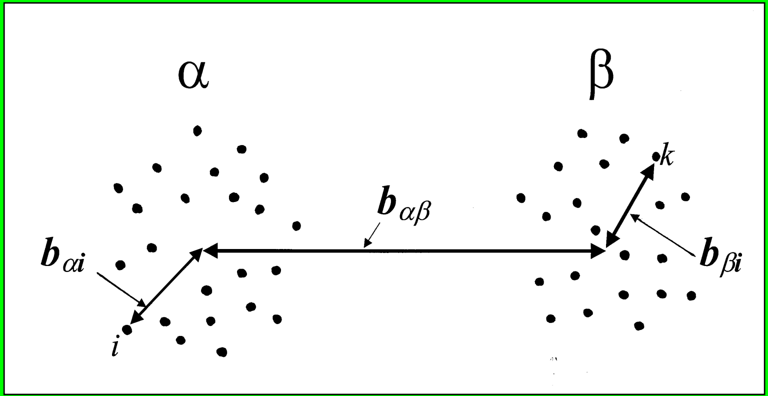
The principle is based on the idea that the correlation between largely spaced parts of a macroscopic system practically vanishes and the distribution is factorized.

CDP ***in Relativistic Nuclear Physics*** was suggested by ***Baldin A.M.*** in four-velocity space.

Due to complementary of r_{ik} and b_{ik} this principle is quite opposite to the Bogolyubov CDP.

The **Bogolyubov CDP** is valid for
$|r_i - r_k|^2 \to \infty$
while the **Baldin CDP** is fulfilled for
$|r_i - r_k|^2 \to 0$ (or $b_{ik} \to \infty$) according to the asymptotic freedom.

Correlation Depletion Principle



$$W\Big|_{b_{\alpha\beta}\to\infty} \to W_\alpha \cdot W_\beta$$

$$\alpha = I, \quad \beta = II$$

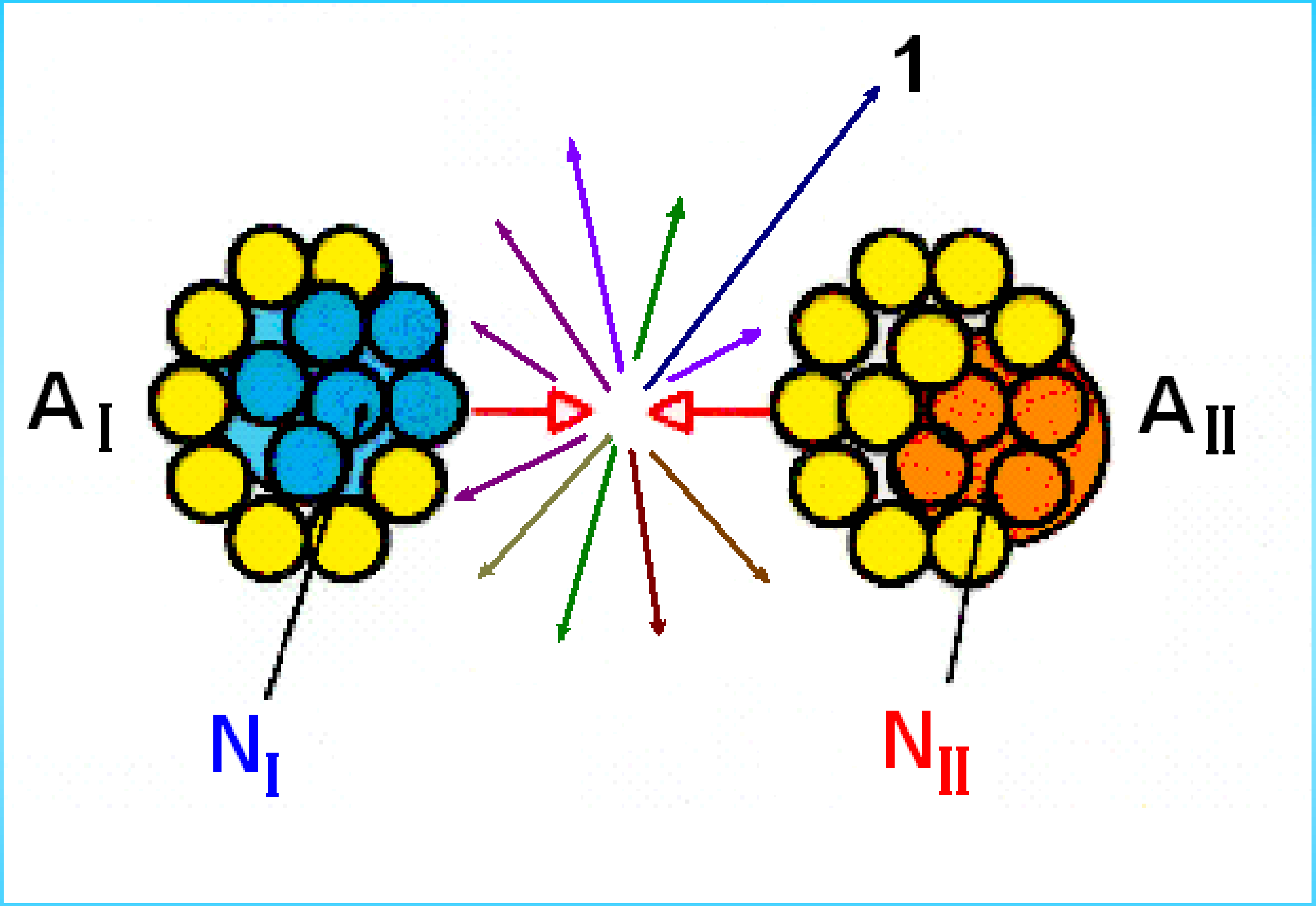
$$I + II \to 1 + \ldots$$

$$d^2\sigma/db_{II1}dx_1 \to F_I \cdot F_{II}(b_{II1}, N_1),$$

$$b_{II1} = (u_{II} - u_1)^2$$

N_1 – *cumulative number*

To study F_{II}, we don't need to accelerate nuclei.


1
A_I
A_{II}
N_I
N_{II}

$$\Pi = min[{}^1/_2\sqrt{(u_I N_I + u_{II} N_{II})^2}]$$

A.M.Baldin, A.I.Malakhov, and A.N.Sissakian. Physics of Particles and Nuclei, Vol.32. Suppl. 1, 2001, pp.S4-S30.

$$E \cdot \frac{d^3\sigma}{d\vec{p}} = C_1 \cdot A_I^{\alpha(N_I)} \cdot A_{II}^{\alpha(N_{II})} \cdot \exp\left(-\frac{\Pi}{C_2}\right)$$

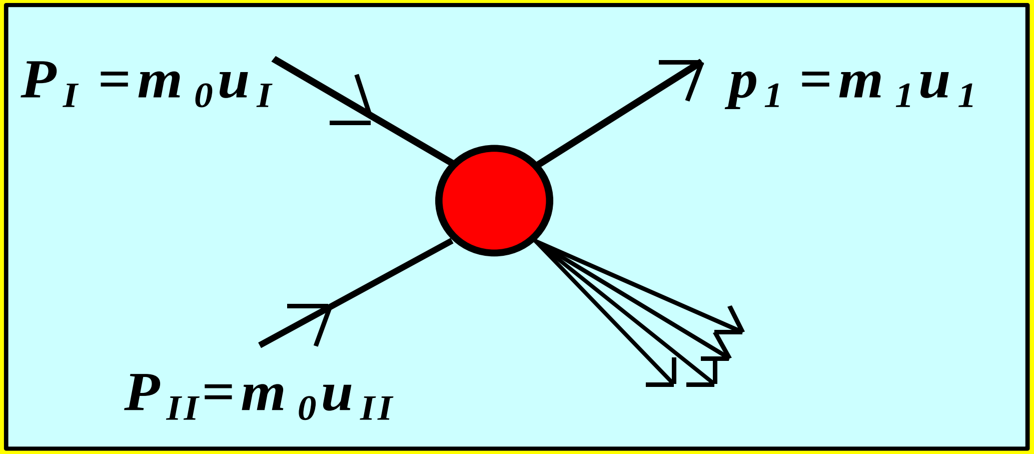
$$\alpha(N_I) = \frac{1}{3} + \frac{N_I}{3}$$

$$\alpha(N_{II}) = \frac{1}{3} + \frac{N_{II}}{3}$$

$$C_1 = 1.9 \cdot 10^4 \ \mathrm{mb} \cdot \mathrm{GeV}^{-2} \cdot c^3 \cdot \mathrm{sr}^{-1}$$

$$C_2 = 0.125 \pm 0.002$$

$$I + II \rightarrow 1 + \ldots$$



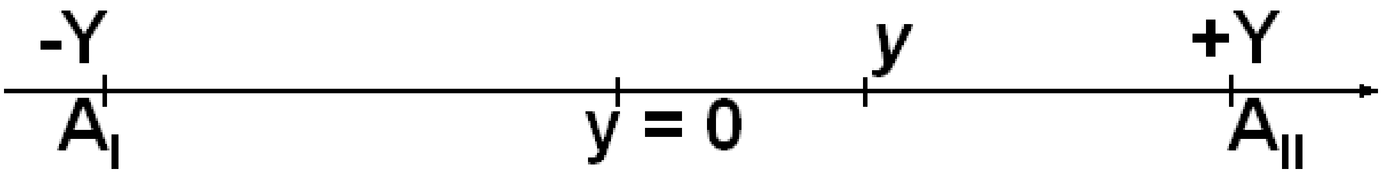
$$(N_I P_I + N_{II} P_{II} - p_1)^2 = $$
$$= (N_I m_0 + N_{II} m_0 + \Delta)^2$$

Δ is the mass of the particle providing conservation of the barion number, strangness and other quantum numbers

$$\Pi^{min} \Rightarrow d\Pi/dN_I = 0; \;\; d\Pi/dN_{II} = 0$$

In the central rapidity region ($y = 0$)

$$(u_1 u_I) = (u_1 u_{II})$$



$$N_I = N_{II} =$$

$$N = [1 + \sqrt{1 + (\Phi_\delta/\Phi^2)}]\Phi,$$

where

$$\Phi = (1/m_0)[m_T chY + \Delta](½\, sh^2 Y)$$

$$\Phi_\delta = (\Delta^2 - m_1^2)(4m_0^2\, sh^2 Y)$$

and

$$\Pi^{min} = N \cdot chY$$

$$\Pi_{min} = \min\,[1/2\sqrt{(u_I N_I + u_{II} N_{II})^2}]$$

$$(N_I m_0 u_I + N_{II} u_{II} m_0 - m_1 u_1)^2 = (N_I m_0 + N_{II} m_0 + \Delta)^2$$

$$N_I \cdot N_{II} - \Phi_I N_I - \Phi_{II} N_{II} = \Phi_\delta ,$$

$$\Phi_I = [(m_1/m_0) \cdot (u_I u_1) + \Delta/m_0]/[(u_I u_{II}) - 1]$$

$$\Phi_{II} = [(m_1/m_0) \cdot (u_{II} u_1) + \Delta/m_0]/[(u_I u_{II}) - 1]$$

$$\Phi_\delta = (\Delta^2 - m_1^2)/[2m_0^2((u_I u_{II}) - 1)].$$

$$[(N_I/\Phi_{II}) - 1] \cdot [(N_{II}/\Phi_I) - 1] = 1 + [\Phi_\delta/(\Phi_I \cdot \Phi_{II})]$$

$$d\Pi/dN_I = 0 , \quad d\Pi/dN_{II} = 0.$$

$$F_I = [(N_I/\Phi_{II}) - 1] , \qquad F_{II} = [(N_{II}/\Phi_I) - 1].$$

$$F_I \cdot F_{II} = 1 + \Phi_\delta/(\Phi_I \cdot \Phi_{II}) = \alpha$$

$$d\Pi/dF_I = 0 , \quad d\Pi/dF_{II} = 0.$$

$$4\Pi^2 = N_I^2 + N_{II}^2 + 2N_I \cdot N_{II} \cdot (u_I u_{II})$$

$$4\Pi^2 = (F_I + 1)^2 \Phi_{II}^2 + (F_{II} + 1)^2 \Phi_I^2 + 2\Phi_I \cdot \Phi_{II} \cdot (F_I + 1) \cdot (F_{II} + 1) \cdot (u_I u_{II})$$

$$F_{II} = \alpha/F_I \qquad d(4\Pi^2)/dF_I = 0$$

$$F_I^4 + F_I^3[1 + (u_I u_{II})/z] - (\alpha/z) \cdot F_I \cdot [(u_I u_{II}) + (1/z)] - \alpha^2/z^2 = 0$$

$$z = \Phi_{II}/\Phi_I$$

$$I \leftrightarrow II: \quad z \to (1/z); \quad F_I \to (\alpha/F_{II}).$$

$$F_{II}^4 + F_{II}^3[1 + (u_I u_{II})z] - z \cdot \alpha \cdot F_{II} \cdot [z + (u_I u_{II})] - \alpha^2 z^2 = 0.$$

In the central rapidity region $(u_1 u_I) = (u_1 u_{II}) \to \quad z = 1 \to$

$$F_I = F_{II}, \ \Phi_I = \Phi_{II} = \Phi$$

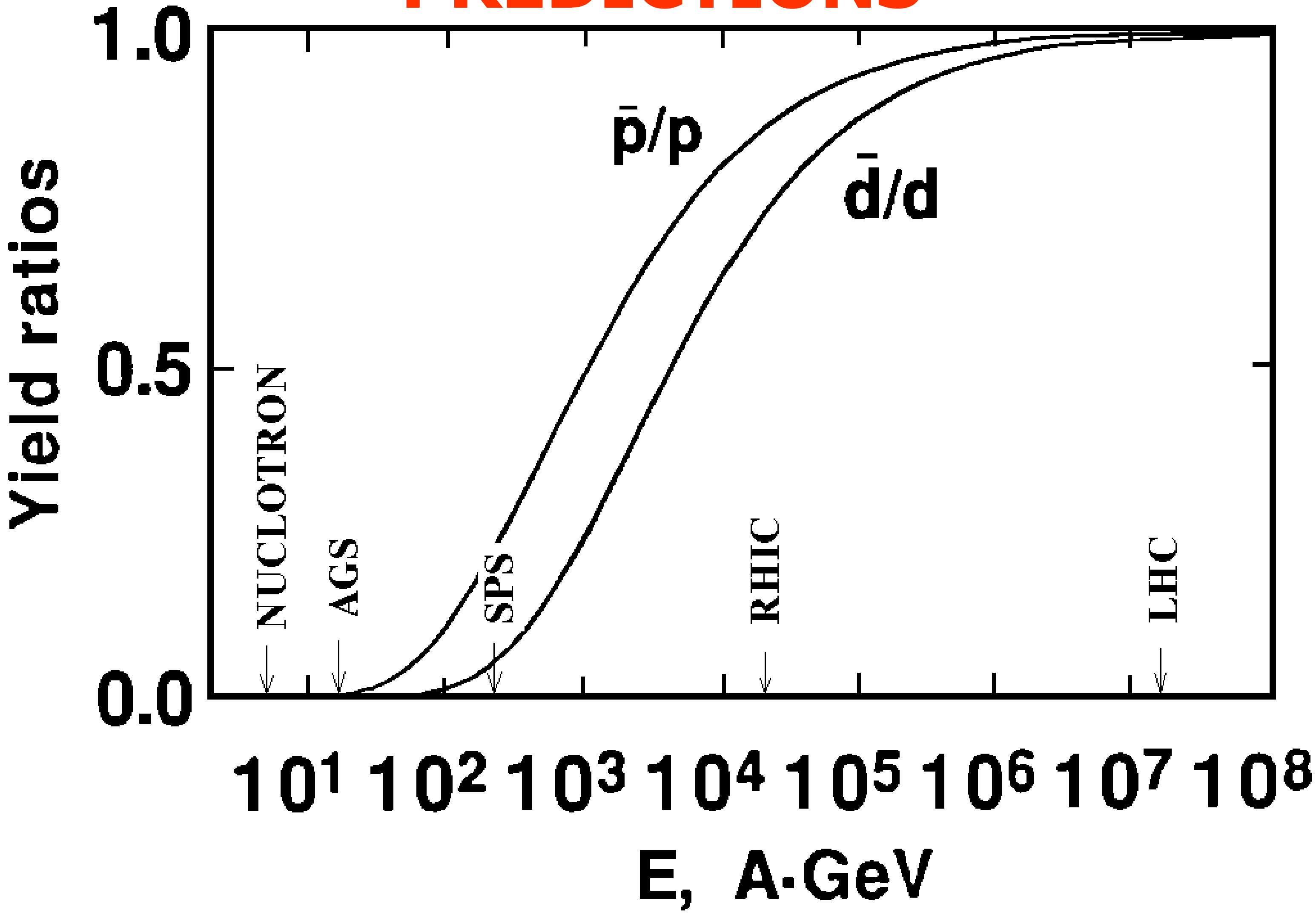
$$F_I = F_{II}, \ (N_I/\Phi - 1) = (N_{II}/\Phi - 1), \ N_I = N_{II} = N$$

$$F^2 = \alpha , \ F_I = F_{II} = \sqrt{\alpha} = \sqrt{1 + (\Phi_\delta/\Phi^2)}$$

$$N_I = N_{II} = N = (1+F) \cdot \Phi = [1 + \sqrt{1 + (\Phi_\delta/\Phi^2)}] \cdot \Phi$$

Baldin A.M., Malakhov A.I.
JINR Rapid Communications,
No.1(87)-98, 1998, pp.5-12.

PREDICTIONS



Asymptotics

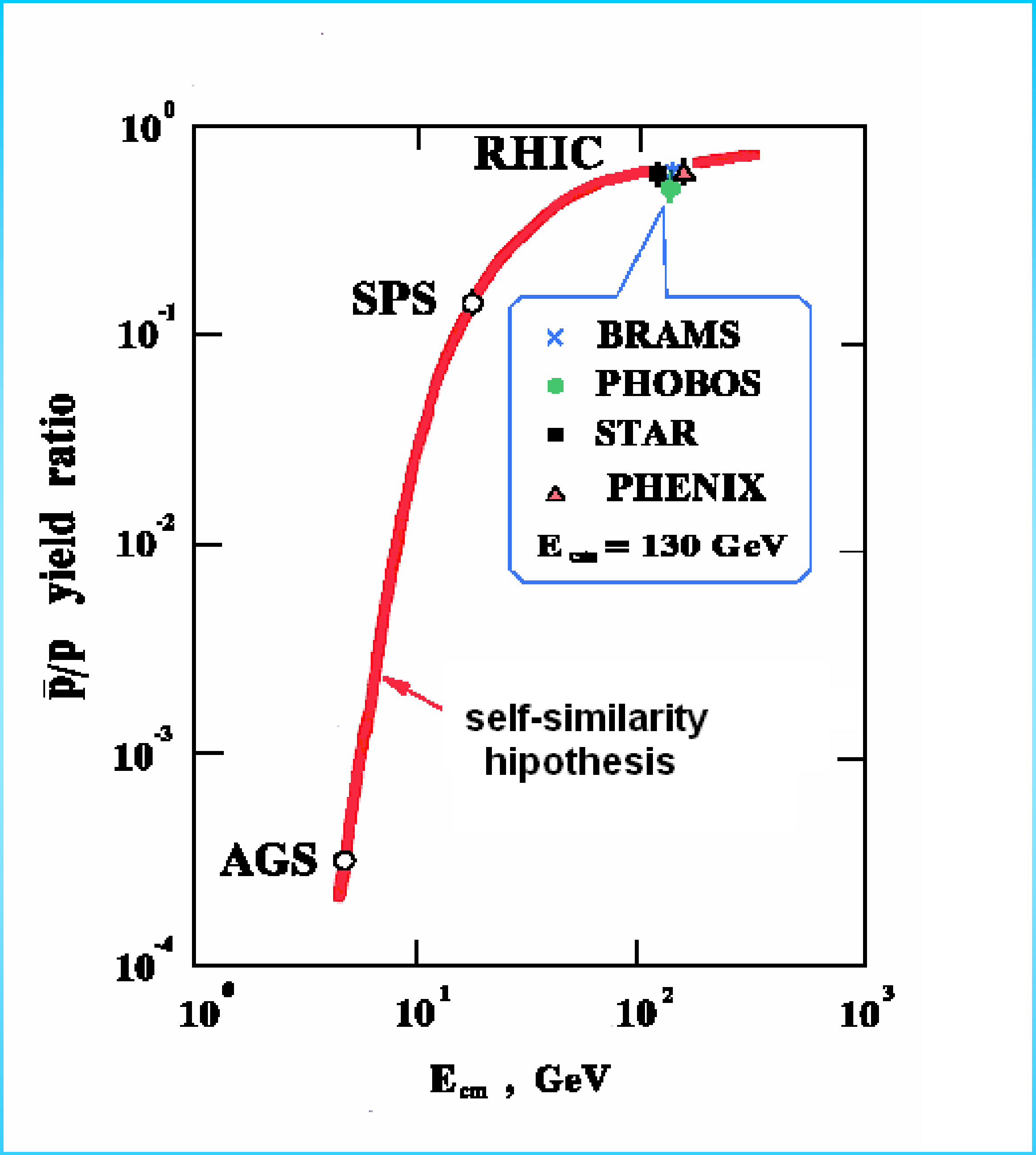
$$s/(2m_I m_{II}) \approx (u_I u_{II}) = \mathrm{ch}2Y \rightarrow \infty$$

$$\Pi_\infty^{min} = (m_T/2m_0)[1+\sqrt{1+(\Delta^2-m_1^2)/m_T^2}$$

$$N_\infty \rightarrow 0$$

The analytical representation for Π leads to the following conclusions:

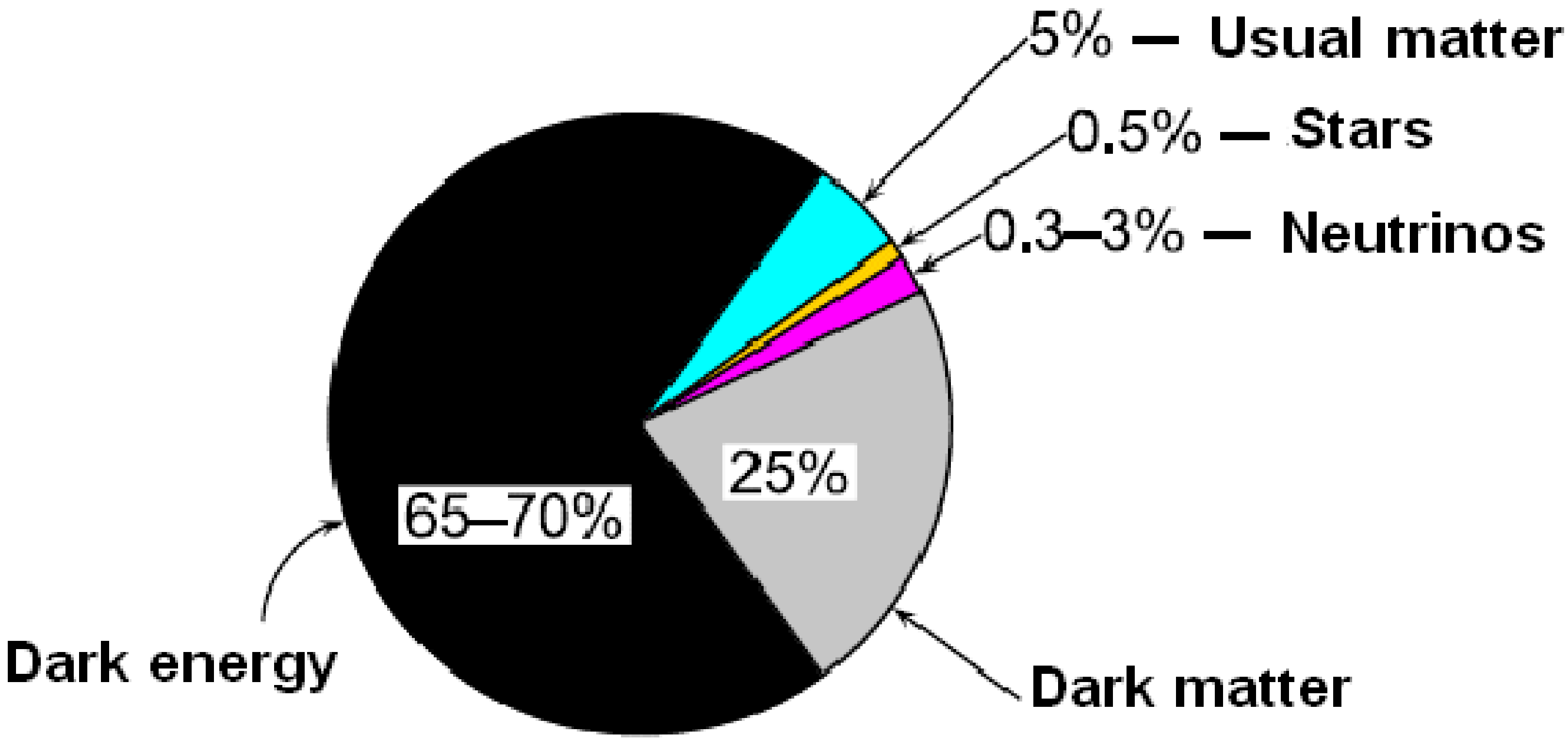
- **There is the limiting value of Π at high energies**
- **The ratio of particle to antiparticle and nucleus to antinucleus production cross-section goes to the unit while energy rising**
- **The effective number of nucleons involved in the reaction decreases with increasing collision energy**
- **Probability of observation of antinuclei and fragments in the central rapidity region is small**
- **Strange particles yield increases with increasing collision energy**



RHIC
SPS
AGS
BRAMS
PHOBOS
STAR
PHENIX
E cm = 130 GeV
self-similarity
hipothesis
p̄/p yield ratio
E cm , GeV
10^0
10^-1
10^-2
10^-3
10^-4
10^0
10^1
10^2
10^3

Dark energy

Energy balance of the modern Universe

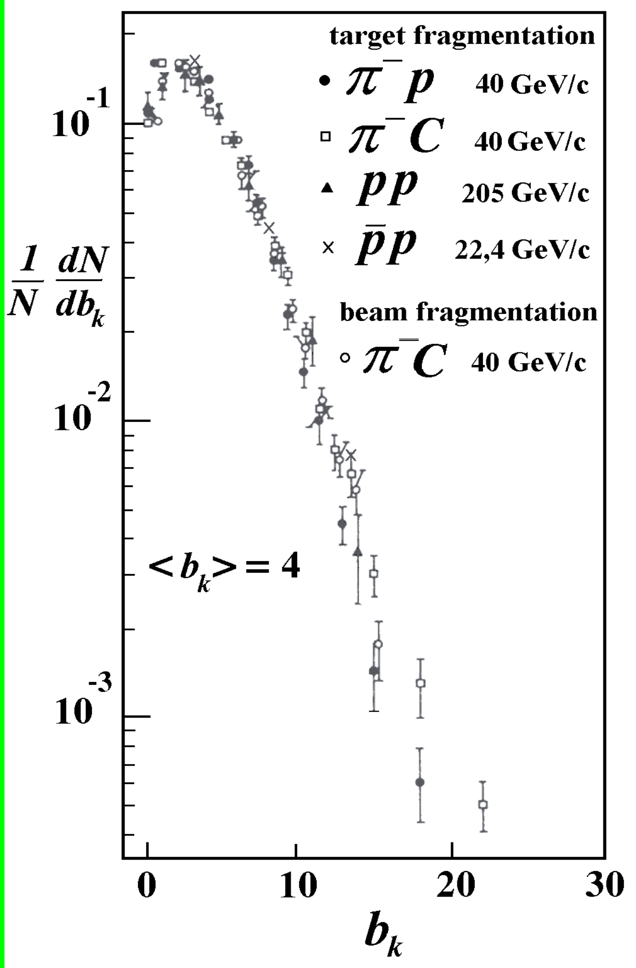


Dark energy

Astronomical observations testify that today (and in recent times) the Universe extends with acceleration: rate of expansion grows in time. In this sense also it is possible to speak about antigravitation: the usual gravitational attraction would slow down scattering galaxies, and in our universe, it turns out, on the contrary.

One of candidates for a role of dark energy - vacuum. The density of energy of vacuum does not change at expansion of the Universe, and it means negative pressure of vacuum.

Change of energy at change of volume is defined by pressure, $\Delta E = -p\Delta V$. At expansion of the Universe energy of vacuum grows together with volume (the density of energy is constant) that is possible, only if pressure of vacuum negatively.



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- $\langle b_k \rangle = 4$ characterizes the average four-velocity of π mesons with respect to the jet axis in the fragmentation of various quark objects

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$$\Delta E = -p\Delta V$$

$$I + II \rightarrow 1 + 2 + \ldots$$

$$b_{I\,II} = -(u_I - u_{II})^2 = -(1 - 2u_I u_{II} - 1) =$$

$$= 2(u_I u_{II} - 1) = 2(E_I/m_I - 1)$$

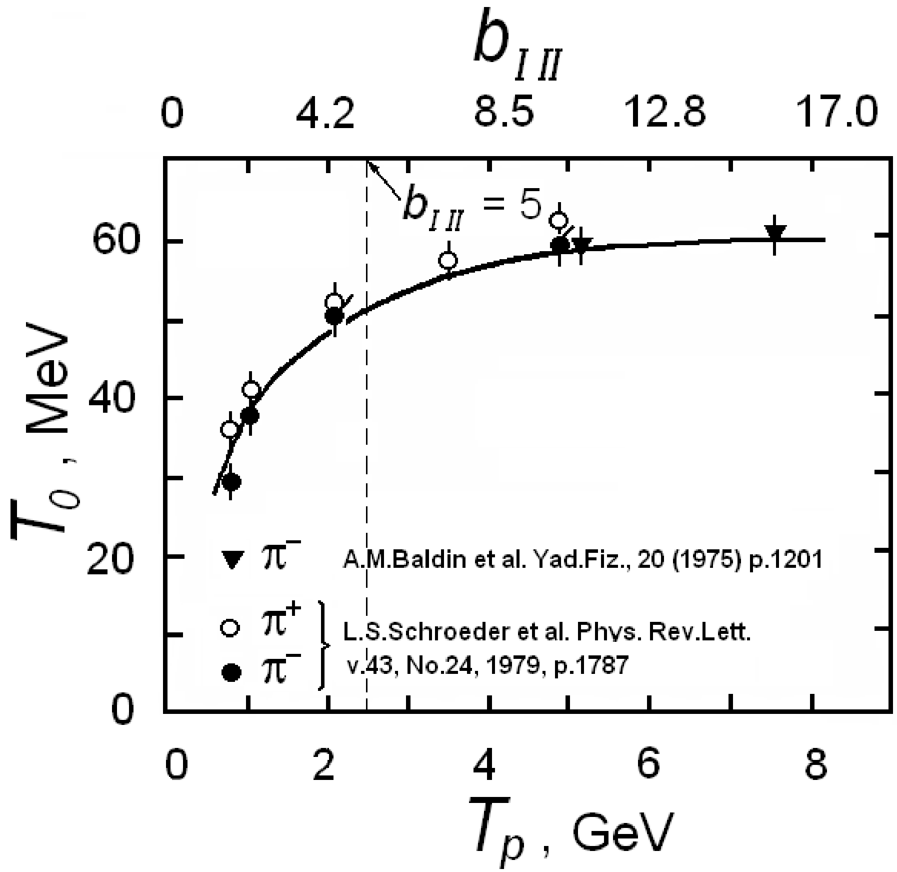
$$\Delta b_{I\,II} = 2\Delta E_I/m_I \longrightarrow \Delta E_I = (m_I/2)\Delta b_{I\,II} = -p\Delta V$$

$$p = -(m_I/2)\Delta b_{I\,II}/\Delta V)$$

$$V = \sigma\, 2r_0 A^{1/3} \longrightarrow \Delta V = \Delta\sigma\, 2r_0 A^{1/3}$$

$$p = -[m_I/4\, r_0 A^{1/3}]\Delta b_{I\,II}/\Delta\sigma$$

$p = - [m_I /4\, r_0 A^{1/3}] \Delta b_{I\,II} / \Delta\sigma$



$\Delta b_{I\,II} > 0$

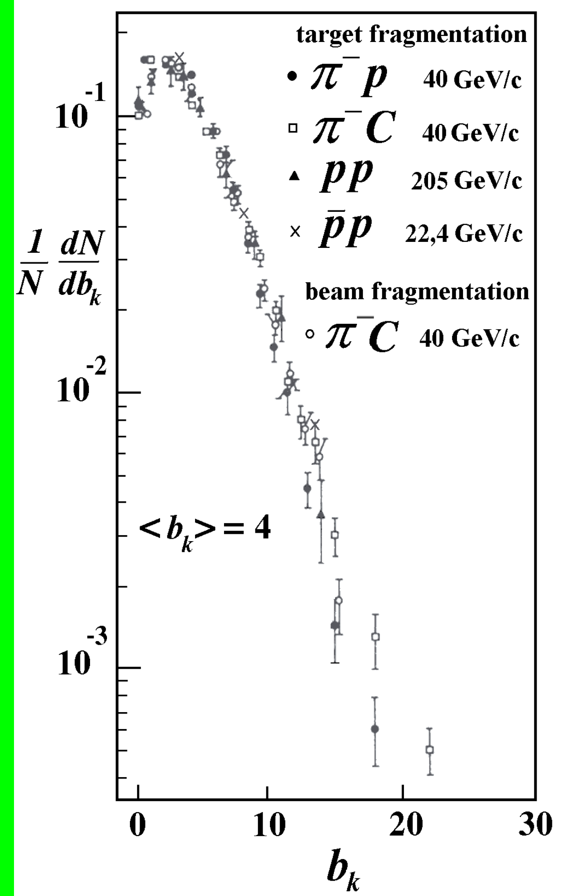
$\Delta\sigma > 0$

$p < 0$

$\sigma \sim exp\,(- T_\pi / T_0)$

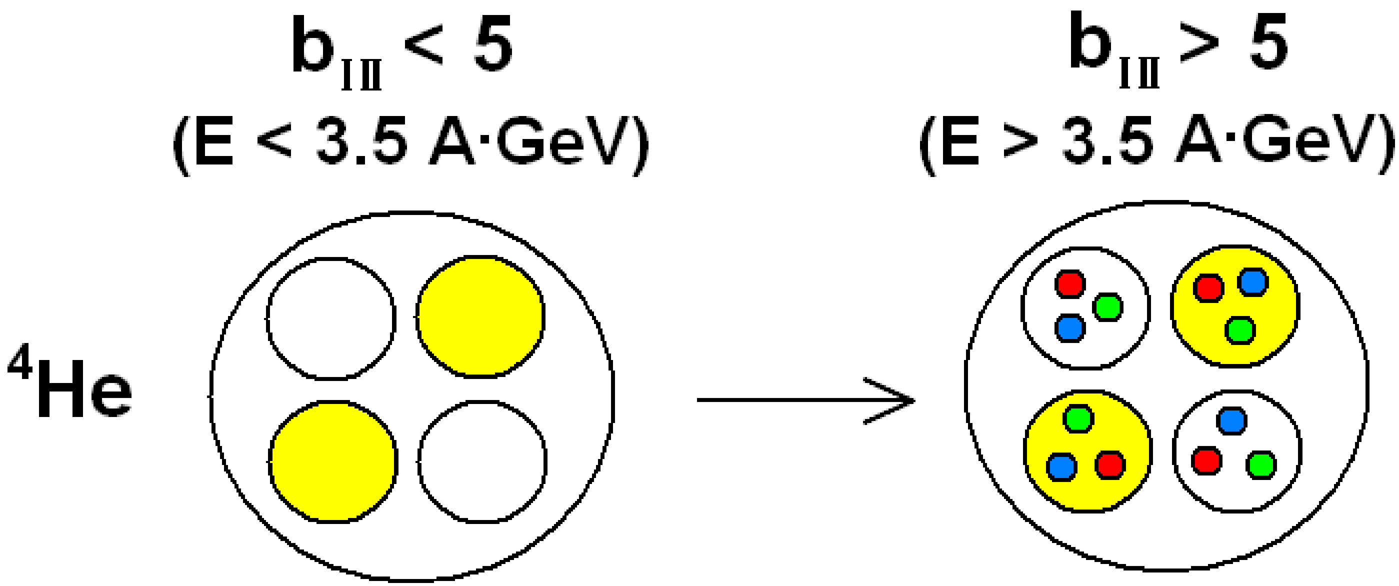
Dependence of T_0 parameter for pion at 180º for $p+Cu$ collisions on the energy of incident proton T_p. Pion cross-section parameterized by the form $E \cdot d^3\sigma/dp^3 = C \cdot exp(-T/T_0)$, where T is the pion laboratory kinetic energy

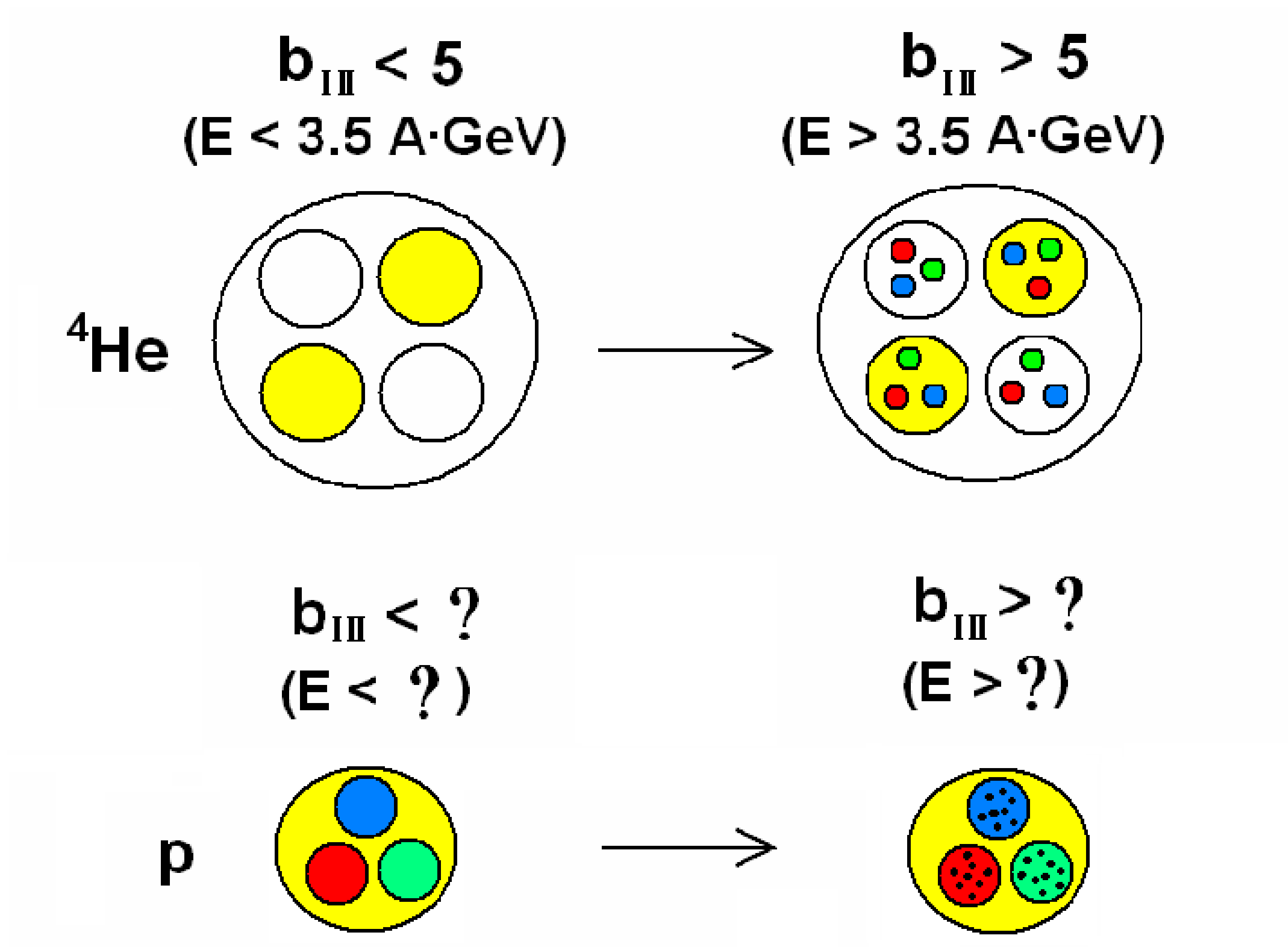
$$p = \frac{\Delta E}{\Delta V} = -\frac{m_k}{4\, r_0 A^{\frac{1}{3}} \left(1 \pm \frac{1}{\beta_k}\right)} \frac{\Delta b_k}{\Delta \sigma}$$

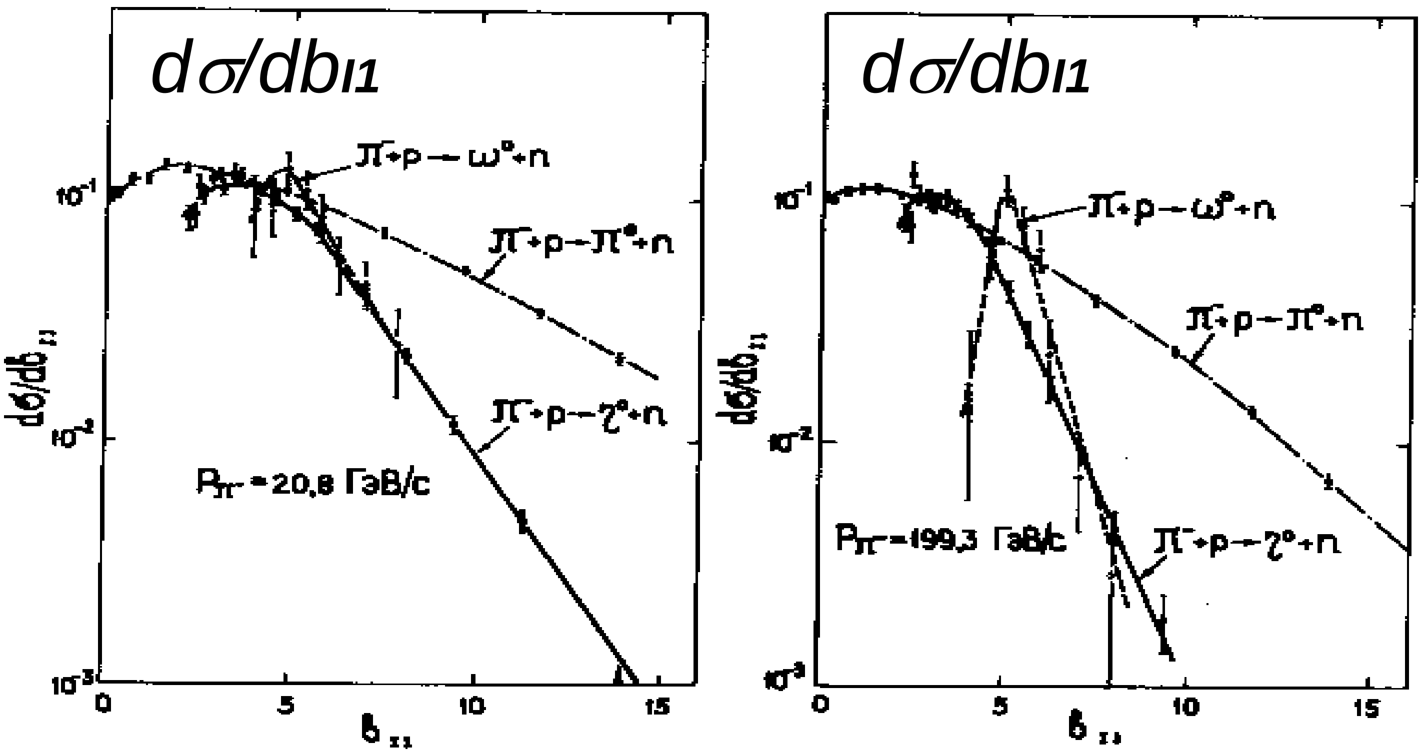


Quark Structure

A.Malakhov. Relativistic Nuclear Physics: from Handres of MeV to TeV. 8th Intern. Workshop. Dubna, May 23-28, 2005. E1,2-2006-30, Dubna (2006) pp.44-46.


b_I II < 5
(E < 3.5 A·GeV)
b_I II > 5
(E > 3.5 A·GeV)
4He

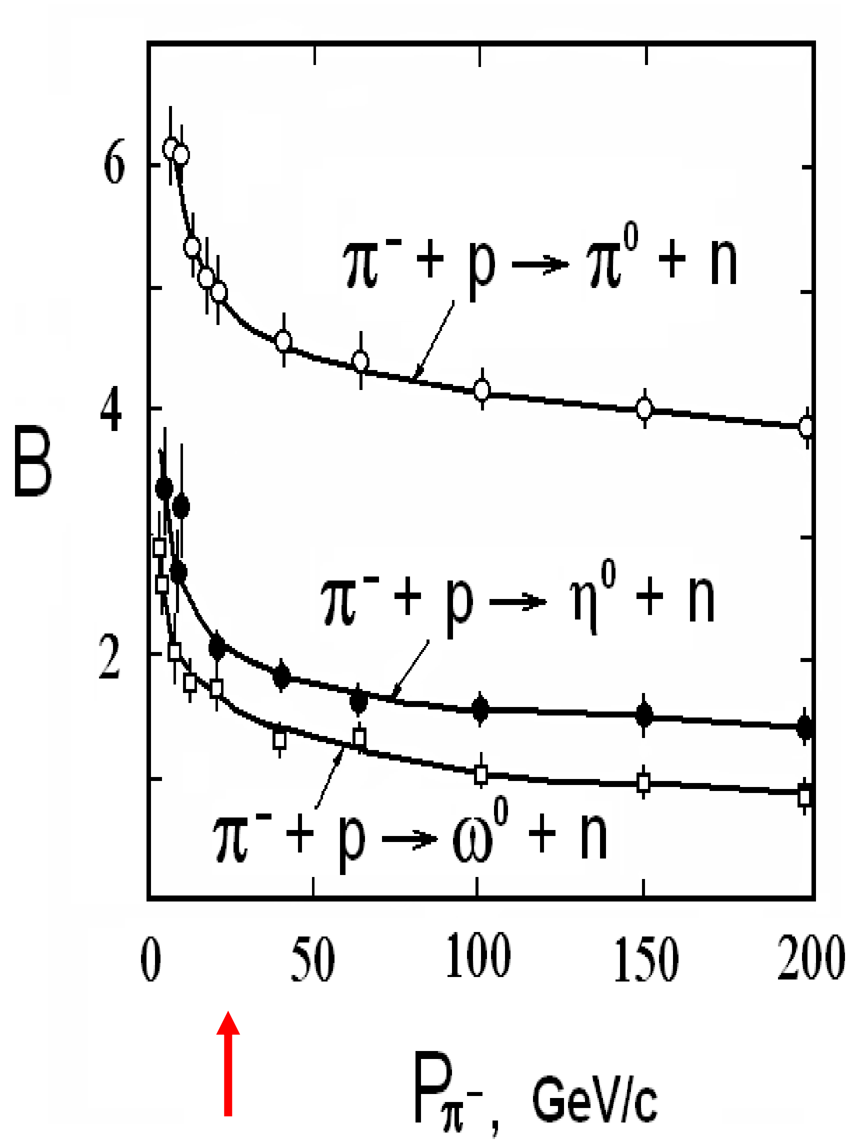

$b_{III} < 5$
($E < 3.5$ A·GeV)
$b_{III} > 5$
($E > 3.5$ A·GeV)
^{4}He
$b_{III} < ?$
($E < ?$)
$b_{III} > ?$
($E > ?$)
p



b I1 ***b I1***

$$d\sigma/db_{I1} = A \cdot \exp(-b_{I1}/B)$$

A.I.Malakhov, G.L.Melkumov. JINR Rapid Commun., No.19-86 (1986) pp.32-39).



As it possible see in figure asymptotic regime is beginning with pion momentum ***p_π* ~ 25 GeV** which is correspond ***$b_{I\,II}$*** ~ 380. Thus we can propose that at ***$b_{I\,II}$*** $\geq$ 380 beginning manifestation of the internal structure of quarks and in this region possible to study internal structure of quarks.

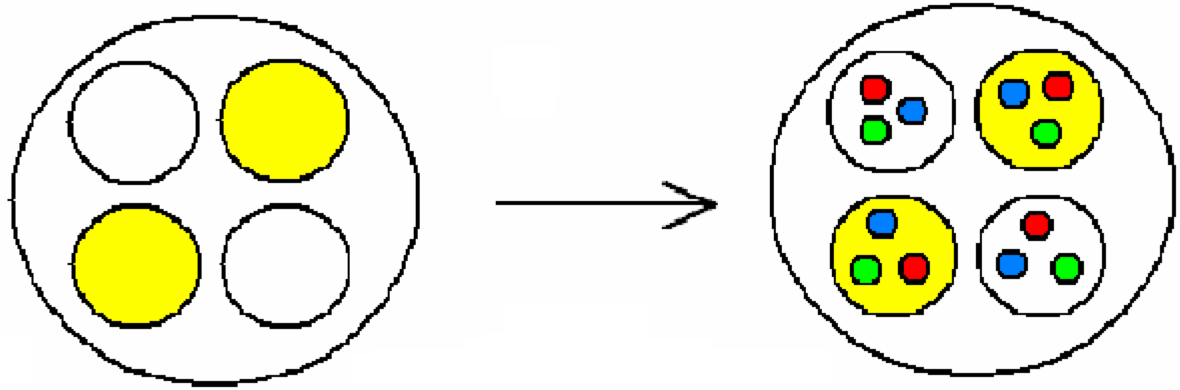
$$b_{I\,II} = -\,(u_\pi - u_p)^2 = -\,(1 - 2u_\pi u_p - 1) =$$

$$= 2(u_\pi u_p - 1) = 2(E_\pi/m_\pi - 1) = 2T_\pi / m_\pi \cong$$

$$\cong 2 \cdot 25/0.130 \cong 380.$$

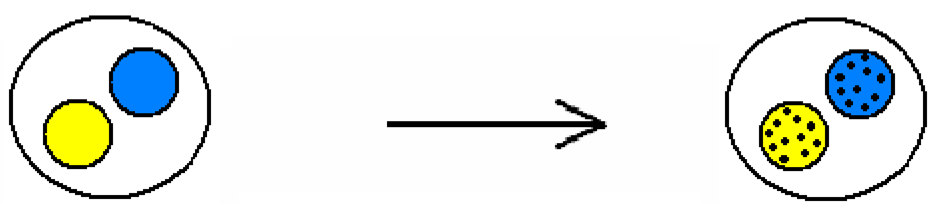
$b_{III} < 5$ ($E < 3.5 \cdot A$ GeV) $b_{III} > 5$ ($E > 3.5 \cdot A$ GeV)

^4He



$b_{III} < 380$ ($E < 25 \cdot A$ GeV) $b_{III} > 380$ ($E > 25 \cdot A$ GeV)

π



Observability of particles from which can consist quarks

Observability of short-lived particles is based on two necessary criteria:

1) The production cross section for really observable products of secondary interaction (decay) can with a sufficient accuracy presented in the form of two factors:

$$\sigma = \sigma_p \cdot W_d$$

Where W_d is interpreted as the decay probability (or secondary interaction probability) a suggested particle, σ_p its production cross section.

2) Universality of W_d or similarity of the W_d properties in various reactions.

$$\mathrm{I} + \mathrm{II} \rightarrow \mathrm{Jet}^{\alpha} + \mathrm{Jet}^{\beta}$$

$$\sigma = \sigma_p \cdot W^{\alpha}(b_k) \cdot W^{\beta}(b_k)$$

Conclusions

- The Serpukhov energy region allows to investigate in details transition and asymptotic areas of nuclear interactions
- Experiments at Serpukhov allow to check up validity of a Automodelity Principle (Self-similarity Hypothesis) and Correlation Depletion Principle for nuclear interactions
- Probably also studying of the exotic phenomena: a dark energy (QCD vacuum) and quark structure

Thank you !

$$b_k = -(V - u_k)^2 = -(V^2 - 2Vu_k + u_k^2) = 2(Vu_k - 1) =$$

$$= 2\left(\frac{Vp_k}{m_k} - 1\right) = 2\left(\frac{E_k}{m_k} - \frac{\vec{V}\vec{P}_k}{m_k} \quad 1\right) = 2\frac{E_k}{m_k} - 2\frac{\vec{V}\vec{P}_k}{m_k} - 2 .$$

$$b_k - 2\frac{E_k}{m_k} + 2 = -2\frac{\vec{V}\vec{P}_k}{m_k}$$

$$\left(b_k - 2\frac{E_k}{m_k} + 2\right)^2 = 4\frac{\vec{V}^2\vec{P}_k^2}{m_k} = 4\frac{p_k^2}{m_k^2}$$

$$b_k - 2\frac{E_k}{m_k} + 2 = \pm 2\frac{p_k}{m_k}$$

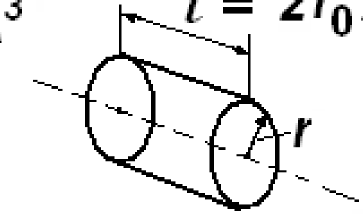
$$\boxed{b_k = 2\frac{p_k}{m_k} + 2\frac{E_k}{m_k} - 2 = \frac{2}{m_k}(\pm p_k + E_k - m_k)}$$

$$p = -\frac{\Delta E}{\Delta V}$$

$$V = \sigma \cdot l = \sigma \cdot 2 r_0 A^{\frac{1}{3}}$$

$$\Delta V = \Delta\sigma \cdot 2 r_0 A^{\frac{1}{3}}$$

$$l = 2 r_0 A^{\frac{1}{3}}$$



$$\sigma = \pi r^2$$

$$b_k = 2\frac{p_k}{m_k} + 2\frac{E_k}{m_k} - 2 = \frac{2}{m_k}(\pm p_k + E_k - m_k)$$

$$\Delta b_k = \frac{2}{m_k}(\pm \Delta p_k + \Delta E_k) = \frac{2}{m_k}\left[\pm \Delta (E_k^2 + m_k^2)^{\frac{1}{2}} + \Delta E_k\right] =$$

$$= \frac{2}{m_k}\left[\pm \frac{1}{2}(E_k^2 - m_k^2)^{-\frac{1}{2}} 2E_k \Delta E_k + \Delta E_k\right] = \frac{2}{m_k}\left(\pm\frac{E_k}{p_k} + 1\right)\Delta E_k$$

$$\Delta E_k = \frac{m_k}{2\left(1 \pm \frac{E_k}{p_k}\right)}\Delta b_k = \frac{m_k}{2\left(1 \pm \frac{1}{\beta_k}\right)}\Delta b_k$$

$$p = -\frac{\Delta E}{\Delta V} = \cdot\ \frac{\left[\dfrac{m_k}{2\left(1 \pm \dfrac{1}{\beta_k}\right)}\right]\Delta b_k}{2 r_0 A^{\frac{1}{3}} \cdot \Delta\sigma} =$$

$$= -\frac{m_k}{4 r_0 A^{\frac{1}{3}}\left(1 \pm \underbrace{\dfrac{1}{\beta_k}}_{\approx 1}\right)}\,\frac{\Delta b_k}{\Delta\sigma} \approx \begin{cases} -\dfrac{1}{8}\,\dfrac{m_k}{r_0 A^{\frac{1}{3}}}\,\dfrac{\Delta b_k}{\Delta\sigma} \\[2ex] +2.25\,\dfrac{m_k}{r_0 A^{\frac{1}{3}}}\,\dfrac{\Delta b_k}{\Delta\sigma}, \end{cases} \qquad \beta_k \approx 0,9$$